

# Strangeness in STAR

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for the STAR Collaboration

"...to myself I seem to have been  
only like a boy playing on the  
seashore, and diverting myself in  
now and then finding a smoother  
pebble or a prettier shell than  
ordinary, whilst the great ocean of  
truth lay all undiscovered before  
me." --Sir Isaac Newton

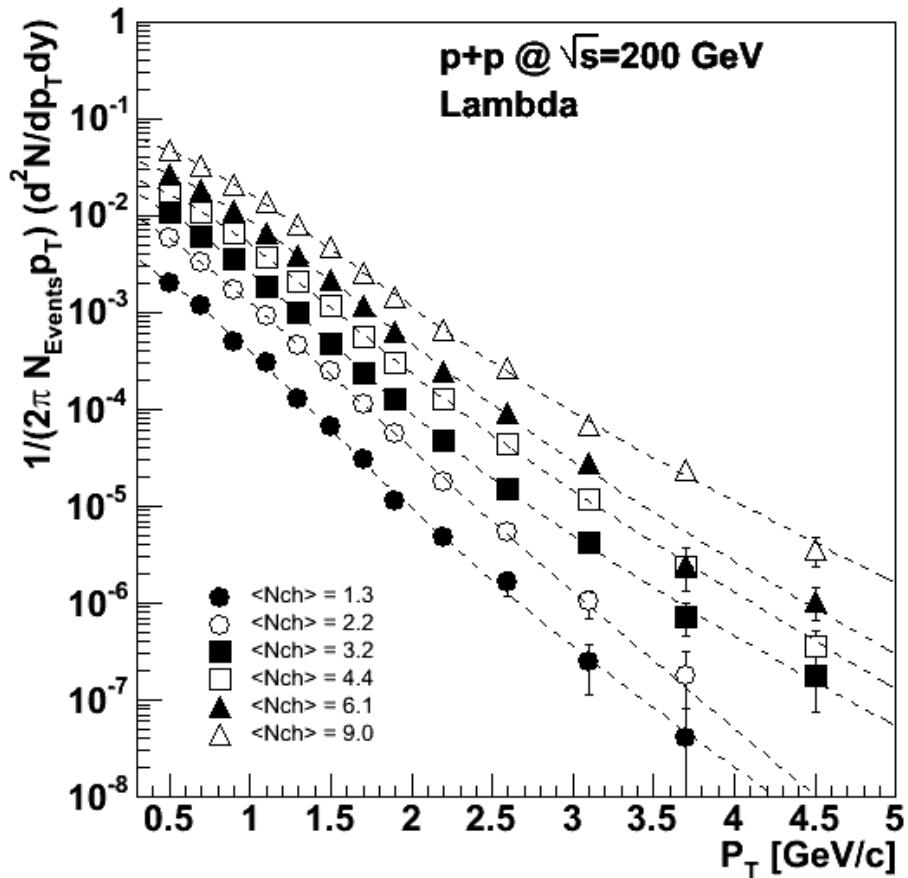
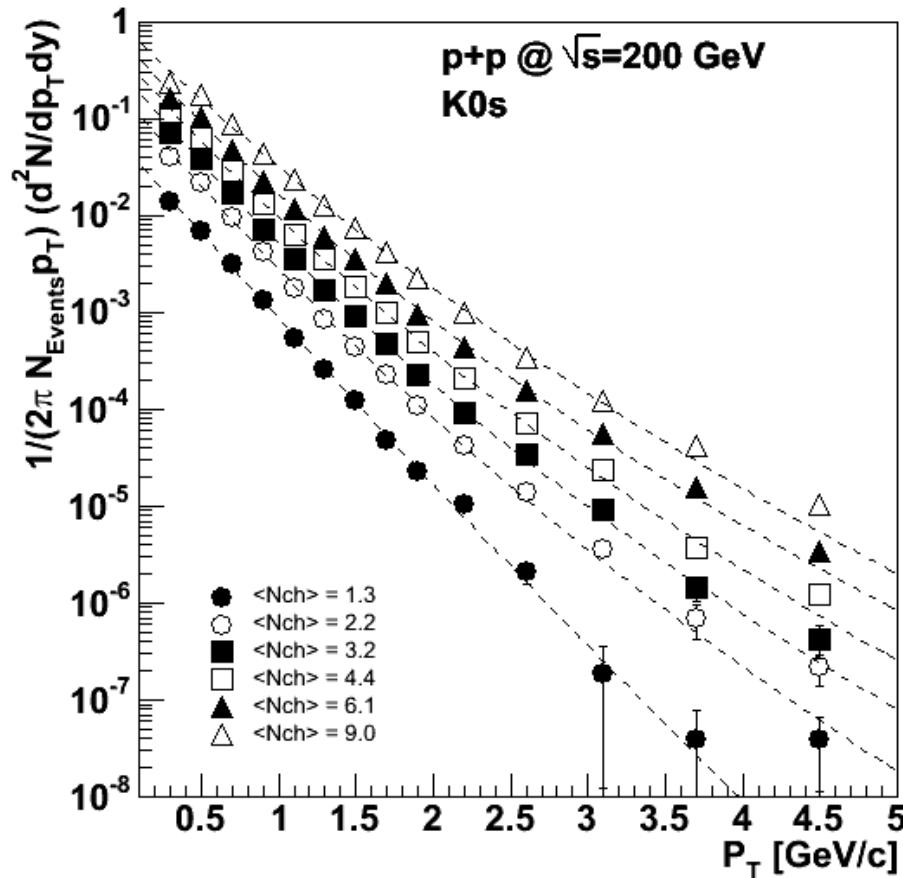


# Outline

- Strange Spectra from  $p+p$
- $\langle p_T \rangle$  Systematics
- $m_T$ -scaling
- Comparisons to Au+Au
- Strangeness Enhancement
- Canonical Suppression
- $N_{\text{Part}}$ ,  $N_{\text{Bin}}$ , & Volume Effects
- Resonances & Time Scales
- Coming Soon
- Conclusions



# $K_S^0$ & $\Lambda$ Spectra ( $p+p$ )

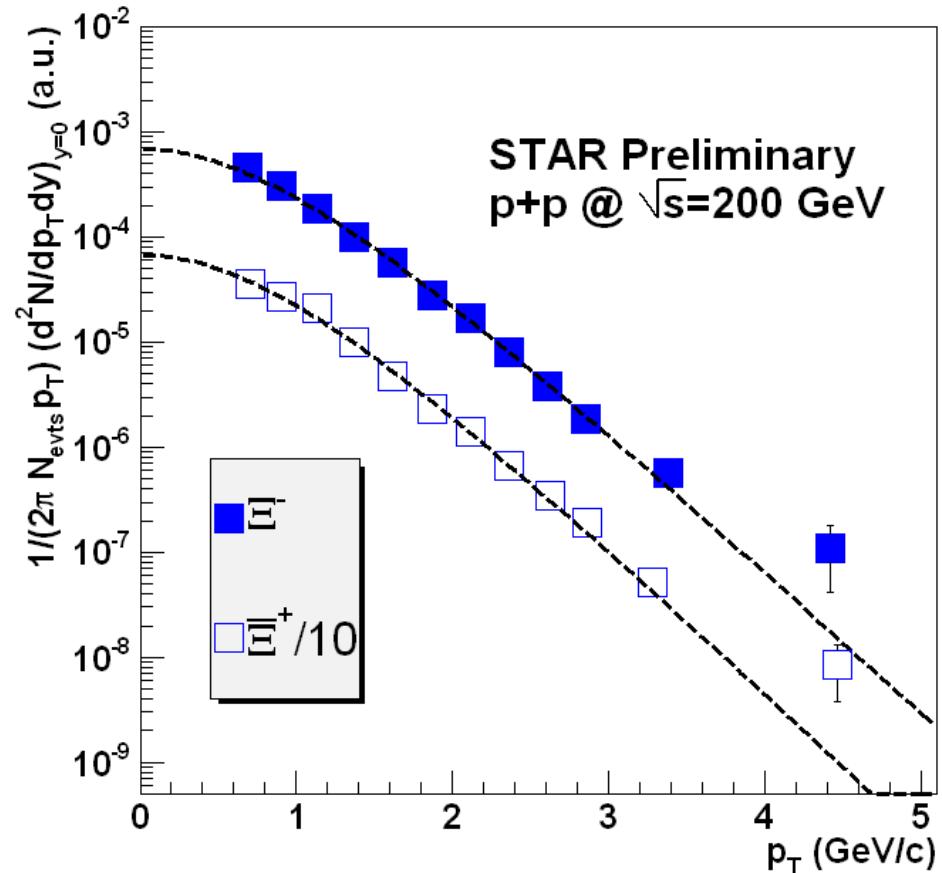


- Results from full  $p+p$  statistics (~14 million events)
- Sufficient statistics for at least 6 multiplicity bins
- Composite fits (Power-law +  $m_T$ -exponential)

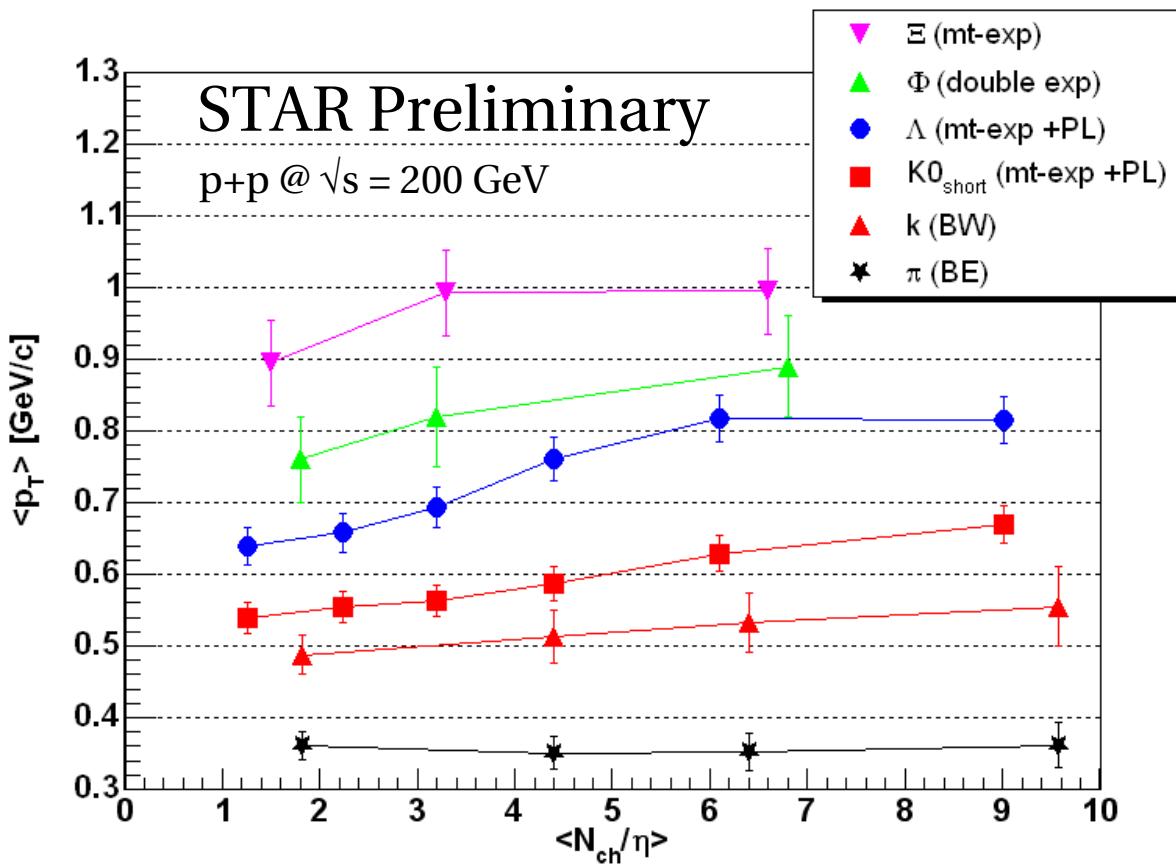
# $\Xi$ Spectra ( $p+p$ )

	STAR $\langle p_T \rangle$	UA5 $\langle p_T \rangle$	STAR $dN/dy$	UA5 $dN/dy$
$K_s^0$	$0.60 \pm 0.006$	$0.53 (+0.8, -0.06)$	$0.128 \pm 0.008$	$0.12 \pm 0.08$
$\Lambda$	$0.76 \pm 0.005$	$0.8 (+0.2, -0.14)$	$0.044 \pm 0.003$	$0.034 \pm 0.01$
$\Xi$	$0.97 \pm 0.02$	$0.8 (+0.4, -0.2)$	$0.0018 \pm 0.0005$	$0.0025 \pm 0.003$

- Fits are  $m_T$ -exponential
- Sufficient for limited binning in multiplicity
- Systematic errors
  - $\langle pT \rangle$ : ~6%
  - $dN/dy$ : ~15%

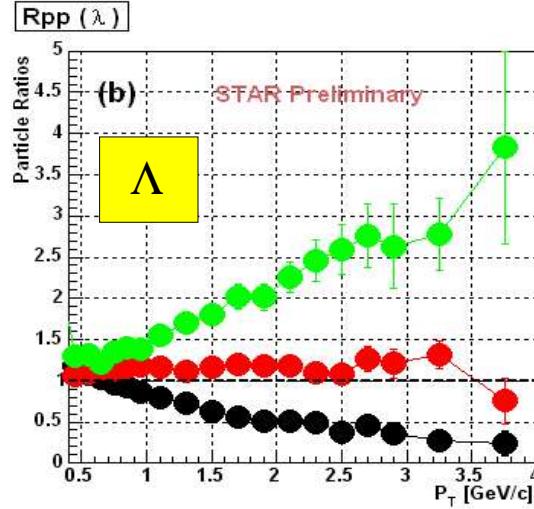
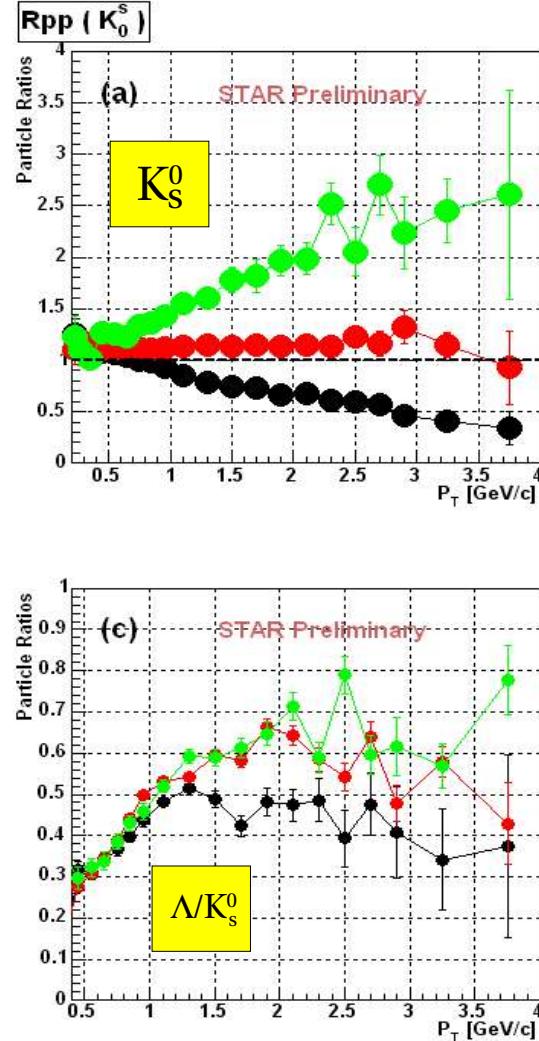


# $\langle p_T \rangle$ vs. Multiplicity



- Clear mass ordering
- Stronger trend with increasing strangeness
- Saturation in the heavier particles?

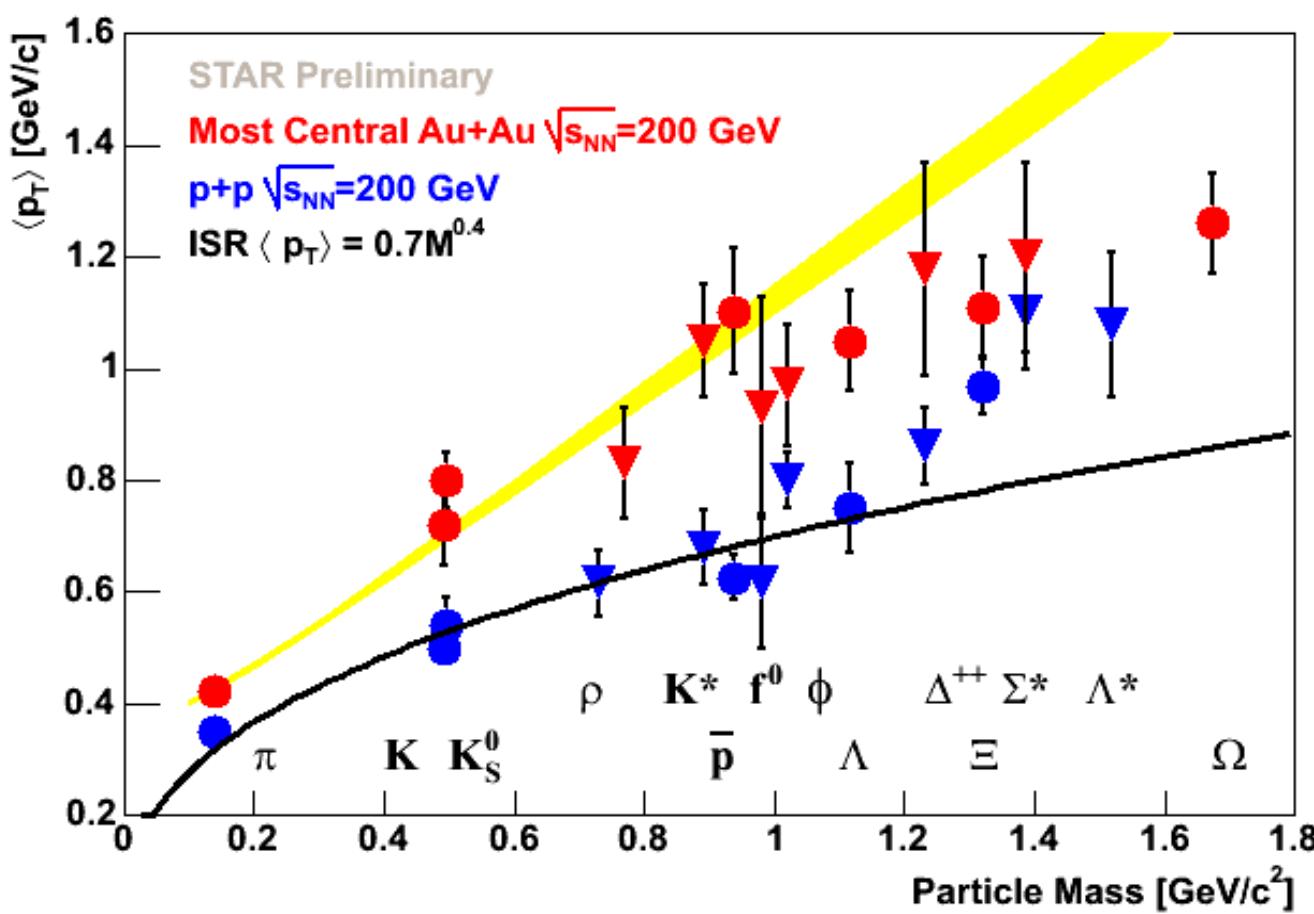
# $\langle p_T \rangle$ vs. Multiplicity ( $R_{pp}$ )



- $\langle N_{\text{charge}} / \eta \rangle = 1.95$
- $\langle N_{\text{charge}} / \eta \rangle = 4.67$
- $\langle N_{\text{charge}} / \eta \rangle = 9.01$

- Multiplicity-binned spectrum divided by the minbias spectrum
- Spectra broadening with increasing multiplicity
- Relative strength visible in the double ratio

# $\langle p_T \rangle$ vs. Particle Mass

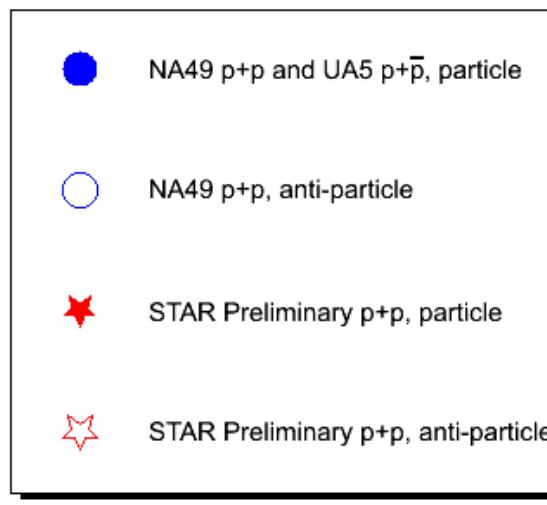
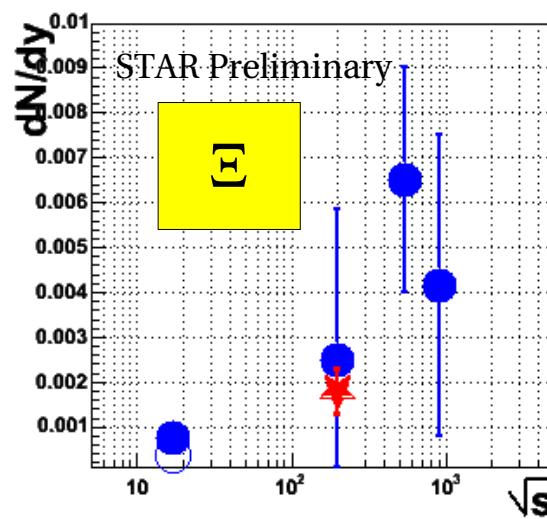
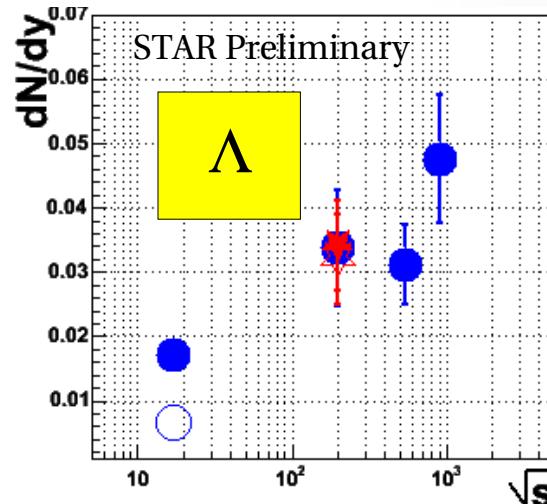
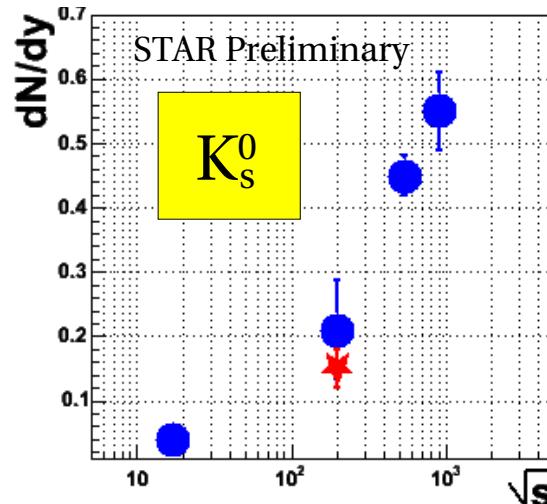


- Convergence for higher masses?
- Another area for resonances to contribute

Greater than 14 species measured in two systems (most in d+Au as well)

Good agreement with parameterization of previous ISR data (only  $\pi$ ,  $K$ ,  $p$ )

# Mid-Rapidity Yields ( $p+p$ )



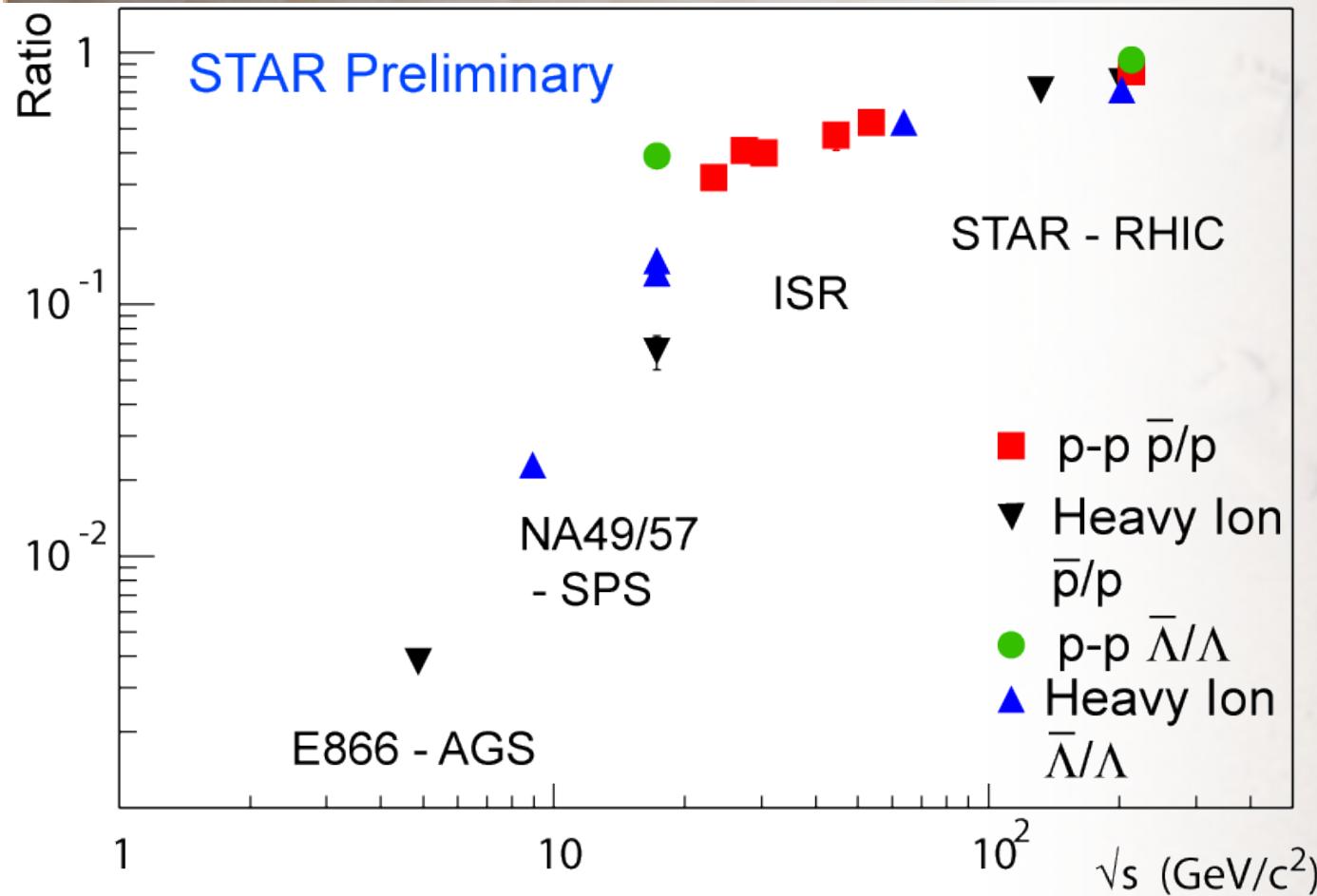
● Excellent agreement with previous measurements

● Greatly improved precision

● Error bars include 15% systematic error

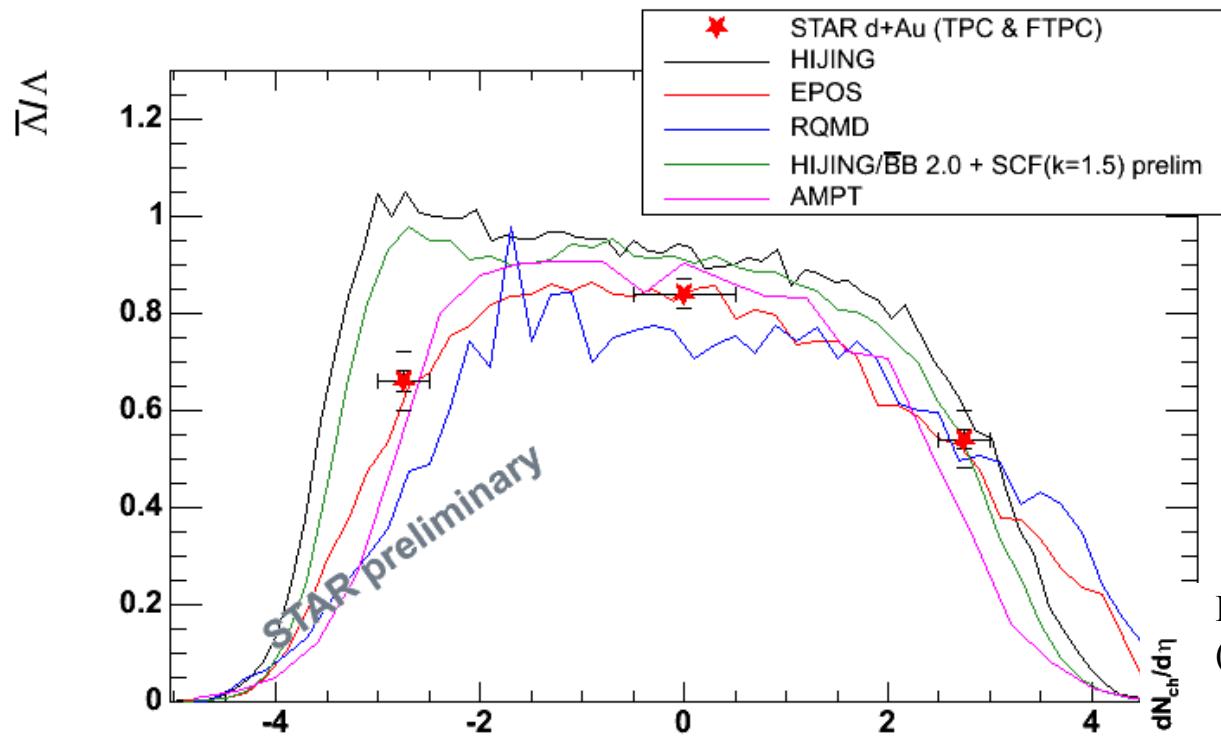
● Anti-particle/particle ratio converging with increasing  $\sqrt{s}$

# $\bar{B}/B$ Ratios from AGS to RHIC

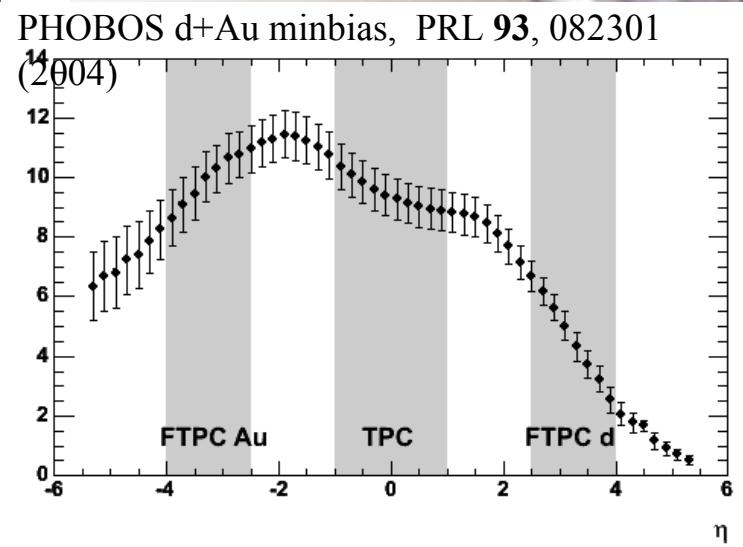
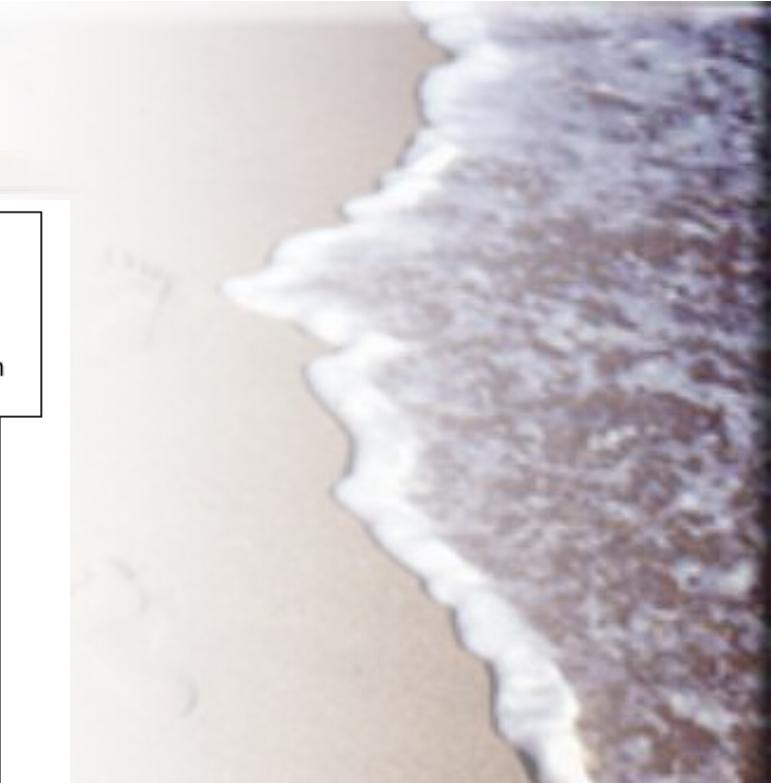


● Not (yet) baryon free at mid-rapidity

# Forward $\Lambda$



- Anti-Baryon/Baryon is changing
- Only EPOS does well on both sides
- Look forward to Au+Au results

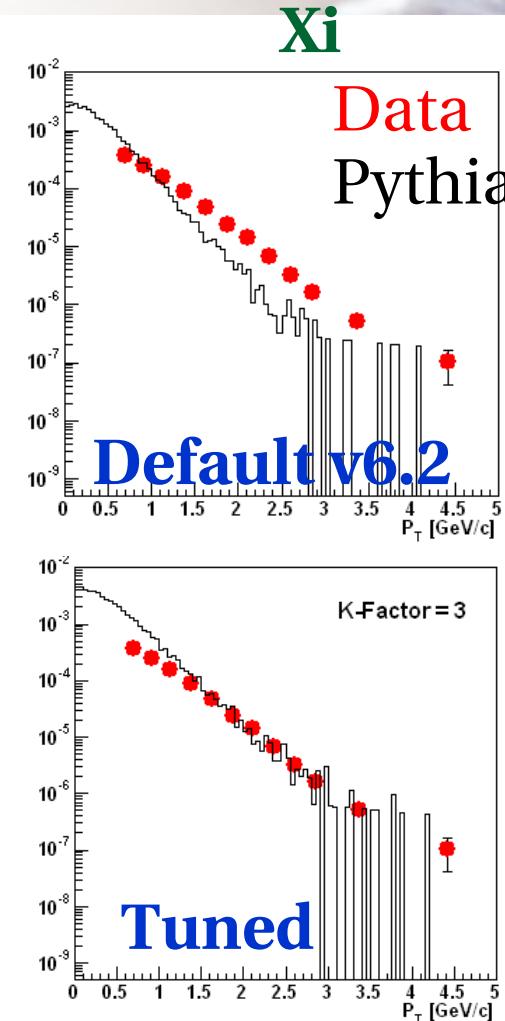
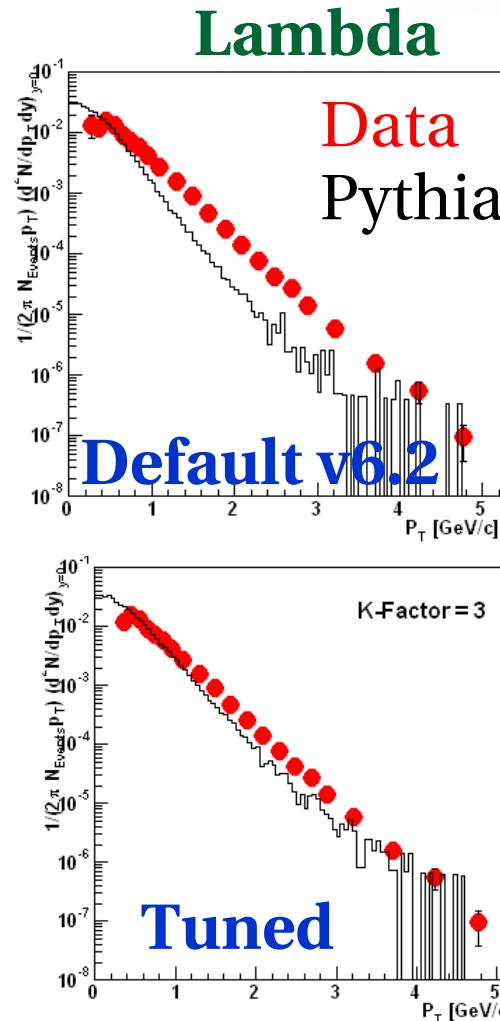
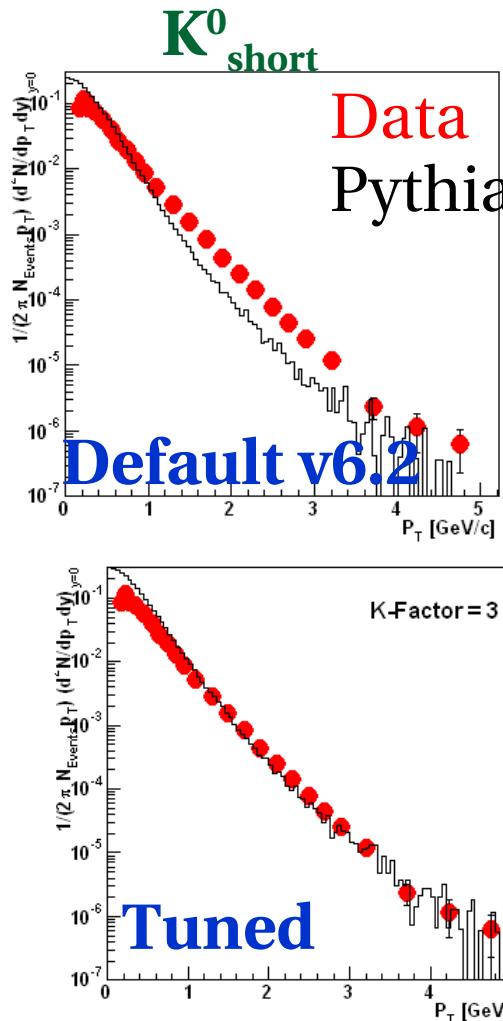


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# PYTHIA Comparisons



Results presented Thursday by M. Heinz



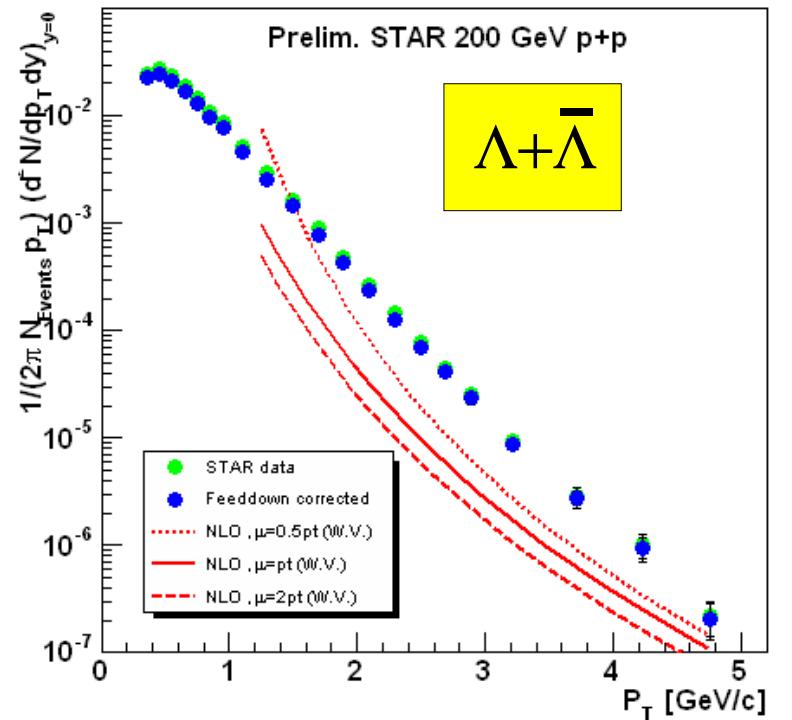
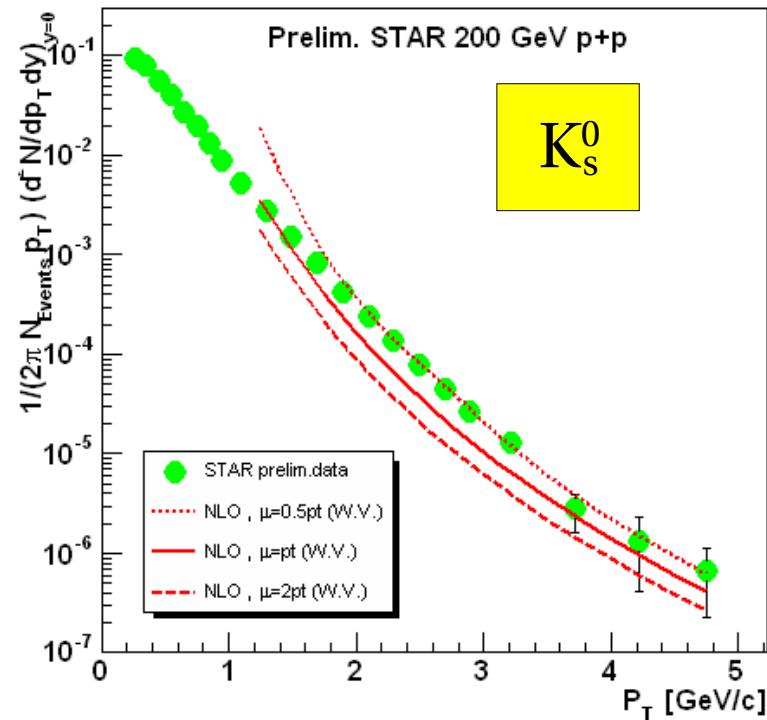
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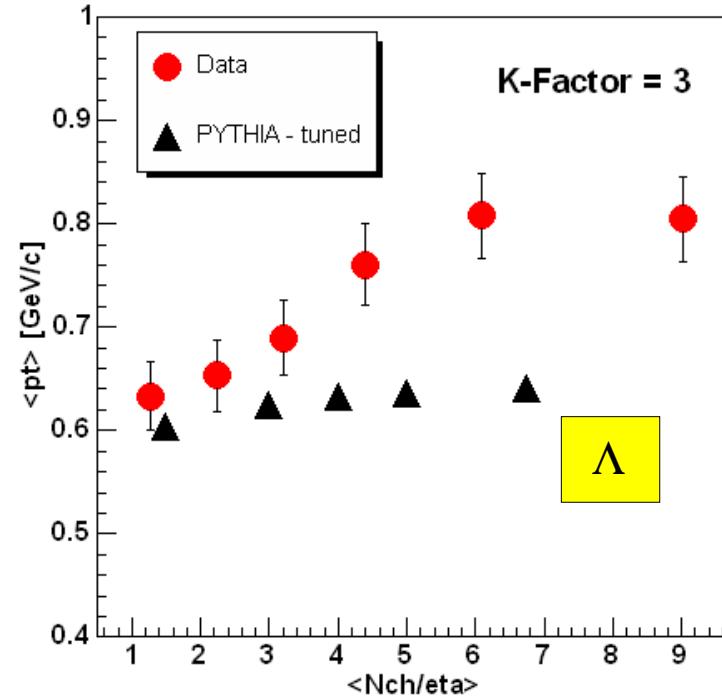
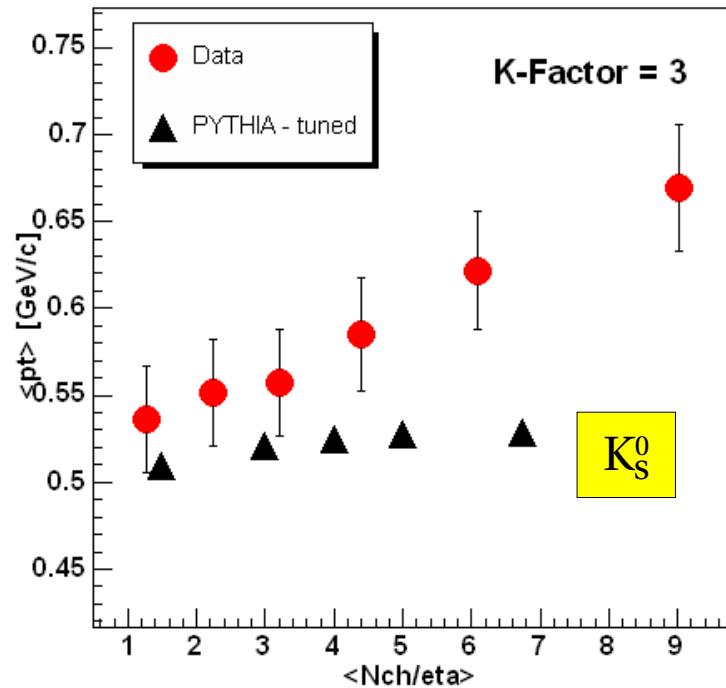
# PYTHIA NLO Comparisons

Thanks to Werner Vogelsang, Riken BNL



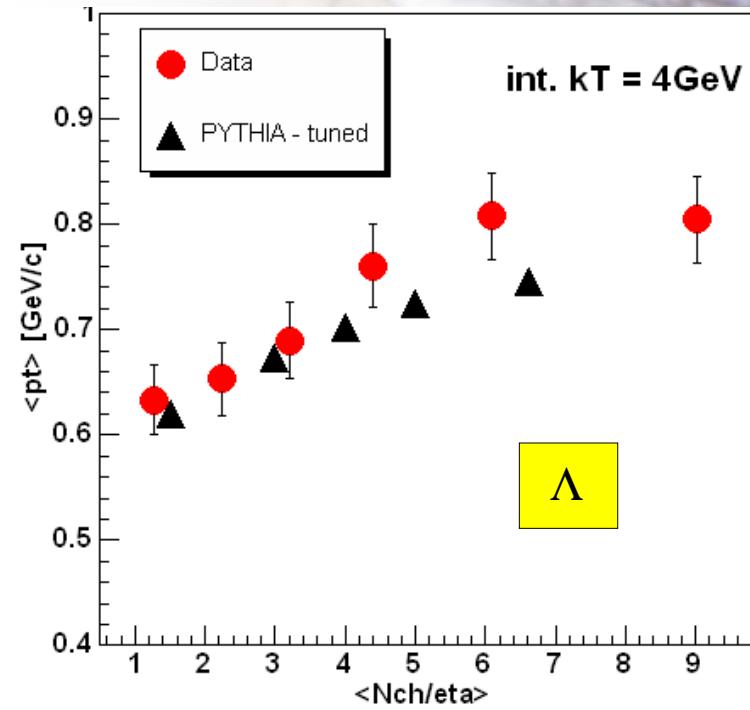
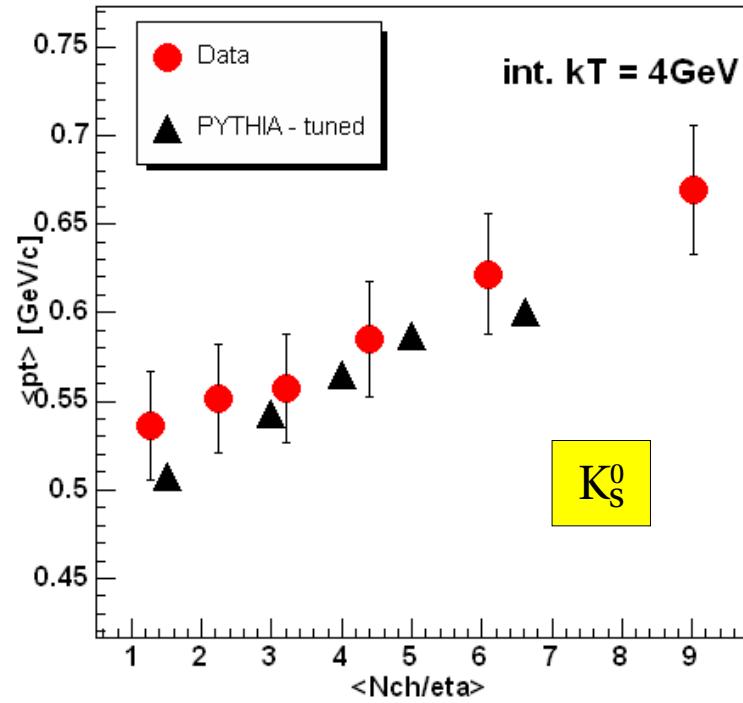
- Seems okay for  $K_0$
- $\Lambda$  has issues
  - Assumed massless in calculation

# PYTHIA Multiplicity Trends



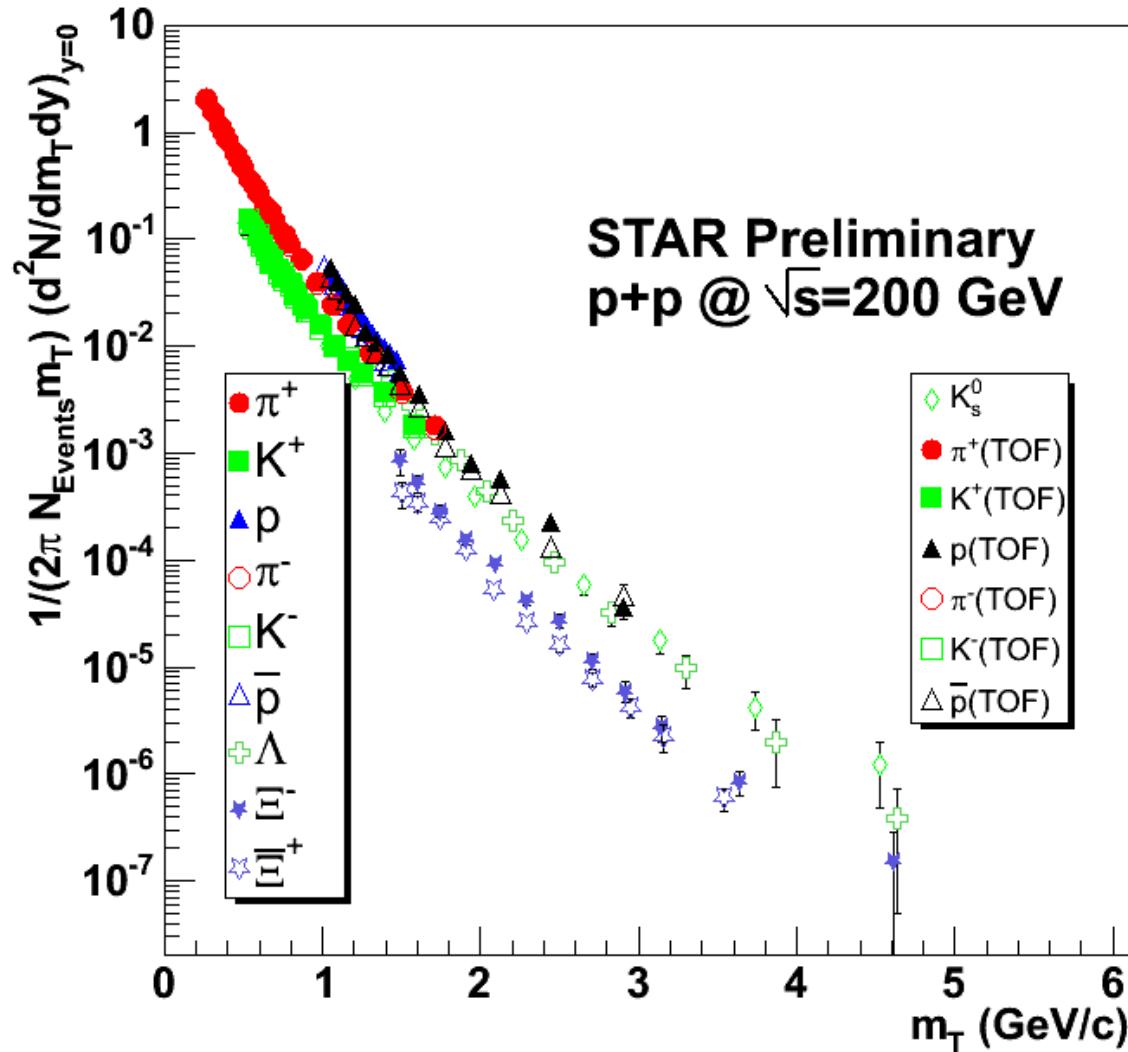
- Adjustment of k does not reproduce the strength or the magnitude.
- CDF sees similar problems for charged hadrons
- Can try other parameters...

# PYTHIA Multiplicity Trends



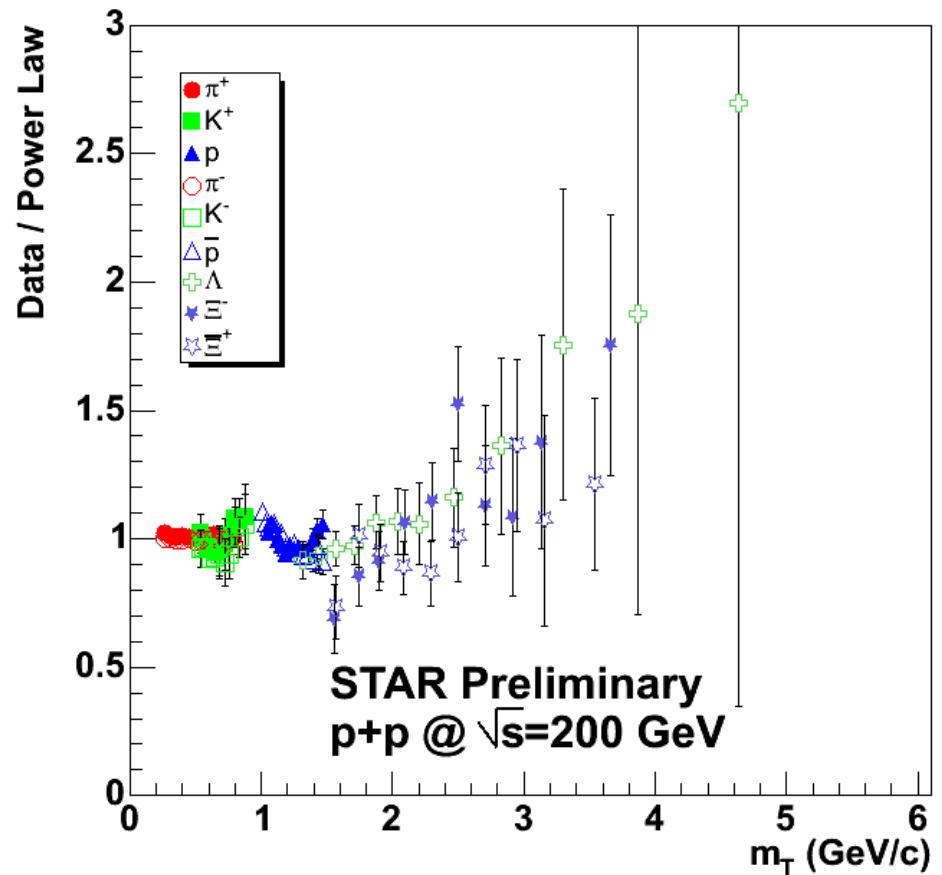
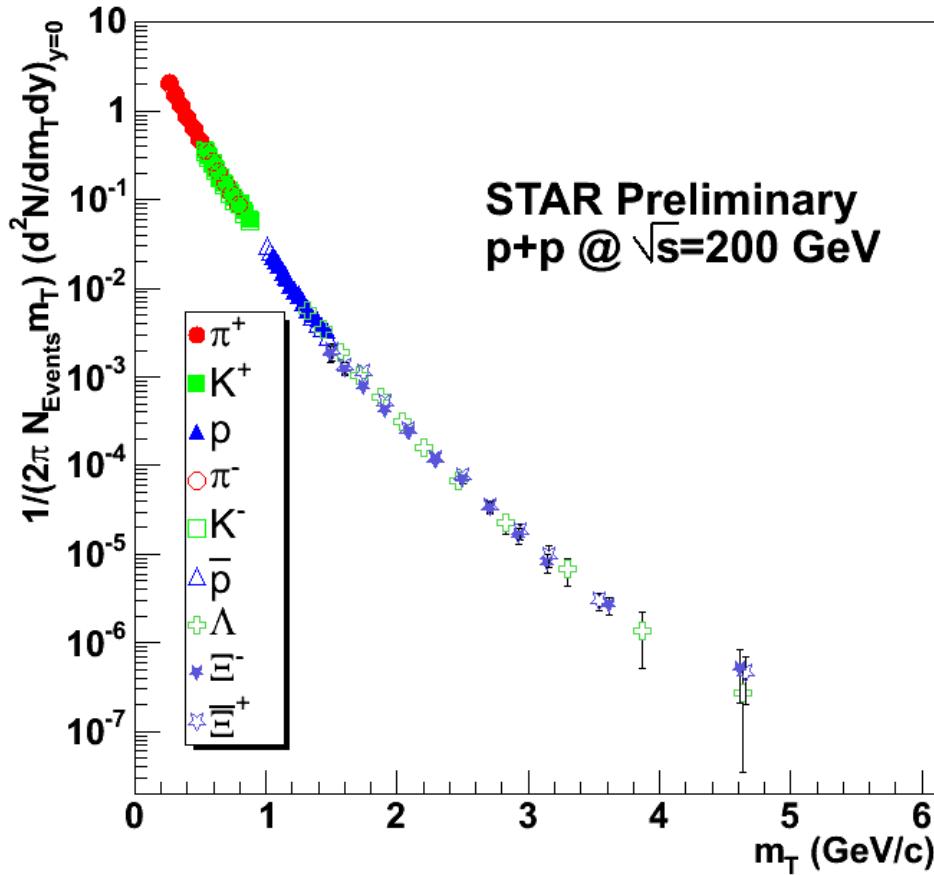
- ...but required  $k_T$  is questionable

# $m_T$ -scaling ( $p+p$ )



- “True”  $m_T$ -scaling means
- Similar shape
- Similar yield
- Single curve
- 6 species (+Antis)
- No absolute  $m_T$ -scaling
- Shapes similar though

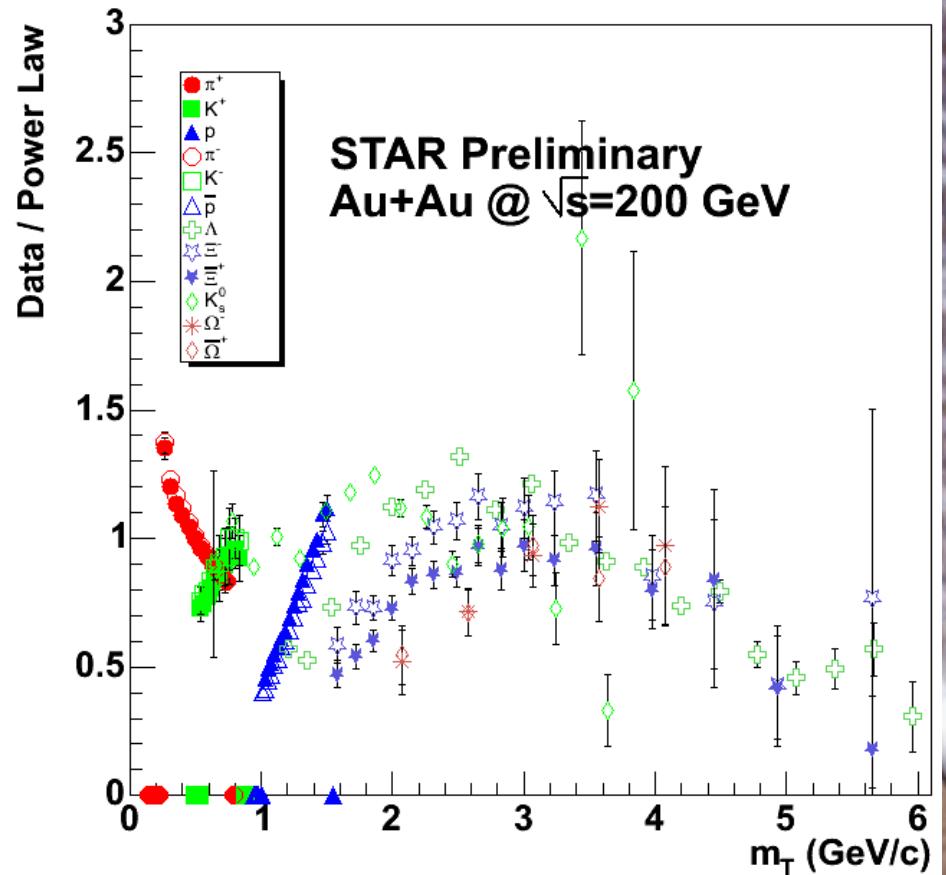
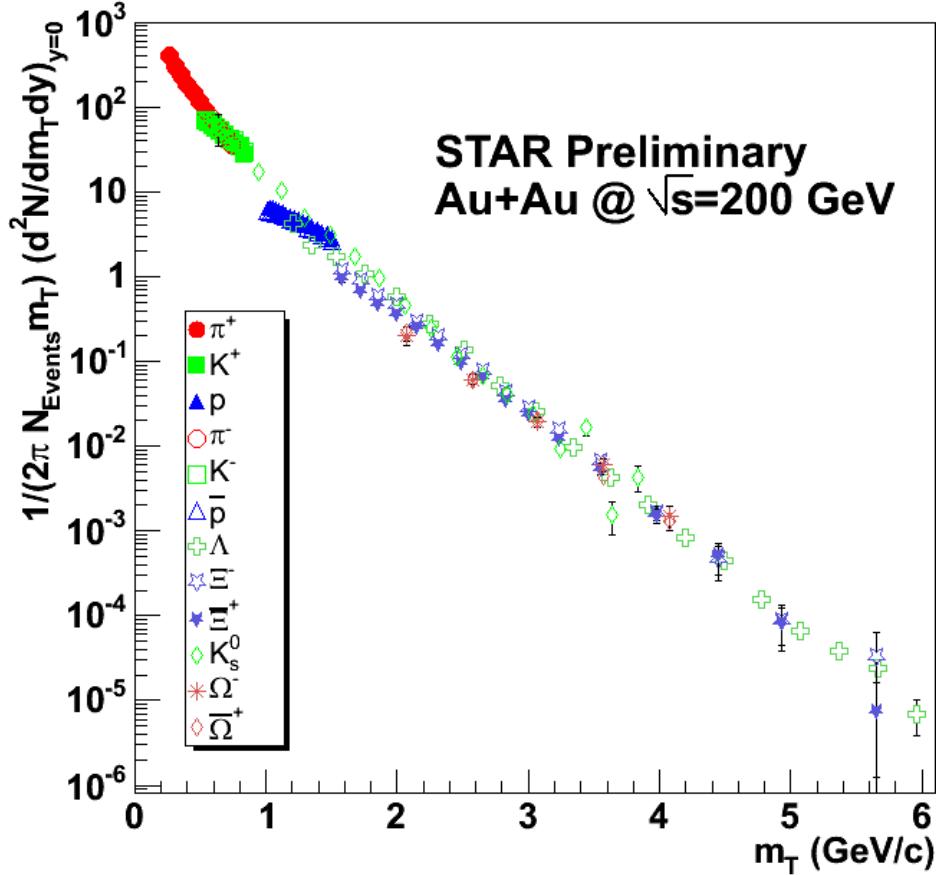
# $m_T$ -scaling ( $p+p$ )



- Arbitrary scaling seems to work!
- Quantify with a fit

- Power-law fit
- Good agreement to within ~30% out to ~3 GeV/c

# $m_T$ -scaling (Au+Au)



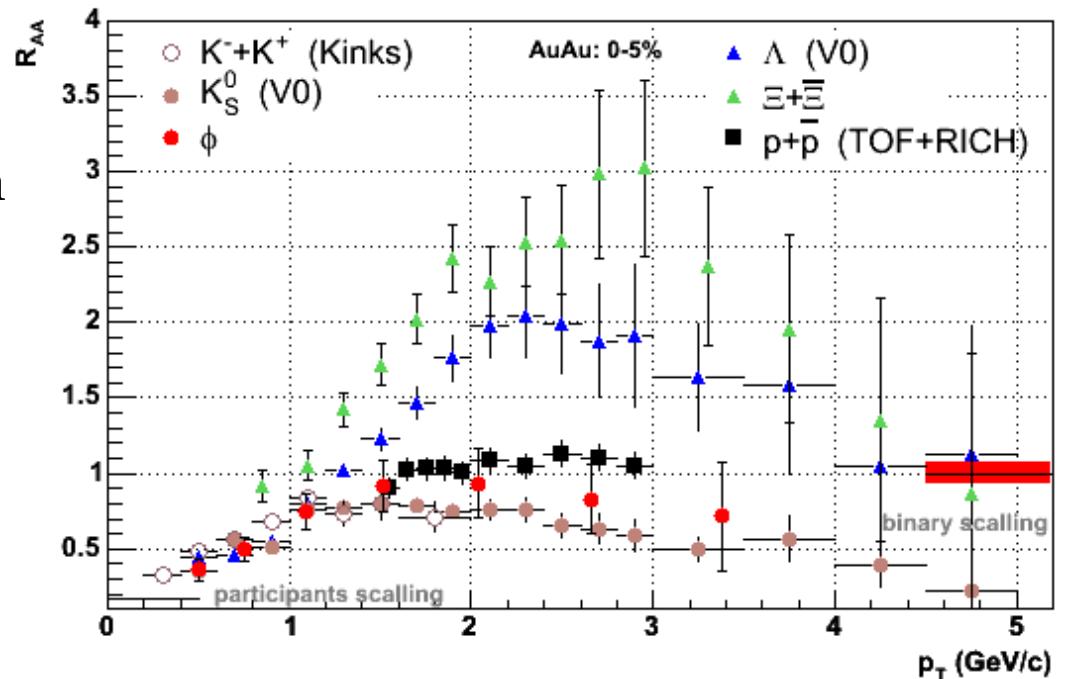
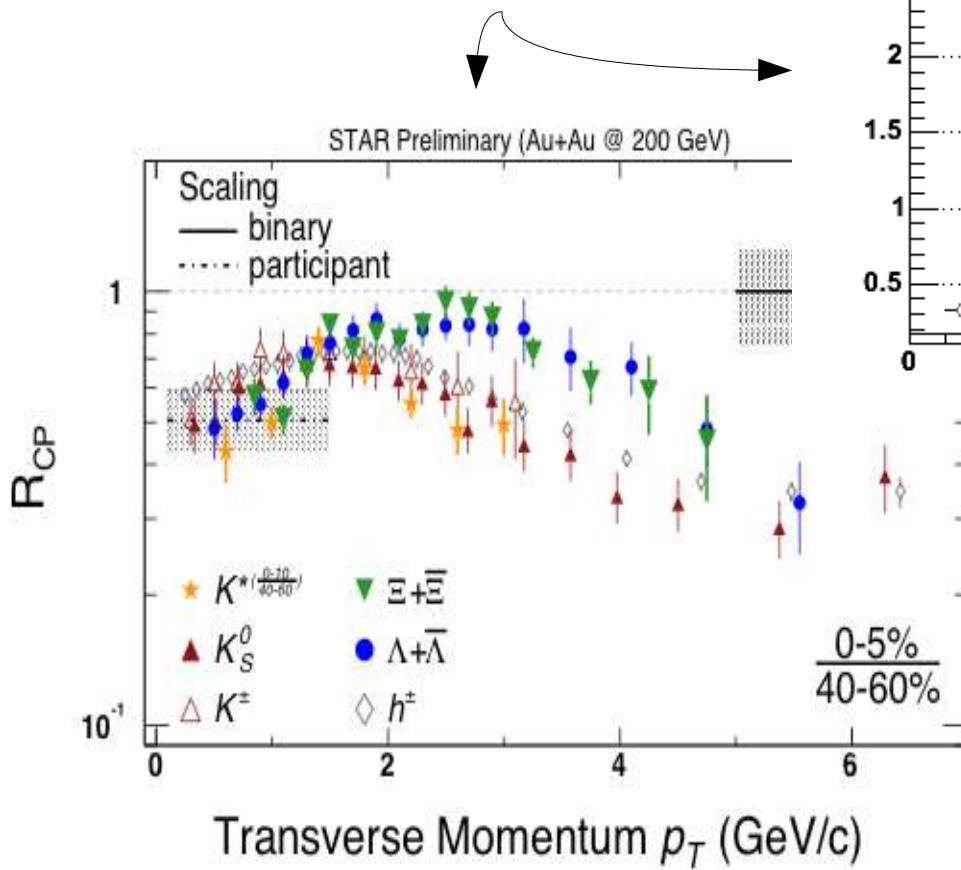
- Very different situation in Au+Au
- Low  $m_T$  turnover (radial flow)

- High or low  $m_T$  could be made to match, but not both.

# $R_{AA}$ and $R_{CP}$

See Talk by C. Mironov

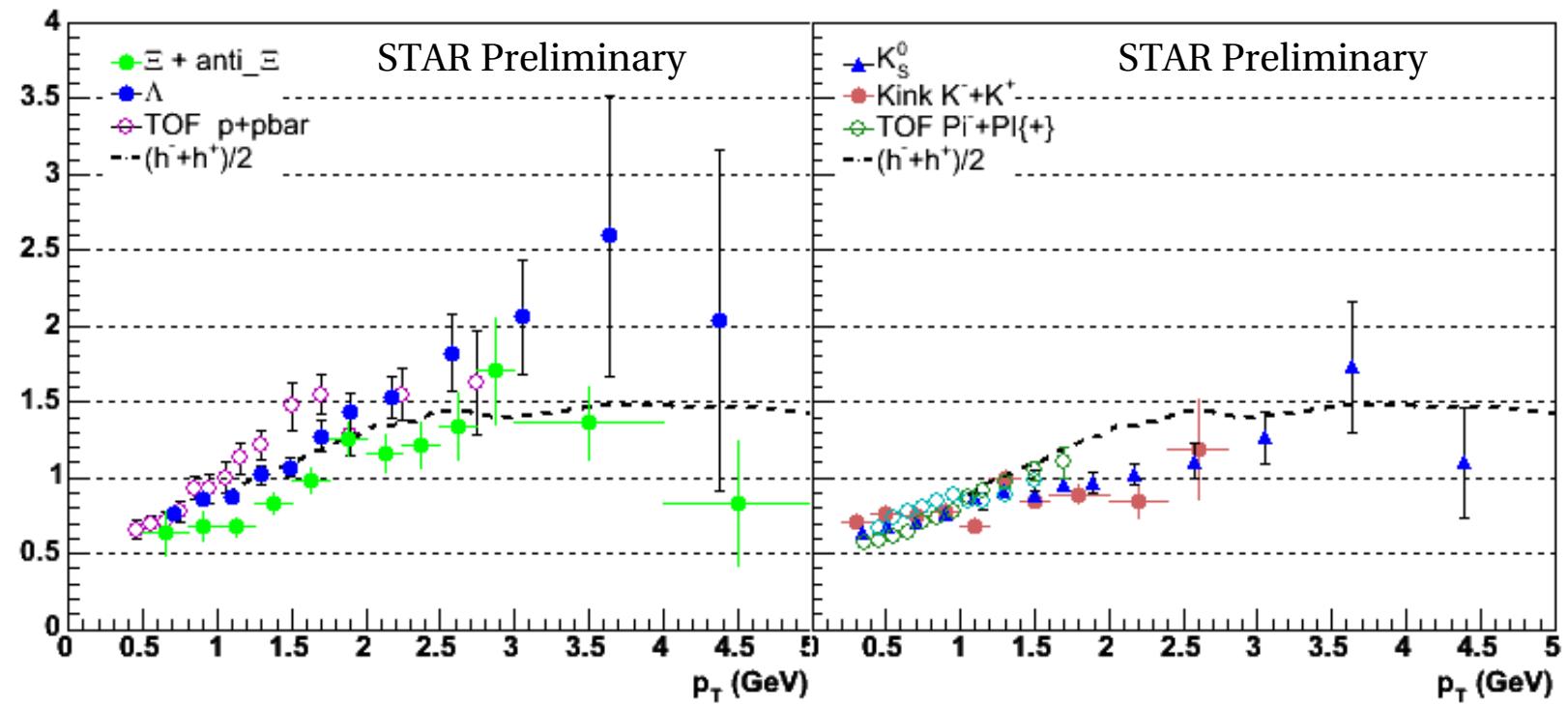
- Baryon-meson splitting in both ratios



- Strong “enhancement” of strange and multistrange baryons in  $R_{AA}$

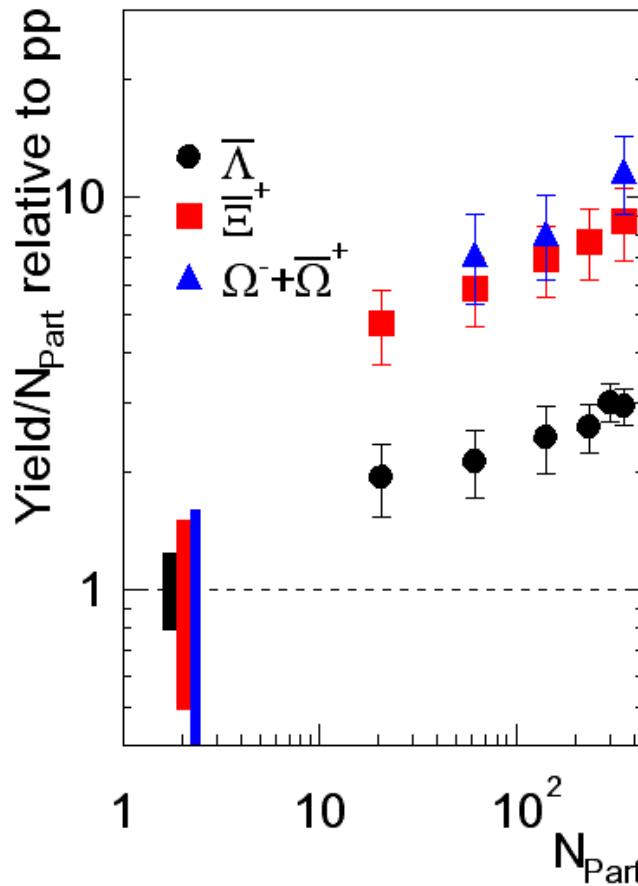
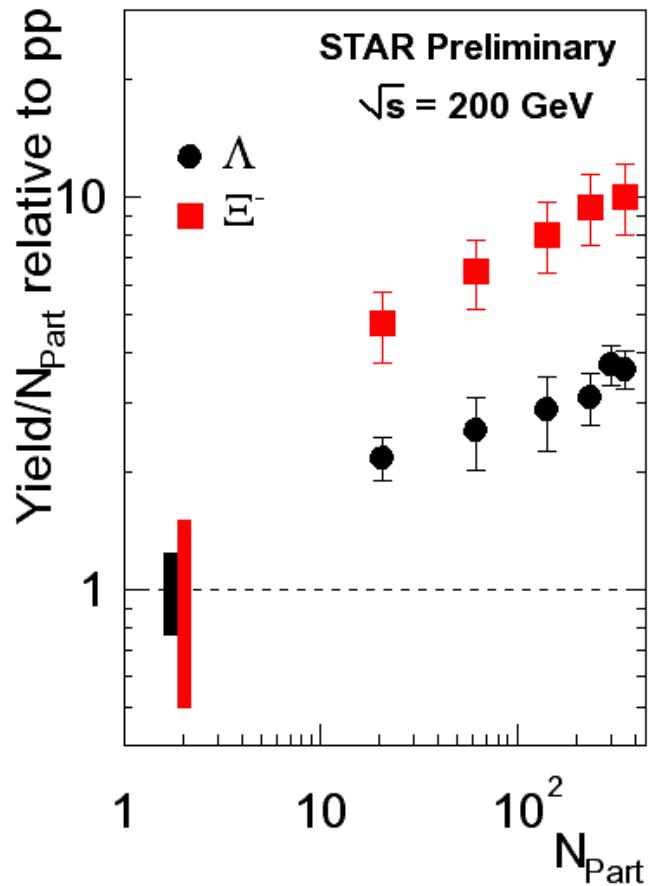
- Manifestation of suppression in  $p+p$

# ... and $R_{dA}$



- No strong “enhancement” of strange baryons
- Partial relief of suppression?

# Strangeness Enhancement



- Near linear rise with centrality
- No clear sign of saturation
- $\bar{\Lambda}$  no longer flat
- Multi-strange very close

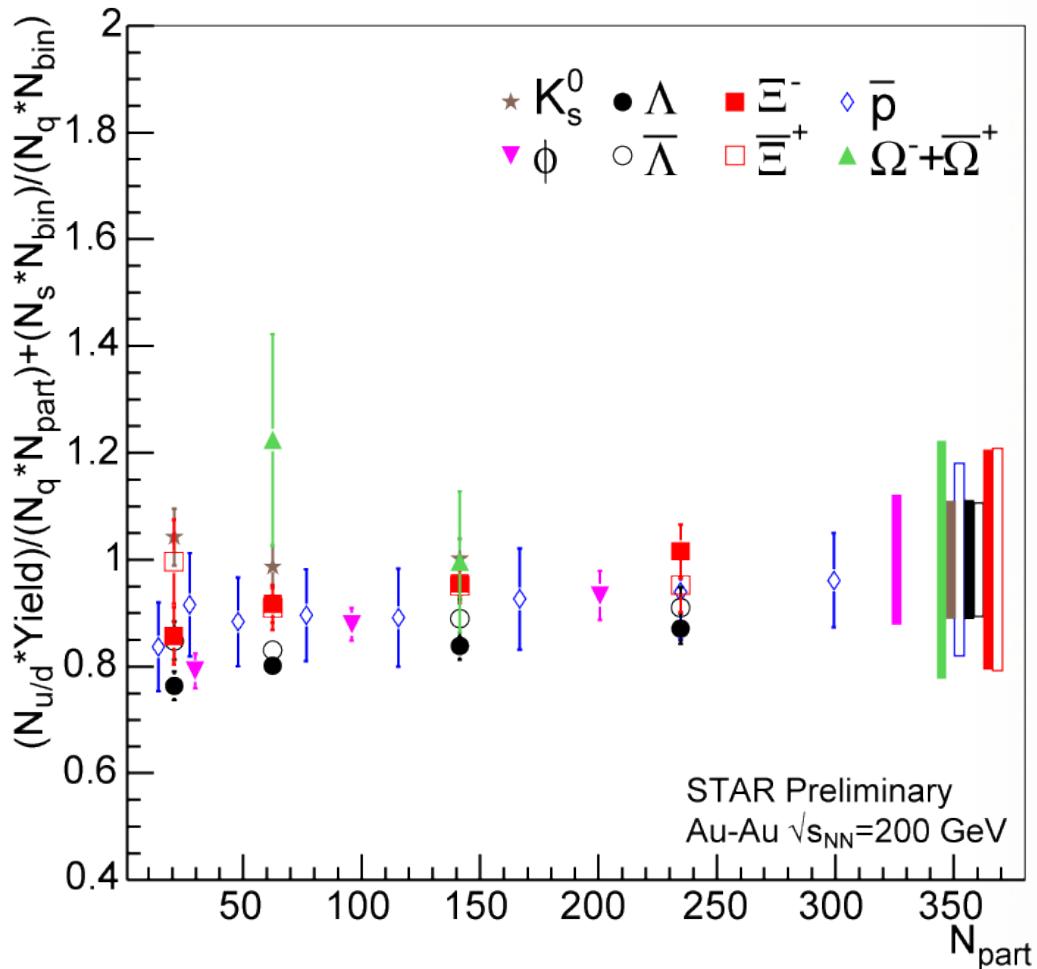
● Maybe “just” suppression in  $p+p$

# Canonical Suppression

- Grand Canonical Ensemble for Au+Au
  - conservation of quantum numbers on average
  - controlled via chemical potential
  - possible due to large multiplicities
- Small multiplicities in  $p+p$
- Canonical Ensemble
  - strict local conservation of quantum numbers
  - reduction of available phase space for strangeness
- Effects
  - Increases with increasing strangeness content
  - Increases with decreasing collision energy
  - volume taken to vary linearly with  $N_{\text{part}}$



# Volume Effects



- Different volume for strangeness?  
Talk by Helen Caines



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● u, d quarks

● Observed to scale well with  $N_{part}$

● s quarks

●  $N_{bin}$  scaling may be better for strangeness

$$K_s^0 - 1/2 * N_{part} + 1/3 * N_{bin}$$

$$p - N_{part}$$

$$\Lambda - 2/3 * N_{part} + 1/3 * N_{bin}$$

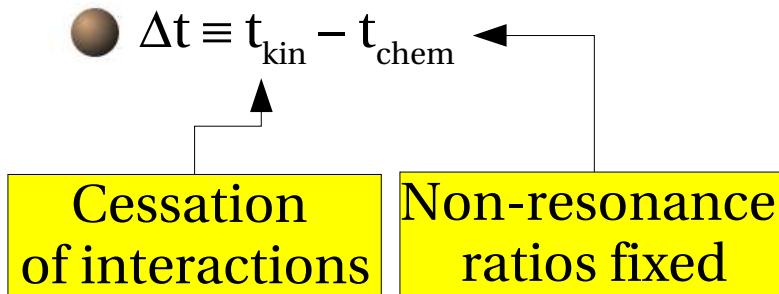
$$\Sigma - 1/3 * N_{part} + 2/3 * N_{bin}$$

$$\phi - N_{part}$$

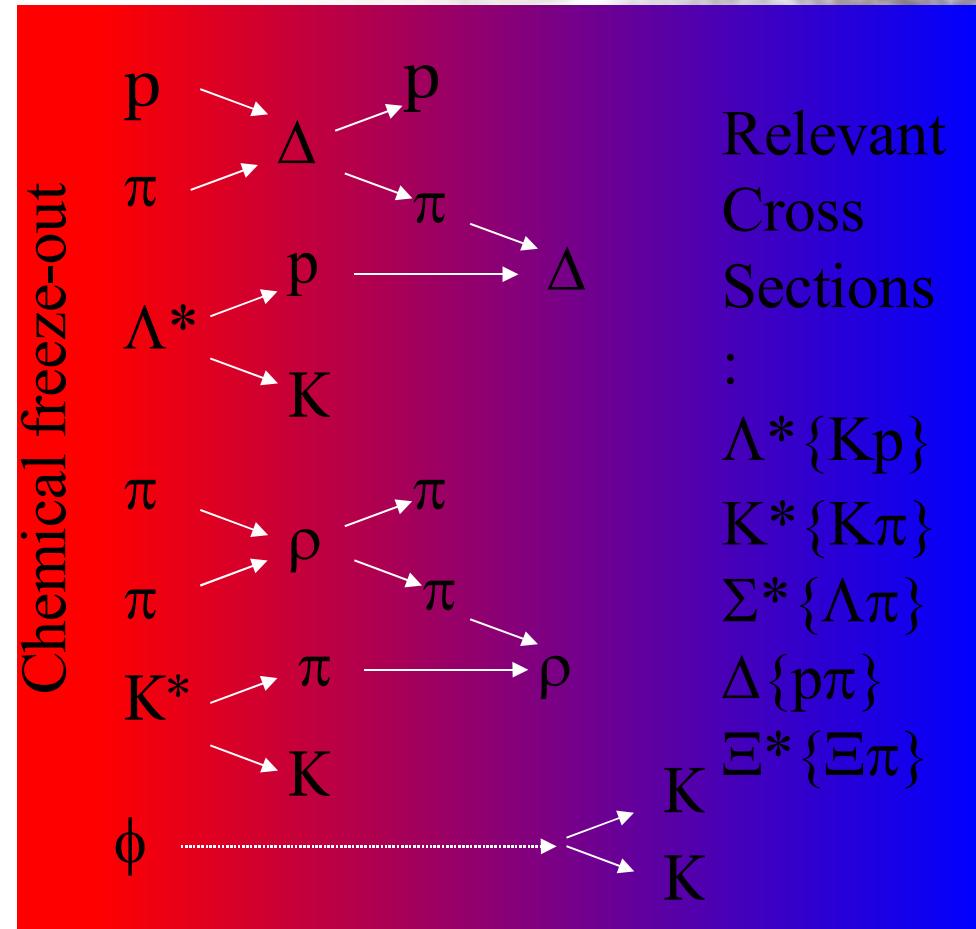


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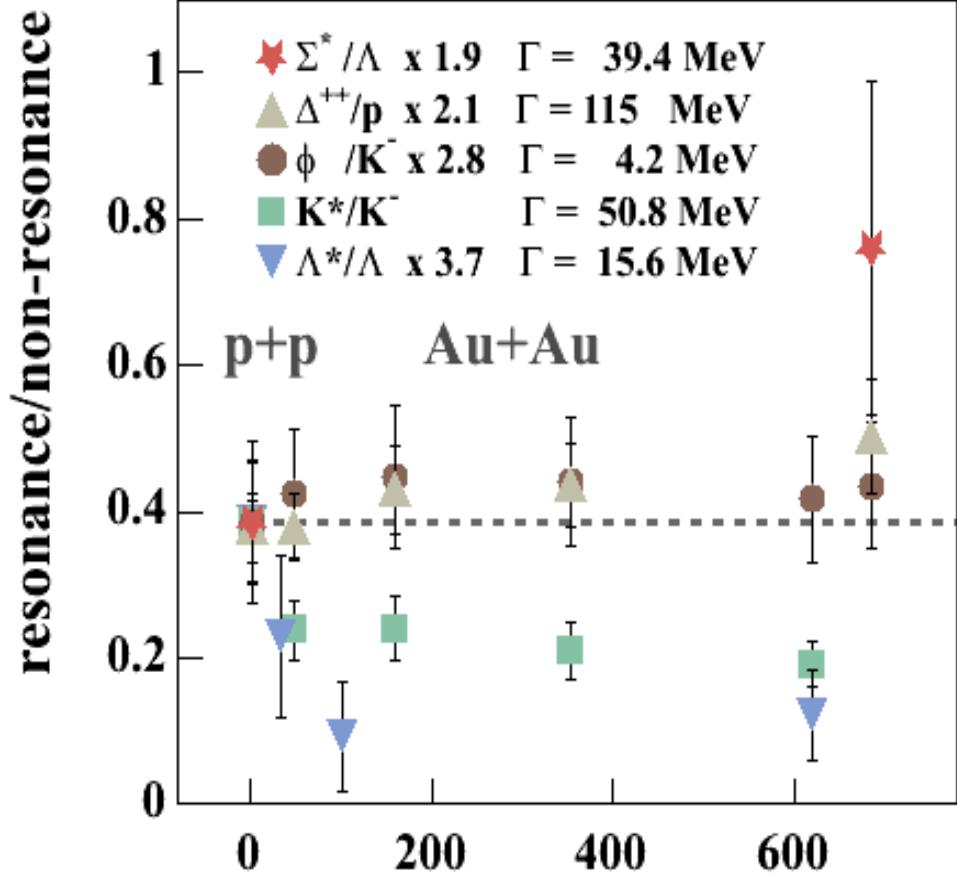
# Resonances & Time Scale



- $\Delta t \equiv t_{\text{kin}} - t_{\text{chem}}$
- Resonances continue to decay
  - Lost due to daughter rescattering
  - $\tau < \Delta t$  for many resonances so...
  - Regeneration ( $\sigma_{\text{hadronic}}$  dependent)



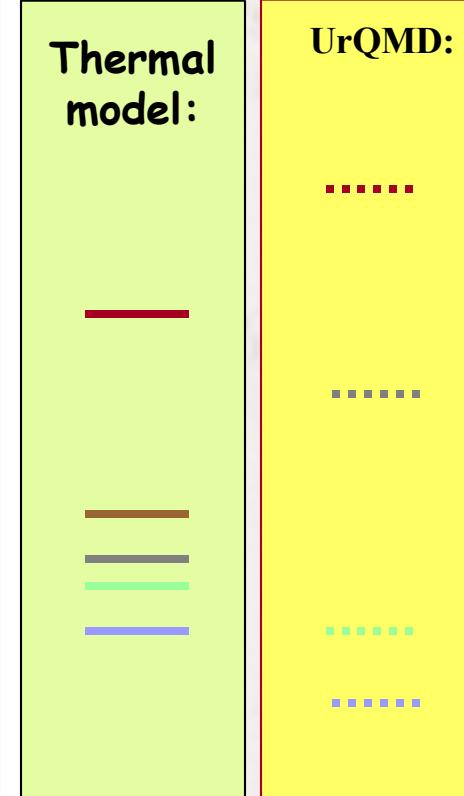
# Resonances & Time Scale



- $\Lambda^*$  indicates rescattering
- $\Sigma^*$  indicates regeneration



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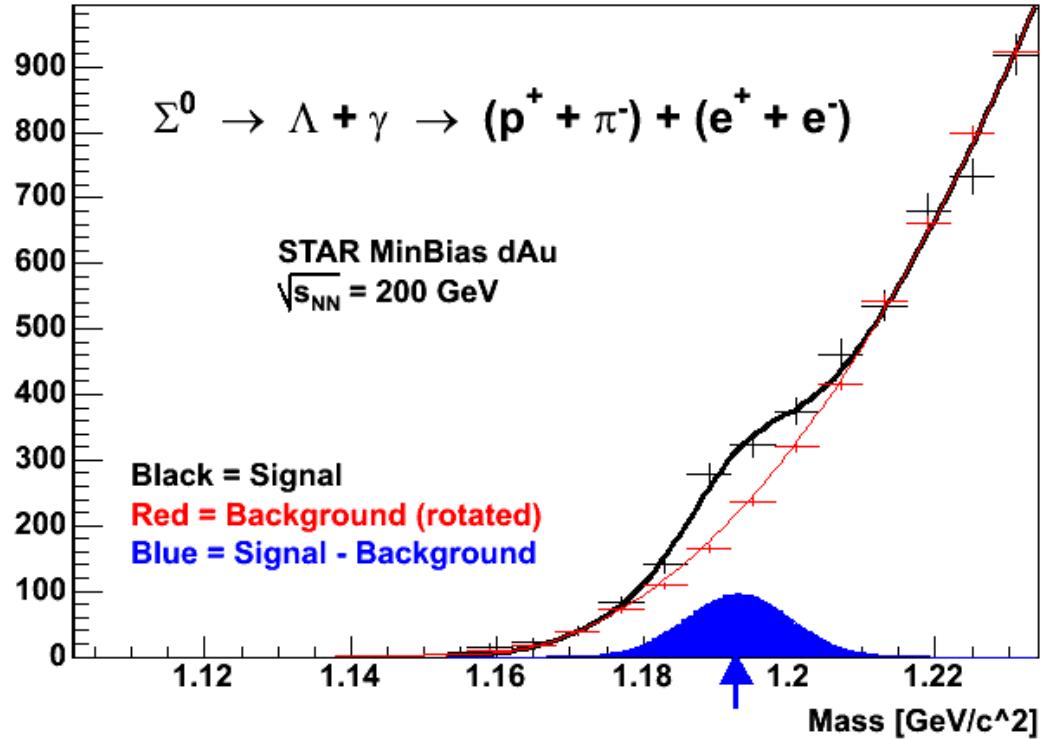


P. Braun-Munzinger et.al., PLB 518(2001) 41  
D.Magestro, M. Kaneta private communication  
Marcus Bleicher and Jörg Aichelin  
Phys. Lett. B530 (2002) 81. M. Bleicher and  
Horst Stöcker .Phys.G30 (2004) 111.



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# Near Future



- $\Sigma^0$  measurement using photon conversions
- Talk by Gene van Buren
- Signal: gaussian fit
- Background: candidate rotation

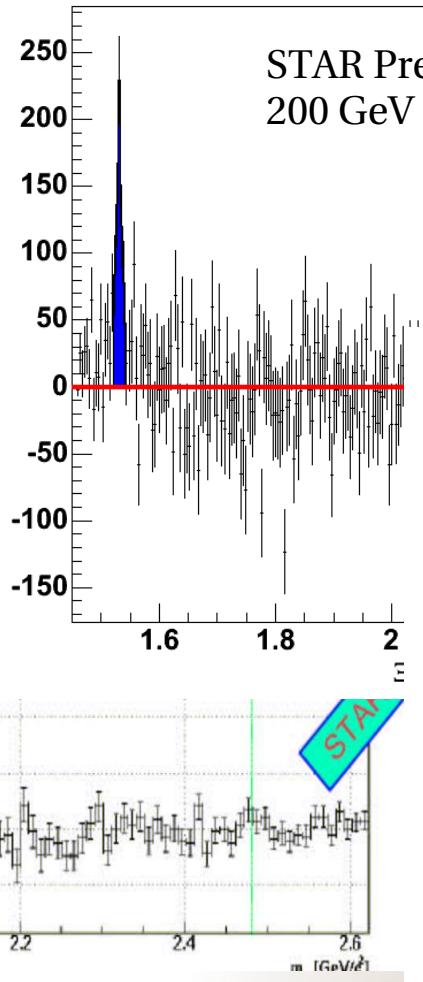
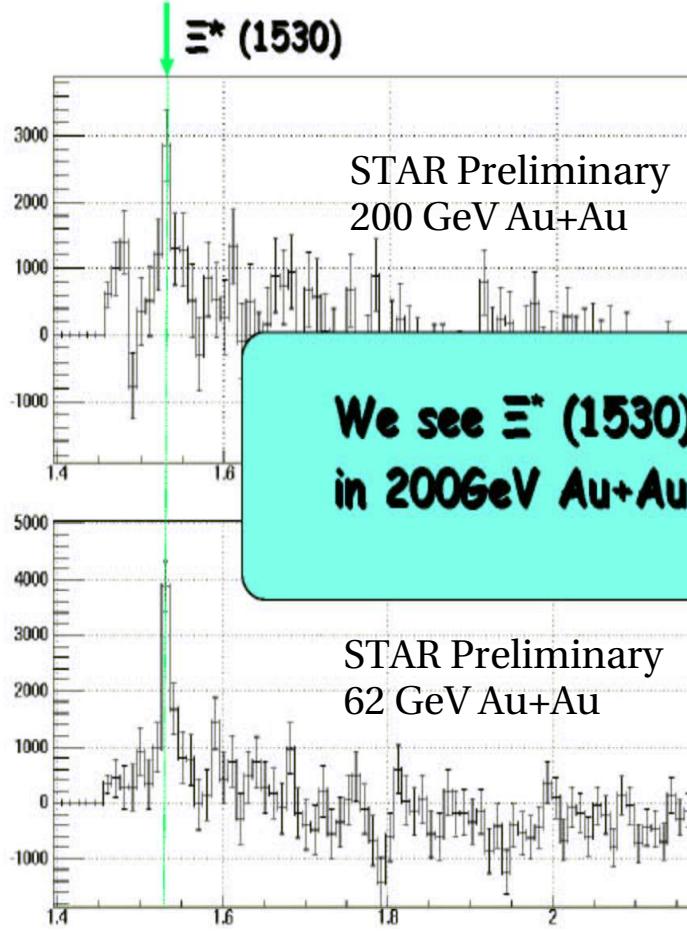


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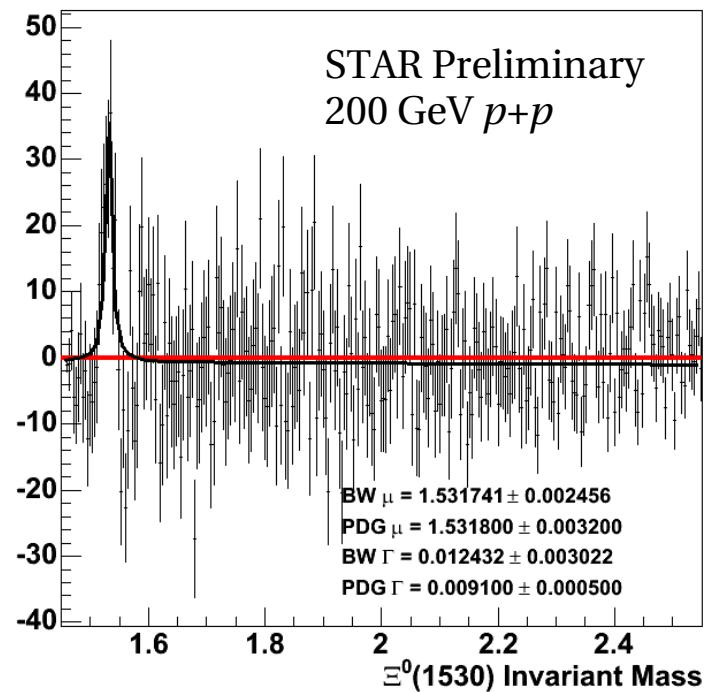
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# Near Future



STAR Preliminary  
200 GeV d+Au



STAR Preliminary  
200 GeV  $p+p$

● Observed in all systems



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# Conclusions

## ❖ $p+p$ Results

- ❖ Greatly improved precision
- ❖ Trend of  $\langle p_T \rangle$  with Multiplicity
- ❖ Mass-ordered
- ❖ Stronger with increasing strangeness
- ❖ Saturation for heaviest?
- ❖ PYTHIA Unable to Reproduce...
  - ❖ spectral shape
  - ❖ trend of  $\langle p_T \rangle$
- ❖ Even NLO calculations have issues
- ❖ Trend of  $\langle p_T \rangle$  with Mass
  - ❖ Converging  $p+p$  & Au+Au for heavies?
  - ❖ No Absolute  $m_T$ -Scaling
  - ❖ Arbitrary scaling seems to work



# Conclusions

## ◆ Au+Au Results

- ◆ No absolute  $m_T$ -scaling
- ◆ Radial flow  $\Rightarrow$  no arbitrary scaling
- ◆ Canonical Suppression in  $p+p$ 
  - ◆ Apparent in  $R_{AA}$  and SE factors
- ◆ Baryon-meson difference in mid- $p_T$
- ◆ Strangeness Enhancement
  - ◆ Partly due to canonical suppression
  - ◆ No sign of saturation
  - ◆  $\bar{\Lambda}$  not flat anymore
- ◆ Quark scaling rather than  $N_{\text{bin}}$  or  $N_{\text{part}}$ 
  - ◆ Different volume for strangeness?
- ◆ Resonance Data Suggest
  - ◆  $\sim 2 \text{ fm}/c \leq \Delta t \leq \sim 6 \text{ fm}/c$



# The STAR Collaboration

Argonne National Laboratory• Institute of High Energy Physics, Beijing• Institute of Physics, Bhubaneswar• University of Bern, Switzerland• University of Birmingham• Brookhaven National Laboratory• University of California, Berkeley• University of California, Davis• University of California, Los Angeles• Carnegie Mellon University• Creighton University• Laboratory for High Energy (JINR), Dubna• Particle Physics Laboratory (JINR), Dubna• University of Frankfurt• Indiana University, Bloomington• Institut de Recherches Subatomiques, Strasbourg• Jammu University• Kent State University• Institute of Modern Physics, Lanzhou• Lawrence Berkeley Laboratory• Max-Planck-Instit fuer Physik, Munich• Michigan State University• Moscow Engineering Physics Institute• Indian Institute of Technology, Mumbai• City College of New York• Ohio State University• Panjab University• Pennsylvania State University• Institute of High Energy Physics, Protvino• Purdue University• University of Rajasthan• Rice University• Universidade de Sao Paulo• University of Science and Technology of China (USTC)• Shanghai Institue of Nuclear Research (SINR)• SUBATECH, Nantes• Texas A & M• University of Texas, Austin• Tsinghua University• Variable Energy Cyclotron Centre, Kolkata• Warsaw University• Warsaw University of Technology• University of Washington• Wayne State University• Institute of Particle Physics, Wuhan• Yale University

Backups After This Point

# Volume Effects

