



Strangeness Production in AA – Collisions at SIS18



Introduction

strangeness in dense baryonic matter

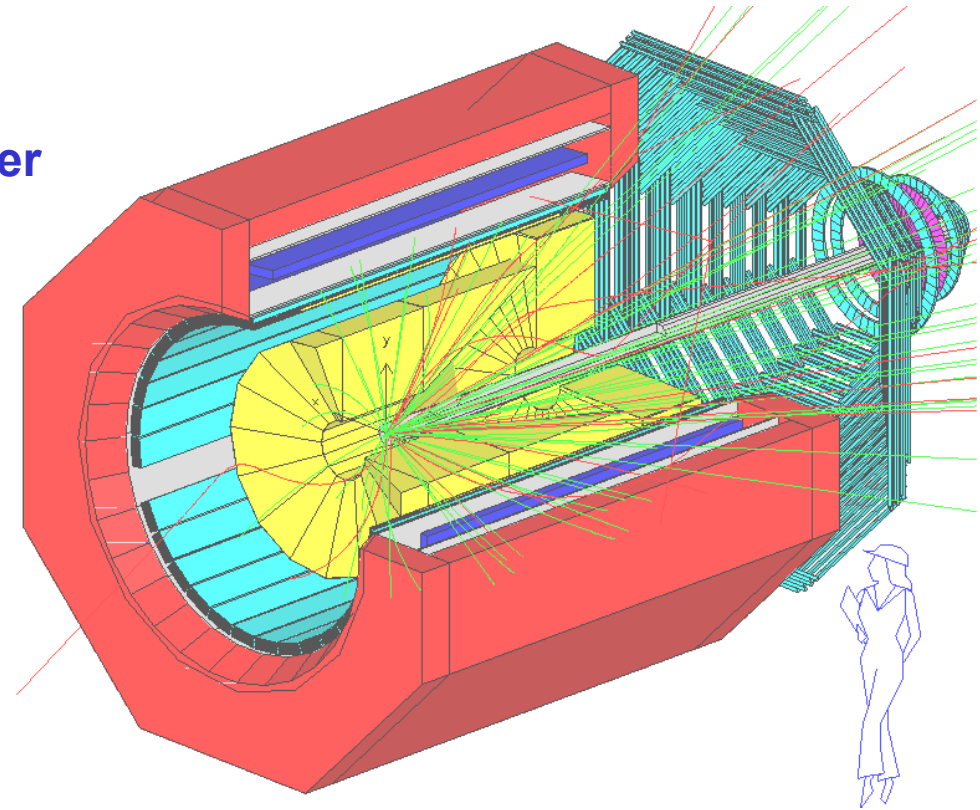
Results

charged kaon flow

lambda – proton correlation

hypertritons

other light hypernuclei



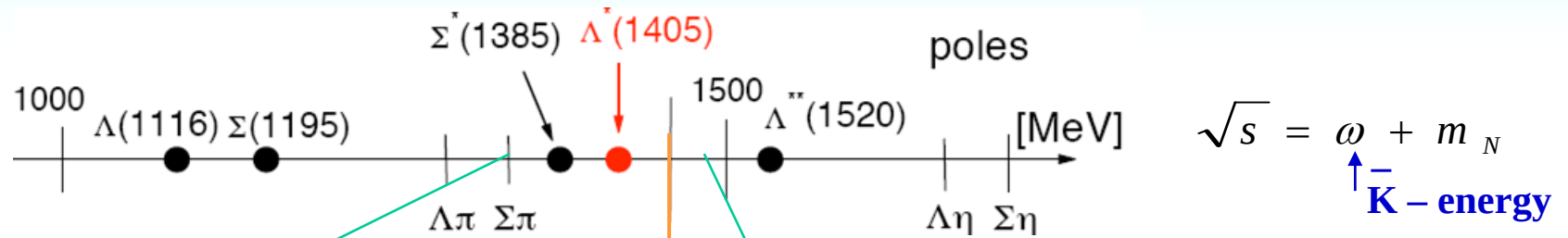
Conclusions / Outlook

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

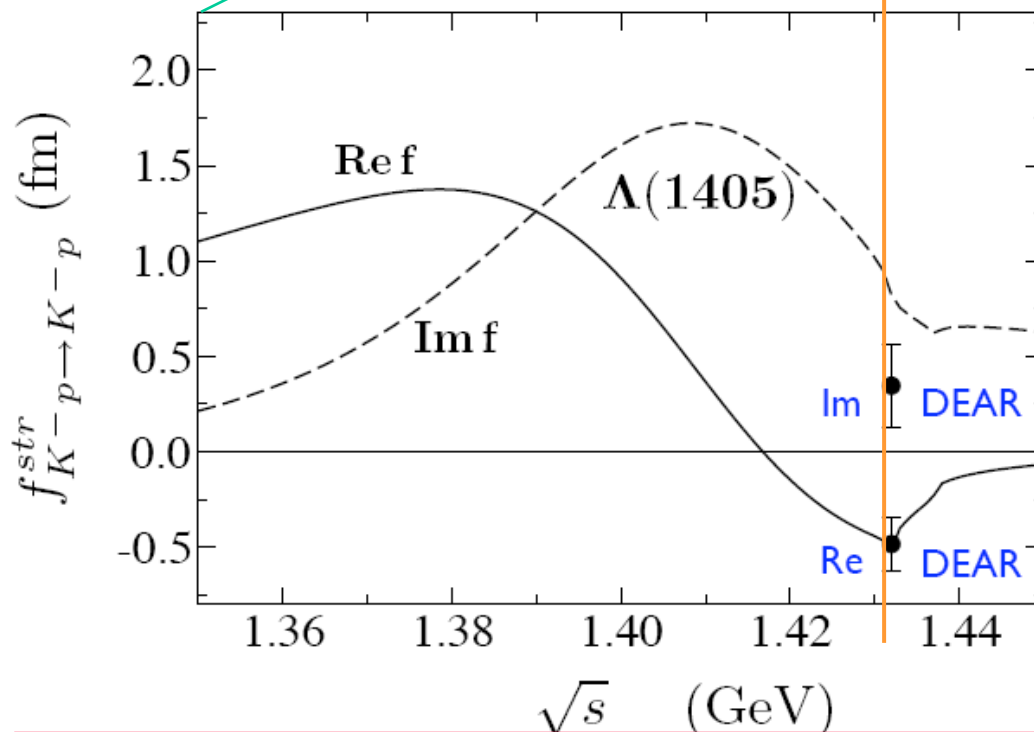
ITEP Moscow, Russia
Kurchatov Institute Moscow, Russia
Korea University, Seoul, Korea
IReS Strasbourg, France
Univ. of Heidelberg, Germany
RBI Zagreb, Croatia
TUM, Munich, Germany



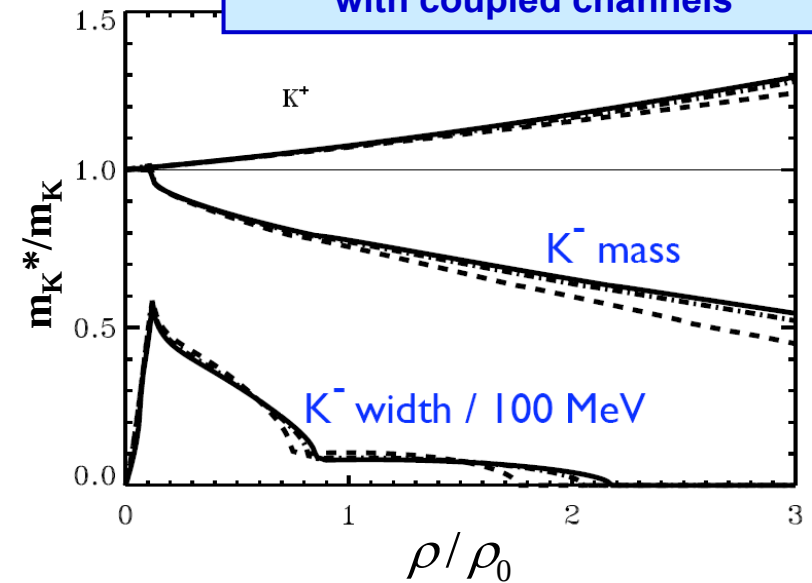
$\bar{K}N$ – interaction



Scattering amplitude f



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



$\bar{K}N$ – interaction is attractive at finite densities, but strength (depth of potential) is unclear
 Experimental signatures: flow of kaons
 bound baryonic states



Experimental strangeness program of FOPI



Reference data from elementary reactions

K^0 , Λ production and phase space distributions in
 $\pi^- + \text{C, Al, Cu, Sn, Pb}$ @ 1.15 GeV/c, (S273, 2004)

K^0 , K^+ , K^- , ϕ , Λ production in
 $\pi^- + \text{LH}_2, \text{C, Pb}$ @ 1.7 GeV/c, (S339, 2011)

Systematics of strangeness data from heavy-ion reactions

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

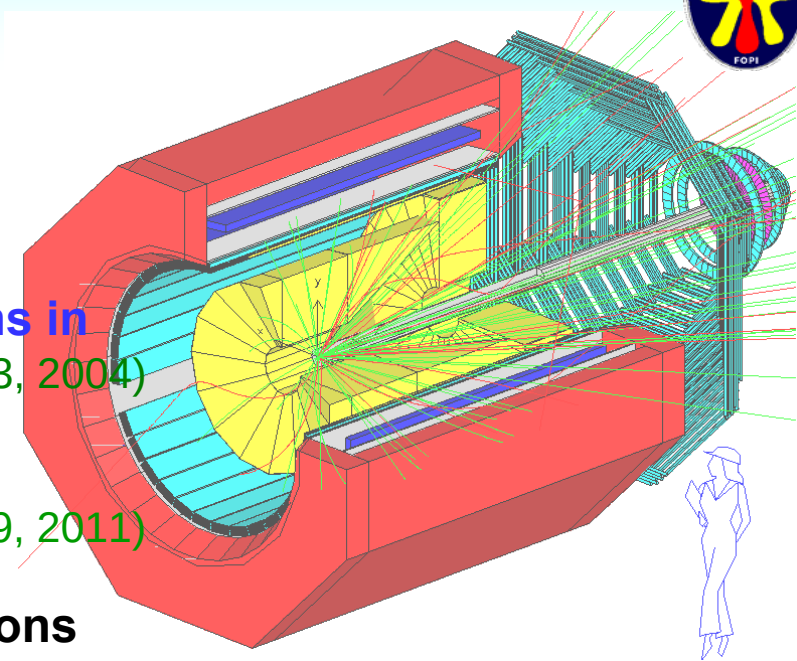
Search for kaonic bound states

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

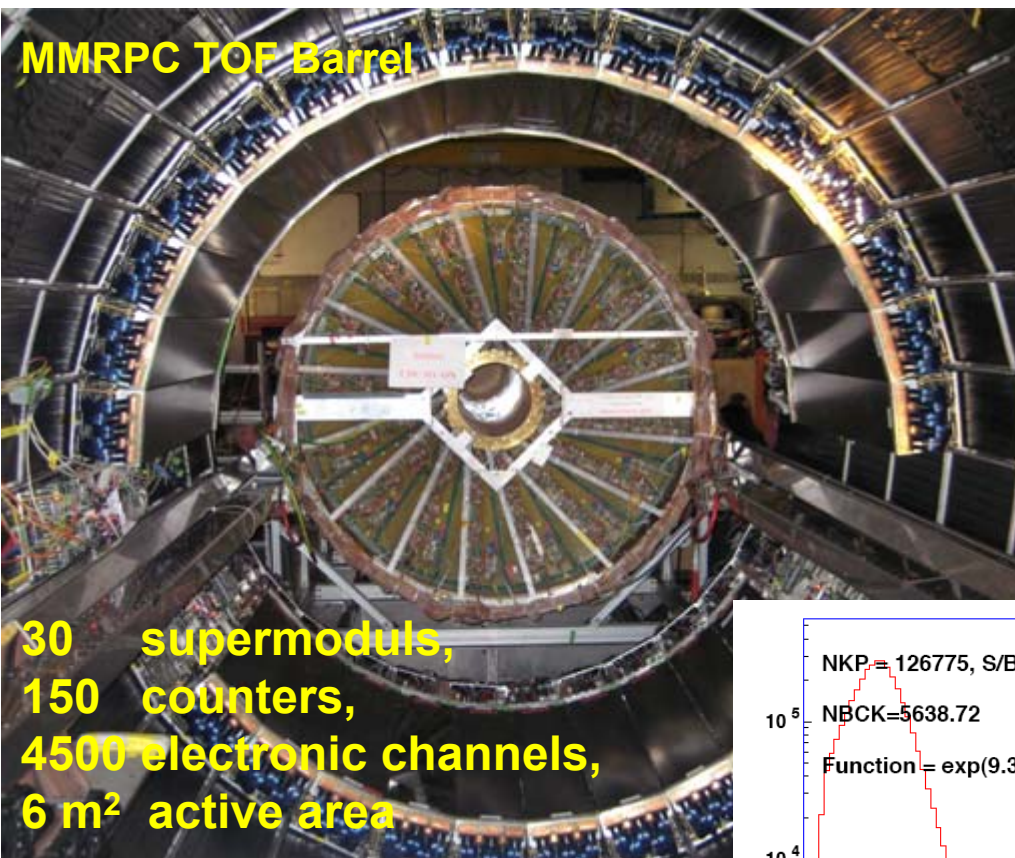
existence of ppK^- - bound state

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





FOPI III (2007 – 2010) with improved PID



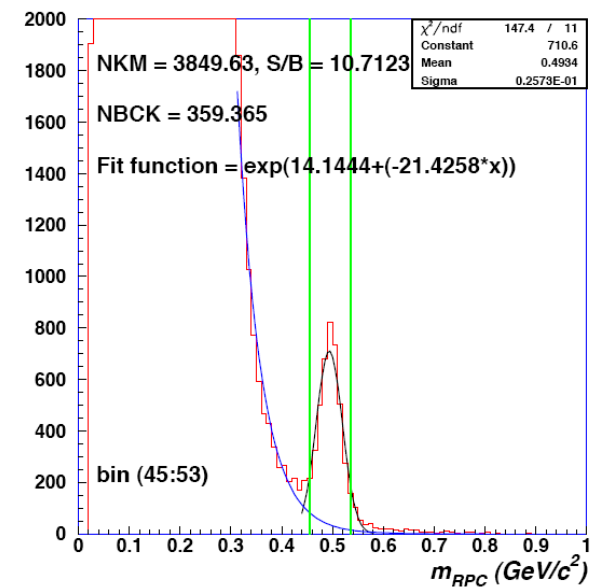
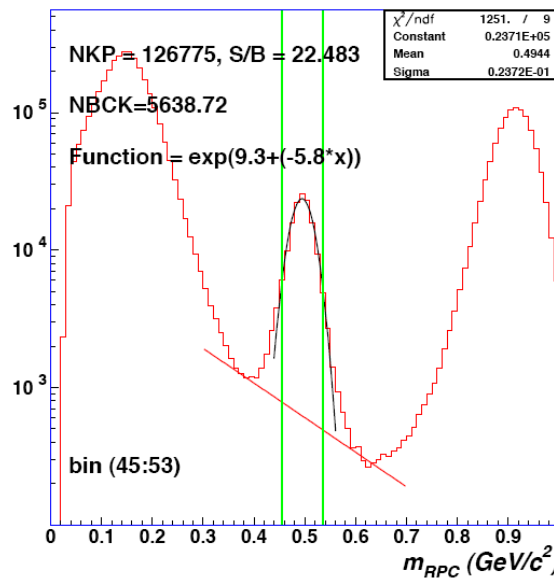
Performance:

$$\sigma_{\text{system}} \sim 88 \text{ ps}$$

$$\sigma_{\text{RPC}} \sim 67 \text{ ps}$$

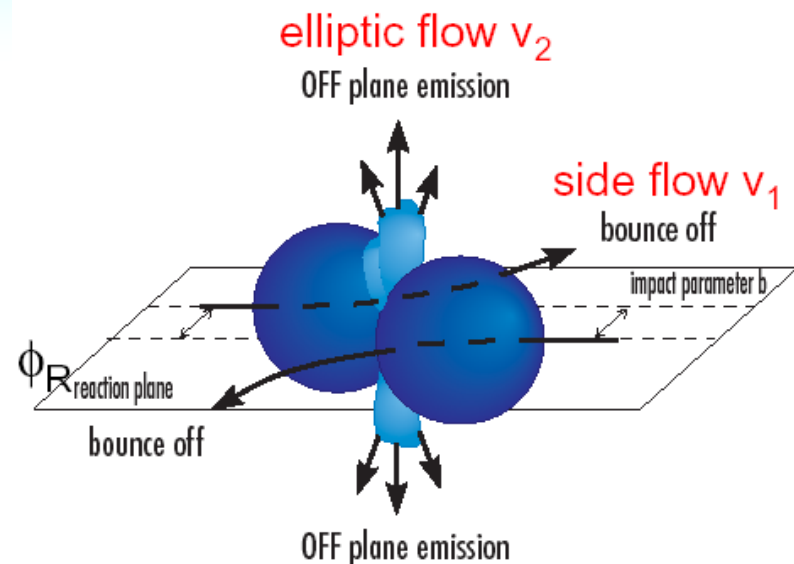
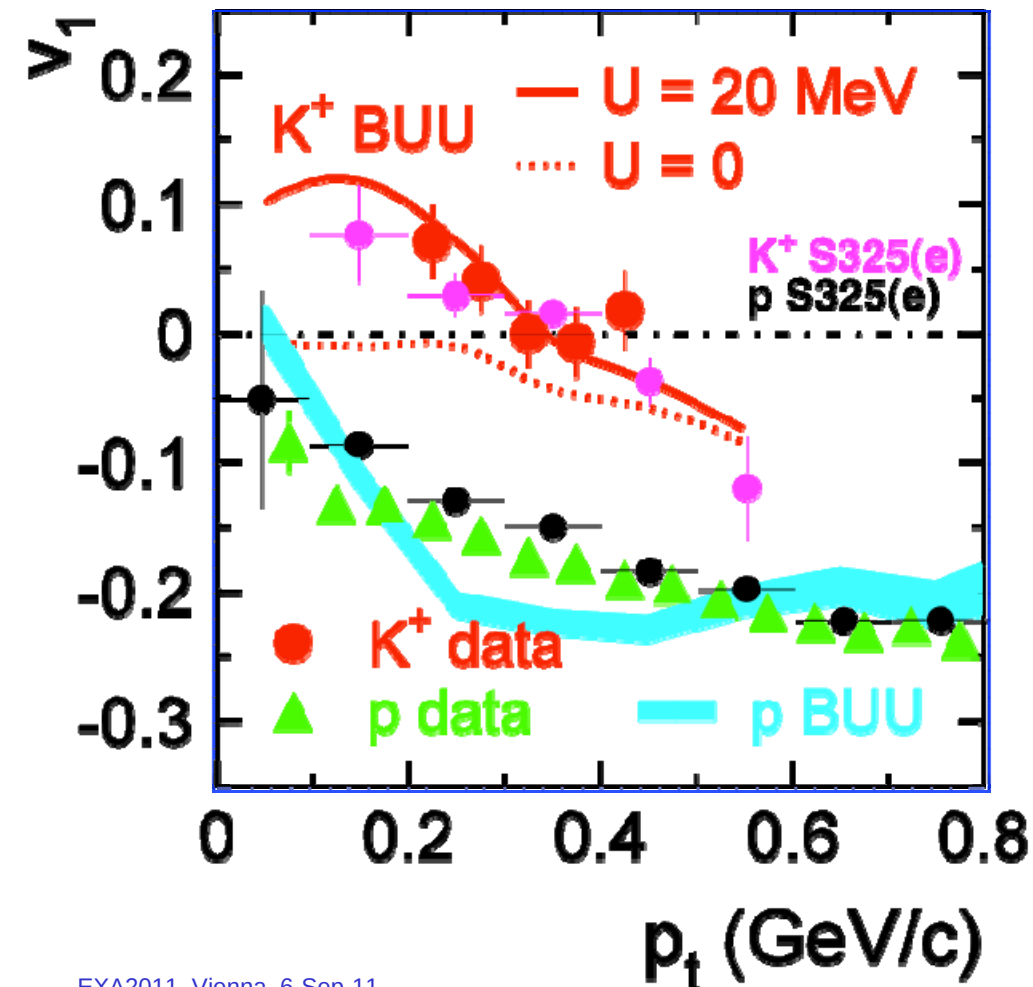
30 supermodules,
150 counters,
4500 electronic channels,
6 m² active area

kaon identification





Differential sideflow of K^+ in central collisions



New data are consistent with earlier data
in range $-1.2 < y^{(0)} < -0.65$,

$\sigma_{\text{geo}} = 200 \text{ mb}$

P.Crochet et al., PLB 486, 6 (2000)

Former conclusion:

Data favor the presence of repulsive potential

$U(\rho = \rho_0) = 20 \text{ MeV}$



Flow of charged kaons



Ni+Ni at 1.91 AGeV
(S325 + S325e data)

$\sigma = 1.5 \text{ b}$

$b_{\text{geo}} = 7 \text{ fm}$

Models with FOPI
acceptance filter

Potentials with linear
density dependence.

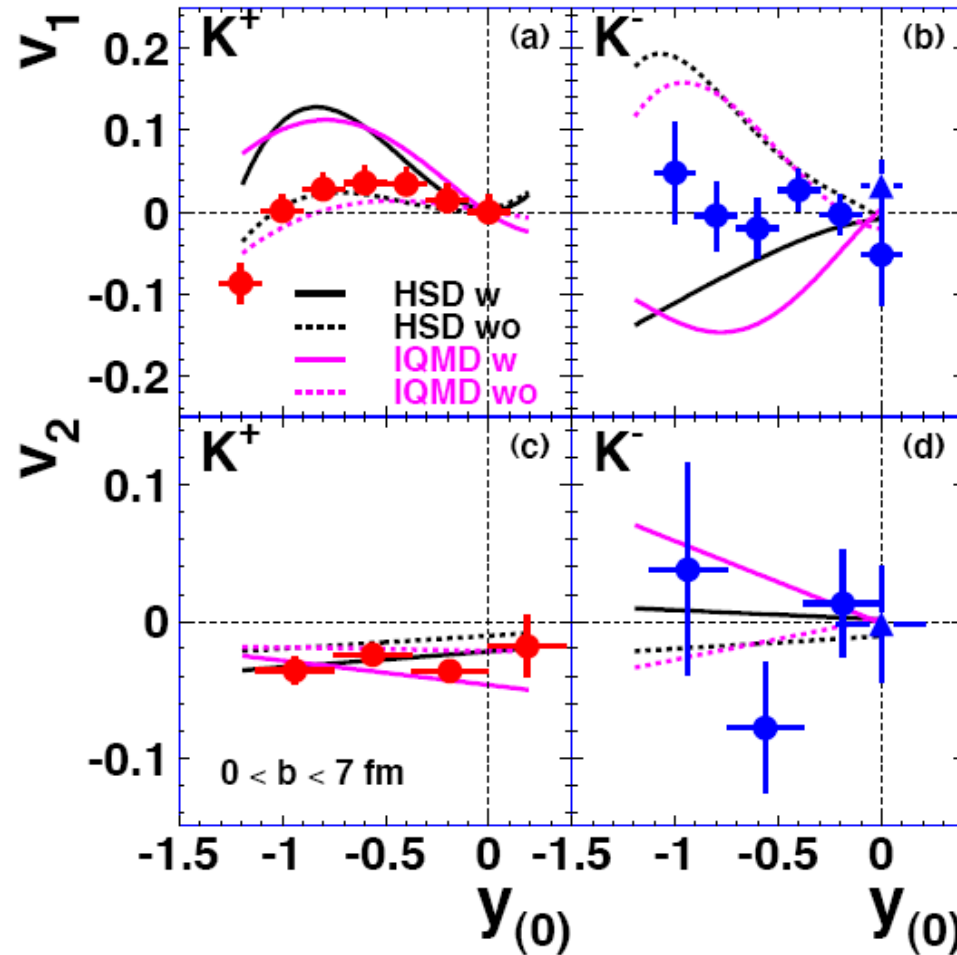
At $\rho = \rho_0$:

$U_{\text{HSD}}(K^+) = 20 \text{ MeV}$

$U_{\text{IQMD}}(K^+) = 40 \text{ MeV}$

$U_{\text{HSD}}(K^-) = 50 \text{ MeV}$

$U_{\text{IQMD}}(K^-) = 90 \text{ MeV}$



T.I.Kang, V.Zinyuk

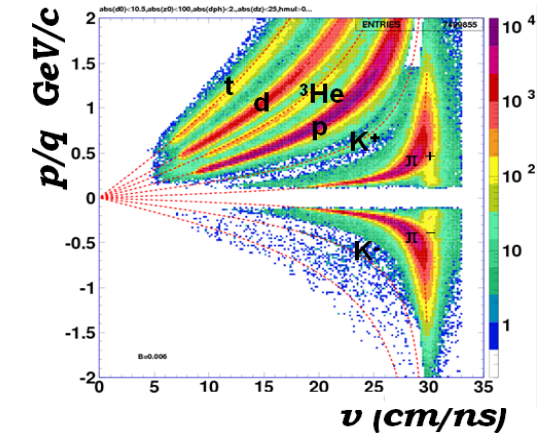
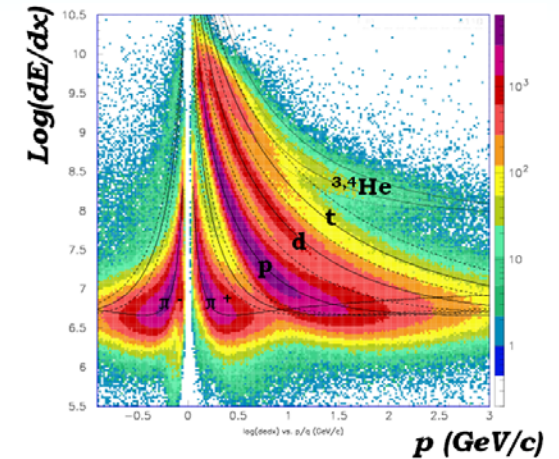
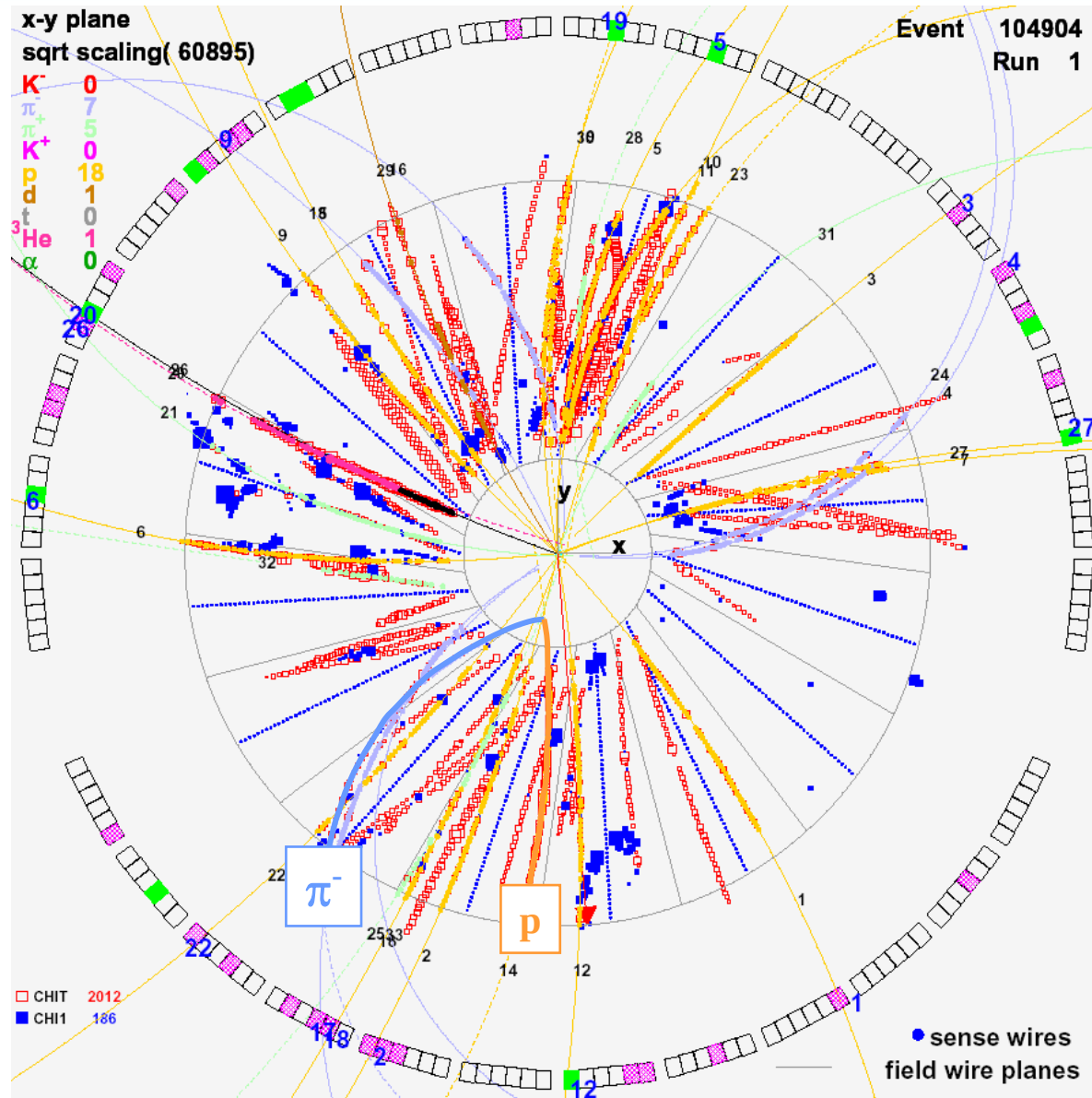
K^+ sideflow much smaller than expectation from model calculations.
 K^- sideflow compatible with zero, in variance with model expectations.
 K^+ - elliptic flow negativ $\rightarrow$ out of plane emission
 K^- - elliptic flow consistent with zero.



Detection / Reconstruction Method



Ni+Ni @ 1.93 AGeV



Analyze $\Lambda - X$ correlations
 $X = \pi, p, d, t, h, \dots$

X originating from primary vertex

Λ from off-vertex $p-\pi^-$ pairs



Reconstruction of short lived resonances in HI collisions



Subthreshold production

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

$$\rightarrow p + \pi^- + \pi$$

$$\Gamma = 39.4 \text{ MeV}$$

$$c\tau = 5 \text{ fm}$$

$$E_{NN}^{\text{thr}} = 2.33 \text{ GeV}$$

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

$$\Gamma = 50.7 \text{ MeV}$$

$$c\tau = 4 \text{ fm}$$

$$E_{NN}^{\text{thr}} = 2.75 \text{ GeV}$$

Exp. Conditions:

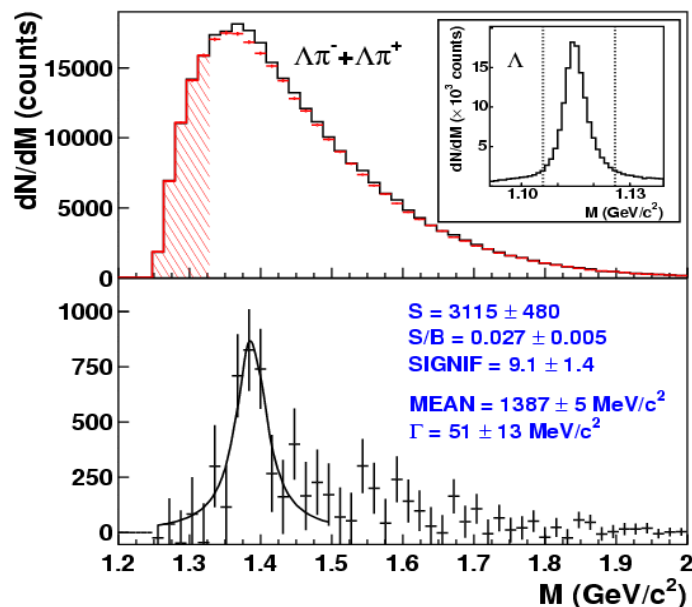
Al+Al at 1.92 AGeV,

21 d running (Aug 2005)

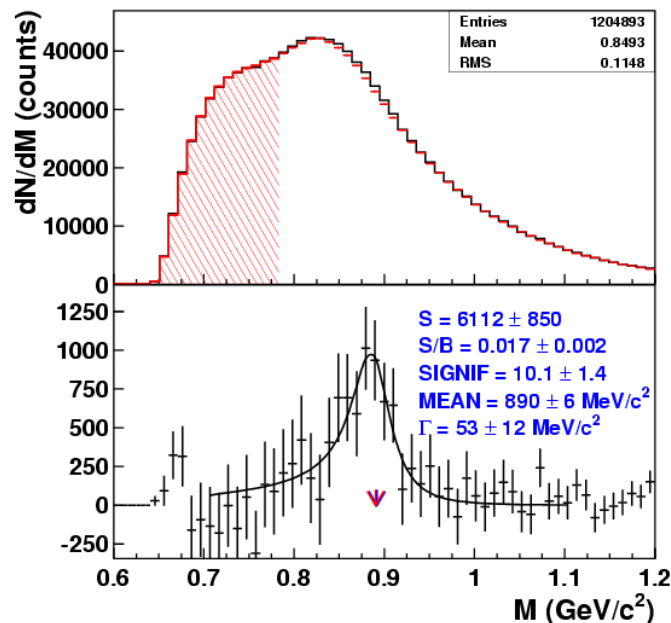
$5 \cdot 10^8$ recorded events

10 TByte raw data

X. Lopez et al. (FOPI), PRC 76, 052203(R) (2007)



X. Lopez et al. (FOPI), PRC 81, 061902 (2010)



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

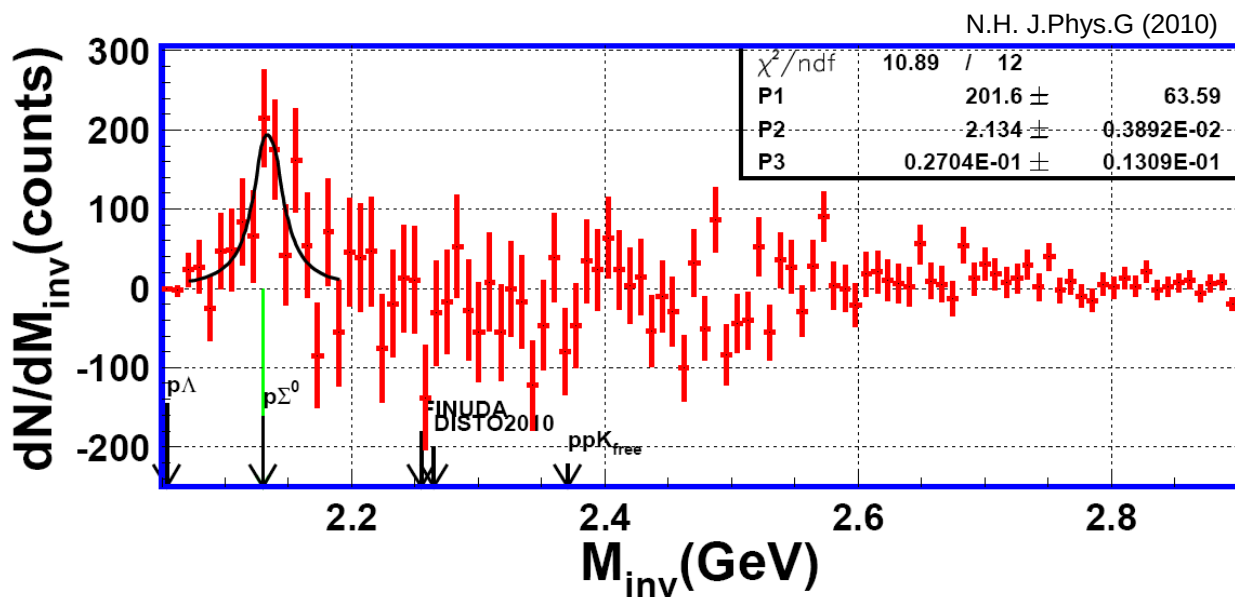
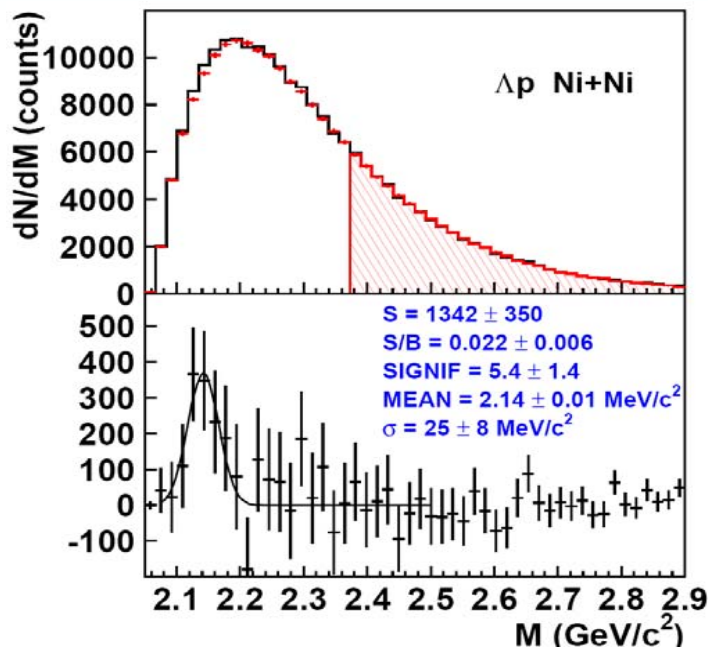
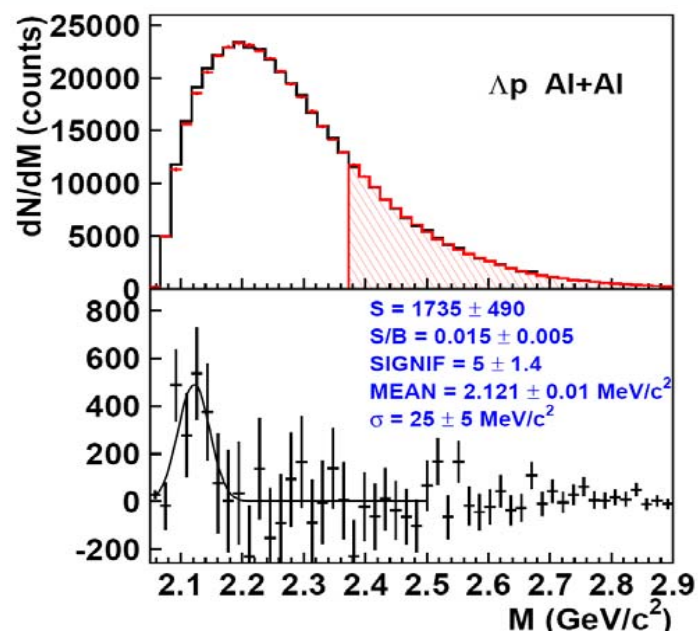
FOPIs reconstruction method and background construction works for wide resonances.

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



Δp – correlation

X.Lopez, HYP2006



$M = 2.134 \pm 0.004 \text{ GeV}$
 $\Gamma = 26 \pm 14 \text{ MeV}$
 (statistical errors)



Δp – Interpretation?

Cusp (?) in pp – reactions:

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

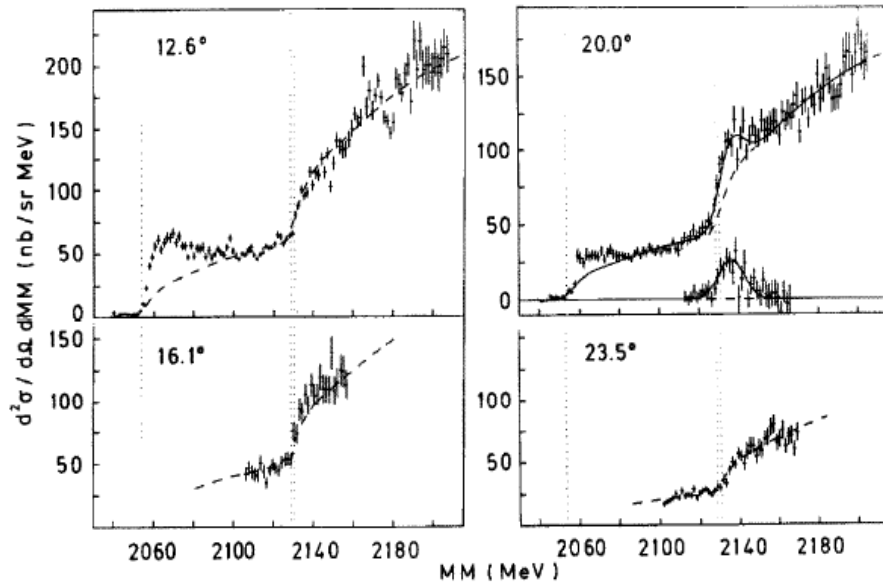
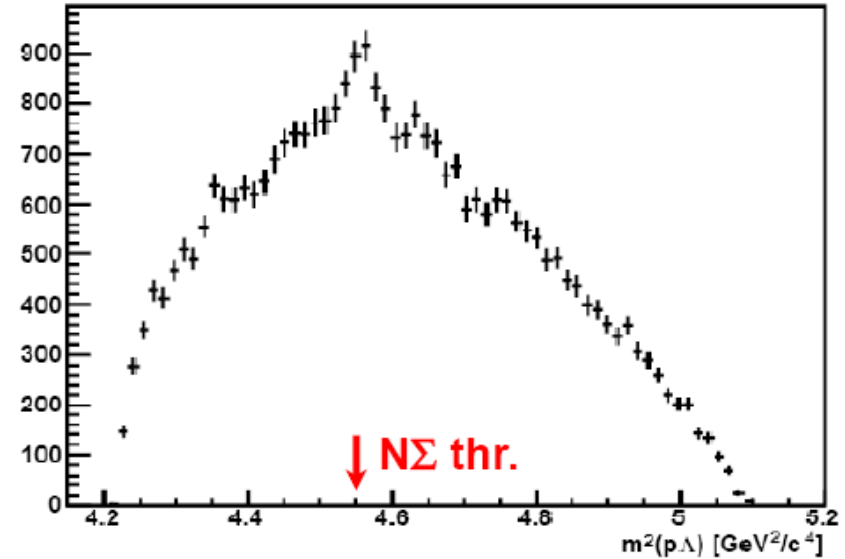


Fig. 6. Inclusive missing mass spectra for $pp \rightarrow K^+X$ at 2.7 GeV incident energy. The kaon laboratory scattering angles are 12.6°, 16.1°, 20.0° and 23.5°. The bins are 1.5 MeV wide. The resolutions (FWHM) are approximately 3 MeV (12.6°), 4 MeV (16.1°), 3.5 MeV (20.0°) and 5 MeV (23.5°). The 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.

COSY TOF @ 2.95 GeV/c

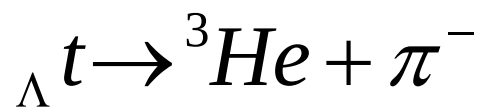
A. Gillitzer, LEANNIS – meeting 2011 (prel.)



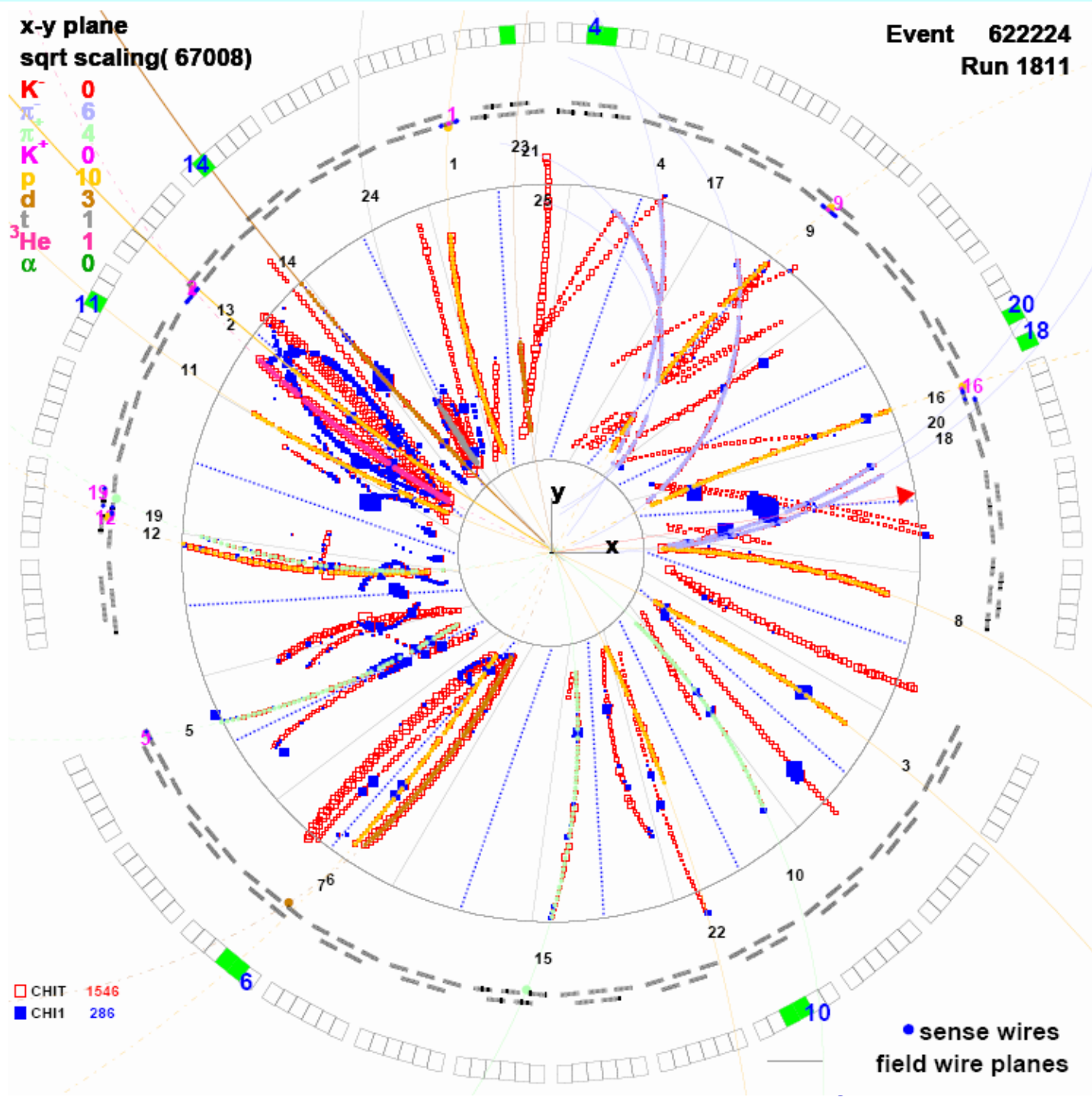
Can cusp survive in HI – final state?
Final state interaction (FSI)?
Are there cusps or FSI in Λd final state?



Λ candidate event



Event 622224
Run 1811



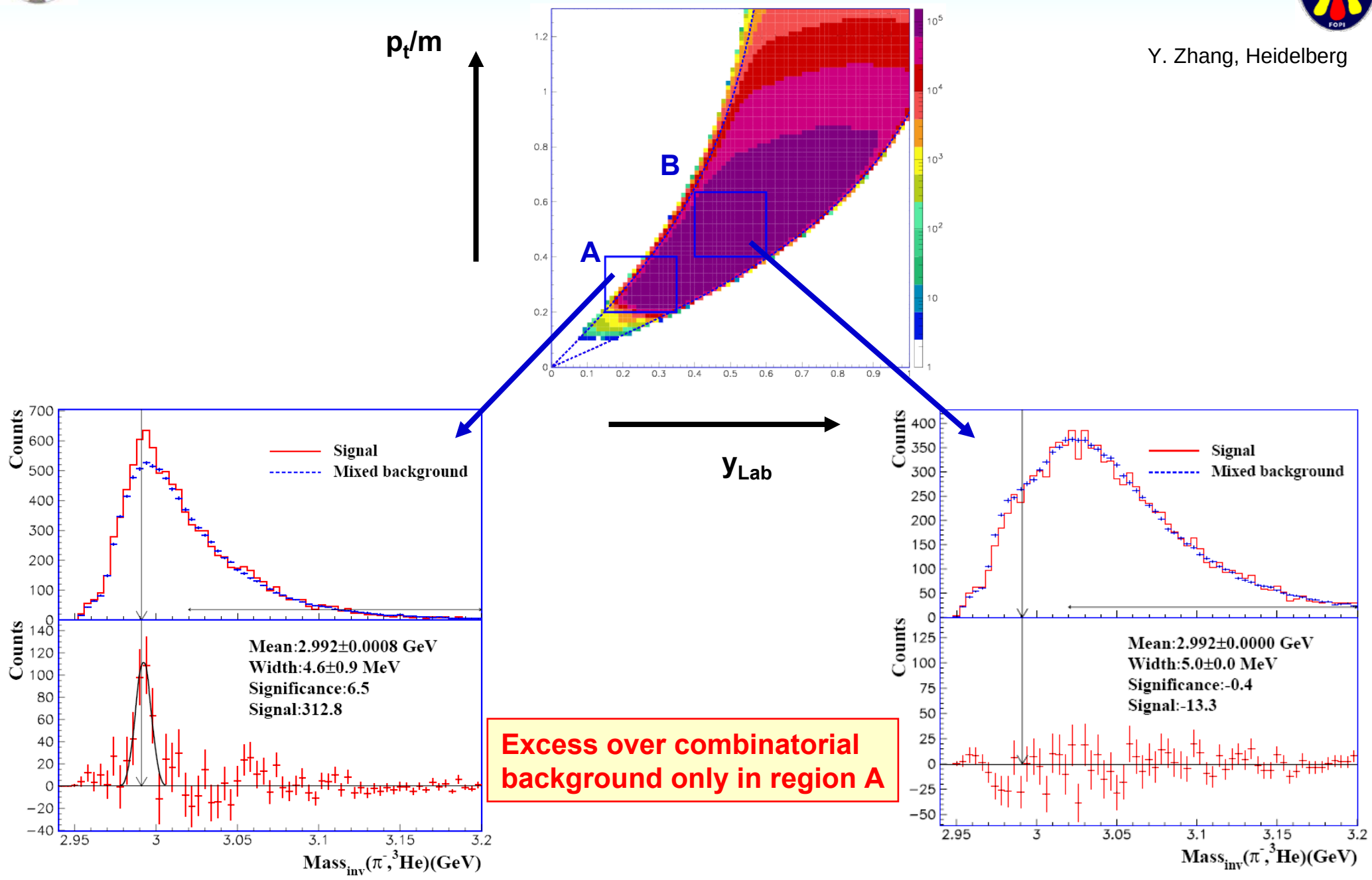
Matching with
RPC – barrel
essential for
 ${}^3\text{He}$ - identification



Hypertriton production in Ni+Ni (S325e)



Y. Zhang, Heidelberg





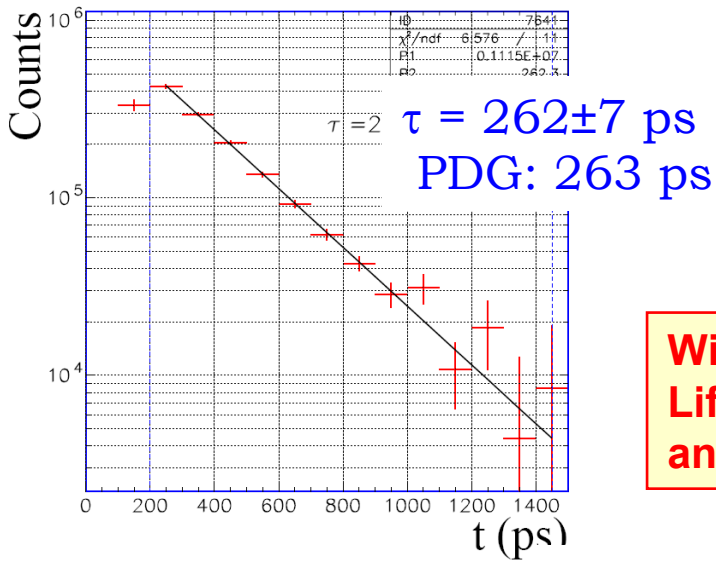
Lifetime of Λ and ${}^3_\Lambda\text{H}$



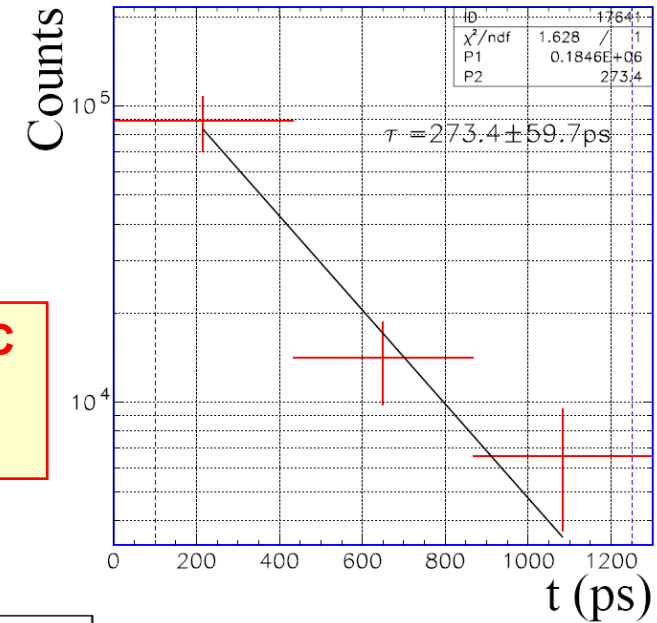
Y. Zhang, Heidelberg

$$N = N_0 e^{-t/\tau}, \quad t = r_s / (\beta\gamma)_T = r_s / (p_t / m)$$

Λ - baryon

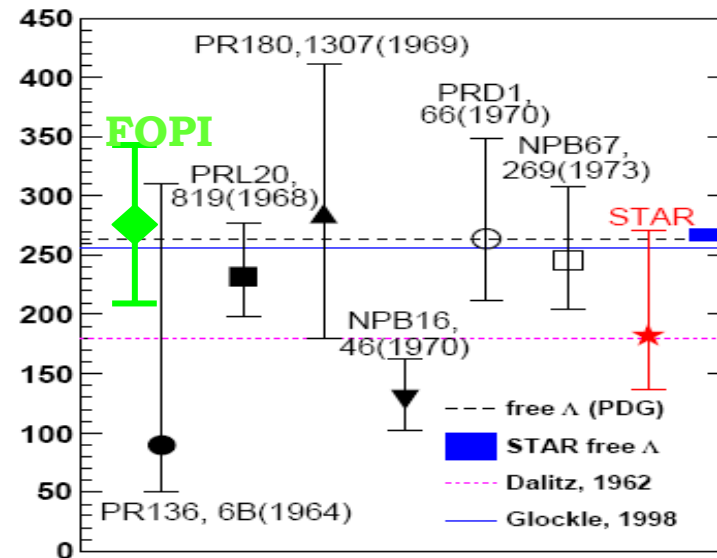


hypertriton



With efficiencies from FOPI MC
Lifetimes agree with PDG (Λ)
and world data (${}^3_\Lambda\text{H}$).

${}^3_\Lambda\text{H}$ lifetime (ps)



arXiv:1003.2030 [nucl-ex] (Star – collaboration)

N.Herrmann, Univ. Heidelberg



Particle yields and production mechanism

Ni + Ni @ 1.93 AGeV (S325e)



Efficiency corrected yield ratios:

	Region A	Region B
$\Lambda t^3\text{He}$	0.010 +/- 0.002	-0.0012 +/- 0.002
$t^3\text{He}$	1.45 +/- 0.01	0.93 +/- 0.01
Λ/d	0.0046 +/- 0.0005	0.0138 +/- 0.0005

Particle ratios incompatible with

- Thermal model
- Coalescence hypothesis



Are there other light hypernuclei in the data sample?

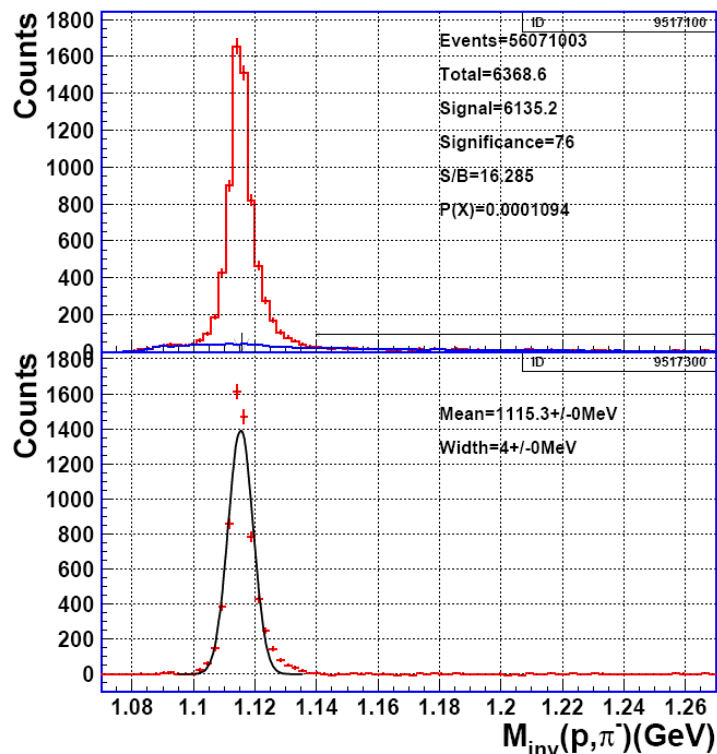
Ni + Ni @ 1.93 AGeV (S325e)



$p+\pi^-$

S325e,03t

2011/06/28 22.05

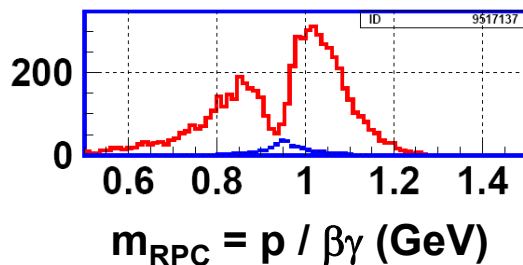
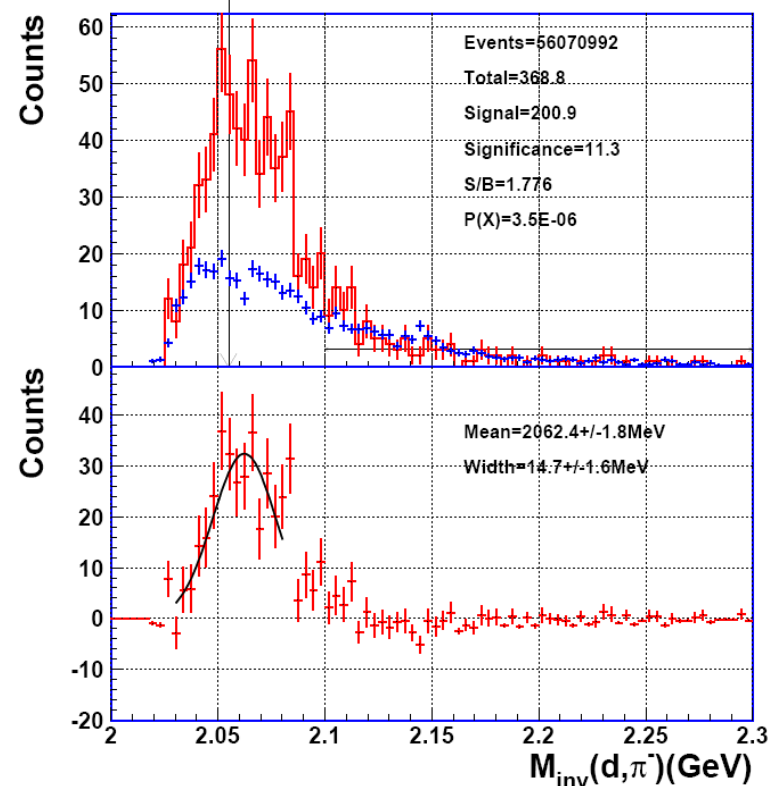


RPC acceptance

$d+\pi^-$

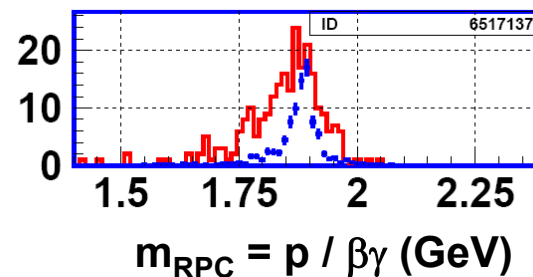
S325e,03t

2011/09/04 08.48



Same cuts except for mass !

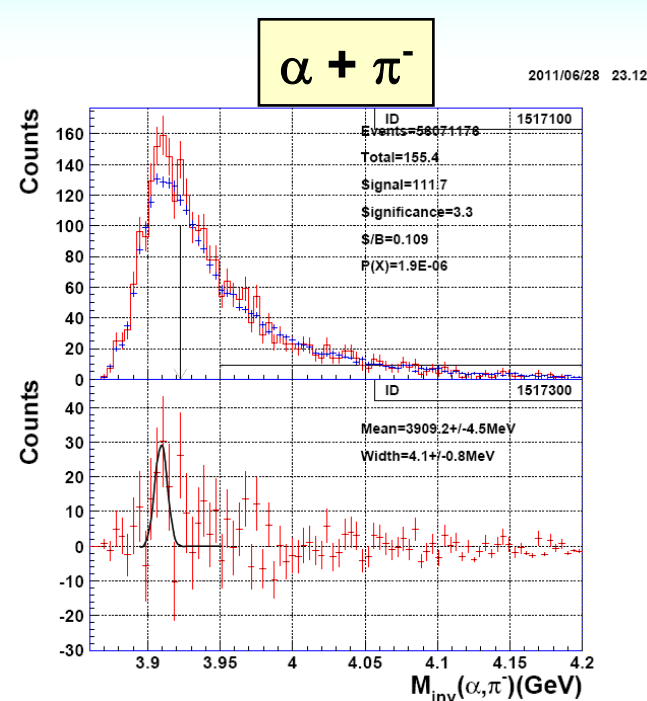
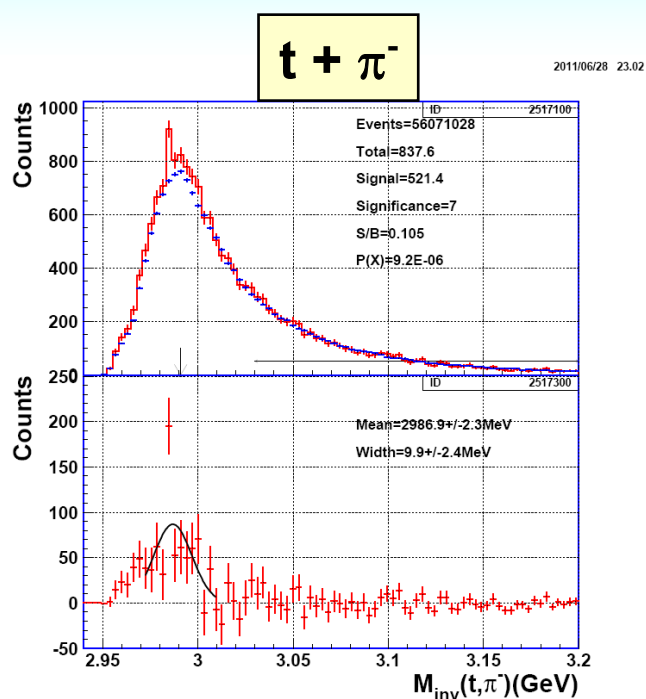
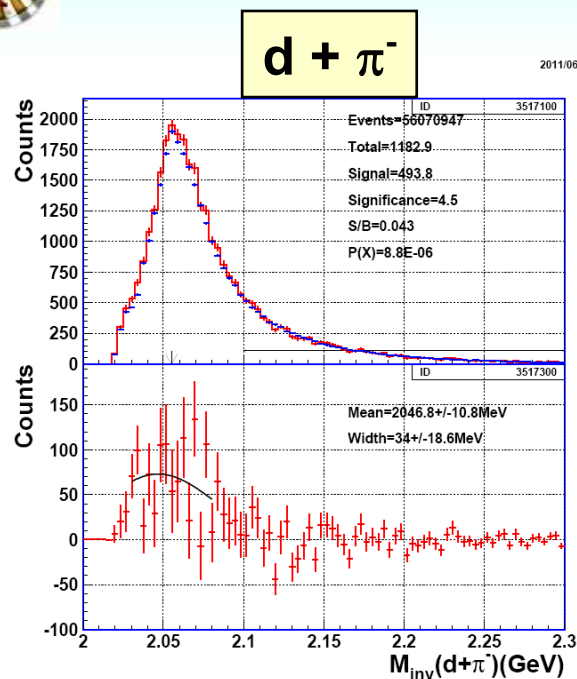
Clear excess observed for $d\pi^-$,
Width too large for bound state,
Evidence for 3-body decays
of heavier hypernuclei





$X + \pi^-$ - correlations in region A

'hyp' - selection cuts



**Yield excess observed in all cases.
-> 3 body decay contributions?**

$${}^3_{\Lambda}H \rightarrow \begin{cases} \pi^- + {}^3\text{He} & (35\%) \\ \pi^- + p + d & (55\%) \end{cases}$$

$${}^4_{\Lambda}H \rightarrow \begin{cases} \pi^- + p + t & (84\%) \\ \pi^- + d + d & (16\%) \end{cases}$$

$${}^4_{\Lambda}\text{He} \rightarrow \begin{cases} \pi^- + p + {}^3\text{He} & (85\%) \\ \pi^- + p + p + d & (15\%) \end{cases}$$

$${}^5_{\Lambda}\text{He} \rightarrow \begin{cases} \pi^- + p + \alpha & (97\%) \\ \pi^- + p + p + t & (1\%) \\ \pi^- + d + {}^3\text{He} & (2\%) \end{cases}$$

Exp. observed decays

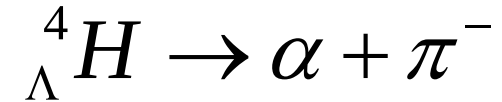
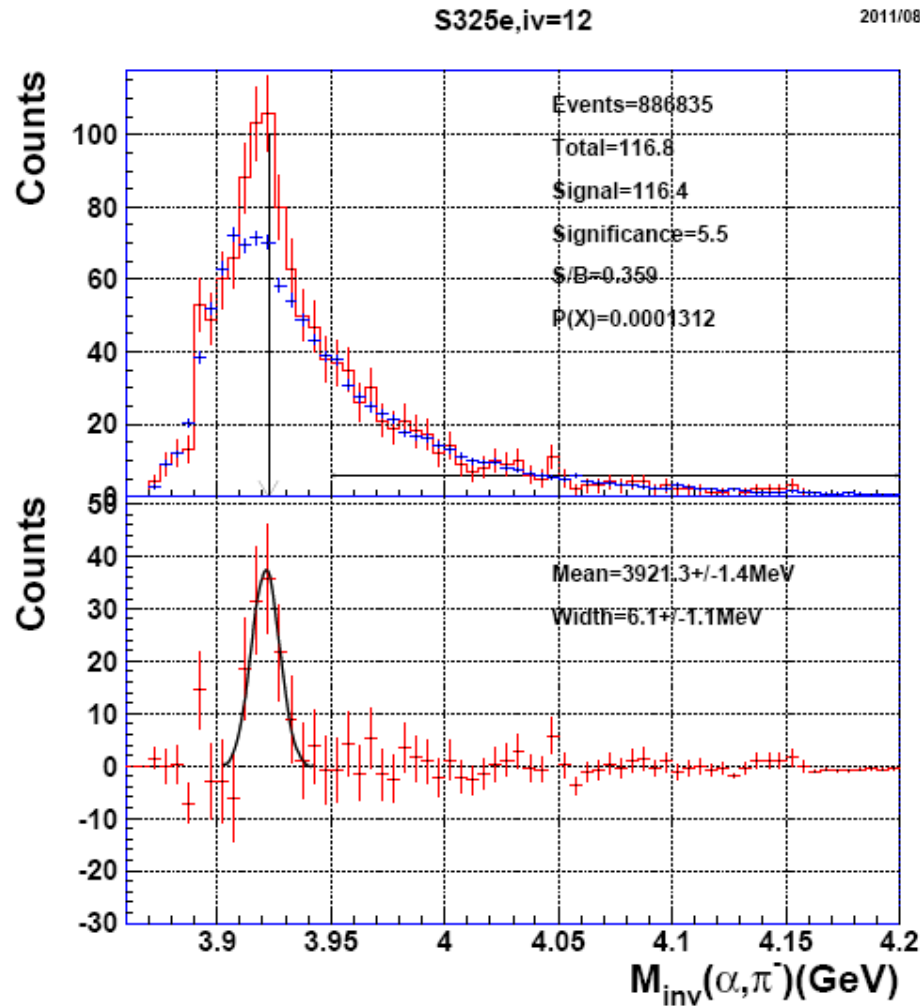
**Emulsion experiment
(stopped K^- - beam, BNL)
M.Juric et al. NPB 52,1(1973)**



Optimized selection cuts for $\alpha + \pi^-$



Ni + Ni @ 1.93 AGeV (S325e)



Reconstructed mass agrees with world data:

$$M({}_{\Lambda}^4H) = 3922.6 \text{ MeV}$$

Lifetime is Λ – like.

Optimization:

- centrality
- vertex quality
- event cleanliness

Work in progress ...

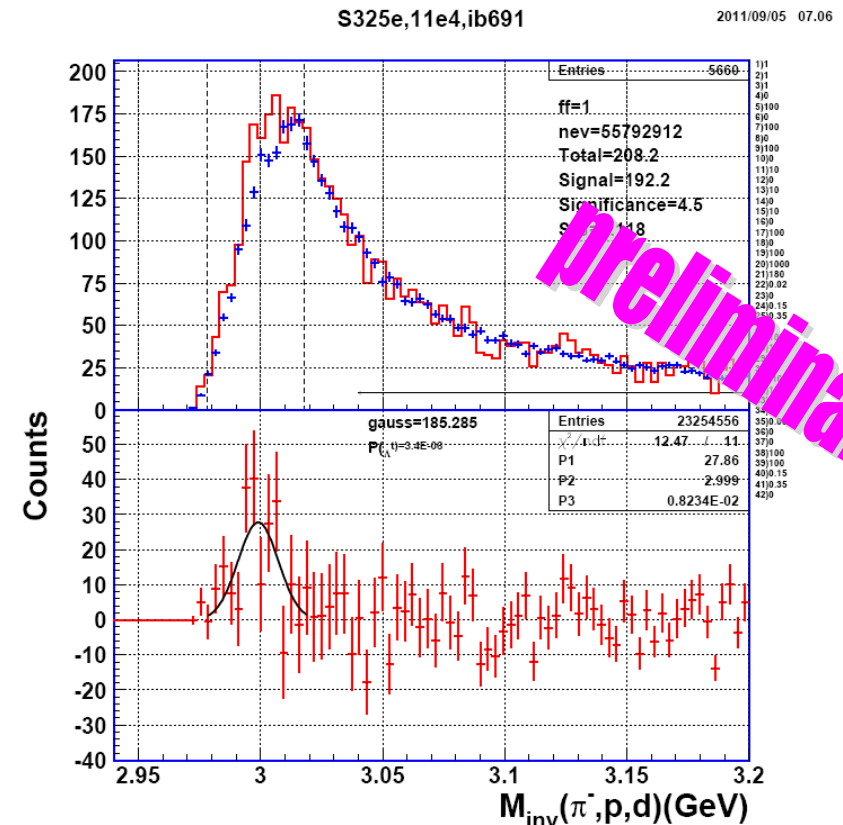
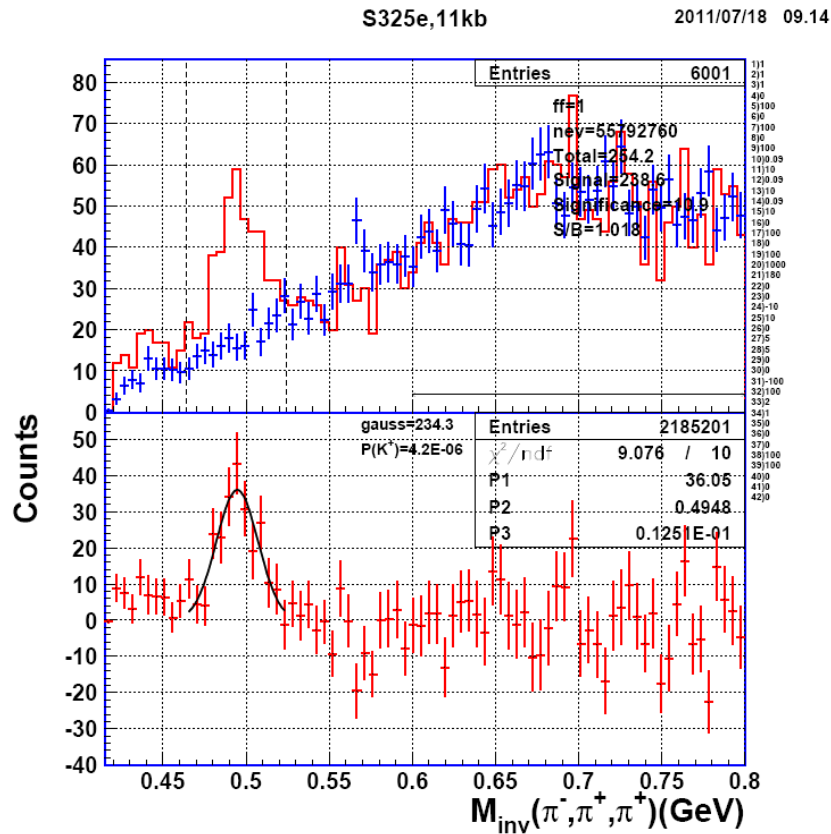


3 – body – reconstruction

Ni + Ni @ 1.93 AGeV (S325e)

Test case: $K^+ \rightarrow \pi^- + \pi^+ + \pi^+$ (5.6 %)

Application: $\Lambda^+ t \rightarrow \pi^- + p + d$





Summary / Conclusion



FOPI RPC TOF barrel operational with $\sigma_{t,\text{system}} \sim 90$ ps.

Calibration is progressing for latest HI – runs (~30 Tbyte).

Current analysis status

- **First measurement of K^- sideflow,
First measurement of K^+ sideflow over large centrality range,
Results are in variance with theoretical expectations.**
- **Evidence for hypertriton production in HI reactions at SIS18.**
- **Evidence for other light hypernuclei,
Reconstruction of 3-body weakly decaying final states necessary.**

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

Serious theoretical effort necessary to interpret available (e.g. Λp) and coming data.

**LoI for new experiment at SIS18 aiming at double strange clusters
using FAIR prototype developments (e.g. GEM – TPC) in preparation.**



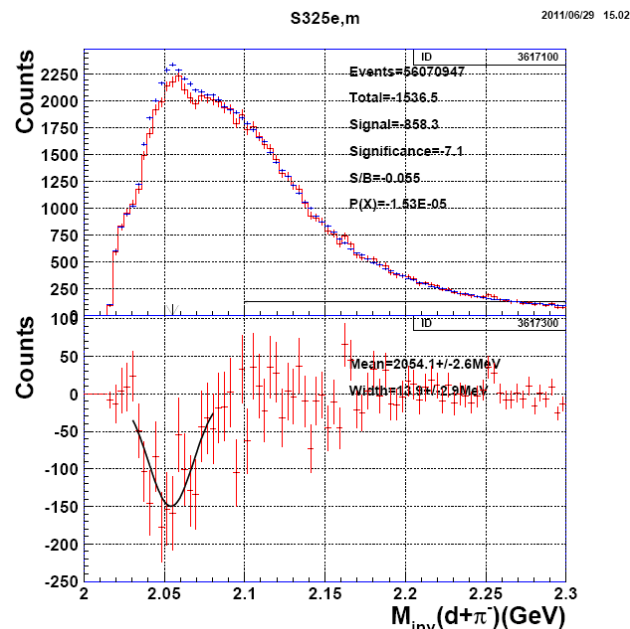


$X+\pi^-$ - correlations in region B

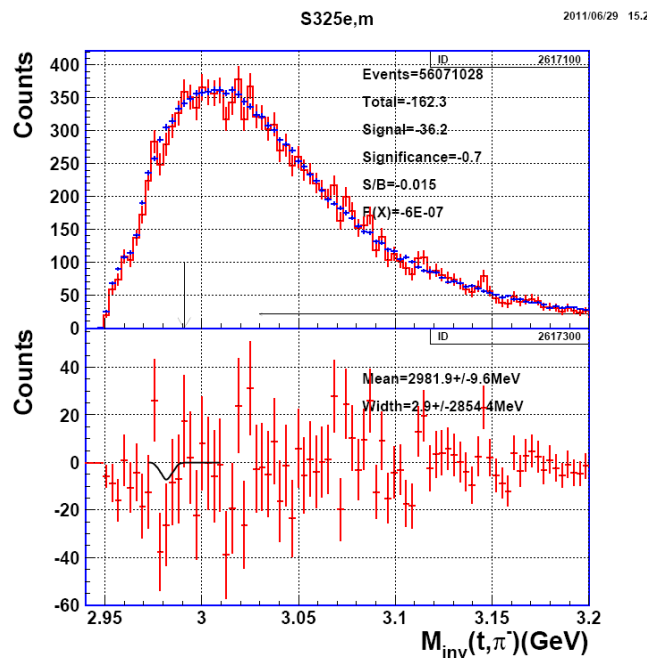
'hyp' – selection cuts

Ni + Ni @ 1.93 AGeV (S325e)

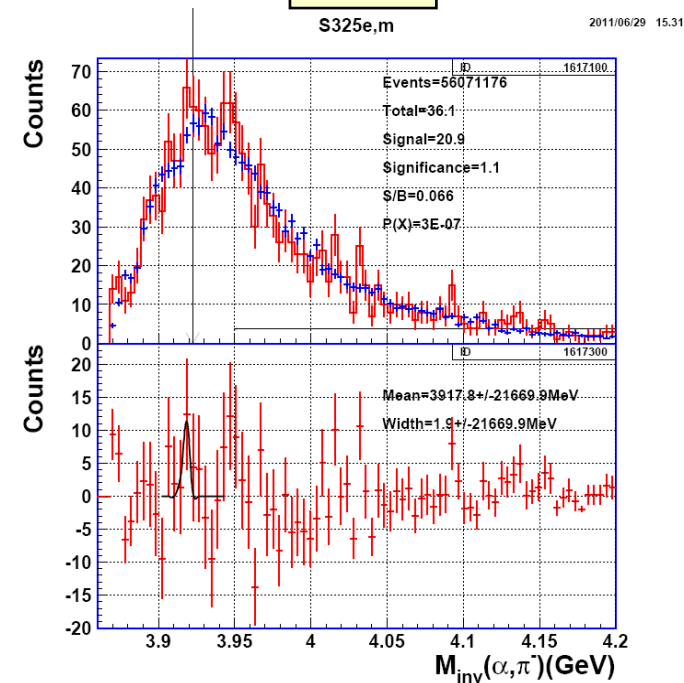
$d+\pi^-$



$t+\pi^-$



$\alpha+\pi^-$



No significant excess observed in region B.
Background not fully under control yet for $d + \pi^-$ - correlation.