EIC Calorimetry: YR Summary and beyond

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EIC-YR-Detector-Calorimetry Group

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EMCal

Goals:

- DIS kinematics
  (through scattered electron)
- Decay electrons
  (e.g. form vector mesons)
- Photons
  (e.g. from DVCS)
- π0
  (e.g. from SIDIS or exclusive DIS)

Challenges:

- Energy resolution
  (particularly at high $|\eta|$, high p)
- Charged hadron suppression for eID
- γ/π0 discrimination
  (Granularity, projectivity)

Limited space => dense, high granularity, high resolution EMCal

HCal

Goal:

- Jet measurements
- Rapidity gap
  (tag diffractive events)

Challenges:

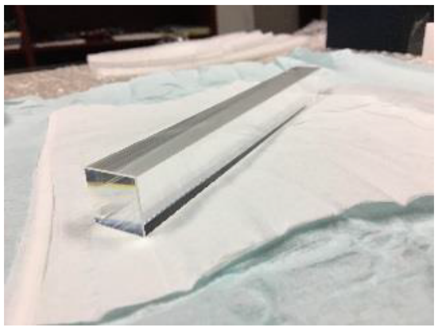
- Energy resolution
  (particularly at high $|\eta|$)
- Neutral/Charged cluster discrimination
  (with help of tracking)

Limited space <=> Resolution

eRD1

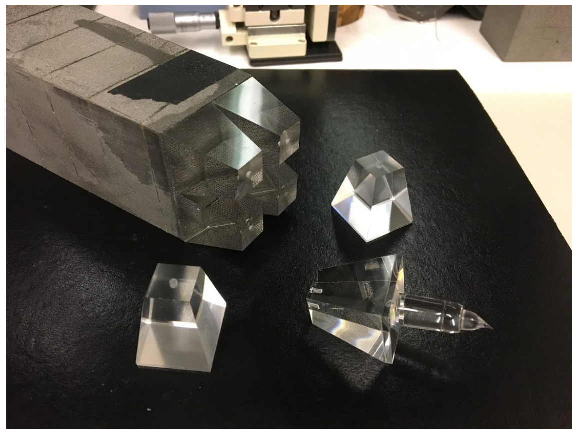
$PbWO_4$ crystal:

High resolution, high granularity, high e/π power



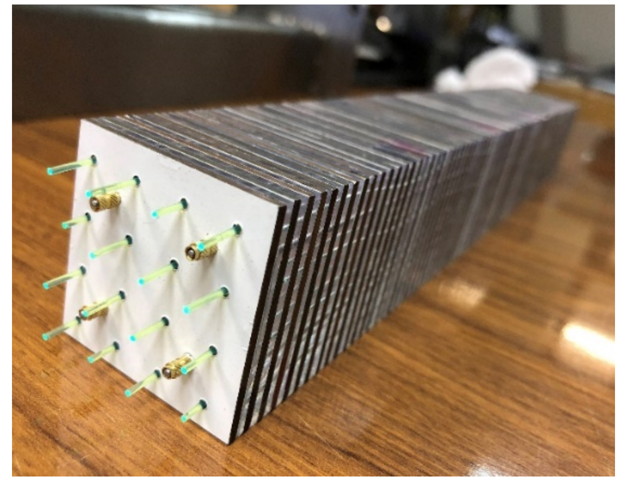
W/SciFi:

Modest resolution, compact, high granularity



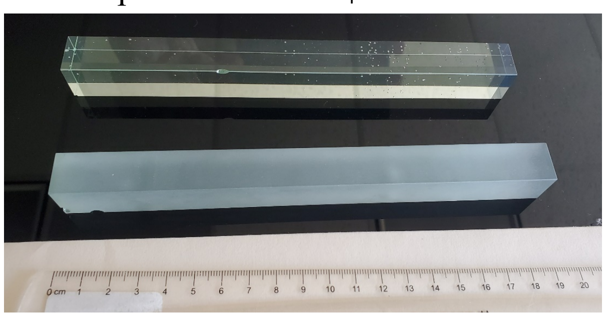
W/Shashlik:

Tunable resolution, super-high “effective” granularity

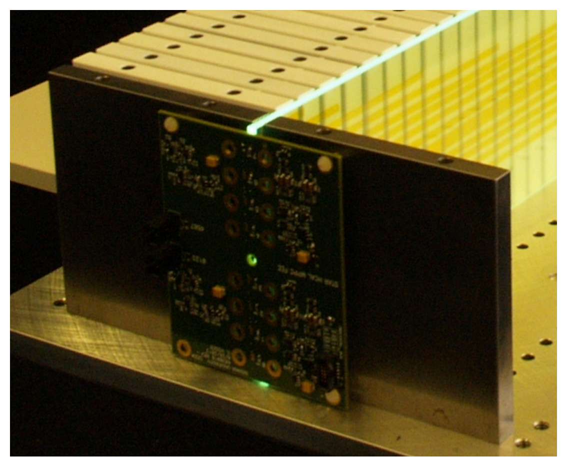


SciGlass:

A competitor to $PbWO_4$

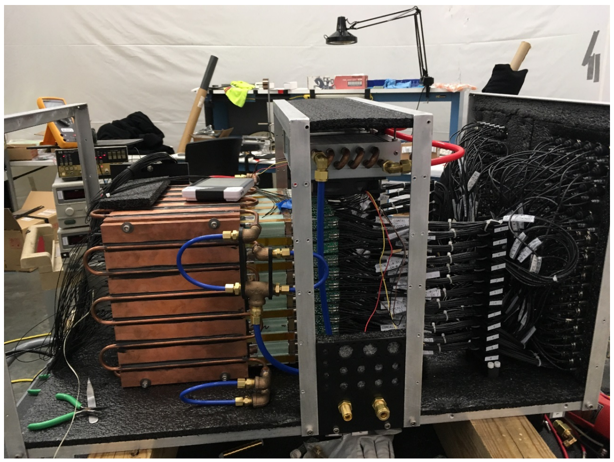


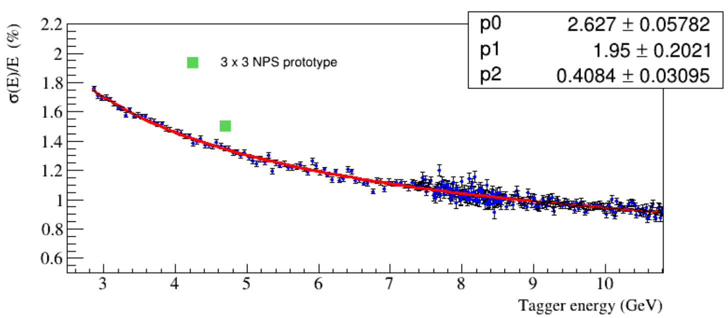
Fe/Sc HCal



Recent Developments

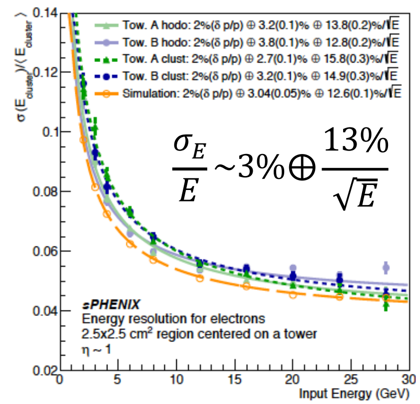
Jlab-PrimEx eta/NPS PWO EMCal prototype





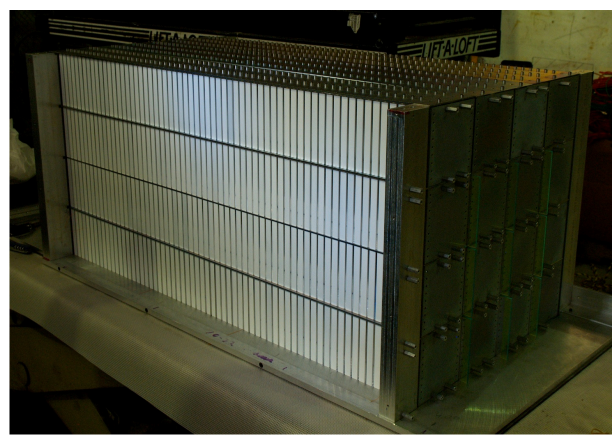
$$\frac{\sigma_E}{E} = 0.4\% \oplus \frac{2.6\%}{\sqrt{E}} \oplus \frac{1.9}{E}$$

BNL-sPHENIX: W/SciFi



$$\frac{\sigma_E}{E} \sim 3\% \oplus \frac{13\%}{\sqrt{E}}$$

BNL-fSTAR: Fe/Sc HCal



$$\frac{\sigma_E}{E} \sim 6\% \oplus \frac{60\%}{\sqrt{E}}$$

Key Characteristics

Depth (long. size)

EMCal: Defined by X_0 and energy range ($L \sim 20X_0$)

HCal: Defined by λ_I and energy range ($L \sim 5\text{-}7\lambda_I$)

Granularity

EMCal: Defined by R_m ($\sim X_0 \cdot 21\text{MeV}/E_{crit}$)

HCal: Defined by λ_I

Minimal detectable energy

Defined by noise level

Resolution

$$\frac{\sigma_E}{E} = a \oplus \frac{b}{\sqrt{E}} \oplus \frac{c}{E}$$

a: defined by syst. effects (non-uniformity, calibration, leakage)

b: defined by sampling fraction, light yield

c: noise term

YR Summary Table

From YR Wiki

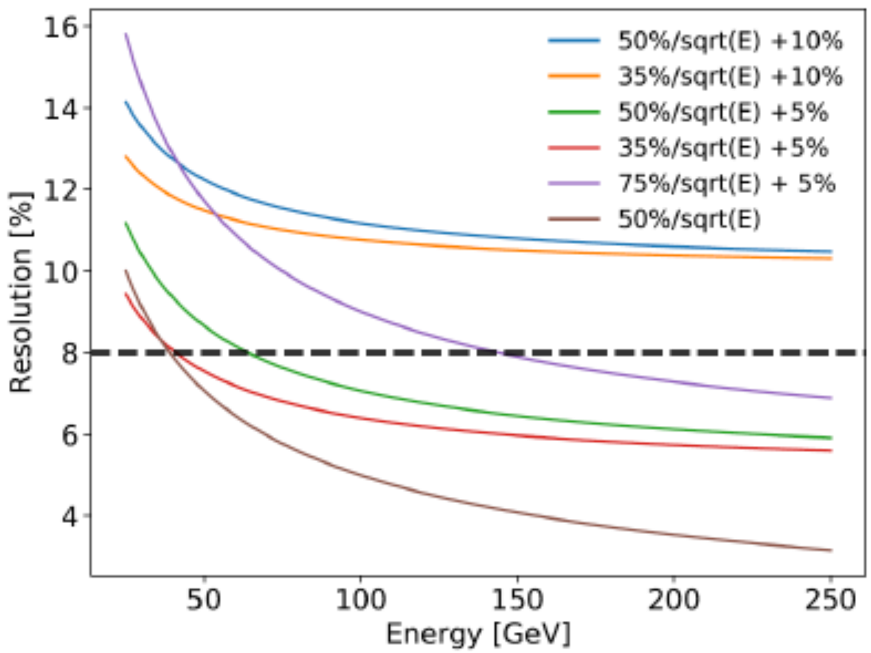
Table.5 **Calorimetry for EIC**

η	ECAL								HCAL				
	Total depth, cm	Depth, RL	Energy resolution σE/E, %	Spacial resolution σX, mm	Granularity, mm^2	Min. photon energy, MeV	PID e/π, π suppression	Technology examples*	total depth, cm	Energy resolution σE/E, %	Spacial resolution σX, mm	Granularity, mm^2	Technology examples
-4.0:-2.0	38	22	1.0⊕2.2/√E⊕1.0/E	3/√E⊕1	20×20	20	1000	$PbWO_4$ crystals	105	50/√E⊕10	50/√E⊕30	100×100	Fe/Sc
-2.0:-1.0	38 38 50 50 (65)**	20 20 22 13* 16*	1.5⊕8.0/√E⊕2/E 2⊕12/√E⊕2/E 1.5⊕(7-8)/√E⊕2/E ? 1.5⊕4.0/√E⊕2/E	3/√E⊕1 3/√E⊕1 6/√E⊕1 6/√E⊕1 6/√E⊕1	25×25 25×25 40×40 40×40 40×40	50 50 50 30 30	300	W/Sc Shashlyk W powder/ScFi Pb/Sc Shashlyk SciGlass SciGlass	105	50/√E⊕10	50/√E⊕30	100×100	Fe/Sc
-1.0:1.0	30 30 38 65 *	18 18 22 16*	2⊕12/√E⊕2/E 3⊕14/√E⊕2/E 1.0⊕2.2/√E⊕1.0/E 1.5⊕4.0/√E⊕2/E	3/√E⊕1 3/√E⊕1 3/√E⊕1 6/√E⊕1	25×25 25×25 20×20 40×40	100 100 20 30	300 300 1000 300	W/Sc Shashlyk W powder/ScFi PWO SciGlass	110	100/√E⊕10	50/√E⊕30	100×100	Fe/Sc
1.0:4.0	38 38 (50)** (65)**	20 20 22 16*	1.5⊕8.0/√E⊕2/E 2⊕12/√E⊕2/E 1.5⊕10.0/√E⊕2/E 1.5⊕4.0/√E⊕2/E	3/√E⊕1 3/√E⊕1 6/√E⊕1 6/√E⊕1	25×25 25×25 40×40 40×40	100 100 100 30	300	W/Sc Shashlyk W powder/ScFi Pb/Sc Shashlyk SciGlass	105	50/√E⊕10	50/√E⊕30	100×100	Fe/Sc

All technologies are either mature or a part of ongoing R&D

HCal: Energy Resolution

Jet energy resolution



From M. Arratia:

HCal energy resolution of

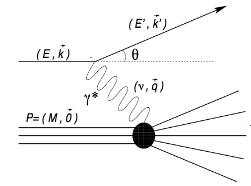
$$\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} \oplus 10\%$$

is not enough at $\eta>2.5$

- Longer HCal: $5\lambda_I \rightarrow 6\text{-}7\ \lambda_I$
- Compensation and coupling with EMCal
- Tail catcher (would limit eff.)
- Dual readout

… See talk by Tanja Horn

EMCal: Energy Resolution



Resolutions for (x,Q^2)

$$\frac{\sigma_{Q^2}}{Q^2} = \frac{\sigma_{E'}}{E'} \qquad \frac{\sigma_x}{x} = \frac{1}{y}\frac{\sigma_{E'}}{E'}$$

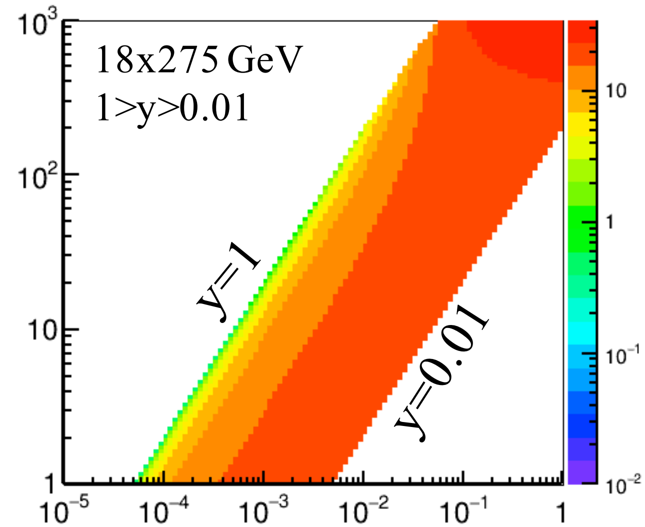
(Minimal effect from angular res.)

$$Q^2 = 4EE'\sin^2\left(\frac{\theta}{2}\right)$$

$$y = 1 - \frac{E'}{E}\cos^2\left(\frac{\theta}{2}\right)$$

$$x = \frac{Q^2}{sy}$$

Electron energy vs (Q^2,x)



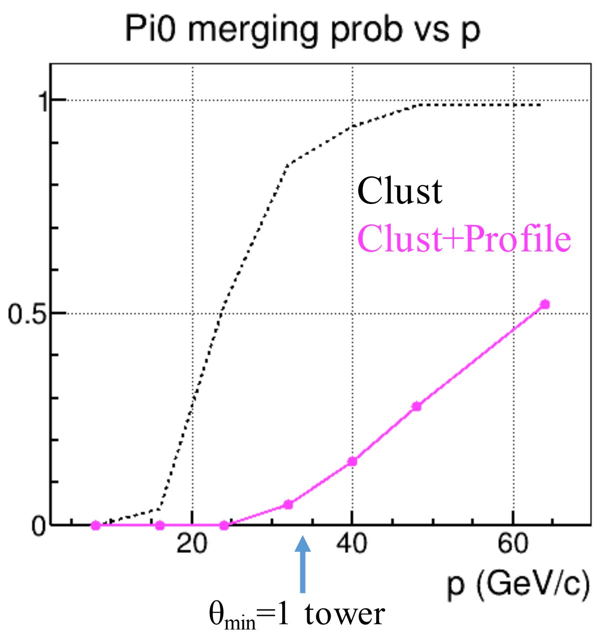
- Looser requirements for lower energy measurements
- Tough requirements for higher energy measurements (due to $1/y$ factor)
- Most of the (Q^2,x) space relates to the highest electron energy

  => Constant term in energy resolution is of primary importance

EMCal: Granularity (~R_m?)

γ/π0 discrimination

$$\theta_{min} = \frac{2m_{\pi 0}}{E_{\pi 0}}$$



GEANT4:
Forward EMCal with granularity ~0.008 (2.5×2.5 cm^2 at z=3m)

Scalable with tower size *d* and location *Z*:

$p \sim Z/d$

W/Shashlik (eRD1 by C.Woody et al.)

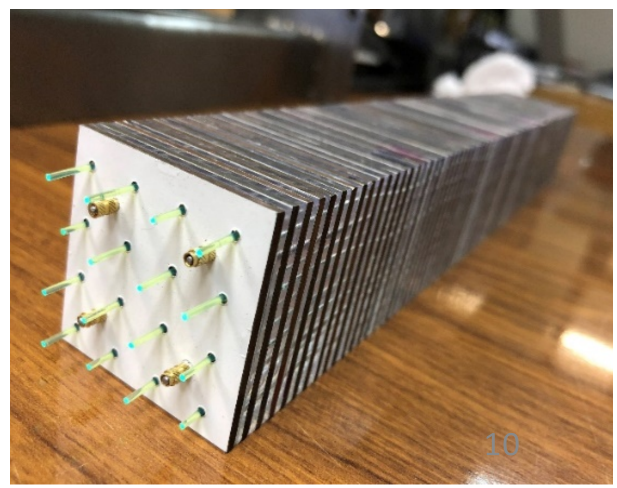
Each fiber readout by its own SiPM

More detailed info on shower development within a tower

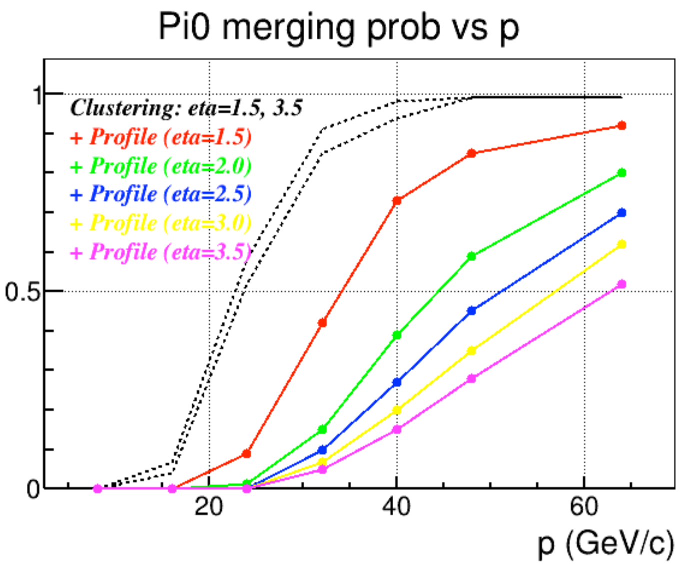
Improve position resolution

Improve energy res. (const term)

Improve γ/π0 discrimination

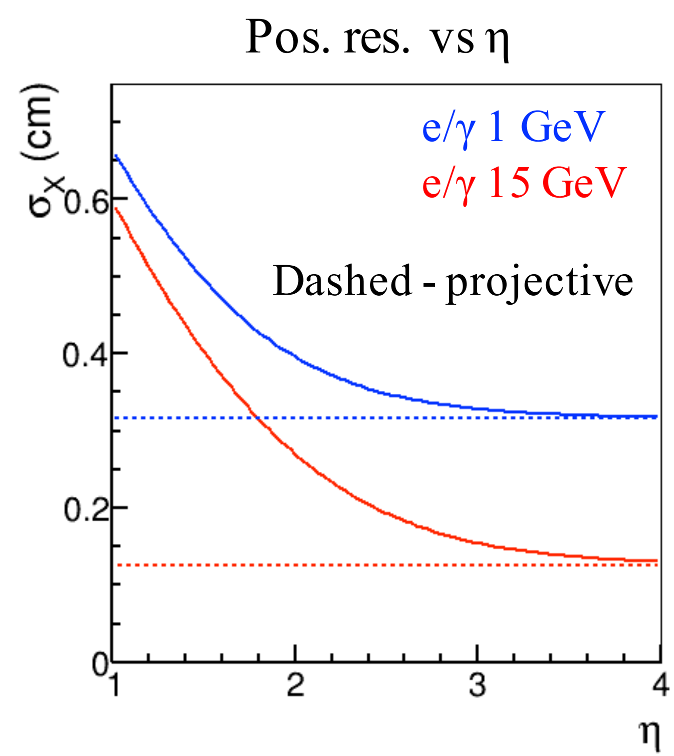


EMCal: Projectivity



GEANT4:
Forward EMCal with granularity ~0.008 (2.5×2.5 cm^2 at z=3m)

Significant loss of $\gamma/\pi0$ discrimination power at lower rapidity in non-projective EMCal



$$\sigma_X(E,\theta_X) = \sigma_X(E,0^0) \oplus d\sin(\theta_X)$$

For projective geometry

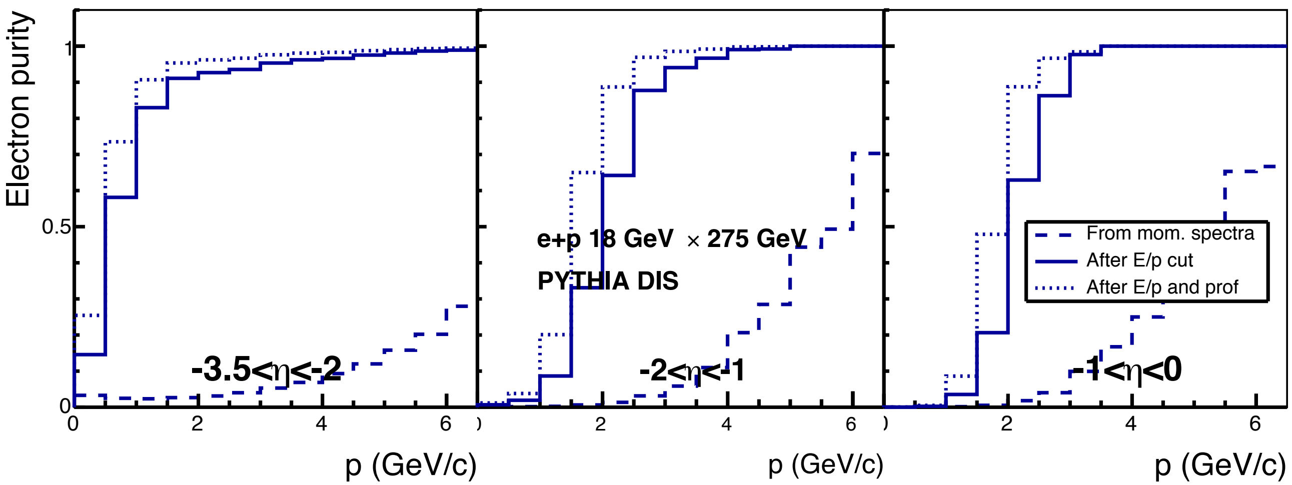
"Non-projectivity" term (from long. shower fluct.) $d \sim X_0$

Position resolution is dominated by "non-projectivity" term

e/π separation

For DIS electron

-3.5<η<-2	-2<η<-1	-1<η<1
$\frac{\sigma_E}{E} = \frac{2.5\%}{\sqrt{E}} \oplus 1\%$	$\frac{\sigma_E}{E} = \frac{7\%}{\sqrt{E}} \oplus 2\%$	$\frac{\sigma_E}{E} = \frac{12\%}{\sqrt{E}} \oplus 2\%$



Ideal case:
- No material on the way to EMCal
- Perfect EMCal (no gaps/cracks)
- Gaussian response to electron

Purity = e / (e+h)

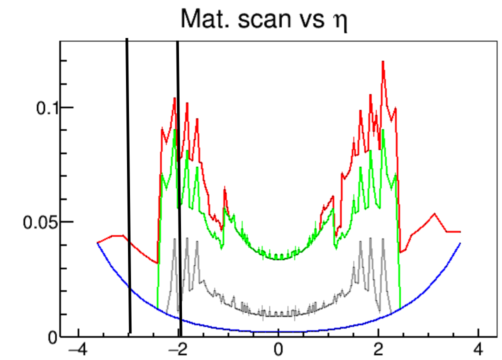
Expect to get high *e* purity at >4 GeV/c for 18 GeV electron beam

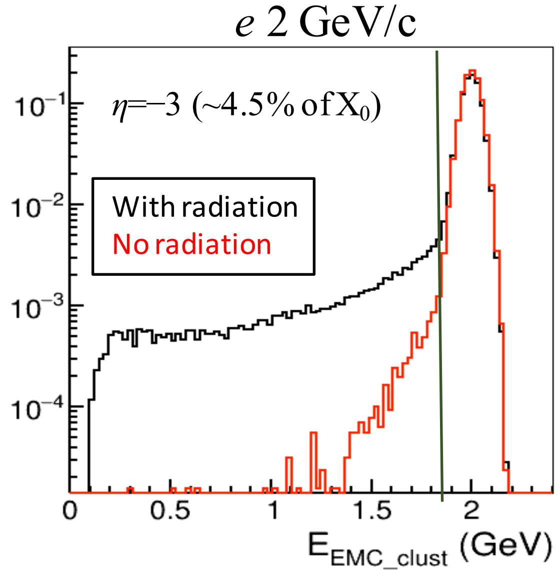
(>3 GeV/c for 10 GeV electron beam)

e-endcup: p<2 GeV/c will be covered by mRICH
barrel: p<1.3 GeV/c will be covered by DIRC

Additional eID capabilities for 1-2<p<4 GeV/c would be highly desirable

EMCal: Effect of Material Upfront





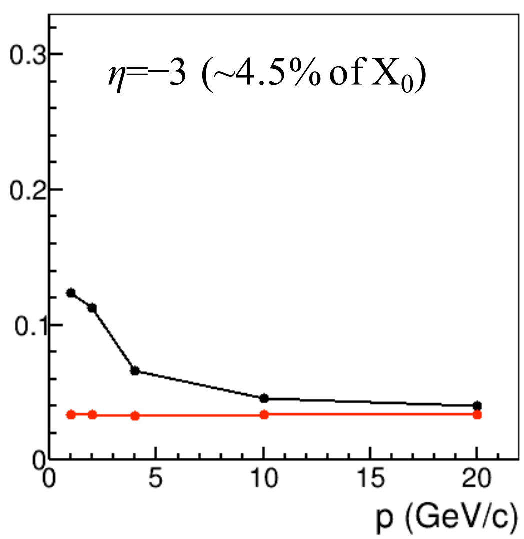
Eff: $E_{EMC} > E_{nom} - 2\ \sigma_{EMC}$

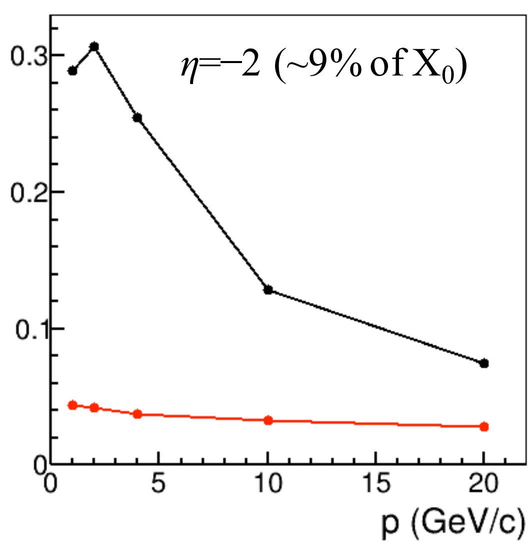
E/p matching performance for eID will be significantly affected!

Material effect may neutralize the power of high resolution tracking and EMCal for e/π separation

We'd better know when we measure *e* vs *e*+*γ* in the EMCal

Losses vs p (GeV/c)





2.3% for a pure Gaussian response

Preshower?

- May address a number of issues raised above
- Will relax the requirements for the EMCal

2-3 X0 absorber + MIP detector

- ➢ High probability to initiate EM shower
  Compared to hadronic shower
- ➢ Small shower transverse size (~1mm)
  A few cm in the EMCal

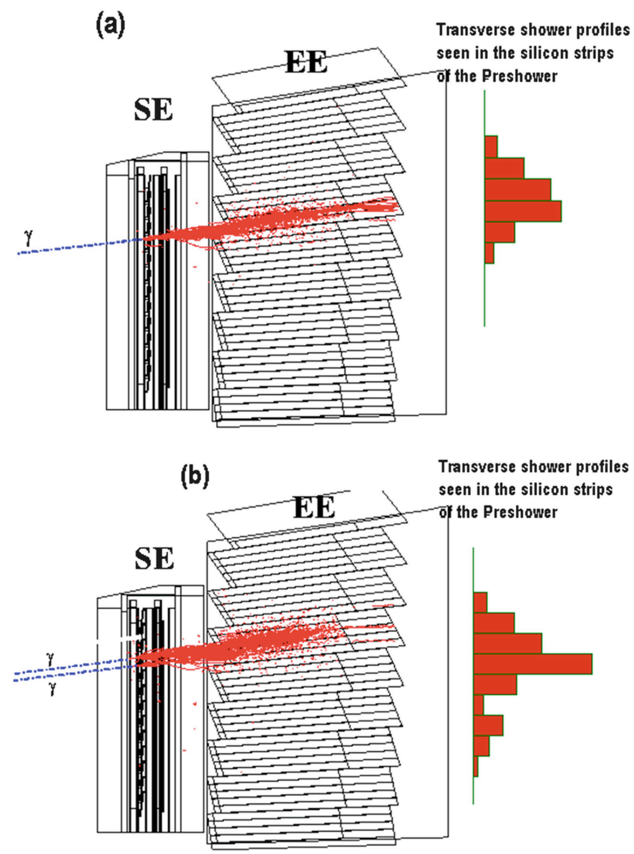
***e/π* separation**
Additional π± suppression factor of 5-10 is expected

***γ/π*^{0} discrimination**
In proposed geometry and *p* range (<50 GeV/c), the minimal distance between decay photons is ~1.5cm
=> 0.5 cm granularity may be enough

***e / e+γ* separation**
Will mitigate the material effect (e.g. in E/p matching)

***e&γ* position resolution improved**
Particularly vs non-projective EMCal

CMS preshower+PWO EMCal



Summary

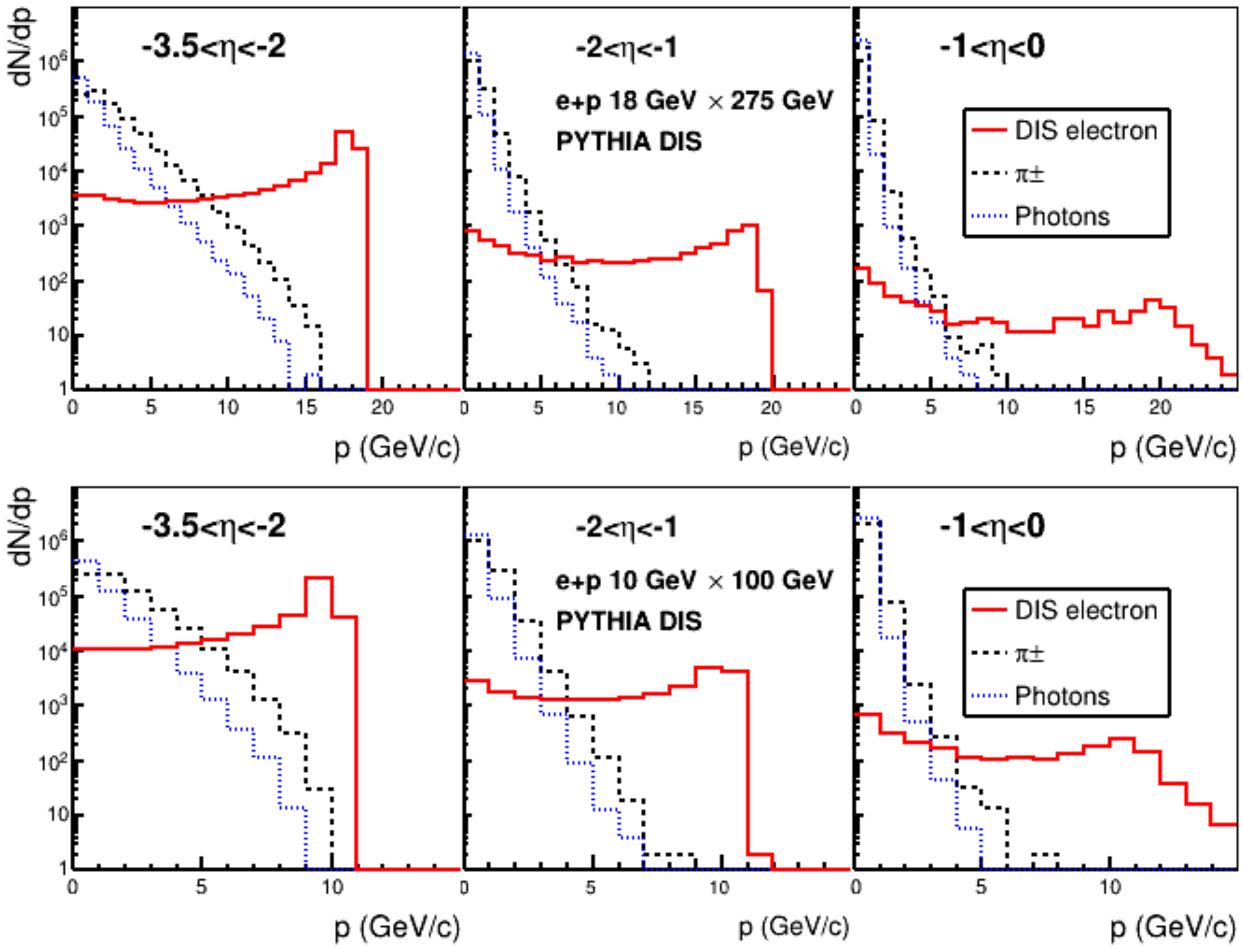
All requirements initially defined for Calorimetry can be satisfied with the existing technologies

- Different technologies can be used in each kin. regions
- Larger space would allow more options
- Additional e/π capabilities are desirable
- New requirement for higher resolution HCal at $\eta > 2.5$

Preshower detector enhances the capabilities and relaxes the requirements for the EMCal (e.g. granularity, projectivity)

- Would require more space

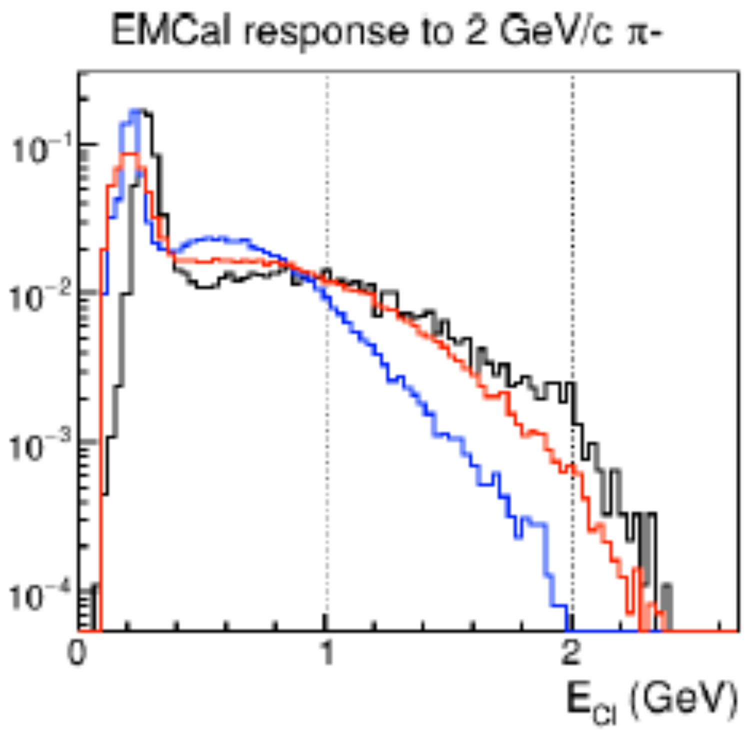
Backup

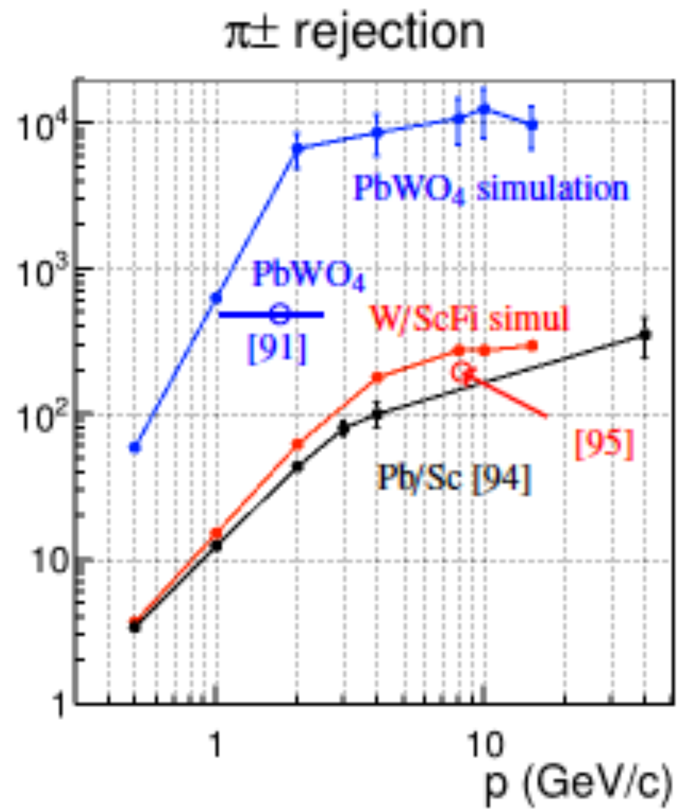


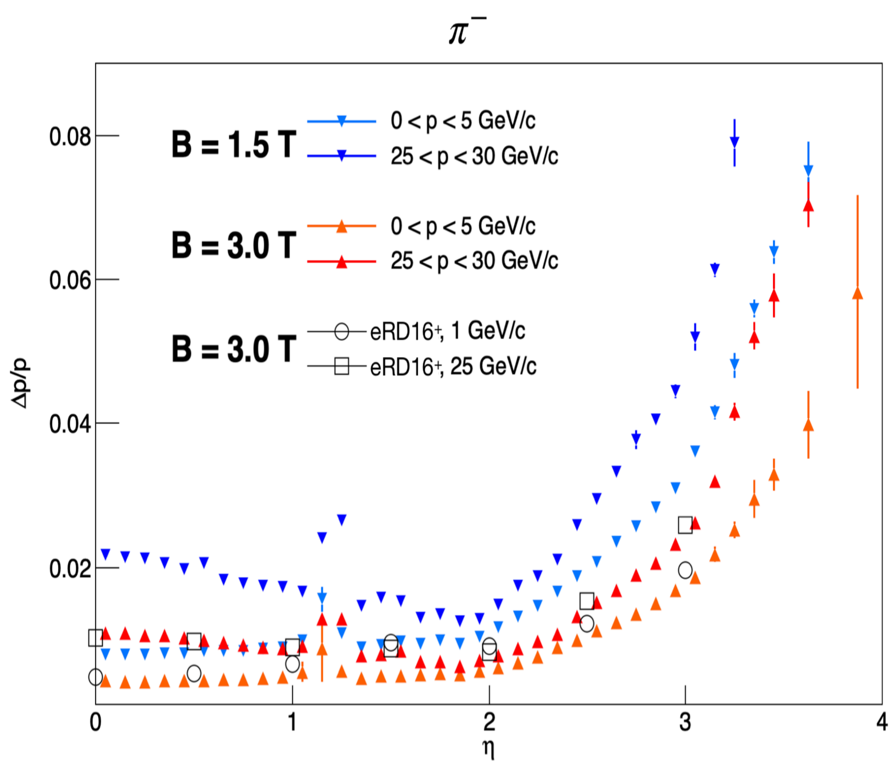
18x275 GeV

10x100 GeV

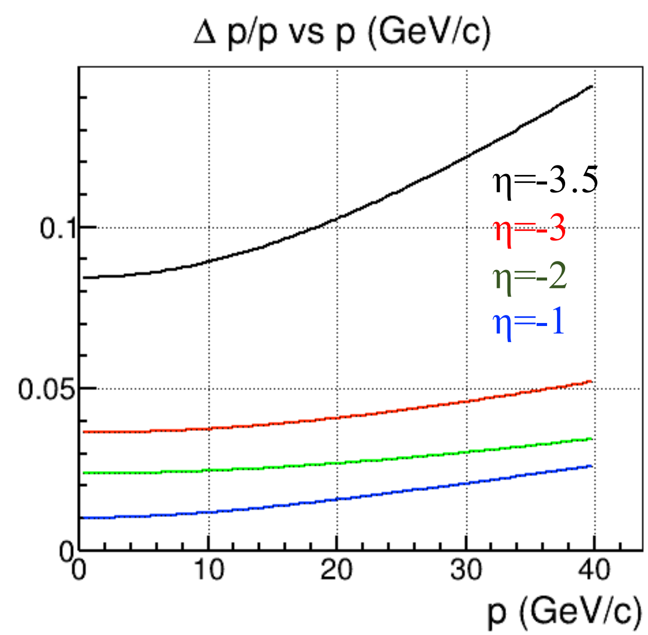
Clean measurements at higher momenta
Huge background at lower momenta


EMCal response to 2 GeV/c π-
E_Cl (GeV)

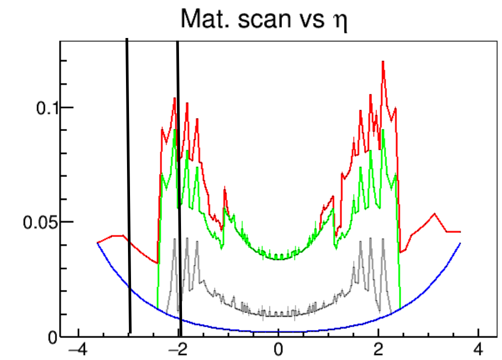

π± rejection
PbWO4 simulation
PbWO4
[91]
W/ScFi simul
[95]
Pb/Sc [94]
p (GeV/c)

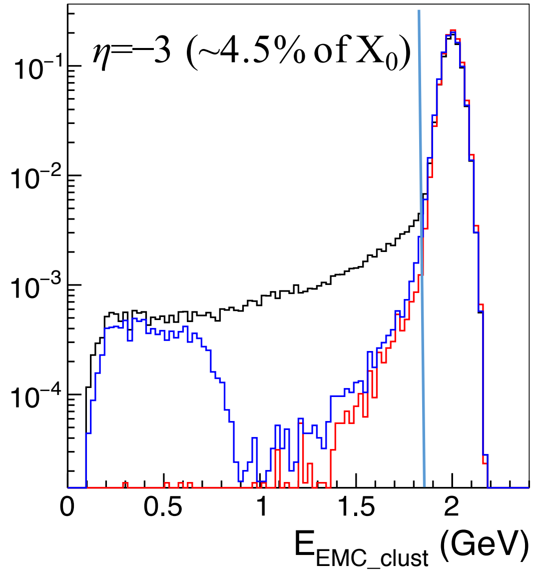


BaBar-based Tracking model:
TPC (barrel), Si +GEM (forw)
(Fun4All-GEANT4 simulation)



EMC: Material upfront



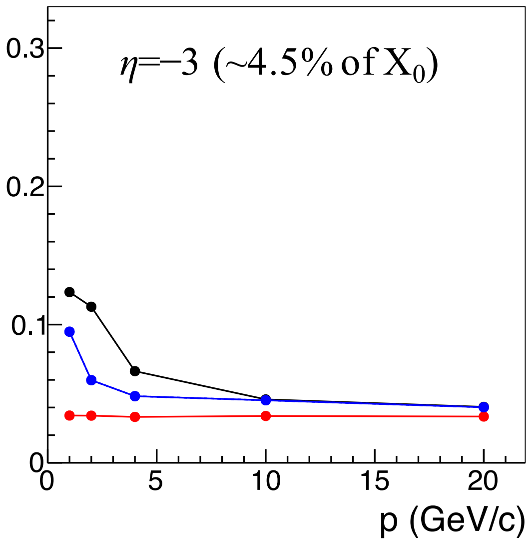


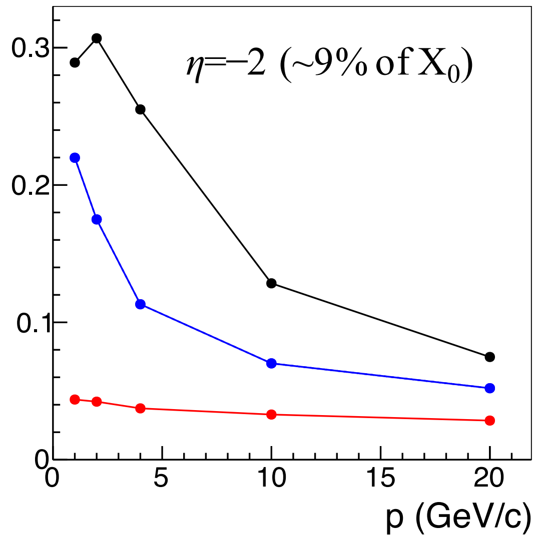
Eff: $E_{EMC} > E_{nom} - 2\ \sigma_{EMC}$

With radiation
No radiation
Difference

How electron is "modified" as seen by the EMCal

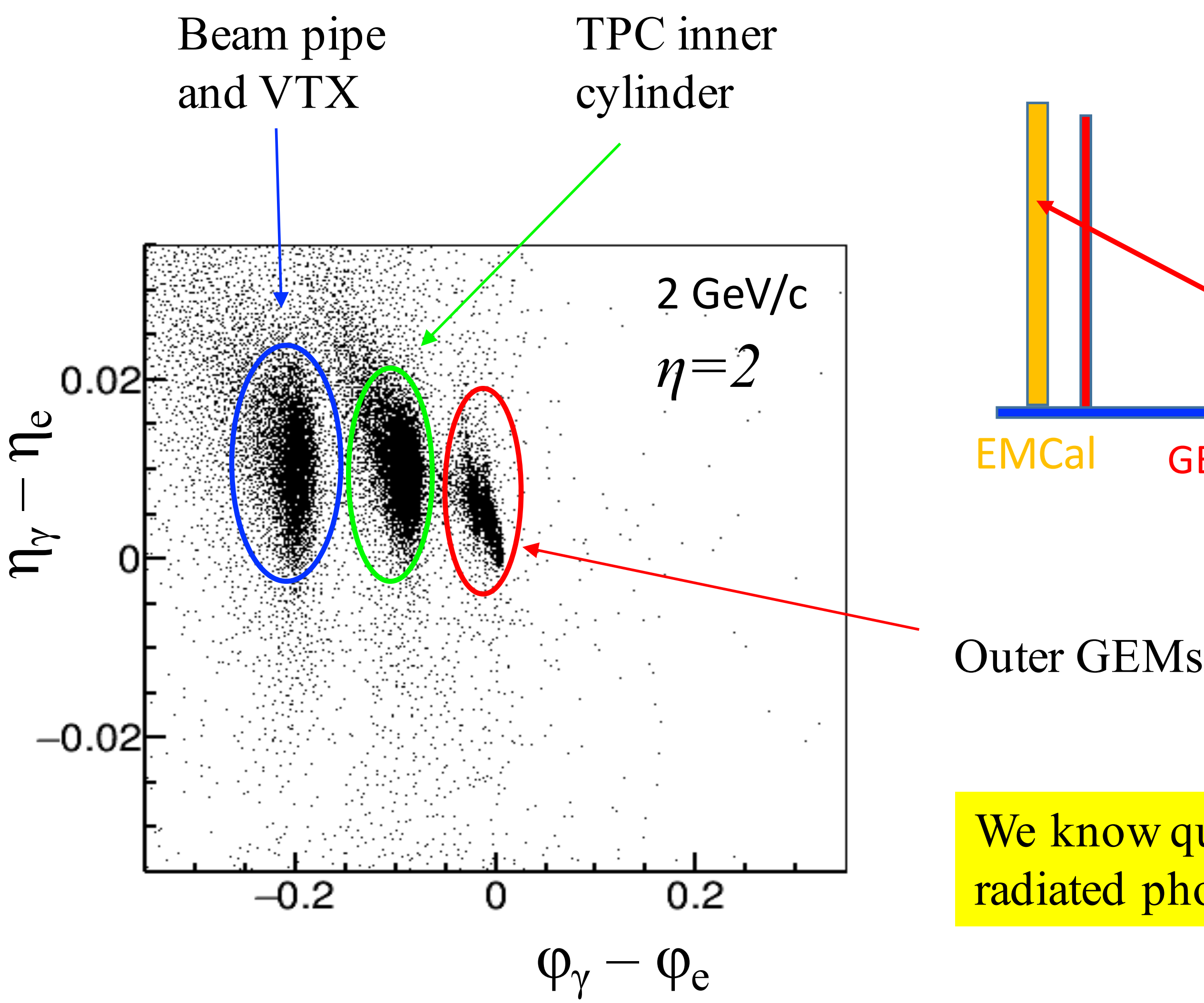
Losses vs p (GeV/c)

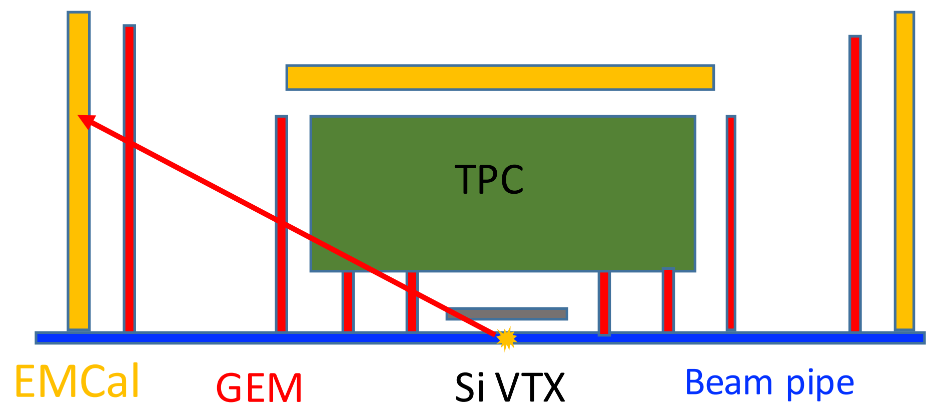




Expected to be 2.3% for a pure gaussian response

Radiated photon topology





We know quite precisely where to look for radiated photons