Search for a ppK$^-$ bound state with FOPI

Strangeness program of FOPI

Detector

Results on bound kaonic nuclear states (incl. ppK-)

Results on hypernuclei

Summary

Strangeness program of FOPI

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, 2011)

Kaonic bound state ppK^- in

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

Systematics of strangeness data from heavy-ion reactions

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

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

Kaonic bound states

Hypernuclei

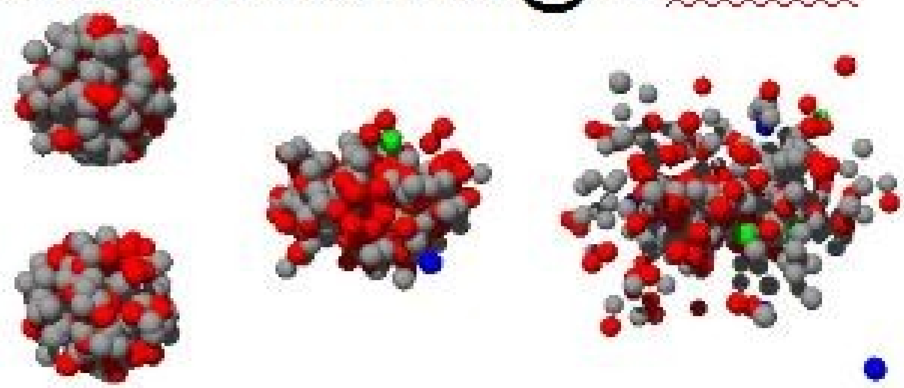
in heavy-ion reactions

Heavy-ion collisions @ SIS

Threshold energy in a fixed-target experiment

$NN \rightarrow K^{+}YN$	$E_{thr} = 1.5GeV$
$NN \rightarrow K^{+}K^{-}NN$	$E_{thr} = 2.5GeV$

Central Au+Au @ 2 AGeV



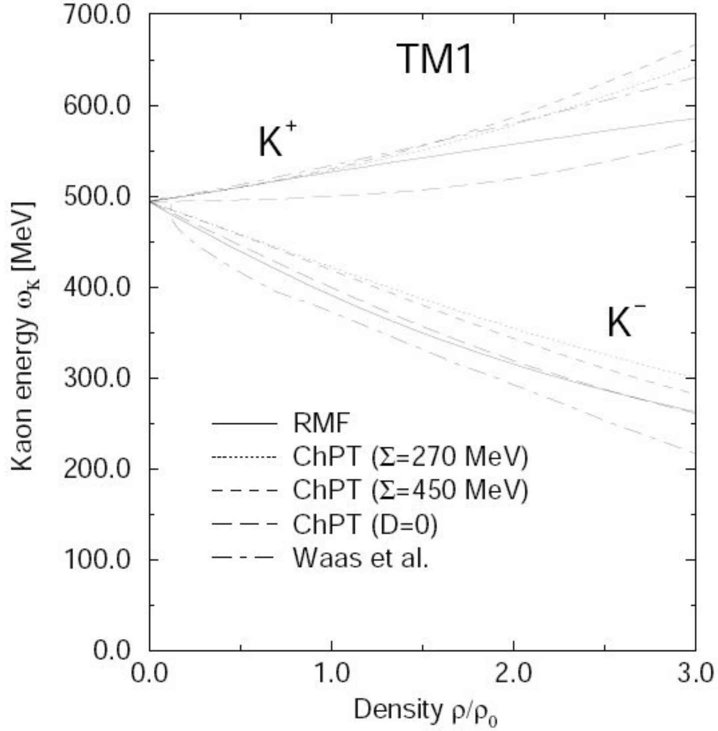
Time → 20 fm/c

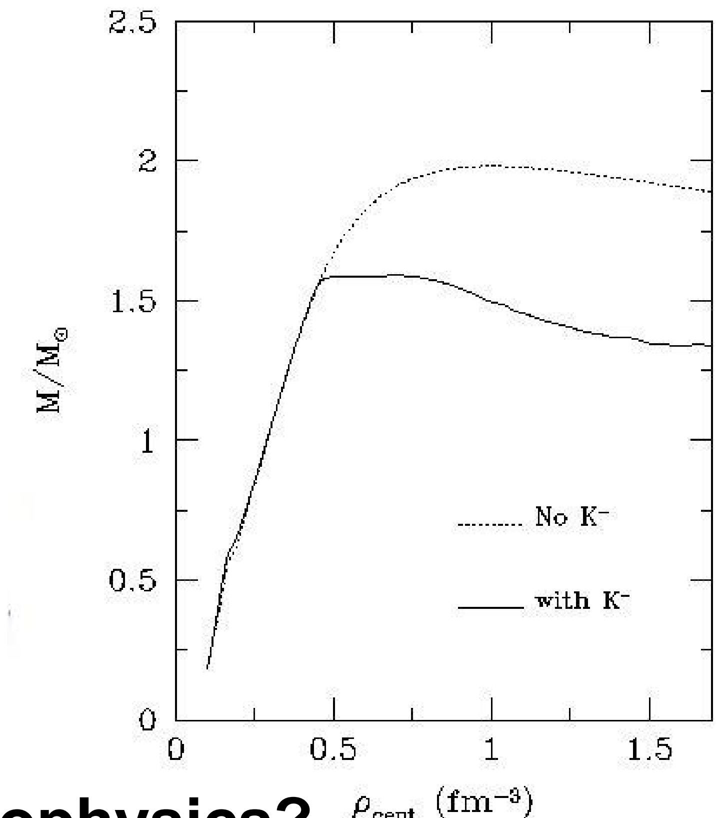
Density a few times ρ_0

Strangeness produced in the early stage

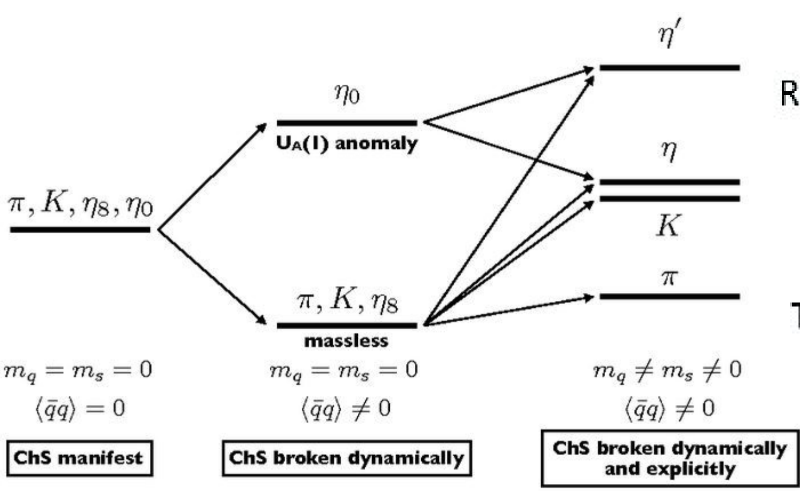
In-medium modifications

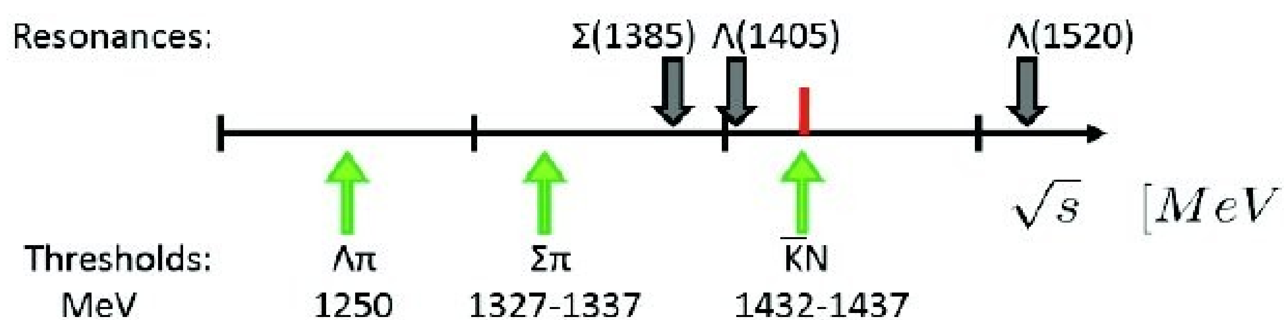
J. Schaffner et. al., PLB 334(1994) 268



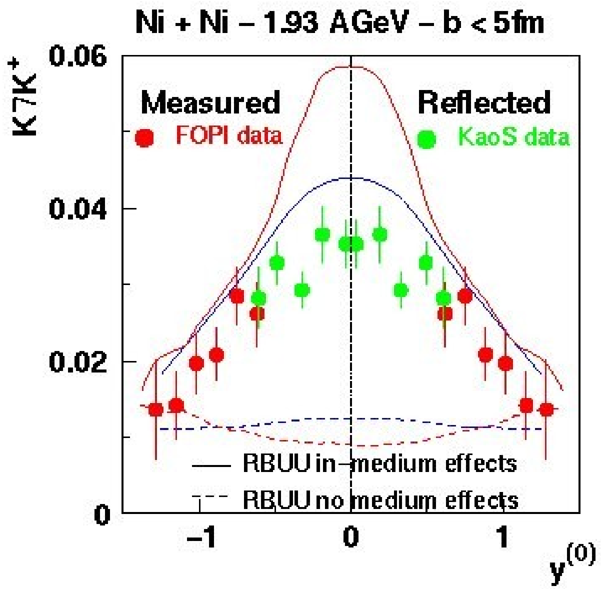


Origin and consequences for astrophysics?

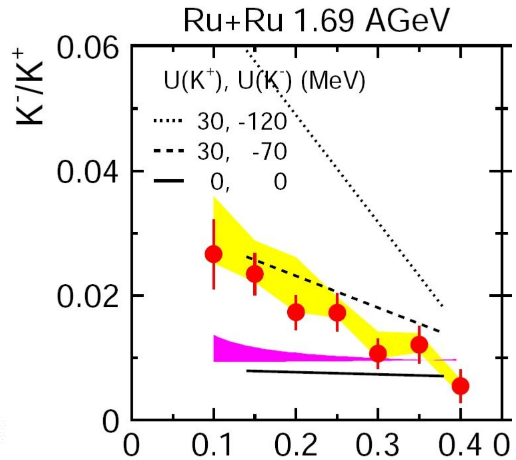


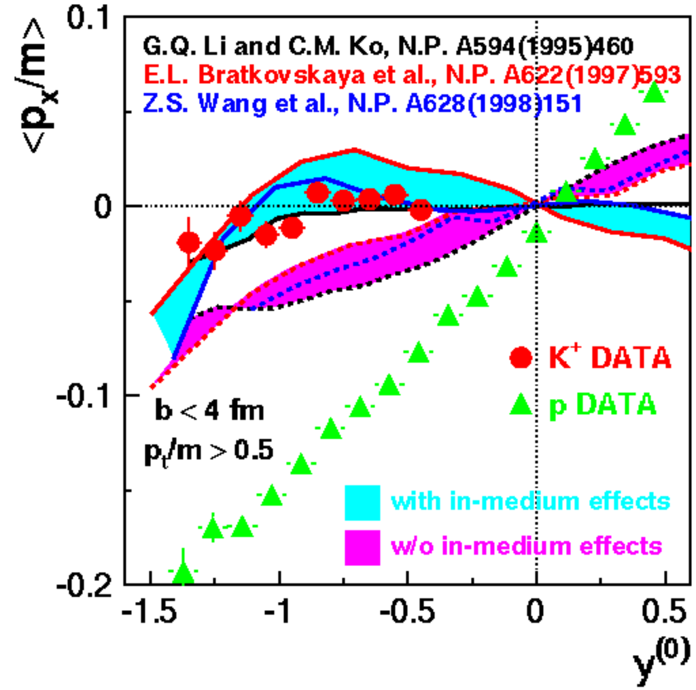


Experimental evidence

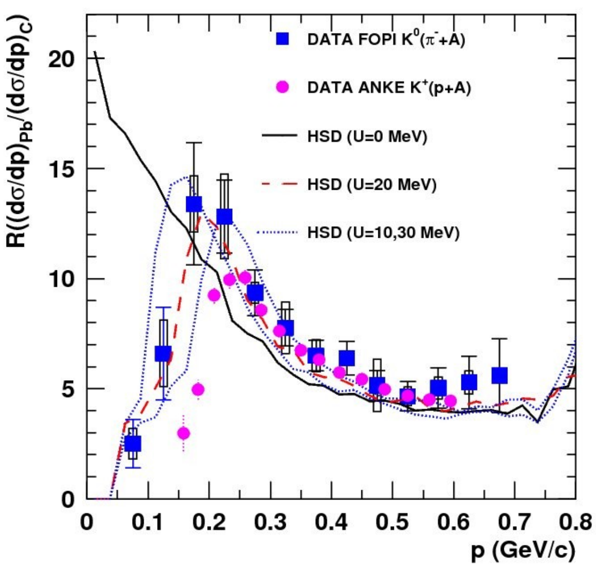


K.Wisniewski et. al.,
Eur. Phys. Journ. A 9 (2000) 515





M.L.Benabderrahmane,
PRL 102 (2009) 182501



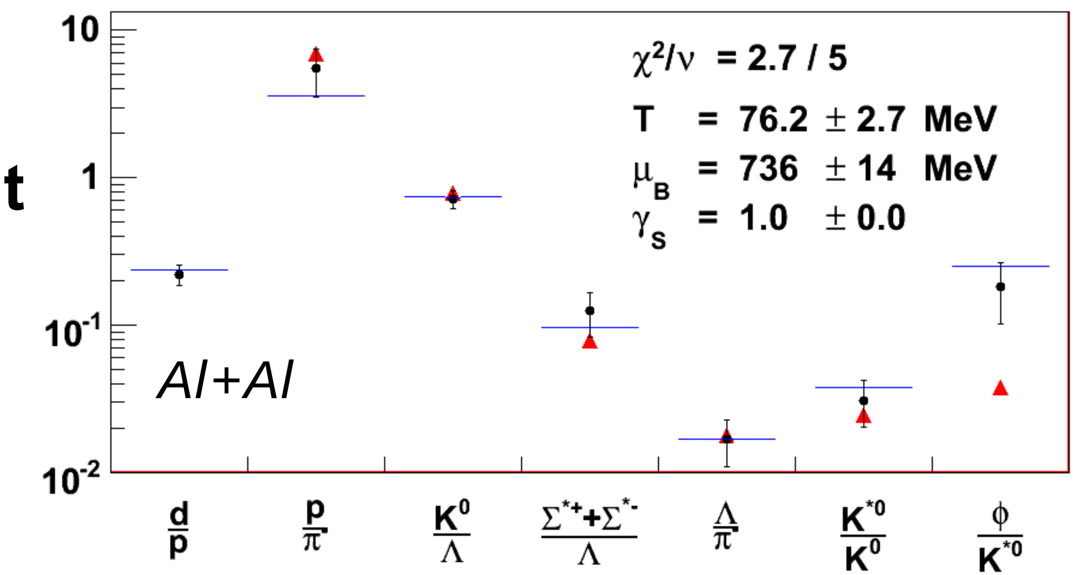
In A-A and in pion-induced

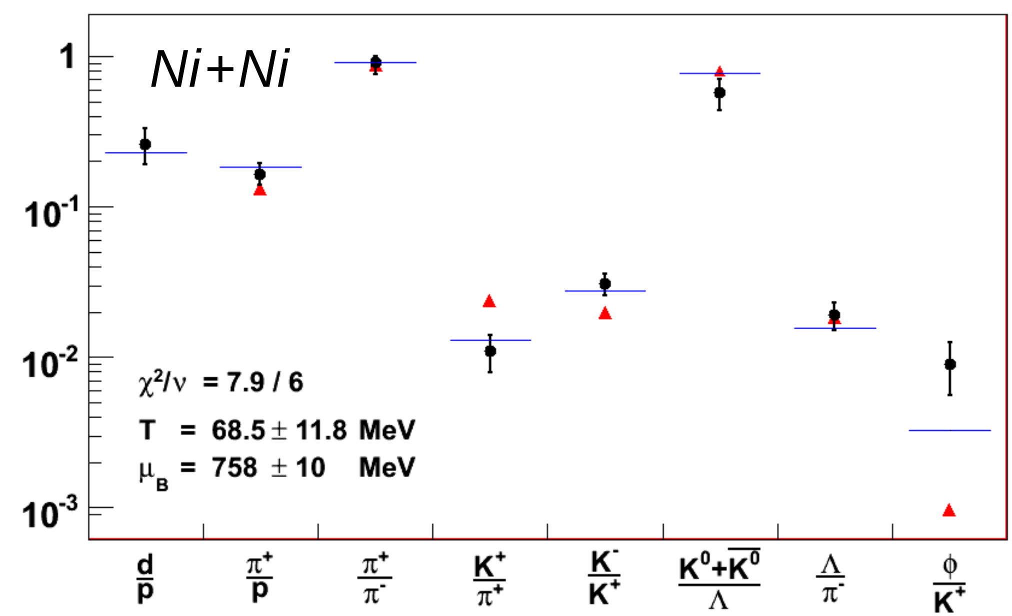
Agreement with KaoS

Yields ratios

Surprisingly good agreement
- with thermus
- and UrQMD

Few discrepancies





Problems and questions

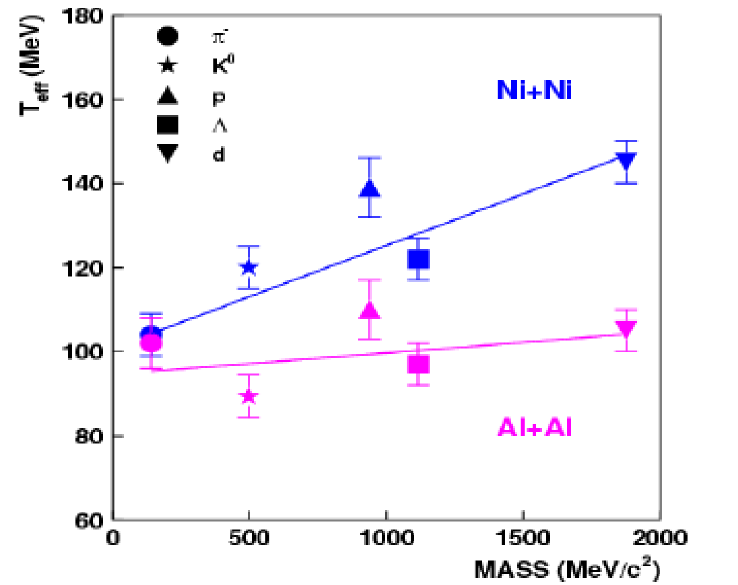
Details of flow in peripheral collisions

Rapidity and mt distributions

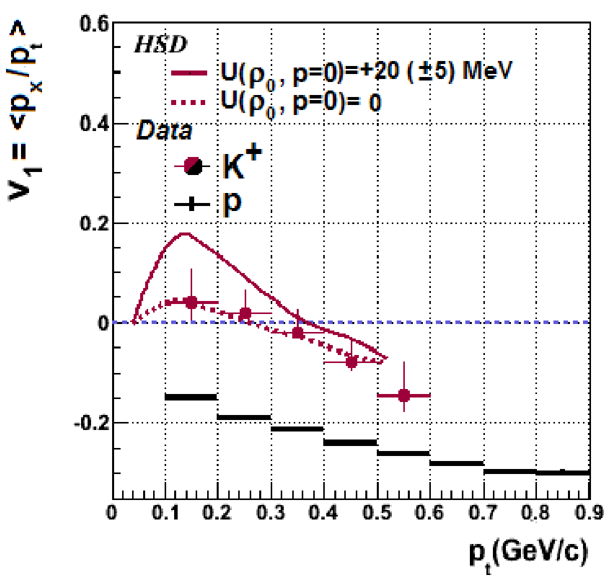
K- from Φ

Elementary cross-secions

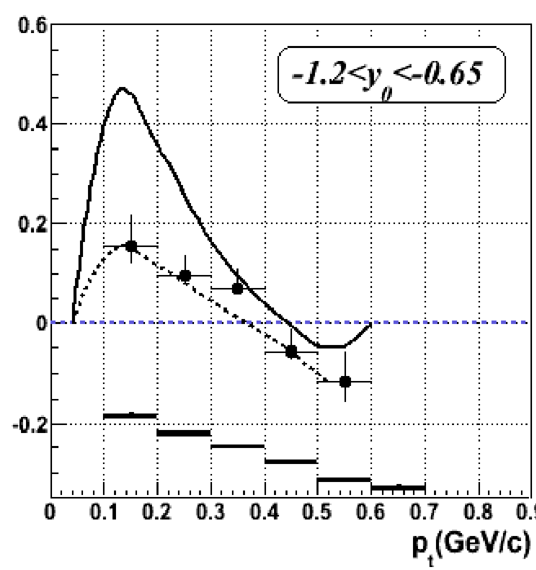
Slopes of m_t spectra at midrapidity



T_{kin} > 95 MeV > T_{chem} >75 MeV



b < 4 fm ≙ 0.2 σ_{geo}



4 fm < b < 7fm ≙ 0.2 - 0.6 σ_{geo}

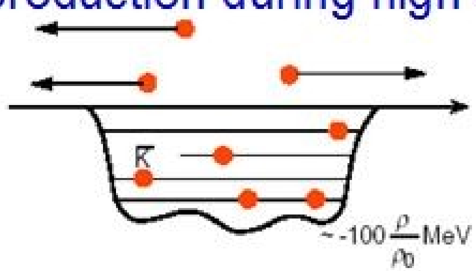
Production of kaonic bound states - theoretical speculation

- Central density in HI collisions from transport model calculations:
  $\rho_{max}=2\text{-}3 \cdot \rho_0$

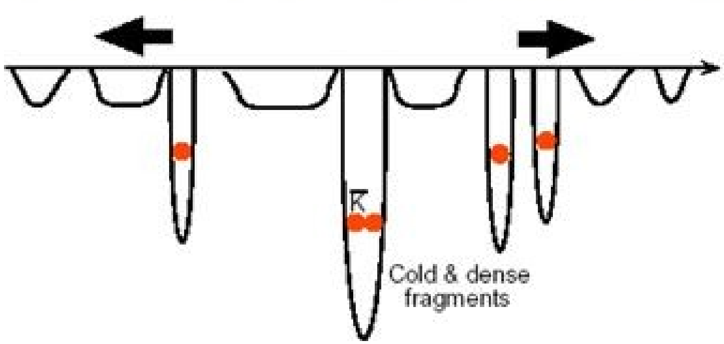
Possible mechanism for cluster formation:

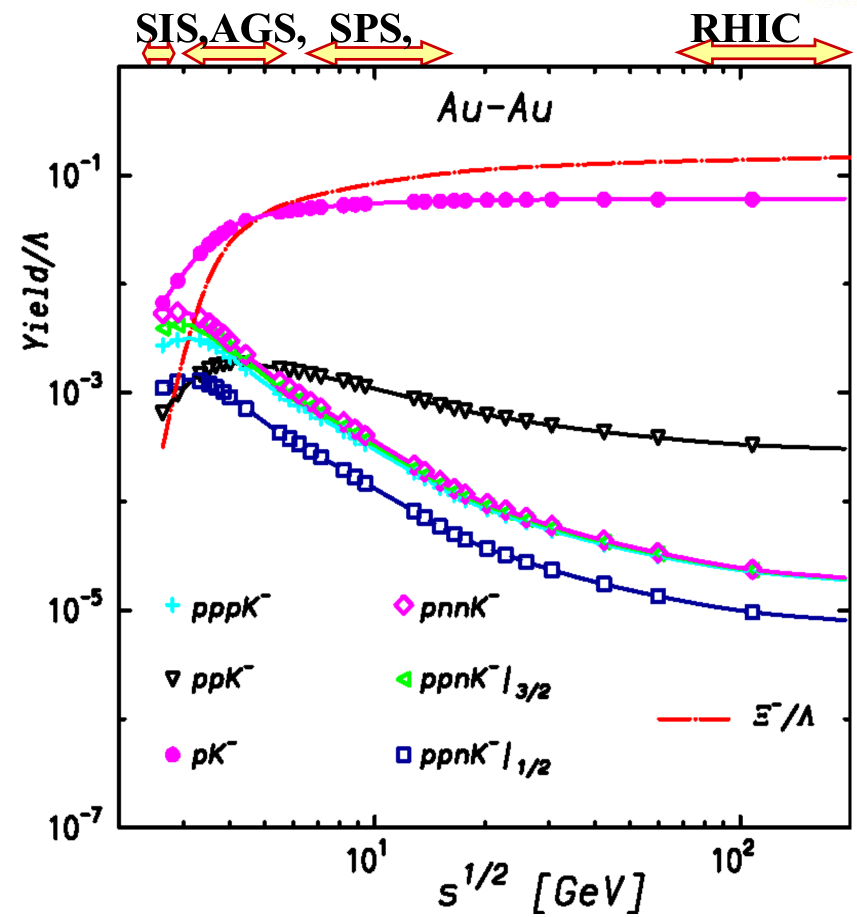
T.Yamazaki et al., NPA738,168 (2004)

1) Kaon production during high density phase



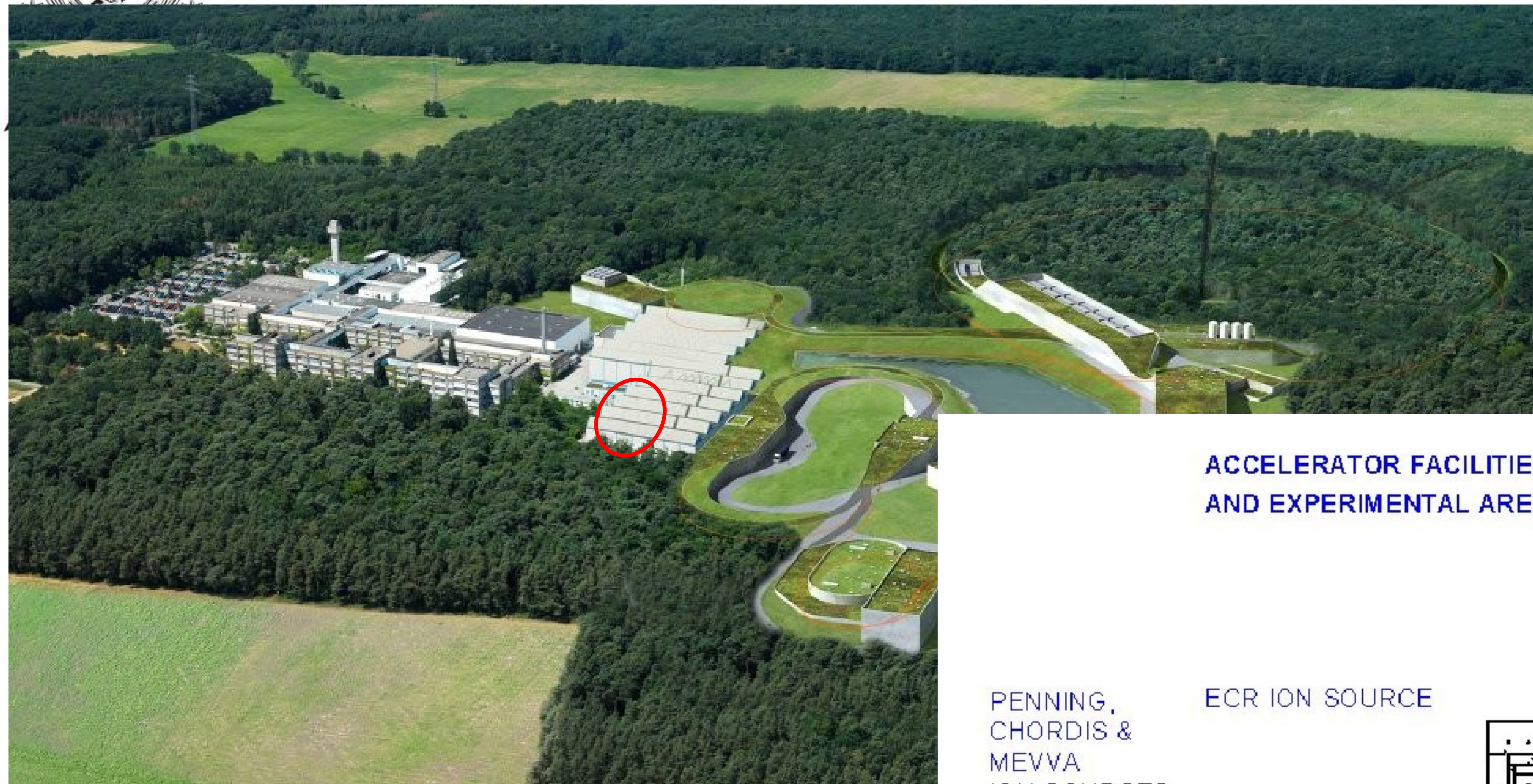
2) capture of K^- in deep trapping centers

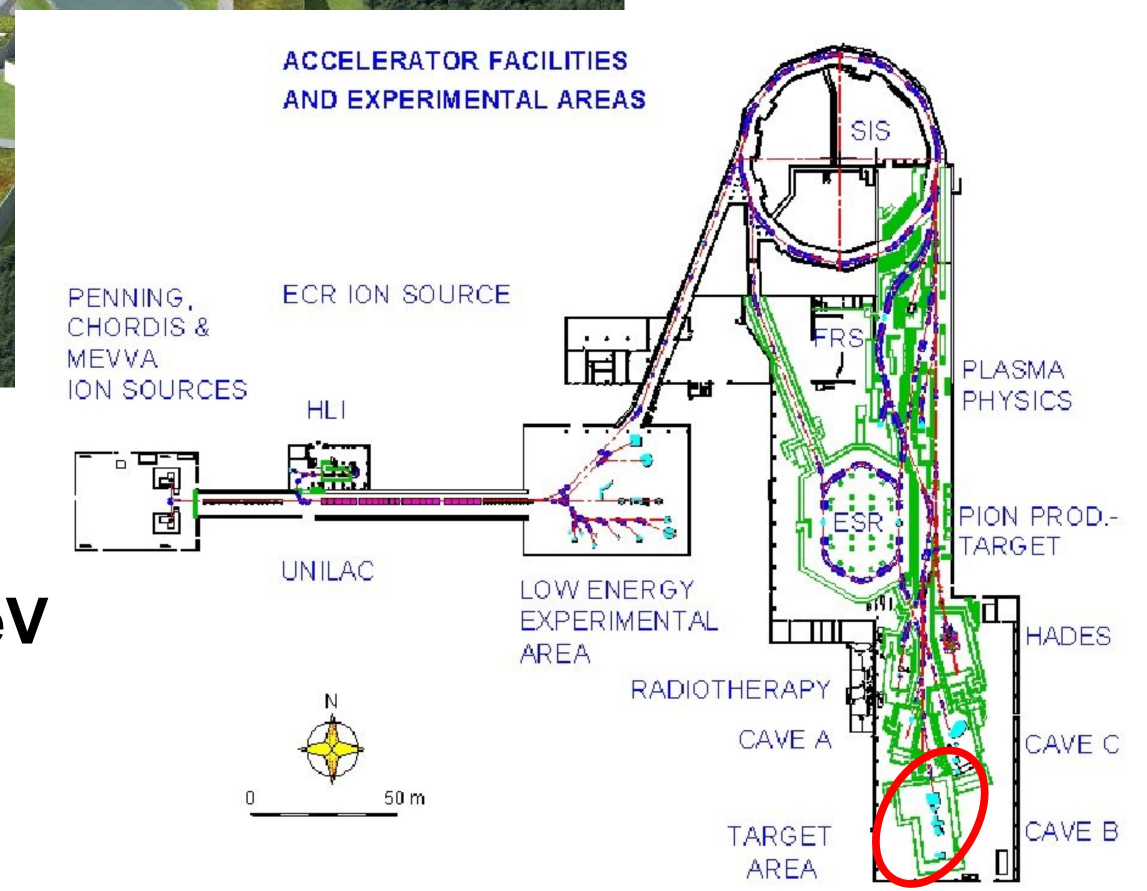




Abundance larger than Ξ^- (according to thermal model)

FOPI @ GSI

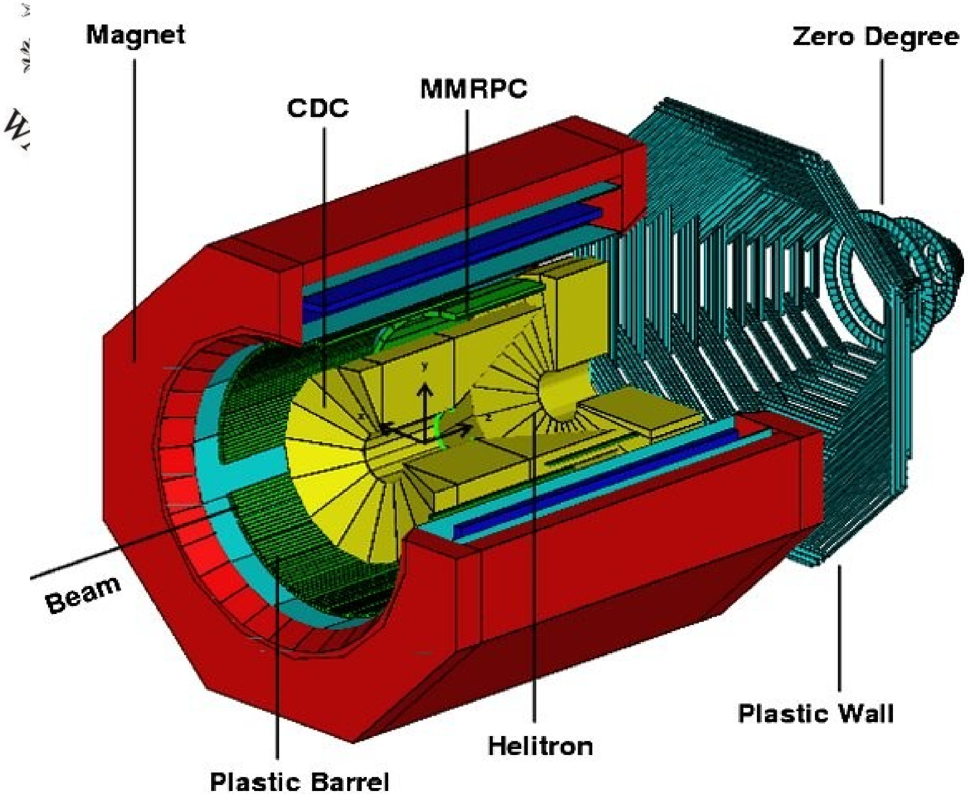




Beams C, ... , Au, p, π

Energies 100 AMeV – 3,5 AGeV

FOPI detector



General purpose

Complete azimuthal symmetry, large acceptance

Helitron+Wall : 1.2^0 - 30^0

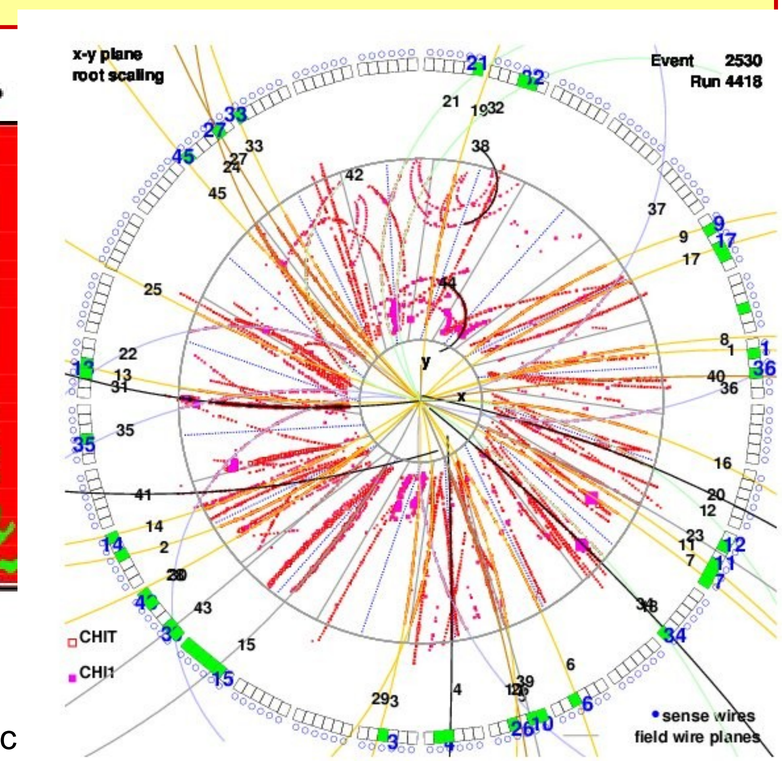
CDC+Barrel : $\Theta_{lab}>35^0$

B =0.6 T

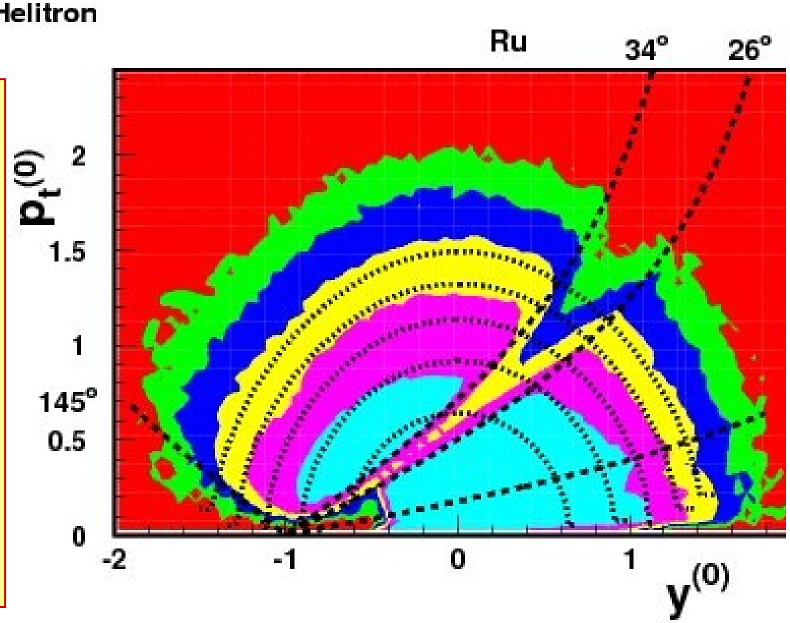
Fixed target experiment (variable target position)

Heavy-ions and elementary

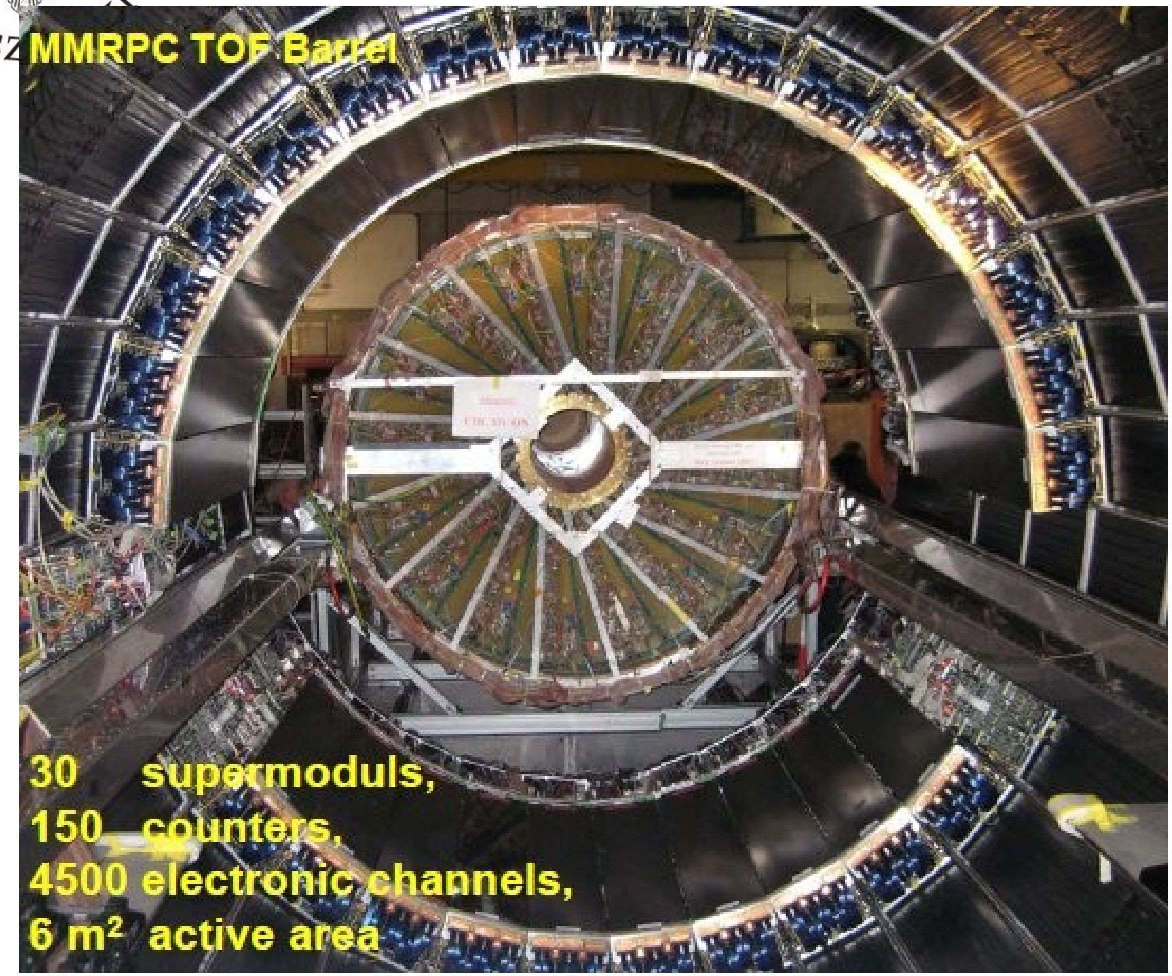
Direct detection of charged particles fragments, pions (95% efficiency)



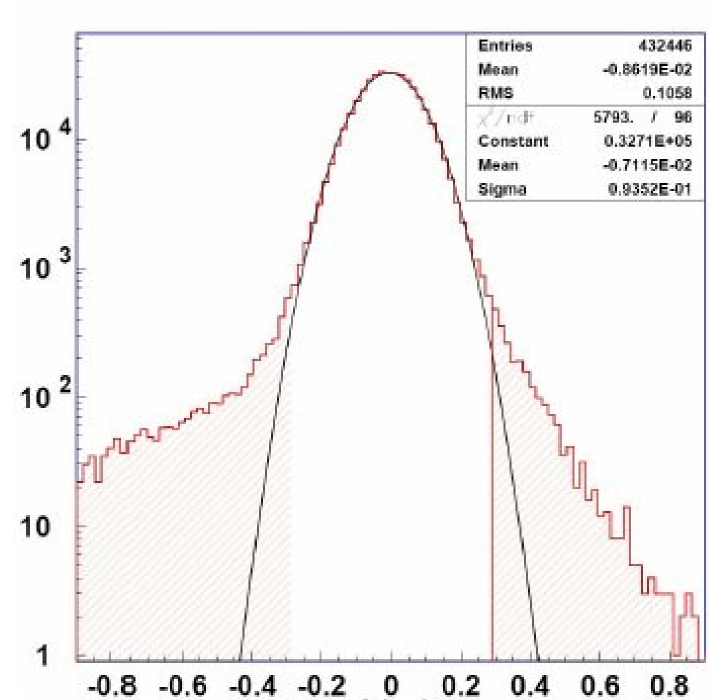
IPNE Bucharest, Romania
ITEP Moscow, Russia
CRIP/KFKI Budapest, Hungary
LPC Clermont-Ferrand, France
Korea University, Seoul, Korea
GSI Darmstadt, Germany
IReS Strasbourg, France
FZ Rossendorf, Germany
Univ. of Heidelberg, Germany
Univ. of Warsaw, Poland
RBI Zagreb, Croatia



Resistive Plate Chambers - TOF Barrel



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

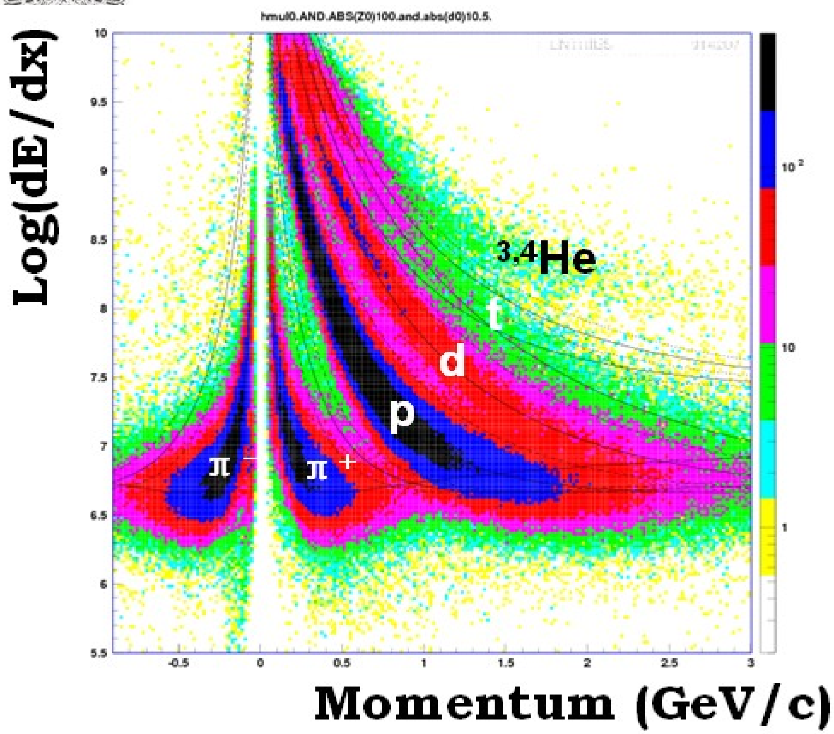


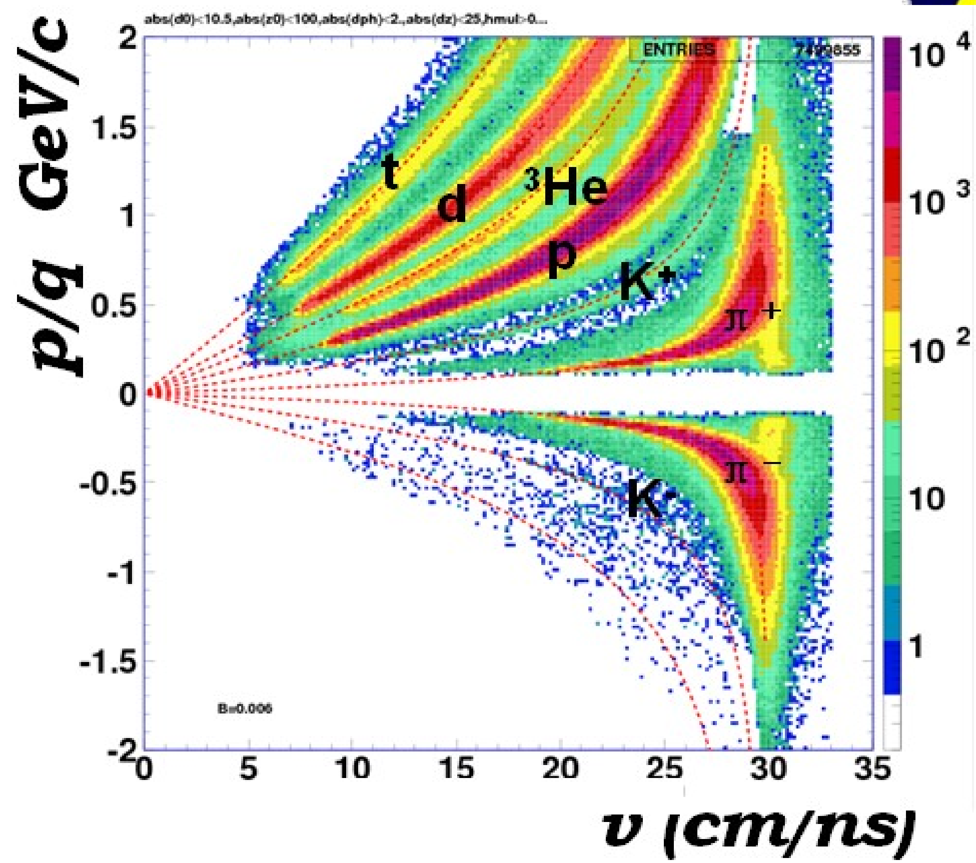
$\Delta t = t_{meas} - t_{exp}$ (ns)

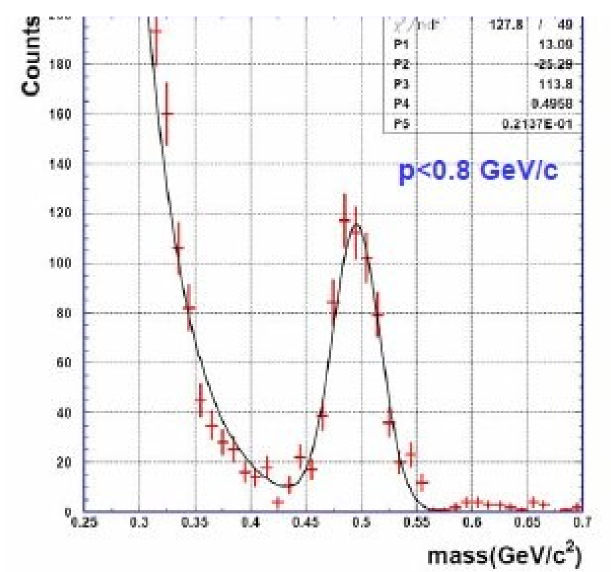
Performance:
σ_{system} ~ 90 ps
σ_{RPC} ~ 65 ps

First RPC-TOF system in the world
Prototyping the TOF system of CBM @ FAIR

Identification of charged particles







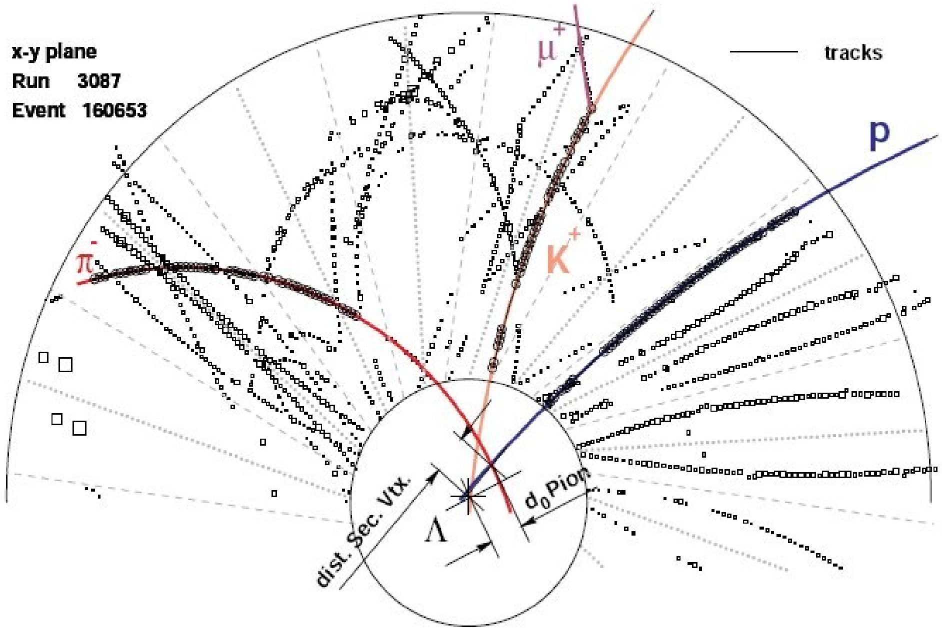
Kaons up to 1 GeV/c – CDC-TOF essential

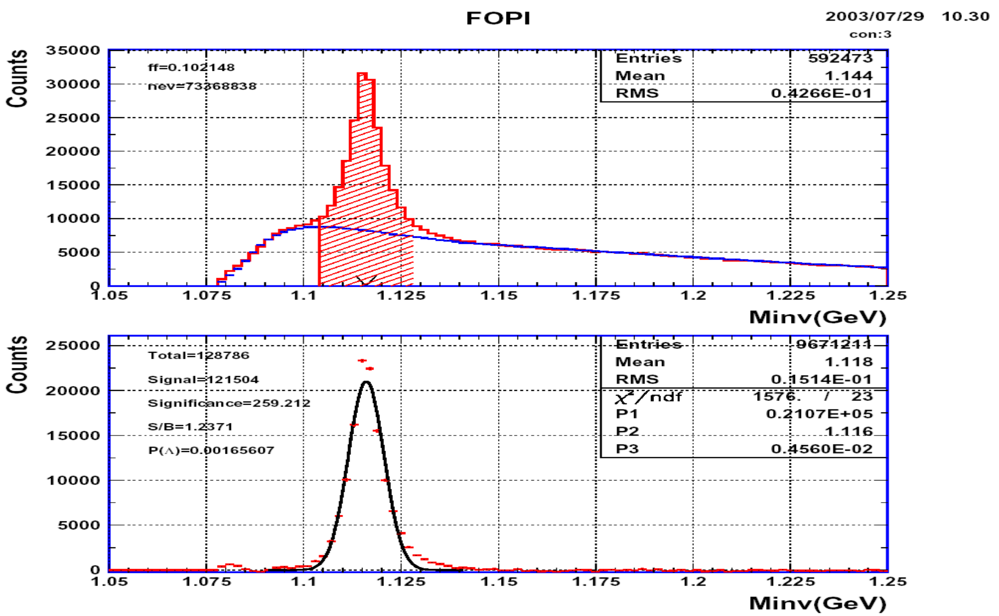
Mid-rapidity not fully covered

Extended thanks to the RPC Barrel

Identification of particles by decay

$\Lambda \rightarrow \pi^- p$ (64%) ,$c\tau$=7.9cm





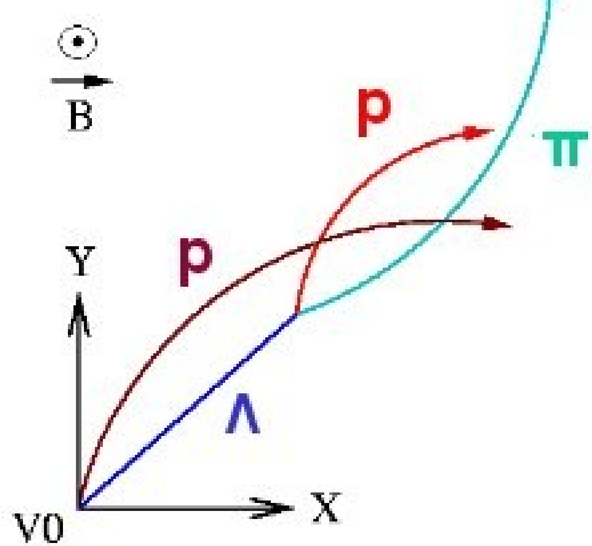
Background reconstructed by event mixing

Topological cuts decisive for the amount of background (S/B ~ 10 no problem)

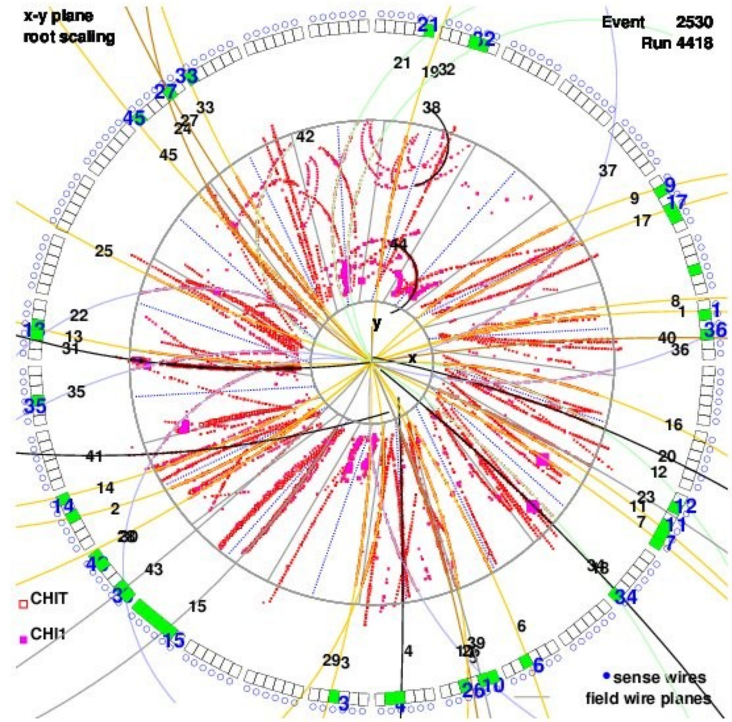
Mass resolution (in the case of weak decay) σ>4 MeV
(depending on momenta of daughters, intrinsic width not extracted)

Reconstruction of bound kaonic nuclear states

ppK- -> pΛ



embeded in



Only invariant mass

K.Wisniewski
Uniwersytet Warszawski,FOPI Collaboration

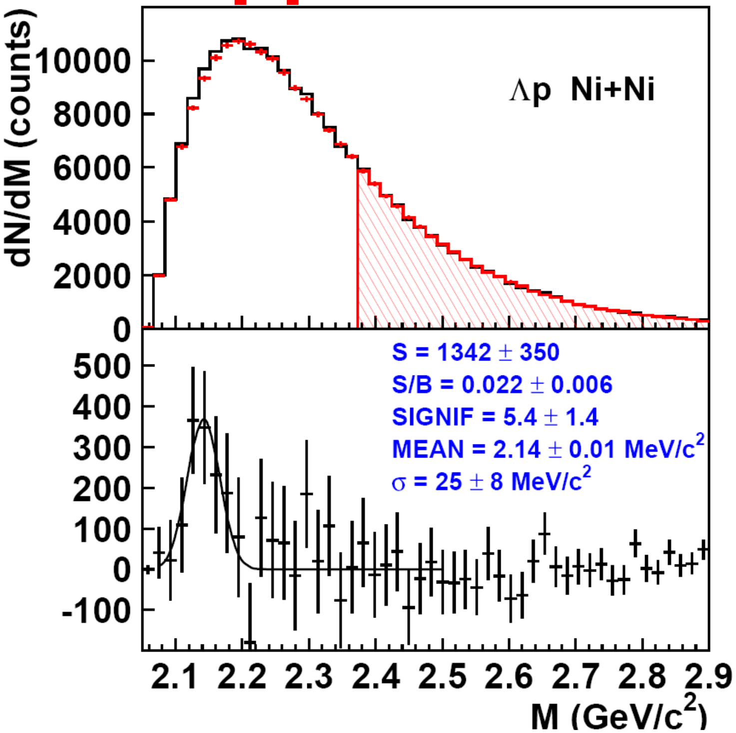
Selection criteria

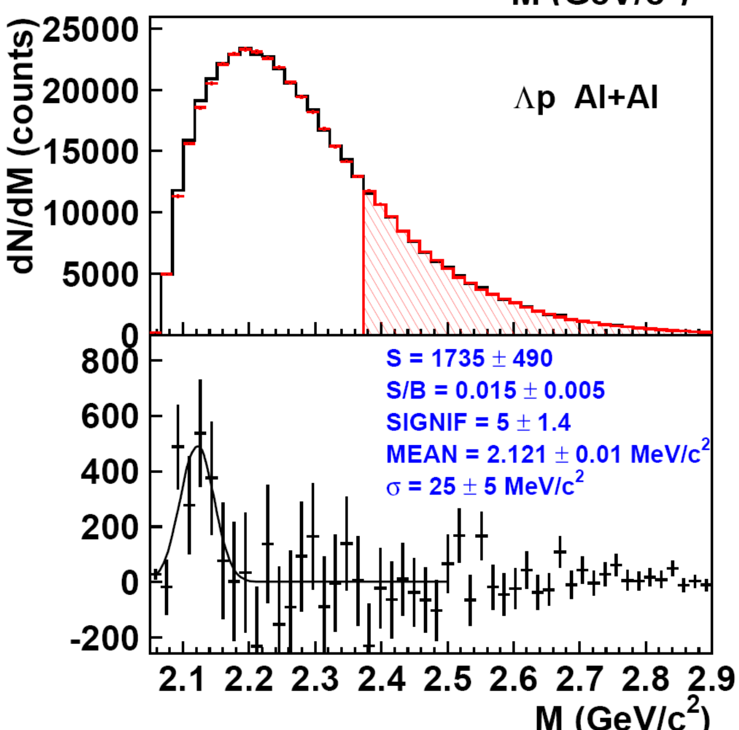
Cuts on

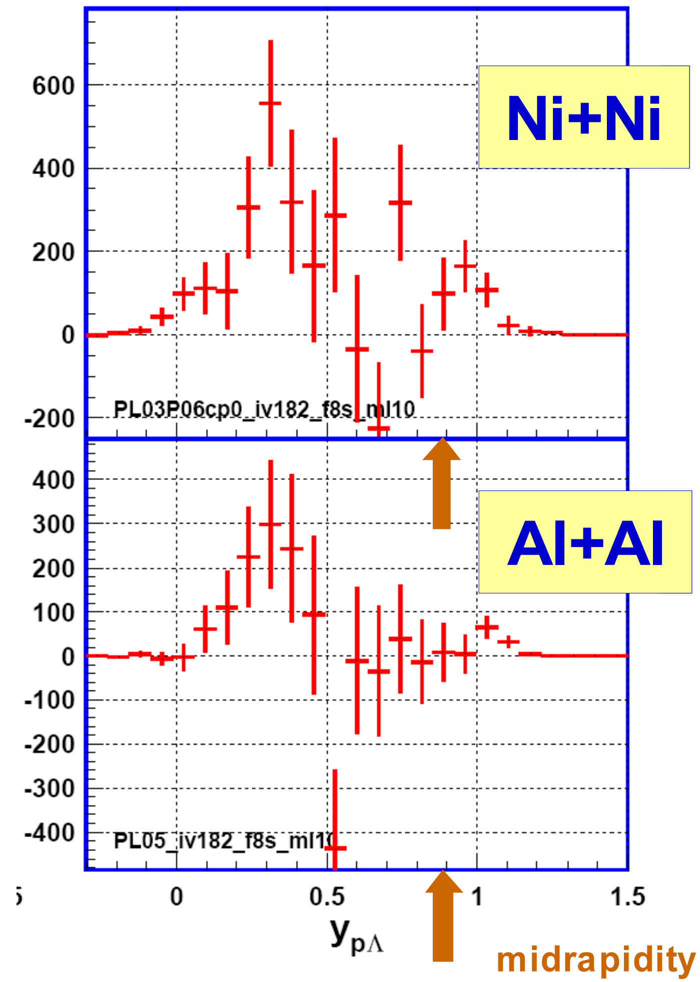
mass of π, p, Λ	$0.08<m_\pi<0.7$, $0.7<m_p<1.5$, $1.16>m_\Lambda>1.26$
p_t of π, p, Λ	$p_t(\pi)>0.09$, $p_t(p)>0.30$, $p_t(\Lambda)>0.30$,
h_{mult} of π,p	$h_{mult}(p)>25$, $h_{mult}(p)>30$
$\sigma(d_{xy})$ of π,p	$\sigma(d_{xy})_\pi<0.1$, $\sigma(d_{xy})_p<0.05$
d_0 of π, p, Λ	$1.9<d_0(p)$, $0.6<d_0(p)$, $d_0(\Lambda)<0.5$
z difference of p and π	$abs(z_p-z_\pi)<20$
phi difference of p and π	$abs(phi_p-phi_s)<2$
and of Λ and p	$abs(phi_{2p}-z_\Lambda)>30$
d_t of Λ	$4<d_t(\Lambda)<30$

Removal of crossing tracks
Background reconstructed by event mixing
Events rotated in order to align reaction planes

ppK- in Al+Al and Ni+Ni @ 1.9 AGeV







Consistent in 2003/2005/2008

Emission at the target-rapidity

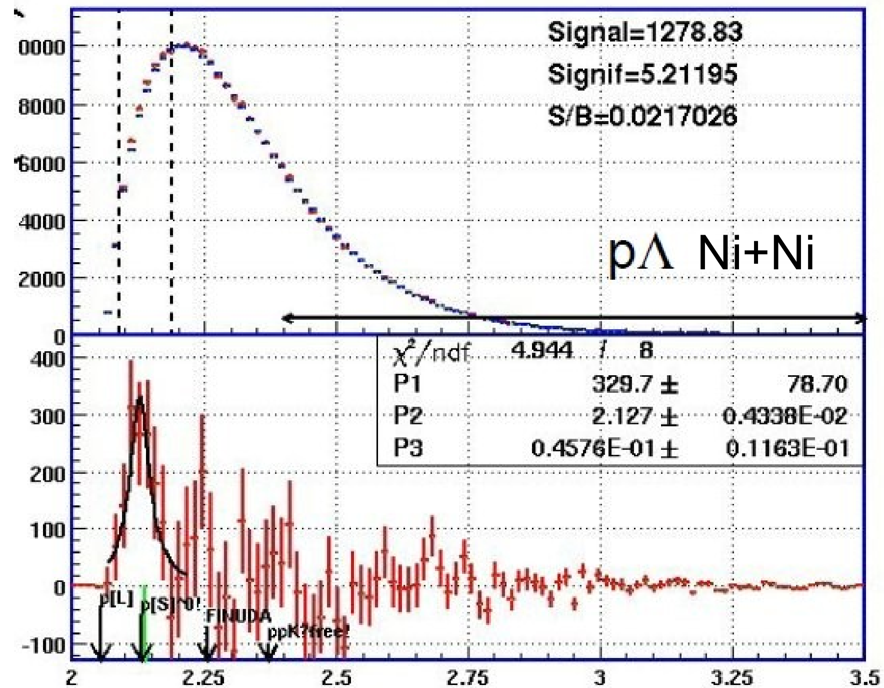
Binding energy and width

Excess found

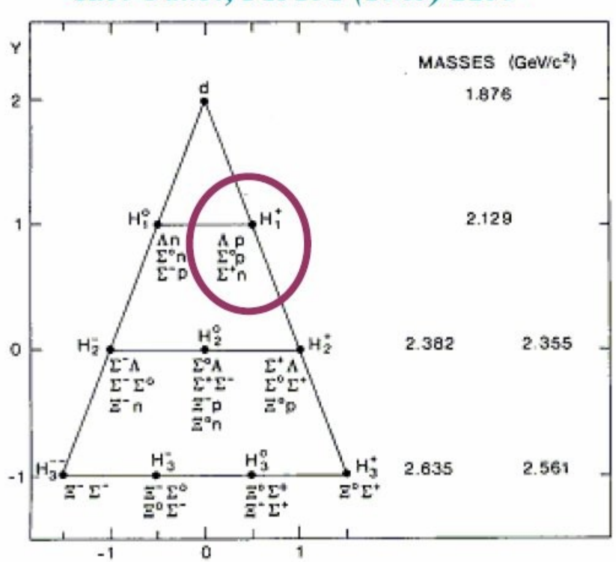
About 100 MeV too much bound

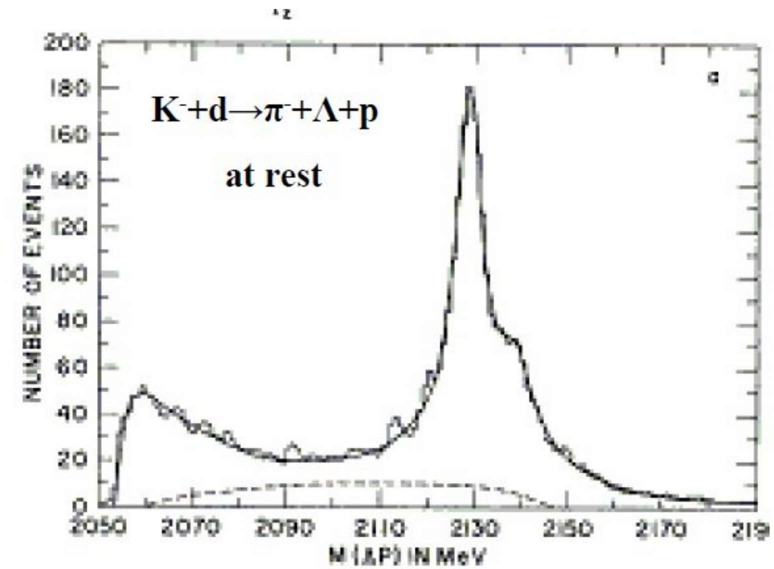
Not a ppK- cluster ?

Could be a final-state interaction



R.J. Oakes, PR 131 (1963) 2239





T.H. Tan, PRL 23 (1969) 395

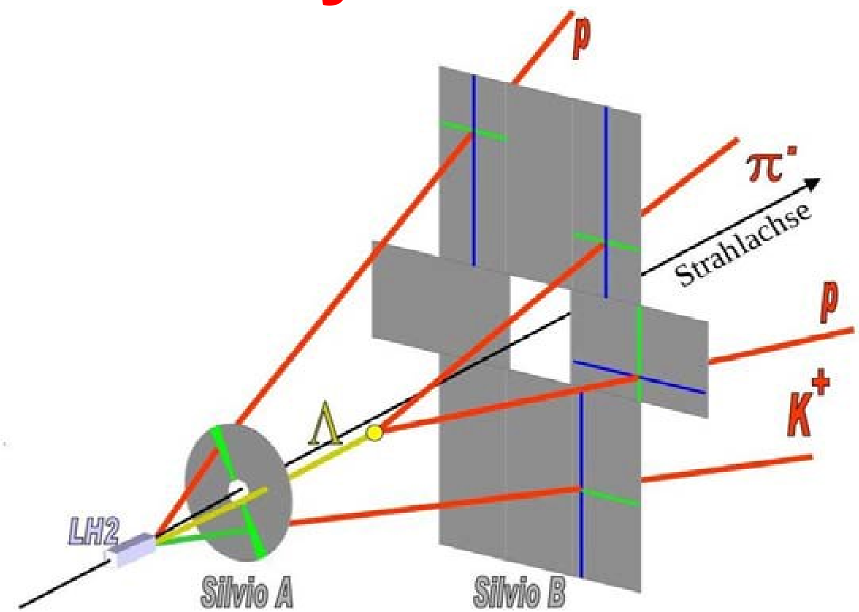
Search for Λp in elementary reactions

$$p + p \xrightarrow{3.1\ GeV} \Lambda(1405) + p + K^+$$

$$\longrightarrow ppK^- + K^+$$

$$ppK^- \longrightarrow \Lambda + p$$

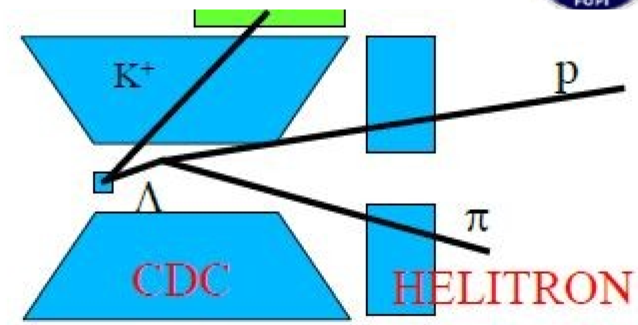
$$\Lambda \longrightarrow \pi^- + p$$



New

- **LV2 trigger**
- **Start detector**
- **Liquid hydrogen target**

Analysis in progress

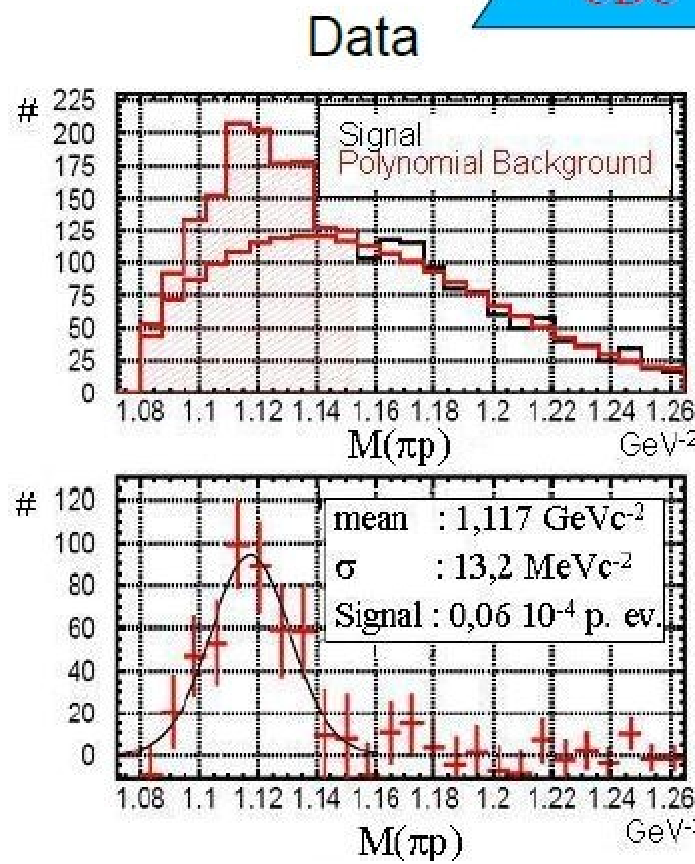


Exclusive measurement

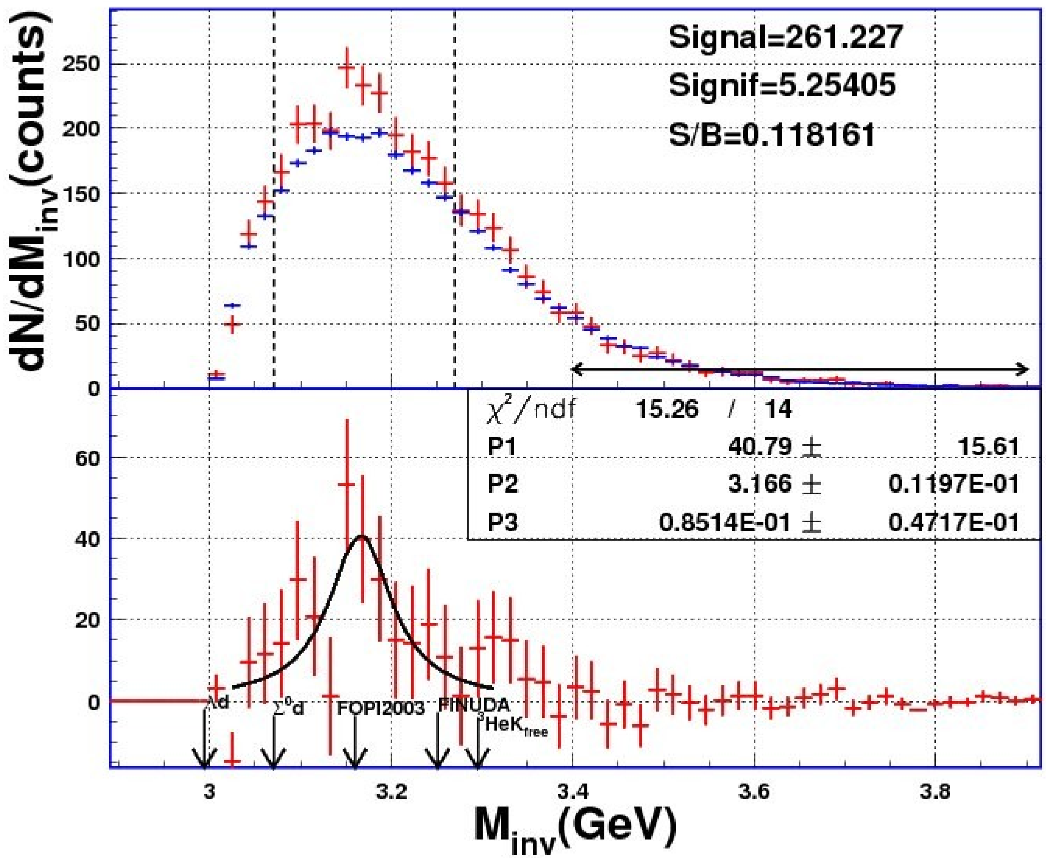
Worse momentum resolution in the forward direction

Λ reconstruction still not satisfactory

Missing mass (will be) available for the first time



nppK- -> dΛ in Ni+Ni @ 1.9 AGeV



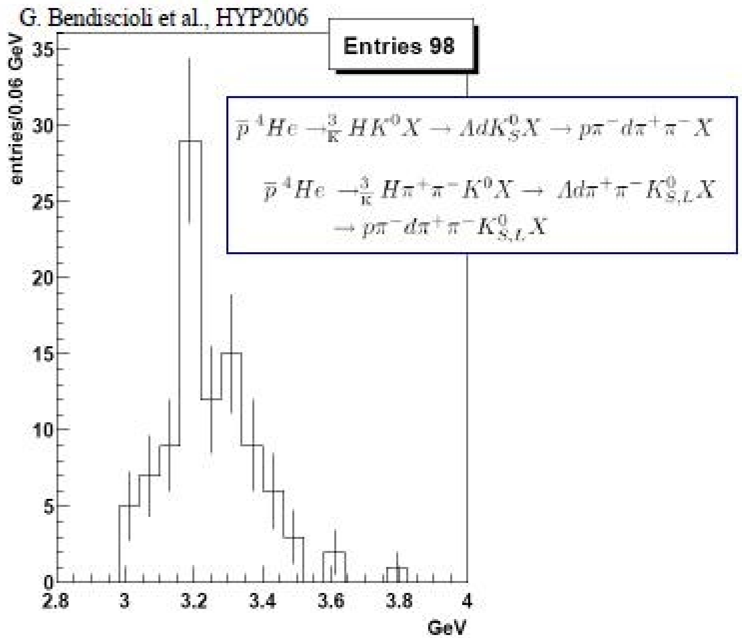
Excess visible

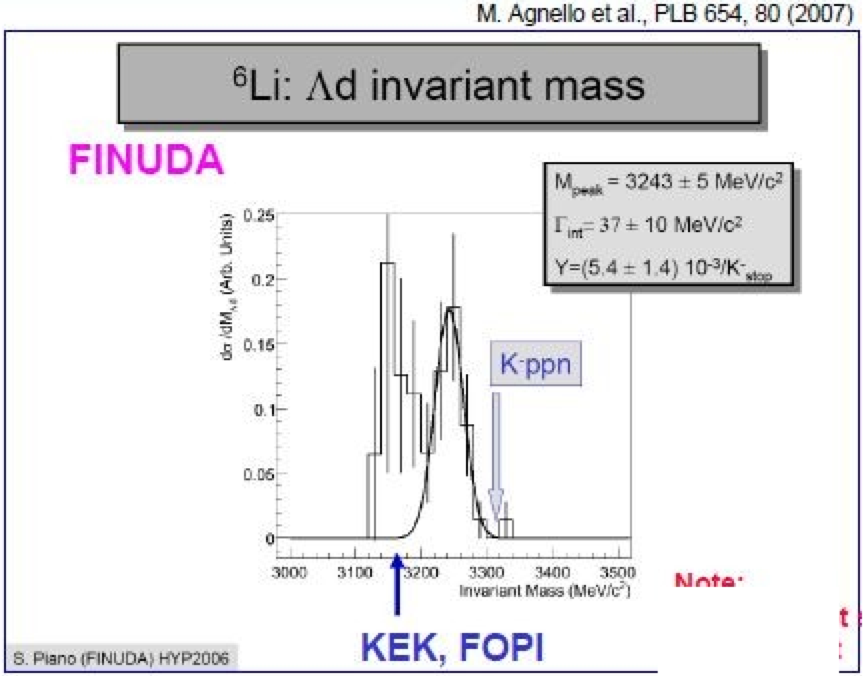
Not at the threshold

Not due to the cusp effect

Binding energy & width compatible with predictions

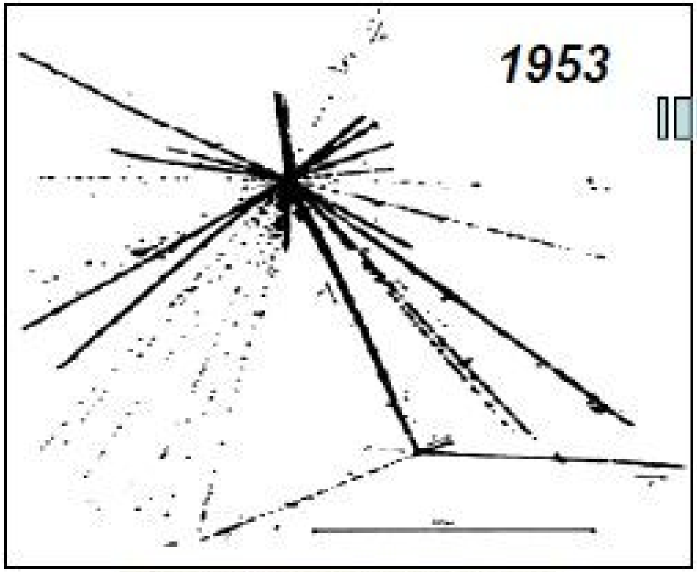
… compared to other experiments

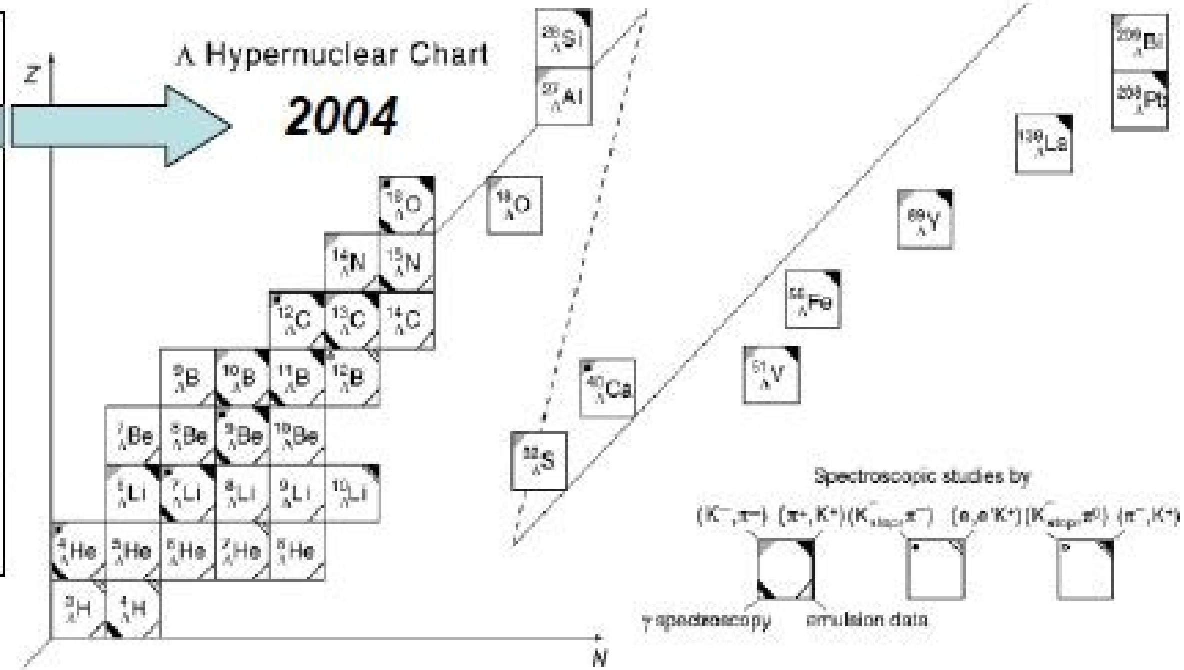


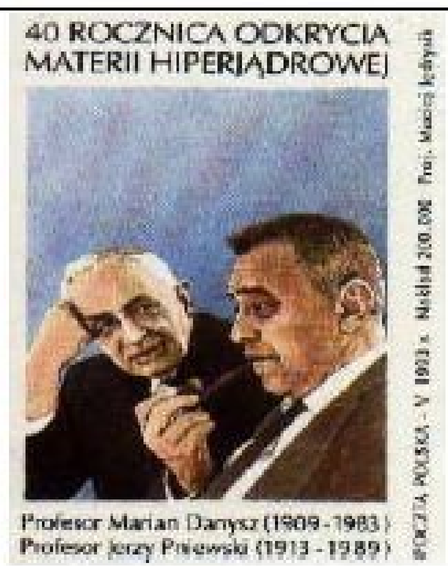


		M (MeV)	Γ (MeV)	P/Λ	P/(IN)	Sign (σ)
FOPI	HI: Al+Al	-	-	-	-	-
	HI: Ni+Ni	3149 ± 15 3166 ± 12	100 ± 49 85 ± 47	$1.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-5}$	4.9 5.2
FINUDA	K^- stopped on ^{6}Li	3251 ± 6	37 ± 14		$4.4 \cdot 10^{-3}$	3.9
KEK E549	K^- stopped in LHe	-	-	-	-	-
Obelix	$\bar{p}$ stopped in ^{4}He	3190 ± 15	< 60.		$>0.4 \cdot 10^{-4}$	2.6

dΛ is also a hypernucleus







(pi$^+$,K$^+$), (K$^-$,pi$^-$), (e,e'K$^+$)

O.Hashimoto, H.Tamra, Progress in Particle and Nuclear physics 57, 564

The first observation of the decay of a hypernucleus

M. Danysz and J. Pniewski, Phil. Mag. 44 (1953) 348

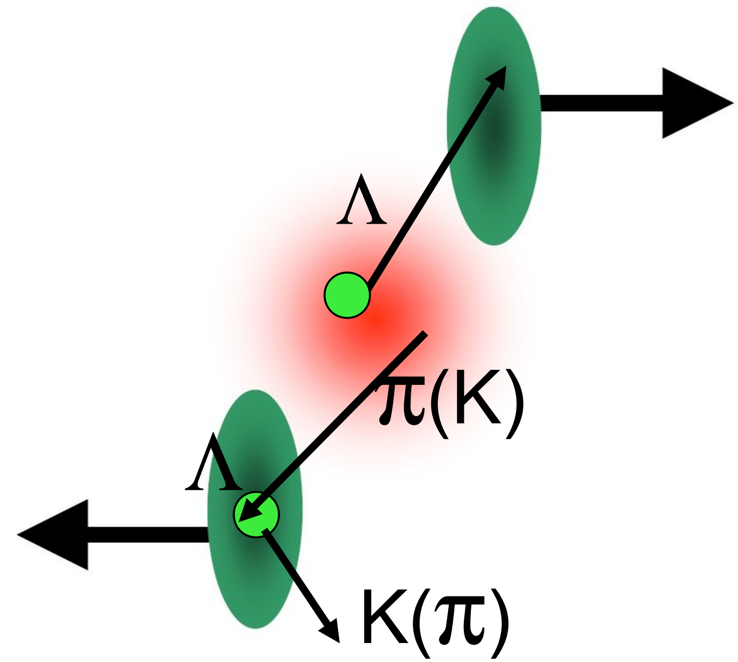
Production mechanism ...

… favours AA collisions

$^{12}C + ^{12}C@2\ AGeV$

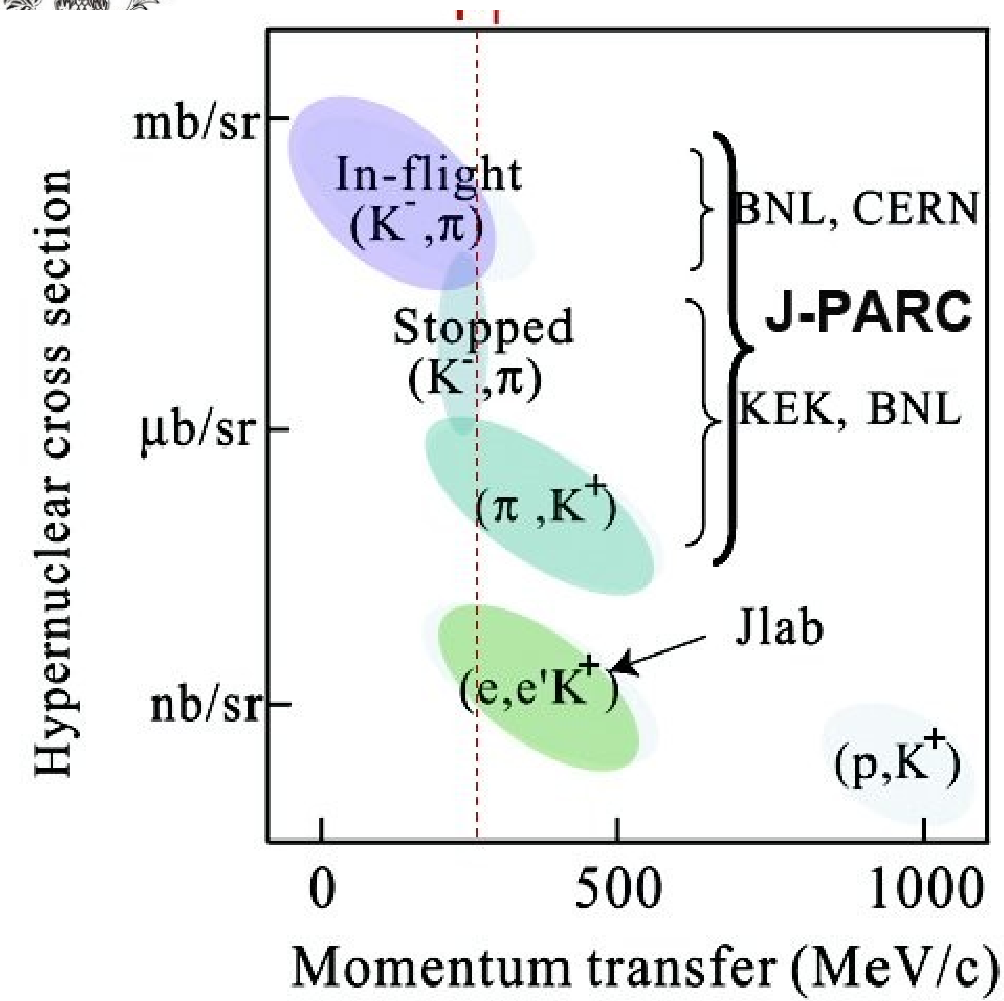
	$^{4}_{\Lambda}H$	$^{4}_{\Lambda}He$	$^{5}_{\Lambda}He$
total yield (μb)	2.2	4	1.4
pionic contribution (μb)	0.3	0.2	0.03

T. Gaitanos et al. / Physics Letters B 675 (2009) 297
(GiBUU+SMM)



No experimental verification

Certain disadvantages



Beam intensity

K^- : 10^4-10^5/s @KEK-PS
~10^6/s @BNL-AGS
~10^7/s @J-PARC
π^+ : 3×10^6/s @KEK-PS
10^9/s @ J-PARC
e : ~ 5×10^{14}/s_Jlab-CEBAF

H. Tamura, SNP 2010

Cross-section definitely not favorable
Beam intensity so-so
No missing-mass measurement, only invariant mass

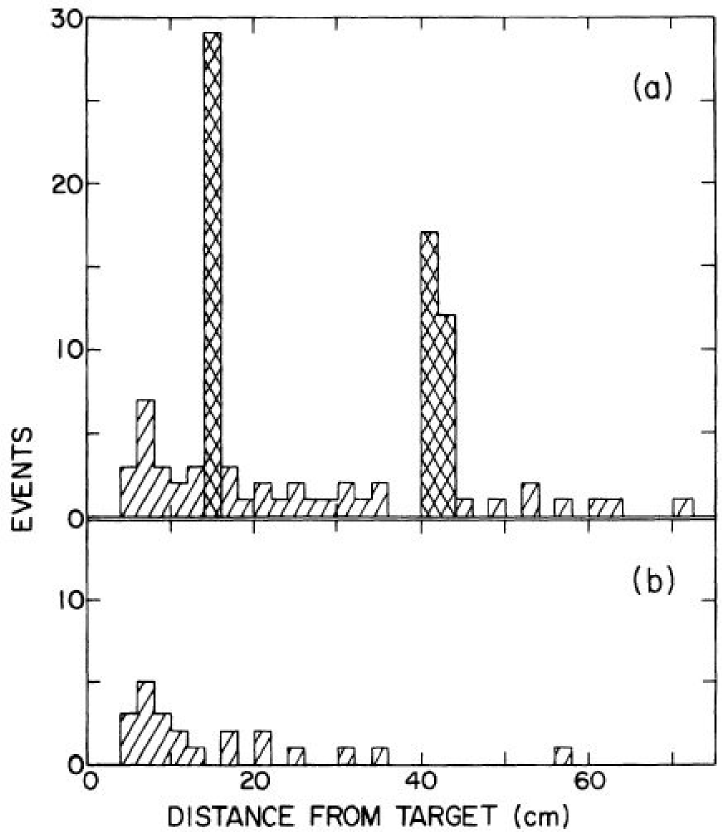
Advantages

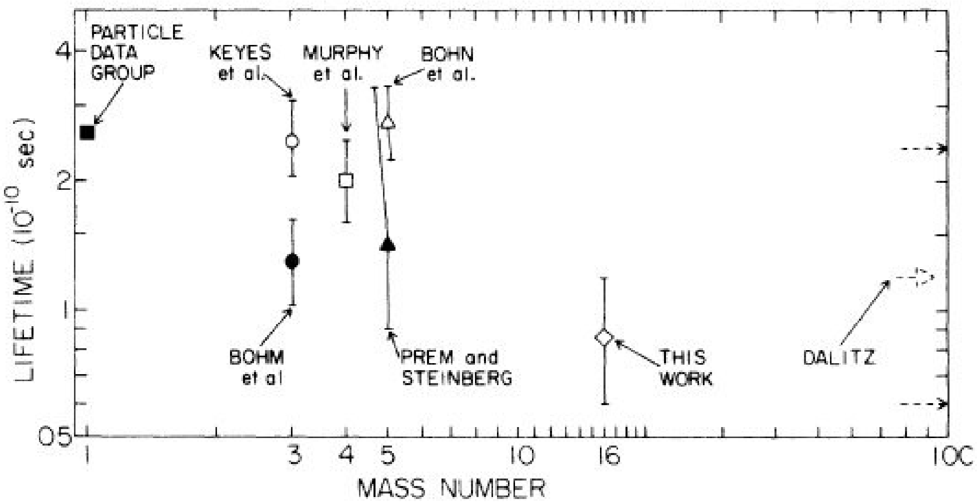
Large momentum transfer and recoil
- (more) precise lifetime measurement
- small detectors in fixed-target experiments

Rare fragments
- population of n/p-rich isotopes

Multi-strange objects
- production of XXΛ-Hypernuclei

First Measurement

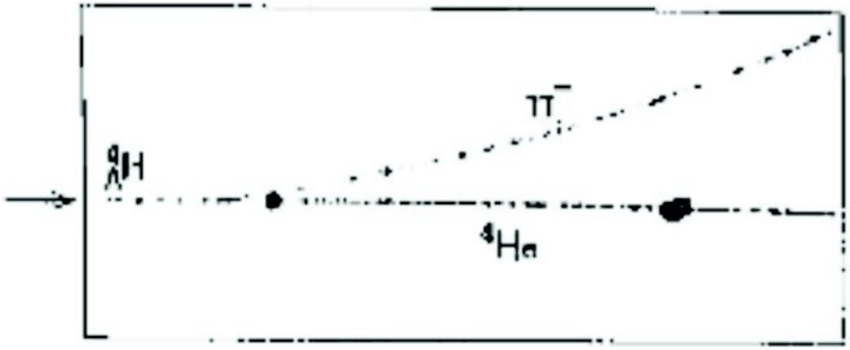




Nield et al. PRC 13, 1263 (1976) Bevalac

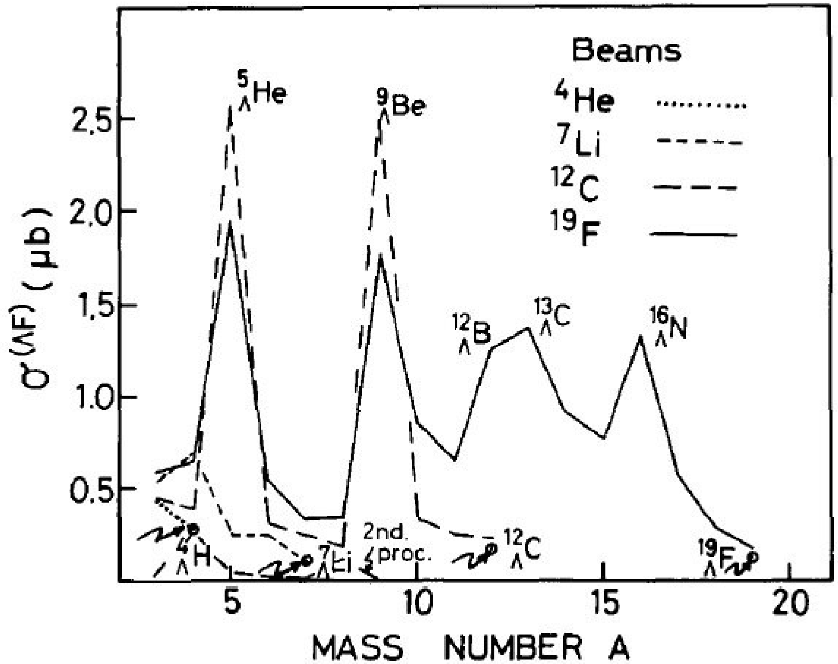
$^{16}O + PE \rightarrow {}^{16}Z_{\Lambda}$ (@2.1AGeV)

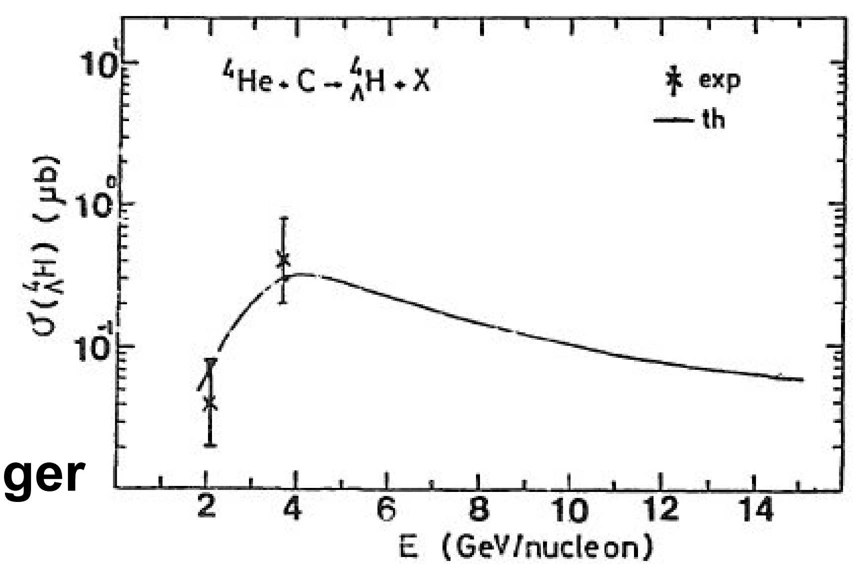
JINR Results



Avramenko et al. NPA 547, 95c (1992)
H.Bando et al. NPA 501,1900 (1989)
M.Wakai NPA 547, 89c (1992)

Beam	Hyper-nuclei	Energy (GeV/nucleon)	Cross Theory	Sections (μb) Experiment
^{3}He	$^{3}_{\Lambda}H$	5.14	0.03	$0.05^{+0.05}_{-0.02}$
^{4}He	$^{3}_{\Lambda}H$	3.7	0.06	<0.1
	$^{4}_{\Lambda}H$	2.2	0.08	<0.08
		3.7	0.29	$0.4^{+0.4}_{-0.2}$
^{6}Li	$^{3}_{\Lambda}H$	3.7	0.09	$0.2^{+0.3}_{-0.15}$
	$^{4}_{\Lambda}H$	3.7	0.2	$0.3^{+0.3}_{-0.15}$
^{7}Li	$^{7}_{\Lambda}Li$	3.0	0.11	<1
	$^{6}_{\Lambda}He$	3.0	0.25	<0.5

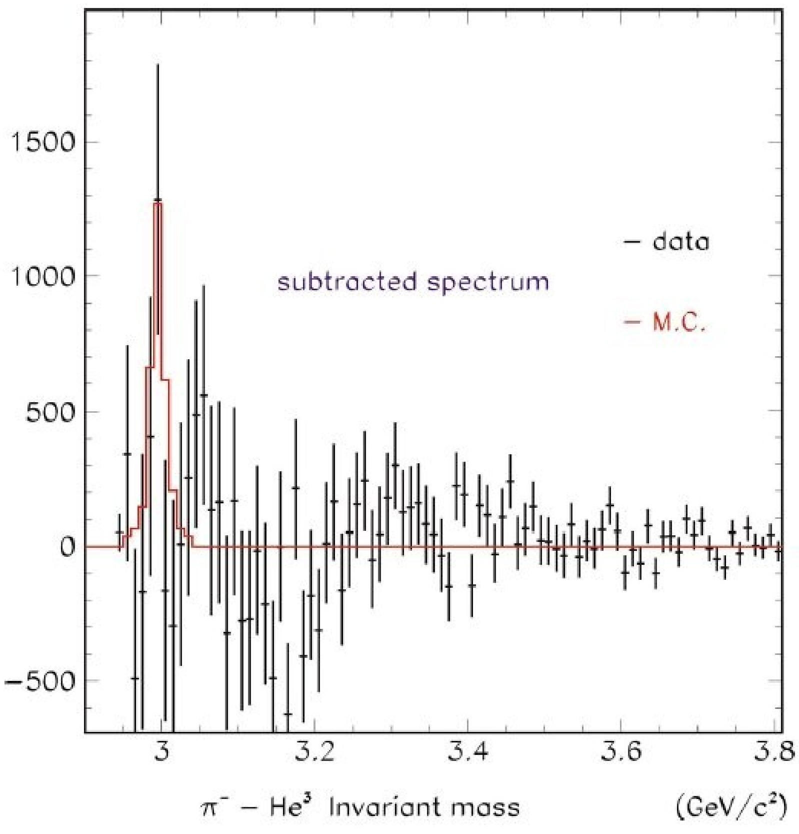




Background reduction by a dedicated trigger
Small statistics, rather poor precision
Cross-sections described by the coalescence model

Second generation experiments

T.Armstrong et al. PRC 70 024902 (2004)



Au + Pt @11.5AGeV

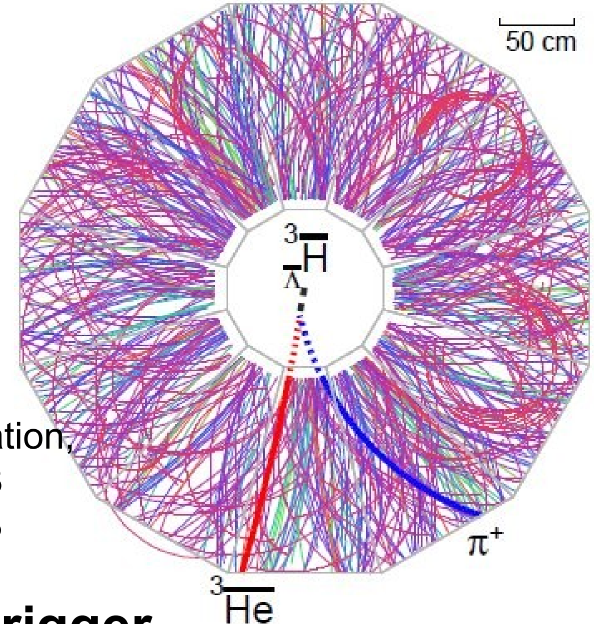
10^{10} central events
with second level trigger on
a heavy fragment

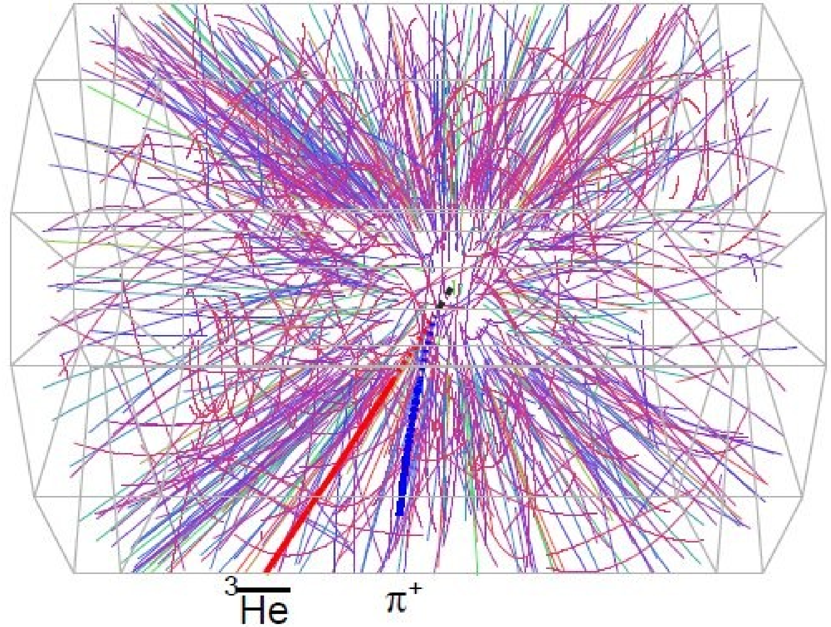
$^3_\Lambda H \rightarrow {}^3He + \pi^-$

Statistical significance 2σ

Precision experiment ?
not fully dedicated
to the hyper-physics

Anti-Hyper-Nuclei





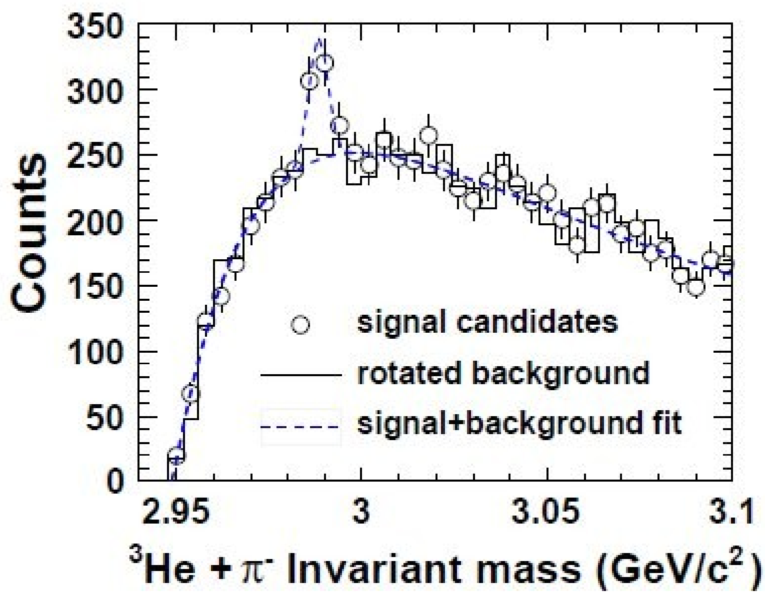
STAR Collaboration,
Science 328, 58
Nature 473, 353

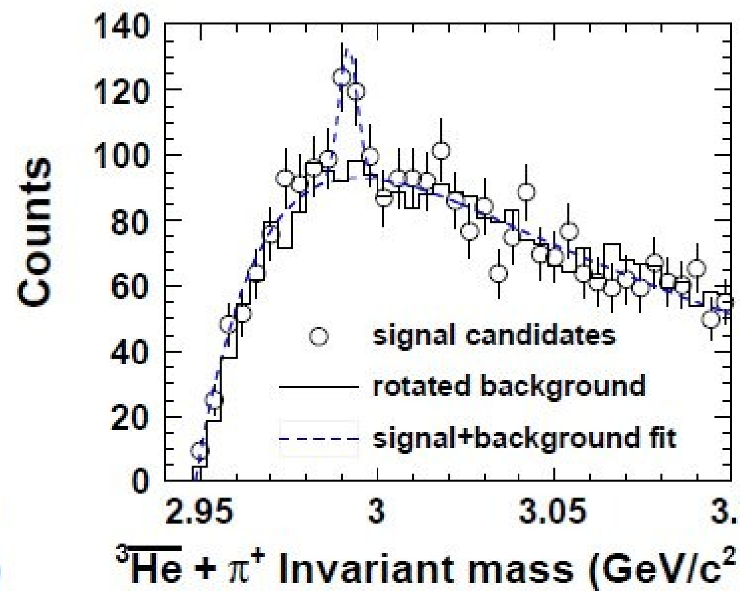
No hyper-trigger
Au+Au @ 200 AGeV
10^8 minimum-bias

Topological cuts

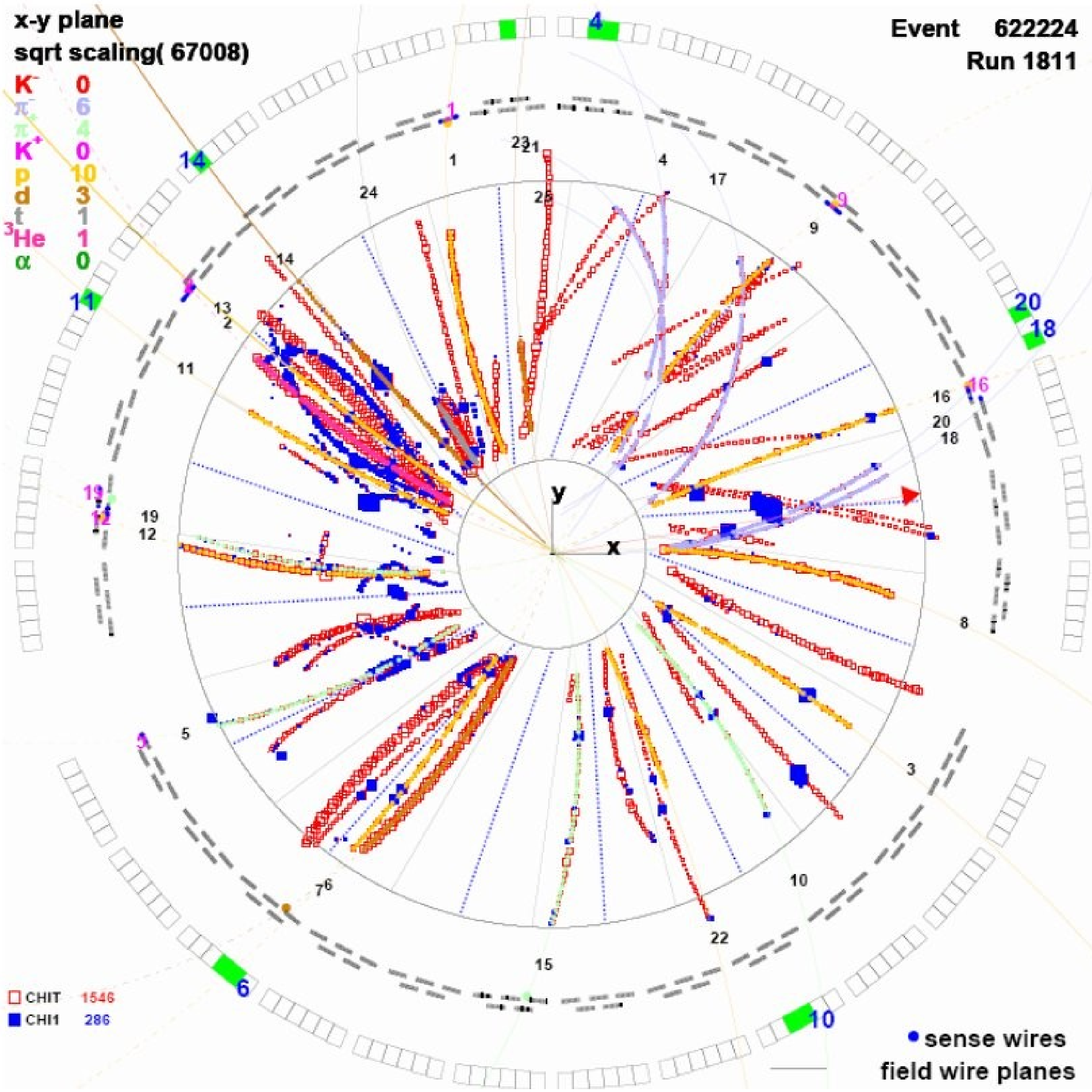
Spatial resolution essential

Great advantage of the TPC



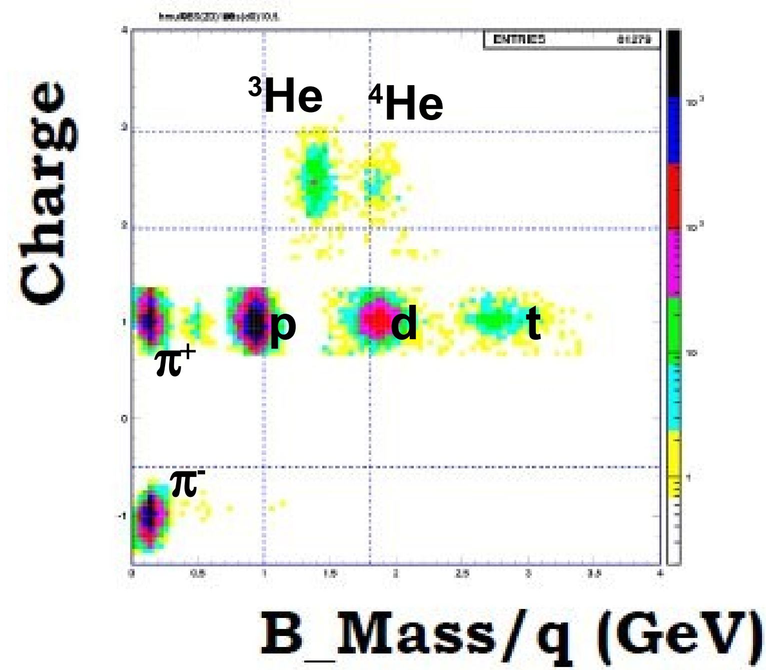


Search for Hypernuclei in Ni+Ni @ 1.9 AGeV



Mesonic 2body decay

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

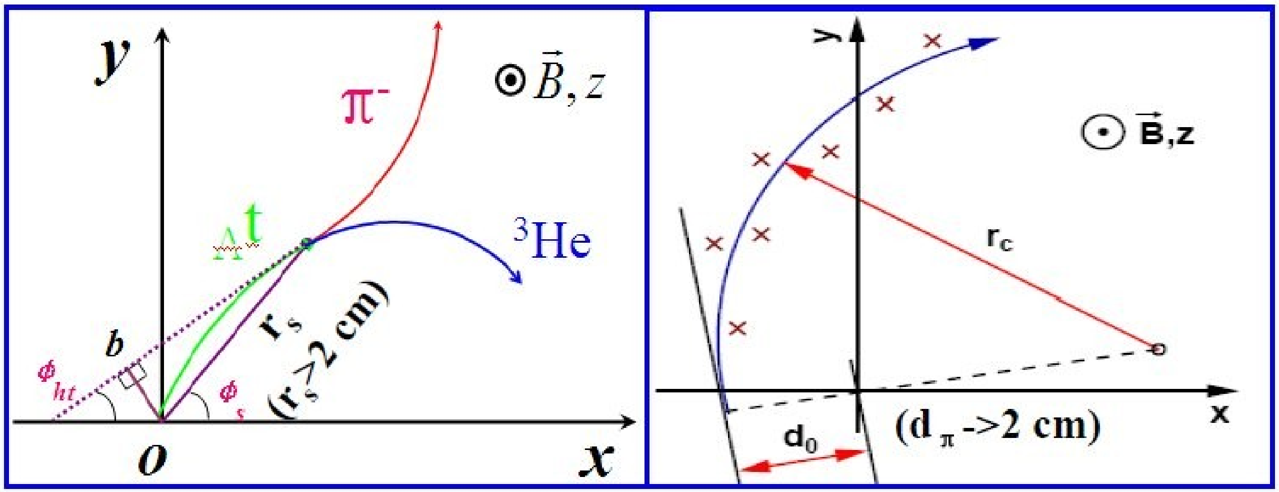


Mass & charge identification

Accurate information about TOF is essential (σ_{RPC} ~ 65 ps)

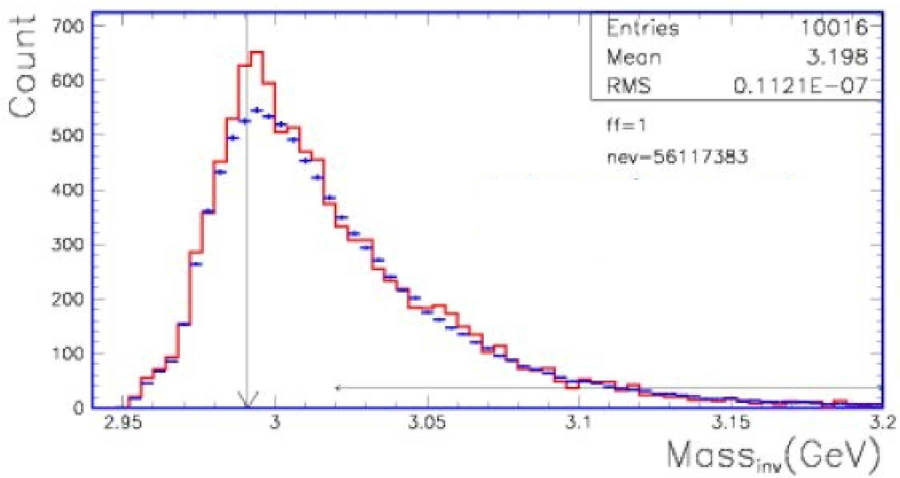
Selection criteria

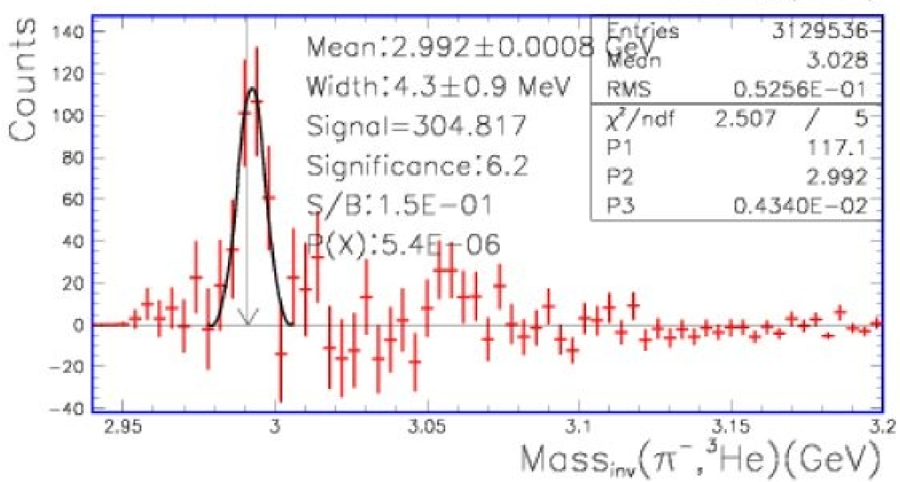
Strategy :
take everything and clean-up



Essential topological cuts:
distance of closest approach (d0)
decay length (r_s) and direction (b, ϕ_{decay}- $\phi_{hypertriton}$)
Large momentum and Lorentz-factor help

$^{3}_{\Lambda}H$ -> $^{3}He+\pi^{-}$ in Ni+Ni @ 1.9 AGeV





$6*10^{7}$ events, 50% central

Topological cuts

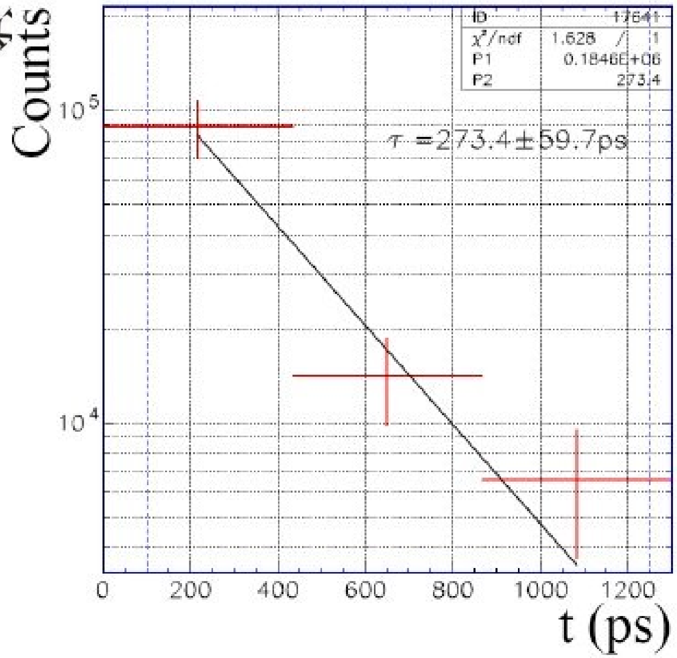
Background reconstructed by mixed-event method:
- **centrality classes**
- **alignment of the reaction planes**

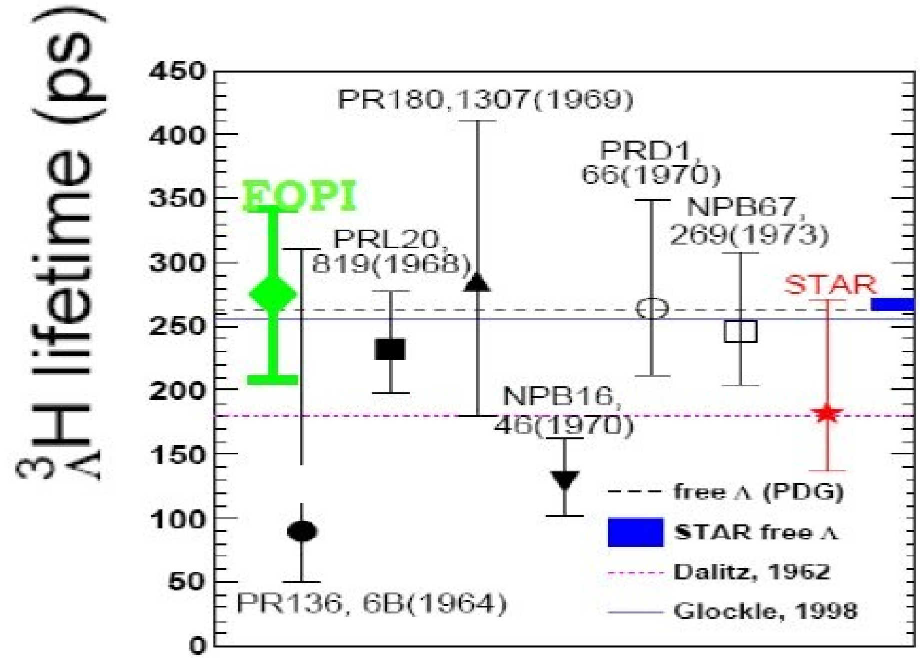
Removal of close/intersecting tracks

Detection rate: 10^{-6}/event

S/B ~ 10^{-1}, Significance ~ 6

$^{3}_{\Lambda}H$ lifetime





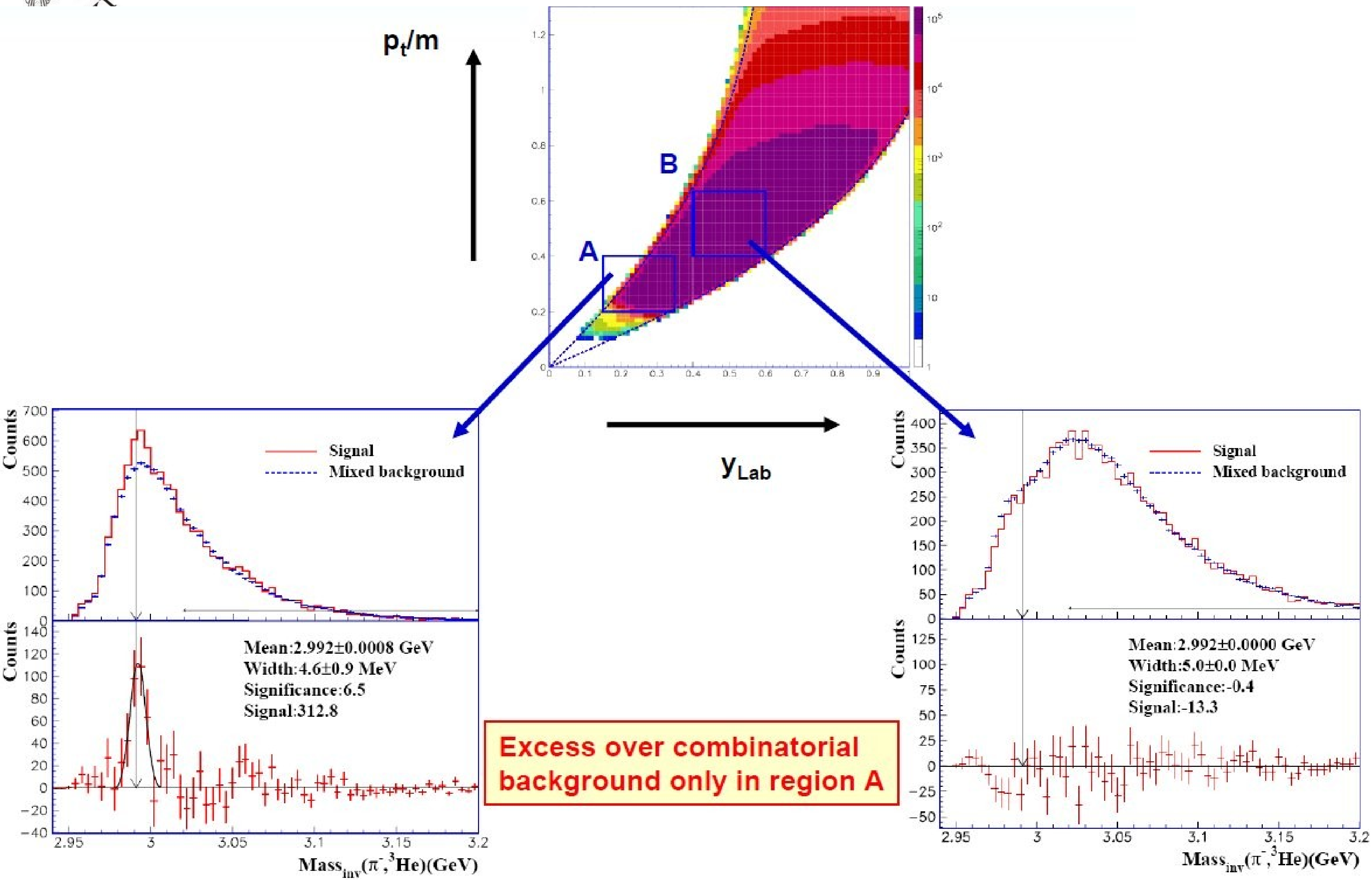
$$N=N_0 e^{-t/\tau},\ t=r_s/(\beta\gamma)_T=r_s/(p_t/m)$$

Decay distribution

Efficiency corrections from MC

Lifetime agrees with the world data
(precision comparable with other measurements)

Phase-space population



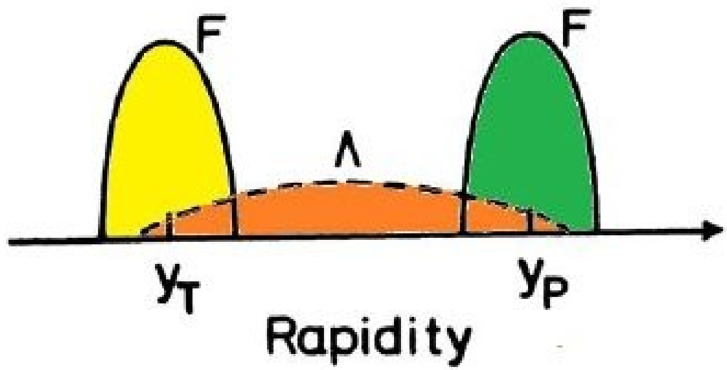
Excess over combinatorial background only in region A

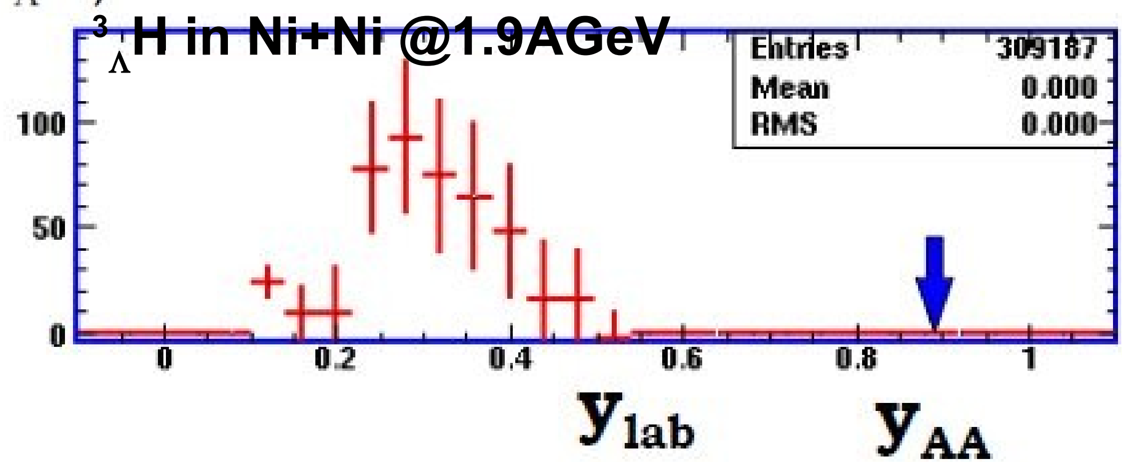
Coalescence

$$\frac{\gamma}{\sigma_r}\frac{d^3\sigma(\Lambda F)}{dk_c^3} = \left(\frac{m_\Lambda + m_F}{m_\Lambda m_F}\right)^3 S_{\Lambda F}\left(\frac{\gamma}{\sigma_r}\frac{d^3\sigma^{(\Lambda)}}{dk_c^3}\right)\left(\frac{\gamma}{\sigma_r}\frac{d^3\sigma^{(F)}}{dk_c^3}\right)$$

H.Bando et al. NPA 501,1900 (1989)

Coalescence process ($\Lambda X \rightarrow {}_\Lambda Y$)

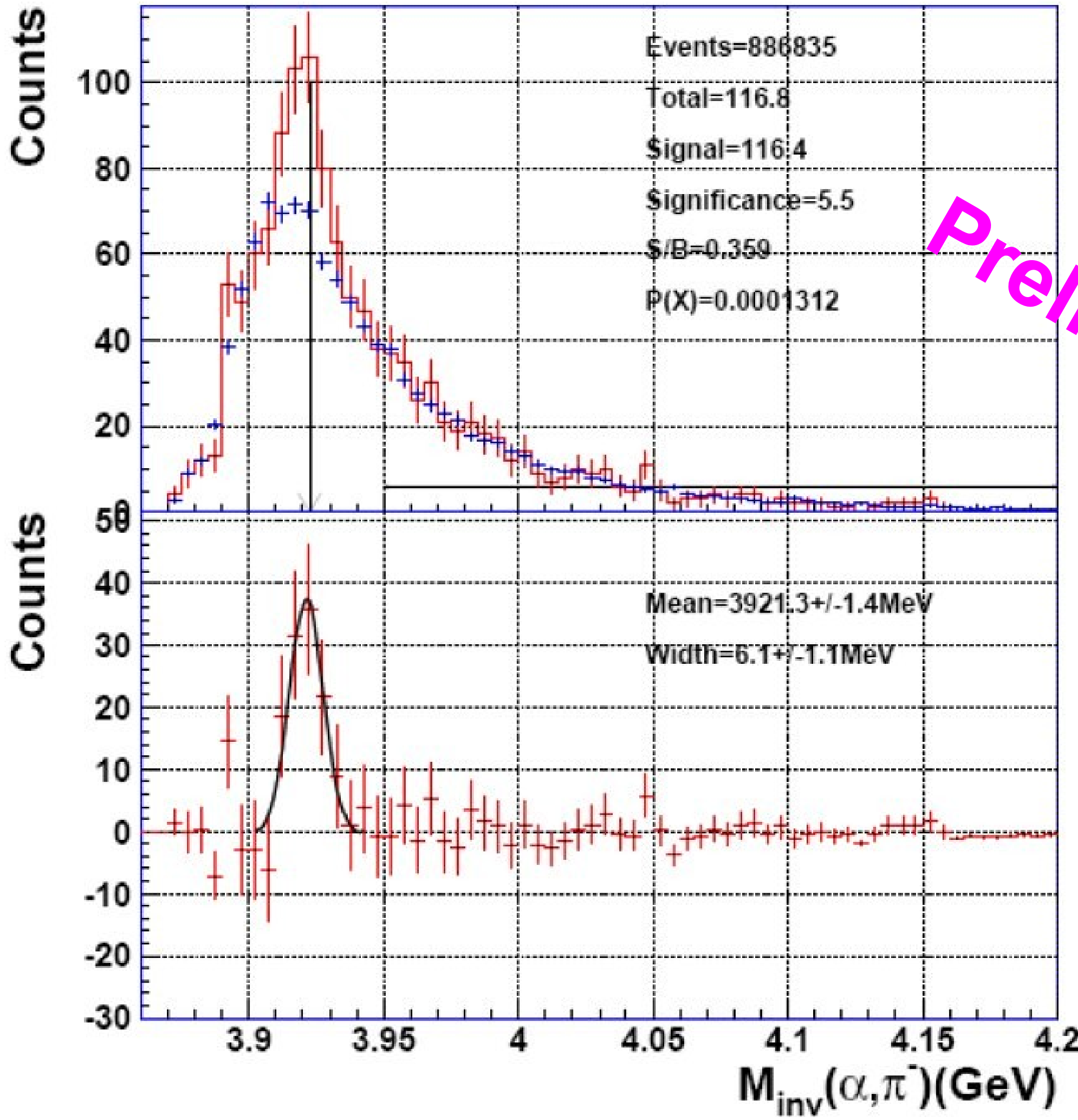




Particle	$P(^3_\Lambda He)$	$P(\Lambda)$	$P(d)$	$S_{\Lambda F}$	Error
Region A	3.4×10^{-4}	8.0×10^{-4}	1.7×10^{-1}	2.5	6.8%
Region B	$< 3.0 \times 10^{-5}$	2.1×10^{-3}	1.6×10^{-1}	$< 8.8 \times 10^{-2}$	23.6%

Coalescence does not work very well

Other Correlations I



Preliminary

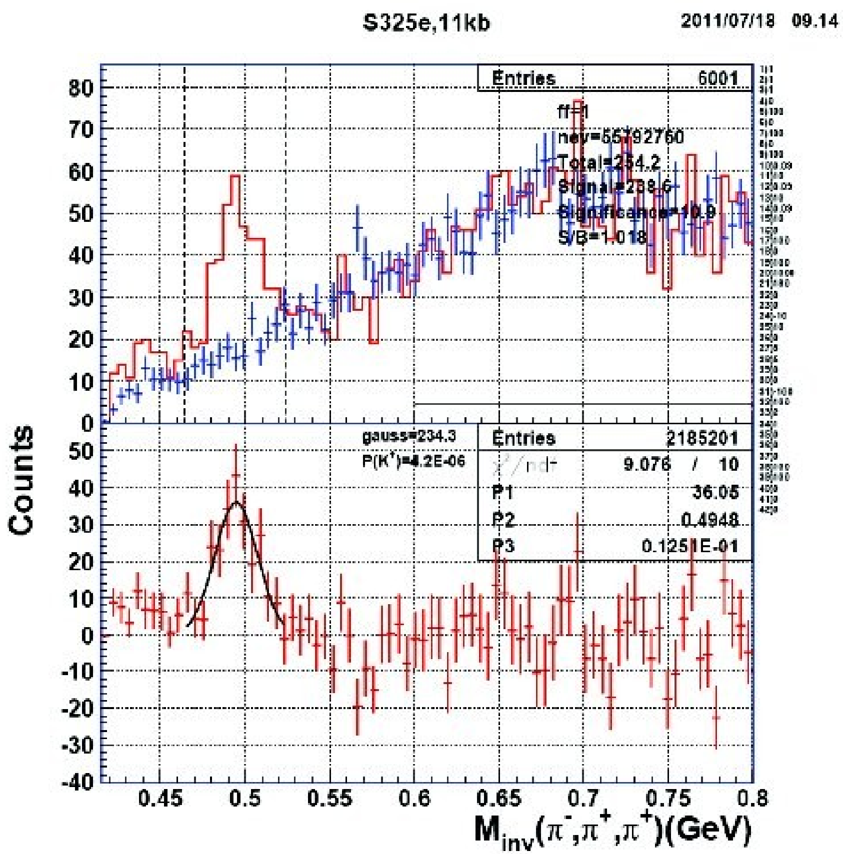
$^4_\Lambda H \rightarrow \alpha + \pi^-$

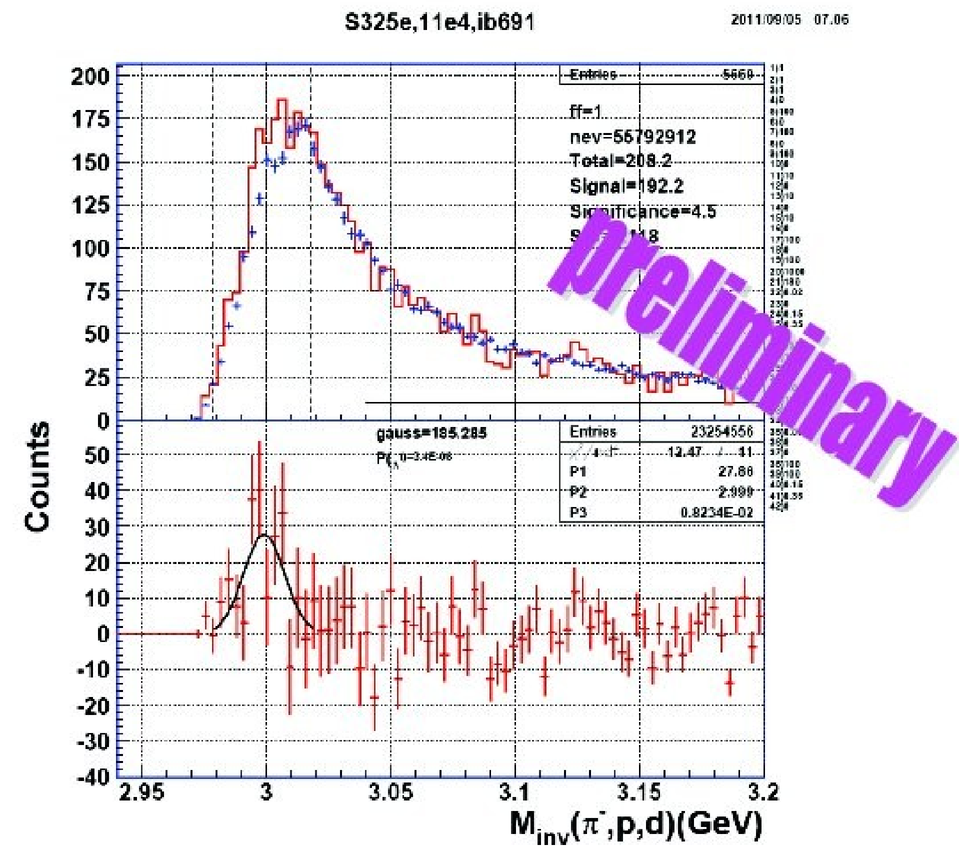
Could be a prelude to something heavier ?

3body-decay Reconstruction

Test case: $K^+ \to \pi^- + \pi^+ + \pi^+ \quad (5.6\,\%)$

Application: ${}_{\Lambda}t \to \pi^- + p + d$

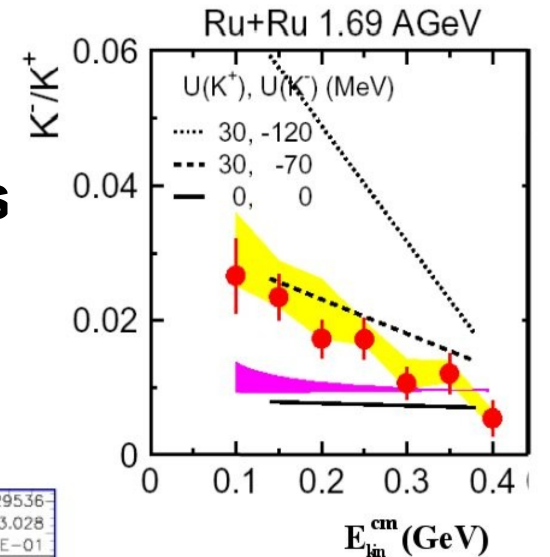




Background reconstruction much more tricky

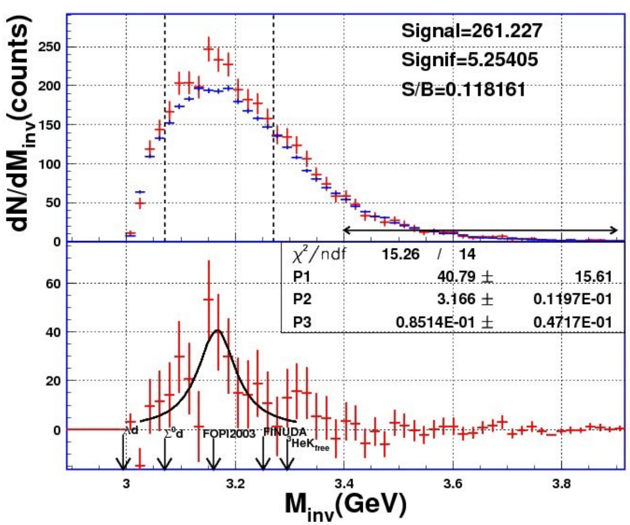
Summary

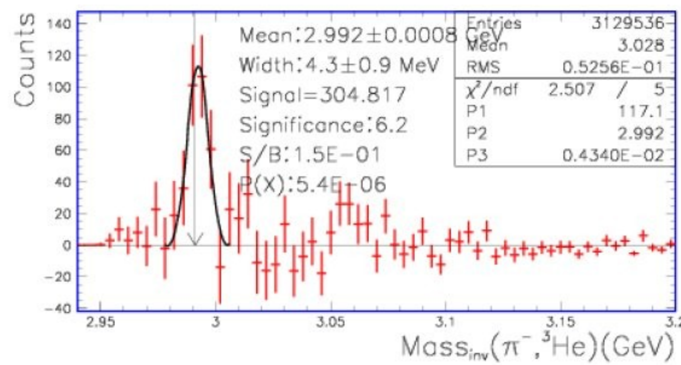
Strangeness in AA collisions studied extensively with FOPI



Evidence for in-medium modifications of K mesons

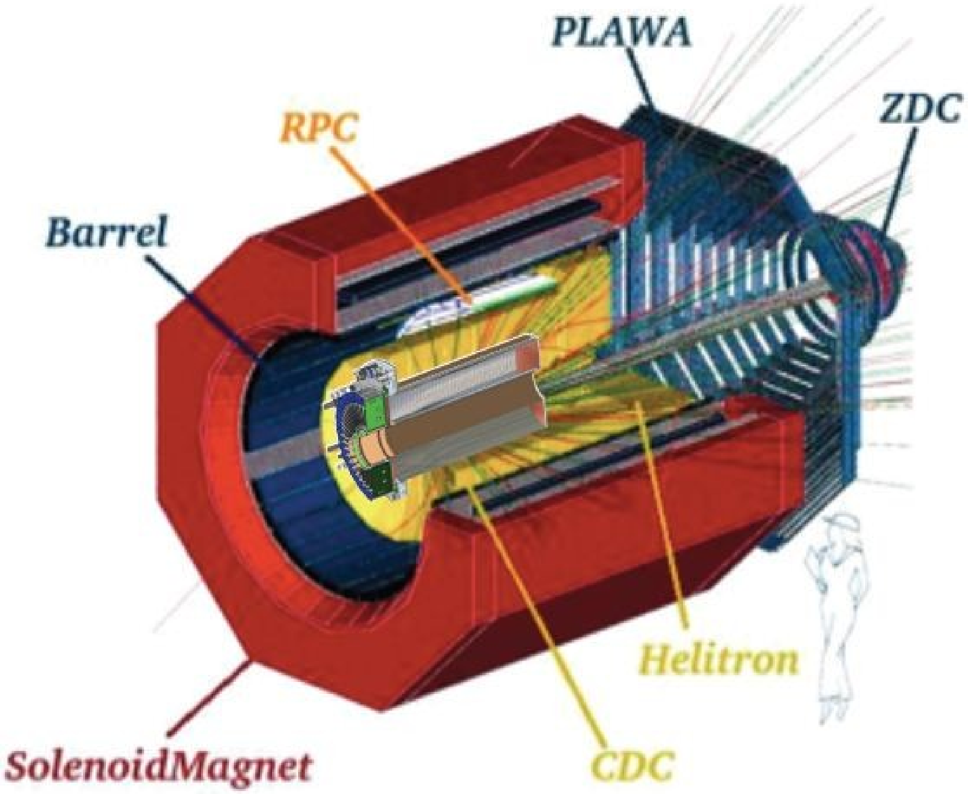
Kaonic nuclear states **and hipernuclei**

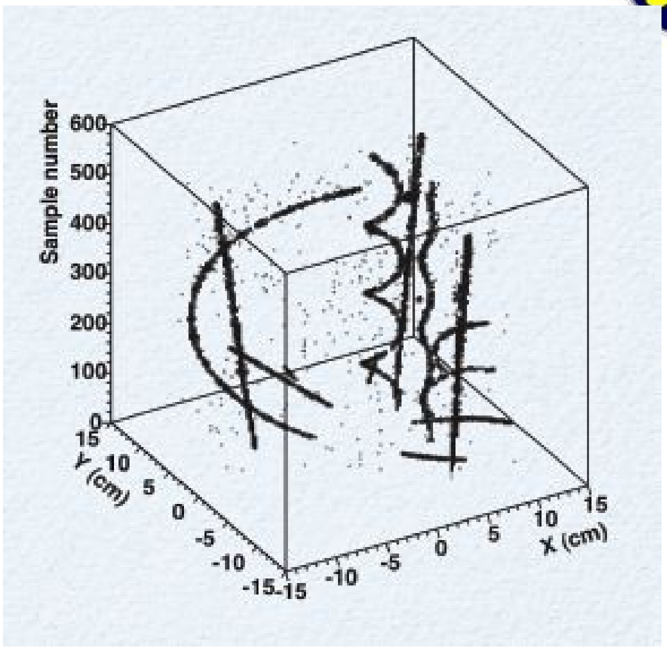




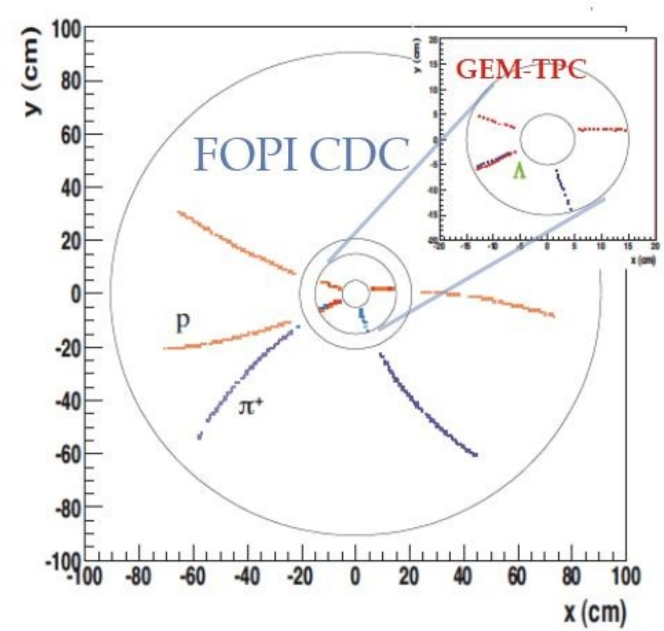
Looks like a good (re-)start …

Future Activity in CaveB of GSI

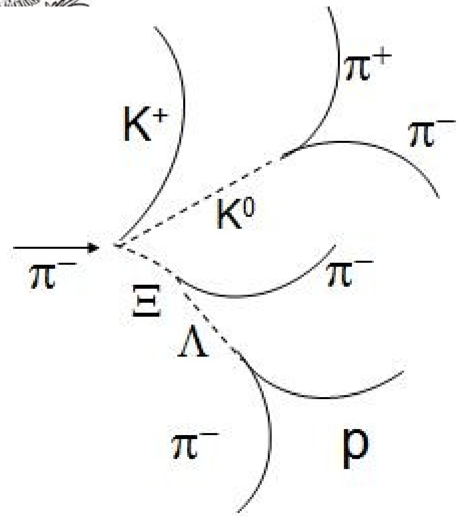




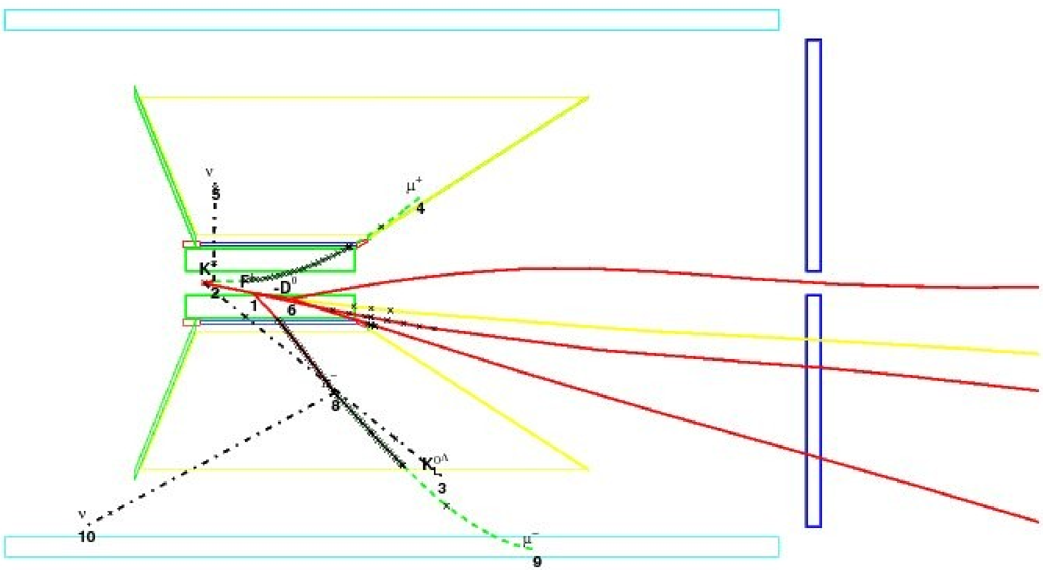
Installation and operation of the PANDA prototype GEM-TPC with a supreme spatial resolution and forward geometrical acceptance



Double strangeness production



Production of Ξ^-
in π induced reactions at 2.5 GeV/c



Production of $^{6}_{\Lambda\Lambda}He$
in heavy-ion reactions

$^{6}_{\Lambda\Lambda}He \rightarrow {}^{6}_{\Lambda}Li + \pi^-$

$^{6}_{\Lambda}Li \rightarrow {}^{6}Be^* + \pi$-

K.Wisniewski
Uniwersytet Warszawski,FOPI Collaboration

Last Slide

FOPI was turned down end of 2012