Calorimeter Simulations for xPHENIX

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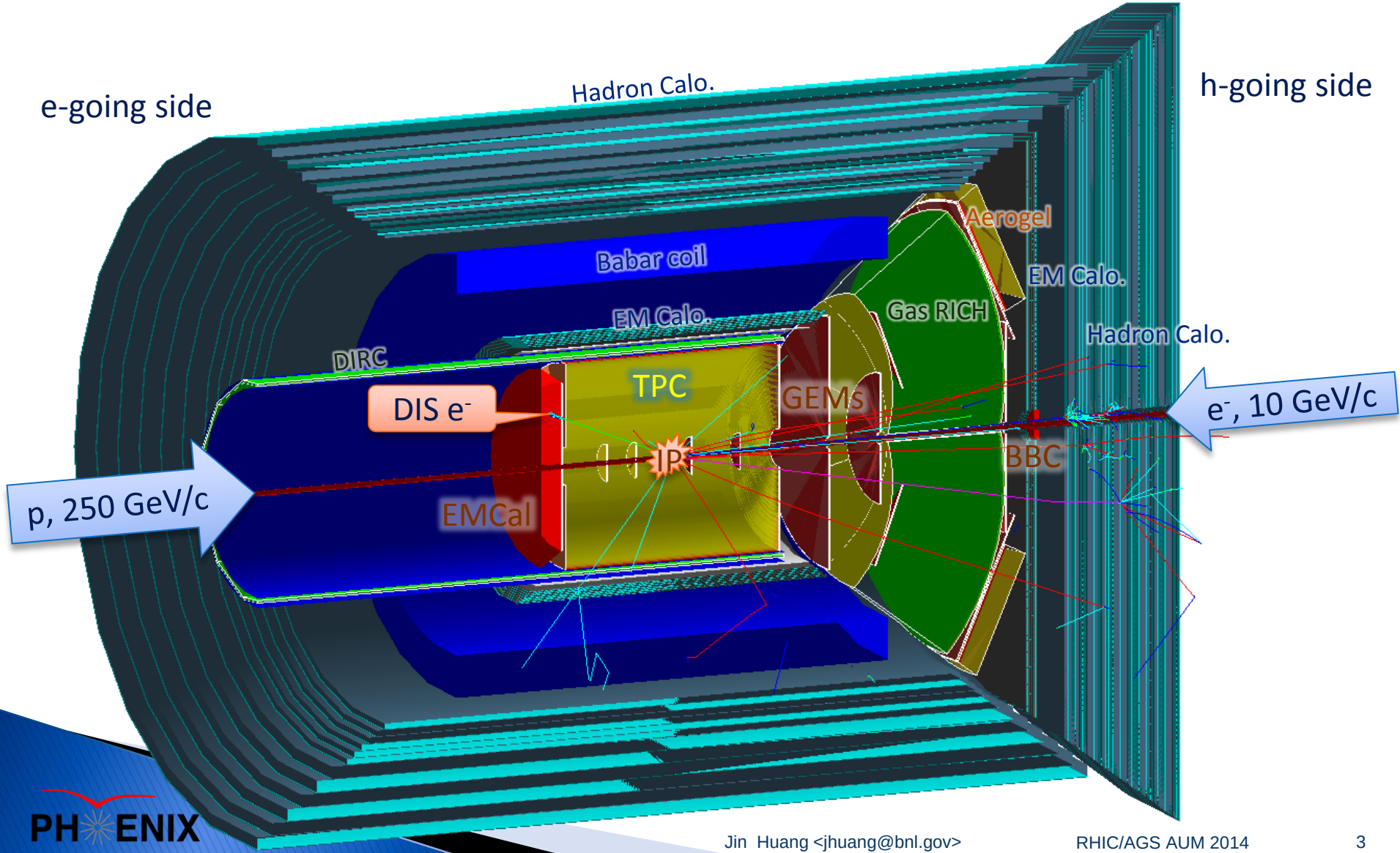
PHENIX

Introduction

- Calorimeters,
  Where they are located?
  What are they used for?

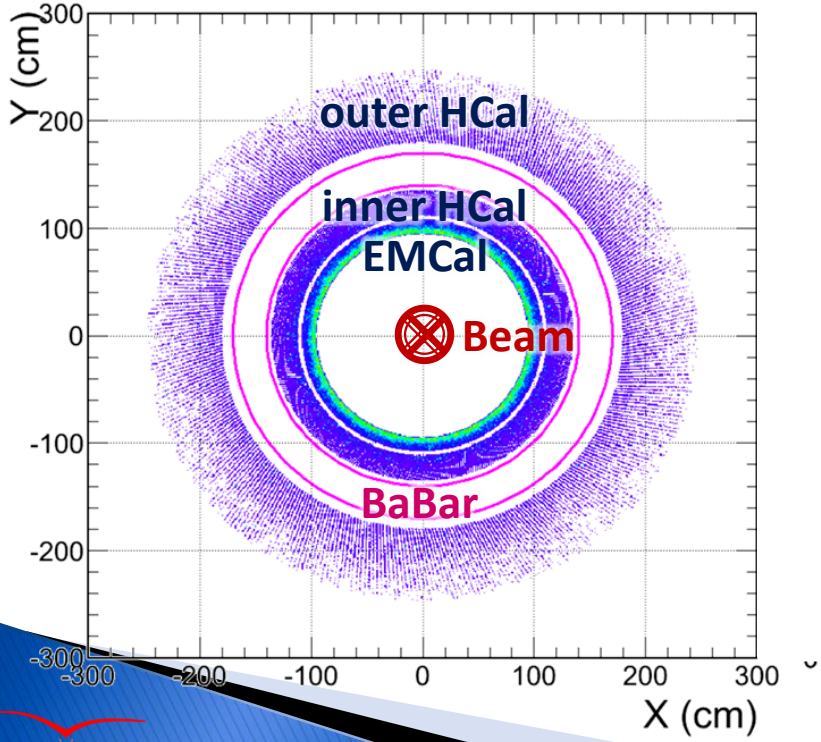
Calorimeters in e/fsPHENIX

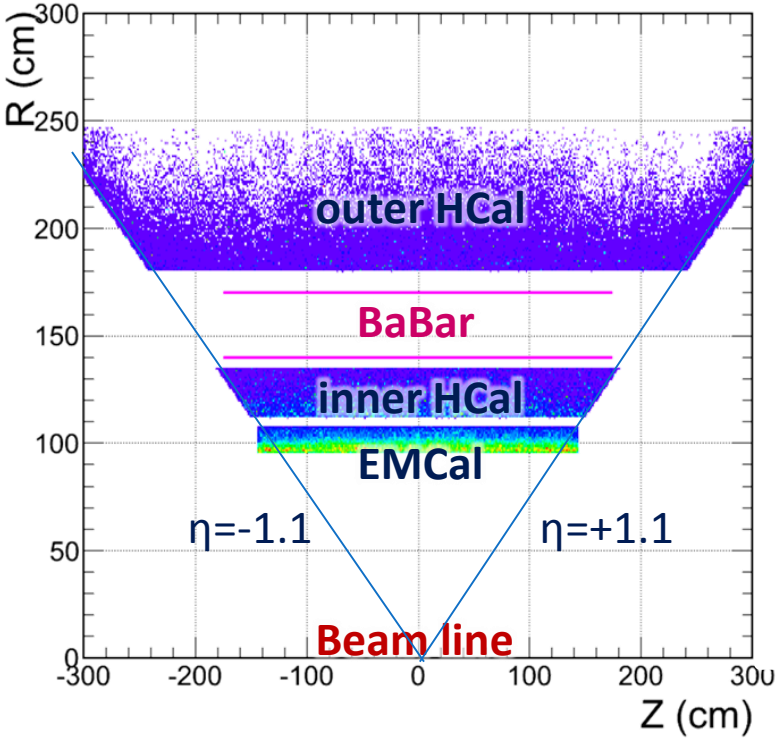


Barrel calorimeters updated in 2014

- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 Cu-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1 X_0
- Outer hadron calorimeter (outer HCal) : 4 λ_0 Steel-Scint. sampling

Calorimeter energy distribution in full event central AuAu collisions and realistic magnetic field



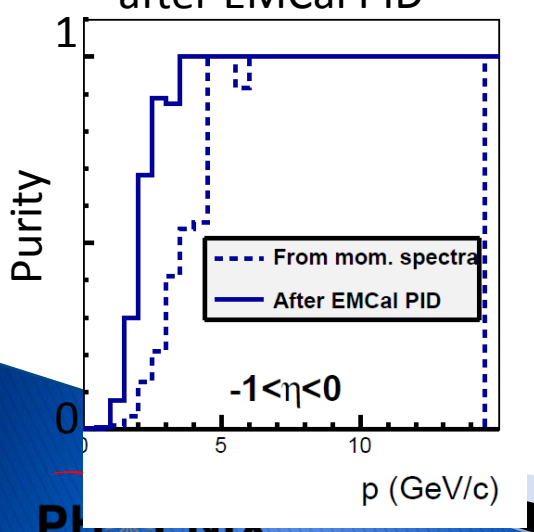


Use of calorimeter for EIC physics

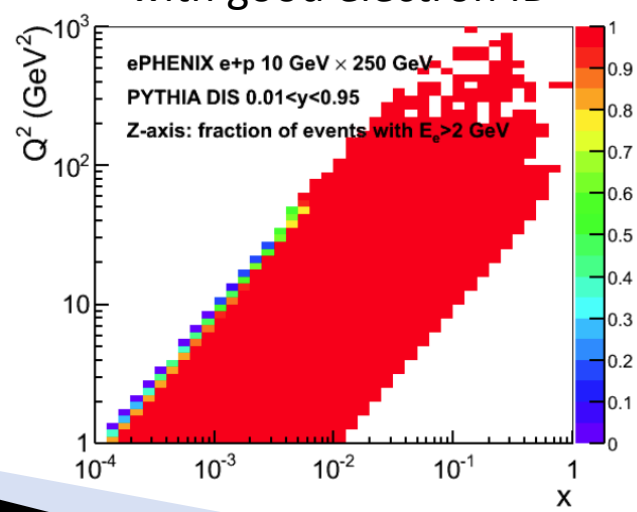
- Electron identification (e-EMC, barrel EMC)
- Electron kinematics measurement (e-EMC, barrel EMC)
- DIS kinematics using hadron final states (barrel EMC/HCal, h-EMC/HCal)
- Photon ID for DVCS (All EMC)
- Diffractive ID (h-HCal)
- High momentum track energy measurement (h-HCal)

From Sasha and Karen using parameterized performance

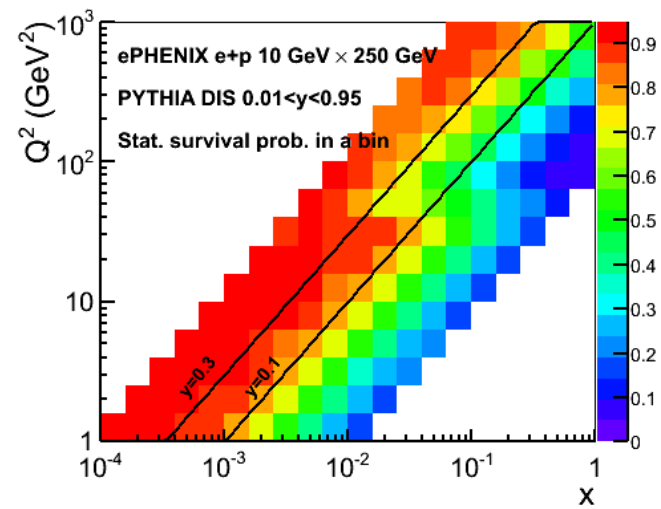
Electron purity after EMCal PID



Fraction of DIS event with good electron ID



DIS kinematics survivability Electron kinematic method

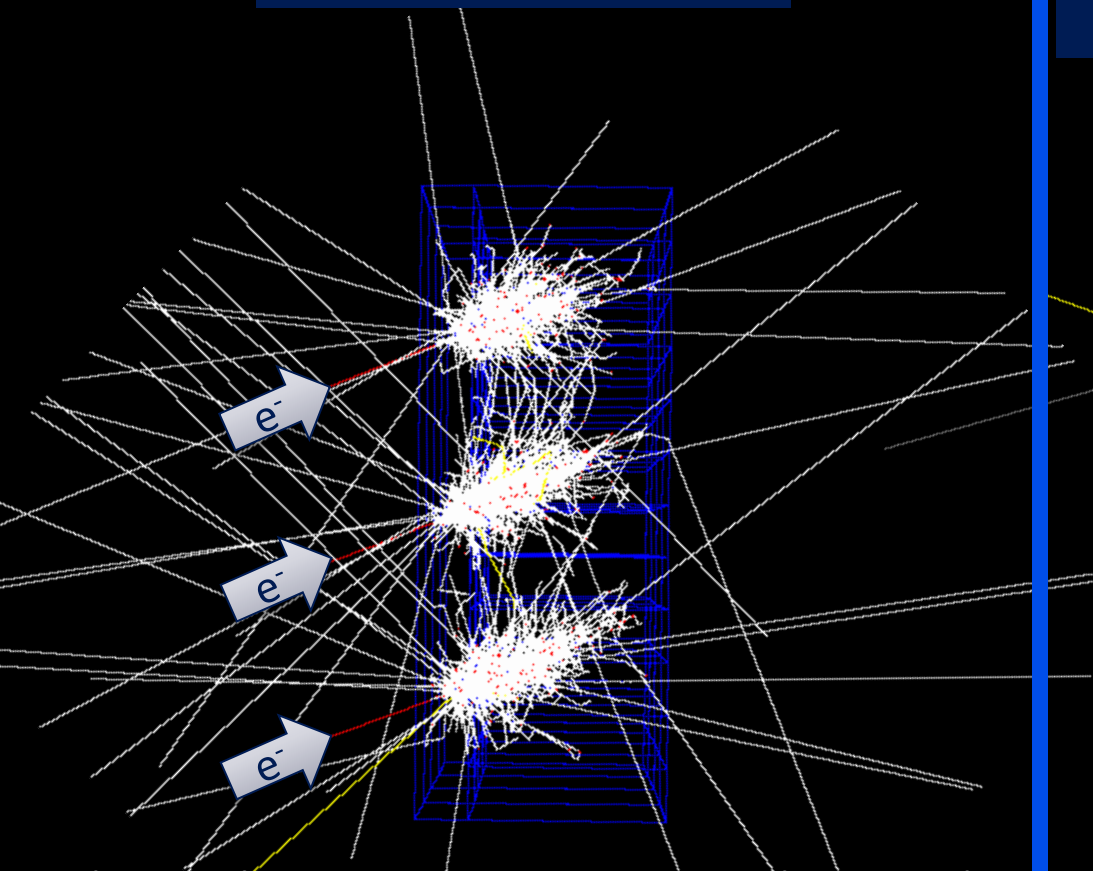


Electron ID study in barrel calorimeter systems

- We can use them in EIC PID
- No systematic e-going/h-going
- Geant4 simulation yet

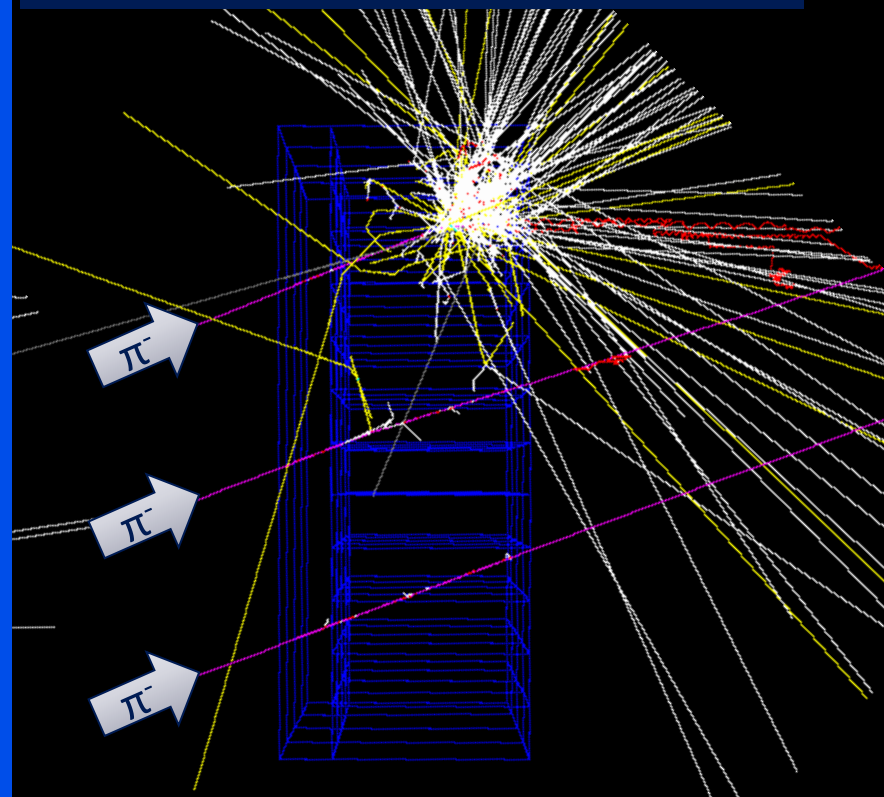
Low energy showers in EMCal

Three Electrons Showers



Electron have most energy contained in EMCal
Forming tight clusters

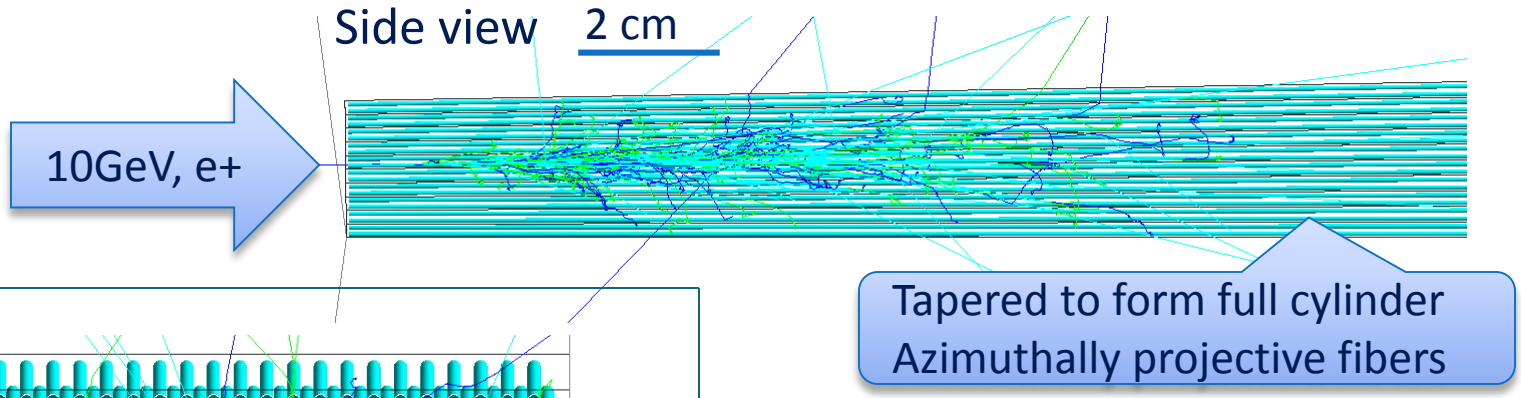
Three Pions
(one of three initiated shower)



Most pions MIP through
while a fraction initiate hadron
shower, forming wider clusters
Leaked energy spread to large area,
can be partially caught by HCal after

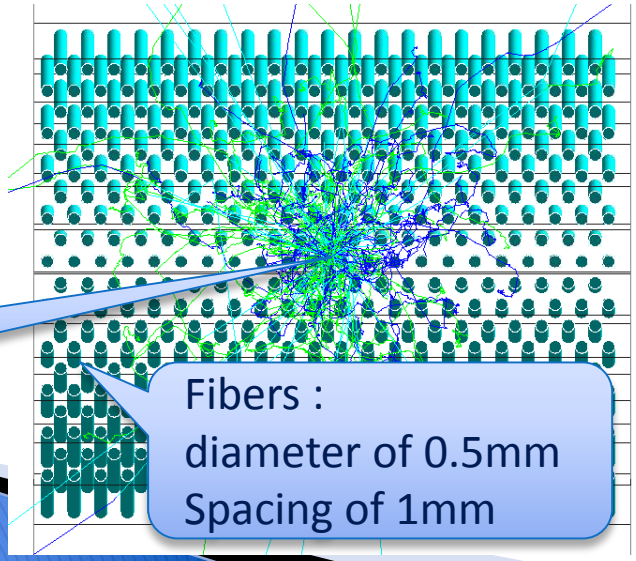
SPACAL simulation

- SPACAL implemented in sPHENIX simulation framework
  - Thanks to reference model from A. Kiselev (EIC taskforce & EIC RD1)
- 10 GeV electron shower in a single SPACAL module shown
- Covered full azimuthal and |η|<1.1 in sPHENIX (Page 4)

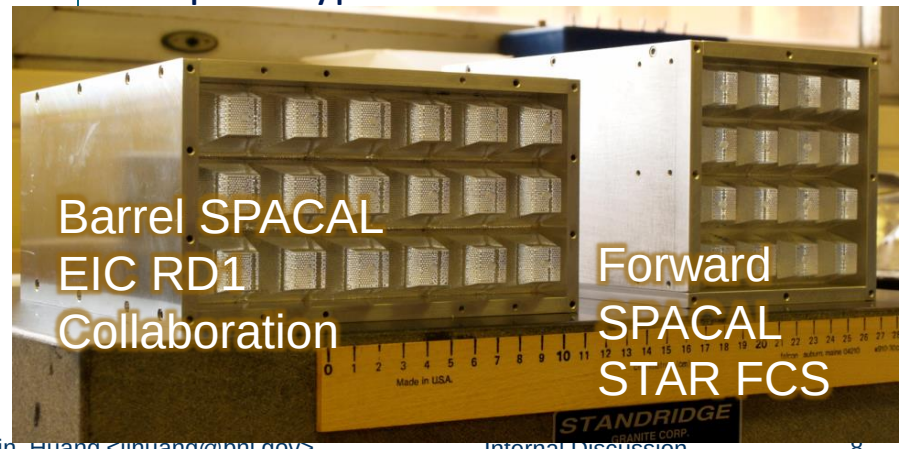


Particle view

1 cm



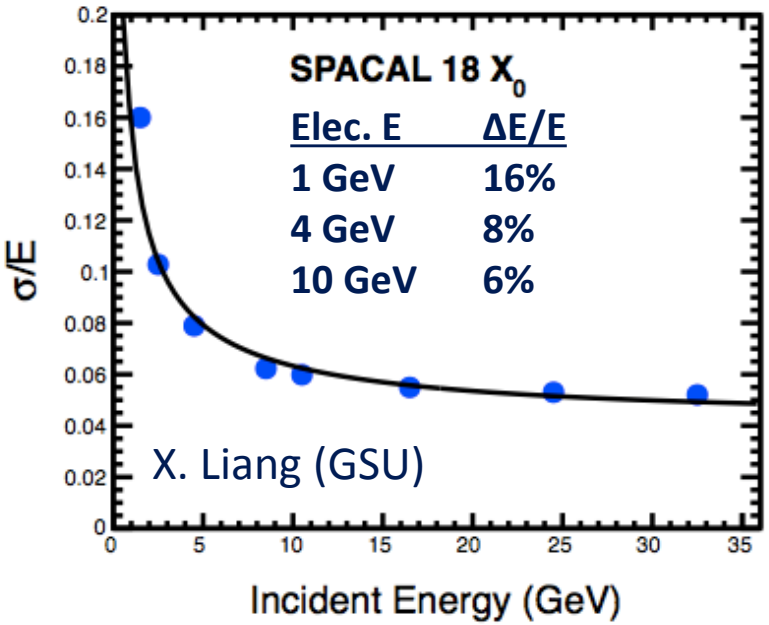
SPACAL prototypes in 2014 Fermilab beam te



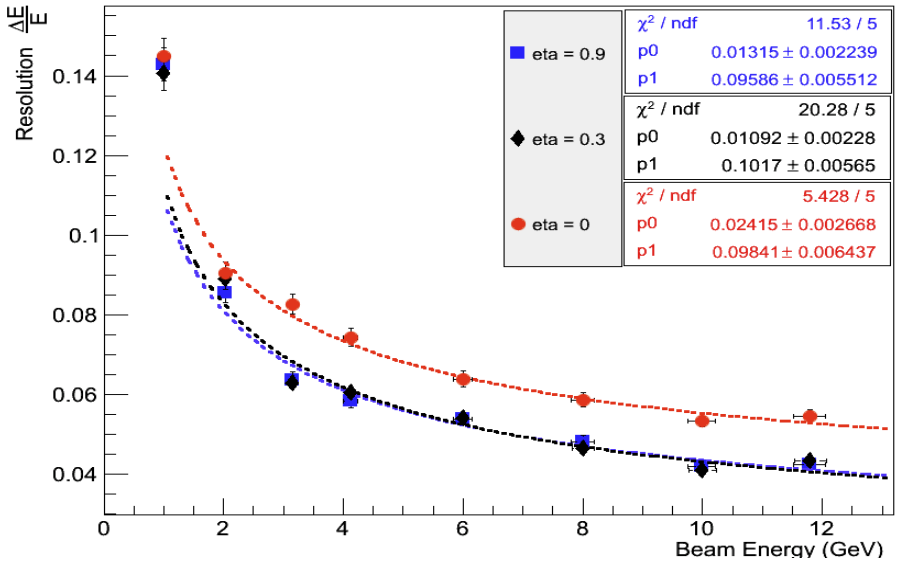
SPACAL study (1): electron resolution

- Electron resolution → Electron PID efficiency
- Compared to simulation from EIC RD1 collaboration and beam test
- Consistent in general; **more work on noise and cell structure simulation**

sPHENIX simulation
5MeV(scint.)/tower zero-suppression



EIC RD1 study
FermiLab beam tests



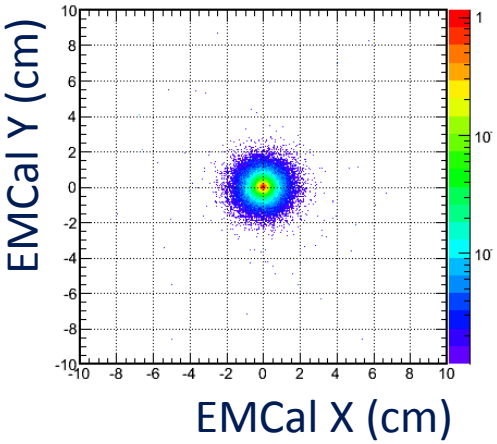
Courtesy: A.Kiselev (BNL)
DIS2014

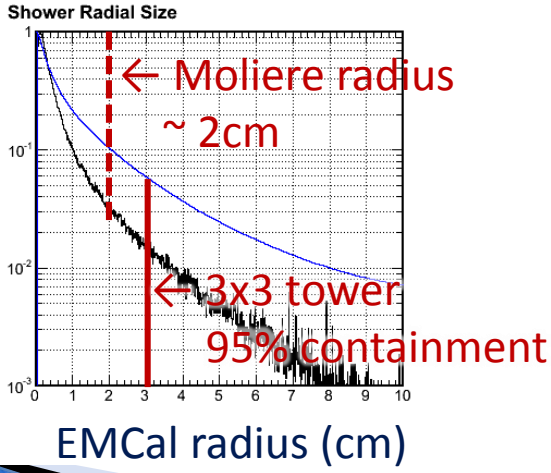
SPACAL study (2): spatial response

- Spacial containment of showers → size of cluster

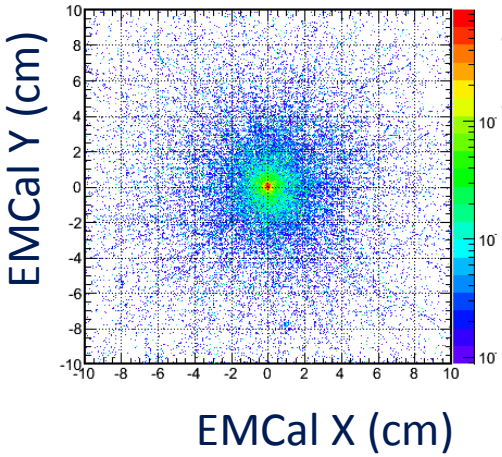
- Energy deposition (A.U.)
- Percentage outside radiu

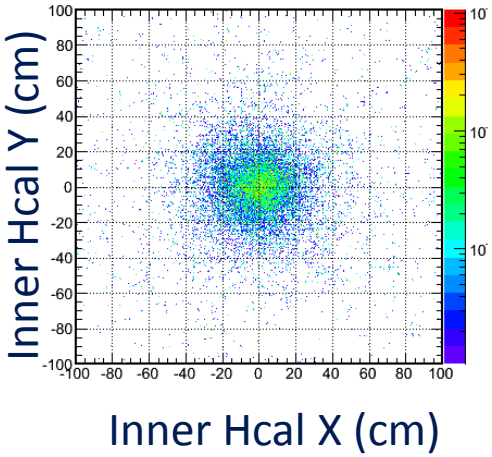
4 GeV Electrons

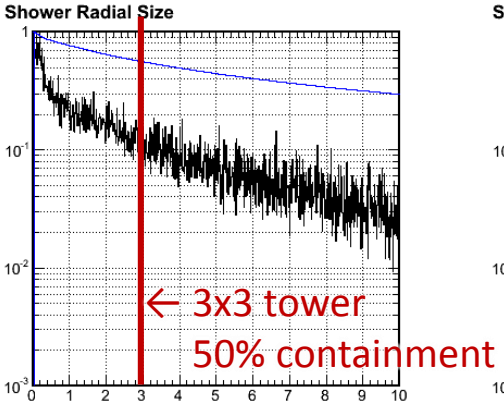


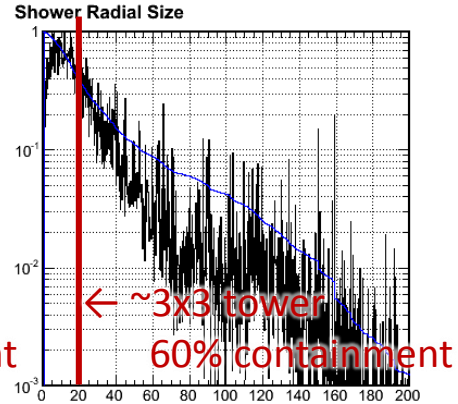


4 GeV Pions, that **passed E/p cut**







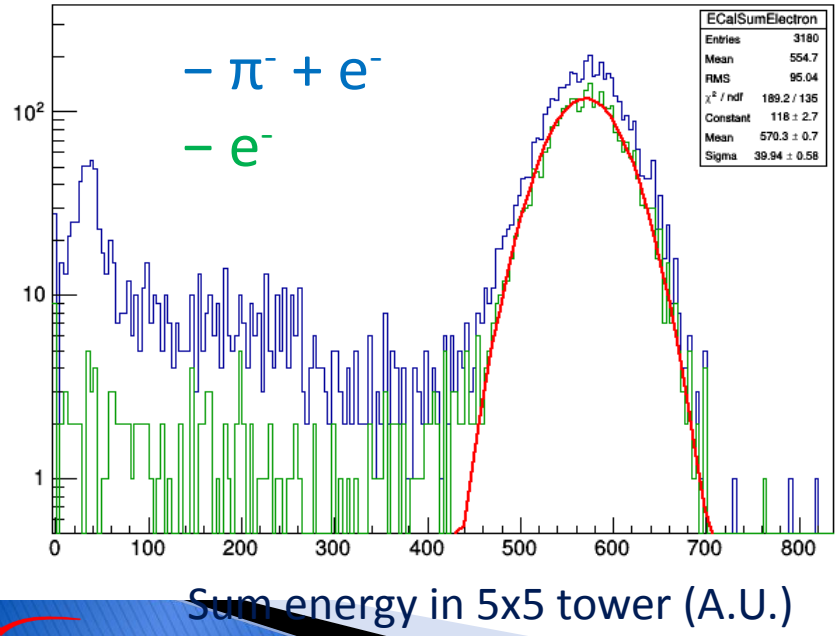


Outtie-HCal has much larger spread. See backup 1

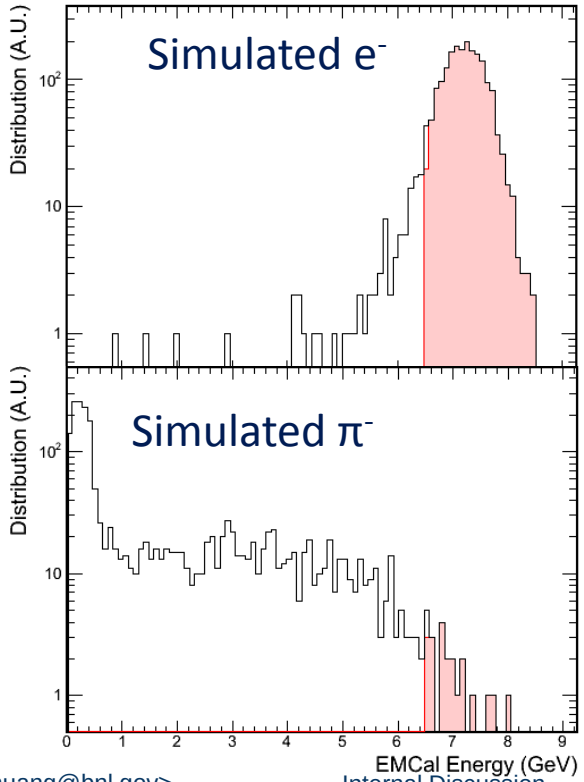
SPACAL study (3): e/pi response

- Pion response → Pion rejections
- **Need to follow up on calibrating hadron simulation to beam tests**

Courtesy : O. Tsai (UCLA)
SPACAL prototypes in 2014 Fermilab beam test
Energy sum for 5x5 towers



sPHENIX simulation of 8GeV e/π⁻
Energy sum for 5x5 towers

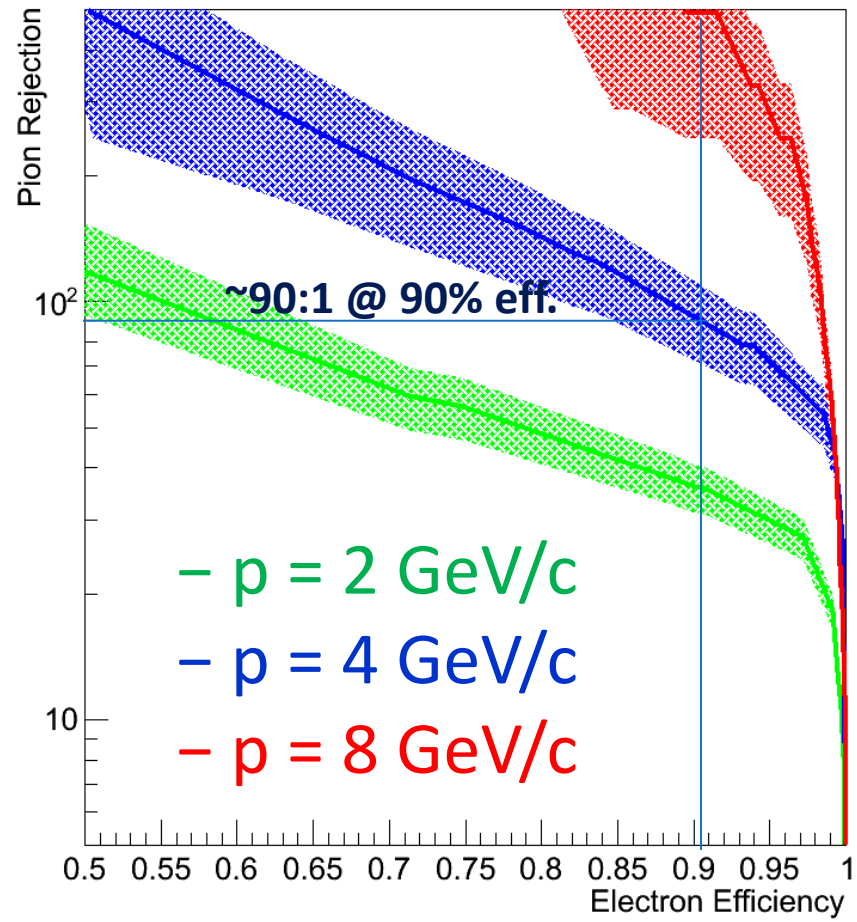


eID and pion rejection in pp : E-p matching

- E-p matching:
  A robust PID selection cut
- Tracking provide precise momentum and EMCal res. dominate E/p resolution
- Background is low in proton-proton collisions
- Use higher efficiency (lower rejection) cuts for pp $\Upsilon \rightarrow e^+e^-$ measurements (next talk)

- **PID is highly momentum dependent, good to check with full Υ simulations**

Simulation of single electron and pions
EMCal – tracking likelihood PID



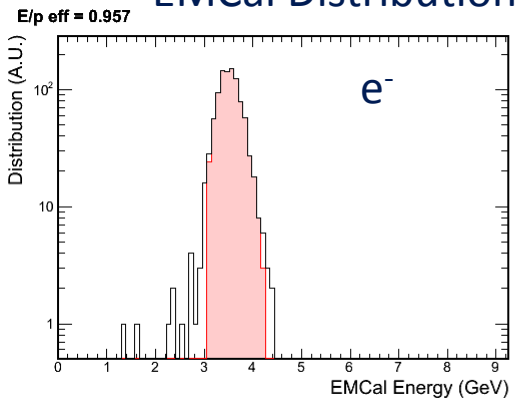
eID and pion rejection in pp : E/p + HCal

4GeV electron and pion-, |η|<0.2

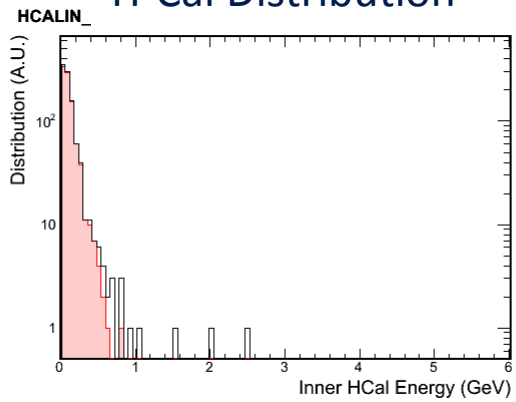
EMCal tower cut : R<3cm, Hcal cut : R<20cm

- all events
- with EMCal E/p cut

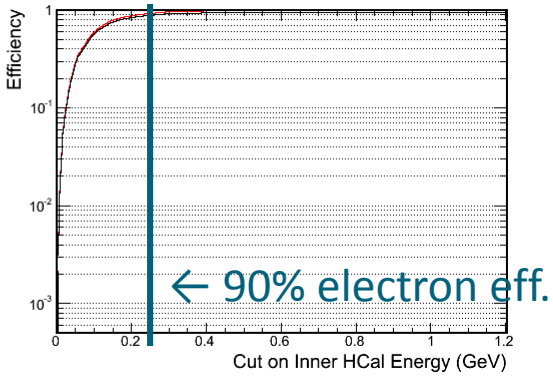
EMCal Distribution



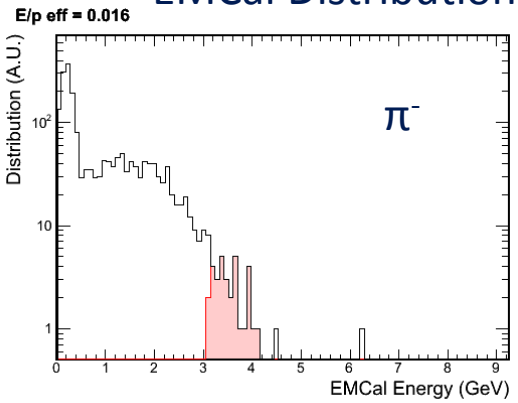
H-Cal Distribution



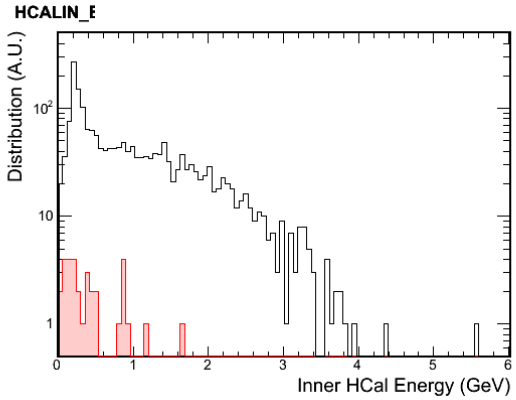
H-Cal Cut Efficiency



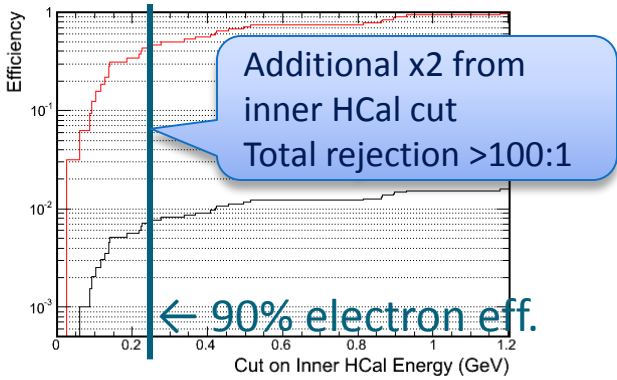
EMCal Distribution



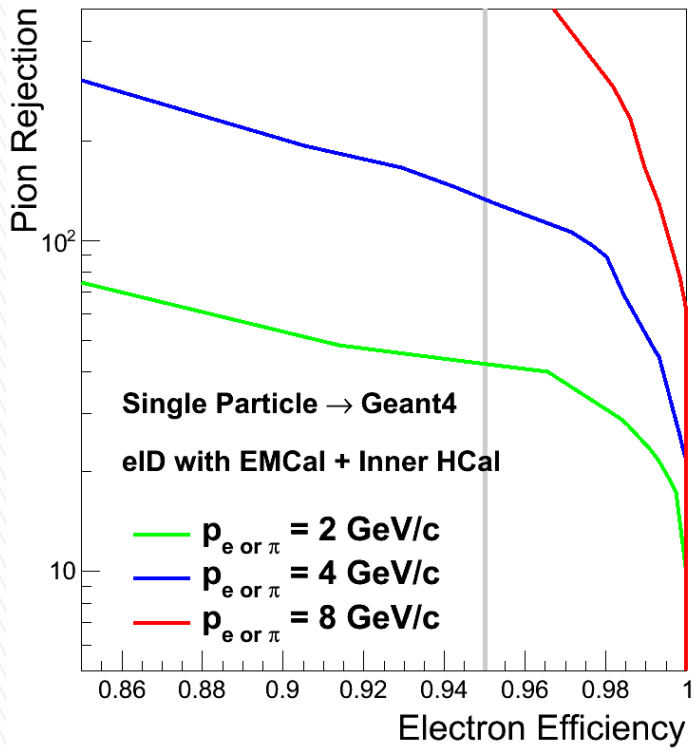
H-Cal Distribution



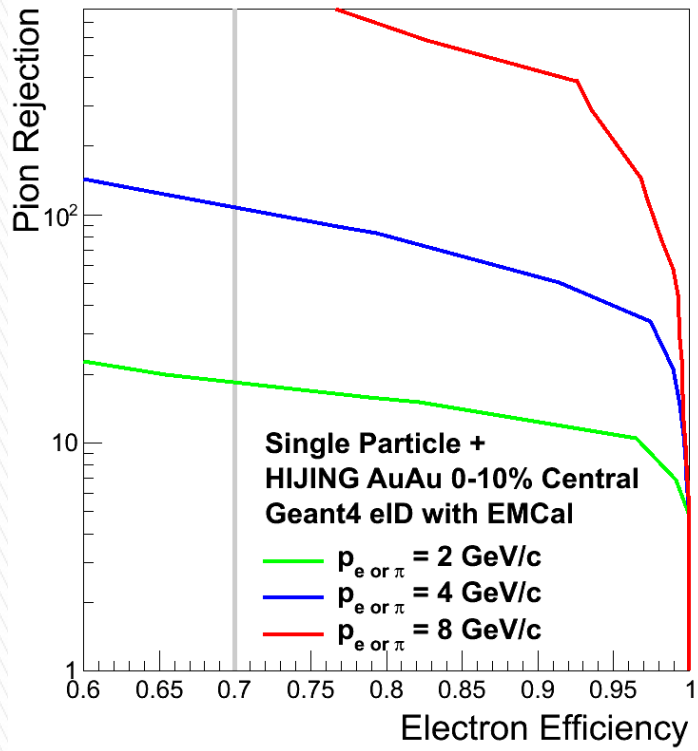
H-Cal Cut Efficiency



Compile everything together for barrel electron ID



pp/ep electron ID (EMC+HCAL)



Central AA electron ID (EMC Only)

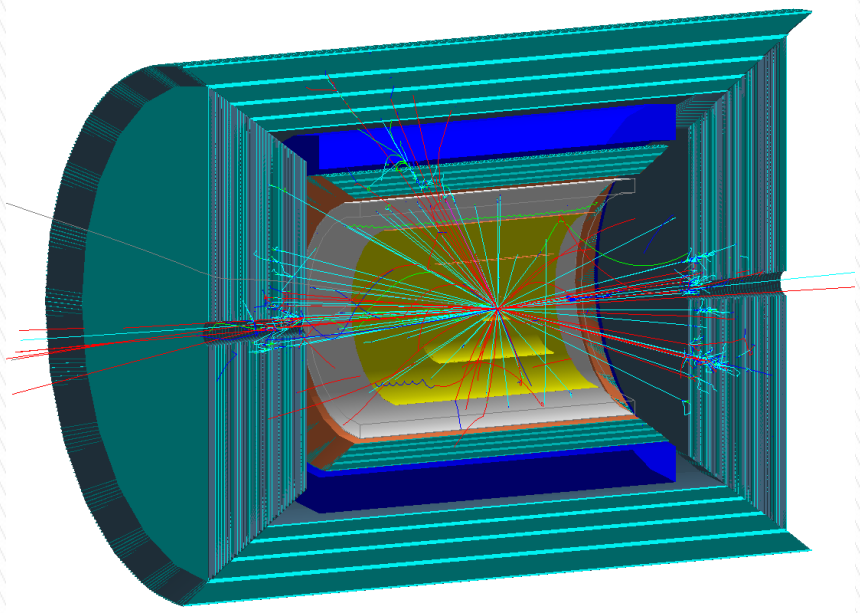
h-going Hadron calorimeters

- Started a simulation for Jet in pp/pA
  Could be borrowed as example for ePHENIX implimentation

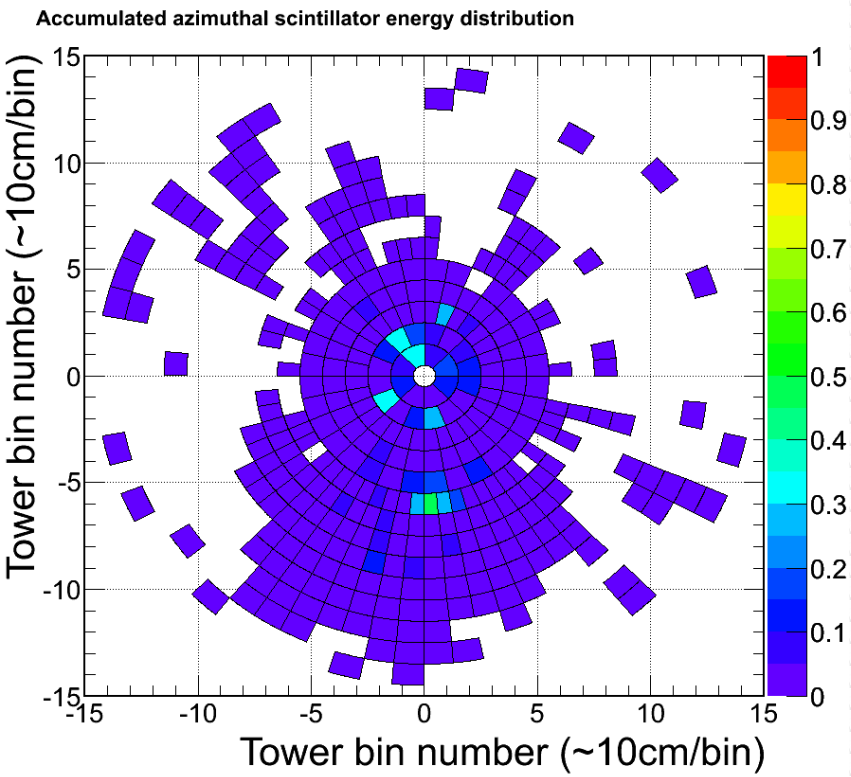
fsPHENIX Geant4 Setup

CVS:/simulation/g4simulation/macros/Fun4All_G4_sPHENIX_plus_fHCAL.C

- Single macro handles event generation/readback/G4 simulation/ jet reconstruction
- Adding embedding since Tue talk



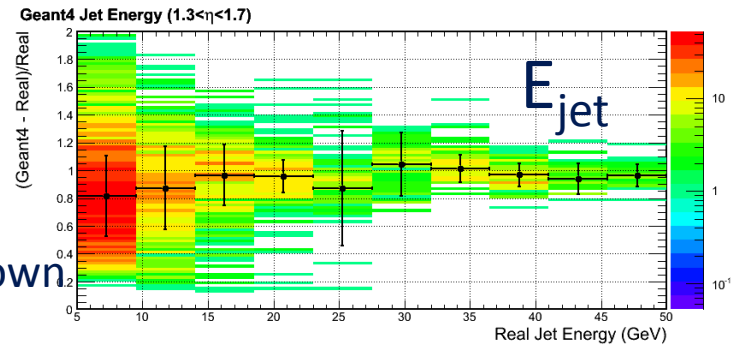
Event display

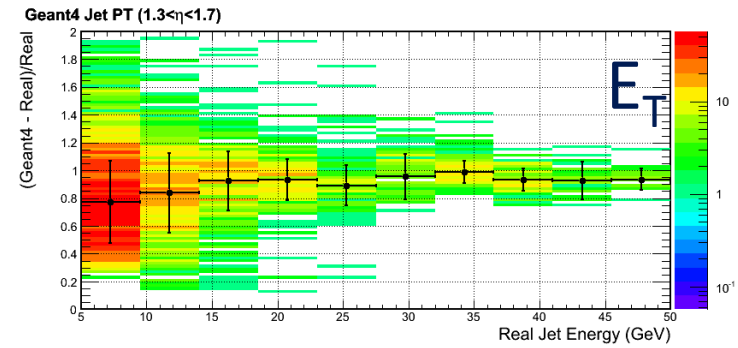


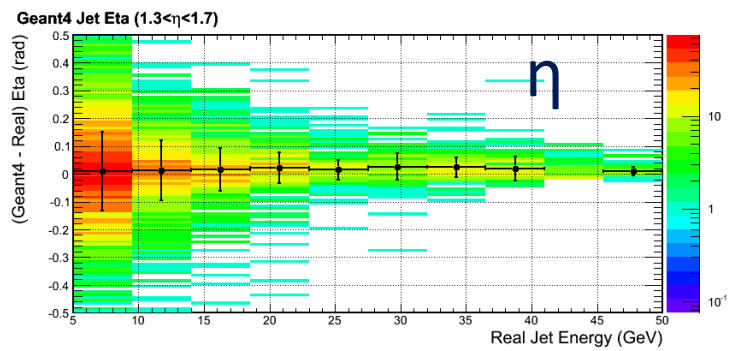
FHCal Segmentation

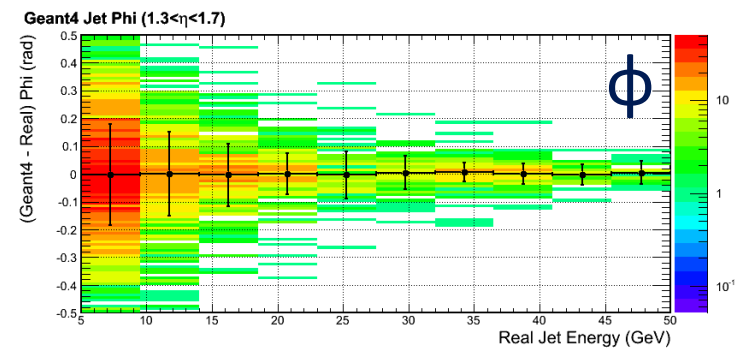
Jet matching studies (G4 VS Pythia jet): Within FHCal outer ring

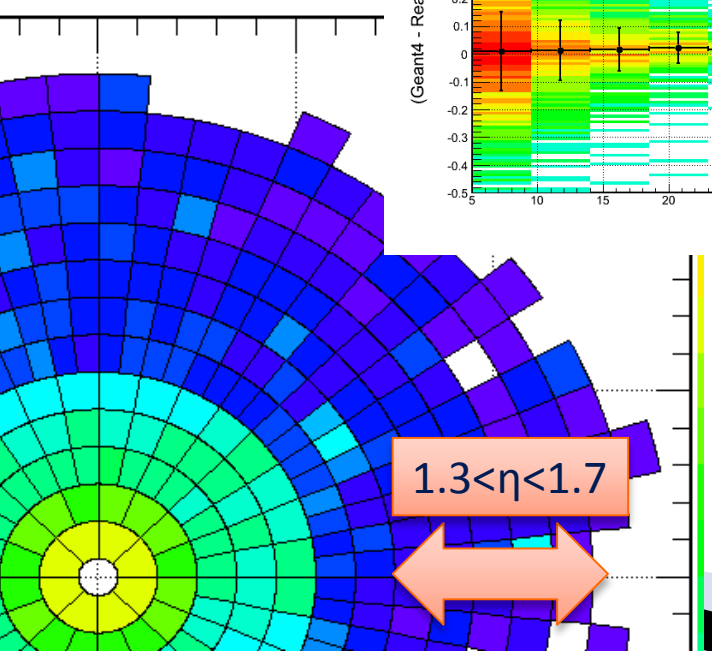
Anti kT w/ R=0.6
Pythia p+p 510GeV
Gaus fit μ and σ shown







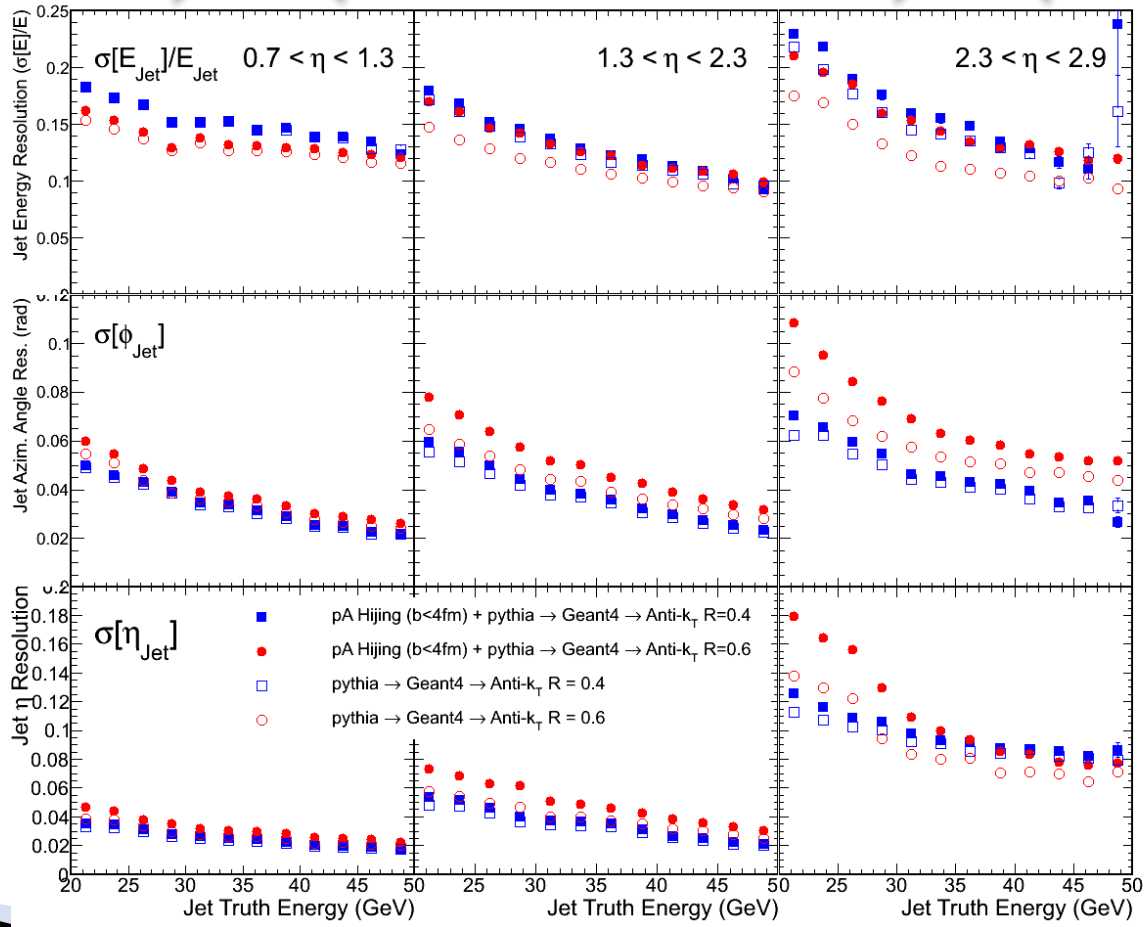




- No apparent leak energy observed
- Energy resolution ~100%/sqrt(E_{Jet})
- Angular reconstruction is centered for the eta and phi
- Angular resolution <0.1 for E_{jet} > 20GeV

Resolution compilation

Barrel calorimeter | Forward calorimeter | Near beam line



Technical details

- A macro to run the calorimeter analysis
- What are the existing modules

Documented in PHENIX webserver

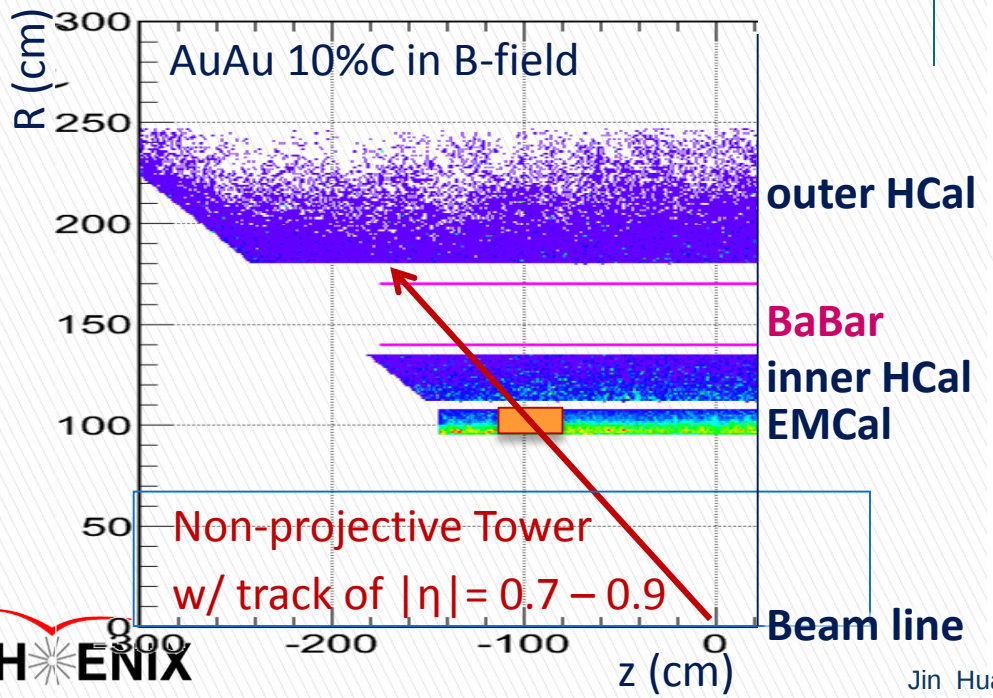
- PHENIX Homepage -> Internal -> Computing -> Doxygen
- Search for "Fun4All_G4_sPHENIX_plus_fHCAL"
  Direct link:
  https://www.phenix.bnl.gov/WWW/offline/doxygen/html/d0/d91/Fun4All__G4__sPHENIX__plus__fHCAL_8C_source.html#l00014
- We will go through the macro in the meeting

Extra Material

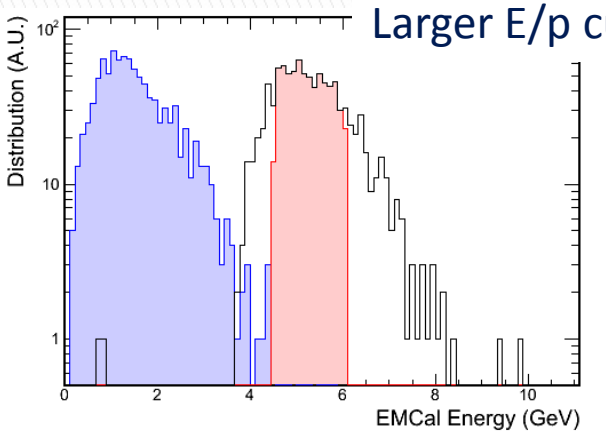
Larger pseudo-rapidity in central AuAu : under study

- Out of the box: larger |η|→ larger background
  - Longer path length in calorimeter
  - Covers more non-projective towers
- Many ways to improved in near future
  - **Better estimate of the underlying background event-by-event (improve x1.5)**
  - **Use (radially) thinner ECal (improve x2)**
  - **Shower shape cuts?**
  - **Possibilities for projective towers?**

- all events (w/ embedding)
- with EMCal E/p cut (w/ embedding)
- Hijing background (AuAu 10%C in B-field)

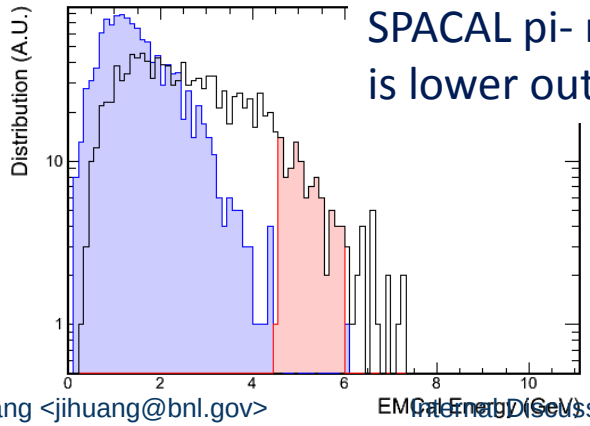


SPACAL e-
Larger E/p cuts



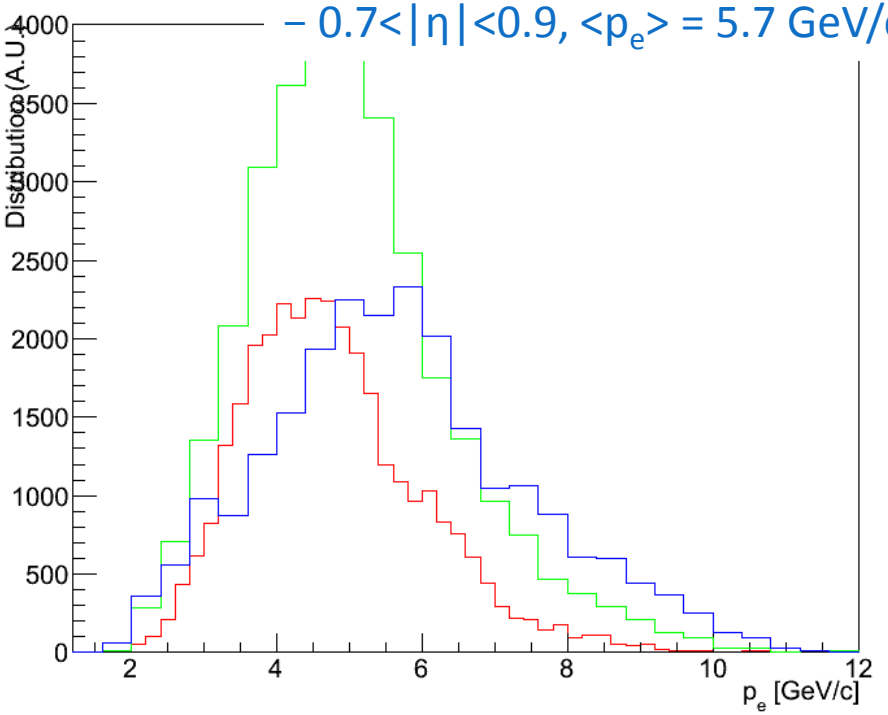
Out of box rejection ~10:1

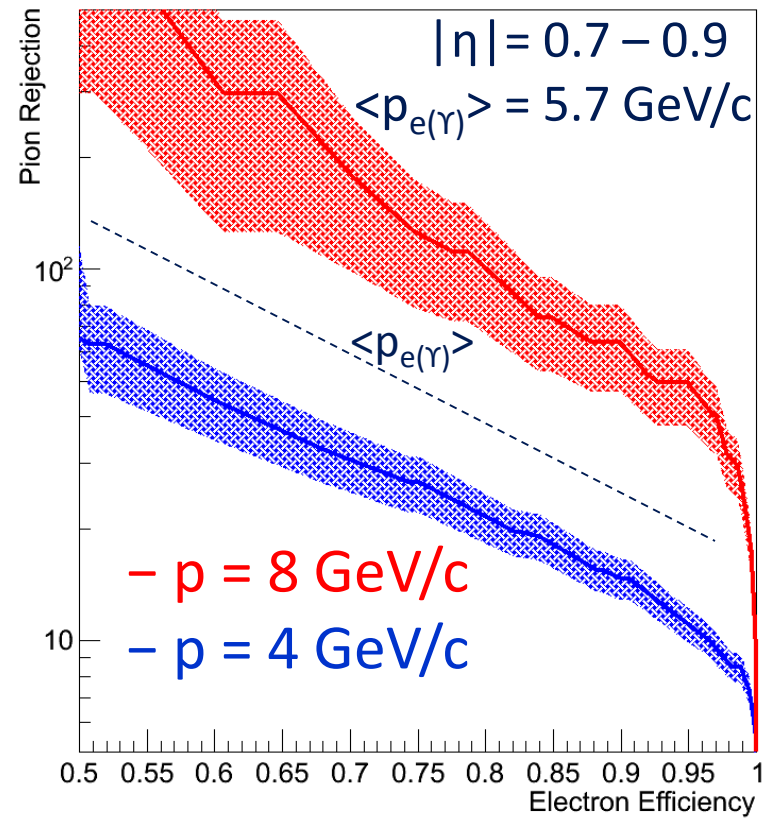
SPACAL pi- rejection
is lower out of the box



Momentum distribution of Upsilon Electrons

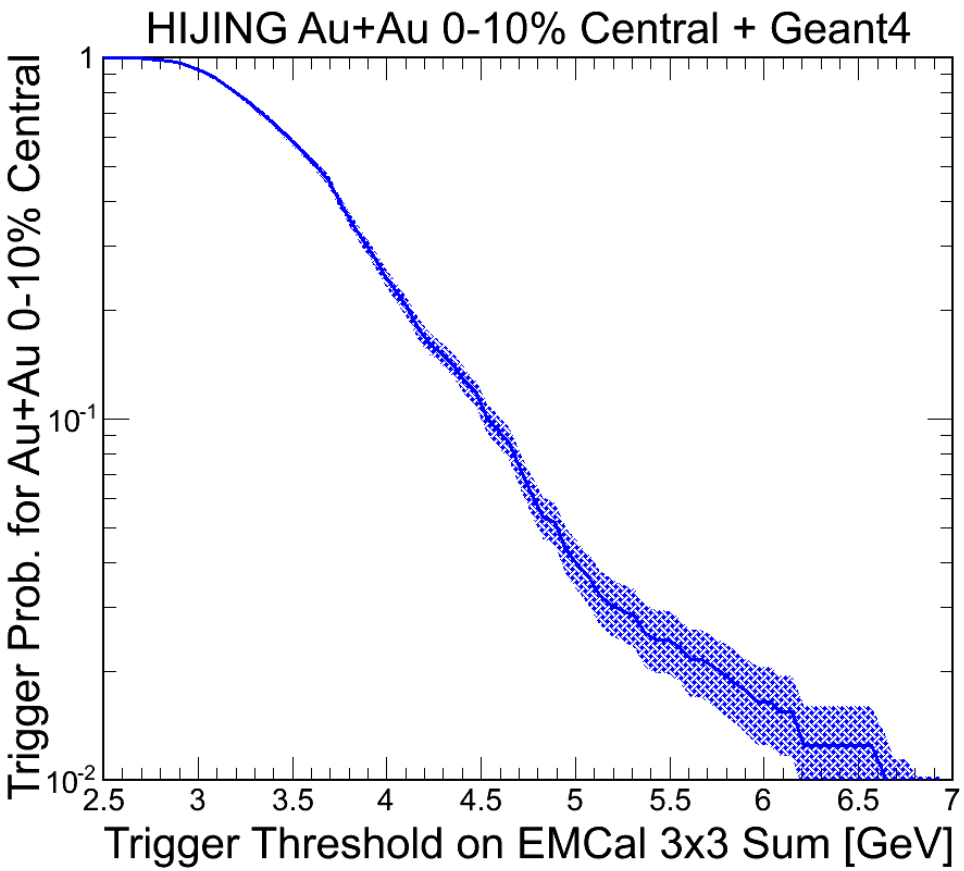
– $0<|\eta|<0.2$, $\langle p_e \rangle = 4.8$ GeV/c
– $0.3<|\eta|<0.5$, $\langle p_e \rangle = 5.0$ GeV/c
– $0.7<|\eta|<0.9$, $\langle p_e \rangle = 5.7$ GeV/c

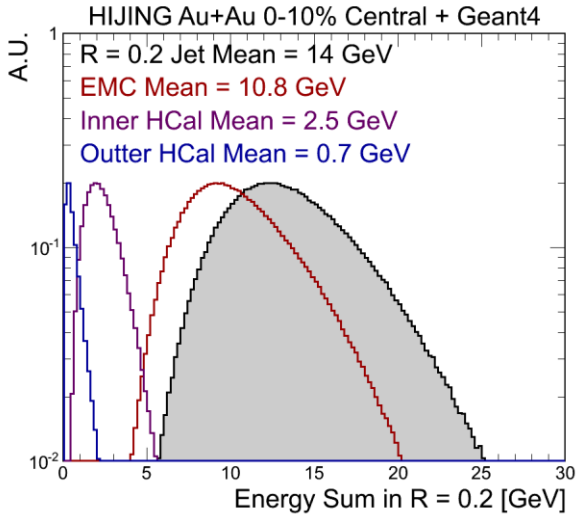


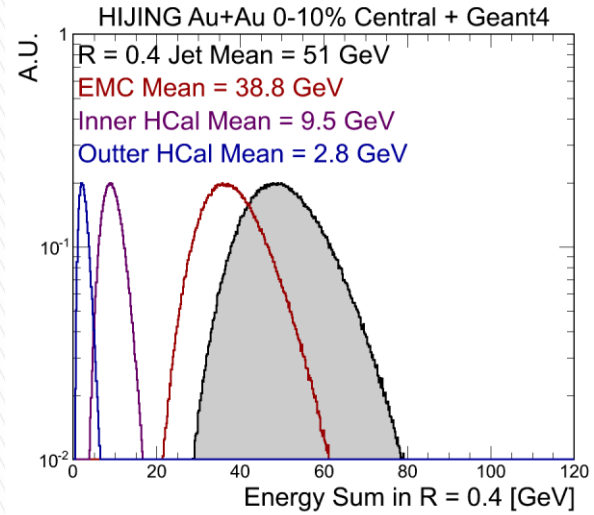


Electron trigger emulations

- Electron triggers under 10%C Hijing events
- Get max EMCal 3x3-SUM within one event
- Histogram probability for a event have one SUM larger than a cut →
- For non-projective larger angle region, we might need larger area SUMs

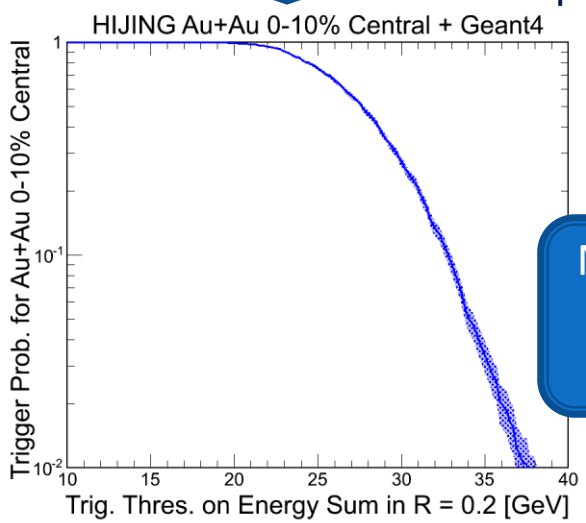




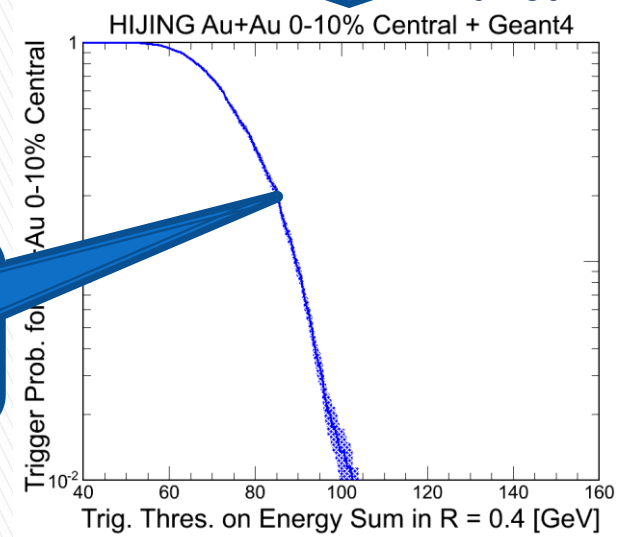


Max sum per event

Max sum per event



Need average background suppression



(R=0.2) Jet triggers

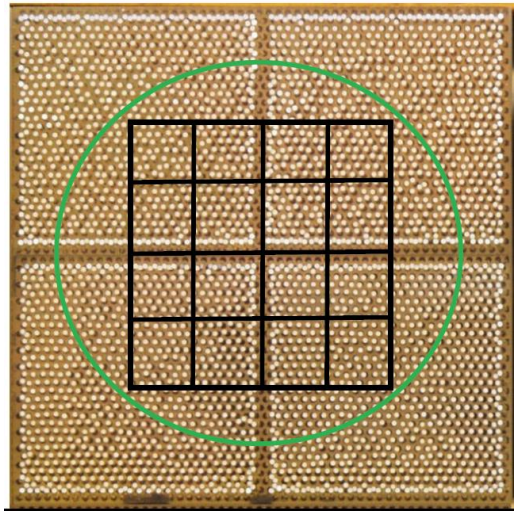
(R=0.4) Jet triggers

SPACAL in Barrel Configuration

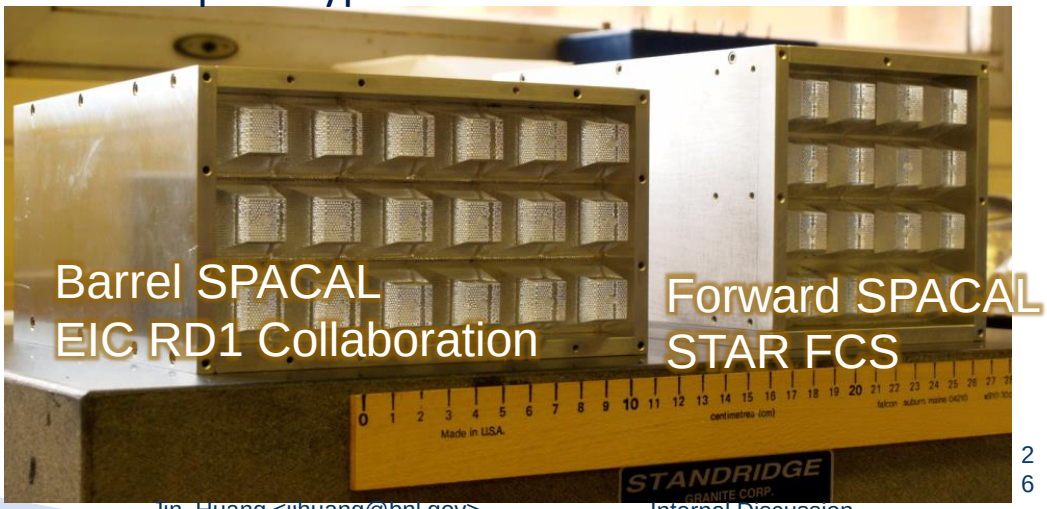
Courtesy: O. Tsai (UCLA) CALOR 2014

- Density - 10.17 g/cm3,
- X0 ~ 7 mm, Rm ~ 2.3 cm,
- Sc. Fibers -SCSF78 Ø 0.47 mm
- Spacing 1 mm center-to-center
- Sf -2% (electrons),
- Resolution ~12%/√E
- Tapered module → Azimuthal projective
- Solid object for ease of mechanical support

End view of 2x2 tower showing fiber matrix



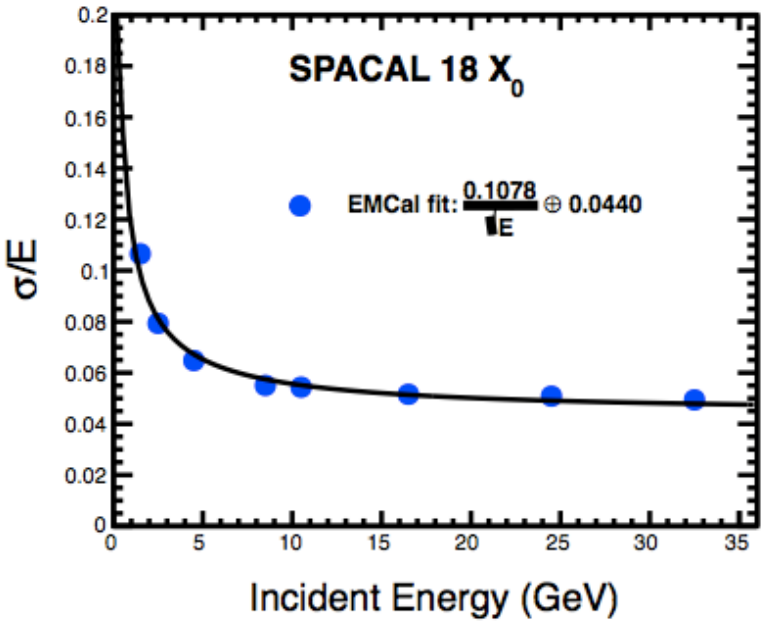
SPACAL prototypes in 2014 Fermilab beam test



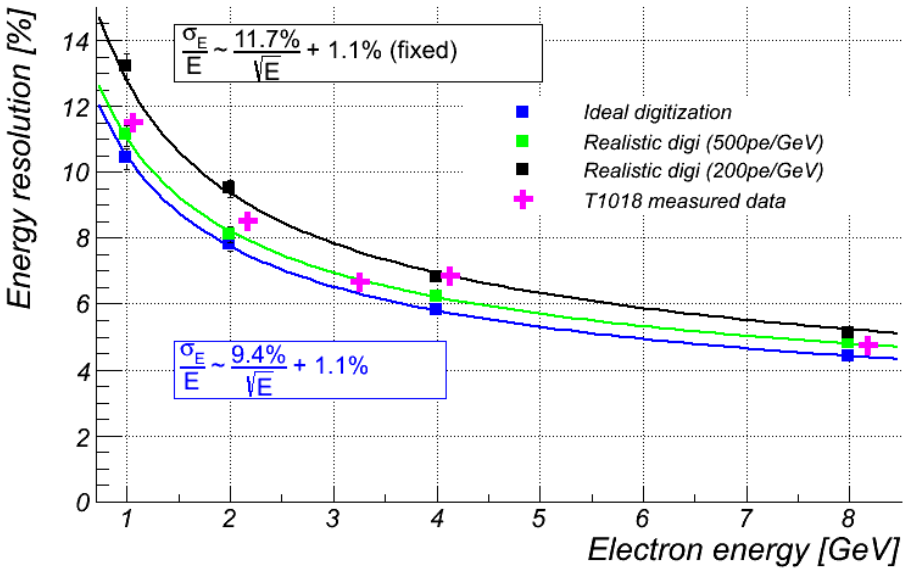
SPACAL study (1): electron resolution

- Electron resolution → Electron PID efficiency
- Compared to simulation from EIC RD1 collaboration and beam test
- Consistent in general

sPHENIX simulation



EIC RD1 simulation, calibrated to beam tests



Courtesy: A.Kiselev (BNL)

With Hijing background

4GeV, innie HCal, zero field

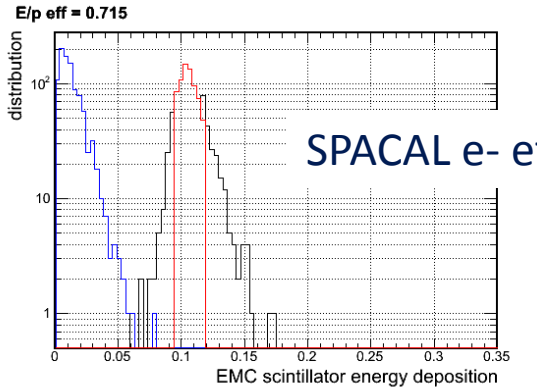
EMCal tower cut : R<3cm

-all events (w/ embedding)

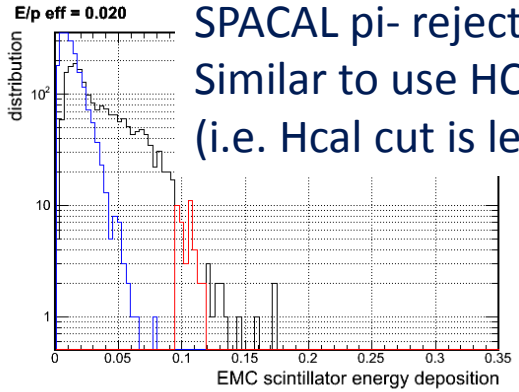
- with EMCal E/p cut (w/ embedding)

- Hijing background (AuAu 10%C in B-field)

FTHP_BERT @ |η|<0.2



SPACAL e- eff = 71%

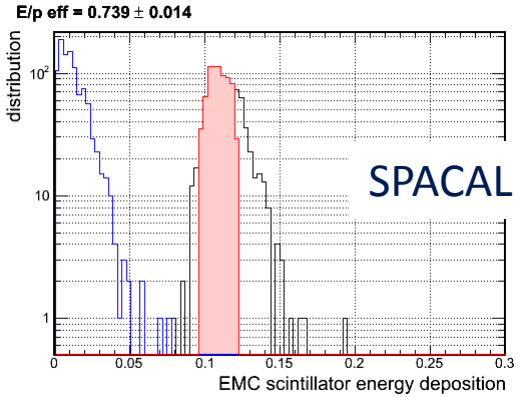


SPACAL pi- rejection = 50:1

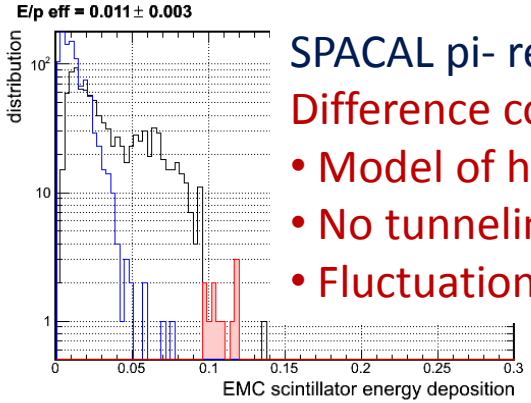
Similar to use HCal-cut

(i.e. Hcal cut is less useful here)

FTHP_BERT_HP @ η = 0.1



SPACAL e- eff = 74%



SPACAL pi- rejection = ~90:1

Difference could be:

- Model of hadron shower
- No tunneling at eta = 0
- Fluctuation

Initial towered shower-shape studies

Efficiencies and rejections for the cut flow just described

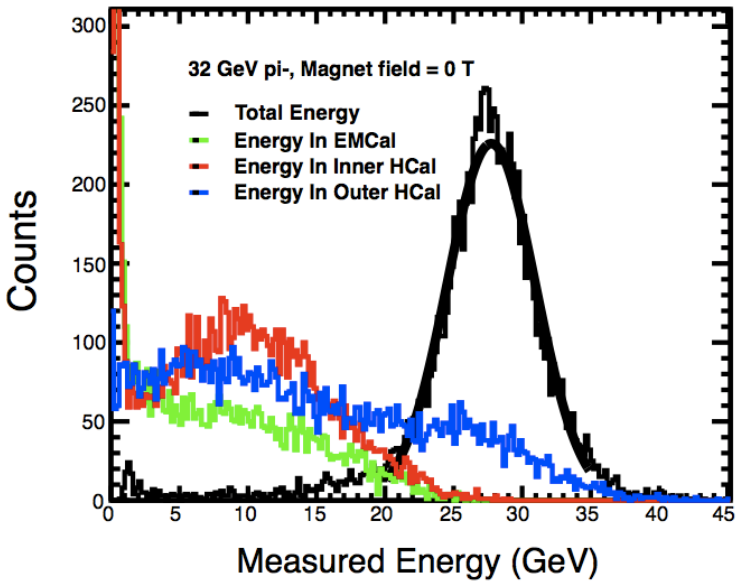
Cut	All	$\lvert\eta\rvert < 0.2$
0.075 GeV > EMcal 3x3 > 0.12 GeV	*e* pion rejection: 31	0.88 36
0.075 GeV > EMcal 3x3 > 0.12 GeV AND HCal 3x3 < 0.1 GeV	0.85 55	0.87 43
0.075 GeV > EMcal 3x3 > 0.12 GeV AND HCal 3x3 < 0.1 GeV AND Shape Parameter > 0.55	0.67 122	0.72 108

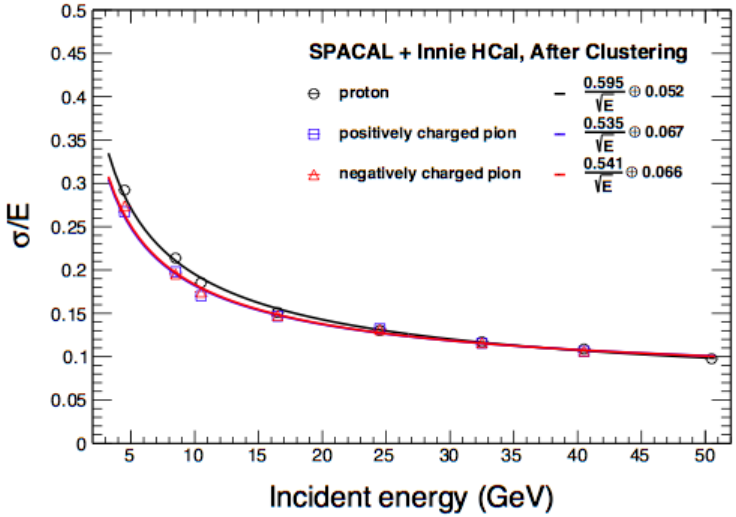
Significant, but less dramatic than what's been shown - need to crosscheck more carefully.

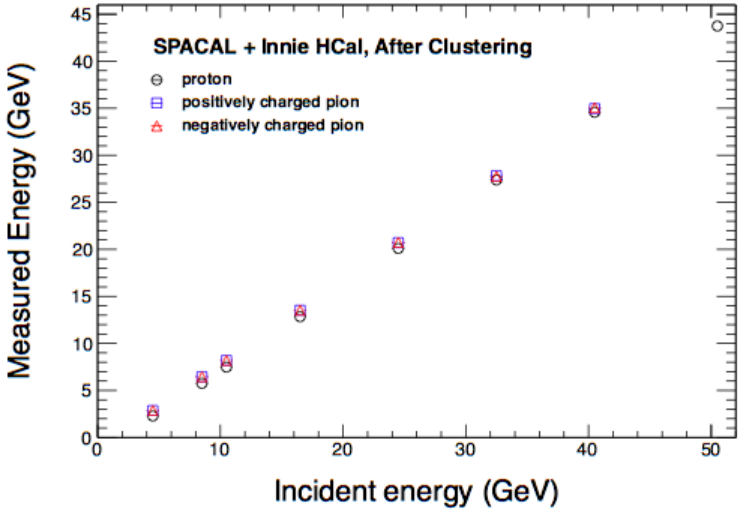
SPACAL + Innie HCal

Clustering:

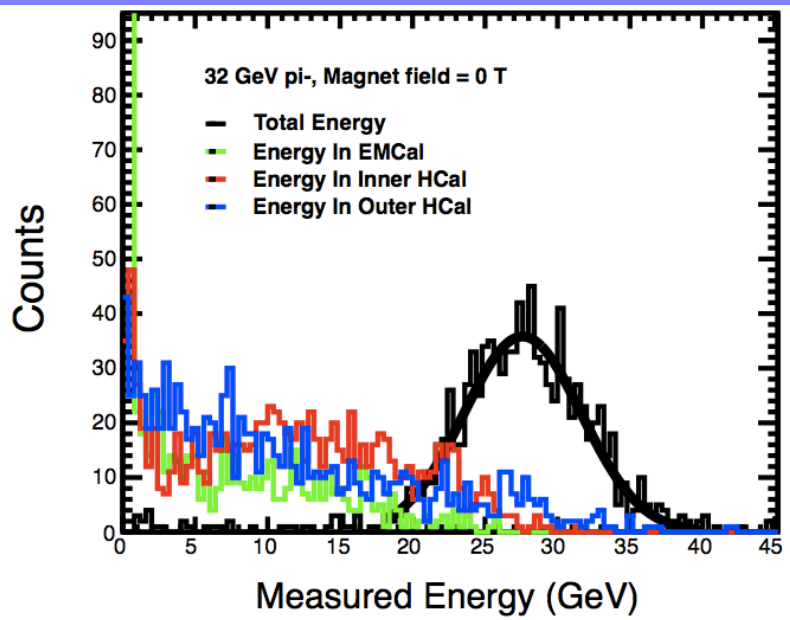
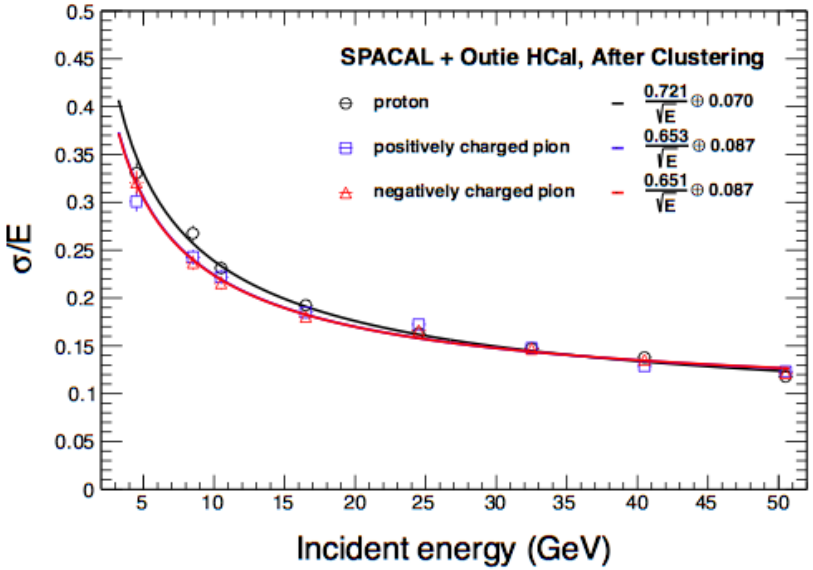
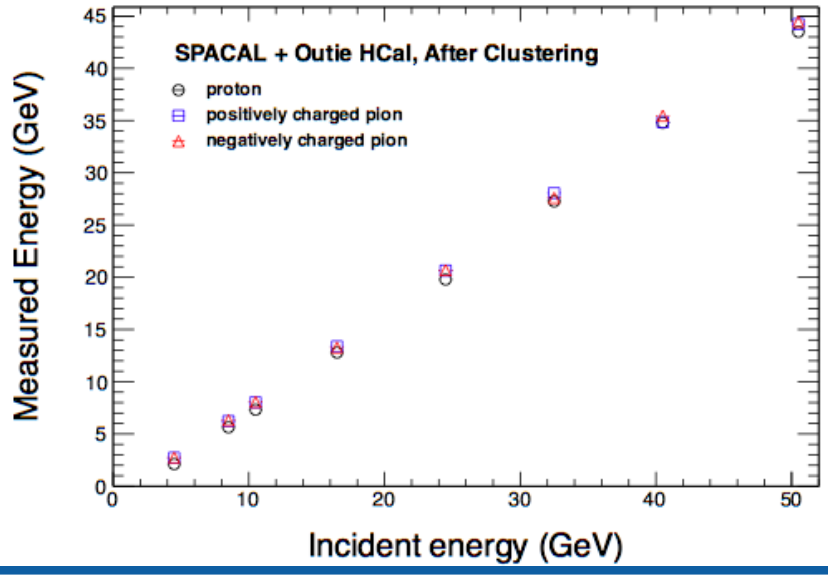
EMCal: 5 MeV tower energy cut
HCal: 10 MeV tower energy cut







SPACAL + Outie HCal

Clustering:

EMCal: 5 MeV tower energy cut
HCal: 10 MeV tower energy cut