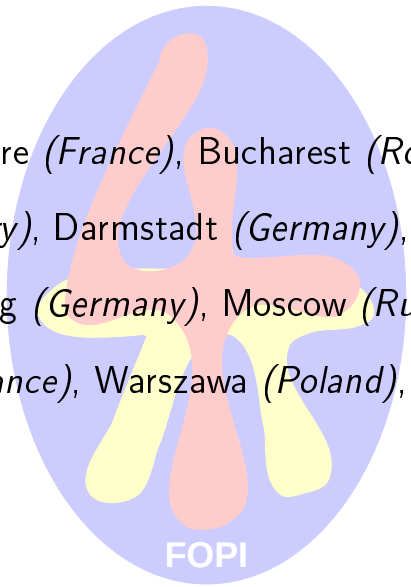
# RESULTS FROM FOPI ON STRANGENESS PRODUCTION AND PROPAGATION IN HOT AND DENSE NUCLEAR MATTER

Aubière *(France)*, Bucharest *(Romania)*

Budapest *(Hungary)*, Darmstadt *(Germany)*, Dresden *(Germany)*

Firenze *(Italy)*, Heidelberg *(Germany)*, Moscow *(Russia)*, Seoul *(South Korea)*

Strasbourg *(France)*, Warszawa *(Poland)*, Zagreb *(Croatia)*




Introduction

1. FOPI experiment

2. Strangeness production

   - $\mathbf{m_t}$ spectra and yield

   - $\mathbf{K^-/K^+}$ ratio

3. Strangeness propagation

   - $\mathbf{K^+}$, $\mathbf{K^0_s}$ and $\mathbf{\Lambda}$ sideward flow

Summary and outlook

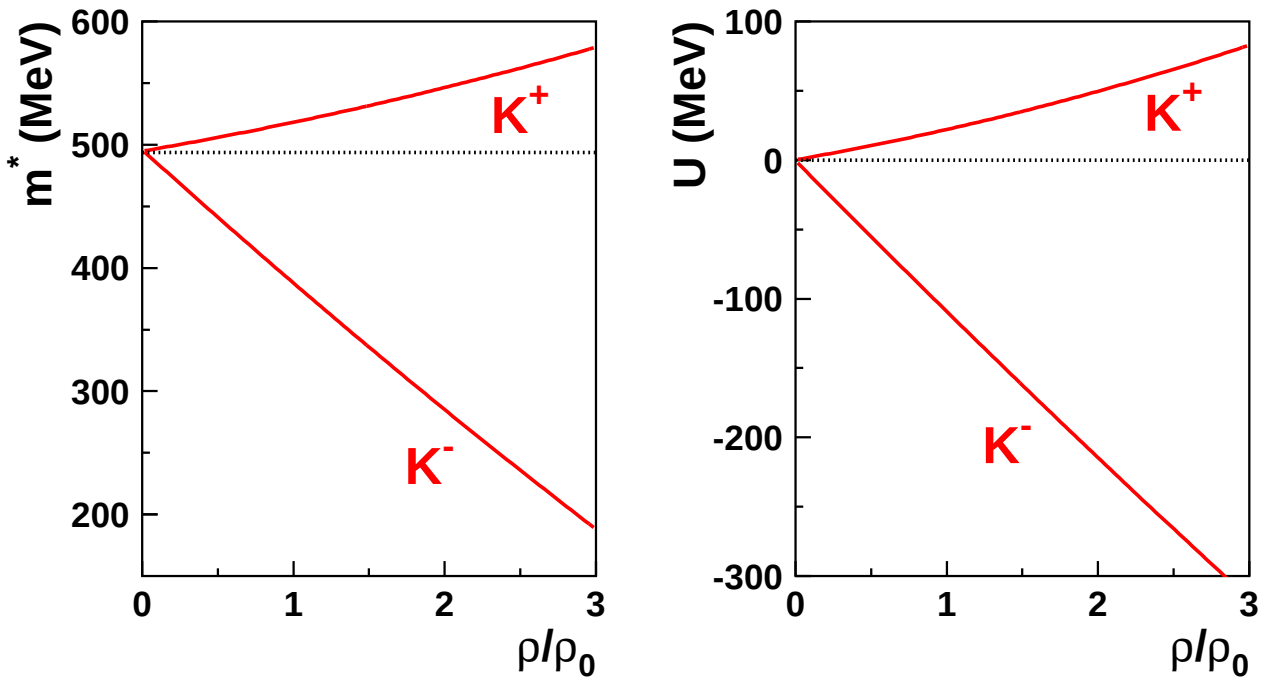
# Kaons in dense nuclear matter

$$w^2_{K^\pm}(k,\rho_B) = m^2_K + k^2 - \frac{\Sigma_{KN}}{f^2}\rho_S \pm \frac{3}{4}\frac{w}{f^2}\rho_B$$

scalar potential: attractive for $\mathbf{K^+}$ and $\mathbf{K^-}$

vector potential: attractive for $\mathbf{K^-}$

repulsive for $\mathbf{K^+}$




$\mathbf{K^+}$: yield ↘ momentum ↗

$\mathbf{K^-}$: yield ↗ momentum ↘

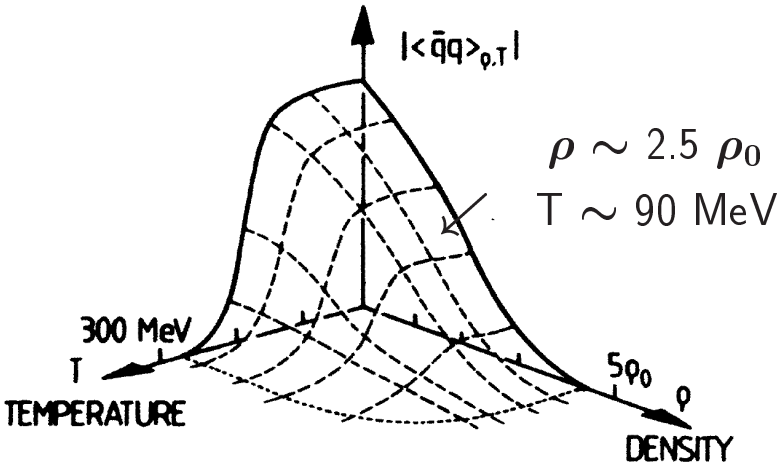

G.Q. Li and C.M. Ko, Nucl.Phys. A594 (1995) 460

W. Cassing et al., Nucl.Phys. A614 (1997) 415

J. Schaffner et al., Phys.Lett. B324 (1994) 268

T. Waas et al., Phys.Lett. B379 (1996) 34

# Why @ SIS?




$\rho \sim 2.5\ \rho_0$

T $\sim$ 90 MeV

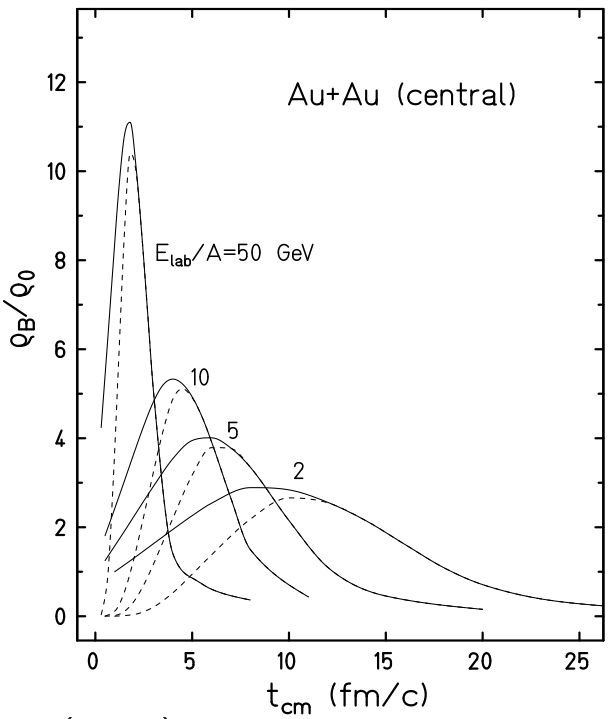
- decreasing part of the quark condensate

- production of kaons close to threshold

$$\mathbf{K^+ : NN \rightarrow K^+ \Lambda N} \qquad \mathbf{E_{thres} = 1.6 GeV}$$

$$\mathbf{K^- : NN \rightarrow K^+ K^- NN} \qquad \mathbf{E_{thres} = 2.5 GeV}$$

- relatively high $\rho$ for a relatively long time



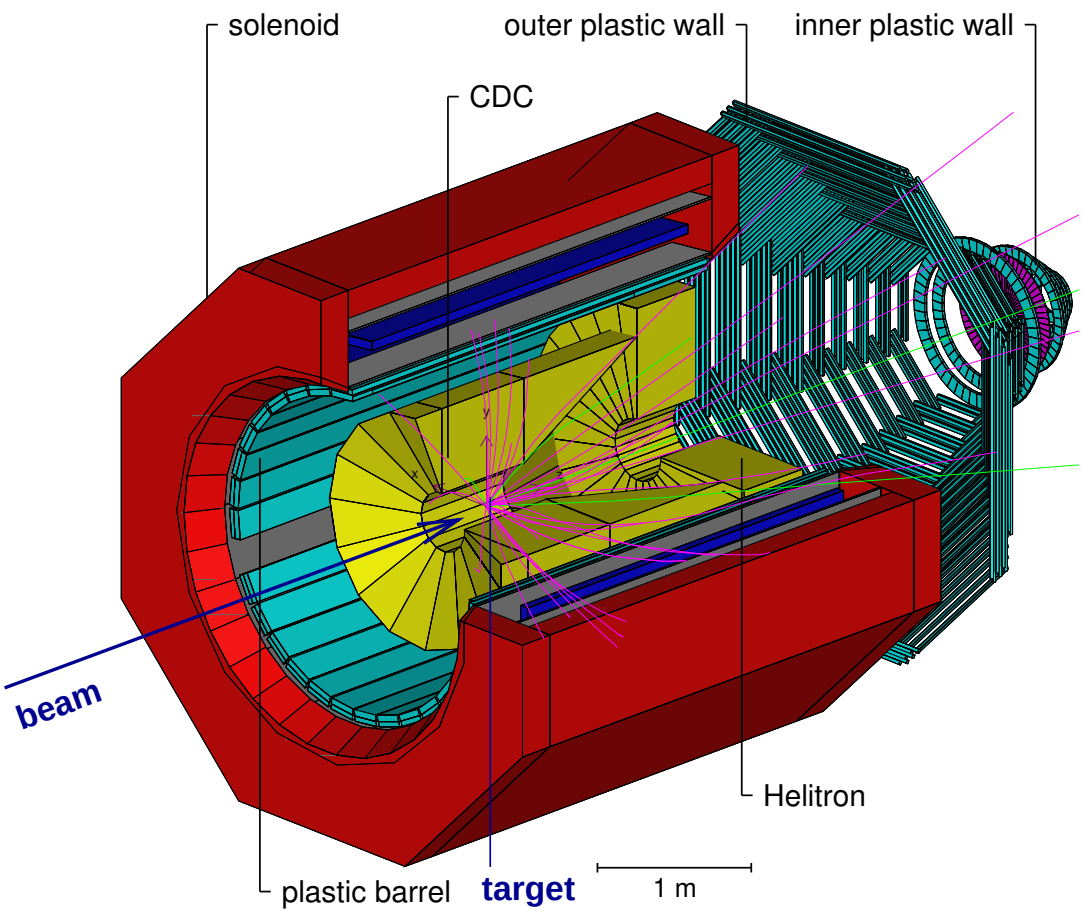


W. Weise, NP A610(1996)35c

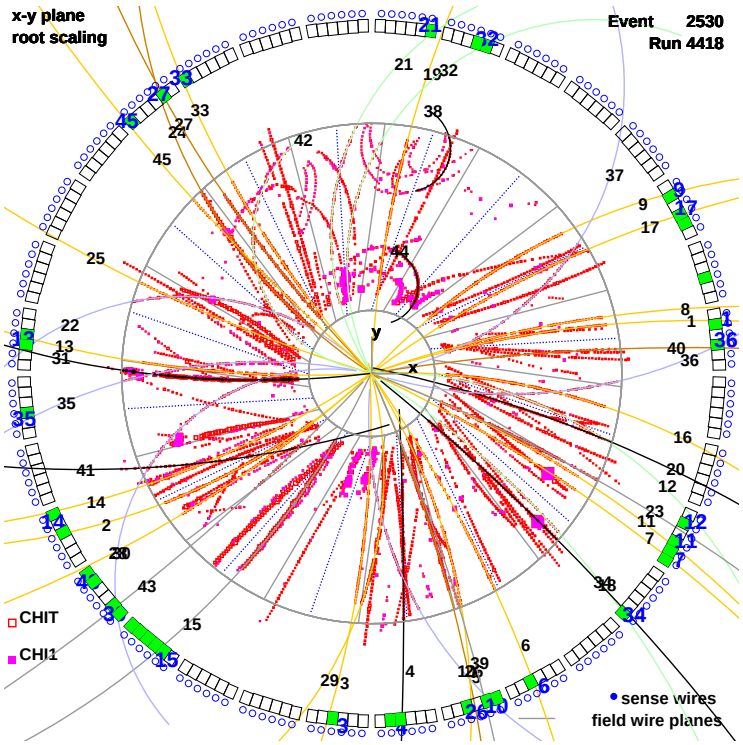
S. Klimt et al., PL B249(1990)386

M. Lutz, S. Klimt and W. Weise, NP A542(1992)52

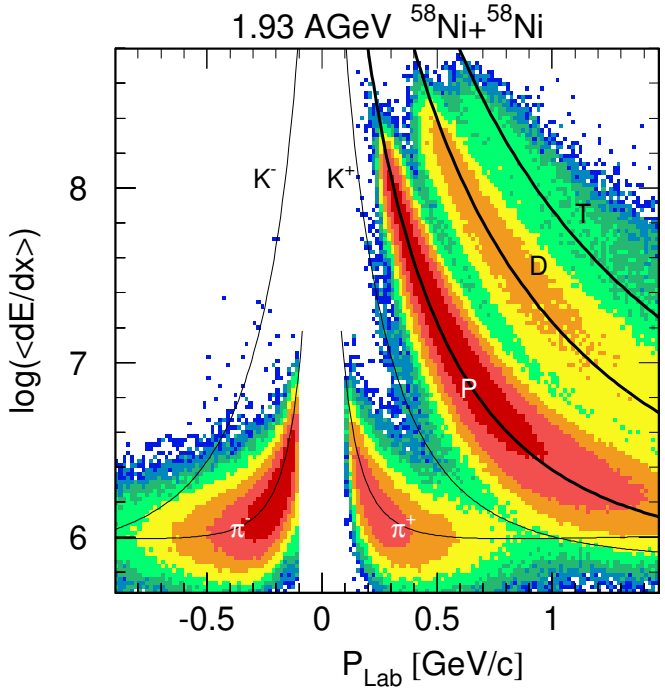
# FOPI experiment @ GSI

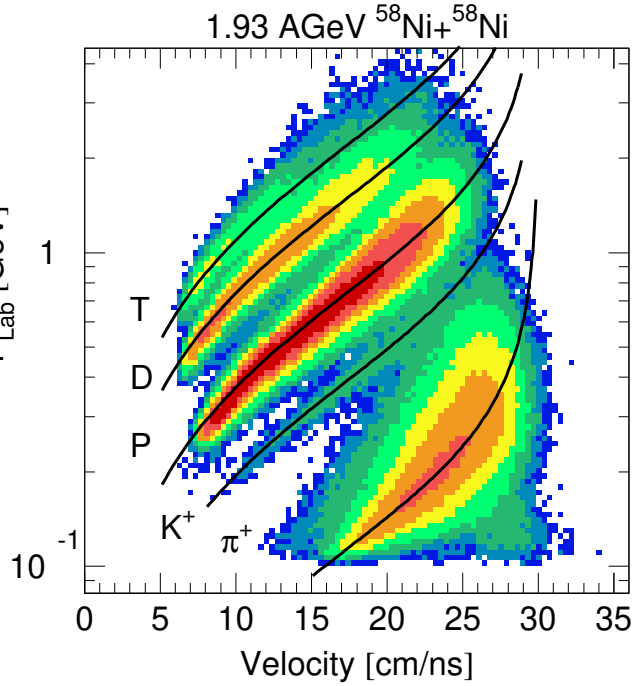



Ru + Ru @ 1.69 AGeV



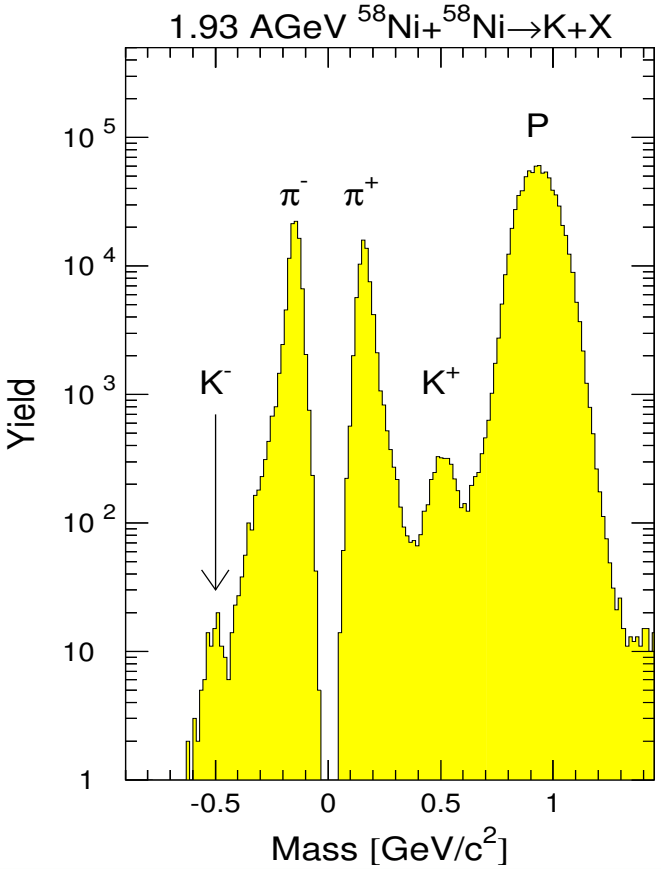
# Charged particle identification



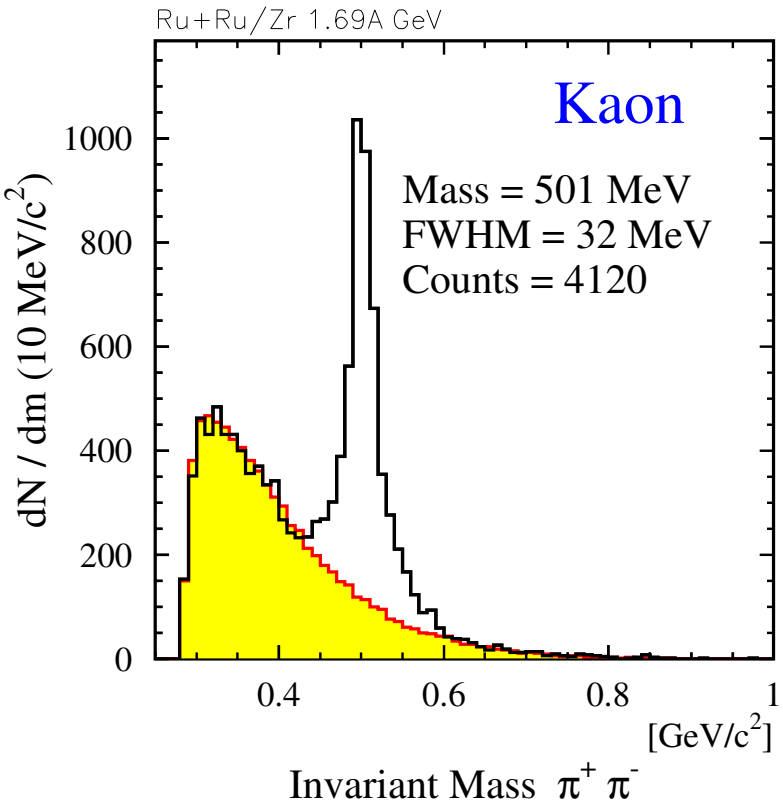

Bethe-Bloch (CDC)

$p = m\gamma\beta$ (CDC+TOF)

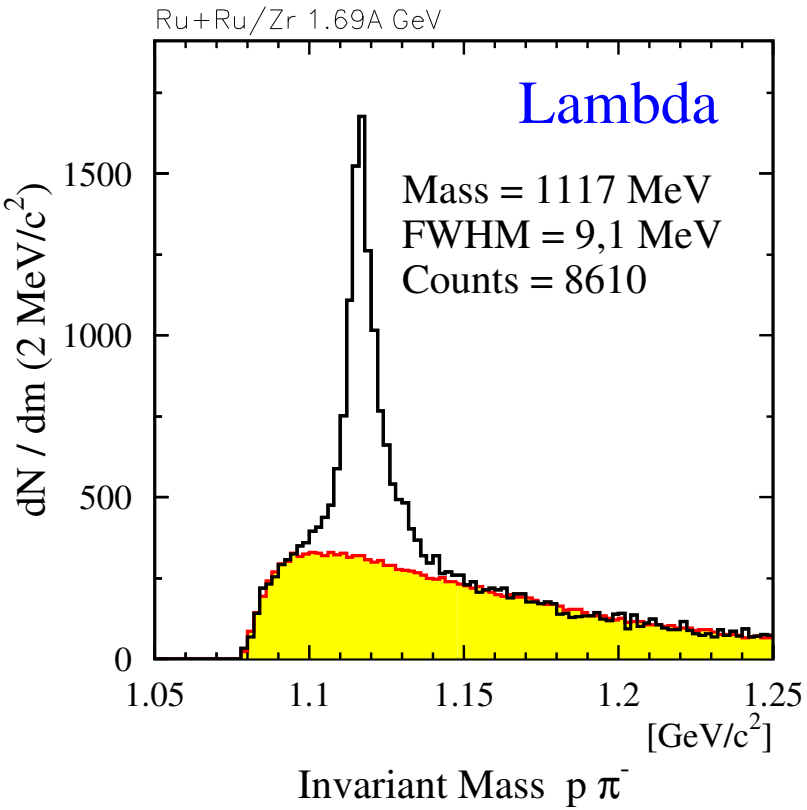


# Neutral particle identification

$\mathbf{K^0_s \rightarrow \pi^+\pi^-(68.6\%)}$

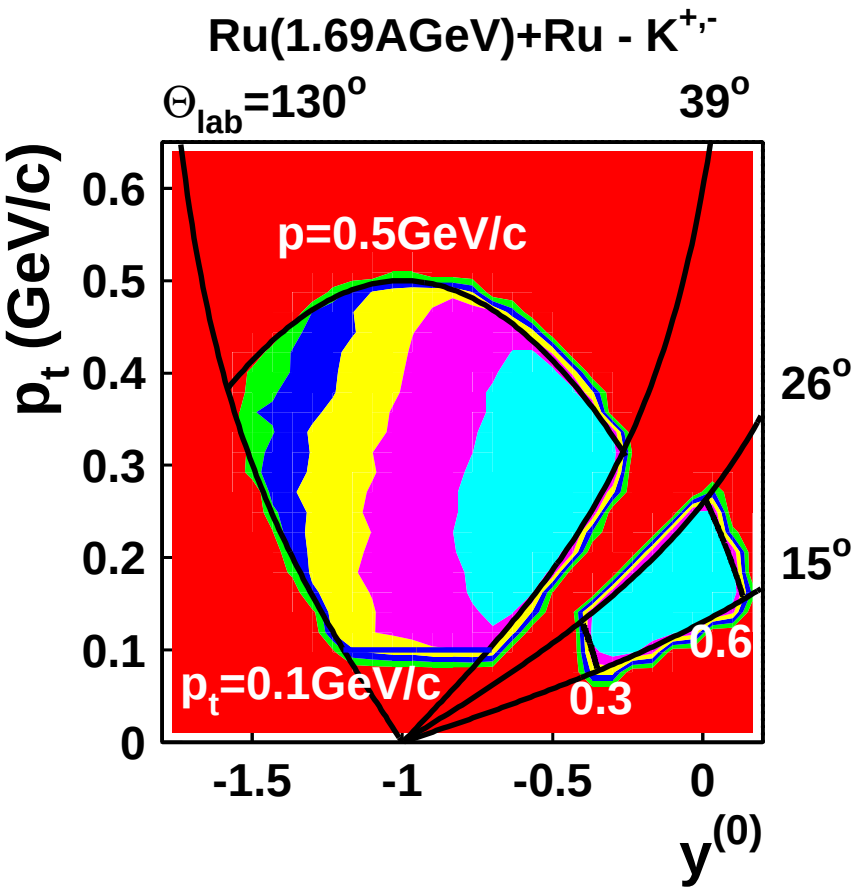



$\mathbf{\Lambda \rightarrow p\pi^-(63.9\%)}$




J. Ritman et al., Z. Phys. A352(1995)156
R. Kutsche, thesis jan. 2000

# $K^{\pm}$ acceptance and statistics



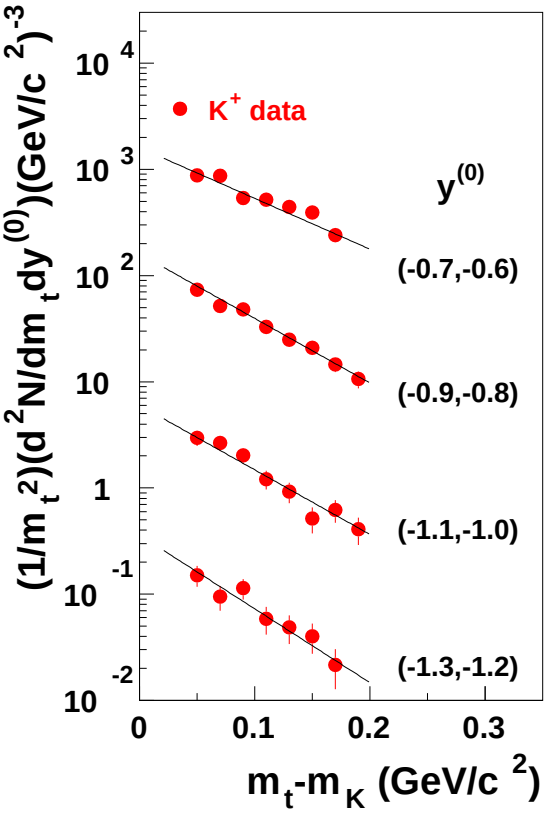

| System | Beam Energy | N events | $K^+*$ | $K^-*$ |
|---|---|---|---|---|
| Ni+Ni | 1.06 AGeV | $2.8 \cdot 10^6$ | 30 | |
| | 1.45 AGeV | $1.8 \cdot 10^6$ | 300 | |
| | 1.93 AGeV | $2.9 \cdot 10^6$ | 3000 | 50 |
| Ni+Ni | 1.93 AGeV | $4.7 \cdot 10^6$ | 30000 | 220 |
| Ru+Ru/Zr | 1.69 AGeV | $7.7 \cdot 10^6$ | 30000 | 240 |
| Ca+Ca | 1.96 AGeV | $5 \cdot 10^5$ | - | - |
| Au+Au | 1.49 AGeV | $5 \cdot 10^5$ | - | - |

next time !!

$*$ CDC/bar

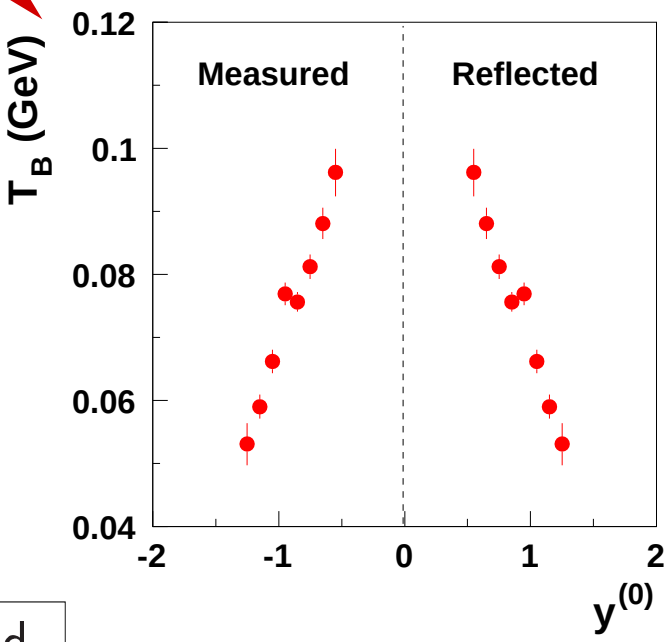
# Transverse masse spectra, $T_B$ and Yield

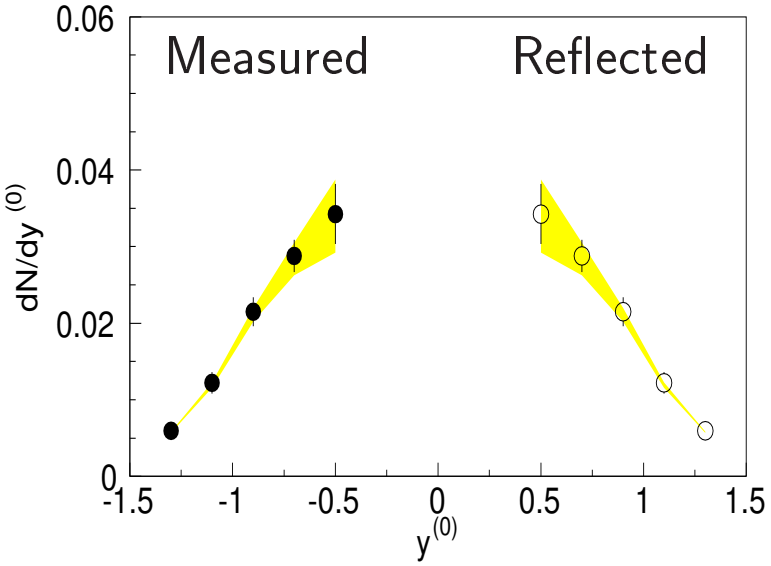
Ru+Ru @ 1.69 AGeV




thermal Boltzmann source:

$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dy^{(0)}} = A \exp\left(\frac{-(m_t - m_0)}{T_B}\right)$$




data extrapolated

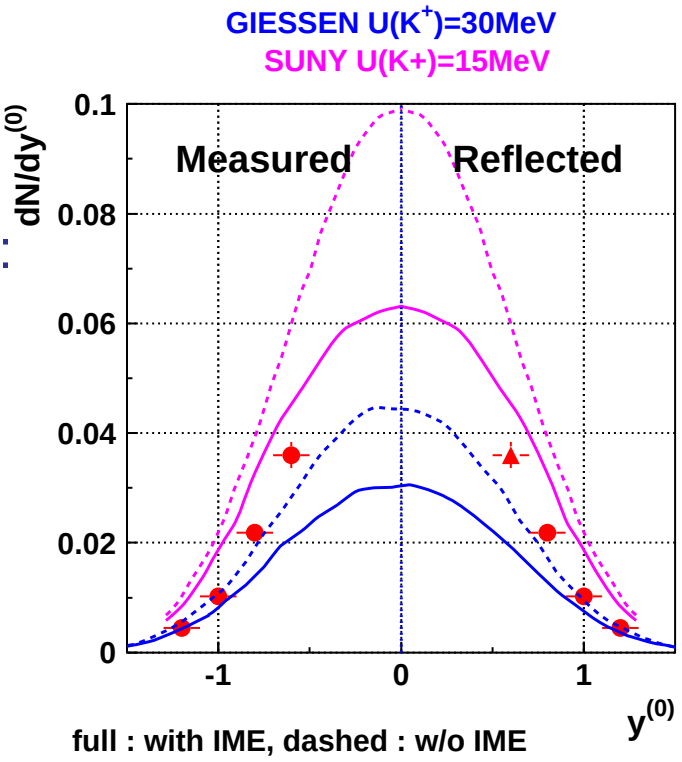
(exponential shape, theor. calculations)

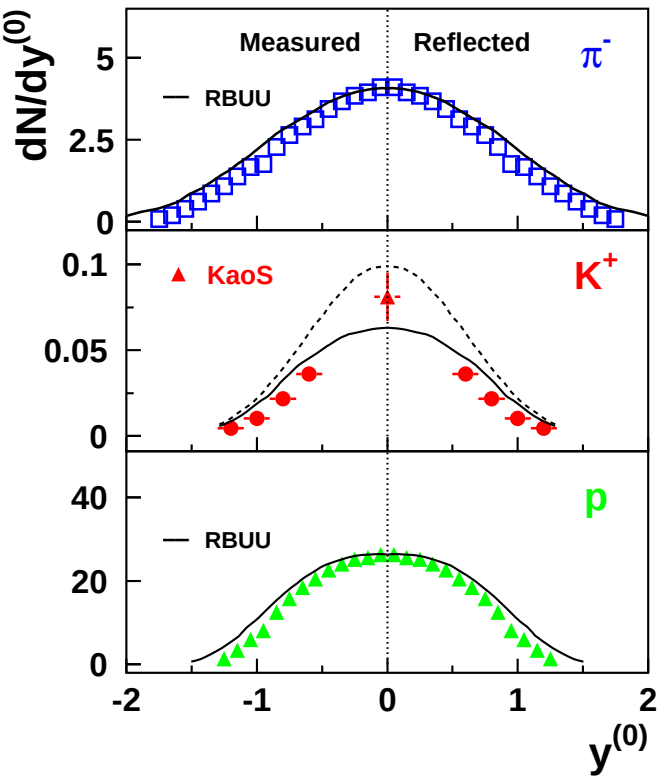
K. Wiśniewski

# Sensitivity to in-medium effects?

central Ni+Ni@1.93 AGeV

- investigated $y^{(0)}$ range:
  low sensitivity
- discrepancy between models




- description of p and $\pi$

data: extrapolated

BUU: projected


D.Best et al., NP A622(1997)574

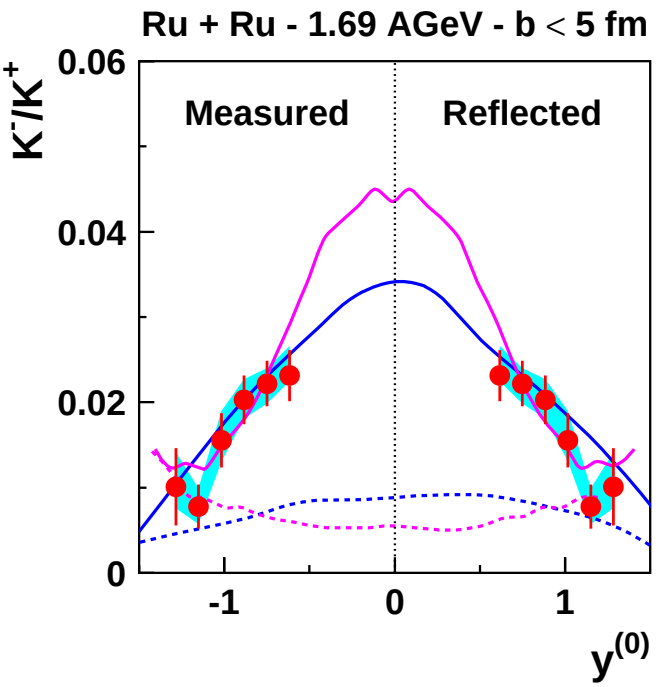
G.Q. Li et al., NP A625(1997)372

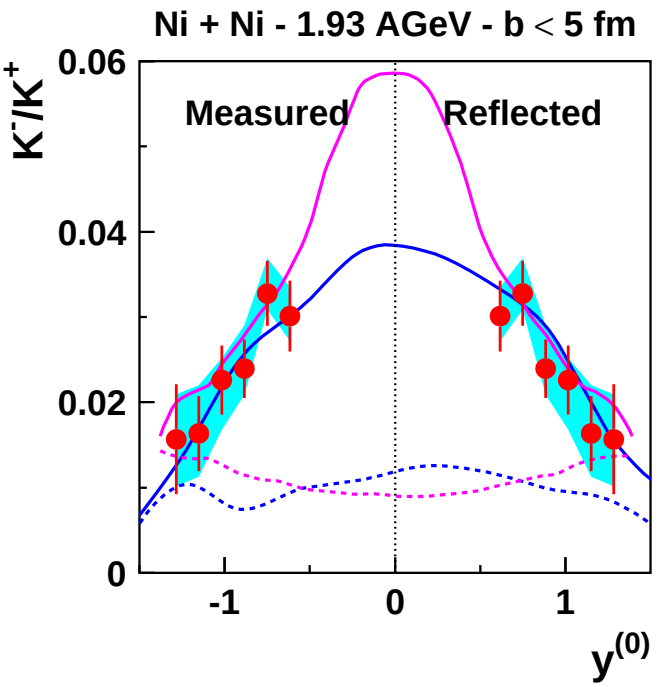
# $K^-/K^+$ ratio

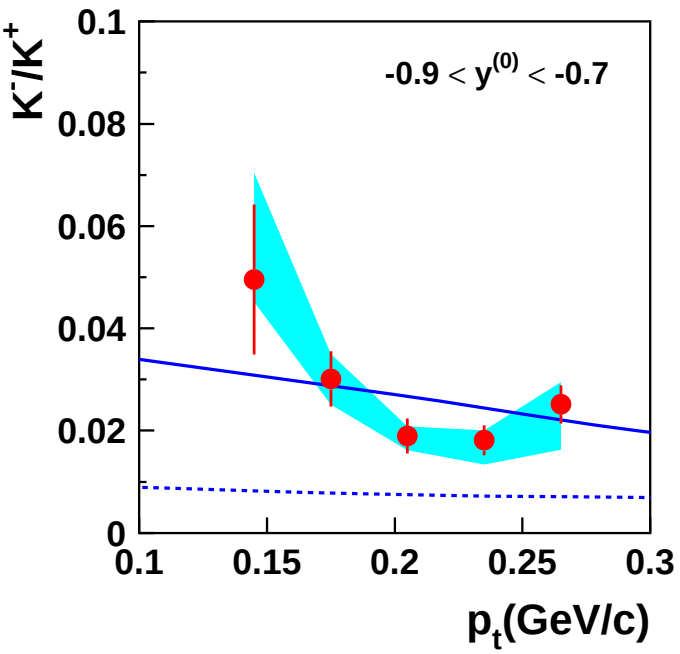
- DATA

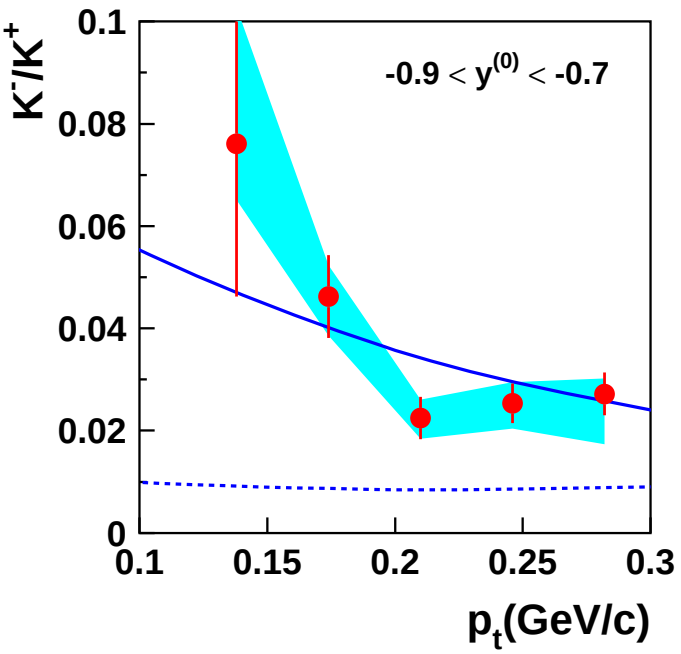
— BUU with IME — G.Q. Li and G.E. Brown, PRC58(1998)1698

- - BUU w/o IME — W. Cassing and E.L. Bratkovskaya, PR306(1999)56



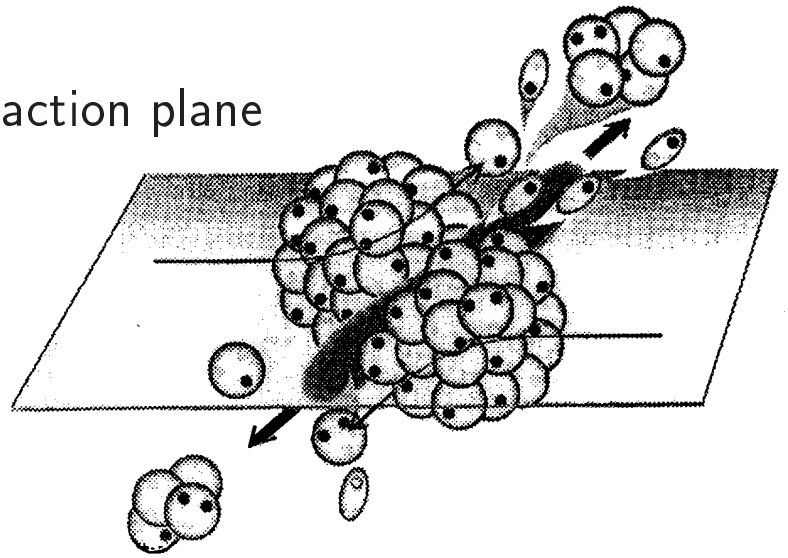



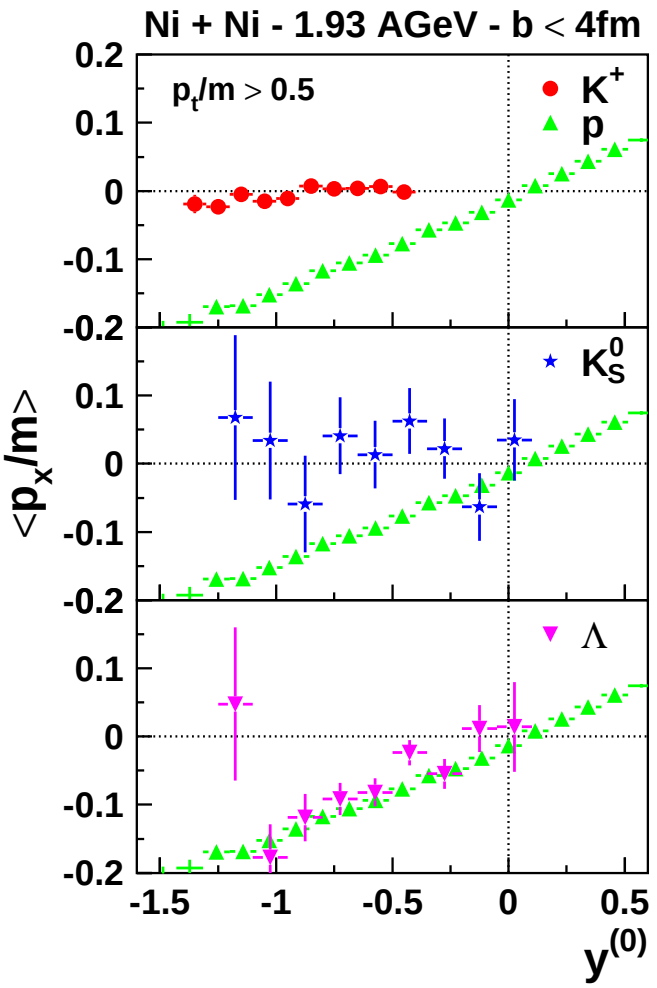

Data favour IME

K. Wiśniewki et al., GSI-report(1997), submitted to Phys. Rev. Lett.

# Sideward flow

- predicted by hydrodynamic '70
- evidenced by Plastic Ball '80



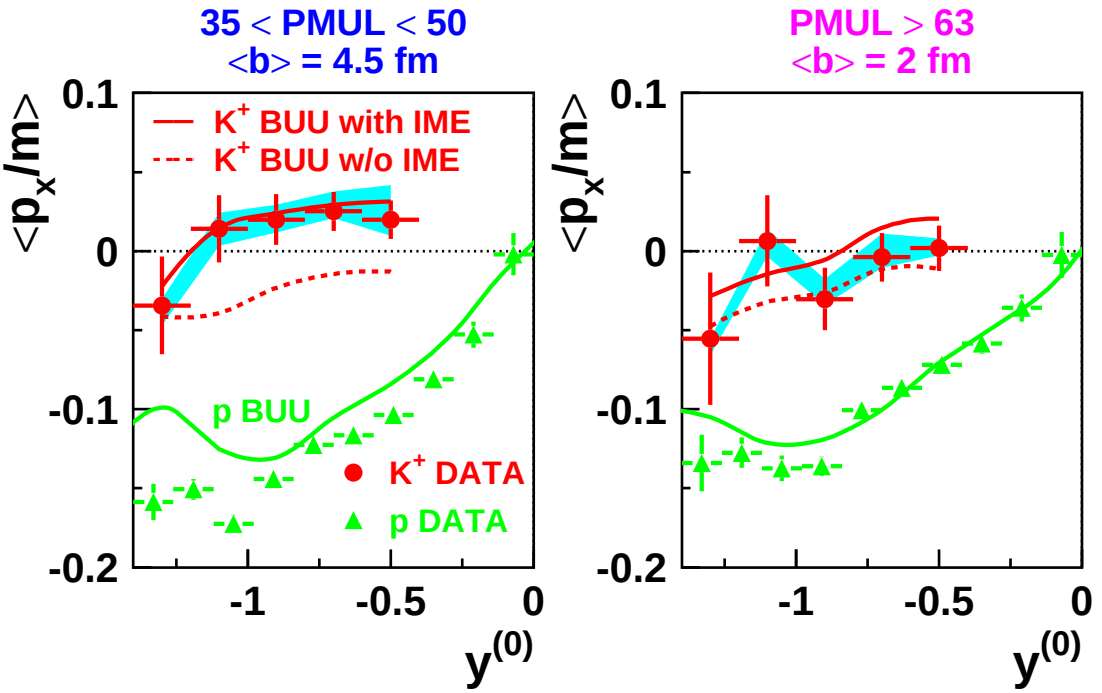

Full statistics for $K^+$ 95' data

$K^+ \& \Lambda$ co-produced but different propagation

J. Ritman et al., Z.Phys. A352 (1995) 156

# $K^+$ sideward flow - comparison to calculations

Ru+Ru@1.69 AGeV




data biased by acceptance ($p_t$ dependence)

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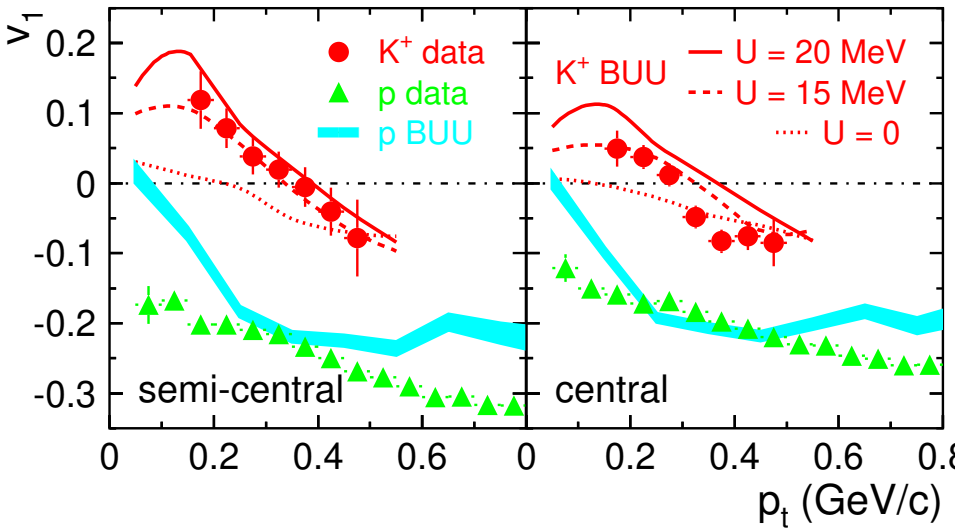
differential sideward flow

$$-1.2 < y^{(0)} < -0.5$$



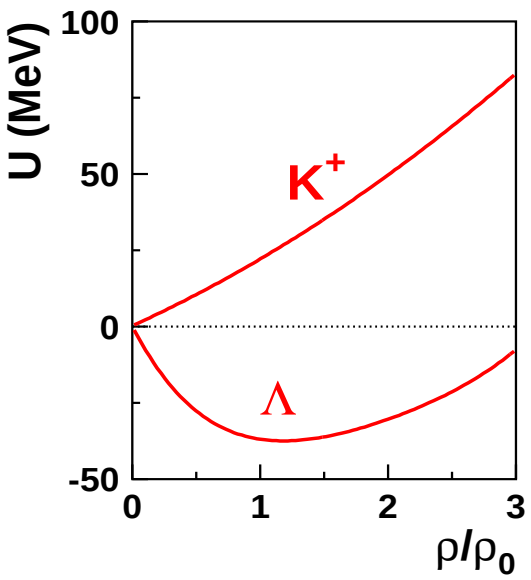

Fourrier coef.:

$$v_1 = < \cos(\phi) > = < p_x/pt >$$

data favour in-medium potential for $K^+$

P. Crochet, BUU: E.L. Bratkovskaya and W. Cassing

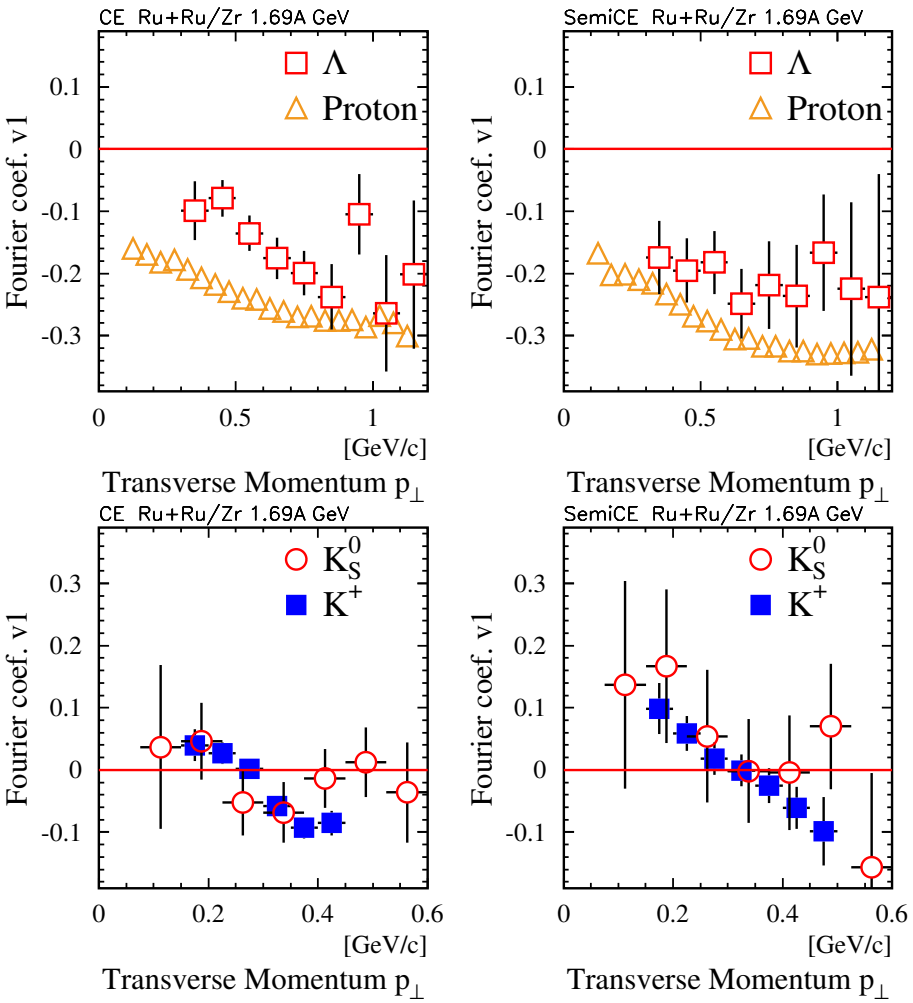
# $K^0_s$ and $\Lambda$ sideward flow




Ru+Ru @ 1.69 AGeV

central

semi-cenral



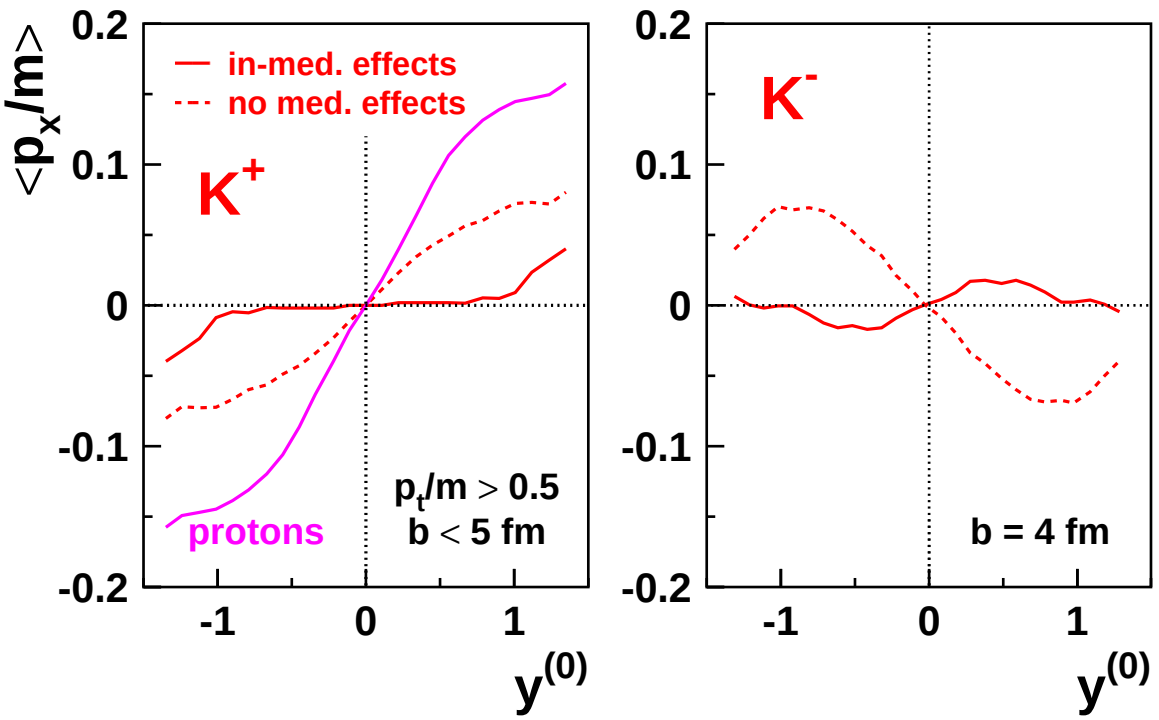

flow pattern changes from central to semi-central collisions

R. Kutsche

thesis jan. 2000

# Sideward flow - model predictions

## Central Ni+Ni @ 1.93 AGeV - RBUU




## WITH IN-MEDIUM EFFECTS:

repulsive for $\mathbf{K}^+$

⇓

pushed away

from nucleons

attractive for $\mathbf{K}^-$

⇓

attracted

towards nucleons


G.Q. Li et al., Phys.Rev.Lett. 74 (1995) 235

G.Q. Li and C.M. Ko, Nucl.Phys. A594 (1995) 460

G.Q. Li and G.E. Brown, Nucl.Phys. A636 (1998) 487

# Summary

strangeness production and propagation
at SIS energies

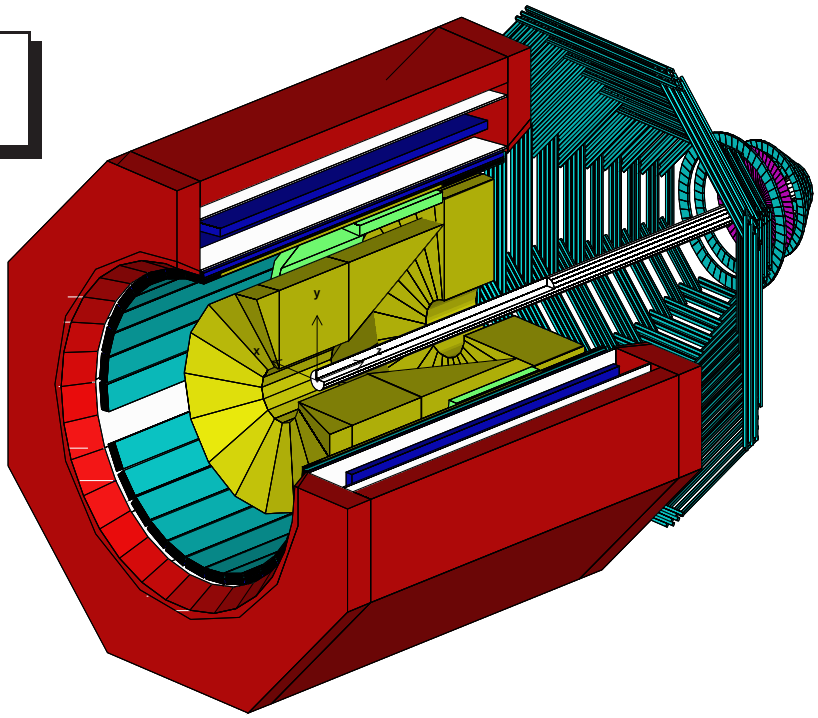
in-medium modifications of
kaon properties needed
to reproduce the data

OPEN QUESTIONS:

- theory:
  - discrepancy between models
  - description of baryons
  - alternative explanations for kaon data
    - in-medium $\Delta$ lifetime
    - momentum dependent potential
    - ....
- experiment:
  - better statistics
  - better quality
  - special emphasize on $\mathbf{K^-}$ and $\mathbf{\Phi}$'s

$\Rightarrow$ FOPI UPGRADE

# What's happening?

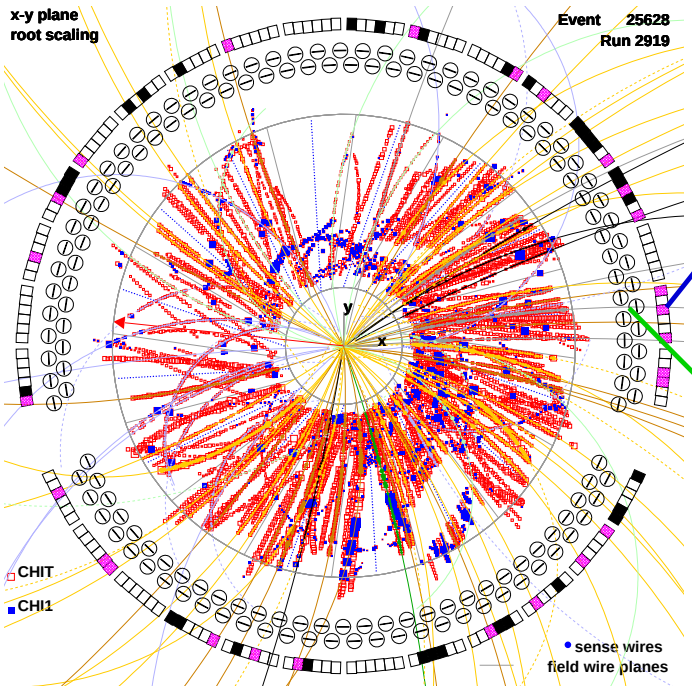


- new DAQ system
- kaon trigger
- new ToF system

Au+Au @ 1.5 AGeV:

$1\ \mathbf{K}^{+}$ each $\mathbf{10}^{\mathbf{2}}$ evts

$1\ \mathbf{K}^{-}$ each $\mathbf{10}^{\mathbf{4}}$ evts




actual scintillators barrel:

* granularity: 180
* resolution $\sim$ 300 ps

new ToF system:

* granularity: 1000
* resolution $\sim$ 60 ps

beginning of 2001