Calorimeter upgrade
~from analysis point of view~

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Sorry, no detail study on a specific detector design. Will be done in the

Quantities to measure by calorimeter

- In any case, we want to measure any
  - Momentum
  - Energy
  - Mass

  of particles.

$$\sigma_0(E) = 1.55 \oplus \frac{5.7}{\sqrt{E}} \quad (mm), \qquad E(GeV)$$

$$\frac{\sigma(E)}{E} = \frac{8.1\%}{\sqrt{E\ (\mathrm{GeV})}} \oplus 2.1\%\ (\mathrm{PbSc}),$$

$$\frac{\sigma(E)}{E} = \frac{5.9\%}{\sqrt{E\ (\mathrm{GeV})}} \oplus 0.8\%\ (\mathrm{PbGl}).$$

$$\sigma_x(E) = \frac{[8.4 \pm 0.3]\mathrm{mm}}{\sqrt{E/\mathrm{GeV}}} \oplus [0.2 \pm 0.1]\mathrm{mm}.$$

- Calorimeter should be able to identify particles and measure their energies
  - Hit Positions of particles are part of the important measurement.
- Can also be complimentary used for momentum measurement
  - Mostly high pT (can not compete with tracking devices at low pT)
  - Another usage: use like a Pad chamber (a component in the track fitting)

Systems and observables

- Au+Au or heavy ions -detail study of QGP using:
  - Jets with various flavor
    - Including high pT identified single particles
  - Penetrating probe (direct photons, electrons)
  - Quarkonium

- d+Au
  - Detail study of nuclear structure and cold nuclear matter effect.
    - Same observables but to extend to forward rapidity region

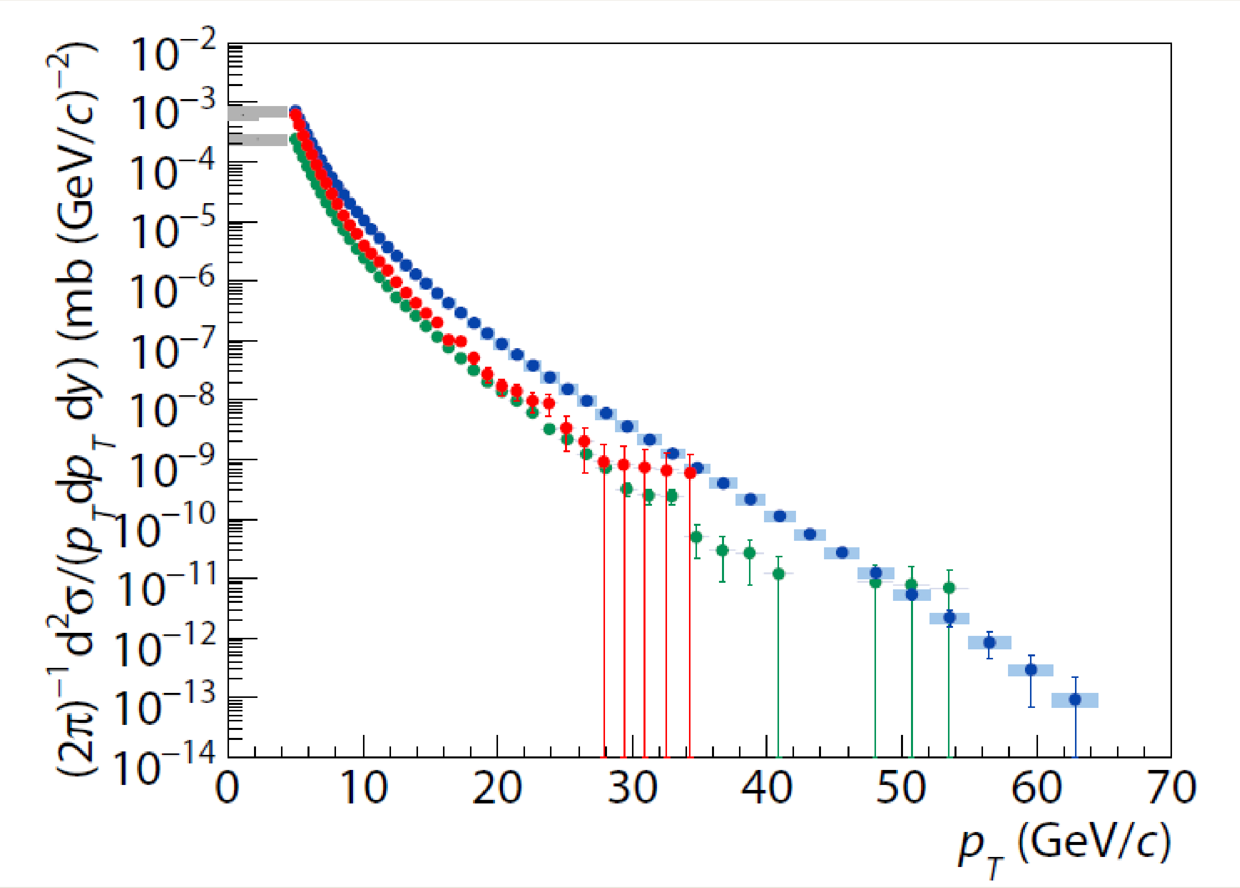
- p+p
  - Baseline for measurement in Au+Au and d+Au
  - Spin physics would like better S/B.
    - Higher PID efficiency and rejection power of particles not in interest.
    - Doesn’t care too much of energy scale.
  - Cleaner background, but sometimes signal is smaller also.

I will take very limited cases

Jets with various flavor (light quark jets)

- Light quark jets
  - Full jet reconstruction
- Systematic errors: ~20%
  - ~15% is coming from energy scale of jets

AN748, Run5 p+p



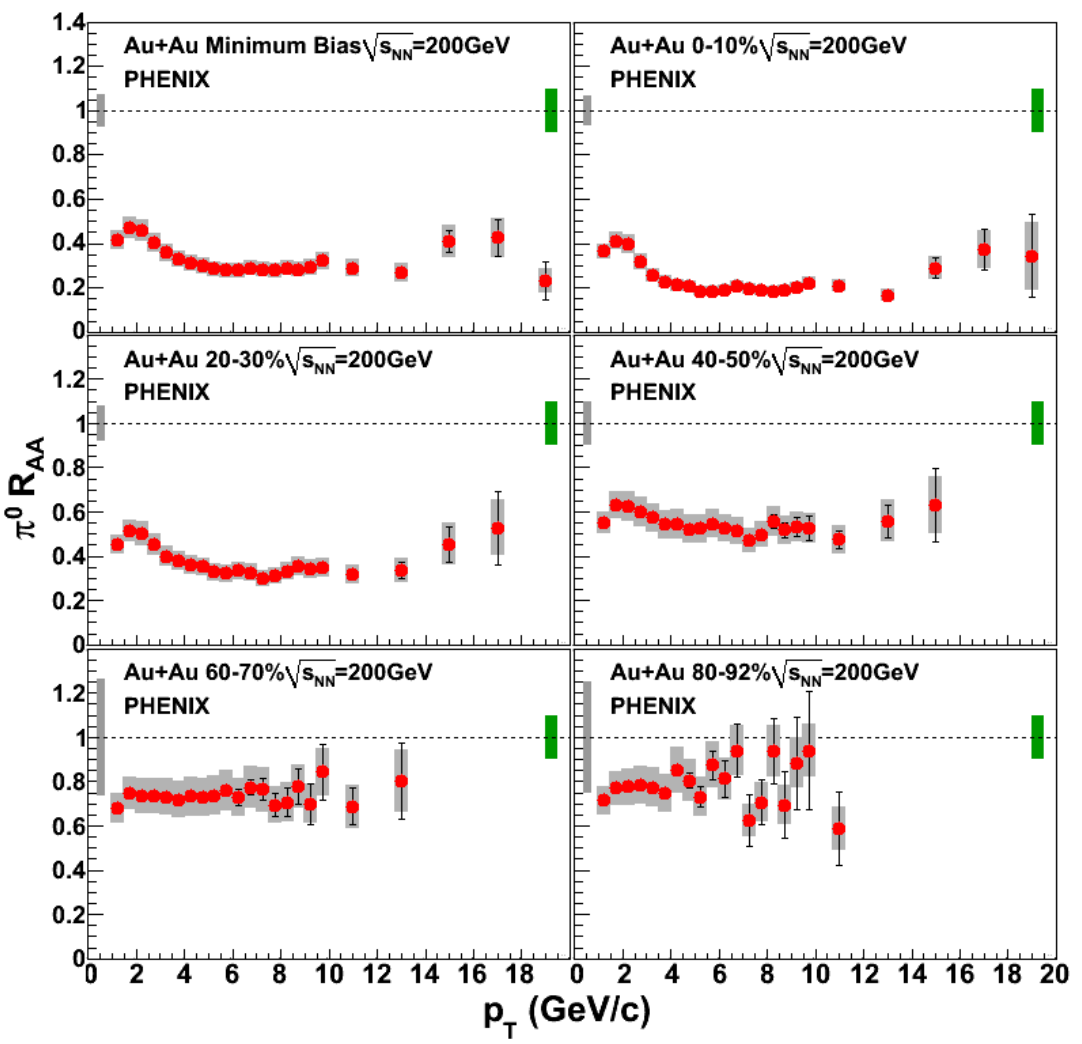
Jets with various flavor (heavy flavor jets)

- To be delivered

Jets with various flavor (single particle)

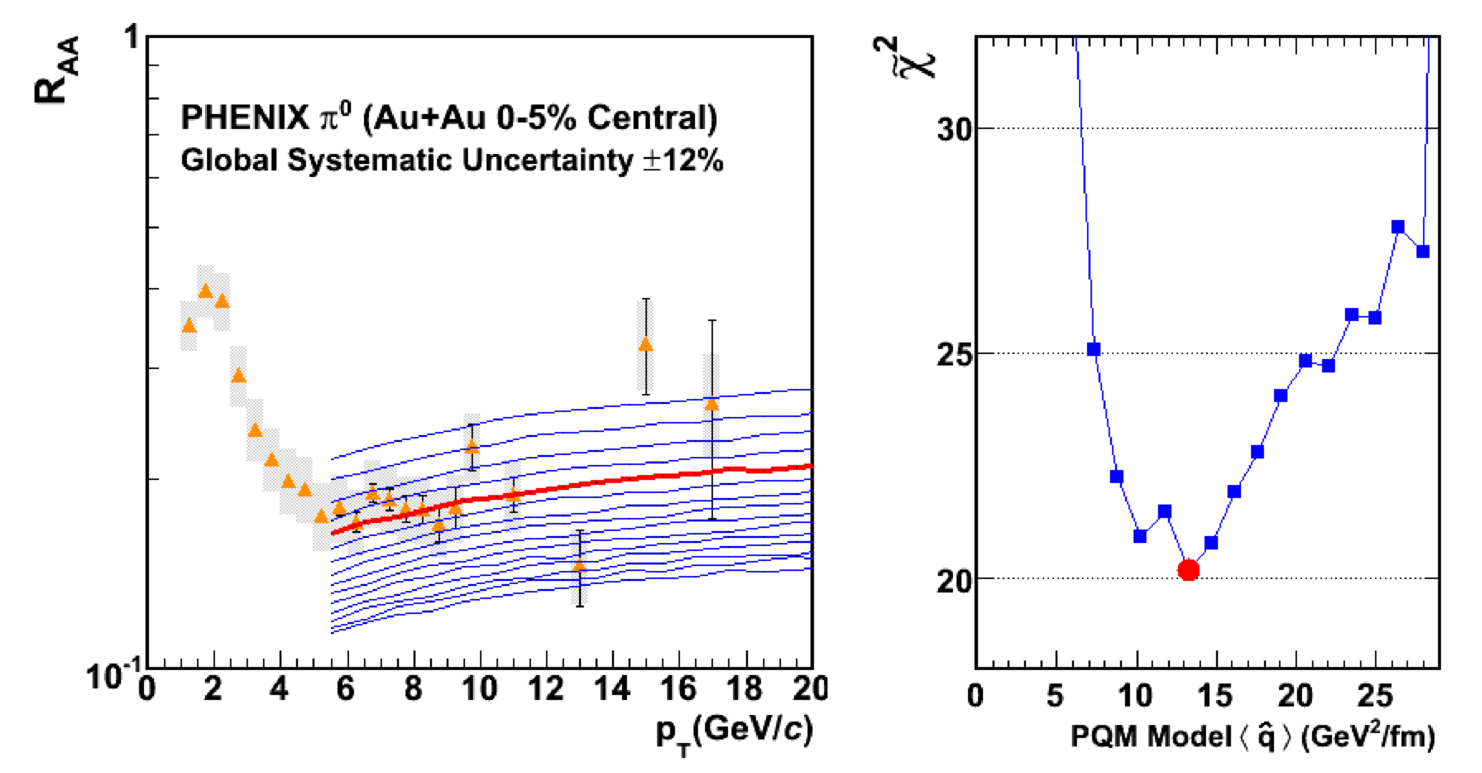
- Became a classic measurement, but still a strong probe
- Single particle measurement up to 20GeV/c
  - Above 10GeV/c, correction for merged two photons from π^0 should be evaluated
- The result exhibited a lot of discussion on energy loss model

Total Systematic error:
~ 9% for low pT
~20% for high pT



More in single particle

- Single high pT particle in precise measurement
- Adding precise higher pT points would increase rejection power to models

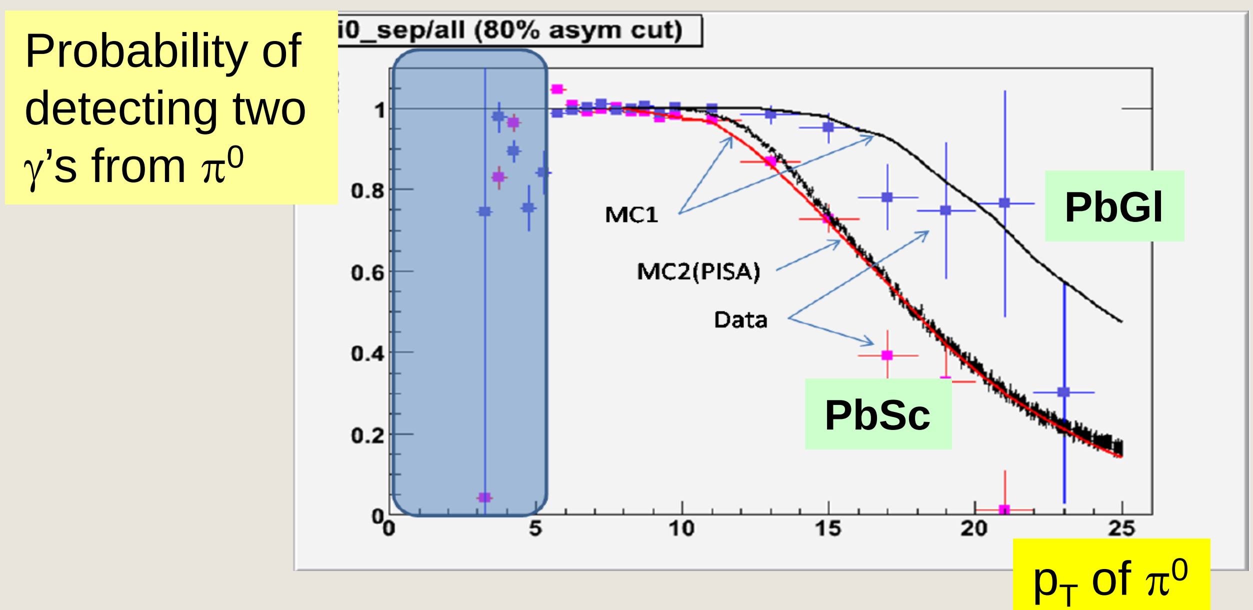


PPG079

What is the merging effect?

- Because of limited granularity of the detector, two γ's from π^0 can not be resolved at very high p_T (γ's merged. mass can not be reconstructed).
  - Opening angle: $\theta \sim$ mass/p_T

- We corrected for the inefficiency due to merging, but also introduced a large systematic error.



How can we offer better data?

- How about **η**? The next lightest meson in the world
  - Pros: p_T reach will be extended by $M\eta/M\pi$=~4, because of a larger opening angle.
  - Cons: one has to assume that η is produced from light quark or ssbar is suppressed the same amount as light quarks.

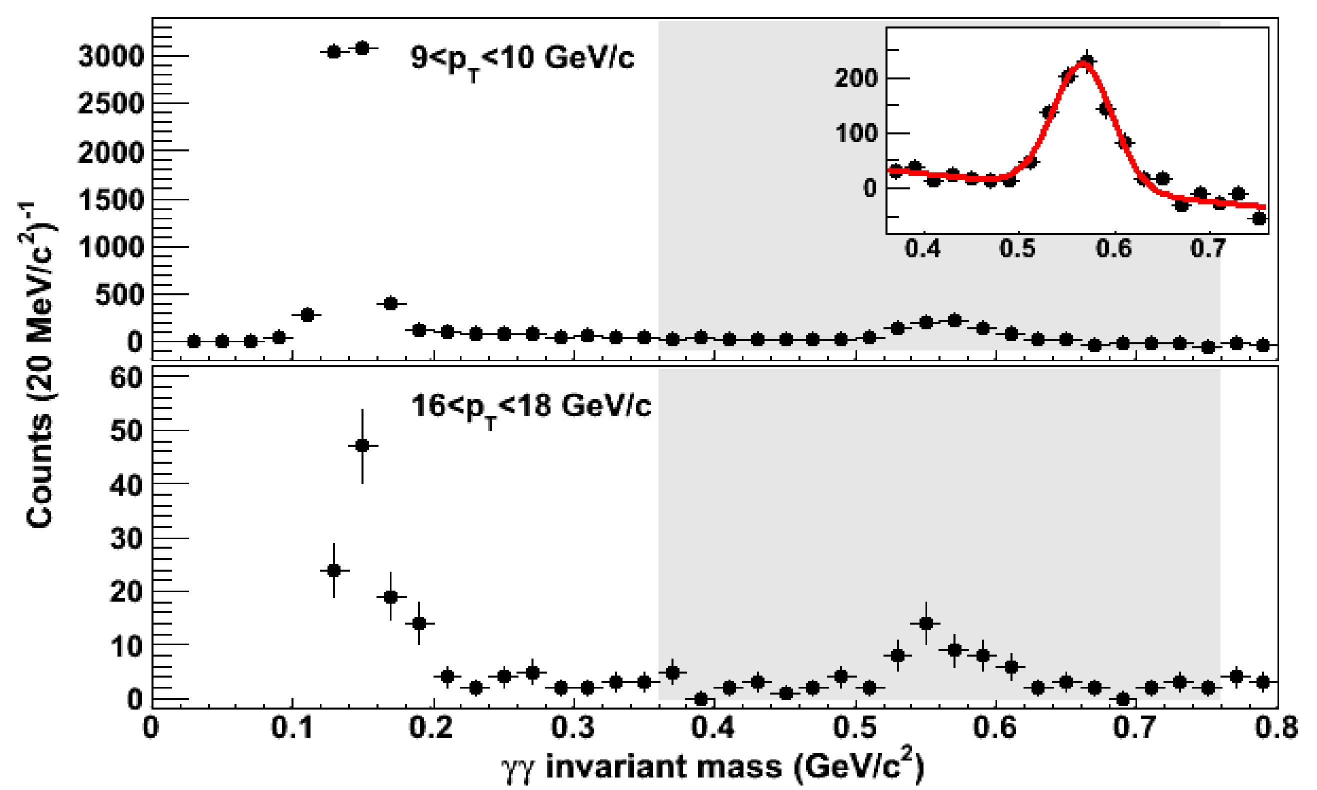
- Name: π^0
- Mass: 0.1350MeV/c^2
- $\Gamma(\pi \rightarrow \gamma\gamma)/ \Gamma(\pi \rightarrow X)$: 0.988
- Wave function:
  - (uubar-ddbar)/√2

- Name: η
- Mass: 0.5479 MeV/c^2
- $\Gamma(\eta \rightarrow \gamma\gamma)/ \Gamma(\eta \rightarrow X)$: 0.393
- Wave function:
  - (uubar+ddbar)/2+ssbar/√2

η/π^0 = ~0.5 (measured at high pT)

Invariant mass distributions

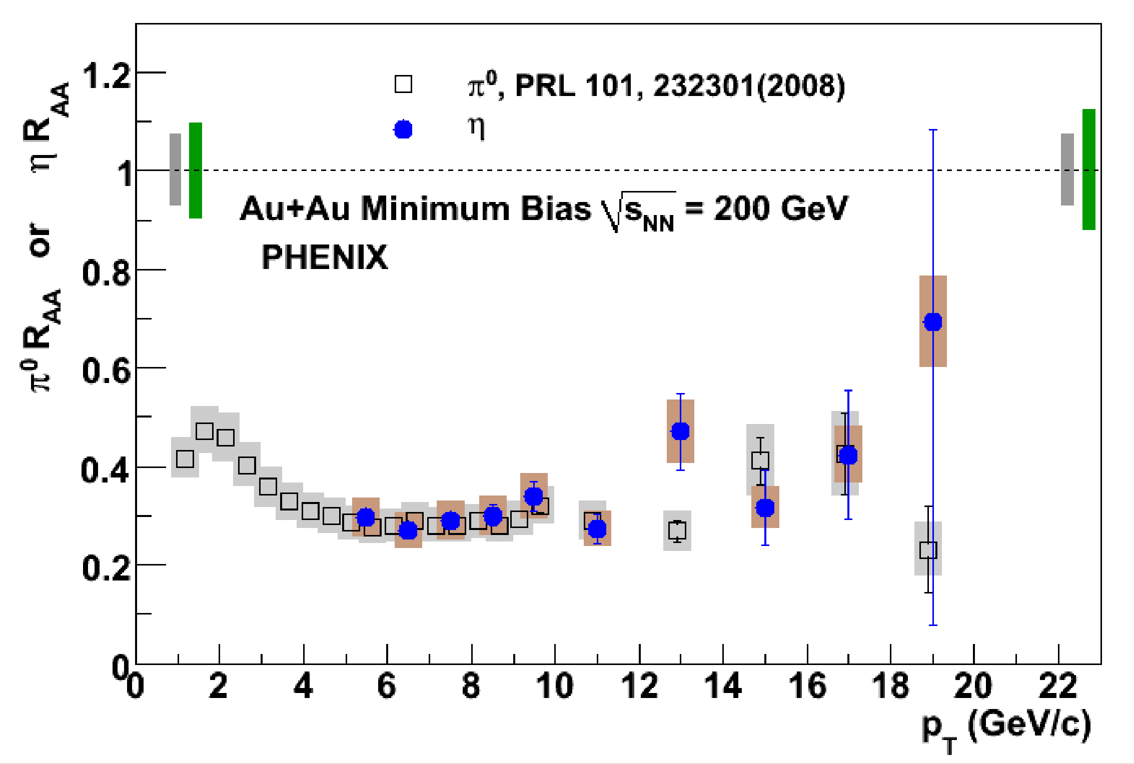
- Successfully reconstructed π^0 and η in RHIC Year-7 Au+Au
  - 3.9B events (80% of recorded events), PbSc EMCal only.
- we can see that reconstructed η to π^0 ratio increases as a function of p_T
- Number of reconstructed π^0 is decreased



π^0 and η R_{AA} in single panel

- We could use eta as an alternative probe for high pT, but obviously, π^0 has much more statistics in the beginning. It would be nice to keep an idea of measuring π^0 up to very high pT.
  - Energy resolution, better **position** resolution (and granularity)
- This would give a direction of calorimeter performance determination

Total Systematic error:
~ 11% for η
(pT independent).



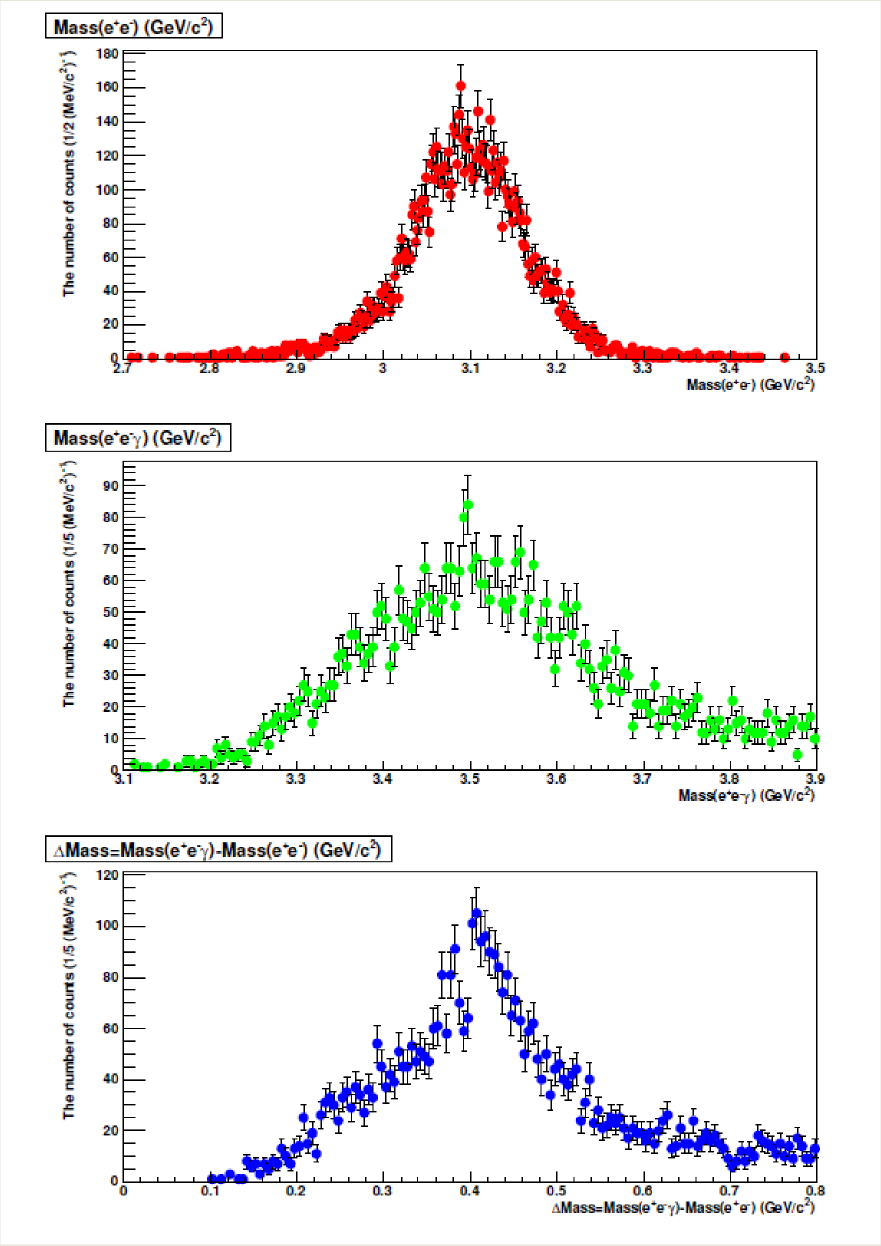
Quarkonium?

- J/ψ, ϕ
  - momentum is reconstructed using trackings
  - EMCal used for complementary identification of electrons

- If you go very high pT, one can measure momentum with calorimeter?

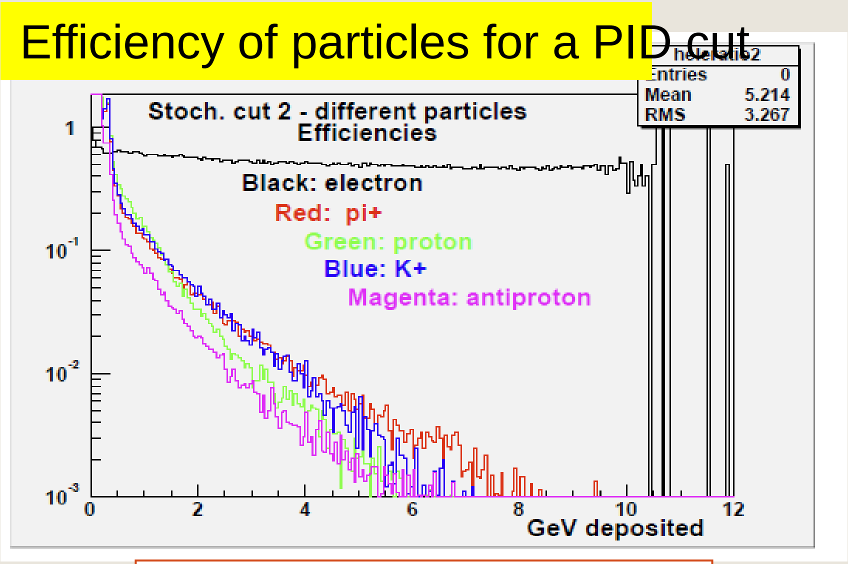
- χ_c measurement uses energy information of EMCal

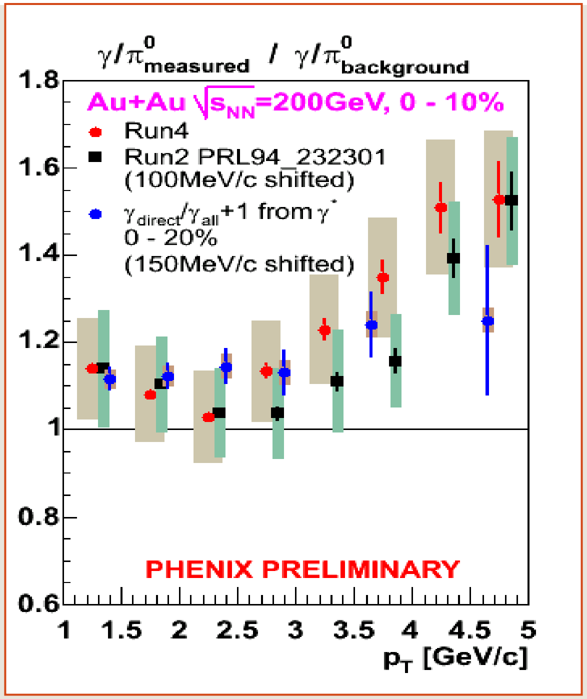
AN632, Run5/6 p+p χ_c measurement
13% sys error due to error on photon energy measurement in EMCal



Direct photons (real photons, 1)

- Low pT
  - Good photon PID power is strongly desired in addition
- No idea at this moment how to reject hadrons (charged and neutral), except for charge VETO and sophisticated shower shape cut.
  - And timing cut..
- Good photon ID (or hadron ID) would be important for inclusive jet measurement
  - Fragmentation function, etc.

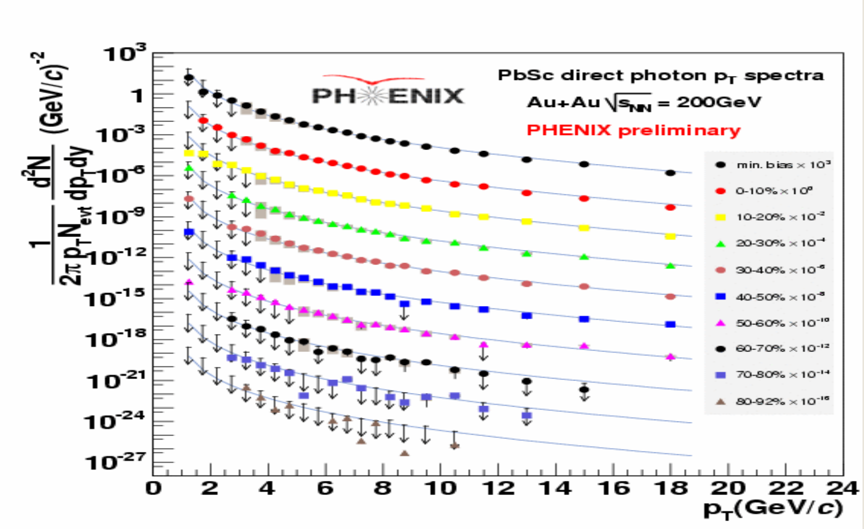


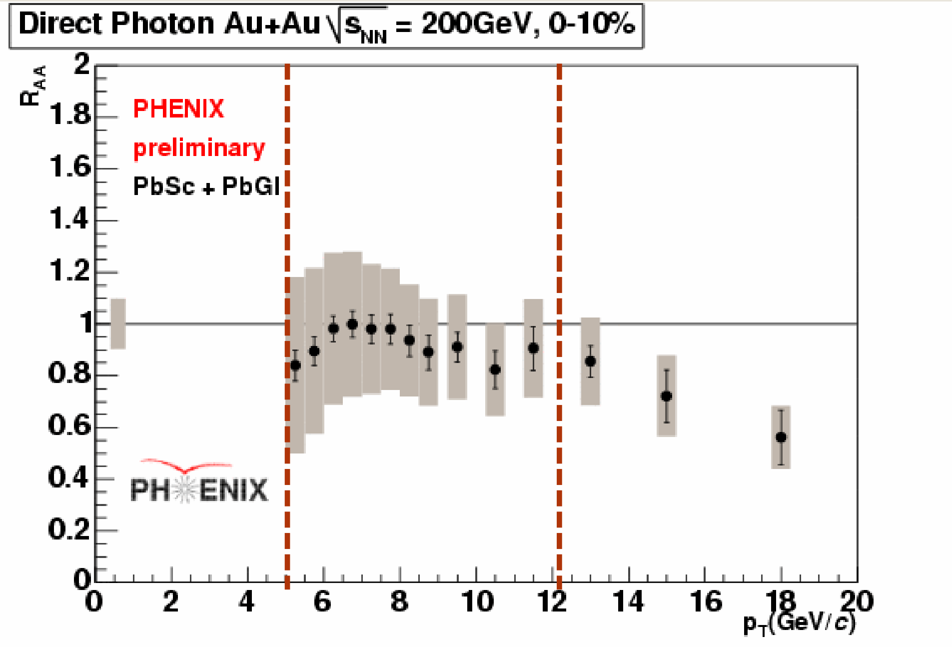


Direct photons (real photons, 2)

- High pT
  - In principle, hadron free
  - Has to fight against merged clusters
    - Should efficiently identify clusters contributed by “single photon”, not from “merged photon” from π^0
- On-going analysis (Run4 Au+Au photons)
  - Trying to subtract merged clusters, estimated by PISA simulation

<u>Better position resolution helps</u>





Key performance parameters (I)

- Energy scale
  - Hope to be accurate at the level of ~ 0.1%
    - In power-law spectra f = A/pT^n, where n=8, 1% off-scale produces 8% yield error

- Energy resolution
  - Accuracy of the energy scale is somewhat relying on the energy resolution
    - How can we set the right energy scale at the level of 0.1%, given the energy resolution is 15%.
    - In order to get 0.1% accuracy under the energy resolution of 15%, we need counts of N = (15/0.1)^2 = 22.5K counts.
      - Sounds small statistics, but need this count for pT>2GeV, each sector or tower, each run, etc.

Key performance parameters (II)

- Position resolution
  - Resolution power of adjacent particles would relate how high in pT we can measure hadrons decaying into two or more particles
    - Current PbSc: π^0 cleanly identified up to 12GeV/c, η to 50GeV/c

- PID power
  - Not necessary for particles decaying into multi particles
  - Better PID would reduce combinatorial background, therefore increase S/B

- Irreducible background
  - Even PID is perfect, the amount of combinatorial background would be constrained by several physical and non-physical reason
    - Conversion of photons, Dalitz decays. Or, the signal itself is two small in our acceptance, e.g., eta-prime is hardly seen in two-photon decay mode.
  - Acceptance or material budget issue. Has to be taken into

My thought on performance determination

- Single particle measurement is a key element of complicated, sophisticated, advanced measurement.

- If we look at the precision of single particle measurement, we would see what the ideal performance is required to the detector.