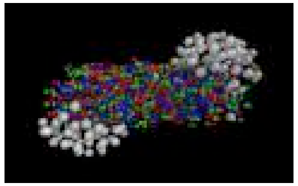
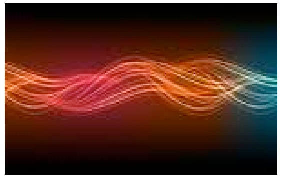
# Strangeness Physics with FOPI

Laura Fabbietti for the FOPI Collaboration

Excellence Cluster Universe TU-München

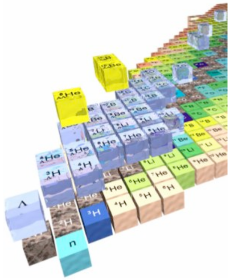
1) Strangeness in Heavy Ion Collisions at SIS18





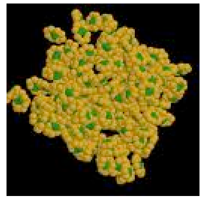
2) K+K- Flow in HIC

3) Hypernuclei in HIC



4) Stranger then strangeness

5) Statistical Model



# Why Heavy Ion Collisions?

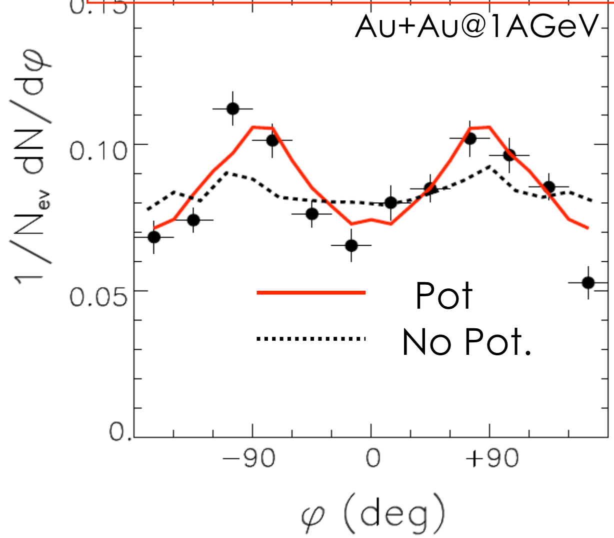
Study the in-medium properties of hadrons.

Heavy Ion Collisions access higher densities $\rho \sim 2\text{-}3\rho_0$ (E=1-3AGeV)

Does the dynamic or the yield of Kaons reflect an In-Medium Potential?

Flow

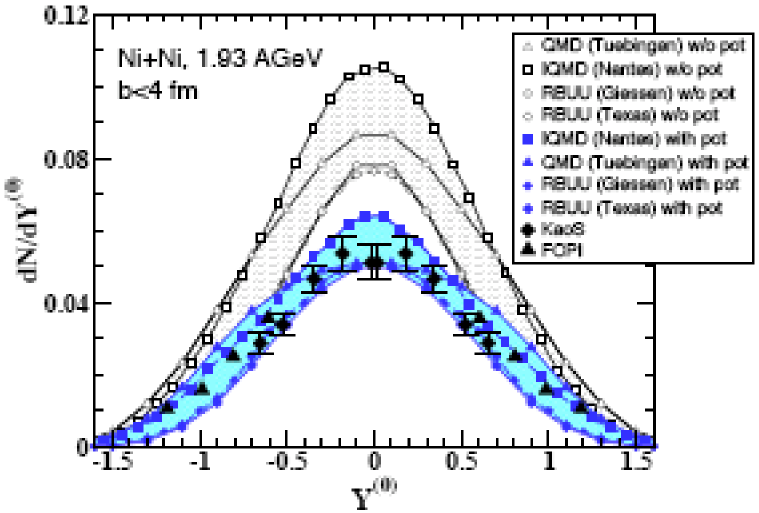
Y. Shin et al. Phys. Rev Lett. 81 (1998) 1576-1579.




RBUU:G.Q.Li et al. Phys. Lett. B 381 (1996) 17.

$K^+$

Yield

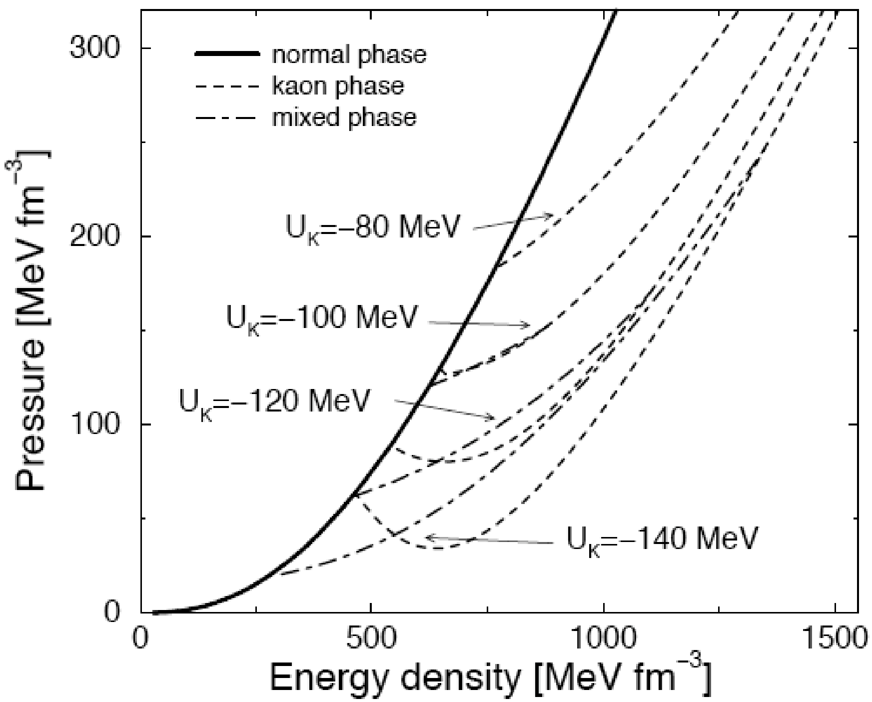



D. Best. et. al (FOPI) Nucl. Phys. A 625 (1997) 307
M- Menzel et al. (KAOS) Phys. Lett. B 495 (2000) 26.

# Consequences of the Kaon Potential

If the K⁻ -Nucleus Potential is attractive and the Equation of State Of Nuclear matter soft, Can kaon condensate occur?
Can this form the core of neutron stars?

N. K. Glenenning et al. Phys. Rev. C 60 025803 (1999)



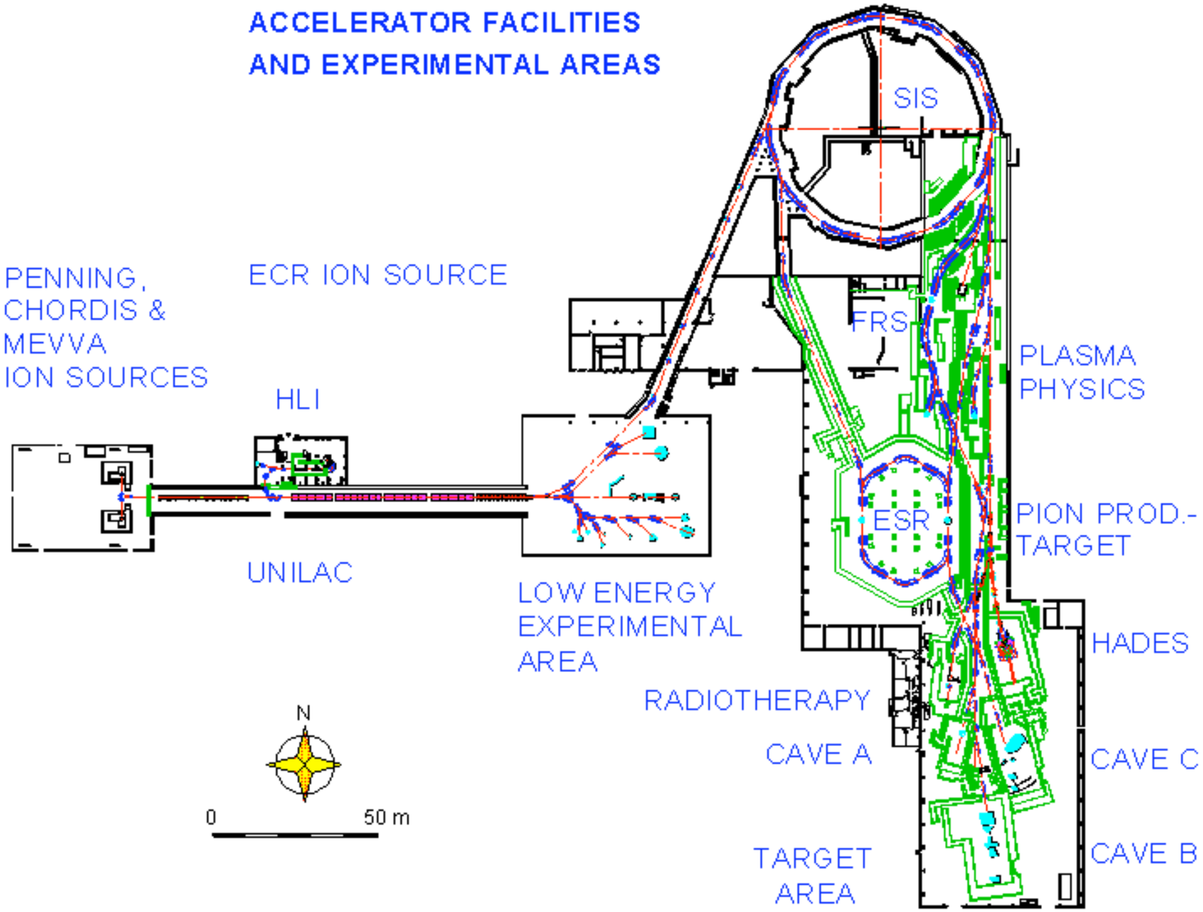

$U_{K-}$ ?

# SIS18 at GSI

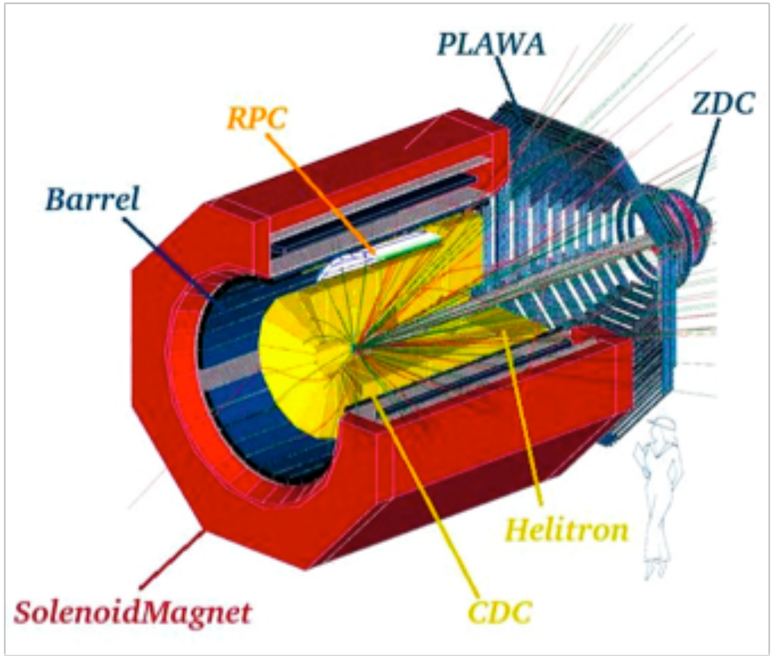
p Beam up to 3.5 GeV

C-U 2AGeV

$\pi^{\pm}$ up to 1.7GeV/c

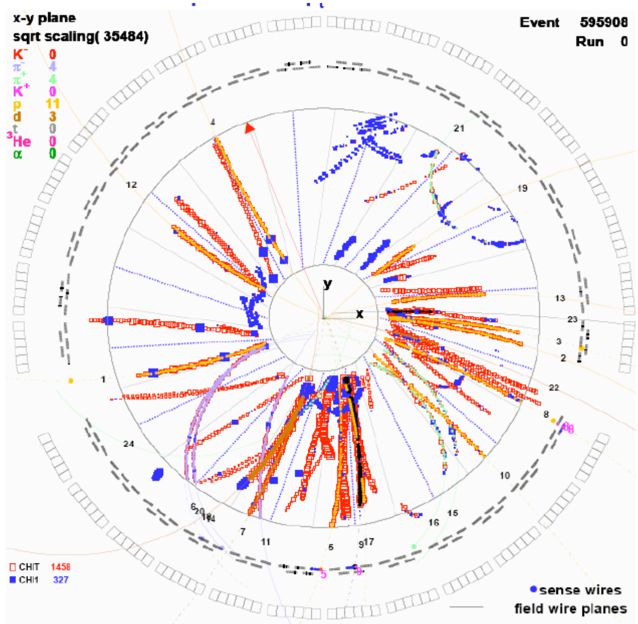


# The FOPI Spectrometer




$4\pi$ Acceptance
$\Delta p/p$ ~5-7%
X-Y Vertex Resolution ~5mm
RPC @ Midrapidity $\sigma_t$ ~80 ps

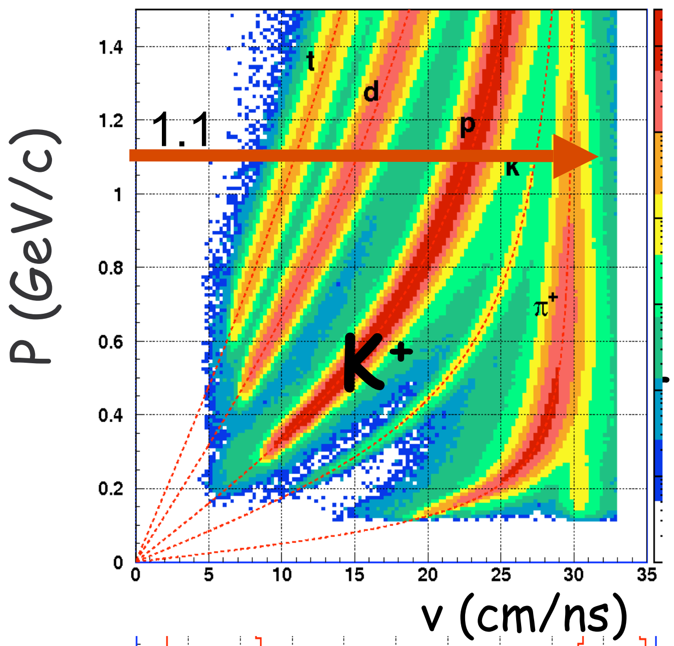
~1,2 Rapidity Units

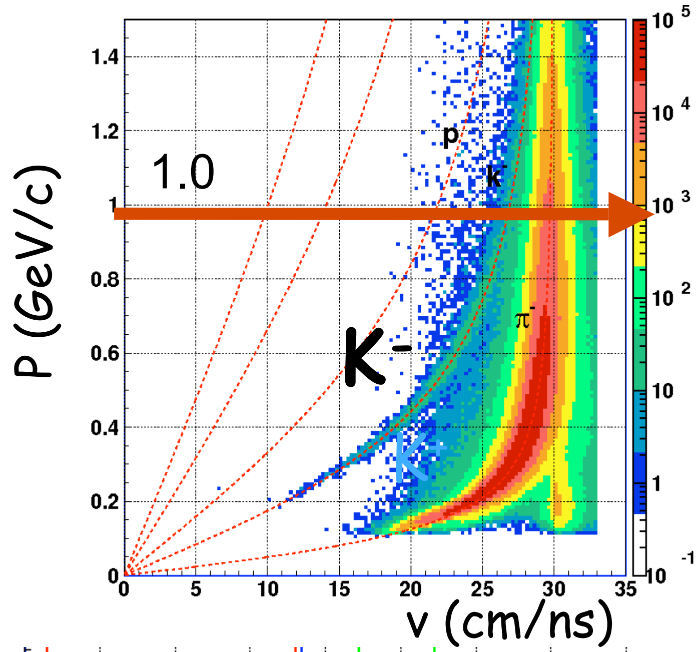


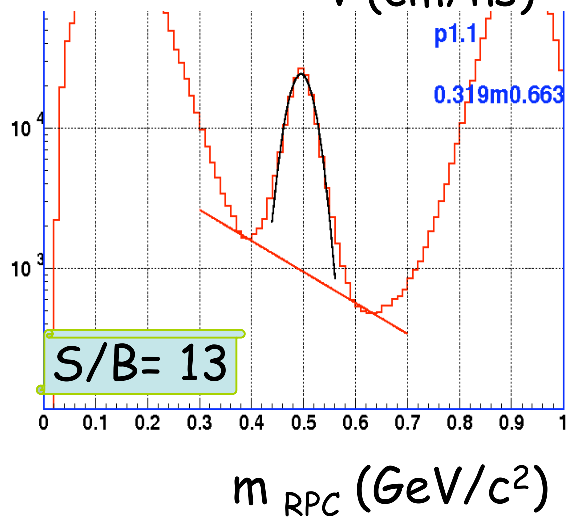

Al+Al at 1.91 AGeV (2005)
Ni+Ni at 1.91 AGeV (2008)
p+p at 3.1 GeV (2009)

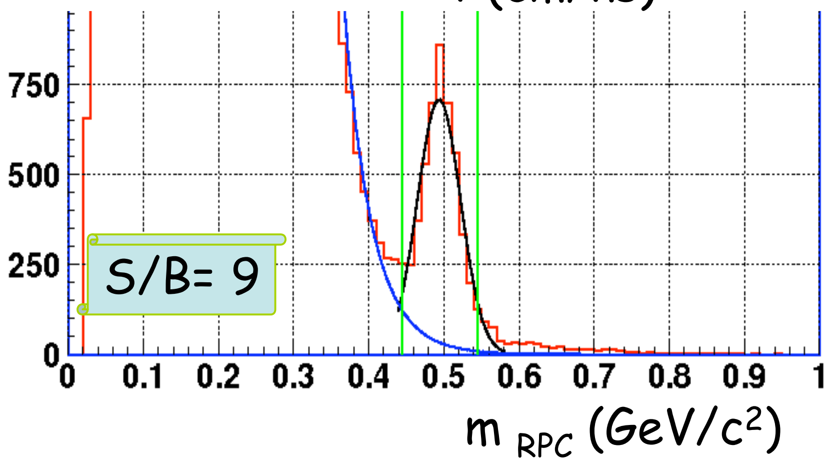
# Particle Identification

T.I. Kang

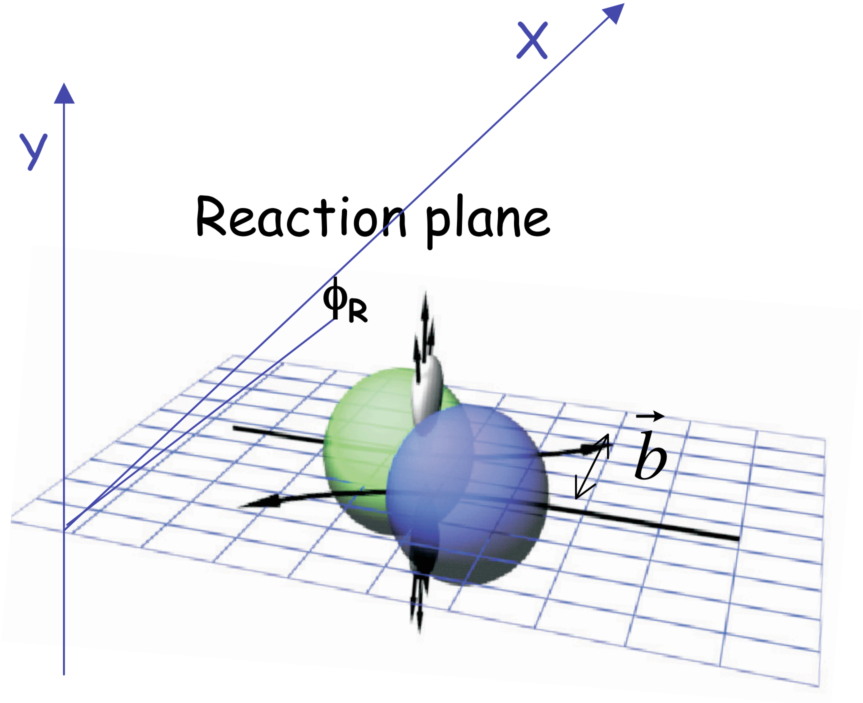


# Flow




J. Y. Ollitrault, Nucl. Phys. A638, 195c (1998)
P. Danielewicz and G. Odyniec, Phys. Lett. 157B, 146 (1985)

$$\frac{dN}{d\varphi} \propto (1 + 2v_1\cos(\varphi) + 2v_2\cos(2\varphi) + \ldots)$$

$$\varphi = \phi - \phi_R$$

- **Directed flow**
  - First order Fourier coefficient
  - $v_1 = \langle p_x/p_t \rangle$
    - Flow, $v_1 < 0$ in backward y
    - Anti-flow, $v_1 > 0$ in backward y
- **Elliptic flow**
  - Second order Fourier coefficient
  - $v_2 = \langle (p_x^2 - p_y^2)/(p_x^2 + p_y^2) \rangle$
    - In-plane flow, $v_2 > 0$
    - Out-of-plane-flow, $v_2 < 0$

# Directed Flow, what for?

K$^+$ and K$^-$ have the same flow when they are produced. Then...

K$^+$ undergo Rescattering

The flow aligns to that of nucleons

+ Potential Effects

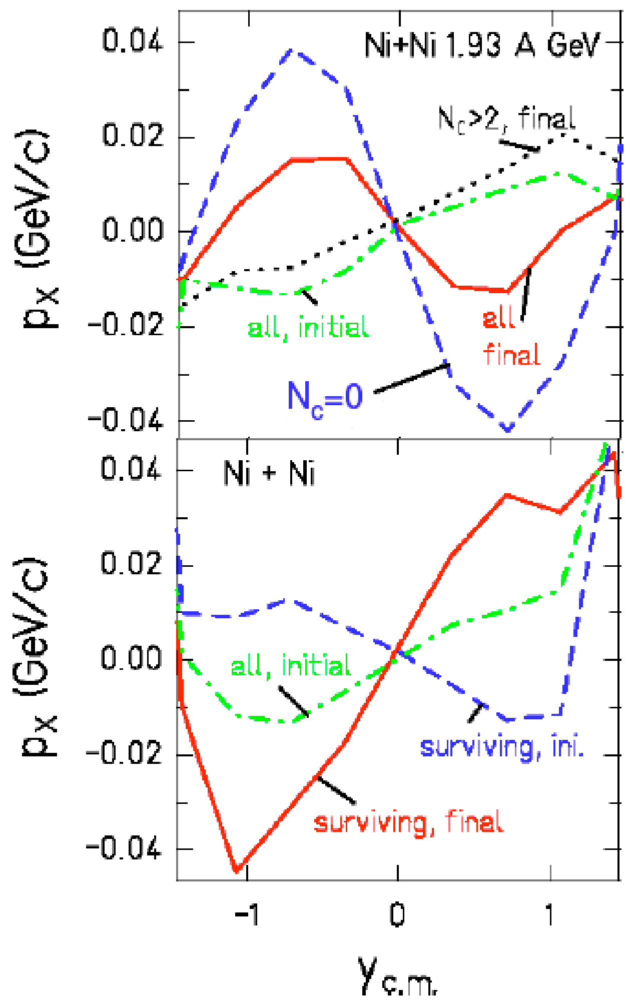
K$^-$ undergo Absorption

+ Potential Effects

Study of the Flow Dependence upon

1) Rapidity
2) Centrality of the Reaction
3) $p_T$

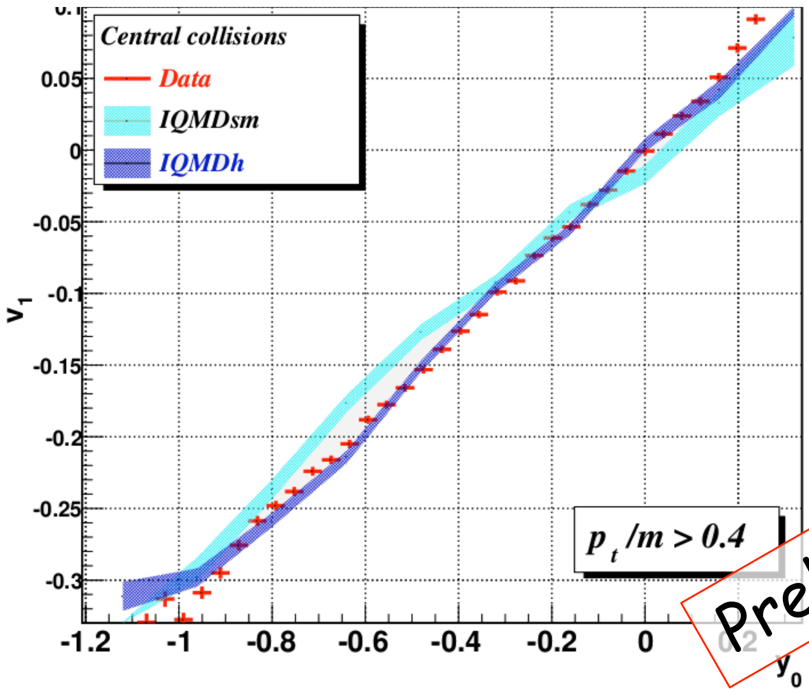
IQMD: C. Hartnack et al. Eur. Phys. J A (1998) 151.



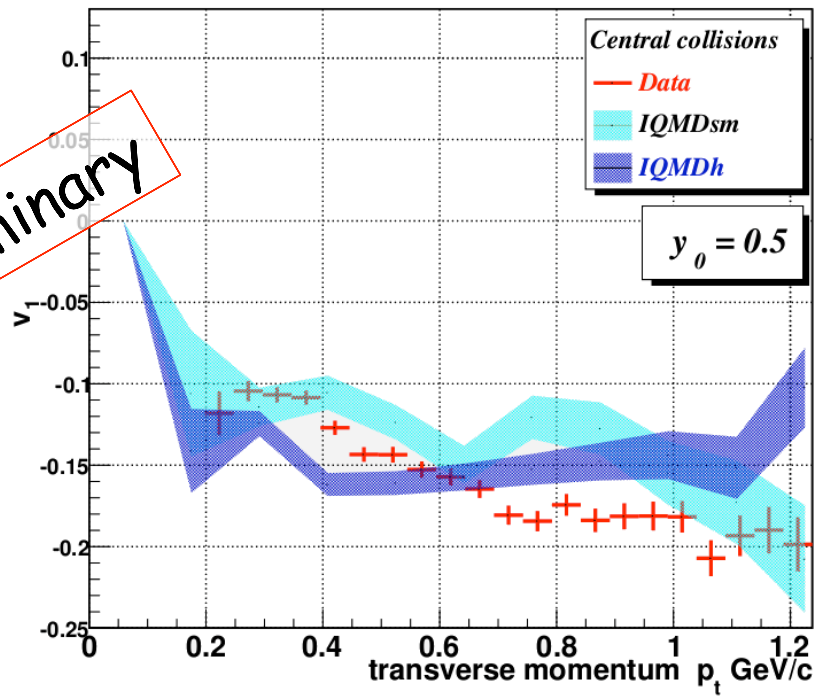
# Proton Flow

Ni+Ni @ 1.91 AGeV

V.Zinyuk



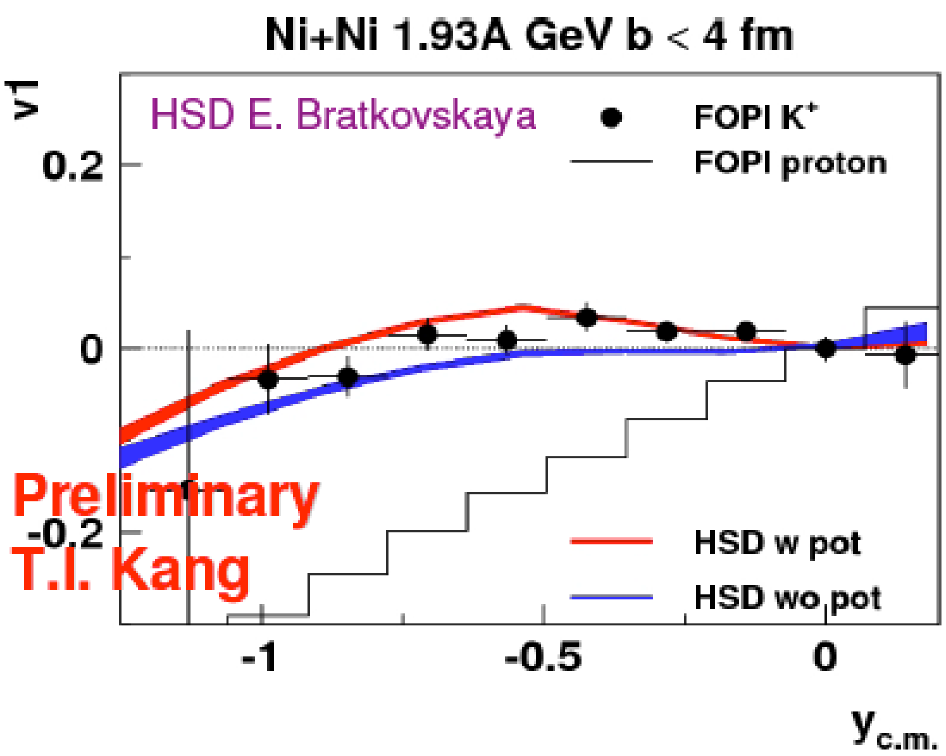

Rapidity distribution
Shows a good agreement between theory and experimental data.. But.. Pt dependences are missed by the model

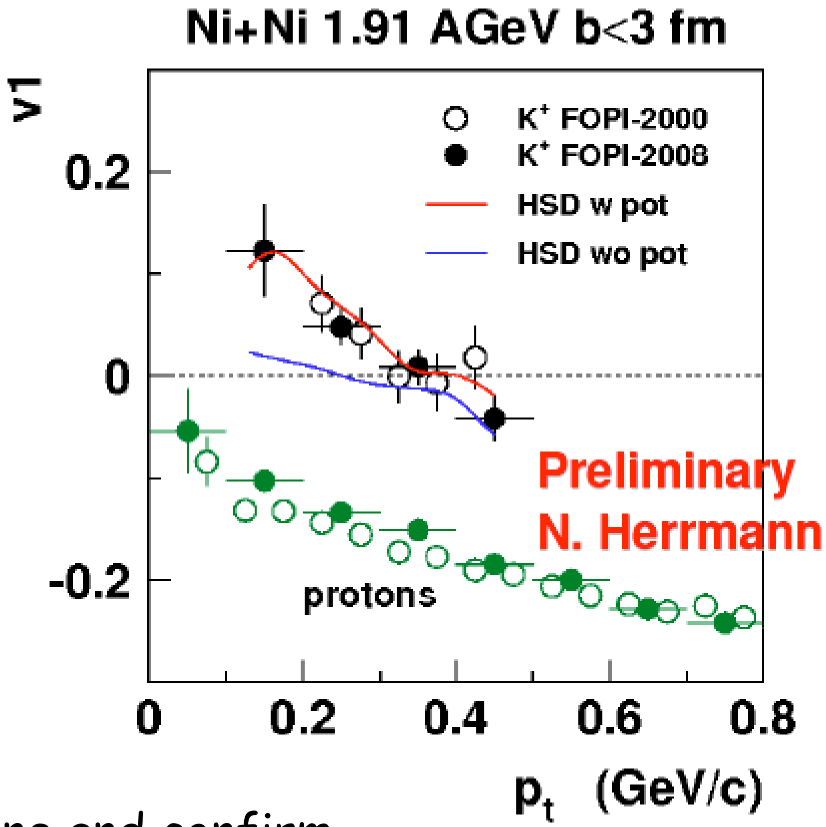


# $p_T$ Dependence I

HSD: W. Cassing et al. Phys. Rep. 308 65 (1999)

P.Crochet et al. Phys. Lett. B 486 (2000) 6.



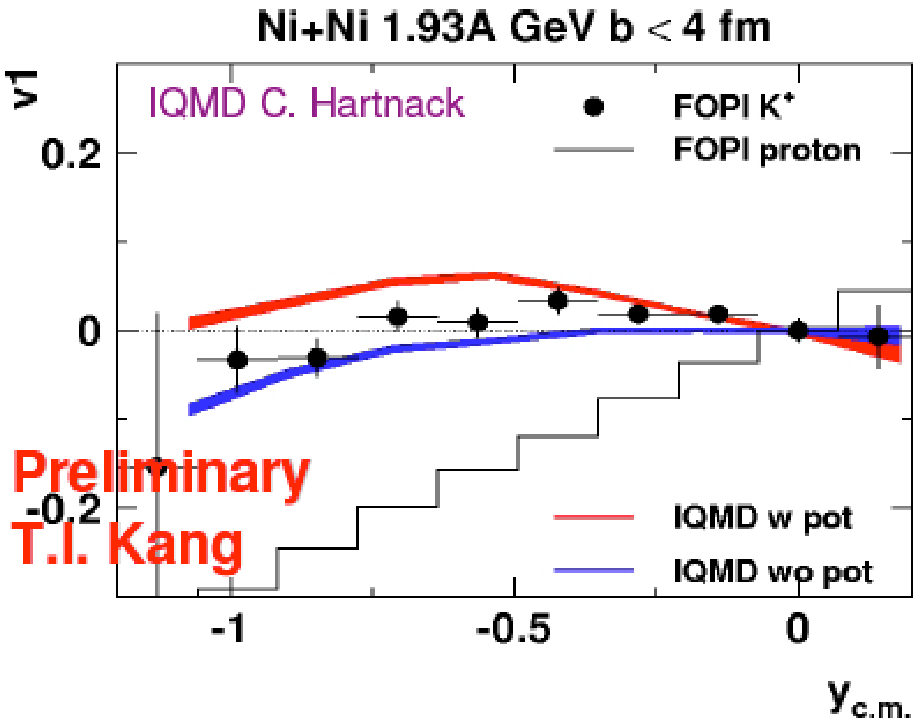



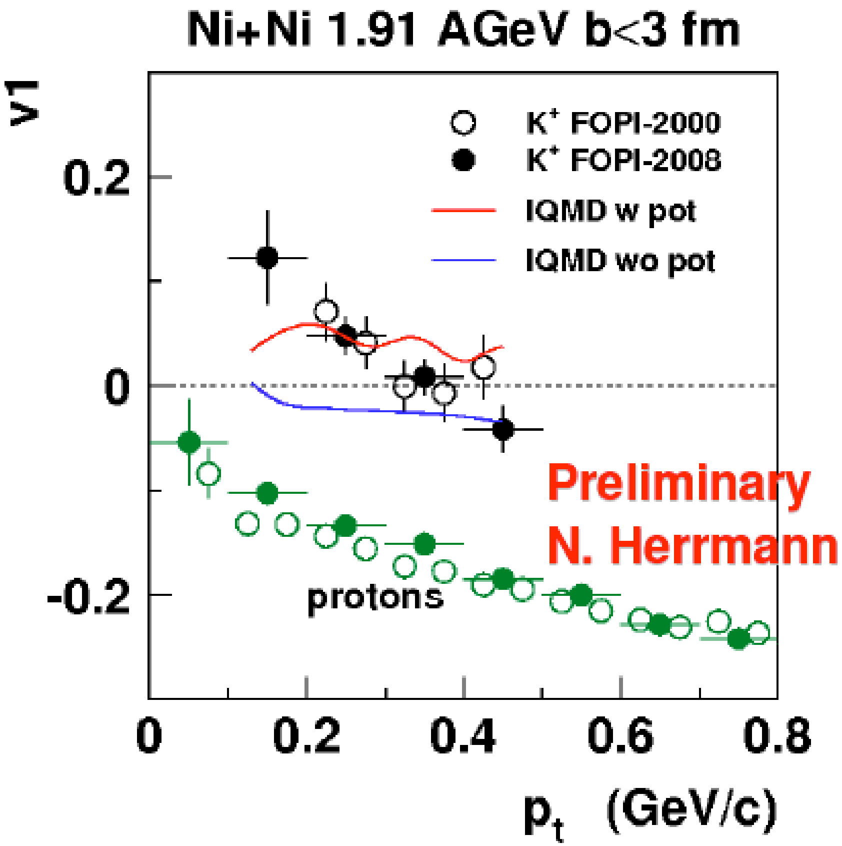

New Data are consistent with old one and confirm

a $K^+$-Nucleus potential of about 20 MeV

# $p_T$ Depence II

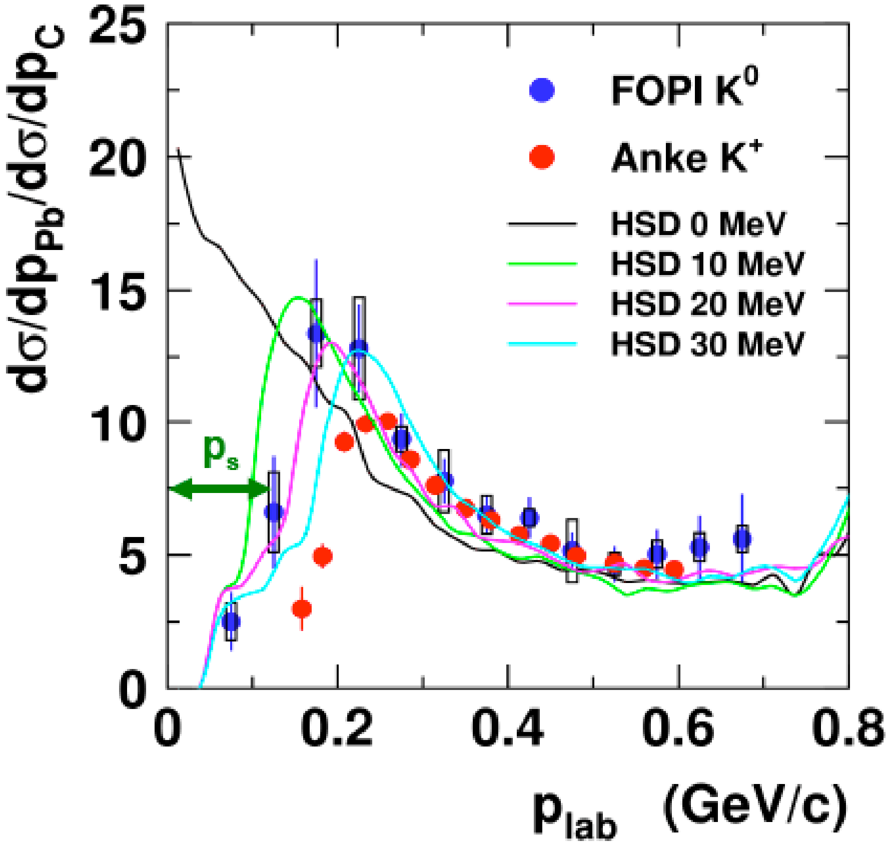
P.Crochet et al. Phys. Lett. B 486 (2000) 6.




Differences between IQMD and HSD!!

# $K_S^0$ from $\pi$+A Reactions




M. L. Benabderramahne et al., Phys. Rev. Lett 102 183591 (2009)

$\pi + A \to K^0 + X$ at 1.15 GeV/c (FOPI)

M. Büscher et al., EPJ A22, 301 (2004)

$p + A \to K^+ + X$ at 2.5 GeV/c (ANKE))

Calculations with the HSD model reproduce the Data using:

**<u>Repulsive Potential of 20 MeV for $K^+$ and $K^0$</u>**

P. Crochet et al., Phys. Lett. B 486 6 (2000)

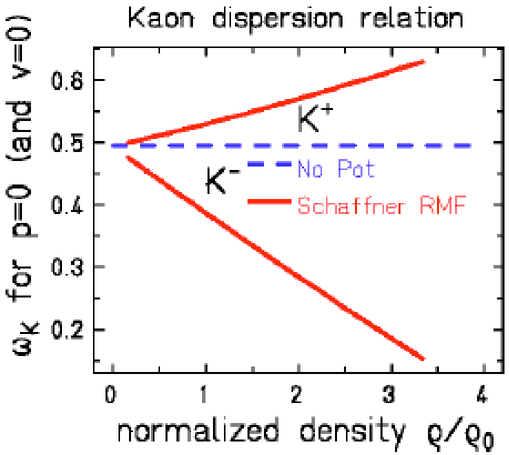
Result supported also by the K+ direct flow measurements!

HIC results are in agreement with pion results

# Different Theories

Y. Leifels

$$m(\rho) = m_0\left(1 + \alpha\frac{\rho}{\rho_0}\right)$$




| HSD | |
|---|---|
| $K^+$ | $\alpha$= 0.04 |
| | $U(\rho_0)$= 20 MeV |
| $K^-$ | G-Matrix |
| | $U(\rho_0)$= 70 MeV |

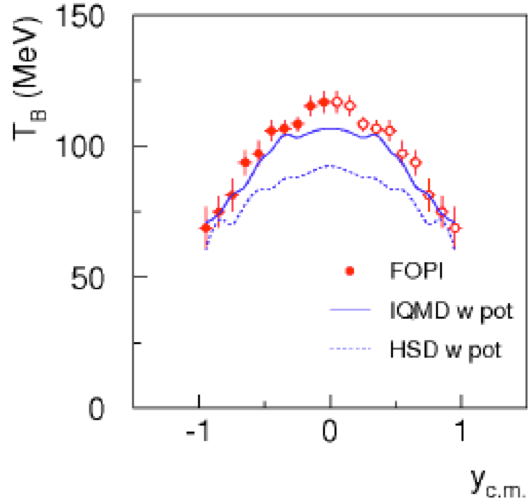
| IQMD | |
|---|---|
| $K^+$ | $\alpha$= 0.07 |
| | $U(\rho_0)$= 40 MeV |
| $K^-$ | $\alpha$= -0.20 |
| | $U(\rho_0)$= 100 MeV |

Shallower Potential!

M. Merschmeyer et al. Phys. Rev. C 76 (2007) 02490

HSD underestimates the Kaon Slopes

Ni+Ni 1.93AGeV b< 3.3 fm $K^0_S$

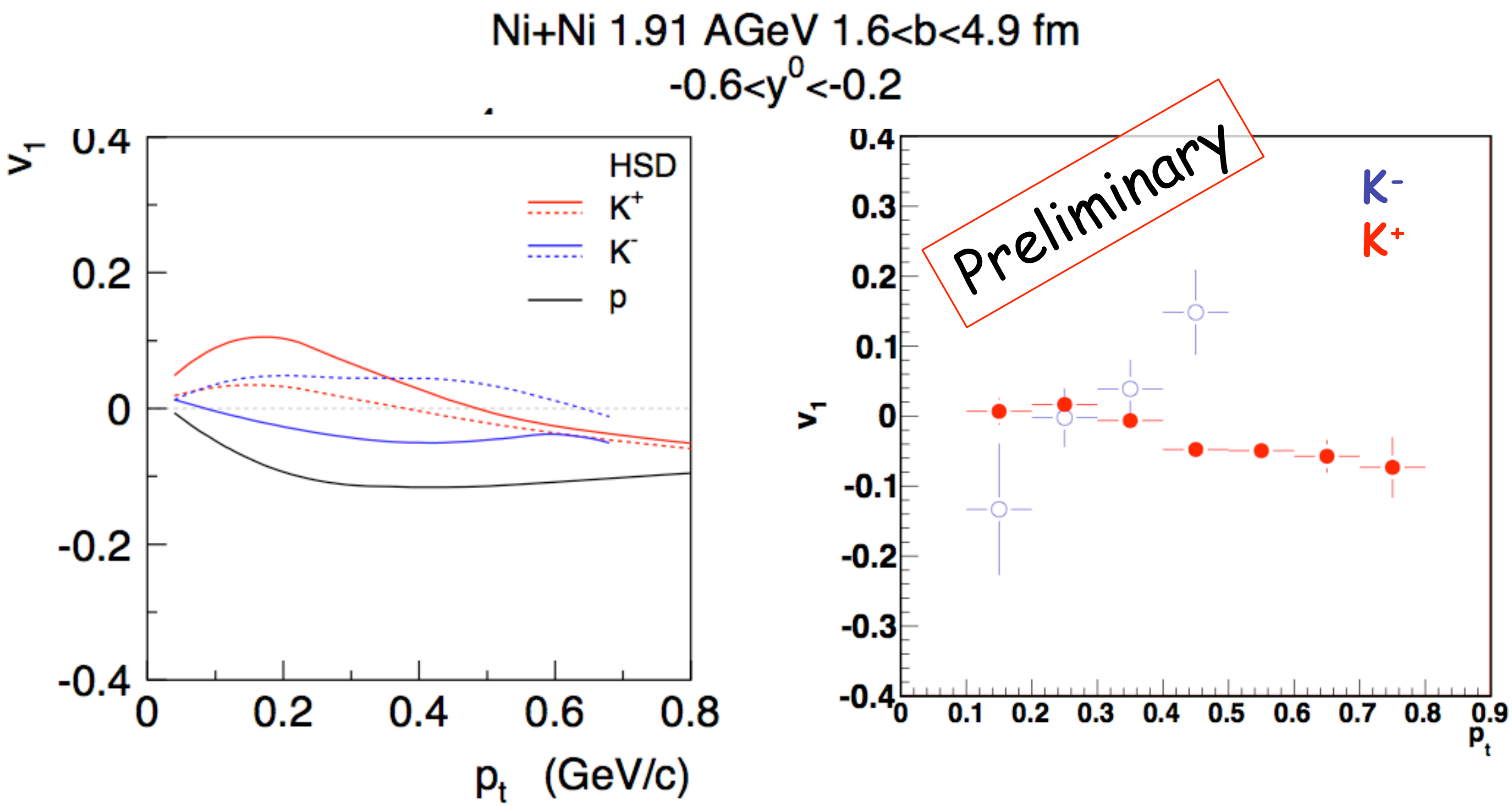


# Centrality Dependence

Y. Leifels
V.Zinyuk

Theoretical Calculations HSD

Experimental Data

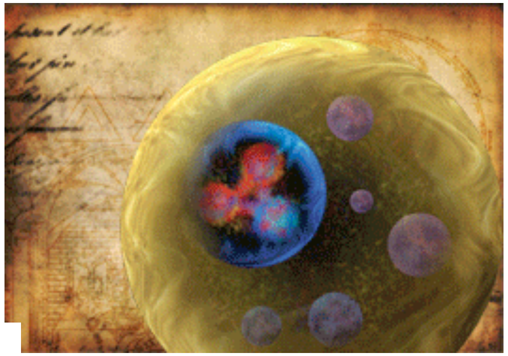



? Strong $p_T$ dependence in mid-central collisions for $K^-$
Transition from Flow to Antiflow?

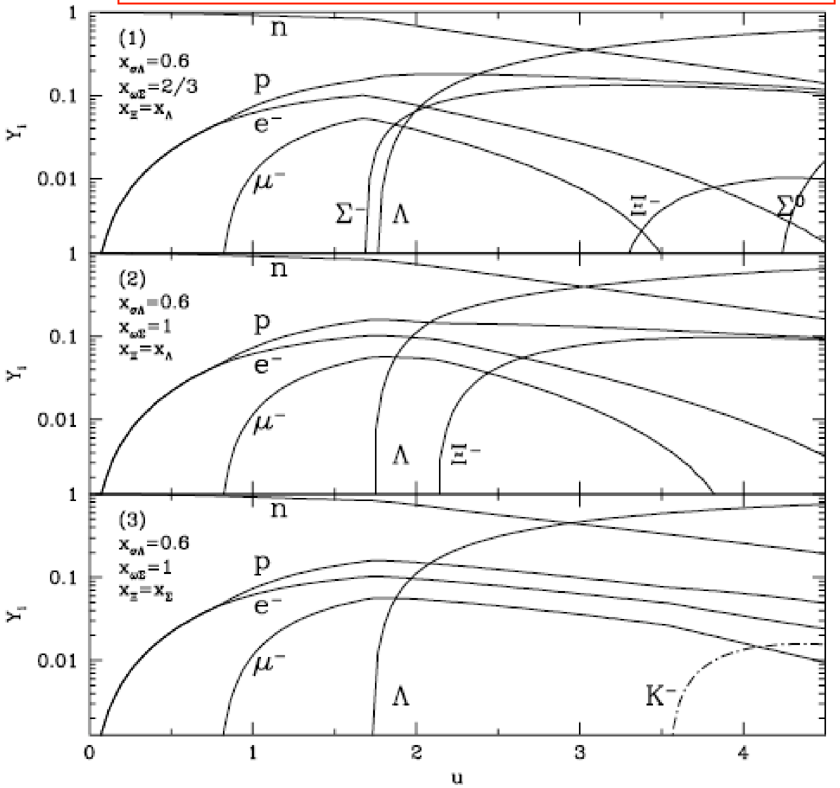
# Hypernuclei in HIC

$_{\Lambda}A$

free ΛN Interaction for different Nuclei
How does it look like in HIC?
Shifts?



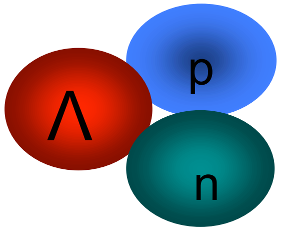
R. Knorren et. al. Phys. Rev. C 52 3470 (1995)




Hyperonazation lowers the probability for K- condensate in Neutron Stars
Modifies the Mass of Neutron star as well.

<u>Lowering by Hyperons:</u>
0.4-0.7 M⊙
Lowering by Kaons:
0.1-0.2 M⊙

# Hypertriton ($_\Lambda$t) production in HIC

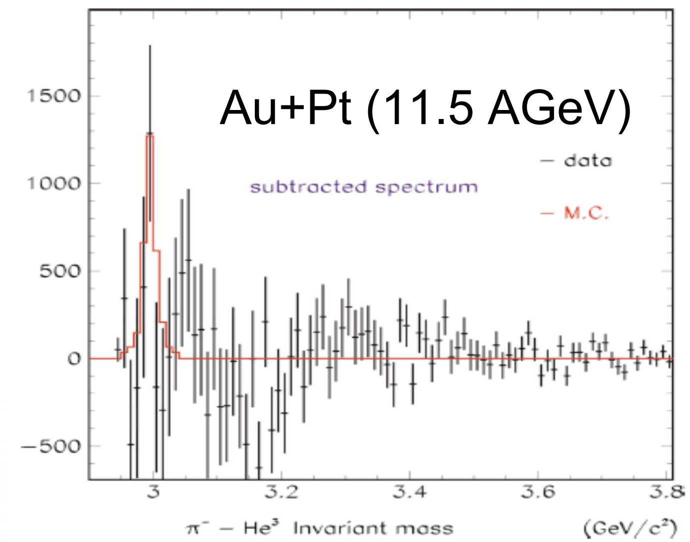



$$_\Lambda t(n + p + \Lambda)$$

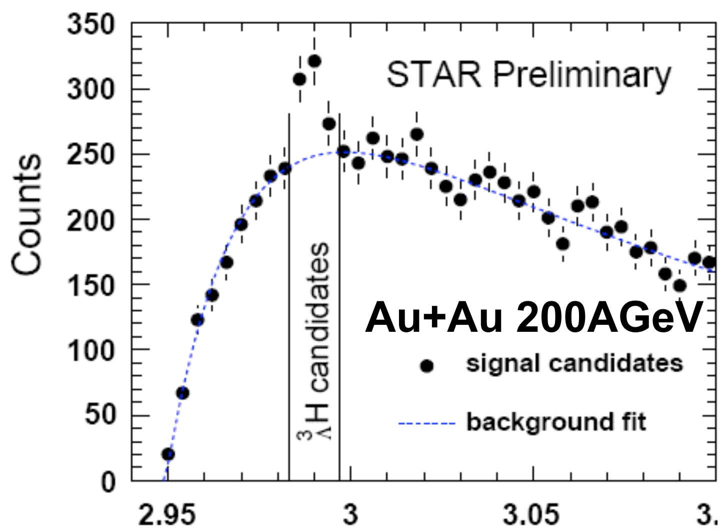
| Weak mesonic decay | B.R. |
|---|---|
| $_\Lambda t \rightarrow {}^3He + \pi^-$ | ~35% |
| $_\Lambda t \rightarrow d + p + \pi^-$ | ~55% |

M.Derrick et al. PRD,1,66 (1970); H.Kamada et al. PRC57,1595 (1998)

E864:T.A.Armstrong et al. PRC70, 024902(2004)



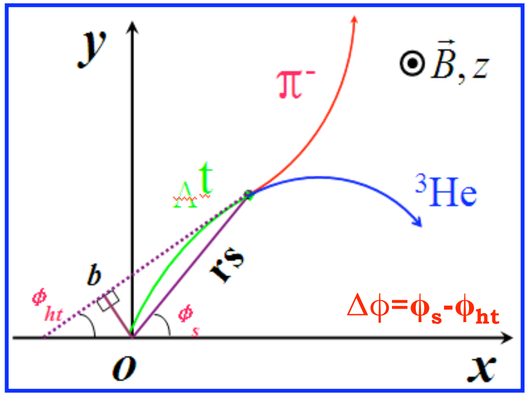

B.I. Abelev et al. (STAR) arXiv:1003.2030



# The FOPI Signal

Y.P. Zhang

$${}_{\Lambda}t \rightarrow \pi^- + {}^3He$$

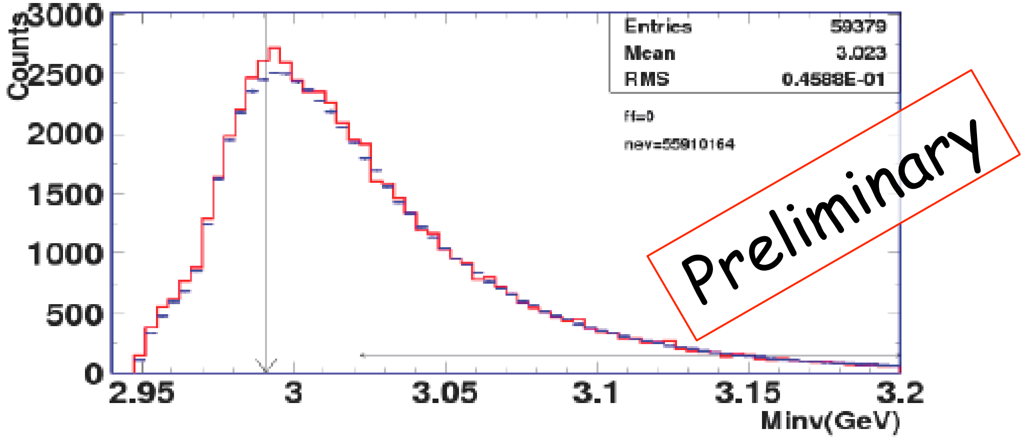


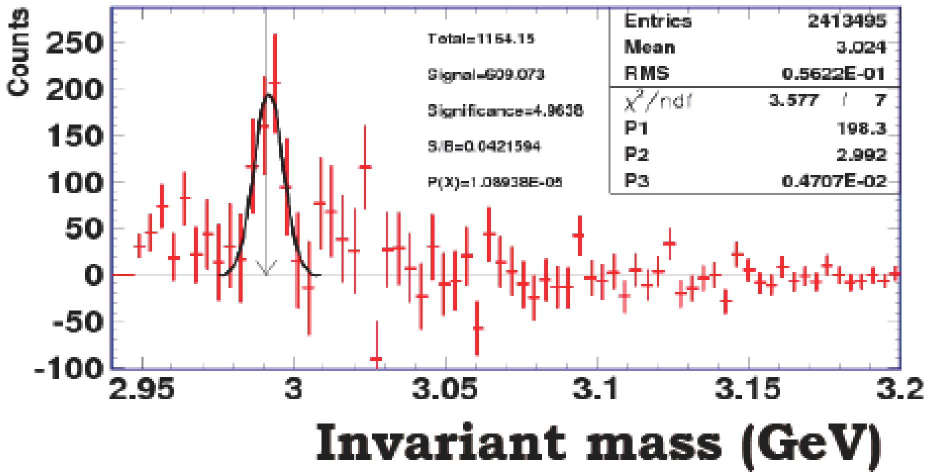

Significance=4.9

600 Candidates in 55*10⁶ Collisions

Efficiency Determination On-Going

Ni+Ni at 1.91 AGeV

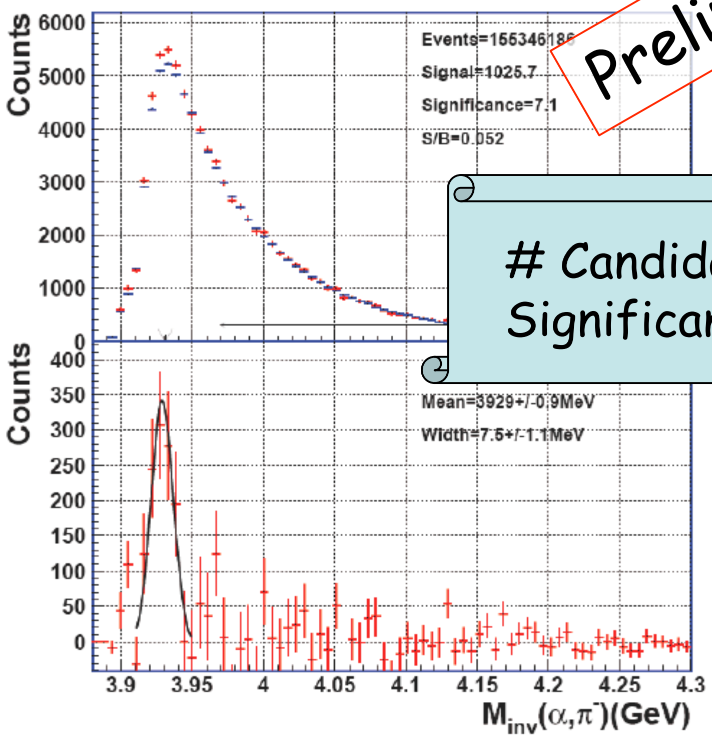


# Hyper-$\alpha$

N. Herrmann

Ni+Ni at 1.91 AGeV



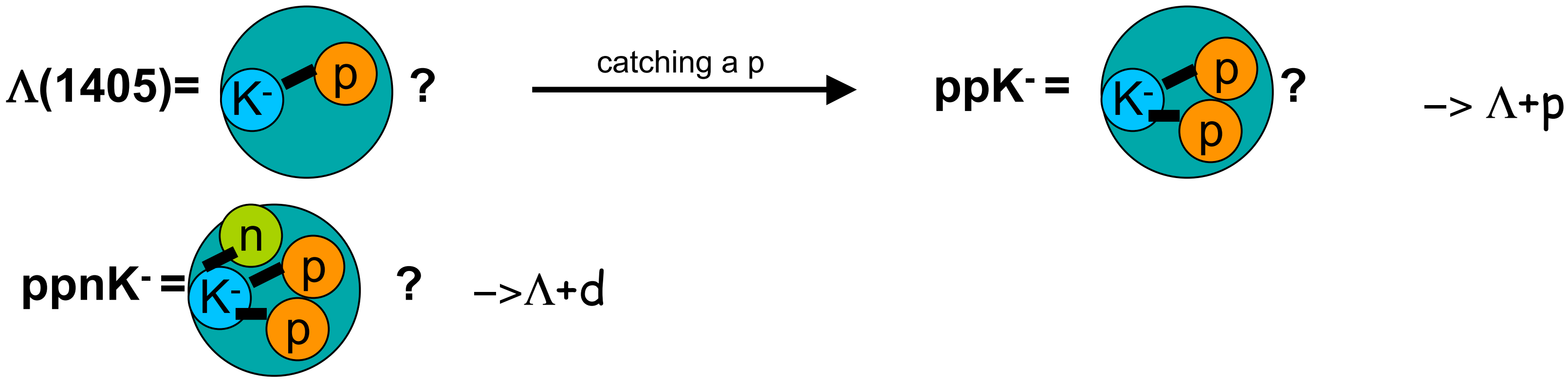

# Candidates= 1026
Significance= 7.1

$$ {}^{4}_{\Lambda}H \rightarrow \pi^- + \alpha $$

Heavier Hypernuclei are accessible as well!

# Some more Exotic Systems

Study the existence of kaonic bound state




Search for the signature in the invariant mass spectrum
Determine the Binding Energy and Width of the systems, if any
Are eventually their properties modified in HIC as well?

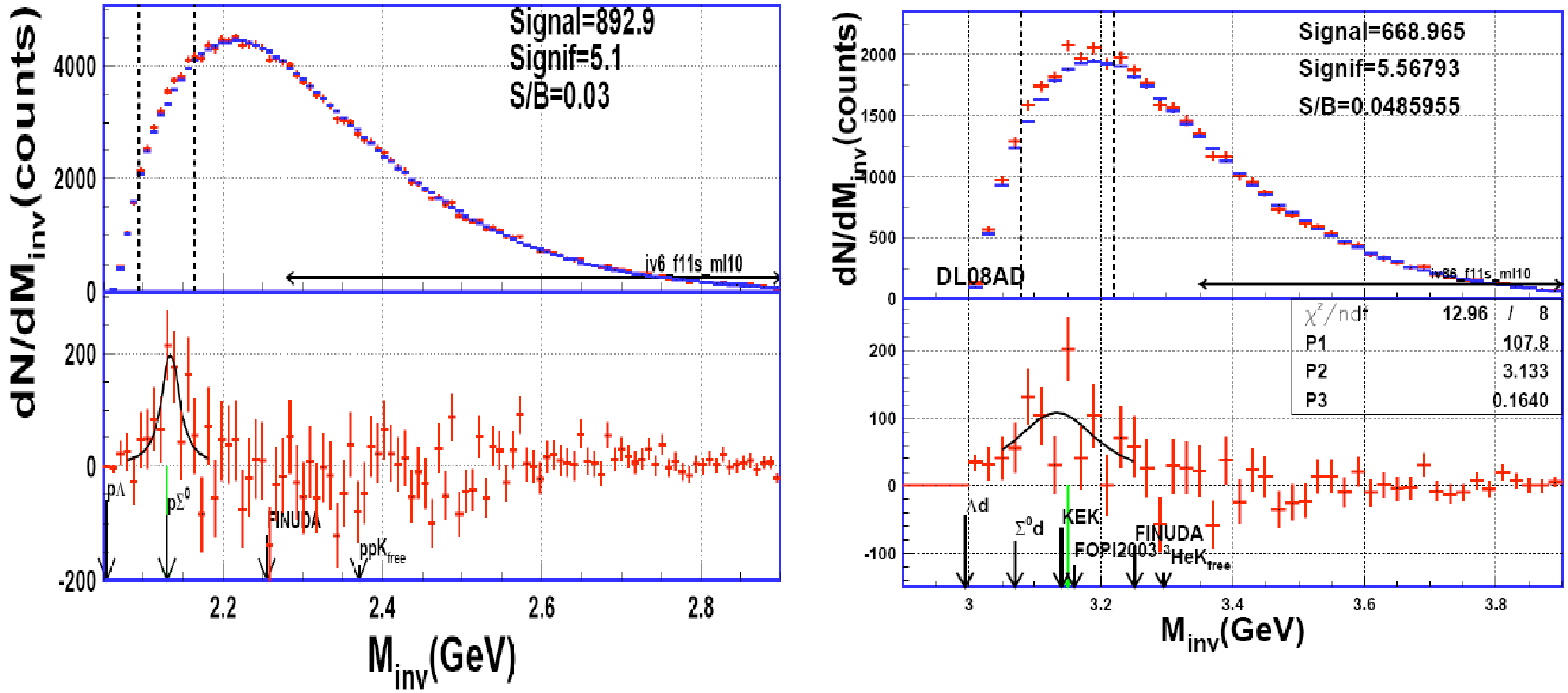
# Λp and Λd Correlations

N. Herrmann

Ni+Ni at 1.91AGeV

$$ppK^- \rightarrow \Lambda + p \;\; ??$$

$$ppnK^- \rightarrow \Lambda + d \;\; ??$$



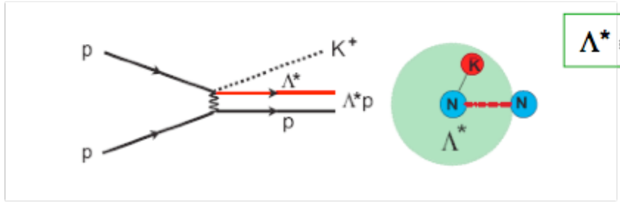

M= 2.134 ±0.004 GeV
Γ= 26 ±14 MeV

Excess:
What is that? πΛN Resonances?

# The ppK- Experiment

R. Münzer
M. Berger

T. Yamazaki et T. Akahishi, Phys. Rev. C 76 (2007) 045201




Λ* ≡Λ(1405)

High Momentum Transfer, E=3-4GeV
Small impact Parameter
Λ(1405)-p rather ,close to each other

## Exclusive Measurement

p+p → 'Λ(1405)'+p+K+

→ ppK-+K+

Λ+p   Σ+p

π- + p   Λ+γ+p

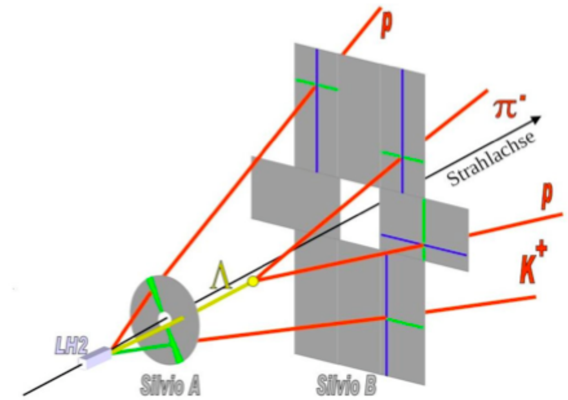
Missing Mass&

Invariant Mass

SiΛVio

silicon Λ Vertexing and identification online

Trigger: Online Comparison of the Multiplicity on siΛVio A and siΛVio B.




1 Detector
32 Segments

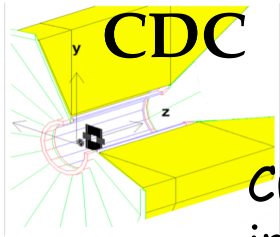
Patchwork:
8 Detector
40x60 Strips

Talk by K. Suzuki

# Collected Data

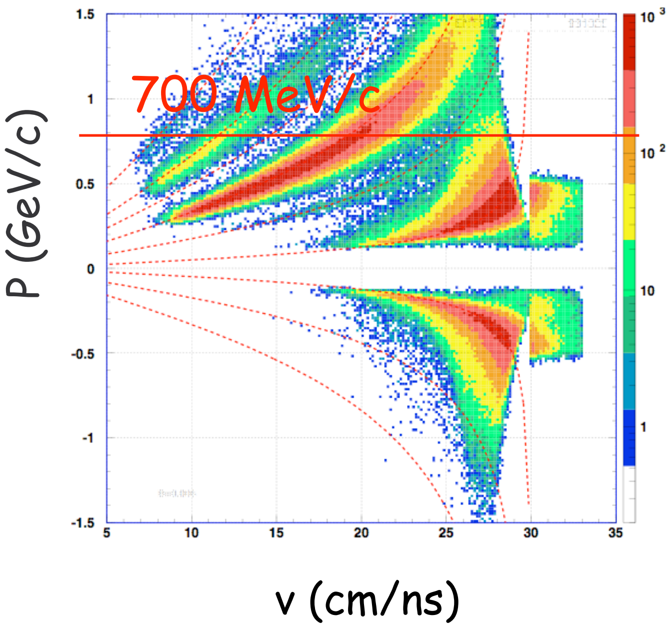
R. Münzer
N. Herrmann
M. Berger

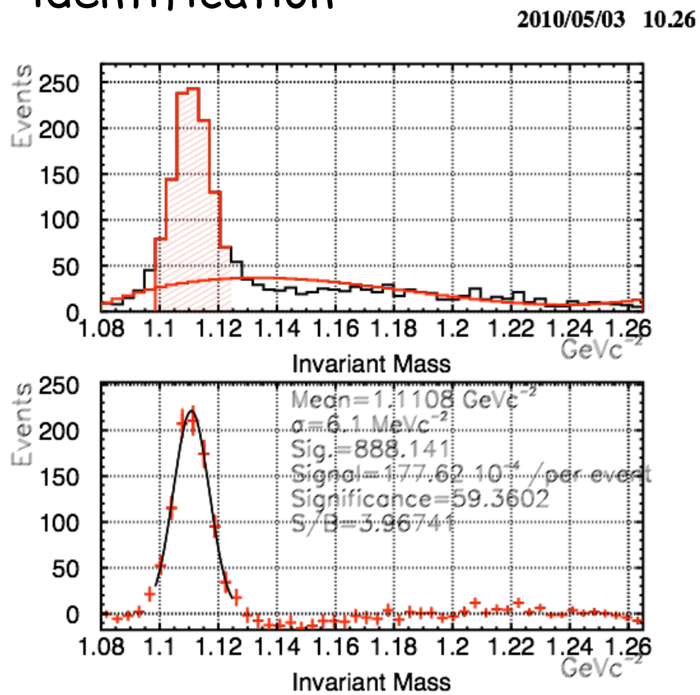
LVL2 Trigger built and installed
LVL2/MB Reduction ~11
100M evt with LVL2 condition collected for p +p at 3.5GeV




Currently Optmizing the Tracking in the Forward-Direction and the TOF calibration to improve the $\Lambda$ identification

K+ Detection with RPC




Talk by K. Suzuki

# Statistical Model

The system is considered in equilibrium at Chemical Freeze-Out
Hence T and $\mu$ can be defined and a Grand-Canonical Description can be used to predict particle yields.

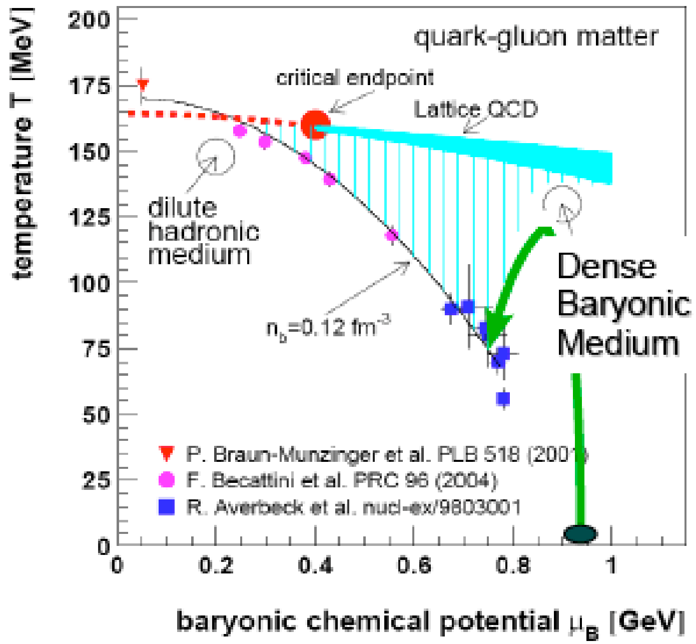
$$n_i(\mu,T) = \frac{N_i}{V} = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{\exp\left(\frac{E_i - \mu_B B_i - \mu_S S_i - \mu_{I_3} I_{3i}}{T}\right) \pm 1}$$

Further correction:

$$\exp(..) \rightarrow \exp(..)\cdot\frac{1}{(\gamma_S)^{n_S}}$$

$\gamma_s$ : strangeness Saturation factor

Does this picture work at SIS18 too?



# Particle Ratios

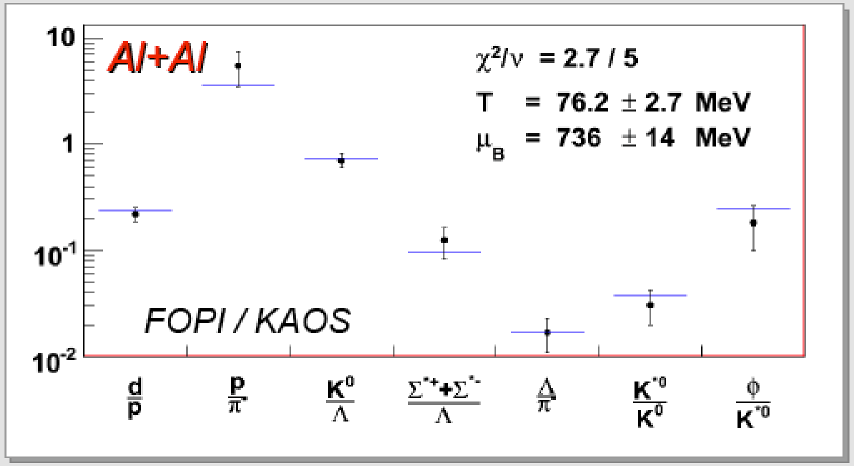
K. Piasecki

- **Al+Al**

  7 independent ratios involving p, d, π⁻, $K^0$, Λ, ϕ, $K^{*0}$, $\Sigma^{*\pm}$

- **Ni+Ni**

  8 independent ratios involving p, d, $\pi^\pm$, $K^\pm$, $K^0$, ϕ, Λ




**Statistical Model**

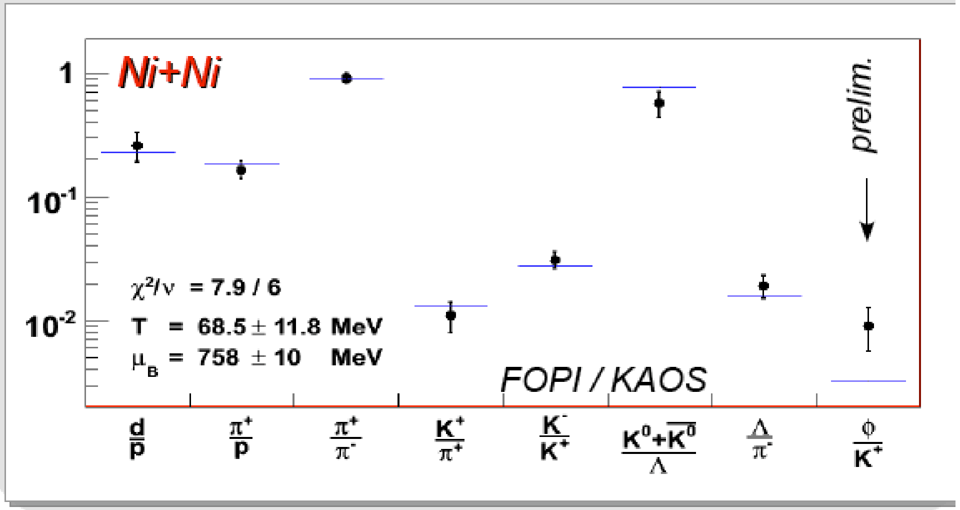
(calc.: **THERMUS** code *S.Wheaton, J.Cleymans hep-ph/0407175*)

Grand Canonical ensemble;
For S≠0, Canonical ensemble

T ~ 72 MeV, $\mu_B$ ~ 745 MeV

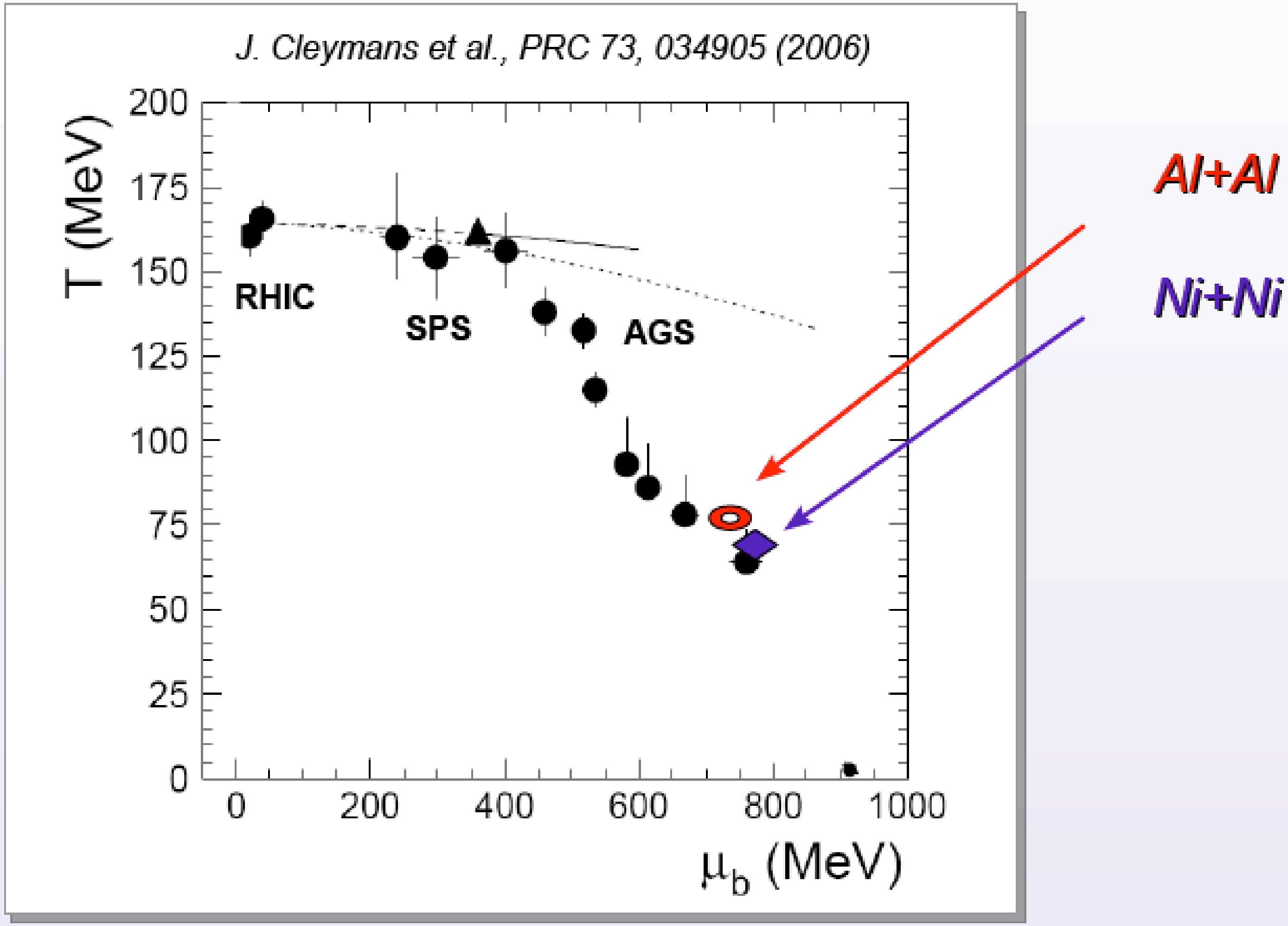
$\gamma_s$ = 1 (fixed)

→ *SM* fitting quite well



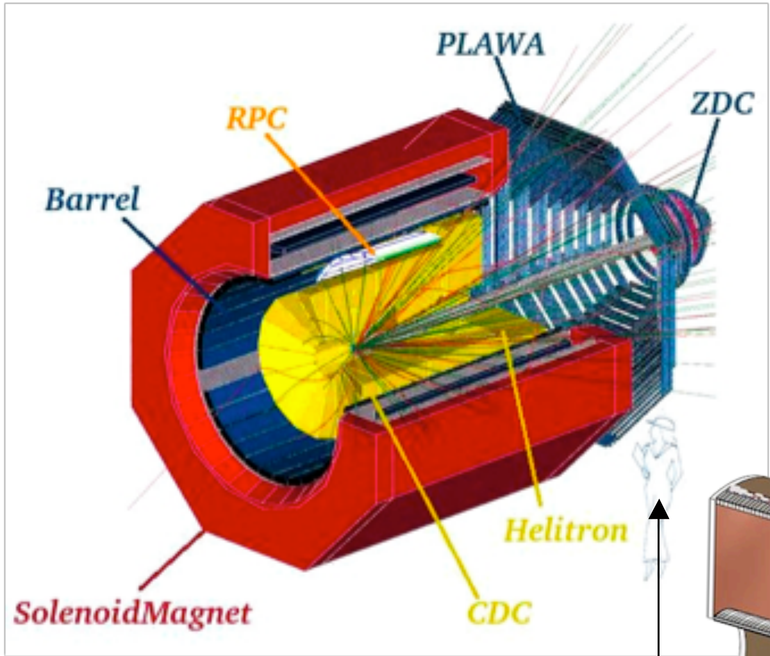
# The Phase Diagramm of Nuclear Matter

K. Piasecki



# Future Activities

GEM-TPC Coll.



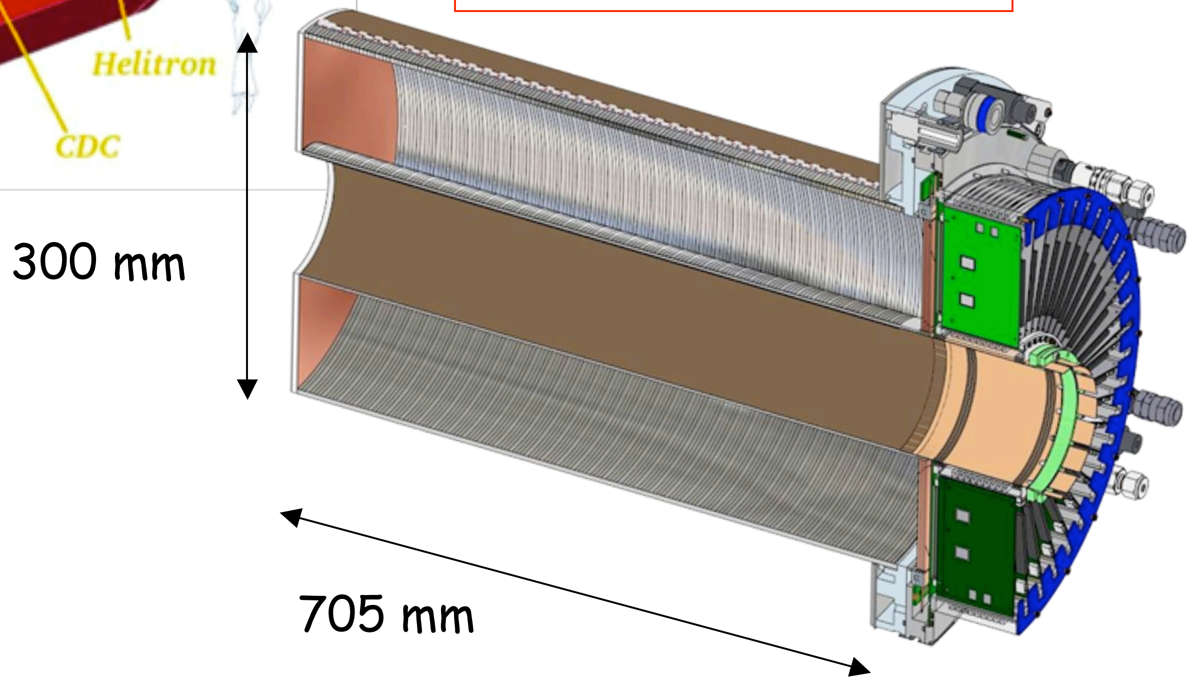

GEM-TPC as a vertex tracker for FOPI

Protype for PANDA

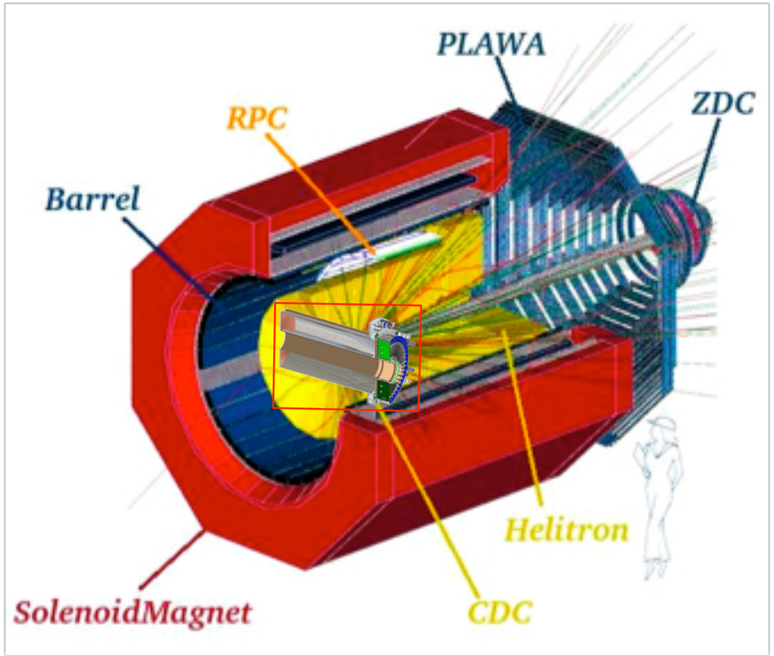
X-Y Vertex Resolution ~0. 3 mm

Z Vertex Res ~1 mm

L. Fabbietti et al. arXiv:1004.4079



# Future Activities




GEM-TPC as a vertex tracker for FOPI

$4\pi$ Acceptance
$\Delta p/p$ ~5-7%
X-Y Vertex Resolution ~0. 3 mm
Z Vertex Res ~1 mm
RPC @ Midrapidity $\sigma_t$ ~80 ps

Employment in $\pi$+A reactions:

- $K^0_S$ Production
- $K^+/K^-/\phi$ Absorption in Different Nuclei

Maybe A+A as well?

First test with FOPI in Fall 2010!

# Summary and Outlook

- Differential Studies of V1 for $K^+$ seem so far to confirm a repulsive potential of 20 MeV for $K^+$-Nucleus

- the $K^-$ Flow Pattern is not yet understood

- On the other hand not all quantities are under control from a theoretical point of view

- A clear signature of light hypernuclei has been found in the Ni+Ni Data

- $\Lambda$p and $\Lambda$d correlations show also an excess yield. Interpretation is on going

- p+p at 3.1GeV-> ppK- + K+ -> $\Lambda$ + p + $K^+$

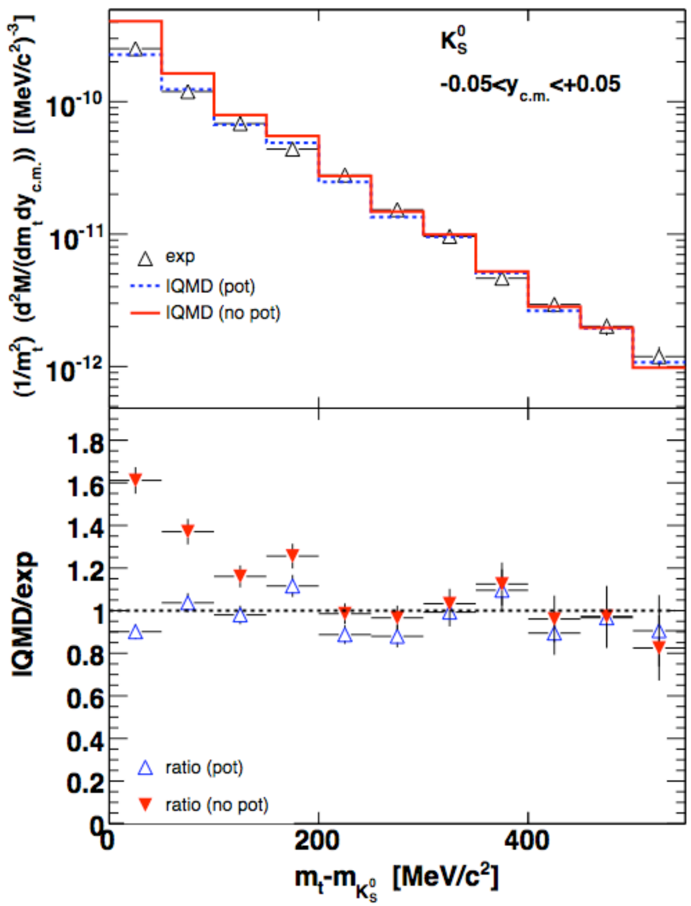
- Many open questions yet which might be clarified with future experiments exploiting the FAIR detector developments.

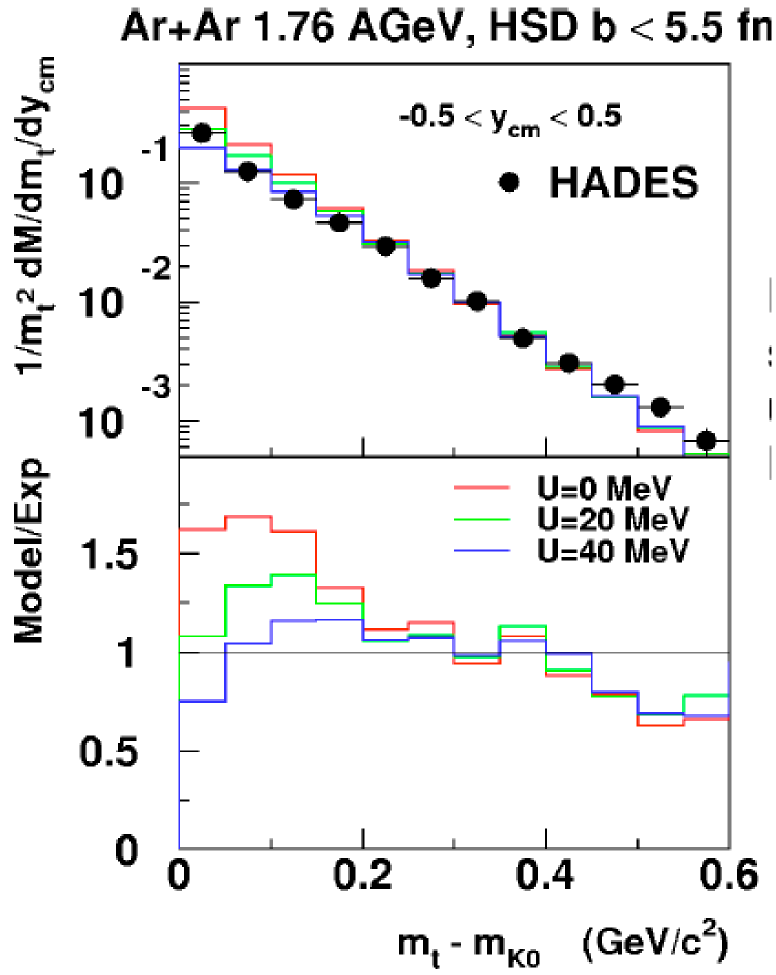
# HADES $K^0$

Y. Leifels

Potential:
V=40MeV @ $\rho=\rho_0$

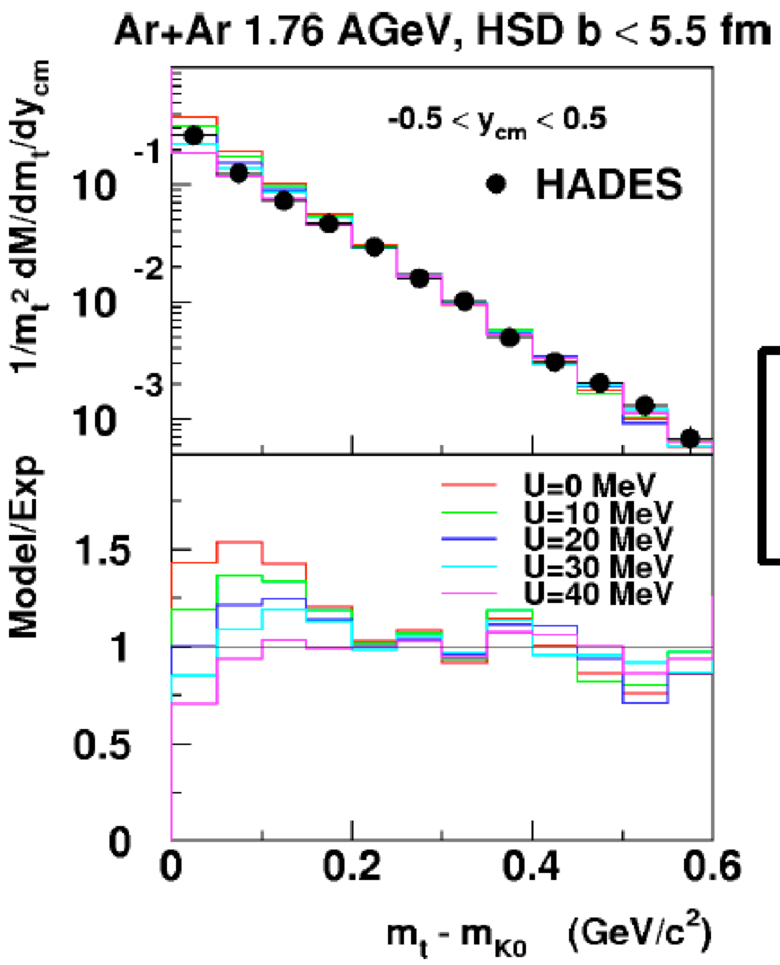
IQMD: *C. Hartnack, J. Aichelin*



# Tuning Parameters

Y. Leifels




rescattering cross section changed:
12 mb → 20 mb
Slope reproduced

# Geometrical acceptance