Measurements of strangeness with HADES

Manuel Lorenz
for the collaboration

EMMI Workshop, CERN 2015

Alexander von Humboldt Stiftung/Foundation
GOETHE UNIVERSITÄT FRANKFURT AM MAIN
University of Utrecht

Outline

Resonances and References

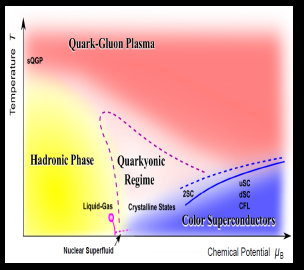
Strangeness production close to threshold (common wisdom)

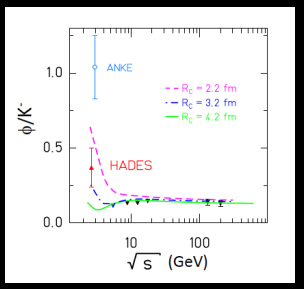
K^- production a closer look: Φ/K^-

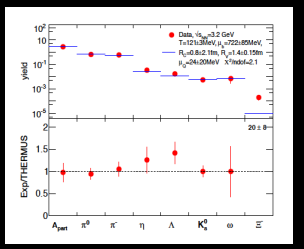
The statistical model

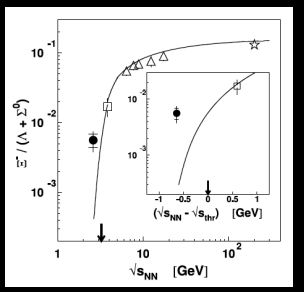
Ξ^- production: Do resonances strike again?

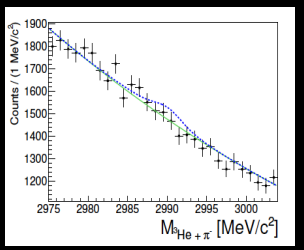
Hyper-matter search with HADES











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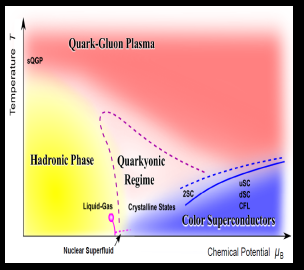
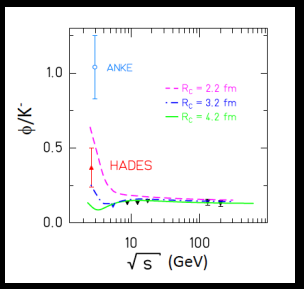
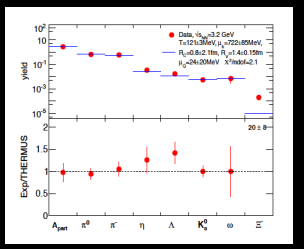
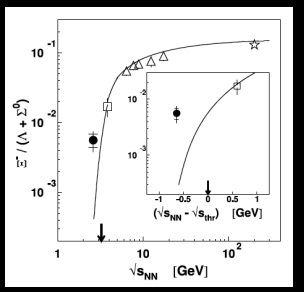
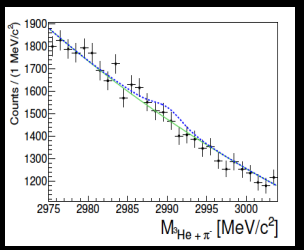


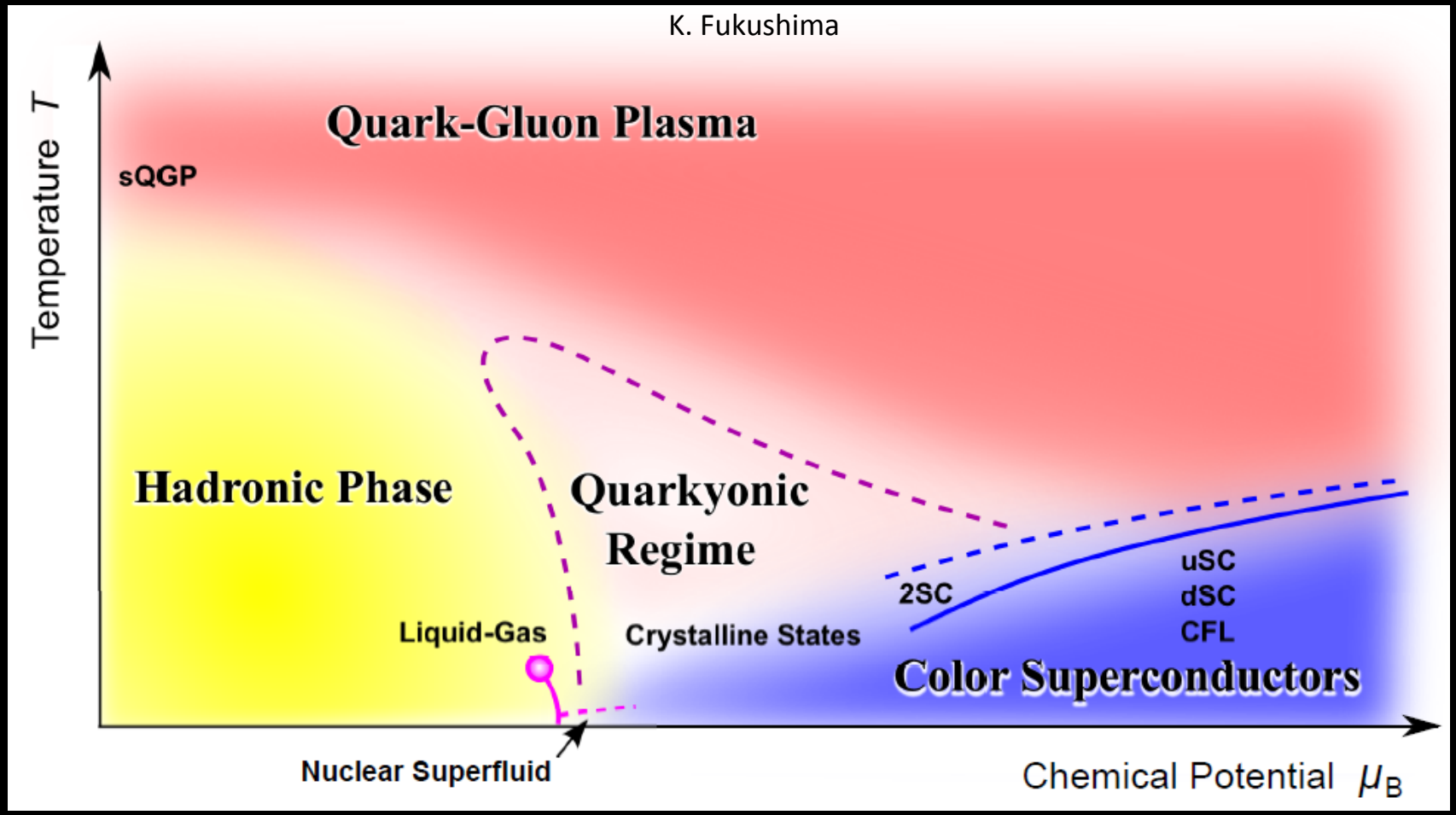








Heavy-ion collisions and QCD phase diagram



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

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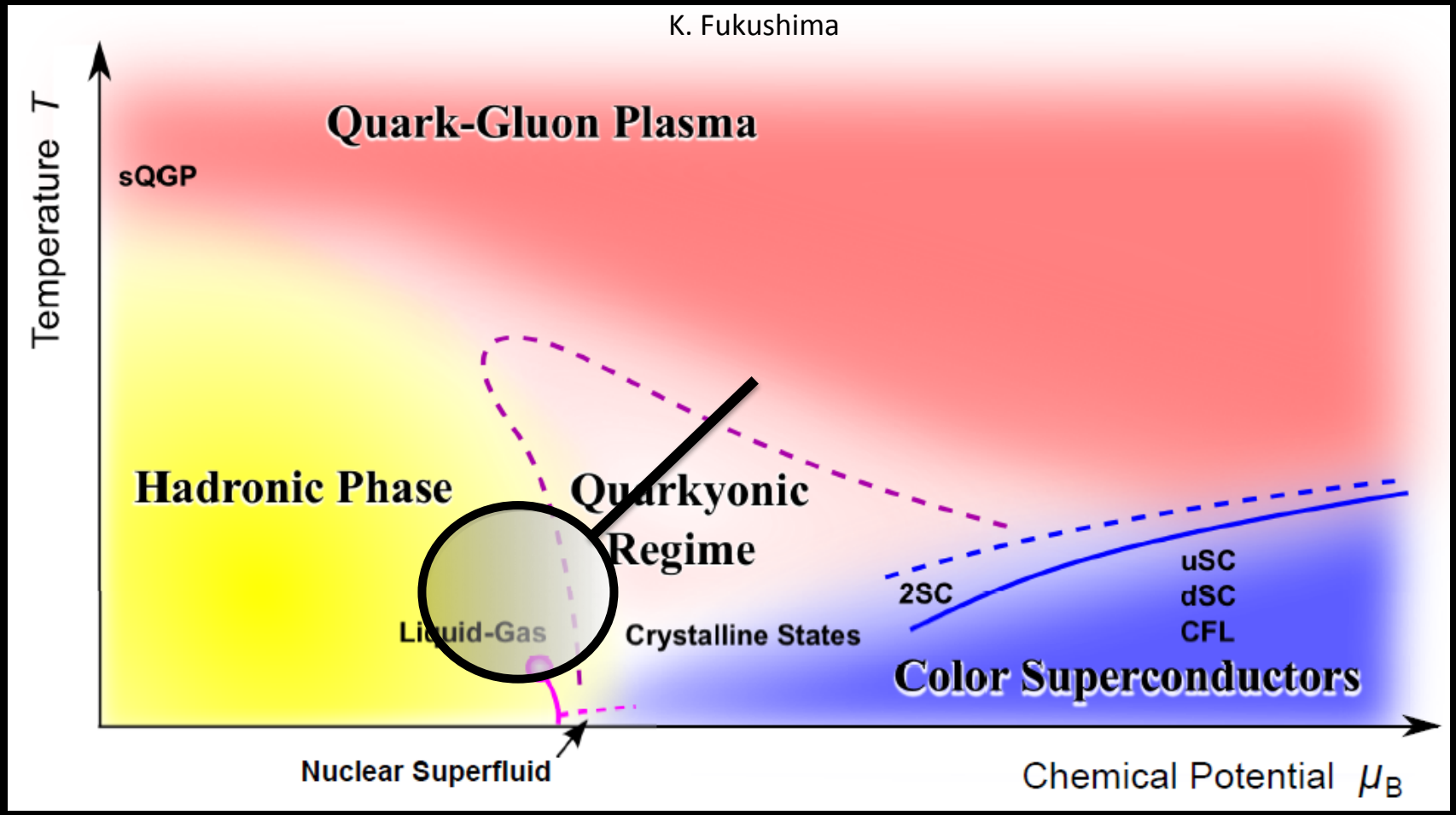

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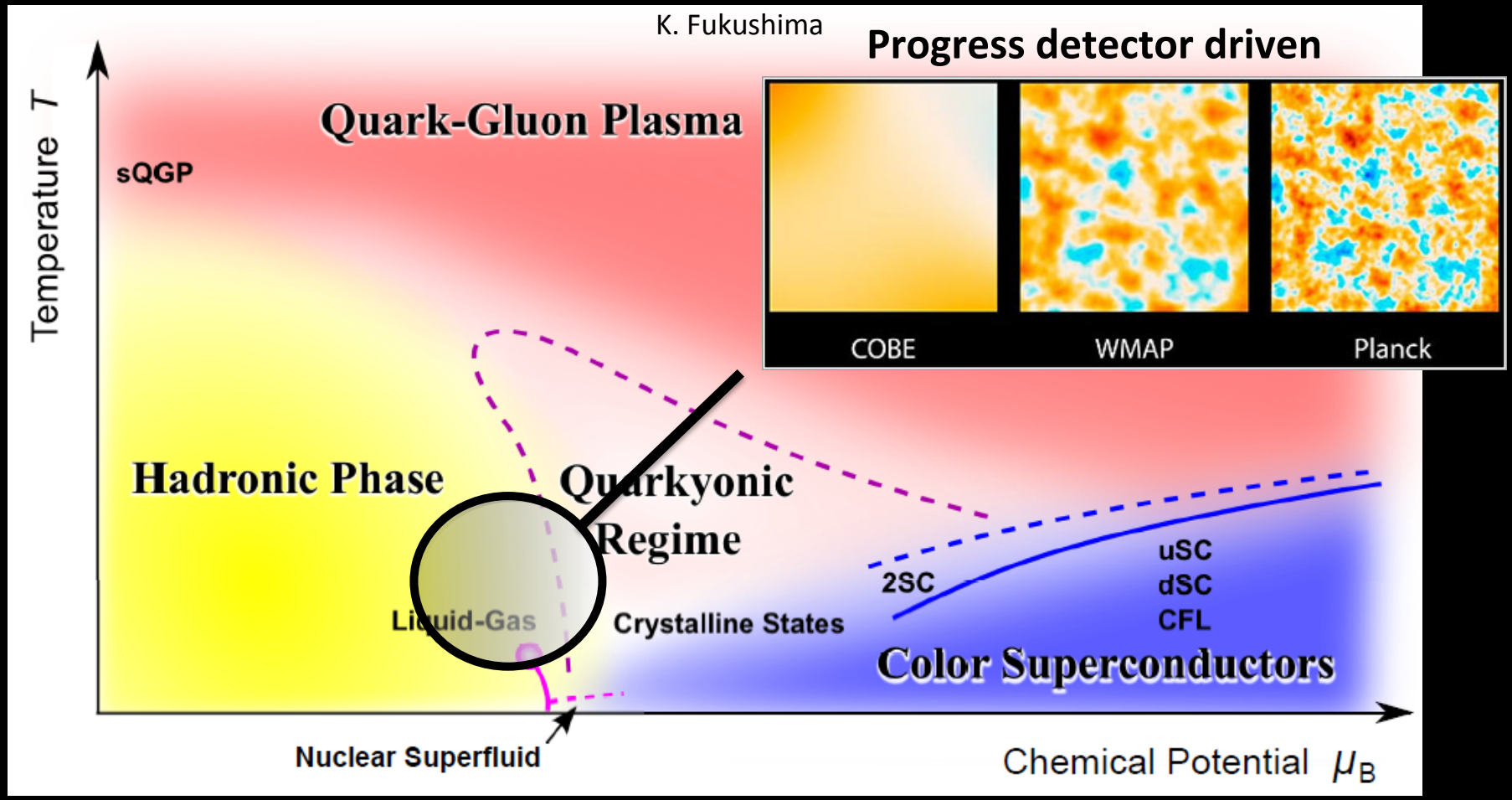
Probe baryonic interactions at low energies



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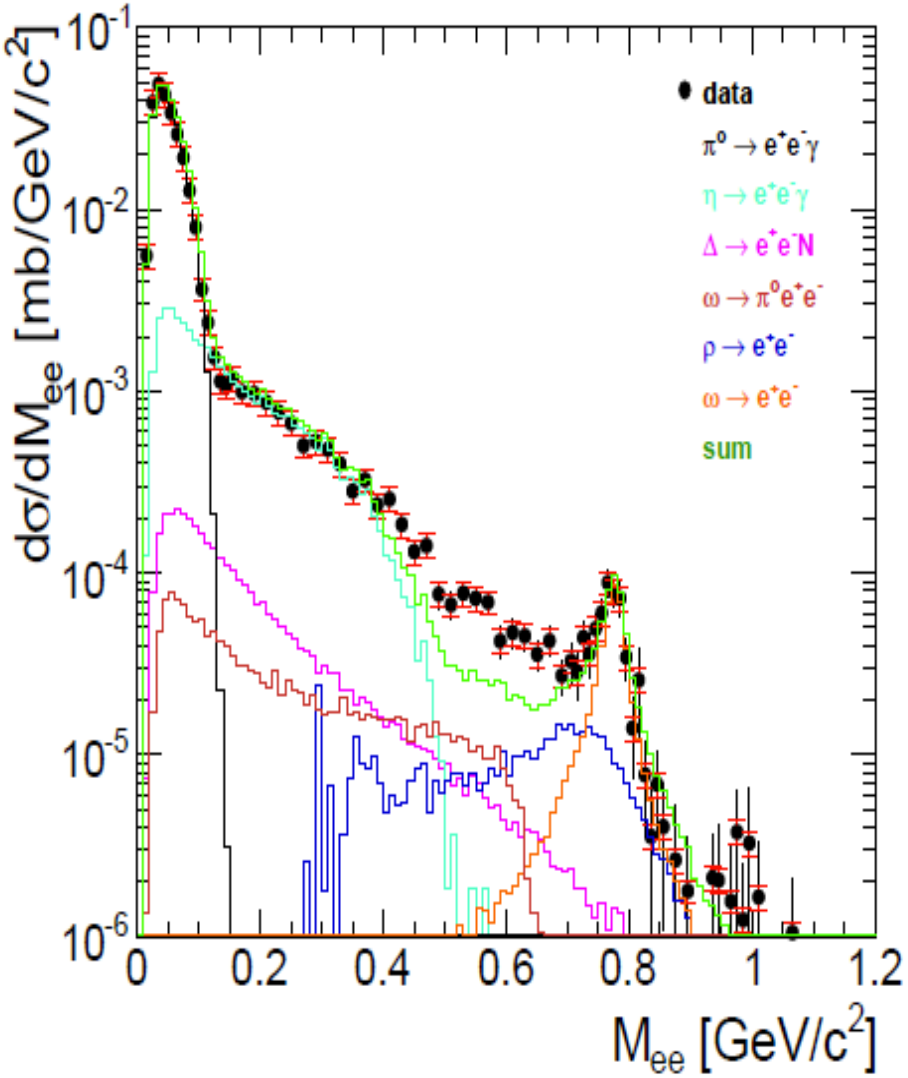
Resonance contribution to dilepton yield



Eur.Phys.J. A48 (2012) 64

Excess in the ρ-region
ρ production via baryonic resonances:
enhanced population below ρ pole mass
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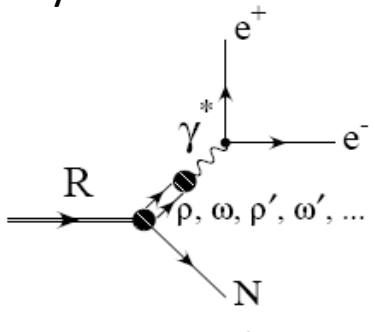
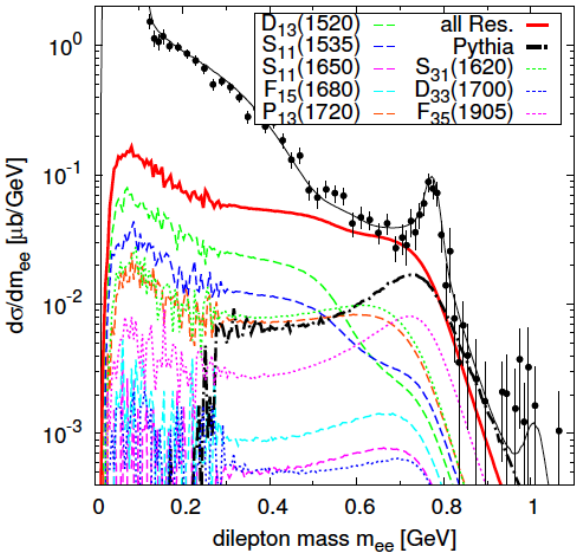


$\rho \to e^+e^-$



GiBUU simulation: J. Weil et al, EPJA48 (2012) 111

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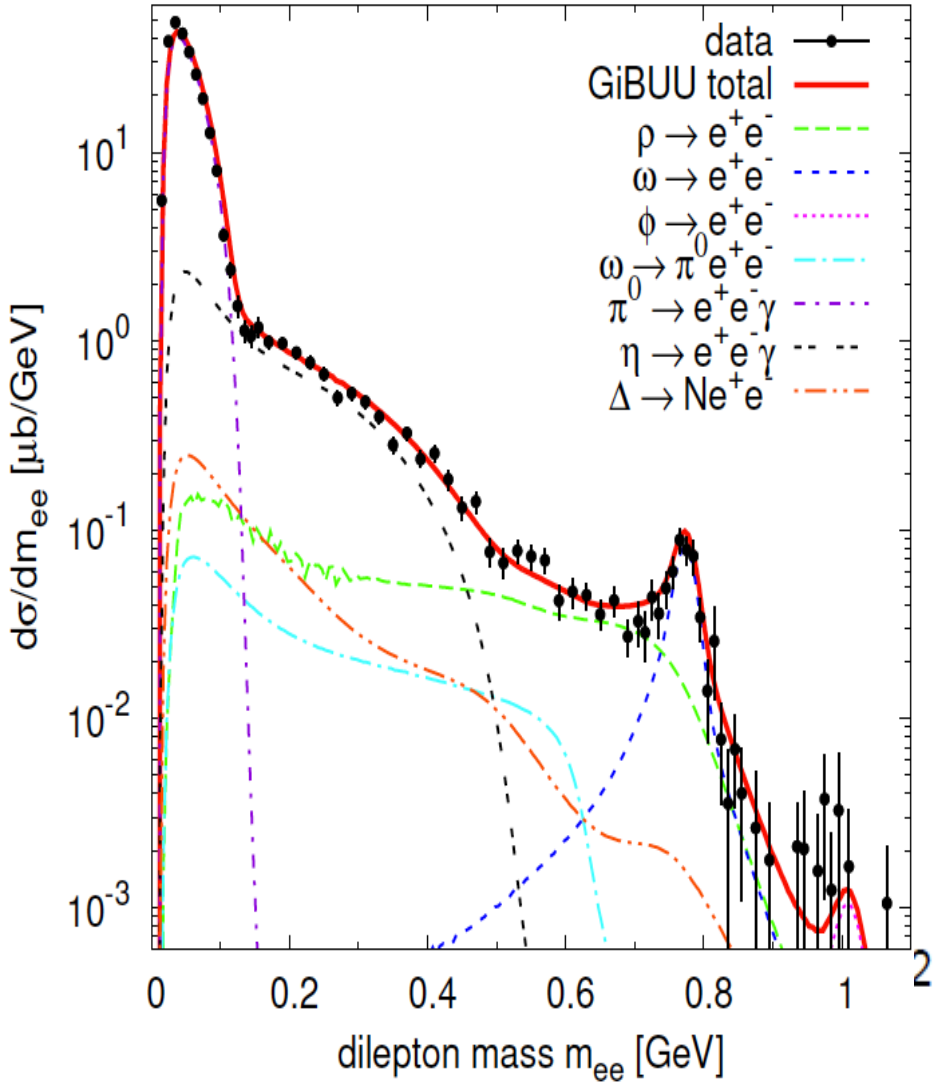

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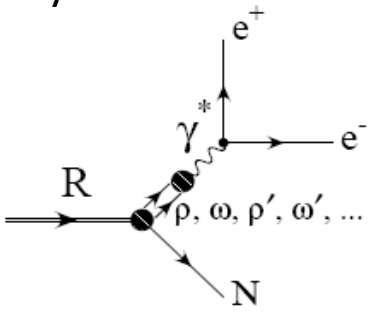

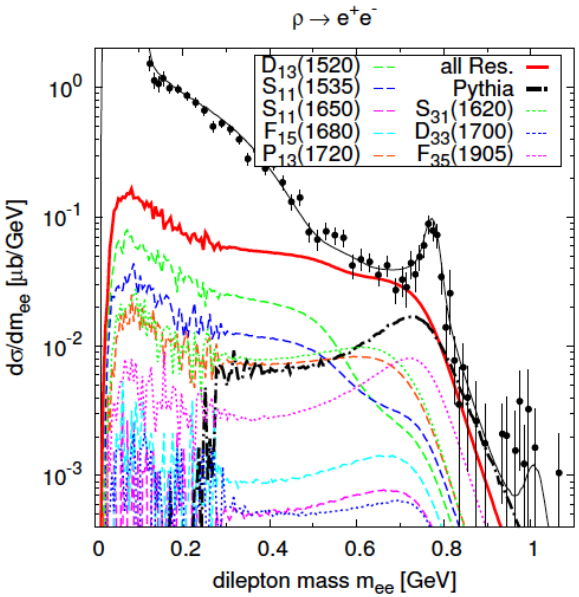

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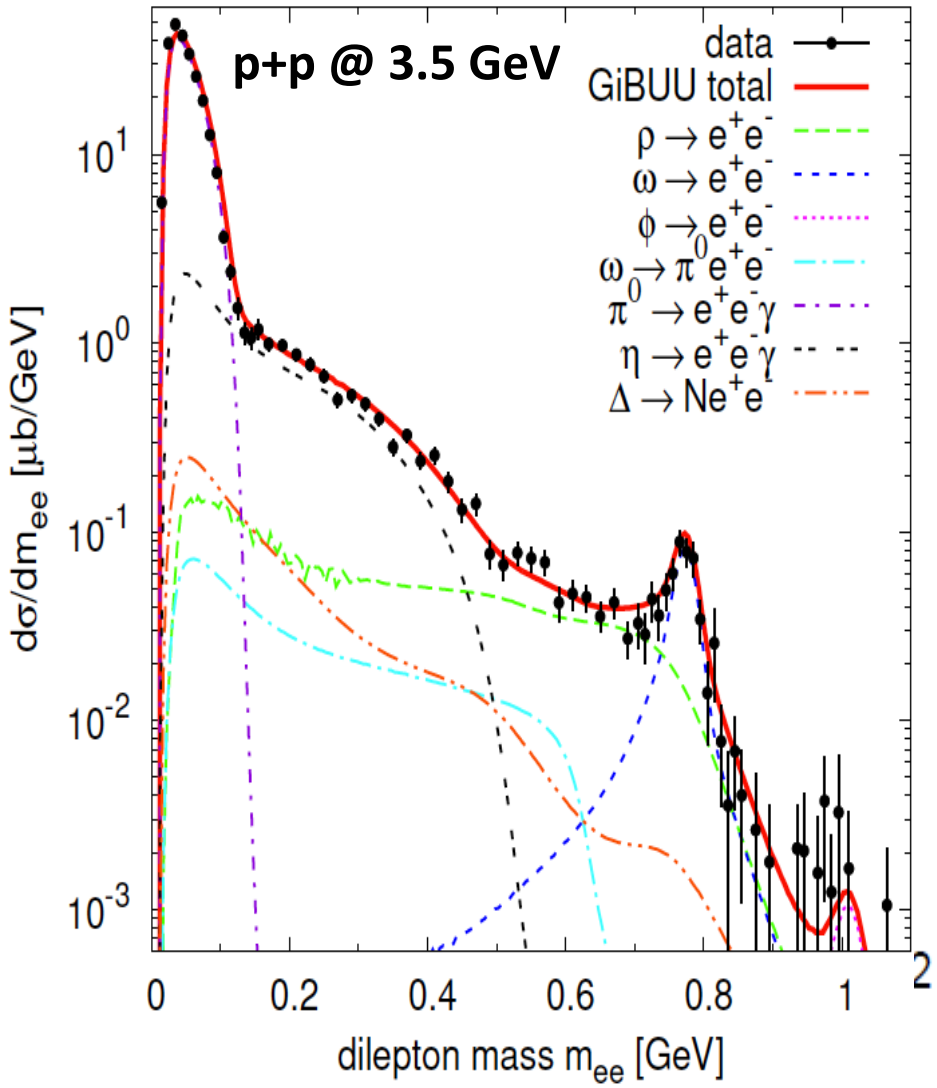

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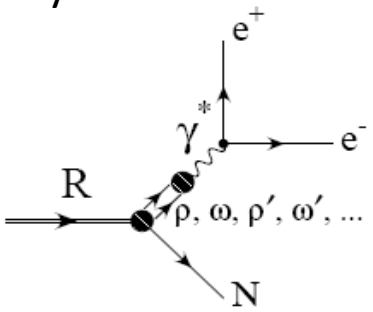

Lessons:

Resonance contributions changes spectral shape (and yield)

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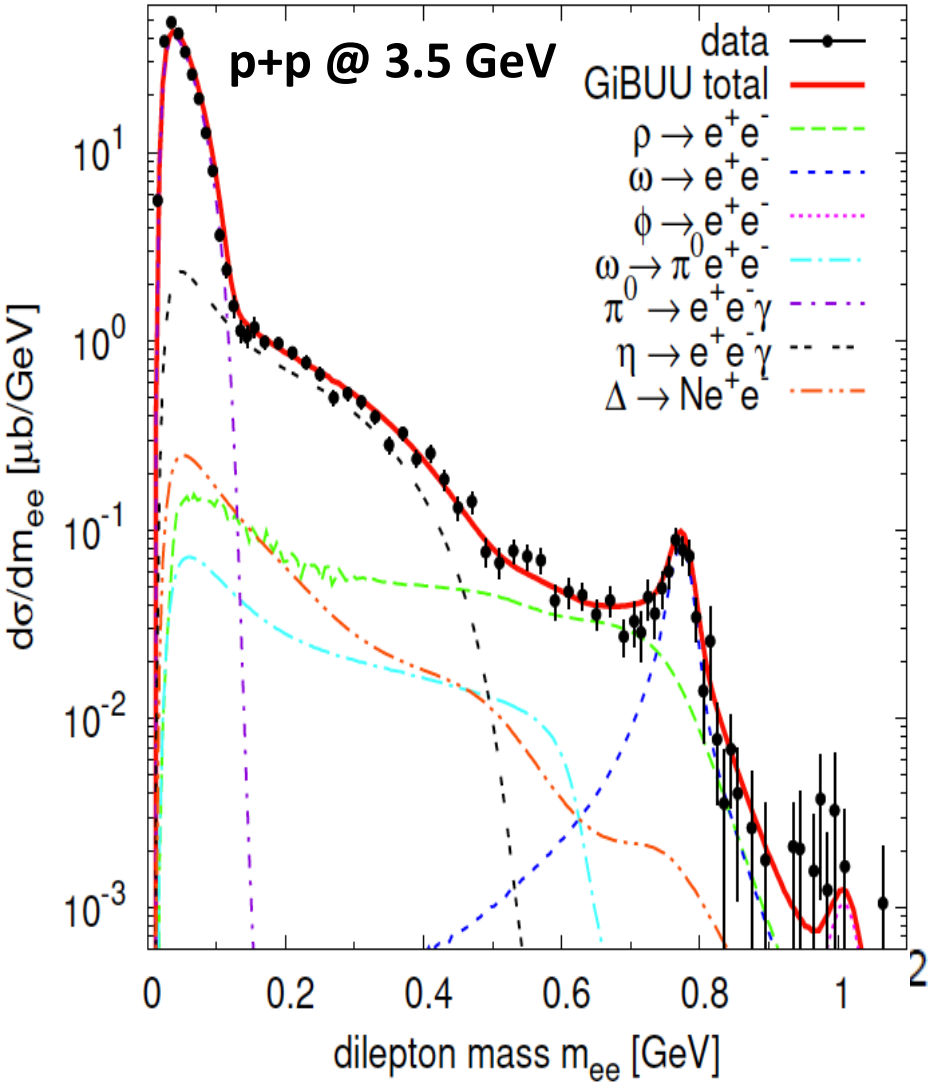

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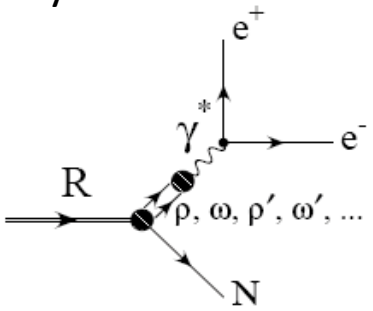

Lessons:

Resonance contributions changes spectral shape (and yield)

Know your reference!

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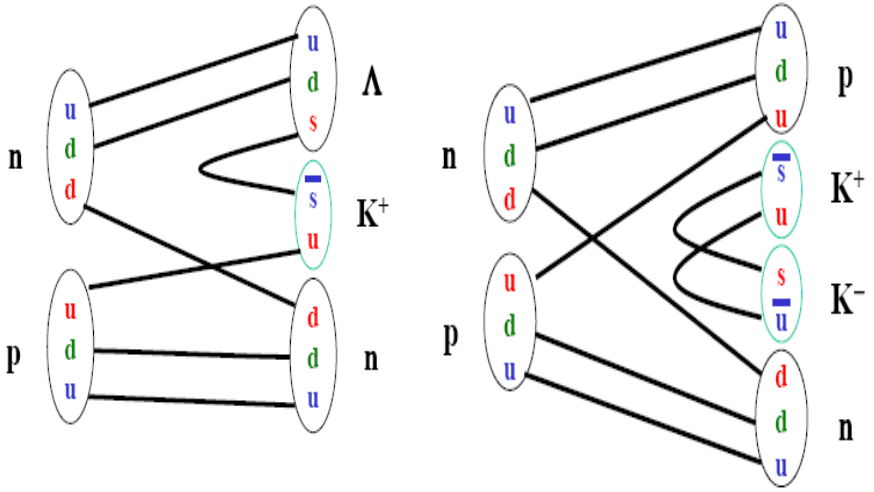
Strangeness production at SIS 18

Elementary collisions

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

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

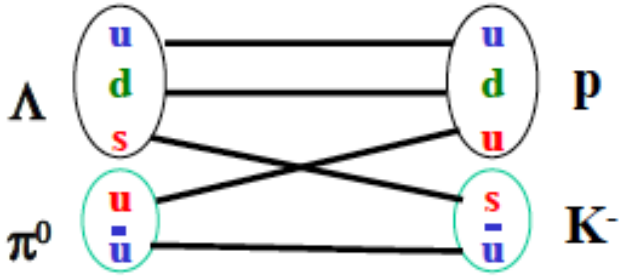
$$NN \rightarrow NN\varphi \qquad (E_{thr} = 2.59\,GeV)$$



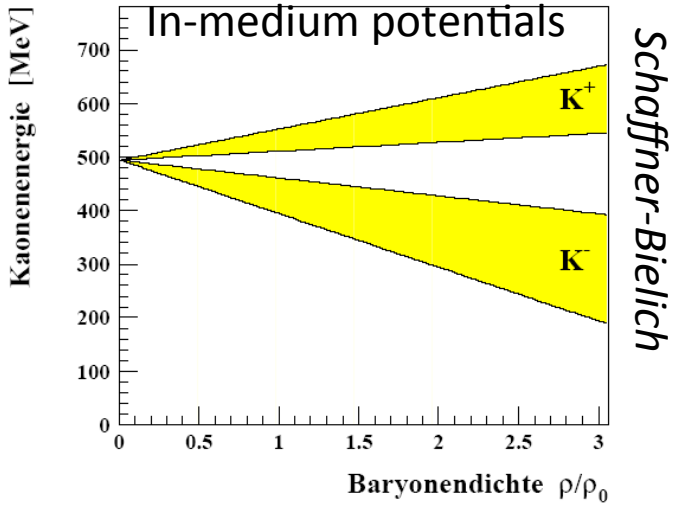
Different production thresholds for K^{+-} due to quark content

Heavy-ion collisions

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

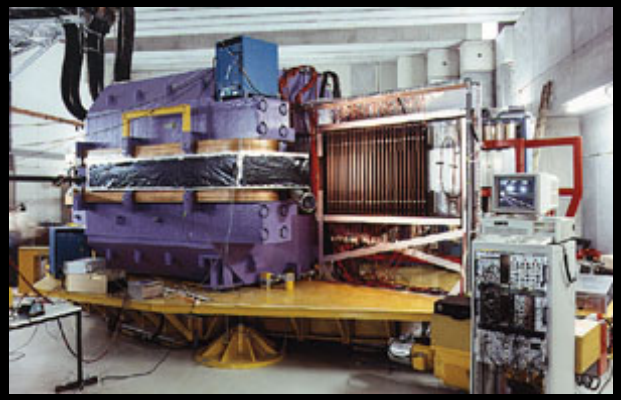


endothermal in vacuum!

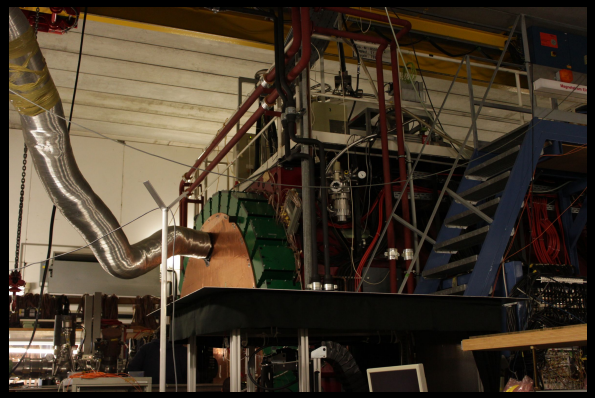


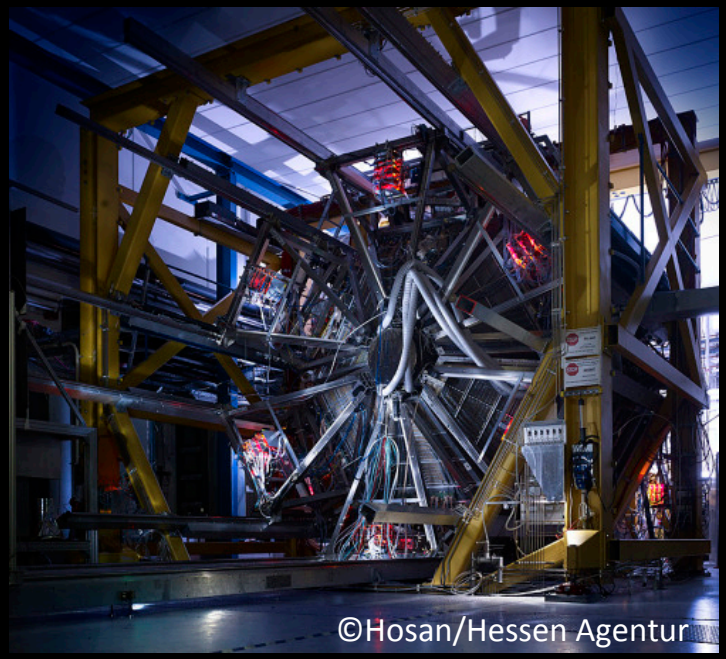
Main players at SIS18

KaoS decommissioned



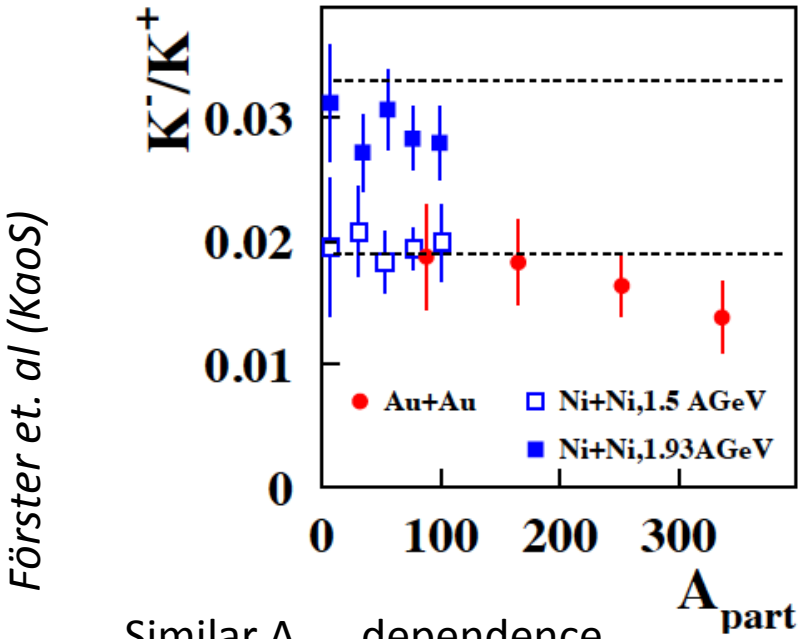
FOPI decommissioned



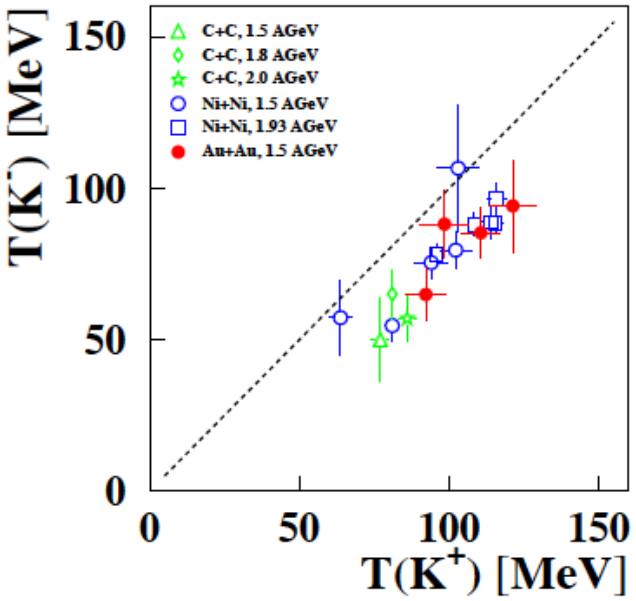


HADES active at SIS18 and SIS100

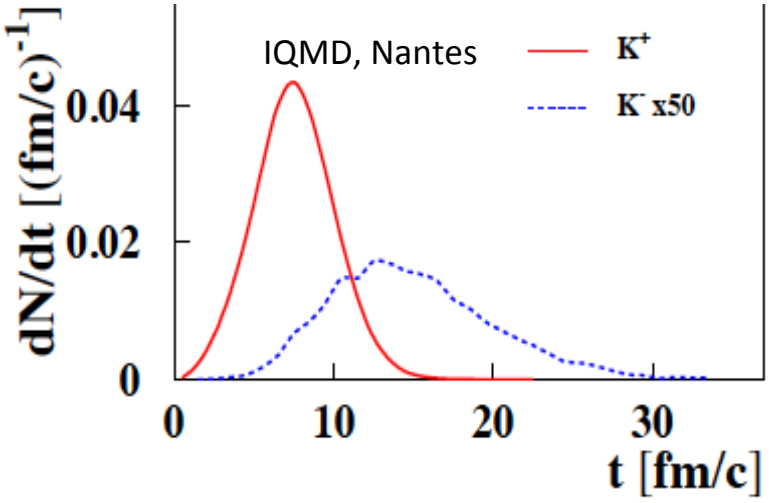
Strangeness production (common wisdom)



Similar A_{part} dependence



Different inverse slope parameters



Conclusions:

- Production of K^+/K^- coupled

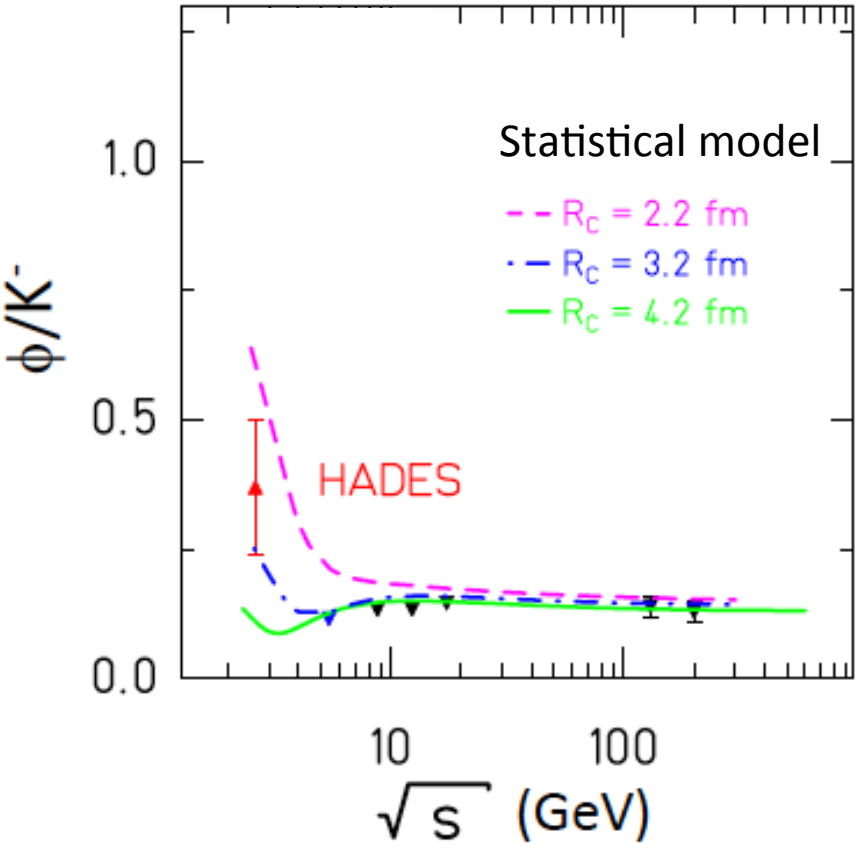
  "Strangeness exchange dominant for K^-"

  "Later freeze-out of K^- compared to K^+, due to coupling to baryons"

  "Strangeness production in HIC is very different from that in elementary interaction"

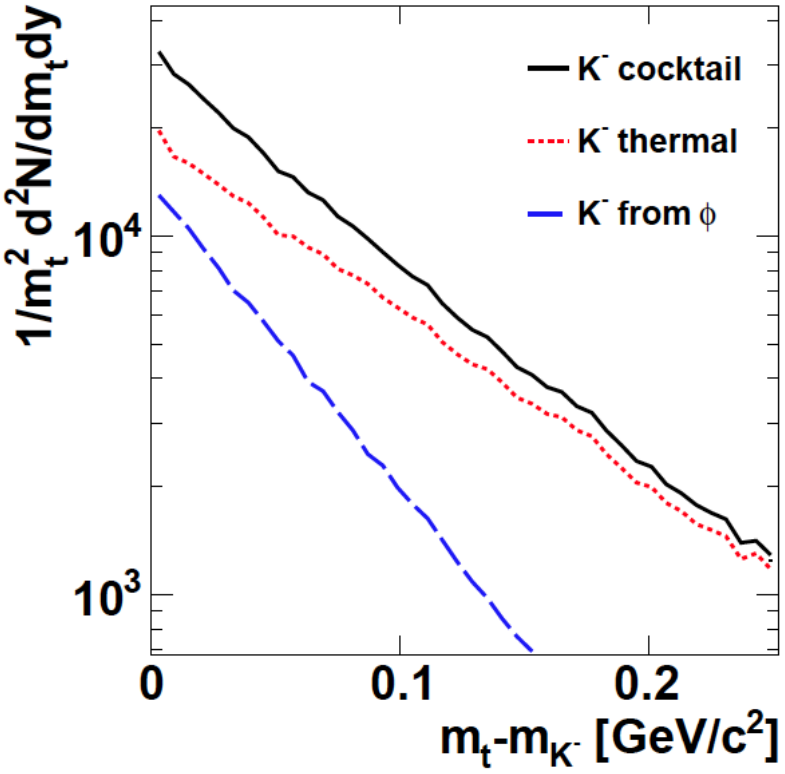
K^- production a closer look: Φ/K^-

Enhanced Φ production at low beam energy
First indication from FOPI



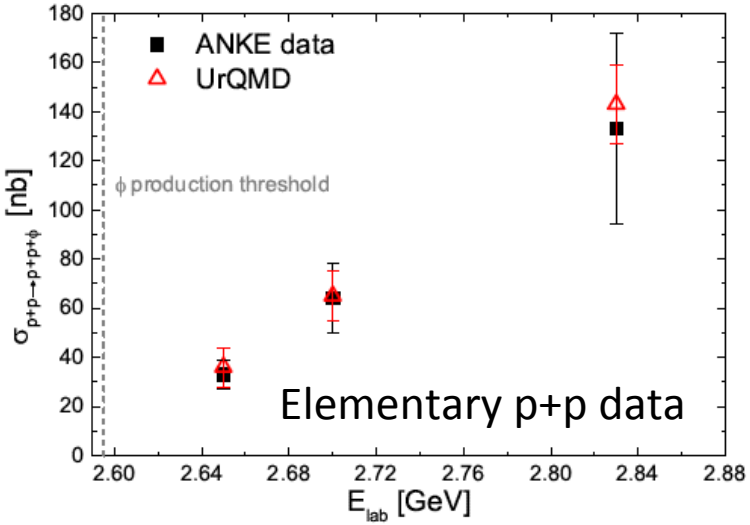
Predicted by stat. model

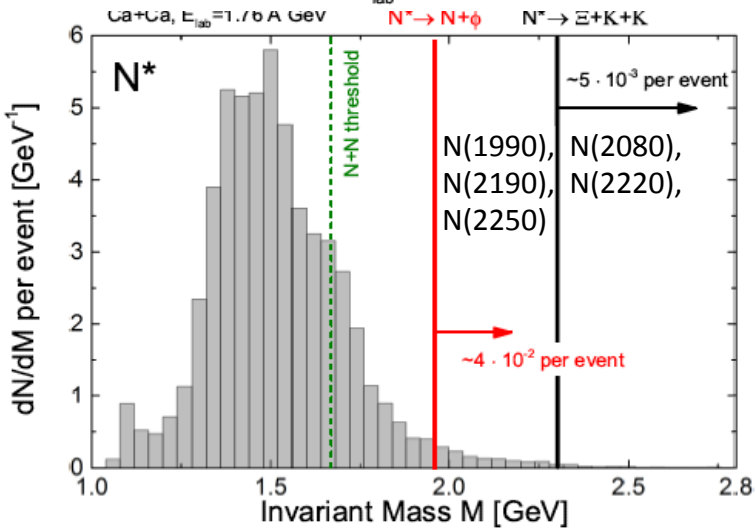
Feed-down of Φ can explain
different slope parameters of K^+ and K^-



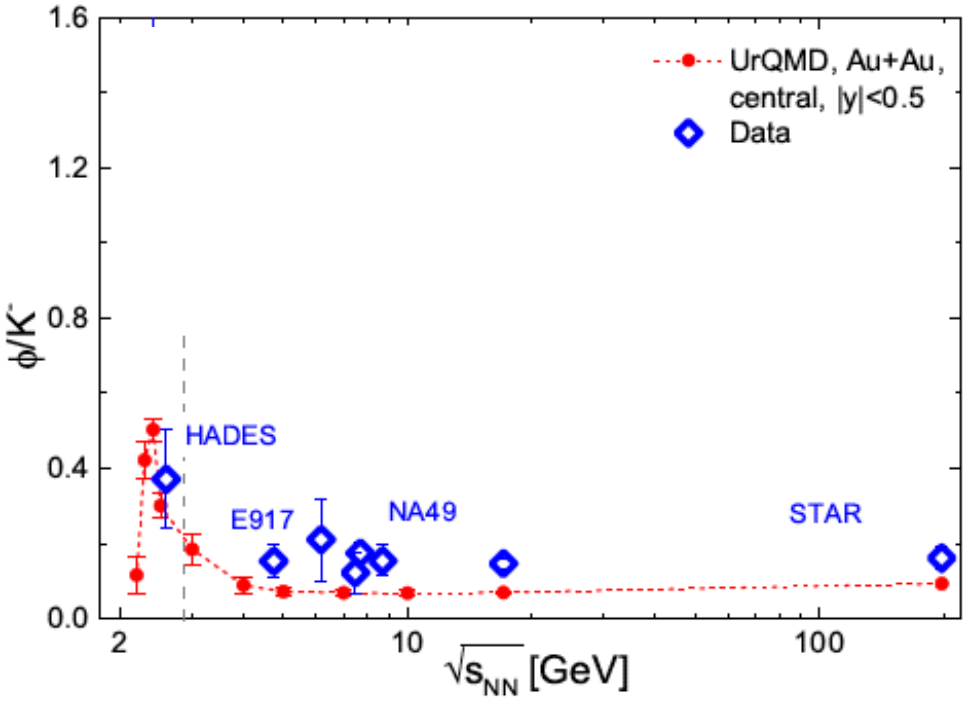
See also new data from FOPI in:
Phys.Rev. C91 (2015) 5, 054904

K^- production a closer look: UrQMD tuned





Tuned to match elementary data by increased branching ratios of N* (needed in the tails of the resonances, consistent with OZI rule)



Φ/K^- described in Ar+KCl

Resonances and References!

Steinheimer, Bleicher, arXiv:1503.07305

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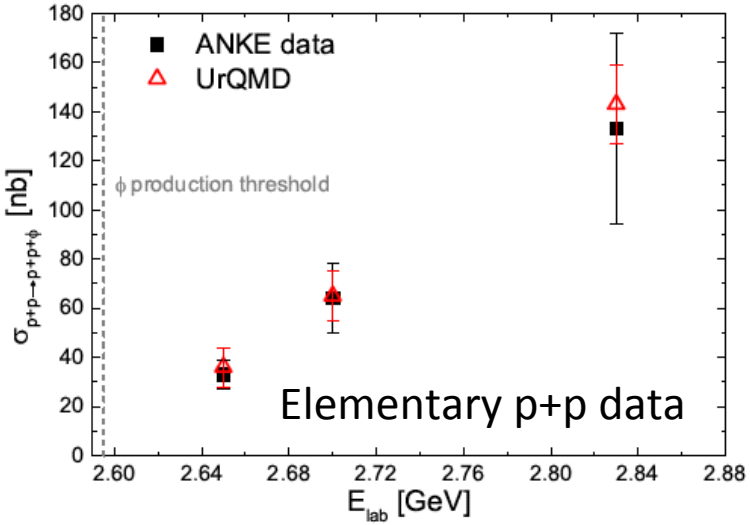

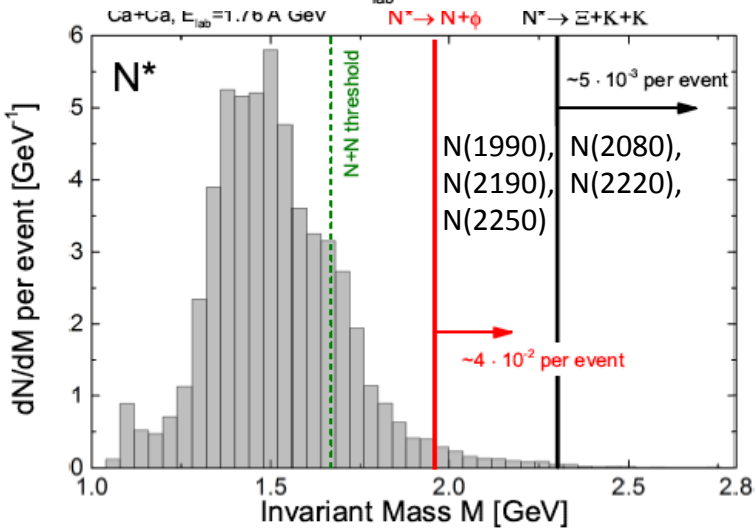

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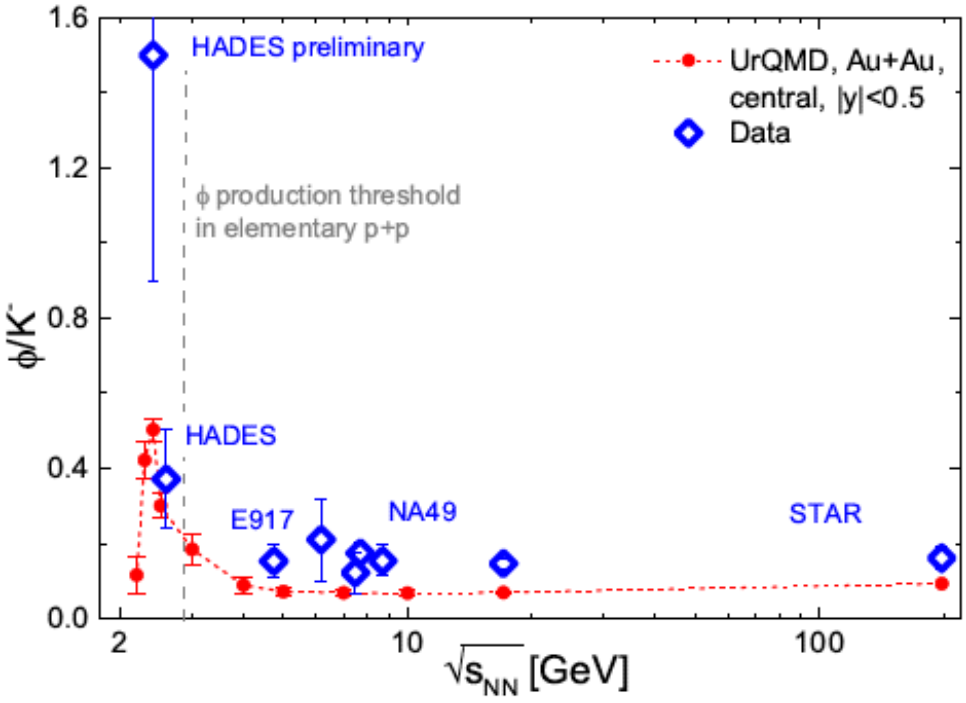

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Resonances and References!

Au+Au@1.23 data:

Larger system, smaller energy

Φ/K^- predicted to rise by stat. model

Complete production of strangeness below NN-threshold

Preliminary ratio at mid-rapidity, PhD H. Schuldes

Steinheimer, Bleicher, arXiv:1503.07305

Statistical model

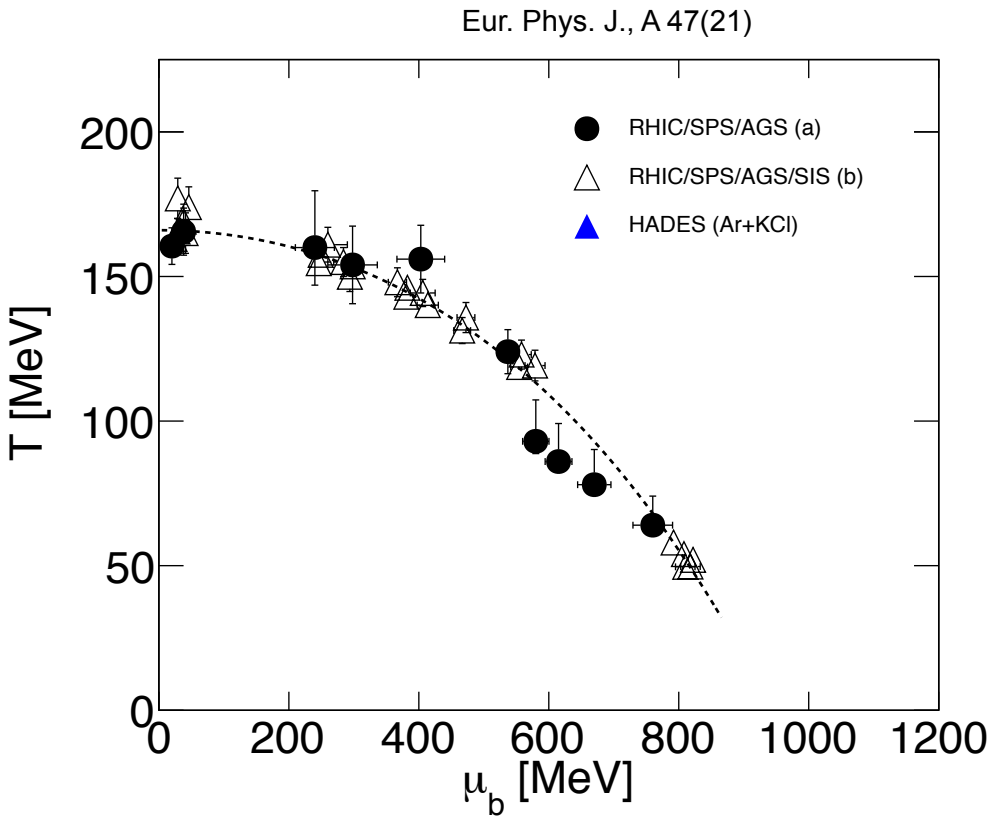
Particle production from a homogeneous source:

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

- Grand canonical ensemble (T, μ= μ_B μ_s μ_Q, V and sometimes γ_s, usually μ_s and μ_Q are constrained)

- Strangeness canonical ensemble (T, μ= μ_B μ_Q, R_c, R) (Strangeness canonically suppressed at low temperatures)

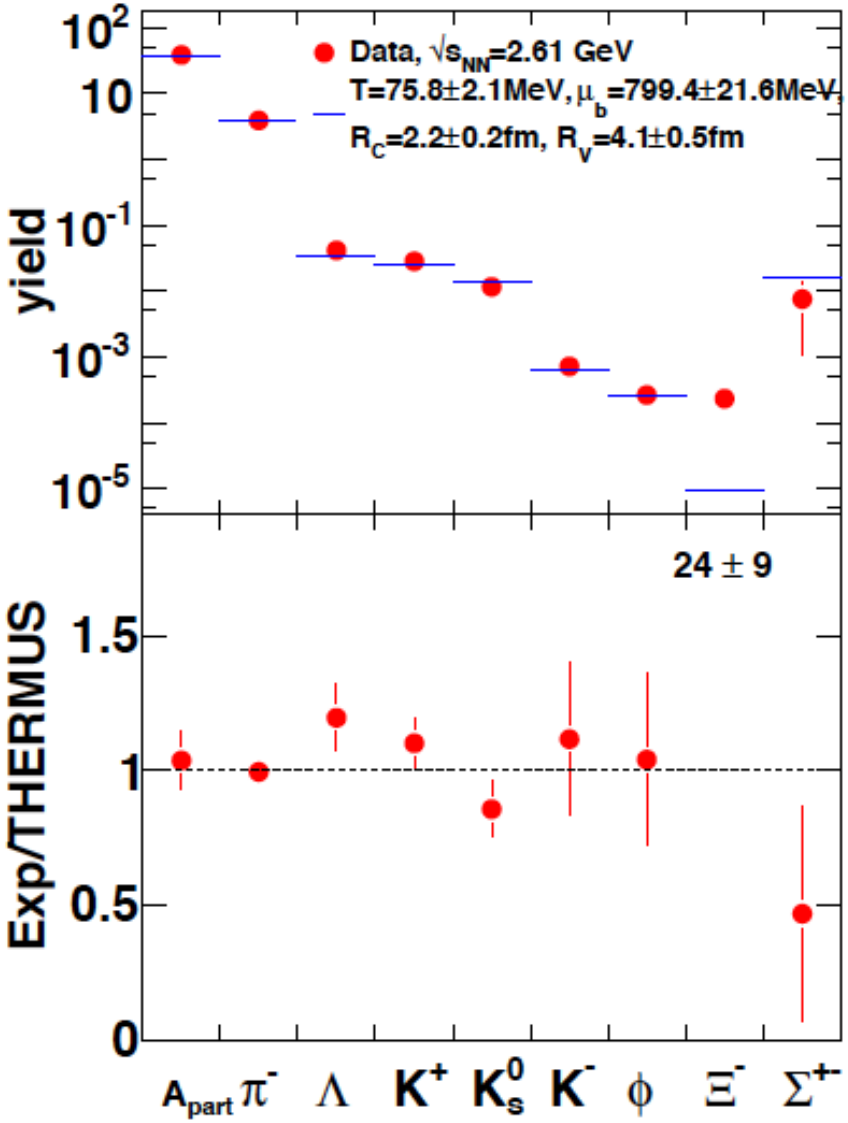
- Fits at low beam energies based on limited number of particle species

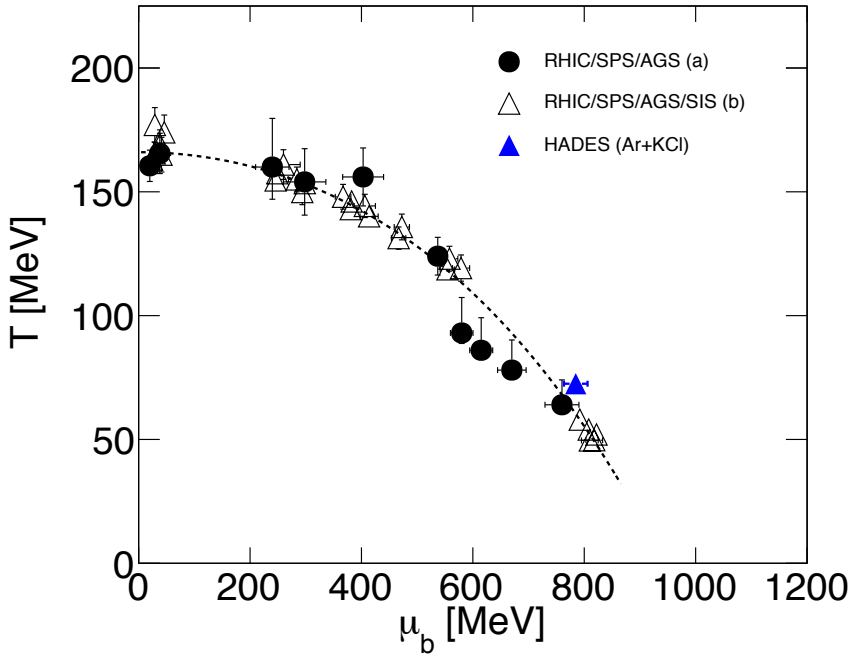


How will it work for more particle species in Ar+KCl?

Statistical model: Ar+KCl@1.76A GeV

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





Statistical model works reasonably well at low energies for medium-sized system
Reference? (lighter and heavier system?)

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

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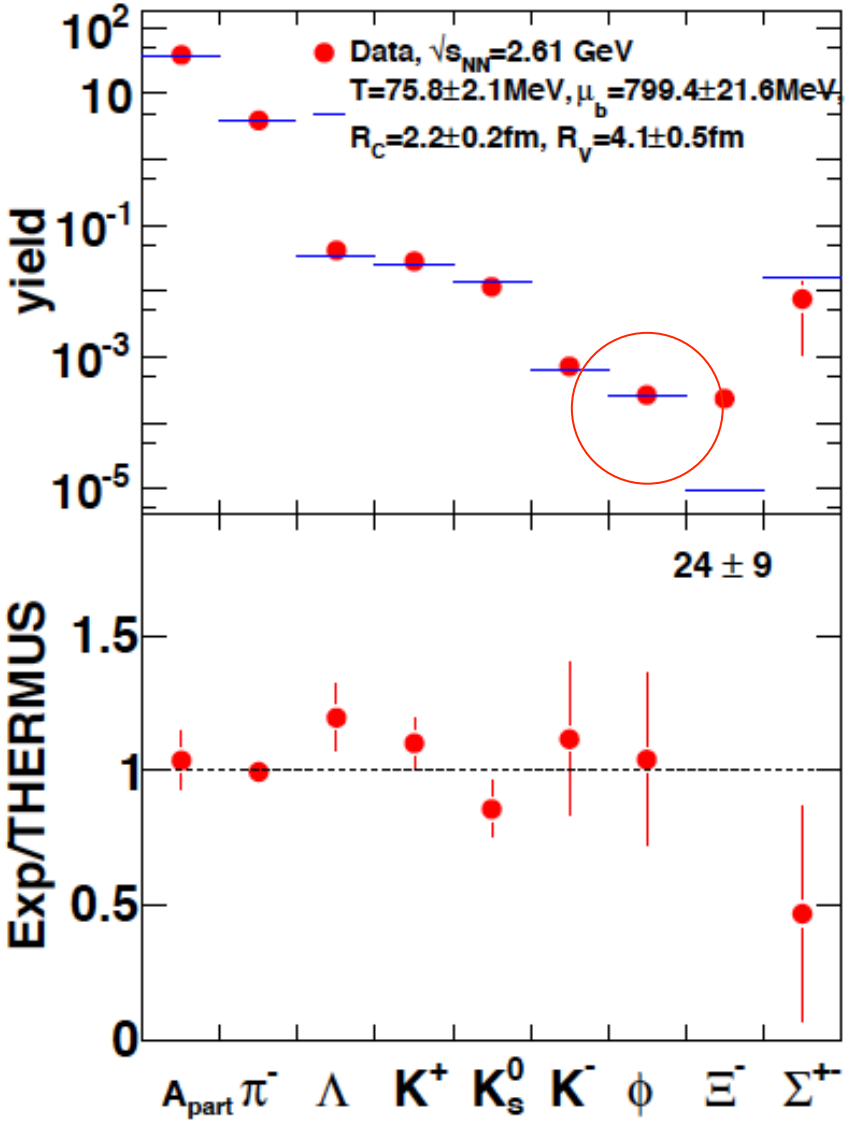

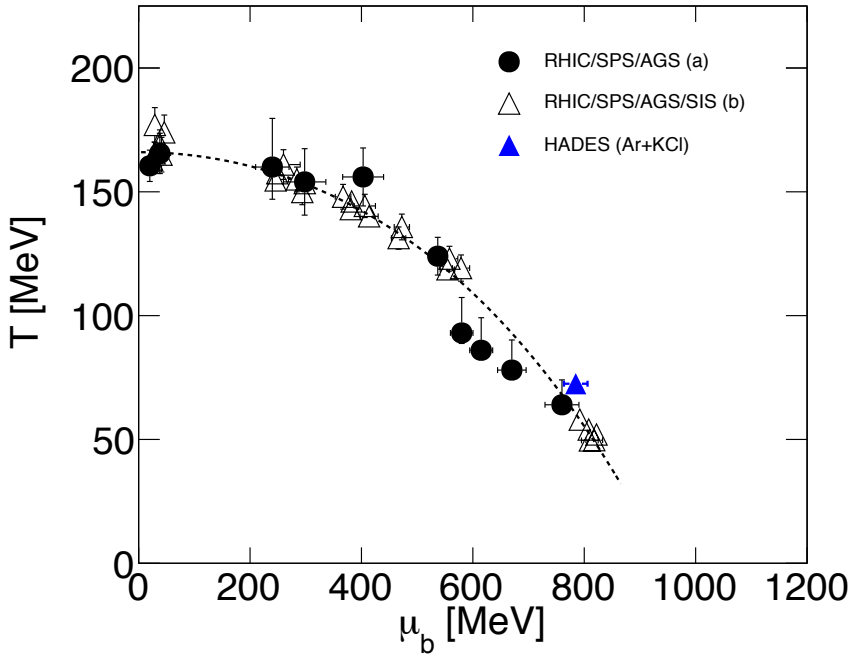

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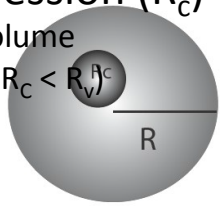
Φ meson described without suppression (R_c)

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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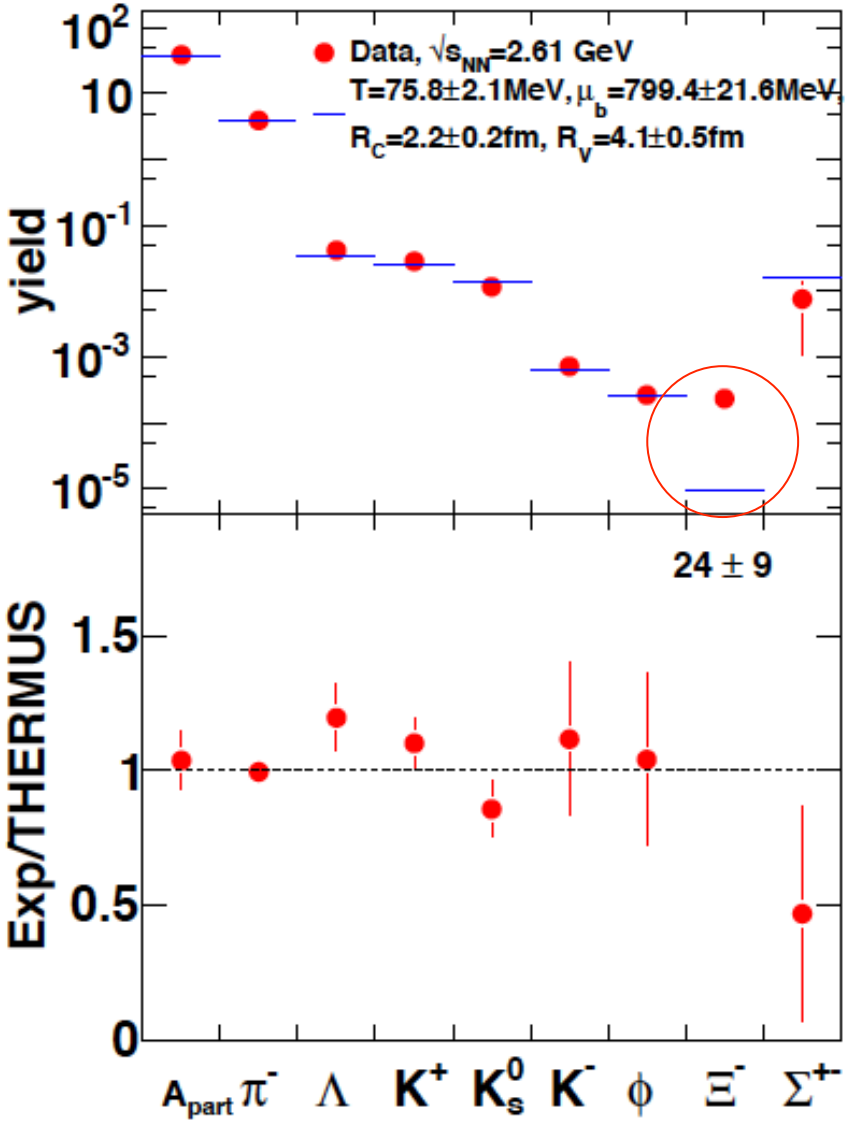

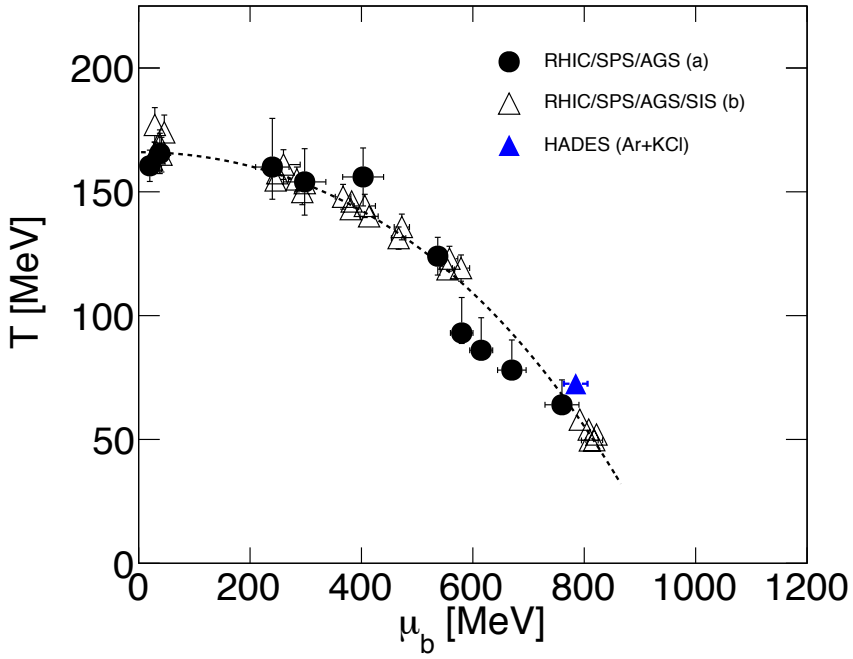

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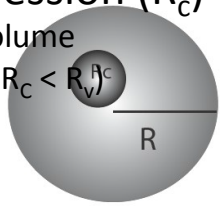

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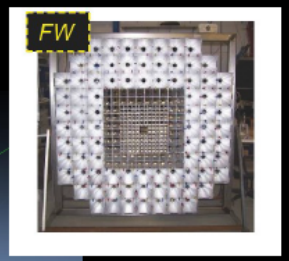
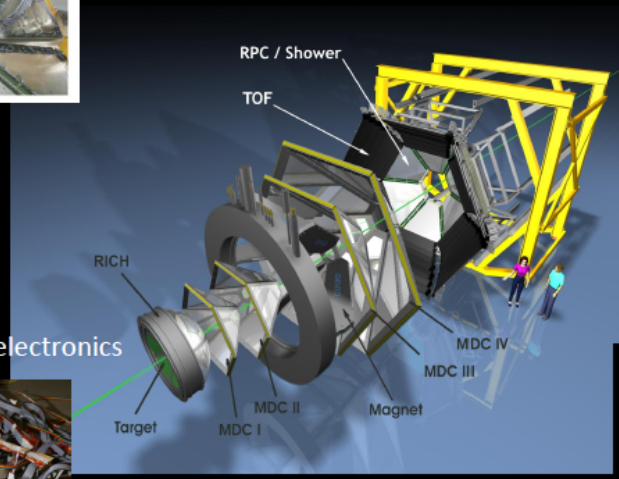
Time-of-flight wall (RPC)

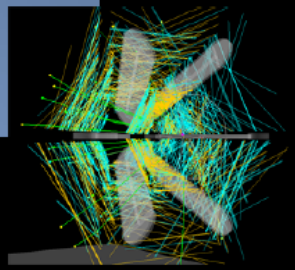
Forward wall





DAQ and readout electronics

Tracking



Statistical model: Au+Au@1.23A GeV

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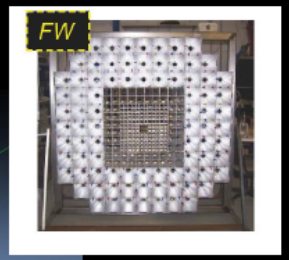

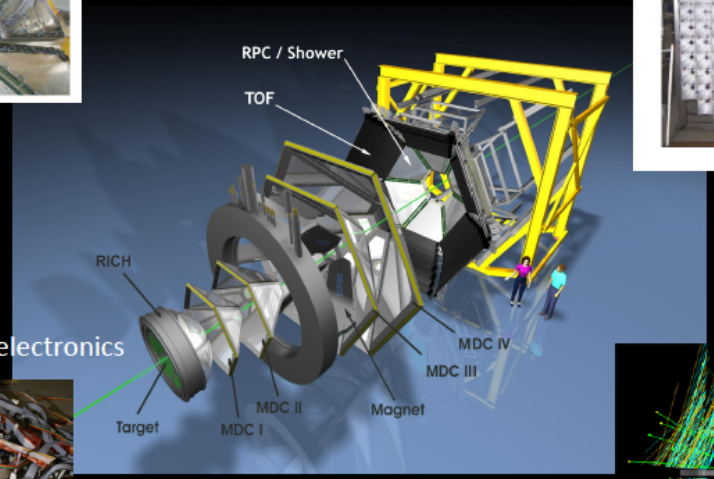

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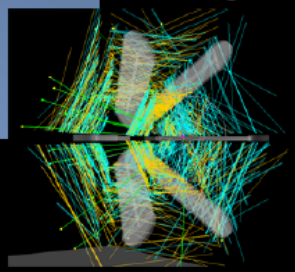
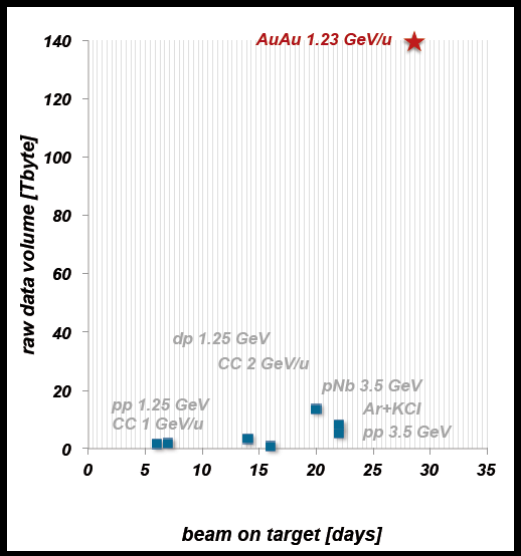
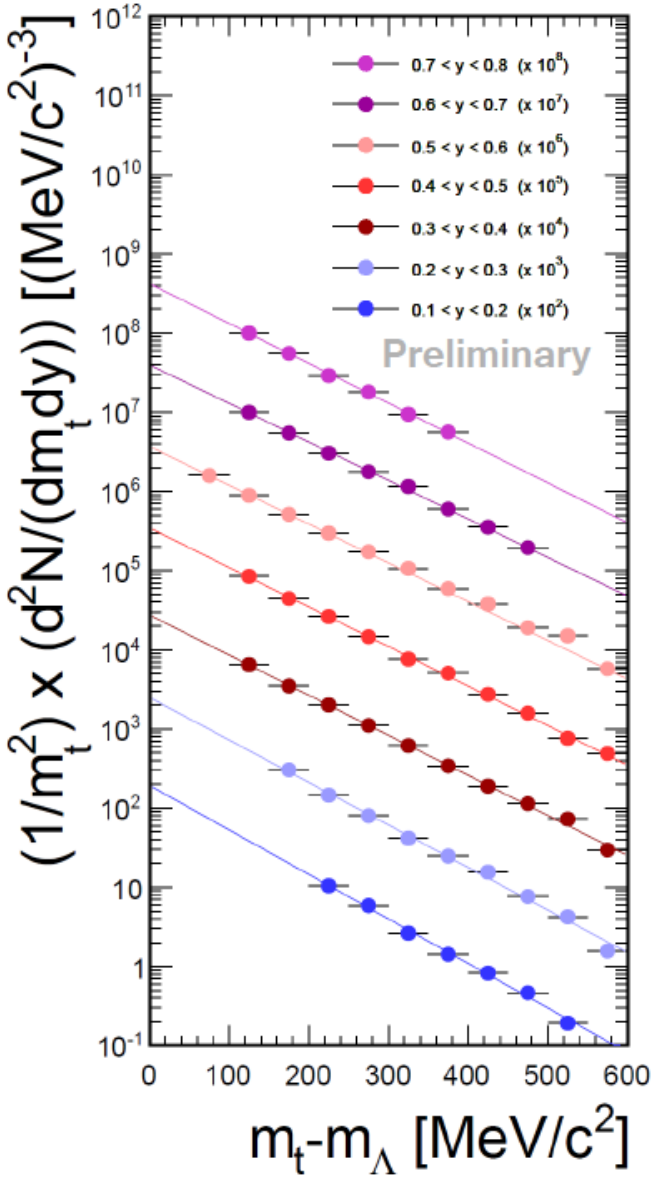
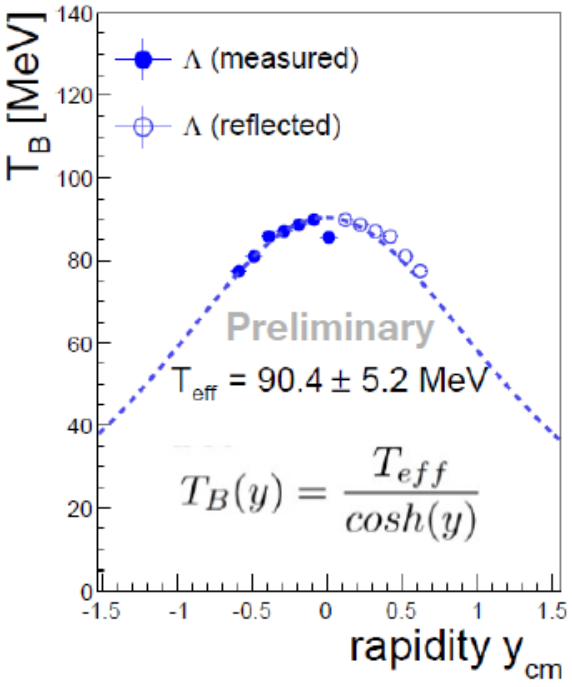
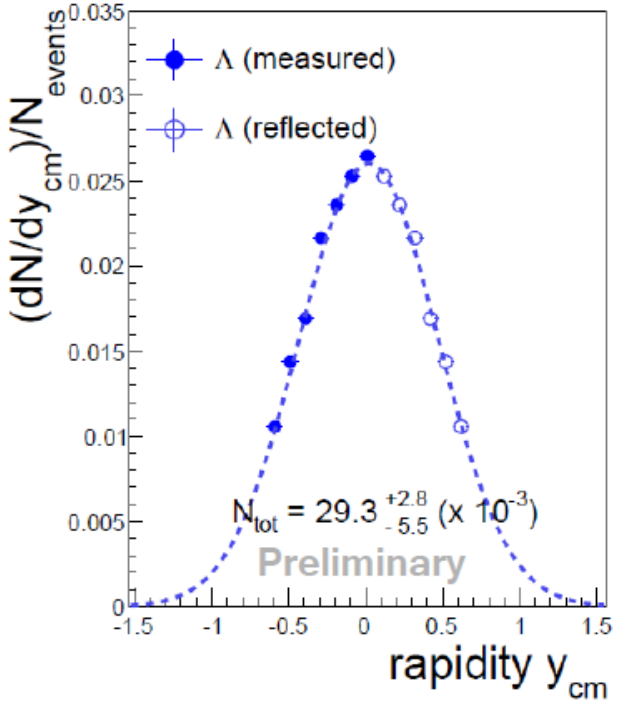




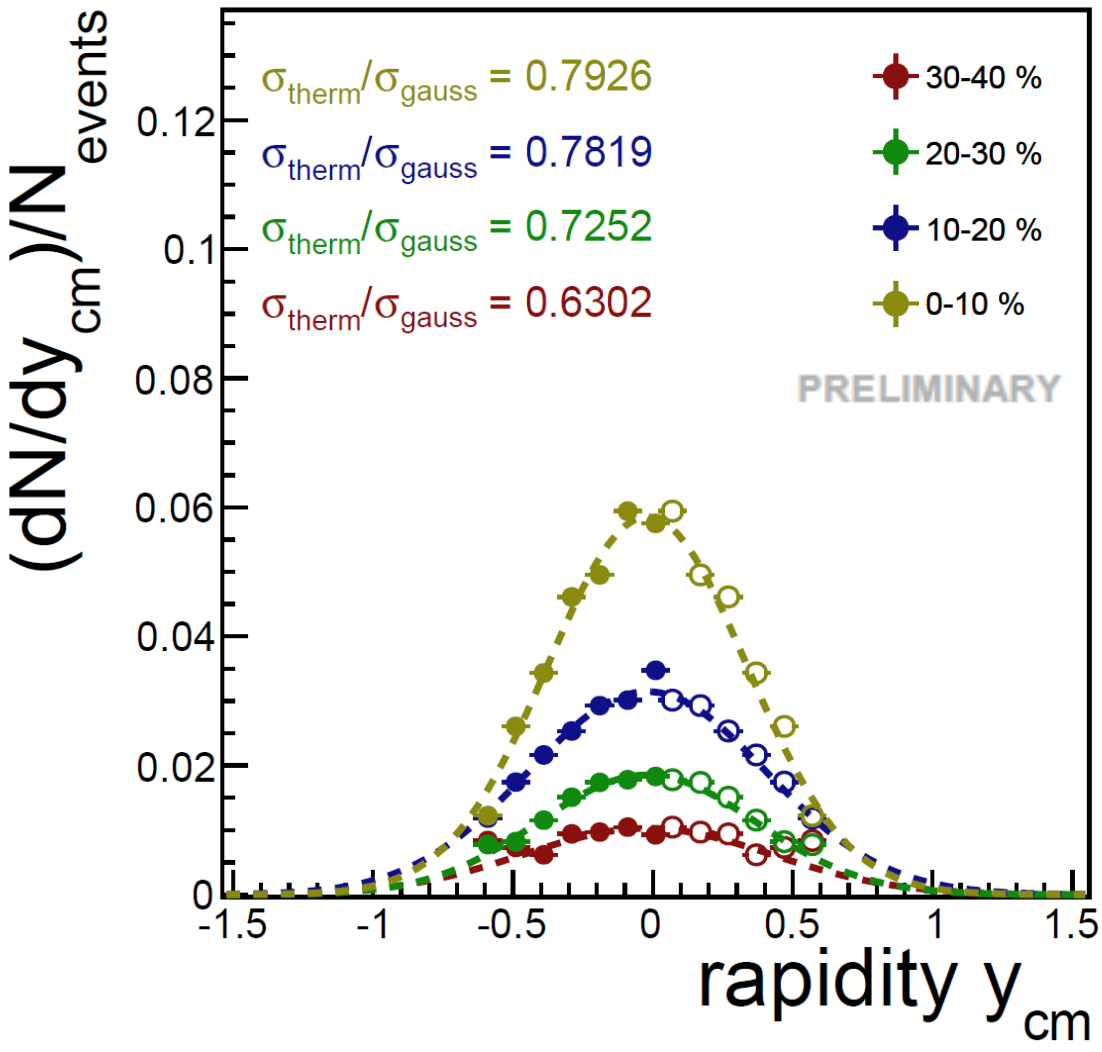
Λ: spectra and y-distribution





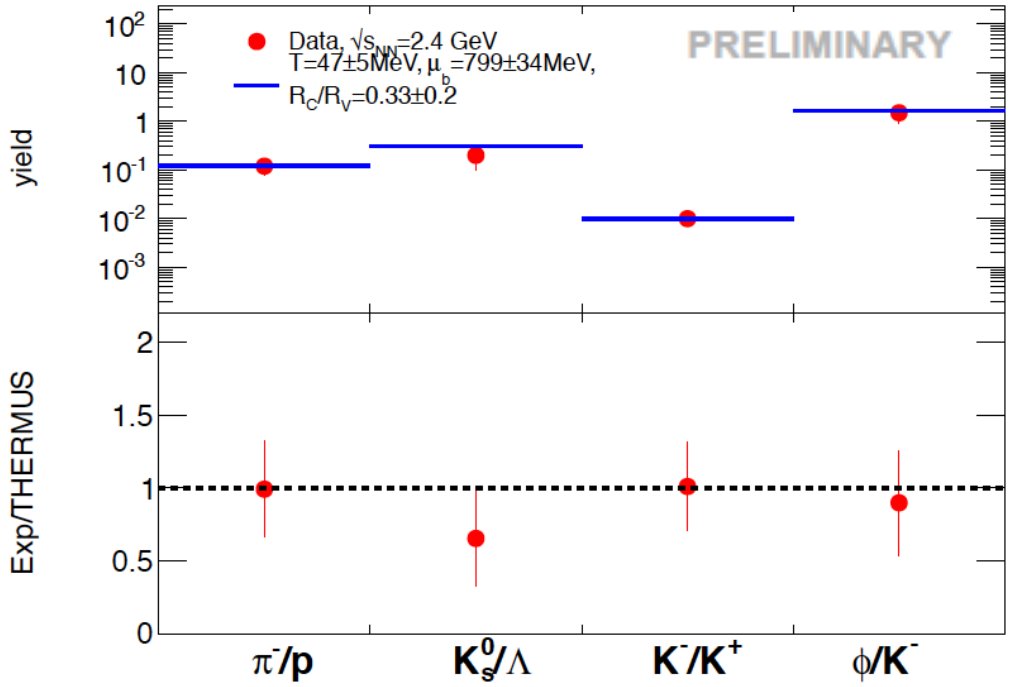


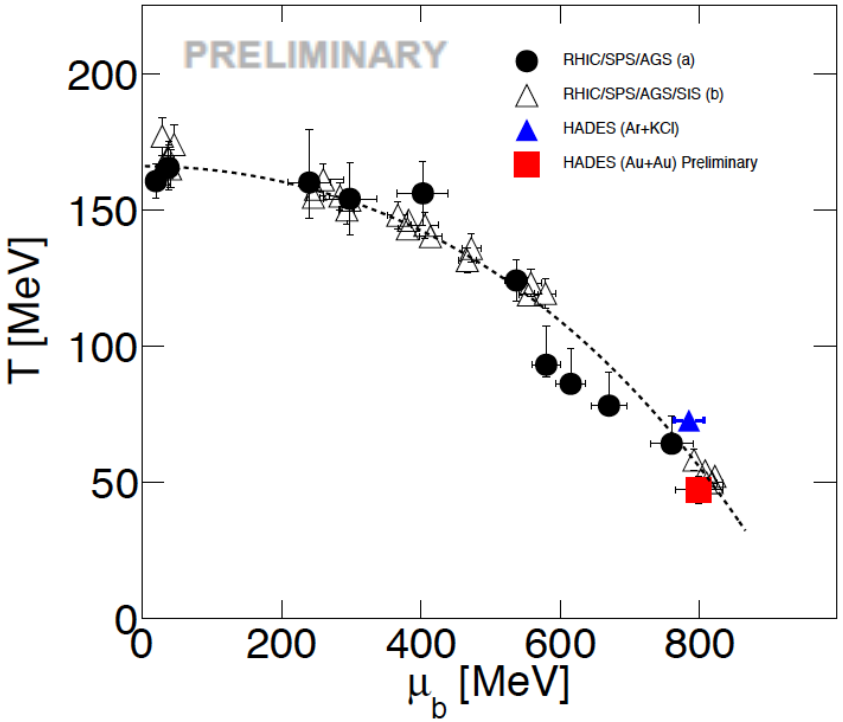
Centrality dependence



Test stat. model in future for central Au+Au collisions, strangeness suppression?

Statistical model: Au+Au@1.23A GeV





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

$T = 47 \pm 5$ MeV

$\mu_B = 799 \pm 34$ MeV

$R_c/R_v = 0.3 \pm 0.2$

(no systematical errors!!)

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

Statistical model: p+Nb @ 3.5 GeV

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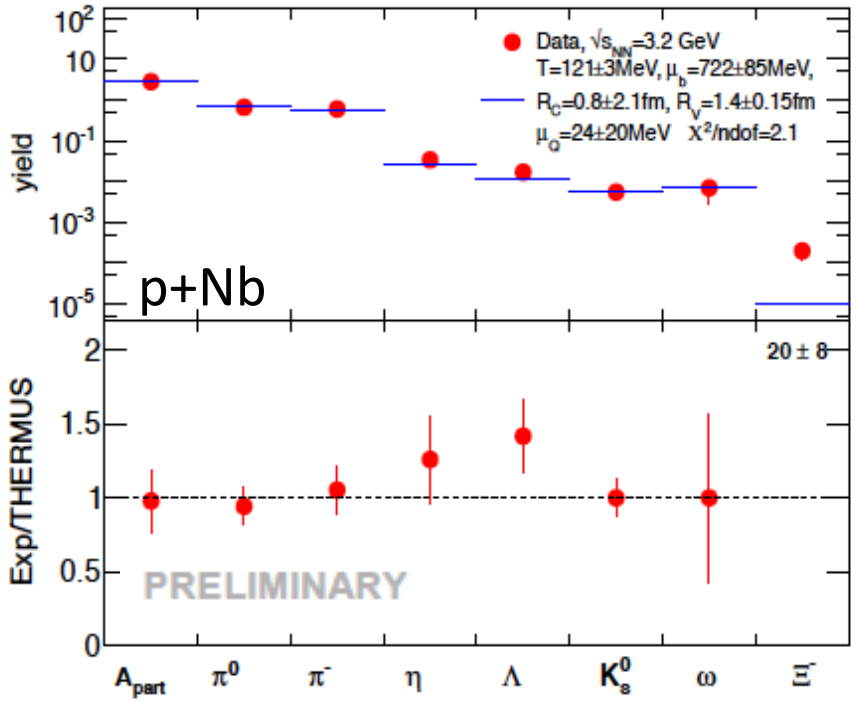

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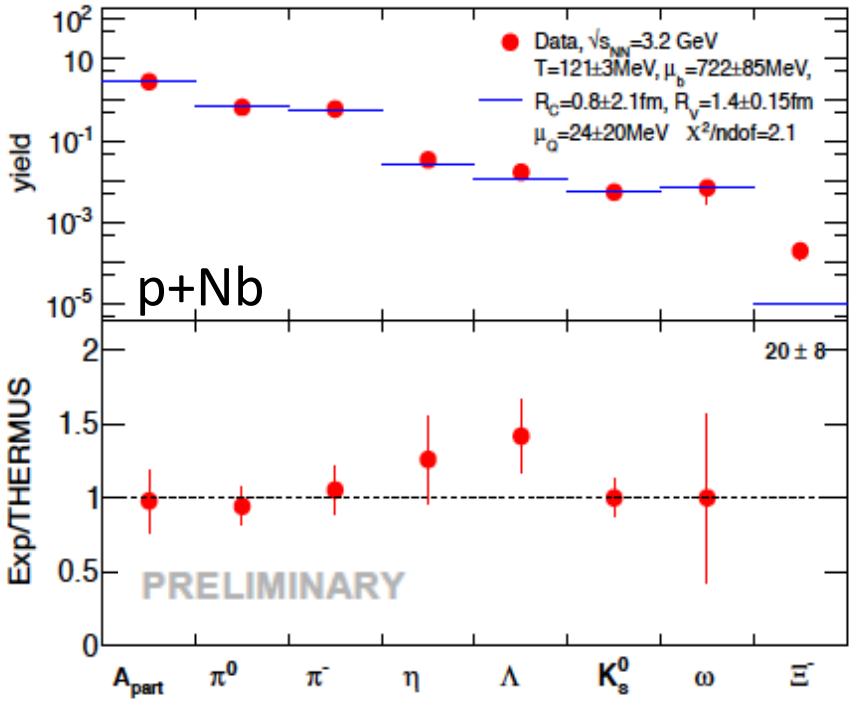

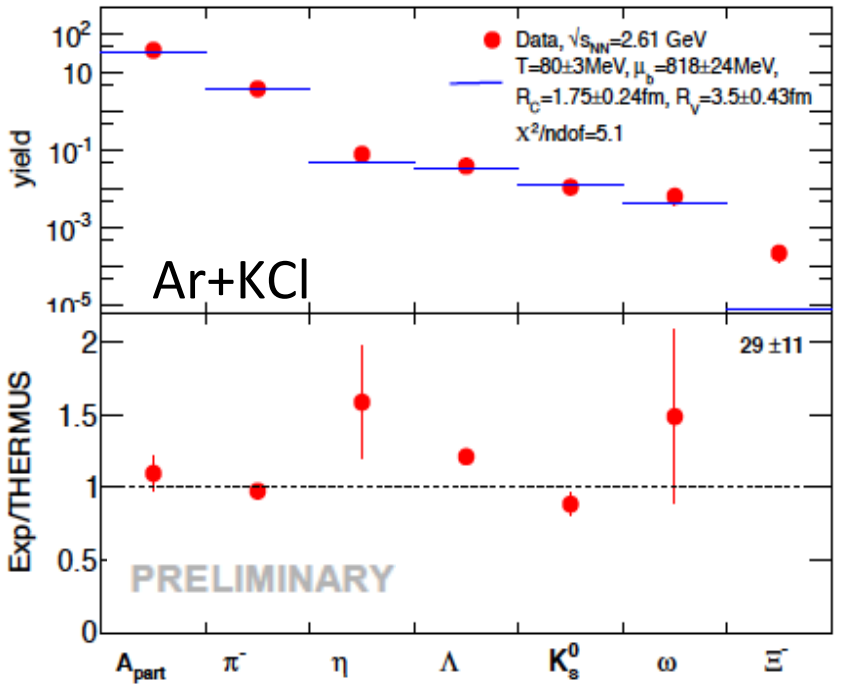

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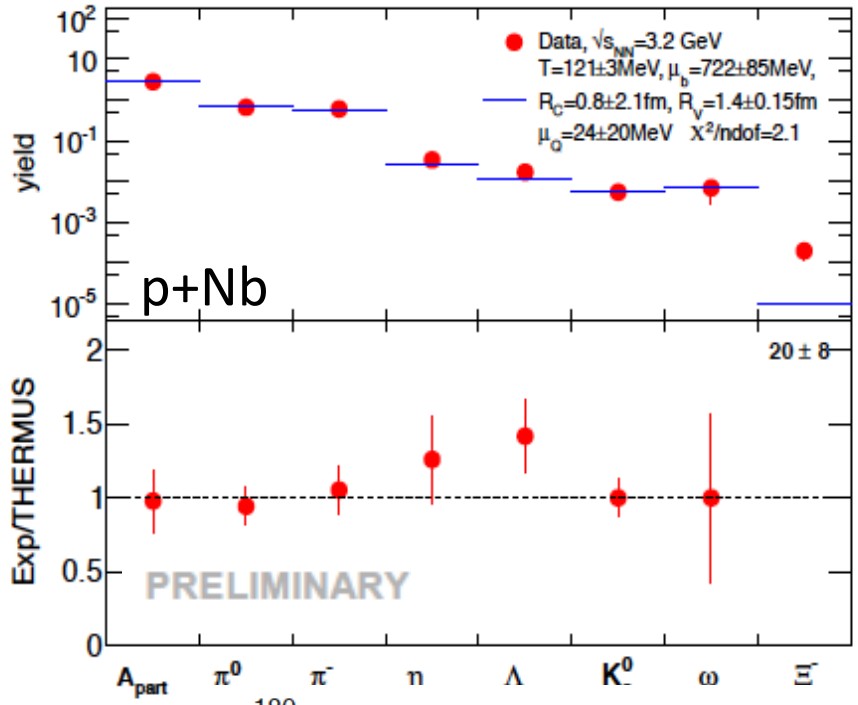
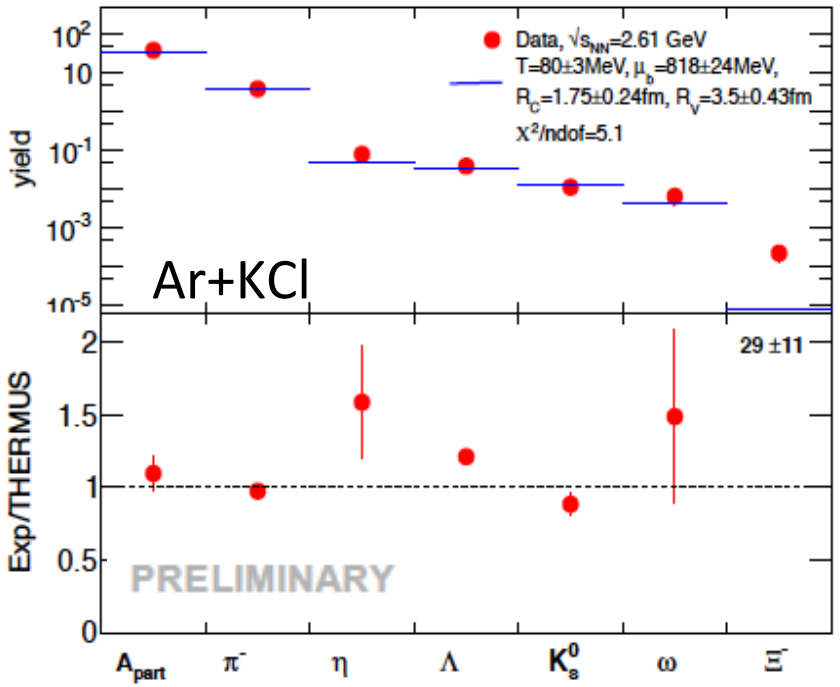
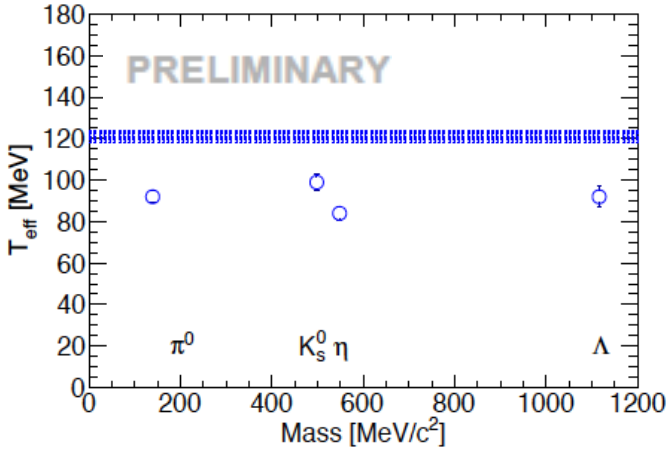




$T_{chem} > T_{kin}$



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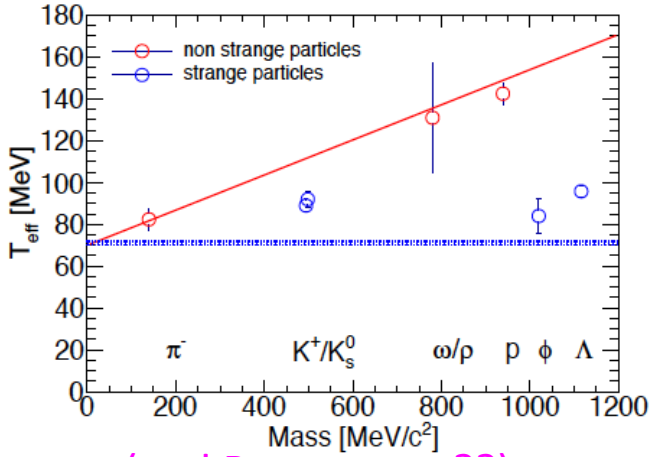
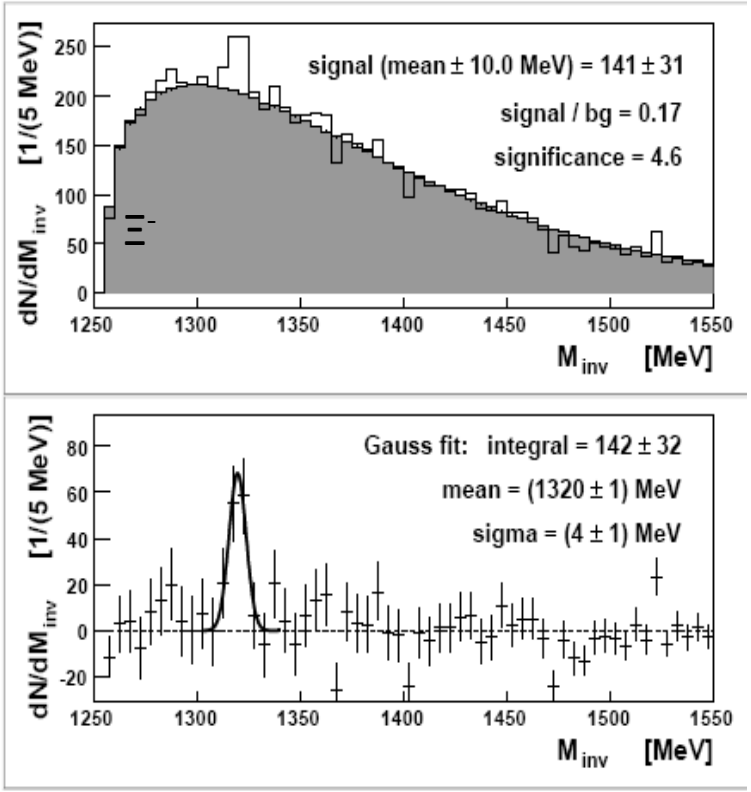
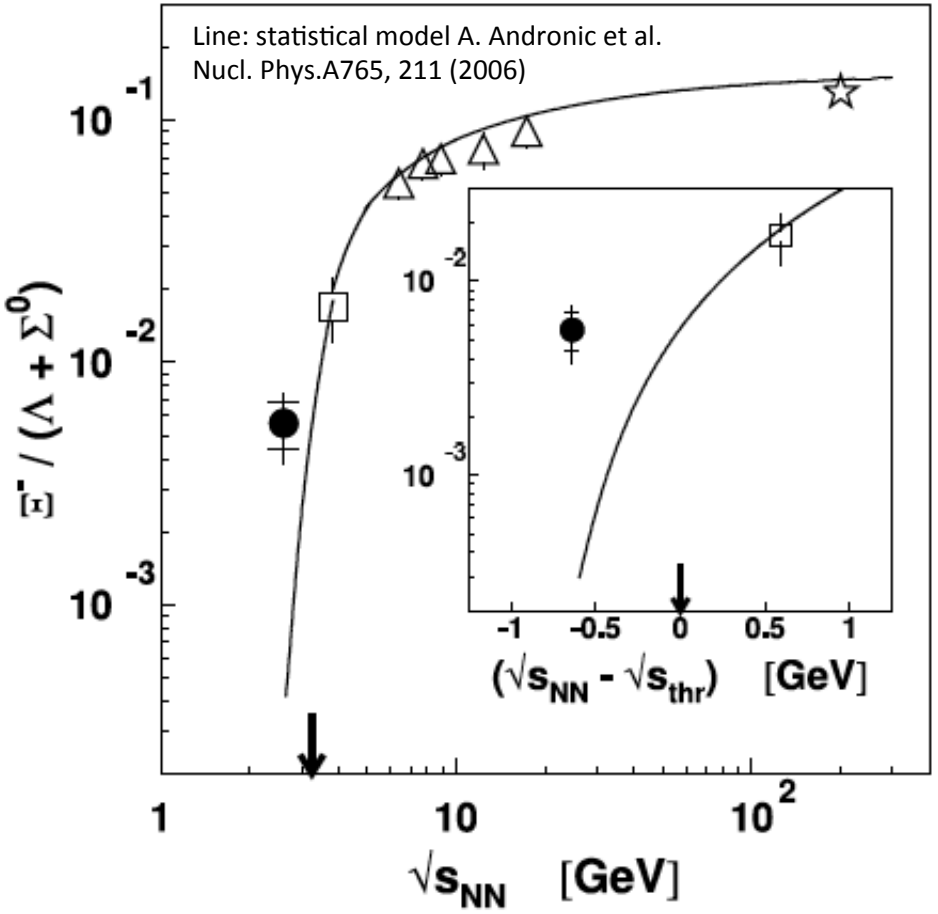


Fit to p+Nb looks reasonable ..why? Reference (and Resonances??)

Ξ^- production in Ar+KCl @ 1.76 GeV





Strong excess of the Ξ^-

NN-threshold:

E_{beam} = 3.74GeV →$\sqrt{s}$-$\sqrt{s_{th}}$=-630MeV!

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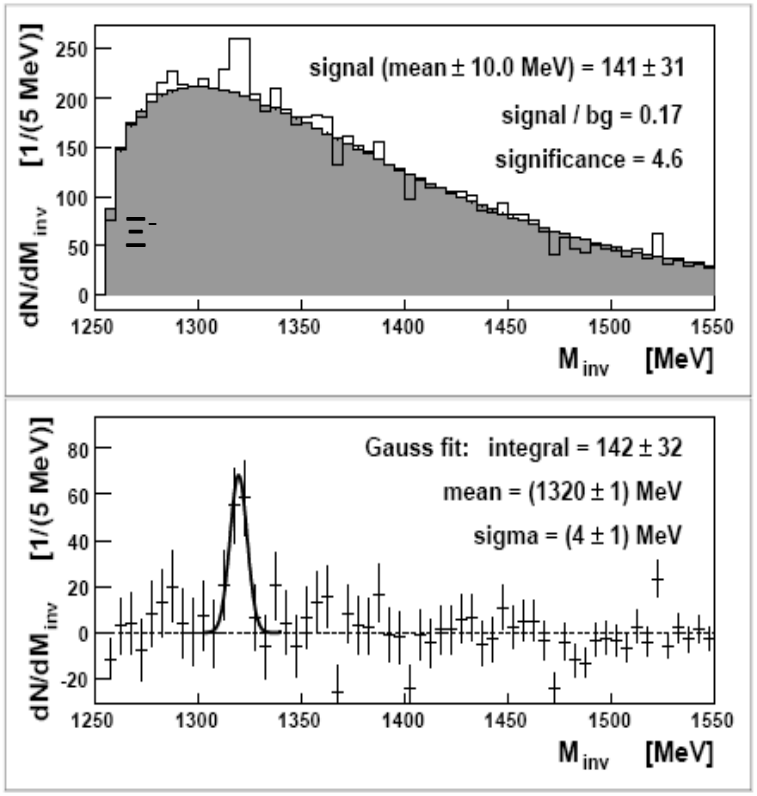
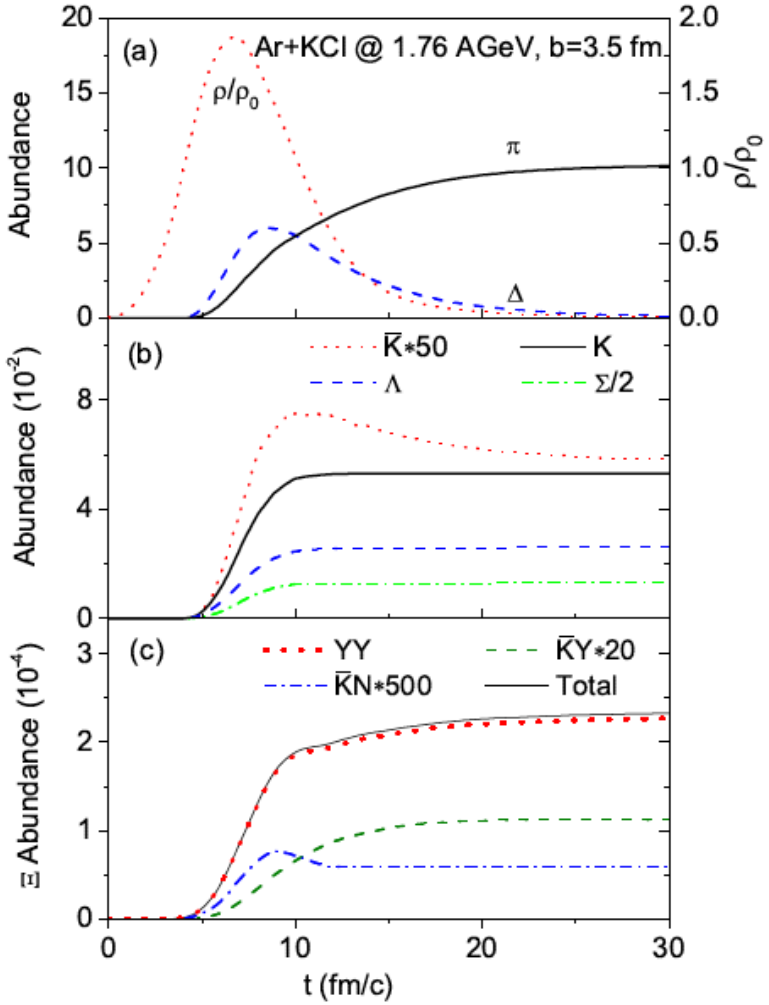


RVUU transport model



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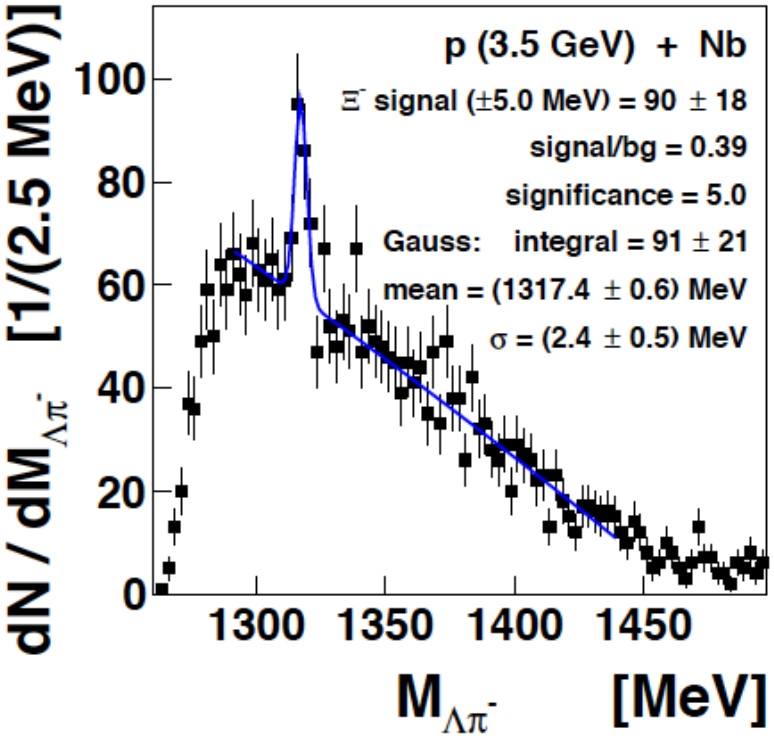
Che Ming Ko et al. Phys.Rev. C85 (2012) 064902

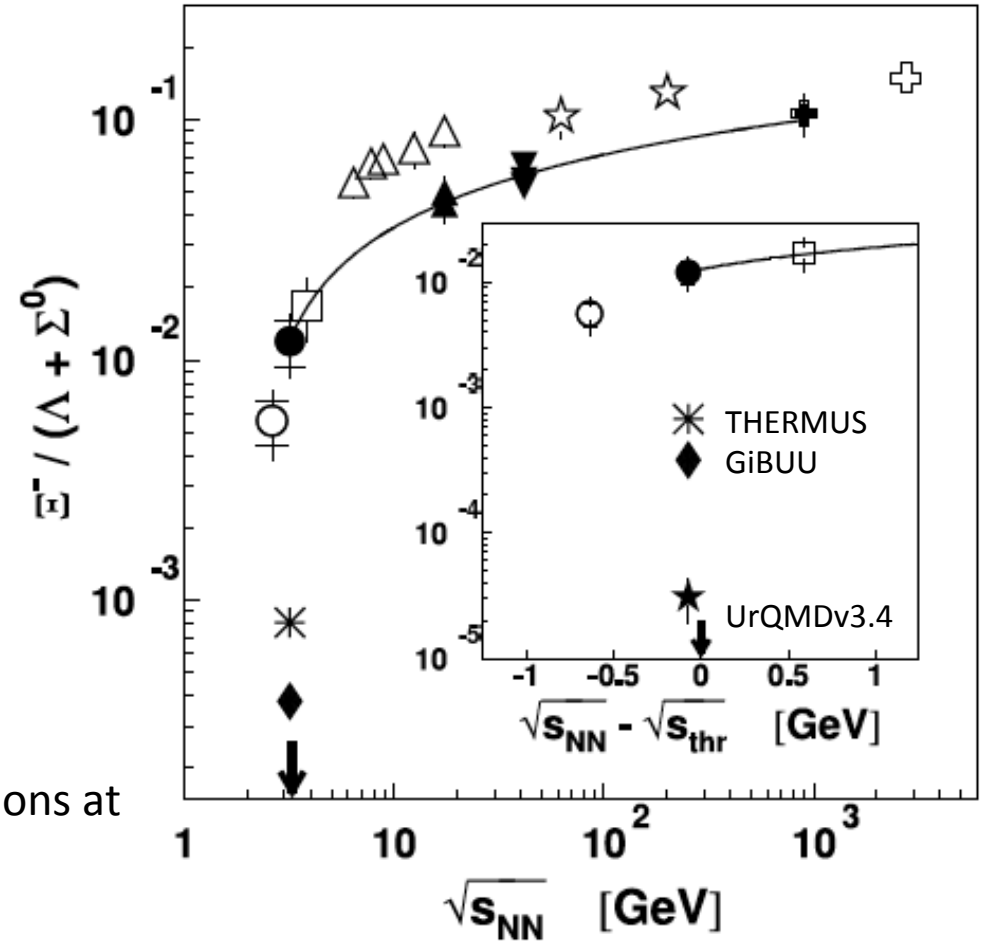
Ξ^- production in p+Nb @ 3.5 GeV

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



Subthreshold Ξ^- production in p+Nb collisions at

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



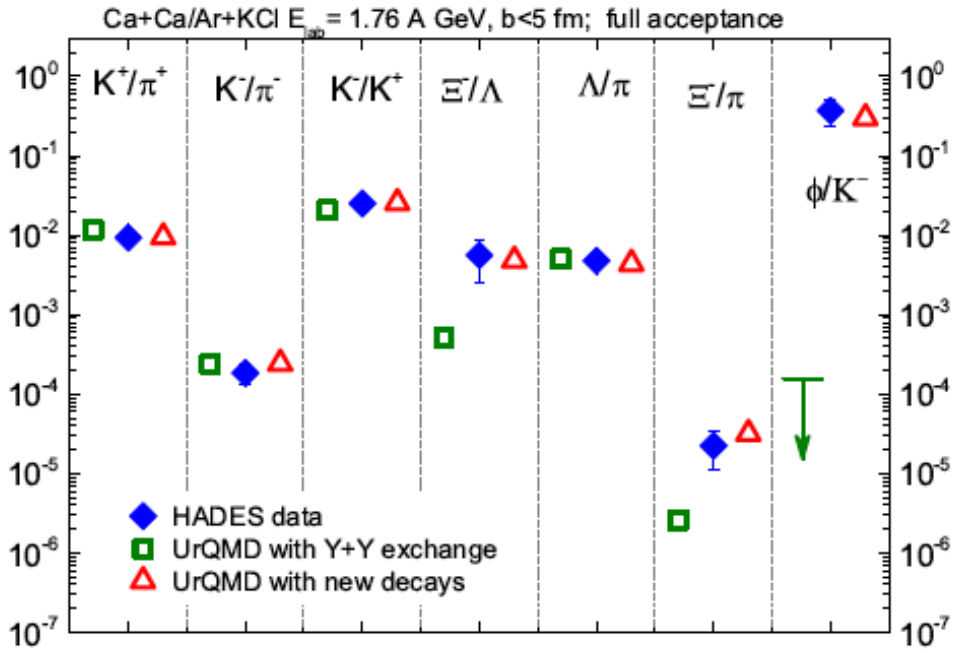
Parameterization: $f(x)=C(1-(D/x)^G)^H$

Excess already present in cold nuclear matter!

Reference

Ξ^- with tuned UrQMD / constraining the resonances

J. Steinheimer and M. Bleicher, arXiv:1503.07305



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

Increased N* branching ratios can explain it.

Resonances!

Not included in Thermus!

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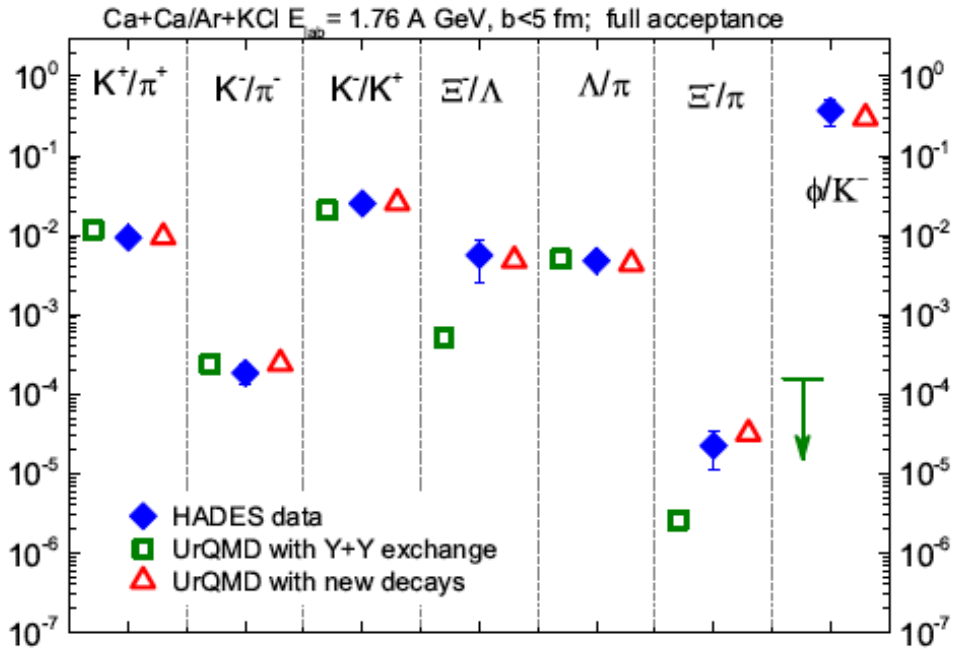

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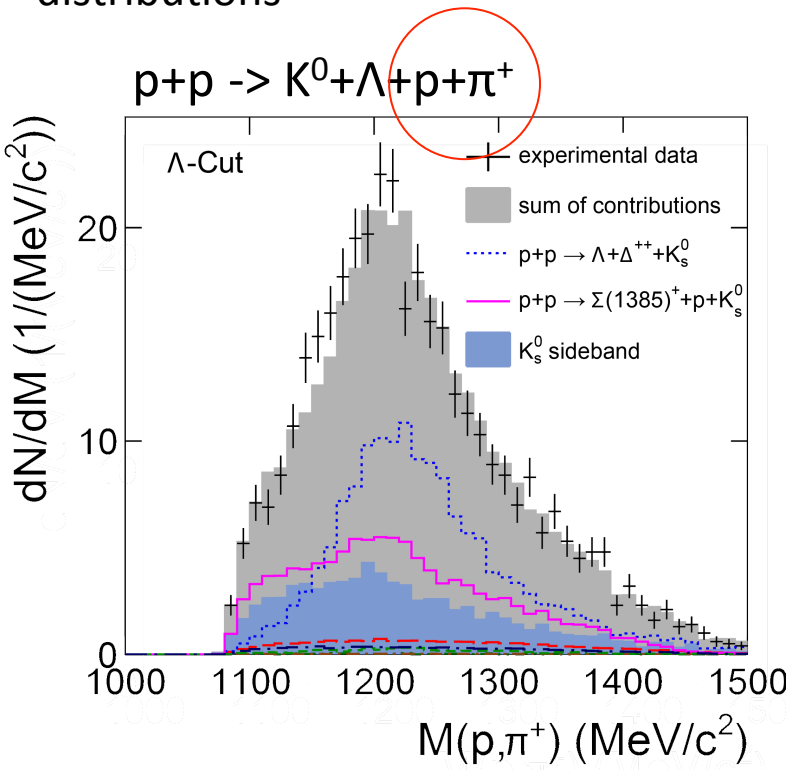
Resonances!

Not included in Thermus!

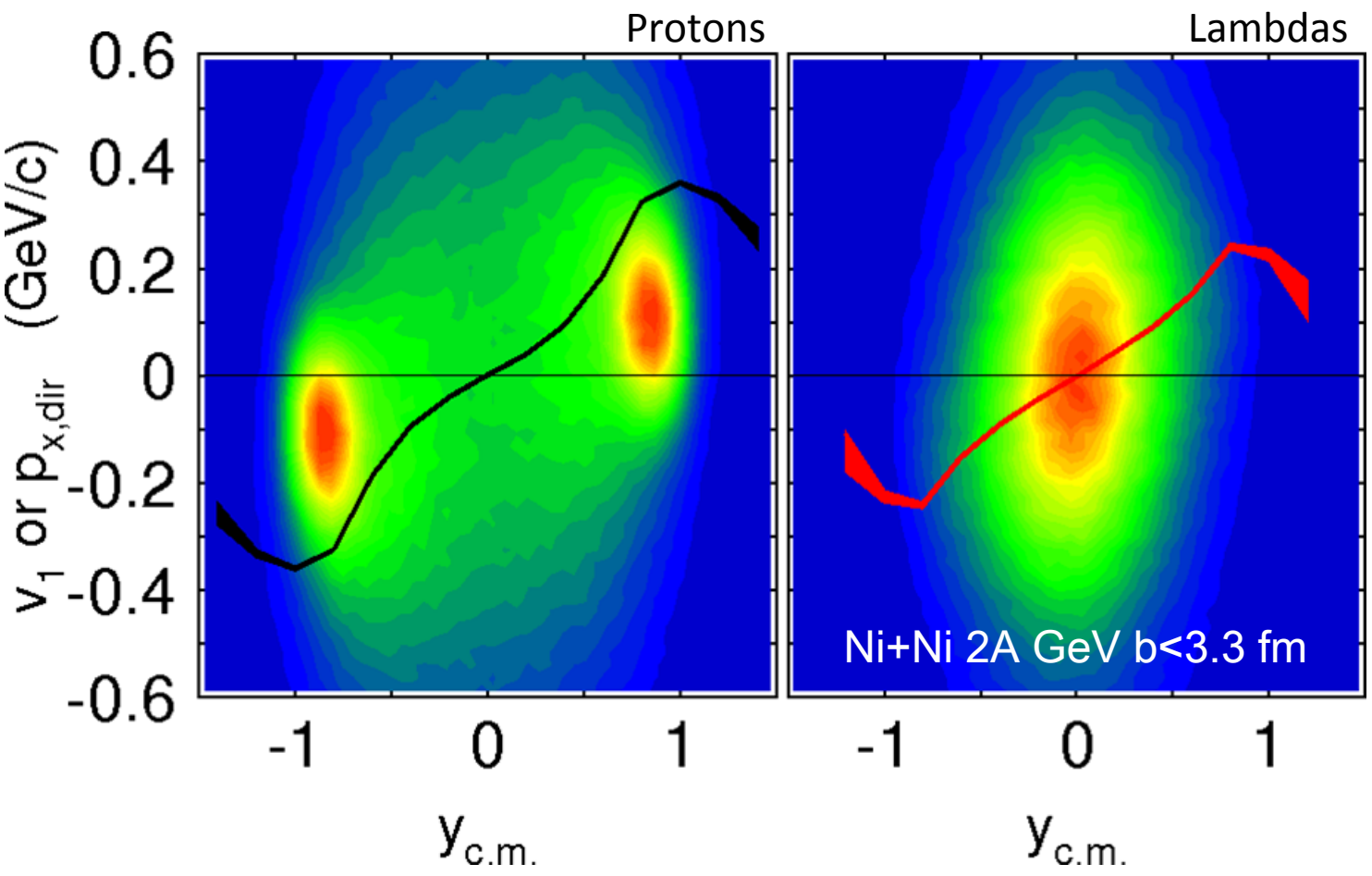
Inclusive measurements in p+p

Resonance contributions to final state can be constraint by e.g. angular distributions

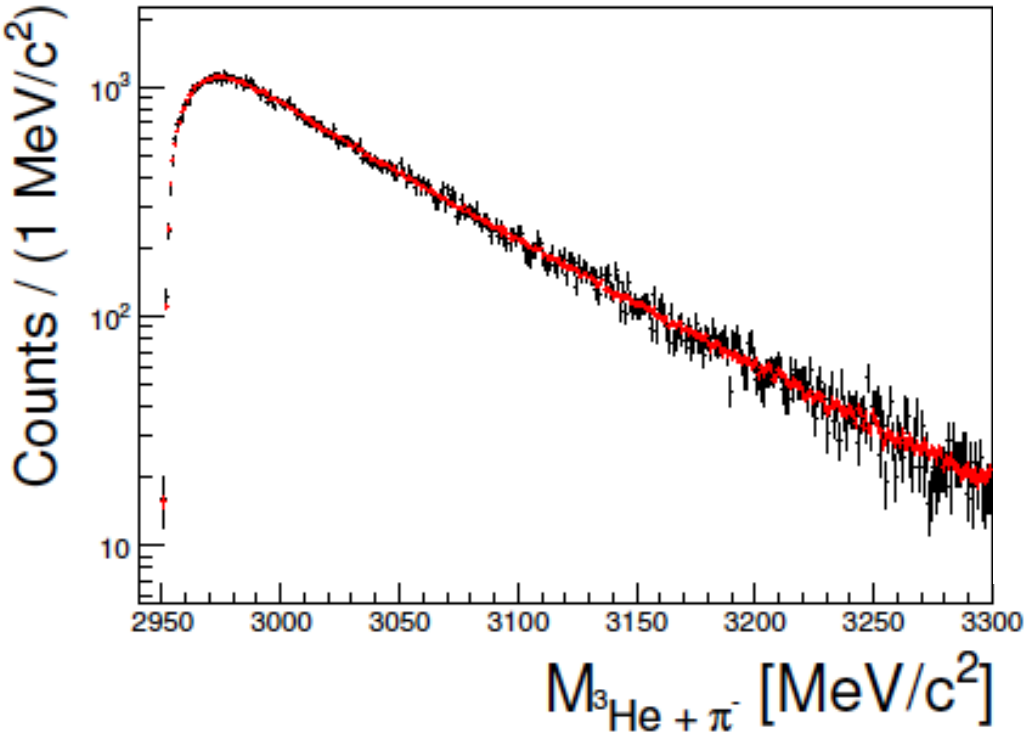


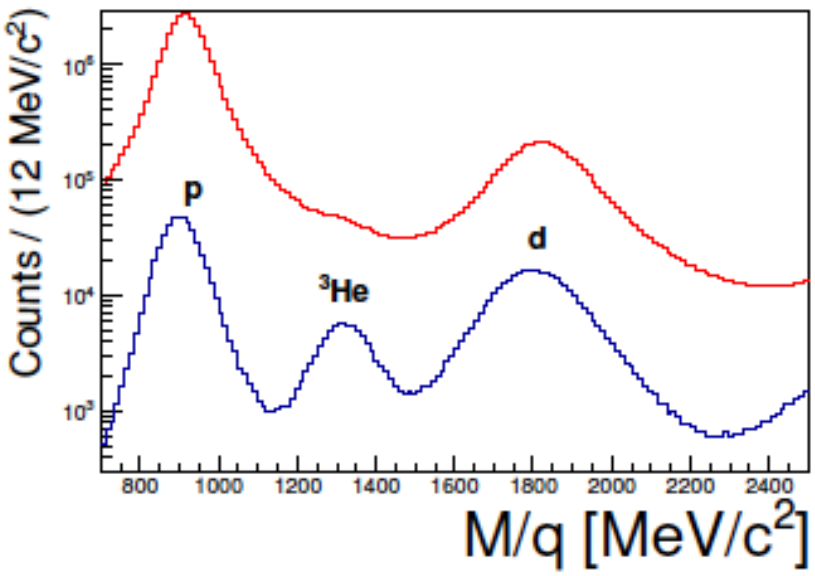
Phys. Rev. C 90, 015202 (2014)

Hypertrition search with HADES



Hypertrition search with HADES (Ar+KCl)





Upper limit:

$$M_{UL} = 1.04 \text{ x } 10^{-3}$$

$$^{3}{}_{\Lambda}\text{He}/\Lambda < (2.5 \pm 0.3) \text{ x } 10^{-2}$$

Future plans:

Investigate Au+Au @ 1.23 AGeV data (lower energy but heavier system) and 3 body decay channel

Eur.Phys.J. A49 (2013) 146

Summary

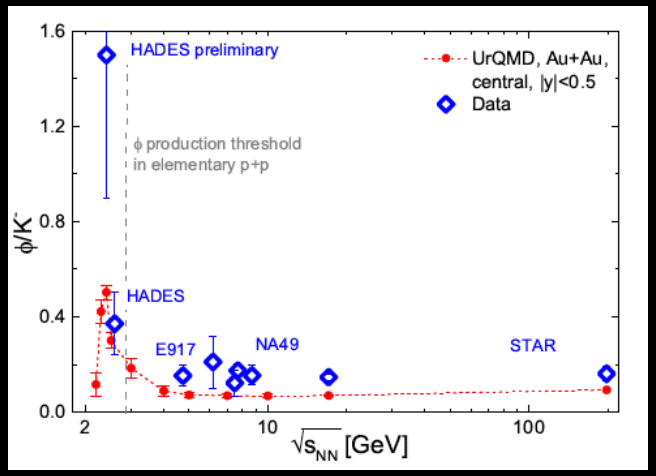
K^-:

"Strangeness exchange dominant for K^-"

"Later freeze-out of K^- compared to K^+, due to coupling to baryons"

"Strangeness production in HIC is very different from that in elementary interaction"

Not necessarily, new data on Φ production



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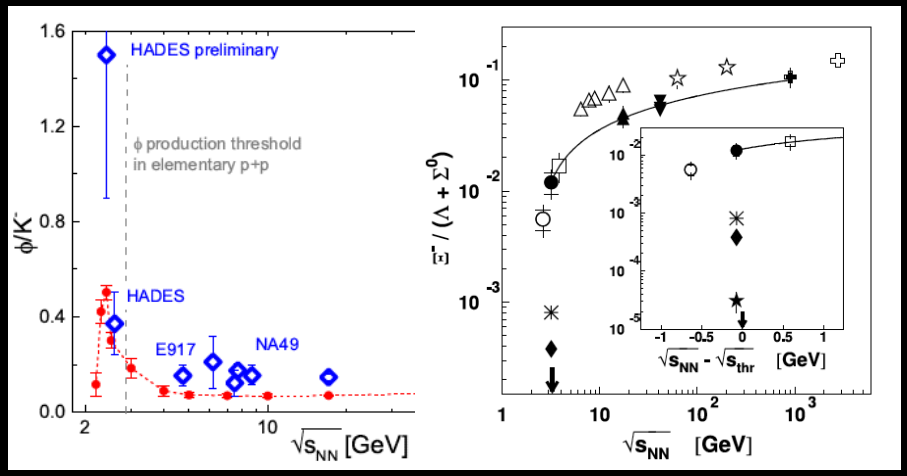

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excess already present in cold nuclear matter

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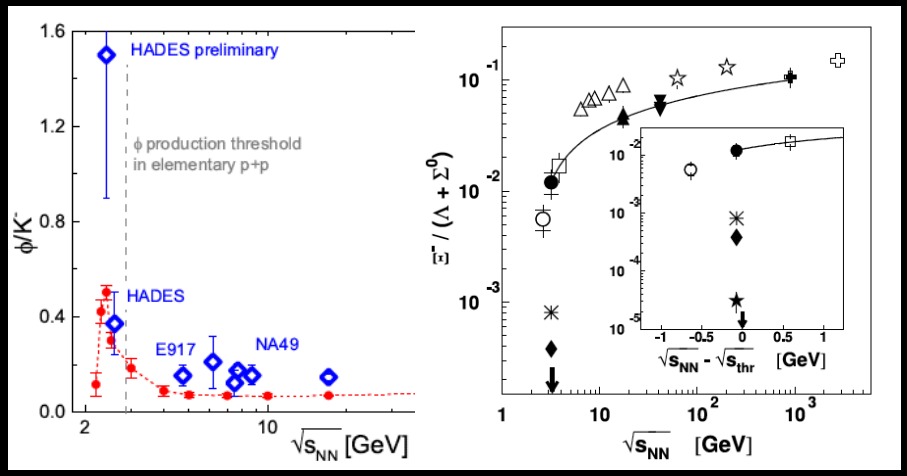

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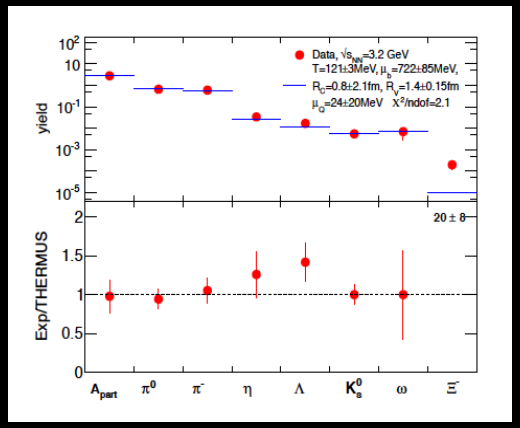
describes also p+Nb yields

test with central Au+Au data in the future



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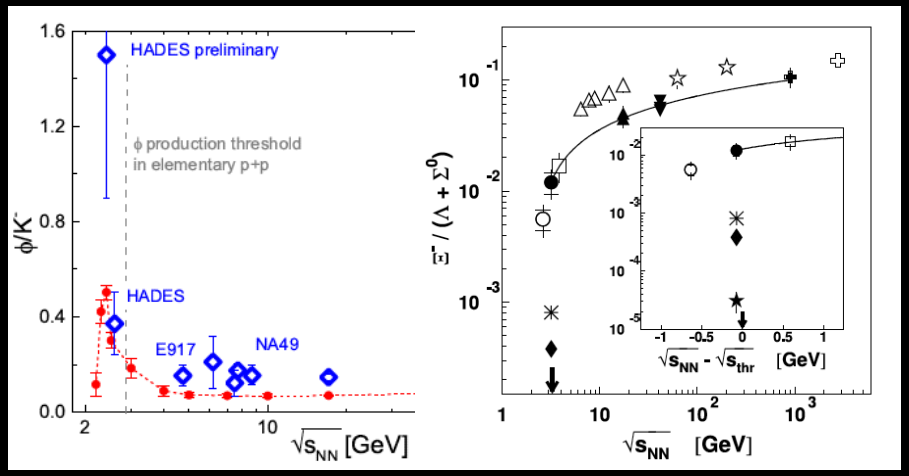

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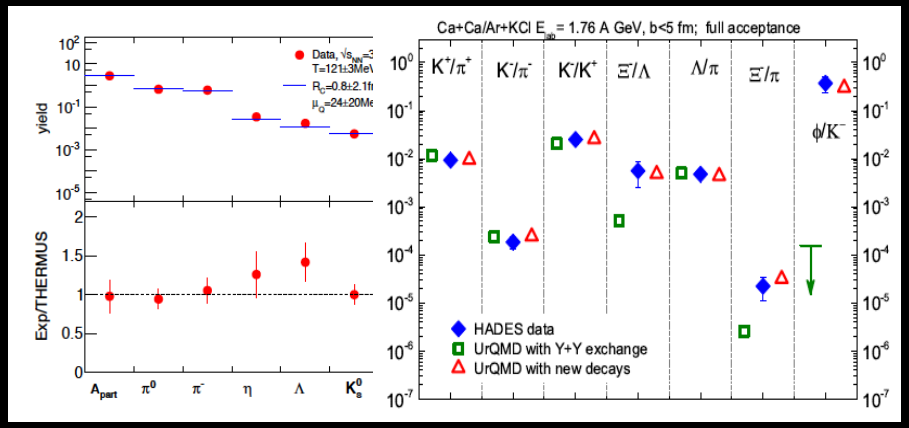

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tuned version (UrQMD) can describe strangeness production by resonance production (similar as for dileptons)

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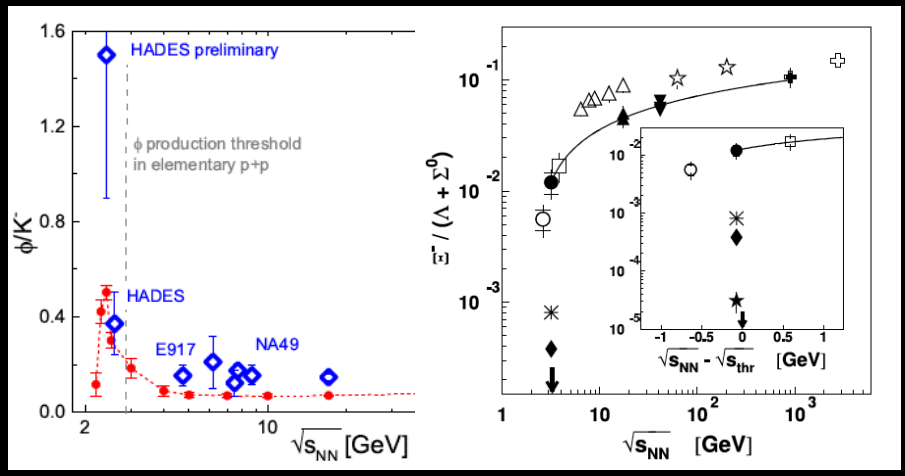

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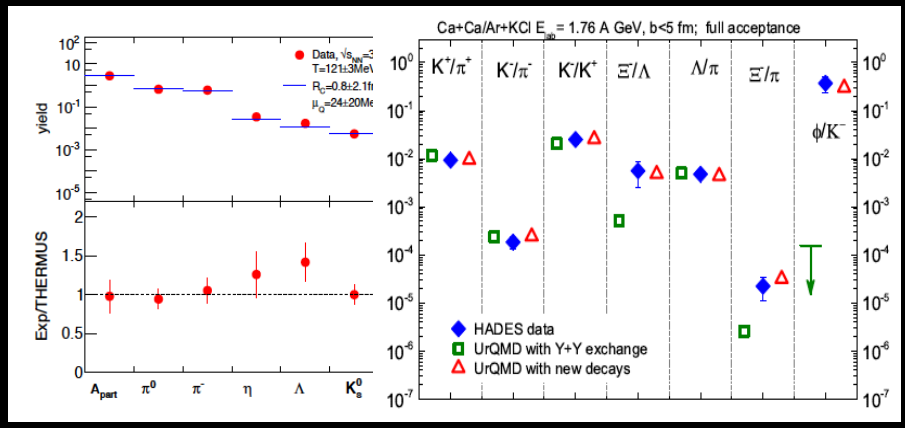

Transport:

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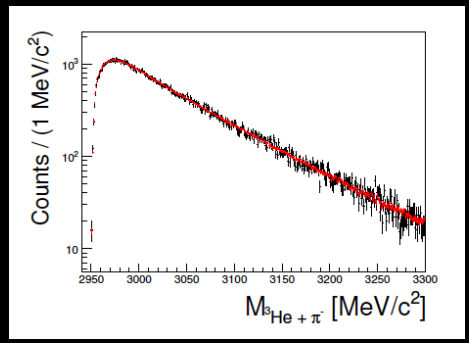
Search for hyper-matter:

yes, we can



Test hadronic (baryonic) interactions at low energies

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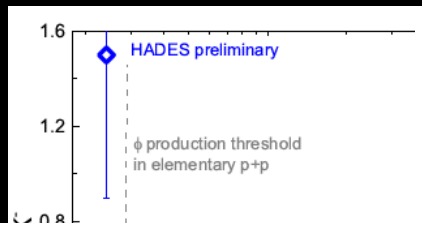
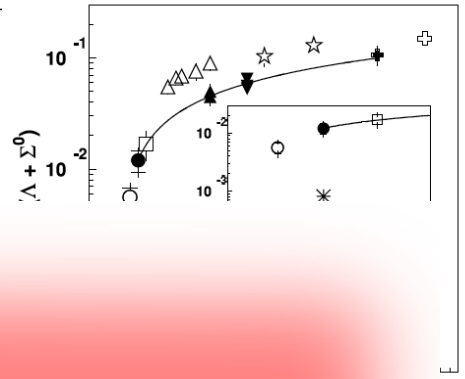
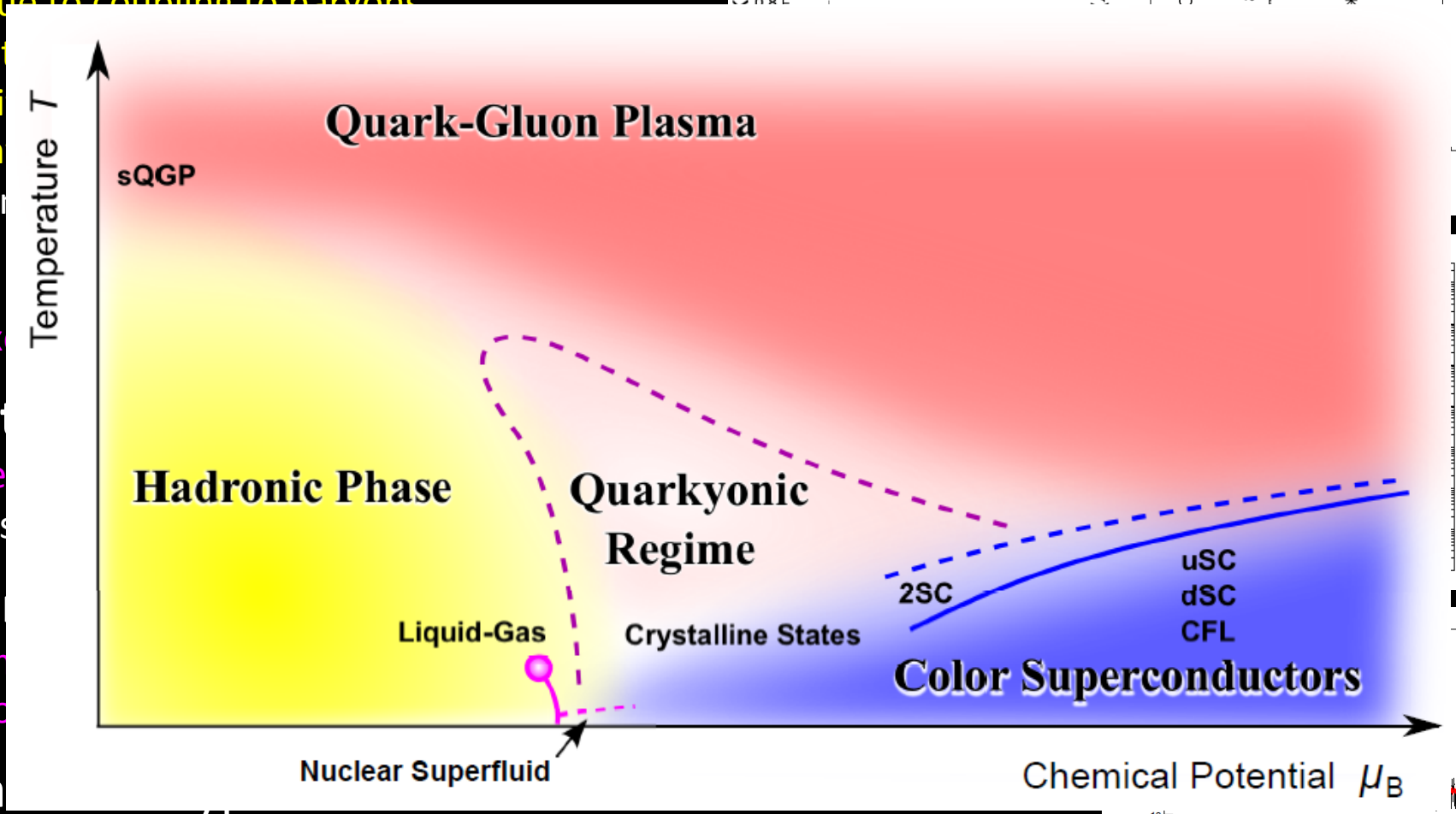






Test hadronic (baryonic) interactions at low energies

The HADES collaboration

Thank you for your attention

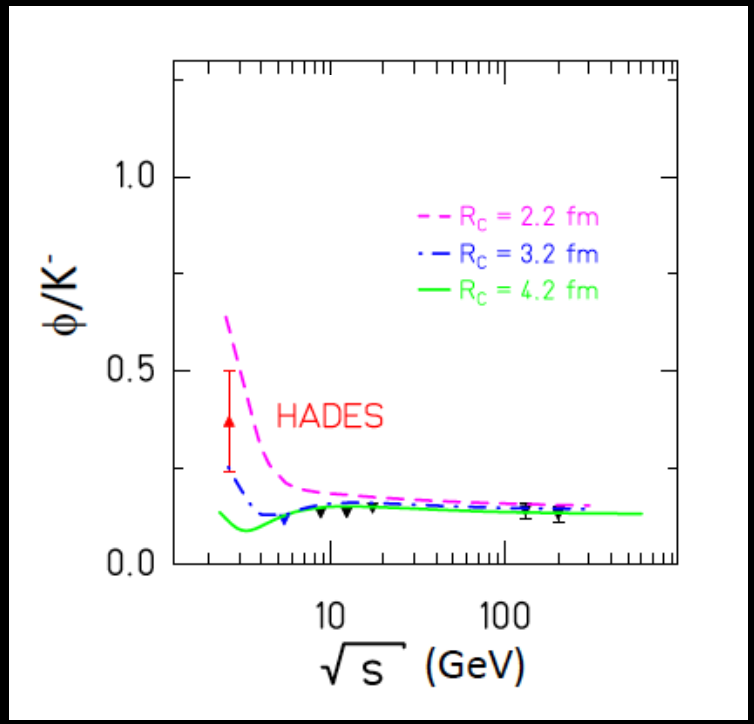
Back up

Au+Au @ 1.23 A GeV:

Lower energy and heavier system

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

$$NN \rightarrow NK^{+}\Lambda \qquad (E_{thr} = 1.58\,GeV)$$
$$NN \rightarrow NNK^{+}K^{-} \qquad (E_{thr} = 2.49\,GeV)$$
$$NN \rightarrow NN\varphi \qquad (E_{thr} = 2.59\,GeV)$$



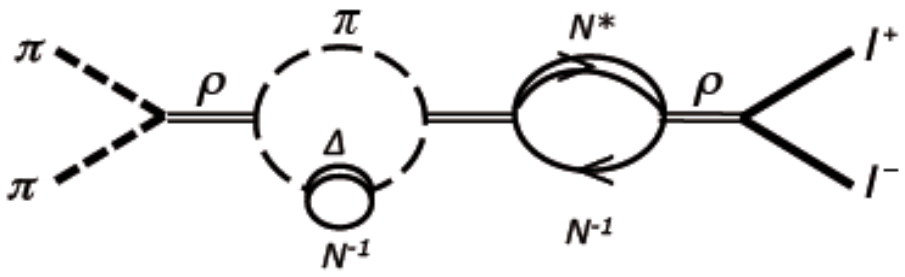
In medium modifications by resonances

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:

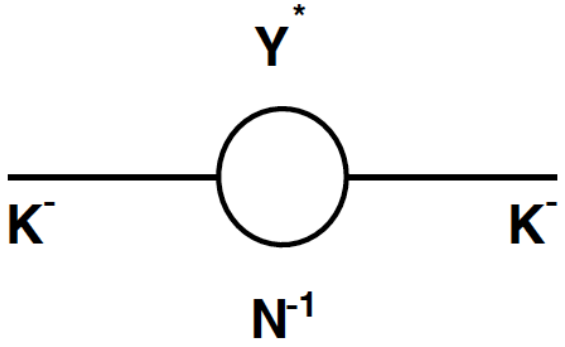
Example: **ρ meson**



Probe: dilepton decay

Observable: Lineshape modifications

Example: **K⁻ meson**



Probe: direct reconstruction of hadron

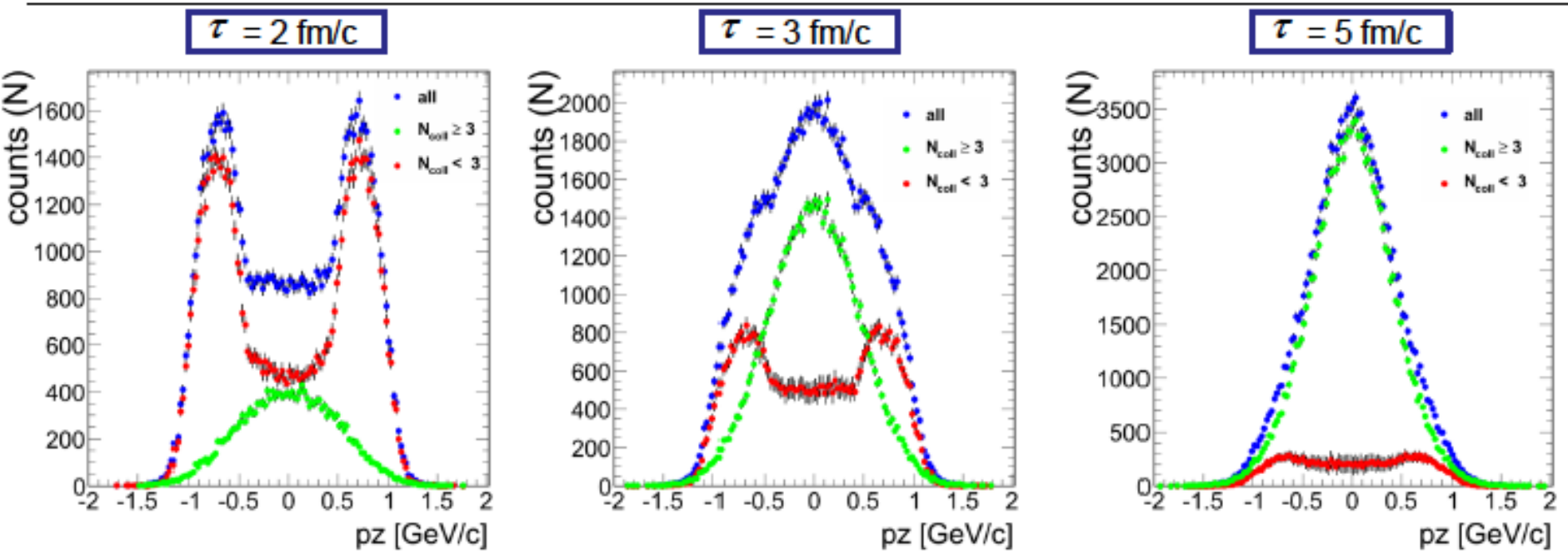
Observable: Production yields (steep excitation functions) and phasespace distributions

Thermalization? Au+Au@1.23A GeV

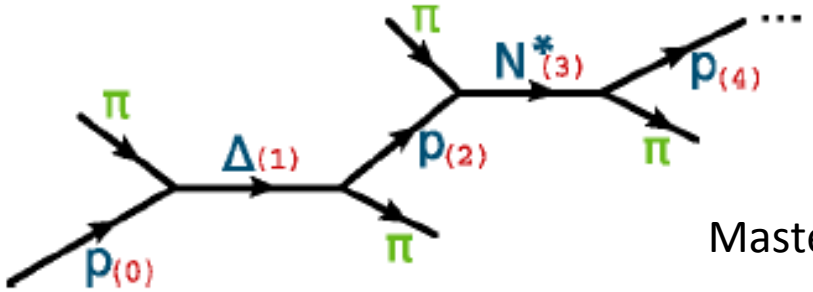
Momentum Evolution ($N_{coll} \geq 3$)

TECHNISCHE UNIVERSITÄT DARMSTADT

AuAu at 1.23 AGeV (Central Cell)



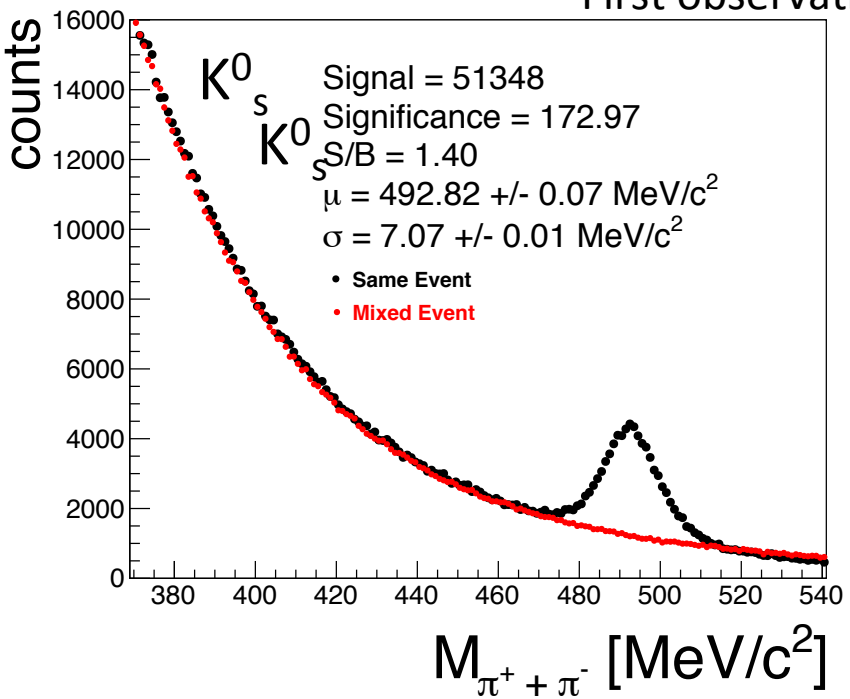
- Number of collisions a particle experiences is accumulated during the whole fireball evolution

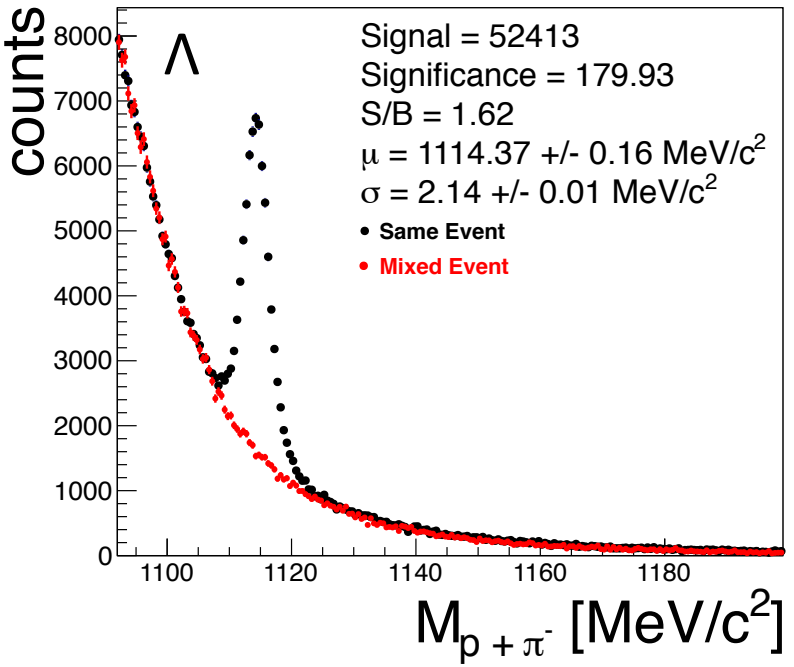


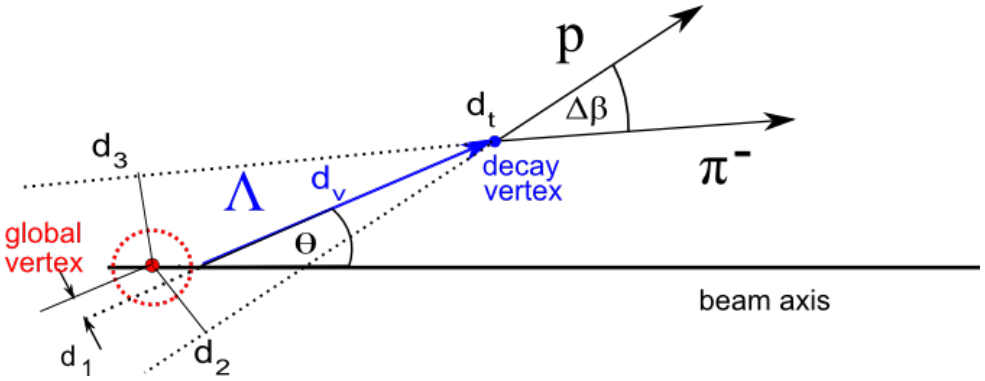
Master Thesis F.Seck

Performance: Secondary vertices

First observation at such low energy

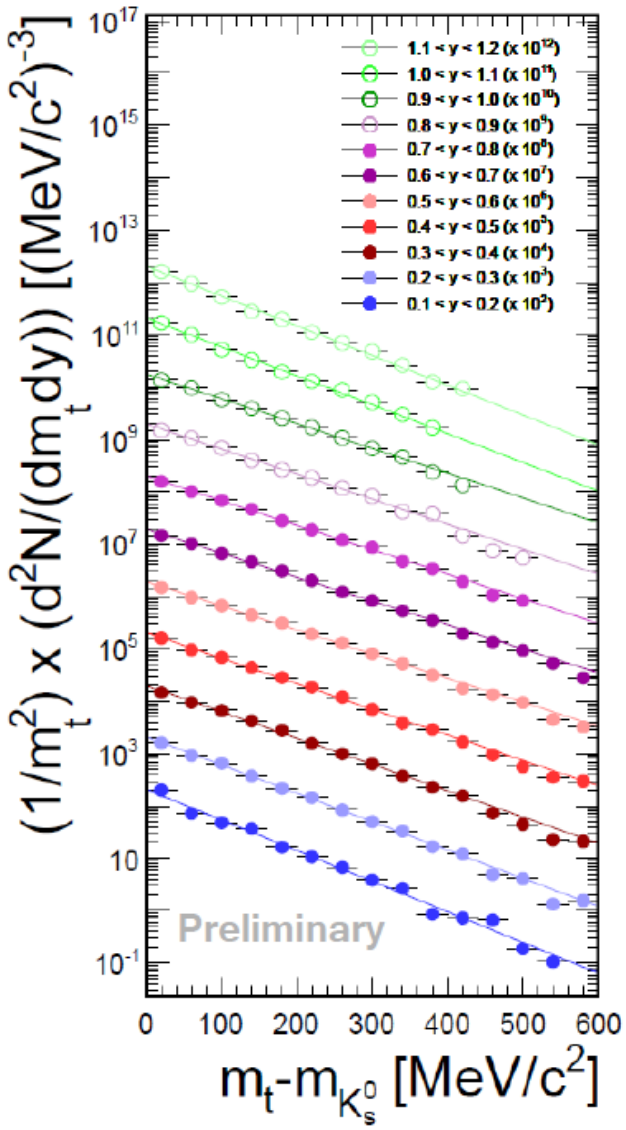


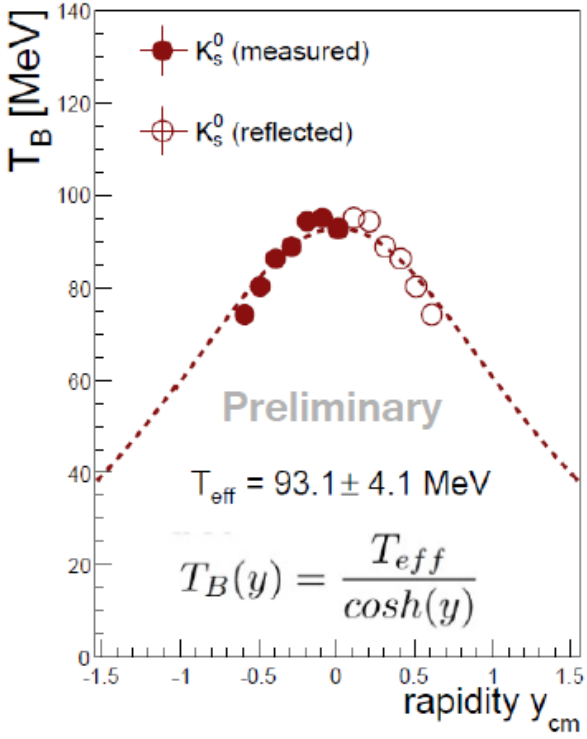


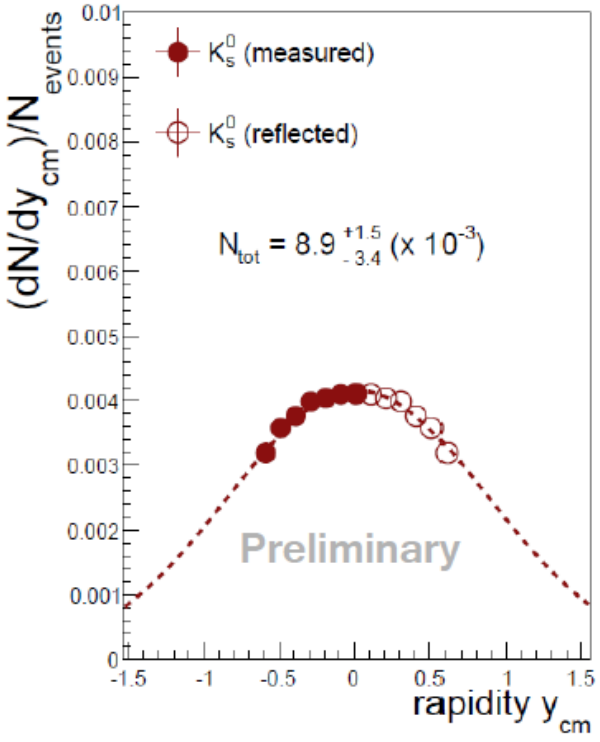


PhD T. Scheib

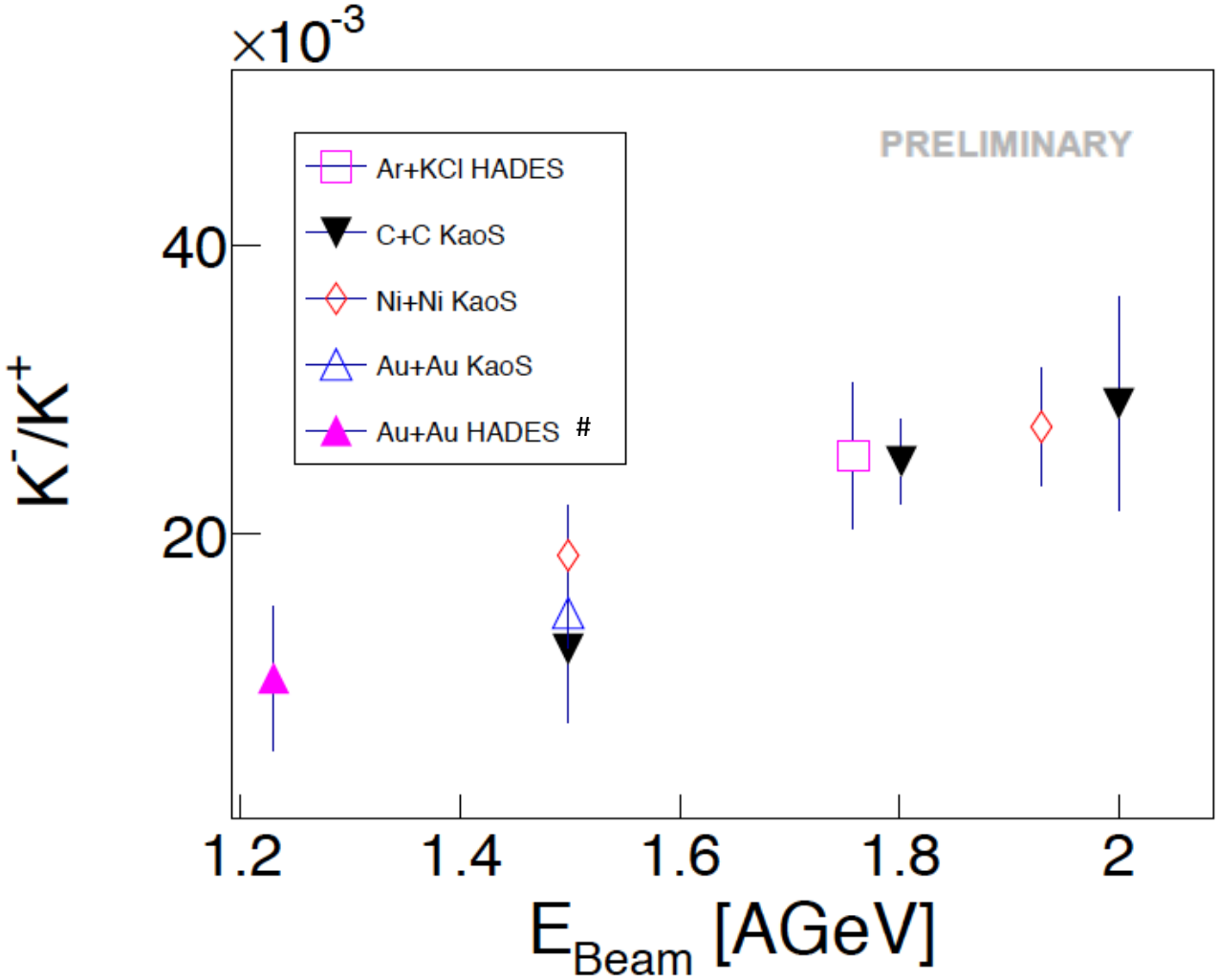
Neutral kaons: spectra and y-distribution







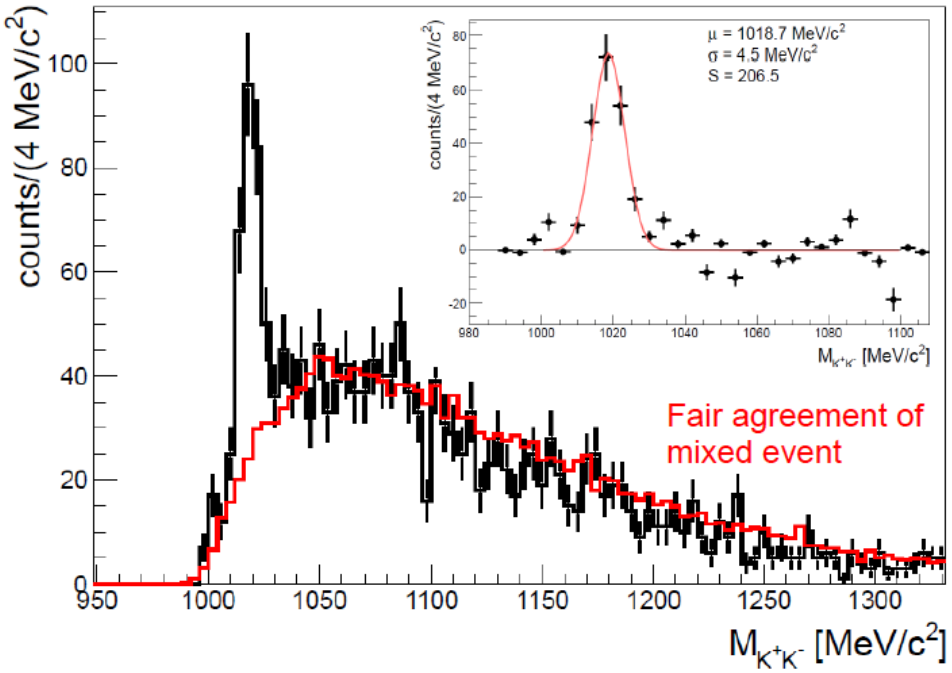
Charged kaons: comparison to other experiments



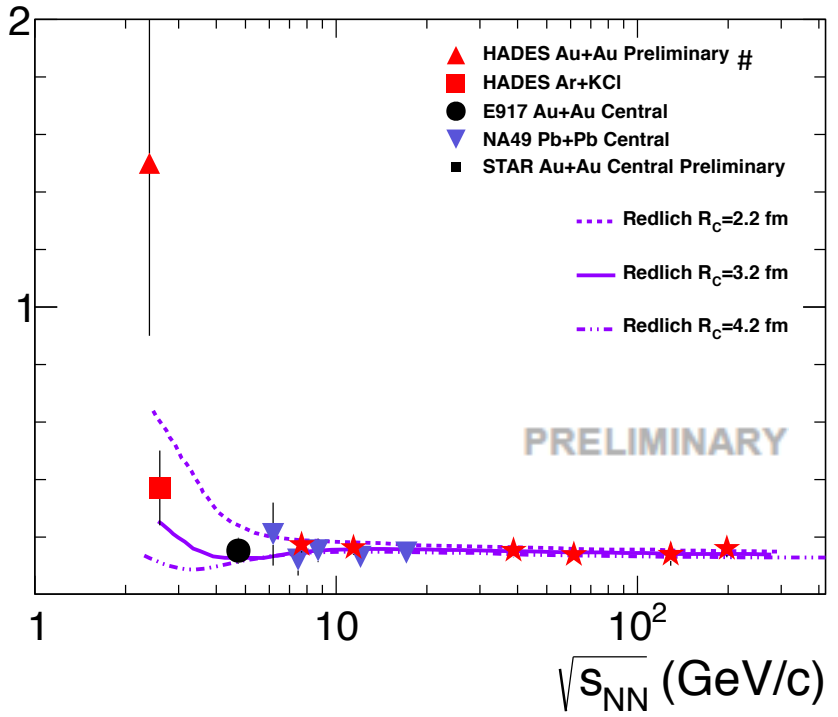
#First observation at such low energy

ratio at mid-rapidity

Φ and K^-



Φ meson reconstructed via charged kaons

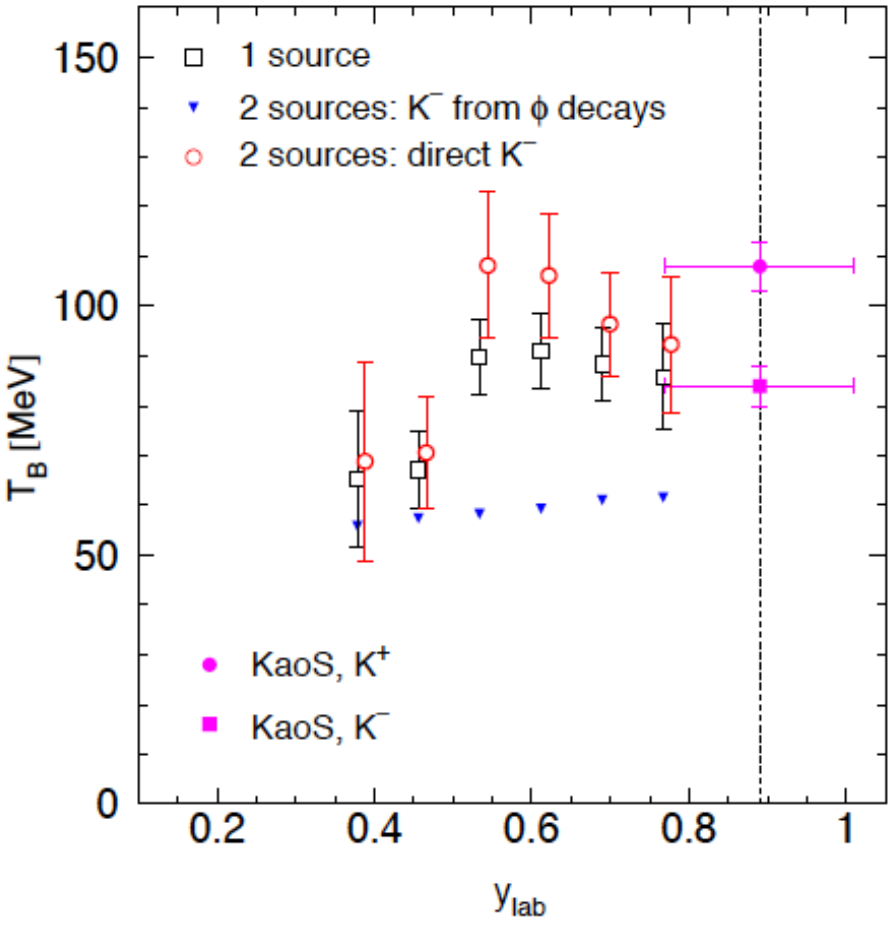


Strong rise of Φ/K^- ratio with decreasing beam energy as predicted by stat. model

PhD H. Schuldes

ratio at mid-rapidity

phi fopi



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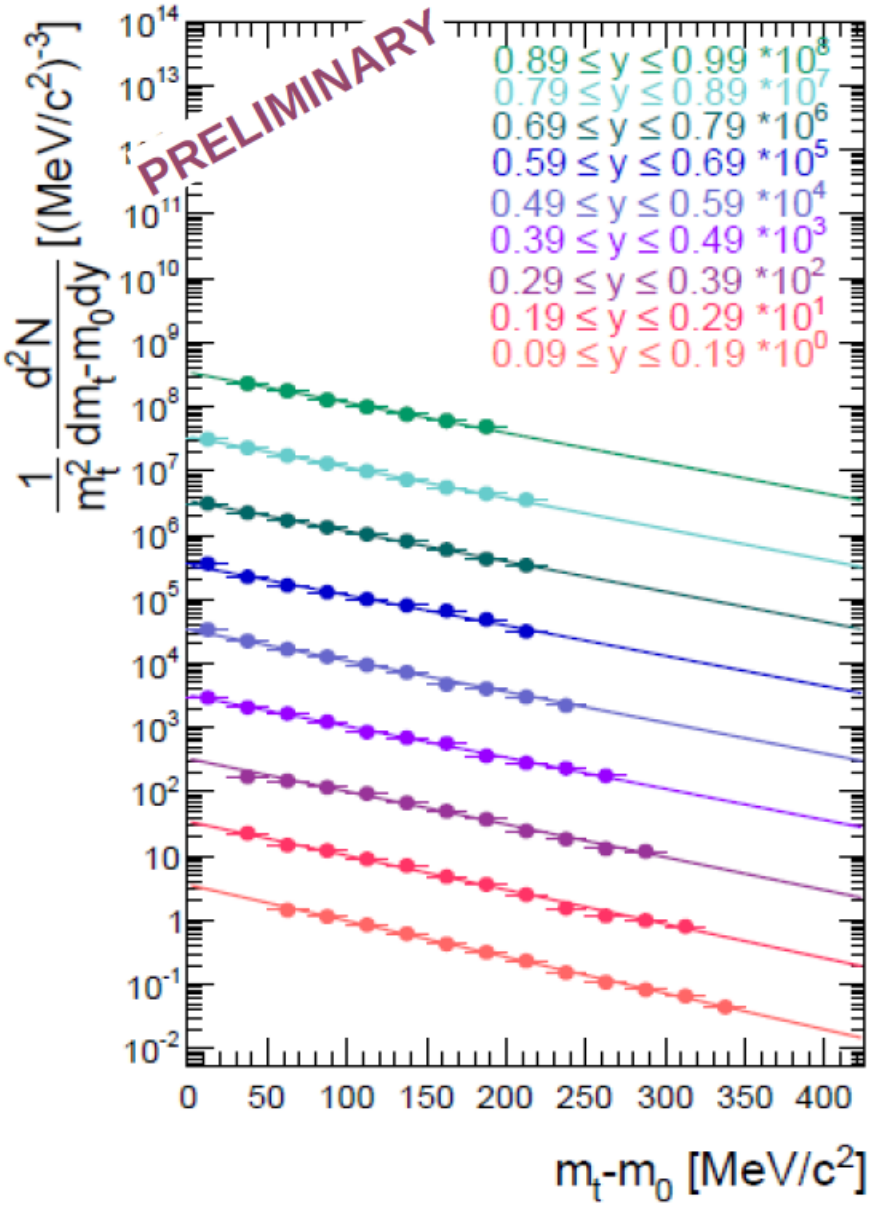
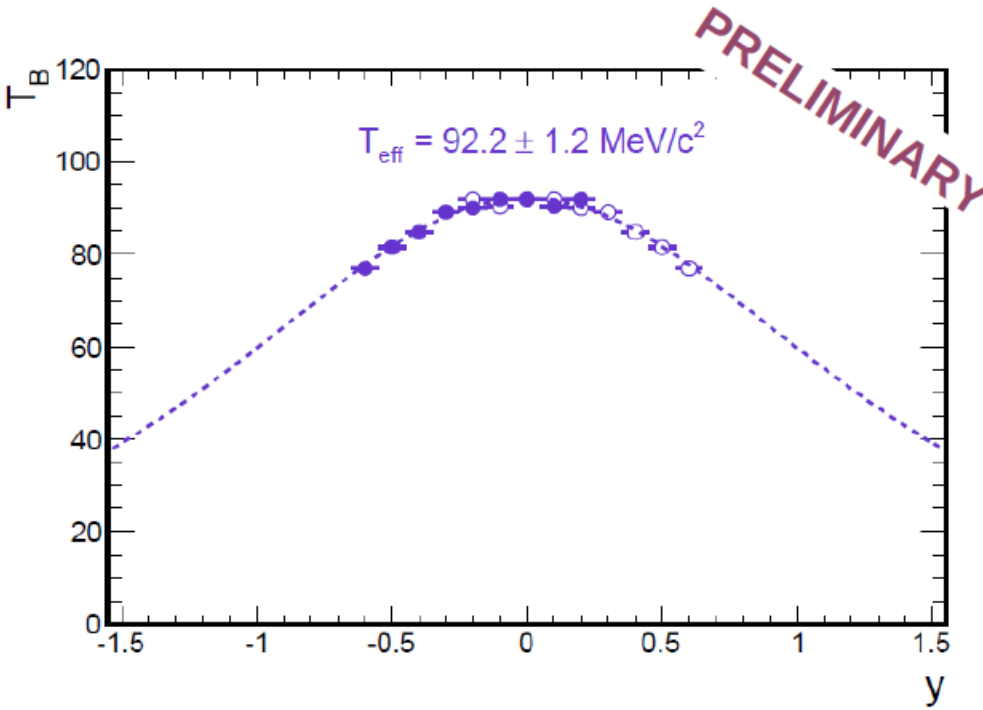
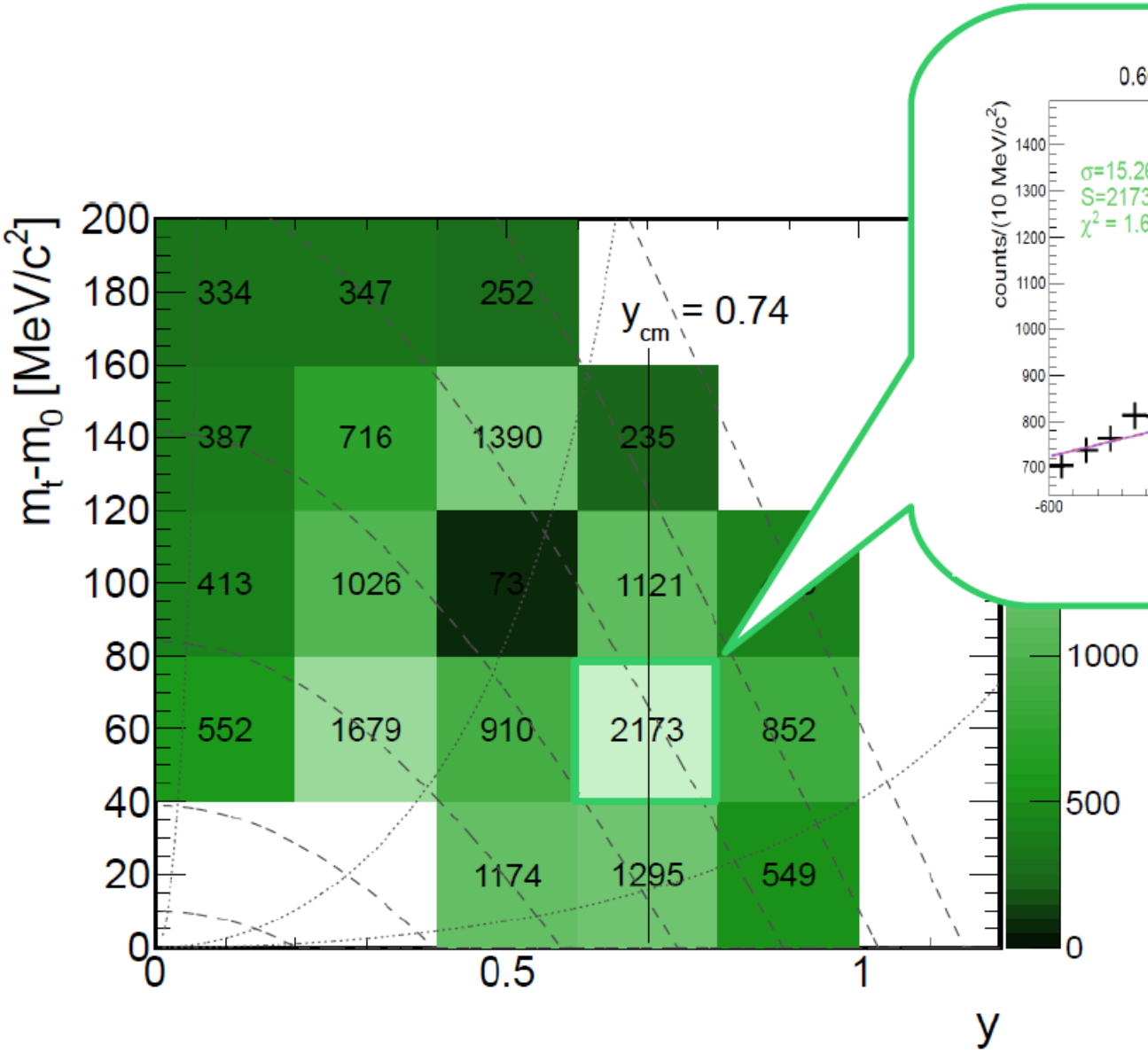
K^+: Phase space coverage

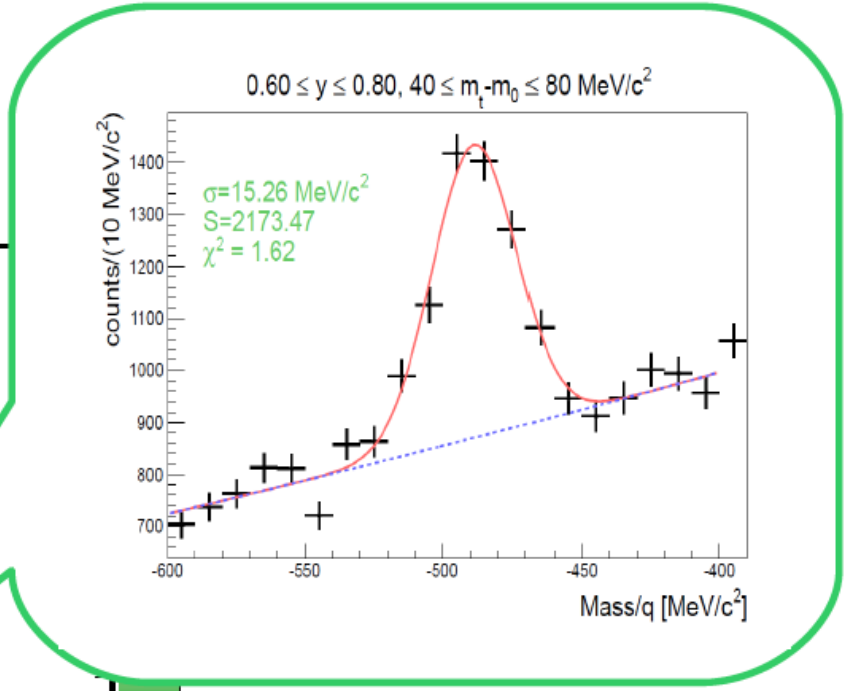


$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dy} = C(y)\cdot exp\left(-\frac{(m_t - m_0)c^2}{T_B(y)}\right)$$



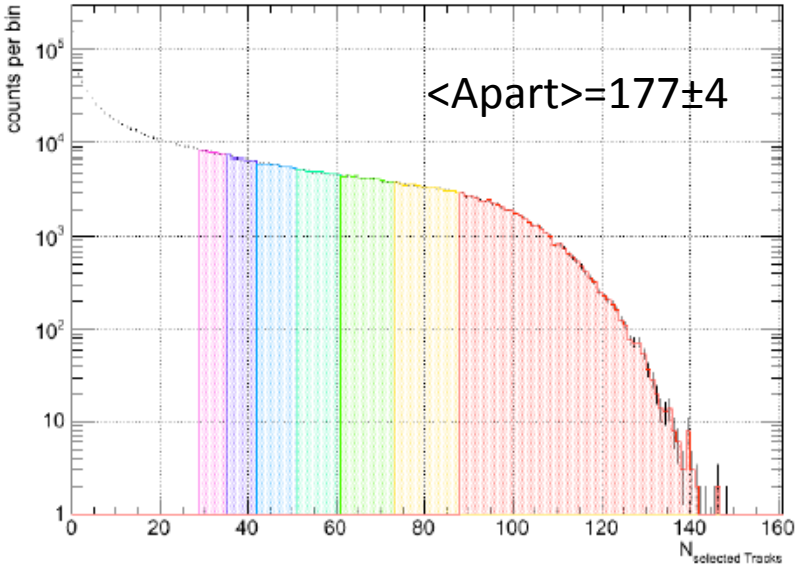
K^- : Phase space coverage



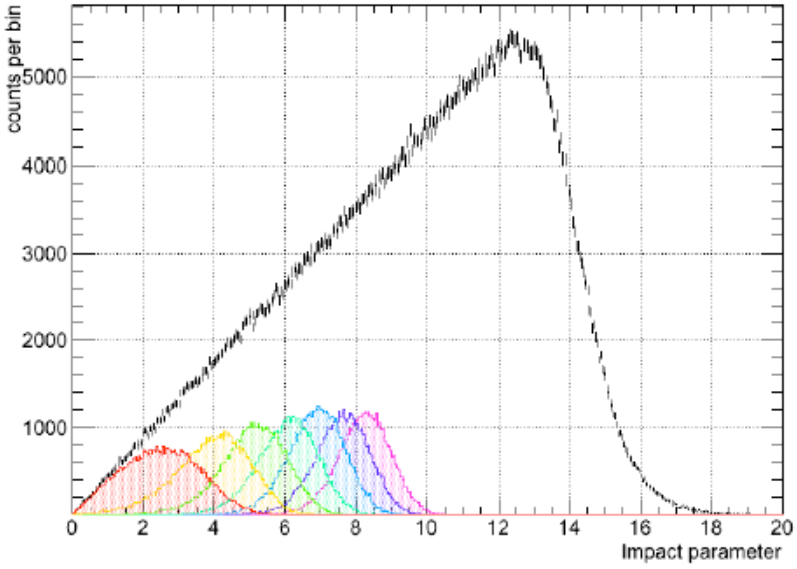


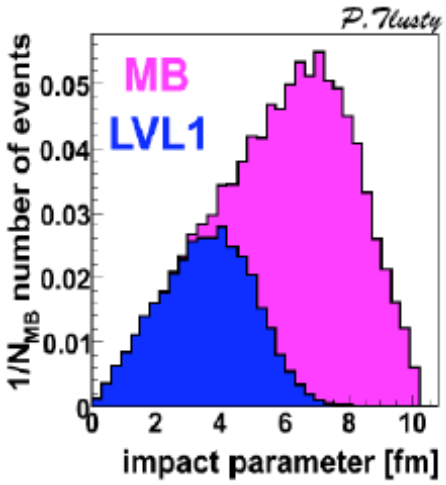
Centrality selection

N_{ch}



Impact parameter





Mean Apart= 177

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

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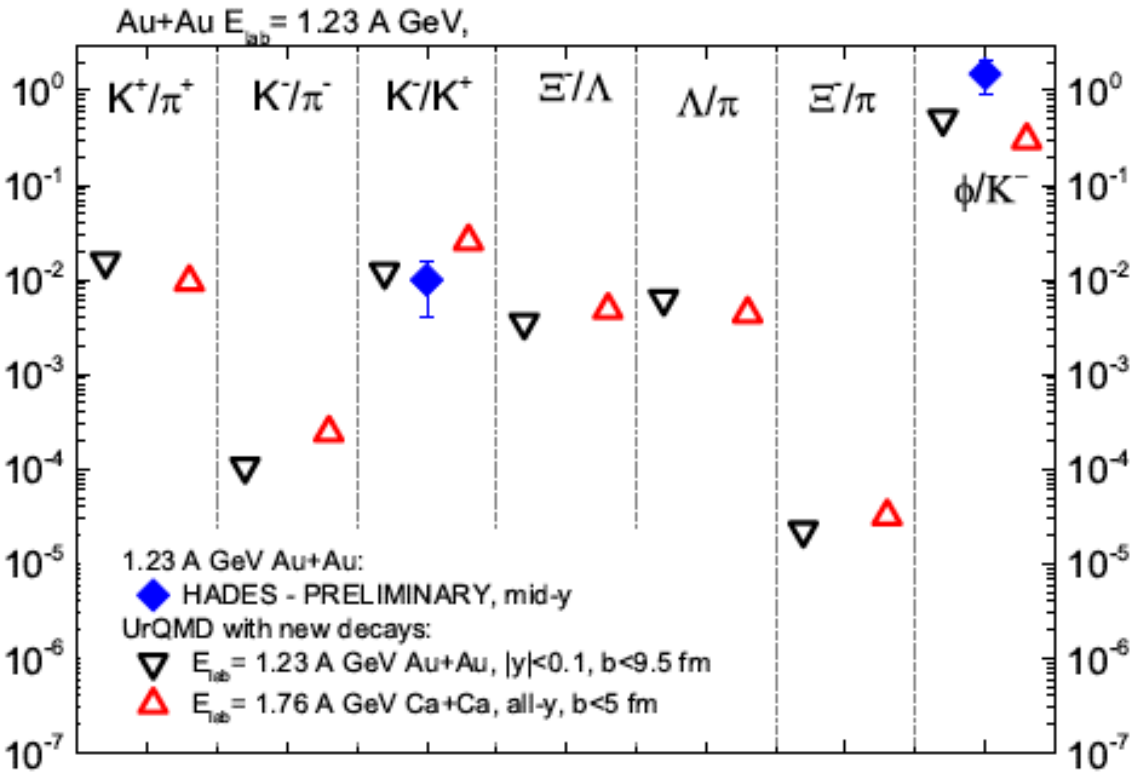
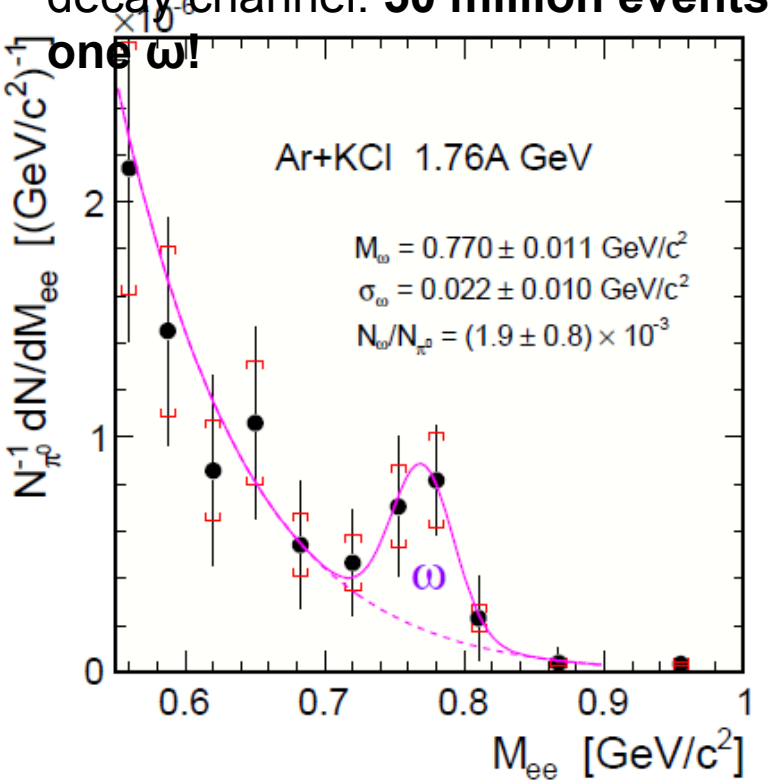
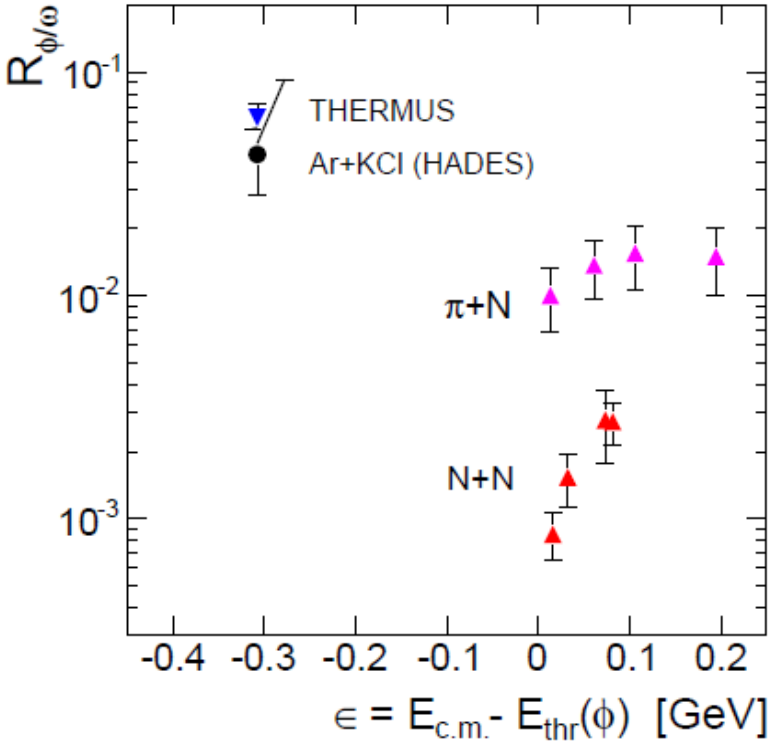


Ar+KCl: vector mesons

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



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



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

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

>> $R_{\phi/\omega}$ 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

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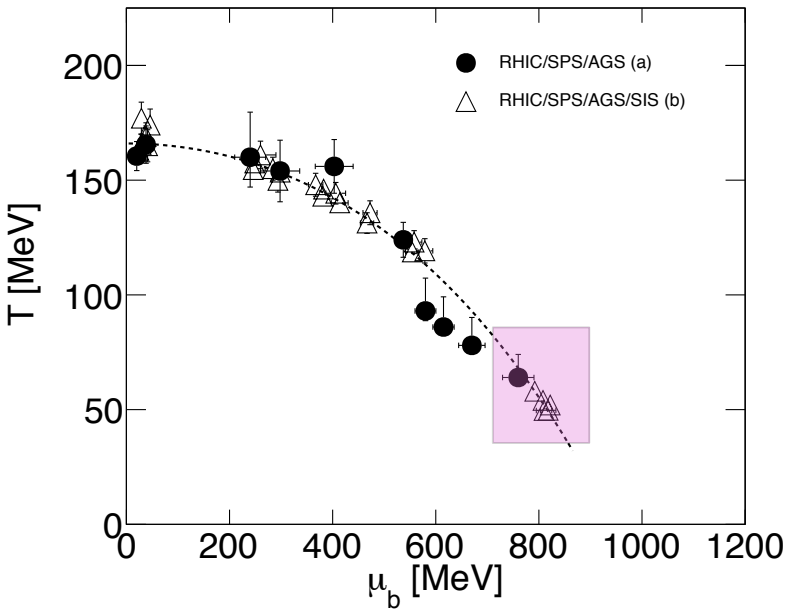


Particle production from a homogeneous source:

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

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)

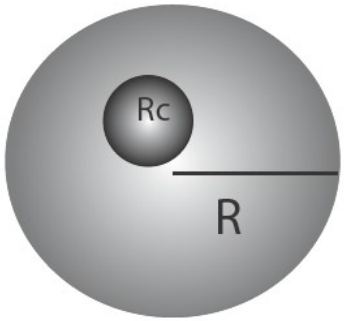
Yields reduced (canonical suppression)

• 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

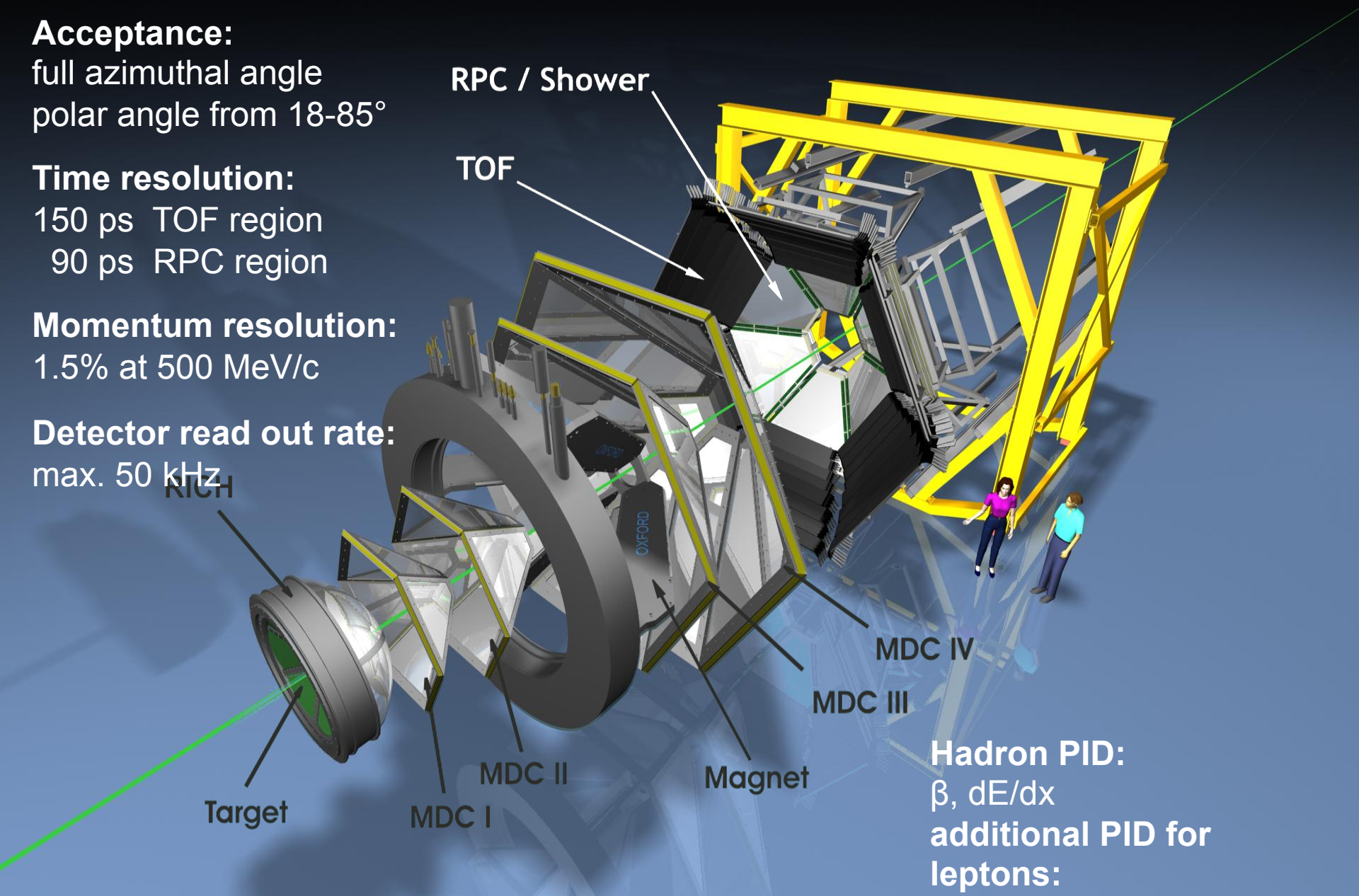
HADES

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:

Performance: data taking and analysis

557 hours beam Au on Au target in April 2012

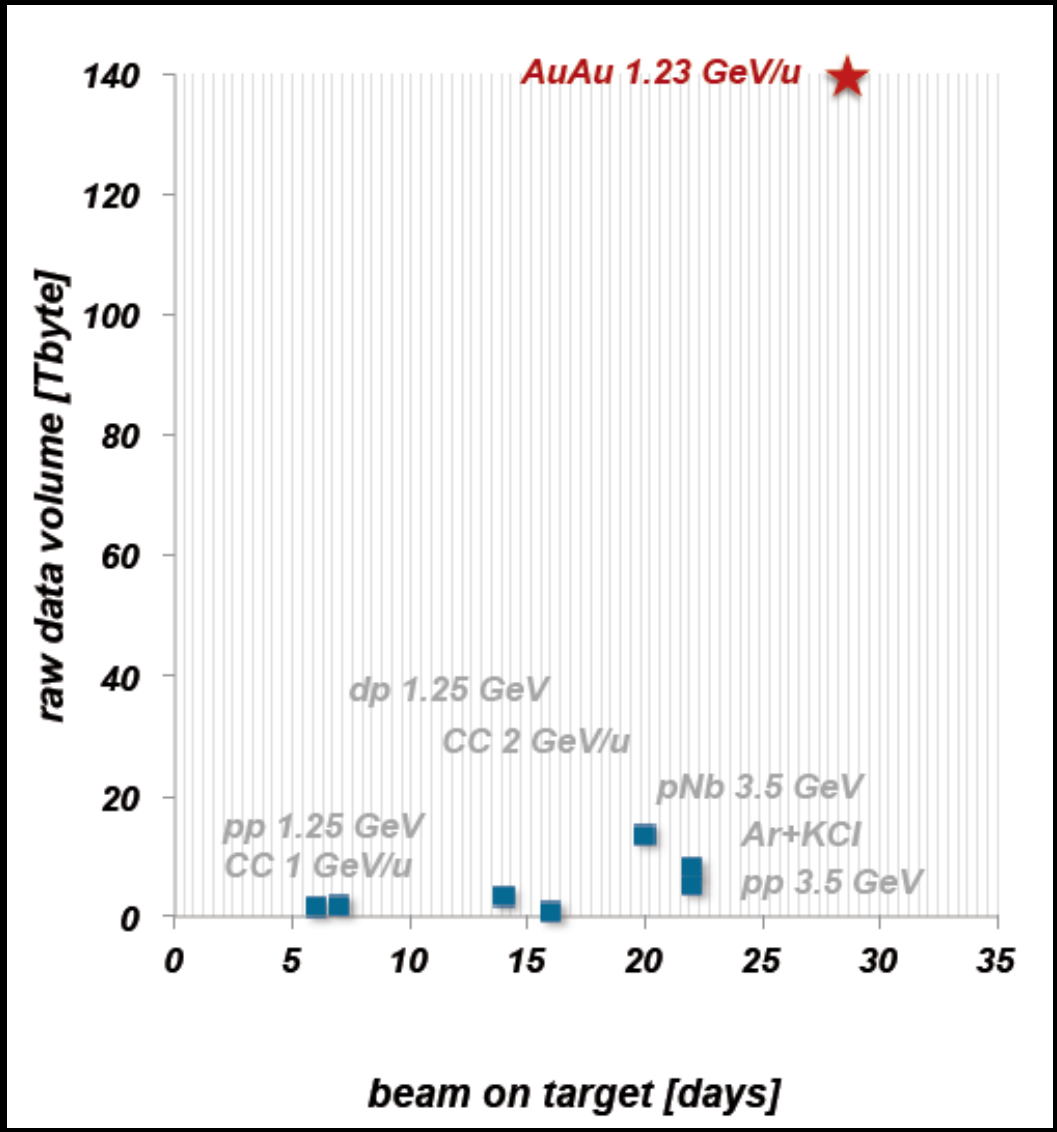
(1.2 - 1.5) x 10^6 ions per second

8 kHz trigger rate

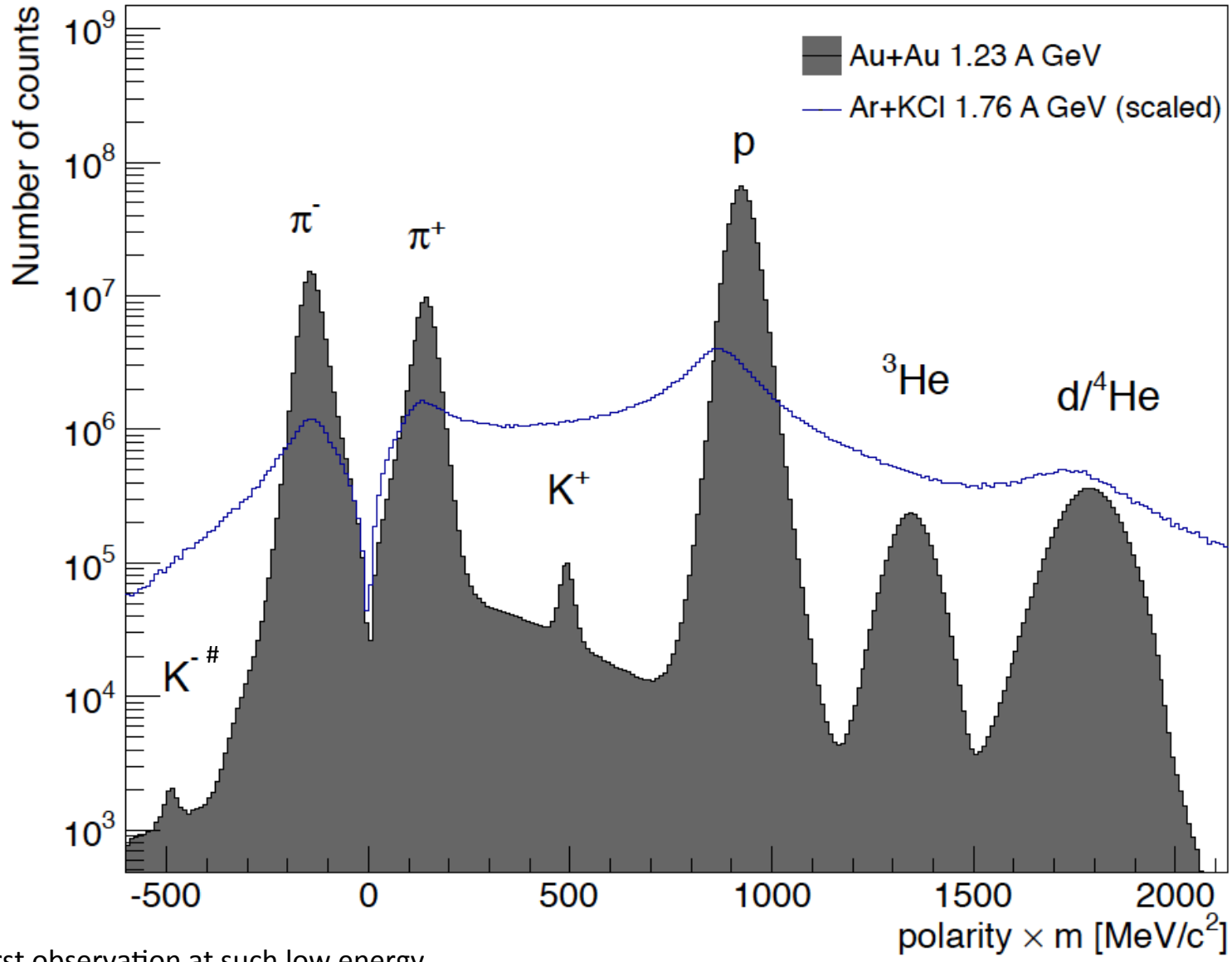
200 Mbyte/s data rate

7.3 x 10^9 events

140 x 10^{12} Bytes of data

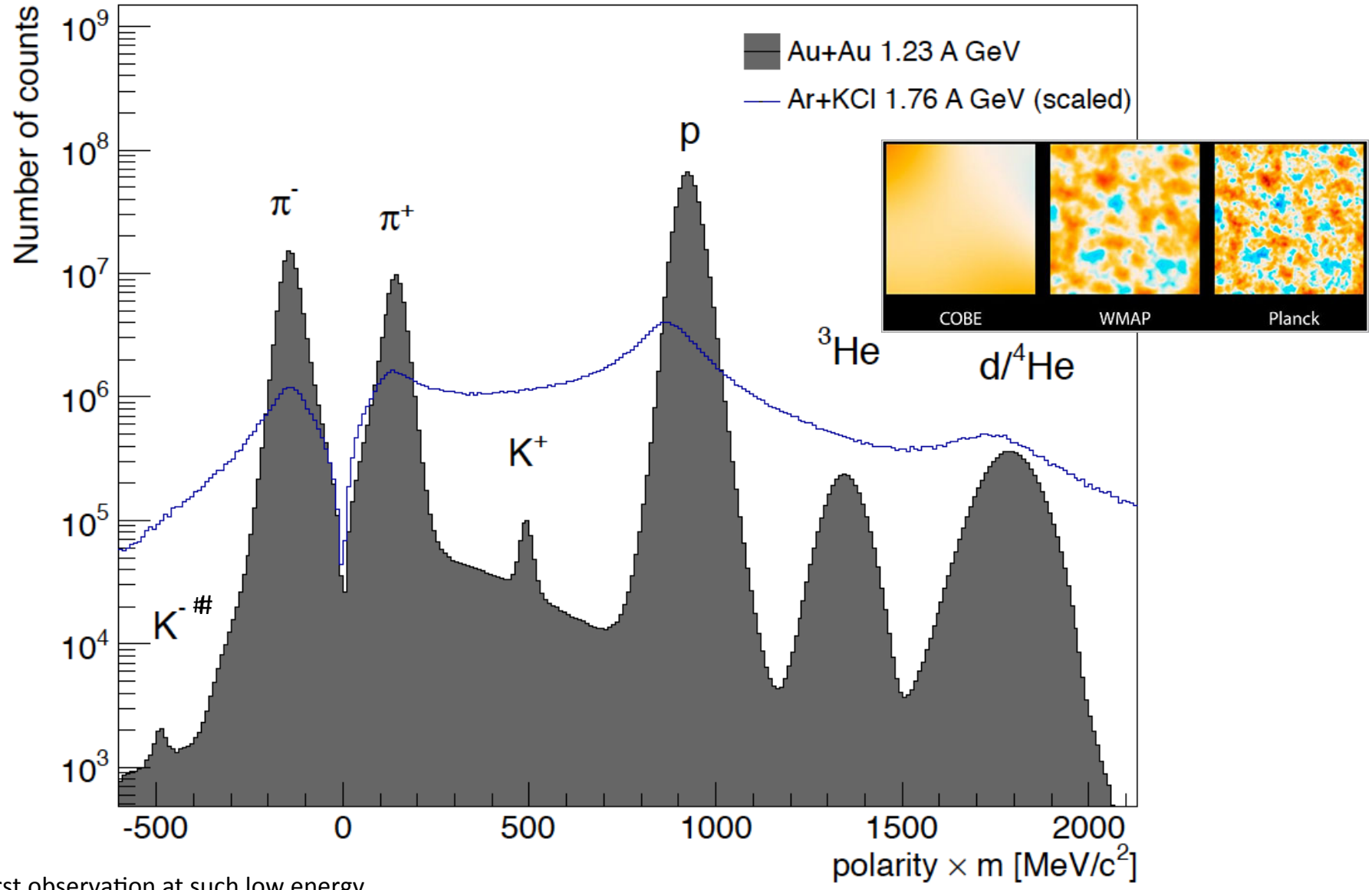


Performance: mass spectrum



#First observation at such low energy

Performance: mass spectrum



#First observation at such low energy