# Studying Strange Meson Production with FOPI

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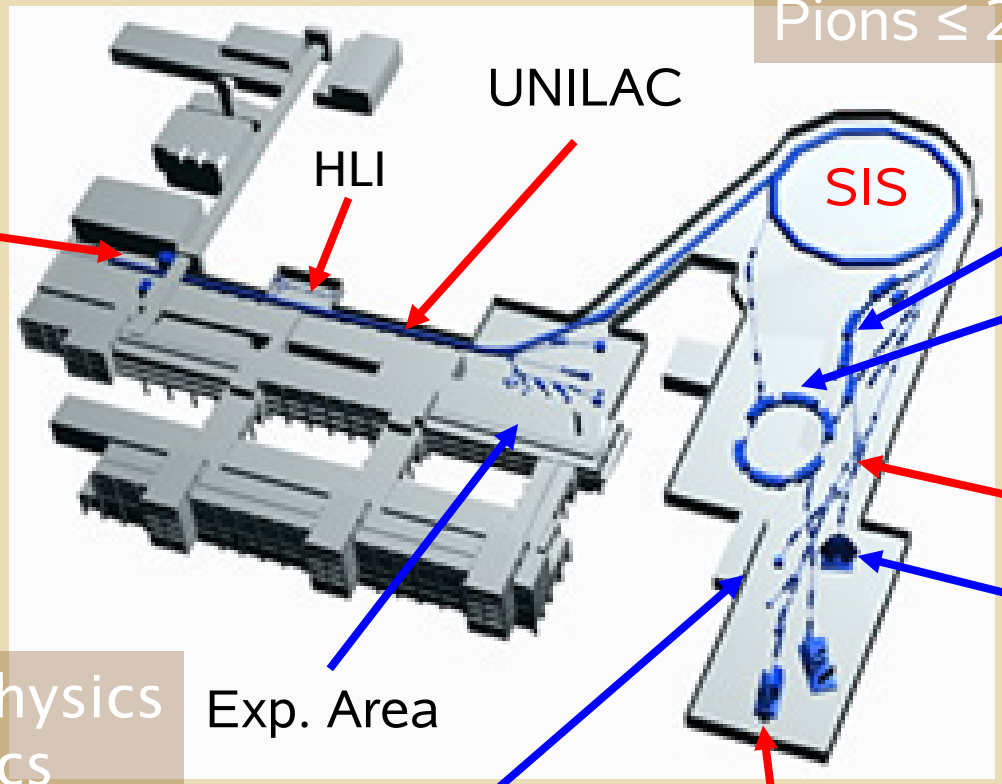
# Contents

- The FOPI Experiment at GSI-SIS
- Strangeness in Pion induced Reactions
- Search for [$K^-pp$] Clusters
- Summary
- Outlook


# The GSI Accelerator Facility

Ions (Li – U) ≤ 2 AGeV ($A/q$=2)
Protons ≤ 4.7 GeV
Pions ≤ 2.8 GeV/c

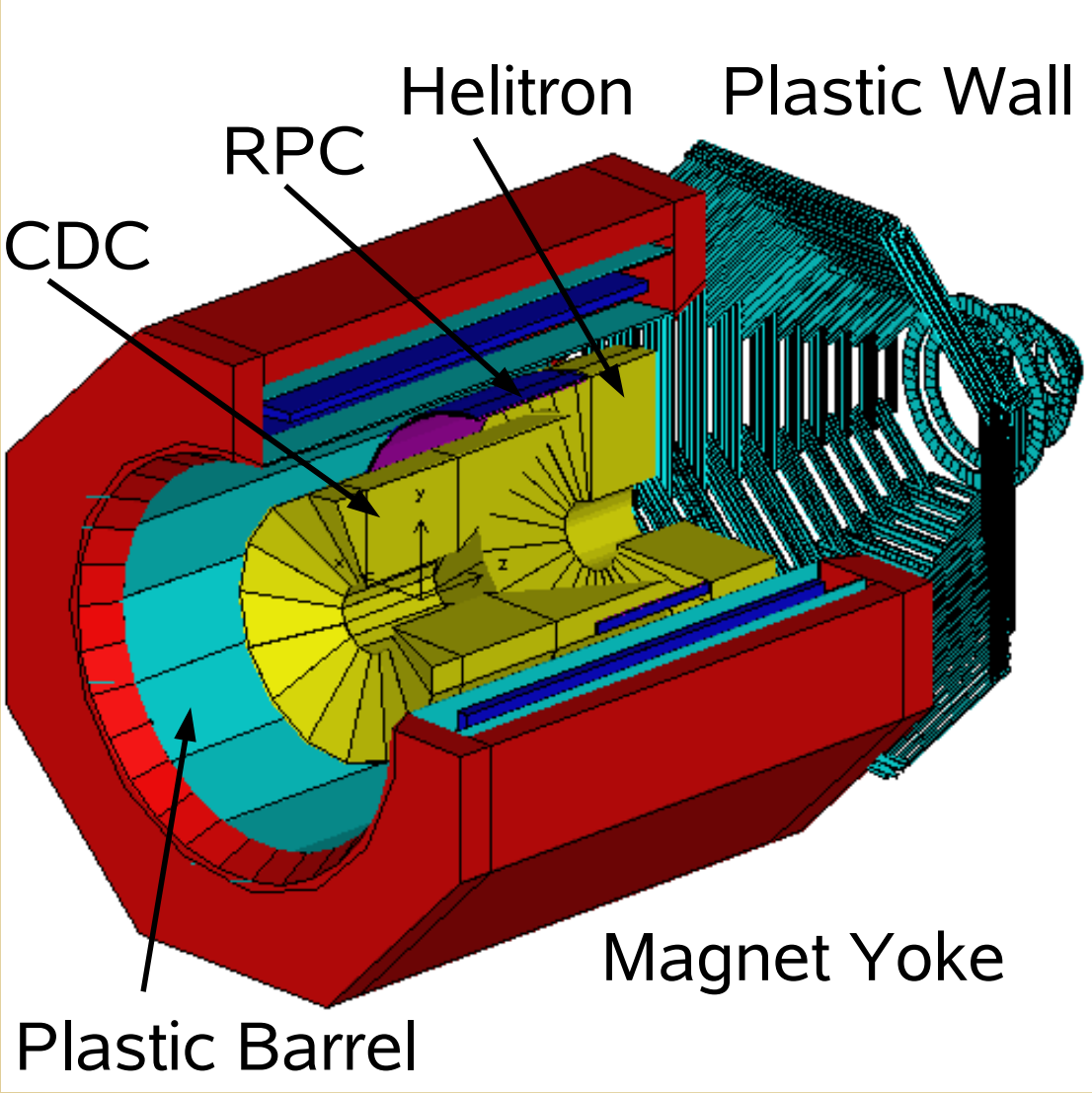



- Accelerator physics
- Atomic physics
- Nuclear physics
- Bio physics
- Plasma physics
- Material research
- Theory

Future Project

FAIR

# The FOPI Experiment




fixed target experiment
with extracted beam

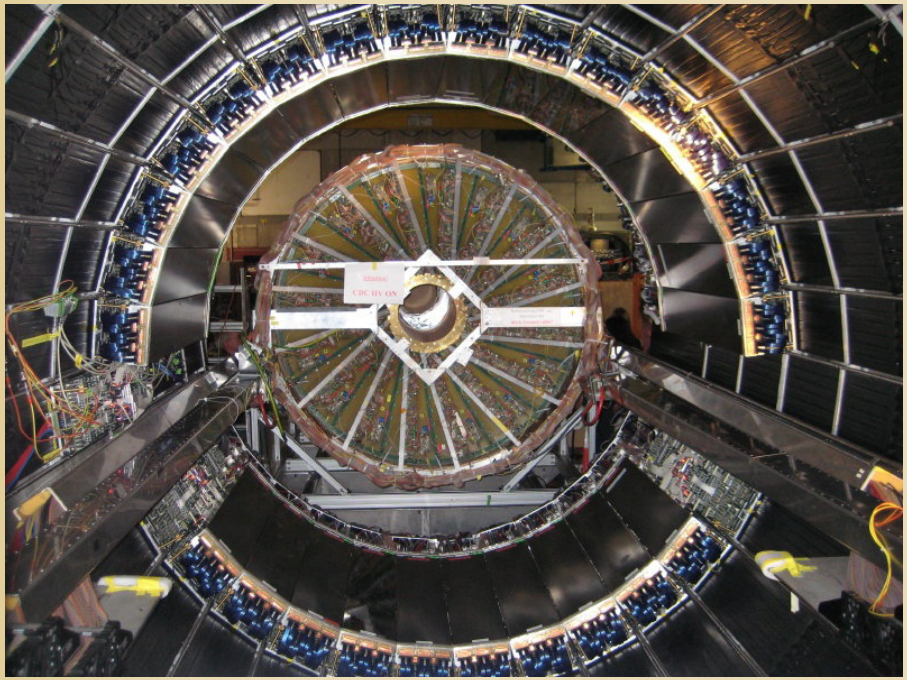
superconducting
Solenoid, 0.6 T

**Drift Chambers**
CDC, Helitron

**Time of Flight Detectors**
Plastic barrel
Plastic wall
RPC barrel

# Upgraded TOF: RPC Barrel

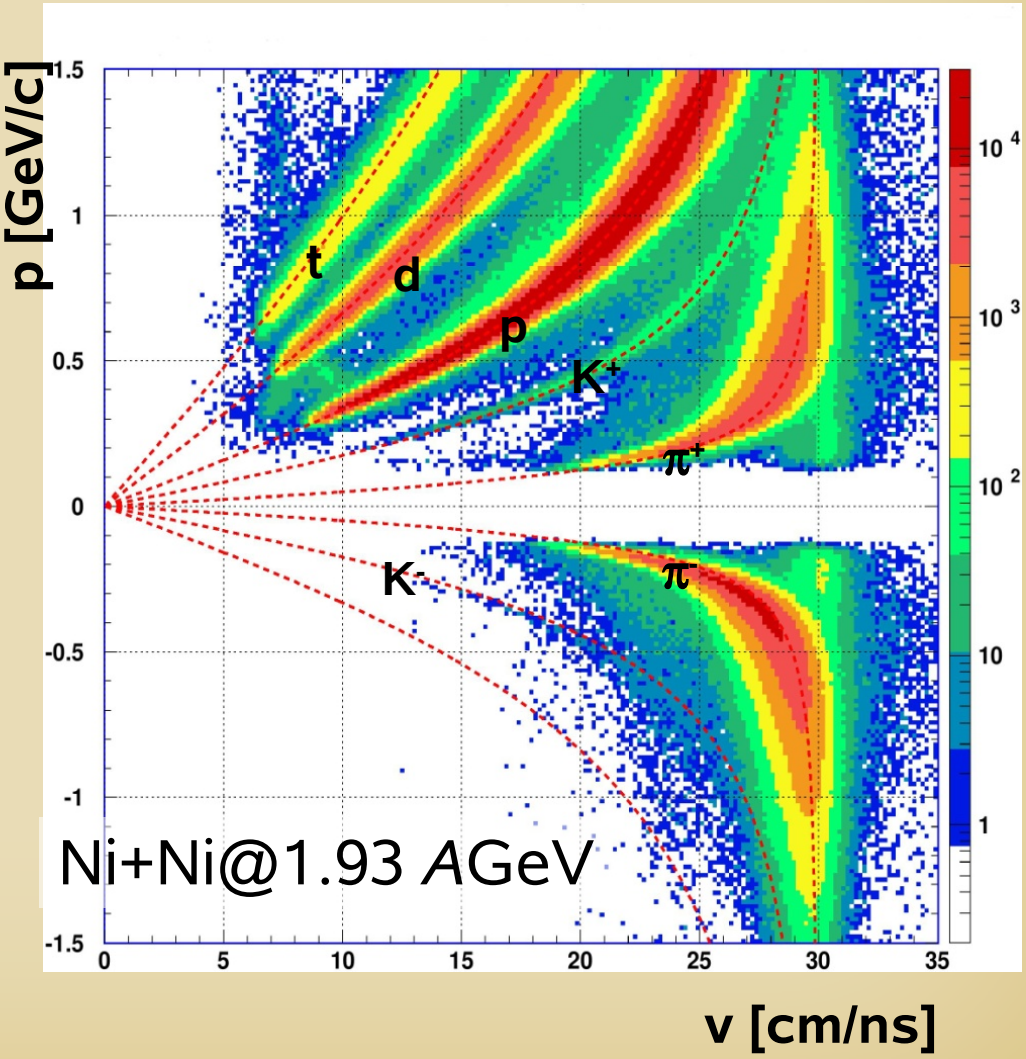
Full Barrel commissioned in 2007



Multistrip-multigap RPC
2080 strips in 26 supermodules

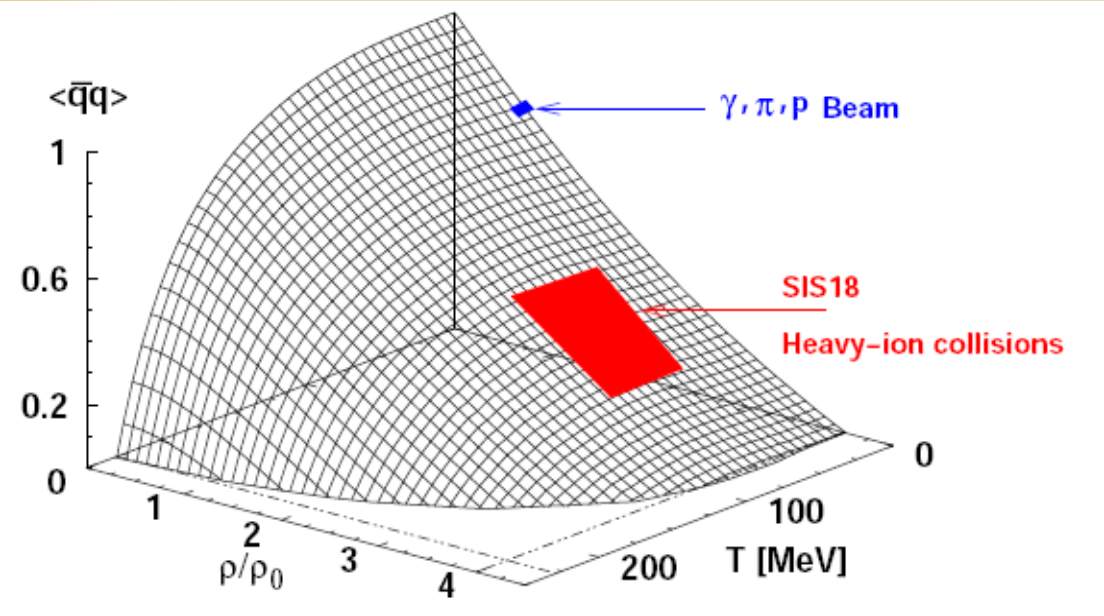
σ(RPC) ≈ 67-72 ps
σ(TOF) ≈ 94 ps (system)

With better TOF resolution
$K^{\pm}$ separation up to ~ 1 GeV



# Particle Production at SIS

W.Weise, Prog.Th.Phys.Suppl.149(2003)1




At SIS energies sizeable decrease of ‹qq›

→ Partial restoration of chiral symmetry?

→ Hadron properties modified in the nuclear medium?

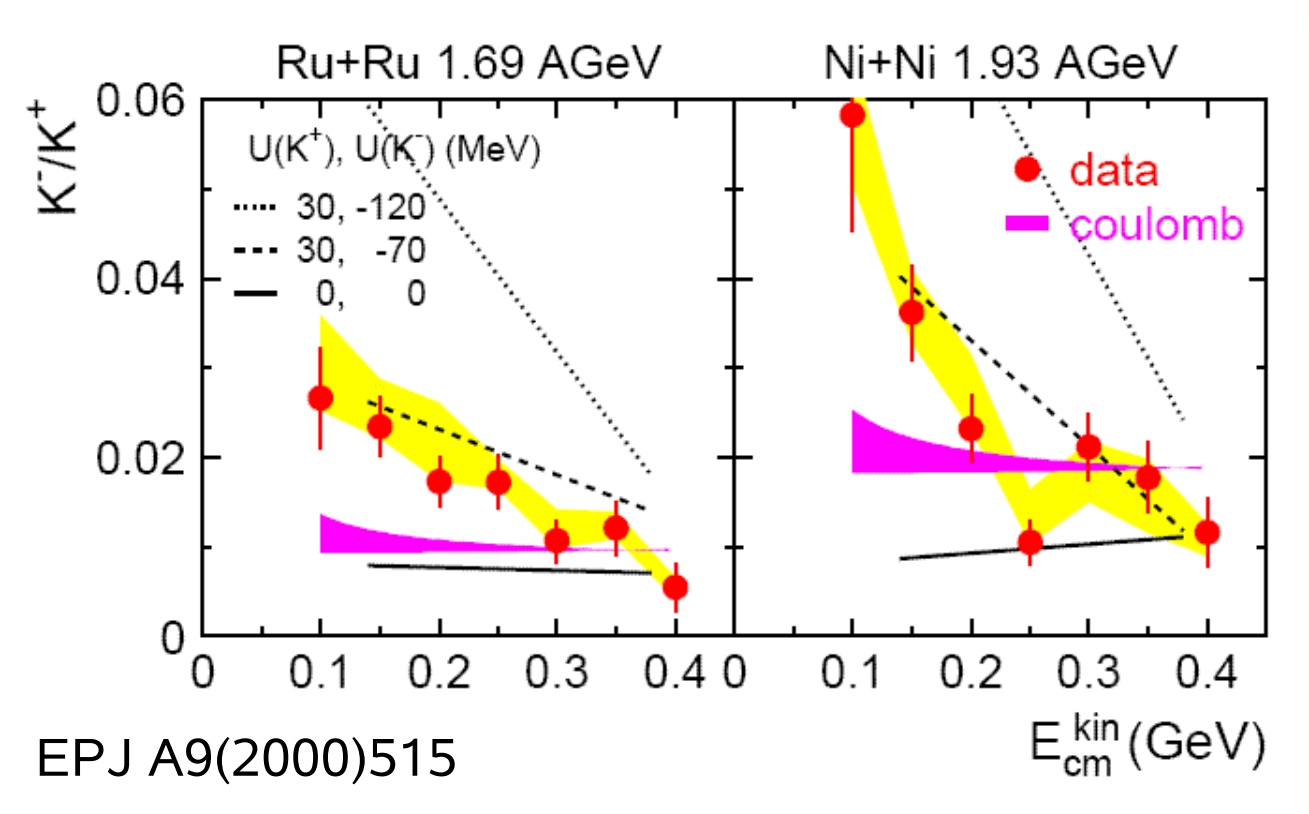
$$m_\pi^2 f_\pi^2 = - < m_q > \langle q\bar{q} \rangle$$

Phys.Rev. 175(1968)

Meson mass
Gell-Mann – Oakes – Renner relation
(in the medium)

Non-trivial in medium effects (mass, width, cross sect., ...) expected.

# Yield of Charged Kaons




EPJ A9(2000)515

**$K^-/K^+$ ratio**

Comparison to RBUU transport model calculations

„in medium potential“

- if U=0 the ratio shows a flat line
- influence of Coulomb potential

U≠ 0 needed to describe the data

$U(K^+)$=30 MeV,
$U(K^-)$=-70 MeV

# $\pi^-$ Induced Reactions: $K^0$

Secondary Pion beam at SIS
$\leq 10^7$ $\pi^\pm$ in p+Be, $^{14}$N+Be

pion momentum
from 0.6 to 2.8 GeV/c
intensity maximum ≈ 1.1 GeV/c

FOPI:
ca. 90 m flight path
$\Delta p/p \approx \pm 1.5\%$
$\rightarrow 10^3$-$10^4$ $\pi^-$/s

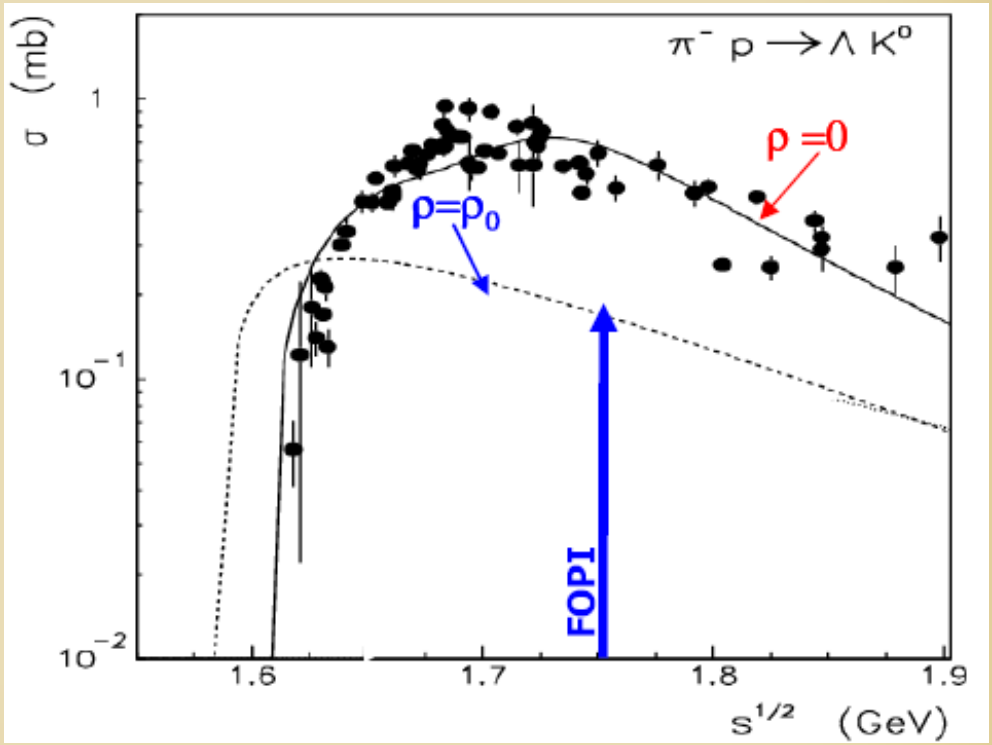
Experiment in 2004:
1.15 GeV/c $\pi^-$ + C,Al,Cu,Sn,Pb

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

in-medium cross section

$\pi^- + p \rightarrow \Lambda + K^0$

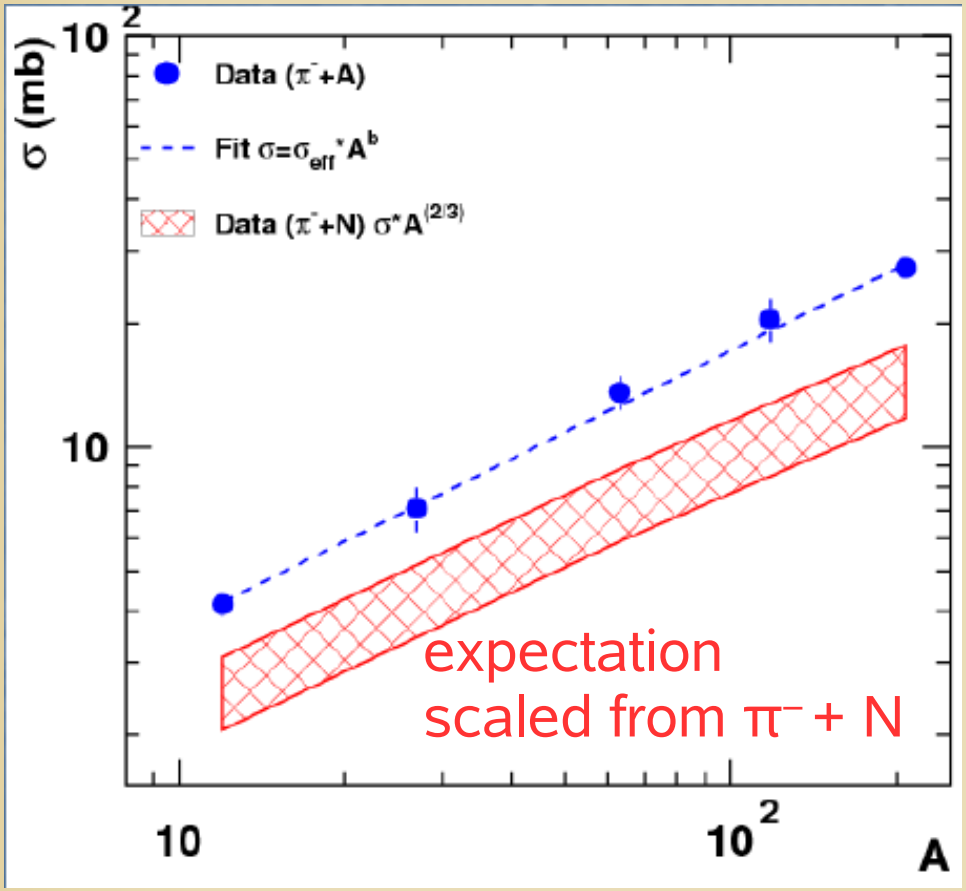
K. Tsushima et al., PRC62(2000)064904




separation from Σ channels not possible
$\rightarrow$ inclusive cross section

# $K^0$ Inclusive Cross Section

M.L. Benabderrahmane




Vacuum expectation under-estimates the data

Indication for in-medium effect in $K^0$ production

*A* systematics of $K^0$ cross section

Power law fit:

$$\sigma = \sigma_{\mathrm{eff}} \cdot A^b$$

$\sigma_{eff}$ = (0.87 ± 0.13) mb

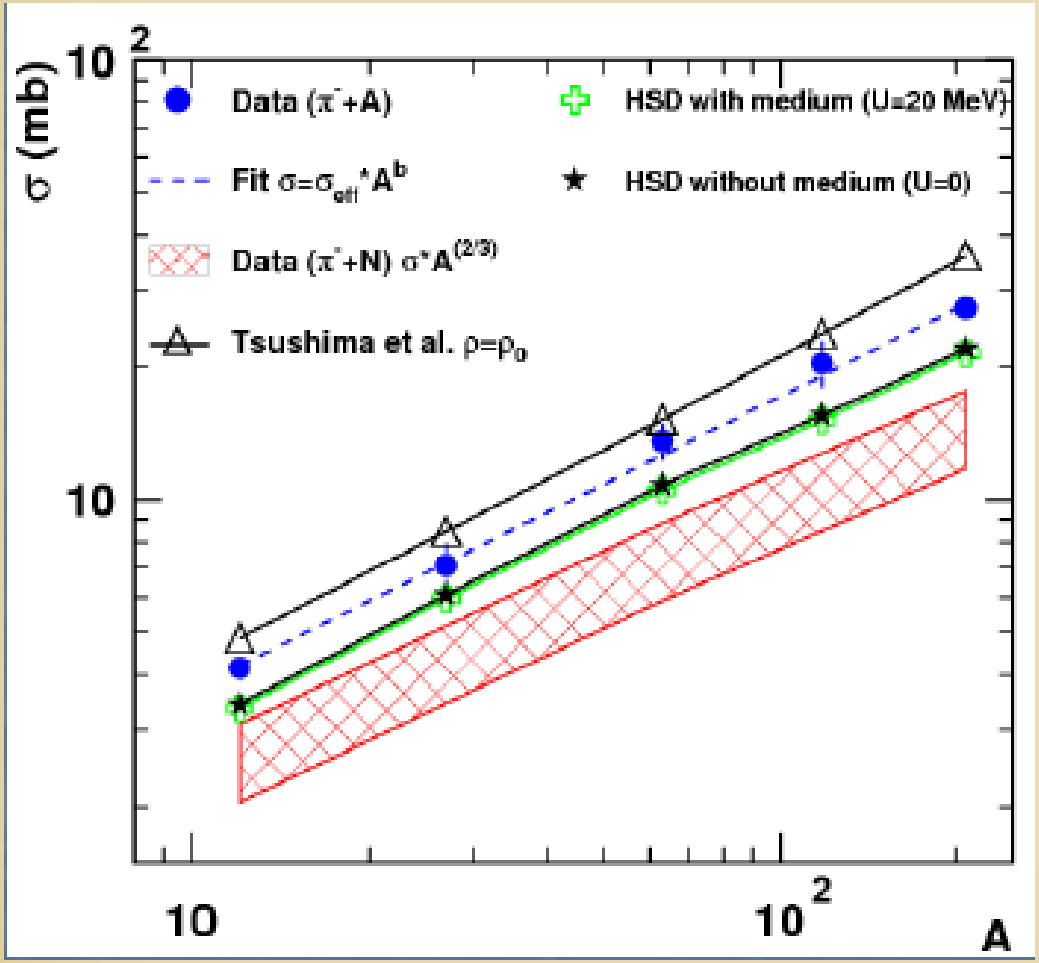
*b* = 0.67 ± 0.03

$\pi^-$ absorption takes place at the surface of the nucleus

at 1 GeV/c $\lambda(\pi^-) \approx 1$ fm

# $K^0$ Inclusive Cross Section

Model comparisons




M.L. Benabderrahmane

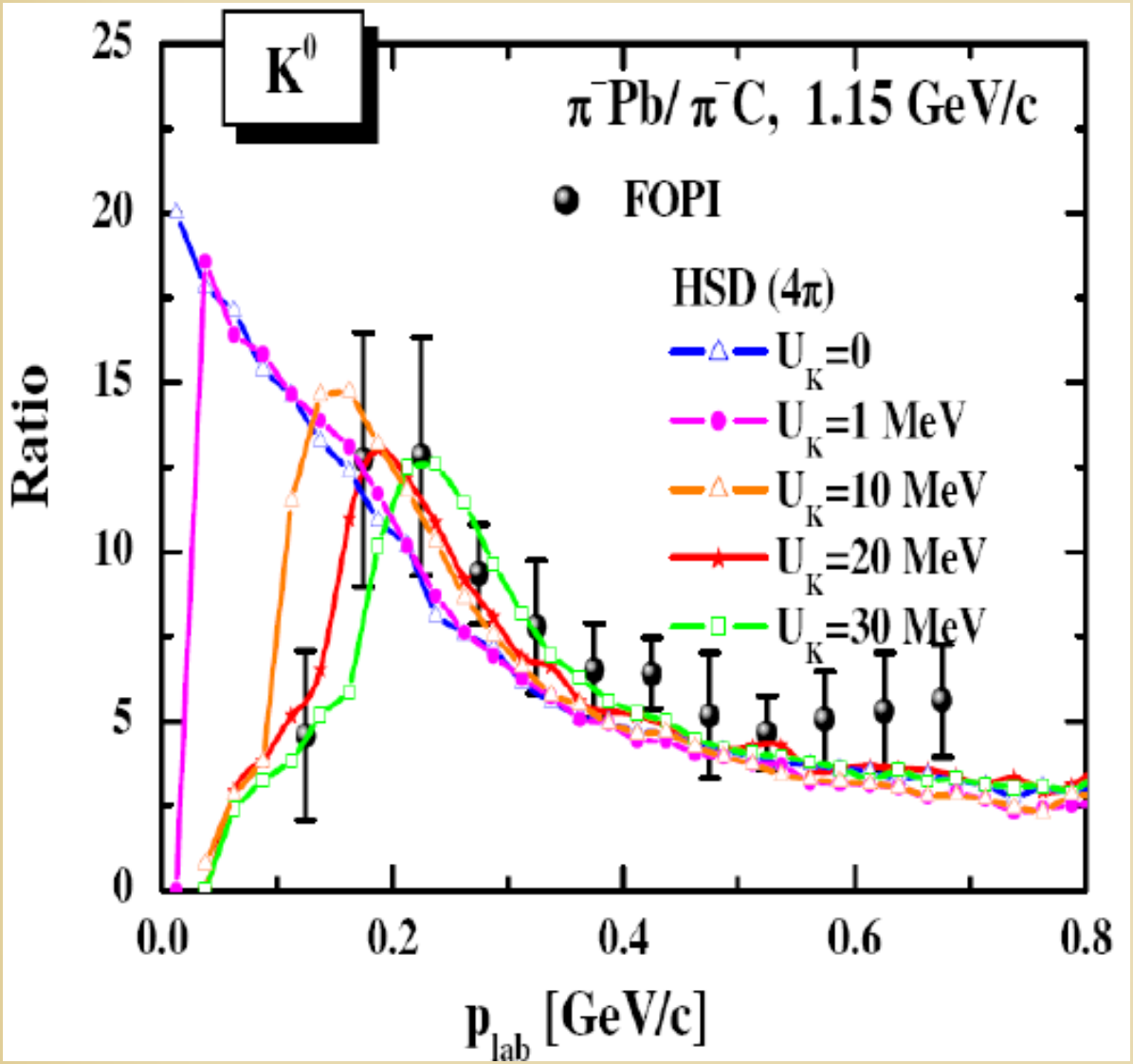
Data lie below predictions by Tsushima et al.

→ $\rho<\rho_0$

HSD Transport Code Calculations
→ no sensitivity to potential

# $K^0N$ Potential

M.L. Benabderrahmane



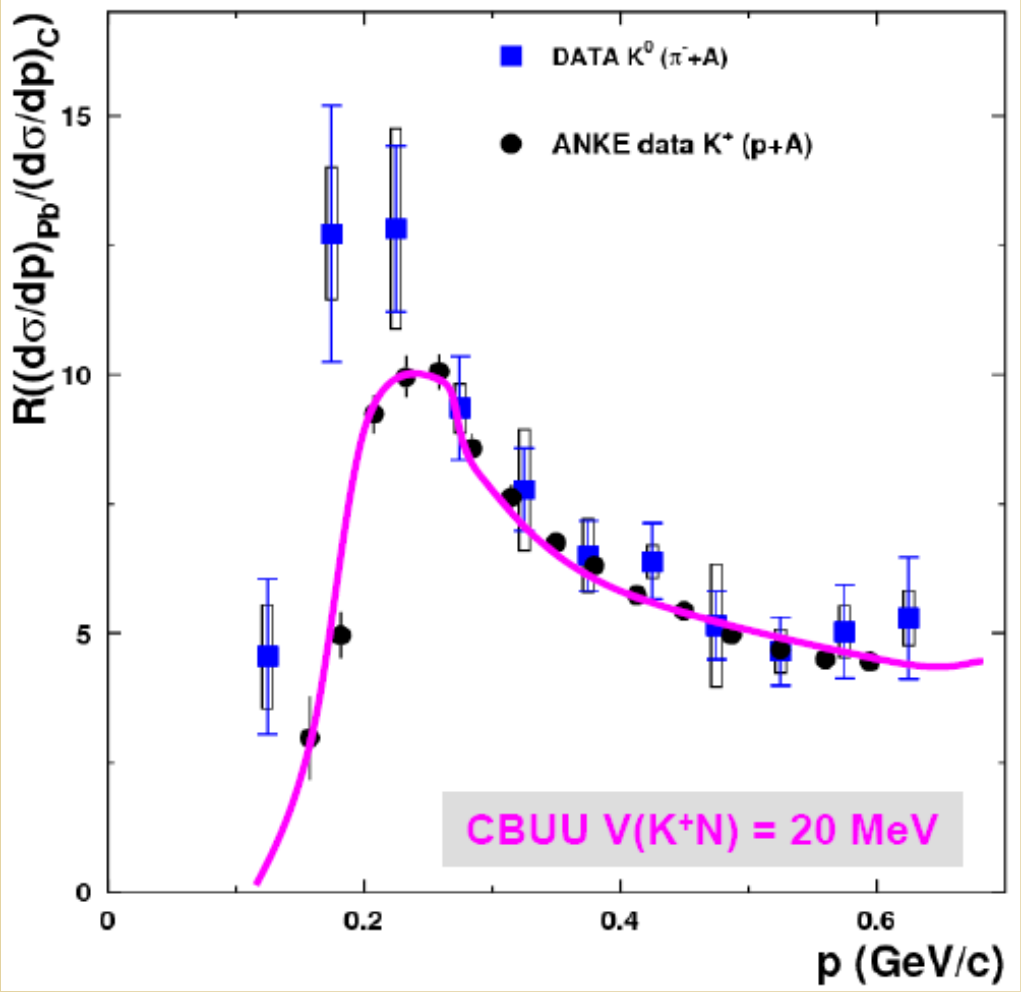

$$\text{ratio} = \frac{\left(\frac{d\sigma}{dp}\right)_{\text{Pb}}}{\left(\frac{d\sigma}{dp}\right)_{\text{C}}}$$

Data compared to HSD transport model

Sensitivity to the potential: Low momentum kaons

$U(K^0N) \approx 20\text{-}30$ MeV suggested

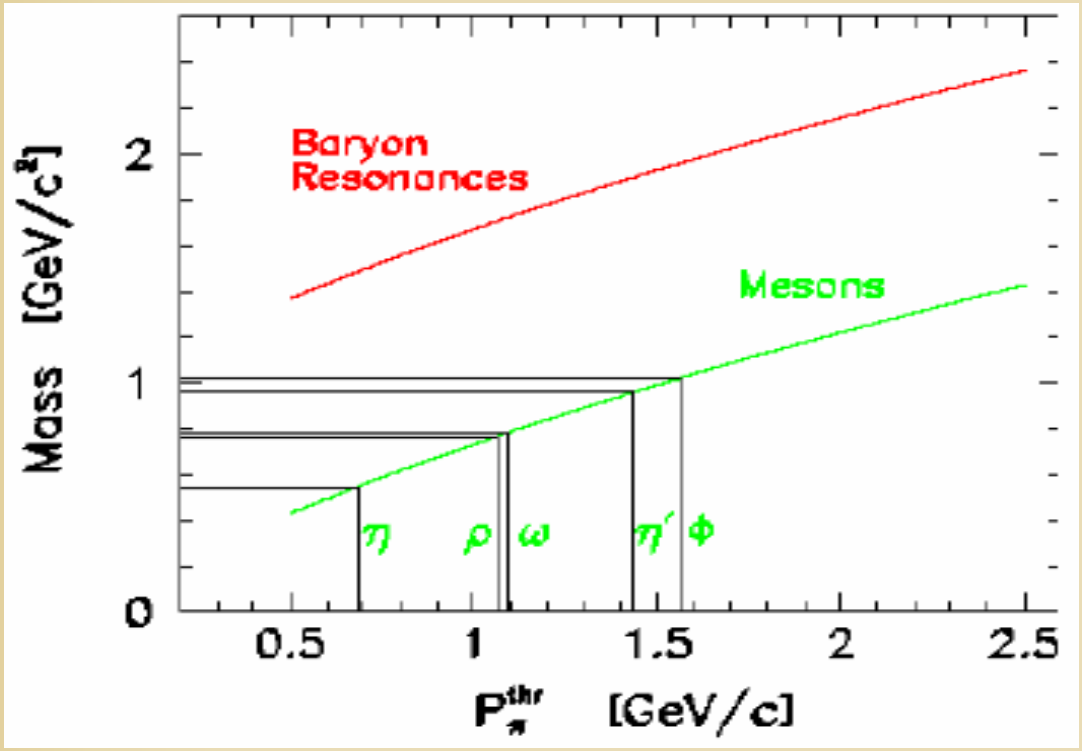
# $K^0N$ – $K^+N$ Potential




Z. Rudy et al., EPJA23(2005)379

Ratio shows the same trend for $K^+$ as well as for $K^0$

# $\pi^-$ Induced Reactions: $\Phi \rightarrow K^+K^-$

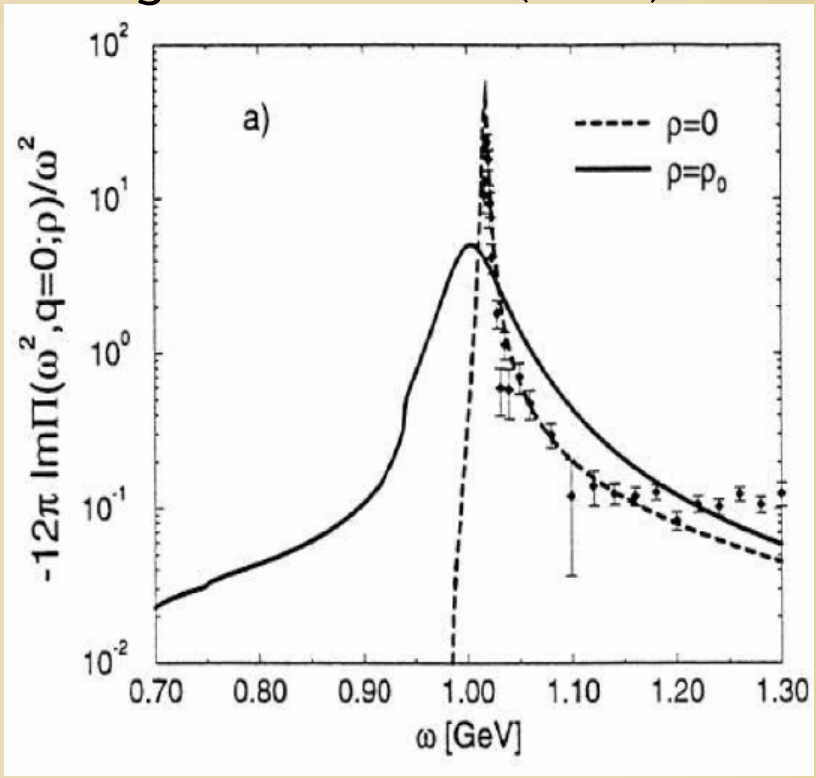



threshold for Φ(1020): 1.56 GeV/c

attenuation measurement:

$$T_Z = \frac{\sigma_{\pi^- A \rightarrow \phi X}}{Z^{\alpha} \sigma_{\pi^- p \rightarrow \phi X}}$$

Klingl et al. PLB431(1998)254

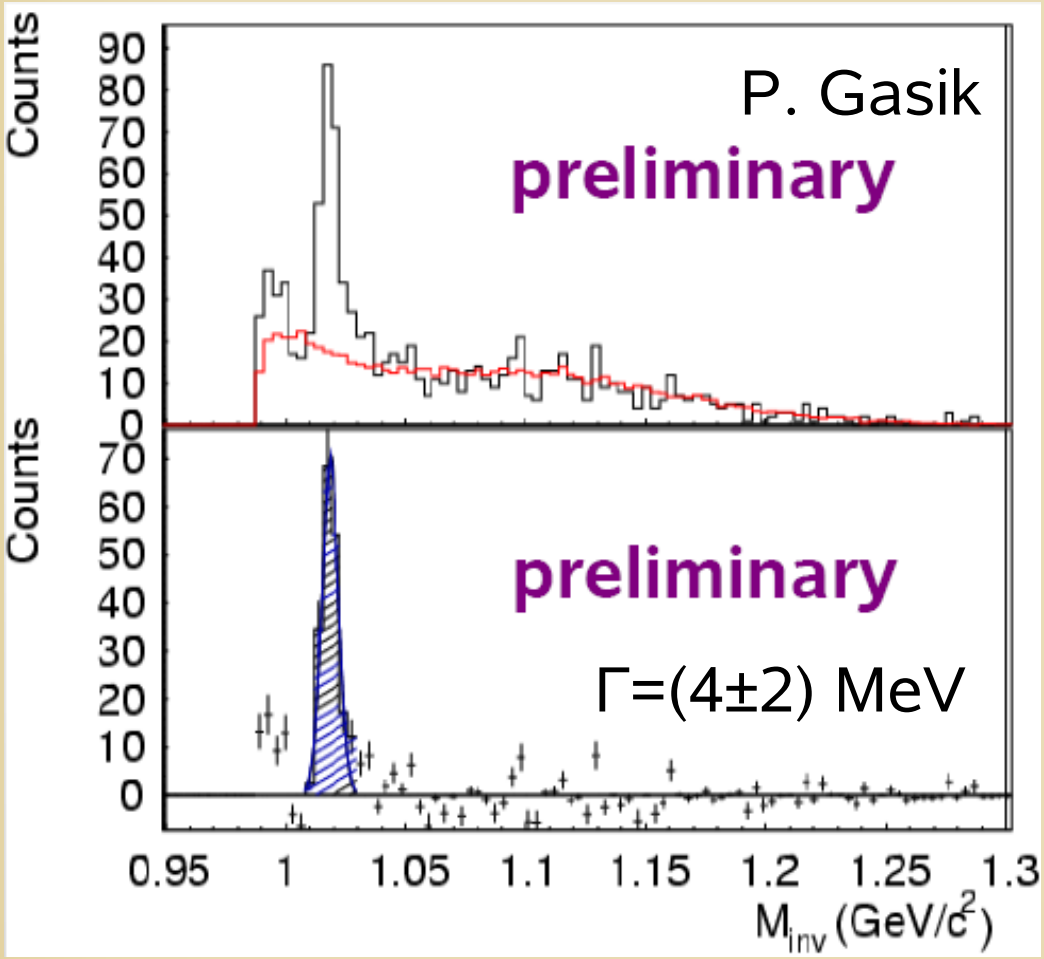



Φ in medium → broadening expected

promising data from p+A, γ+A experiments

# ϕ(1020) Measurement

Al+Al 1.93 *A*GeV



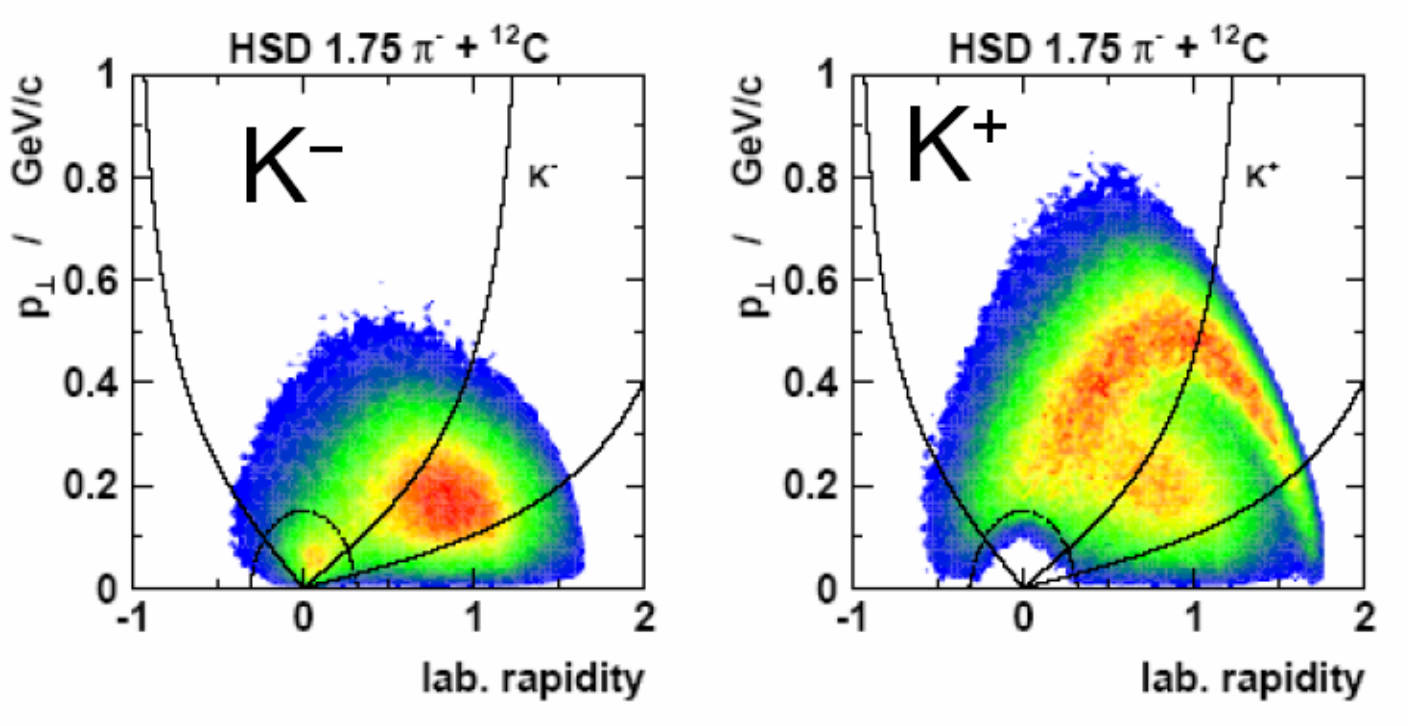

$K^+K^-$ invariant mass

$\Phi \rightarrow K^+K^-$
analysed in heavy-ion collisions

Al+Al, 1.93 AGeV

S/B = 1.9
$P(\Phi) = (4.9 \pm 1.1) \cdot 10^{-5}$/coll.

# $\pi^-$ Induced Reactions: $K^+K^-$




Predictions from HSD transport calculations

(no ϕ resonance included)

looking for co-produced $K^+K^-$
- yield as function of *A*
- spectral shape

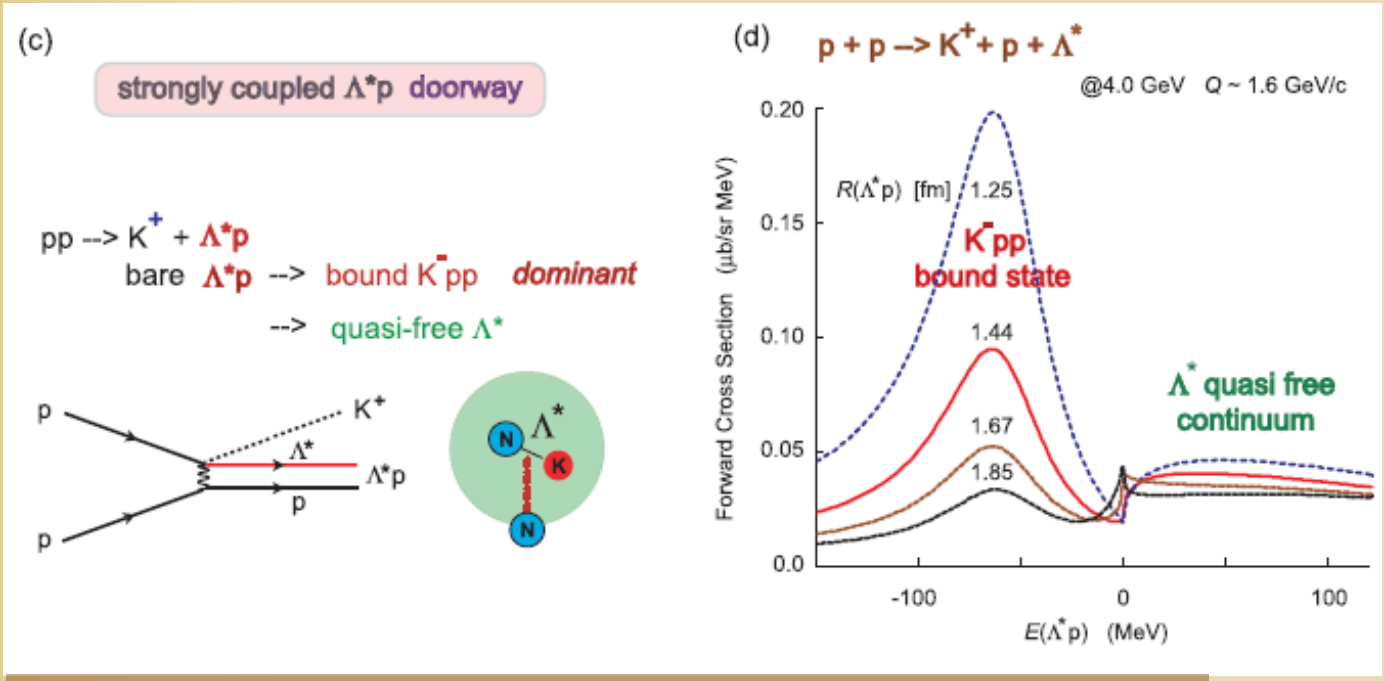
Experiment planned for 2009:

$\pi^- + A \rightarrow K^+K^-X$

A = $LH_2$, C, (Cu,) Pb

# Search for a [K⁻pp] Bound State

Prediction by T. Yamazaki and Y. Akaishi (2002):
existence of strongly bound Antikaon-Nucleon state

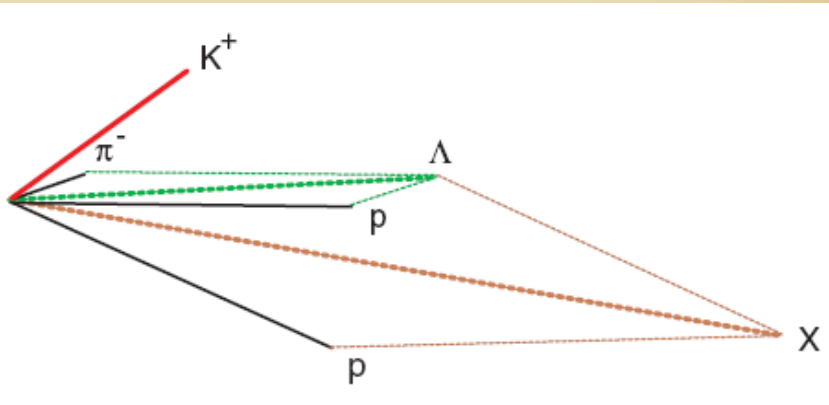



lightest cluster [K⁻pp]

M = 2223 MeV/c
B.E.= 48 MeV
Γ = 61 MeV

T. Yamazaki and Y. Akaishi
PRC 76(007)04501

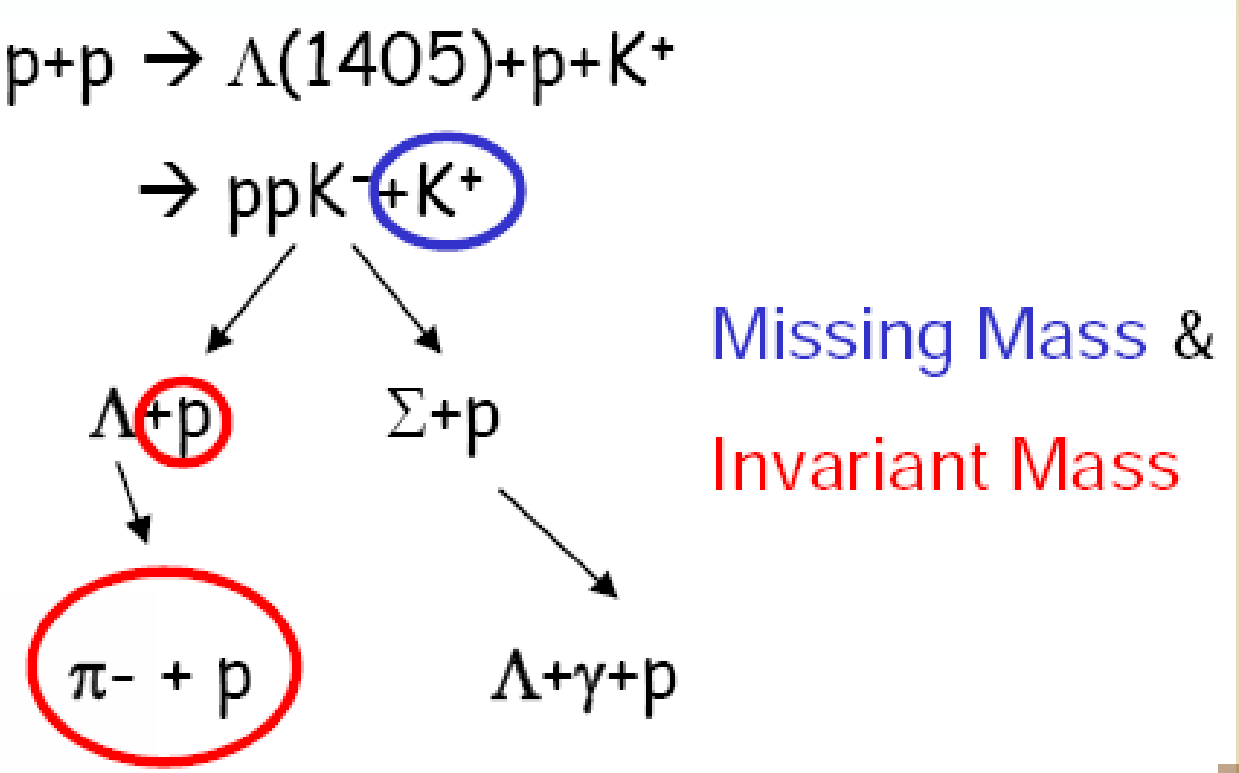
$p + p \rightarrow K^+ + \Lambda^* + p$, $Q \approx 1.6$ GeV/c




enhanced probability for Λ*p ↔ [K⁻pp]

Maximum of the cross section ≈ 3 GeV

# Detecting [K⁻pp] in with FOPI




Missing Mass &

Invariant Mass

Directly measurable:

charged decay products

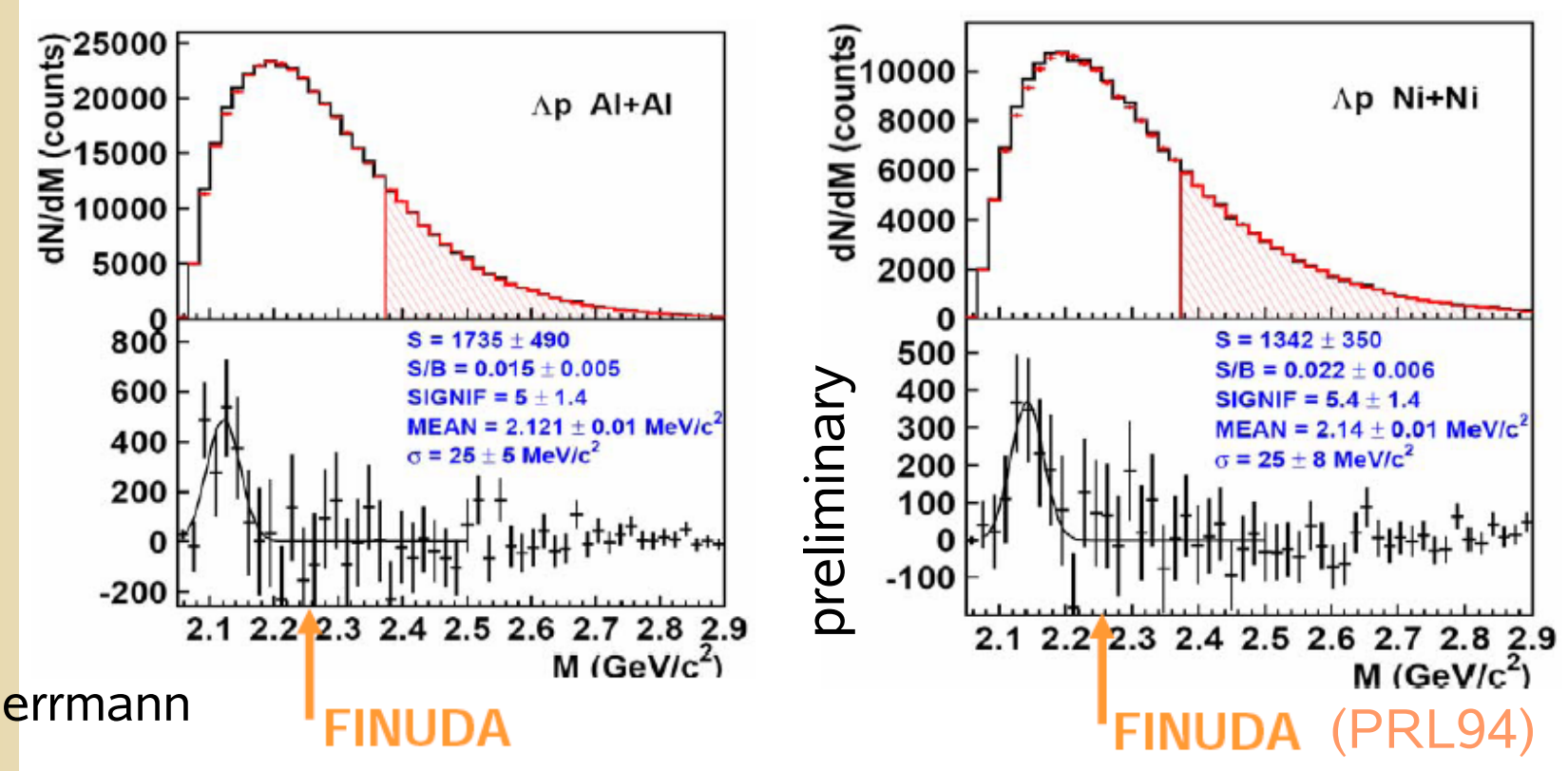
Λ reconstructed from $p\pi^-$ invariant mass

[K⁻pp] decay involves hyperons

in p+p
cross sections at 3 GeV

| | |
|---|---|
| 44 mb | total |
| 0.1 mb | Λ + X |
| 3 μb | $K^+$ + [K⁻pp] |

# Λp Correlations in Heavy-Ion Collisions

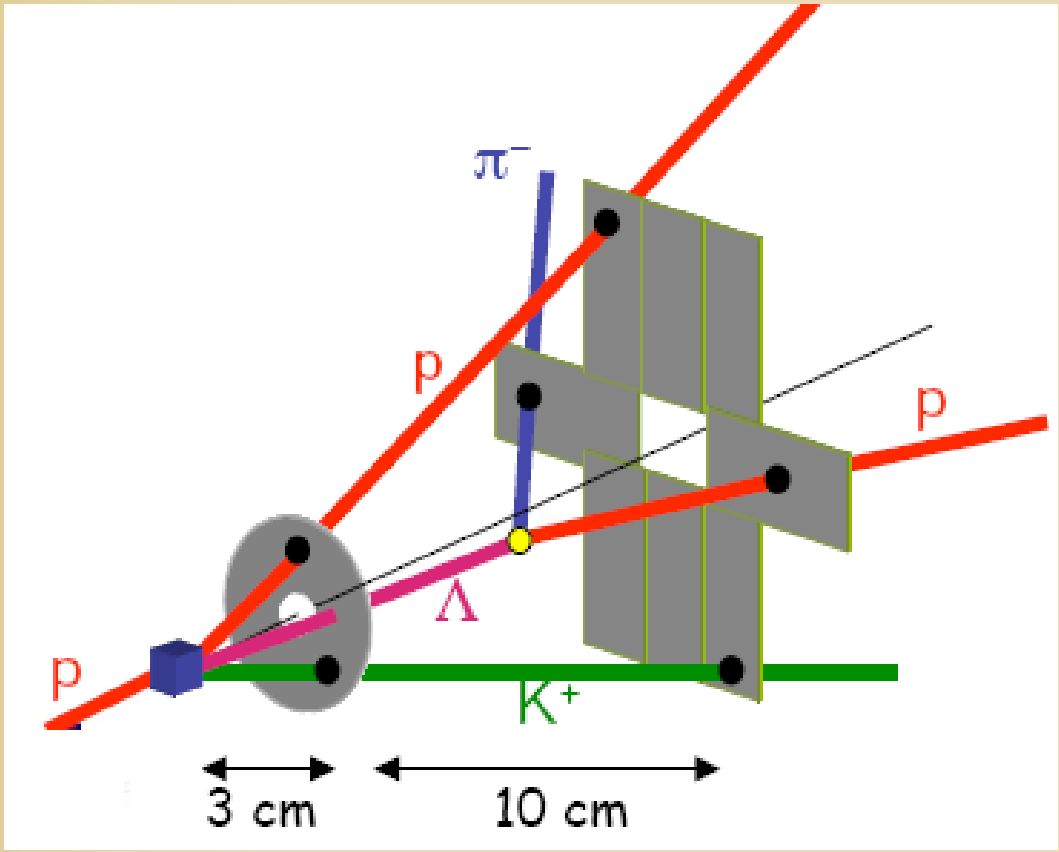



N. Herrmann

Ni+Ni/Al+Al collisions: excess observed (significance ~5)

Interpretation unclear - (ΣN FSI? Bound state? Partial inv. mass of heavier state (e.g. $_{\Lambda}$He-4) ?)

# Adding a Λ Trigger to FOPI




Idea:

At least two detector layers

Λ decays behind the first and before the second layer

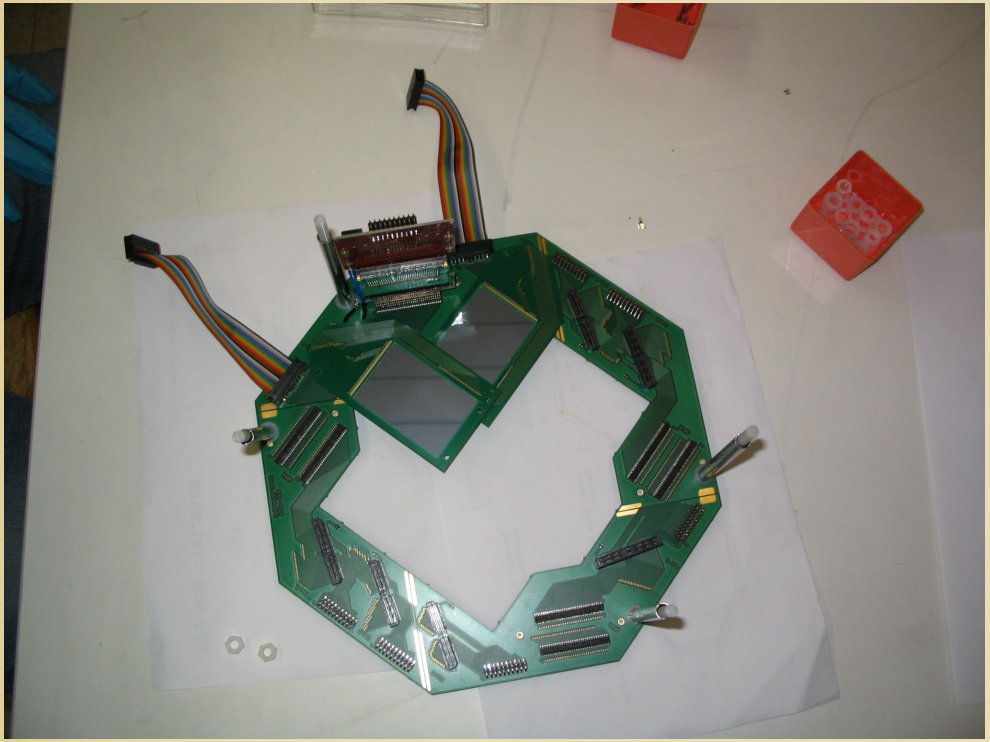
trigger on different multiplicity

*additional point(s) for forward tracking*

Solution:

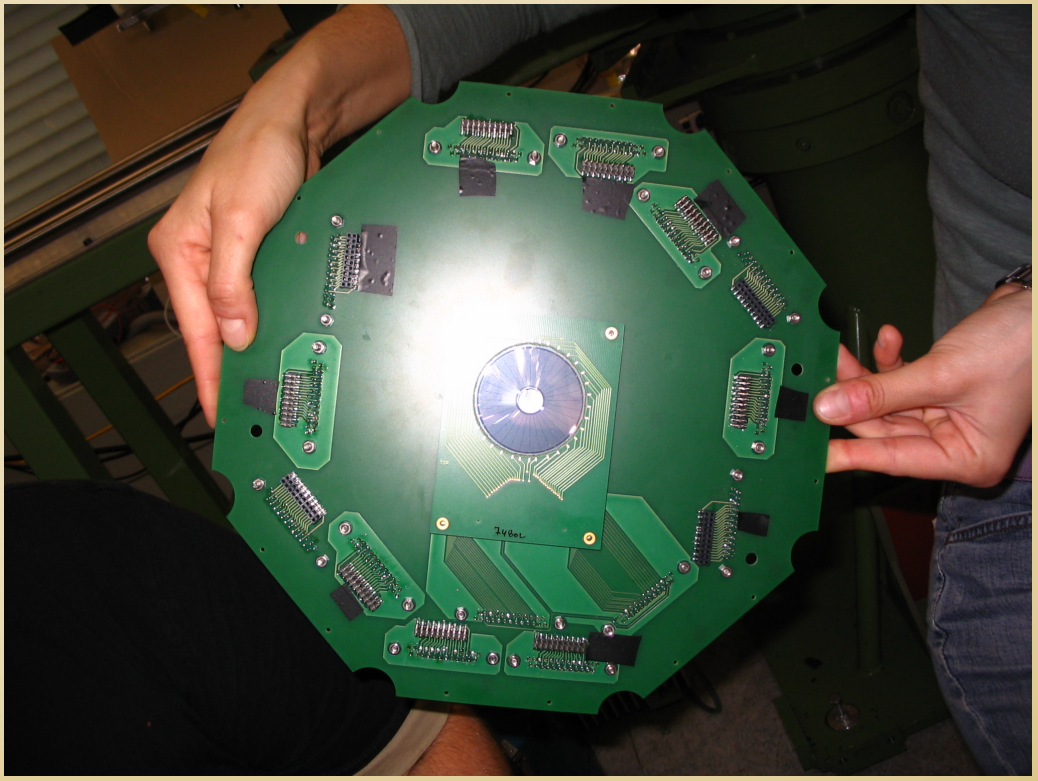
two layers of (double sided) silicon strip detectors
readout capable to deliver a fast multiplicity output → trigger logic

# Silicon Detector Test May-June 2008

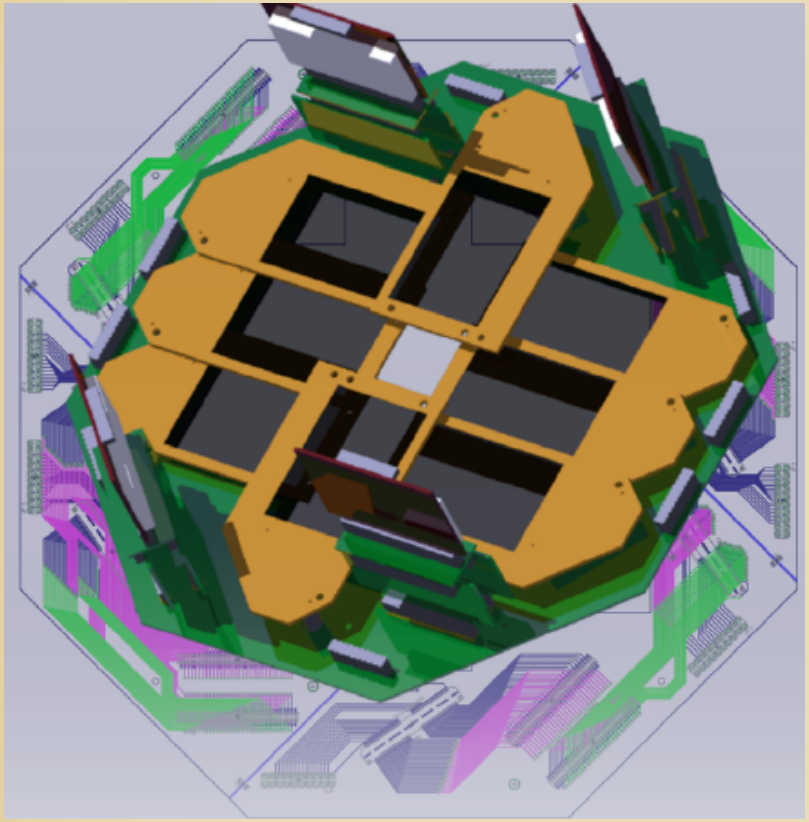


2 Rectangular Silicons

Annular Silicon



# Status: Λ Trigger/p+p Experiment



- SSD's are available and tested
- readout electronics modules
  Mesytec and APV
- in beam test of the trigger
  concept successfully done
- simulations on background and
  trigger efficiency are performed
- construction of target, start and
  beam counter under way

September 2008: final in-beam test of all components

Production run starts in early 2009

# Summary

## Study of $K^0$, $K^+$, $K^-$, $\Phi$ Production

- $K^-/K^+$ yield points to an in-medium kaon potential of the order of 20-30 MeV
- $\pi^-$A: hint for in-medium effect in the $K^0$ production;
- ratio of yields Pb/C shows sensitivity to $K^0$N potential
- new experiment: $\Phi(1020)/K^+K^-$ on p, C, Pb

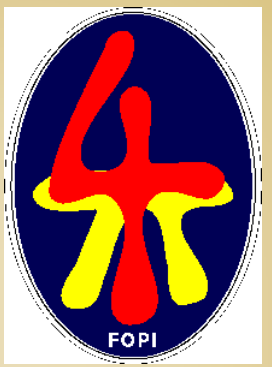
## [$K^-$pp] Search in the 3 GeV p+p Reaction

- excess in $\Lambda$p invariant mass in heavy ion collisions
- for p+p experiment: $\Lambda$ trigger added to the FOPI setup

# Outlook

- Heavy Ion Programm: Ni+Ni, Ru+Ru, Ni+Pb
  - Strangeness Production
    - $\Lambda$, $K^0$, $\Phi$ — $\Sigma(1385)$, K(892)
  - Search for Strange Clusters
    - $\Lambda$p, $\Lambda$d, $\Lambda$t correlations
    - $H_1^+$? $^3_\Lambda$He or other multibaryonic states?
- Test of a Forward TPC
  - Prototype of the PANDA GEM-TPC will be tested in FOPI
- Pioneering Studies for FAIR-CBM, PANDA

# FOPI Collaboration




A. Andronic, V. Barret, Z. Basrak, N. Bastid, M. L. Benabderrahmane,
P. Bühler, M. Cargnelli, R. Čaplar, E. Cordier, P. Crochet, P. Dupieux,
M. Dželalija, L. Fabbietti, Z. Fodor, I. Gašparić, Y. Grishkin, O.N. Hartmann,
N. Herrmann, K. D. Hildenbrand, B. Hong, T. I. Kang, J. Kecskemeti,
M. Kirejczyk, Y. J. Kim, M. Kiš, P. Koczon, M. Korolija, R. Kotte, A. Lebedev,
Y. Leifels, X. Lopez, V. Manko, J. Marton, T. Matulewicz, M. Merschmeyer,
W. Neubert, D. Pelte, M. Petrovici, K. Piasecki, F. Rami, M. Reithner,
W. Reisdorf, M. S. Ryu, A. Schüttauf, Z. Seres, B. Sikora, K. S. Sim, V. Simion,
K. Siwek-Wilczyńska, V. Smolyankin, G. Stoicea, K. Suzuki, Z. Tyminski,
P. Wagner, E. Widmann, K. Wisniewski, D. Wohlfarth, Z. G. Xiao, I. Yushmanov,
X. Y. Zhang, A. Zhilin, and J. Zmeskal

**KFKI Budapest, NIPNE Bucharest, LPC Clermont-Ferrand, GSI Darmstadt, FZ Dresden-Rossendorf, U Heidelberg, IMP Lanzhou, ITEP Moscow, KI Moscow, TU München, U Split, KU Seoul, IPHC Strasbourg, SMI Vienna, U Warsaw, RBI Zagreb**