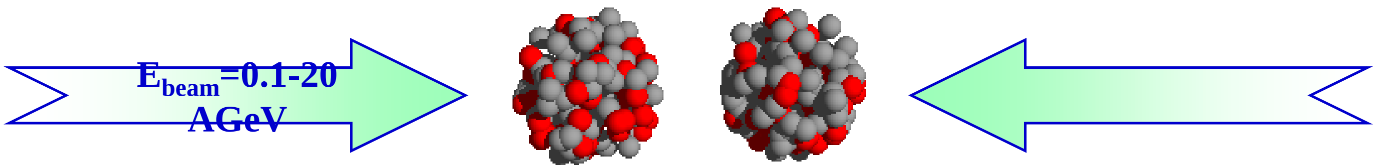
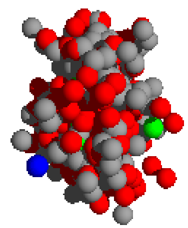
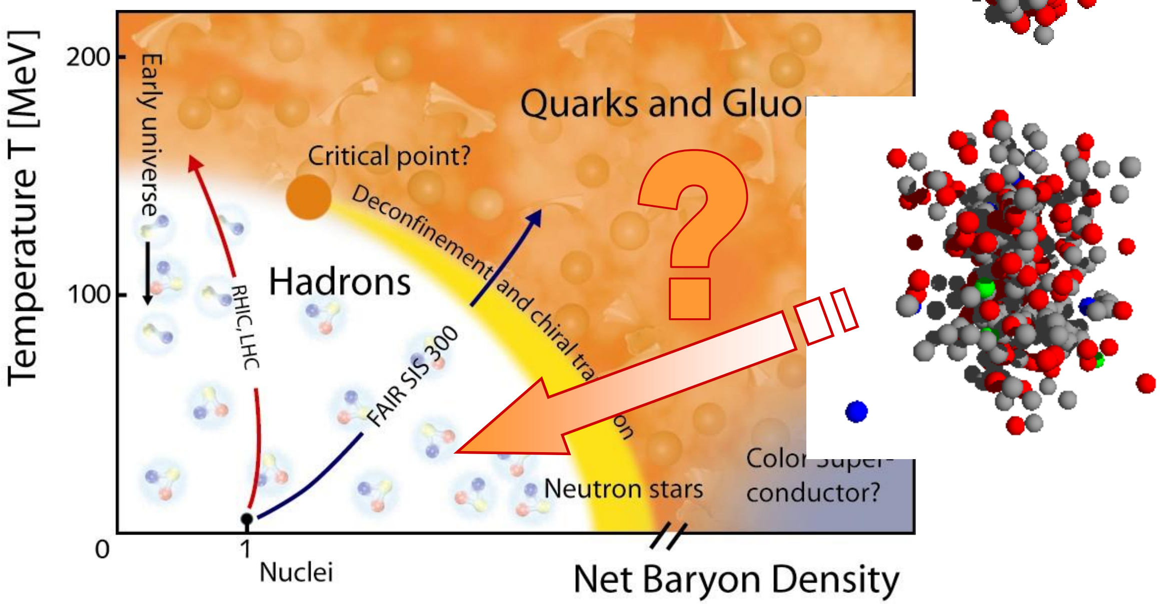
Properties of Dense Baryonic Matter: Status & Perspectives







Outline:

Reaction scenario

- Equilibration?
- Isospin mixing
- Stopping
- Collective flow

Hadronic Probes of Dense Matter

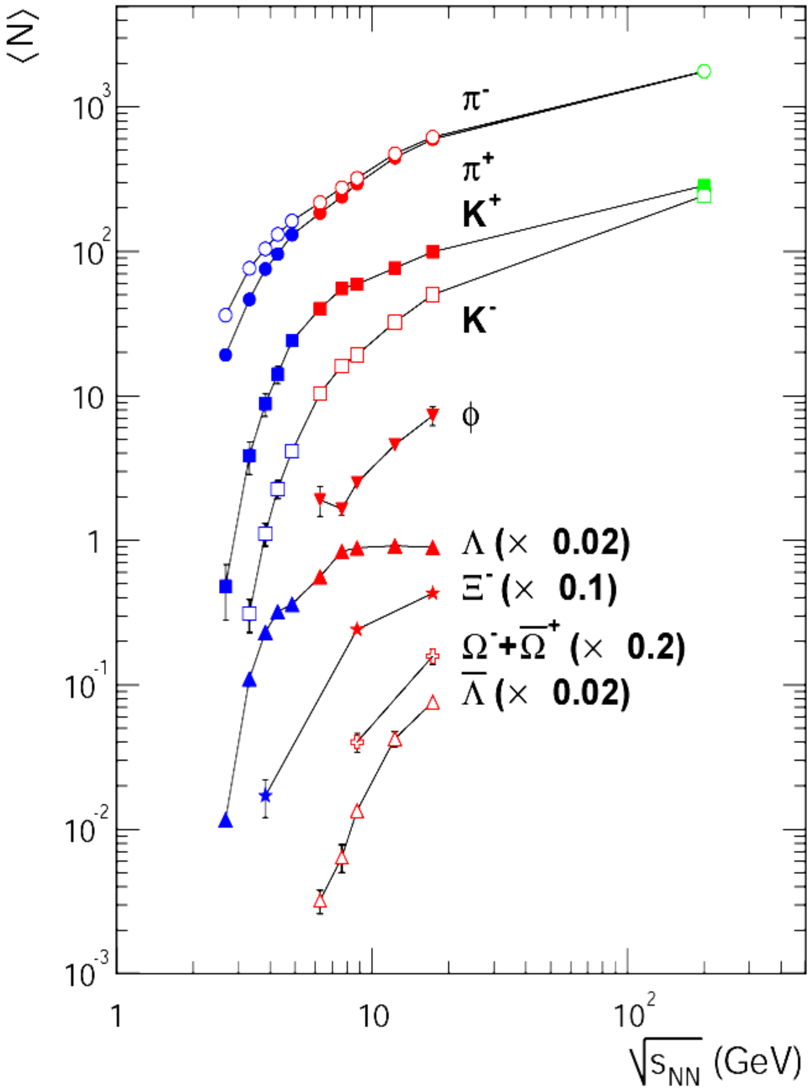
- Medium effects
- Equation-of-State (EOS)
- (Anti) Kaon yields
- Kaon flow
- Strange resonances
- Deeply bound states

Outlook

- FOPI & CBM @ FAIR

Conclusion

Yields & Thermal Model



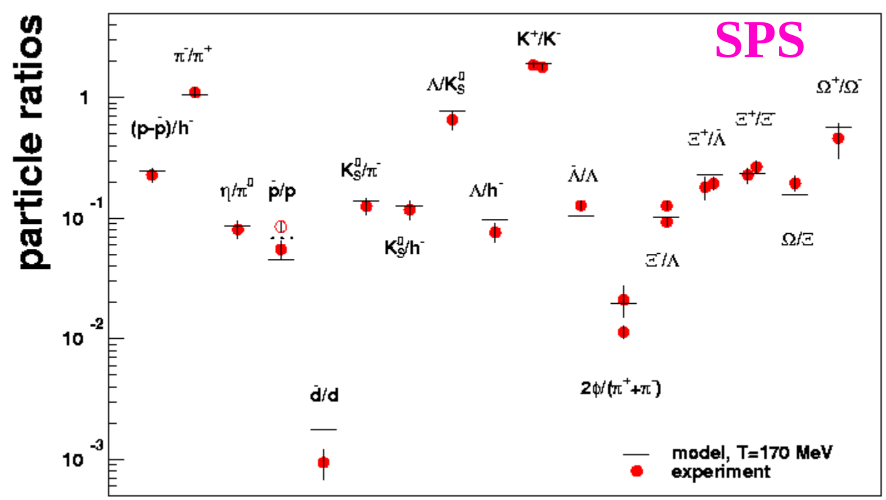
Density of species i (in grandcanonical ensemble) **:**

$$n_i(\mu,T) = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{\frac{E_i-\mu_B B_i-\mu_S S_i-\mu_{I_3} I_{3i}}{T}} \pm 1}$$

Free parameter: chemical potential μ_B, temperature T

Fixed by conservation laws: V, μ_S, μ_{I3}

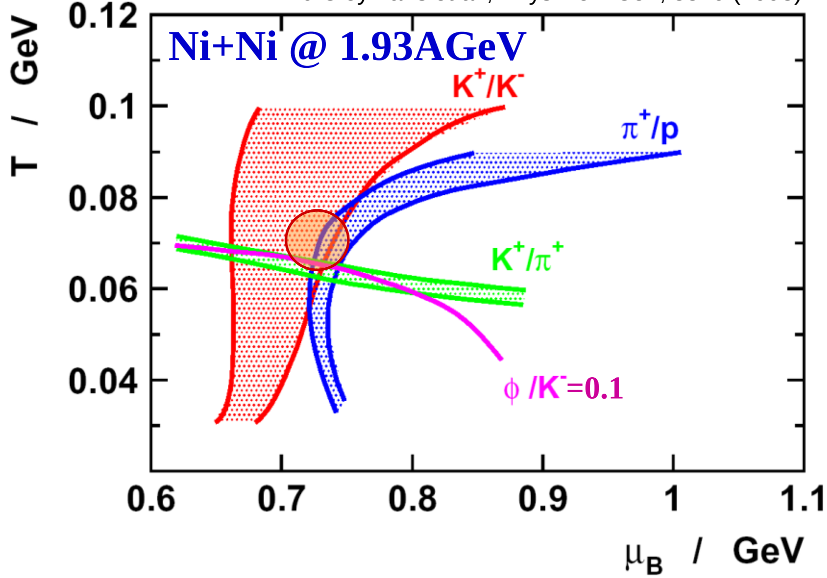
P. Braun-Munzinger, I. Heppe, J. Stachel, Phys.Lett.B465, 15(1999) , *nucl-th/9903010*



Thermal Model ↔ Dynamical evolution

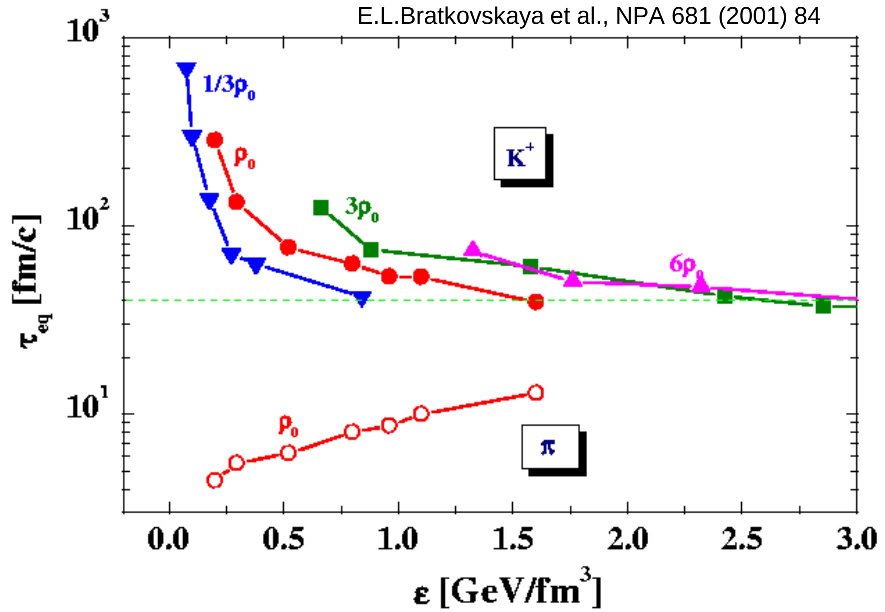
Canonical formulation of thermal model

J.Cleymans et al., Phys.Rev. C57, 3319 (1998)



Chemical equilibration in transport models

E.L.Bratkovskaya et al., NPA 681 (2001) 84



exact strangeness conservation
particle yield: $n_i = n_i(T,\mu_B,V)$
Ansatz is working

$T = 70 \pm 10$ MeV
$\mu_B = 720 \pm 30$ MeV

But: only few ratios available

$\tau_{eq} >> \tau_{reac}$

Equilibrium cannot be reached at SIS energies

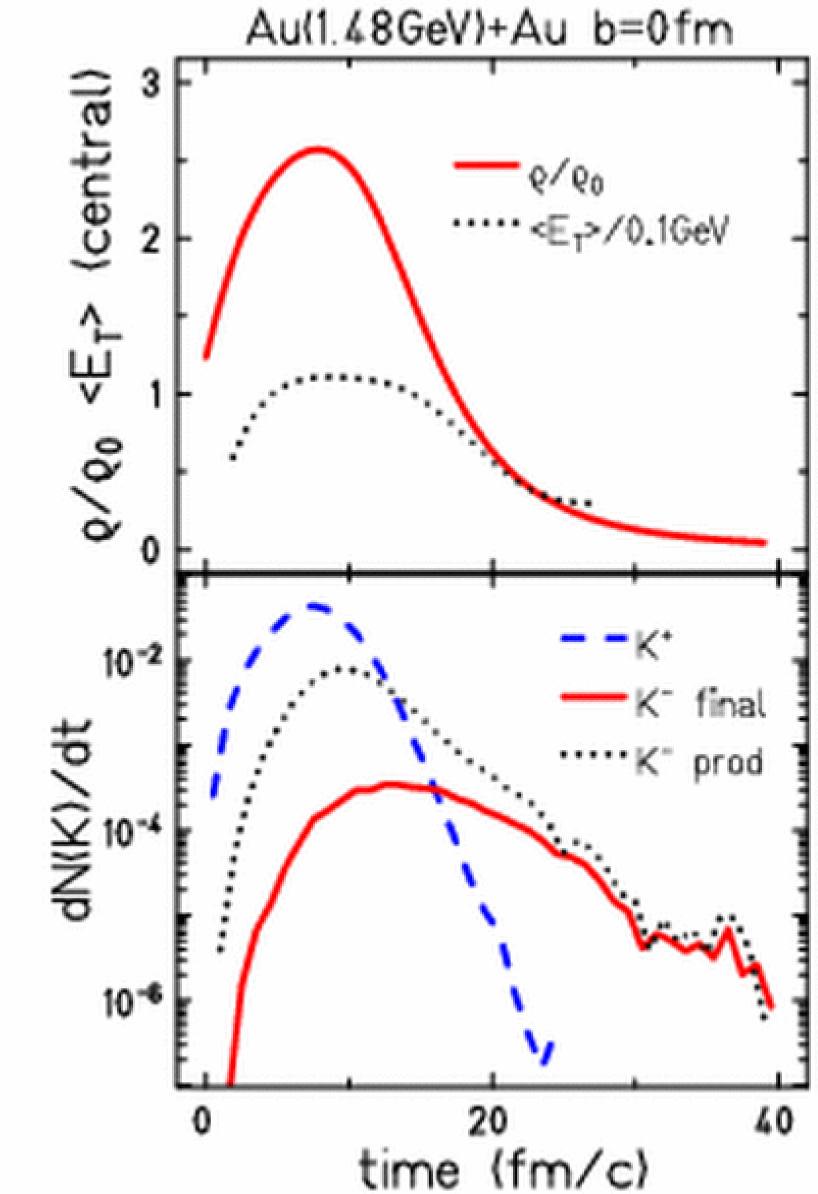
⇓

Sensitivity of particle yields to initial conditions

Thermal equilibrium ⇒ No memory of particle yields to initial conditions

Time scales in HI collisions at SIS

IQMD, C.Hartnack, Nantes



Central density in HI collisions at SIS from transport model calculations:

ρ_{max}=2-3 · ρ_0

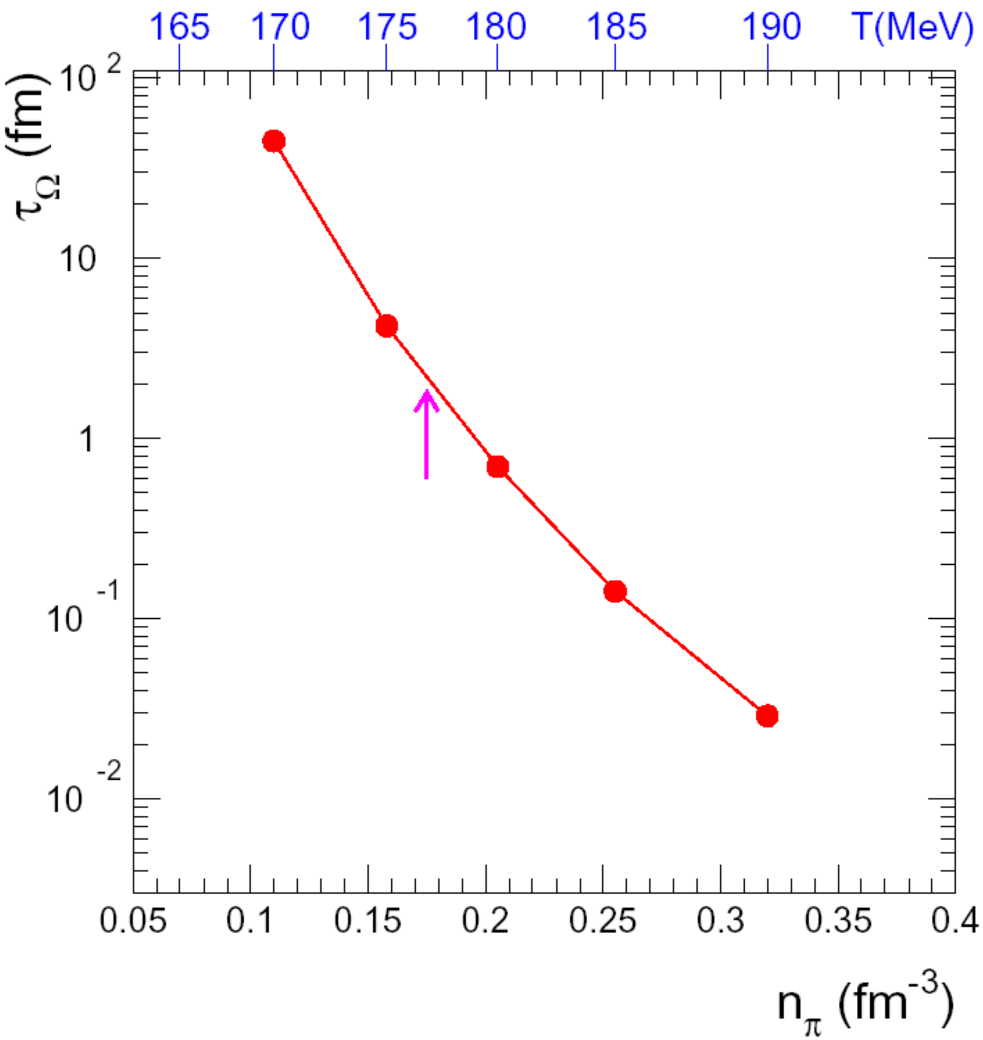
Time duration

t_{reac} ~ 20 fm/c

Different freeze-out times for different particle species

Phase Transition as Equilibration Mechanism

P. Braun-Munzinger, J. Stachel, C. Wetterich, PLB 596, 61(2004), nucl-th/0311005



Close to QGP phase transition:

- **Particle density varies rapidly with T**
- **Multi-particle collisions are strongly enhanced, e.g.**

  $$KKK\pi\pi \rightarrow \Omega N_{bar}$$

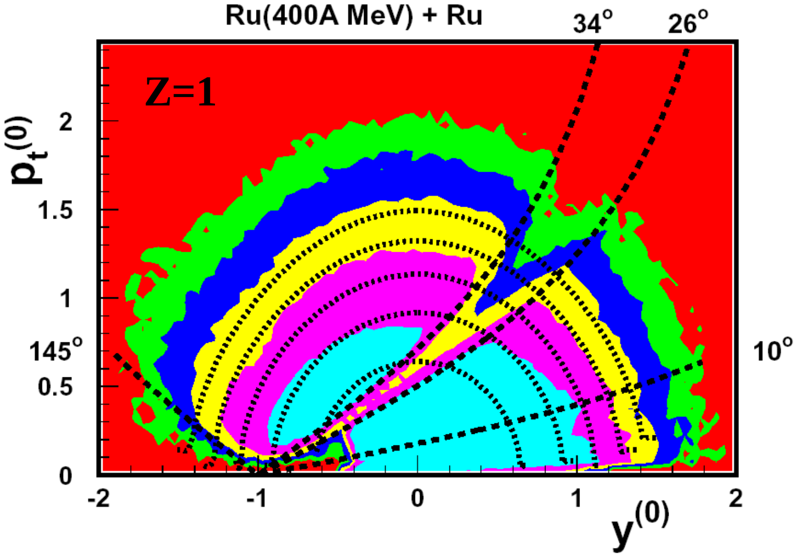
- **Equilibration time: $t \propto T^{-60}$**
- **All particles freeze out within a very narrow temperature window**

Equilibration mechanism at SIS ?

Stopping

Typical phase space distributions for central collisions (b_{geo} < 2 fm)

F.Rami et al., (FOPI), PRL 84, 1120 (2000)

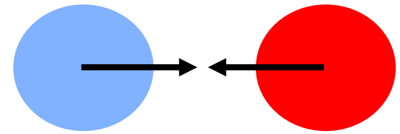


Rapidity distribution looks stooped.

<u>Model independent analysis</u> by comparing proton rapditiy density distributions from equal mass systems under same centrality selection

Possible reaction scenarios:

Initial state:

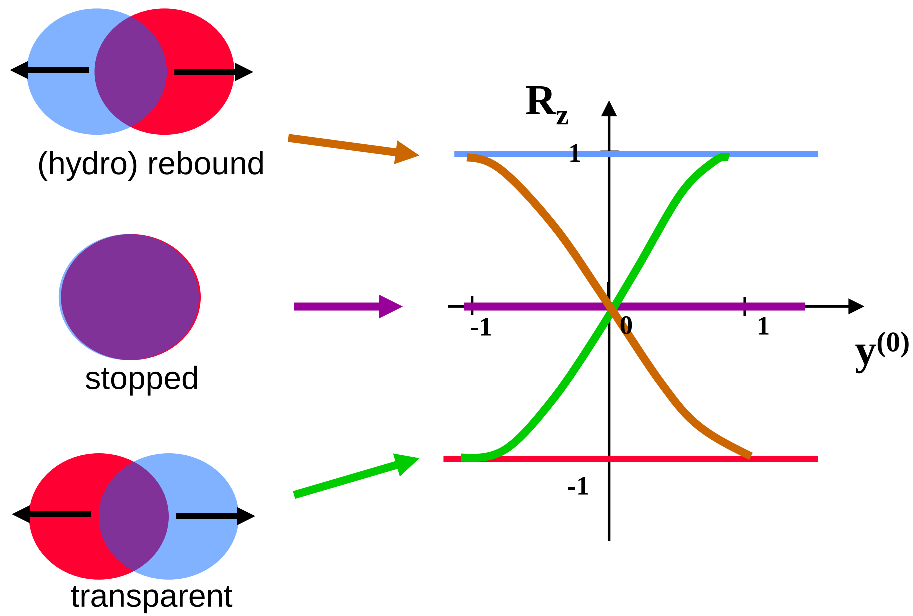


Use isospin as 'color'

$^{96}Zr_{56}$ + $^{96}Ru_{52}$

N/Z=1.4 N/Z=1.18

Final state:

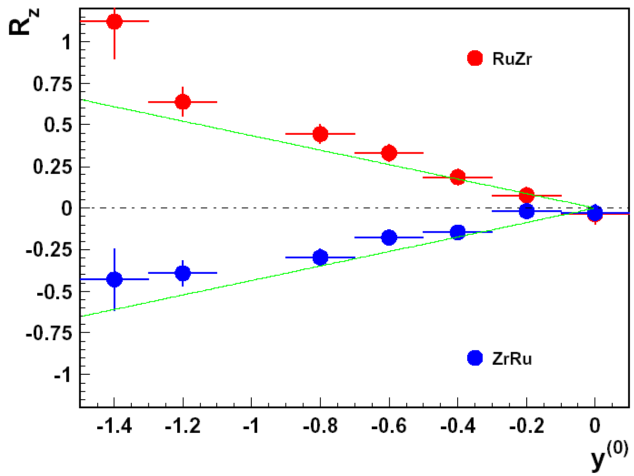


$$R_Z = \frac{\frac{dN}{dy}^{mix} - \frac{1}{2}\left(\frac{dN}{dy}^{ZrZr} + \frac{dN}{dy}^{RuRu}\right)}{\frac{1}{2}\left(\frac{dN}{dy}^{ZrZr} - \frac{dN}{dy}^{RuRu}\right)}$$

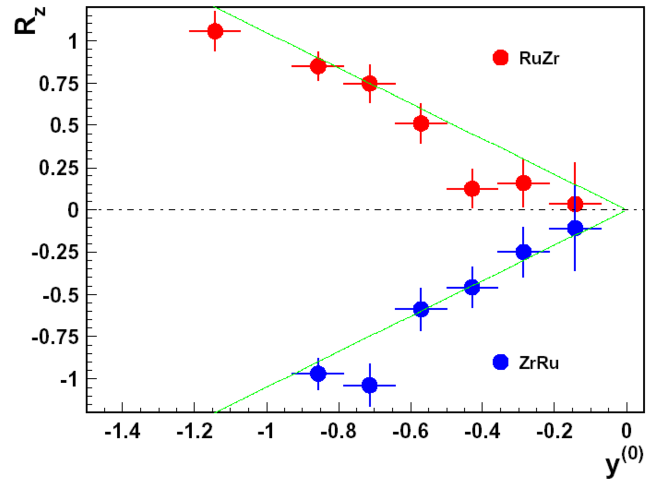
Stopping & isospin mixing in A=96 systems

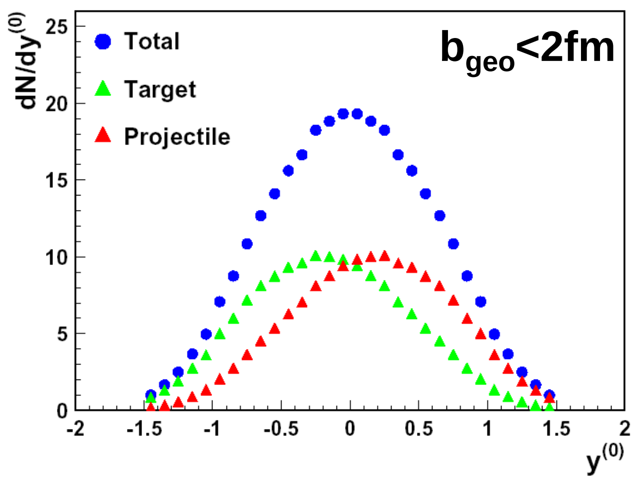
Y.J.Kim (2004)

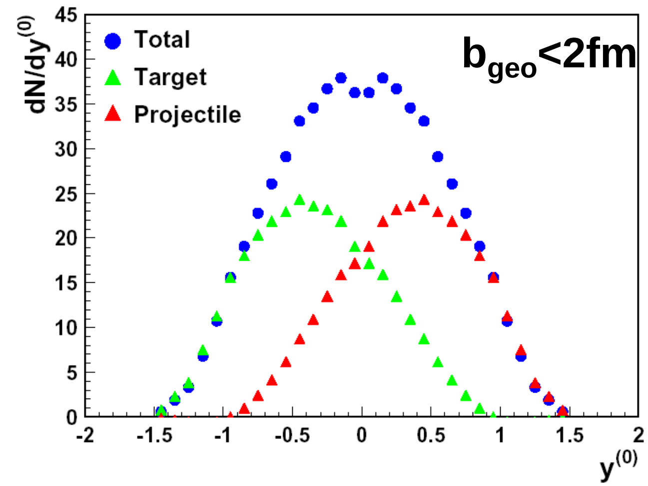
E_{beam}=400AMeV



E_{beam}=1500AMeV





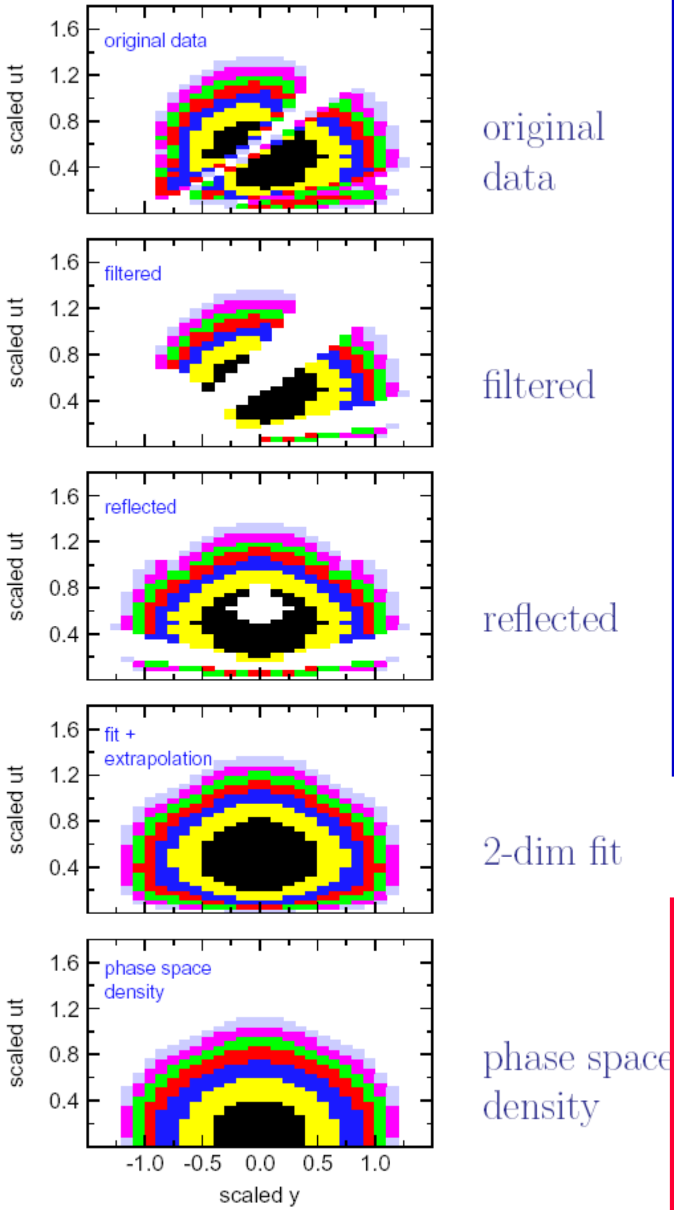


Decomposition of rapidity distribution

$$\frac{dN^{projectile}_{target}}{dy^{(0)}} = \frac{1}{2}\left(1 \pm S \times y^{(0)}\right)\frac{dN}{dy^{(0)}}$$

Mass 100 system is more transparent at 1500 AMeV as compared to 400 AMeV

Excitation function of stopping and flow



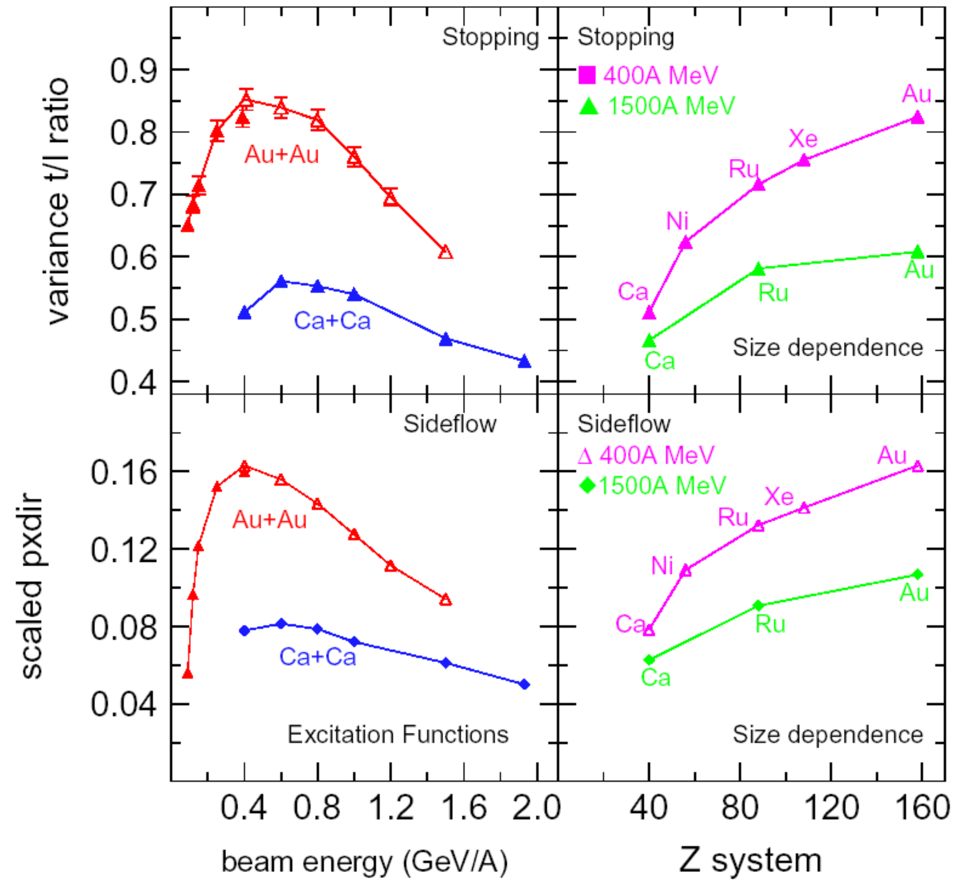
Stopping
$b/b_{max}<0.15$

$$\frac{\sigma^2(y_t)}{\sigma^2(y_z)}$$

Sideflow
$b/b_{max}\approx 0.4$

$$p_x^{dir} = \frac{\sum_i sign(y_i) Z_i u_{xi}}{\sum_i Z_i}$$

W.Reisdorf et al. (FOPI), PRL 92 (2004) 232301

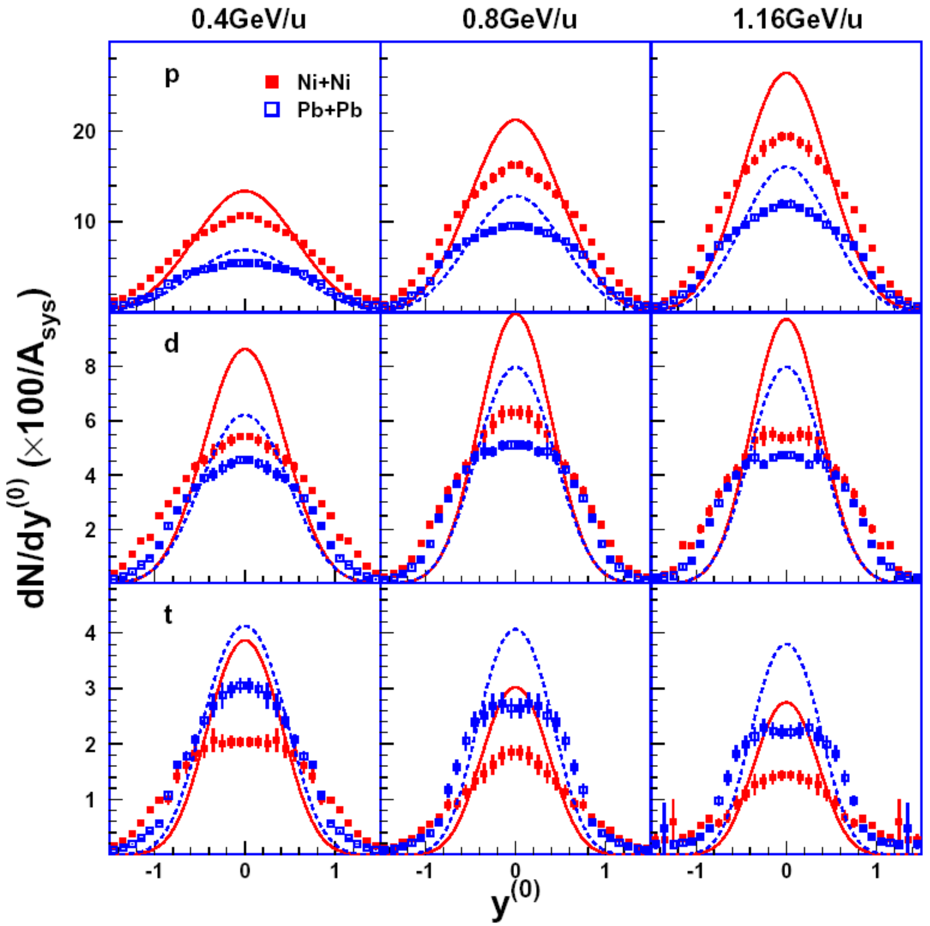


- **Stopping correlated with flow and pressure.**
- **Stopping maximal at 400 AMeV,**
  always below hydrodynamical expectations,
  decreasing toward higher beam energies.
- **Stopping increasing with system size,**
  systems are always transparent.

⇒ Dynamical description necessary ⇒Transport models

Rapidity distributions

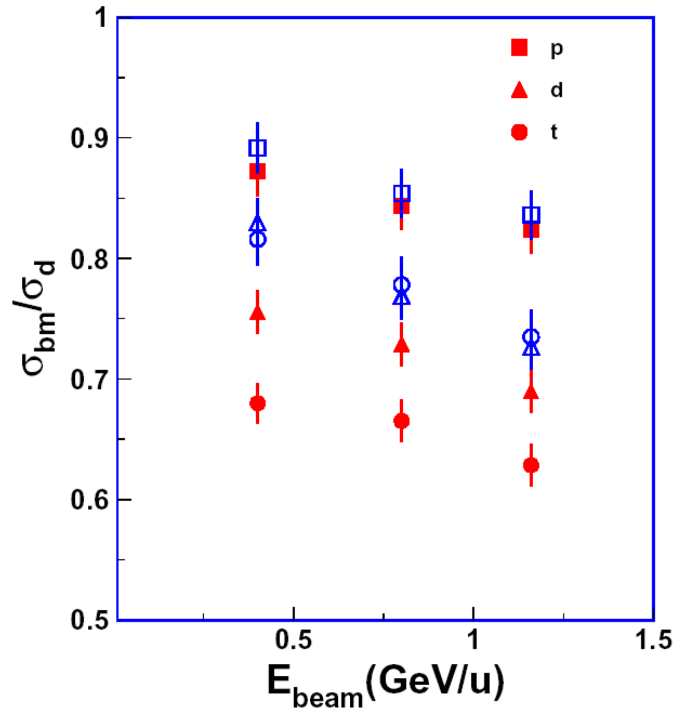
Z. Xiao (FOPI), (2004)



Data: **Pb + Pb**
Ni + Ni

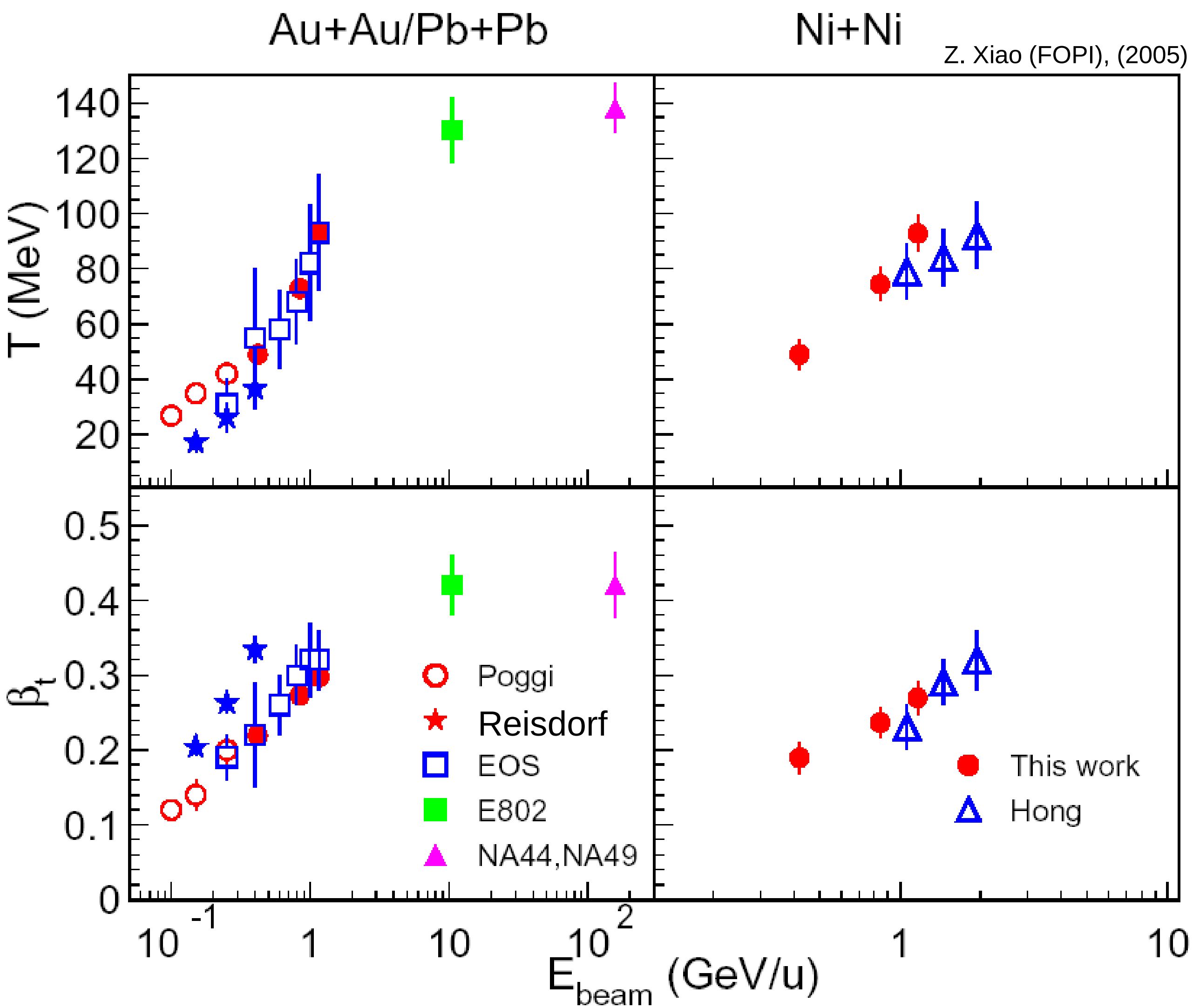
(curves): thermal expectation
from fits to m_t – spectra at midrapidity

Width



Centrality: 3% most central events

Systematics of thermal source parameter



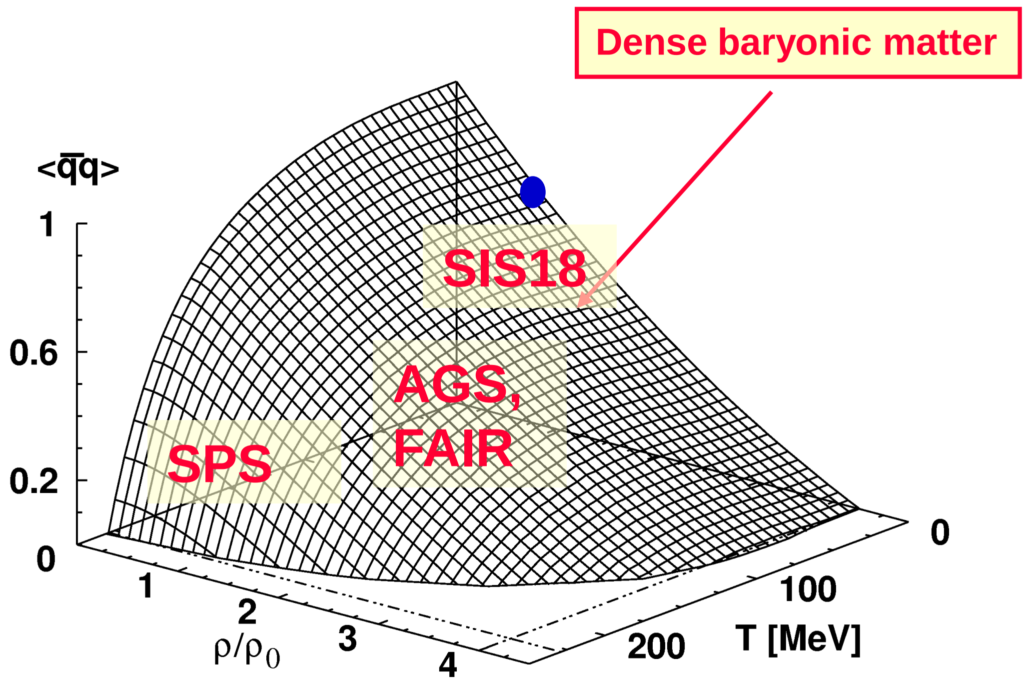
Fit – parameter:

T – kinetic freeze-out temperature
β – average expansion velocity

Top SIS energy:
T ~ 100 MeV
<β> ~ 0.35

AGS energies & above:
Saturation of T and β!

Hadrons in Medium



GOR – relation:

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

Goal:
Modified properties of hadrons in dense baryonic matter?

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

In-medium effects in finite systems:
'Trivial'

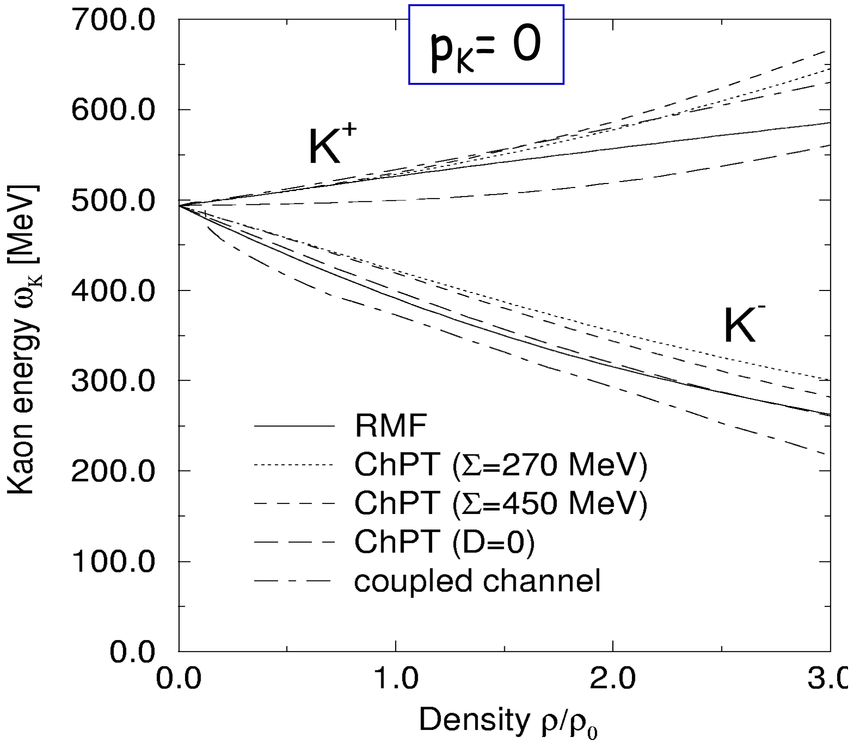
- Fermi motion
- Pauli blocking
- Collisional broadening

'Non-trivial'

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

Kaons in hadronic matter

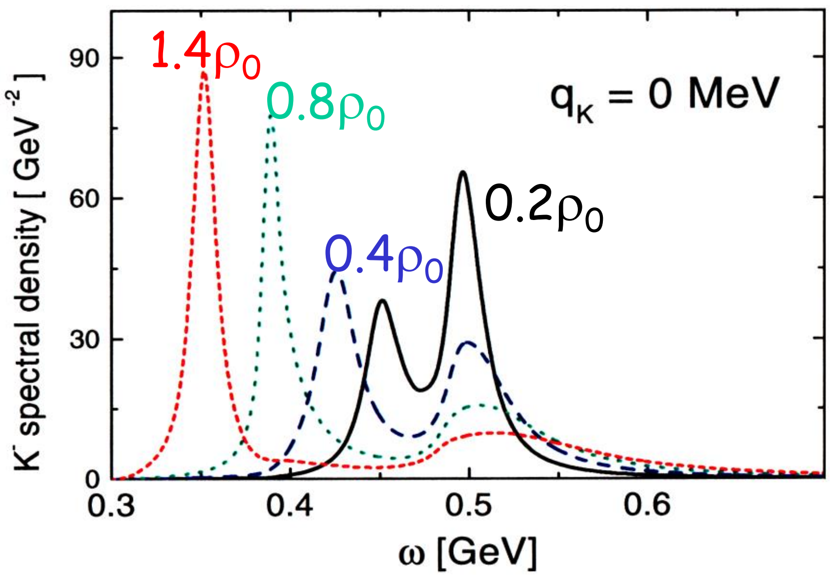
in-medium energy



spectral function of antikaons in dense matter

Coupled channel calculation

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



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

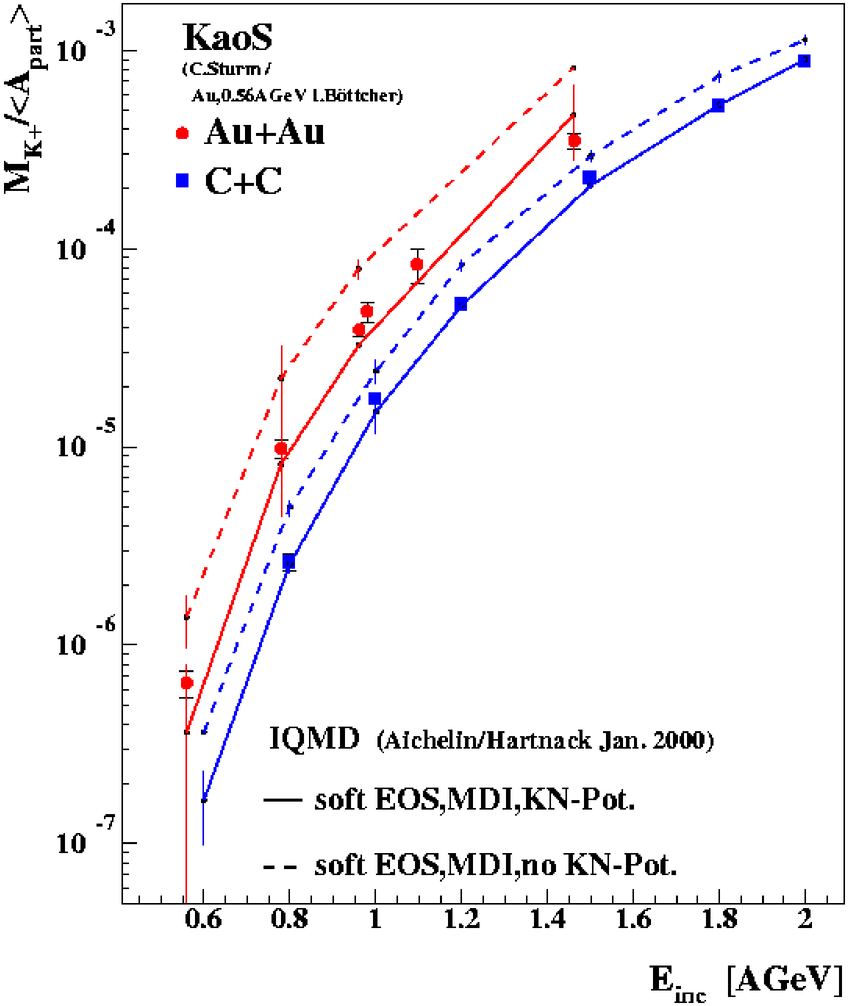
effective mass **Kaon potential**

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

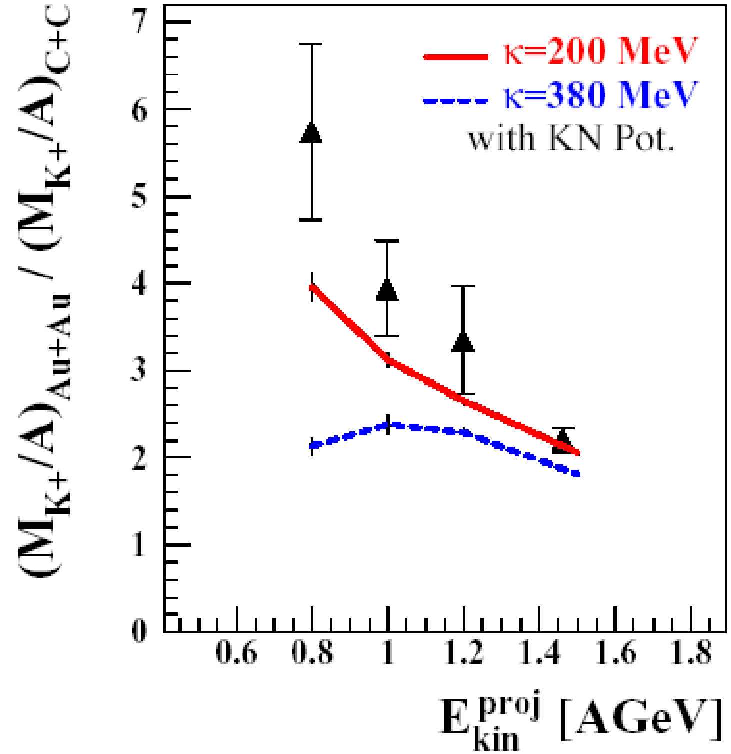
Propagation: F=-∇U → K-flow

Subthreshold Kaon Yields

C.Sturm et al. (KaoS), PRL 86 (2001) 39



C. Fuchs et al., PRL 86 (2001) 1974



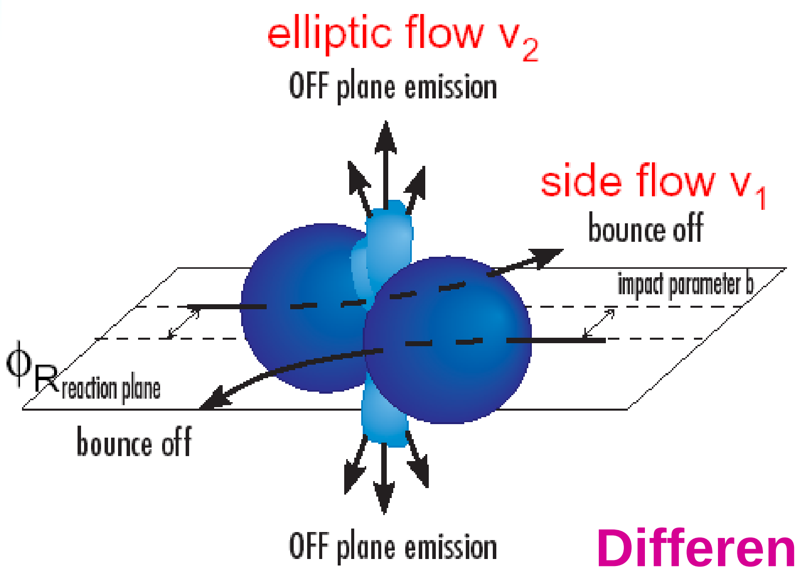
K^+ yield is described only when KN potential is used.

Ratio of yields stable against variation of K^+ production cross section

strong sensitivity to EOS

soft EOS

Medium effects for Kaons



Azimuthal distributions with respect to reaction plane

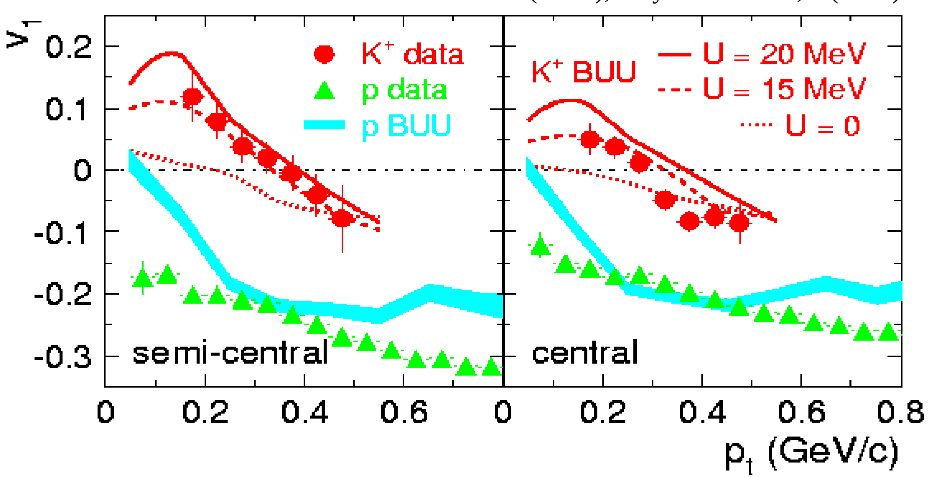
$$\varphi' := \varphi - \Phi_R$$

$$\frac{d^3N}{p_t dp_t dy d\varphi'} \propto (1 + 2v_1 \cos(\varphi') + 2v_2 \cos(2\varphi') + \ldots)$$

Differential sideflow of Kaons:

Ru+Ru @ 1.7 AGeV

P. Crochet et al. (FOPI), Phys.Lett.B 486,6 (2000)



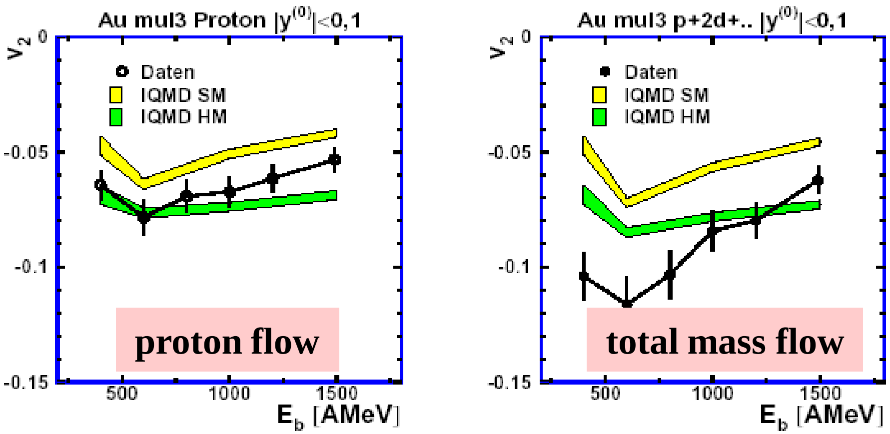
Differential K^+- sideflow

$\Rightarrow U_K(\rho_0)$=15-20MeV by model comparison!

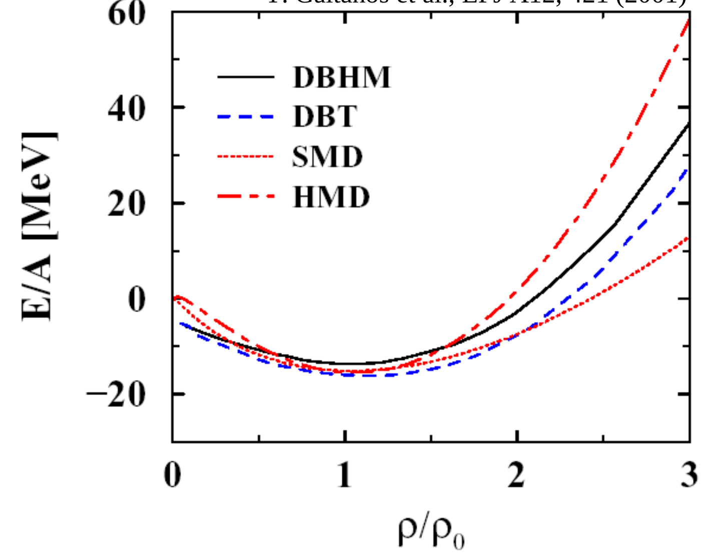
(RBUU – E. Bratkovskaya et al., Giessen)

EoS from elliptic flow (v2) of baryons

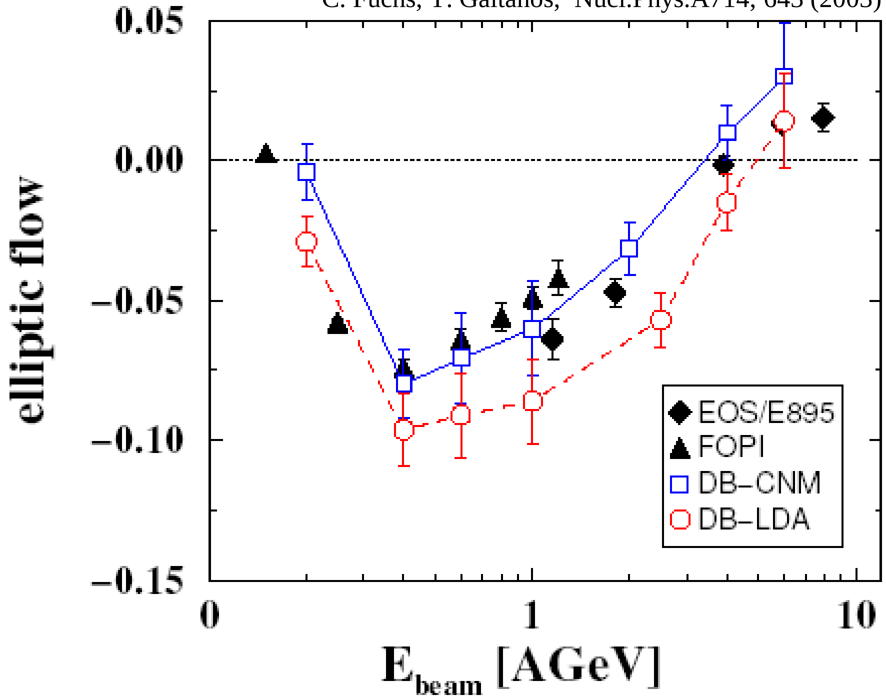
T.Kress (FOPI), PhD thesis, TU Darmstadt (2002)



T. Gaitanos et al., EPJ A12, 421 (2001)



C. Fuchs, T. Gaitanos, Nucl.Phys.A714, 643 (2003)



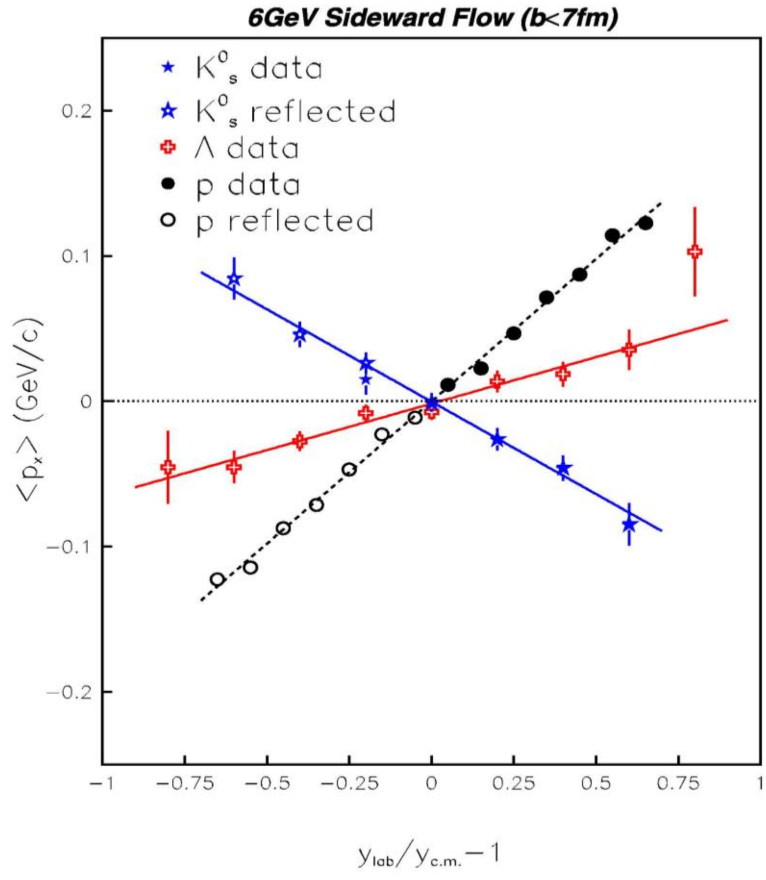
EOS has more degrees of freedom than incompressibility at $\rho=\rho_0$.

Many body theory (relativistic DBHF) generates ‘soft’ EOS with strong momentum dependence.

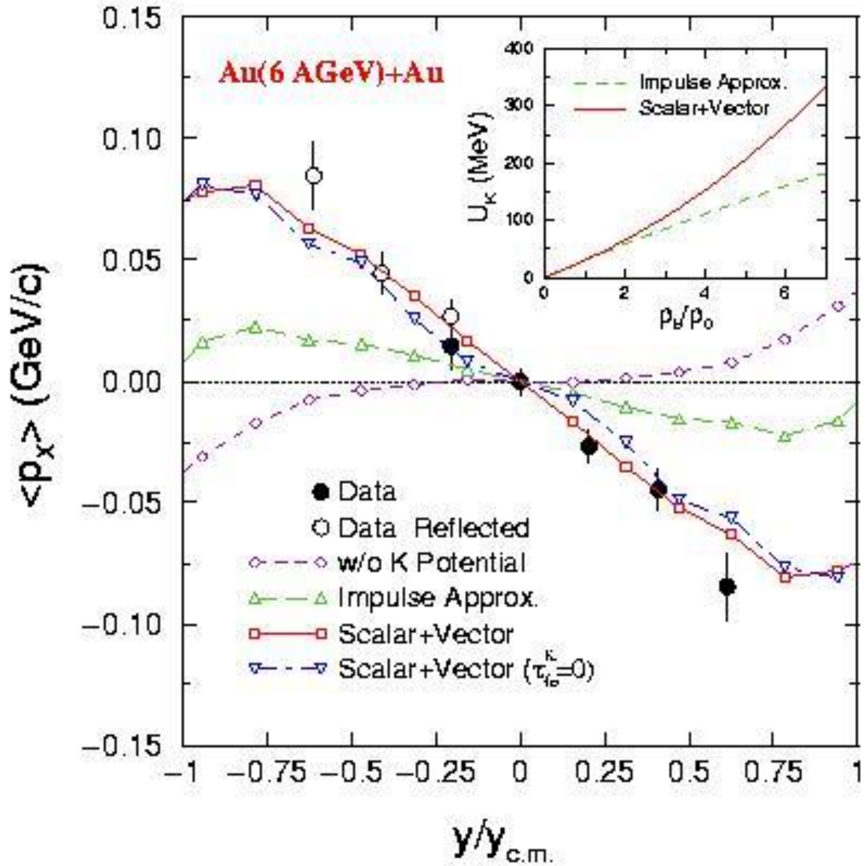
Non-equilibrium implementation important!

Kaon sideflow at 6AGeV

Data: P. Chung et al. (E895), PRL85, 940 (2000)



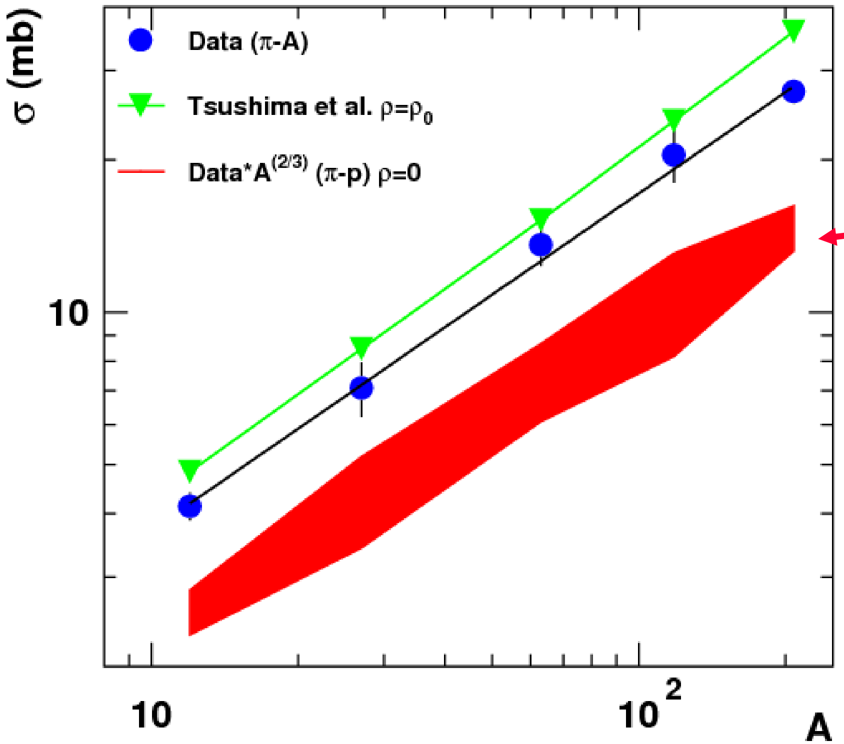
Theo: S. Pal et al., Phys.Rev.C62:061903, (2000)



Very strong Kaon antiflow signal, as big as proton flow!

Evidence for in-medium effect at $\rho=\rho_0$

Inclusive K^0 production in π^- + A reactions at 1.15 GeV/c



$$\sigma(\pi + A \rightarrow K^0 + X) = \sigma_{eff} A^{2/3}$$

Expectation for vacuum cross section

FOPI observed enhanced K0 production.

Model dependent interpretation:

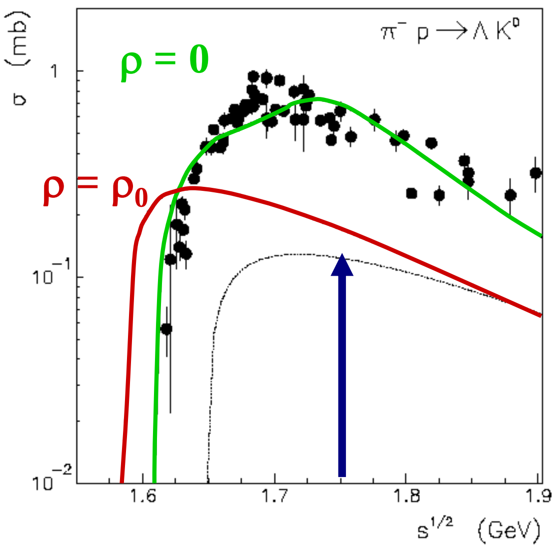
$U(K^0) = +20$ MeV

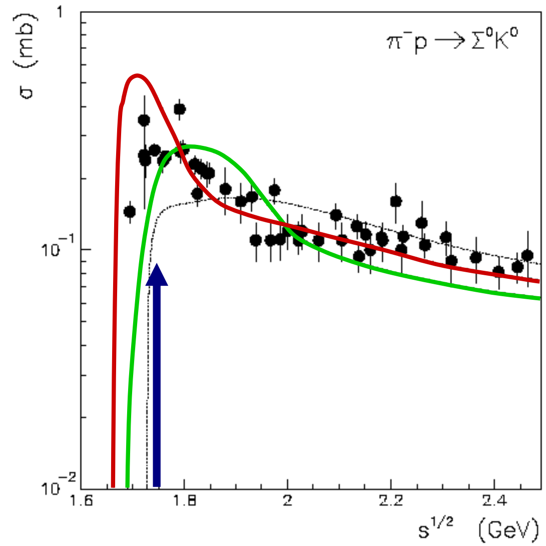
Consistent with heavy-ion data on K^+.

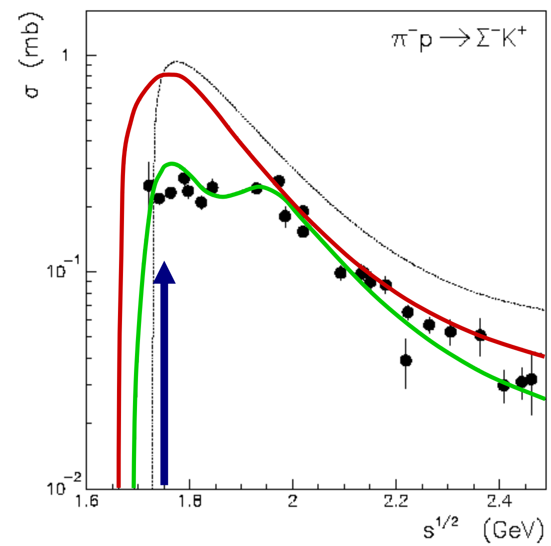
Pion induced strangeness production

QMC – Quark-Meson Coupling Model + Resonance model,
(infinite nuclear matter)

K. Saito, K. Tsushima, A.W. Thomas, hep-ph/0506314





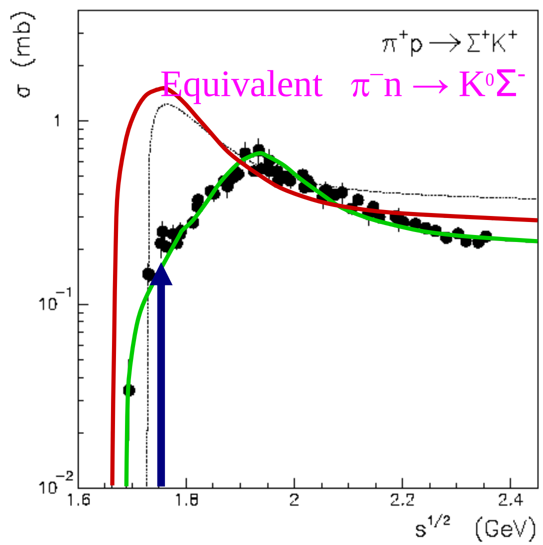


Strangeness production in π^-A reactions:

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

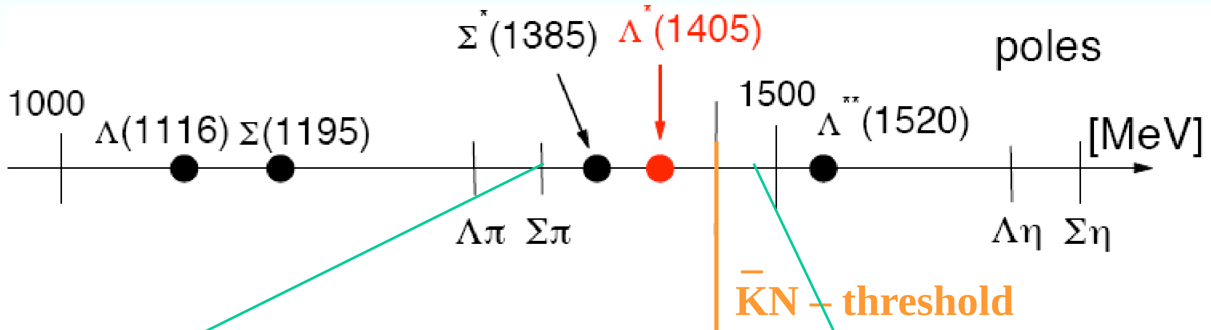
$\pi^- + n \rightarrow \Sigma^- + K^0$
$\pi^- + p \rightarrow \Sigma^- + K^+$

All channels have different density dependence.



Plans:
Confirm picture by new measurement at p_π=1.7 GeV/c ($\sqrt{s}$=2 GeV)
and
by analysing all channels, i.e. K^0, K^+, K^-, Φ and Λ

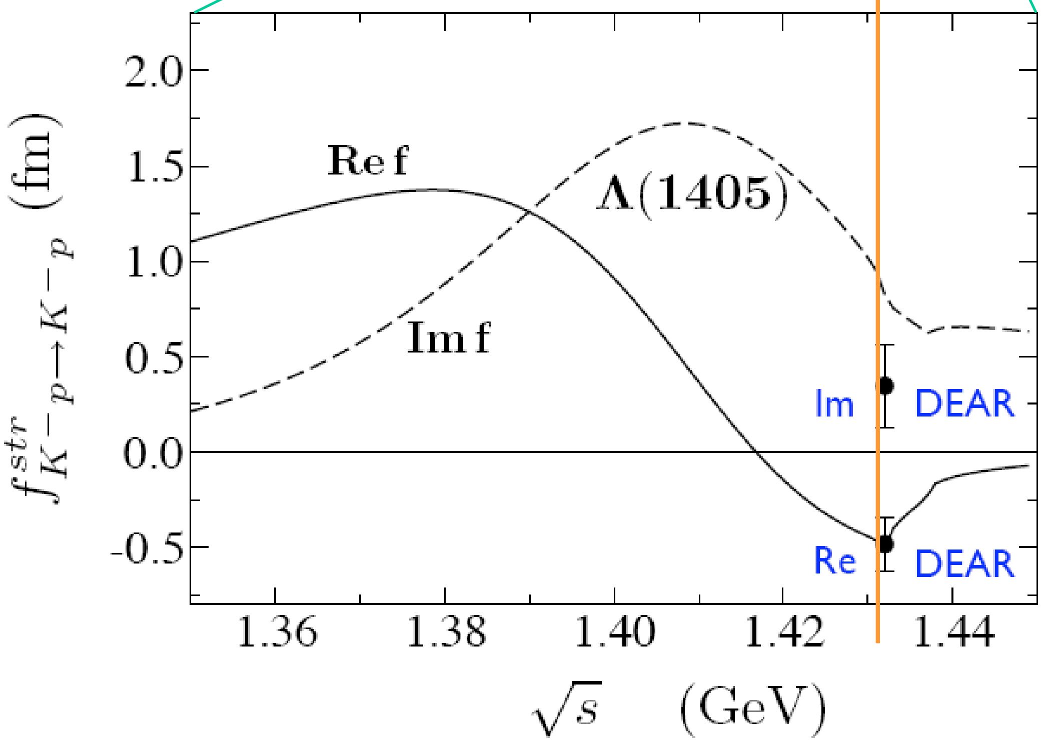
$\bar{K}N$ – interaction



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

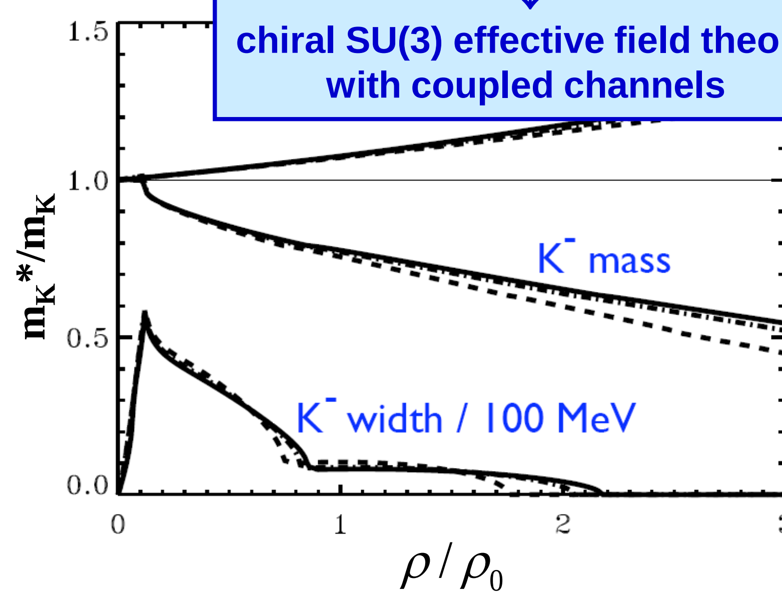
$\bar{K}$ – energy

Scattering amplitude f



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

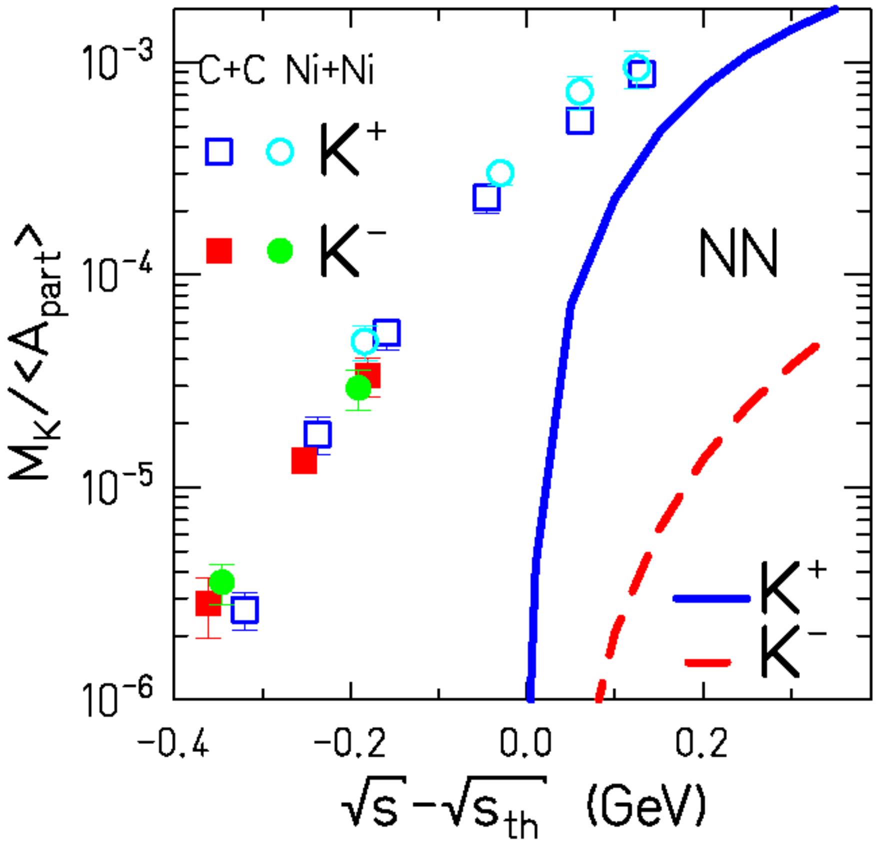
due to presence of resonances
↓
non – perturbative problem
↓
chiral SU(3) effective field theory with coupled channels



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

Antikaon Production at SIS (KaoS results)

P.Senger et al., KAOS
F. Laue et al. , PRL 82, 1640 (1999), updated



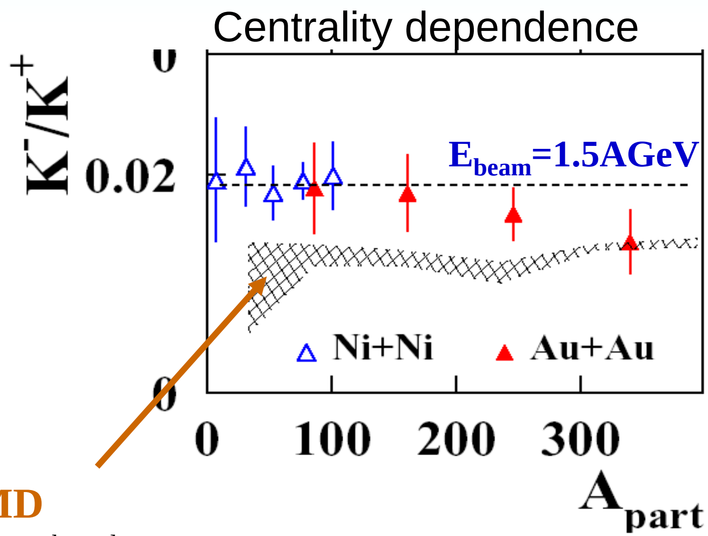
Production thresholds:
NN → $NK^+\Lambda$ E_{lab}=1.6 AGeV
NN → K^+K^-NN E_{lab}=2.5 AGeV

Enhanced production of K^+, K^- observed in HI – coll.

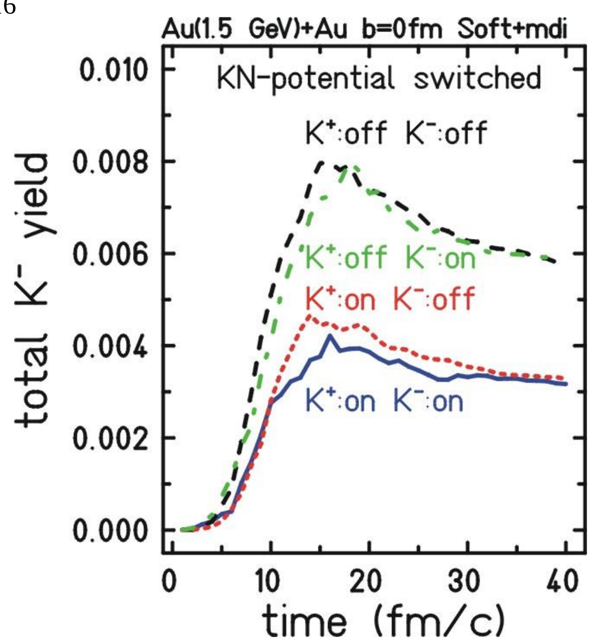
Medium effects (?):
multistep processes: $\Delta N \rightarrow NK^+\Lambda$,
effective mass: $m^*(\rho)$,
equation-of-state: EOS

Antikaon yields and distributions

A.Förster et al. (KAOS), PRL 91, 152301(2003)



IQMD
Ch. Hartnack et al.,
nucl-th/0109016



K^-/K^+ ratio independent of centrality

⇓

Λ - yield is linked to K^+ yield by associated production: NN → NΛK^+

K^- yield linked to K^+ yield by Λπ -> K^-N
↓
K^- yield insensitive to KN - potential

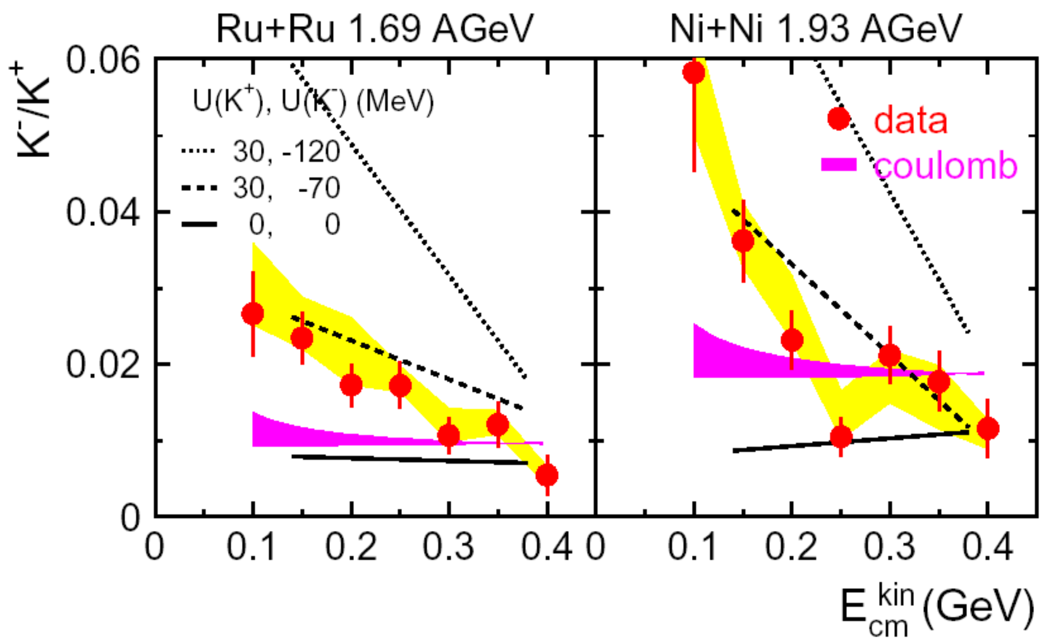
⇓

Other observables,
e.g. differential K^- - distributions needed
to pin down K^-N-potential !

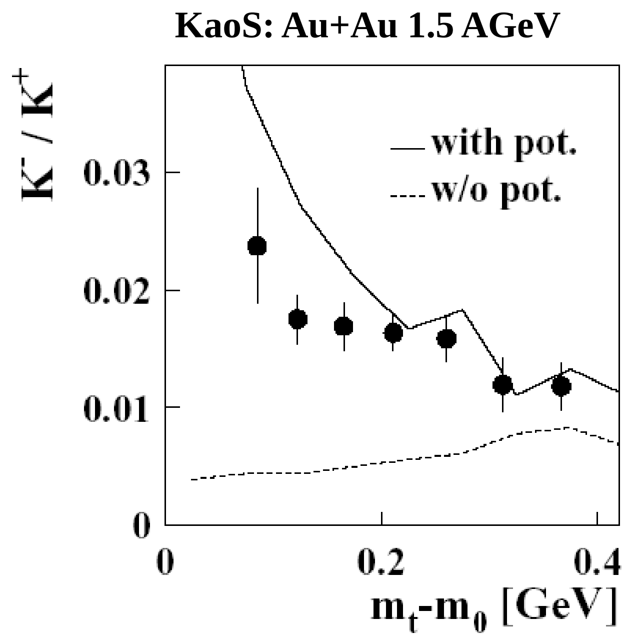
Antikaon phase space distributions

K^-/K^+ ratio

K. Wisniewski et al., (FOPI), Eur.Phys.J.A9,515 (2000)



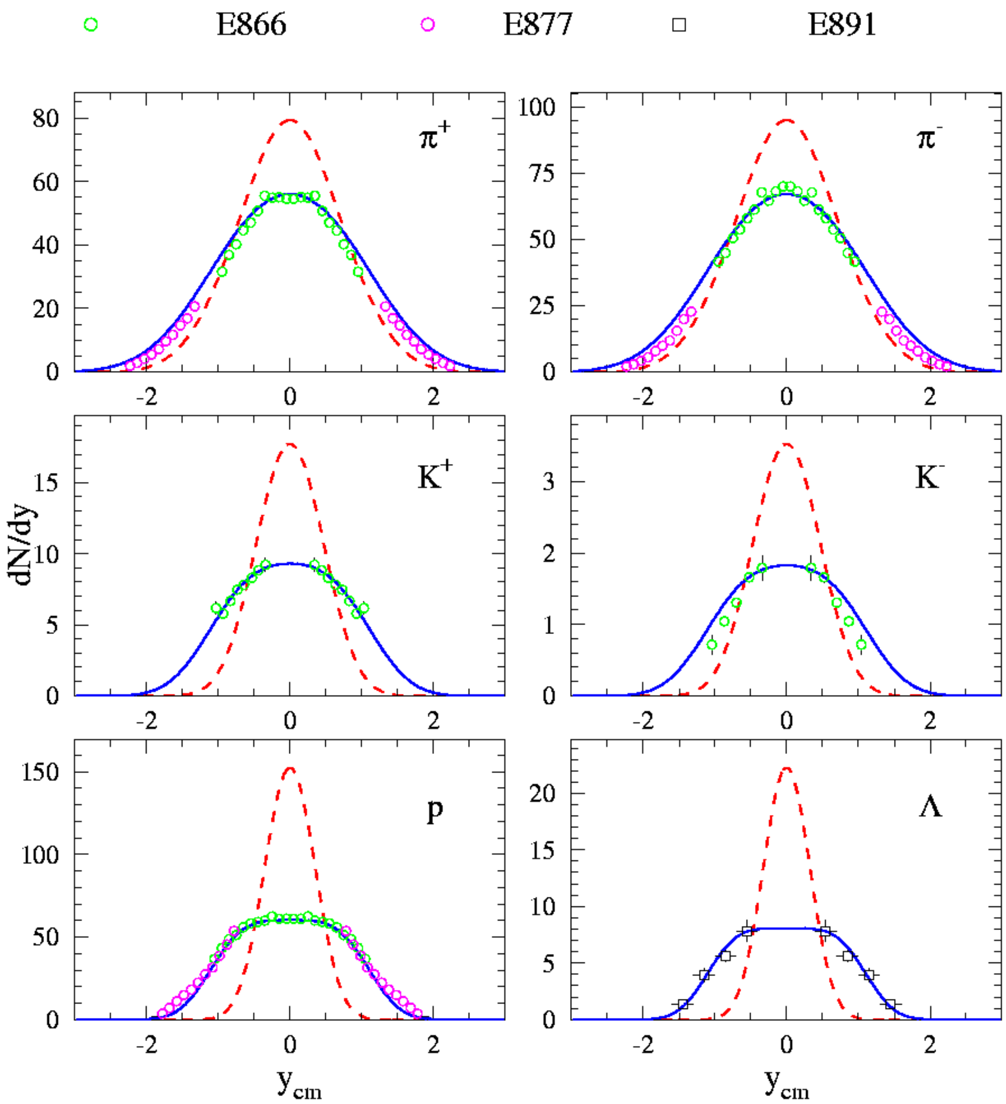
A.Förster et al., (KaoS), PRL 91, 152301 (2003)



K^- phase space distribution different from K^+

⇒ $U_{K^-}(\rho_0)$= - 70 MeV by model comparison (RBUU)

Rapidity distributions @ AGS



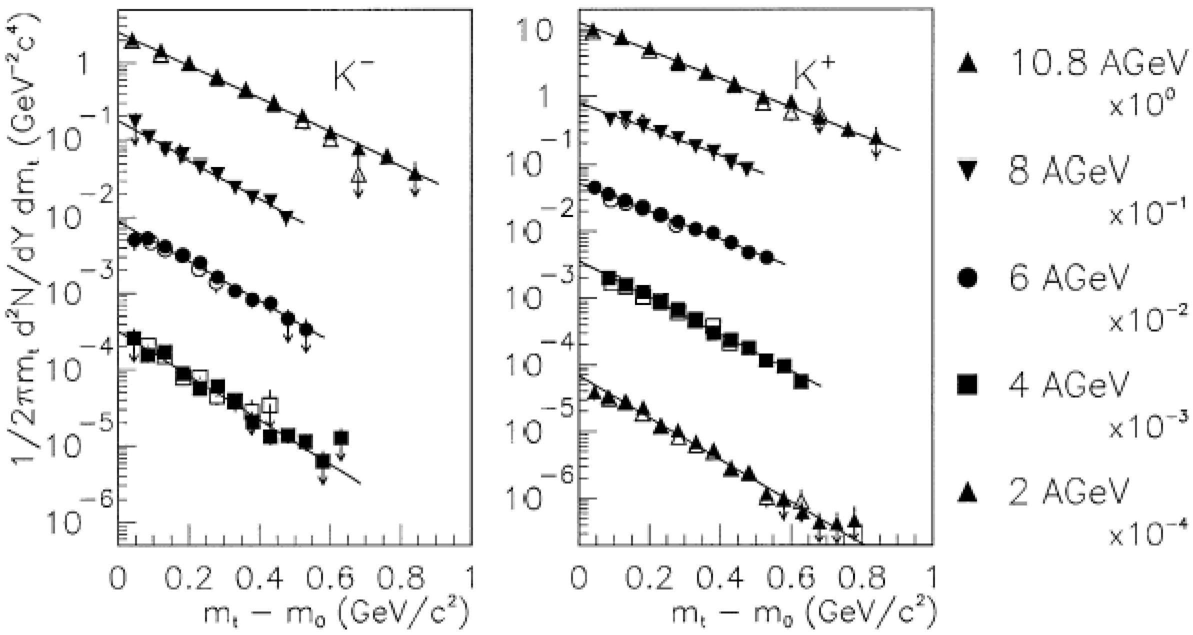
Au + Au @ 10.7 AGeV

Different shapes of the rapidity density distributions for the various species.

Distributions can be described by longitudinal expansion.
(superposition of longitudinally flowing fireballs)

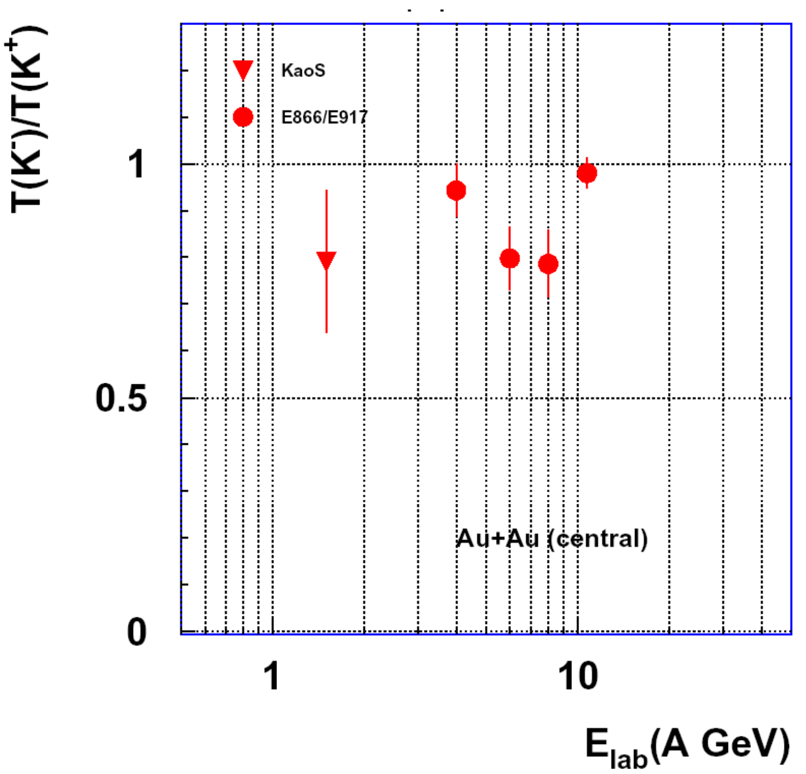
K^- show deviations.

Slopes of Kaon Spectra @ AGS



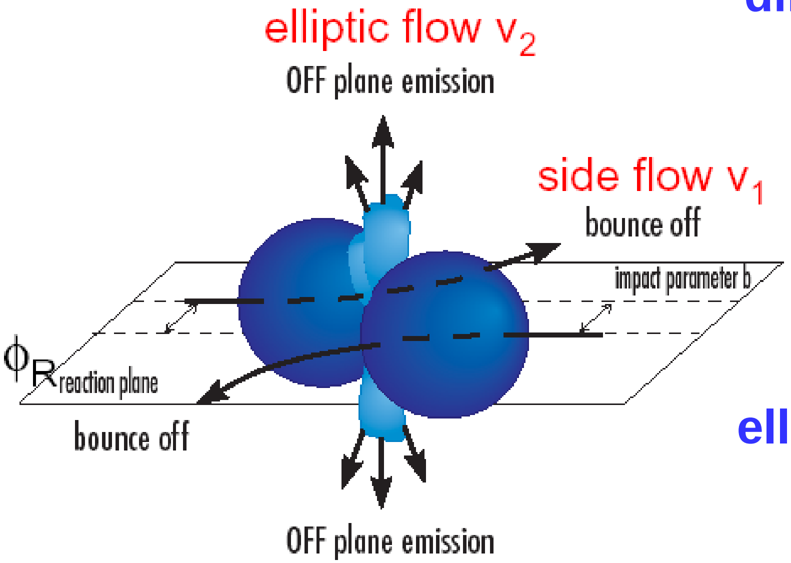
L.Ahle et al. (E866,E917) PLB 490, 53 (2000)

Au + Au (5% most central)



Antikaon spectra are steeper than Kaon spectra.
No clear dependence on incident beam energy.

Kaon – flow measurements

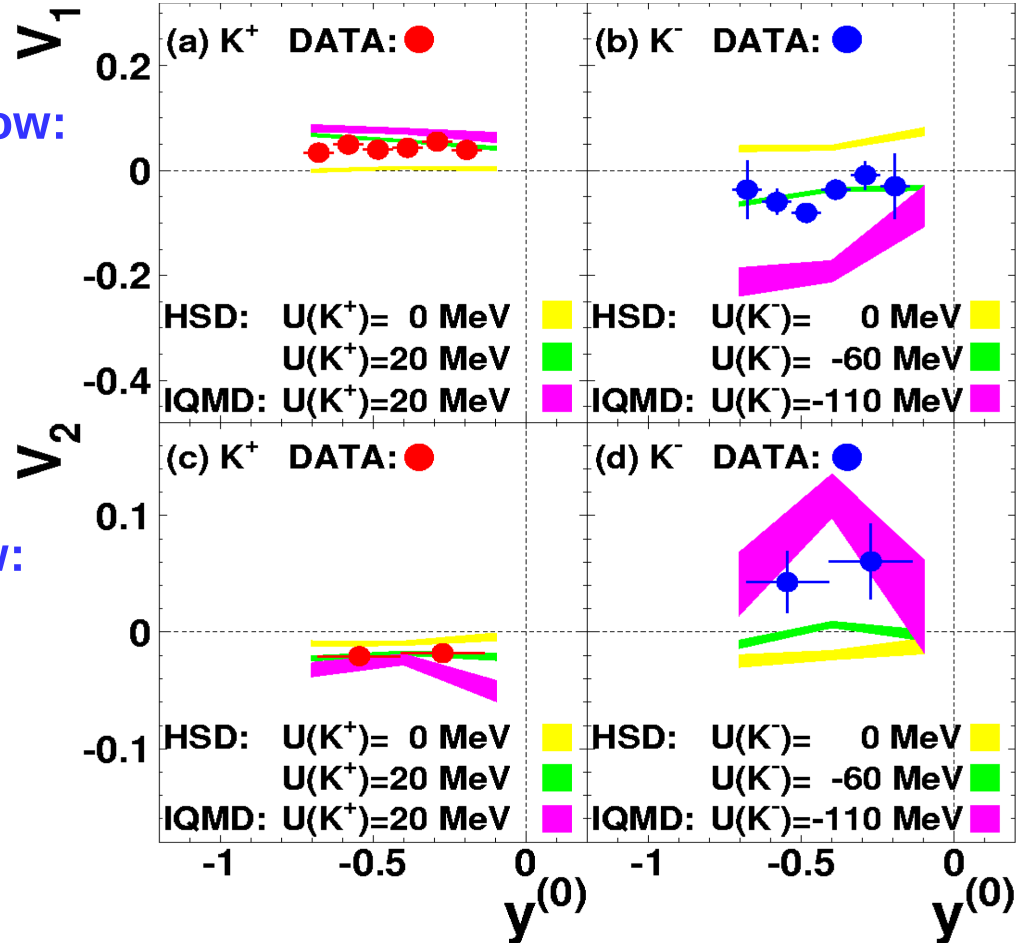


directed flow:

elliptic flow:

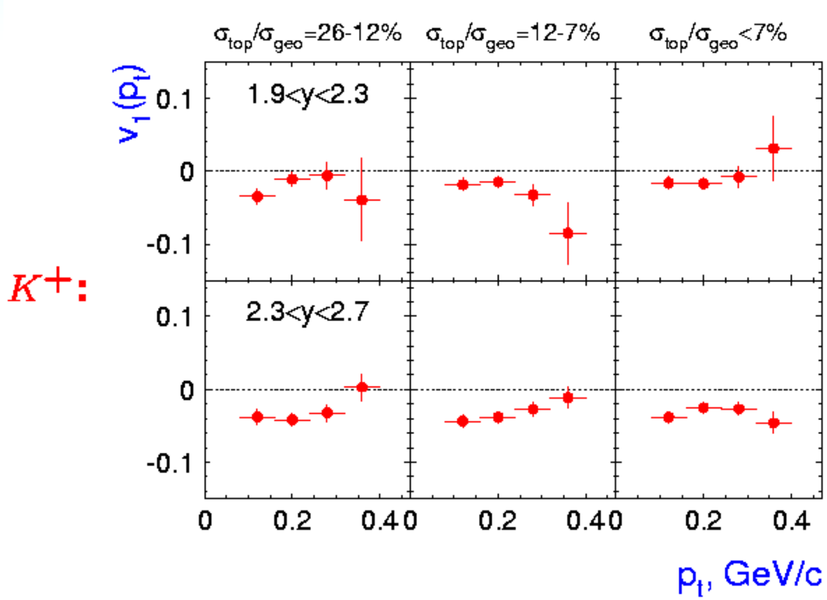
Ni+Ni @ 1.93 AGeV

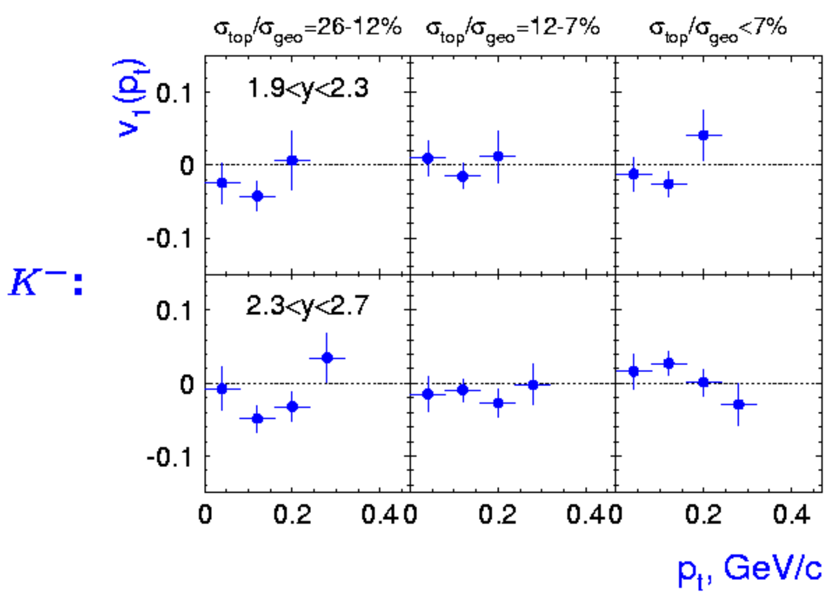
Y.J.Kim (FOPI)



Sensitivity of collective flow to depth of kaon potential.
U(K+) = + 20 MeV,
For K^- no consistent description yet by transport models.
HSD – E. Bratkovskaya et al. (Frankfurt, Giessen)
IQMD – C. Hartnack et al. (Nantes)

Kaon sideflow @ AGS





E877 – Data: Au+Au @ 10.7 AGeV

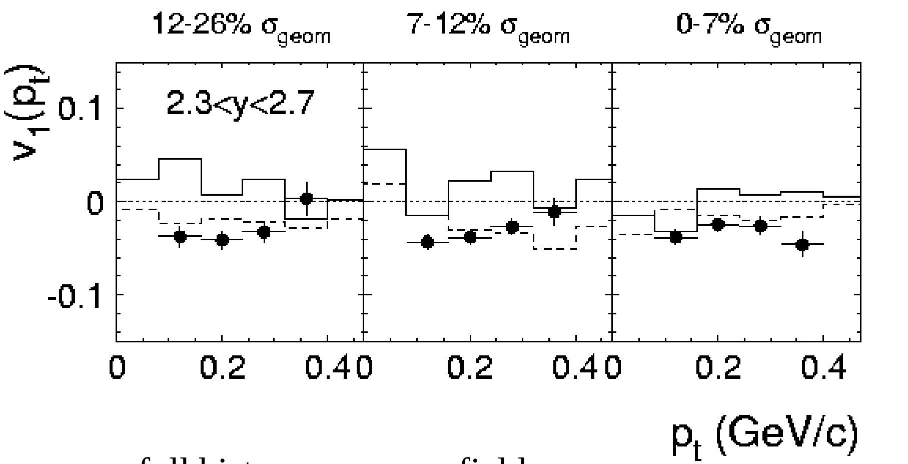
(K.Filimonov et al.)

K^+ show flow, no potential required

K^- ??

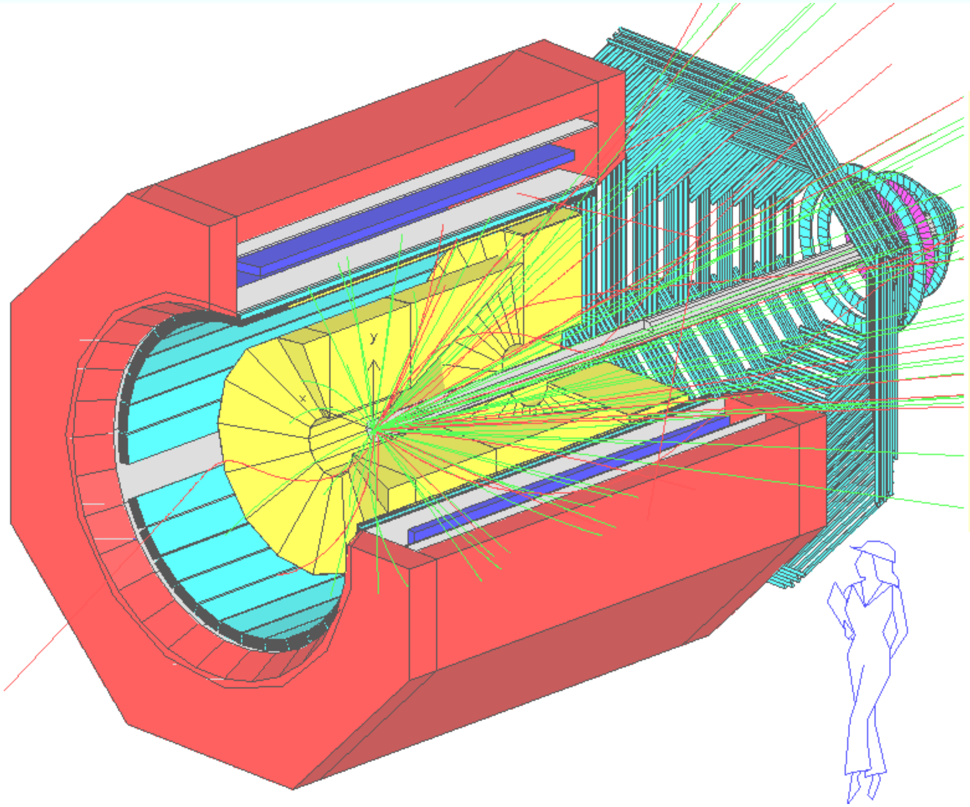
Model comparison to RQMD 2.3

J.Barrette et al. (E877), NPA 661, 379c (1999)
J.Barrette et al. (E877), PRC 63, 014902 (2001)



full histogram: mean field
dashed histogramm: cascade mode

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

ITEP Moscow, Russia
Kurchatov Institute Moscow, Russia
Korea University, Seoul, Korea
IReS Strasbourg, France
Univ. of Heidelberg, Germany
RBI Zagreb, Croatia
+ IMP Lanzhou, China
+ SMI Vienna, Austria
+ TUM, Munich, Germany

+ P. Kienle (TUM), T.Yamazaki(RIKEN)

A.Andronic, Z.Basrak, N.Bastid, M.L. Benabderramahne, P. Bühler, R. Caplar, M. Cargnelli, M. Ciobanu, E. Cordier, P. Crochet, P. Dupieux, M. Dzelalija, L.Fabietti, F. Fu, 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, X. Lopez, A. Mangiarotti, J. Marton, M. Merschmeyer, D. Moisa, D. Pelte, M. Petrovici, F. Rami, V. Ramillien, M.S. Ryu, W. Reisdorf, A. Schüttauf, Z. Seres, B. Sikora, K.S. Sim, V. Simion, K. Siwek-Wilczynska, M. Stockmeier, G. Stoicea, K. Suzuki, Z. Tyminski, K. Wisniewski, Z. Xiao, H.S. Xu, J.T. Yang, I. Yushmanov, A.Zhilin, J.Zmeskal

Goals:

associate production
- Λ – phase space
- strangeness balance

(chemical) equilibration

exotica
- strange multibaryonic states

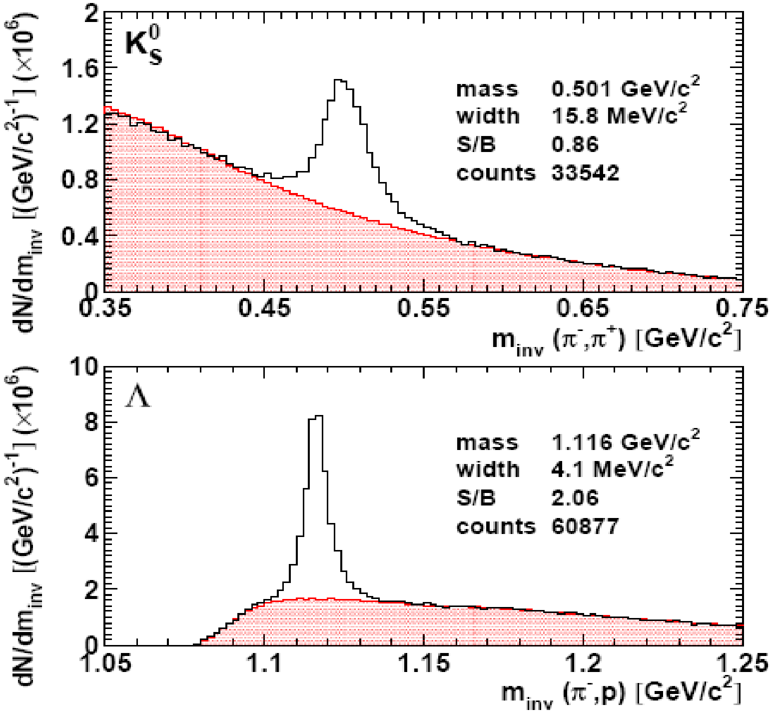
K^0 and Λ measurements

M. Merschmeyer et al. (FOPI), submitted to PRC (2007), *nucl-ex/0703036*

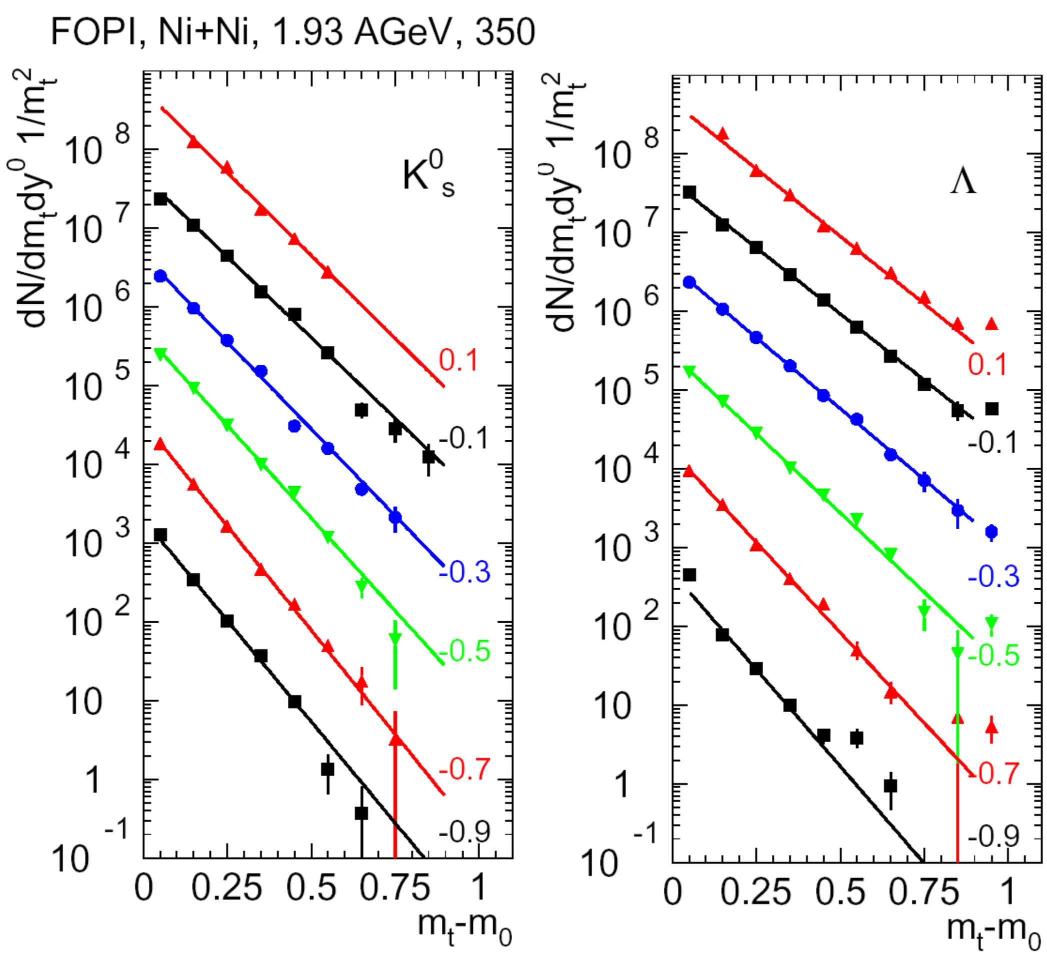
Reconstruction of secondary vertices

~ 60k (100k) Λ in Ni (Al)

~ 30k (60k) K^0 in Ni (Al)



Transverse mass spectra



Typical detection probability

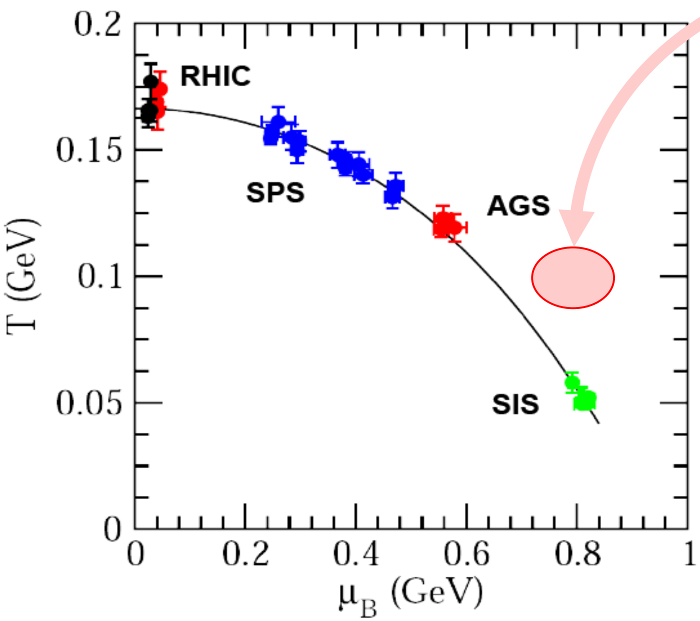
$$P_{det} = P_{prod} \cdot \varepsilon \approx 10^{-1} \cdot 10^{-2} = 10^{-3}$$

Full acceptance coverage of backward hemisphere.

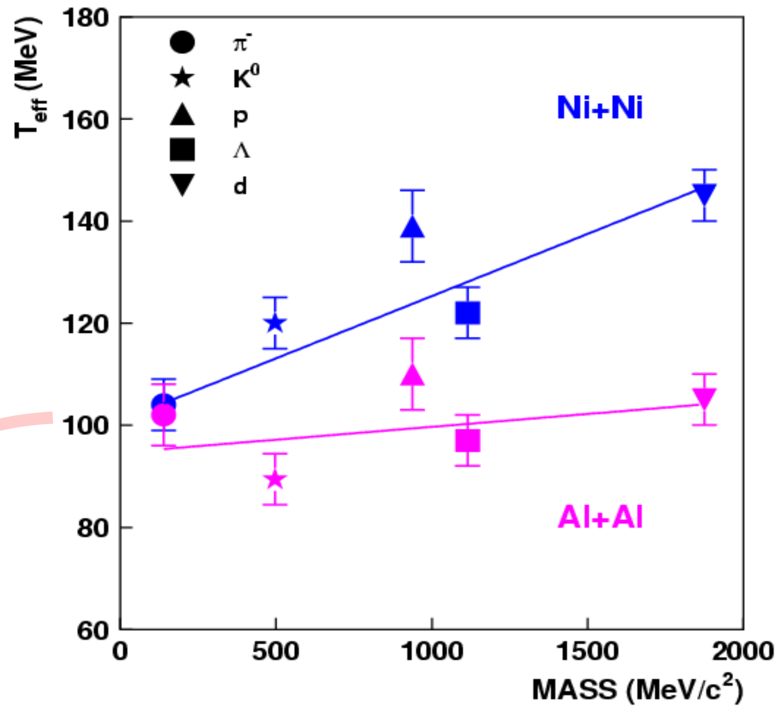
K^0 and Λ measurements

Freeze-out points in phase diagram

J. Cleymans, et al., hep-ph/0511094



Transverse Expansion



No transverse flow in Al system.

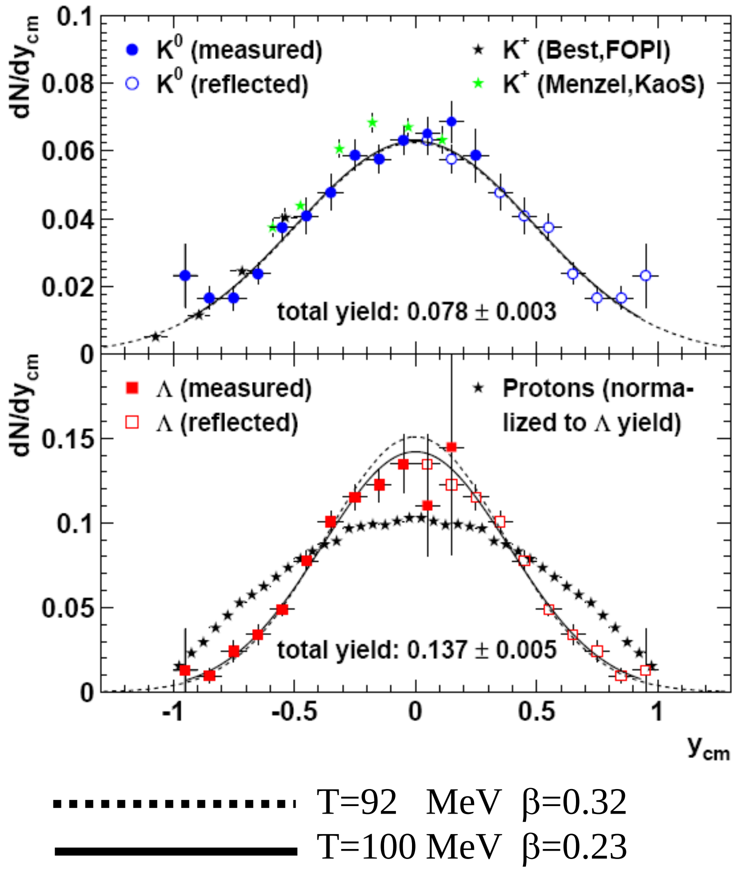
$T_{fo}^{kinetic} > T_{fo}^{chemical}$

Strange particles appear 'cooler'.

Does the chemical equilibration concept hold ?

Need for more particle species!

Rapidity density distributions



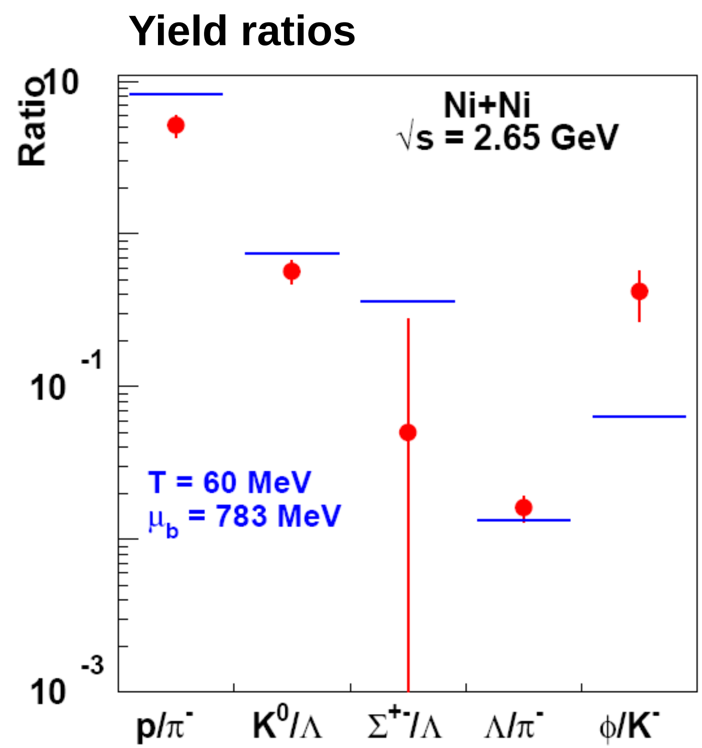
Strange strangeness balance:

$\Sigma^+ + \Sigma^- = K^+ + (K^0 + \bar{K}^0) - (\Sigma^0 + \Lambda) - 3K^-$

$= 0.007 \pm 0.008$ (stat.) ± 0.032 (syst.)

very small!
low T?

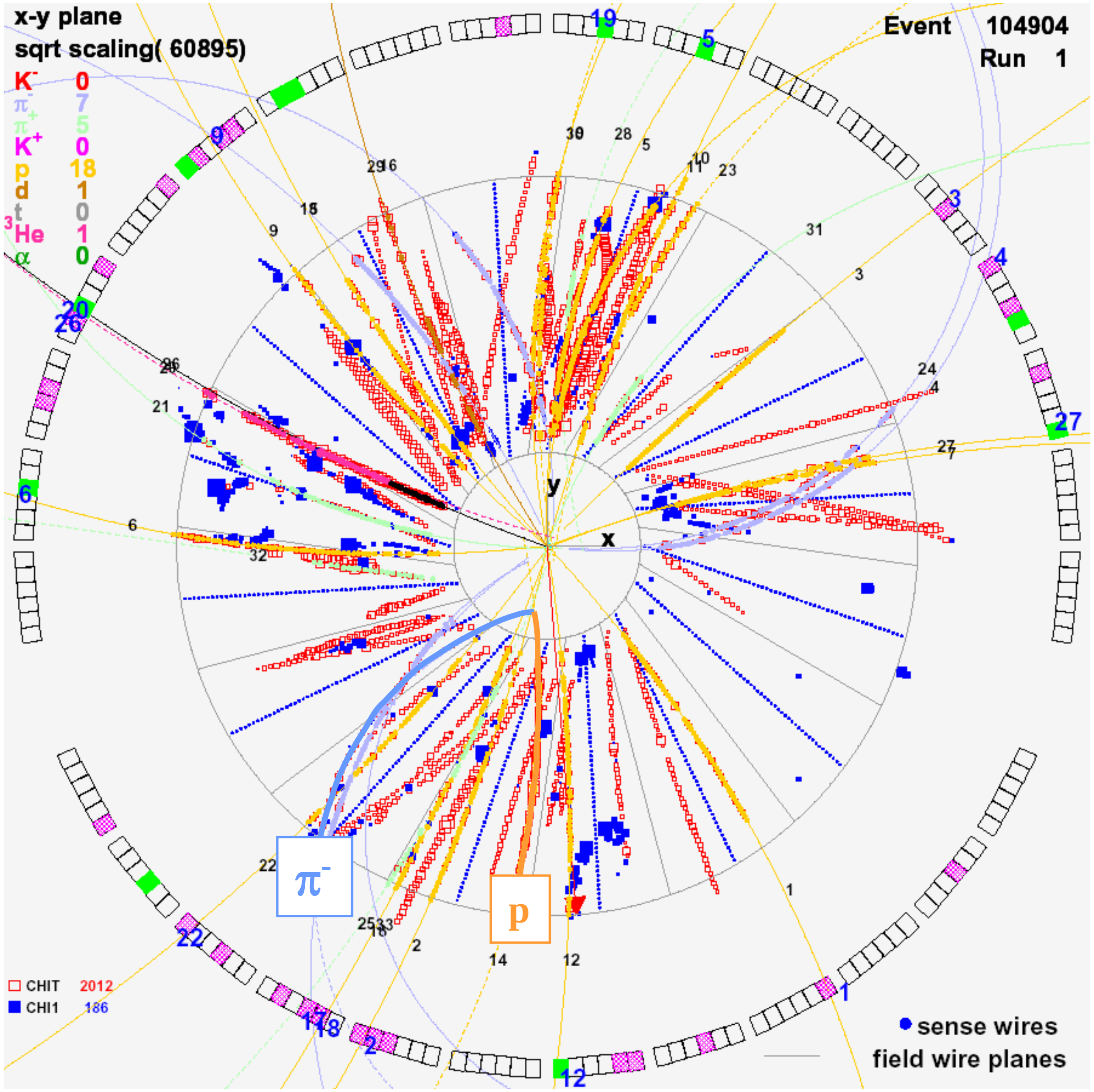
No kinetic equilibrium between Λ and proton.

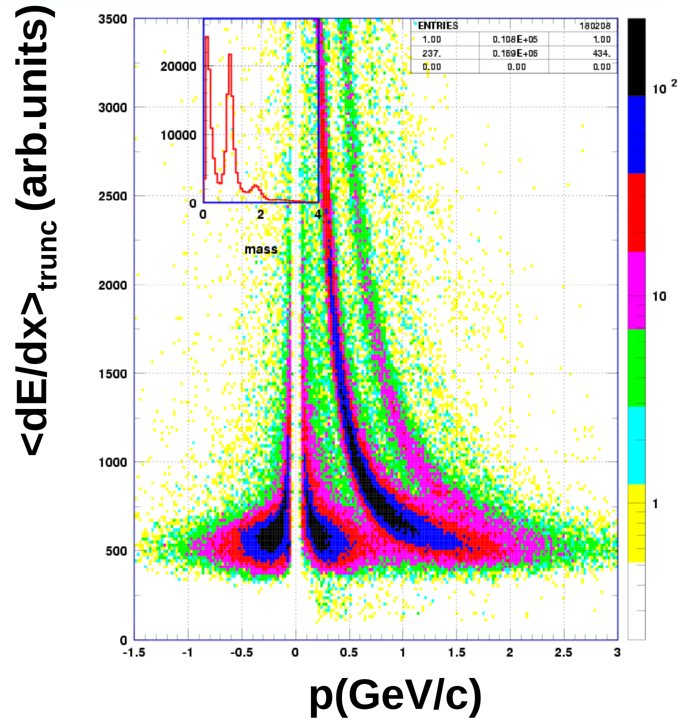


Equilibrium interpretation doubtful.
Non – equilibrium allows for sensitivity to high density phase.
Interpretation needs complete transport models.

Identification of strange baryons with FOPI

Ni+Ni @ 1.93 AGeV (2003)





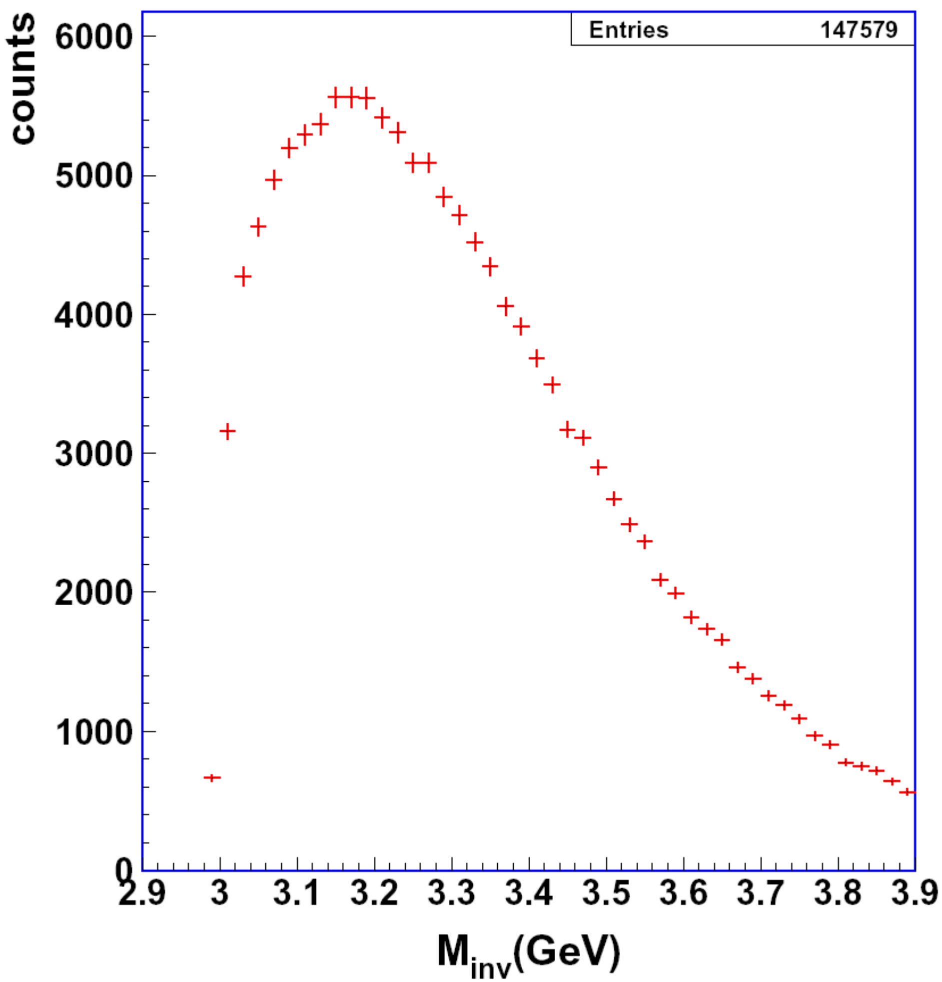
Analyze Λ and Λ – X correlations
X=$\pi^{\pm}$,p,d,t,h,…

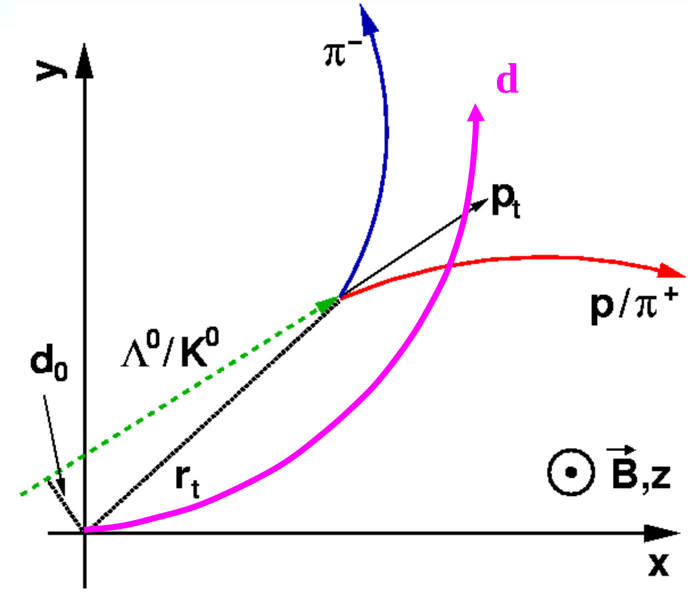
X originating from primary vertex

Λ from off-vertex p-π^- pairs

Reconstruction of short lived ΛX resonances

Invariant mass distribution of Λd pairs





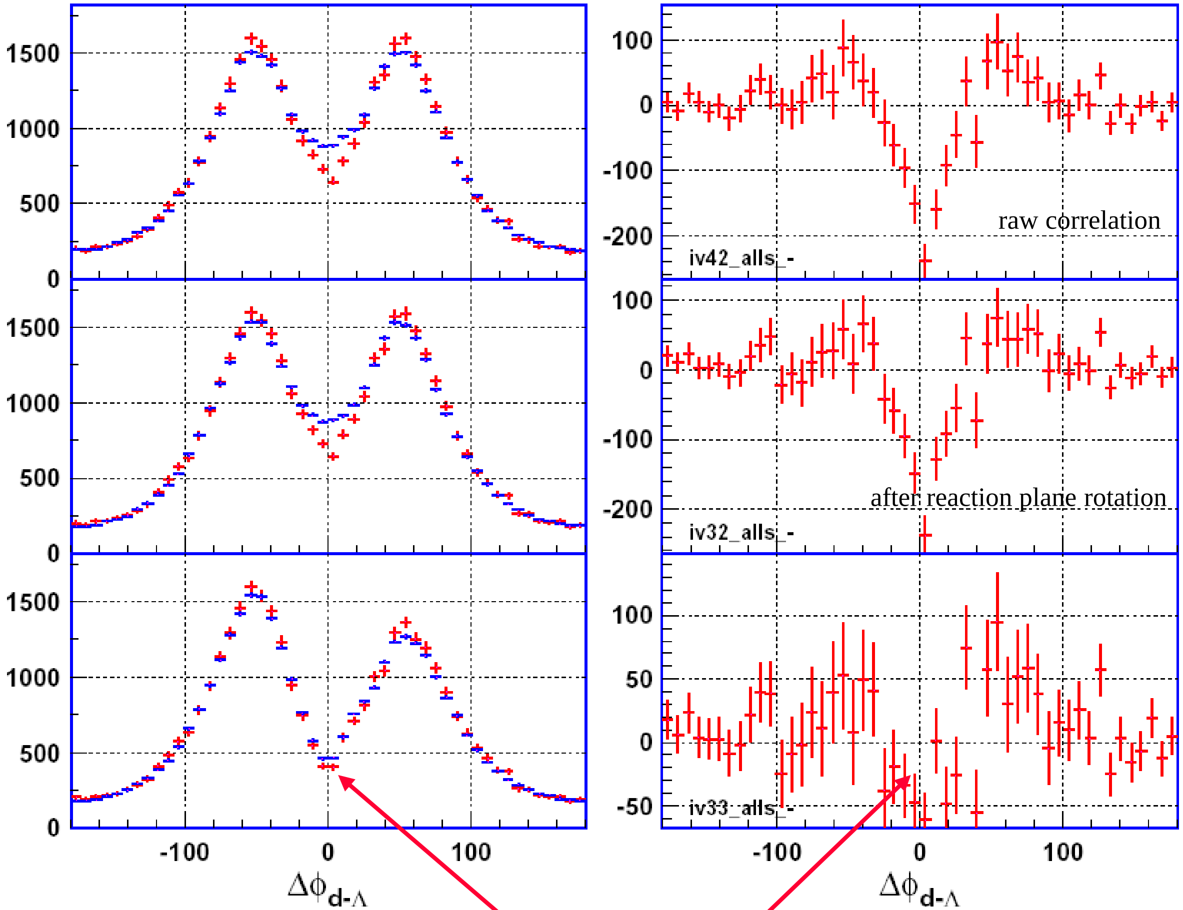
Reconstruct ~ 150k pairs from 75k Λ - candidates

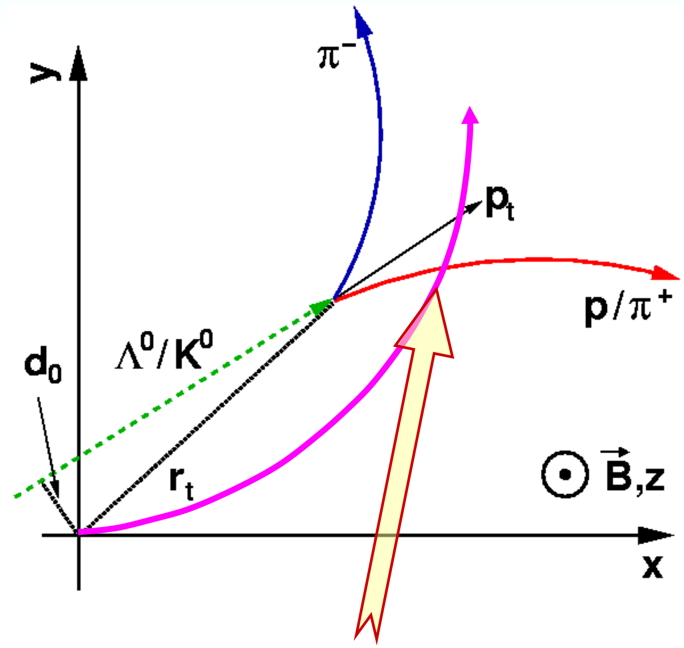
No obvious structure in yield distribution

Better reference needed !
→ mixed event distribution

Strategy:
Mix Λ – candidates with d from other Λ – candidate events with same
track multiplicity in CDC
deuteron multiplicity in CDC

Relative azimutal angle





Tracking efficiency lower
Deficiency not present for mixed events

after reaction plane rotation &&
after crossing tracks removal

Crossing track removal not sufficient to remove all detector biases

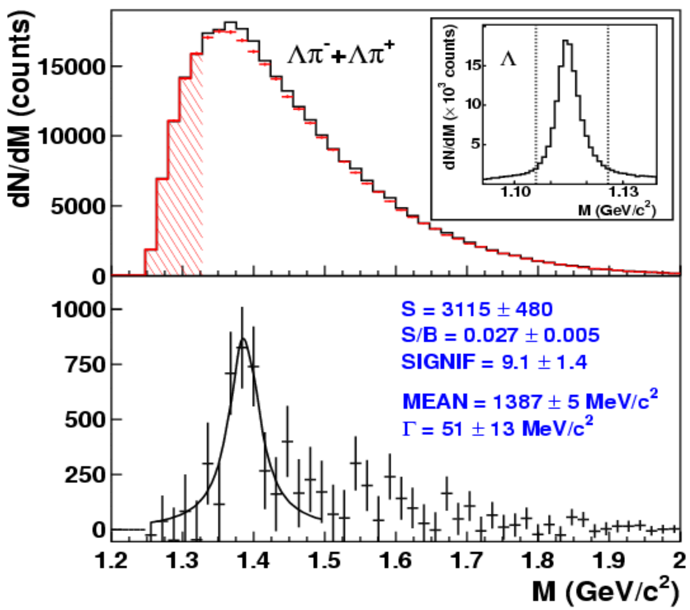
Reconstruction of short lived resonances in HI collisions

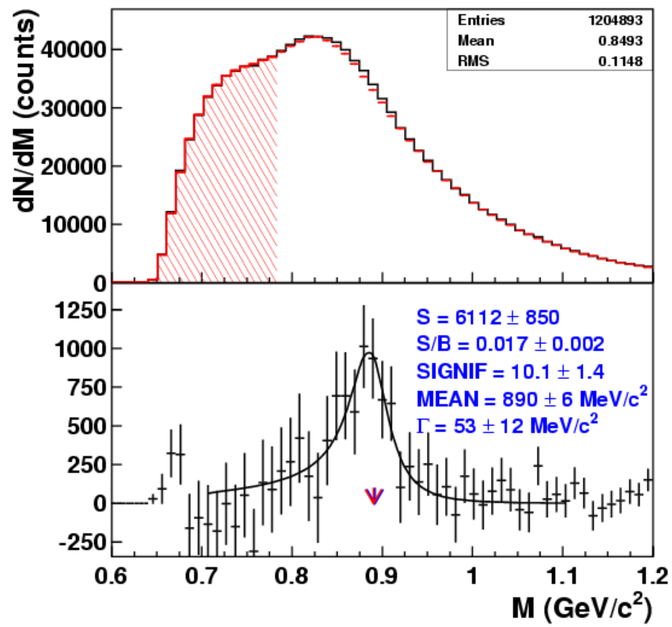
Σ^*(1385) subthreshold production,
X. Lopez et al. (FOPI collaboration), submitted to PRL (2007)

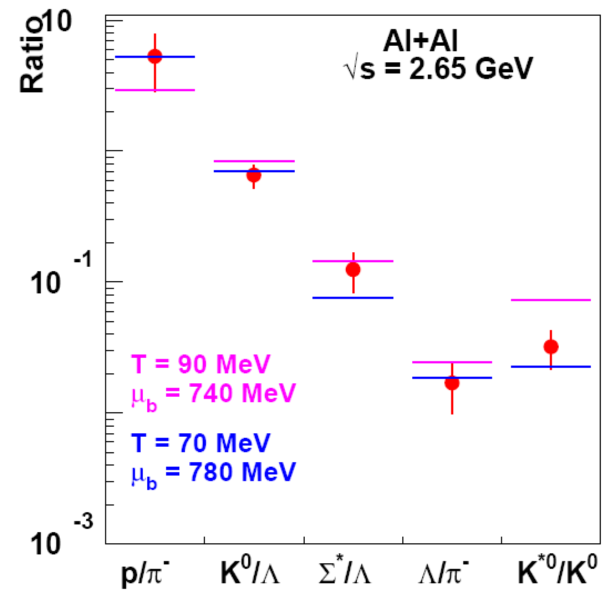
$\Sigma^* \rightarrow \Lambda + \pi \quad (88 \pm 2\%)$
$\rightarrow p + \pi^- + \pi$
Γ = 39.4 MeV
cτ = 5 fm

$K^* \rightarrow K + \pi \quad (88 \pm 2\%)$
Γ = 50.7 MeV
cτ = 4 fm

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





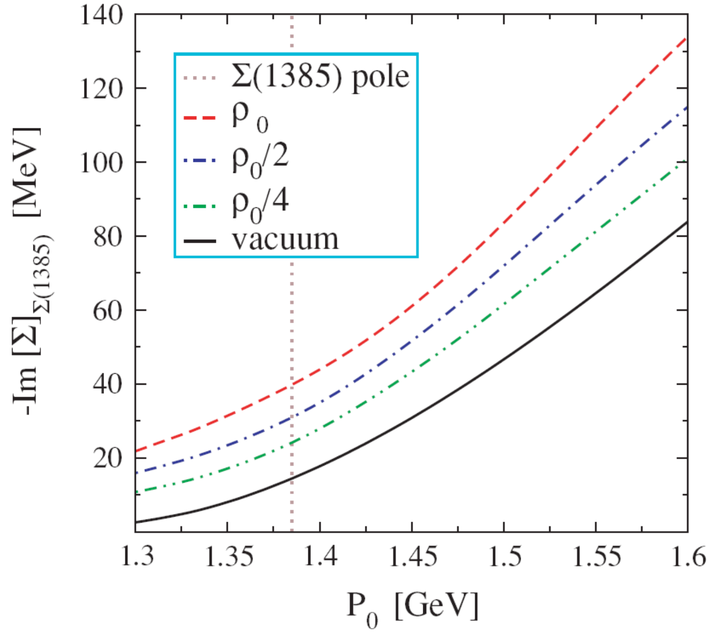


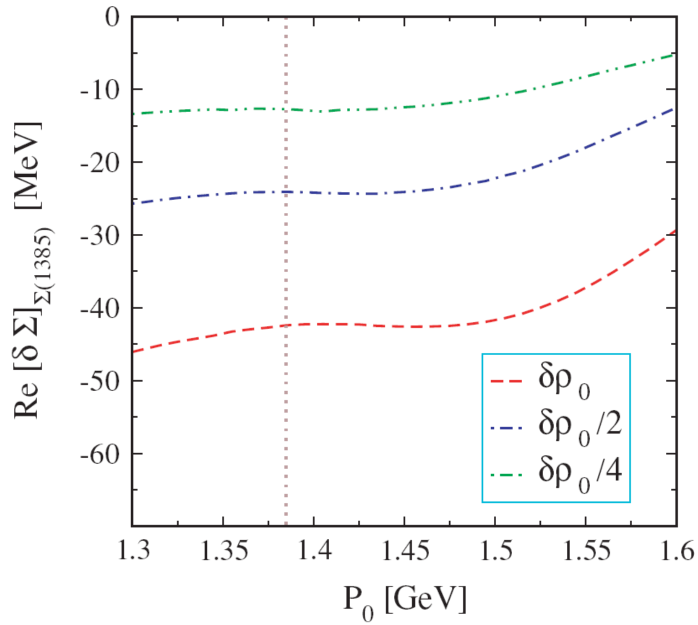
FOPIs reconstruction method and background construction works for wide resonances.
Masses and widths consistent with PDG values.
New particle (resonance) species available to test chemical equilibration.
Necessary to extend studies to larger size systems.

Σ*(1385) - physics

Chiral unitary theory

Murat M. Kaskulov, E. Oset, PRC 73 (2006) 045213





Γ = -2Im$[\Sigma]_{\Sigma(1385)}$ = 76 MeV at $\rho = \rho_0$!

Mean mass: attractive potential ≈ - 45 MeV at $\rho = \rho_0$

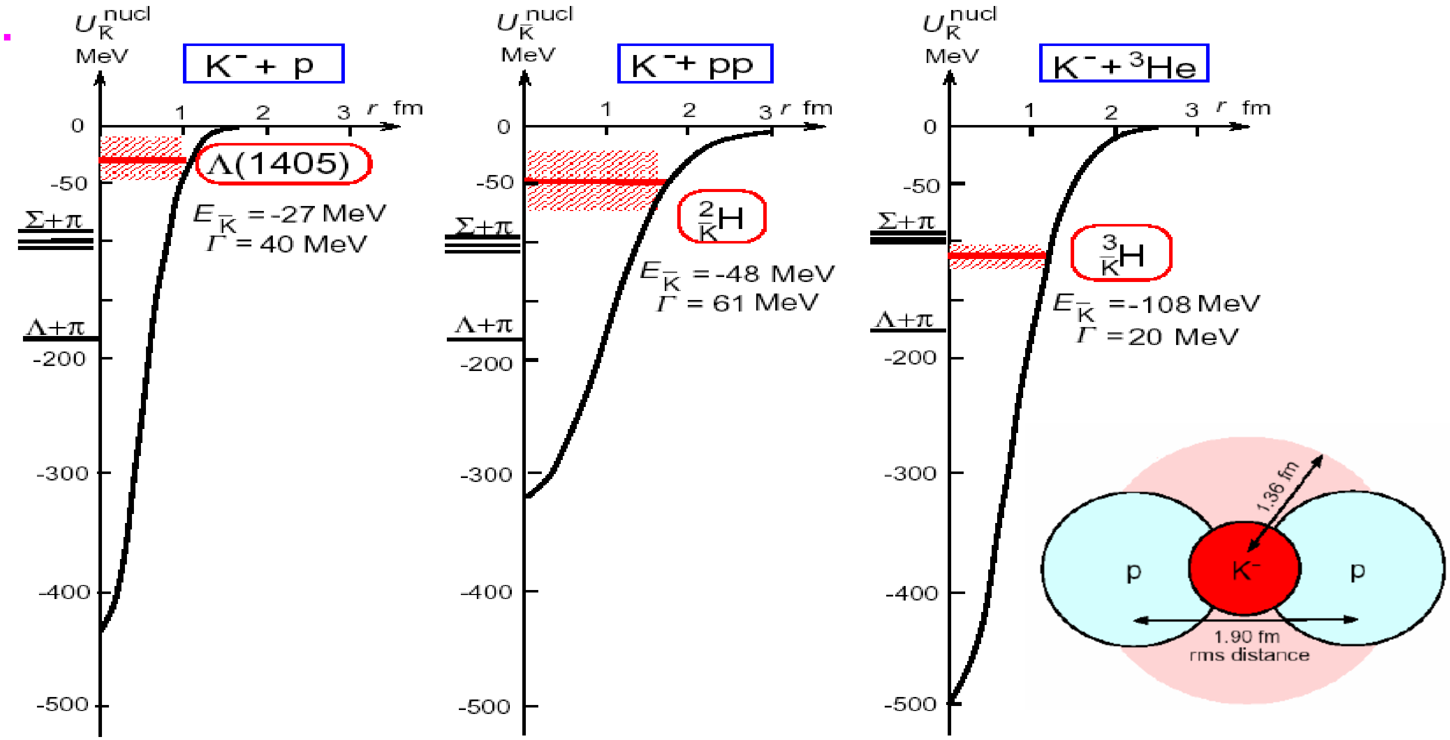
- **due to short lifetime Σ* should probe finite density!**
- **Broadening of the width not yet observed (needs more statistics)**
- **Need for measurement with heavier system**
- **Need to include spectral function in transport codes**

Phenomenological $\bar{K}N$ - potential

Y. Akaishi, T.Yamazaki (2002):

KN interaction is strongly attractive !

Λ(1405) is (K⁻p) bound state.



AY- potential designed to:

- describe scattering length of free KN scattering
- X-ray shifts of kaonic hydrogen atom
- mean and width of Λ(1405)

Deep optical potential:

Y. Akaishi, T.Yamazaki, Phys.Rev.C65, 044005 (2002)
T.Yamazaki and Y. Akaishi, Phys.Lett.B535, 70 (2002)
N.Kaiser et.al, Nucl. Phys. A594 (1995) 325;

Shallow optical potential:

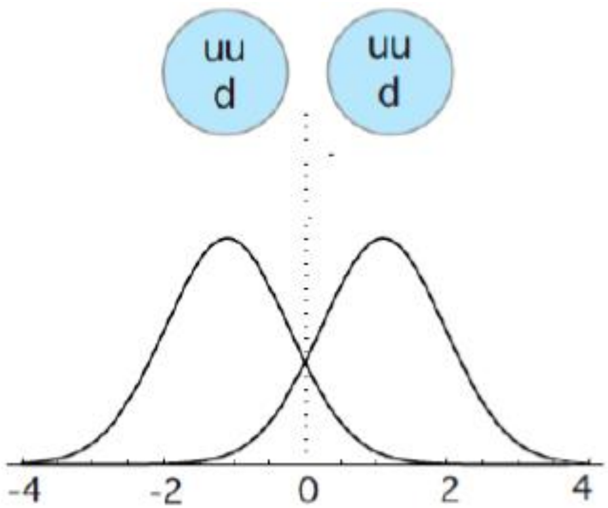
(microscopic treatment)
M.F.M. Lutz, Phys. Lett. B426 (1998) 12.
J.Schaffner-Bielich et.al, N.P. A669 (2000) 153,
Ramos et.al,N.P. A671 (2000) 481,
Cieply et al.,N.P. A696 (2001) 173

Motivation of high density kaonic clusters

NN- interaction:

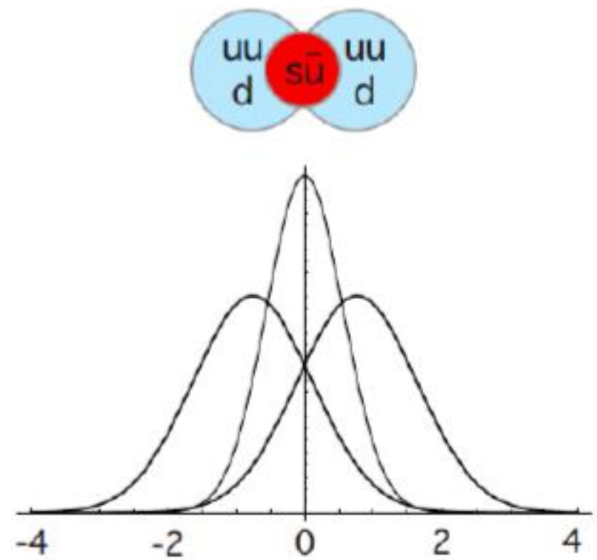
Repulsive at small distances

Pauli-blocking on quark level



ppK$^-$ - molecule:

K^- = ($\bar{u}$,s), no u,d quark
No Pauli repulsion
Strong attraction between $u\bar{u}$ and $d\bar{d}$

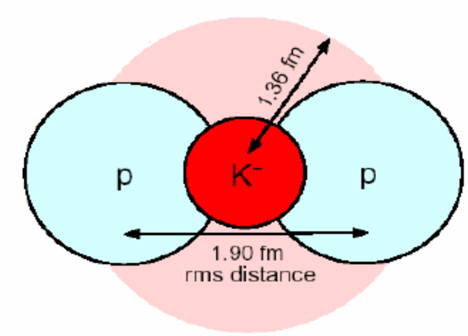


r (fm)

Analogy to H_2^+ - molecule and covalent binding

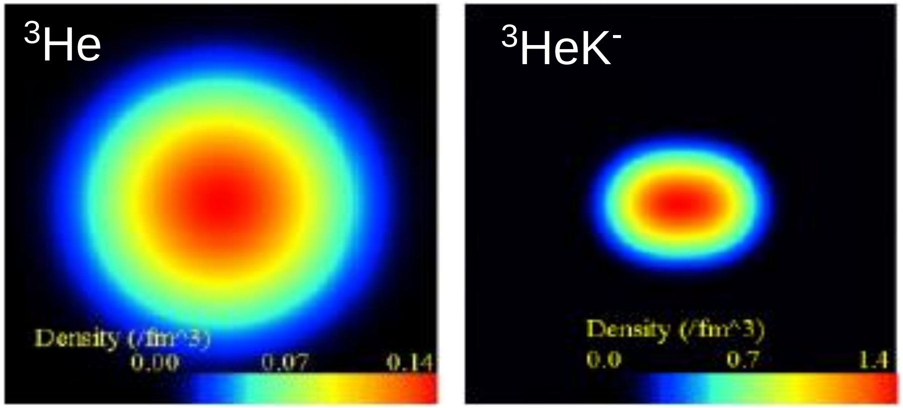
Antikaon-Clusters

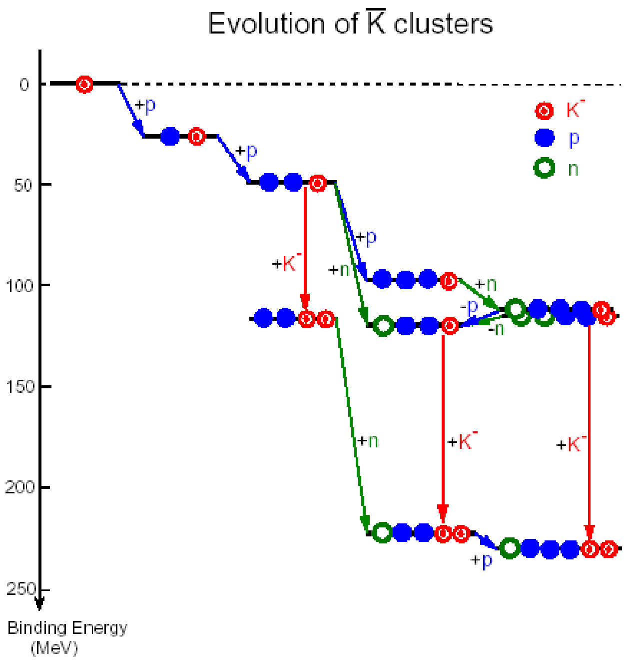
Structure of kaonic cluster states



Large central densities!

A.Dote et al., PRC70,044313(2004)



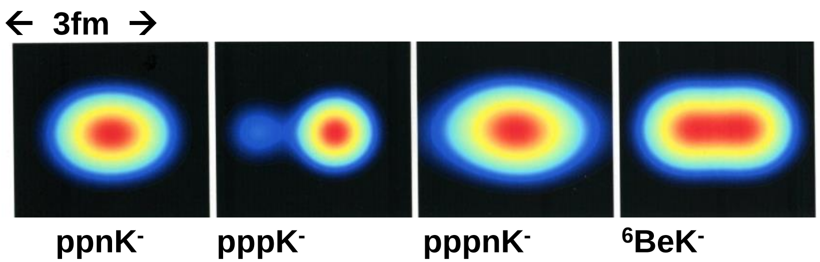


Series of states predicted !

T. Yamazaki et al. (2004)

K^- – cluster	(I, I_z)	J^π	Mc^2 [MeV]	E_K [MeV]	Γ_K [MeV]	$\rho(0)$ [fm^{-3}]	R_{rms} [fm]
pK^- ($\Lambda(1405)$)	$(0,0)$	$(1/2)^-$	1407	27	40	0.59	0.45
ppK^-	$(1/2, 1/2)$	0^-	2322	48	61	0.52	0.99
$pppK^-$	$(1,1)$	$(3/2)^+$	3122	186	13	1.56	0.81
$ppnK^-$	$(0,0)$	$(1/2)^-$	3152	170	21	1.50	0.72
$ppnK^-$	$(1,0)$	$(3/2)^+$	3118	190	13	1.56	0.81
$pnnK^-$	$(1,-1)$	$(3/2)^+$	3117	191	13	1.56	0.81

Theory comparison for ppK^-



Extreme compression prohibited by the strong NN repulsion

First AMD: $\langle\rho\rangle \sim \mathbf{3}\ \rho_0$

Absorption

$K^-N \rightarrow \pi\Sigma, \pi\Lambda$ $\qquad$ $K^-NN \rightarrow \Sigma N, \Lambda N$

$\Gamma = -2\langle\Psi|\mathrm{Im}\ U_{abs}|\Psi\rangle$

Akaishi-Yamazaki

Binding energy	B = 48 MeV
Decay width	Γ = 60 MeV

Weise-Dote

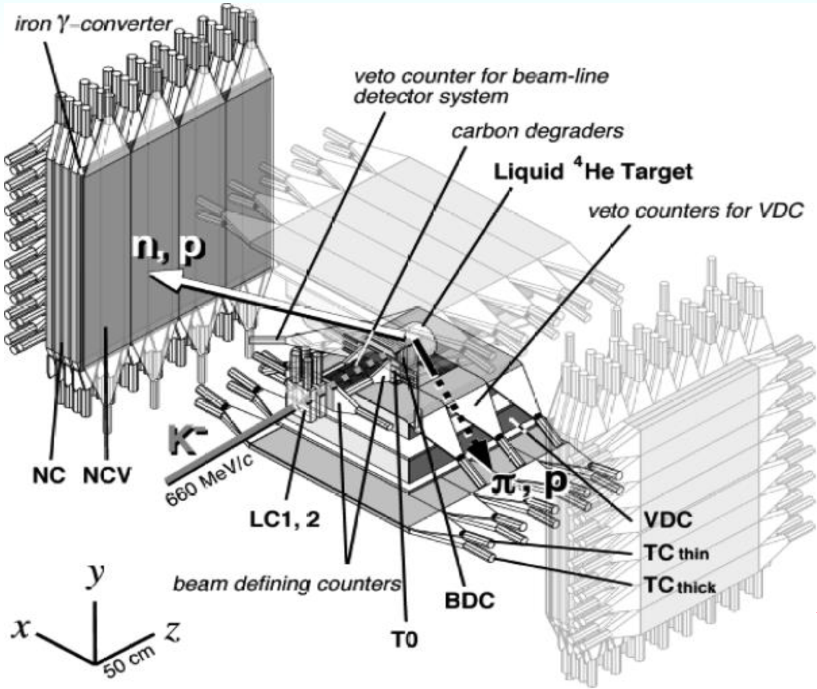
Binding energy	B~ 60 MeV
Decay width	Γ~100 MeV

Dote and W. Weise, HYP2006 Proc., nucl-th/0701050

N.V. Shevchenko et al., Phys. Rev. Lett. 98, 082301 (2007)

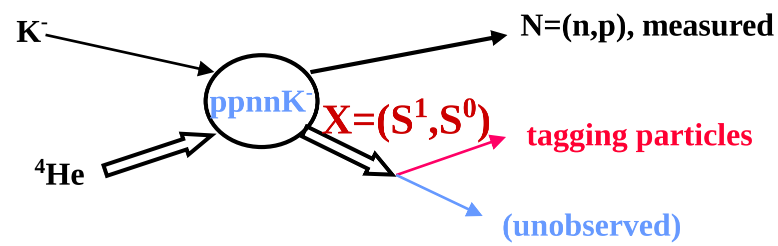
Bound states exist but they could have large width.

KEK experiment E471



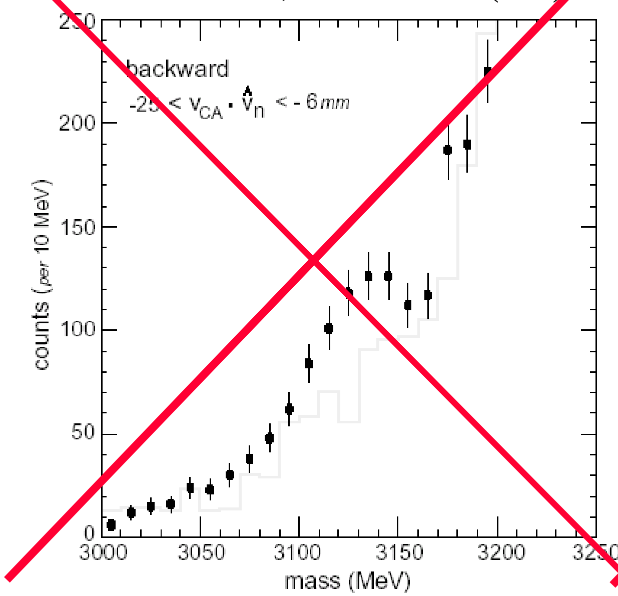
Statistics: 2 ×10^8 stopped kaons

Missing mass spectroscopy



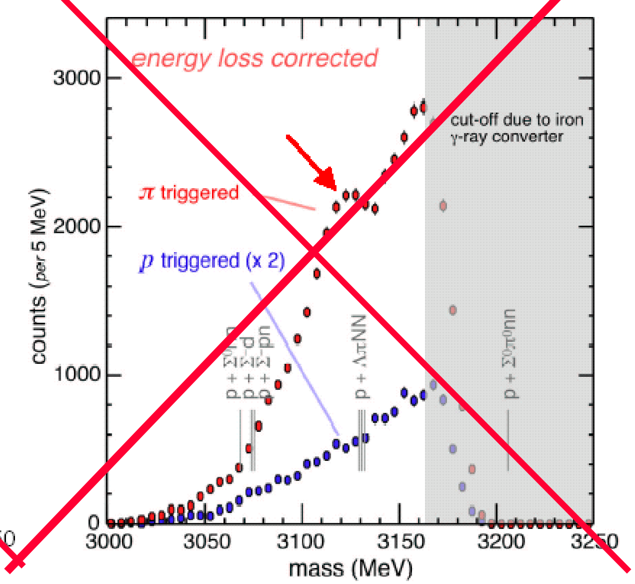
^{4}He(stopped K$^-$,n) ppnK$^-$ (T=0,1)
Mc^2 = 3140 MeV, Γ ~ 20 MeV
B_K = 170 MeV
S^1(3140)

M. Iwasaki et al., nucl-ex/0310018 (2003)



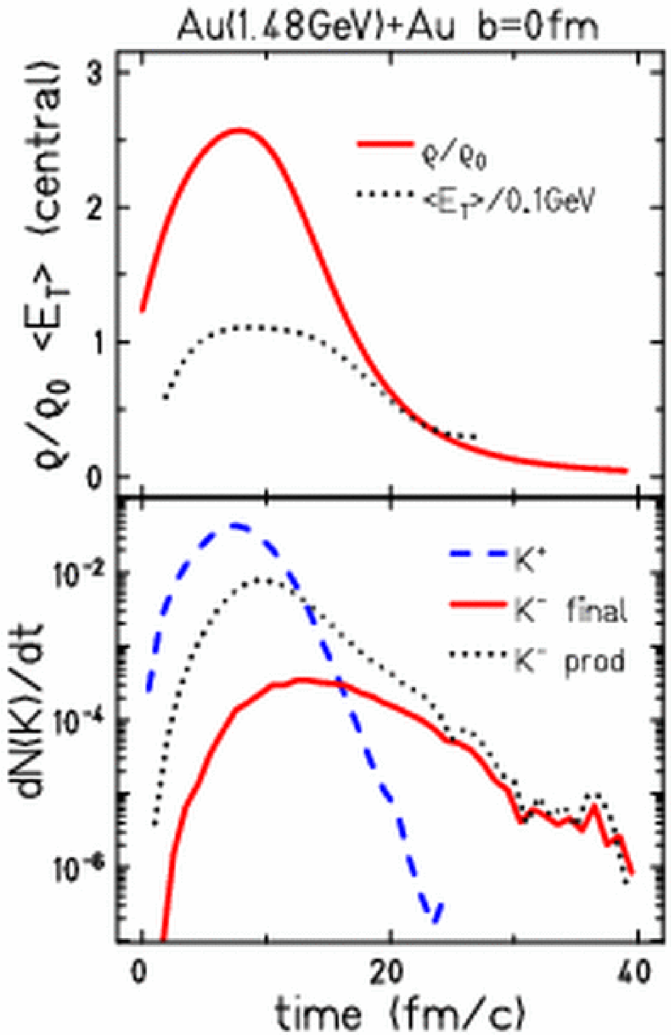
^{4}He(stopped K$^-$,p) pnnK$^-$ (T=
Mc^2 = 3117 MeV, Γ~20 MeV
B_K =190 MeV
S^0(3115)

T. Suzuki et al., Phys. Lett. B 597 (2004) 263



Antikaon Cluster Production in HI collisions

IQMD, C.Hartnack, Nantes



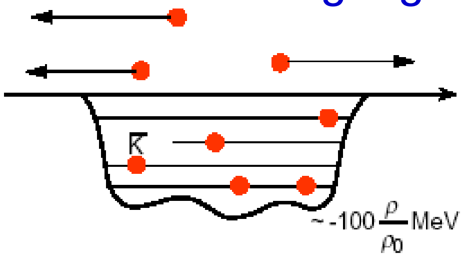
Central density in HI collisions
from transport model calculations:

$$\rho_{max} = 2\text{-}3 \cdot \rho_0$$

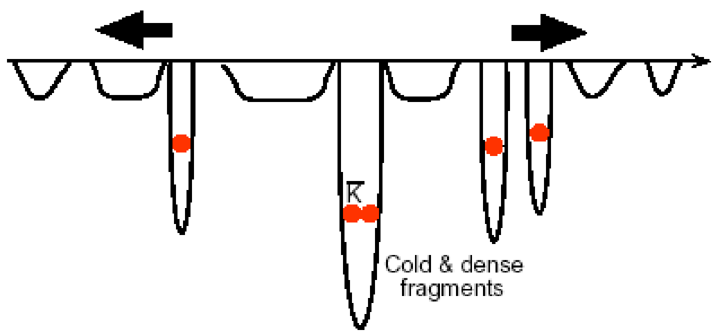
Possible mechanism for cluster formation:

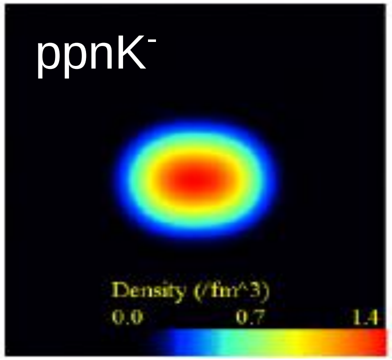
T.Yamazaki et al., NPA738,168 (2004)

1) Kaon production during high density phase

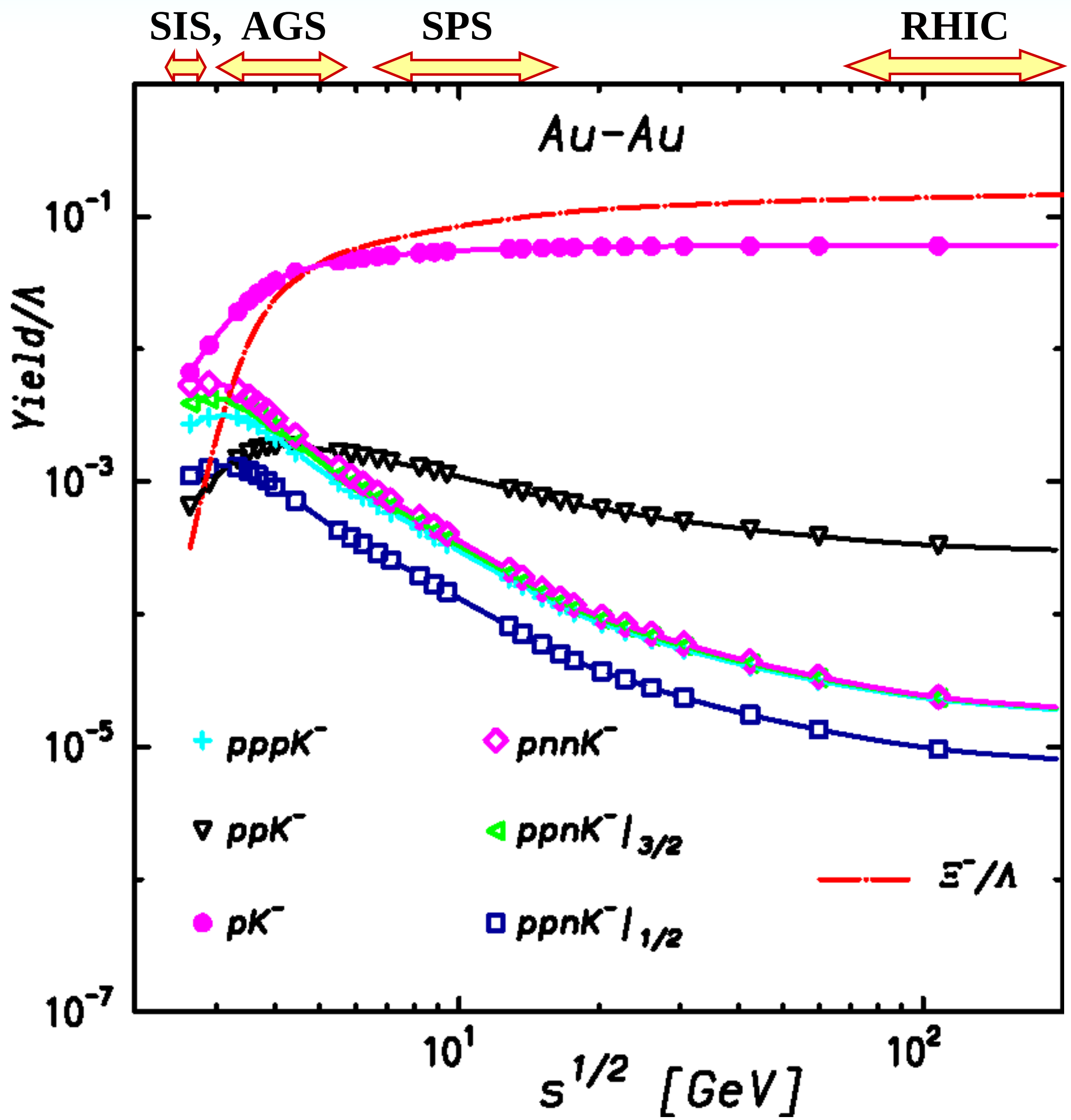


2) capture of K^- in deep trapping centers





Thermal model predictions



A.Andronic, P.Braun-Munzinger, K.Redlich (2005)
arXiv:nucl-th/0506083

Density of species i :
(in grandcanonical ensemble)

$$n_i(\mu,T) = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{\frac{E_i - \mu_B B_i - \mu_S S_i - \mu_{I_3} I_{3i}}{T}} \pm 1}$$

Free parameter: chemical potential μ_B
temperature T

Fixed by conservation laws: V, μ_S, μ_{I3}

Yield of single strange clusters per Λ peaked at lowest beam energies

Abundance larger than Ξ - baryon

September 2003

* described in proceedings EXA05, Vienna (2005)

Λd – Correlation Signal

Preliminary

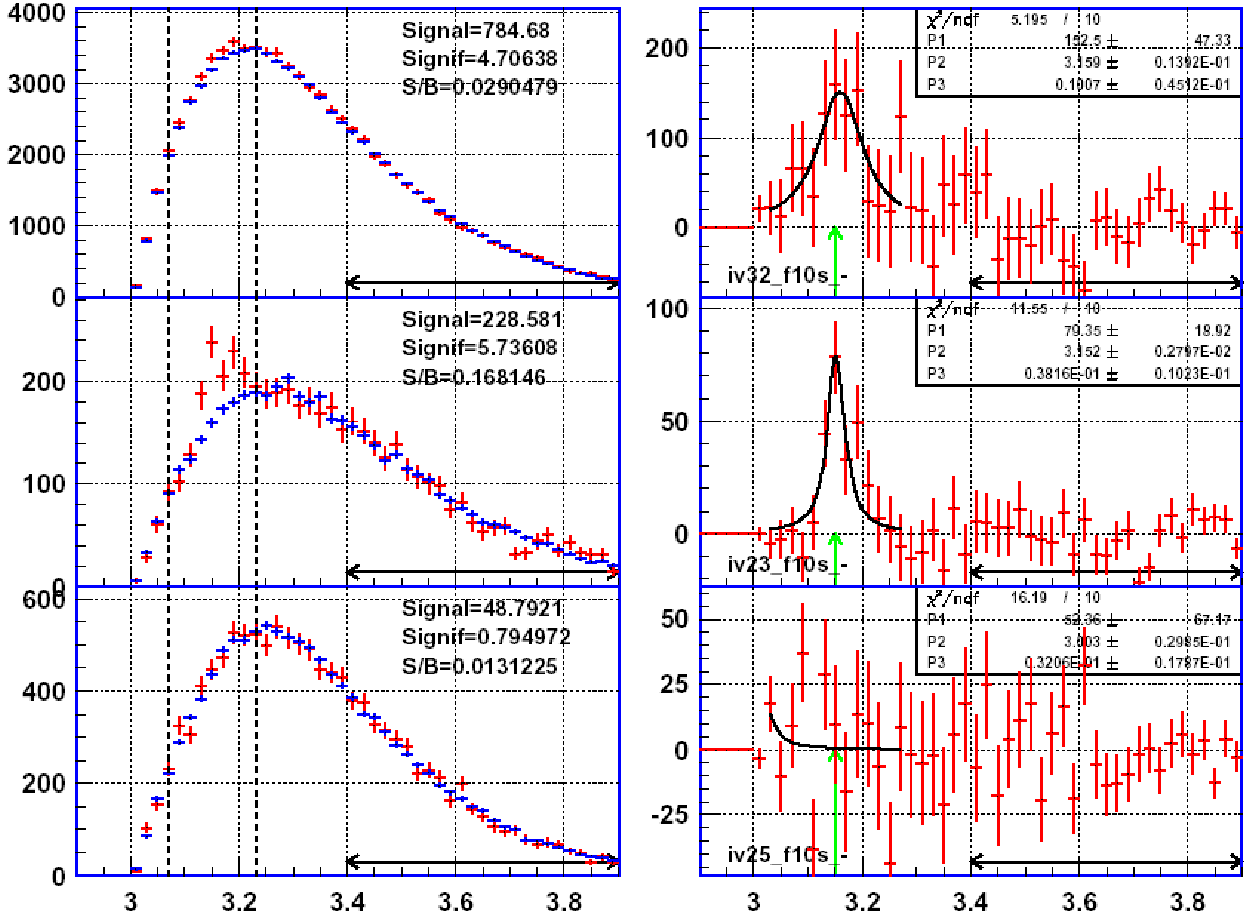
Subevents rotated
Vertex shifted
Lambda Cut "s"

Possible decay channel:

$$ppnK^- \rightarrow \Lambda + d$$

d-Cuts:

HM3MIN	
D03MAX	
PT3MIN	
PT3MAX	
Sdxy3max	
M3LOW	1,7
M3HIGH	
DML	
DPHL3MIN	30
YDLMAX	0,65
PTDLMIN	
PTDLMAX	
CCNT	<10
BM3MIN	
	F10



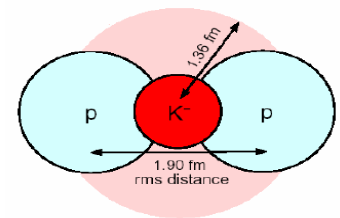
M_{inv} (Λ+d) (GeV)

Data

additional cuts:
$|\Delta\phi|>30^0$
$y_{pair} < 0.65$

Signal-MC

Background-MC



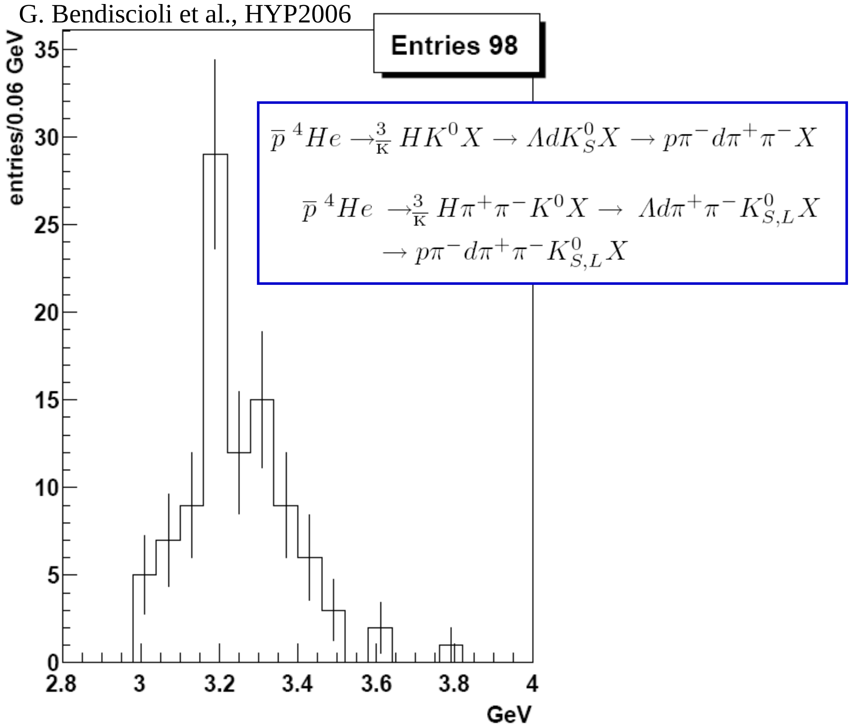
Properties: (?)

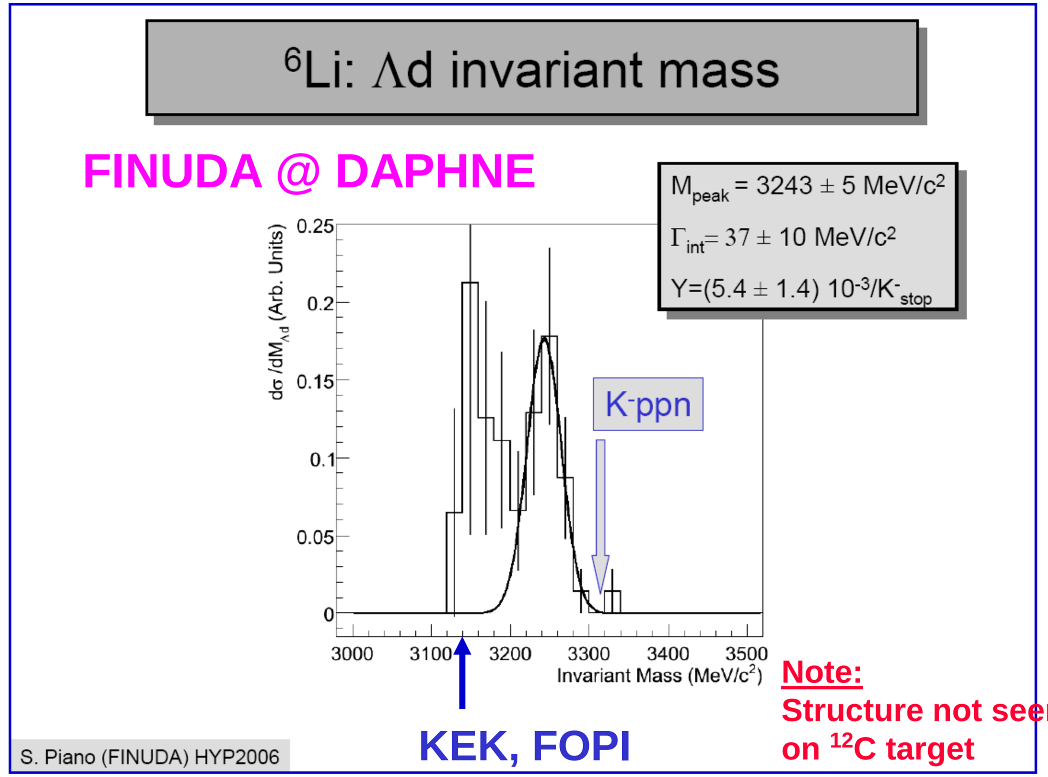
M ≈ M(KEK) = 3.14 GeV

Γ >> 20 MeV > Γ(KEK)

Status of ppnK$^-$ $\rightarrow \Lambda d$ - search

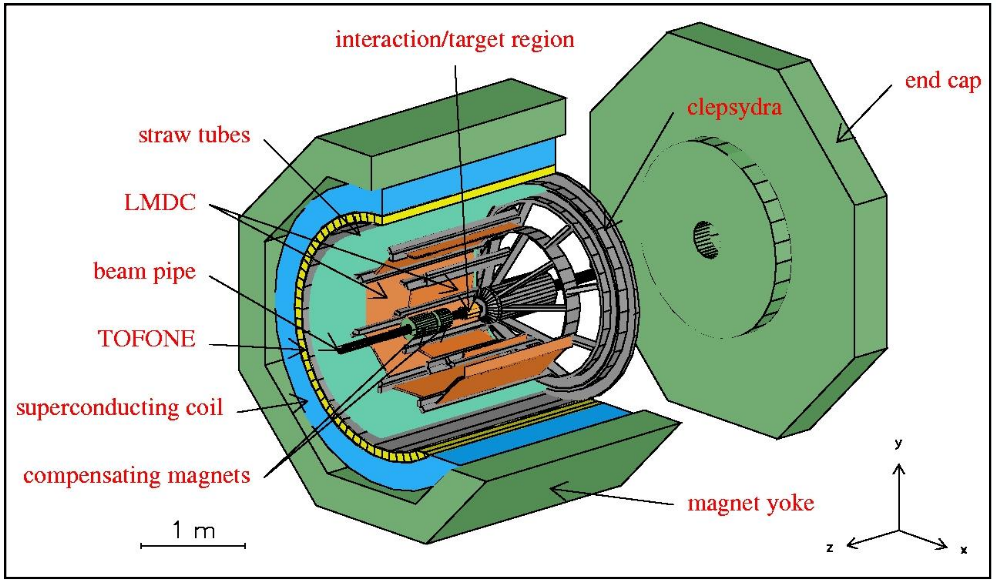
OBELIX @ LEAR





		M (MeV)	Γ (MeV)	P/Λ	P/(IN)	Sign (σ)
FOPI	HI: Al+Al	-	-	-	-	-
	HI: Ni+Ni	3149 ± 15	100 ± 49	$1.3 \cdot 10^{-2}$	$1.0 \cdot 10^{-5}$	4.9
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

Evidence for $(ppK^-)_{bound}$ by FINUDA @ DaΦne



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

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

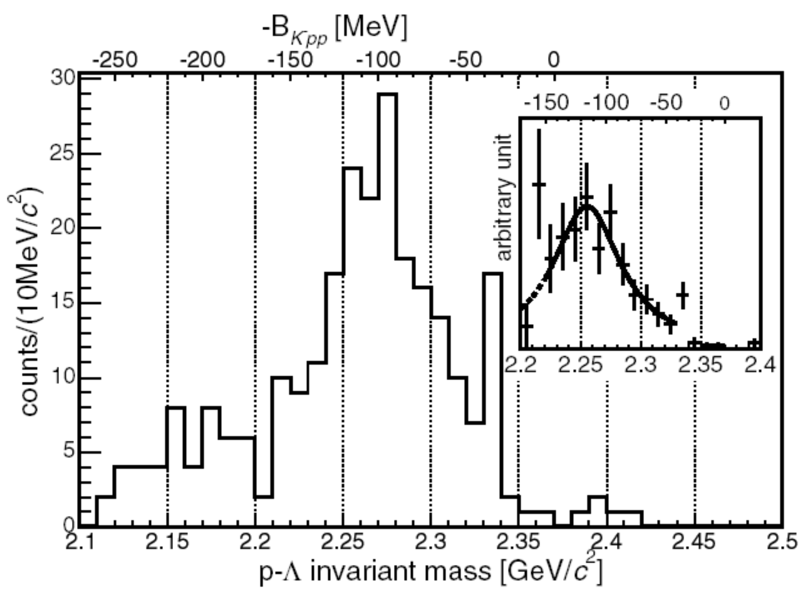
$K^- + A \rightarrow \Lambda + p + X$

Invariant mass spectroscopy

$ppK^- \rightarrow \Lambda + p$

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

Theoretical AY – prediction:
$M(ppK^-)$ = 2.322 GeV
Γ = 61 MeV



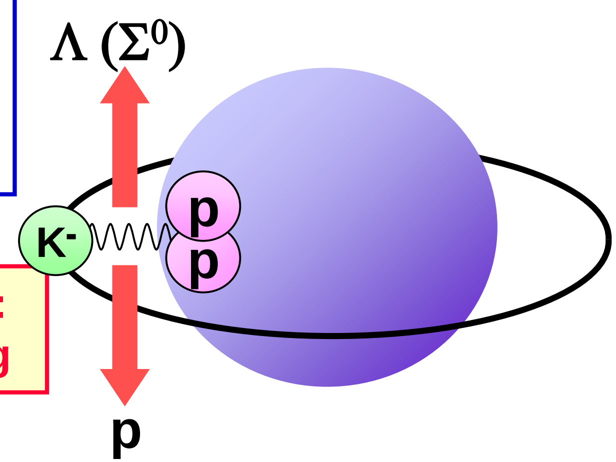
Production probability:
P·BR = 0.1% per stopped K^-
Peak parameter:

$$M = 2.255 \pm 0.009\ \text{GeV}$$

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

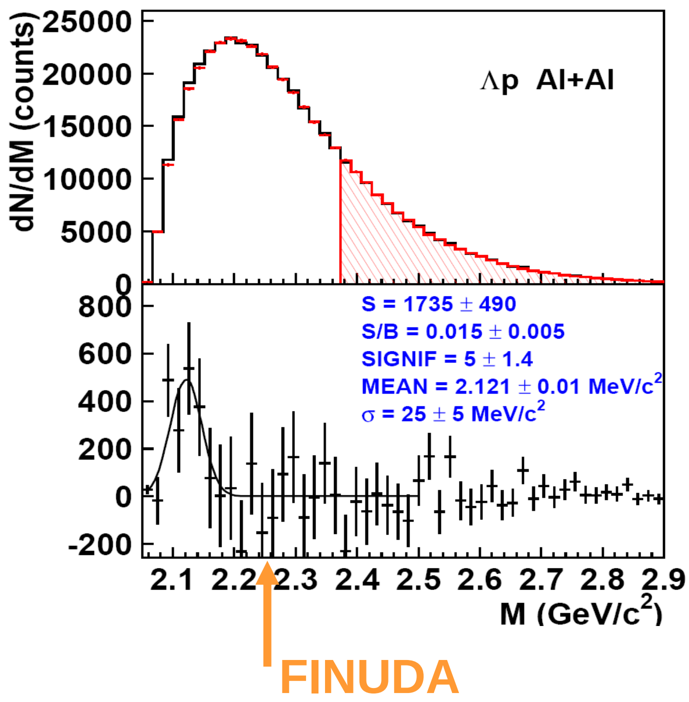
Controversial interpretation:
2N absorption + rescattering

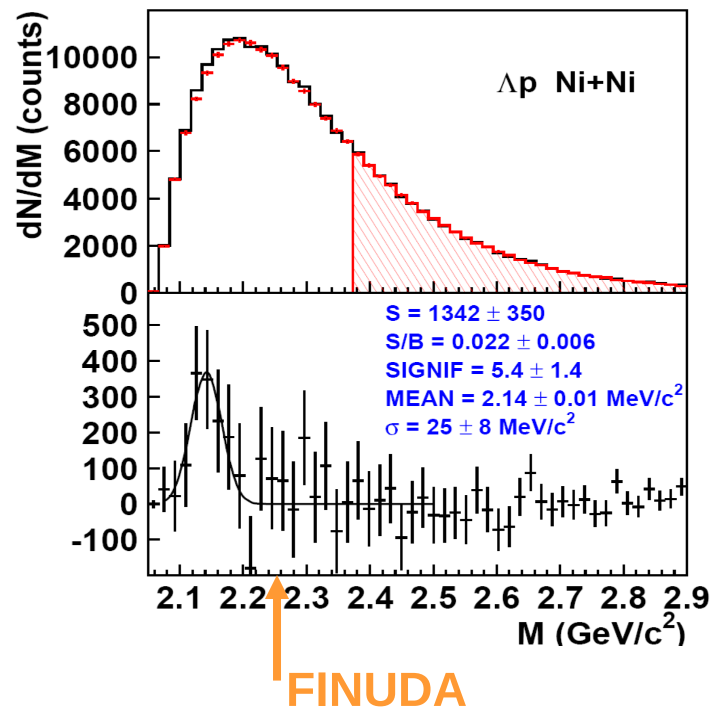
V.K. Magas, E. Oset, et al., nucl-th/0601013



Search for ppK$^-$

Λp – invariant mass





Excess observed in Ni+Ni and Al+Al with statistical significance of ~ 5.

Peak position in variance with FINUDA result.

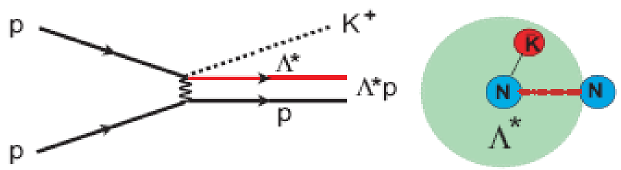
Interpretation unclear: ΣN – FSI,

bound state (H1$^+$),

partial inv. mass of heavier state (e.g. $^4{}_\Lambda$He).

ppK^- production in p+p reactions

T. Yamazaki et Y. Akahishi, nucl-th/0604049 (2006)



$\Lambda^* \equiv \Lambda(1405)$

$p+p \rightarrow \Lambda(1405)+p+K^+$

$\rightarrow ppK^- + K^+$

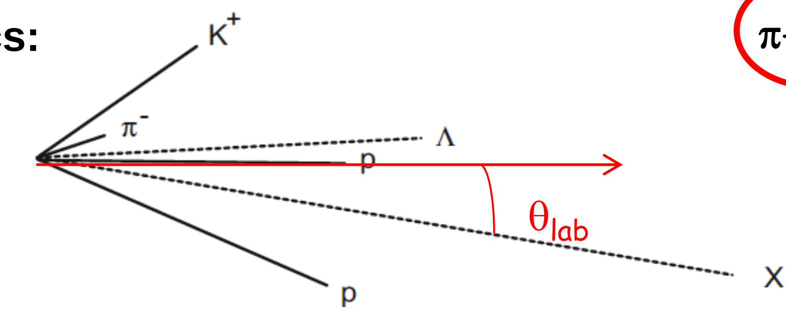
$\Lambda+p$ → $\pi^- + p$

$\Sigma+p$ → $\Lambda+\gamma+p$

Missing Mass &

Invariant Mass

Typical kinematics:



Akaishi-Yamazaki

Binding energy	B = 48 MeV
Decay width	Γ = 60 MeV

Weise-Dote:

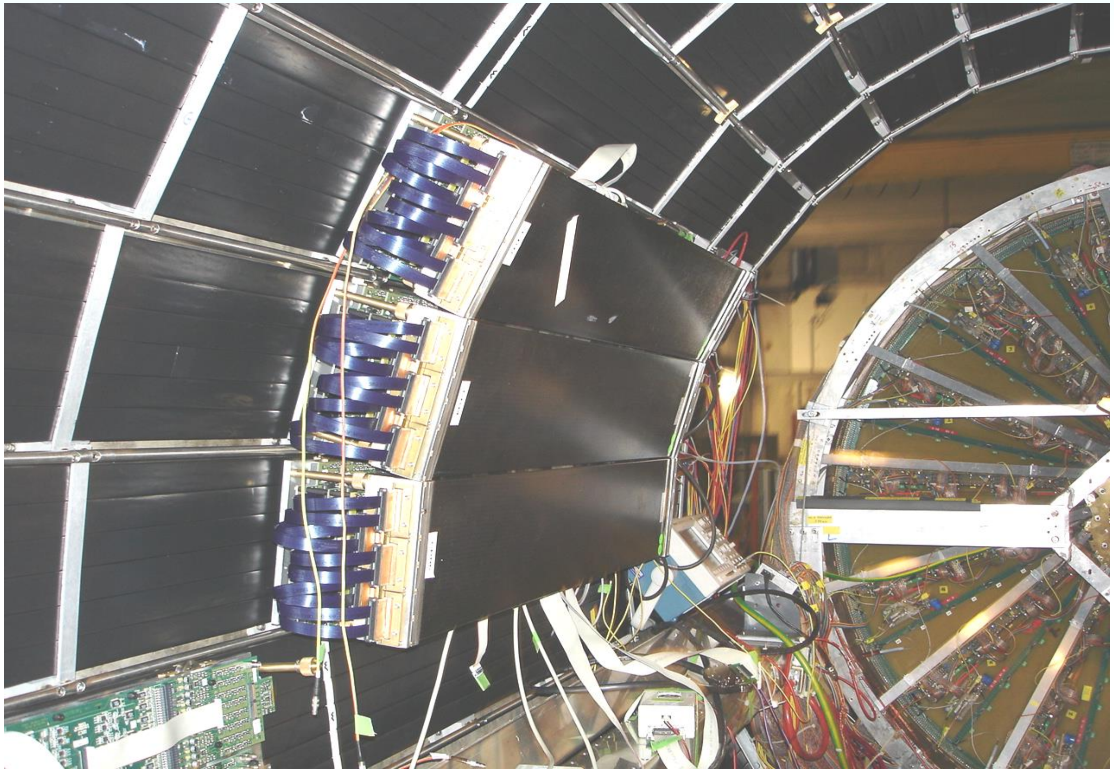
Binding energy	B~ 60 MeV
Decay width	Γ~100 MeV

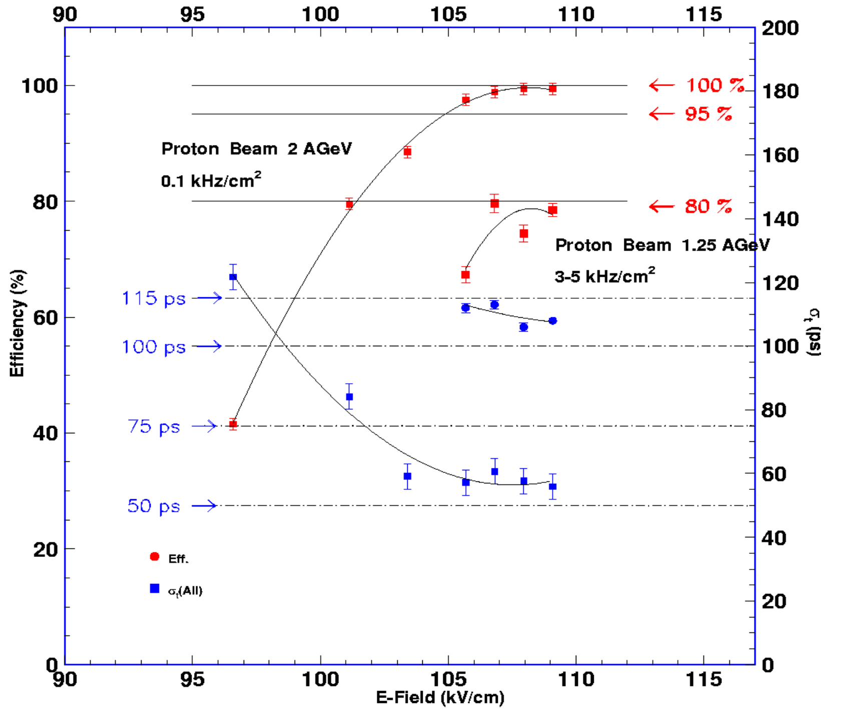
Dote and W. Weise, HYP2006 Proc., nucl-th/0701050

N.V. Shevchenko et al., Phys. Rev. Lett. 98, 082301 (2007)

Bound states exist but they could have very large width.

Near Future: FOPI – Timing RPC





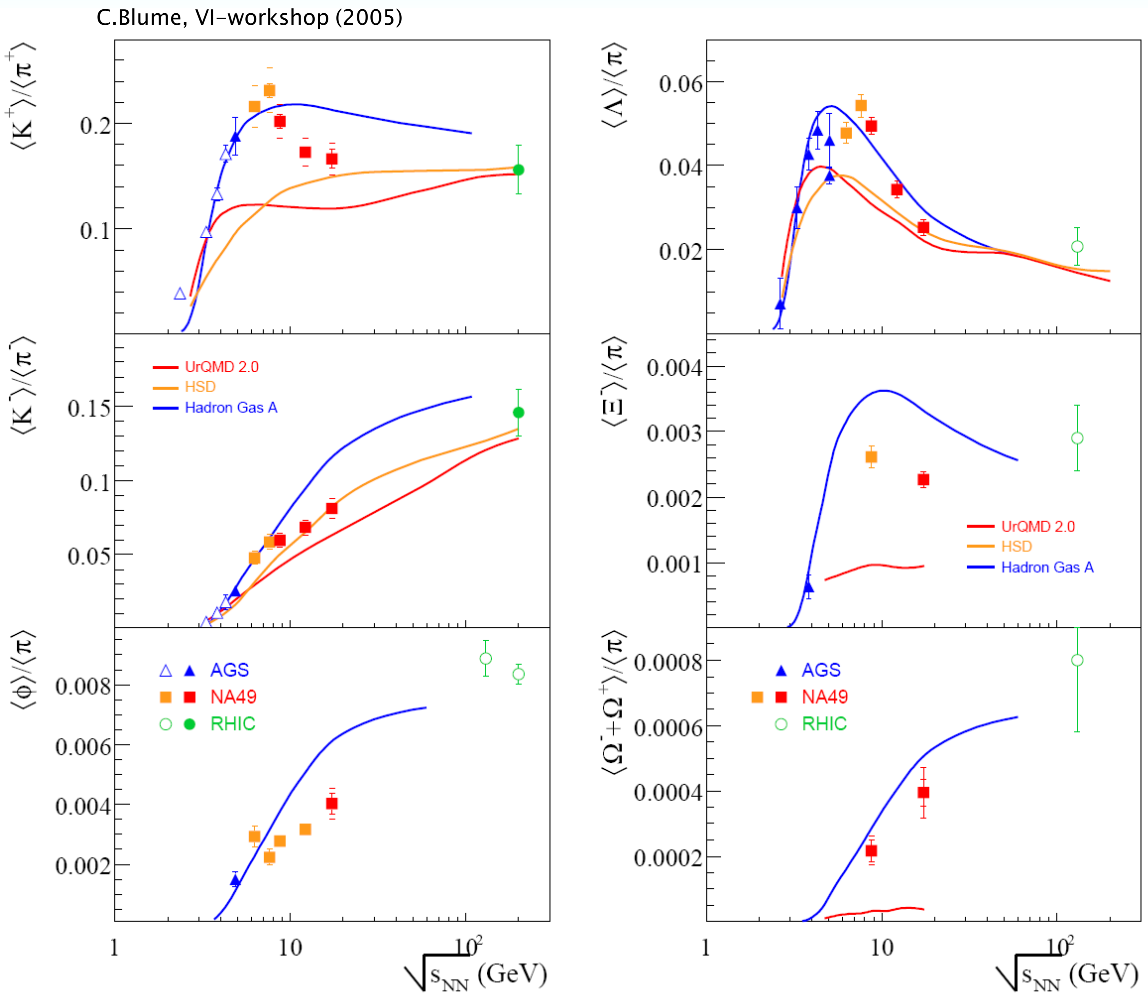
HadronPhysics I3 – Study of Strongly Interacting Matter

bmb+f - Förderschwerpunkt Hadronen- und Kernphysik Großgeräte der physikalischen Grundlagenforschung

GSI

2000 - 2005	**development of high resolution TOF system**	
	FOPI – MMRPC	
2006	**production of subsystem**	
2007	**integration &**	
	start of physics data taking (S335, Ni+Ni @ 1.93 AGeV)	

Excitation function for strangeness production



Statistical hadron gas:

P. Braun-Munzinger, J. Cleymans, H. Oeschler, and K. Redlich
Nucl. Phys. A697 (2002) 902

UrQMD + HSD

E.L. Bratkovskaya et al.,
PRC 69 (2004), 054907

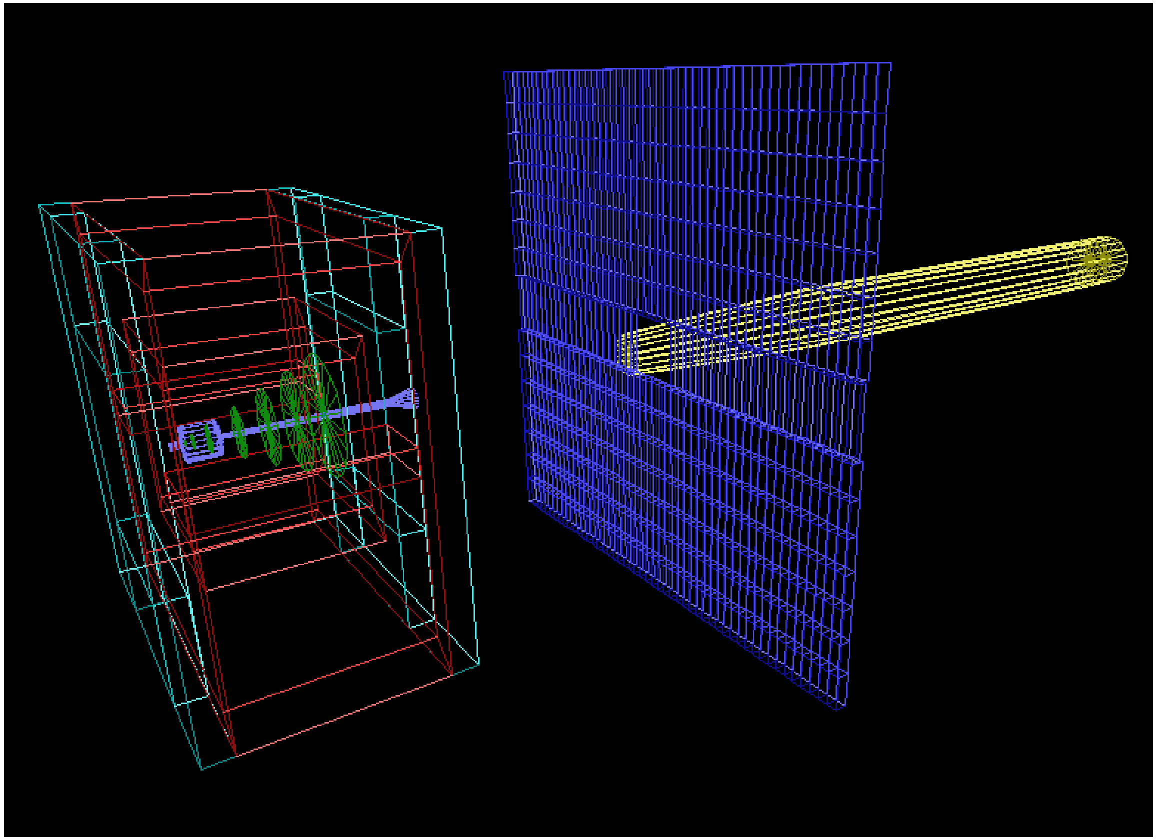
Structures in the data not understood.
Link to phase transition possible.
Models operate with on-shell particles.

CBM @ SIS100

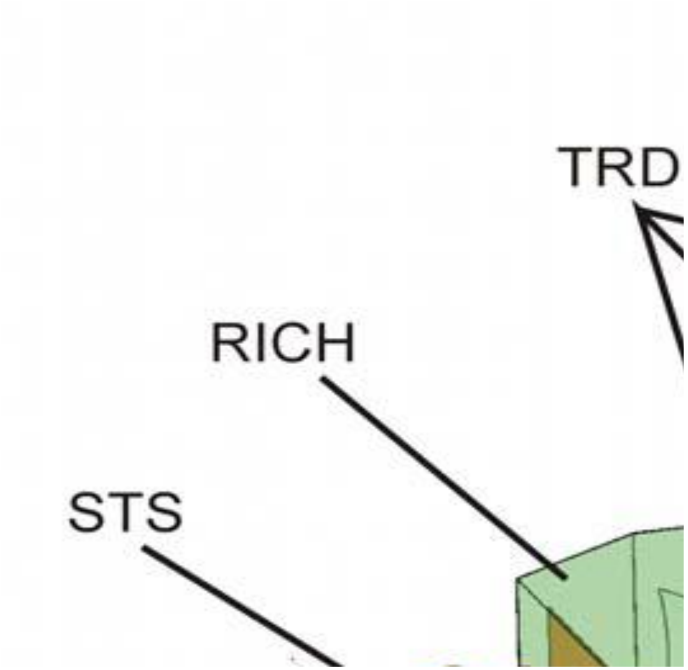
Physics questions can be addressed with reduced CBM - setup,
Allows for staging of detector implementation

Minimal setup: Si-strip stations in Magnet
+ TOF
+ intermediate tracker for matching
+ high speed DAQ

Full CBM



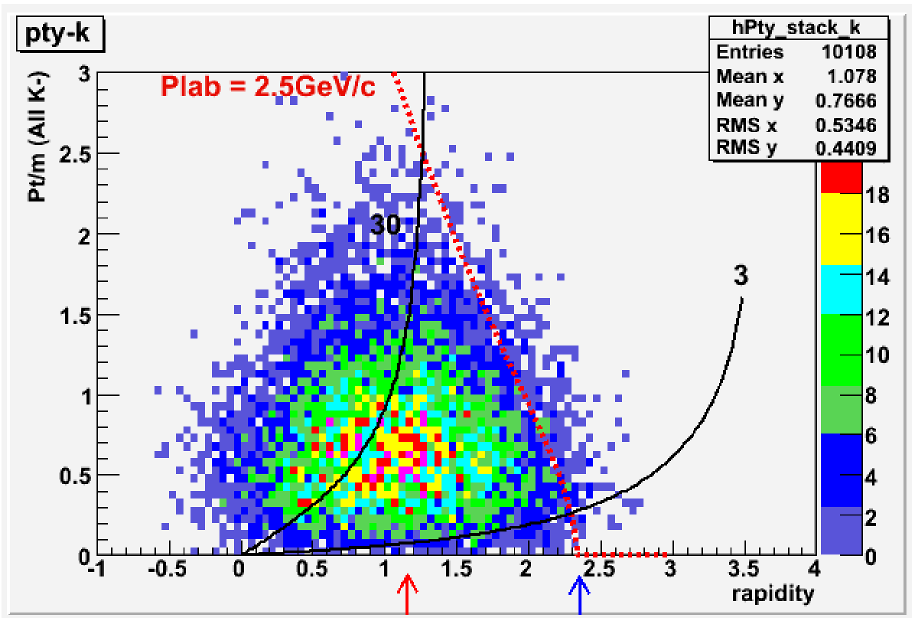
D(TOF) = 4 m (use inner part of final TOF wall, 16% of final detector)



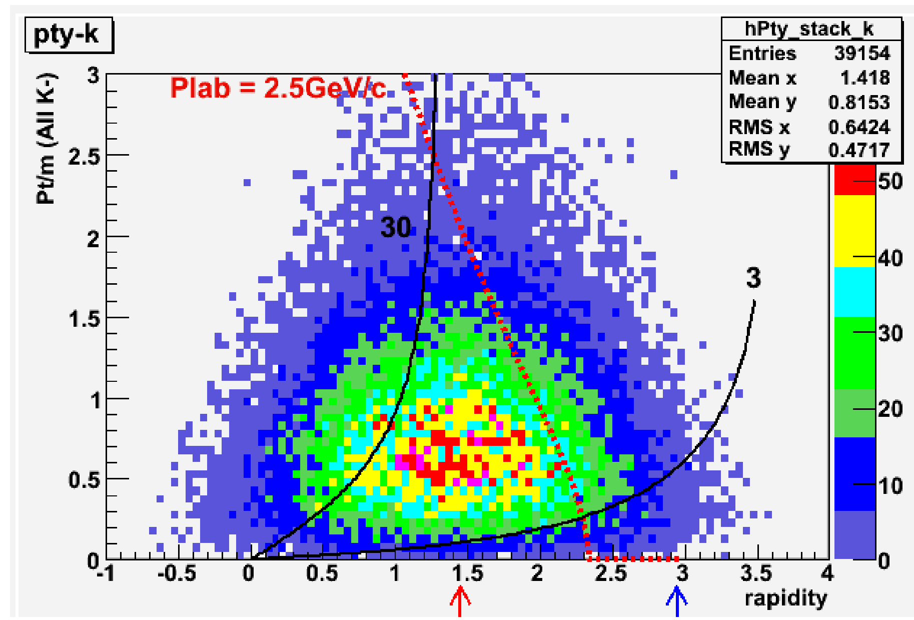
Kaon acceptance @ SIS100

URQMD acceptance simulations:

4AGeV



8AGeV



Charged Kaon acceptance with 3σ – TOF separation:

E_{lab} (AGeV)	4	6	8
ε	77%	64%	55%

Coverage of low – p_t range of the spectrum !

Summary / Conclusion

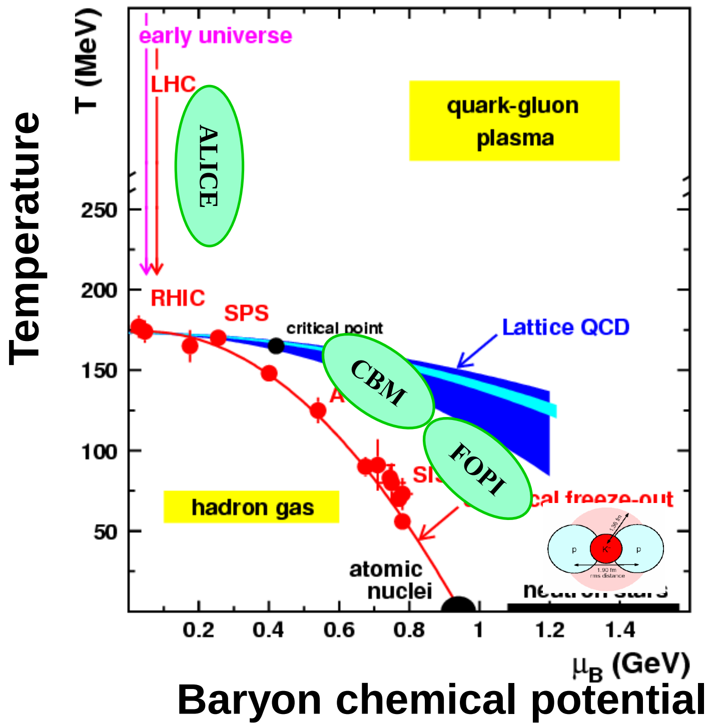
Strangeness production in baryonic matter is still far from being understood.
Baryons are essential to address in-medium effects.

Medium effects necessary for K^+, K^0 $\rightarrow$ $U(\rho_0)$=+20MeV,
Depth of K^- - potential unknown.

New high statistics HI-data available at 2 AGeV
Phase space distribution of baryons
point to non-equilibrated final state.

Short lived strange resonances reconstructed
for the first time below NN - threshold.

Search for multi-baryonic strange clusters
Structures seen in Λd und Λp final states in diff. reactions.
Conflicting peak positions and widths.



Future experiments of FOPI @ GSI

HI:	Ni + Ni, Pb @ 1.93 AGeV, Ru + Ru @ 1.69 AGeV
ppK^- - search:	p + p @ 3 AGeV
K^- -production:	π^- + p,Pb @ 1.7 GeV/c

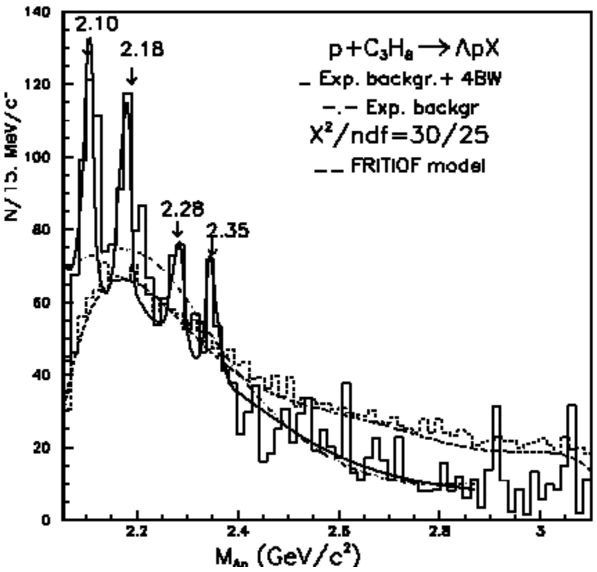
Interesting program for CBM-light @ FAIR (SIS100, 2-10 AGeV)

Strange multi-baryonic clusters are an exiting possibility
to explore the properties of cold dense baryonic matter and non-perturbative QCD.

THE END

Further observations of Λp – correlations

pA collisions @ 10 GeV/c
JINR 2m – propane bubble chamber
700.000 stereo photographs
of 10^6 p + propane inelastic interactions

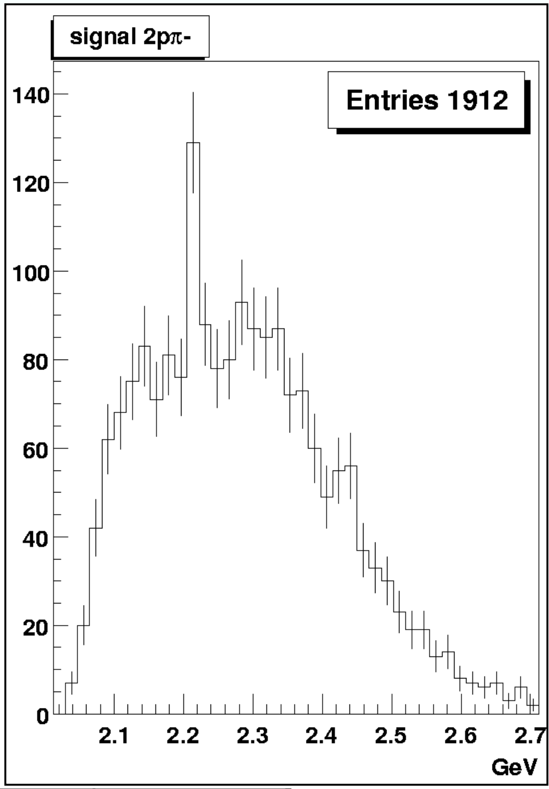


P. Aslanyan, hep-ex/0610086

Obelix:
200 MeV/c antiprotons
stopped in helium (NTP)
10^4 events

Cuts:
IM(Λ) in [1085 – 1145] MeV
and cosΘ < -0.4

Θ – angle between Λ and K^0_S



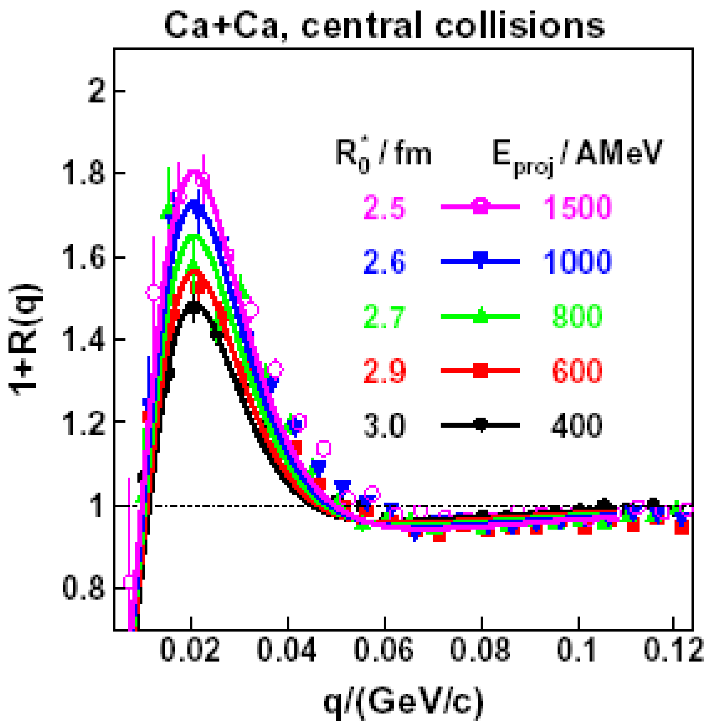
→ **talk by P. Aslanyan**

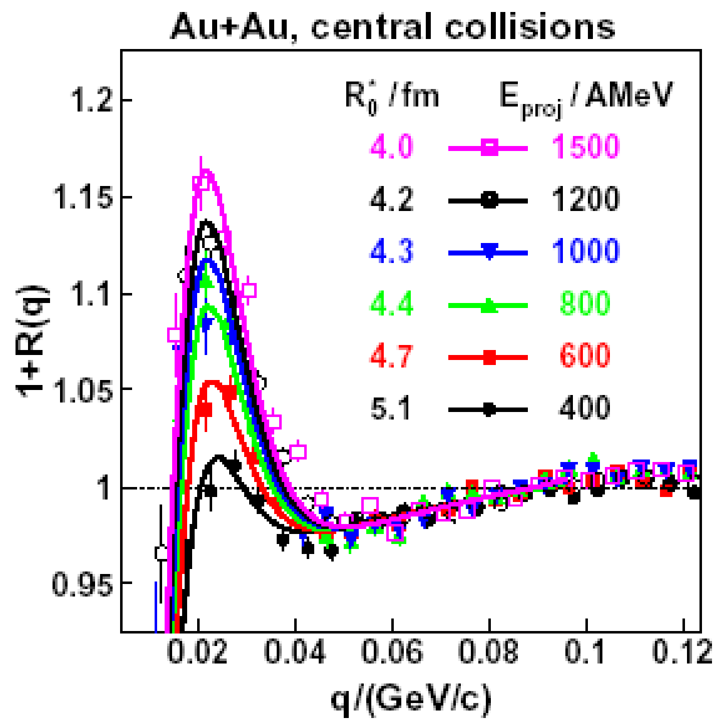
		M (MeV)	Γ (MeV)	P/Λ	P/(IN)	Sign (σ)
FOPI	HI: Al+Al	2120 ± 10	59 ± 12	$1.7 \cdot 10^{-2}$		5.0
	HI: Ni+Ni	2140 ± 10	59 ± 19	$2.2 \cdot 10^{-2}$		5.4
FINUDA *PRL 94(2005)212303*	K^- stopped on ^{12}C, $^{6,7}Li$	2255 ± 9	67 ± 14	$3\text{-}4 \cdot 10^{-2}$	$1. \cdot 10^{-3}$	? (10)
Obelix	$\bar{p}$ stopped in ^4He	2209 ± 5	< 24.4		$>1.4 \cdot 10^{-4}$	3.7
Dubna	p + A	2100, 2180, …	<10		?	?

Freeze-out from 2-particle correlations

2-proton correlation functions

R. Kotte et al. (FOPI), EPJ A 23 (2005) 271





Correlation function:

$$1+R(p_1,p_2) = N\,\frac{\sum_{events} Y_{12}(p_1,p_2)}{\sum_{events} Y_{12,mixed}(p_1,p_2)}$$

$$q = |q| = \frac{1}{2}\left|p_1^{cm} - p_2^{cm}\right|$$

Apparent radius R_0^*

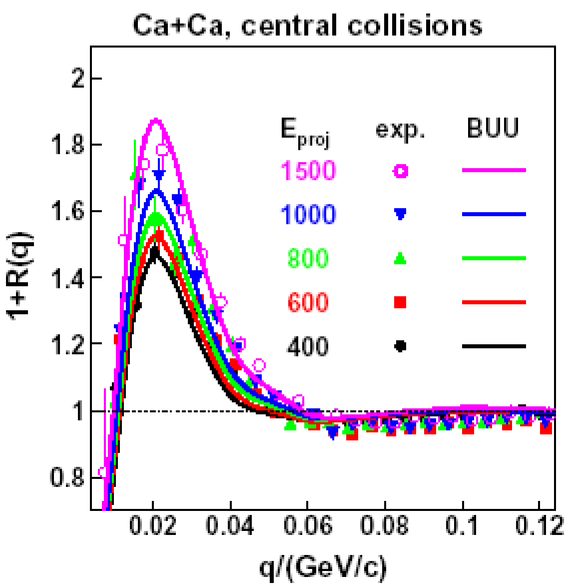
$$R_0^* = \sqrt{\frac{R_0^2}{1+\varepsilon} + (\mathrm{v}\tau)^2}$$

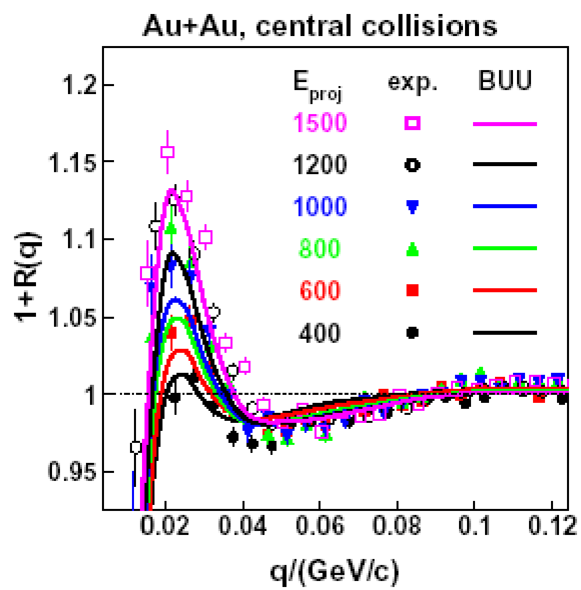
$$\varepsilon = E_{flow} / E_{therm}$$ ratio radial flow / thermal energy

$$\mathrm{v} = P / 2m$$ pair velocity - emission duration τ

2-proton correlations (II)

R. Kotte et al. (FOPI), EPJ A 23 (2005) 271





Construction of 2-proton correlation from BUU + FSI:

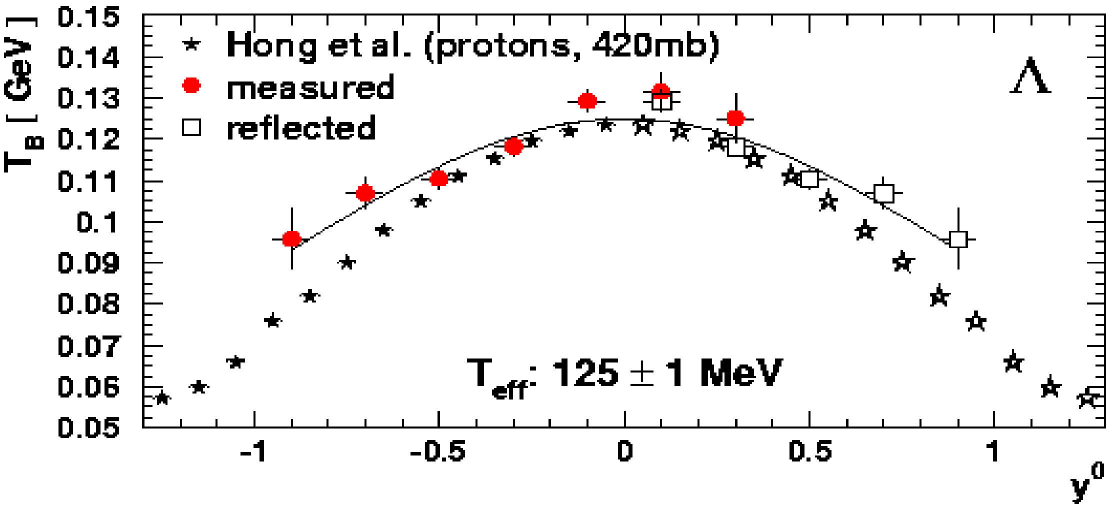
excitation function and
system size dependence well reproduced.

Change of the apparent freeze-out conditions ρ^*/ρ_0:

	Ca+Ca	Au+Au
E_{beam}=0.4 AGeV	0.27±0.06	0.29±0.05
E_{beam}=1.5 AGeV	0.47 ±0.11	0.60±0.10

Dynamical Evolution

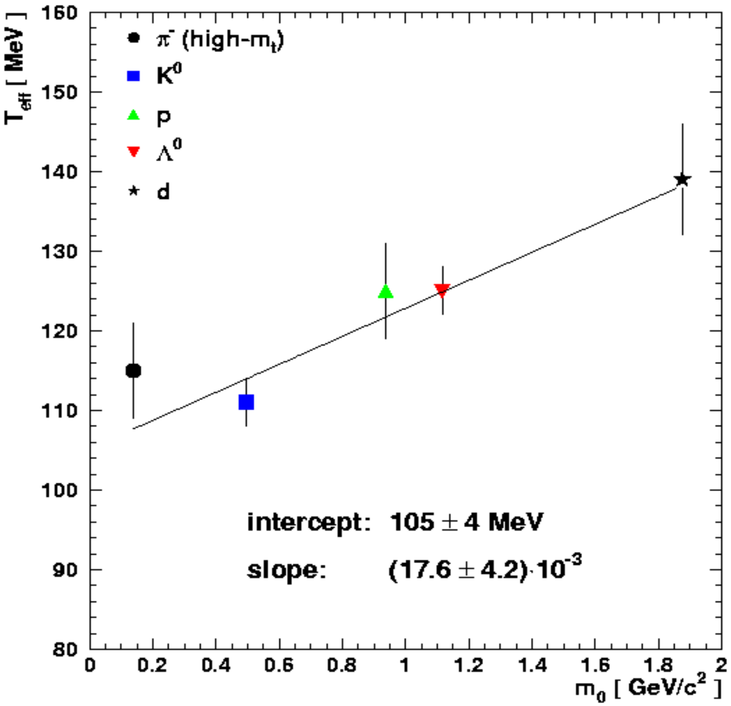
Inverse slope parameter systematics



Thermal expectation:

$$T_B = T_{eff} / \cosh(y)$$

For Λ the variation of the inverse slope T_B with rapidity agrees with the emission from a single isotropically radiating thermal source.



Transverse collective expansion

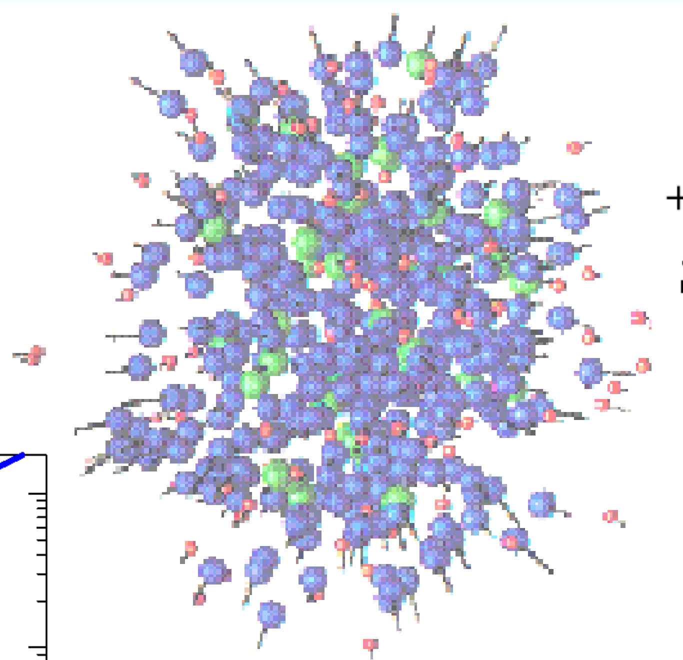
The extraction of the final temperature requires the disentanglement of the contribution from the collective expansion to T_{eff}.

$$<E> = E_{thermal}(T) + E_{collective}(\beta, m)$$

⇩

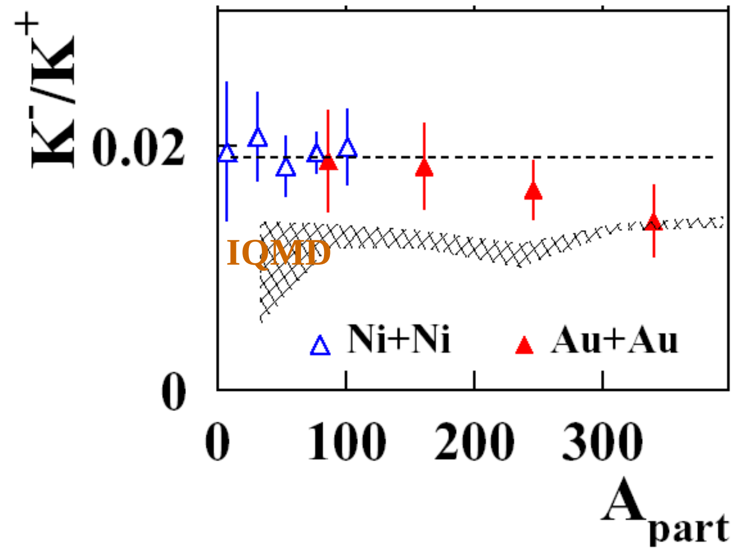
T ≈ 100 MeV
β ≈ 0.23

Kaon & Antikaon Yields close to NN – Production Threshold

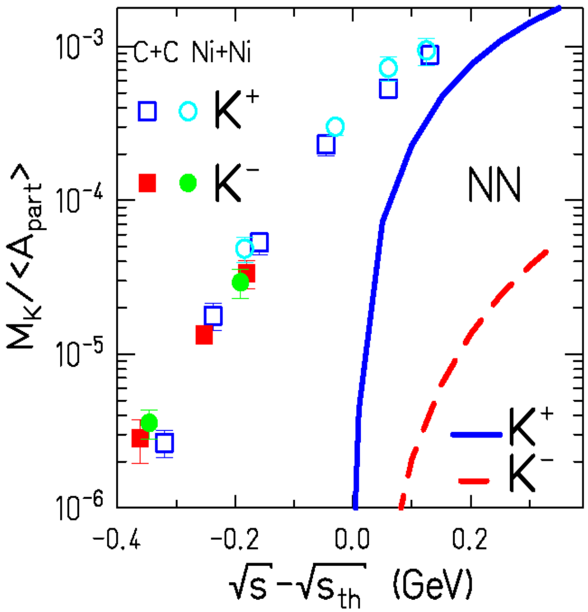


A.Förster et al. (KAOS), PRL 91, 152301(2003)

Centrality dependence



P.Senger et al. (KAOS),
F. Laue et al. , PRL 82 (1999), updated



Production thresholds:

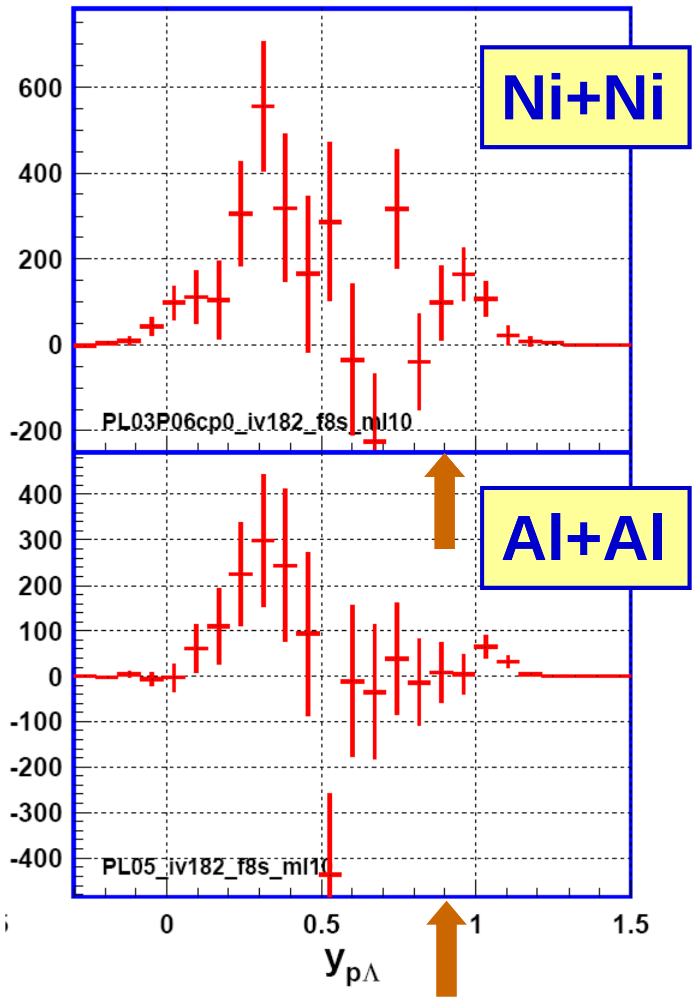
$NN \rightarrow NK^+\Lambda$ E_{lab}= 1.6 AGeV

$NN \rightarrow K^+K^-NN$ E_{lab}= 2.5 AGeV

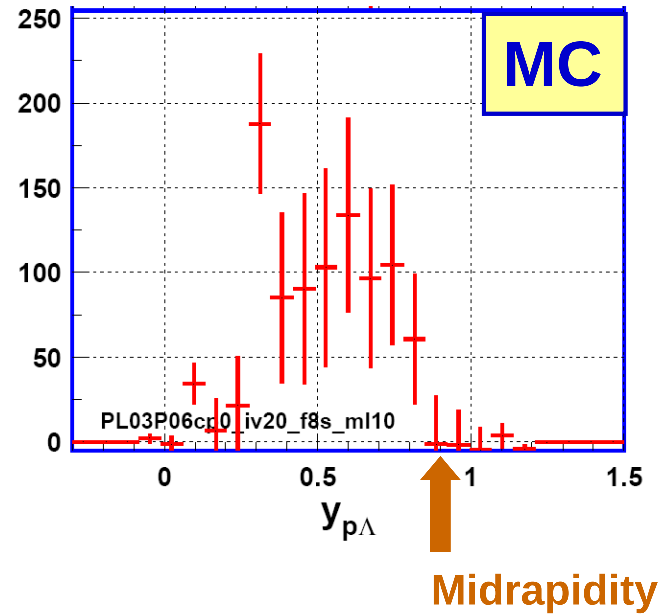
Enhanced production of K^+, K^- observed in HI – coll.
Medium effects:
multistep processes: $\Delta N \rightarrow NK^+\Lambda$, m*(ρ), EOS

Transport models:
no sensitivity of K^-/K^+ - ratio to in-medium mass of K^- due to strangeness exchange reaction $\pi\Lambda \leftrightarrow K^-N$

Phasespace distribution of Λp – excess



Filtered MC distribution from isotropic midrapidity source, T=90 MeV



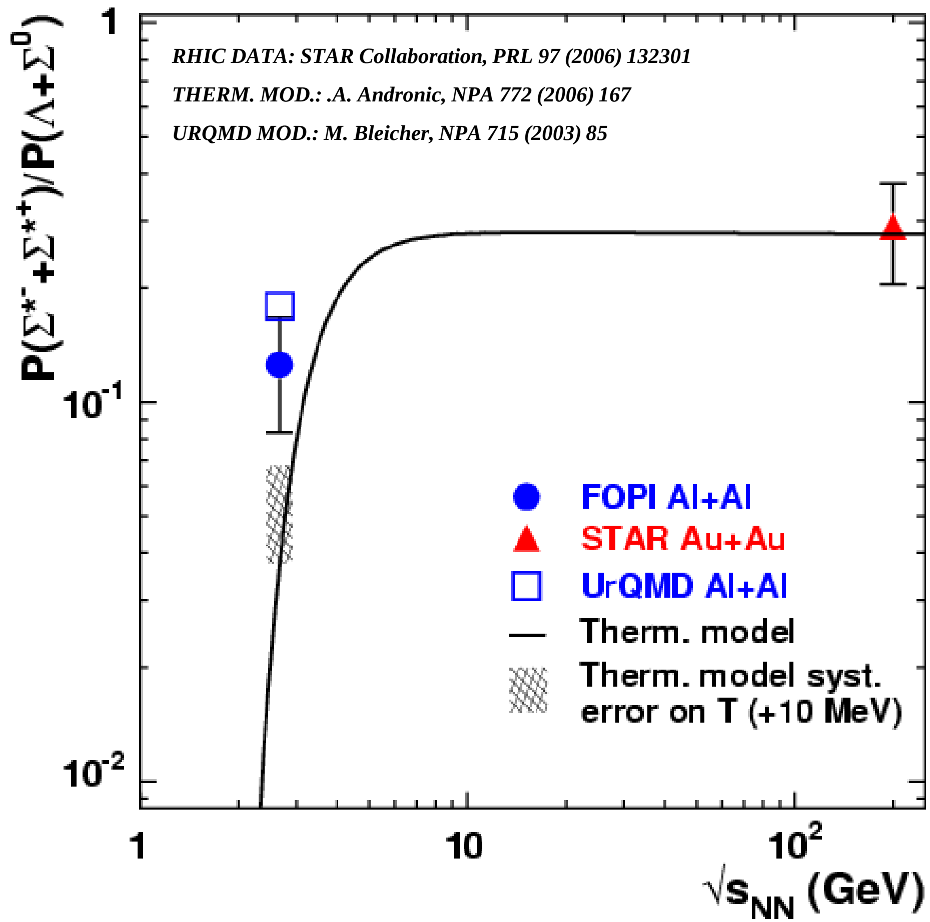
Data are peaked at backward rapidities with respect to isotropic emission pattern → coupling to spectator matter ?

rapidity

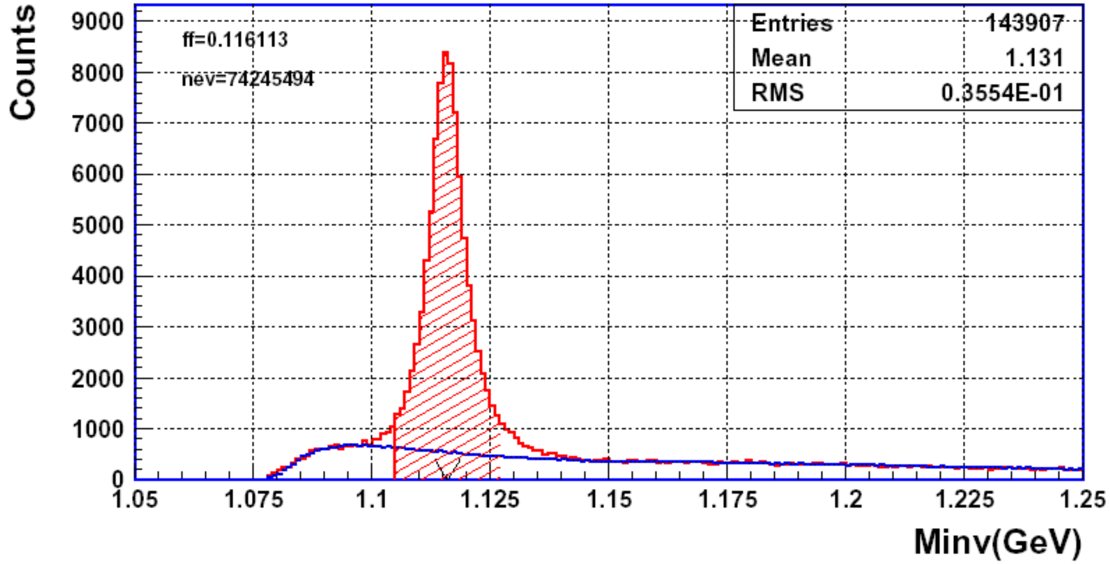
Σ* - production in UrQMD

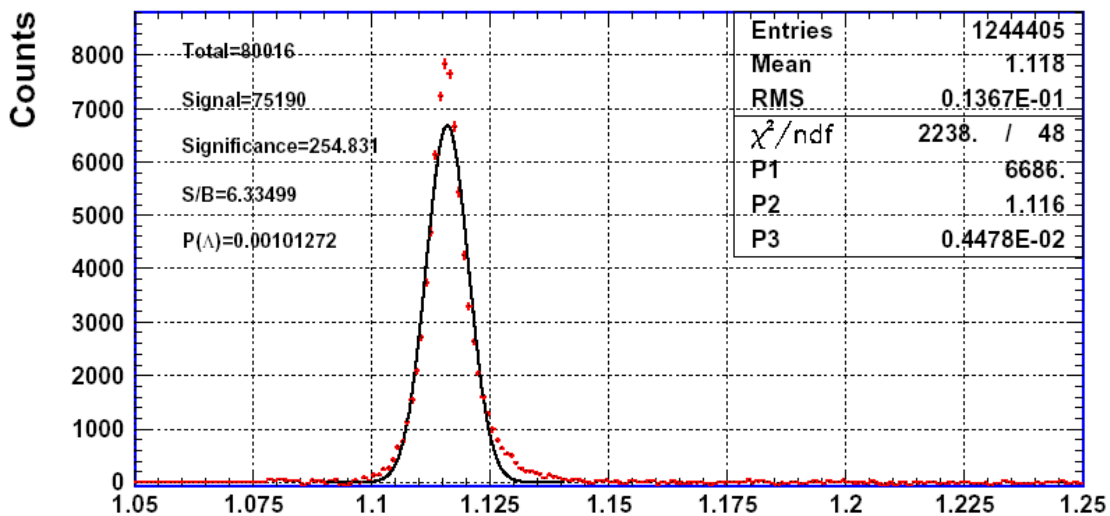
- **Σ* creation processes**

76%	Λ+π→Σ*	σ ~ 37 mb
12%	Σ+π→Σ*	
12%	N*(Δ)+B →Σ*	

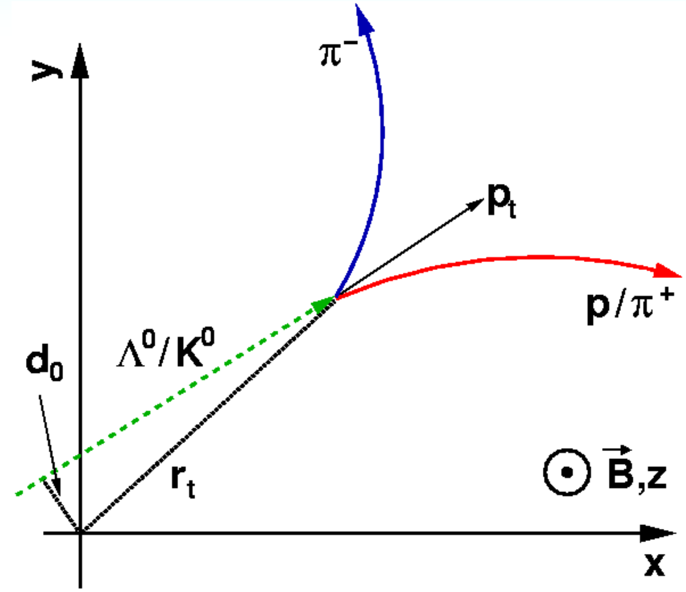


Λ - reconstruction





$M_{inv}(p,\pi^-)$ (GeV)



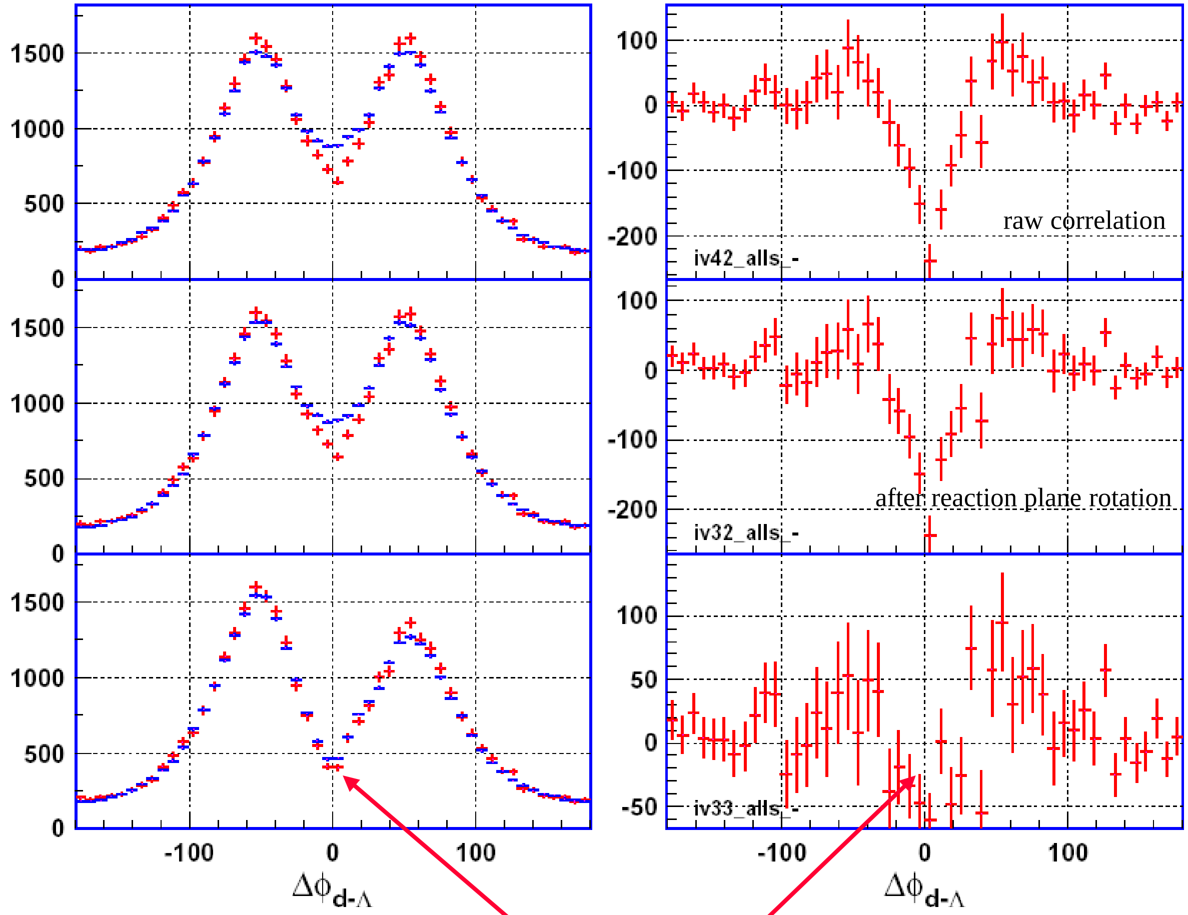
Signal-over-background depends on selection cuts

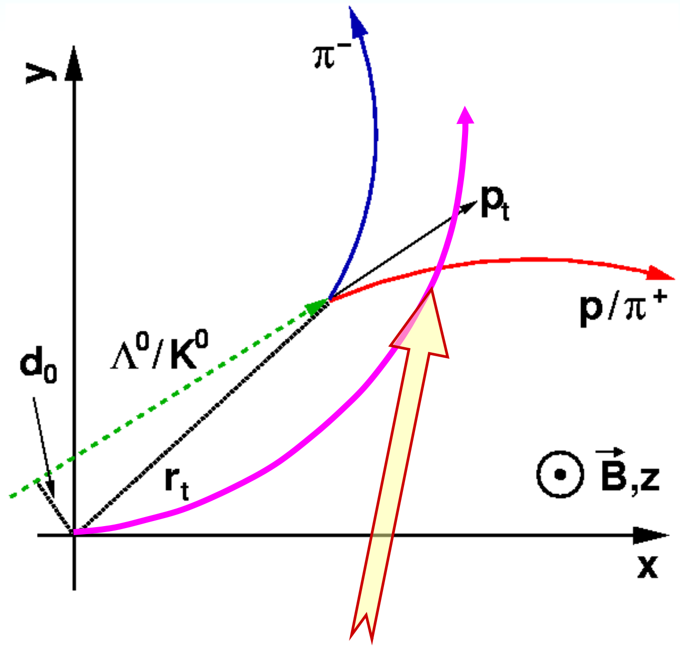
Cut	"p"	"s"
Signal	136k	75k
S/B	1.6	6.0
Signal scaling	2	1
Background scaling	8	1

Detection probability

$$P_{\det} = P_{prod} \cdot \varepsilon \approx 10^{-1} \cdot 10^{-2} = 10^{-3}$$

Relative Azimutal Angle





Tracking efficiency lower
Deficiency not present for mixed events

after reaction plane rotation &&
after crossing tracks removal

Crossing track removal not sufficient to remove all detector biases

The quest for (deeply) bound kaonic states

Introduction

- K^- N interaction
- AY – model
- Initial experimental evidence for kaonic clusters

FOPI measurements

- Kaonic cluster production in HI collisions
- Baryon phase space distributions
- Λ-X correlation analysis
  - invariant mass distributions of
  - Λ + d , Λ + p, Λ + π^-

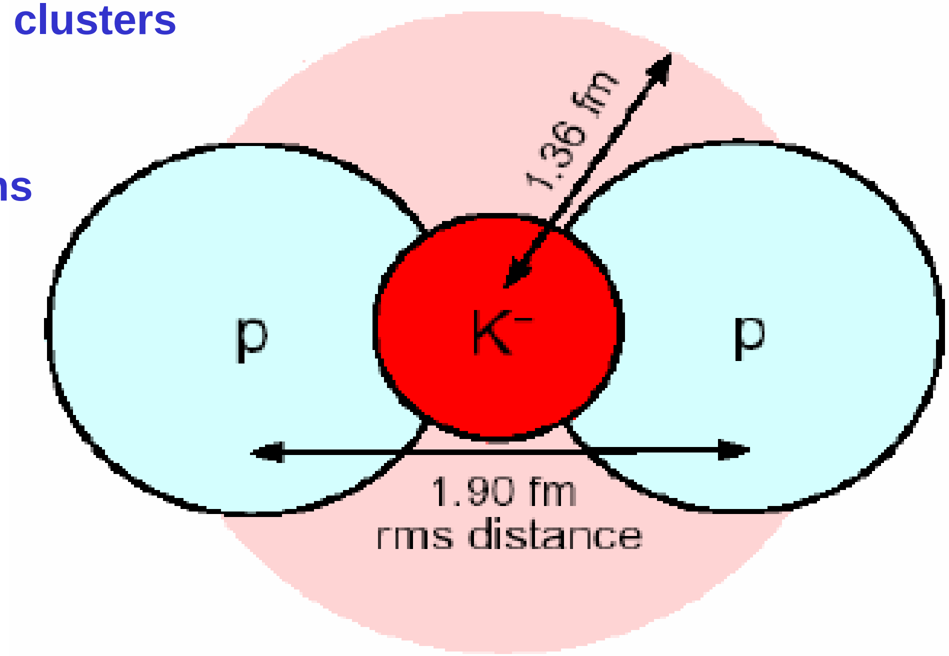
Comparison of different methods

- KEK 549
- FINUDA
- Obelix (PS201)
- Dubna

Planned experiments

- p + LH_2 @ 3.0 GeV

Summary/Conclusions



Antikaons: $\bar{K}^0 : \; s\,\bar{d}$

$K^- : \; s\,\bar{u}$

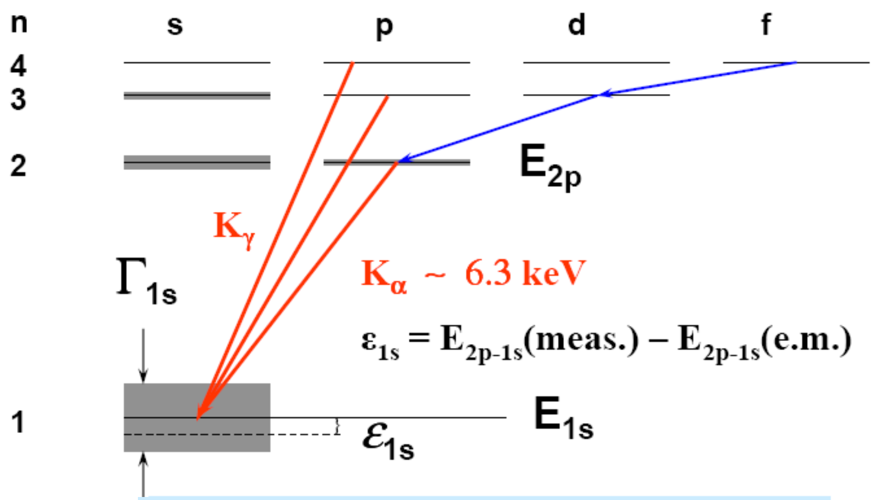
Deuteron - radius: R_{rms}=1.95 fm

$K\bar{N}$ – interaction from kaonic hydrogen

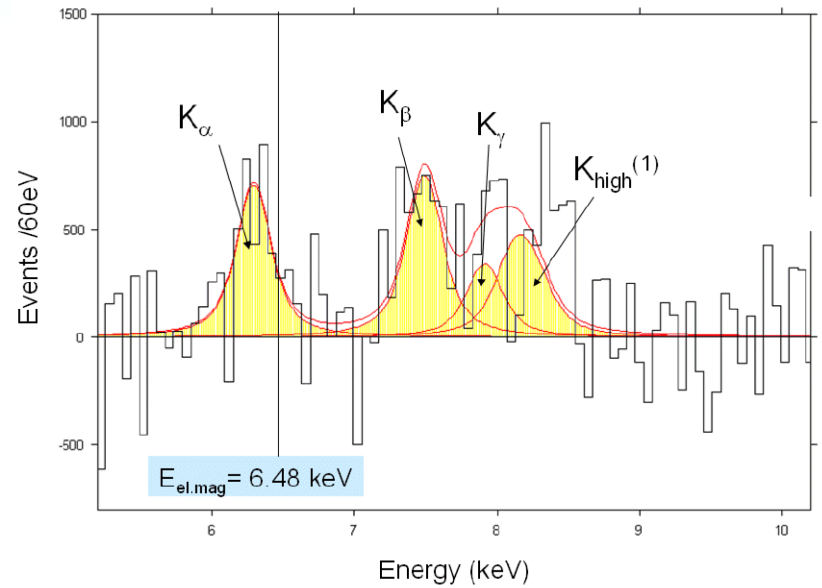
DEAR - results: X-rays from kaonic hydrogen

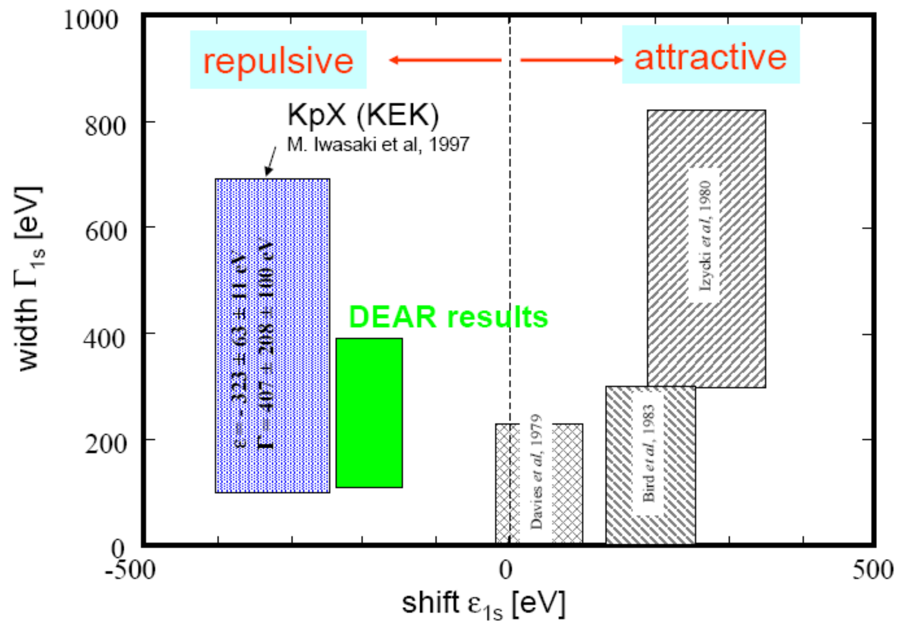
G.Beer et al., PRL 94, 212302 (2005)

Level diagram



as the kaon interacts strongly with the nucleus the 1s energy level is shifted and broadened





Deser-Trueman-formula:

$$\varepsilon_{1s} + \frac{i}{2}\Gamma_{1s} = 2\alpha^3\mu^2 a_{K^-p}$$

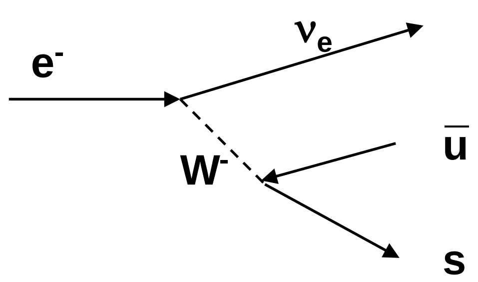
Scattering length: $a_{K^-p} = \lim_{p\to 0} f_{K^-p}$

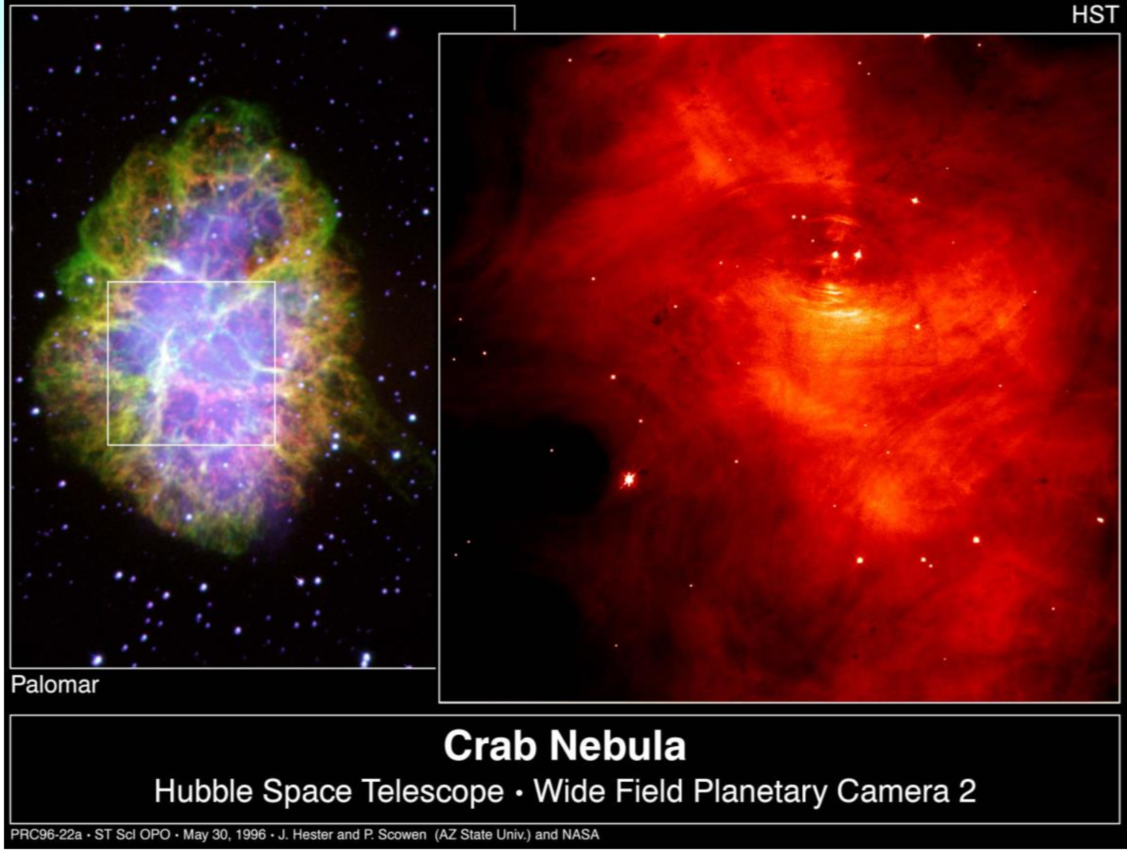
Neutron stars

Antikaons in Neutron stars:
“Kaon condensate”

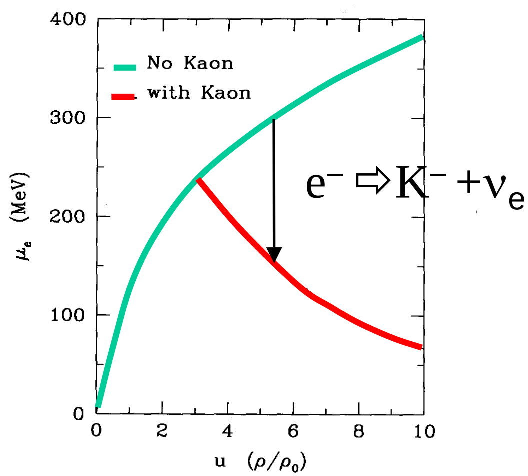
$e^- \Rightarrow K^- + \nu_e$, n $\Rightarrow$ $p + K^-$

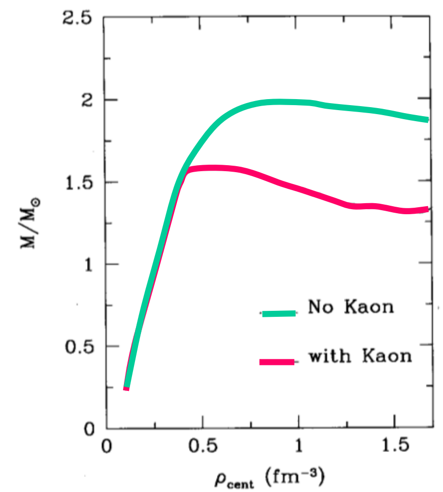
G.E. Brown, H.A. Bethe, Astrophys. Jour. 423 (1994) 659
G.Q.Li, C.H. Lee, G.E. Brown , Nucl. Phys. A 625 (1997)



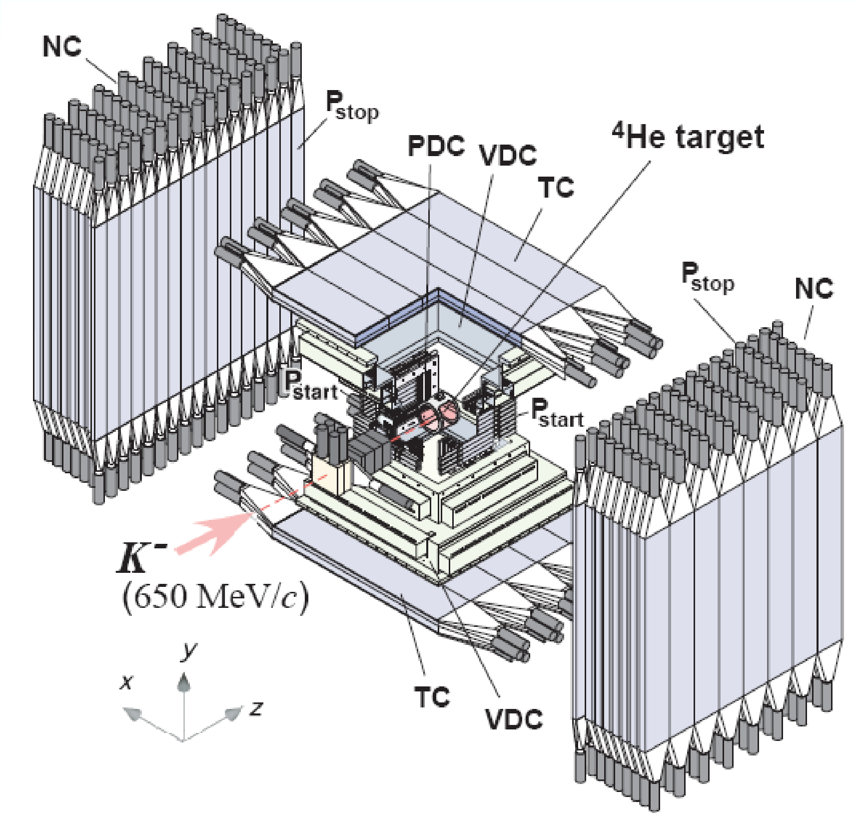


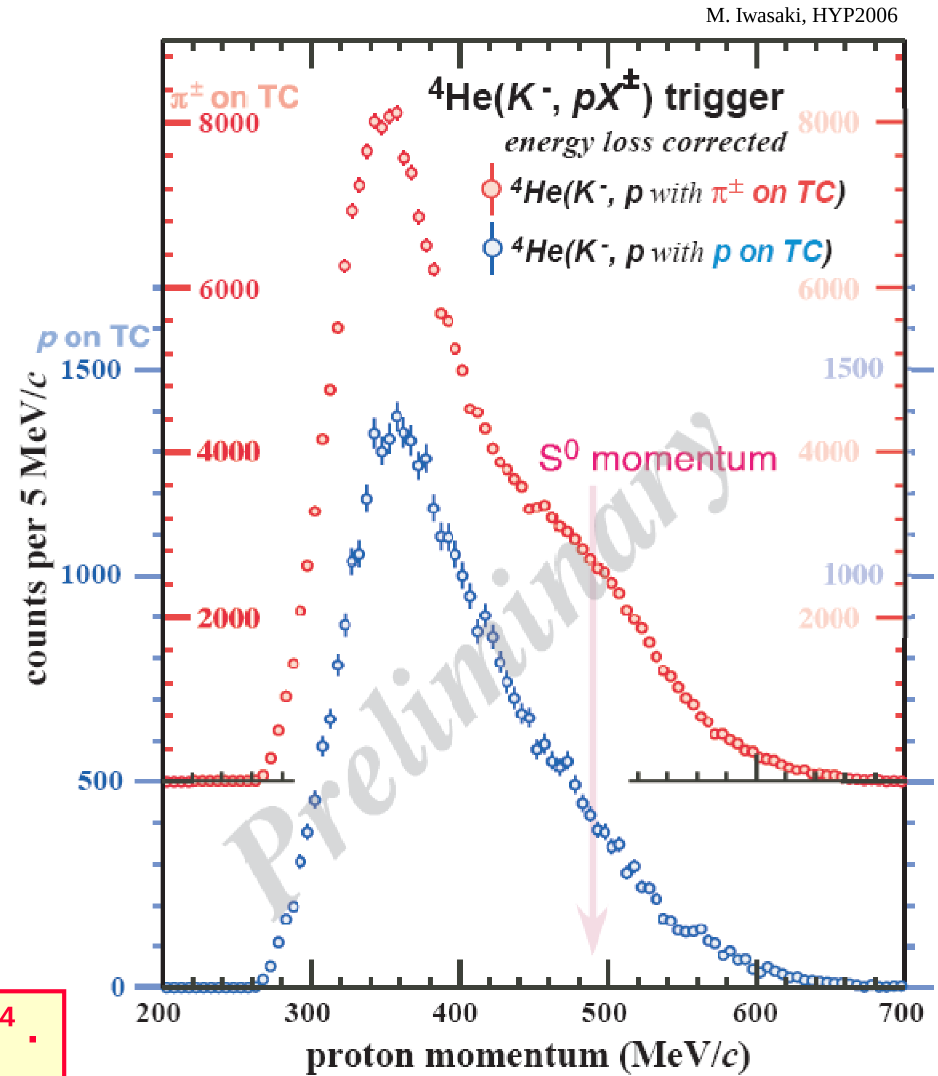
$U_{K^-}(\rho=\rho_0) = -110$ MeV:





KEK-E549

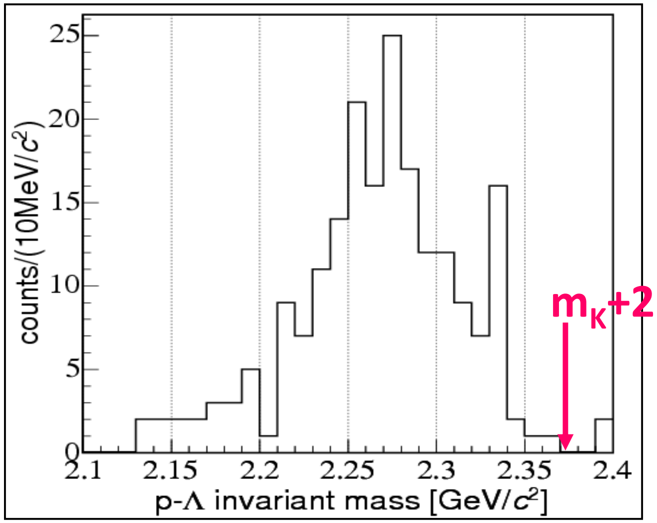


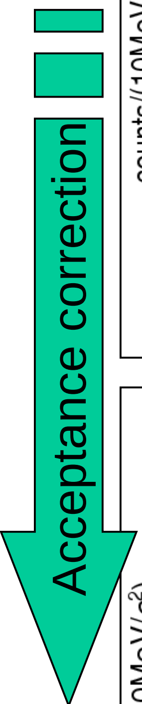


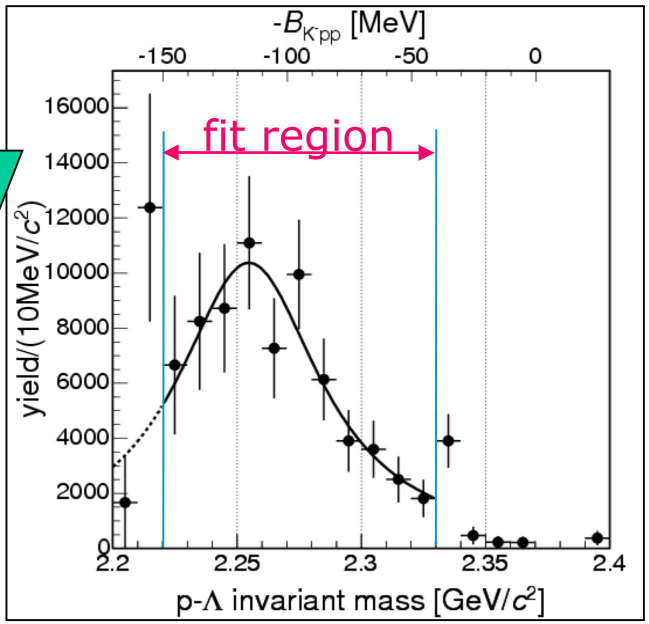
Formation probability at S^0 mass: P (Γ<20MeV) < 10^{-4} .

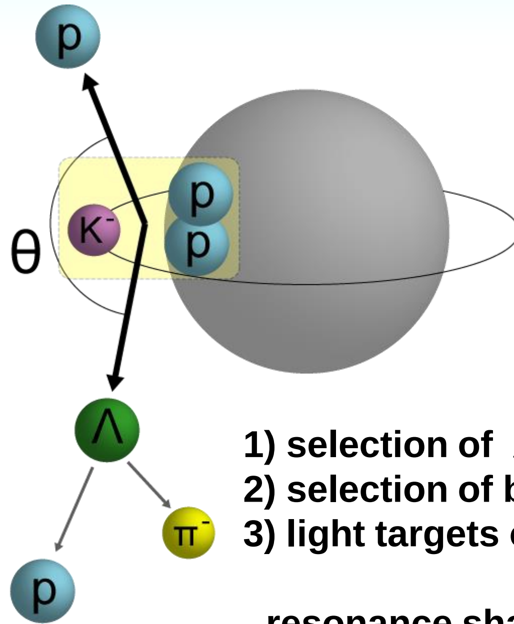
Note: P($^4_\Lambda$He) ~ 10^{-2}

Comparison of evidence for ppK$^-$









1) selection of Λ invariant mass
2) selection of back – to – back Λp pairs
3) light targets only (3x ^{12}C, 2x ^{6}Li, 1x ^{7}Li)

- resonance shape / width sensitive to acceptance
- no background estimate from quasi-free production
- FOPI peak outside FINUDA acceptance

		M (GeV)	Γ (MeV)	P/Λ	P/K$^-$
FOPI	HI: Al+Al	2.12 ± 0.01	59 ± 12	$1.7 \cdot 10^{-2}$	
	HI: Ni+Ni	2.14 ± 0.01	59 ± 19	$2.2 \cdot 10^{-2}$	
FINUDA PRL 94(2005)212303	K$^-$ stopped on ^{12}C, ^{6,7}Li	2.255 ± 0.009	67 ± 14	$3\text{-}4 \cdot 10^{-2}$	$1 \cdot 10^{-3}$

Obelix (PS201) @ LEAR

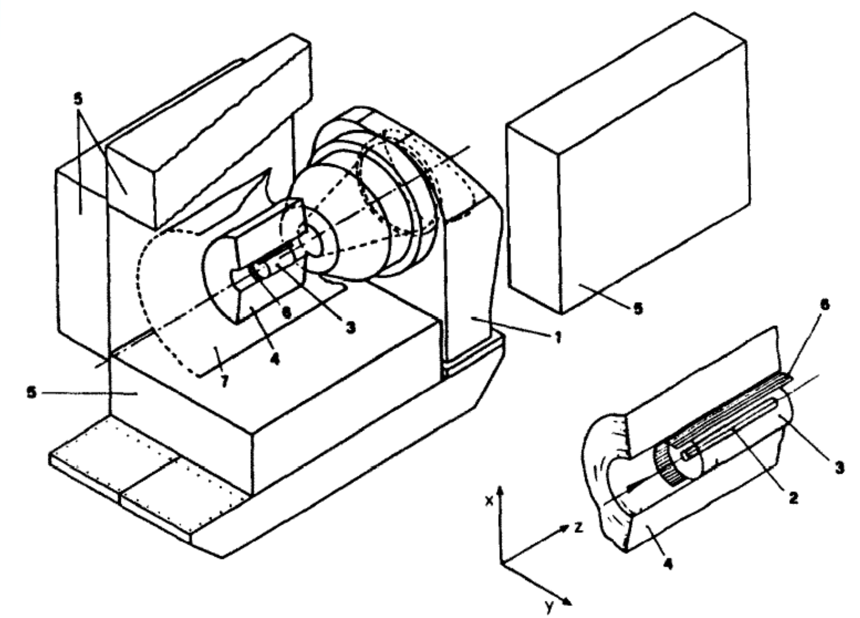


Fig. 1. OBELIX spectrometer: view with a lateral supermodule of the E. M. calorimeter shifted in maintenance position. (1) Open axial field magnet; (2) Target (∅= 6 cm, length 60 cm); (3) Spiral projection chamber (SPC, $\varnothing_{int} = 6$ cm, $\varnothing_{ext} = 30$ cm, length 60 cm, 90 sense wires); (4) Jet-Drift Chambers (JDC, $\varnothing_{int} = 40$ cm, $\varnothing_{ext} = 160$ cm, length 140 cm, 1722 sense wires for each chamber; 41 azimuthal sectors of 4° for each chamber); (5) High angular resolution gamma detector (HARGD, four supermodules $300 \times 400 \times 80$ cm^3 each). Time of flight system: (6) internal scintillator barrel ($\varnothing_{int} = 36$ cm, thickness = 1 cm, length 80 cm, 30 elements); (7) external scintillator barrel ($\varnothing_{int} = 270$ cm, thickness = 4 cm, 84 elements).

$$\bar{p}\,^4He \rightarrow {}^2_{\bar{K}}H\, n K^\circ X \rightarrow \Lambda p\, n K^\circ_S X \rightarrow p\pi^- p\pi^+\pi^- nX$$

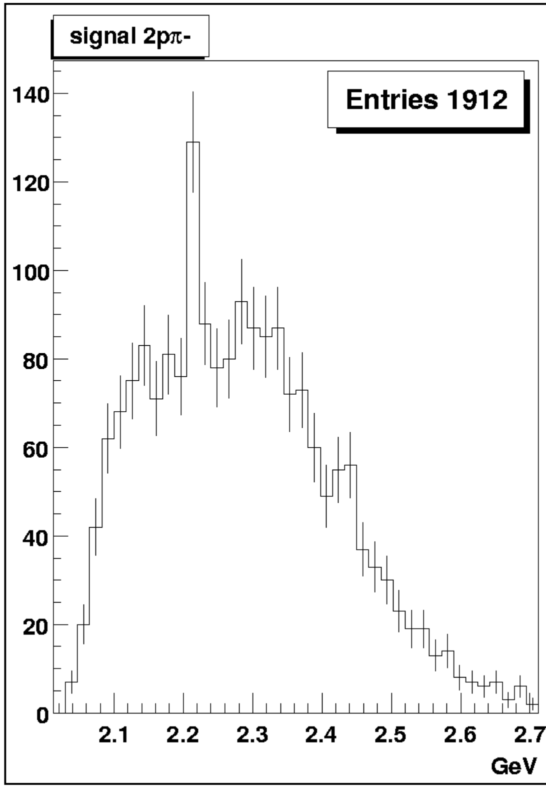
$$\bar{p}\,^4He \rightarrow {}^2_{\bar{K}}H\, n\pi^+\pi^- K^\circ X \rightarrow \Lambda p\,\pi^+\pi^- n K^\circ_{S,L} X \rightarrow p\pi^- p\pi^+\pi^- n K^\circ_{S,L} X$$

200 MeV/c antiprotons stopped in helium (NTP)
10^4 events

Cuts:
IM(Λ) in [1085 – 1145] MeV
and cosΘ < -0.4

Θ – angle between Λ and K^0_S

G. Bendiscioli et al., submitted to NPA (2007)

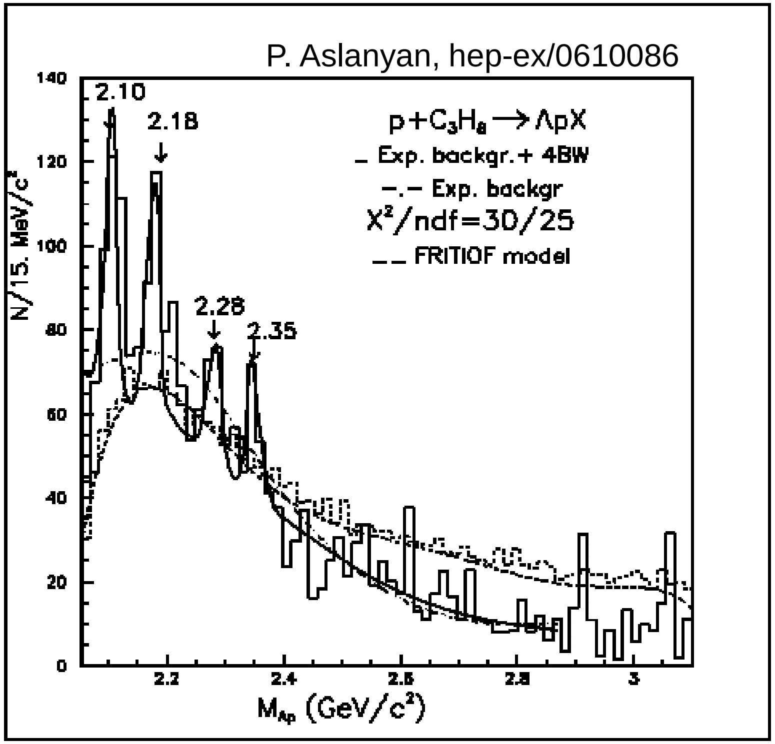


		M (MeV)	Γ (MeV)	P/Λ	P/(IN)	Sign (σ)
FOPI	HI: Al+Al	2120 ± 10	59 ± 12	$1.7 \cdot 10^{-2}$		5.0
	HI: Ni+Ni	2140 ± 10	59 ± 19	$2.2 \cdot 10^{-2}$		5.4
FINUDA *PRL 94(2005)212303*	K^- stopped on ^{12}C, $^{6,7}Li$	2255 ± 9	67 ± 14	3-4 $\cdot 10^{-2}$	$1. \cdot 10^{-3}$	? (10)
Obelix	$\bar{p}$ stopped in ^4He	2209 ± 5	< 24.4		$>1.4 \cdot 10^{-4}$	3.7

pA collisions @ 10 GeV/c

JINR 2m – propane bubble chamber

700000 stereo photographs
of 10^6 p + propane inelastic interactions



		M (MeV)	Γ (MeV)	P/Λ	P/(IN)	Sign (σ)
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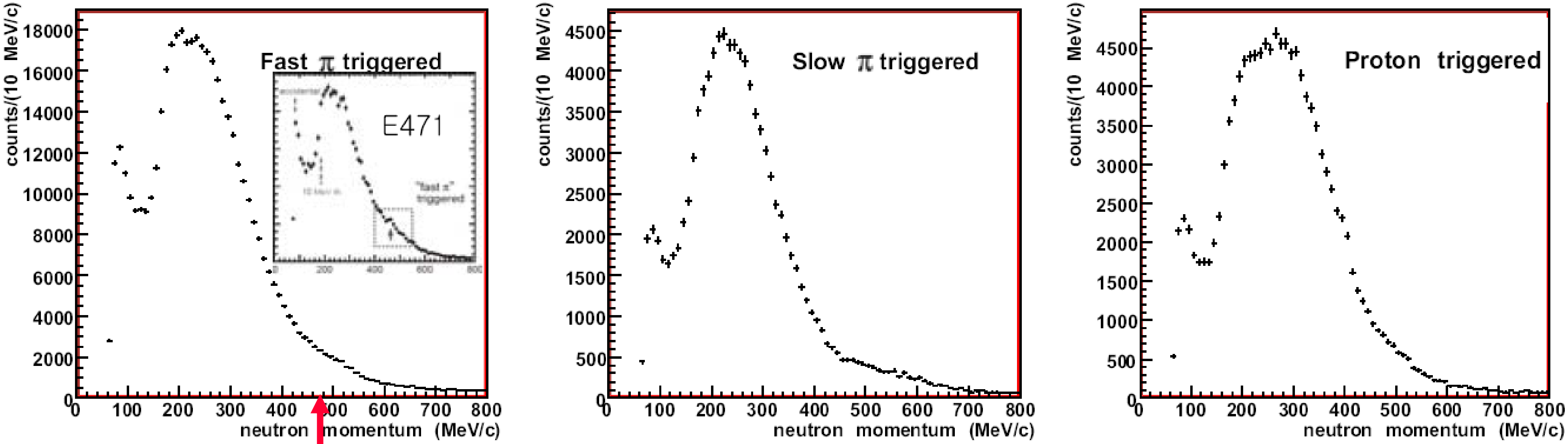
Obelix	$\bar{p}$ stopped in ^4He	2209 ± 5	< 24.4		$>1.4 \cdot 10^{-4}$	3.7
Dubna	p + A	many	<10		?	?

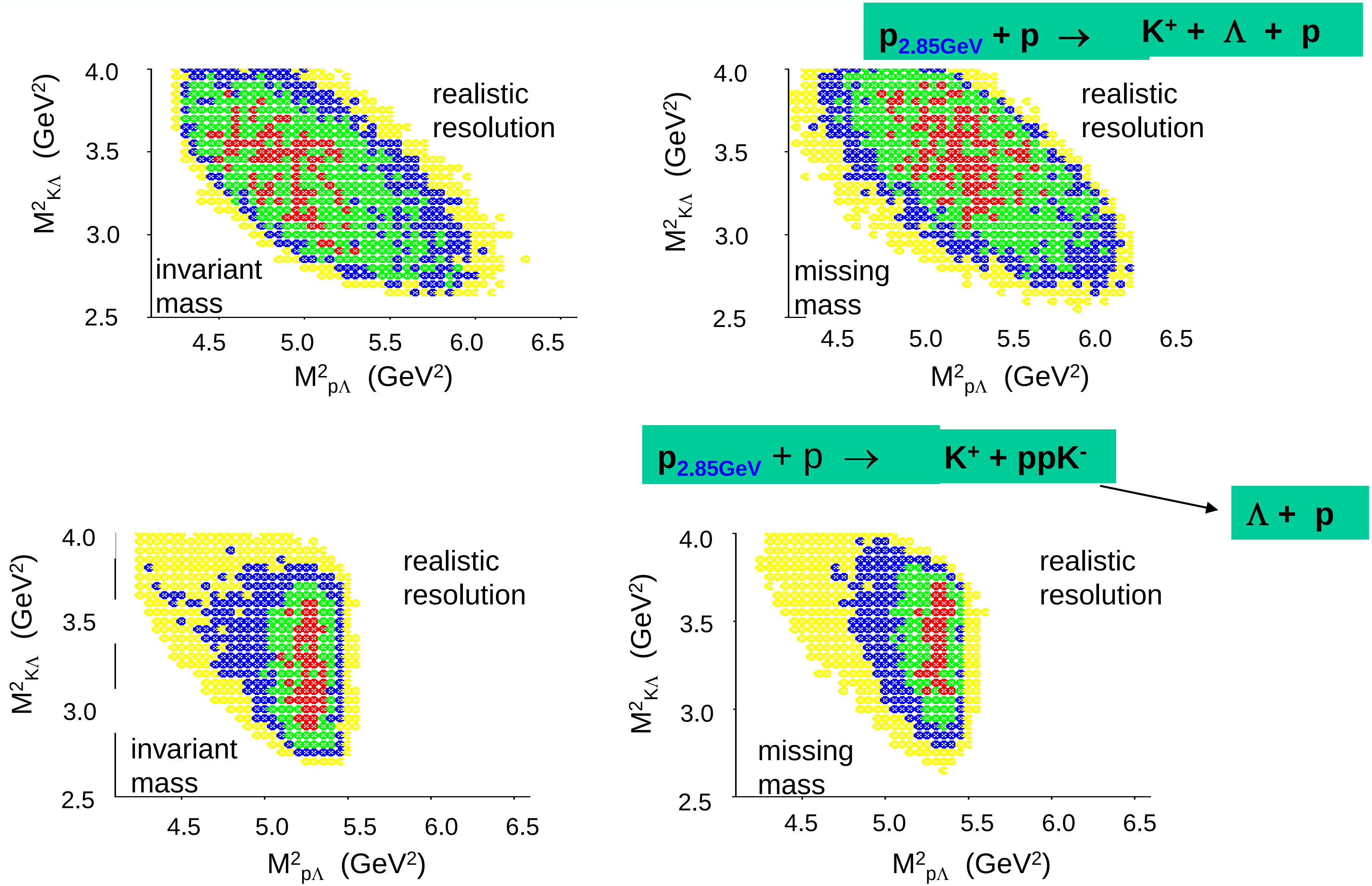
Tribaryons: ppnK$^-$ - search by E549

H. Yim et al., HYP2006



No evidence for narrow structure in new high statistics data.
Analysis for a wider resonance (Γ>60 MeV) is in progress.

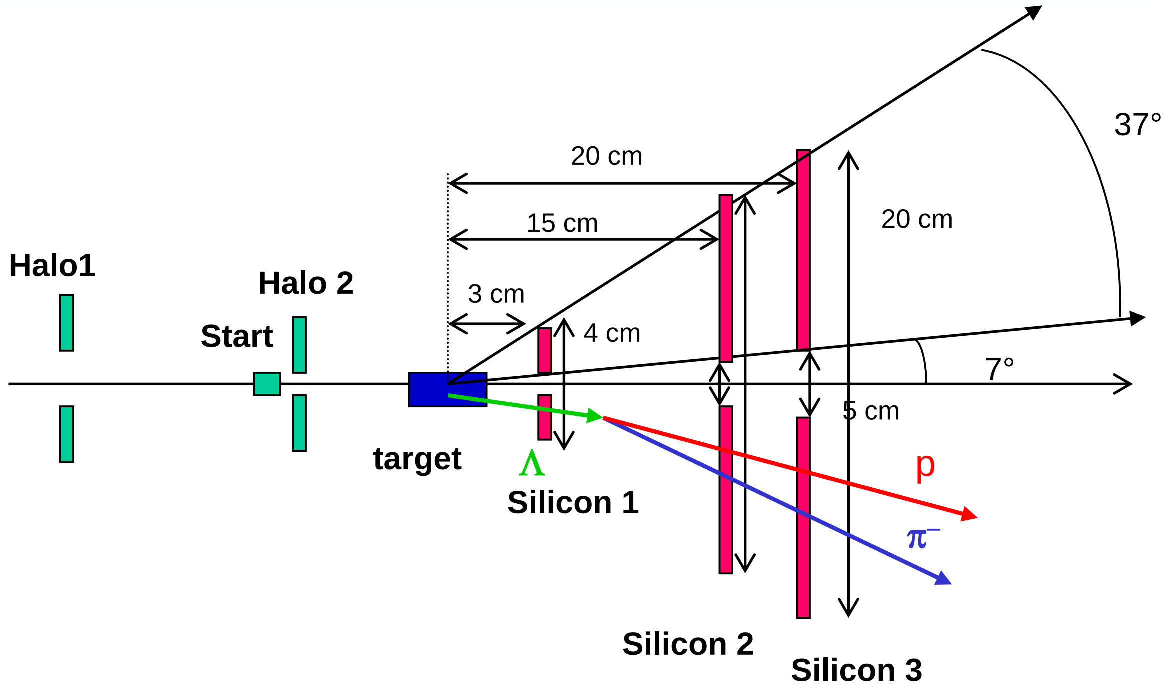
Dalitz plots



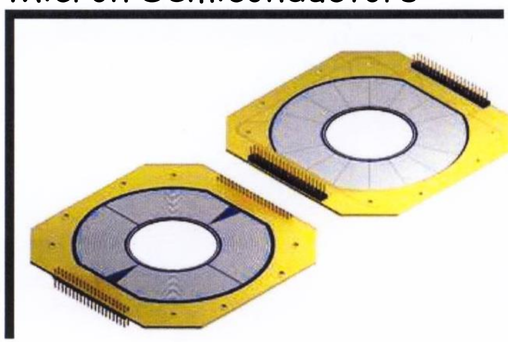
New Inner Tracker for FOPI

Λ – Trigger

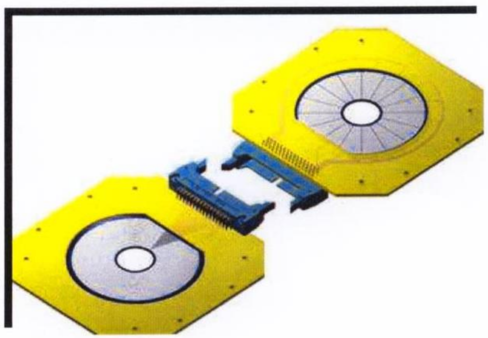
(L. Fabietti, TUM Munich)



Micron Semiconductors



S1 detector and PCB as viewed from the p- and n-side.



S2 detector and PCB as viewed from the p- and n-side

	Back. No Λ	Back. Λ	Signal
LVL1 M>3	11%	40%	45%
Λ Trigger	0.17%	16%	16%

Future Options

$$s = \frac{S}{\sqrt{S+B}} \approx \sqrt{S}\sqrt{\frac{S}{B}}$$

$$S = \frac{s^2}{(S/B)} = (P \cdot BR) \cdot \varepsilon \cdot N_{events}$$

$$N_{events} = \frac{s^2}{(S/B)\cdot(P\cdot BR)\cdot\varepsilon}$$

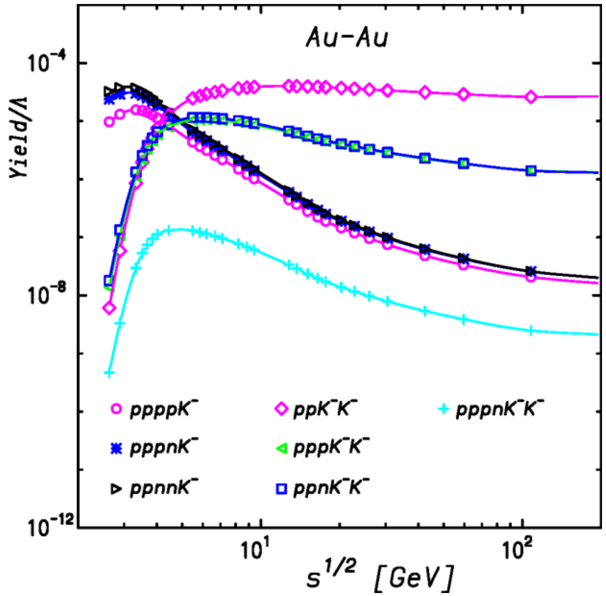
Yield of single and double strange clusters per Λ peaked in SIS 18/100 range

Experiment should reach sensitivity of $X/\Lambda \sim 10^{-5}$

Necessary statistics: $N_{event} > 25/(10^{-2} \cdot 10^{-5} \cdot 10^{-2}) = 2.5 \cdot 10^{10}$

Thermal model predictions

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



Note: observations (cut - dependence of yield) not consistent with thermal distribution

What could be done (in the near future) at SIS 18?

Signal in HI is statistics limited

Rate capabitity of FOPI 2005: 1kHz in spill (700 Hz DC)

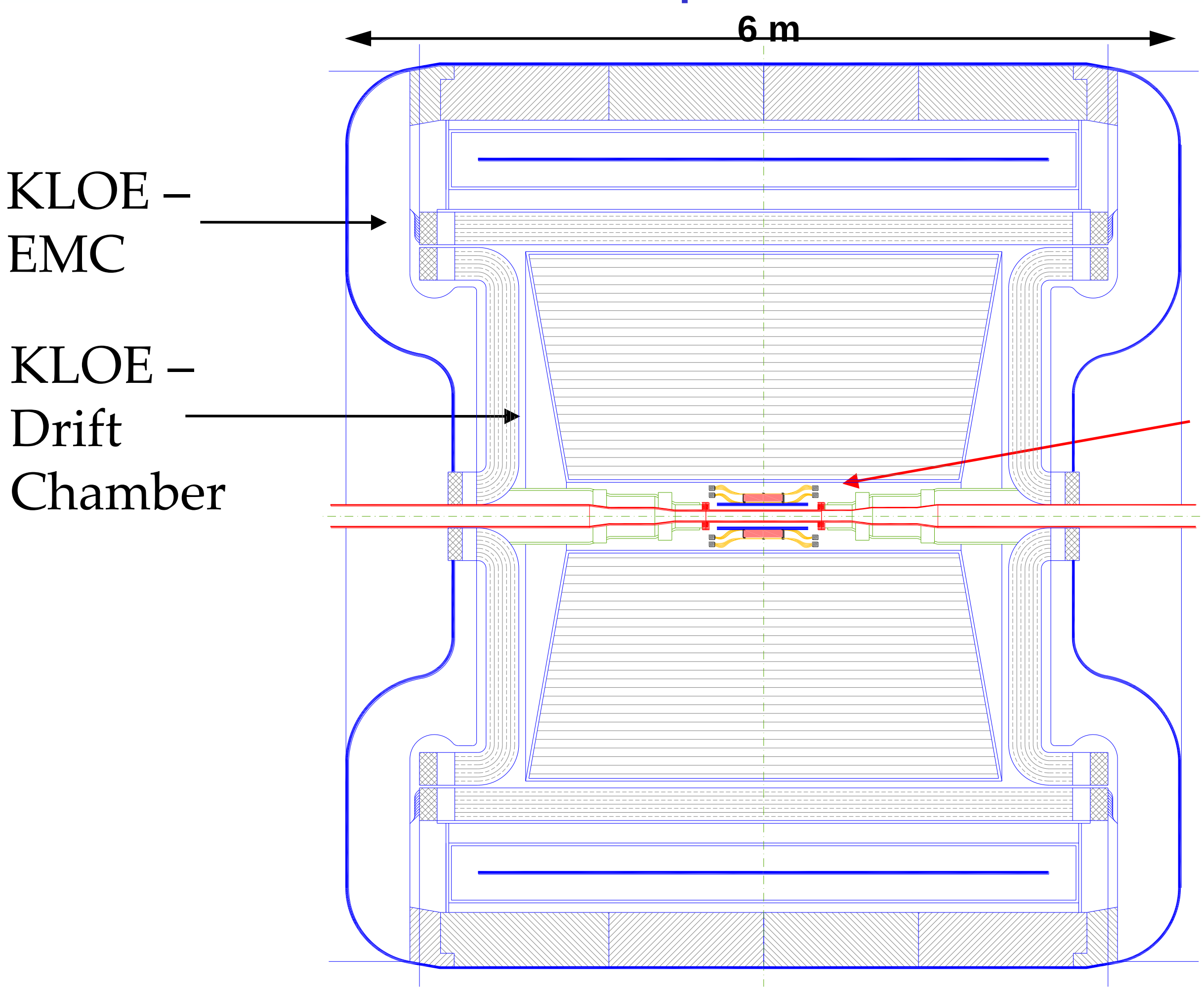
Max. Rate tolerable by FOPIs drift chambers: T_{drift}=5µs
R_{max}(in spill) = 200 kHz → 100 kHz (with pile-up reject)
R_{max}(DC) → 70 kHz

Factor 100!

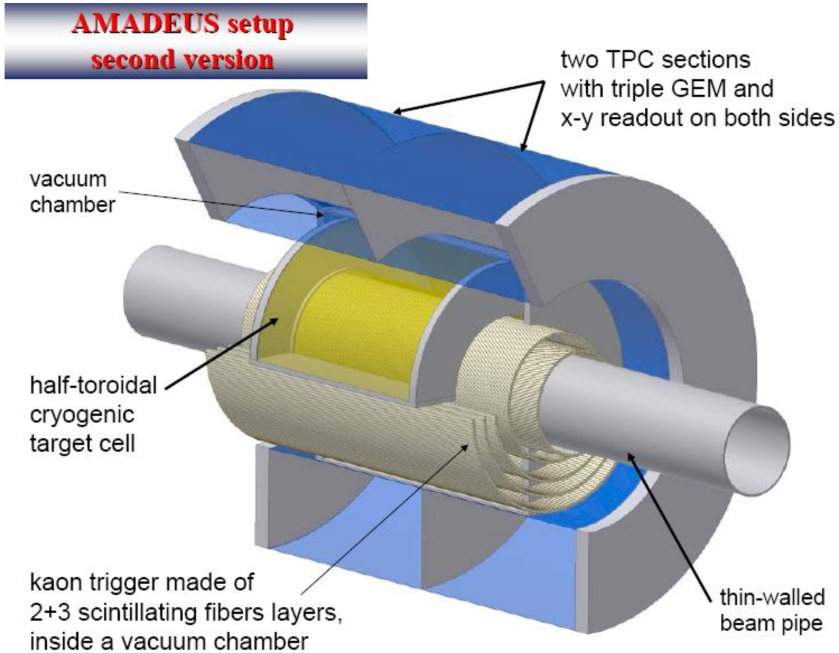
How? deadtime free DAQ system for FOPI
use CBM prototypes
relevant system test for CBM

AMADEUS

AMADEUS Implemented in KLOE

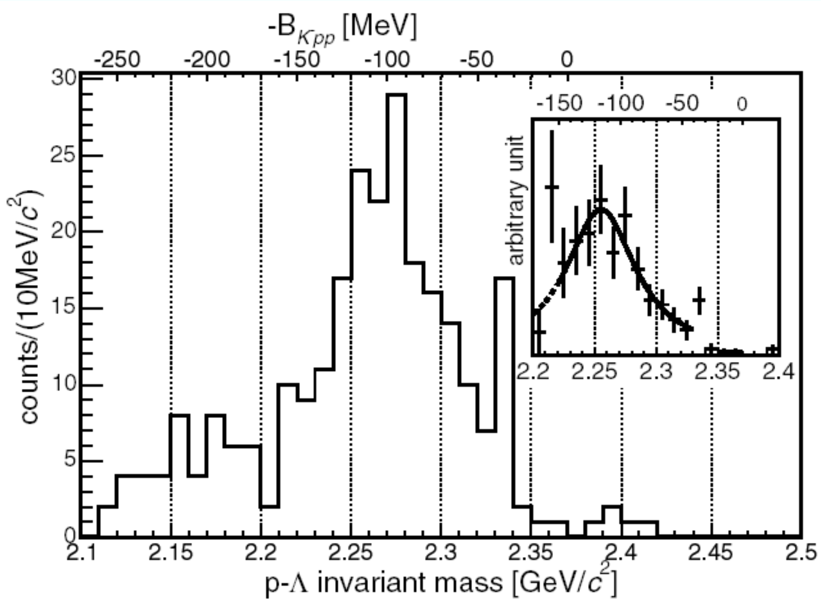


Possible setup for AMADEUS within KLOE:

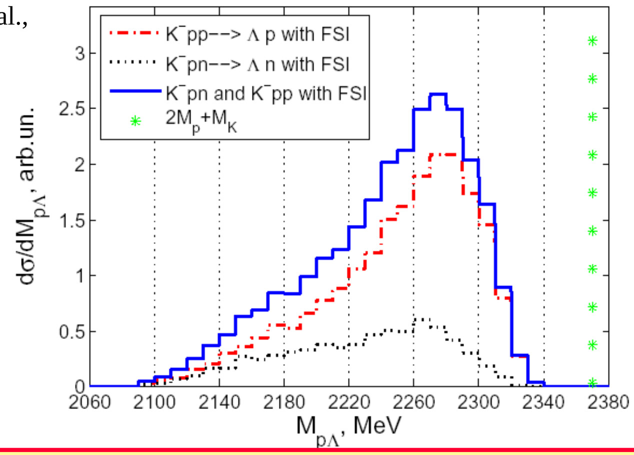


Λp from ppK⁻ or ΣN?

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



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



Oset et al.: Peak in invariant mass distribution is due to final state interaction of Λ or N (p or n) with target nucleus (^{7}Li, ^{12}C)

Prediction: no peak structure should be observed in pp - reactions

Tai Ho Tan, PRL 23, 101 (1969)

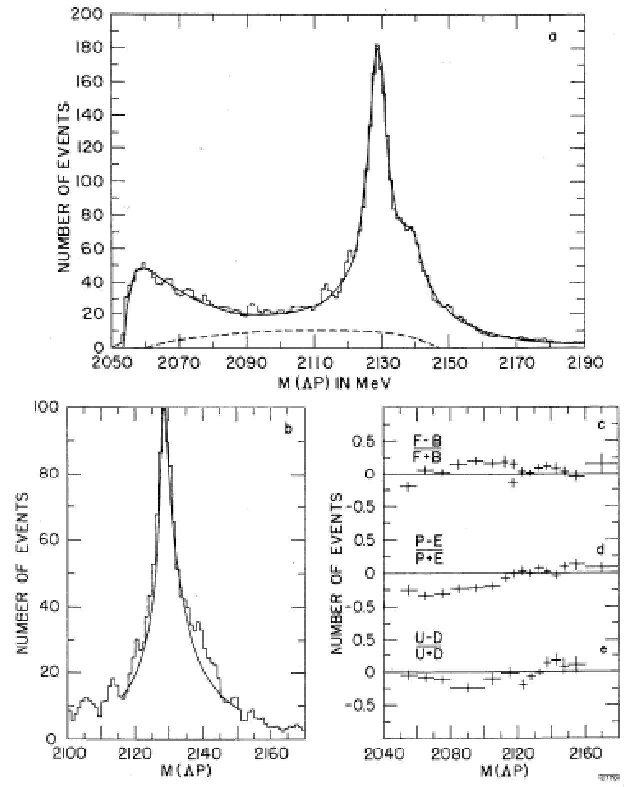


Fig. 3

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 → π⁻pΛ 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)

Exotic narrow resonance searches in the systems $K^0_s\,\pi$, $K^0_s\,p$, $K^0_s\,\Lambda$, $\Lambda\pi$, Λp and Λpp in pA interactions at 10 GeV/c

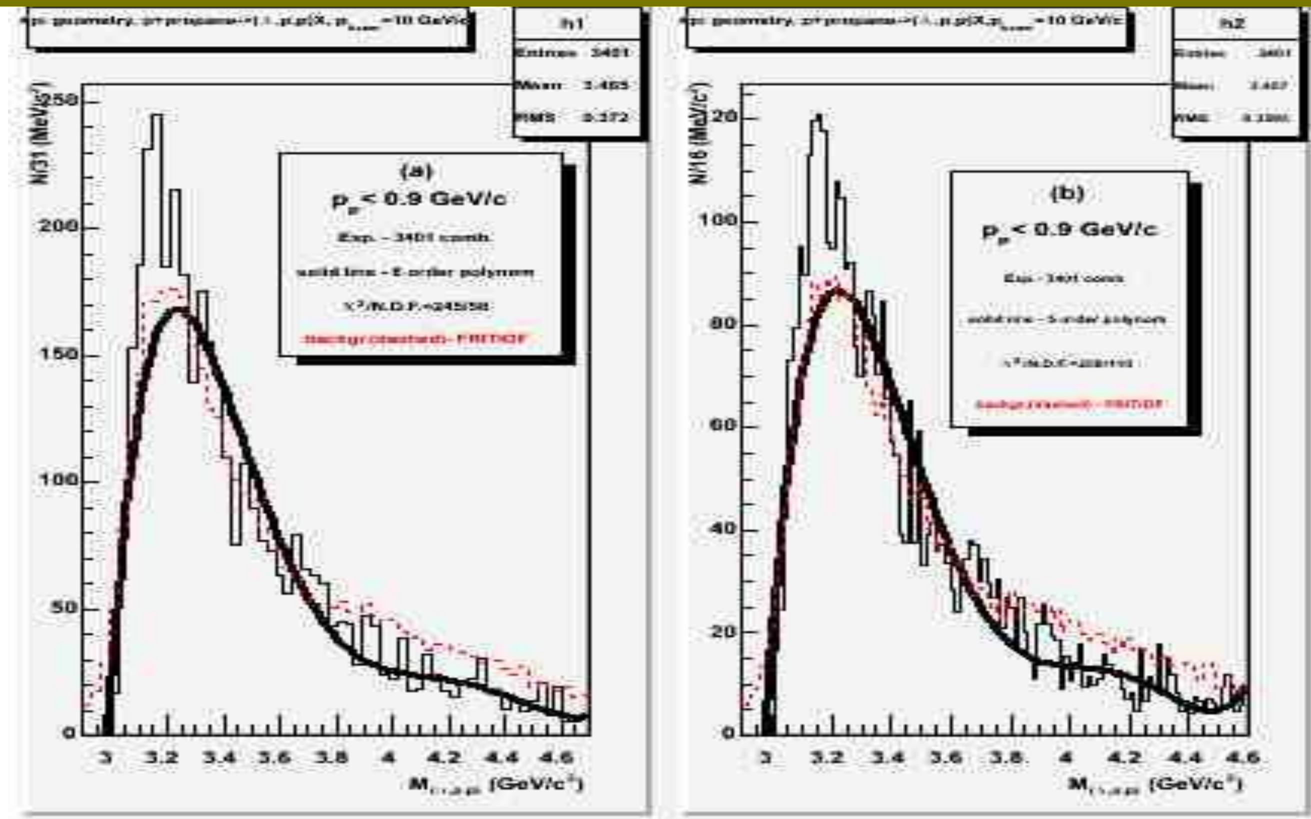
Recentry, E471 experiment have discovered two kinds of strange tribaryons by measuring nucleon energy spectra from the stopped K^- reaction on ^{4}He [1] (KEK PS), which was motivated by the prediction of a deeply bound K−ppn state by Akaishi and Yamazaki [2]. The first kind, S0(3115), was discovered in

$(K^- - {}^4He)_{atomic} \rightarrow S^0(3115) + p$ (1)

reaction [3]. The observed state has isospin T = 1, charge Z = 0 and mass M_{S0} = 3118 MeV/c2. The second kind, S+(3140), was indicated from

$(K^- - {}^4He)_{atomic} \rightarrow S^+(3140) + n$ (2)

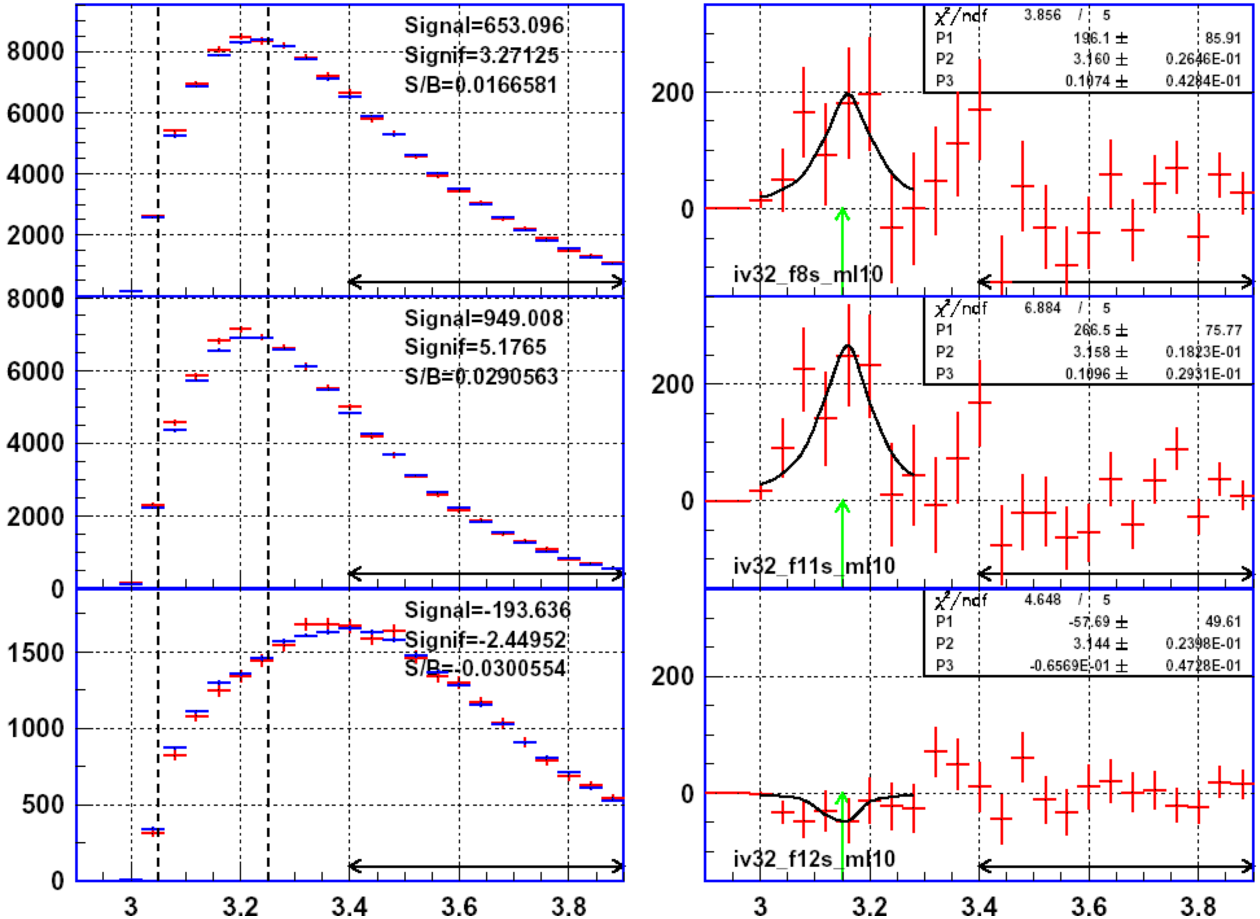
reaction [4] originally proposed to search for the K^-ppn state, which was predicted to be at M = 3194 MeV/c^2 with T = 0 and Z = 1 [2].



Preliminary (Λ,p,p) spectrum in p+propane collision at 10 GeV/c. The Λpp effective mass distribution of 3401 combinations for identified protons with a momentum of P <0.9 GeV/c is shown in Figure. The solid curve is the 6-order polynomial function(χ^2/n.d.f=245/58, Fig.a). The backgrounds for analysis of the experimental data are based on FRITIOF and the polynomial method. There are significant enhancements in mass regions of 3087(2.2 S.D.), 3138(6.1 S.D.), 3199(3.3 S.D.), 3320(5.1 S.D.), 3440(3.9 S.D) and 3652MeV/c^2(2.6 S.D.). These peaks in ranges of 3138 and 3199MeV/c^2 were agreed with registered peaks from reports[3-4] of E471 experiment, KEK.

1. M. Iwasaki et al., Nucl. Instrum. Meth. A 473 (2001) 286.2. Y. Akaishi and T. Yamazaki, Phys. Rev. C 65 (2002) 044005.3. T. Suzuki et al., Phys. Lett. B 597 (2004) 263.4. M. Iwasaki et al., nucl-ex/0310018, submitted to Phys. Lett. B.

Λd: Rapidity Dependence of Correlation Signal



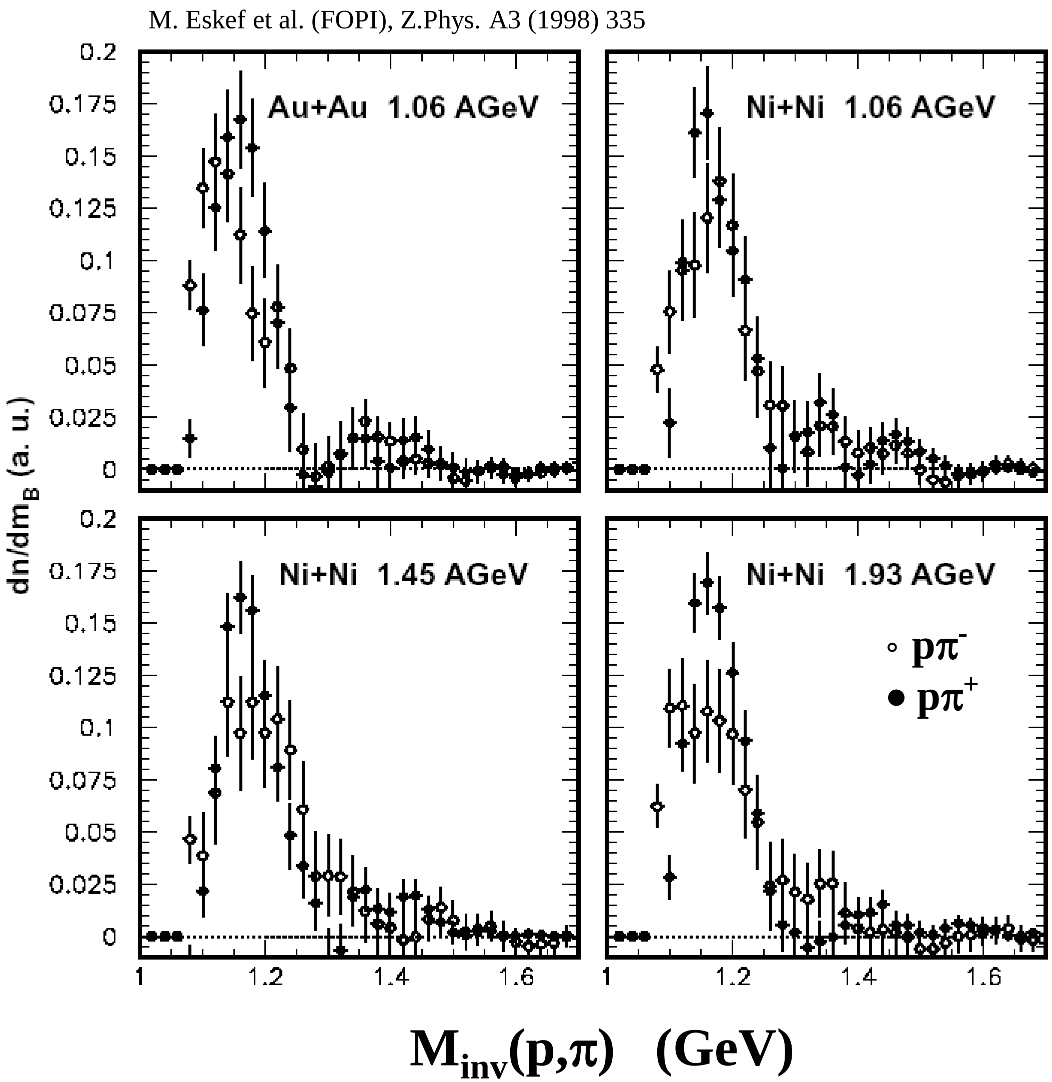
all rapidities

y < 0.65

y > 0.65

$M_{inv}(\Lambda d)$ (GeV)

History: Reconstruction of Δ - resonances



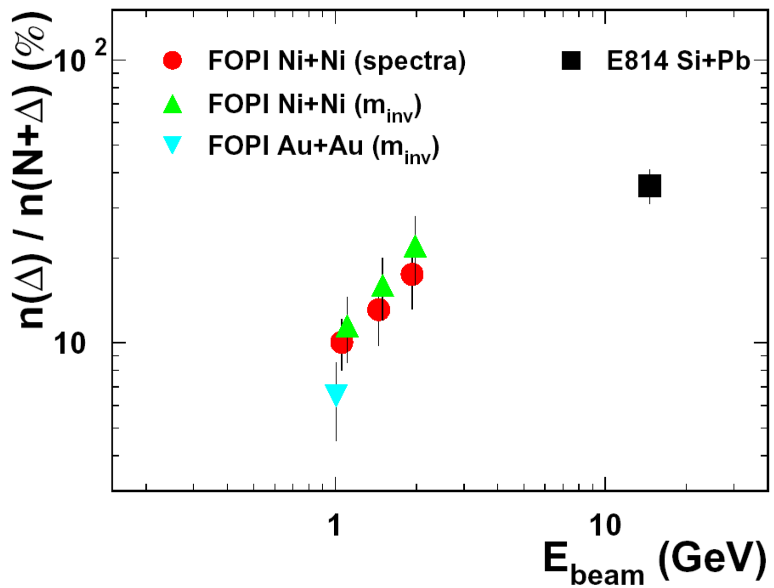
Properties:

Mass shift: - 50 - 60 MeV

Gaussian Width: ~ 50 MeV

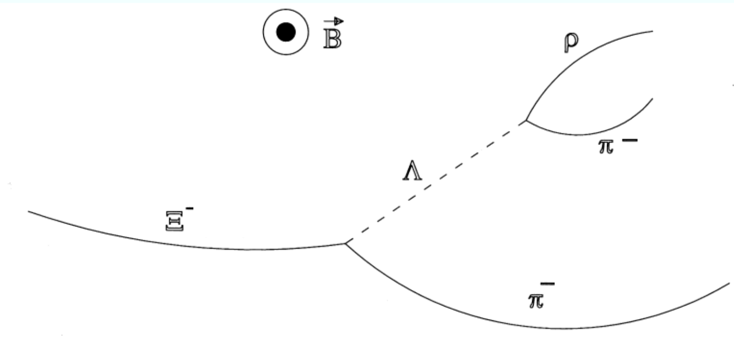
Decay width: Γ ~ 120 MeV

Yields:



Signal/Background ~ 1%

Ξ^- - reconstruction

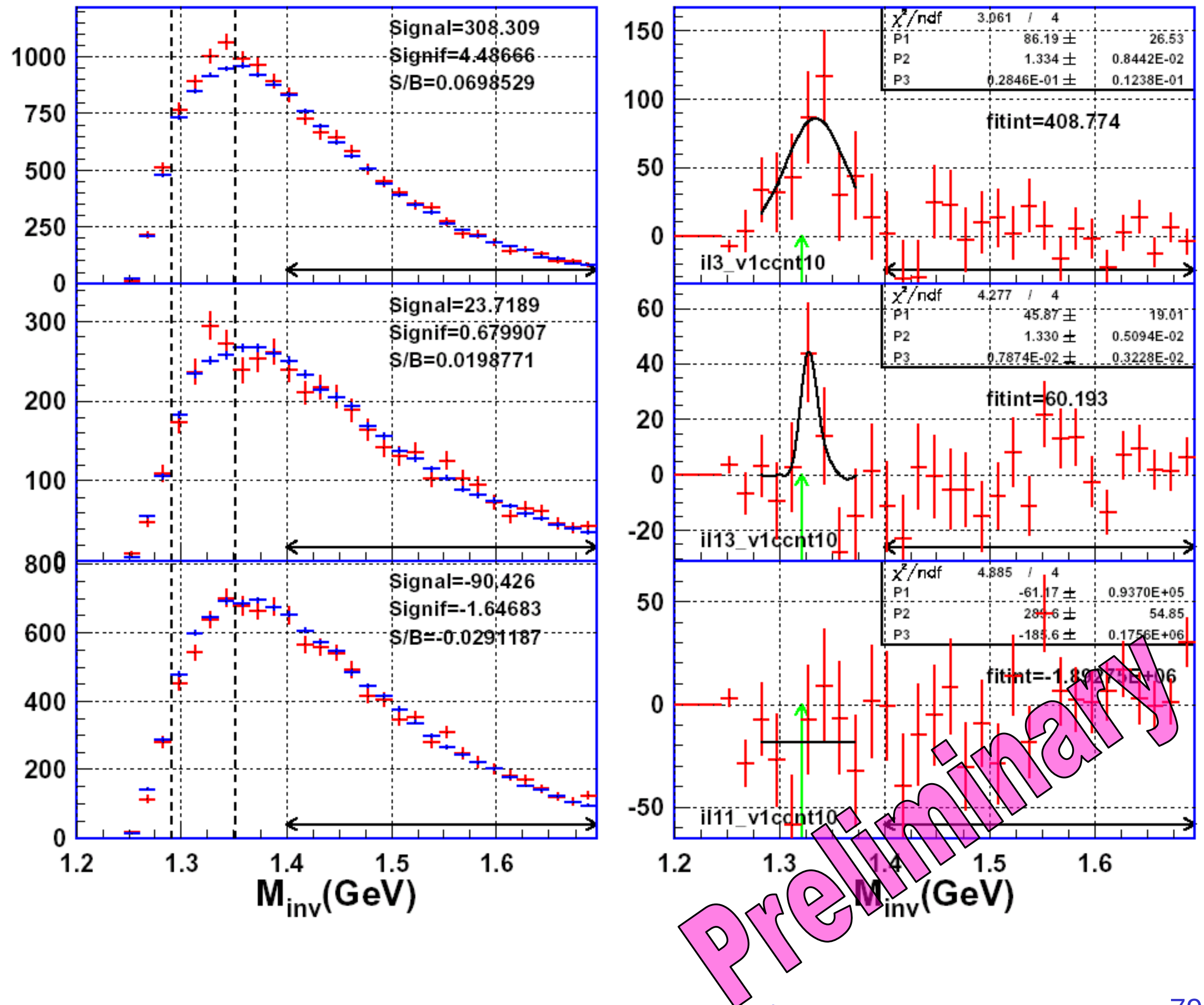


FOPI Preliminary (Jan2003 – Data)

Number of central events: 120M
Number of Lambda: 100.000
Number of Ξ: ~100

P.Crochet, M.Merschmeyer, X.Lopez

Ni+Ni @ 1.93AGeV



Ξ^- properties:

Mass $M(\Xi^-) = 1.321$ GeV

Decay mode:

$\Xi^- \rightarrow \Lambda + \pi^-$ $c\tau = 4.91$ cm

$\Lambda \rightarrow p + \pi^-$ $c\tau = 7.89$ cm

NN threshold: $E_{beam} = 3.74$ GeV

Thermal model prediction:

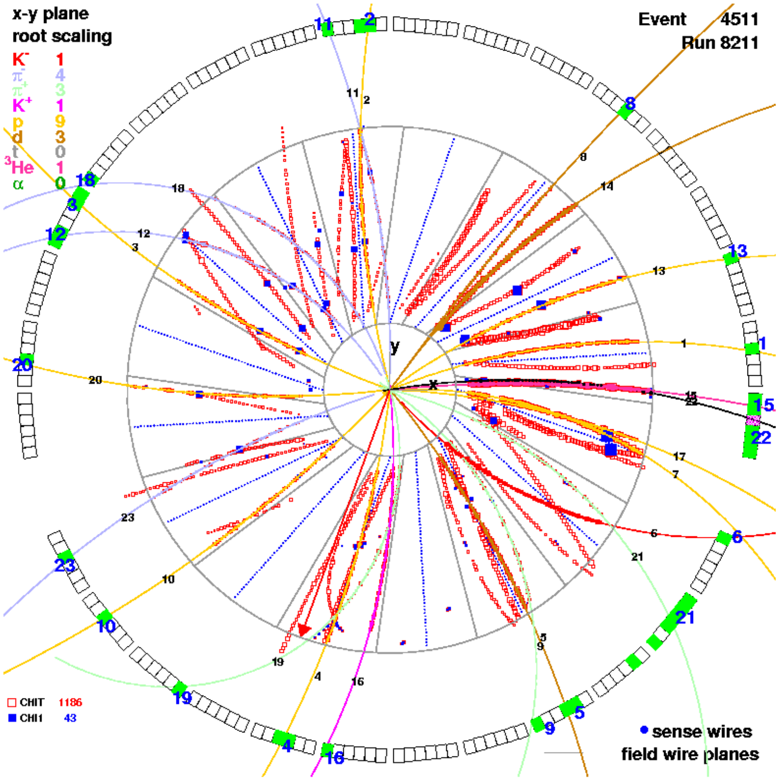
$\Lambda / \Xi = 8.6\ (\pm 2.0) \cdot 10^{-4}$

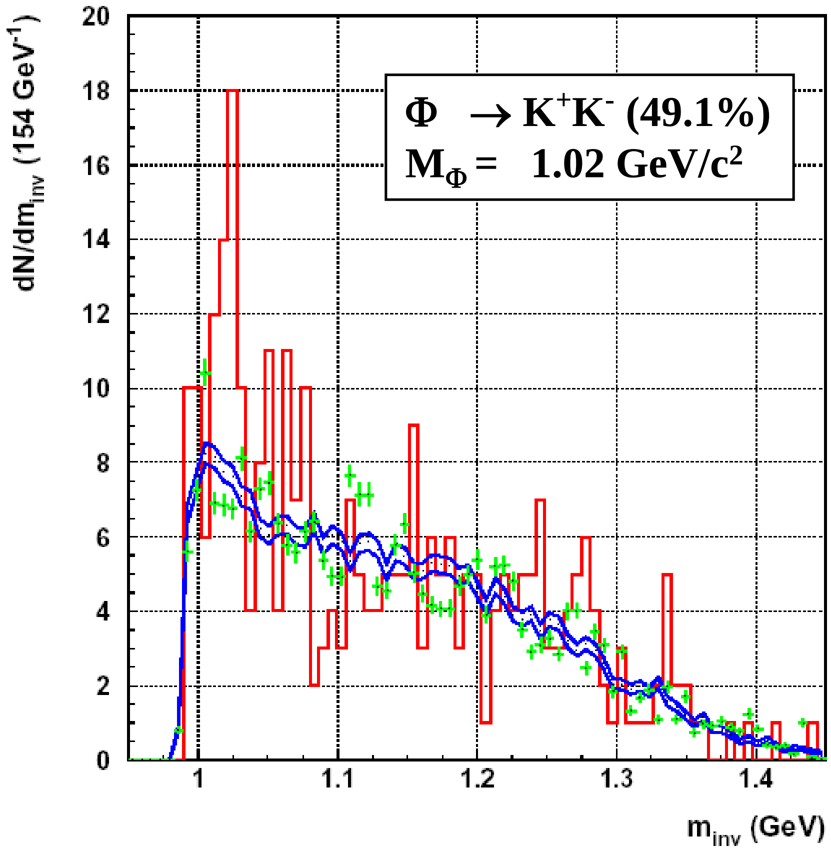
Efficiency of cuts on data needs to be quantified

Φ-abundance

Ni+Ni @ 1.93AGeV

A. Mangiarotti et al., (FOPI), Nucl. Phys. A 714 (2003) 89





Production probability in central collisions: $P_{acc} = (1.5 \pm 0.45 \pm 0.7) \cdot 10^{-5}$

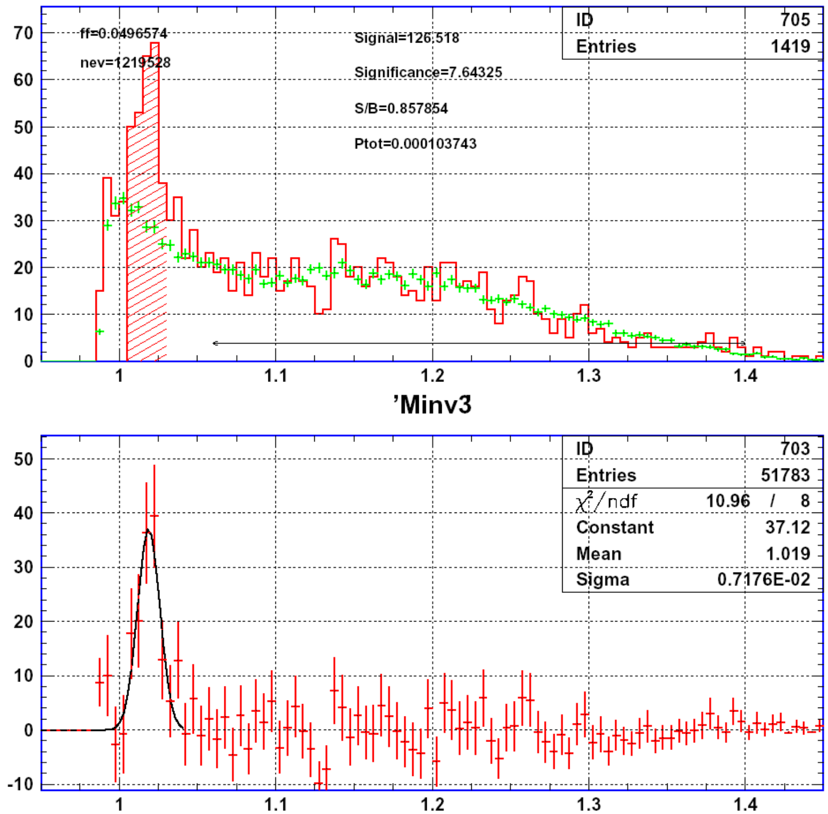
Extrapolated Φ/K⁻ - ratio (T_{eff}=130MeV): $R = 0.44 \pm 0.15 \pm 0.21$

Thermal model analysis: $R = 0.1$

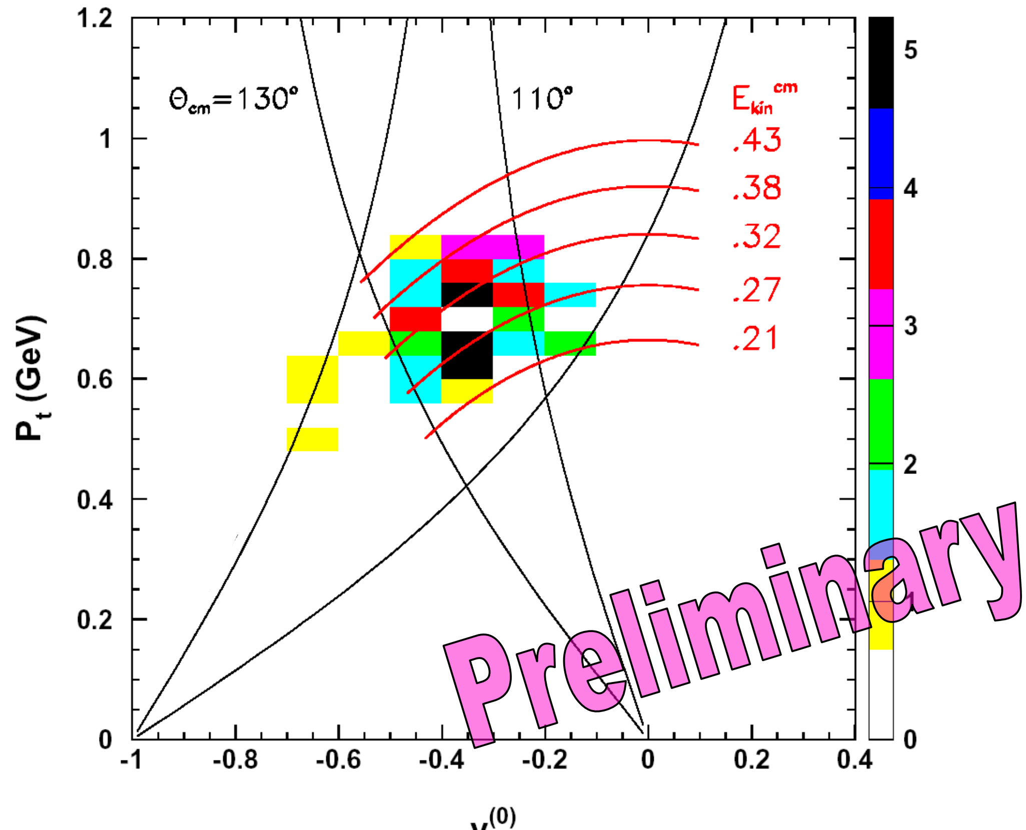
Φ-meson from January 2003 Data

Data sample: $1.2 \cdot 10^{8}$ events

Total available statistics for Φ-meson: 100 – 200 depending on cuts (purity)



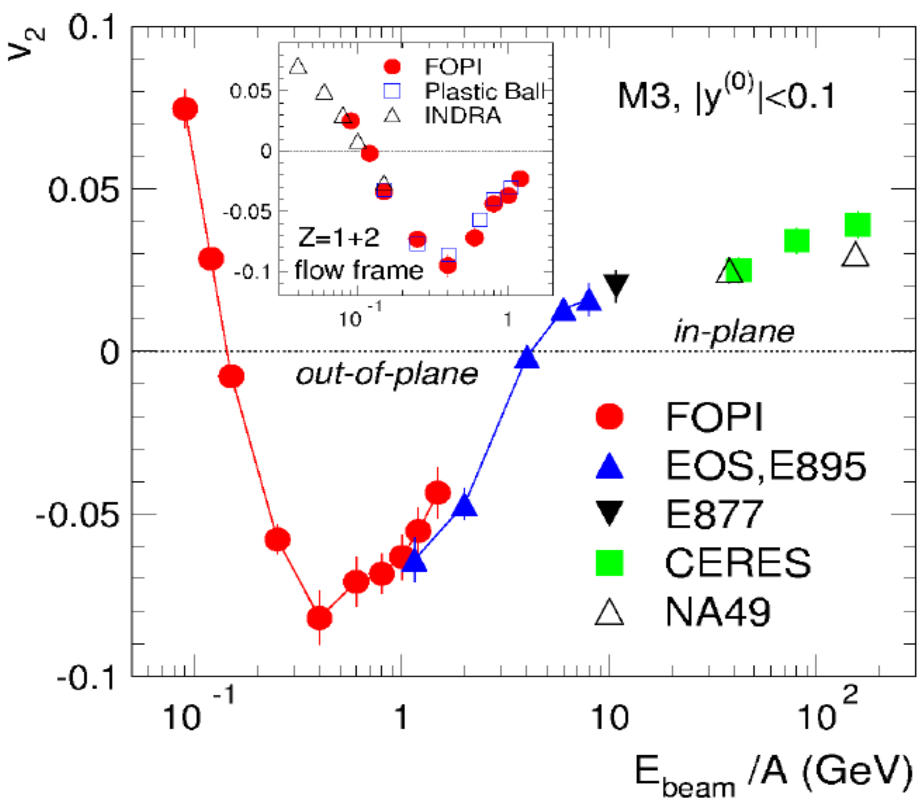
$M_{inv}(K^{+},K^{-})$ (GeV)

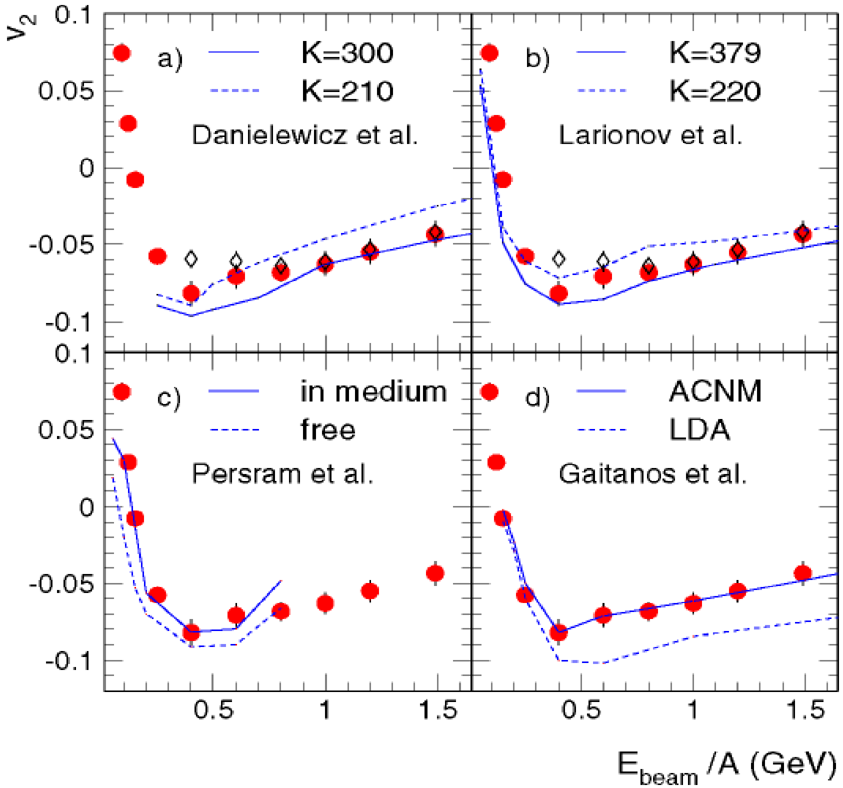


Yield agrees with '95 analysis
Slope parameter can be extracted (work in progress)

Excitation function of elliptic flow and the nuclear matter equation-of-state

A. Andronic et al. (FOPI collaboration), Phys. Lett. B 612 (2005) 173-180

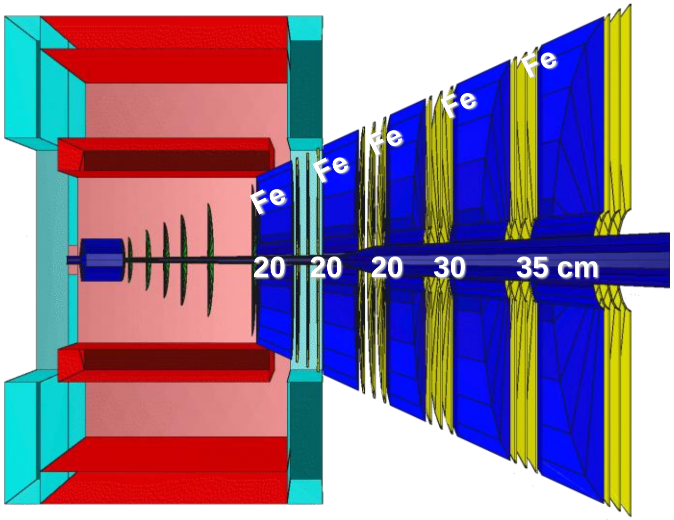


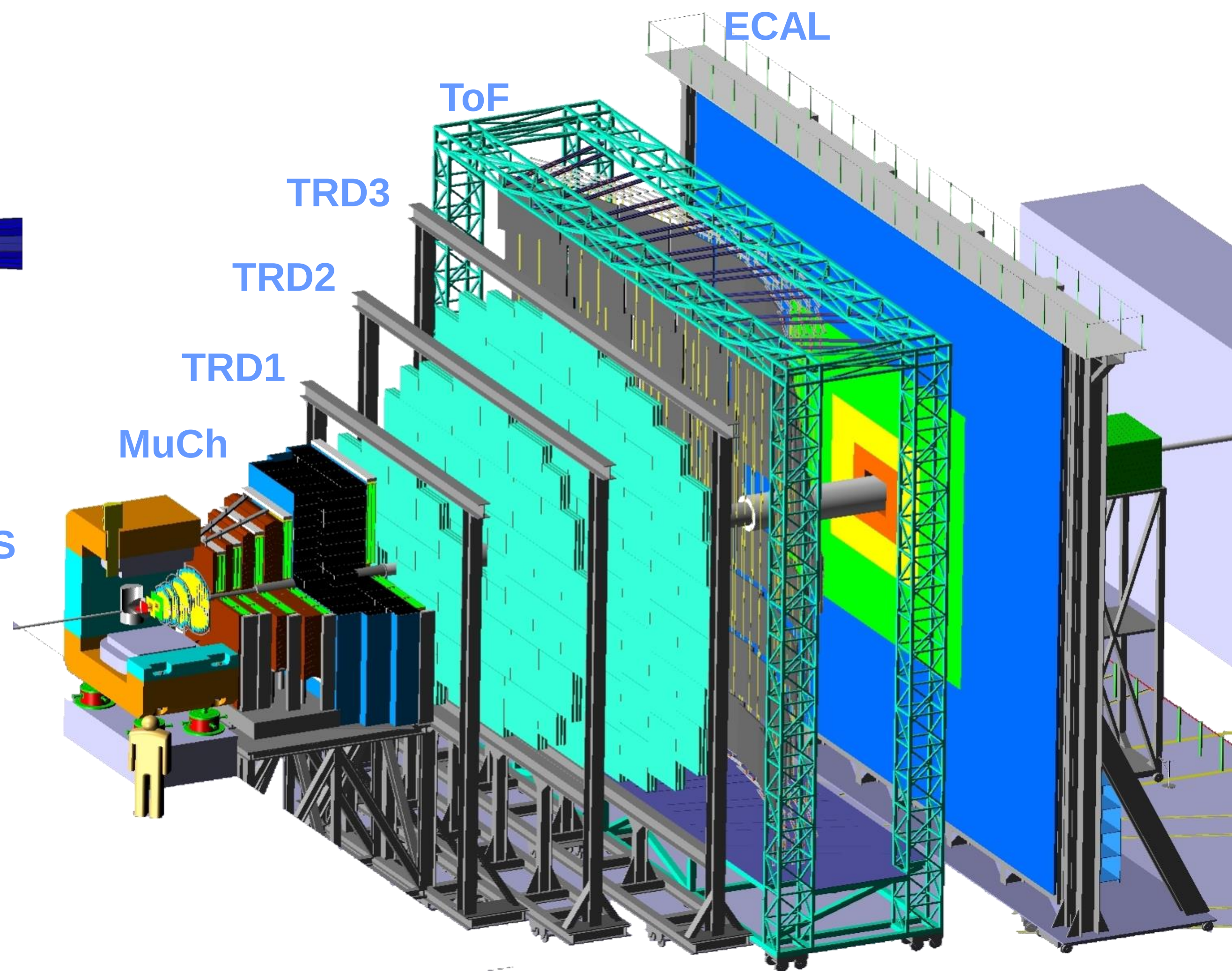


Large body of high quality integral and differential flow data published.

For interpretation: close collaboration with theory groups in Giessen, Frankfurt, München, Nantes and Tübingen

New Challenge: low energy muon detection



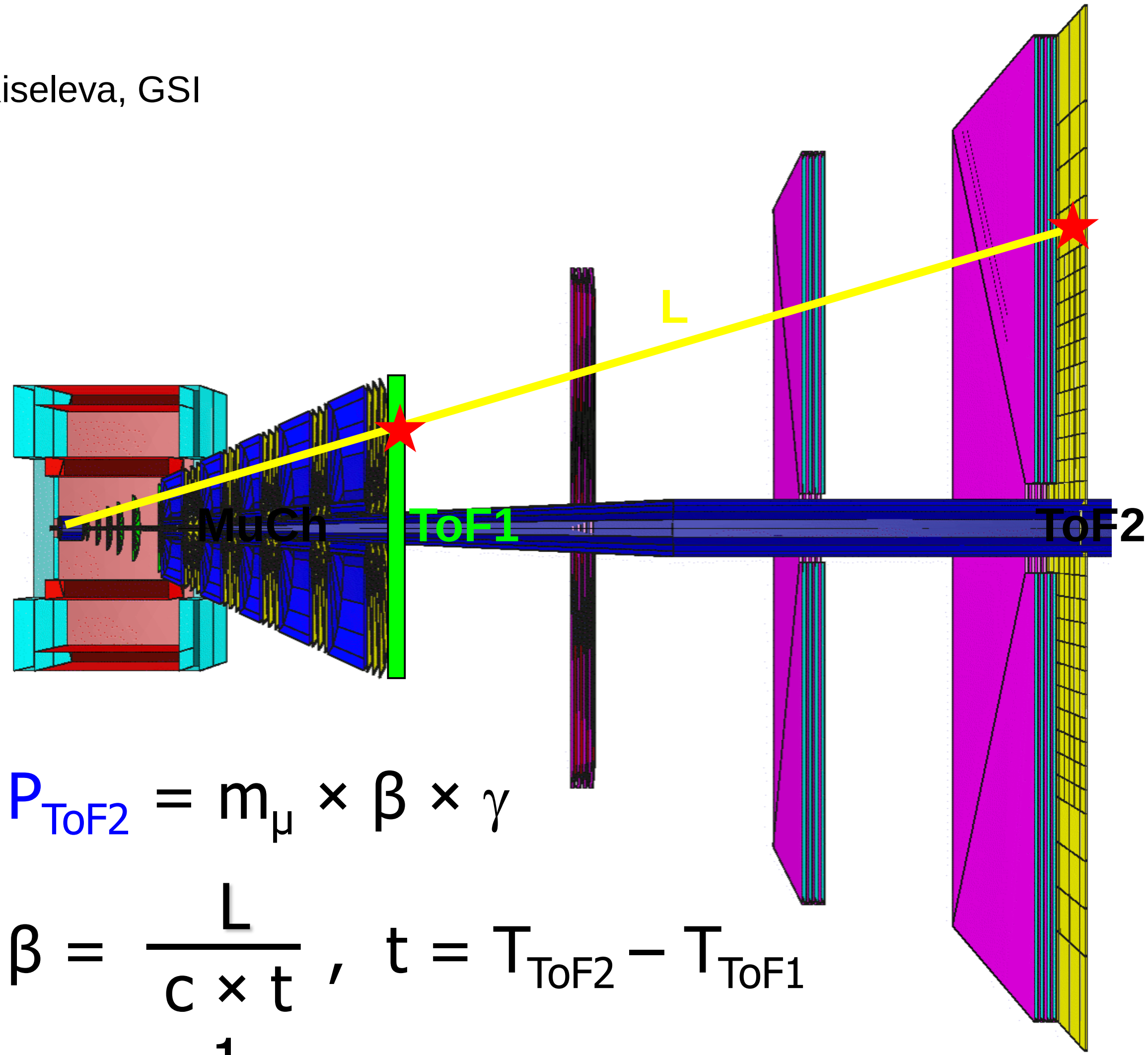


STS	track, vertex and momentum reconstruction
MuCh	muon identification
TRD	identification of high-energy electrons, global tracking
RPC-ToF	time-of-flight measurement
ECAL	electron and photon identification

TOF – Layer inside/after MuCh for stopped/slowed down pion-muon separation?

Feasibilty study for $\Phi \to \mu^+\mu^-$

A. Kiseleva, GSI



$$P_{ToF2} = m_\mu \times \beta \times \gamma$$

$$\beta = \frac{L}{c \times t}, \quad t = T_{ToF2} - T_{ToF1}$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

P_{MuCh} – Kalman Filter track extrapolation