The Physics of TOF-West

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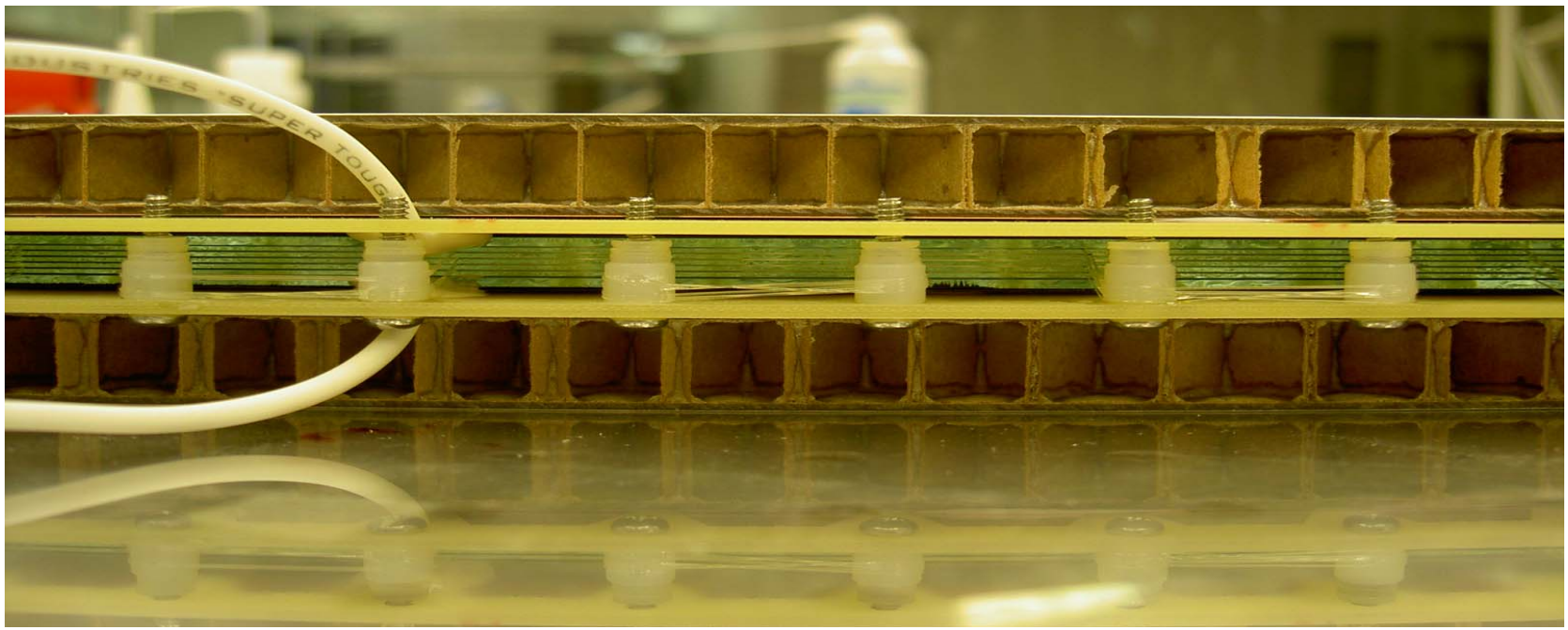
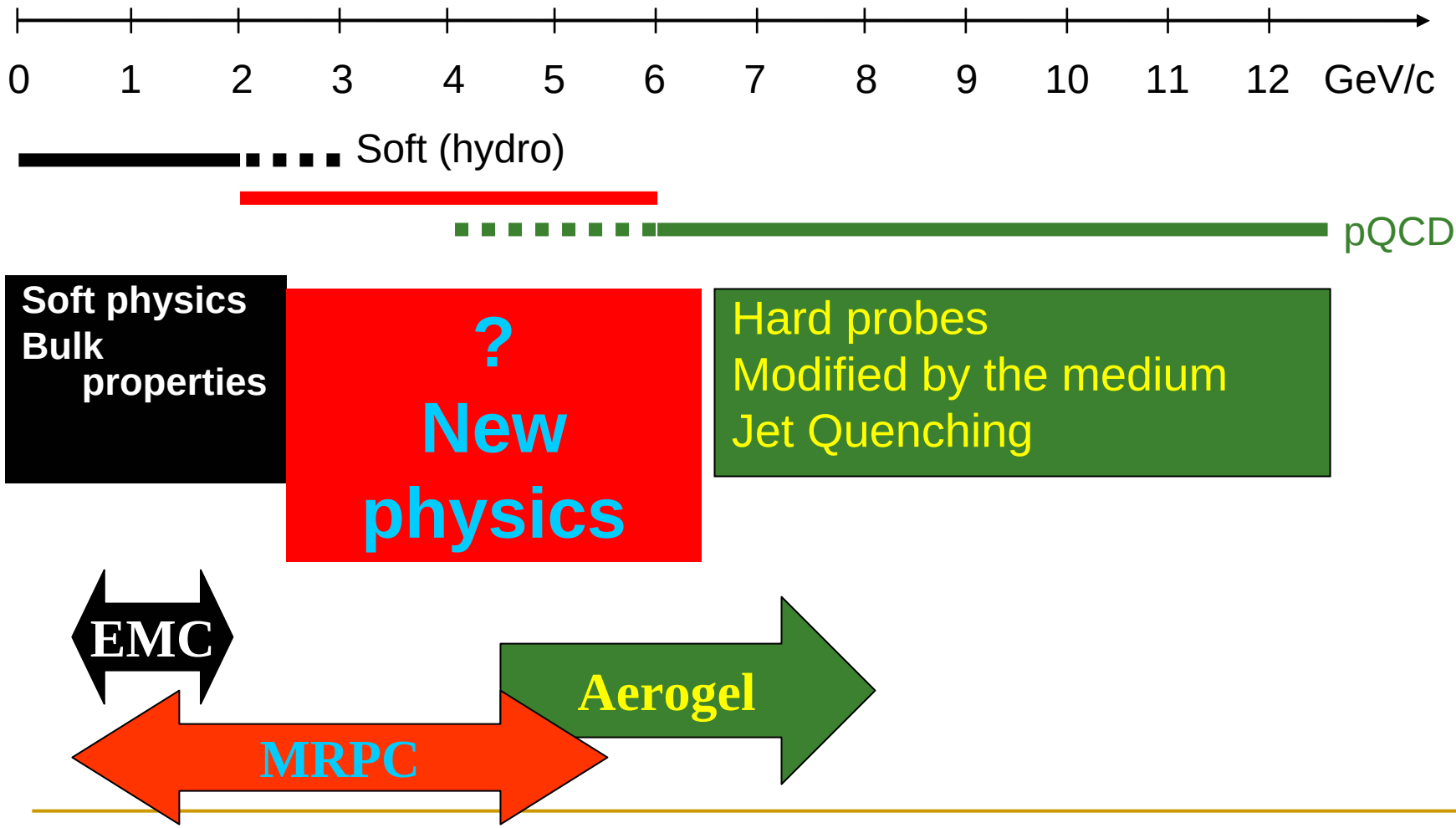


Physics Motivation

" The **large (anti)baryon to pion excess** relative to expectations from parton fragmentation functions remains **the most striking unpredicted experimental observation at RHIC**. The data clearly indicates that **a new mechanism** other than universal parton fragmentation is the dominant source of baryons and anti-baryons in the intermediate p_T range in heavy ion collisions. "

Conclusions : PHENIX white paper (+ p.34-42 devoted to hadron formation)

Particle production at RHIC



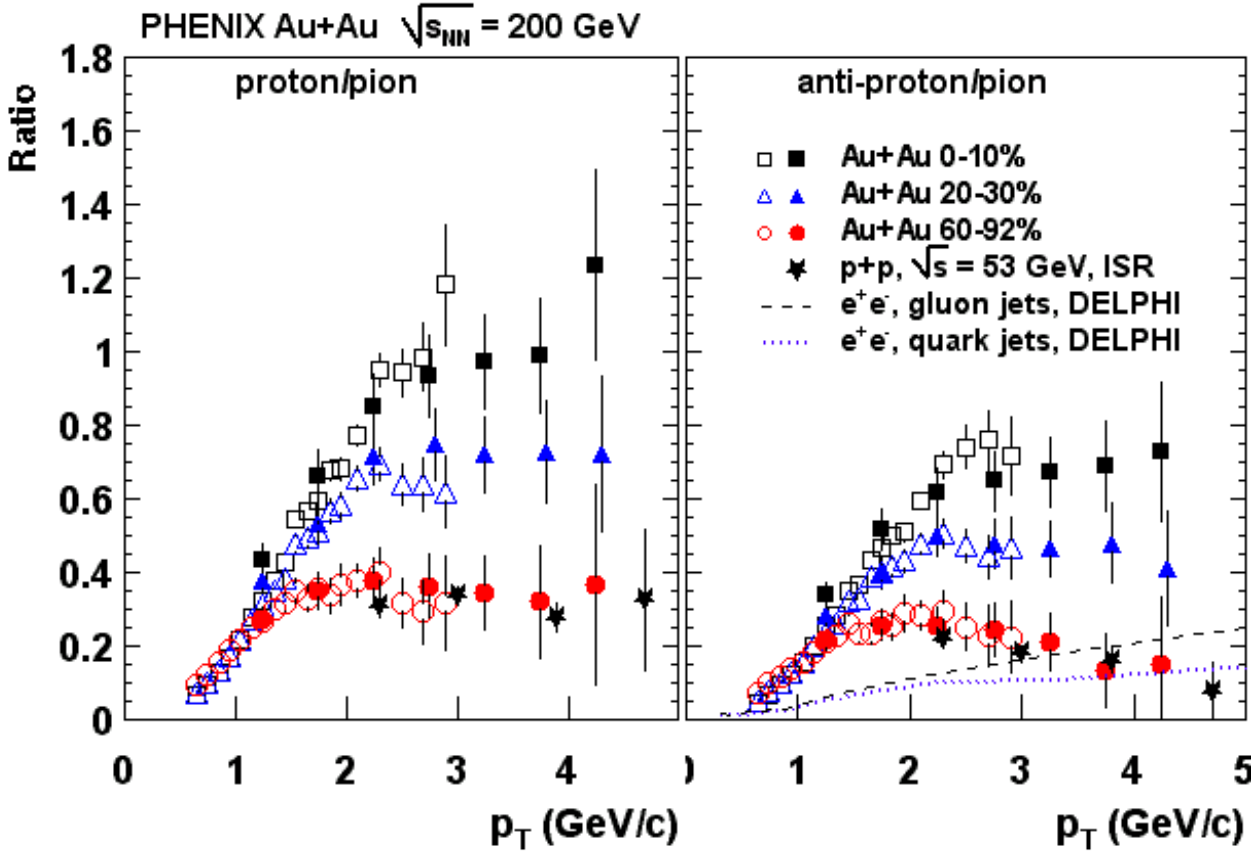
Outline

- Go through the (now old) results that motivated the construction of TOF.W
- What do TOF.W + ACC add to those (and why do we need both)
  - Single particle measurements: π,K,p,Λ,ϕ
  - 2-particle correlations

The interesting physics in brief : at the time we started building TOF.West

Large!!! baryon/meson ratios

Phys. Rev. Lett 91, 172301 (2003).

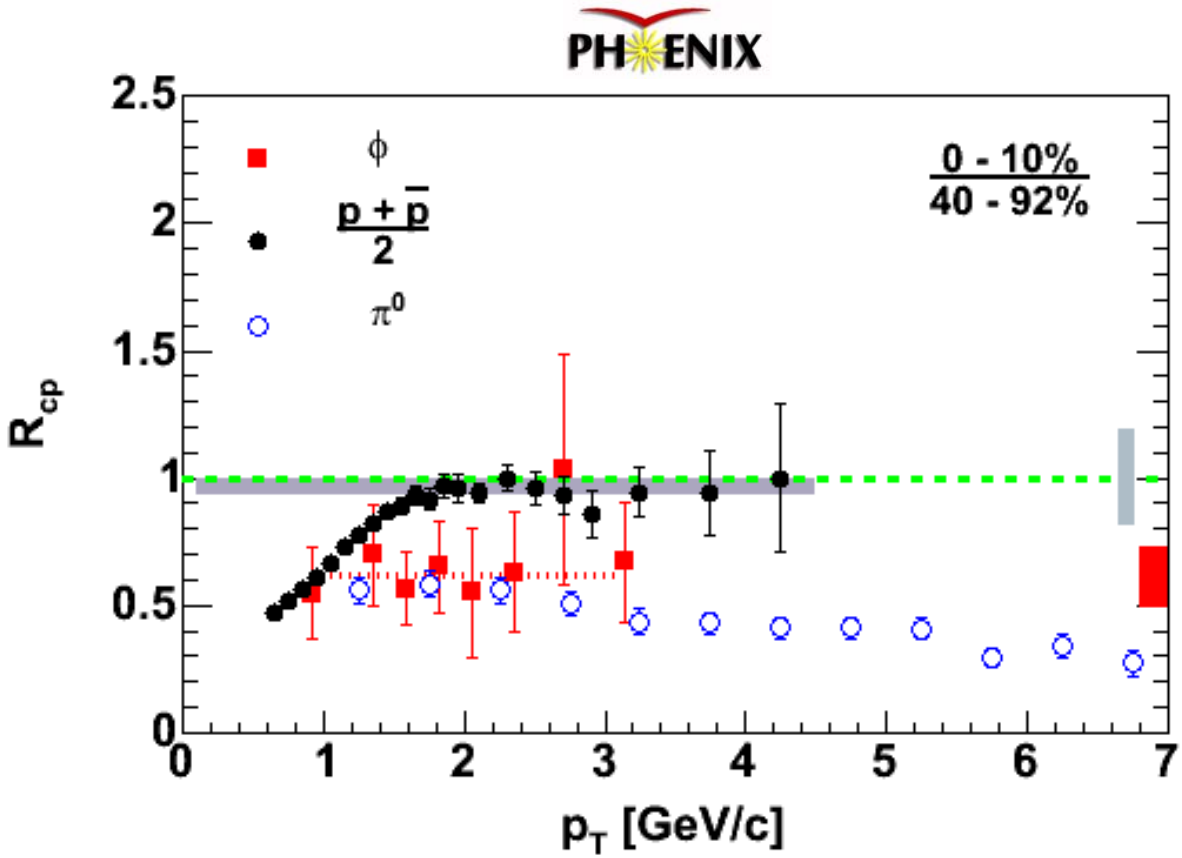


Peripheral: consistent with standard fragmentation

Central: a factor ~ 3 higher than peripheral, e^+e^- and ISR pp data

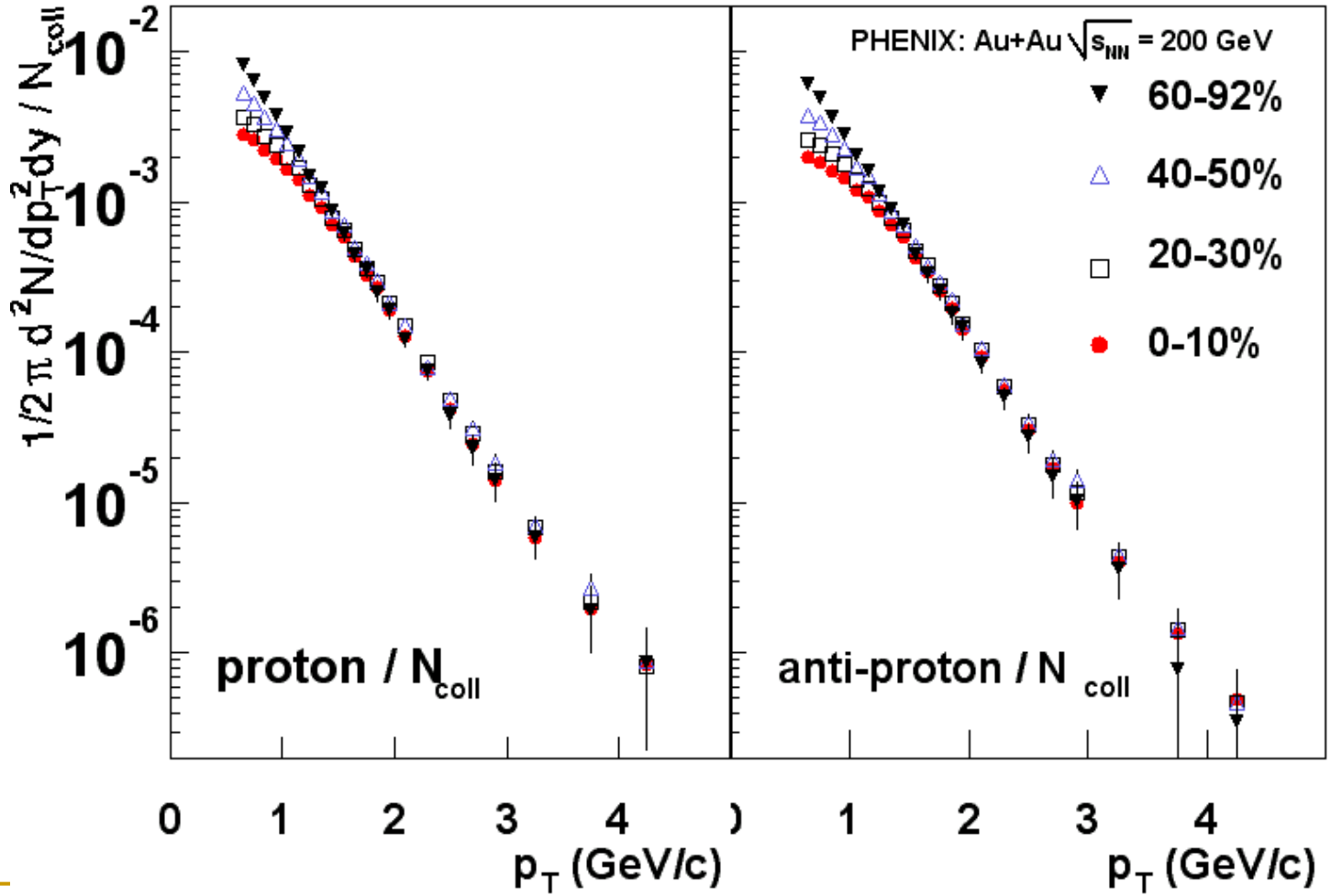
p and pbar at p_T 2-5 GeV/c : SOFT OR HARD ?

R_{cp} of p,π,ϕ

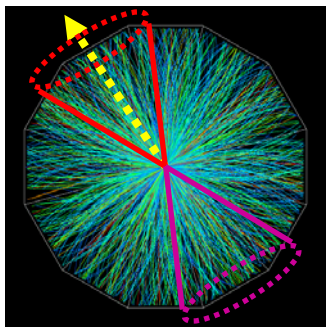


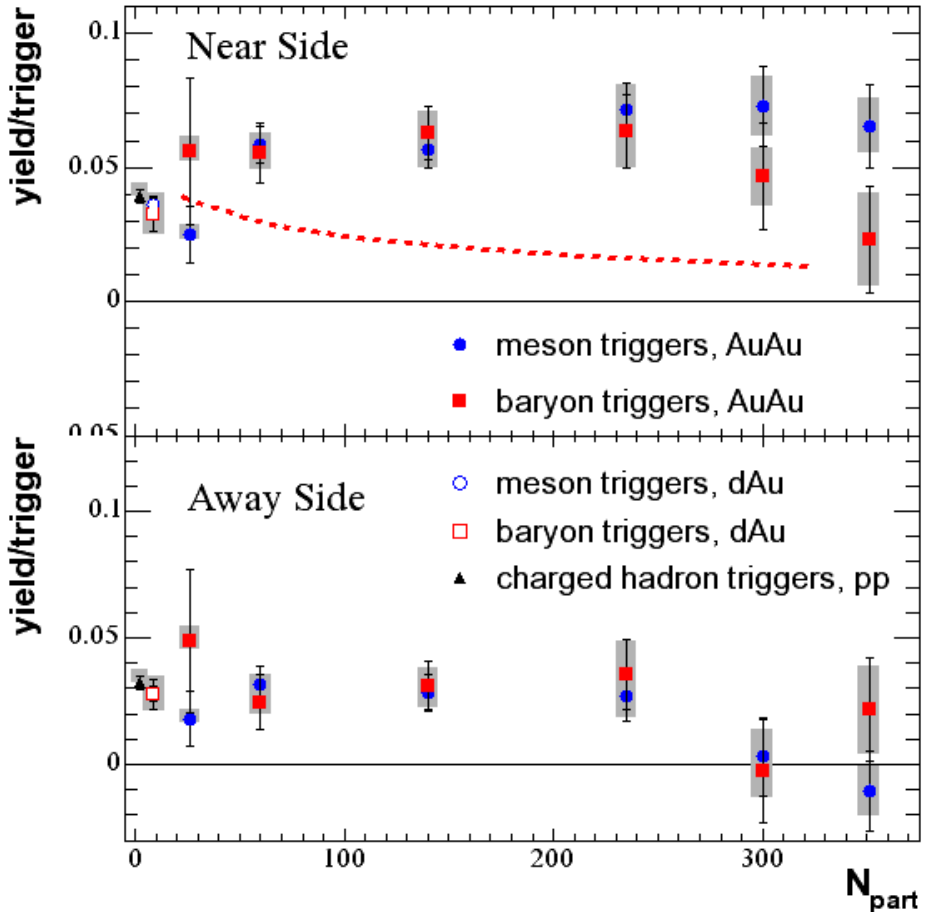
- **Φ mesons are heavy, but follow π^0, not p+pbar!**
- **Indicates the absence of suppression of proton at intermediate p_T is not a mass effect.**

(Anti)Protons scale with N_{coll} for all centralities. A coincidence ?



Jet correlations with identified mesons and baryons





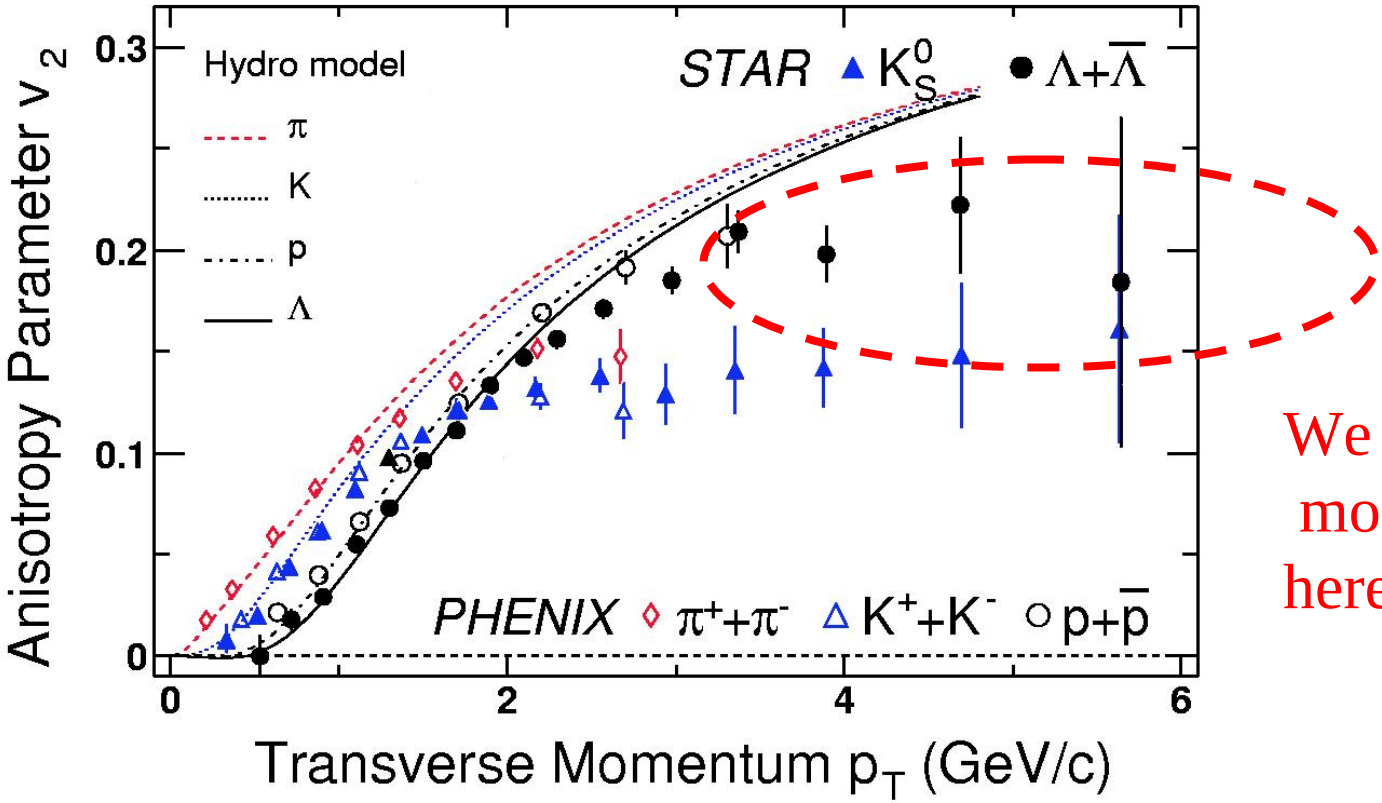
- jet partner equally likely for trigger baryons & mesons
- ▪▪▪ expected from purely thermal recombination (nucl-th/0306027)

A. Sickles

Need partons from jets to explain the data!!

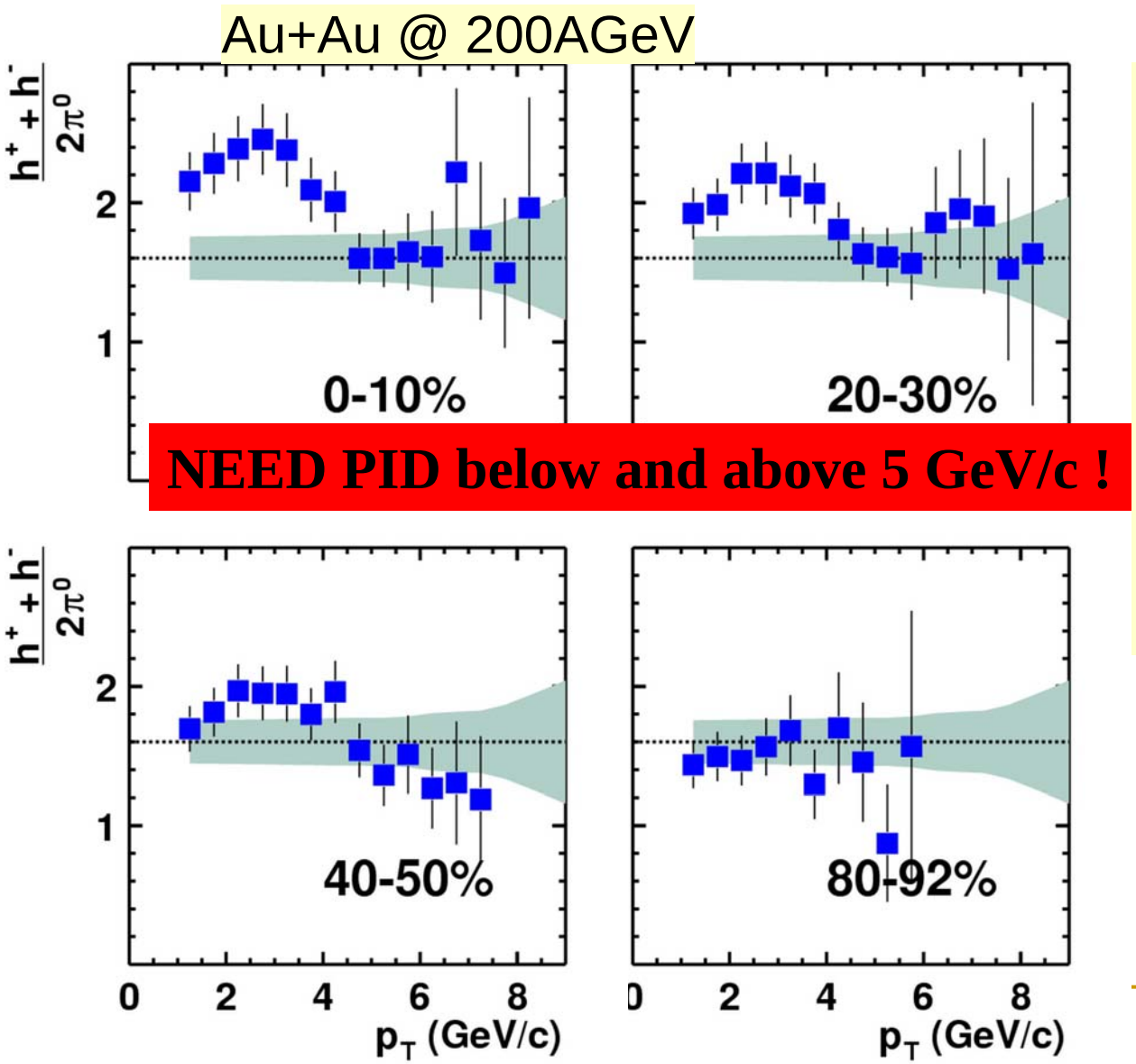
High-pt PID in both arms will improve this measurement

V2 with identified particles



We want to add more particles here and beyond

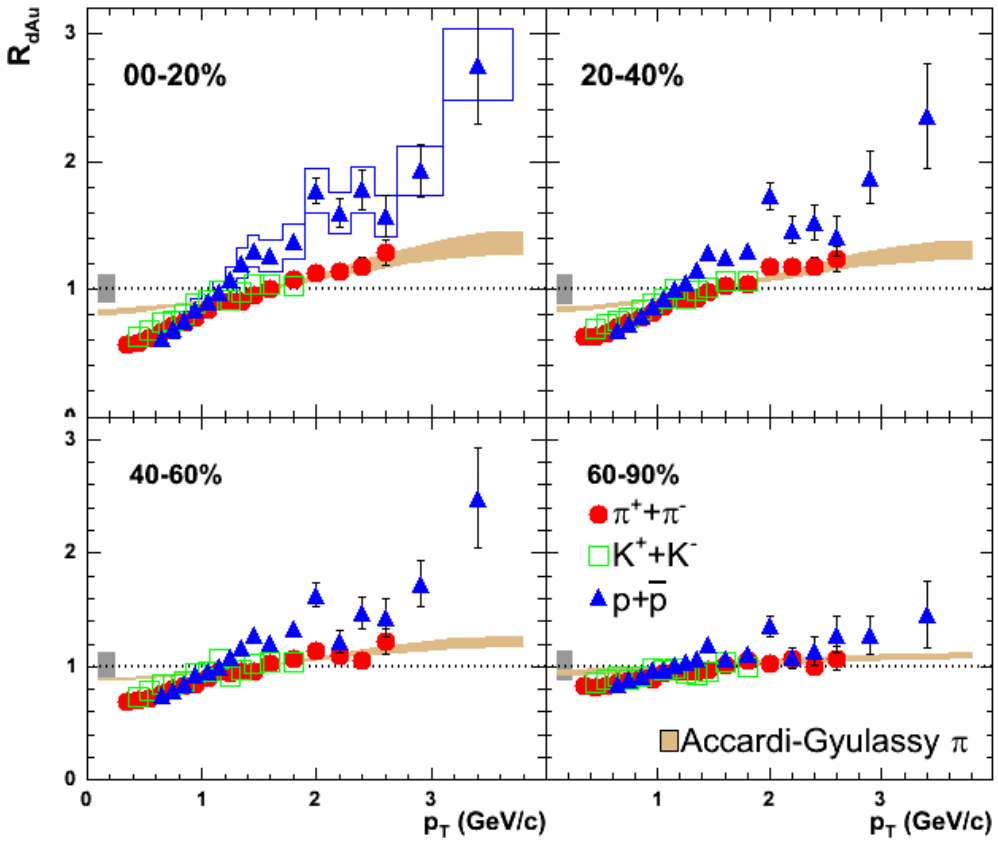
Transition region is ~ 5 GeV/c?: h/π ratios



Expectation (pp, e^+e^-):
h/π ≈ 1.6

Above 5 GeV/c and in peripheral collisions: recover standard fragmentation

Baryon/meson differences seen in dAu collisions as well

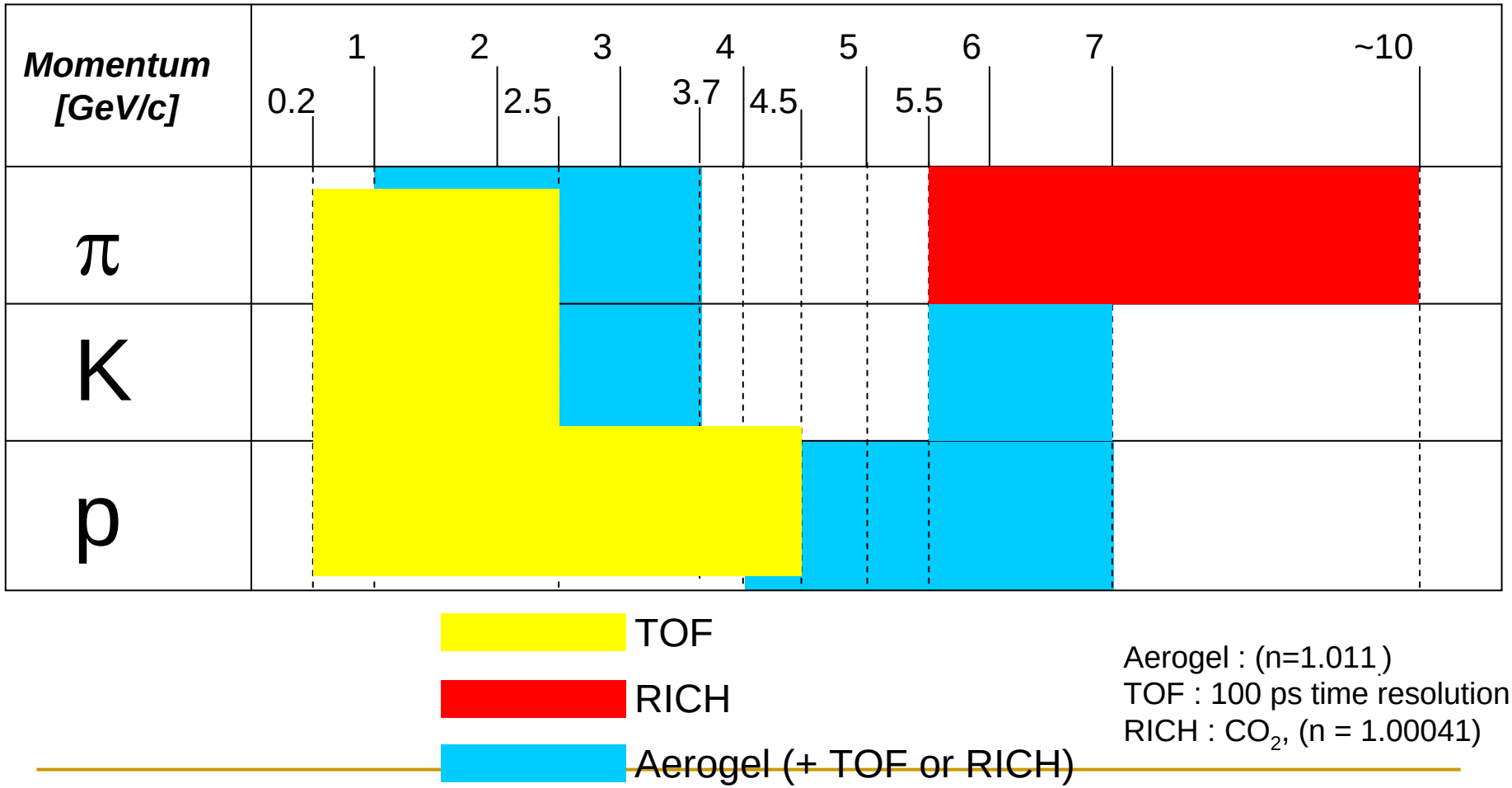


ppg030

- Generally unknown why protons show stronger Cronin enhancement.
- Rudy Hwa: "part of the Cronin enhancement is due to the final state – explained by recombination"
- NEED ~ 10 % measurements in the region $2 < p_T < 8$ GeV/c

The high-pt detector with TOF.W

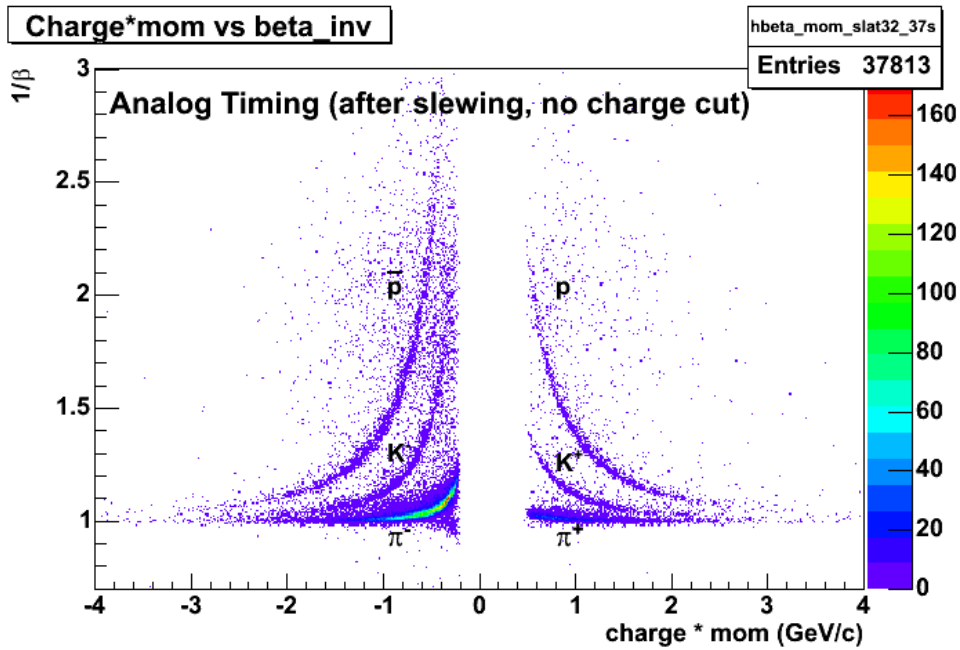
slide stolen from Satoshi Takagi; Modified the order of PID boxes appearance



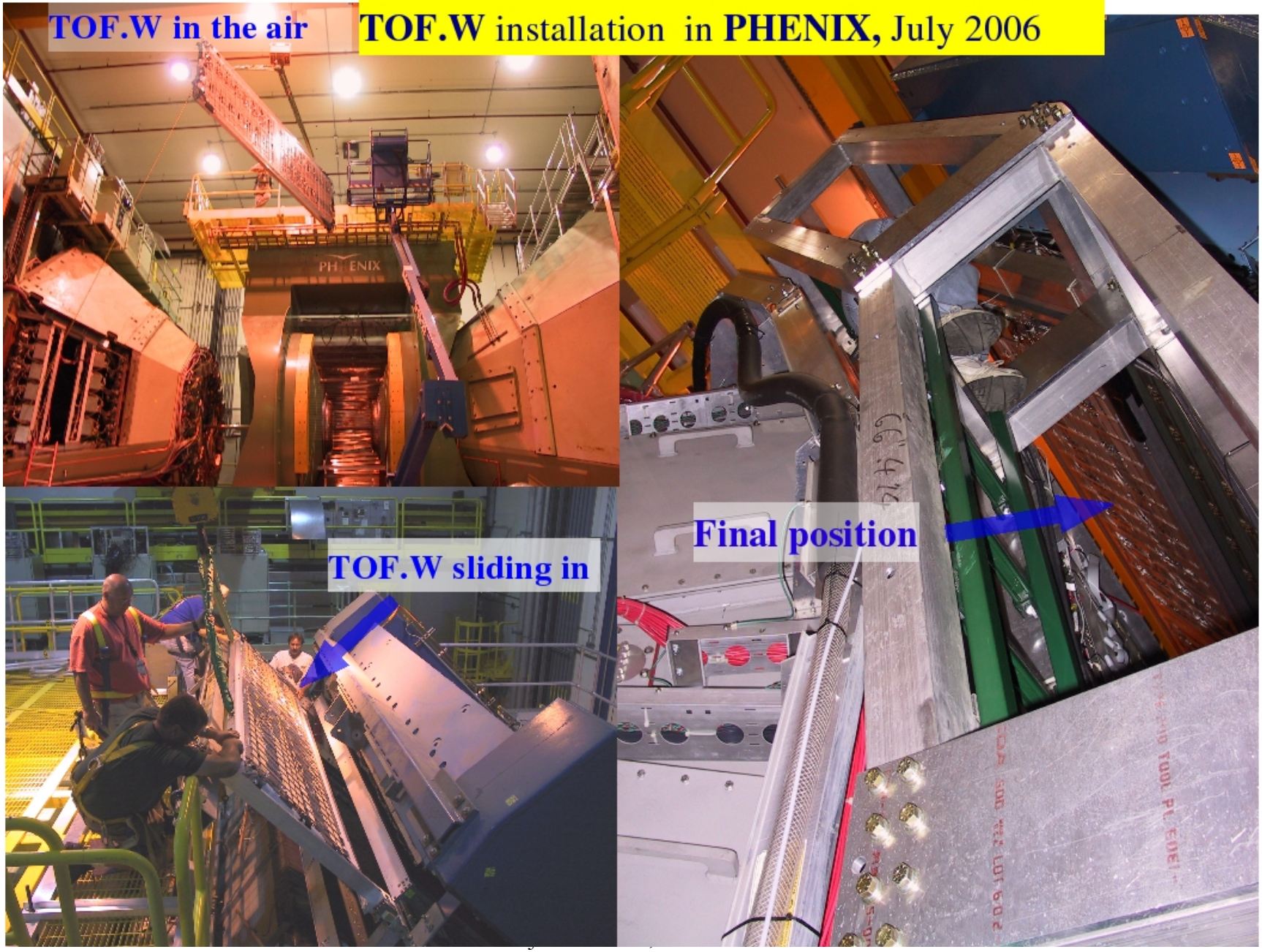
Aerogel : (n=1.011)
TOF : 100 ps time resolution
RICH : CO_2, (n = 1.00041)

TOF.W specifications

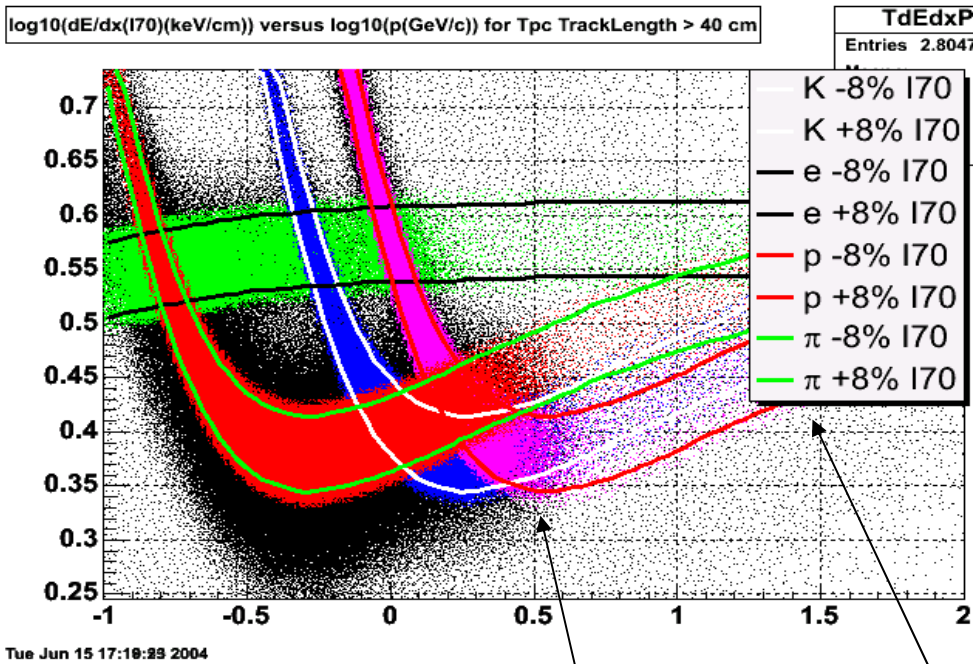
- System requirements:
  - Resolution $\sigma \sim 100$ ps
  - Efficiency ~ 95 %
  - Occupancy < 10 %
  - Minimize the total cost - → MRPC is cheap compared to scintillator+phototubes
- Run5 prototype results achieved these goals

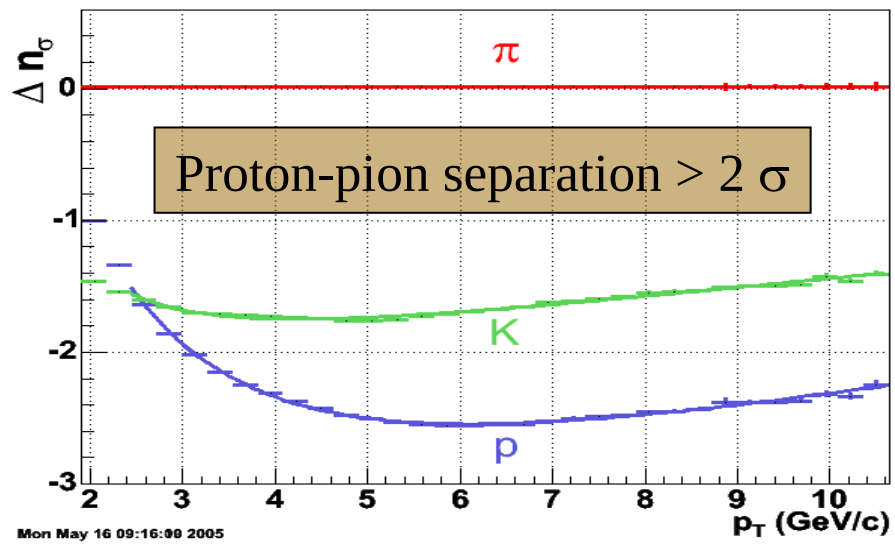


TOF.W installation in PHENIX, July 2006



While we were building TOF.W … the competition (STAR) was also working on extending PID for protons: TPC PID

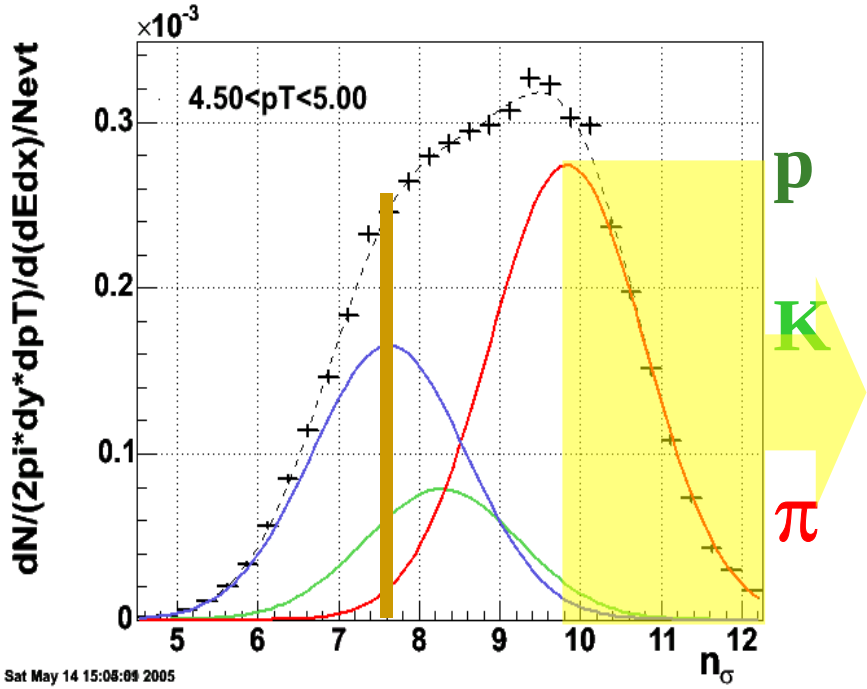


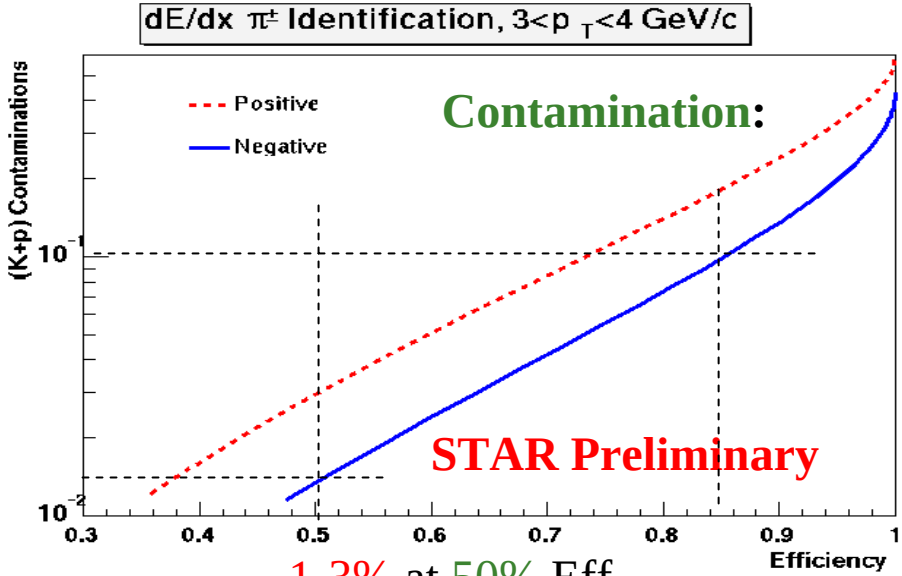


1.6 GeV/c

5 GeV/c

Example of STAR PID:





1-3% at 50% Eff ,

10% at 70-90% Eff

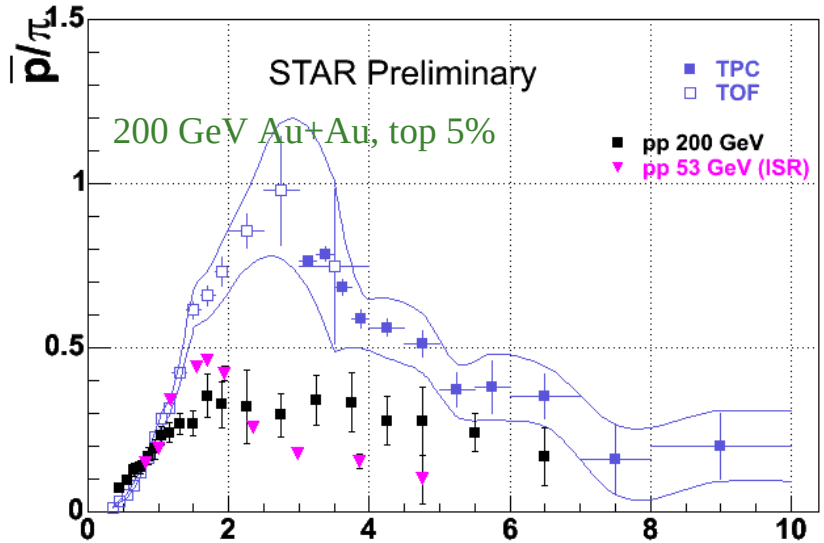
Two Counting methods:

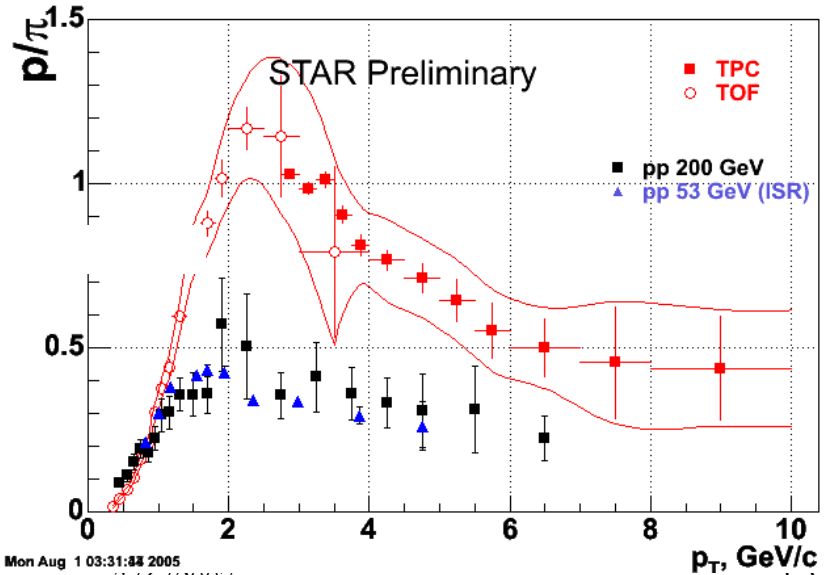
a) $K + p = h - \pi$ (1) $c_1 p + c_2 K = X$ **(2)**

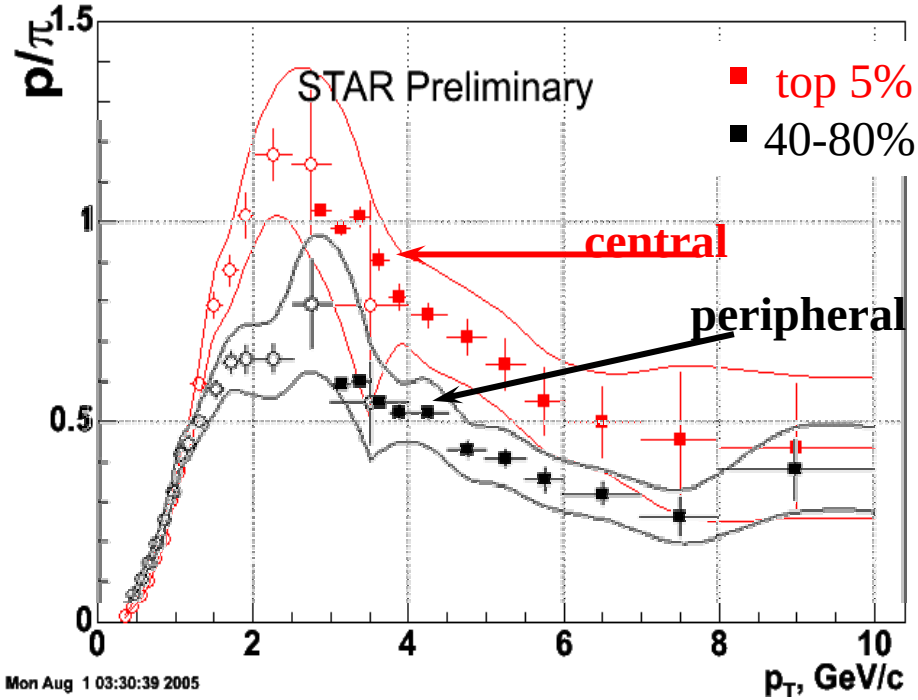
b) $c_1 p + c_2 K = X$ **(2)**, where K is constrained by K^0_s

c_1, c_2 are K, p contributions, and X is the total yield in the counting region

STAR results on p/pi ratios



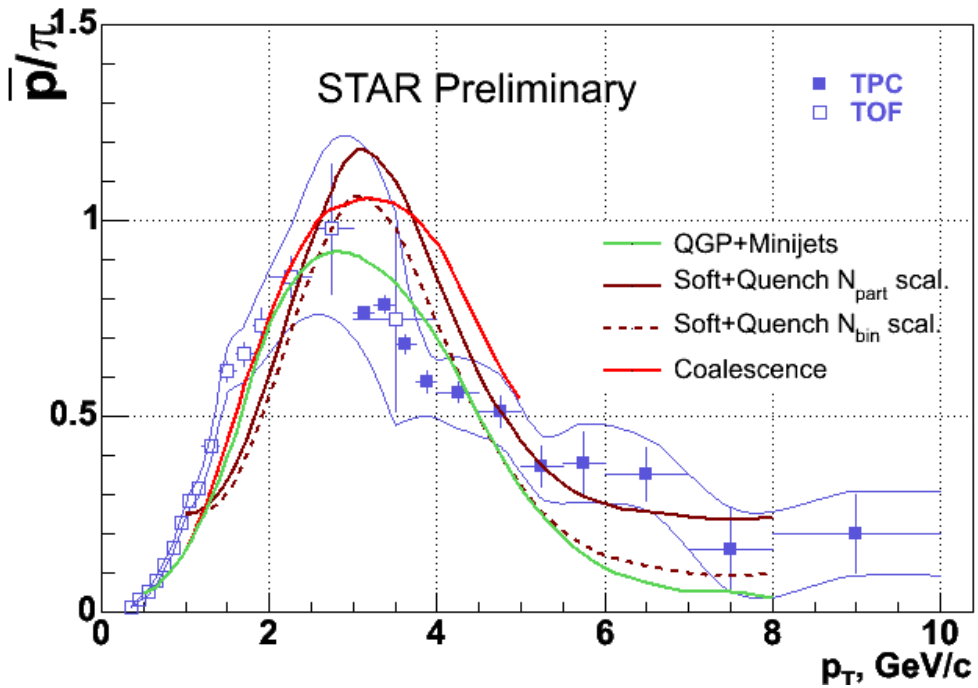




p/pi ratios measured to 10 GeV/c

Extend previous systematics

Model Predictions compared to STAR data



- **All models agree with the data within errors !**
- **Smaller statistical and systematic errors are needed to have discriminative power**
- **PHENIX advantage:**
  - **track-by-track PID !!**
  - **Small acceptance, but fast DAQ!**

— *V. Greco, C.M. Ko, P. L`evai, Phys. Rev. C 68, 034904(2003), Phys. Rev. Lett. 90 202302 (2003).*

— 200 GeV calculations based on *I. Vitev and M. Gyulassy, Phys. Rev. C, 65, 041902(R) (2002).*

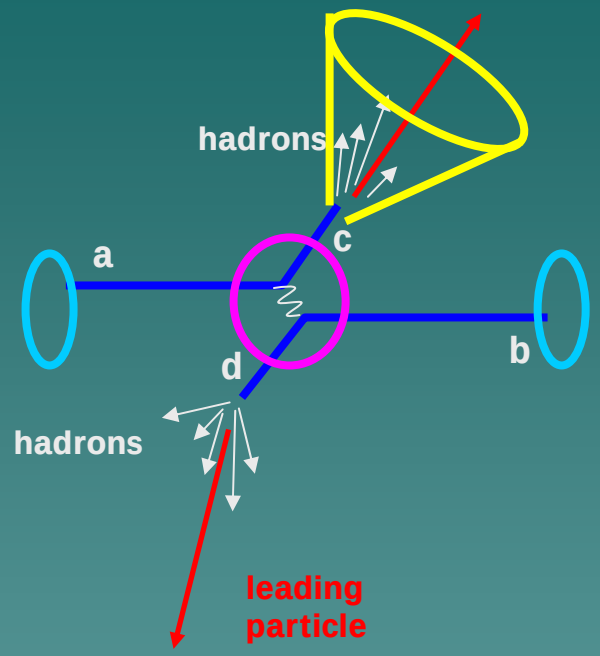
— *R. C. Hwa and C. B. Yang, Phys. Rev. C 70, 024905 (2004).*

Let's take a step back:

To understand the particle production mechanism at high p_T in Au+Au, we need to understand all the ingredients, starting from pp data

High p_T Particle Production in pp

Jet: A localized collection of hadrons which come from a fragmenting parton



Parton Distribution Functions

Hard-scattering cross-section

Fragmentation Function

"Collinear factorization"

$$\frac{d\sigma_{pp}^{h}}{dyd^2p_T} = K\sum_{abcd}\int dx_a dx_b f_a(x_a,Q^2) f_b(x_b,Q^2)\frac{d\sigma}{d\hat{t}}(ab\to cd)\frac{D_{h/c}^{0}}{\pi z_c}$$

High p_T Particle Production in A+A

$$\frac{dN^h_{AB}}{dyd^2p_T} = ABK\sum_{abcd}\int dx_a dx_b \int d^2\mathbf{k}_a d^2\mathbf{k}_b$$

(pQCD context...)

$\otimes f_{a/A}(x_a,Q^2)f_{b/B}(x_b,Q^2)$ — Parton Distribution Functions

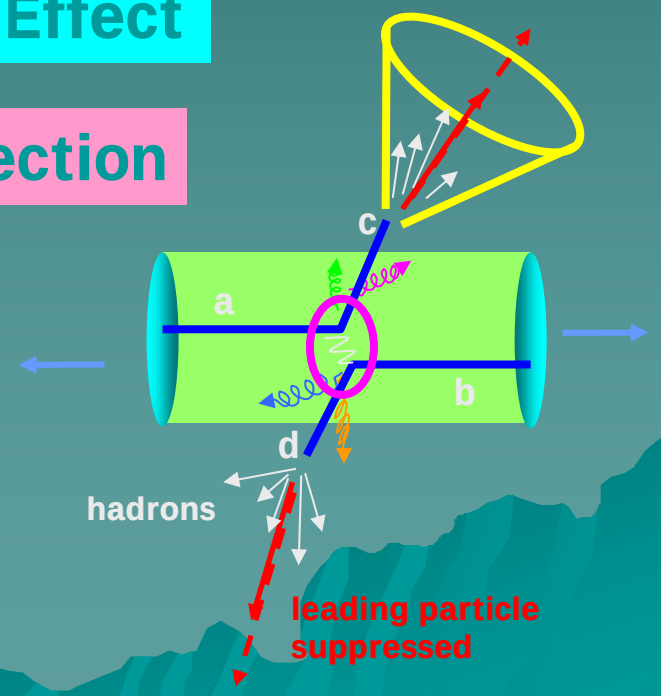
$\otimes g(\mathbf{k}_a)g(\mathbf{k}_b)$ — Intrinsic k_T , Cronin Effect

$\otimes S_A(x_a,Q_a^2)S_B(x_b,Q_b^2)$ — Shadowing, EMC Effect

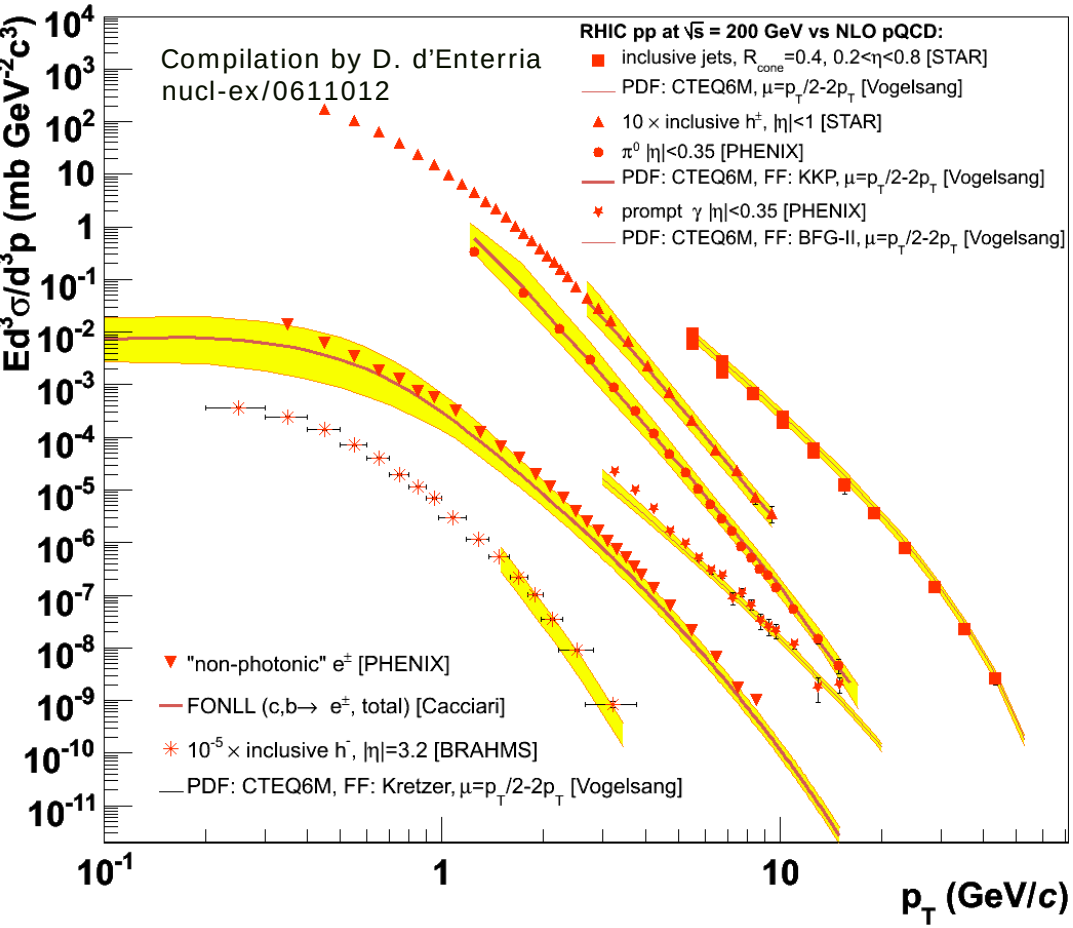
$\otimes \frac{d\sigma}{d\hat{t}}(ab\rightarrow cd)$ — Hard-scattering cross-section

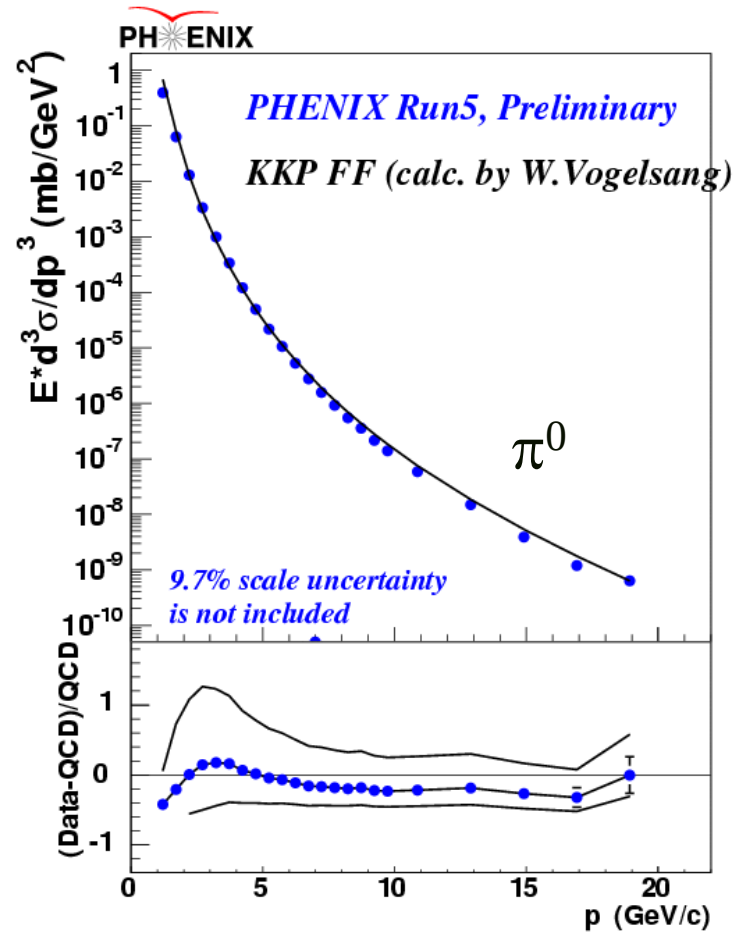
$\otimes \int_0^1 d\varepsilon P(\varepsilon)\frac{z_c^*}{z_c}$ — Partonic Energy Loss

$\otimes \frac{D^0_{h/c}(z_c^*,Q_c^2)}{\pi z_c}$ — Fragmentation Function



pp reference @ 200 GeV vs pQCD

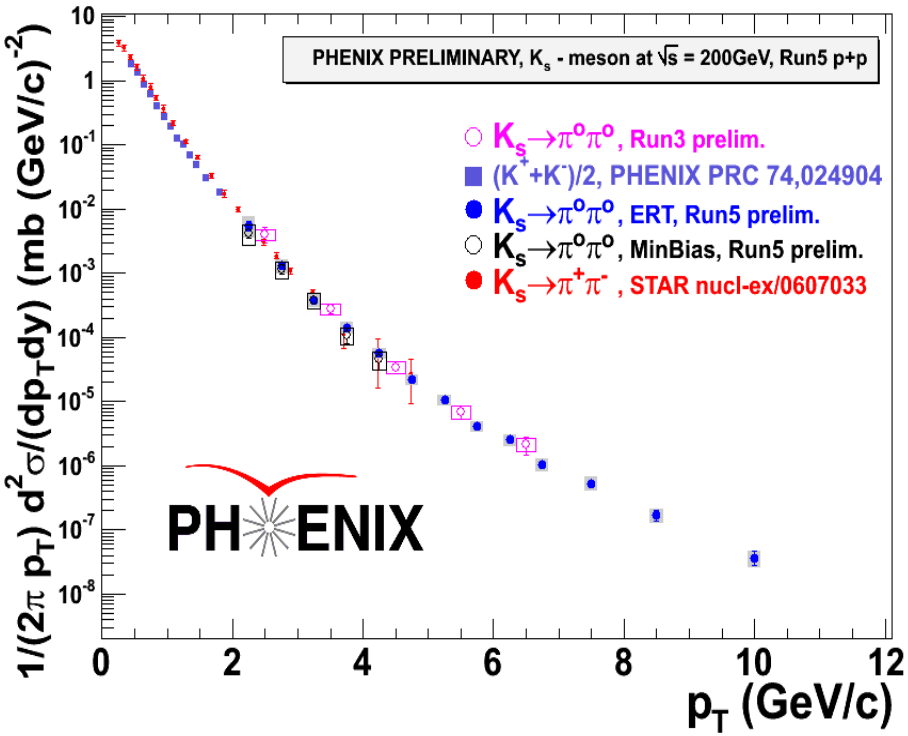


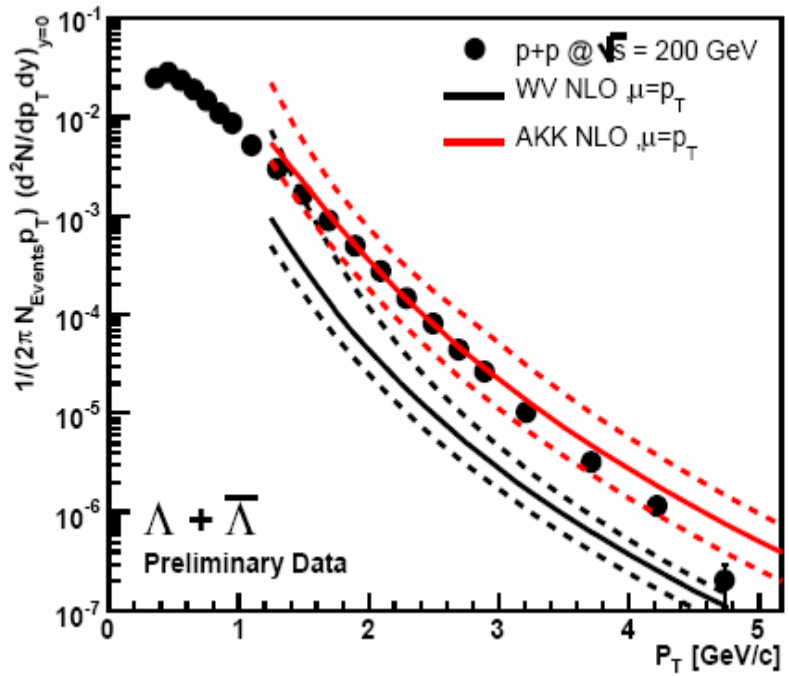


Good agreement with theory

A closer look at pions

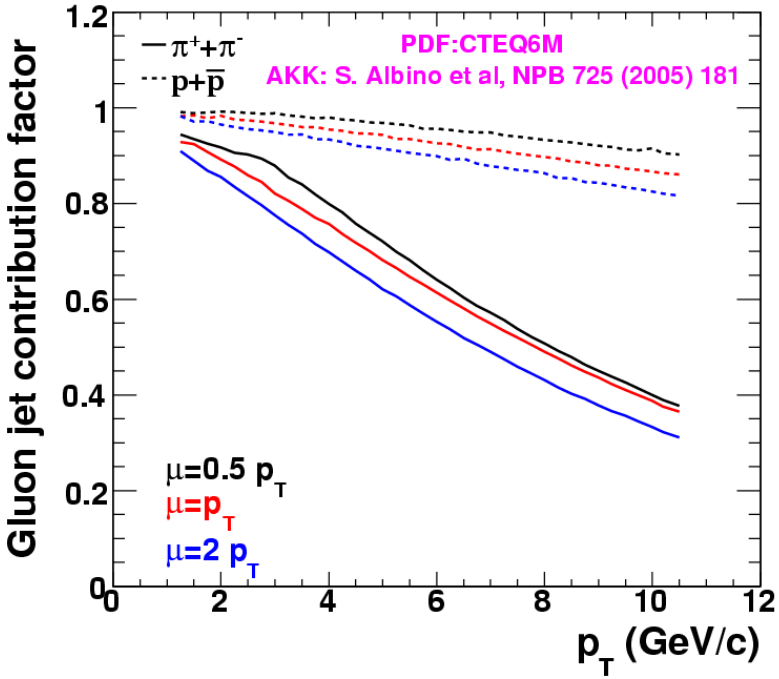
Strange hadrons in pp @ 200 GeV

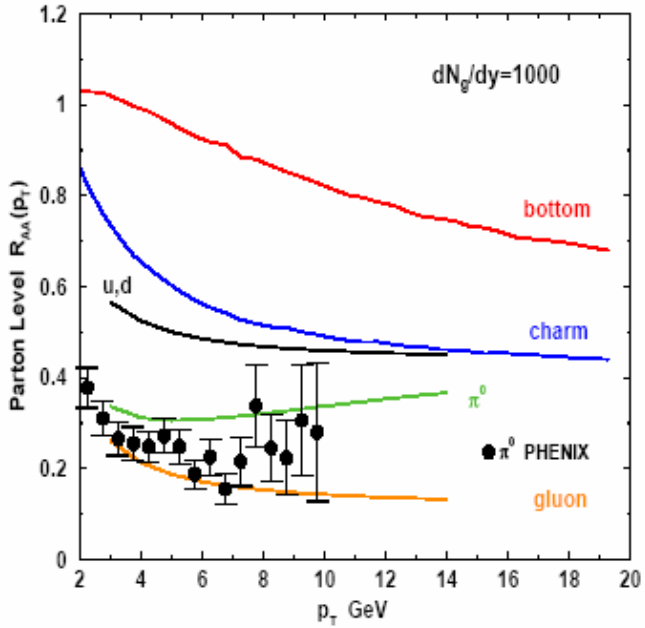




- The same FFs that describe π do not work so well for strange particles
- FFs based on Opal e+e- flavor tagged data (AKK) in agreement with RHIC pp data. Measured pp reference is essential for understanding AA
- PHENIX can do better than STAR in K_s. With TOF.W and ACC – we can measure Λ to 10 GeV/c

Estimate quark and gluon fraction from FFs at high p_T for different particle species



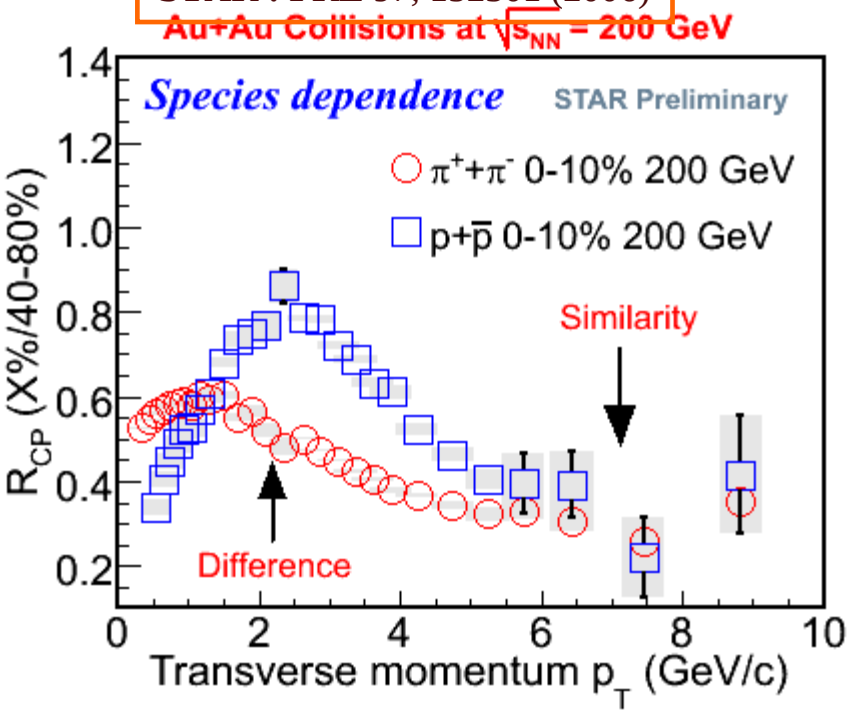


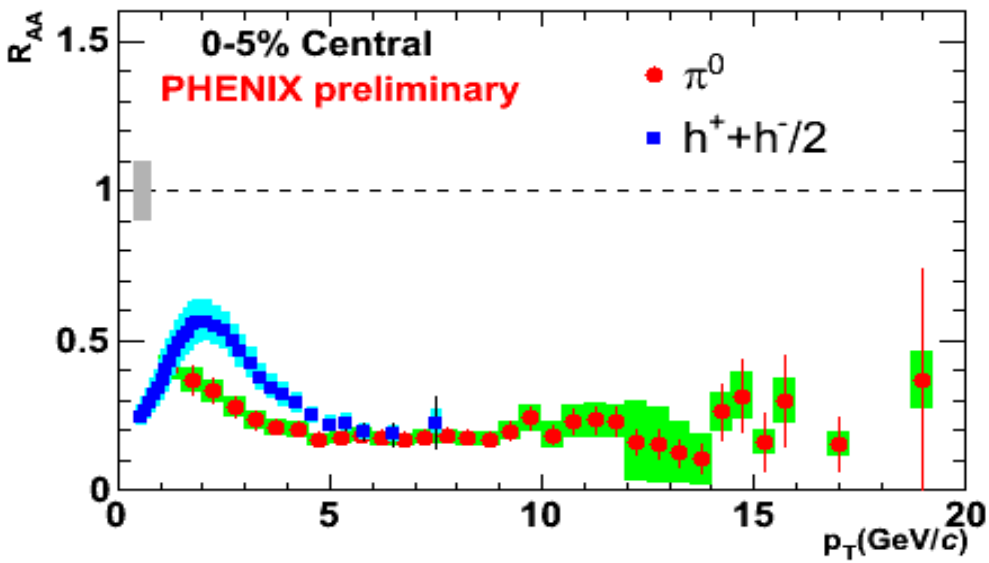
Djorjevic,et al.nucl-th/0507019

- Gluons have stronger eloss. Can we see this in the data using different particle species ?

Can we distinguish gluon from quark energy loss ?

STAR : PRL 97, 152301 (2006)





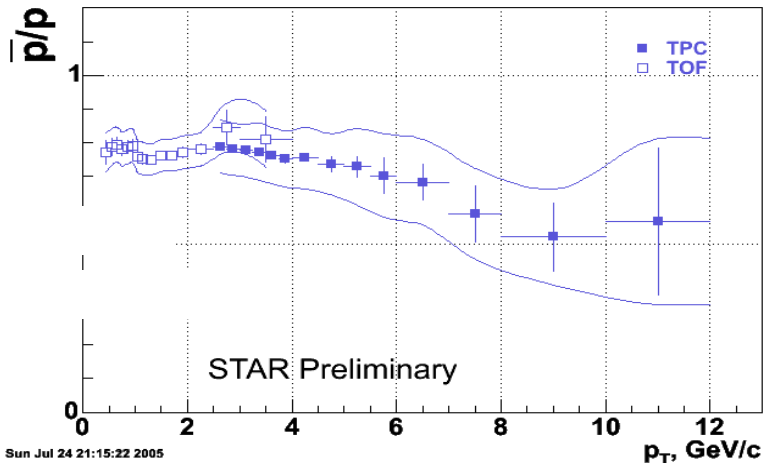
- Protons are expected to have larger contribution from gluons compared to pions => larger energy loss
- But above p_T ~ 6 GeV/c – same suppression pattern !

How big a difference do we expect for R_{AA} of p and π ?

- Let's put in some numbers:
- I read off the R_{AA} plot on slide 25
  - At p_T = 6 GeV/c, R_{AA}(glue) = 0.18, R_{AA}(u,d) = 0.5
- I read off that protons have F_g = 0.95 and pions have F_g = 0.65
- Then I get at 6 GeV/c:
- $R_{AA}(\pi)$ = 0.18 *0.65 + 0.5*0.35 = 0.29
- R_{AA}(p) = 0.18 *0.95 + 0.5*0.05 = 0.196
- Or … R_{AA}(p) = 0.67 $R_{AA}(\pi)$
- Hmm. We need much smaller systematic error to prove/disprove Abelian energy loss … or we need to go to higher p_T where the differences are larger.

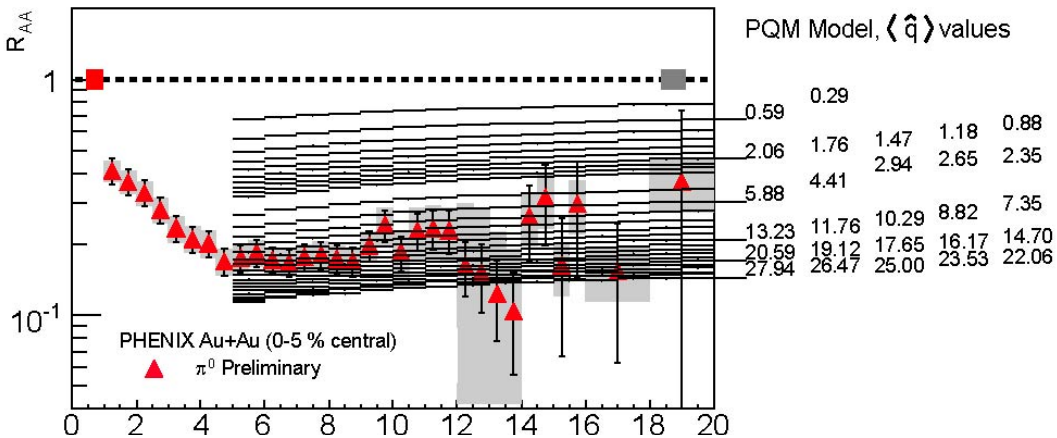
Ratios $\overline{p}$ / p , $\bar{\Lambda}$ / Λ

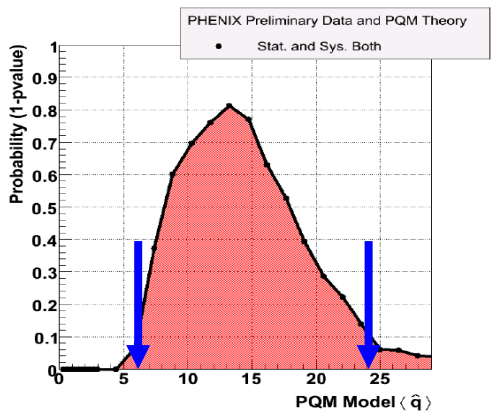
Au+Au min.bias: STAR

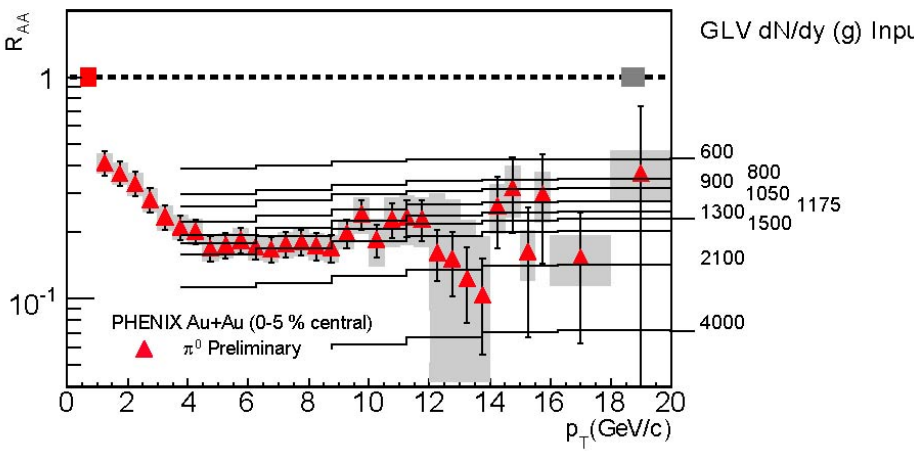


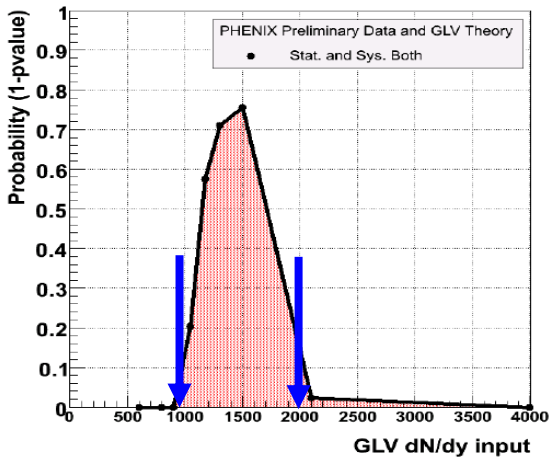
- Anti-particle to particle ratios are also sensitive to the gluon fraction.
- We need much better statistical and systematic errors to distinguish the energy loss mechanism
- We can do this with TOF.W and ACC !

Sensitivity of single particle R_{AA} to models





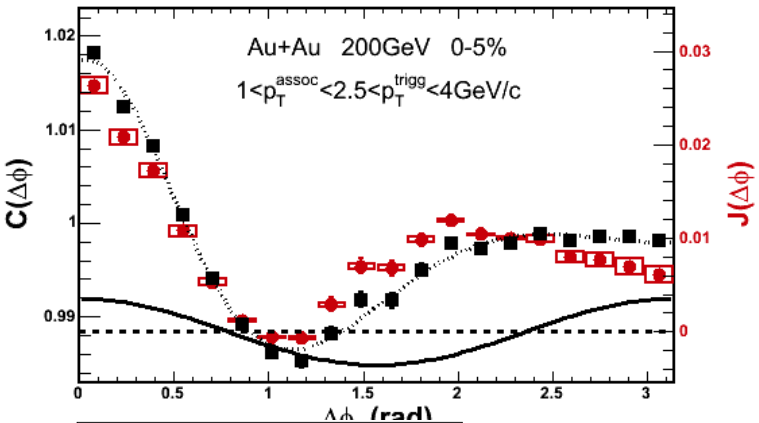


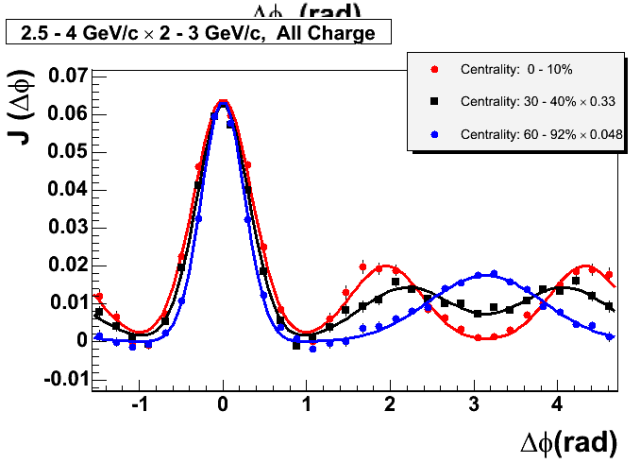


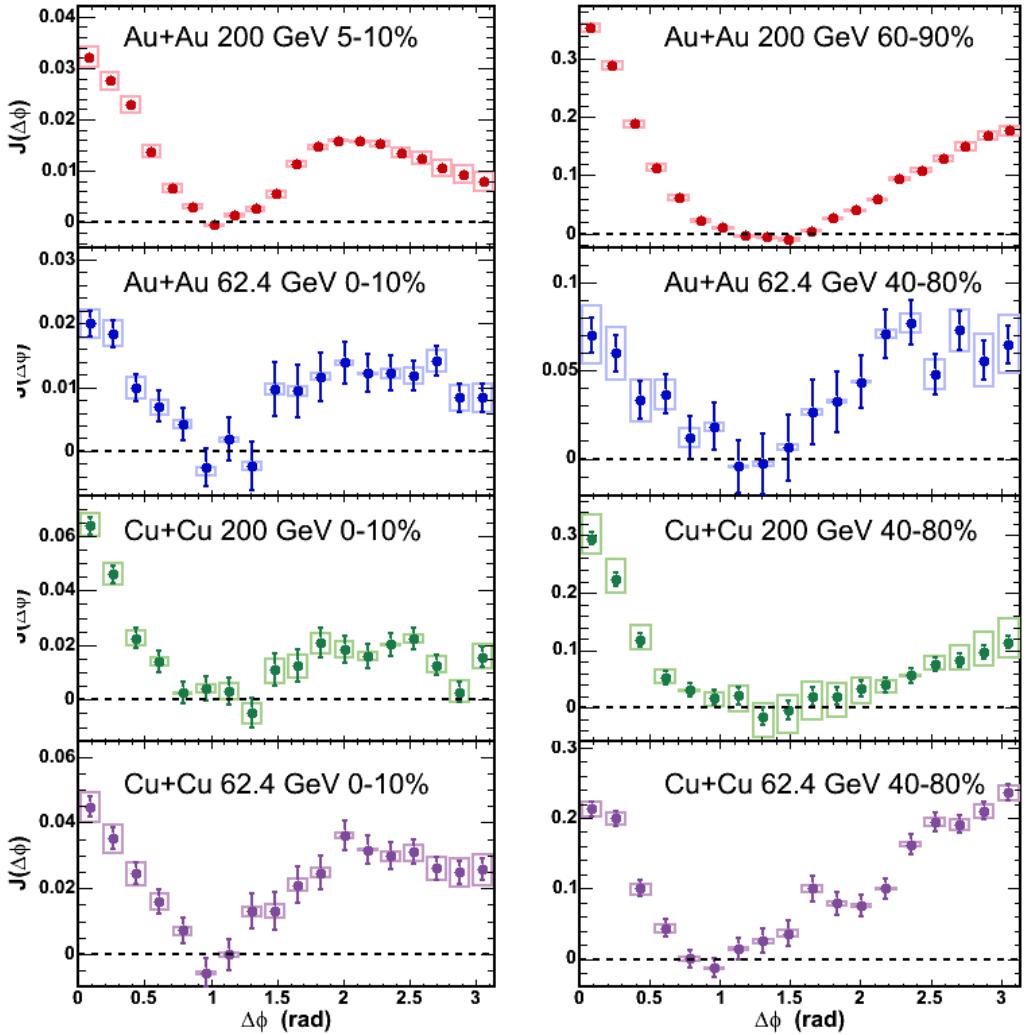
- We need to go beyond single particle measurements to understand Eloss

The volcano:

nucl-ex/0611019
(submitted to Phys. Rev. Lett.)

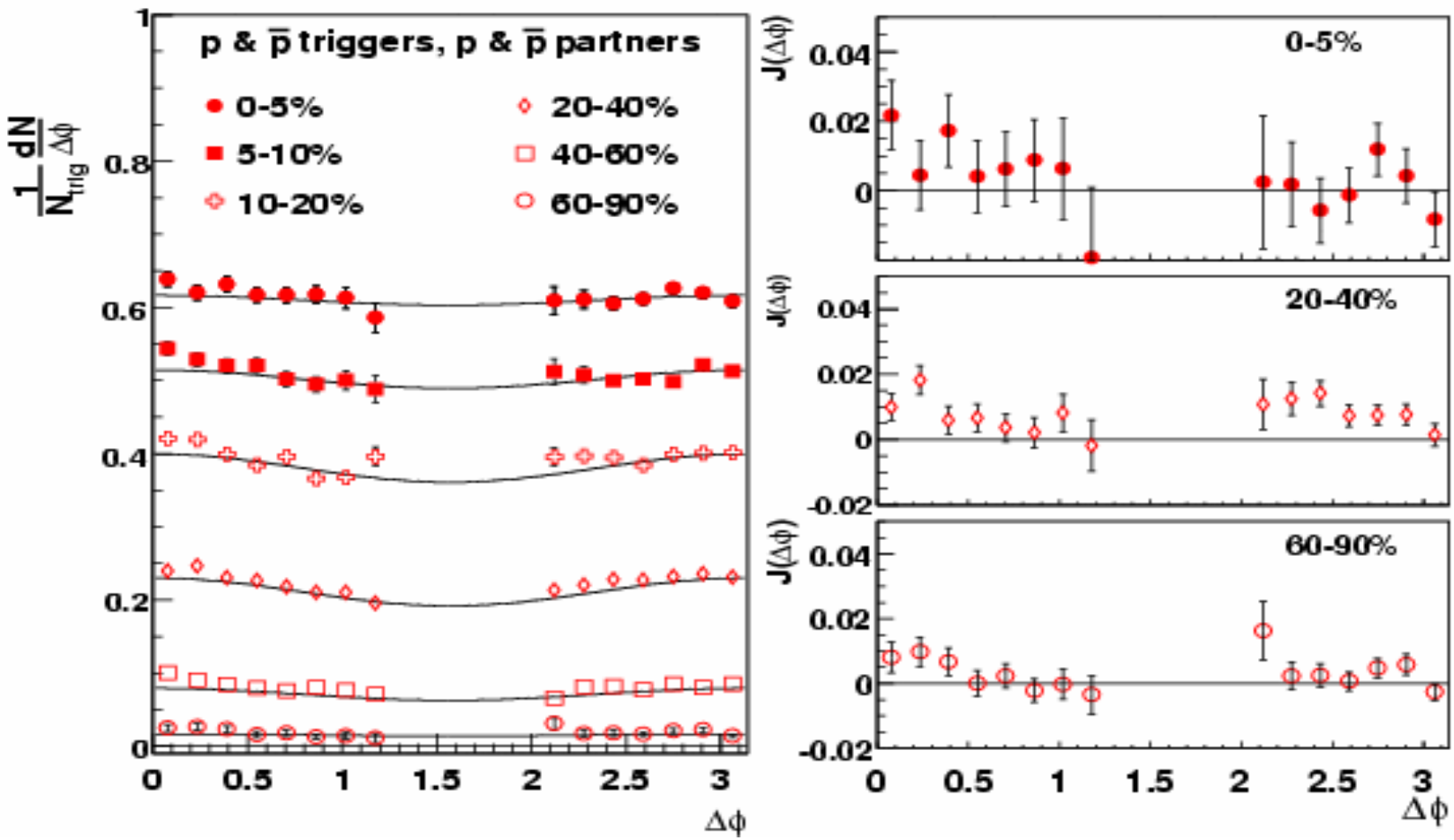




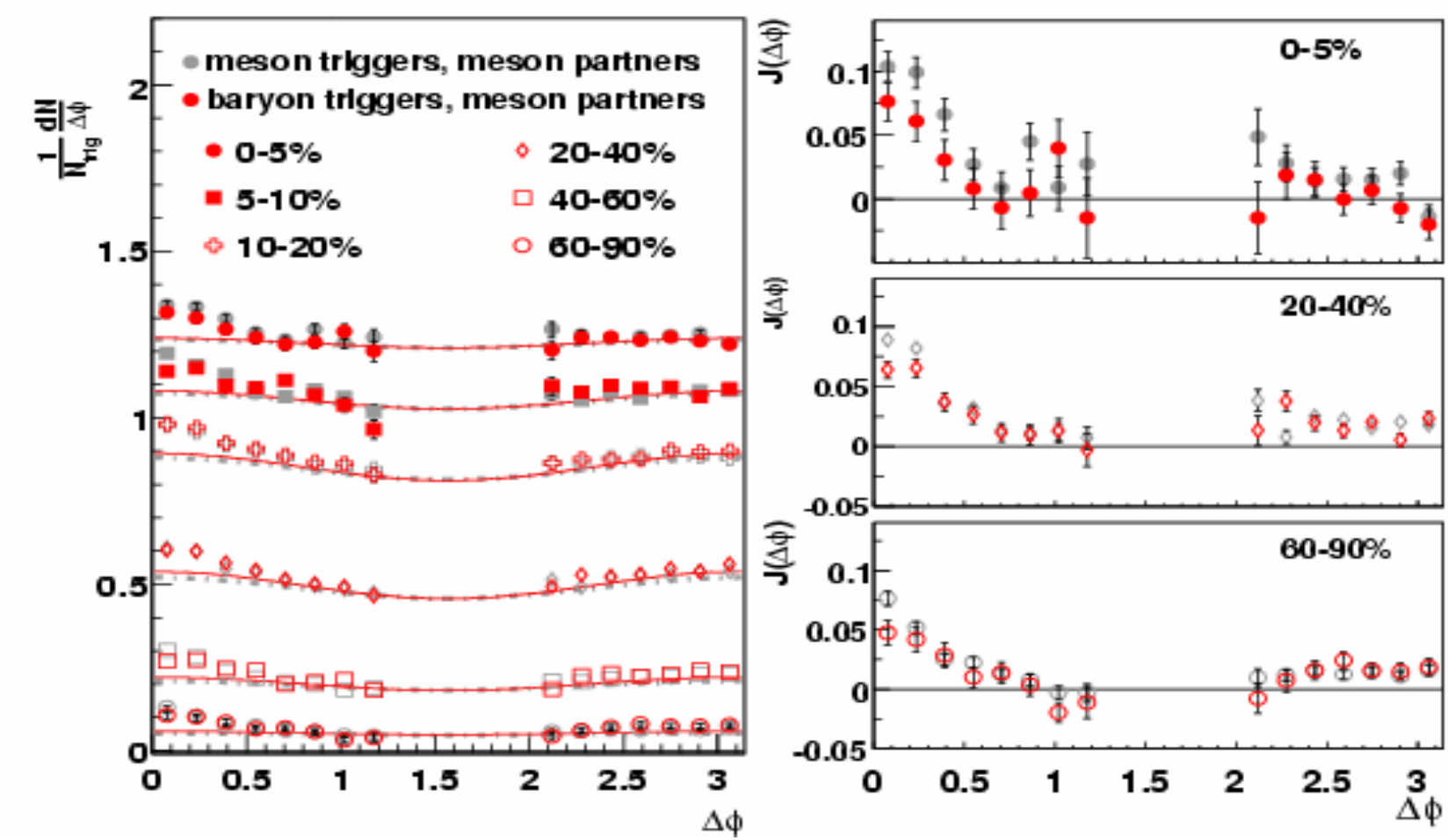


But, before TOF.W – no acceptance with PID at $\Delta\phi = 90^{O}$

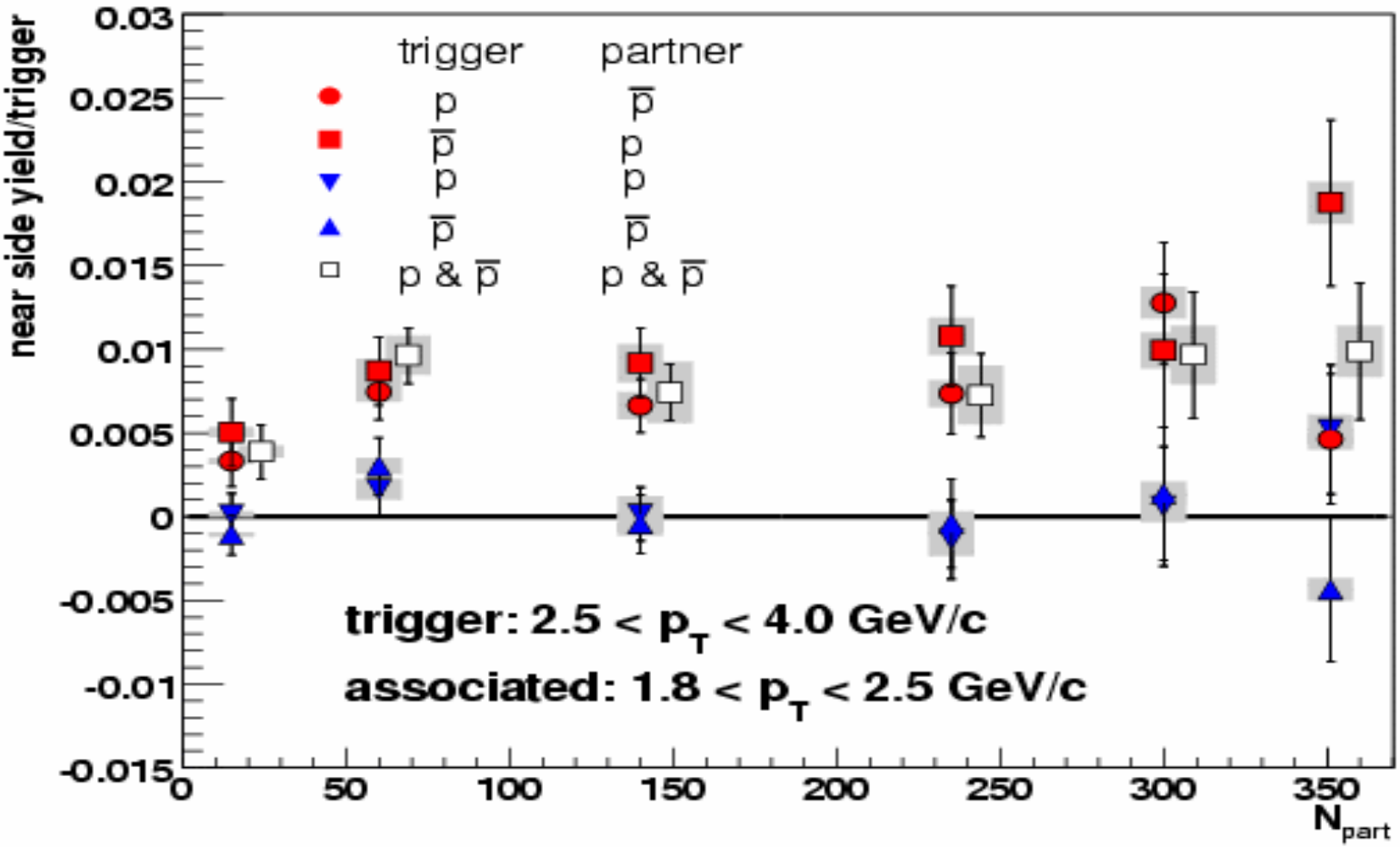
Here is what we have with TOF.E and EMC



Baryons/mesons show similar correlations (ppg072) at intermediate p_T



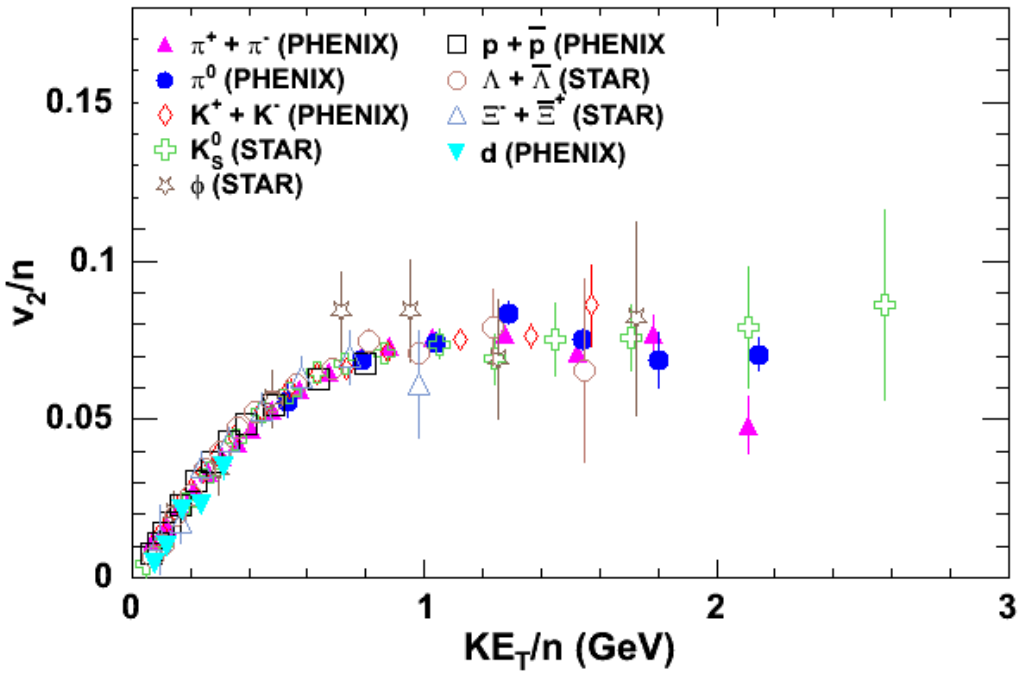
p and pbar come together (as you would expect from jets!



TOF.W will improve correlations measurements

- PID in the jet cone (both near and away side)
- Smaller systematic errors (due to added acceptance at all $\Delta\phi$)
- Study volcanoes with PID
- Added PID for strange baryons/mesons (Λ,ϕ)
- Reco models predict no jet-like correlation for ϕ mesons at intermediate p_T (all soft production) – we can test that

With TOF.W and ACC extend v_2 systematics at high p_T



- How far in p_T does this scaling hold ?
- Extend the p_T range for p, ϕ,Λ,
- Study v_2 and R_{AA} vs reaction plane

Conclusion

- Precision measurements needed to understand particle production at all p_T
- Lot's of added capabilities for with TOF.W

(both new measurements and improved systematics for "old" results)

  - Tack-by-track PID up to 9-10 GeV/c
  - Near and away side PID for jet physics
  - Complete $\Delta\phi$ coverage for correlation studies