Physics analysis

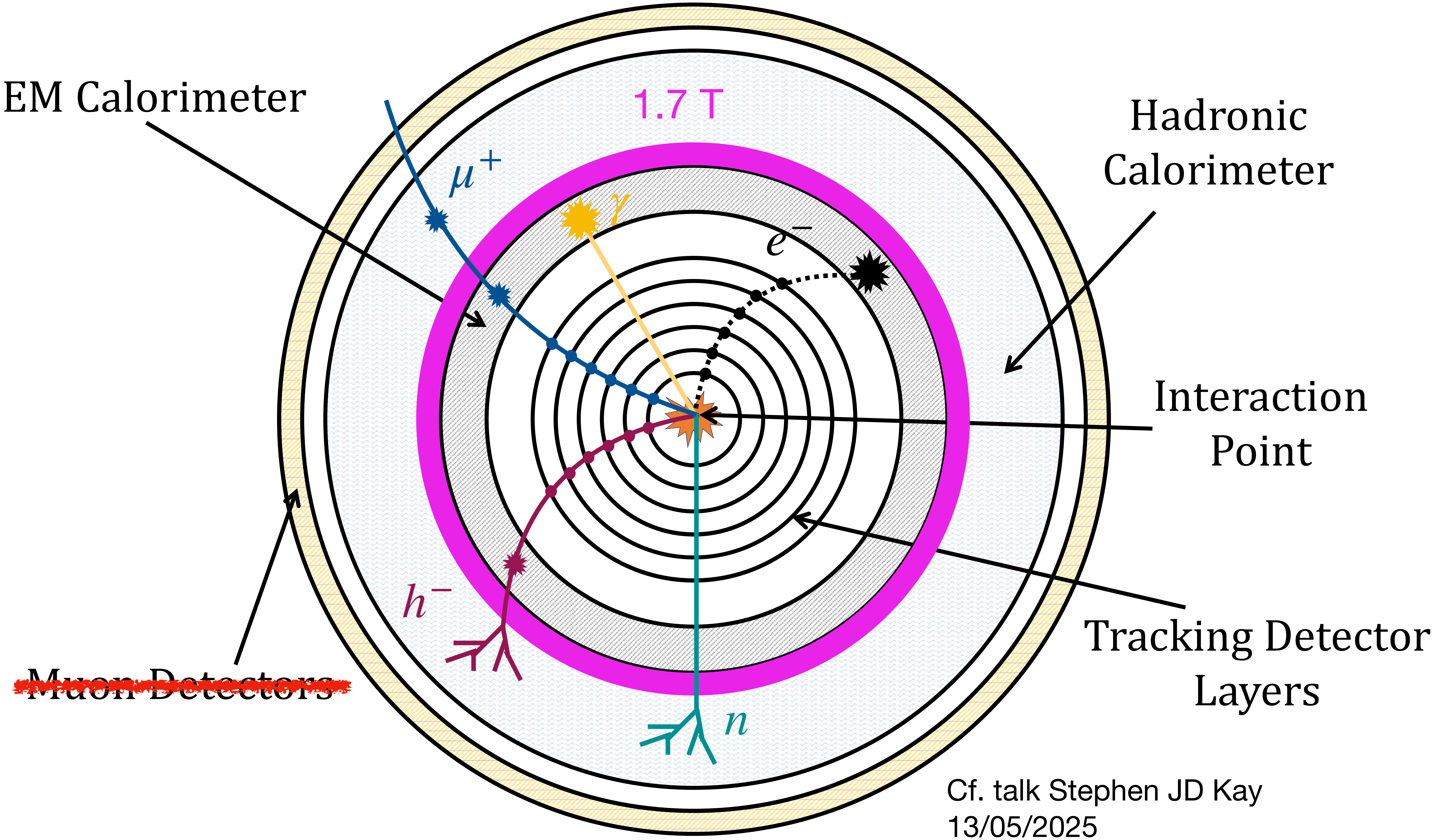
AdT

Comunidad de Madrid

Charlotte Van Hulse
University of Alcalá

HSF-India/ePIC Workshop
Mumbai, India
May 13–17, 2025

The electron-proton/ion collider (ePIC) detector



Cf. talk Stephen JD Kay
13/05/2025

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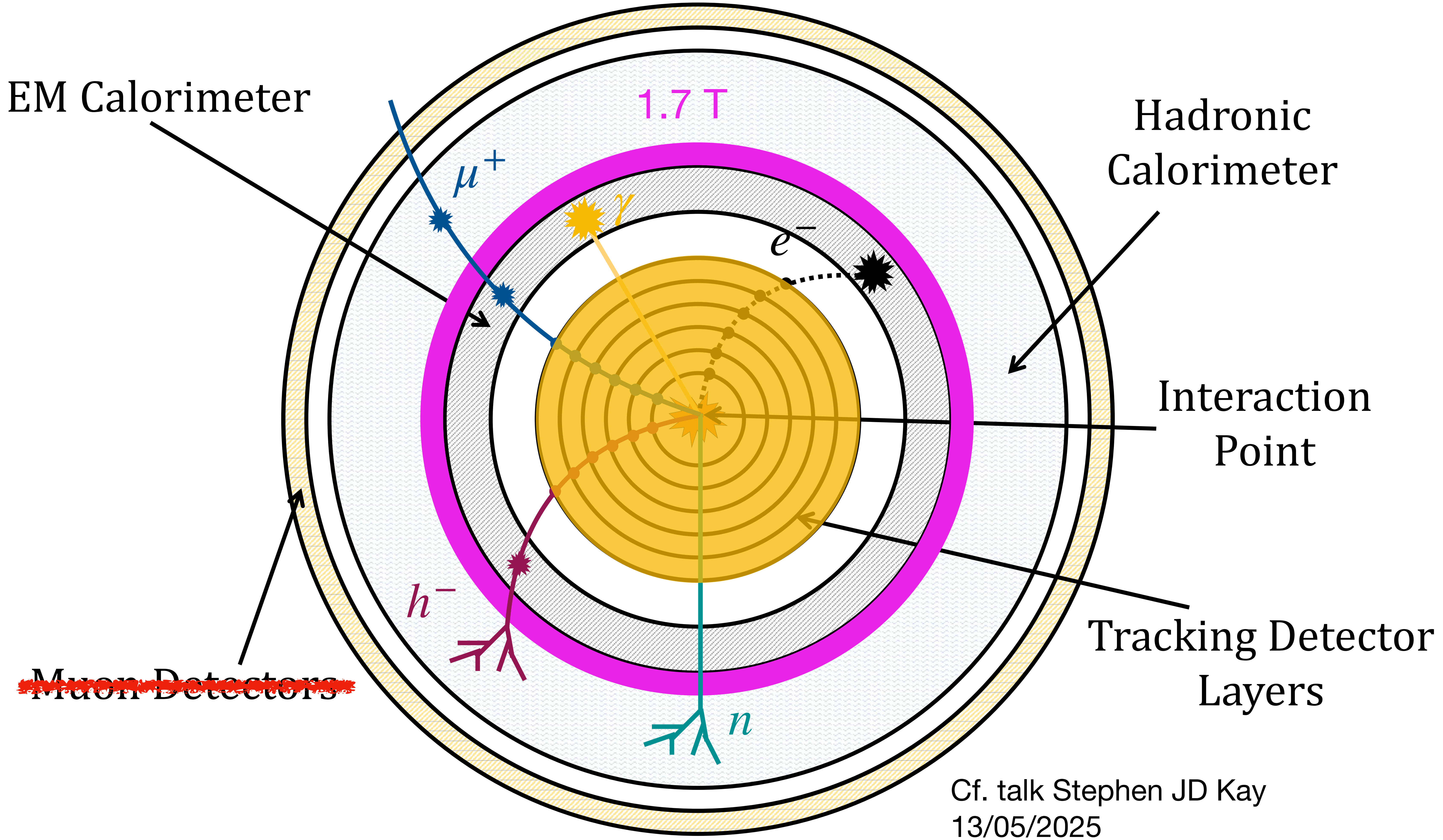

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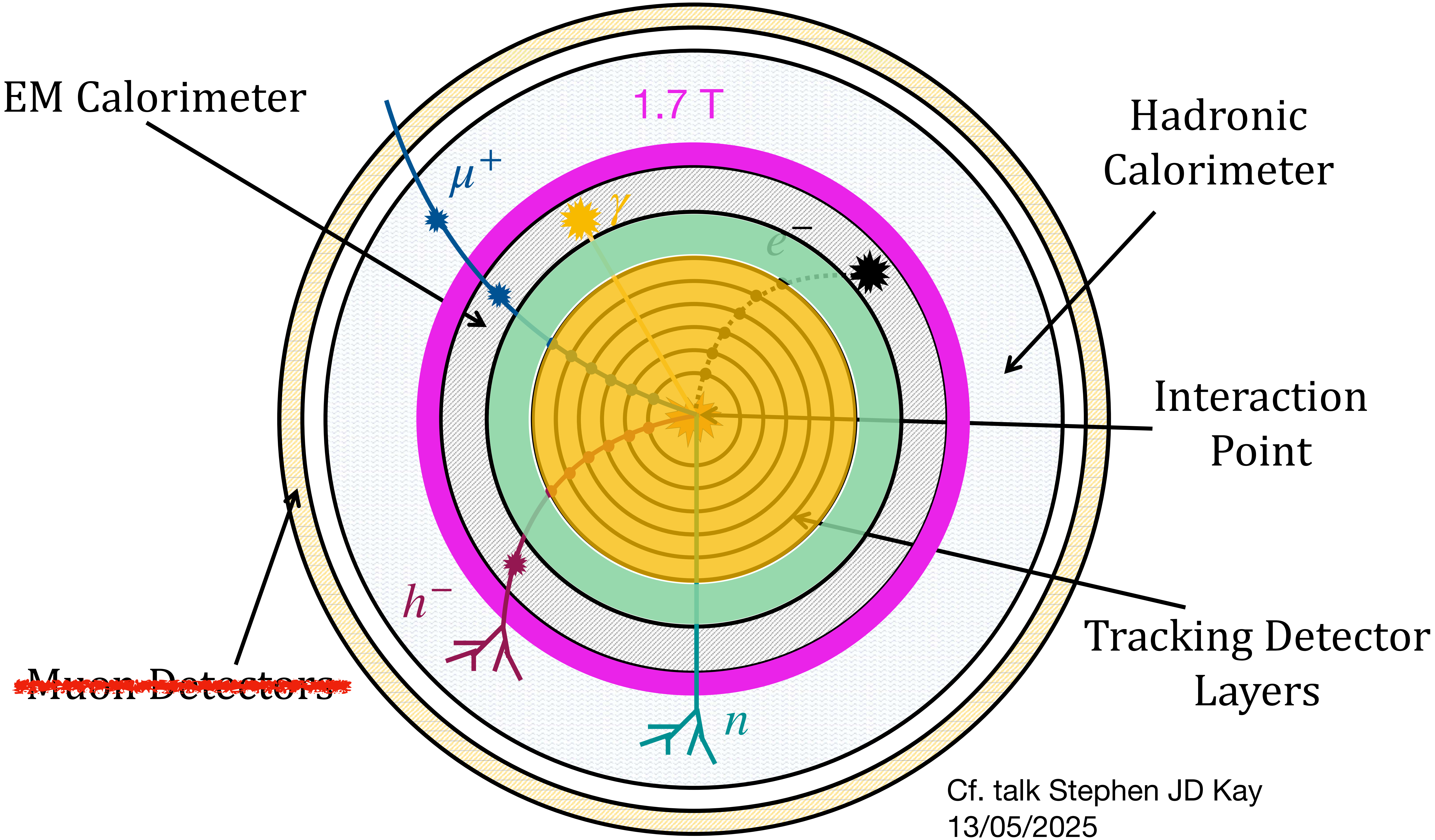
Electric signal

The electron-proton/ion collider (ePIC) detector



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Electric signal

Cherenkov light converted to electric signal

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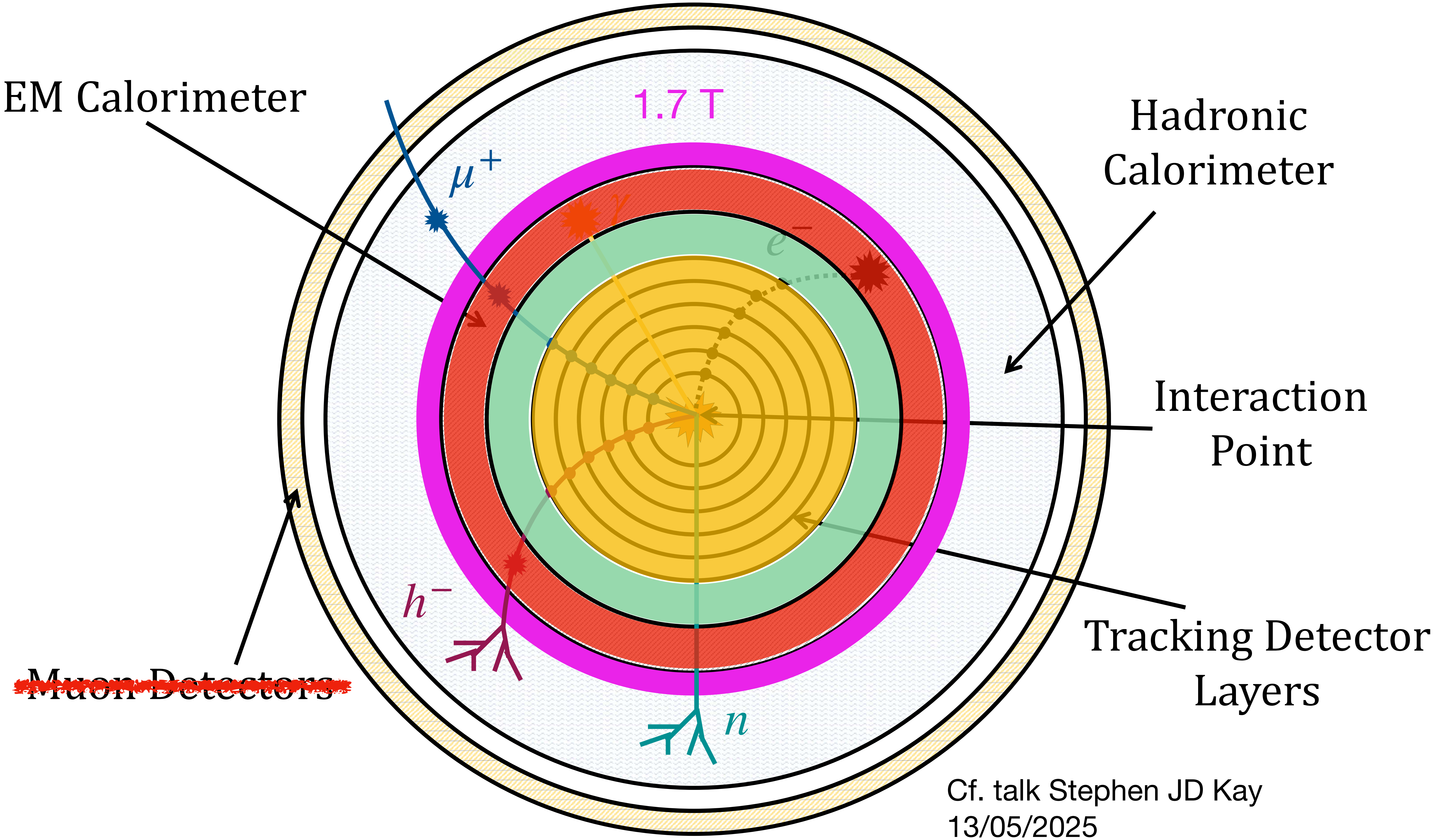

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Light converted to electric signal

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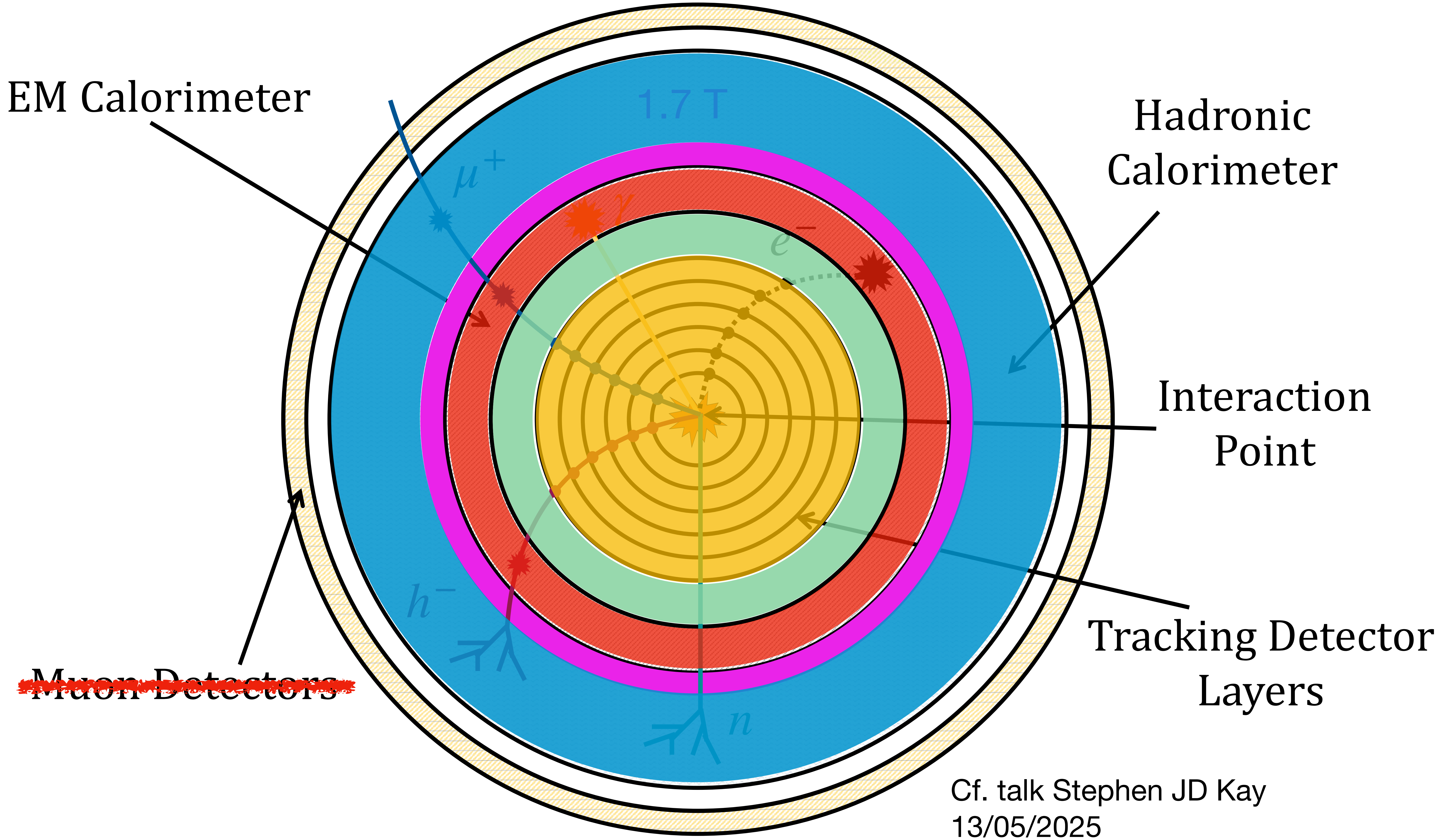

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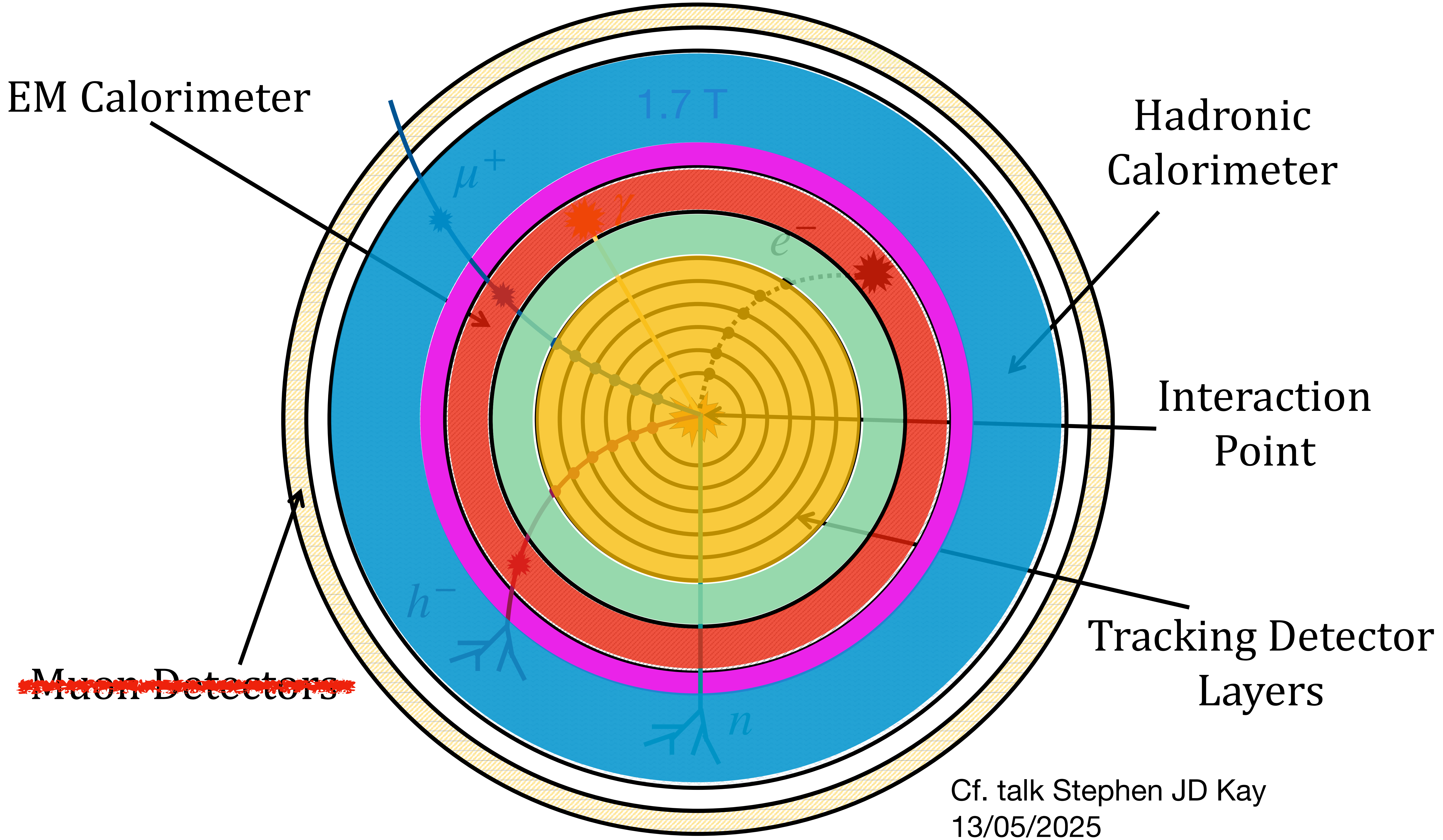

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calibration →

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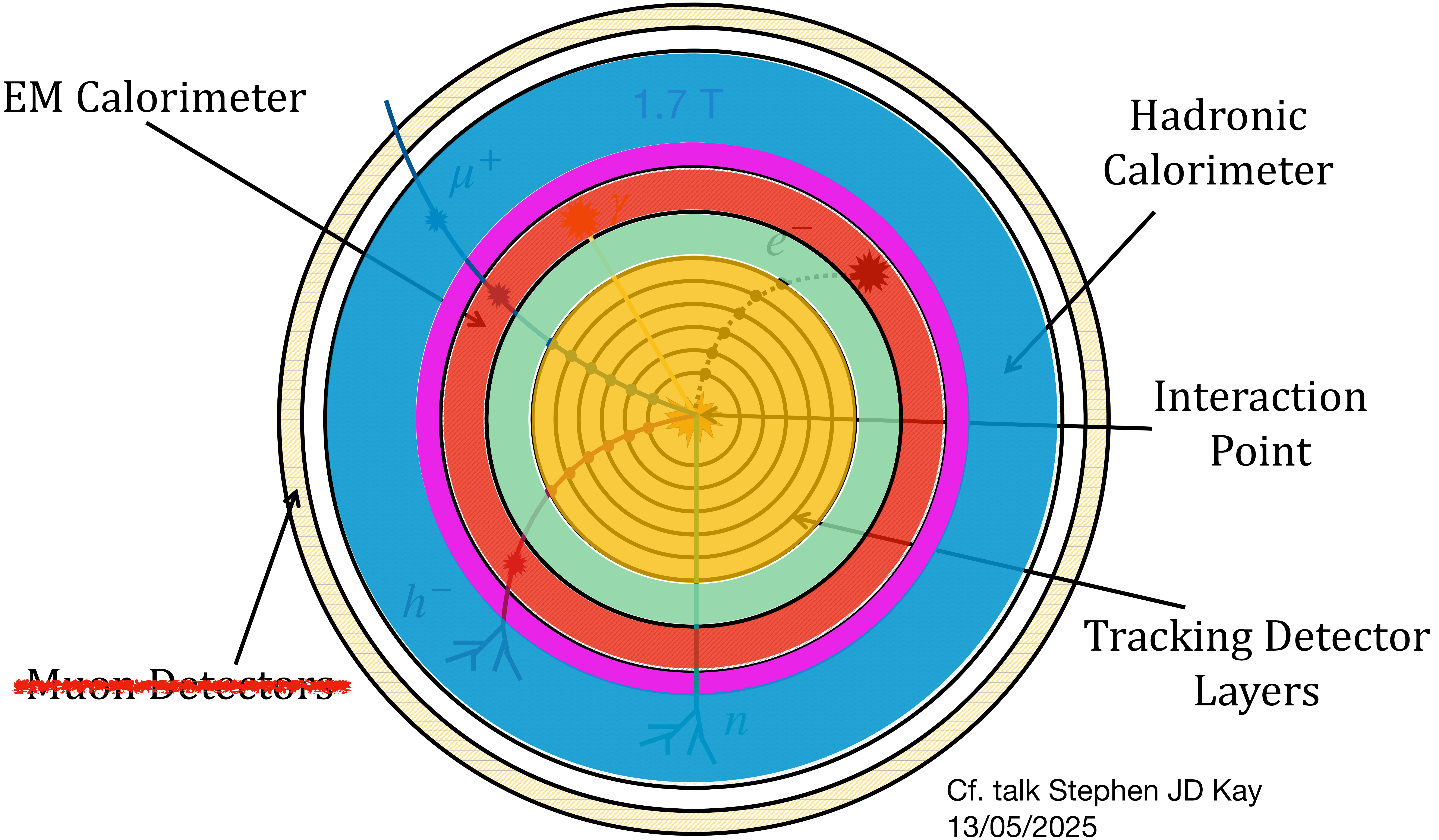

Cf. talk Stephen JD Kay 13/05/2025

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calibration →

Collection of hits with energy deposition timing information

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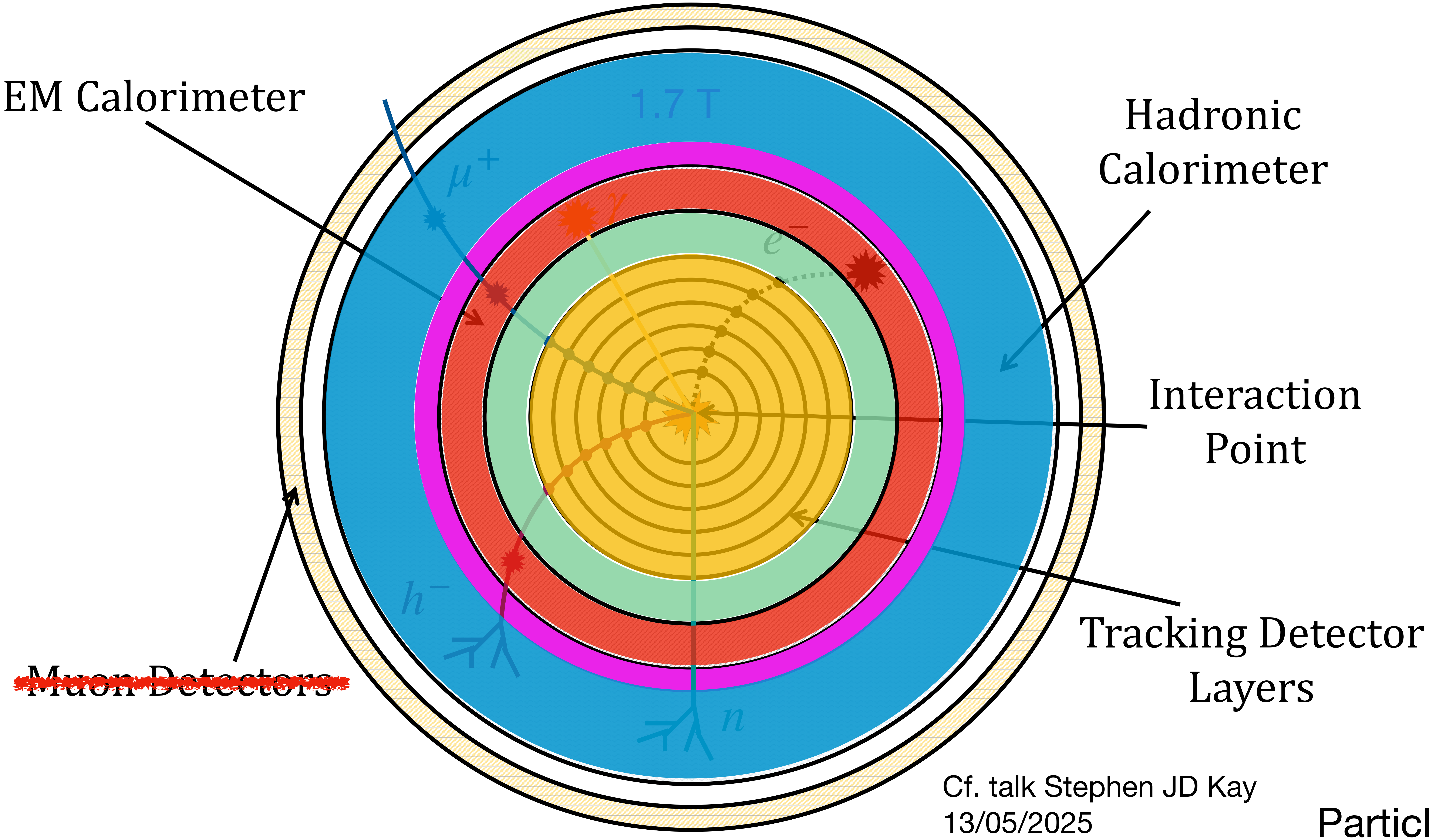

Cf. talk Stephen JD Kay
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Electric signal

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calibration →

Collection of hits with
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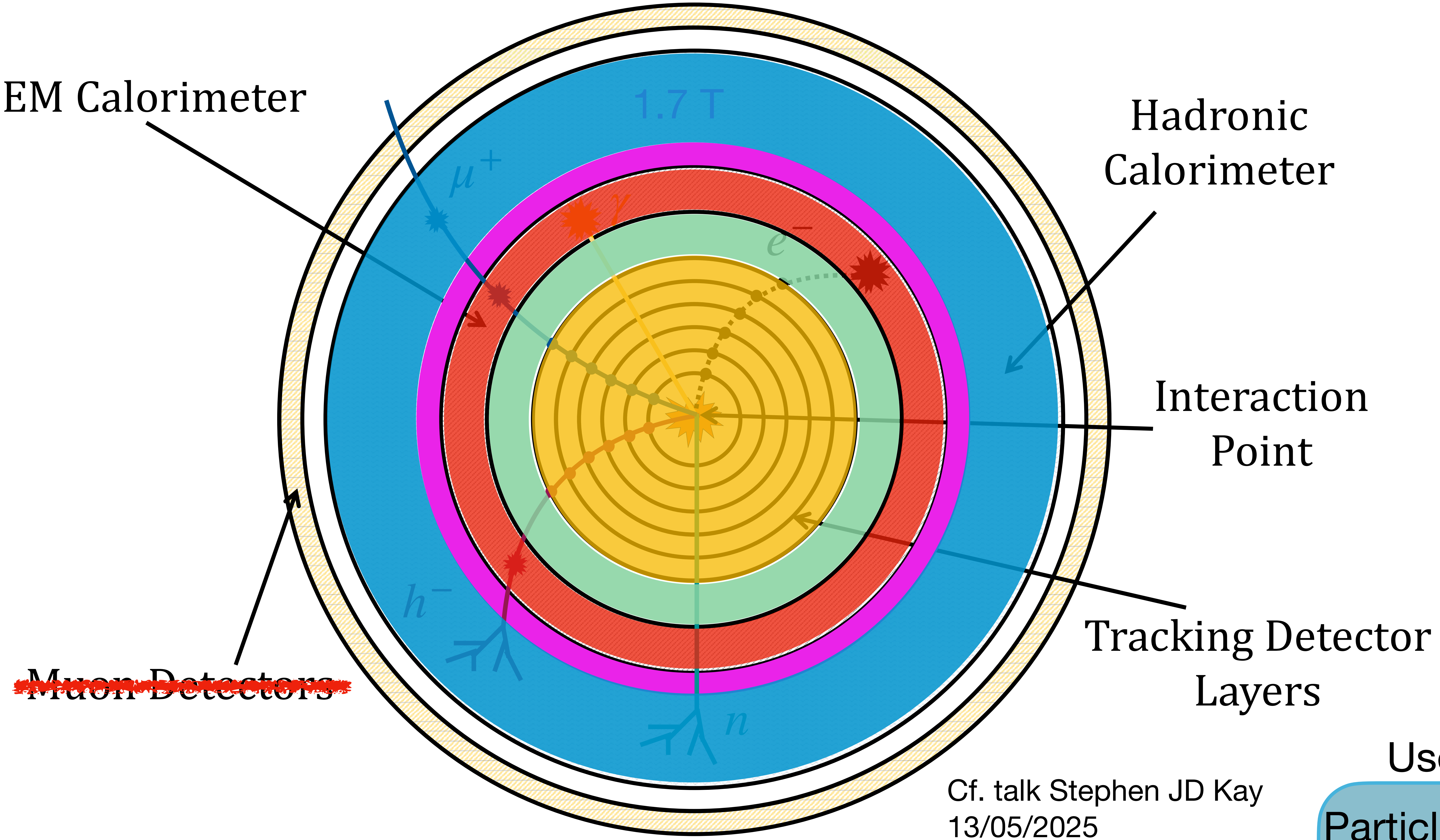
→ Particle information
momentum

→ energy

→ primary/secondary vertex

→ PID

The electron-proton/ion collider (ePIC) detector



Cf. talk Stephen JD Kay
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Electric signal
Cherenkov light converted to electric signal
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calibration → Collection of hits with energy deposition timing information

Used by analysers

- Particle information
- momentum
- energy
- primary/secondary vertex
- PID

From the available information to the observable

Common observables: cross sections or asymmetries of a specific process in deep-inelastic scattering (DIS).

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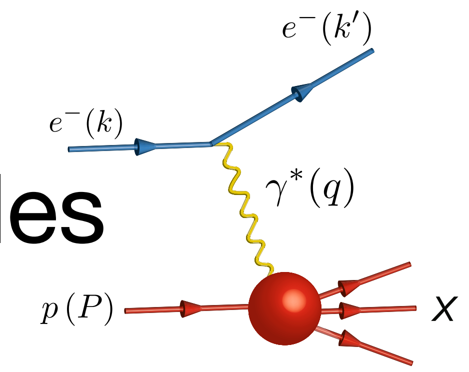
1 Reconstruction of DIS variables



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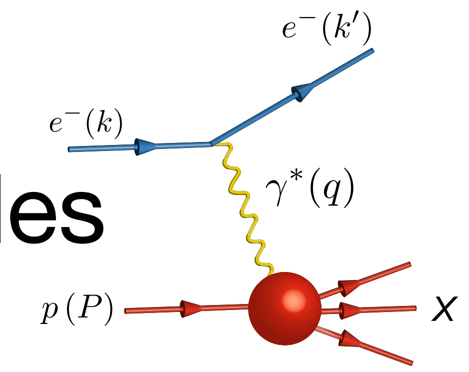

Various methods exist:

- Using the information from the scattered lepton only (electron method).
- Using the information from all final-state particles but the scattered lepton (Jacquet-Blondel method): useful when the scattered lepton is not detected.
- Using information from all final-state particles and the scattered lepton (Double-angle method, Σ method):
  Provides better resolution than the electron method in some kinematic region (at low y)

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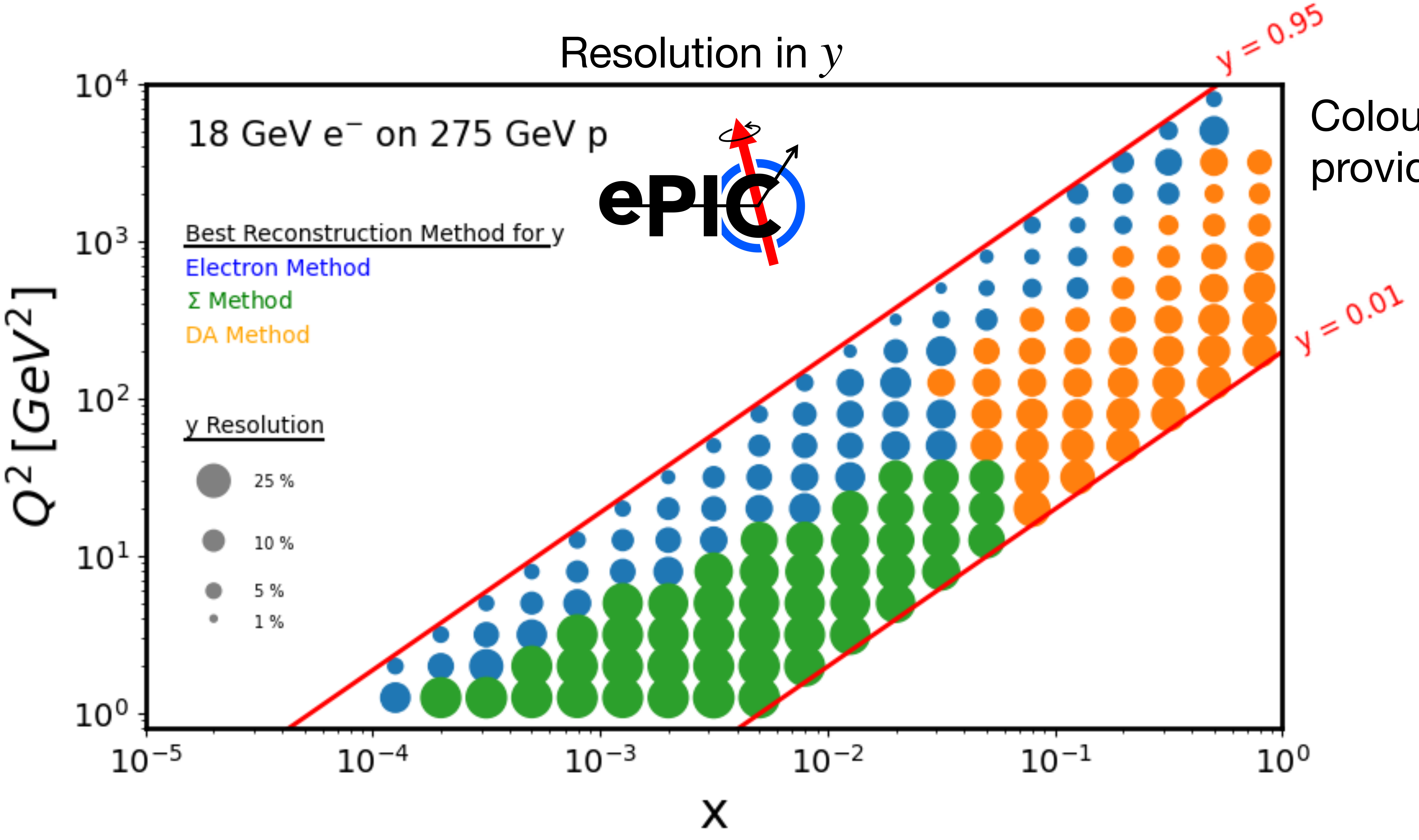
1 Reconstruction of DIS variables



Colour indicates method providing best resolution.

From the available information to the observable

Common observables: cross sections or asymmetries of a specific process in deep-inelastic scattering (DIS).

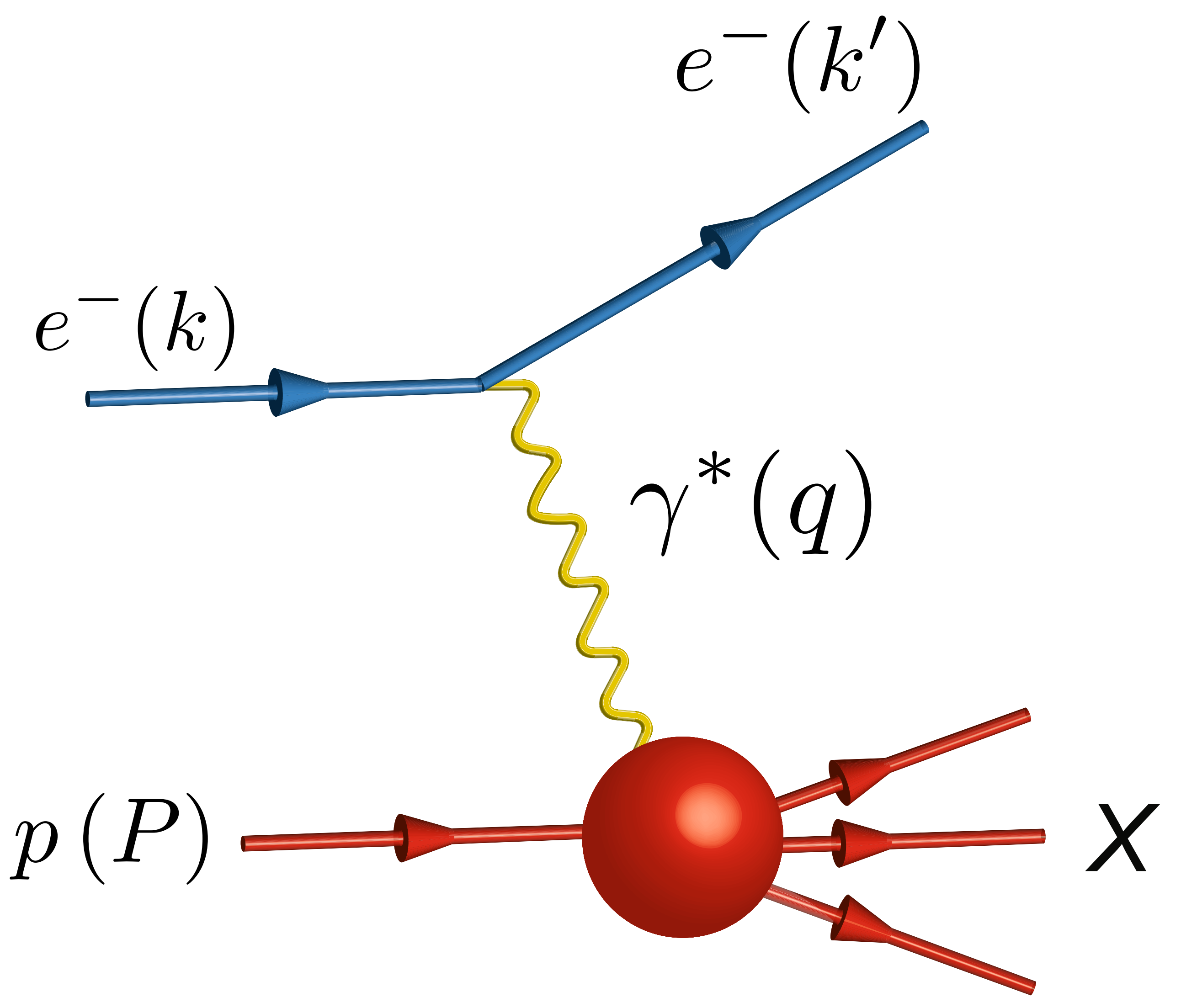
1 Reconstruction of DIS variables – electron method (requires PID for electron)

$$Q^2 = -q^2 = -(k - k')^2$$

$$x_B = \frac{Q^2}{2P \cdot q} \quad \text{(Bjorken-x)}$$

$$y = \frac{P \cdot q}{P \cdot k} \overset{\text{proton rest frame}}{=} \frac{E_e - E'_e}{E_e} \quad \text{(inelasticity)}$$

$$W^2 = (P + q)^2 = m_p^2 - Q^2 + 2P \cdot q \quad \text{(photon-proton centre-of-mass energy)}$$



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Common observables: cross sections or asymmetries of a specific process in deep-inelastic scattering.

2 Selection of DIS events

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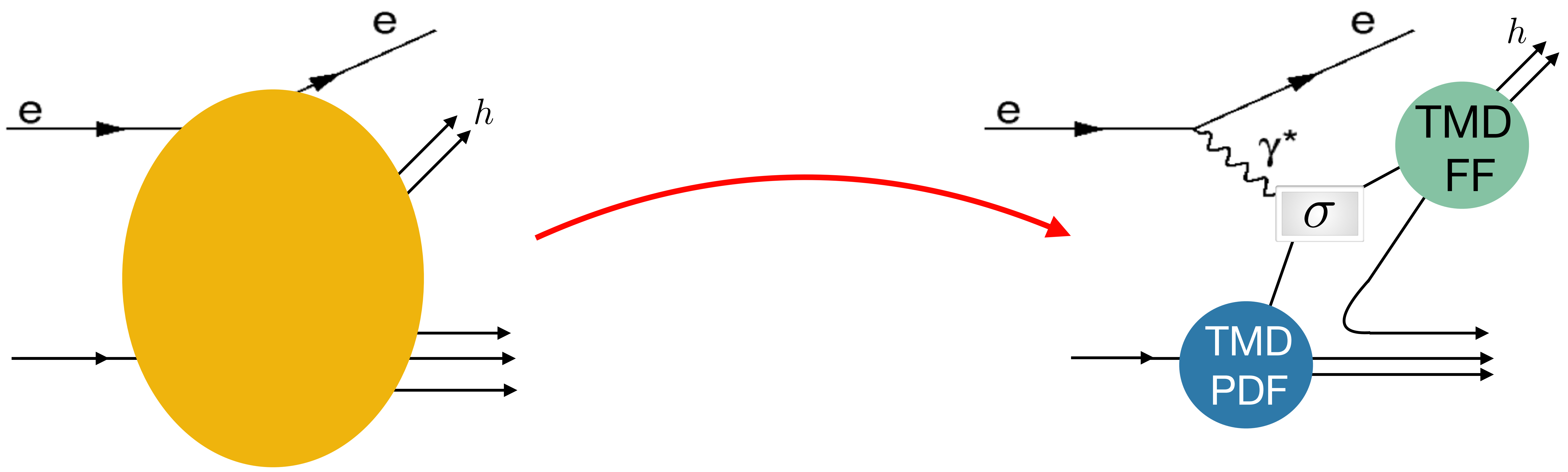
$Q^2 > 1$ GeV^2 selection of DIS regime



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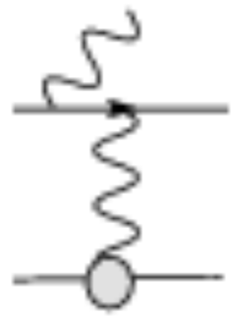
remove events with degraded momentum resolution $0.01 < y < 0.95$ limit contributions from QED radiation



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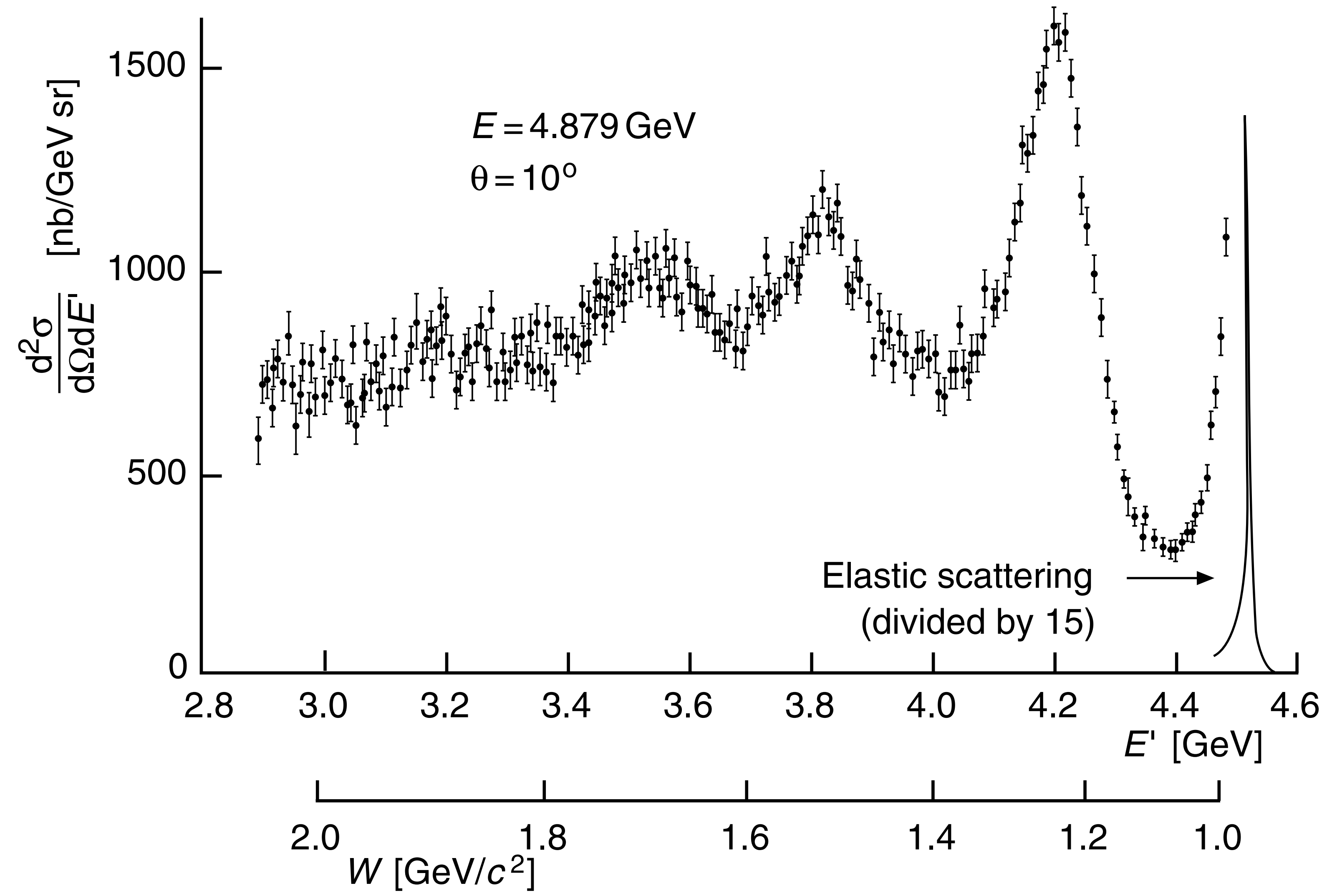
2 Selection of DIS events

$Q^2 > 1$ GeV^2 selection of DIS regime

remove events with degraded momentum resolution $0.01 < y < 0.95$ limit contributions from QED radiation

$W^2 > 10$ GeV^2 avoid region dominated by baryon-resonance production



W. Bartel et al., Phys. Lett. B **28** (1968) 148.

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3 Selection requirements specific to process under study

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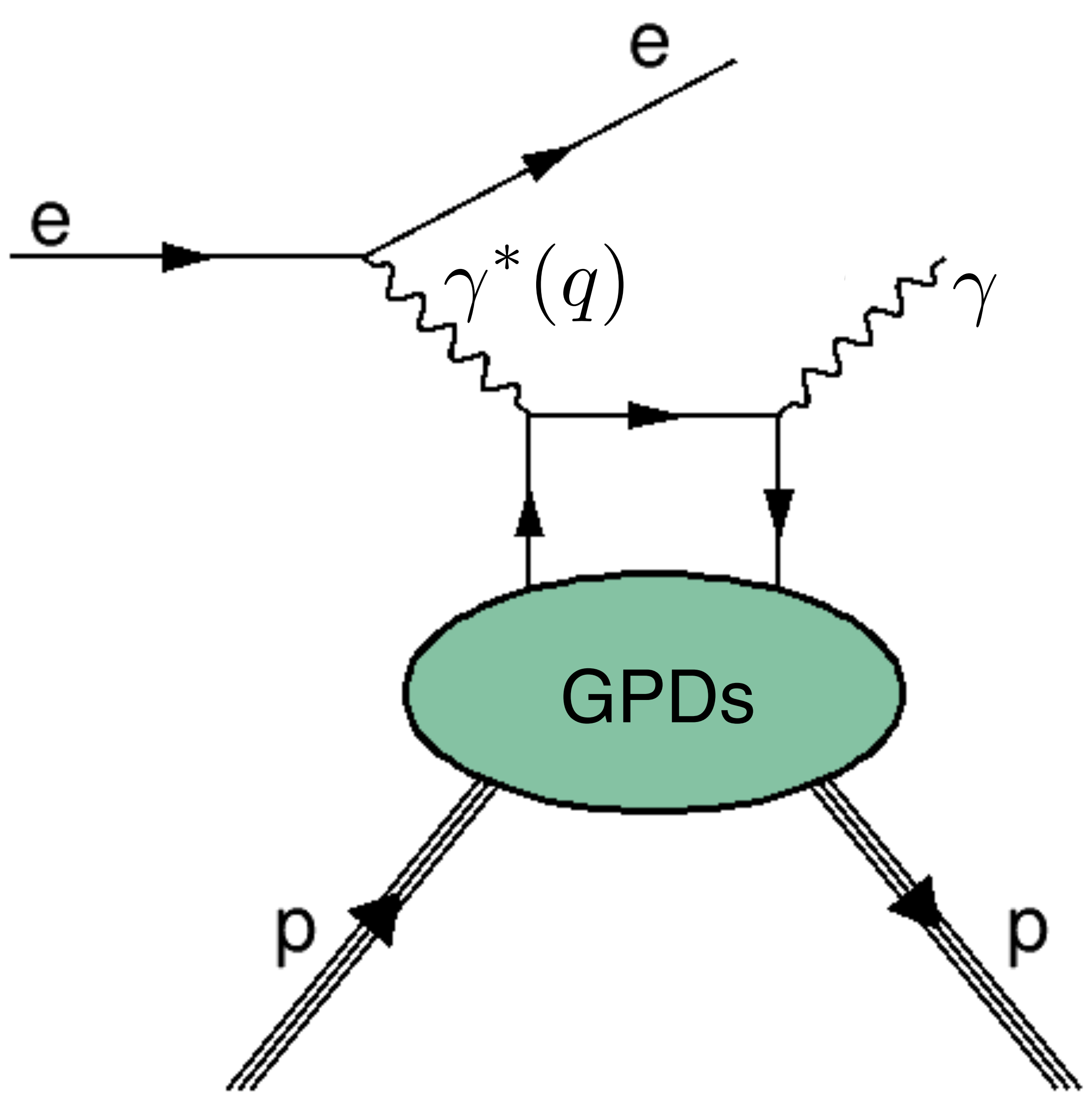

- signal in electromagnetic calorimeter
- absence of reconstructed track linked to cluster of electromagnetic calorimeter
- potentially: detection of proton in far-forward system
- exclusivity cuts (e.g. cuts on mass from scattered proton reconstructed from information from the other particles)

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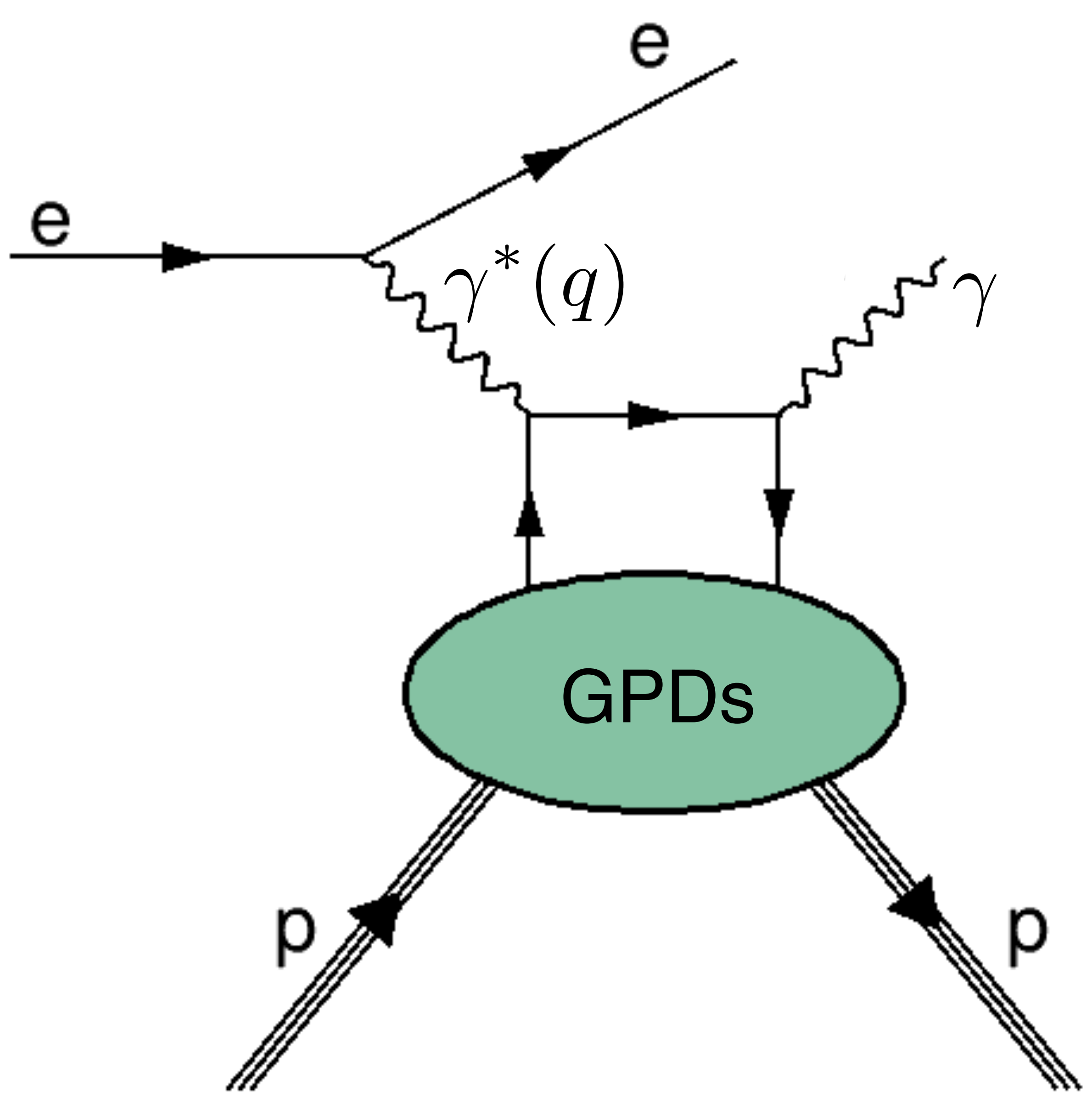

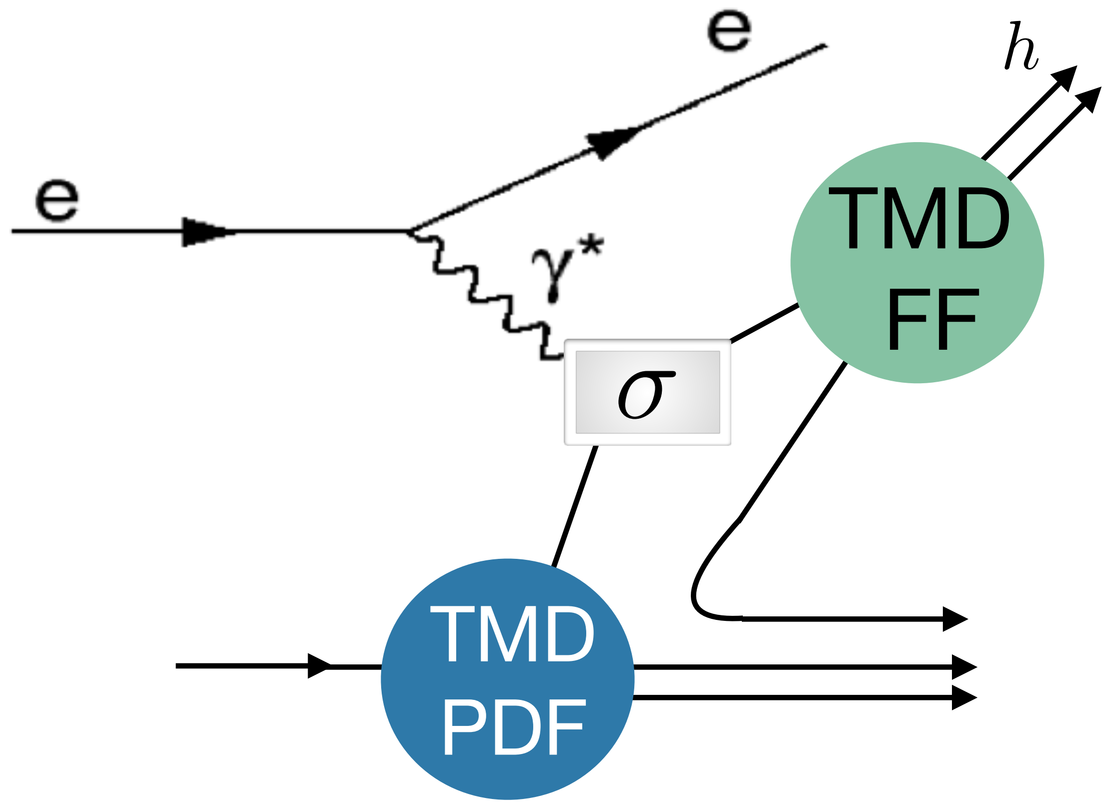

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- select additional charged particles
- collect information on their PID (weight).
- assign additional kinematic cuts (e.g. on z)

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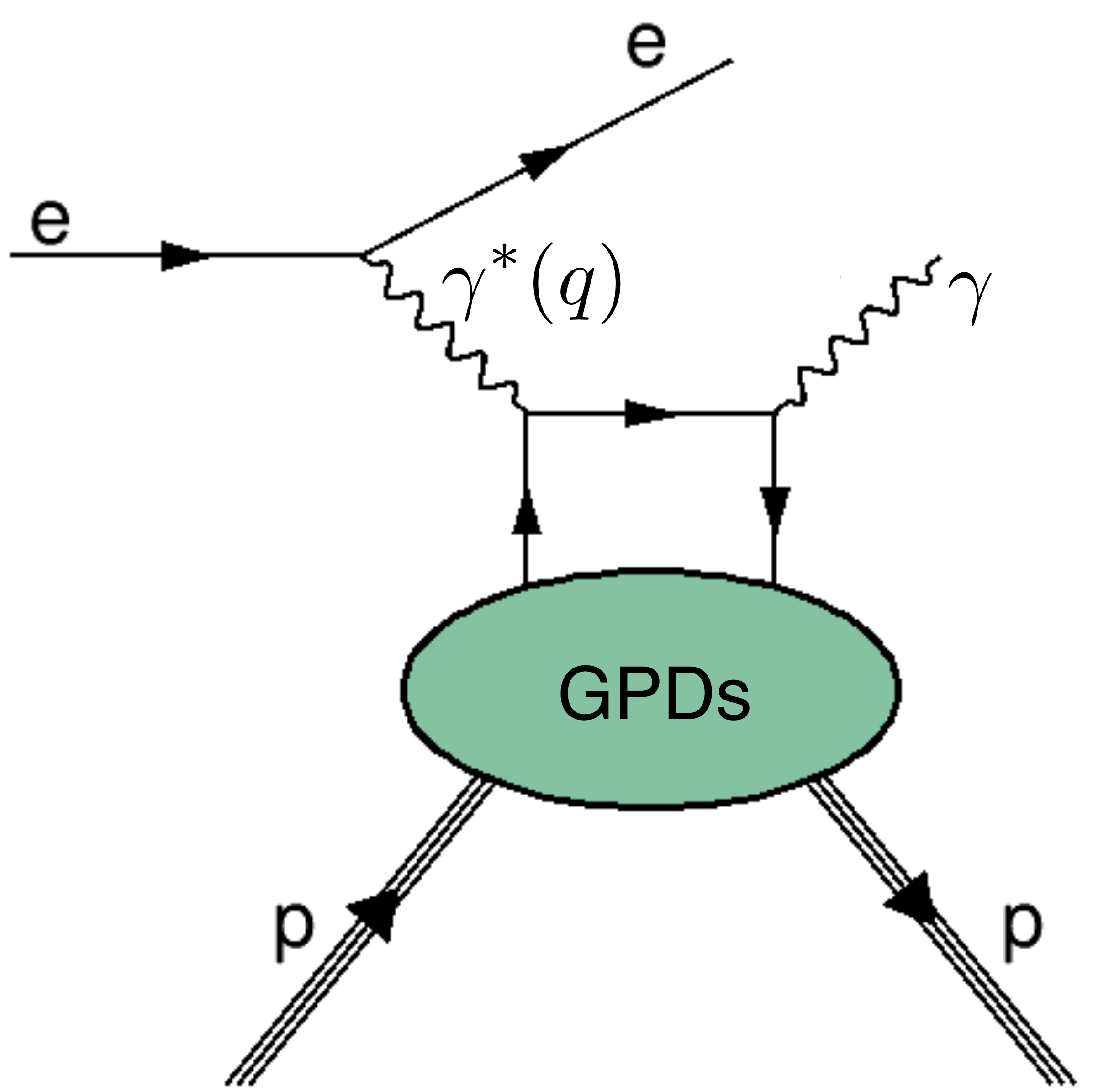

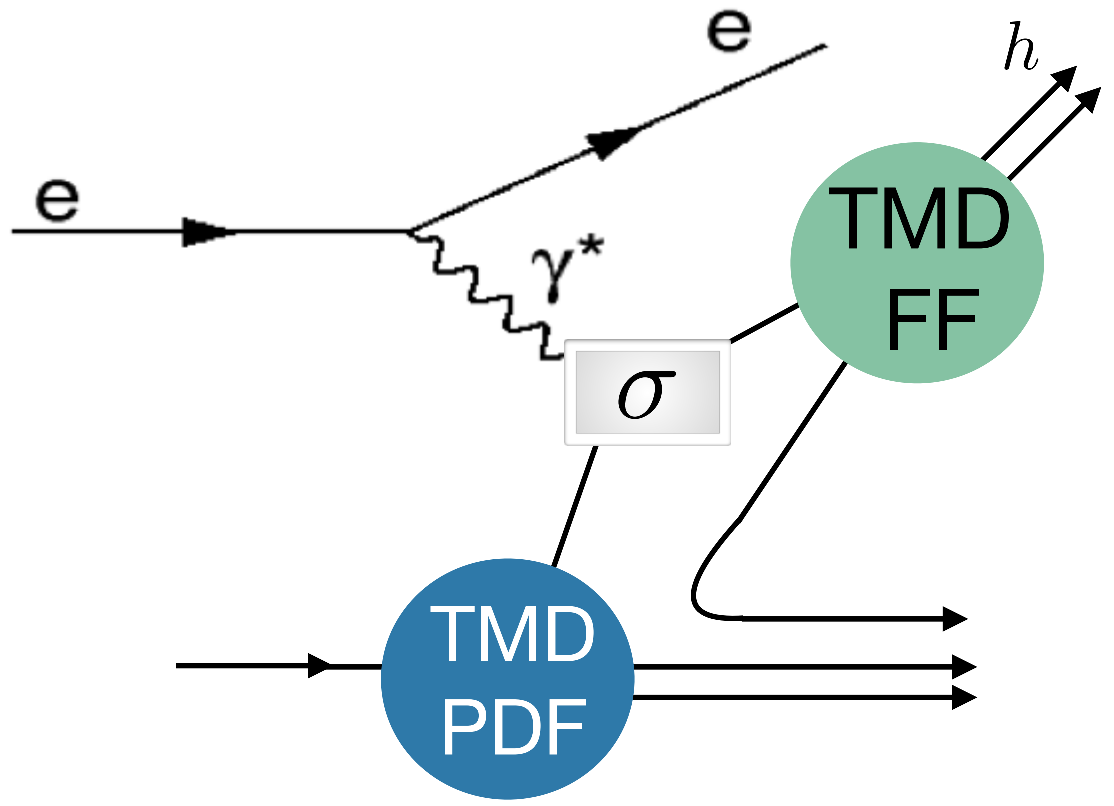

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Some selection criteria are motivated by physics requirements; others are motivated by detector limitations.

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$$\longrightarrow N$$

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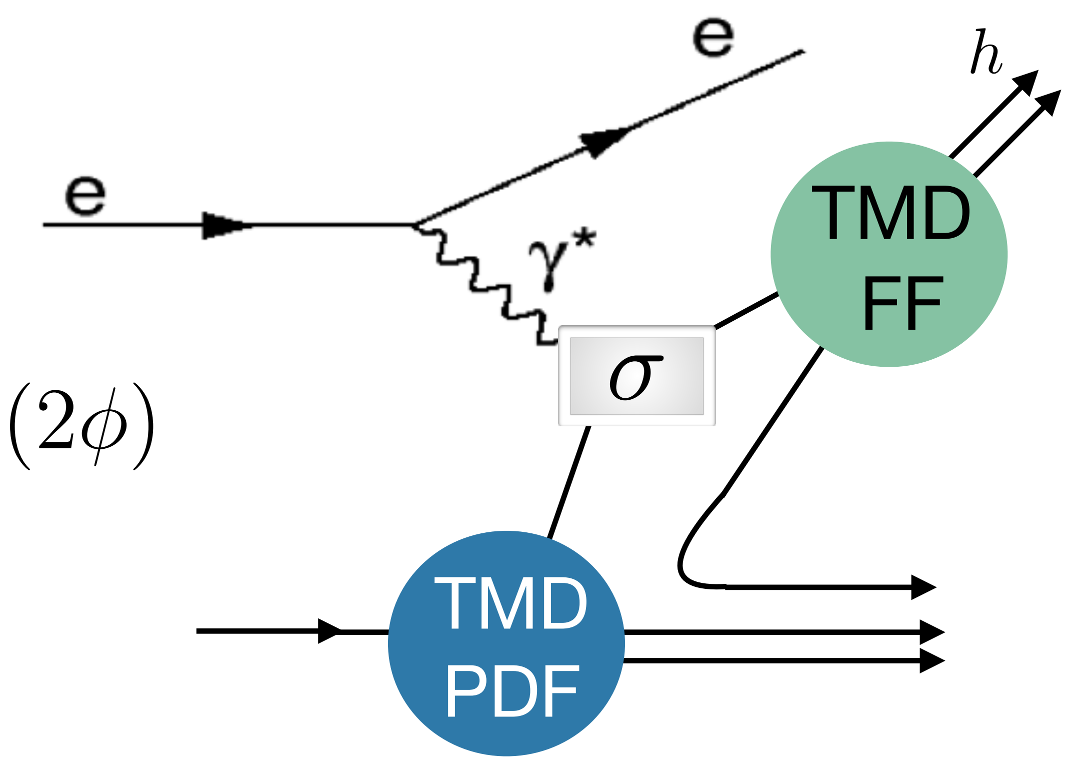
5 Corrections

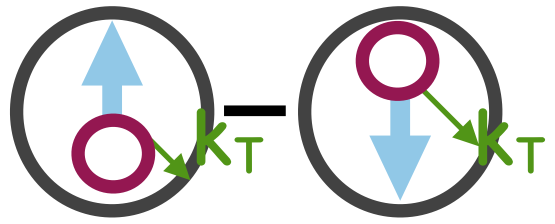
for
- tracking efficiency
- selection efficiency
- corrections for limited resolution
- corrections for limited detector acceptance
- background corrections:
  correct for contamination from processes other than that under study
- ….

On the importance of accounting for physics and detector effects

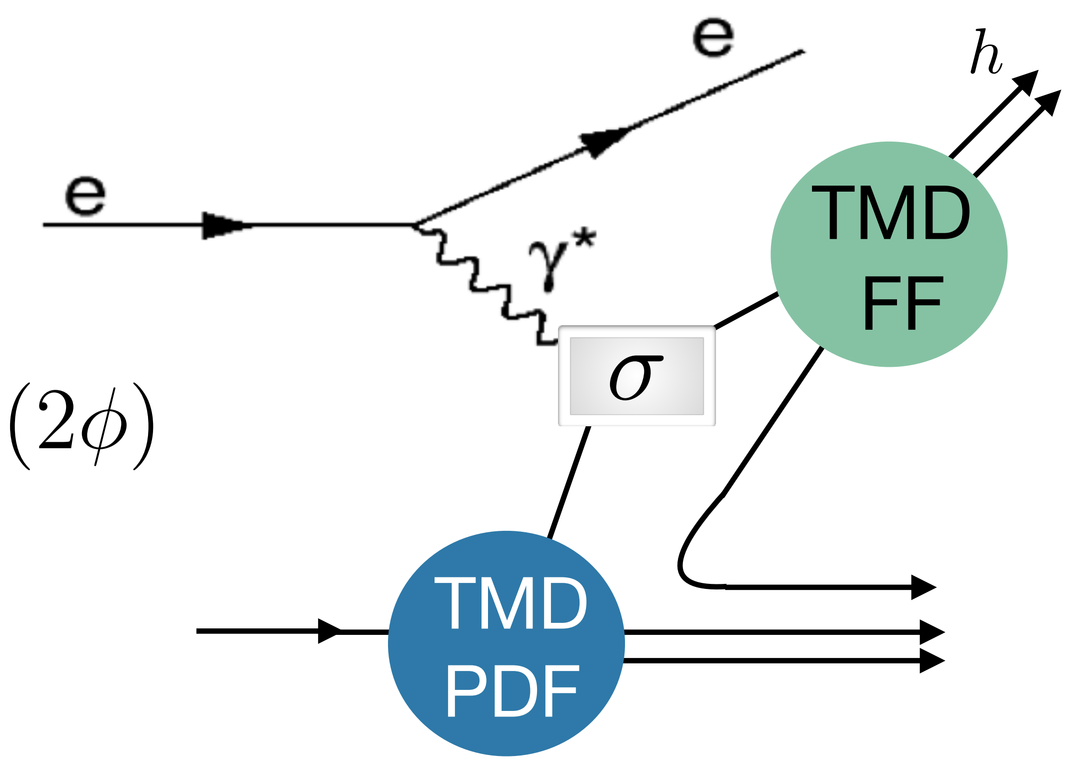


$$
\begin{aligned}
\sigma^h(\phi,\phi_S) &= \sigma^h_{UU}\Big\{1 + 2\langle\cos(\phi)\rangle^h_{UU}\,\cos(\phi) + 2\langle\cos(2\phi)\rangle^h_{UU}\,\cos(2\phi)\\
&+ \lambda_l\, 2\langle\sin(\phi)\rangle^h_{LU}\,\sin(\phi)\\
&+ S_L\Big[2\langle\sin(\phi)\rangle^h_{UL}\,\sin(\phi) + 2\langle\sin(2\phi)\rangle^h_{UL}\,\sin(2\phi)\\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

On the importance of accounting for physics and detector effects



$$\mathscr{C}\left[h_1^{\perp,q} \times H_1^{\perp,q}\right]$$



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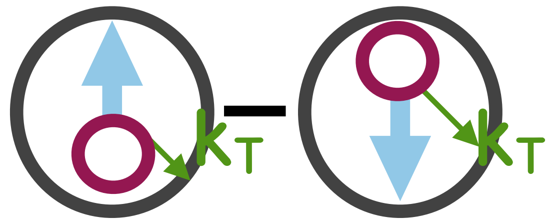
\end{aligned}$$

On the importance of accounting for physics and detector effects



$\langle\cos(2\phi_h)\rangle_{Born}(j)$ ← $\langle\cos(2\phi_h)\rangle_{meas}(i)$

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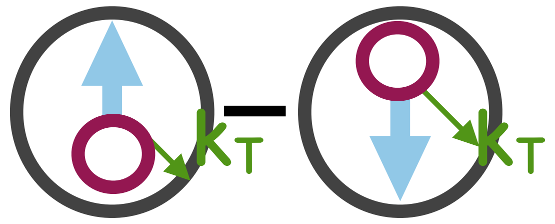

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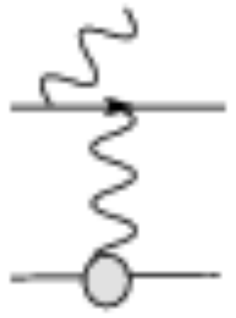
- QED radiate effects



(d)

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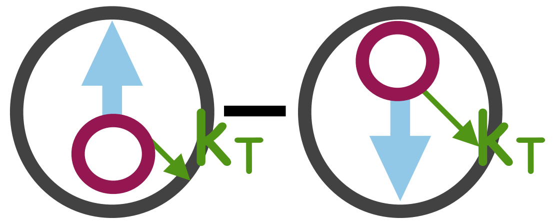

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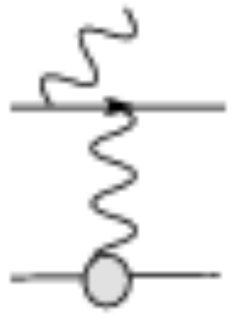

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- limited geometric and kinematic acceptance of detector

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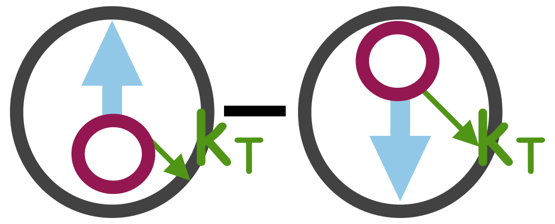

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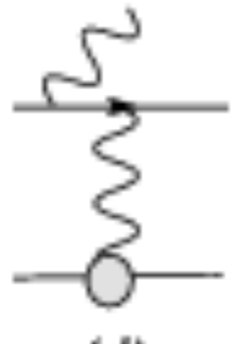
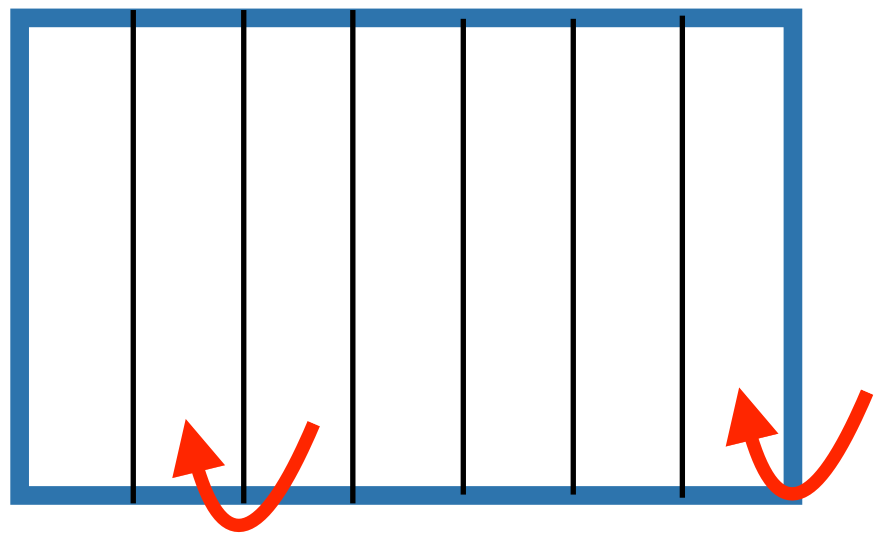


- limited geometric and kinematic acceptance of detector
- limited detector resolution



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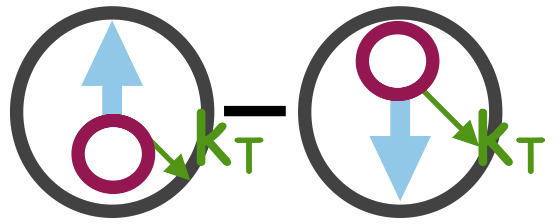

$$\langle\cos(2\phi_h)\rangle_{Born}(j) \quad \longleftarrow \quad \langle\cos(2\phi_h)\rangle_{meas}(i)$$

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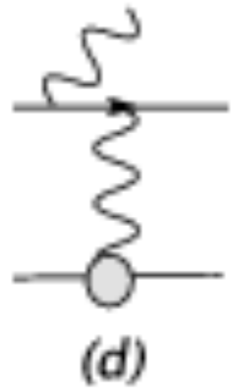

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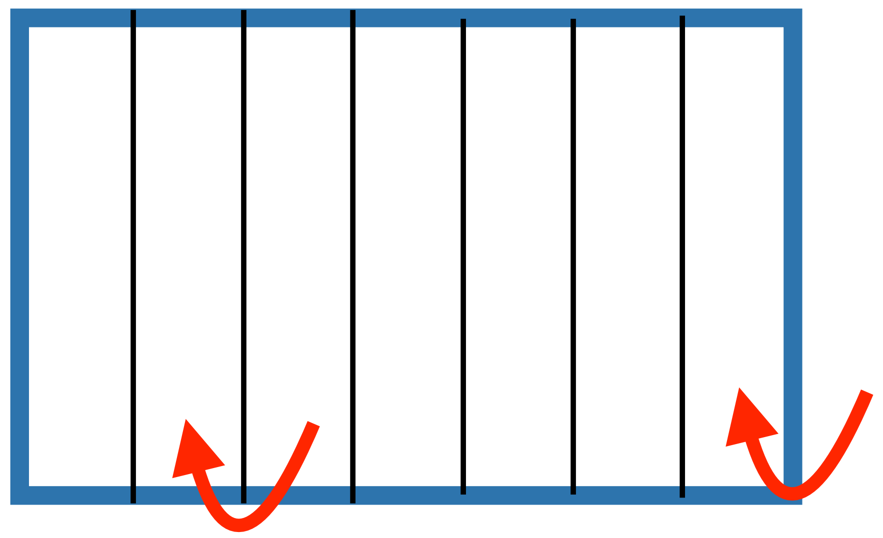

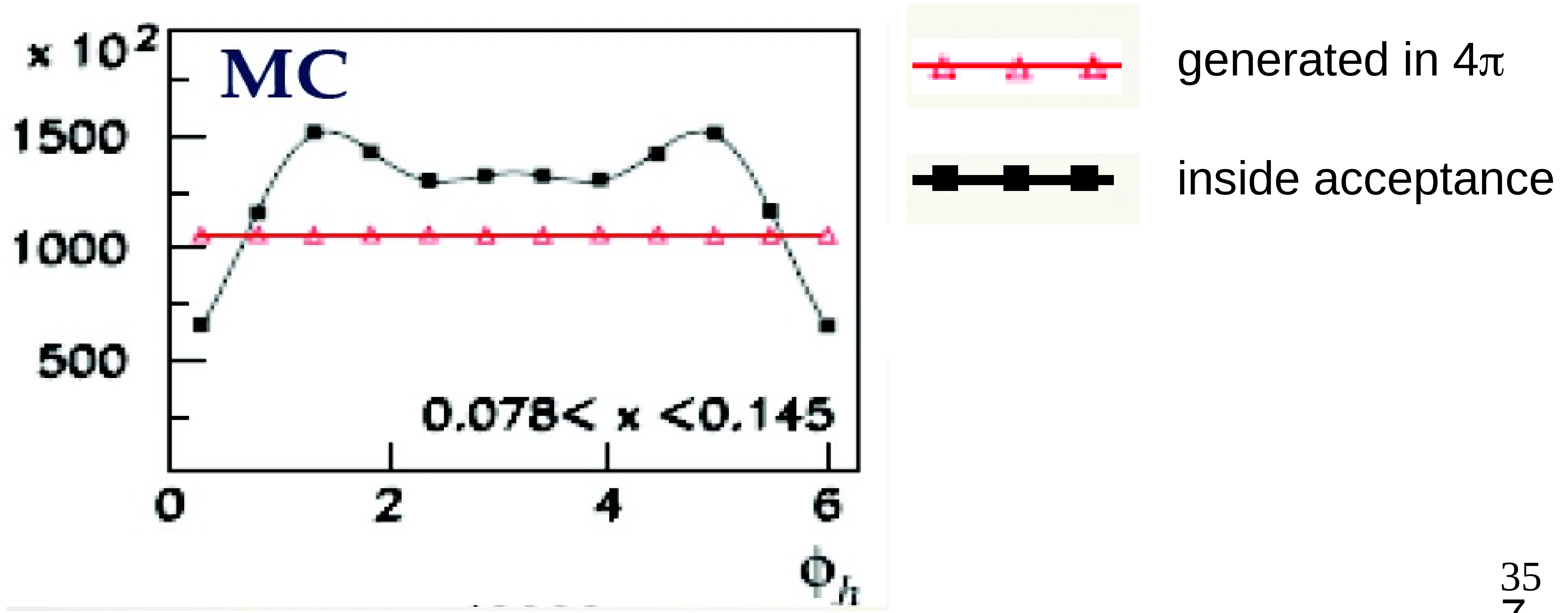

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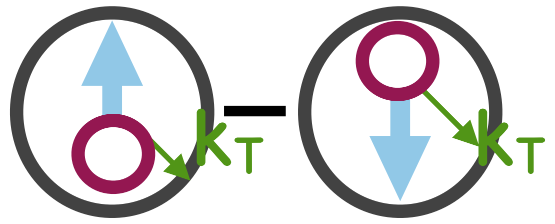


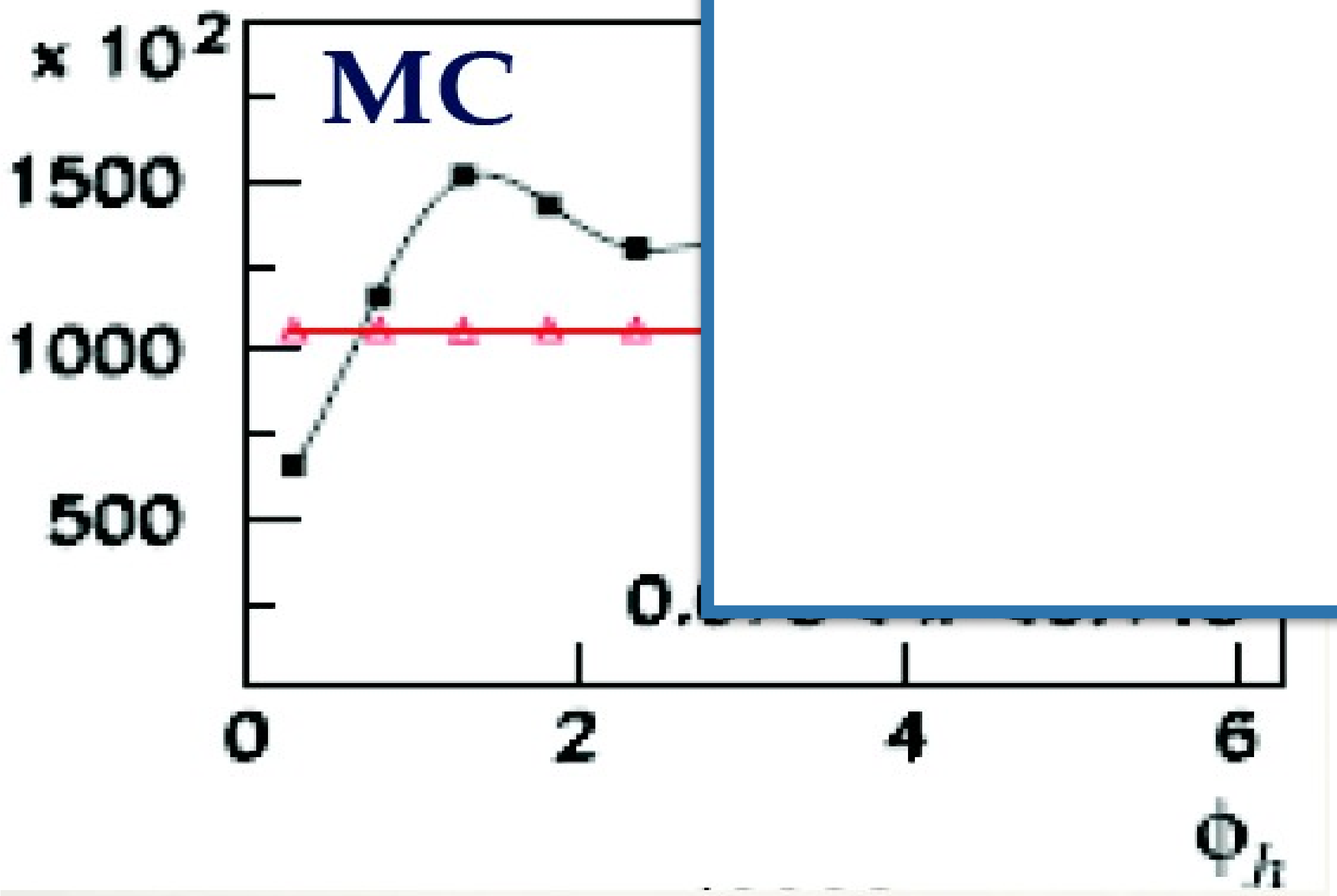
$\langle \cos(2\phi_h) \rangle_{Born}(i)$ $\langle \cos(2\phi_h) \rangle_{meas}(i)$

Fully differential analysis

Unfolding in 400 x 12 bins

BINNING 400 kinematic bins x 12 ϕ-bins							
Variable	Bin limits						#
x	0.023	0.042	0.078	0.145	0.27	1	5
y	0.3	0.45	0.6	0.7	0.85		4
z	0.2	0.3	0.45	0.6	0.75	1	5
P_{hT}	0.05	0.2	0.35	0.5	0.75		4

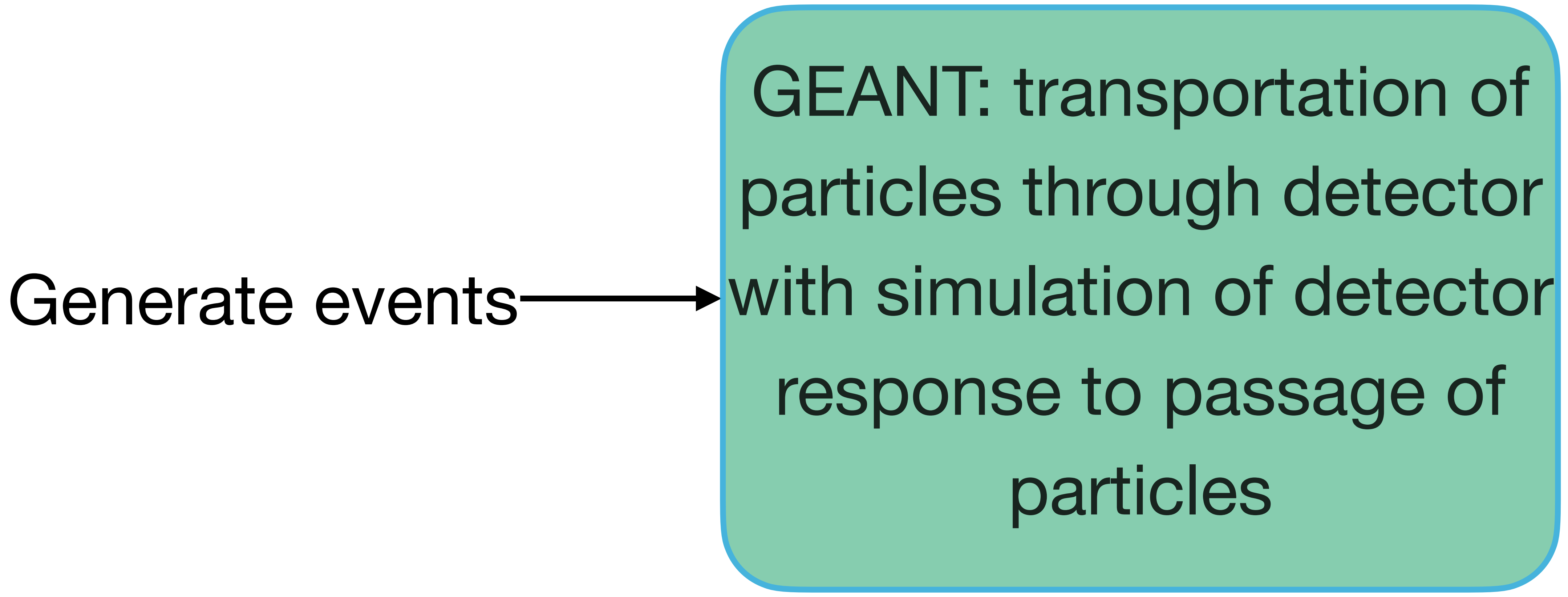
etector



Constructing an unfolding matrix

Generate events

Constructing an unfolding matrix



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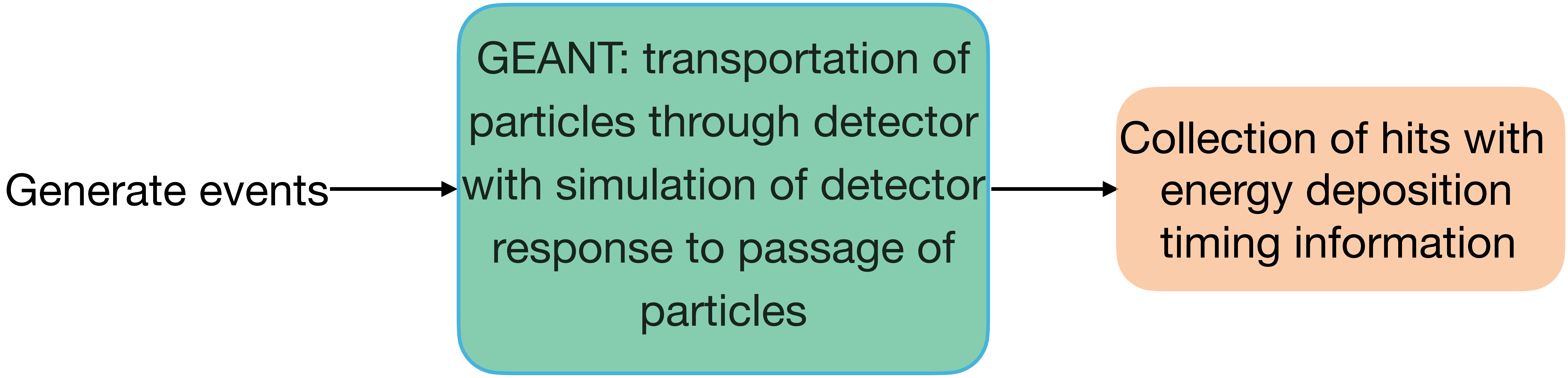

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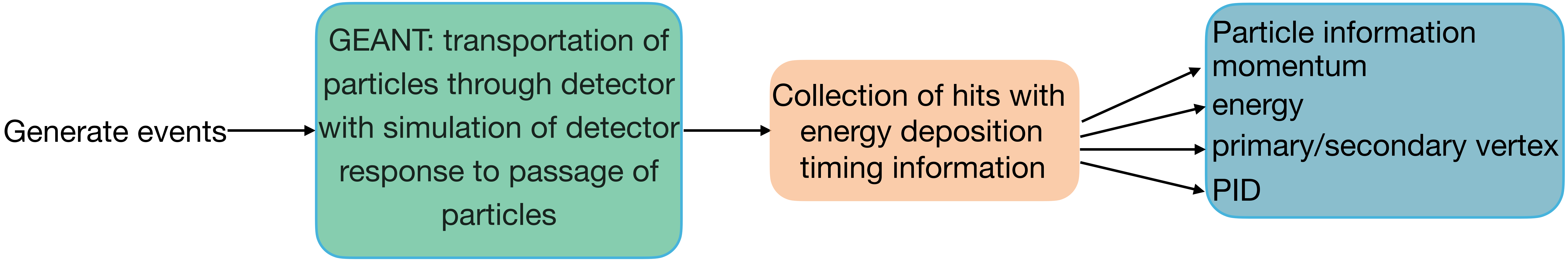
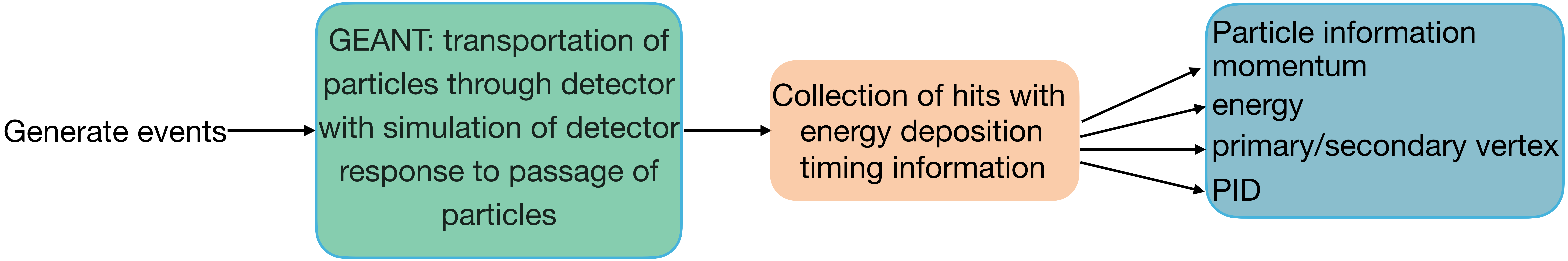


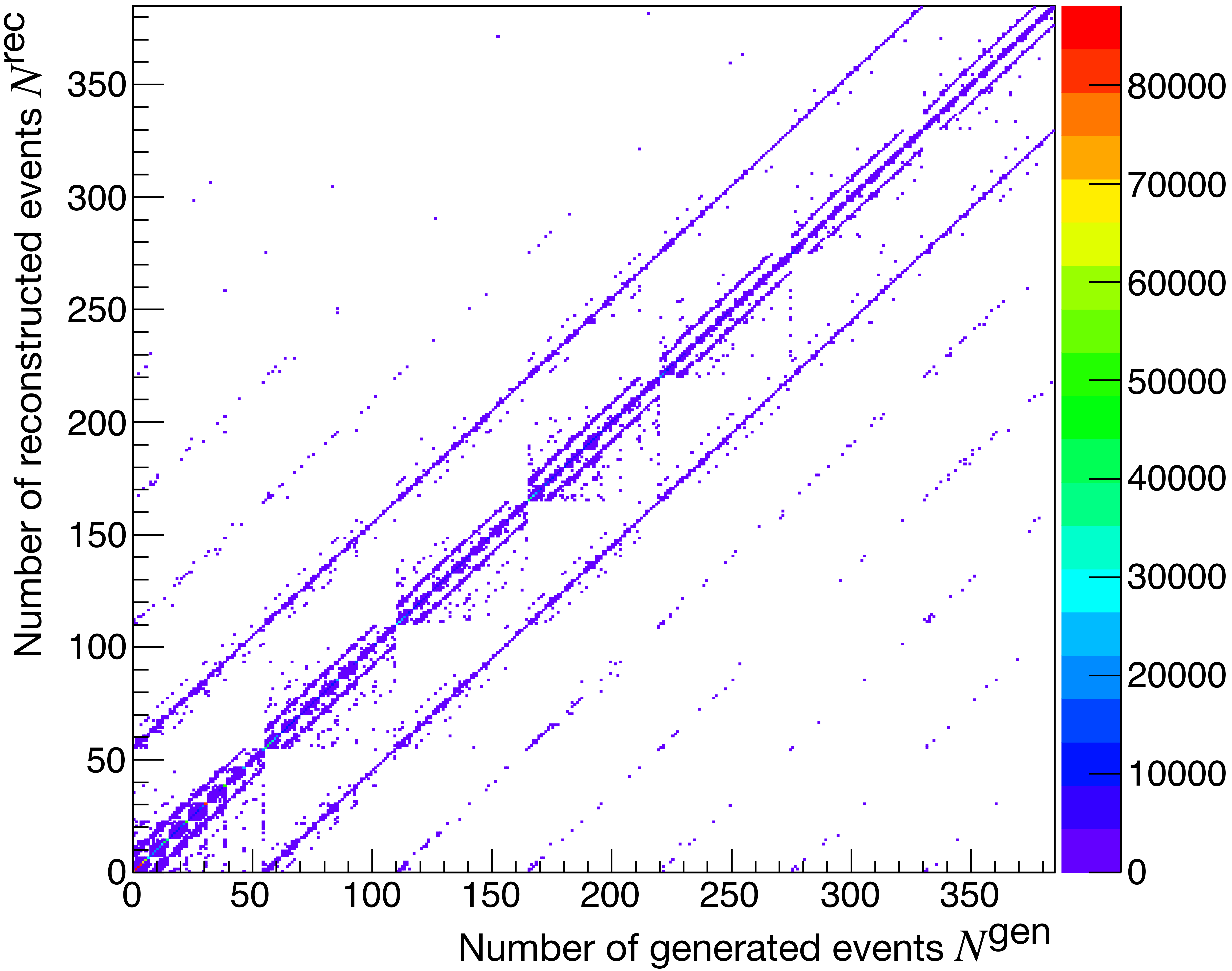
Constructing an unfolding matrix



Apply selection requirements and count the number of events N (in bins of kinematic variables)

Example of an unfolding matrix

Hypothetical binning in x_B, Q^2 and z.



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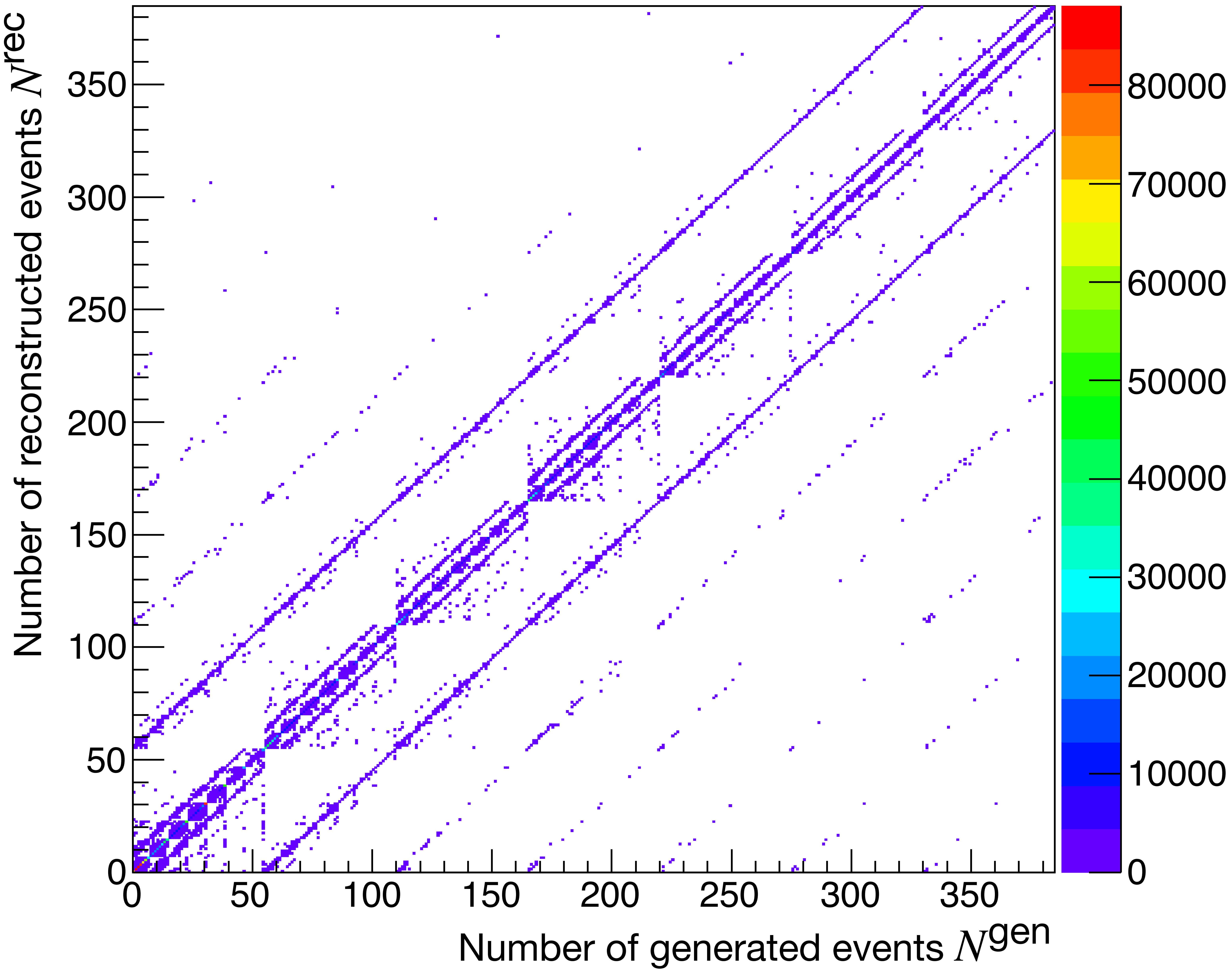

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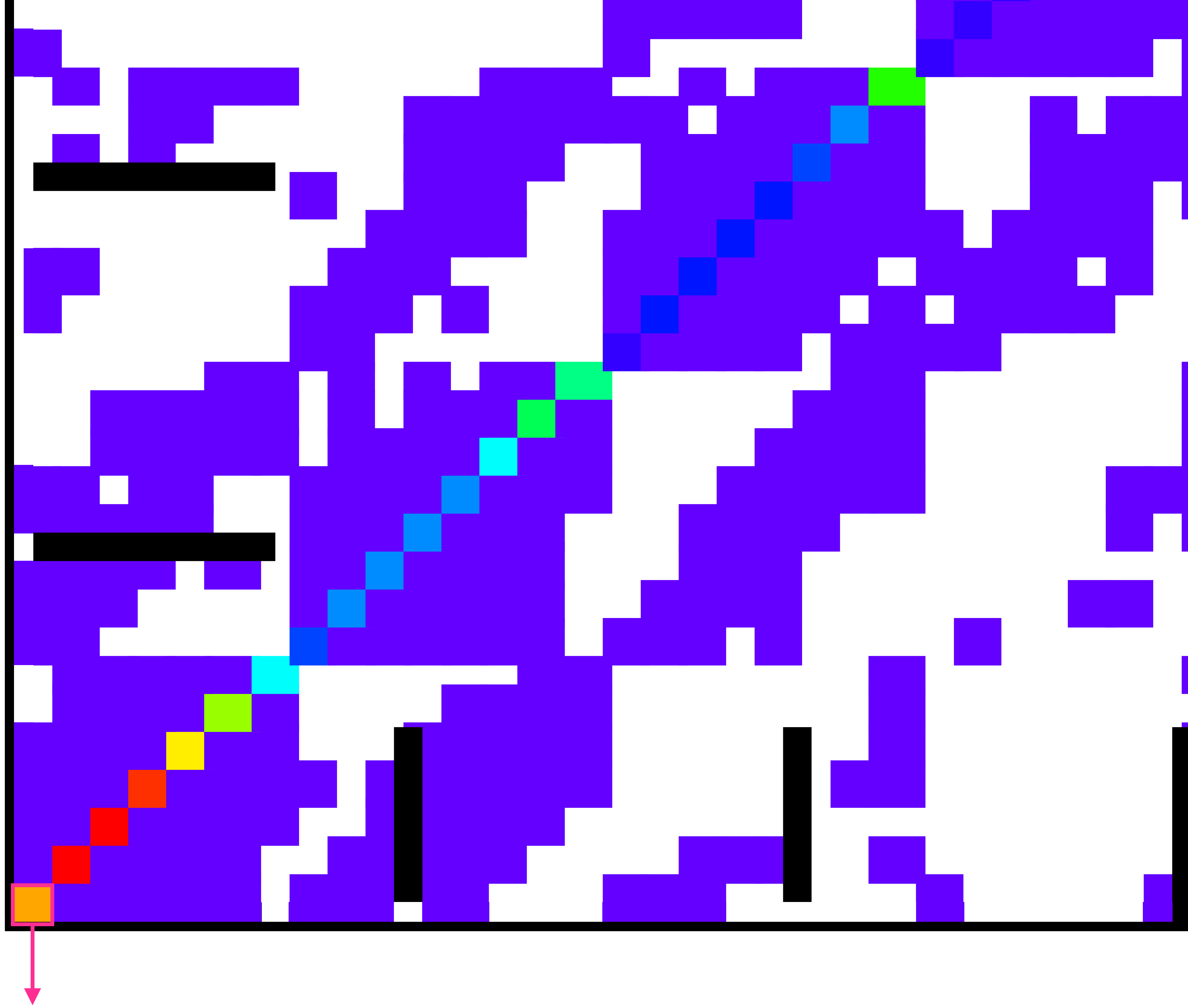

Number of generated events in
x_B bin 1,
Q^2 bin 1,
z bin 1
and number of reconstructed events in
x_B bin 1,
Q^2 bin 1,
z bin 1

Example of an unfolding matrix

Number of generated events in
x_B bin 1,
Q^2 bin 1,
z bin 1
and number of reconstructed events in
x_B bin 2,
Q^2 bin 1,
z bin 1

Number of generated events in
x_B bin 1,
Q^2 bin 1,
z bin 1
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x_B bin 1,
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Example of an unfolding matrix

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Number of generated events in
x_B bin 2,
Q^2 bin 1,
z bin 1
and number of reconstructed events in
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Example of an unfolding matrix

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x_B bin 1,
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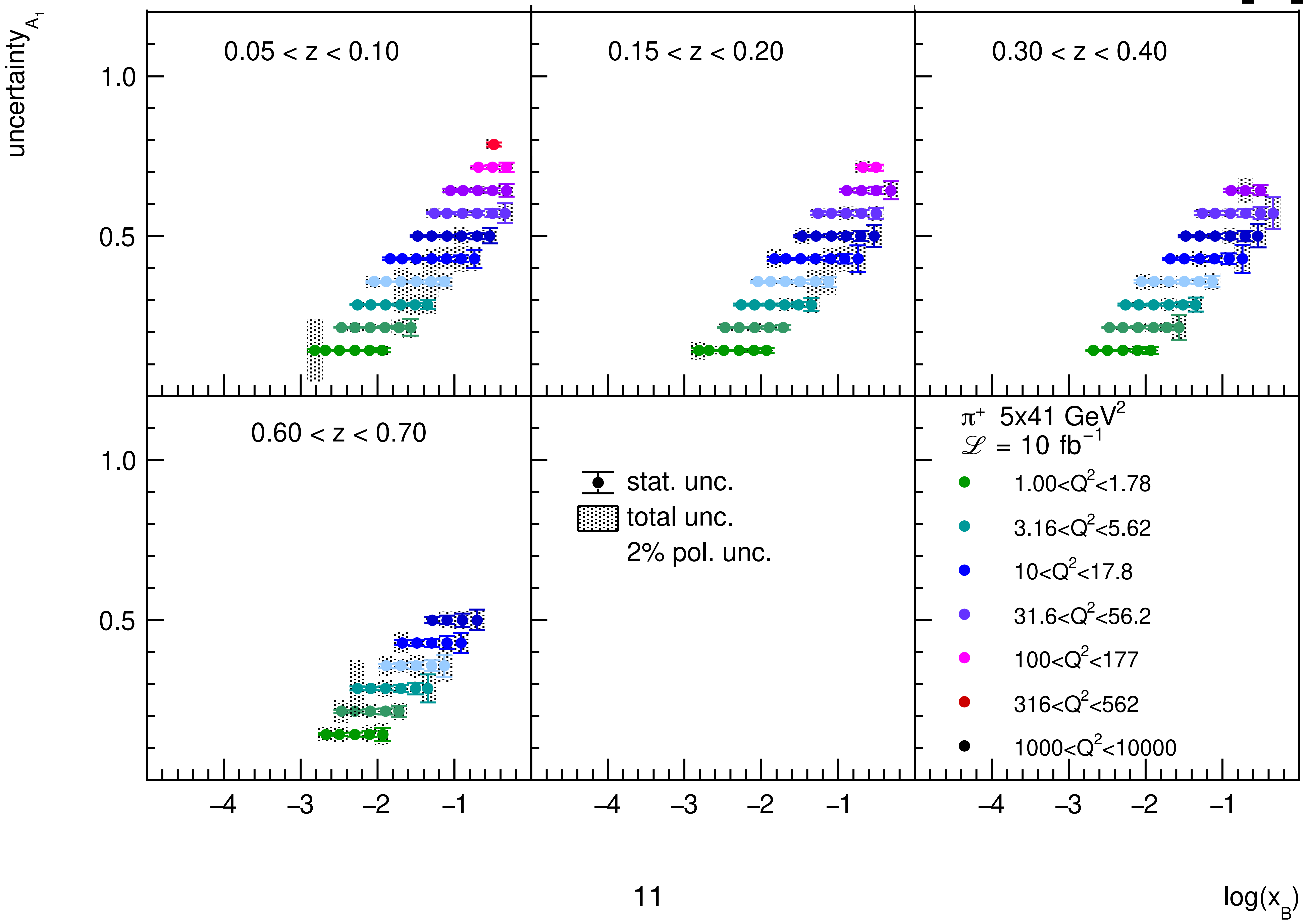
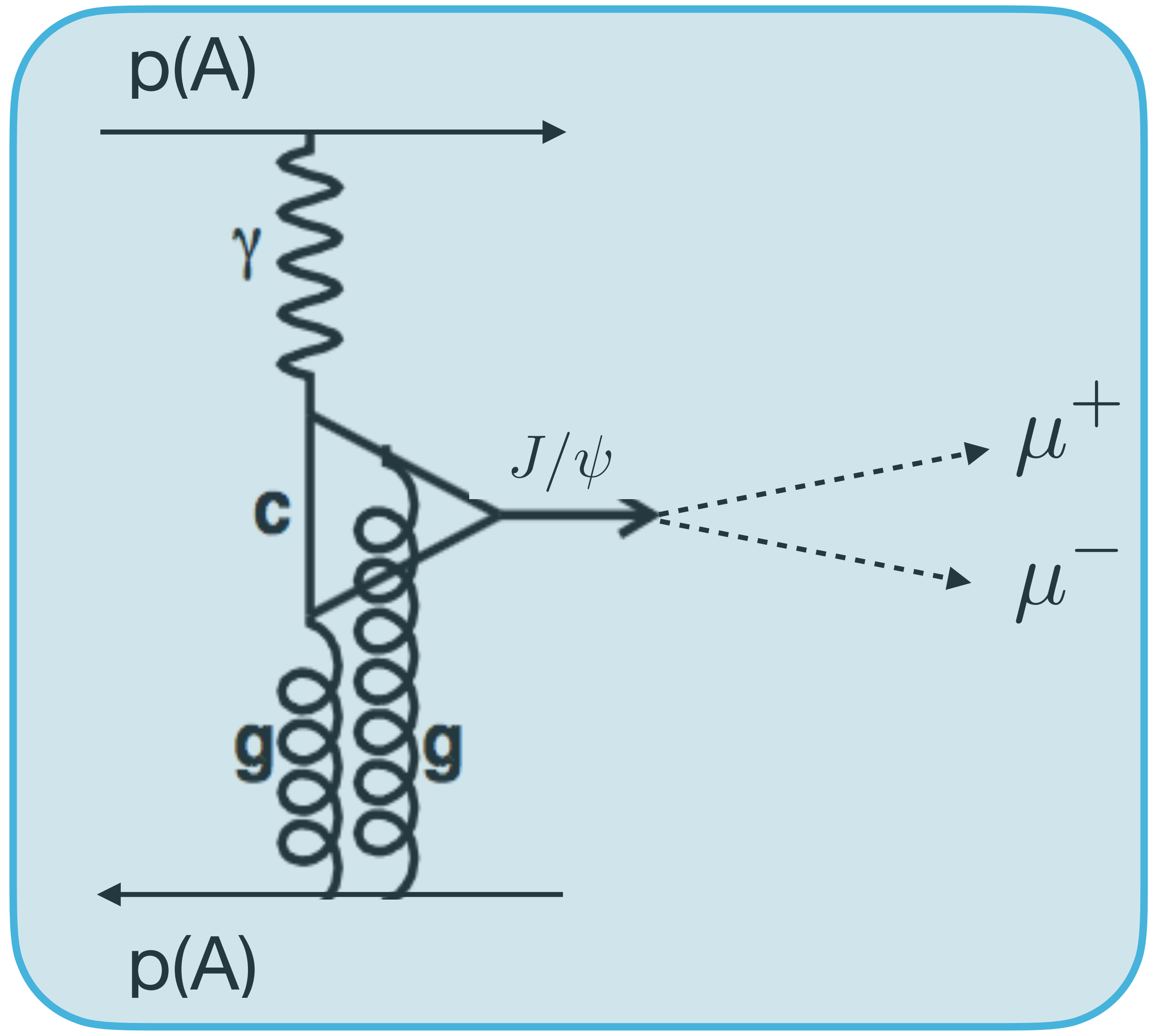
For each bin in x_B, Q^2, z: correspondence between number of reconstructed and generated events is now known → can correct for finite detector resolution, acceptance effects and QED radiation

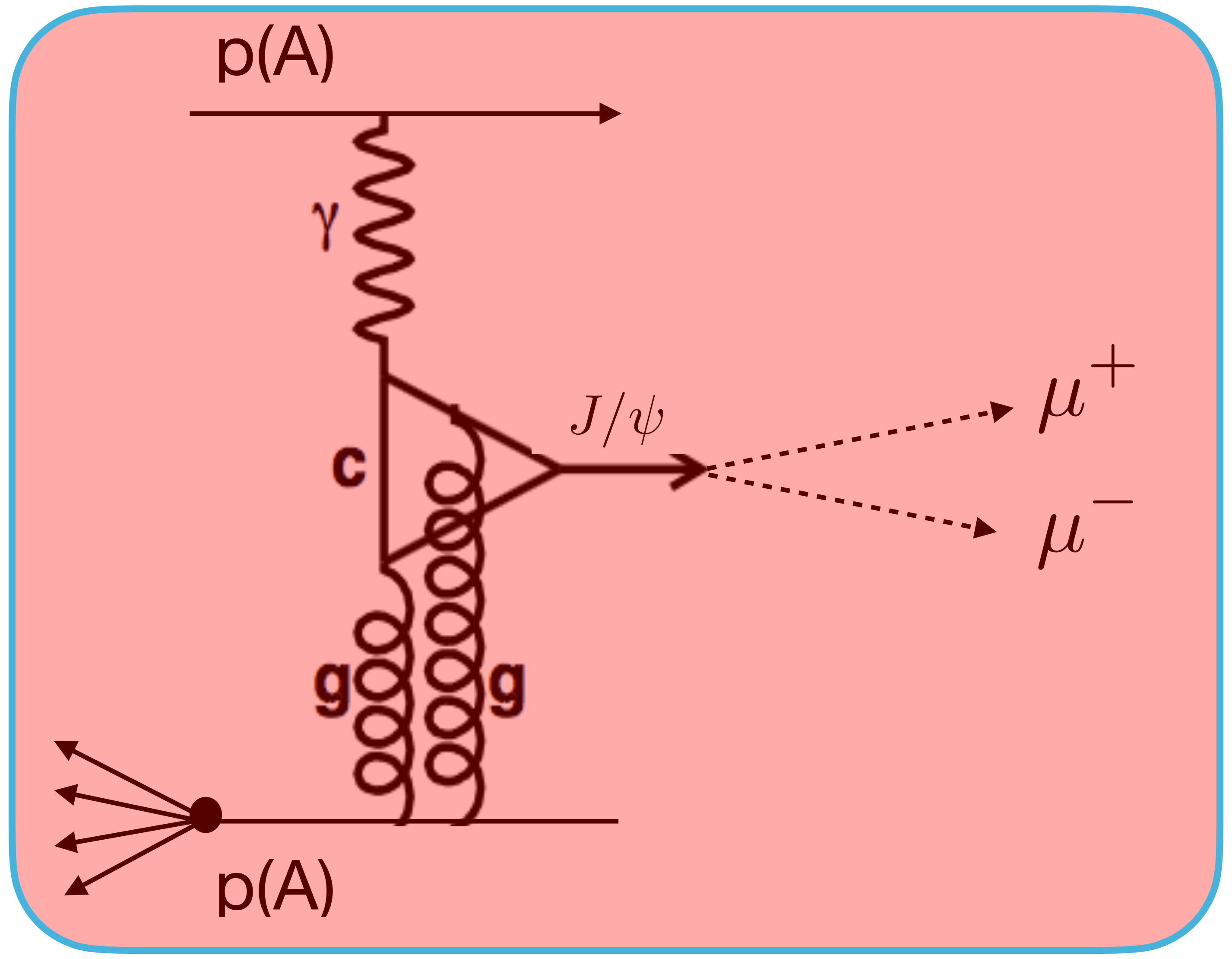
Example of difference between generated and reconstructed observable at ePIC

Helicity asymmetry uncertainties



Example of correction for background contribution





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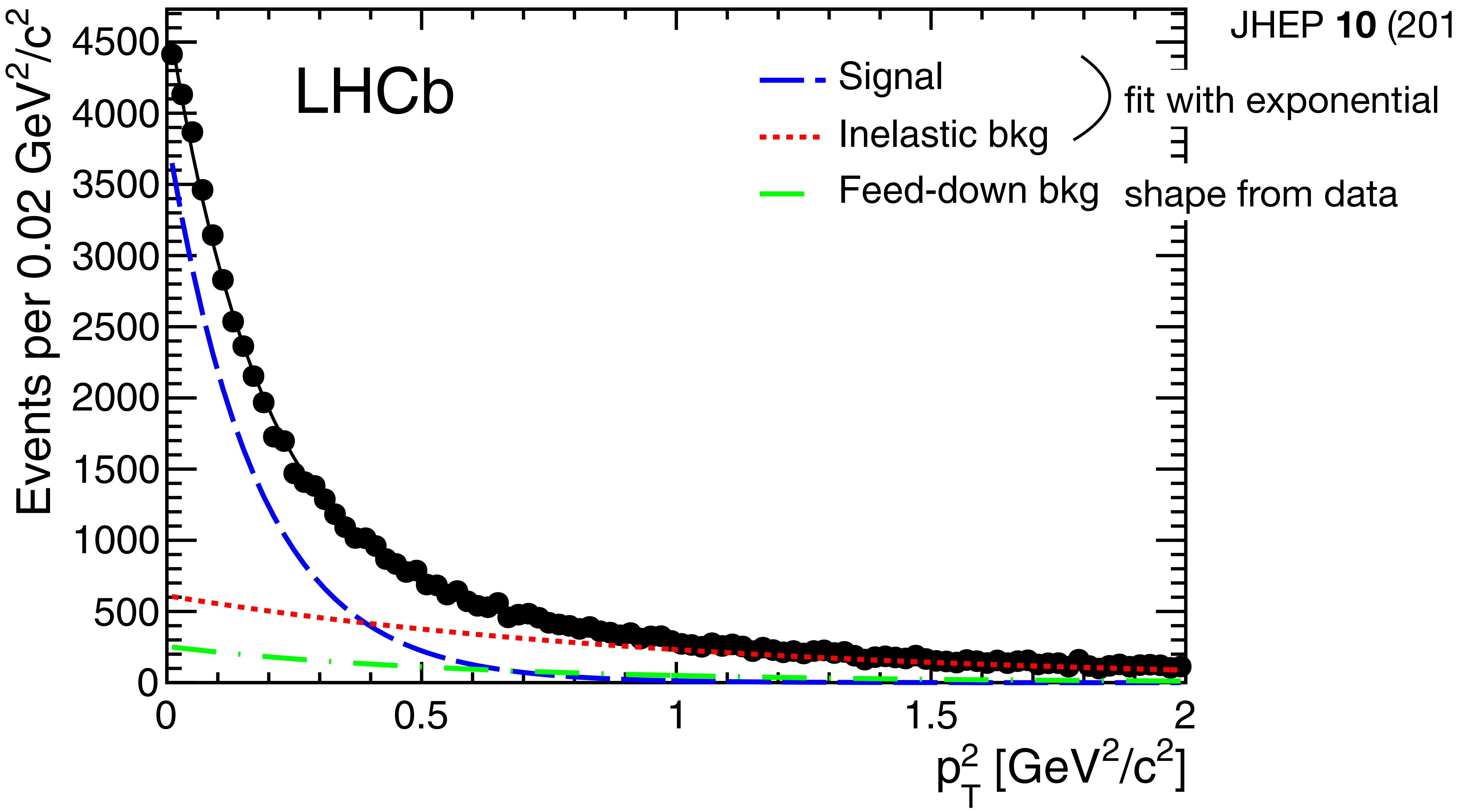

From the available information to the observable

Common observables: cross sections or asymmetries of a specific process in deep-inelastic scattering.

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6 Construction of observable

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Width of bins x_B, Q^2, z

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7 Evaluation of statistical uncertainty

$$\sim \sqrt{N^{\text{corrected}}} \quad \text{or} \quad \sqrt{\sum_{\text{event } i} w_i^2} \quad (w_i = \text{weight})$$

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8 Evaluation of all the systematic uncertainties

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- applied efficiency corrections
- unfolding procedure
- background evaluation
- luminosity determination
- PID determination
- ….

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} long list

Commonly used procedure:
- Evaluation of alternative method to apply specific correction.
- Extract the observable again.
- Difference between two methods = systematic uncertainty.

To end

- The extraction of the raw signal is straight-forward.
- The evaluation of all necessary corrections and all systematic uncertainties constitutes the core of the analysis.
  - Methods to evaluate the corrections and systematic uncertainties are based on a mix of simulation and experimental data.
  - The applied corrections and evaluation of the systematic uncertainties cannot depend on physics models!