sPHENIX Director's Review
Calorimeter Simulations

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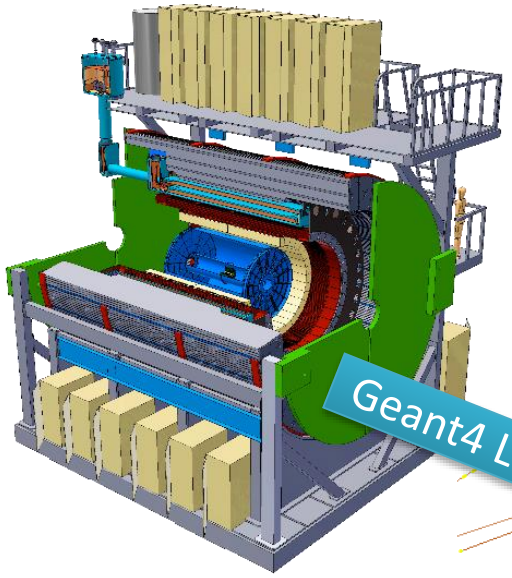
August 2-4, 2017

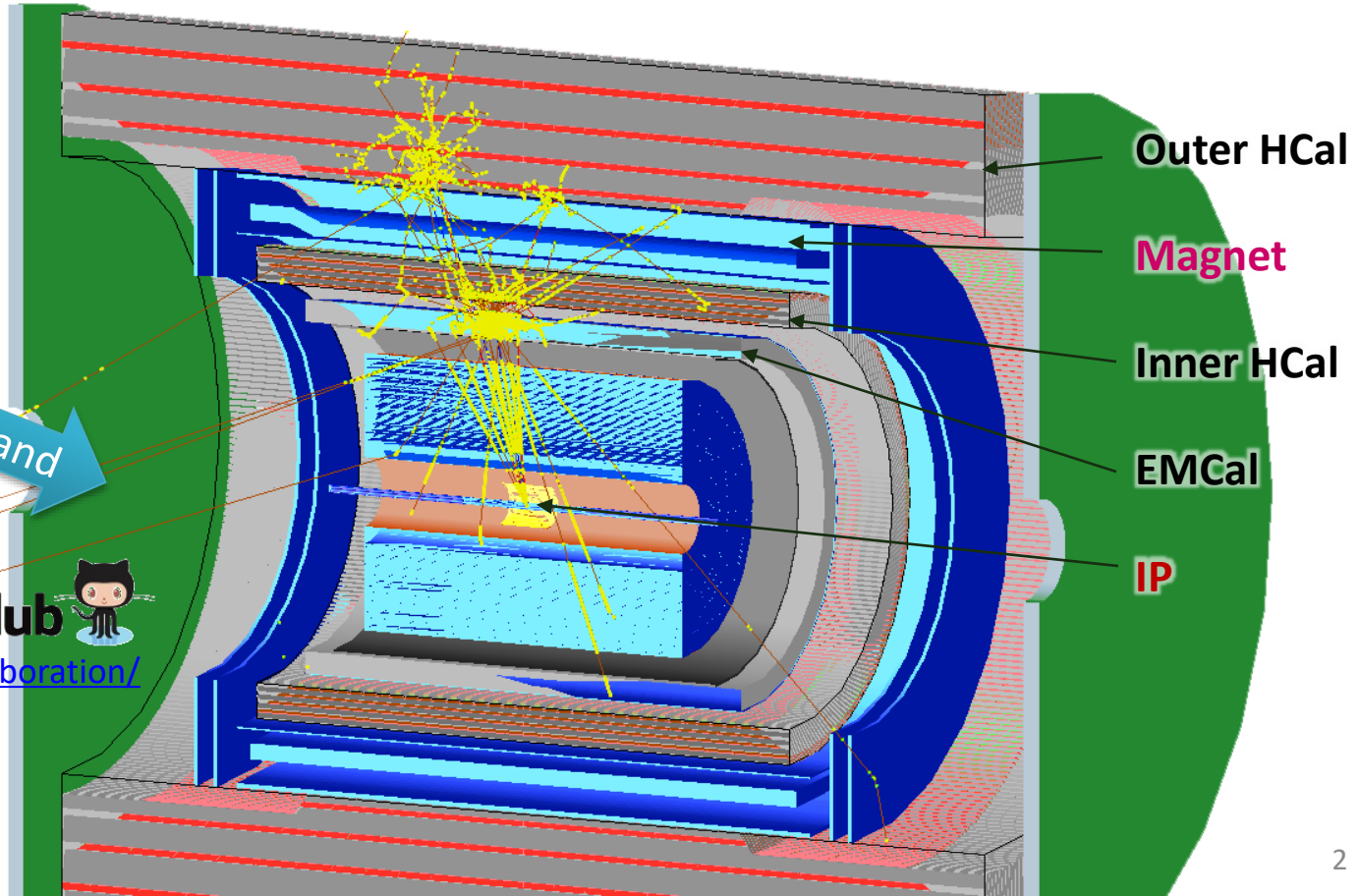
BNL

sPHENIX Calorimeters in Simulation

• EM calorimeter	(EMCal) :	18 X_0	W-SPACAL
• Inner hadron calorimeter	(Inner HCal) :	1 λ_0	SS-Scint. sampling
• sPHENIX coil and cryostat.	(Magnet):	1.4 X_0	Coil & Cryostat
• Outer hadron calorimeter	(Outer HCal) :	4 λ_0	SS-Scint. sampling



Geant4 Land



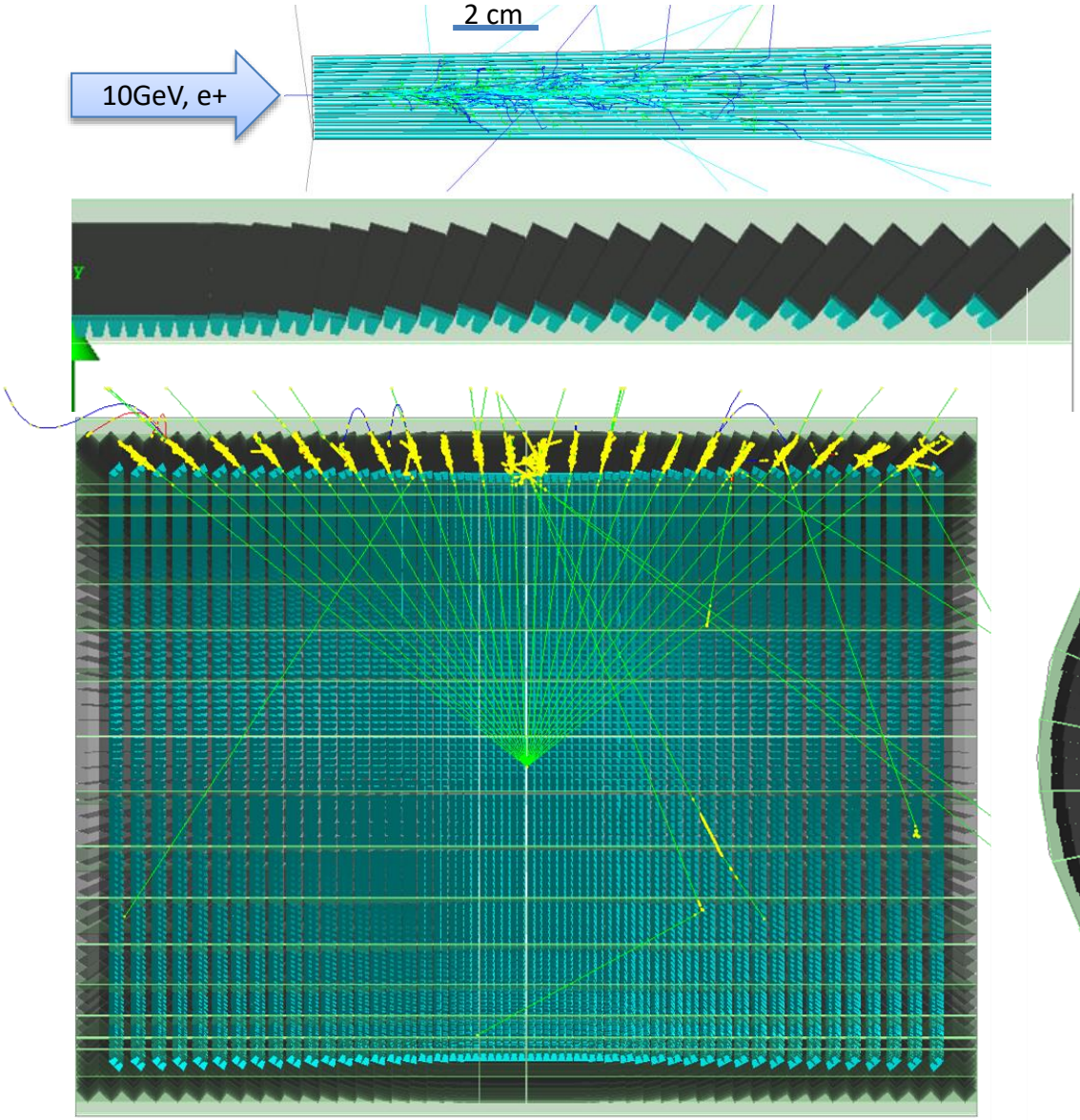
Open source @ GitHub

https://github.com/sPHENIX-Collaboration/

Core software: 200k line of code

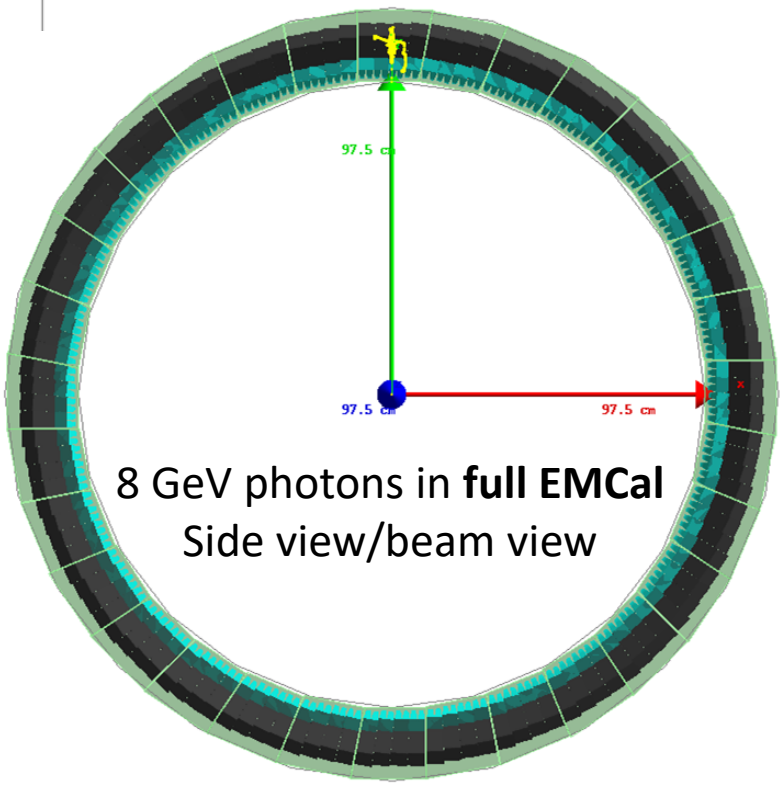
Analysis: 59k line of code

Simulation Setup: EMCal



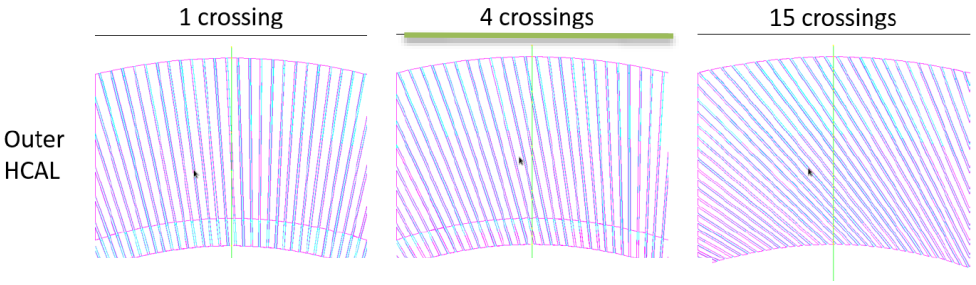
SPACAL Tower
w/ fibers displayed

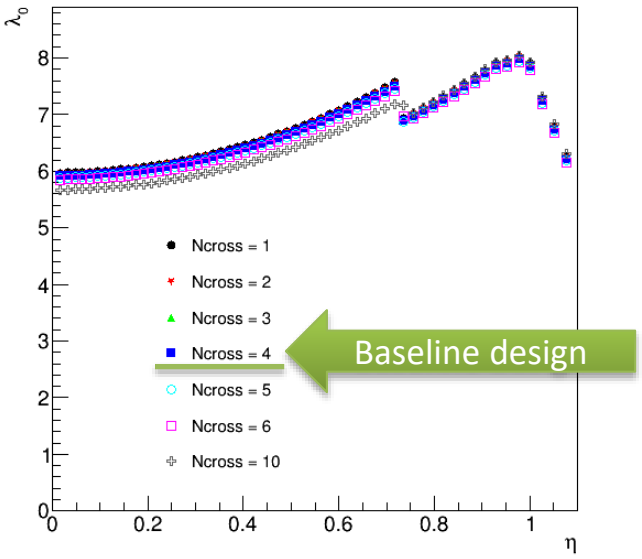
EMCal Half Sector
(fibers simulated but hidden from display)



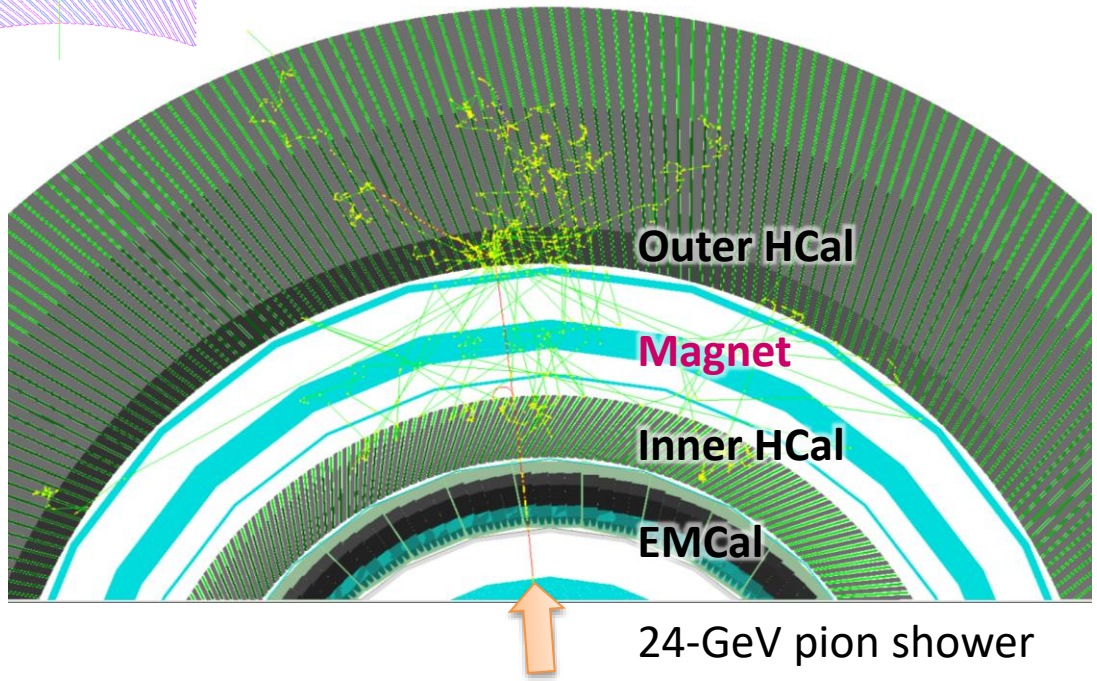
8 GeV photons in **full EMCal**
Side view/beam view

Simulation Setup: HCal





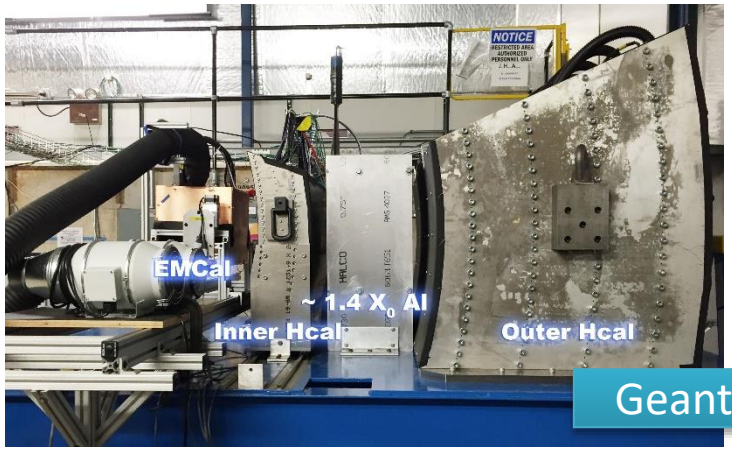
Beam view of **full calorimeters**



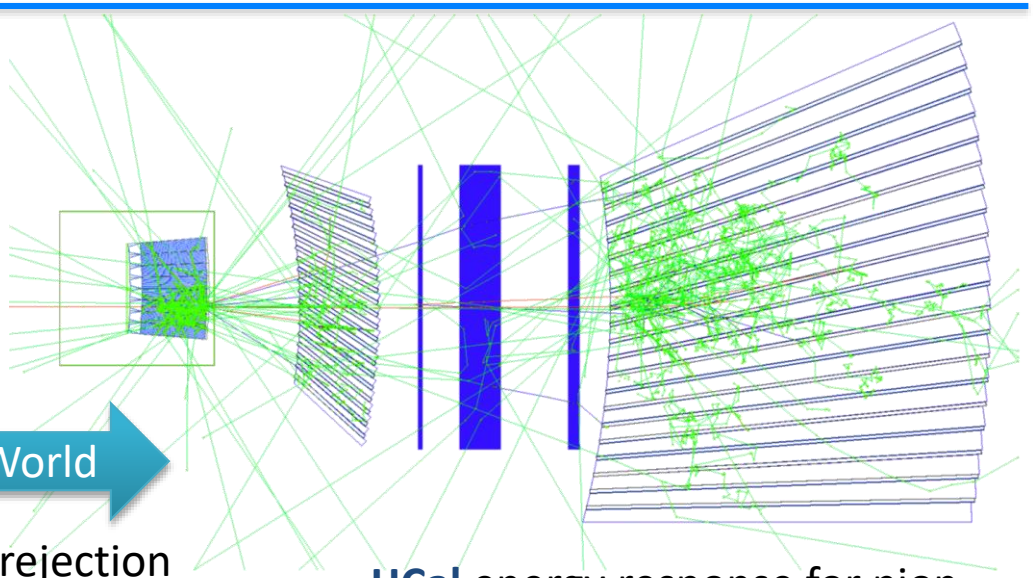
Calorimeter simulation & analysis chain:

GEANT4 hit → Scintillation light model → Light collection model → Tower readout → Digitization → Calibrated tower energy → Clustering/Track matching/Jet finding

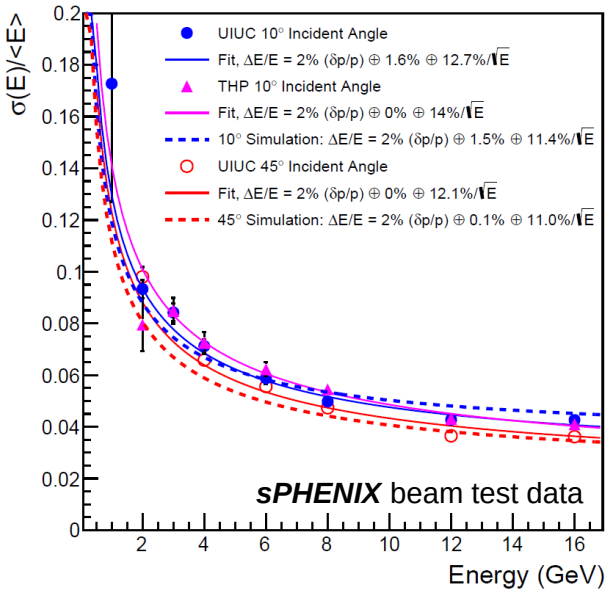
Test Beam Verification [arXiv:1704.01461]



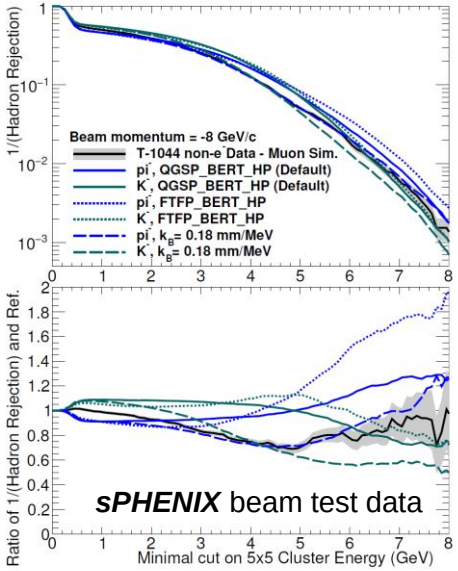
Geant4 World



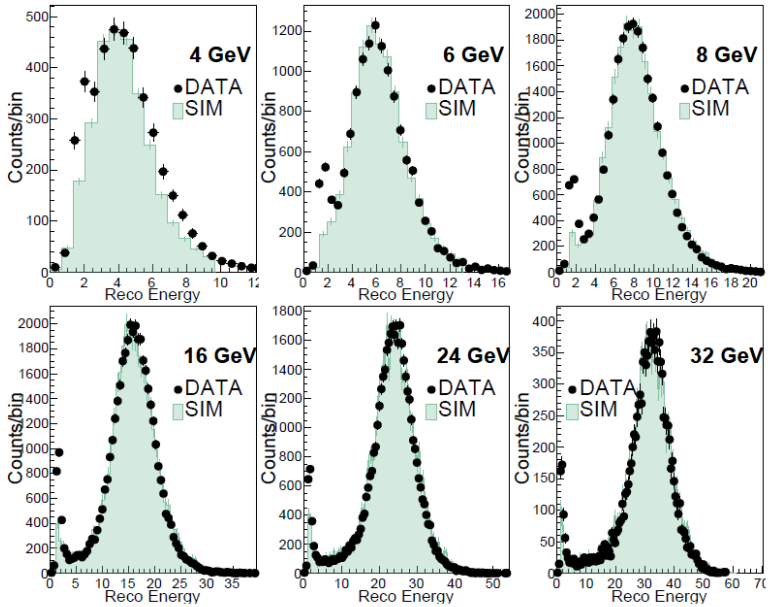
EMCal energy resolution for EM shower in tower center



EMCal rejection for pion-

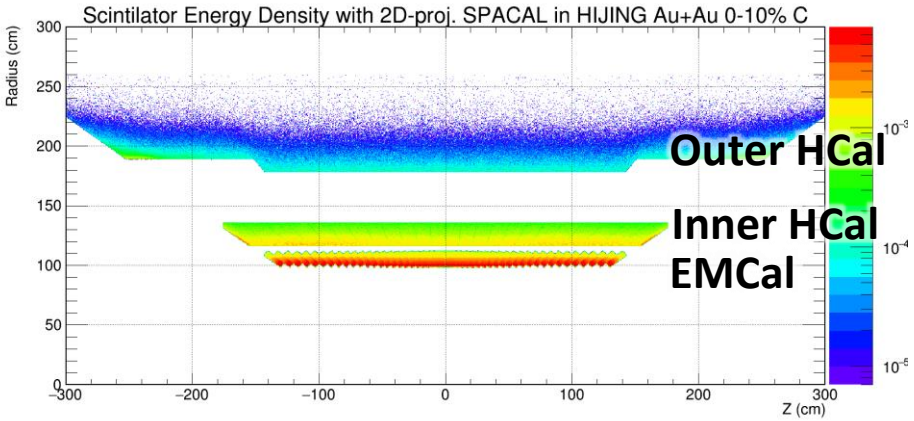


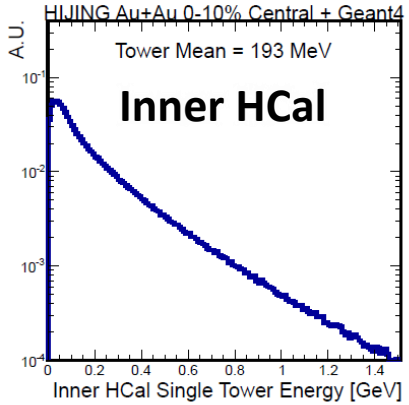
HCal energy response for pion-

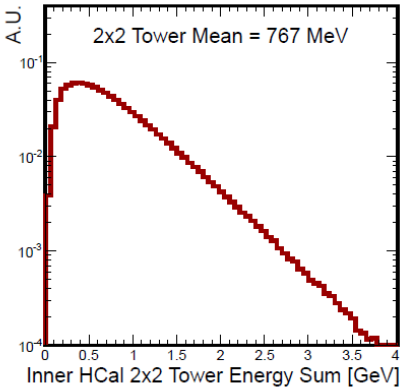


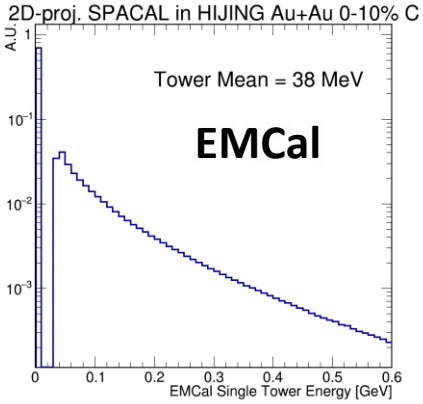
Occupancy in Central Au+Au Events

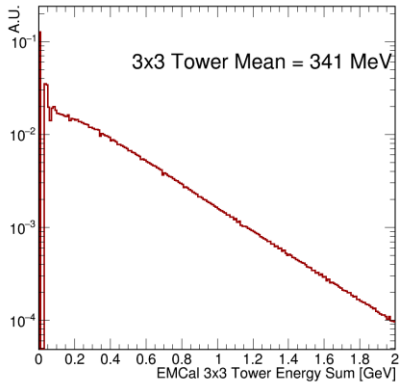
- sPHENIX is designed to handle large background environment of central AuAu collisions
- Such background is simulated with HIJING → full detector in Geant4 → full analysis chain
- Taken into account for electron ID and jet performance via embedding

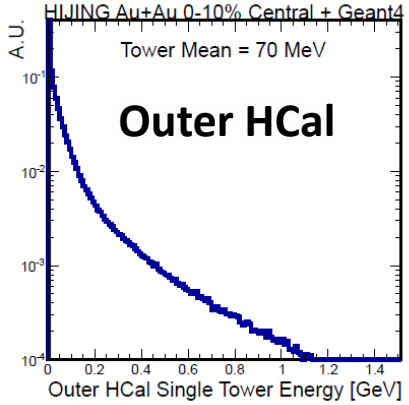


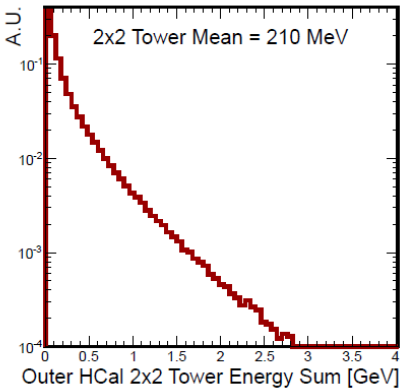








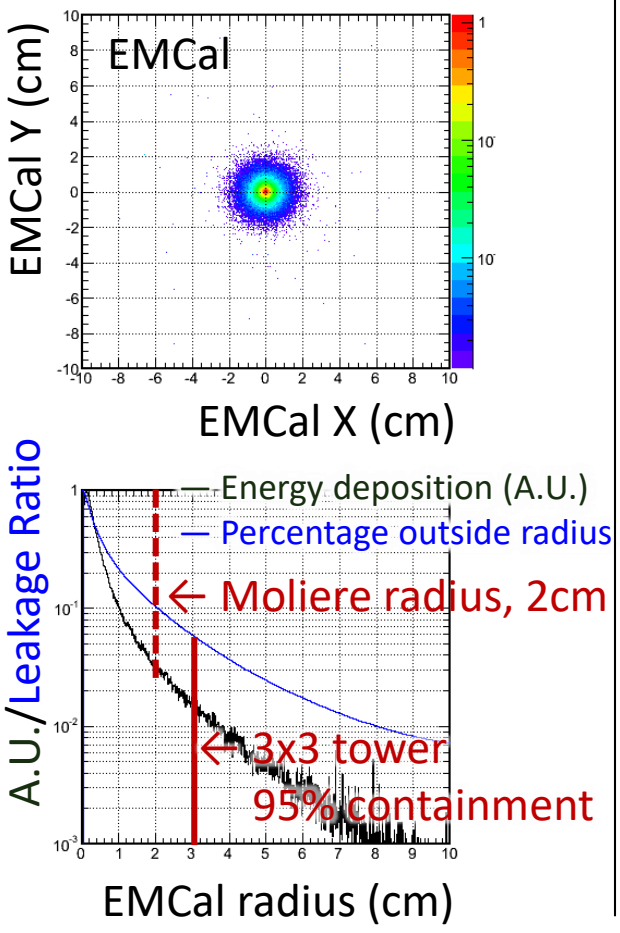




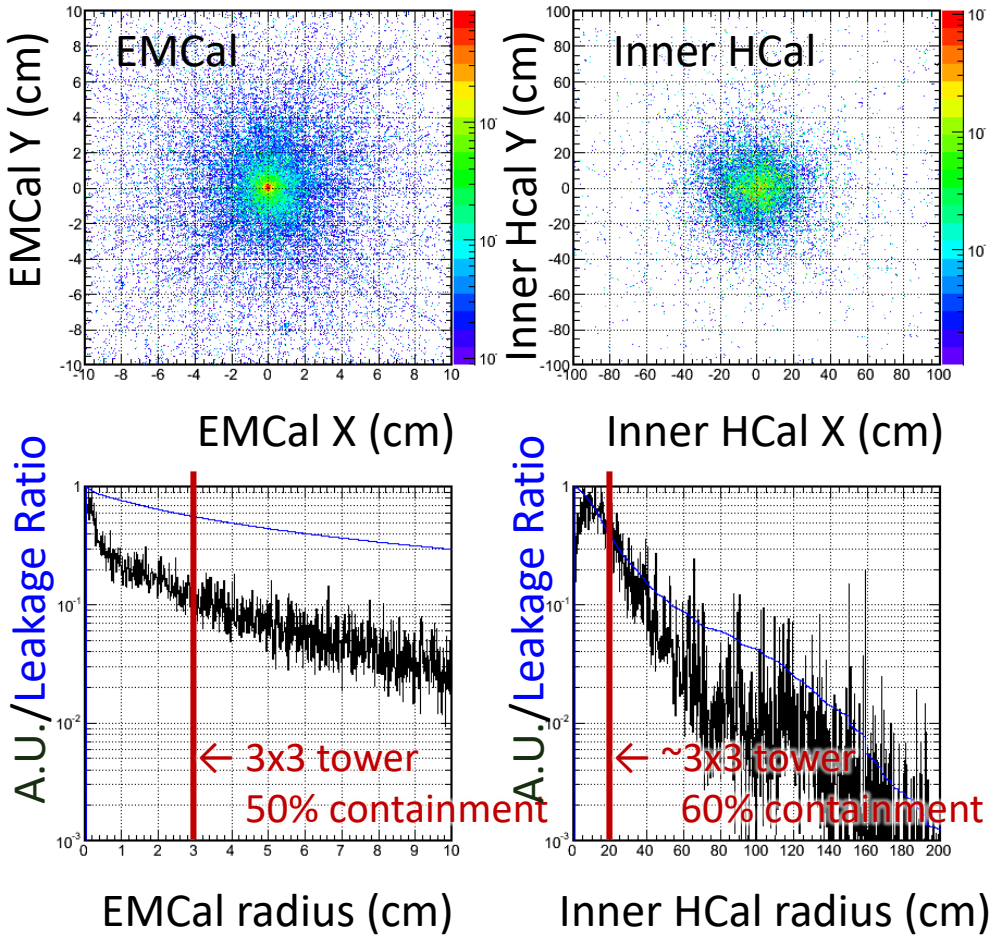
Spatial responses

EMCal design has a tight Moliere radius of 2 cm → Reduce background in Au+Au

4 GeV Electrons



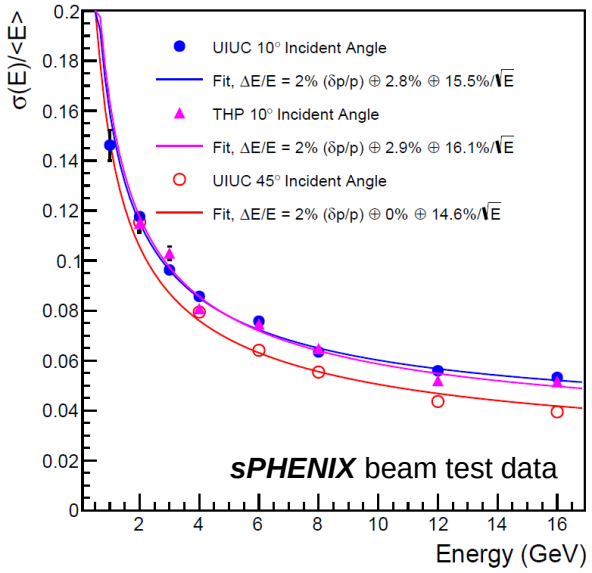
4 GeV Pions, that **passed E/p electron-ID cut**



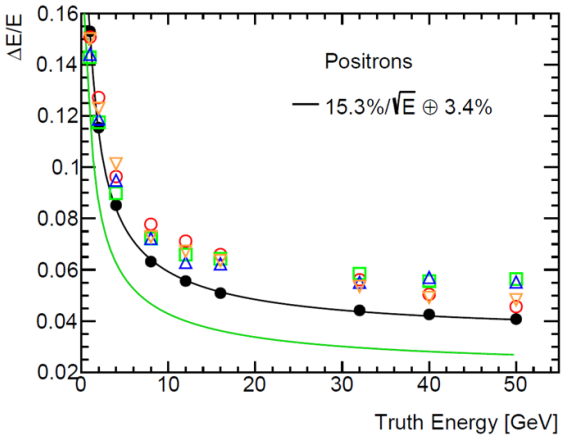
Performance : Single EM Showers

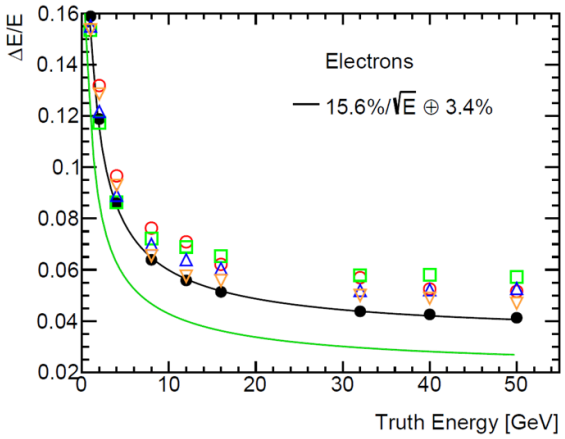
- Applied cluster-position-based non-uniformity correction as used in test beam analysis
- dE/E ~ 15%/ √(E) + 4% (meets sPHENIX goal)

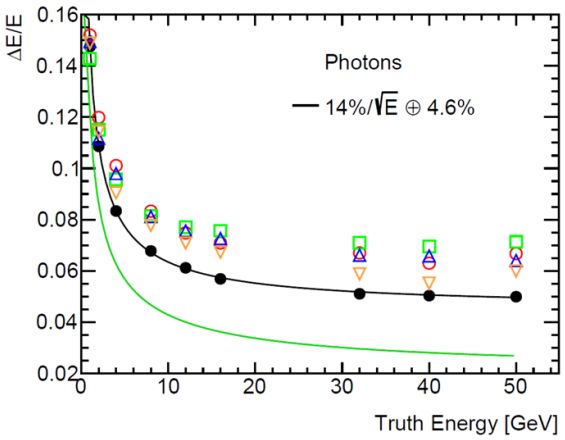
Beam test [arXiv:1704.01461]

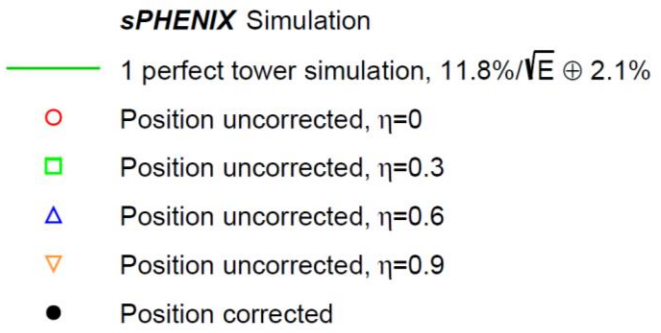


Full sPHENIX detector **simulation**

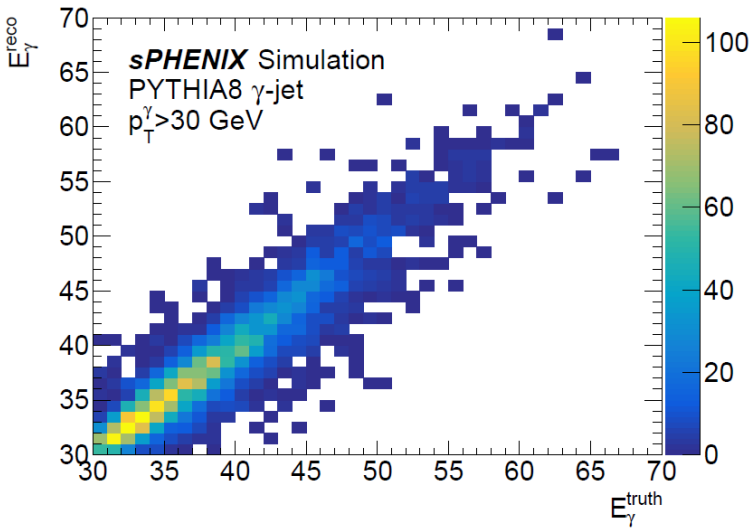




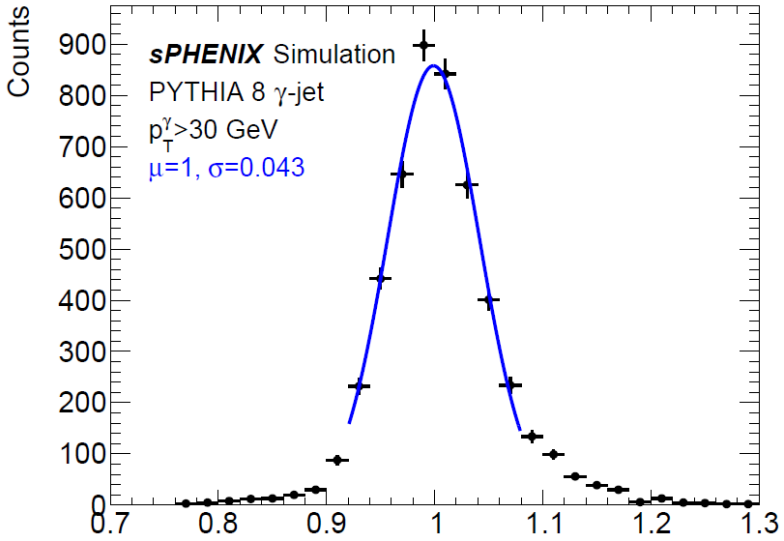


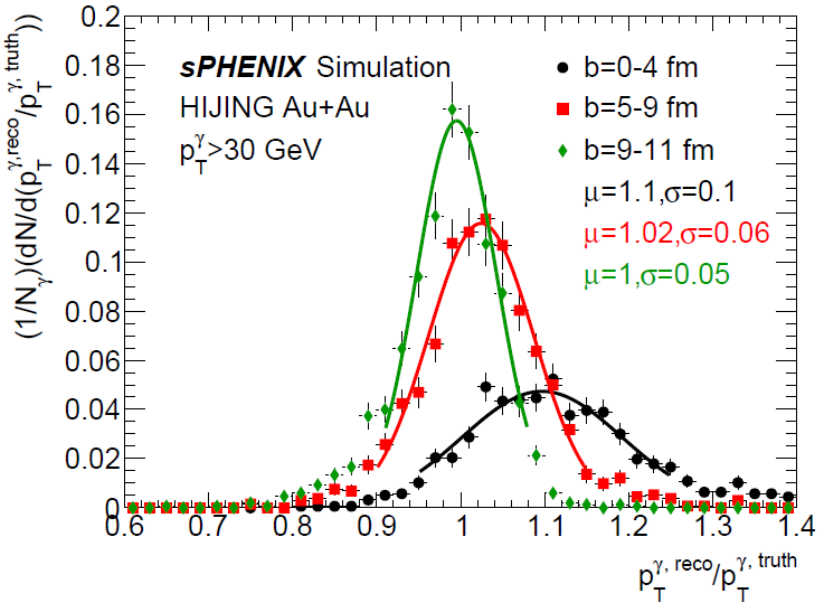


Performance : Photon in Full Event



- Good linearity up to photon kinematic limit of sPHENIX
- Good photon response shown in full gamma-jet event simulations
- In progress: improving clustering algorithm to minimize background pickup in central Au+Au collisions.
- Nevertheless, jet energy resolution dominates precision for gamma-jet momentum balance measurements

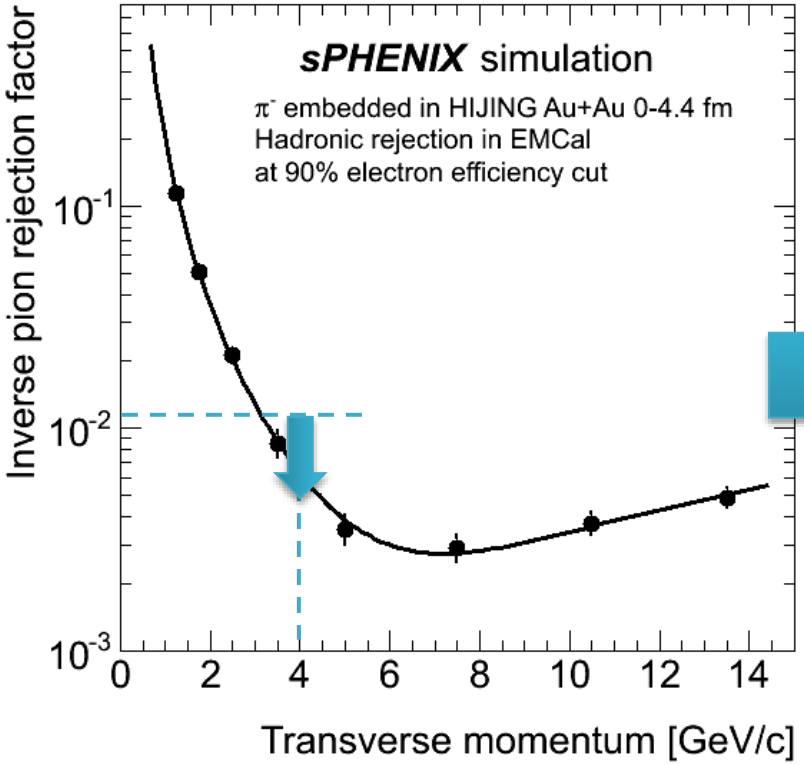




Physics Performance : Electron-ID

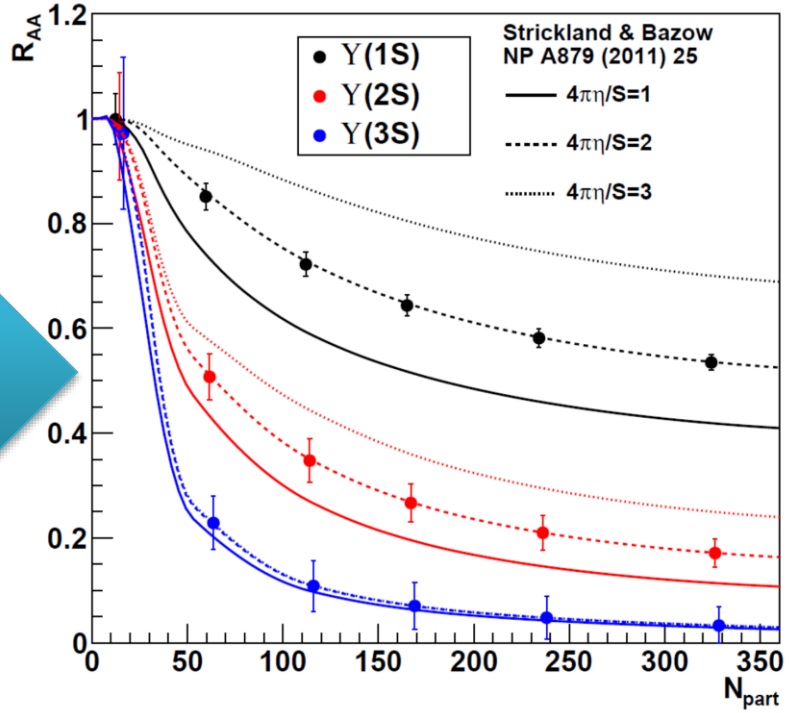
- Critical driving factor for EMCal design: Upsilon electron ID
- Satisfied detector requirement (>90:1-pion rejection @ p_T=4 GeV/c in central Au+Au collisions at 70% efficiency)
- Updating Upsilon background and R_{AA} projections

Pion rejection @ (improved) 90% efficiency



Updating ...

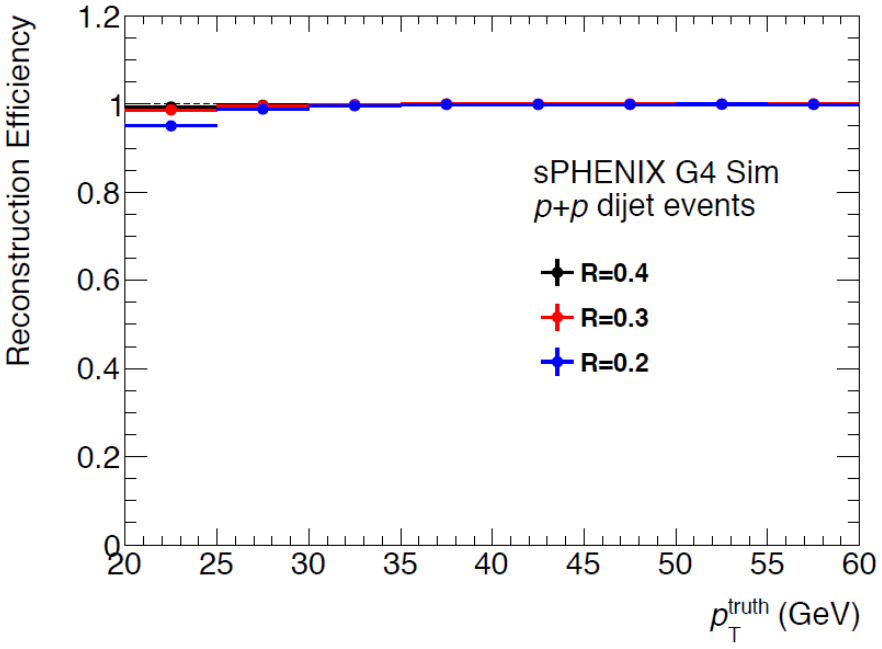
Upsilon R_{AA} projections in **sPHENIX proposal**
Assuming 90:1 pion rejection @ 70% e-eff.

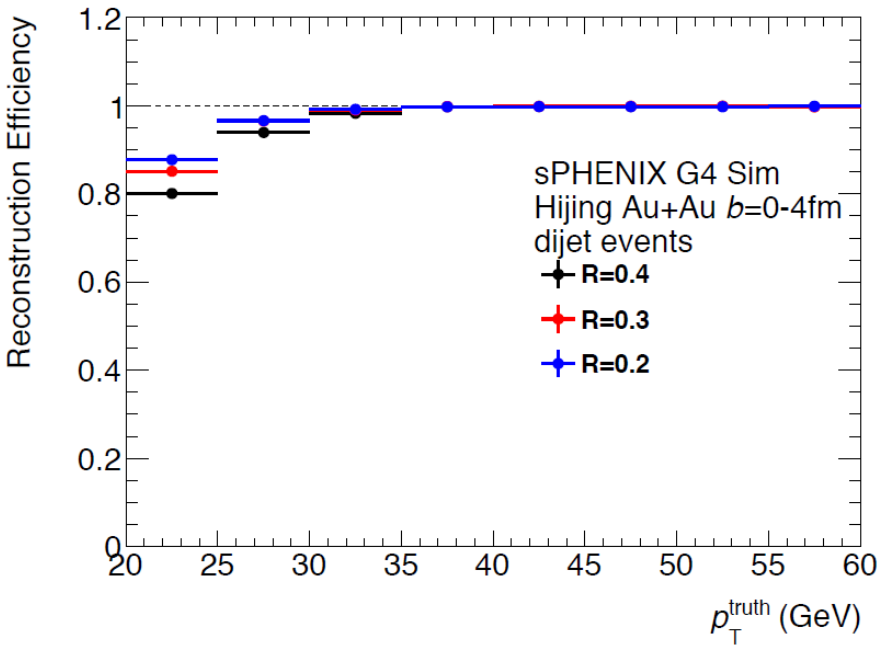


arXiv:1501.06197

Performance : Jet Finding

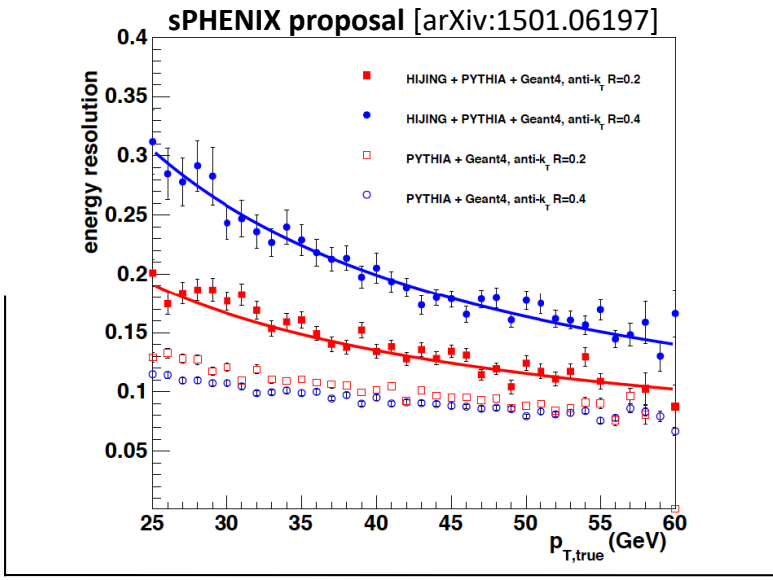
- Jets in p+p and central Au+Au collisions are also studied in full detector simulations
- Jet finding followed by iterative background subtraction [10.1103/PhysRevC.86.024908]
- Study are in progress updating the jet performance plots as in sPHENIX proposal
- Preliminary results show good efficiency (>80% for p_T>20 GeV/c jet in central Au+Au collisions)
- Further improving underlying event subtraction and fake-jet rejection algorithm based on RHIC and LHC experiences



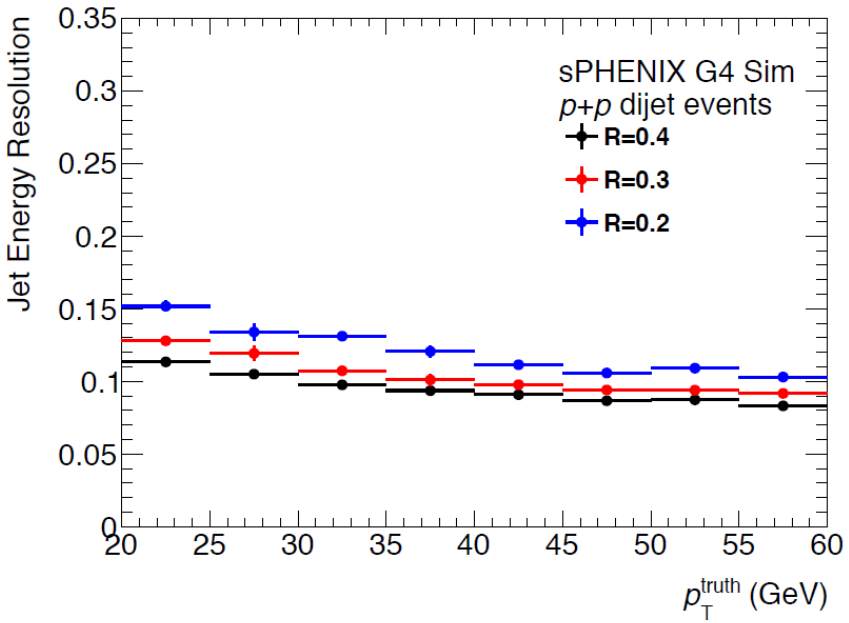


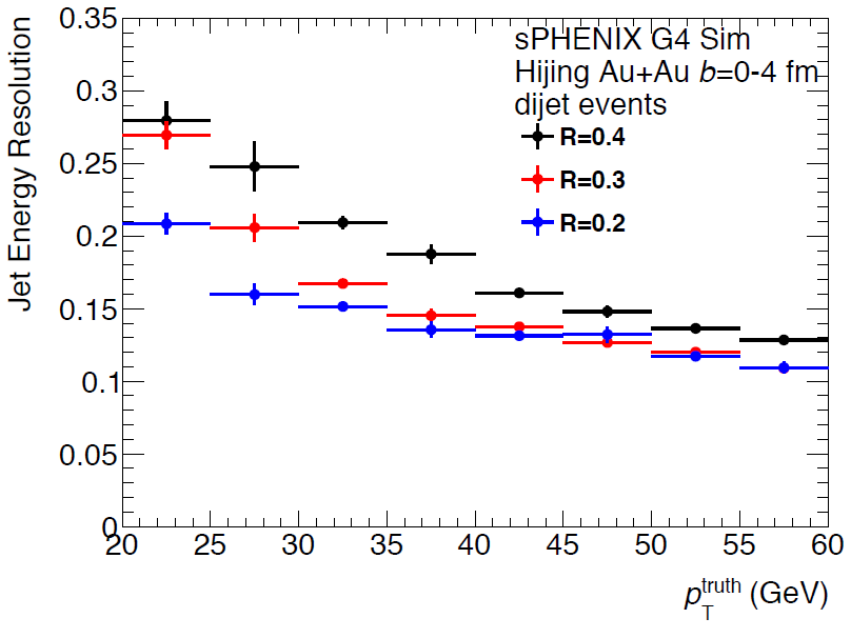
Performance : Jet Energy Resolution

- Detector simulations has been updated with detailed engineering design and beam test tunings
- Study are in progress, results are still preliminary
- Preliminary energy resolution was found consistent with simulation study as in sPHENIX proposal [arXiv:1501.06197]



Full detector simulation with the current design

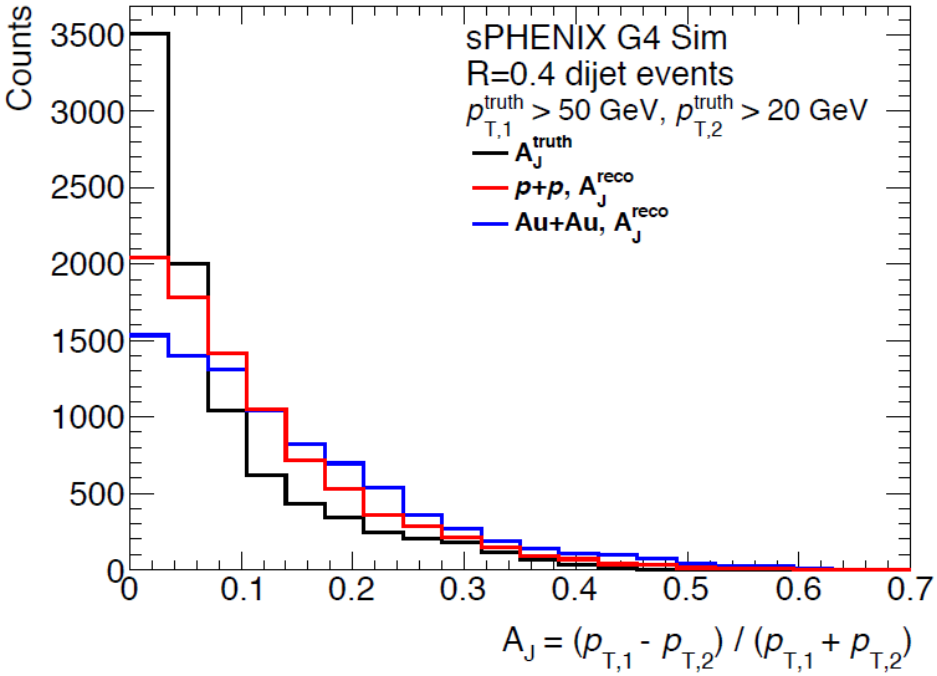




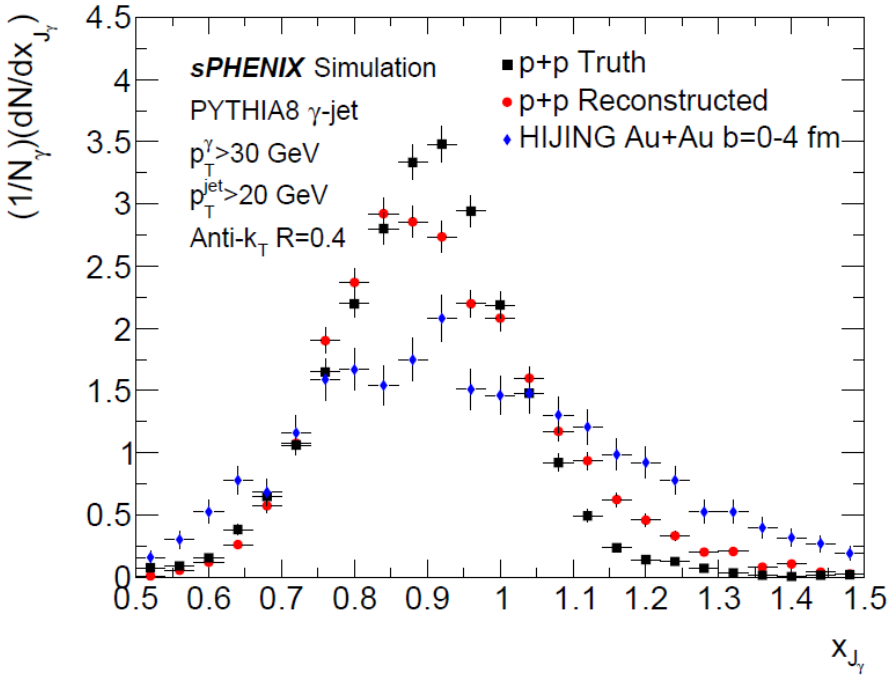
Physics Performance : Jet Observables

- Jet-balance/imbalance observables simulated in full detector events: day-1 measurement, resolution under control
- On-going effort in understanding the details of the jet simulations and unfolding studies.
- Expanding jet observables studied with the updated design and simulations

Di-jet transverse momentum asymmetry



γ-jet transverse momentum balance



Summary

- A detailed model of the sPHENIX calorimeter has been implemented in GEANT4, and used for design and performance studies
- Simulation has very good agreement with test beam data
- Calorimeter performance achieves the specification
- Work in progress to update reconstruction algorithms and the physics performance plots with refined detector design and simulation

Response to questions on Simulation for descope options

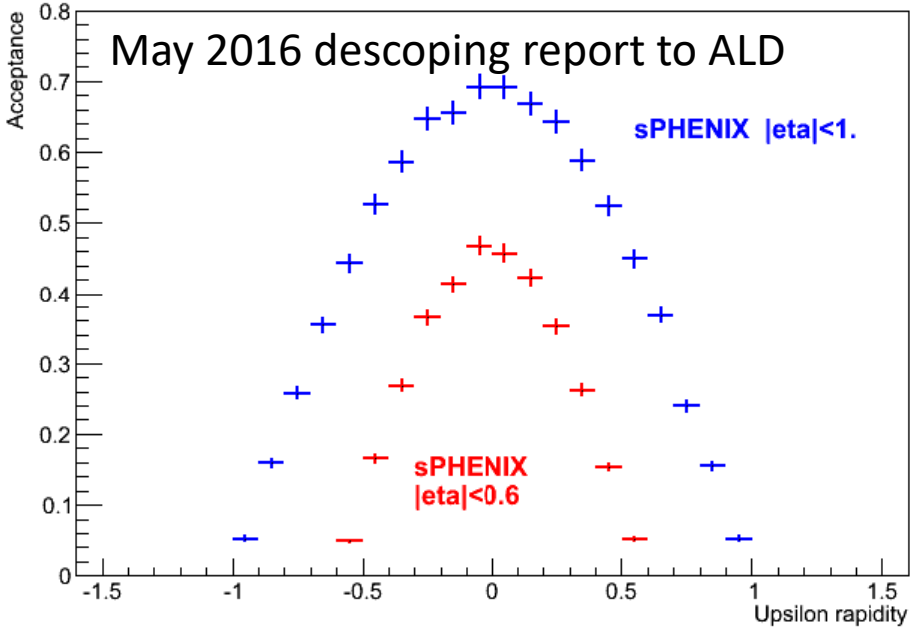
Descoping simulation

- Current simulation focus on full sPHENIX scope, and on producing full physics simulation with the updated design
- Past: descope simulation was exercised one year ago (May 2016, with slightly older design)
  - **Documented and submitted to ALD**
  - **Few plots appended to illustrate likely out come of new descope studies**
- New descope simulation for CD-1 review?
  - **Few scenario possible**
  - **Resolution, acceptance can be studied quickly**
  - **Systematic/calibration are harder to simulate, but they lead to important implications for descoped detector options**

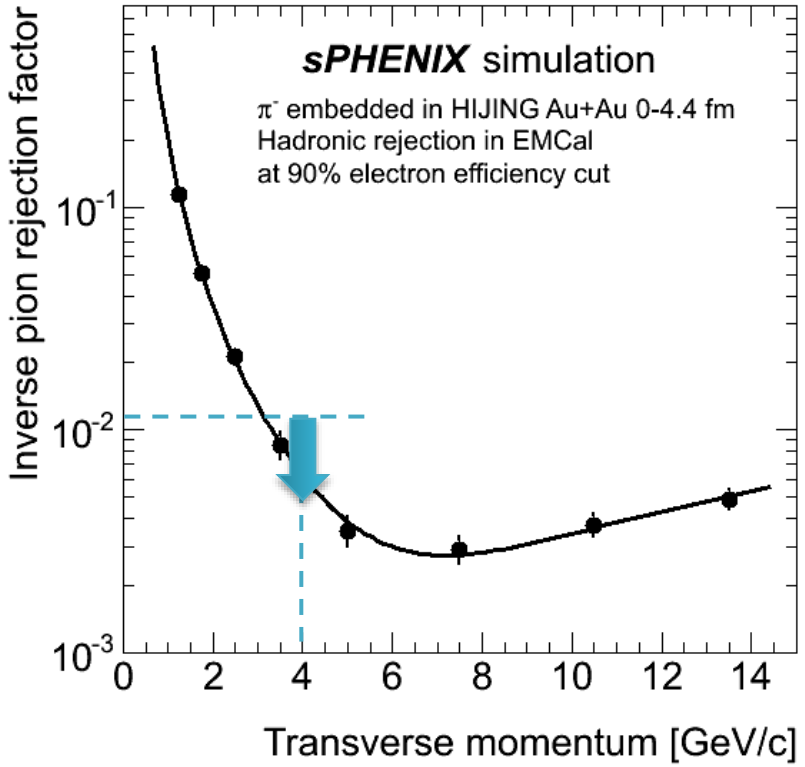
EMCal descoping - Upsilon

- Acceptance & statistics changes – can be easily simulated
- Electron ID
  - **Current study not using inner HCal yet**
  - **With inner HCal: improving x2 (expected value from past iterations sim.)**

Upsilon acceptance (fast simulation)



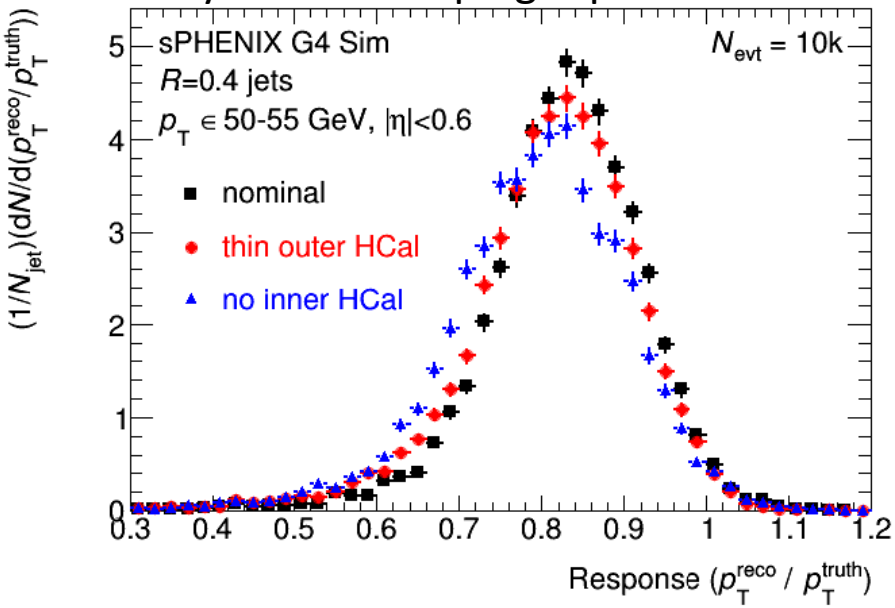
Pion rejection @ 90% efficiency, NO inner HCal



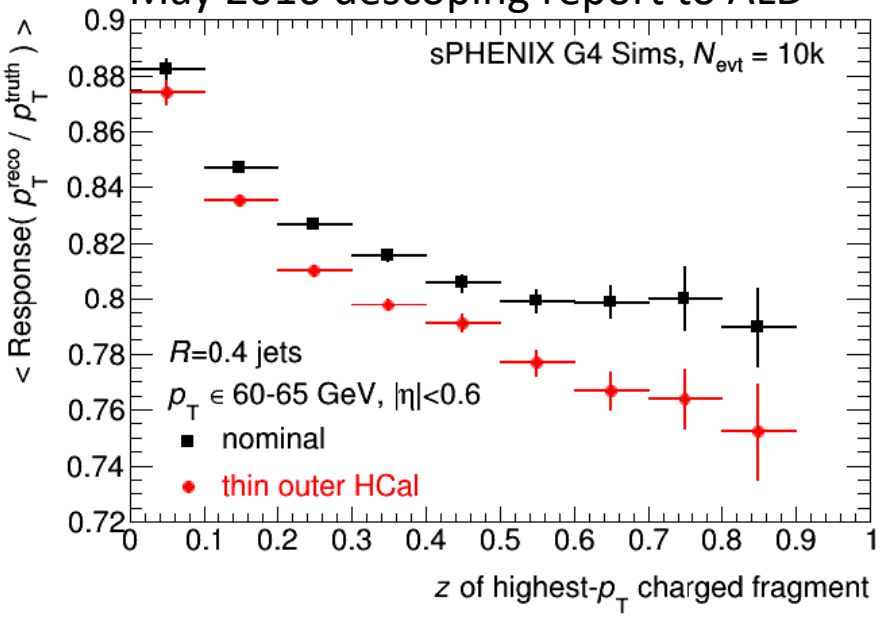
Descoping - Jets

- From past simulation studies:
  Jet energy resolution would be fine by reducing 1 interaction length of calorimeter
- But there are many effect from descoped detector, that has strong physics implications but difficult to quantify in simulating:
  - **Systematics of hard fragmentation-bias with a thinner calorimeter stack**
  - **Edge effects for jet measurements with reduced EMCal**
  - **Calibration and determining jet energy scale with reduced EMCal**

May 2016 descoping report to ALD



May 2016 descoping report to ALD

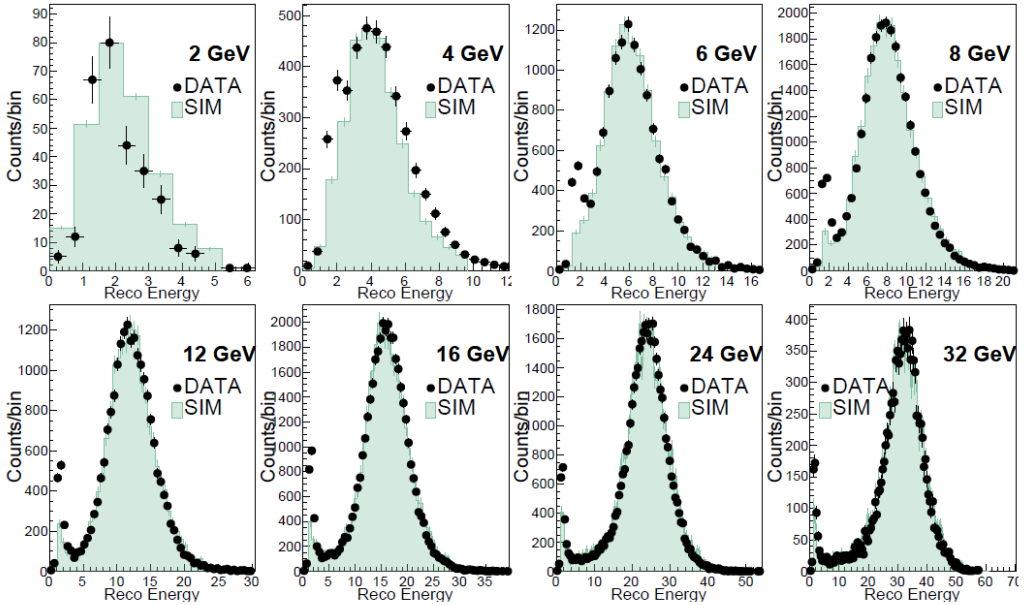


A

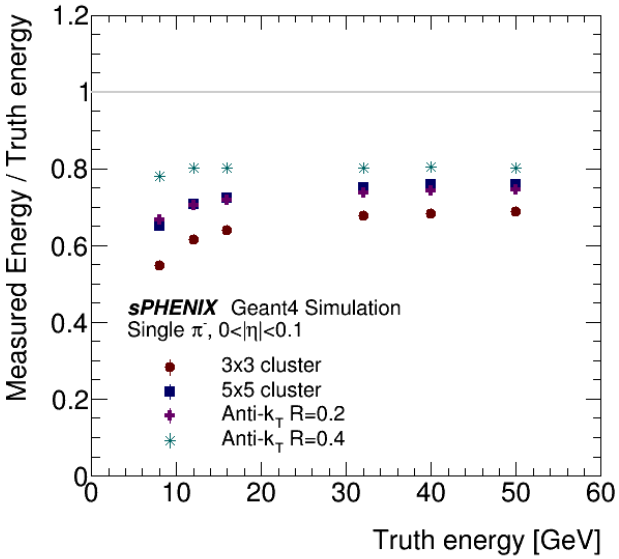
Extra information

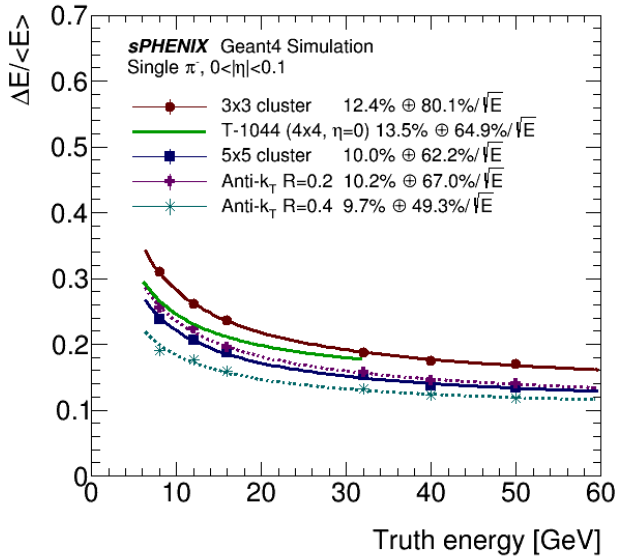
HCal simulation verification

HCal prototype @ eta = 0
energy response for pion-
T-1044 test beam and simulation
arXiv:1704.01461

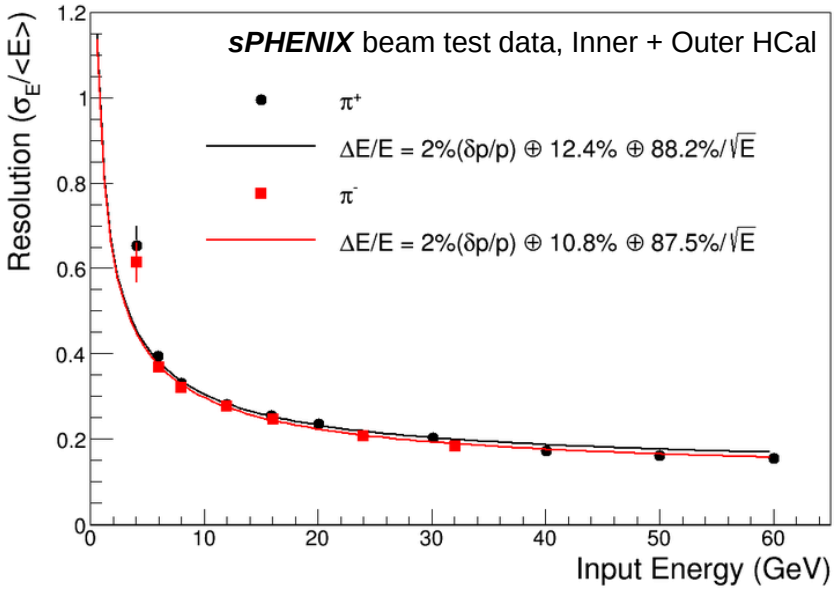


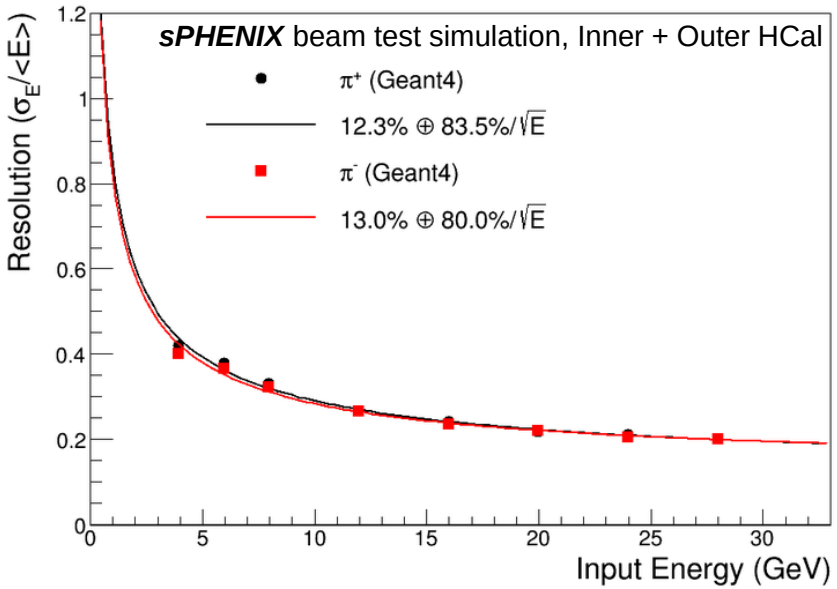
Full sPHENIX
energy response for pion-

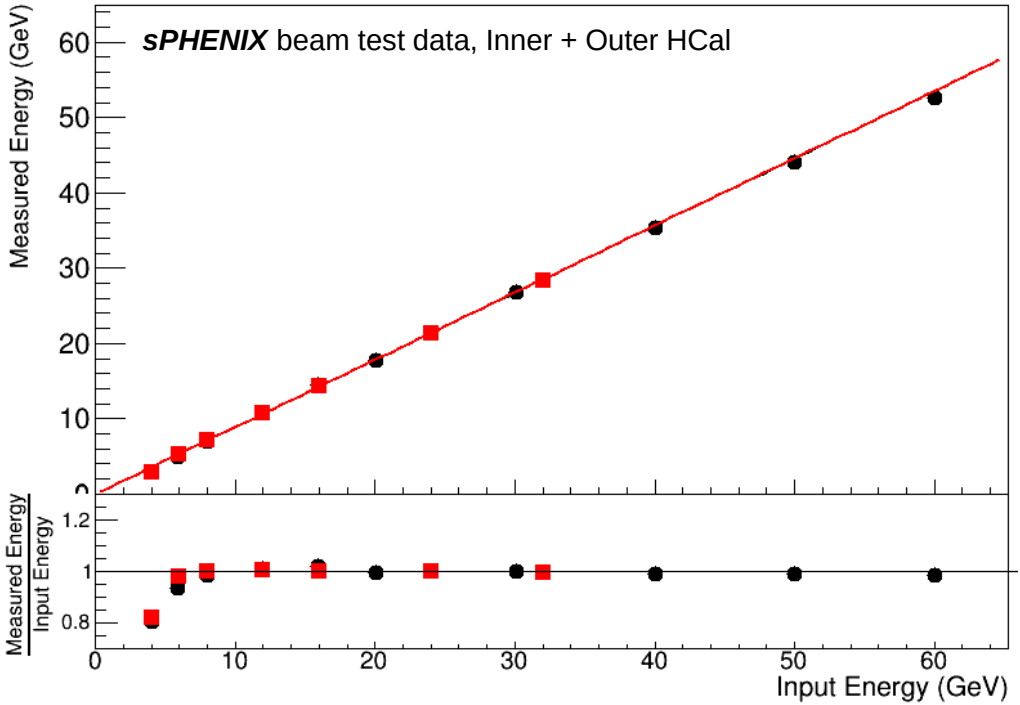




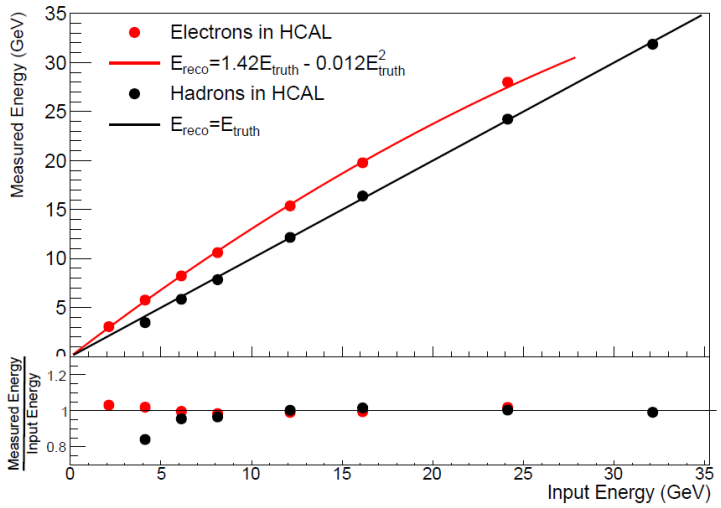
HCal prototype 3 @ η = 1



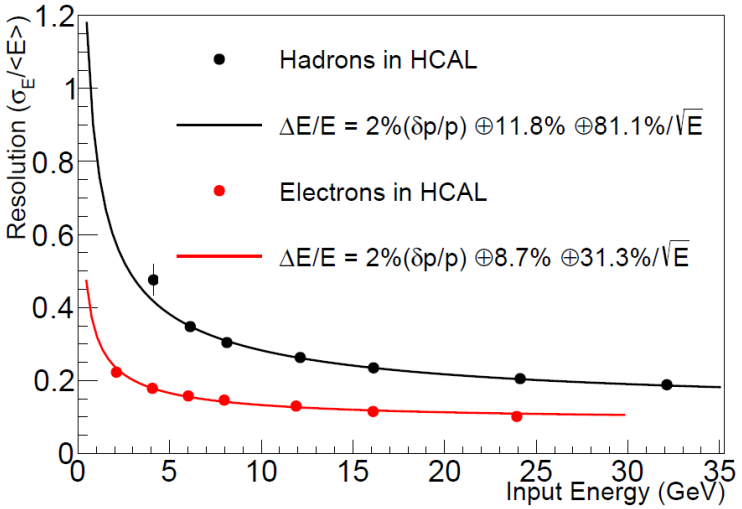




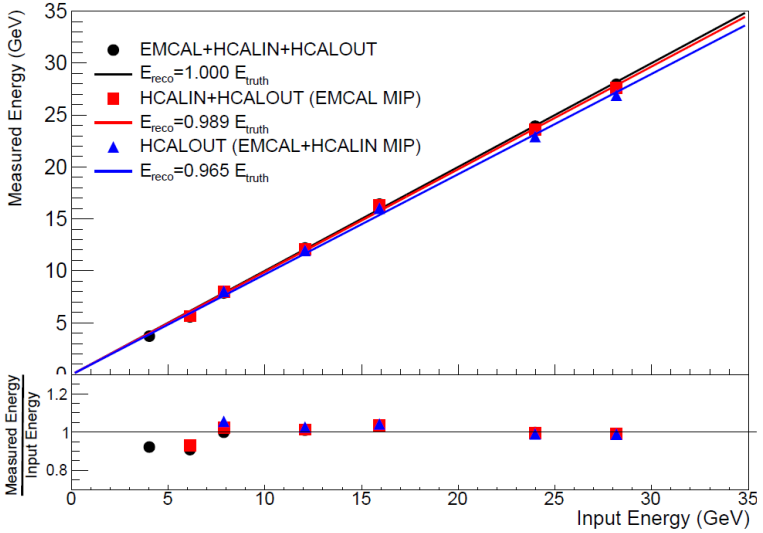
HCal prototype 2 @ η = 0



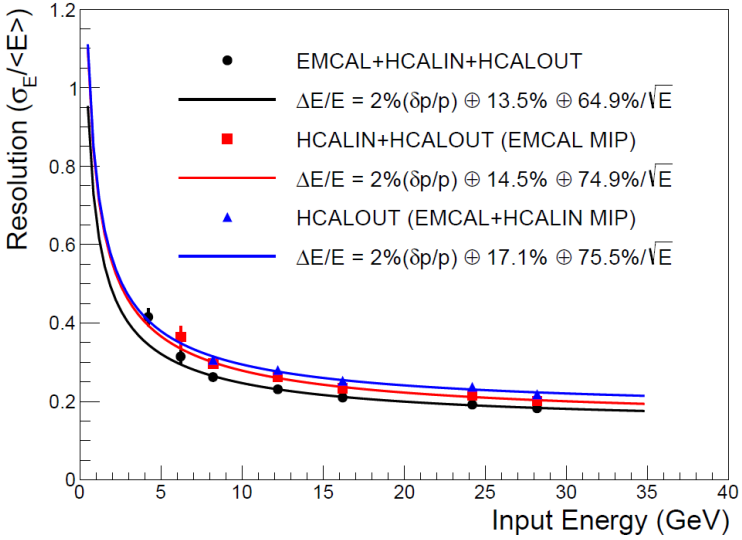
(a)



(b)



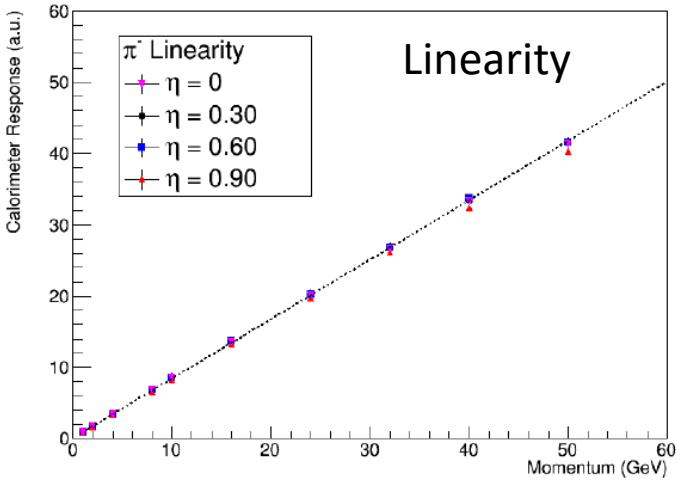
(a)

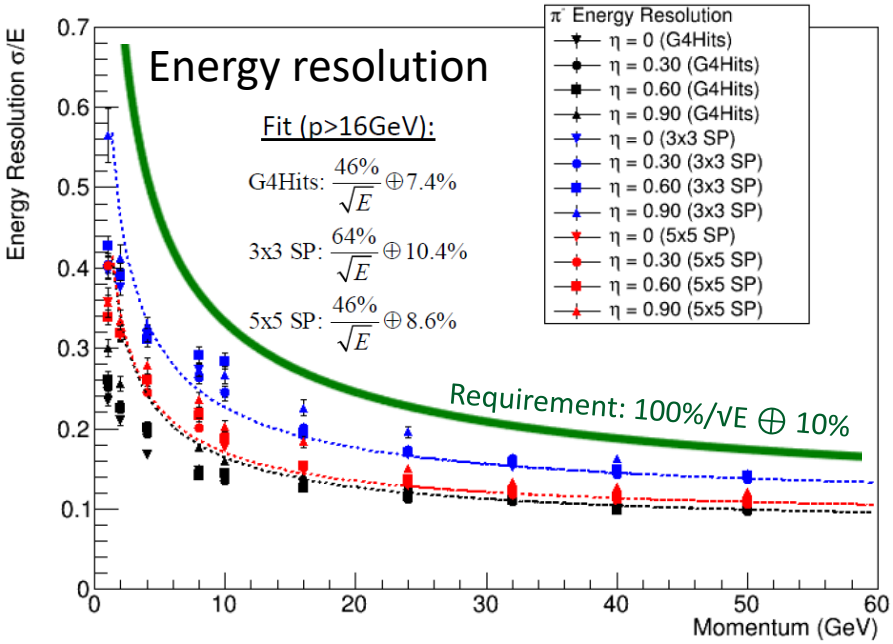


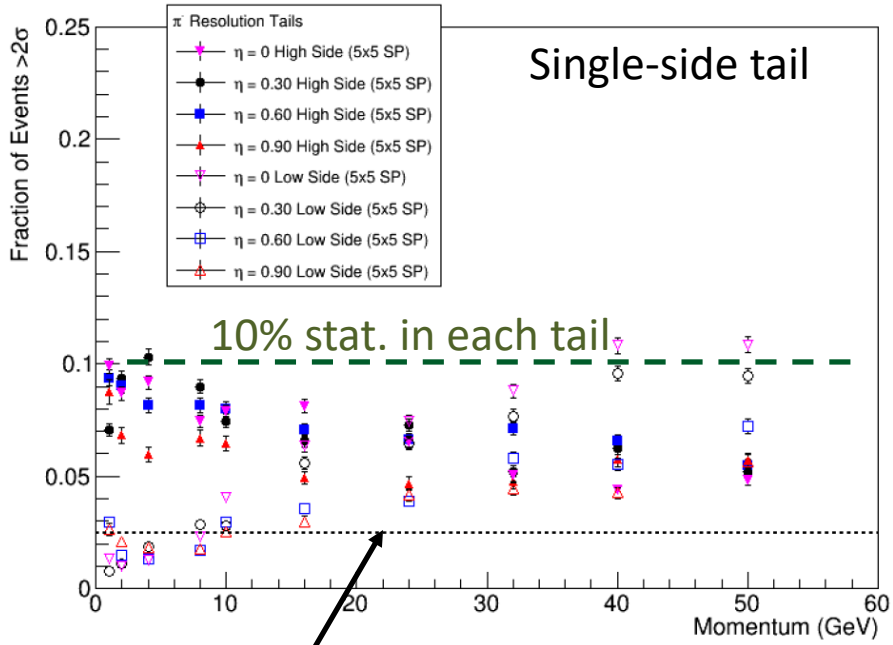
(b)

Performance : Single Hadron showers

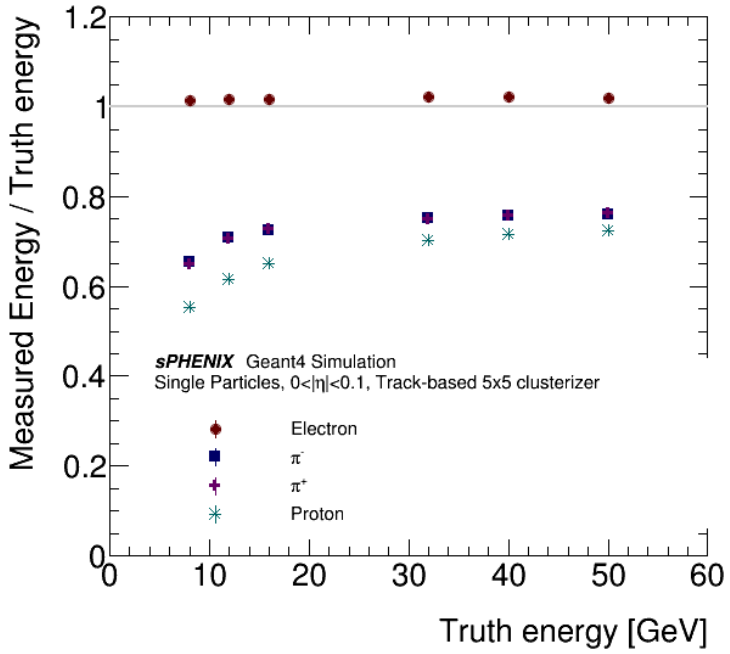
- Single pion shower studied with clusters of digitized towers (3x3 and 5x5 clusters), which is compared with ideal sum of Geant4 hit in scintillator (label G4Hits)
- Energy resolution satisfied design goal. Tails <= 10%

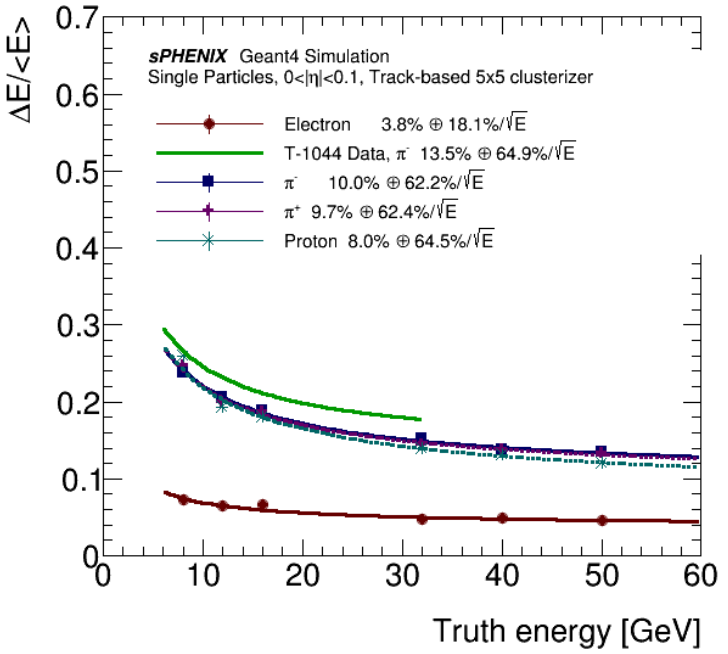


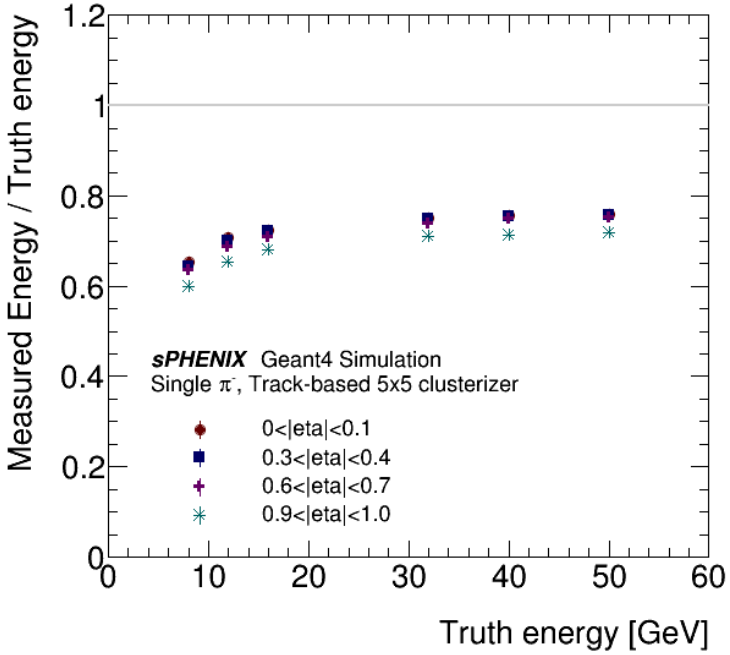


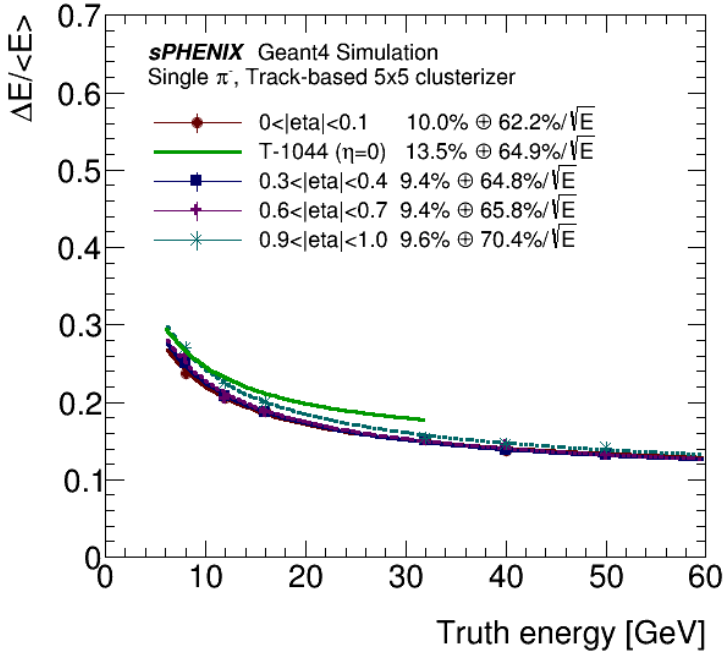


2.5% stat. in tails as expected from Gauss shape

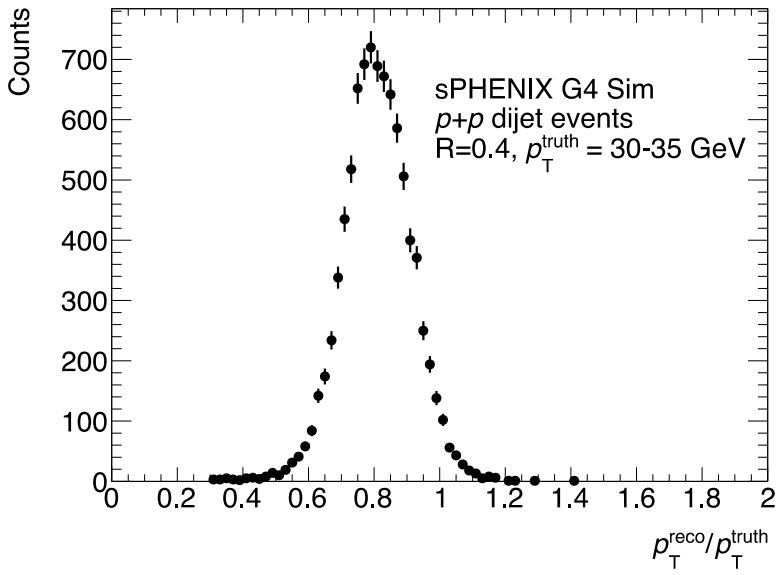

Measured Energy / Truth energy
Truth energy [GeV]
sPHENIX Geant4 Simulation
Single Particles, 0<|η|<0.1, Track-based 5x5 clusterizer
Electron
π⁻
π⁺
Proton

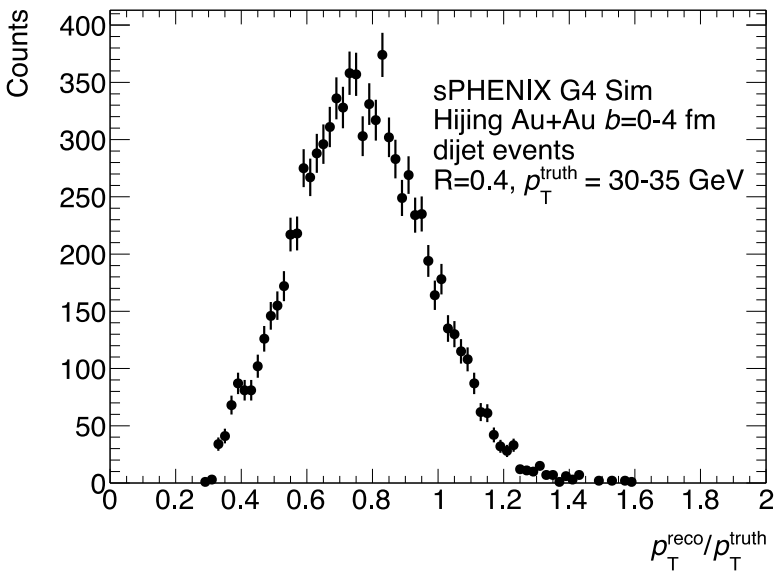

ΔE/<E>
Truth energy [GeV]
sPHENIX Geant4 Simulation
Single Particles, 0<|η|<0.1, Track-based 5x5 clusterizer
Electron 3.8% ⊕ 18.1%/√E
T-1044 Data, π⁻ 13.5% ⊕ 64.9%/√E
π⁻ 10.0% ⊕ 62.2%/√E
π⁺ 9.7% ⊕ 62.4%/√E
Proton 8.0% ⊕ 64.5%/√E

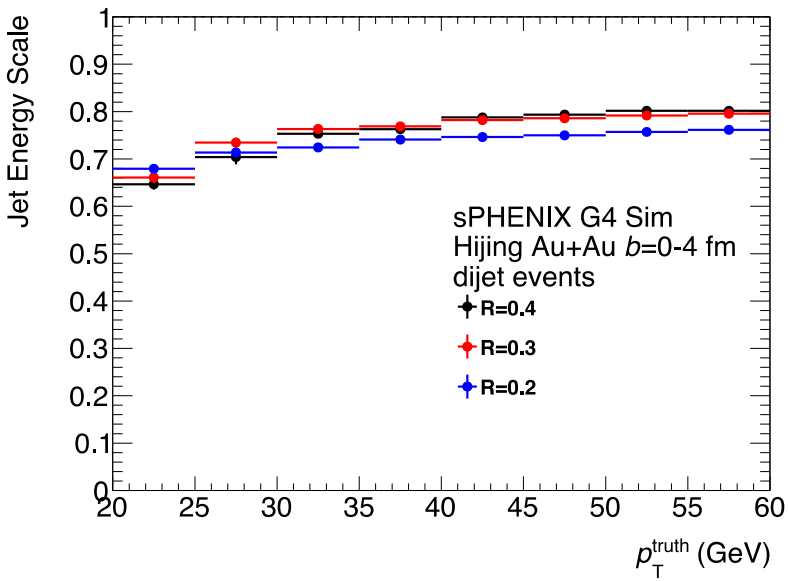

Measured Energy / Truth energy
Truth energy [GeV]
sPHENIX Geant4 Simulation
Single π⁻, Track-based 5x5 clusterizer
0<|eta|<0.1
0.3<|eta|<0.4
0.6<|eta|<0.7
0.9<|eta|<1.0

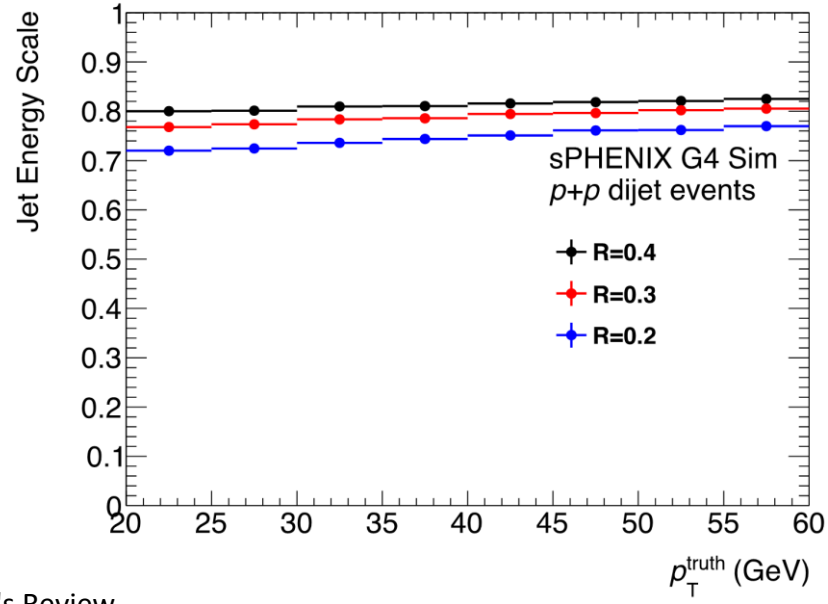

ΔE/<E>
Truth energy [GeV]
sPHENIX Geant4 Simulation
Single π⁻, Track-based 5x5 clusterizer
0<|eta|<0.1 10.0% ⊕ 62.2%/√E
T-1044 (η=0) 13.5% ⊕ 64.9%/√E
0.3<|eta|<0.4 9.4% ⊕ 64.8%/√E
0.6<|eta|<0.7 9.4% ⊕ 65.8%/√E
0.9<|eta|<1.0 9.6% ⊕ 70.4%/√E

Jet energy response and scale

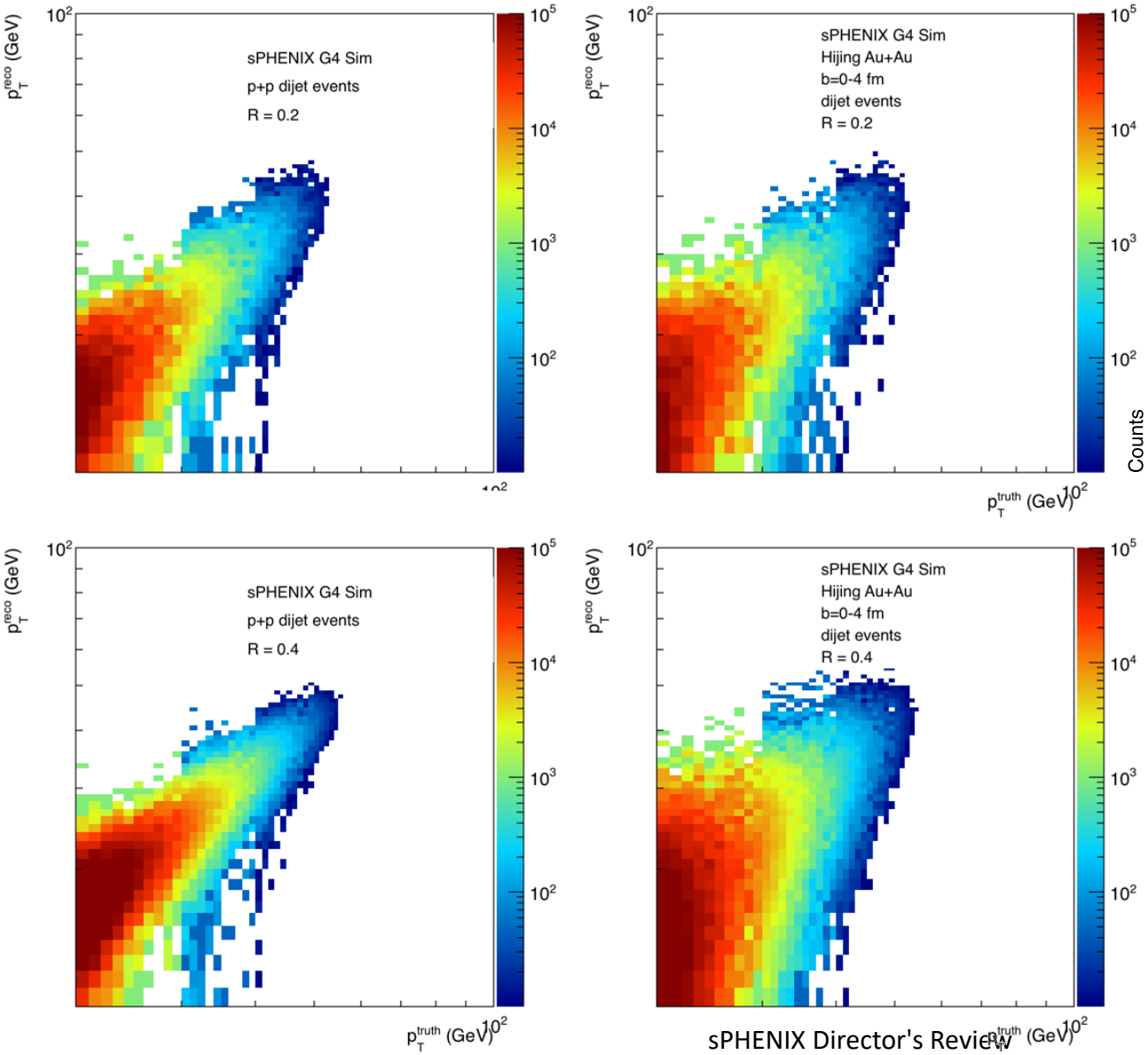


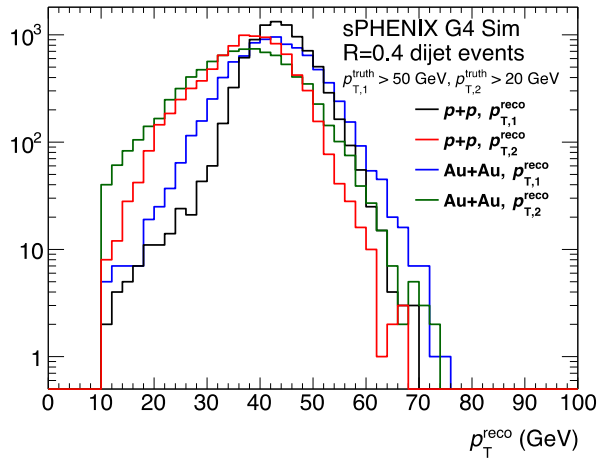






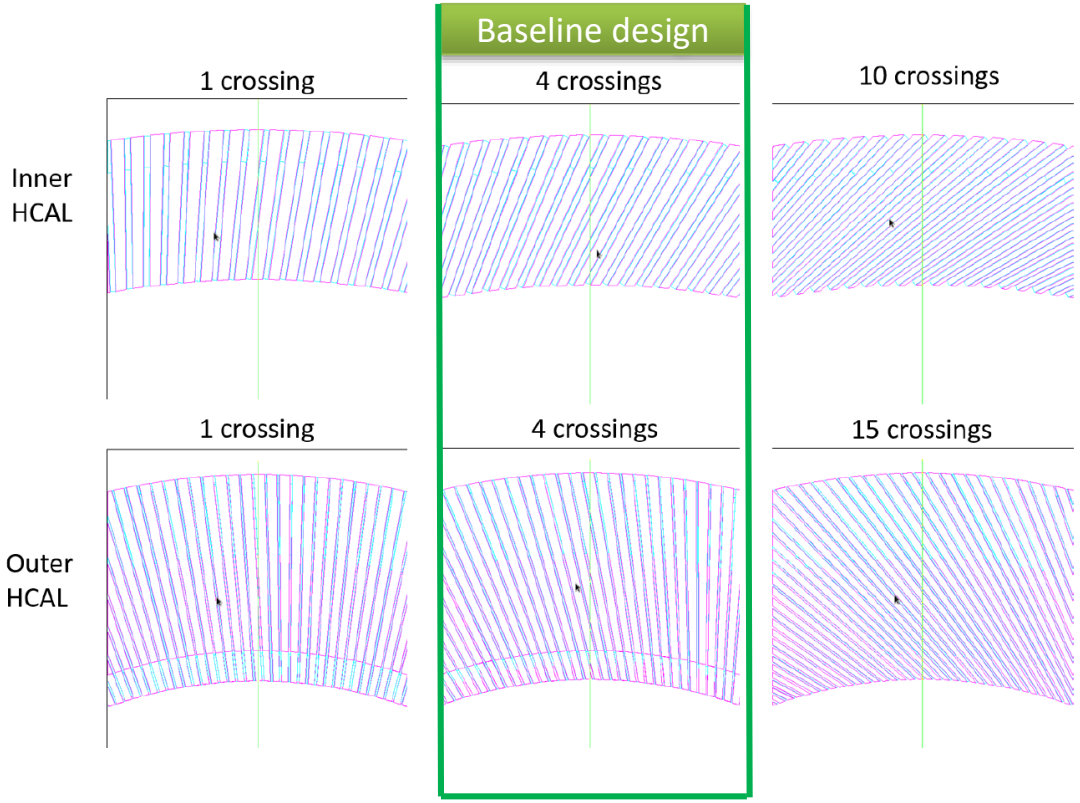
Jet and di-jet response

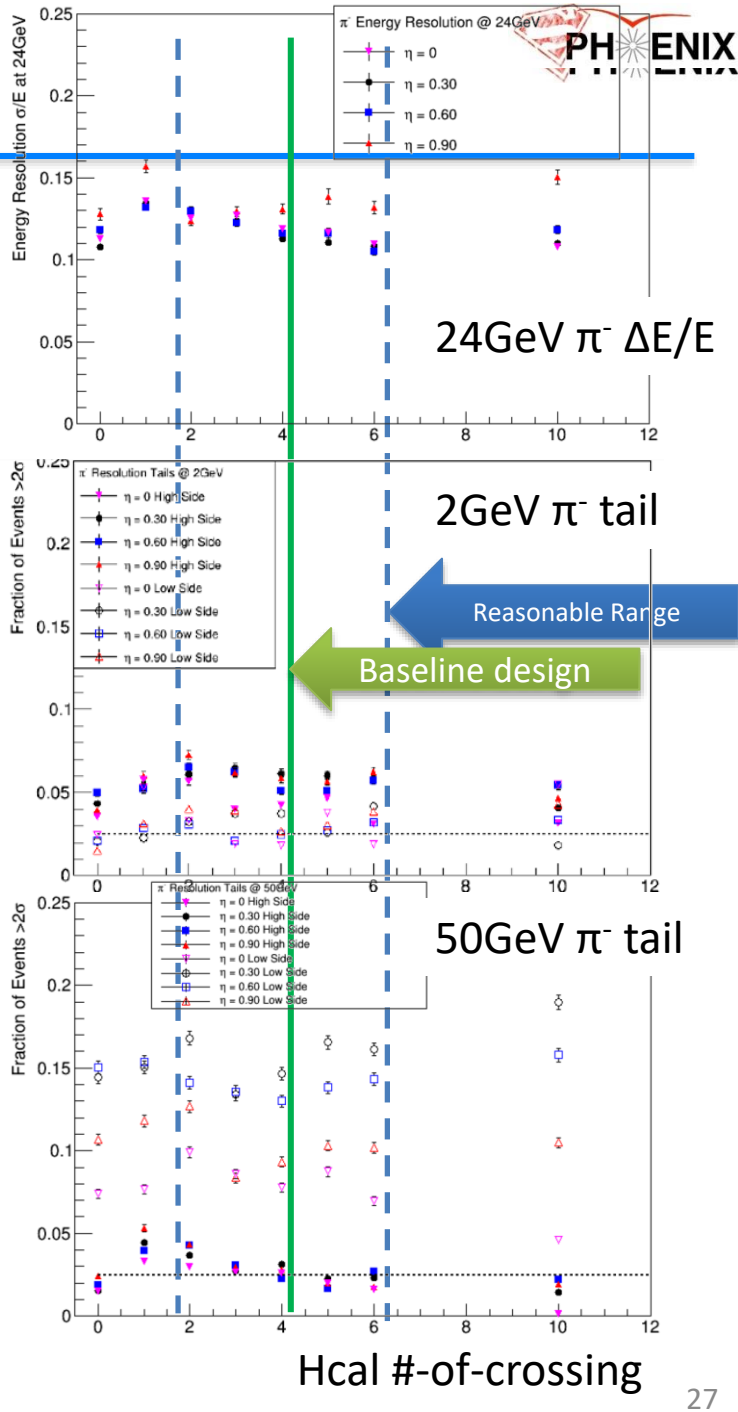




Tilt angle optimization

- Performance not a strong function of tilt angle of Hcal iron plates
- Baseline design (4-crossing tilt angle) is a reasonable choice





Fast simulation for Jets in central Au+Au

- Algorithm developed based on ATLAS and CMS heavy ion experience
- Good efficiency and purity
- Resolution/tails fit for unfolding jet spectrum
- Need to keep updated as detector design/performance evolves