Strange Hadrons, High Density Matter and Searches for Exotics @RHIC

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The STAR Collaboration

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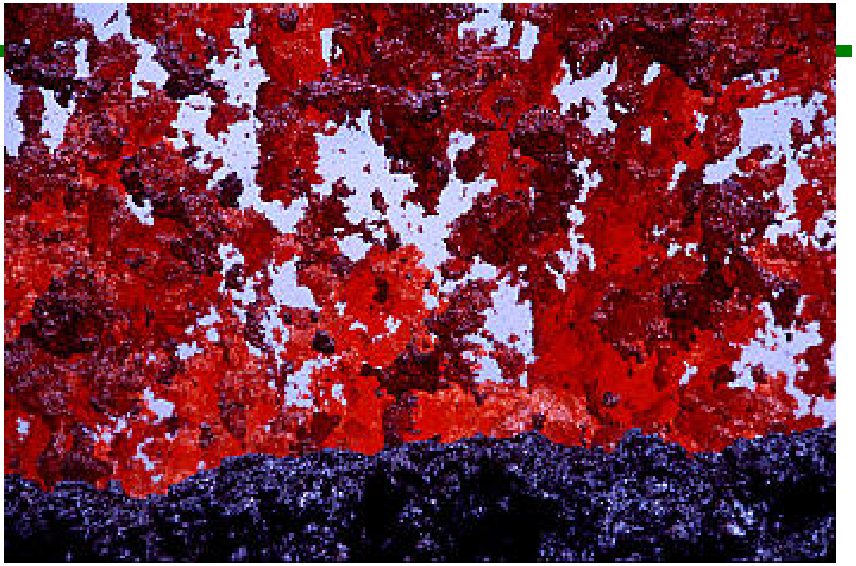
Nucleus-Nucleus Collisions and Volcanic Eruption

Volcanic high p_T -- Strombolian eruption



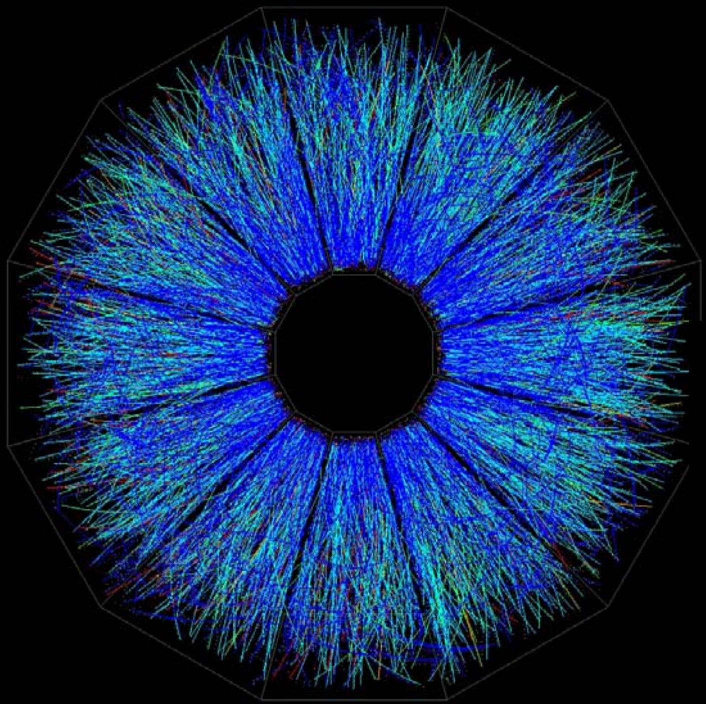
Volcanic mediate p_T – Spatter (clumps)

Volcanic low p_T – Bulk matter flows

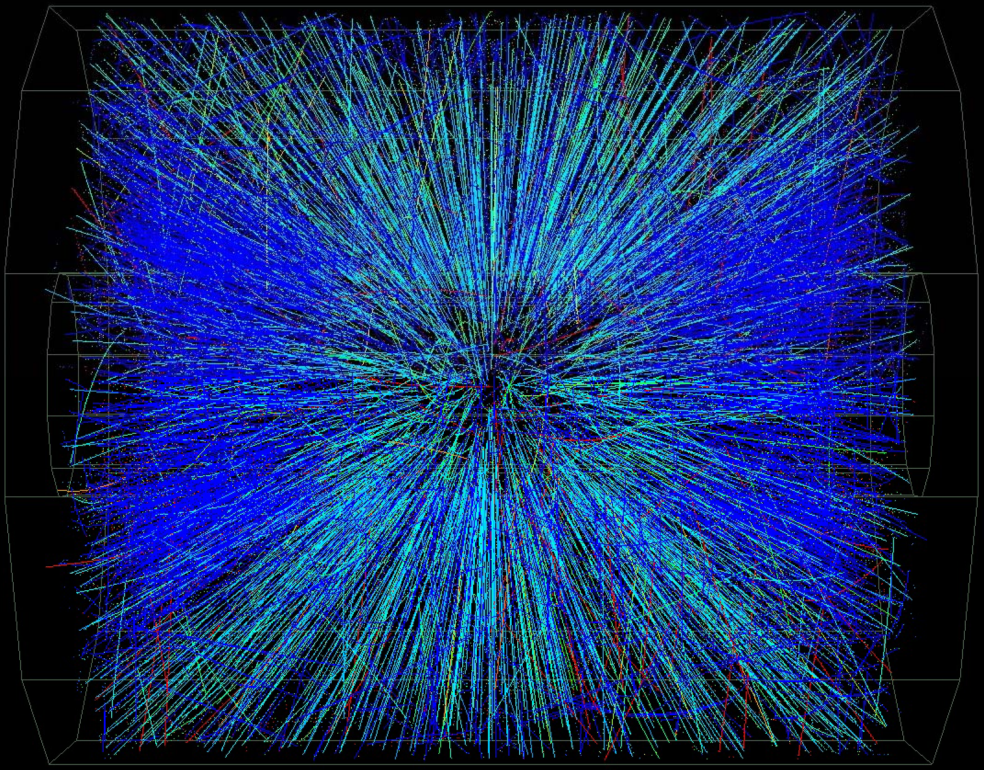
Outline

- Strange Probes of Dense Matter and Hadronization Features
- Pentaquark Searches in STAR
- The Puzzle Continues

Au + Au Collisions at RHIC

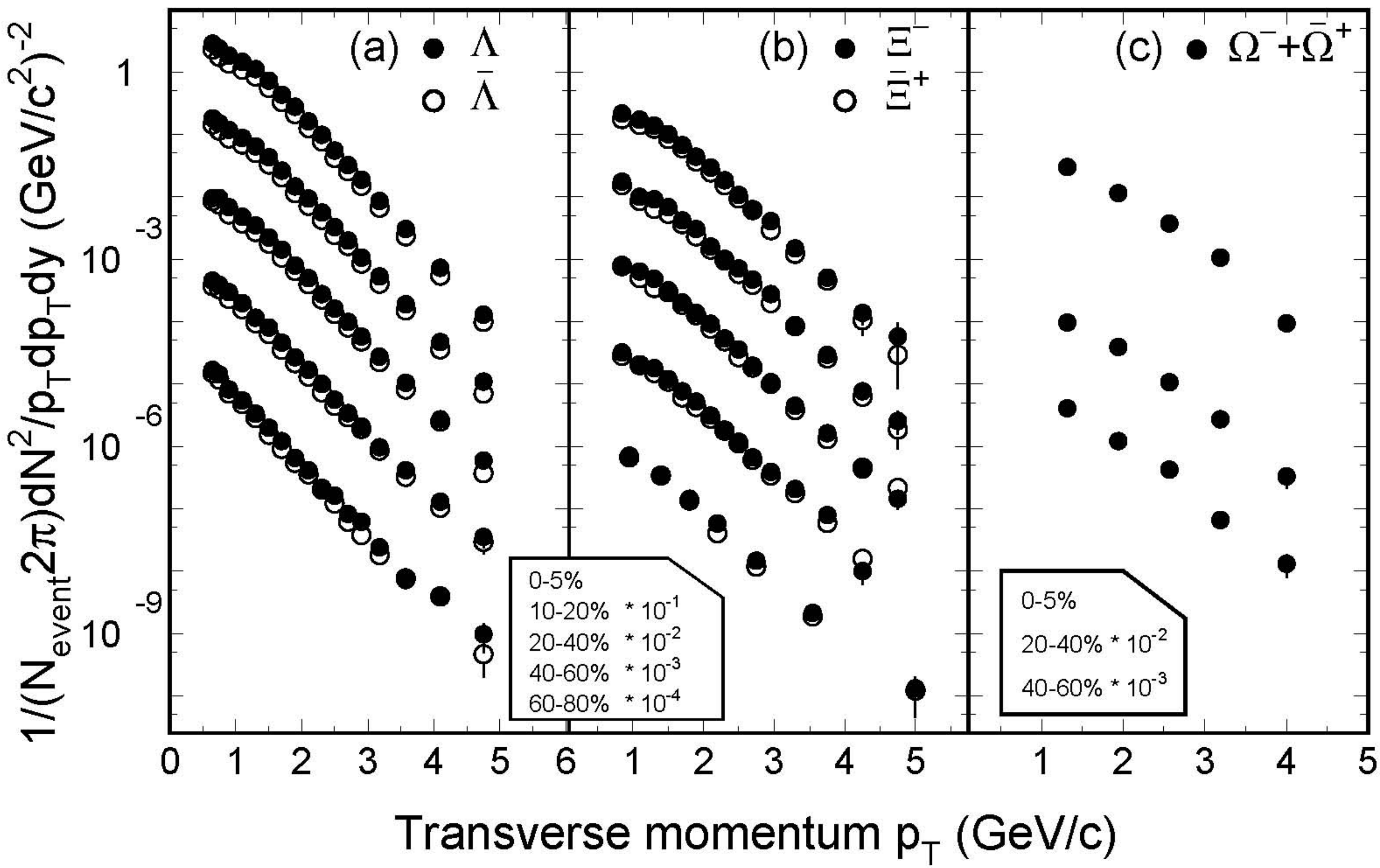


Central Event



STAR (real-time Level 3)

Strange Baryon Production from Au+Au 200 GeV



Mid-rapidity dn/dy

Centrality	0–5%	10–20%	20–40%	40–60%	60–80%
N_{part}	352.0	234.6	141.1	62.4	20.9
Λ	16.1±1.8	9.3±1.4	5.2±1.1	2.1±0.6	0.61±0.07
$\overline{\Lambda}$	12.2±1.3	7.3±1.0	4.1±0.8	1.6±0.5	0.48±0.12
Ξ^-	2.24± 0.10	1.41±0.06	0.73±0.02	0.25±0.01	0.064±0.005
$\overline{\Xi}^+$	1.91±0.10	1.13±0.06	0.62±0.02	0.22±0.03	0.063±0.005
$\Omega + \overline{\Omega}^+$	0.6±0.1		0.17±0.02	0.07±0.01	

Λ with weak decay correction

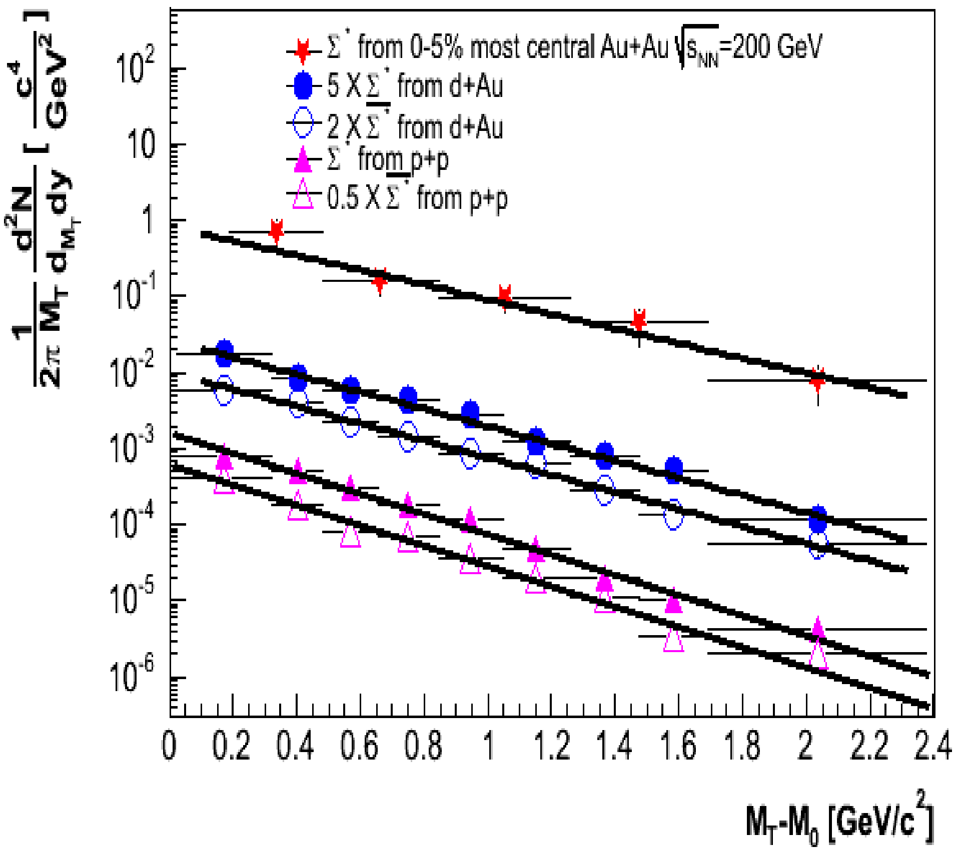
Anti-particle/particle ratios: $\overline{\Lambda}/\Lambda \sim 0.76$

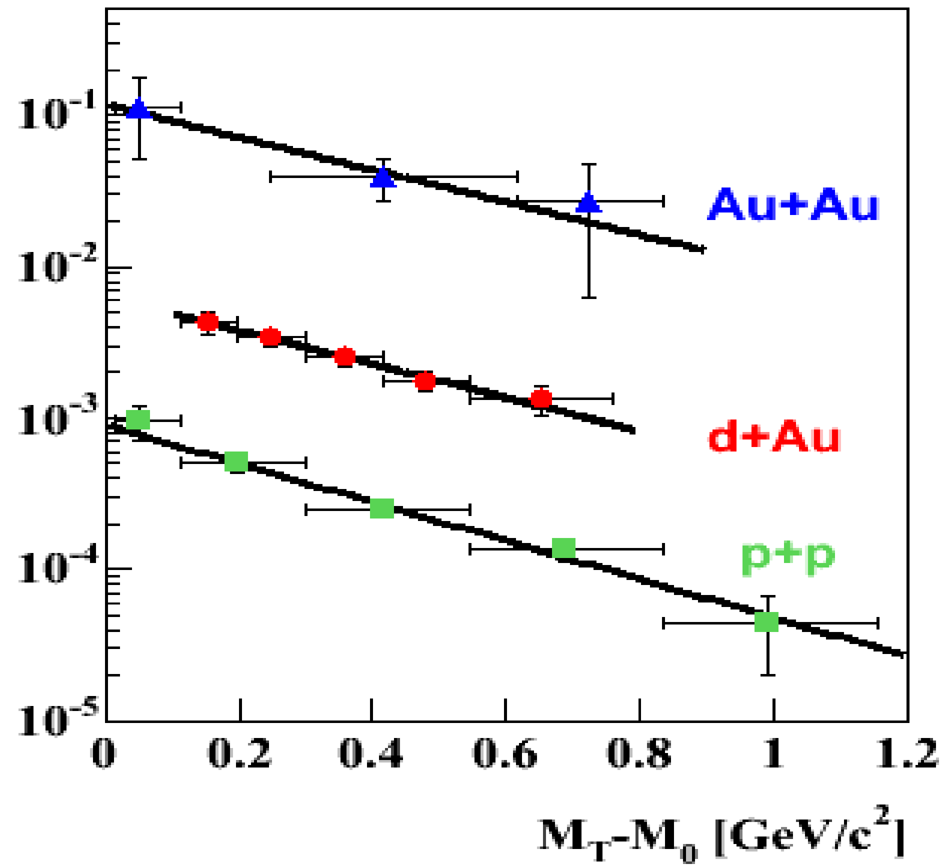
$\overline{\Xi}/\Xi \sim 0.85$

$\overline{\Omega}/\Omega \sim 1.0$

STAR Preliminary Results on Strange Baryon Resonance

$\Sigma^*(1385)$ (uus) | $\Lambda^*(1520)$ (uds)





Expectations for High p_T from Au+Au

Use number of binary nucleon-nucleon collisions to gauge the colliding parton flux:

$$R_{AA}(p_T) = \frac{\dfrac{dN^2_{AA}}{dp_T d\eta} / N_{coll}}{\dfrac{dN^2_{pp}}{dp_T d\eta}}$$

N-Binary Scaling → $R_{AA} = 1$

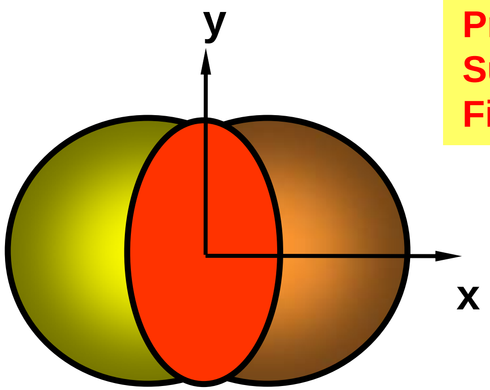
N-Binary Scaling works for very rare processes
i.g., Drell-Yan and direct photon production
with some caveats (parton F_2 and G change in A).

R_{AA} can also be measured using central/peripheral ratios !

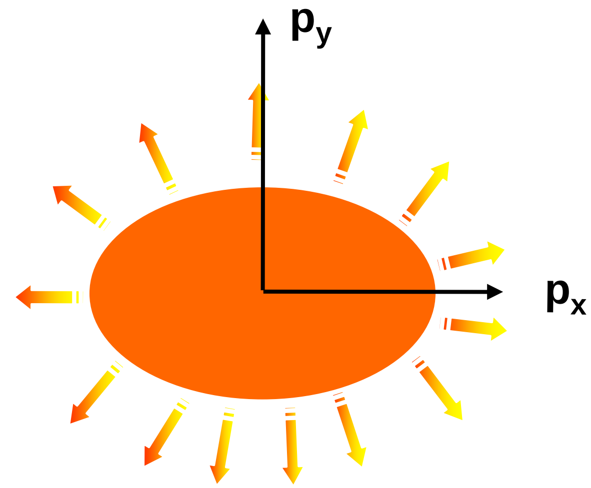
Elliptic Flow v_2 and Early Dynamics

Coordinate space:
initial asymmetry

Momentum space:
final asymmetry



Pressure induced flow +
Surface emission pattern +
Final state rescattering –

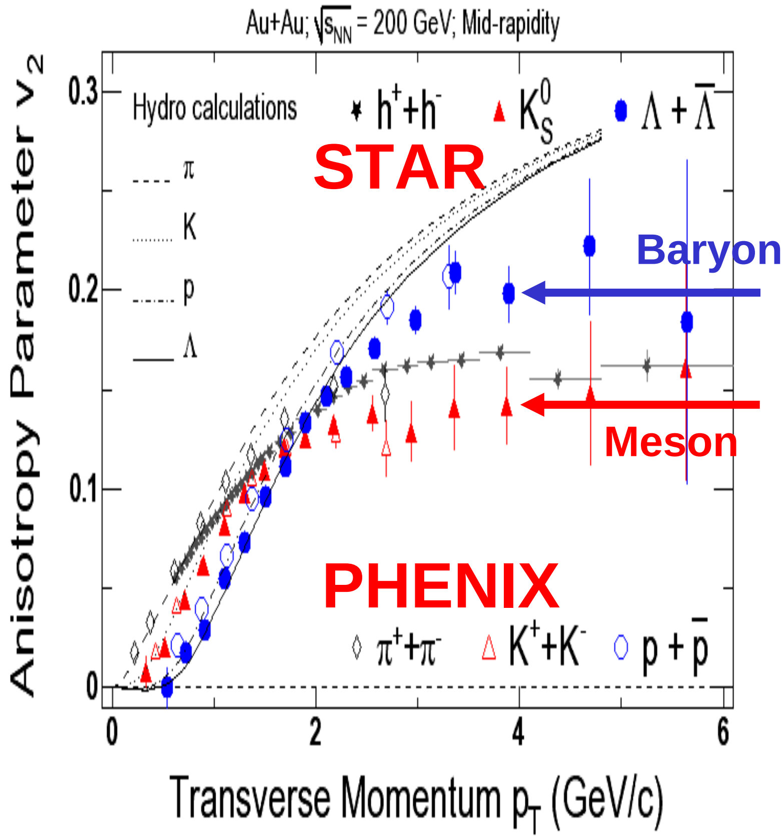


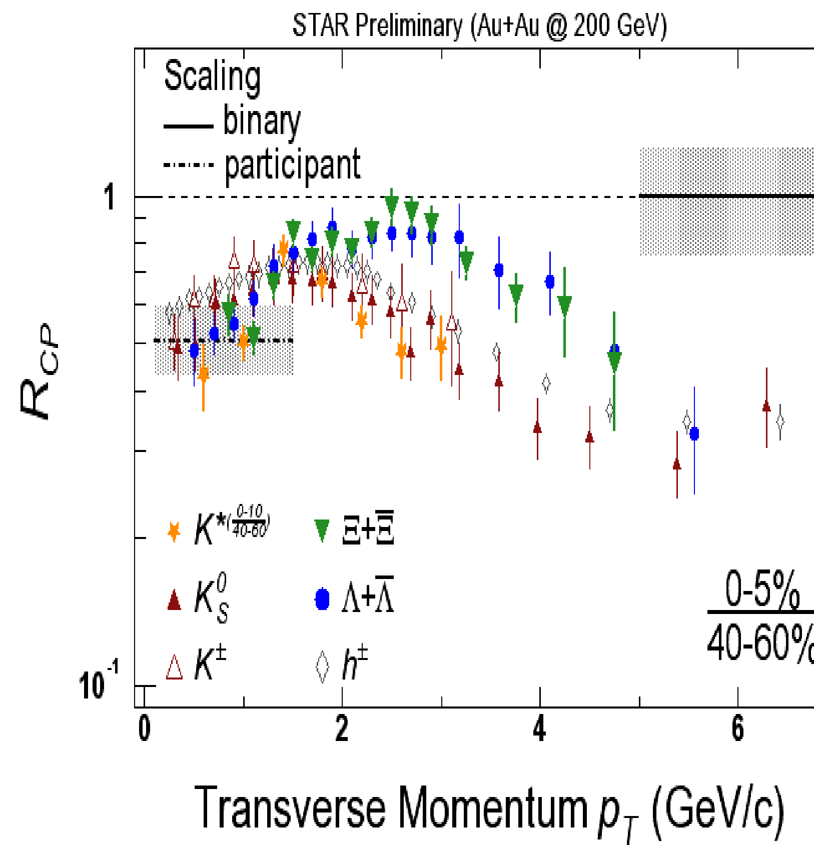
$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

$$v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

$$dN/d\phi \propto 1 + 2v_2 \cos 2(\phi)$$

Empirical Quark Scaling in R_{AA} and v_2





Constituent (n) Quark Scaling

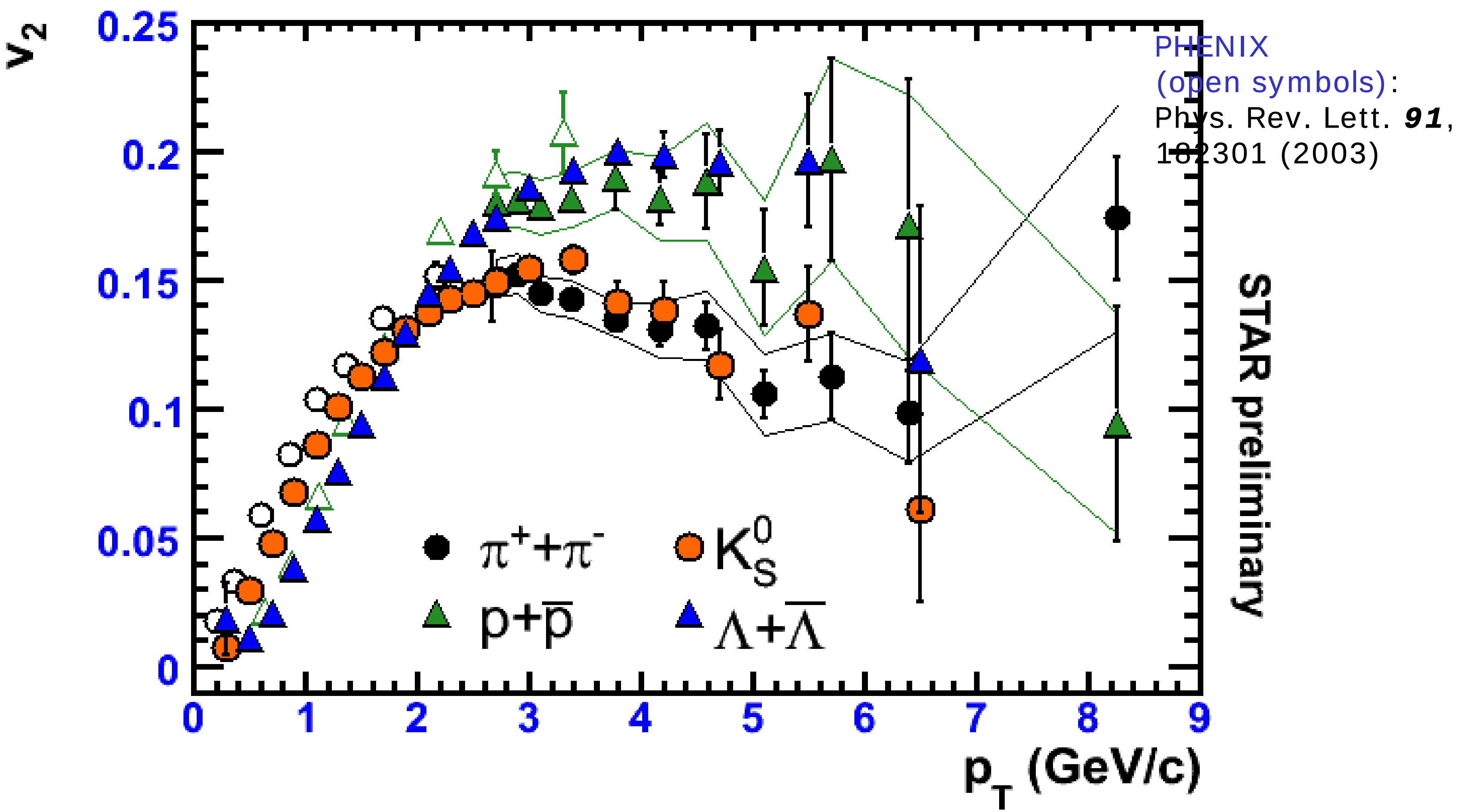
-- Meson n=2 and Baryon n=3 grouping

Saturation of v_2 at Intermediate p_T

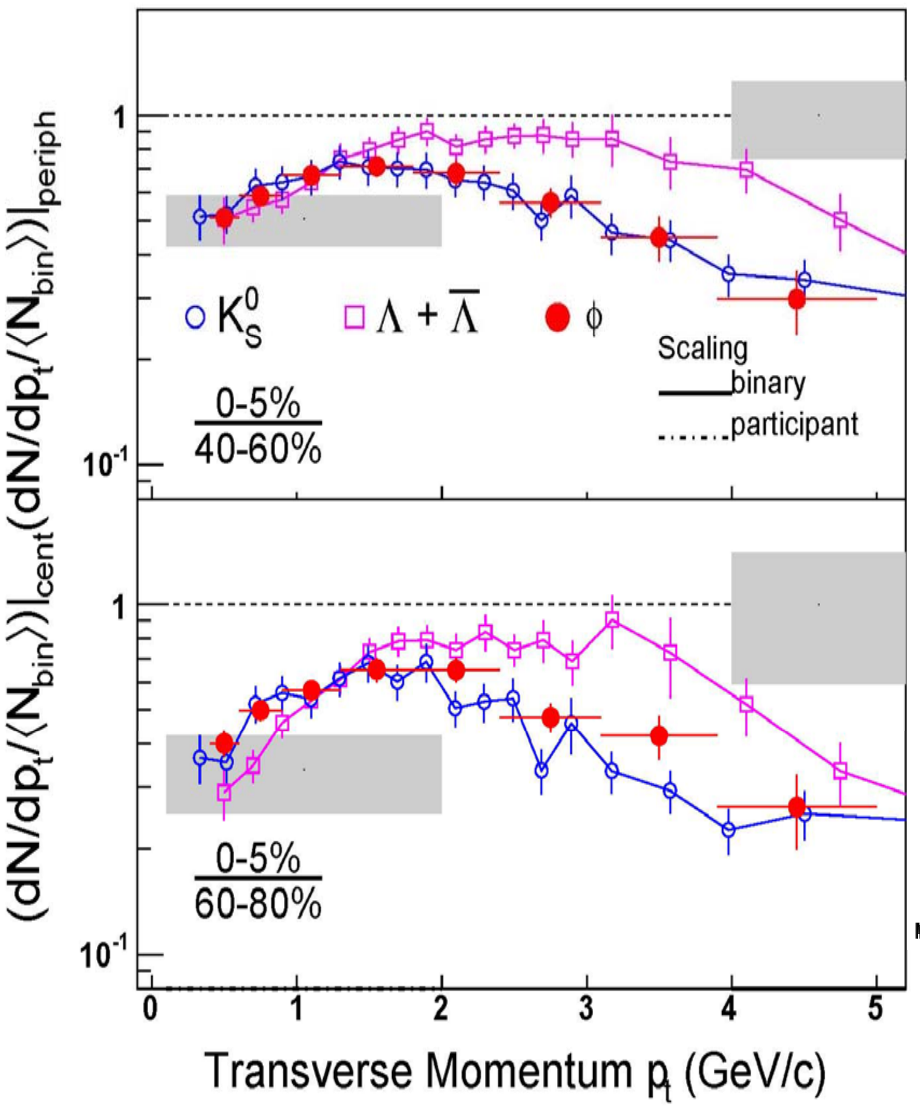
Very different from fragmentation formation scheme !!

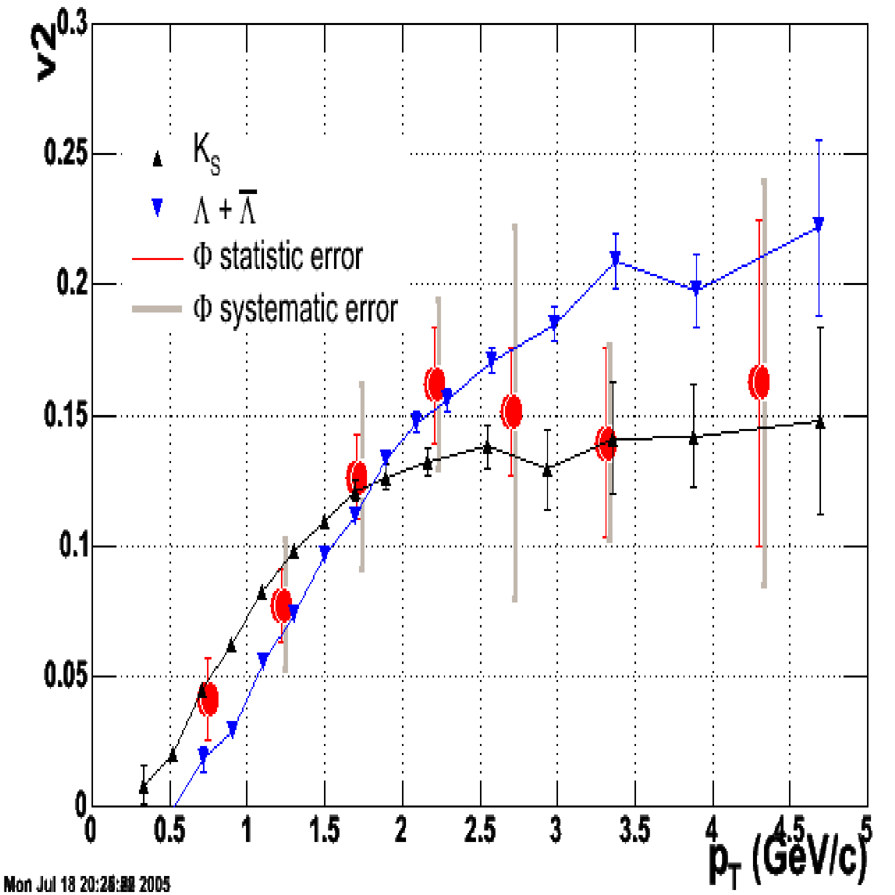
Very Much Improved Data !!

Meson-Baryon Scaling in v_2 at Intermediate p_T !!

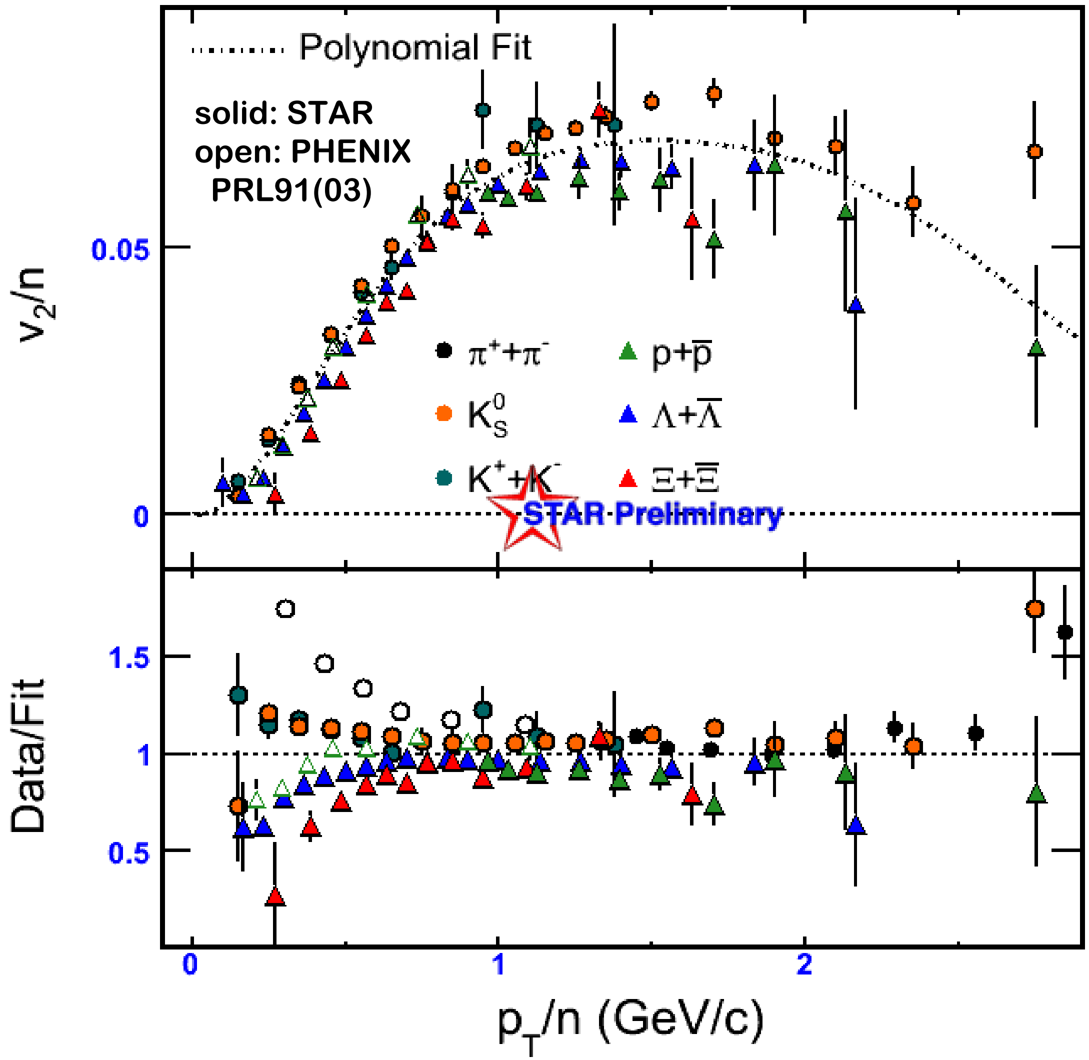


Φ Meson – Strange Quark Collective Behavior





Constituent Quark Degree of Freedom



At hadron formation time there is a collective v_2 among constituent quarks

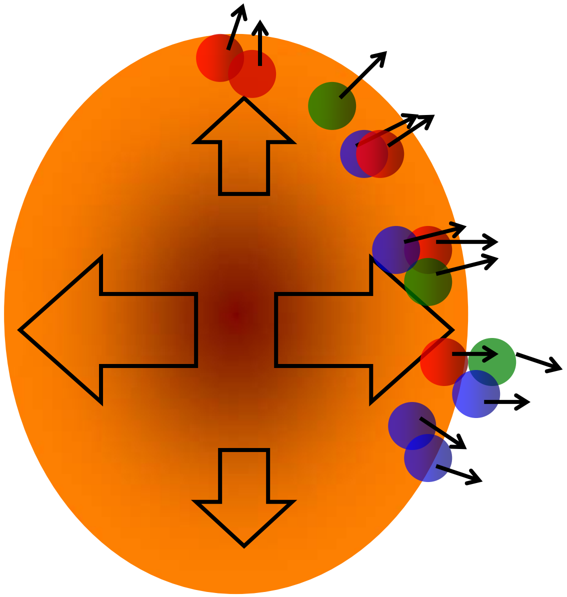
Recombination/coalescence provides a hadronization scheme
(not necessarily related to partonic matter, works for d+Au)

Possible geometrical nature of v_2 saturation
– surface emission

Why does the meson-baryon scaling work so well ?

Quark Cluster Formation from Strongly Interacting Partonic Matter

Volcanic mediate p_T – Spatter (clumps)



Enhancement of Clusters at intermediate p_T ! (baryons and hyperons)

Search for Multi-quark (>3) Cluster State at RHIC !

Multi-Parton Dynamics for Bulk Matter Hadronization

Essential difference:

Traditional fragmentation → particle properties mostly determined by the leading quark !

Emerging picture from RHIC data (R_{AA}/R_{CP} and v_2) → all constituent quarks are almost equally important in determining particle properties !

v_2 of hadron comes from v_2 of all constituent quarks !

The fact that in order to explain the v_2 of hadrons individual constituent quarks (n=2-meson,3-baryon) must have a collective elliptic flow v_2 and the hadron v_2 is the sum of quark v_2 → Clear Evidence for Deconfiement !

Favorable Environment for Exotic Particle Formation !

RHIC – Exotic Particle Factory

RHIC – Dense Partonic Matter and
Rapid Hadronization
→Unique Collision Environment for
Possible Exotic Particles Formation
→Exotic Mesons, Pentaquarks, Di-baryons
[ΞΞ] (G.Miller), [ΩΩ] (Zhang)
and Strangelets

STAR Pentaquark Searches

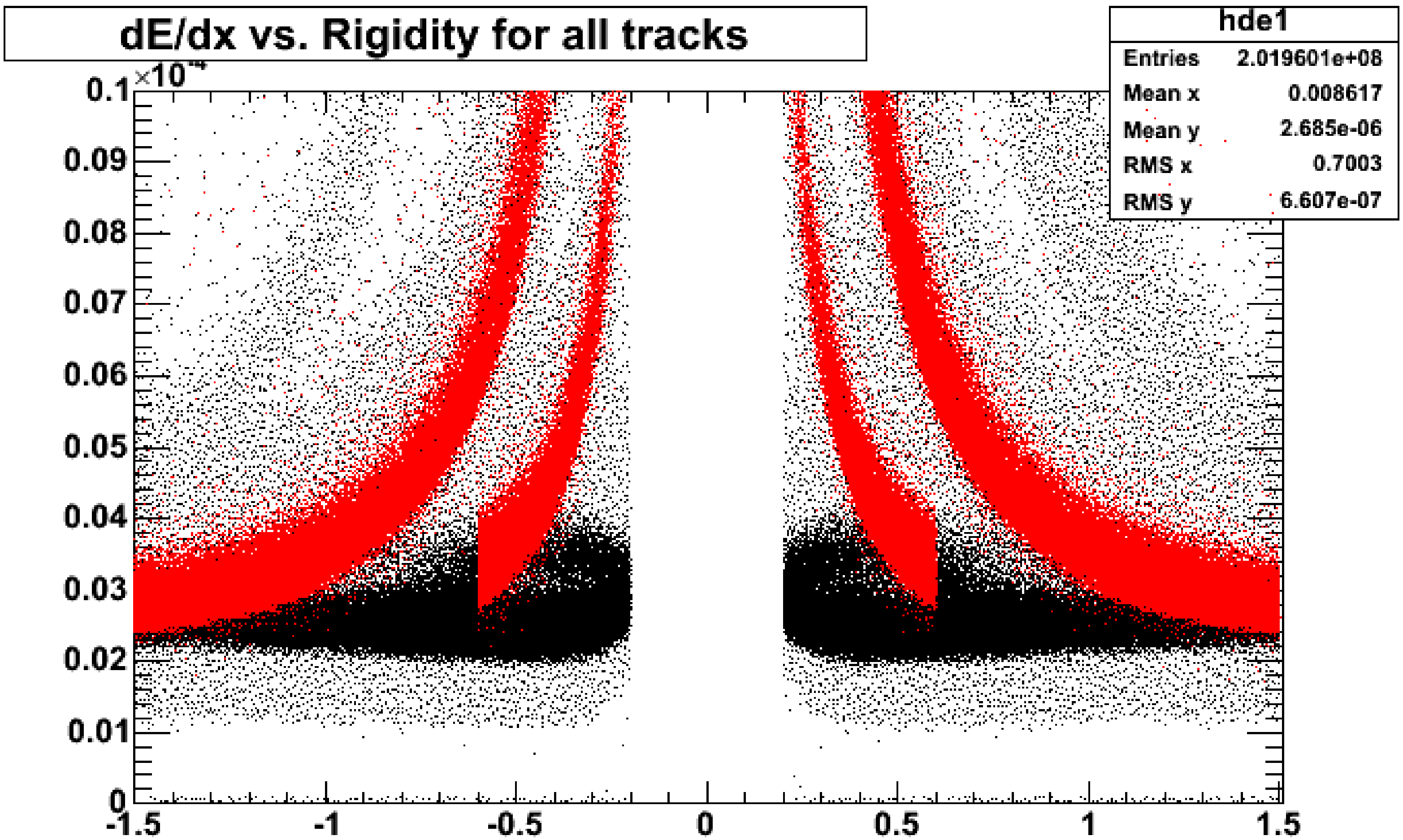
$\Theta^{++} \rightarrow p + K^{+}$

Data Set:

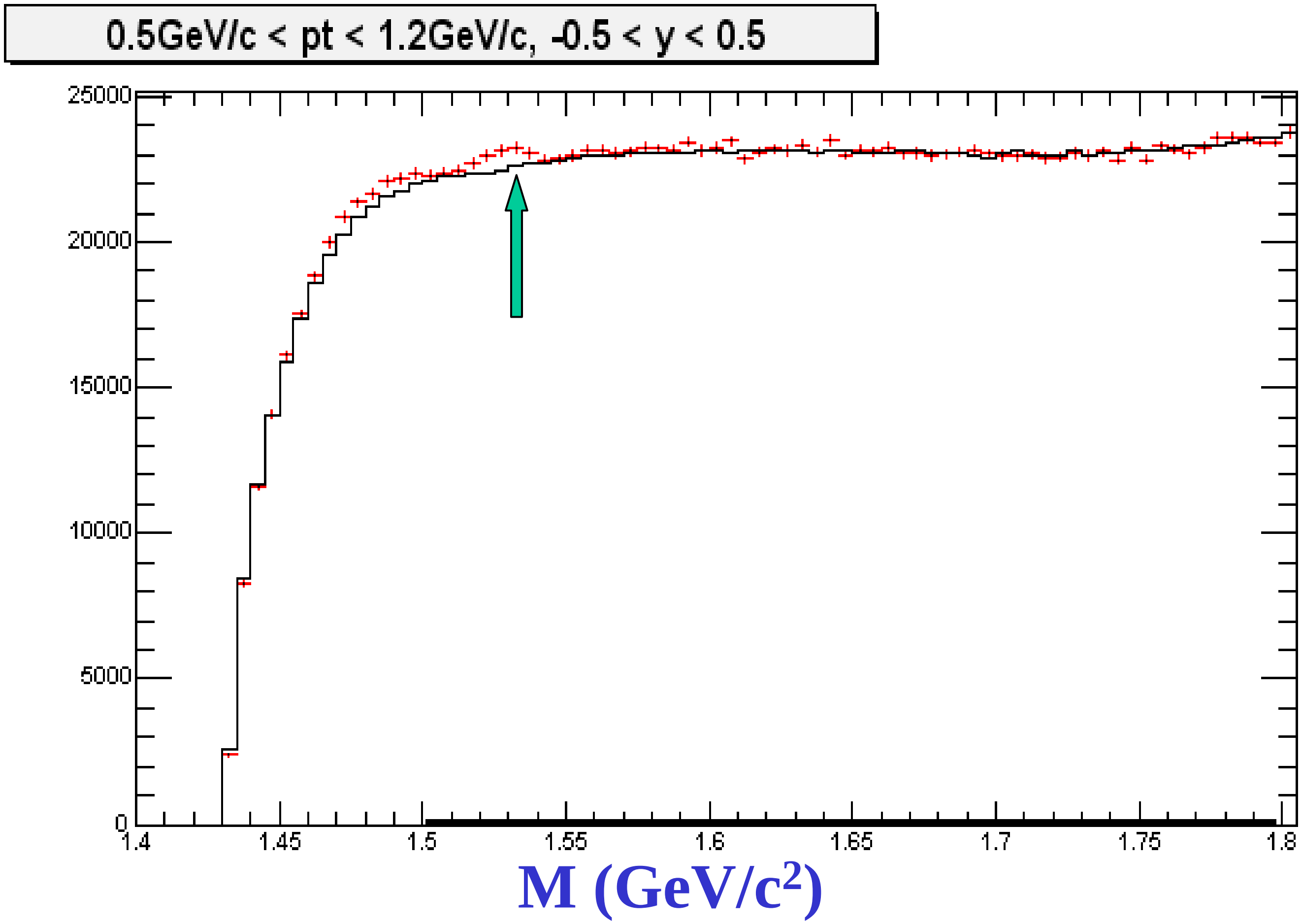
Au + Au 200 GeV run 2 (~1.7 M, 30-80%)
p + p data 200 GeV run 2 (~6.5 M)
d + Au 200 GeV run 3 (18.6 M)
Au + Au 63 GeV run 4 (5.6 M)
Cu + Cu 63 GeV run 5 (16.5 M)
Au + Au 200 GeV Run 4 (10.7 M, 20-80%)

Particle identification

Particle Identification: dE/dx from TPC



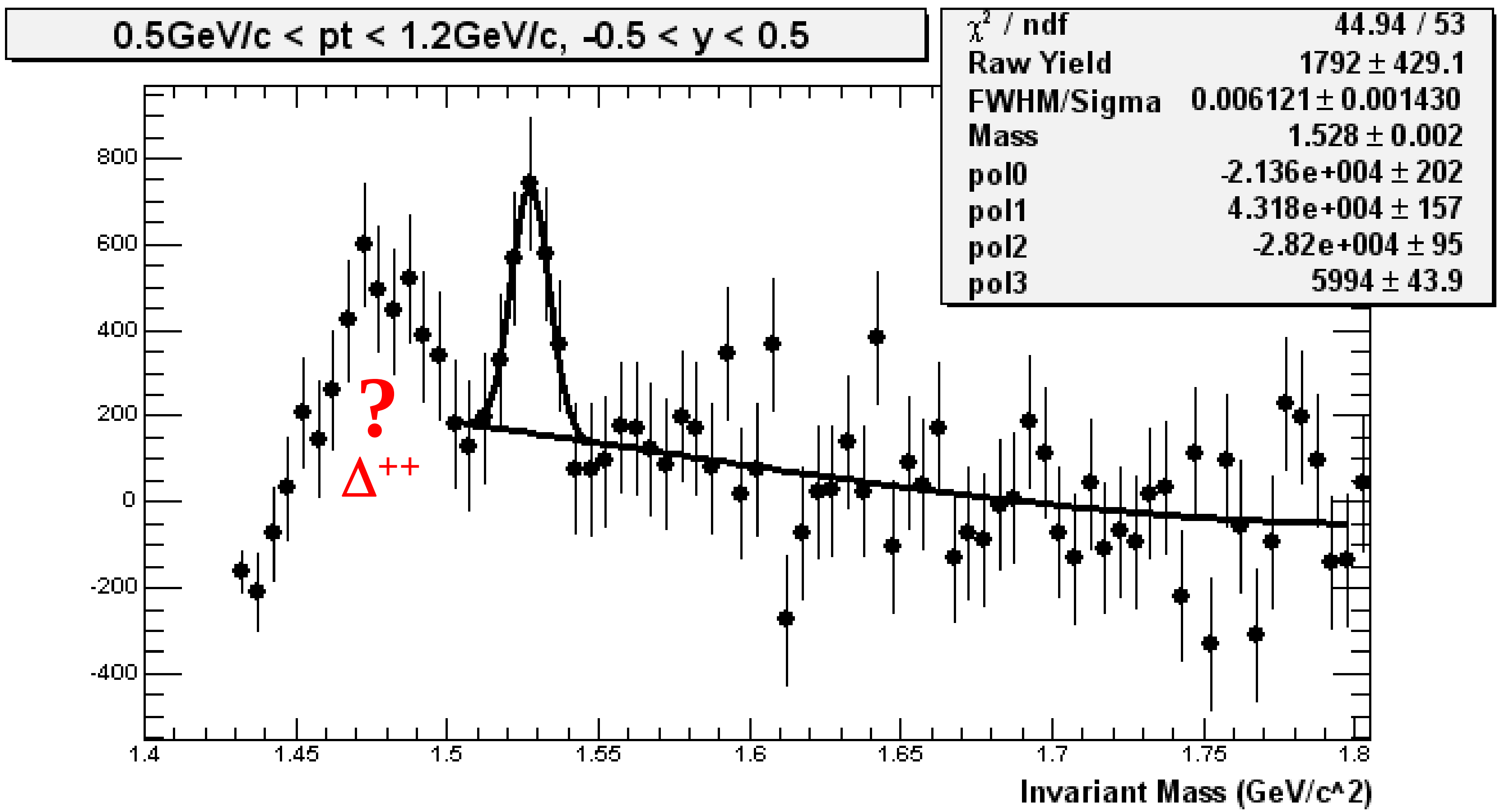
dAu results



pK^+ and $\bar{p}K^-$ from 18.6 M d+Au at 200 GeV

Background – Combinatorial and Correlated Pairs

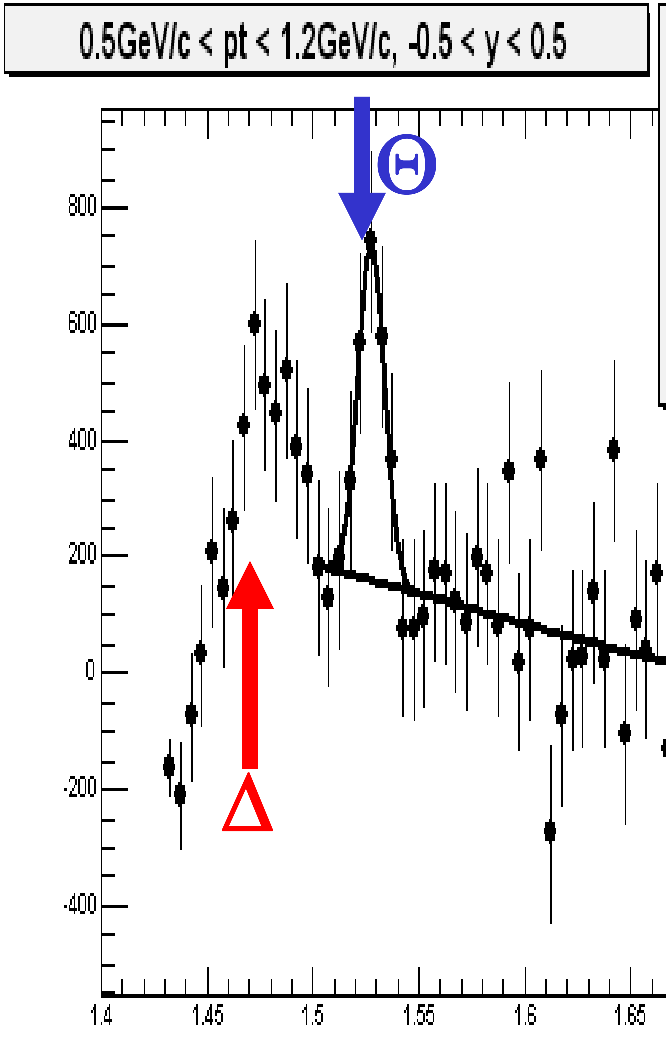
dAu results

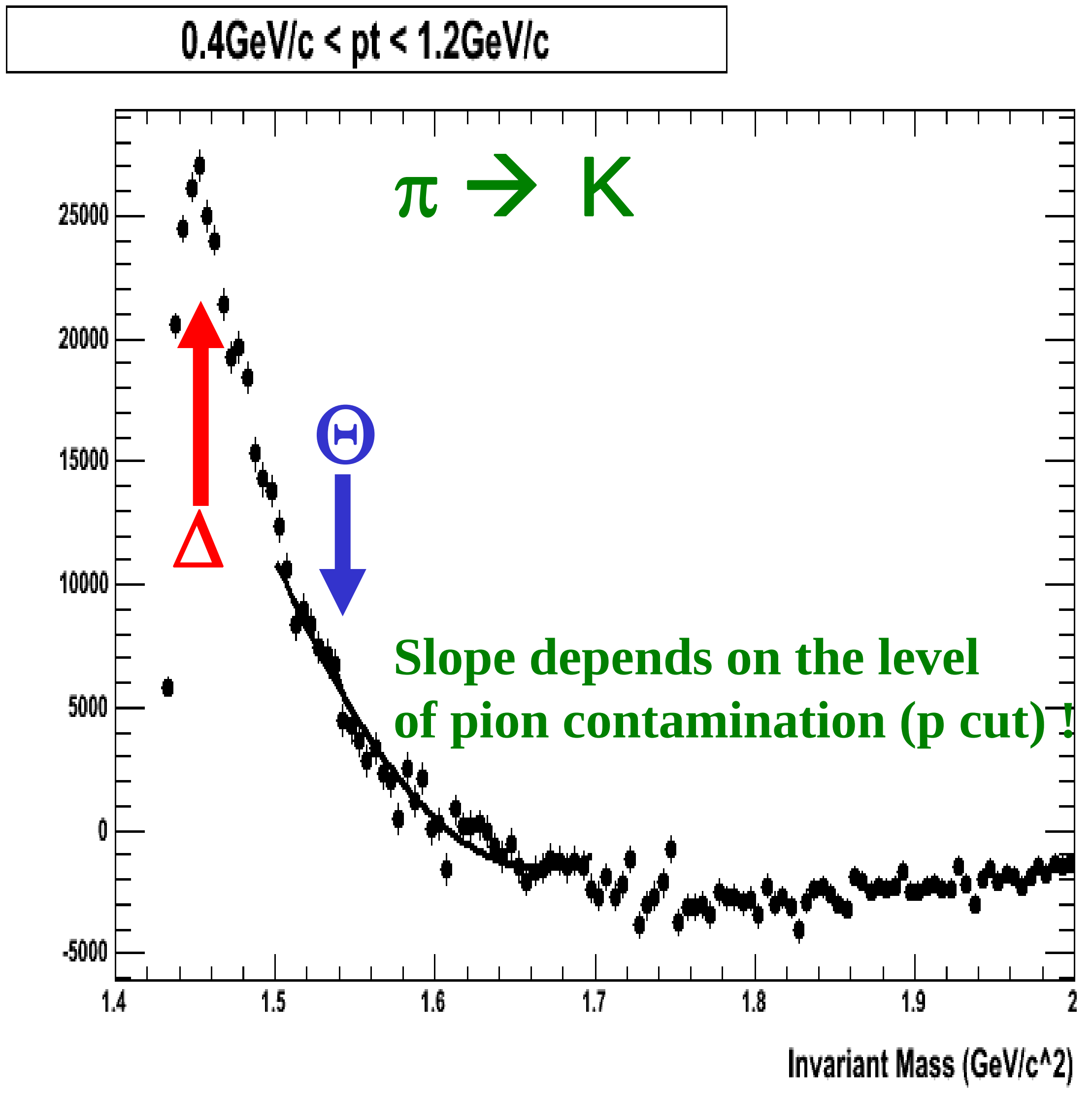


The invariant mass distribution is fitted to a Gaussian plus a linear function. A 3.5-5.0 sigma signal is seen

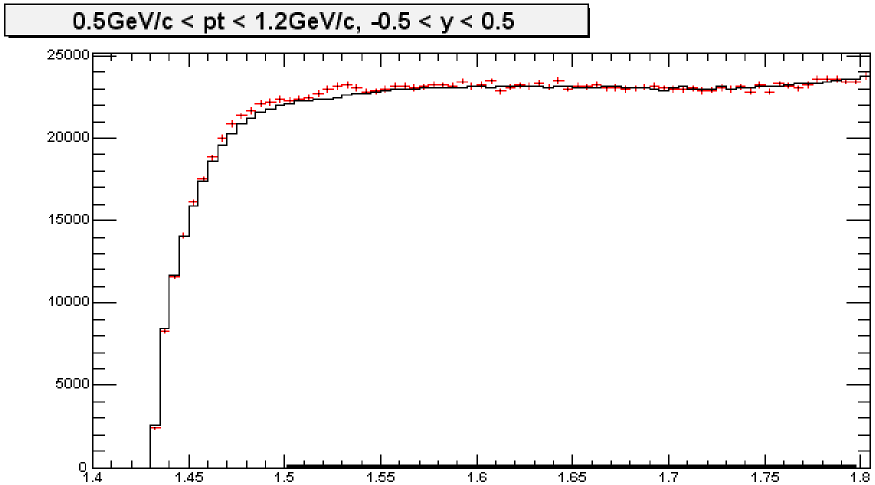
Measured mass is about 1.53 GeV/c^2. Full width is about 15 MeV

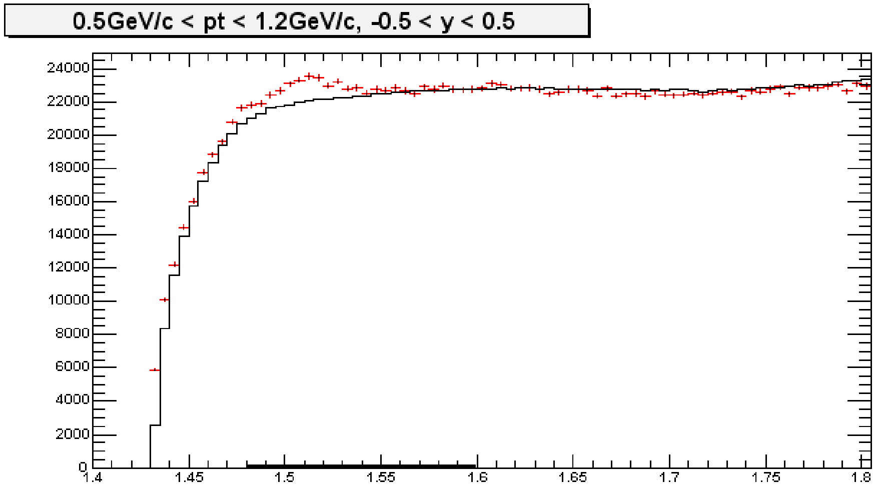
$\Delta^{++} \rightarrow \pi + p$ and using π as K



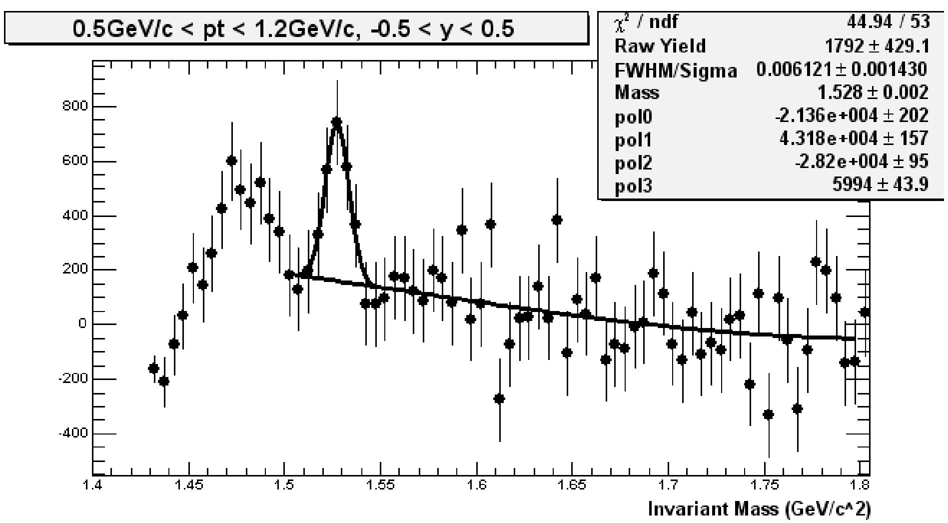


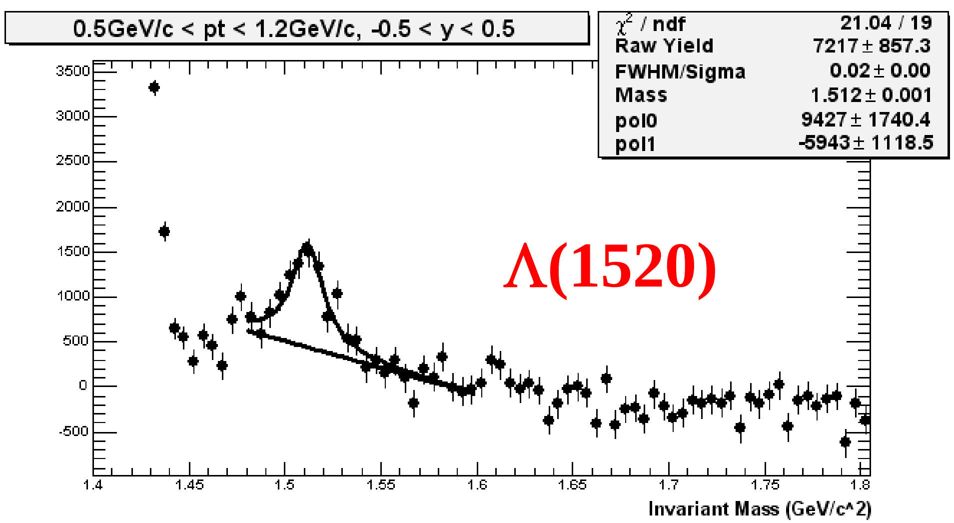
Θ^{++} and $\Lambda(1520)$ Using the Same Analysis Procedure





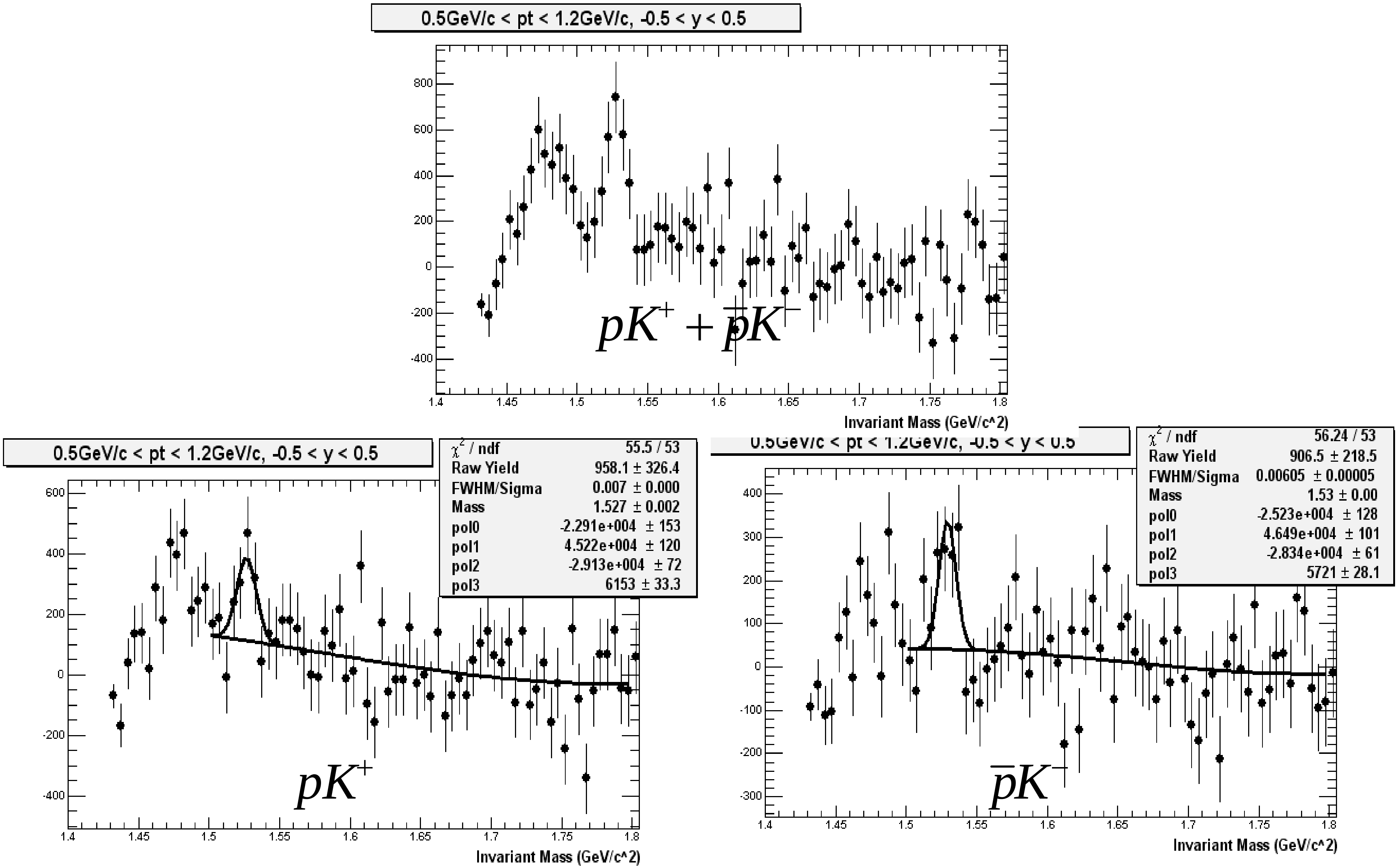
$pK^+ + \overline{p}K^-$ $\qquad$ $pK^- + \overline{p}K^+$



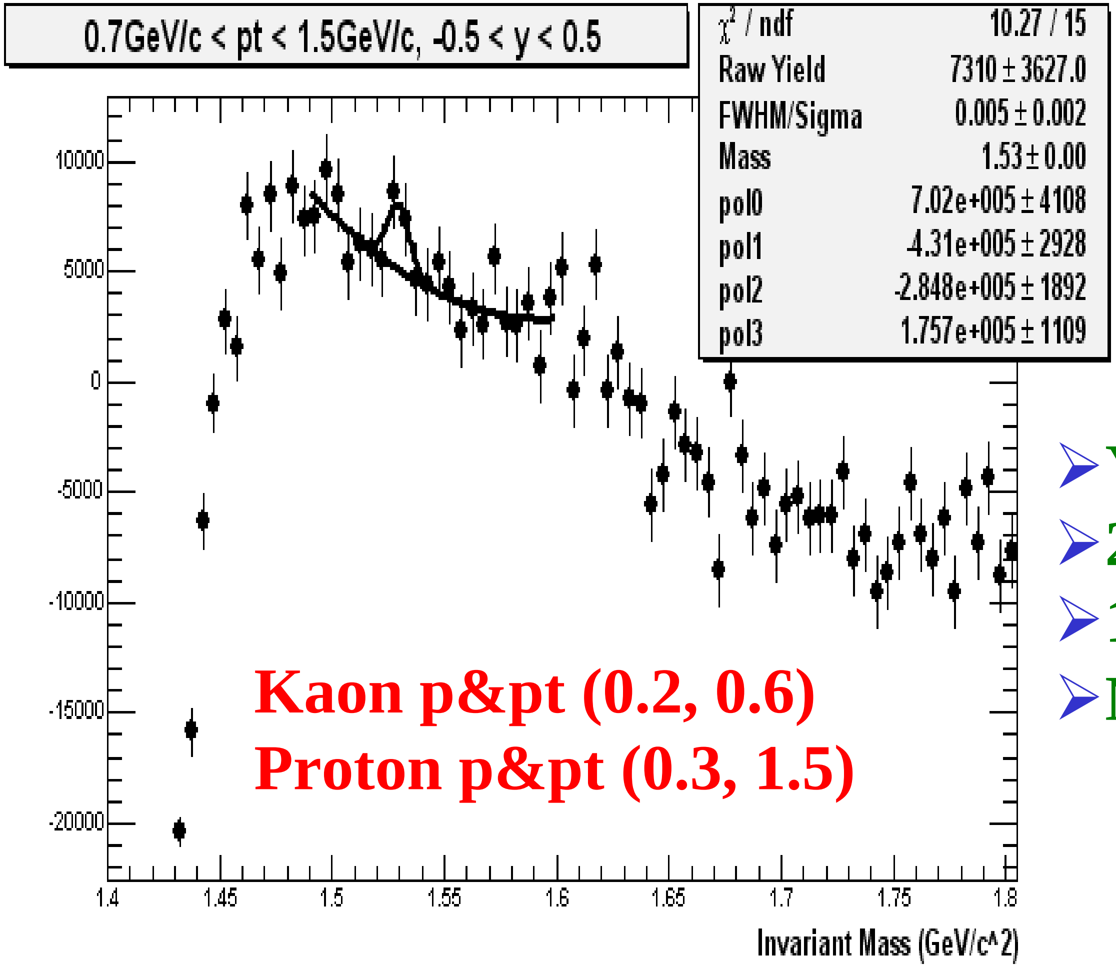


Same charge Sign (SS) and Opposite Sign (OS) background different

Can the Peak Be Real ??

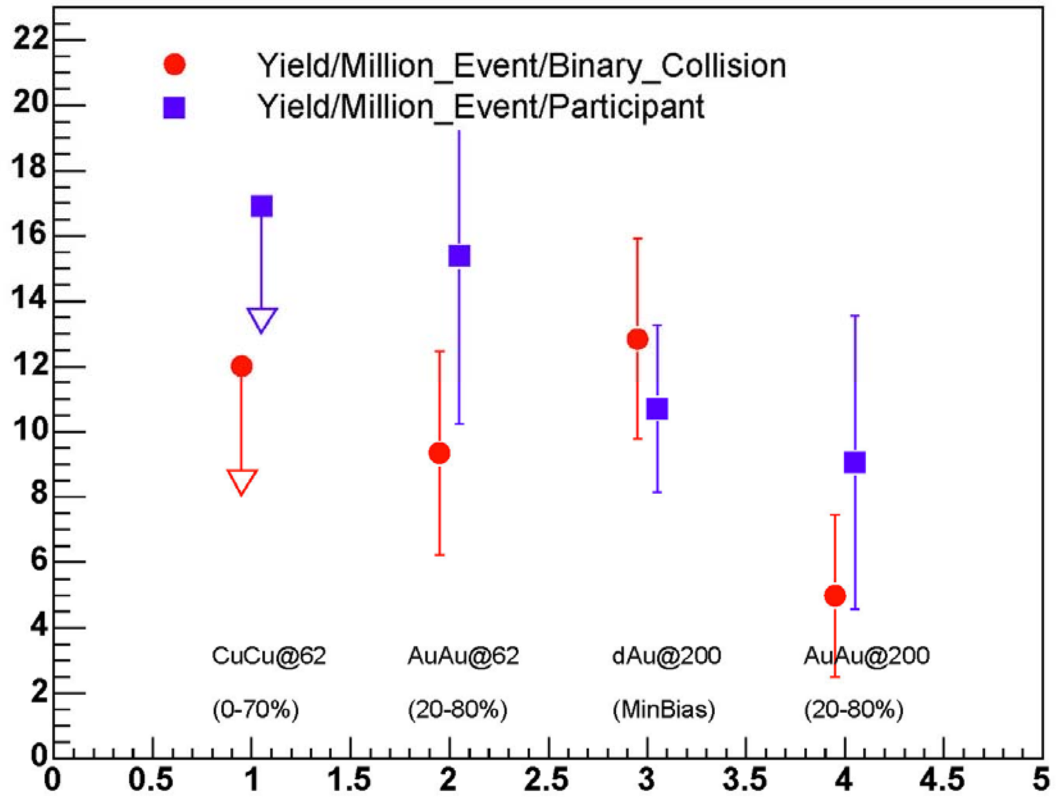


AuAu 200 GeV Run 4 Results



- Year 4 AuAu 200 GeV data
- 20-80% centrality bin
- 10.7 M events
- No Significant Signal (2σ)

Is There an Obvious Contradiction ?



The signal is not significant in Au+Au systems !
d+Au is indeed a favored system:
signal strength and combinatorial background !!
RHIC should have another long d+Au run !!

A Stringent Limit from HERA-B

HERA-B	**hep-ex/0408048**
sqrt(s)	**42 GeV**
pA (C,Ti,W)	**200 M inelastic events**
θ^+/Λ	**<0.92%; 95%CL**
$\theta^+/\Lambda(1520)$	**<2.7%; 95% CL**

Does this imply $\Lambda(1520)/\Lambda \sim 34\%$?

Our Estimate in STAR	
d+Au	**sqrt(s) 200 GeV**
θ^{++}/Λ	**~ 0.35%**

STAR $\Lambda(1520)/\Lambda \sim 10\%$ (corrected for branching ratio) !

The Puzzle Continues

1) If pK^+ peak at 1530 MeV/c^2 is a real pentaquark, then I = 1 likely, there must be a θ^+. But the recent JLab null result on θ^+ casts serious doubt on the observation of θ^+.

2) The STAR observed yield is so small such that many experiments would not have the sensitivity to see it.

3) Within the STAR data we have not seen any significant peak signal in p+p data, Au+Au at 200 GeV, Cu+Cu at 62 and 200 GeV.
   What do these null observations mean?
   Production dynamics or data set bias unknown to us?
   What is so special about d+Au 200 GeV (18.6 M events)?

4) Can the formation is such that photo-production is not favored?

An Intriguing Production Mechanism

If θ is a real particle, the production is different from normal hadrons which can be described by thermal statistical model.

Coalescence Mechanism --

pK^+ Interaction – Repulsive (not favored)

ΔK^+ Interaction – Attractive !!

ΔK Coalescence → Θ → pK^+
($N\pi K$ = 1575 MeV; $\Delta K > N\pi K$; but Δ is very wide !)

Δ lifetime ~ 1 fm → not easy for the coalescence process in e+e, photo-production and p+p collisions.

Θ spin 3/2, parity -1; pK d-wave decay → narrow width (KN formation scattering may not be so sensitive?!)

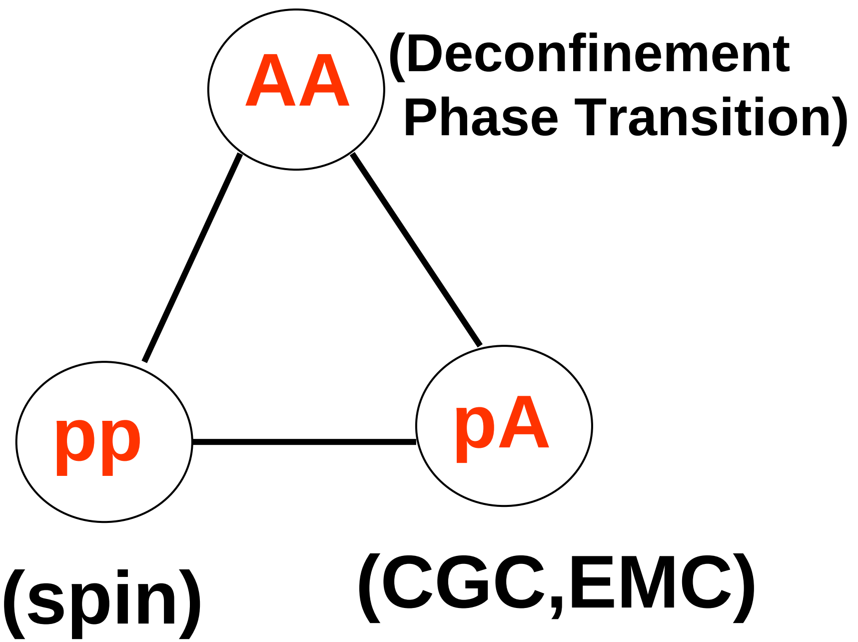
p+A collisions favored and another d+Au Run !

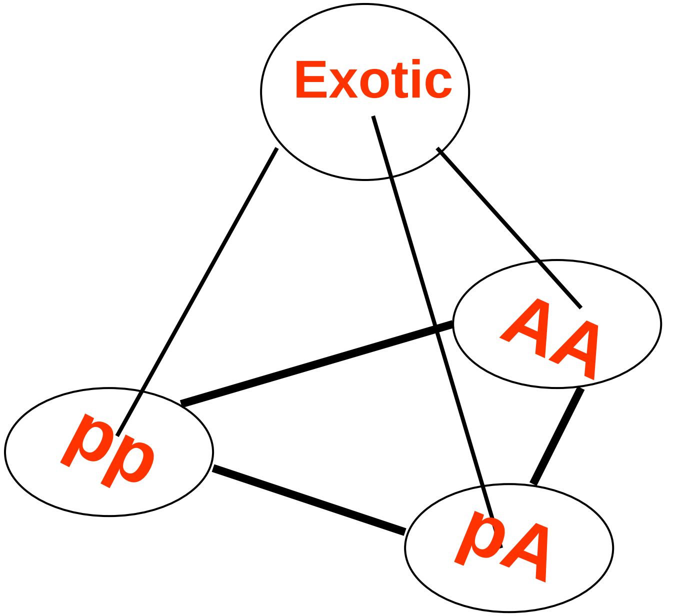
Exotic Particles

Hadrons with internal structure beyond existing QCD qqq and q-qbar framework !!

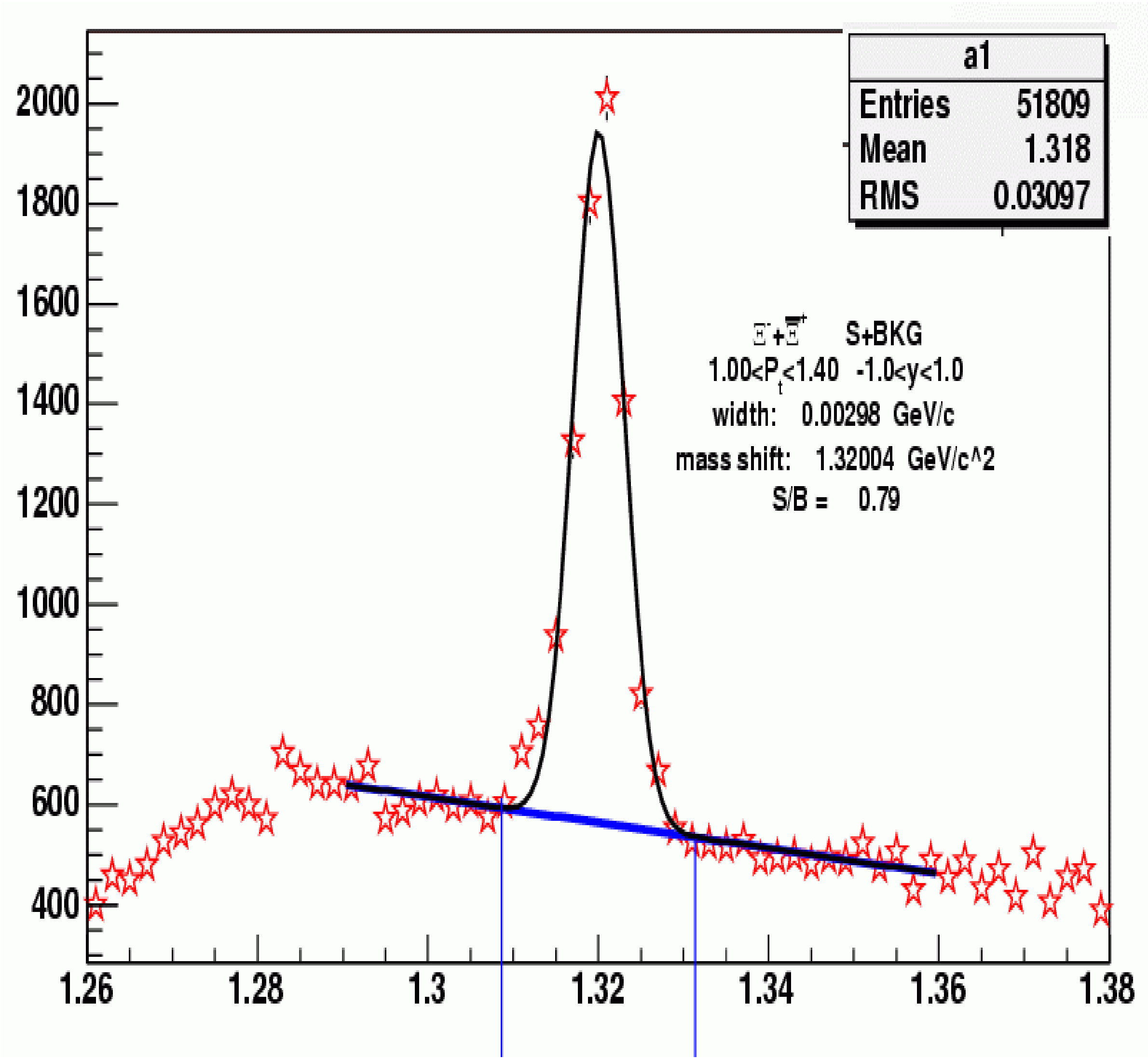
RHIC –

Dedicated QCD Machine & Beyond





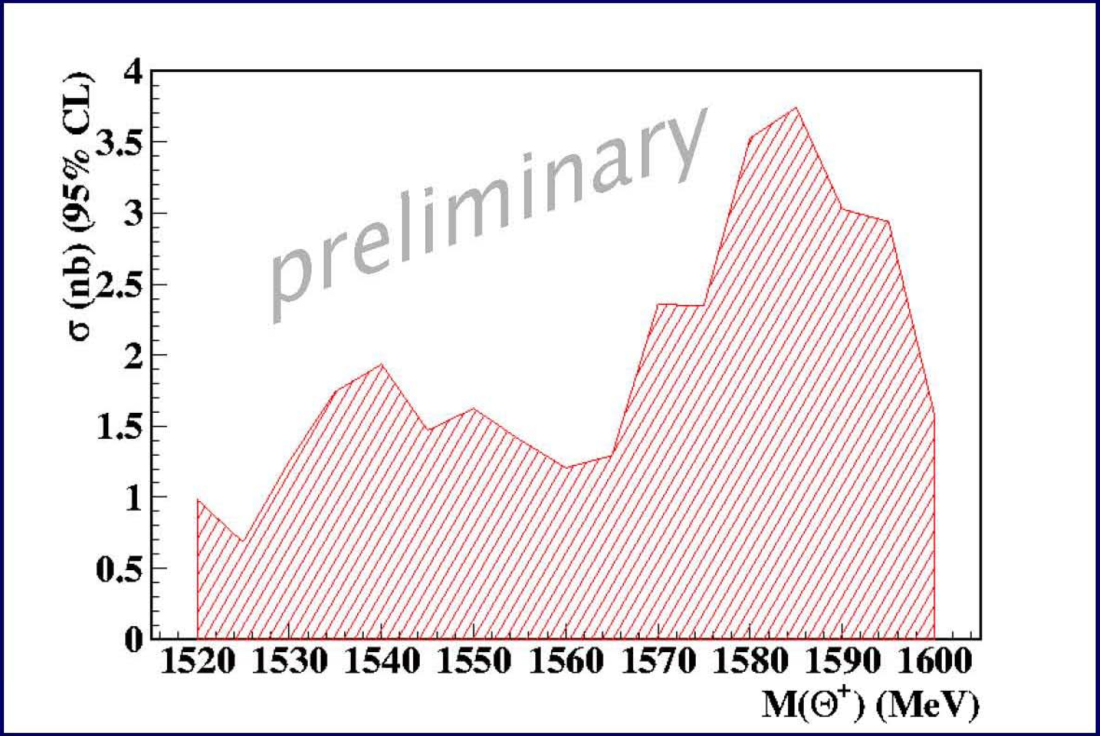
The End



a1
Entries 51809
Mean 1.318
RMS 0.03097
$\Xi^- + \bar{\Xi}^+$ S+BKG
$1.00<P_t<1.40$ $-1.0<y<1.0$
width: 0.00298 GeV/c
mass shift: 1.32004 GeV/c^2
S/B = 0.79
2000
1800
1600
1400
1200
1000
800
600
400
1.26
1.28
1.3
1.32
1.34
1.36
1.38

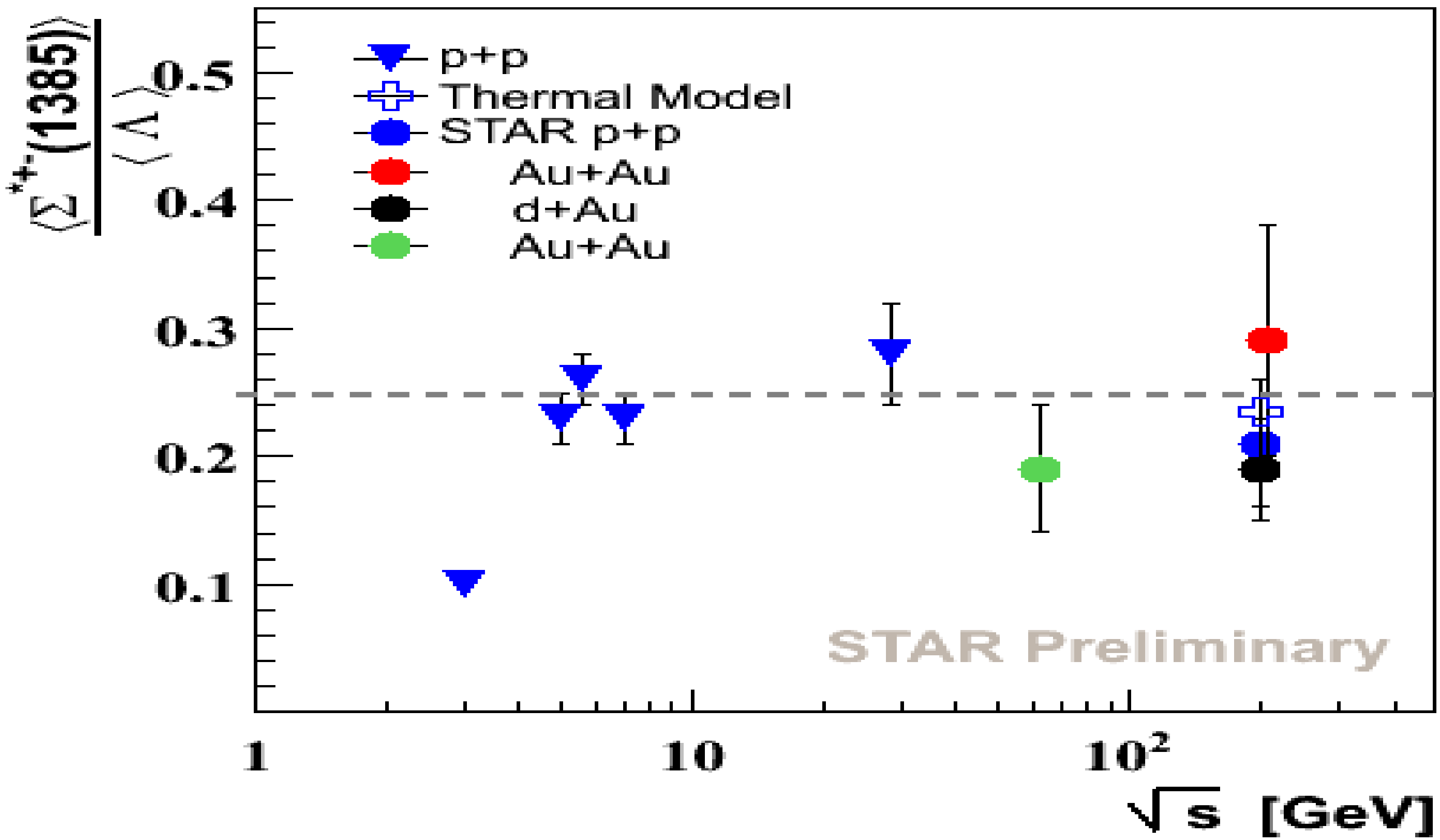
Upper Limit on the Θ^+ Cross section

mass dependence



Upper limit (95% CL)

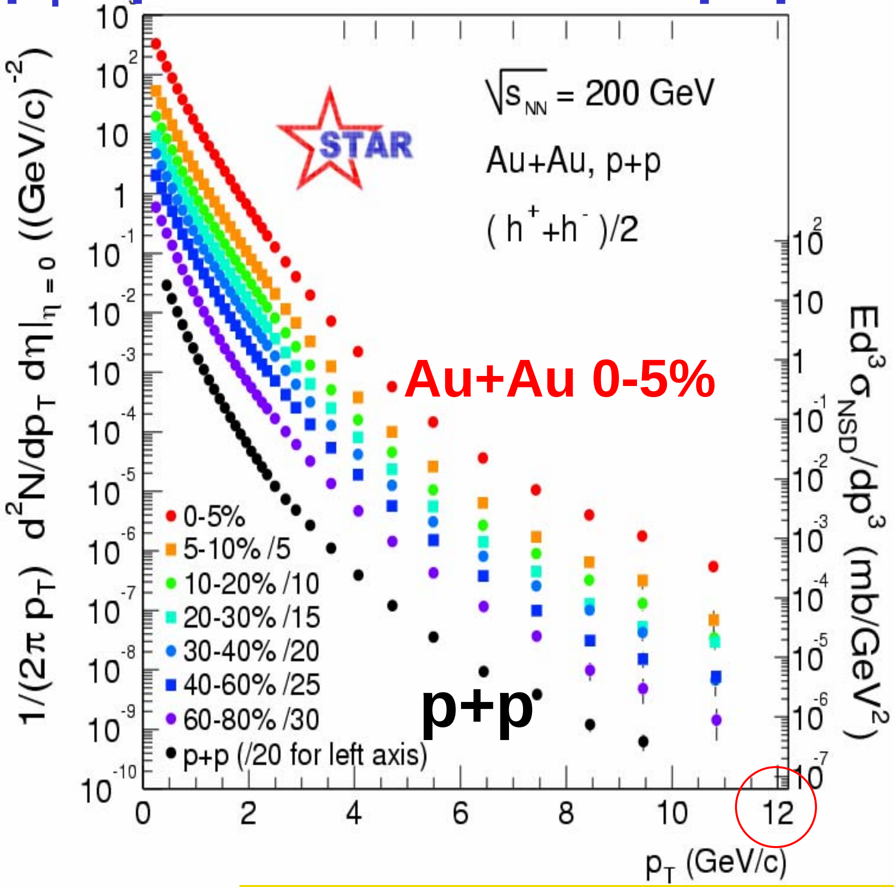
$\sigma_{\gamma p \to \Theta^+ K^0} < 1\text{–}4$ nb



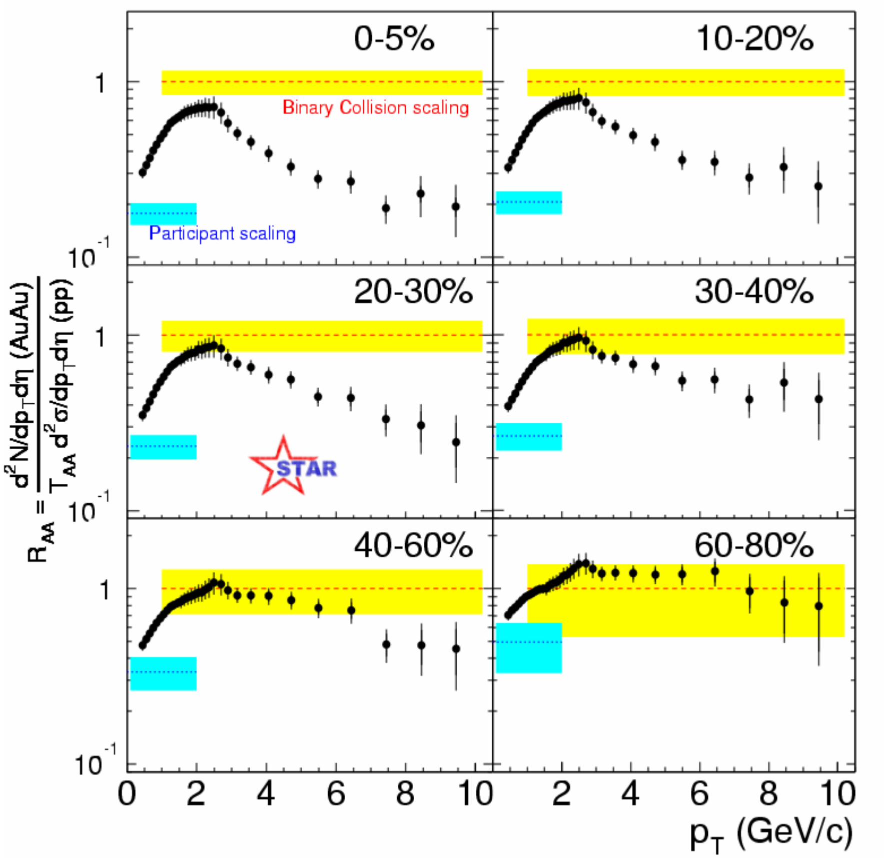
Σ^*/Λ independent of system size at 200 GeV and equal to p+p values at lower energies.

Suppression of high p_T particles

p_T Spectra Au+Au and p+p

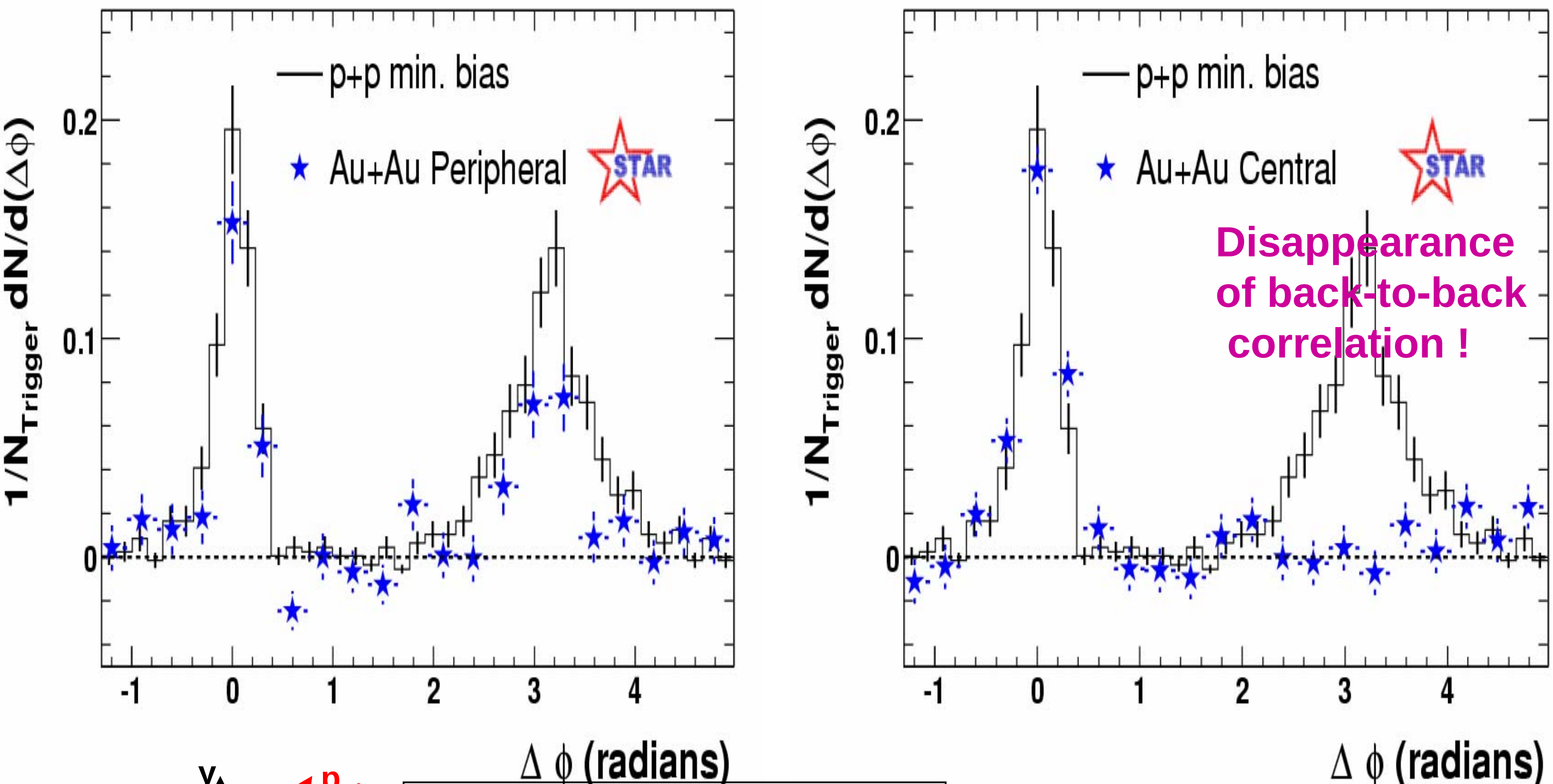


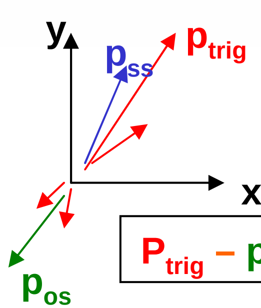
R_{AA}=(Au+Au)/[N_{binary}x(p+p)]



Strong high p_T suppression by a factor of 4-5 in central Au+Au collisions !
The suppression sets in gradually from peripheral to central Au+Au collisions !

Disappearance of back-to-back angular correlations





P_{trig} – p_{ss} same side ϕ correlation

p_{trig}> 4 GeV/c, p_{ss} p_{os} $2<p_T<p_{trig}$

P_{trig} – p_{os} opposite side ϕ corr.