

EIC measurements and conclusions



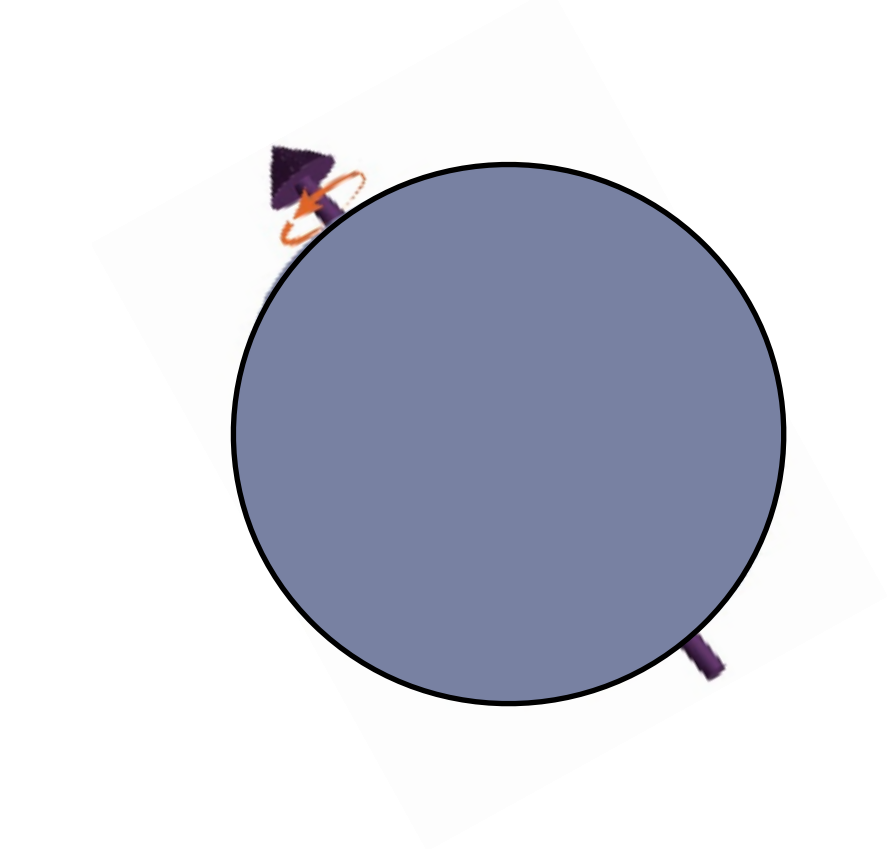
Charlotte Van Hulse
University of Alcalá

2nd European school on the physics of the EIC and related topics
Benicàssim, Spain
June 23 – July 2, 2025

Why an EIC?

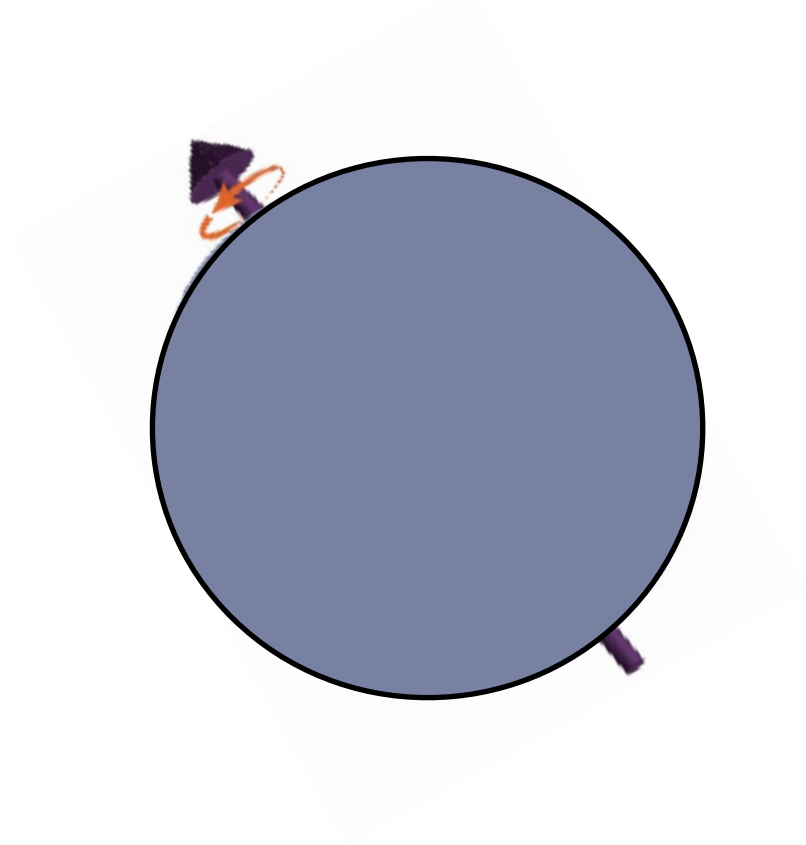
Why an EIC?

Nucleon spin structure

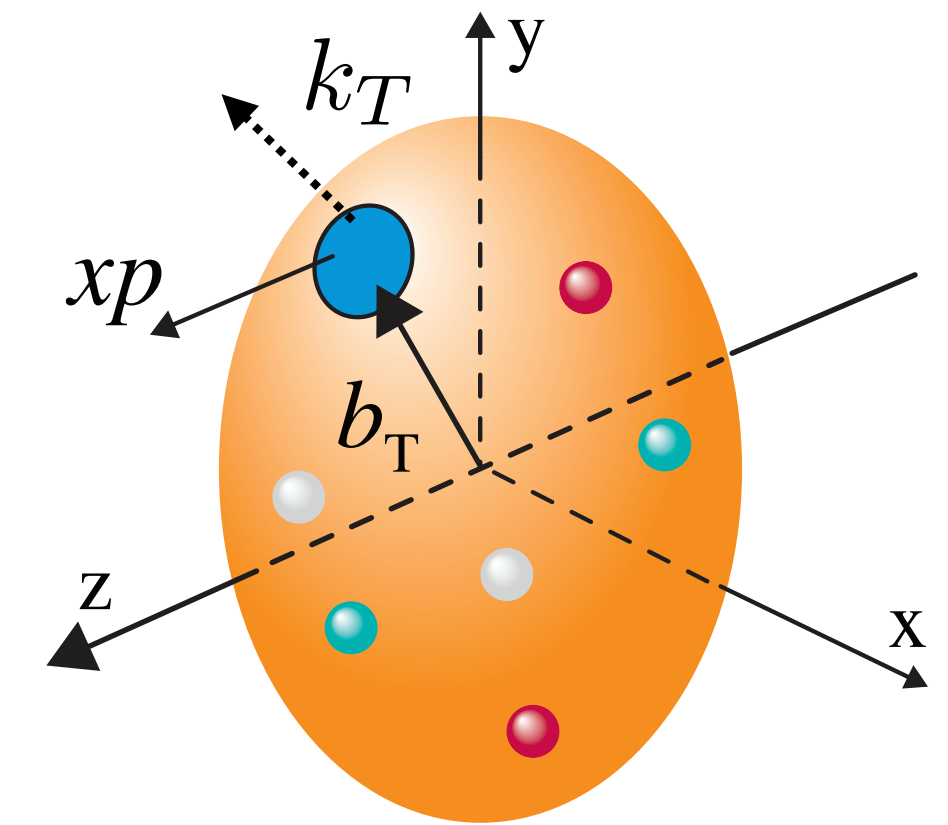


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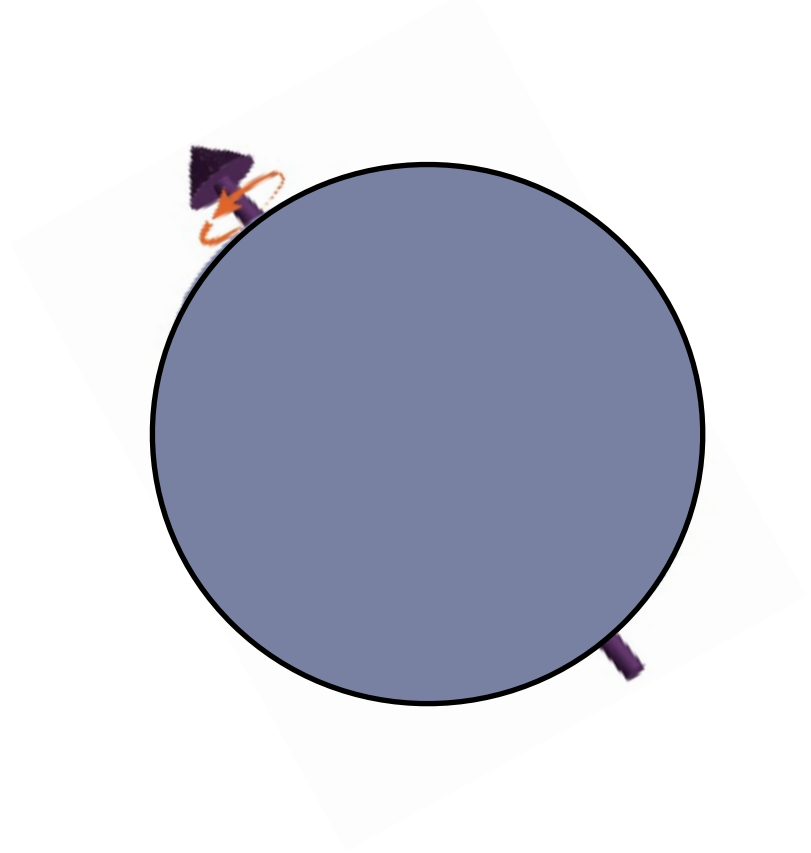


Nucleon multi-dimensional structure

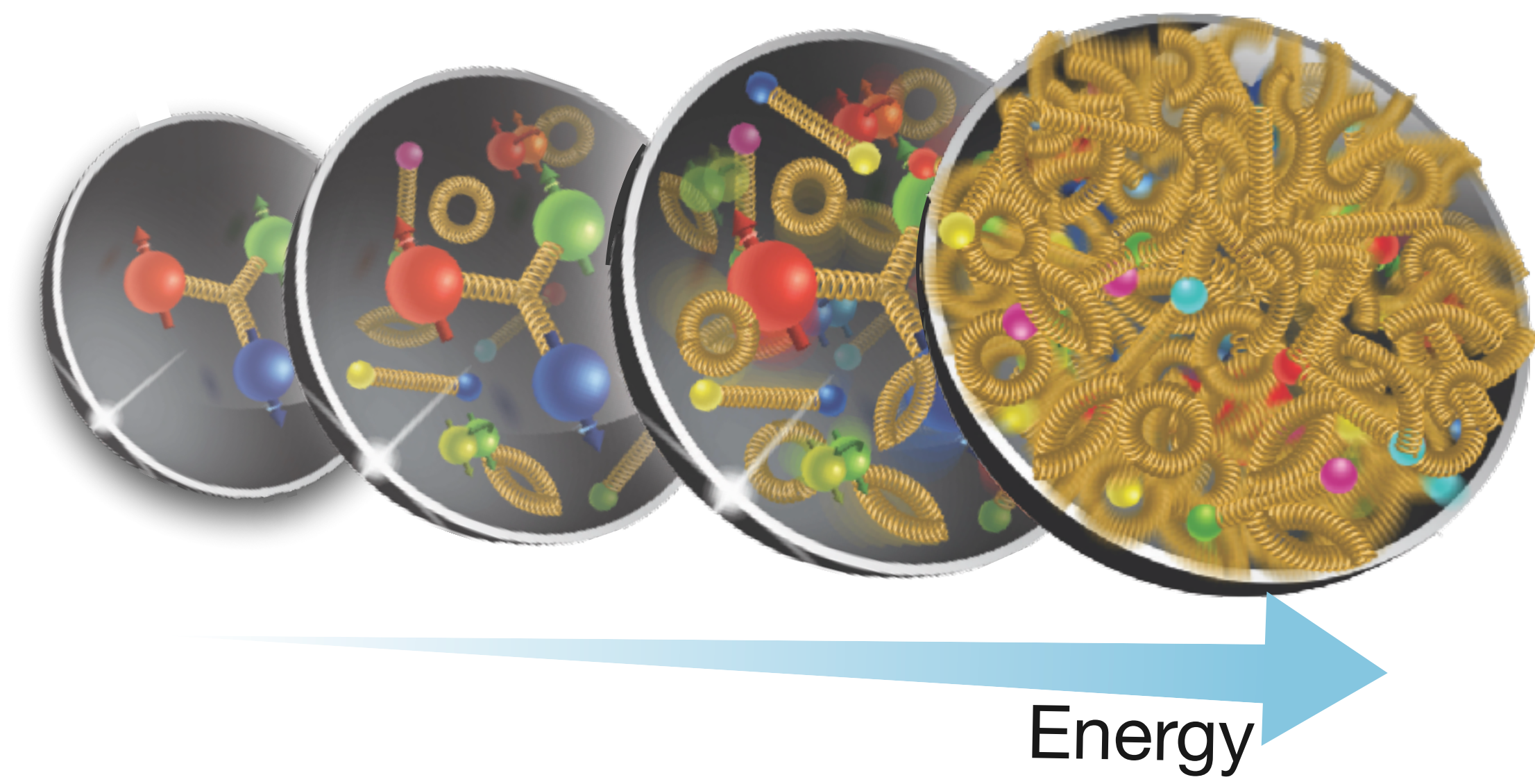


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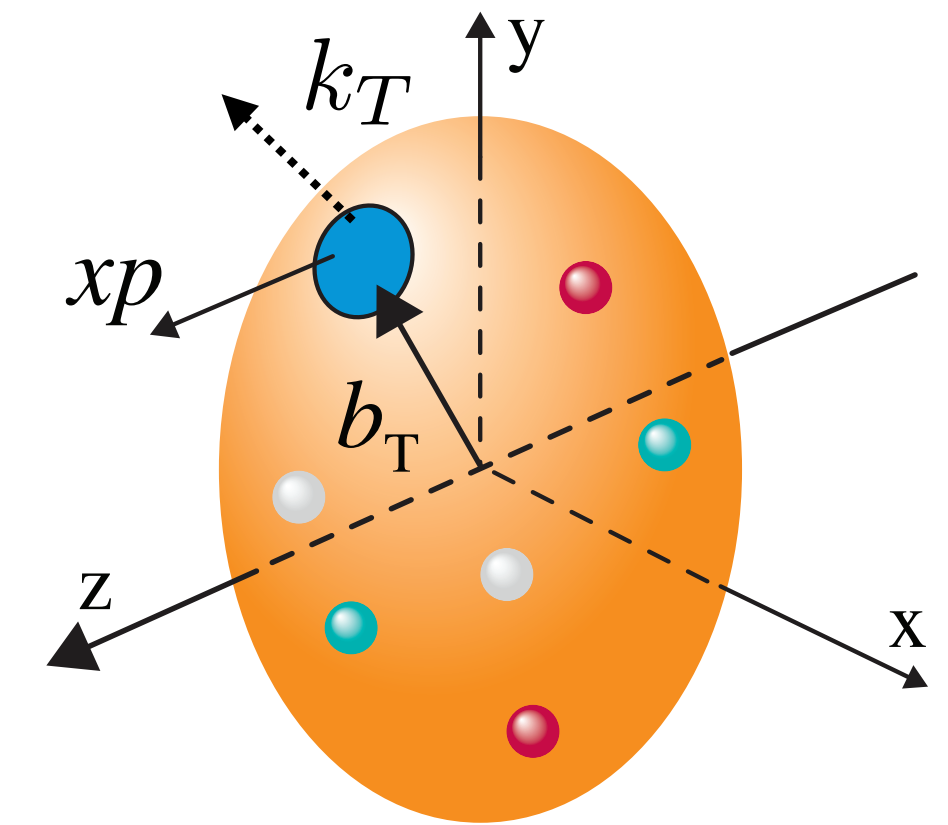
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Gluon saturation

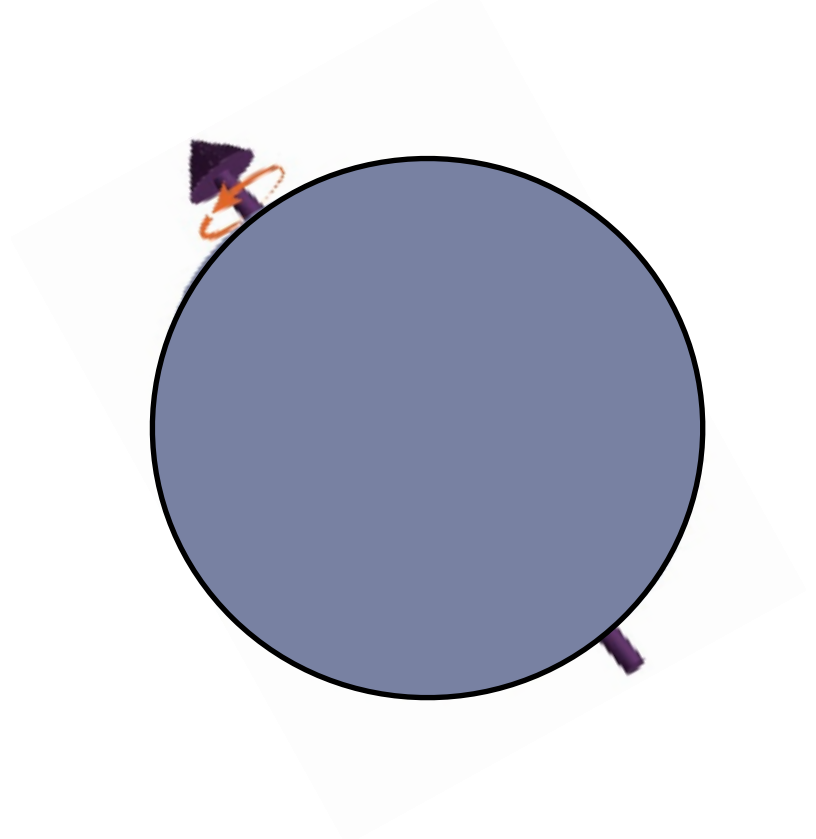


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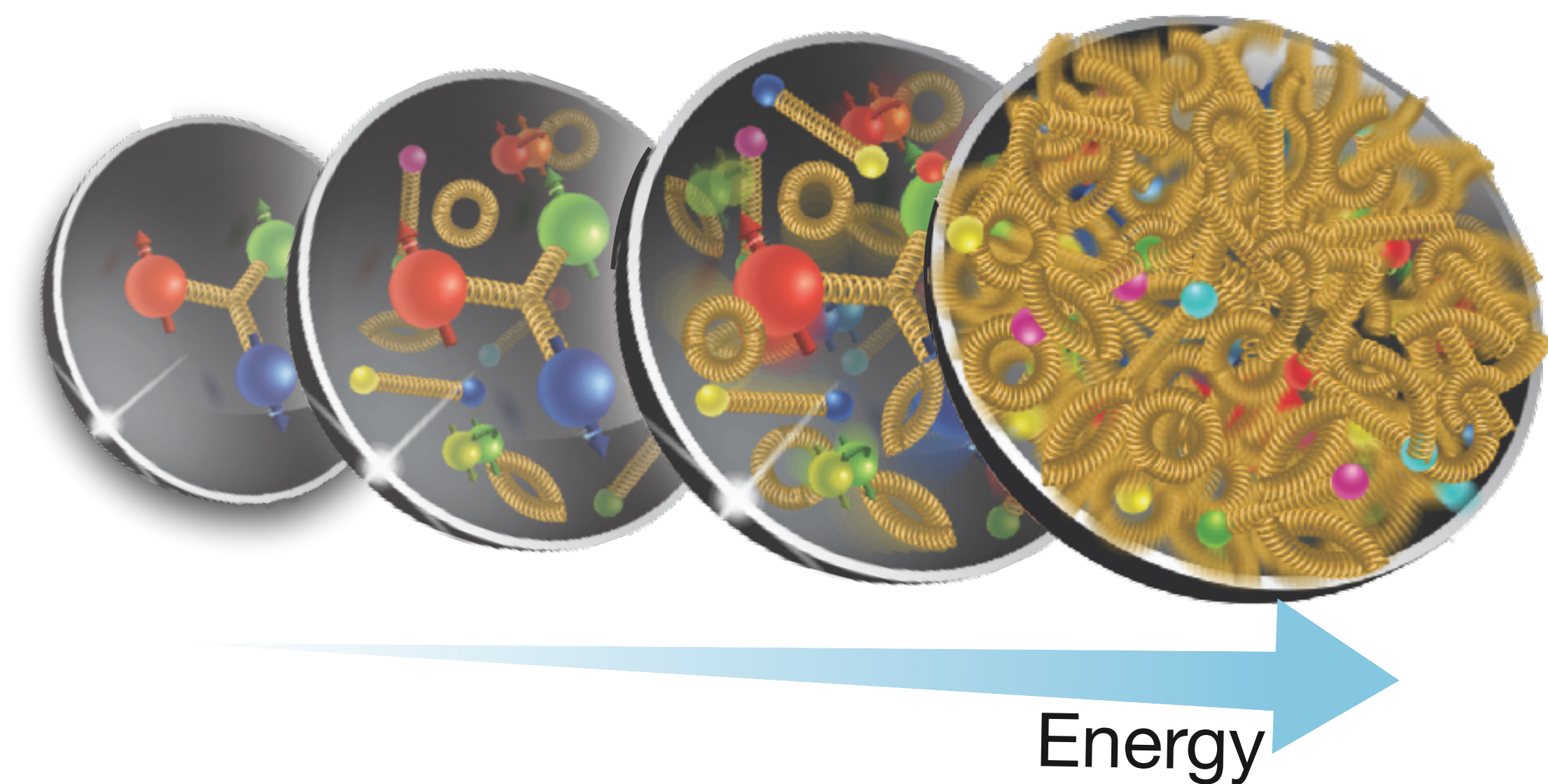


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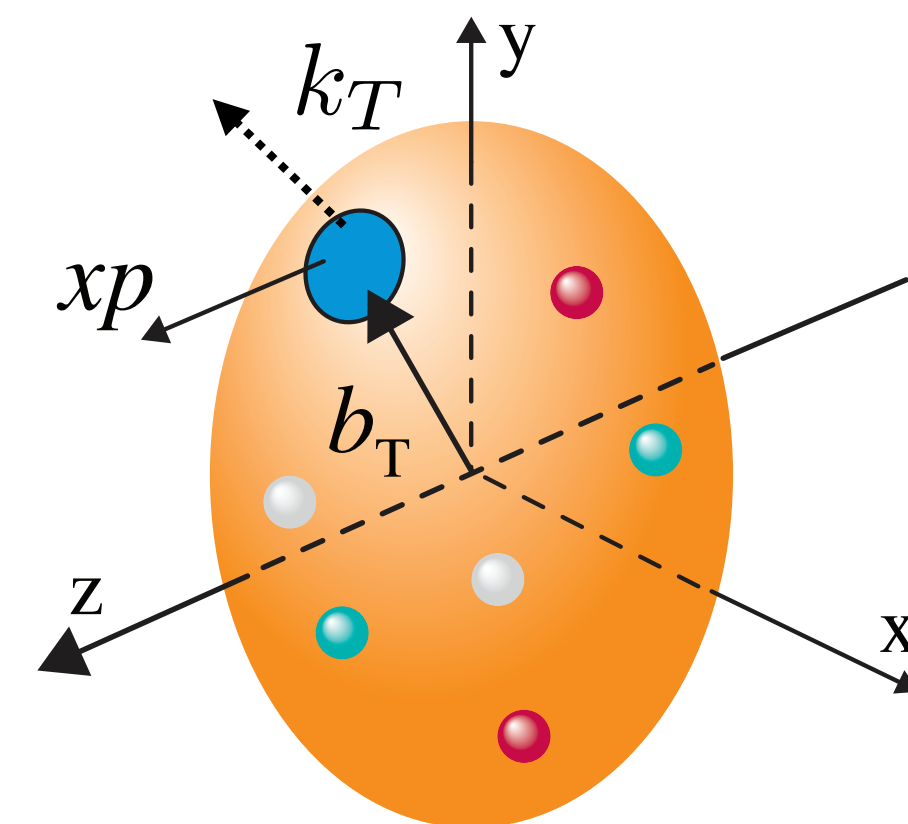
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Hadronisation



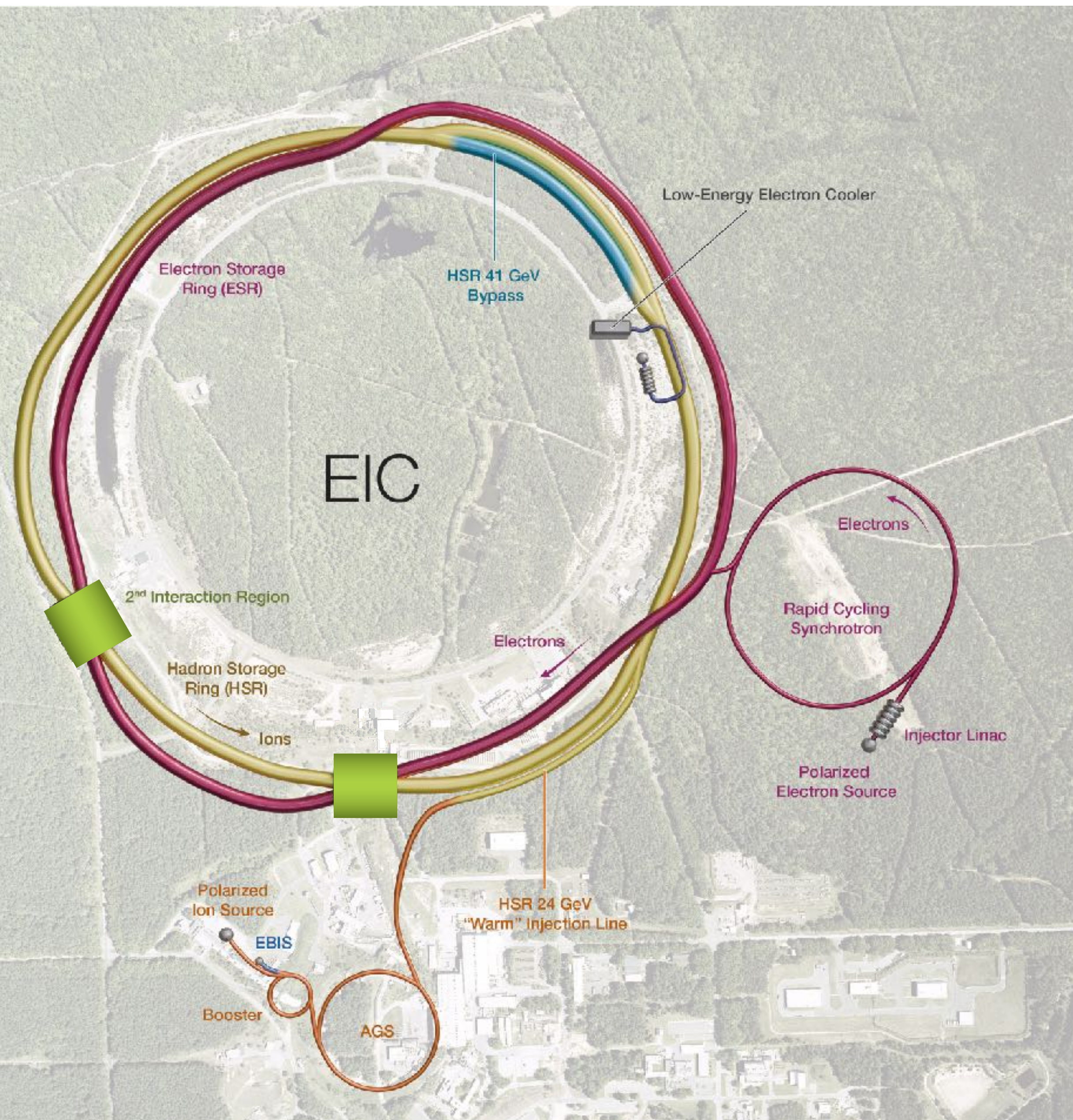
The electron-ion collider (EIC)



The diagram illustrates the layout of the Electron-Ion Collider (EIC) at Brookhaven National Laboratory. The central feature is the large circular Electron Storage Ring (ESR) and Hadron Storage Ring (HSR). The ESR is shown in yellow and the HSR in red. Two interaction regions are marked with green squares. The HSR is labeled 'HSR 41 GeV Bypass' and 'HSR 24 GeV "Warm" Injection Line'. The ESR is labeled 'Electron Storage Ring (ESR)'. A 'Low-Energy Electron Cooler' is shown on the right side of the ESR. The 'Rapid Cycling Synchrotron' and 'Injector Linac' are shown on the right. The 'Polarized Electron Source' is shown below the Injector Linac. The 'Polarized Ion Source' and 'EBIS' are shown at the bottom left. The 'Booster' and 'AGS' are shown at the bottom. The '2nd Interaction Region' is marked on the left. The 'Electrons' and 'Ions' paths are indicated with arrows. The background is an aerial photograph of the site.

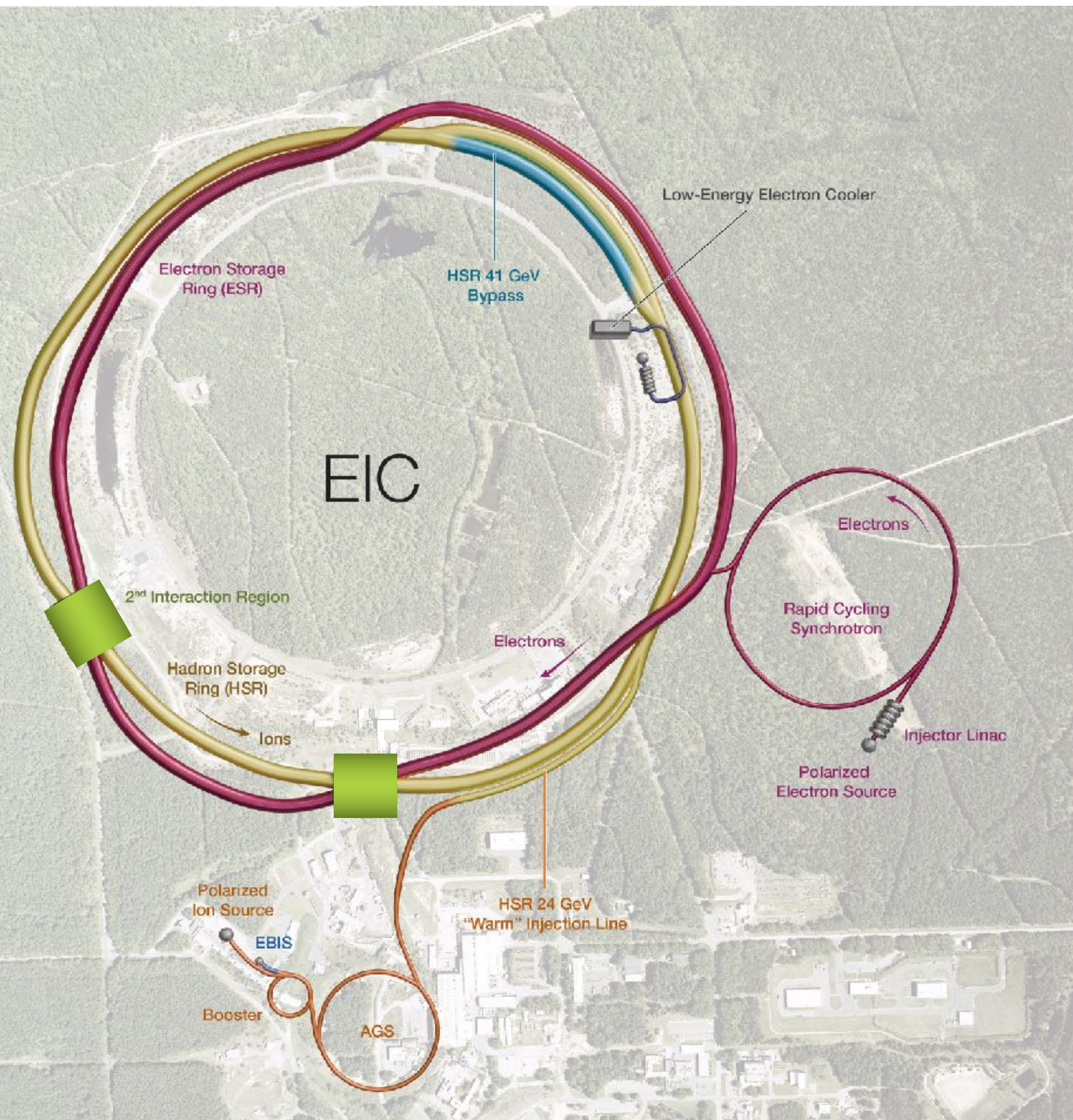
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 - use exiting hadron storage ring
energy: 41–275 GeV
 - add electron storage ring in RHIC tunnel
energy: 5–18 GeV

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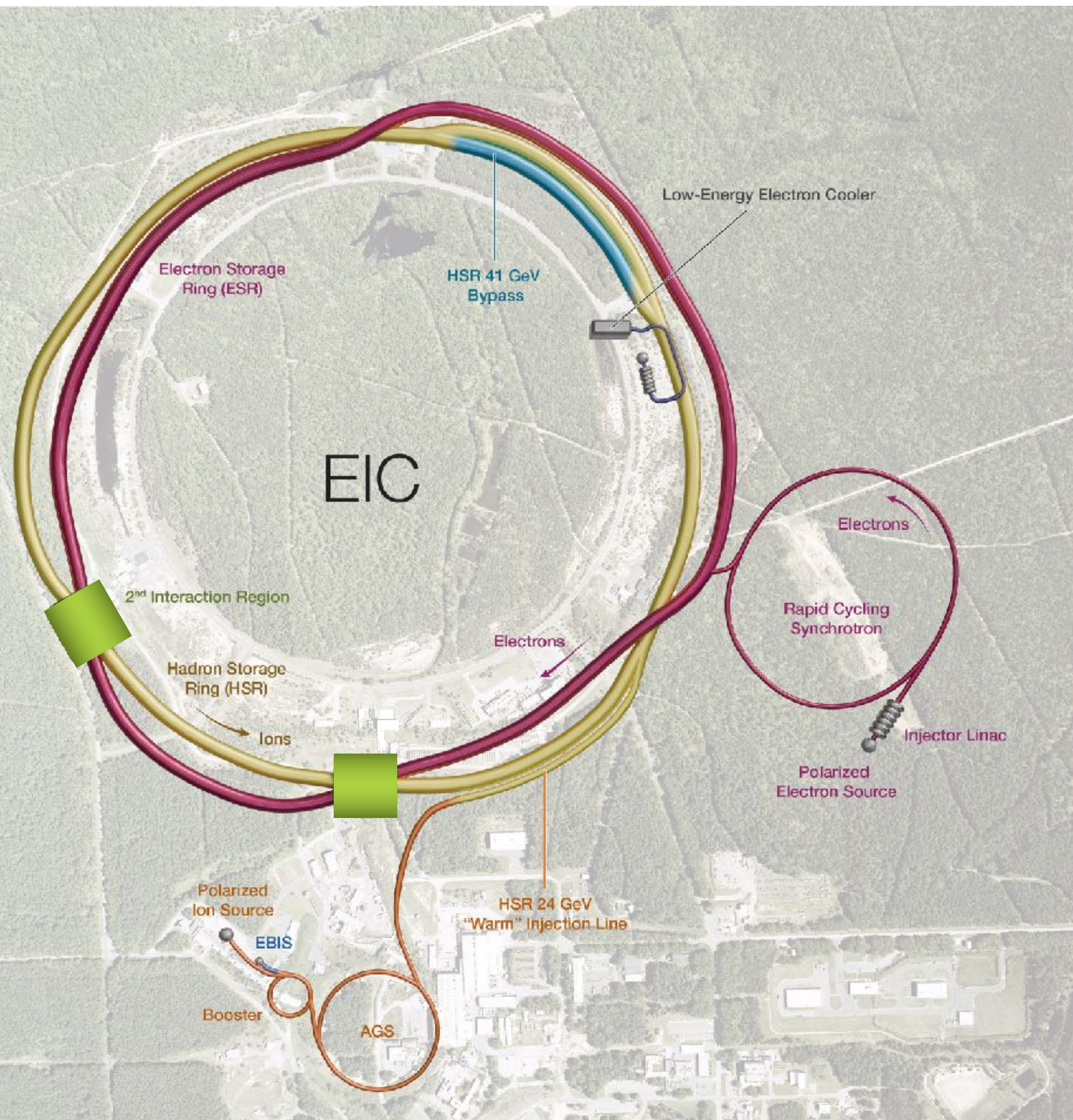
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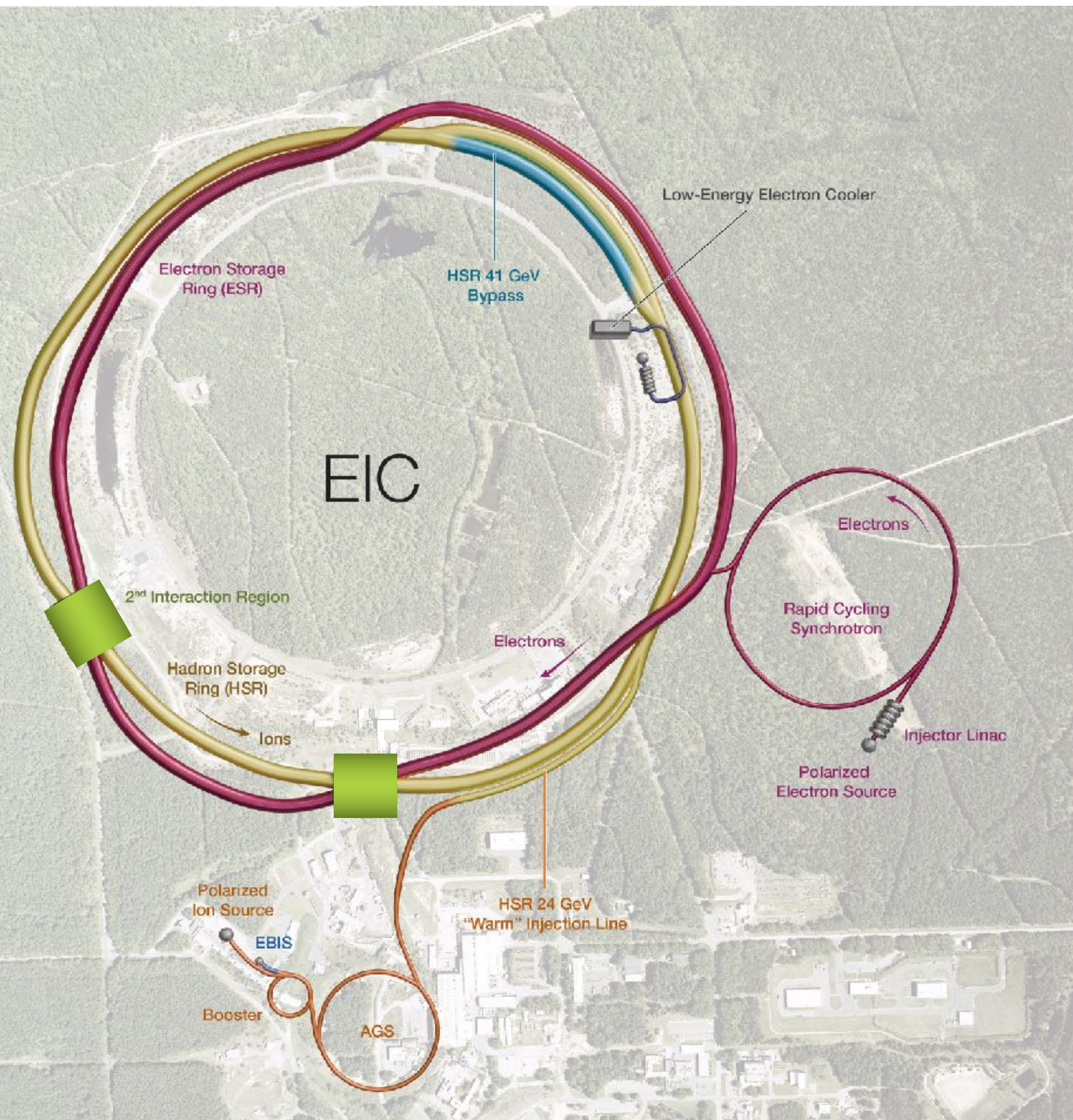
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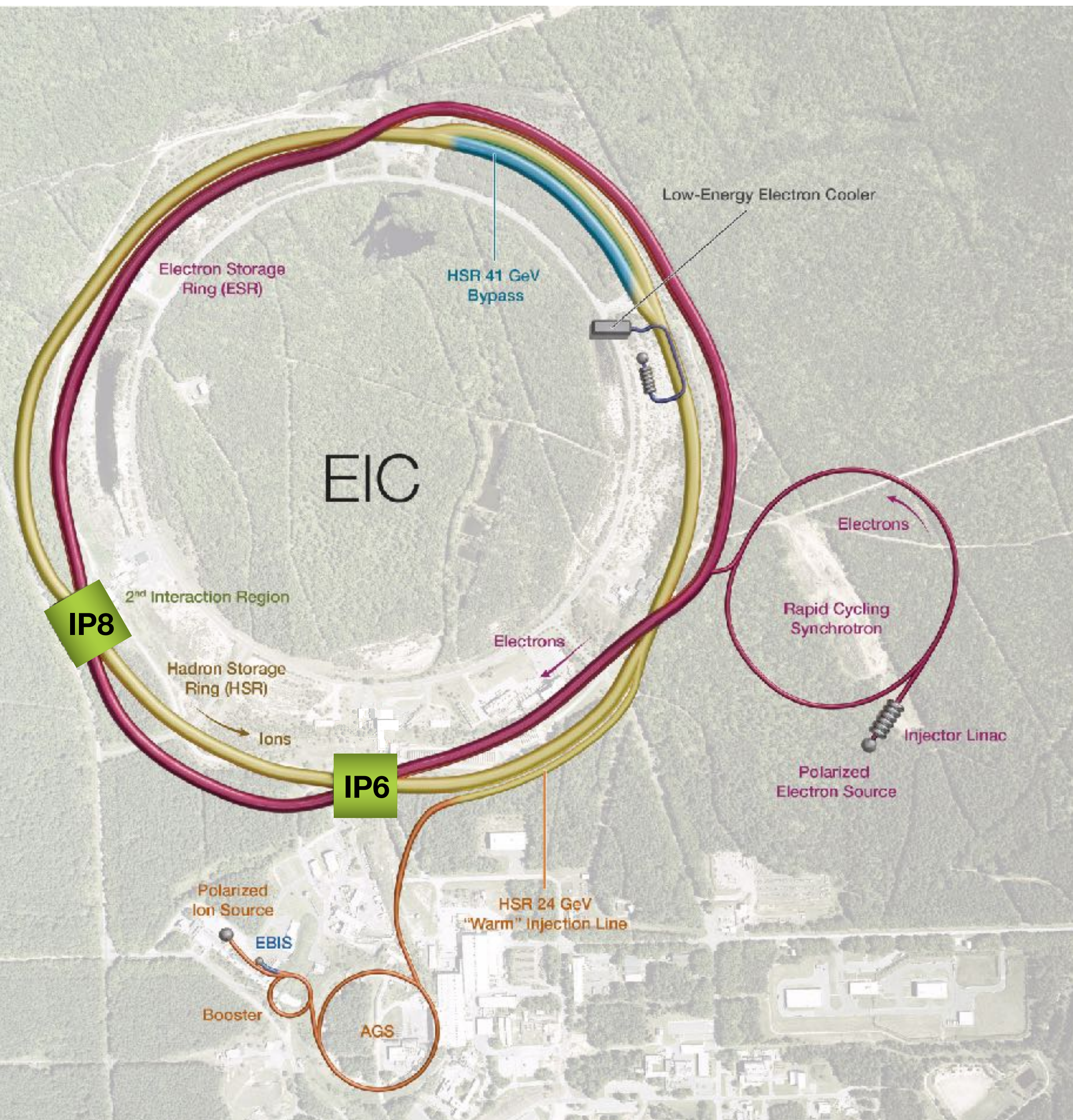
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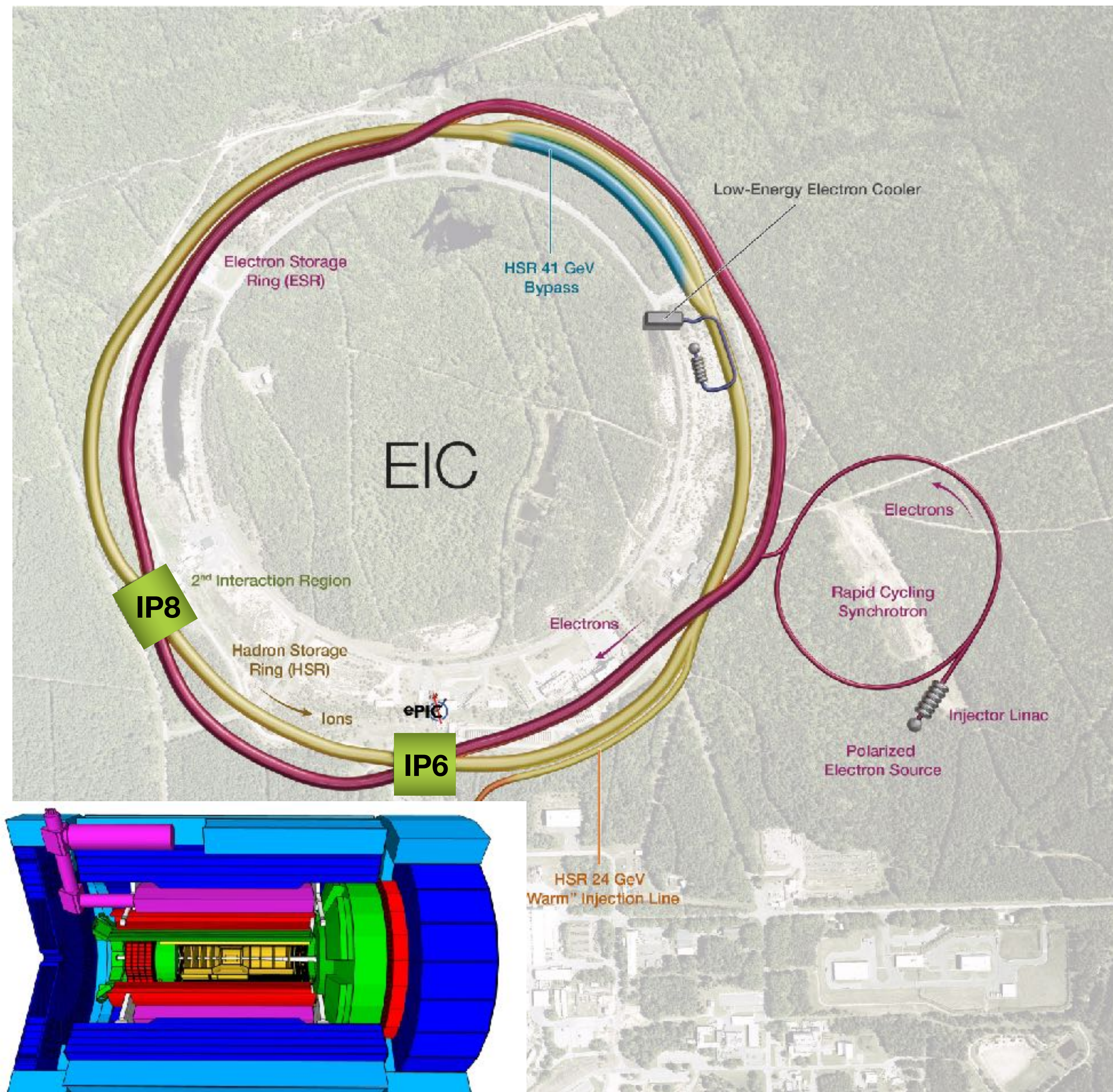
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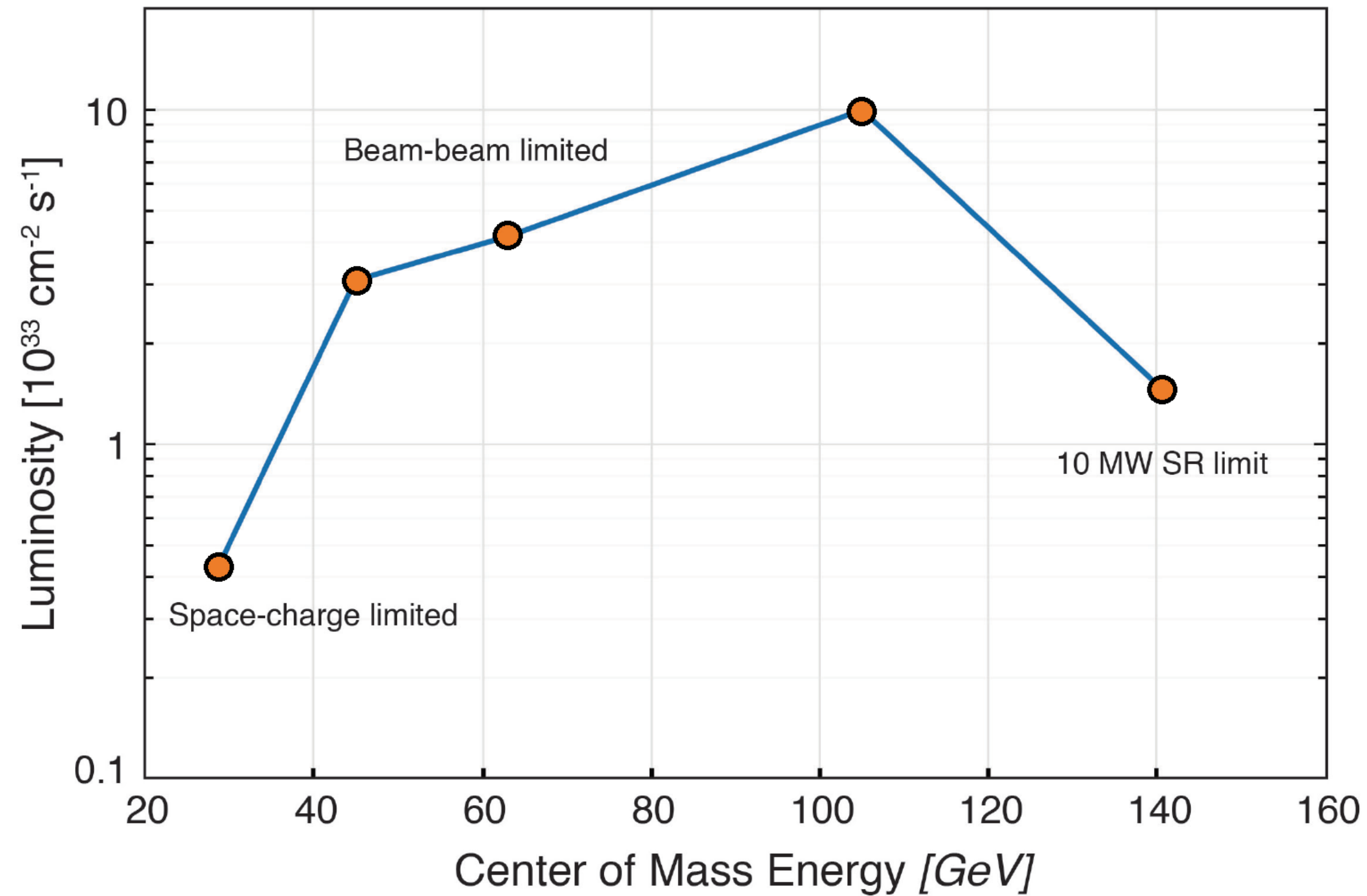
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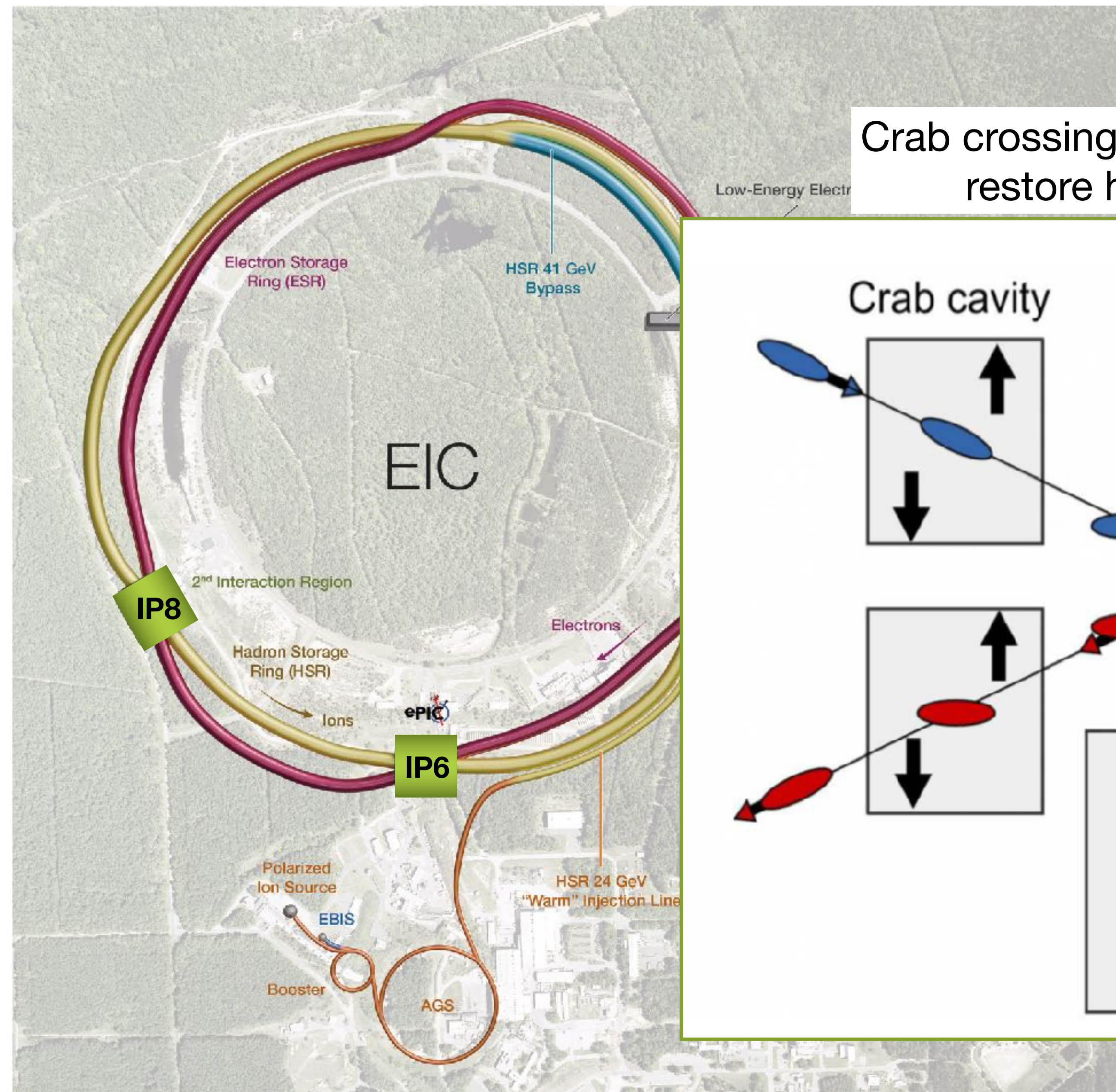
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Luminosity and centre-of-mass energy: ep collisions

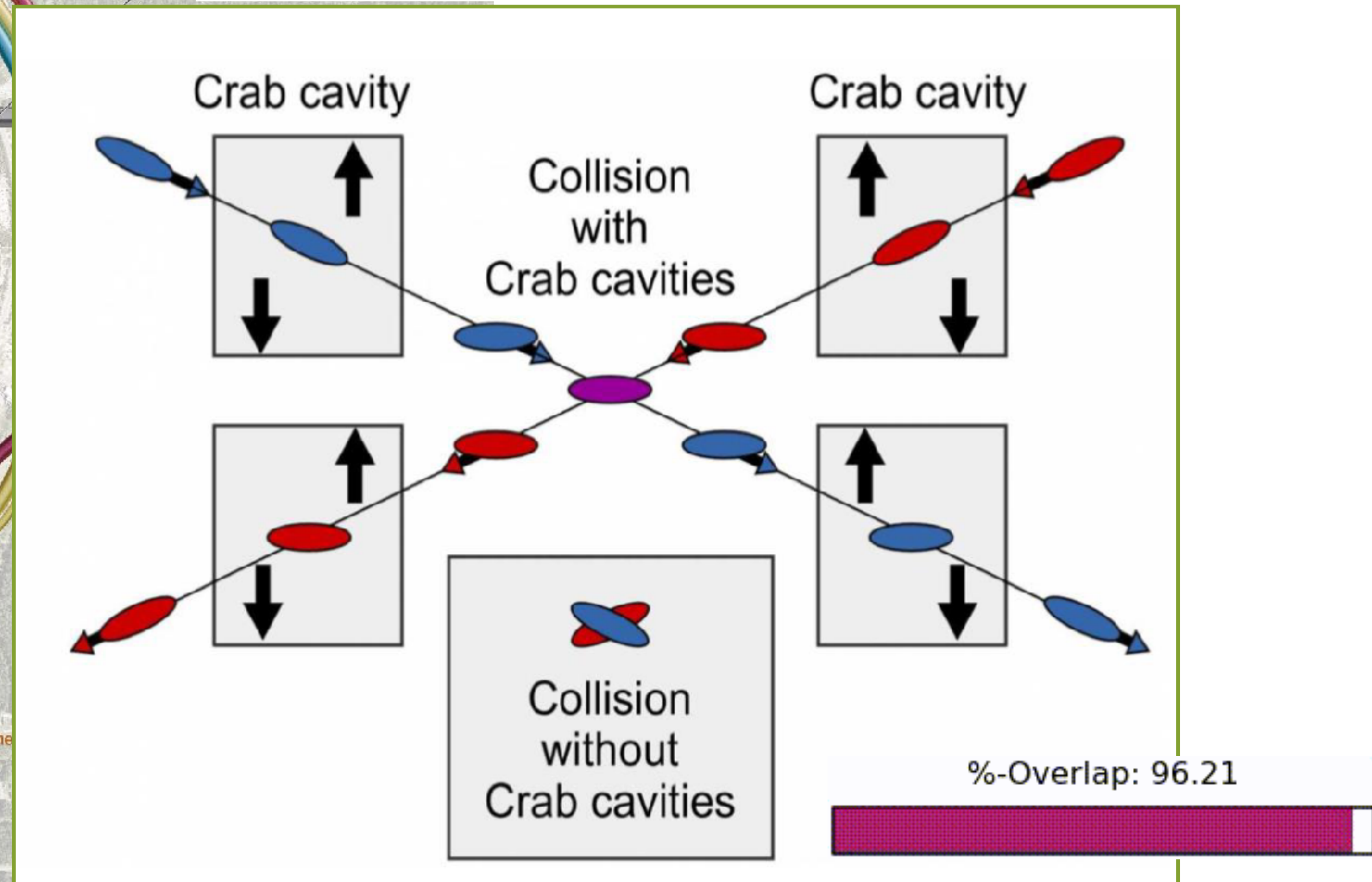


Luminosity for eA similar within factor 2–3

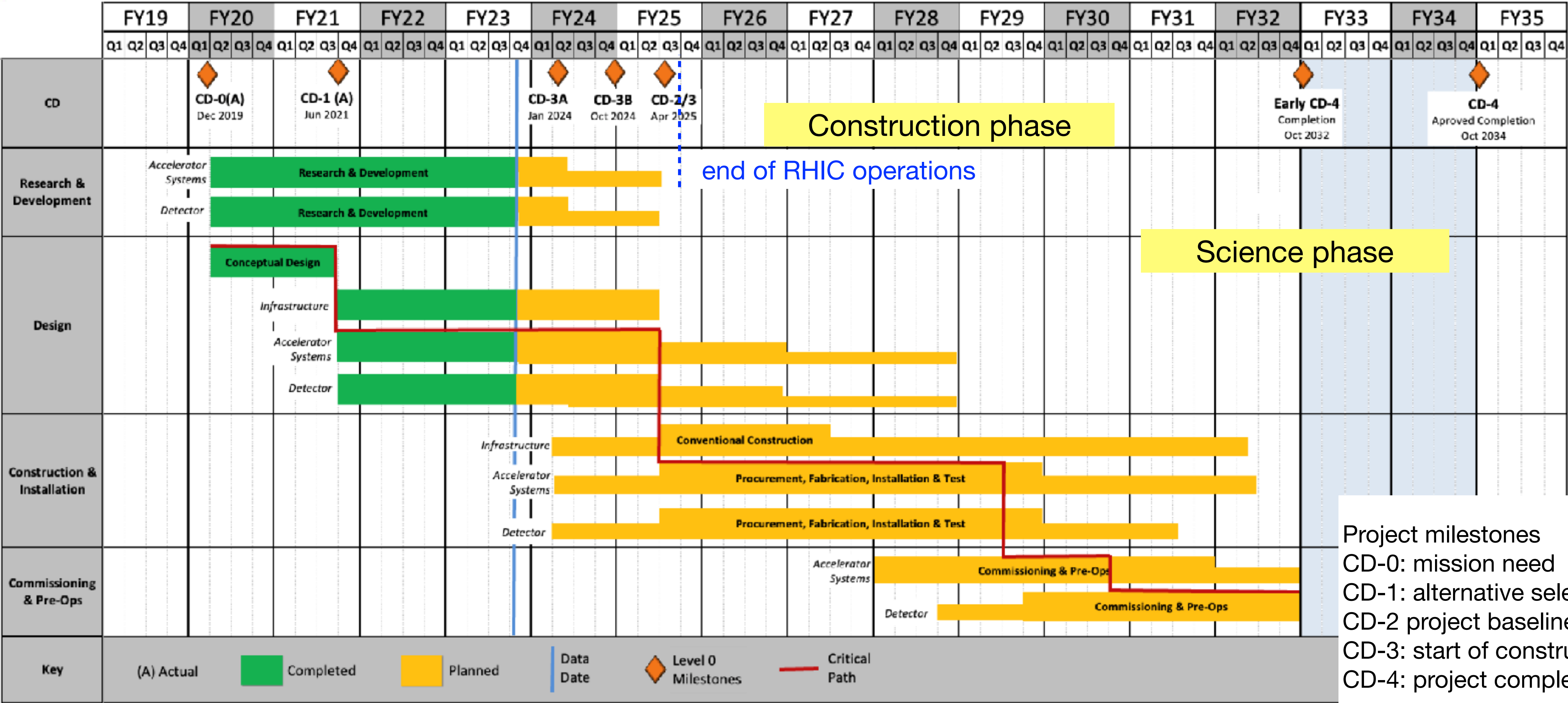
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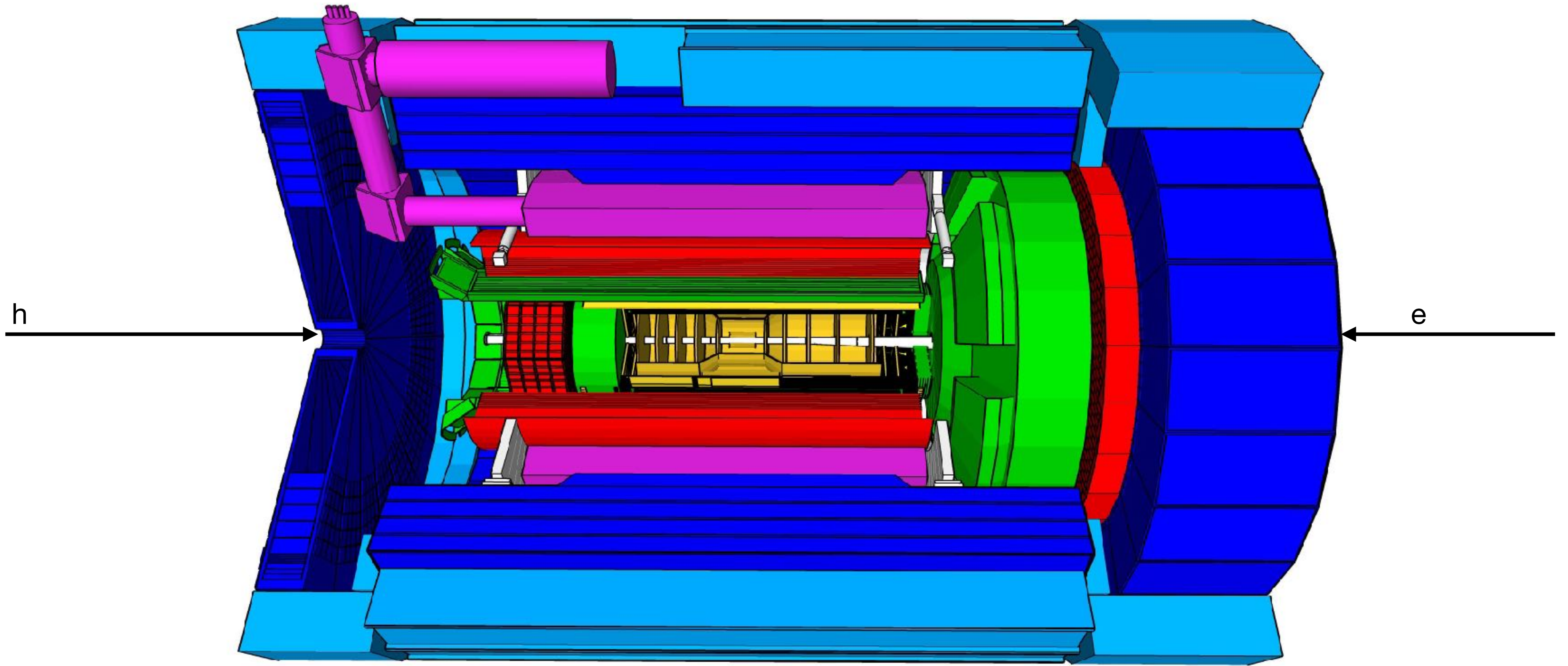
Crab crossing angle (25 mrad) at IP6:
restore head-on collisions



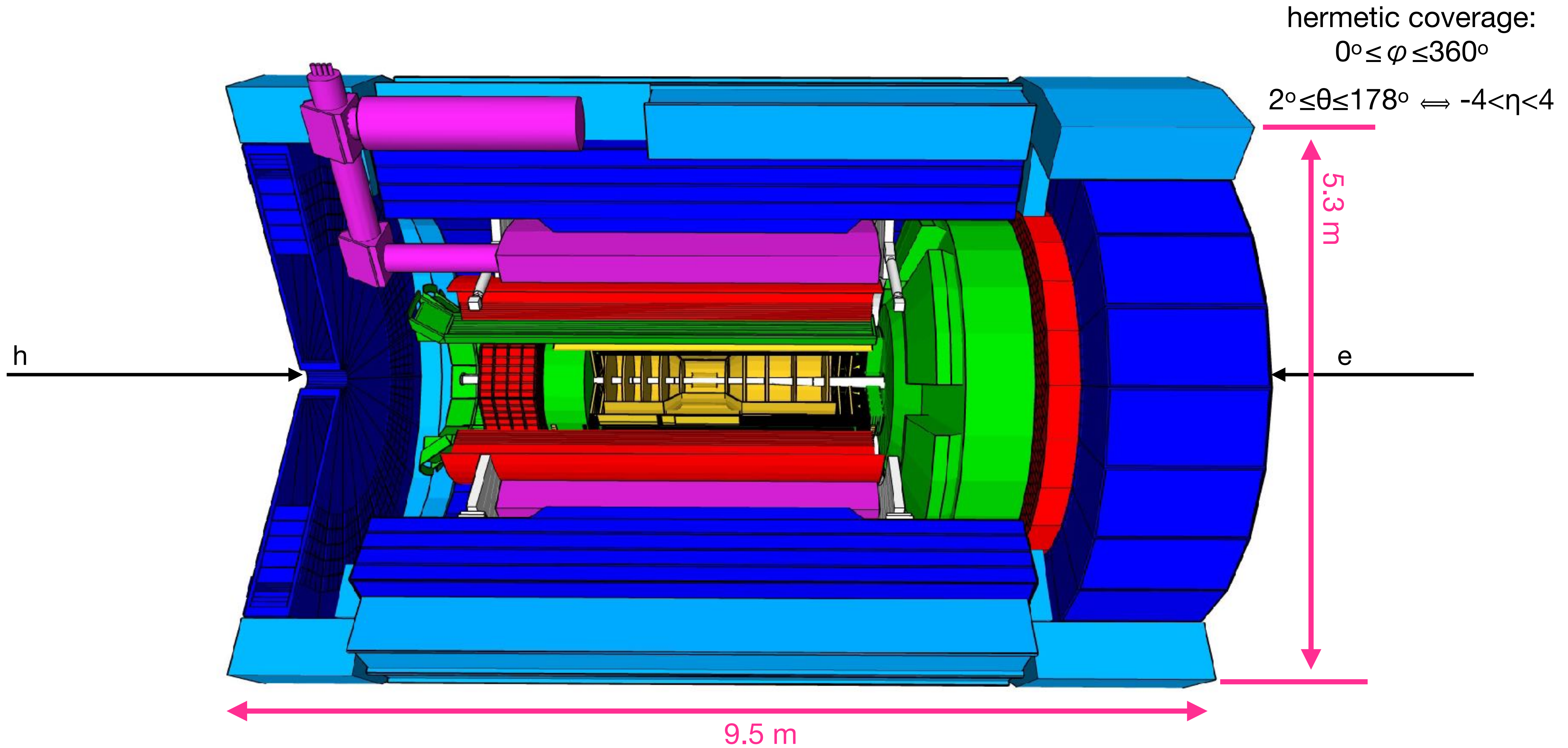
Timeline



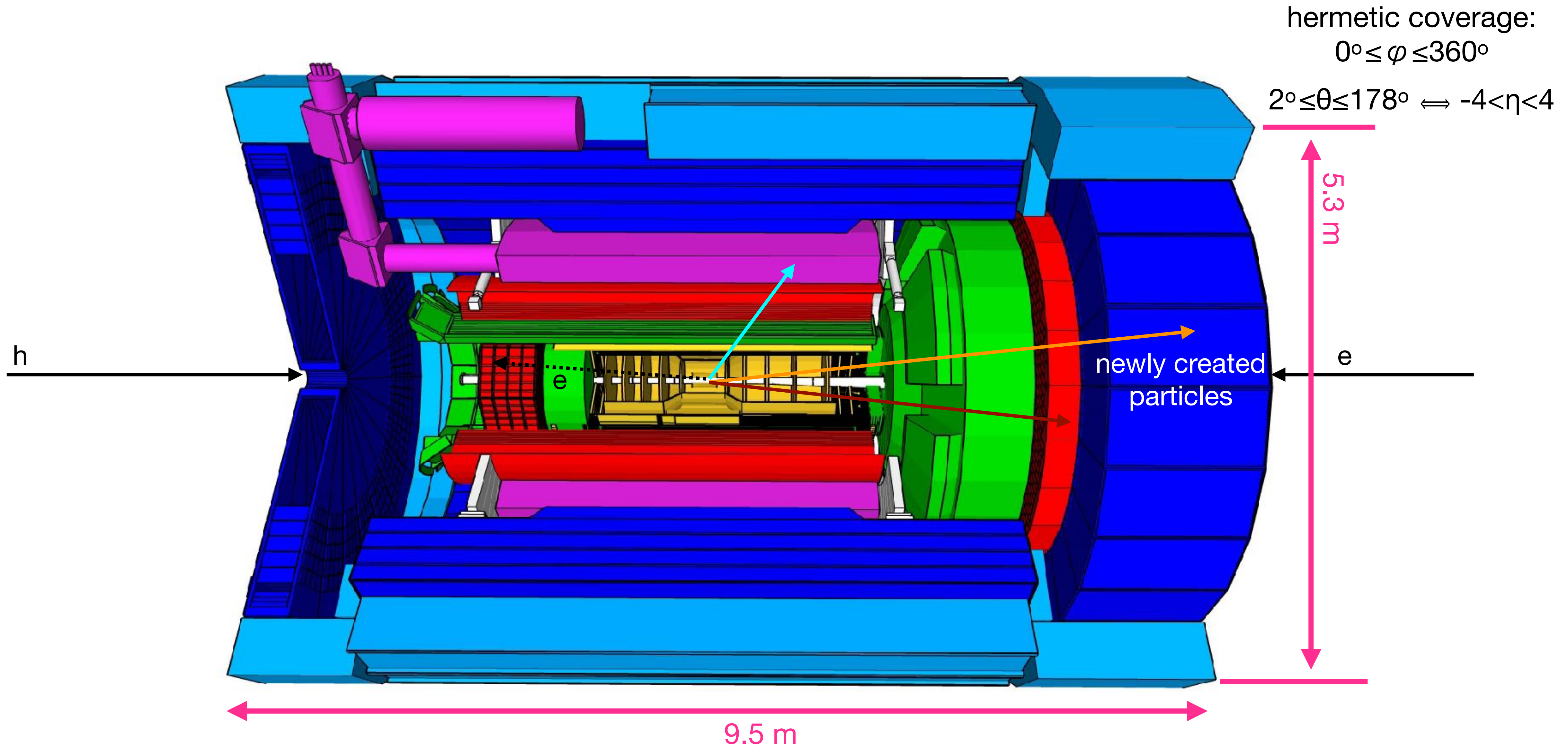
The electron-proton/ion collider (ePIC) detector



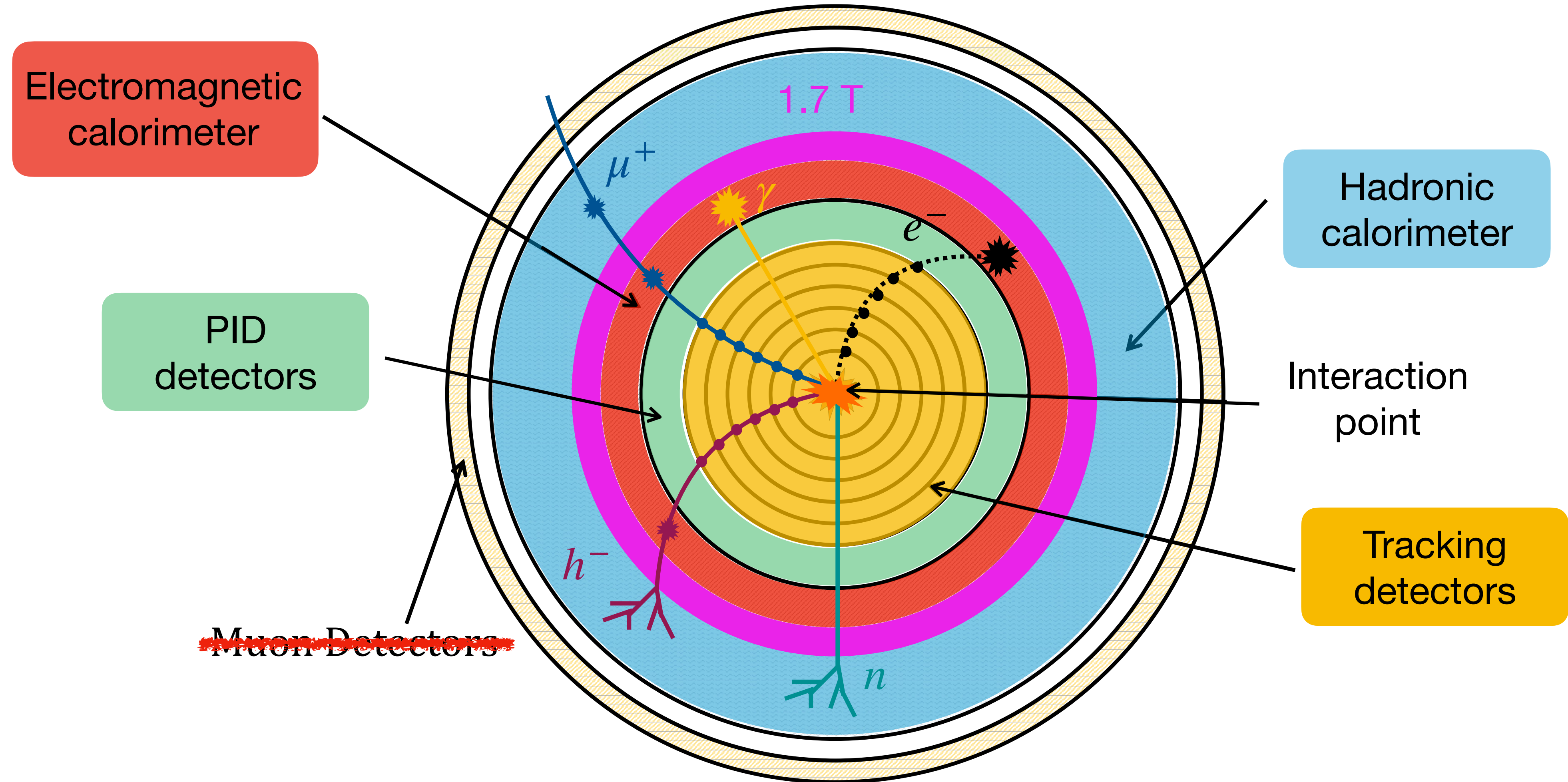
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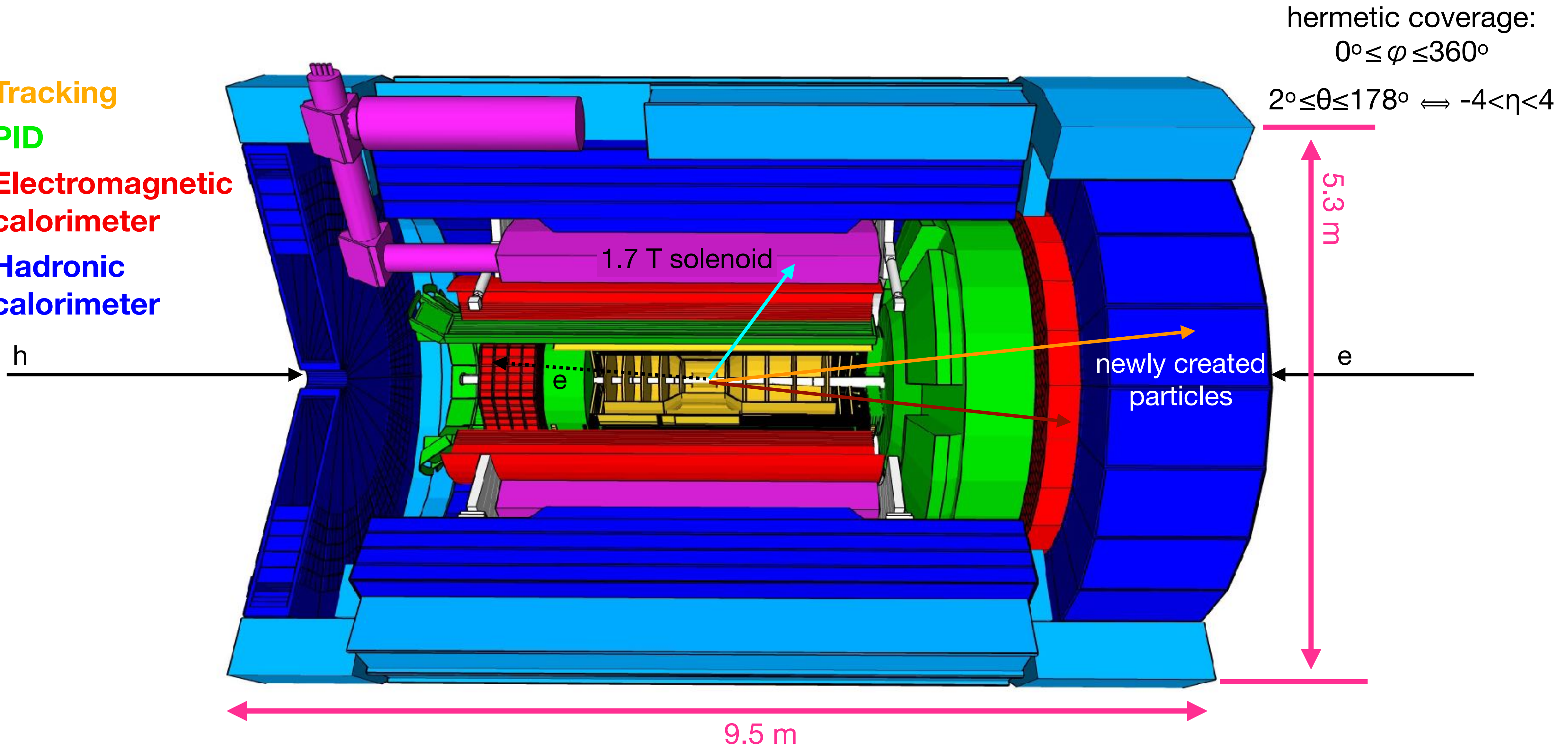


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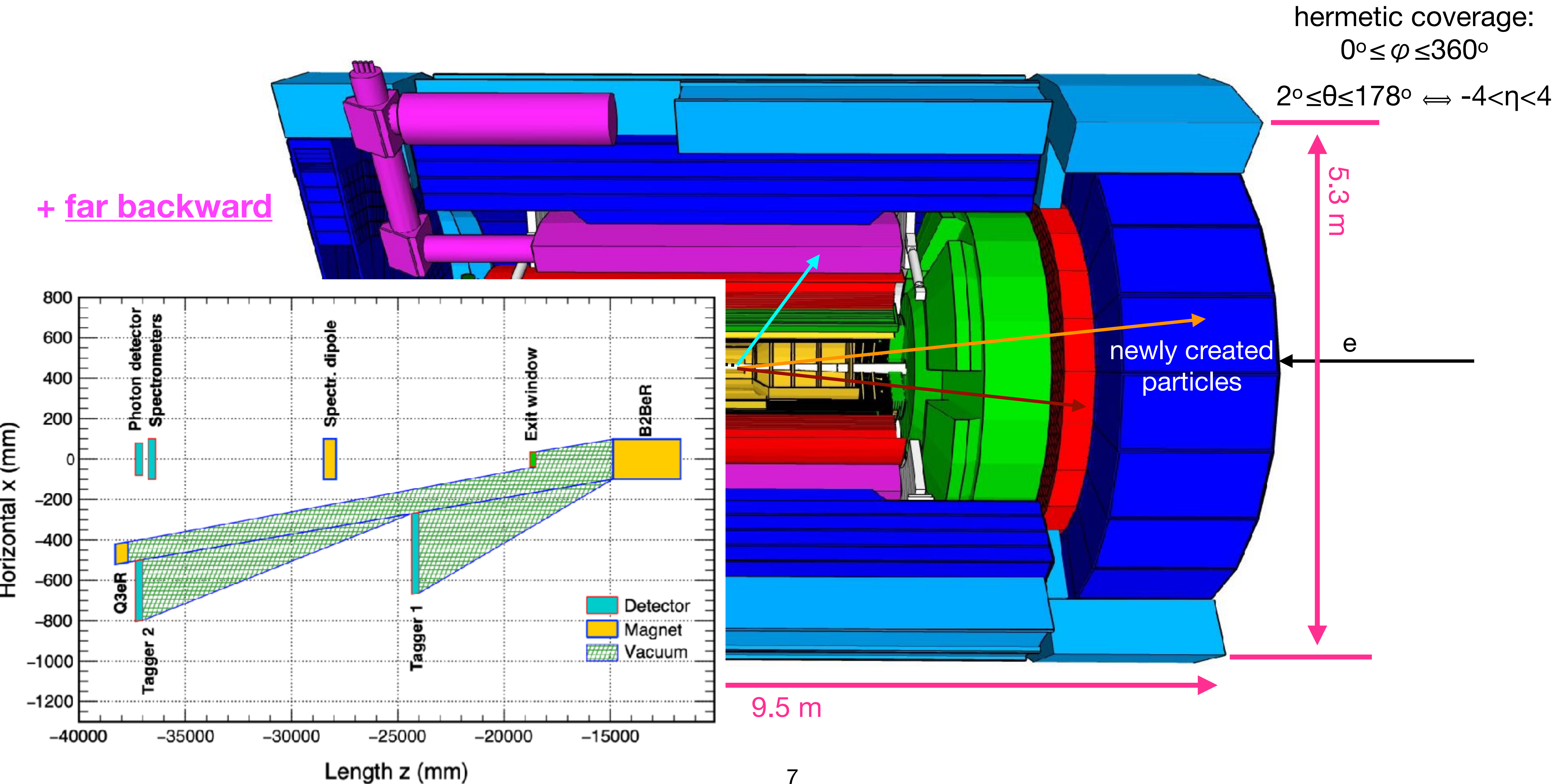


The electron-proton/ion collider (ePIC) detector

- Tracking
- PID
- Electromagnetic calorimeter
- Hadronic calorimeter

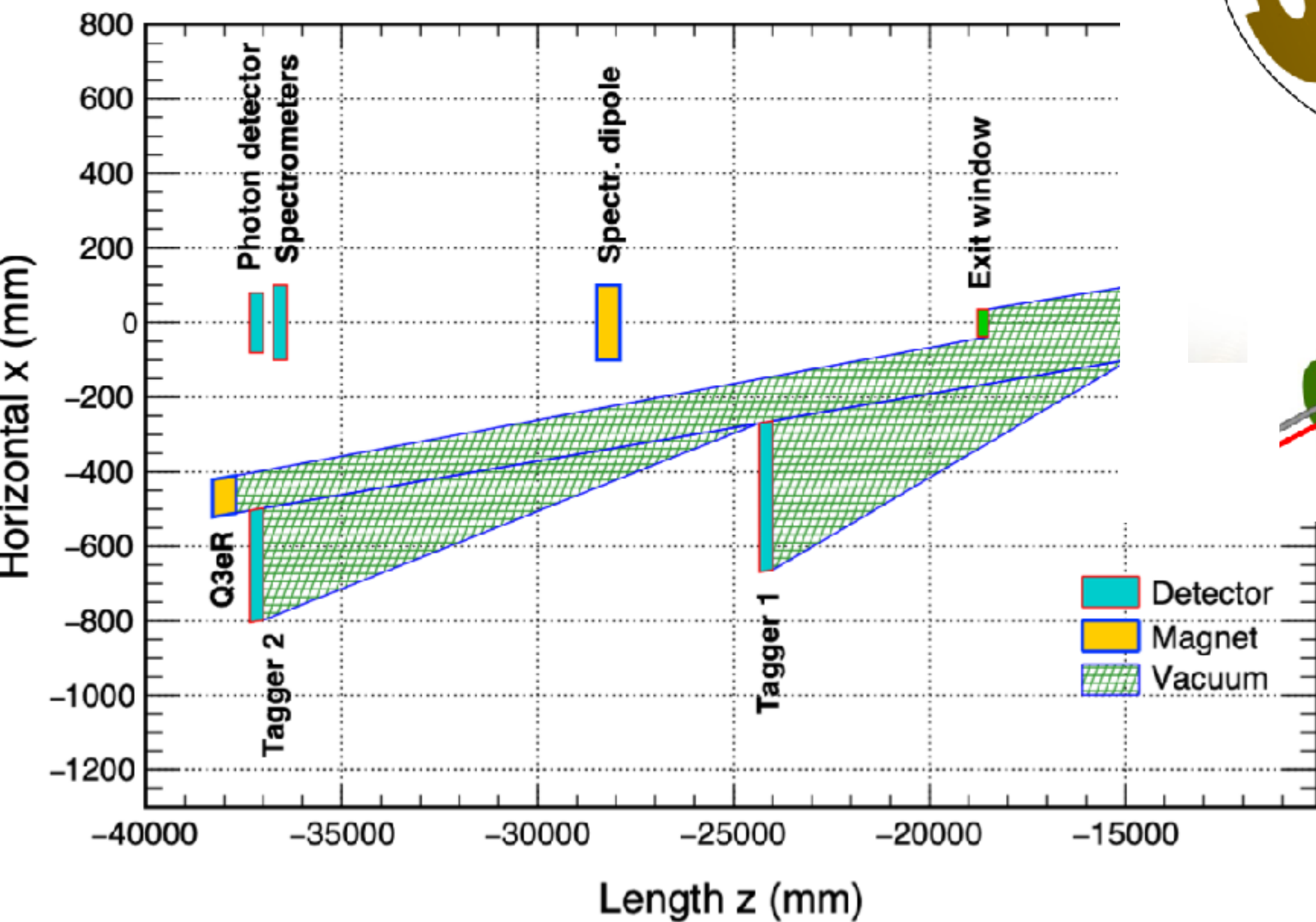
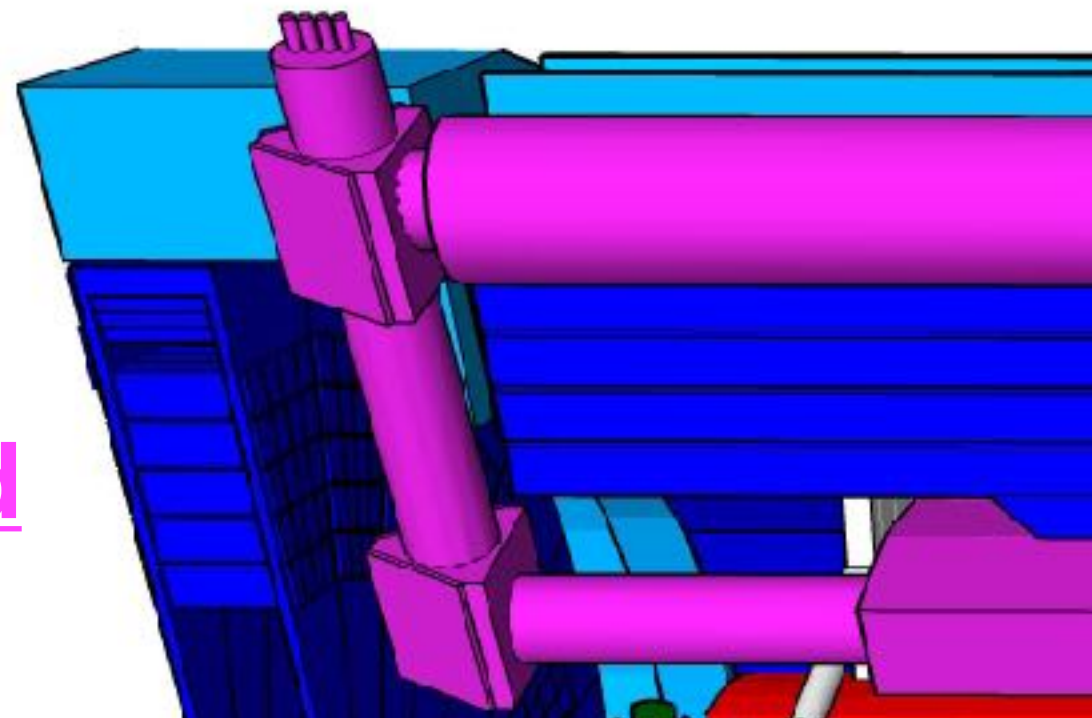


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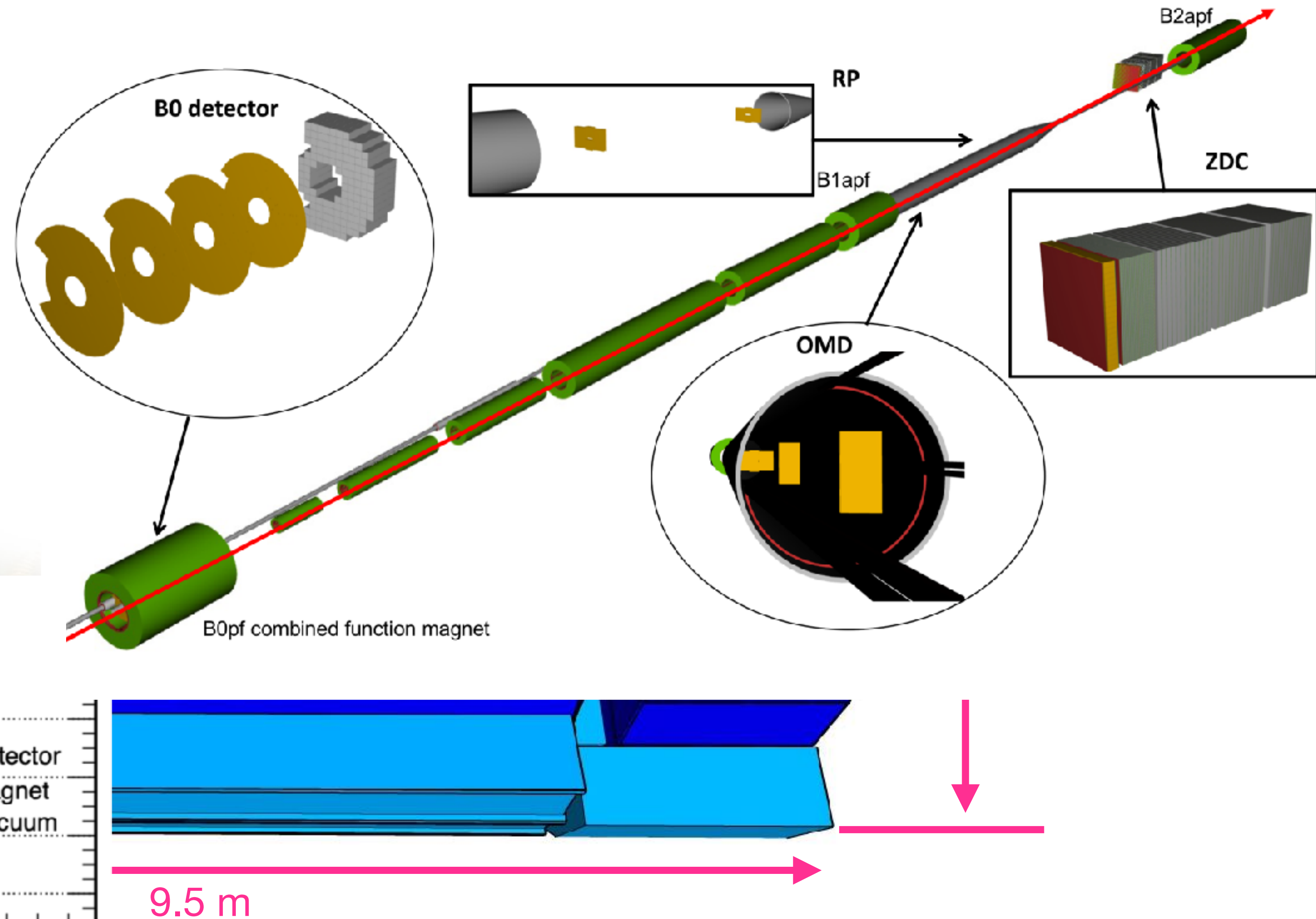


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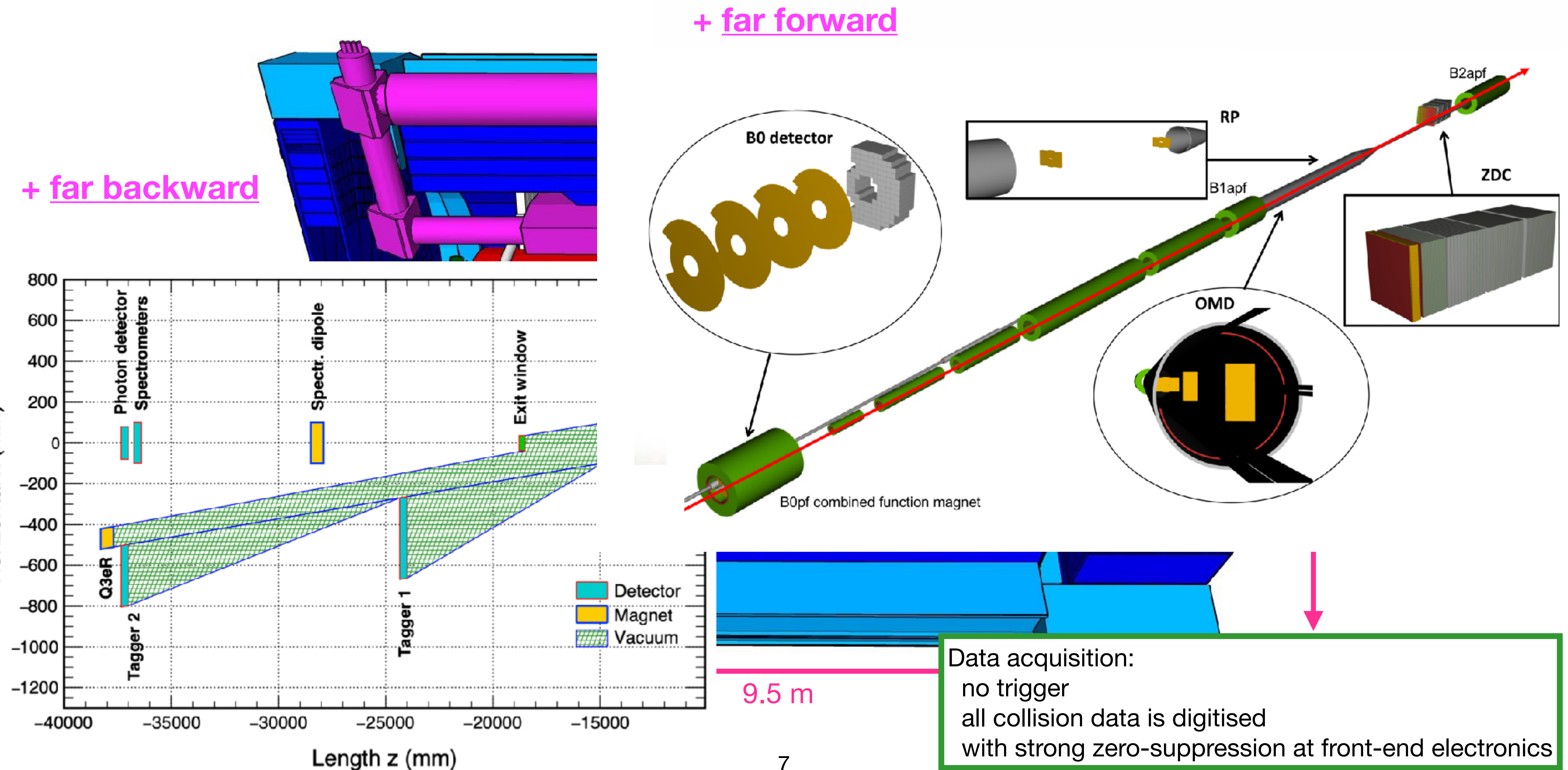
+ far backward



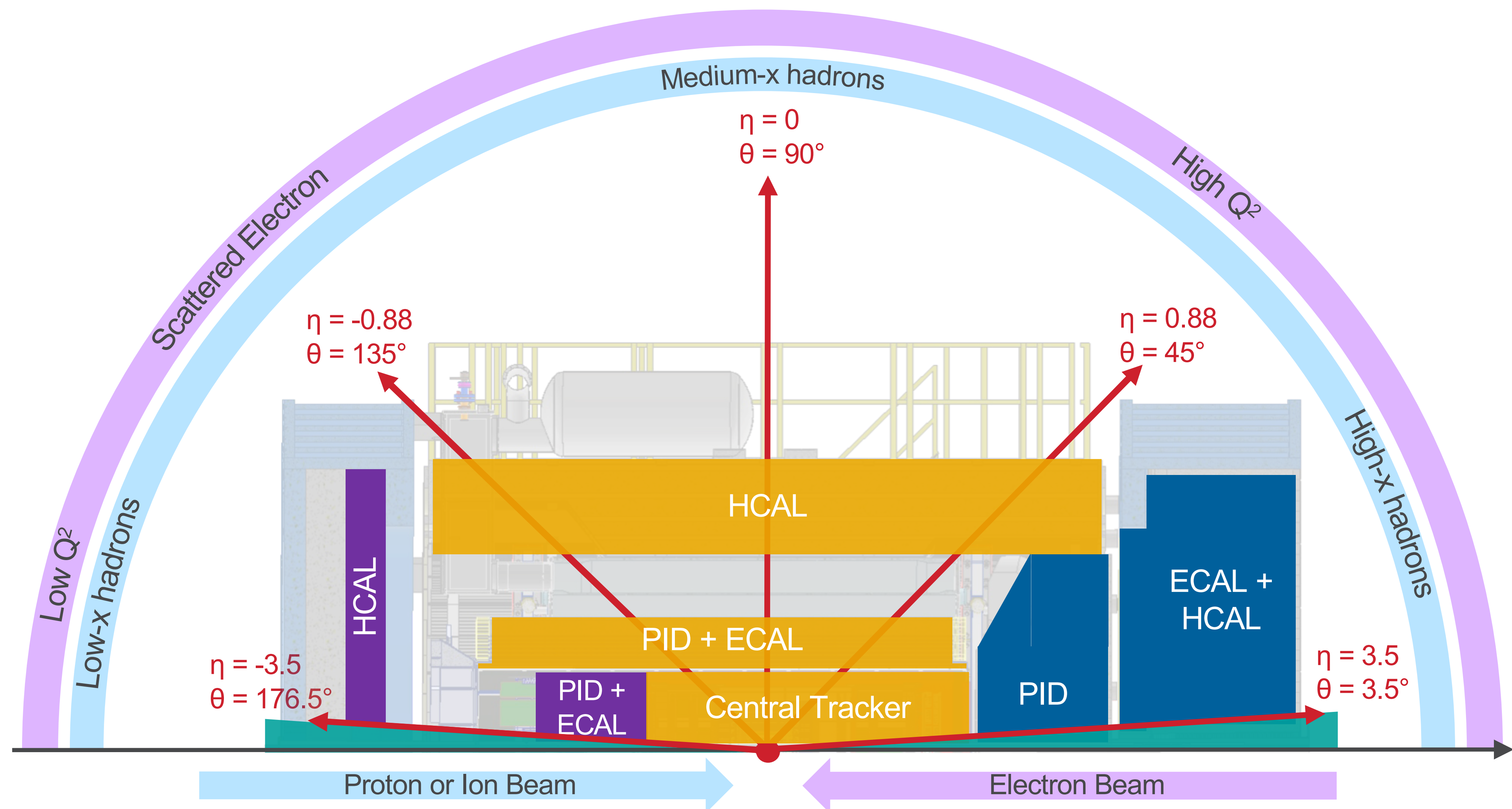
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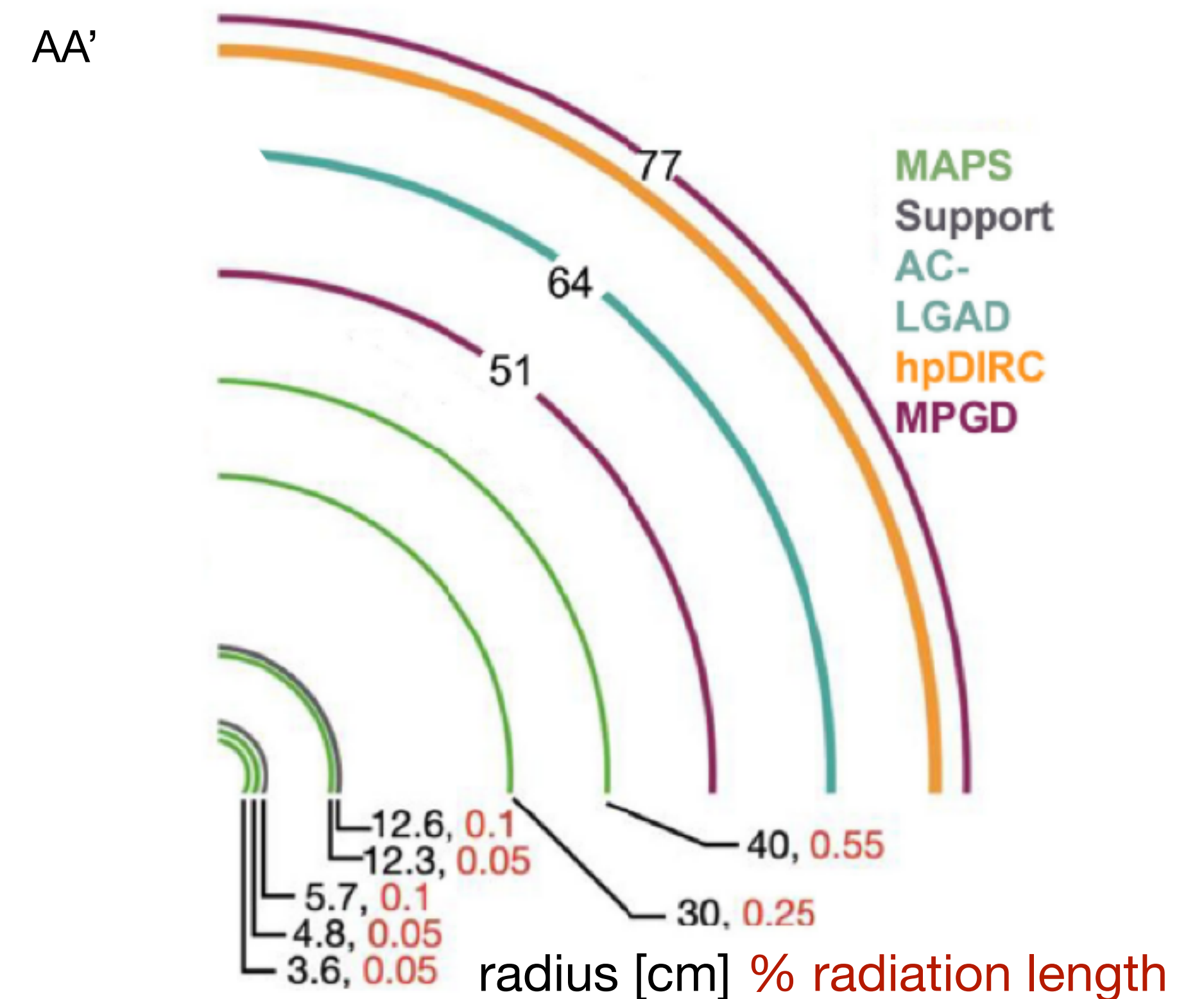
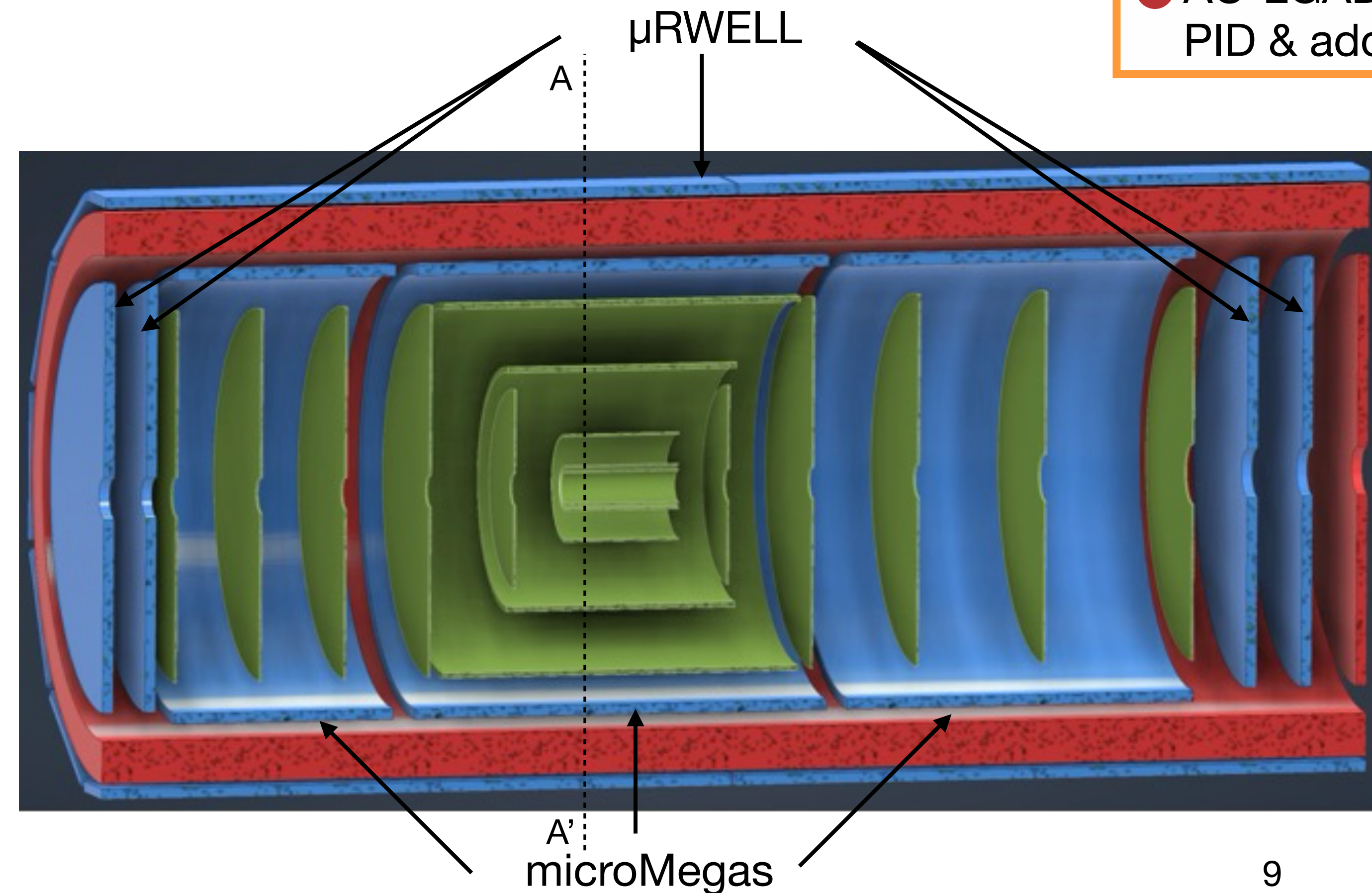


Kinematic coverage of central detector



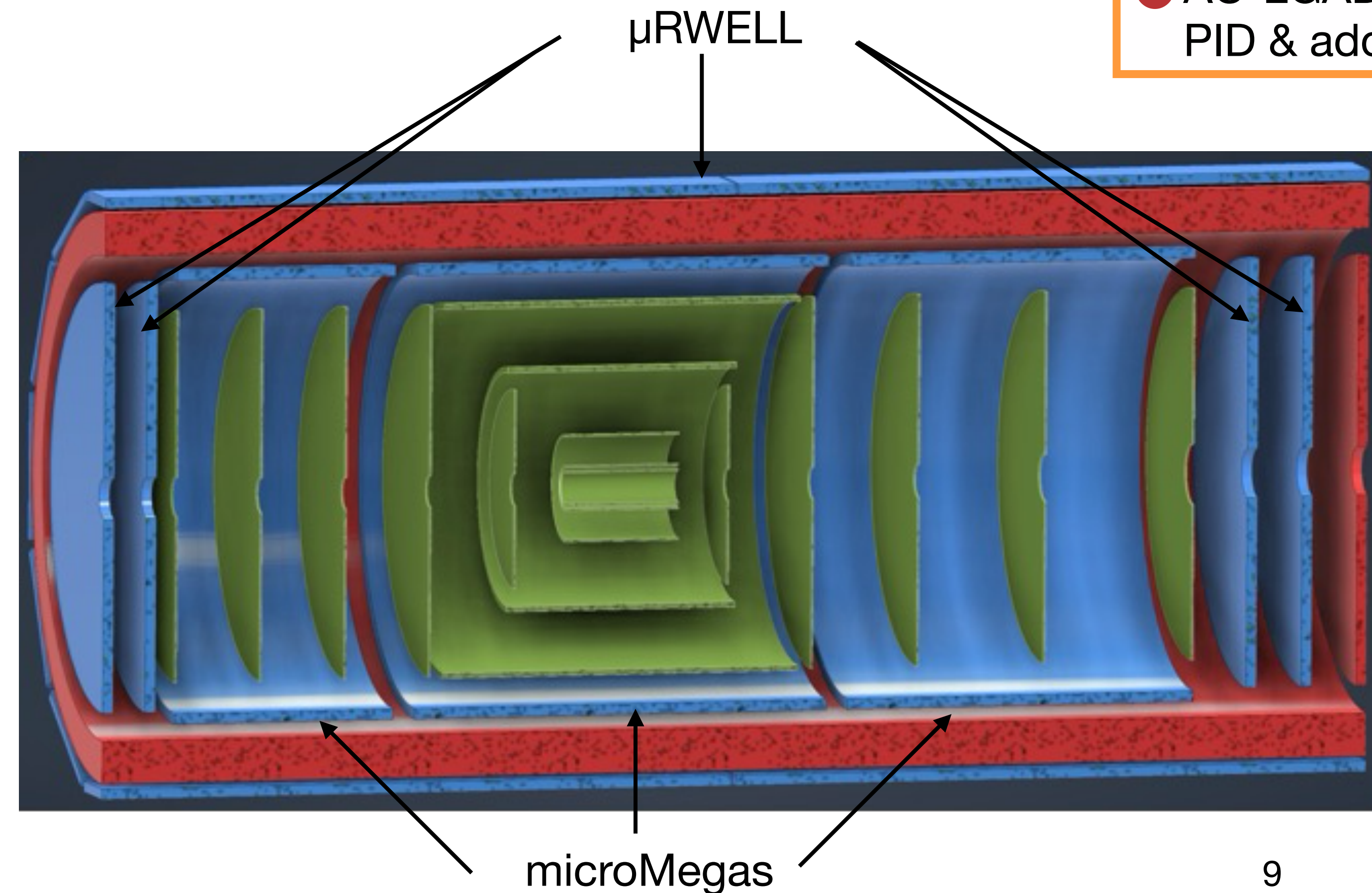
The tracking system

- 1.7 T solenoid
- Monolithic Active Pixel Sensor (MAPS)
Silicon vertexing/inner tracker: high spatial and moment
- Micro-pattern gaseous detectors
 μ RWELL/microMegas:
timing (resolution: 10–20 ns) & pattern recognition
- AC-LGAD based TOF:
PID & additional tracking point

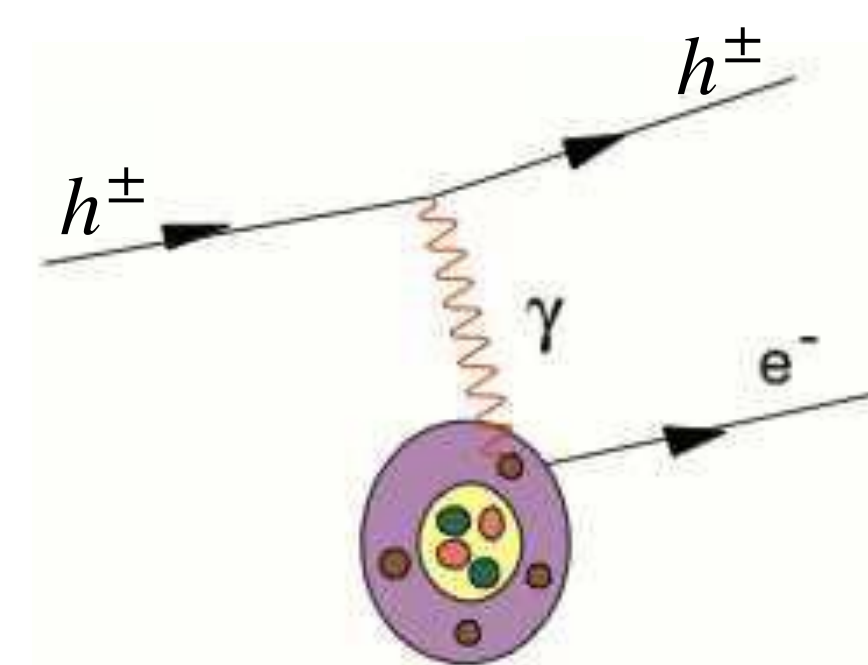


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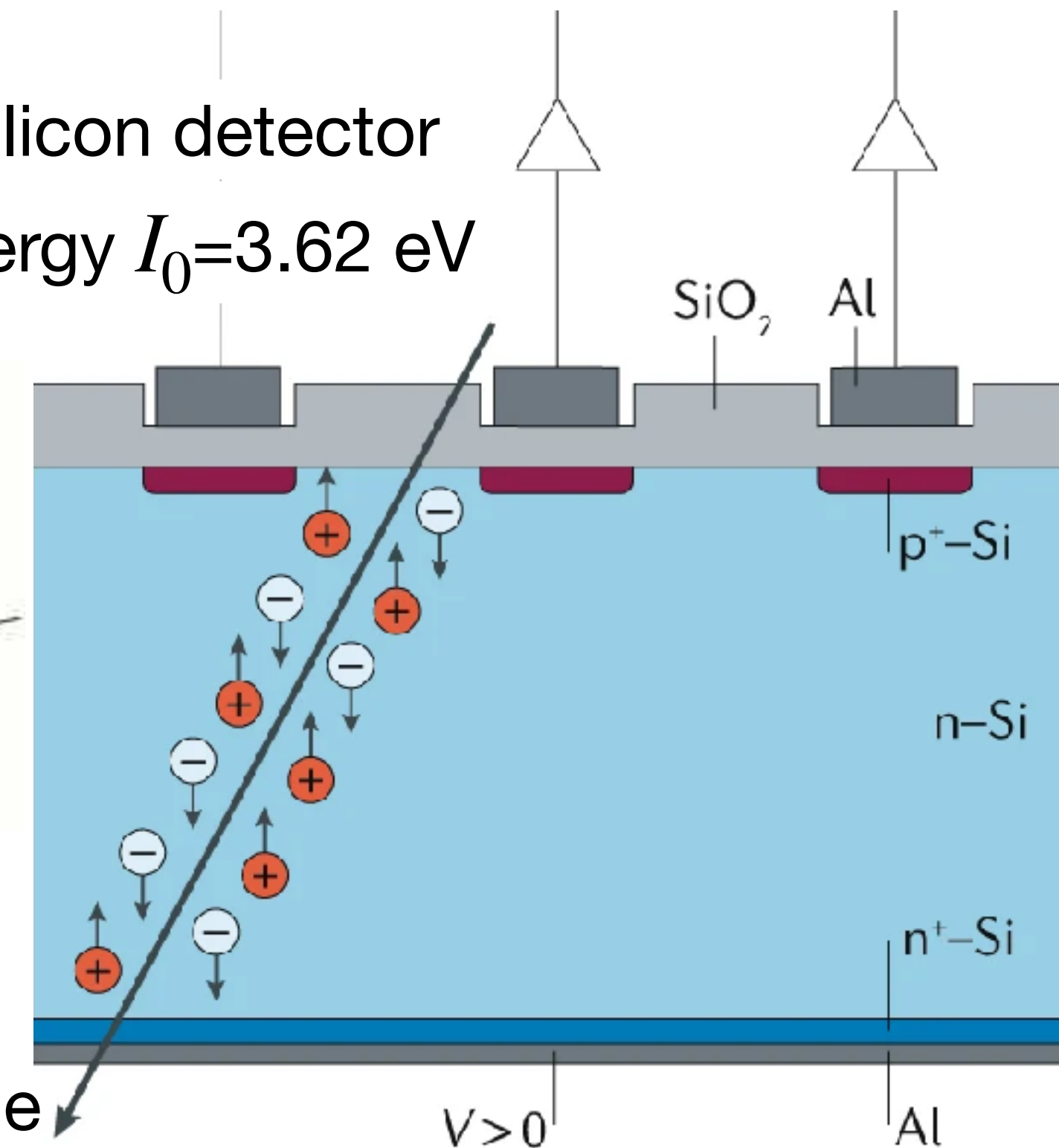
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Working principle silicon detector
Mean ionisation energy $I_0 = 3.62$ eV

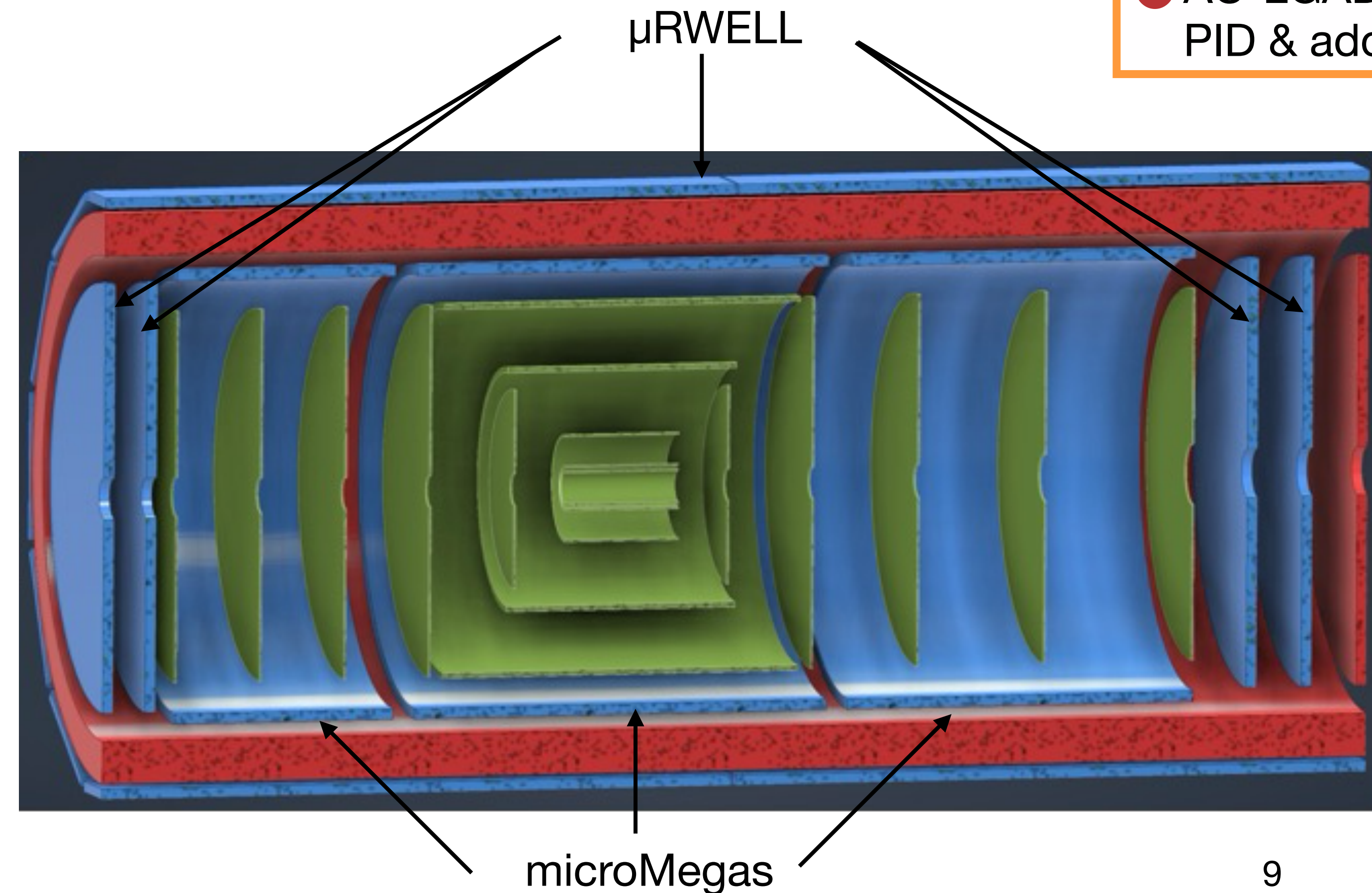


charged particle

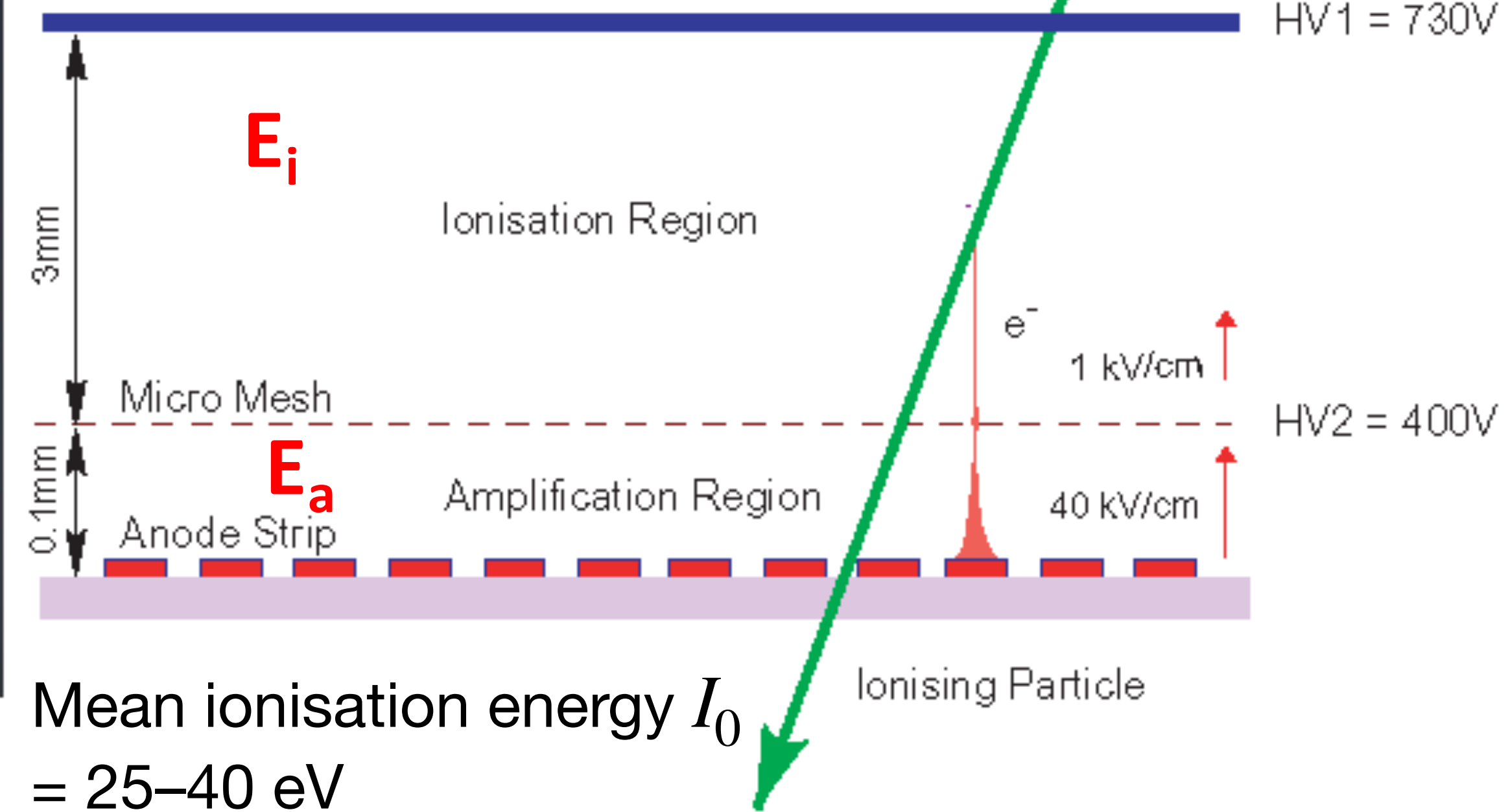


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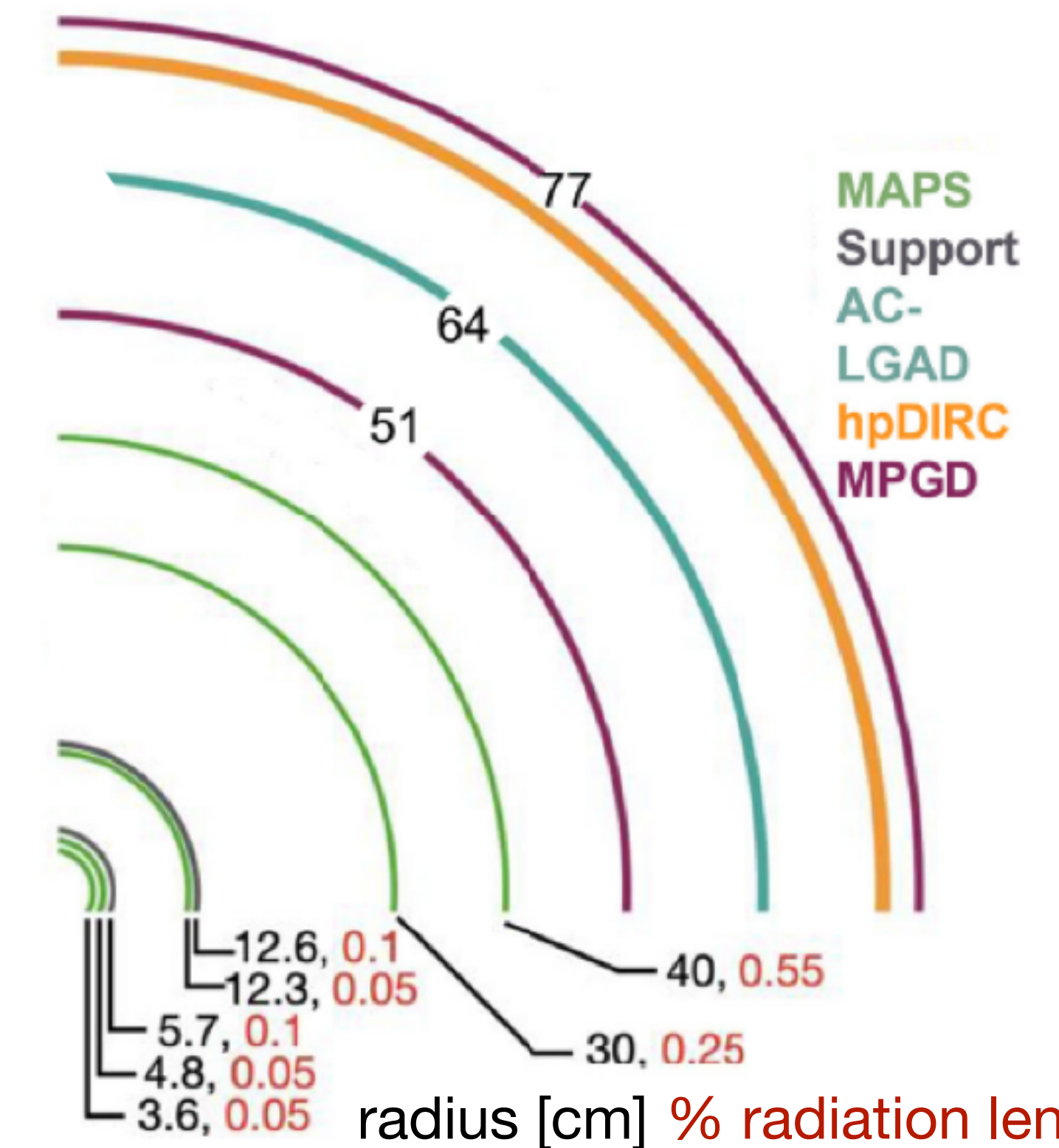
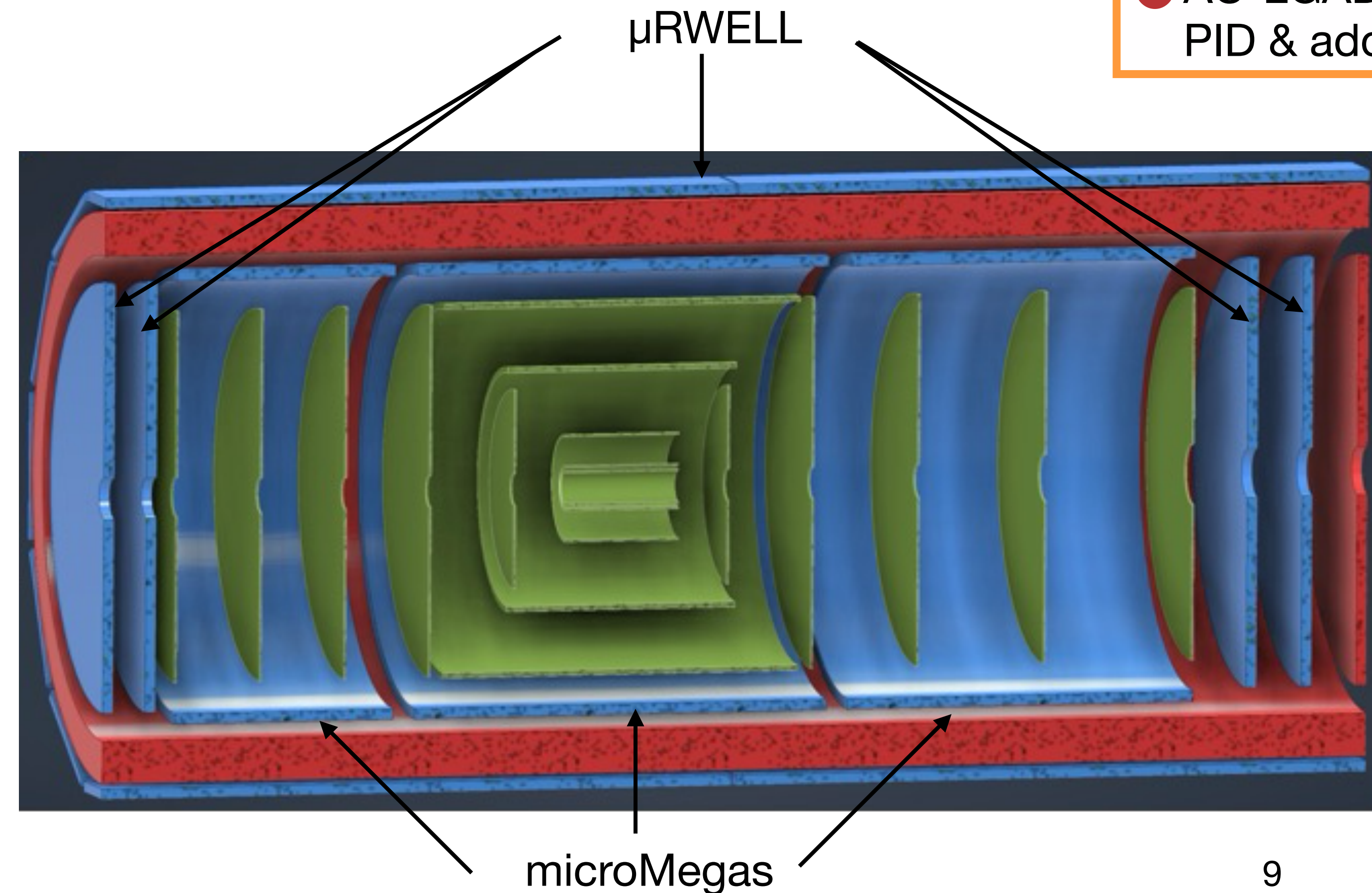


Working principle micro-pattern gaseous detectors (microMegas)



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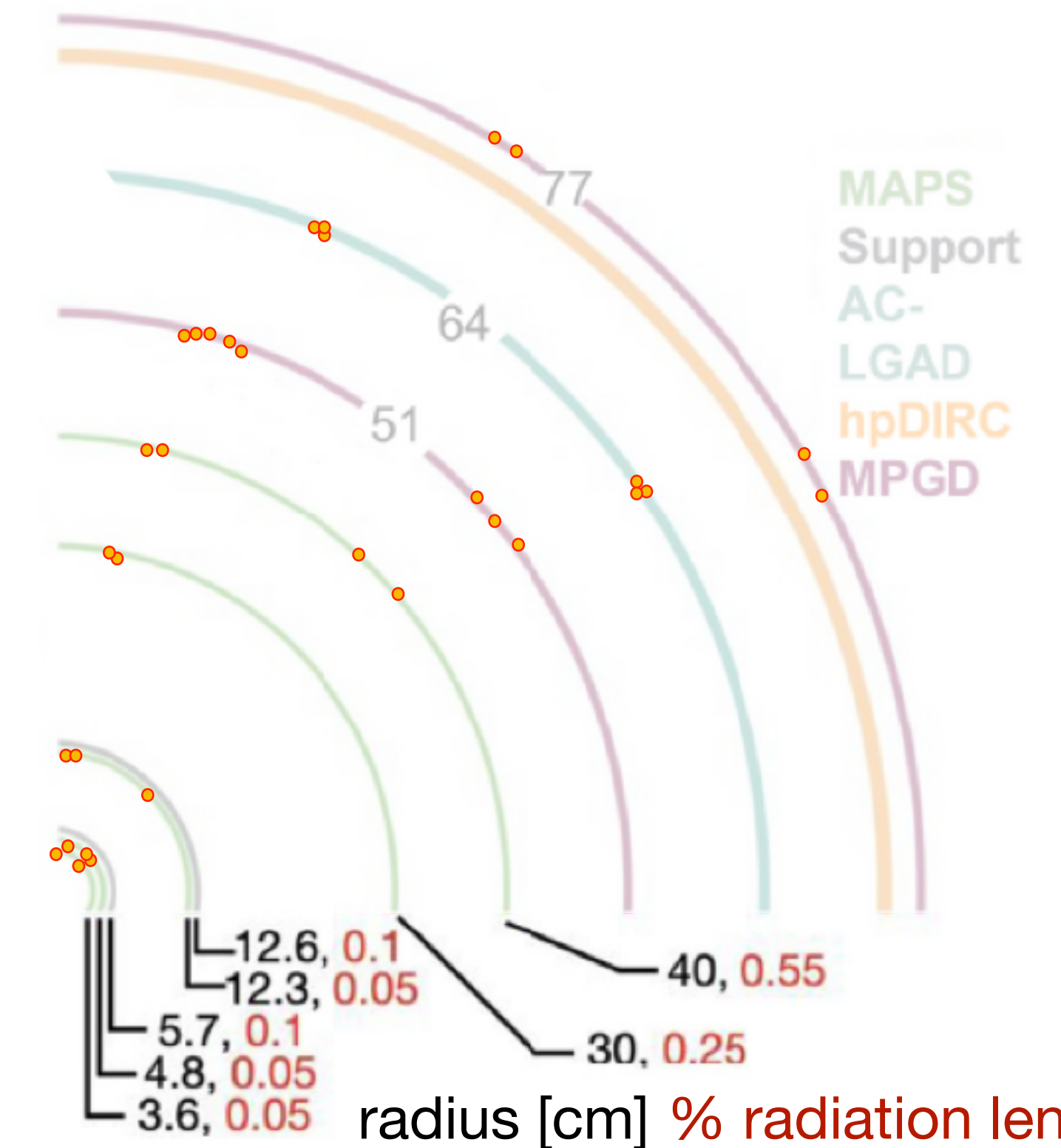
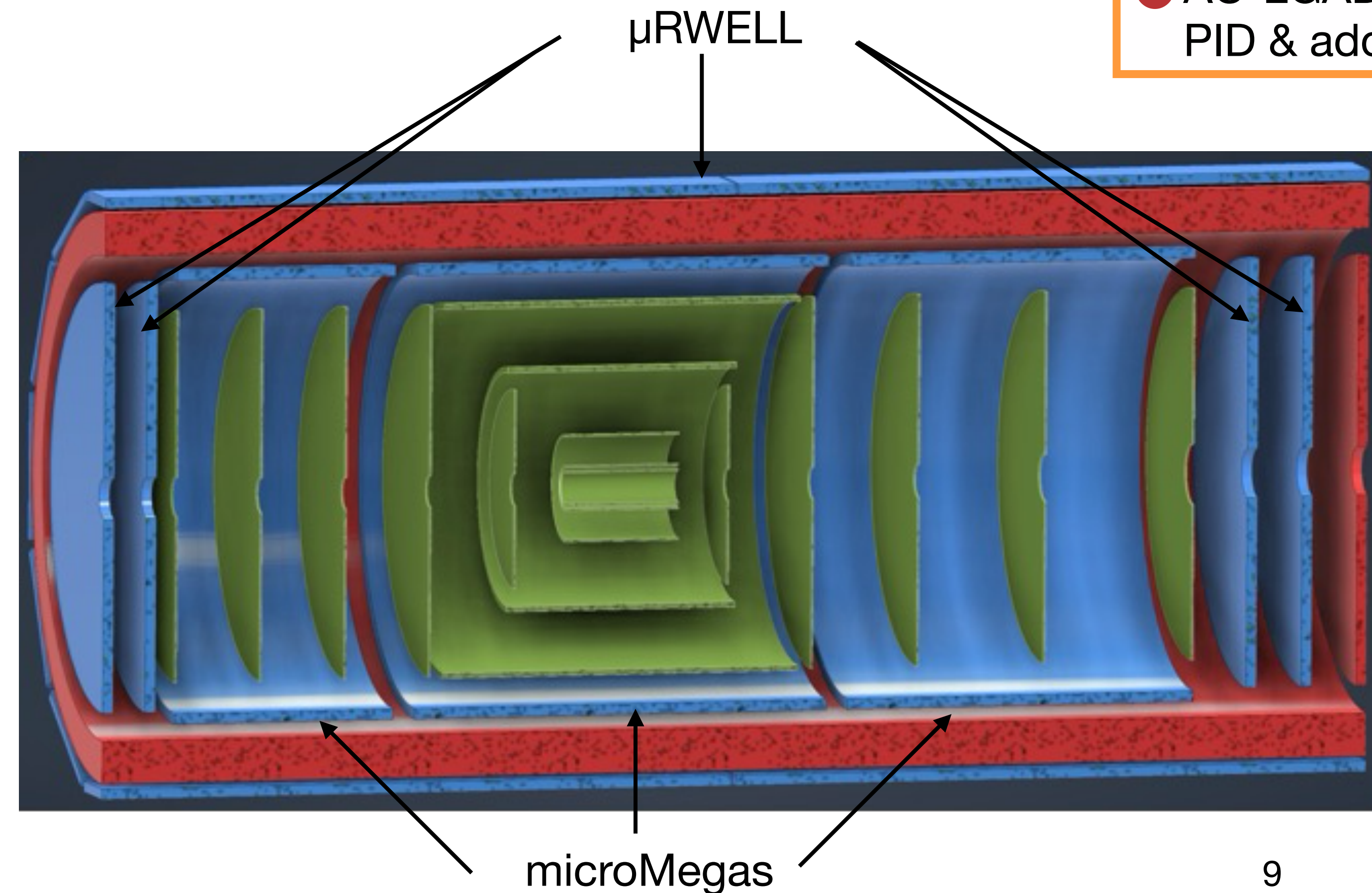
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radius [cm] % radiation length
(radiation length= $\langle L \rangle$ at which e^- E reduced by 1/e)

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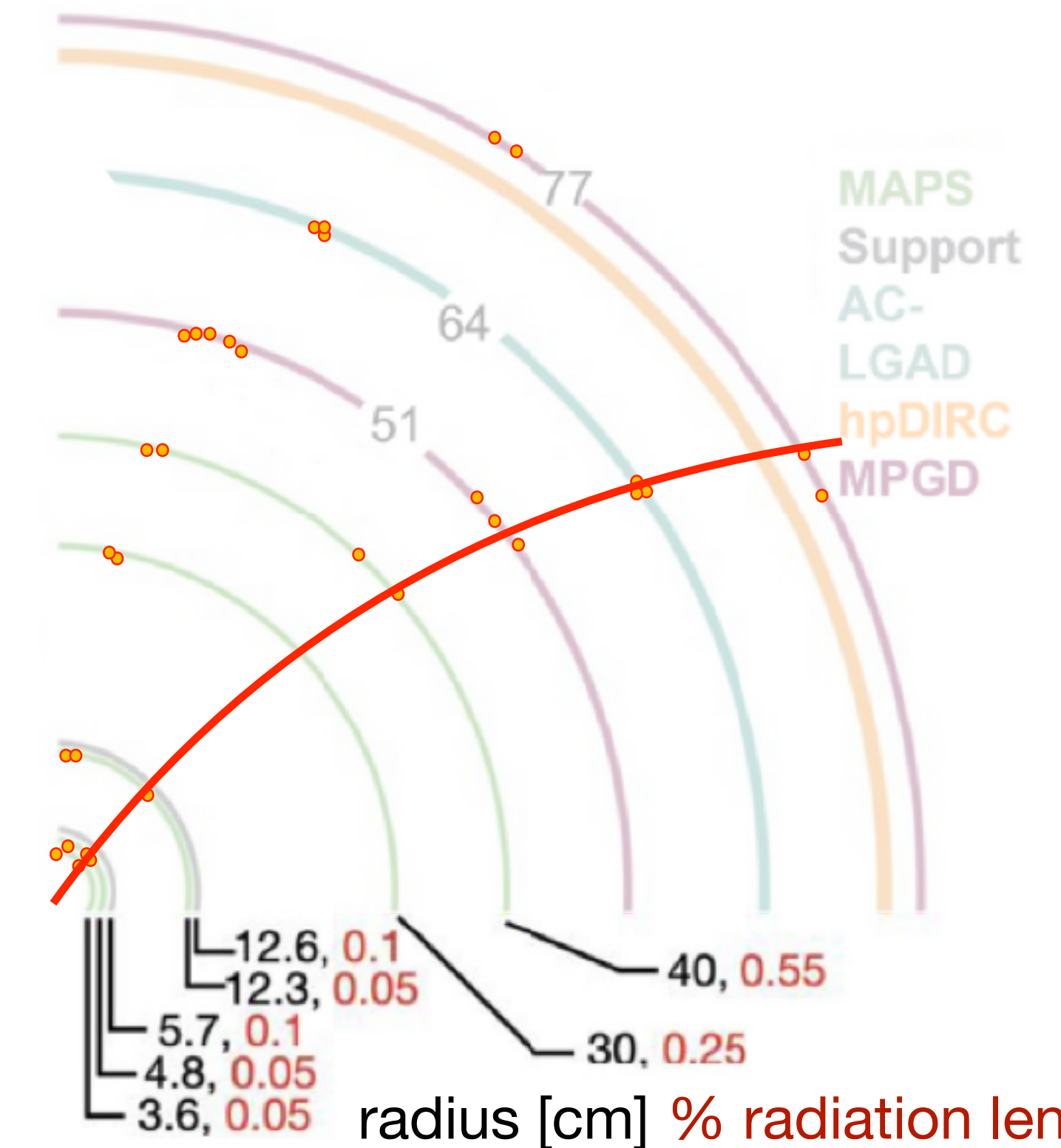
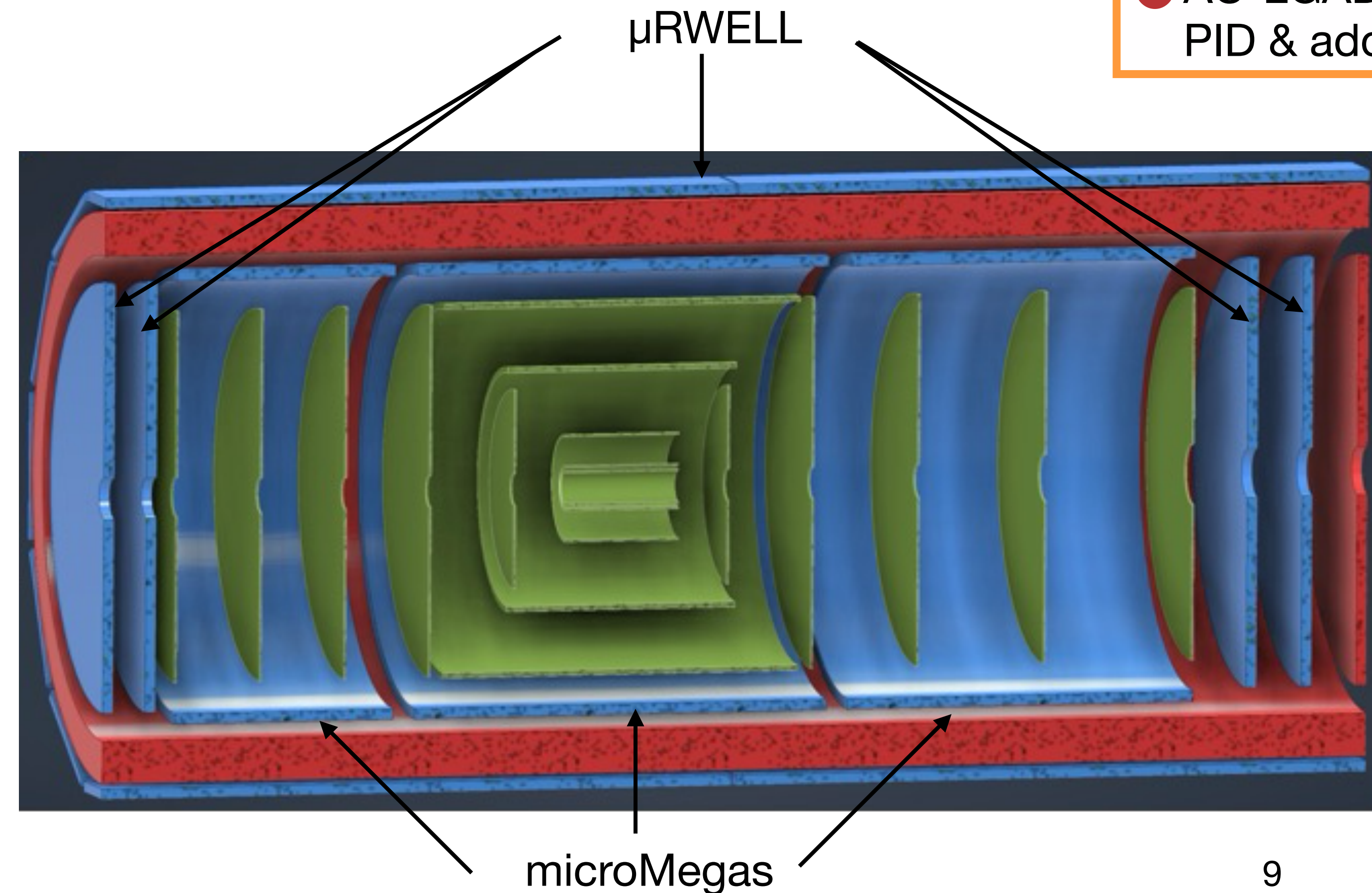
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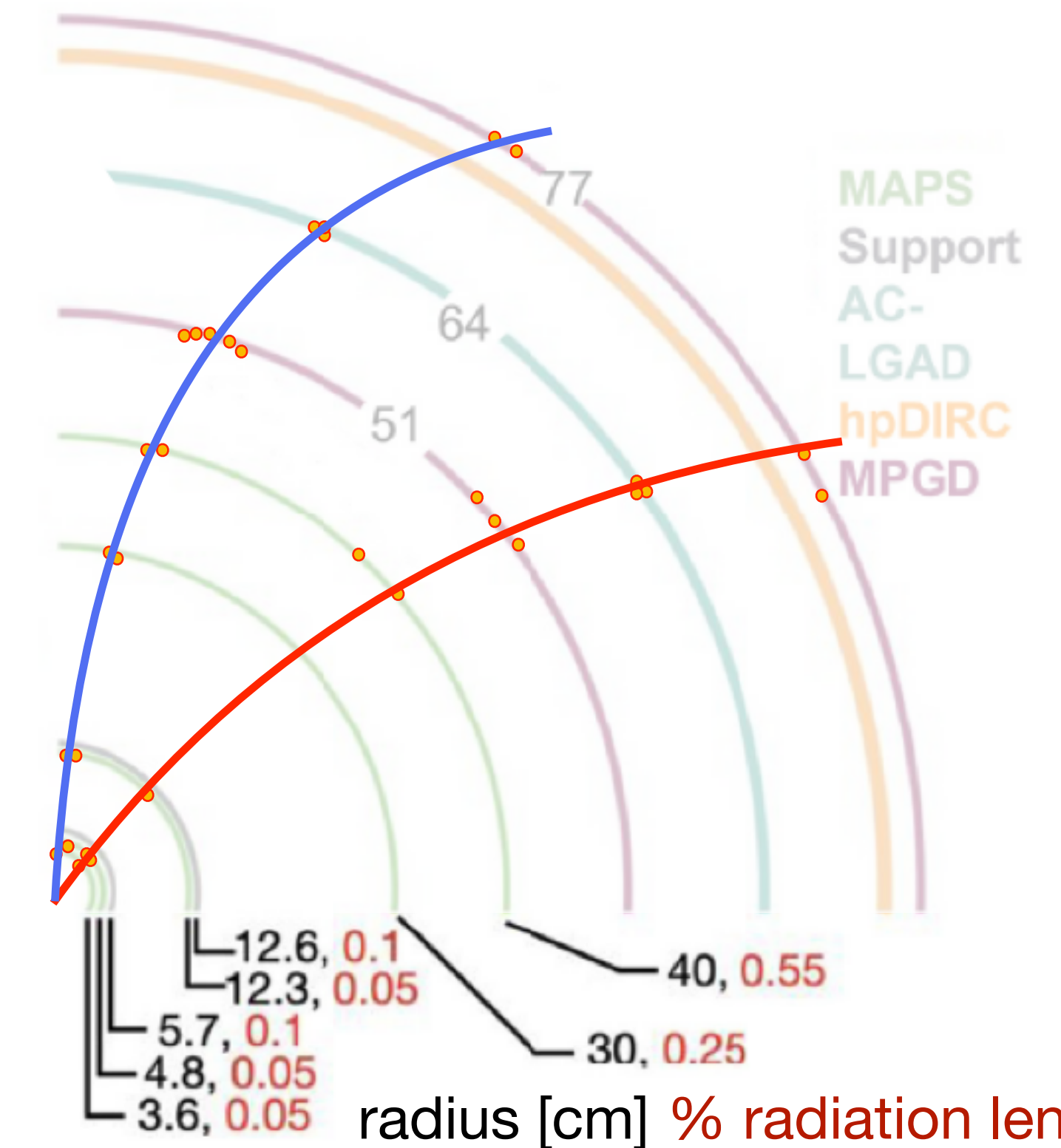
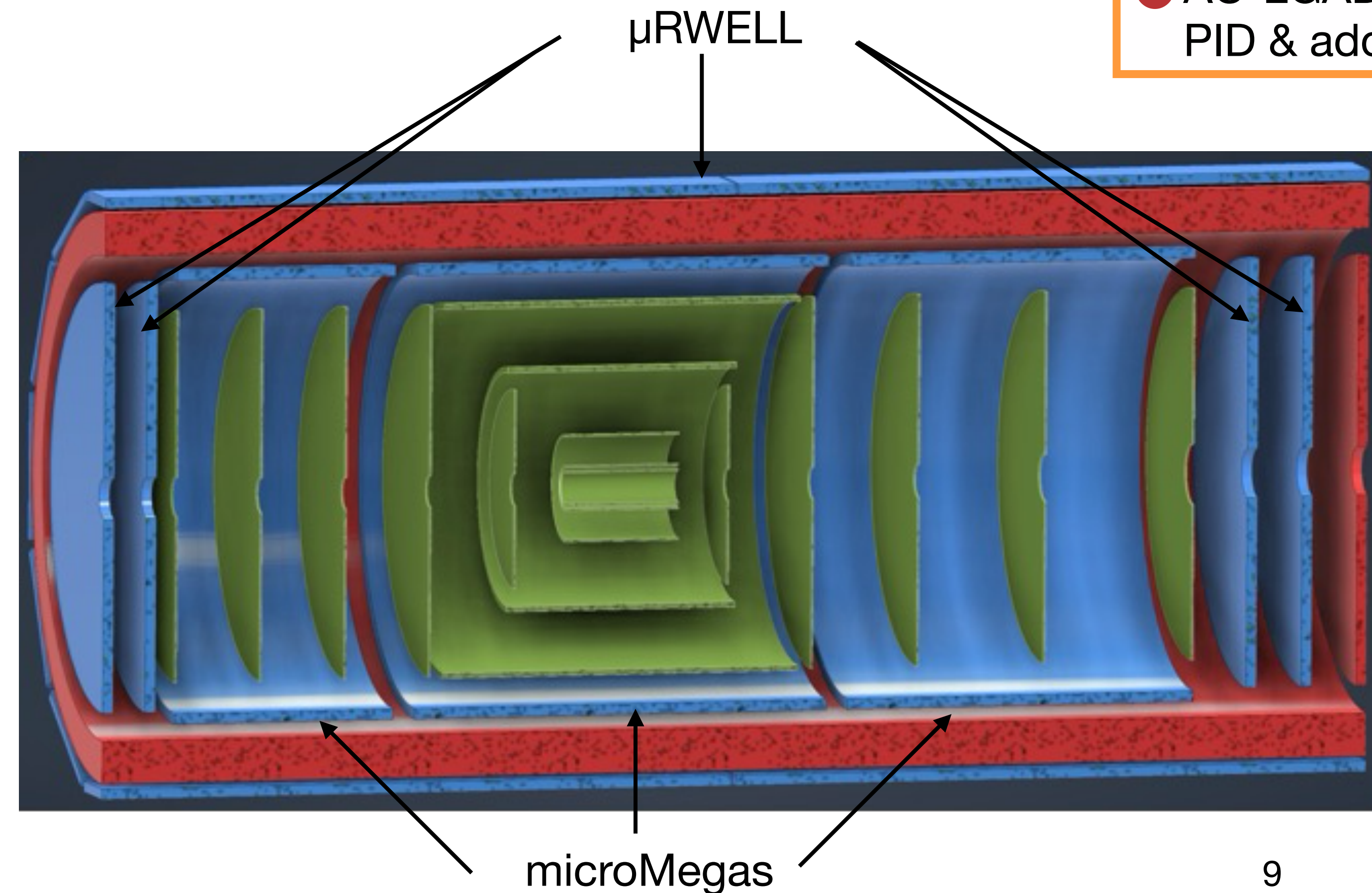
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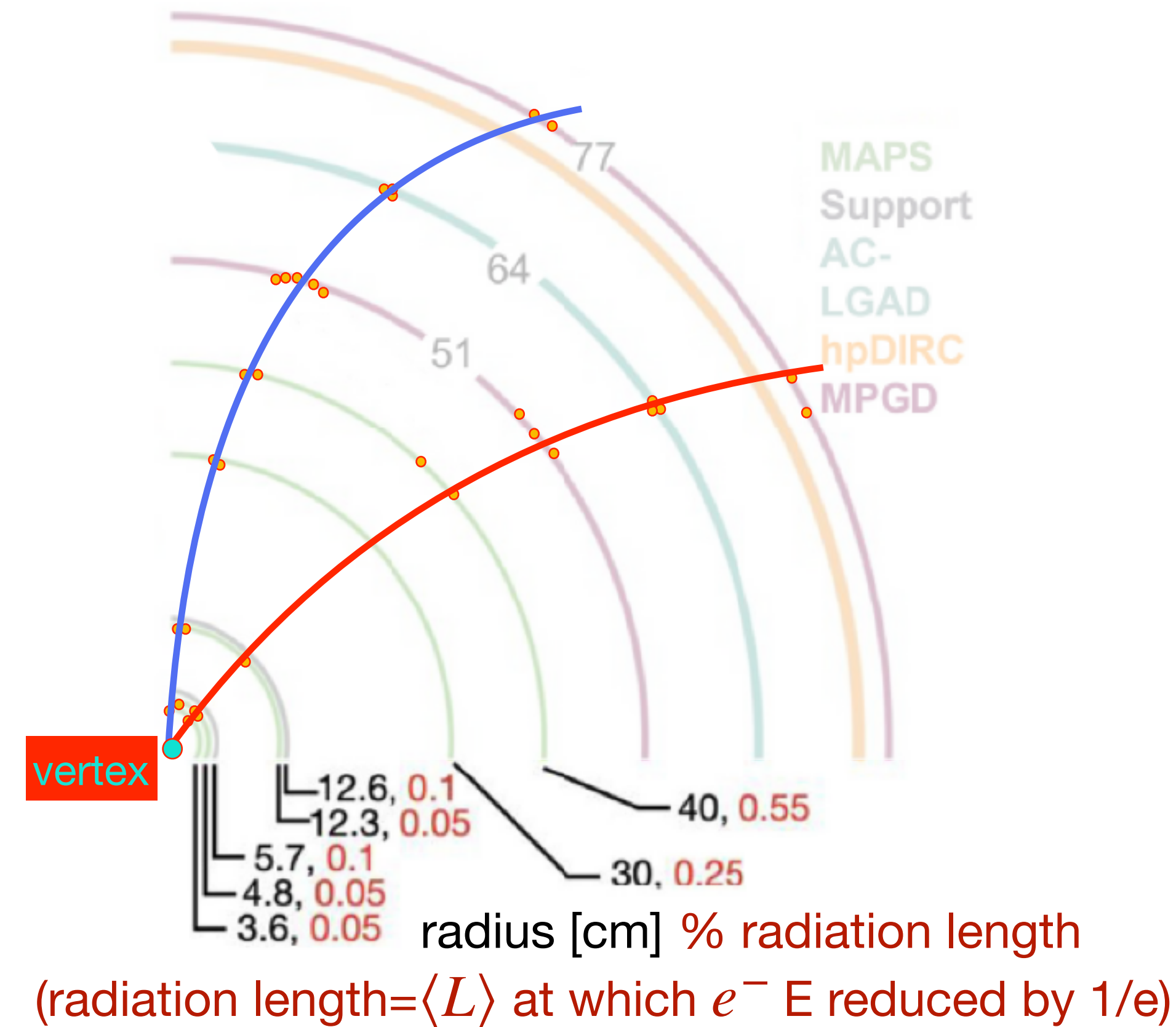
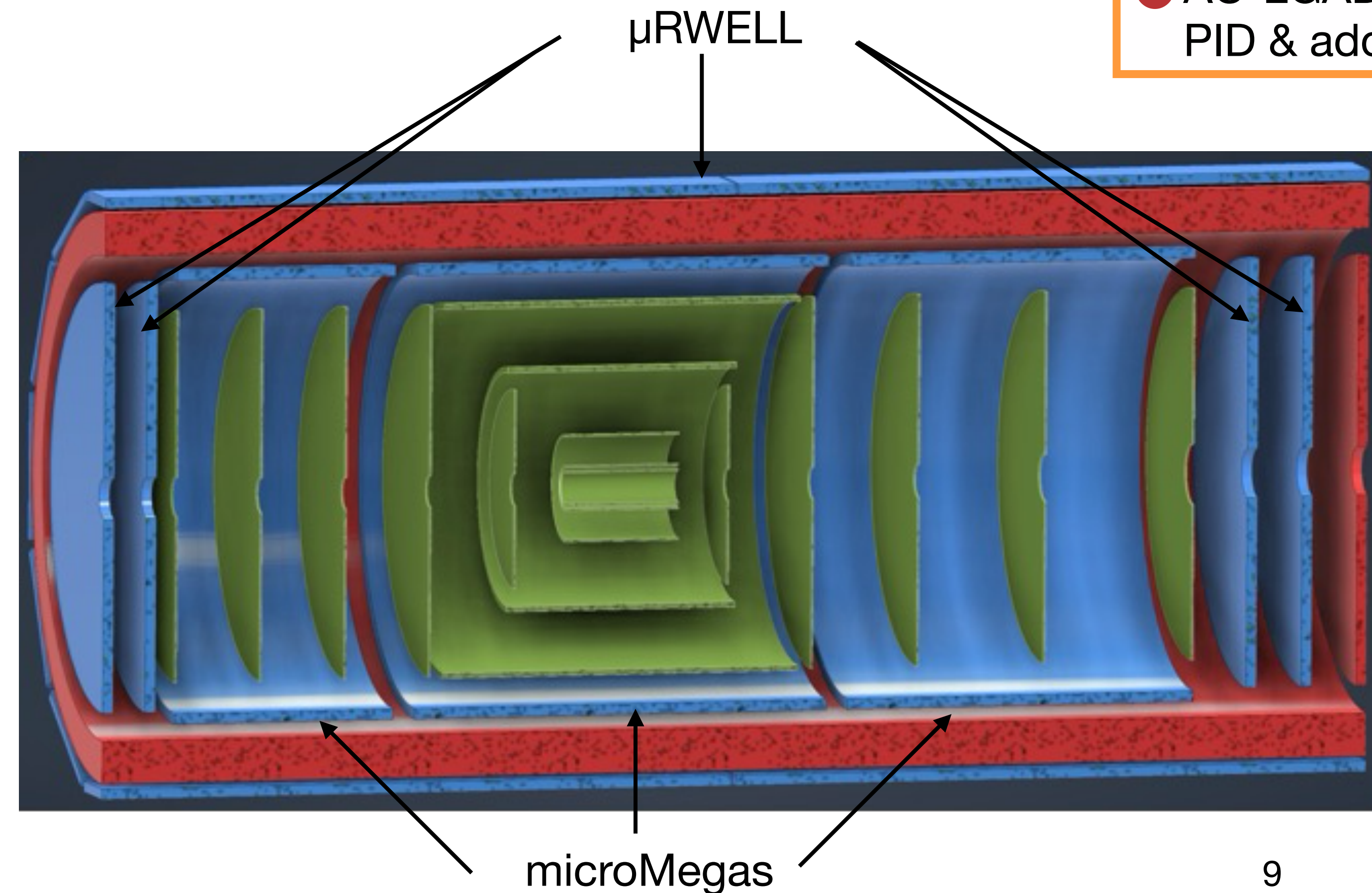
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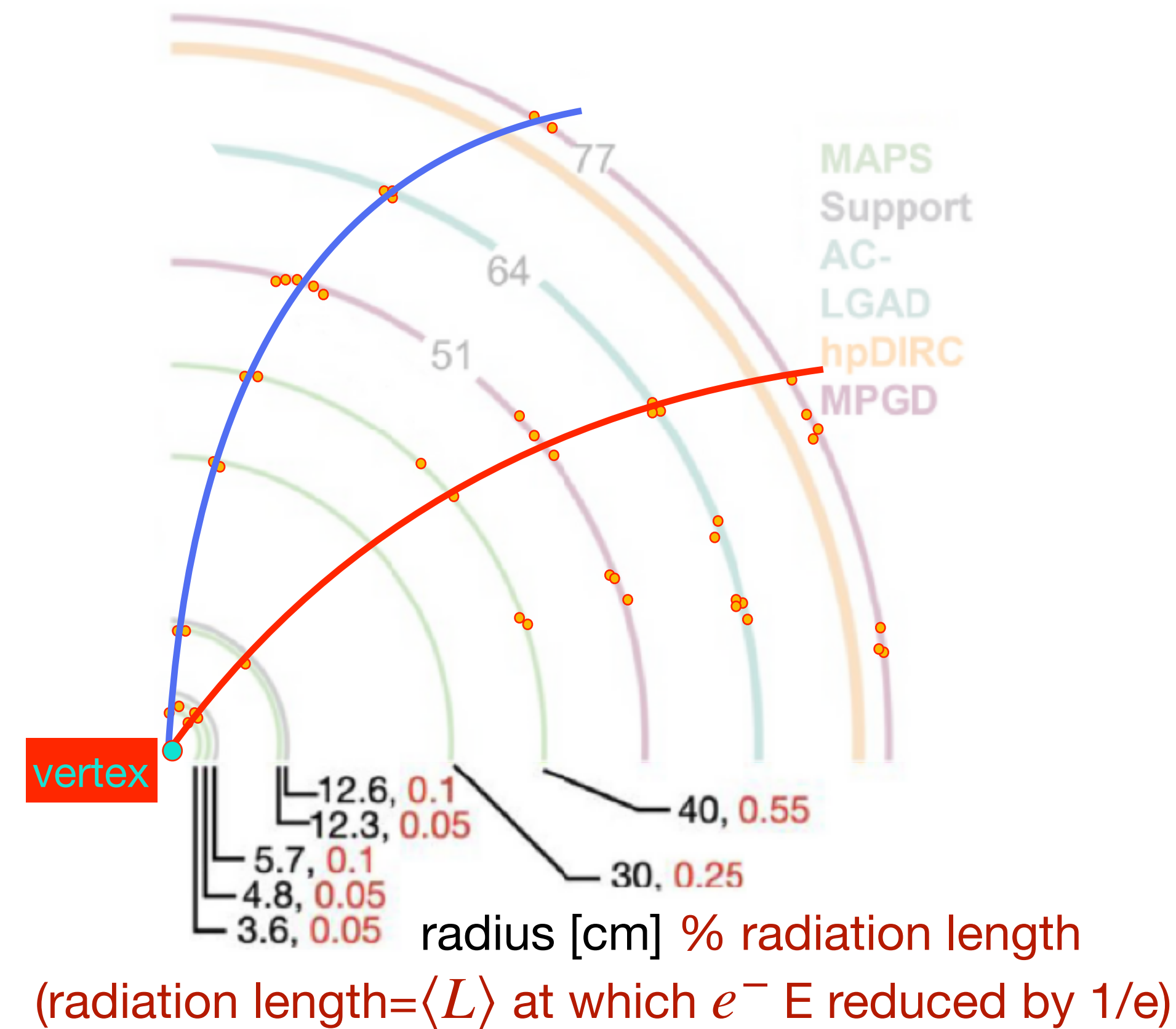
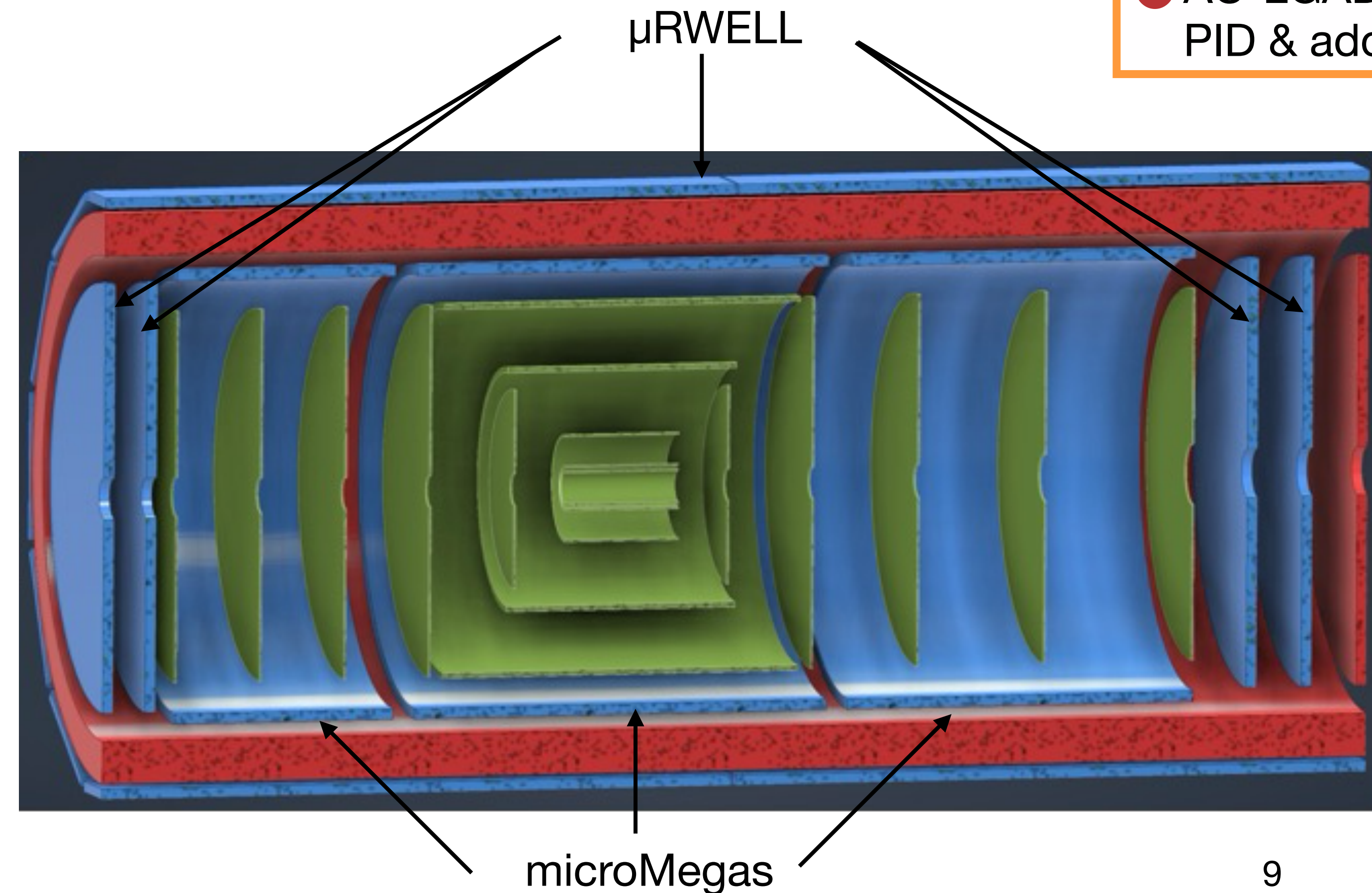
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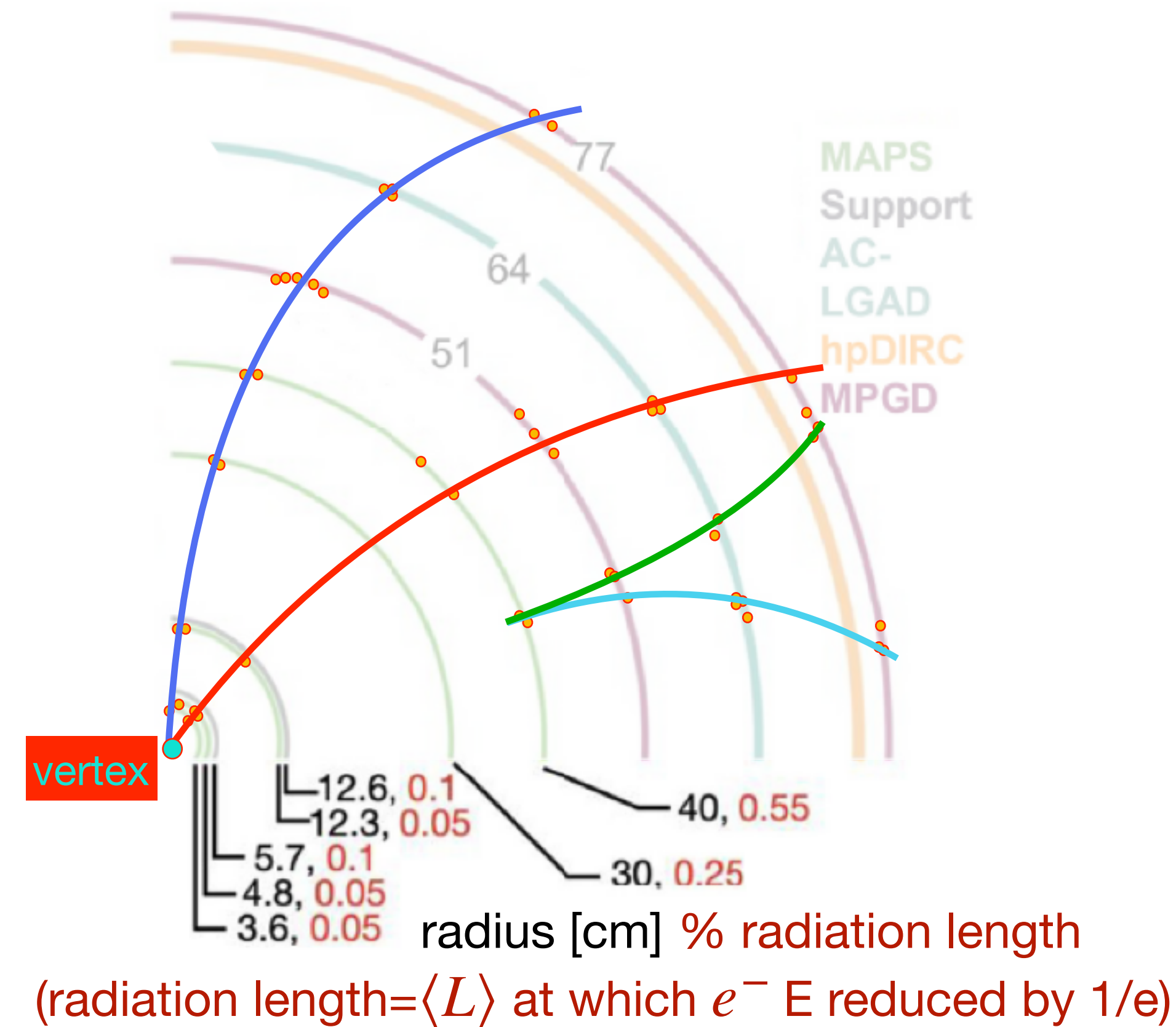
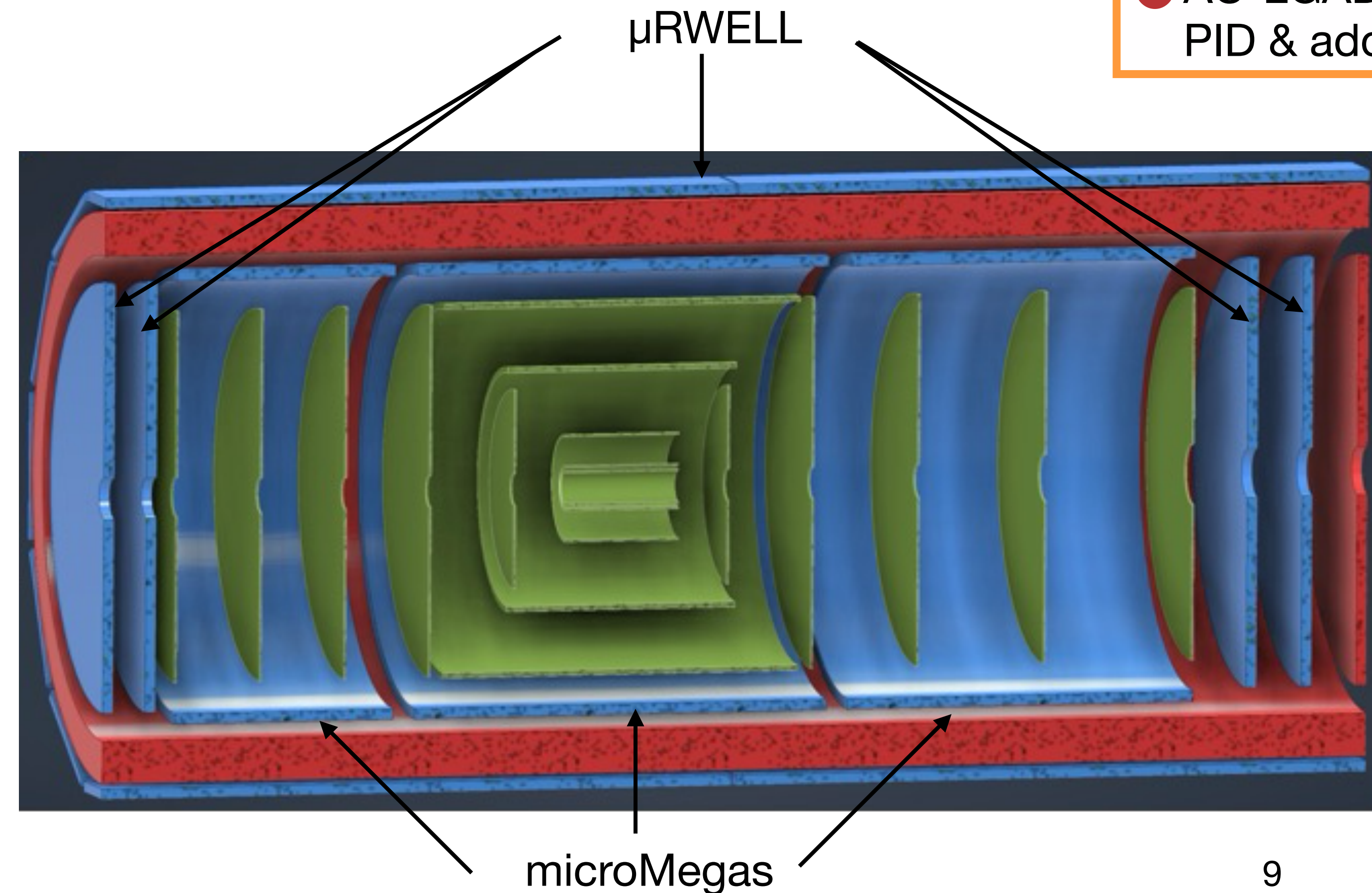
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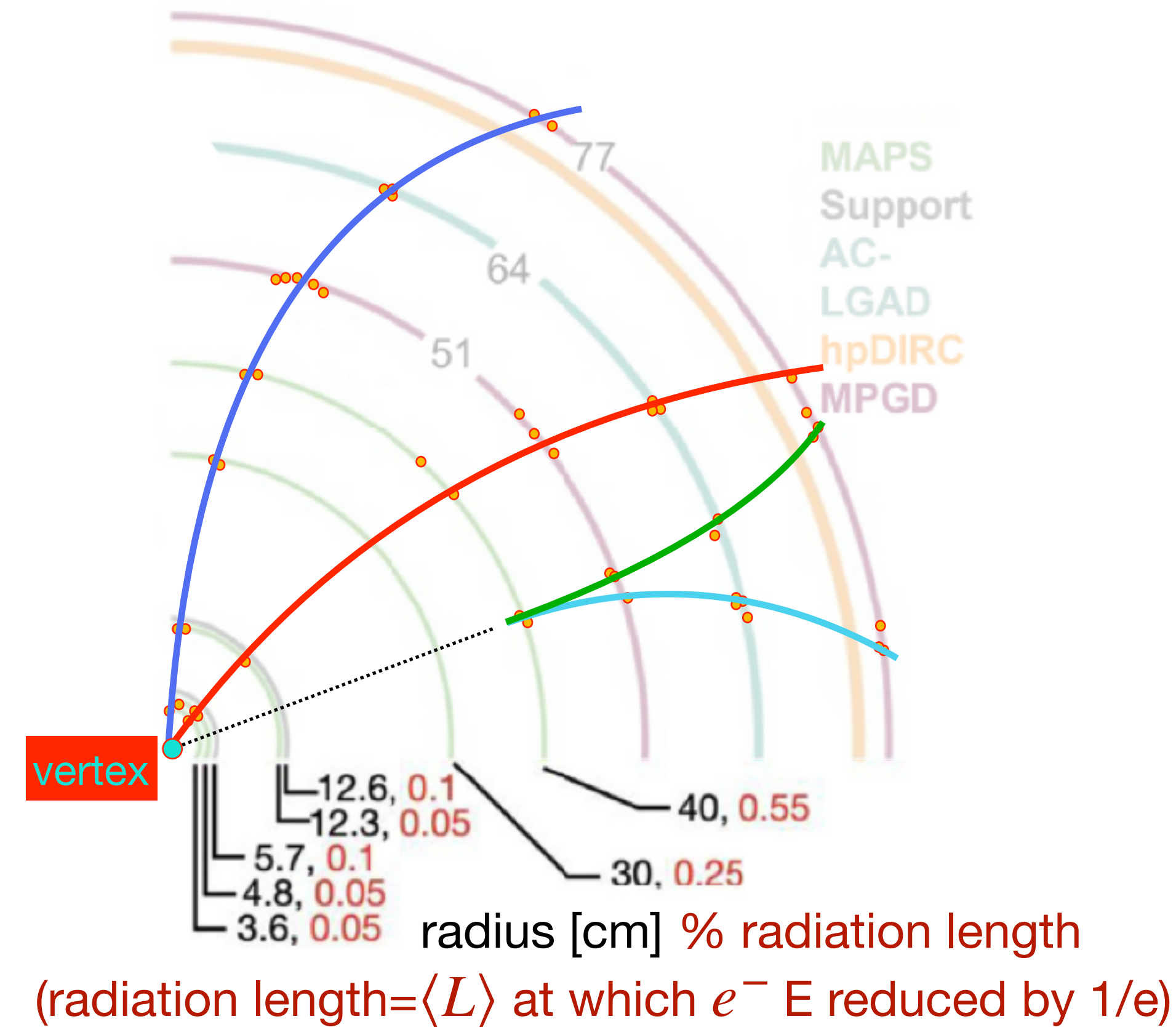
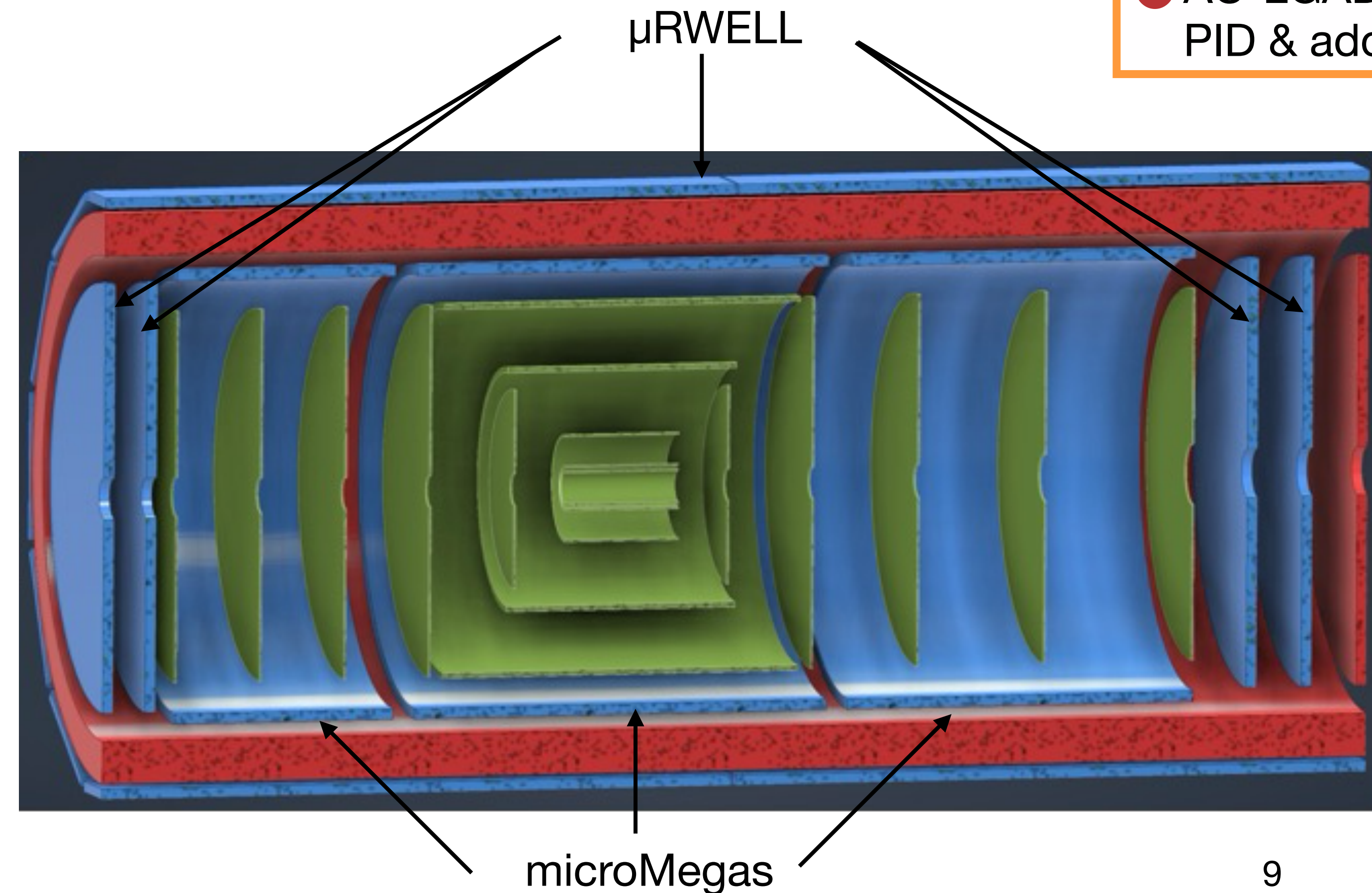
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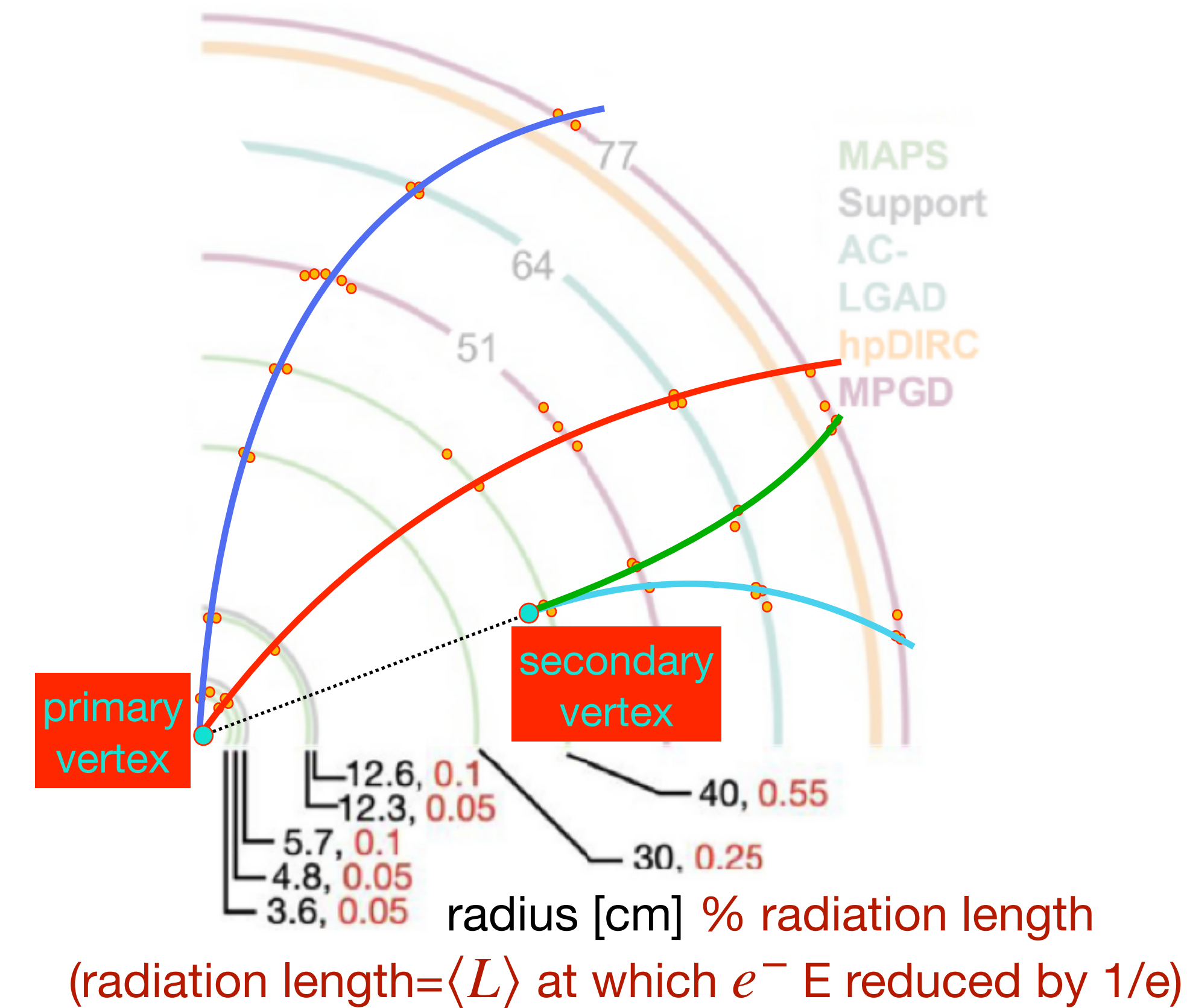
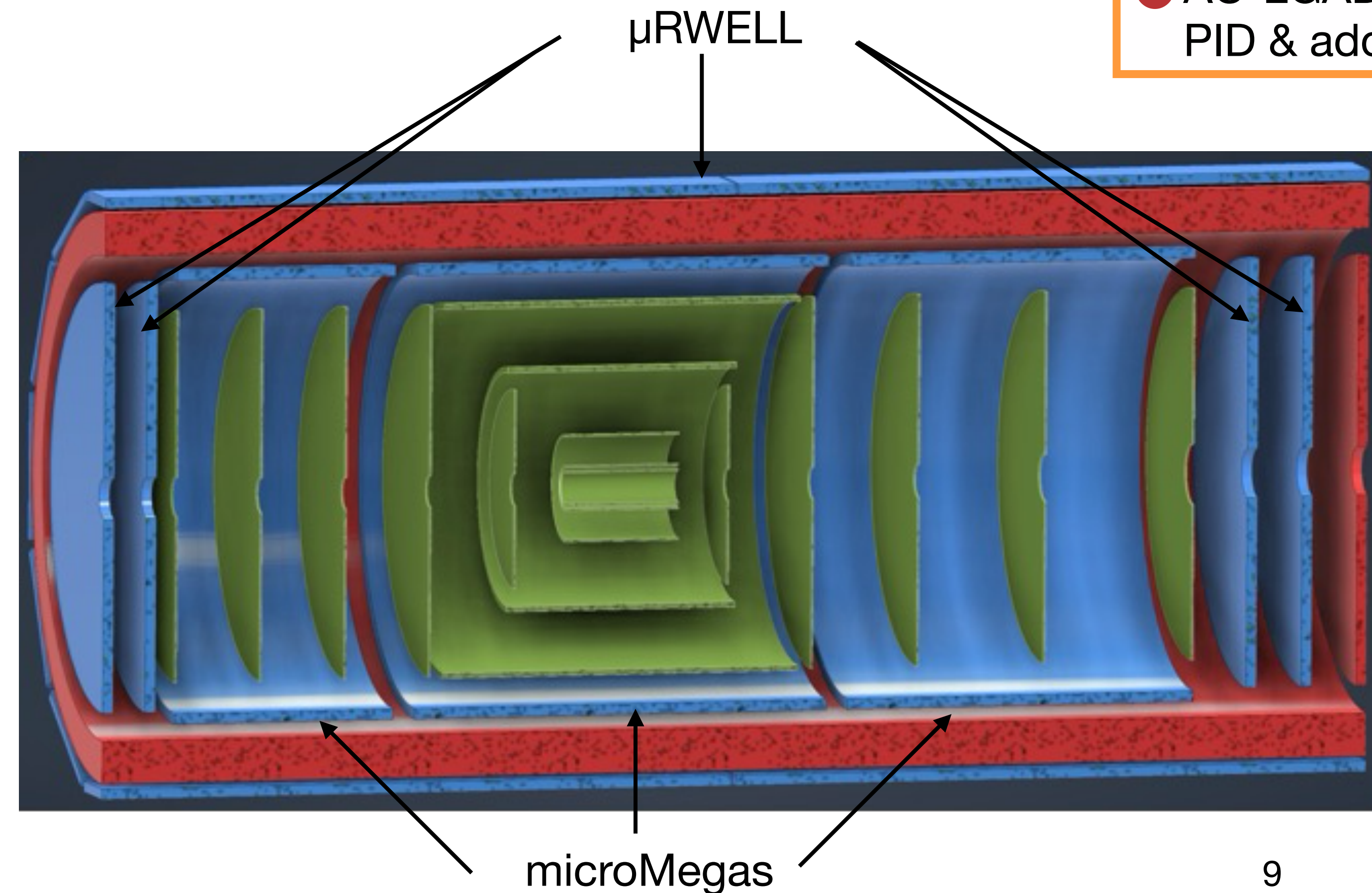
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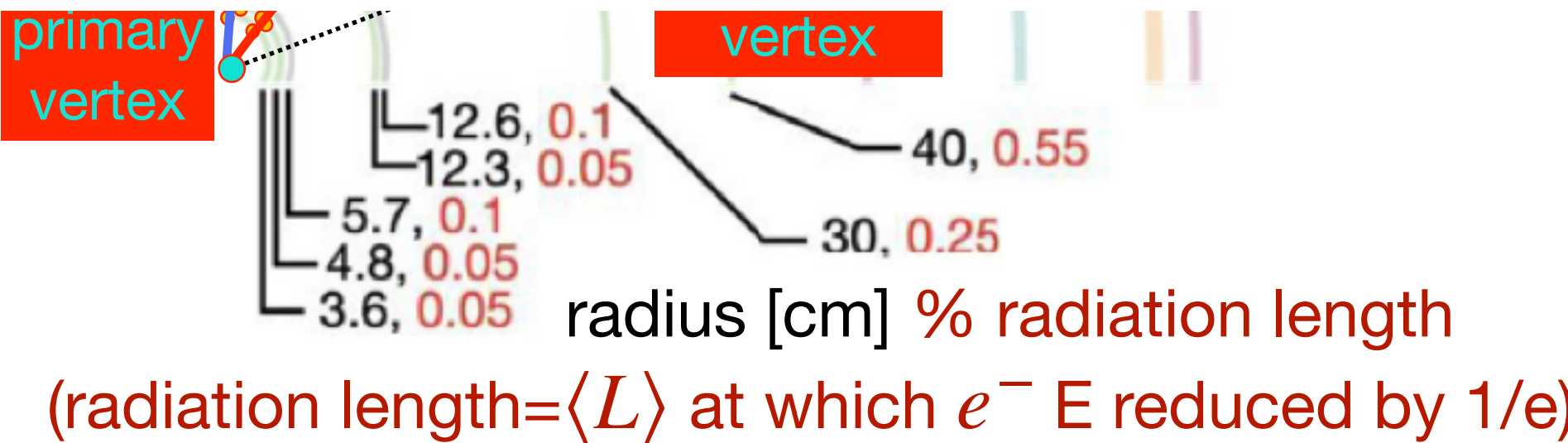
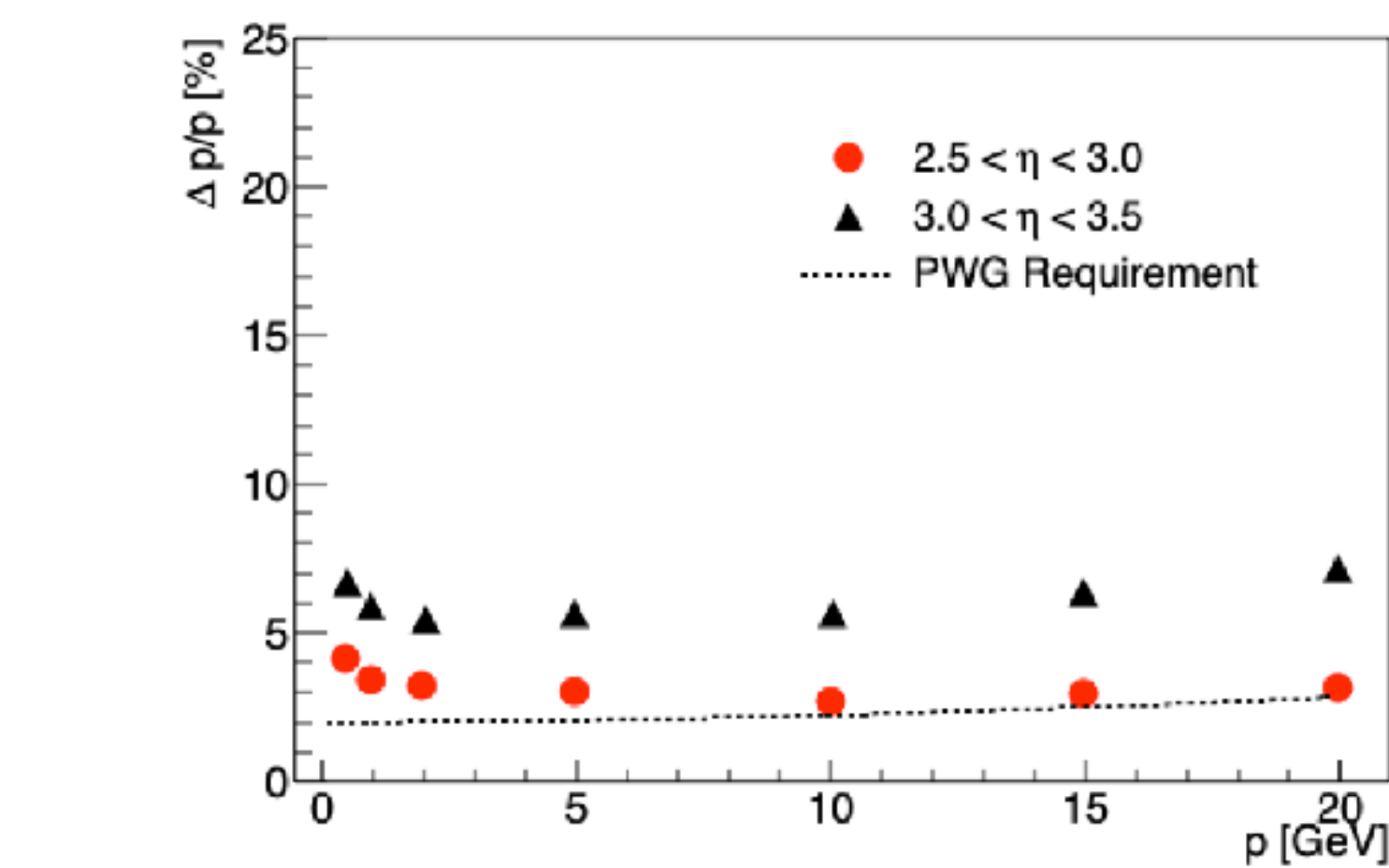
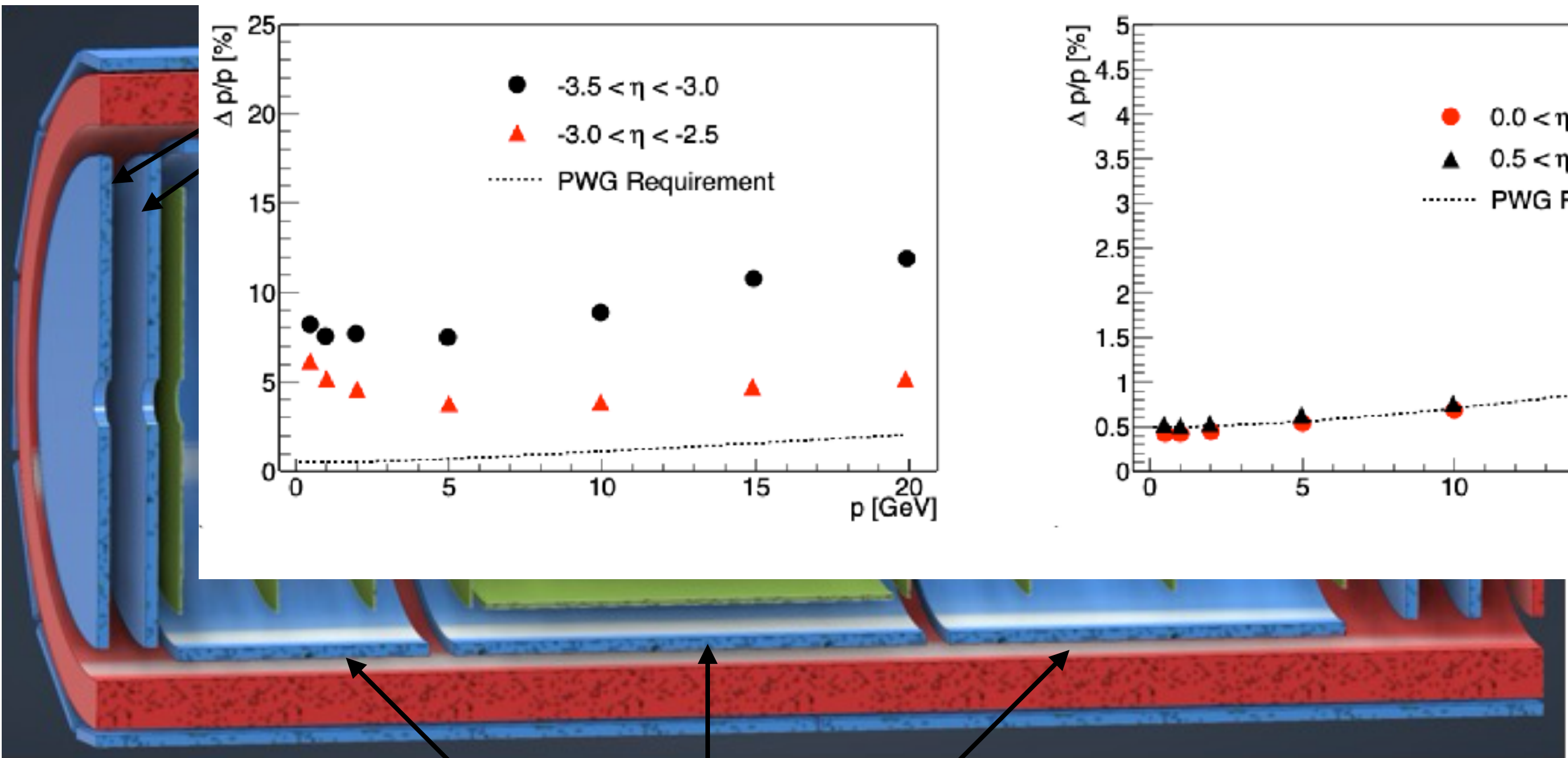


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μ RWELL

momentum resolution

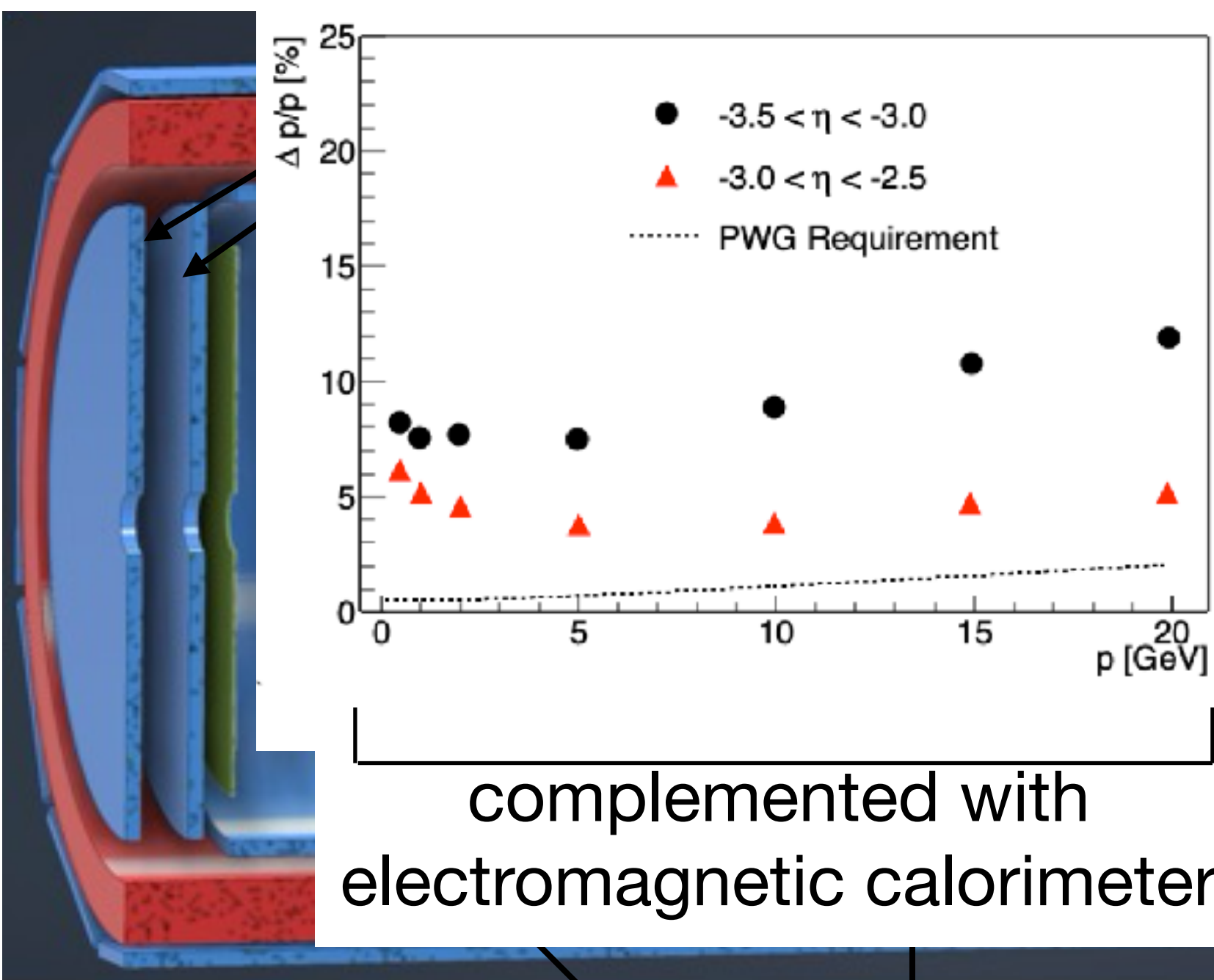


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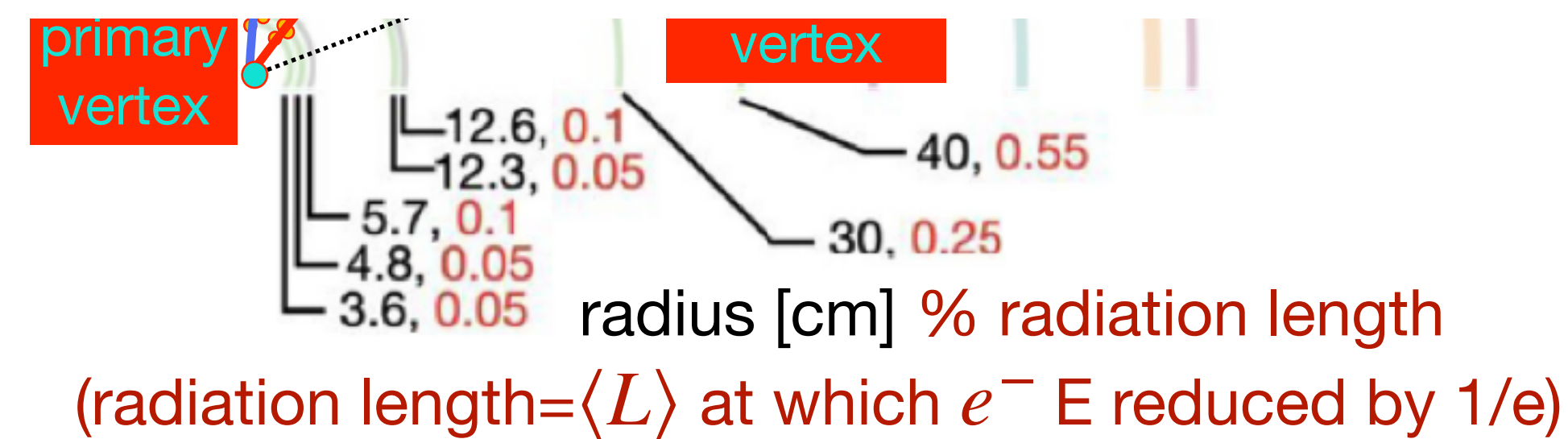
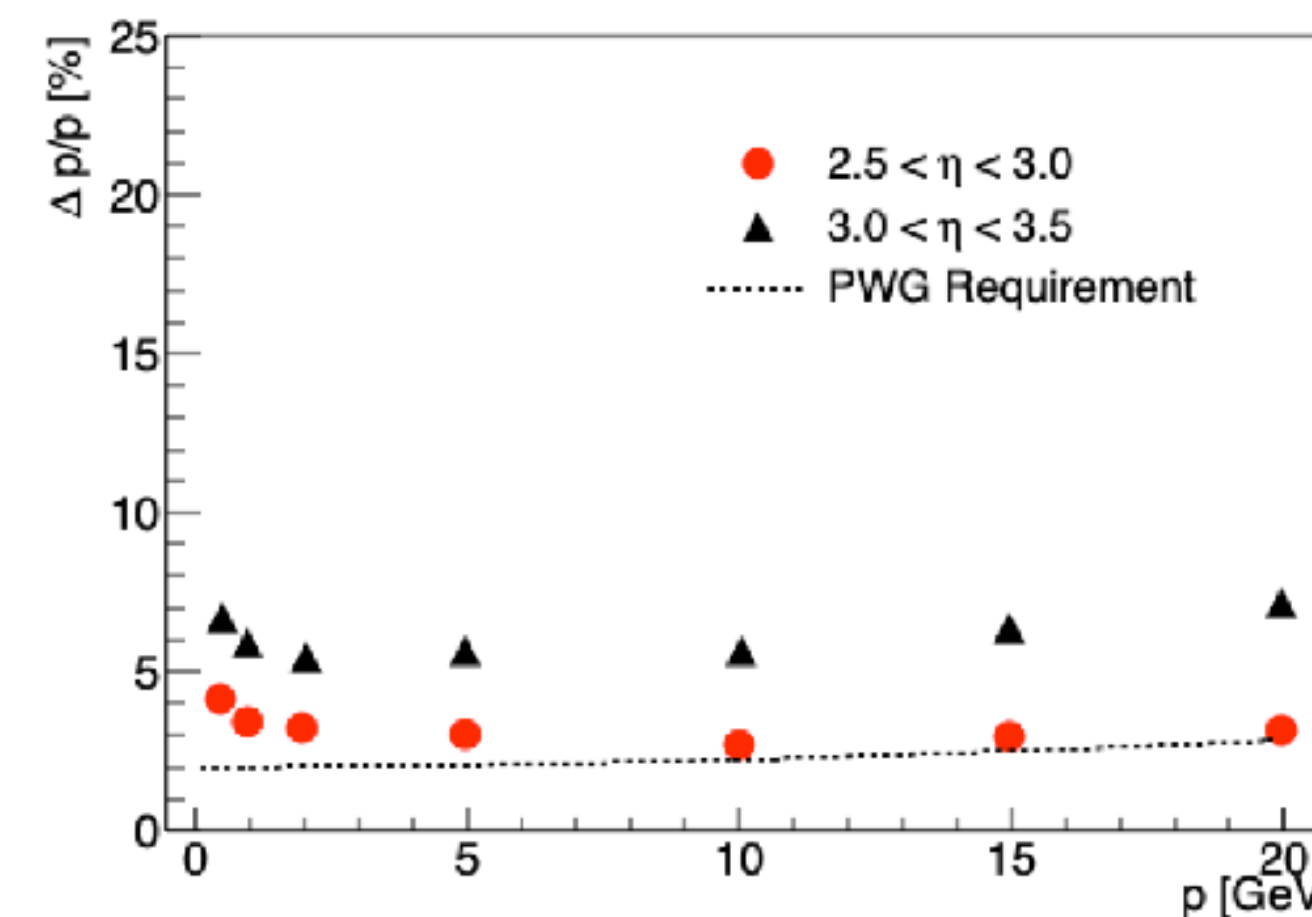
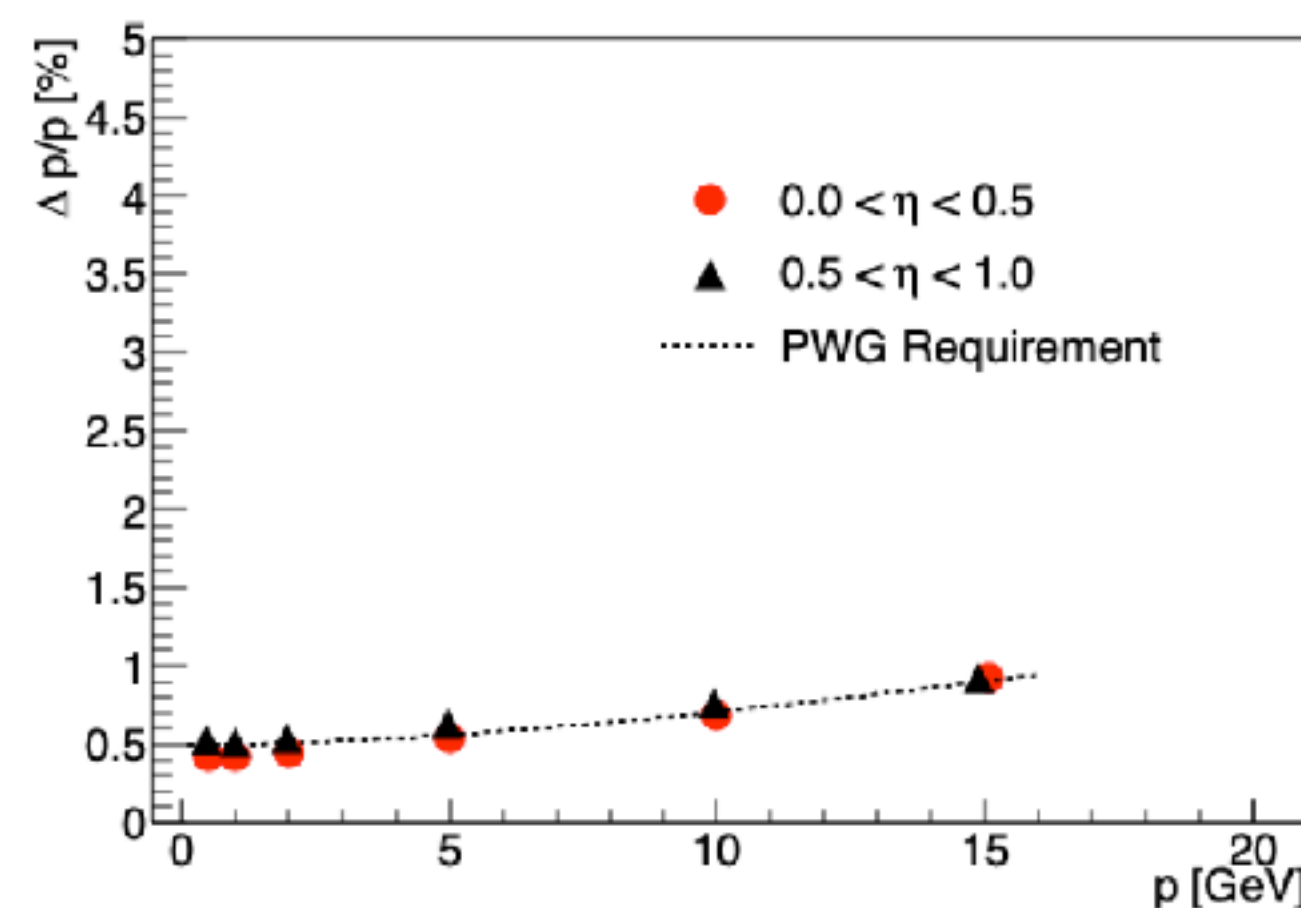
momentum resolution



complemented with
electromagnetic calorimeter



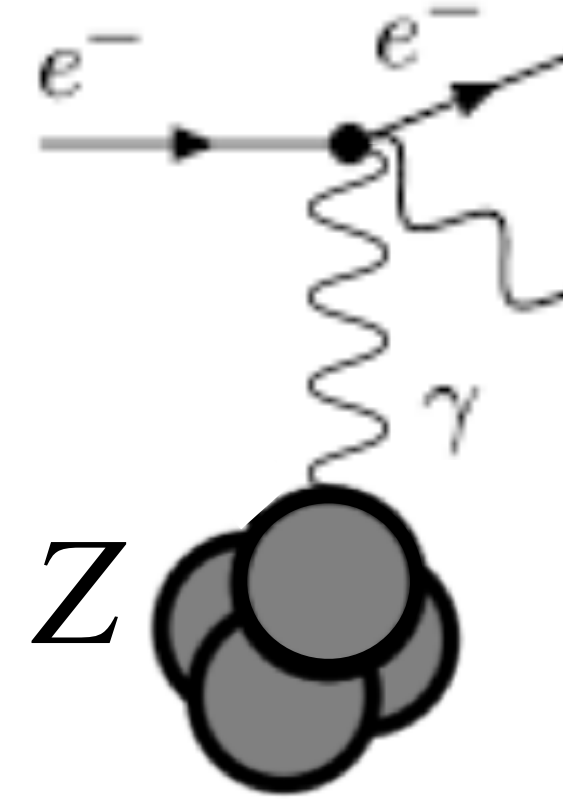
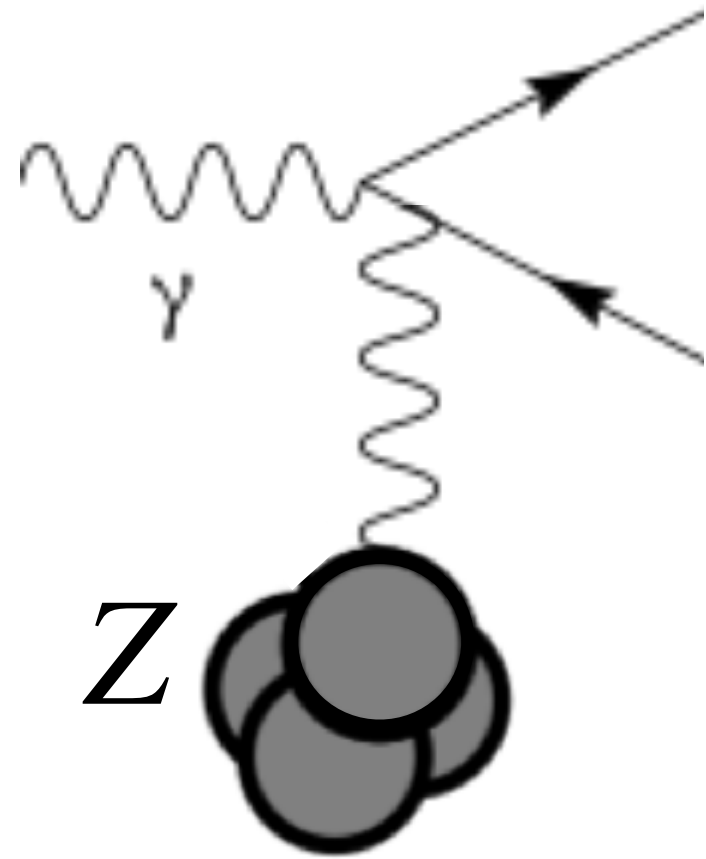
microMegas



Electromagnetic calorimeter

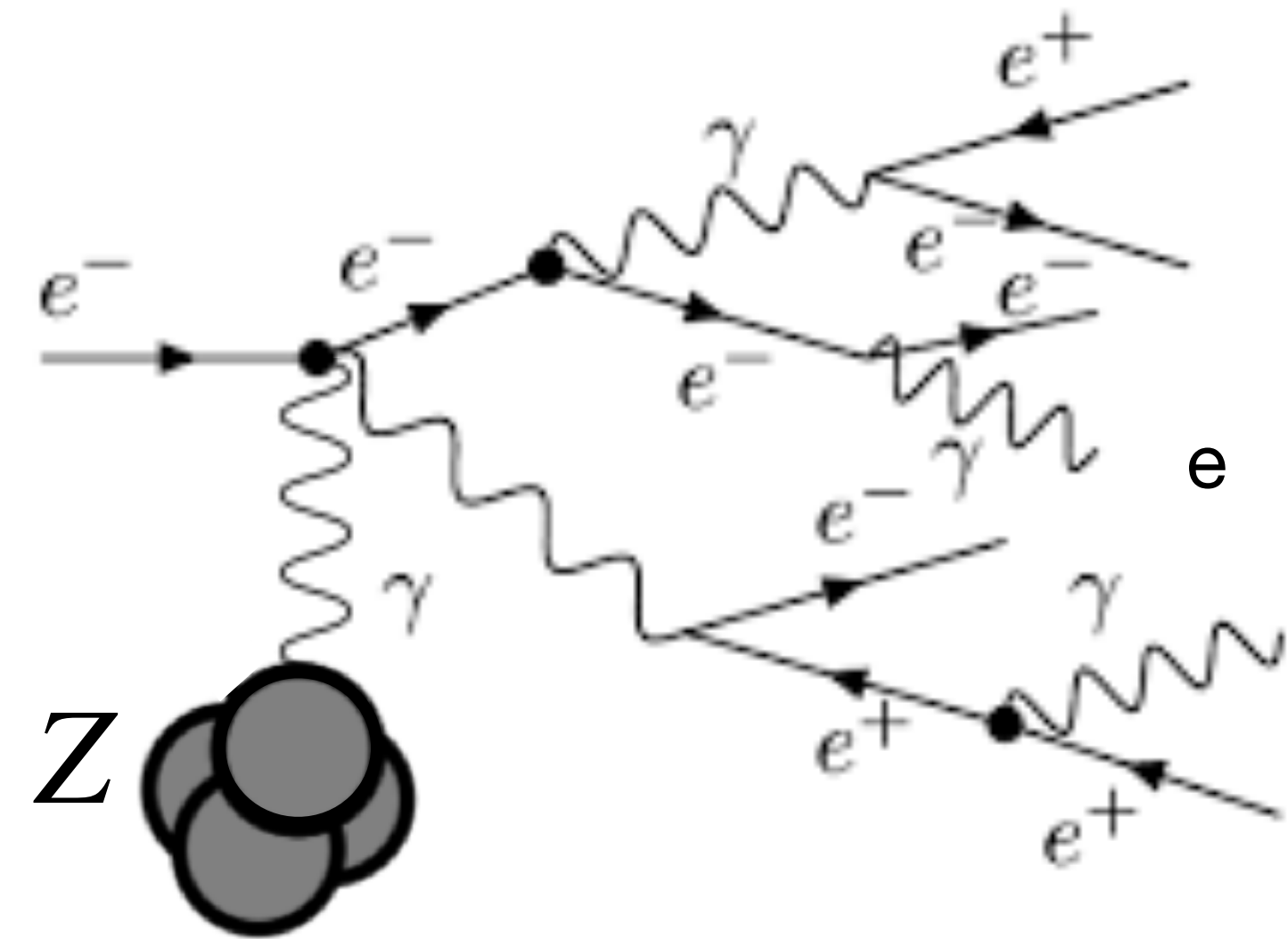
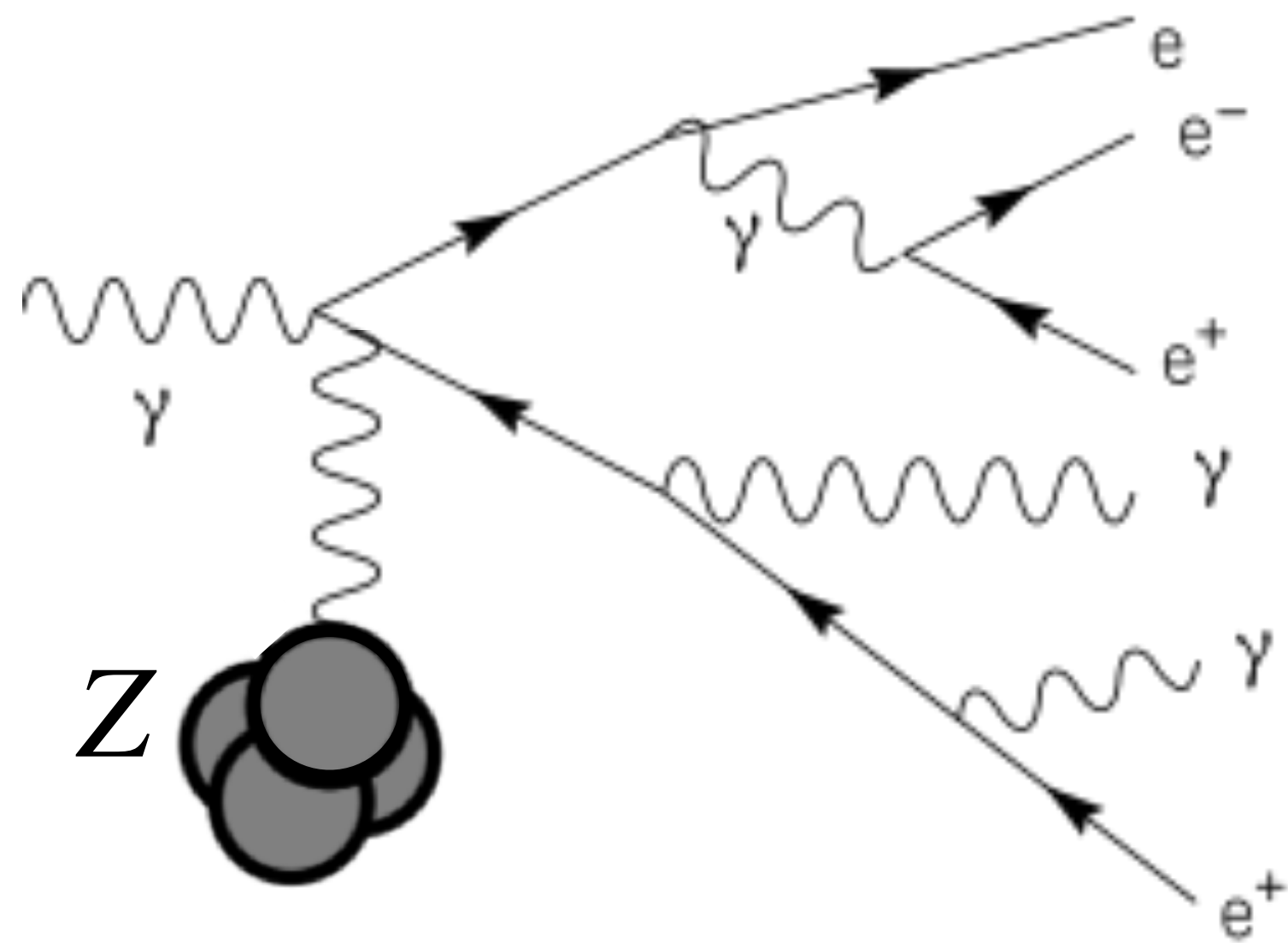
Electromagnetic calorimeter

Electromagnetic showers

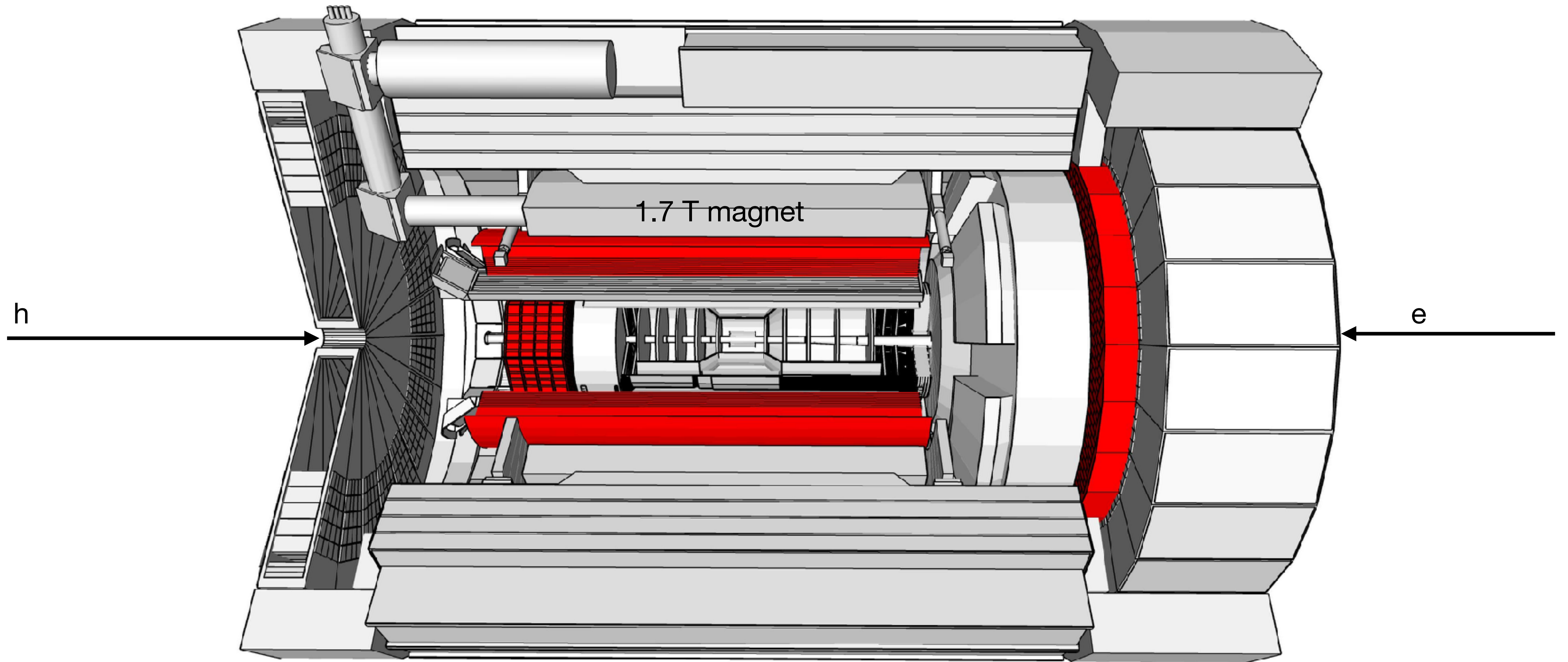


Electromagnetic calorimeter

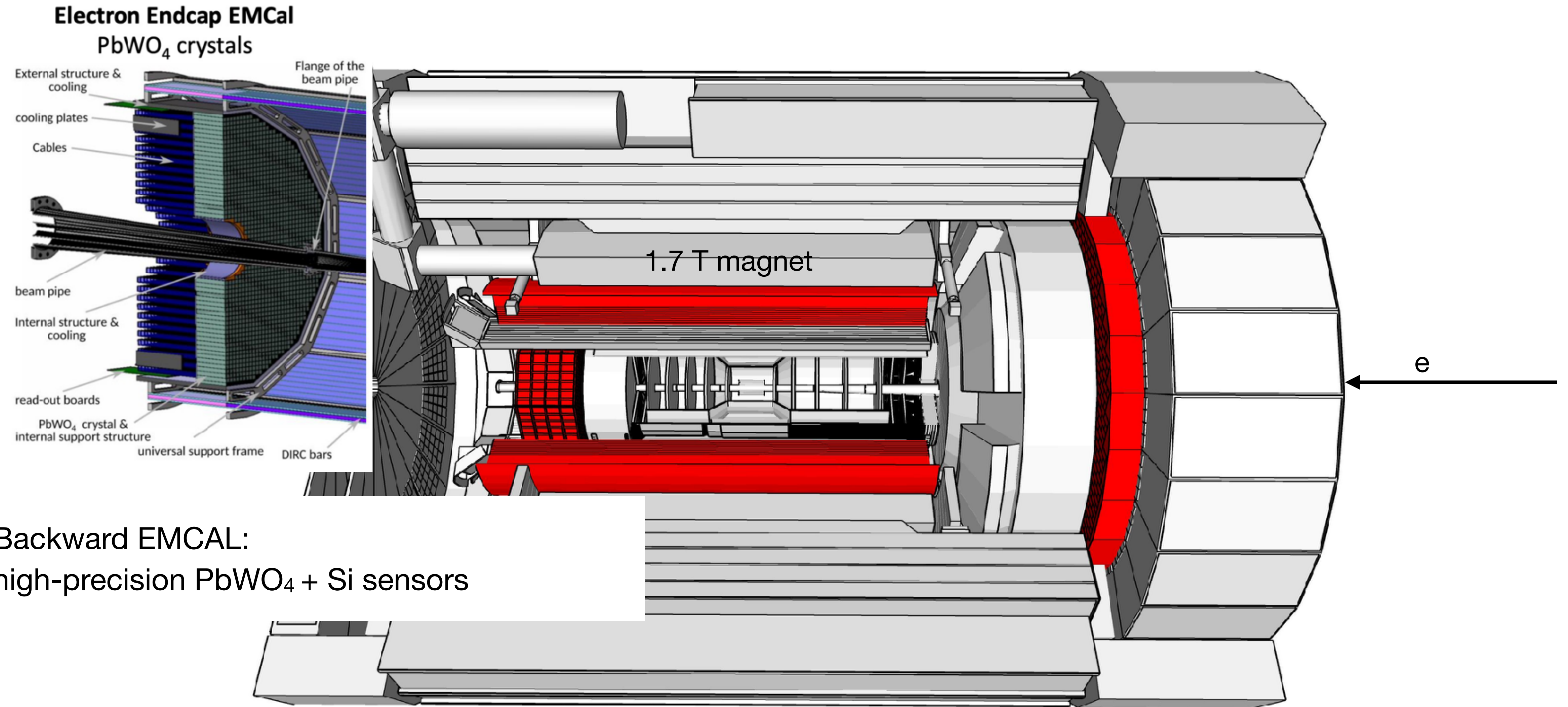
Electromagnetic showers



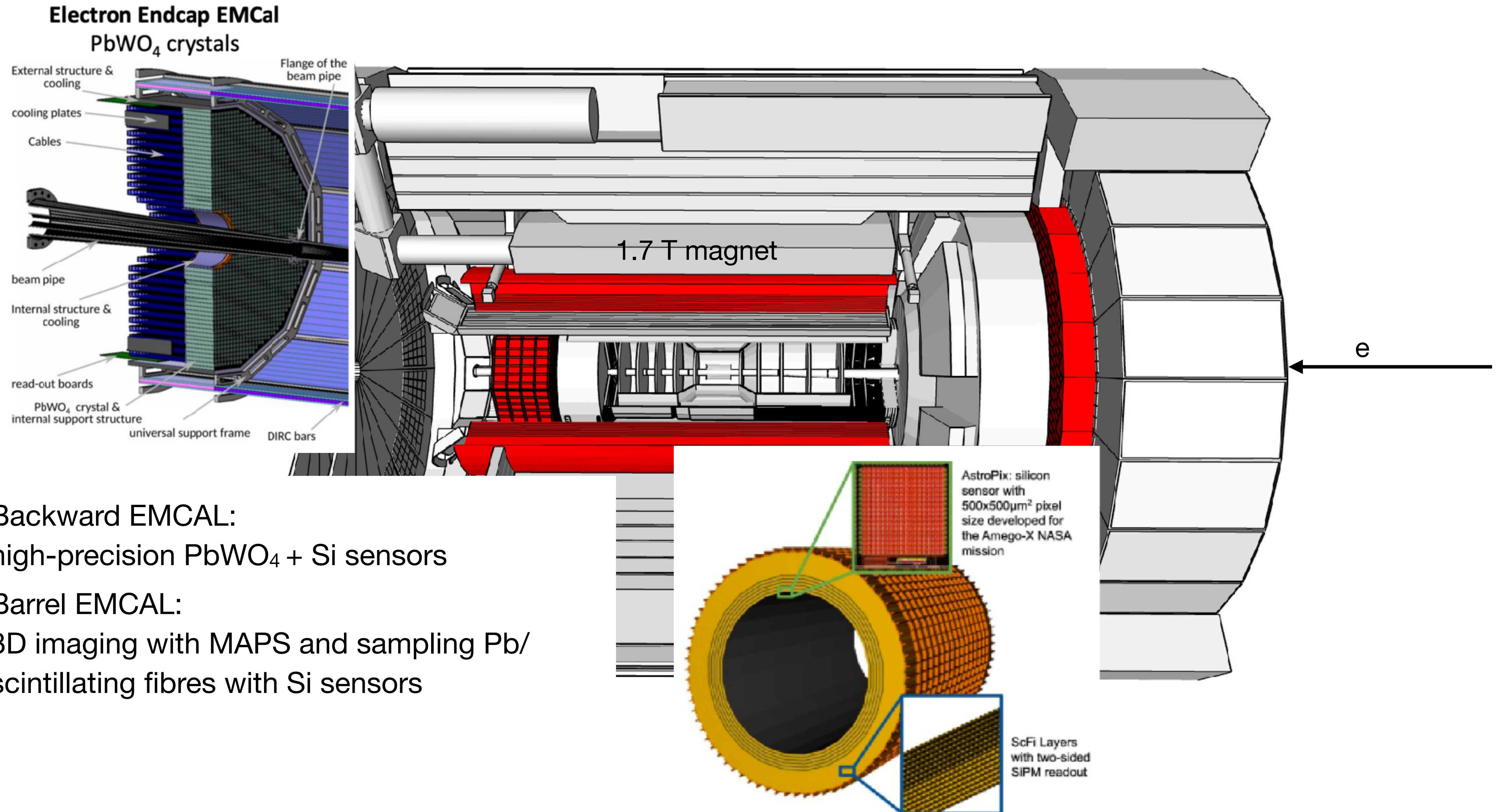
Electromagnetic calorimeter



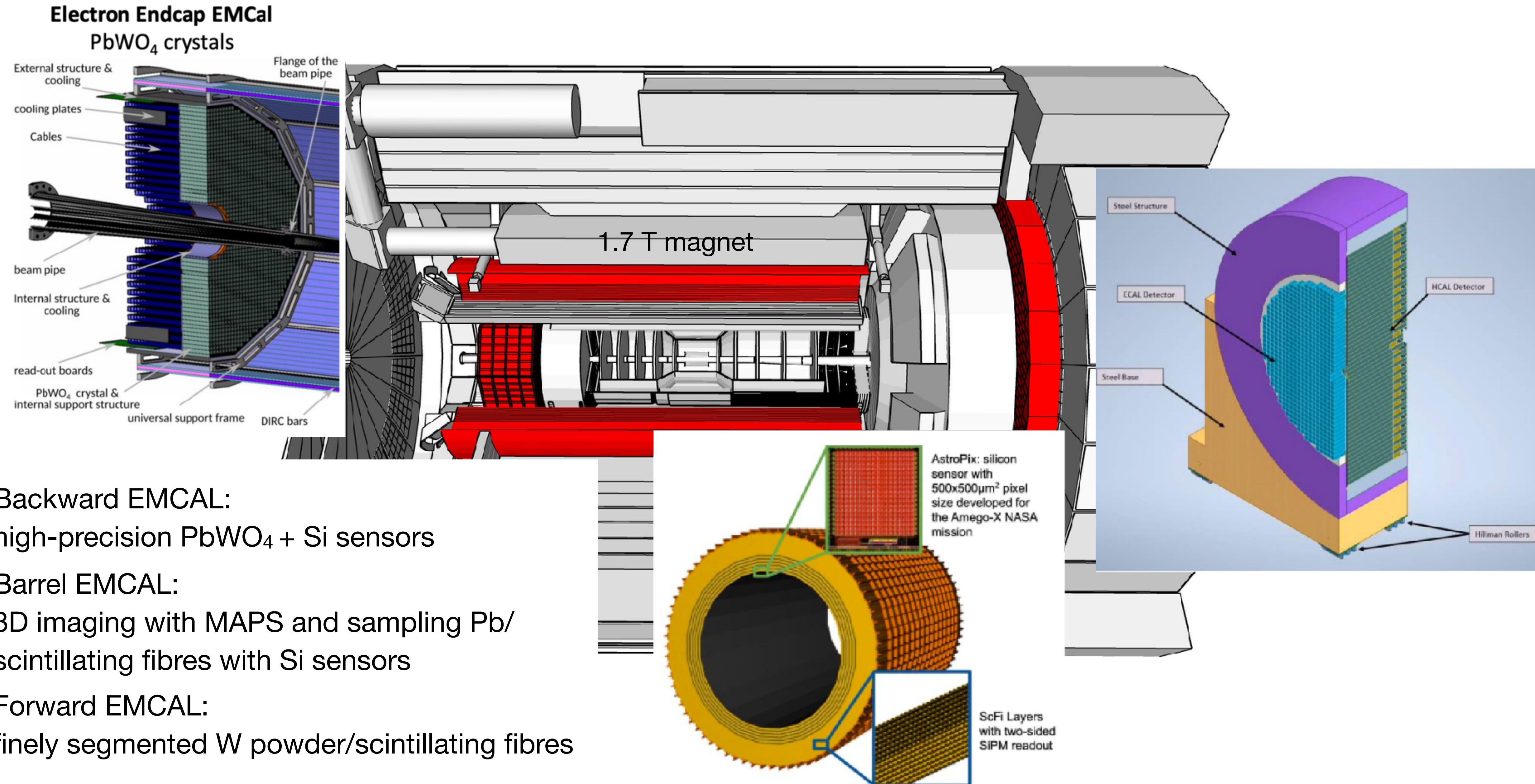
Electromagnetic calorimeter



Electromagnetic calorimeter



Electromagnetic calorimeter



Hadronic calorimeter

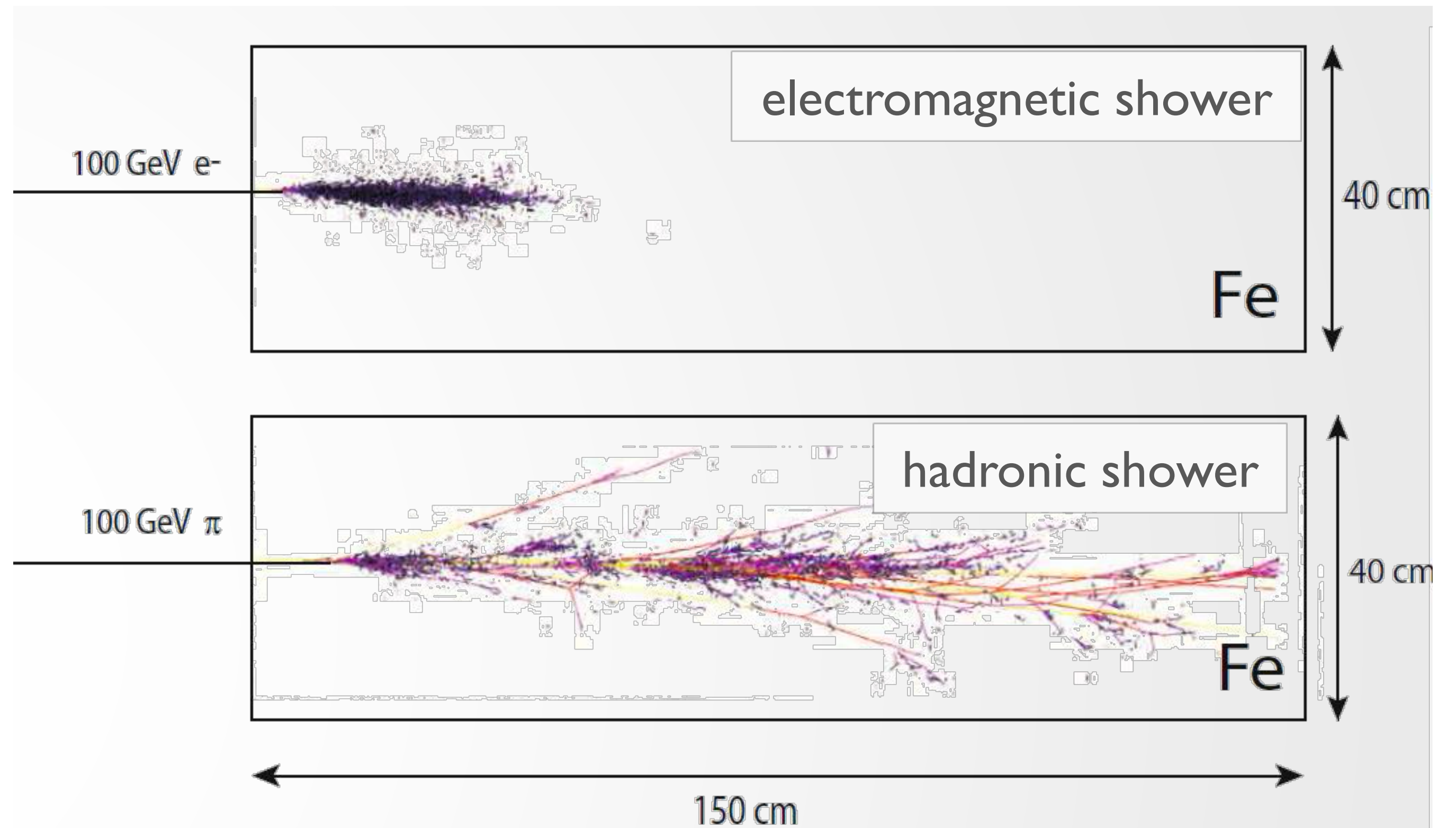
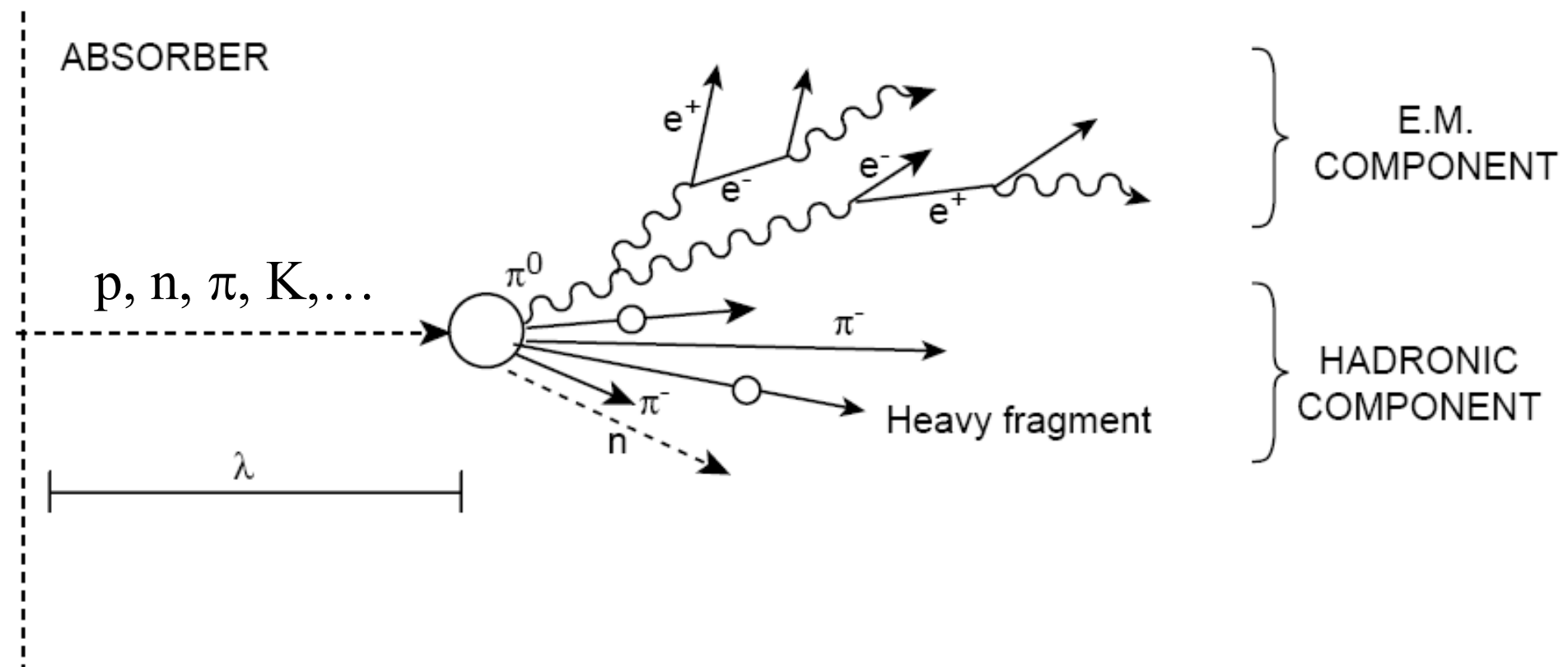
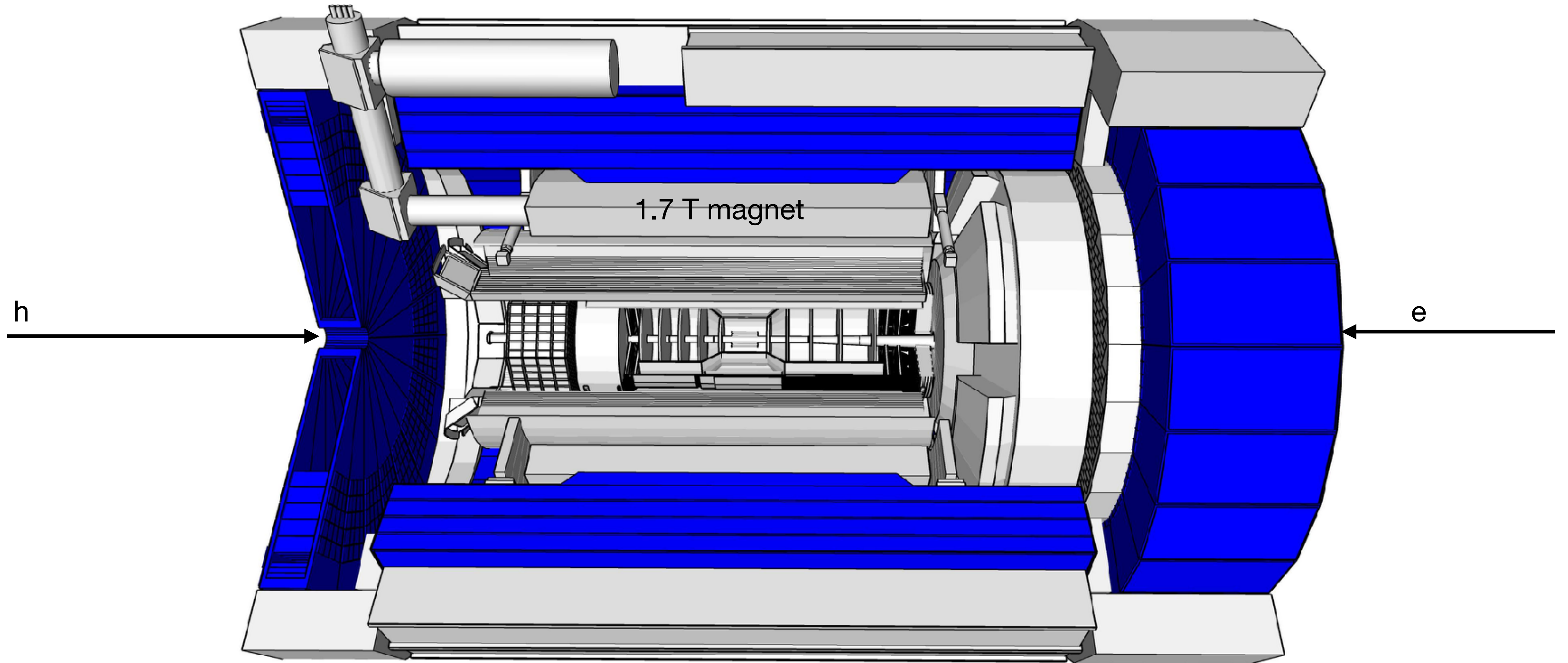
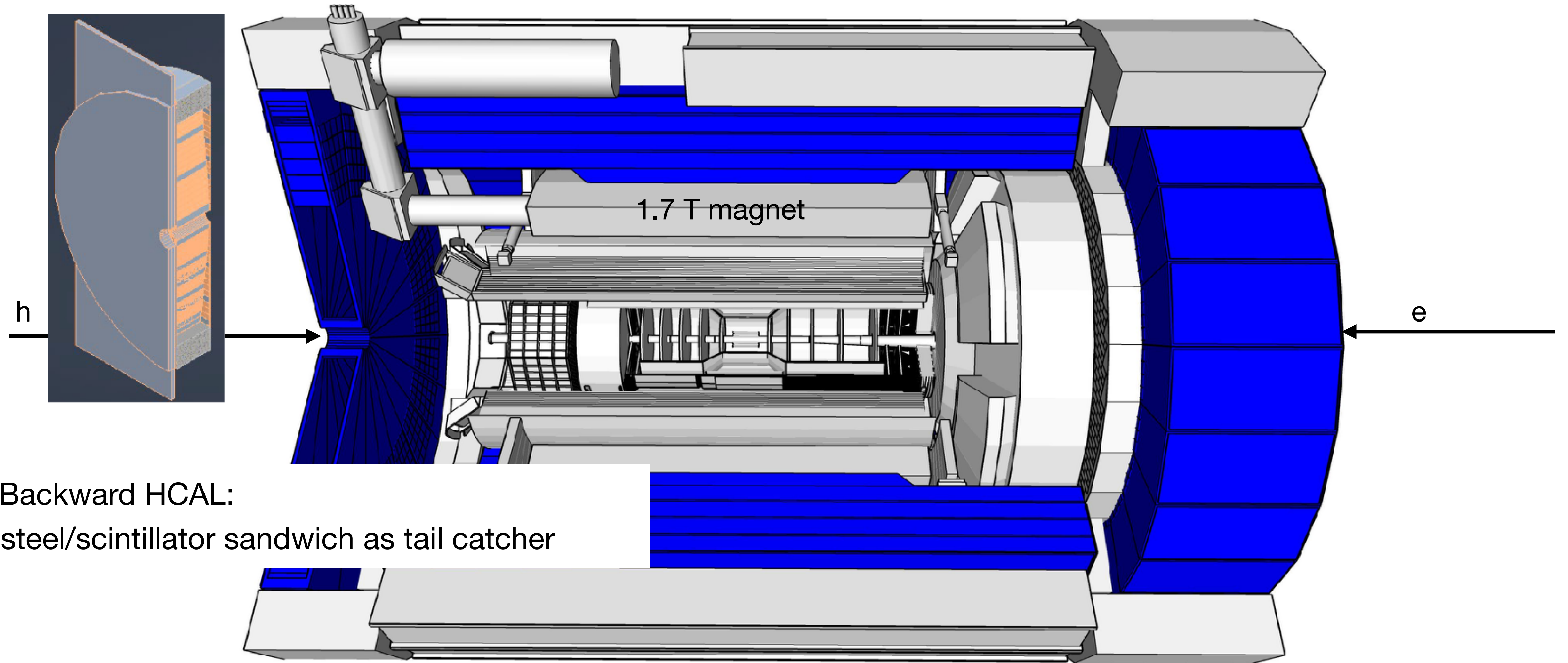


Fig. from R. Schoefbeck
Experimental Particle Physics Lecture
20 Novembre 2020

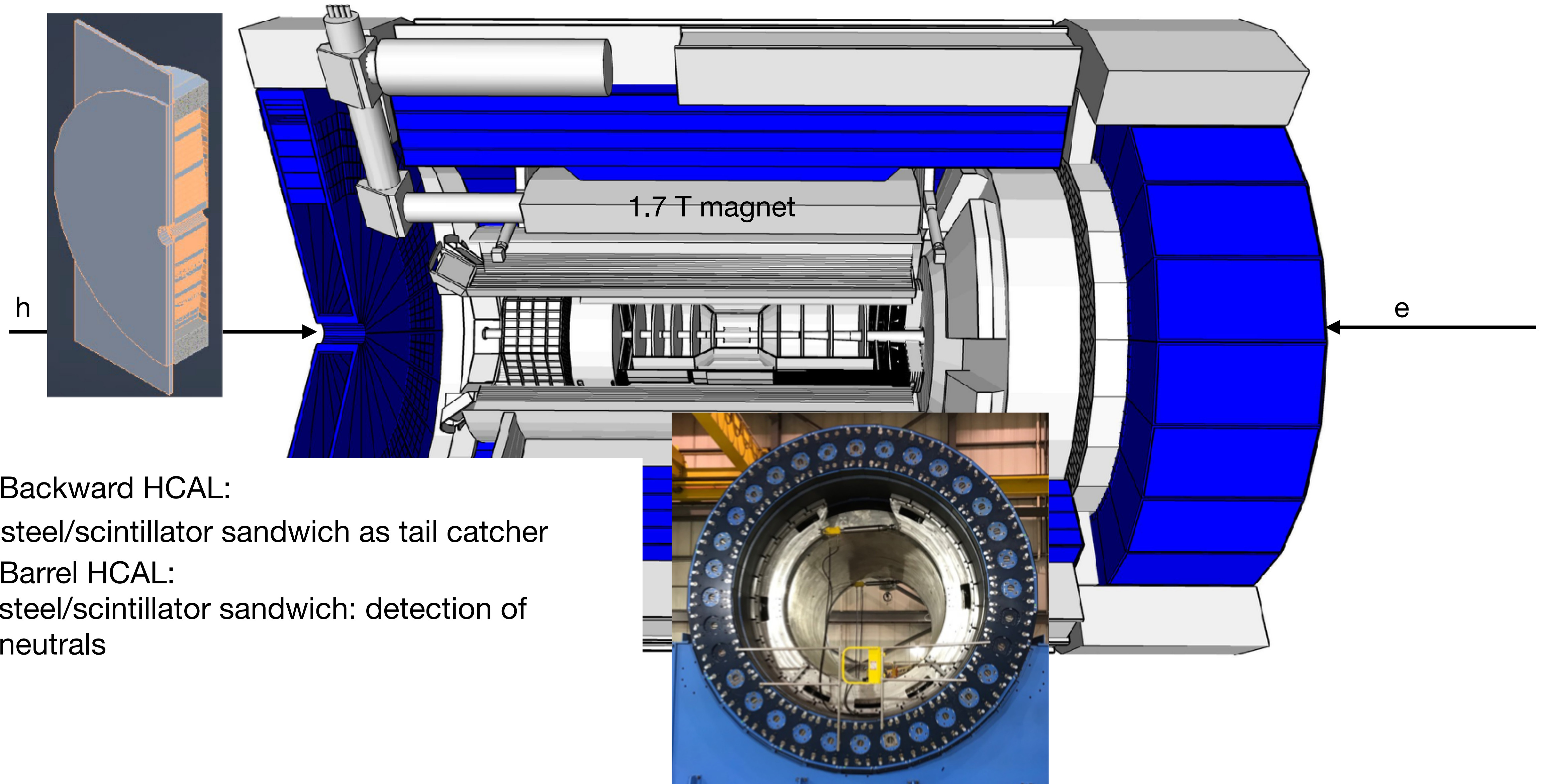
Hadronic calorimeter



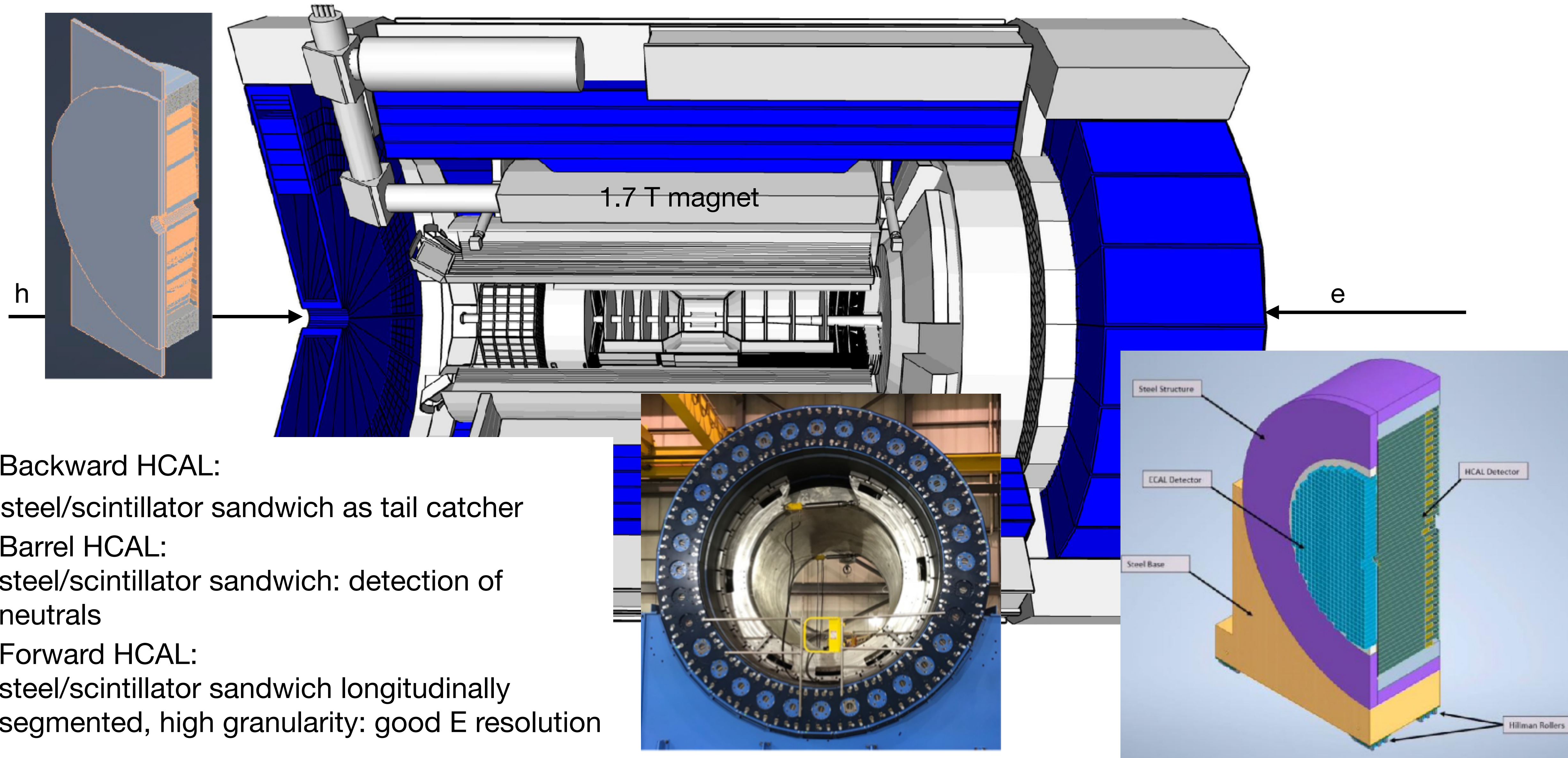
Hadronic calorimeter



Hadronic calorimeter

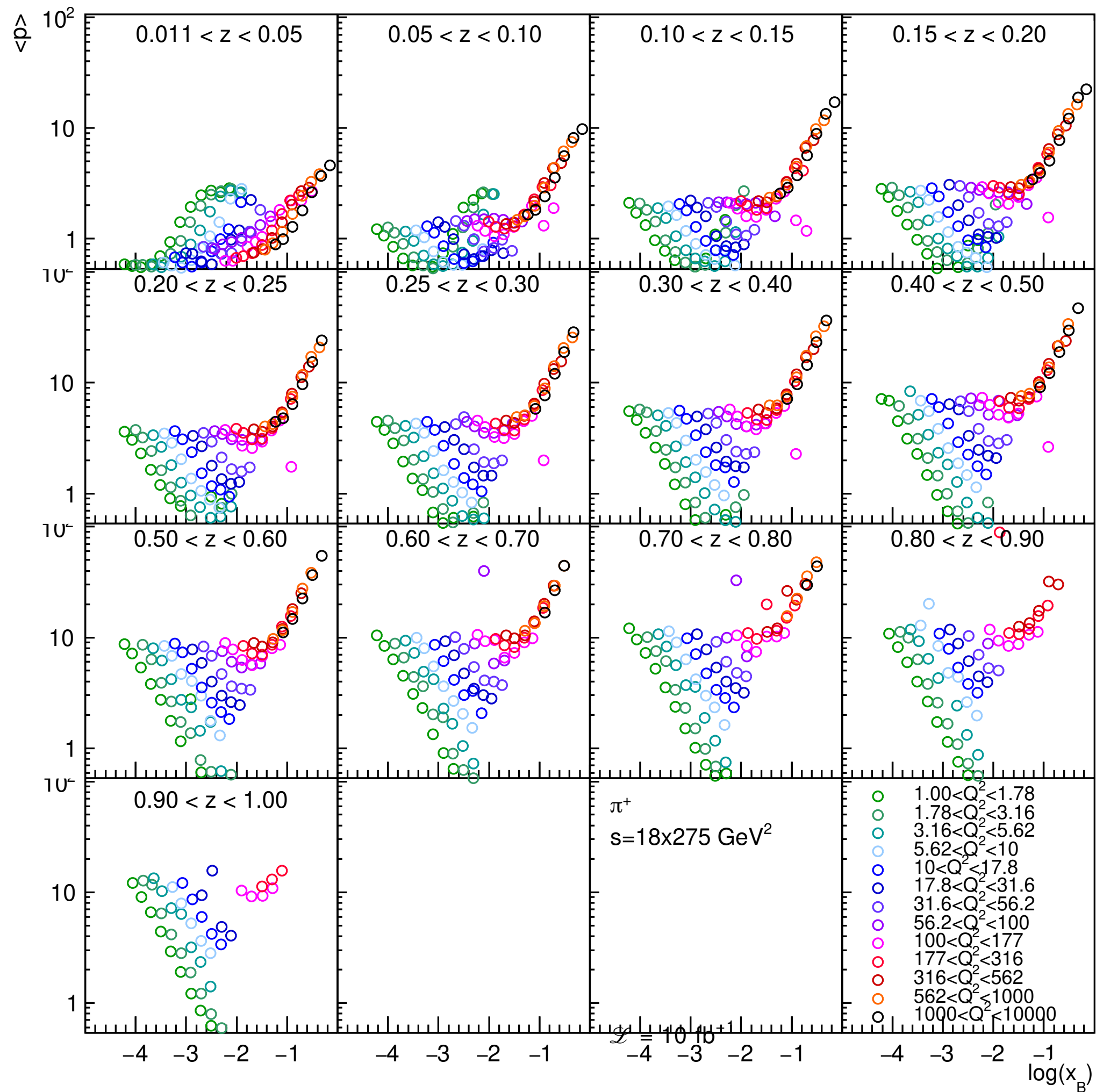


Hadronic calorimeter

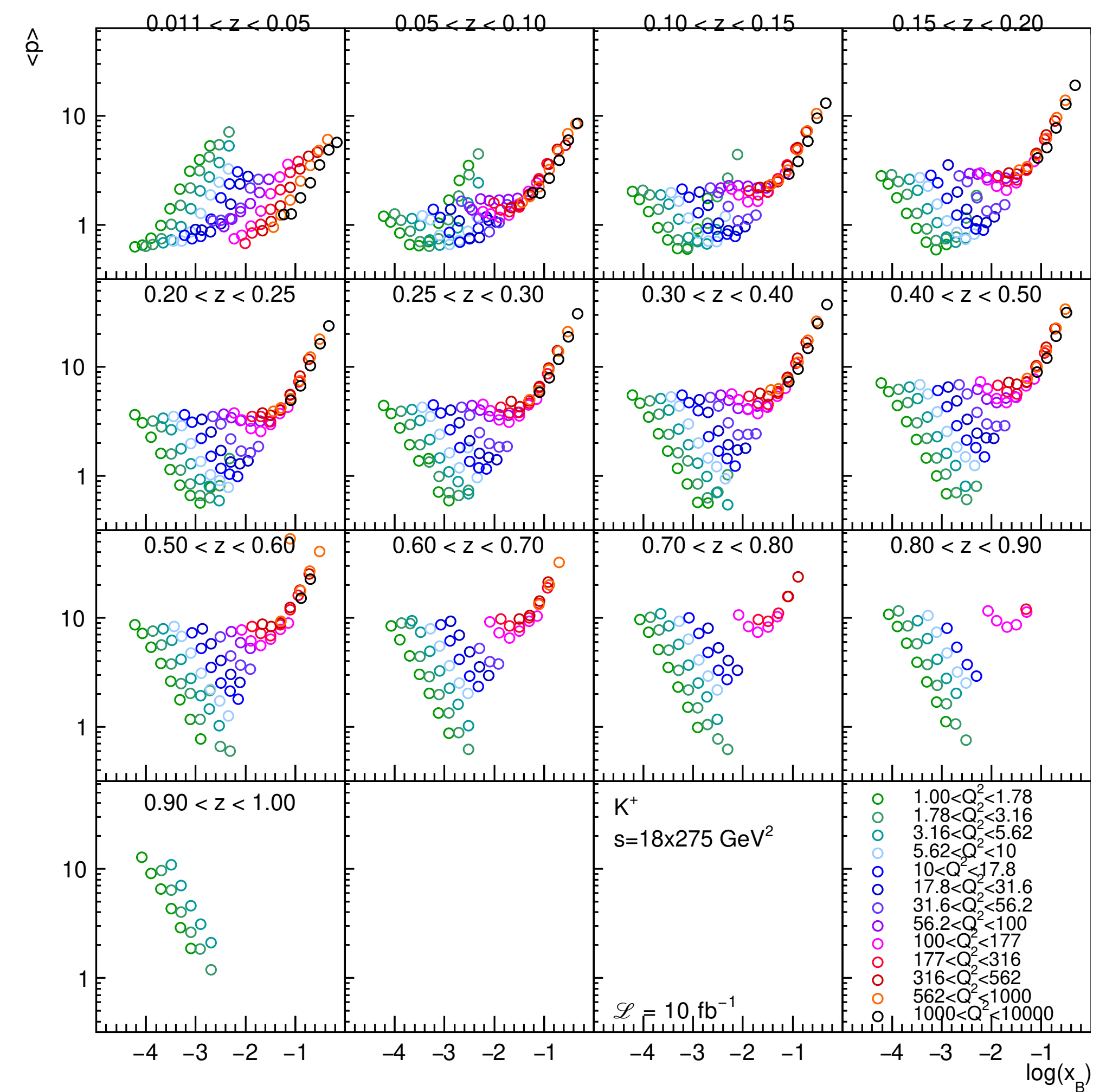


Kinematic coverage and hadron momentum reach

Positive pions

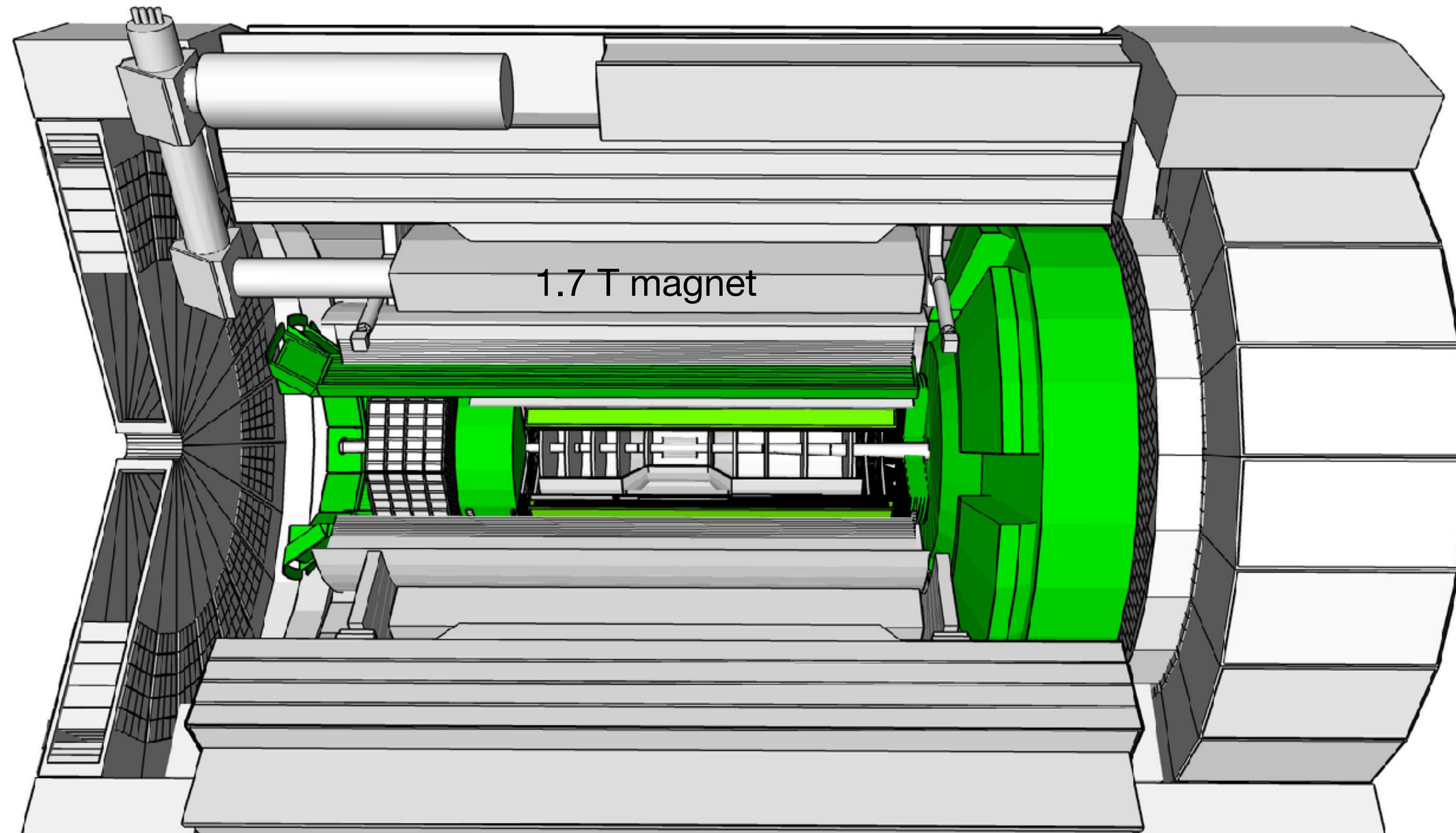


Positive kaons



studies for semi-inclusive DIS

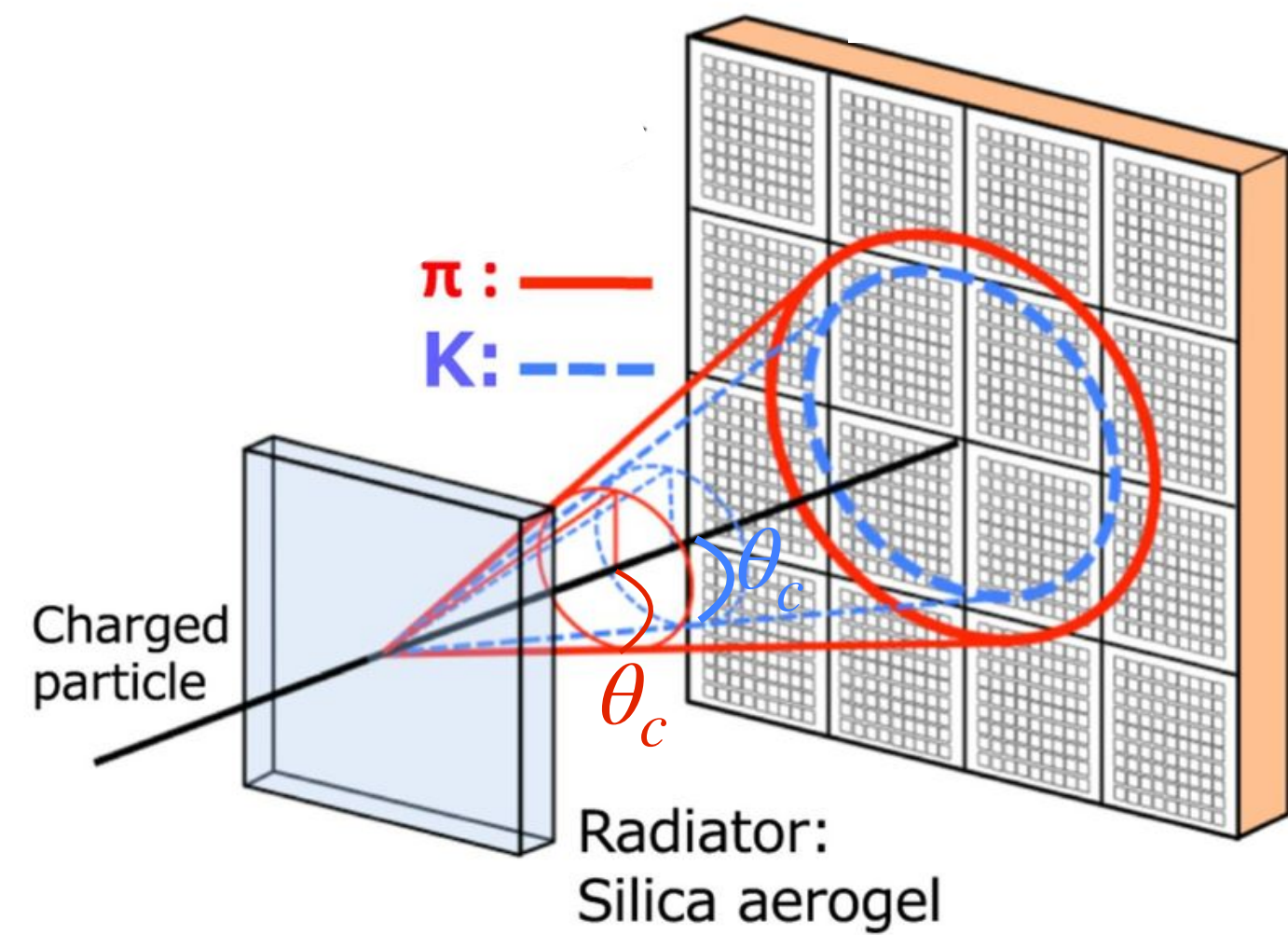
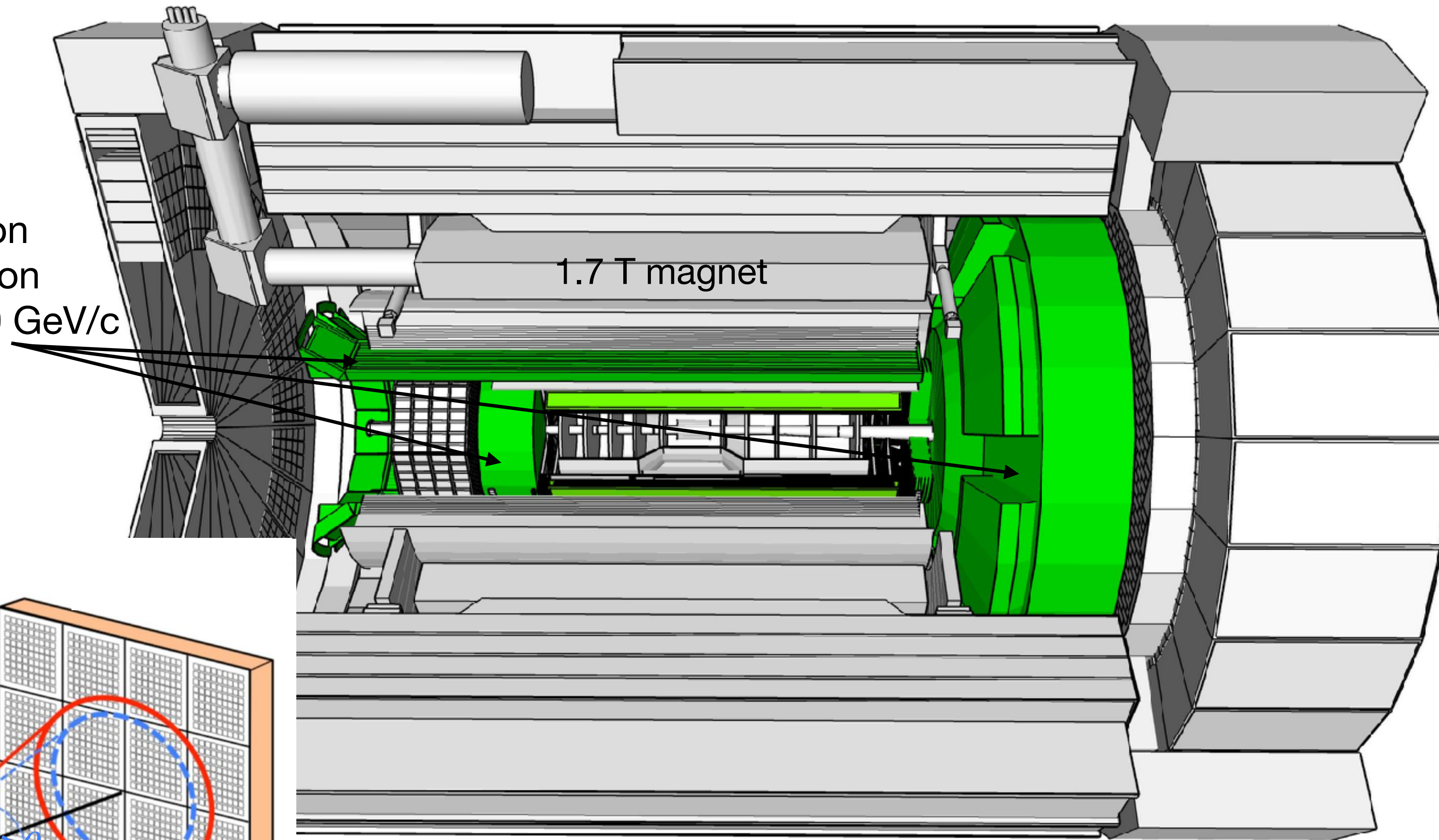
Particle identification



1. Support electromagnetic calorimeters in providing $e^{\pm}/\pi^{\pm}$ separation: suppress $\pi^{\pm}$ contamination down to 10^{-4}
2. Provide hadron identification (π , K , p) over a wide rapidity and momentum range

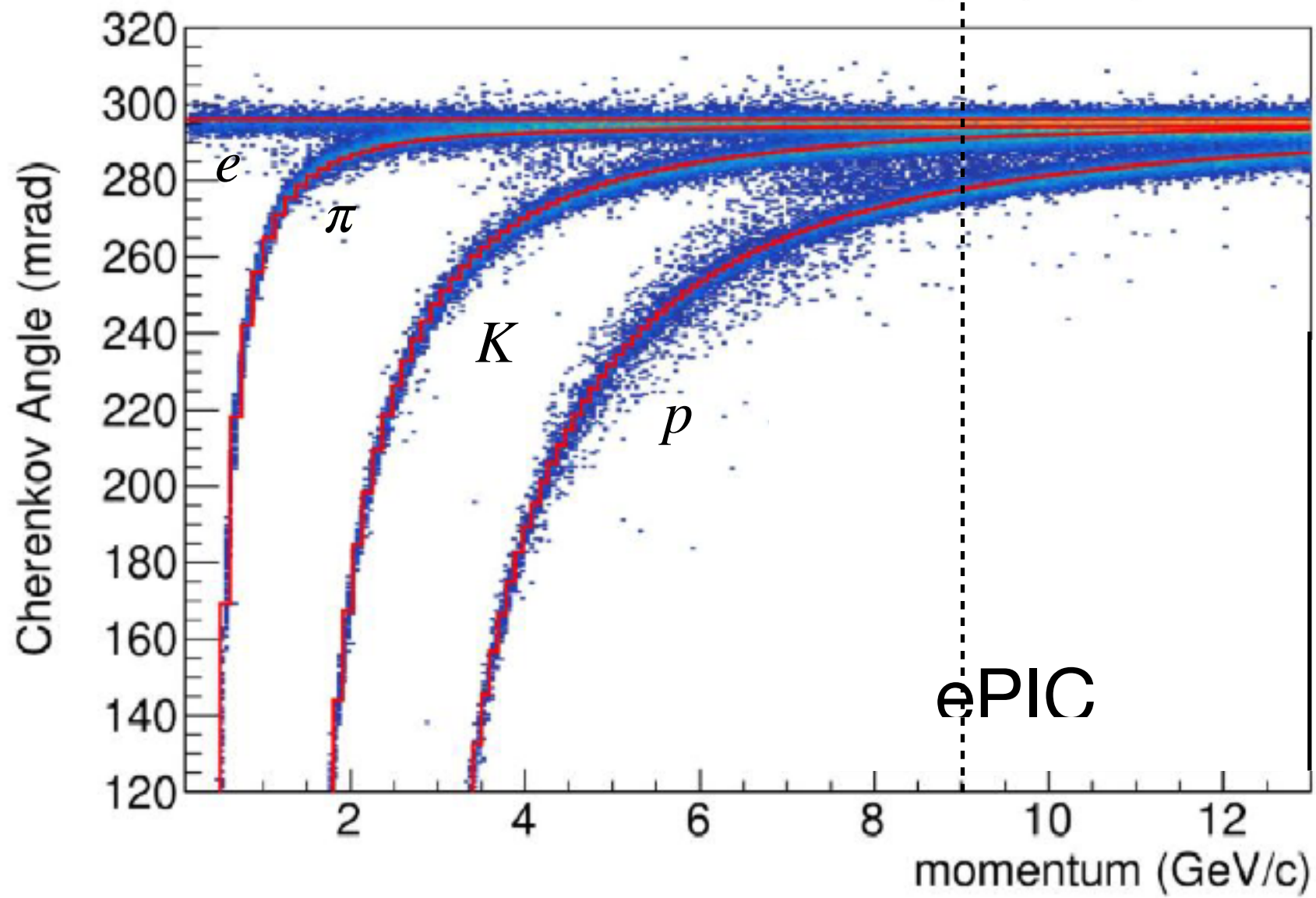
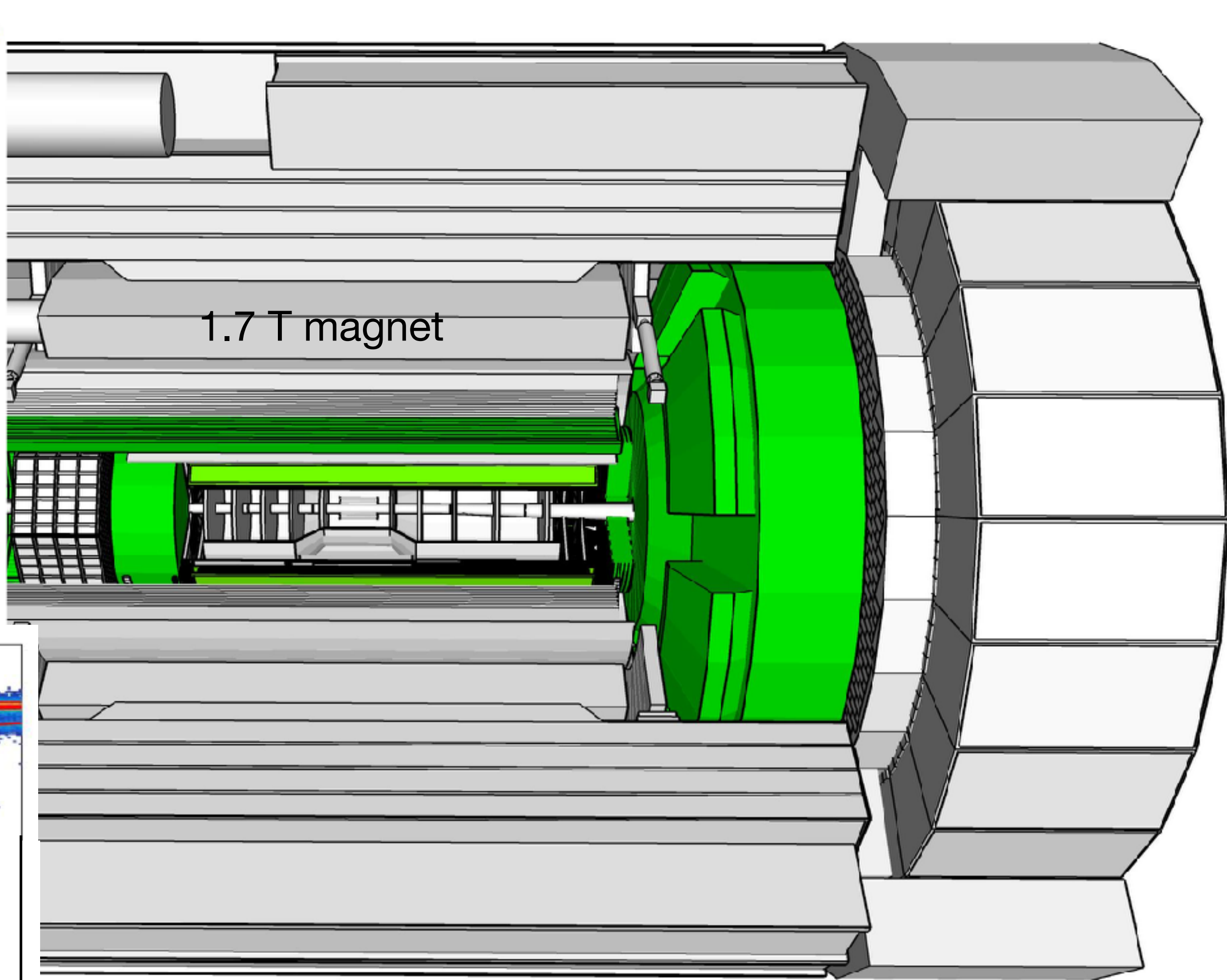
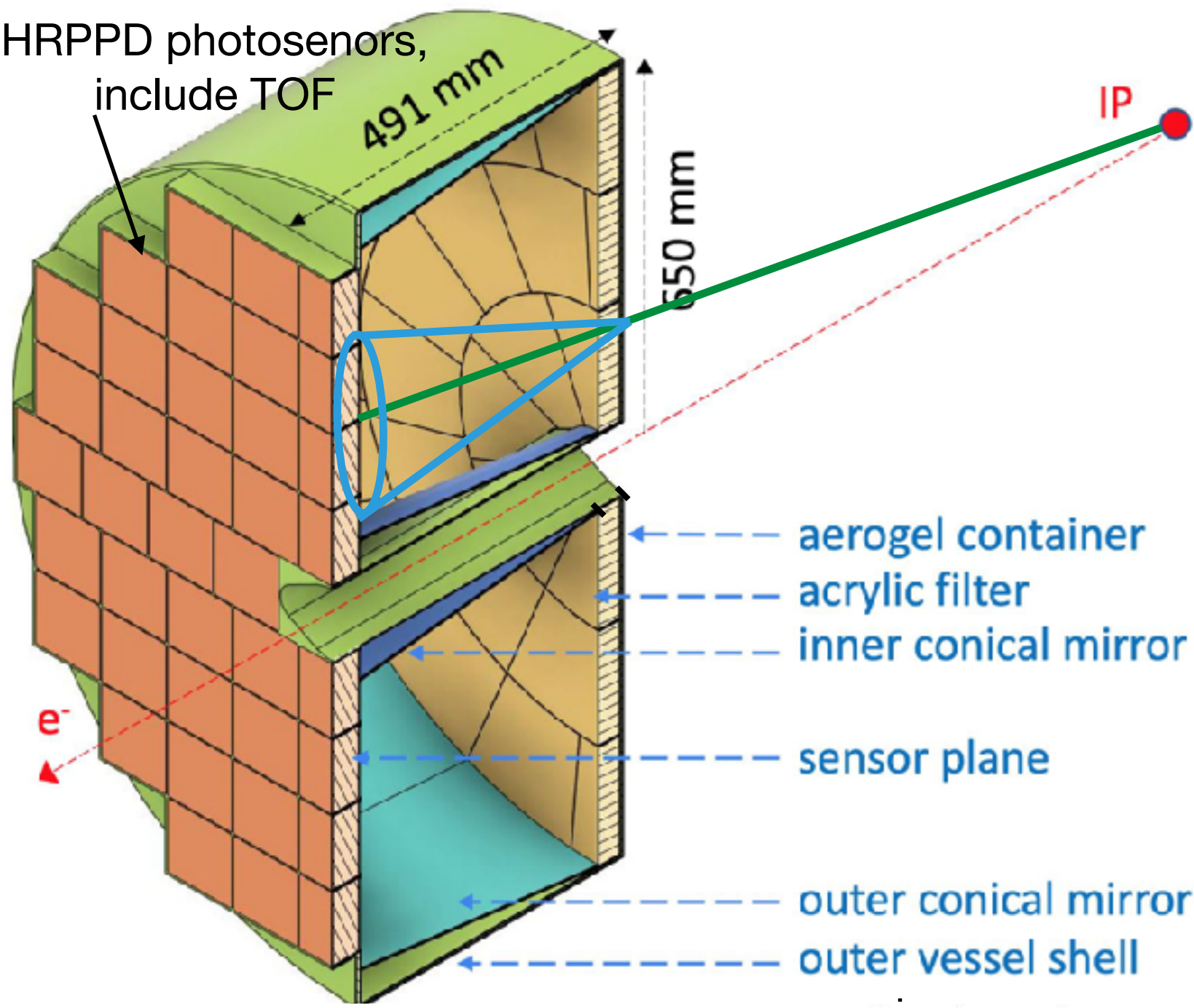
Particle identification

detectors based on
Cherenkov radiation
for $1 \text{ GeV}/c < p < 50 \text{ GeV}/c$

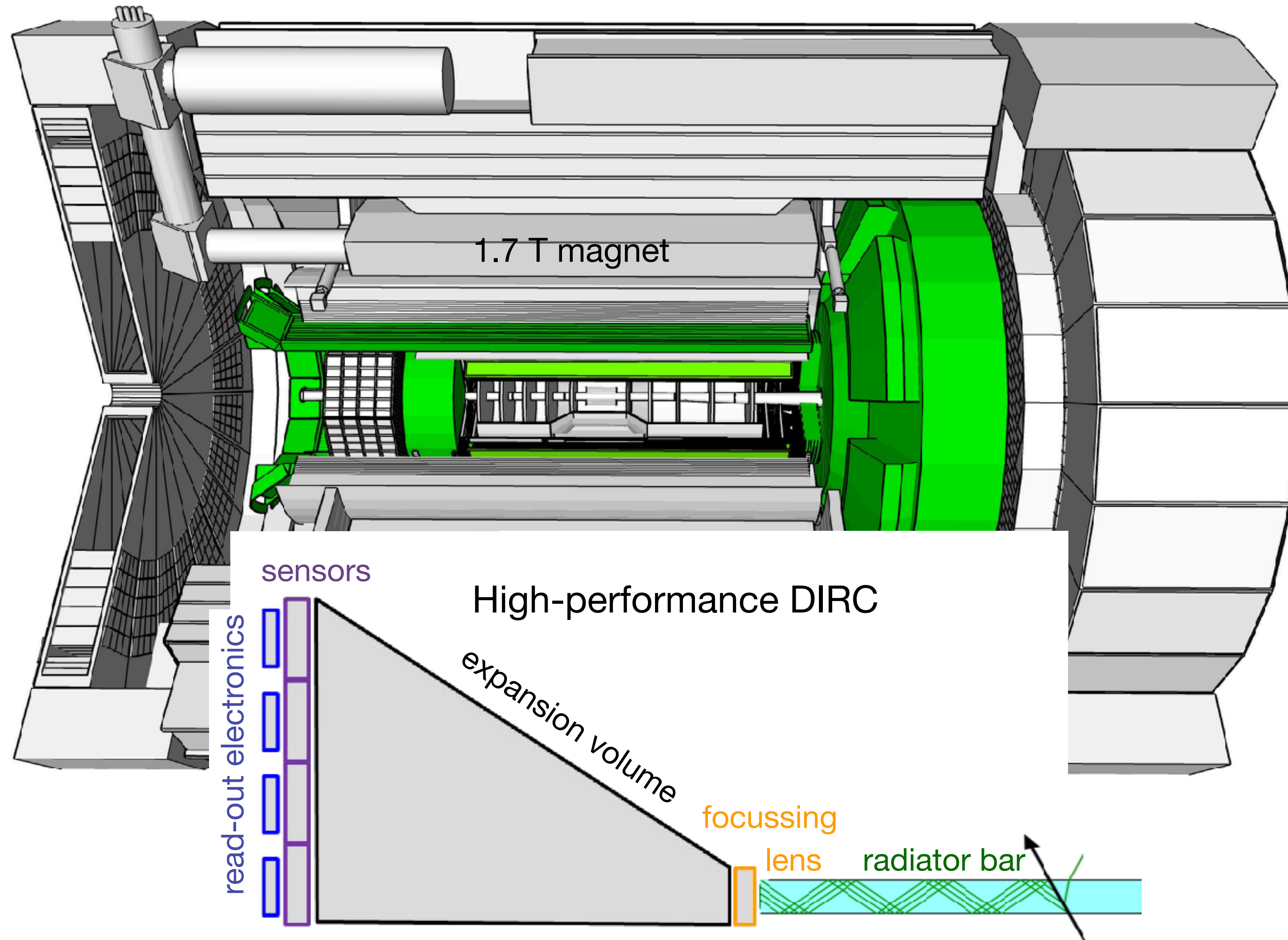


$$\cos \theta_c \propto \frac{1}{\beta}$$

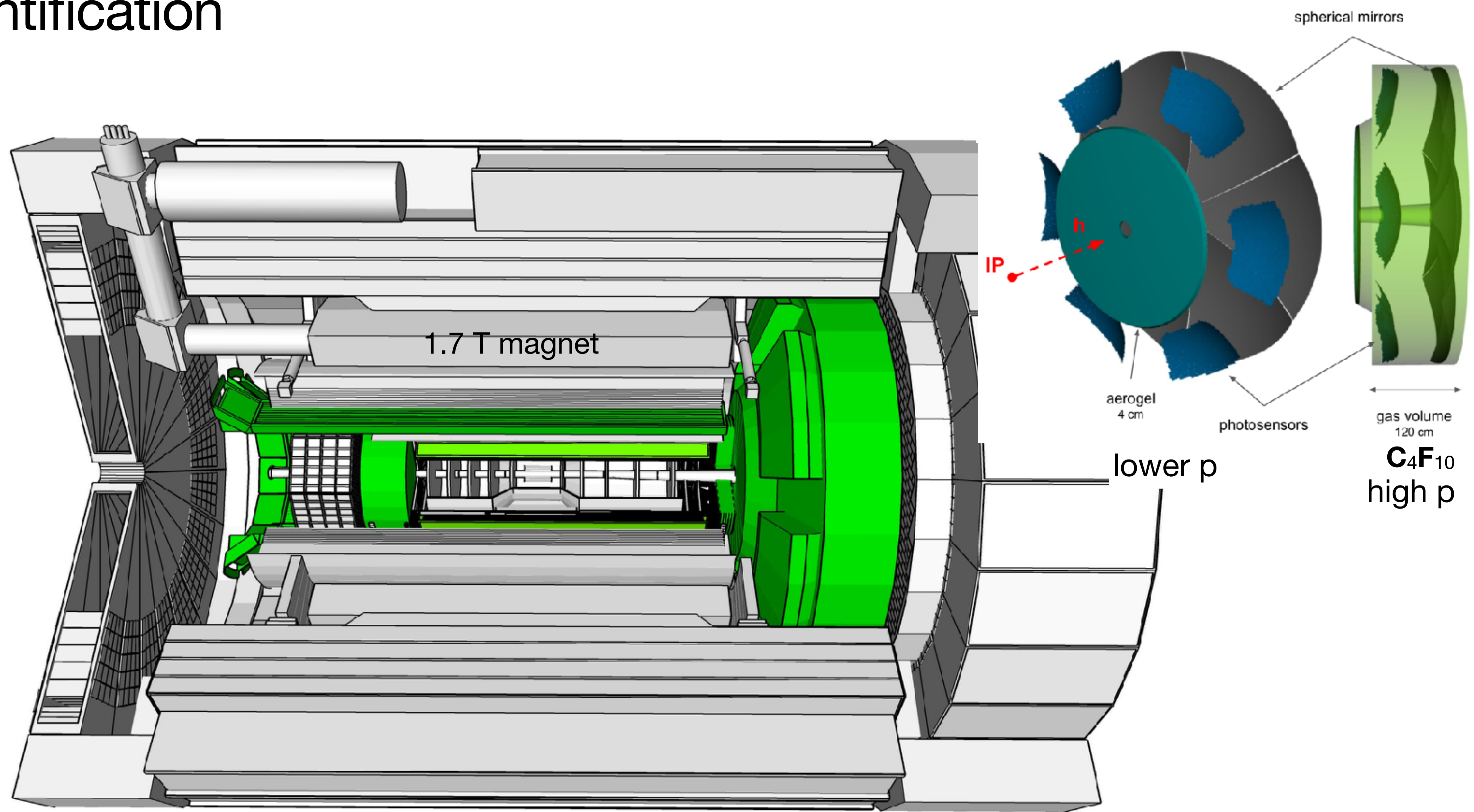
Particle identification



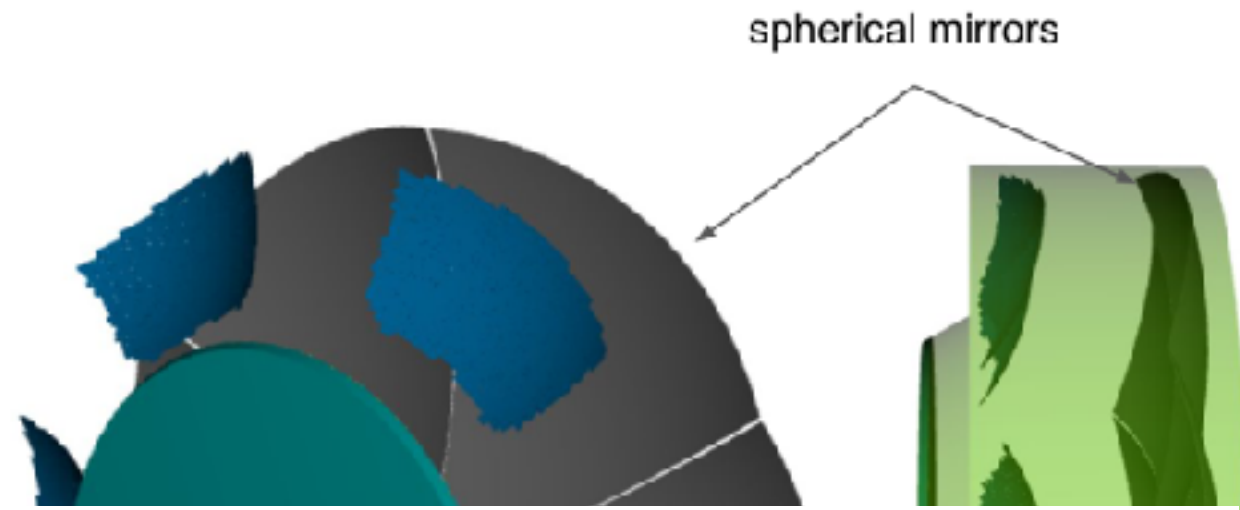
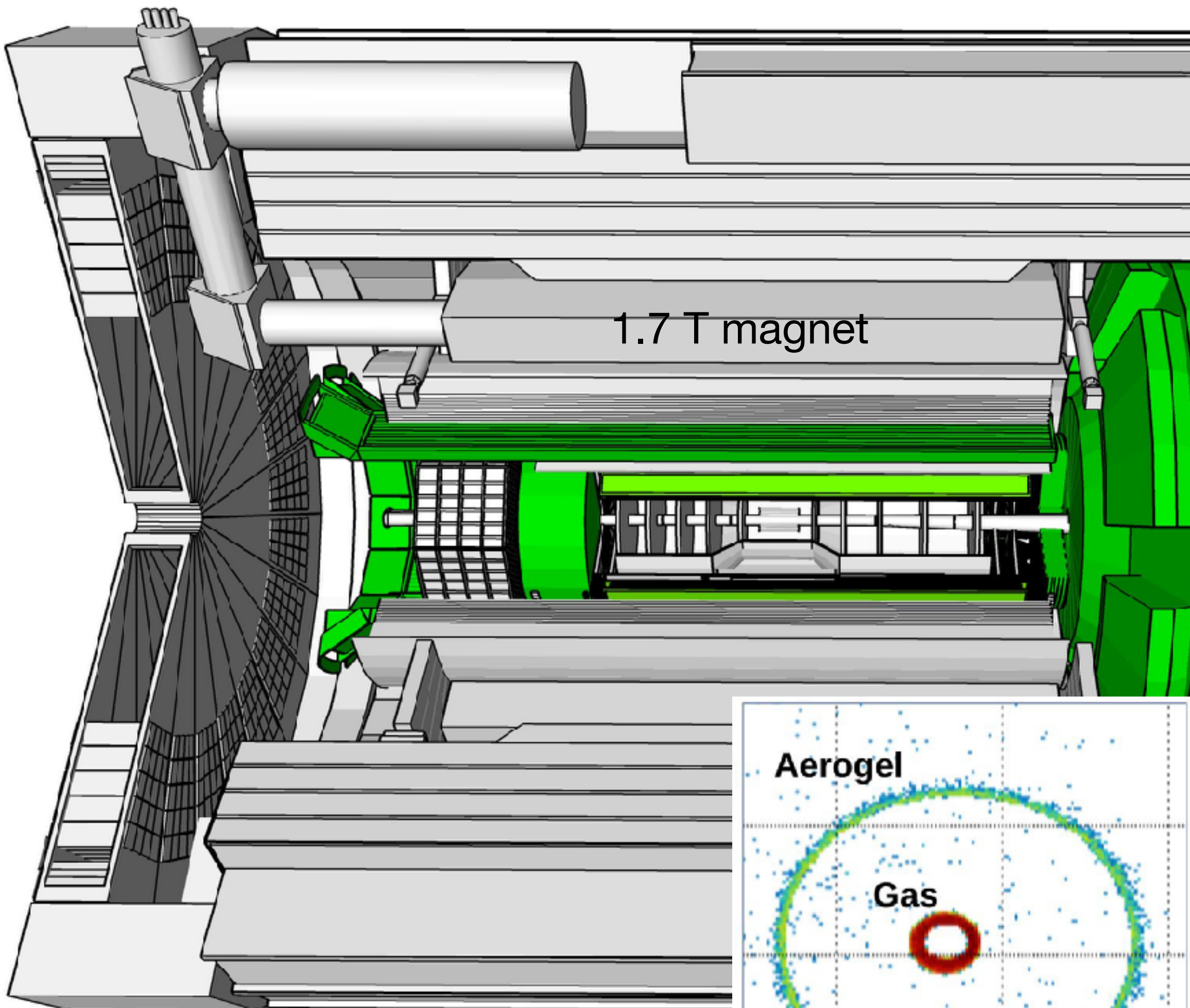
Particle identification



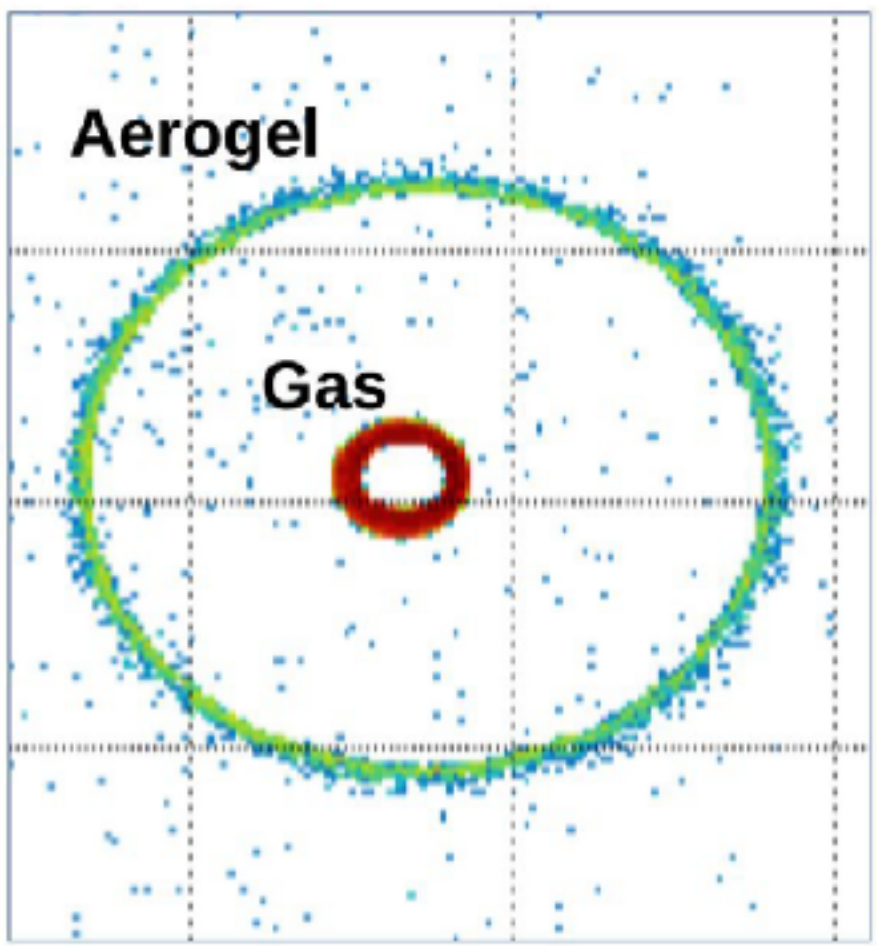
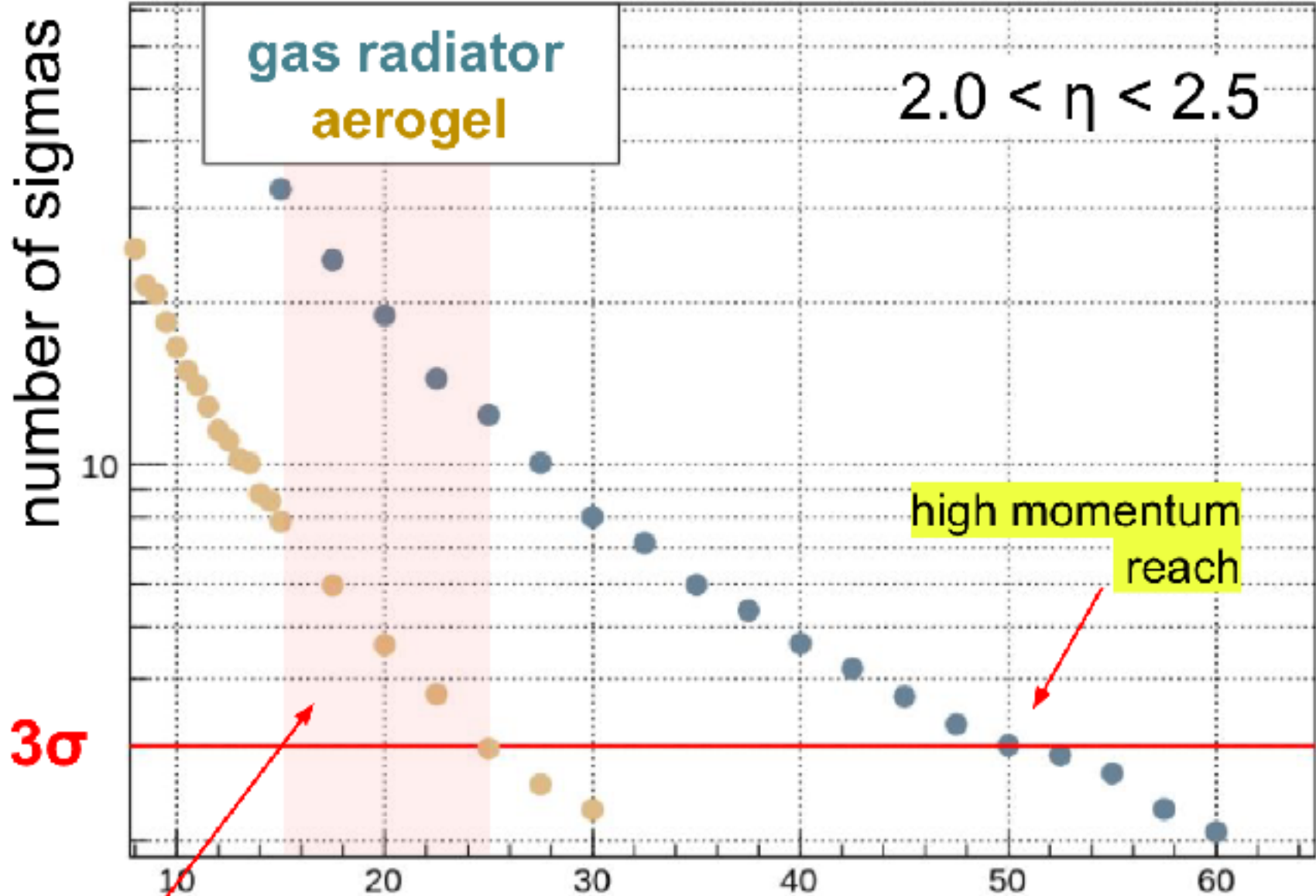
Particle identification



Particle identification



π/K separation power



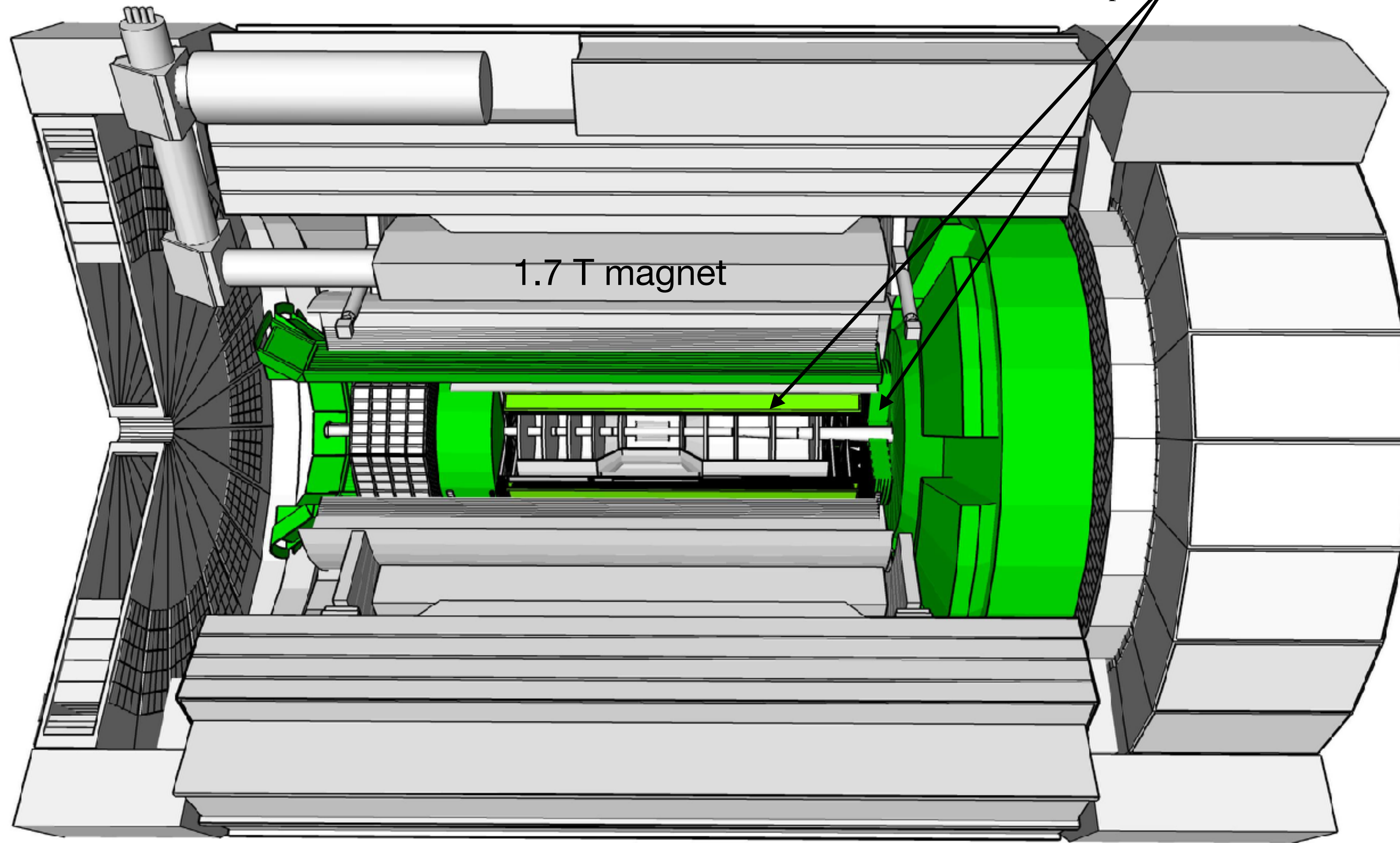
interplay between radiators

within ePIC simulation framework

Particle identification

AC-LGAD based TOF, for $p < 0.5 - 3 \text{ GeV}/c$

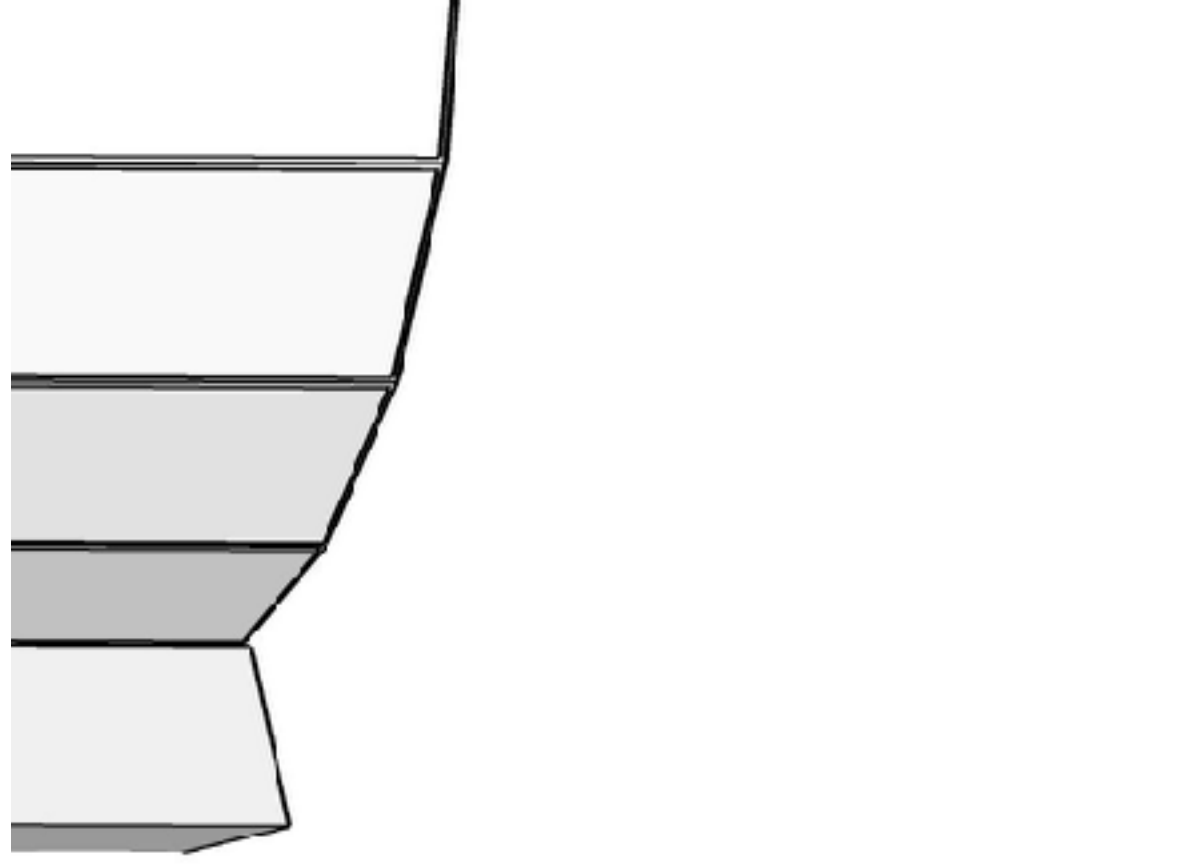
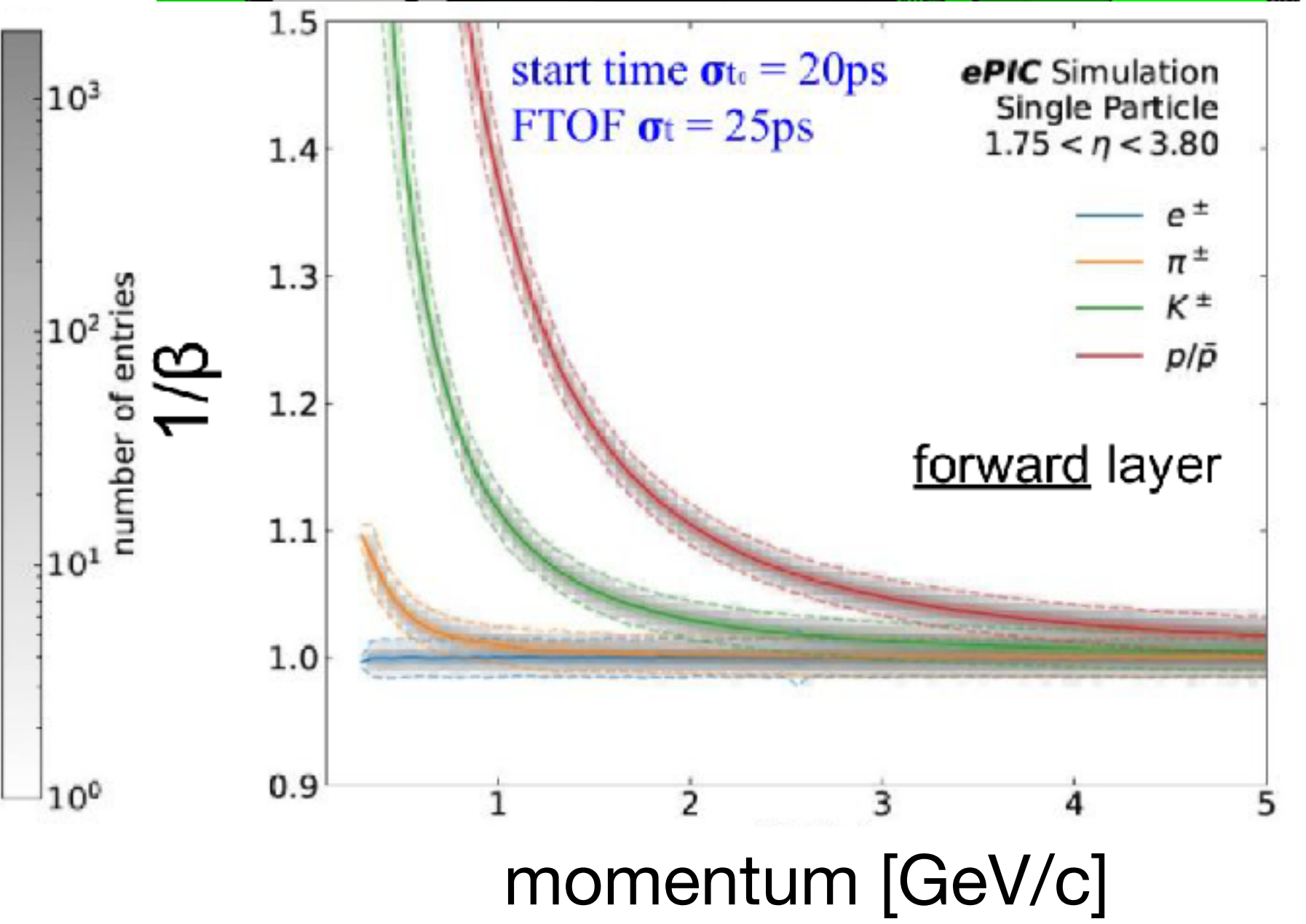
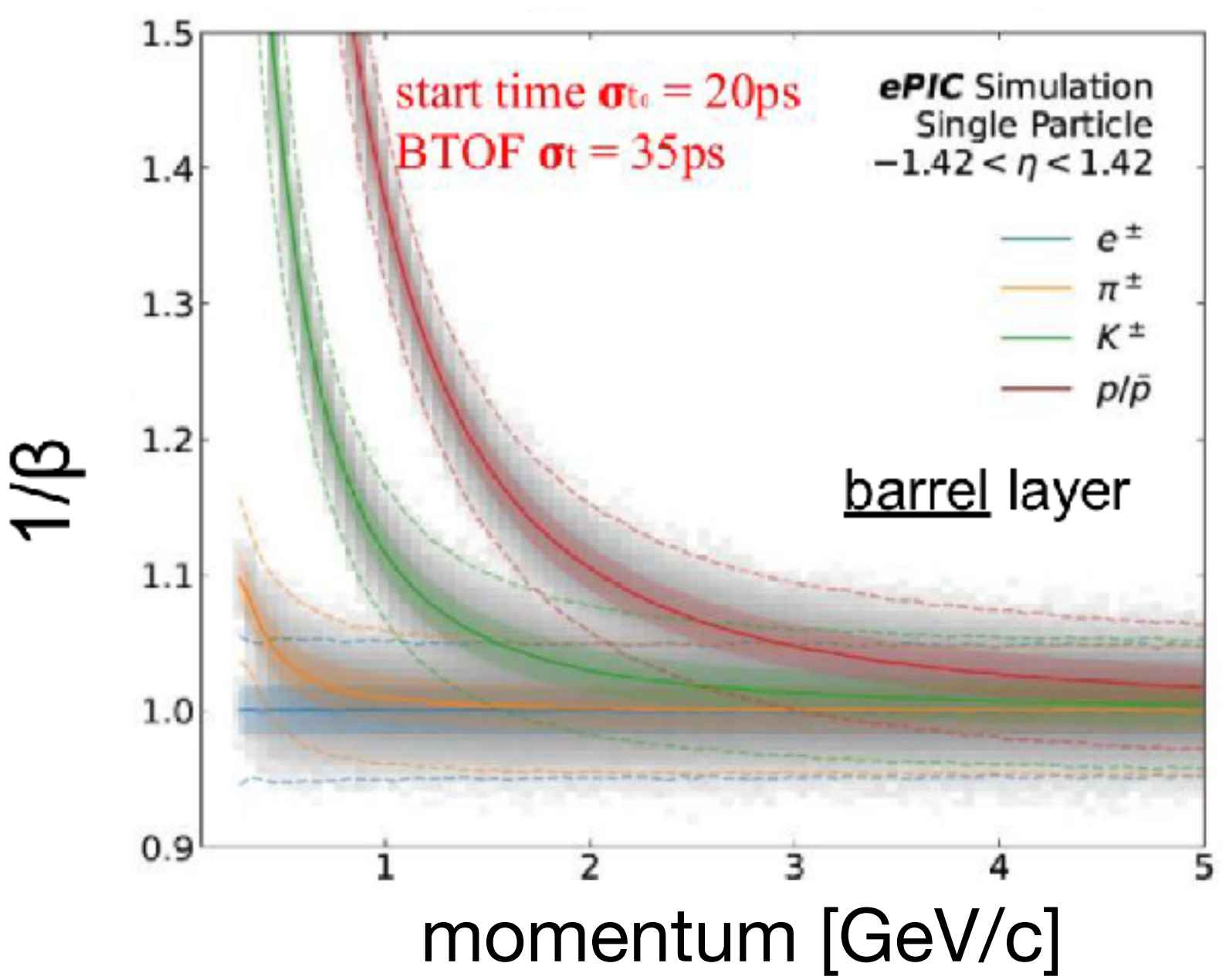
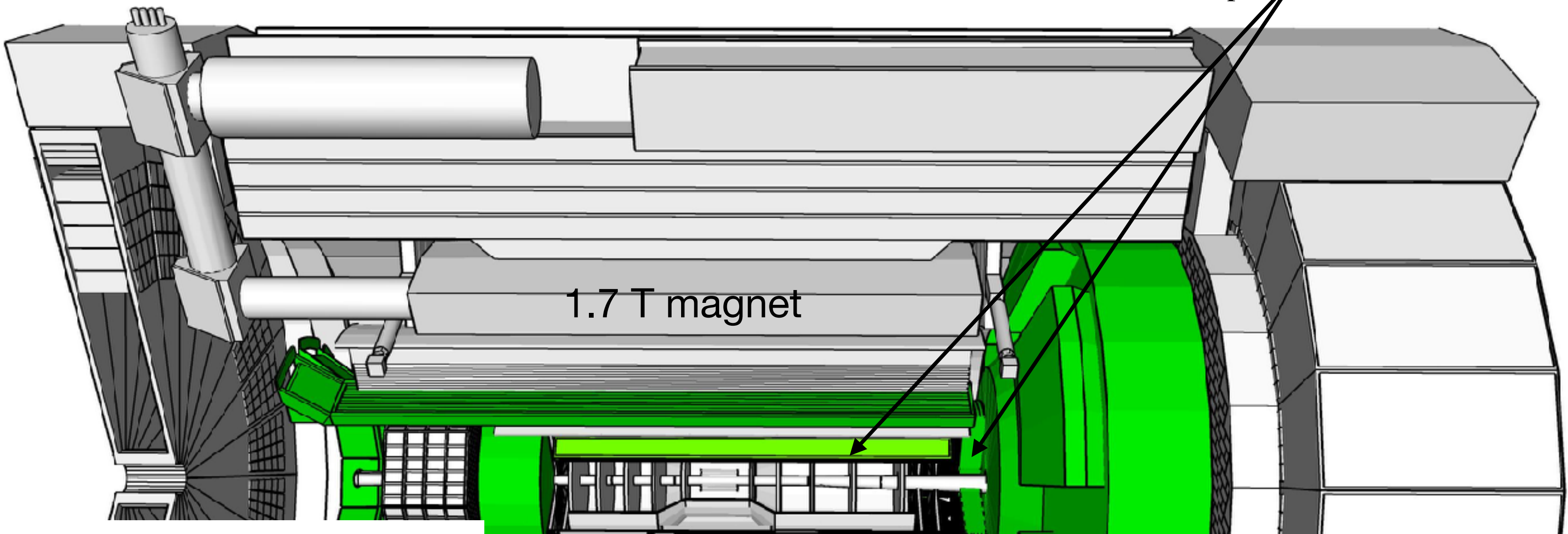
$$v = \frac{L}{t_{stop} - t_{start}}$$



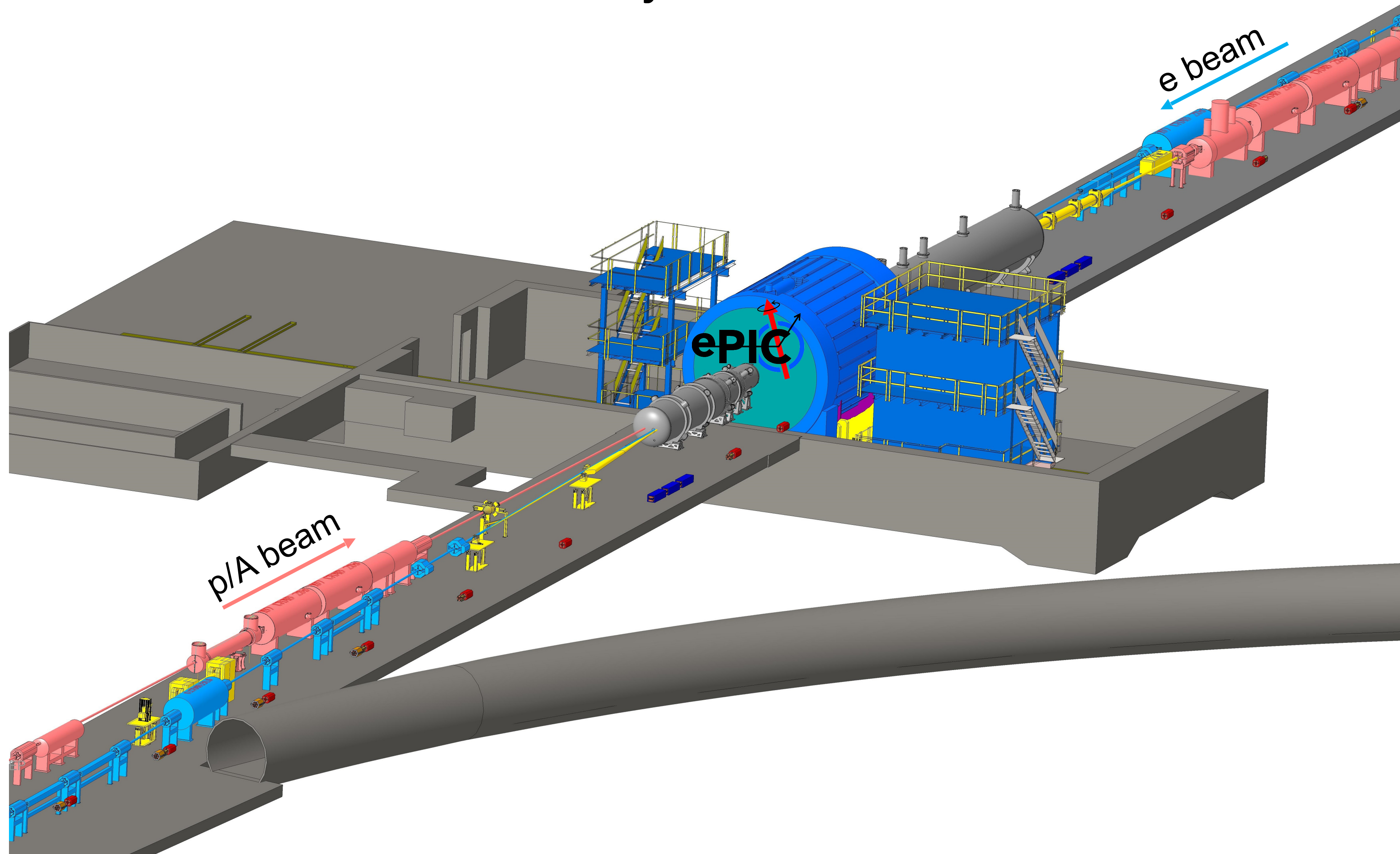
Particle identification

AC-LGAD based TOF, for $p < 0.5 - 3 \text{ GeV/c}$

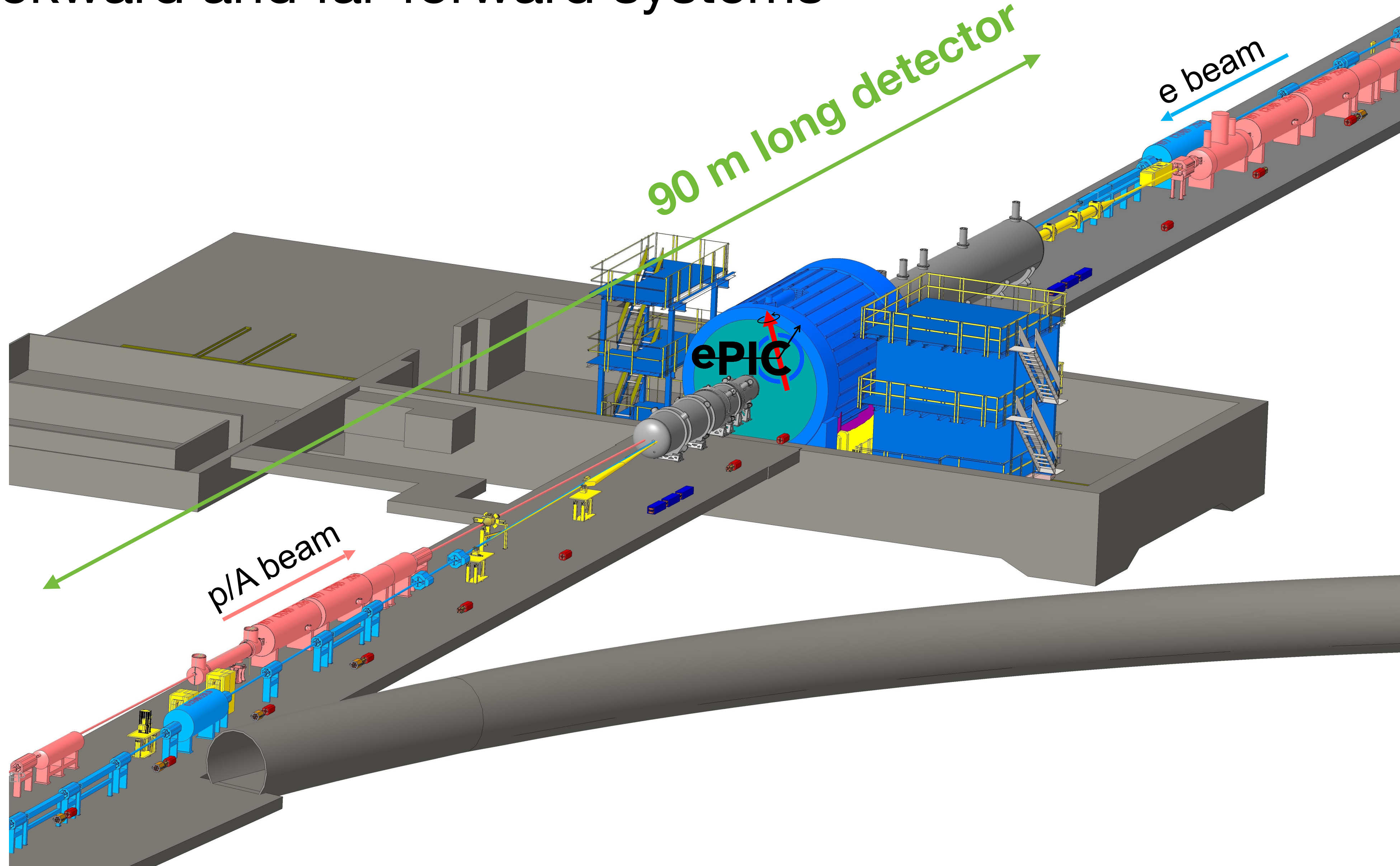
$$v = \frac{L}{t_{stop} - t_{start}}$$



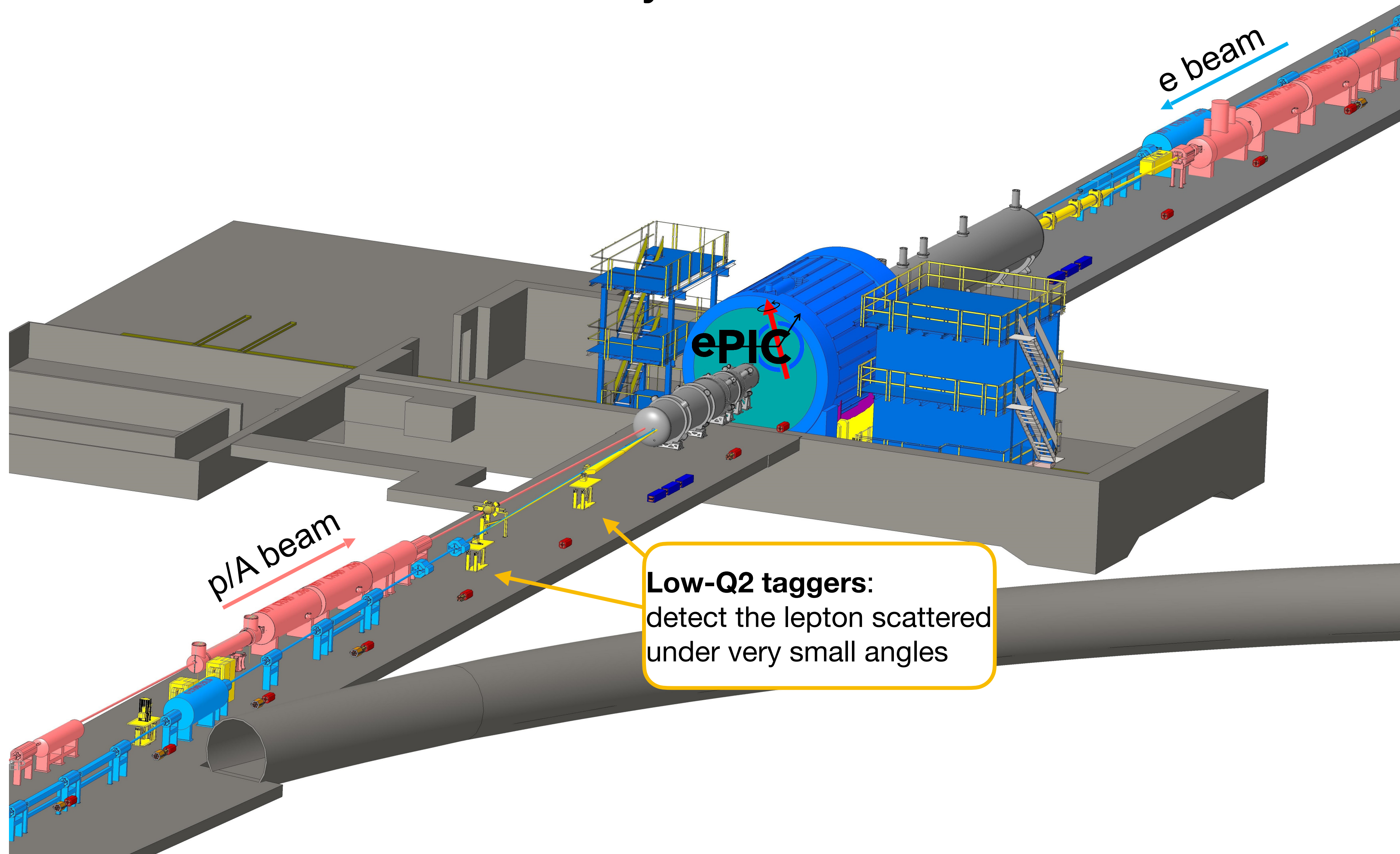
Far-backward and far-forward systems



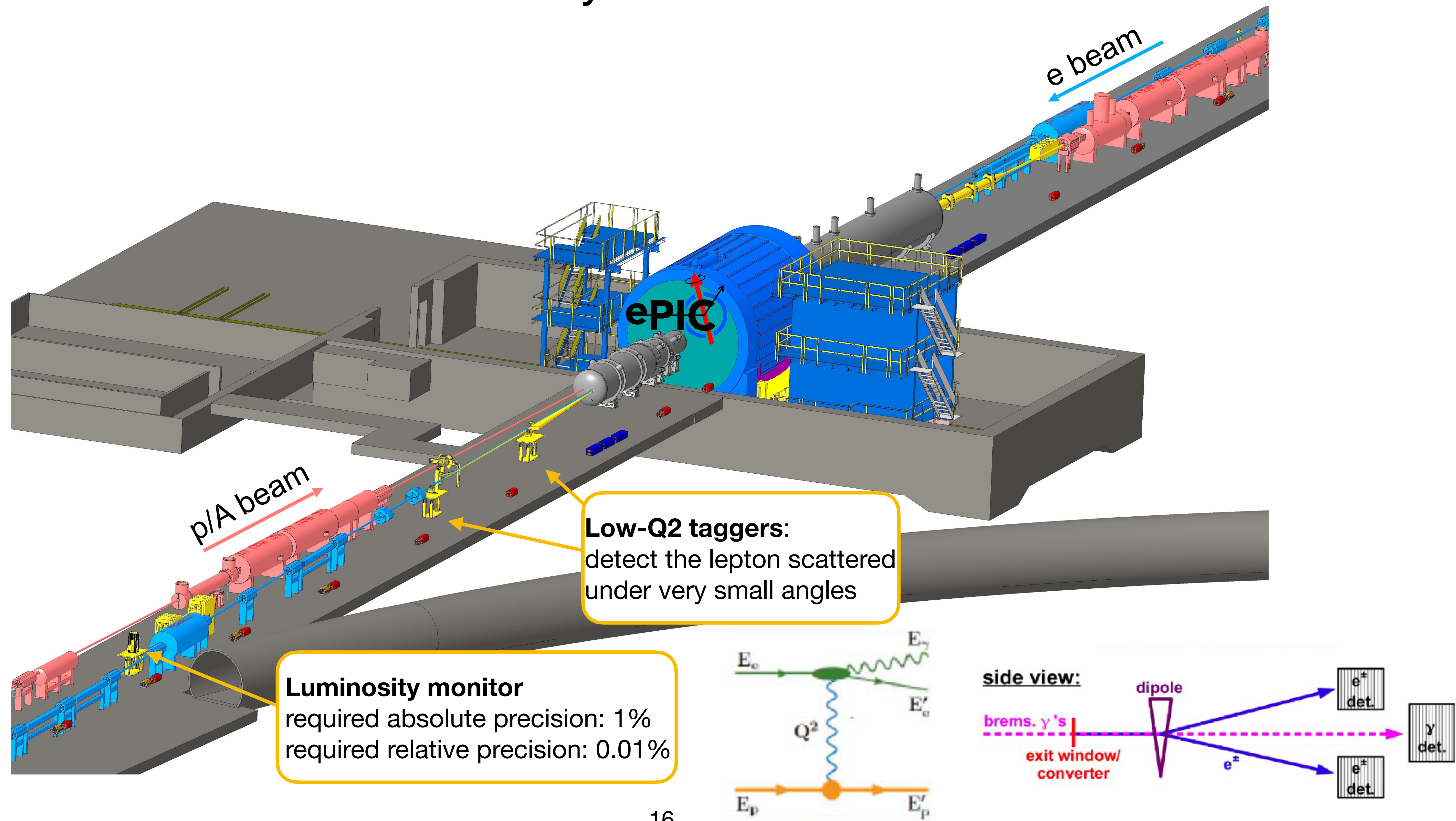
Far-backward and far-forward systems



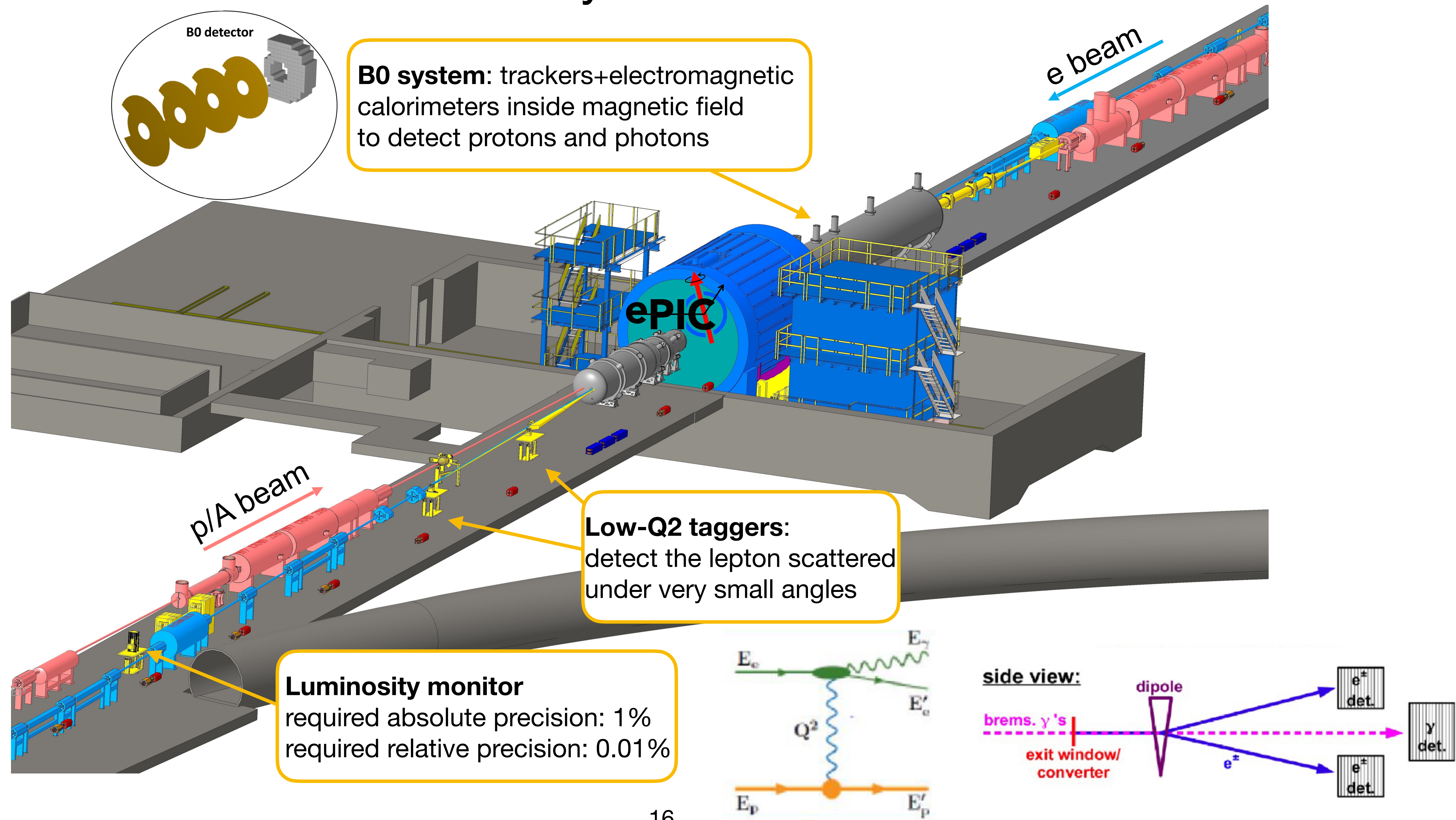
Far-backward and far-forward systems



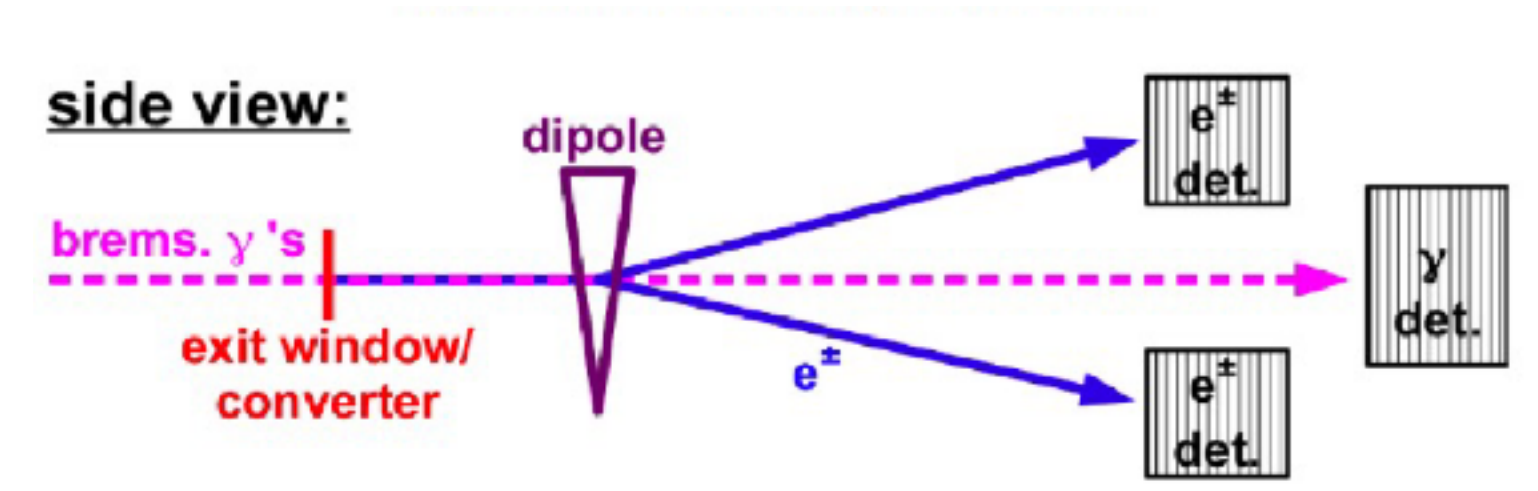
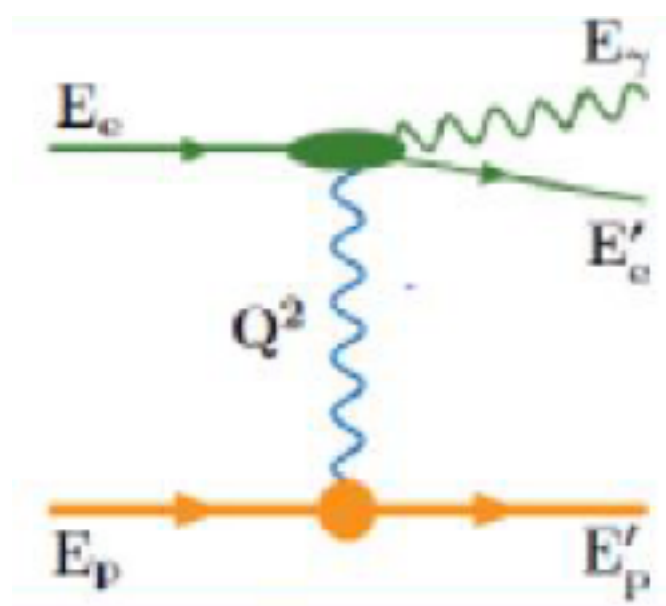
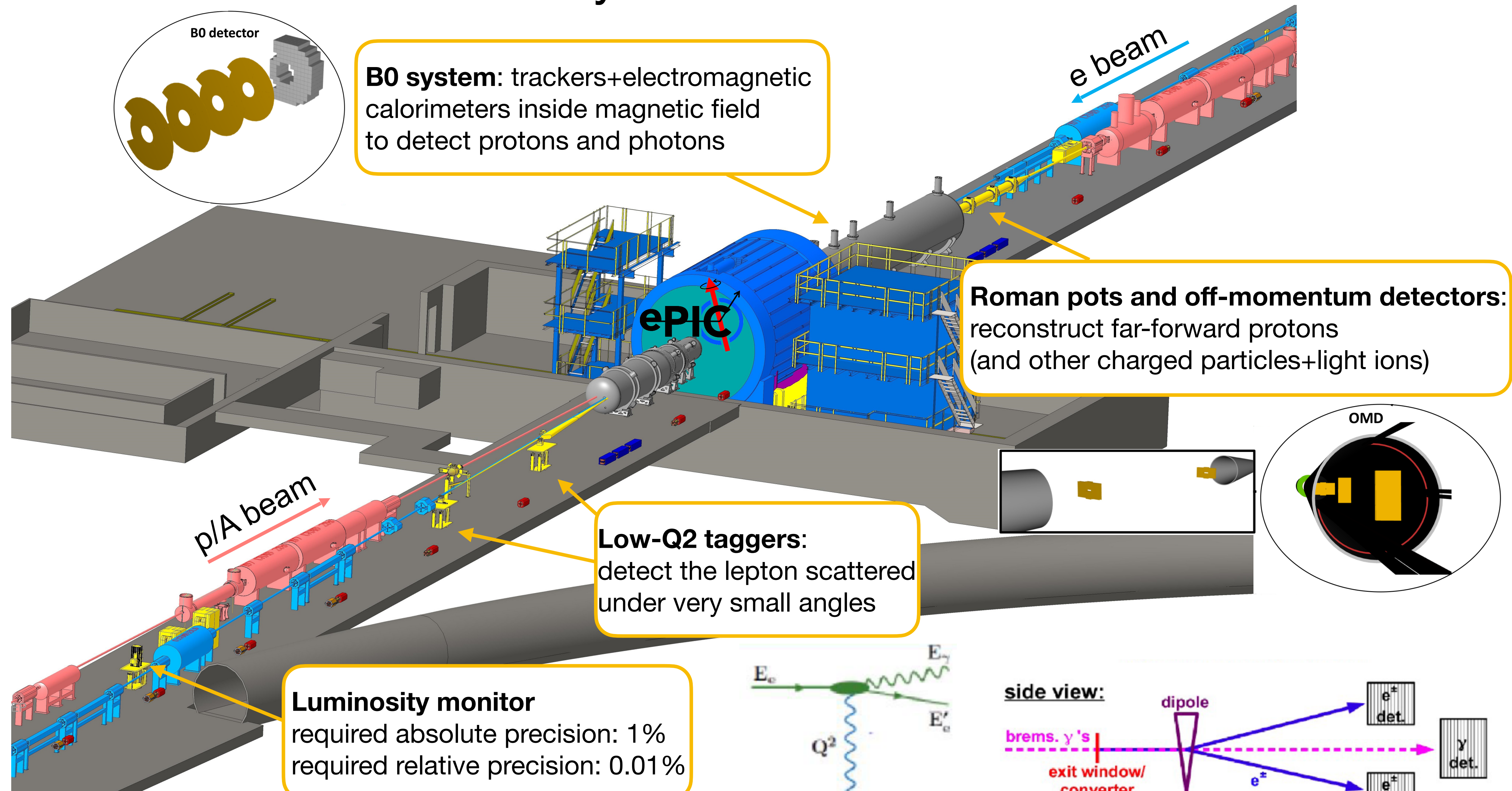
Far-backward and far-forward systems



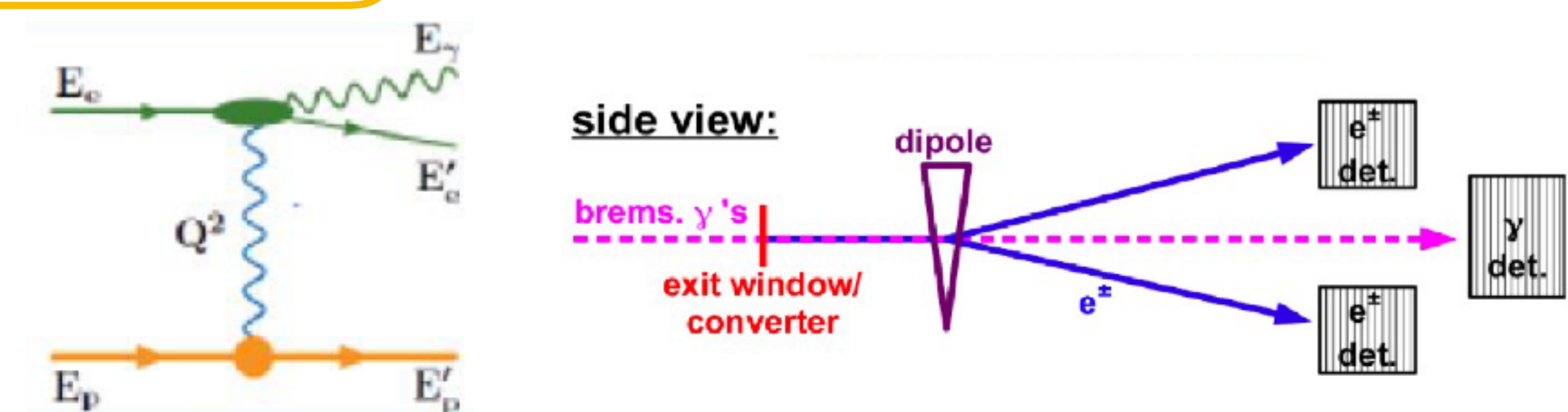
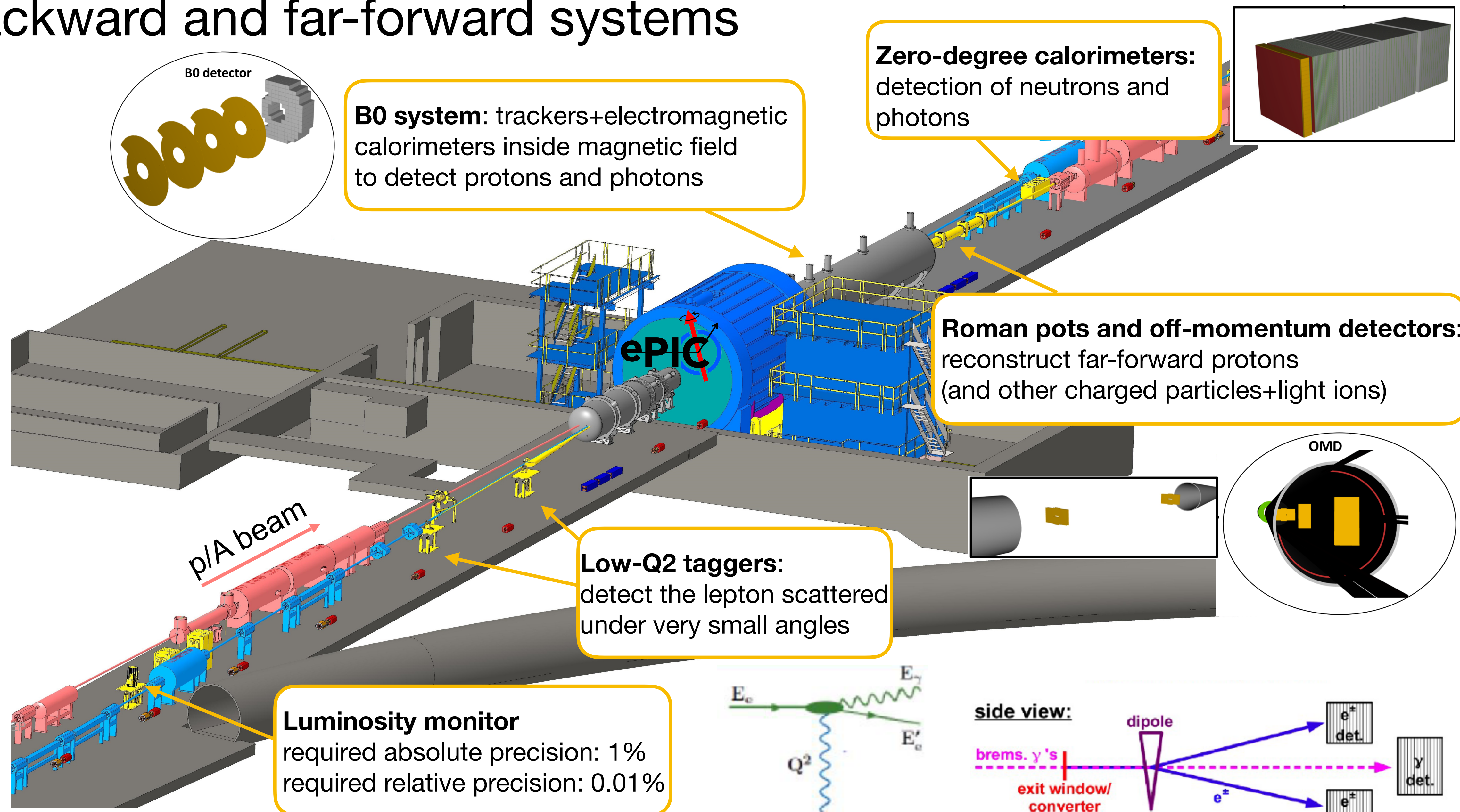
Far-backward and far-forward systems



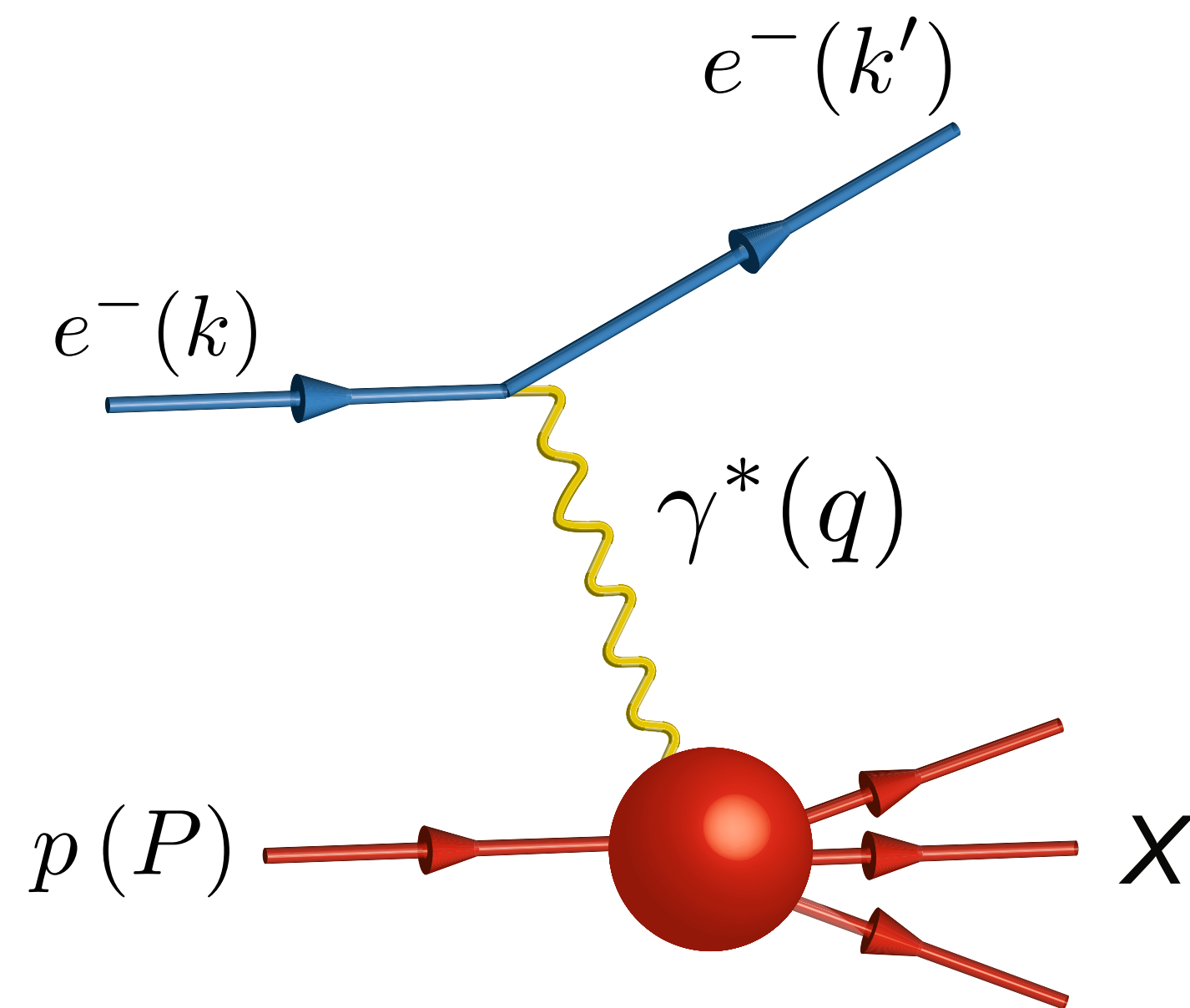
Far-backward and far-forward systems



Far-backward and far-forward systems



Deep-inelastic scattering (DIS) of electrons and nucleons/nuclei

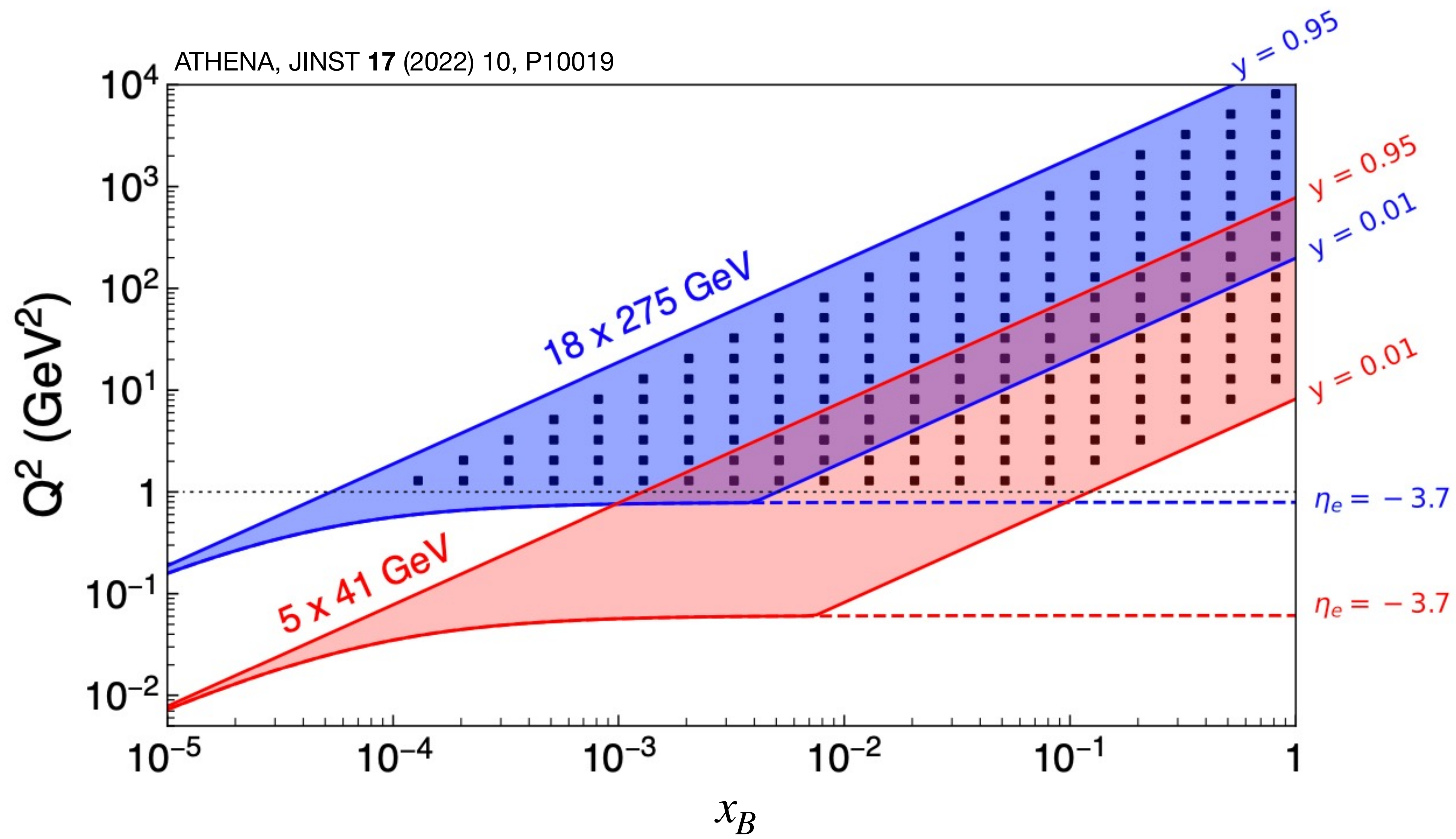


$$Q^2 = -q^2$$

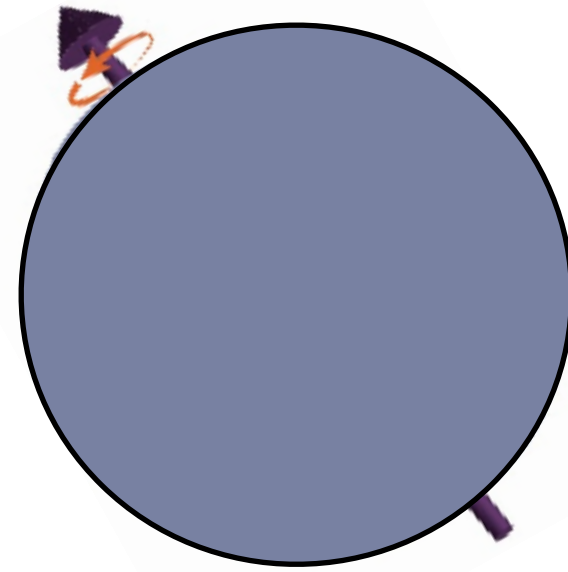
Highly virtual photon:
 $Q^2 \gg 1 \text{ GeV}^2$
provides hard
scale of process

$$x_B = \frac{Q^2}{2P \cdot q}$$

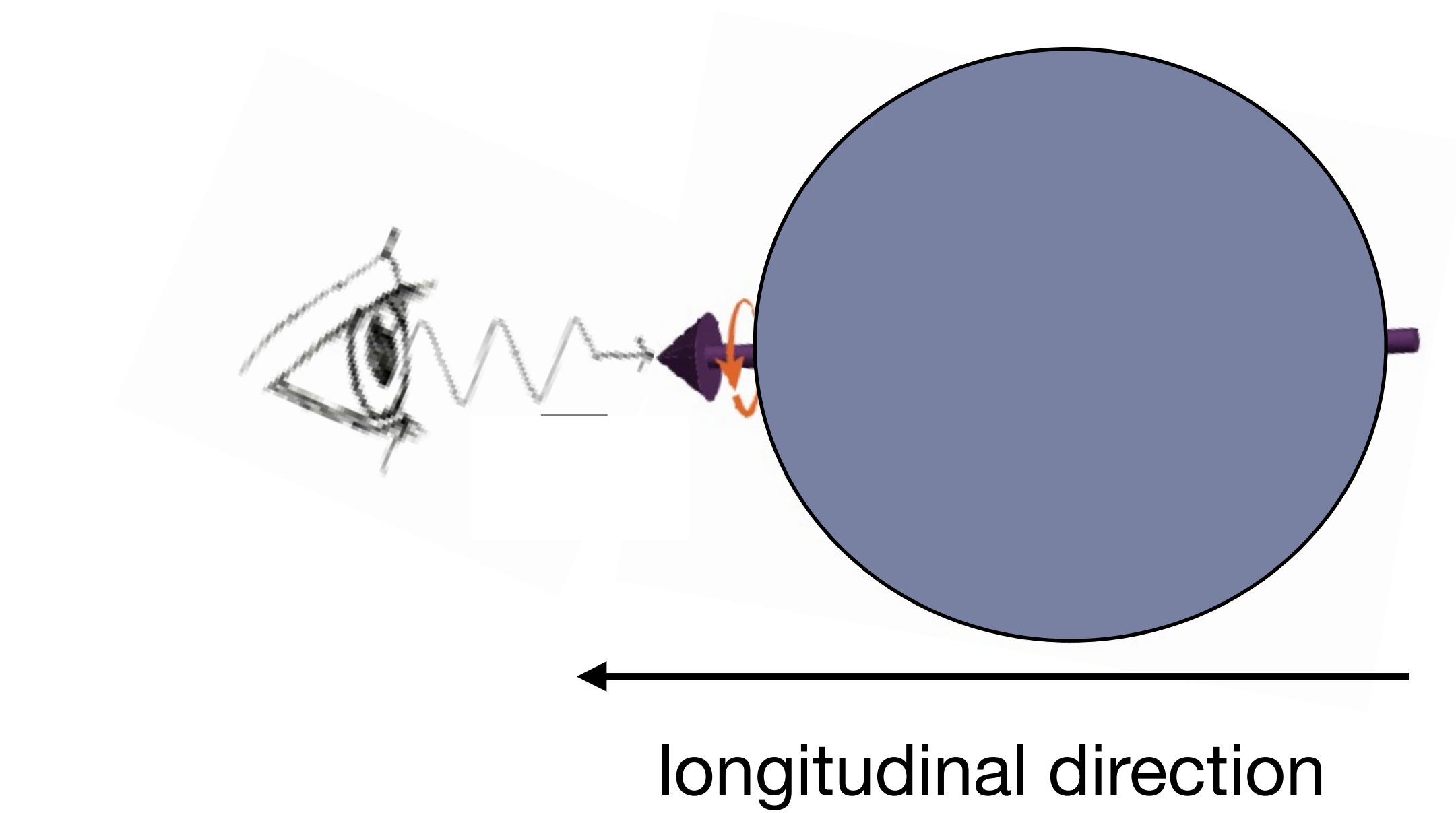
Kinematic coverage at the EIC



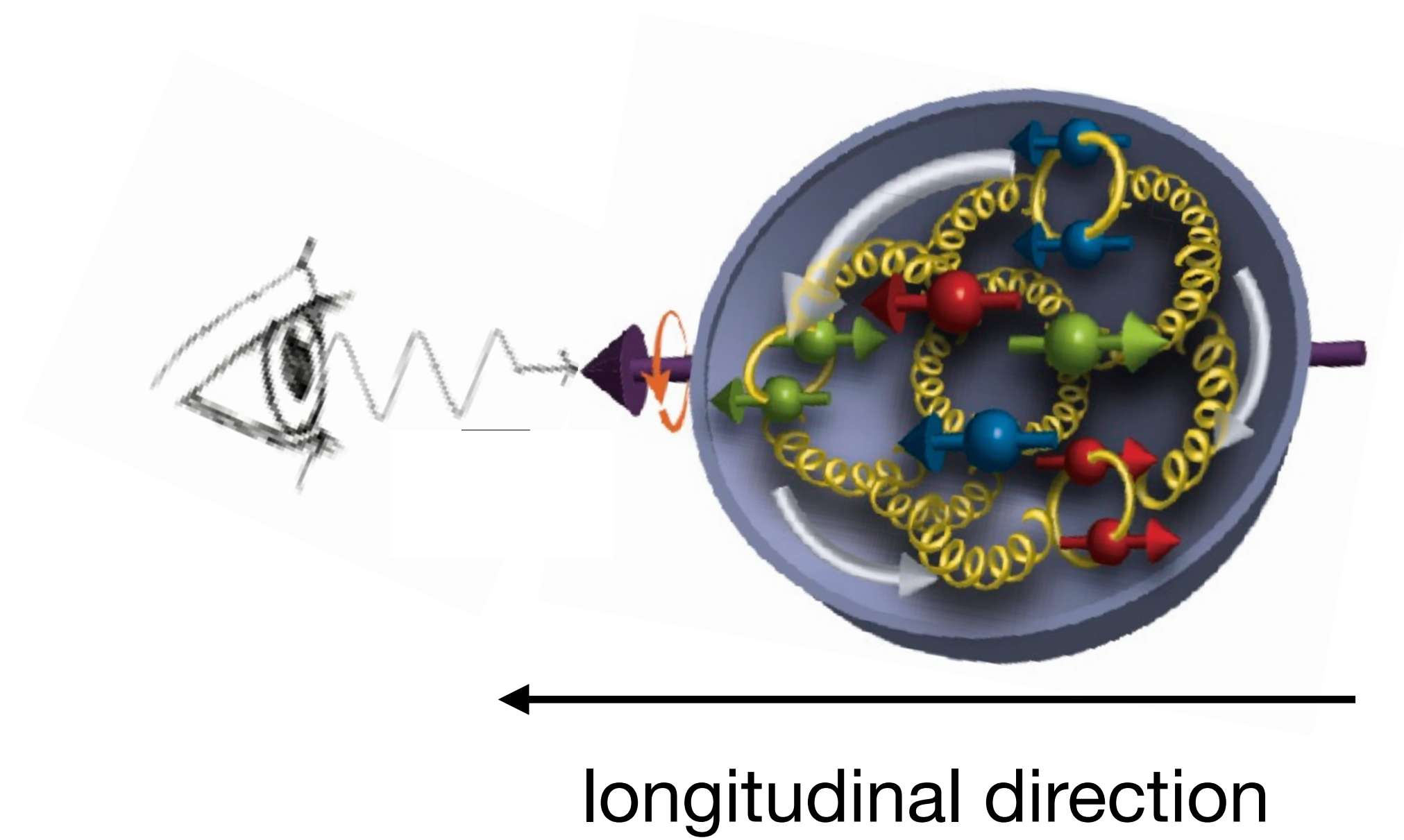
Nucleon spin structure



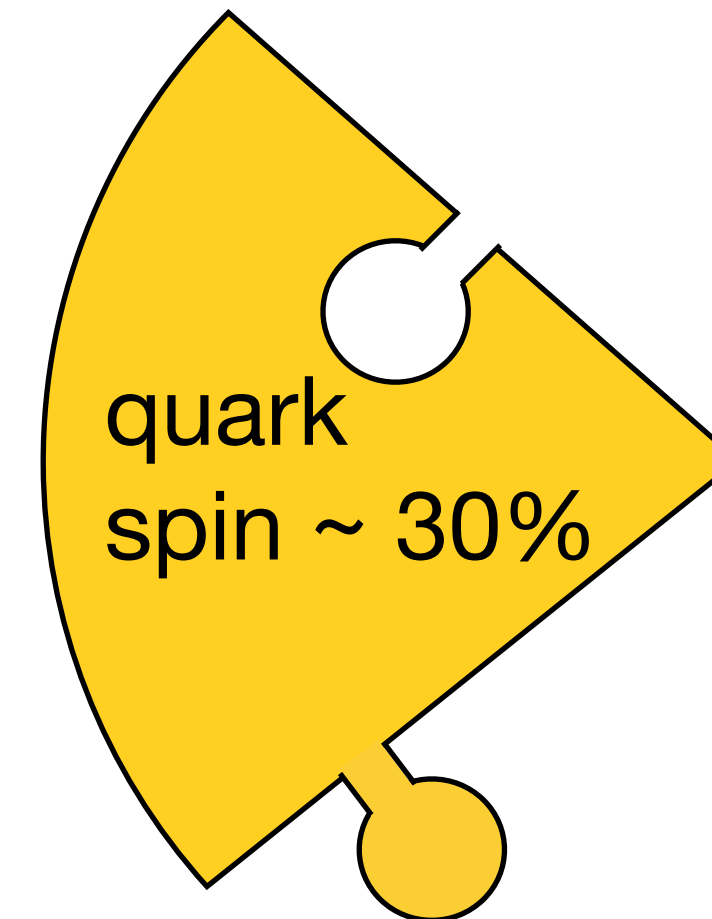
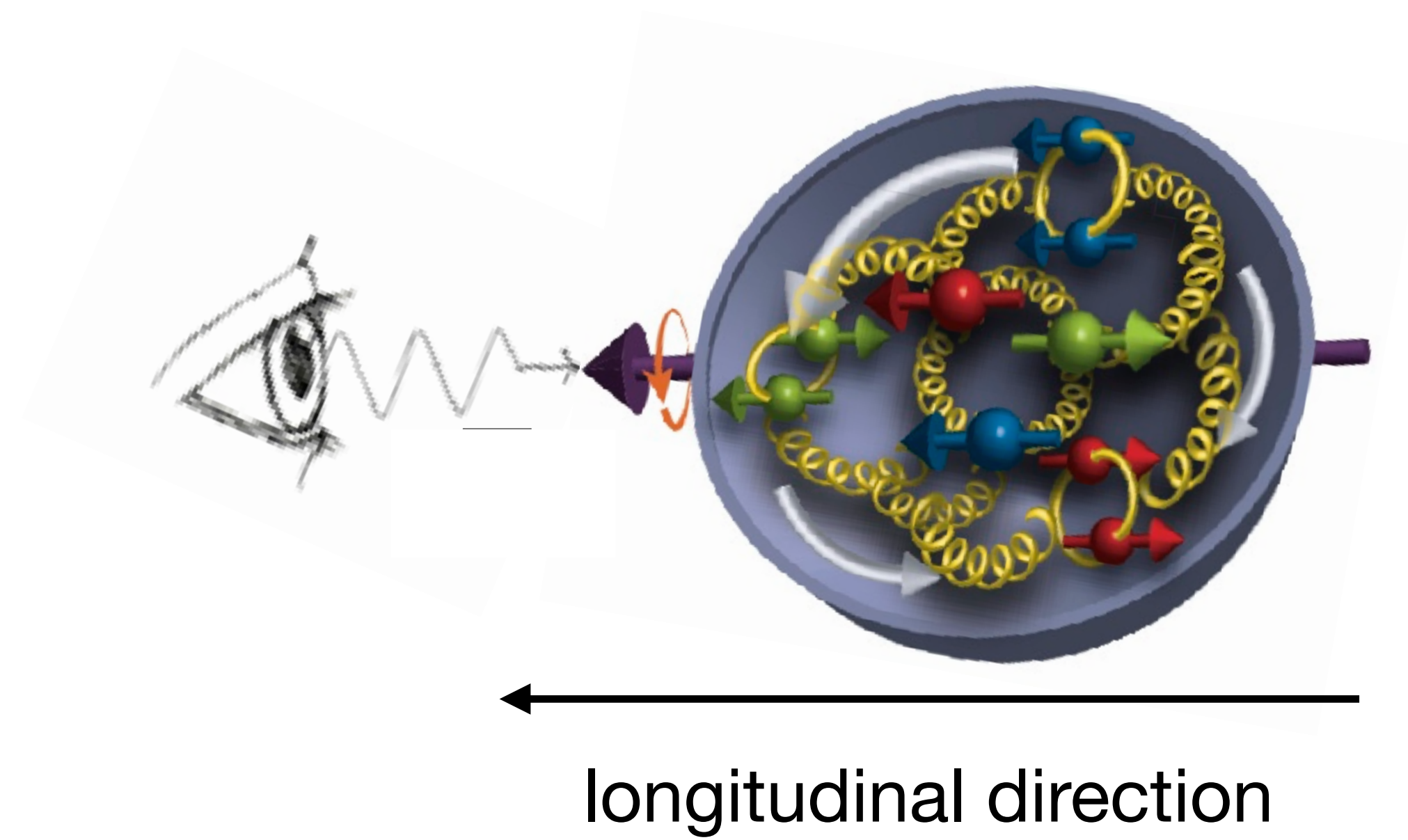
The nucleon spin



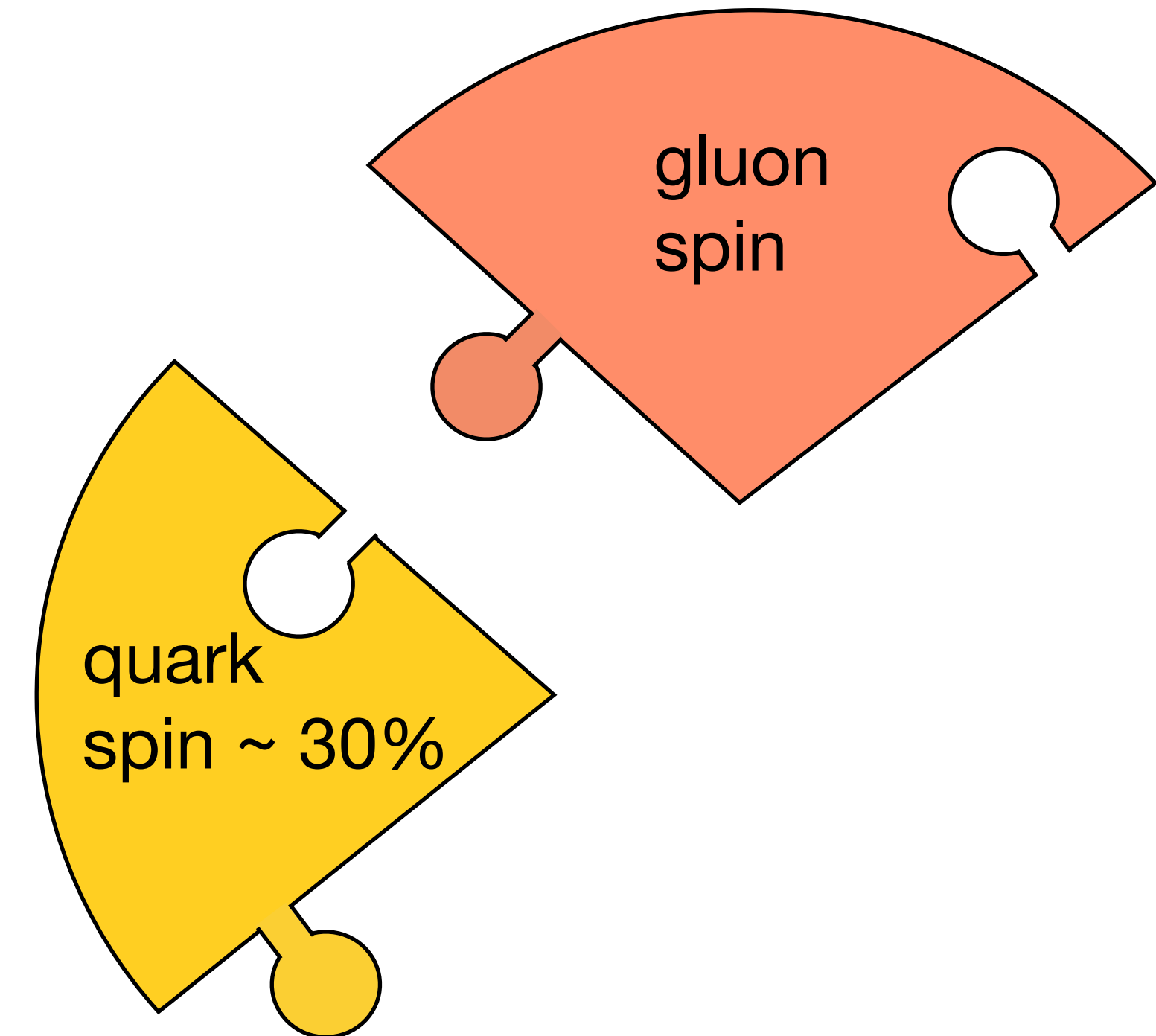
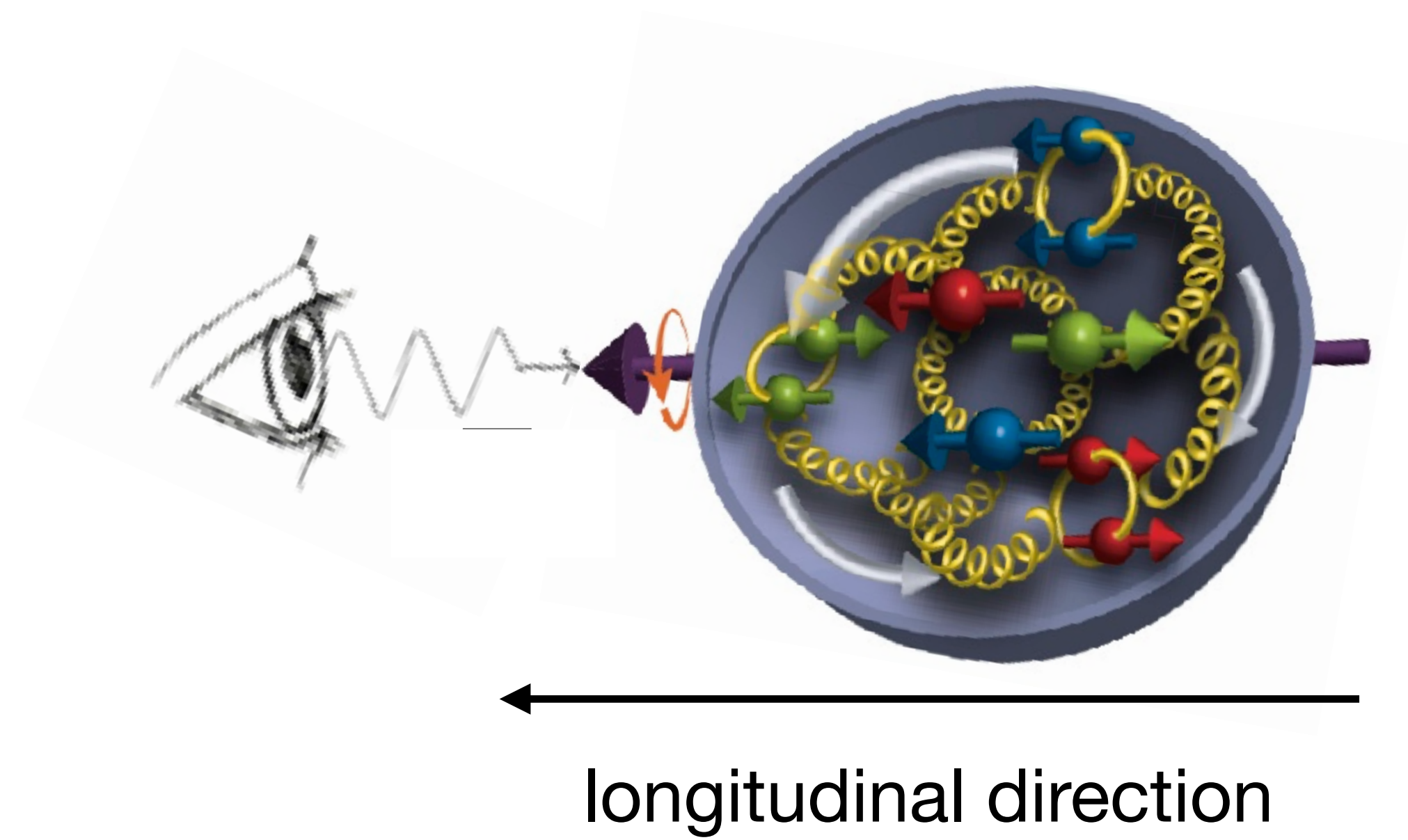
The nucleon spin



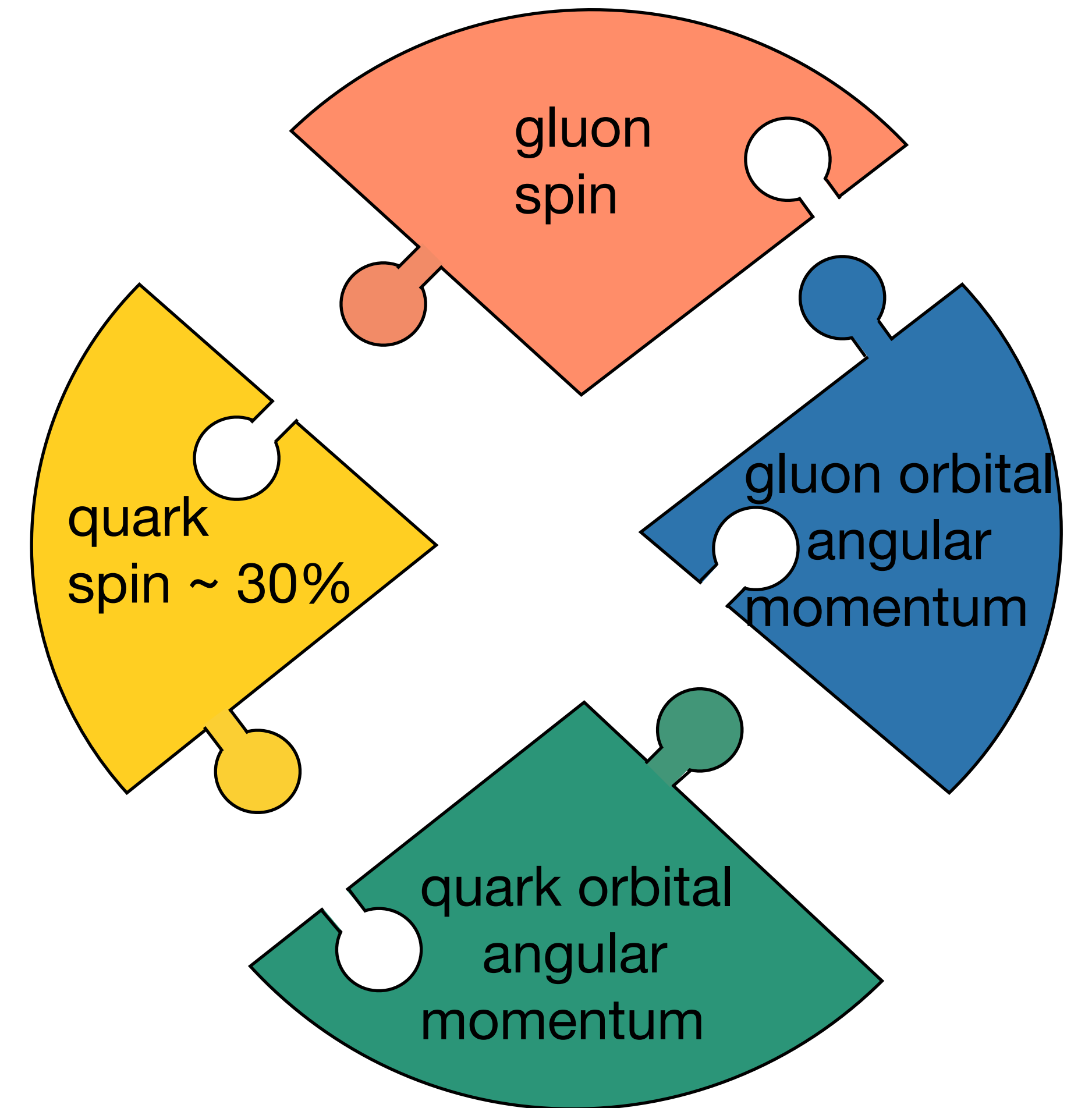
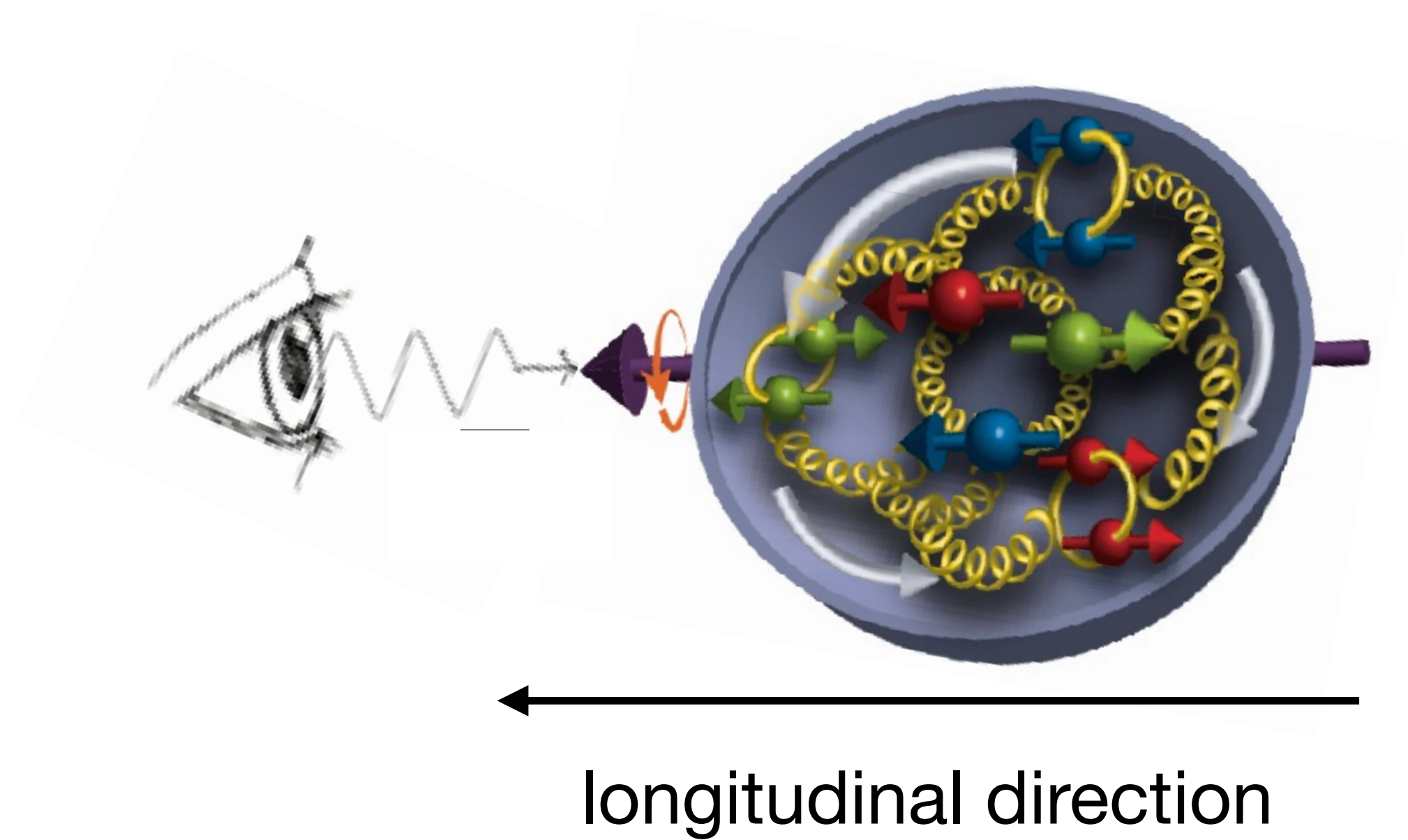
The nucleon spin



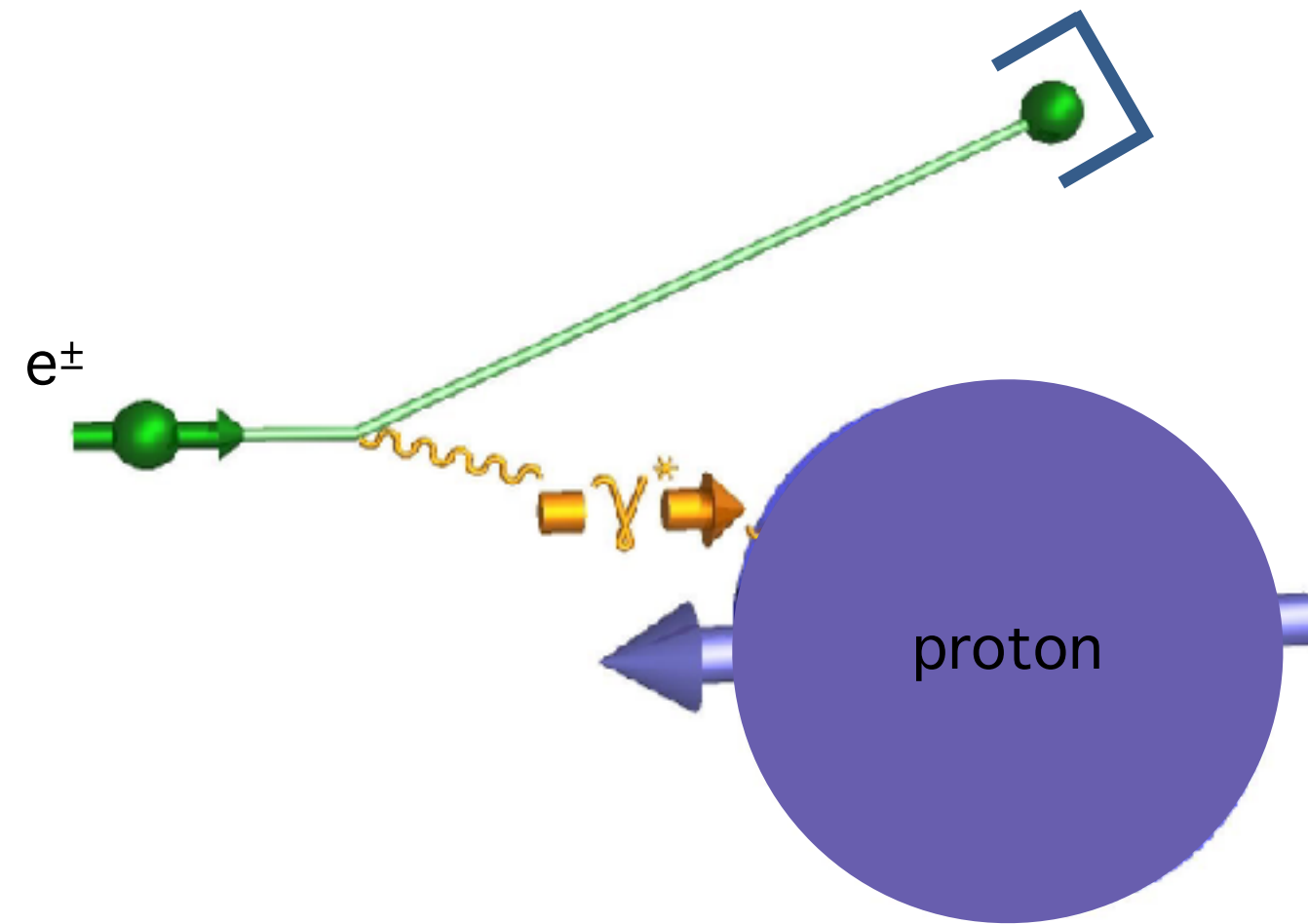
The nucleon spin



The nucleon spin

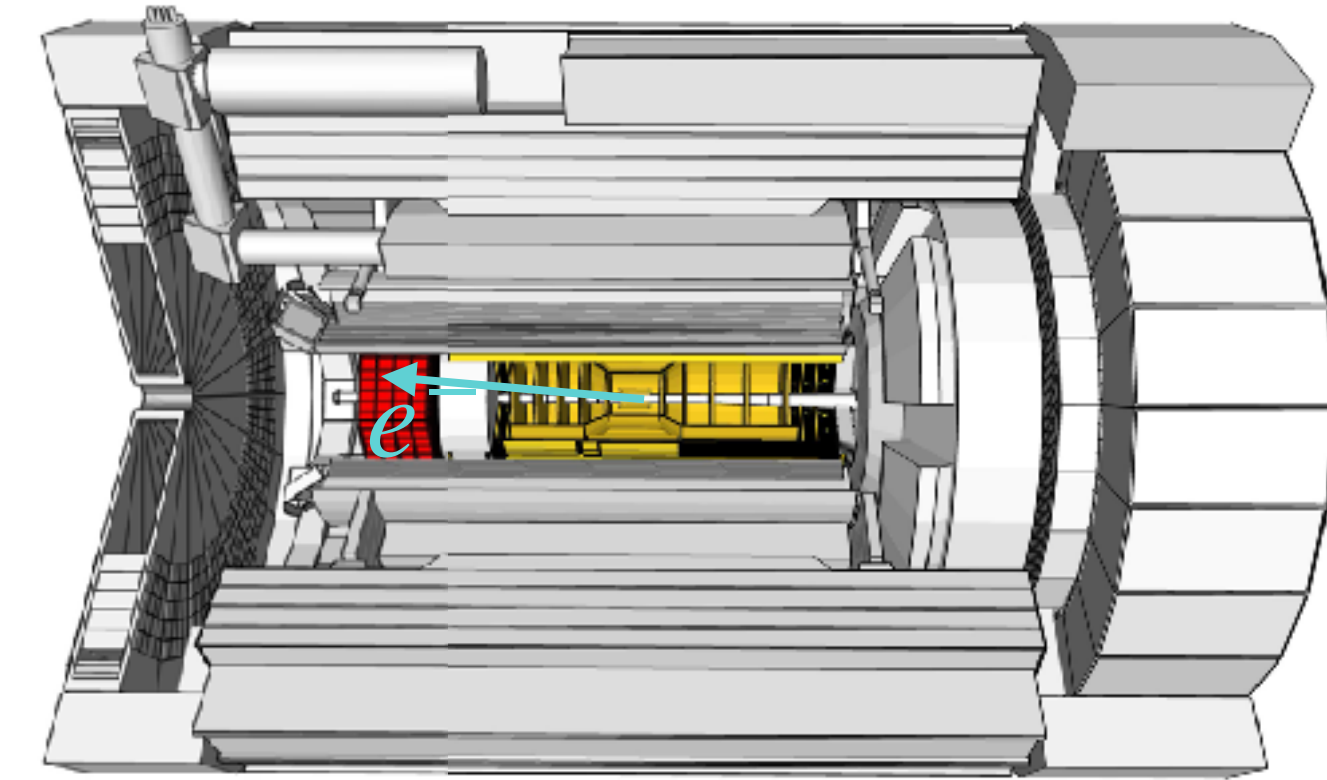


Helicity structure of the nucleon

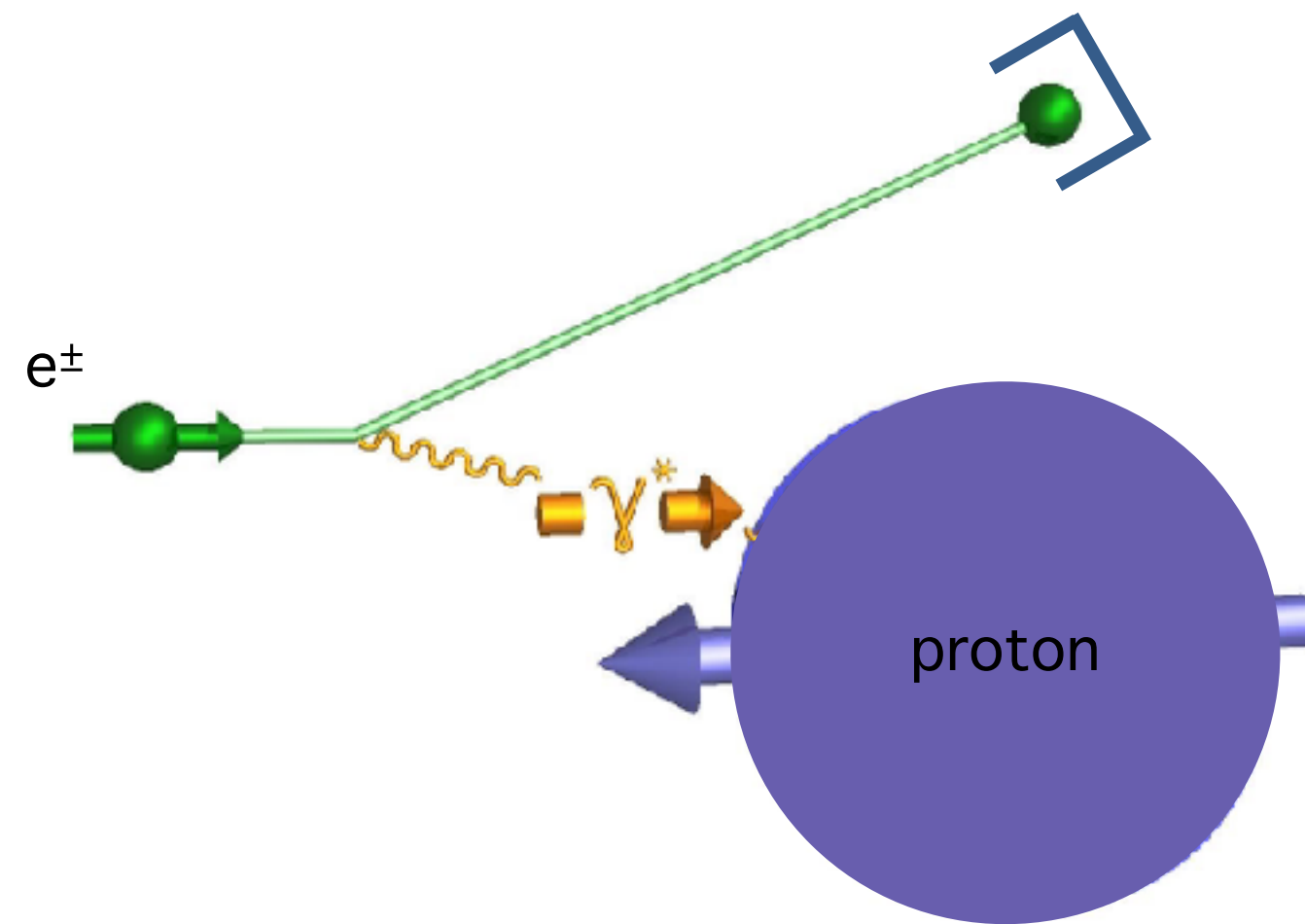


- longitudinally polarised proton
- longitudinally polarised $e^\pm$ beam
- count...

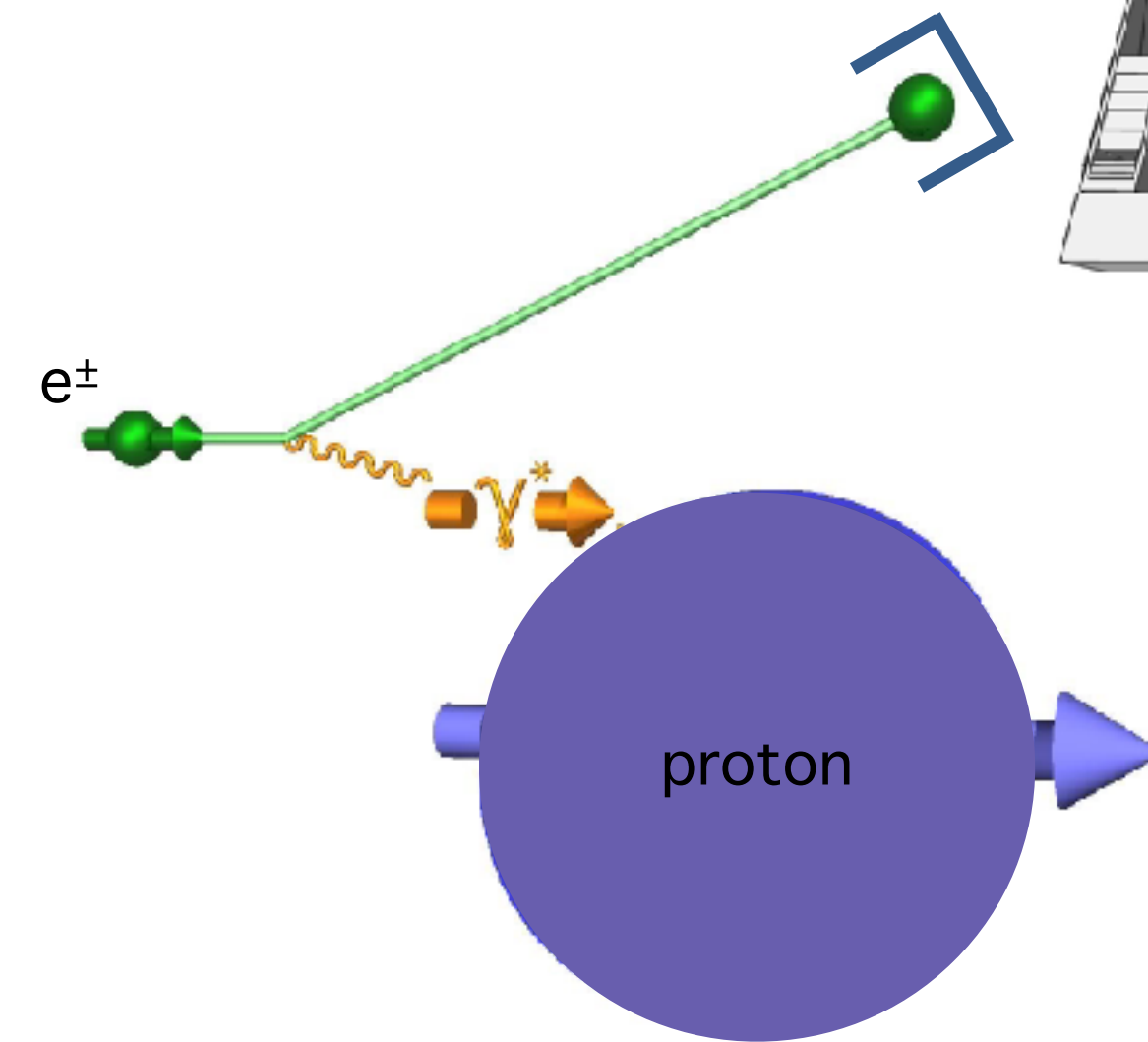
0	2	4	6	8	10
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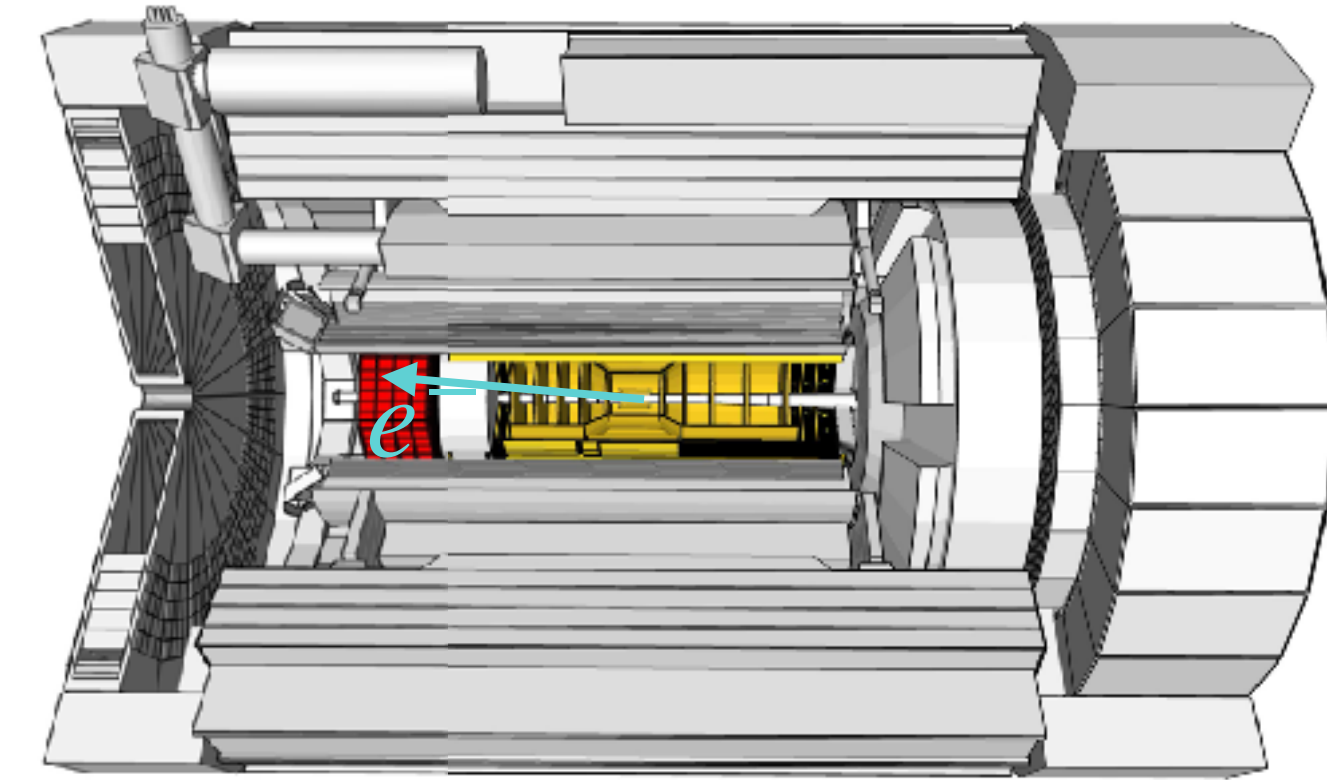
Helicity structure of the nucleon



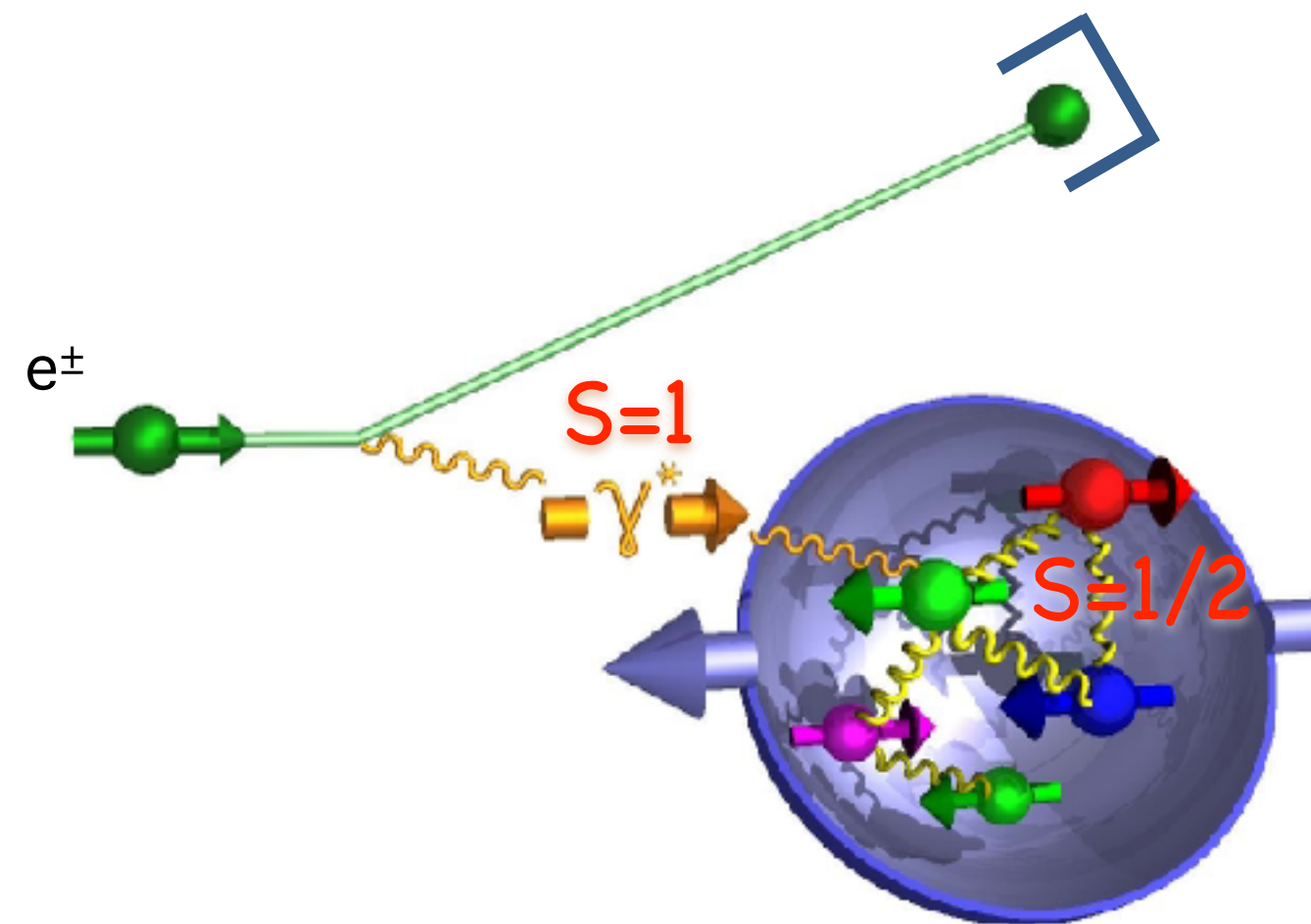
- longitudinally polarised proton
- longitudinally polarised $e^\pm$ beam
- count... 02488



- flip proton spin and count... 02488

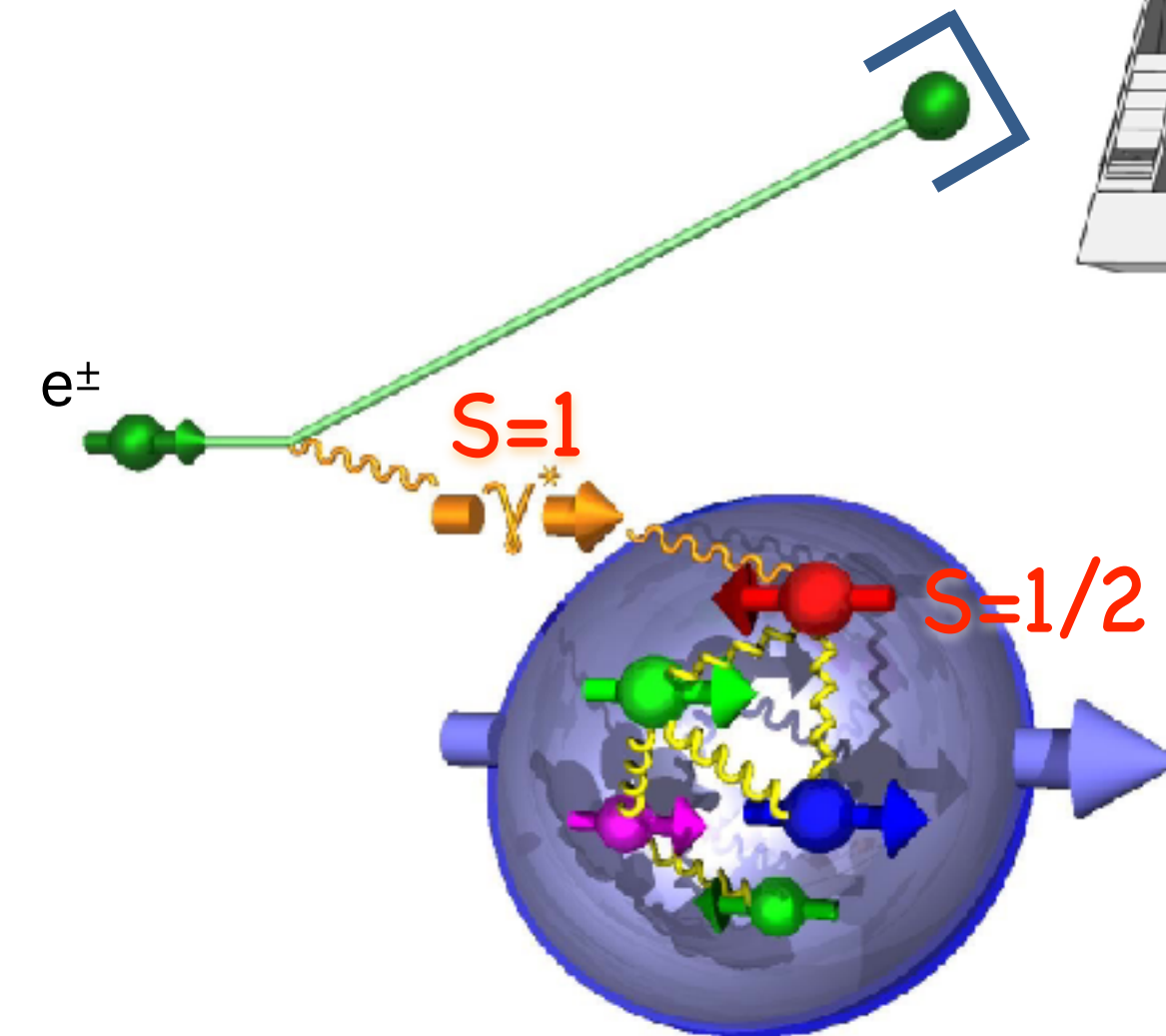


Helicity structure of the nucleon



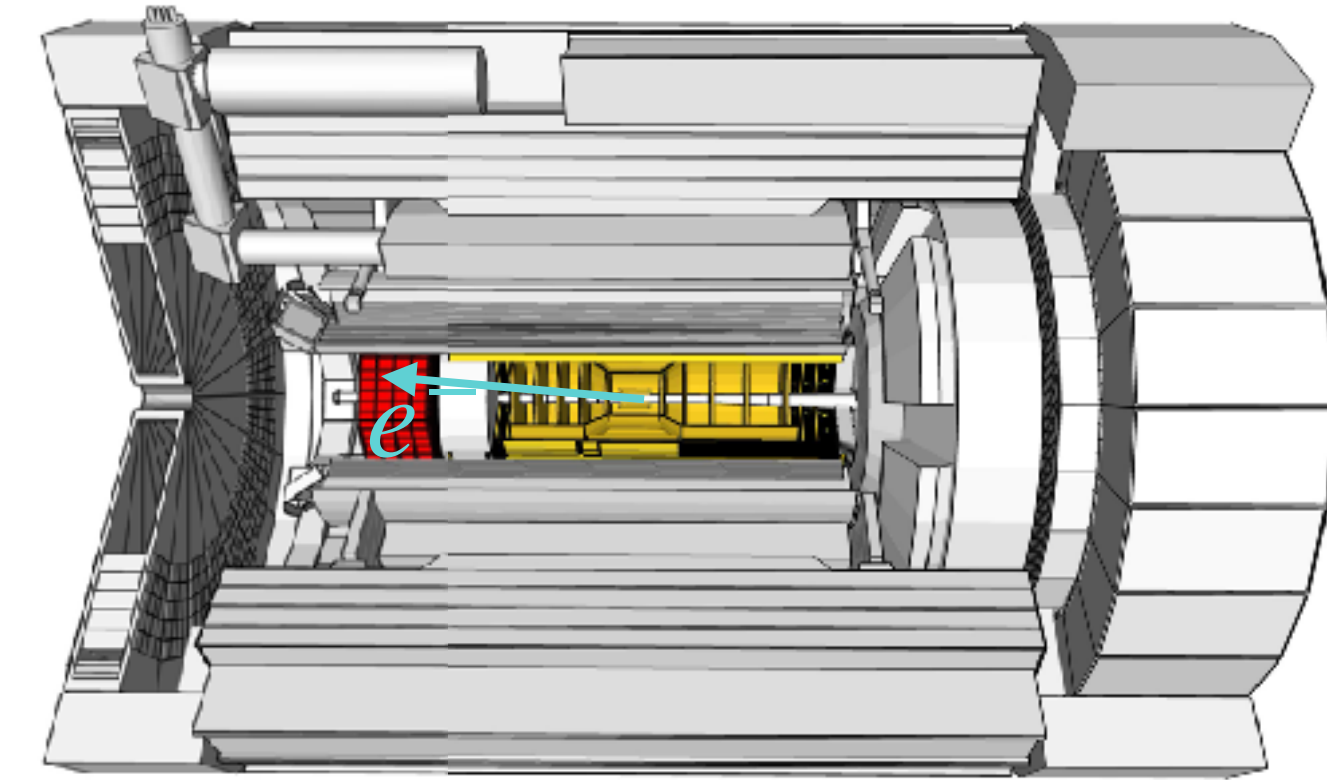
- longitudinally polarised proton
- longitudinally polarised $e^\pm$ beam
- count...

0	2	4	6	8
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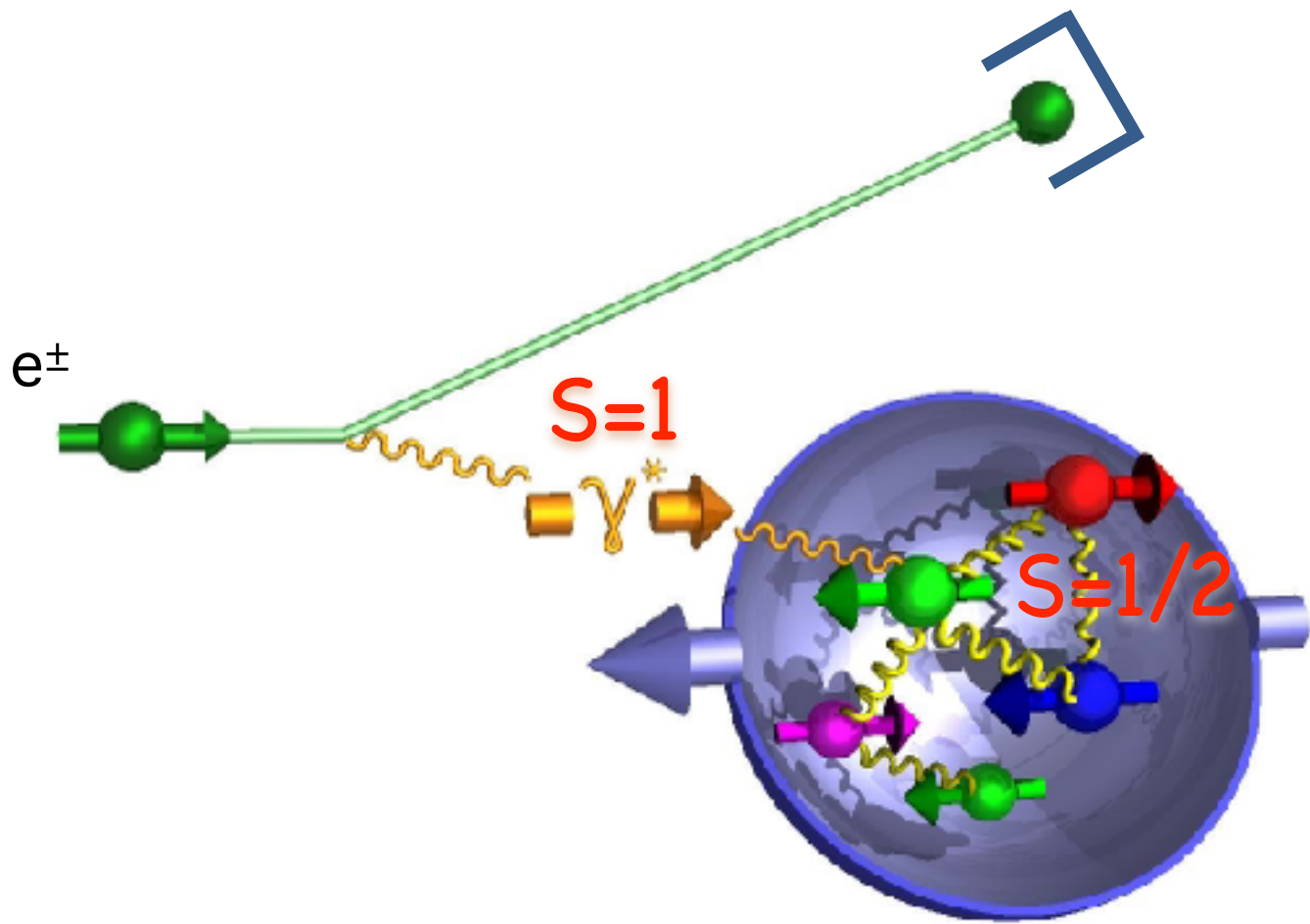


- flip proton spin and count...

0	2	4	6	8
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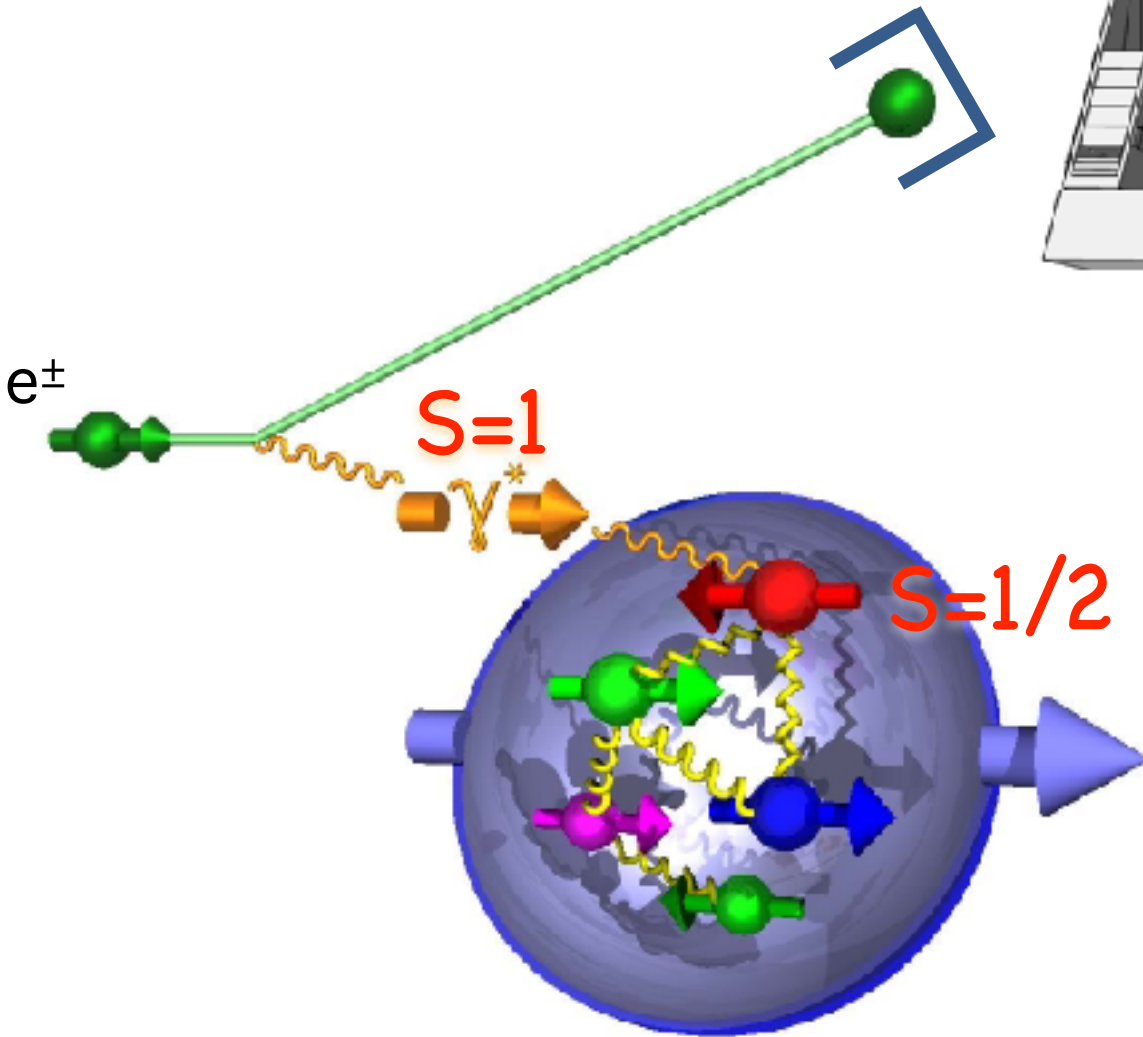


Helicity structure of the nucleon

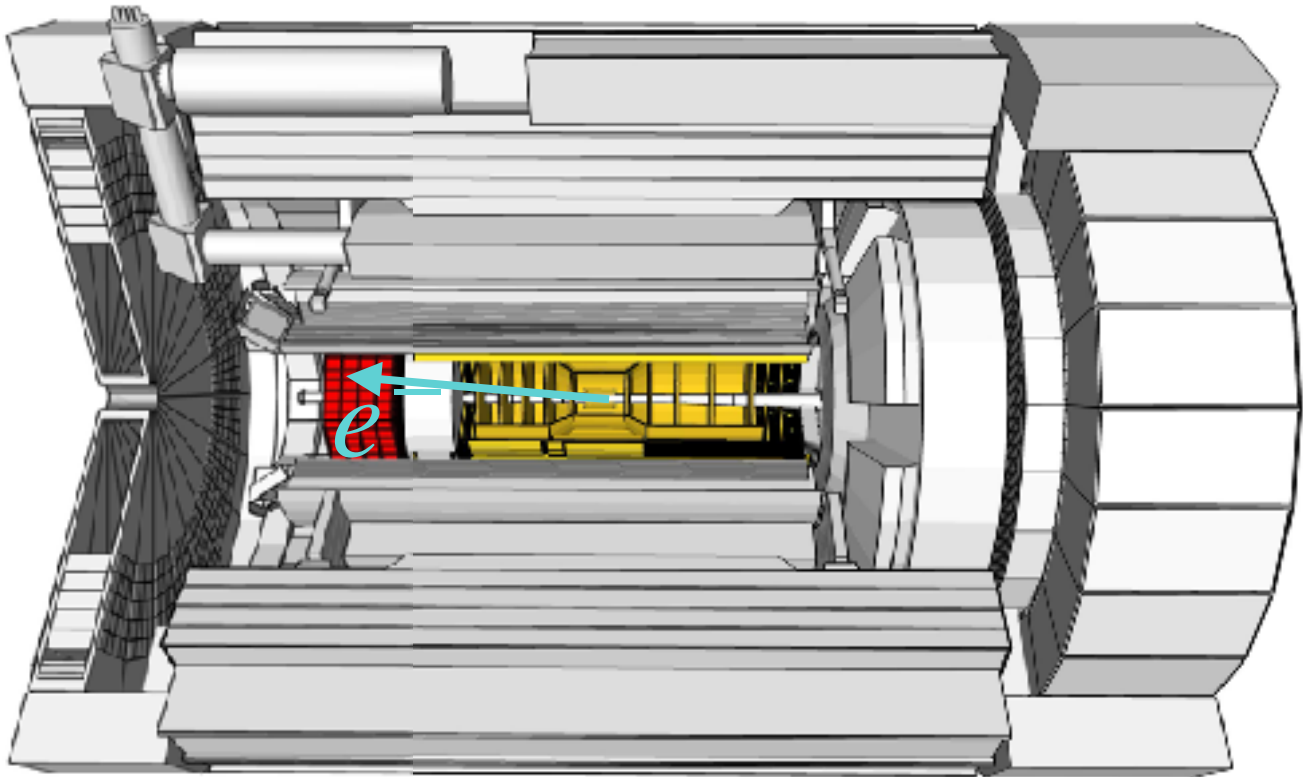


- longitudinally polarised proton
- longitudinally polarised $e^\pm$ beam
- count... 02488

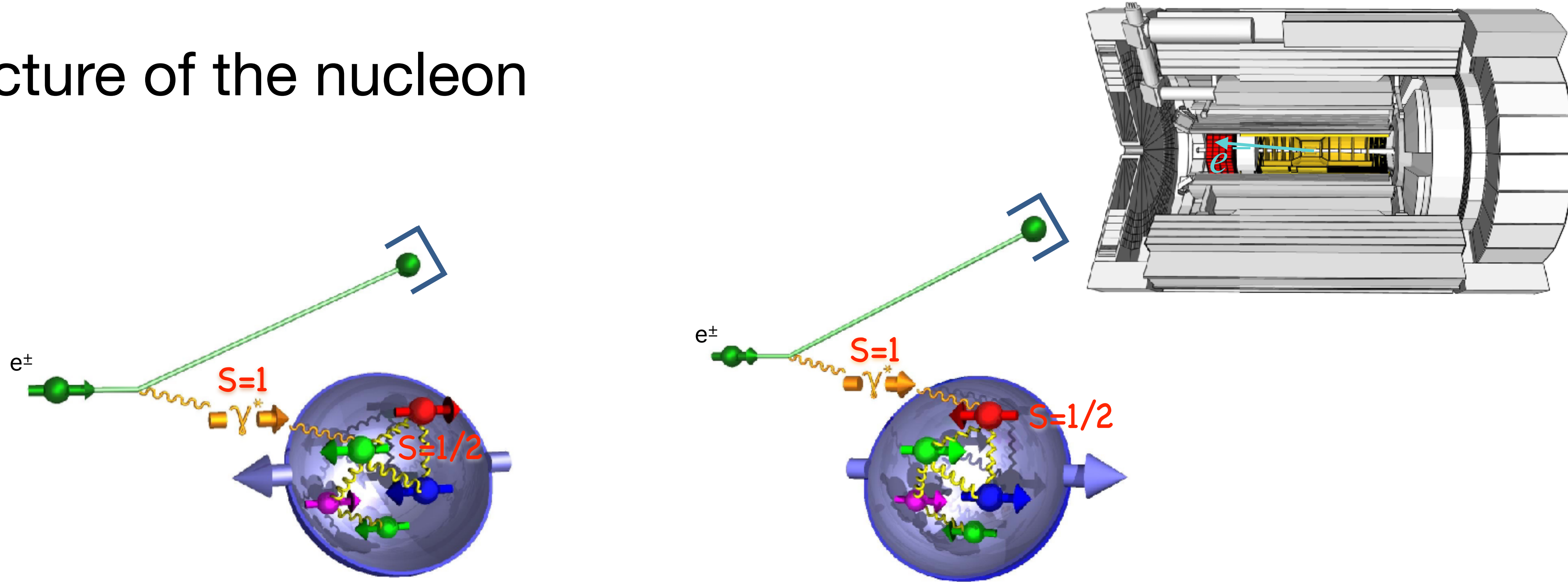
$$\frac{\begin{matrix} \leftarrow \uparrow & \rightarrow \uparrow \\ \sigma & - & \sigma \end{matrix}}{\begin{matrix} \leftarrow \uparrow & \rightarrow \uparrow \\ \sigma & + & \sigma \end{matrix}}$$



- flip proton spin and count... 02488



Helicity structure of the nucleon

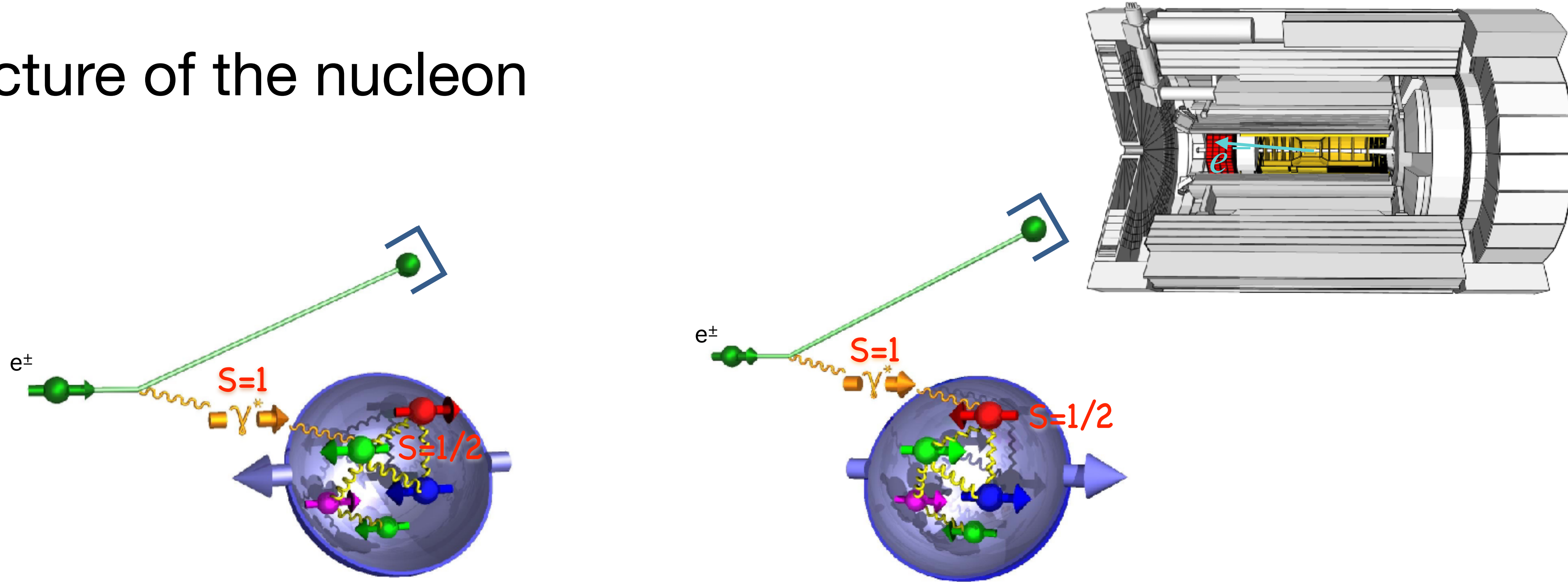


- longitudinally polarised proton
- longitudinally polarised $e^\pm$ beam
- count... 0 2 4 6 8
- flip proton spin and count... 0 2 4 6 8

$$\frac{\frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}}}{\frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}}} \propto g_1(x) = \frac{1}{2} \sum_q e_q^2 \left(\overrightarrow{q}(x) - \overleftarrow{q}(x) \right)$$

$\downarrow$
 parton fractional longitudinal
 momentum: x_B

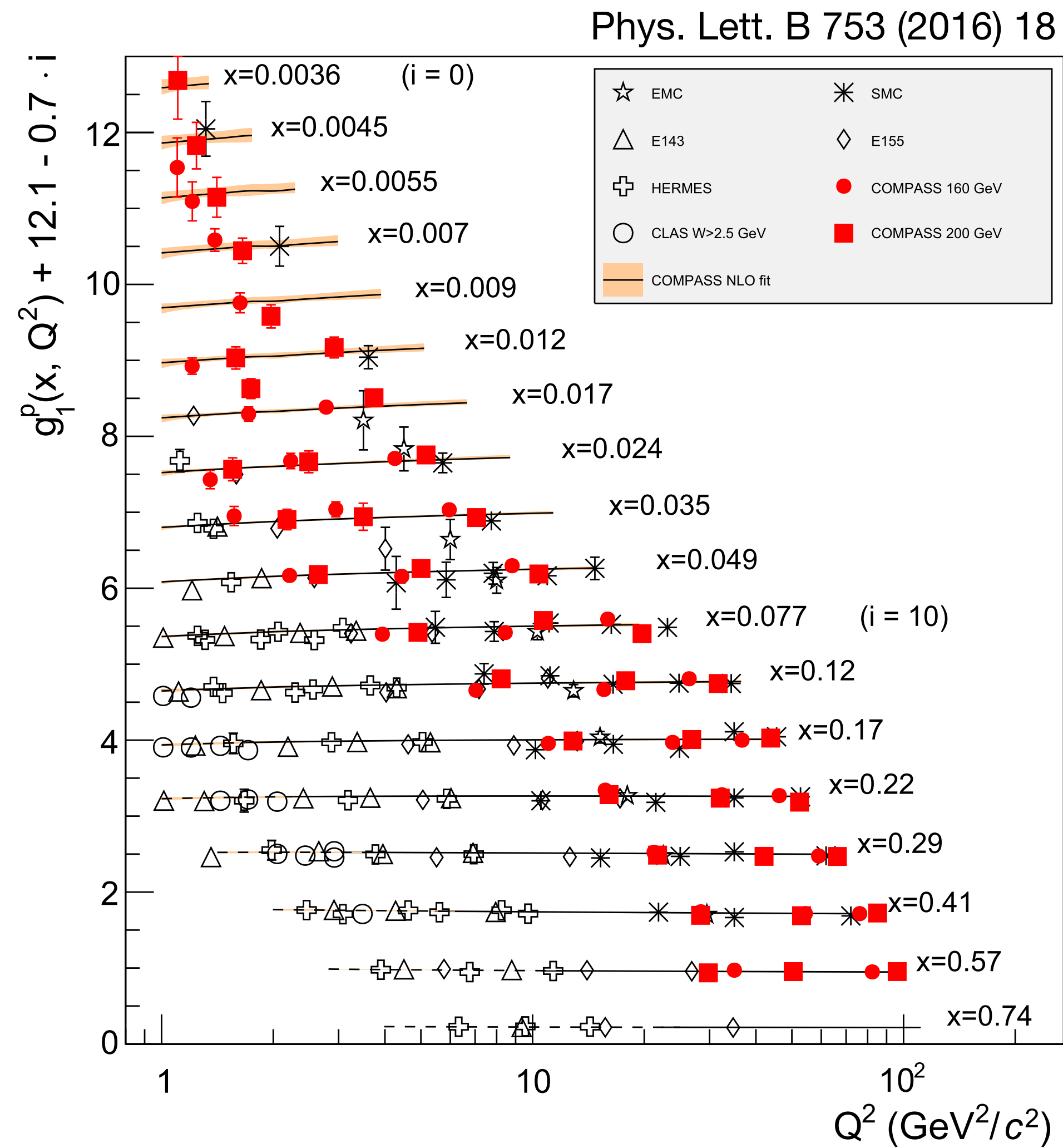
Helicity structure of the nucleon



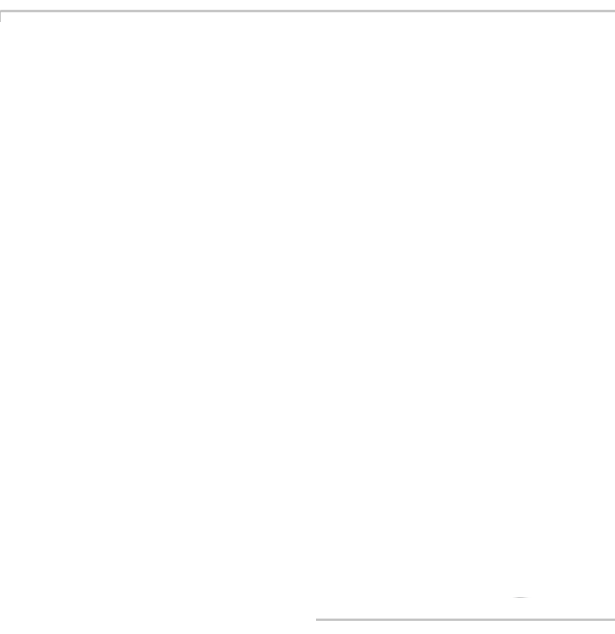
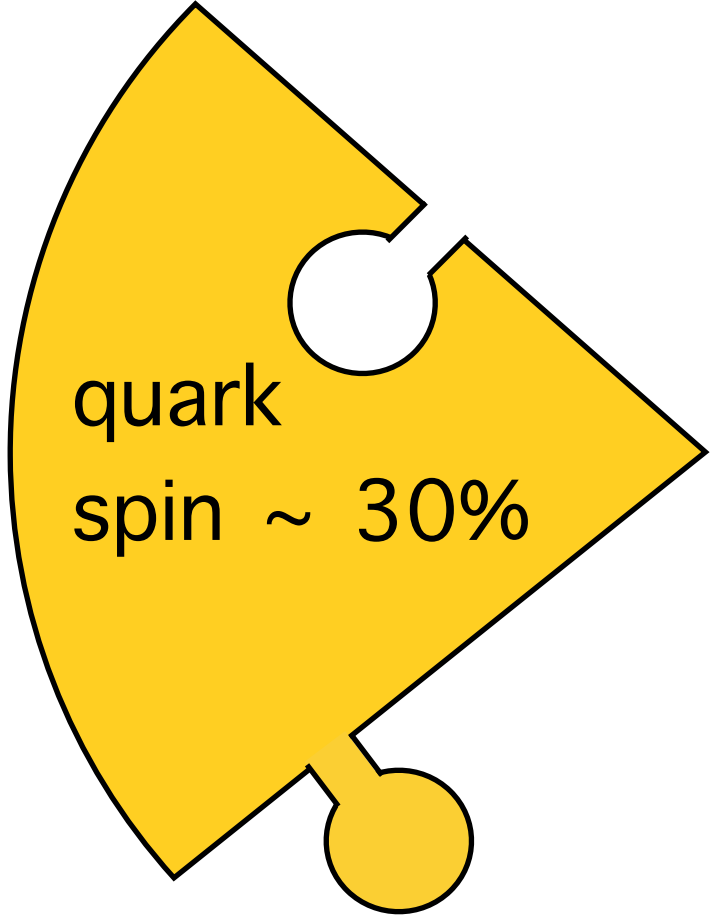
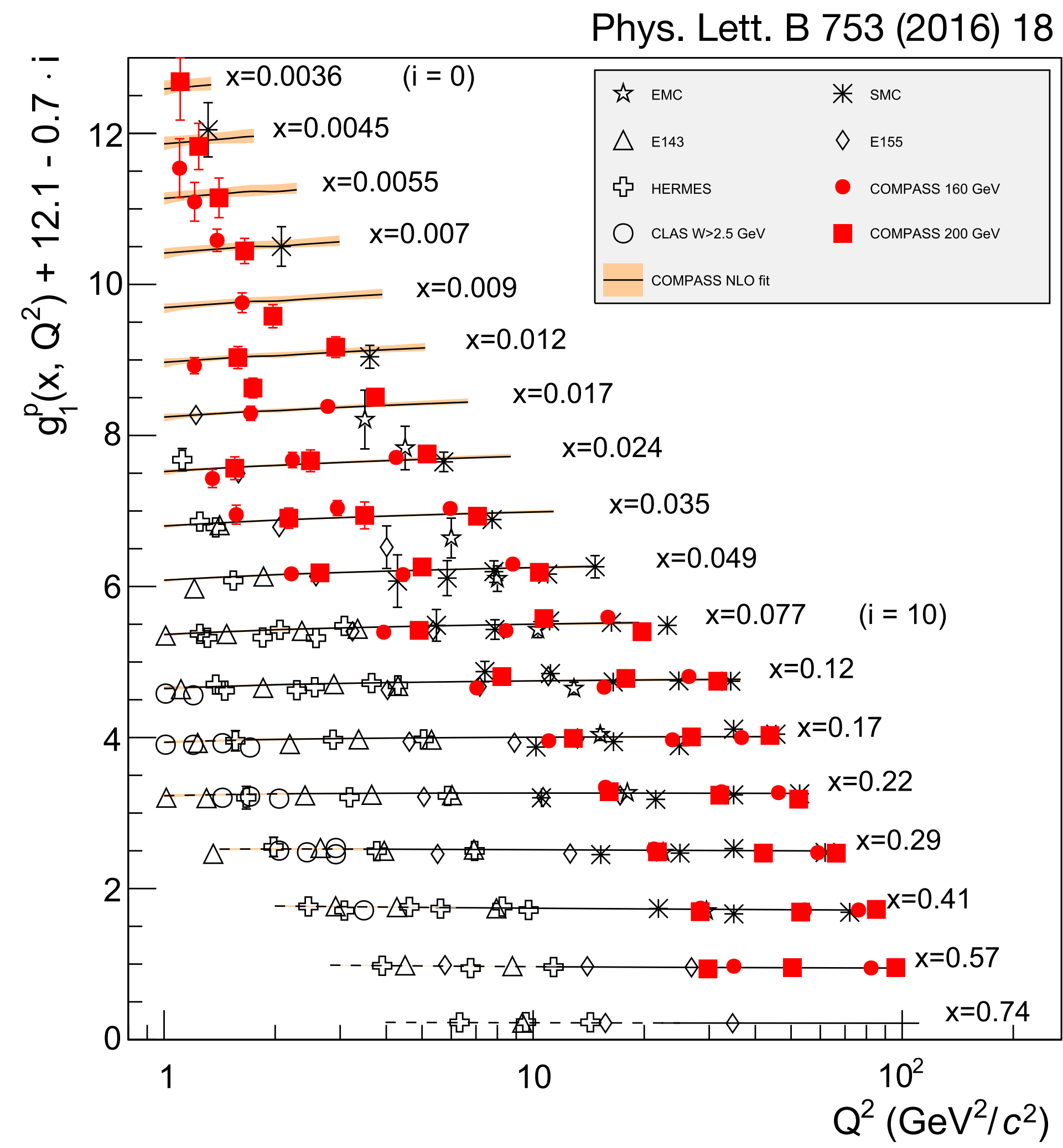
- longitudinally polarised proton
 - longitudinally polarised $e^\pm$ beam
 - count... 0 2 4 6 8
- flip proton spin and count... 0 2 4 6 8

$$\frac{\frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}}}{\propto} g_1(x) = \frac{1}{2} \sum_q e_q^2 \left(\underbrace{\overrightarrow{q}(x)}_{\substack{\text{parton fractional longitudinal} \\ \text{momentum: } x_B}} - \underbrace{\overleftarrow{q}(x)}_{\substack{\text{helicity parton distribution} \\ \text{function (PDF)}}} \right) = \frac{1}{2} \sum_q e_q^2 \Delta q(x)$$

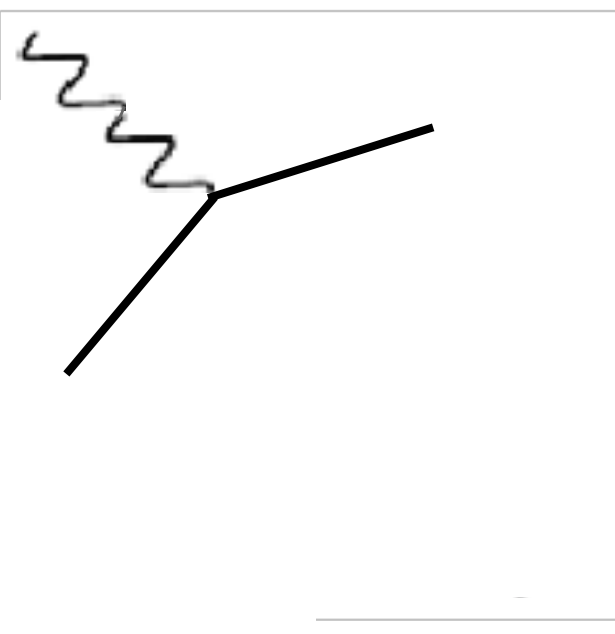
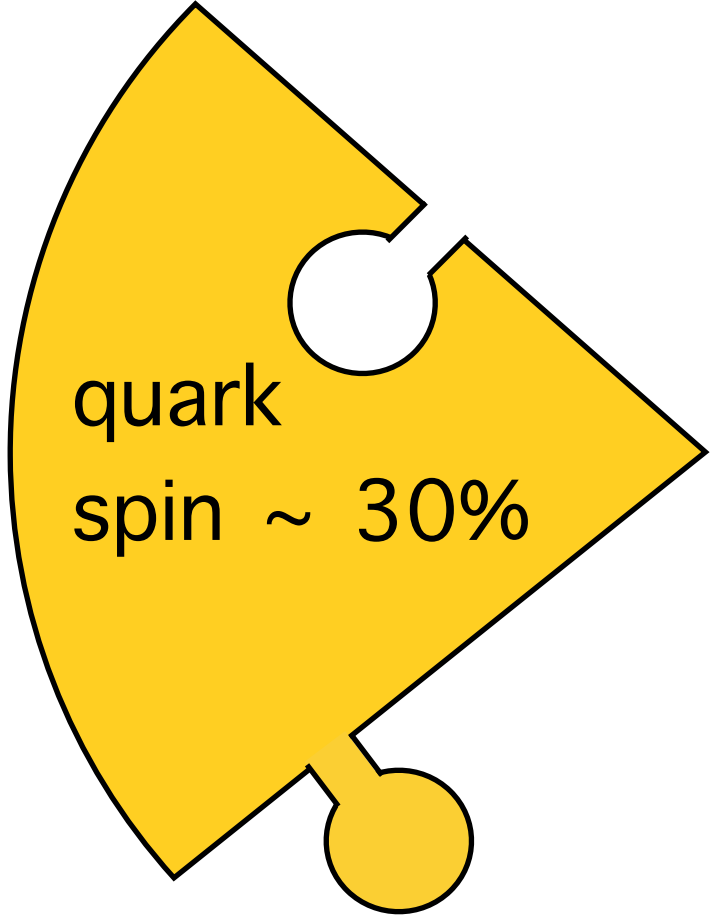
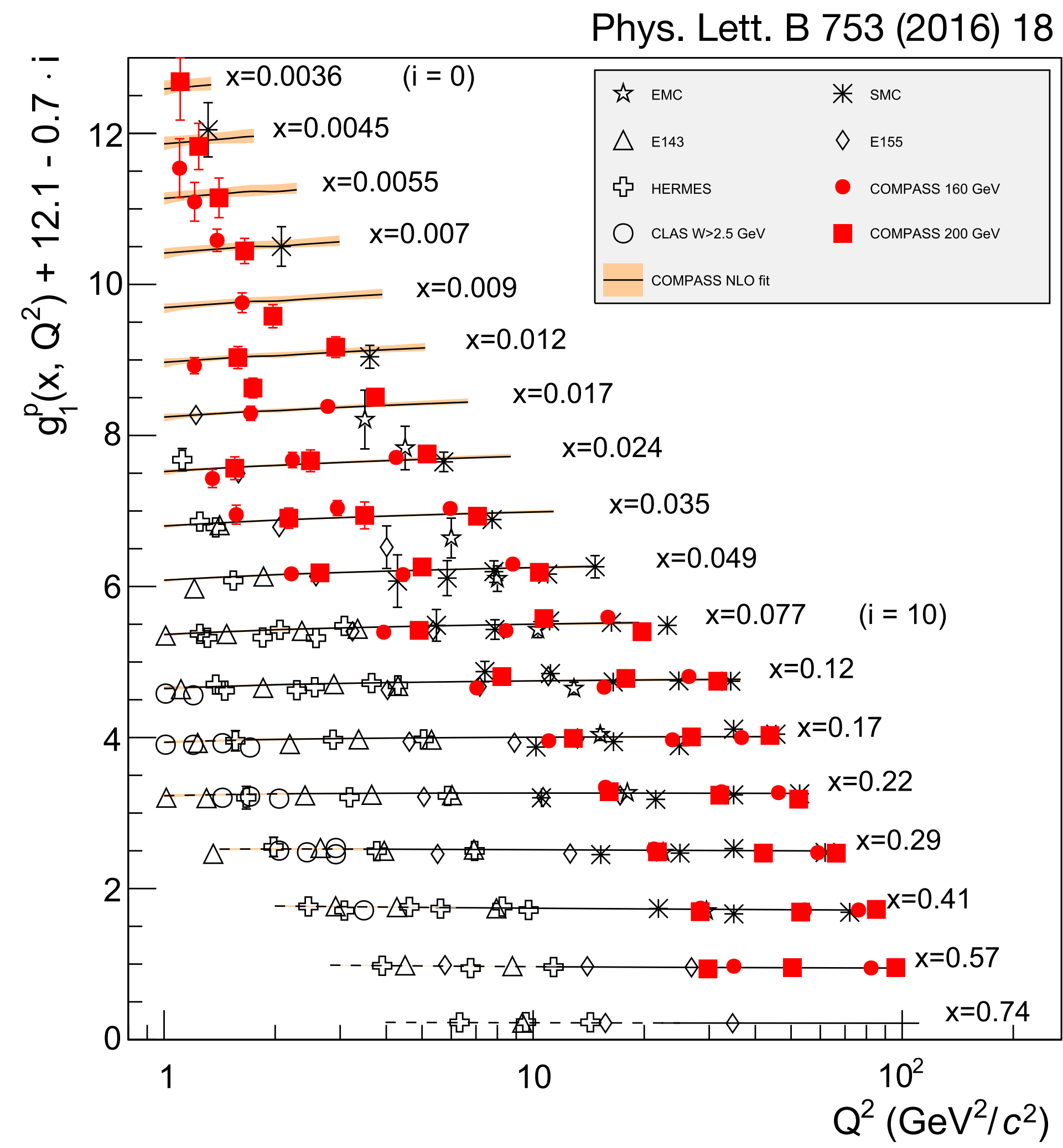
Helicity structure of the nucleon: existing measurements



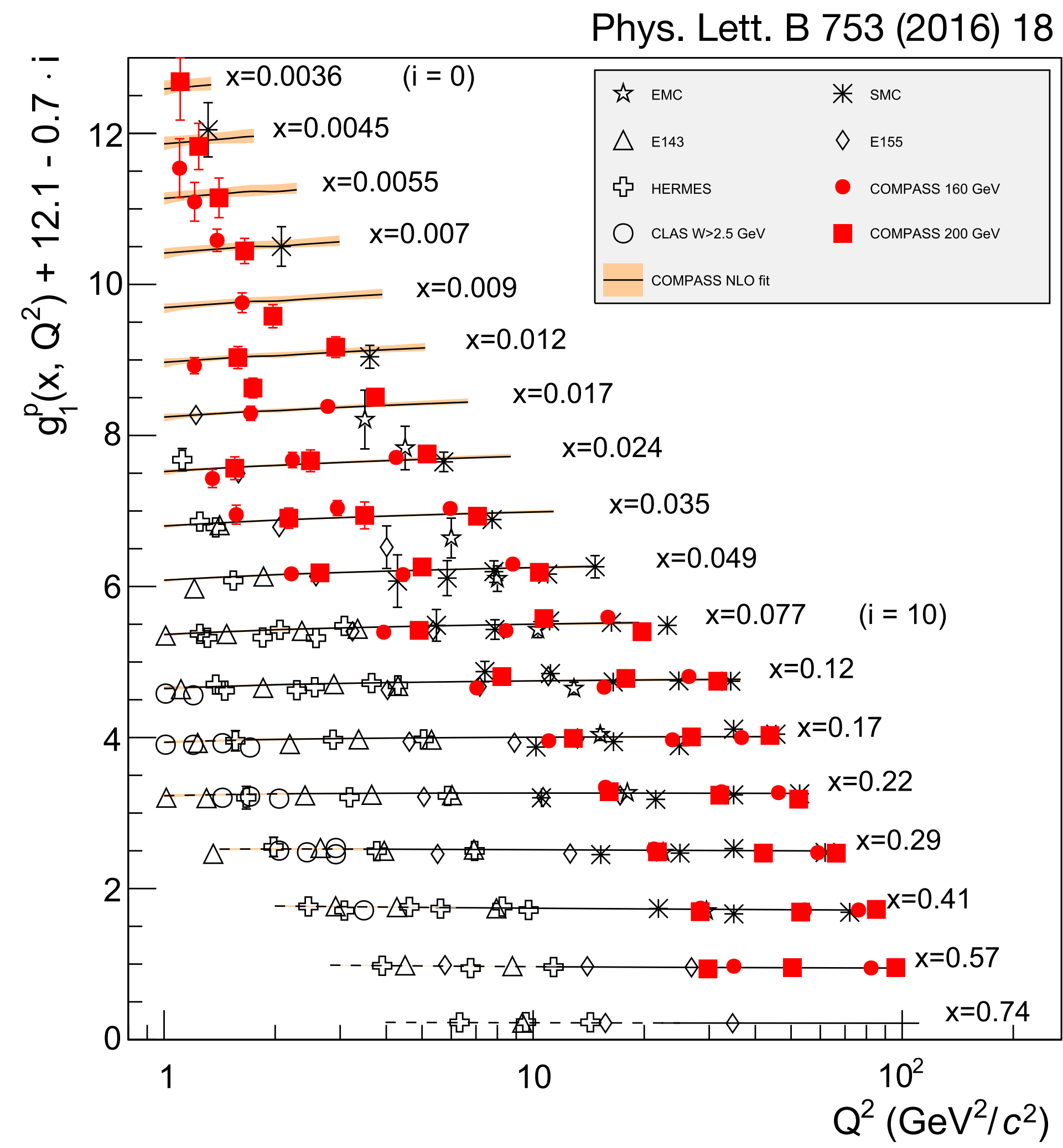
Helicity structure of the nucleon: existing measurements



Helicity structure of the nucleon: existing measurements



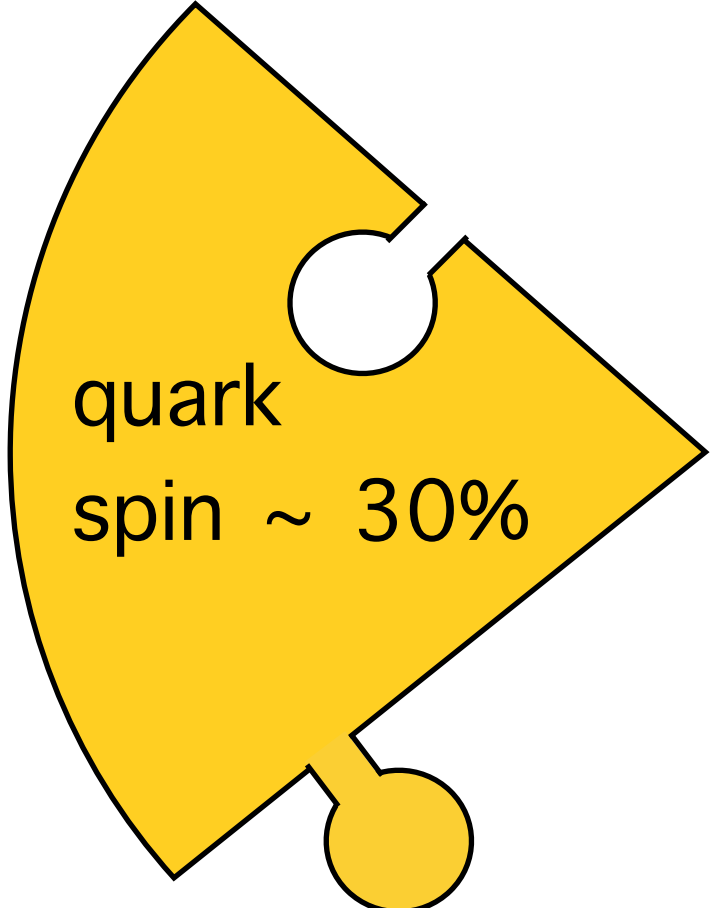
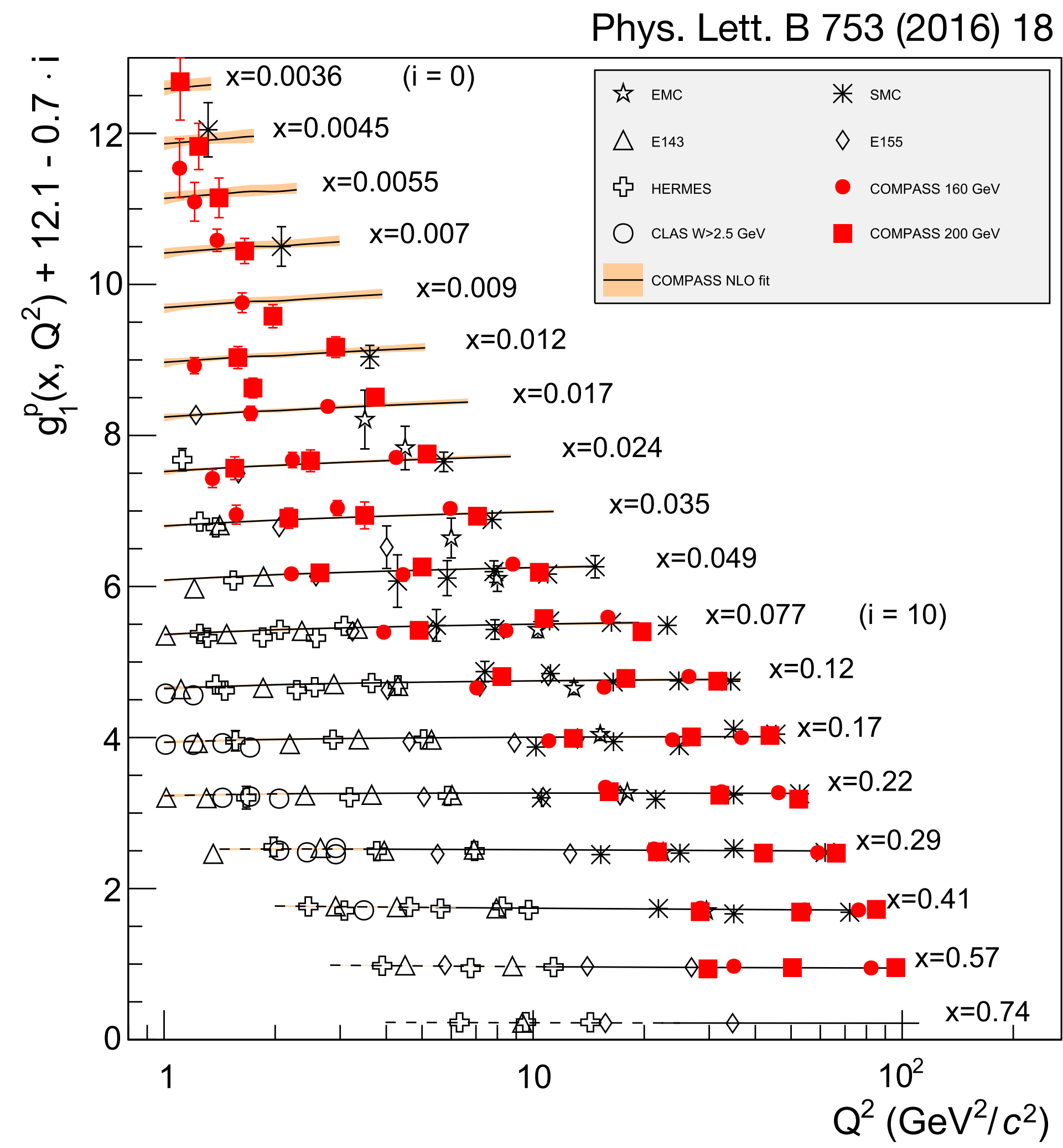
Helicity structure of the nucleon: existing measurements



quark
spin ~ 30%



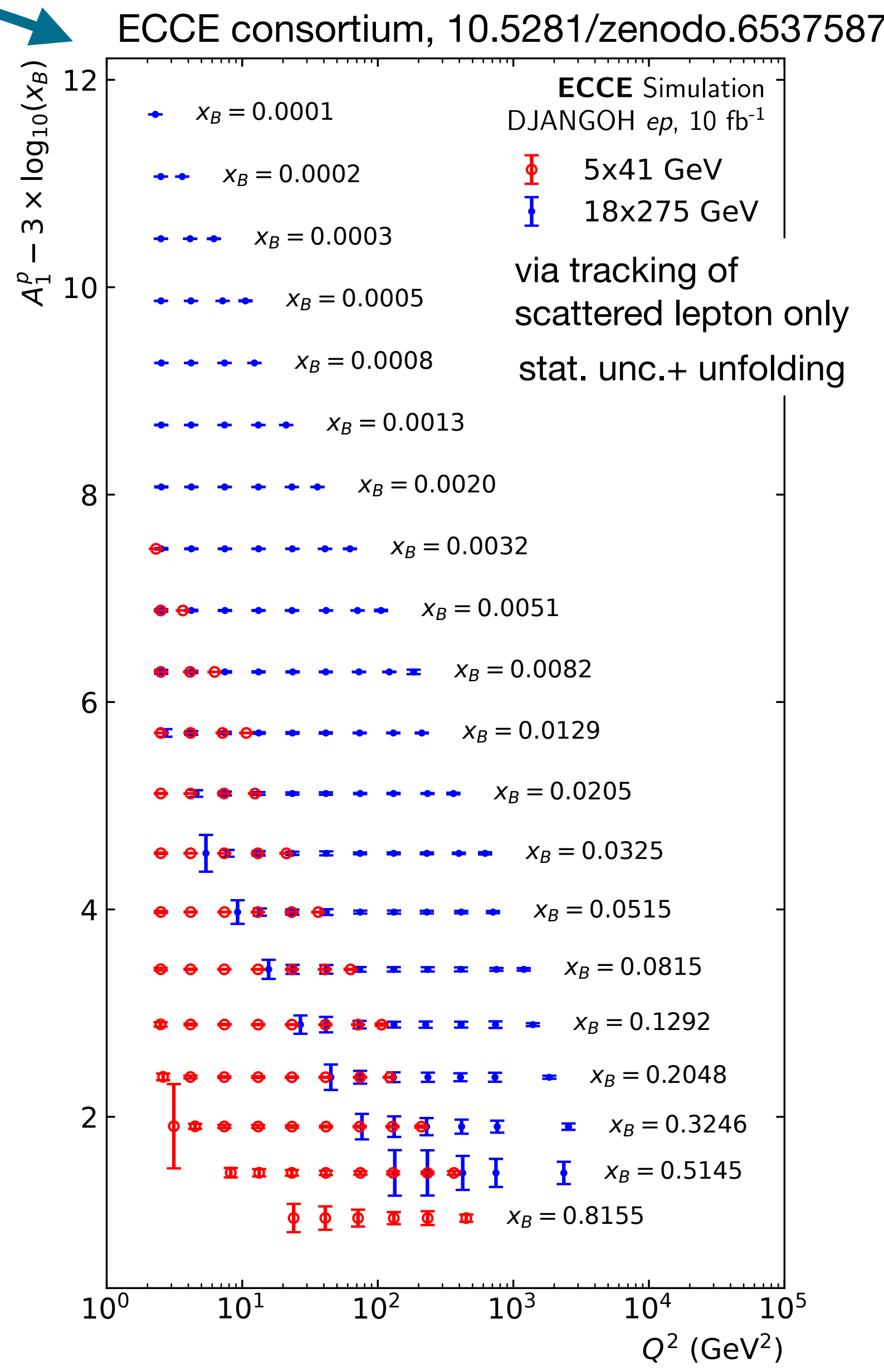
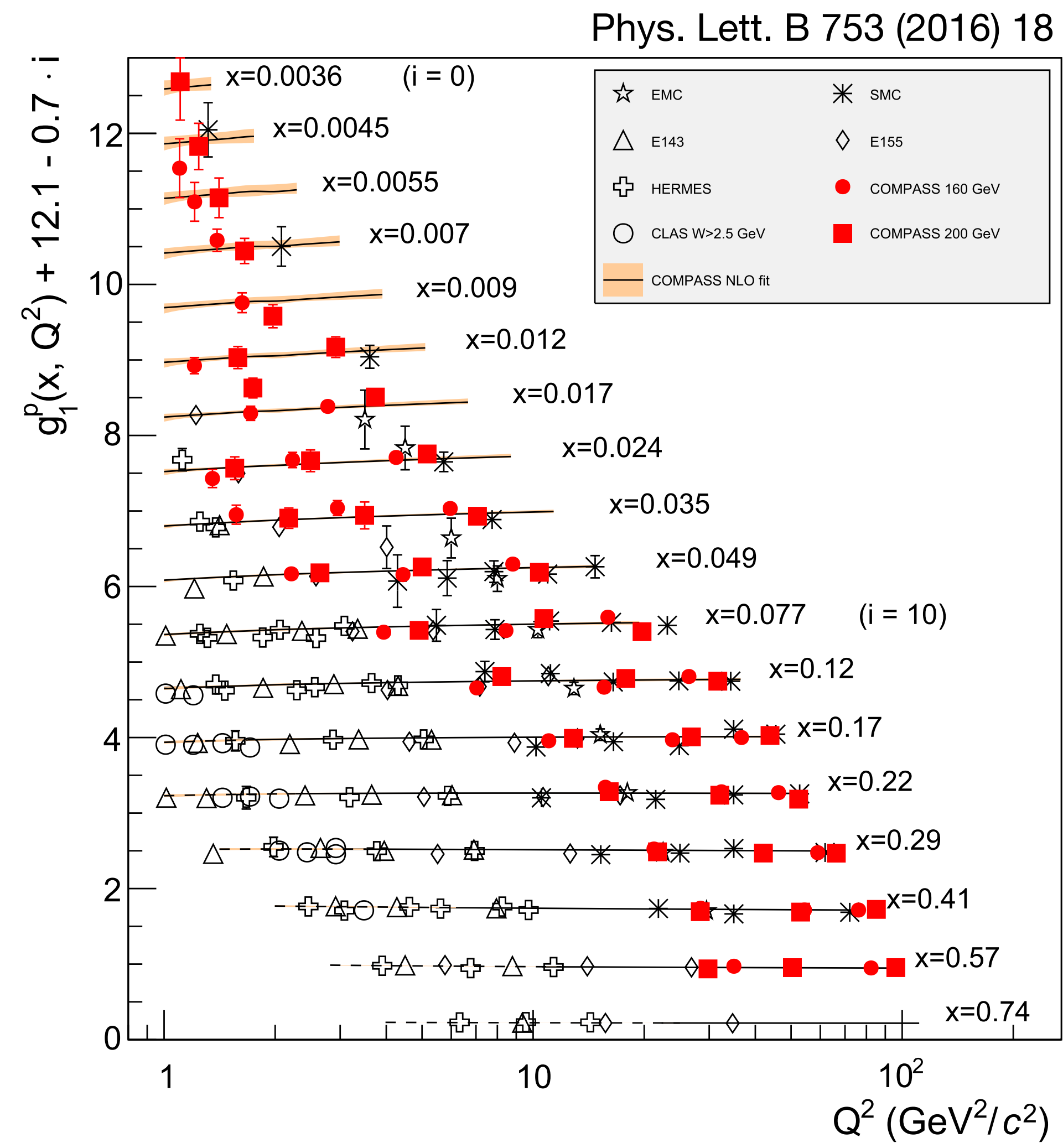
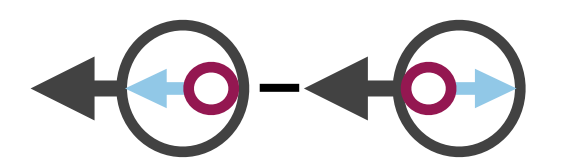
Helicity structure of the nucleon: existing measurements



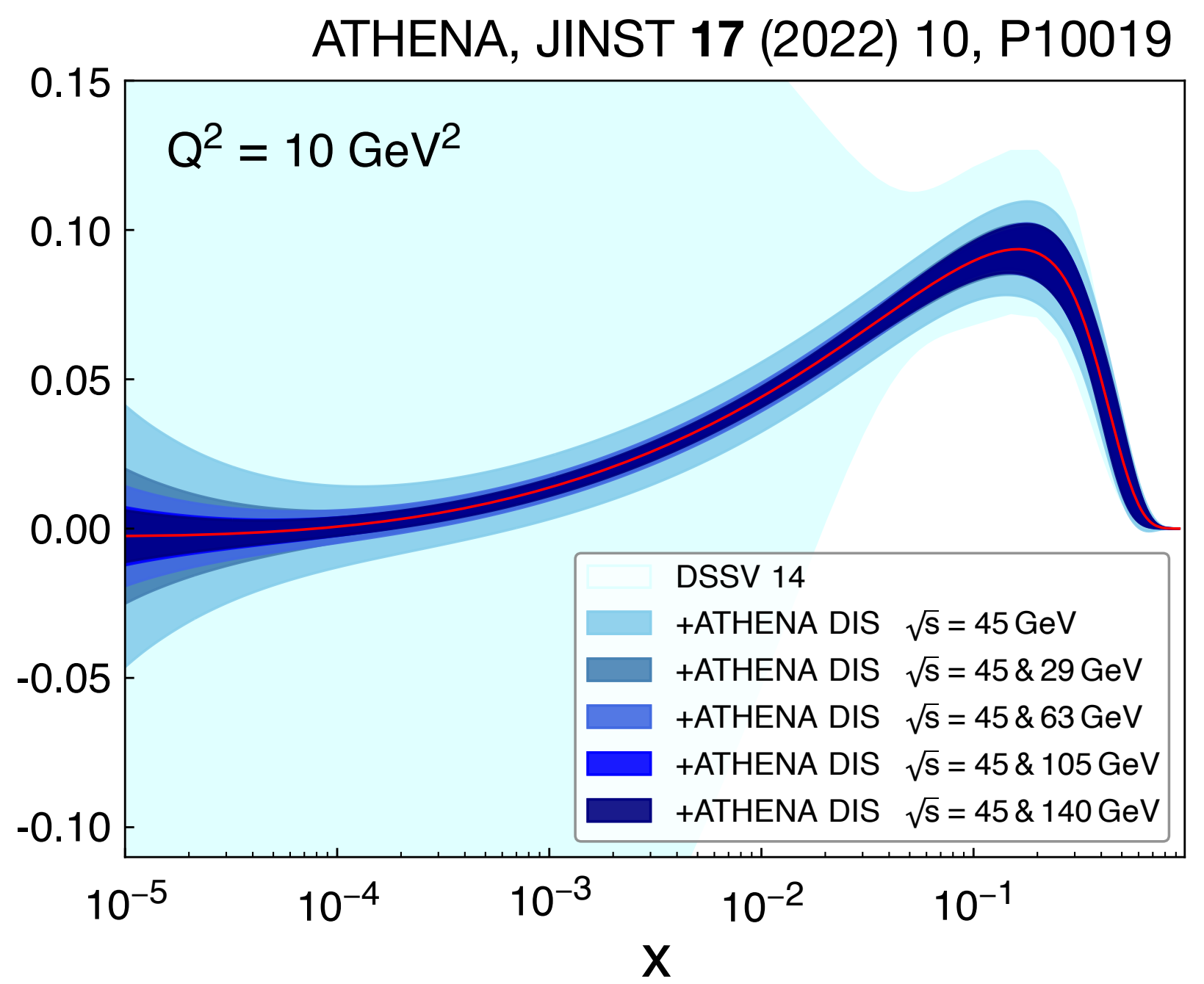
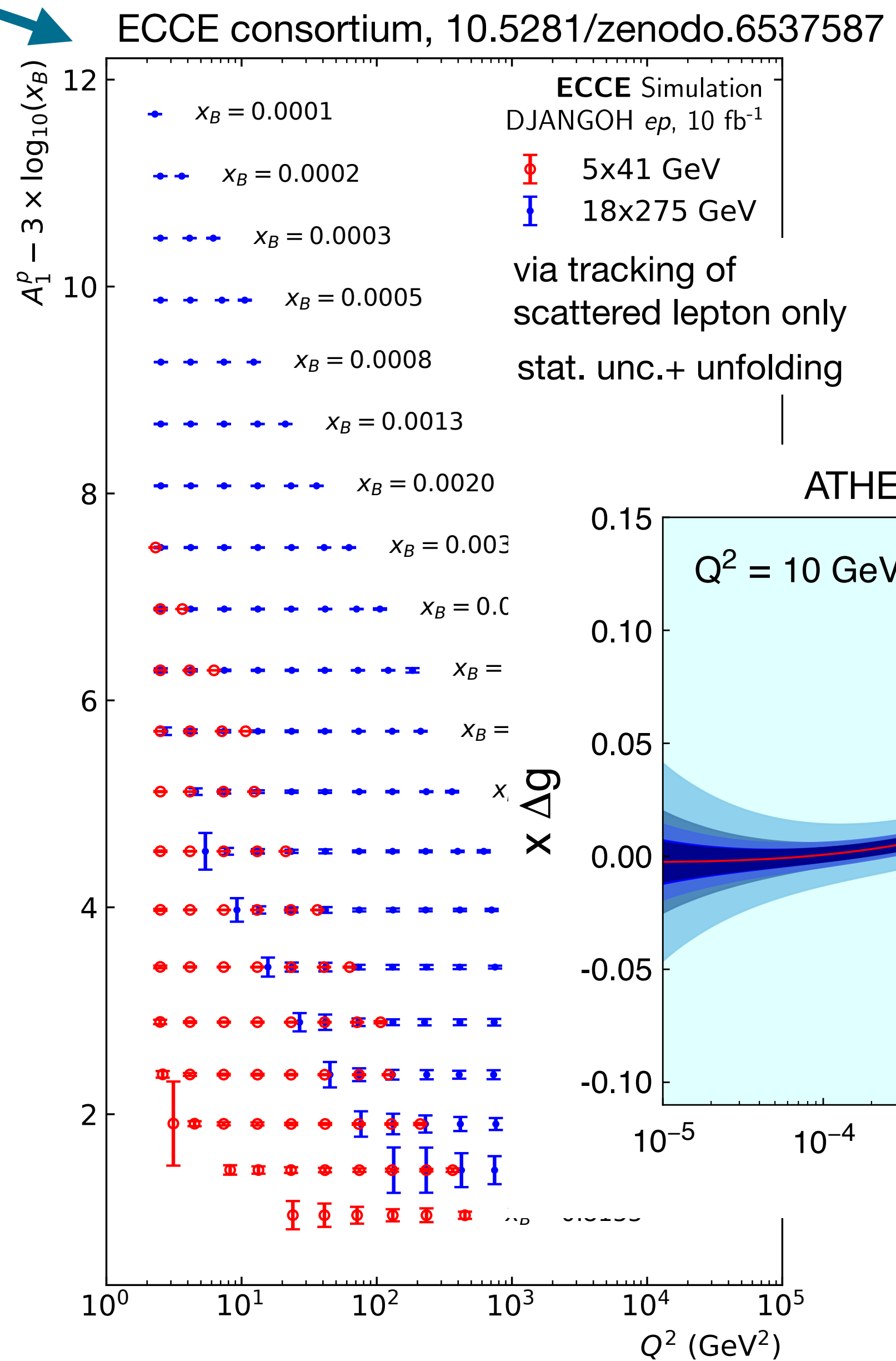
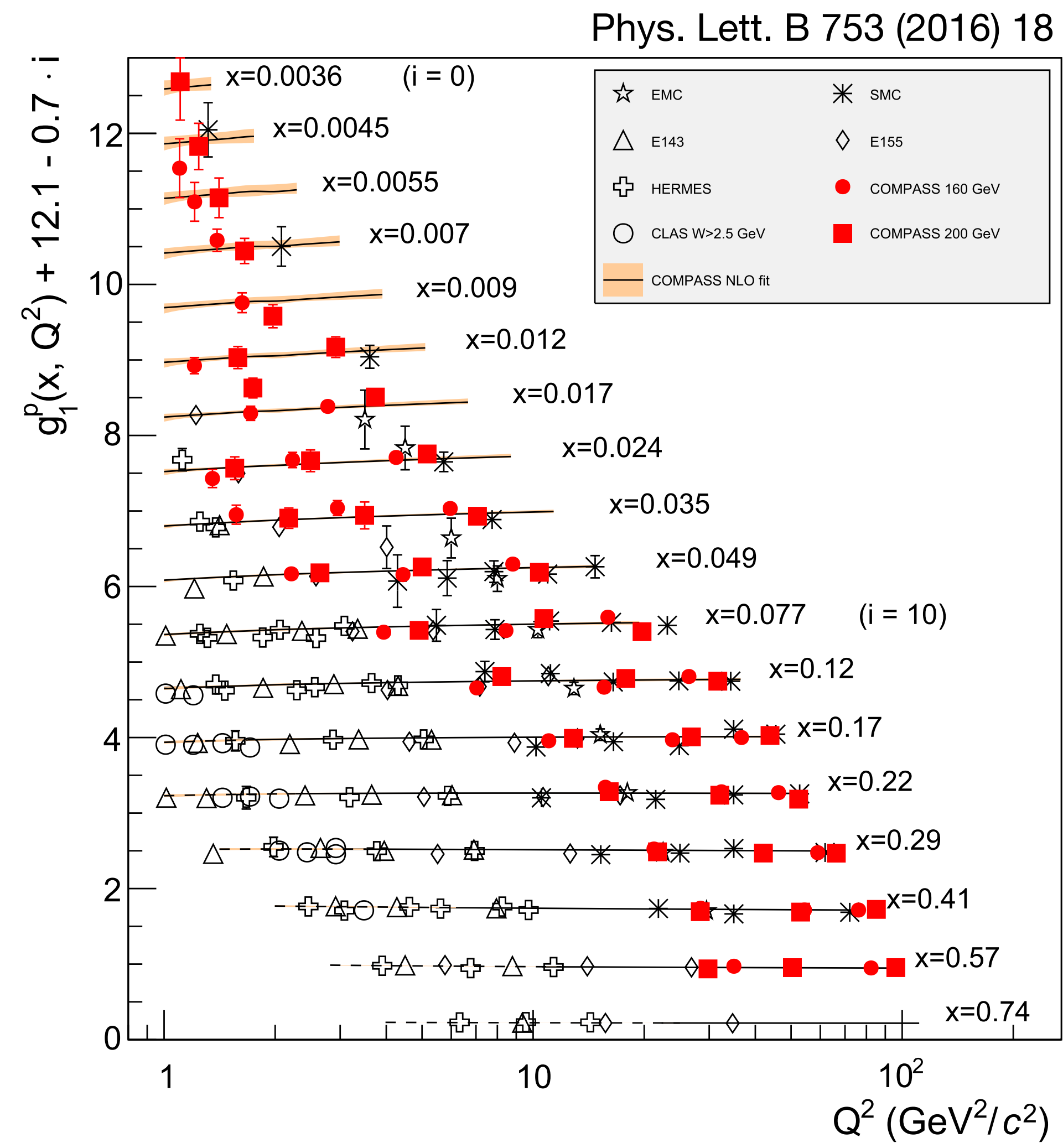
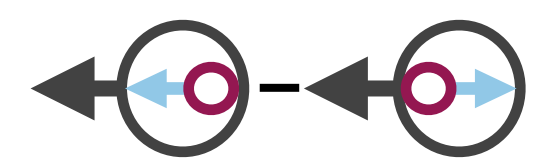
$$\frac{dg_1(x, Q^2)}{d \ln Q^2} \propto -\Delta g(x, Q^2)$$

—————> gluon spin

Gluon helicity distribution at the EIC



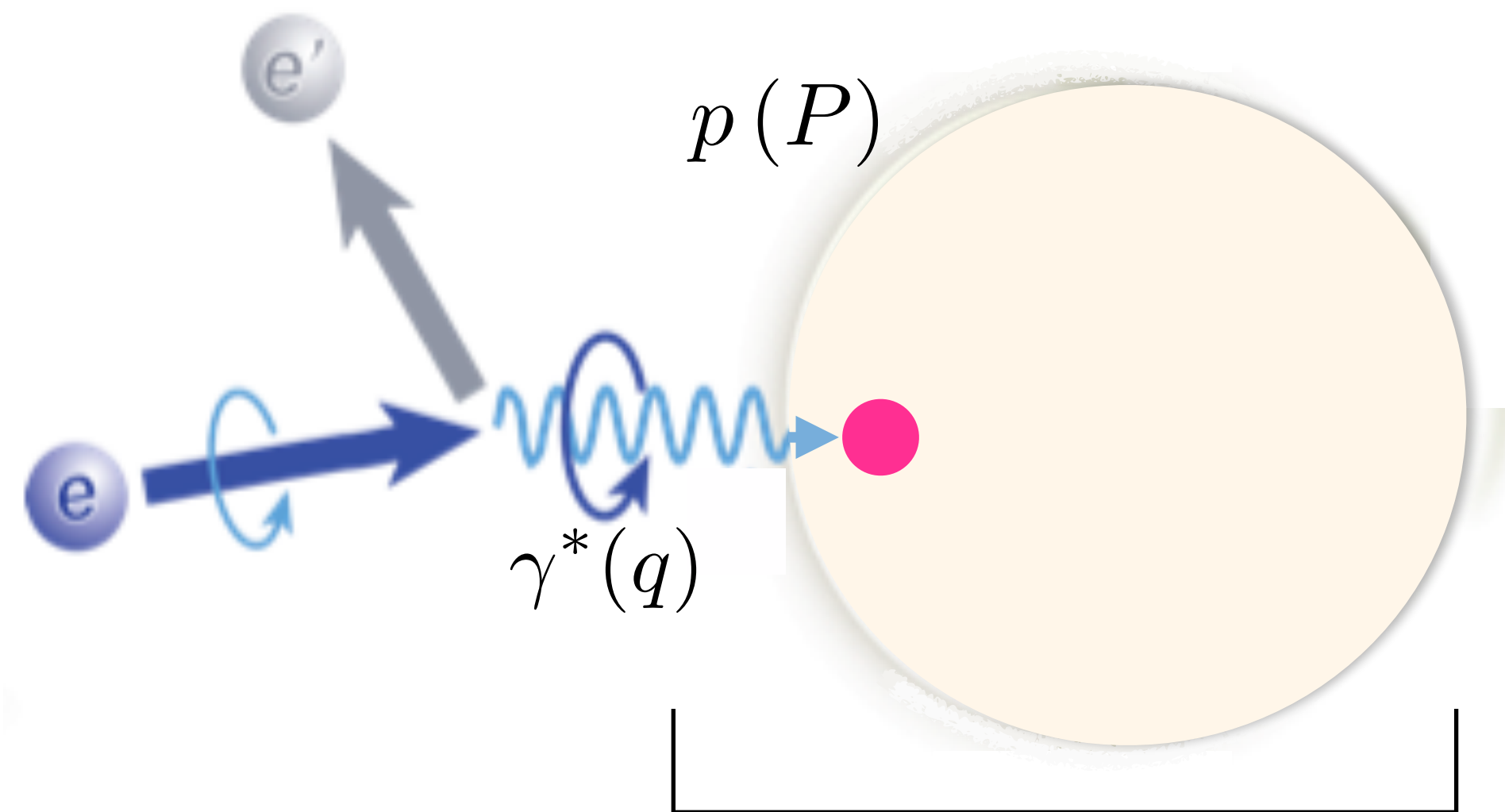
Gluon helicity distribution at the EIC



Single-hadron production in semi-inclusive DIS

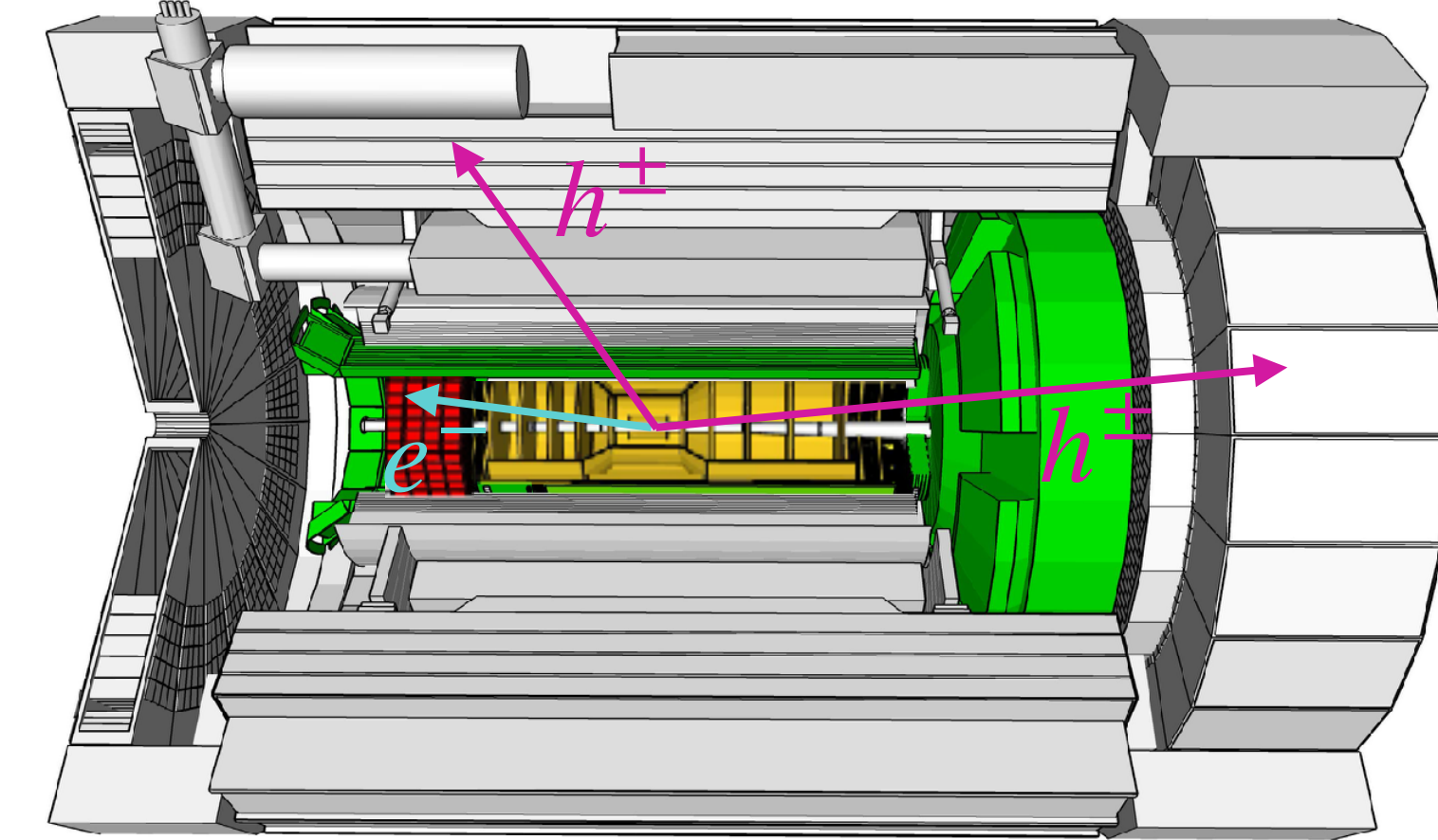
$$Q^2 = -q^2$$

$$x_B = \frac{Q^2}{2P \cdot q}$$



parton distribution function $PDF(x_B, Q^2)$

Single-hadron production in semi-inclusive DIS

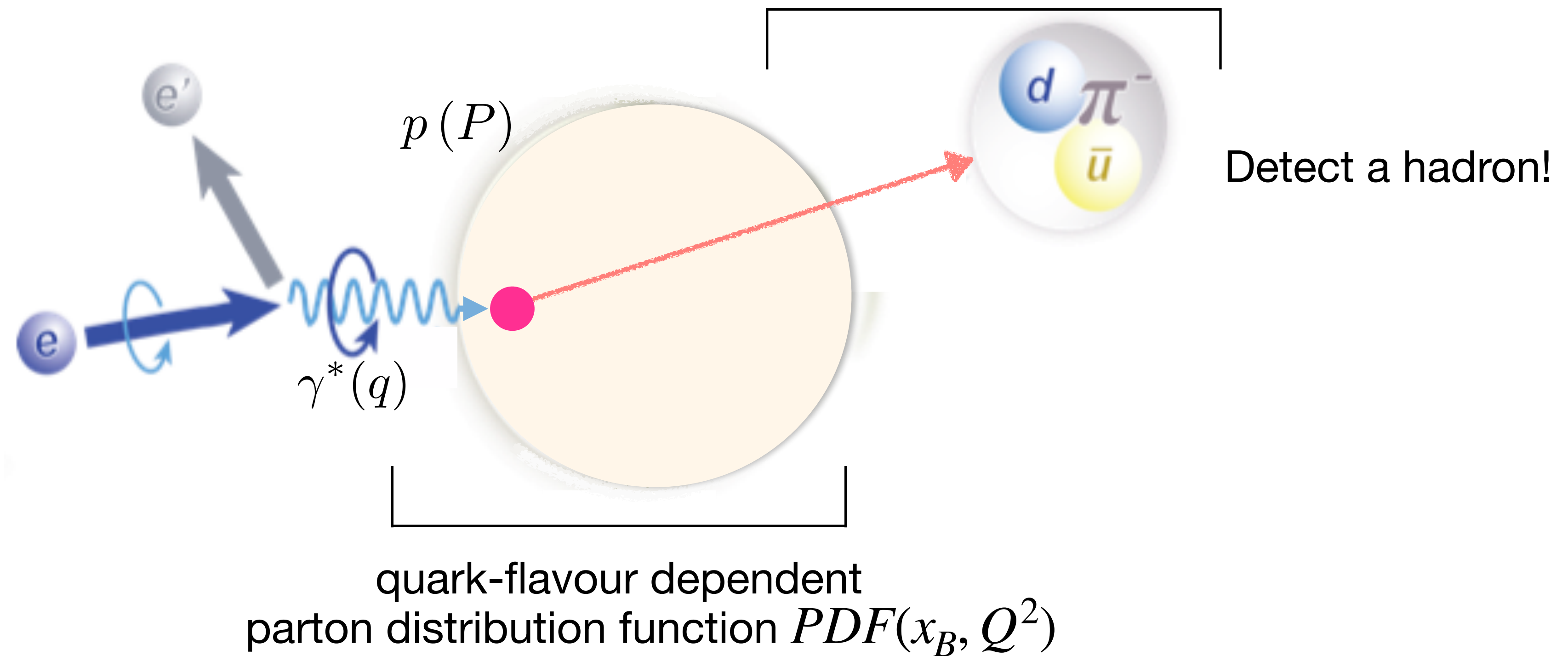


fragmentation function $FF(z, Q^2)$

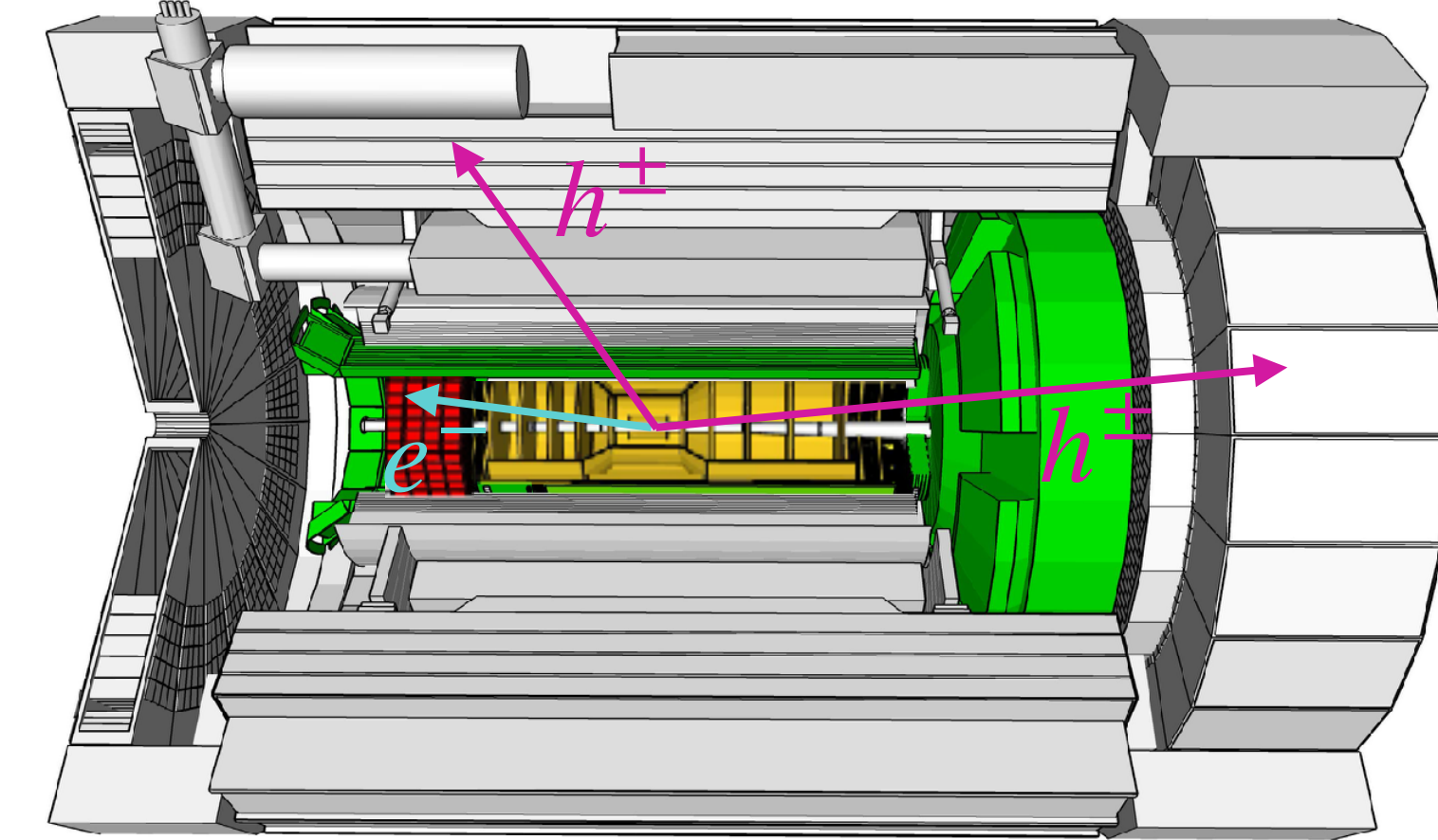
$$Q^2 = -q^2$$

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$$z \stackrel{\text{lab}}{=} \frac{E_h}{E_{\gamma^*}}$$



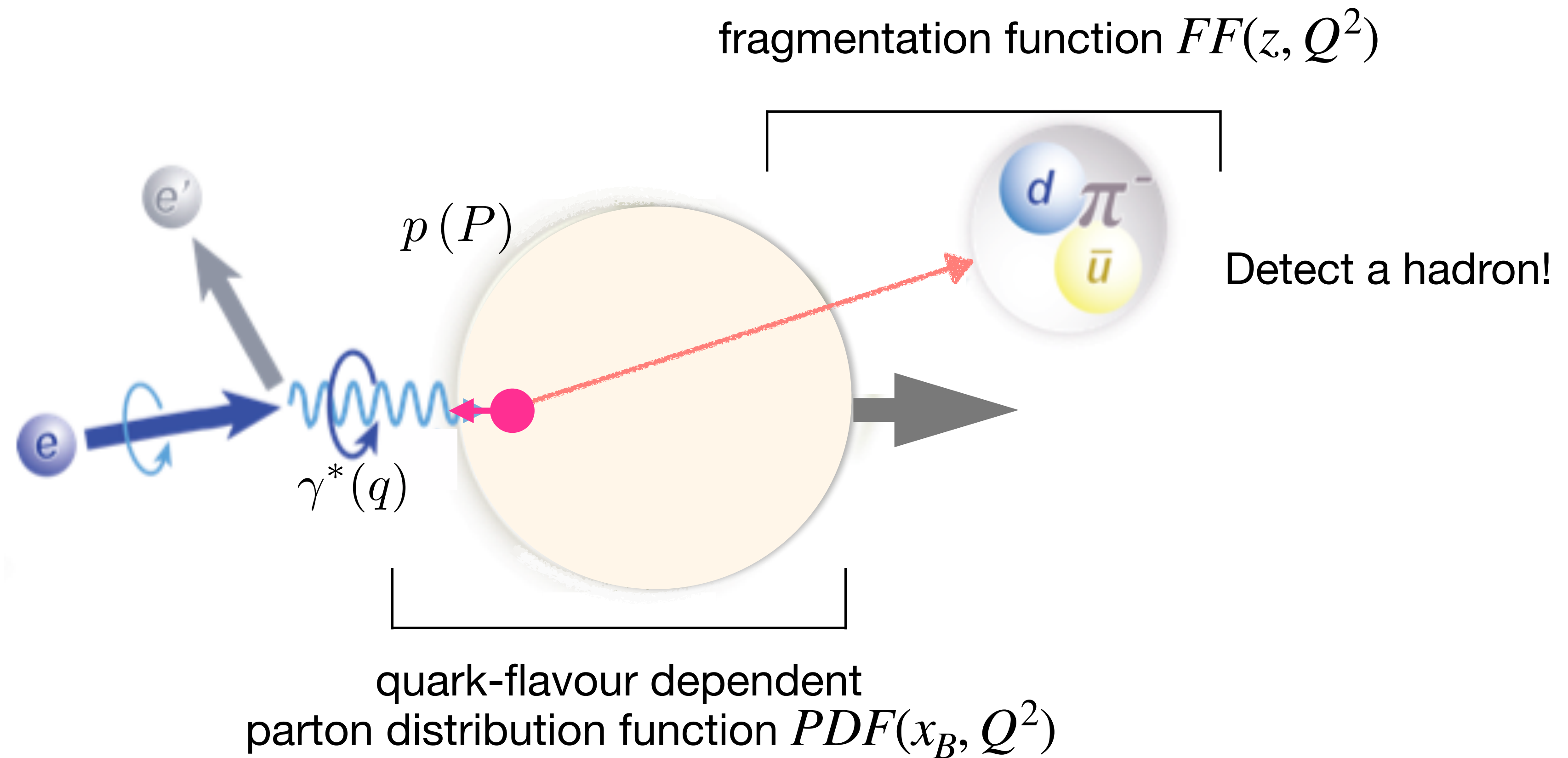
Single-hadron production in semi-inclusive DIS



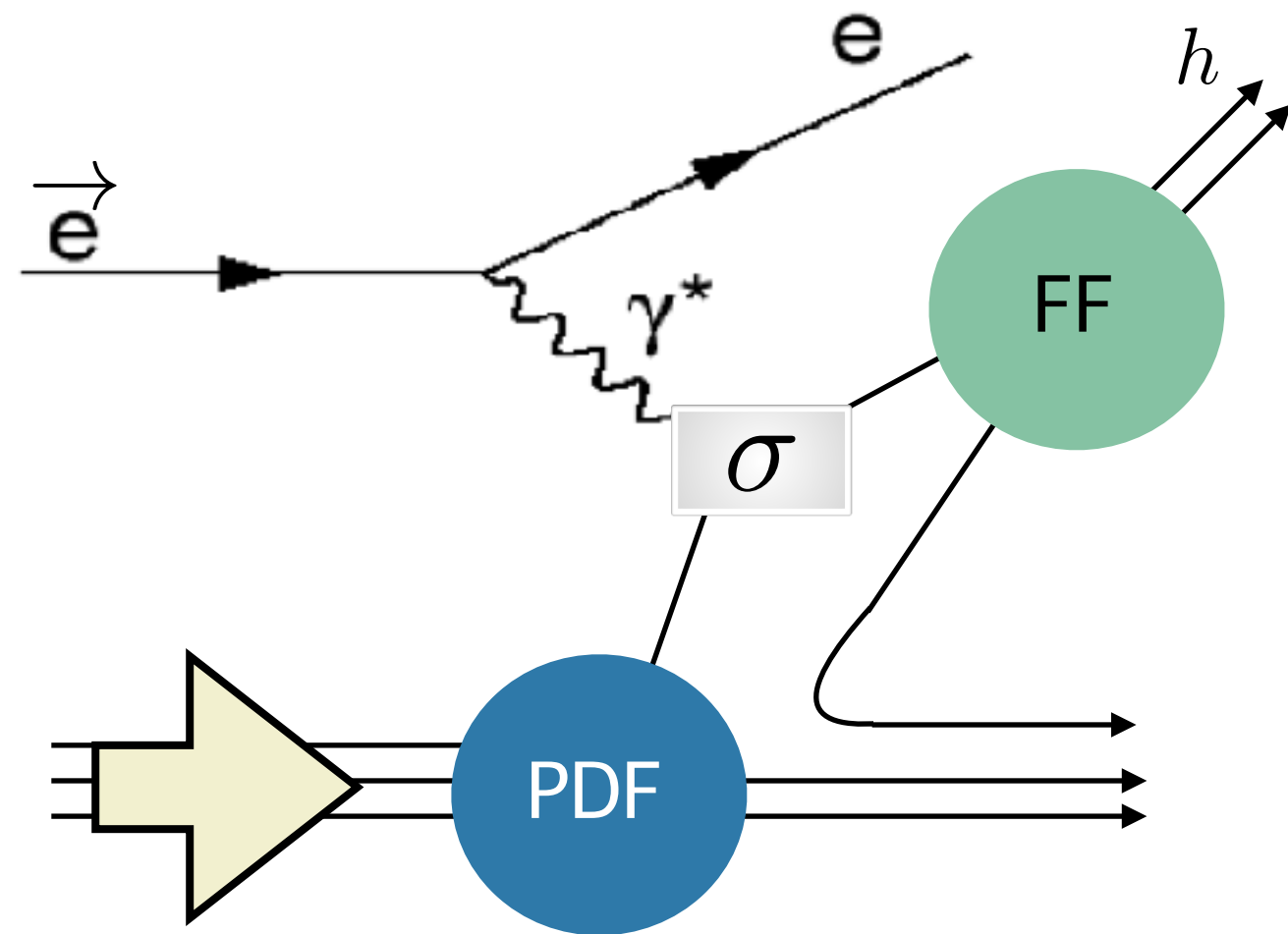
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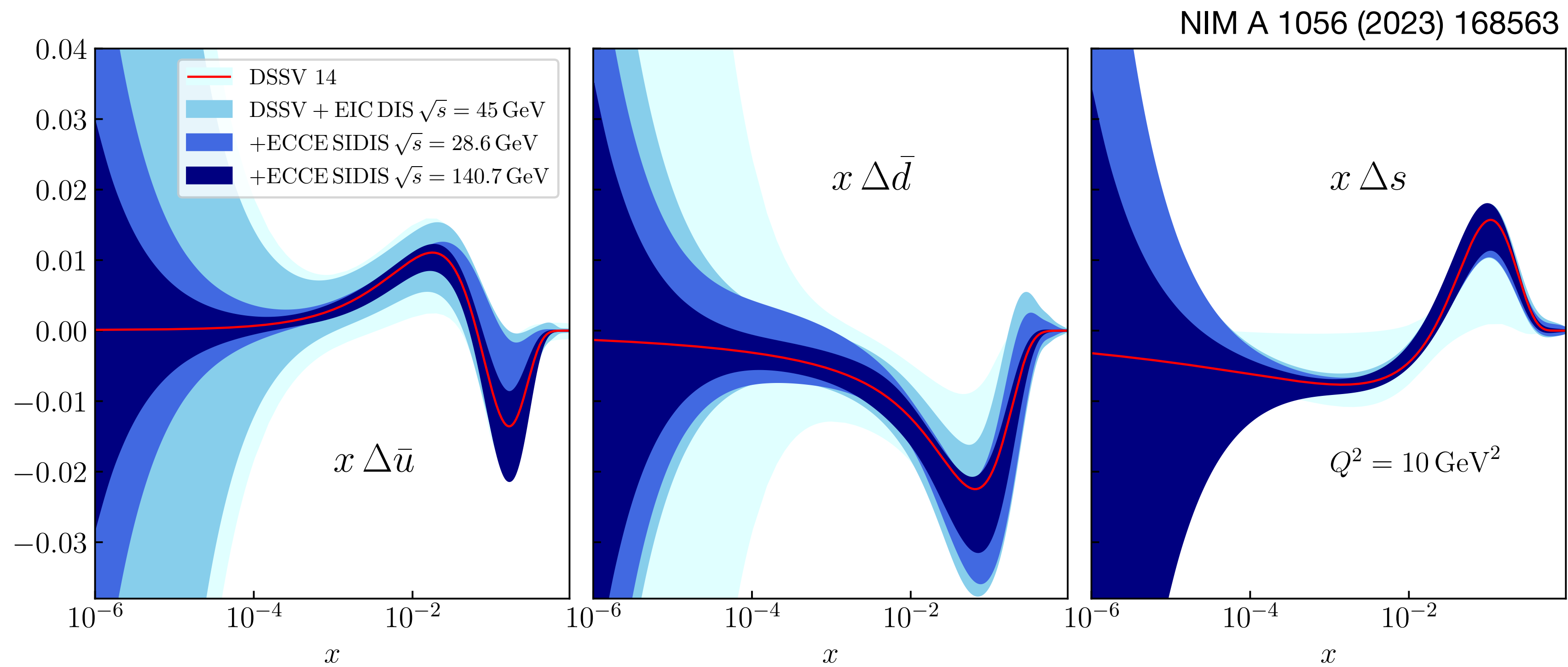
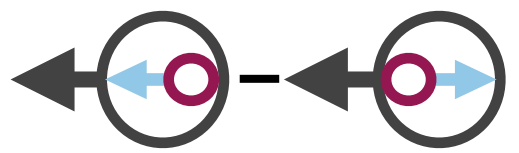
Sea-quark helicity distributions



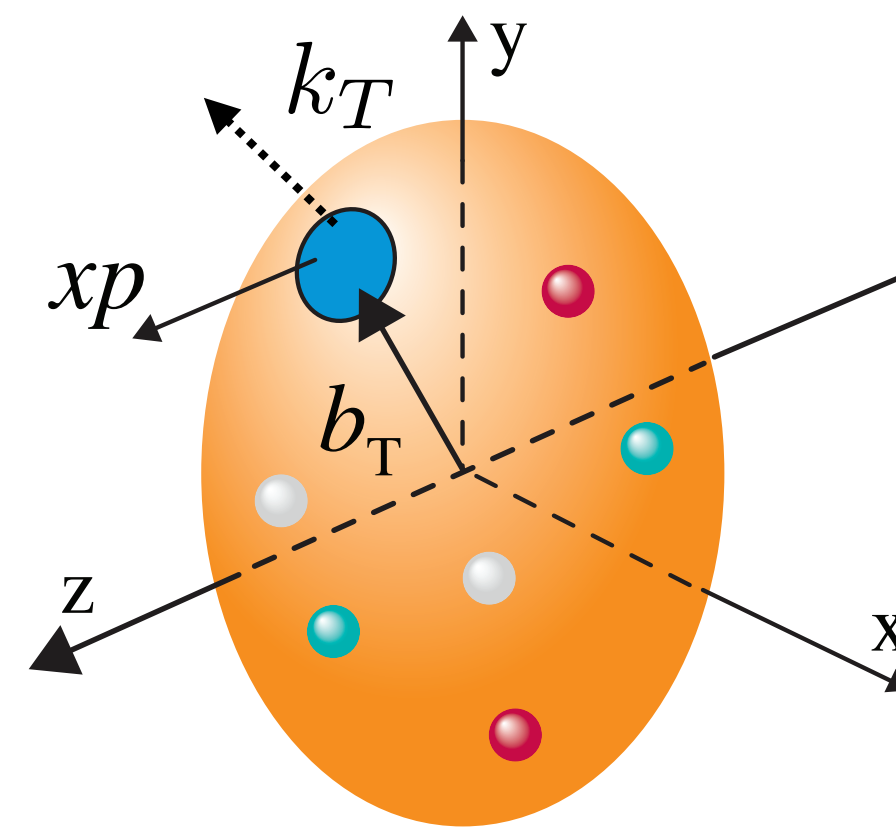
Semi-inclusive measurements
→ access to sea-quark spin

$$\frac{\overleftrightarrow{\sigma}^h - \overrightarrow{\sigma}^h}{\overleftrightarrow{\sigma}^h + \overrightarrow{\sigma}^h} \propto \sum_q e_q^2 \left[\Delta q \otimes w_1 D_1^{q \rightarrow h} \right]$$

Sea-quark helicity distributions at the EIC

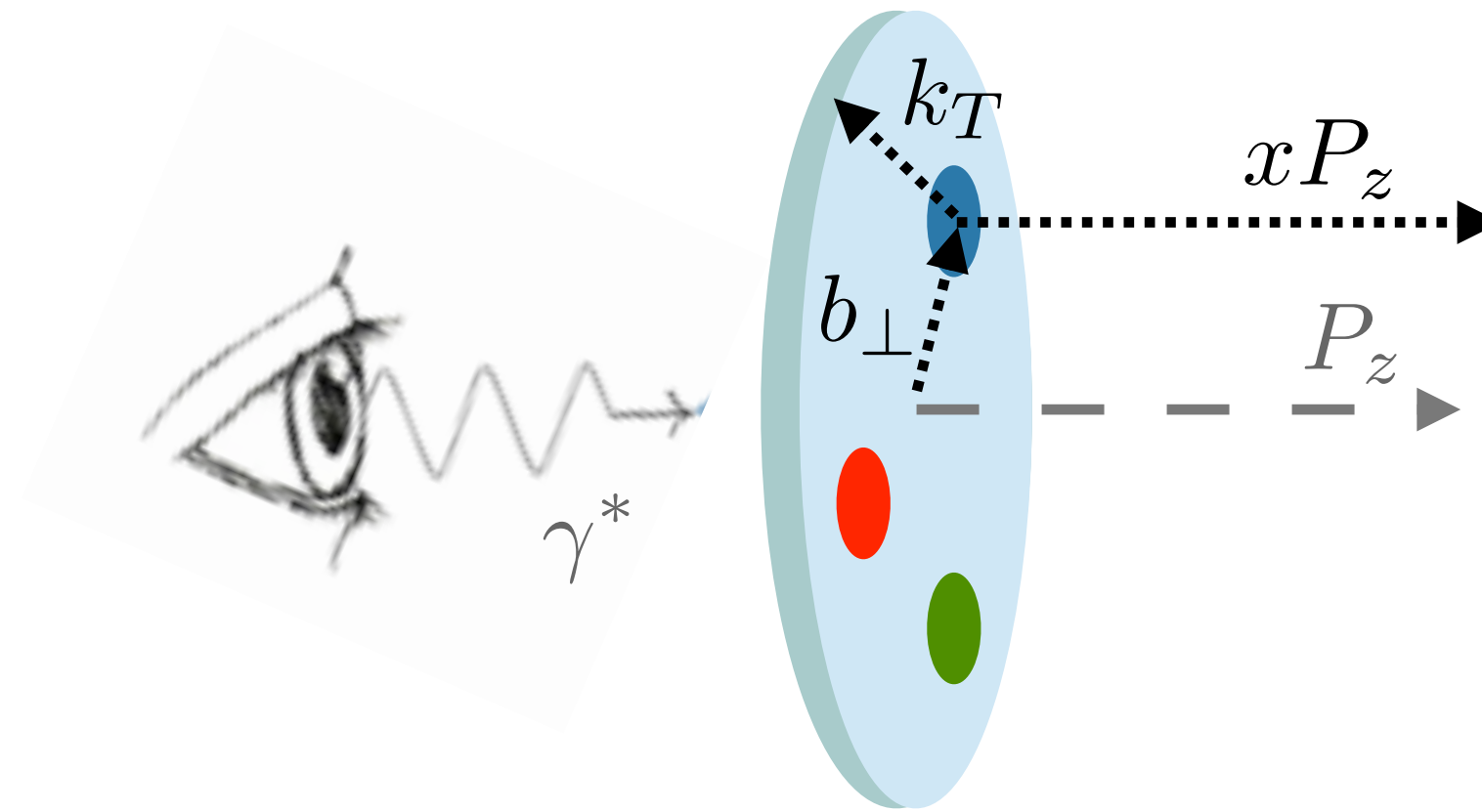


Nucleon multi-dimensional structure

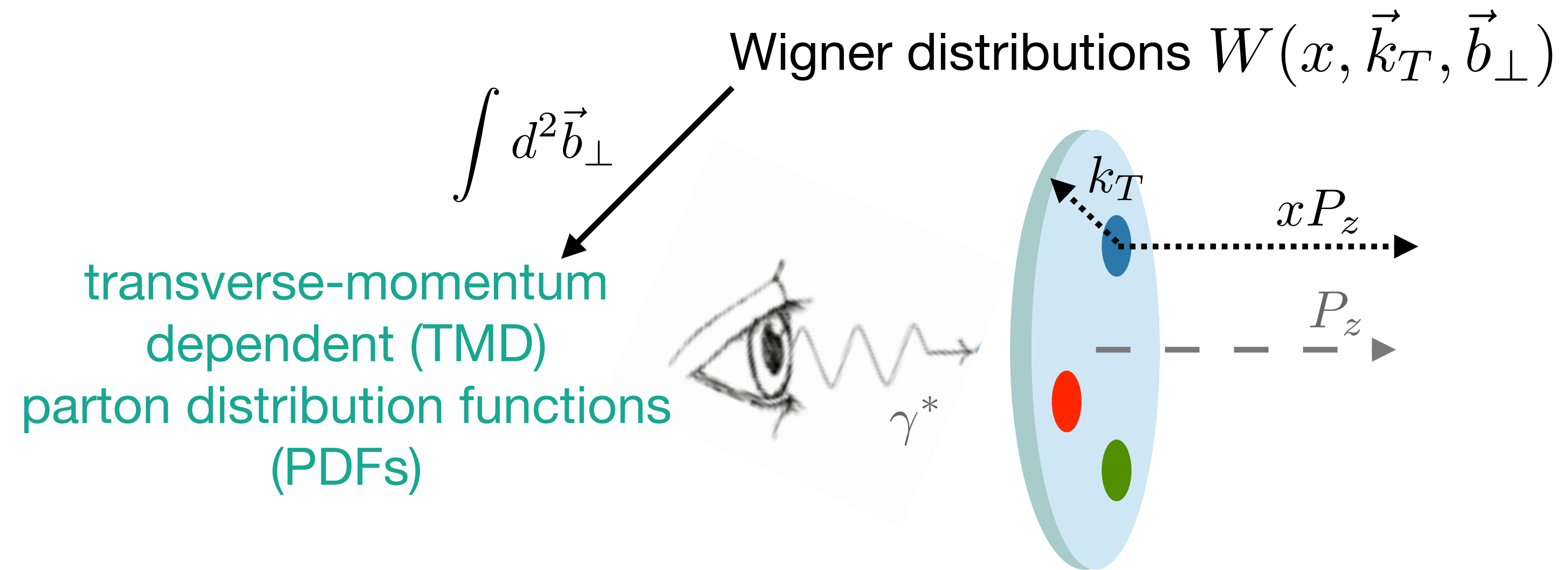


The nucleon multi-dimensional structure

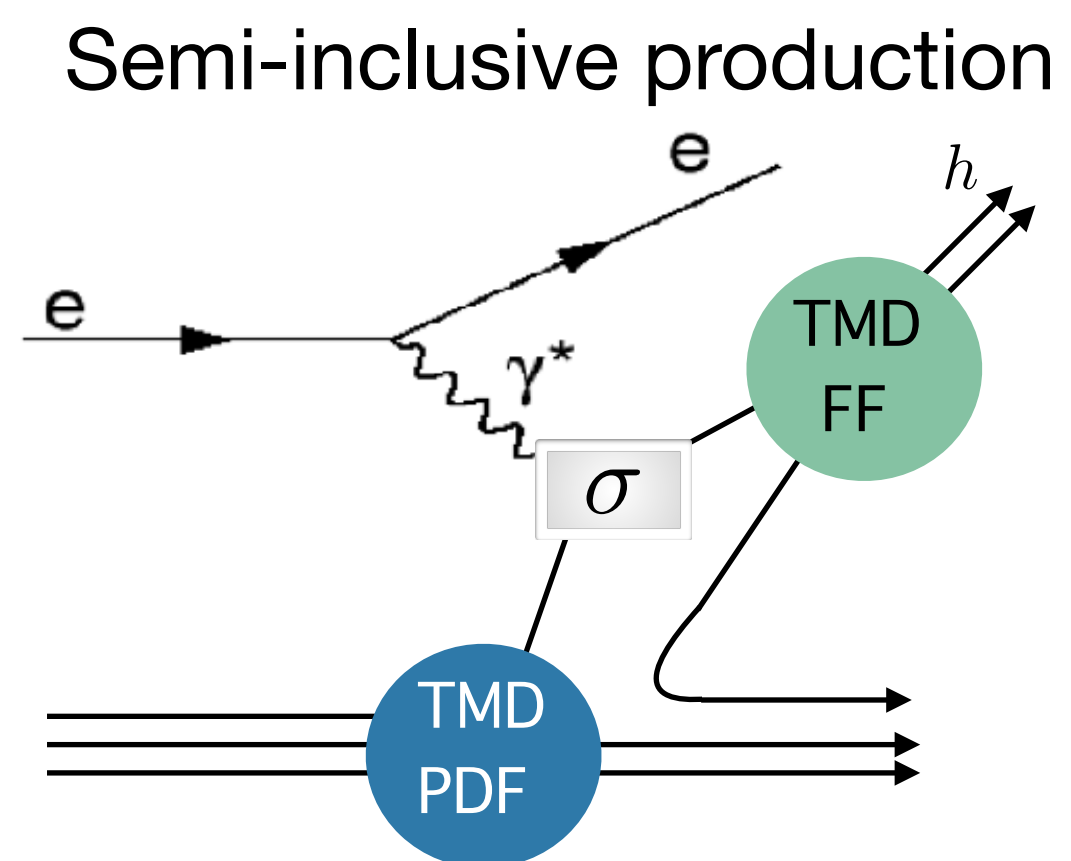
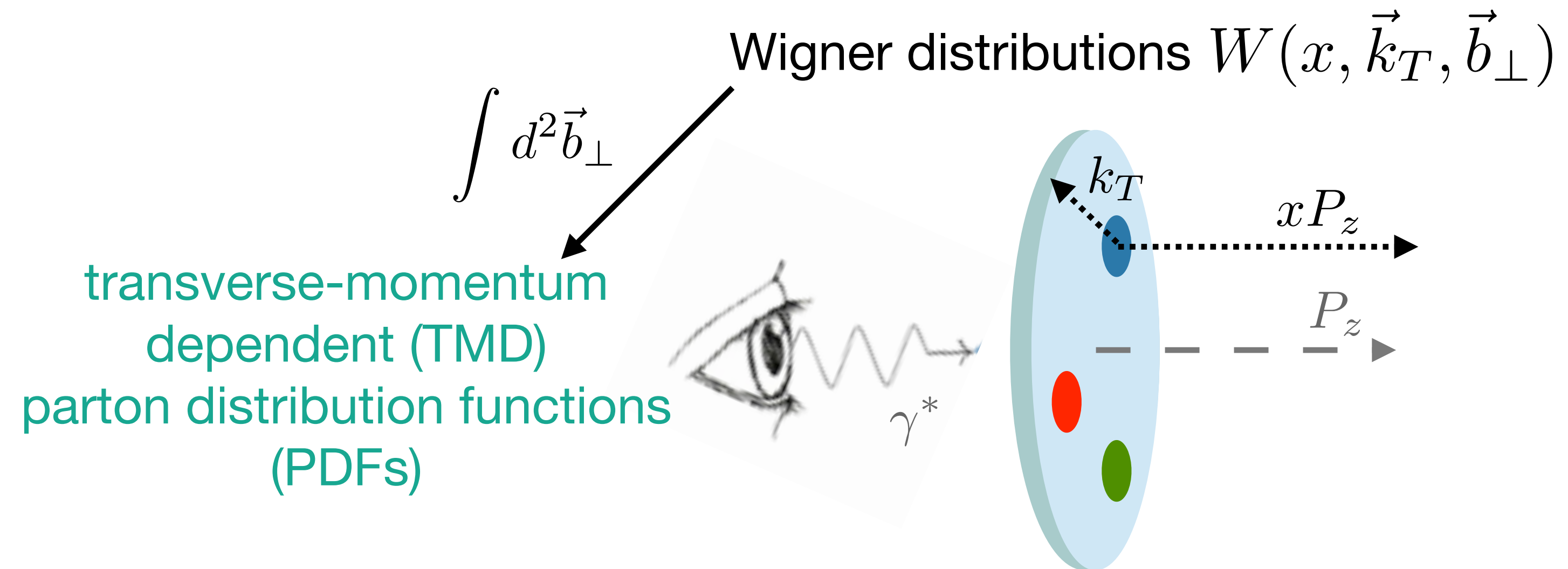
Wigner distributions $W(x, \vec{k}_T, \vec{b}_\perp)$



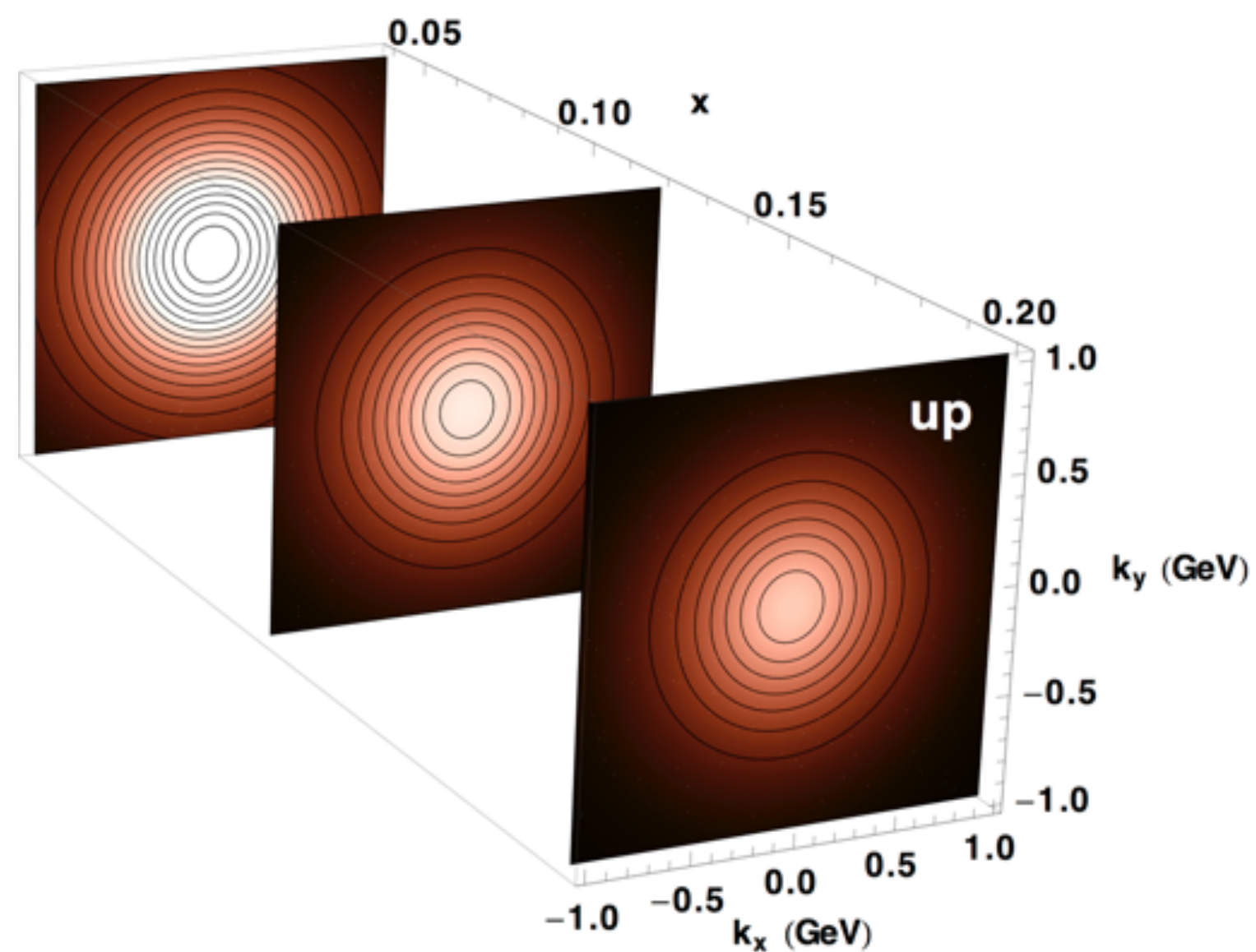
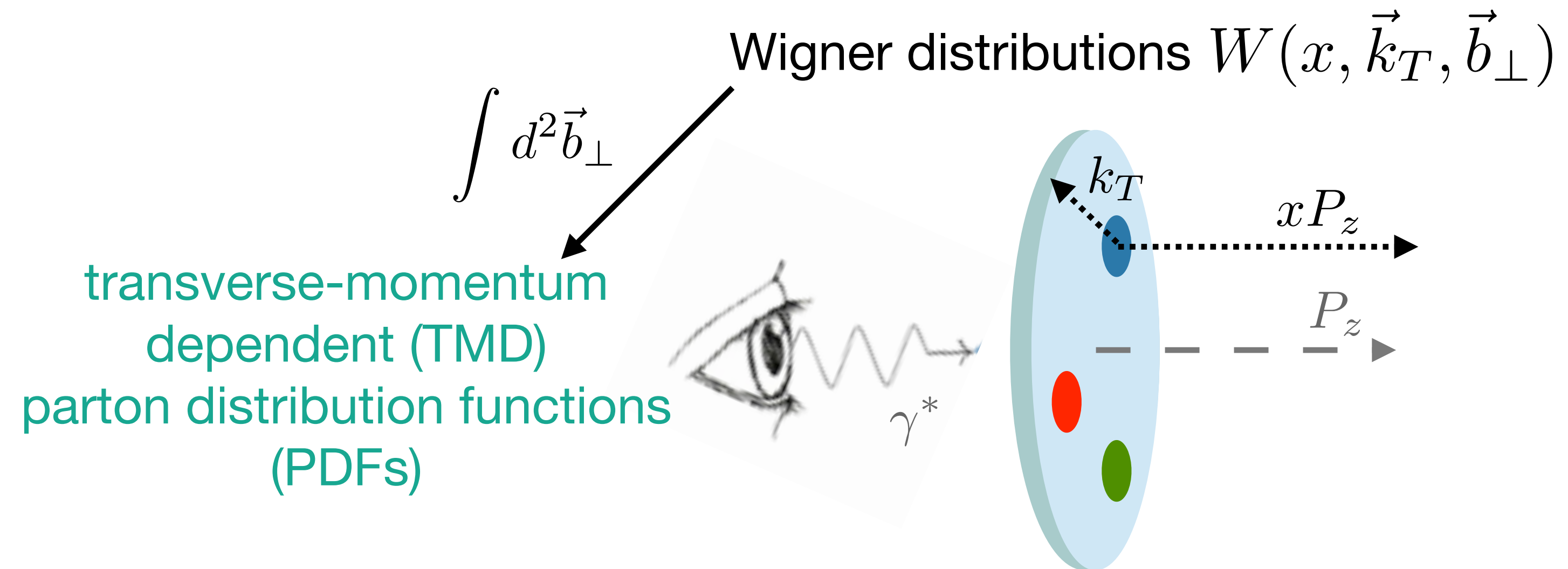
The nucleon multi-dimensional structure



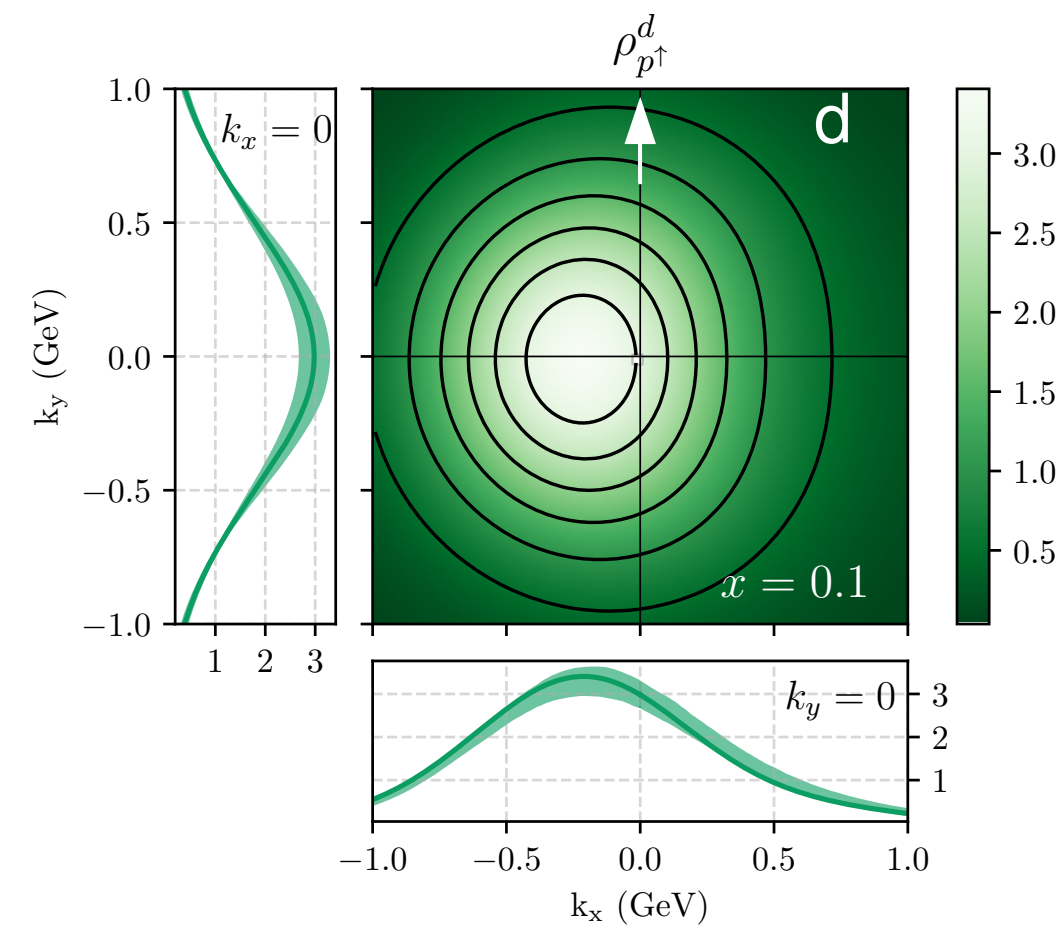
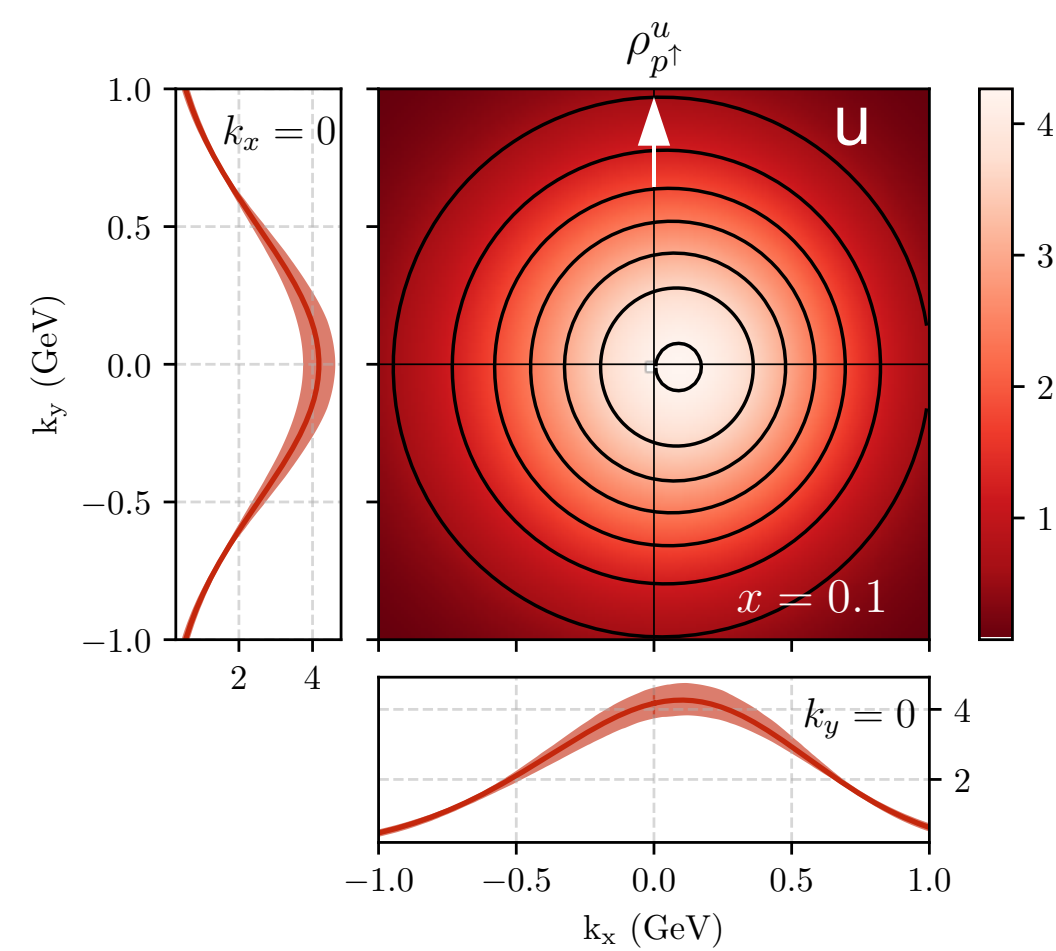
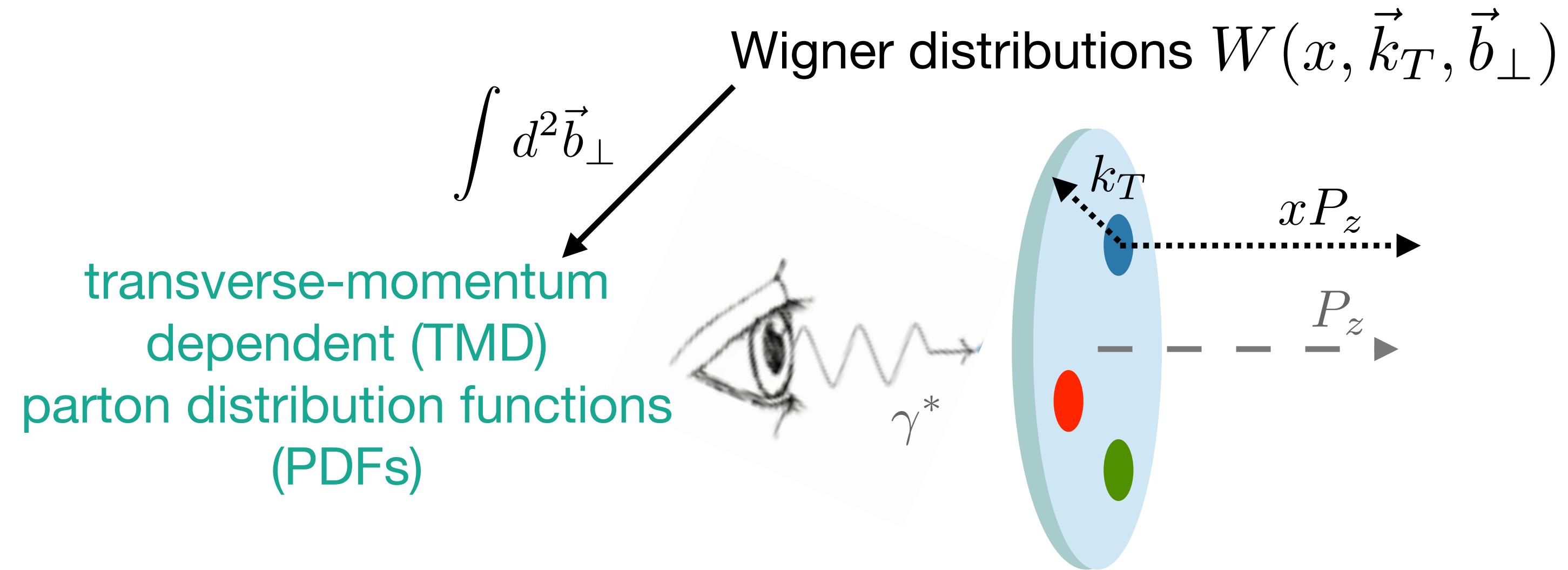
The nucleon multi-dimensional structure



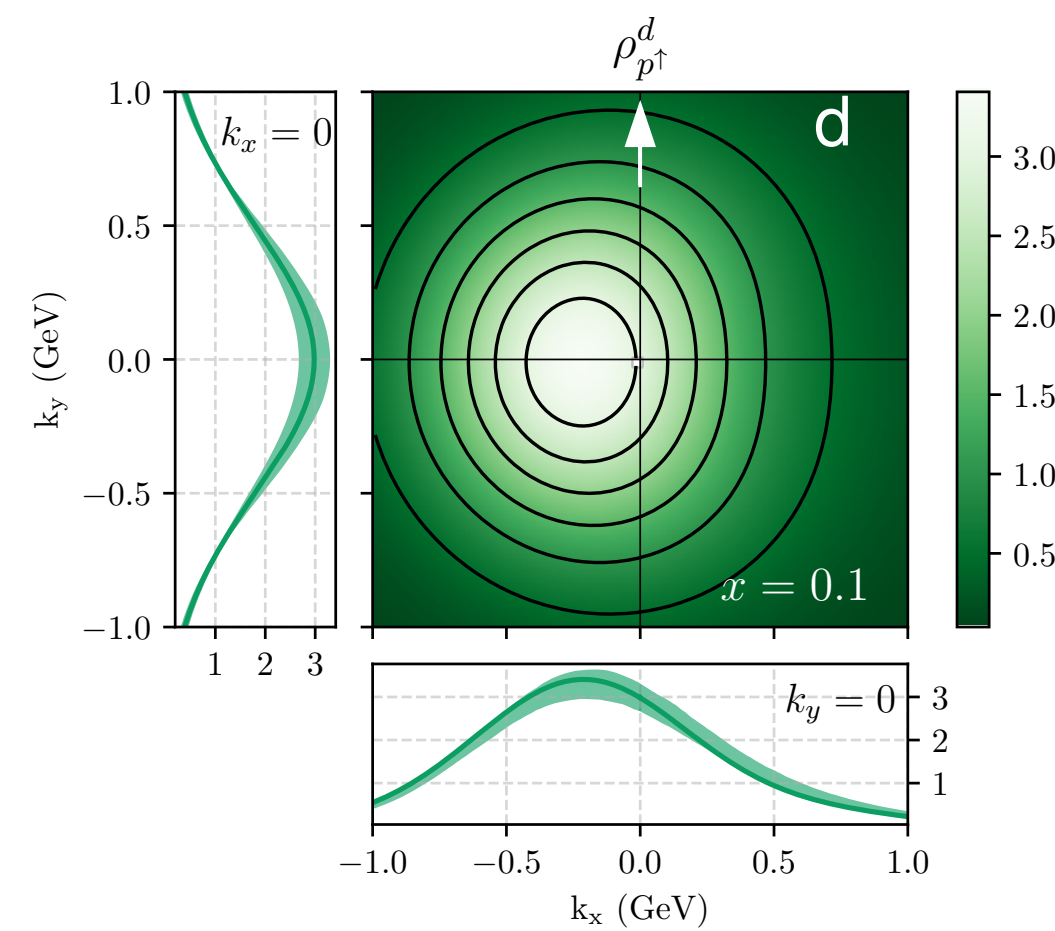
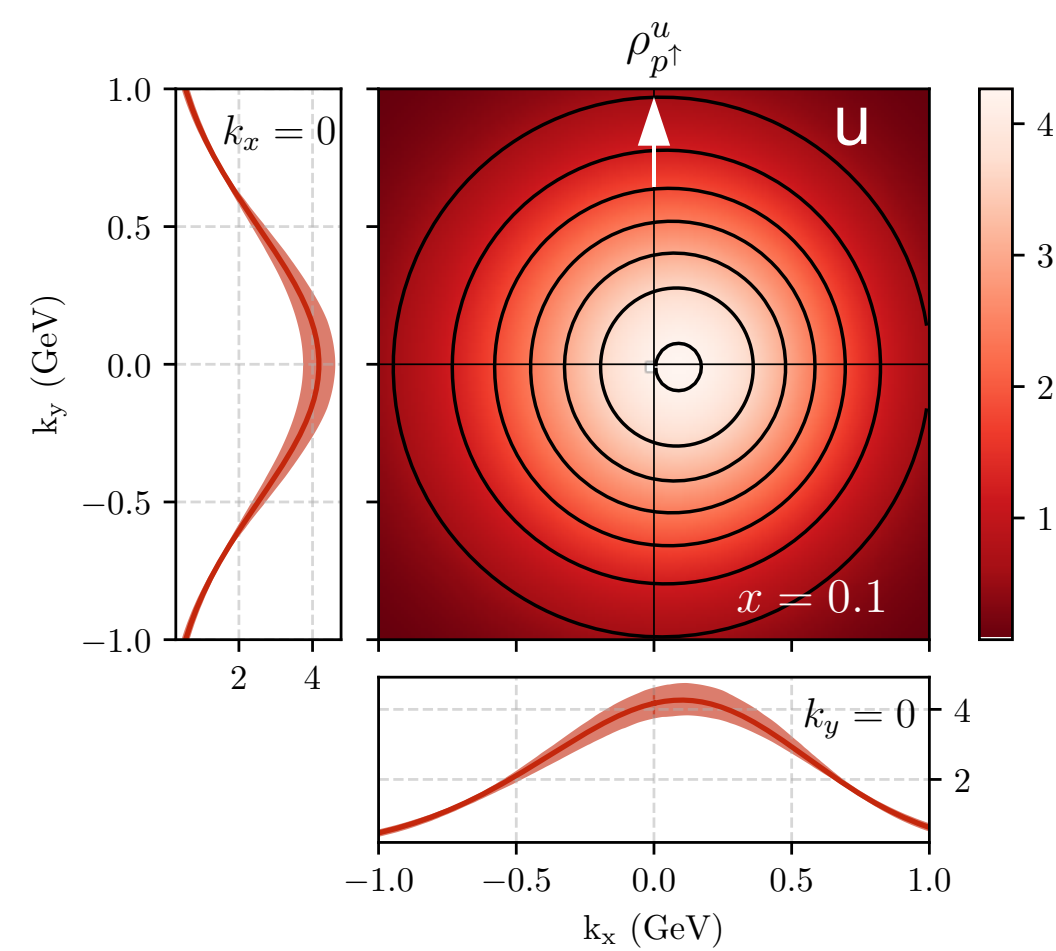
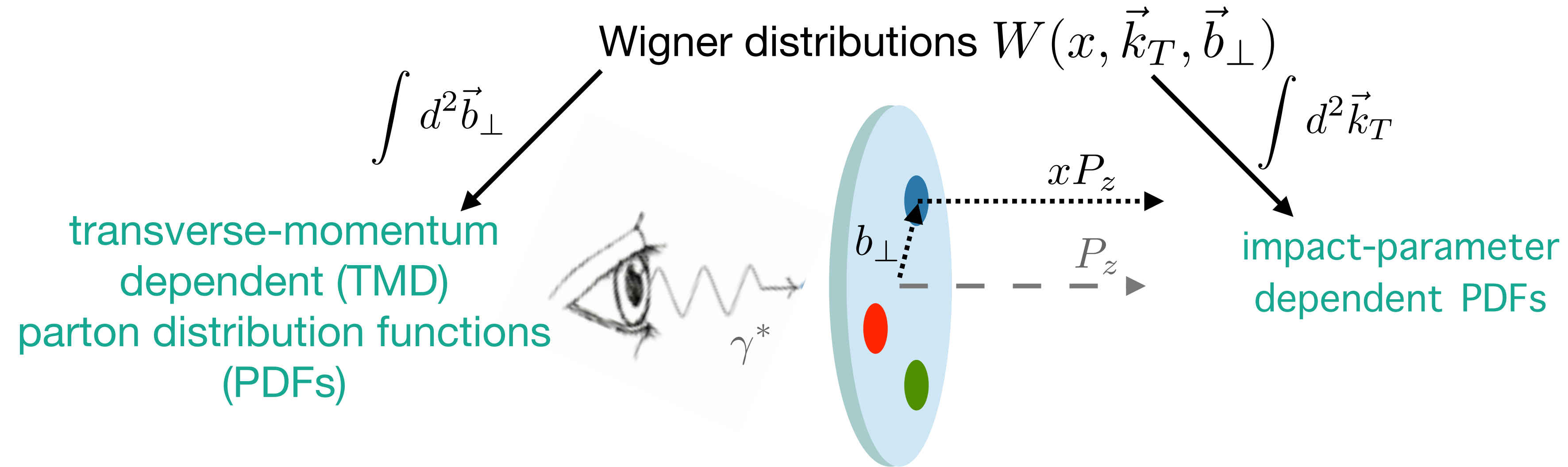
The nucleon multi-dimensional structure



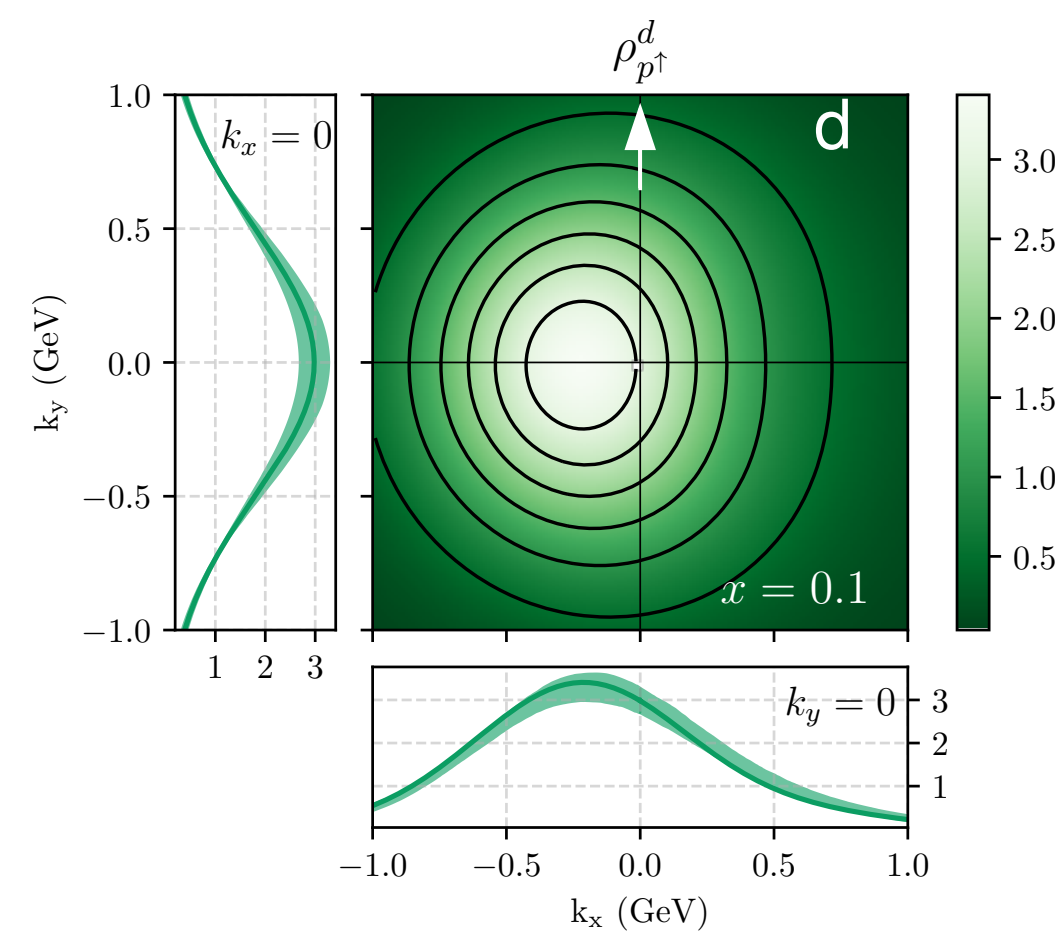
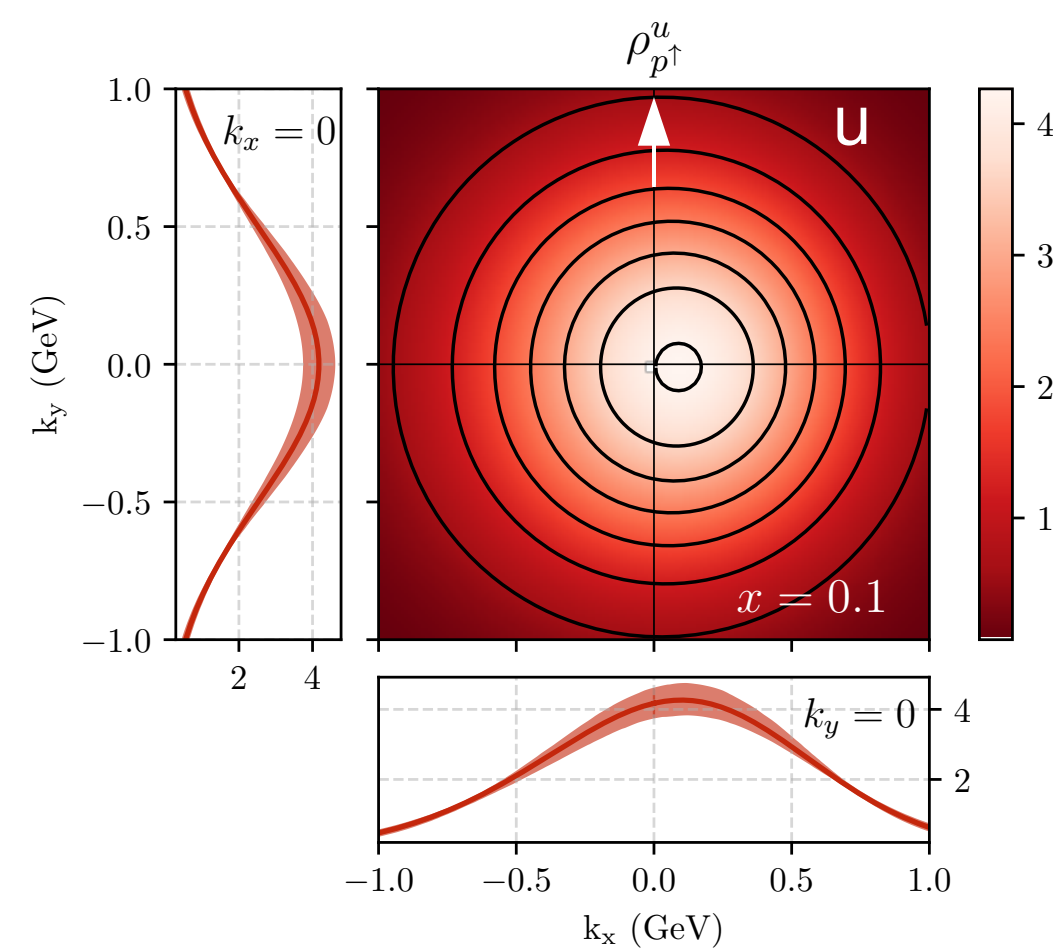
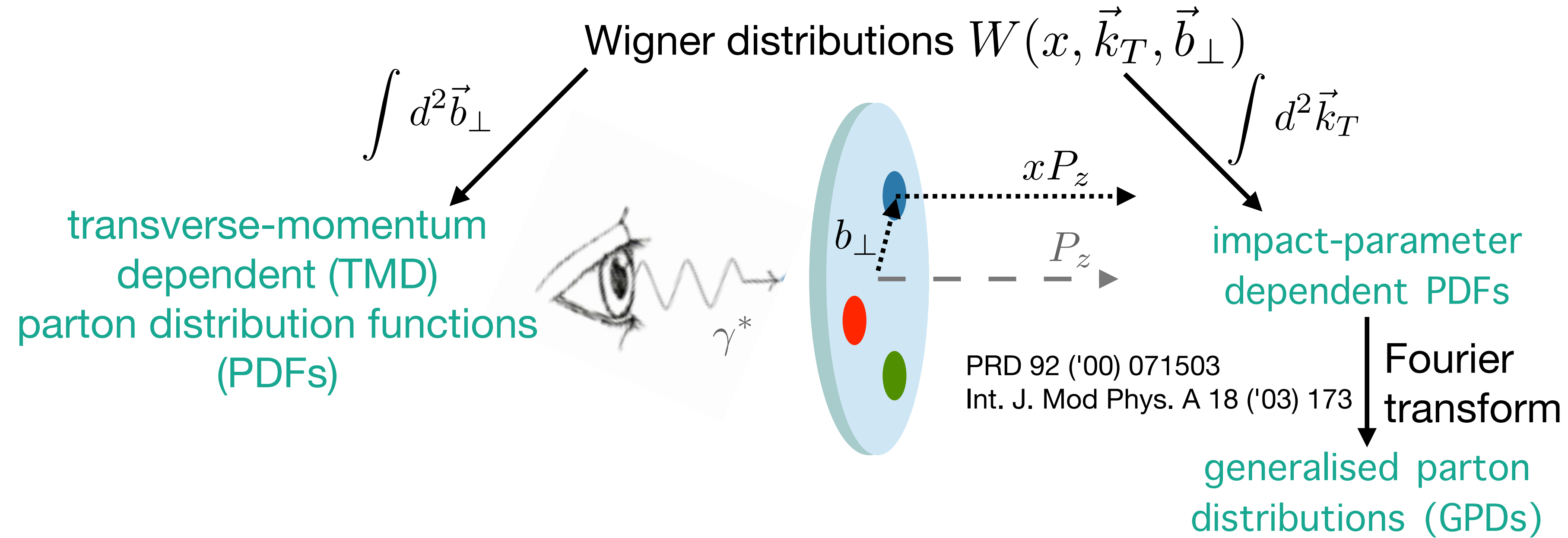
The nucleon multi-dimensional structure



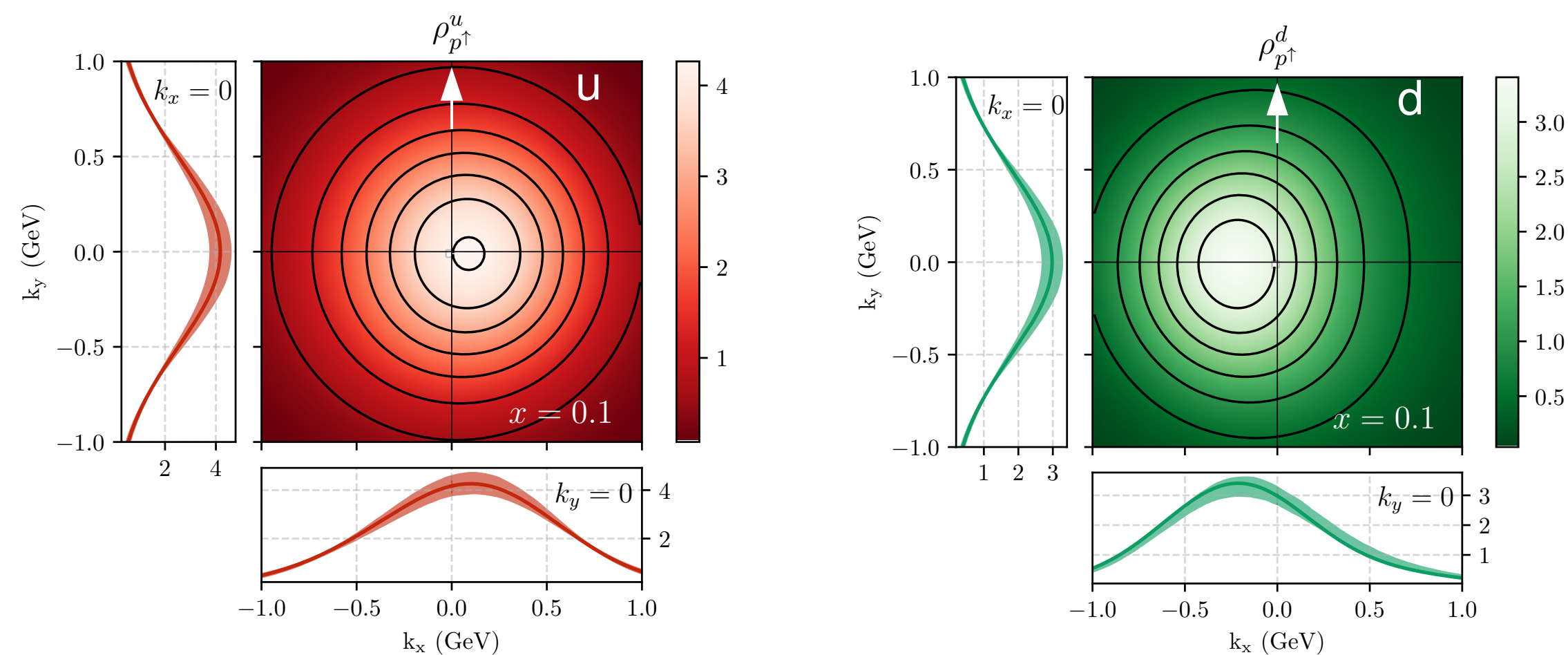
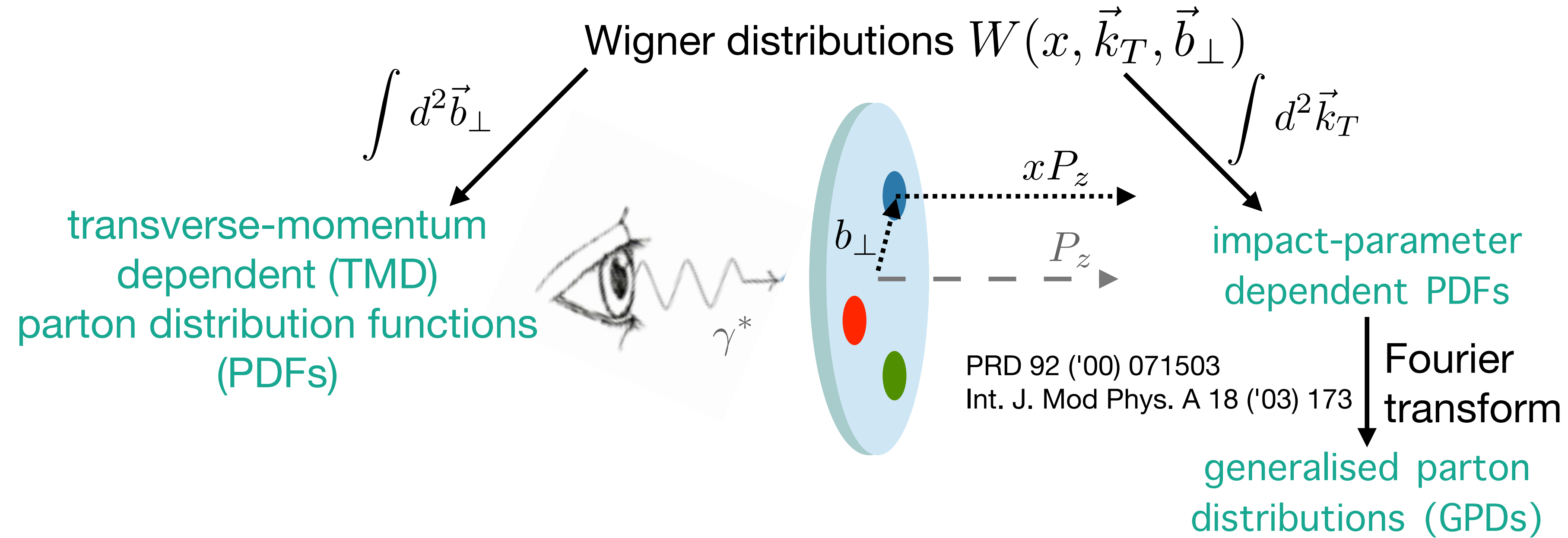
The nucleon multi-dimensional structure



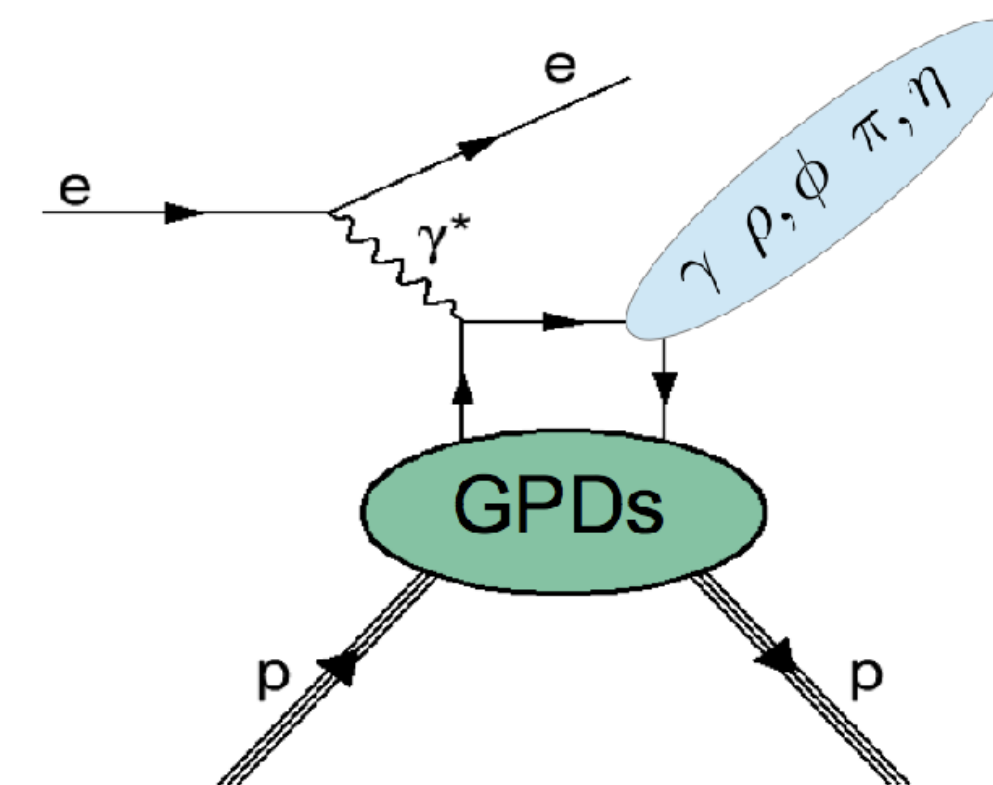
The nucleon multi-dimensional structure



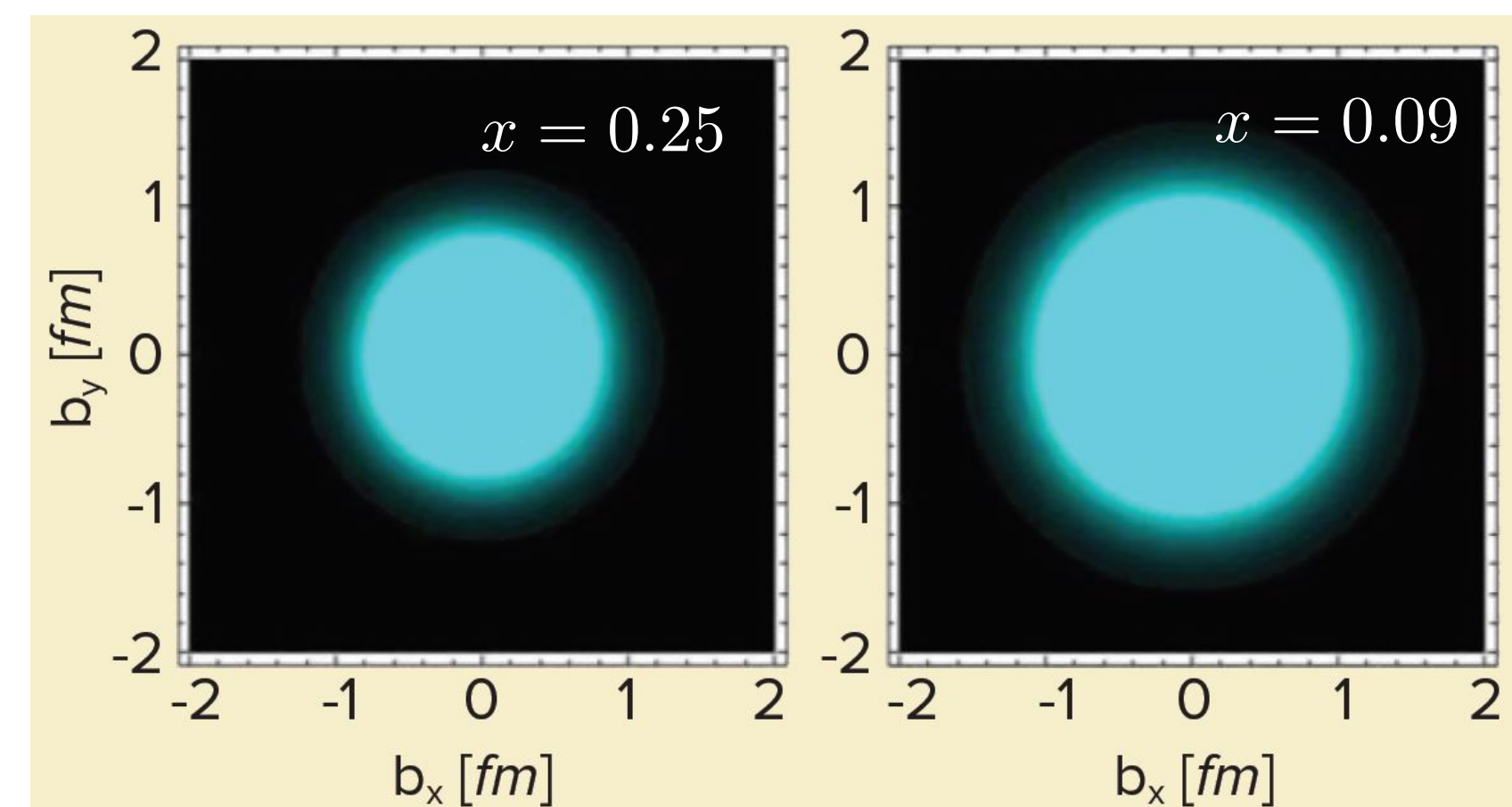
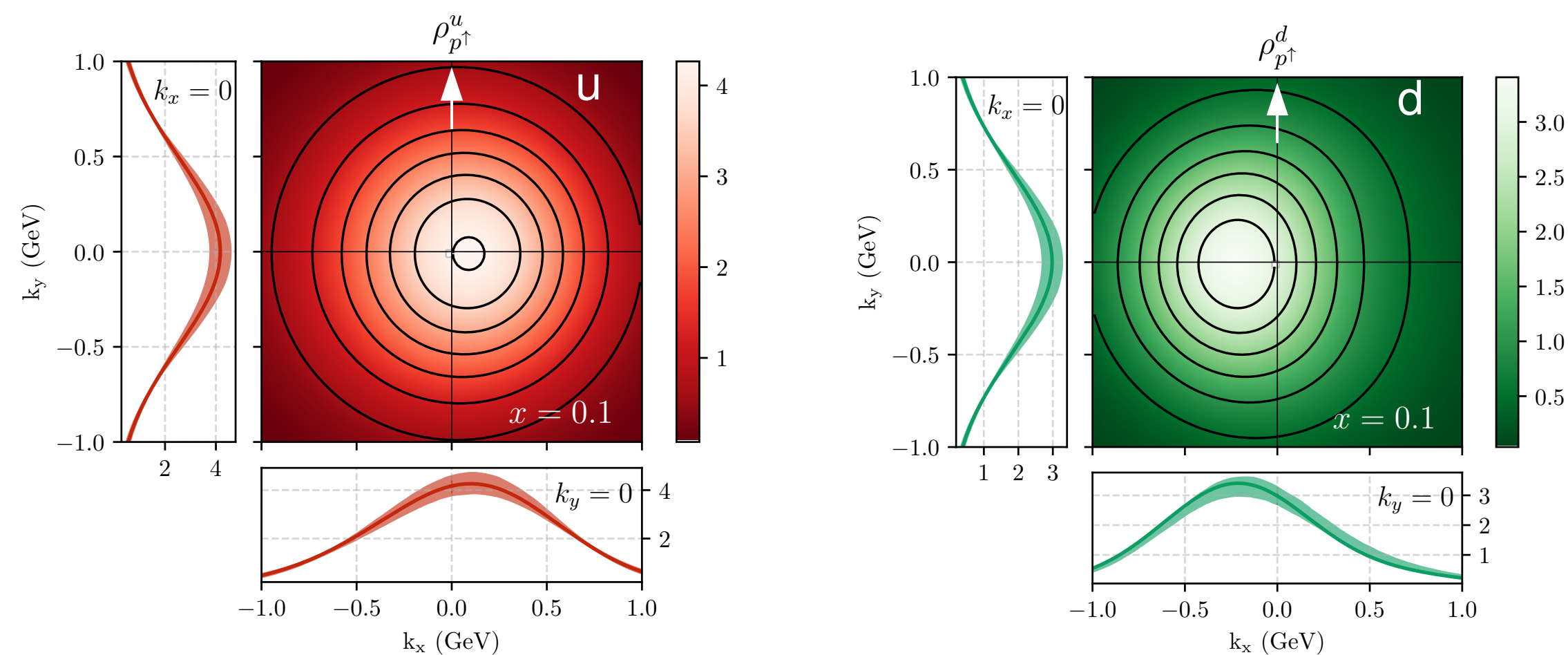
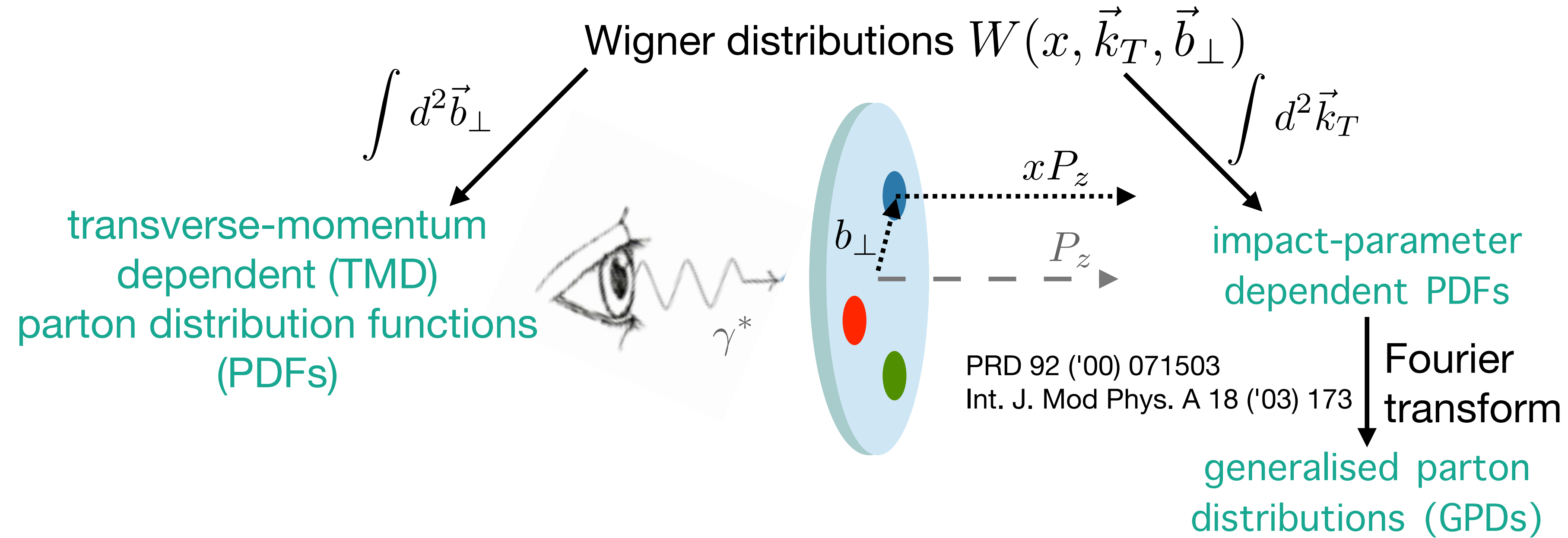
The nucleon multi-dimensional structure



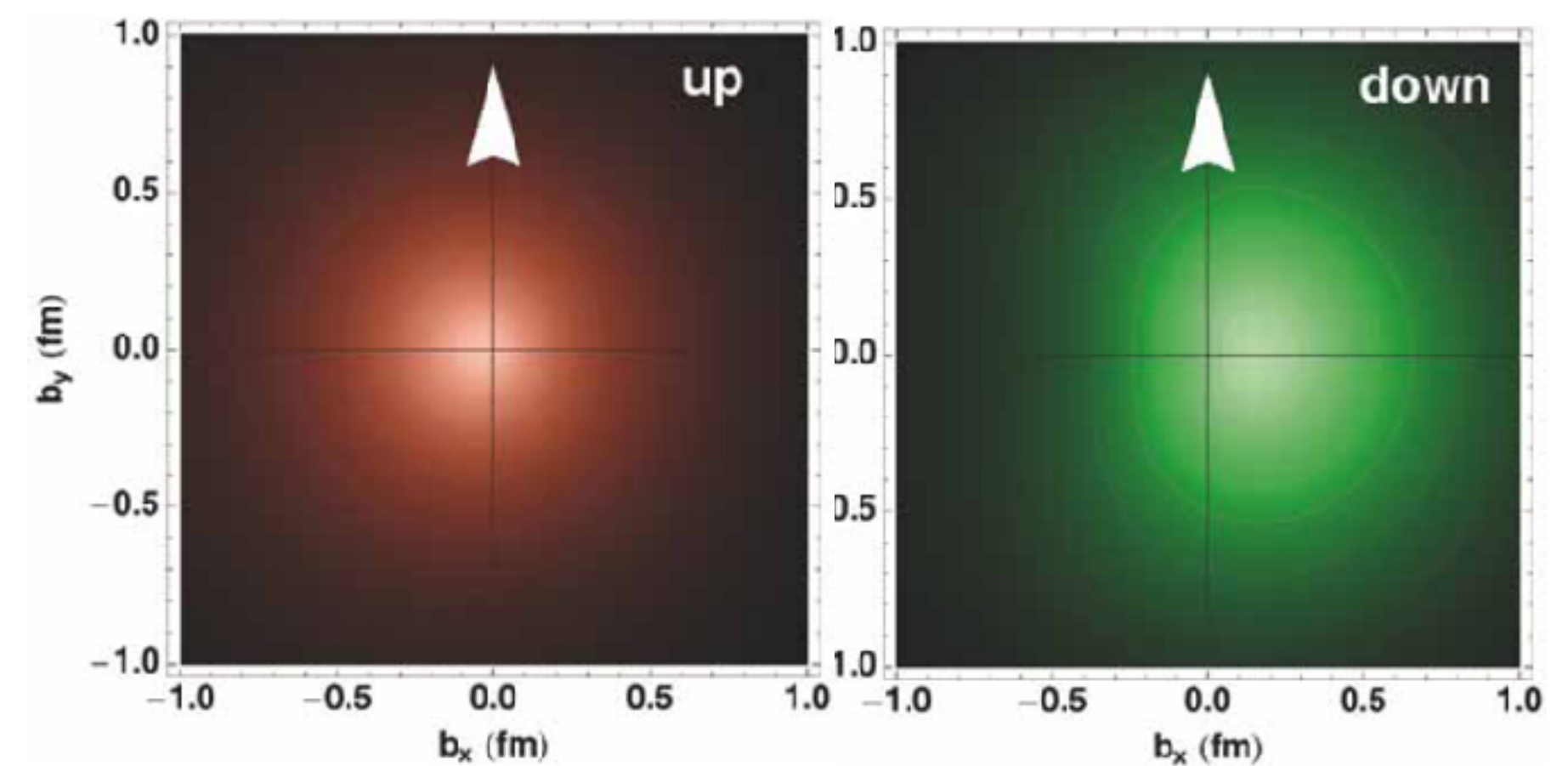
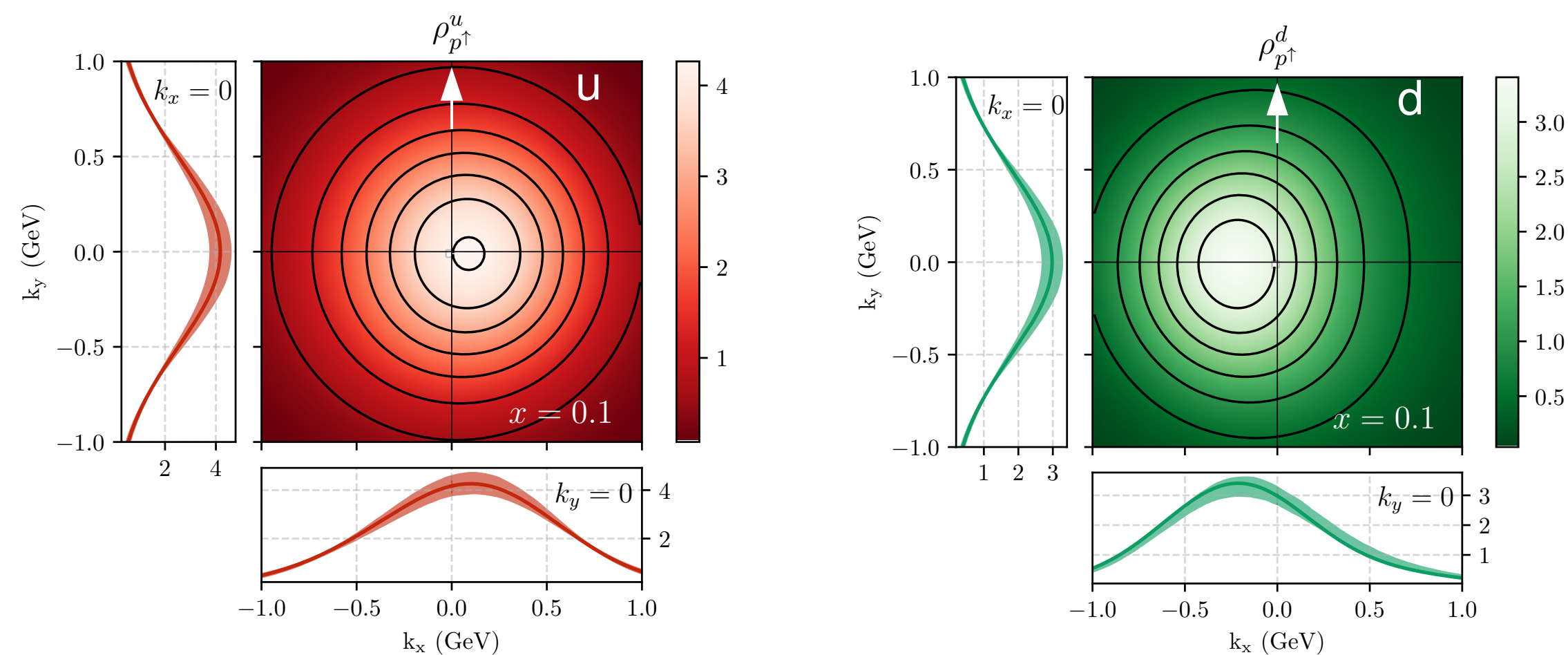
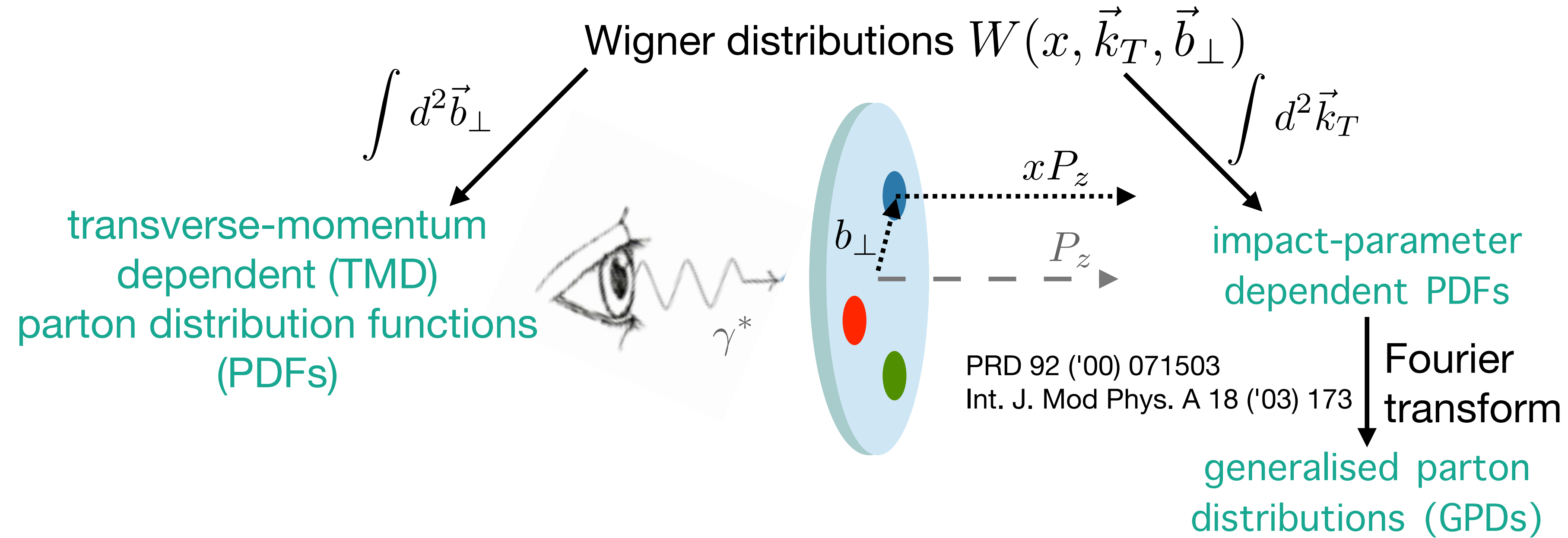
Exclusive production



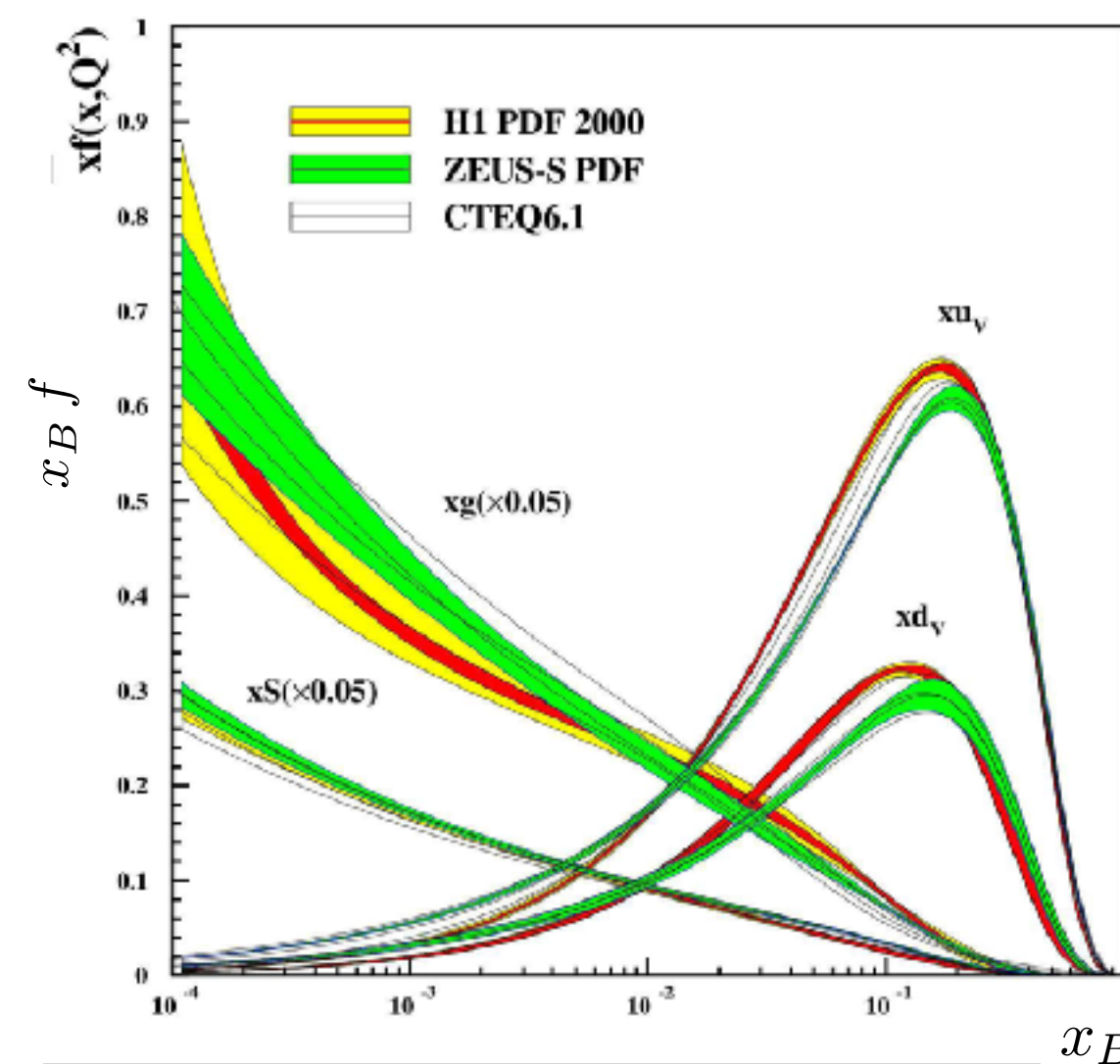
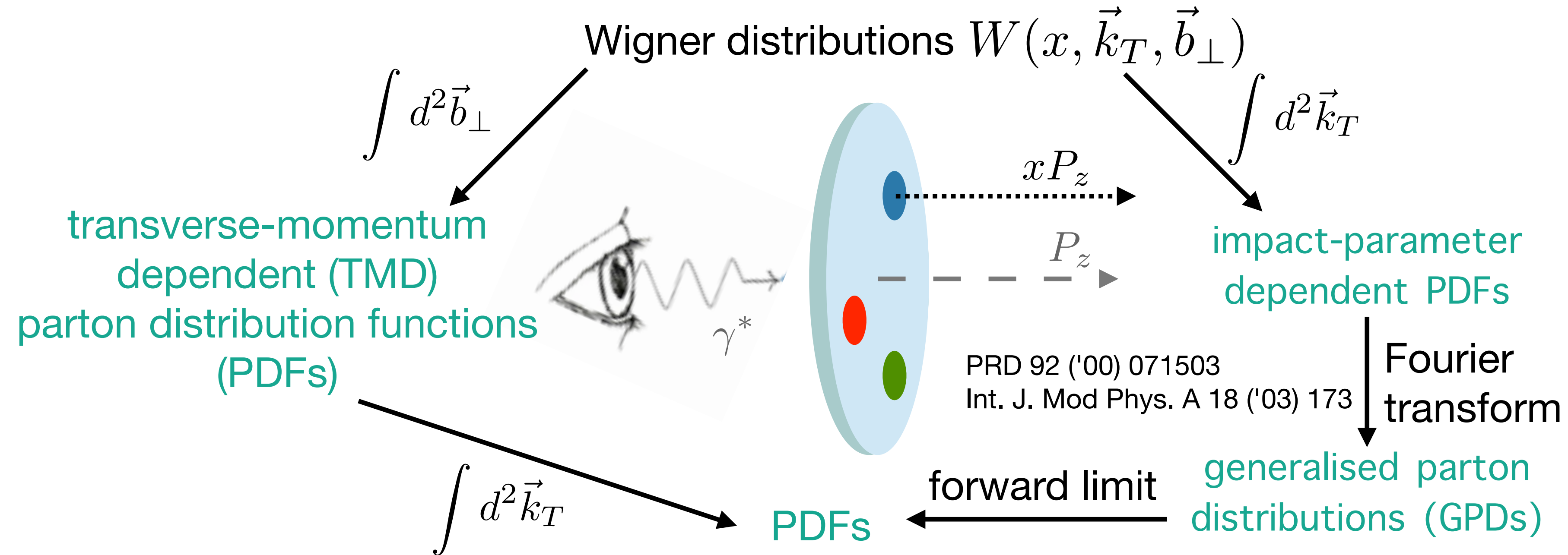
The nucleon multi-dimensional structure



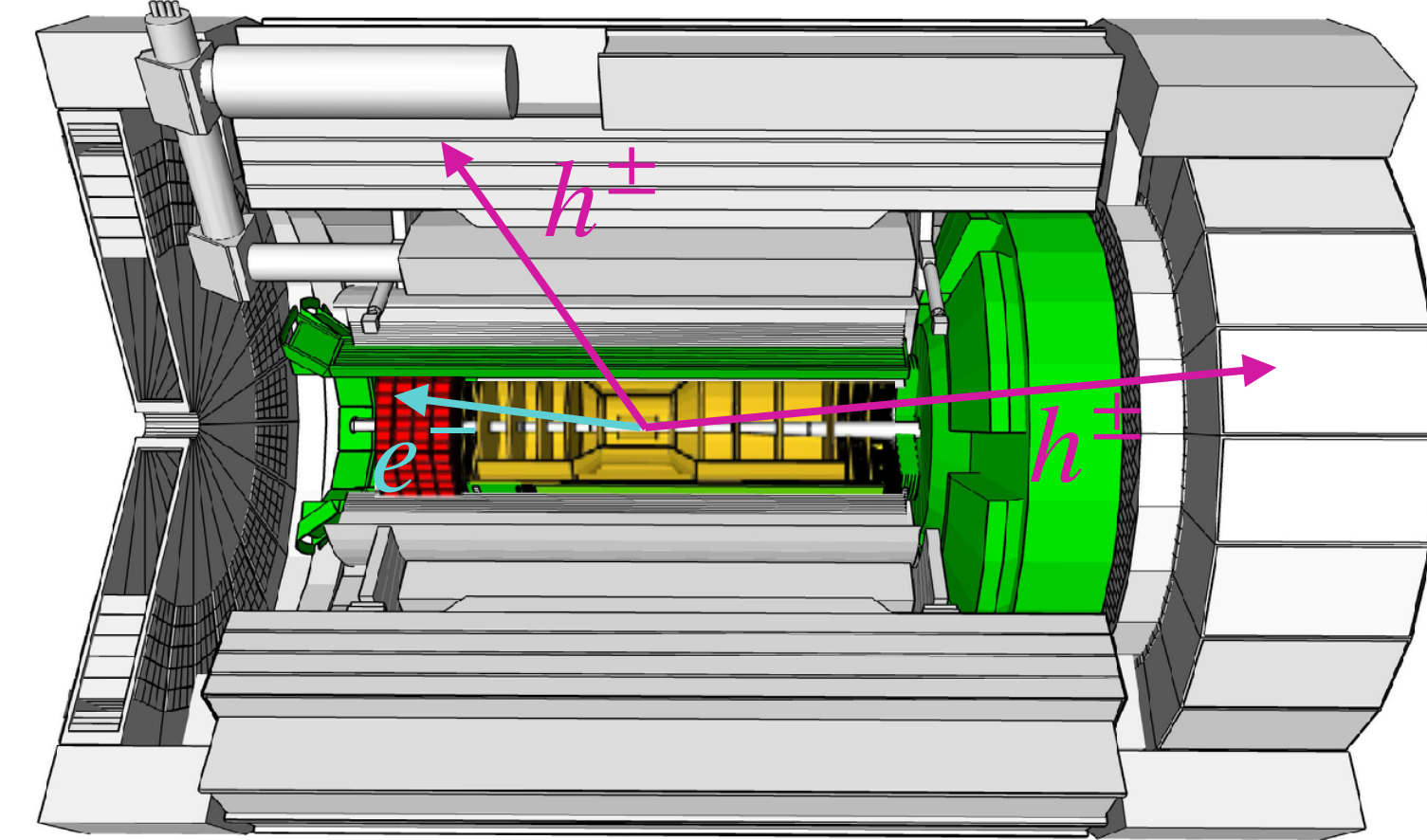
The nucleon multi-dimensional structure



The nucleon multi-dimensional structure



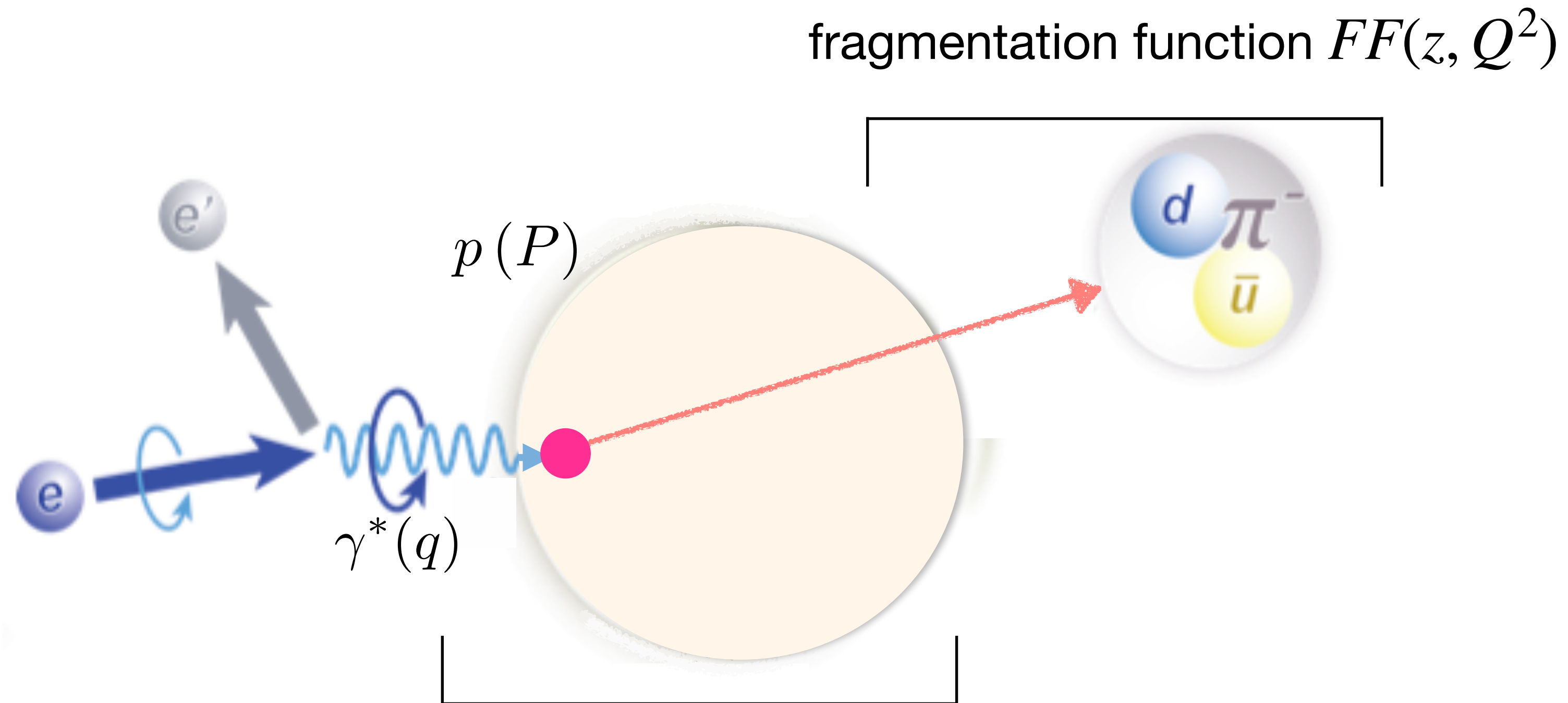
Single-hadron production in semi-inclusive DIS



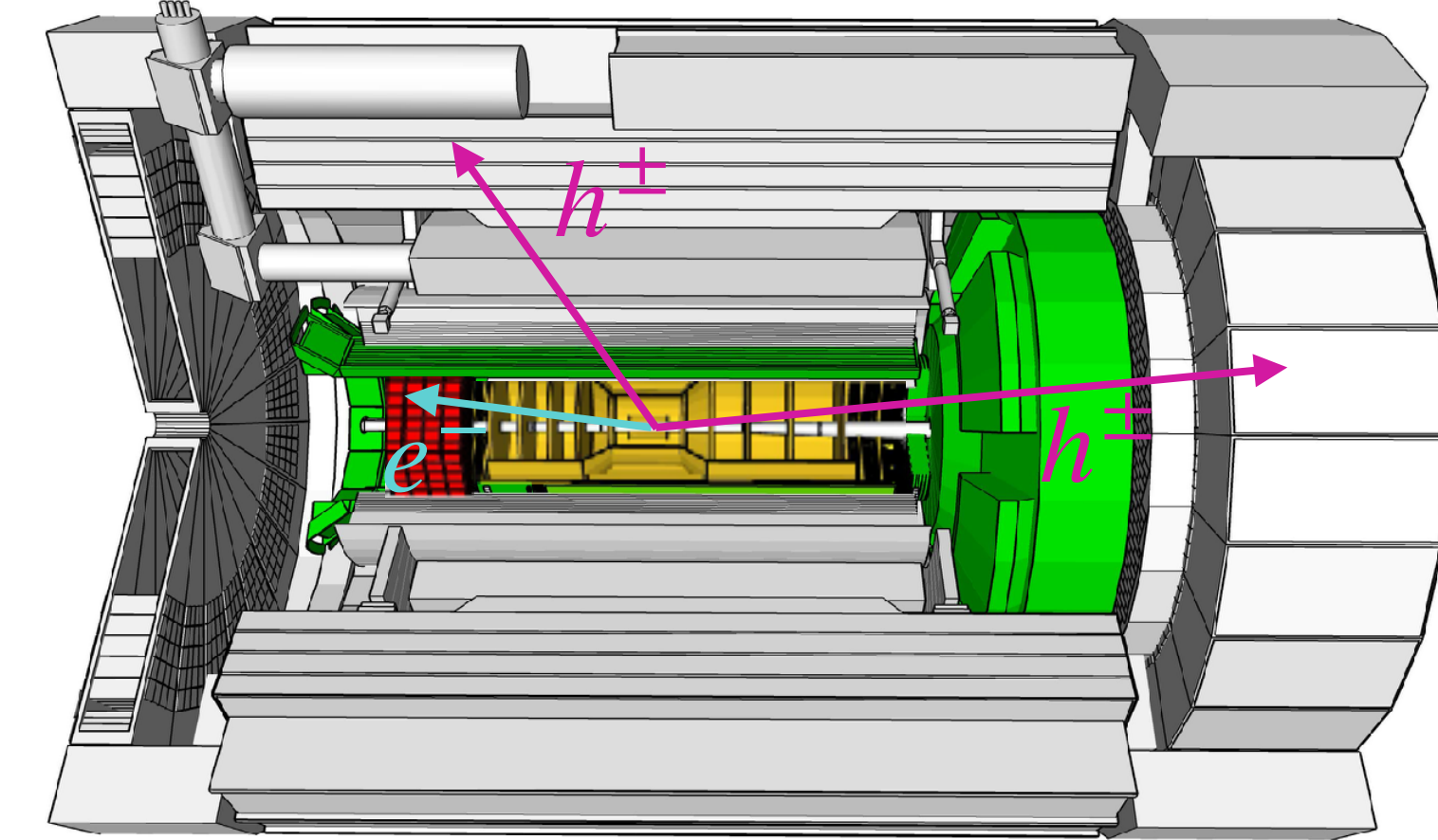
$$Q^2 = -q^2$$

$$x_B = \frac{Q^2}{2P \cdot q}$$

$$z \stackrel{\text{lab}}{=} \frac{E_h}{E_{\gamma^*}}$$



Single-hadron production in semi-inclusive DIS

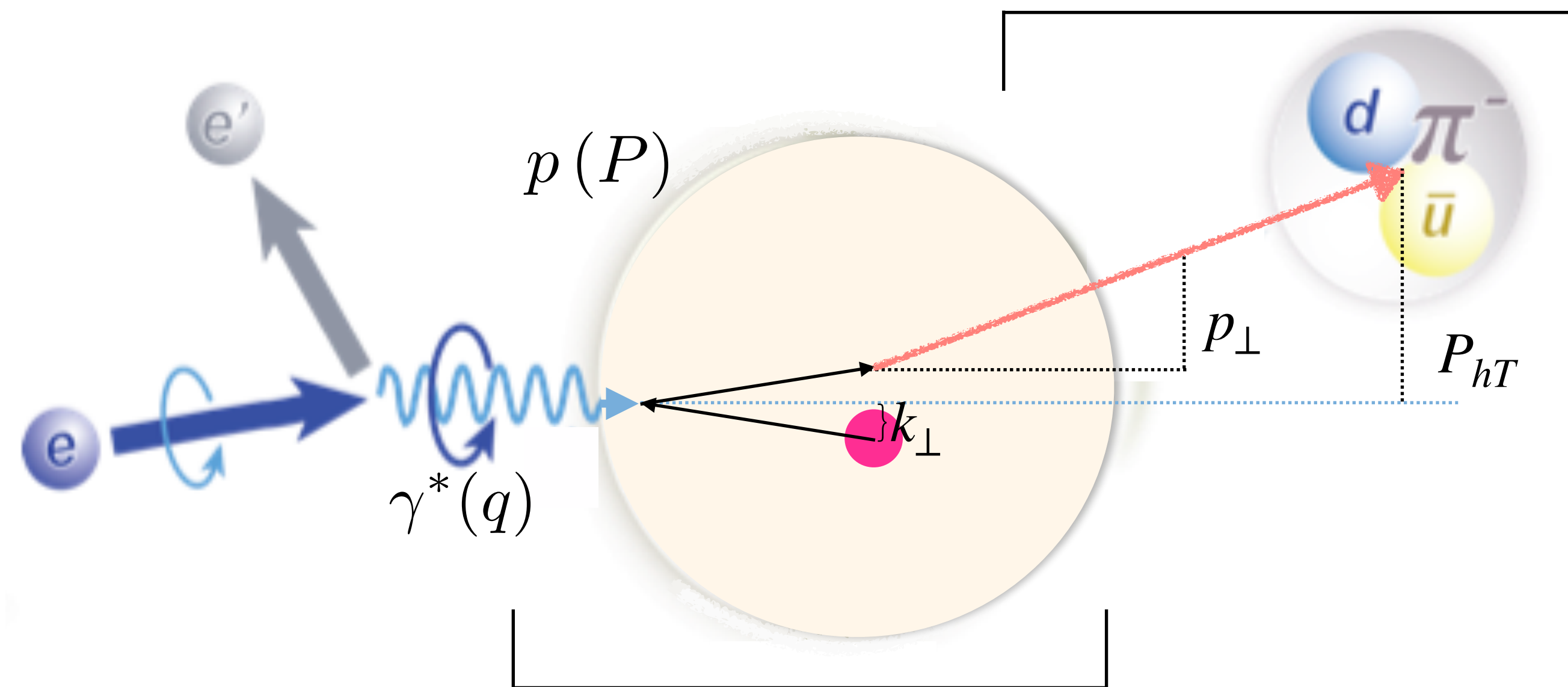


Transverse-momentum-dependent (TMD)
fragmentation function $FF(z, p_{\perp}, Q^2)$

$$Q^2 = -q^2$$

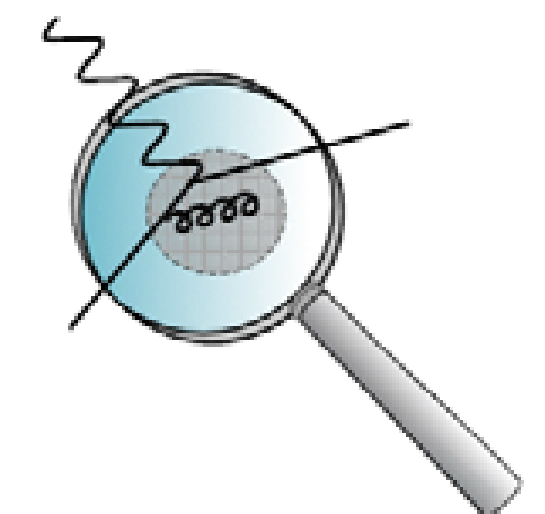
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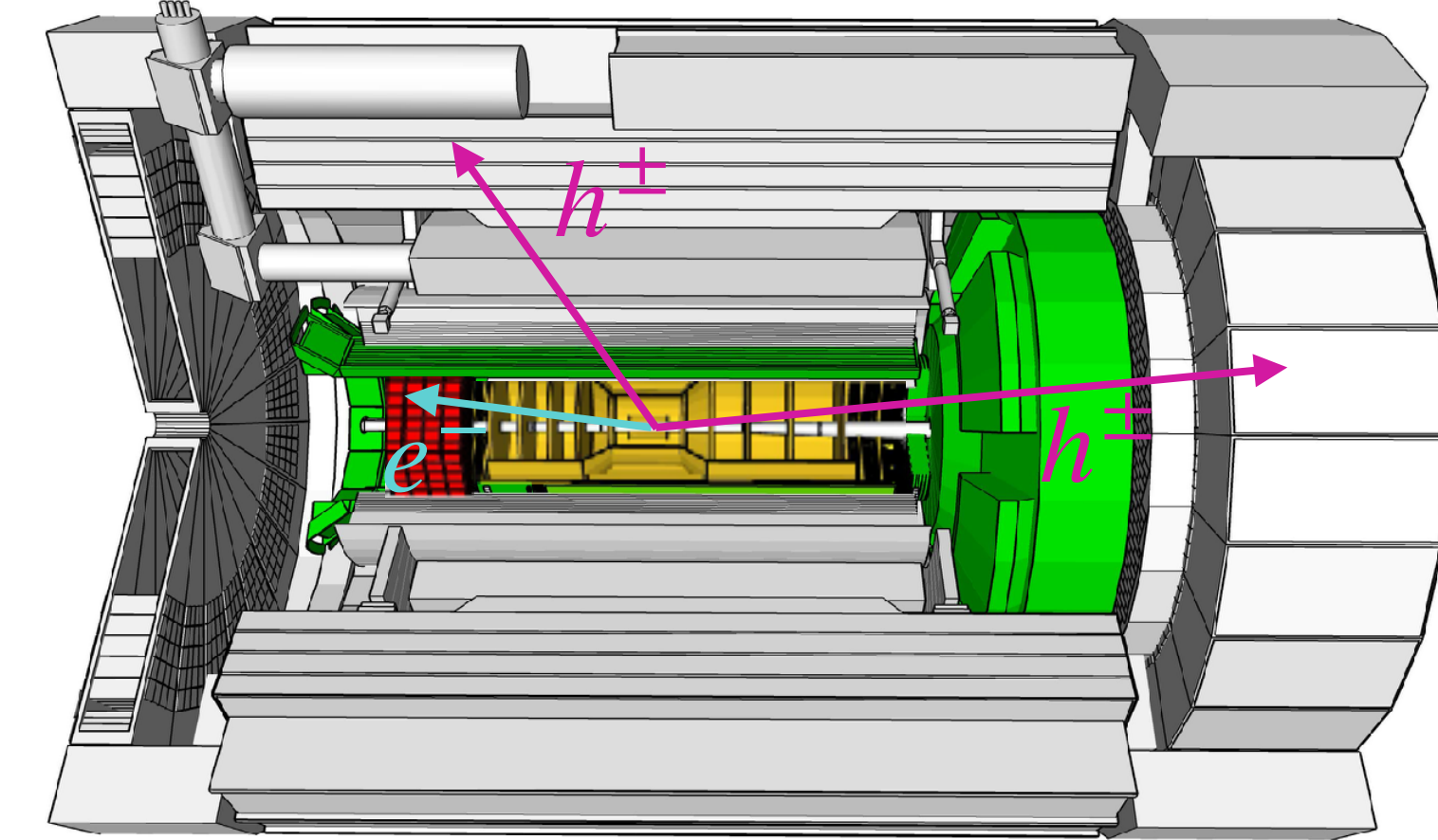


Transverse-momentum-dependent (TMD)
parton distribution function $PDF(x_B, k_{\perp}, Q^2)$

TMD evolution



Single-hadron production in semi-inclusive DIS

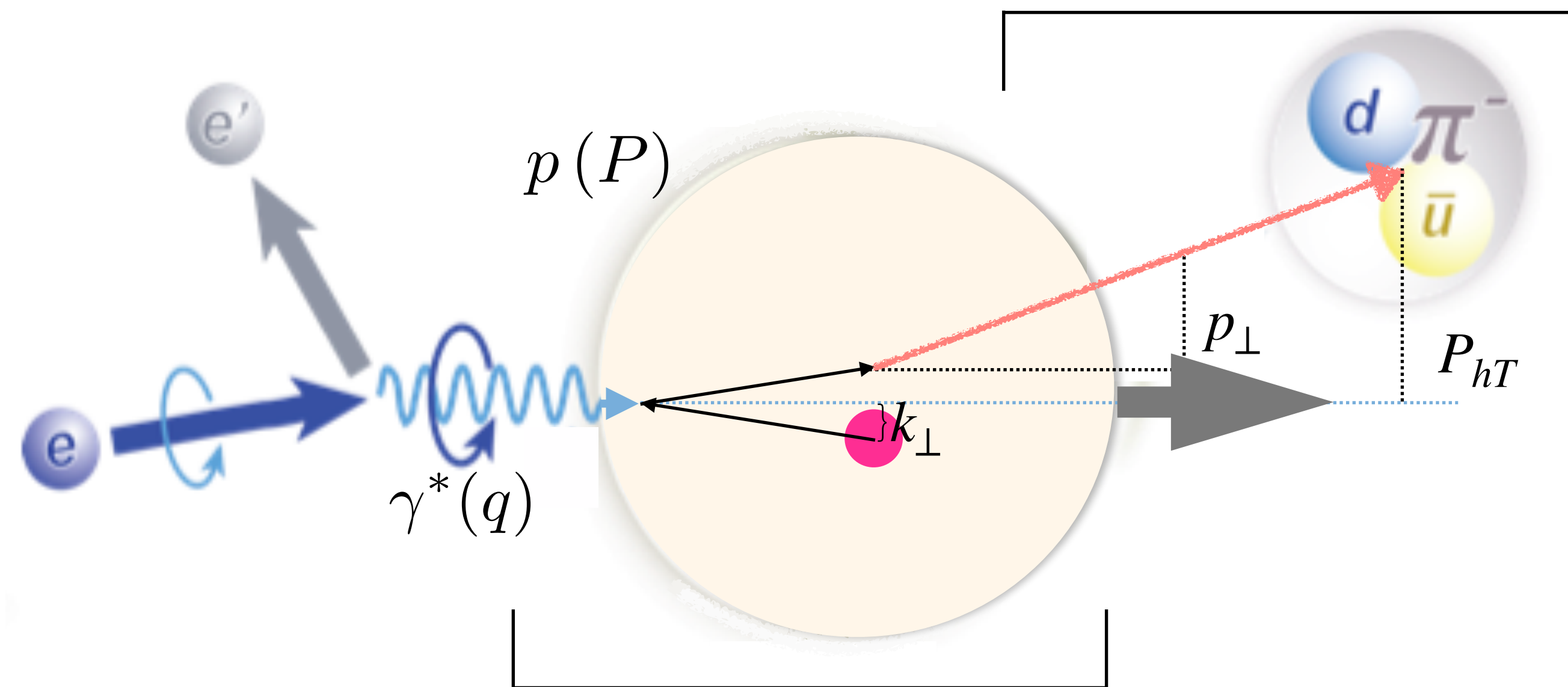


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$$Q^2 = -q^2$$

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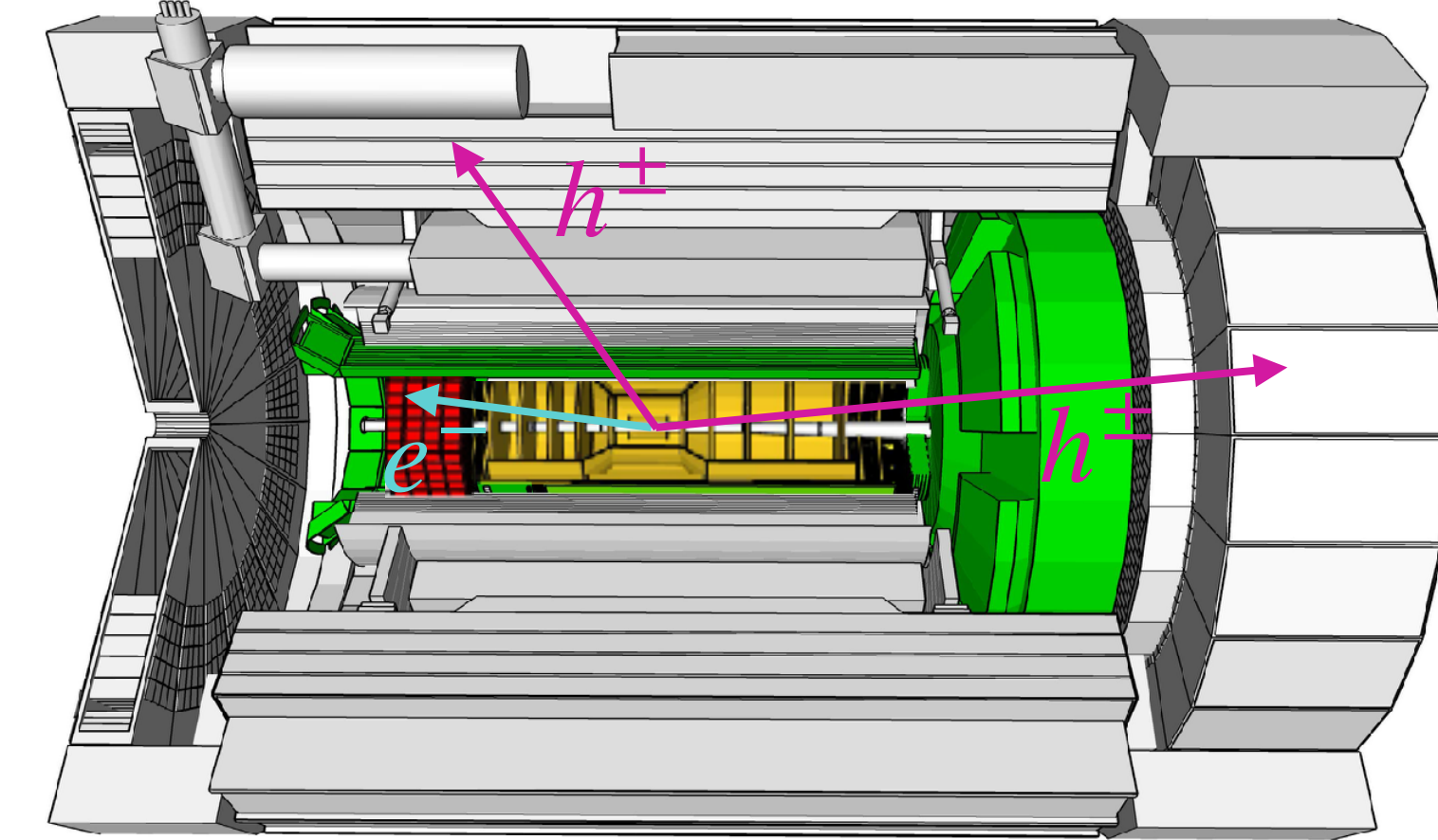


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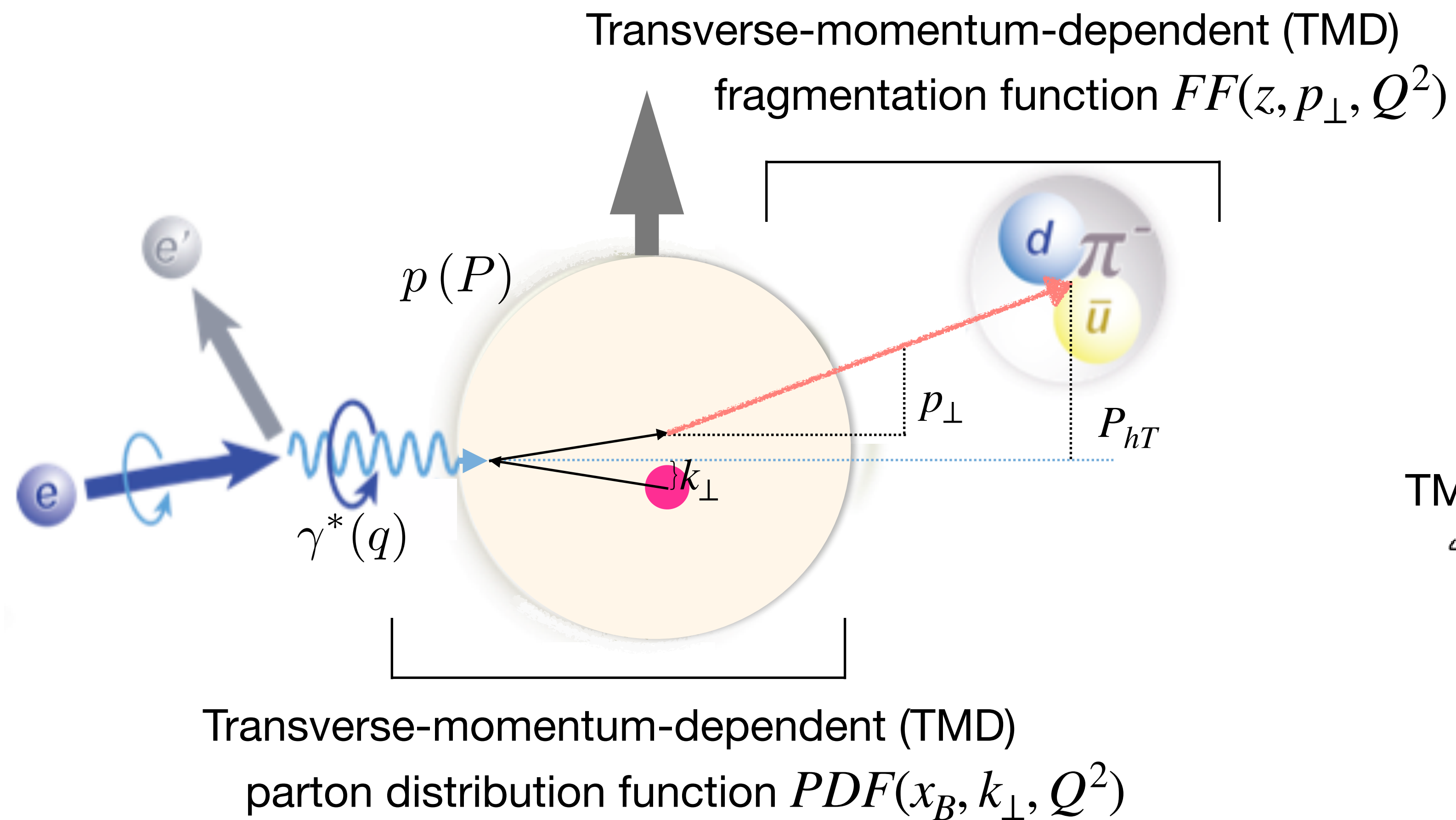
Single-hadron production in semi-inclusive DIS



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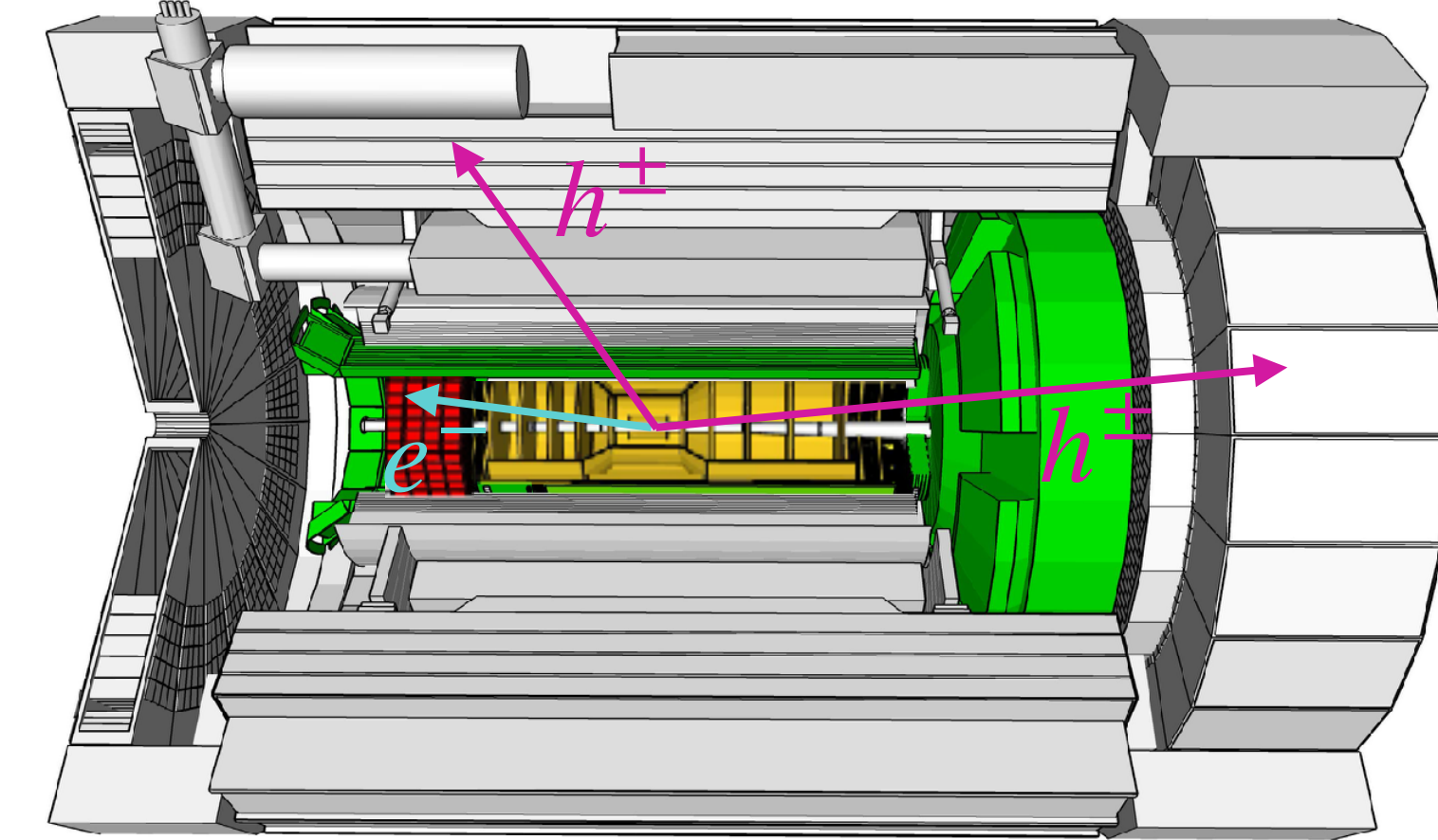
$$z \stackrel{\text{lab}}{=} \frac{E_h}{E_{\gamma^*}}$$



TMD evolution



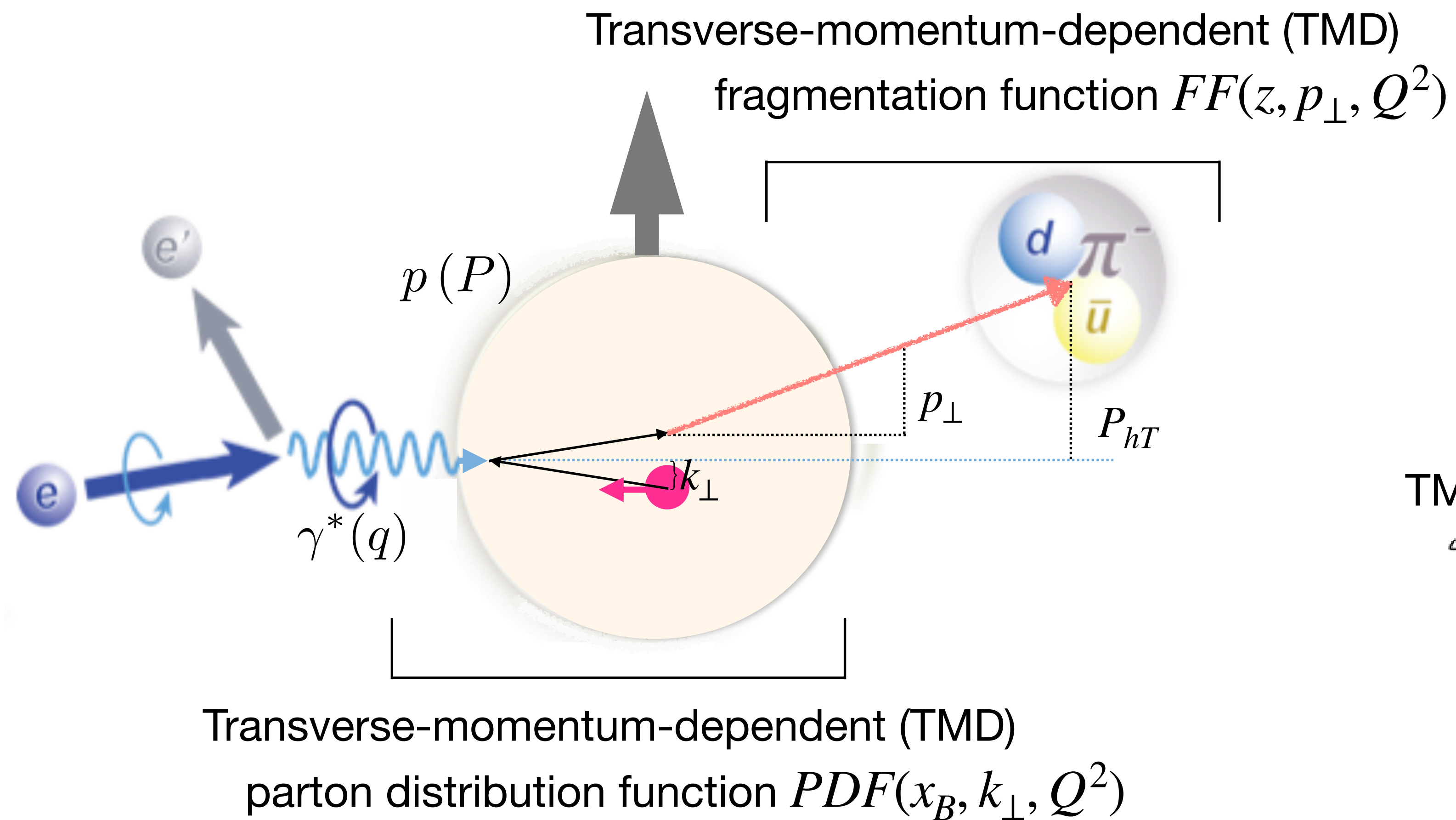
Single-hadron production in semi-inclusive DIS



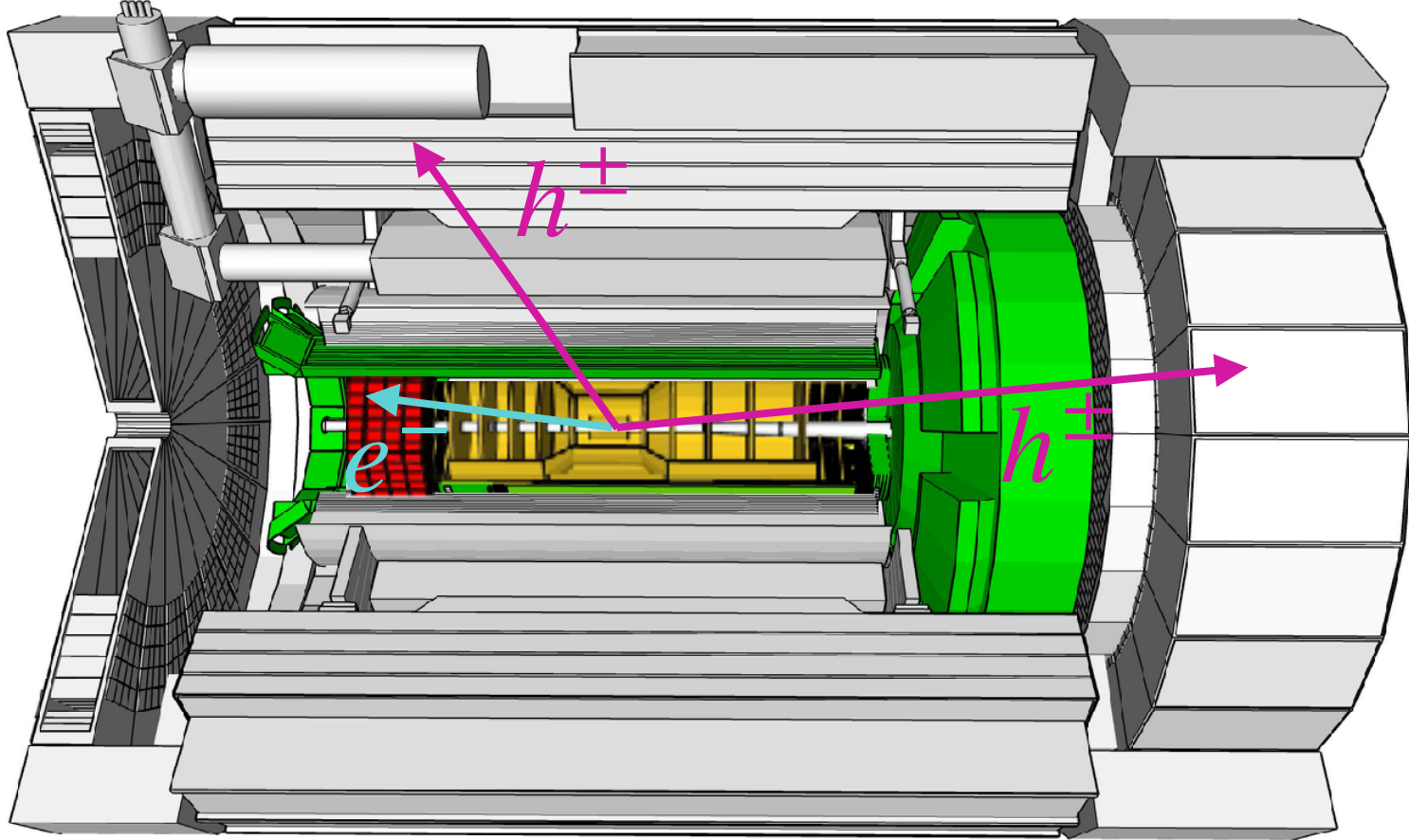
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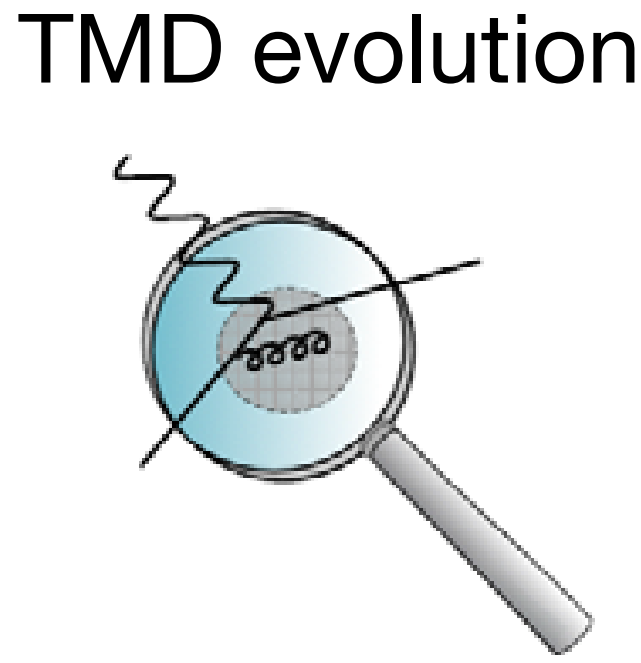
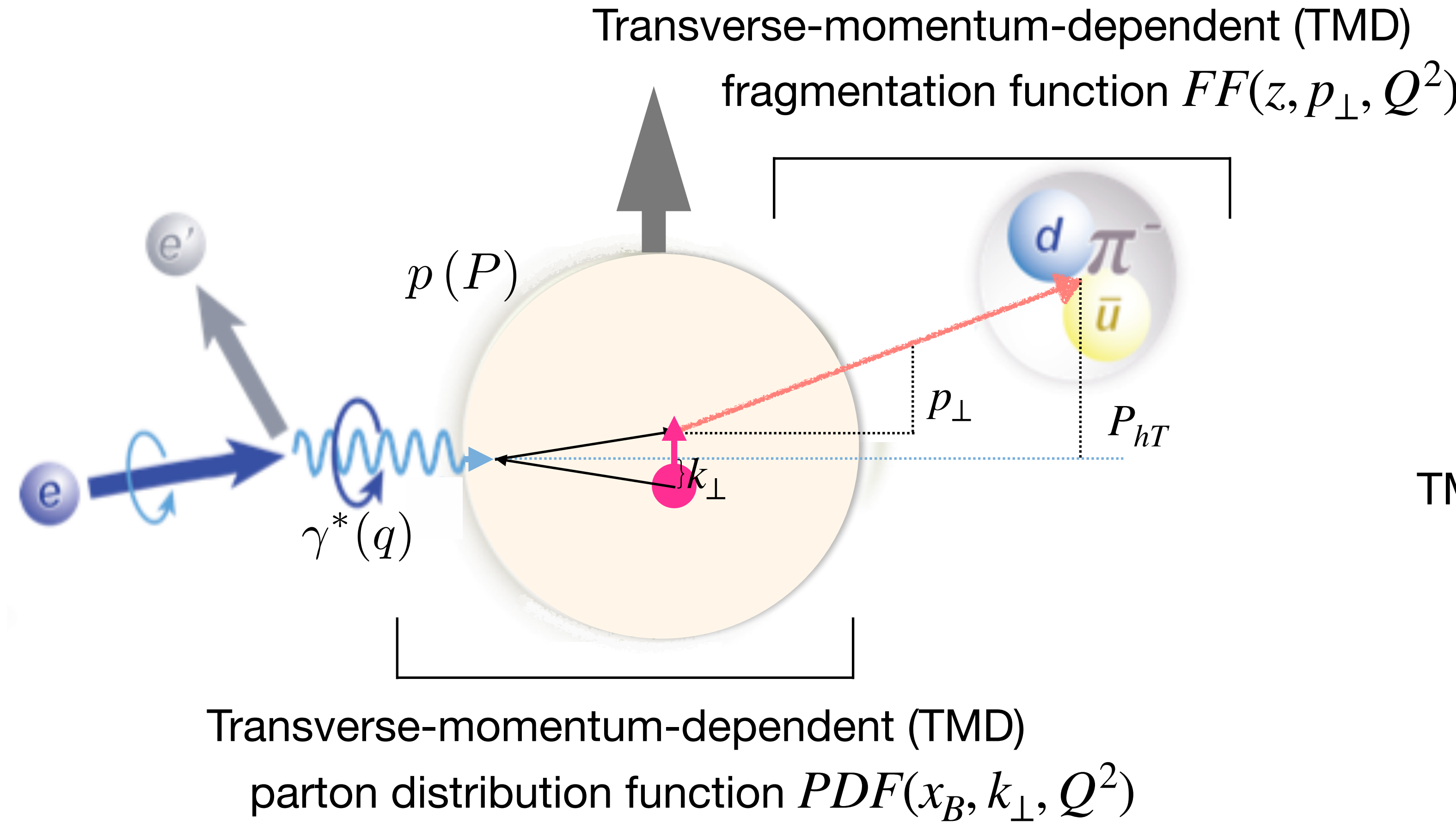
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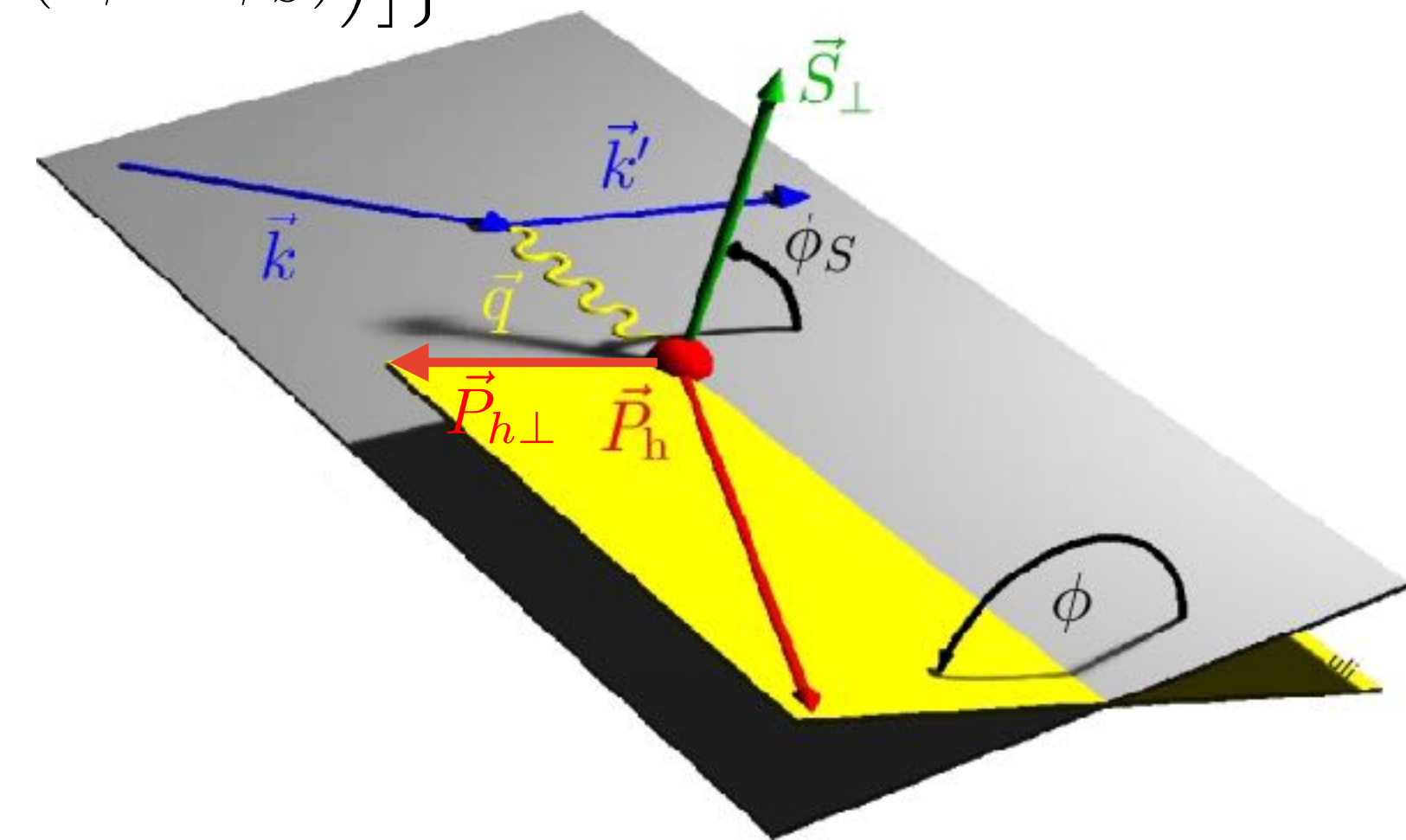
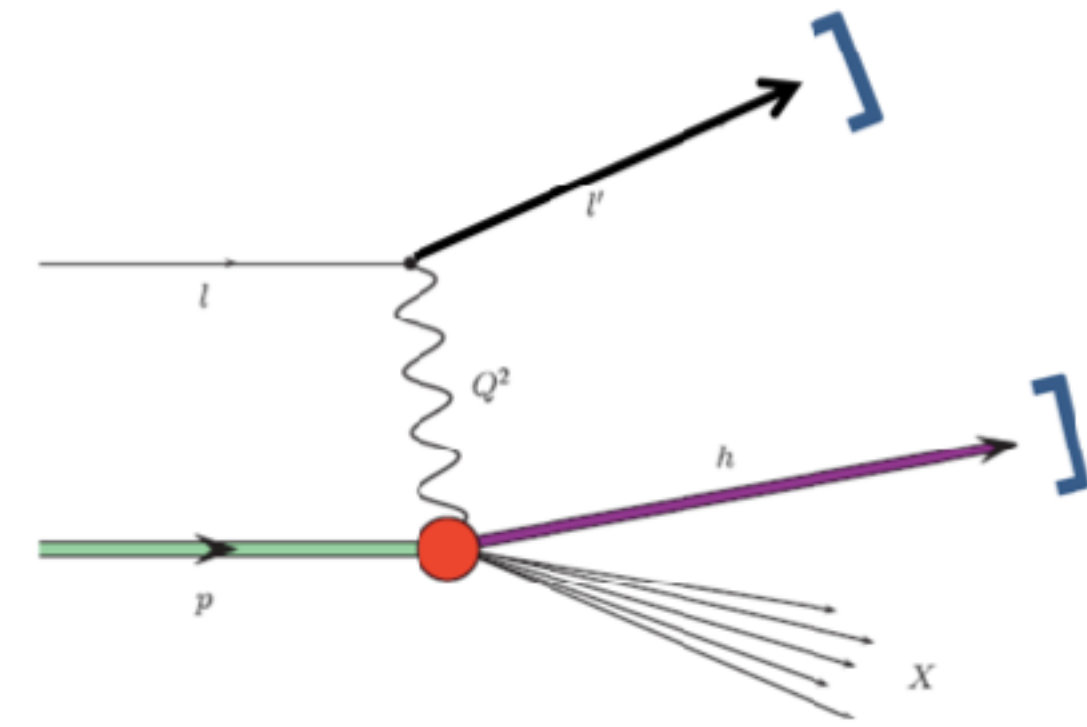


Transverse-momentum-dependent parton distribution functions

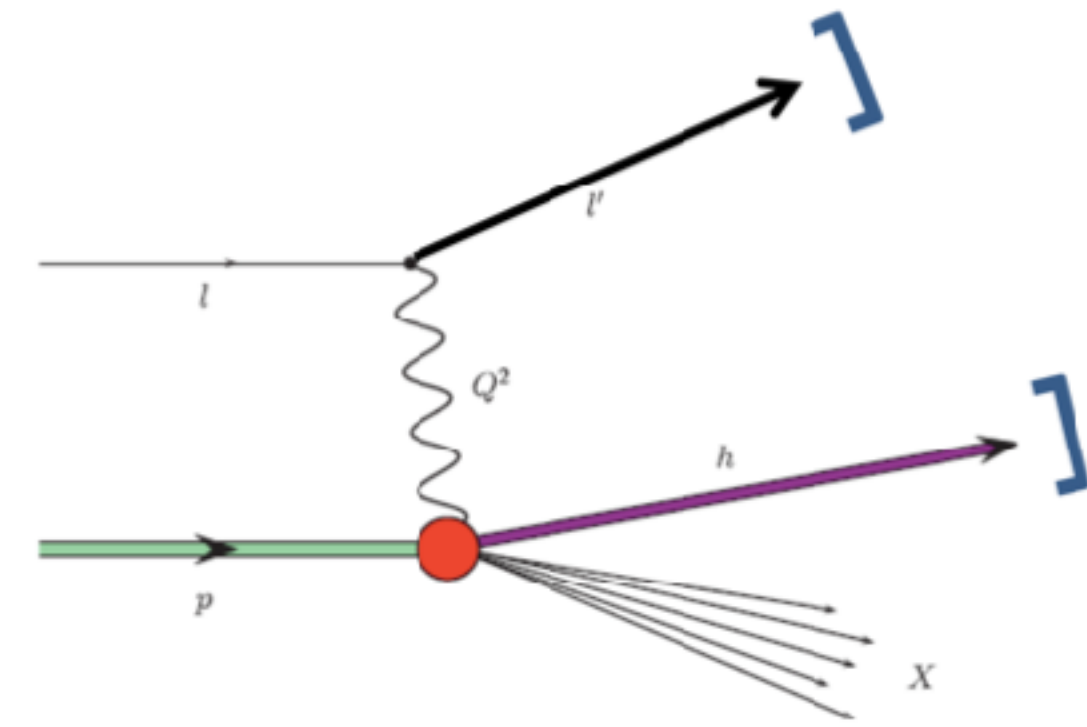
		quark polarisation		
nucleon polarisation		U	L	T
	U	f_1		$h_1^\perp$
	L		g_{1L}	$h_{1L}^\perp$
	T	$f_{1T}^\perp$	$g_{1T}^\perp$	$h_{1T} h_{1T}^\perp$

Semi-inclusive DIS cross section

$$\begin{aligned}
 \sigma^h(\phi, \phi_S) = & \sigma_{UU}^h \left\{ 1 + 2\langle \cos(\phi) \rangle_{UU}^h \cos(\phi) + 2\langle \cos(2\phi) \rangle_{UU}^h \cos(2\phi) \right. \\
 & + \lambda_l 2\langle \sin(\phi) \rangle_{LU}^h \sin(\phi) \\
 & + S_L \left[2\langle \sin(\phi) \rangle_{UL}^h \sin(\phi) + 2\langle \sin(2\phi) \rangle_{UL}^h \sin(2\phi) \right. \\
 & + \lambda_l \left(2\langle \cos(0\phi) \rangle_{LL}^h \cos(0\phi) + 2\langle \cos(\phi) \rangle_{LL}^h \cos(\phi) \right) \Big] \\
 & + S_T \left[2\langle \sin(\phi - \phi_S) \rangle_{UT}^h \sin(\phi - \phi_S) + 2\langle \sin(\phi + \phi_S) \rangle_{UT}^h \sin(\phi + \phi_S) \right. \\
 & + 2\langle \sin(3\phi - \phi_S) \rangle_{UT}^h \sin(3\phi - \phi_S) + 2\langle \sin(\phi_S) \rangle_{UT}^h \sin(\phi_S) \\
 & + 2\langle \sin(2\phi - \phi_S) \rangle_{UT}^h \sin(2\phi - \phi_S) \\
 & + \lambda_l \left(2\langle \cos(\phi - \phi_S) \rangle_{LT}^h \cos(\phi - \phi_S) \right. \\
 & + \left. \left. 2\langle \cos(\phi_S) \rangle_{LT}^h \cos(\phi_S) + 2\langle \cos(2\phi - \phi_S) \rangle_{LT}^h \cos(2\phi - \phi_S) \right) \right] \Big\}
 \end{aligned}$$

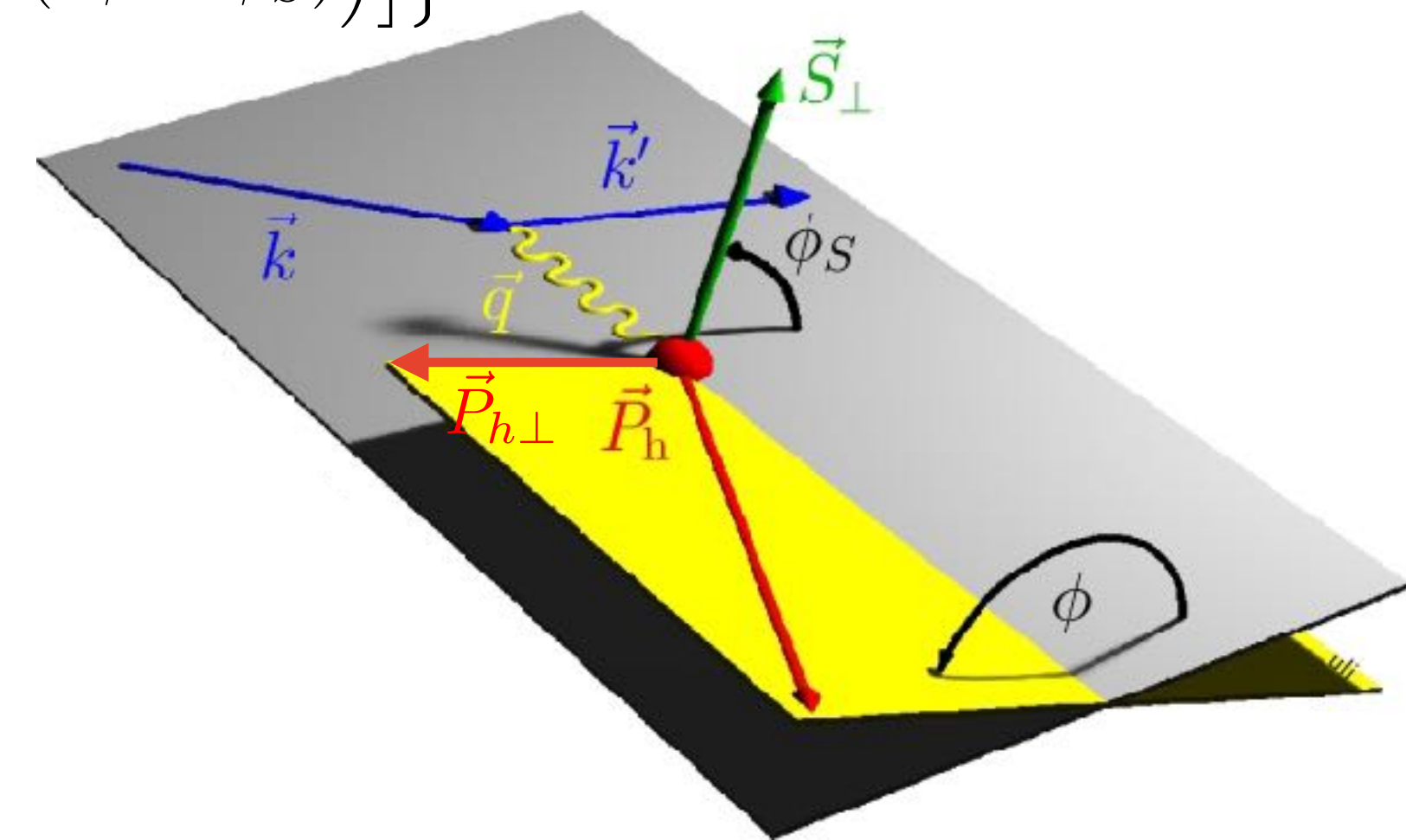


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 & \xleftarrow{\text{longitudinal target polarisation}} + S_L \left[2\langle \sin(\phi) \rangle_{UL}^h \sin(\phi) + 2\langle \sin(2\phi) \rangle_{UL}^h \sin(2\phi) \right. \\
 & + \lambda_l \left(2\langle \cos(0\phi) \rangle_{LL}^h \cos(0\phi) + 2\langle \cos(\phi) \rangle_{LL}^h \cos(\phi) \right) \Big] \\
 & \xleftarrow{\text{transverse target polarisation}} + S_T \left[2\langle \sin(\phi - \phi_S) \rangle_{UT}^h \sin(\phi - \phi_S) + 2\langle \sin(\phi + \phi_S) \rangle_{UT}^h \sin(\phi + \phi_S) \right. \\
 & + 2\langle \sin(3\phi - \phi_S) \rangle_{UT}^h \sin(3\phi - \phi_S) + 2\langle \sin(\phi_S) \rangle_{UT}^h \sin(\phi_S) \\
 & + 2\langle \sin(2\phi - \phi_S) \rangle_{UT}^h \sin(2\phi - \phi_S) \\
 & \xleftarrow{\text{beam polarisation}} + \lambda_l \left(2\langle \cos(\phi - \phi_S) \rangle_{LT}^h \cos(\phi - \phi_S) \right. \\
 & + \left. \left. 2\langle \cos(\phi_S) \rangle_{LT}^h \cos(\phi_S) + 2\langle \cos(2\phi - \phi_S) \rangle_{LT}^h \cos(2\phi - \phi_S) \right) \right] \Big\}
 \end{aligned}$$

$\swarrow$ beam polarisation $\searrow$ target polarisation



TMD PDFs and fragmentation functions (FFs)

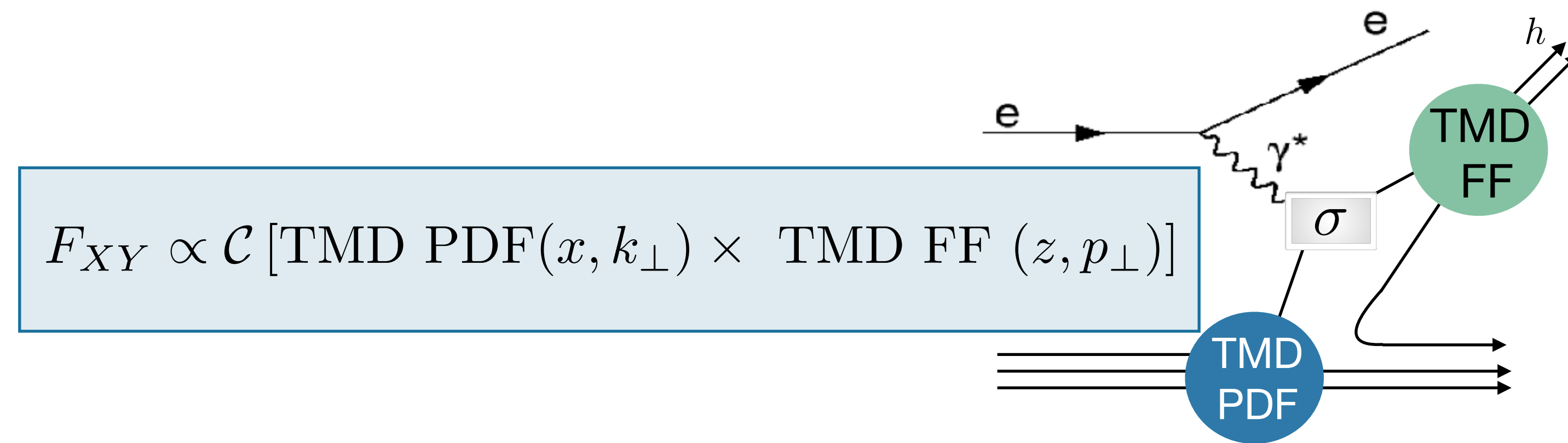
Azimuthal amplitudes related to structure functions F_{XY} :

$$2\langle \sin(\phi + \phi_S) \rangle_{UT}^h = \epsilon F_{UT}^{\sin(\phi + \phi_S)}$$

TMD PDFs and fragmentation functions (FFs)

Azimuthal amplitudes related to structure functions F_{XY} :

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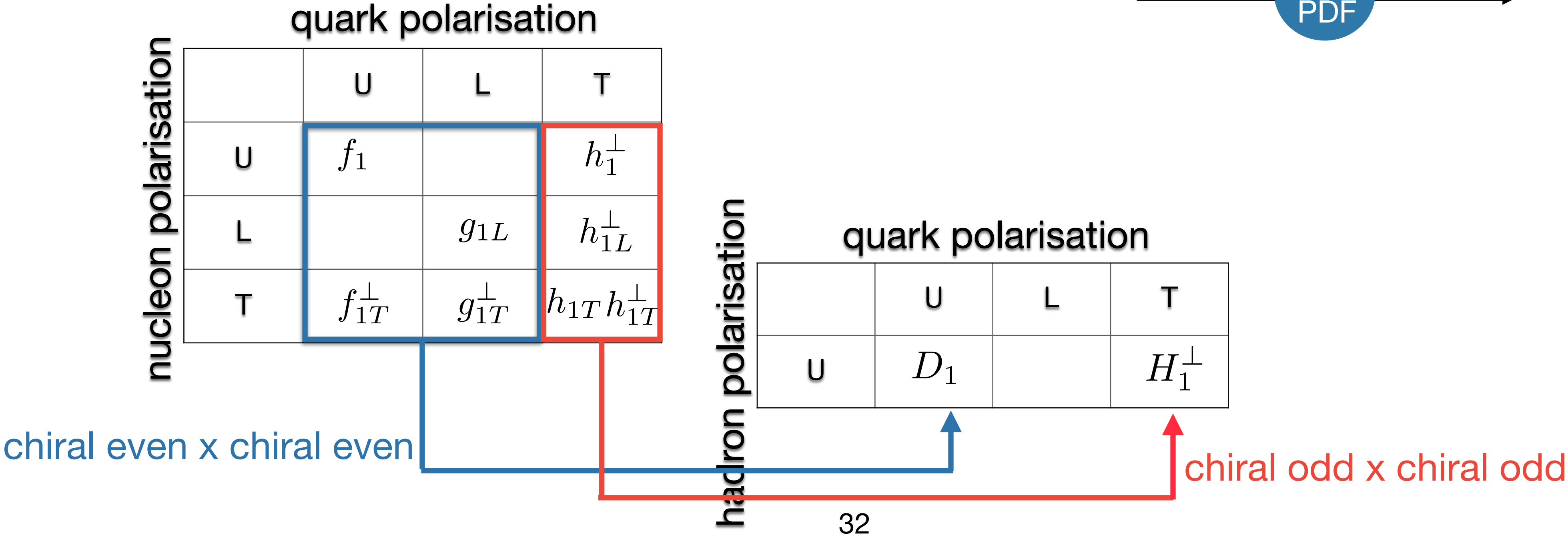
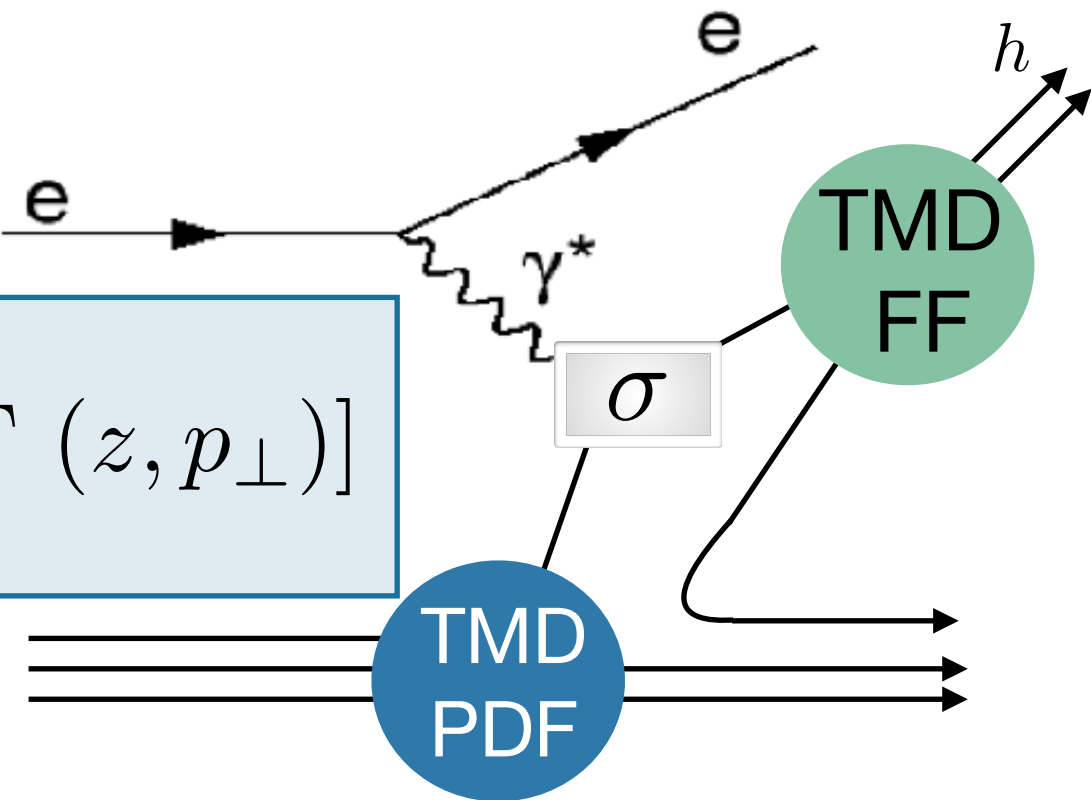


TMD PDFs and fragmentation functions (FFs)

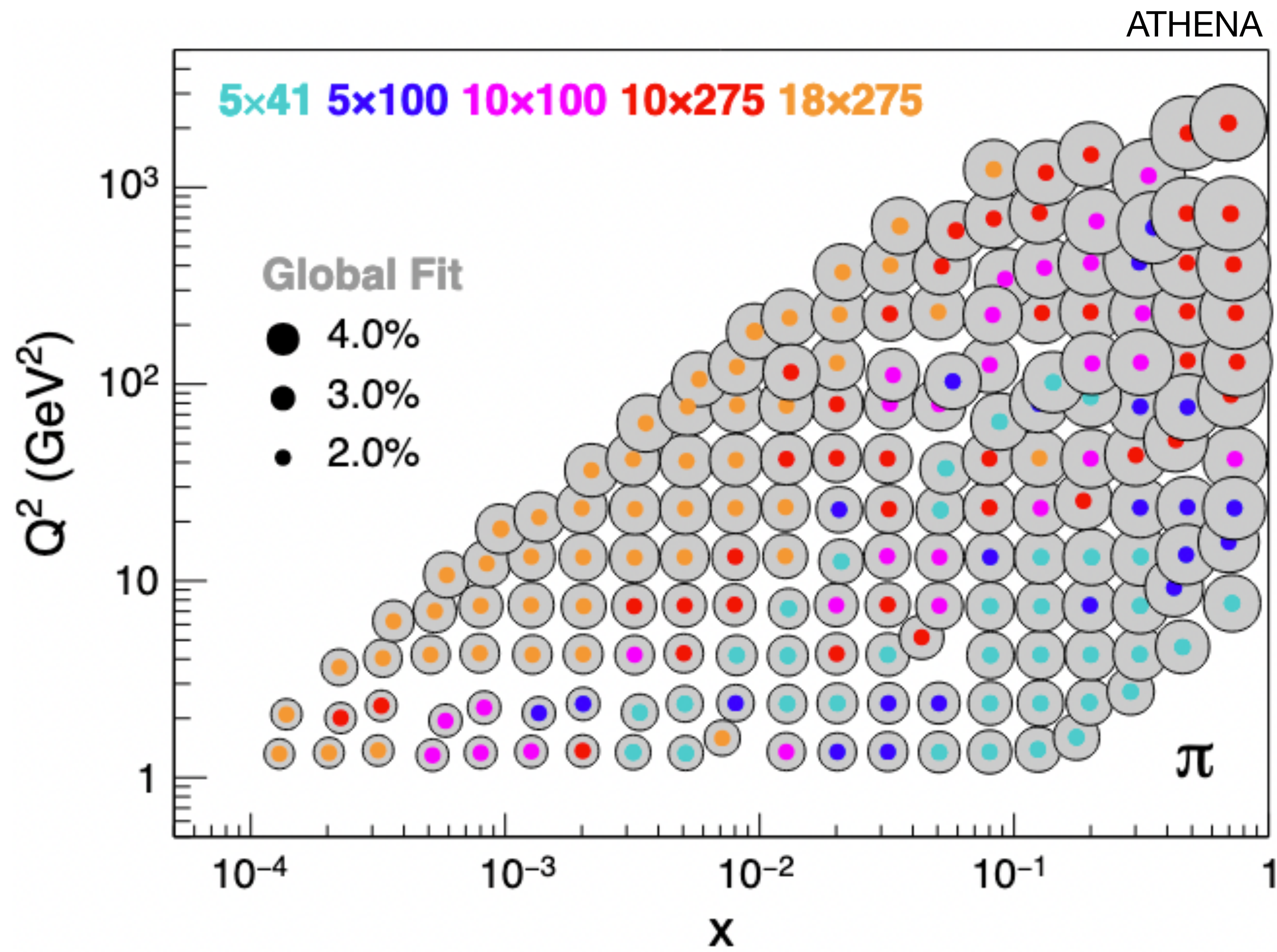
Azimuthal amplitudes related to structure functions F_{XY} :

$$2\langle \sin(\phi + \phi_S) \rangle_{UT}^h = \epsilon F_{UT}^{\sin(\phi + \phi_S)}$$

$F_{XY} \propto \mathcal{C} [\text{TMD PDF}(x, k_{\perp}) \times \text{TMD FF}(z, p_{\perp})]$



Spin-independent TMD PDFs at EIC



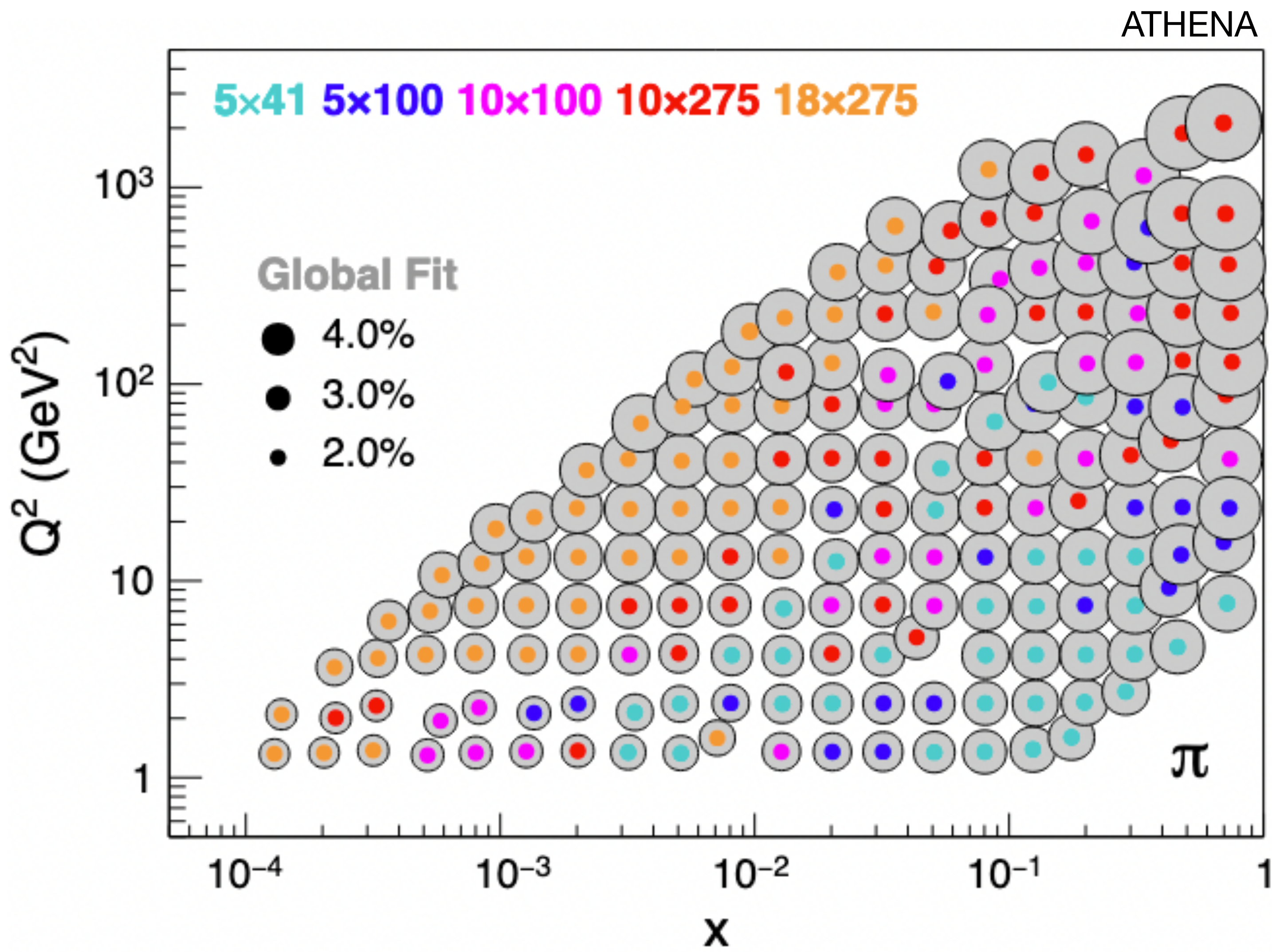
Fit:
A. Bacchetta et al.,
JHEP 06 (2017) 081,
JHEP 06 (2019) 051 (erratum)

EIC uncertainties dominated
by assumed
3% point-to-point uncorrelated uncertainty
3% scale uncertainty

Theory uncertainties dominated by
TMD evolution.

Spin-independent TMD PDFs at EIC

Large lever-arm in Q^2 over large x range
→ Q^2 evolution of TMD PDF

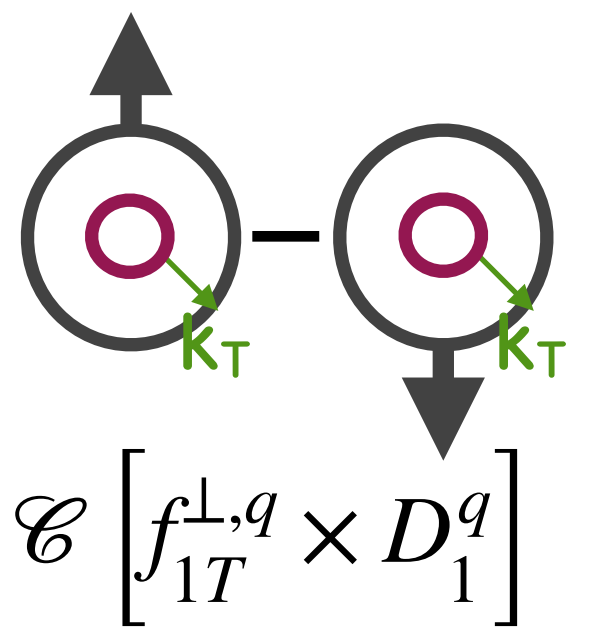


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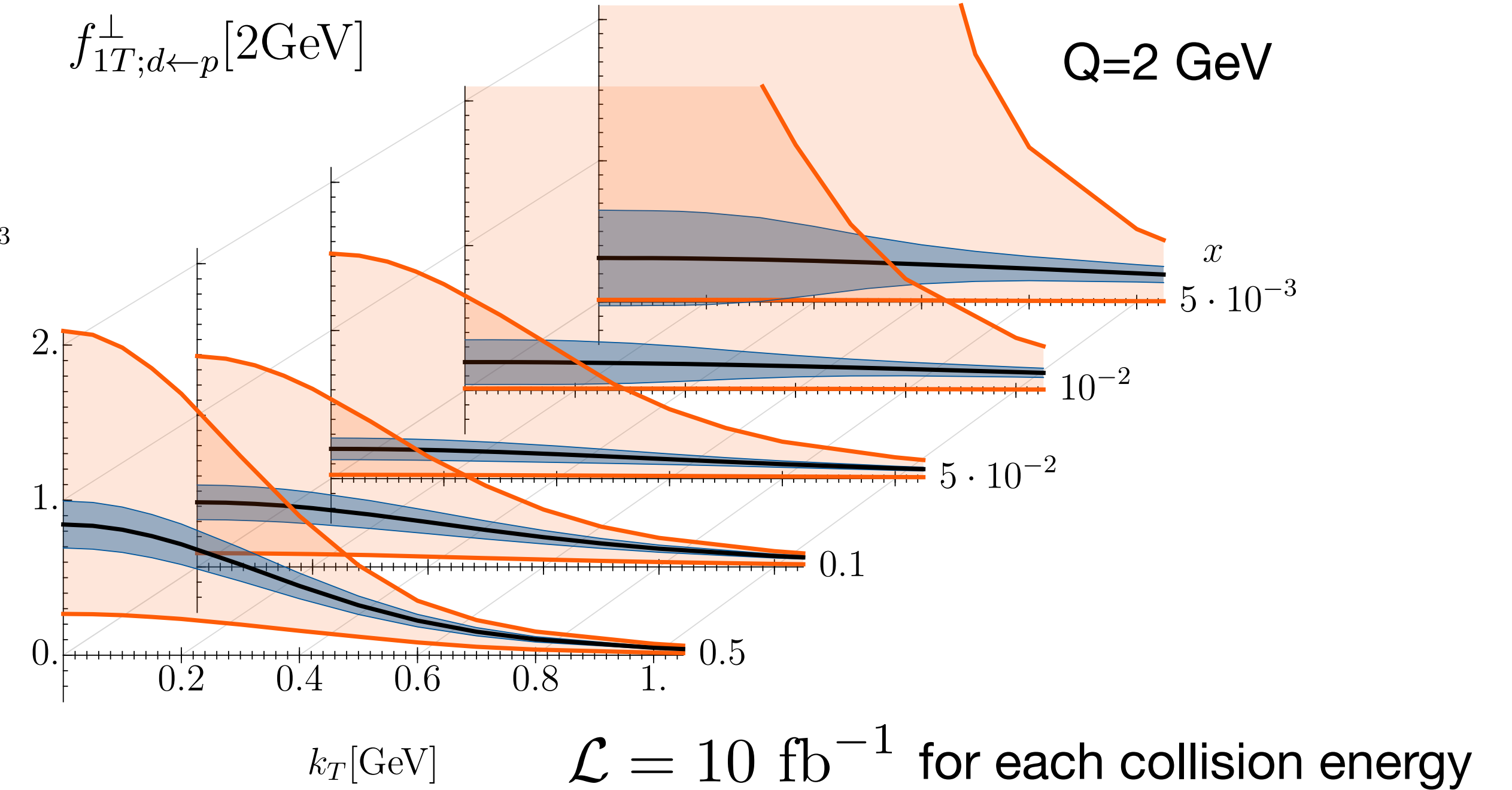
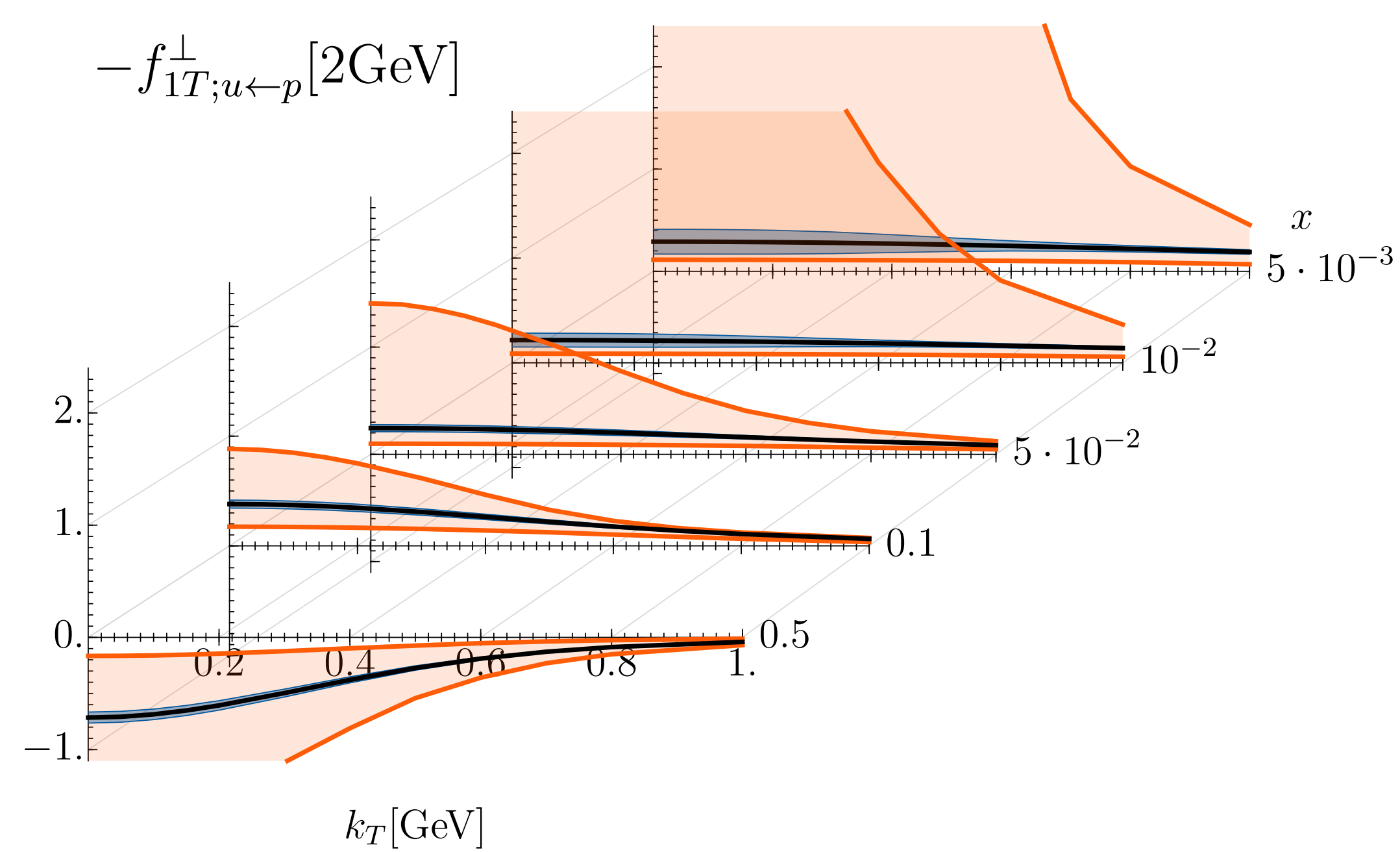
EIC uncertainties dominated
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Theory uncertainties dominated by
TMD evolution.

Impact of EIC on Sivers TMD PDFs



$$\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \propto \sin(\phi - \phi_S) \sum_q e_q^2 \mathcal{C} \left[f_{1T}^{\perp,q}(x, k_{\perp}) \times D_1^q(z, p_{\perp}) \right]$$

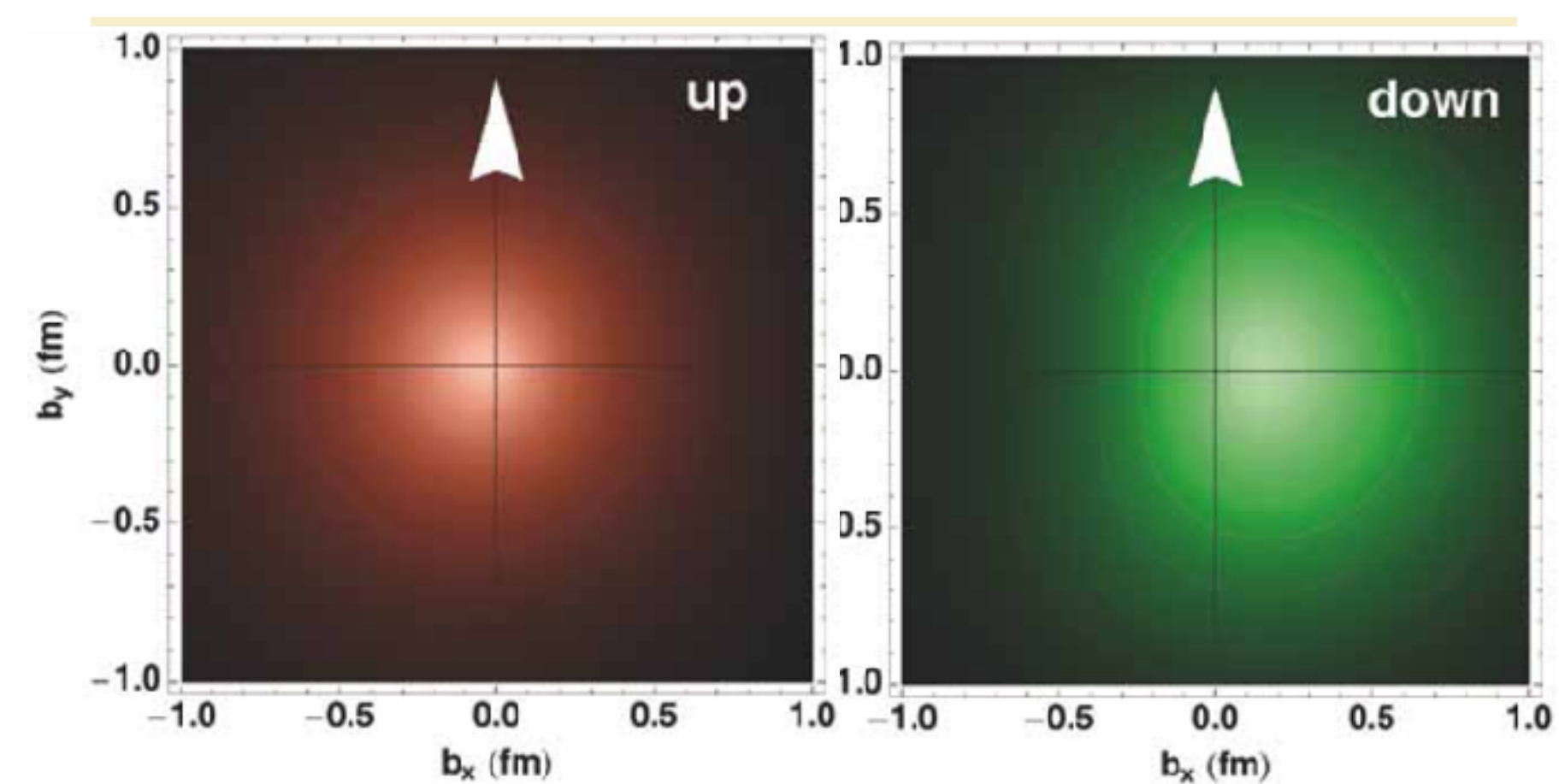
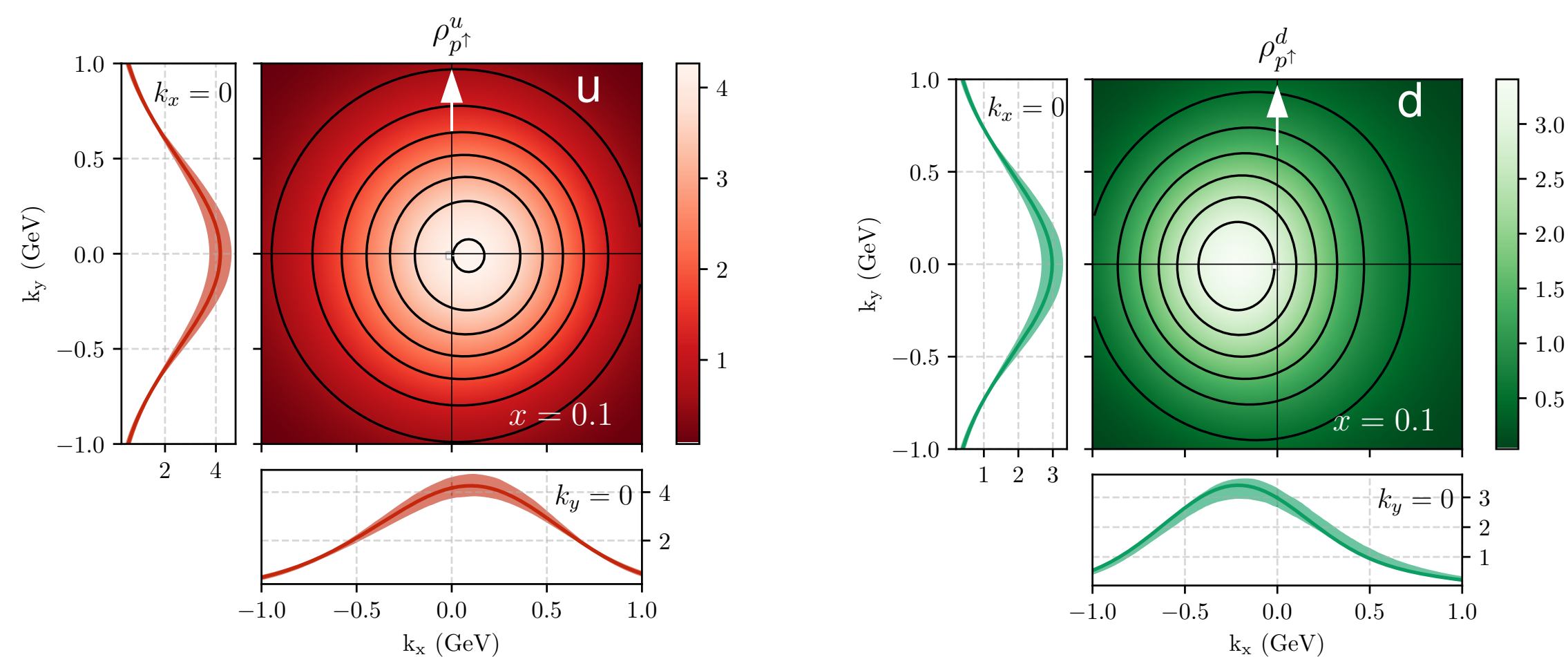
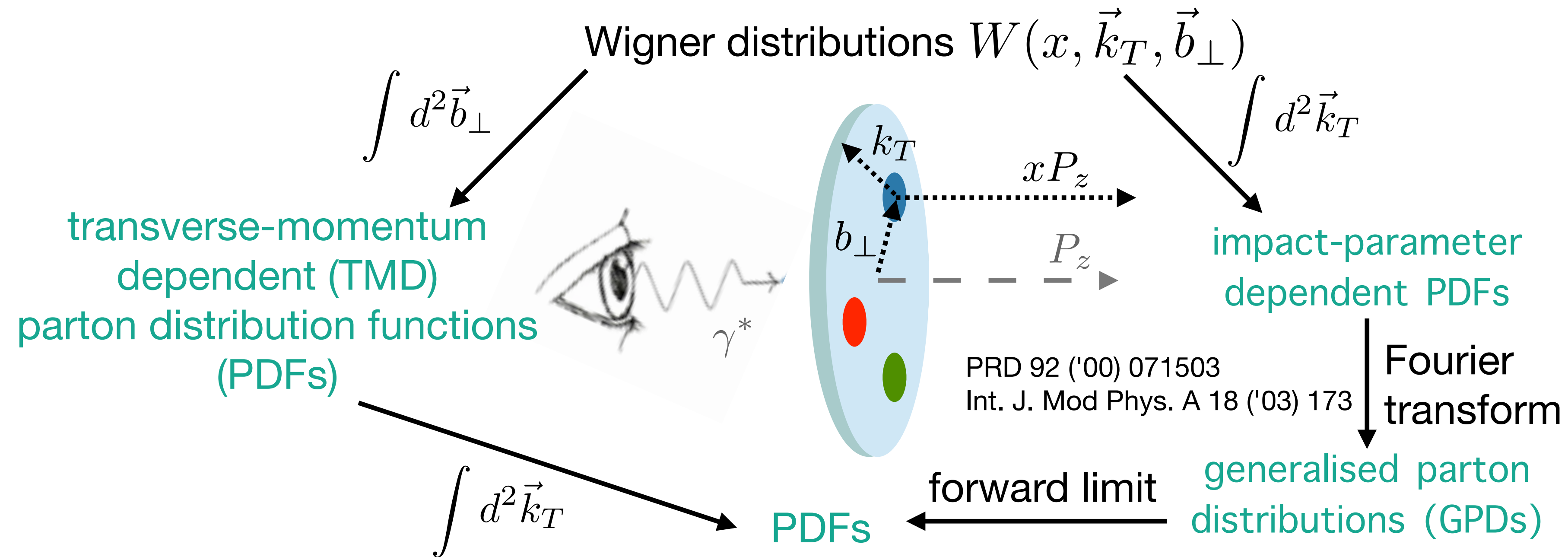


Gluon TMDs

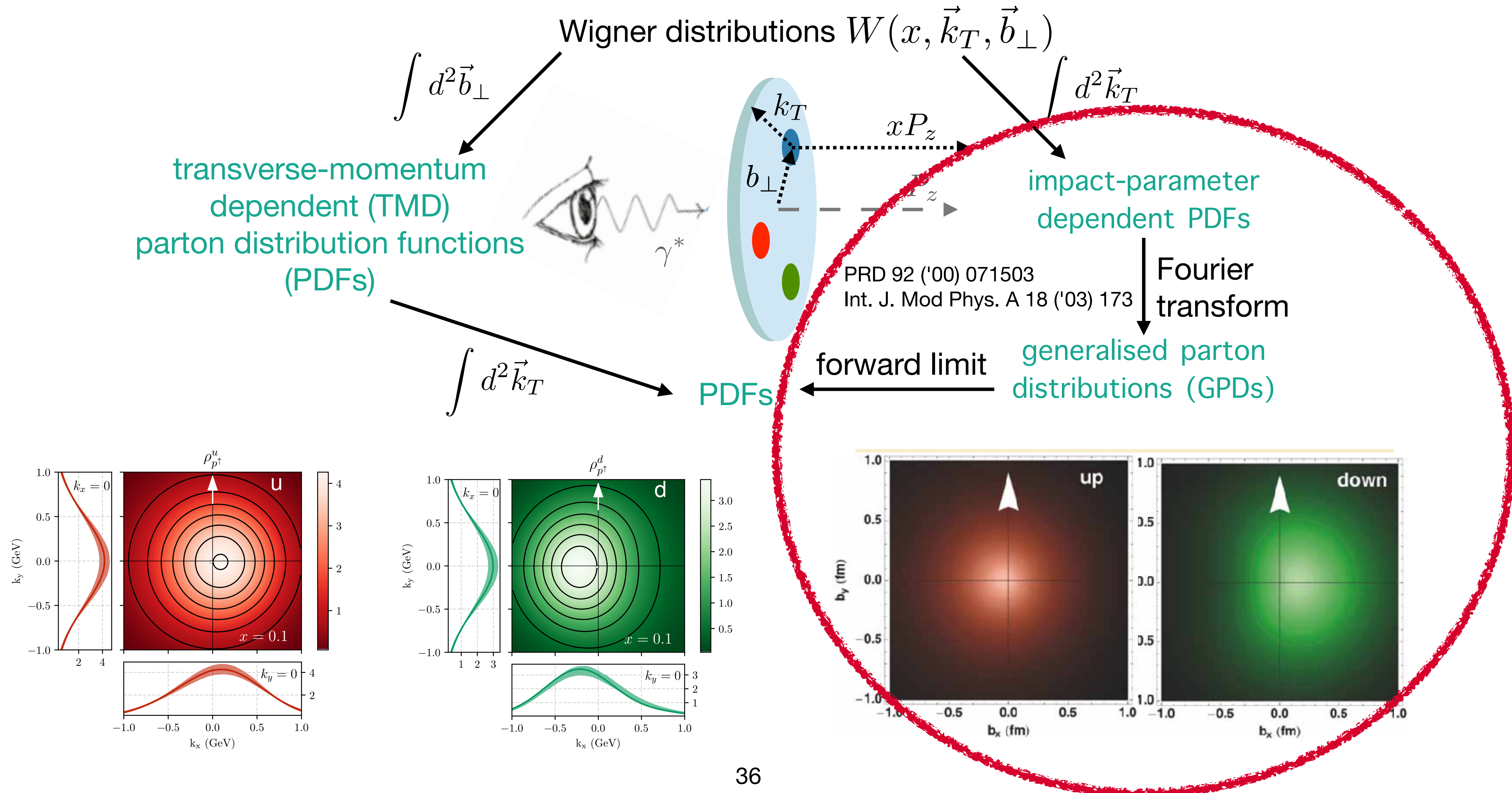
GLUONS	<i>unpolarized</i>	<i>circular</i>	<i>linear</i>
U	f_1^g		$h_1^{\perp g}$
L		g_{1L}^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	$h_{1T}^g, h_{1T}^{\perp g}$

- In contrast to quark TMDs, gluon TMDs are almost unknown
- Accessible through production of dijets, high- P_T hadron pairs, quarkonia

The various dimensions of the nucleon structure

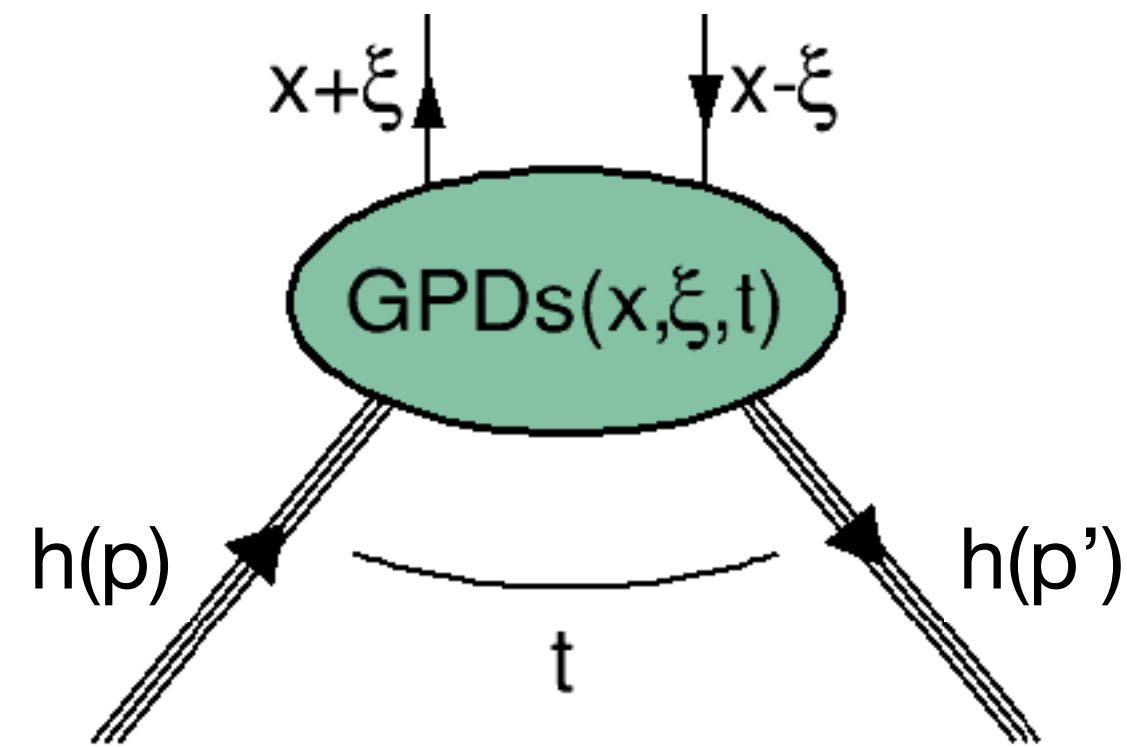


The various dimensions of the nucleon structure



Generalised parton distributions (GPDs)

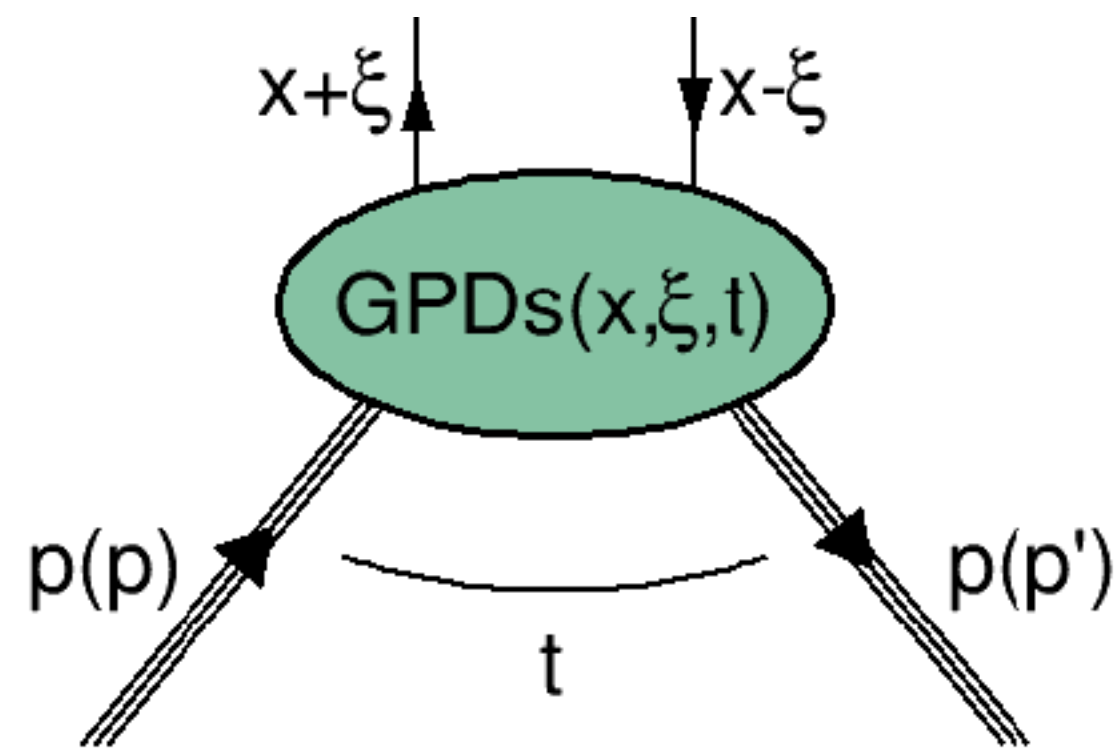
GPDs are probability amplitudes



- x =average longitudinal momentum fraction
- 2ξ =longitudinal momentum transfer
- t =squared momentum transfer to hadron
- experimental access to t and ξ
- in general: no experimental access to x

Generalised parton distributions (GPDs)

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• for spin-1/2 hadron:

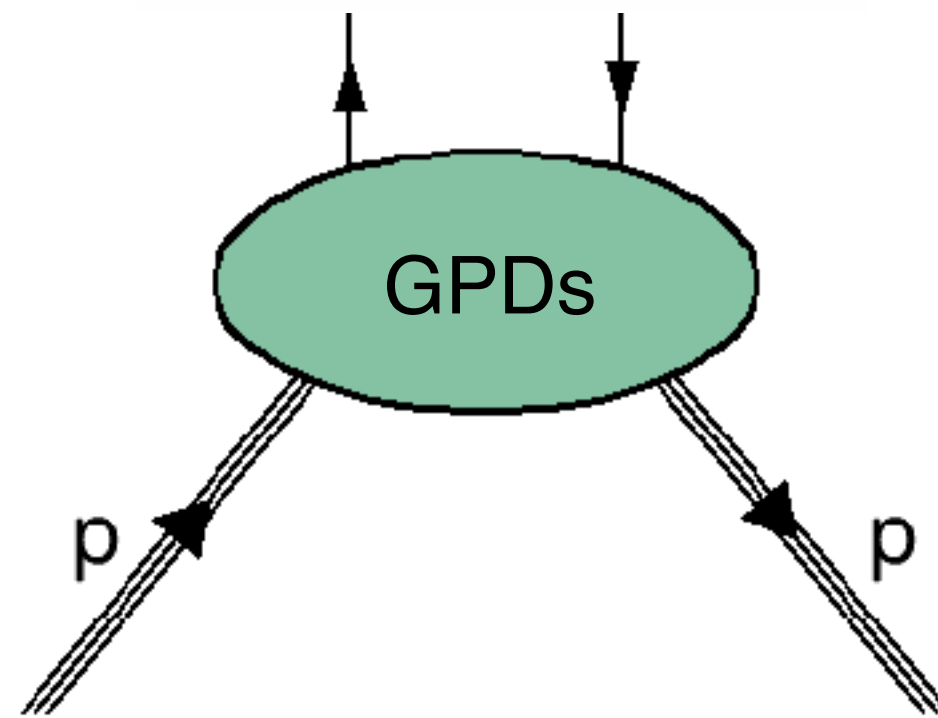
Four parton helicity-conserving twist-2 GPDs

$H(x, \xi, t)$	$E(x, \xi, t)$	parton-spin independent
$\tilde{H}(x, \xi, t)$	$\tilde{E}(x, \xi, t)$	
proton helicity non flip	proton helicity flip	

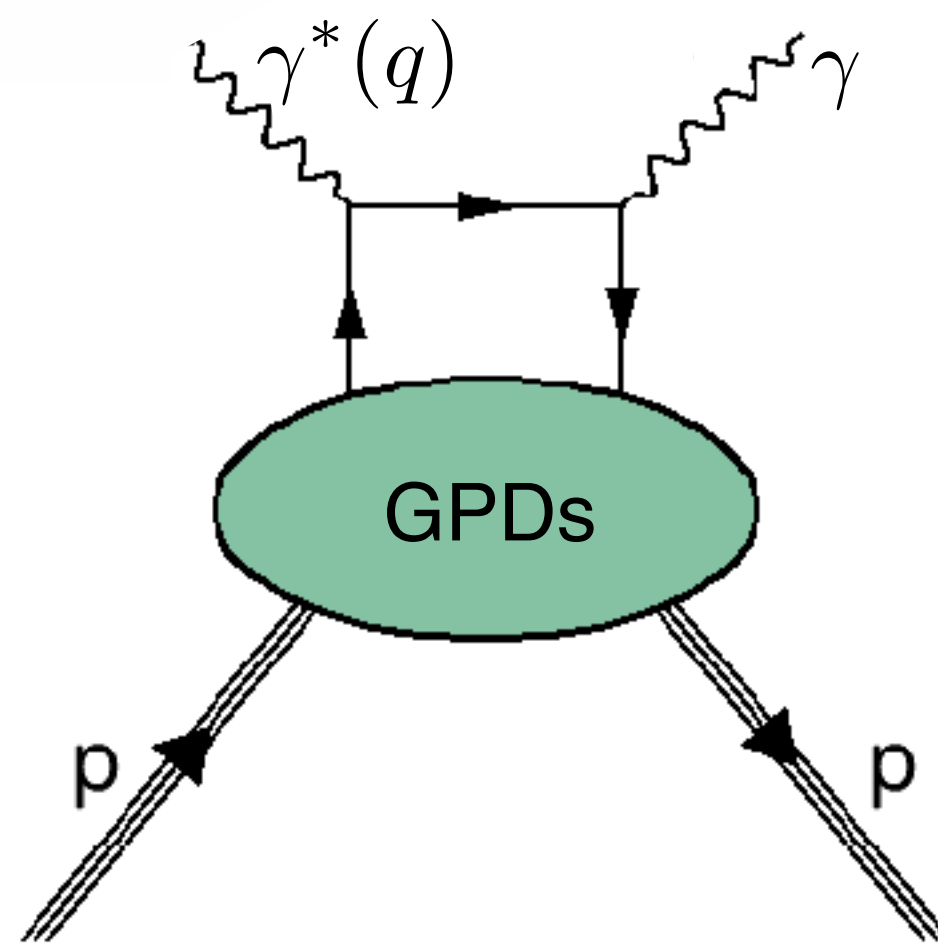
Four parton helicity-flip twist-2 GPDs

$H_T(x, \xi, t)$	$E_T(x, \xi, t)$
$\tilde{H}_T(x, \xi, t)$	$\tilde{E}_T(x, \xi, t)$

Experimental access to GPDs

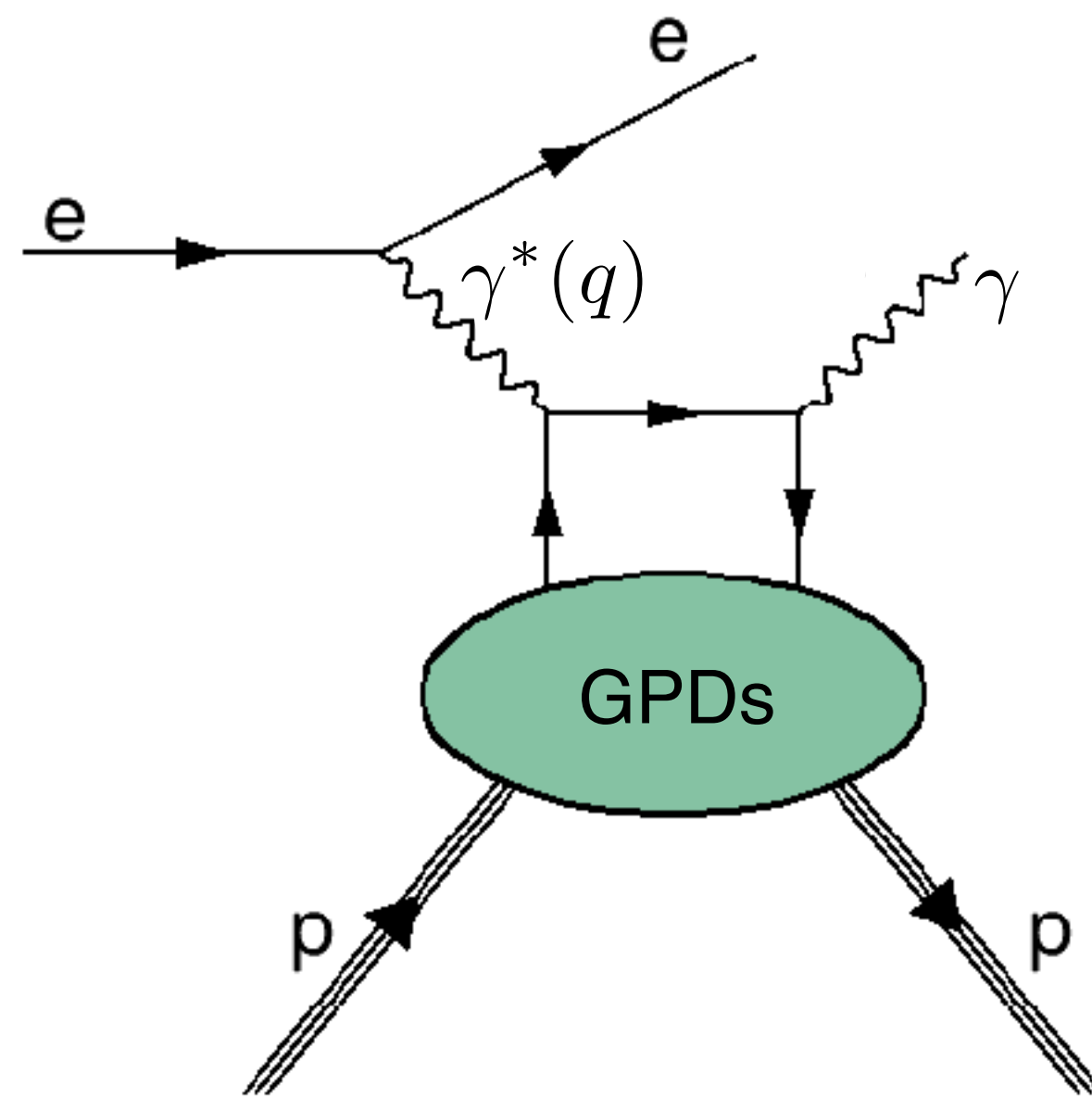


Experimental access to GPDs



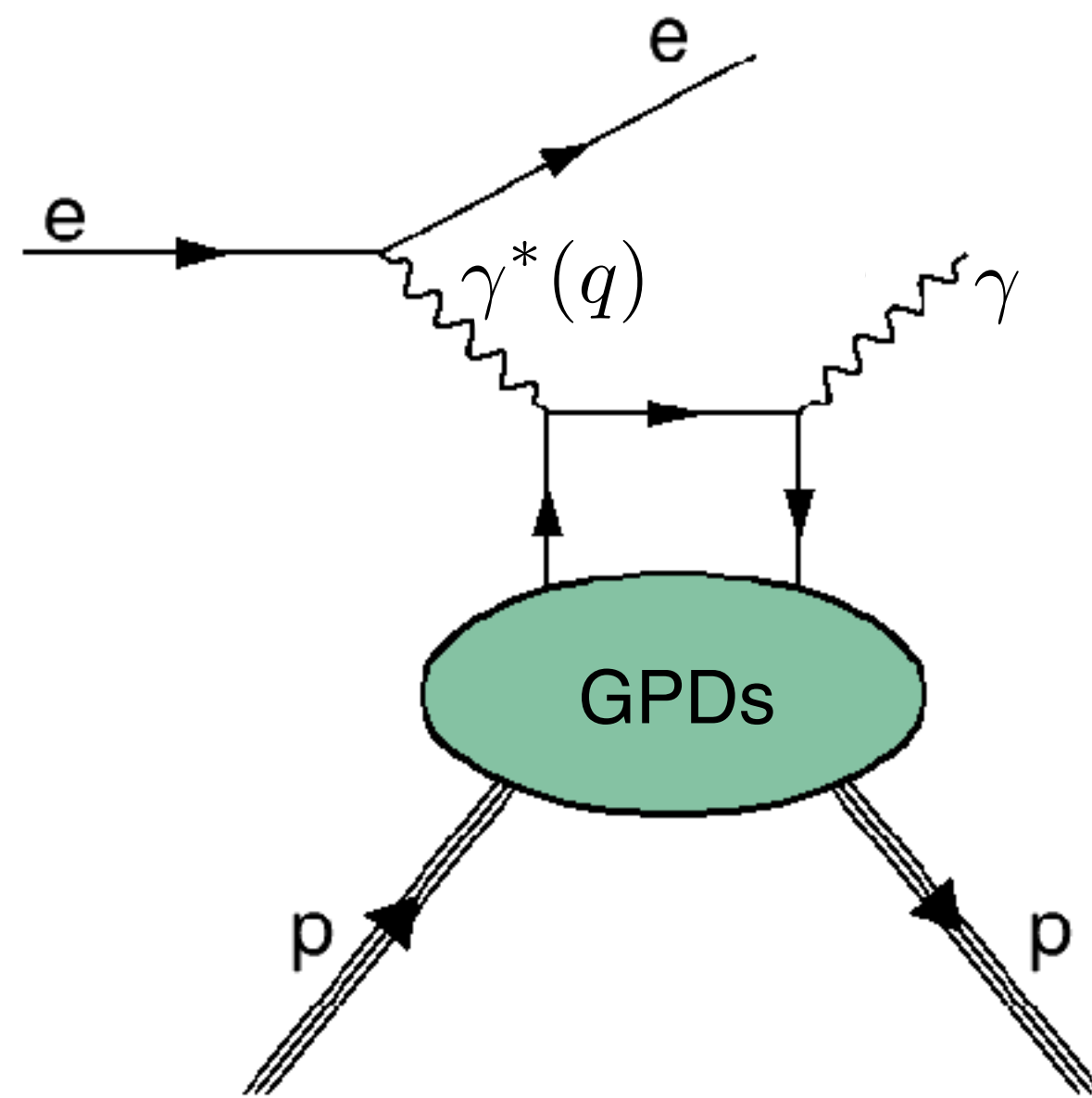
Deeply virtual Compton scattering (DVCS)
Hard scale=large $Q^2=-q^2$

Experimental access to GPDs

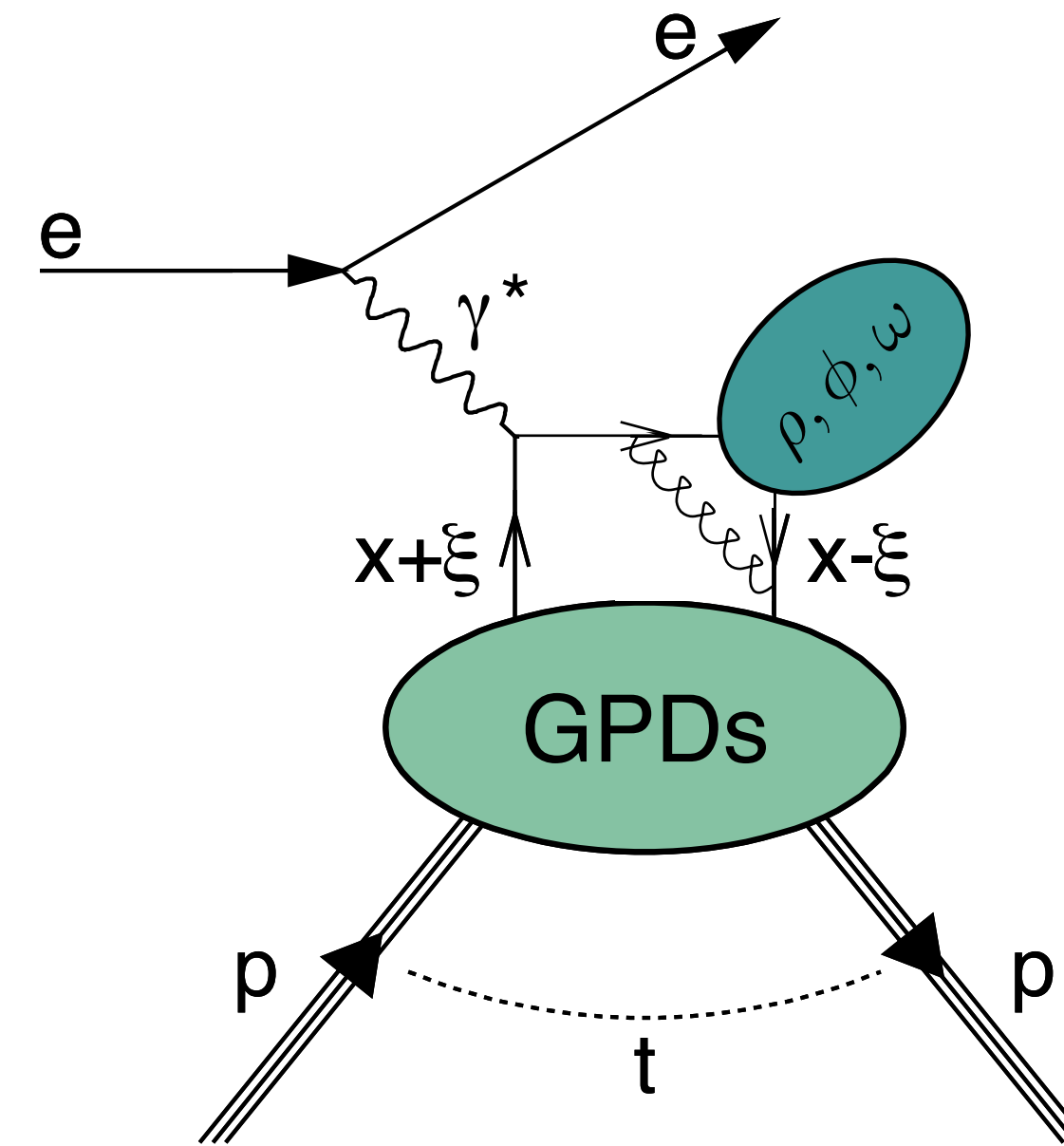


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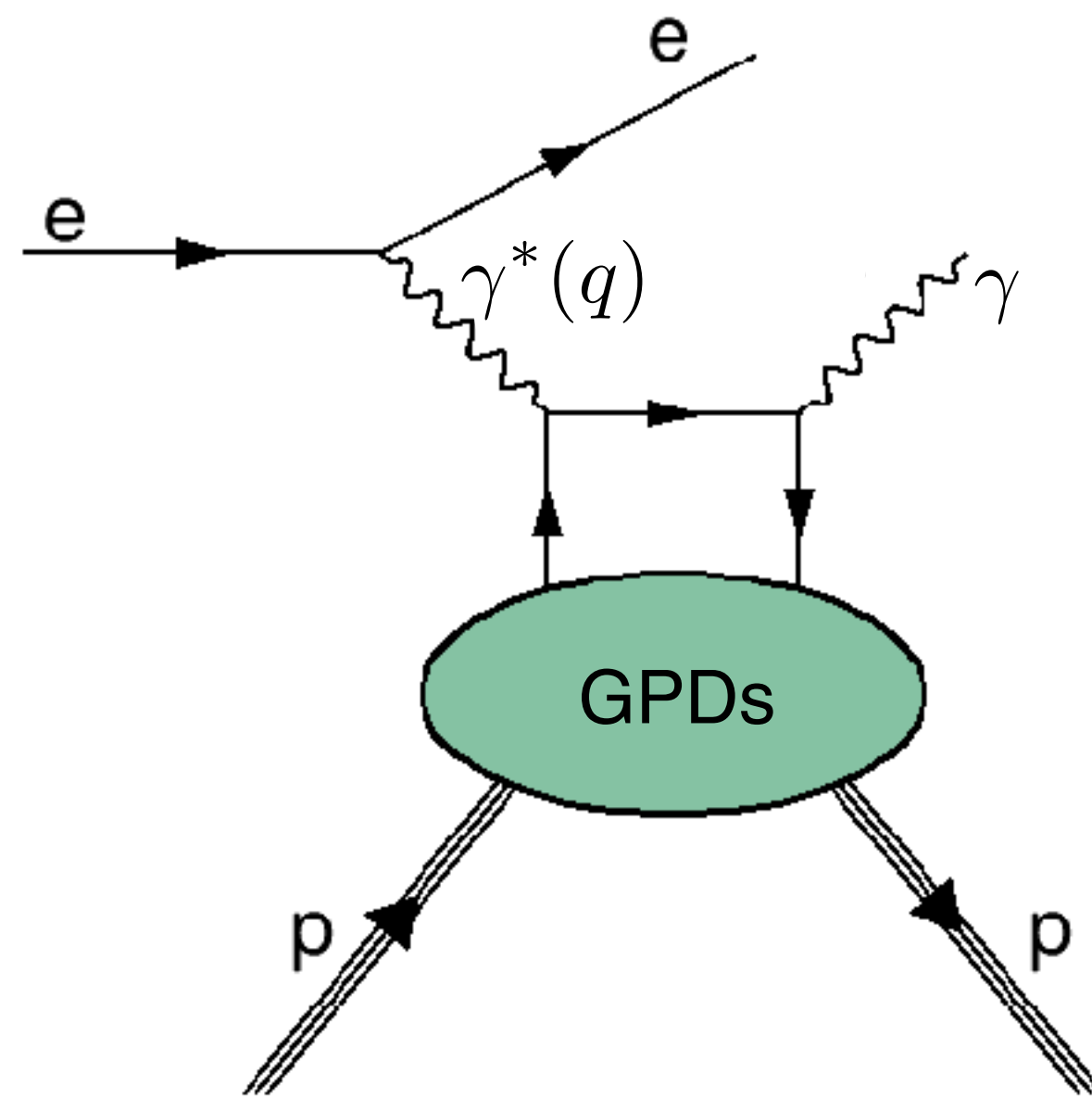


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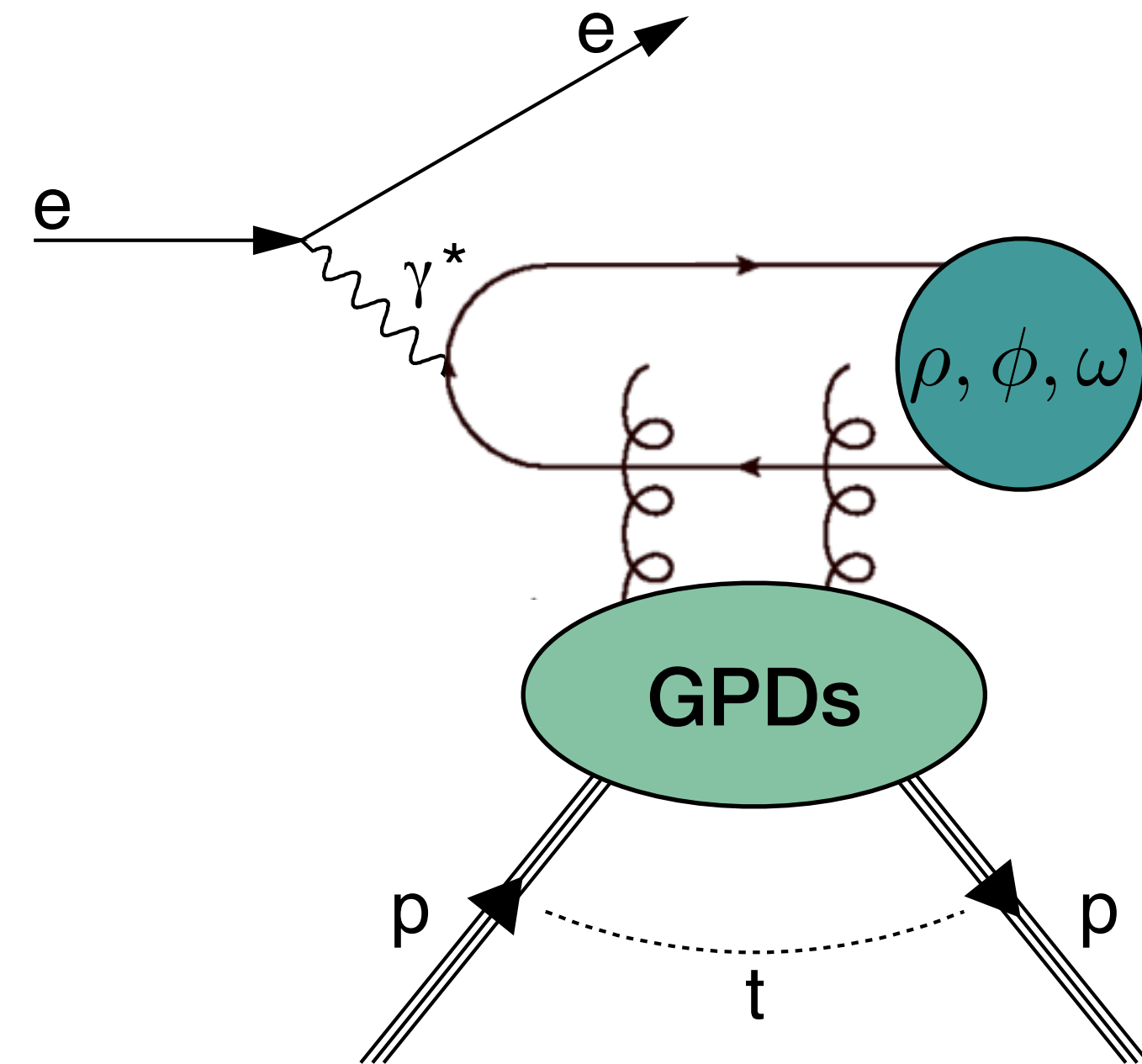


Hard exclusive meson production
Hard scale=large Q^2

Experimental access to GPDs

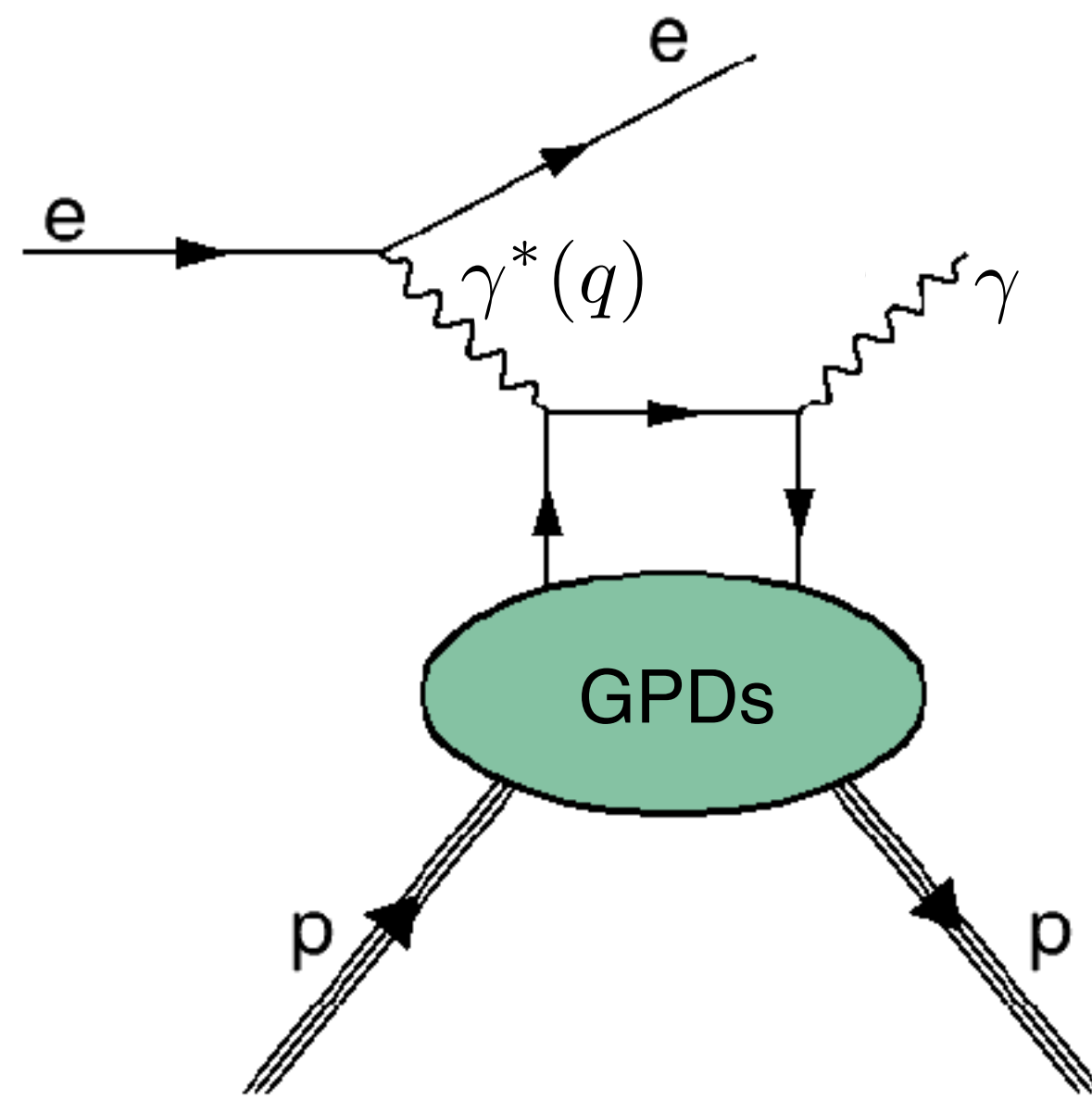


Deeply virtual Compton scattering (DVCS)
Hard scale=large $Q^2=-q^2$

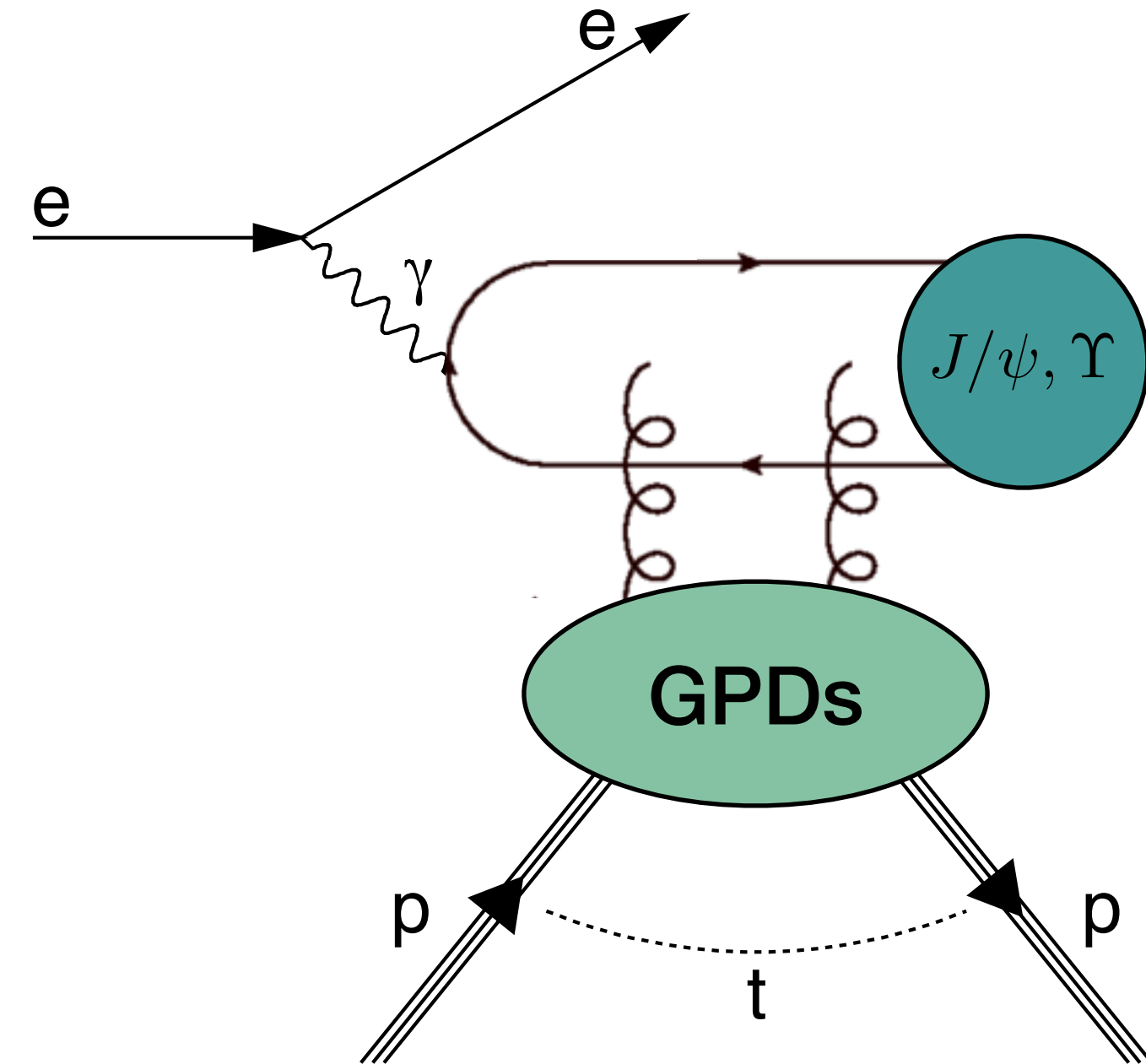


Hard exclusive meson production
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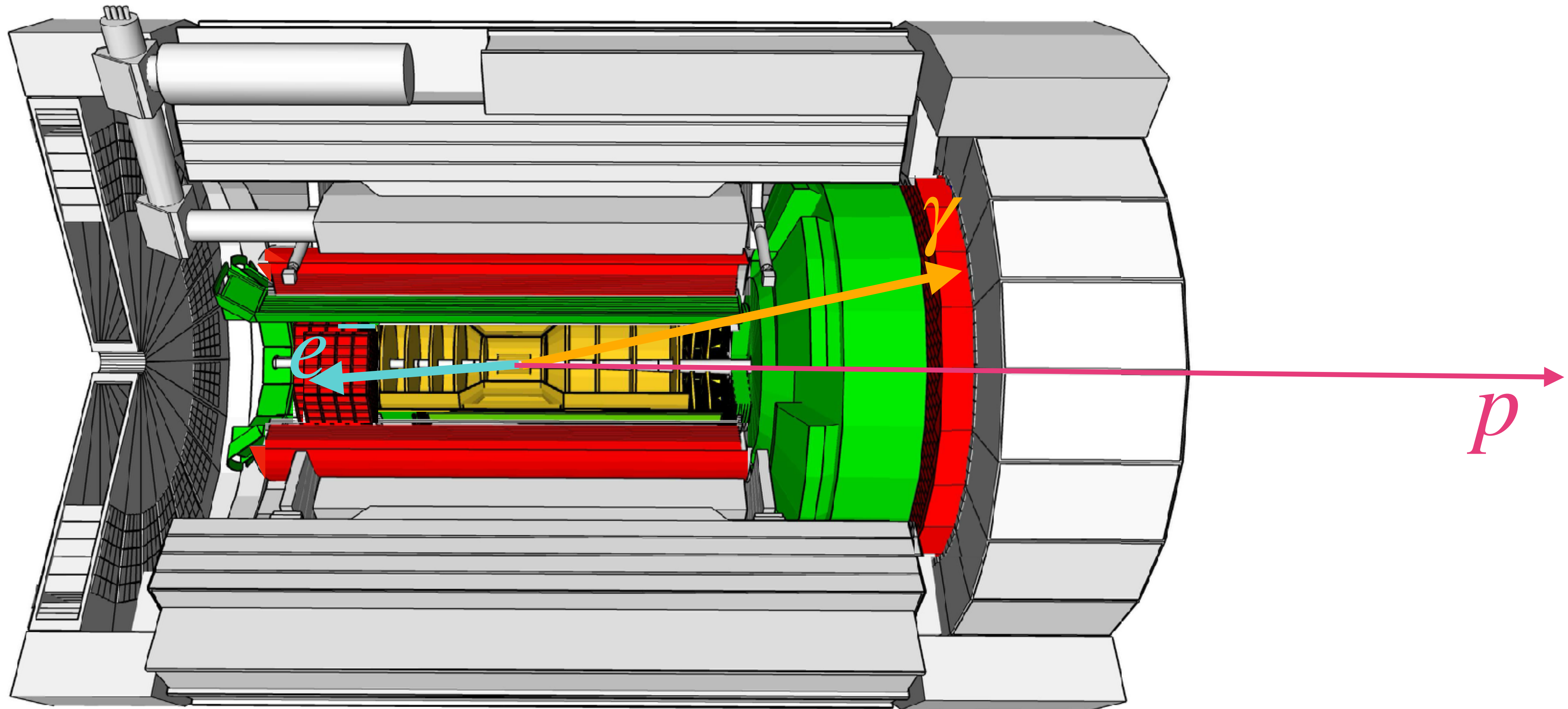


Deeply virtual Compton scattering (DVCS)
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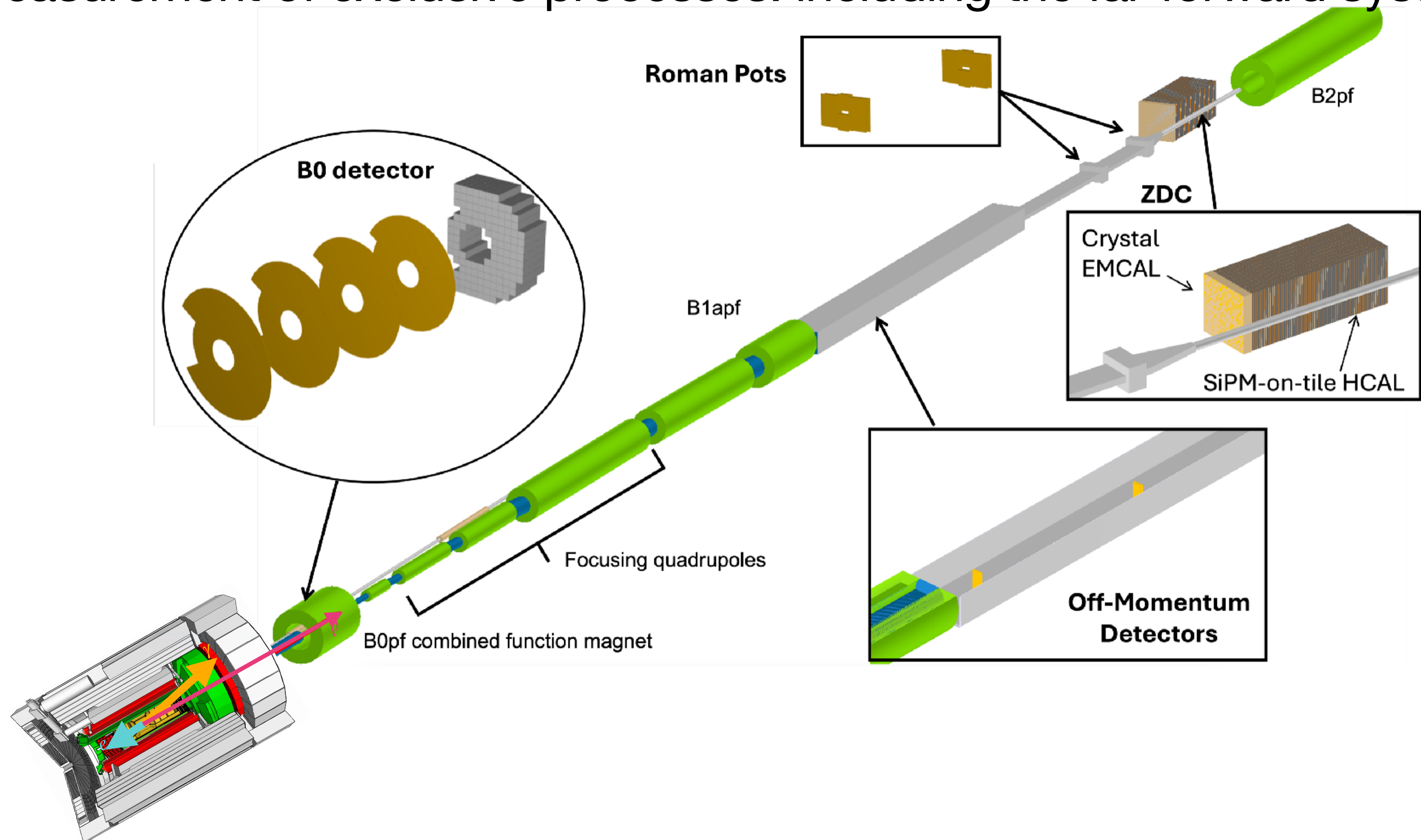


Exclusive meson photoproduction
Hard scale = large charm/bottom-quark mass

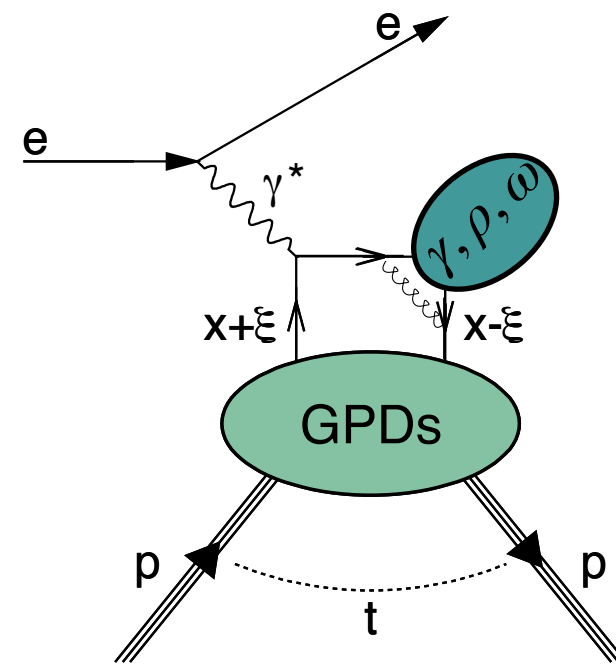
Measurement of exclusive processes



Measurement of exclusive processes: including the far-forward system

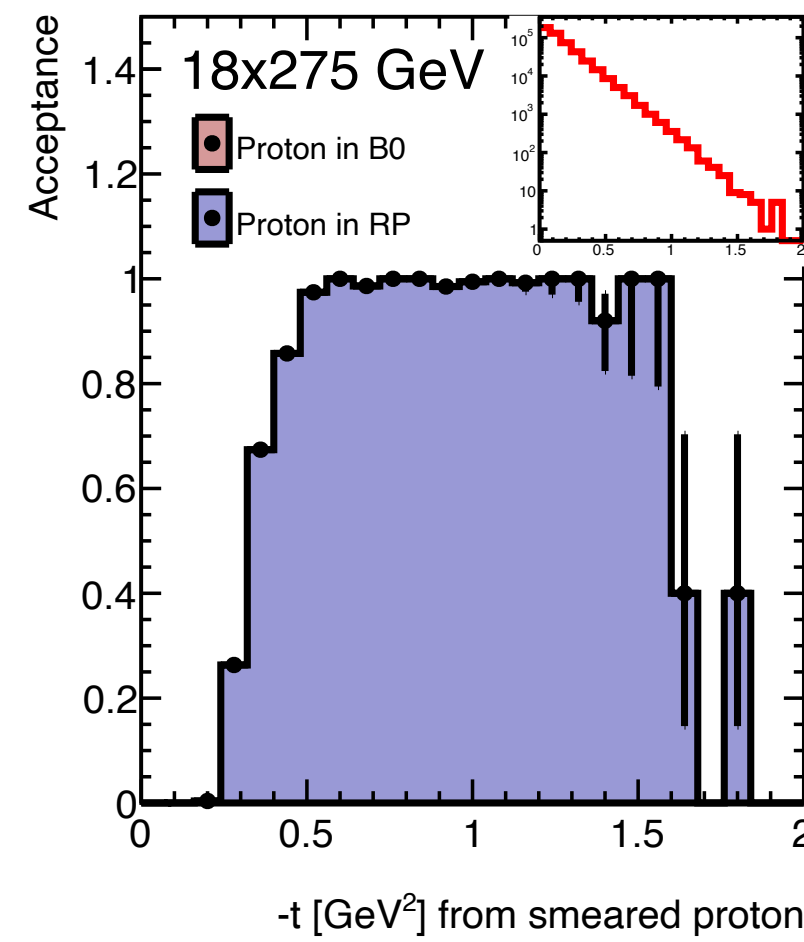
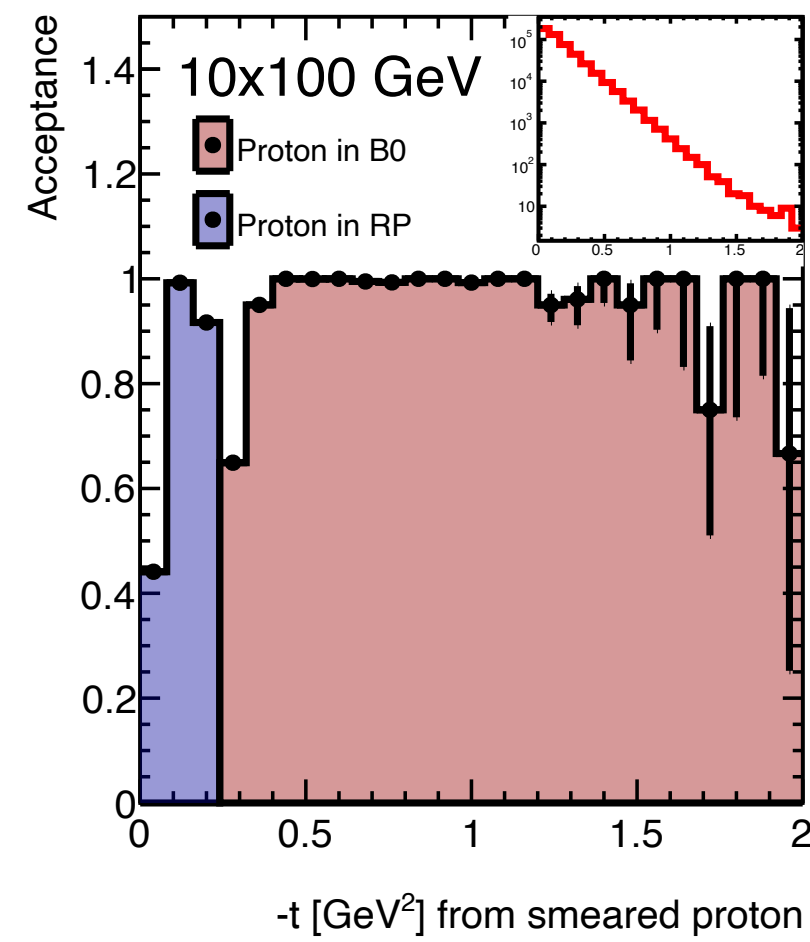
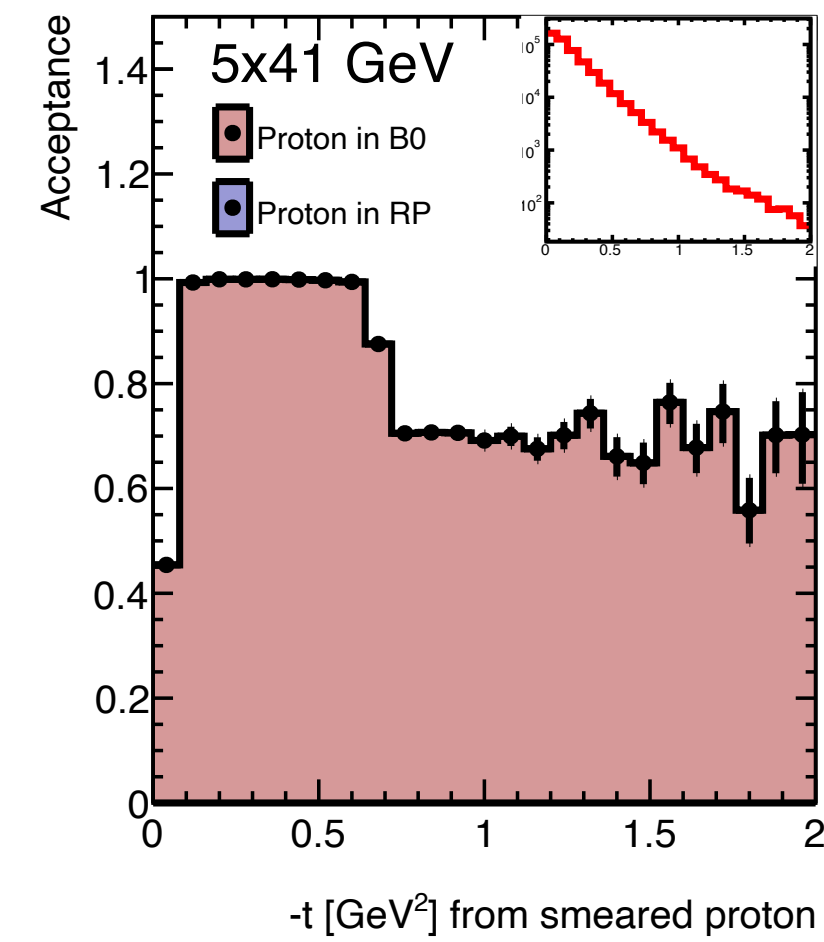


The far-forward system and proton detection for exclusive processes

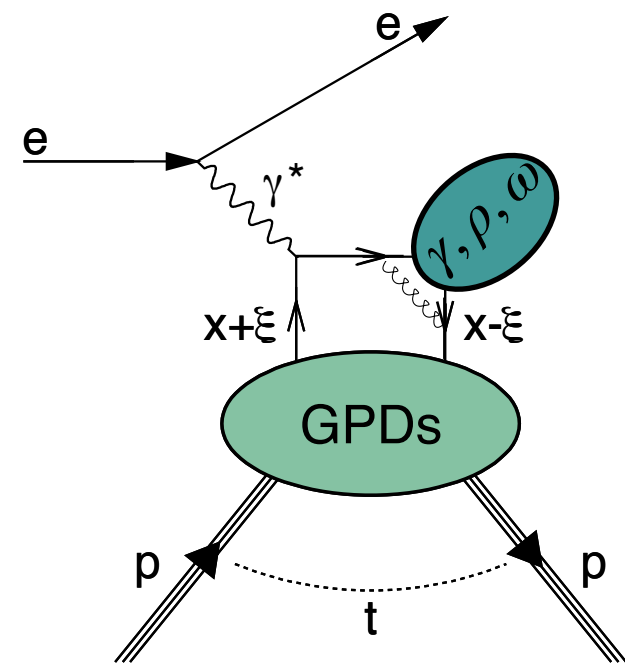


Exclusive production on proton

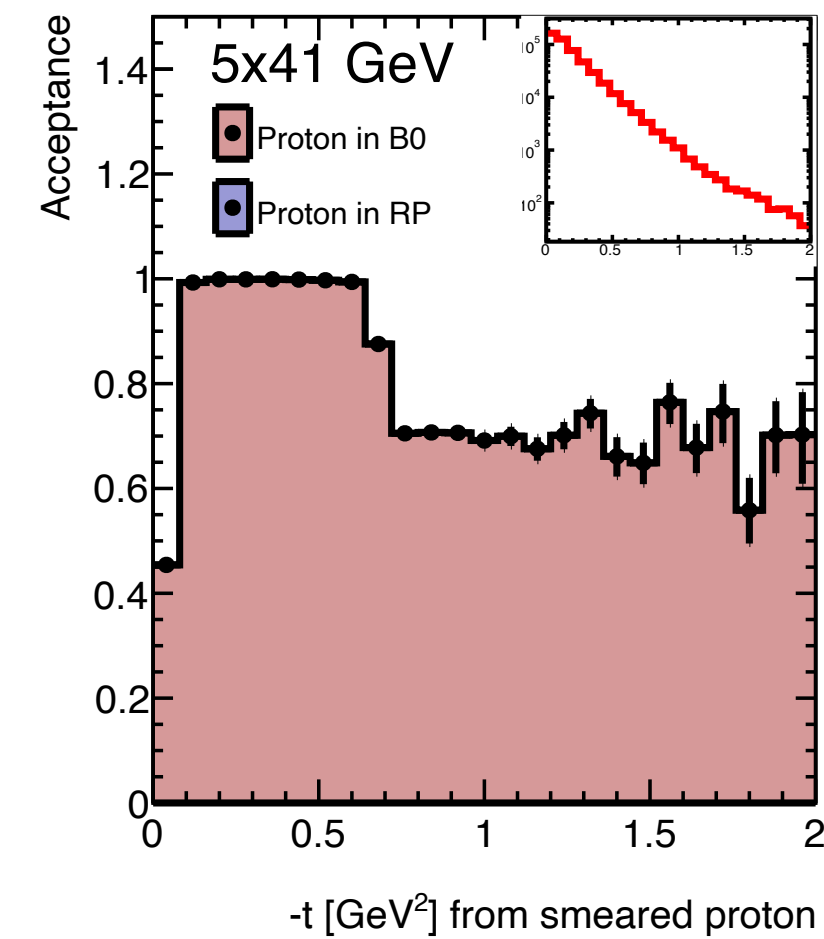
ECCE



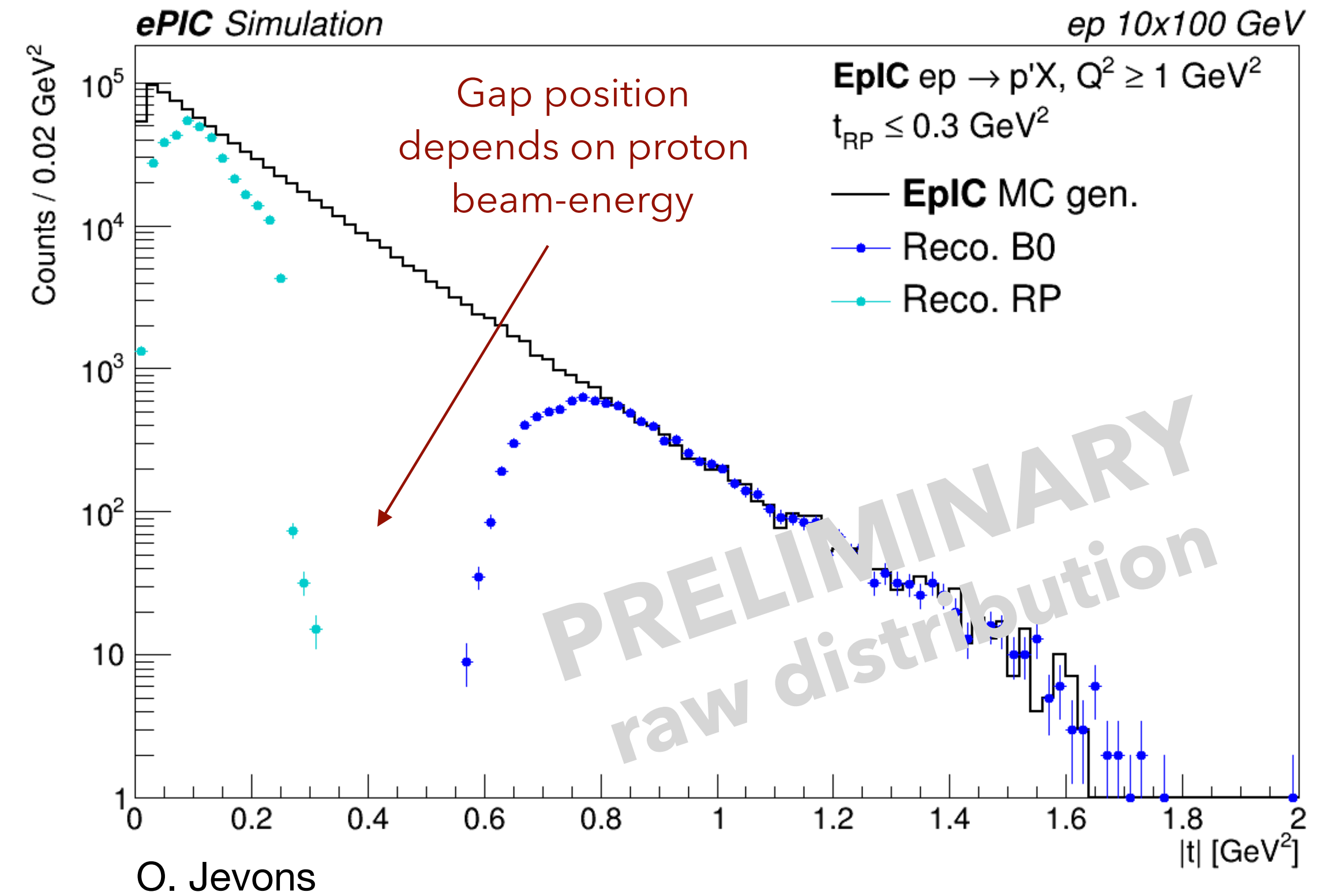
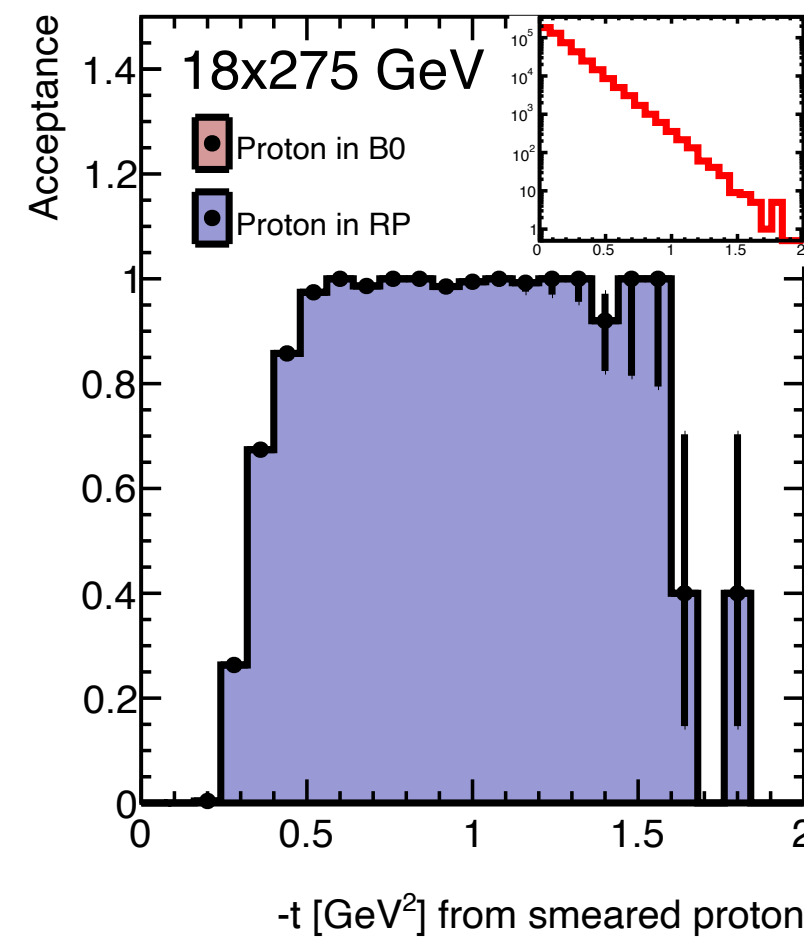
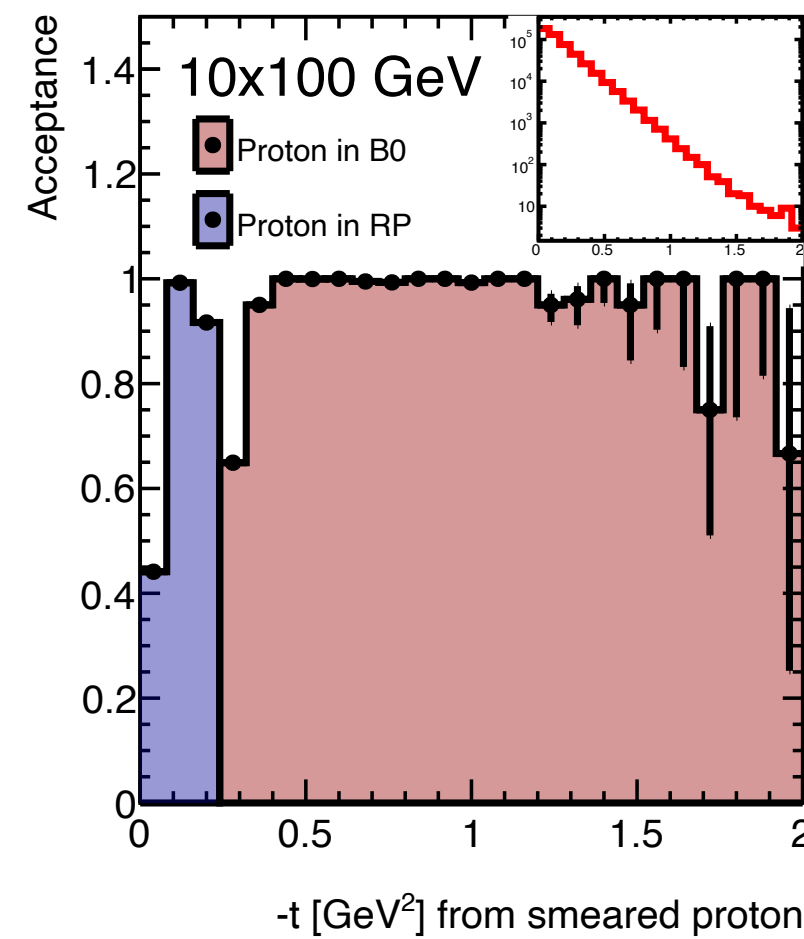
The far-forward system and proton detection for exclusive processes



ECCE

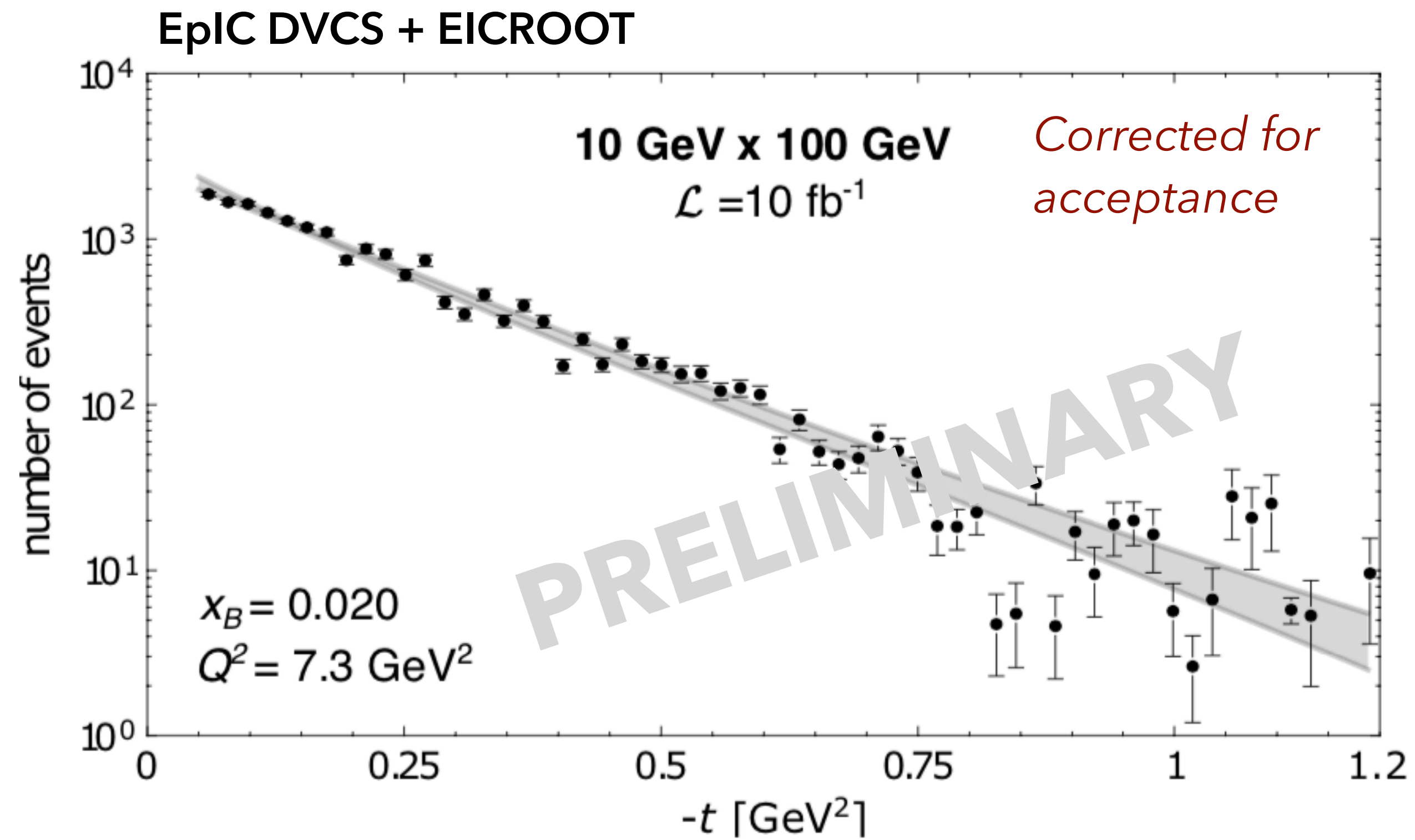
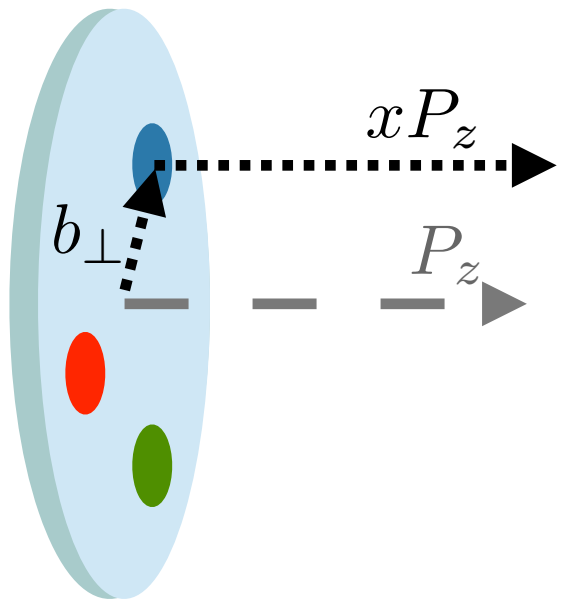


Exclusive production on proton

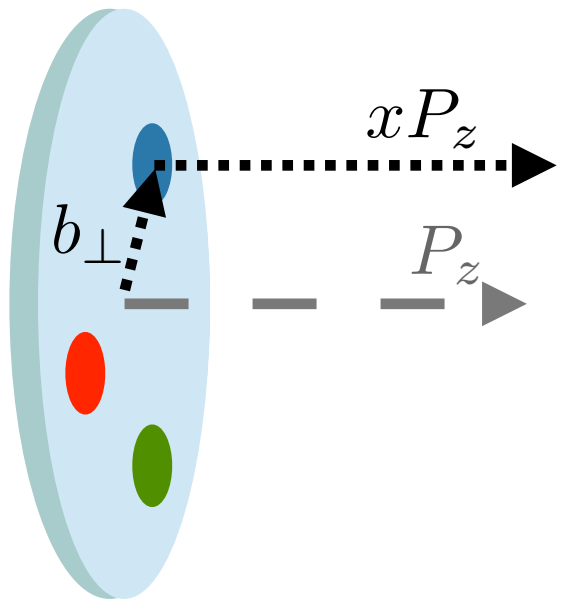


Exclusive measurements on p with the EIC

Deeply virtual Compton scattering
→ sensitive to quarks (and gluons)



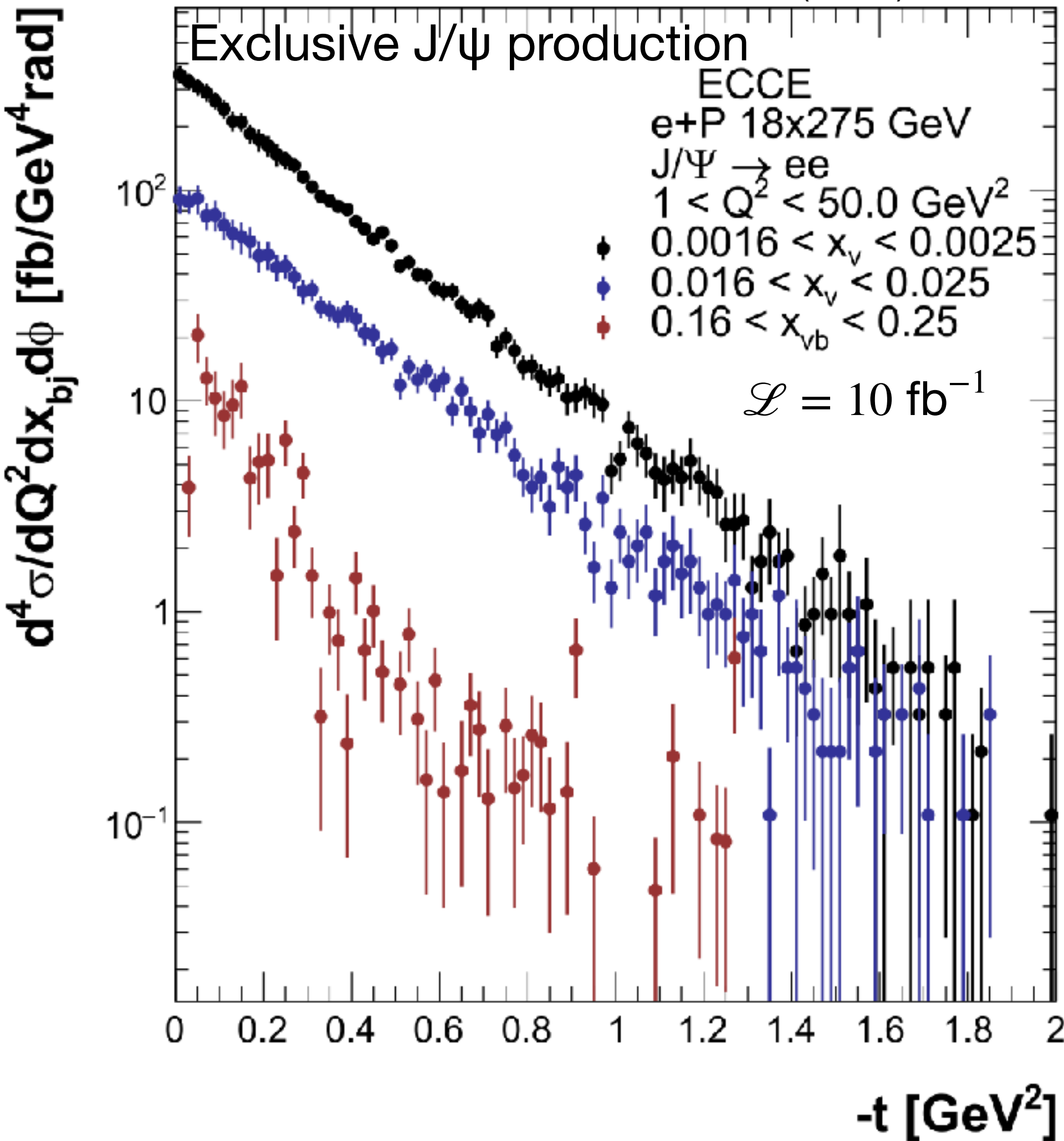
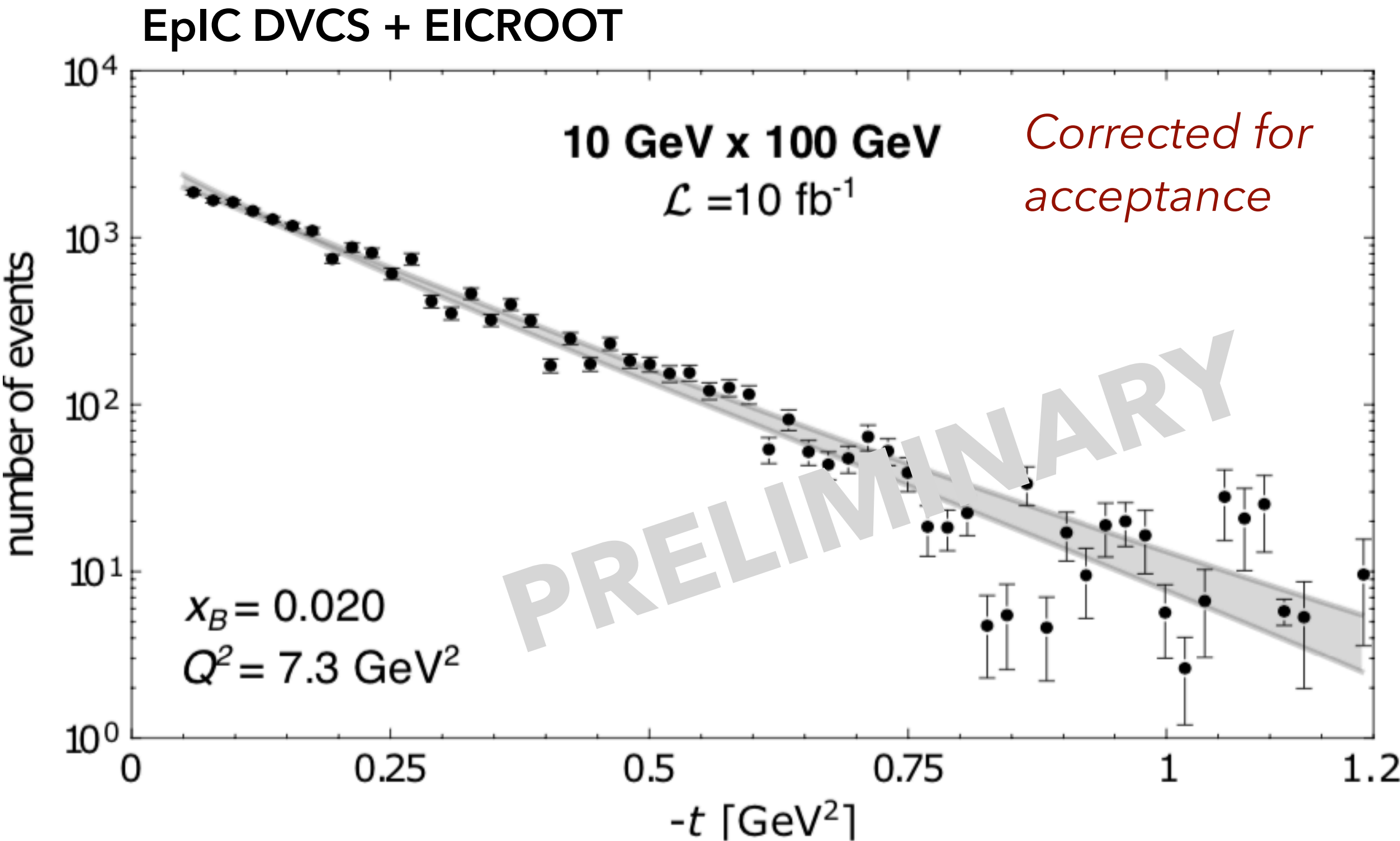
Exclusive measurements on p with the EIC



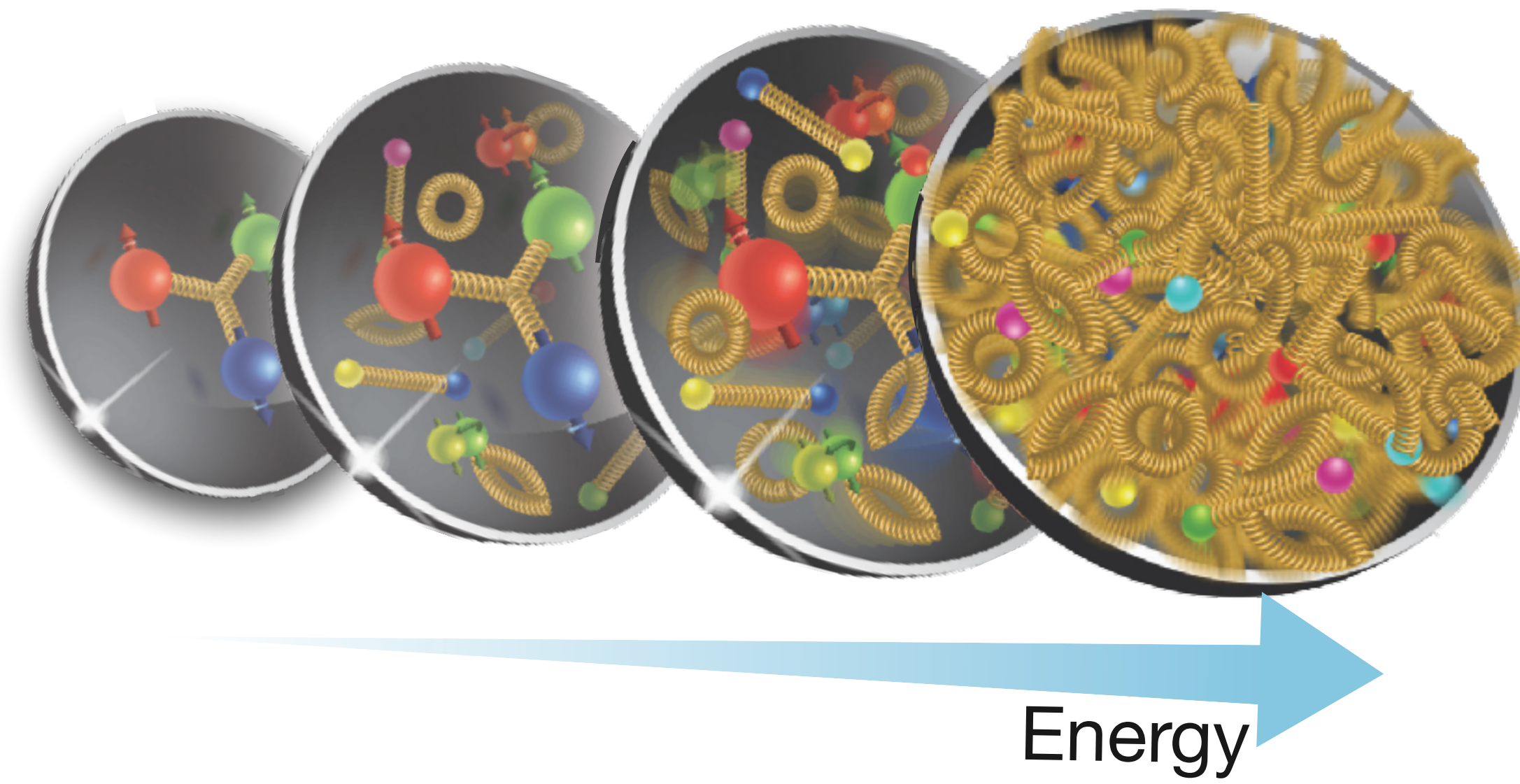
Deeply virtual Compton scattering
→ sensitive to quarks (and gluons)

Exclusive J/ψ production
→ excellent to probe gluon GPDs

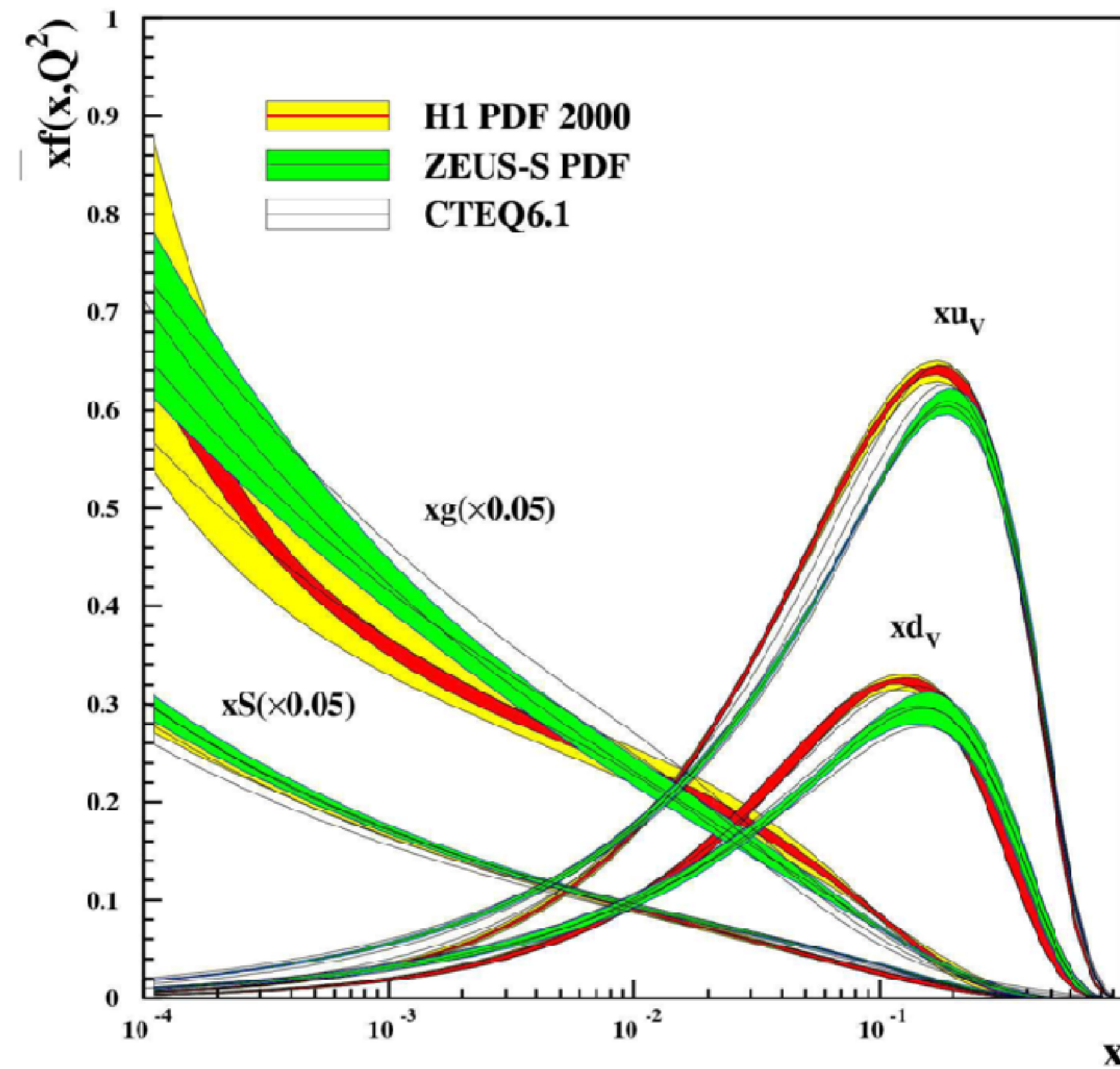
ECCE, NIMA 1052 (2023) 168238



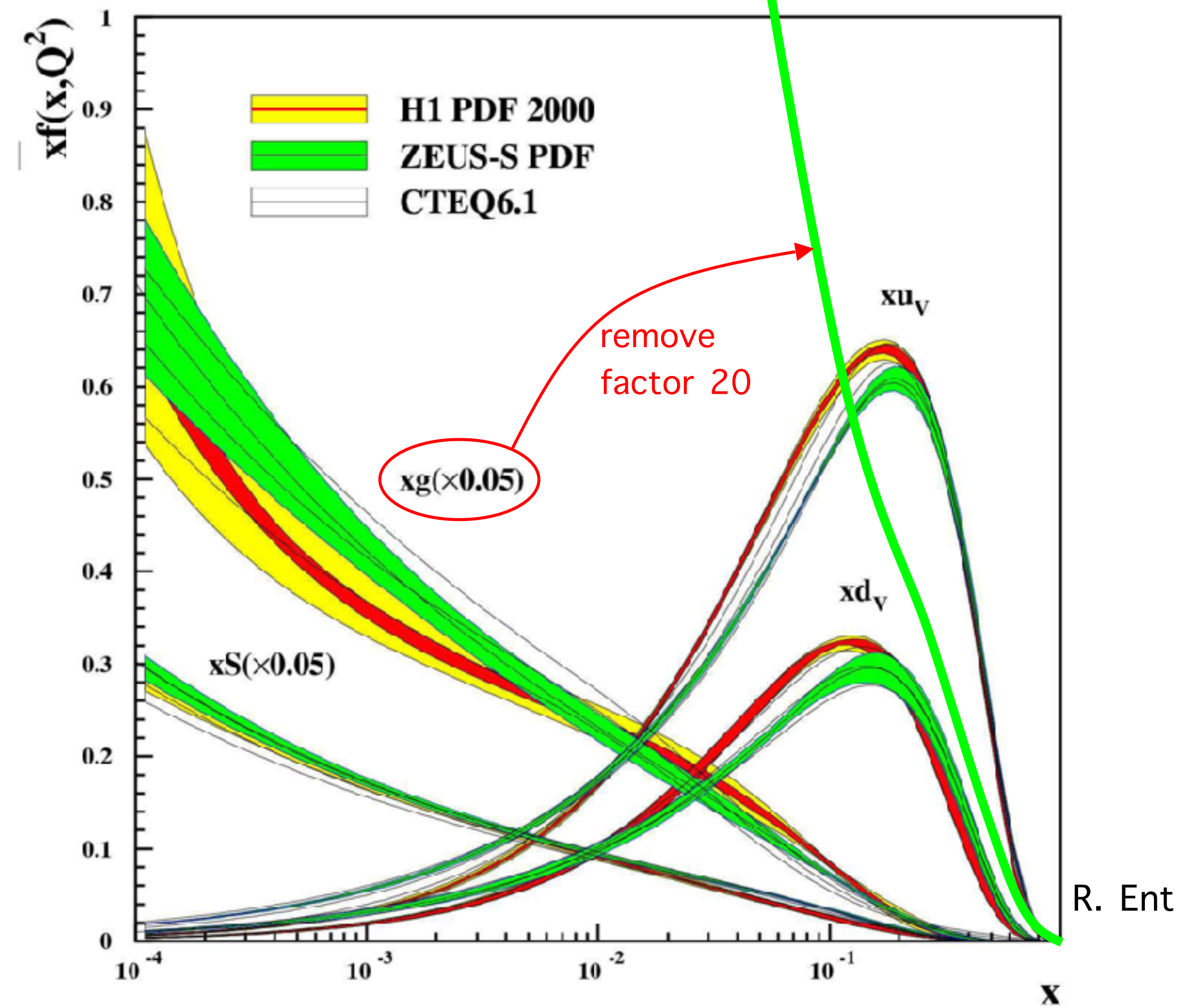
Gluon saturation



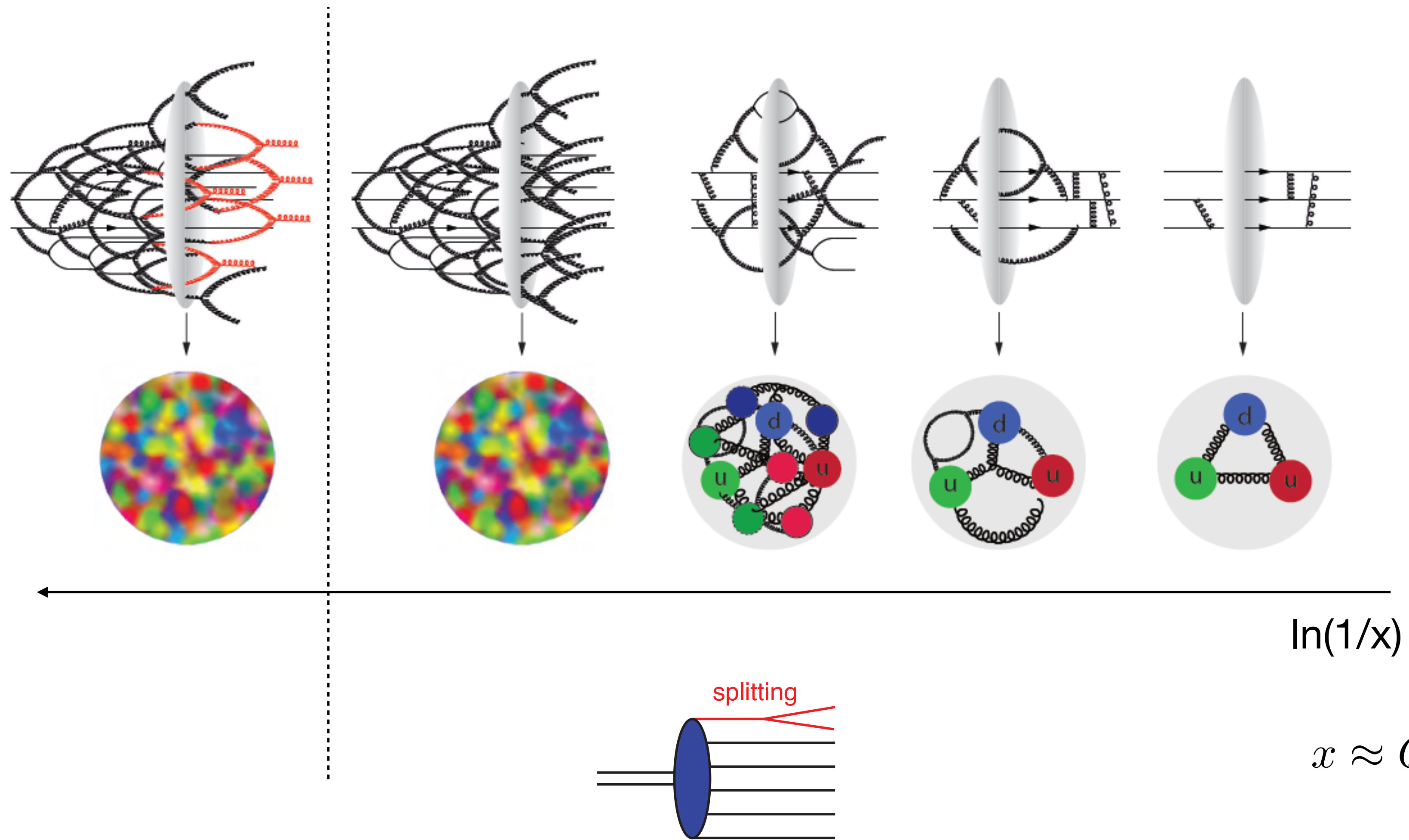
Spin-independent parton distributions



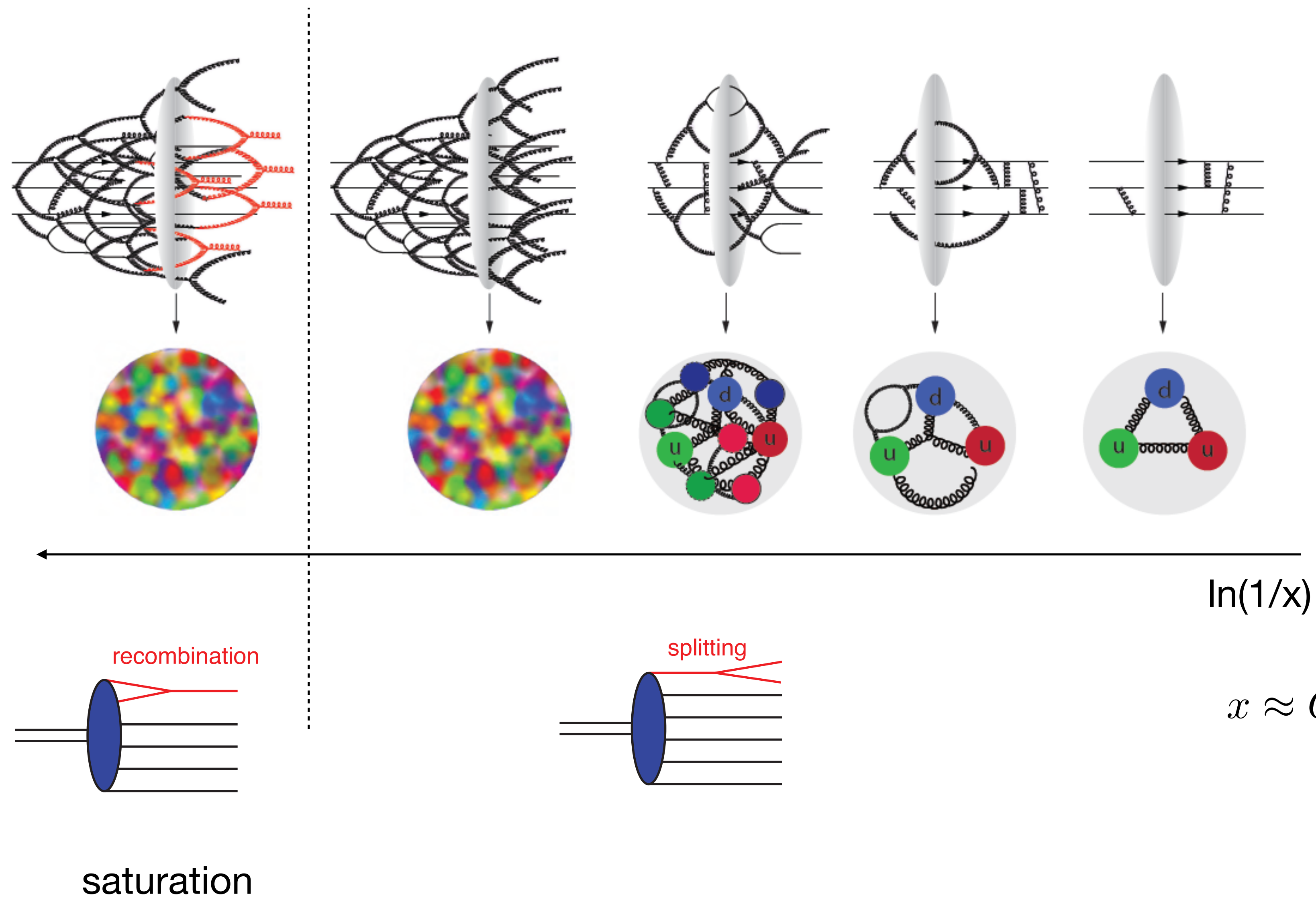
Spin-independent parton distributions



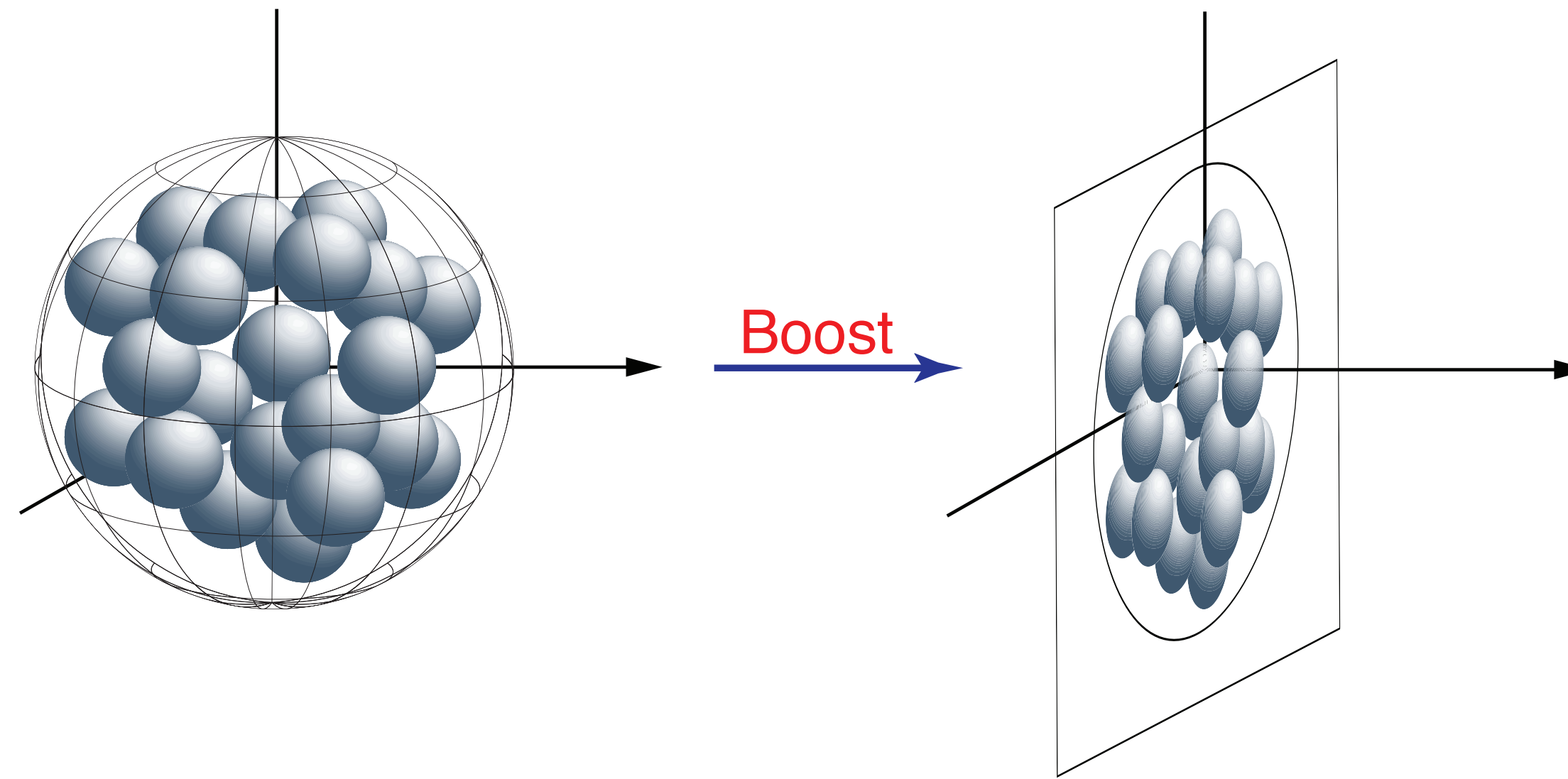
Gluon splitting and recombination



Gluon splitting and recombination



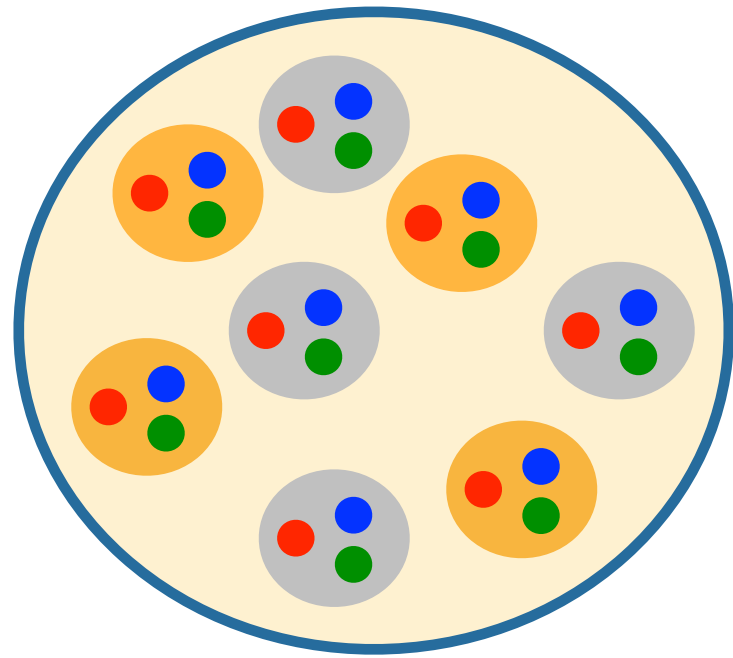
The Oomph factor



Oomph factor: $A^{1/3}$ enhancement of saturation effect

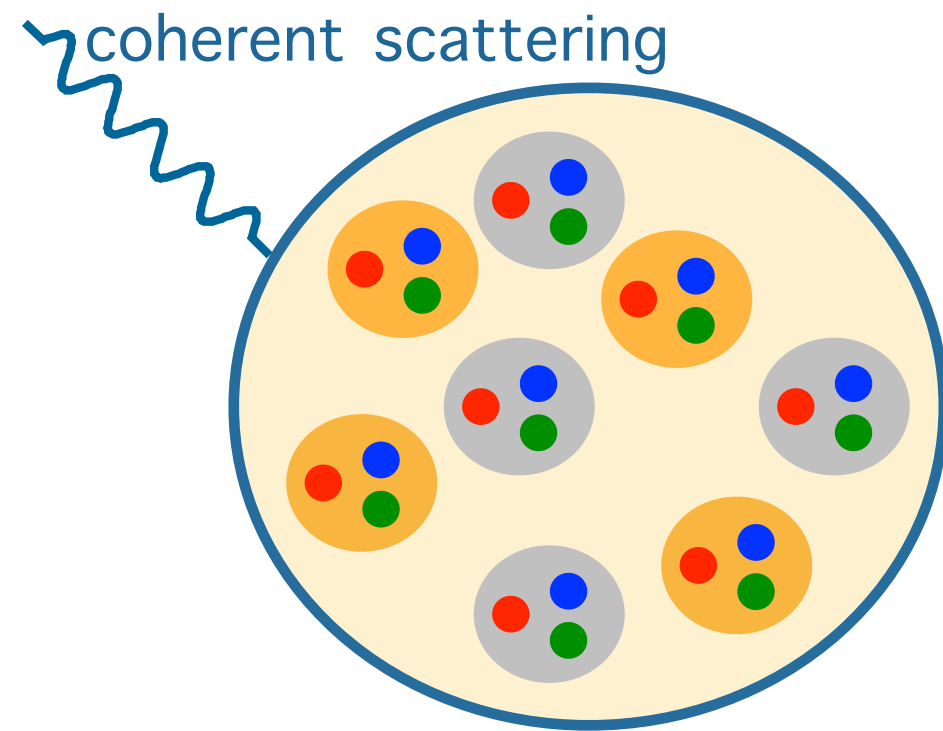
Exclusive/diffractive measurements on nuclei

What object are we probing?



Exclusive/diffractive measurements on nuclei

What object are we probing?



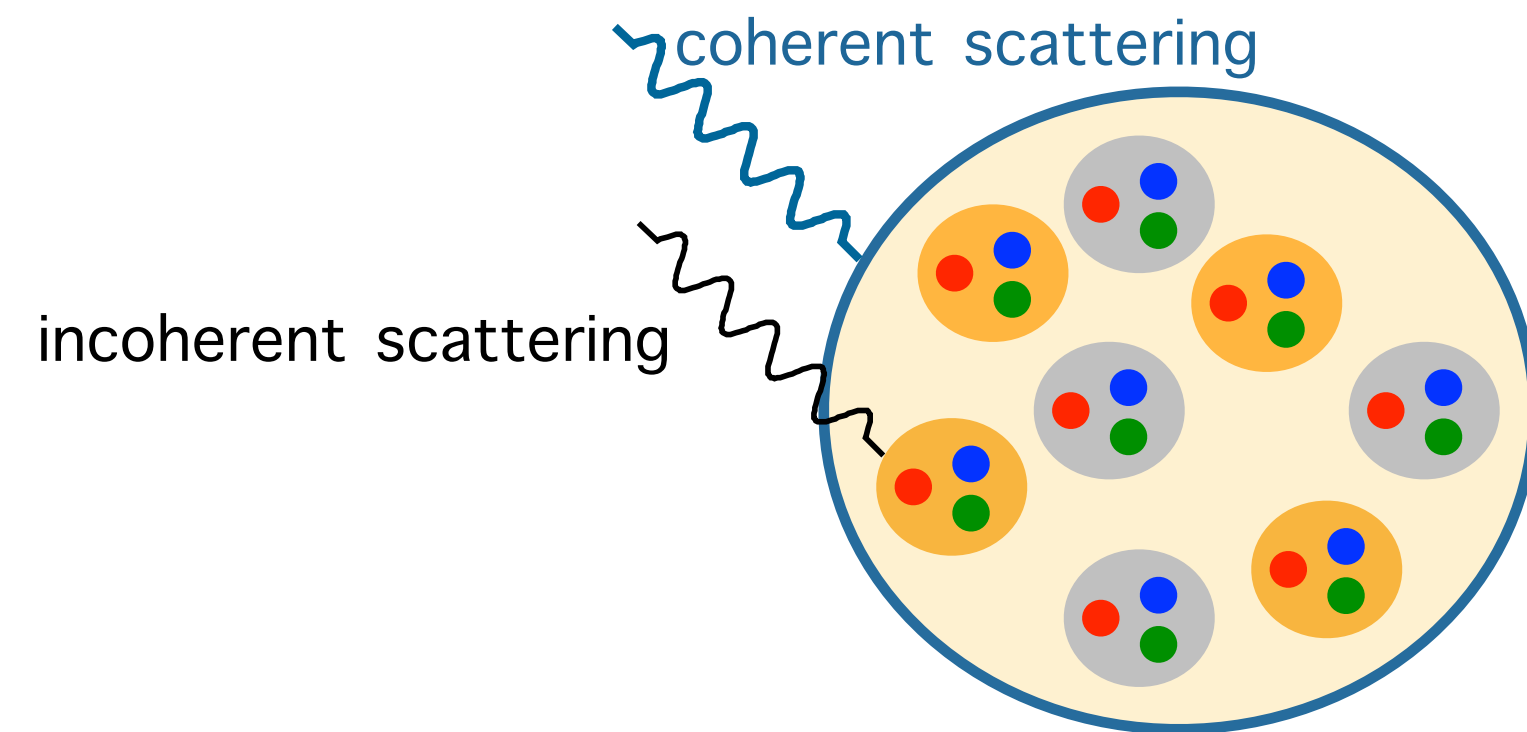
Coherent interaction: interaction with target as a whole.

~ target remains in same quantum state.

→ saturation, nuclear GPDs

Exclusive/diffractive measurements on nuclei

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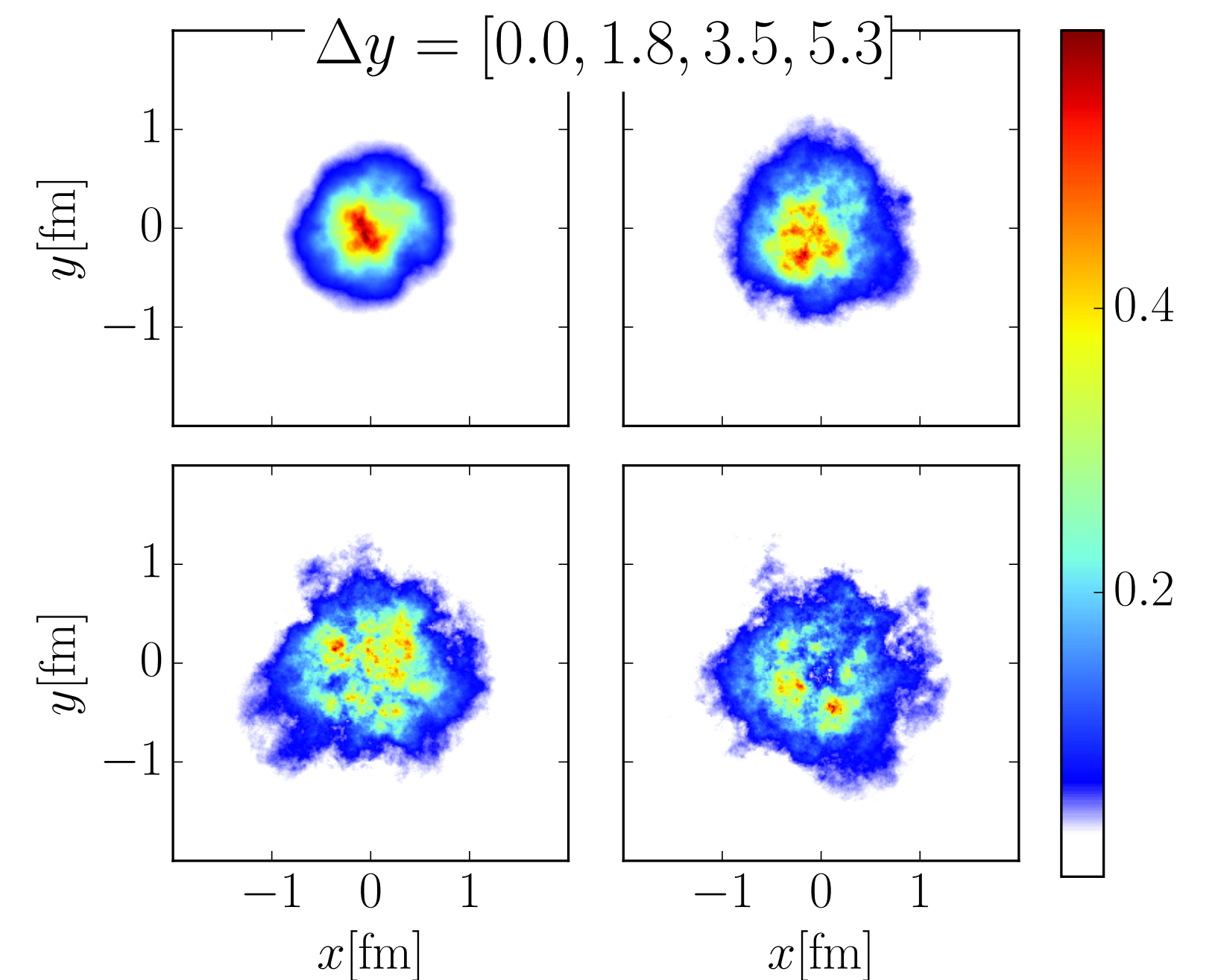
Coherent interaction: interaction with target as a whole.
~ target remains in same quantum state.

→ saturation, nuclear GPDs

Incoherent interaction: interaction with constituents inside target.
~ target does not remain in same quantum state.

Ex.: target dissociation, excitation

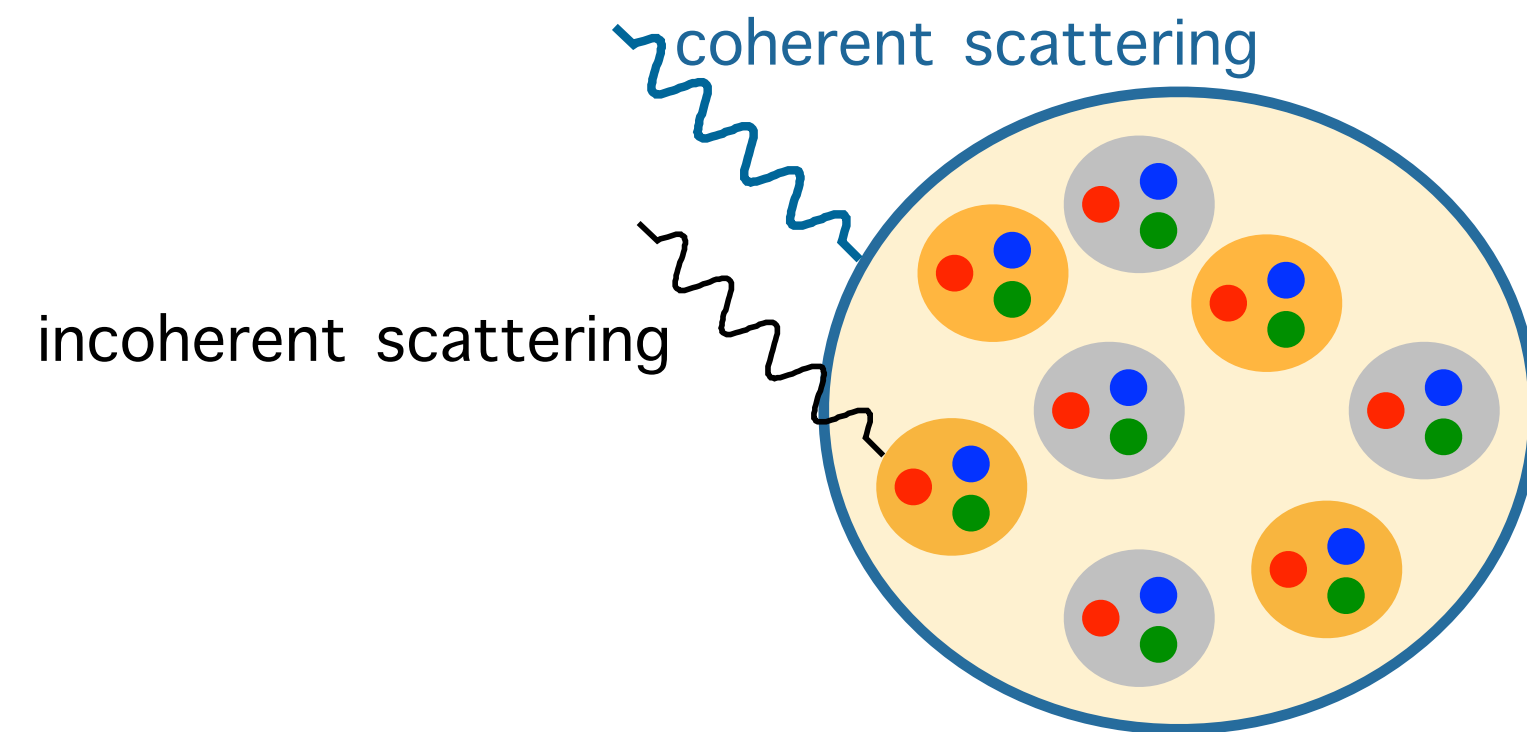
→ saturation, fluctuations in transverse position



H. Mäntysaari and B. Schenke.
Phys. Rev. D 98, 034013 (2018)

Exclusive/diffractive measurements on nuclei

What object are we probing?



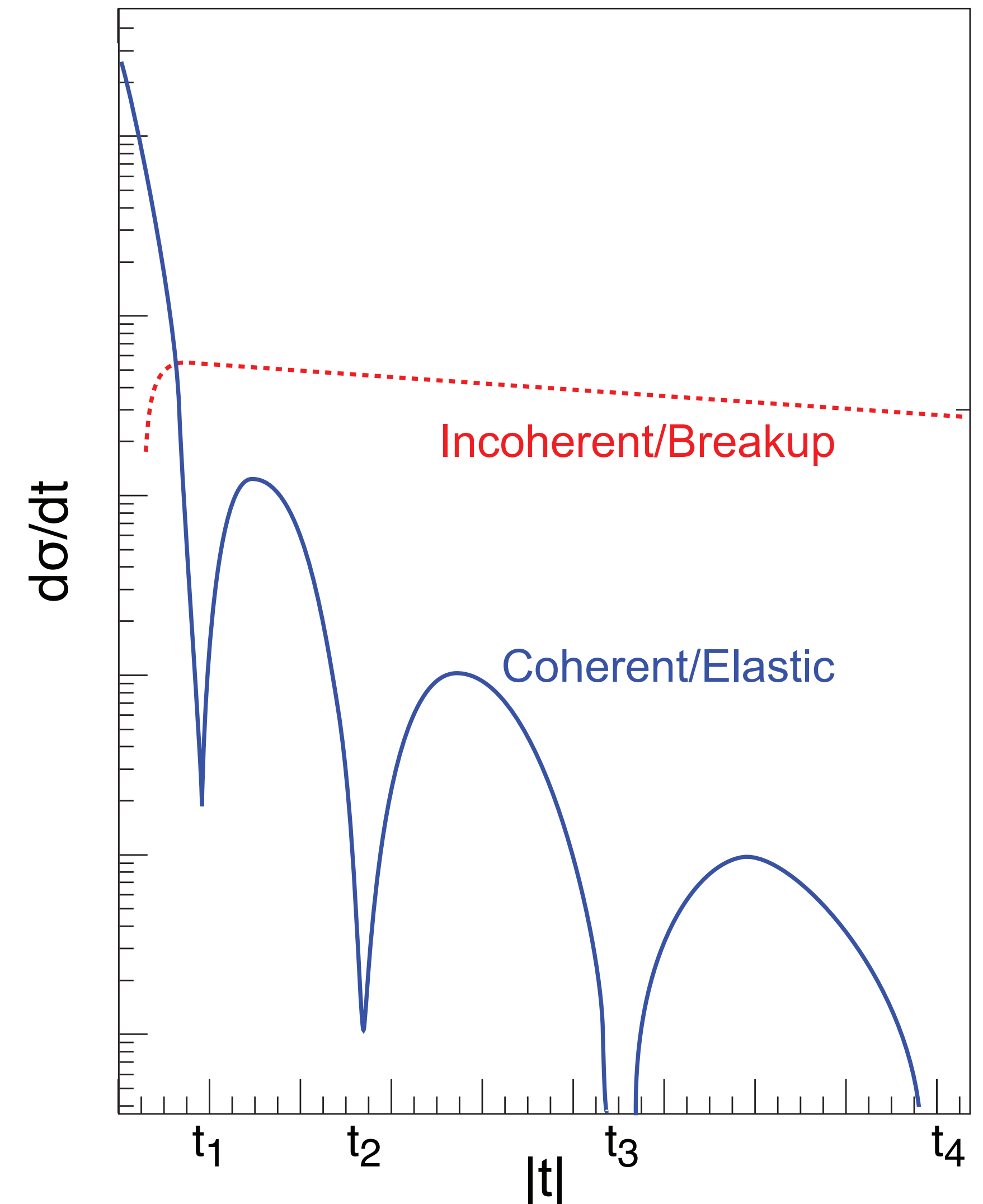
Coherent interaction: interaction with target as a whole.
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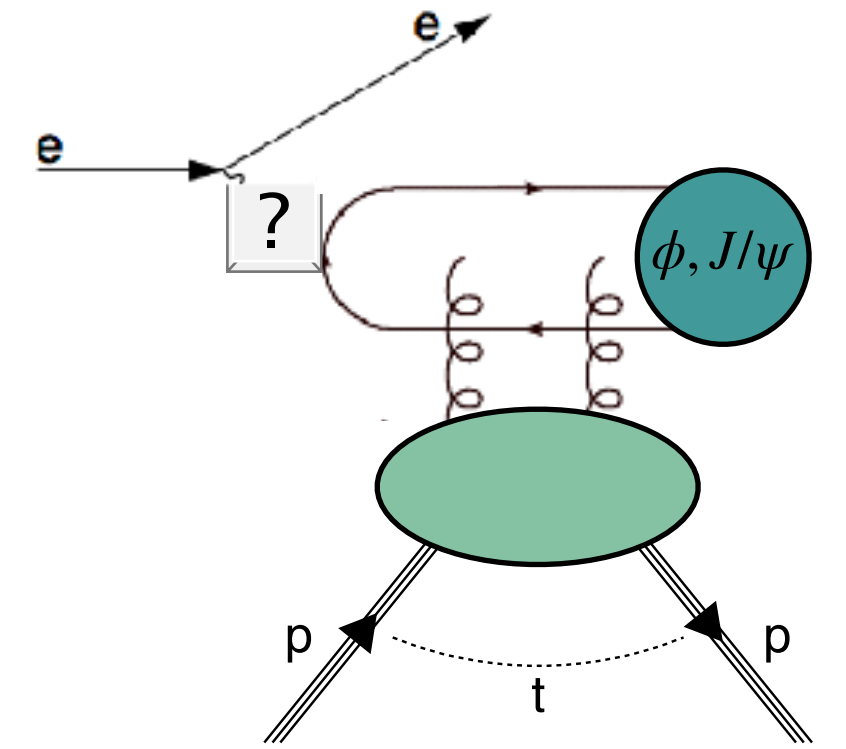
Incoherent interaction: interaction with constituents inside target.
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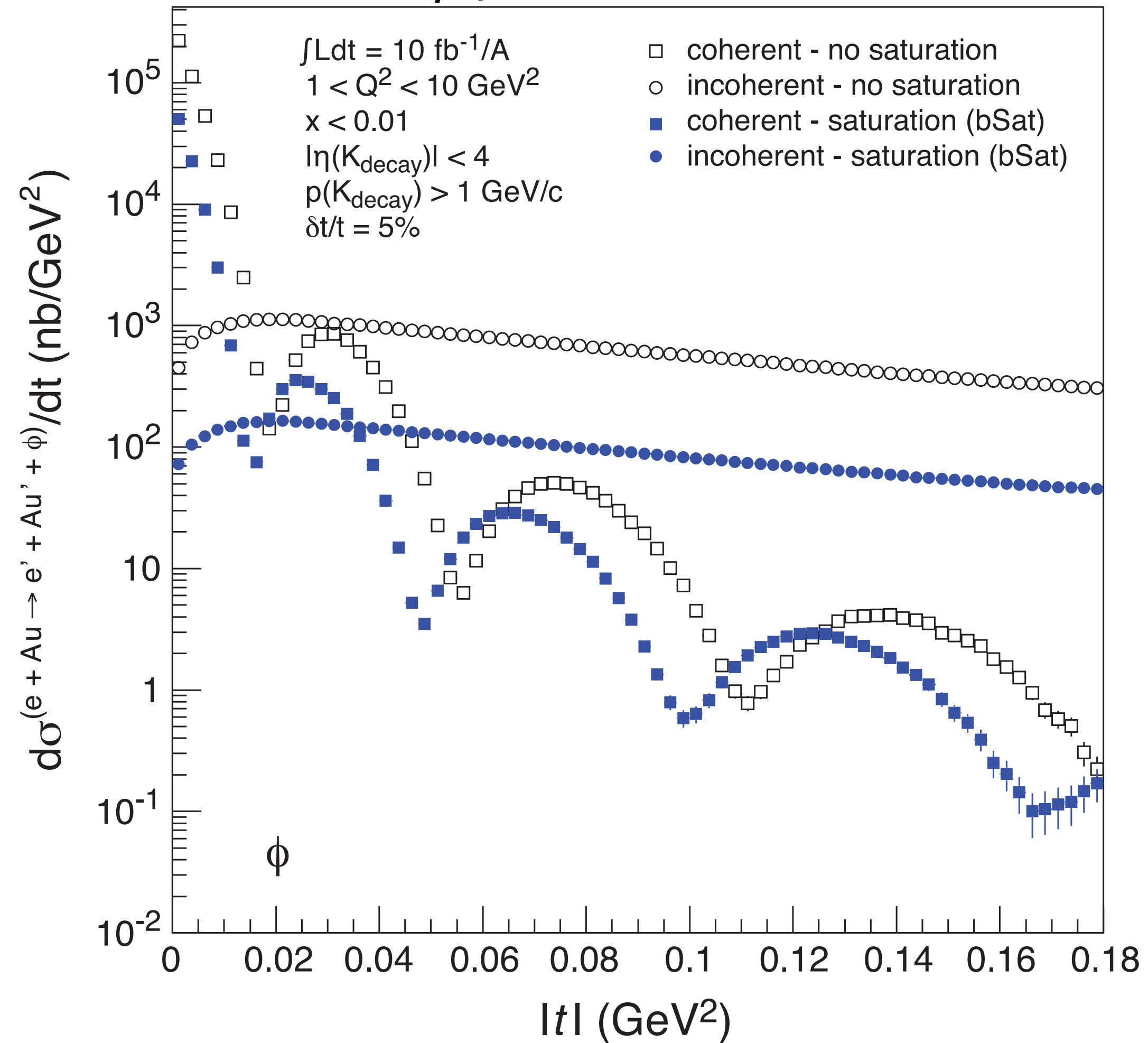


Diffractive measurements and saturation

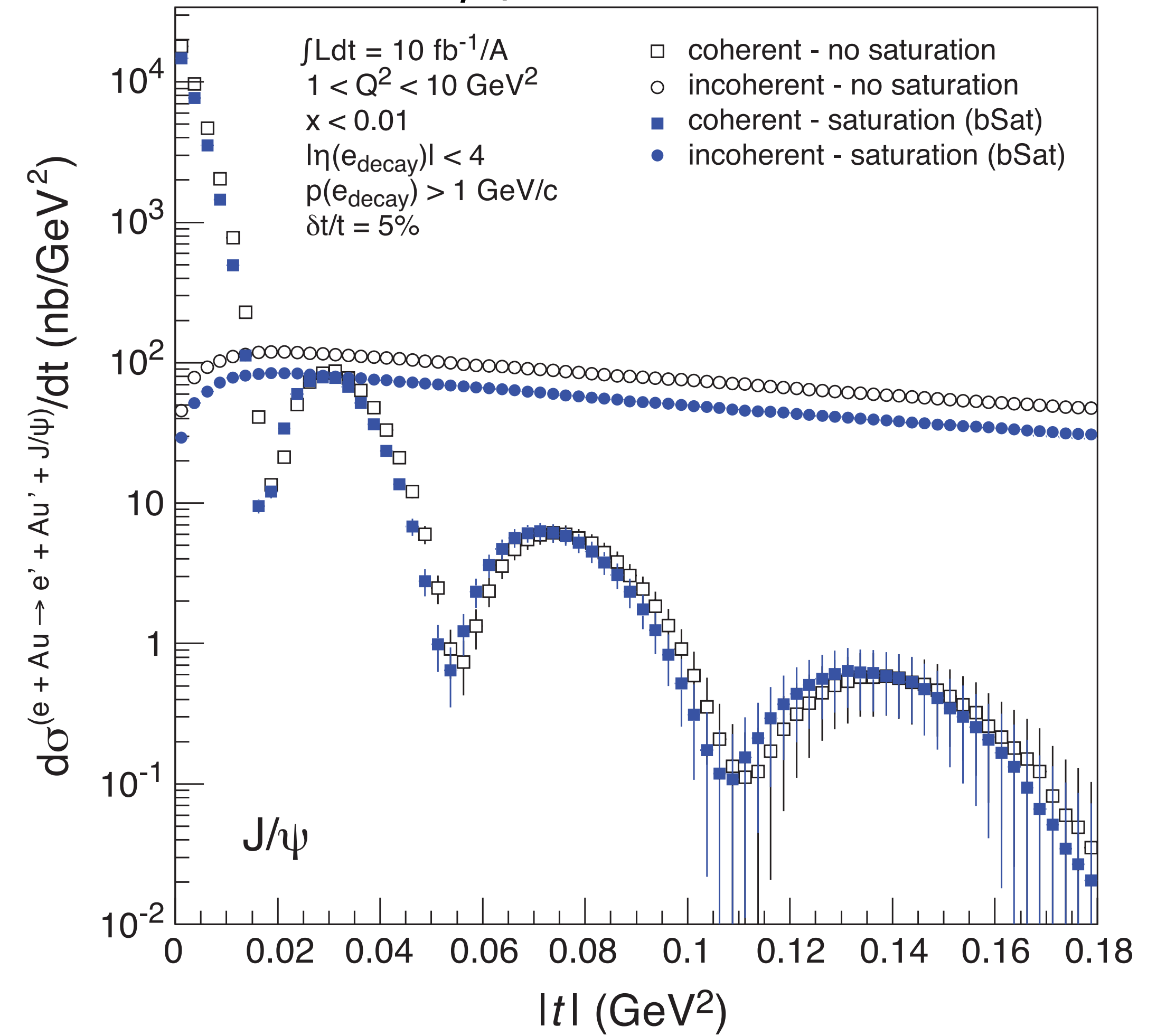


ϕ production

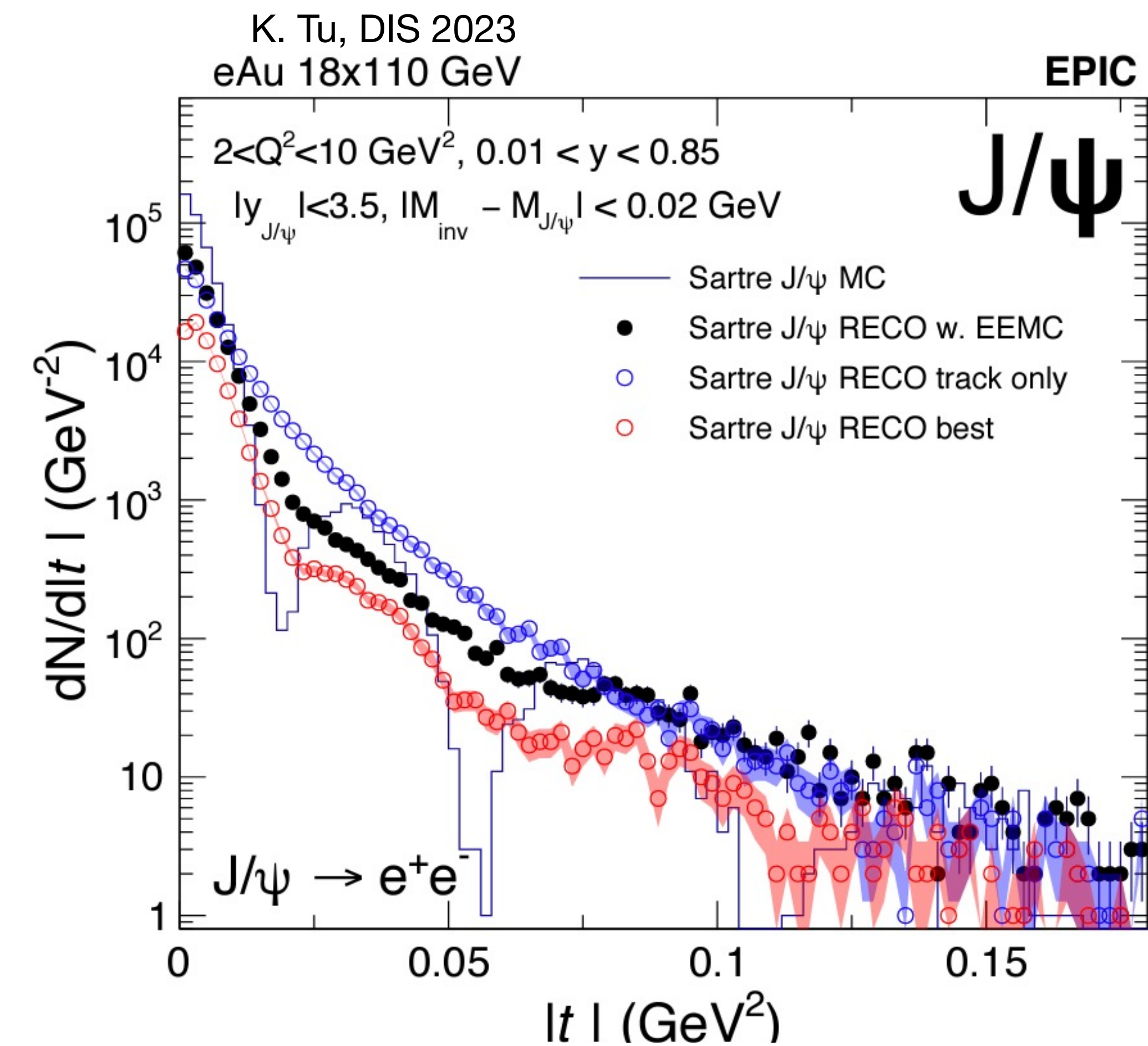
A. Accardi et al., arXiv:1212.1701



J/ψ production

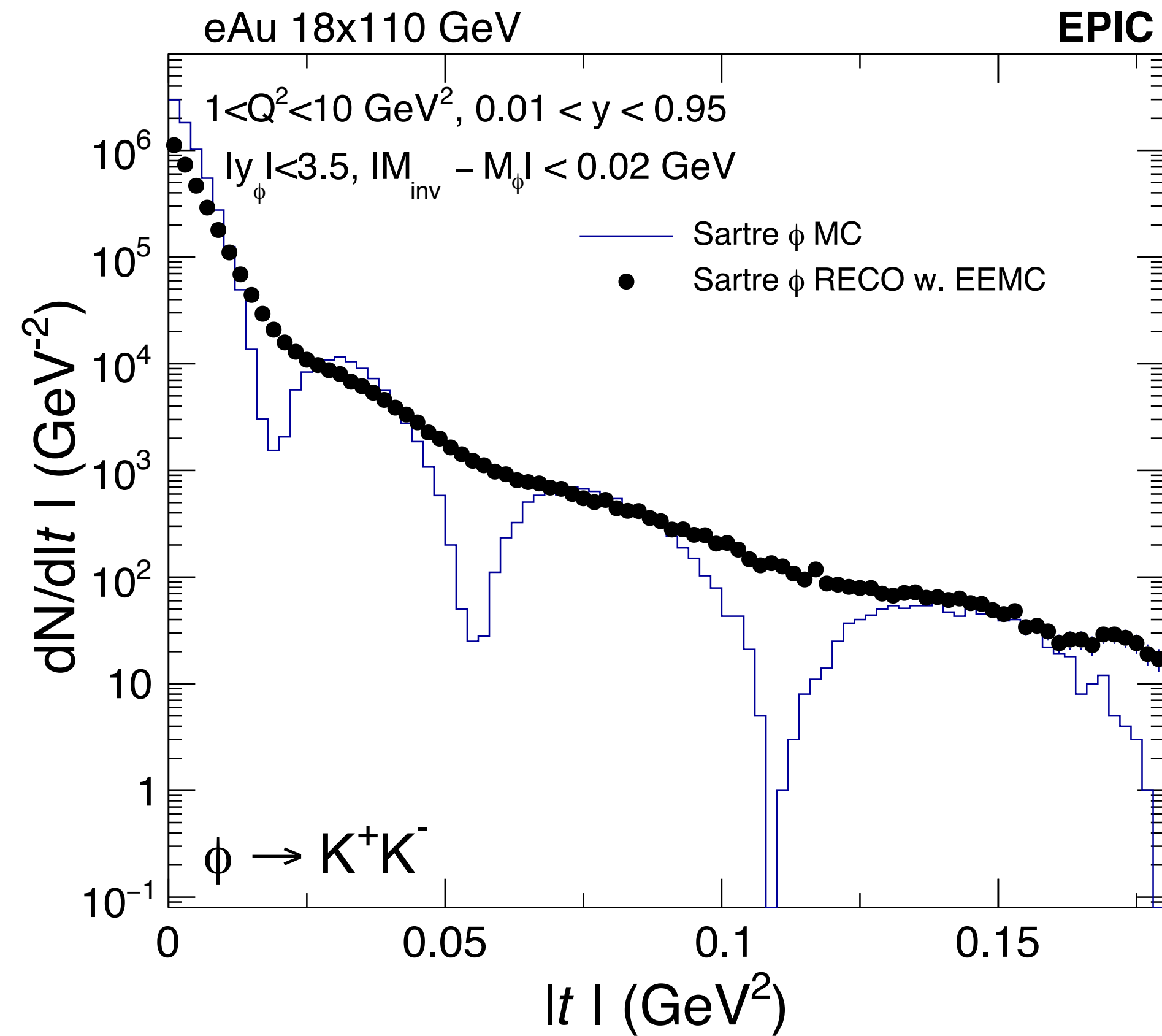


Exclusive measurements on nuclear targets with the EIC

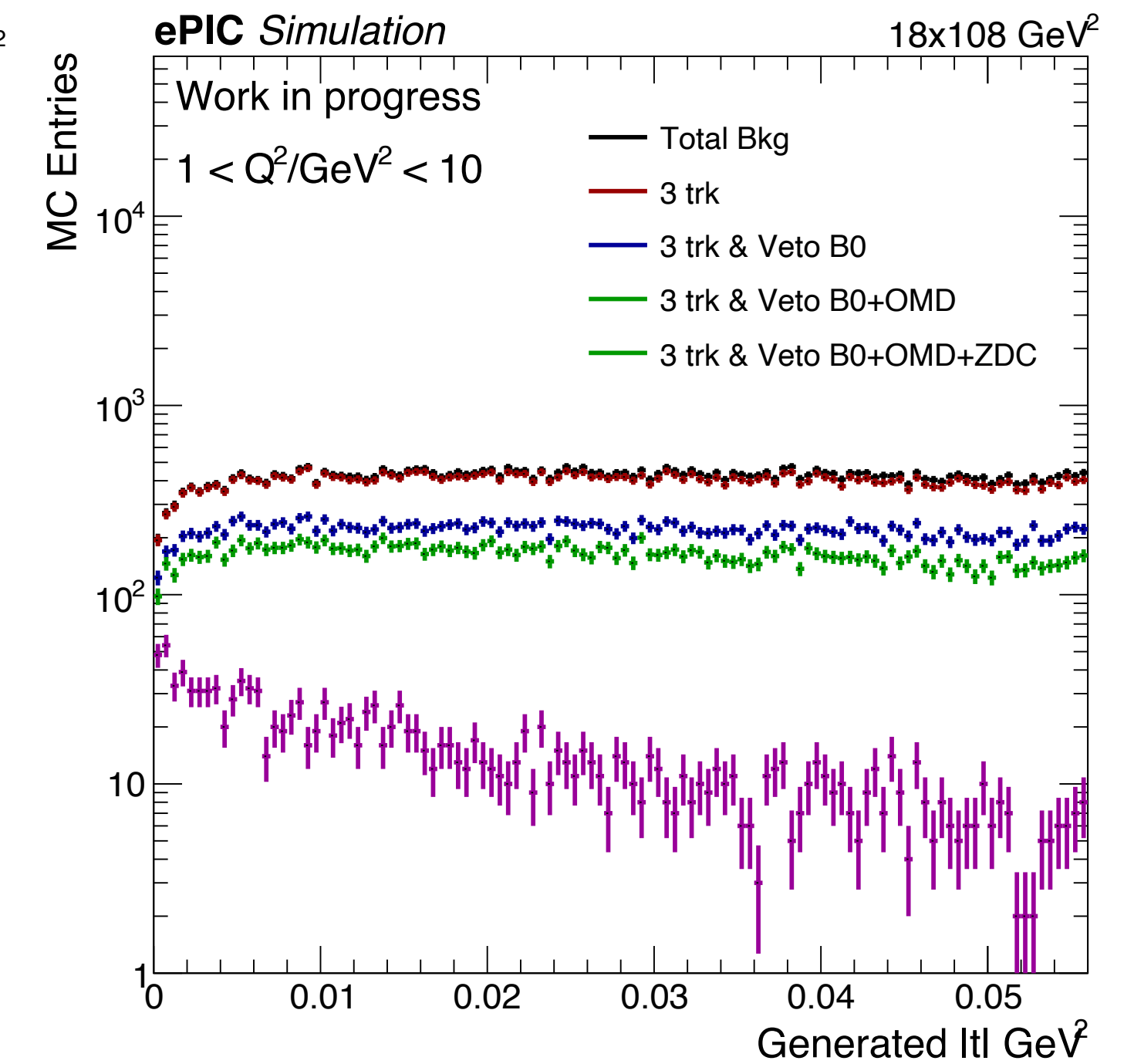
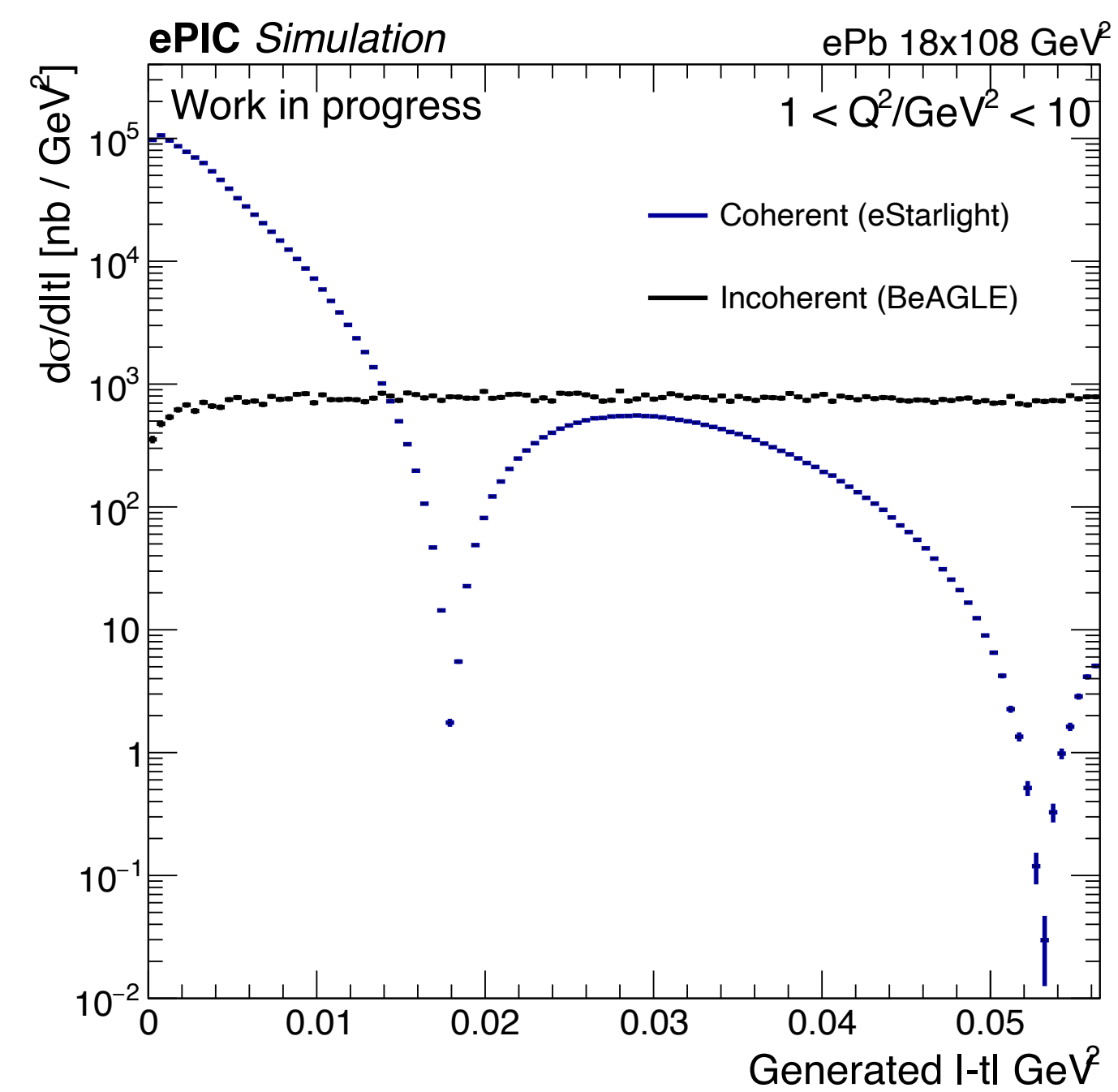


Exclusive measurements on nuclear targets with the EIC

Reconstruction of the coherent signal



Suppression of the incoherent signal

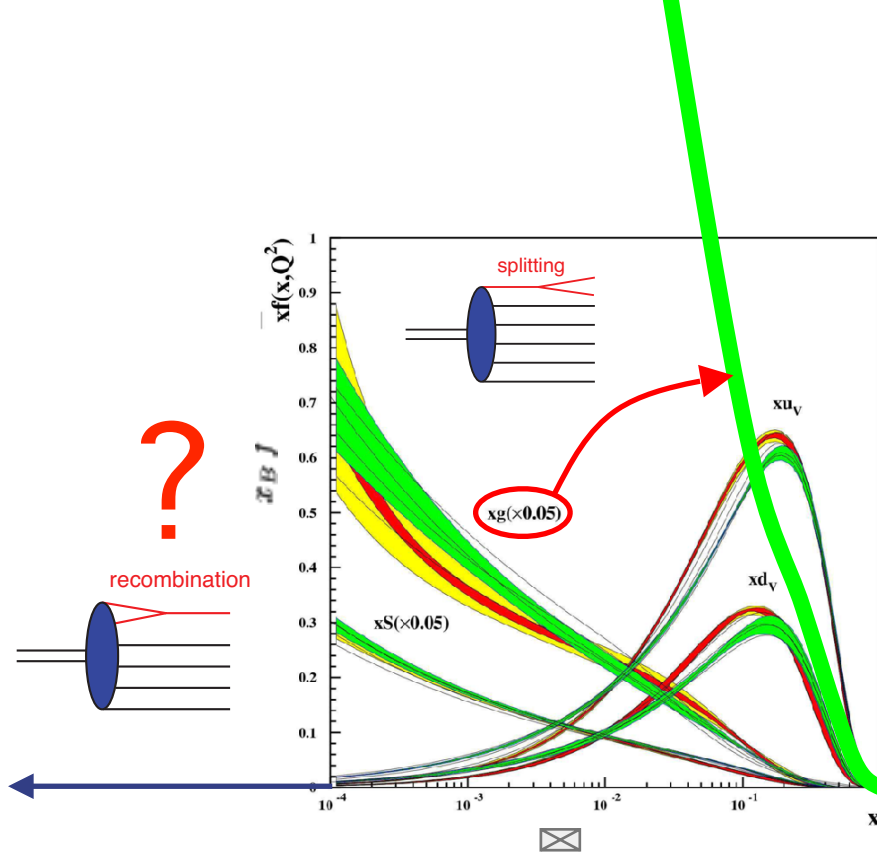
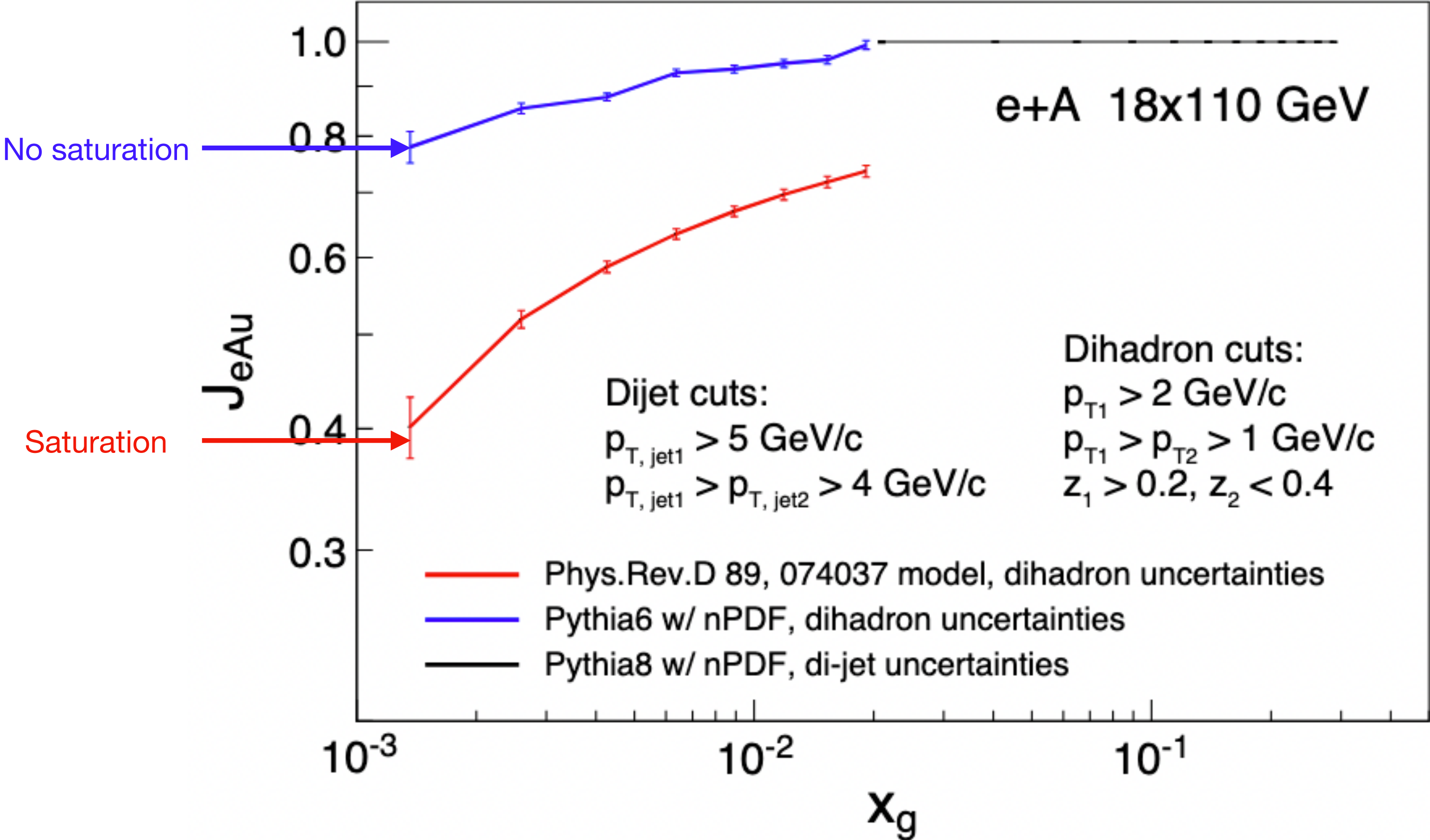


Di-hadron production in eA collisions

- Complementarity region covered by dihadron and jet production

correlated back-to-back hadron pairs in
e+Au/e+p scaled by $A^{1/3}$
Away-side suppression

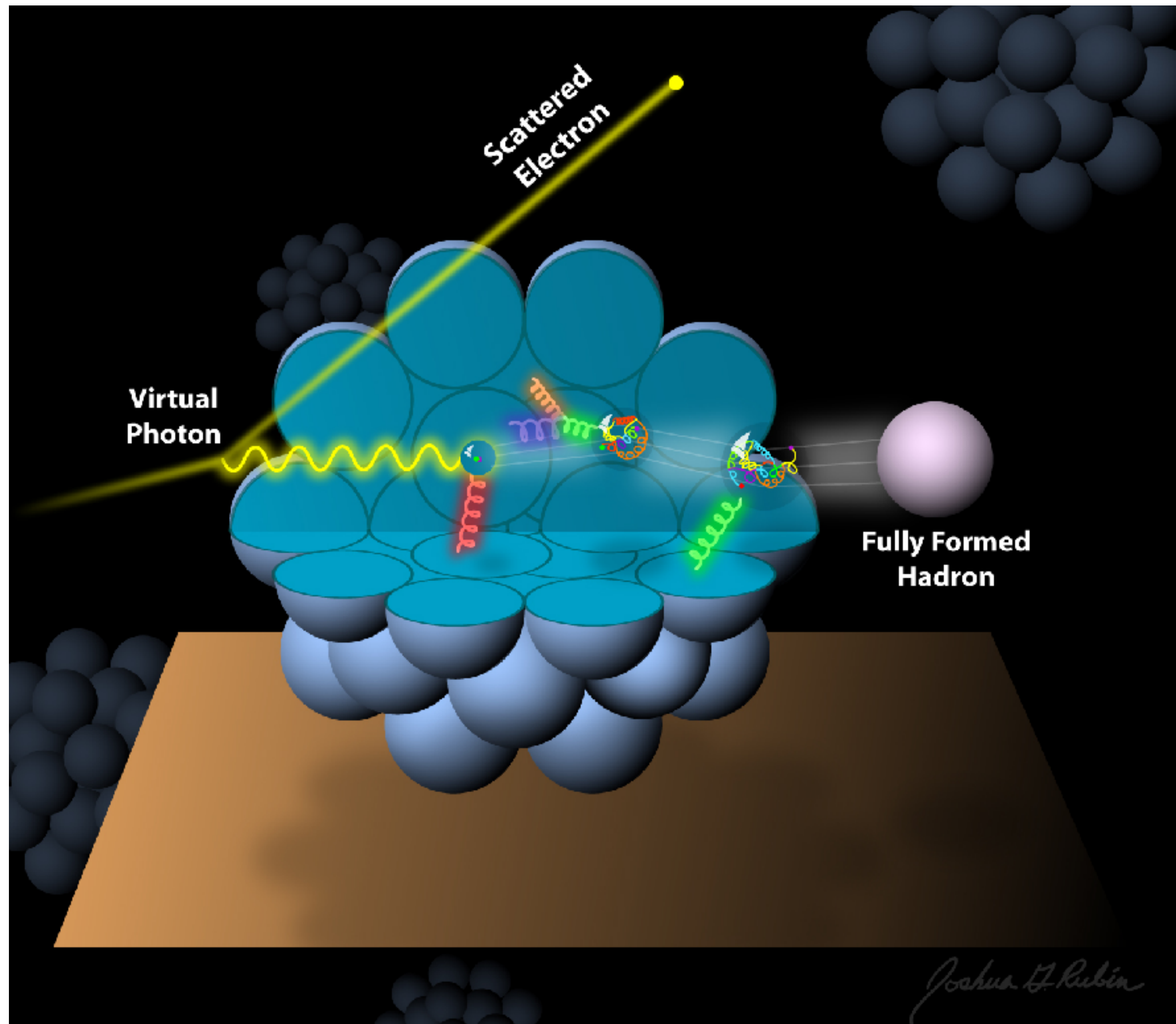
ATHENA



Hadronisation



Probing space-time evolution of hadronisation



- Energy loss of parton by medium-induced gluon radiation

- Energy loss of (pre-)hadrons

- absorption

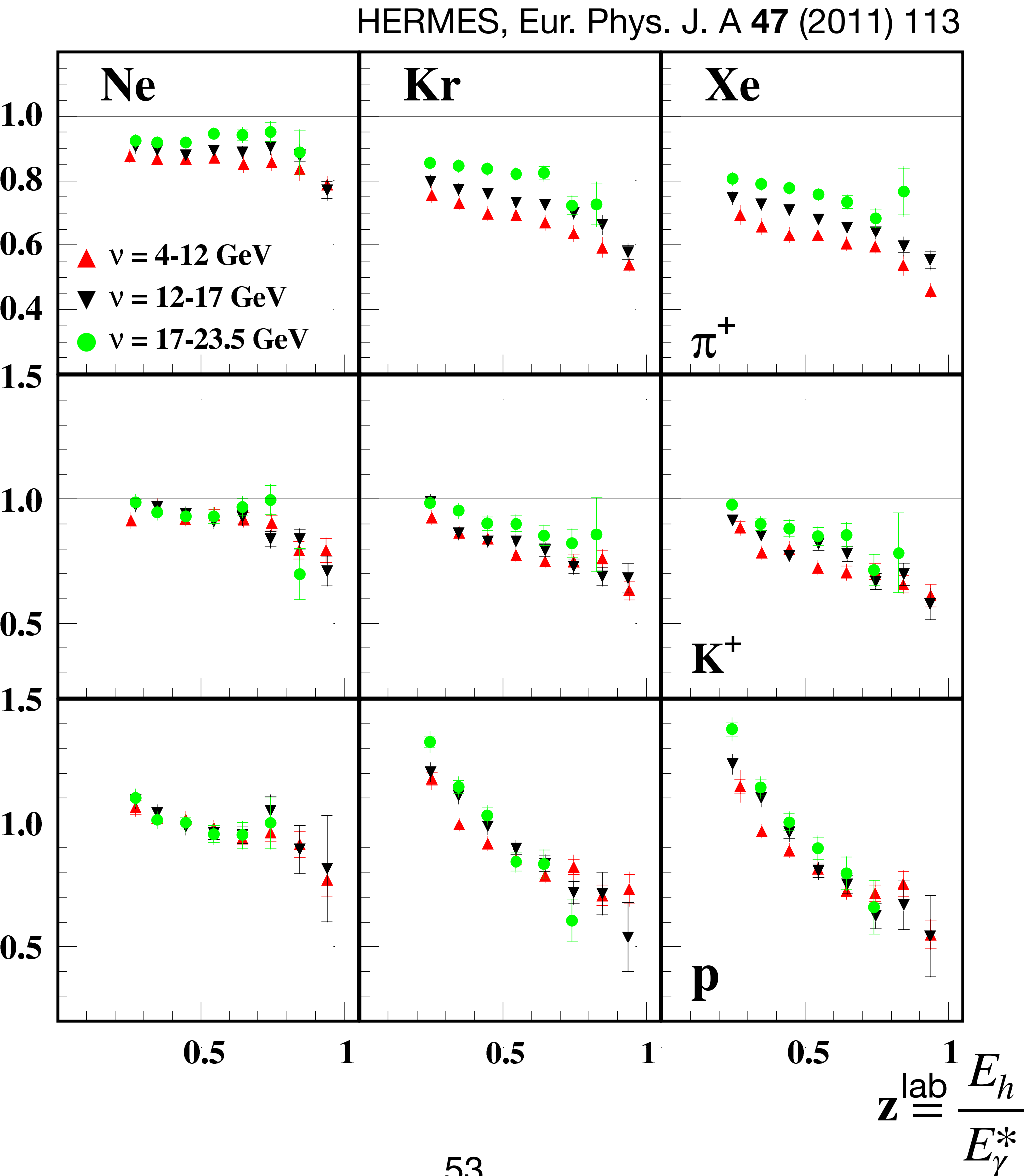
- rescattering (small)

- Partonic and hadronic processes: different signature

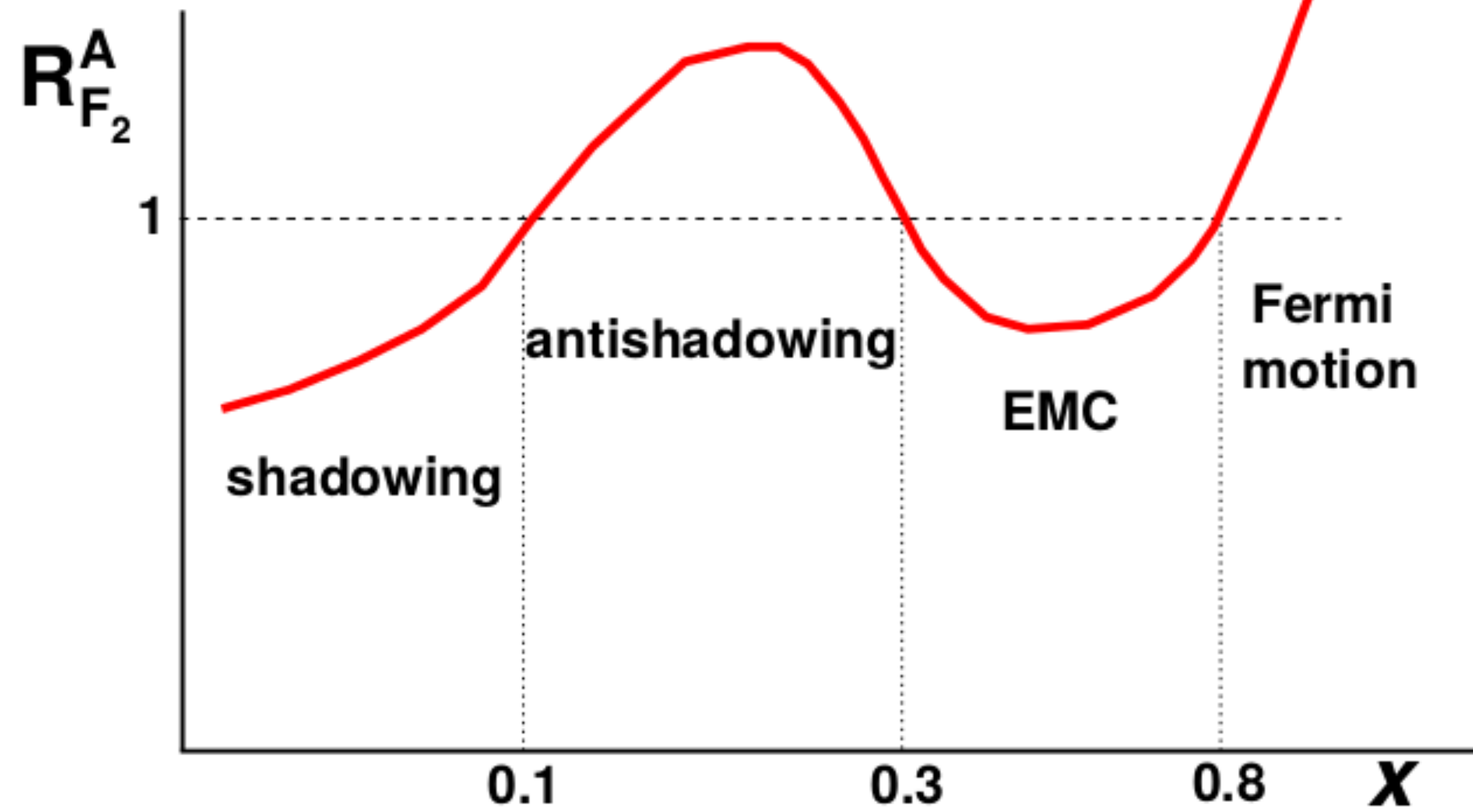
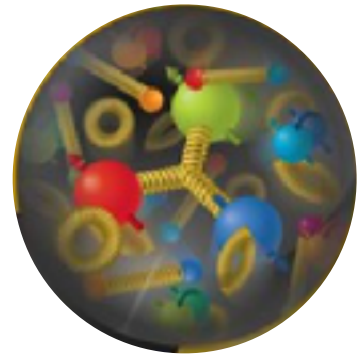
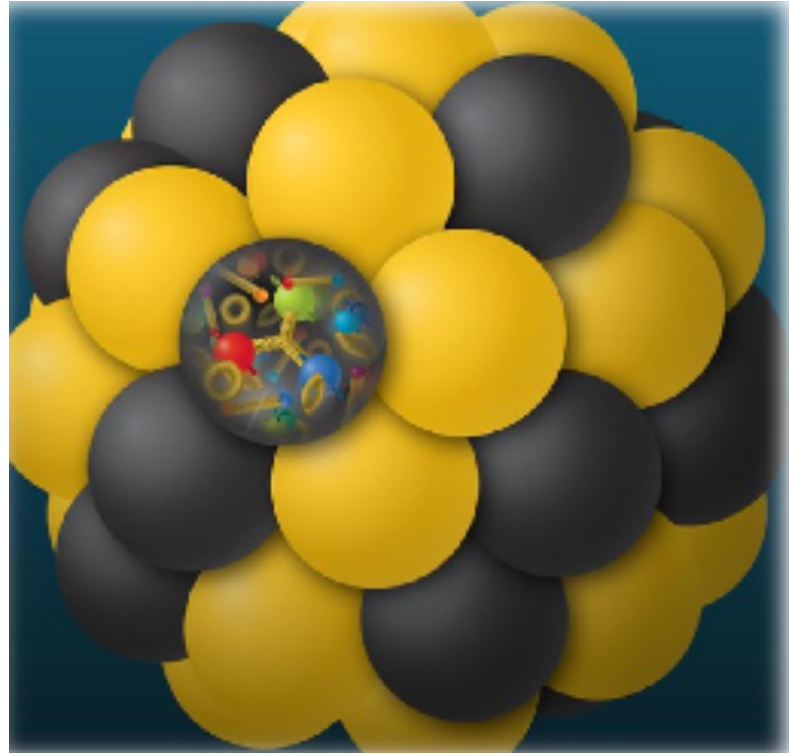
➡ probe space-time evolution of hadron formation

Multiplicity ratios

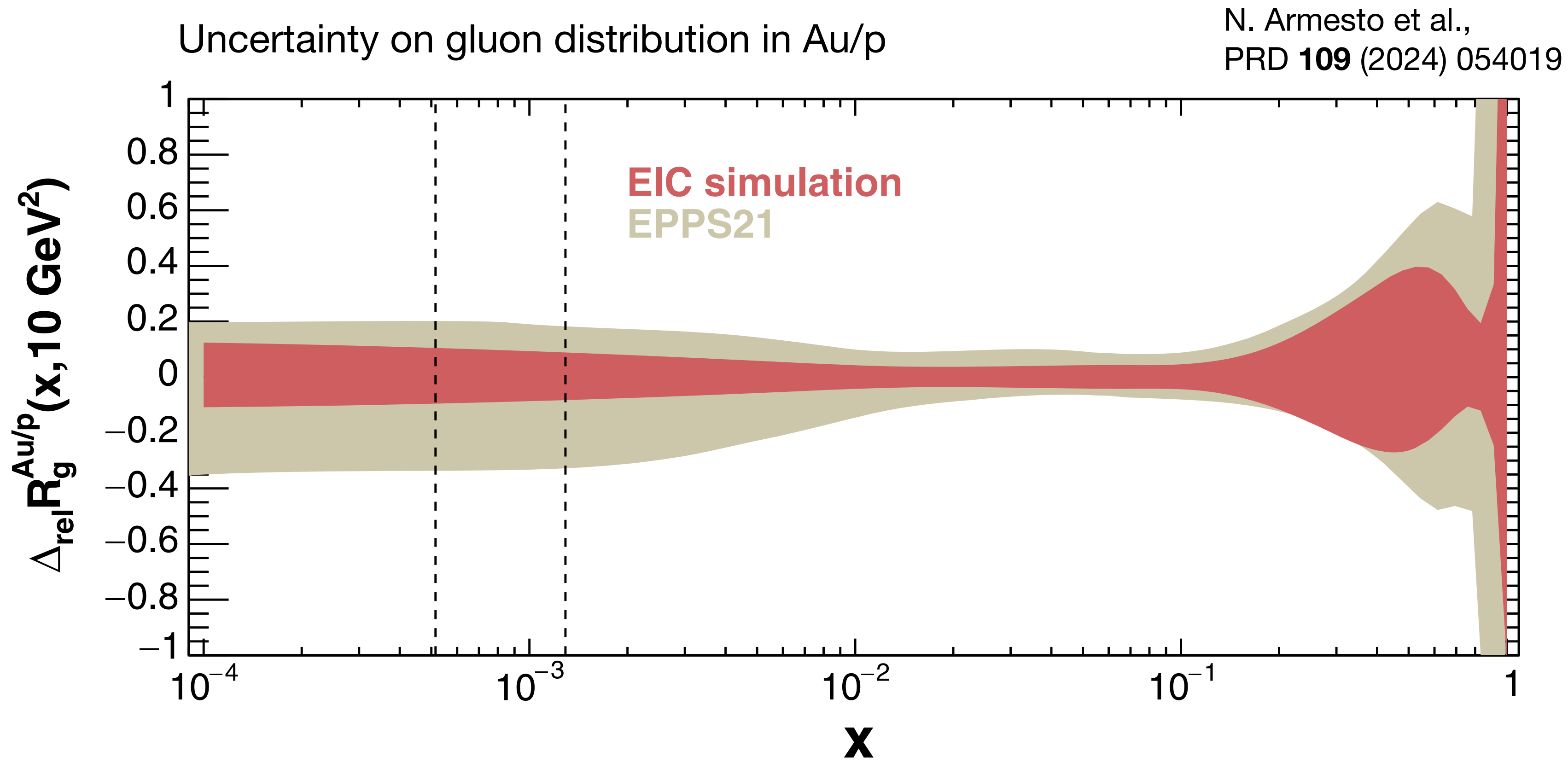
$$R_A^h = \frac{\left(\frac{N^h}{N_{DIS}}\right)_A}{\left(\frac{N^h}{N_{DIS}}\right)_D}$$



Nuclear PDFs

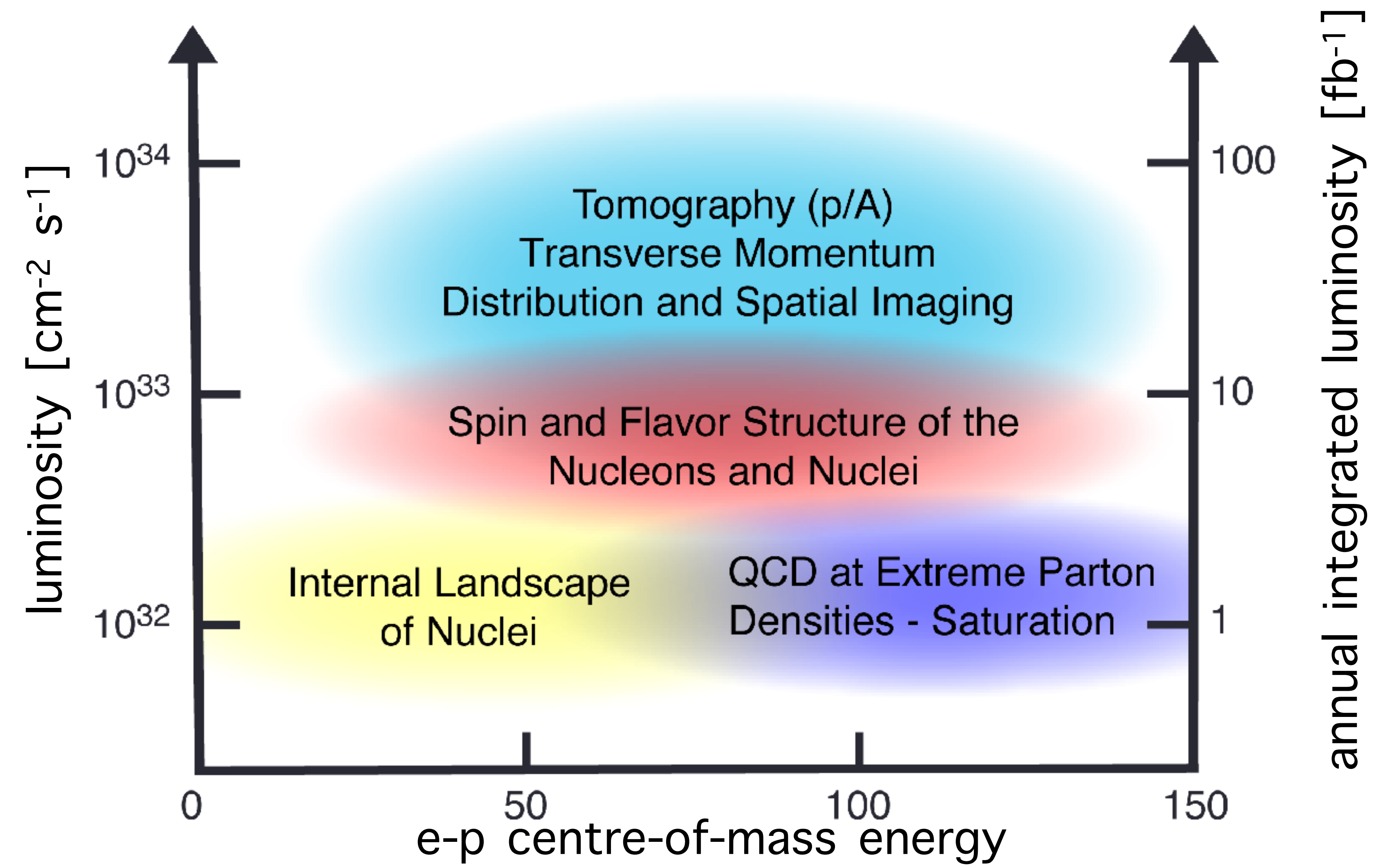


Nuclear PDFs at EIC



Inclusive e-Au data only:
constrain of nuclear PDF one single nucleus!

Luminosity and COM E needs for physics topics



Early science programme

	Species	Energy (GeV)	Luminosity/nucleon per year (fb ⁻¹)	Electron polarization	p/A polarization
YEAR 1	e+Ru or e+Cu	10 x 115	0.9	NO (Commissioning)	N/A
YEAR 2	e+D e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS
YEAR 3	e+p	10 x 130	4.95 - 5.33	LONG	TRANS and/or LONG
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG	N/A TRANS and/or LONG
YEAR 5	e+Au e+3He	10 x 100 10 x 166	0.84 8.65	LONG	N/A TRANS and/or LONG

J. Lajoie,
Early Science Workshop
April 24–25, 2025

Summary

EIC with ePIC can address various aspects of the nucleon and nuclear structure through:

- Precise inclusive and semi-inclusive DIS measurements to probe the parton spin contribution to the nucleon spin.
- Measurements for 3D (spin-dependent) tomography in momentum space and position space.
- Measurements on a large variety of nuclei:
 - understand nuclear structure
 - probe gluon saturation
 - study the space-time evolution of hadron formation.

Close out

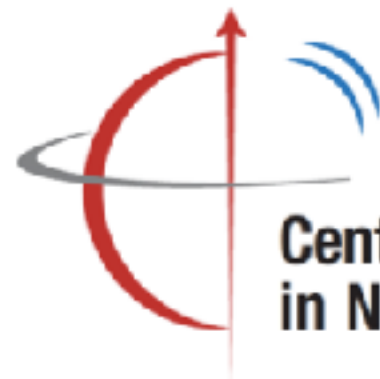
Thank you very much

- to Albergue juvenil Argentina of Benicàssim

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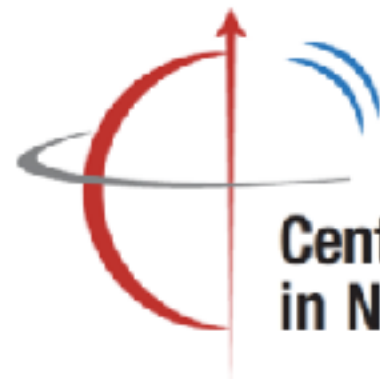


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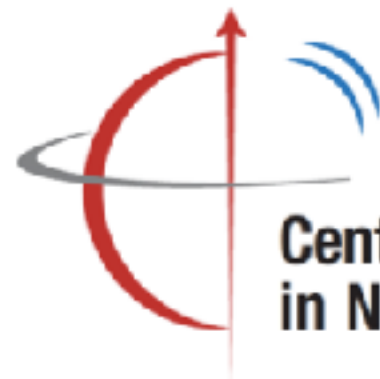
- Emanuele Nocera
- Davide Gamba
- Francesco Bossu
- Pia Zurita
- Ignazio Scimemi
- Carlos Muñoz Camacho

- Salvatore Fazio
- Barbara Pasquini
- Tuomas Lappi
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- to the participants presenting their work

and to all of you!

