Status of the search for kaonic clusters in heavy ion collisions with FOPI

Introduction

- strangeness in dense baryonic matter
- kaonic cluster production in HI collisions

Experimental details

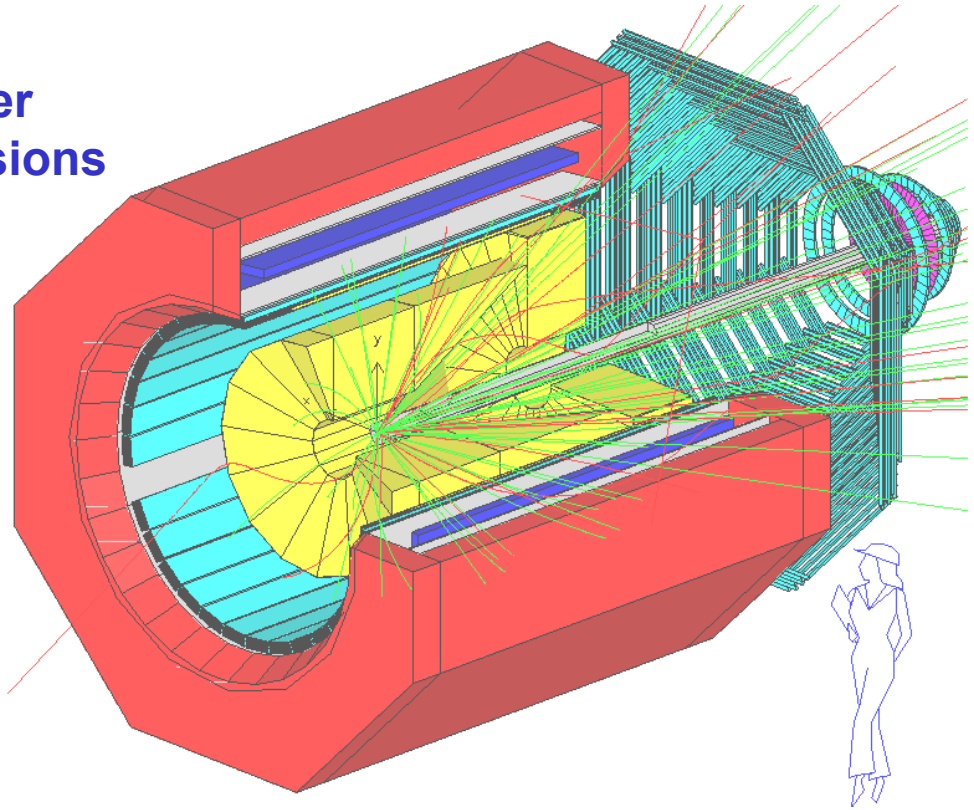
- kaon flow
- event mixing technique

Correlation Results

- Λ + p - correlations
- Λ + π - correlations
- (Λ + d - correlations)

Outlook

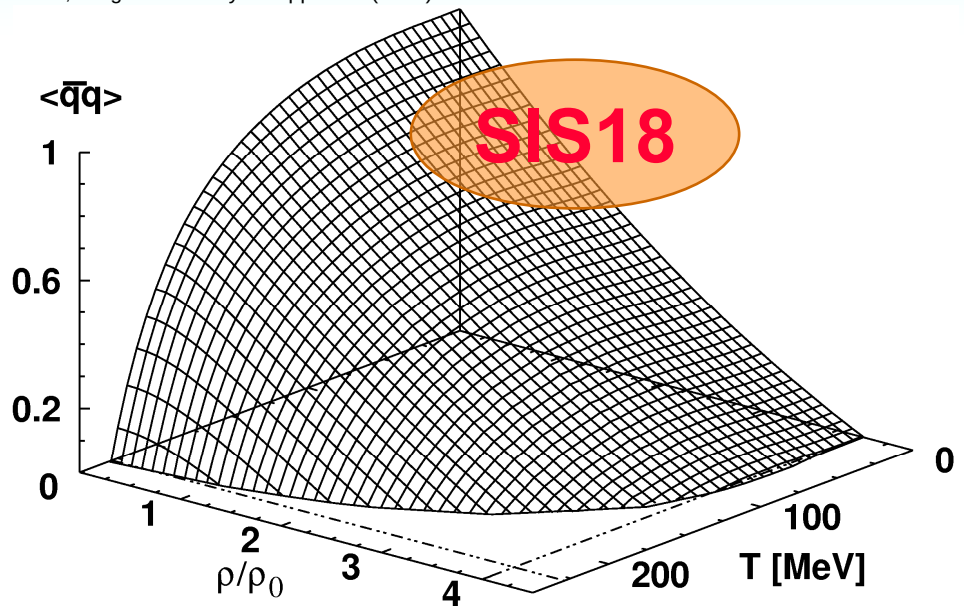
Conclusions



IPNE Bucharest, Romania
CRIP/KFKI Budapest, Hungary
LPC Clermont-Ferrand, France
GSI Darmstadt, Germany
FZ Rossendorf, Germany
Univ. of Warsaw, Poland
IMP Lanzhou, China
SMI, Vienna, Austria
ITEP Moscow, Russia
Kurchatov Institute Moscow, Russia
Korea University, Seoul, Korea
IReS Strasbourg, France
Univ. of Heidelberg, Germany
RBI Zagreb, Croatia
TUM, Munich, Germany

Hadrons in Medium

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



GOR – relation: $m_\pi^2 f_\pi^2 = -\langle m_q \rangle \langle \bar{q}q \rangle$

In-medium effects in finite systems:

'Trivial'

- Fermi motion
- Pauli blocking
- Collisional broadening

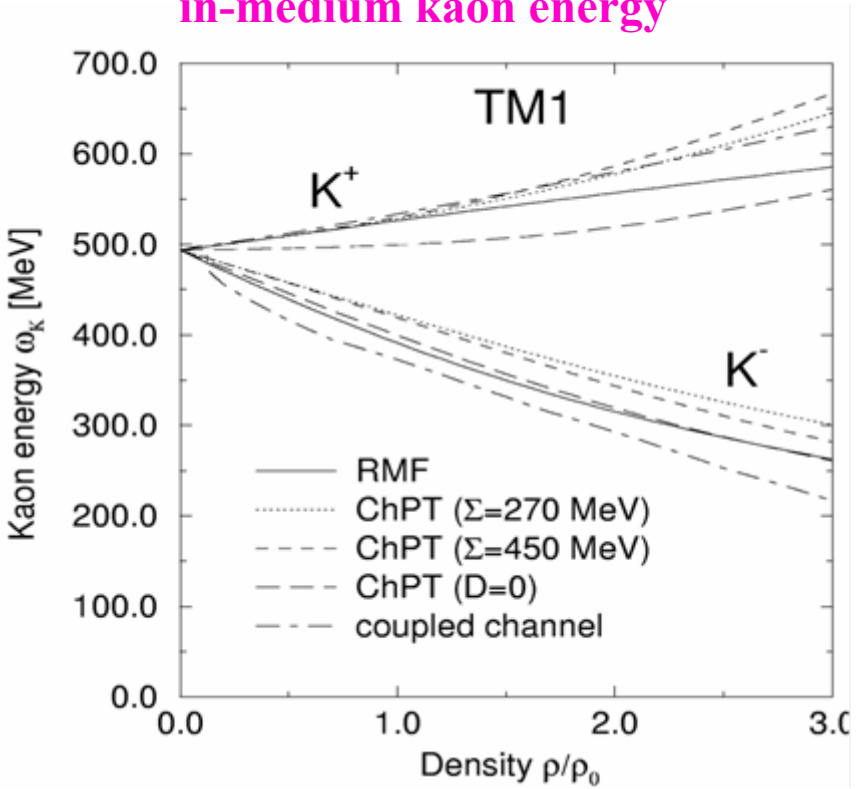
'Non-trivial'

- Partial restoration of chiral symmetry
- Meson – baryon coupling
- Bound states

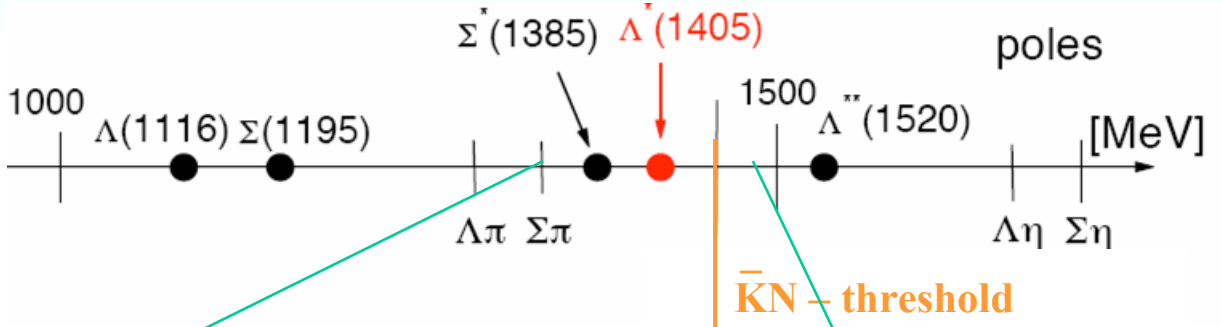
Modified properties of hadrons in dense baryonic matter?

M*(ρ)	(mass)
Γ* (ρ)	(width)
σ* (ρ)	(cross section)

in-medium kaon energy



$\bar{K}N$ – interaction

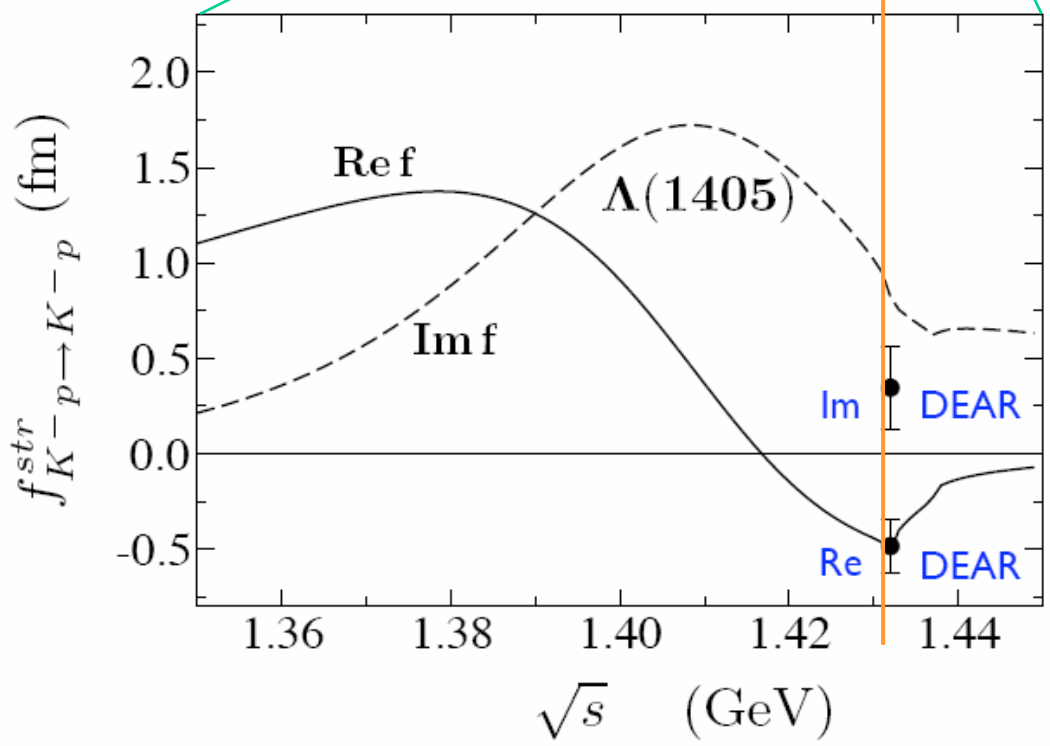


$\bar{K}N$ – threshold

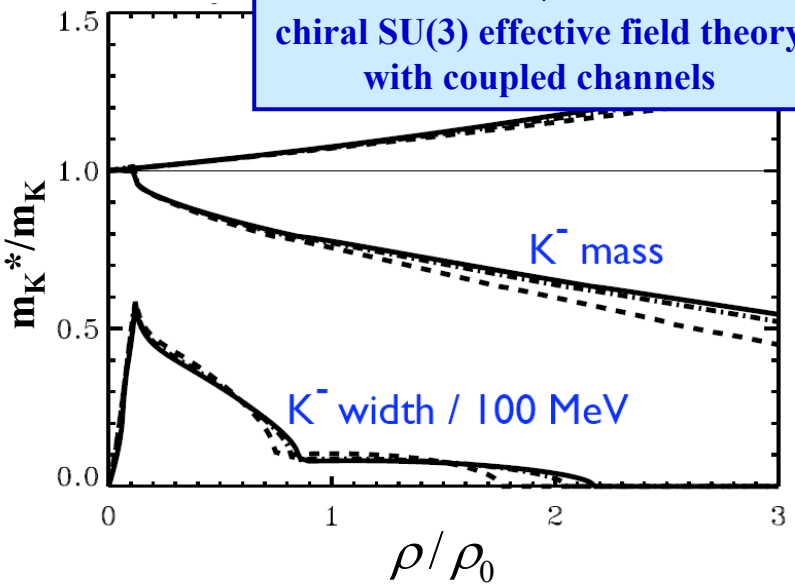
$$\sqrt{s} = \omega + m_N$$

$\bar{K}$ – energy

Scattering amplitude f



due to presence of resonances
↓
non – perturbative problem
↓
chiral SU(3) effective field theory with coupled channels



W.Weise et al.: PLB 379, 34 (1996), PRL 94, 213401 (2005)

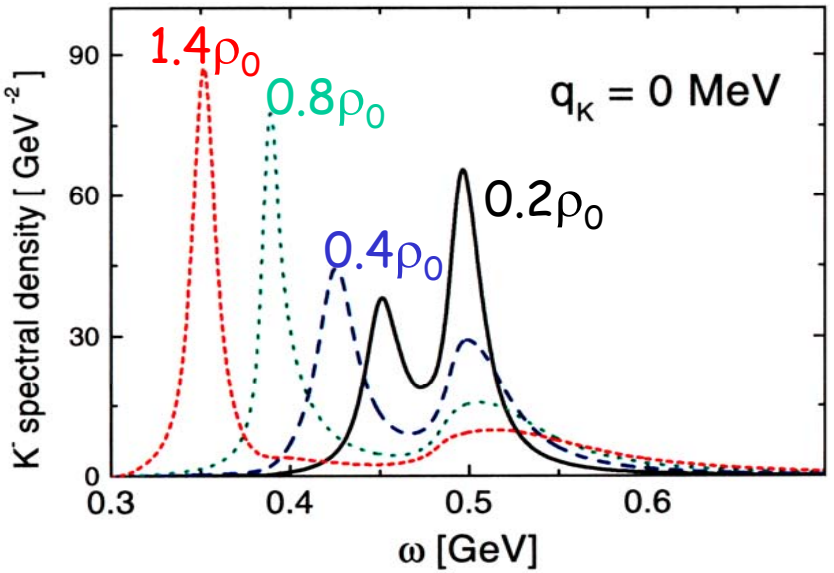
Summary: $\bar{K}N$ – interaction is attractive at finite densities, but strength (depth of potential) is unclear

Kaons in hadronic matter

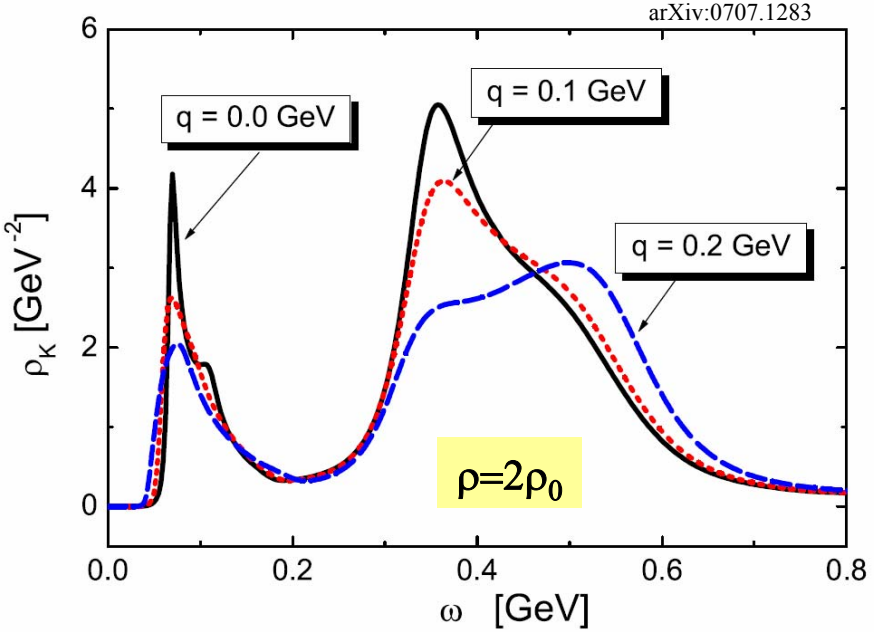
spectral function of antikaons in dense matter

Coupled channel calculation

M.F.M. Lutz, Phys. Lett. B426 (1998) 12



M.F.M. Lutz et al., Nucl.Phys.A808,124 (2008), arXiv:0707.1283



$$\omega_{K^{\pm}}(p,\rho) = \left(m^{*2} + p^2\right)^{\frac{1}{2}} = U + \left(m_K^2 + p^2\right)^{\frac{1}{2}}$$

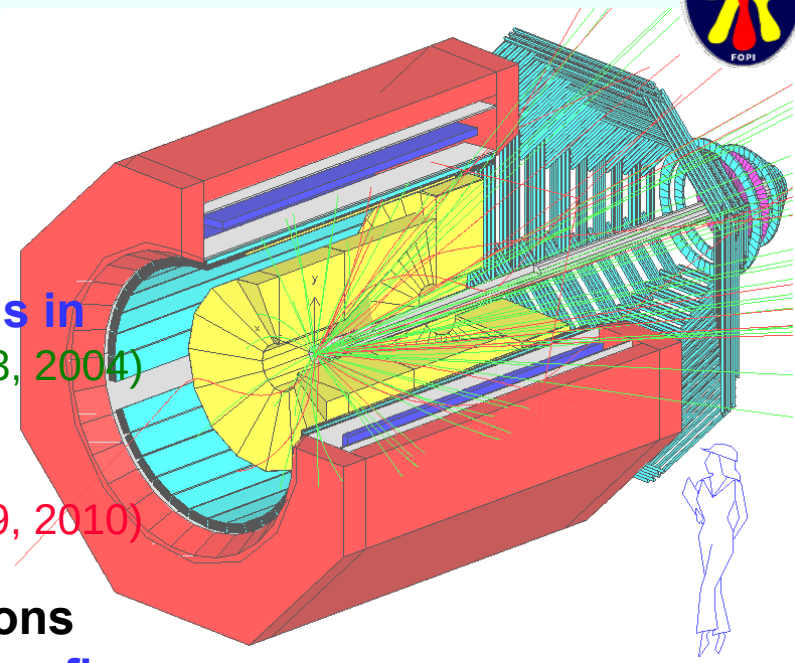
effective mass — Kaon potential

~~**Production:**~~
~~**P ~ exp (-m*/T)**~~
~~**→ K-yields**~~

Propagation:
F=-∇U
→ K-flow

Bound states:
B = $\Sigma_i m_i - \Sigma_i m_i^*$
→ Search for Λ+X states

Experimental program



Reference data from elementary reactions

K^0 , Λ production and phase space distributions in

π^- + C, Al, Cu, Sn, Pb @ 1.15 GeV/c, (S273, 2004)

K^0 , K^+, K^-, ϕ, Λ production in

π^- + LH_2, C, Pb @ 1.7 GeV/c, (S339, 2010)

Systematics of strangeness data from heavy-ion reactions

K^0 , K^+, K^-, ϕ, K^*, Λ, $\Sigma^*(1385)$ production and kaon flow

Search for kaonic bound states

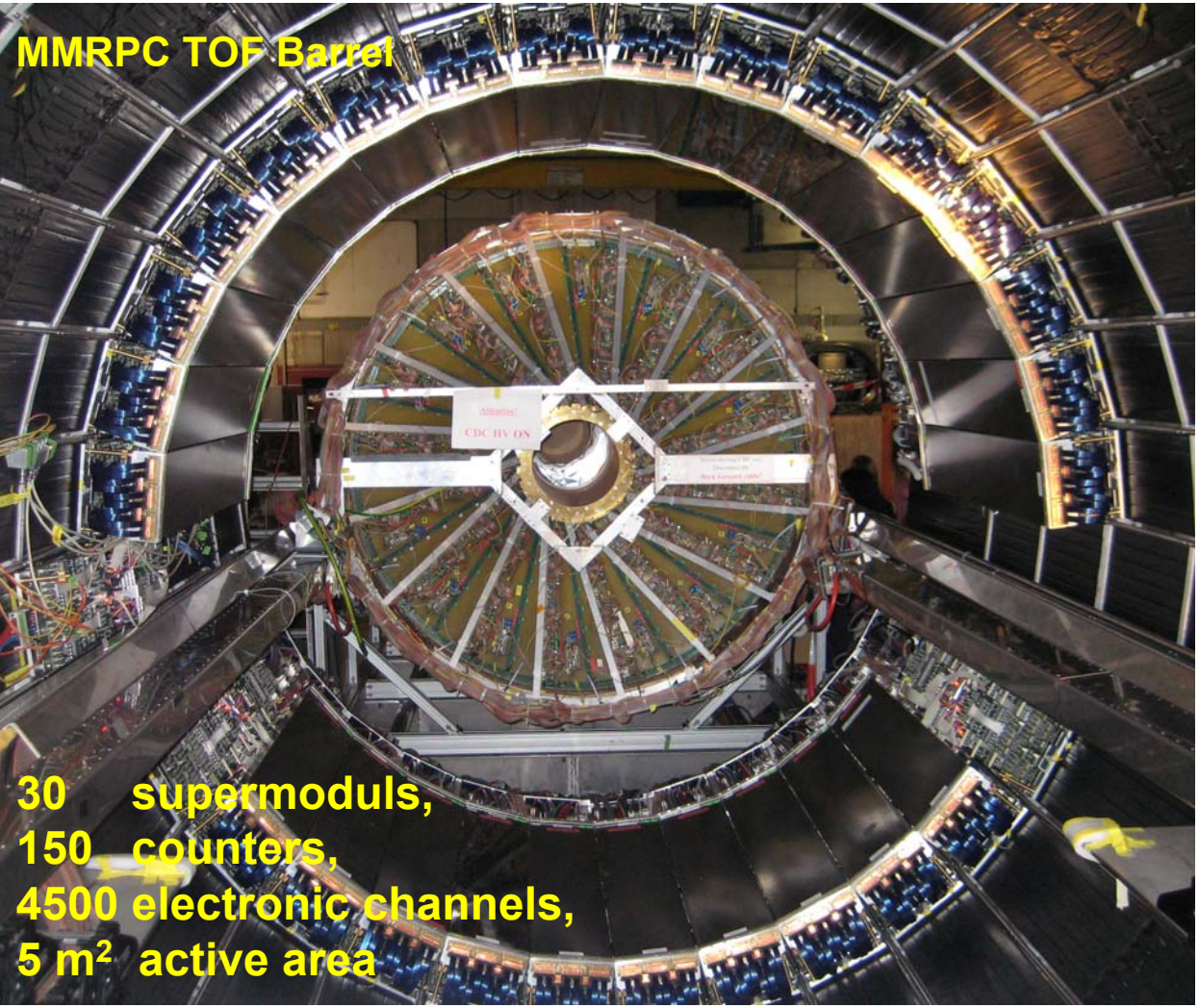
System	beam energy	events	(proposal, year)
Ni + Ni	1.93 AGeV,	100M	(S261, 2003)
Al + Al	1.91 AGeV,	200M	(S297, 2005)
Ni + Ni	1.91 AGeV,	80M	(S325, 2008)
Ni + Pb	1.91 AGeV,	100M	(S338, 2009)
Ru+ Ru	1.7 AGeV,	210M	(S338, 2009)

Search for exotica in elementary reaction

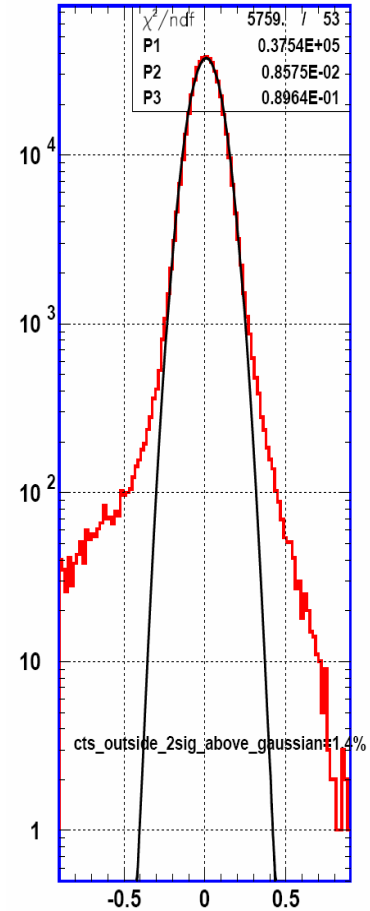
existance of ppK^- - bound state

p + p 3 GeV, 80M (S349, 2009)

FOPI III (2008 – 2010) with improved PID



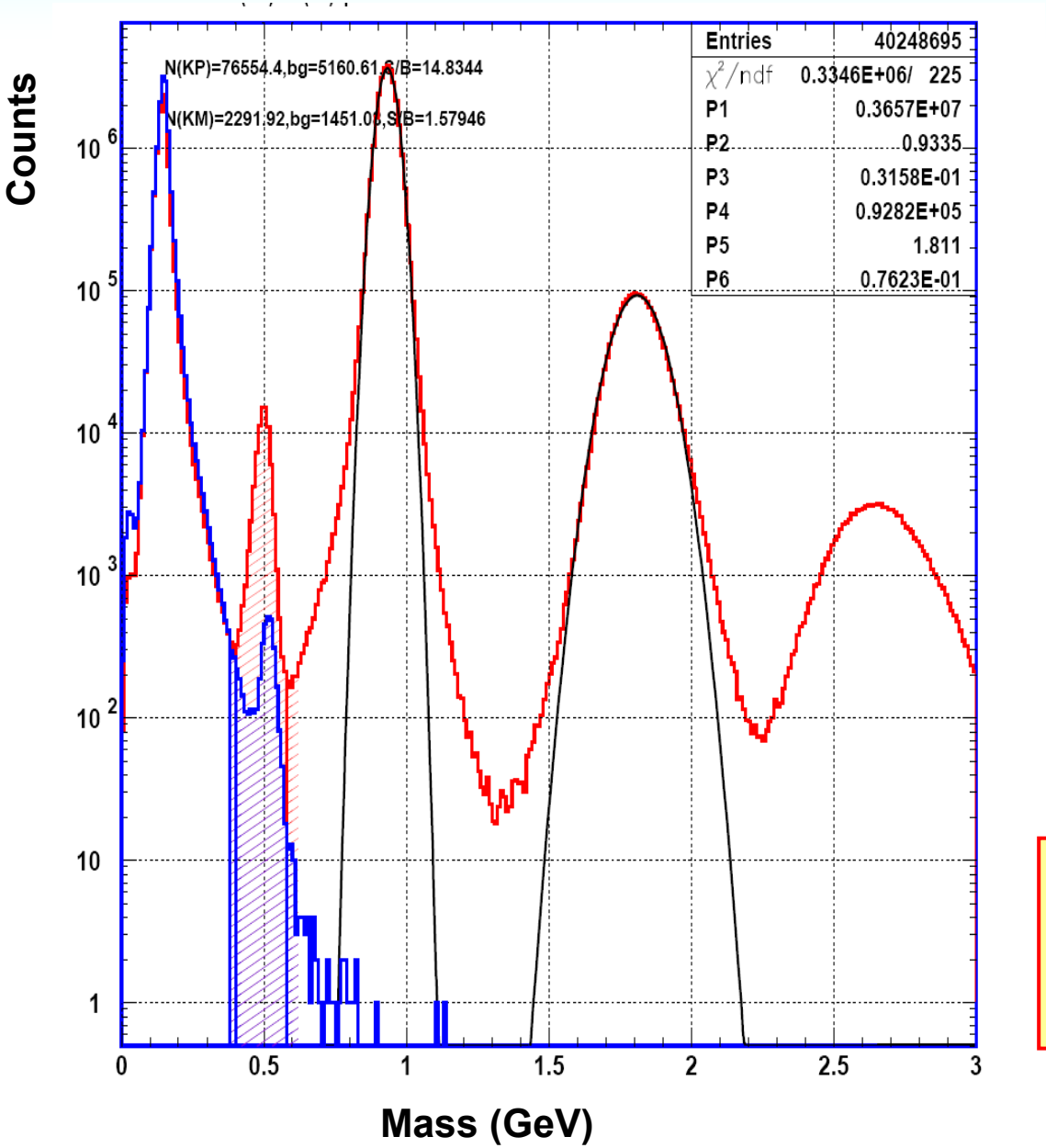
Time resolution from fast pion tracks (p_{lab}>0.5GeV/c)



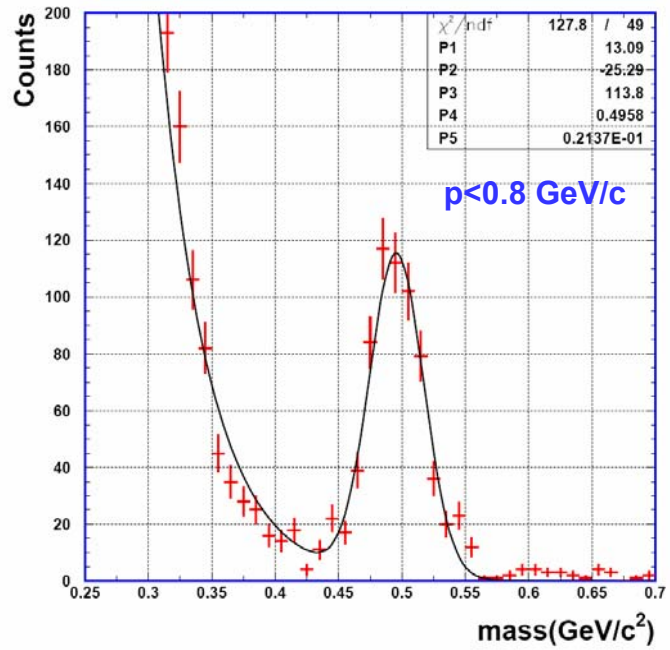
$\Delta t = t_{meas} - t_{exp}$ (ns)

Performance:
σ_{system} ~ 90 ps
σ_{RPC} ~ 65 ps

PID with FOPI III



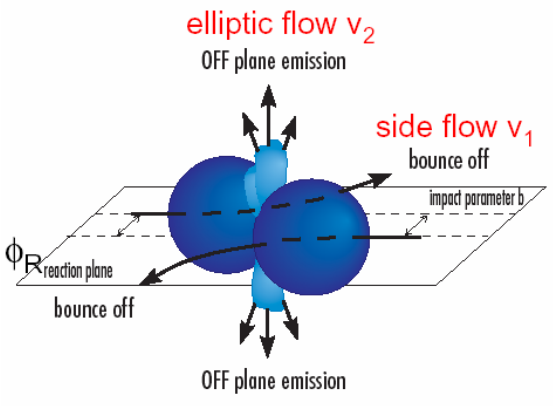
K⁻ - PID: S/B > 10



Significant improvement of Signal-over-Background (S/B) ratio.

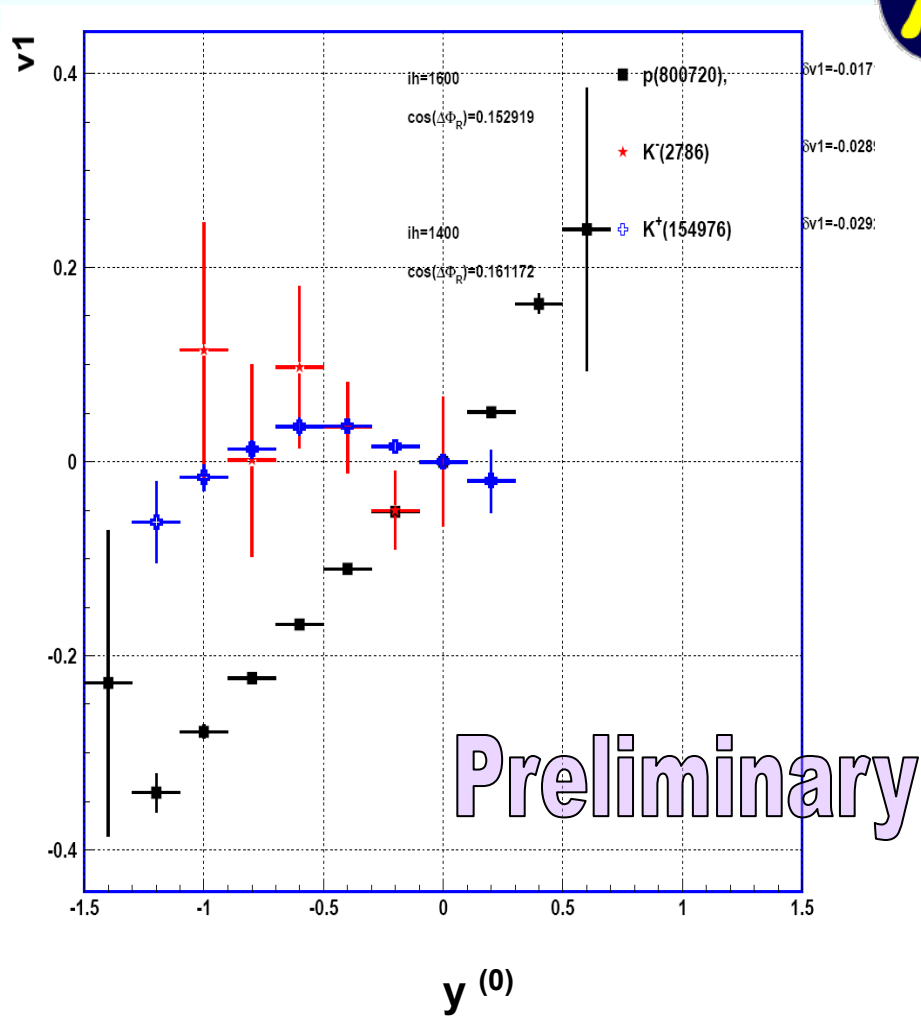
Extension of Phase-space with TOF - PID

Kaon – flow measurements

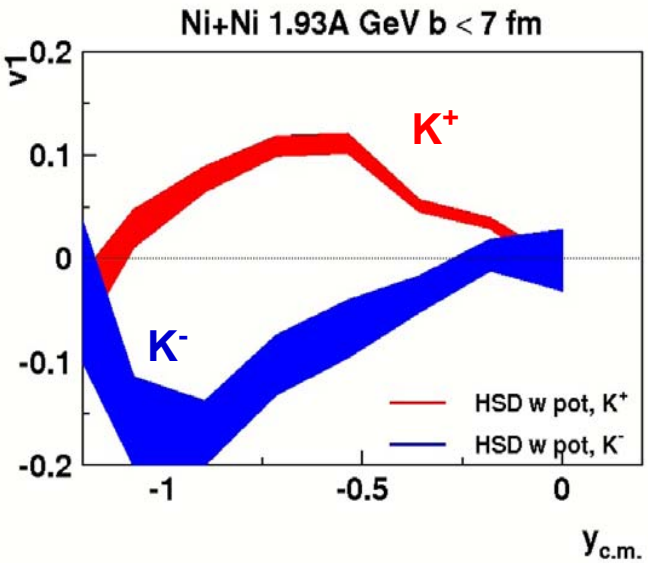


directed flow:

Ni+Ni @ 1.91 AGeV
(2008 data)
$\sigma_{trig}/\sigma_{reac}$=40%



Theoretical expectation (HSD)

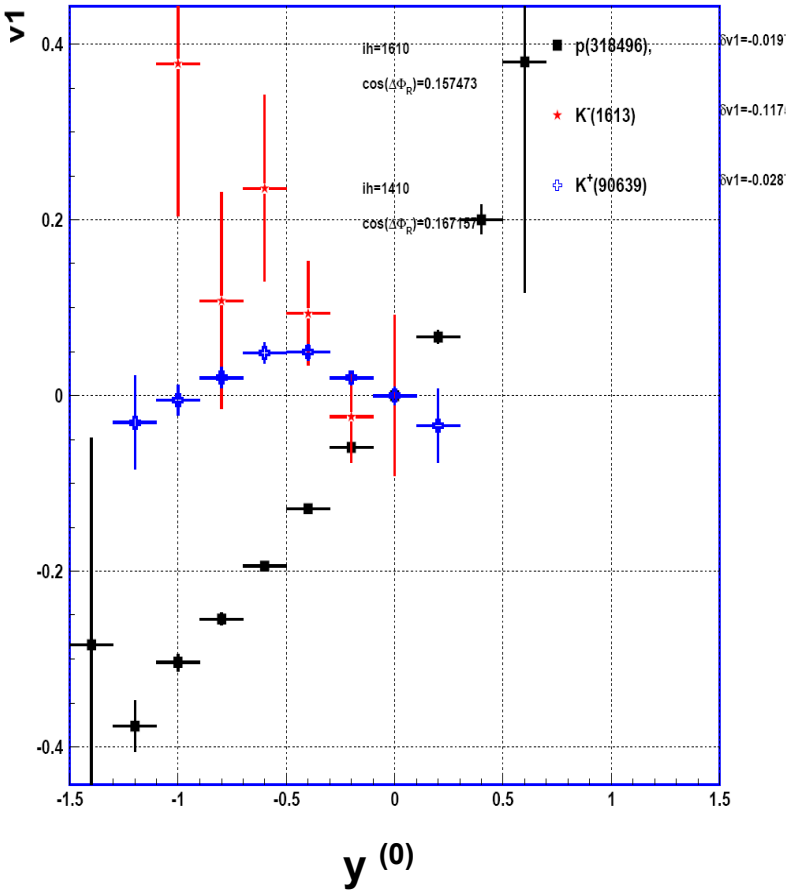


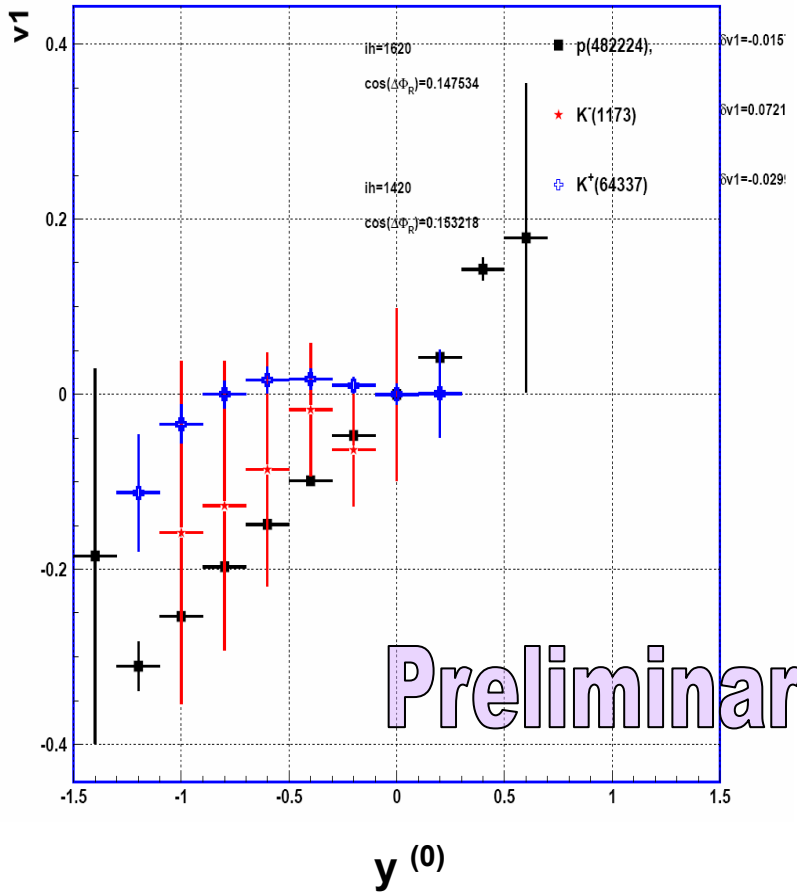
For K^- no consistent description yet by transport models.
HSD – E. Bratkovskaya et al. (Frankfurt, Giessen)
IQMD – C. Hartnack et al. (Nantes)

Centrality dependence of Kaon flow

Ni + Ni at 1.91 AGeV (2008 data)

peripheral **central**



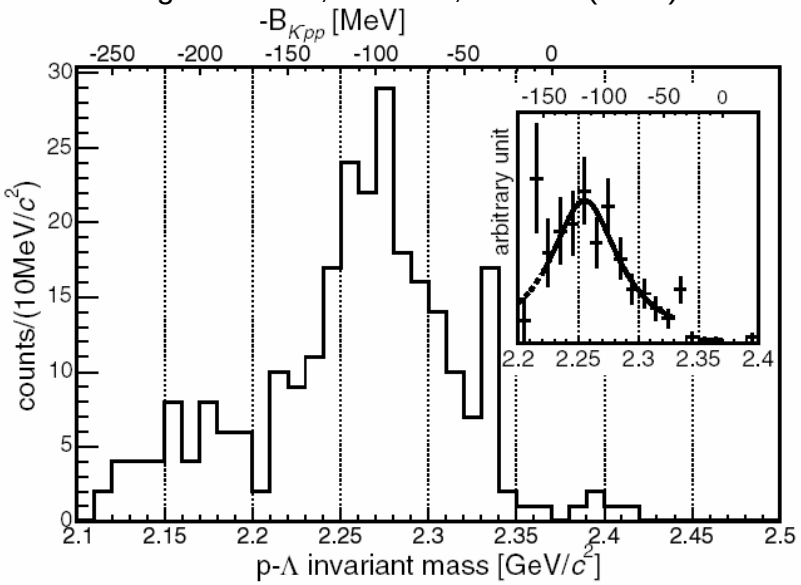


Very strong centrality dependence of directed sideflow of K^-, K- - interaction not properly modeled yet within transport models.

Evidence for $(ppK^-)_{bound}$

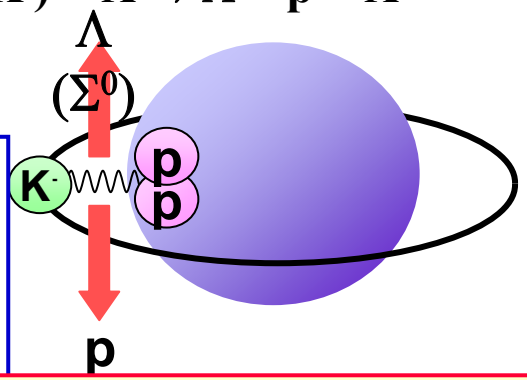
FINUDA @ DaΦne

M. Agnello et al., PRL 94, 212303 (2005)



$e^+e^- \rightarrow \Phi \rightarrow K^+K^-$

$K^- + A \rightarrow (ppK^-) + X \rightarrow \Lambda + p + X$



Production probability:

P·BR = 0.1% per stopped K^-

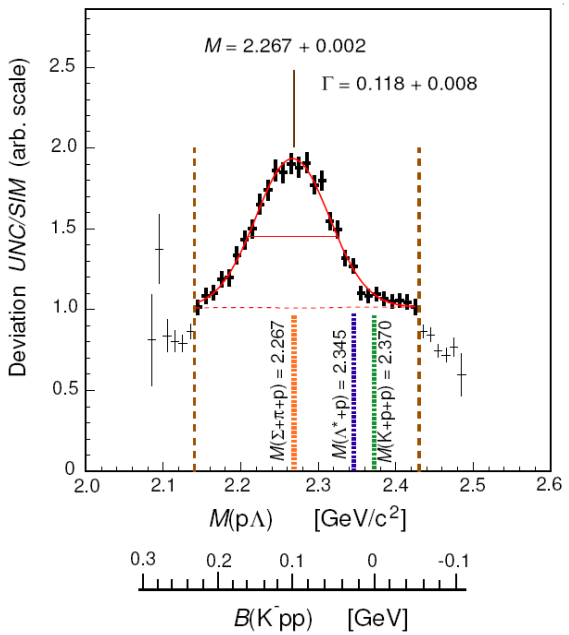
Peak parameter:

$M = 2.255 \pm 0.009$ GeV

$\Gamma = 67^{+14+2}_{-11-3}$ MeV

Controversial interpretation:
2N absorption + rescattering

V.K. Magas, E. Oset, et al., nucl-th/0601013



Reanalysis of old DISTO data:

T. Yamazaki, et al., Exa2008, Vienna, Sep. 2008, arXiv:0810.5182 (nucl-ex)

$p + p \rightarrow K^+ + X \rightarrow K^+ + \Lambda + p$ at 2.85GeV

Production probability:

$X / \Lambda = 0.1$

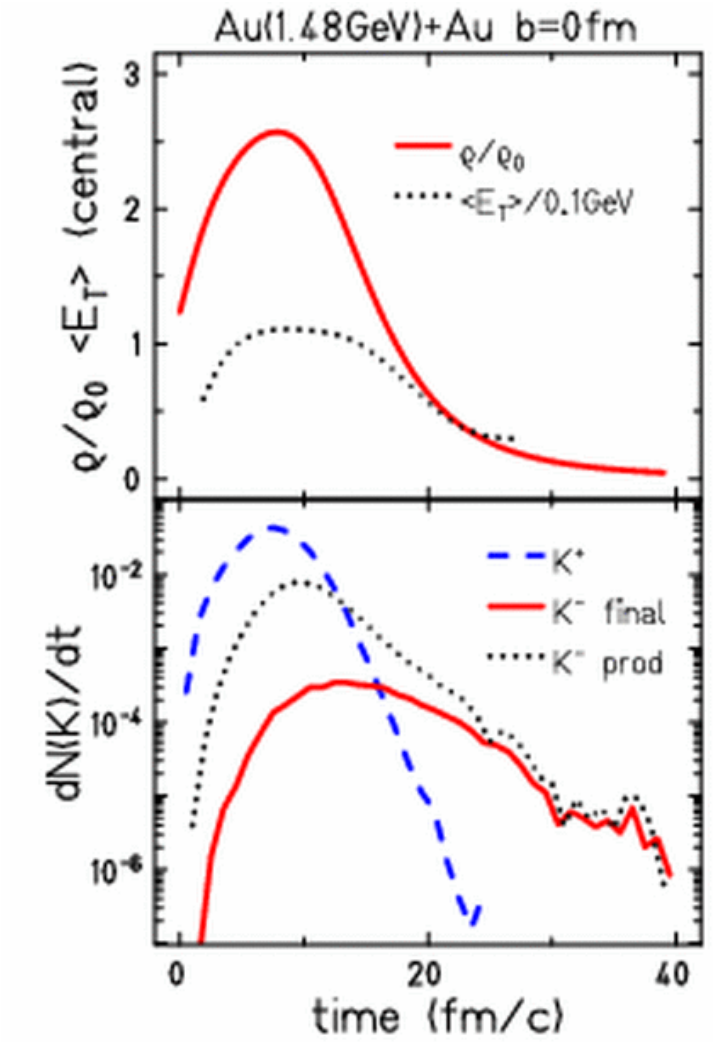
Peak parameter:

$M = 2.265 \pm 0.002$ GeV

$\Gamma = 118 \pm 0.008$ MeV

Antikaon Cluster Production in HI collisions

IQMD, C.Hartnack, Nantes



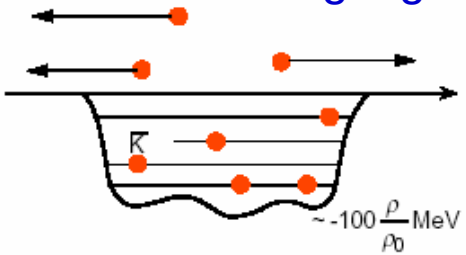
Central density in HI collisions from transport model calculations:

ρ_{max}=2-3 · ρ_0

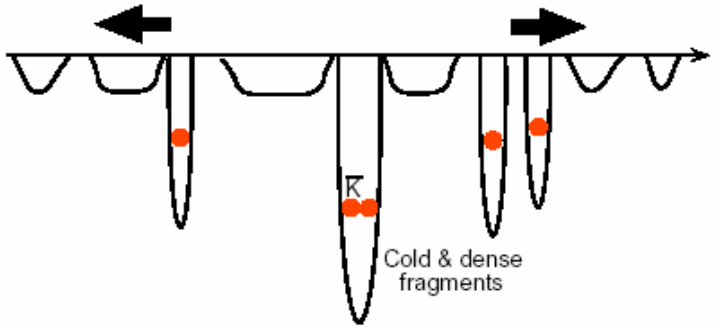
Possible mechanism for cluster formation:

T.Yamazaki et al., NPA738,168 (2004)

1) Kaon production during high density phase

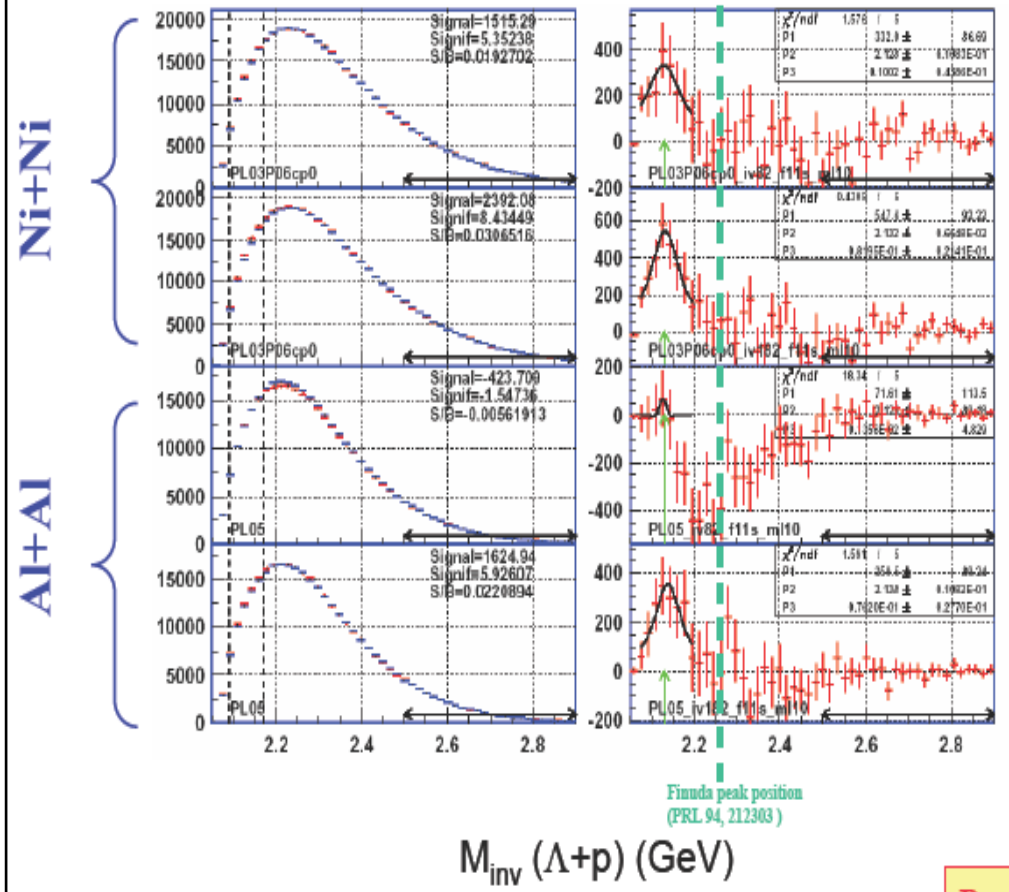


2) capture of K^- in deep trapping centers



Status 2006 (Paul Kienle Symposium, Vienna)

Dibaryons: Ni (2003) – Al (2005) comparison



alignment of reaction plane

alignment of Λ direction

alignment of reaction plane

alignment of Λ direction

Literature:

Strange Dibaryon H_1^+, M=2.13 GeV, Γ=17 MeV
C.Pigot et al. (Rome-Saclay-Vanderbilt Collaboration), NPB 249 (1985) 172

Λp resonance in $K^-D \rightarrow \pi^- p\Lambda$ at rest,
M_1=2.128 GeV, Γ_1=7 MeV and M_2=2.138 GeV, Γ_2= 9.1 MeV
Tai Ho Tan, PRL 23, 101 (1969)

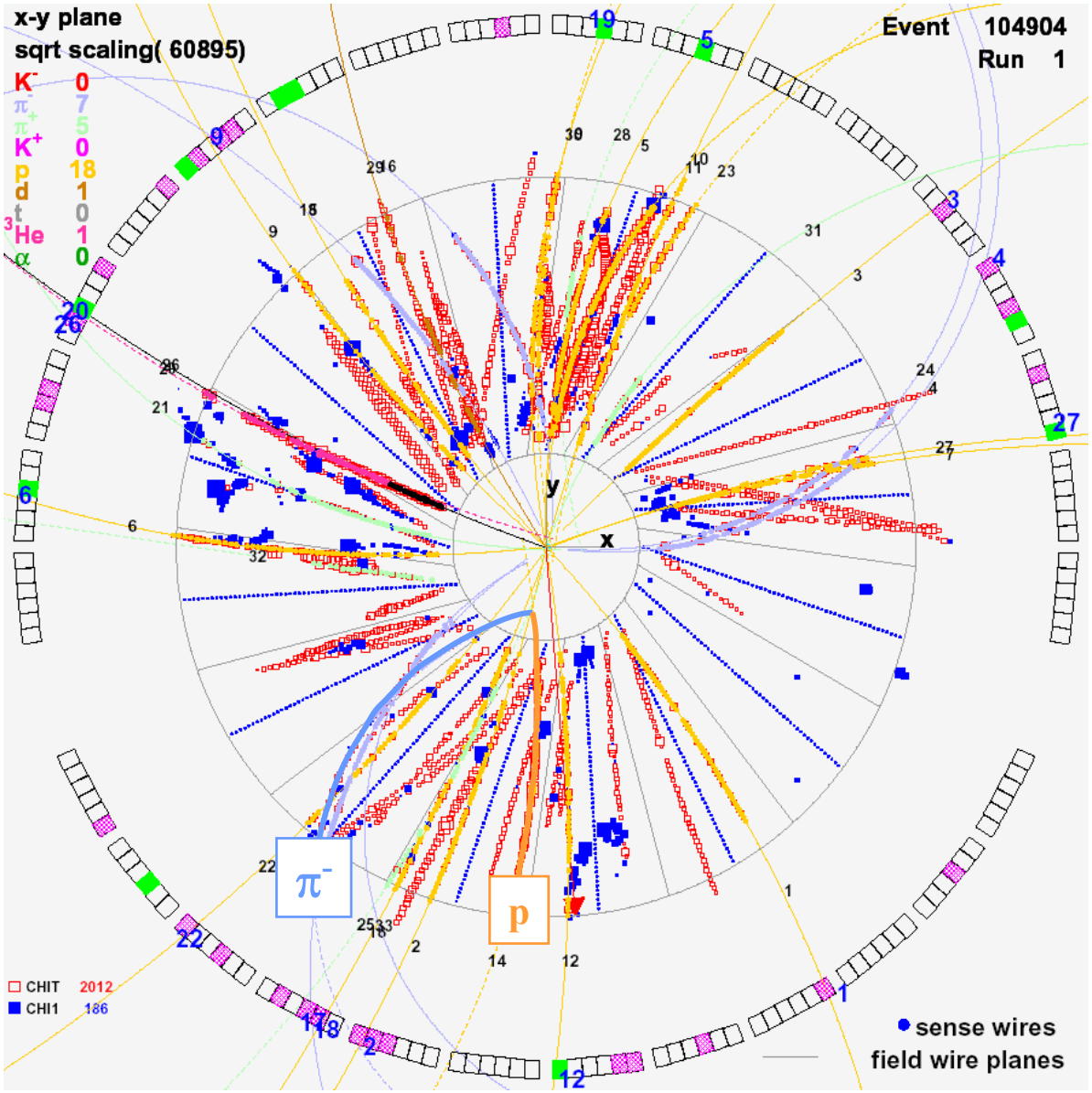
Peak position: 2.13 ± 0.02 GeV
Reflection of other resonances?
Work in progress …

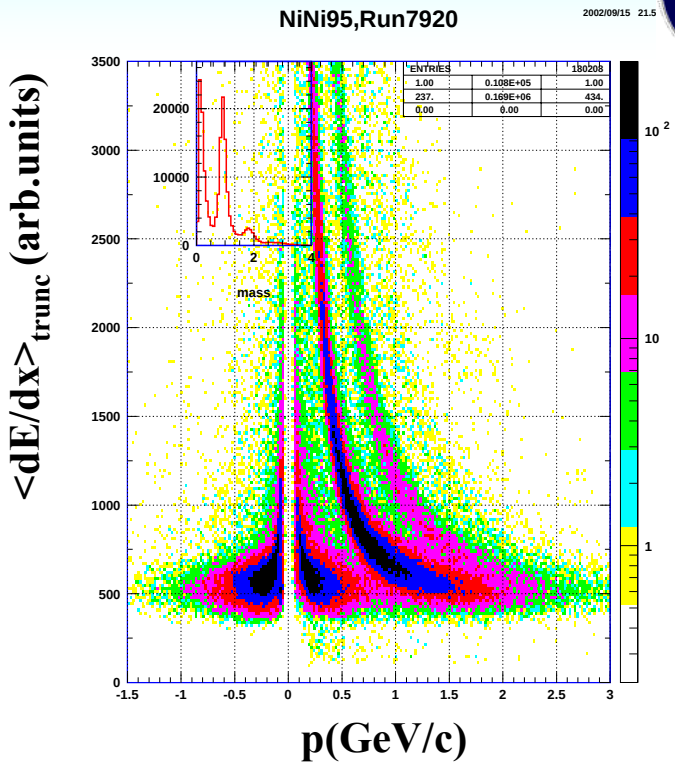
24/27

N.Herrmann, Uni-HD

Detection / Reconstruction Method

Ni+Ni @ 1.93 AGeV





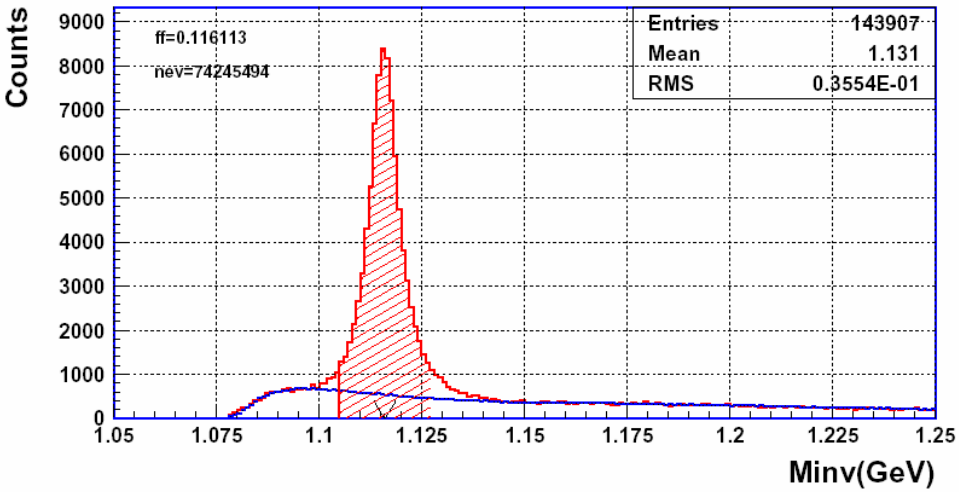
Analyze Λ – X correlations
X = π, p, d, t, h, …

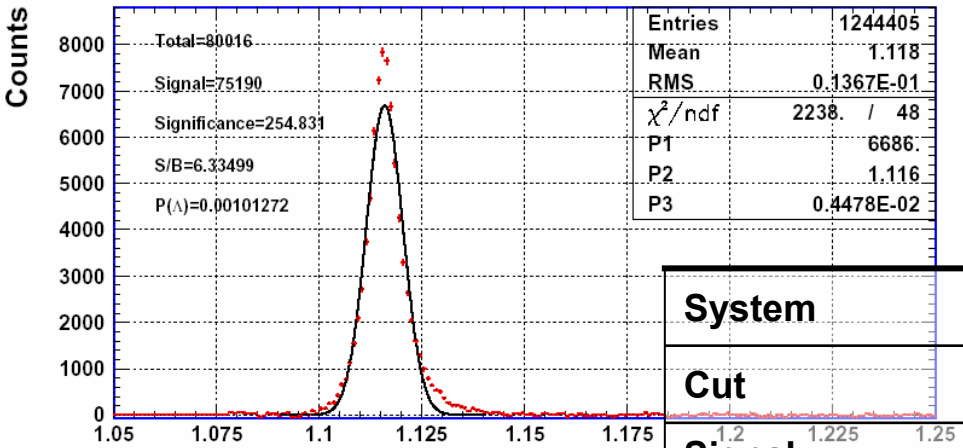
X originating from primary vertex

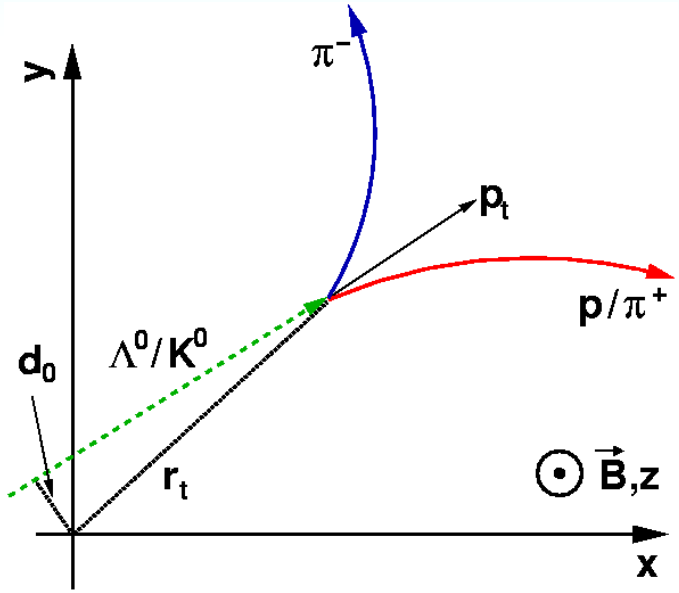
Λ from off-vertex p-π⁻ pairs

Λ – reconstruction

Ni+Ni @ 1.93 AGeV (2003)







Signal-over-background depends on selection cuts

System	Ni+Ni		Al+Al		p+CH_2		p+CD_2	
Cut	"p"	"s"	"p"	"s"	"p"	"s"	"p"	"s"
Signal	136k	75k	207k	109k	8760	4420	2390	1275
S/B	1.6	6.0	2.7	8.9	6.0	17.6	4.6	15.5
Signal scaling	2	1	1.9	1	2.0	1	1.9	1
Background scaling	8	1	6.3	1	5.8	1	6.3	1

Reconstruction of short lived resonances in HI collisions

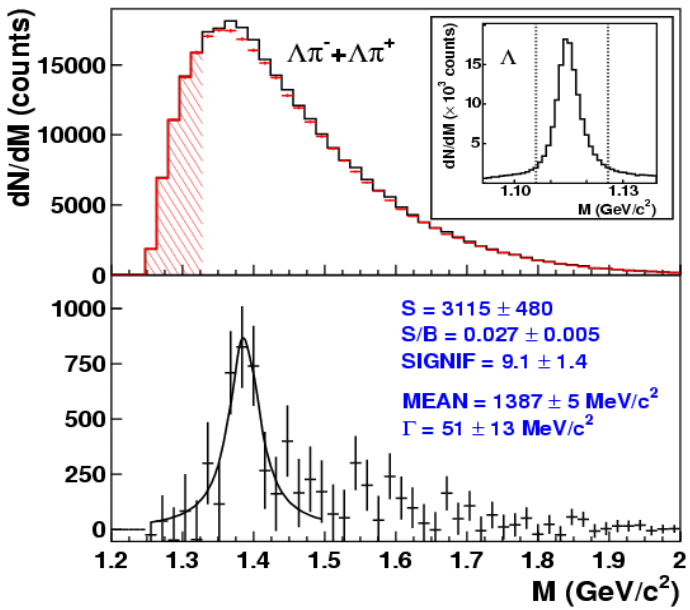
$\Sigma^*(1385)$ subthreshold production,
X. Lopez et al. (FOPI), PRC 76, 052203(R) (2007)

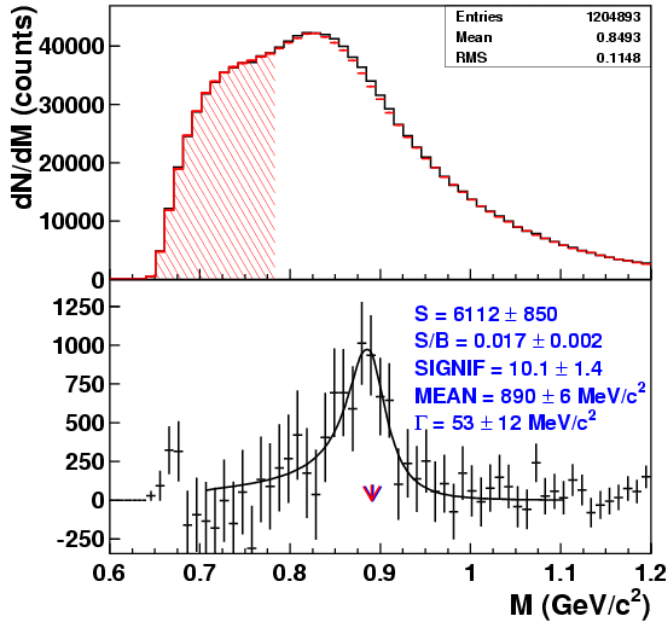
$\Sigma^* \rightarrow \Lambda + \pi \quad (88 \pm 2\%)$
$\rightarrow p + \pi^- + \pi$
$\Gamma = 39.4$ MeV
$c\tau = 5$ fm
$E^{thr}_{NN} = 2.33$ GeV

$K^* \rightarrow K + \pi \quad (88 \pm 2\%)$

$\Gamma = 50.7$ MeV
$c\tau = 4$ fm
$E^{thr}_{NN} = 2.75$ GeV

Exp. Conditions:
Al+Al at 1.92 AGeV,
21 d running (Aug 2005)
$5 \cdot 10^8$ recorded events
10 TByte raw data





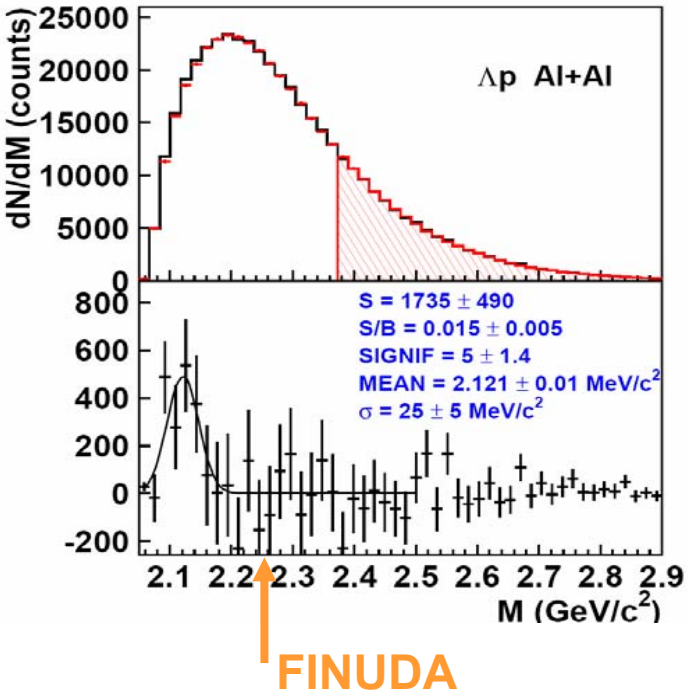
$$P_{det} \approx 10^{-5}$$

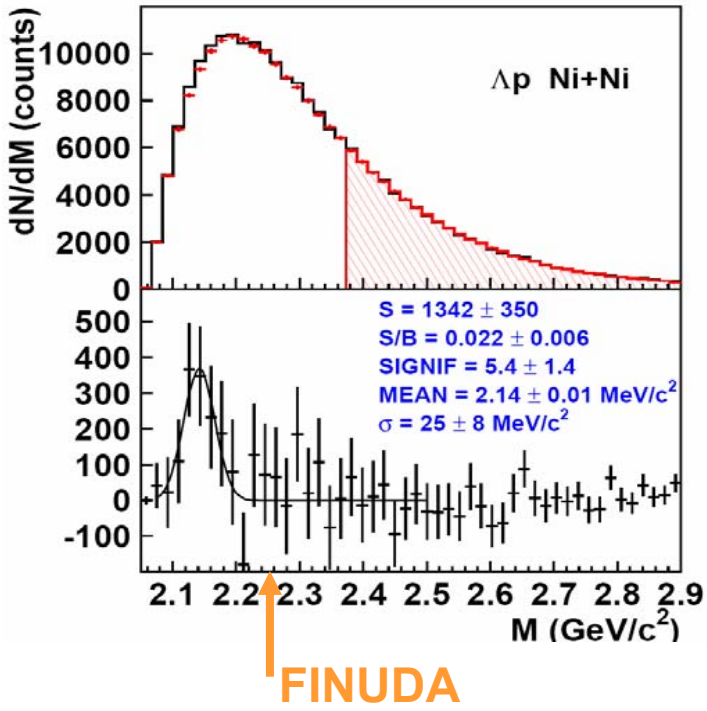
FOPIs reconstruction method and background construction by event mixing works for wide resonances.

Masses and widths of Σ^* and K^* consistent with PDG values.

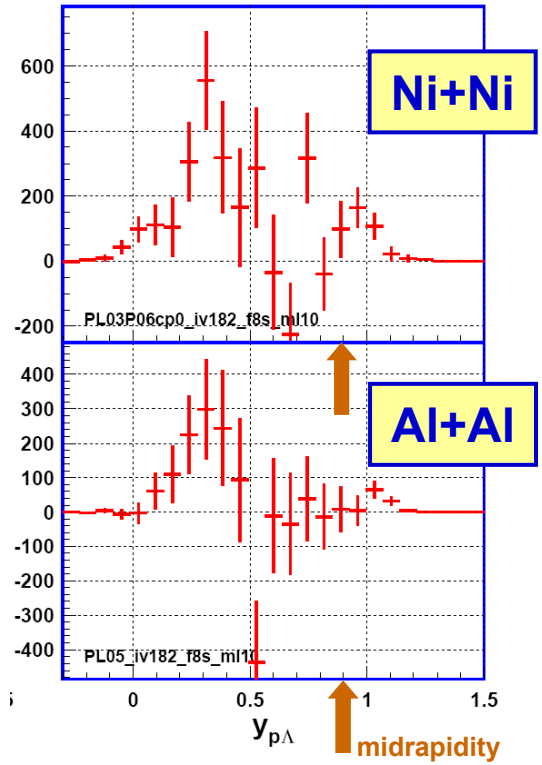
Search for ppK$^-$ (2003/2005 data)

Λp – invariant mass



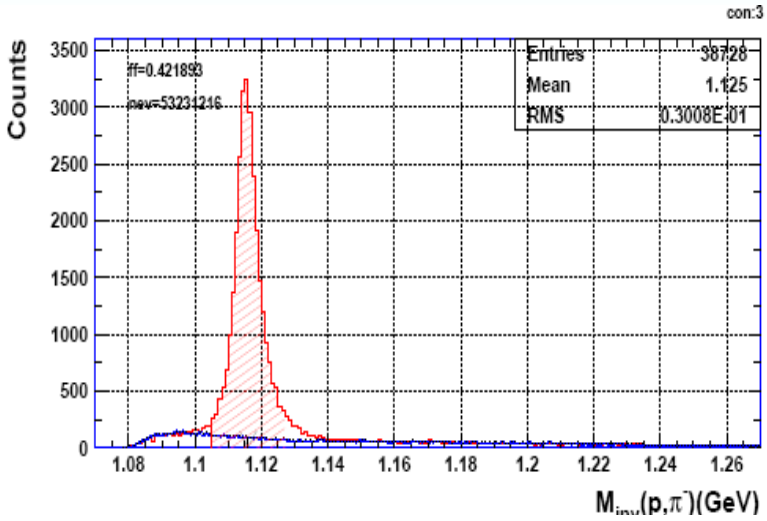


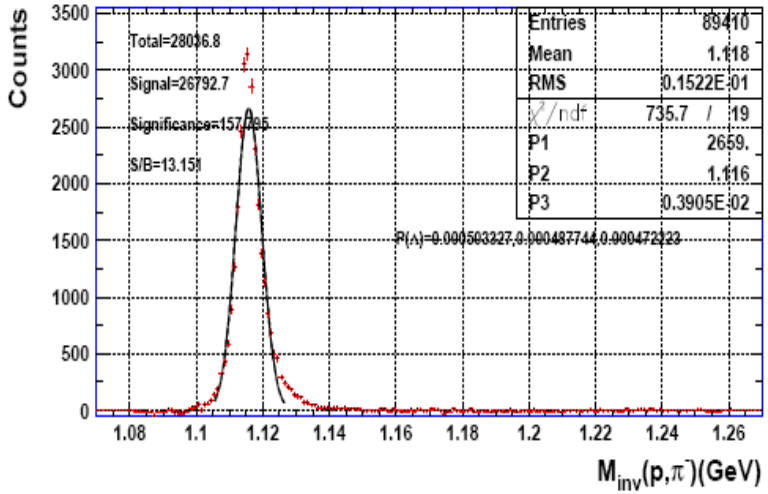
Rapidity distribution



Excess observed in Ni+Ni and Al+Al with statistical significance of ~ 5
in 2 independent analysis.
Yield located in spectator/fireball interface region y < 0.65 (like non-strange clusters).

New data S325/S325e (2007/2008)

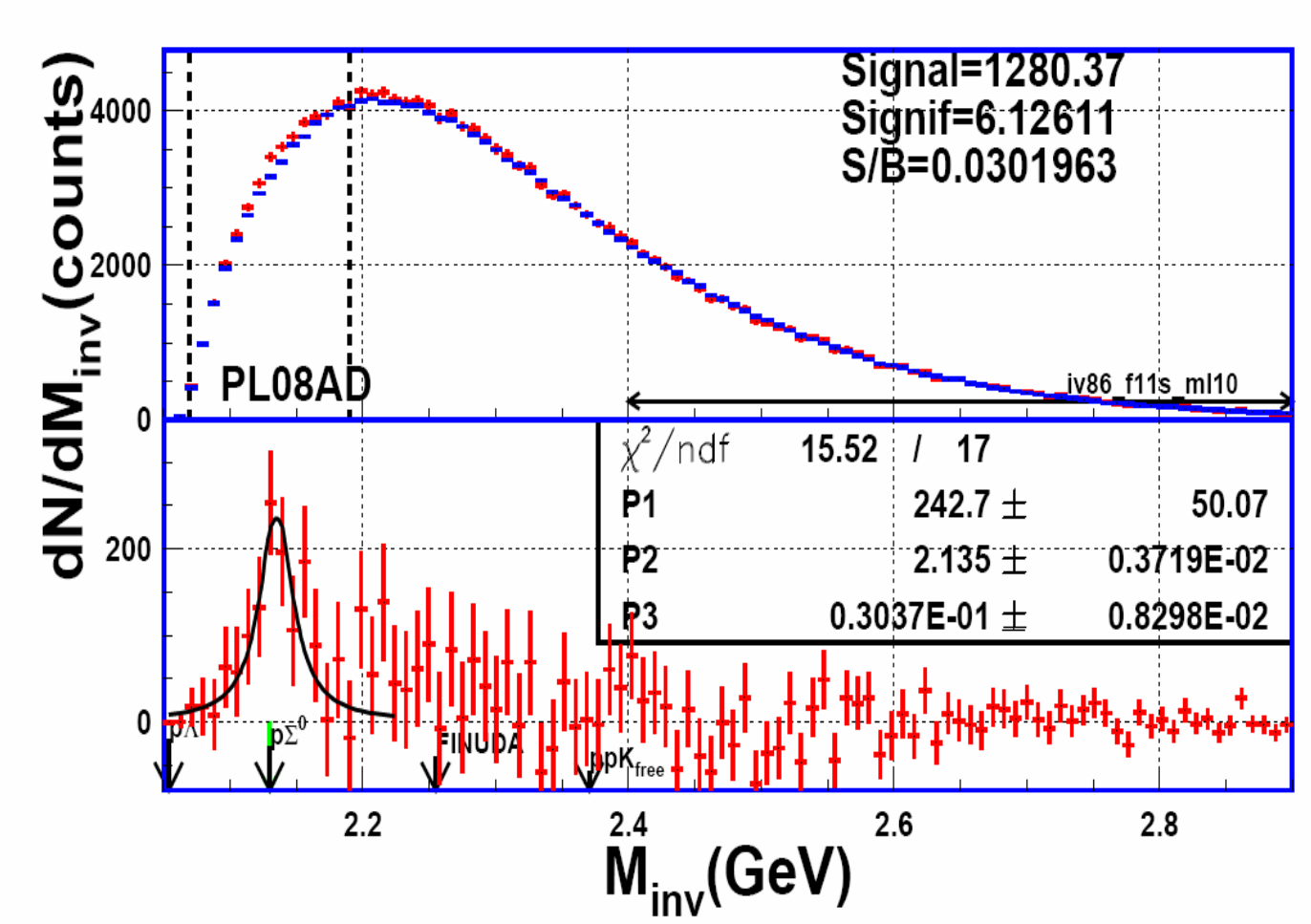




System	Ni+Ni (2003)		Al+Al(2005)		Ni+Ni (2007)		Ni+Ni(2008)	
Cut	"p"	"s"	"p"	"s"	"p"	"s"	"p"	"s"
Signal	136k	75k	207k	109k	20k	10k	54k	27k
S/B	1.6	6.0	2.7	8.9	2.4	8.7	3.4	12.2
Signal scaling	2.0	1	1.9	1	2.0	1	2.0	1
Background scaling	6.8	1	6.3	1	7.2	1	7.2	1

2007/2008 data triggered with less stringent centrality requirement

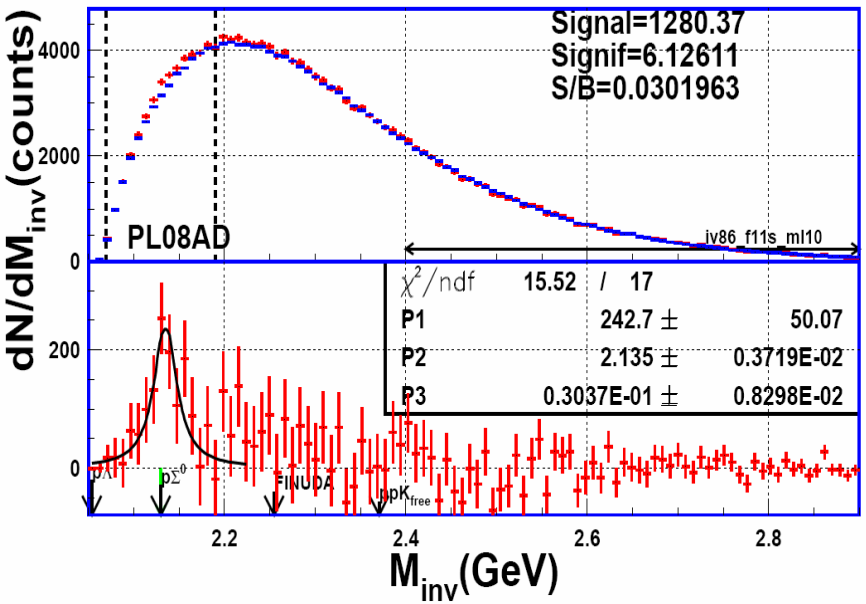
Λp – invariant mass (2008 data)



Peak present in 2008 data with same cuts as for 2003/2005 data,
S/B larger than in 2003 data,
Additional strength in the mass range 2.2 < M_{inv}<2.3 GeV possible.

Strange Dibaryon

Λp – invariant mass (2008 data)



R.Siebert et al., NPA 567,819 (1984) - SPES4/SATURNE II

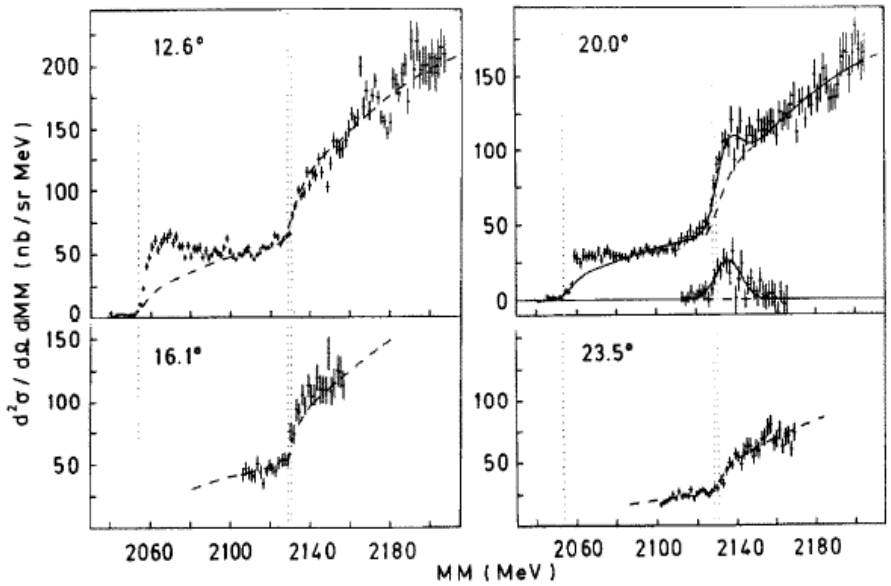


Fig. 6. Inclusive missing mass spectra for pp → K⁺X at 2.7 GeV incident energy. The kaon laboratory scattering angles are 12.6°, 16.1°, 20.0° and 23.5°. The bins are 1.5 MeV wide. The resolutions (FWHM) are approximately 3 MeV (12.6°), 4 MeV (16.1°), 3.5 MeV (20.0°) and 5 MeV (23.5°). The dashed lines show the 3-body phase-space to which a fitted gaussian distribution centered at 2136 MeV was added at 20.0°. This peak is also shown separately.

Peak position consistent with p+p scattering data: M=2.315 ± 0.004GeV

Suggested interpretation: D_t (q4 x q2 structure)

A.T.M. Aerts and C.B. Dover, Phys. Lett. B146, 95 (1984)

Object also seen in $K^- + d \rightarrow \Lambda p \pi^-$ (O. Braun et al., NPB 124,45 (1977))

Interpretation: ΣN – bound state H(2129)

Transport model calculations including Cusp in K^+ - production ongoing

Yield –ratio (Λp)/Λ=0.024 consistent with thermal model prediction: 0.018 (x3)

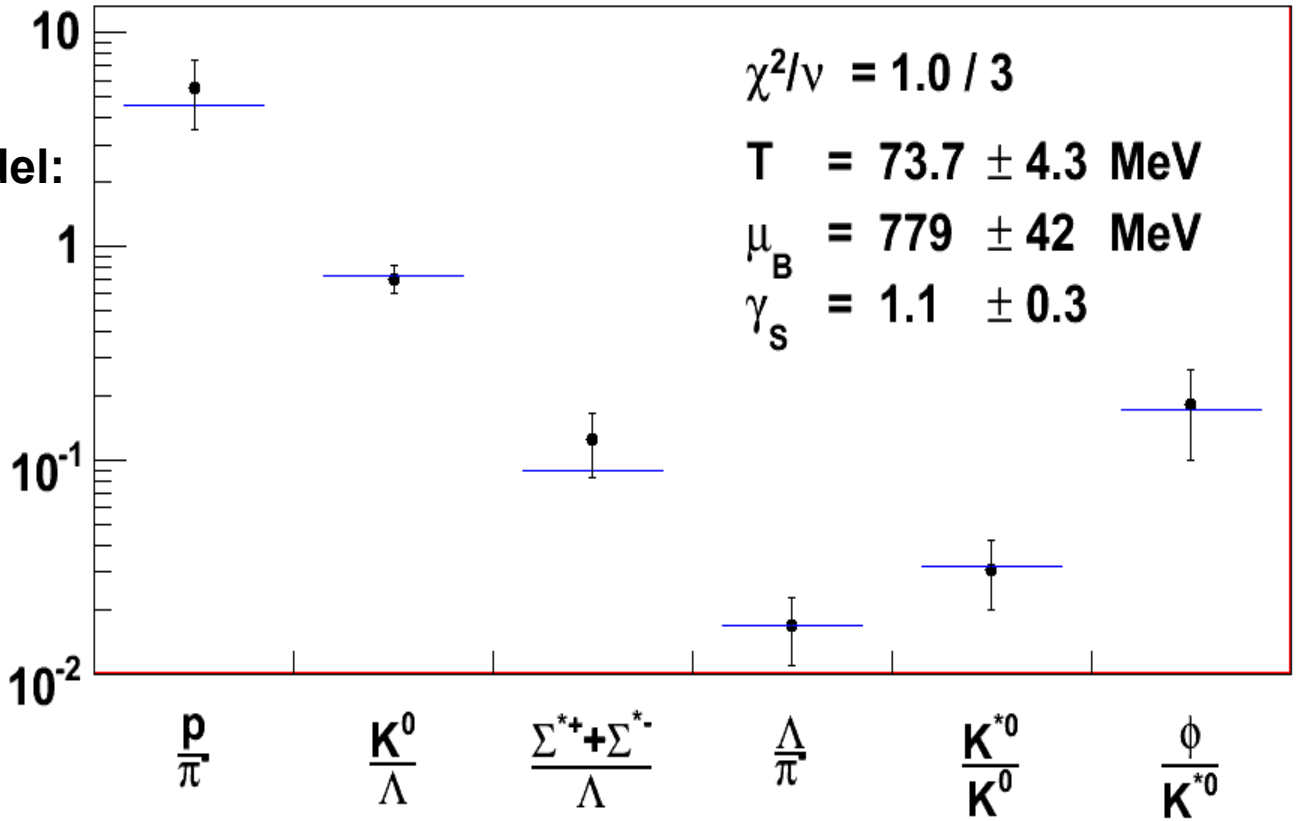
Particle yields at freeze-out

6 independent ratios with 5 strange particles:
p, π^-, K^0, (Λ+Σ^0), K^{*0}(892) and $\Sigma^{*\pm}$(1385), ϕ
in Al+Al @ 1.9 AGeV

Preliminary

Comparison to statistical model:

- **canonical ensemble (γ_s = 1)**
- **fit to 5 ratios**
- **Φ/K^{*0} is a prediction**

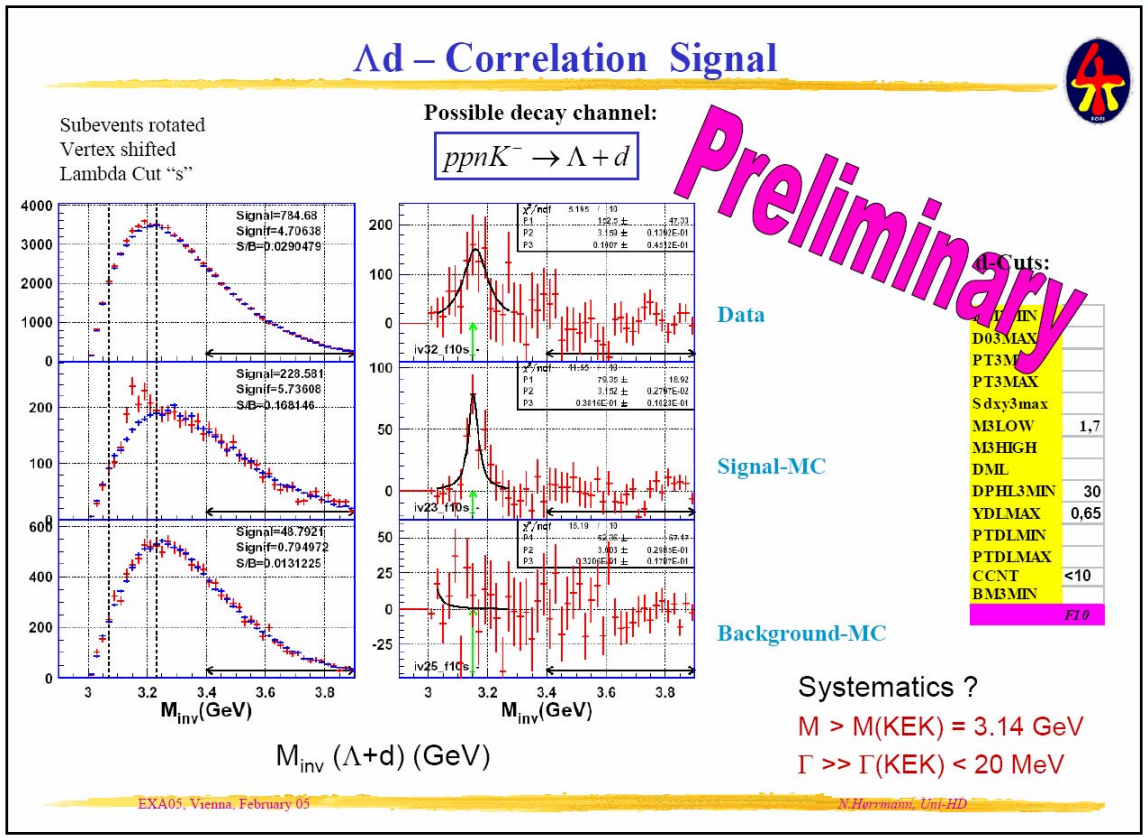


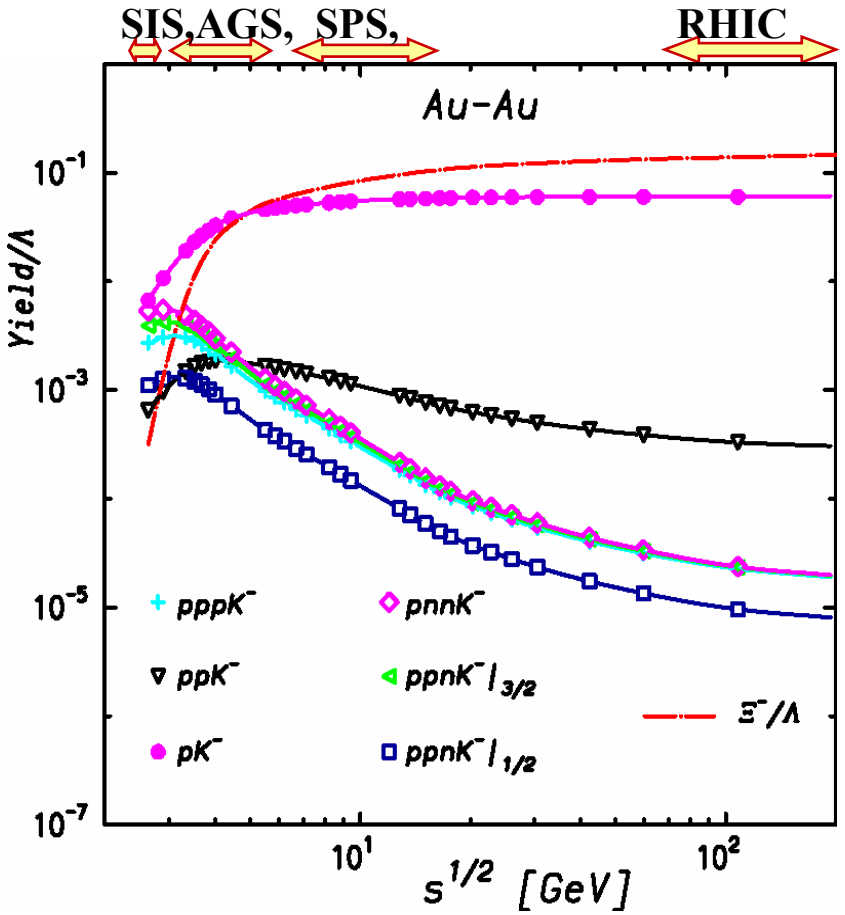
Calc.: K. Piasecki (THERMUS)

Thermal equilibrium model works surprisingly well for Al+Al with γ_s=1 !

Strange Cluster search in HI - collisions

since 2003: $ppnK^-$??





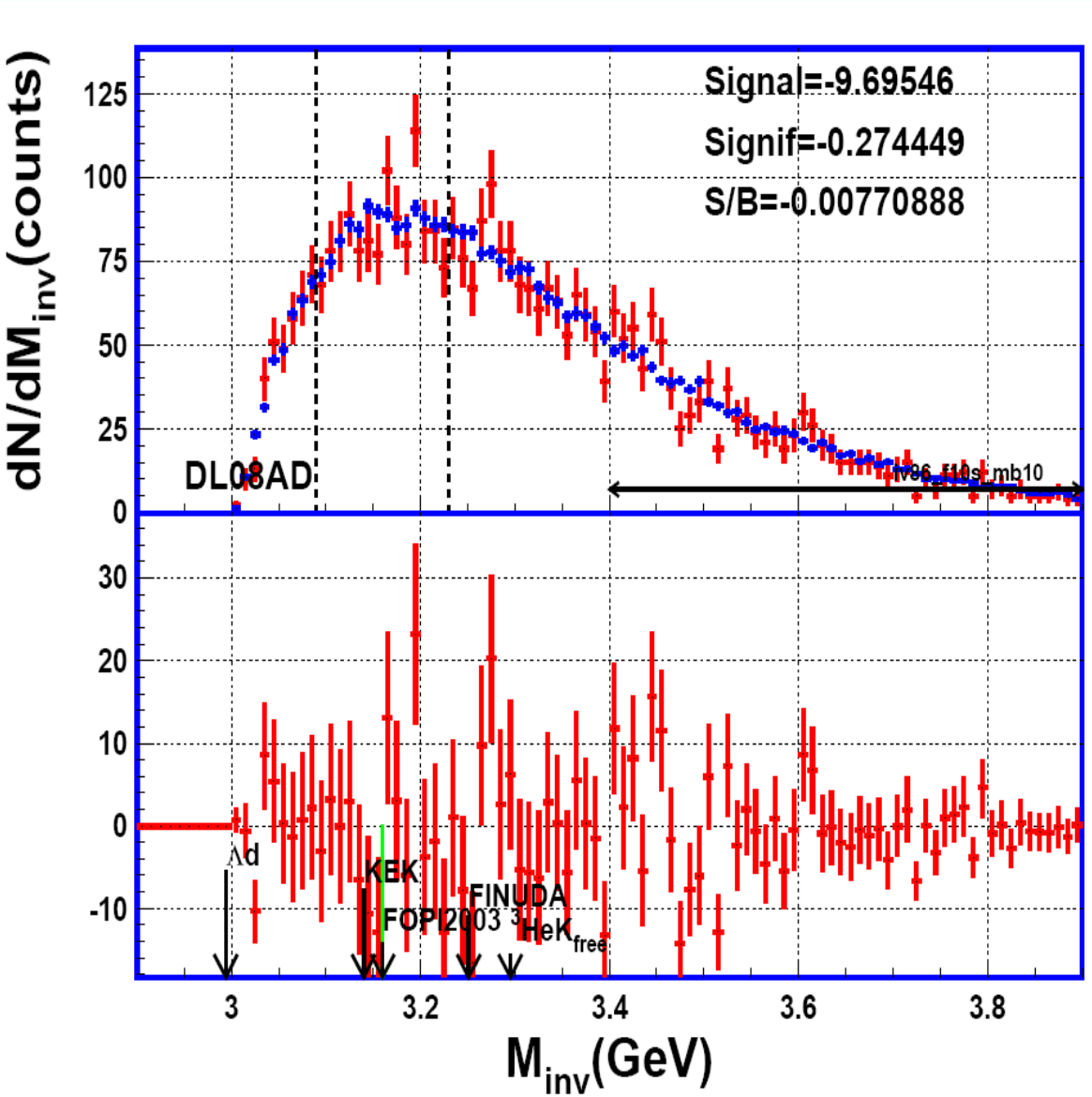
A.Andronic, PBM, K. Redlich (2005), nucl-th/0506083

Yield of single strange clusters per Λ predicted to peak at lowest beam energies

Abundance larger than Ξ – baryon

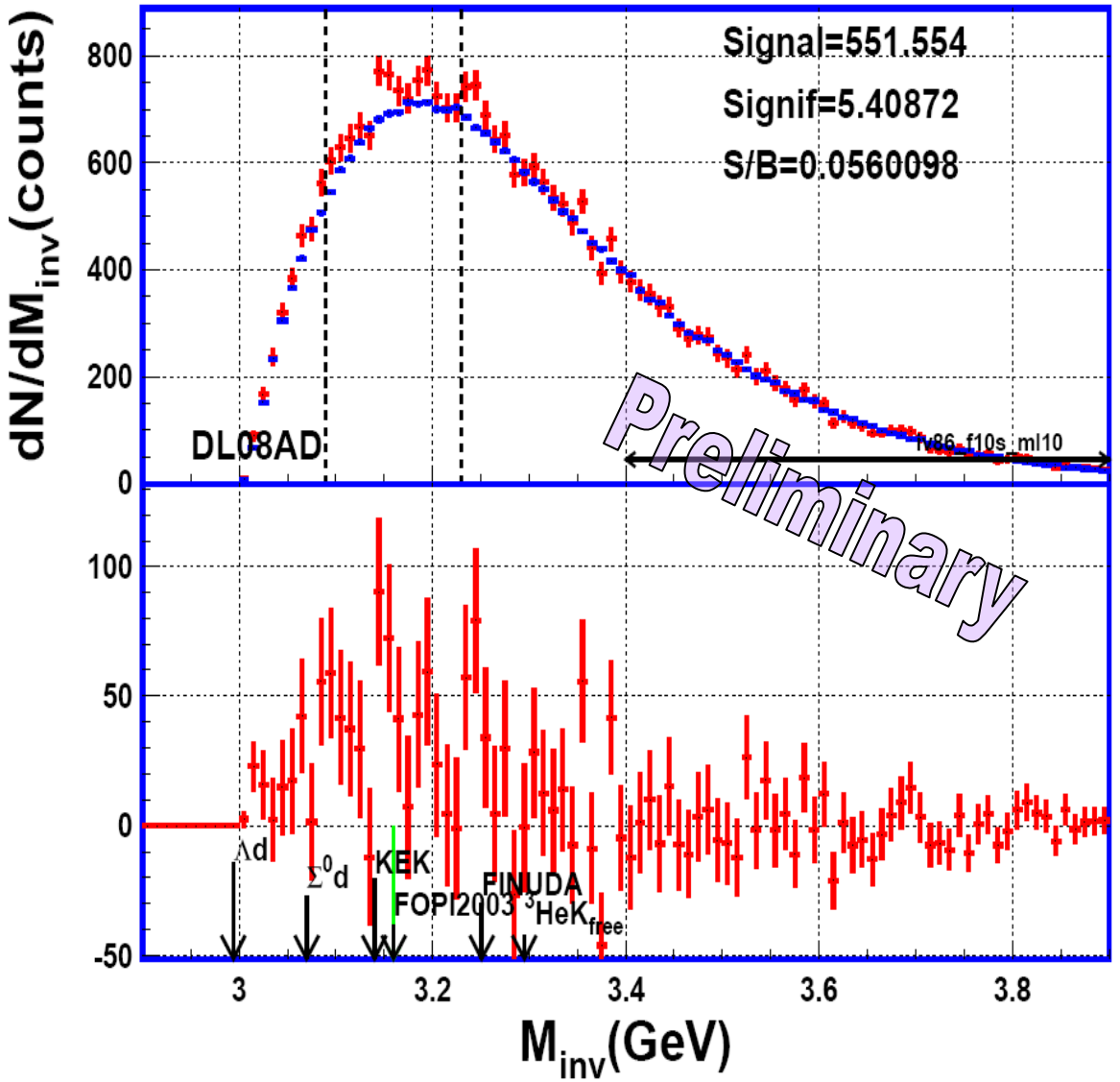
More data are needed …

Λd – correlation (2008 – data)



Sideband analysis: 10 MeV < $|M_\Lambda^{rec} - m_\Lambda^{PDG}|$ < 20 MeV - no enhancement observed.

Λd – correlation (2008 – data)



Current status of analysis:
(using same selection cuts And procedures as in 2003)

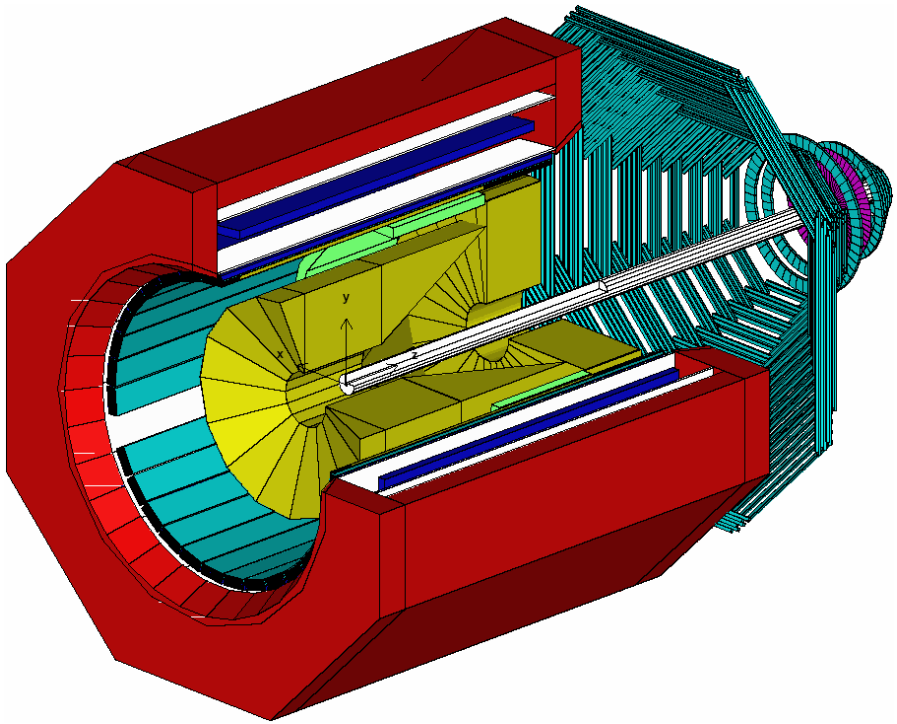
Excess statistically consistent with 2003 – data.

Statistics not enough to resolve narrow structures.

Slightly more data available (~factor 4, although different reactions: Ni+Pb, Ru+Ru)

Significantly more data needed → new experiment

Strange baryon program with FOPI @ GSI



IPNE Bucharest, Romania
CRIP/KFKI Budapest, Hungary
LPC Clermont-Ferrand, France
GSI Darmstadt, Germany
FZ Rossendorf, Germany
Univ. of Warsaw, Poland
IMP Lanzhou, China
TUM, Munich, Germany
+ P. Kienle (TUM), T.Yamazaki(RIKEN)

ITEP Moscow, Russia
Kurchatov Institute Moscow, Russia
Korea University, Seoul, Korea
IReS Strasbourg, France
Univ. of Heidelberg, Germany
RBI Zagreb, Croatia
SMI Vienna, Austria

A. Andronic, R. Averbeck, Z. Basrak, N. Bastid, M.L. Benabderramahne, P. Bühler, R. Caplar, M. Cargnelli, M. Ciobanu, P. Crochet, I. Deppner, P. Dupieux, M. Dzelalija, L. Fabbietti, F. Fu, P. Gasik, O. Hartmann, N. Herrmann, K.D. Hildenbrand, B. Hong, T.I. Kang, J. Keskemeti, Y.J. Kim, M. Kis, M. Kirejczyk, P. Koczon, M. Korolija, R. Kotte, A. Lebedev, K.S. Lee, Y. Leifels, P.-A. Loizeau, X. Lopez, J. Marton, M. Merschmeyer, D. Moisa, R. Muenzer, M. Petrovici, K. Piasecki, F. Rami, V. Ramillien, A. Reischl, W. Reisdorf, M.S. Ryu, A. Schüttauf, Z. Seres, B. Sikora, K.S. Sim, V. Simion, K. Siwek-Wilczynska, K. Suzuki, Z. Tyminski, K. Wisniewski, Z. Xiao, H.S. Xu, J.T. Yang, I. Yushmanov, A. Zhilin, Y. Zhang, J. Zmeskal

Objectives:

Strangeness in

HI collision

pion induced reactions

proton-proton collisions

Further talks:

L. Fabietti: Wed. afternoon
O. Hartmann: Fri. morning

Summary / Conclusion

Strangeness production close to threshold is still not understood.

New RPC TOF barrel operational with $\sigma_{t,system}$ ~ 90 ps.

New data from FOPI at SIS18

- **Short lived strange resonances: ϕ, K*(892), Σ*(1395)**
  chemical equilibrium in Al + Al @ 1.9 AGeV ?
- **Flow of charged kaons**
  strong centrality dependence of K^- - sideflow
- **Some indications for strange dibaryon production ($H1^+$, D_t)**
  first observation of strange dibaryon in HI – collisions

Search for multi-baryonic strange clusters ($ppnK^-$, $pppK^-$) ongoing.

Serious theoretical effort necessary to interpret available and coming data.

Strange hadrons, especially strange multi-baryonic clusters, are an exiting possibility towards the properties of cold dense baryonic matter and non-perturbative QCD.

Strangeness physics from 2-10 AGeV must be continued/ revisited with high statistics!
=> FOPI(?)/HADES@SIS18/GSI => HADES/CBM @ SIS100/FAIR

bmb+f - Förderschwerpunkt
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