Stony Brook University

Center for Frontiers in Nuclear Science

IISER PUNE

Event Kinematic Reconstruction Studies on Diffractive processes at EIC

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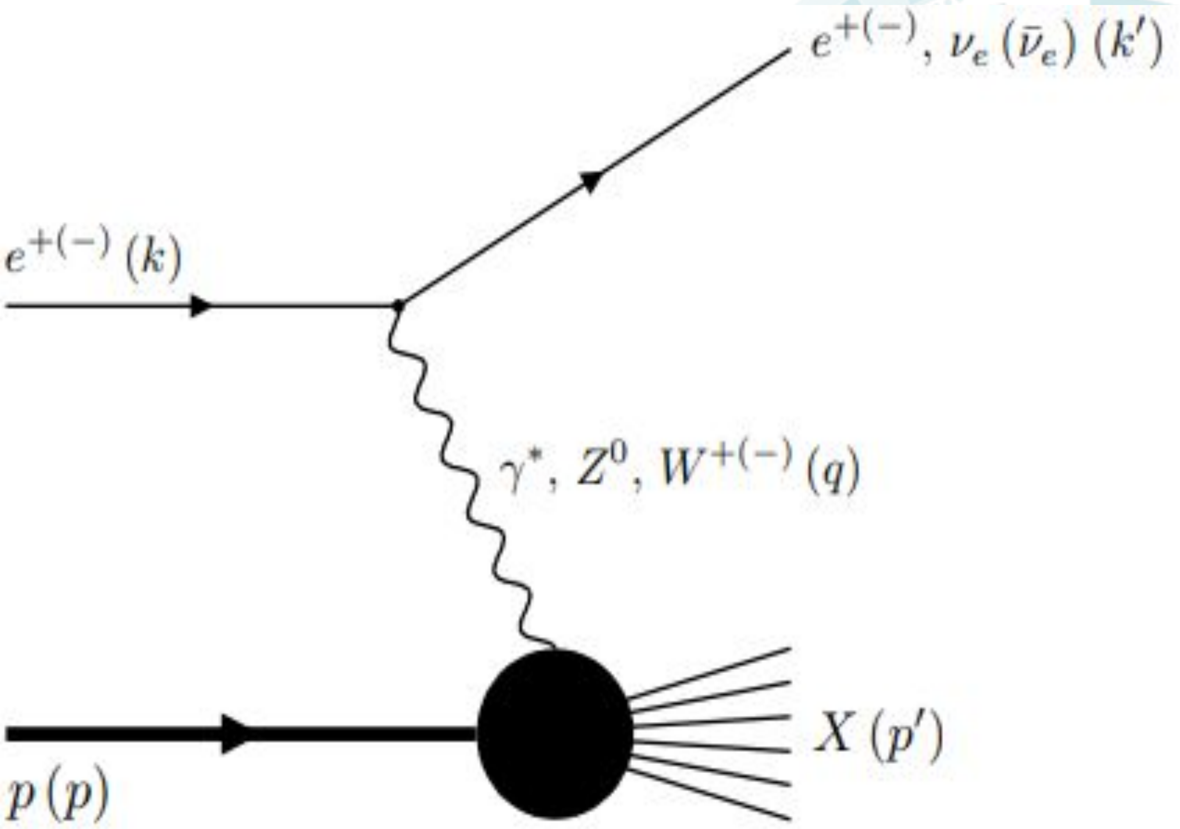
May 25, 2020

Electron ion collider



the strong force in nature

CoM Energy $s = (k + P)^2 \simeq 4 E_e E_p$

Virtuality $Q^2 = -q^2$

p Inelastic Scattering

Inelasticity $y = 1 - E_e'/E_e$

Mandelstam $t = (P - P')^2$

:ors- electrons and

Invariant mass $W^2 = (P + q)^2 \simeq s + t$

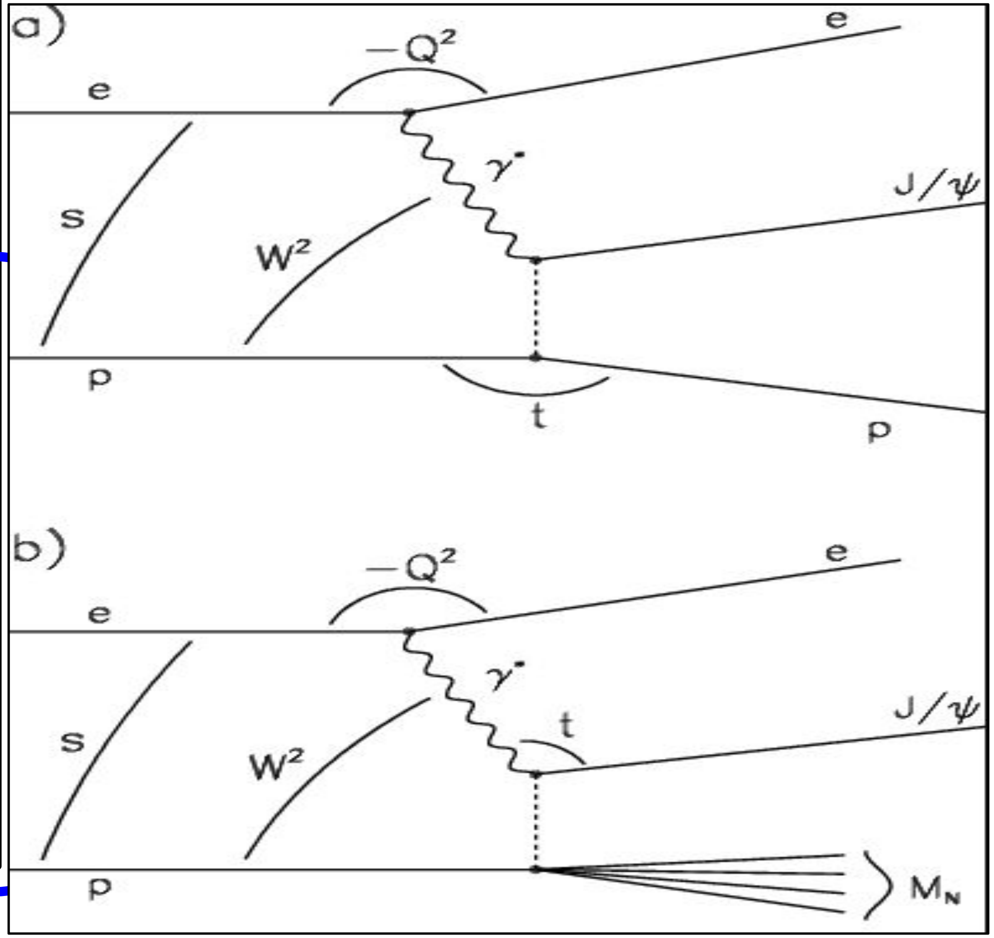
to head-on collisions

Bjorken scaling $x = Q^2 / 2P_p.q$

Deep Inelastic Scattering - Categories

Measurement	Beam	Measured Final State
Inclusive DIS	e+p	scattered e^-
Semi-Inclusive DIS	e+p	scattered e^- identified hadron
DVCS	e+p	scattered e^- photon scattered p
DVMP with J/Ψ	e+p	scattered e^- $e^- + e^+$ from J/Ψ decay scattered p
Diffraction	e+A	scattered e^- rapidity gap n from nuclear dissociation

Taken from LOI 2018



Overview

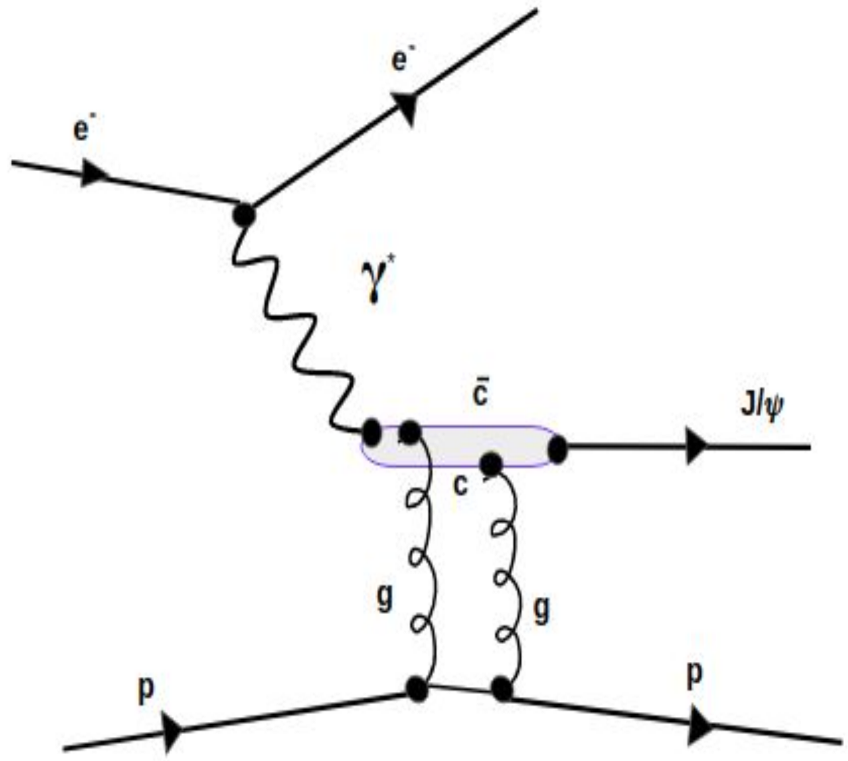
- Polarization effects in Sartre
- Event kinematic reconstruction
- Detector smearing

Sartre

[arXiv:1307.8059]

- The **dipole model** Monte Carlo generator - for studies at future facilities such as EIC and LHeC.

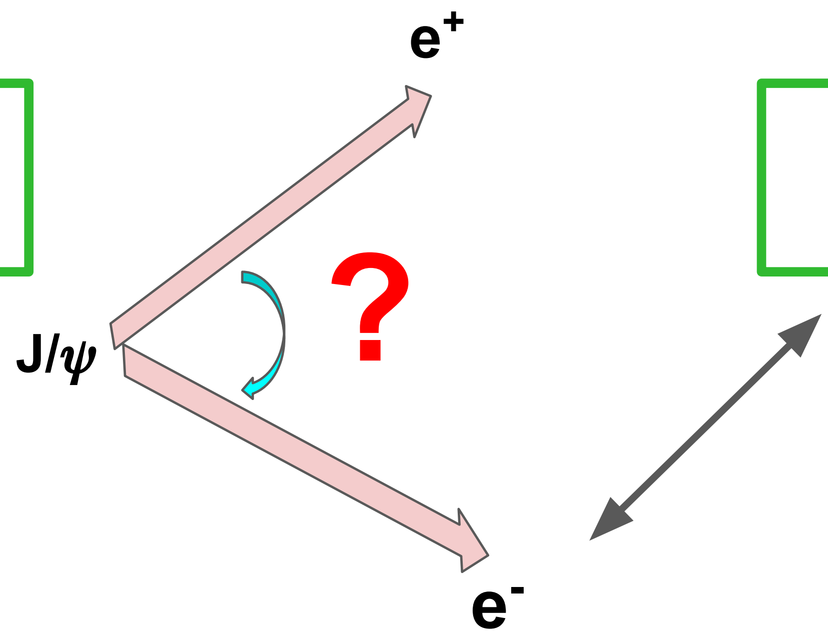
- Exclusive diffractive vector meson production and DVCS in ep and eA collisions based on the dipole model.



The Path Forward..

Significance of photon polarization ? Does Sartre know?

Scattered Electron method



e- primary electron

Polarization of the virtual photon accounts for decay angular distribution of the VM!!

$Q^2 \rightarrow 0$

Photons are transversely polarized.

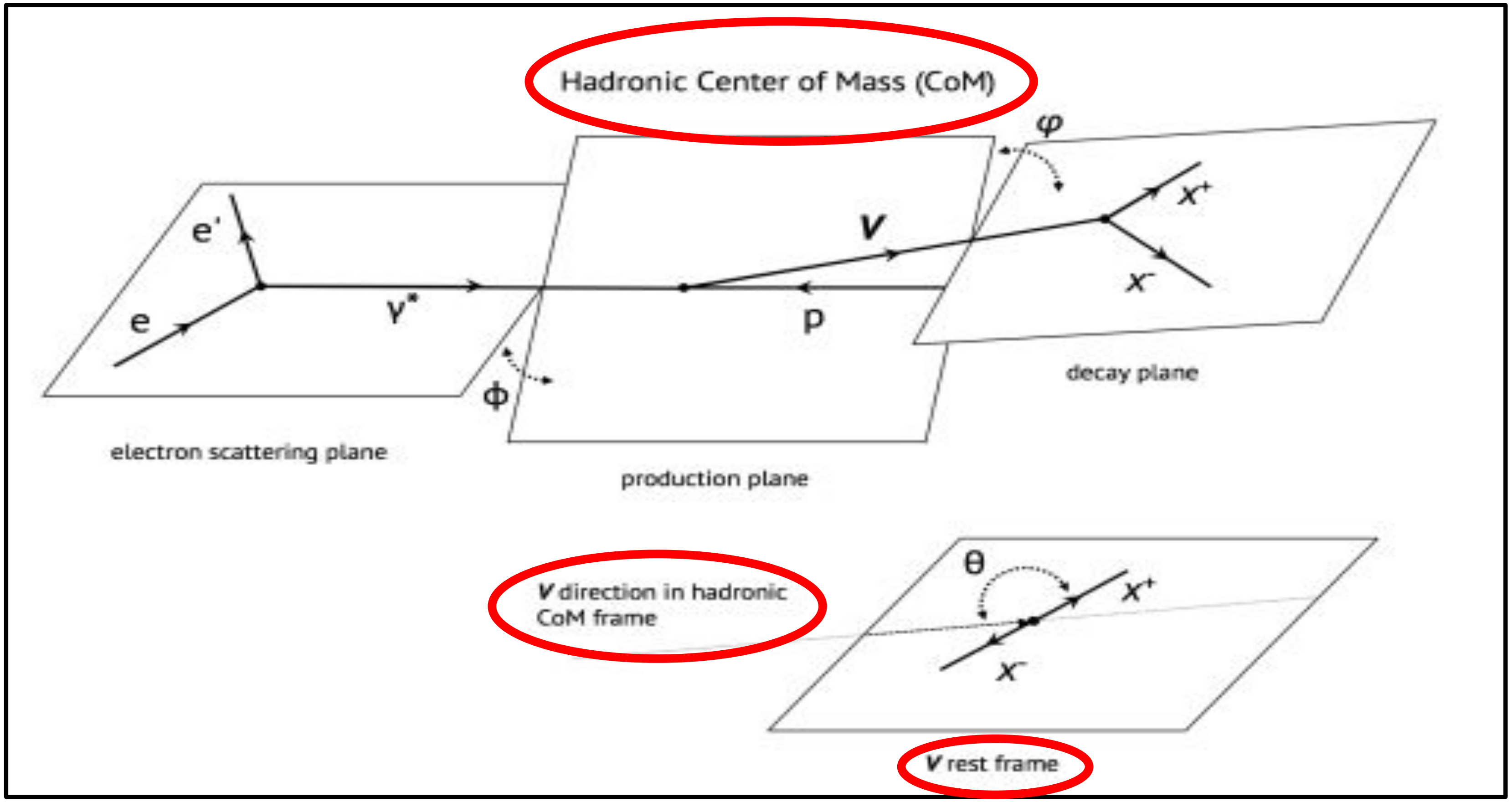
The VM retains the photon spin state, the angular distributions given by **spherical harmonics and Clebsch-Gordan coefficients**

$Q^2 > 0$

The photons can also be longitudinally polarized, along the direction of motion.

The angular distributions become more **complicated.**

VM production $ep \rightarrow eVp$ and subsequent decay $V \rightarrow X^+ X^-$



Exclusive vector meson production at an electron-ion collider ,Michael Lomnitz and Spencer Klein

The ratio of the longitudinal to transverse cross-section can be written as,

$$R_V(W^2,Q^2) = \frac{\sigma_{L,\gamma^* p\to Vp}}{\sigma_{T,\gamma^* p\to Vp}}$$
$$= \frac{(Q^2+m_{V,T}^2)^2}{m_{V,T}^4}\xi_V^2\left[\frac{\pi}{2}\frac{m_{V,L}^2}{Q^2} - \frac{m_{V,L}^3}{\sqrt{Q^2}(Q^2+m_{V,L}^2)} - \frac{m_{V,L}^2}{Q^2}\arctan\left(\frac{m_{V,L}}{\sqrt{Q^2}}\right)\right]^2 \quad (16)$$

Sartre

According to the SCHC approximation, this can be expressed in terms of the spin matrix element in the following way,

$$R = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1-r_{00}^{04}}$$

Modulation only in θ

For ρ and ϕ mesons which decay to **spin-0 mesons,**

$$\boxed{\Omega(\cos\theta) \propto 1 - r_{00}^{04} + (3r_{00}^{04} - 1)\cos^2(\theta)}$$

For J/Psi meson which decay to **spin-½ leptons,**

$$\boxed{\Omega(\cos\theta) \propto 1 + r_{00}^{04} + (1 - 3r_{00}^{04})\cos^2(\theta)}$$

Method of Approach

1

Boosted the VM from lab frame to hadronic COM frame

2

Generated VM decay in the VM rest frame

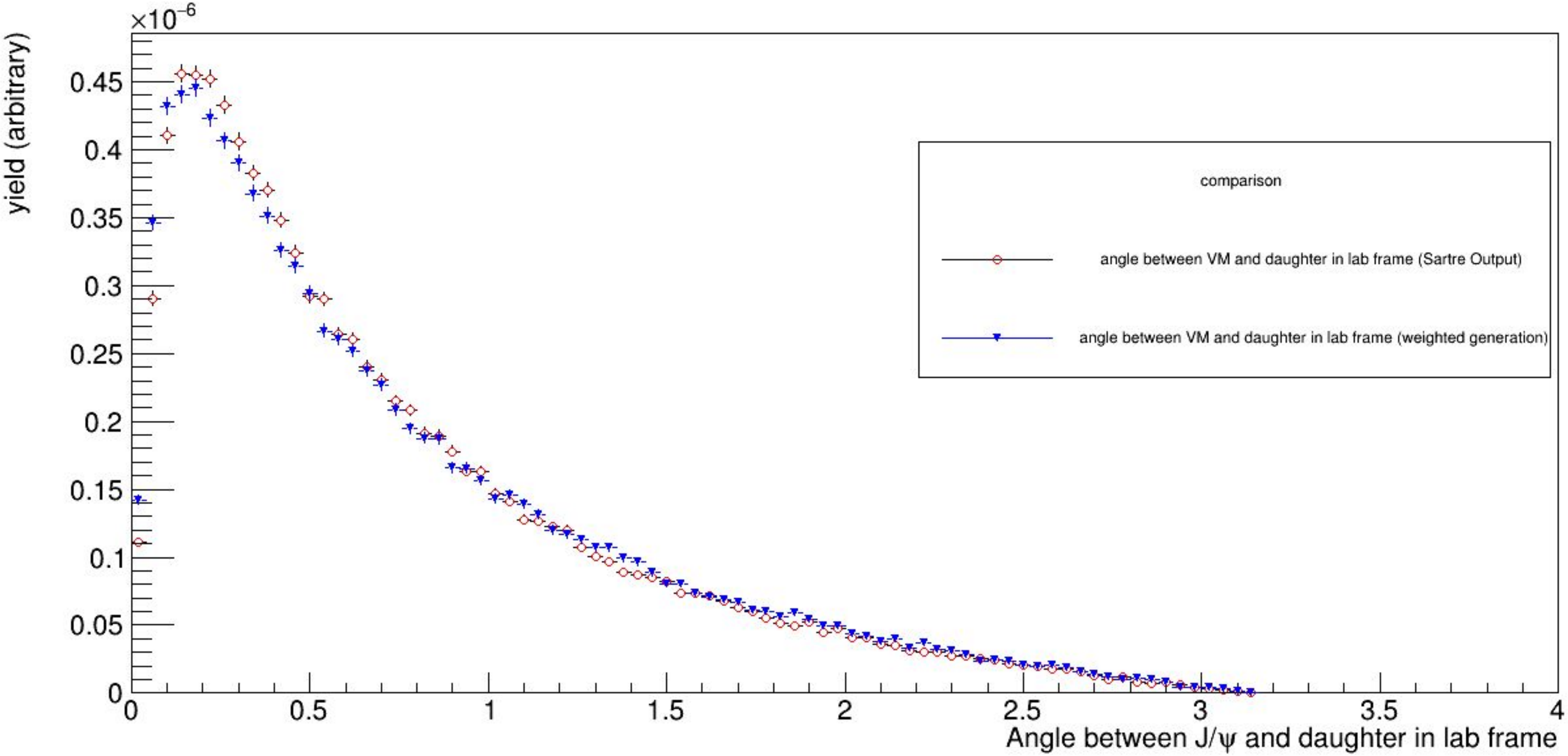
3

In the VM rest frame, the angle between one of the VM daughters and the VM momentum direction in the hadronic COM frame is calculated - provide the event weight.

4

VM daughters are first boosted to the hadronic COM frame, then to the lab frame - calculated the angle between VM and daughter after applying weight

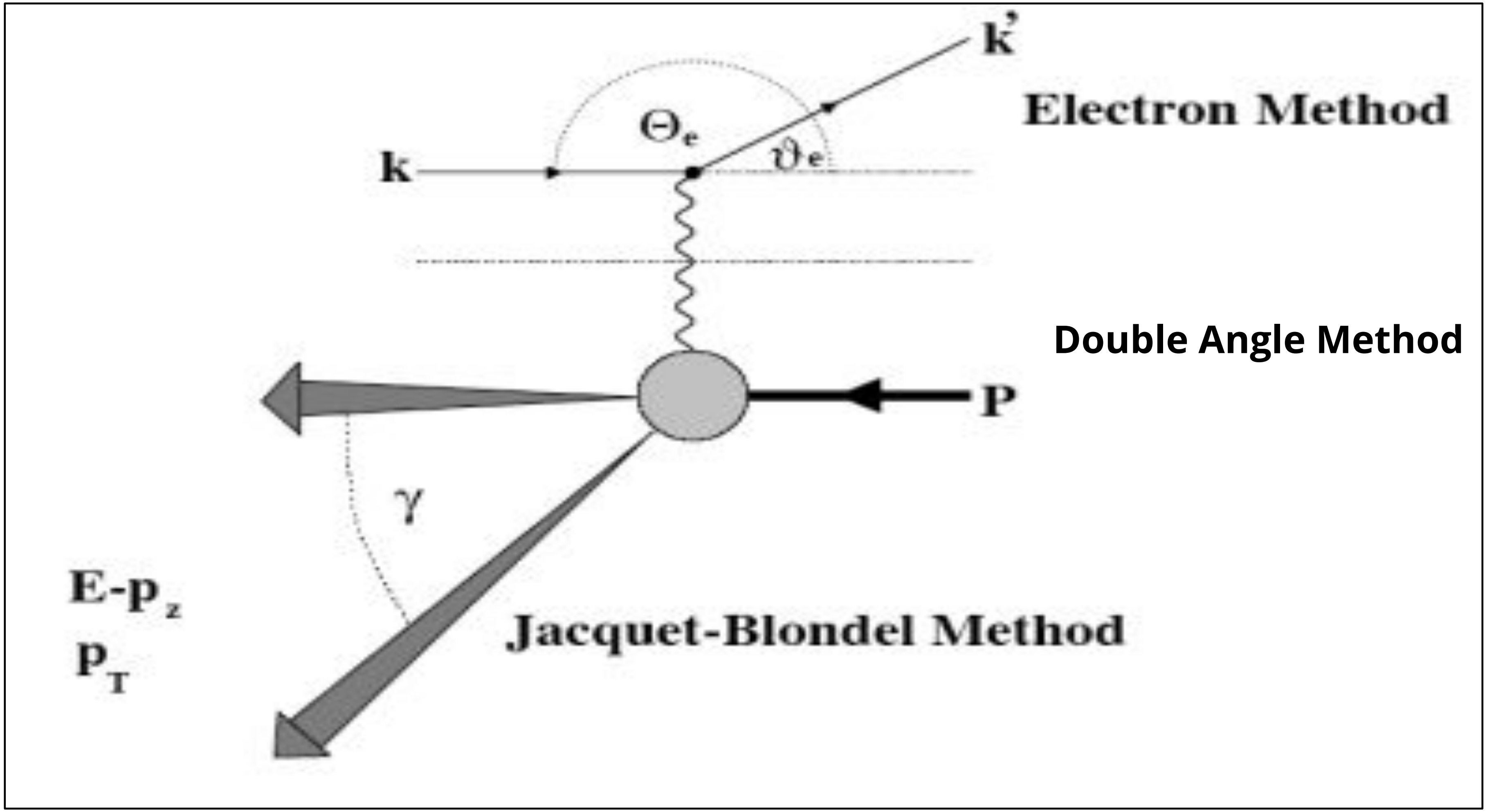
The normalized decay angular distribution



Summary

1. **Polarization of the virtual photon affects the decay angular distribution of the VM**
2. The ratio of the longitudinal to transverse cross-section has **no significant dependence on t or W** but **depends on Q^2**
3. The primary electron and the J/ψ daughter are **well separated** in detector φ but overlap in certain η regimes.

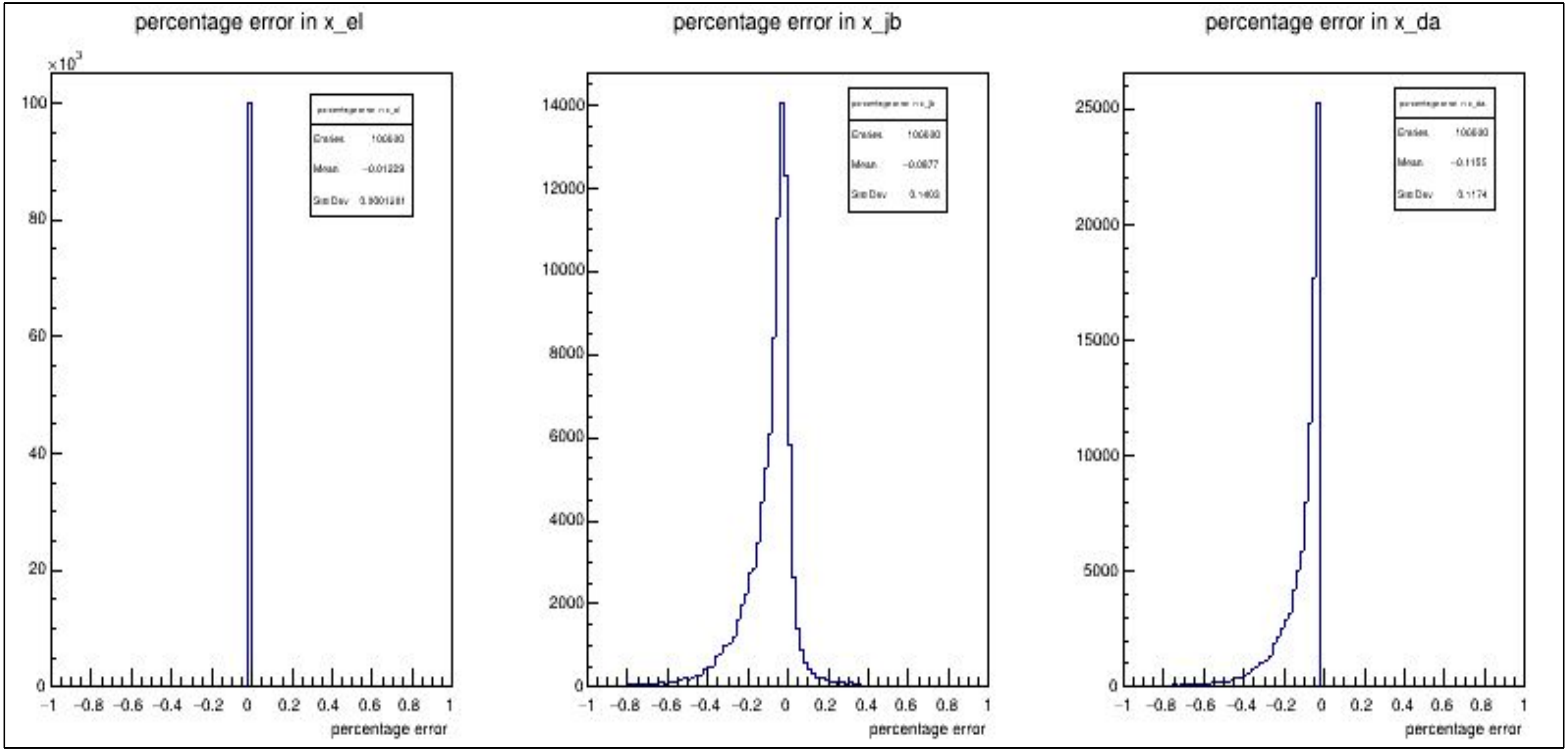
Event Kinematic Reconstruction Methods



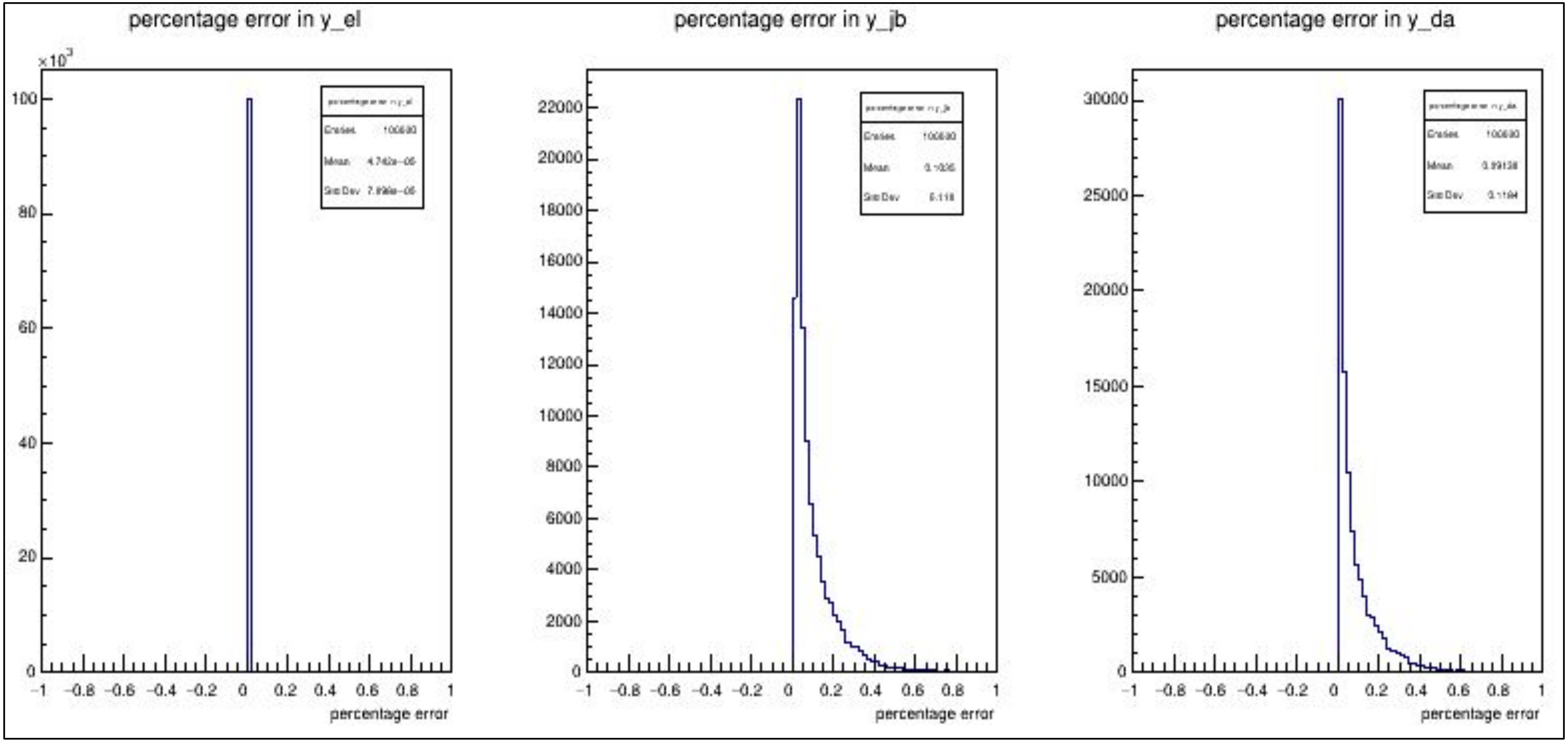
https://arxiv.org/pdf/hep-ex/9903037.pdf

Percentage error in the reconstructed values

percentage error = (calculated value - true value)/true value * 100

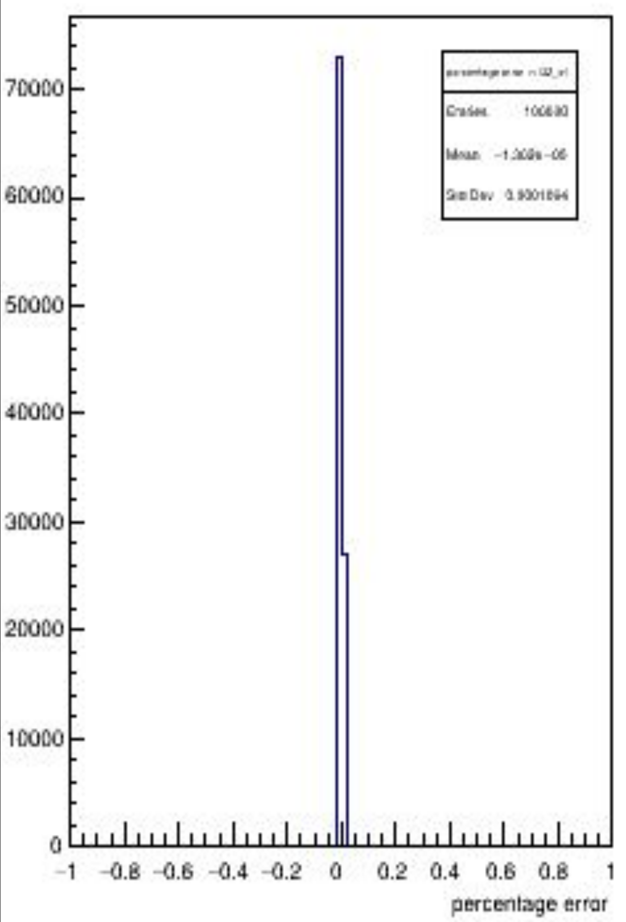


percentage error = (calculated value - true value)/true value * 100

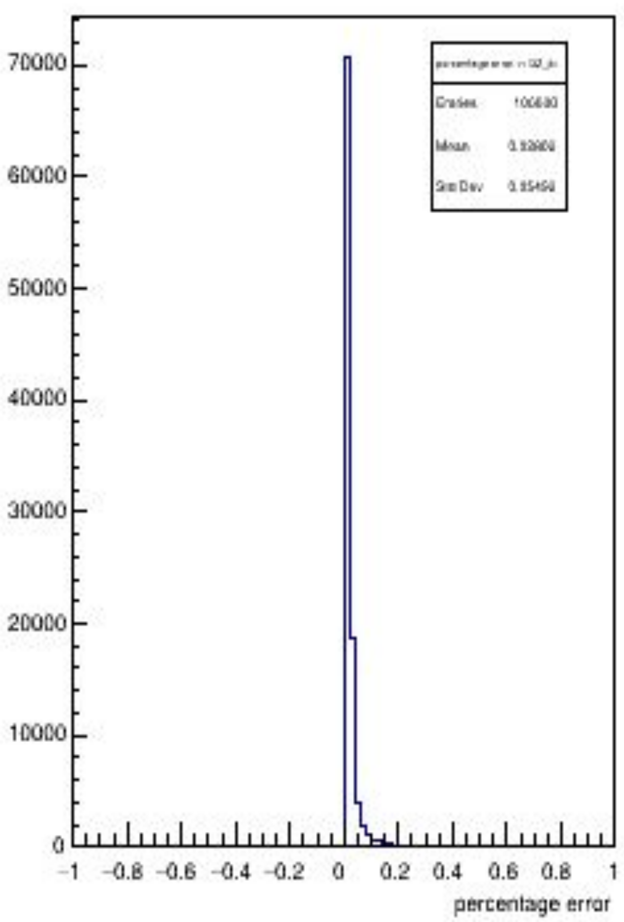


percentage error = (calculated value - true value)/true value * 100

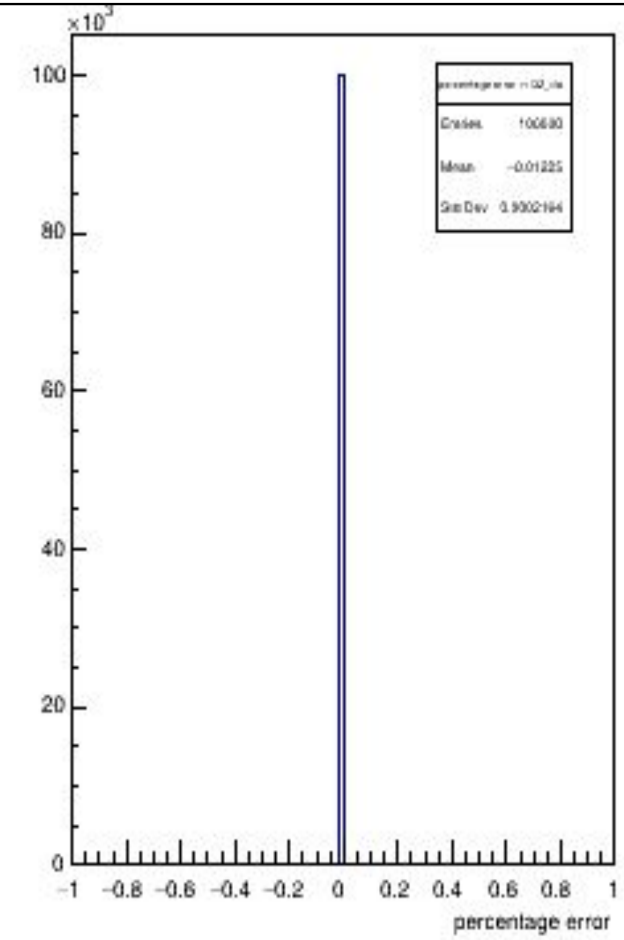
Q^2_El



Q^2_JB

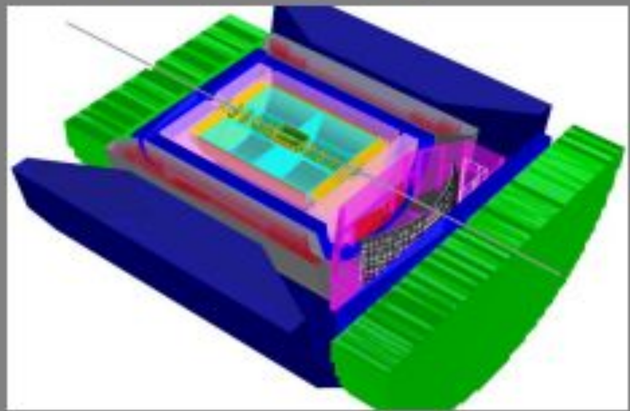


Q^2_DA



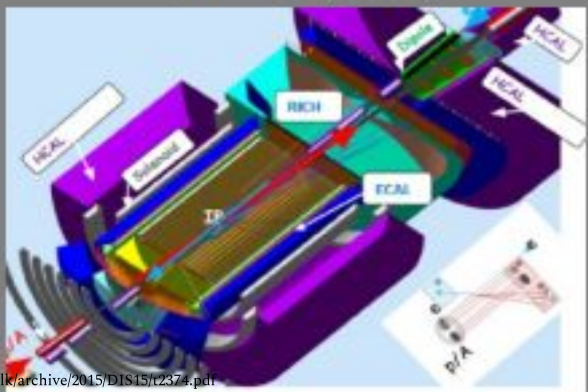
Detector Concepts

BEAST (BNL)

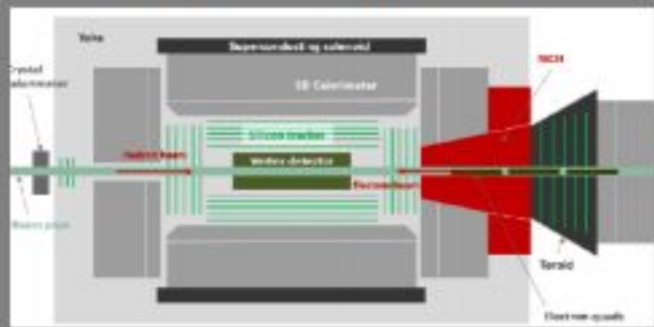


ePHENIX @RHIC

JLEIC (Jlab)

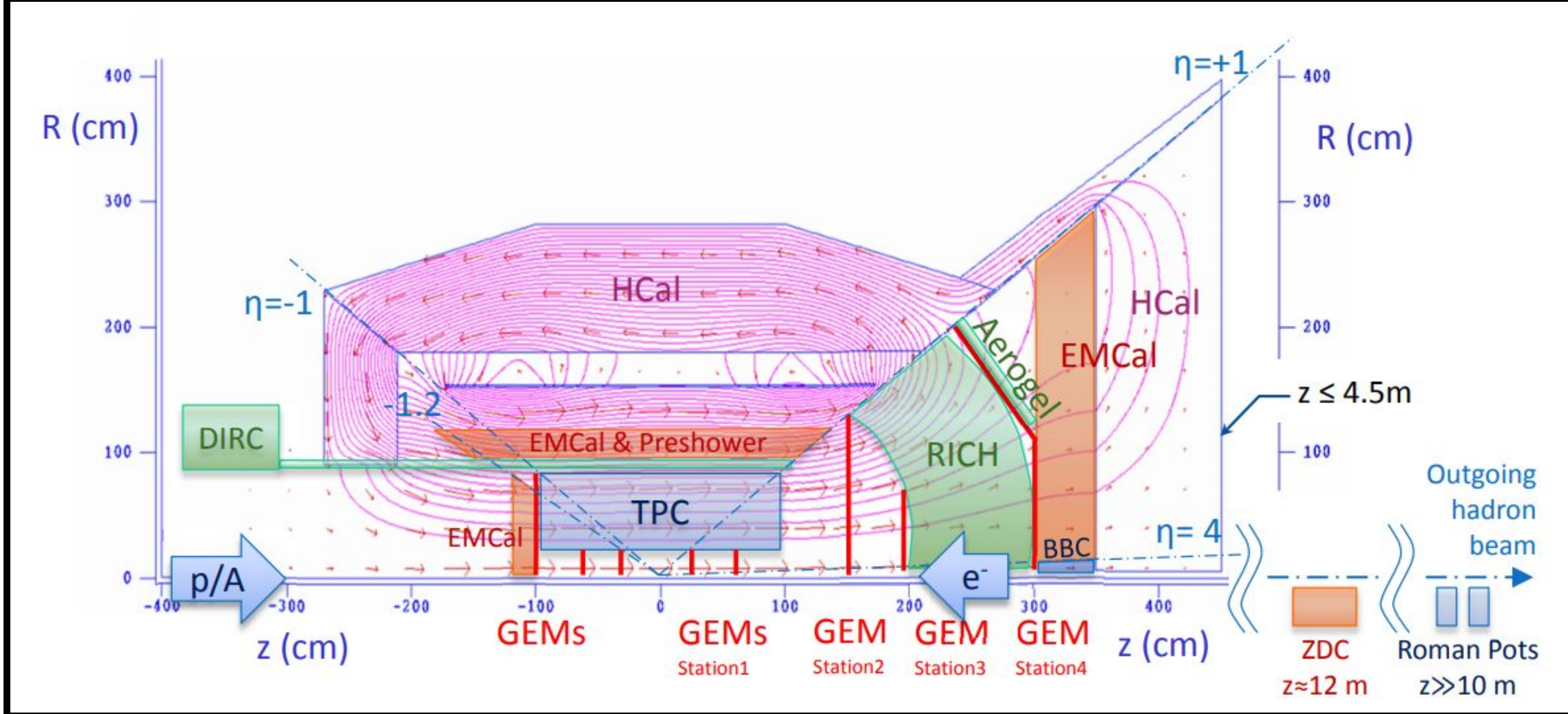


TOPSiDE (Argonne)

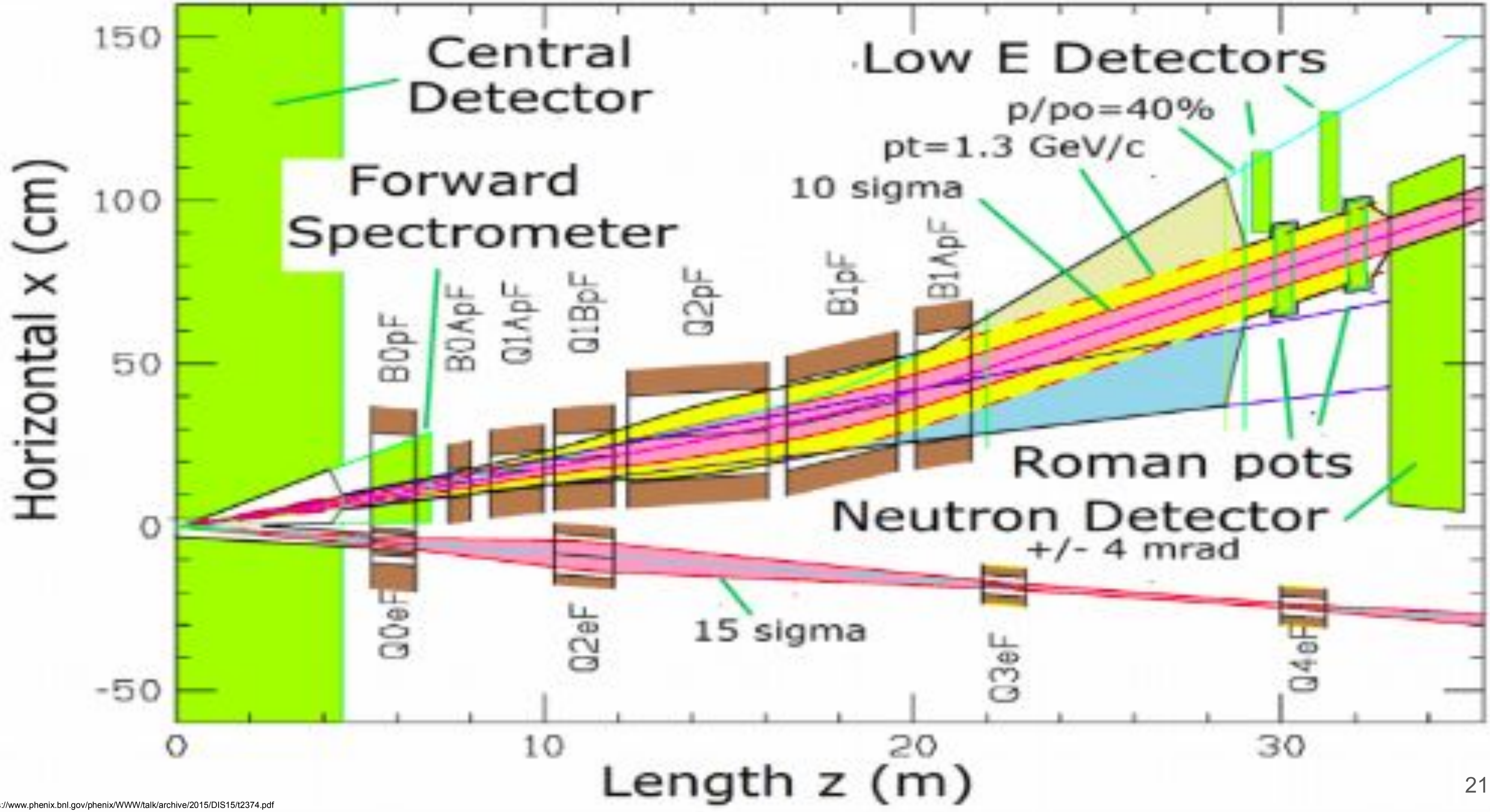


https://www.phenix.bnl.gov/phenix/WWW/talk/archive/2015/DIS15/t2374.pdf

ePHENIX



https://www.phenix.bnl.gov/phenix/WWW/talk/archive/2015/DIS15/t2374.pdf

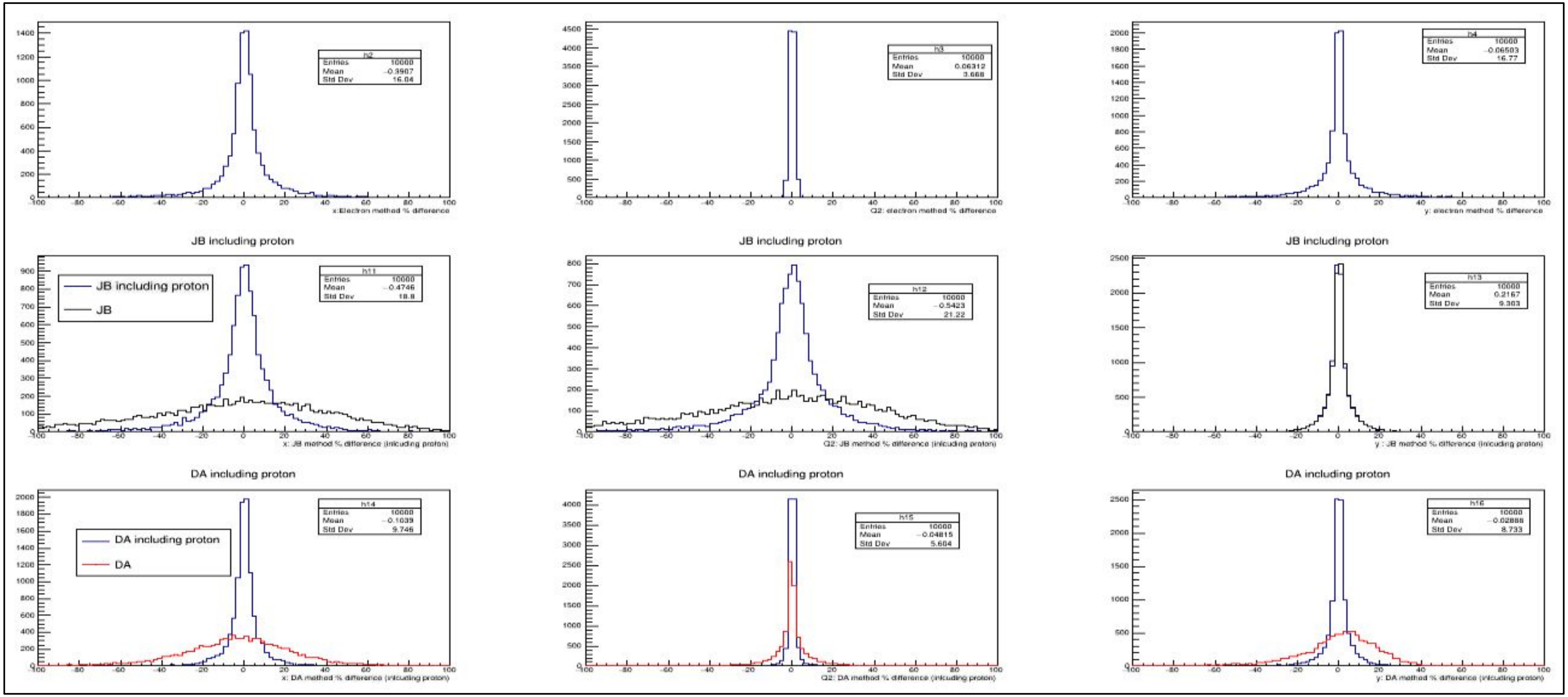


https://www.phenix.bnl.gov/phenix/WWW/talk/archive/2015/DIS15/t2374.pdf

EIC Smear Analysis

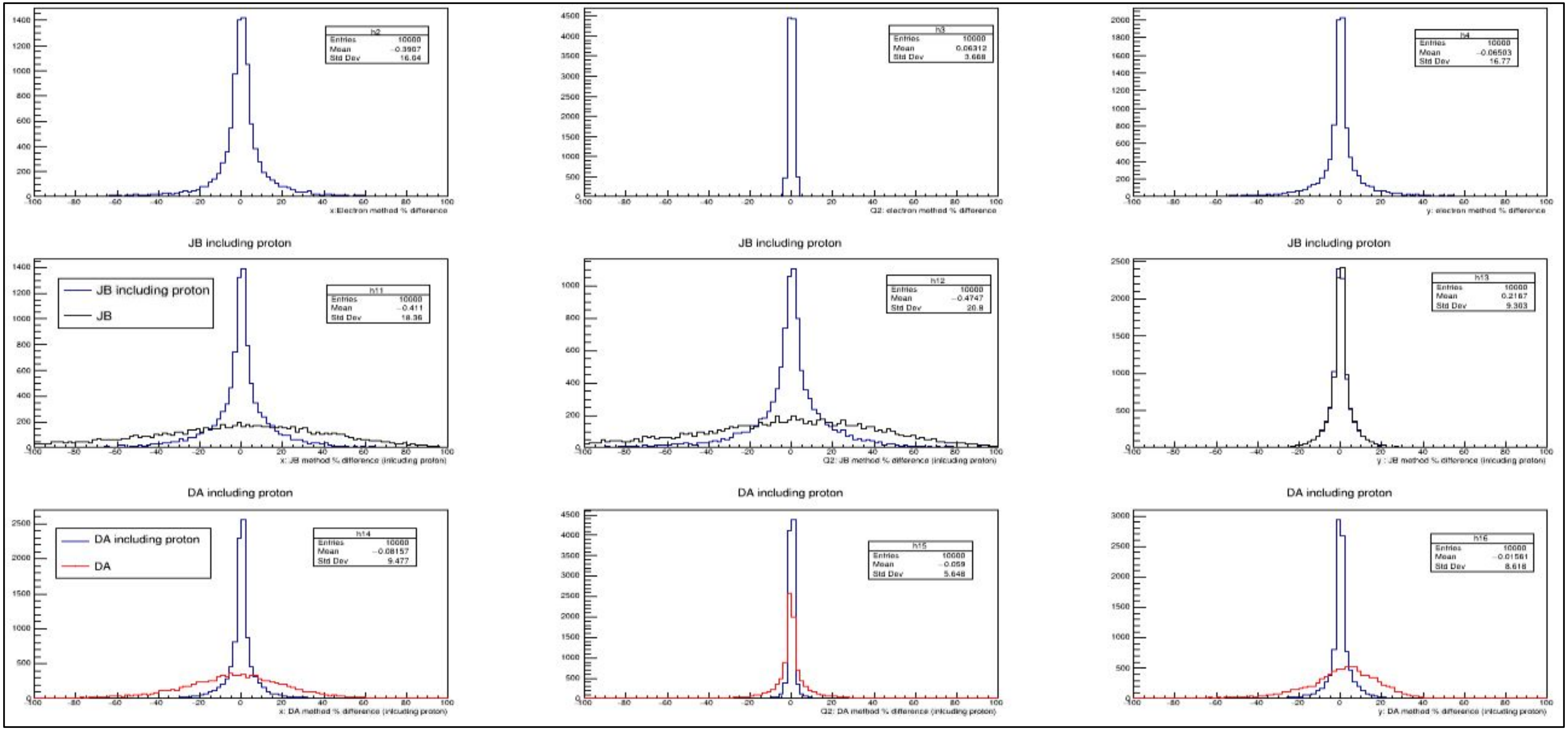
1. Kinematic reconstruction studies done on Sartre events.
2. e-p coherent diffractive events at varying Q^2
3. Implementing the three different event kinematic reconstruction methods and compare with MC events.
4. Smearing done using EIC-sPHENIX (setting 1) including roman pots and ZDC.

x **Q^2** **y**



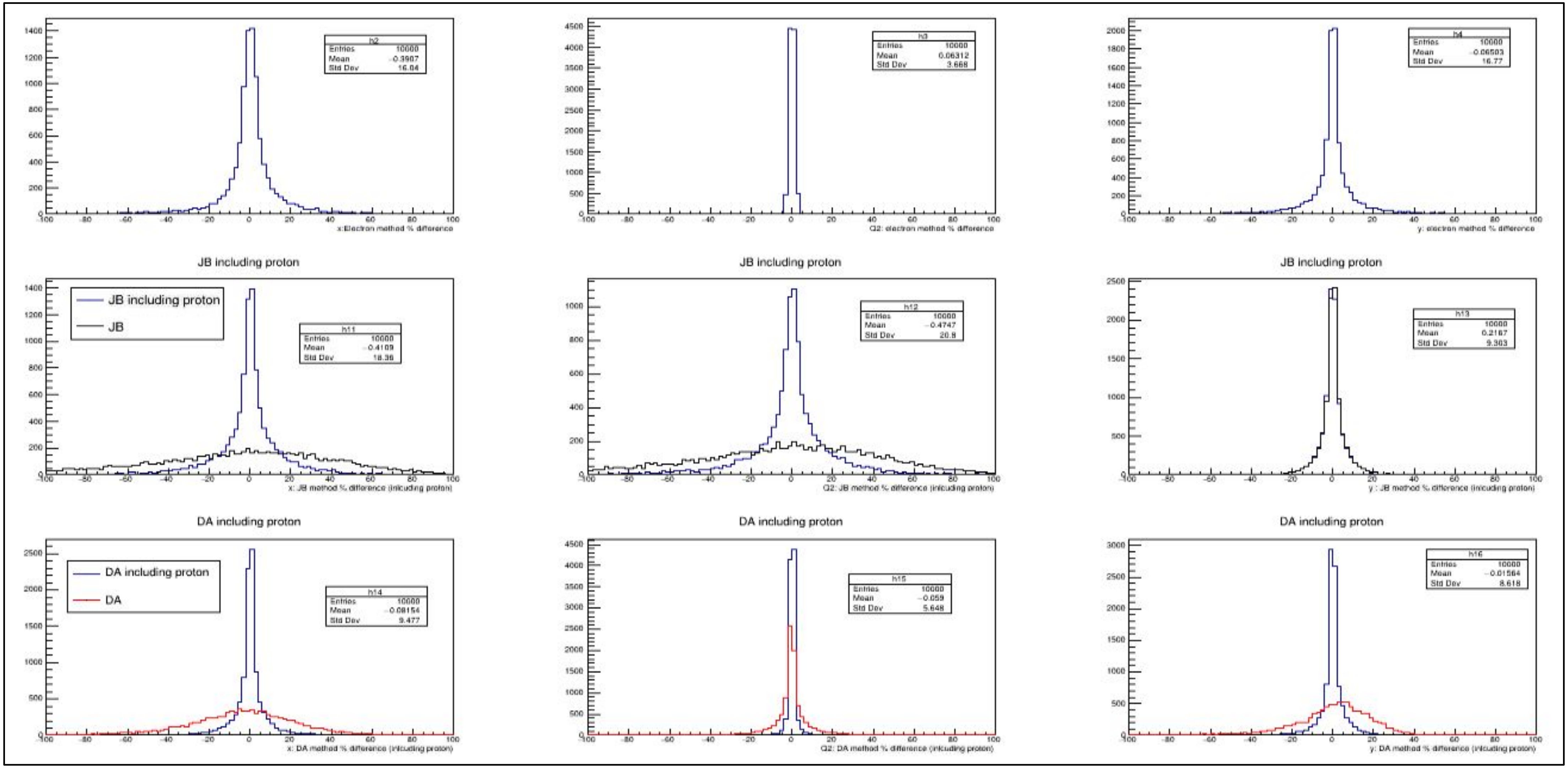
Roman pots kept 40m away from IP with low position resolution

x Q^2 y



Roman pots kept 40m away from IP with high position resolution

x Q^2 y



Roman pots kept 30m away from IP with high position resolution

Observations

1. **Electron method** is highly correlated with the true value -**ideal at larger y** while **hadronic methods at lower y**.

2. At **higher** $\mathbf{Q^2}$, JB and DA reconstruction seem to **improve** significantly!

3. Including the **outgoing proton** as a part of the hadronic final state, improves the accuracy of reconstruction using **JB and DA methods** to a fair amount.

4. In hadronic methods, while **JB method** gives a better reconstruction in **y**, **DA method** provides better $\mathbf{Q^2}$ reconstruction in all kinematic regimes

Three methods are complementary!

Supervisor : Prof. Dr. Abhay Deshpande
Co-supervisors : Dr. Tobias Toll
Dr. Barak Schmookler

References

1. Electron Ion Collider: The Next QCD Frontier - Understanding the glue that binds us all [https://arxiv.org/abs/1212.1701]
2. The dipole model Monte Carlo generator Sartre 1 [https://arxiv.org/abs/1307.8059]
3. Collider Physics at HERA [https://arxiv.org/pdf/0805.3334.pdf]
4. Exclusive vector meson production at an electron-ion collider [https://arxiv.org/abs/1803.06420]
5. Elastic electroproduction of ρ mesons at HERA [https://arxiv.org/abs/hep-ex/9902019]
6. https://wiki.bnl.gov/sPHENIX/index.php/EICSPHENIXLOI2018
7. https://wiki.bnl.gov/eic/index.php/Monte_Carlo_and_Smearing

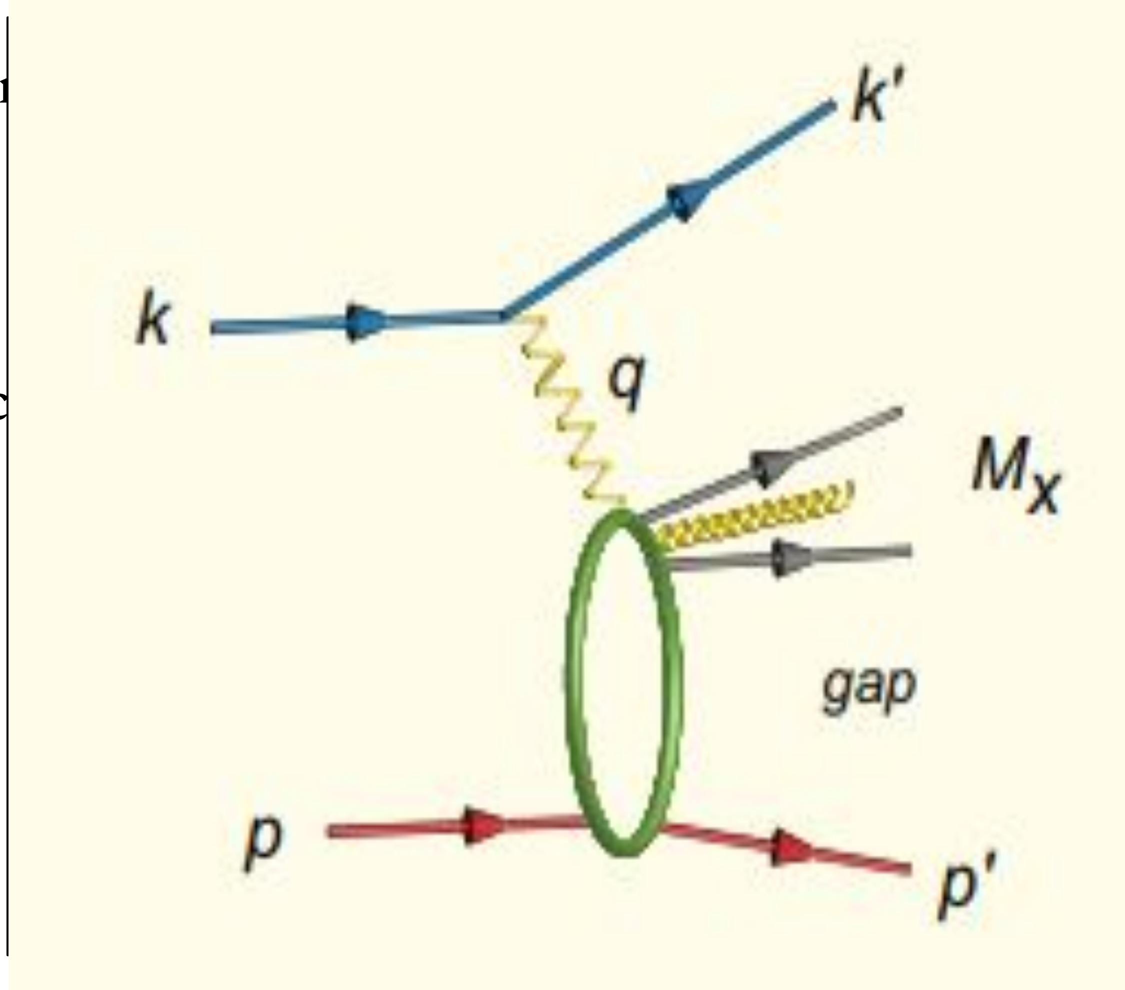
Thank You!

Thanks to wikimedia!

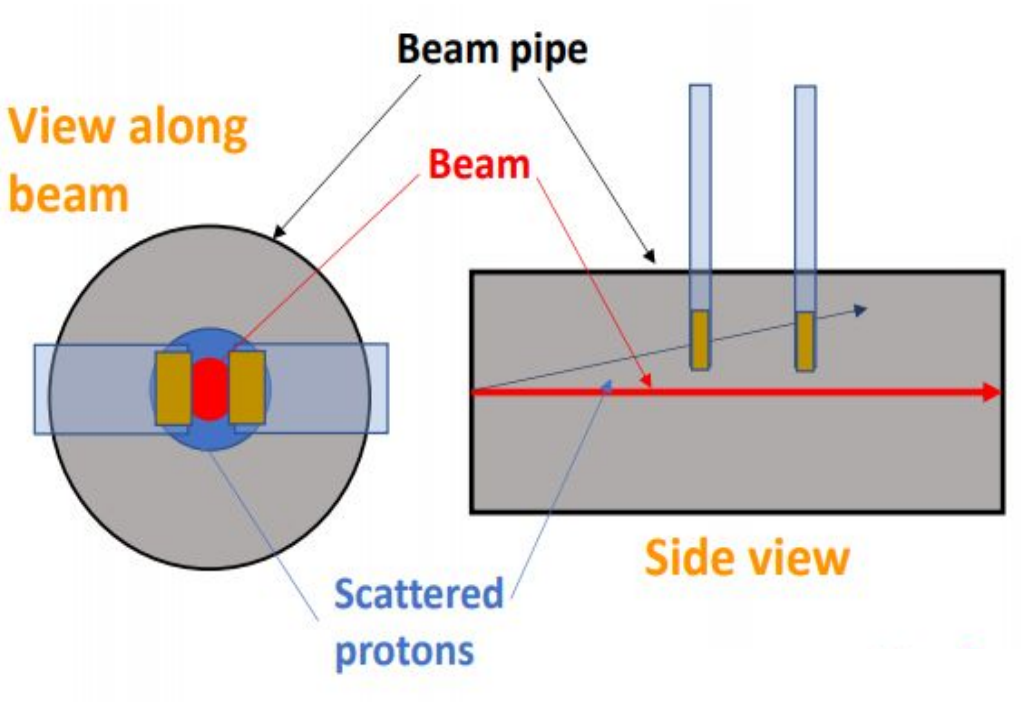
Backup

Diffractive Deep Inelastic Scattering (DDIS)

- Sensitive to geometric structure of hadr
- Sensitive to saturation phenomena
- Gluon spatial distribution inside nuc
- Presence of rapidity gap



Roman pots



- Silicon sensors injected into the beam pipe tens of metres away from the interaction point.
- For protons with high transverse momentum, detector closer to IP required.
- The tracks curve in the dipole field and momentum is reconstructed from the radius of curvature of the track.

EIC Smear

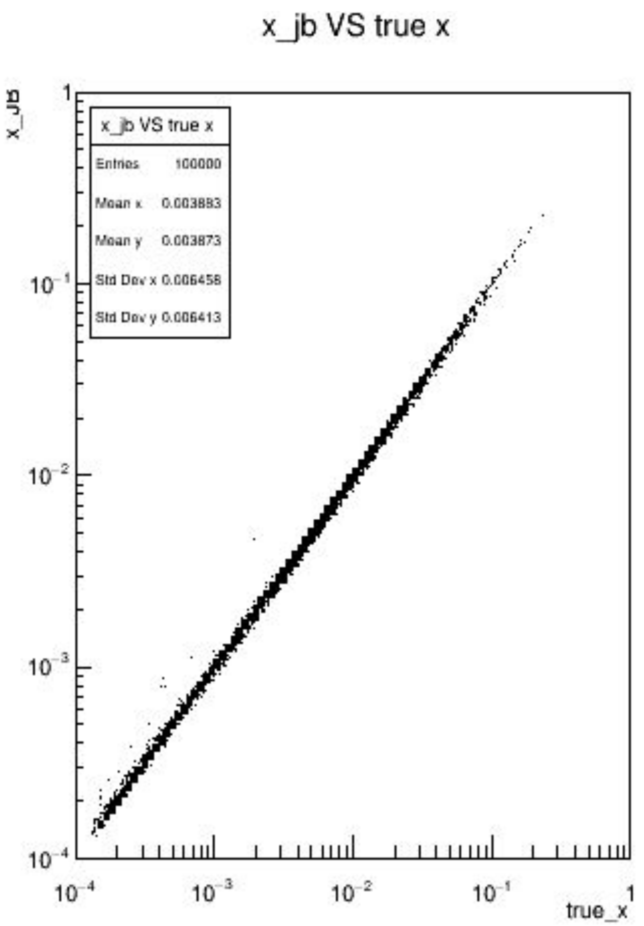
- Smearing is designed to allow rapid, approximate estimates of the effect of detector acceptance and performance on physics observables.
- The smearing code is "not" intended as a replacement for full detector simulations. Rather, it is a complementary tool for roughly assessing the impact of changes in detector performance on a physics measurement, in a way that is much more rapid, but less detailed, than a full detector simulation.

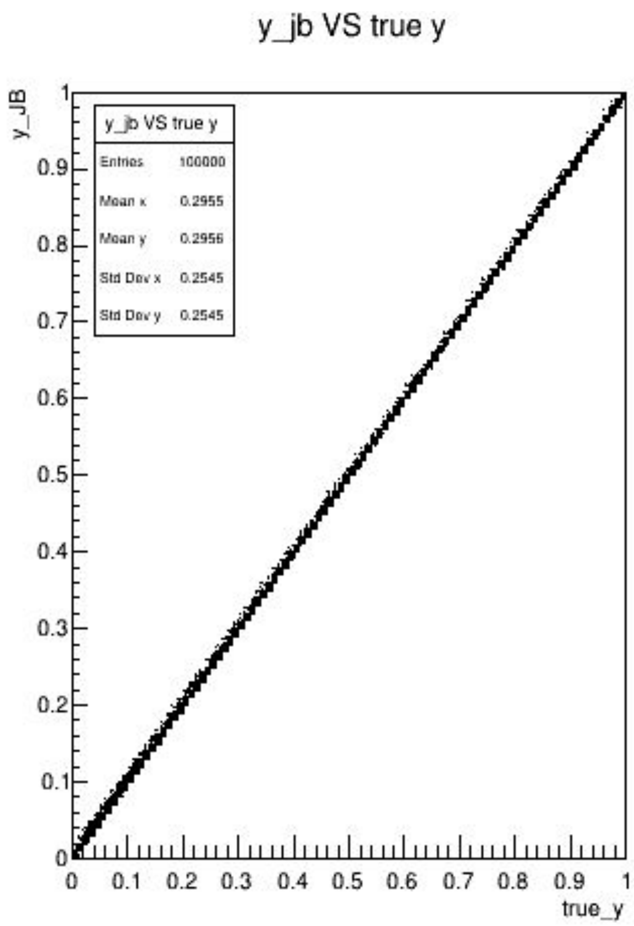
https://wiki.bnl.gov/eic/index.php/Smearing

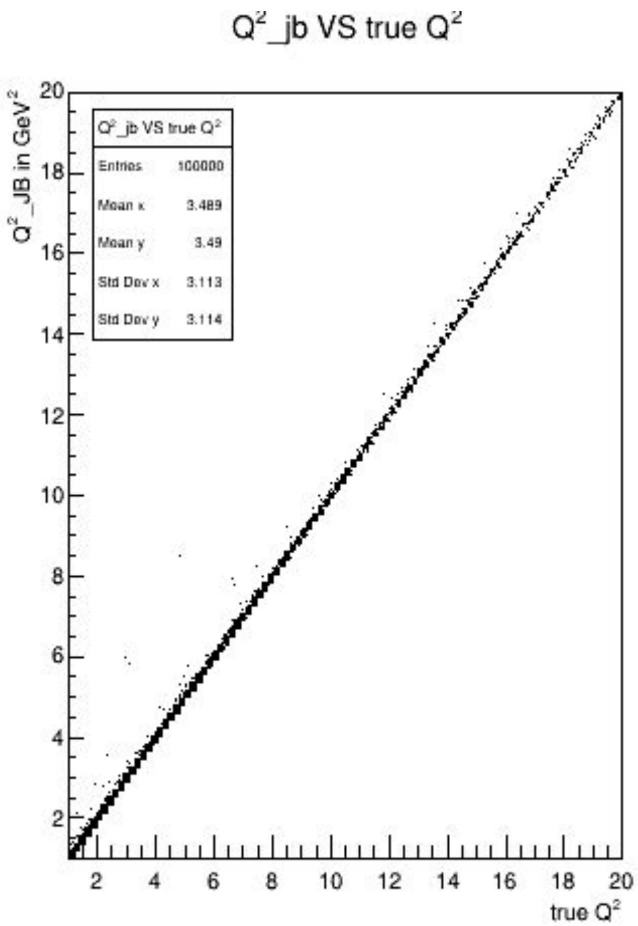
Acceptances for 2018 Letter of Intent

Setting 0	sPHENIX as defined in MIE
Setting 1	Ideal case (combines Setting 2 & Setting 3)
Setting 2	Only extend CEMC in e-going direction
Setting 3	Only cut CEMC and inner HCAL corners + extend CEMC active area in h-going direction + extend RICH coverages in h-going direction
Setting 4	No changes to sPHENIX calorimeter
Setting 5	No changes to sPHENIX calorimeter, no ERICH

	Setting 0 - sPHENIX		Setting 1		Setting 2		Setting 3		Setting 4		Setting 5	
Detector	eta_min	eta_max	eta_min	eta_max	eta_min	eta_max	eta_min	eta_max	eta_min	eta_max	eta_min	eta_max
TPC	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1
Tracking	-1.1	1.1	-4	4	-4	4	-4	4	-4	4	-4	4
EEMC	0	0	-4	-1.55	-4	-1.55	-4	-1.55	-4	-1.55	-4	-1.434
CEMC	-1.1	1.1	-1.55	1.242	-1.55	1.1	-1.1	1.242	-1.1	1.1	-1.1	1.1
FEMC	0	0	1.242	4	1.45	4	1.242	4	1.45	4	1.45	4
IHCAL	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1
OHCAL	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1	-1.1	1.1
FHCAL	0	0	1.242	5	1.45	5	1.242	5	1.45	5	1.45	5
EPID	0	0	-4	-1.55	-4	-1.55	-4	-1.55	-4	-1.55	0	0
CPID ('DIRC/TOF')	0	0	-1.55	1.242	-1.55	1.242	-1.55	1.242	-1.55	1.242	-1.55	1.242
FPID0 ('RICH')	0	0	1.242	4	1.45	4	1.242	4	1.45	4	1.45	4
FPID1 ('mRICH')	0	0	1.242	1.85	1.45	1.85	1.242	1.85	1.45	1.85	1.45	1.85
FPID2 ('TOF')	0	0	1.85	4	1.85	4	1.85	4	1.85	4	1.85	4


x_jb VS true x
x_JB
true_x
x_jb VS true x
Entries 100000
Mean x 0.003883
Mean y 0.003873
Std Dev x 0.006458
Std Dev y 0.006413


y_jb VS true y
y_JB
true_y
y_jb VS true y
Entries 100000
Mean x 0.2955
Mean y 0.2956
Std Dev x 0.2545
Std Dev y 0.2545


Q²_jb VS true Q²
Q²_JB in GeV²
true Q²
Q²_jb VS true Q²
Entries 100000
Mean x 3.489
Mean y 3.49
Std Dev x 3.113
Std Dev y 3.114

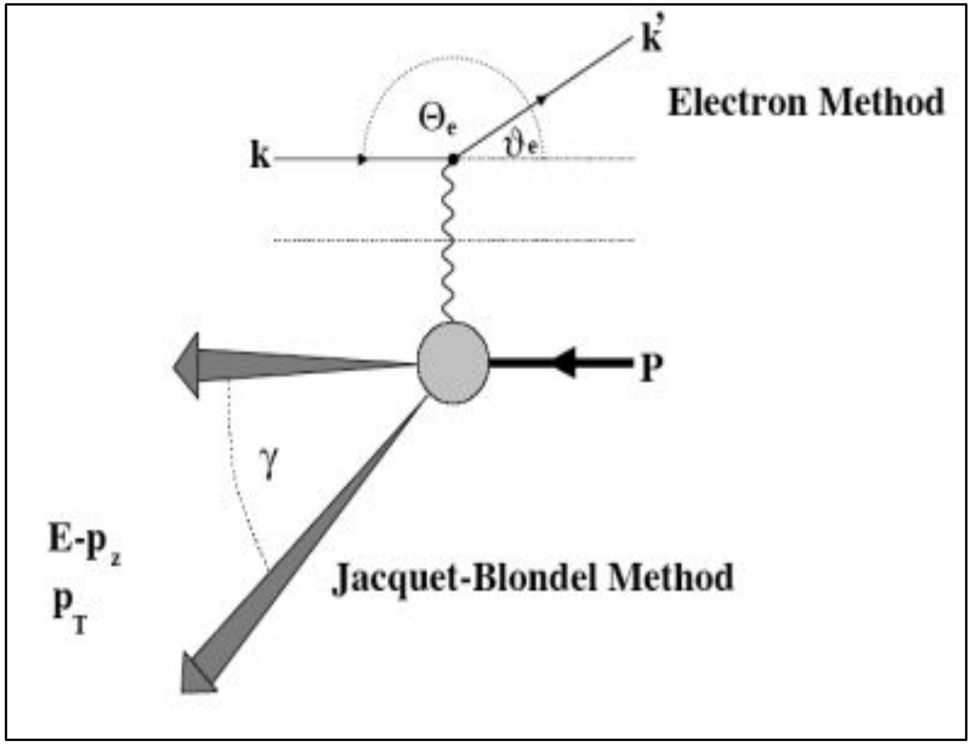
Scattered Electron Method

- E_e' and θ_e are measured to give the following variables:

$$Q_e^2 = -q^2 = 4 E_e E_e' \cos^2 \theta_e/2$$

$$y_e = \frac{Pq}{Pk} = 1 - \frac{Pk'}{Pk} = 1 - \frac{E_e'}{2E_e}(1 - \cos\theta_e).$$

$$Q_e^2 = s. x_e .y_e$$

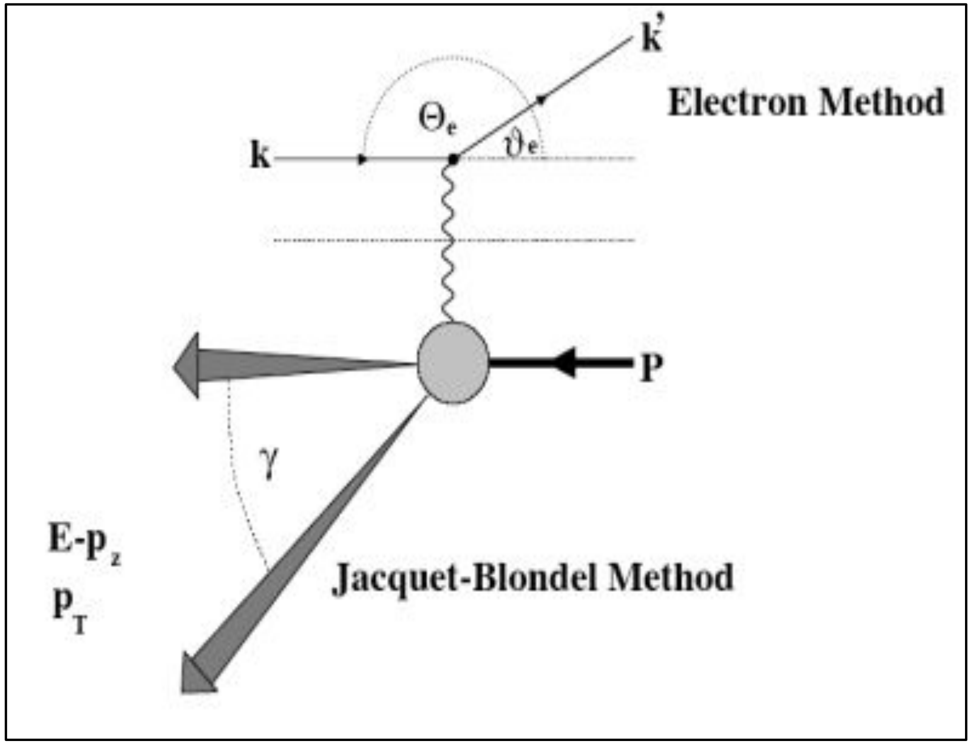


Jacquet Blondel Method

- The following equations can be derived using the energy conservation laws from the hadronic final state

$$y_h = \frac{\Sigma_h}{2E_e} \qquad Q_h^2 = \frac{p_{t,h}^2}{1 - y_h},$$

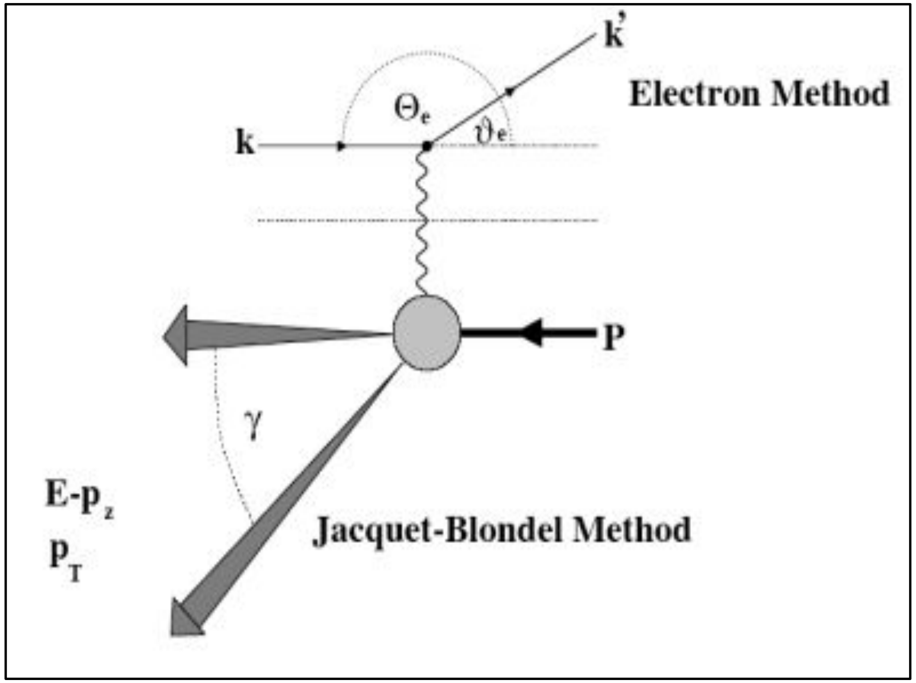
$$\Sigma_h = \sum_i (E_i - p_{z,i})$$



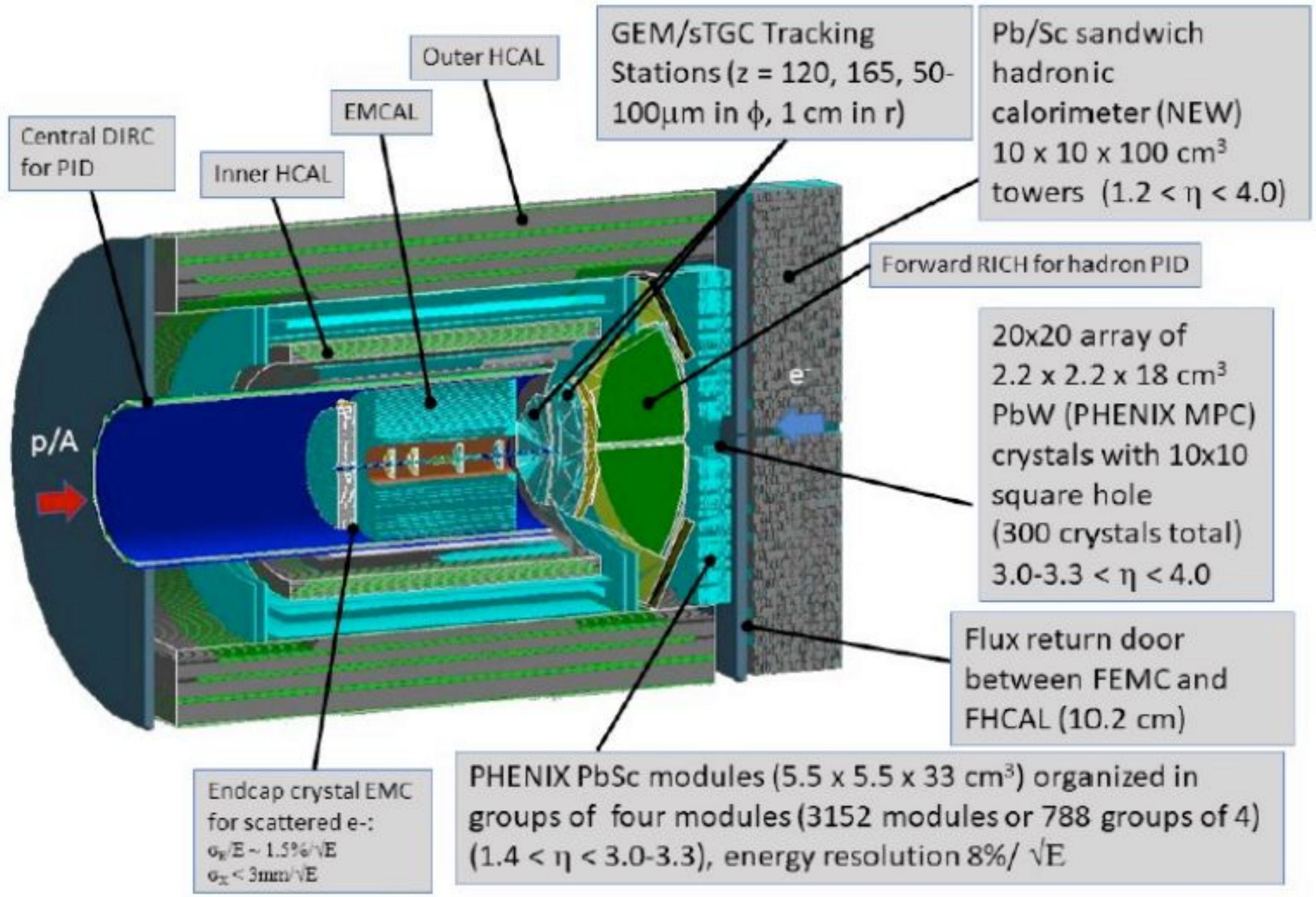
Double Angle Method

- Measuring the electron scattering angle θ_e and the effective angle γ_H of the final hadronic system give the following equations for x, Q^2 and y

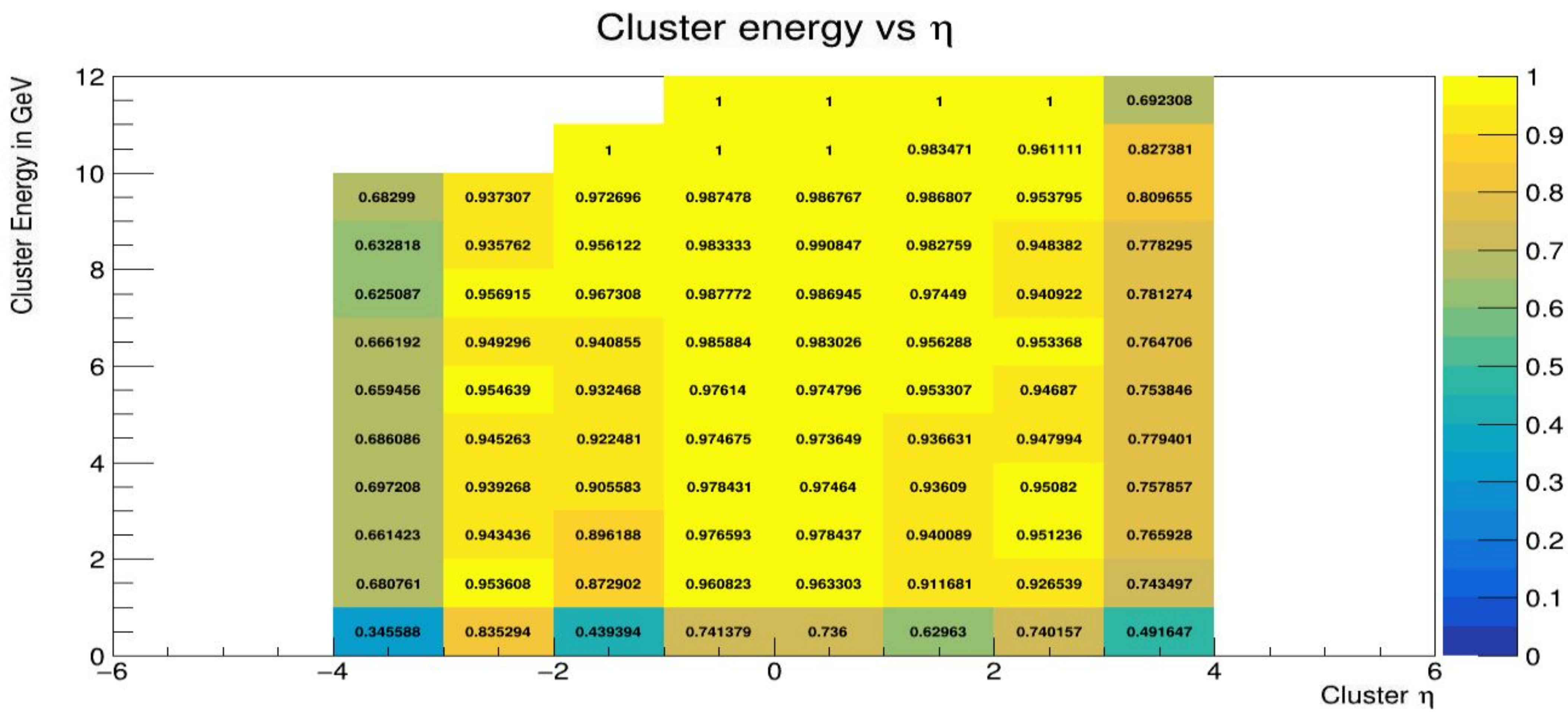
$$
\begin{aligned}
Q^2_{DA} &= 4E^2_{e,beam}\frac{\sin\gamma_H(1+\cos\theta_e)}{\sin\gamma_H+\sin\theta_e-\sin(\theta_e+\gamma_H)} \\
y_{DA} &= \frac{\sin\theta_e(1-\cos\gamma_H)}{\sin\gamma_H+\sin\theta_e-\sin(\theta_e+\gamma_H)} \\
x_{DA} &= \frac{Q^2}{ys}
\end{aligned}
$$



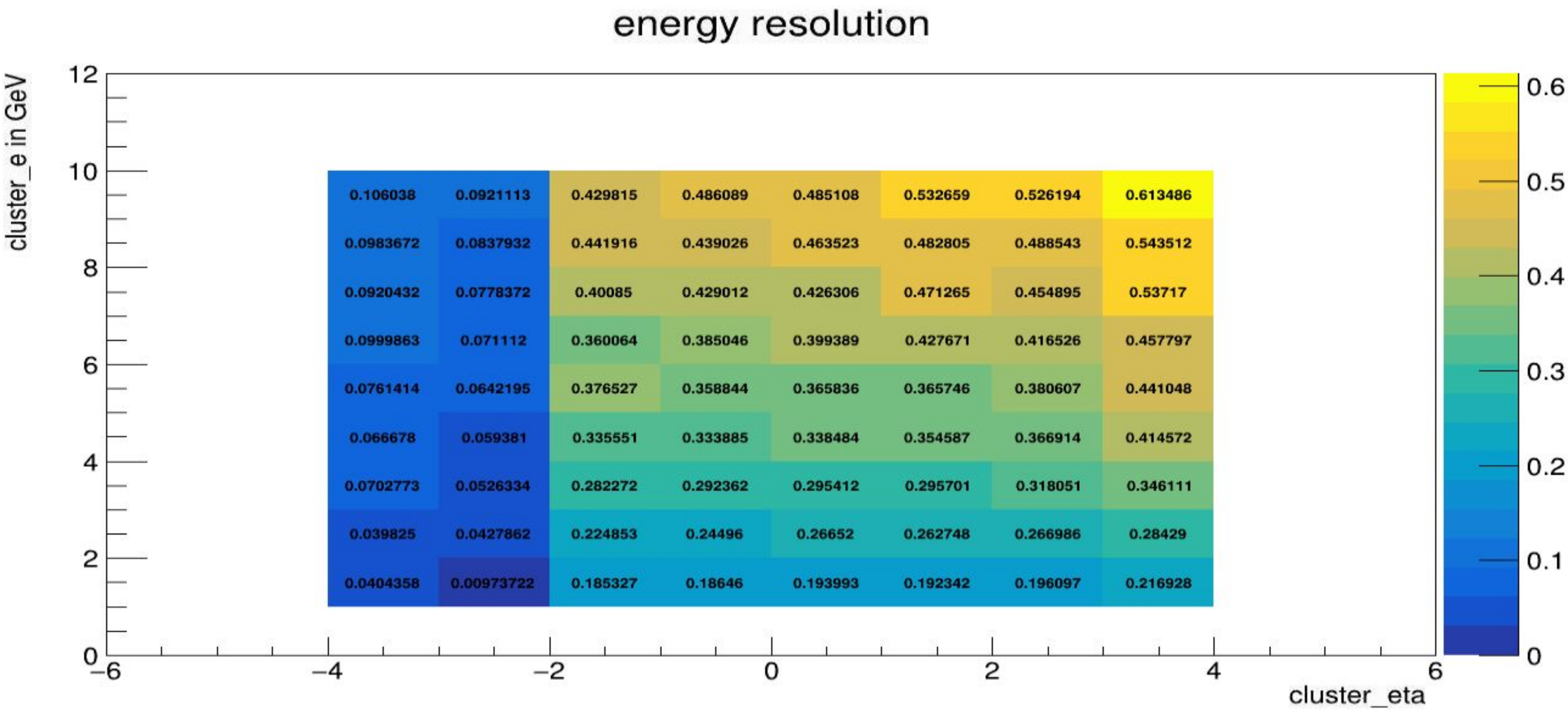
GEANT4

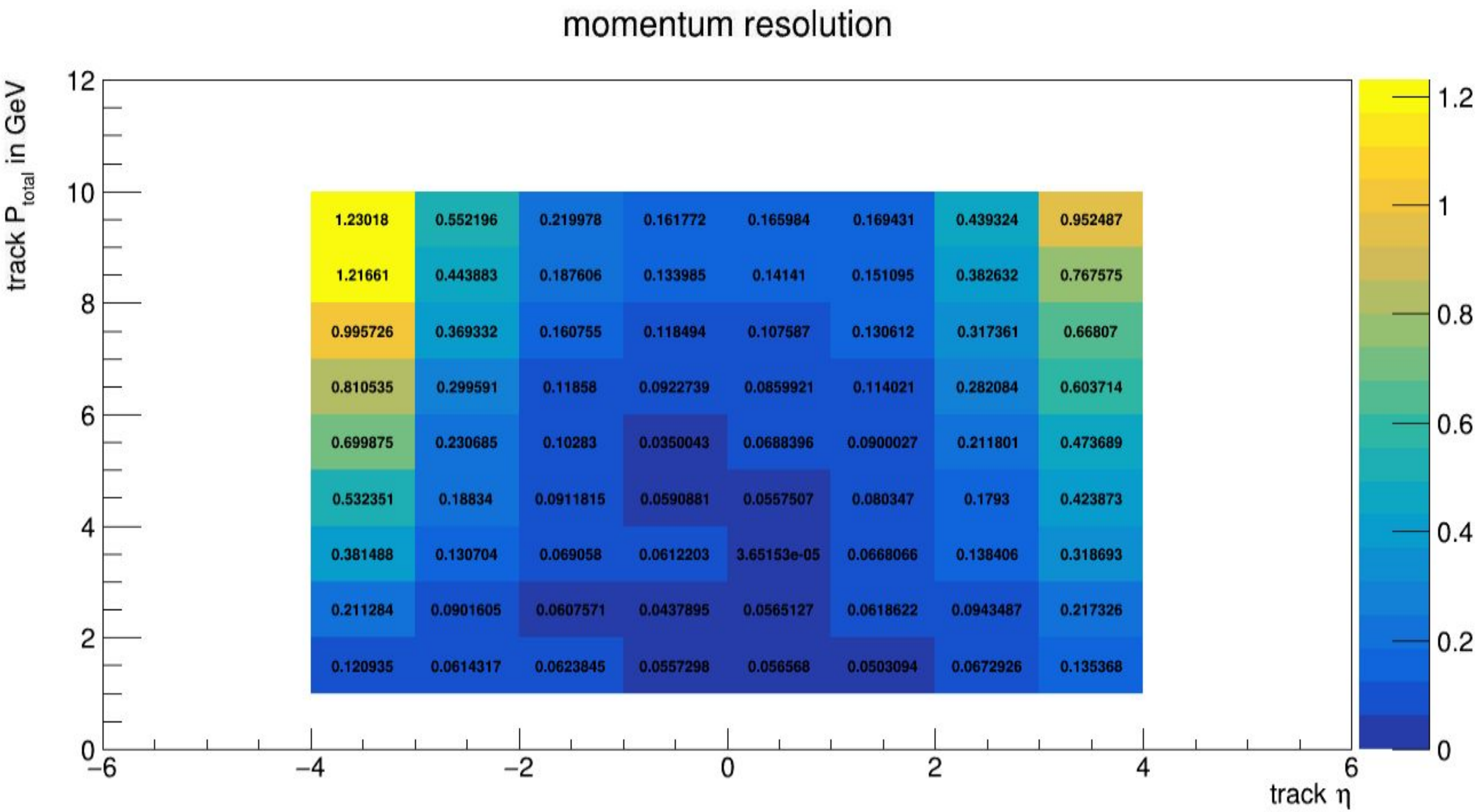


Fun4All Eic-sPHENIX



Cluster energy vs η
Cluster Energy in GeV
Cluster η
1 1 1 1 0.692308
1 1 1 0.983471 0.961111 0.827381
0.68299 0.937307 0.972696 0.987478 0.986767 0.986807 0.953795 0.809655
0.632818 0.935762 0.956122 0.983333 0.990847 0.982759 0.948382 0.778295
0.625087 0.956915 0.967308 0.987772 0.986945 0.97449 0.940922 0.781274
0.666192 0.949296 0.940855 0.985884 0.983026 0.956288 0.953368 0.764706
0.659456 0.954639 0.932468 0.97614 0.974796 0.953307 0.94687 0.753846
0.686086 0.945263 0.922481 0.974675 0.973649 0.936631 0.947994 0.779401
0.697208 0.939268 0.905583 0.978431 0.97464 0.93609 0.95082 0.757857
0.661423 0.943436 0.896188 0.976593 0.978437 0.940089 0.951236 0.765928
0.680761 0.953608 0.872902 0.960823 0.963303 0.911681 0.926539 0.743497
0.345588 0.835294 0.439394 0.741379 0.736 0.62963 0.740157 0.491647


energy resolution
cluster_e in GeV
cluster_eta
0.106038 0.0921113 0.429815 0.486089 0.485108 0.532659 0.526194 0.613486
0.0983672 0.0837932 0.441916 0.439026 0.463523 0.482805 0.488543 0.543512
0.0920432 0.0778372 0.40085 0.429012 0.426306 0.471265 0.454895 0.53717
0.0999863 0.071112 0.360064 0.385046 0.399389 0.427671 0.416526 0.457797
0.0761414 0.0642195 0.376527 0.358844 0.365836 0.365746 0.380607 0.441048
0.066678 0.059381 0.335551 0.333885 0.338484 0.354587 0.366914 0.414572
0.0702773 0.0526334 0.282272 0.292362 0.295412 0.295701 0.318051 0.346111
0.039825 0.0427862 0.224853 0.24496 0.26652 0.262748 0.266986 0.28429
0.0404358 0.00973722 0.185327 0.18646 0.193993 0.192342 0.196097 0.216928


momentum resolution
track P_{total} in GeV
track η
1.23018
0.552196
0.219978
0.161772
0.165984
0.169431
0.439324
0.952487
1.21661
0.443883
0.187606
0.133985
0.14141
0.151095
0.382632
0.767575
0.995726
0.369332
0.160755
0.118494
0.107587
0.130612
0.317361
0.66807
0.810535
0.299591
0.11858
0.0922739
0.0859921
0.114021
0.282084
0.603714
0.699875
0.230685
0.10283
0.0350043
0.0688396
0.0900027
0.211801
0.473689
0.532351
0.18834
0.0911815
0.0590881
0.0557507
0.080347
0.1793
0.423873
0.381488
0.130704
0.069058
0.0612203
3.65153e-05
0.0668066
0.138406
0.318693
0.211284
0.0901605
0.0607571
0.0437895
0.0565127
0.0618622
0.0943487
0.217326
0.120935
0.0614317
0.0623845
0.0557298
0.056568
0.0503094
0.0672926
0.135368