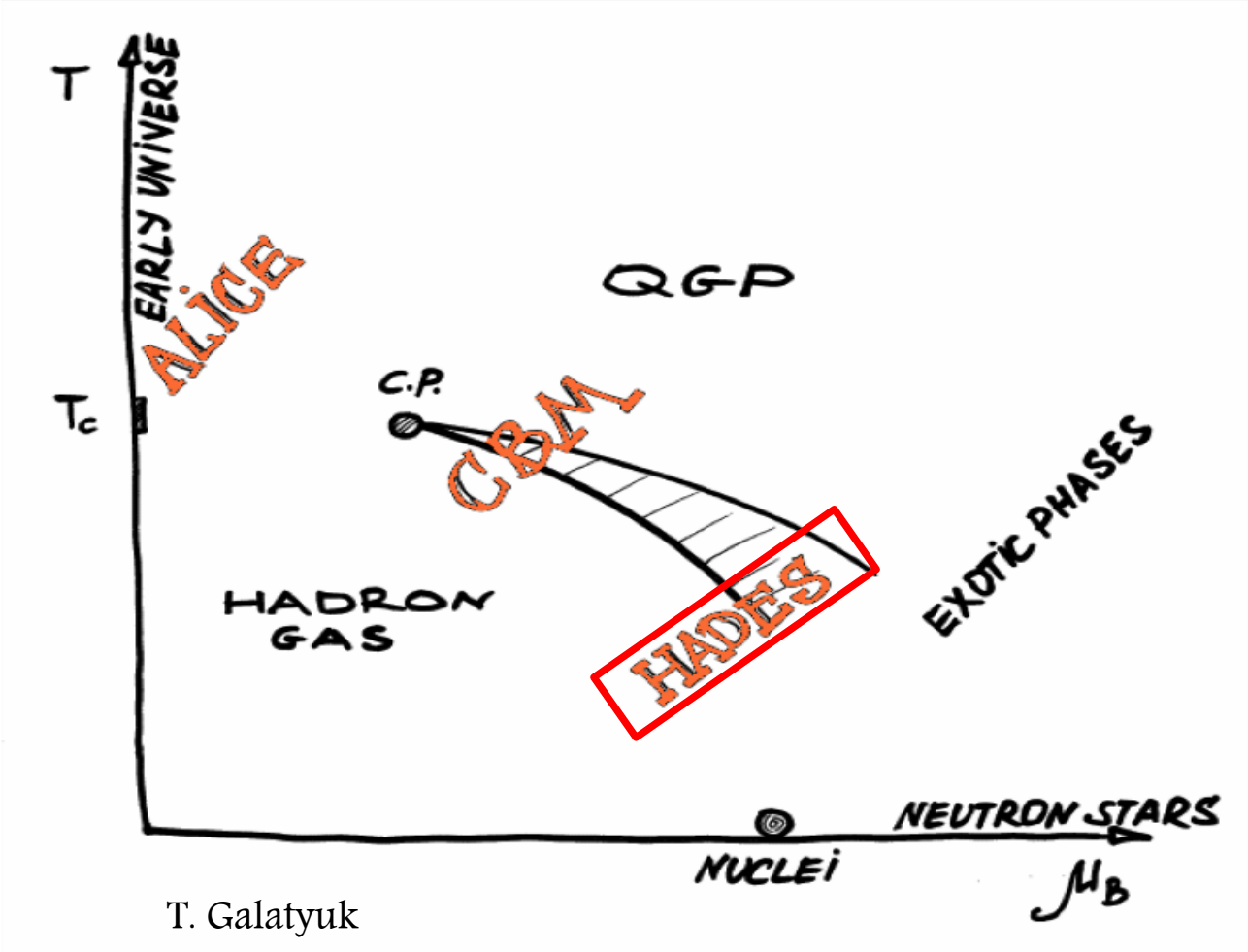
Rare Hadronic Probes in Au+Au at 1.23 AGeV with HADES

Timo Scheib

Outline

- Hadron Production at SIS energies
- Au+Au at 1.23 AGeV with HADES
- Reconstruction of
  uncharged hadrons Λ, K_S^0 and ϕ
- Comparison of preliminary results to statistical model

Heavy Ion Collisions and QCD Phase Diagram



Strangeness Production @ SIS Energies (1-2 AGeV)

Elementary collisions (nucleon - nucleon)

$$
\begin{aligned}
NN &\rightarrow K^+ \Lambda N && (E_{kin} = 1.58\ AGeV)\\
NN &\rightarrow K^0_S \Lambda N && (E_{kin} = 1.59\ AGeV)\\
NN &\rightarrow K^+ K^- NN && (E_{kin} = 2.49\ AGeV)\\
NN &\rightarrow \phi NN && (E_{kin} = 2.59\ AGeV)
\end{aligned}
$$

Heavy-Ion collisions (nucleus - nucleus)

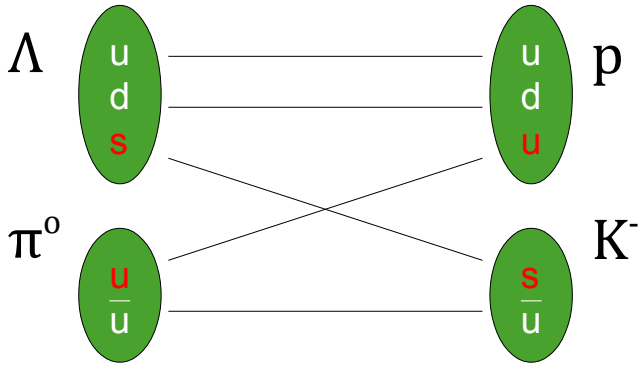
1

Accumulation of energy in secondary collisions

$$NN \rightarrow N\Delta \qquad NN \rightarrow N\Delta$$
$$N\Delta \rightarrow NNK^+K^- \qquad N\Delta \rightarrow NK^+\Lambda$$

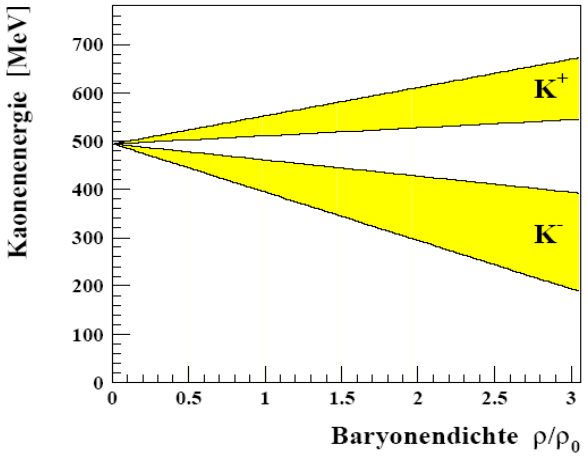
2

Strangeness exchange



3

Effective Kaon potentials

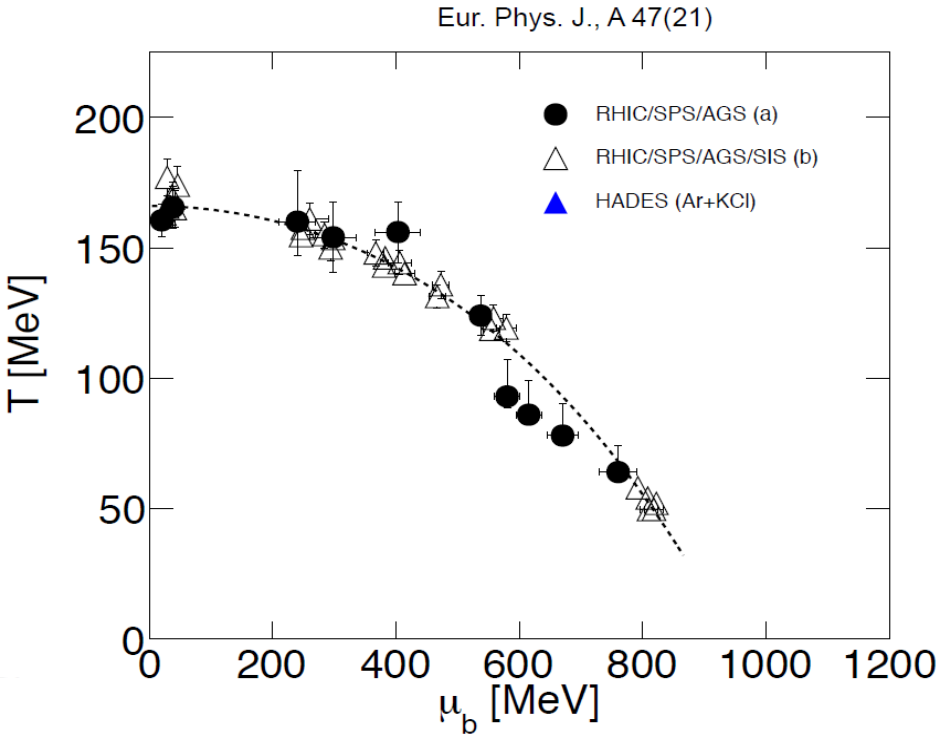


Calculation by J. Schaffner-Bielich

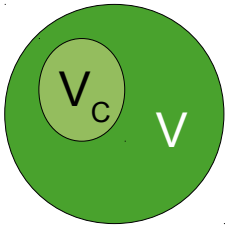
Statistical Model

- Determination of particle production yields coming from a thermal source (volume V, temperature T and chemical potential μ)

$$Z_i^1 = \pm \frac{g_i}{2\pi^2} \int_0^\infty p^2 dp \ln\left[1 \pm \exp\left(\frac{\vec{q}_i\vec{\mu} - E_i}{T}\right)\right]$$



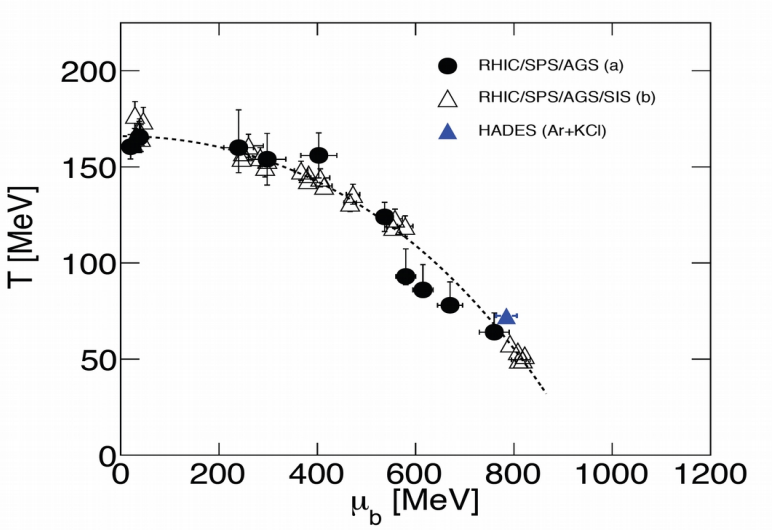
- (Strangeness-)canonical ensemble for SIS energies (1-2 AGeV):
  - Number of particles carrying quantum number (strangeness) is small
    → exact strangeness conservation over sub-volume with R_C in Au+Au at 1.23 AGeV needed

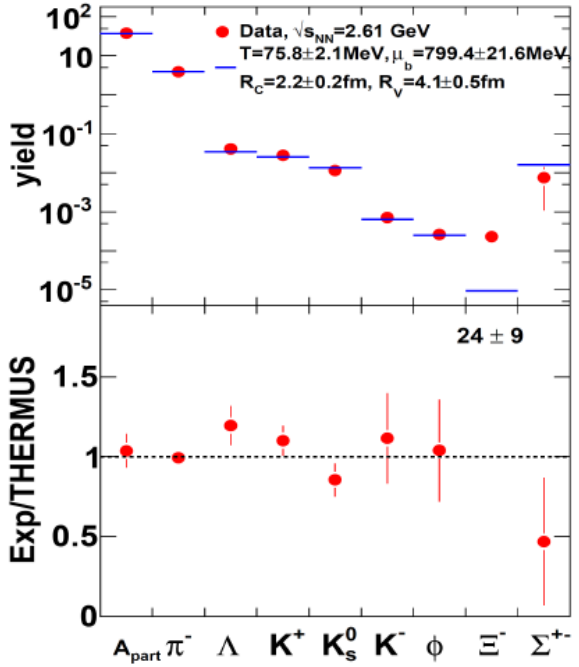


Hadron Production with HADES

- Ar+KCl at 1.76 AGeV: complete set of strange hadron yields measured/determined
- Description of particle production yields with Statistical Hadronization Model (SHM) in good agreement with data

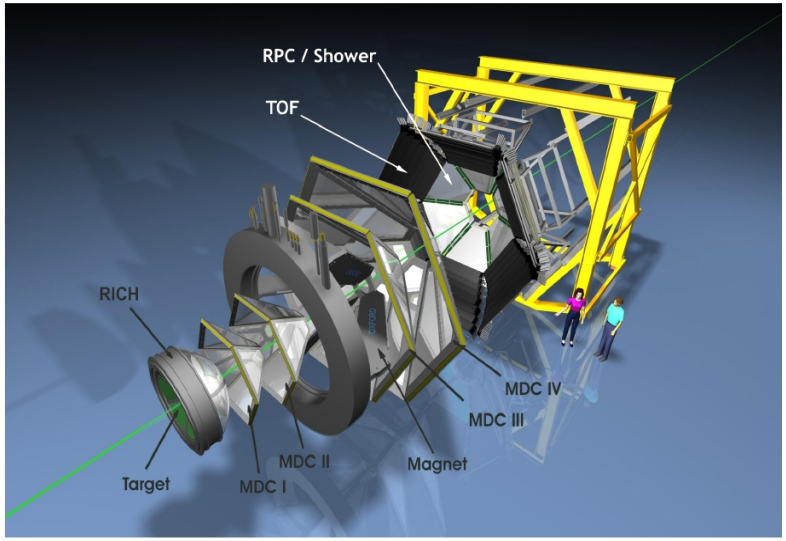
Particle	Multiplicity	T_{eff} [MeV]
π^-	$3.9 \pm 0.1 \pm 0.1$	$82.4 \pm 0.1^{+9.1}_{-4.6}$
$\Lambda + \Sigma^0$	$(4.09 \pm 0.1 \pm 0.17^{+0.17}_{-0.37}) \times 10^{-2}$	$95.5 \pm 0.7 + 2.2$
K^+	$(2.8 \pm 0.2 \pm 0.1 \pm 0.1) \times 10^{-2}$	$89 \pm 1 \pm 2$
K^0_S	$(1.15 \pm 0.05 \pm 0.09) \times 10^{-2}$	92 ± 2
K^-	$(7.1 \pm 1.5 \pm 0.3 \pm 0.1) \times 10^{-4}$	$69 \pm 2 \pm 4$
ϕ	$(2.6 \pm 0.7 \pm 0.1 - 0.3) \times 10^{-4}$	84 ± 8
Ξ^-	$(2.3 \pm 0.9) \times 10^{-4}$	-
$\Sigma^+ + \Sigma^-$	$(0.75 \pm 0.65) \times 10^{-2}$	-





G. Agakishiev et al., (HADES Collaboration), Eur. Phys. J. A 47, 21 (2011)

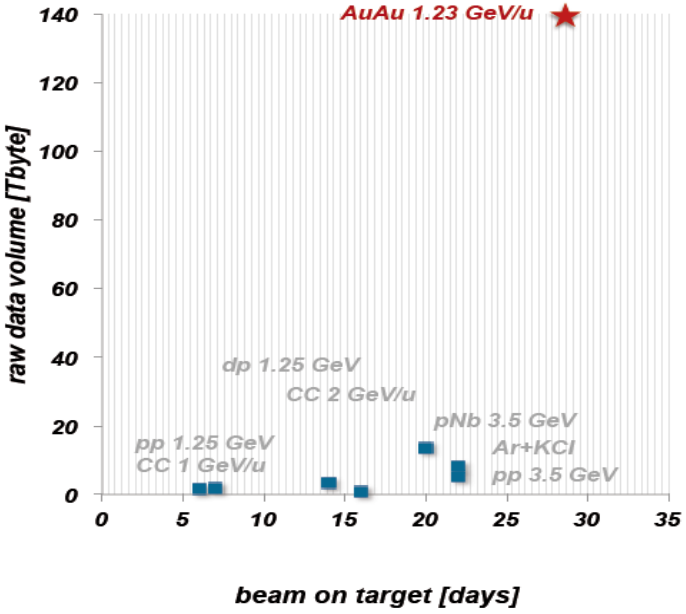
Au+Au Collisions at 1.23 AGeV with HADES



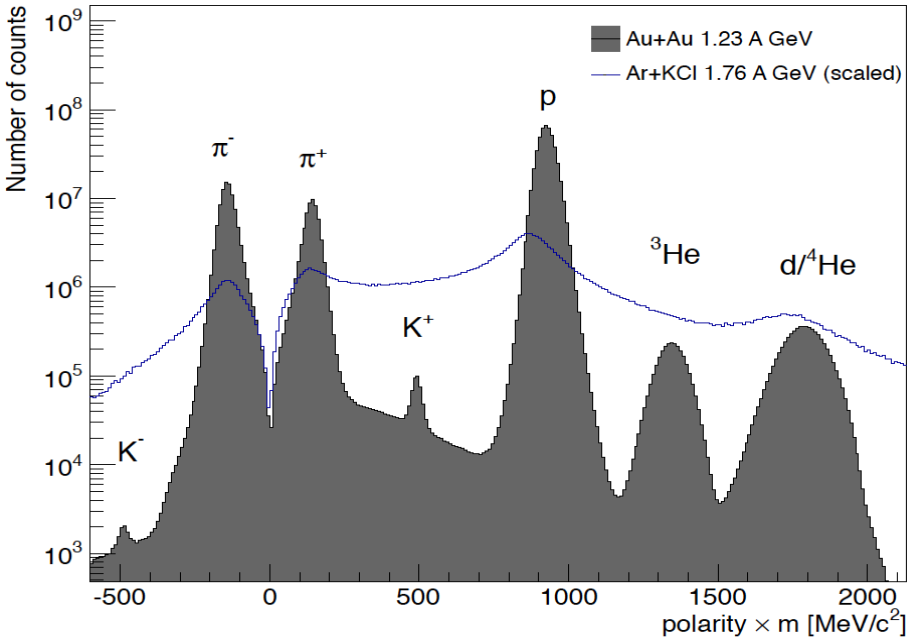
- High geometrical acceptance optimized for e^+/e^- pairs
- Full azimuthal coverage ϕ
  Polar angle θ = 18°-85°
- Multi-Wire Drift Chambers (MDC) +
  Magnetic field: Track reconstruction (incl. p)
- Hadron identification:
  energy-loss in MDC/TOF
  time-of-flight walls: TOF & RPC

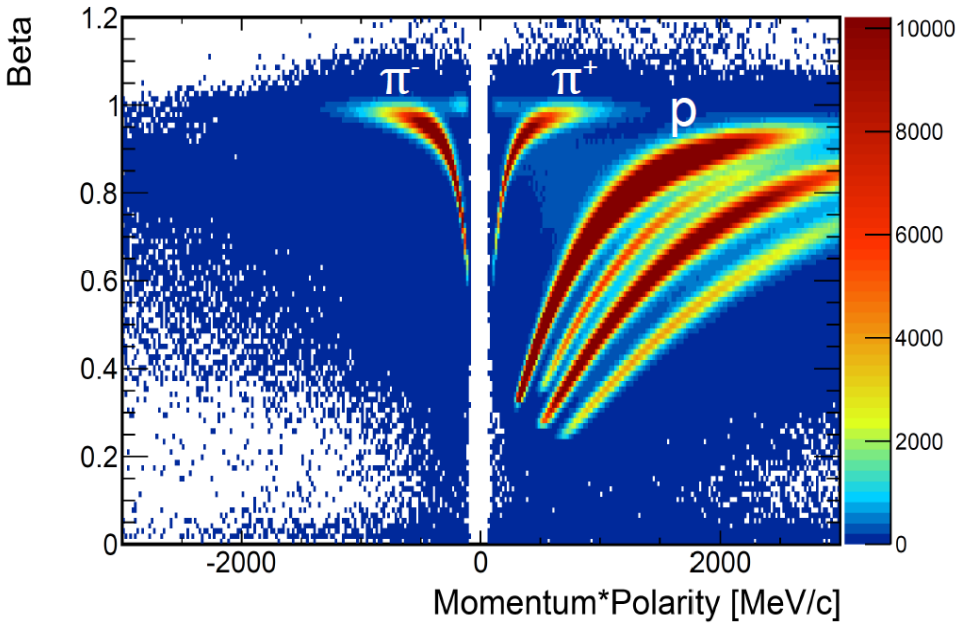
Au+Au in April 2012

- 557 hours of beam
- Beam Rate: 1.2 – 1.5 x 10^6 ions / sec
- Trigger Rate: 8 kHz (200 Mbyte/s)
  → 7.4 x 10^9 events recorded
- $\langle A_{part} \rangle \approx 174$



Mass Spectrum





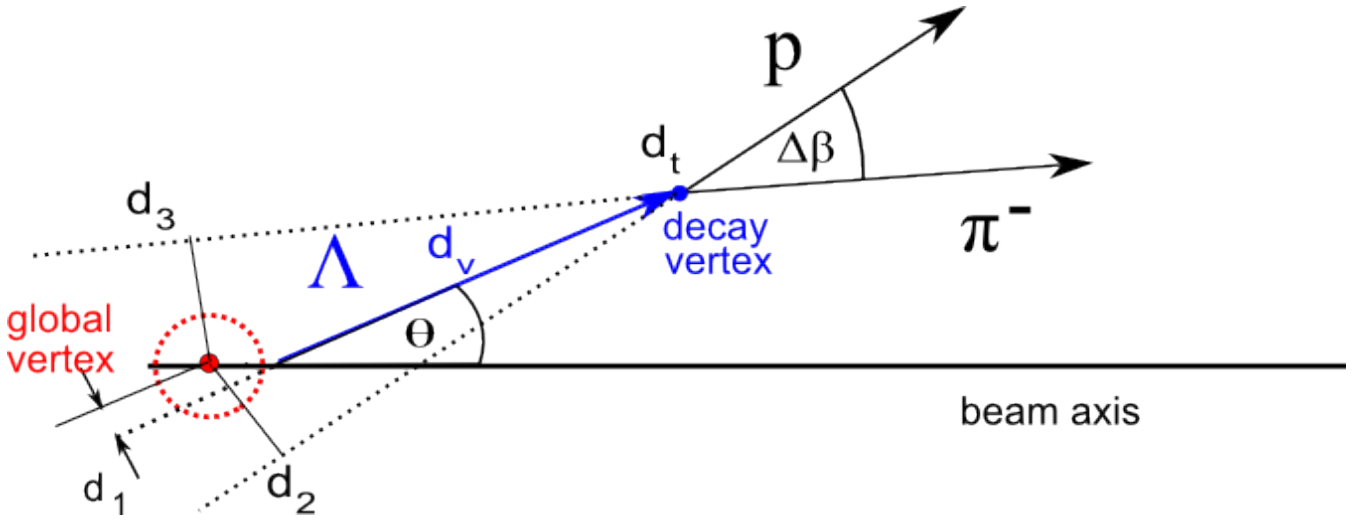
- Sizeable improvement in HADES performance
- First measurement of negative kaons at such low energies

Reconstruction of Uncharged Hadrons

	Decay Length $c\tau$ [cm]	BR [%]	$\sqrt{s_{tr}}$ [GeV]	$\sqrt{s} - \sqrt{s_{tr}}$ [GeV]
$K^0_s((d\bar{s} + \bar{d}s)\sqrt{2}) \rightarrow \pi^+\pi^-$	**2.68**	**69.2**	**2.55**	**−0.14**
$\Lambda(uds) \rightarrow p\pi^-$	**7.89**	**63.9**	**2.55**	**−0.14**
$\phi(s\bar{s}) \rightarrow K^+K^-$	$\mathbf{4.1 \cdot 10^{-12}}$	**48.9**	**2.9**	**−0.49**

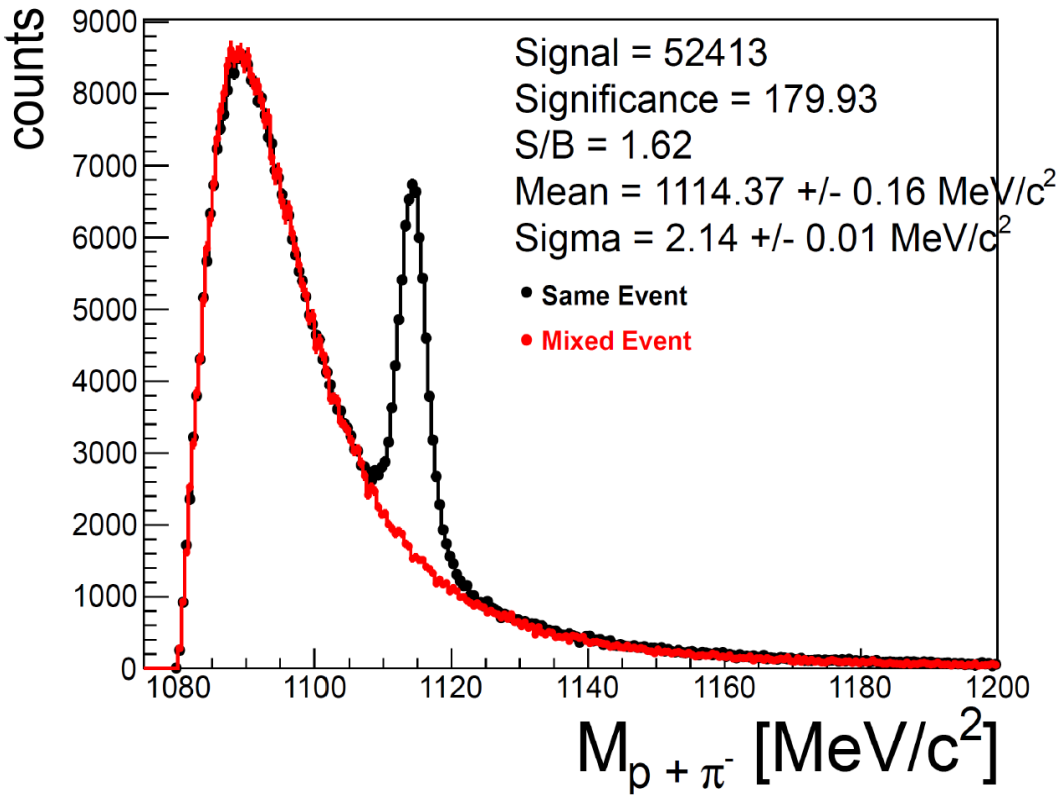
- reconstruction via invariant mass of charged particles
- long life-times allow for secondary vertex reconstruction
- Au-Au @ 1.23 AGeV: all strange particles produced below their NN threshold

Background Suppression

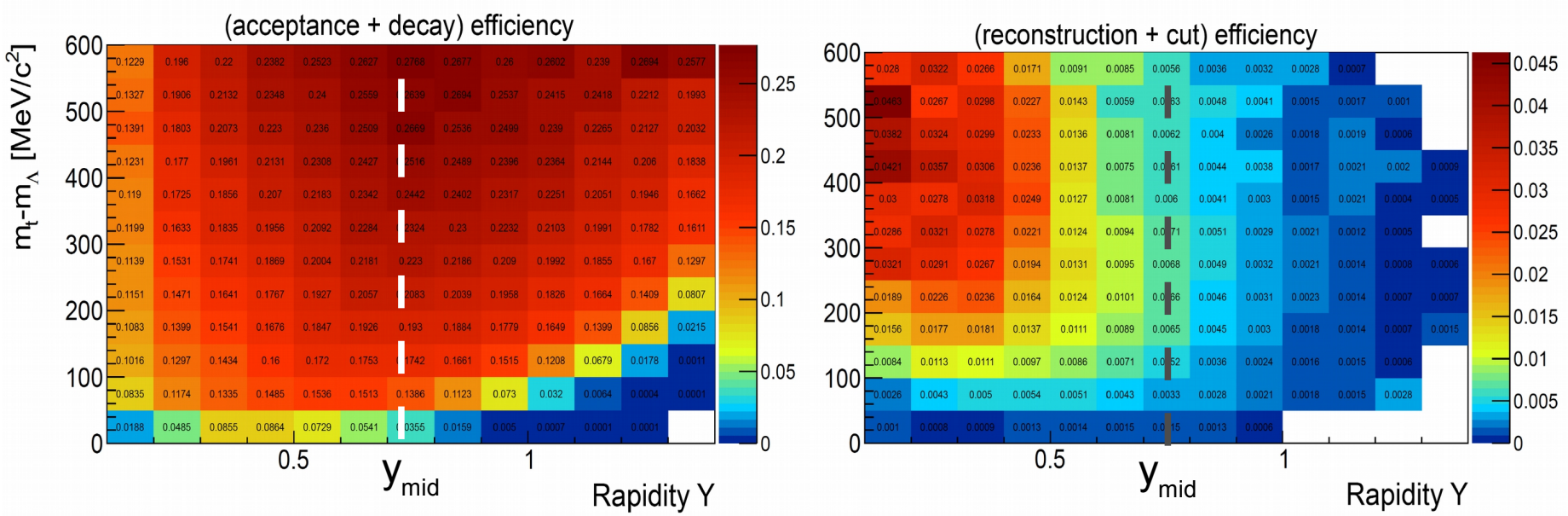


d_1: dist. primary particle track – prim. Vertex
d_v: dist. prim. vertex – decay vertex
d_2: min. dist. prim. vertex – daughter$_1$ track
d_3: min. dist. prim. vertex – daughter$_2$ track
d_t : distance of closest approach of daughter particles

Δβ: opening angle



- First observation of sub-threshold Λ production
- Background description via Mixed Event method
- Highly significant data sample comparable to Ar+KCl
- Sufficient statistics for differential analysis as a function of m_t and y

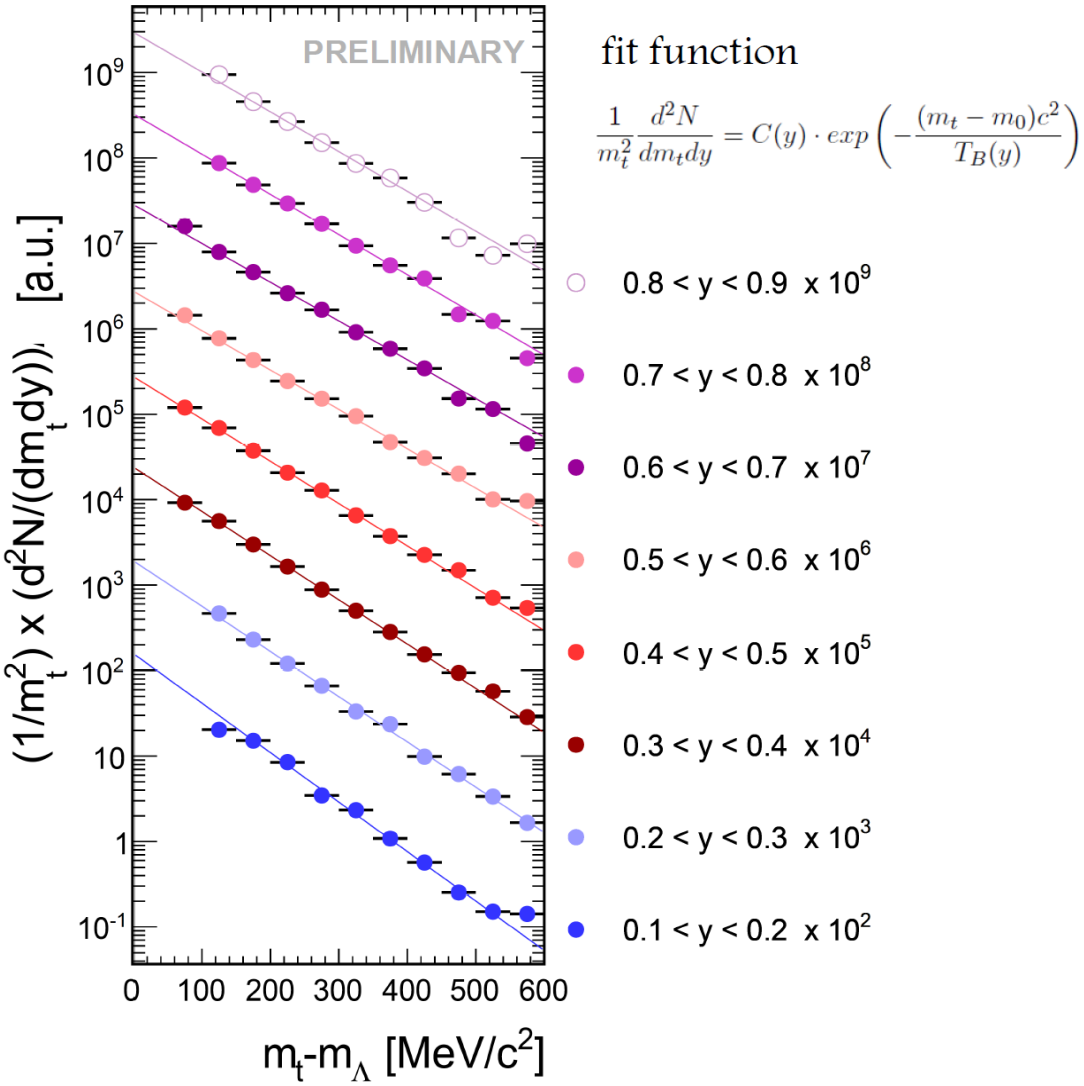


- Particles produced in Monte Carlo Simulation (Pluto) and propagated through GEANT
- Acceptance around 15-25%
- Reconstruction efficiency an order of magnitude lower due to strong off vertex constraints

Preliminary results in Au+Au at 1.23 AGeV...

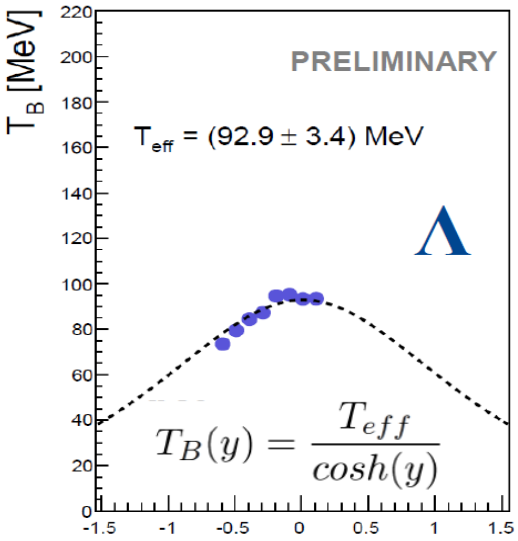
Differential Phase Space Analysis

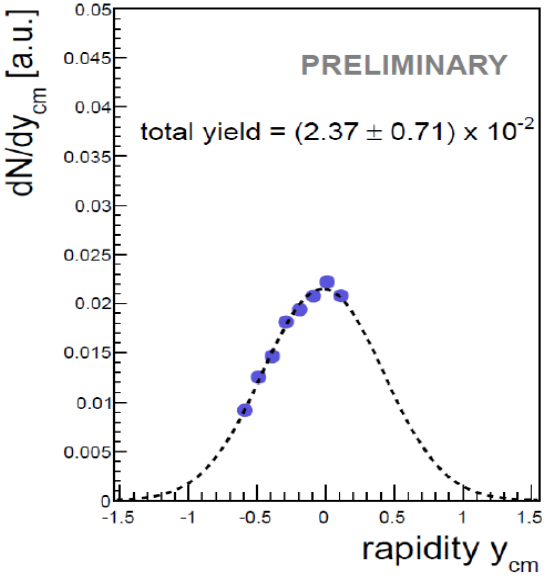
$\Lambda \rightarrow p+\pi^-$

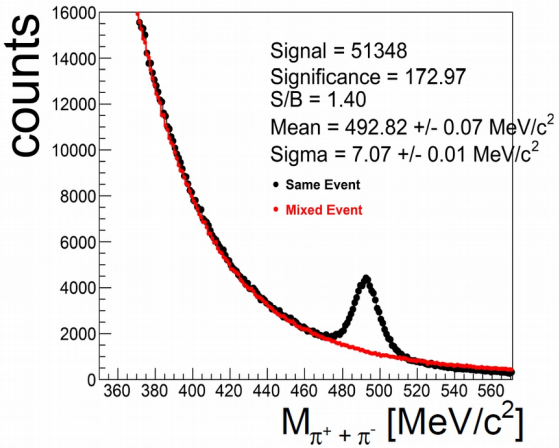


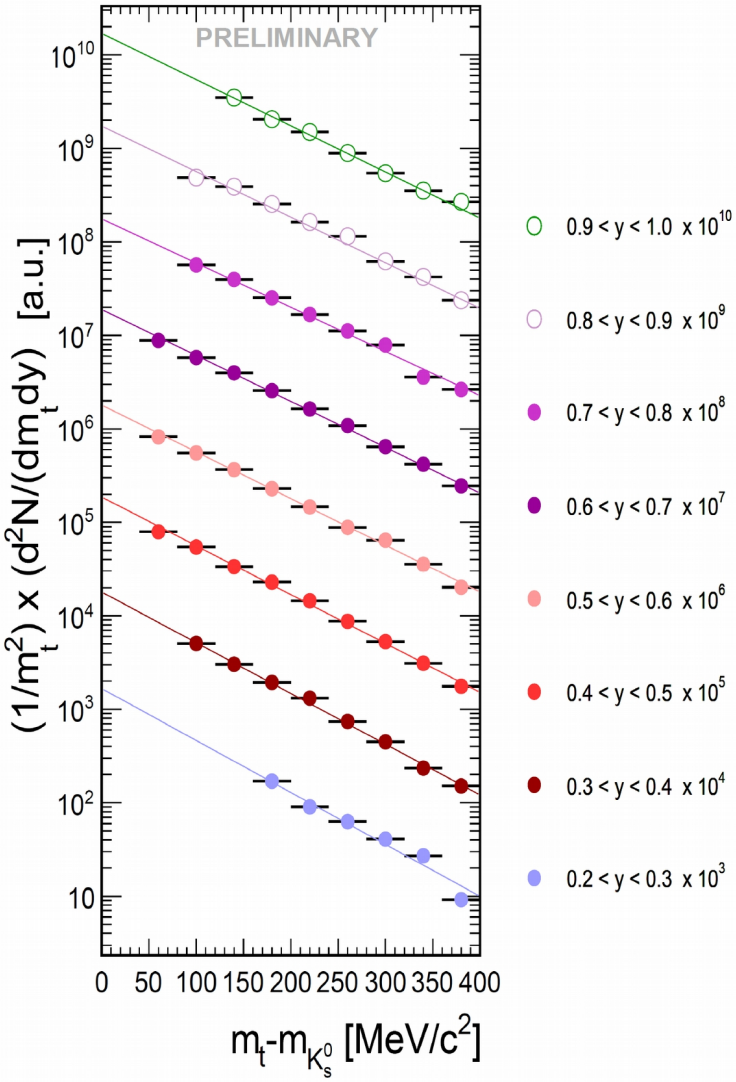
fit function

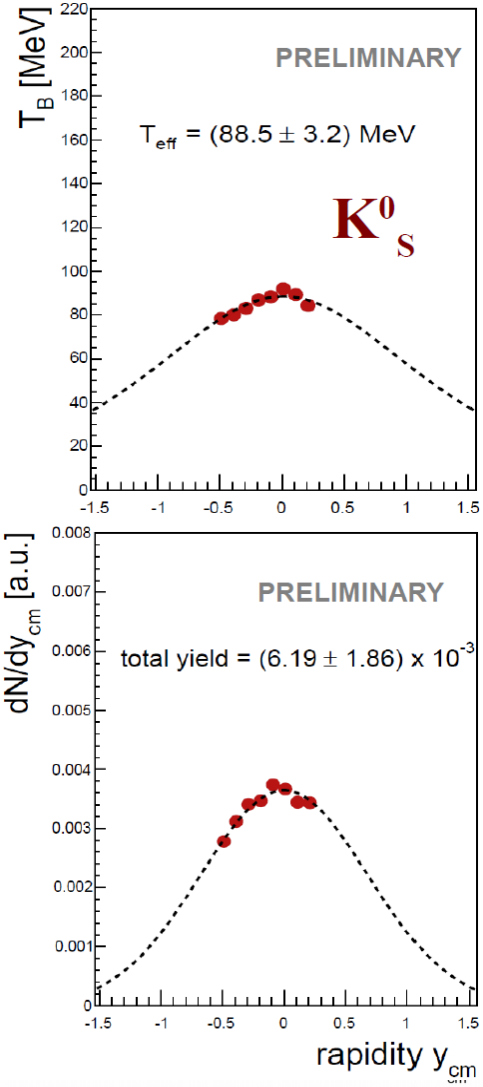
$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dy} = C(y) \cdot exp\left(-\frac{(m_t - m_0)c^2}{T_B(y)}\right)$$

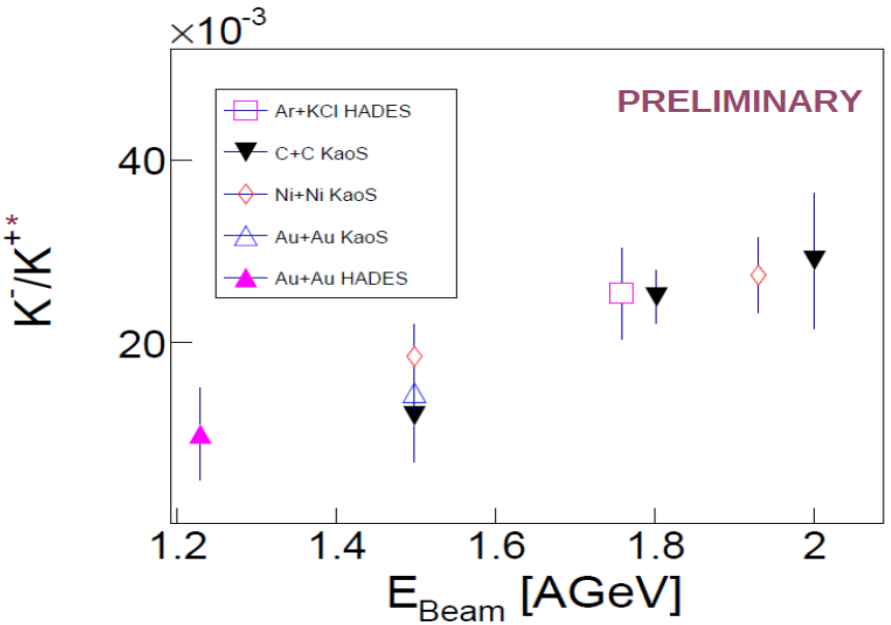


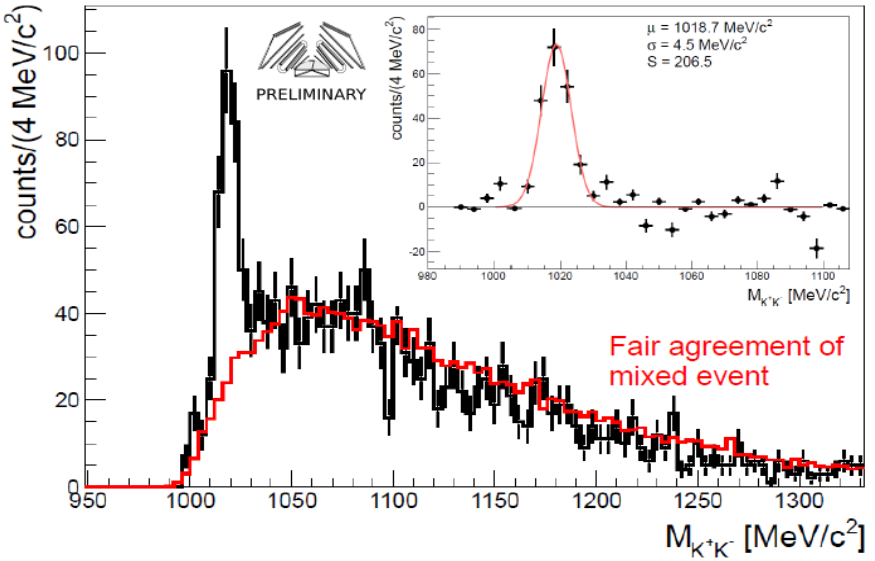



counts
Signal = 51348
Significance = 172.97
S/B = 1.40
Mean = 492.82 +/- 0.07 MeV/c²
Sigma = 7.07 +/- 0.01 MeV/c²
Same Event
Mixed Event
M π⁺ + π⁻ [MeV/c²]


PRELIMINARY
(1/m_t²) x (d²N/(dm_t dy)) [a.u.]
m_t-m_K⁰s [MeV/c²]
0.9 < y < 1.0 x 10¹⁰
0.8 < y < 0.9 x 10⁹
0.7 < y < 0.8 x 10⁸
0.6 < y < 0.7 x 10⁷
0.5 < y < 0.6 x 10⁶
0.4 < y < 0.5 x 10⁵
0.3 < y < 0.4 x 10⁴
0.2 < y < 0.3 x 10³


PRELIMINARY
T_B [MeV]
T_eff = (88.5 ± 3.2) MeV
K⁰S
PRELIMINARY
dN/dy_cm [a.u.]
total yield = (6.19 ± 1.86) x 10⁻³
rapidity y_cm

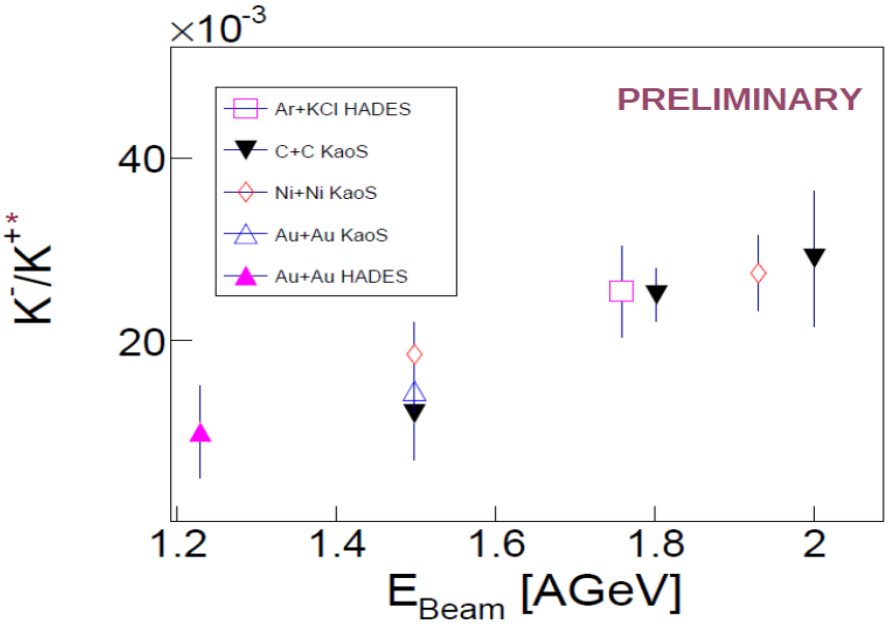


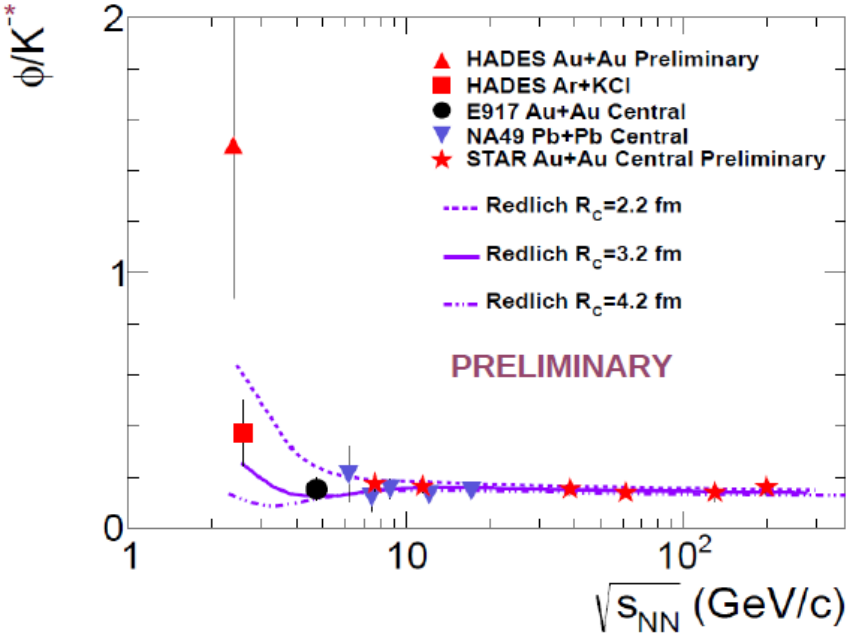


PhD Thesis H. Schuldes

- Charged Kaon production fits to trend indicated by previous data
- ϕ meson nicely reconstructed via $K^+ + K^-$ decay channel

* yields are calculated for midrapidity

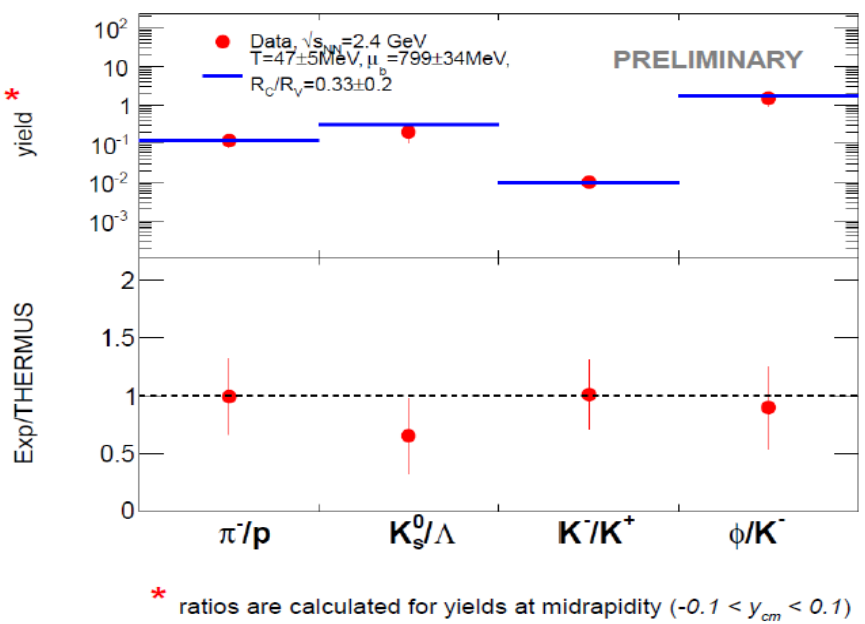


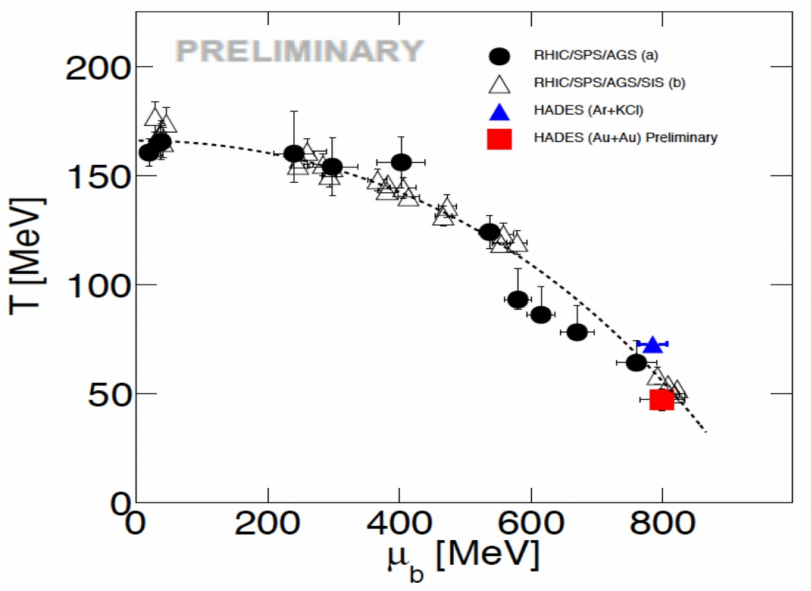


- Charged Kaon production fits to trend indicated by previous data
- ϕ meson nicely reconstructed via $K^+ + K^-$ decay channel
- preliminary ϕ to K^- ratio shows strong increase towards lower beam energies

* yields are calculated for midrapidity

Statistical Model Fit in Au+Au





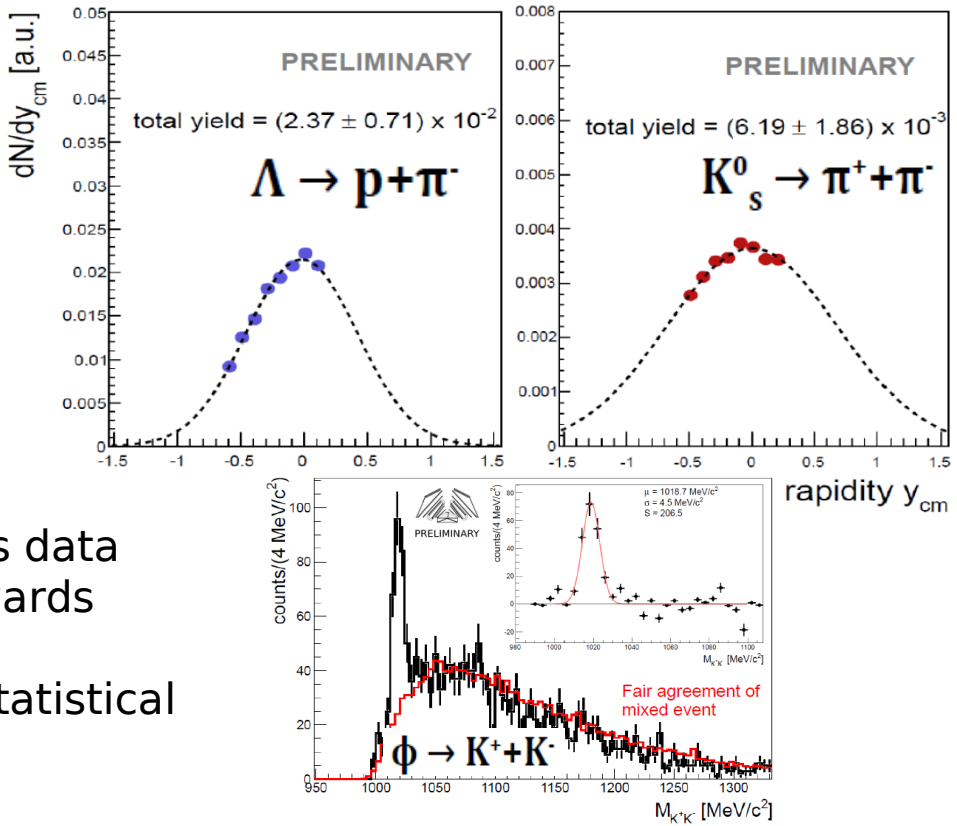
Dr. M. Lorenz

- First attempt of statistical model fit gives reasonable values:

$T = 47 \pm 5$ MeV
$\mu_B = 799 \pm 34$ MeV
$R_C/R_V = 0.3 \pm 0.2$

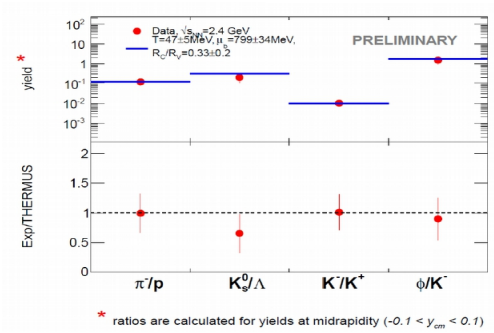
Summary

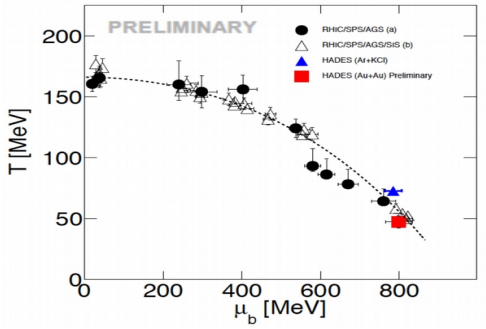
- Successful Au+Au run with HADES with high precision
- High statistic data sample allows for differential analysis in terms of m_t – y
- Preliminary corrected m_t, dN/dy, T_B spectra for Λ and K^0_S
- K^+ and K^- yields fit trend of previous data
- ϕ to K^- ratio strongly increasing towards decreasing energies
- Preliminary ratios consistent with statistical hadronization model



Outlook

- Finalizing results (systematics)
- Search for deep subthreshold particle states

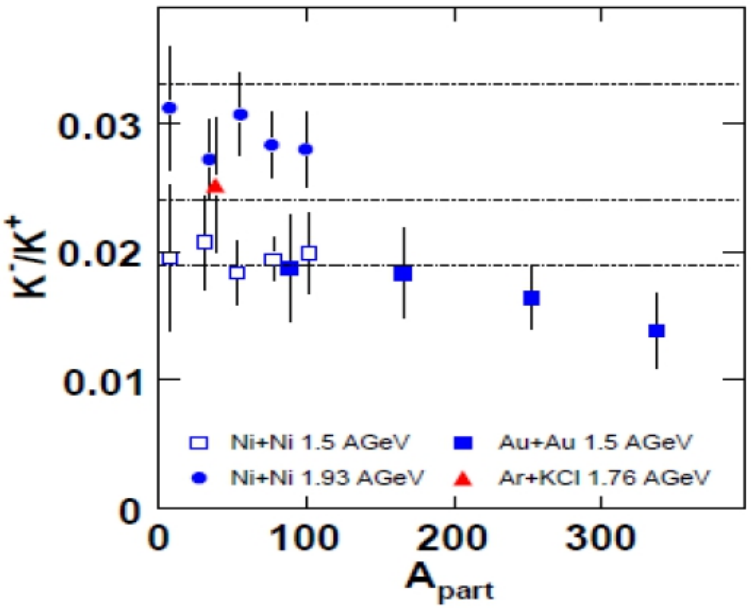


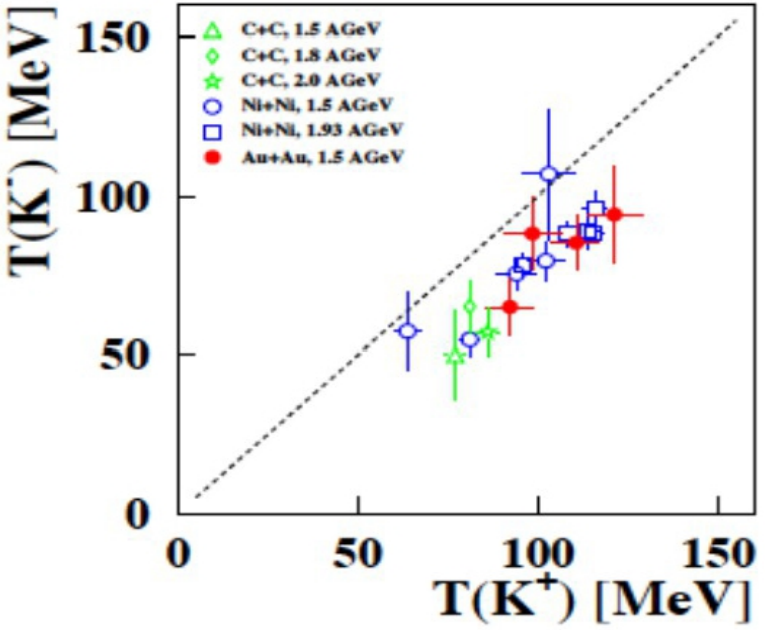


HADES Collaboration

Backup...

Strangeness Production @ SIS Energies





G. Agakishiev et al., Phys.Rev. C 80 : 025209

- Ratio K^-/K^+ hardly dependent on centrality → coupled production
- Inverse slope parameter T_{eff} of K^- systematically below the one of K^+

→ Strangeness exchange dominant

Strangeness Production @ SIS Energies

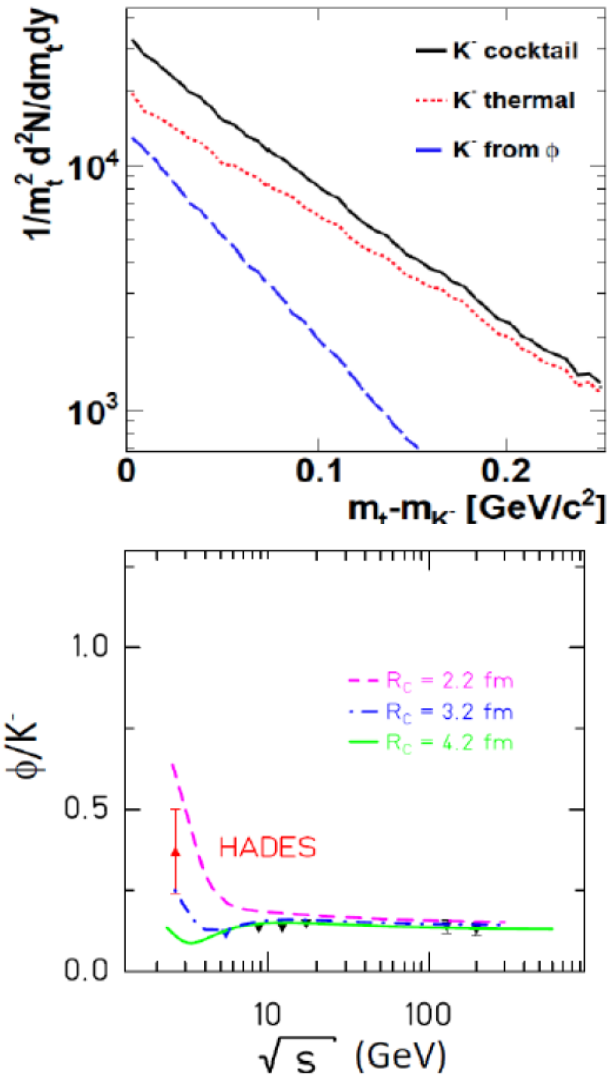
- HADES provided first consistent measurement of K^+, K^- and ϕ (Ar+KCl @ 1.76 AGeV)
- Consideration of ϕ decay feeding the K^- yield ($\phi \rightarrow K^+ + K^-$)
- Significant contribution: $\phi / K^- = 0.3$

→ Feed-down explains difference in freeze-out temperature between K^+ and K^-

- Comparison to statistical model predictions and data at higher energies

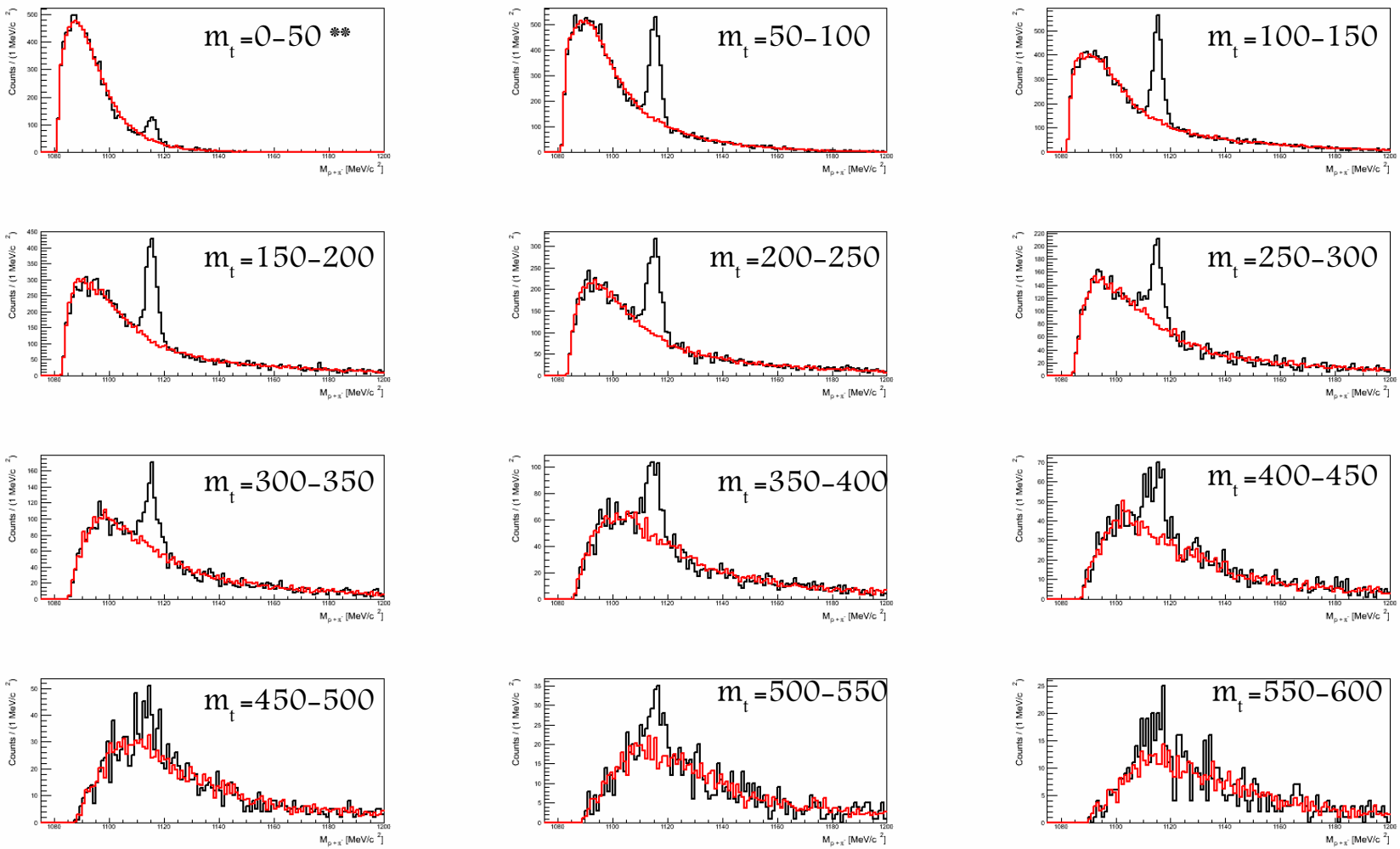
→ Which trend do we observe towards lower energies (Au+Au @ 1.23 AGeV) ?

G. Agakishiev et al., Phys.Rev. C 80 : 025209



Differential Phase Space Analysis (*e.g. 0.7 < y < 0.8*)

$\Lambda \rightarrow p\pi^-$



** in [MeV/c²]

data

mixed event

Differential Phase Space Analysis (*e.g. 0.7 < y < 0.8*)

$\Lambda \rightarrow p\pi^-$