Strangeness Physics with FOPI at GSI-SIS

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Österreichische Akademie der Wissenschaften

Der Wissenschaftsfonds.

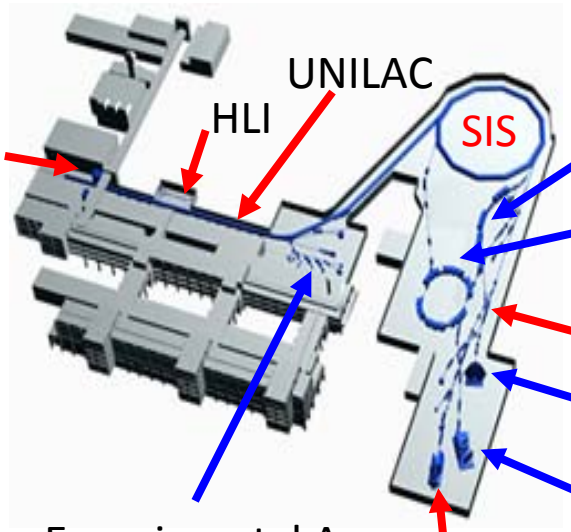
Contents

- The Heavy Ion Synchrotron SIS at the GSI
- The FOPI Detector
- Strangeness Production
  - Heavy ion collions (dense baryonic matter)
  - Proton+proton collisions
  - Pion induced reactions
- Future Plans
- Conclusions

SIS – **S**chwer**i**onen-**S**ynchrotron

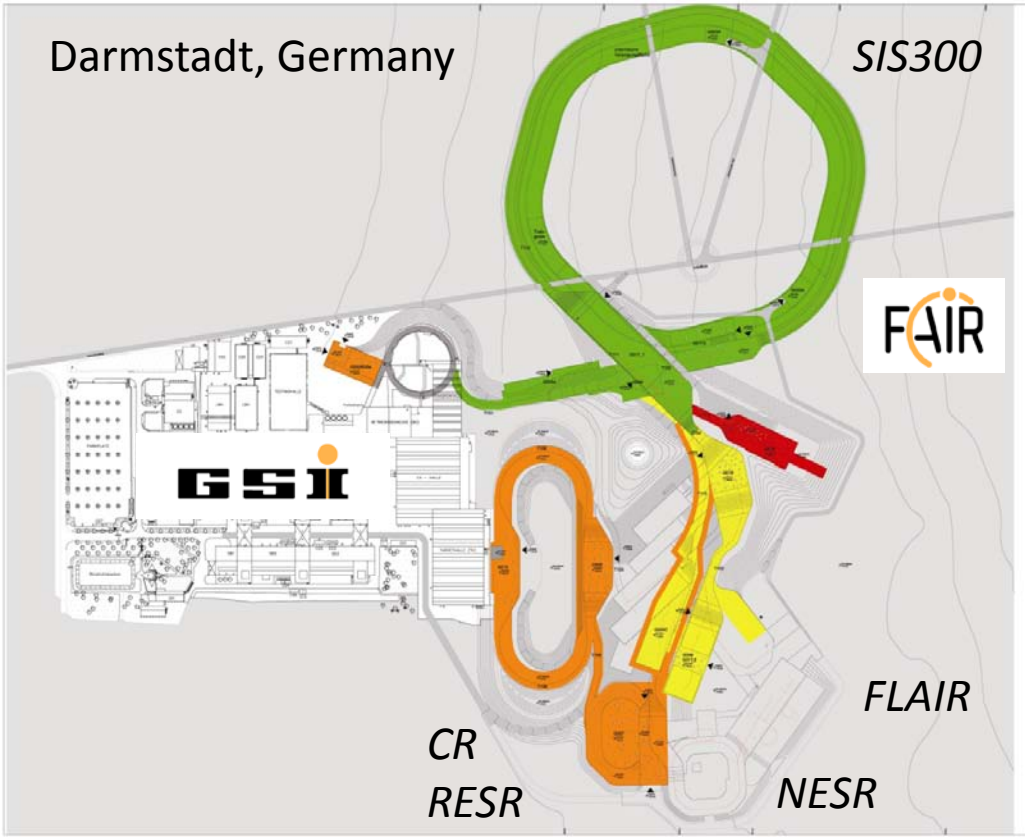
216 m circumference
18 Tm bending power

Beams at the SIS:
Ions (Li – U) ≤ 2 GeV/u (A/q=2)
Protons ≤ 4.5 GeV
Pions ≤ 2.8 GeV/c



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

The **F**acility for **A**ntiproton and **I**on **R**esearch



later: RESR, FLAIR, SIS300

"Modularized Start Version"

SIS100

CBM @SIS100

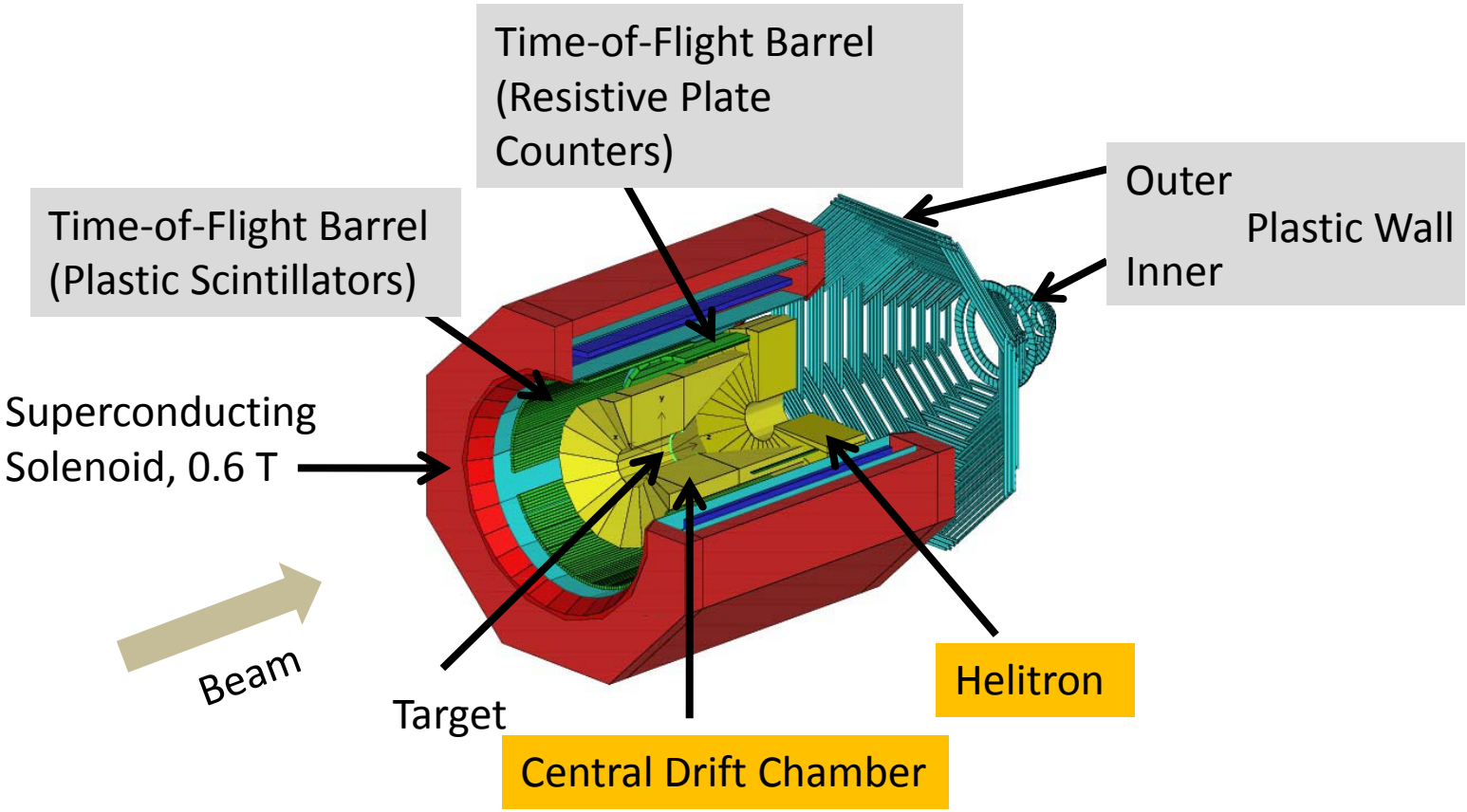
SuperFRS

Proton Linac
Antiproton production target
CollectorRing
High Energy Storage Ring

Start of Civil Construction still in 2011

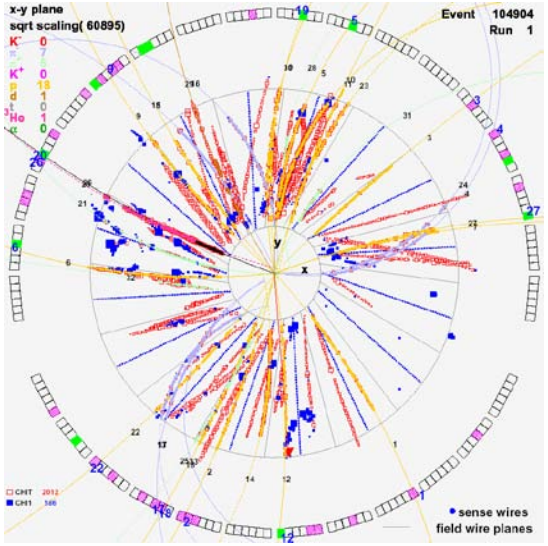
First Physics expected in 2018

The FOPI Detector

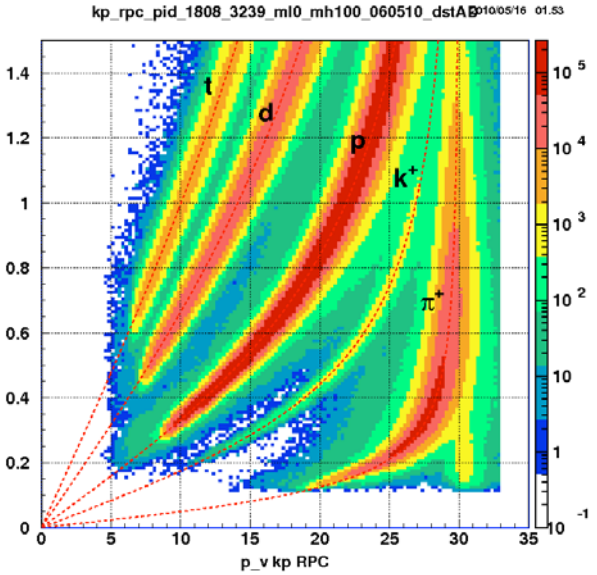


NIPNE Bucharest, KFKI Budapest, LPC Clermont-Ferrand, GSI Darmstadt, FZ Dresden-Rossendorf, University Heidelberg, ITEP Moscow, KI Moscow, TU Munich, Korea U Seoul, IReS Strasbourg, University Warsaw, SMI Vienna, RBI Zagreb

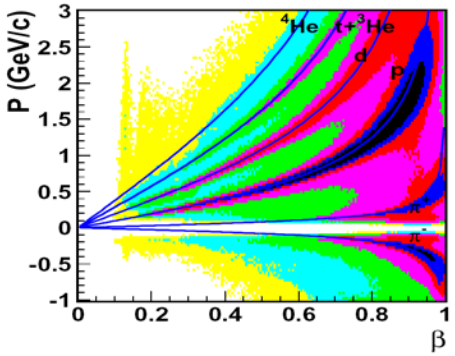
Particle Identification



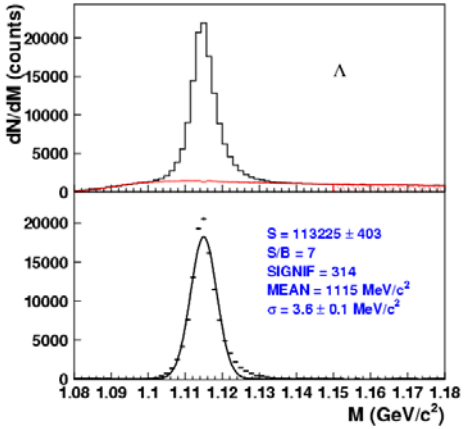
Event Display
Central Drift Chamber
(x,y) plane
Ni+Ni@1.93 AGeV



PID:
Matched tracks
CDC-RPC



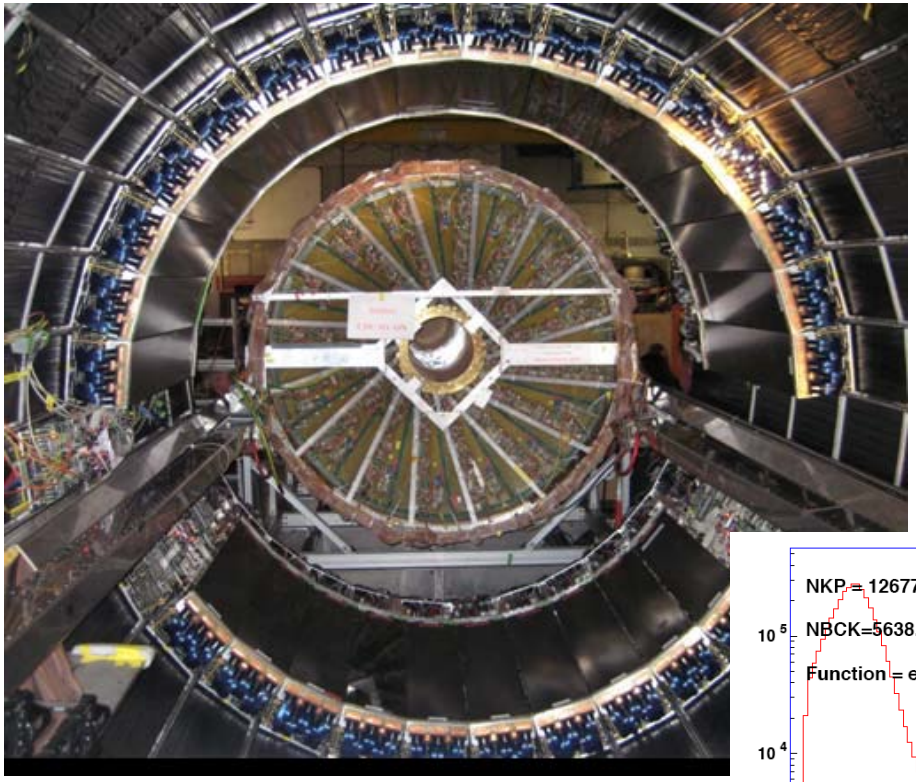
Forward
Detectors
Helitron+
Plastic Wall



Reconstruction
of neutral particles
like Λ, K^0_S
from their charged
decay products

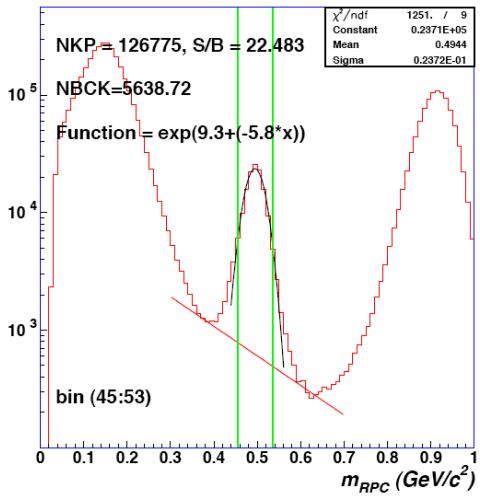
The RPC Time-of-Flight Barrel

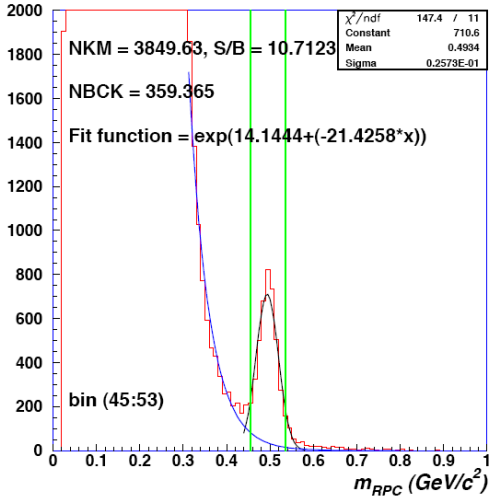
(FOPI Phase III)



Multigap-Multistrip RPC
σ(RPC): 67 ps
σ(system): ca. 90 ps

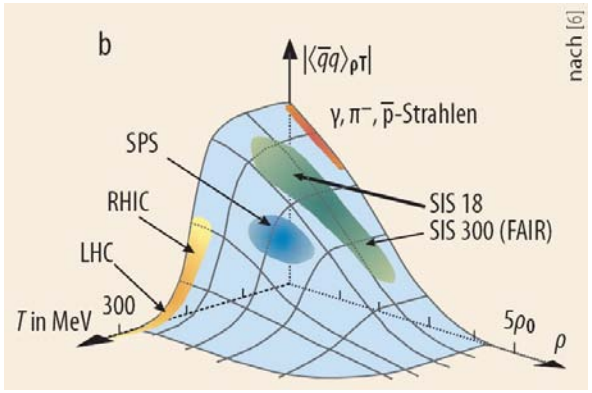
Charged Kaon Identification



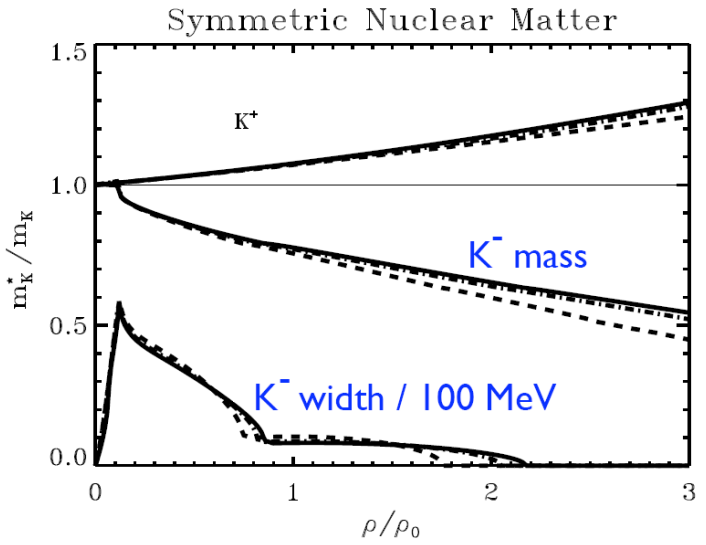


Why Strangeness?

Physik Journal 8, Nr. 3



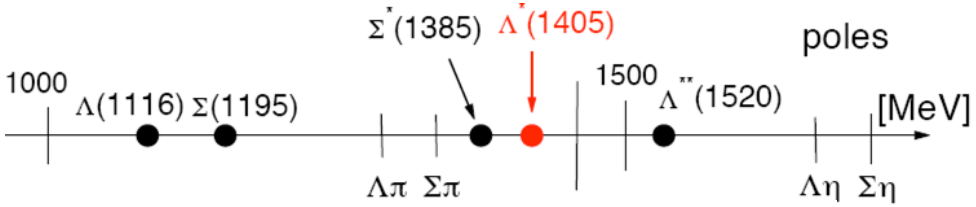
Modification of Particle Properties in Medium (density and temperature dependent)



T. Waas et al., PLB379(96)34

Strong attractive Interaction of the Antikaon in the Medium

- Flow
- Bound States



$\bar{K}N$-threshold

Complicated Situation due to the presence of resonances

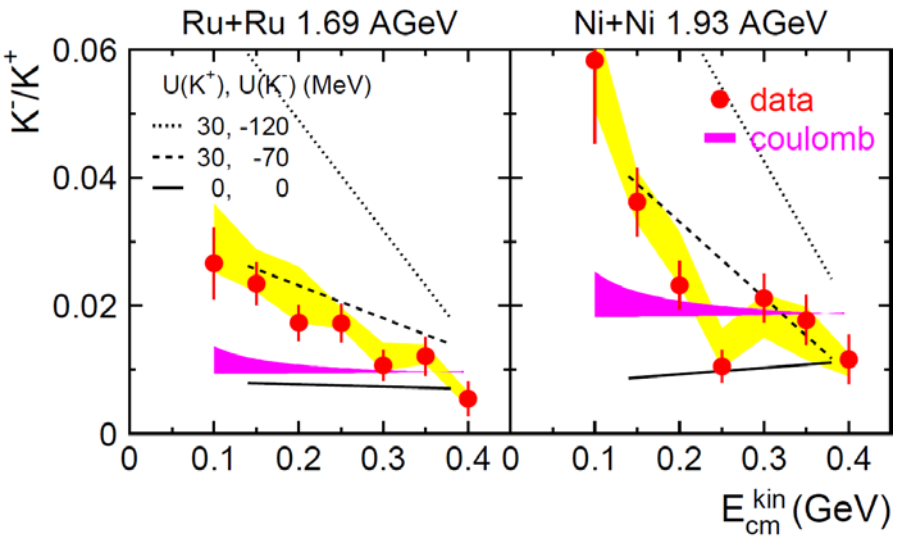
Systems studied by FOPI

2003-2011

- Heavy Ion Reactions
  K^0, $K^{\pm}$, Λ, ϕ, K^*, Σ^*
  Ni+Ni (1.93 and 1.91 AGeV), Al+Al (1.91 AGeV),
  Ni+Pb (1.91 AGeV), Ru+Ru (1.69 AGeV)
- Pion Induced Reactions
  K^0, $K^{\pm}$, Λ, ϕ
  π^- + C, Al, Cu, Sn, Pb (1.15 GeV/c, 1.7 GeV/c)
- Proton+proton 3.1 GeV
  search for ppK^- bound state

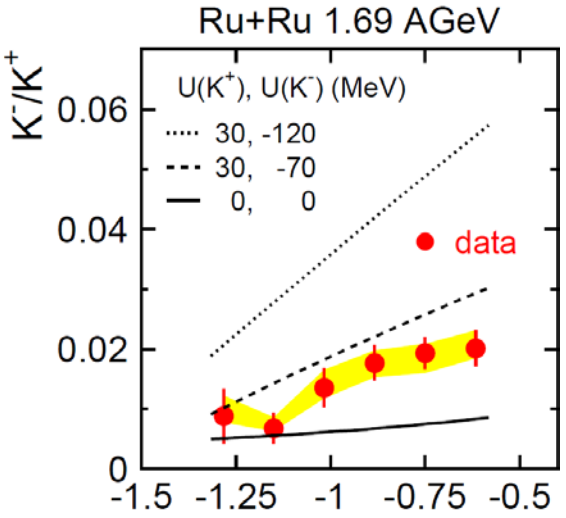
Charged Kaon Yields

K. Wisniewski et al., EPJA9(2000)



Comparison to transport Models (RBUU, filtered)

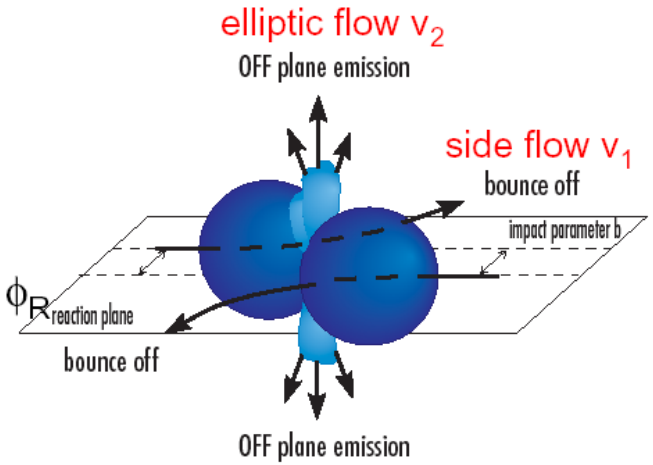
→ non-zero in-medium potentials suggested



Yield ratio varies of the studied region of phase space

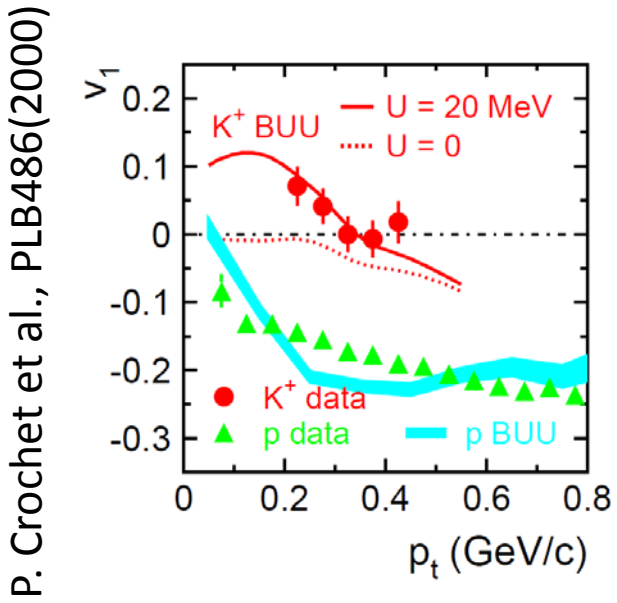
→ in-medium modifications of charged Kaon properties?

Charged Kaon Flow



Looking to Flow in terms of v_1 and v_2

$$\frac{dN}{d\phi} \propto 1 + v_1 \cos\phi + v_2 \cos 2\phi$$



P. Crochet et al., PLB486(2000)

Sideward Flow (v_1) of K^+
$-1.2 < Y^0 < -0.6$
low p_t → anti-flow

$\sigma_{geo} \approx 200$mb

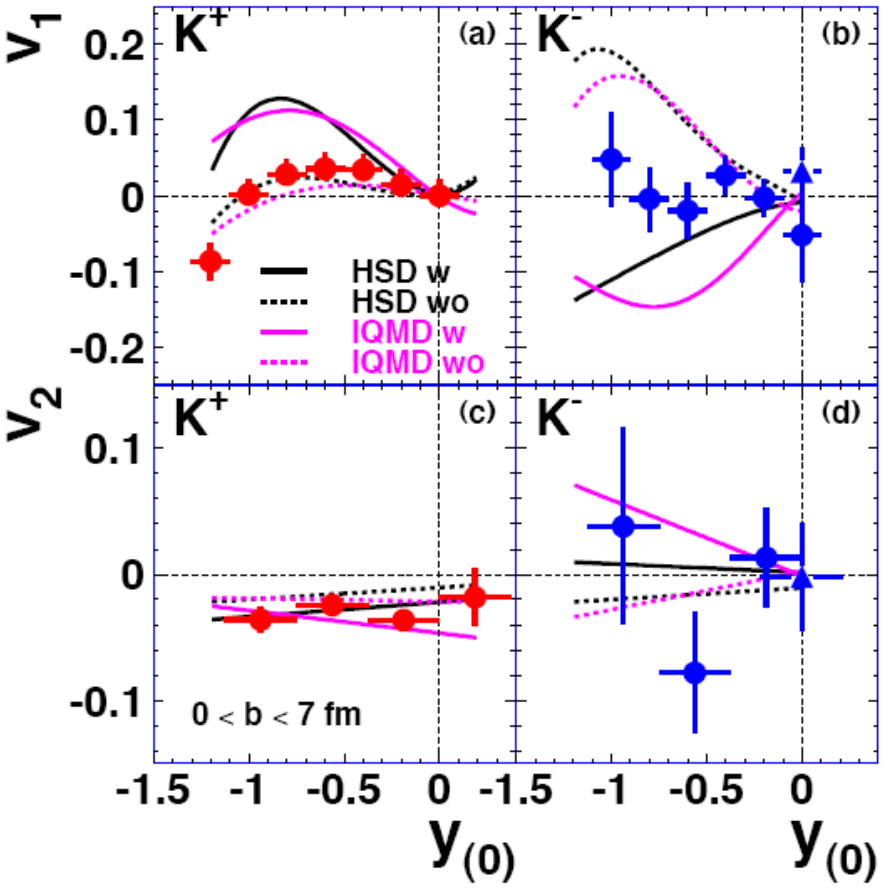
Comparison to transport model (filtered):
In-medium repulsive potential of 20 MeV

but: Proton flow not consistently described

K^- not available at this time

Charged Kaon Flow Updated

T.I. Kang, V. Zinyuk (Heidelberg)



Data consistent with previous ones

Ni+Ni. 1.91 AGeV (S325, S325e)

σ=1.5b, b_{geo}=7 fm

Transport models (filtered)
Potentials at $\rho=\rho_0$:
HSD:
$U(K^+)$=20 MeV, $U(K^-)$=50 MeV
IQMD:
$U(K^+)$=40 MeV, $U(K^-)$=90 MeV

Small sideflow of K^+
Vanishing K^- sideflow

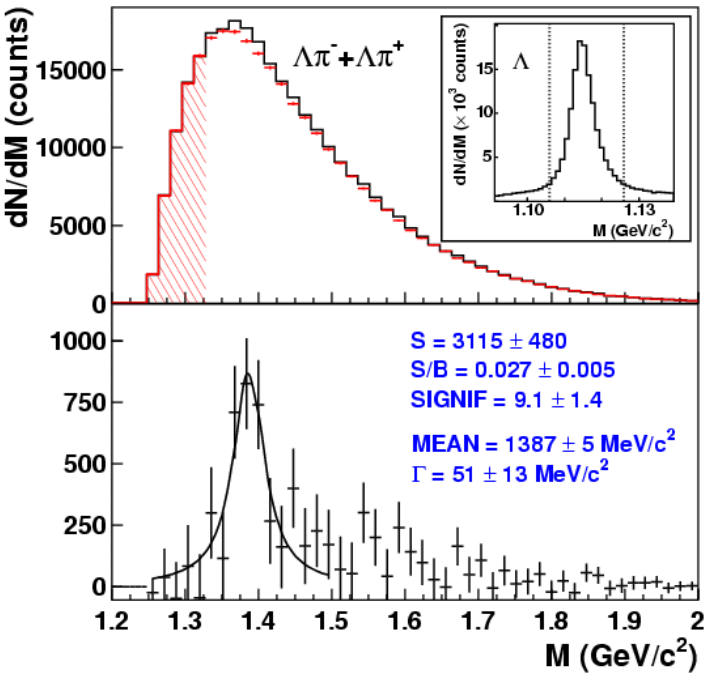
K^+ elliptic flow <0 (out of plane)
K^- sideflow consitent with zero

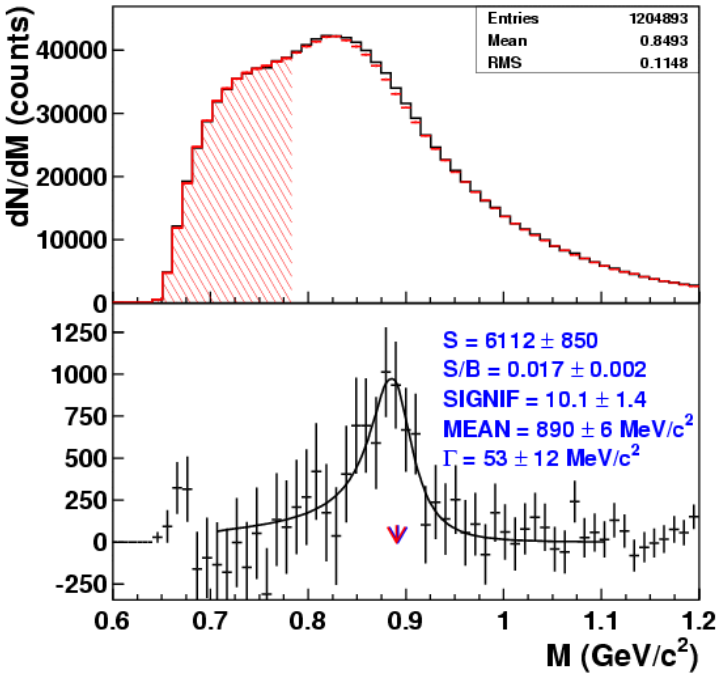
Short lived Strange Resonances

$\Sigma^* \rightarrow \Lambda + \pi$ (88±2%)
Γ = 39.4 MeV, $c\tau$ = 5 fm
NN-threshold 2.33 GeV

$K^* \rightarrow K + \pi$
Γ = 50.7 MeV, $c\tau$ = 4 fm
NN-threshold 2.75 GeV

X. Lopez et al., PRC76(2007)052203





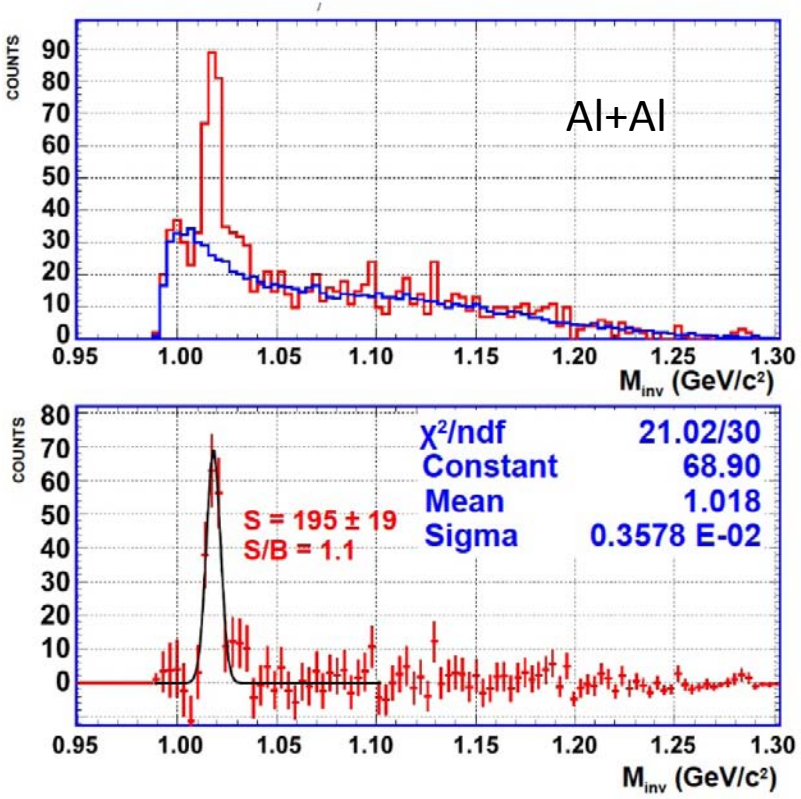
X. Lopez et al., PRC81(2010)061902

Al+Al 1.92 AGeV, $5 \cdot 10^8$ events, $P_{det} \sim 10^{-5}$

Reconstructable
consistent with PDG values

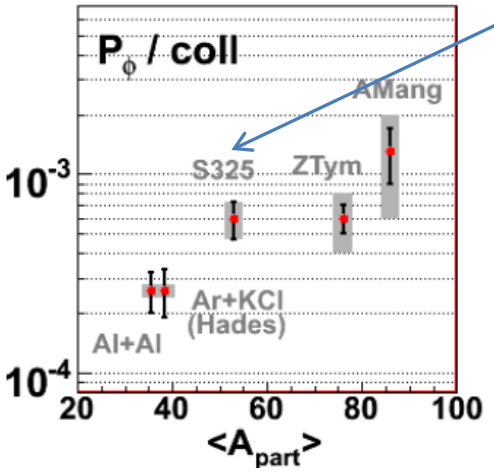
$K^{+/-}$ and ϕ in Ni+Ni and Al+Al

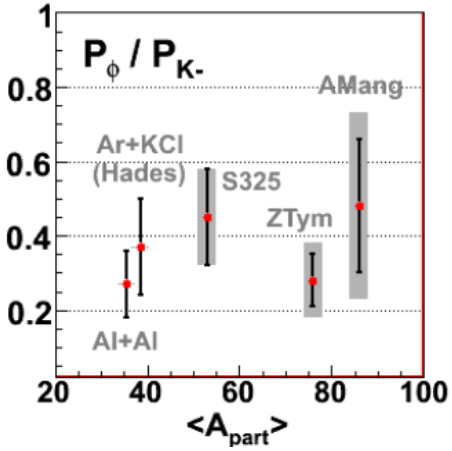
P. Gasik, K. Piasecki 2009, 2010



PDG values for ϕ:
m=1019 MeV, Γ=(4.26±0.04) MeV

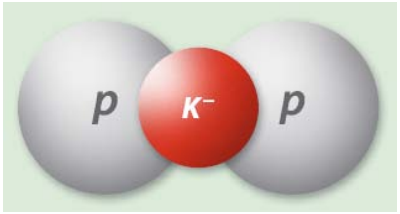
Ni+Ni



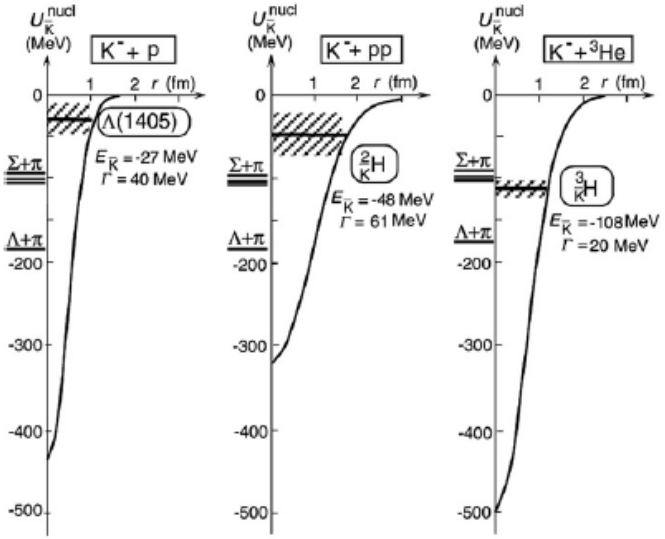


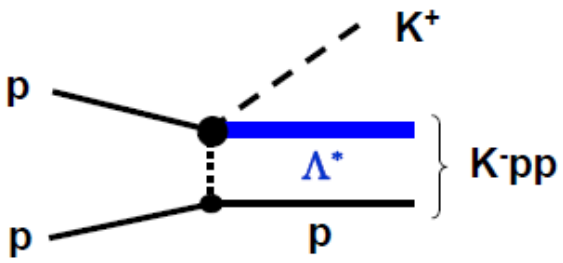
HADES: PRC 80(2009)025209

Strange Meson-Baryon Clusters



Deeply bound $\bar{K}$ clusters?





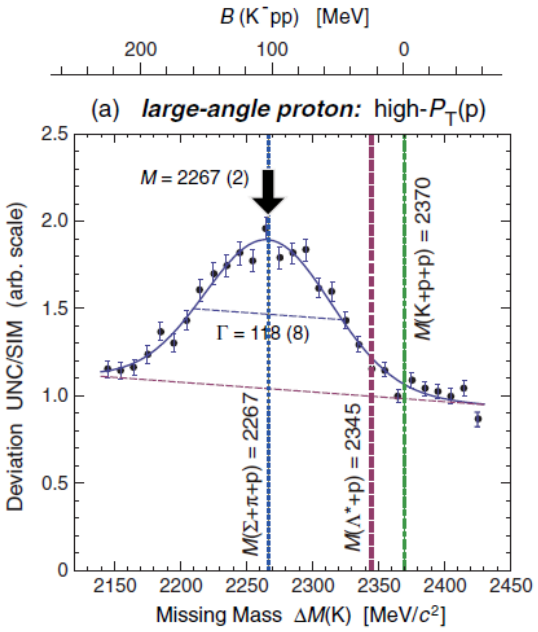
Y. Akaishi and T. Yamazaki, PRC65(2002)044005

binding energies even > 100 MeV

→ Production of "prototype" state, ppK^-, in p+p collions

Evidences for ppK⁻

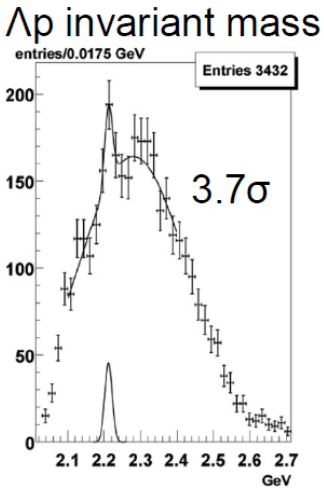
PRL104(2010)132502



DISTO

p+p

NPA789(2007)222



m = (2212.1±4.9) MeV

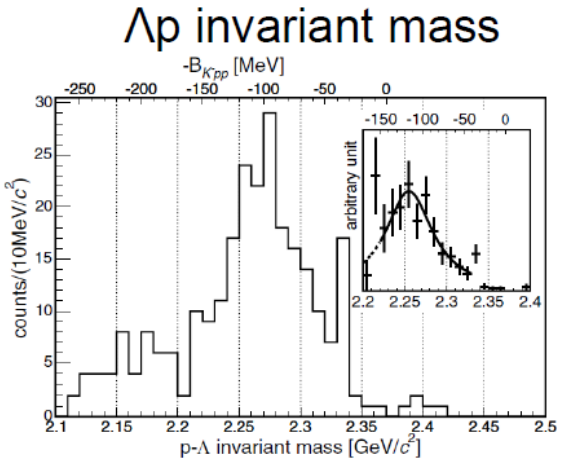
B.E. = −(160.9±4.9) MeV

Γ < (24.4±8.0) MeV 1.5·10⁻⁴

OBELIX

$\bar{p}$+He

PRL94(2005)212303



m = (2255 ± 9) MeV

B.E. = −(115 ± 9) MeV

Γ = (67±15.0) MeV

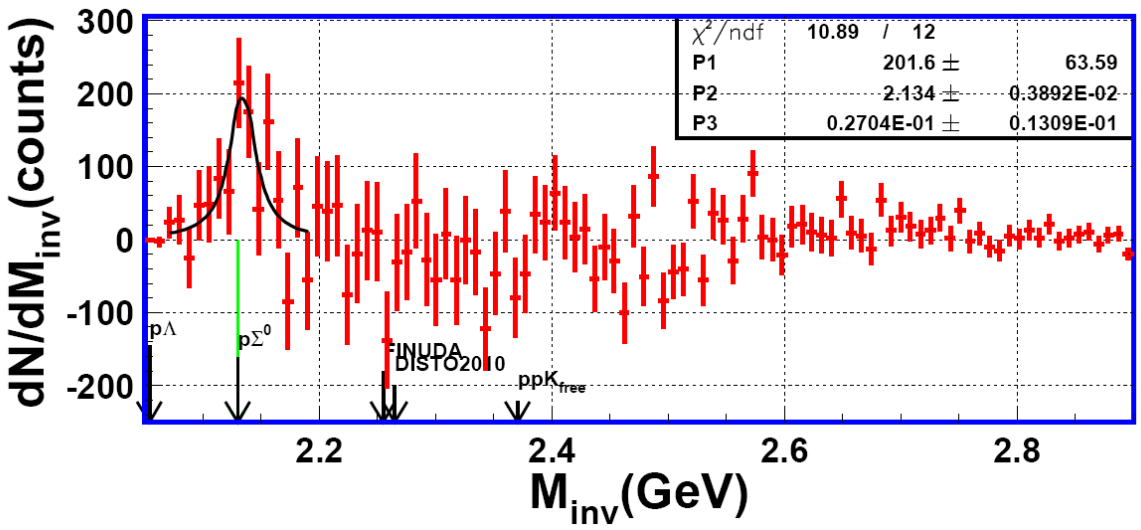
FINUDA

$K^-_{stopped}$+A (Li, C)

Data are not consistent and differ from predicted values for B.E. and width!

Status FOPI ppK⁻ in Heavy Ions

N. Herrmann, J.Phys.G(2010) Λ-p correlations



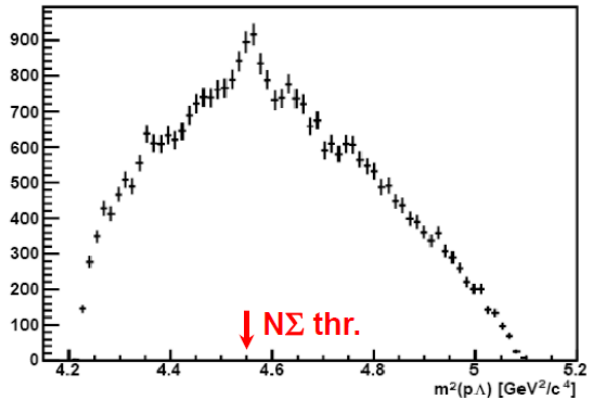
m=2.134 GeV ± 4 MeV

Γ = 26 ± 14 MeV (statistical err.)

Peak (cusp) at NΣ threshold ?

seen in p+p collisions

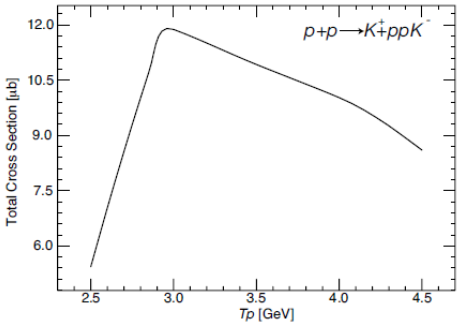
FSI ?



COSY-TOF preliminary

2.95 GeV/c proton momentum (2.16 GeV)

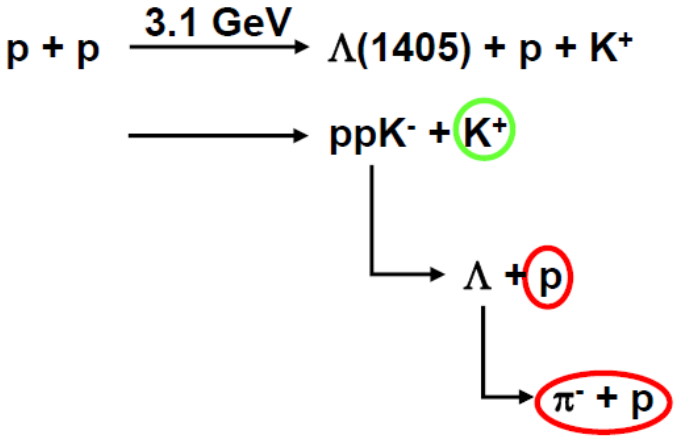
σ(p+p→pK⁺Λ) ≈ 30 μb



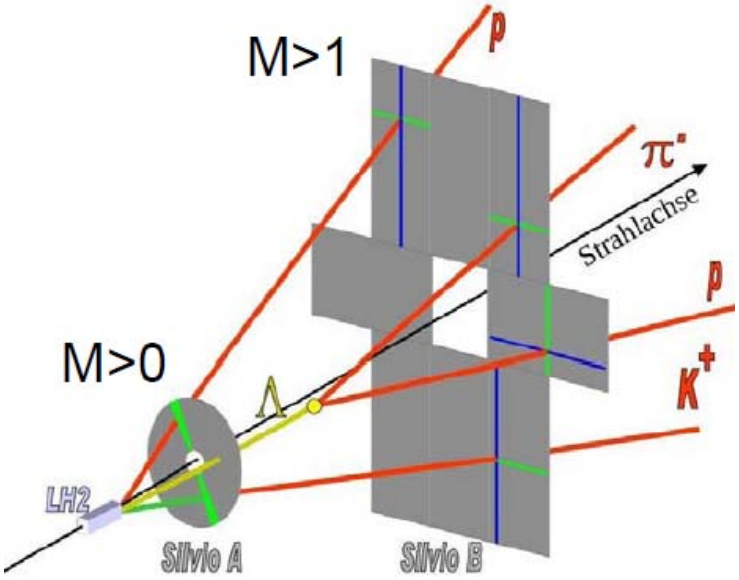
Search for ppK⁻ in p+p

R. Münzer, München

Data taking 08-09/2009



LH2 target + SIΛVIO
(silicon strip detectors)



Analysis still in progress

- Λ reconstruction
- K^+ identification

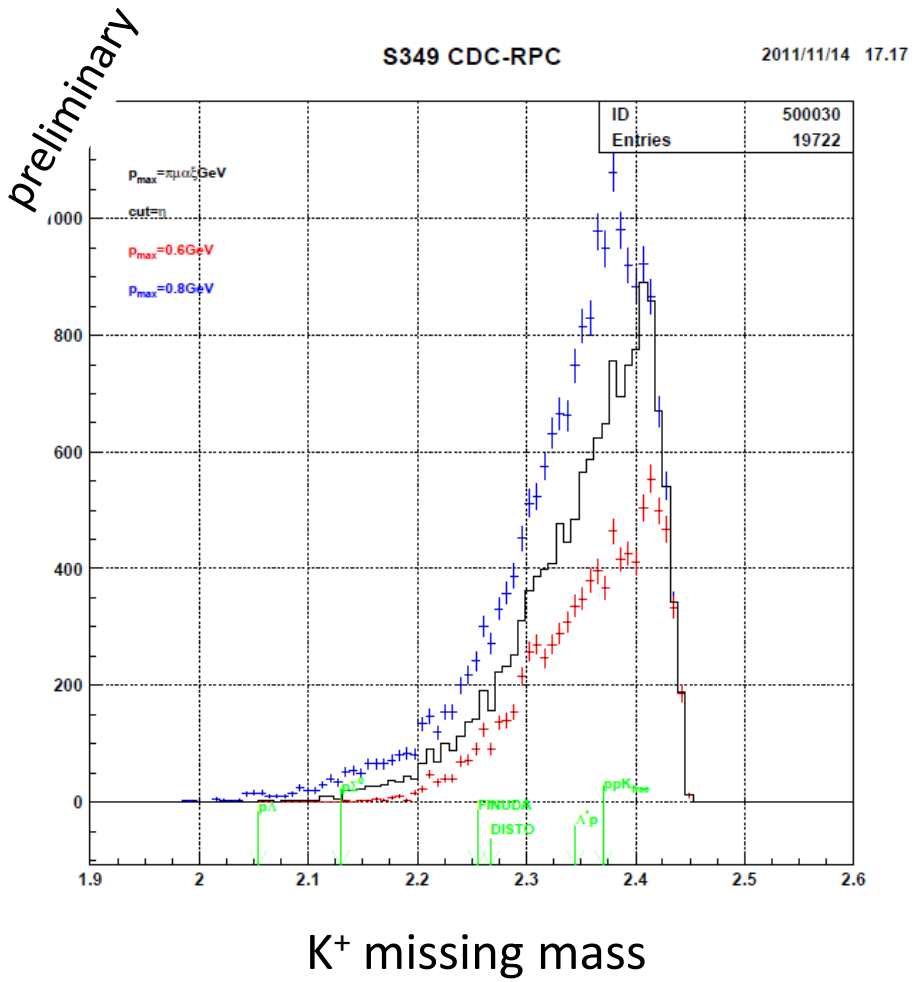
- Λp correlation

- K^+ missing mass

Two body final state?

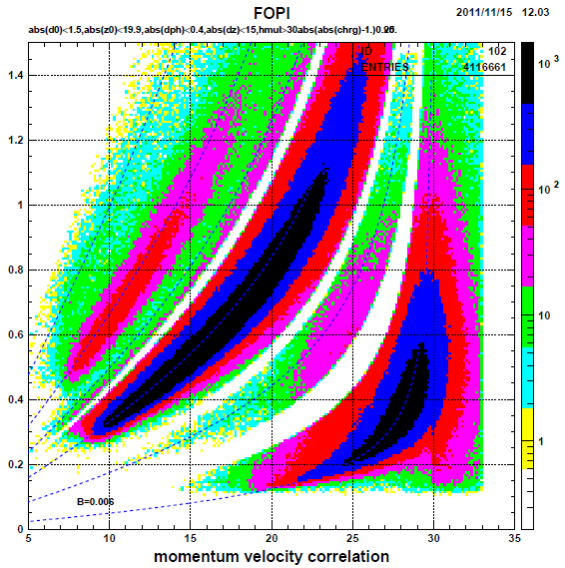
Suppression of non-strange background by factor 20 (simulation with UrQMD)

Search for ppK⁻ in p+p



K⁺ missing mass

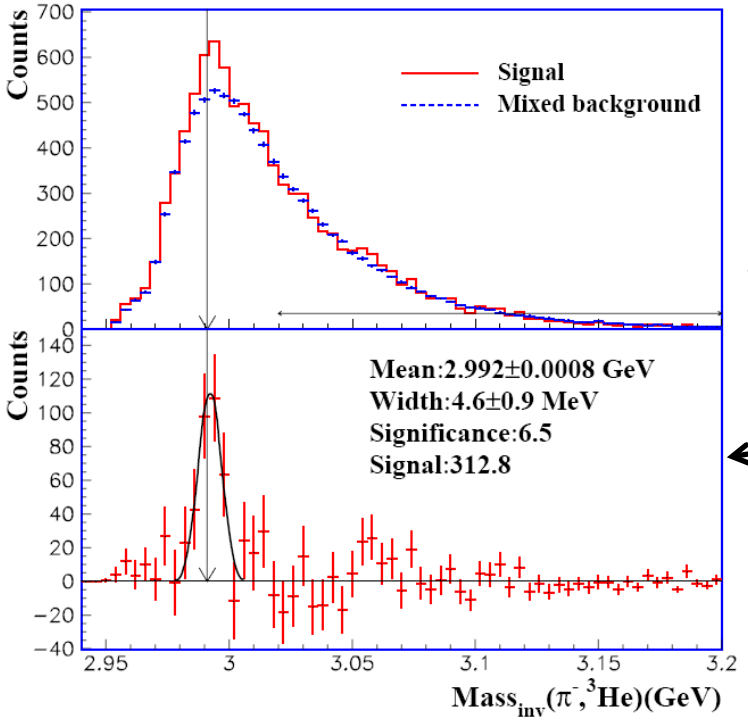
all K⁺
(no Λ requested)



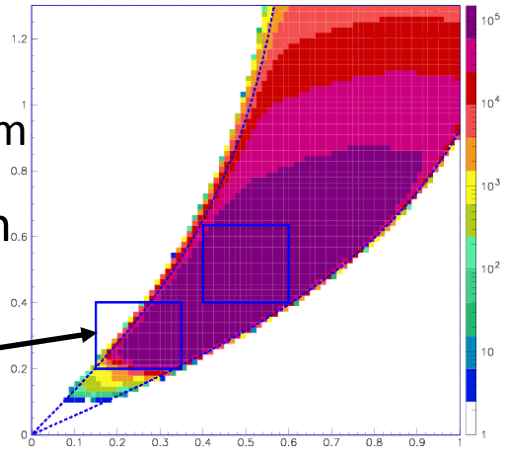
still working on improved calibration

Light Hypernuclei

Y.P. Zhang (Heidelberg)



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



Signal only in a certain region of phasespace

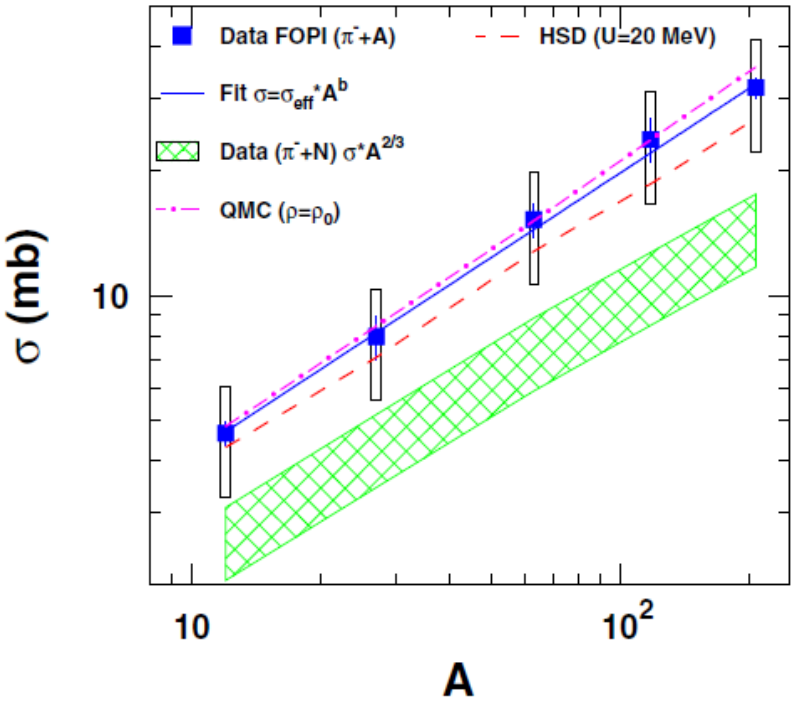
Lifetime of Λ and $_{\Lambda}$t consistent with PDG resp. world data

3-body decay and heavier hypernuclei under study

yields (ratios) not understood so far …

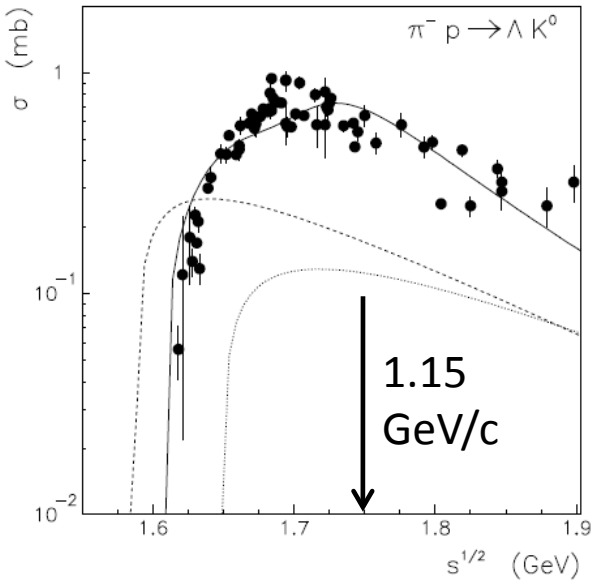
Pion Induced Reactions 1.15 GeV/c

K^0 inclusive cross section



σ_{eff} = (0.87 ± 0.13) mb
b = 0.68 ± 0.03

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



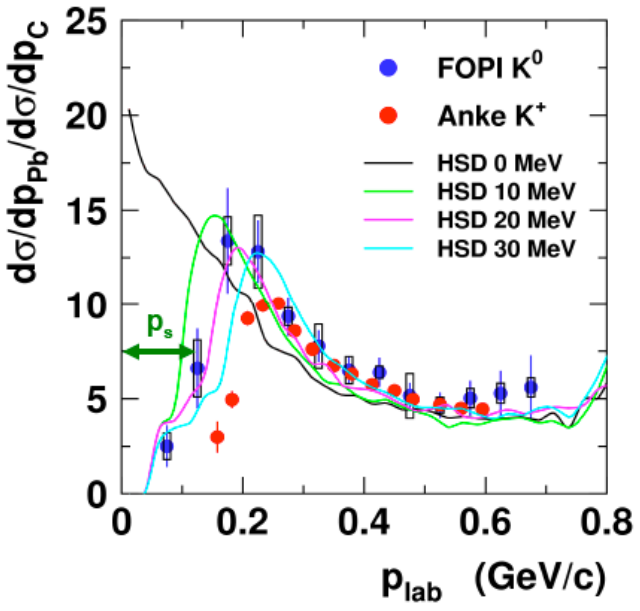
dashed: $\rho = \rho_0$

K. Tsushima et al., PRC62

Pion Induced Reactions 1.15 GeV/c

M.L. Benabderramahne et al., PRL102
M. Büscher et al., EPJA 22

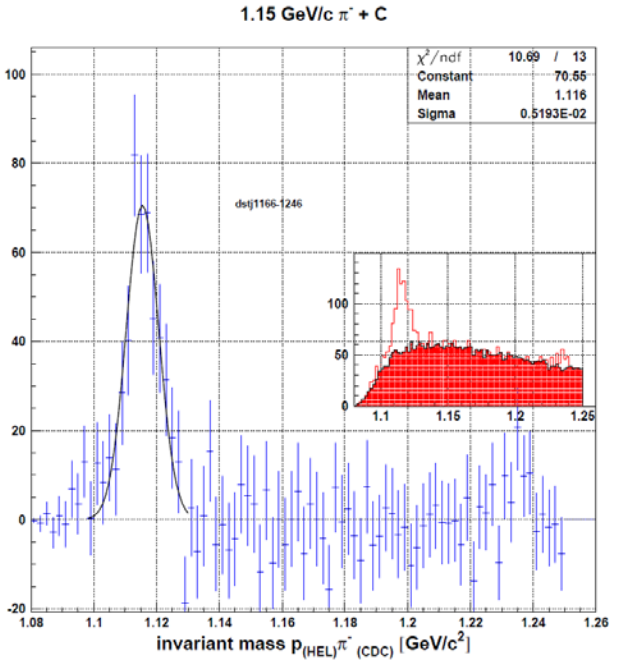
ratio Pb/C target



inclusive cross sections

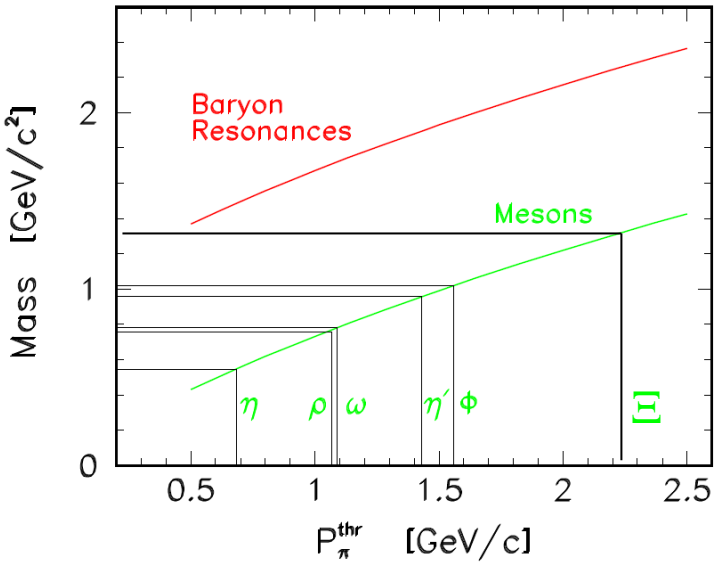
Comparison to HSD → repulsive Potential of ~ 20 MeV

Ongoing analysis: Λ yields



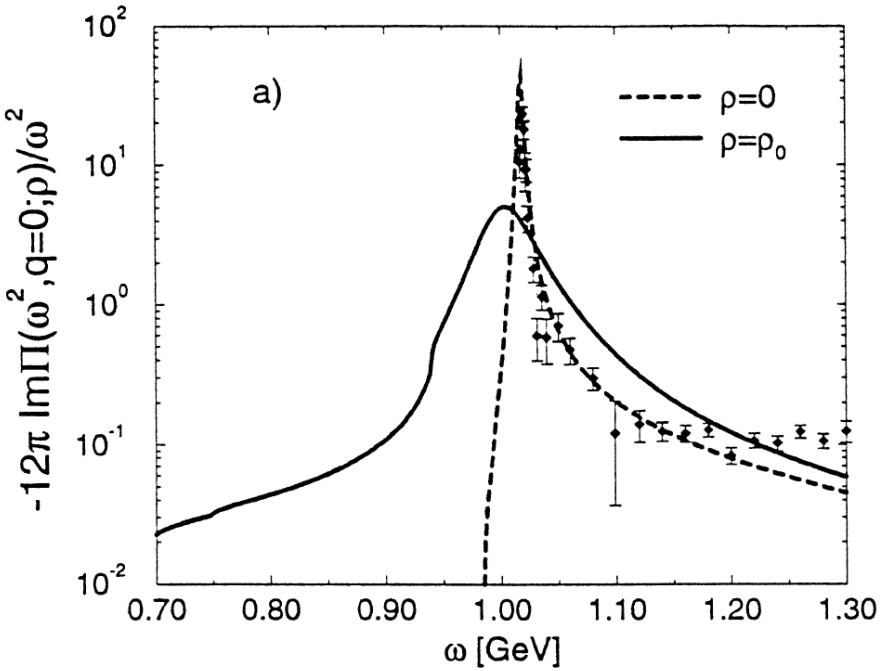
refitting of Helitron-PLAWA tracks with silicon tracker information (if available)

Pion Induced Reactions at 1.7 GeV/c



$$\pi^- + p \rightarrow \phi + n \rightarrow K^+K^- + n$$

Data taking finished end of June 2011, calibration and analysis ongoing



Nuclear optical potential

$$\Pi/2\omega = \Re(U) + \Im(U)$$

mass width

K$^+$/K$^-$ spectra φ yields

Experimental Data on the Φ in medium

Experiment	Chan	In-medium mass	In-medium width	Reference
KEK-PS E325 12 GeV p+C 12 GeV p+Cu	K^+K^-	M_{inv} reproduced by rel. Breit-Wigner	Yield $\sigma=\sigma_0 A^{\alpha}$ $\alpha^{\Phi}_{KK}-\alpha^{\Phi}_{ee}=0.14\pm0.12$ Γ_{KK} increased by factor ≤6	Sakuma et al., PRL98(2007)152302
	e^+e^-	For $\beta\gamma<1.25$ excess on low mass side of M_{inv} → 3.4% mass decrease	Γ_{ee} increased by factor 3.6 at ρ_0	Muto et al., PRL98(2007)042501
Spring-8-LEPS 1.5-2.4 GeV γ+Li, C, Al, Cu	K^+K^-	≡ free Φ	yield~$A^{0.72\pm0.07}$ ⟶ $\sigma_{\phi N}=(35^{+17}_{-11})$ mb ($\Gamma\sim$ 80 MeV/c², ANKE conditions)	Ishikawa et al., PLB608(2005)215
JLab-CLAS ≤4 GeV γ+ H,C,Ti, Fe, Pb	e^+e^-		Transparency ratio $\sigma_{\phi N}$= 16 to 70 mb	Wood et al., PRL105(2010)112301
COSY-ANKE 2.83 GeV p+C, Cu, Ag, Au	K^+K^-		Transparency ratio yield~$A^{0.56\pm0.03}$ ⟶ $\Gamma\sim 50$ MeV/c²	Polyanskiy et al., PLB695(2011)74

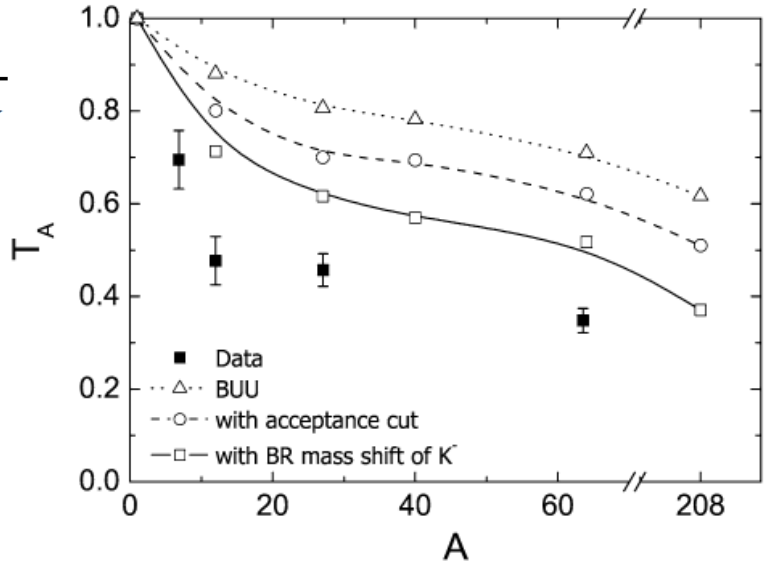
Φ significantly broadened in nuclear medium, no (or small) mass shift

Transparency Ratio

$$T_A = \frac{\sigma_{\gamma A \to \phi X}}{A \sigma_{\gamma N \to \phi X}}$$

P. Mühlich, NPA765(2006)188

GiBUU



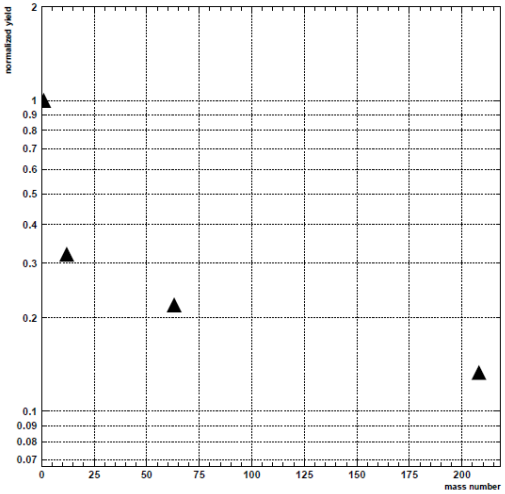
photoproduction data:

measure ϕ yields as a function of mass number ("attenuation measurement")

→ deduce in medium-properties comparing to transport model

For pion induced reactions:

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

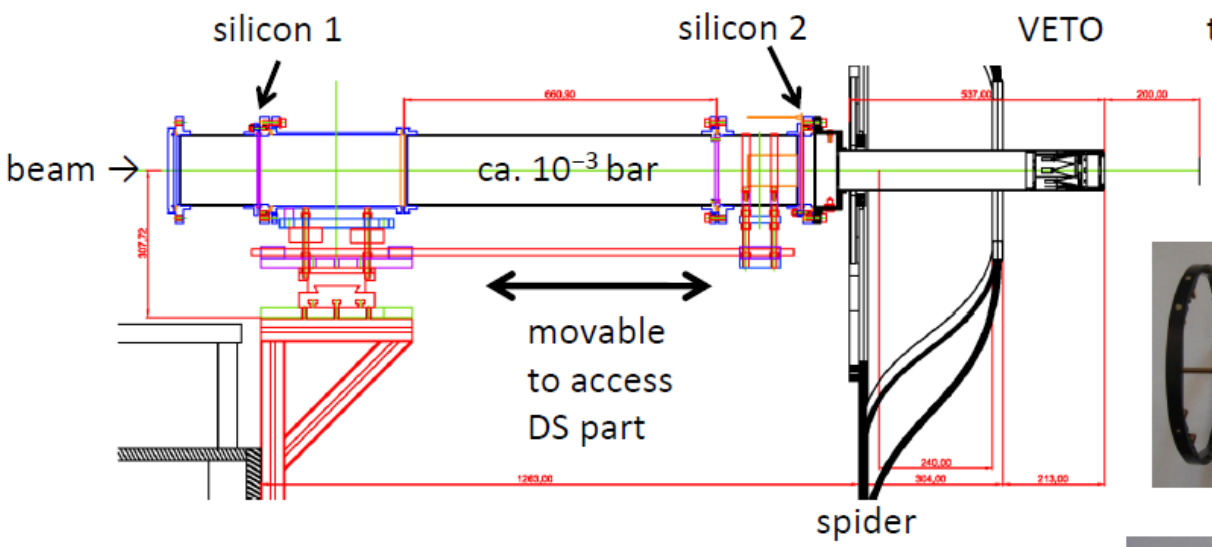


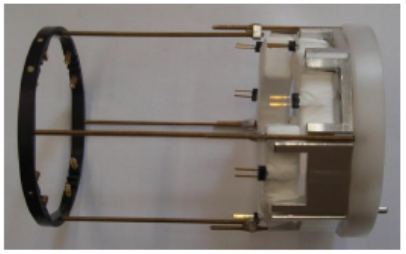
GiBUU prediction for K^+K^- events:

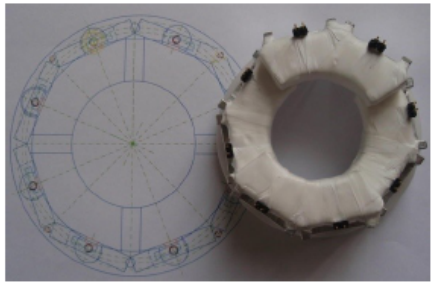
p	$1.5 \cdot 10^{-3}$/event
^{12}C	$4.8 \cdot 10^{-4}$/event
^{63}Cu	$3.3 \cdot 10^{-4}$/event
^{208}Pb	$2.0 \cdot 10^{-4}$/event

(no in-medium potential)

Pion Induced Reactions at 1.7 GeV/c



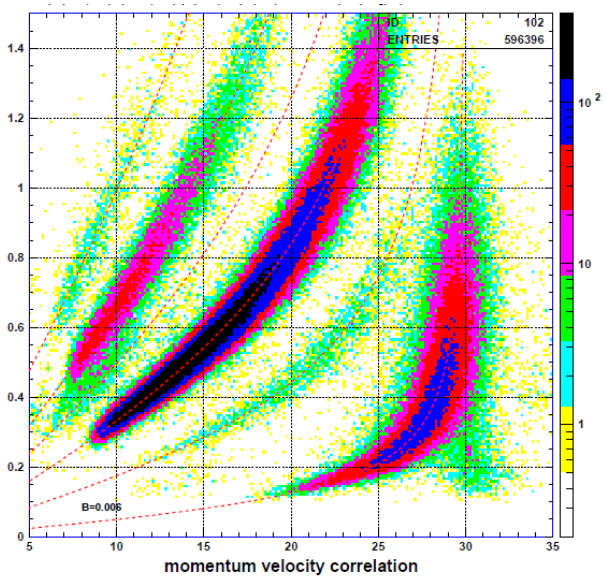


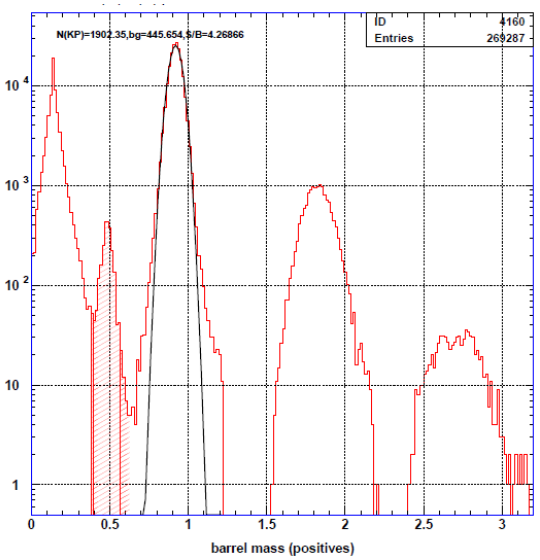


New setup, designed and built at SMI Vienna
- *foresees two silicon stations (sensors in vacuum)*
- enter in inner hole of TPC (10 cm diameter)
- VETO counter (scintillators, read out by SiPM, 3.5 cm hole) close to the target

The two SSD's where eventually not mounted (readout problems with N-XYTER chip)

Pion Induced Reactions at 1.7 GeV/c

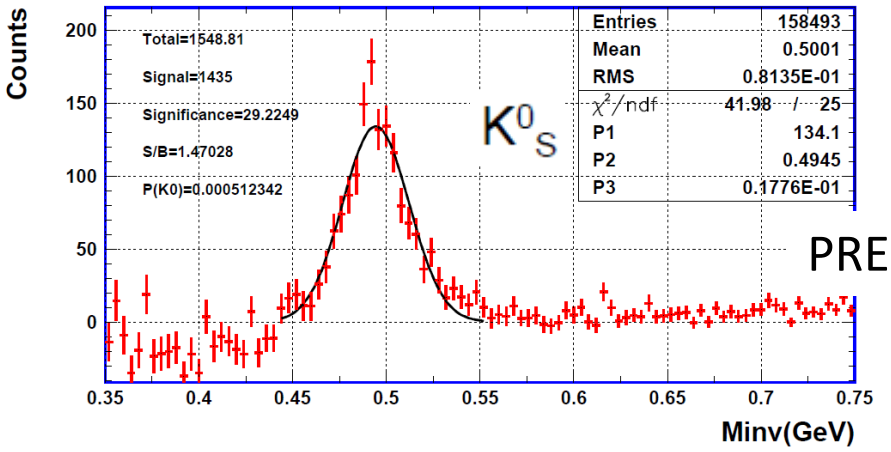


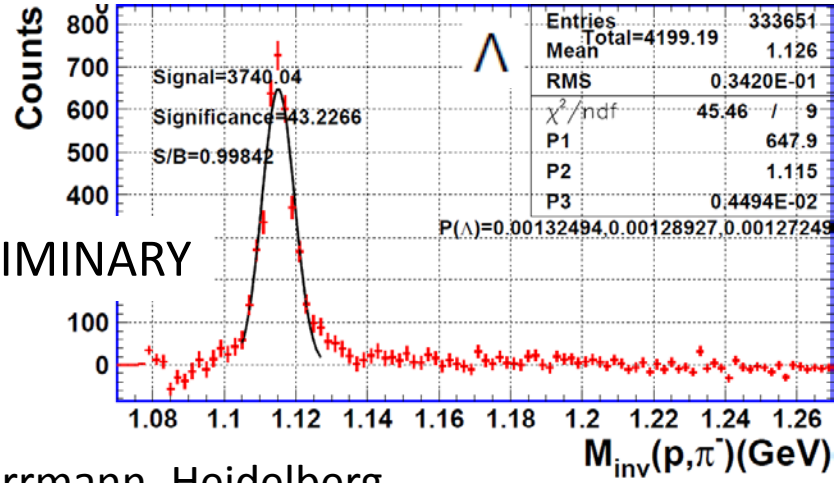


Carbon target

2.8 M events

from GiBUU we expect ca. 1000 K^+K^- events



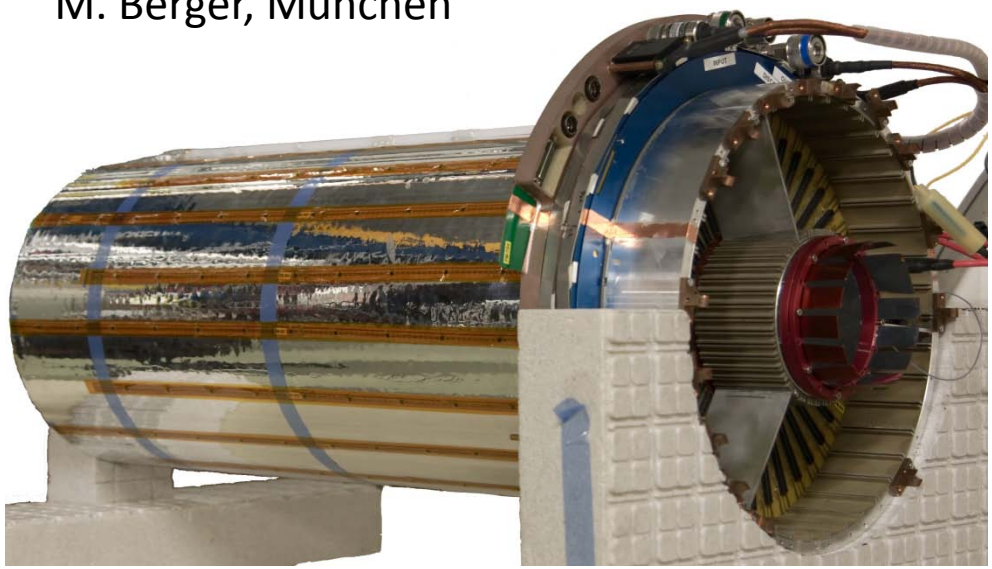


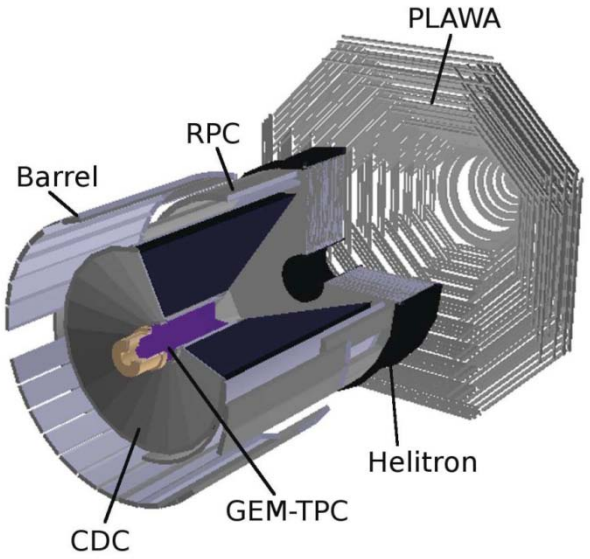
PRELIMINARY

N. Herrmann, Heidelberg

GEM-TPC

M. Berger, München

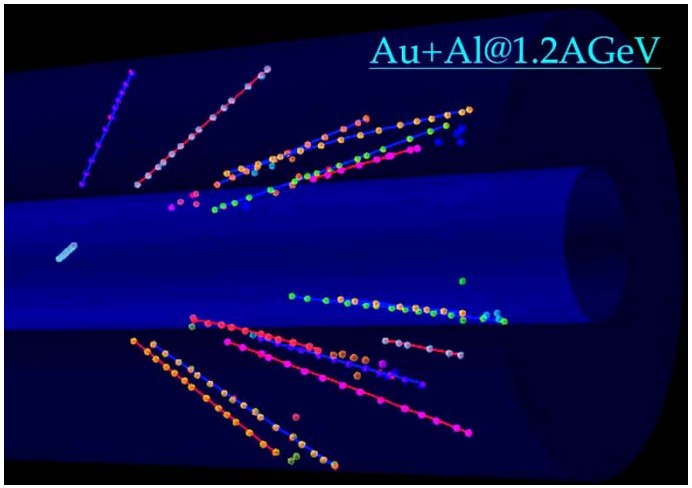




TPC as upgrade for FOPI:

- Vertex resolution: ~1 mm in X,Y + Z
- Larger geometrical acceptance for:
  - Λ and K^0_s
- Improved resolution of secondary vertices (min factor 10)

→ good for weakly decaying resonances



Future Plans

- *The June 2011 pion beam experiment was the last official FOPI beamtime*
- Replace/extend hardware with components for FAIR experiments (CBM, PANDA)
- Exploit improved resolution: GEM-TPC
- Physics case: double strangeness production ($\Xi^- X$, $K^- K^- X$)
  - Pion beam
  - ^{3}He beam

Conclusions

- FOPI@SIS since > 20 years
- New hardware (RPC, SIΛVIO, GEM-TPC, …)
- Measurement of reactions involving strangeness
- New results on charged kaon flow, associated strangeness production, bound states including hypernuclei
  - Still many open questions, theoretical effort needed
- Ongoing analysis (e.g. ϕ/K^+K^- production in medium)