Strange hadron production at SIS energies: an update from HADES

Manuel Lorenz
for the collaboration

SQM, Dubna 2015

Alexander von Humboldt Stiftung/Foundation

GOETHE

University of Utrecht

Outline

Introduction

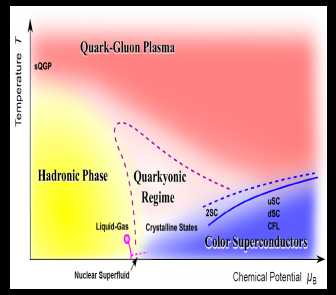
- Strangeness production in the 1-2 A GeV energy regime
  - Charged kaons
  - Φ mesons , Ξ^- hyperons and statistical model

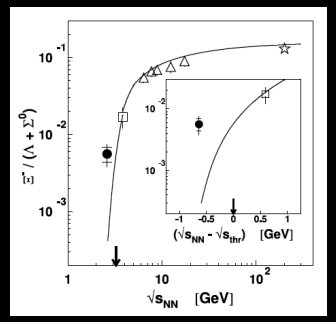
Au+Au @ 1.23 A GeV

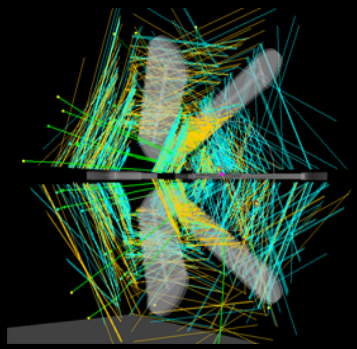
- Upgraded HADES
- Performance
  - Data taking and analysis
  - Mass spectra and reconstruction of secondary vertices
- Preliminaries
  - K^0_s, Λ spectra and rapidity distributions
  - Φ/K^- ratio

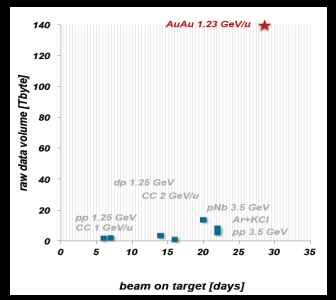
Ξ^- hyperons .. stranger than expected

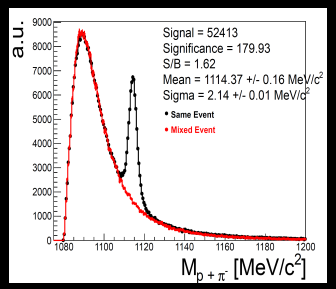
Summary





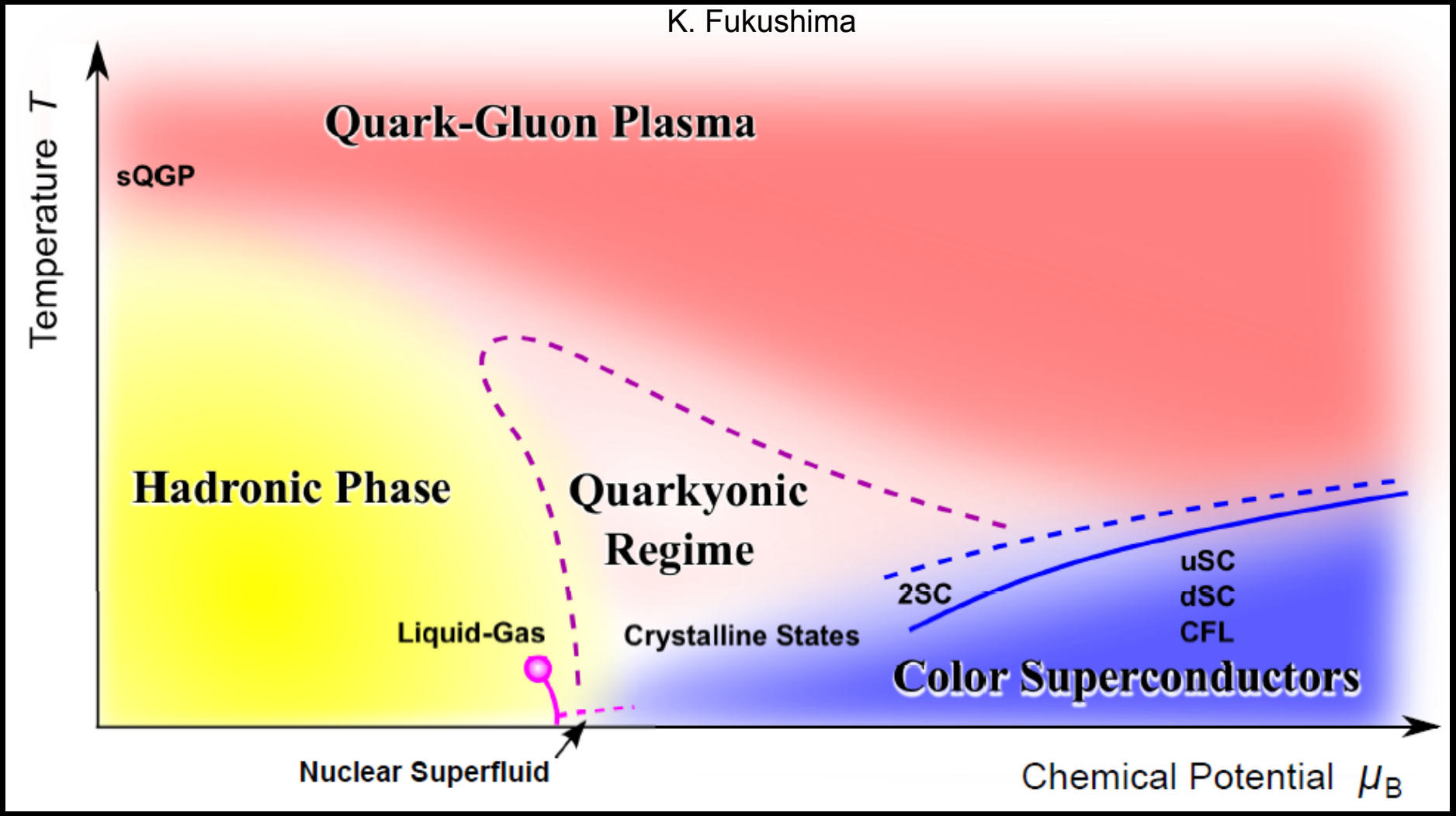






Heavy-ion collisions and QCD phase diagram

Systematic probing of the phase diagram by varying kinetic beam energy



SIS 18 energy regime:
beam energies of 1-2 AGeV for ions, baryon dominated rather long living

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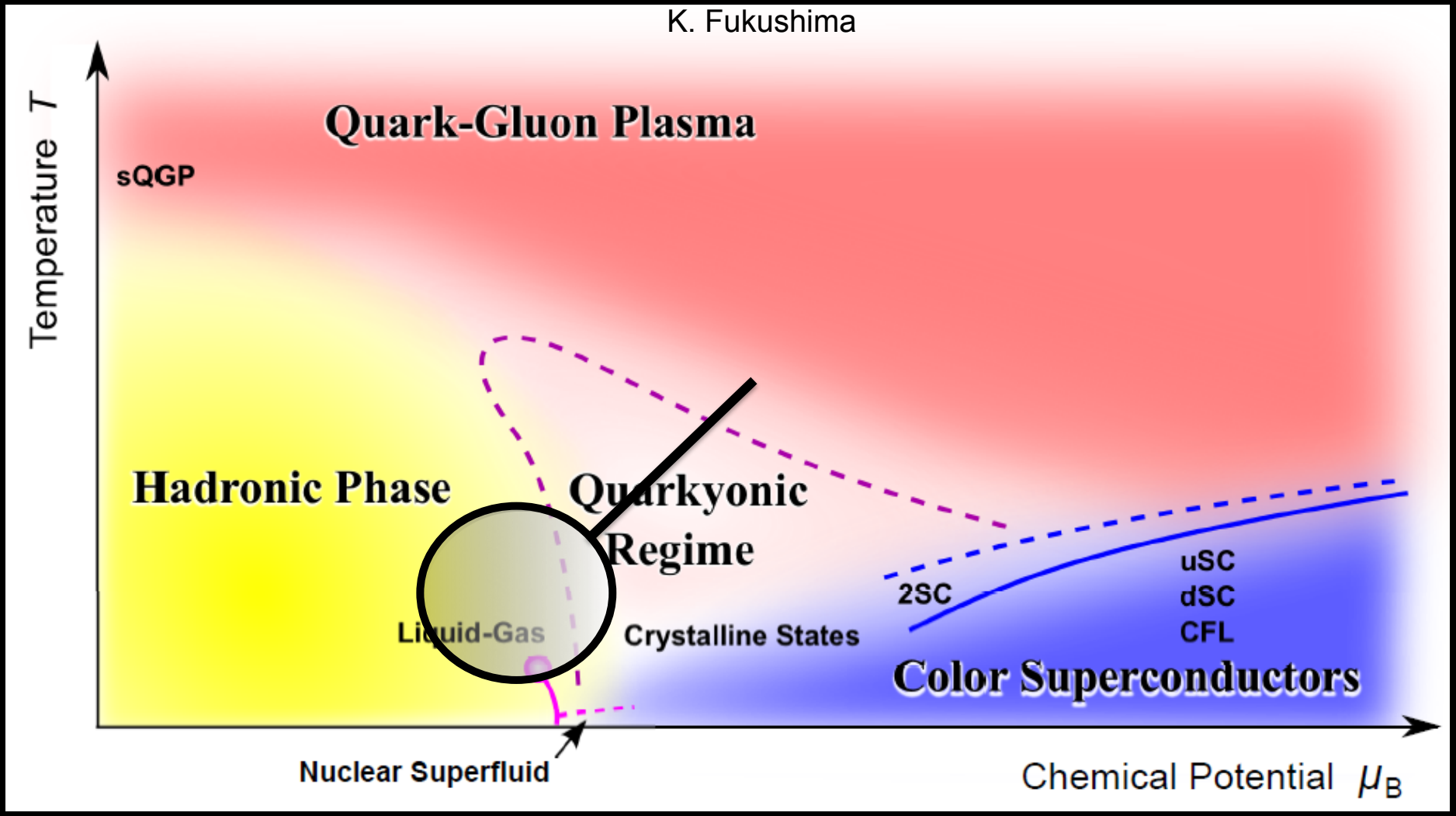

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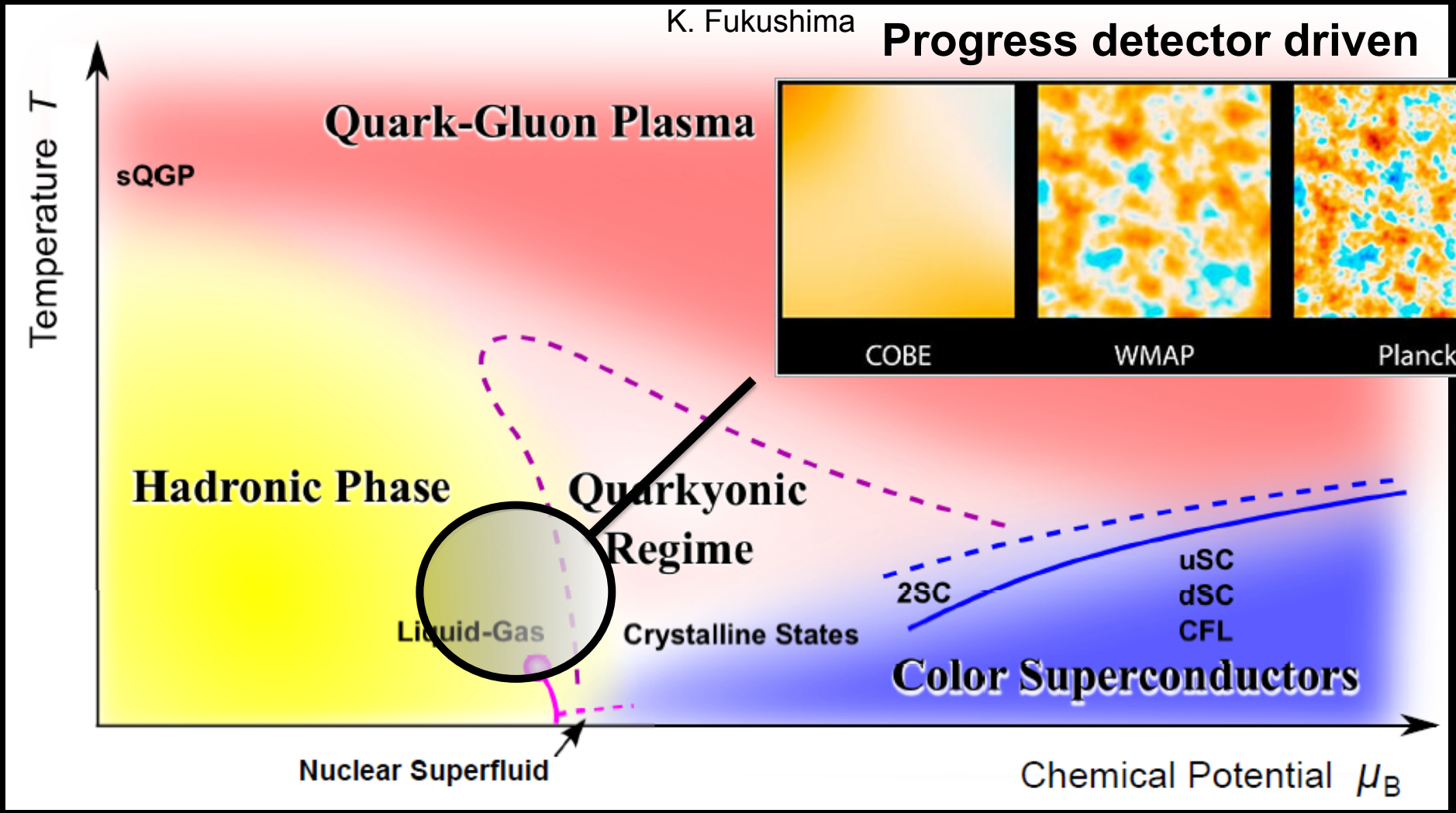

SIS 18 energy regime:
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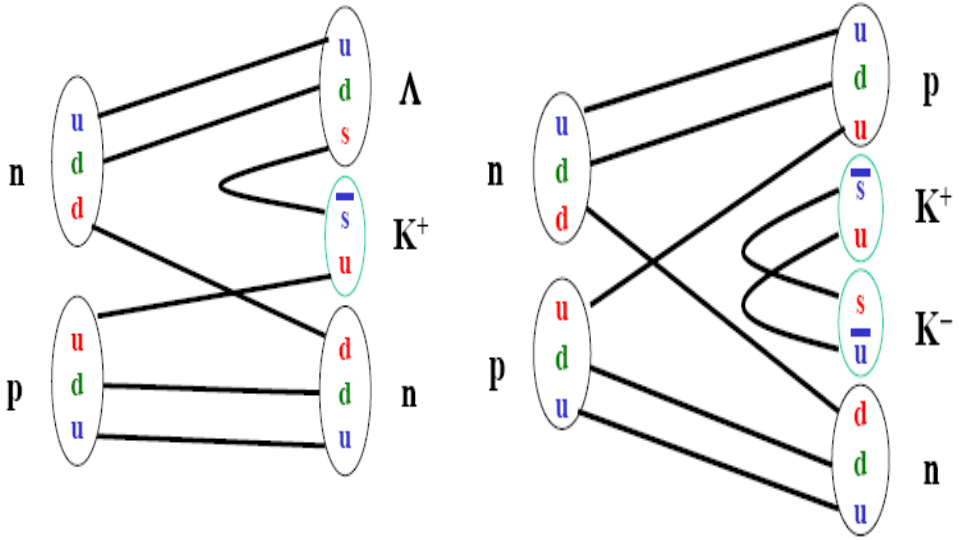
Strangeness production

Elementary collisions

$$NN \rightarrow NK^{+}\Lambda \qquad (E_{thr} = 1.58\,GeV)$$

$$NN \rightarrow NNK^{+}K^{-} \qquad (E_{thr} = 2.49\,GeV)$$

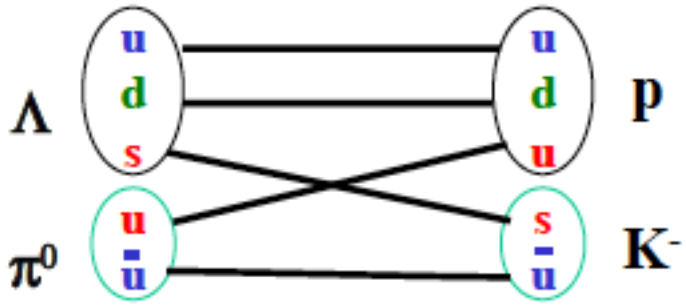
$$NN \rightarrow NN\varphi \qquad (E_{thr} = 2.59\,GeV)$$



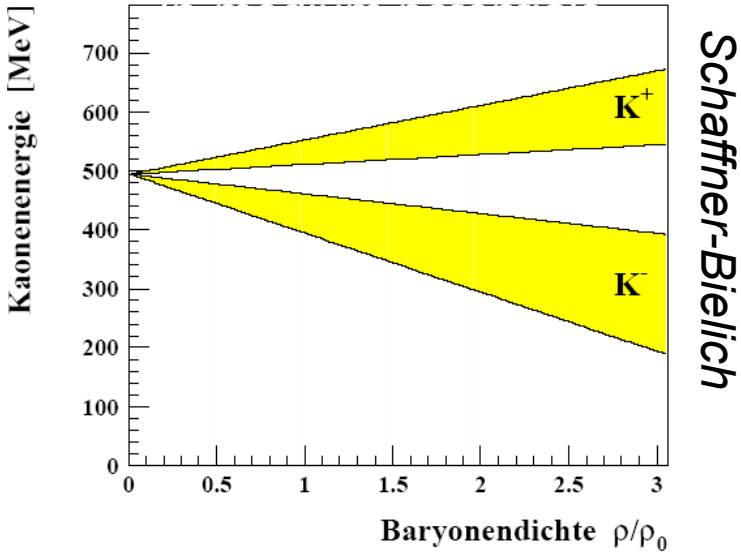
Different production thresholds

Heavy-ion collisions

- Accumulation of energy in multi–step processes
- Strangeness exchange reactions + potentials



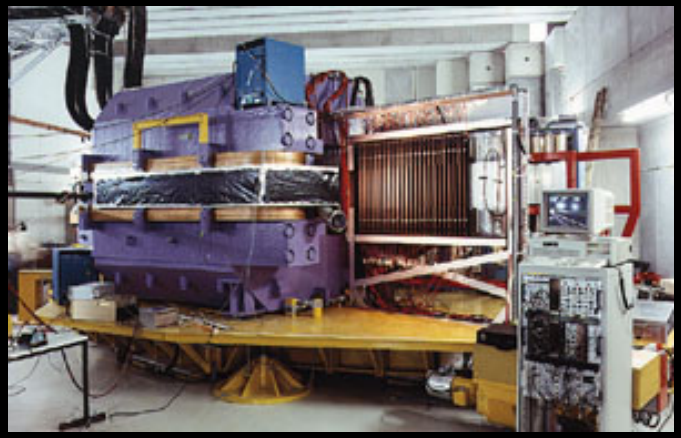
endothermal in vacuum!



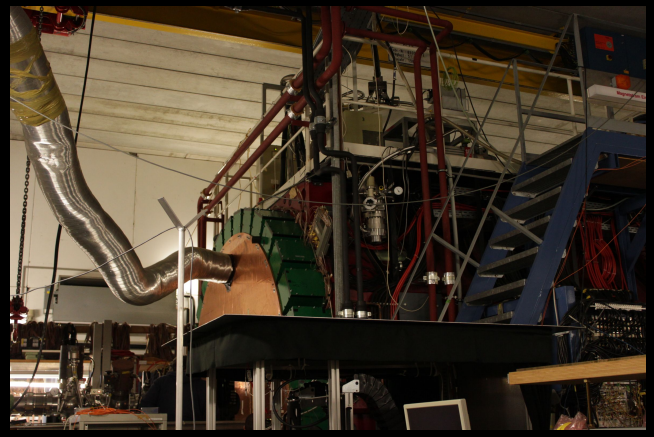
Schaffner-Bielich

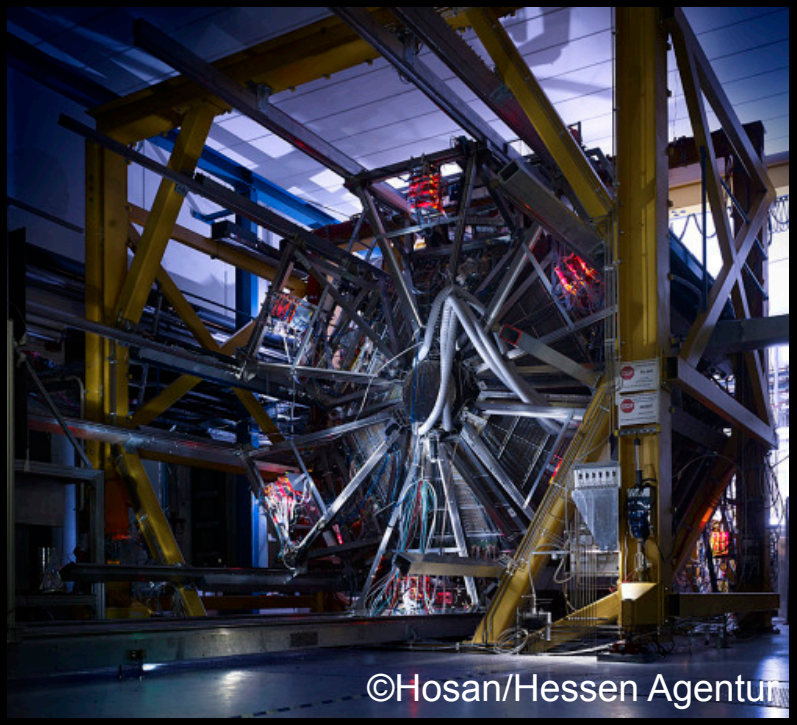
Main players at SIS18

KaoS decommissioned



FOPI decommissioned

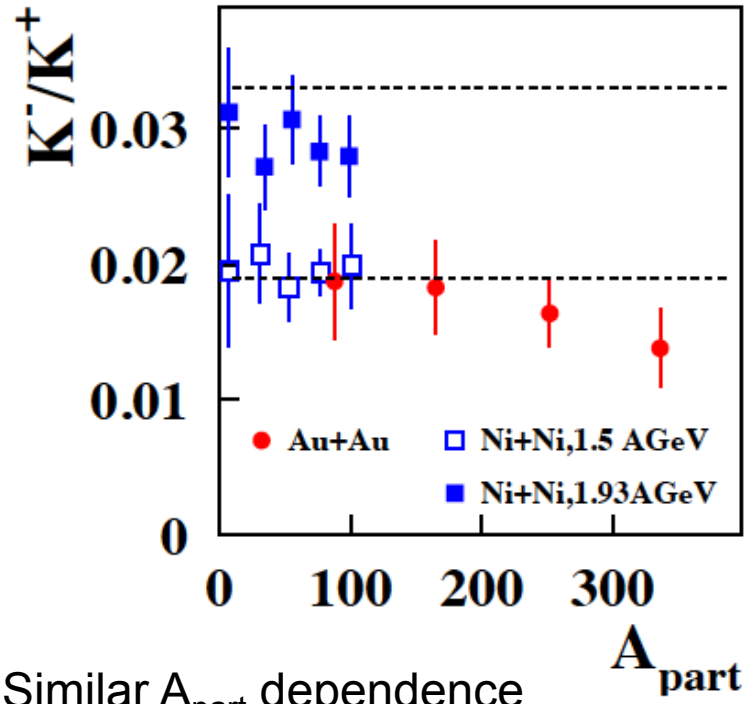




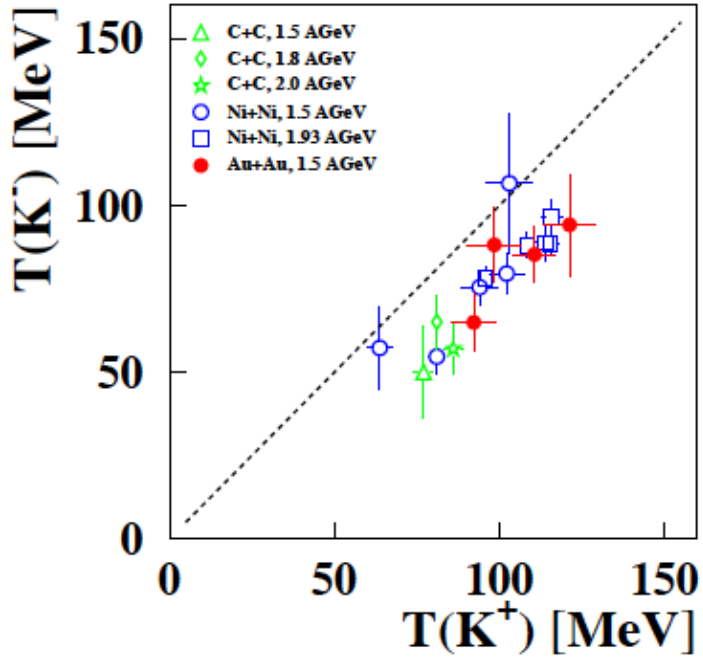
HADES active at SIS18 and SIS100

Strangeness production

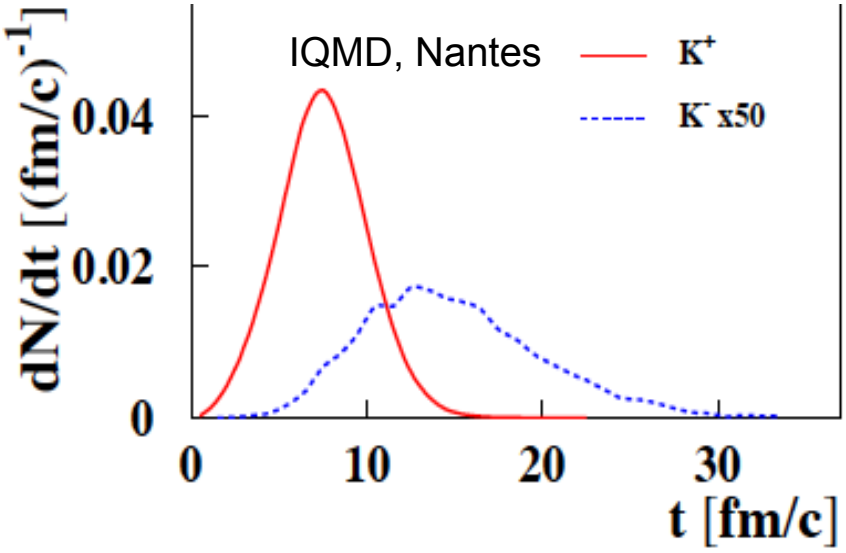
Förster et. al (KaoS)



Similar A_{part} dependence



Different inverse slope parameters

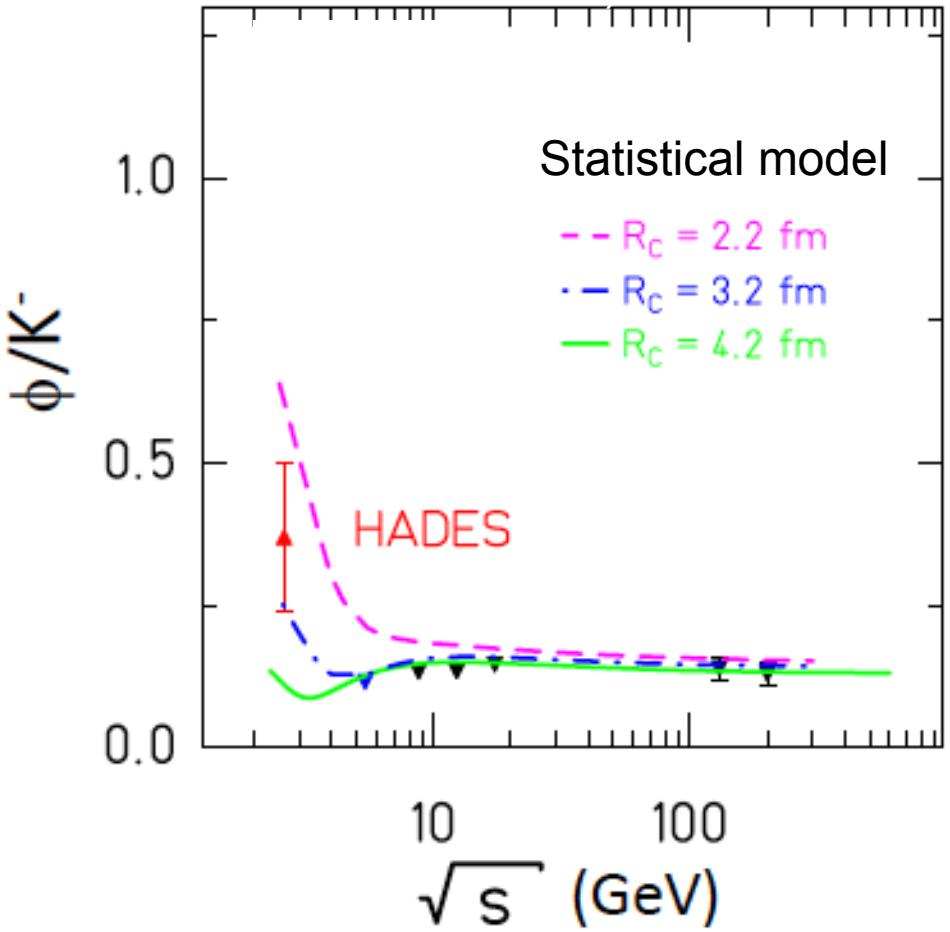


Transport:

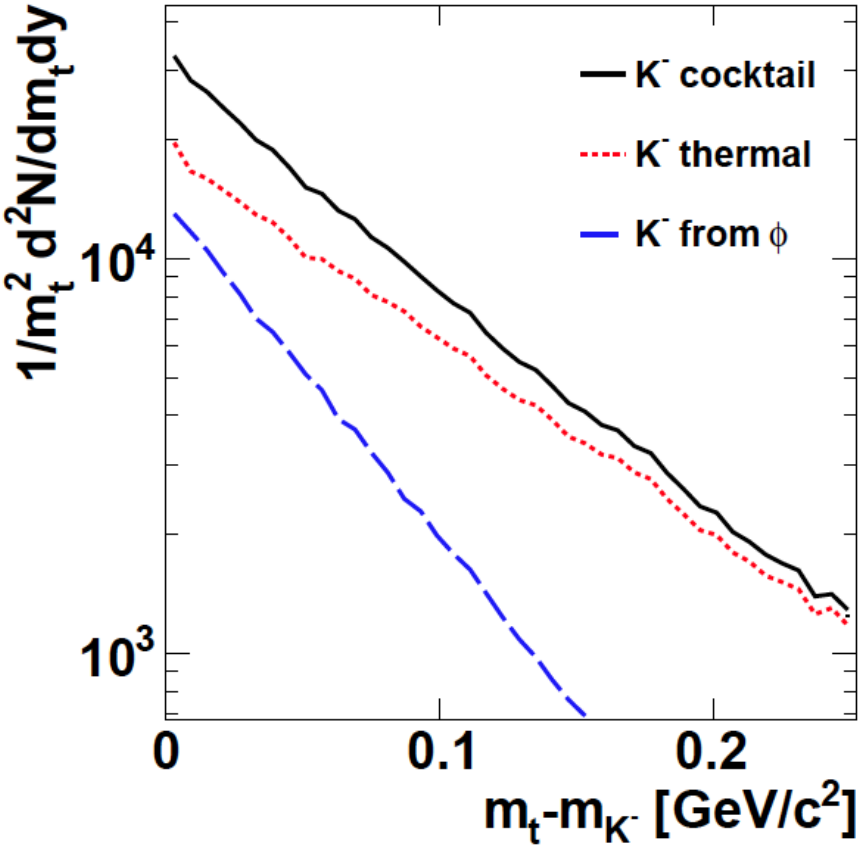
- Production of K^+/K^- coupled
- Strangeness exchange dominant for K^-
- Later freeze-out of K^- compared to K^+, due to coupling to baryons

Strangeness production

Enhanced Φ production at low beam energy
First indication from FOPI



Feed-down of Φ can explain
different slope parameters of K^+ and K^-



See also new data from FOPI in:
Phys.Rev. C91 (2015) 5, 054904

Can we understand the yields, with fewer assumptions? (Ockham's razor)

Hadrons in Ar+KCl@1.76A GeV

Particle production from a homogeneous source:

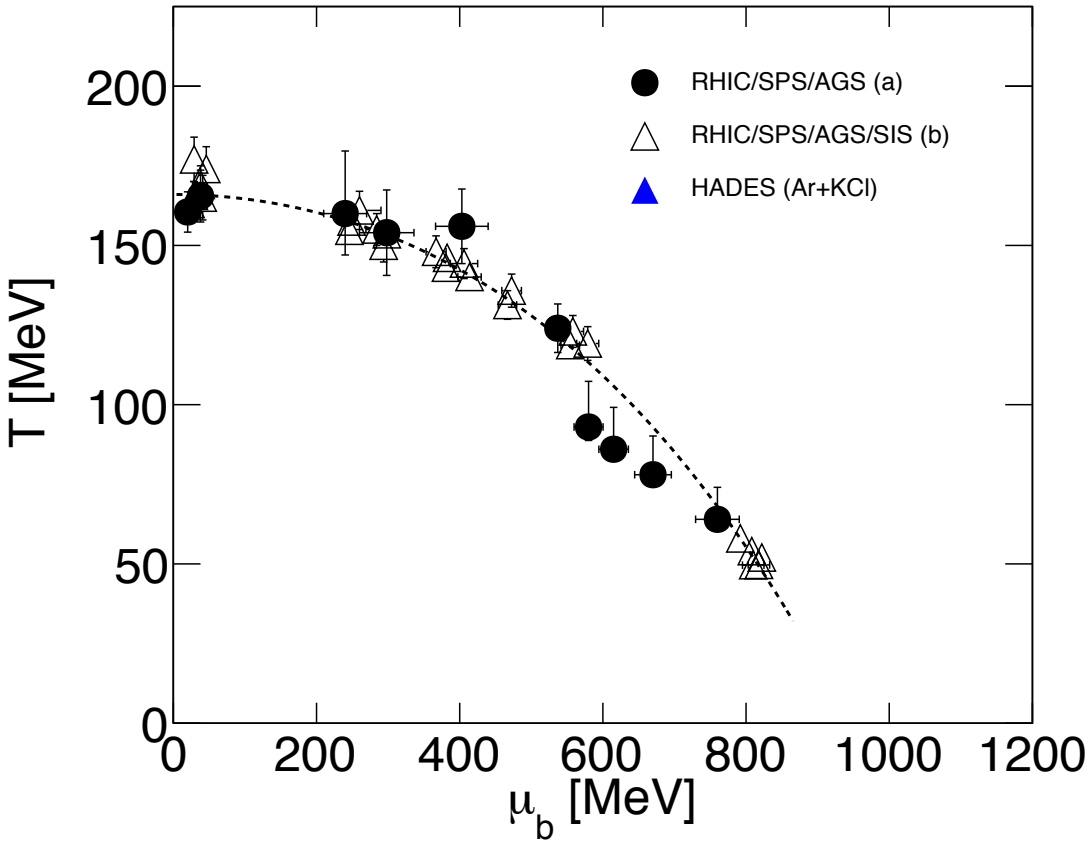
$$\rho_{i,q} \propto \int_0^\infty p^2 dp \; exp\left(\frac{-E_i + \vec{\mu}\vec{q_i}}{kT}\right)$$

- Grand canonical ensemble (T, $\mu = \mu_B\ \mu_s\ \mu_Q$, V and sometimes γ_s, usually μ_s and μ_Q are constrained)

- Strangeness canonical ensemble (T, $\mu = \mu_B\ \mu_Q$, R_c, R) (Strangeness canonically suppressed at low temperatures)

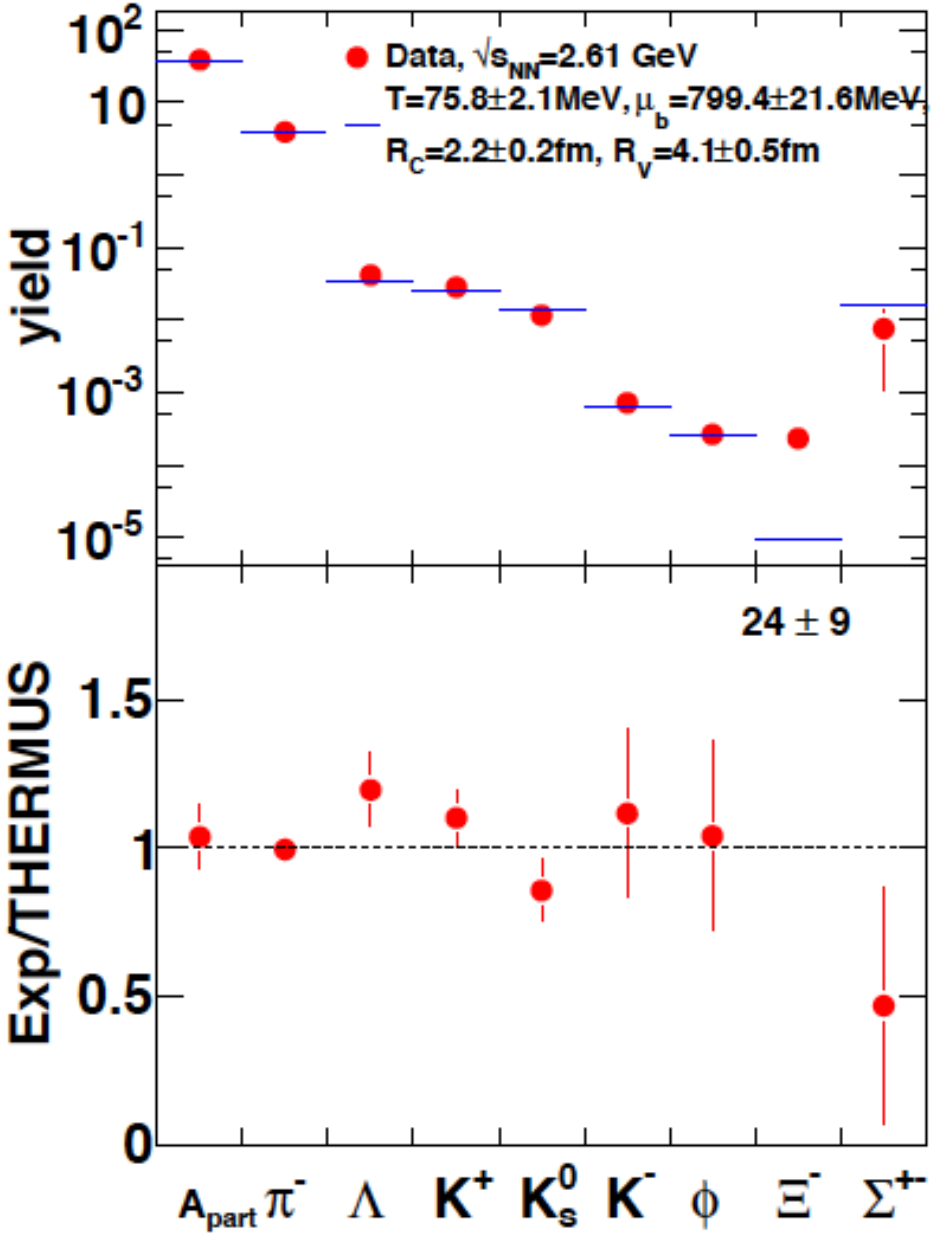
- Fits at low beam energies based on limited number of particle species

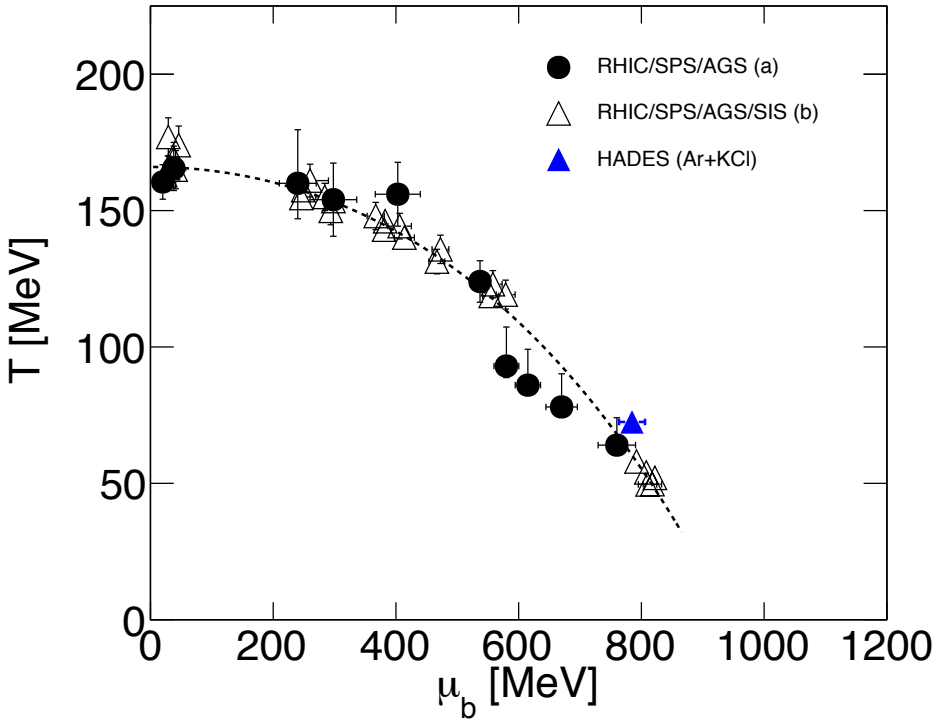
Eur. Phys. J., A 47(21)



How will it work for more particle species in Ar+KCl?

Hadrons in Ar+KCl@1.76A GeV





Statistical model works reasonably well at low energies for medium-sized system

THERMUS: S. Wheaton, J.Cleymans: Comput.Phys.Commun.180:84-106,2009

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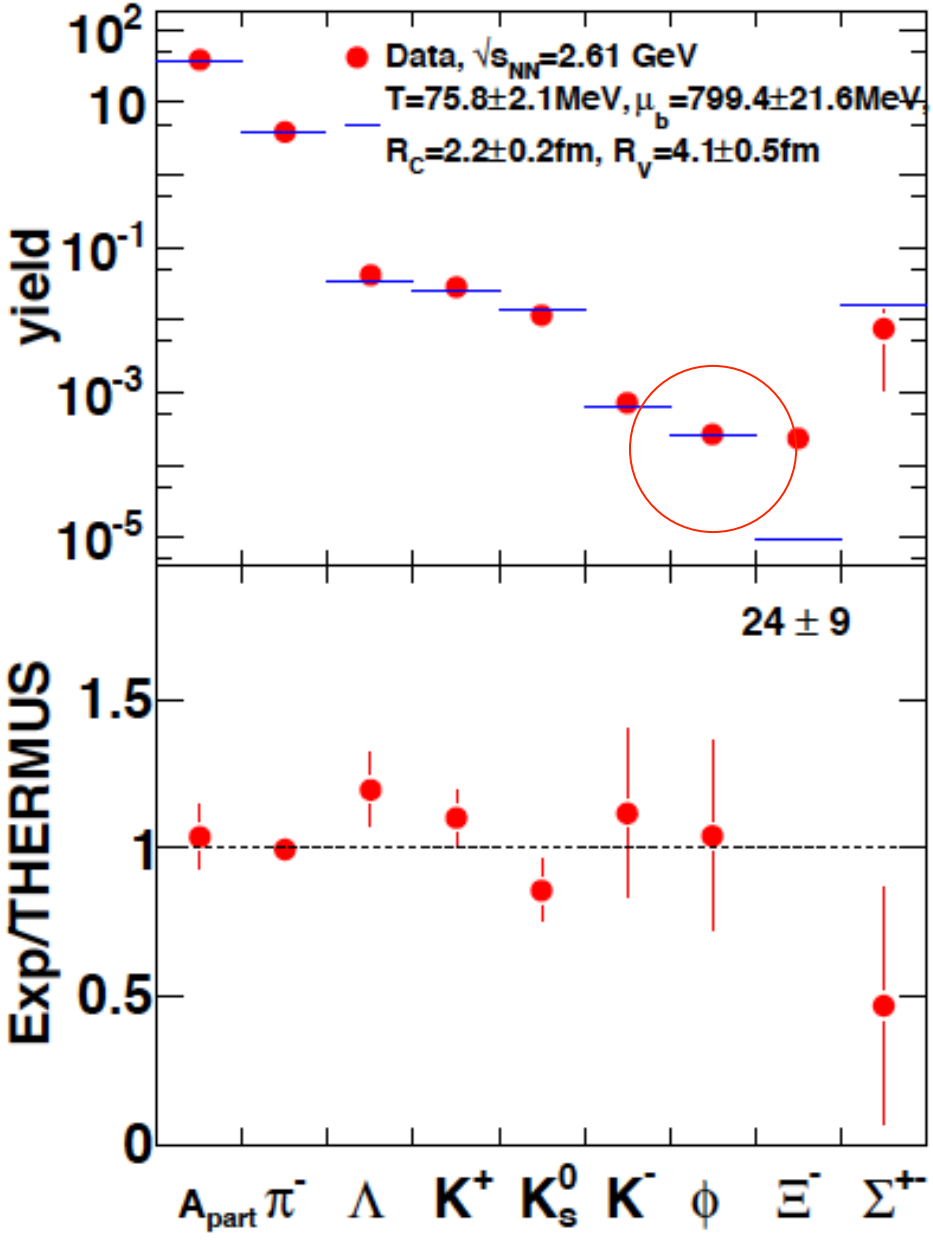

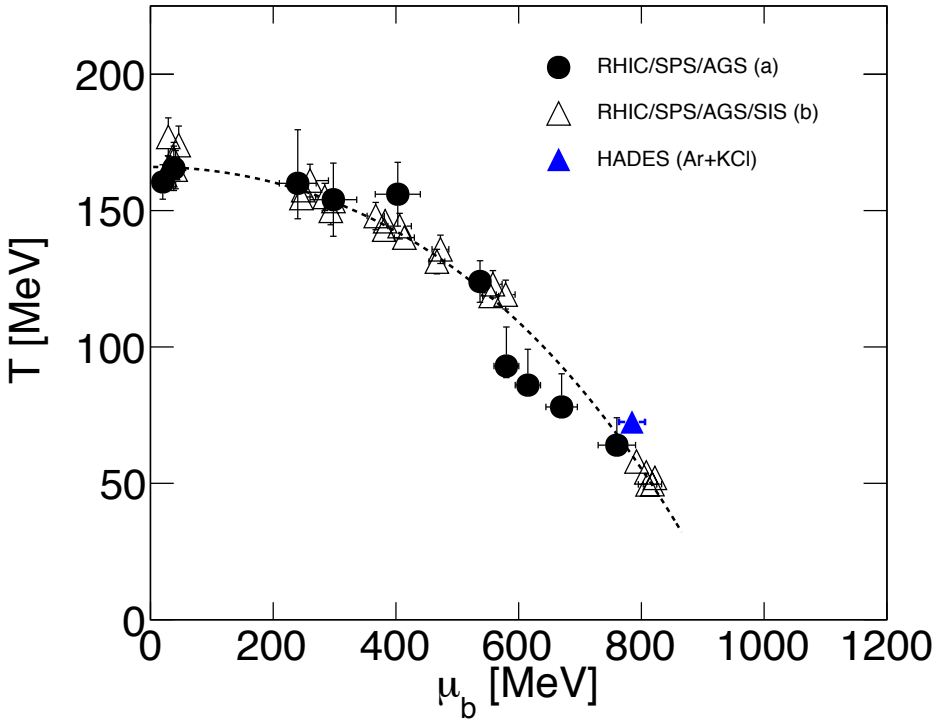

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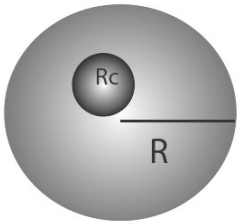
Φ meson described without suppression (R_c)

Strangeness has to be conserved exactly in a volume smaller than the volume of the system (radius: $R_C < R_V$)



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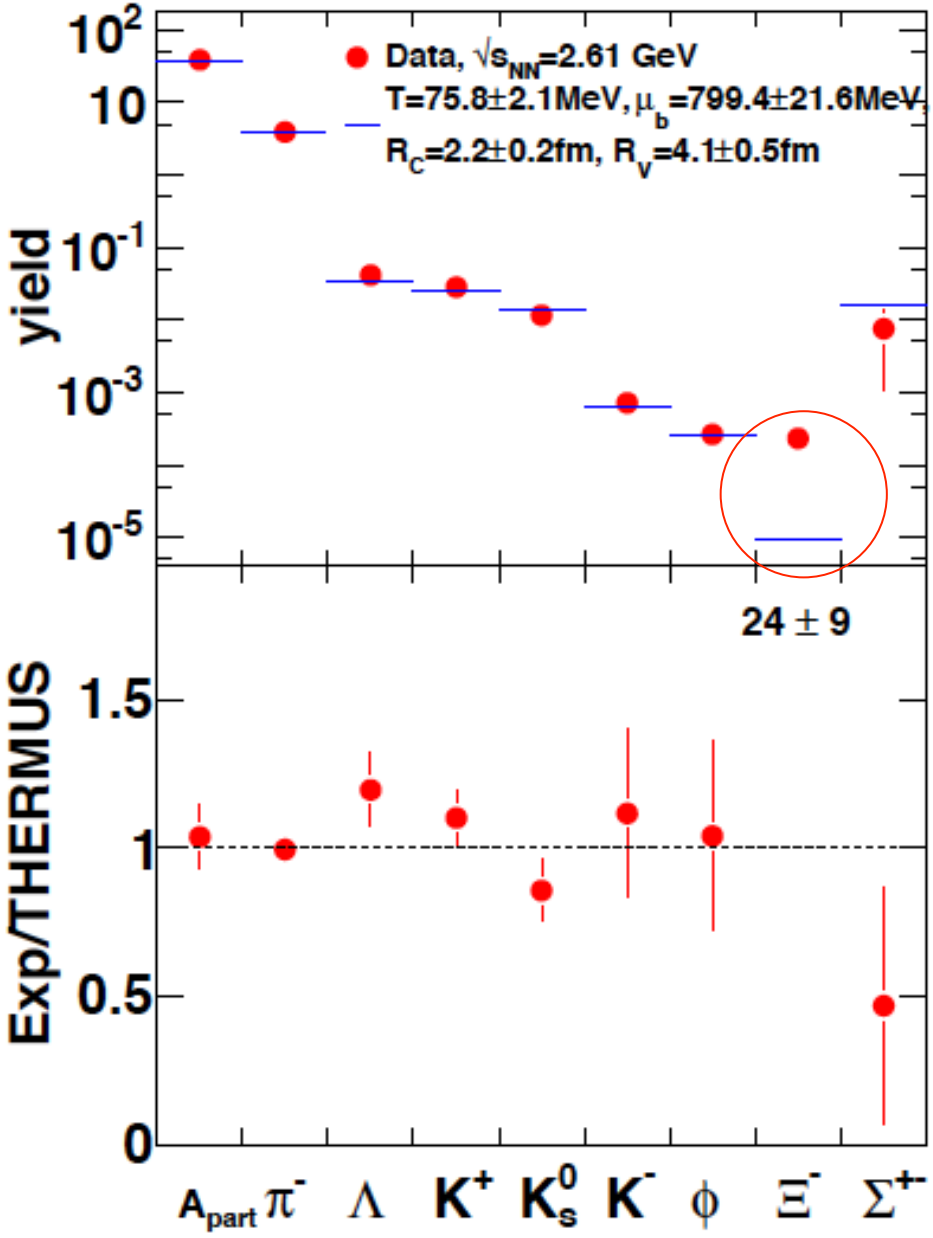

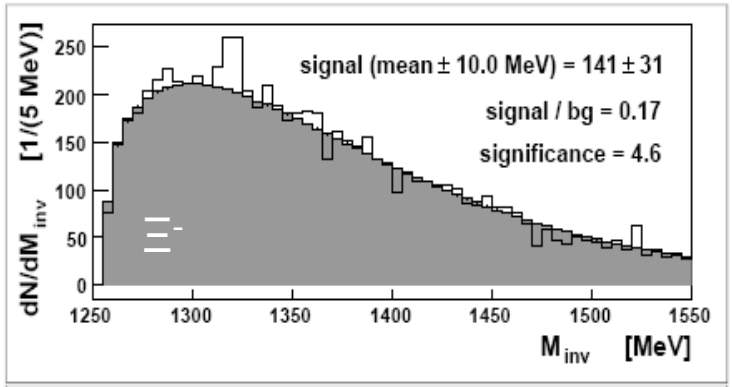

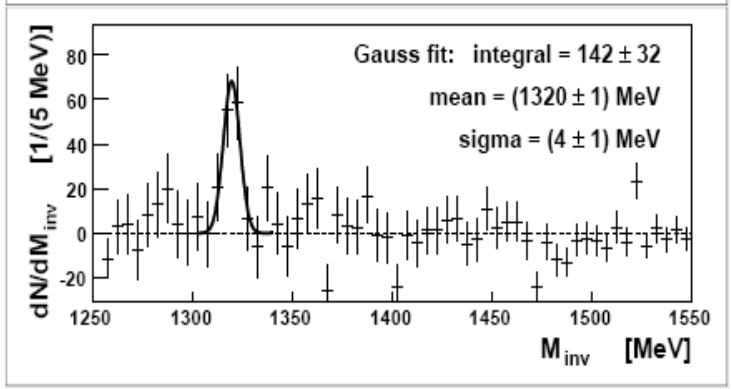

Strong excess of the Ξ^-

NN-threshold:
E_{beam}= 3.74GeV $\rightarrow \sqrt{s}-\sqrt{s_{th}}$=-630MeV!

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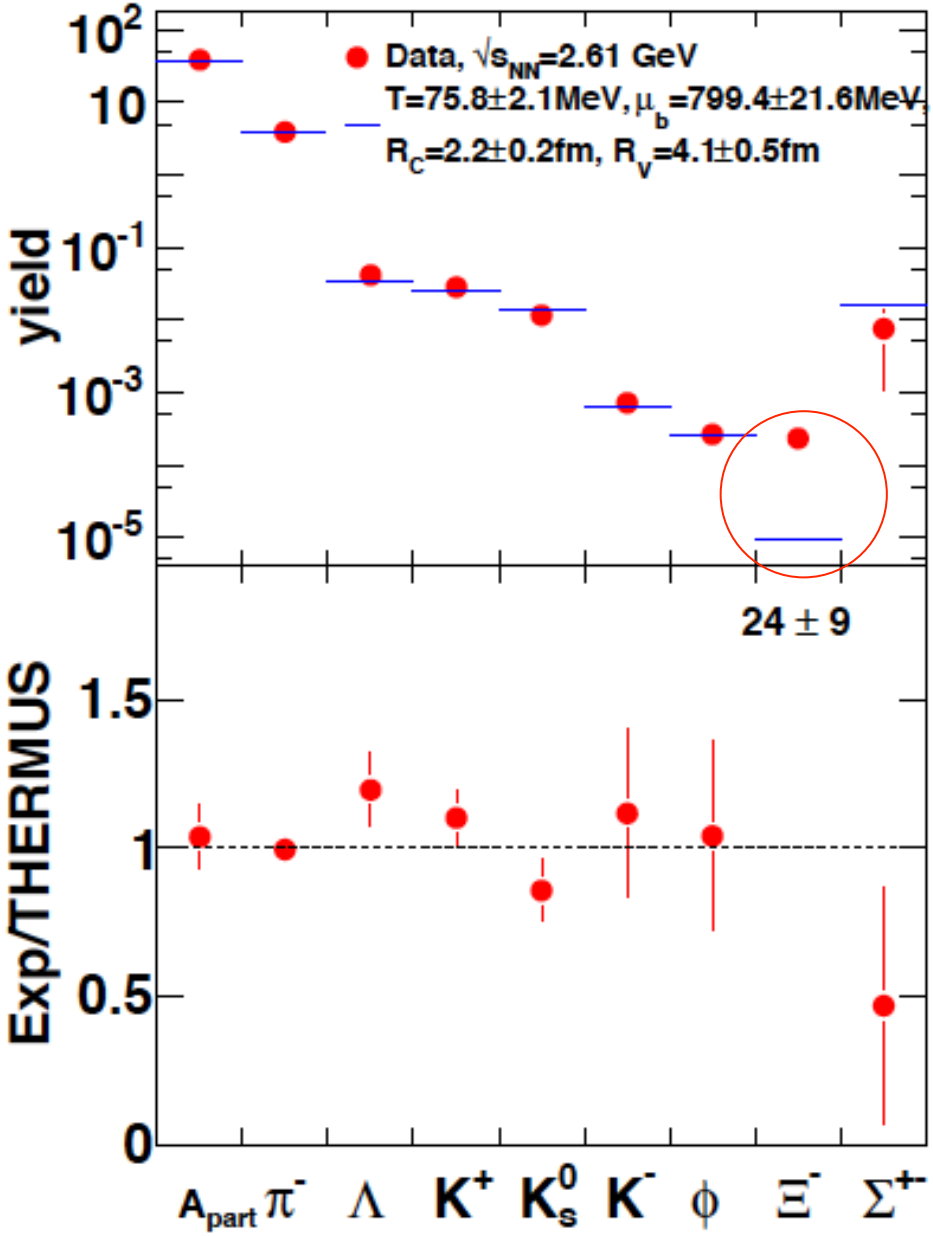

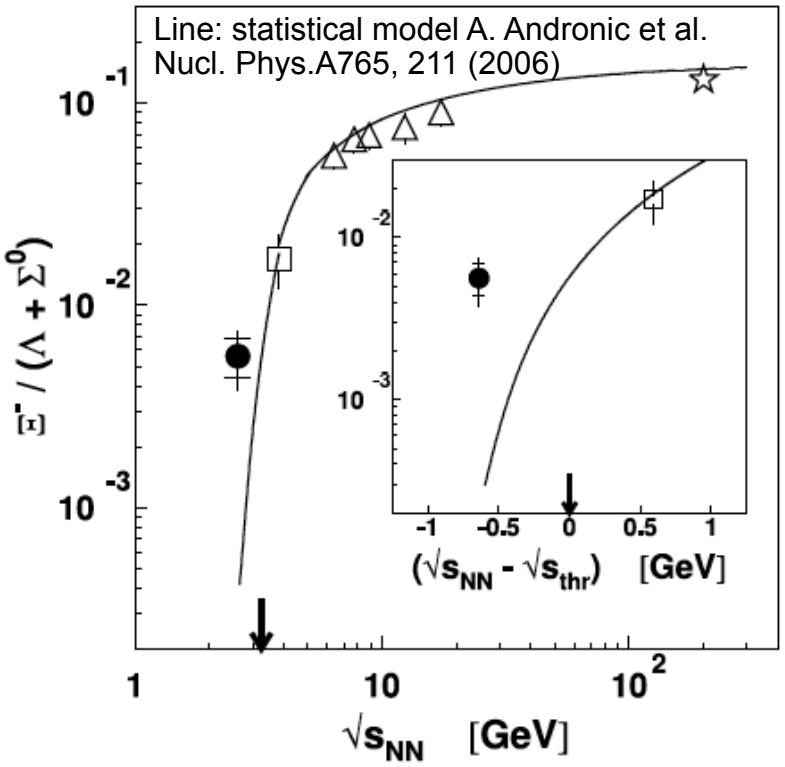

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Au+Au @ 1.23 A GeV:
Lower energy and heavier system

Complete strangeness production below NN-threshold
(production and propagation)

$$NN \rightarrow NK^{+}\Lambda \qquad (E_{thr} = 1.58\,GeV)$$
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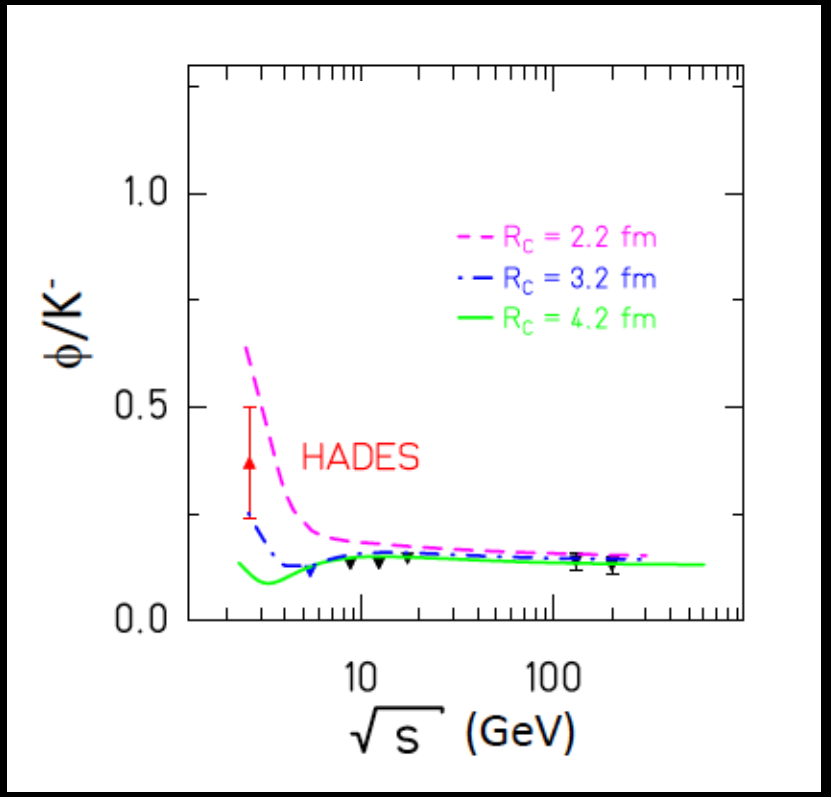


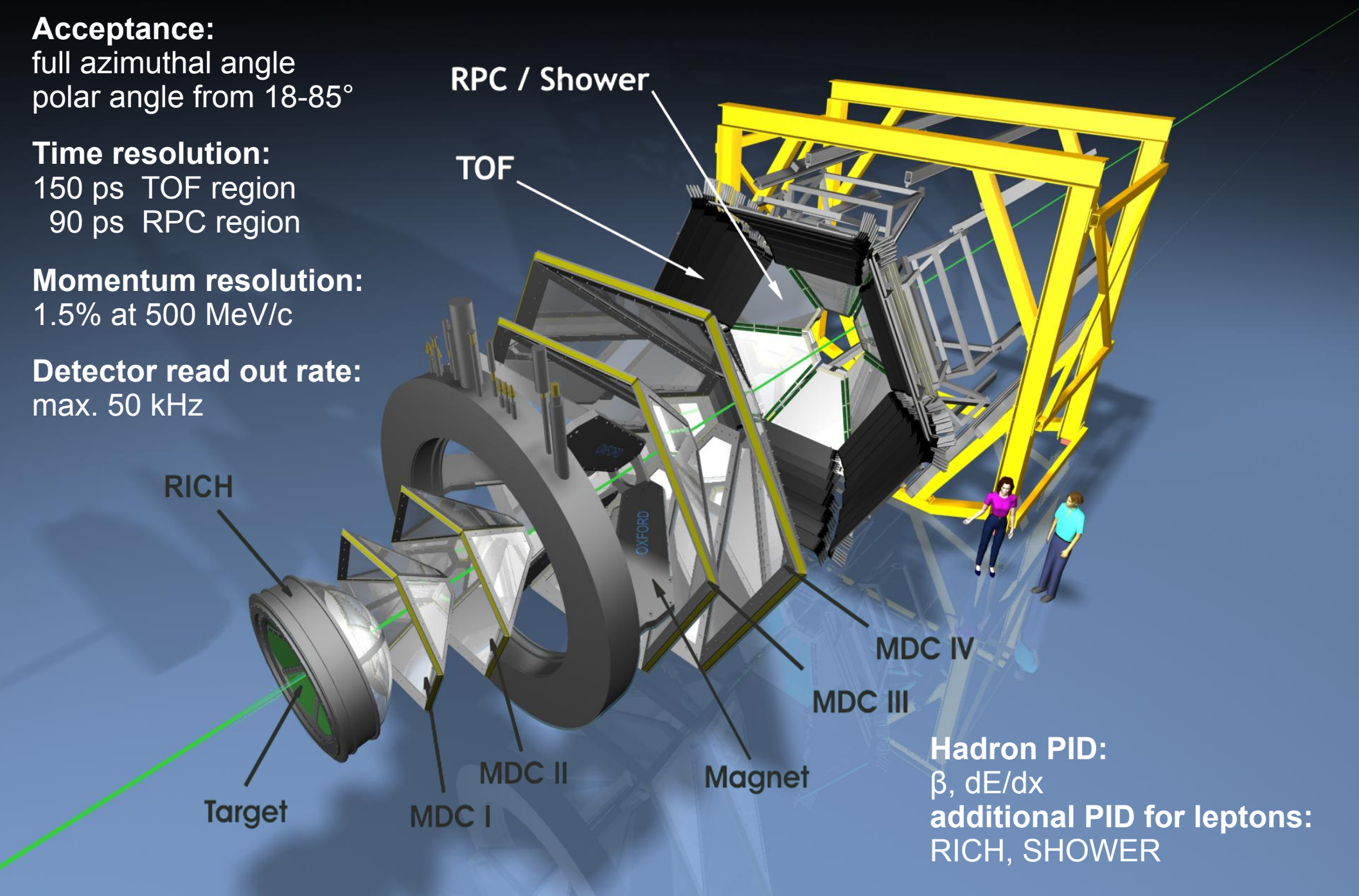
HADES

Acceptance:
full azimuthal angle
polar angle from 18-85°

Time resolution:
150 ps TOF region
90 ps RPC region

Momentum resolution:
1.5% at 500 MeV/c

Detector read out rate:
max. 50 kHz

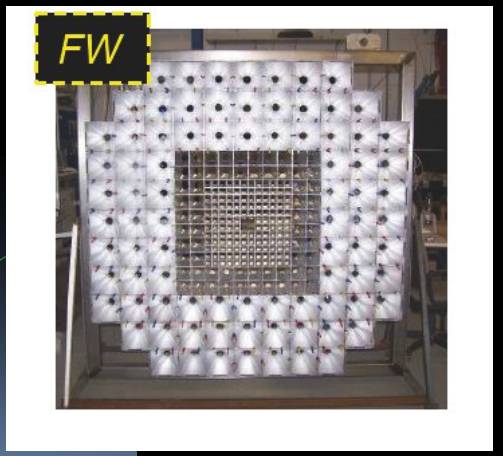


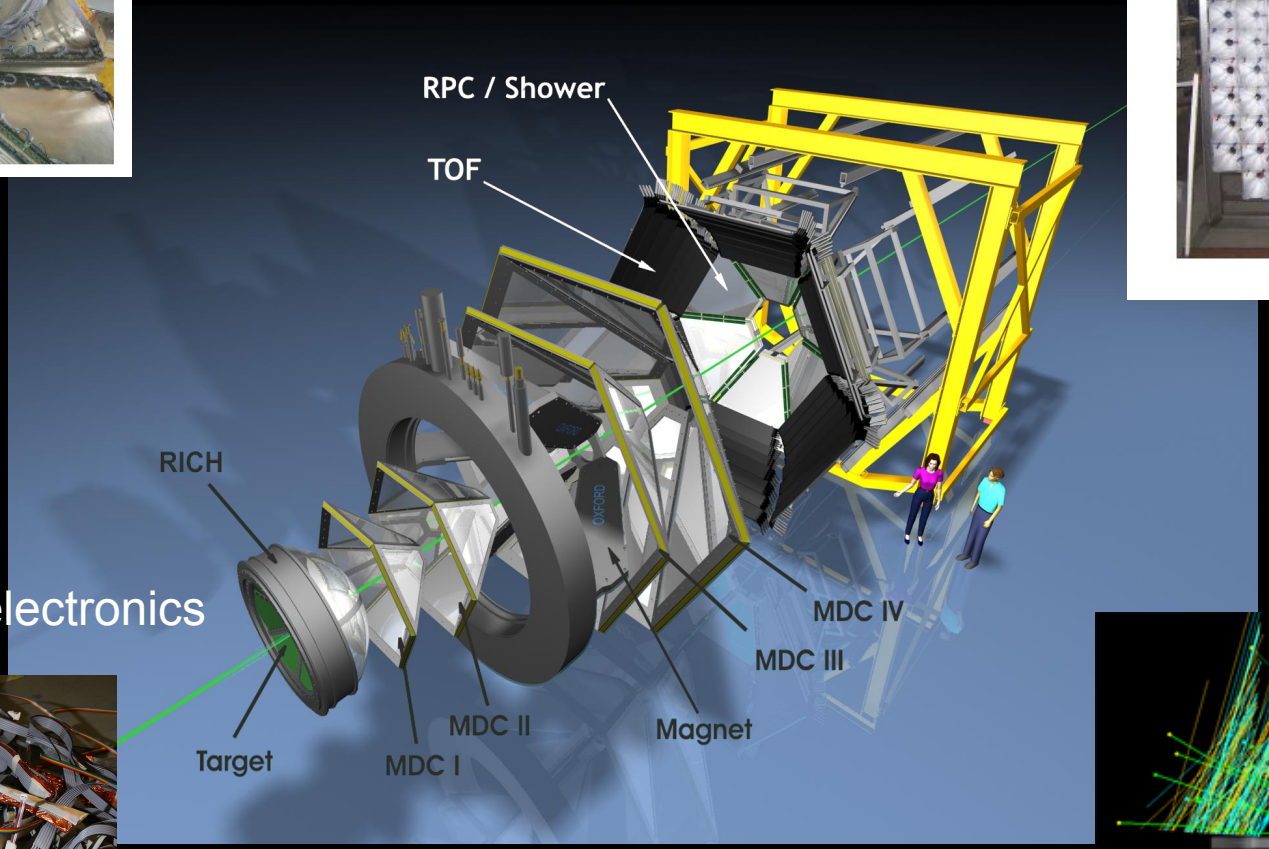
Hadron PID:
β, dE/dx
additional PID for leptons:
RICH, SHOWER

Upgrades for Au+Au

Time-of-flight wall (RPC)

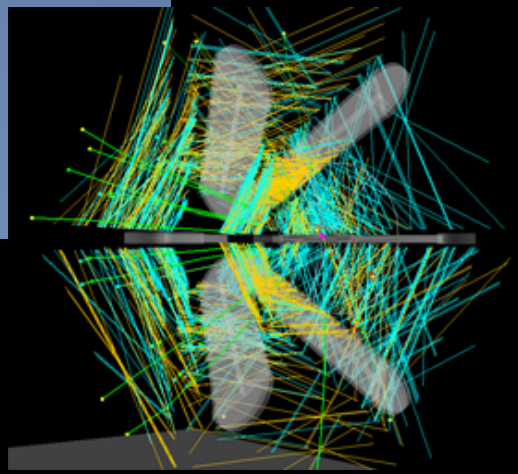
Forward wall





DAQ and readout electronics

Tracking



Performance: data taking and analysis

557 hours beam Au on Au target in April 2012

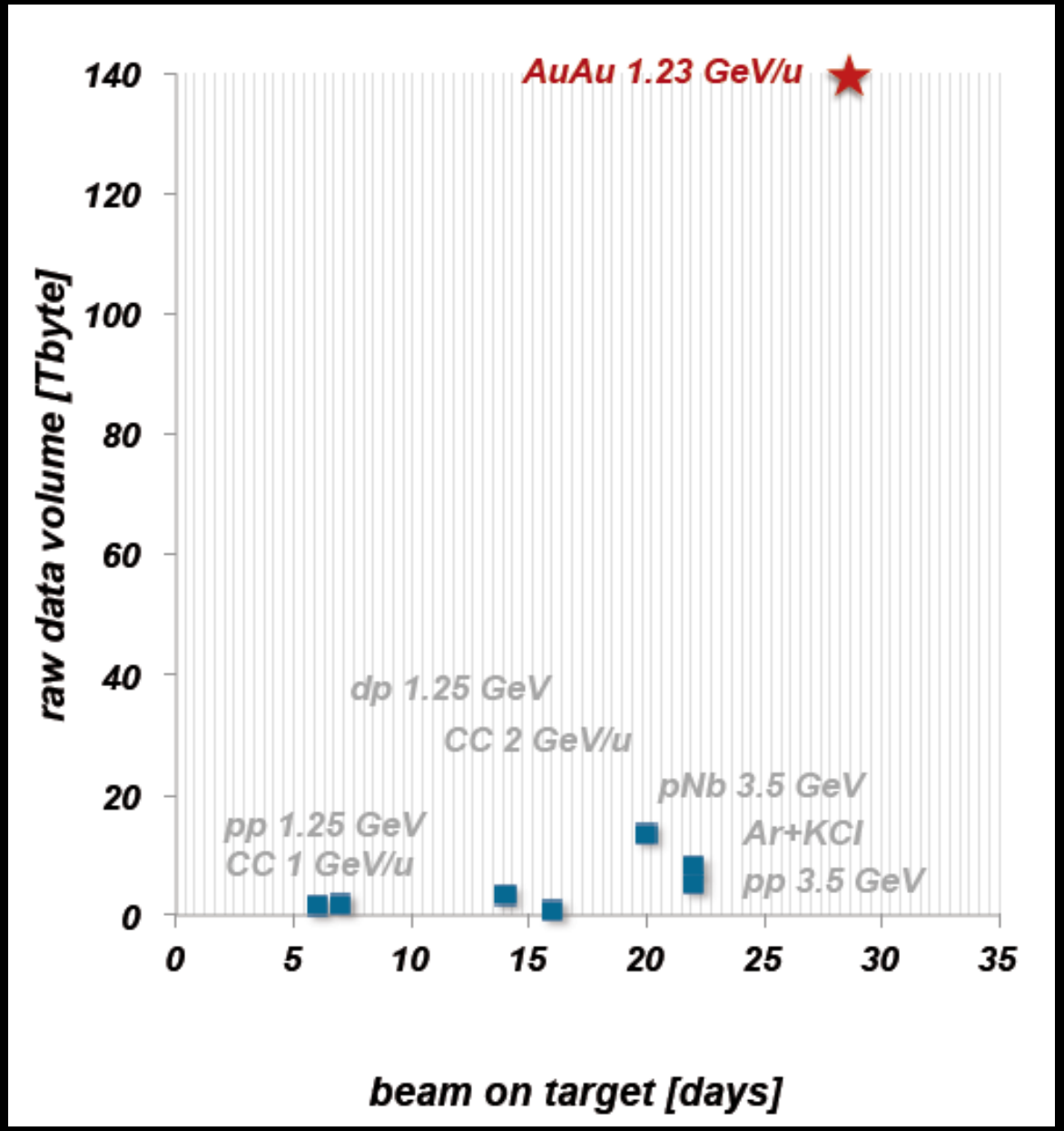
(1.2 - 1.5) x 10^6 ions per second

8 kHz trigger rate

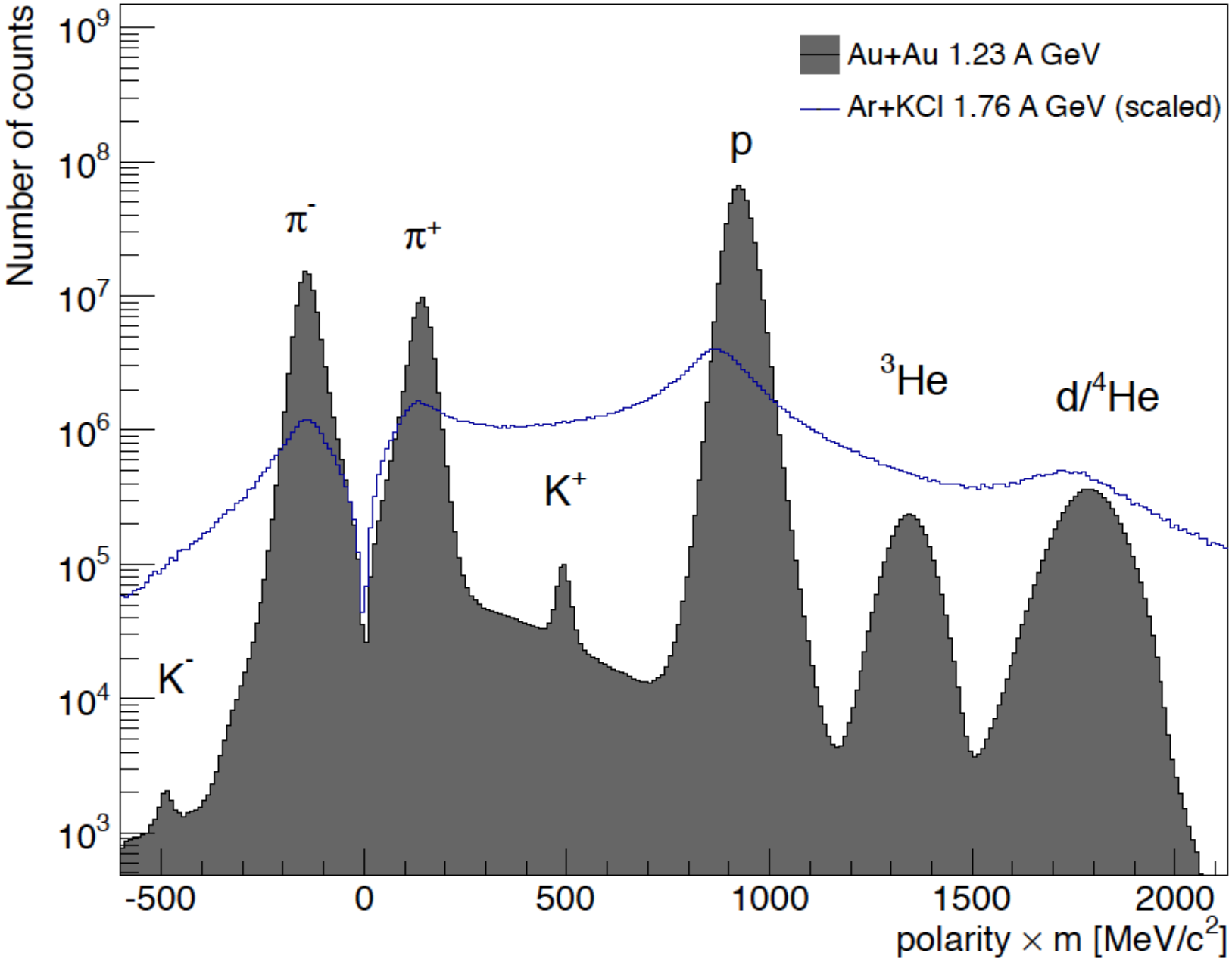
200 Mbyte/s data rate

7.3 x 10^9 events

140 x 10^{12} Bytes of data



Performance: mass spectrum



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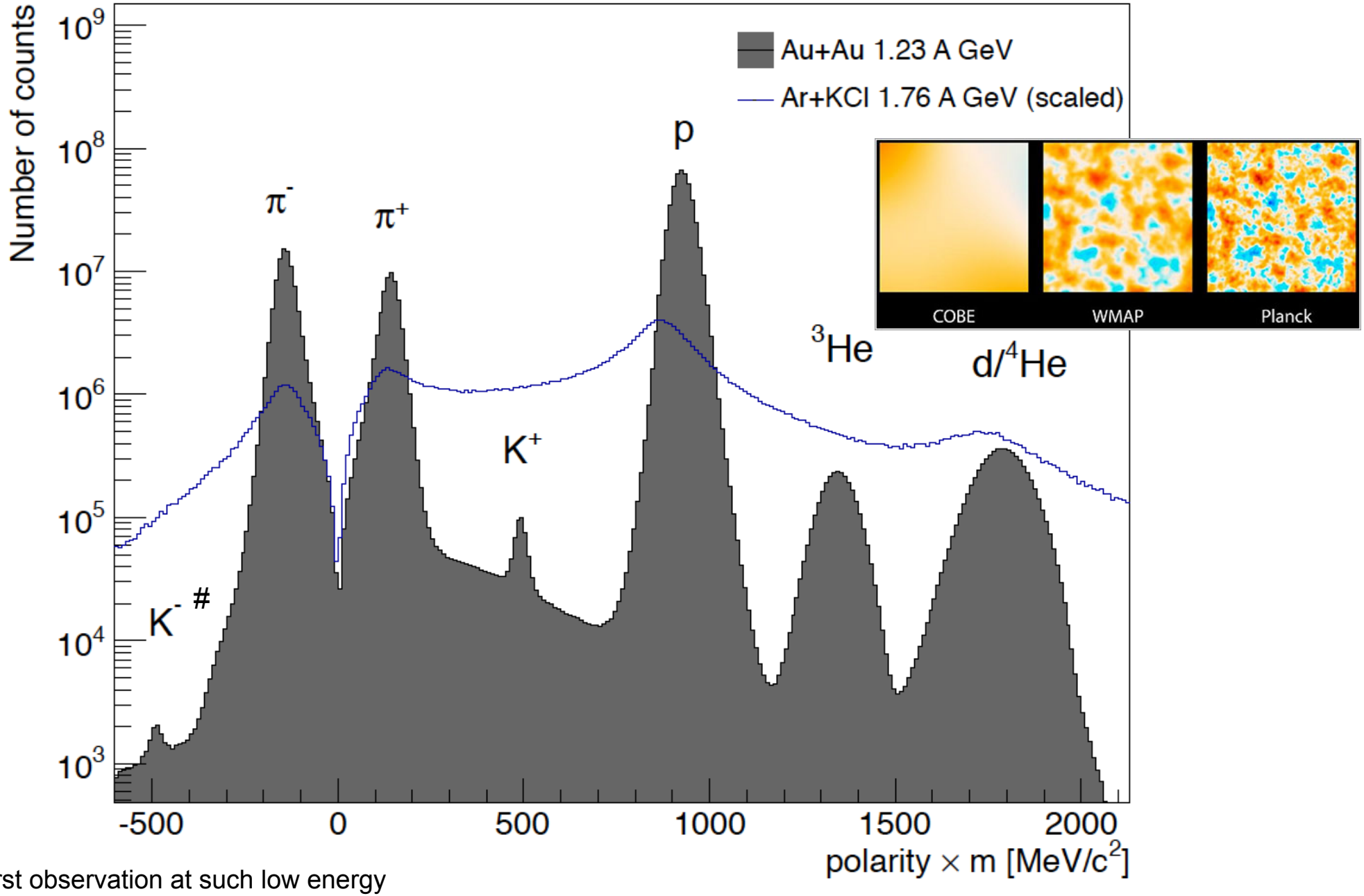
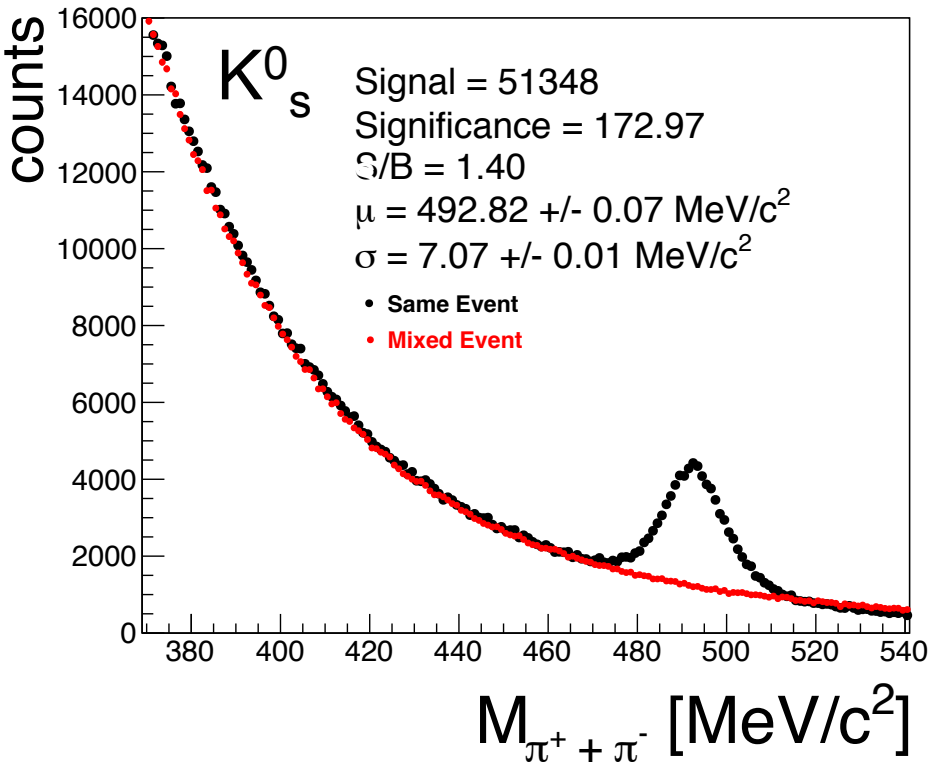
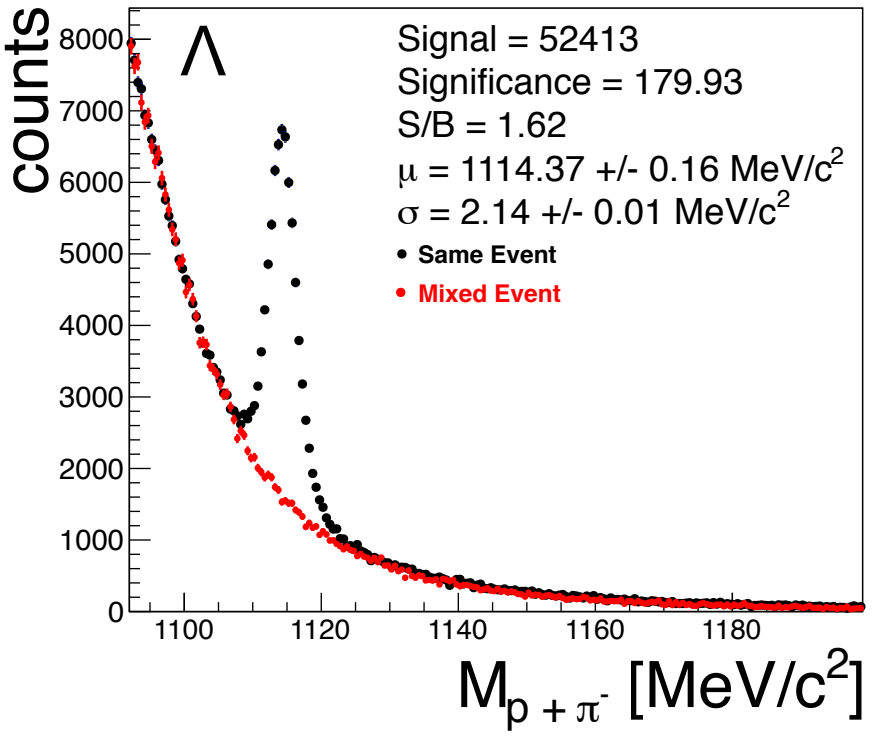
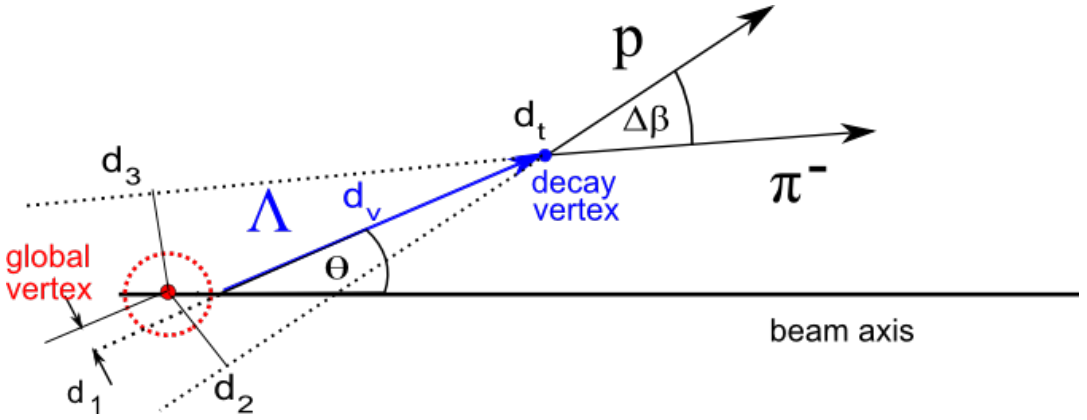


#First observation at such low energy

Performance: Secondary vertices

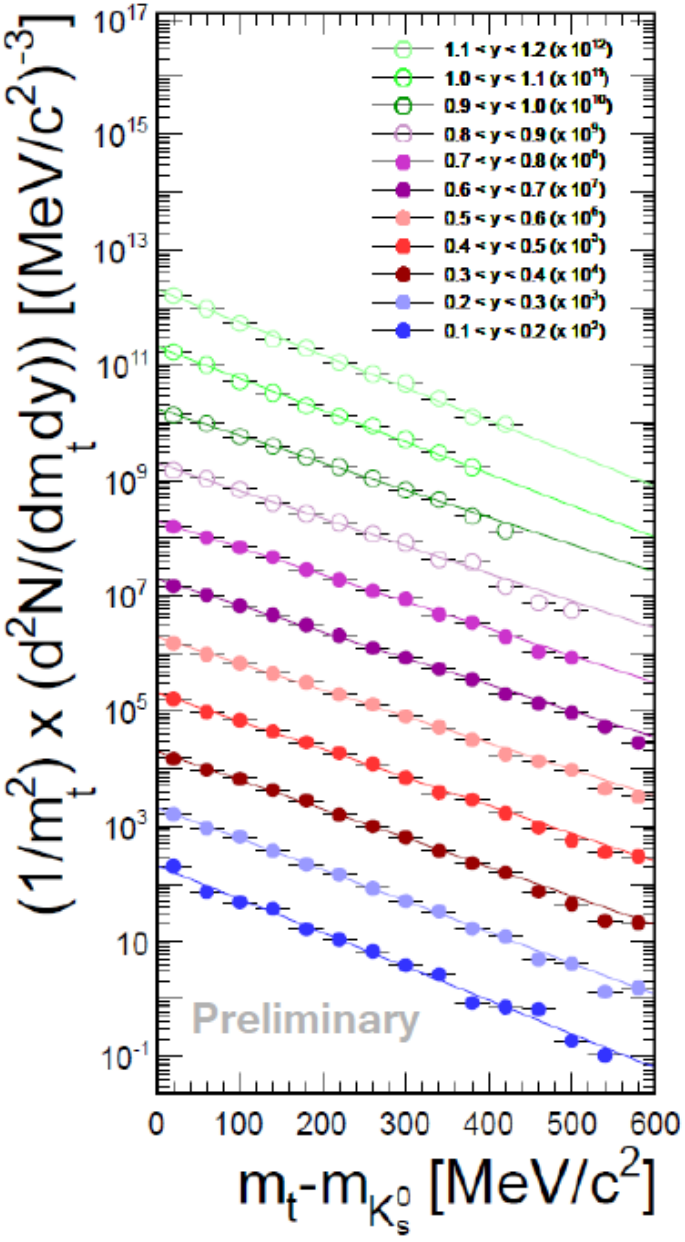


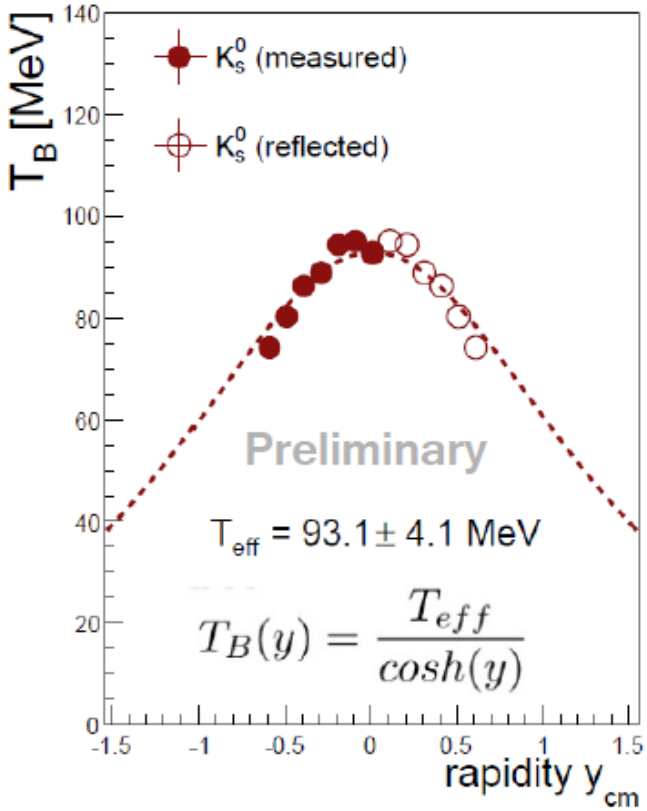


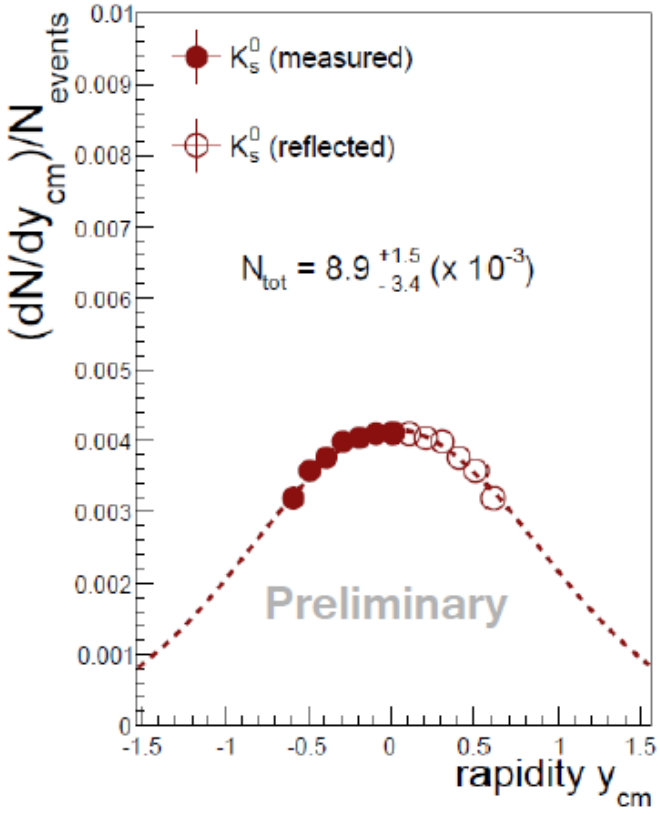


PhD T. Scheib

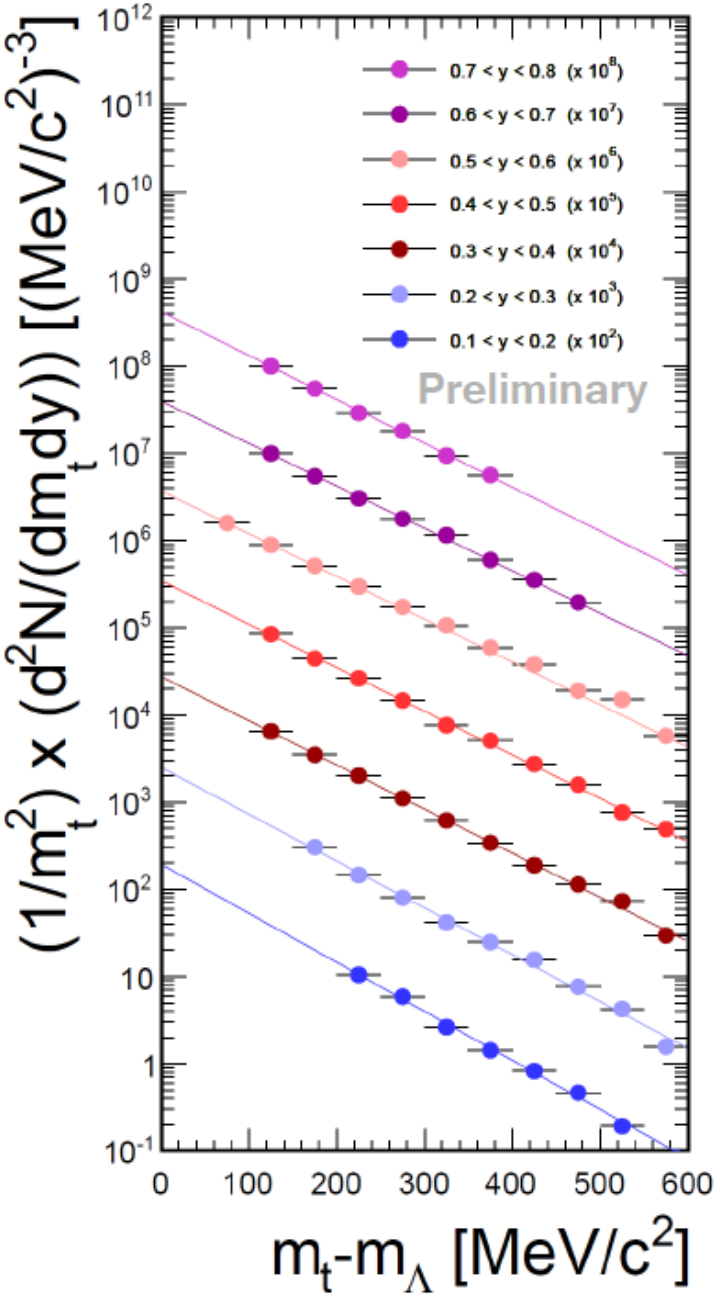
Neutral kaons: spectra and y-distribution

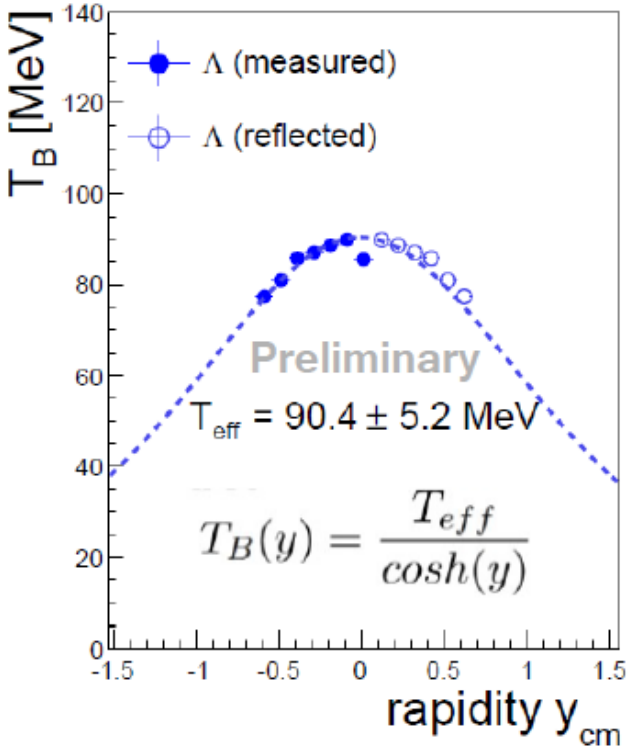


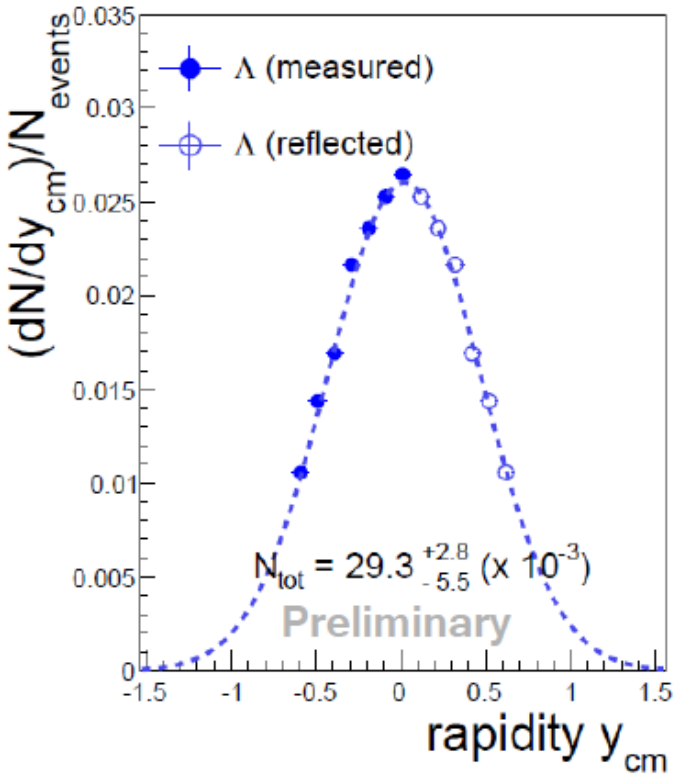




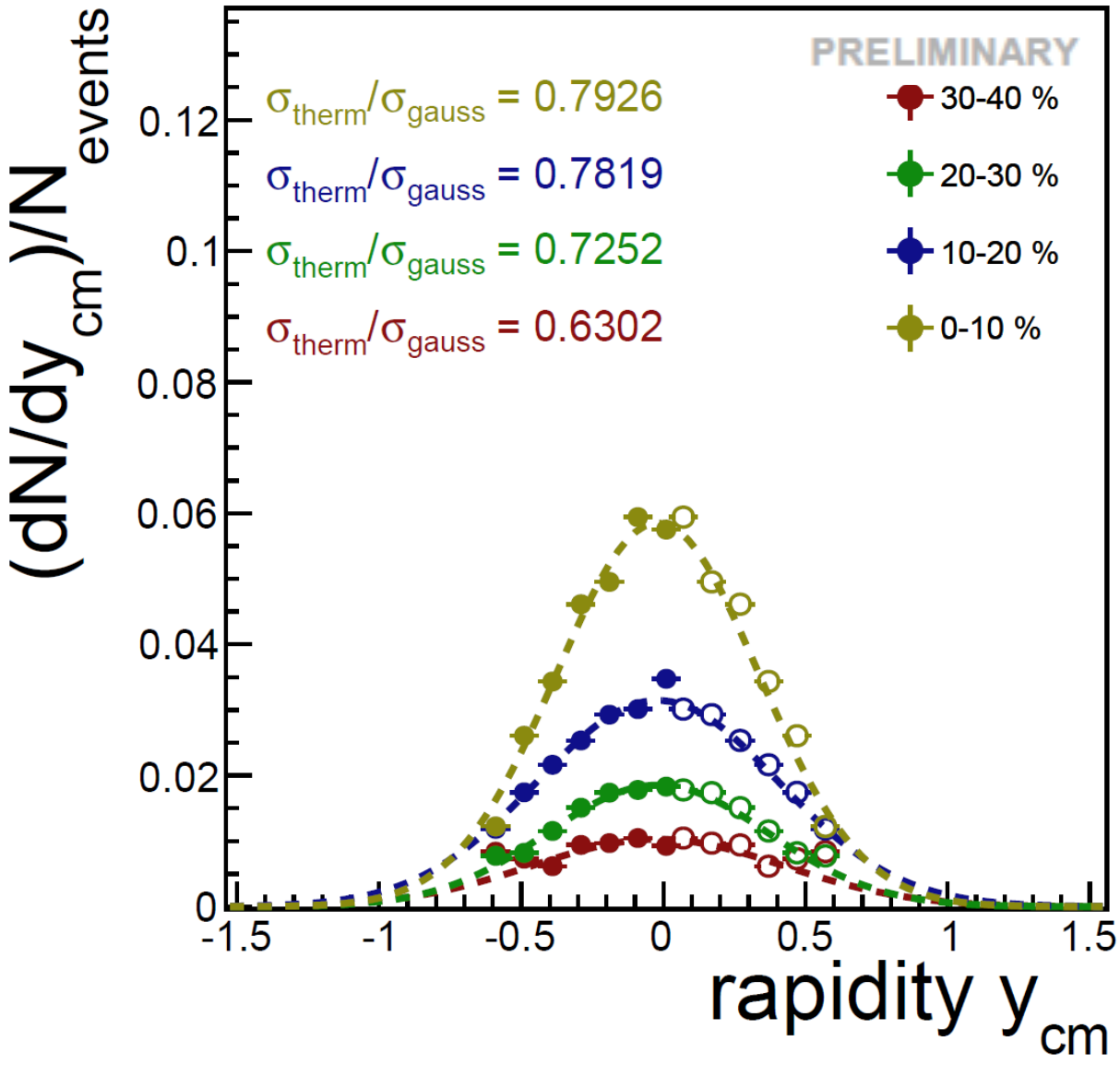
Λ: spectra and y-distribution



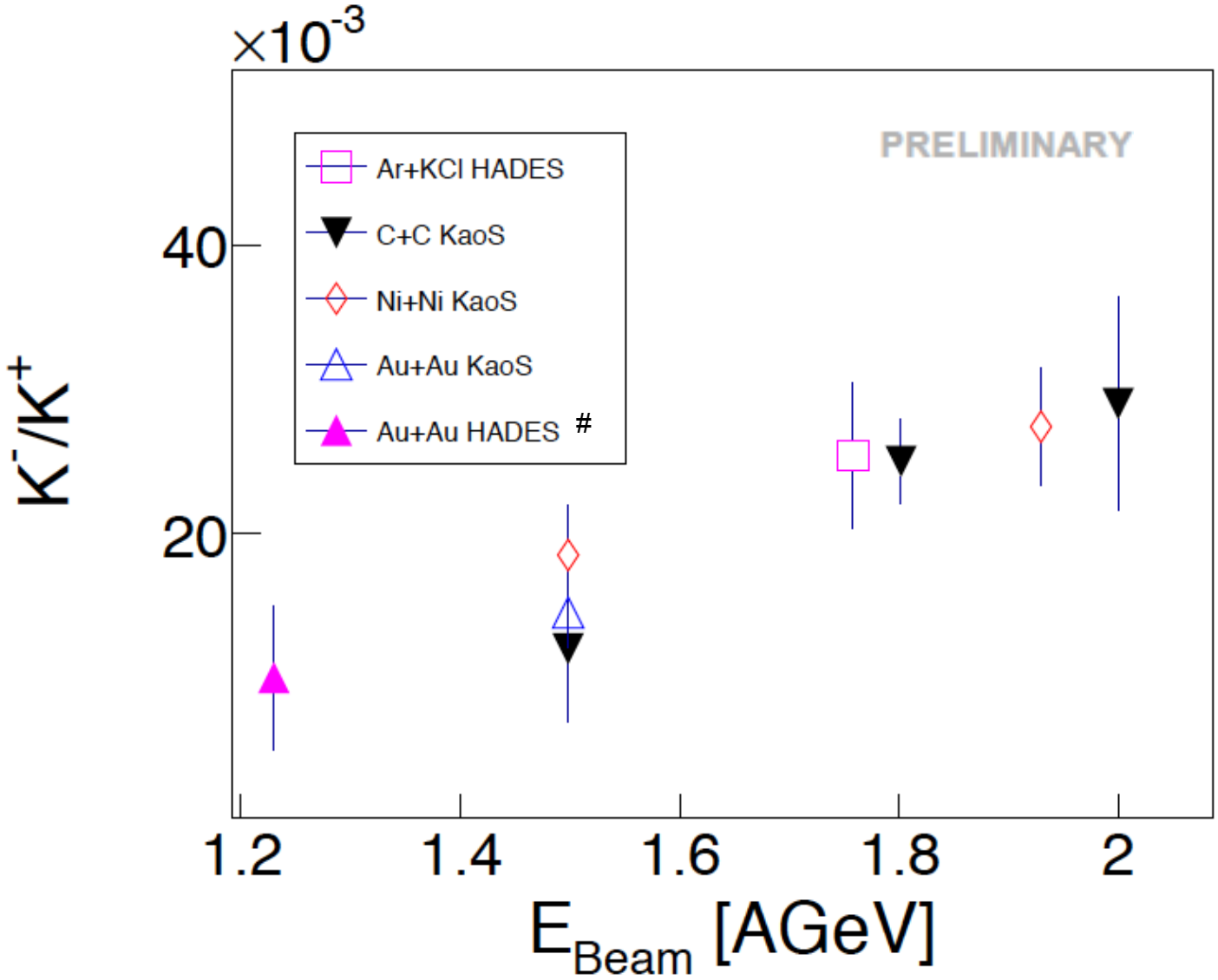




Centrality dependence

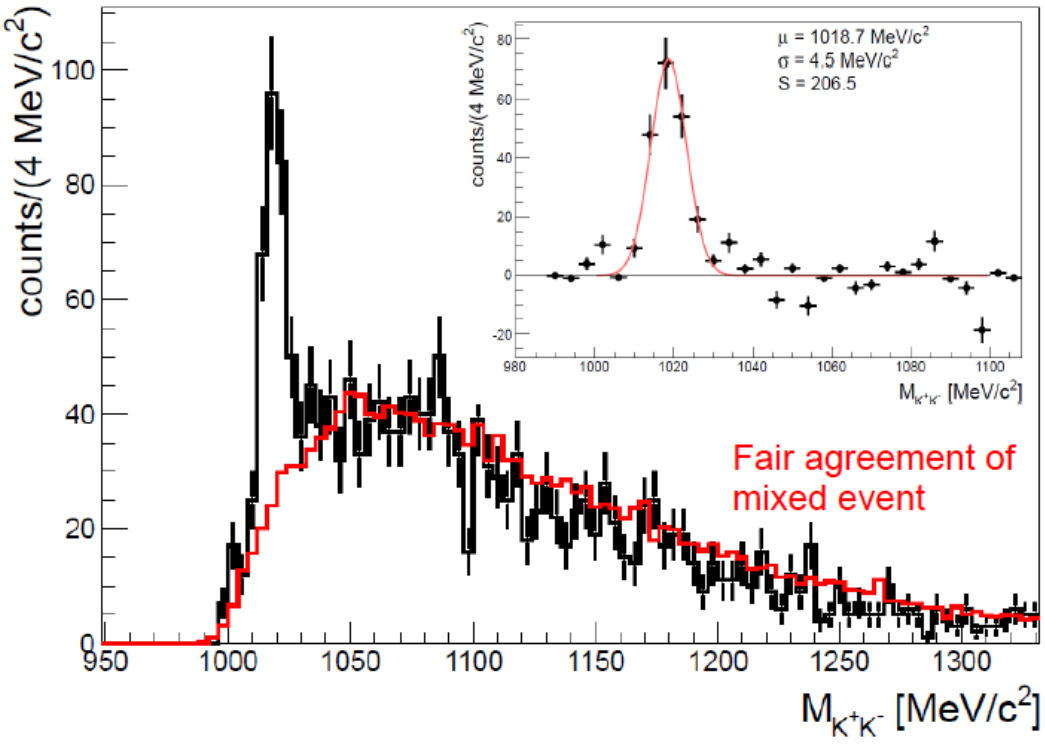


Charged kaons: comparison to other experiments



ratio at mid-rapidity

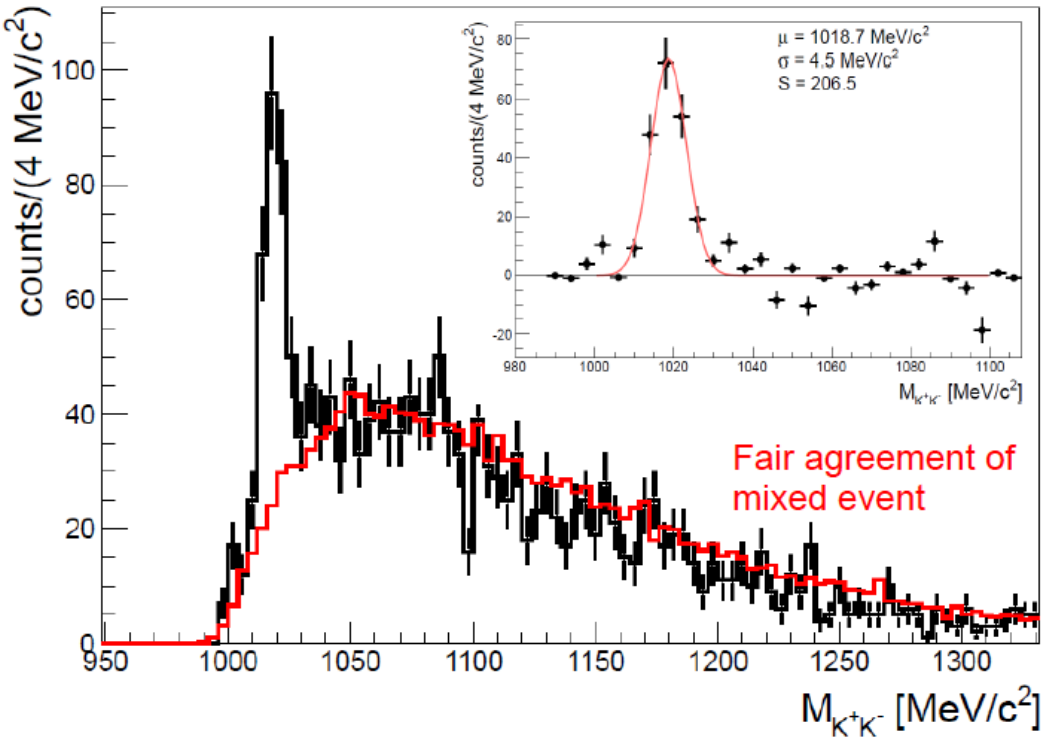
Φ and K^-



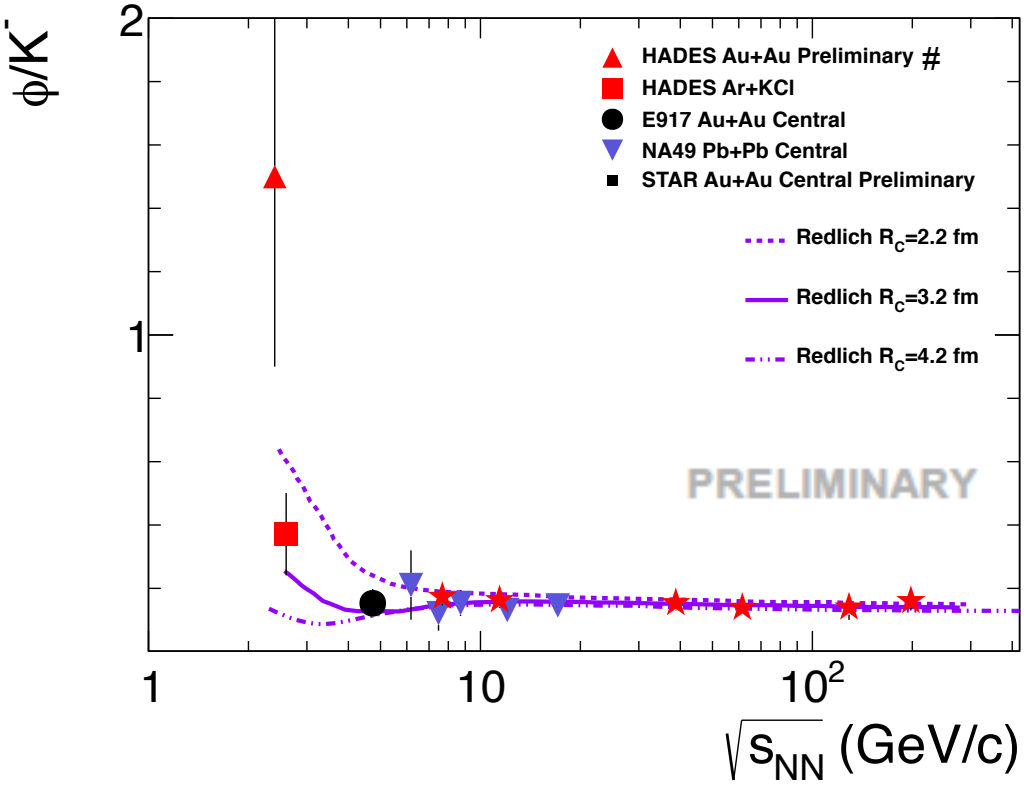
Φ meson reconstructed via charged kaons

PhD H. Schuldes

Φ and K-



Φ meson reconstructed via charged kaons

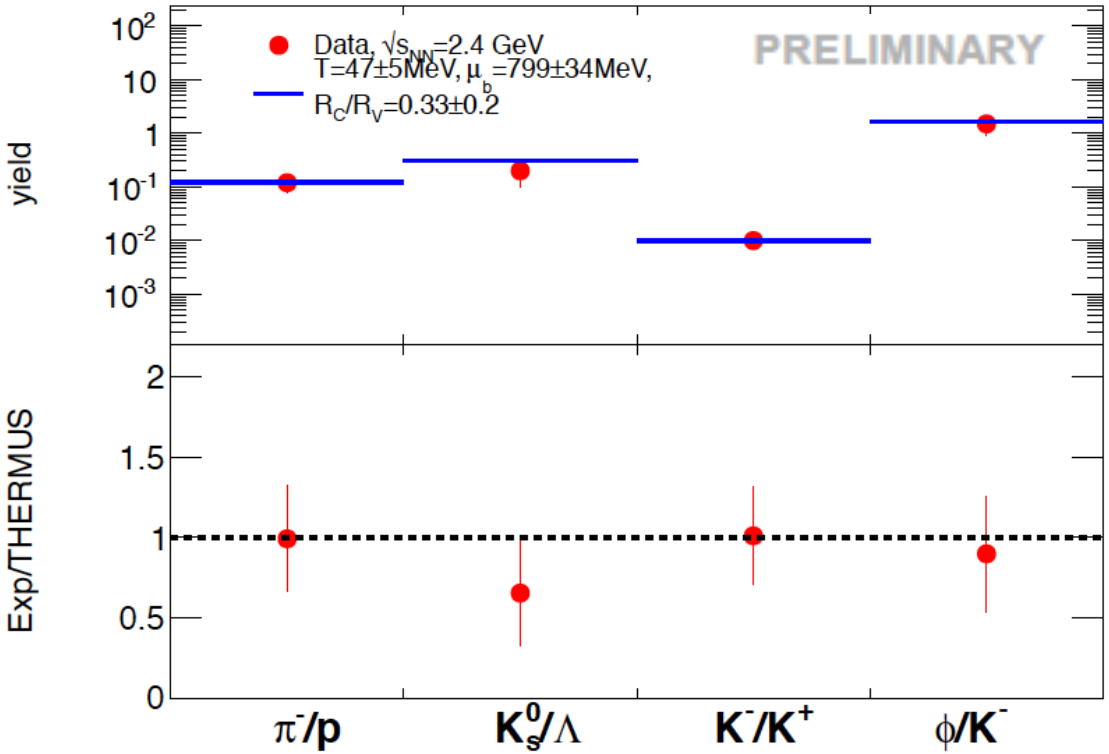


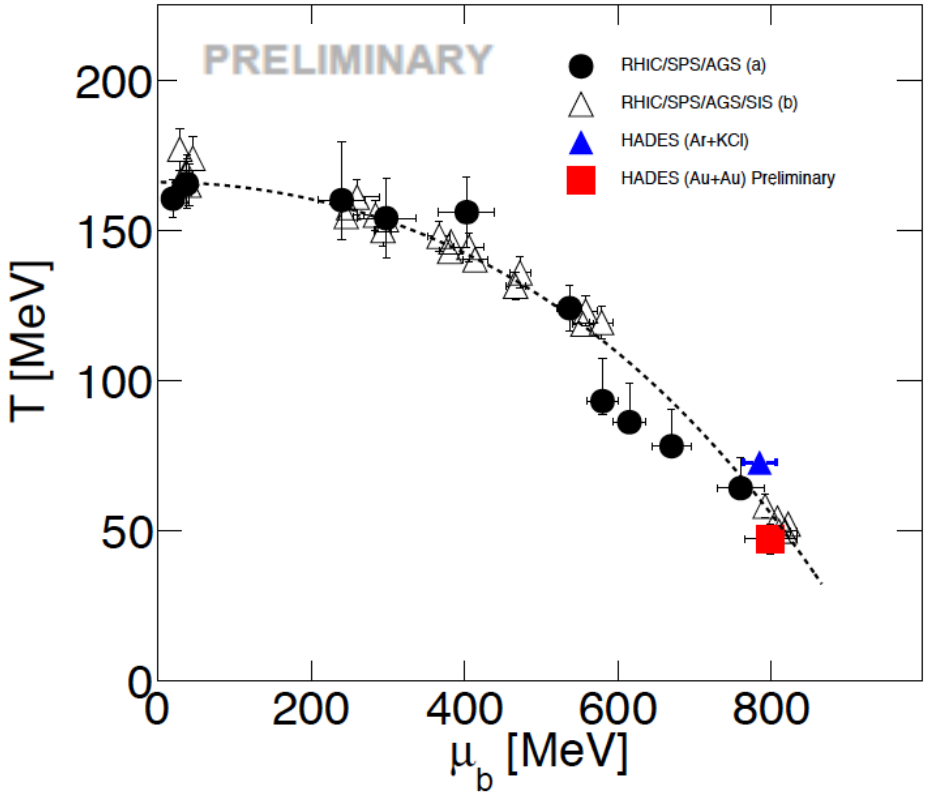
Strong rise of Φ/K- ratio with decreasing beam energy as predicted by stat. model

PhD H. Schuldes

ratio at mid-rapidity

Statistical model fit: first attempt





First attempt of statistical model fit to ratios gives reasonable values:

T= 47±5 MeV

μ_B= 799±34 MeV

R_c/R_v= 0.3±0.2

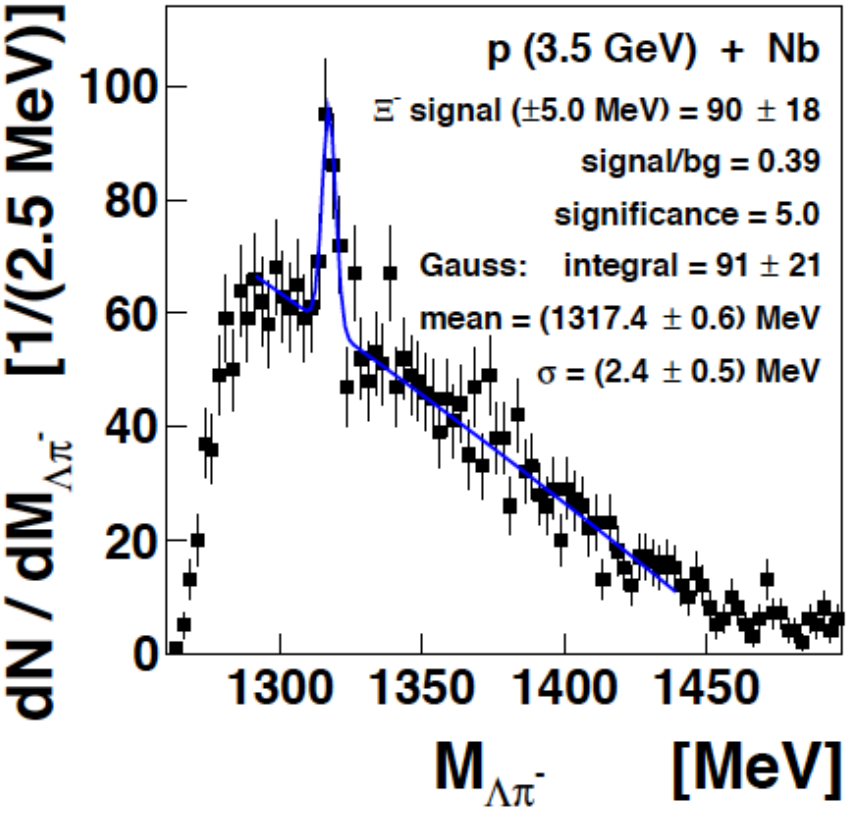
(no systematical errors!!)

THERMUS: S. Wheaton, J.Cleymans: Comput.Phys.Commun.180:84-106,2009

What about the Ξ^-

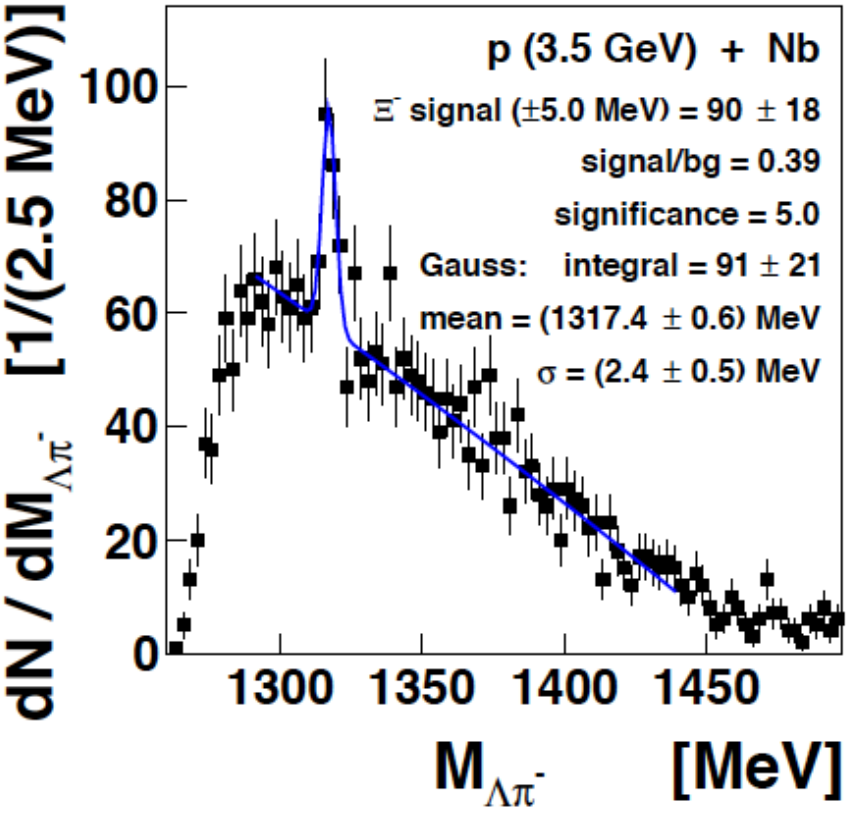
Here it comes..

Phys.Rev.Lett. 114 (2015) 21, 212301



Here it comes..

Phys.Rev.Lett. 114 (2015) 21, 212301

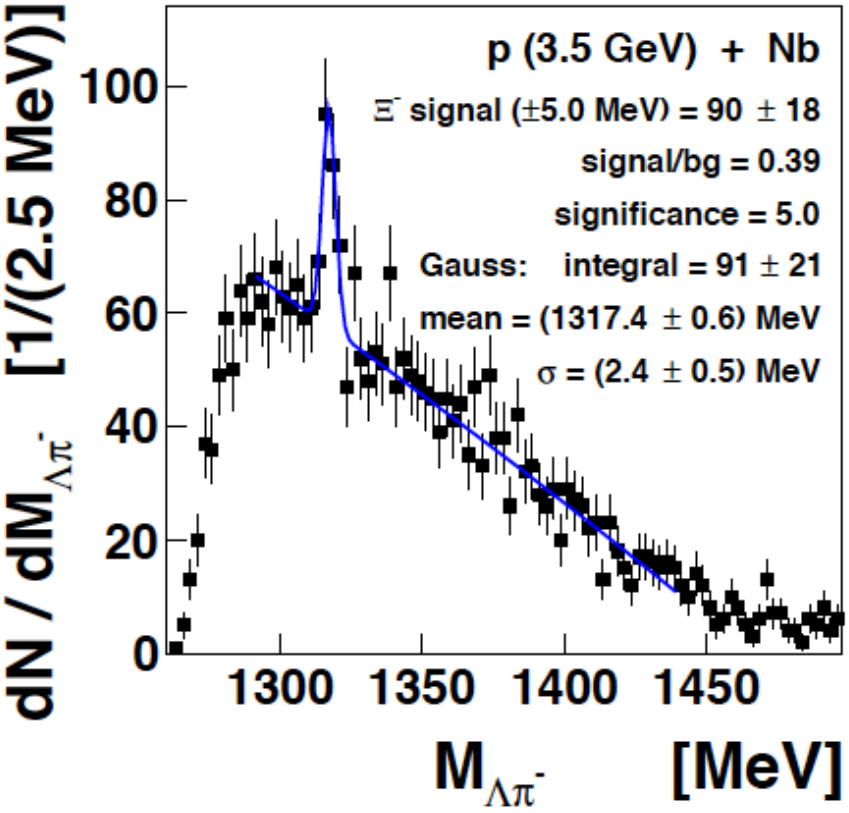


Subthreshold Ξ^- production in p+Nb collisions at

E_{beam}= 3.5 GeV $\rightarrow \sqrt{s}-\sqrt{s_{th}}$=-70MeV

Here it comes..

Phys.Rev.Lett. 114 (2015) 21, 212301



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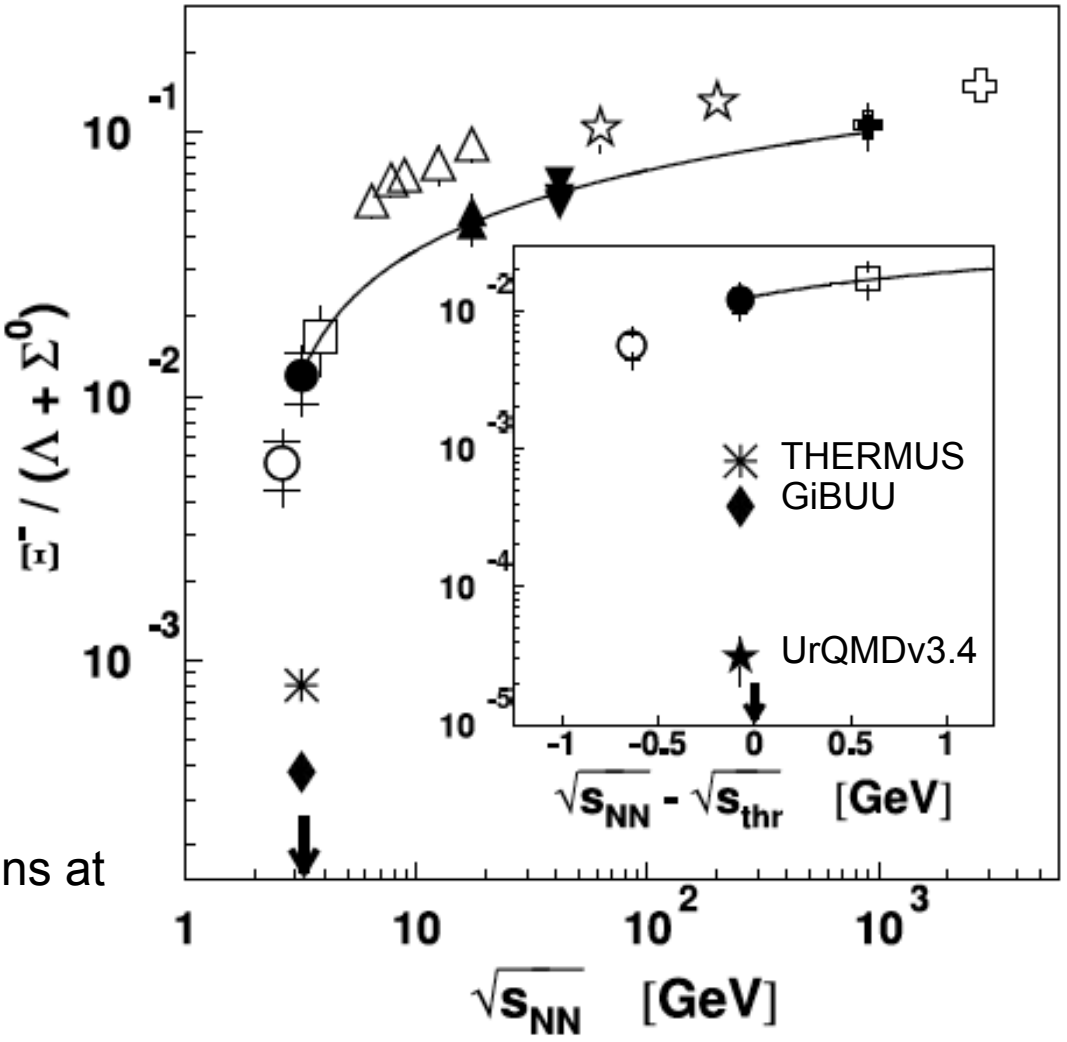
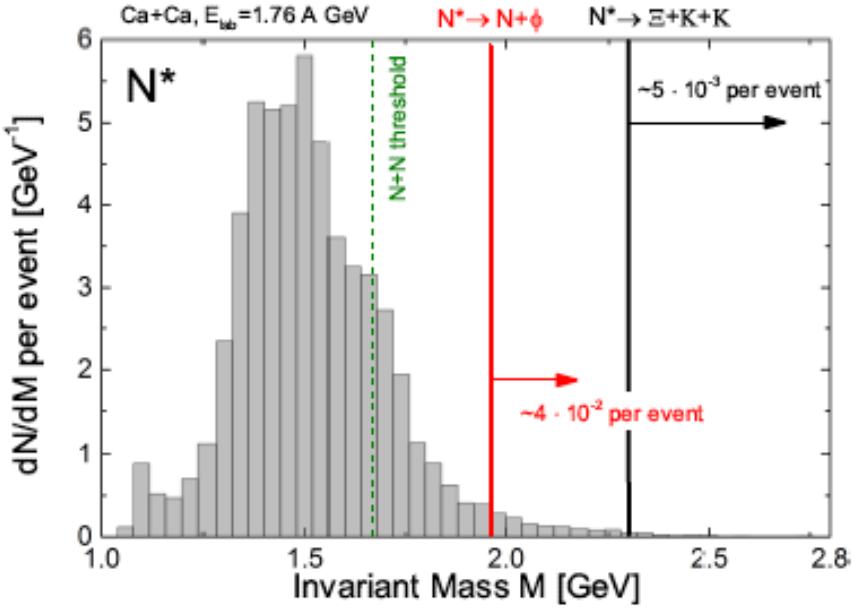


Parameterization: $f(x)=C(1-(D/x)^G)^H$

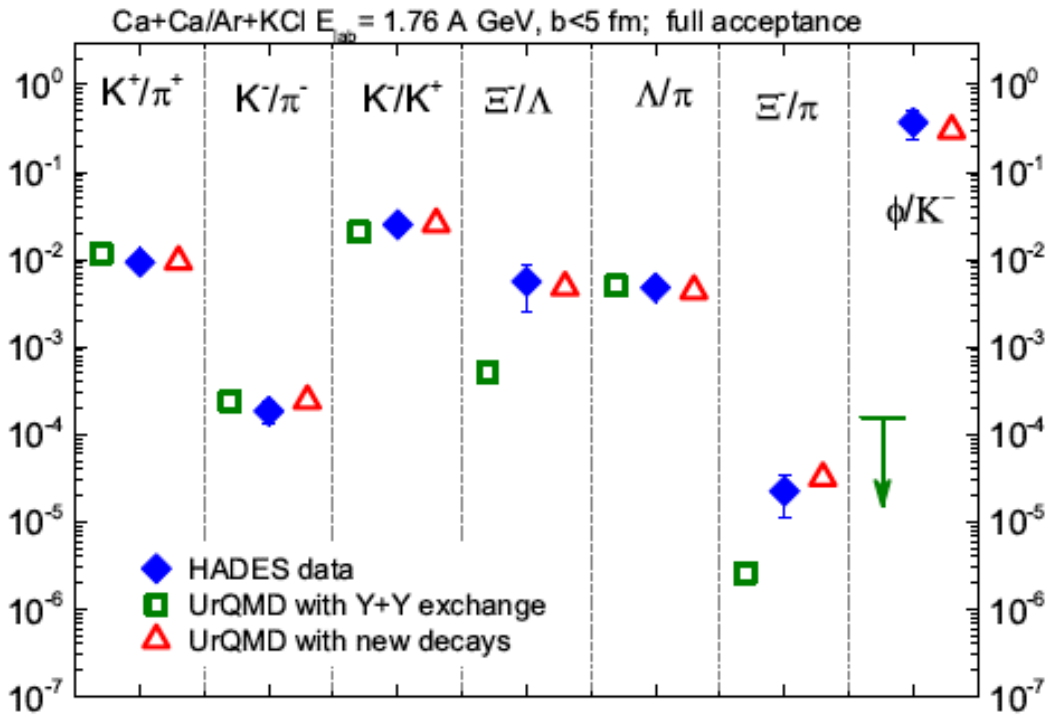
Excess already present in cold nuclear matter!

Transport UrQMD tuned

J. Steinheimer and M. Bleicher, arXiv:1503.07305



Tuned to match elementary data by increased branching ratios of N* to final states containing Ξ and ϕ.

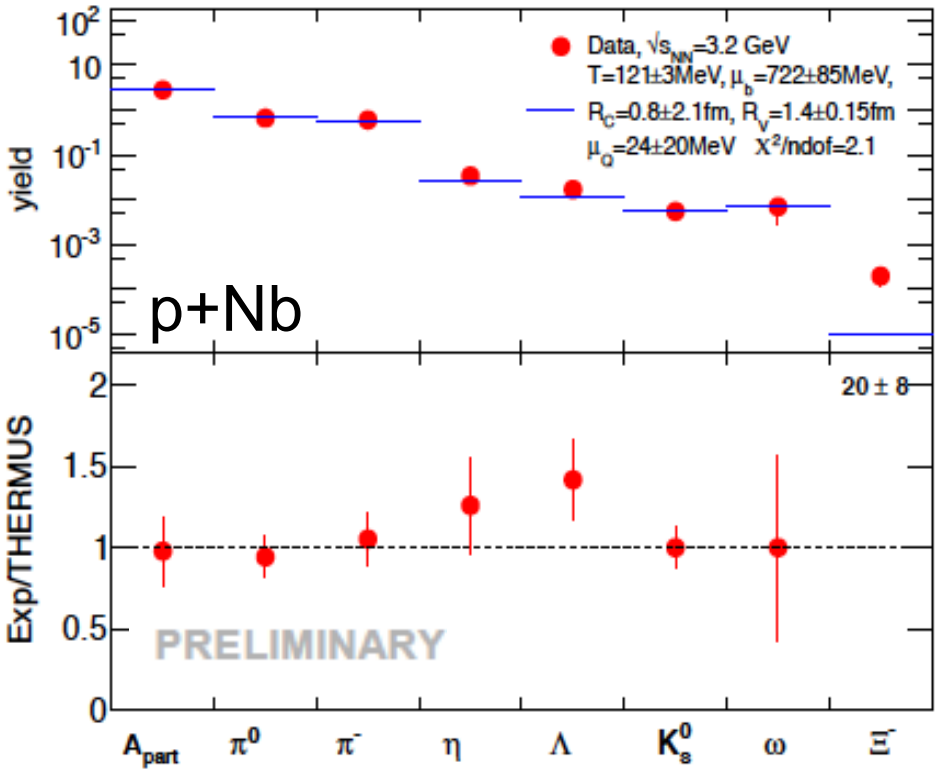


Increased hyperon-hyperon cross sections not sufficient to explain Ξ^-/Λ ratio

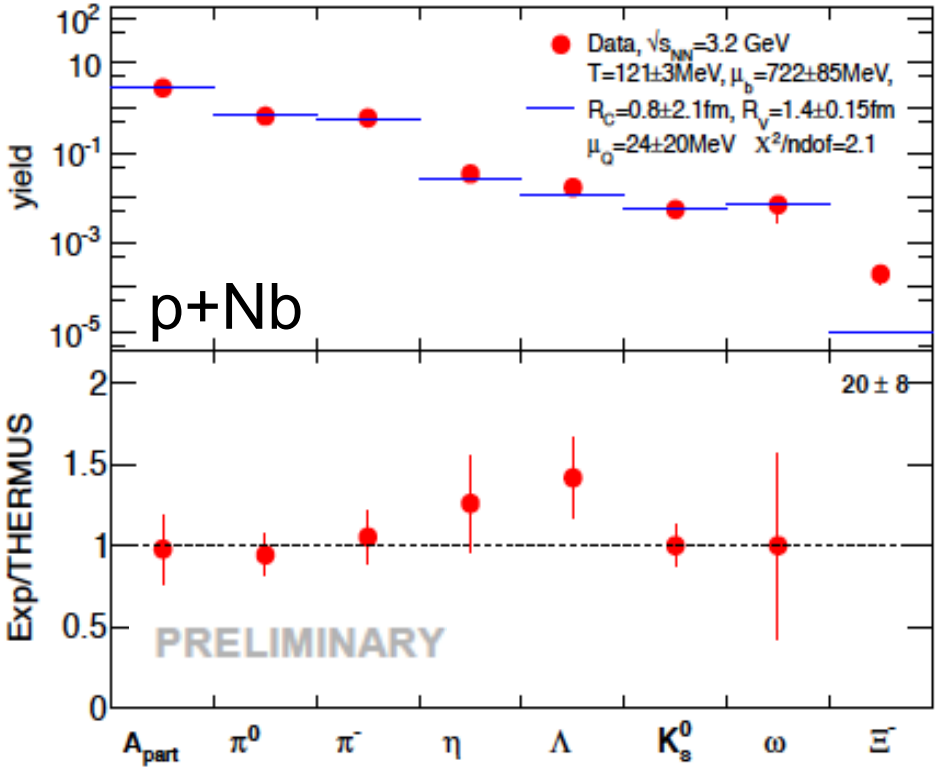
Increased N* branching ratios can explain it.

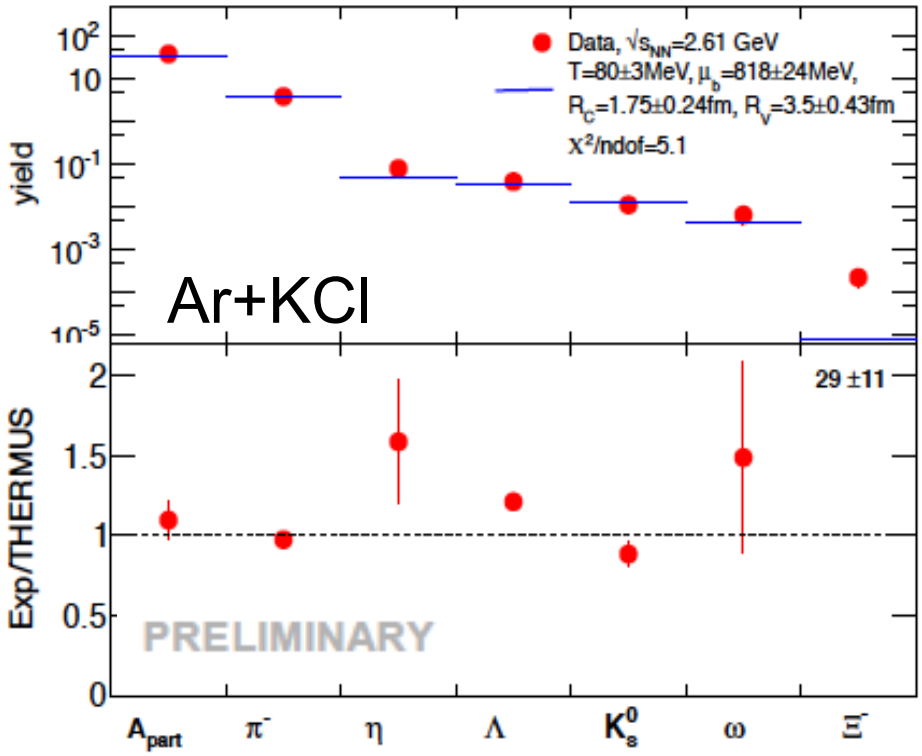
Test differentially with final Au+Au data and also pion-induced reaction

Statistical model fit to p+Nb data

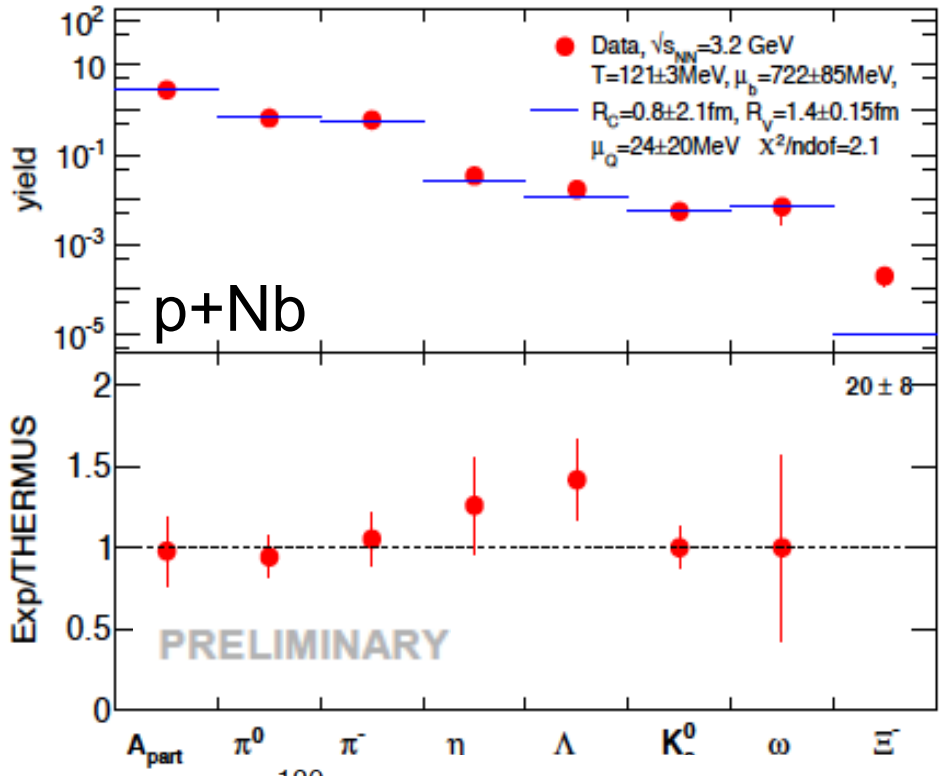


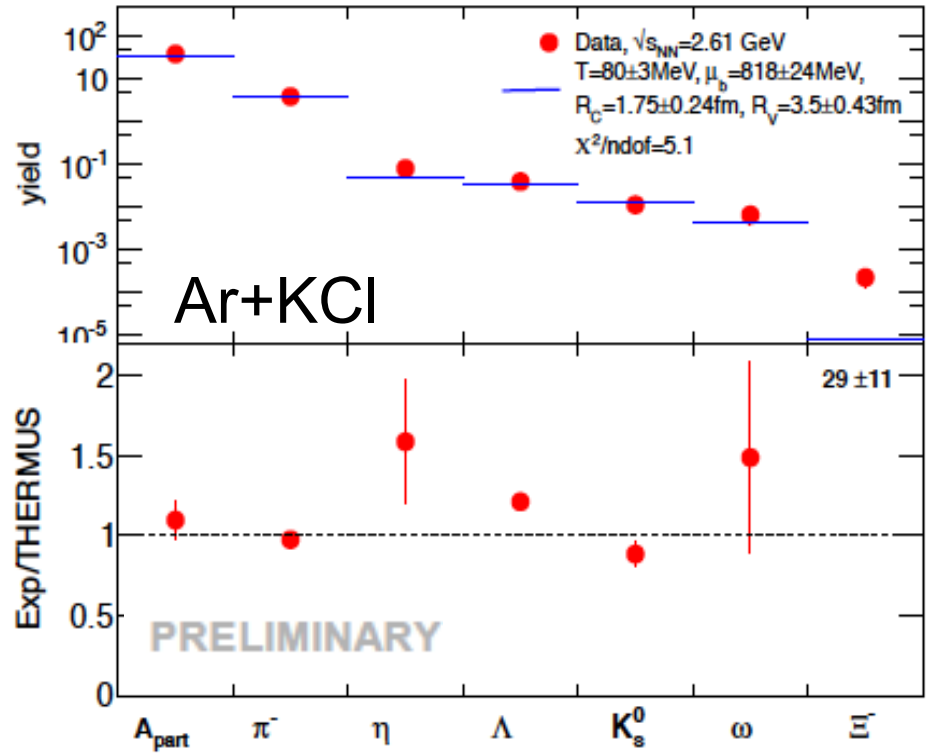
Statistical model fit to p+Nb data



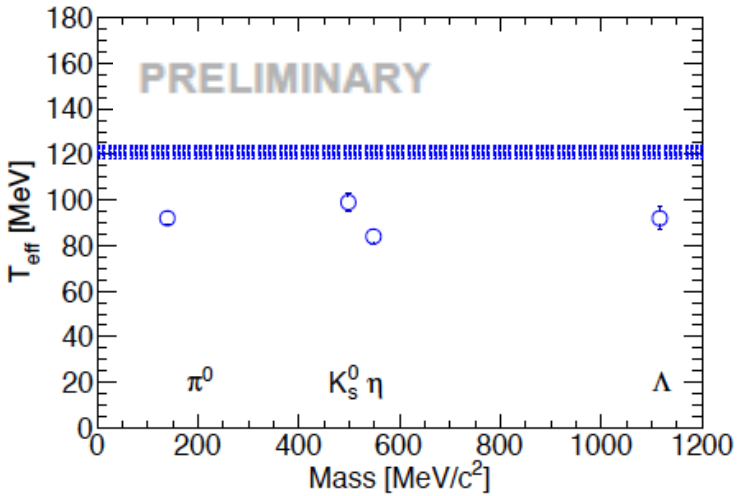


Statistical model fit to p+Nb data

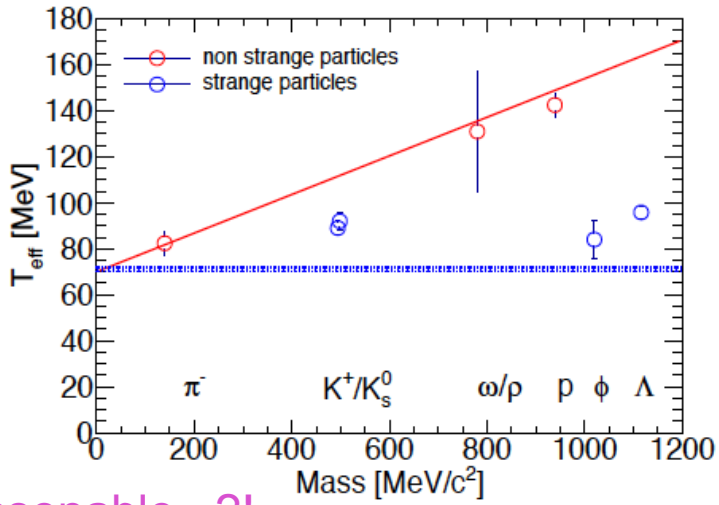




$T_{chem} > T_{kin}$

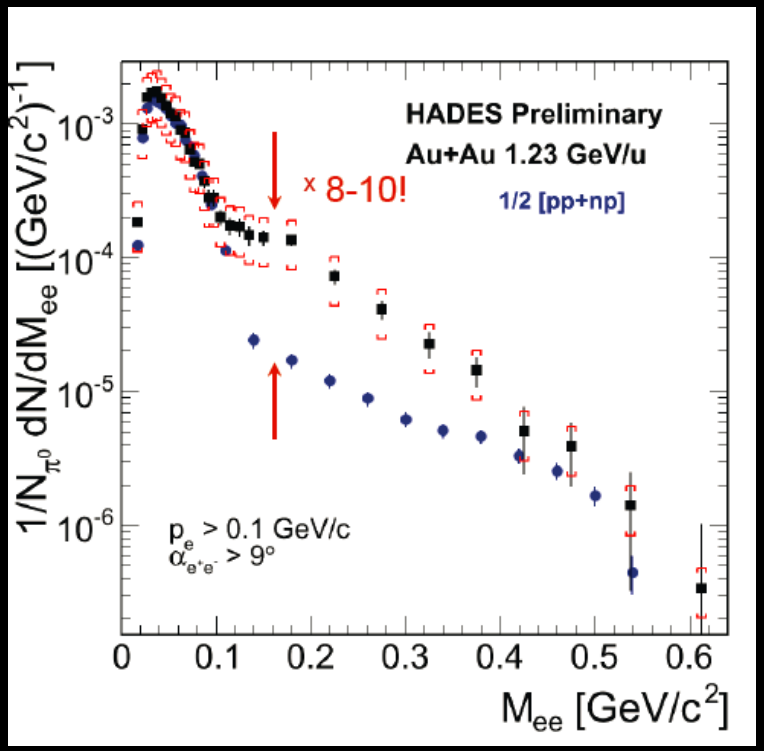


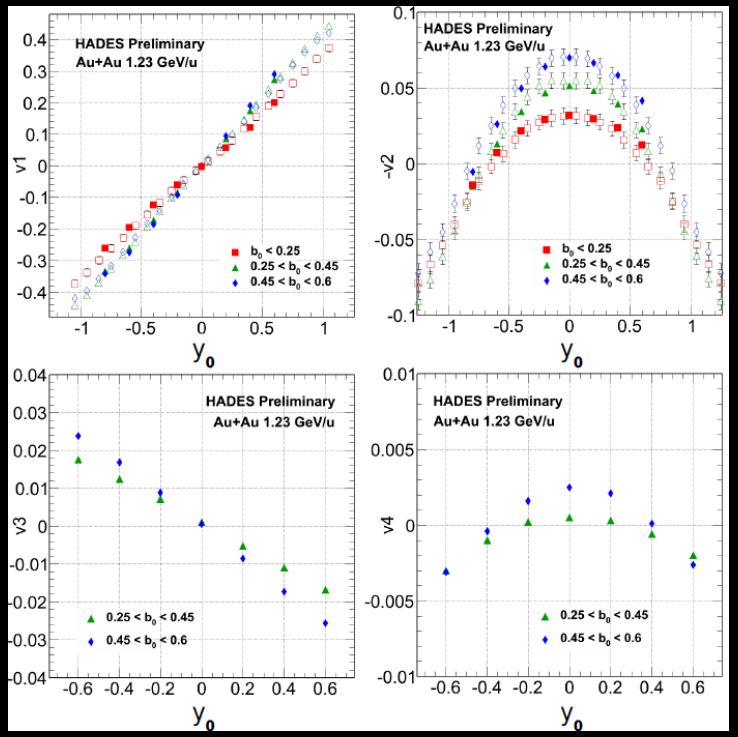
$T_{chem} \leq T_{kin}$



Fit to p+Nb looks more reasonable ..?!

What else?





Very long shopping list:

- Fluctuations
- Flow analysis (v1,v2,v3,v4)
- Dileptons

See talk by S.Sadovsky

Elementary and cold nuclear matter:
Rafal Lalik: Tuesday
Oliver Arnold: Thursday

Summary

High statistic data sample for Au+Au @1.23 A GeV

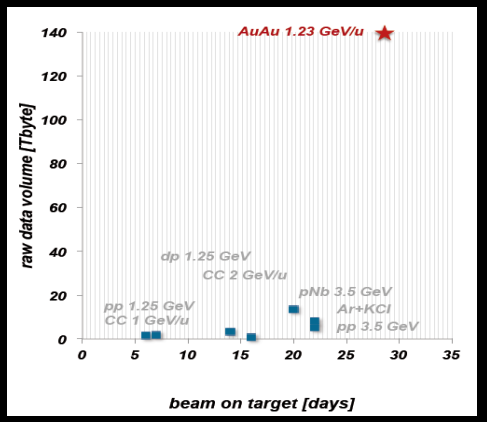
Complete strangeness produced below free NN-threshold

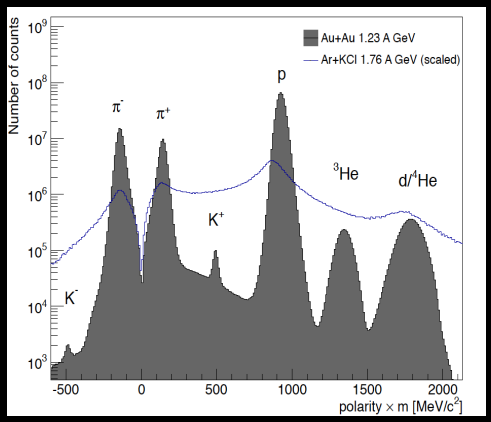
ϕ/K- ratio rises towards lower energies

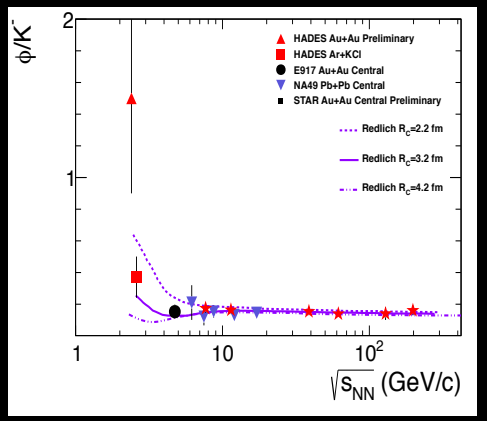
Ξ excess already present in cold nuclear matter

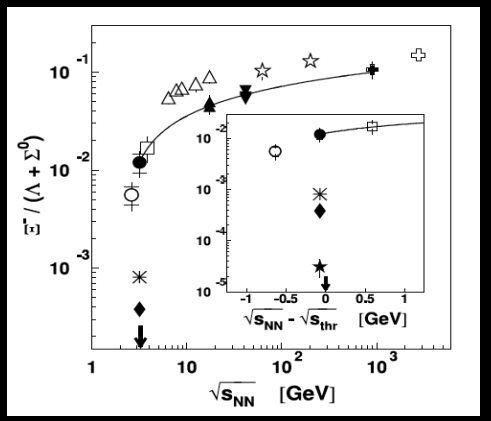
Statistical model describes p+A *(better than Ar+KCl)*

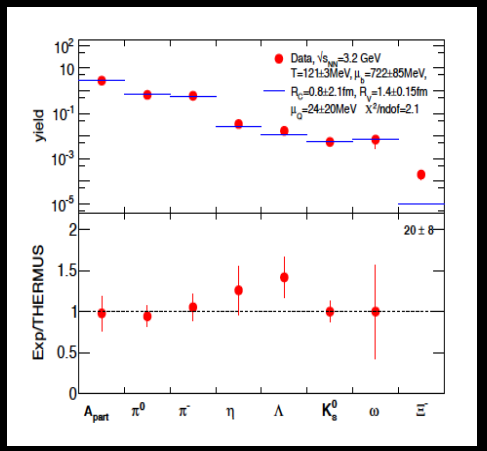
Much more to come: dileptons, fluctuations, flow anisotropies

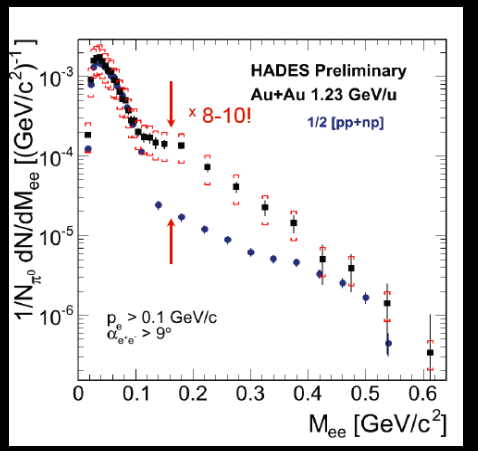












The HADES collaboration

Thank you for your attention!

Back up

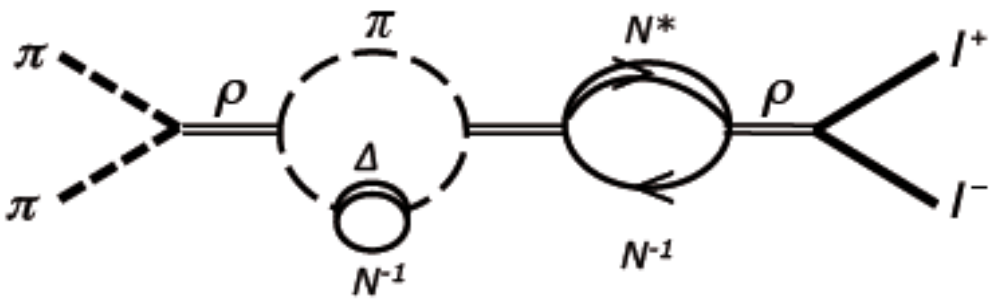
Hadronic models

Chiral condensates can only be related to the integral over hadronic spectral functions by QCD sum rules: → spectral function constrained but not determined

Hadronic models needed to predict hadron properties inside the medium

Additional contributions to particle self energy by coupling to resonances inside the medium:

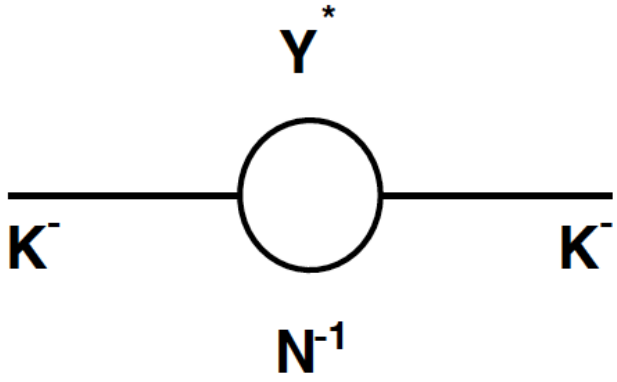
Example: **ρ meson**



Probe: dilepton decay

Observable: Lineshape modifications

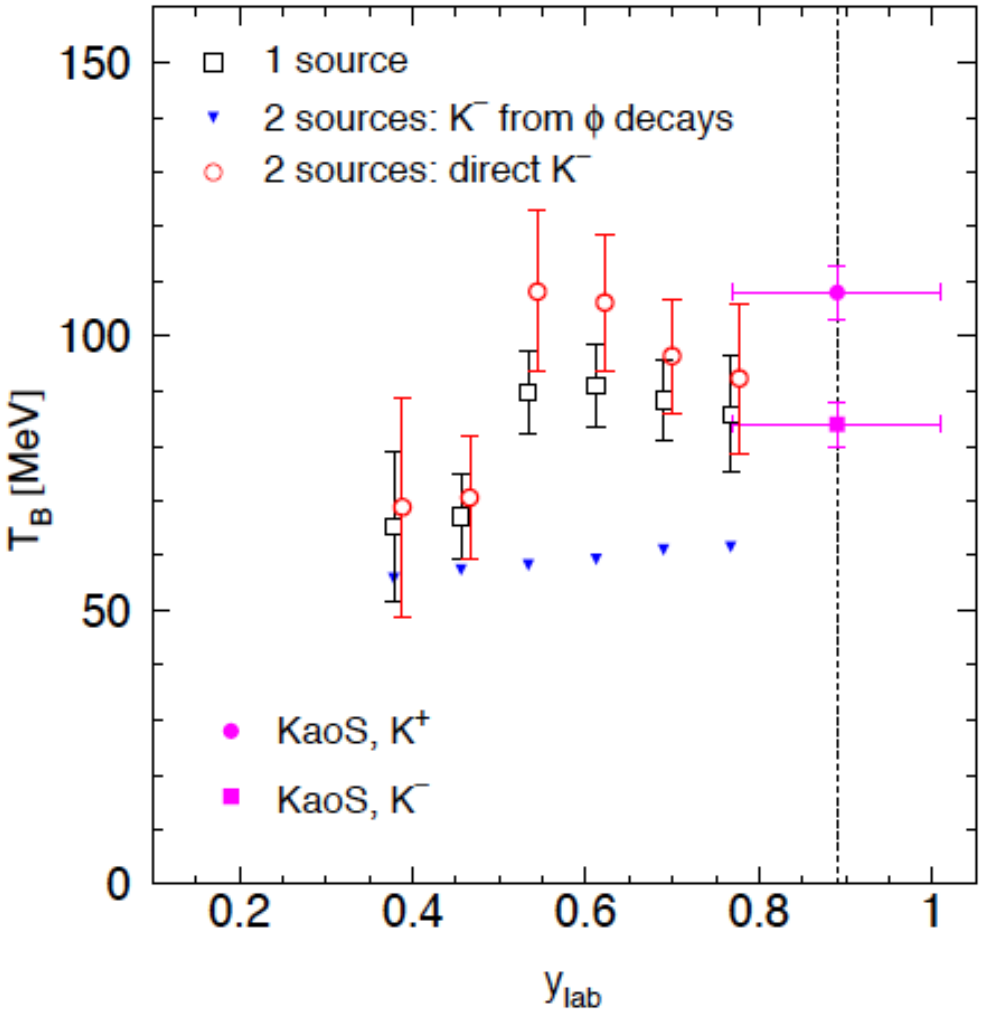
Example: **K- meson**



Probe: direct reconstruction of hadron

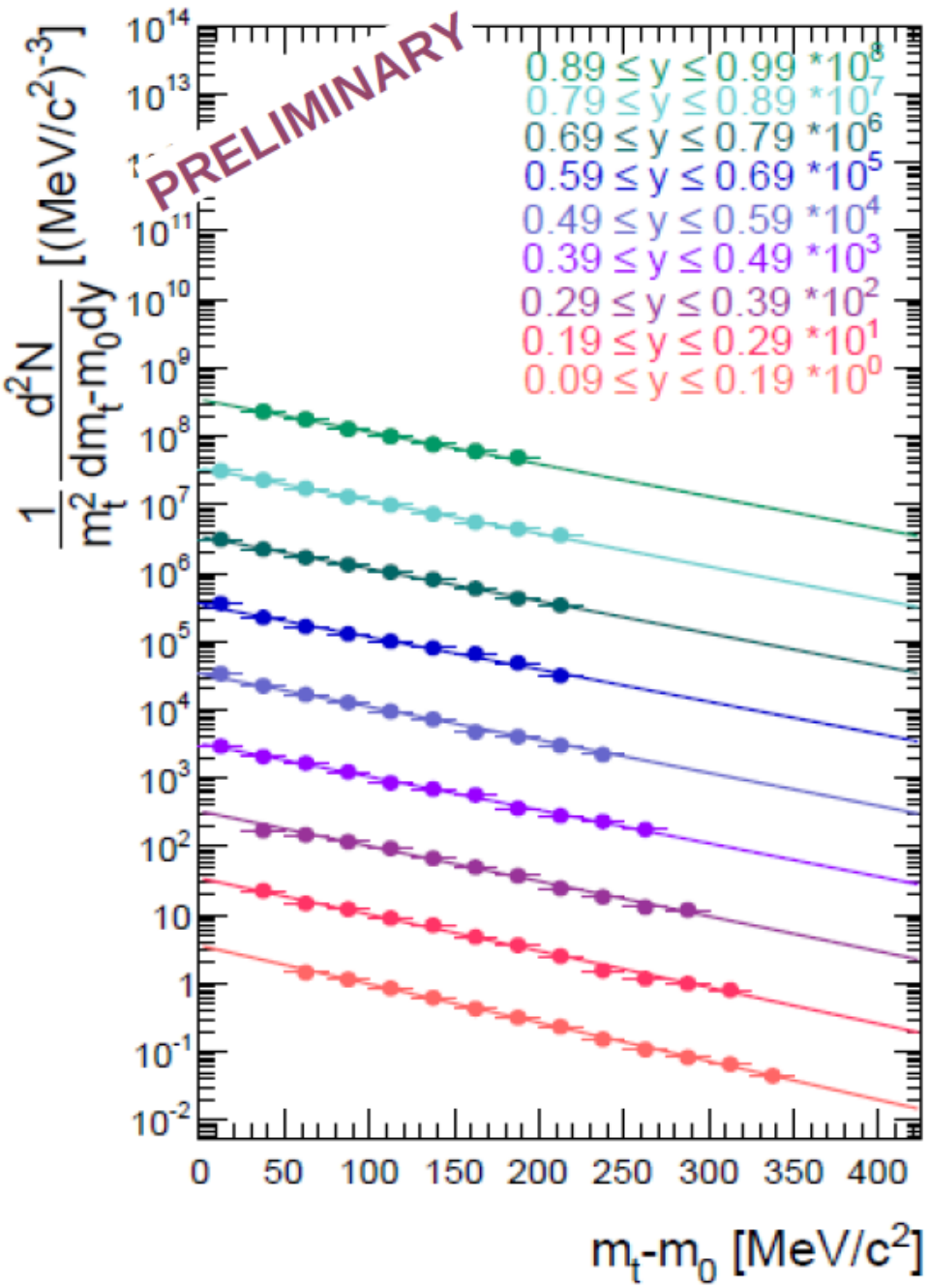
Observable: Production yields (steep excitation functions) and phase space distributions

phi fopi

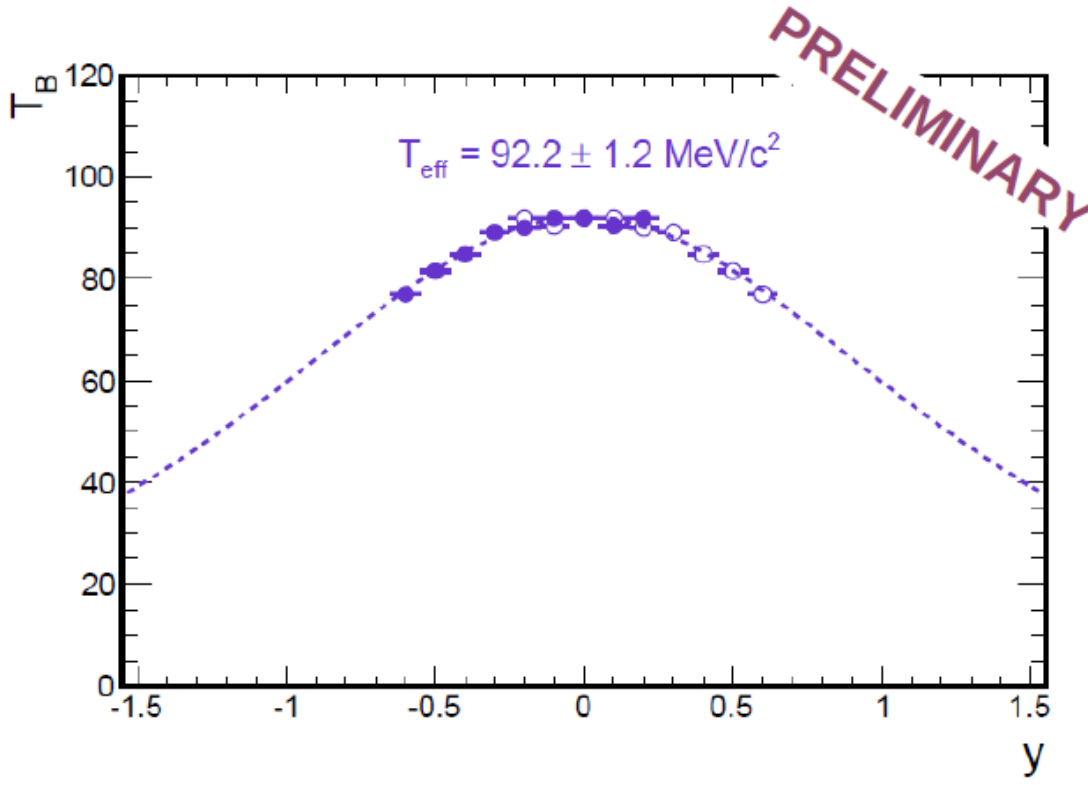


Phys.Rev. C91 (2015) 5, 054904

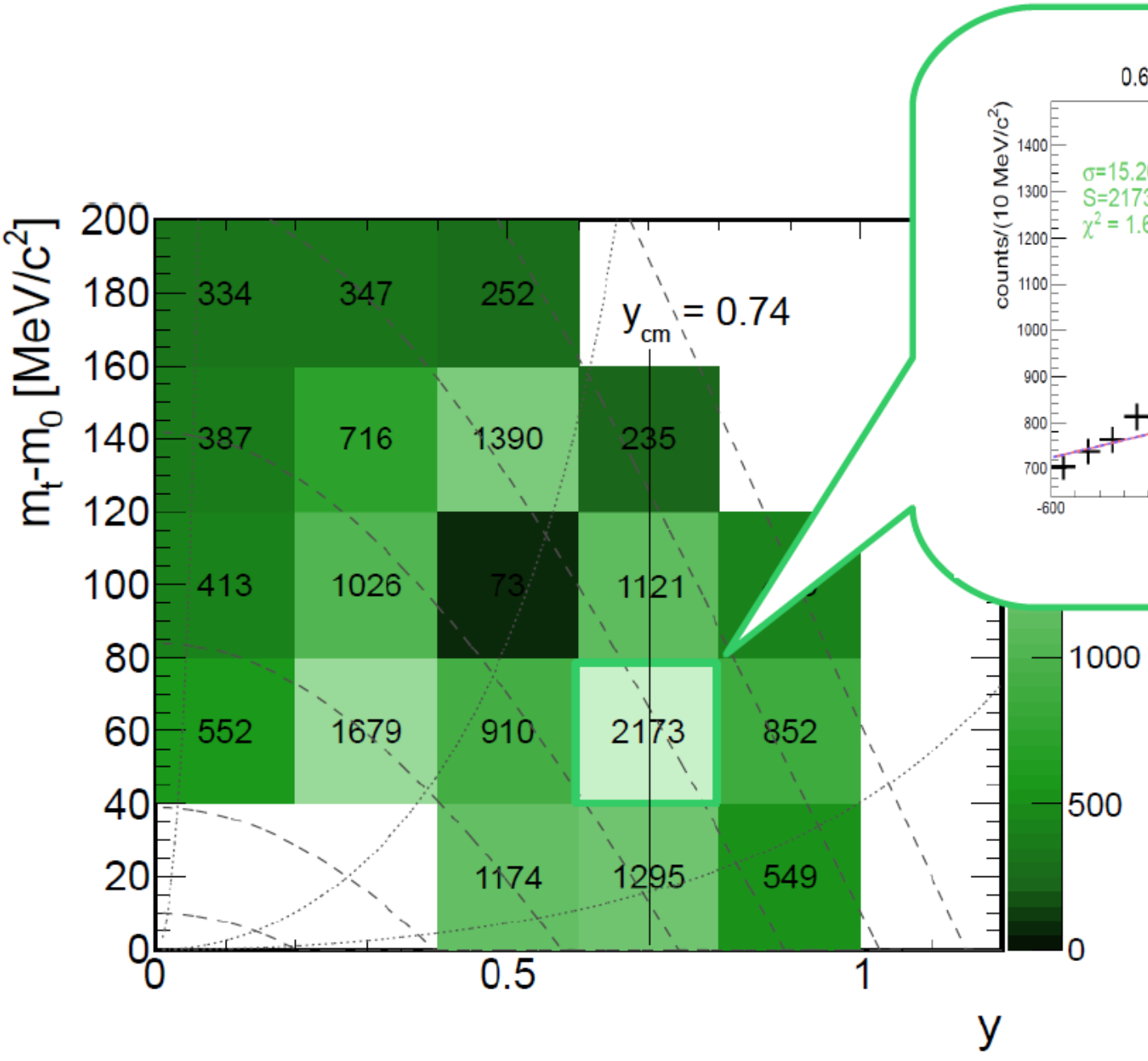
K^+: Phase space coverage

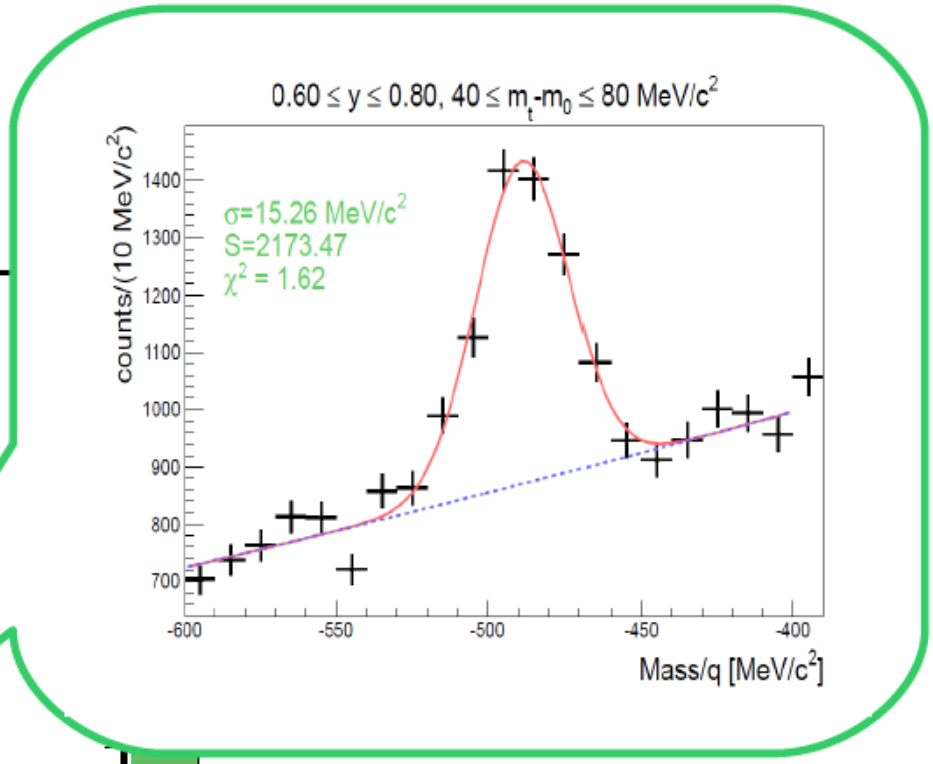


$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dy} = C(y)\cdot exp\left(-\frac{(m_t - m_0)c^2}{T_B(y)}\right)$$



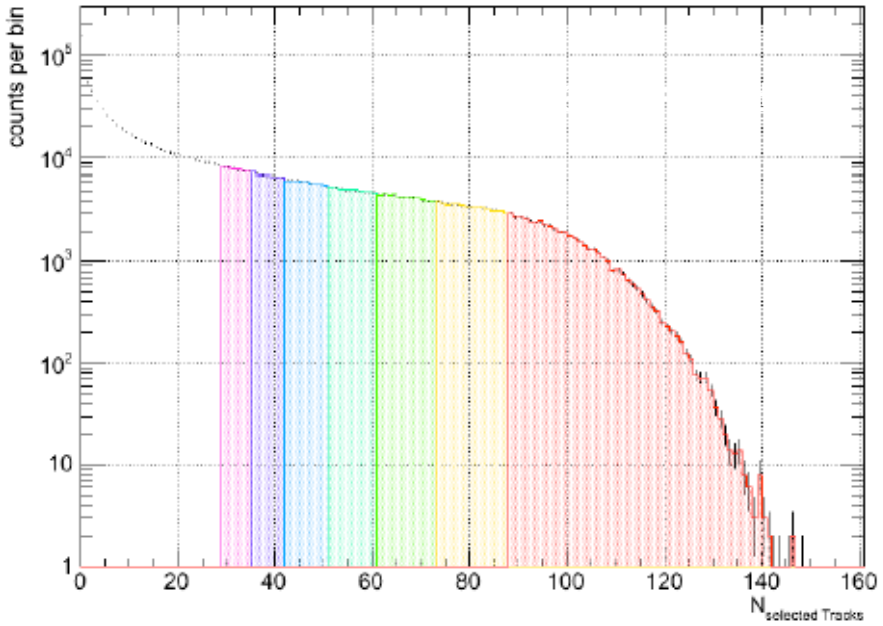
K^- : Phase space coverage



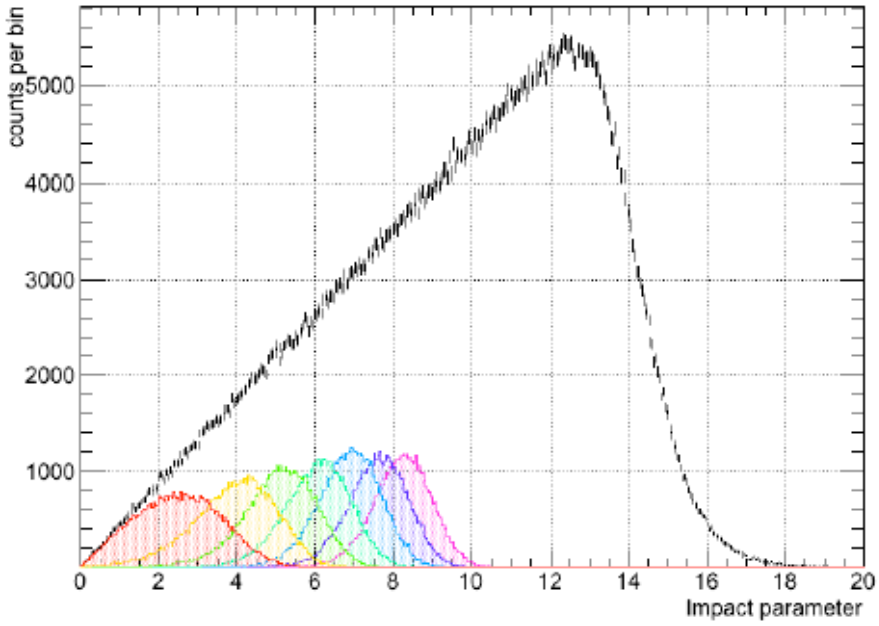


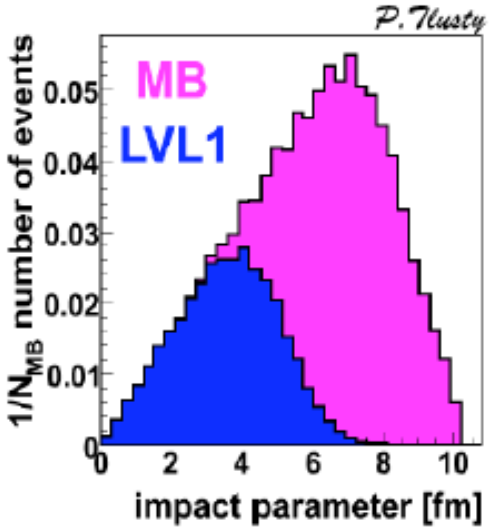
Centrality selection

N_{ch}



Impact parameter

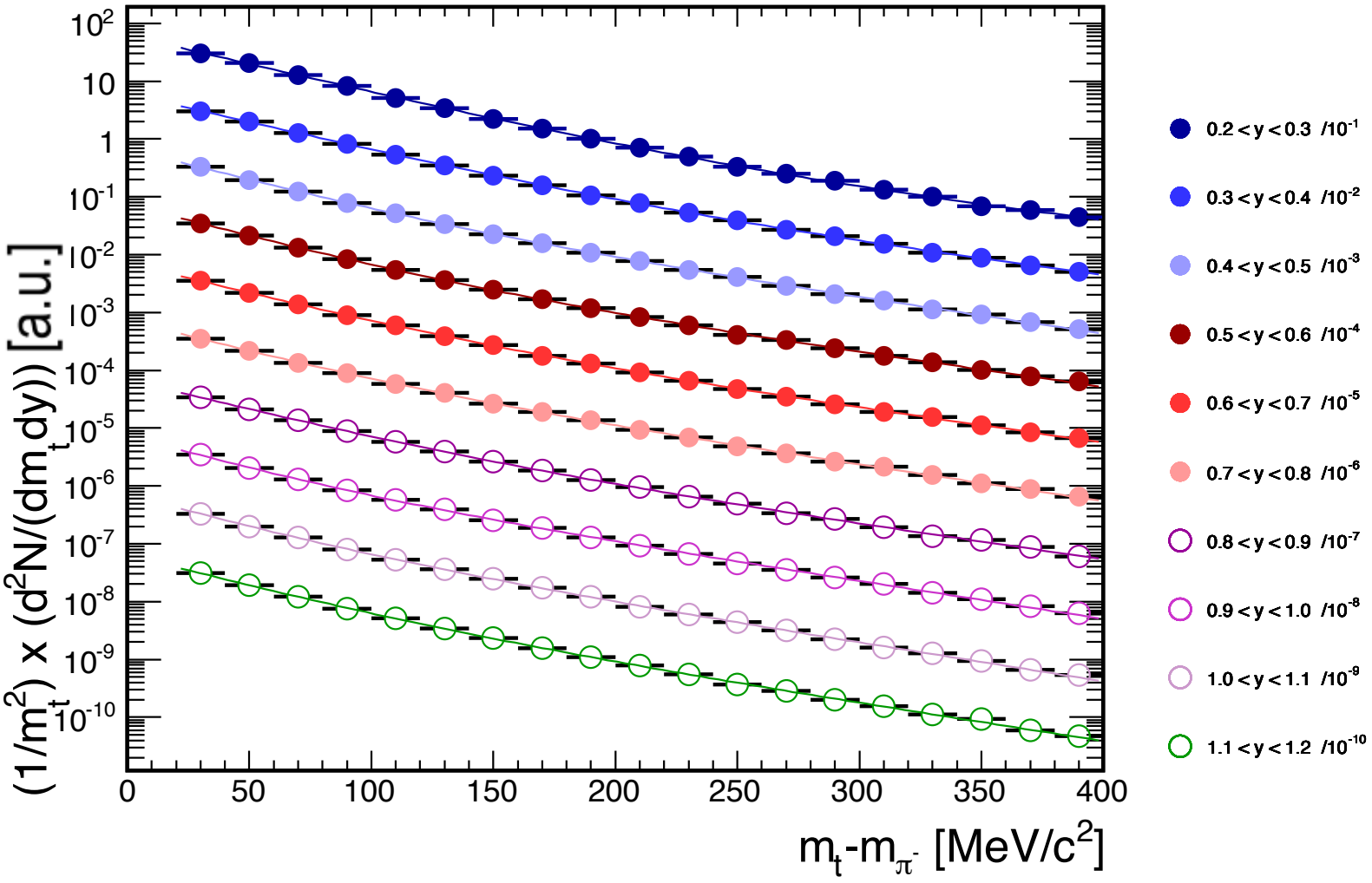


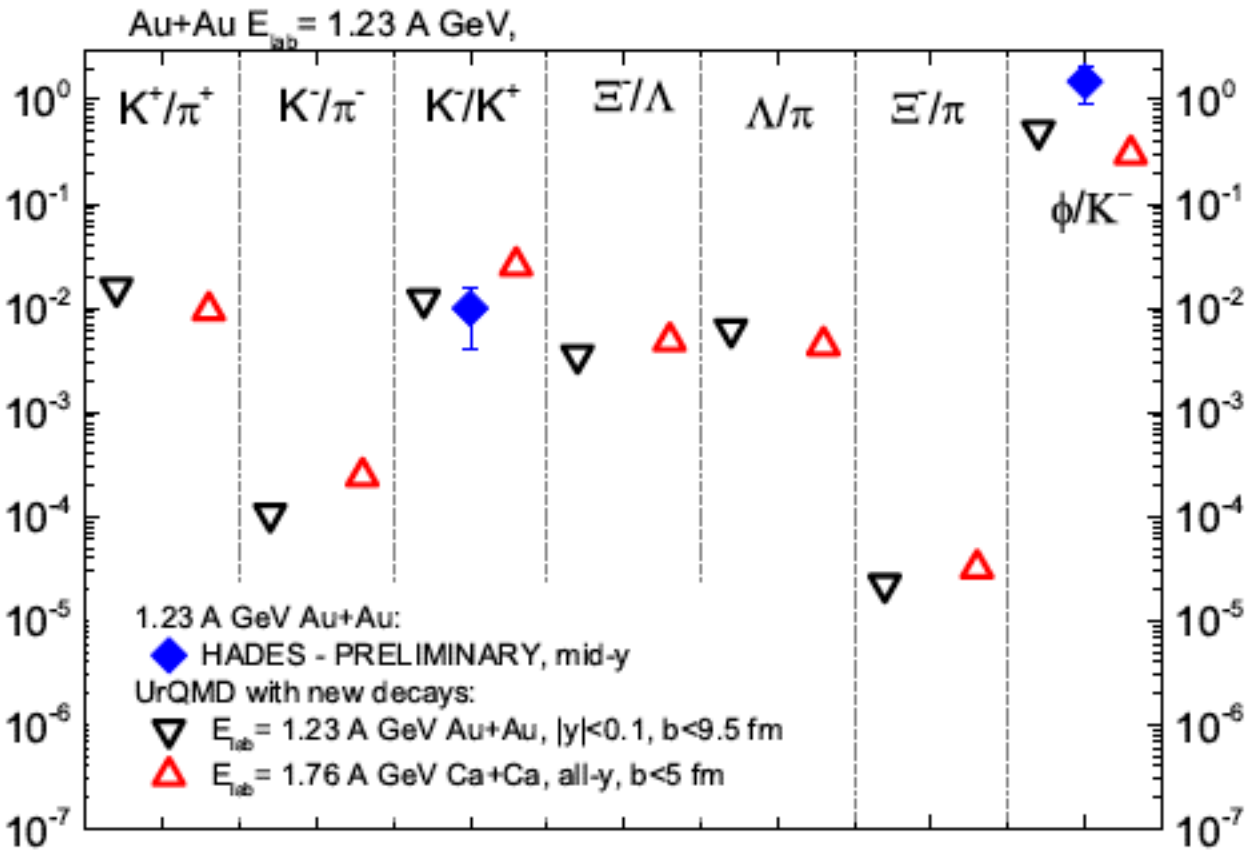


Mean Apart= 177

	<b> (fm)	$<N_{part.}>$
min. bias	5.83	19.25
LVL1	3.54	38.5

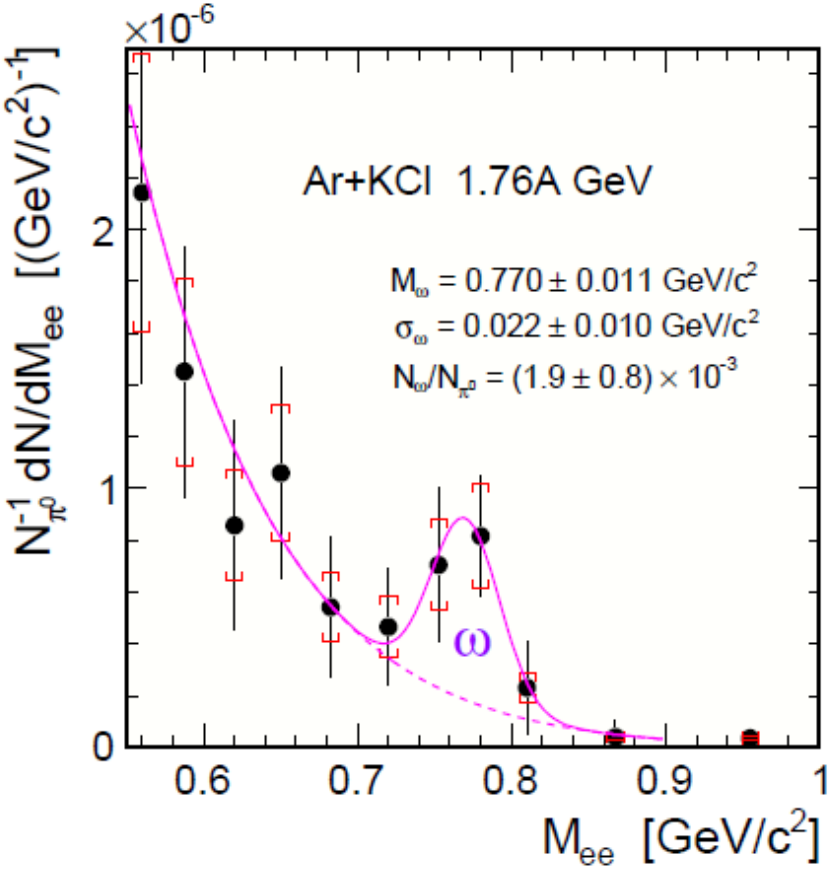
Pions


$(1/m_t^2) \times (d^2N/(dm_t dy))$ [a.u.]
m_t-m_{π^-} [MeV/c^2]
0.2 < y < 0.3 /10^{-1}
0.3 < y < 0.4 /10^{-2}
0.4 < y < 0.5 /10^{-3}
0.5 < y < 0.6 /10^{-4}
0.6 < y < 0.7 /10^{-5}
0.7 < y < 0.8 /10^{-6}
0.8 < y < 0.9 /10^{-7}
0.9 < y < 1.0 /10^{-8}
1.0 < y < 1.1 /10^{-9}
1.1 < y < 1.2 /10^{-10}


Au+Au E_lab = 1.23 A GeV,
K+/π+
K-/π-
K-/K+
Ξ-/Λ
Λ/π
Ξ-/π
ϕ/K-
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1.23 A GeV Au+Au:
HADES - PRELIMINARY, mid-y
UrQMD with new decays:
E_lab = 1.23 A GeV Au+Au, |y|<0.1, b<9.5 fm
E_lab = 1.76 A GeV Ca+Ca, all-y, b<5 fm

Ar+KCl: vector mesons

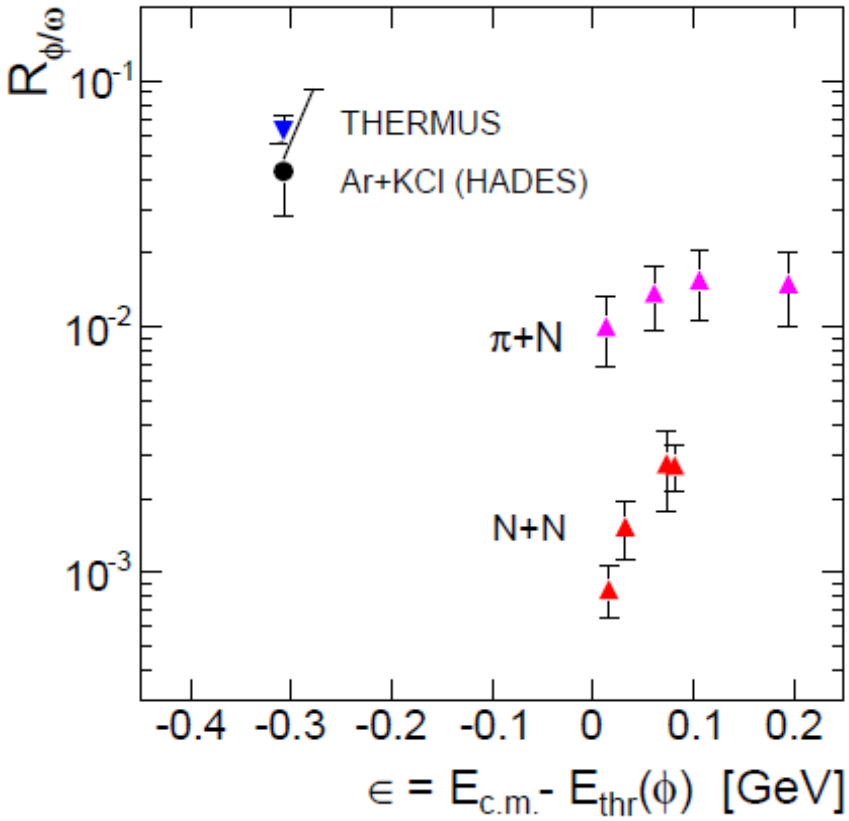
ω-meson:
subthreshold + electromagnetic decay channel: **50 million events for one ω!**



$\phi \rightarrow K^+K^-$, multiplicity: $(2.6 \pm 0.7) \cdot 10^{-4}$

$\omega \rightarrow e^+e^-$, multiplicity: $(6.7 \pm 2.8) \cdot 10^{-3}$

Φ/ω ratio:
suppressed in elementary reactions due to OZI rule

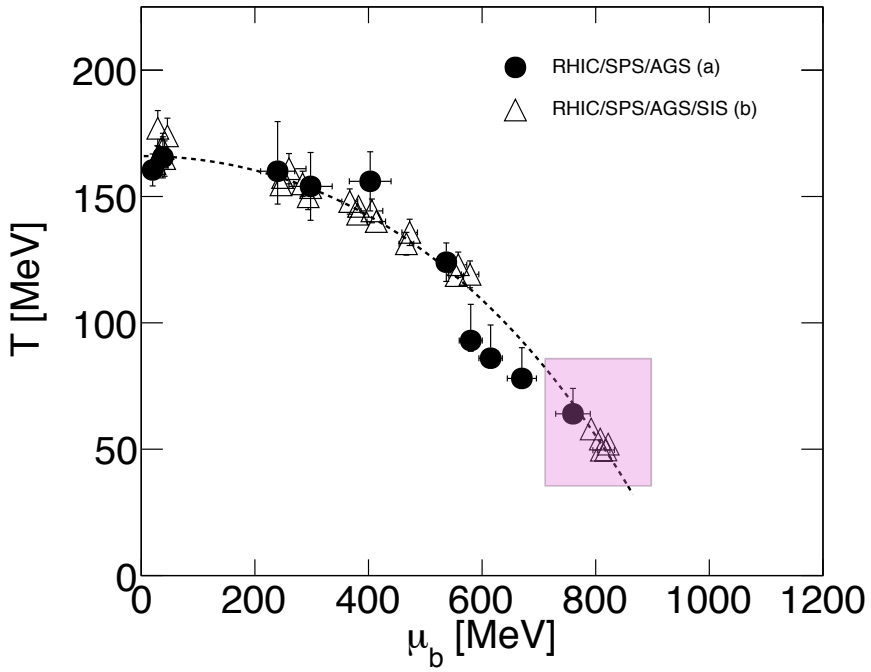


>> $R_{\phi/\omega}$ in NN and πN reactions !
Impact of other channels besides NN and πN ? (e.g. ρN, ρΔ, …) Effect of the medium?

G. Agakishiev et al. [HADES Collaboration]. Dielectron production in Ar+KCl collisions at 1.76A GeV. Phys. Rev., C84(014902), [arXiv:1103.0876 [nucl-ex]]. 2011

Statistical model

Eur. Phys. J., A 47(21)



Particle production from a homogeneous source:

$$\rho_{i,q} \propto \int_0^\infty p^2 dp \; exp\left(\frac{-E_i + \vec{\mu}\vec{q_i}}{kT}\right)$$

Grand canonical ensemble

Quantum numbers conserved on average using chemical potentials

Parameters: **T, μ= μ_B μ_s μ_Q, V**
(usually μ_s and μ_Q are constrained from initial conditions)

- Measurements at different √s line up in a hadron freeze-out curve (E/N≈1 GeV)

- How to interpret this apparent equilibrium, or why does the model work so well?

- How well is well? Similar as at higher energies? Look also at reference systems e.g. p+A

- Focus on data at SIS18 energies, are they consistent?

Data sample a) Andronic et. al. (Grand canonical T, μ_B)
Data sample b) Cleymans, Becattini (Strangeness canonical+γ_S)

Statistical model at SIS energies

Strangeness canonical
(exactly conserved)

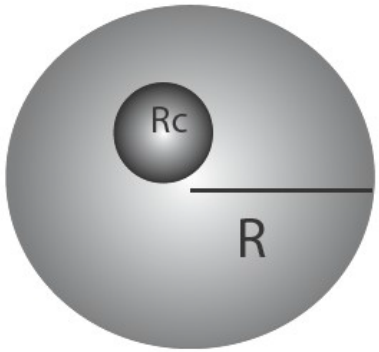
Yields reduced (canonical suppression)

• Not enough to explain data:

• Strangeness has to be conserved exactly in a volume smaller than the volume of the system (radius: $R_C < R_v$)

• Empirical under-saturation parameter (γ_S)

• φ meson (hidden strangeness, not canonically suppressed)



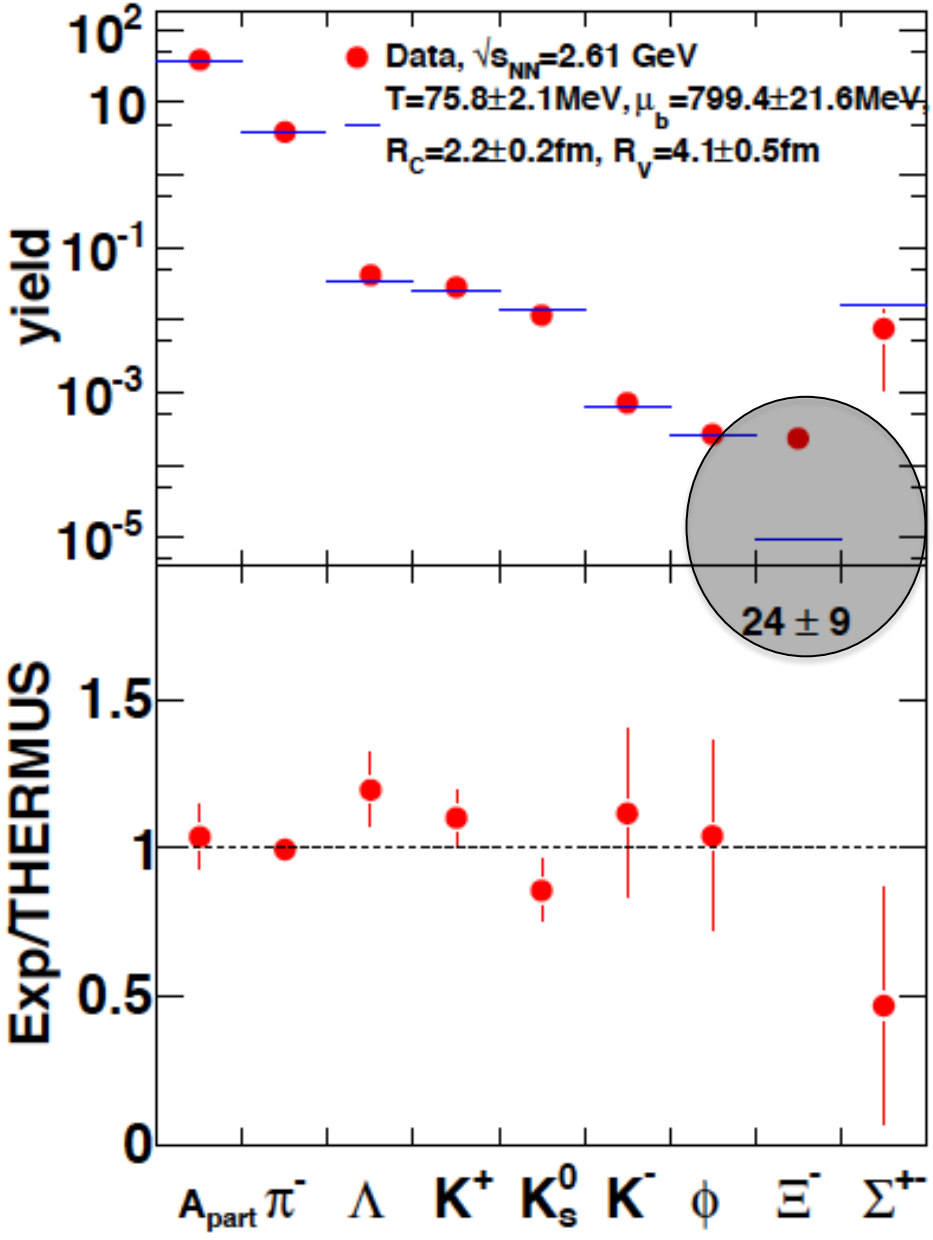
In the strangeness canonical ensemble
μ_B constrained by:
π/p, K^+/K^- (due to strangeness content in the Λ)

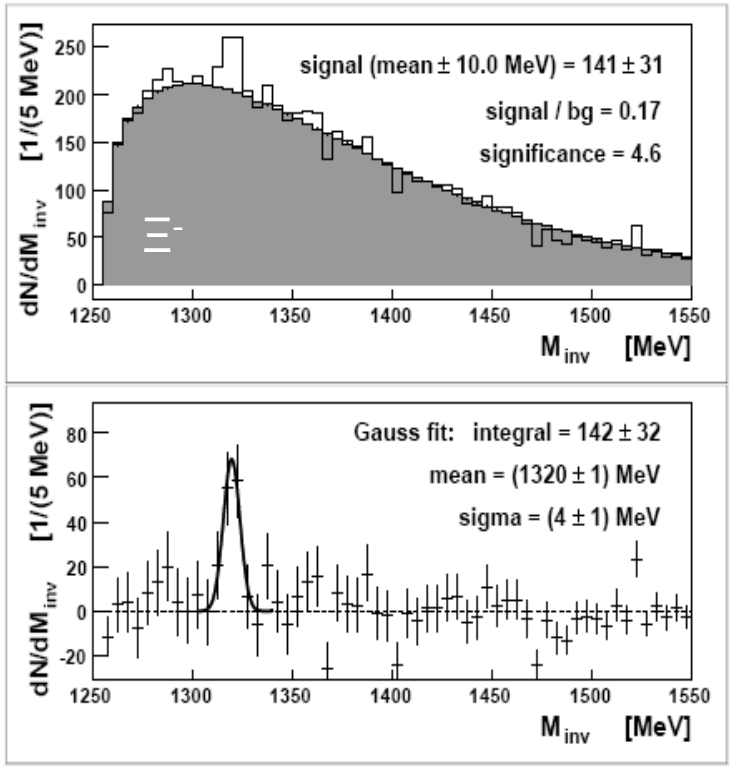
T constrained by:
K/π, φ/K (p/Λ) usually R_c or γ_S is also involved

Additional input:
Resonance states and their BR to final states

Yields vs. ratios:
Cancellation of systematic errors
R and R_c determined

Hadrons in Ar+KCl@1.76A GeV





Probability P_{ss} to produce a strange quark pair ≈ 0.05 → $\mathbf{P_{\Xi^-} \approx 0.1\ P_{ss}^2}$

Strangeness production not independent?