Λ and K^0_s Reconstruction in Au+Au at 1.23A GeV

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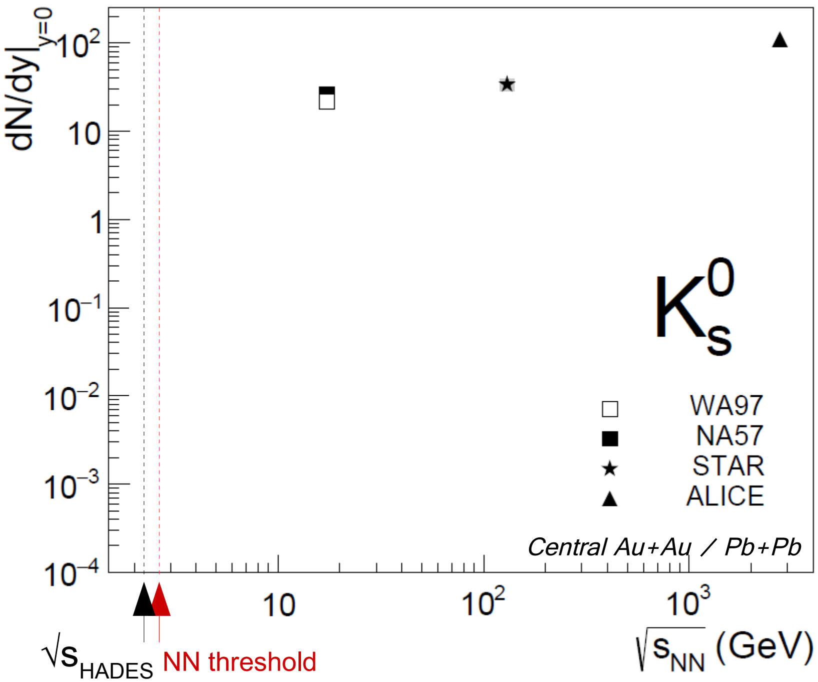
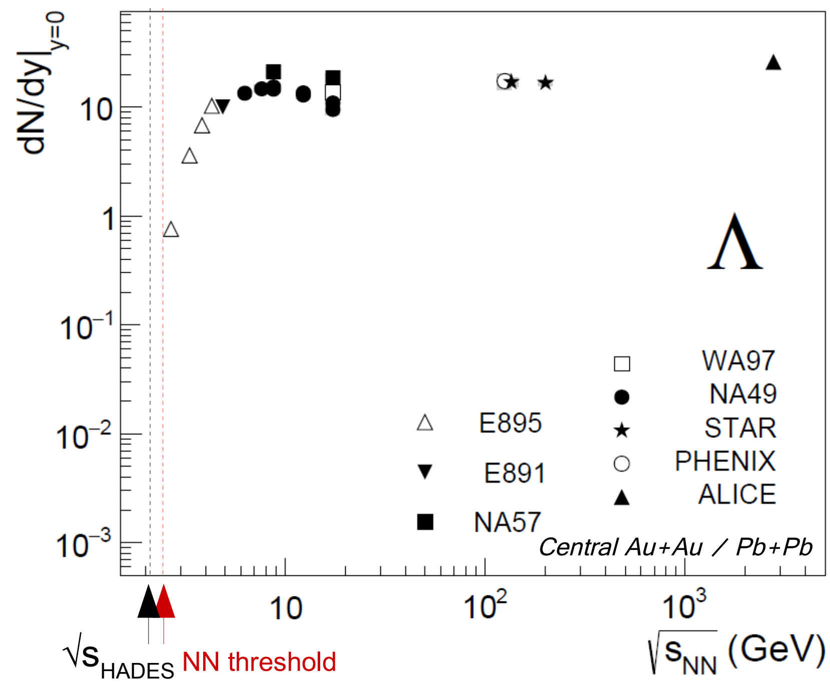
// Outline

- Motivation
- Off-Vertex Reconstruction of Λ and K_S^0
- Preliminary Results on Λ and K_S^0
  - Multidifferential analysis: m_T, y and centrality
  - Complete measured strange hadron set
  - Comparison to transport
  - K^0 to K^+ Ratio
  - World data

// Excitation Function





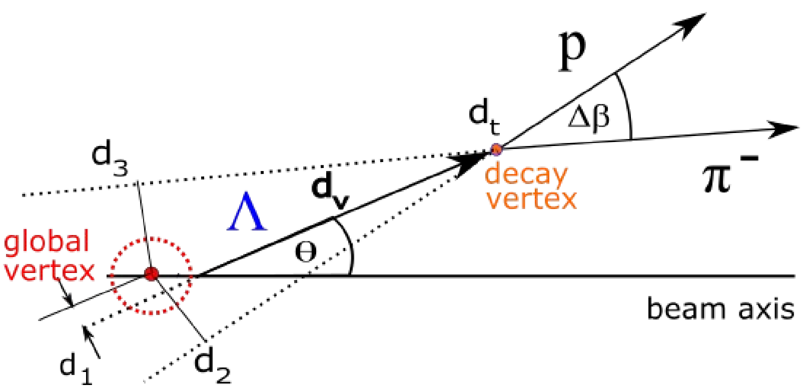
C. Blume, C. Markert: arXiv:1105.2798v2 [nucl-ex] 19 Aug 2011

- Central Au+Au/Pb+Pb yields at midrapidity
- No Au+Au data for K^0_S at SIS energy regime
- Steep excitation function towards low energies
- No distortions through Coulomb interaction in the medium for K^0 and Λ
- Au+Au at 1.23A GeV:
  - First observation below NN threshold for strange particle production???
  - High sensitivity to medium effects (deep sub-threshold and large system size)

// Reconstruction of Decayed Hadrons

	Decay Length $c\tau$ [cm]	BR [%]	$\sqrt{s_{tr}}$ [GeV]	$\sqrt{s}-\sqrt{s_{tr}}$ [GeV]
$K^0_s((d\bar{s}+\bar{d}s)\sqrt{2}) \to \pi^+\pi^-$	**2.68**	**69.2**	**2.55**	**−0.14**
$\Lambda(uds) \to p\pi^-$	**7.89**	**63.9**	**2.55**	**−0.14**

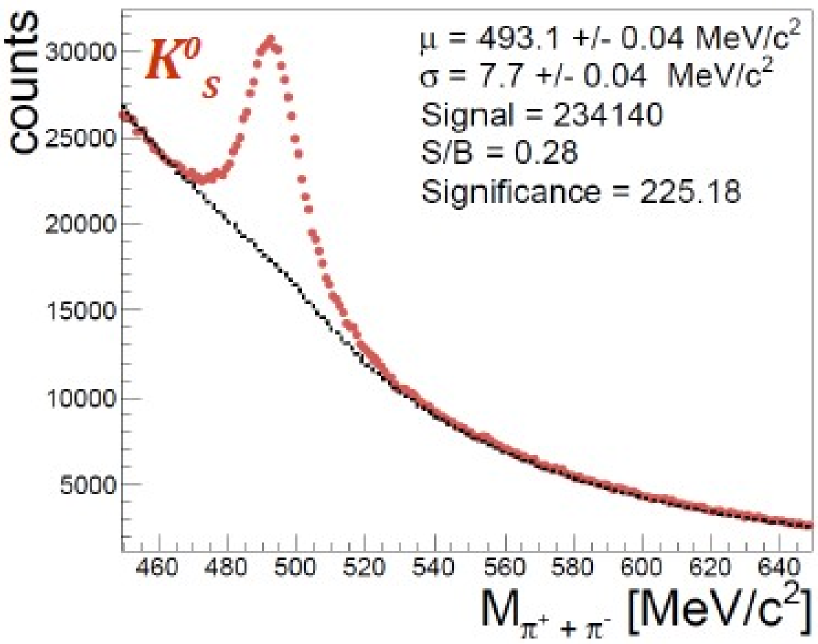
- Reconstruction via invariant mass of charged particles
- Long life times allow for secondary vertex reconstruction
- Background suppression via cuts on decay topology

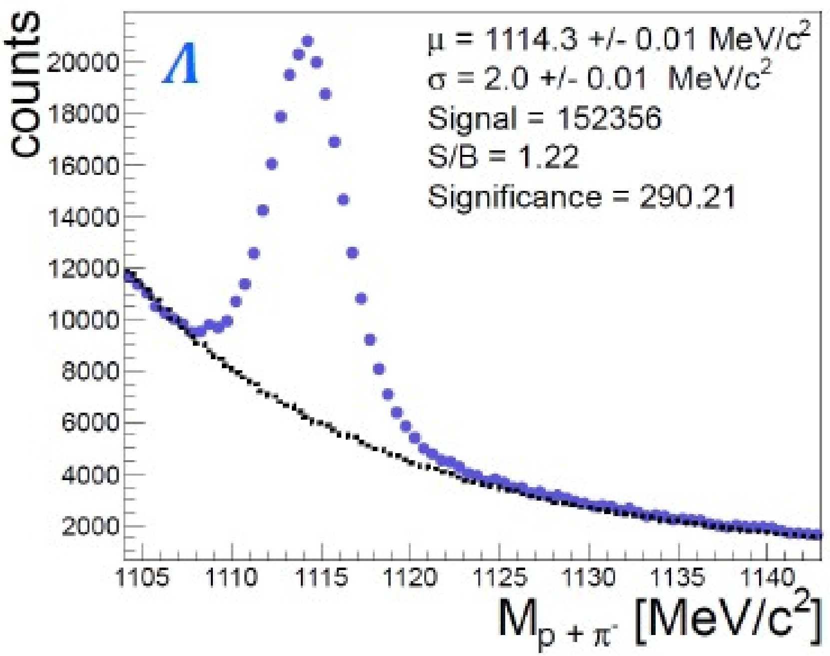


d_1: dist. primary particle track – prim. Vertex
d_v: dist. prim. vertex – decay vertex
d_2: min. dist. prim. vertex – daughter_1 track
d_3: min. dist. prim. vertex – daughter_2 track
d_t: distance of closest approach of daughter particles

$\Delta\beta$: opening angle

// Particle Reconstruction

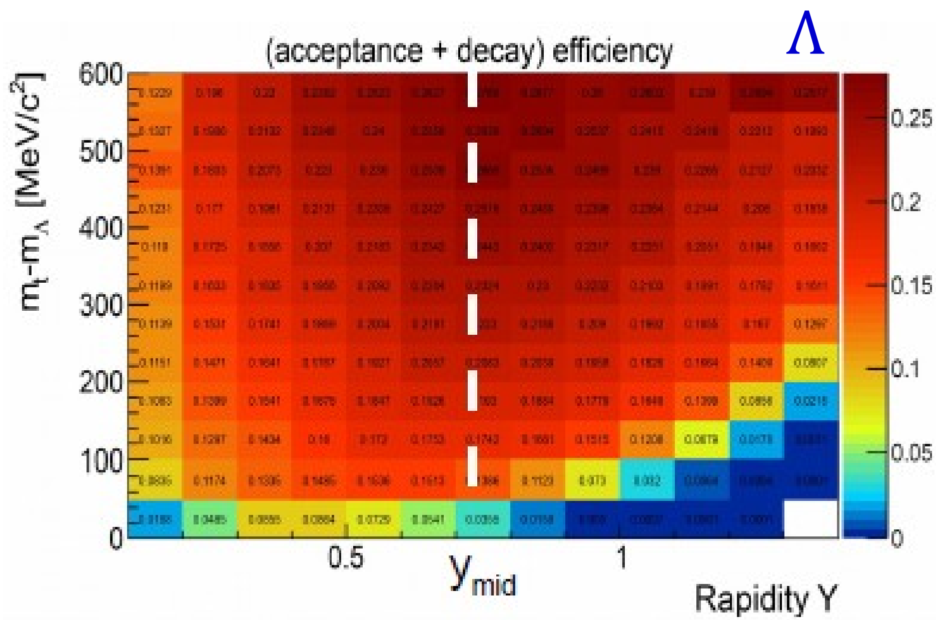


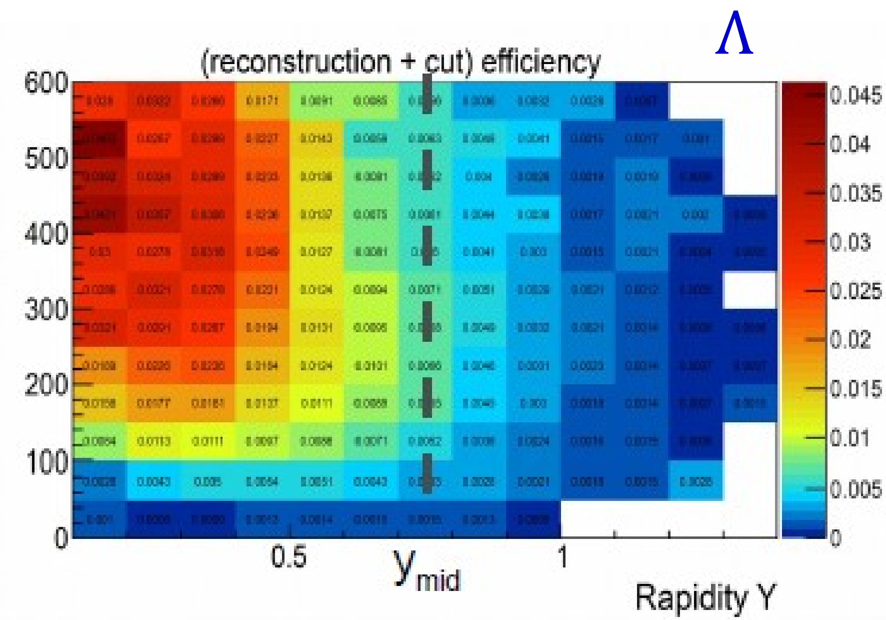


- High statistic signal (S), high significance
- Background (B) described by Mixed Event Method
- Sufficient statistics for (3-d) differential analysis vs. rapidity, transverse mass and centrality

// Multi-Differential Analysis: Efficiency Correction

- Particles produced thermally in Monte Carlo Simulation (Pluto) and propagated through GEANT





Both decay particles in geometrical acceptance: 15-25%

Detector and reconstruction efficiency (incl. Off-Vertex Cuts): 0.5-5%

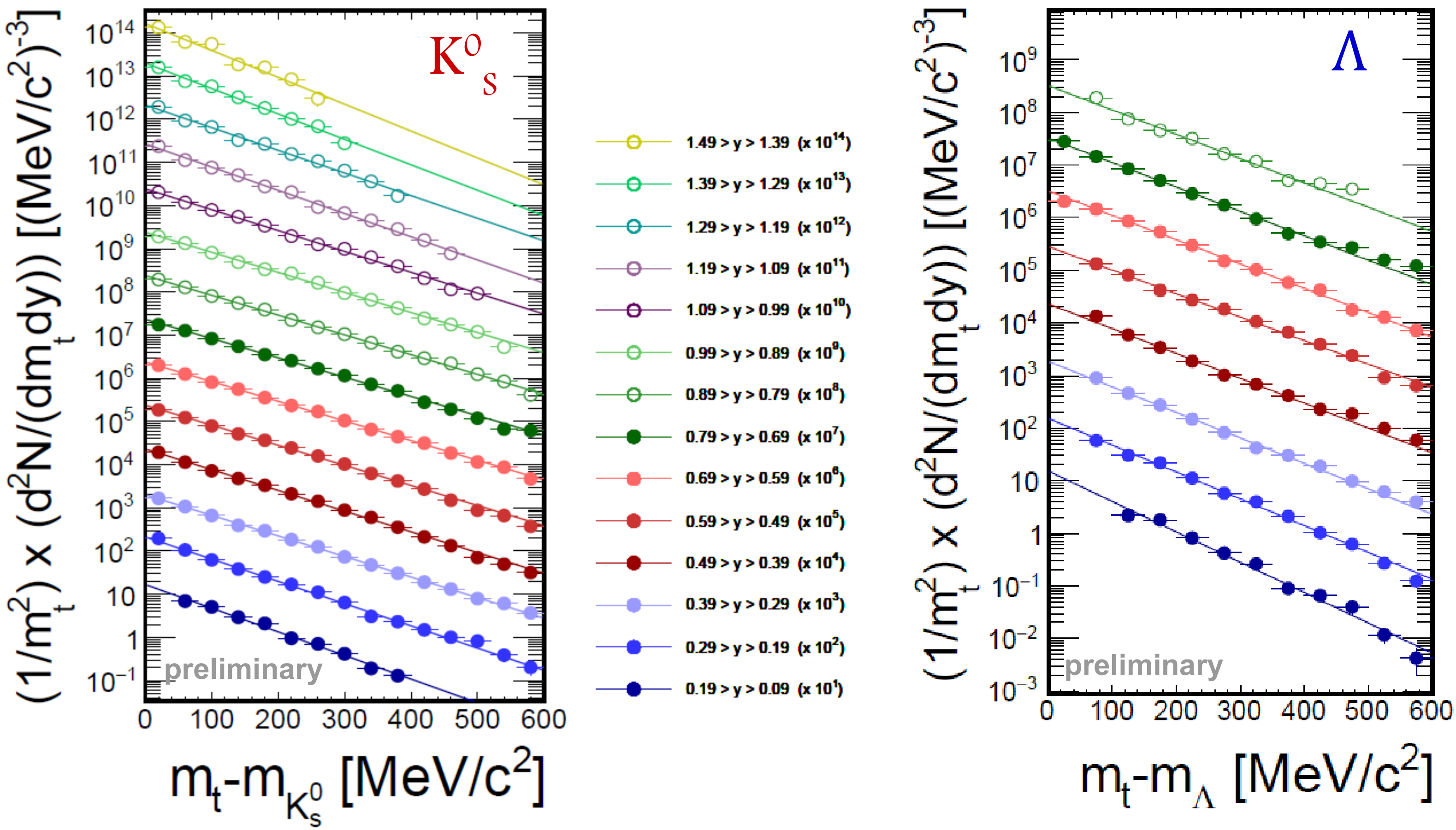
- Topology cuts main contributor to systematic uncertainty (besides background determination)
- Different systematics compared to charged Kaon analysis

// Results

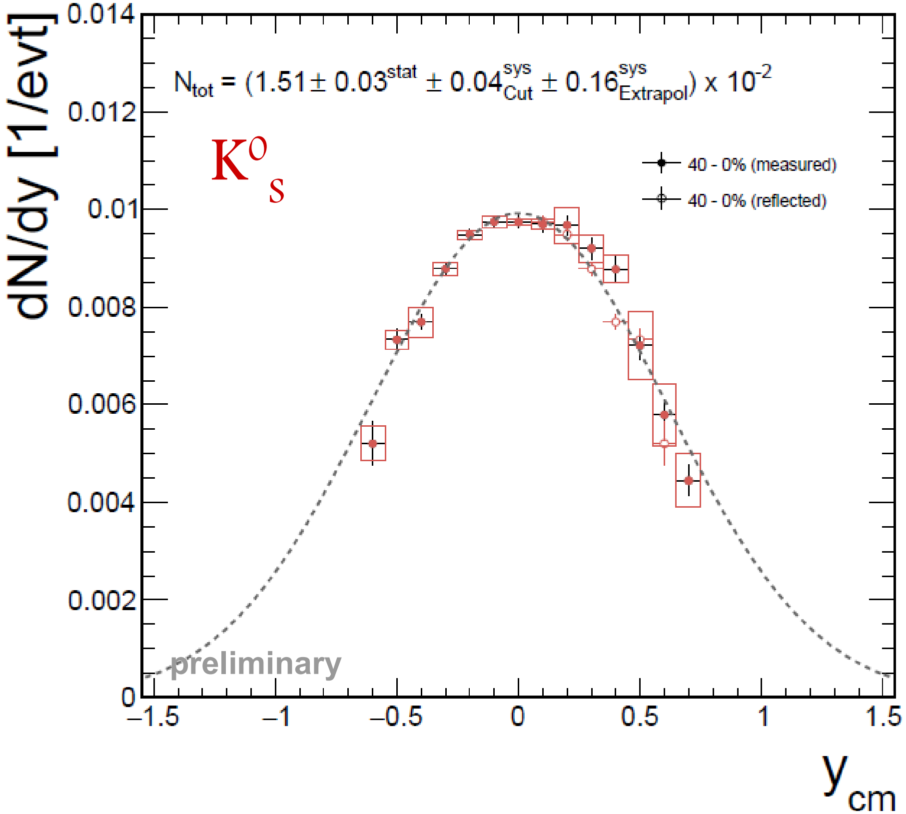
// Mt Spectra

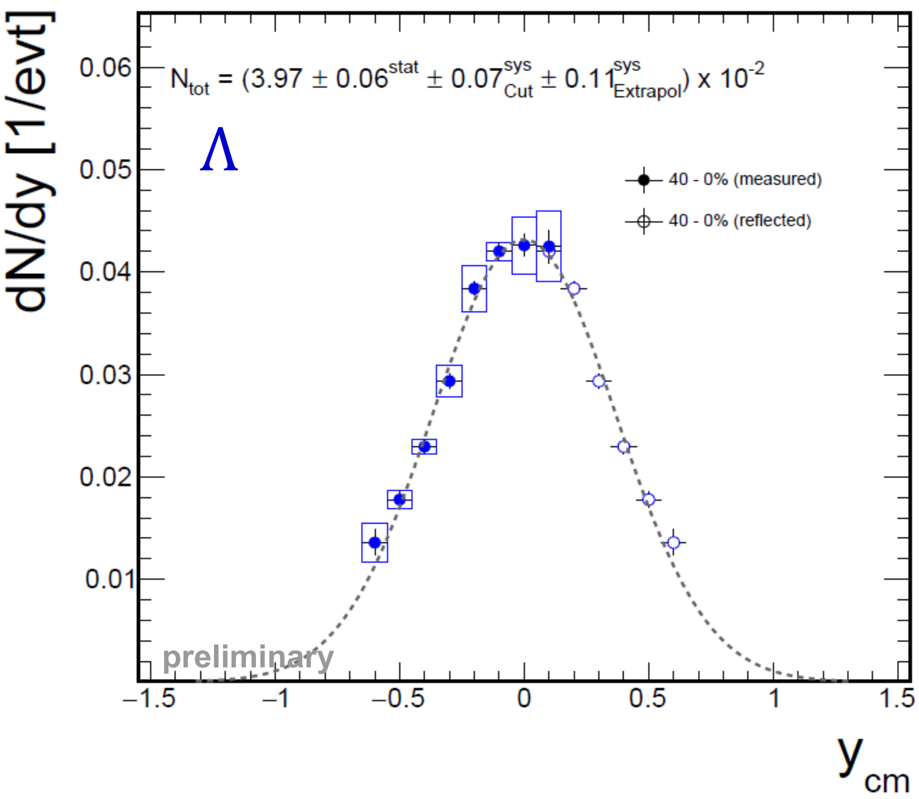
Boltzmann function

$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dy} = C(y) \cdot exp\left(-\frac{(m_t - m_0)c^2}{T_B(y)}\right)$$

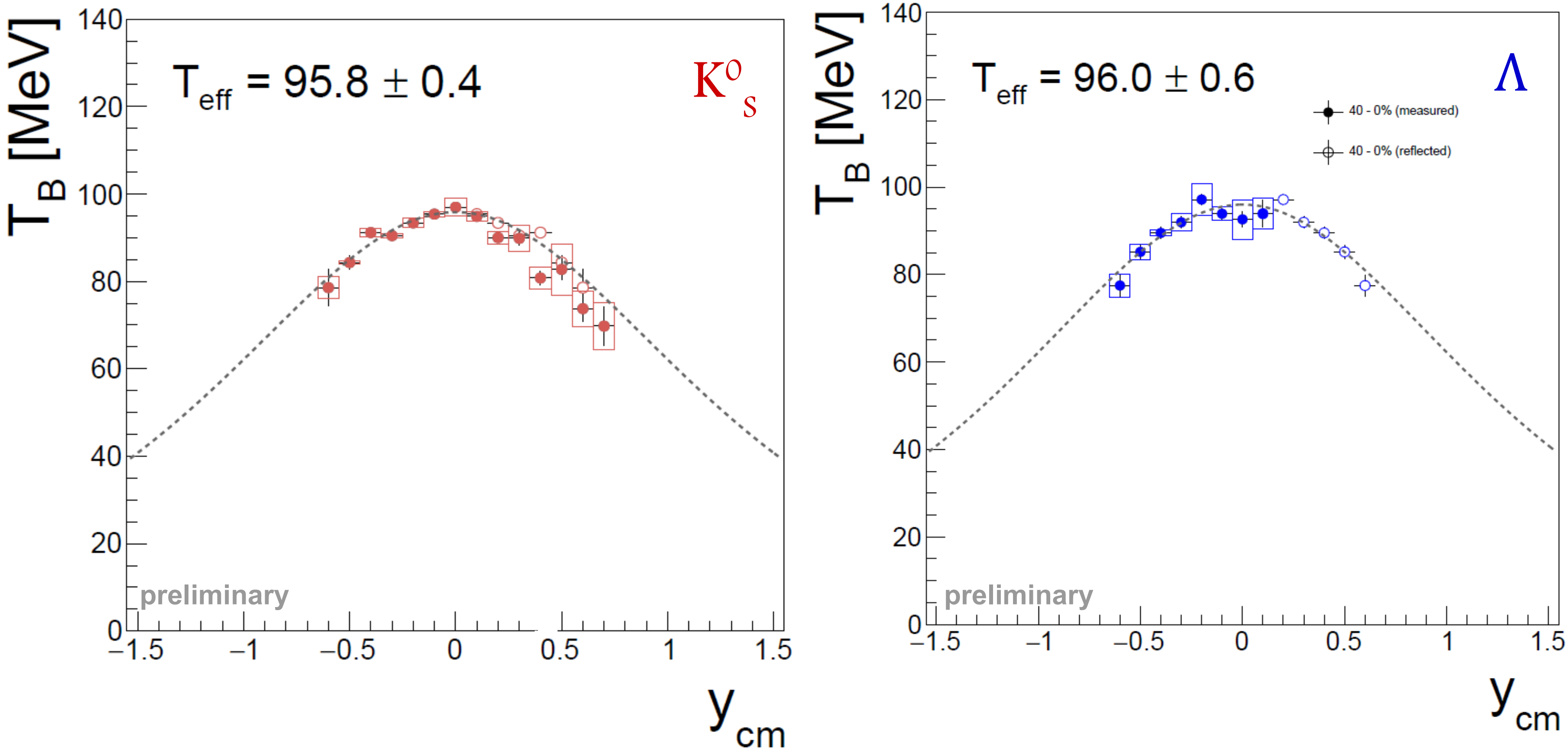


// Rapidity Density Distribution dN/dy

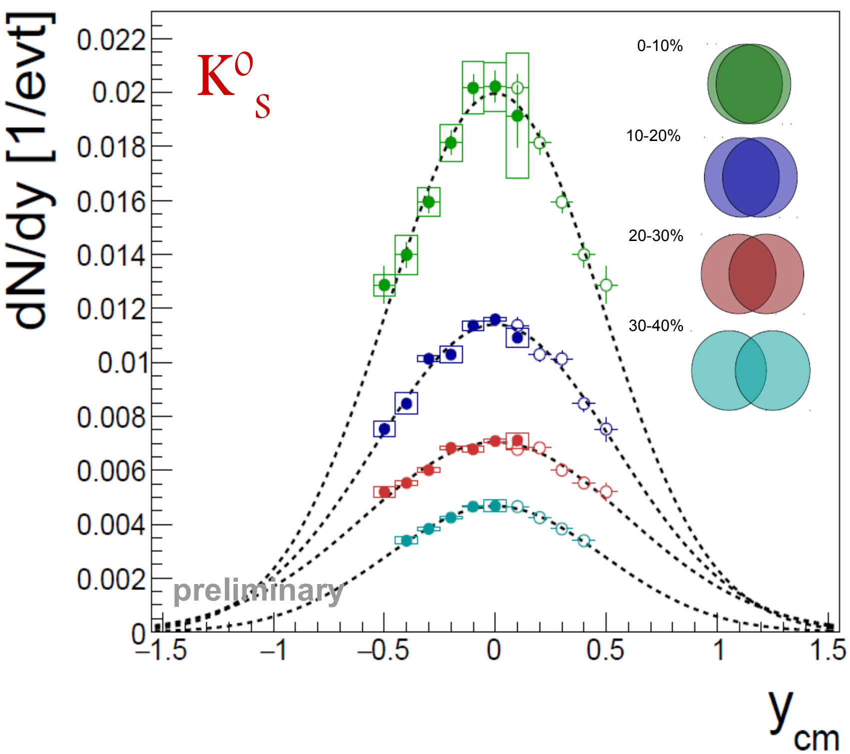


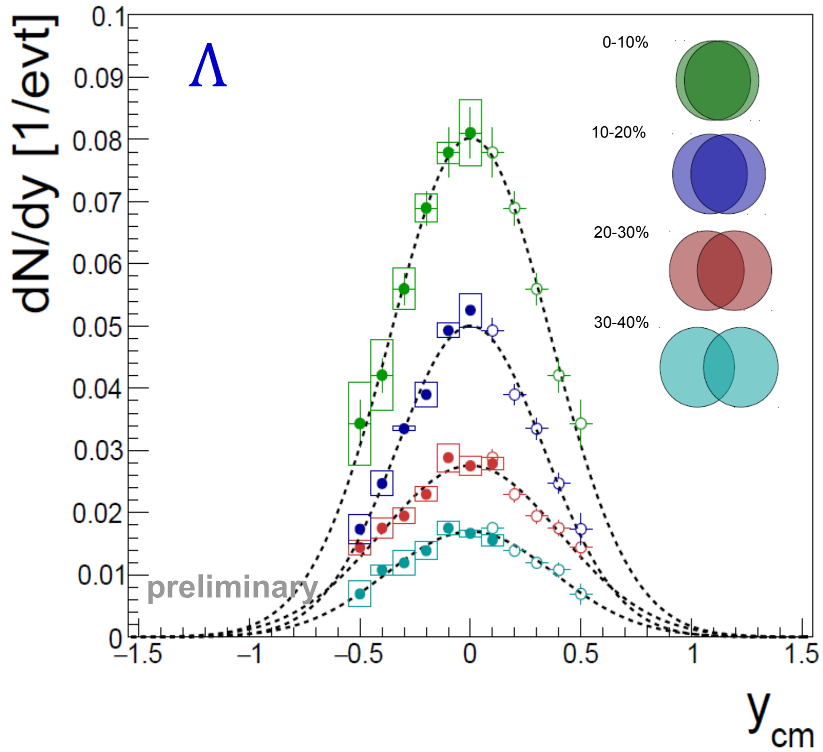


// Inverse Slope Spectra



// Centrality Dependence





- Same analysis for centrality bins in 10% steps from 0% to 40%
- First centrality dependent measurement of K^0_s and Λ below NN threshold!
- Rising yield towards more central collisions

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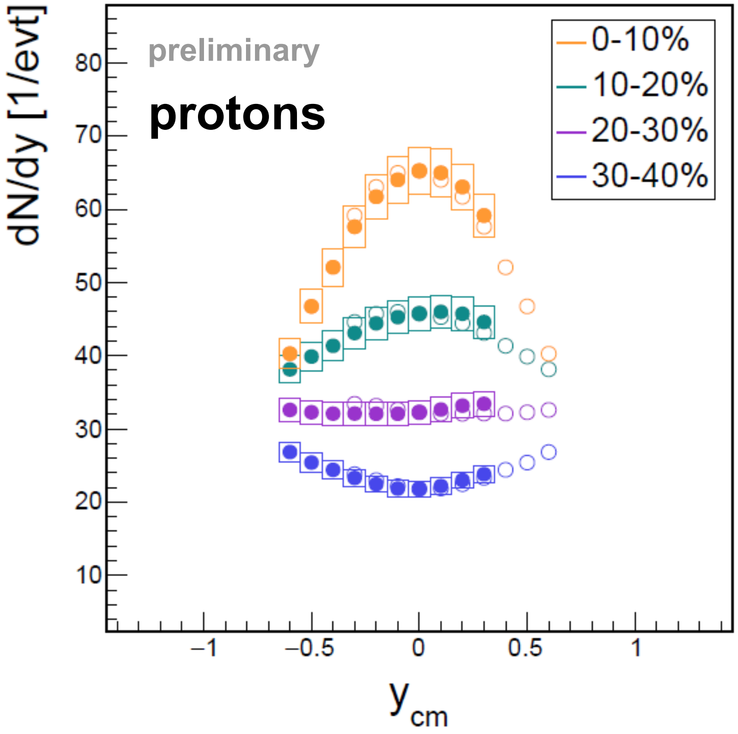

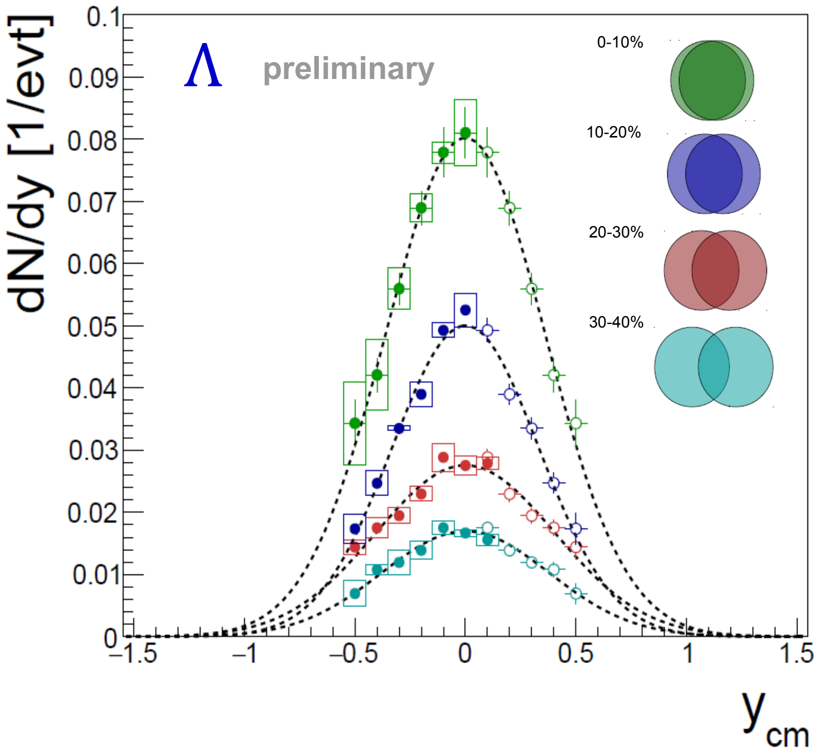

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- Rising yield towards more central collisions
- No broadening of spectra for Lambda towards peripheral collisions
- Spectator-like distributions for protons going to peripheral collisions

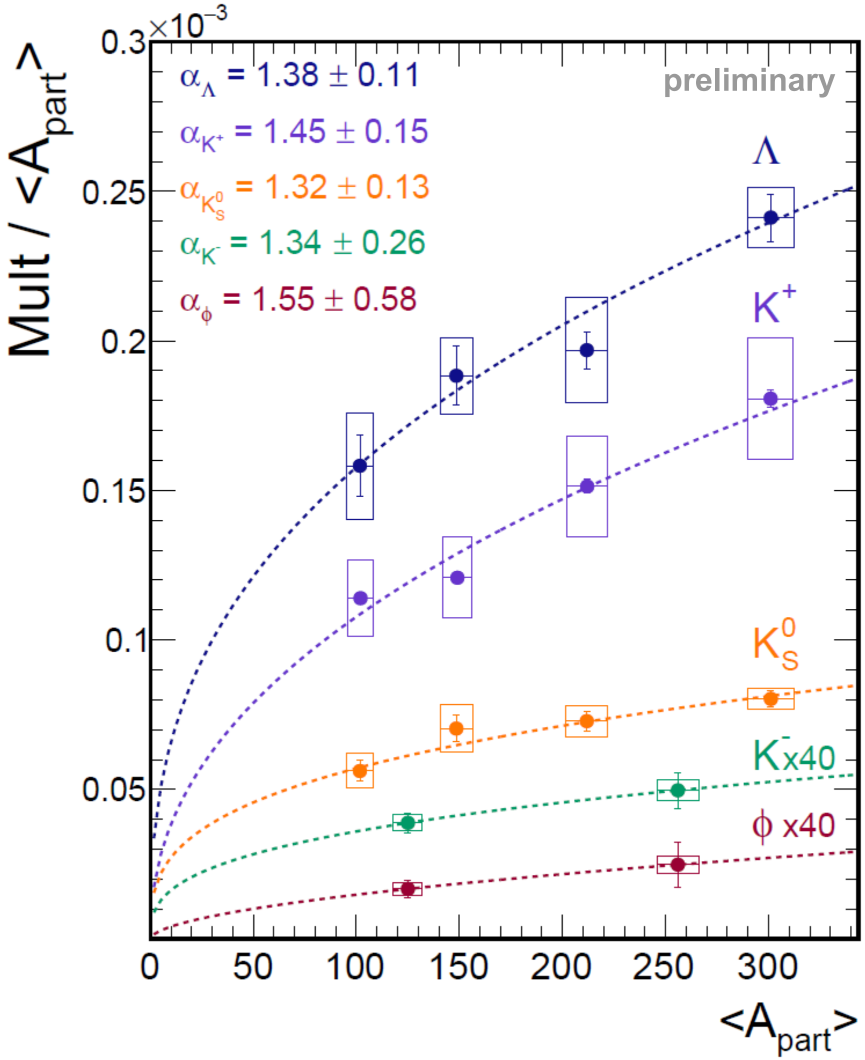
// Strange Particle Multiplicities vs Number of Participants

- All strange particles in this system are produced below elementary production threshold
- Particle yields rise more than linear with centrality ($M/A_{Part} \sim A_{Part}^{\alpha}$)
- Similar trend for all strange particles!
- Within errors same trend as measured by KaoS and FOPI at higher energies

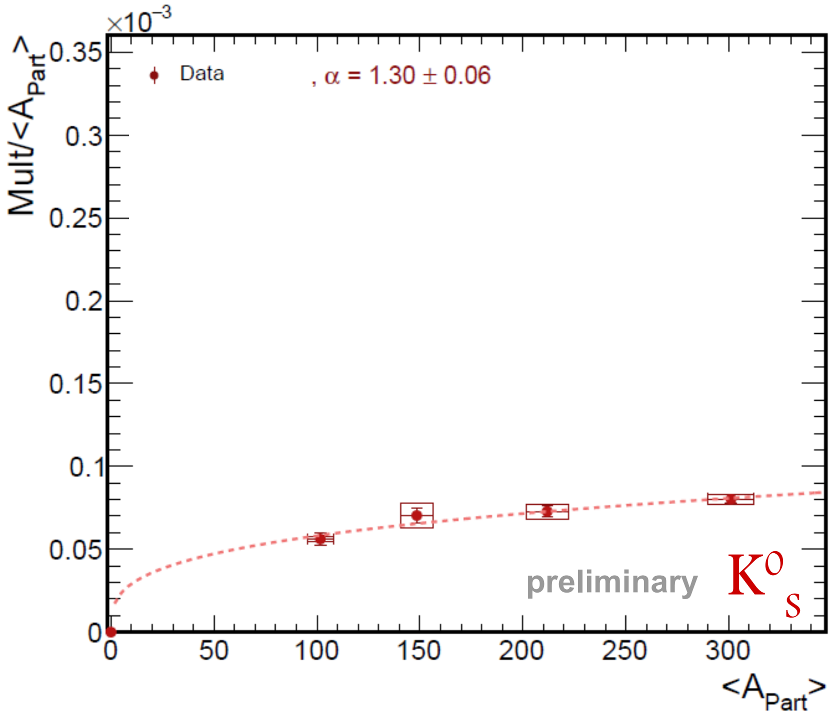
  (α_{K+}=1.34 ± 0.16, α_{K-}= 1.22 ± 0.27,
  α_{Φ} = 1.7 ± 0.5, $\alpha_{K^{\circ}}$ = 1.20 ± 0.25,
  α_{Λ} = 1.34 ± 0.16)

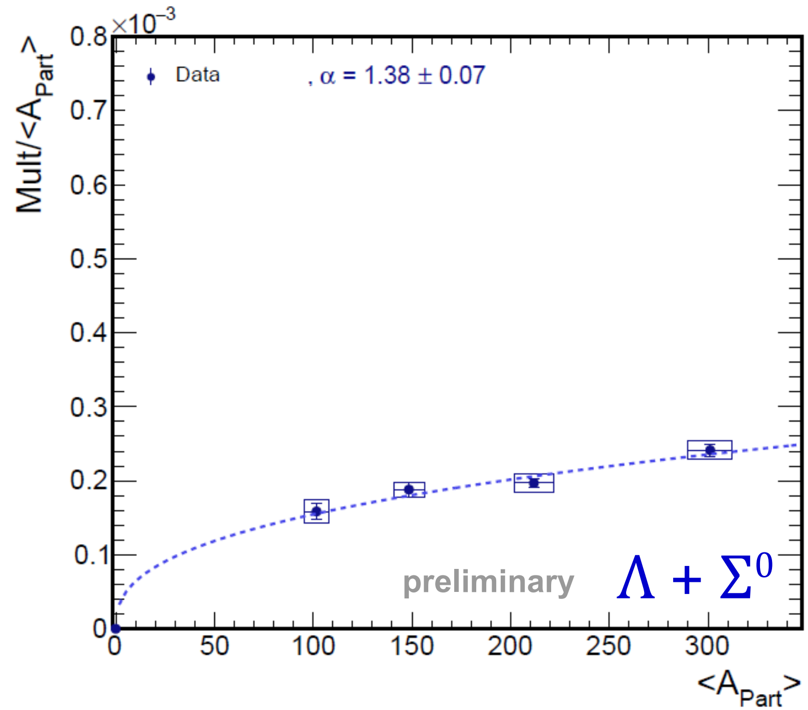
- Statistical production of strangeness?

  →see talk by M. Lorenz tomorrow



// Particle Yields vs Centrality: Comparison to Transport





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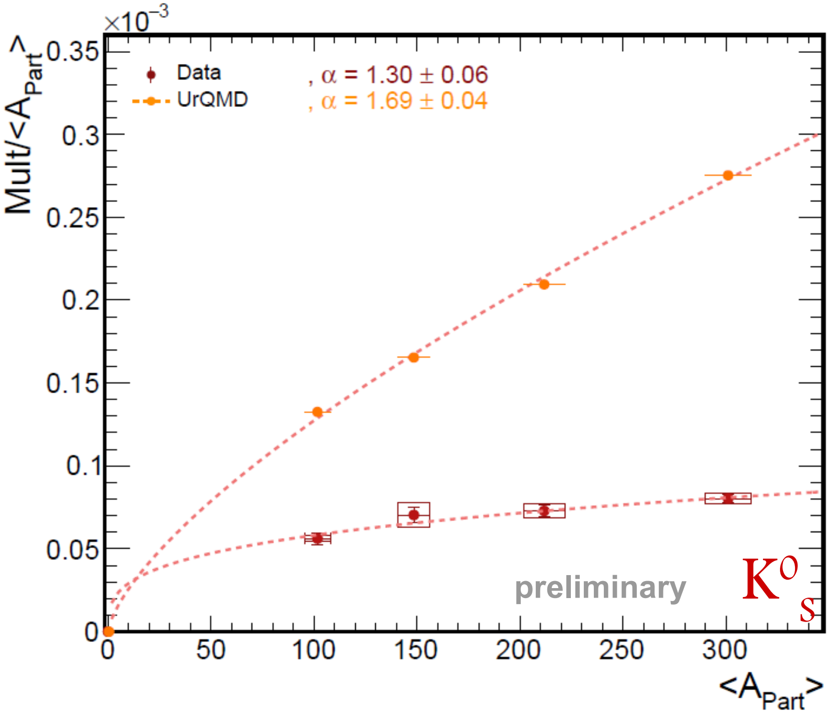

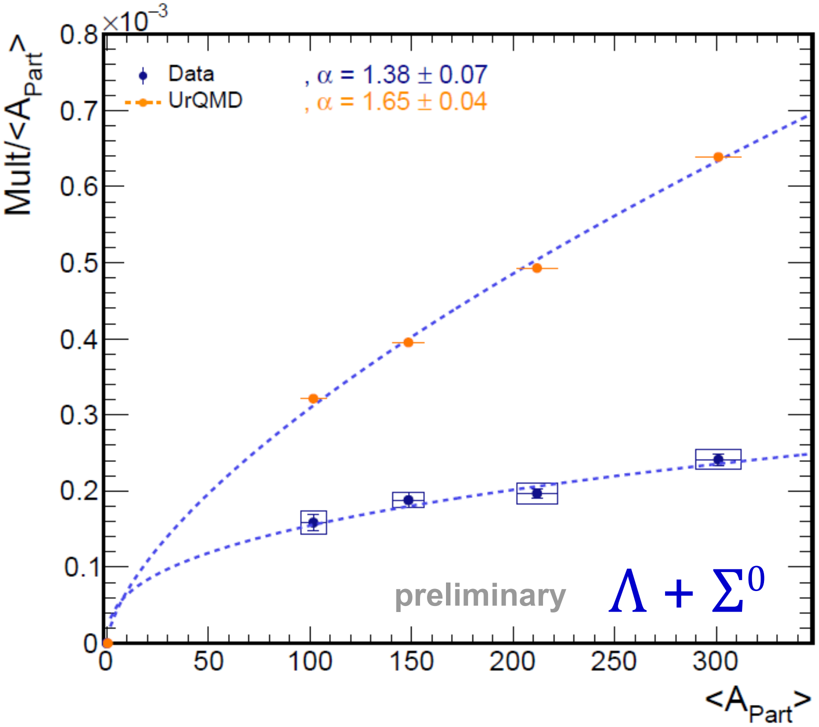

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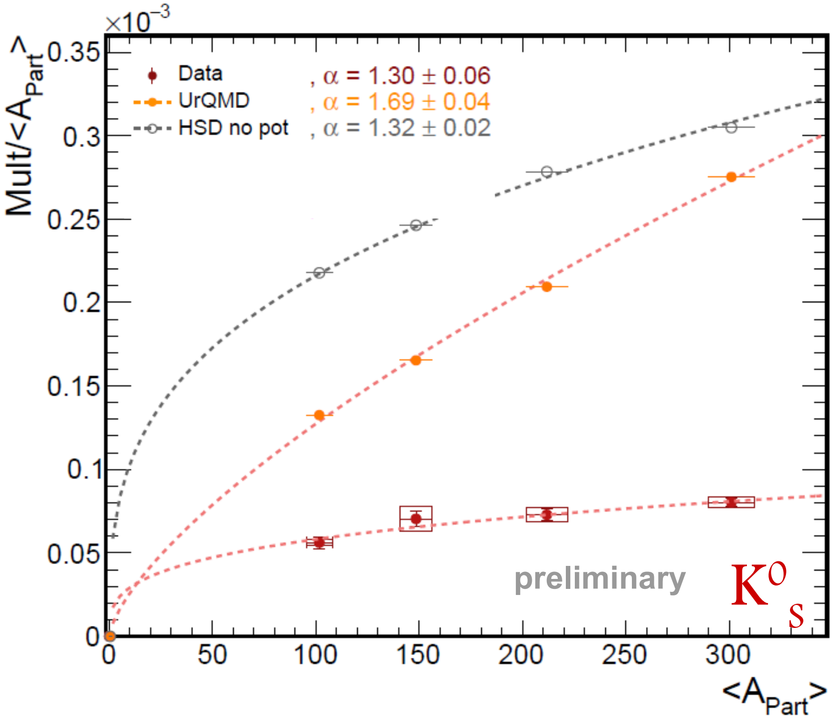

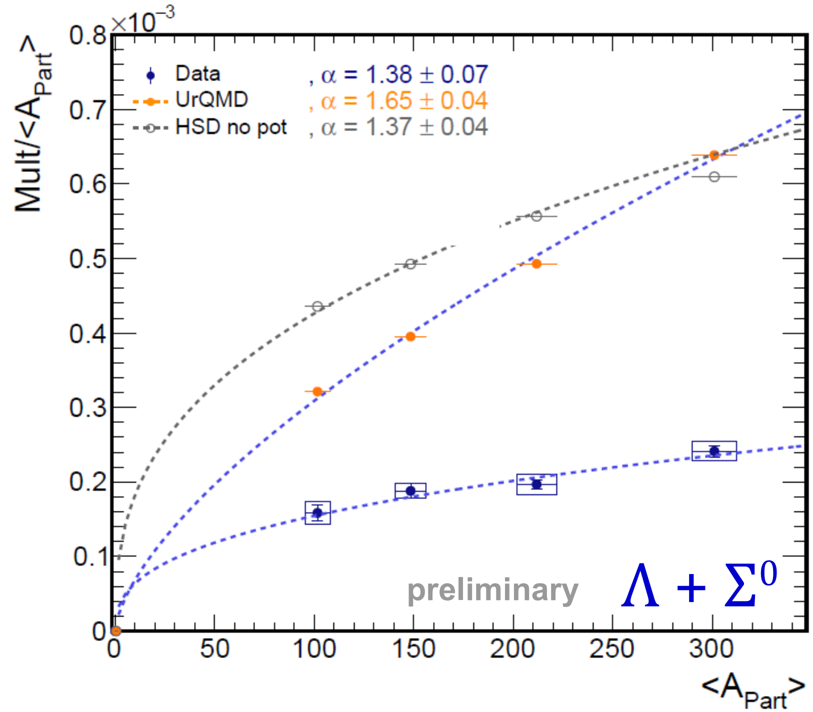

- Sensitive to multi-particle interactions → Comparison to transport models
- UrQMD 3.3 patch 2: Enhanced yields, stronger rise with centrality
- HSD 711n:
  - No medium potential: enhanced yields, similar rise

Thanks to Y. Leifels for providing model spectra

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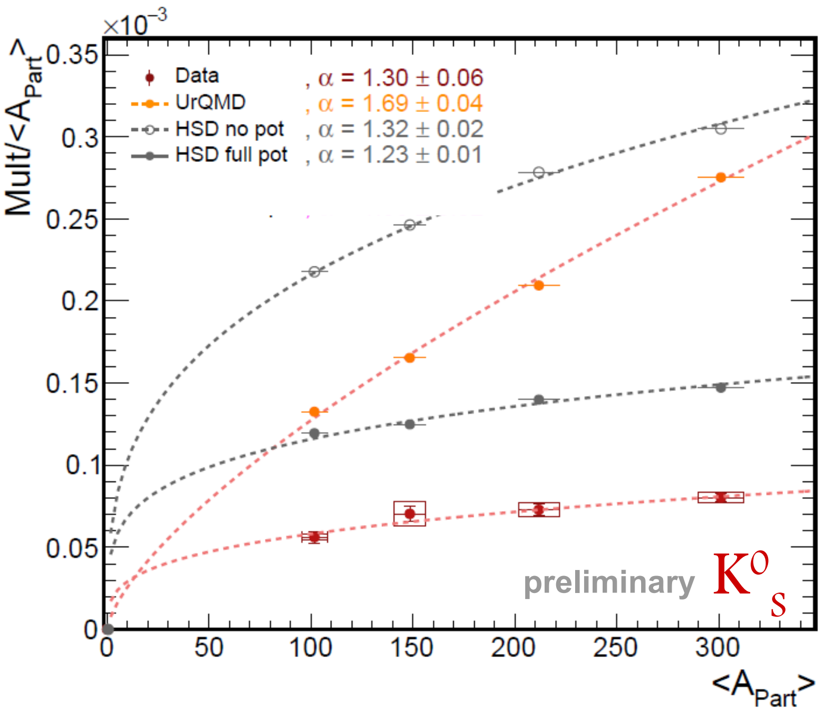

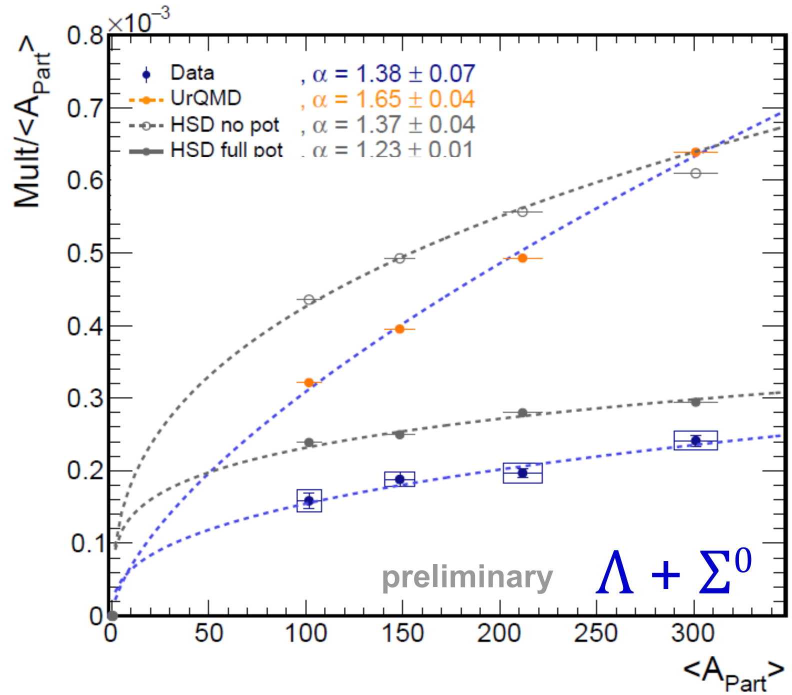

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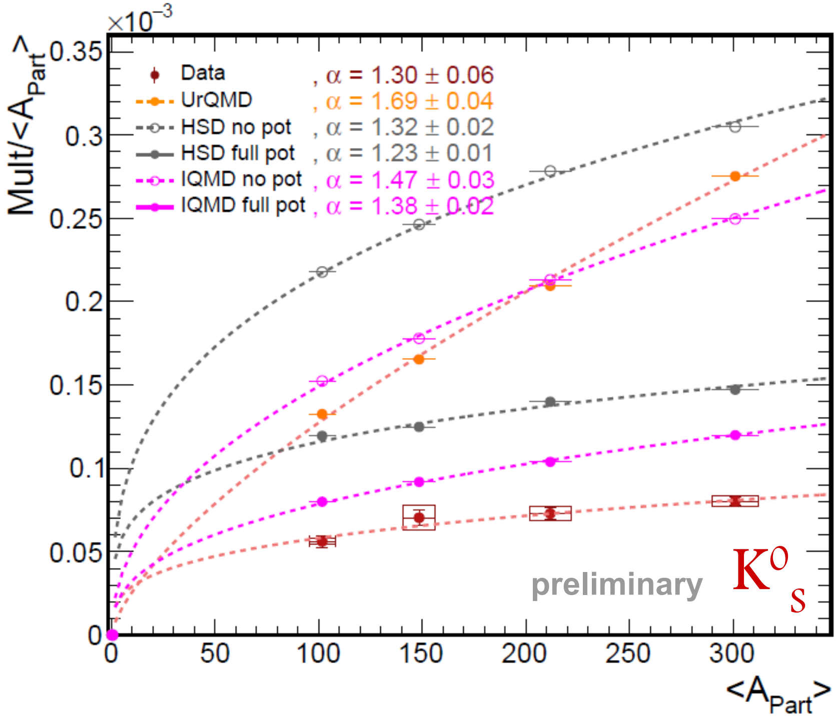

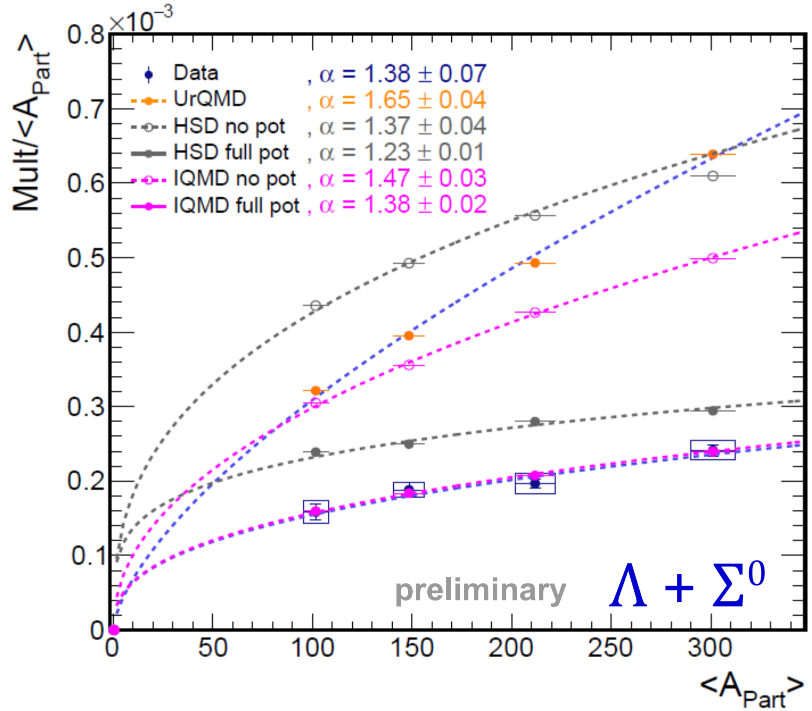

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- UrQMD 3.3 patch 2: Enhanced yields, stronger rise with centrality
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  - No medium potential: enhanced yields, similar rise
  - 40 MeV potential: smaller yield than without potential, still enhanced, smaller rise
- IQMD c8 (without Coulomb pot):
  - Same trends as HSD, but yields closer to data. Λ yield with full potential perfect landing

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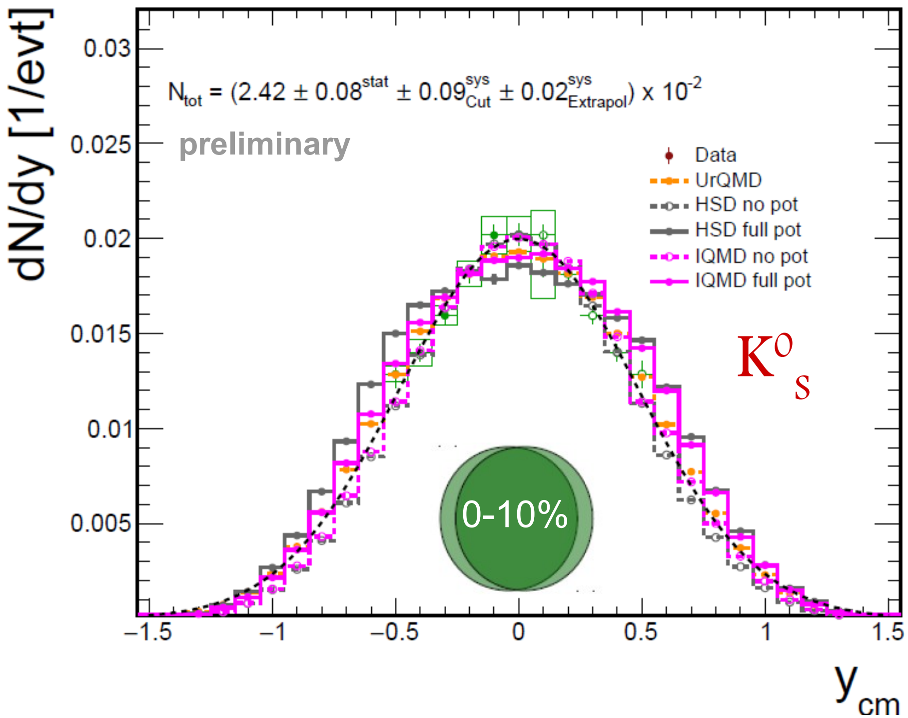
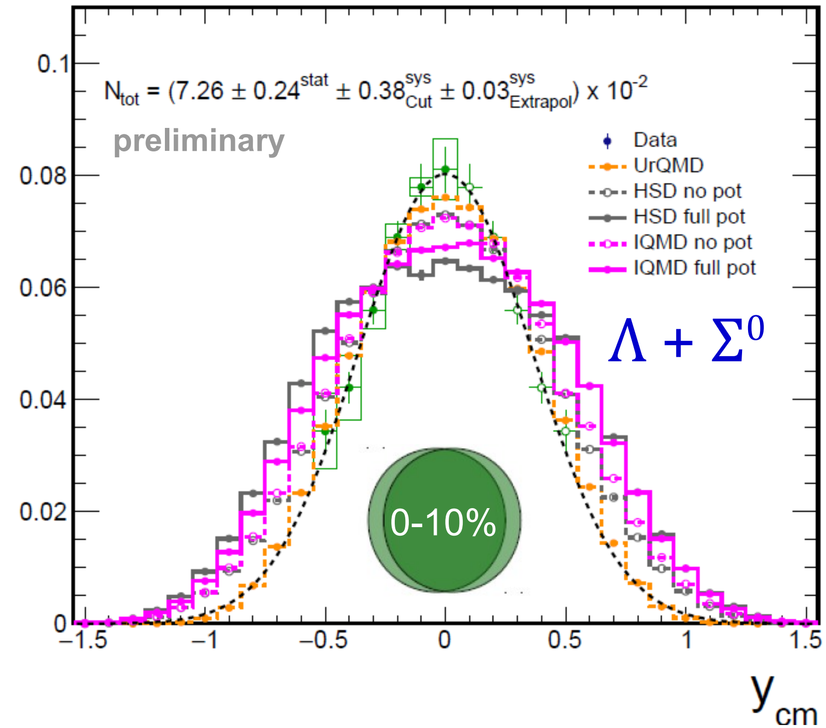
// dN/dy Spectra: Comparison to Transport (Most Central)





- Spectra from Transport **normalized** to integral of data
- Kaon Shape well reproduced by all models, better matching without potential
- Lambda Shape reproduced by UrQMD; HSD and IQMD broader

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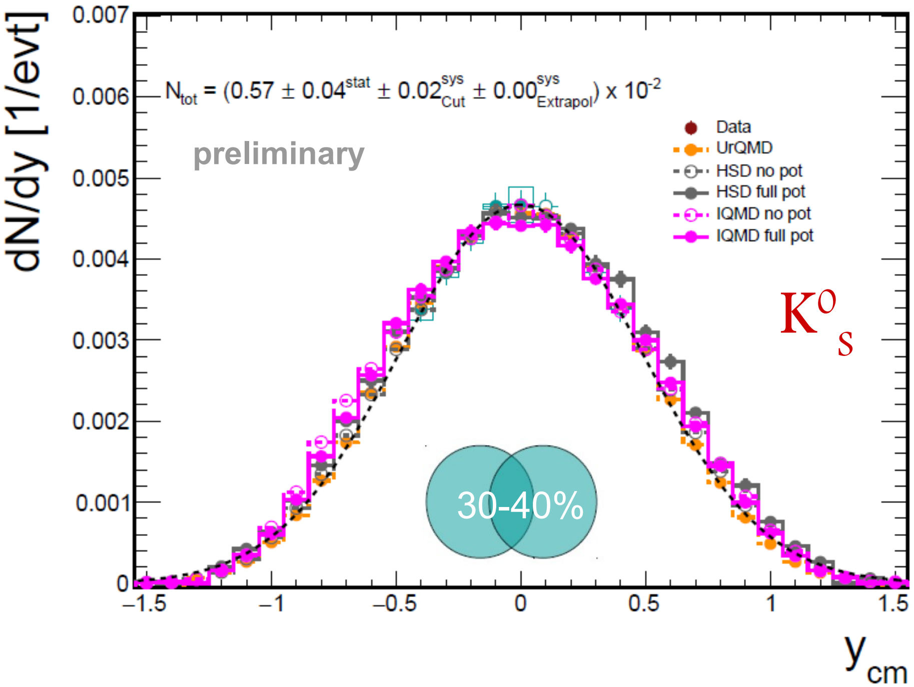
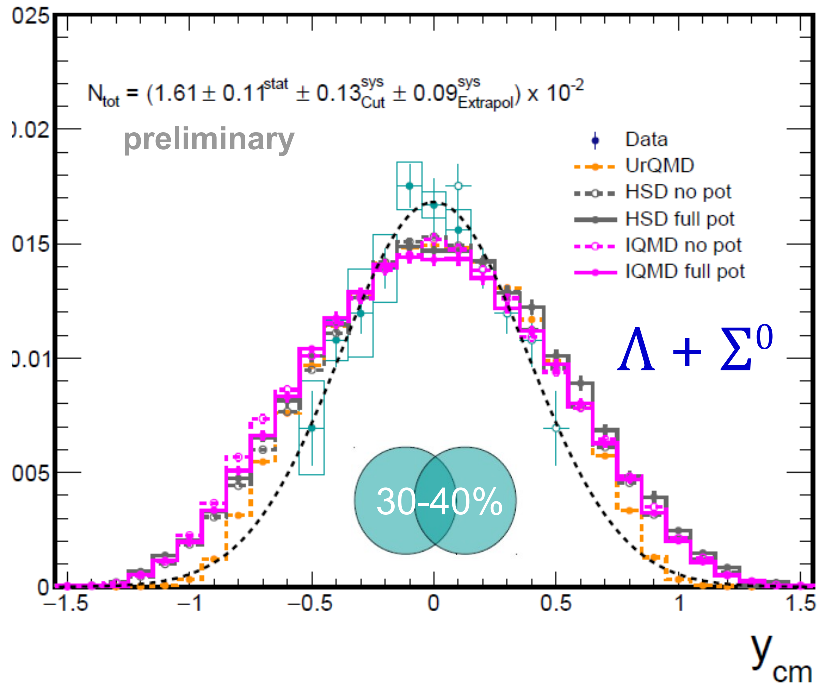
// dN/dy Spectra: Comparison to Transport (Peripheral)

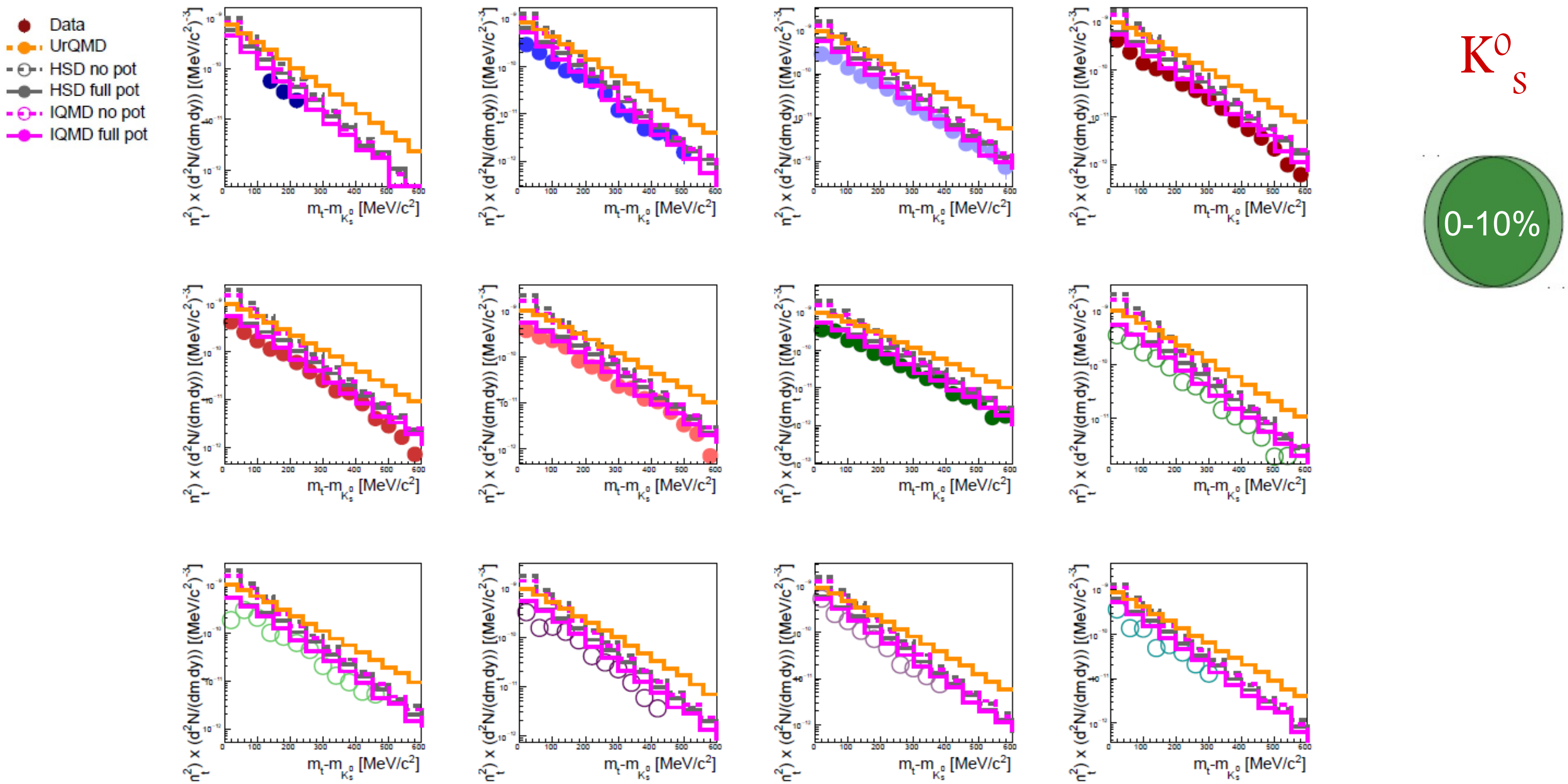




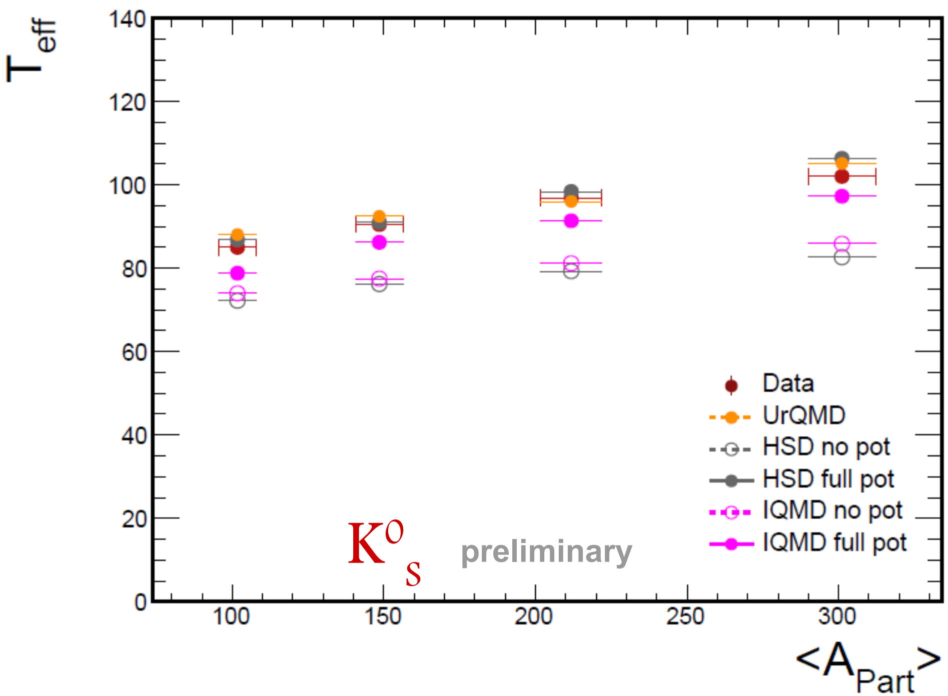
- Spectra from Transport normalized to integral of data
- Kaon Shape well reproduced by **all** models, slightly better matching with potential
- Lambda Models broader

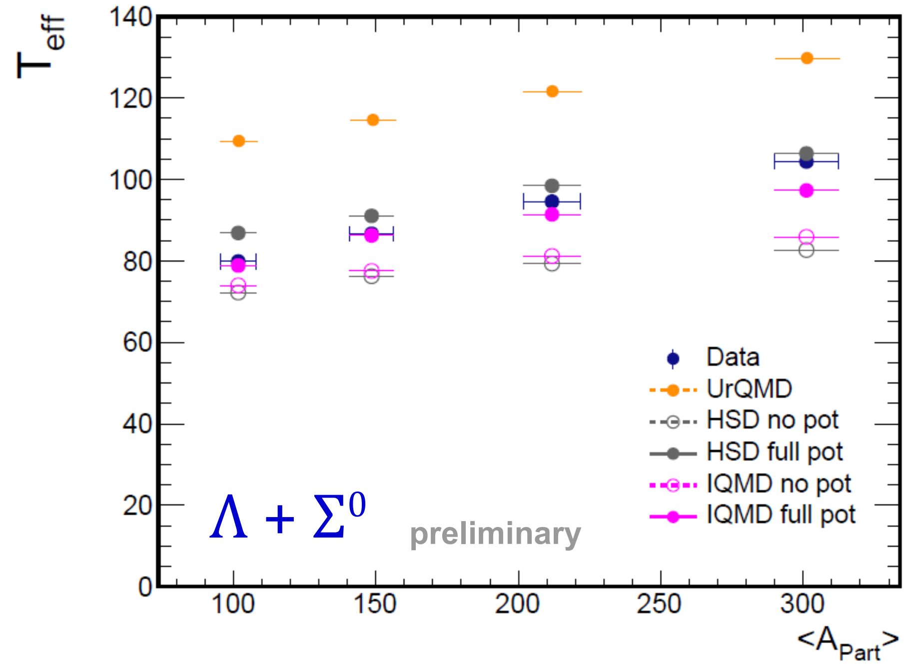
Thanks to Y. Leifels for providing model spectra

// Comparison M_T Spectra: Central



// Inverse Slope vs Number of Participants

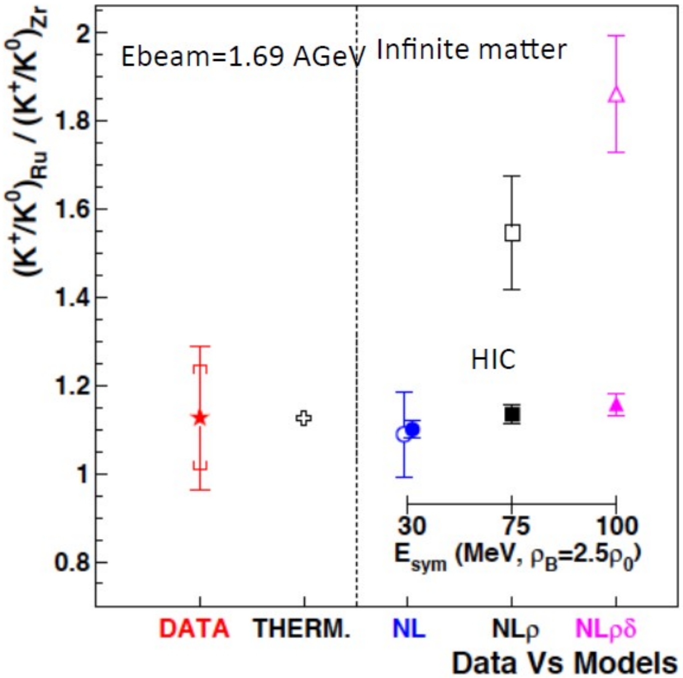




// Neutral to Charged Kaon Ratio

- Neutral to charged kaon ratio observable for symmetry energy term in EoS
- Sensitive to symmetry energy term in EoS when comparing to transport?

FOPI: PHYSICAL REVIEW C **75**, 011901(R) (2007)

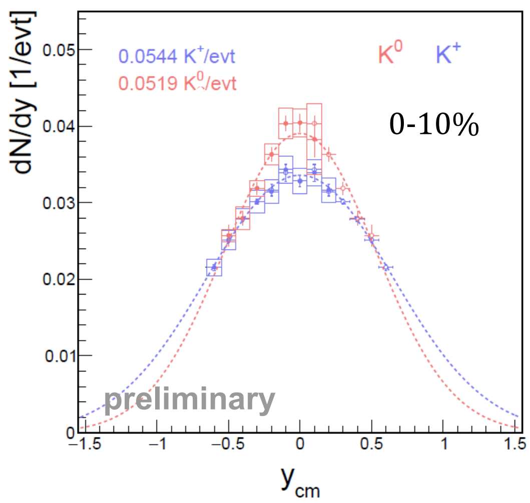


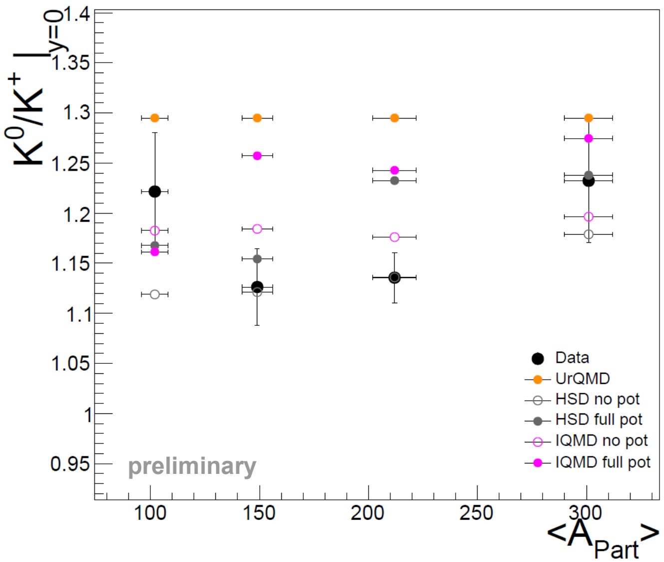
// Neutral to Charged Kaon Ratio

- Neutral to charged kaon ratio observable for symmetry energy term in EoS
- Sensitive to symmetry energy term in EoS when comparing to transport?
- Measured K^0 over K^+ ratio gives:

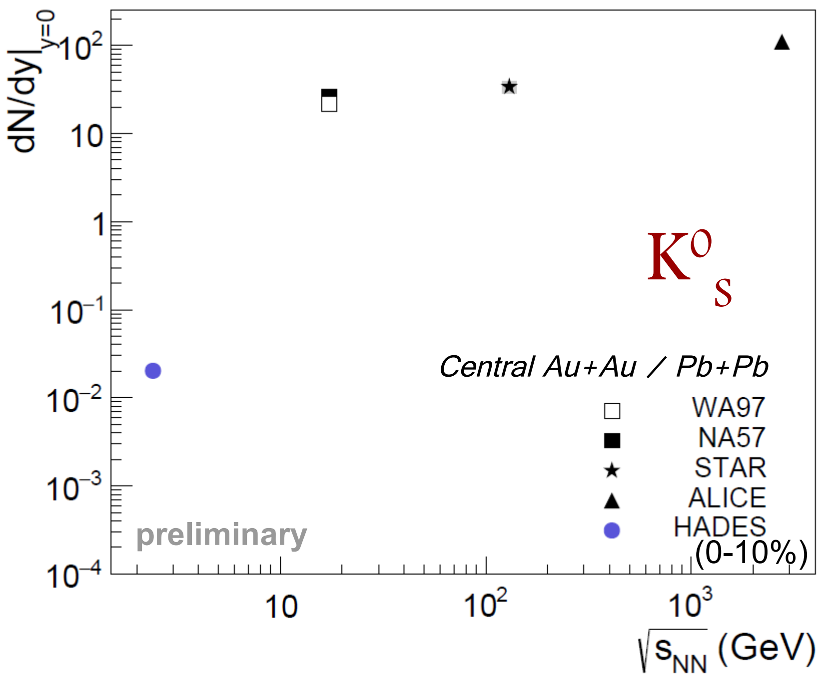
$$\text{Mult}\ (K^0/K^+)\ |_{y=0} = 1.1 - 1.25$$

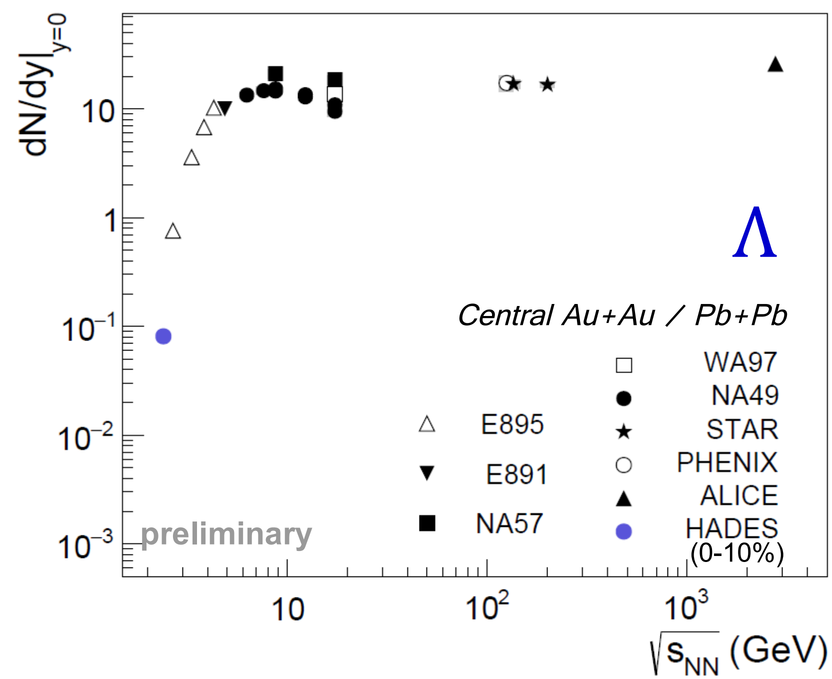
- Measured mean: 1.15 ± 0.018
- More fundamental comparisons → p_T spectra





// Comparison World Data: Steep Excitation Function



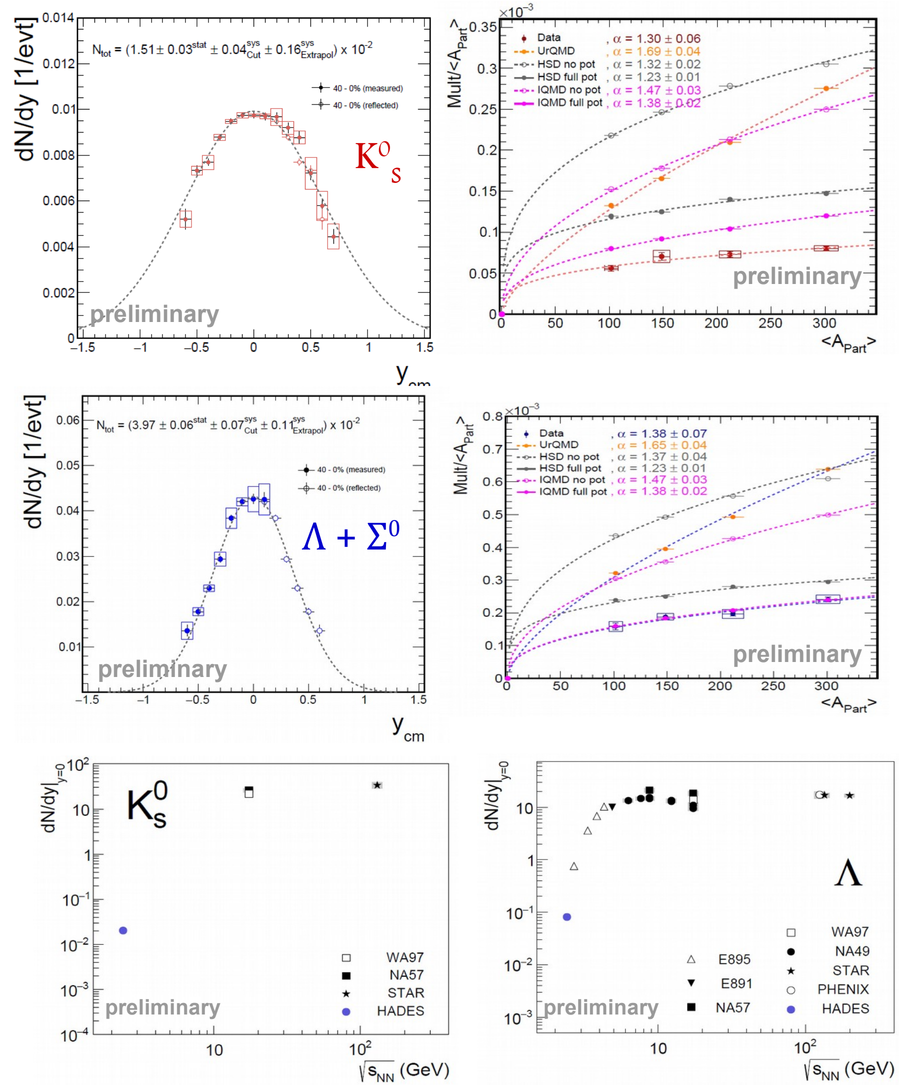


C. Blume, C. Markert: arXiv:1105.2798v2 [nucl-ex] 19 Aug 2011

- Central Au+Au/Pb+Pb yields at midrapidity
- Steep excitation function towards low energies
- HADES data points first below elementary production threshold

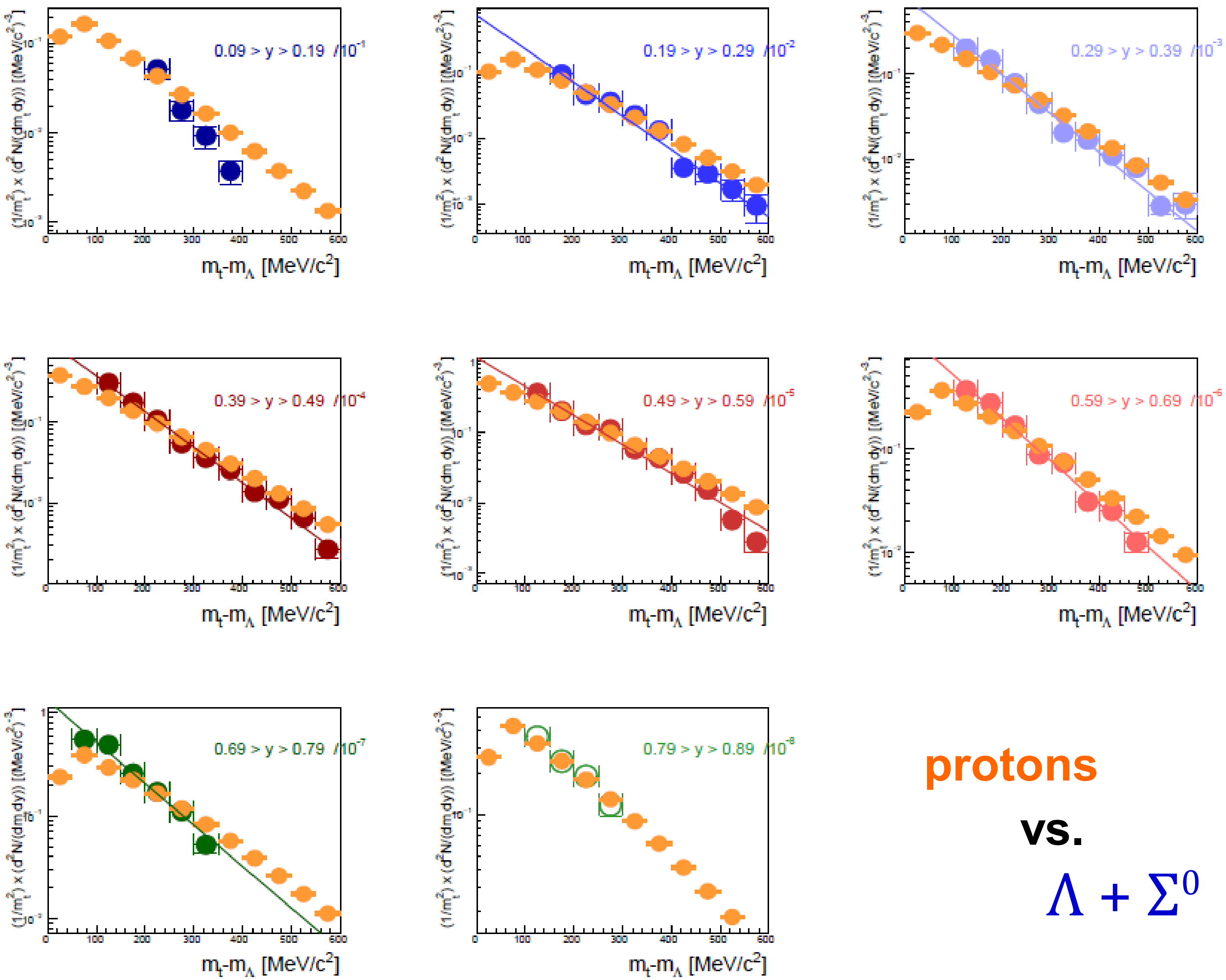
// Summary and Outlook

- Successful reconstruction of Λ and K^0_S as a function of m_T, y and centrality
- Close to final dN/dy spectra presented
- Strange particle multiplicities show similar rise with <A_{Part}> towards central collisions.
- Comparisons to Transport ongoing:
  - Yields enhanced over data
  - Including medium potentials lowers yields by 30-50%
  - dN/dy spectral shape reproduced for K^0, Λ slightly broader
- Comparison of K^0 to K^+:
  Data sensitive to symmetry term in equation of state?
- First observation below elementary threshold
  →point added to steep excitation function



// Backup...

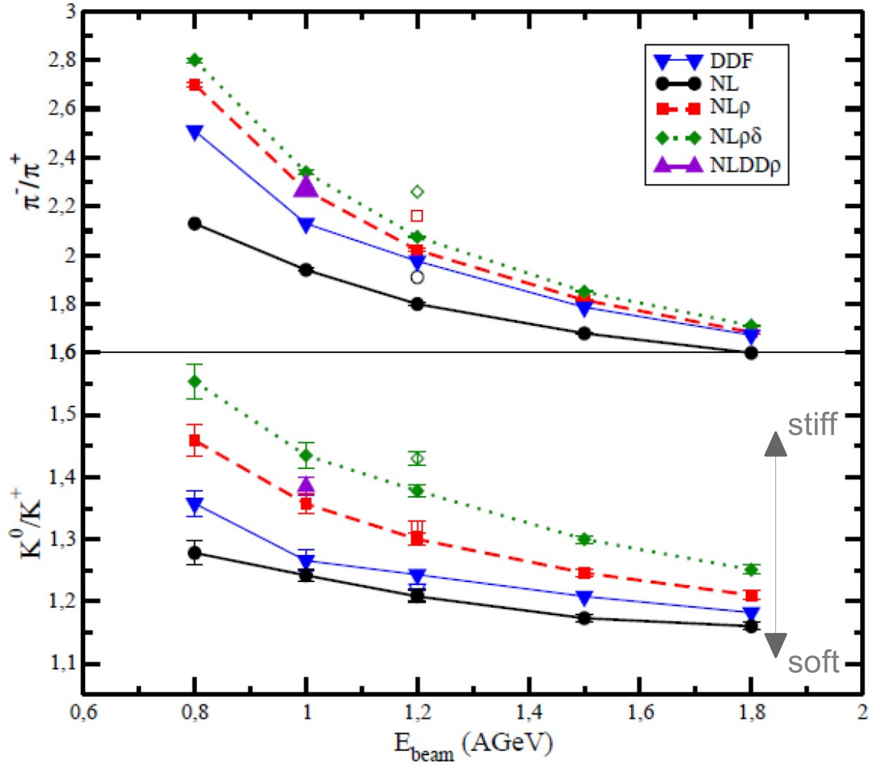
// Comparison M_T Spectra: Most Central

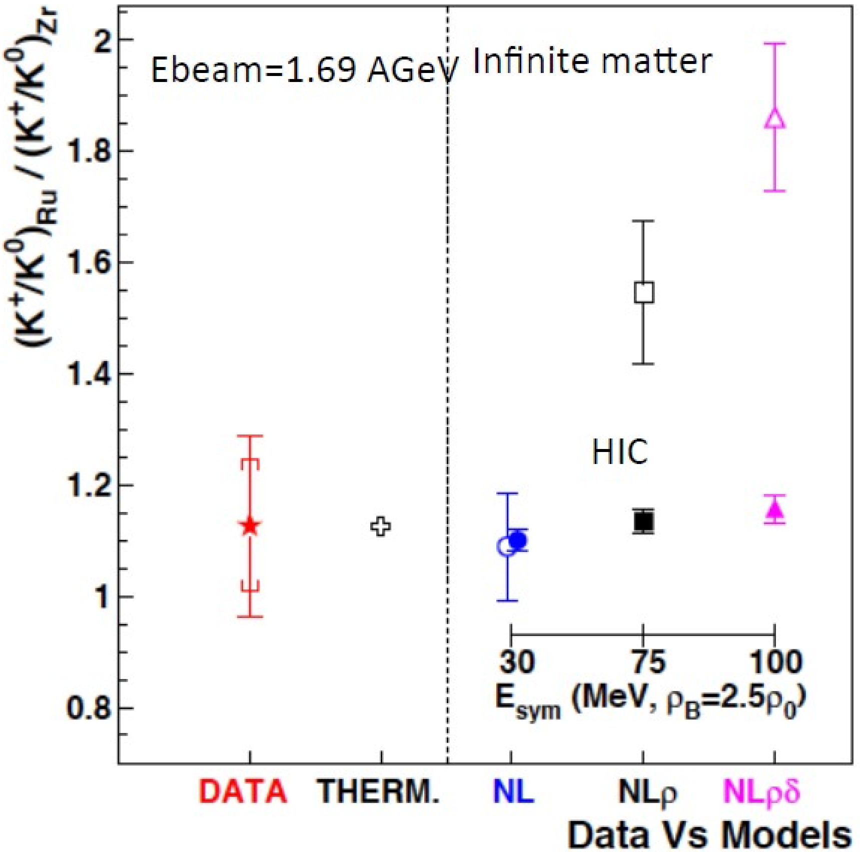


protons

vs.

$\Lambda + \Sigma^0$


DDF
NL
NLρ
NLρδ
NLDDρ
π^-/π^+
K^0/K^+
stiff
soft
E_{beam} (AGeV)


$(K^+/K^0)_{Ru} / (K^+/K^0)_{Zr}$
Ebeam=1.69 AGeV
Infinite matter
HIC
30
75
100
E_{sym} (MeV, ρ_B=2.5ρ_0)
DATA
THERM.
NL
NLρ
NLρδ
Data Vs Models

Lifetime Measurements

Measure and compare well-known mean lifetime τ of K^0_s and Λ

Exponential Decay

$$N(\Delta t) = N_0 \cdot exp^{\frac{-\Delta t}{\tau}}$$

Time-of flight of relativistic particle P in lab frame:

(I) $\Delta t_{lab} = \Delta t'_P \cdot \gamma$ ($\Delta t'_P$: Eigentime)

Time-of flight can be calculated from observables:

(II) $\Delta t_{lab} = \frac{\Delta l}{\beta \cdot c}$ (Δl : Dist. Prim. – Seco. Vertex, β : Velocity)

(I) = (II)

$$\Longrightarrow \Delta t'_P = \frac{\Delta l}{\beta \gamma c}$$

$\beta\gamma c = |p|/m$

$$\Longrightarrow \Delta t'_P = \frac{\Delta l \cdot m}{|p|}$$

(m : mass
p : momentum)