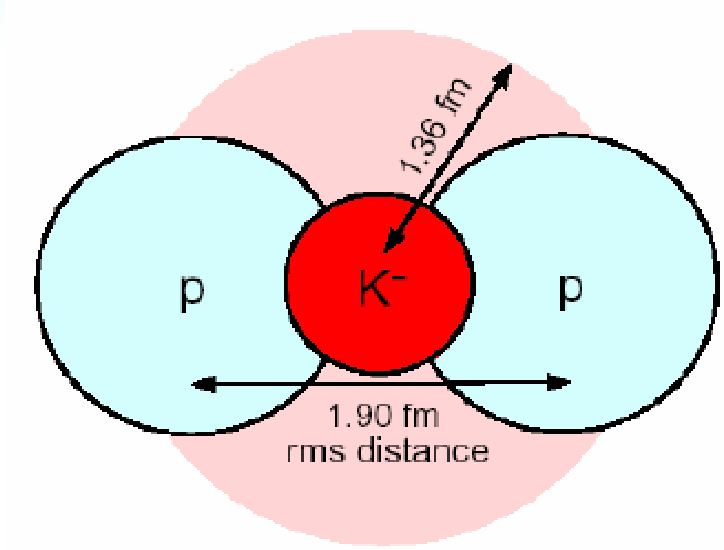
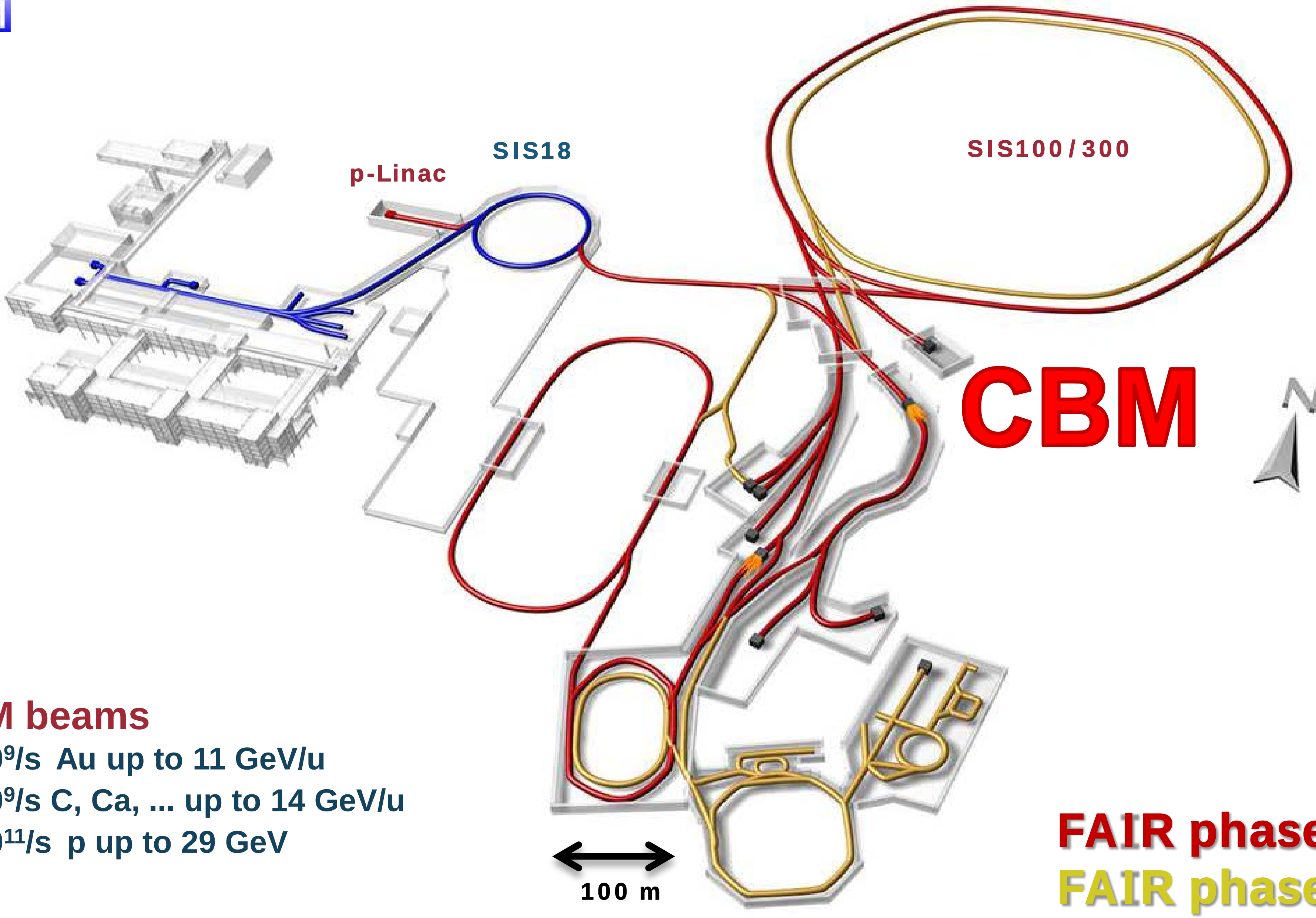


Perspectives of measuring deeply bound states at FAIR

N. Herrmann, Univ. Heidelberg

Facility for Antiproton & Ion Research

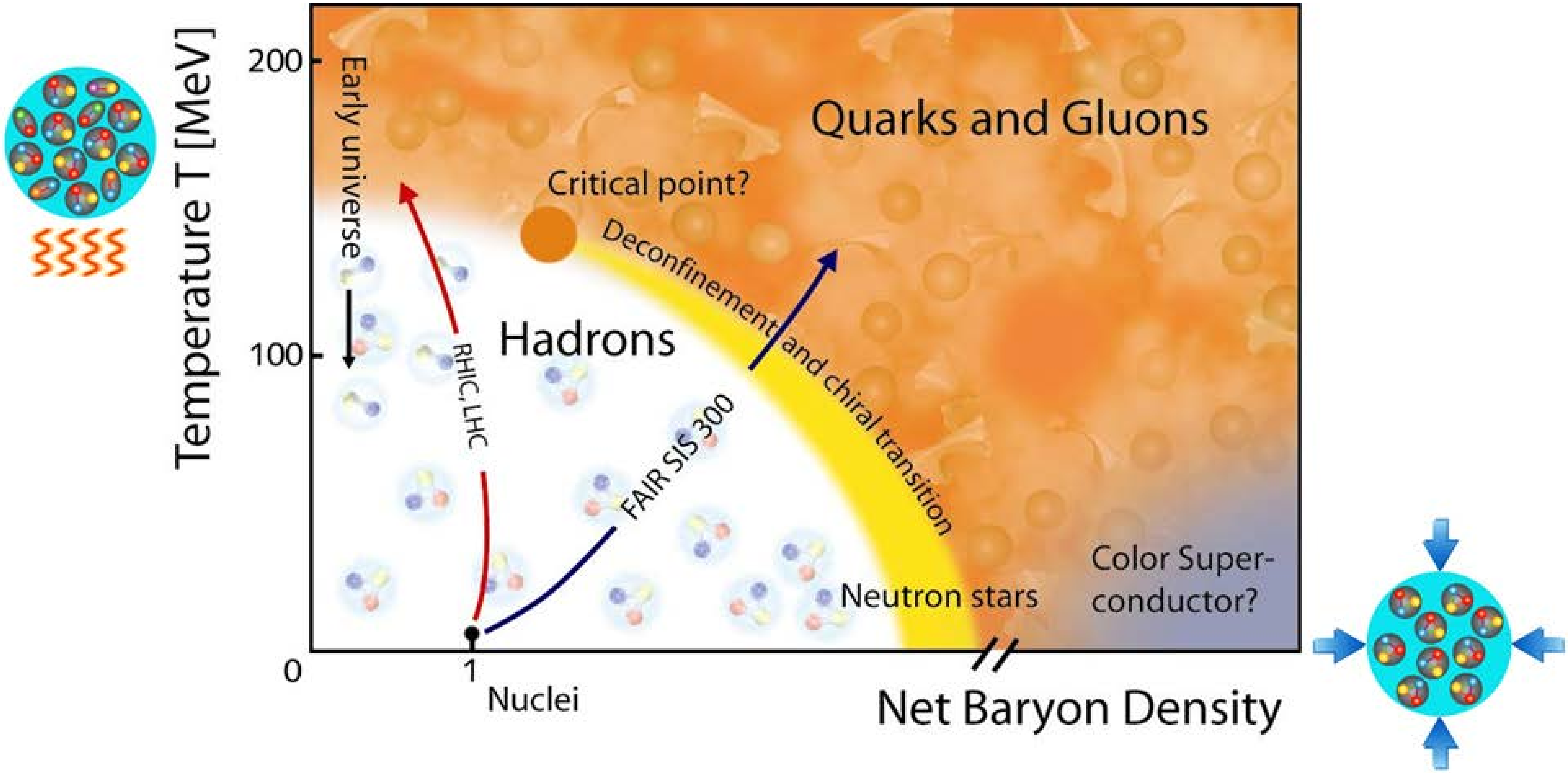


CBM beams

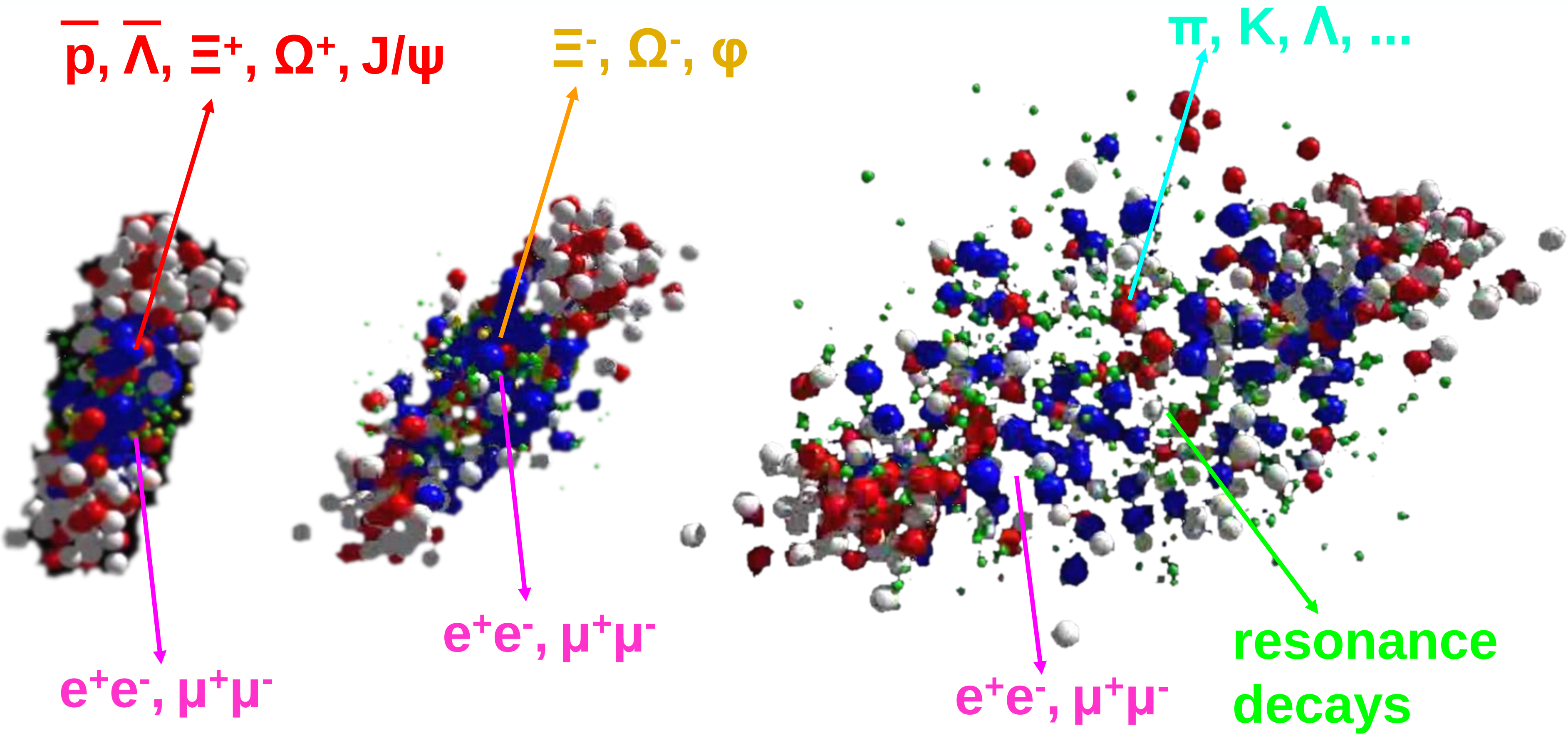
- 10^9/s Au up to 11 GeV/u
- 10^9/s C, Ca, ... up to 14 GeV/u
- 10^{11}/s p up to 29 GeV

FAIR phase 1
FAIR phase 2

The CBM mission: QCD phase diagram



Heavy – Ion Collisions



Hard probes
(initial state)

Penetrating probes
(integrate over collision history)
Relics
(produced in dense phase)

Freeze-out
(final state particles)

Thermalized (?) hadrons

Problem: Temperature!

Outline

Background

anti-Kaonic Nuclear Clusters (KNC)

Past

Experimental observations

Present

FOPI Analysis status

Future

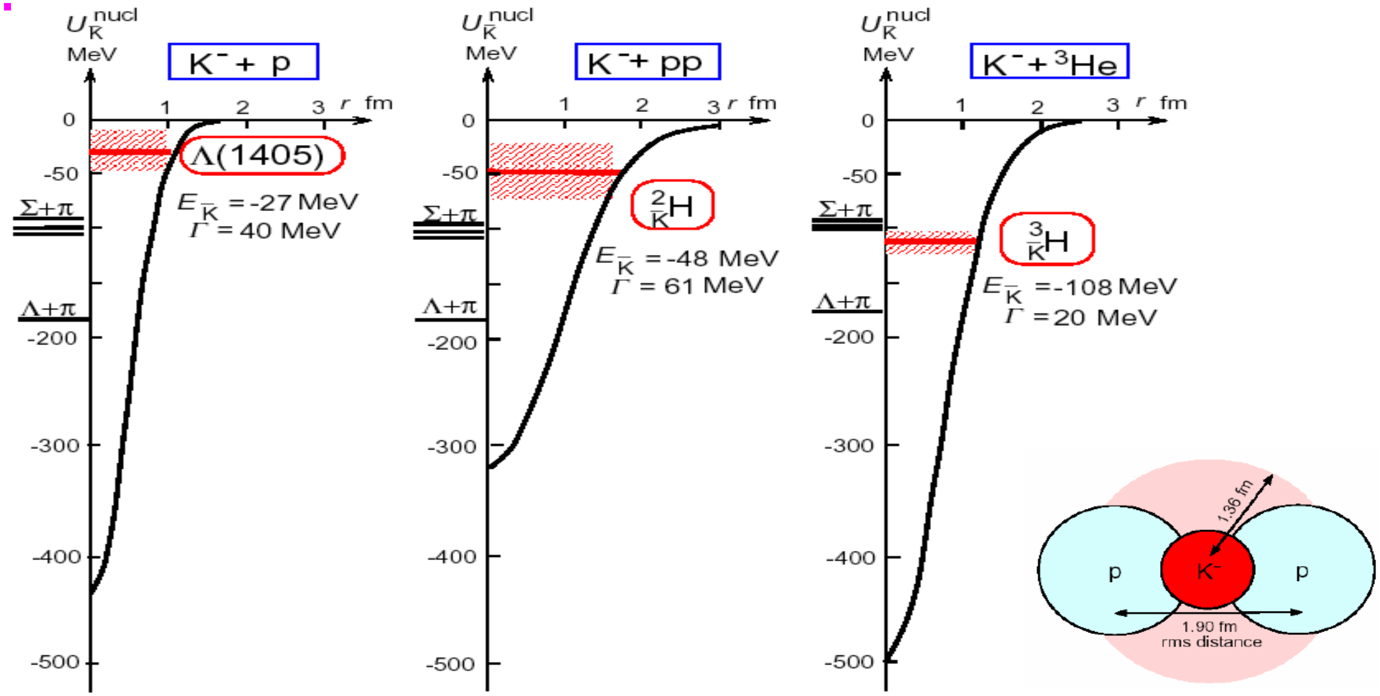
CBM

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:

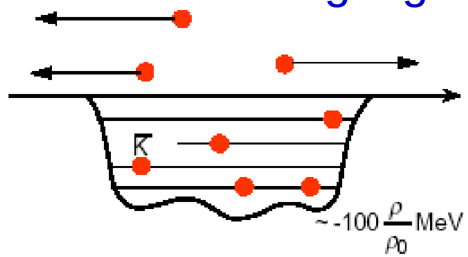
(microscopic chiral treatment)
M.F.M. Lutz, Phys. Lett. B426 (1998) 12.
J.Schaffner-Bielich et.al, N.P. A669 (2000) 153,
Ramos et.al,N.P. A671 (2000) 481,
Cieply et al.,N.P. A696 (2001) 173

Cold Dense Baryonic Matter

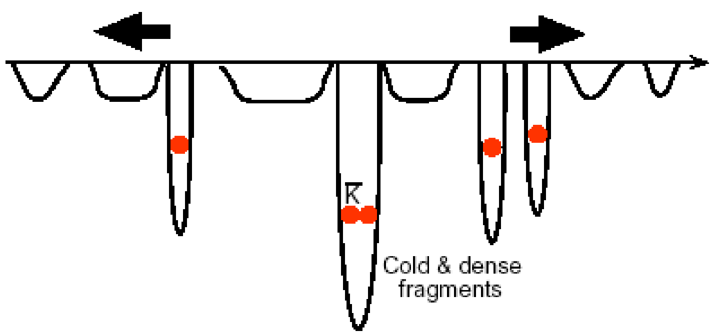
Possible mechanism for cluster formation:

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

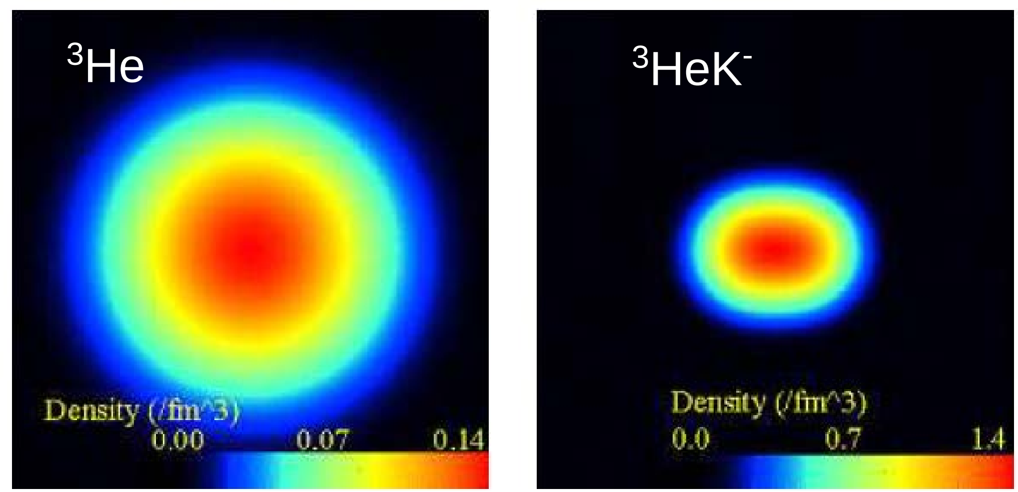
1) Kaon production during high density phase



2) capture of K^- in deep trapping centers



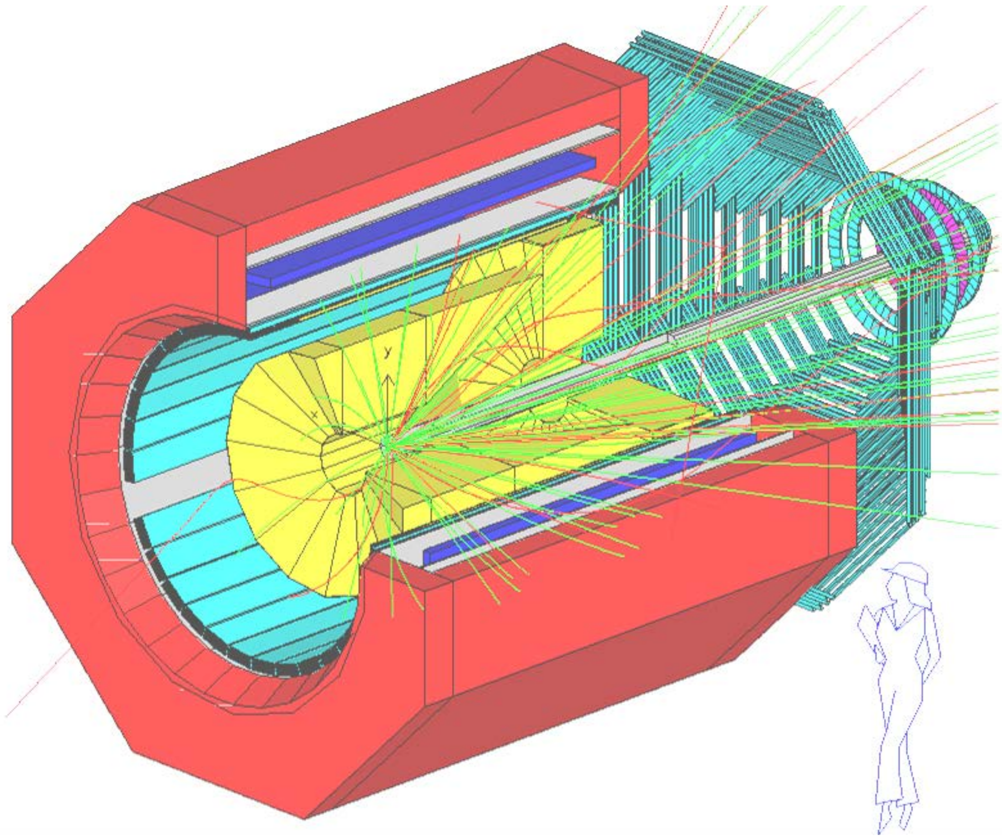
3) Shrinkage → Large densities!

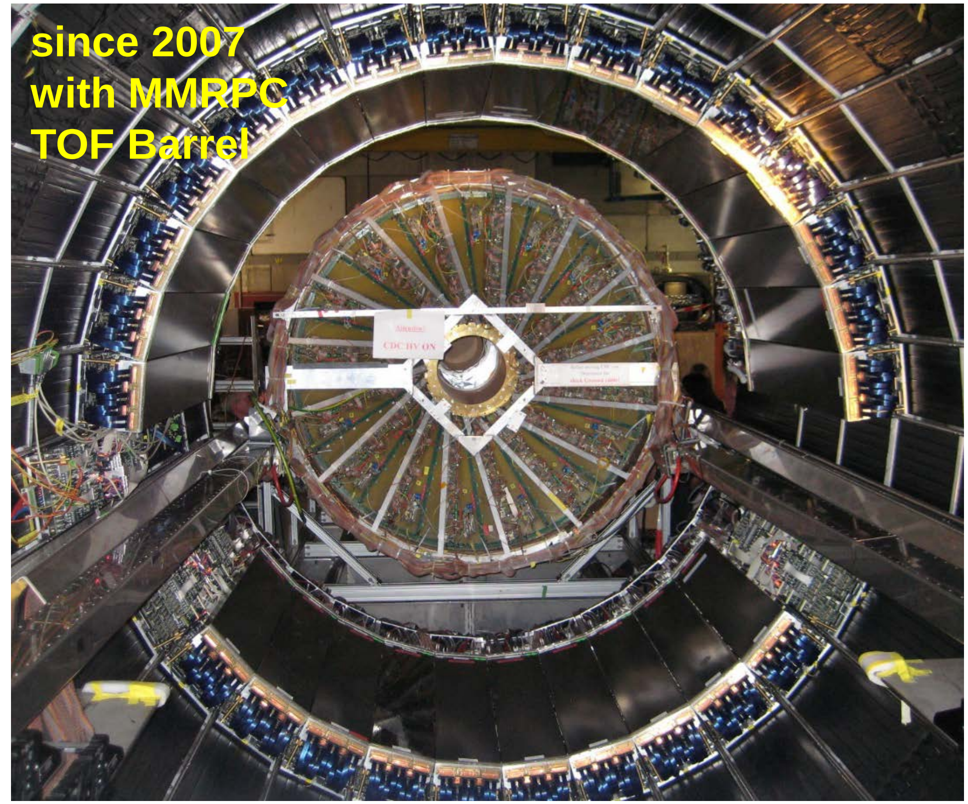


A. Dote et al., PLB 590, 51 (2004)

FOPI apparatus at SIS18

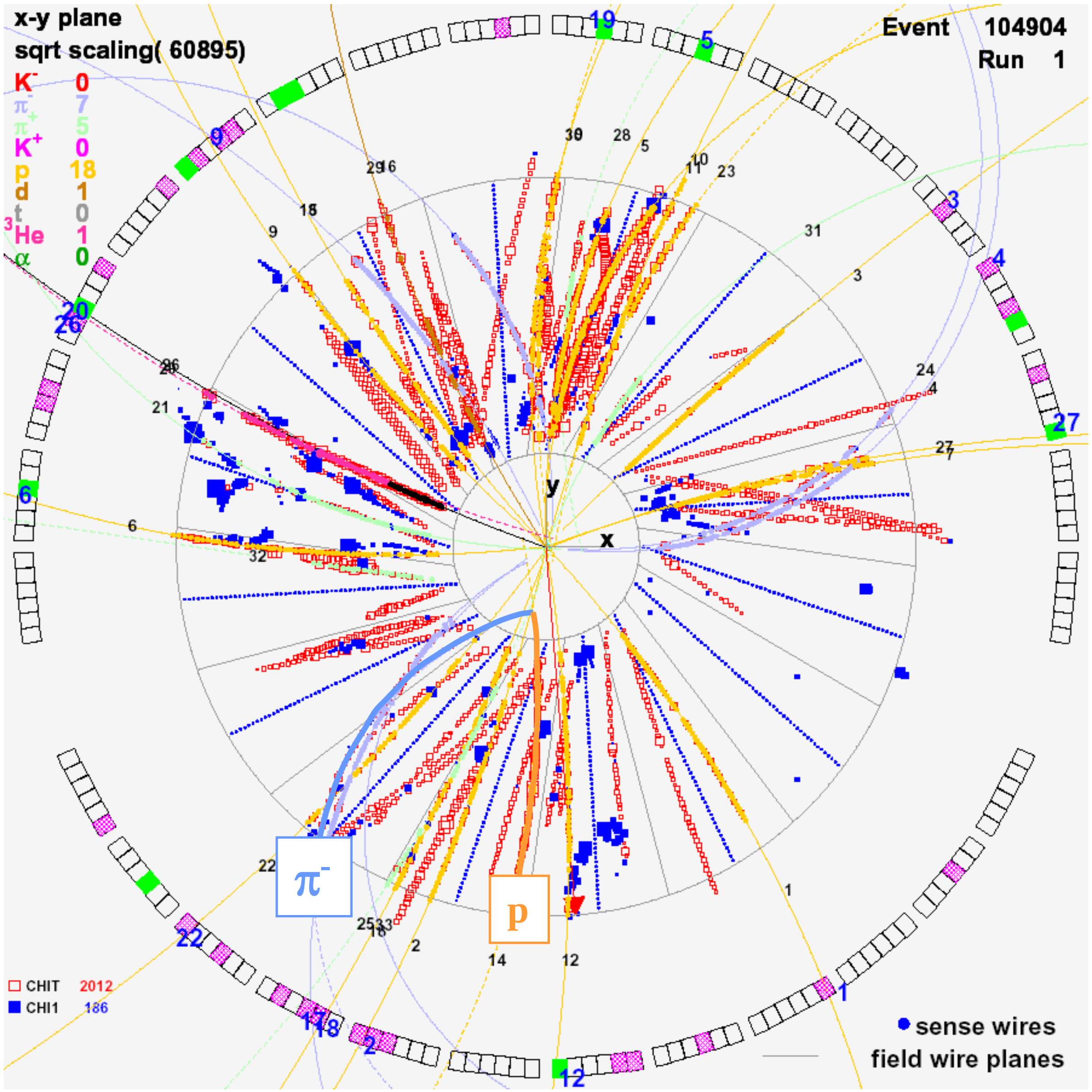
Data taking period: 1991 - 2011

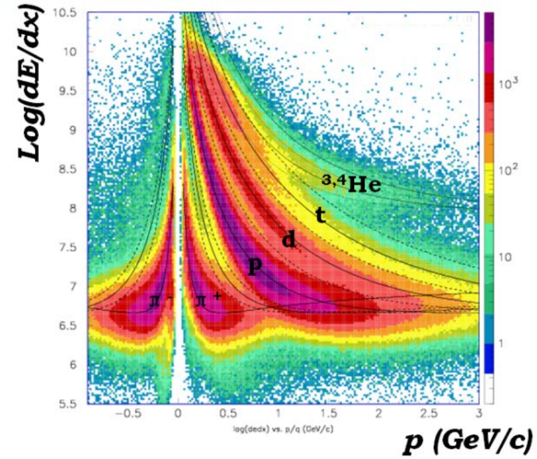


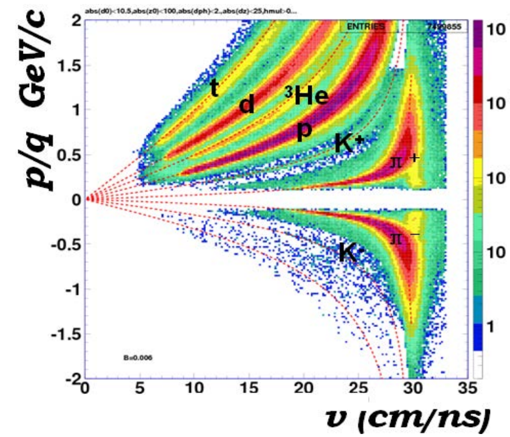


Detection / Reconstruction Method

Ni+Ni @ 1.93 AGeV







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

X originating from primary vertex

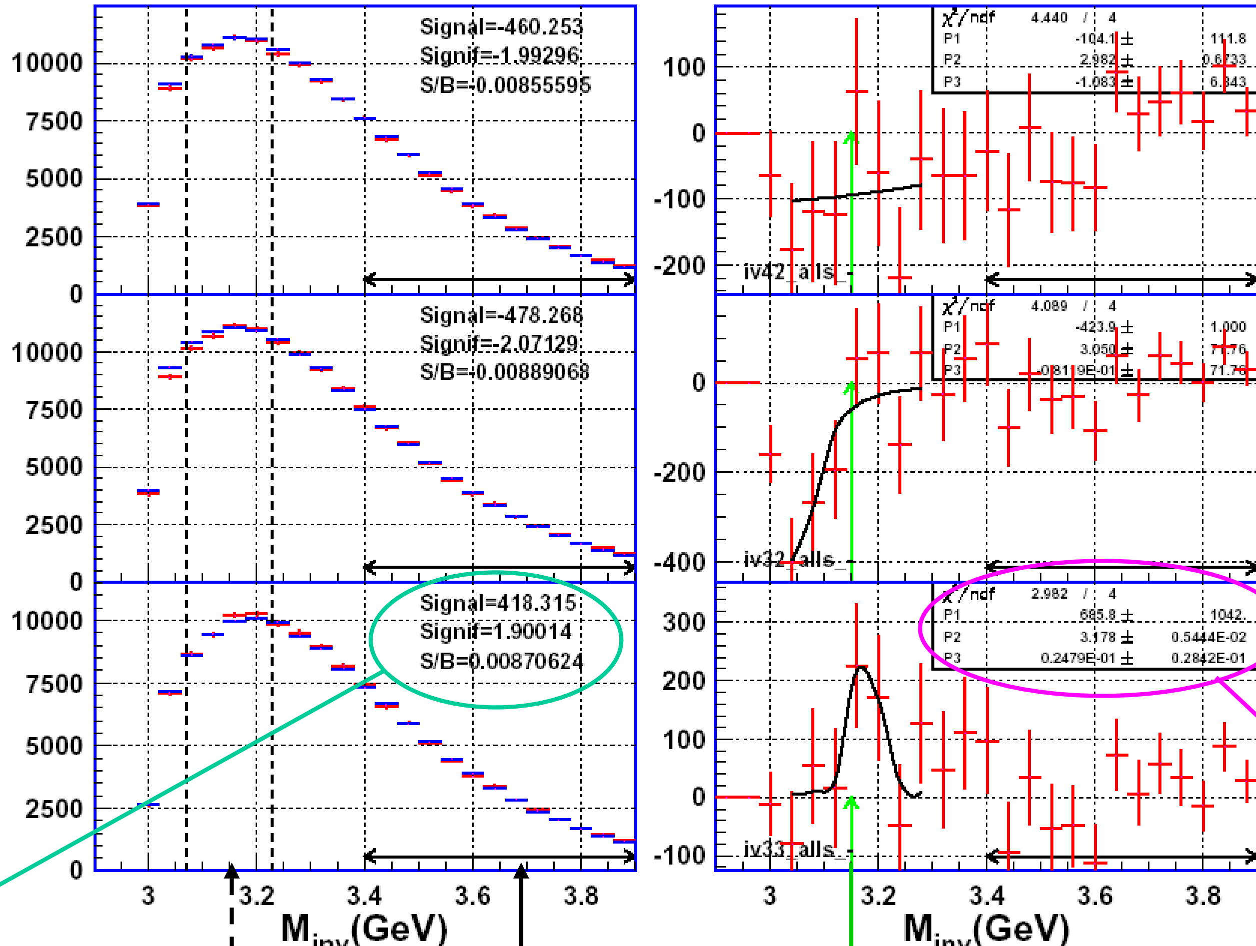
Λ from off-vertex p-π- pairs

Data processing (S261, Ni+Ni at 1.93 AGeV, 2003)

Red: Combinatorics

Blue: Mixed event

Difference = Combinatorics – Mixed event



raw correlation

after reaction plane rotation

after reaction plane rotation && after crossing tracks removal

Statistical information

Breit-Wigner fit parameter

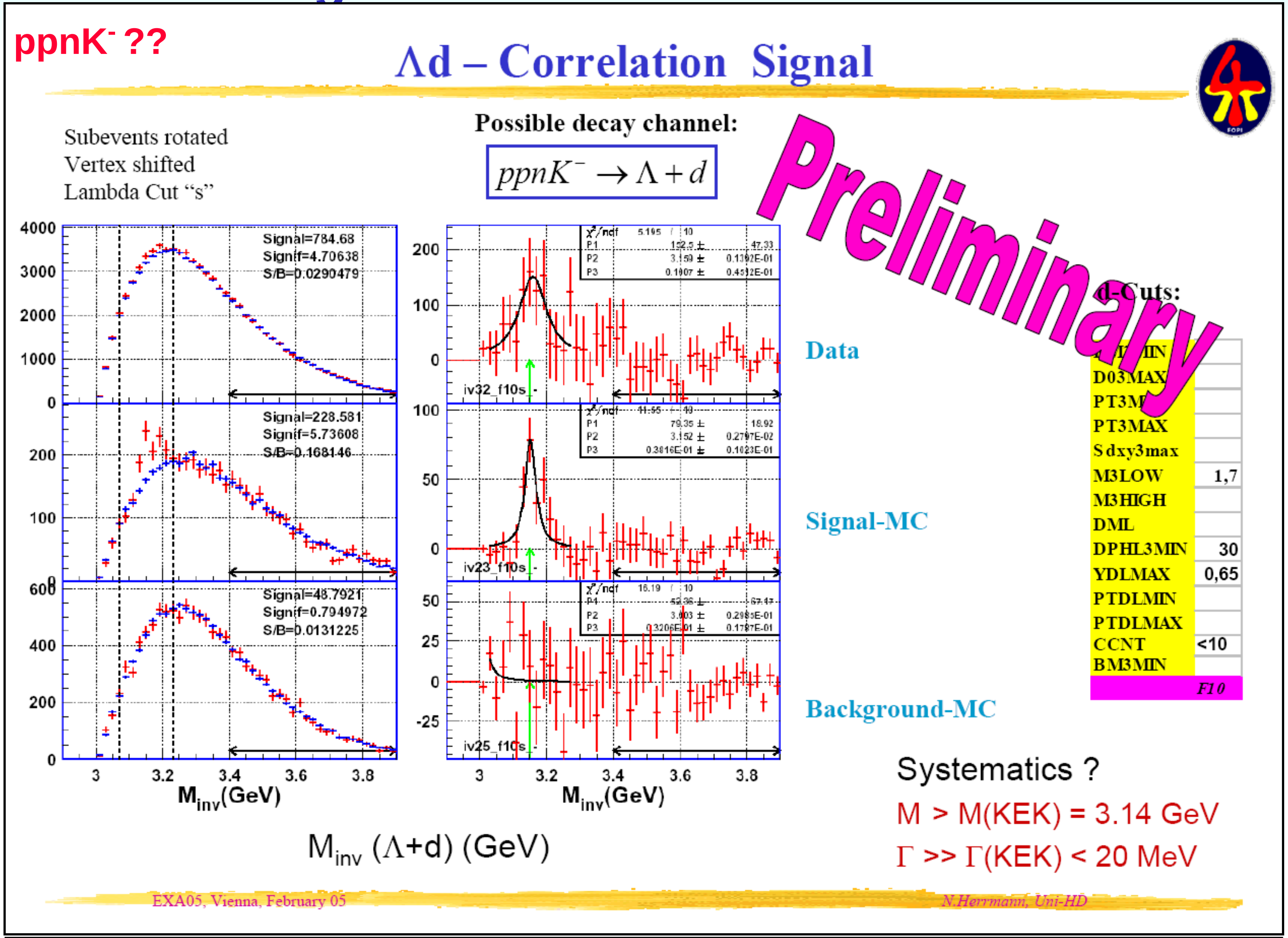
Reference: 3.15 GeV

Normalisation interval

Signal evaluation interval

Strange cluster search in HI - collisions

since 2003: ppnK$^-$ **??**



NH, proceedings EXA05, ÖAW, 73 (2005), ISBN 3-7001-3616-1

Rapidity constraint necessary for statistical significance,
Width much larger than early predictions,

More data are needed …

Experiment proposal 2004

Measurements of
Strange Baryons and Kaonic Nuclear Clusters
with FOPI

A. Andronic[4], V. Barret[3], Z. Basrak[12], N. Bastid[3], L. Benabderrahmane[6], R. Čaplar[12], E. Cordier[6], P. Crochet[3], P. Dupieux[3], M. Dželalija[12], Z. Fodor[2], O.N. Hartmann[4], N. Herrmann[6], K.D. Hildenbrand[4], B. Hong[9], J. Kecskemeti[2], Y.J. Kim[9], M. Kirejczyk[11], P. Koczon[4], M. Korolija[12], R. Kotte[5], A. Lebedev[7], Y. Leifels[4], X. Lopez[3], A. Mangiarotti[6], V. Manko[8], T. Matulewicz[11], M. Merschmeyer[6], D. Pelte[6], M. Petrovici[1], F. Rami[10], W. Reisdorf[4], A. Schüttauf[4], Z. Seres[2], B. Sikora[11], K.S. Sim[9], V. Simion[1], K. Siwek-Wilczyńska[11], V. Smolyankin[7], G. Stoicea[1], Z. Tyminski[4,11], K. Wiśniewski[11], Z.-G. Xiao[4], I. Yushmanov[8], A. Zhilin[7]
(FOPI Collaboration)
and
T. Yamazaki[13], K. Suzuki[14], L. Fabbietti[14], J. Zmeskal[15], J. Marton[15], M. Cargnelli[15] and P. Kienle[14,15]

[1] National Institute for Physics and Nuclear Engineering, Bucharest, Romania
[2] KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
[3] Laboratoire de Physique Corpusculaire, IN2P3/CNRS, and Université Blaise Pascal, Clermont-Ferrand, France
[4] Gesellschaft für Schwerionenforschung, Darmstadt, Germany
[5] IKH, Forschungszentrum Rossendorf, Dresden, Germany
[6] Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany
[7] Institute for Theoretical and Experimental Physics, Moscow, Russia
[8] Kurchatov Institute, Moscow, Russia
[9] Korea University, Seoul, South Korea
[10] Institut de Recherches Subatomiques, IN2P3-CNRS, Université Louis Pasteur, Strasbourg, France
[11] Institute of Experimental Physics, Warsaw University, Poland
[12] Rudjer Boskovic Institute, Zagreb, Croatia

[13] Heavy-Ion Nuclear Physics Laboratory, RIKEN, Wako,Saitama 351-0198, Japan,
[14] Physik Department, Technische Universität München, D-85748 Garching, Germany,
[15] Institut für Mittelenergie-Physik, Östereichische Akademie der Wissenschaften, Boltzmanngasse 3, A-1090, Wien, Austria

Summary

We propose experiments to measure the production of strange baryon resonances (Σ^*, etc.) and $\bar{K}$ clusters (ppK^-, $ppnK^-$, $pppK^-$, etc.) in Al + Al reactions at 2 AGeV and in $p+d$ and $p+C$ reactions at 4.6 GeV with the FOPI apparatus.

Proposed signature of KNC

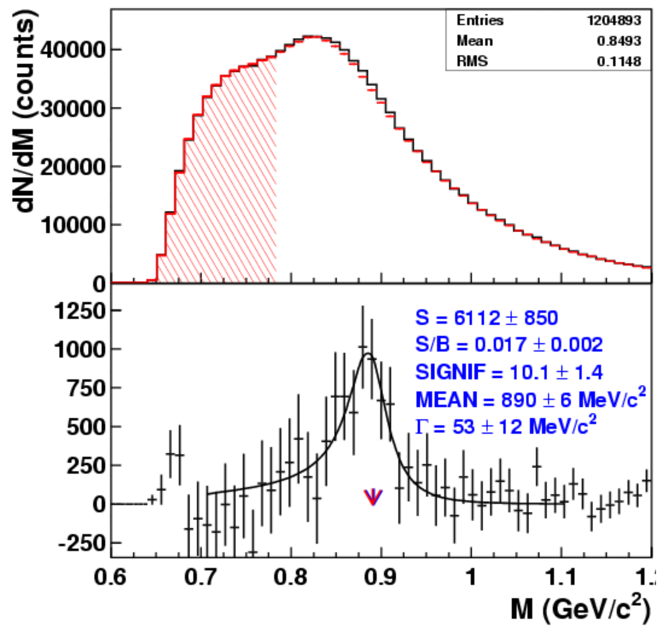
$$i)\quad ppK^-(T=1/2) \rightarrow \Lambda + p,$$
$$ii)\quad ppnK^-(T=0) \rightarrow \Lambda + d,$$
$$iii)\quad pppK^-(T=1) \rightarrow \Lambda + p + p.$$

Request: Al + Al, 2 AGeV, 21 days,
p + d, 4.6 GeV, 7 days,
p + C, 4.6 GeV, 14 days

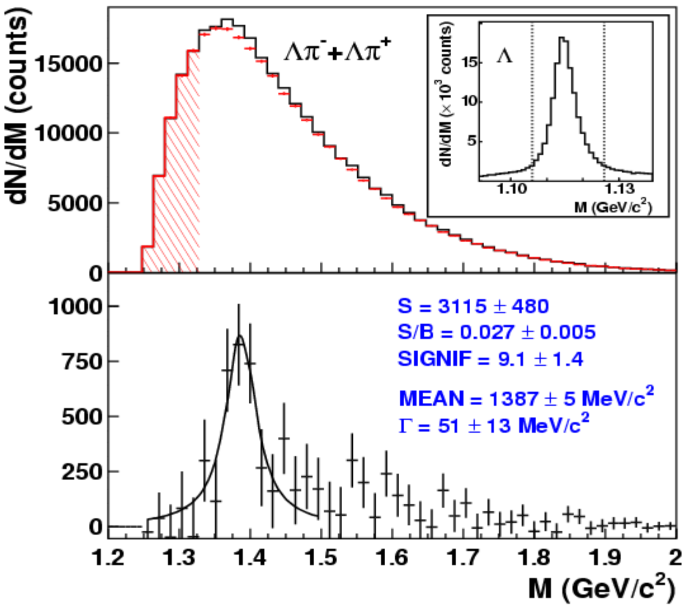
Results from Al + Al run (S297)

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

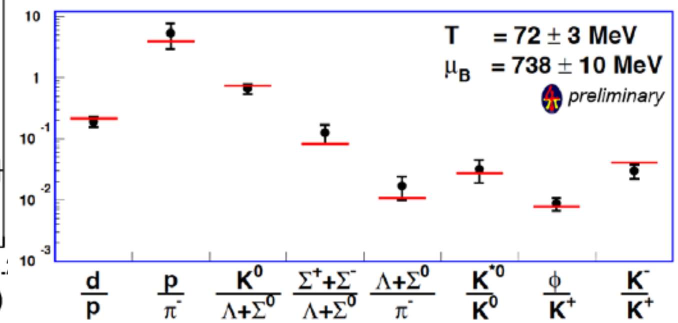
X. Lopez et al. (FOPI), PRC 81, 061902 (2010)

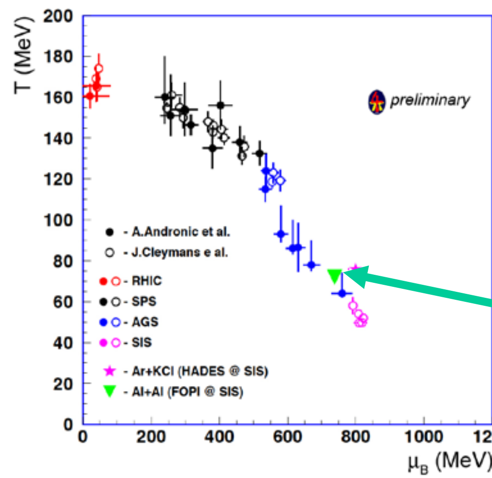


X. Lopez et al. (FOPI), PRC 76, 052203(R) (2007)



P. Gasik et al., Eur.Phys.J. A52 (2016) 177

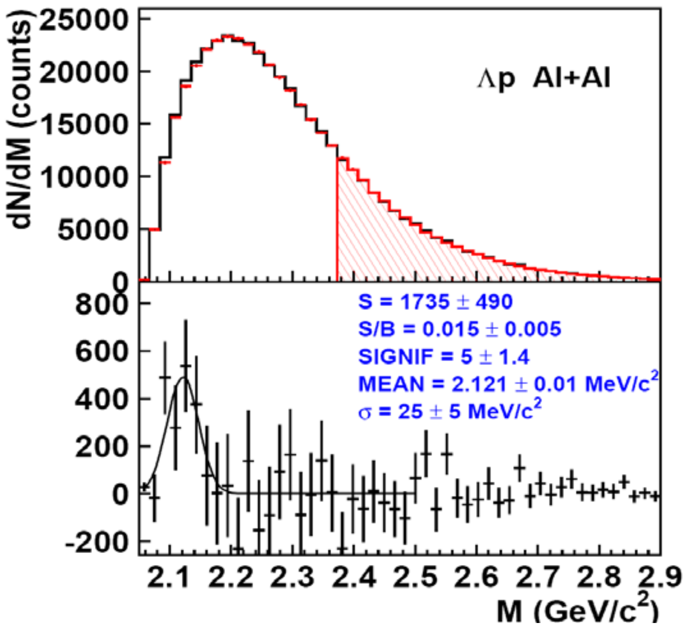


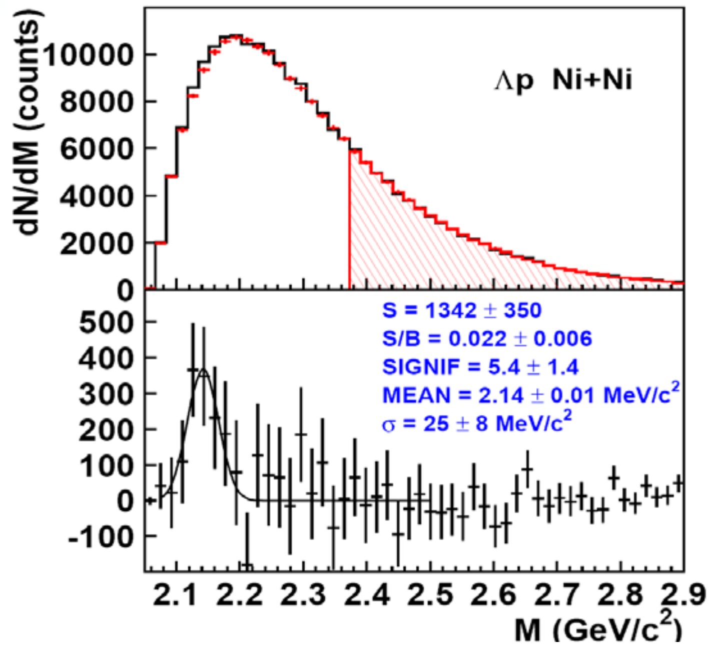


Al + Al @ 1.9 AGeV
Chemical equilibrium?

Search for hadronic molecules: Λp – correlation

X.Lopez, HYP2006

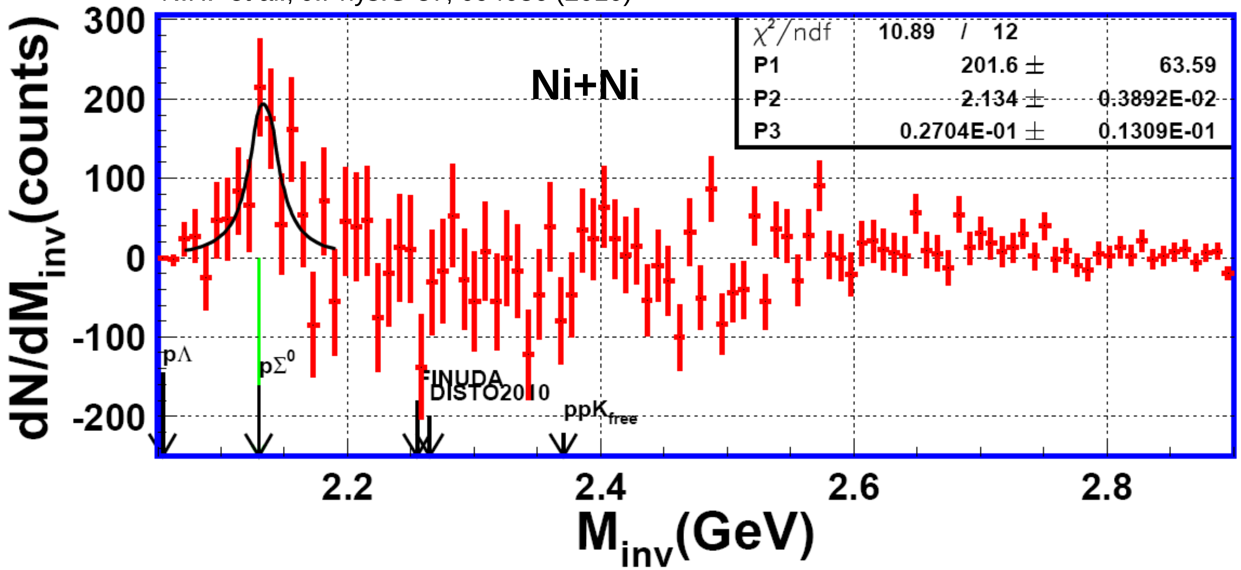




Method:

Subtract
mixed event background
from
event wise correlations

N.H. et al., J.Phys.G 37, 094036 (2010)



M = 2.134+/-0.004 GeV
Γ= 26 +/-14 MeV
(statistical errors only)

Λp – Interpretation?

Cusp in pp – reactions: $p + p \rightarrow K^+ + \Lambda + p$

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

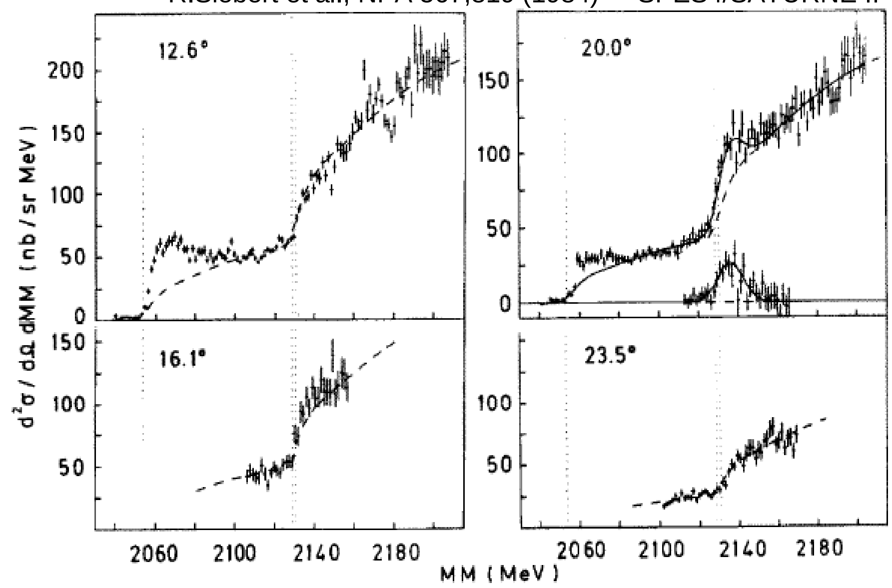
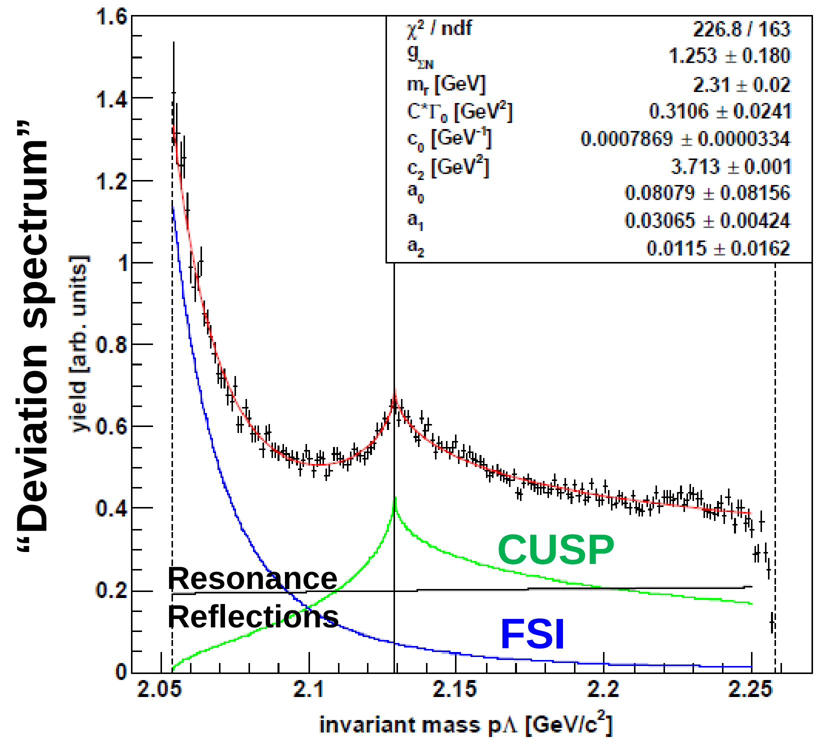


Fig. 6. Inclusive missing mass spectra for pp → K⁺X at 2.7 GeV incident energy. The kaon laboratory scattering angles are 12.6°, 16.1°, 20.0° and 23.5°. The bins are 1.5 MeV wide. The resolutions (FWHM) are approximately 3 MeV (12.6°), 4 MeV (16.1°), 3.5 MeV (20.0°) and 5 MeV (23.5°). The dashed lines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

COSY TOF @ 2.95 GeV/c

S. Jowzaee et al., Eur.Phys.J. A52 (2016) 7



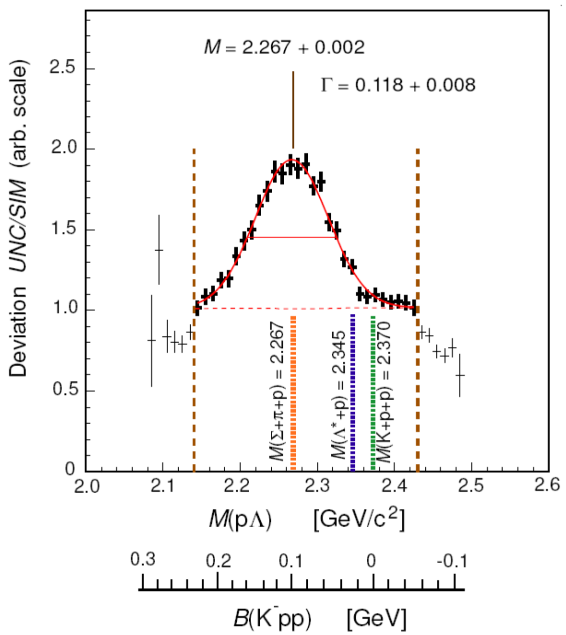
Peak position in FOPI data consistent with p+p scattering data: M = 2.136 ± 0.004GeV

Earlier observations and interpretations:

A.T.M. Aerts and C.B. Dover, Phys. Lett. B146, 95 (1984): D_t (q4 x q2 structure)

O. Braun et al., NPB 124,45 (1977), reaction $K^- + d \rightarrow \Lambda p \pi^-$: ΣN – bound state H(2129)

Doorway state X2265: evidence for $(ppK^-)_{bound}$



Reanalysis of DISTO data:

T. Yamazaki, et al., PRL 104,132502, 2010.

$p + p \rightarrow K^+ + X \rightarrow K^+ + \Lambda + p$ at 2.85GeV, q=1.6 GeV

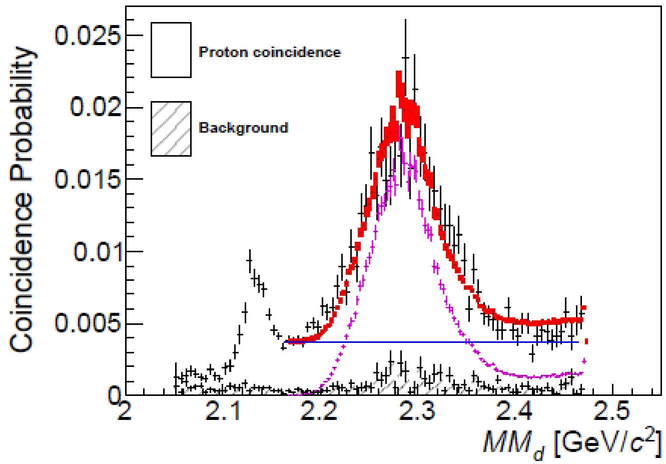
Production probability:

$X / \Lambda = 0.1$

Peak parameter:

$$M = 2.265 \pm 0.002 \text{ GeV}$$

$$\Gamma = 118 \pm 8 \text{ MeV}$$



J-PARC E27:

Y. Ichikawa et al., Prog. Theor. Exp. Phys. 2013, 0

$\pi^+ + d \rightarrow K^+ + X$ at 1.69 GeV, q=0.3 GeV

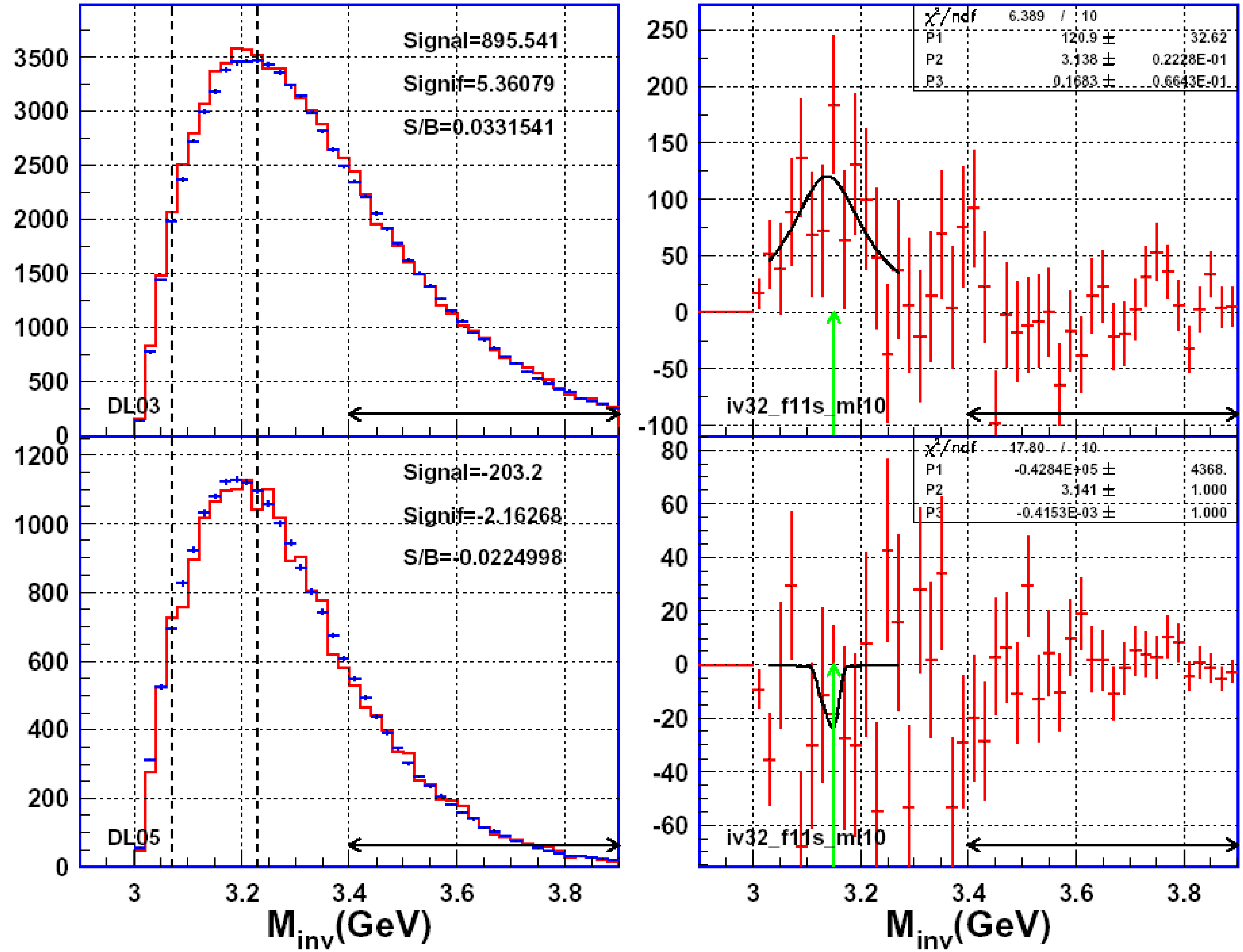
Event selection: high momentum proton at backward angles

M= 2.27 GeV,

B= 95 +18−17 (stat.) +30−21 (syst.) MeV,

Γ=162 +87−45 (stat.) +66 −78 (syst.) MeV.

Λd correlation: comparison Al+Al ↔ Ni+Ni



Ni+Ni

S261 data (2003)

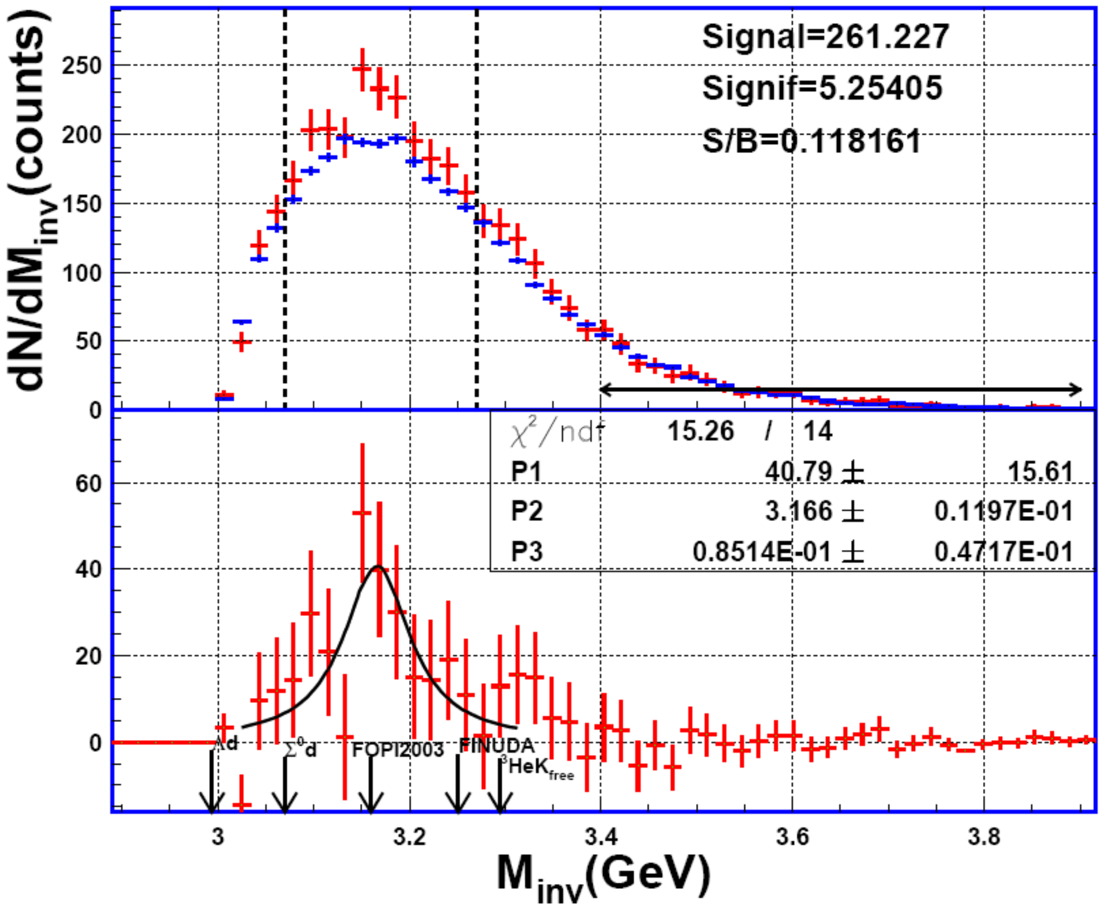
Al+Al

S297 data (2005)

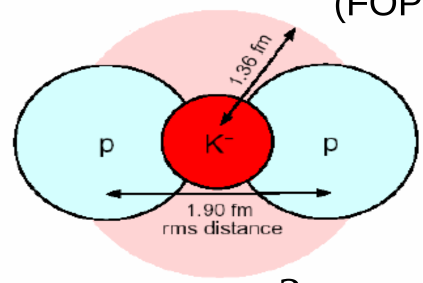
Λd – correlations

Ni+Ni at 1.91 AGeV (S325e data (2008))

K. Wisniewski (FOPI, HD)



(FOPI, work in progress)



$$\left(ppnK^-\right) \overset{?}{\rightarrow} \Lambda + d$$

FOPI experimental scenario:

Data taking:	**2 weeks,**
DAQ rate:	**1kHz,**
Event sample:	**~ 100 M events,**
Statistical significance:	**~ 5,**
Production probability:	**P ~ 10^{-4}**

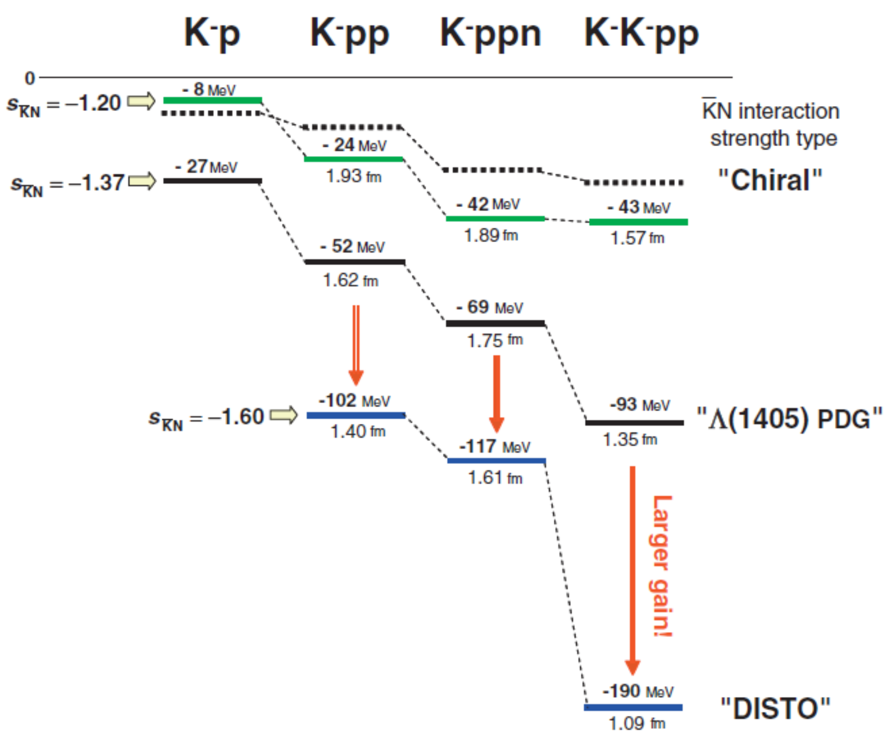
Significance does not include systematic uncertainties

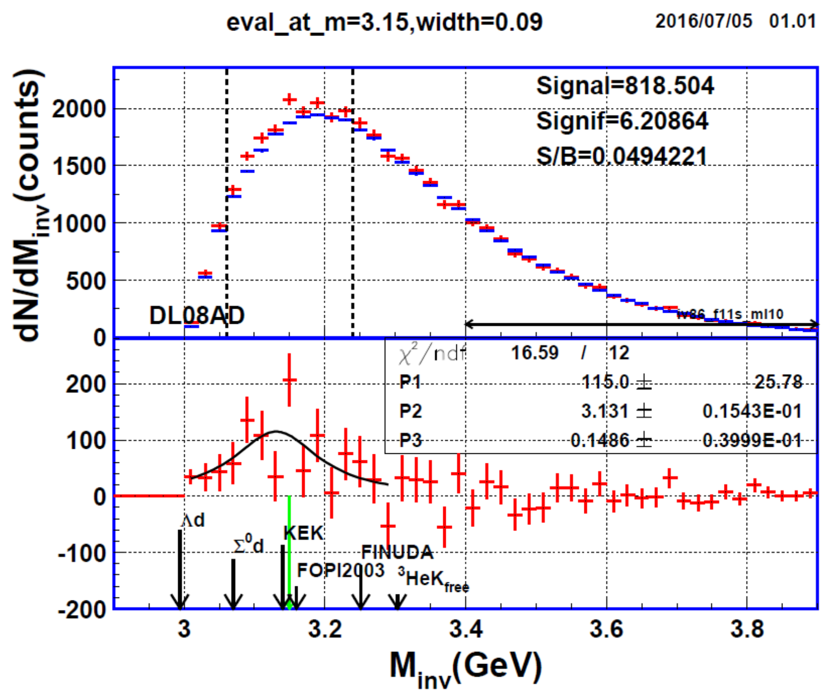
non – thermal phase space population
non – monotonous centrality dependence
non – trivial mixed event bkgd determination
LEE – Look elsewhere effect (?)

FOPI 2003 and 2008 data are consistent, inconsistent with cusp (Σ – d – threshold), compatible with latest theoretical developments?

Comparison to Theory

S. Maeda, Y. Akaishi, T. Yamazaki, Proc. Jpn. Acad., Ser. B89, 418 (2013)

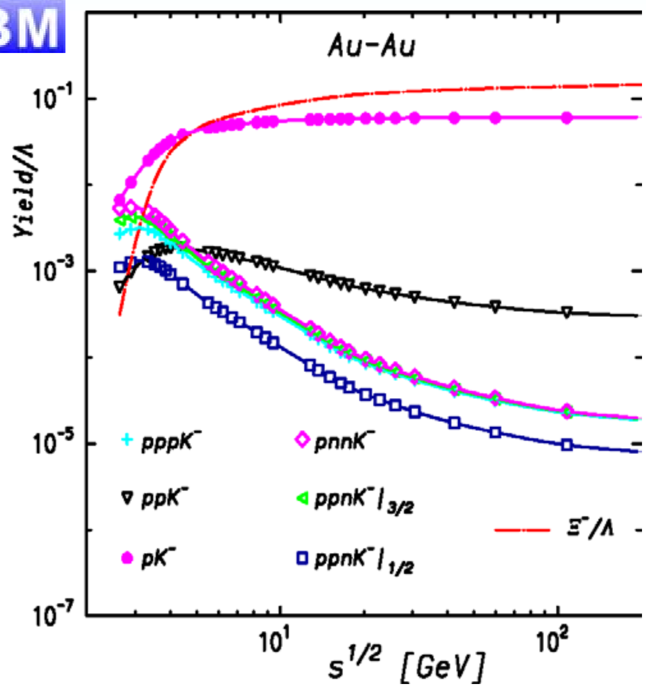


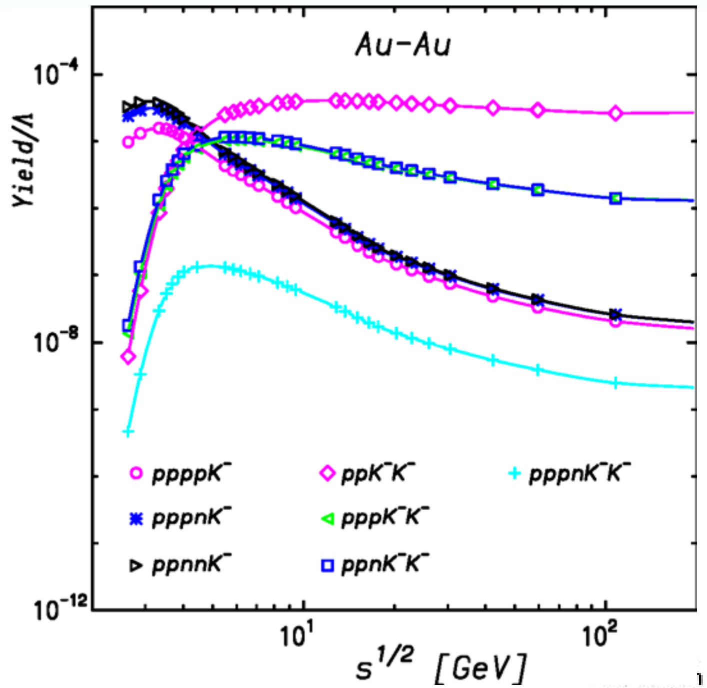


FOPI - Λd - peak parameter:

$N_{K\text{-}ppn}$	= 261 ± 100 (stat.)	819 ± 183 (stat)
N_Λ	= 27 k	27 k
S/B	= 0.118	0.049
$N_{K\text{-}ppn}/N_\Lambda$	> 0.01	> 0.03
M	= 3.167 ± 0.012 GeV	3.131 ± 0.015 GeV
B	= 143 ± 12 MeV	178 ± 15 MeV
Γ	= 85 ± 47 MeV	149 ± 40 MeV

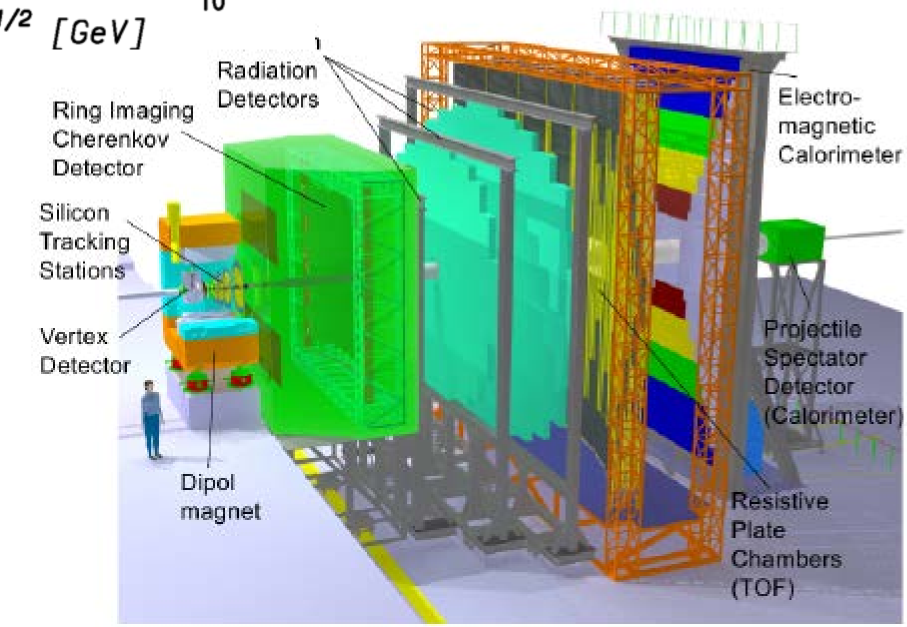
Experimental strategy towards KNC states





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

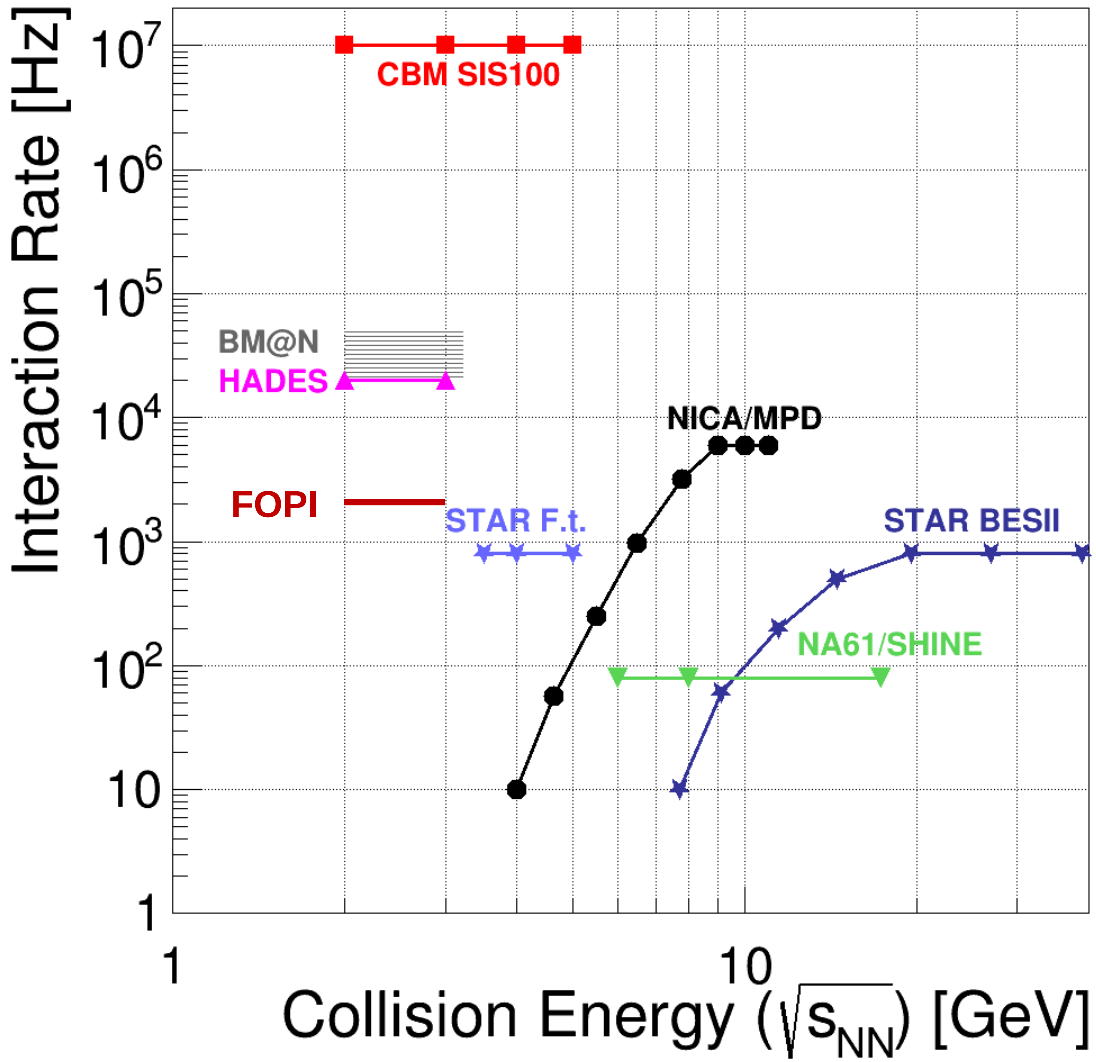
CBM @ FAIR



Experimental strategy at beam energies < 10 AGeV:

- allow for large event samples
- reduce combinatorial background as much as possible
- tag events for strangeness content (by K^+, (K^0))
- detect K^+ as efficiently as possible
- compact Kaon PID

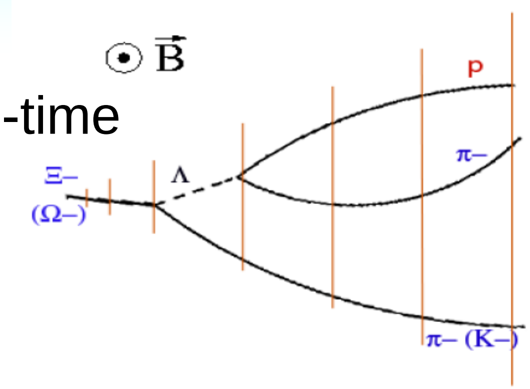
Experiments exploring dense QCD matter

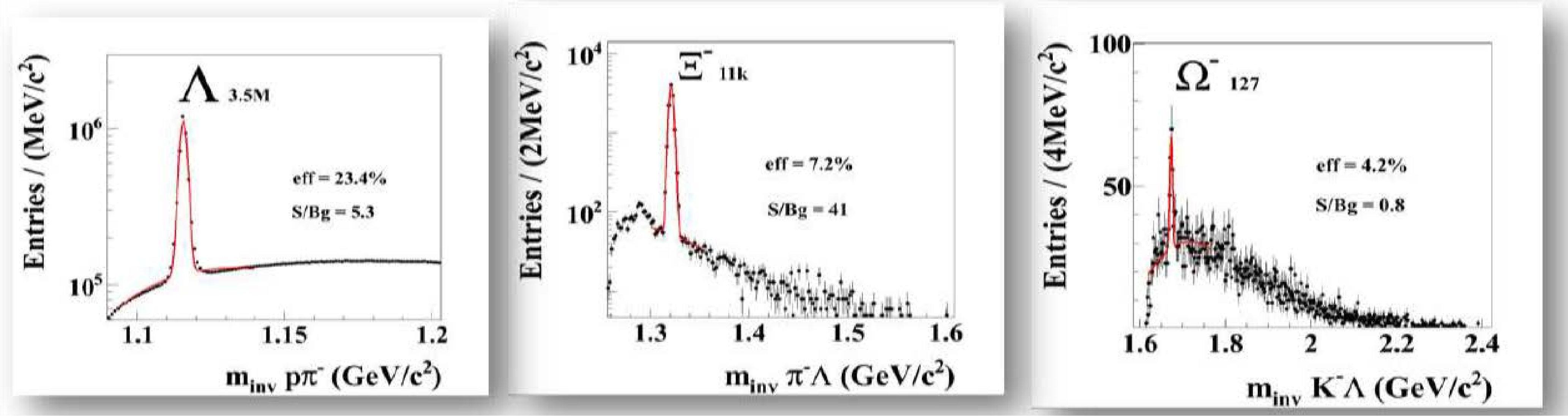


SIS 100- Hyperons

Central (b=0fm) Au+Au collisions at 8 AGeV, 1M events

- Massively parallel data reconstruction and selection in real-time
- 100 kHz archival rate:
  - → 500k Ω^- /week
  - → flow, correlations, …
  - → hypernuclei,
  - → deeply bound kaonic clusters?





Expectations for 4AGeV: **<M(Λ)> ~ 10,** **Counts in 1 week run: N(Λ) ~ $4 \cdot 10^{10}$**

$N_{K\text{-}ppn}/N_\Lambda$ (SHM) ~ $5 \cdot 10^{-3}$ **$N(K^-ppn)$ ~ $2 \cdot 10^8$**

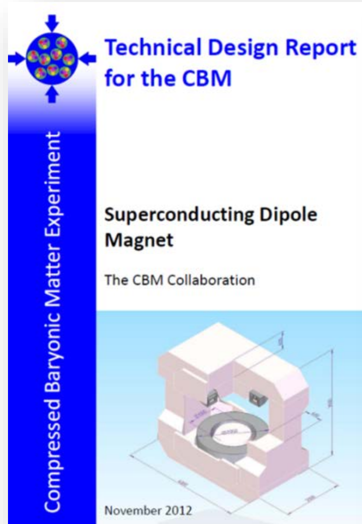
$N_{K\text{-}K\text{-}pp}/N_\Lambda$ (SHM) ~ $2 \cdot 10^{-7}$ **$N(K^-K^-pp)$ ~ $8 \cdot 10^3$**

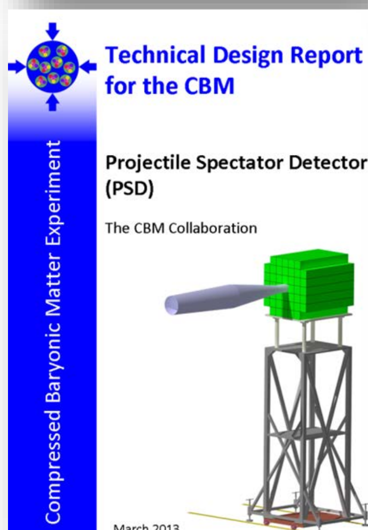
@ 10MHz: ~ $8 \cdot 10^5$

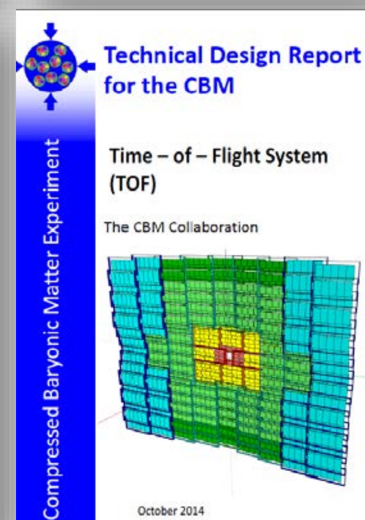
CBM Technical Design Reports

http://www.fair-center.eu/en/for-users/experiments/cbm/documents.html

#	Project	TDR Status
1	Magnet	approved
2	STS	approved
3	RICH	approved
4	TOF	approved
5	MuCh	approved
6	HADES ECAL	approved
7	PSD	approved
8	MVD	submission 2016
9	DAQ/FLES	submission 2017
10	TRD	submission 2016
11	ECAL	submission 2016



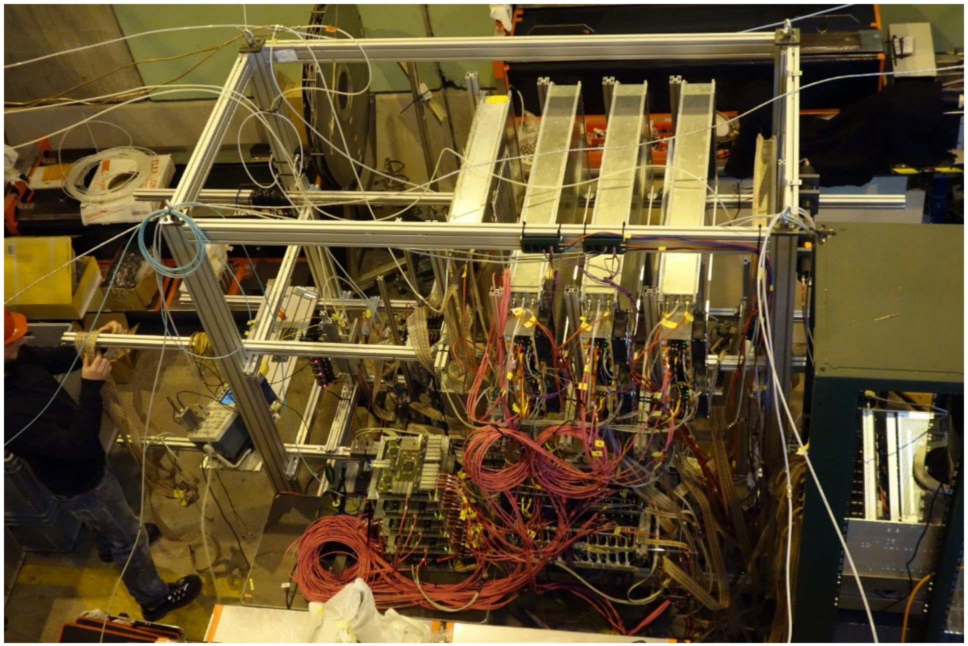


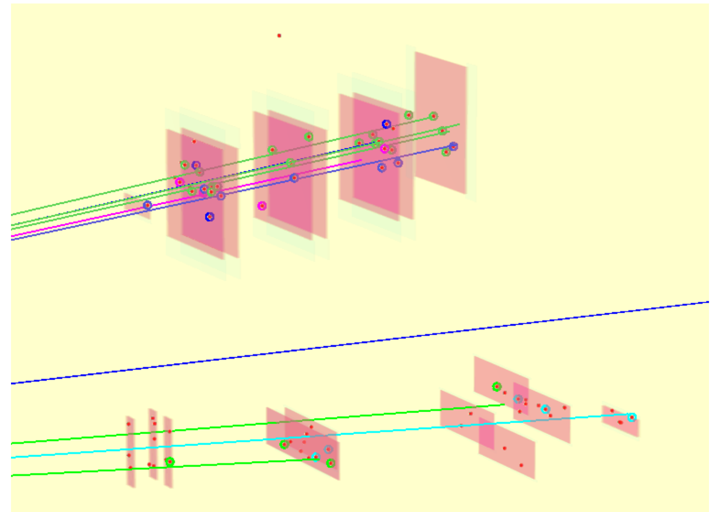


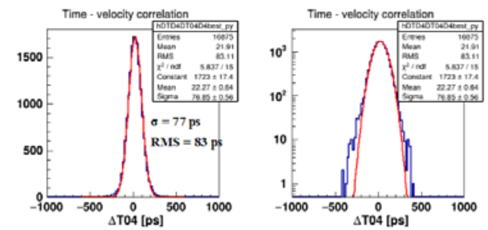
CERN SPS Testbeam (Nov2015)

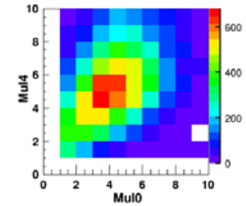
Pb + Pb @ 30 A GeV

MRPC setup in H4 beamline with 20 different counter types, 1000 timing channels, flux on counter surfaces 5 – 10 kHz / cm^2







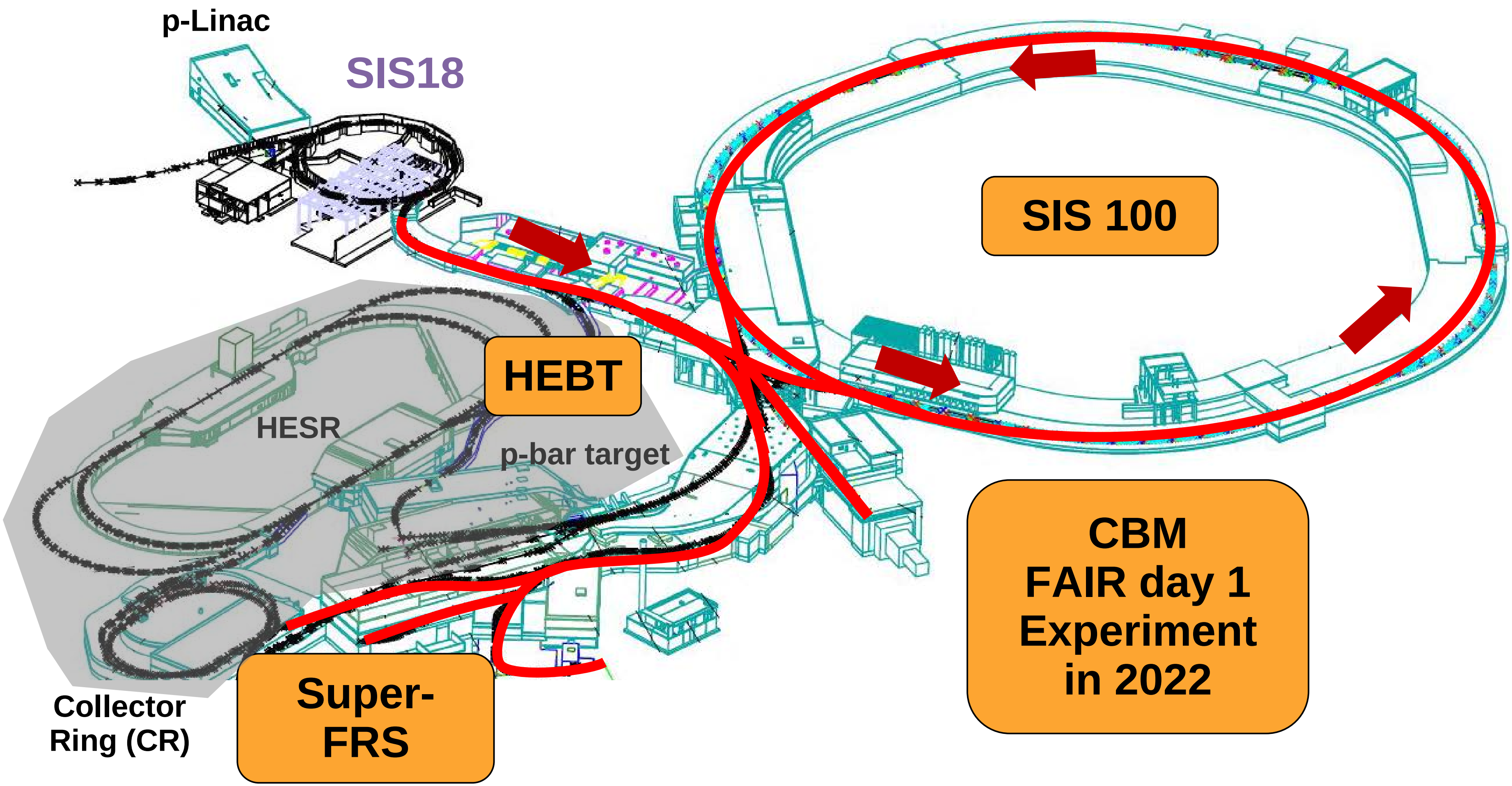


Efficiency = 0.940,
CluSize Buc2012_703 = 2.3;
CluSize Buc2015DS = 2.6;

System time resolution of 80 ps achieved with conductive glass electrodes (Yakang glass, Beijing – Tsinghua Univ.).

CBM perspectives

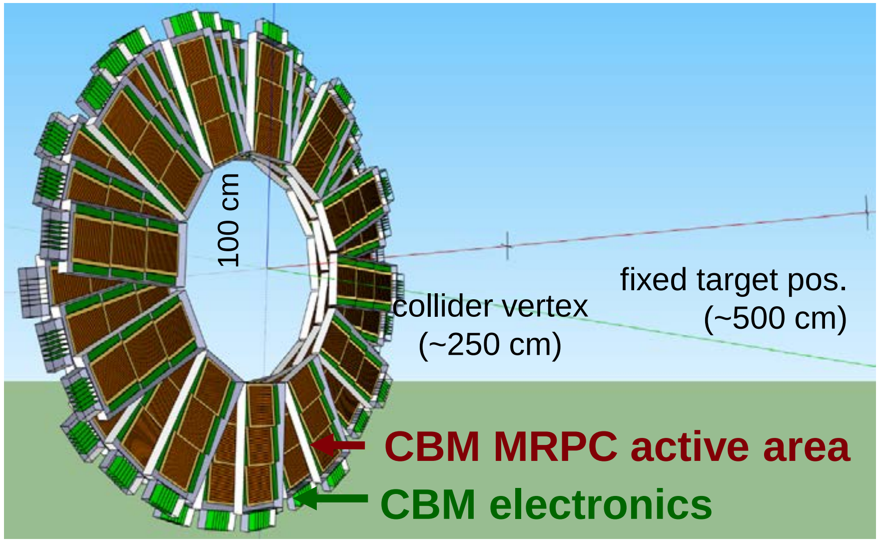
GSI/FAIR strategy: staged realization along the beam towards MSV

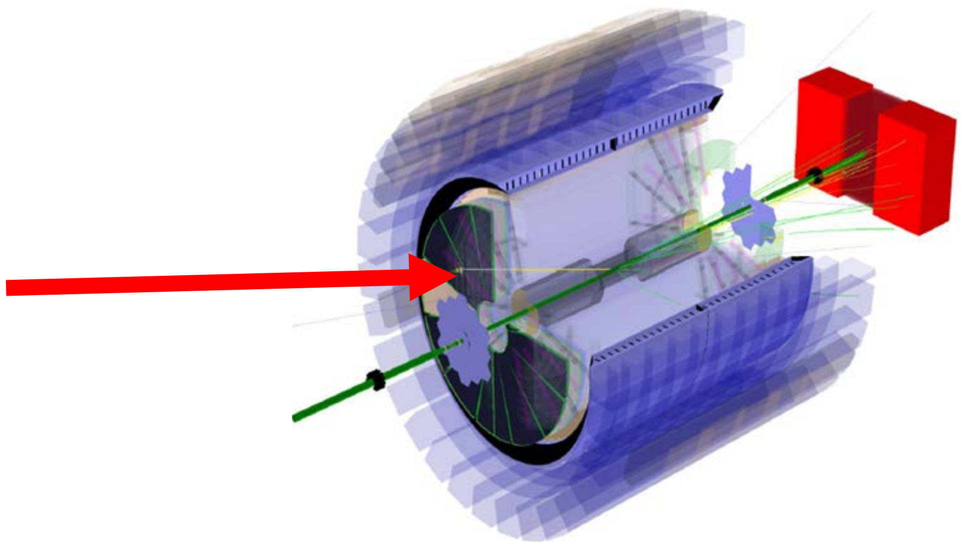


Search for deeply bound KNC states will be continued at FAIR with unprecedented rates.

FAIR Phase 0 experiments

Install, commission and use 10% of the CBM TOF modules including CBM read-out chain at STAR/RHIC (BES II 2019/2020).





Planned beam energies:

$\sqrt{s_{NN}}$ (GeV) Collider	$\sqrt{s_{NN}}$ (GeV) Fixed Target	T AGeV
62.4	7.74	30.3
39	6.17	18.6
27	5.18	12.6
19.6	4.47	8.9
14.5	3.90	6.3
11.5	3.53	4.8
9.1	3.20	3.6
7.7	2.99	2.9

Anticipated statistics: ~ 10^8 events each

CBM Collaboration: 60 institutions, ~530 members

Croatia:
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei
CTGU Yichang

Czech Republic:
CAS, Rez
Techn. Univ.Prague

France:
IPHC Strasbourg

Hungary:
KFKI Budapest
Budapest Univ.

Germany:
Darmstadt TU
FAIR
Frankfurt Univ. IKF
Frankfurt Univ. FIAS
Frankfurt Univ. ICS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
KIT Karlsruhe
Münster Univ.
Tübingen Univ.
Wuppertal Univ.
ZIB Berlin

India:
Aligarh Muslim Univ.
Bose Inst. Kolkata
Panjab Univ.
Rajasthan Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
IOP Bhubaneswar
IIT Kharagpur
IIT Indore
Gauhati Univ.

Korea:
Pusan Nat. Univ.

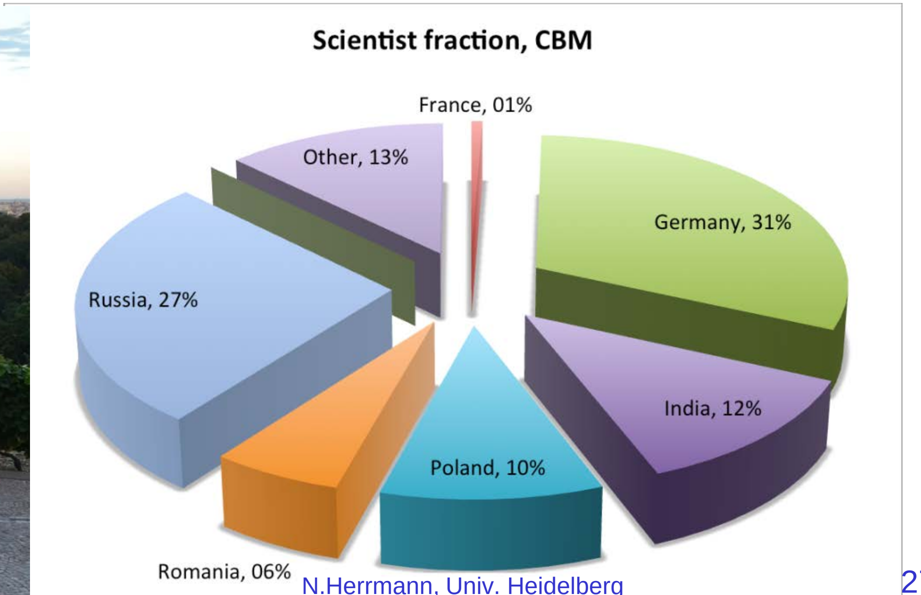
Poland:
AGH Krakow
Jag. Univ. Krakow
Silesia Univ. Katowice
Warsaw Univ.
Warsaw TU

Romania:
NIPNE Bucharest
Univ. Bucharest

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk Univ.
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.
Ioffe Phys.-Tech. Inst. St. Pb.

Ukraine:
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research

26th CBM Collaboration meeting in Prague, CZ
14 -18 Sept. 2015



Summary / Conclusion

Deeply bound KNC are an intriguing way towards cold dense baryonic matter.

Λp final state:

ΣN – cusp seen in Al + Al and Ni + Ni at 1.9 AGeV,
X2265 (DISTO, E27) not found.

Λd final state:

Correlation signal seen in Ni + Ni reactions at 1.9 AGeV,

non – thermal phase space population
non – monotonous centrality dependence
non – trivial mixed event background determination
selection bias (?)
needs further work

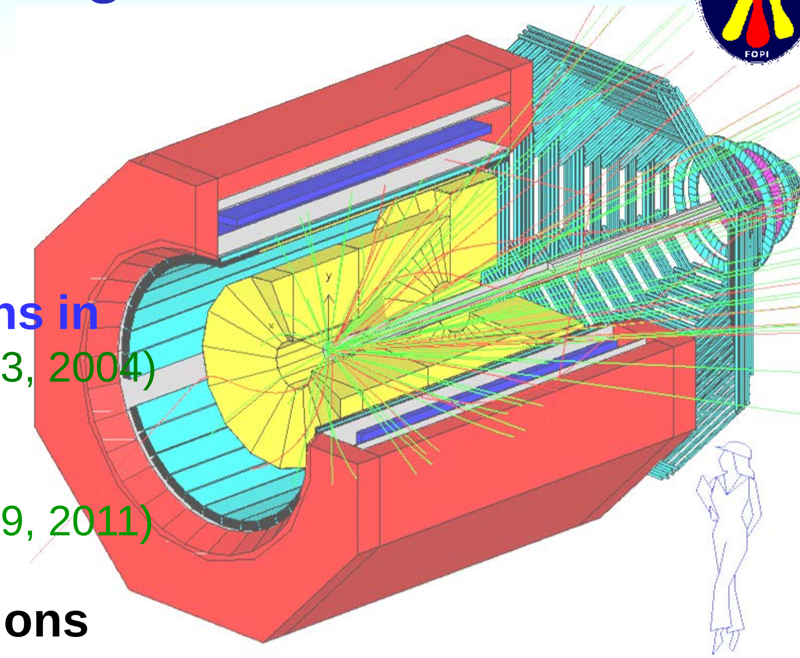
no signal seen in Al + Al at 1.9 AGeV

Statistical significance can be improved with CBM by factor 100.

New data expected from RHIC/STAR BESII run in 2019/2020.

Thank you!

Experimental strangeness program of FOPI



Reference data from elementary reactions

K^0 , Λ production and phase space distributions in

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

K^0 , K^+, K^-, ϕ, Λ production in

π^- + LH_2, C, Pb @ 1.7 GeV/c, (S339, 2011)

Systematics of strangeness data from heavy-ion reactions

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

Search for kaonic bound states

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

Search for exotica in elementary reaction

existence of ppK^- - bound state

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

T. Yamazaki's coauthored FOPI publications

SiΛvio: A trigger for Λ-hyperons
FOPI Collaboration (Robert Münzer (Munich, Tech. U., Universe) et al.). Jul 29, 2013. 12 pp.
Published in Nucl.Instrum.Meth. A745 (2014) 38-49

Measurement of K∗(892)0 and K0 mesons in Al+Al collisions at 1.9A GeV
FOPI Collaboration (X. Lopez (Clermont-Ferrand U.) et al.). Jun 2010. 5 pp.
Published in Phys.Rev. C81 (2010) 061902

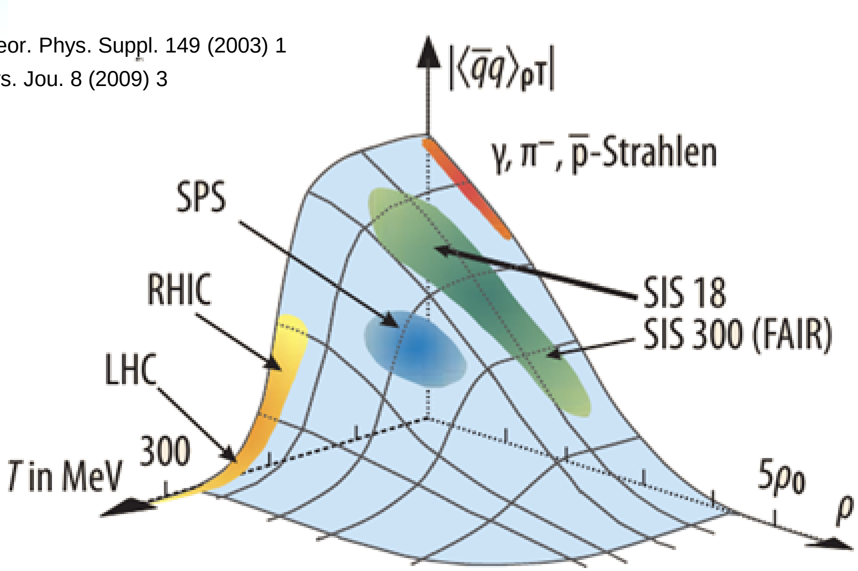
Search for the Kaonic Nuclear State, K- p p, in the exclusive p p ---> p Lambda K+ channel
FOPI Collaboration (K. Suzuki (Stefan Meyer Inst. Subatomare Phys.) et al.). 2009. 3 pp.
Published in Nucl.Phys. A827 (2009) 312C-314C

Measurement of the in-medium K0 inclusive cross section in pi- -induced reactions at 1.15-GeV/c
FOPI Collaboration (M.L. Benabderrahmane (Heidelberg U.) et al.). Jul 2008. 4 pp.
Published in Phys.Rev.Lett. 102 (2009) 182501

Sub-threshold production of Sigma(1385) baryons in Al + Al collisions at 1.9-A-GeV
FOPI Collaboration (X. Lopez et al.). Oct 2007. 5 pp.
Published in Submitted to: Phys.Rev.C (2007)

Hadrons in Medium

W. Weise, Prog. Theor. Phys. Suppl. 149 (2003) 1
M. Kotulla et al, Phys. Jou. 8 (2009) 3



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

In-medium effects in finite systems:

'Trivial'

Fermi motion
Pauli blocking
Collisional broadening

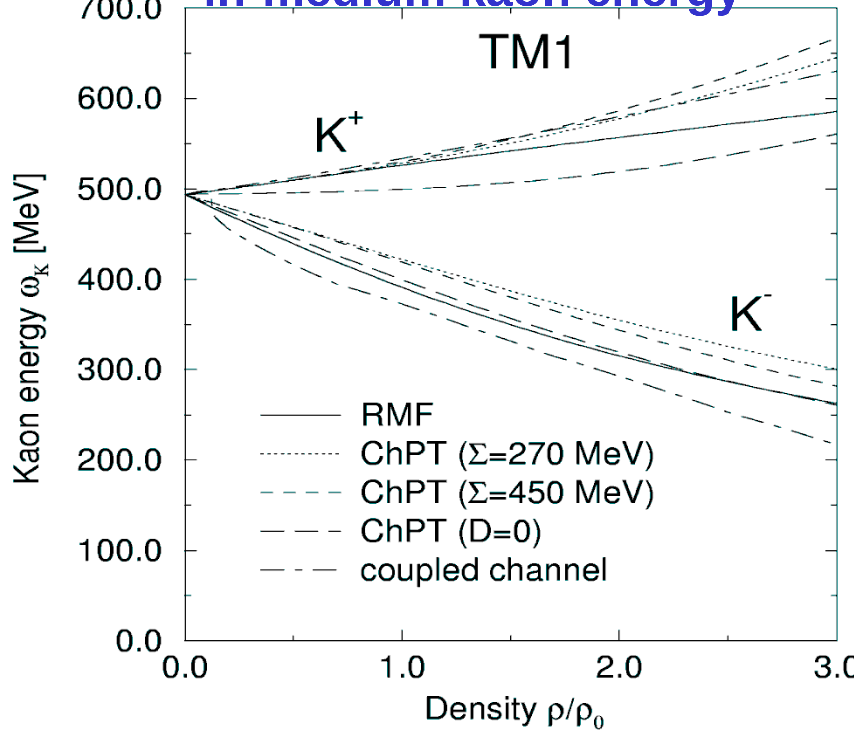
'Non-trivial'

Partial restoration of chiral symmetry
Meson – baryon coupling
Bound states

Modified properties of hadrons in dense baryonic matter?

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

in-medium kaon energy

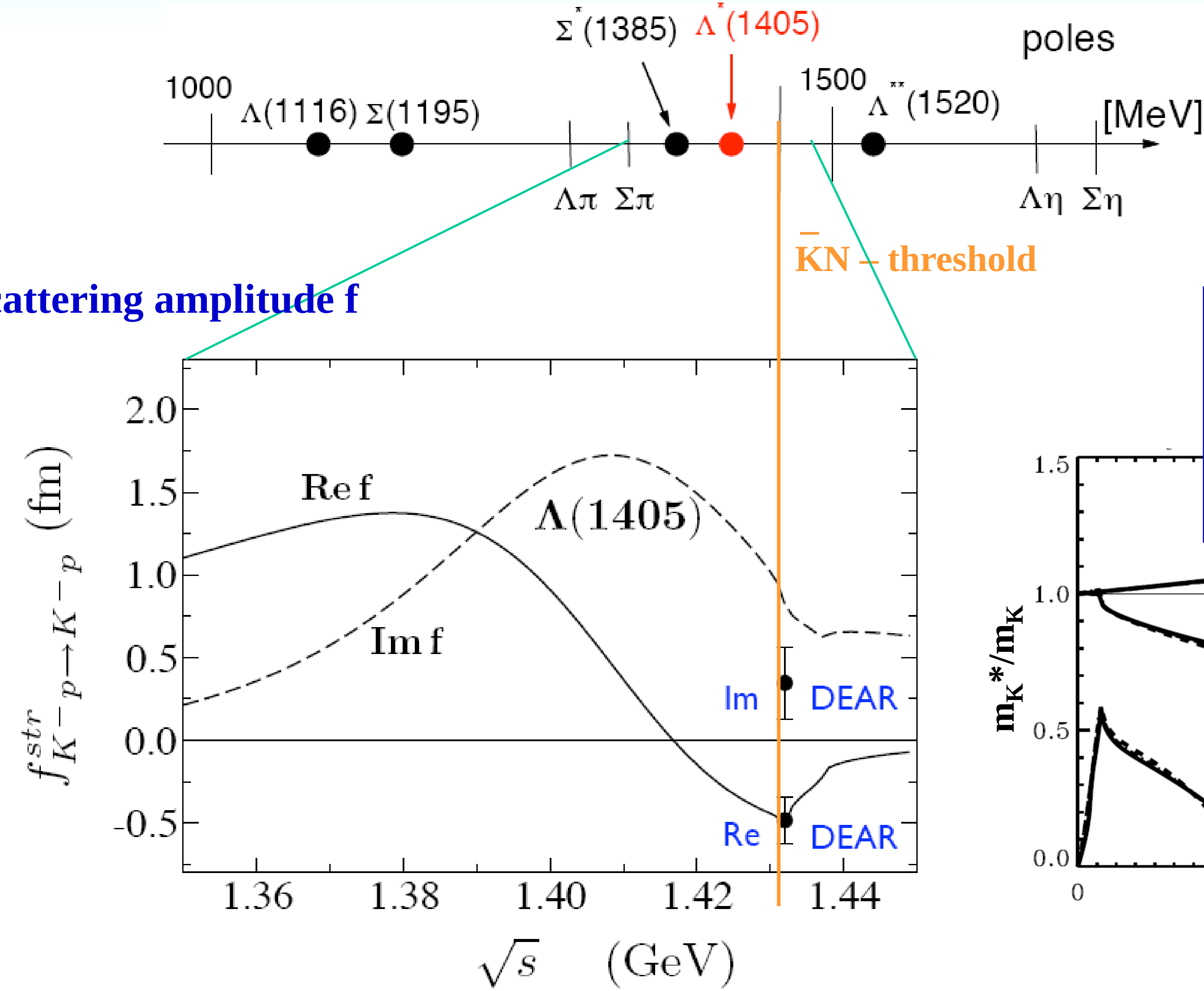


$\bar{K}N$ – interaction

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

$\bar{K}$ – energy

Scattering amplitude f



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

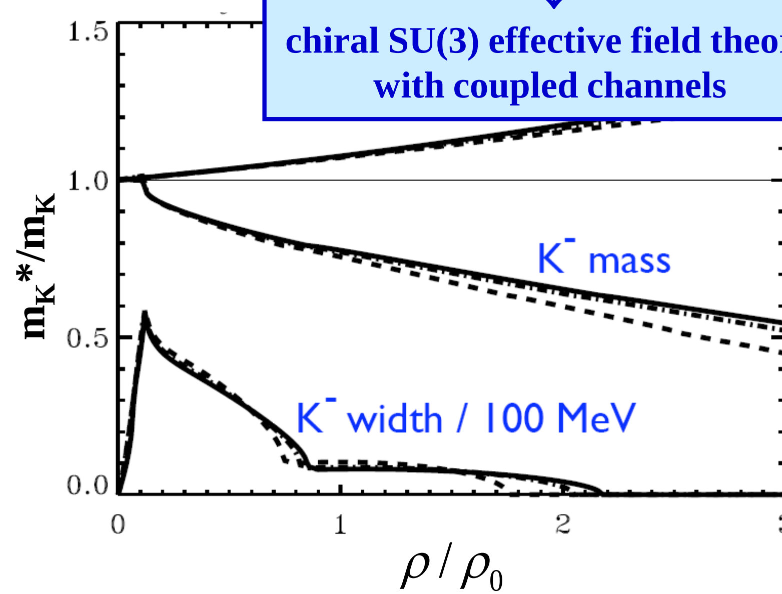
due to presence of resonances

↓

non – perturbative problem

↓

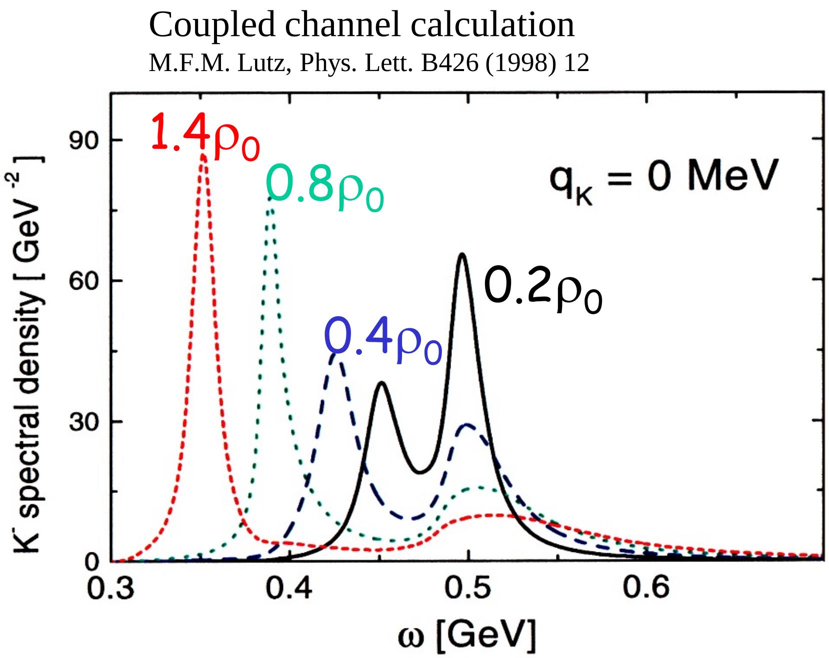
chiral SU(3) effective field theory with coupled channels



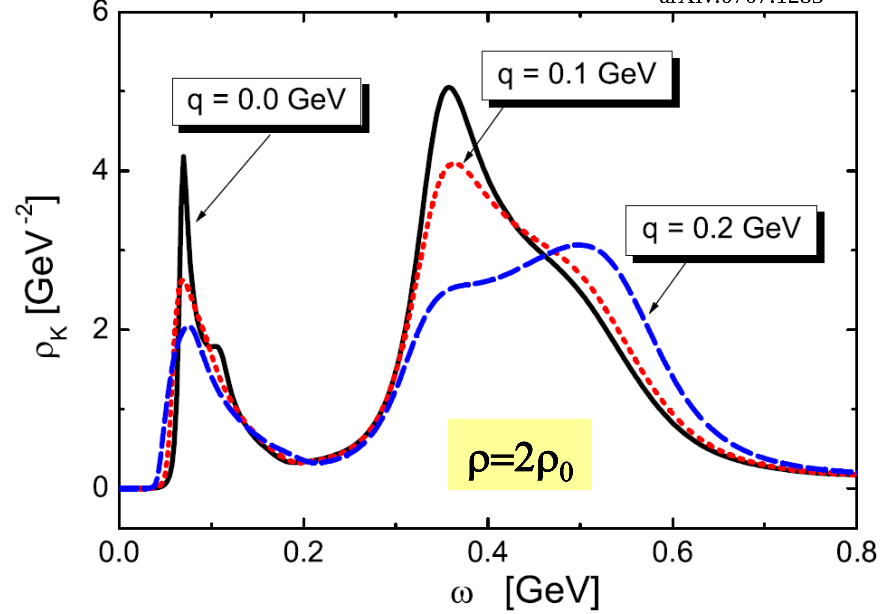
Summary: $\bar{K}N$ – interaction is attractive at finite densities, but strength (depth of potential) is unclear

Kaons in hadronic matter

spectral function of antikaons in dense matter



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



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

effective mass — Kaon potential

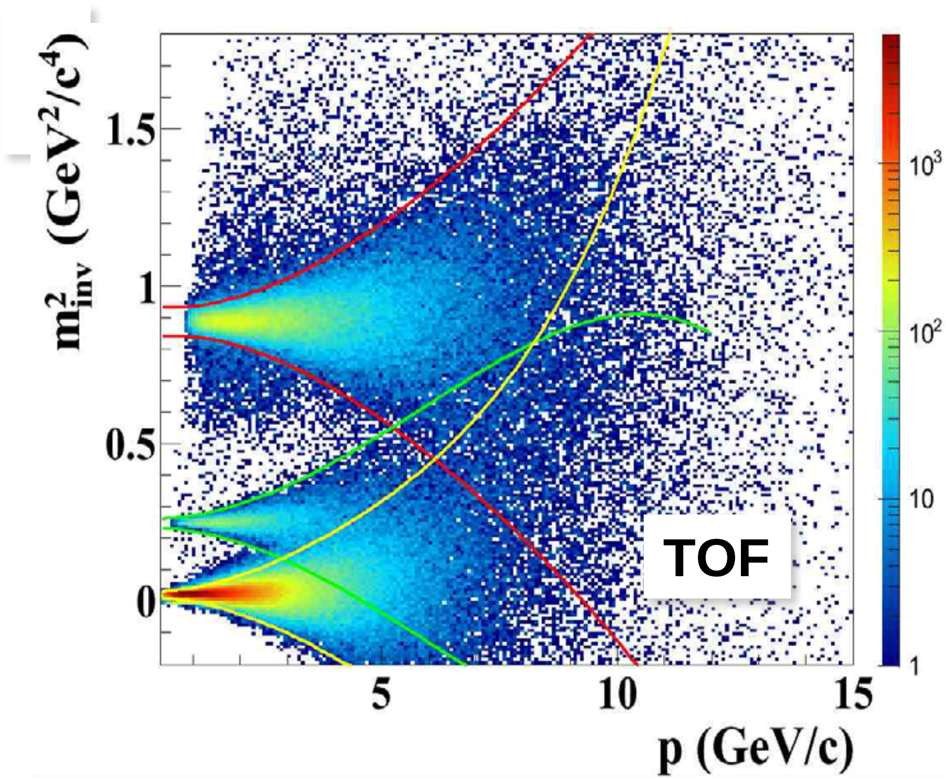
~~**Production:**~~
~~**P ~ exp (-m*/T)**~~
~~**→ K-yields**~~

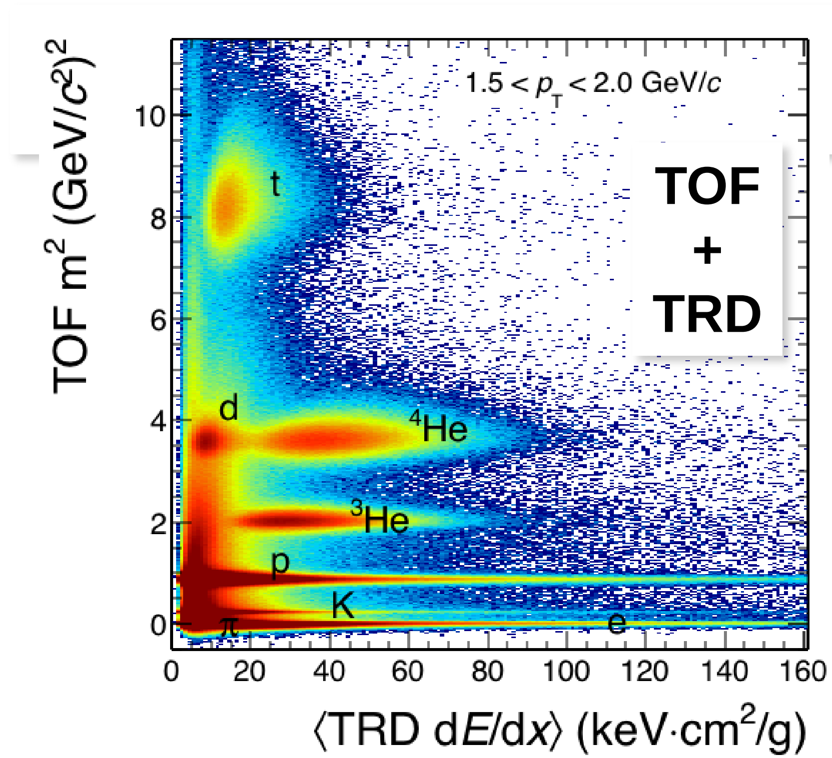
Propagation:
F=-∇U
→ K-flow

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

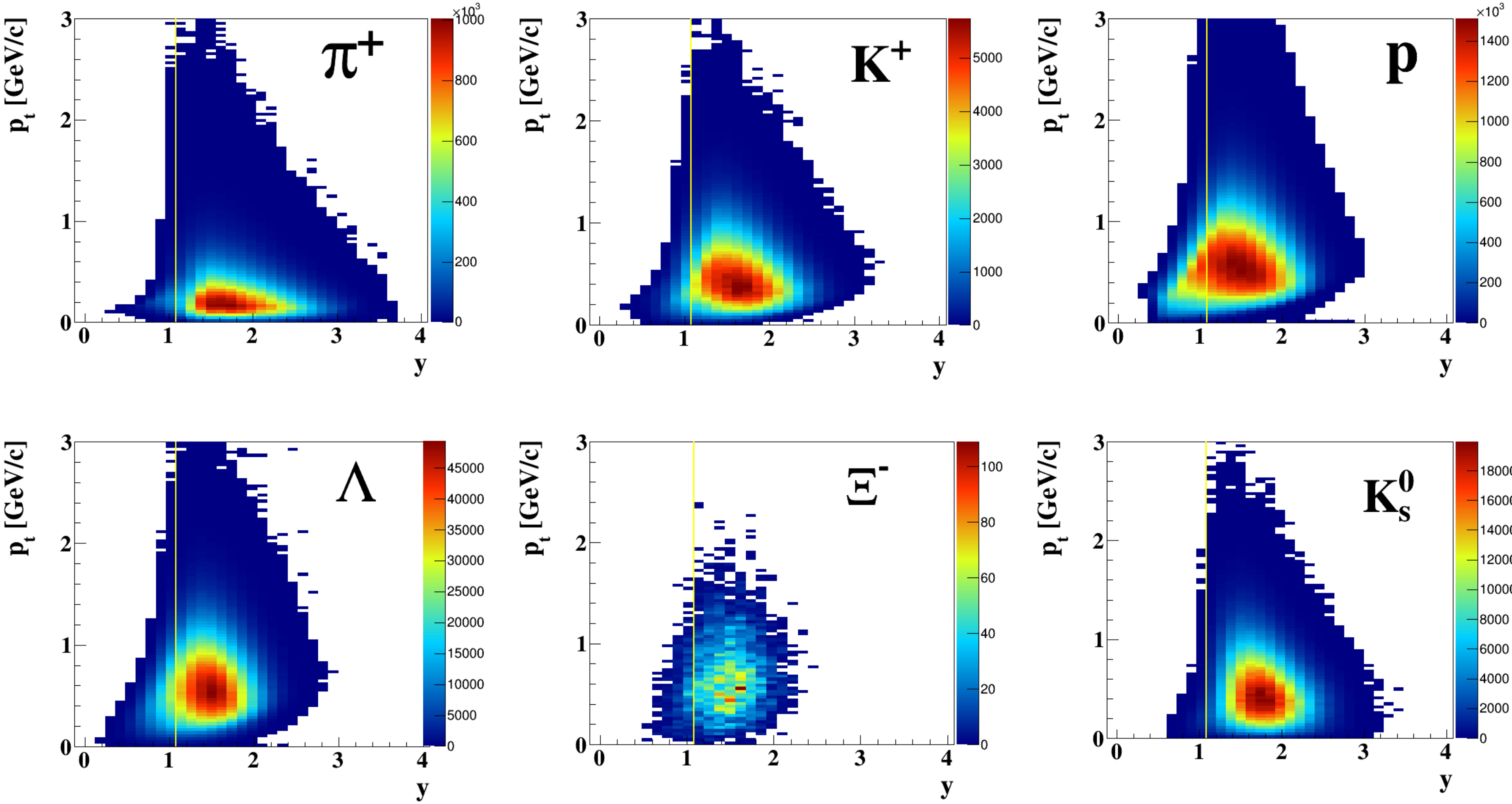
Particle Identification

Detectors used: STS, TOF, TRD

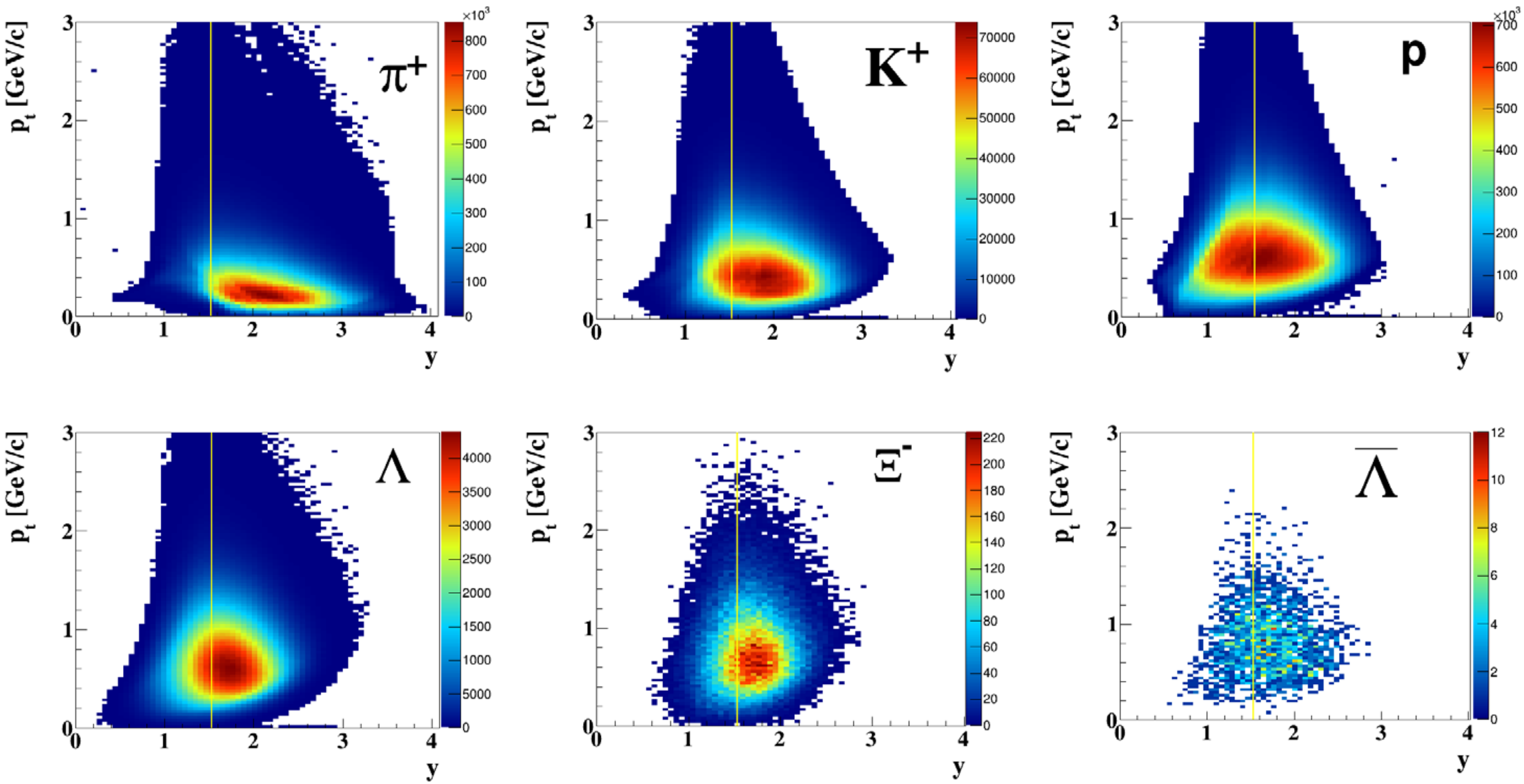




Particle acceptance
central Au+Au collisions at 4 A GeV



Particle acceptance
central Au+Au collisions at 10 A GeV



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

Introduction

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

Experimental details

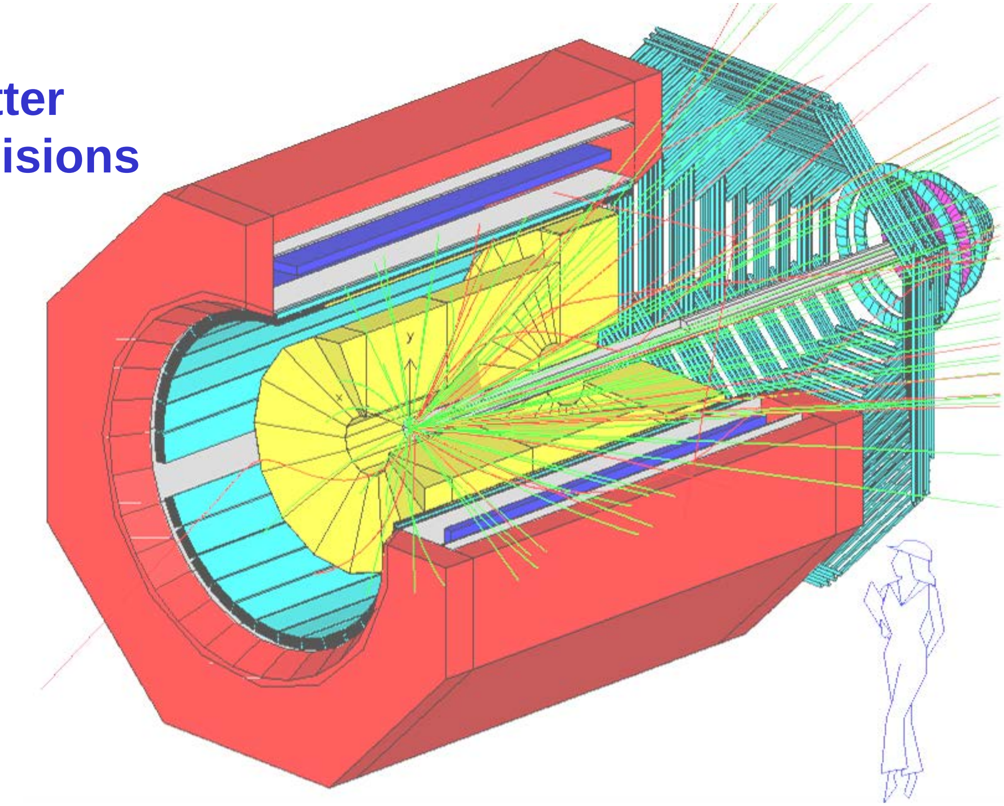
- kaon flow
- event mixing technique

Correlation Results

- $\Lambda + p$ - correlations
- $\Lambda + \pi$ - correlations
- ($\Lambda + d$ - correlations)

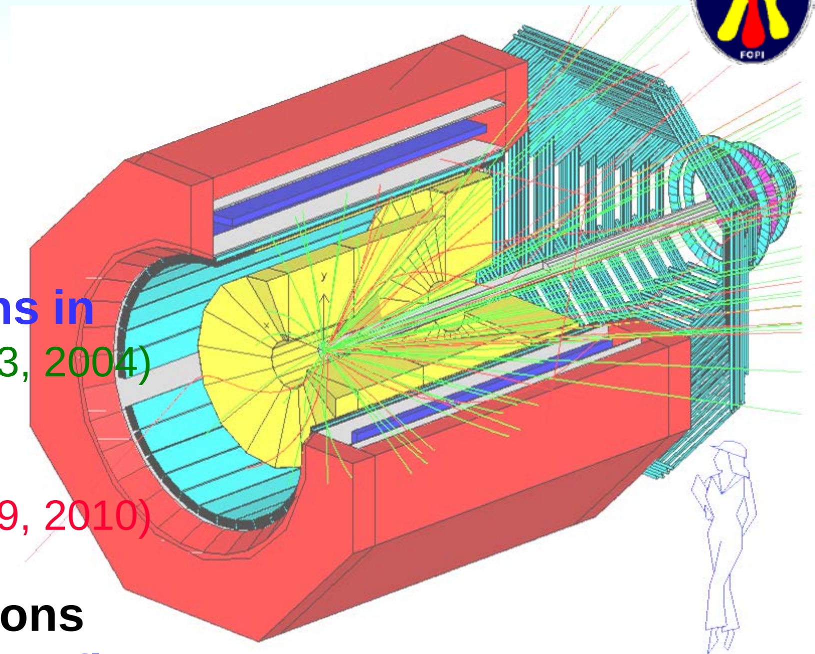
Outlook

Conclusions



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

Experimental program



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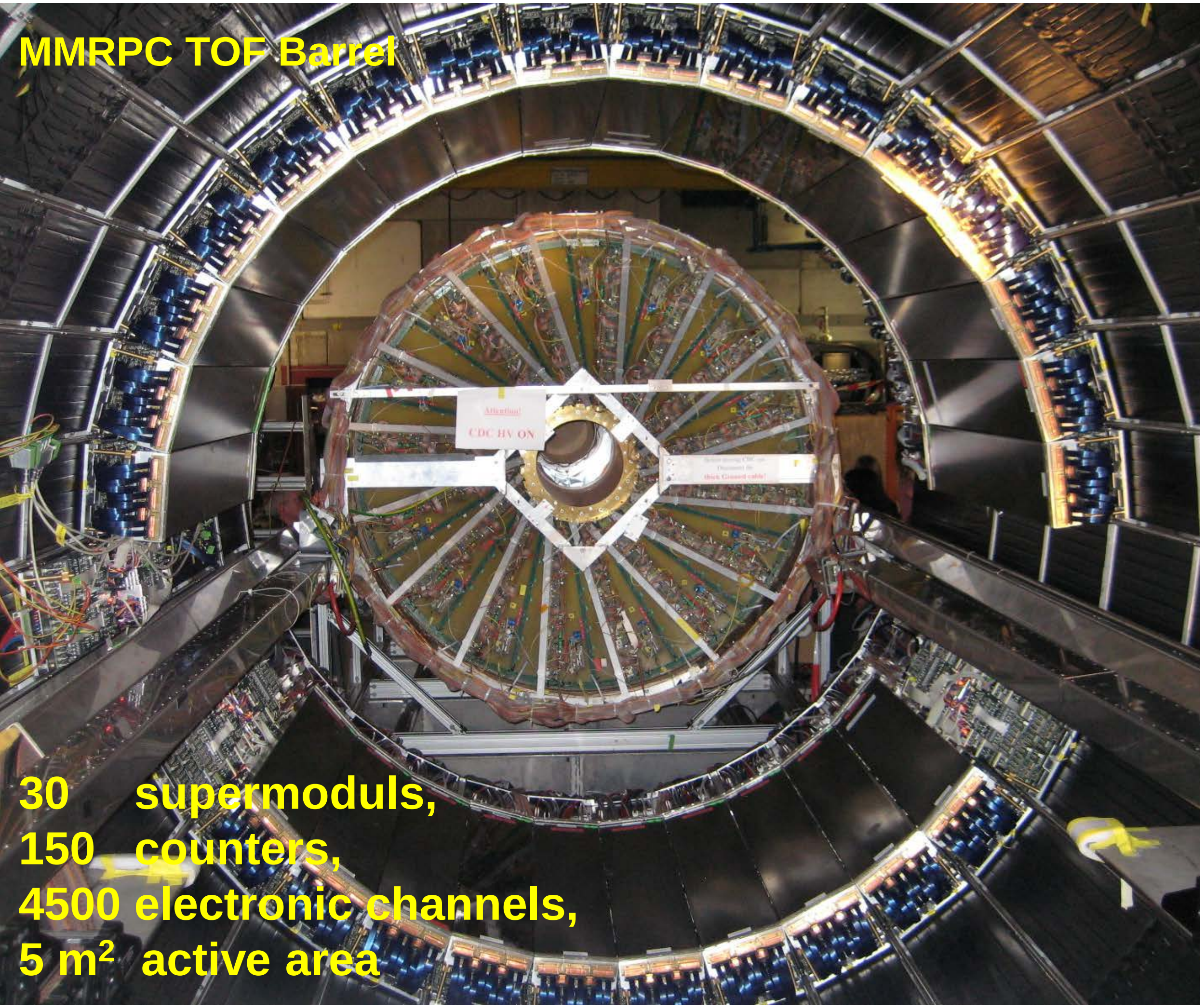
Ni + Ni	1.91 AGeV,	80M	(S325, 2008)	
Ni + Pb	1.91 AGeV,		100M	(S338, 2009)
Ru+ Ru	1.7 AGeV,		210M	(S338, 2009)

Search for exotica in elementary reaction

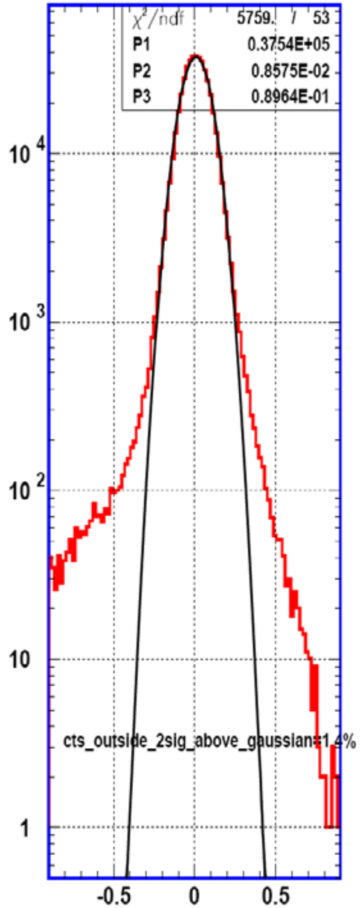
existance of ppK^- - bound state

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

FOPI III (2008 – 2010) with improved PID



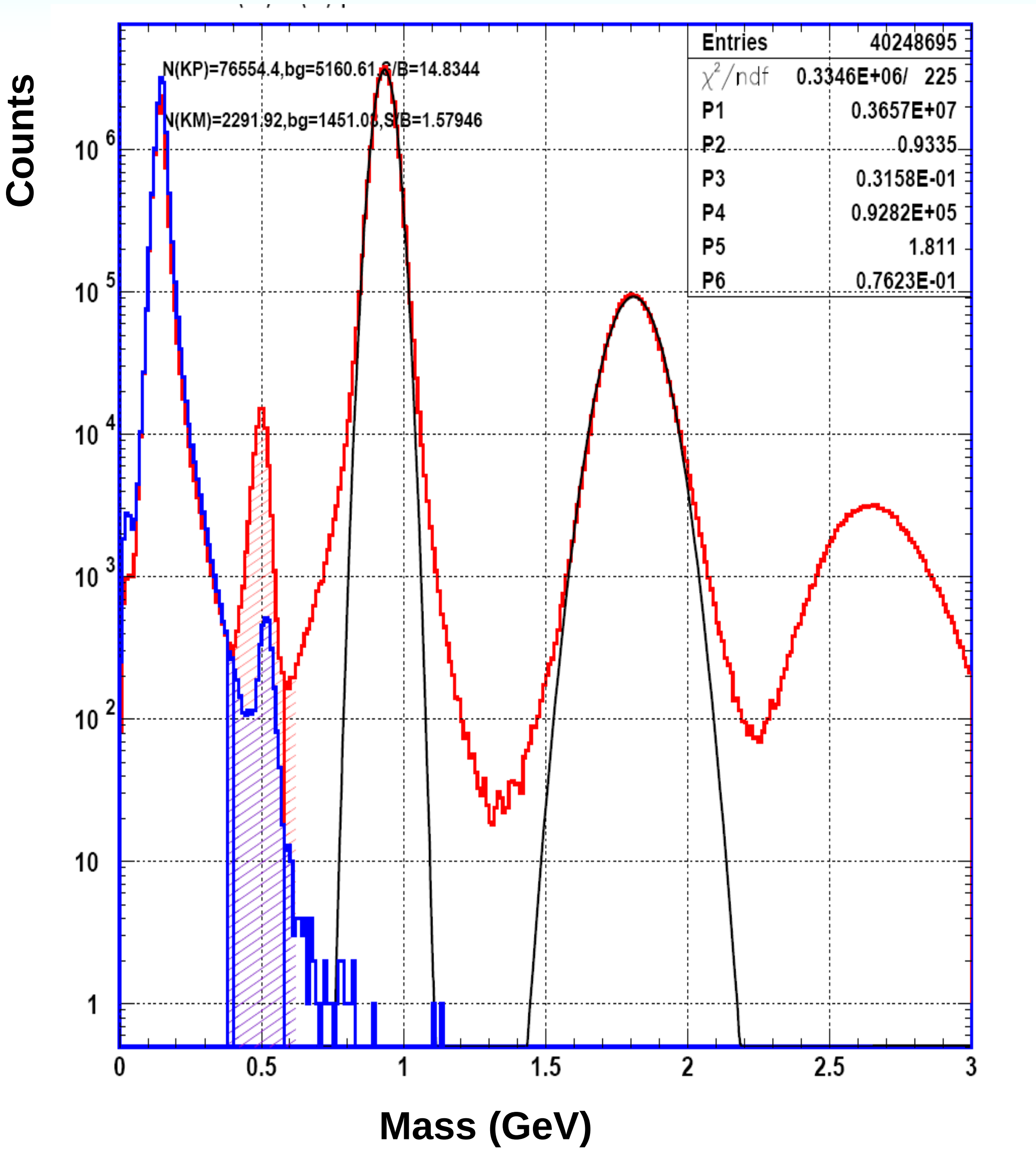
Time resolution from fast pion tracks (p_{lab}>0.5GeV/c)



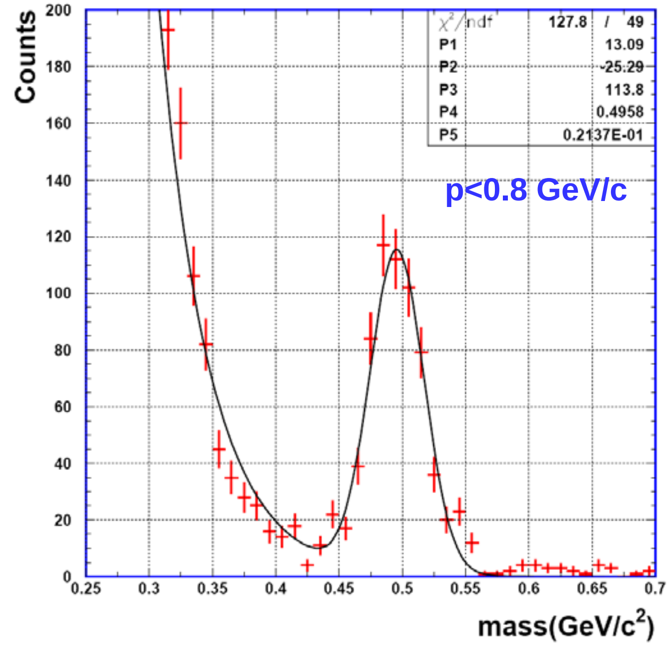
$\Delta t = t_{meas} - t_{exp}$ (ns)

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

PID with FOPI III



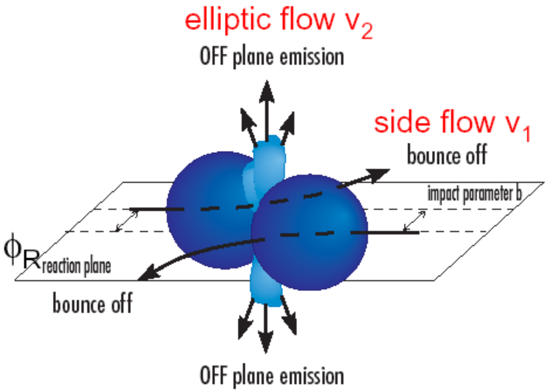
K⁻ - PID: S/B > 10



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

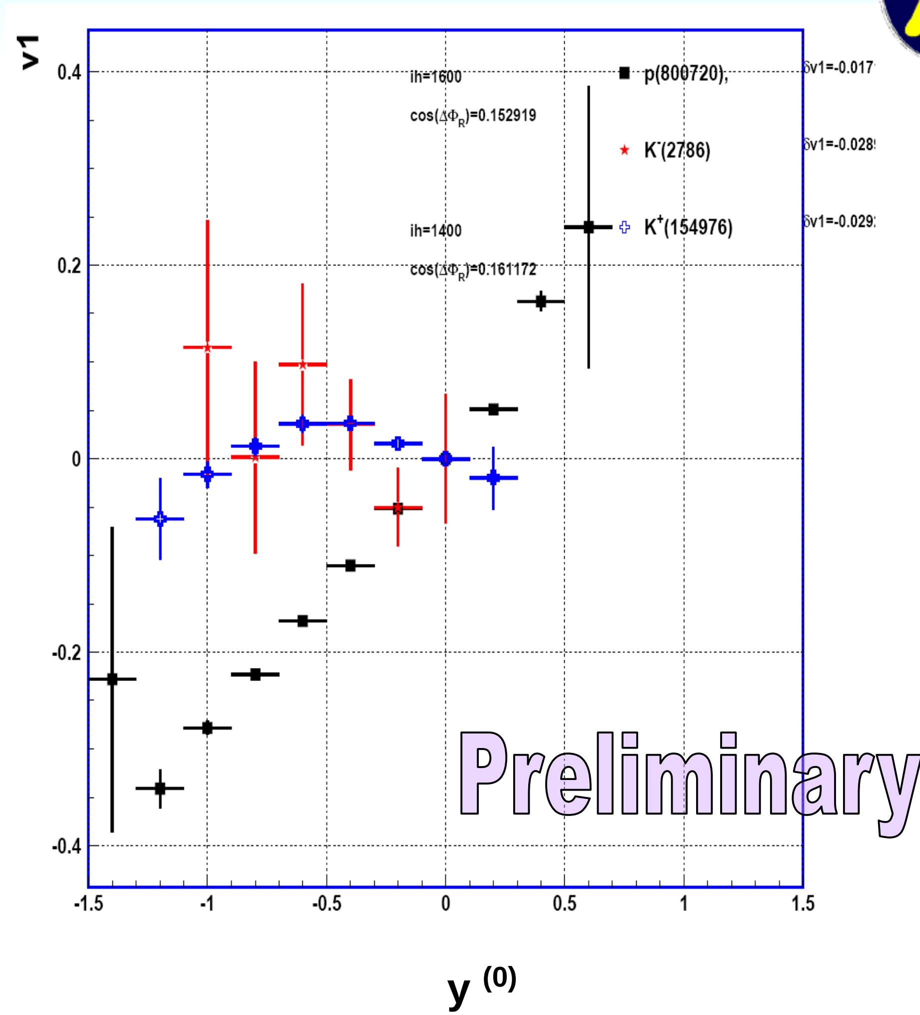
Extension of Phase-space with TOF - PID

Kaon – flow measurements

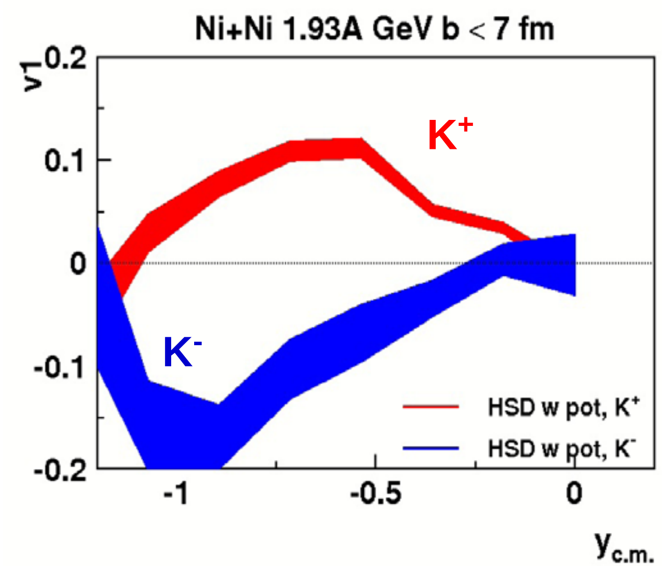


directed flow:

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



Theoretical expectation (HSD)

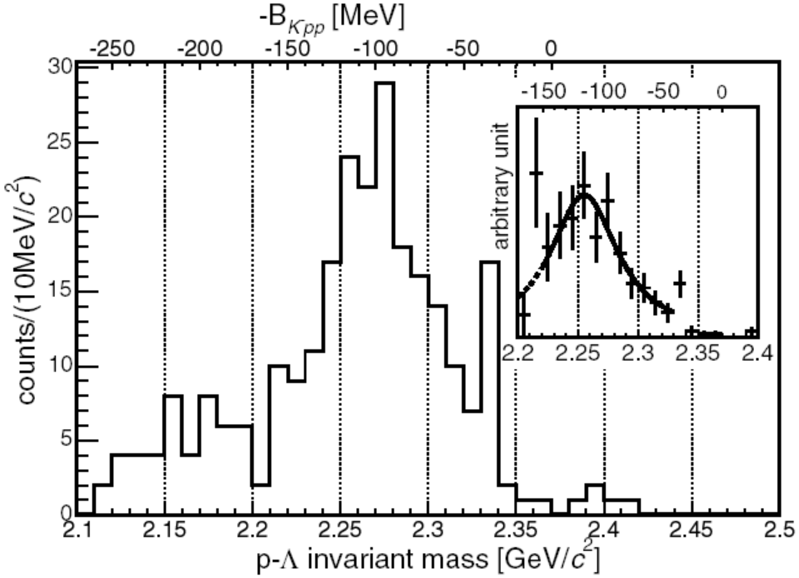


For K^- no consistent description yet by transport models.
HSD – E. Bratkovskaya et al. (Frankfurt, Giessen)
IQMD – C. Hartnack et al. (Nantes)

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

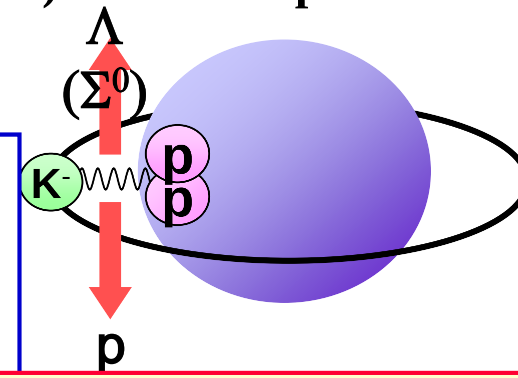
FINUDA @ DaΦne

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



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

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



Production probability:

P·BR = 0.1% per stopped K^-

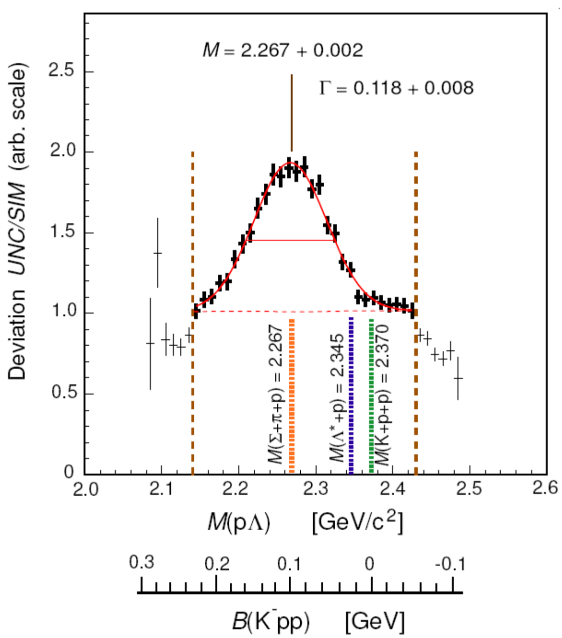
Peak parameter:

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

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

Controversial interpretation: 2N absorption + rescattering

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



Reanalysis of old DISTO data:

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

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

Production probability:

$X / \Lambda = 0.1$

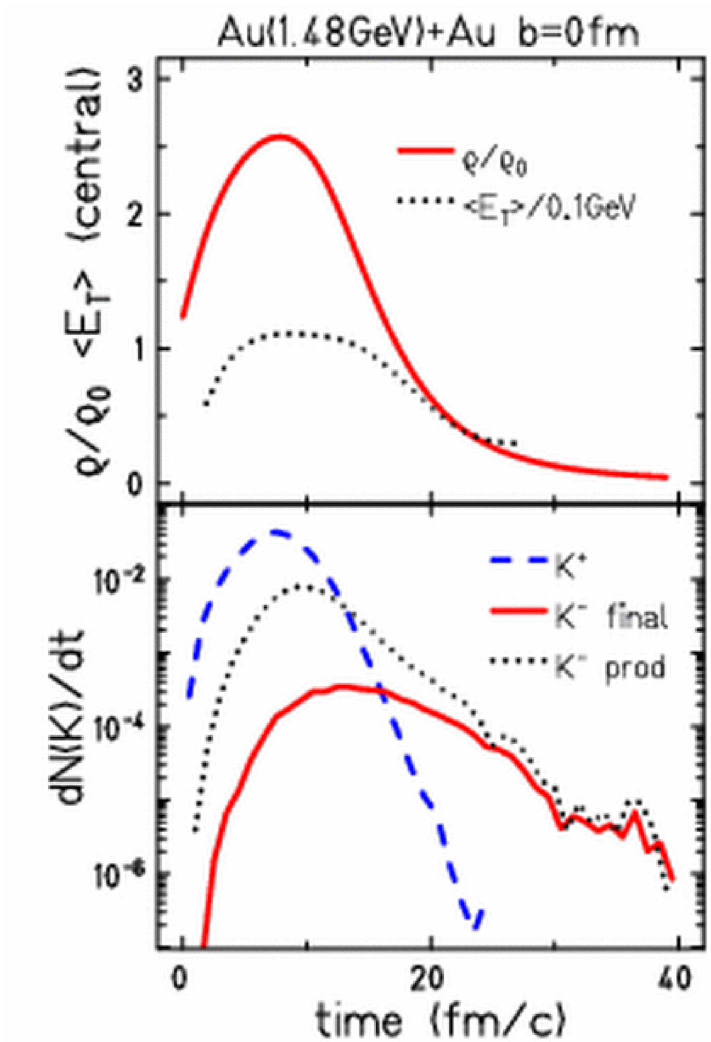
Peak parameter:

$$M = 2.265 \pm 0.002\ \text{GeV}$$

$$\Gamma = 118 \pm 0.008\ \text{MeV}$$

Antikaon Cluster Production in HI collisions

IQMD, C.Hartnack, Nantes



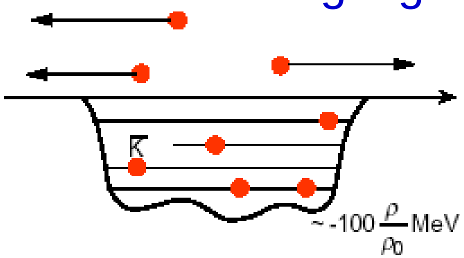
Central density in HI collisions from transport model calculations:

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

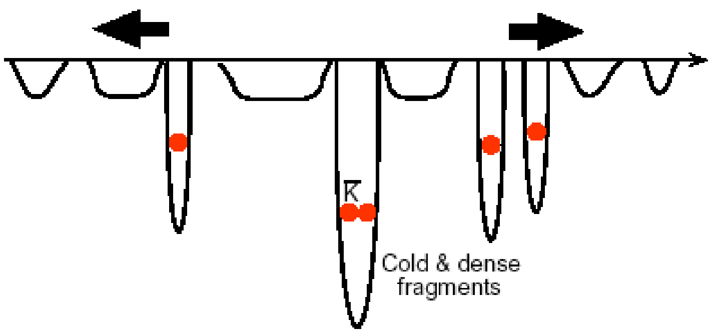
Possible mechanism for cluster formation:

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

1) Kaon production during high density phase

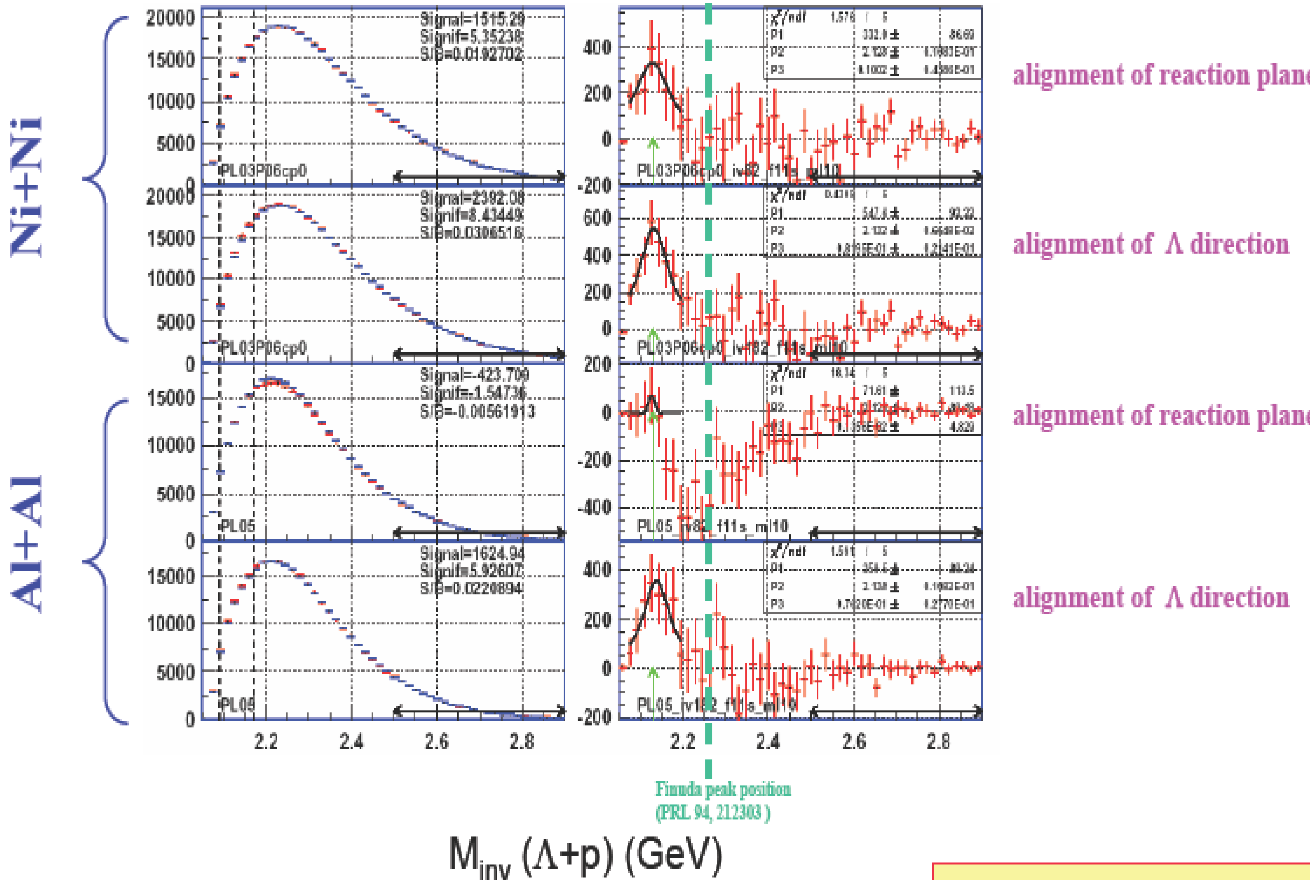


2) capture of K^- in deep trapping centers



Status 2006 (Paul Kienle Symposium, Vienna)

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



Literature:

Strange Dibaryon H_1^+, M=2.13 GeV, Γ=17 MeV
C.Pigot et al. (Rome-Saclay-Vanderbilt Collaboration), NPB 249 (1985) 172
Λp resonance in $K^-D \rightarrow \pi^- p \Lambda$ at rest,
M_1=2.128 GeV, Γ_1=7 MeV and M_2=2.138 GeV, Γ_2= 9.1 MeV
Tai Ho Tan, PRL 23, 101 (1969)

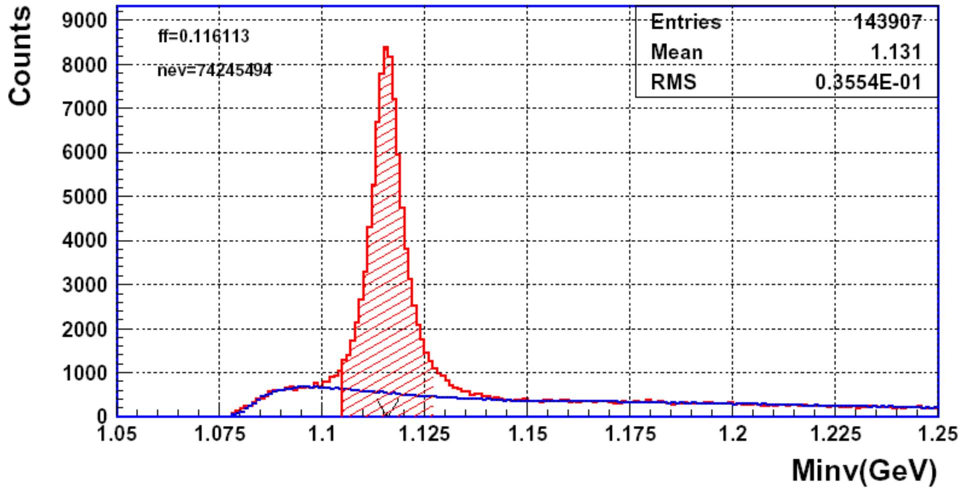
Peak position: 2.13 ± 0.02 GeV
Reflection of other resonances?
Work in progress …

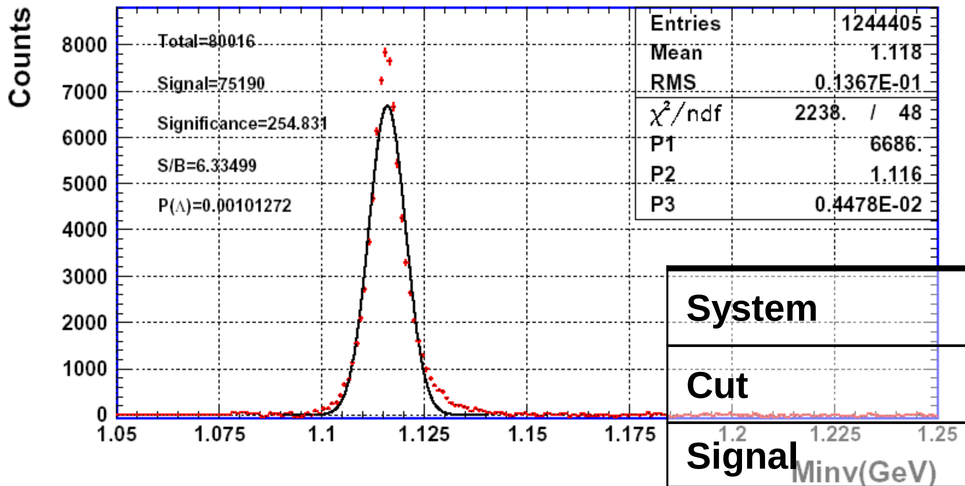
24/27

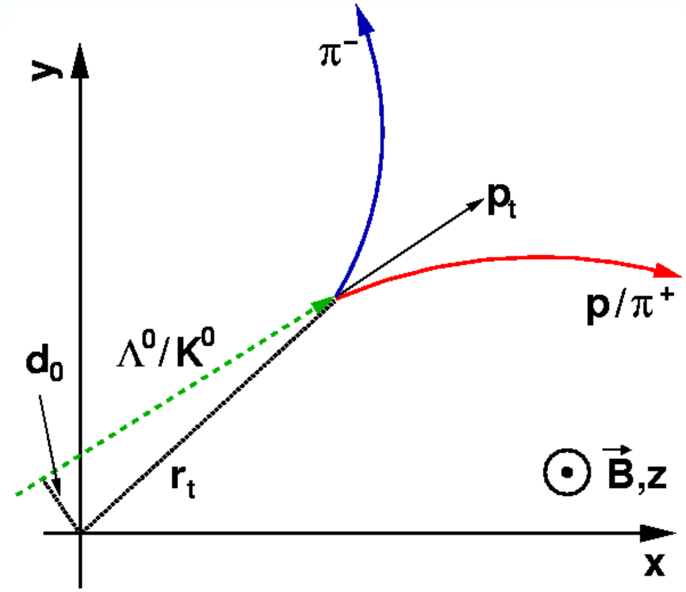
N.Herrmann, Uni-HD

Λ – reconstruction

Ni+Ni @ 1.93 AGeV (2003)







Signal-over-background depends on selection cuts

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

Reconstruction of short lived resonances in HI collisions

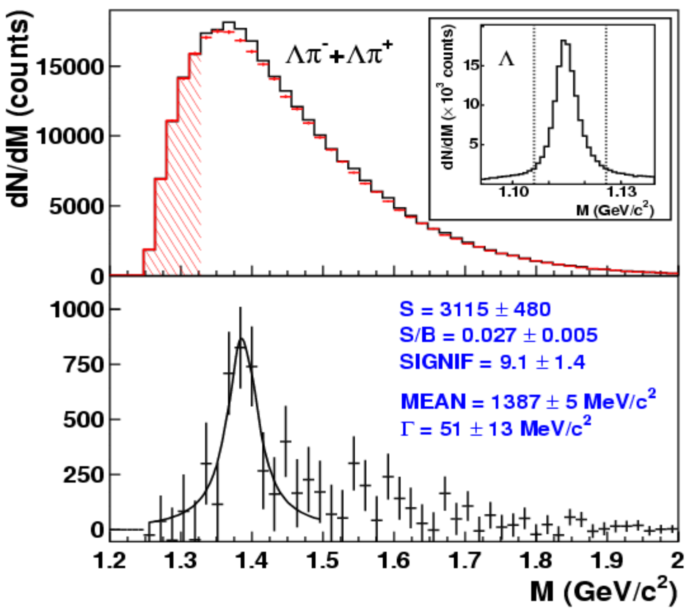
Σ^*(1385) subthreshold production,
X. Lopez et al. (FOPI), PRC 76, 052203(R) (2007)

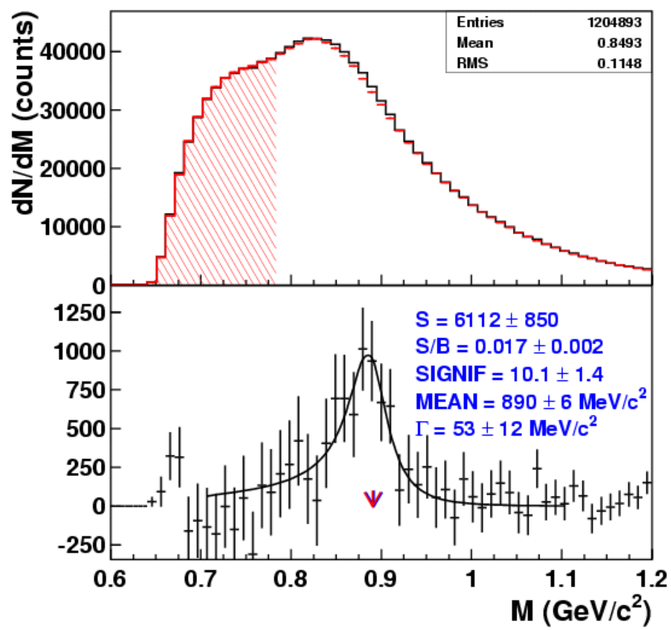
$\Sigma^* \rightarrow \Lambda + \pi \quad (88 \pm 2\%)$
$\quad \rightarrow p + \pi^- + \pi$
$\Gamma = 39.4$ MeV
$c\tau = 5$ fm
E^{thr}_{NN}=2.33 GeV

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

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

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





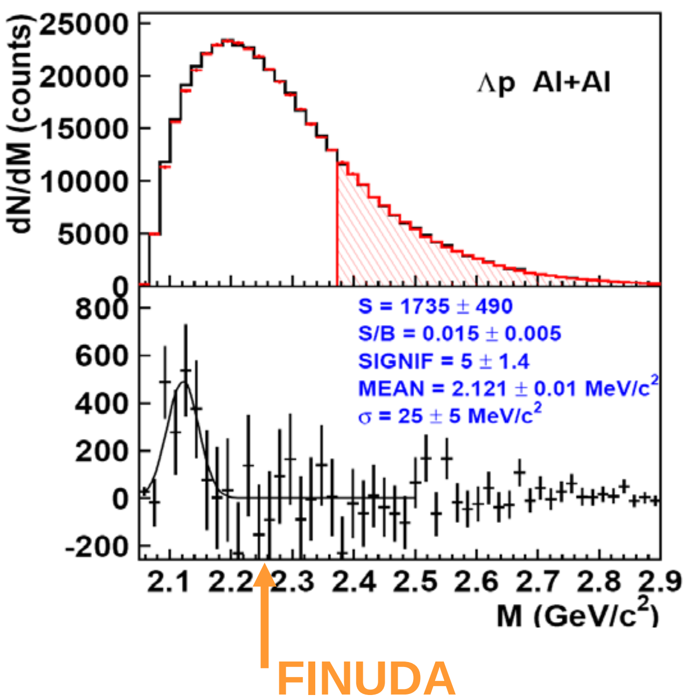
$$P_{det} \approx 10^{-5}$$

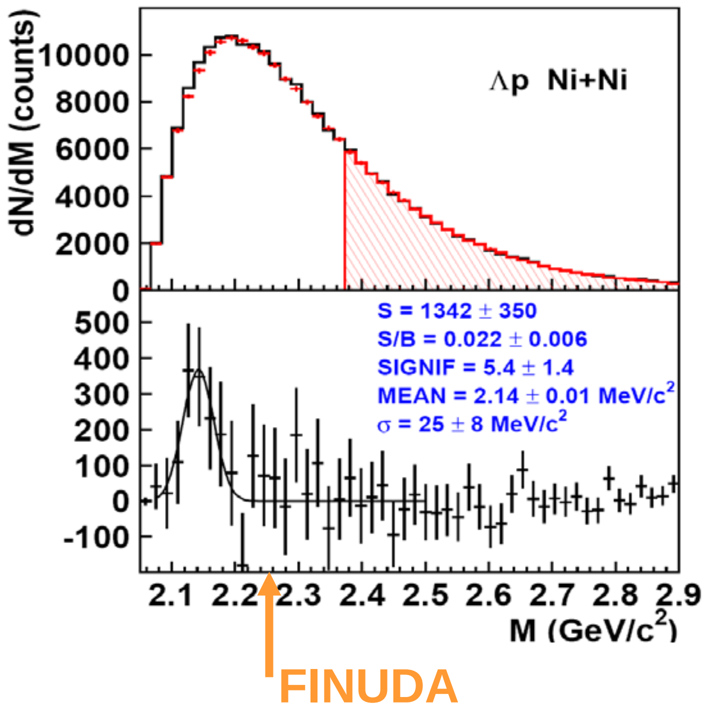
FOPIs reconstruction method and background construction by event mixing works for wide resonances.

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

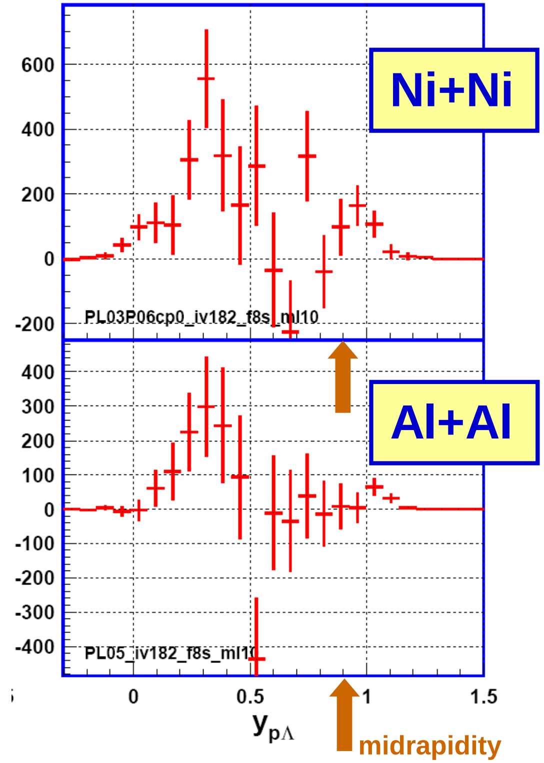
Search for ppK⁻ (2003/2005 data)

Λp – invariant mass



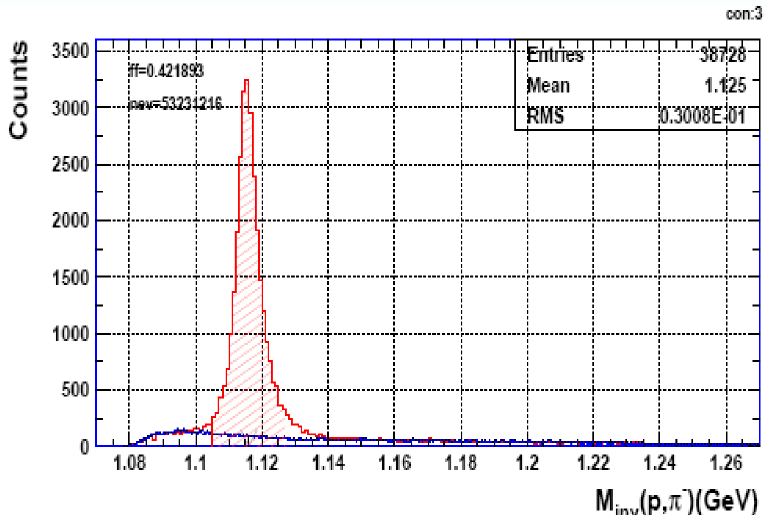


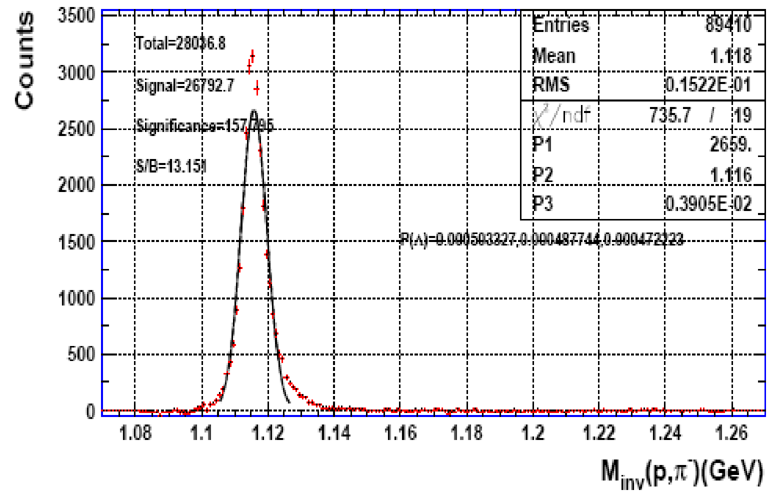
Rapidity distribution



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

New data S325/S325e (2007/2008)

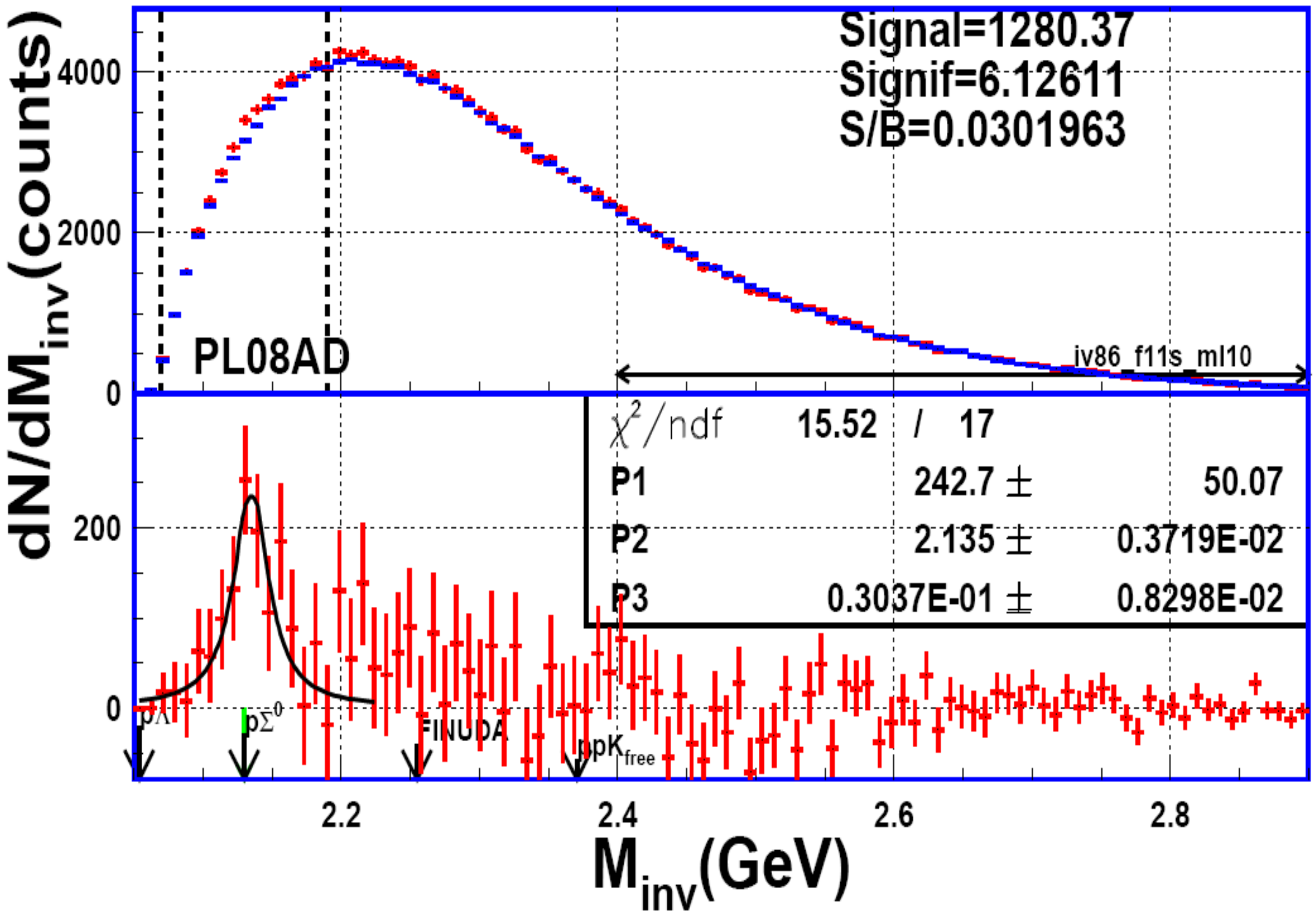




System	Ni+Ni (2003)		Al+Al(2005)		Ni+Ni (2007)		Ni+Ni(2008)	
Cut	"p"	"s"	"p"	"s"	"p"	"s"	"p"	"s"
Signal	136k	75k	207k	109k	20k	10k	54k	27k
S/B	1.6	6.0	2.7	8.9	2.4	8.7	3.4	12.2
Signal scaling	2.0	1	1.9	1	2.0	1	2.0	1
Background scaling	6.8	1	6.3	1	7.2	1	7.2	1

2007/2008 data triggered with less stringent centrality requirement

Λp – invariant mass (2008 data)



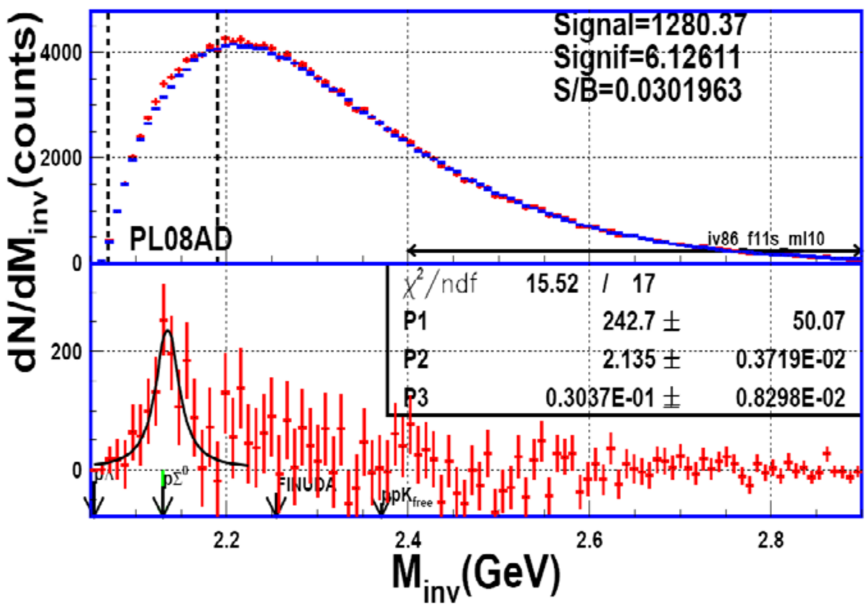
Peak present in 2008 data with same cuts as for 2003/2005 data,

S/B larger than in 2003 data,

Additional strength in the mass range 2.2 < M_{inv}<2.3 GeV possible.

Strange Dibaryon

Λp – invariant mass (2008 data)



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

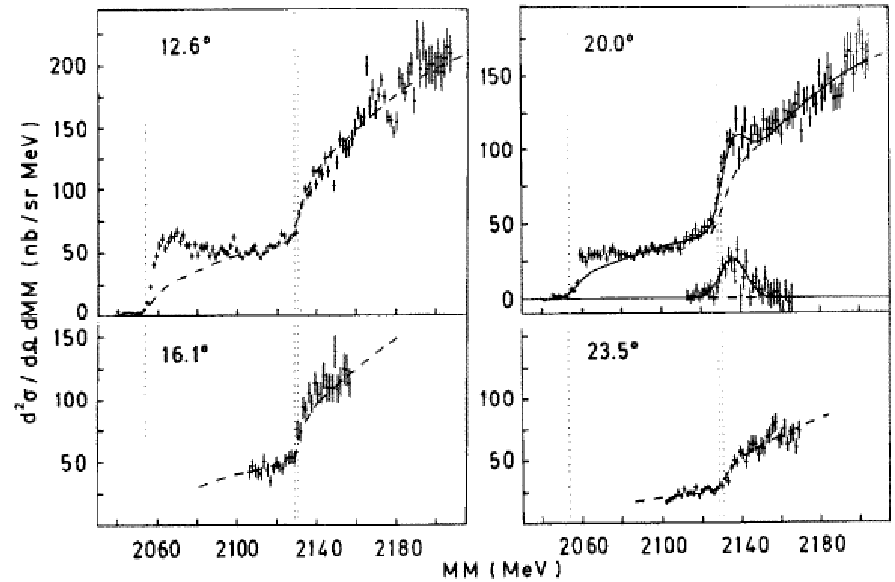


Fig. 6. Inclusive missing mass spectra for pp → K⁺X at 2.7 GeV incident energy. The kaon laboratory scattering angles are 12.6°, 16.1°, 20.0° and 23.5°. The bins are 1.5 MeV wide. The resolutions (FWHM) are approximately 3 MeV (12.6°), 4 MeV (16.1°), 3.5 MeV (20.0°) and 5 MeV (23.5°). The dashed lines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

Peak position consistent with p+p scattering data: M=2.135 ± 0.004GeV

Suggested interpretation: D_t (q4 x q2 structure)

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

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

Interpretation: ΣN – bound state H(2129)

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

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

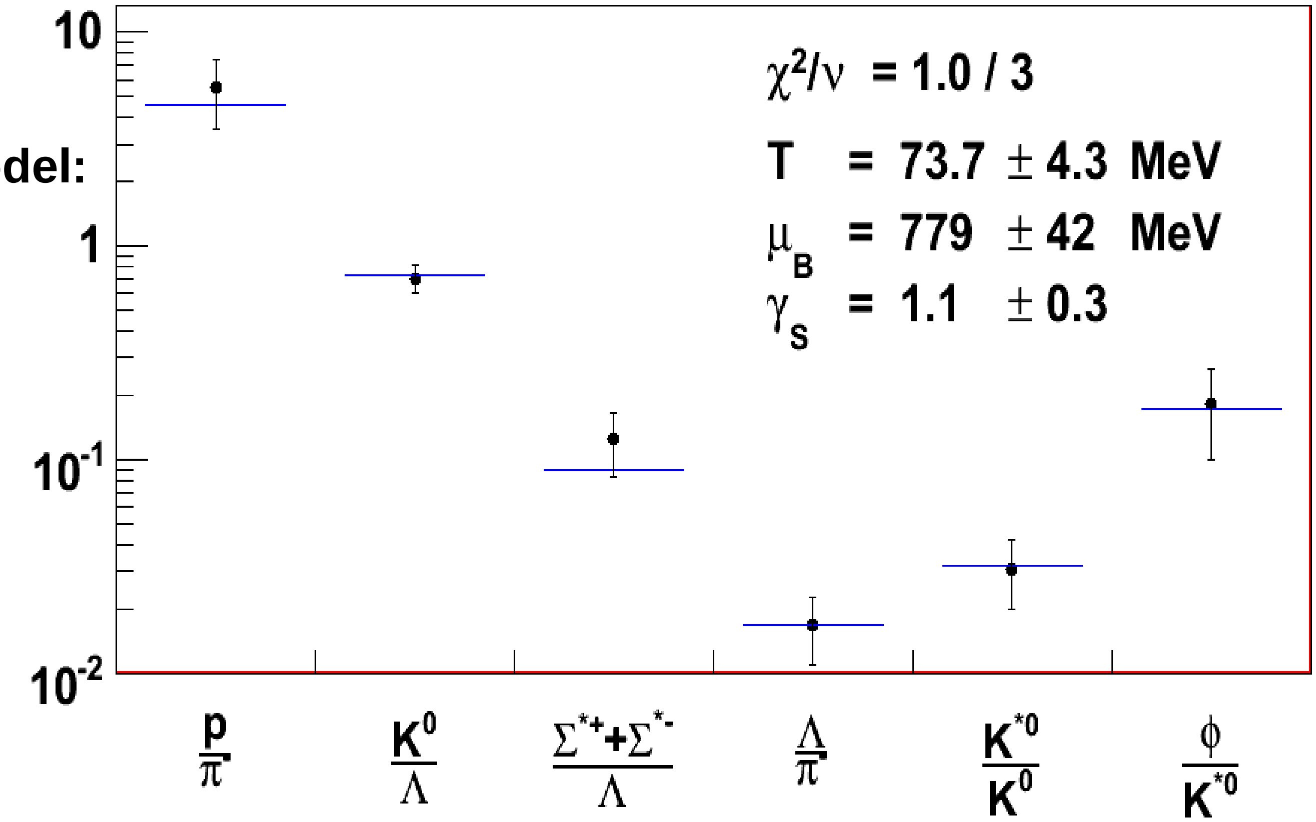
Particle yields at freeze-out

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

Preliminary

Comparison to statistical model:

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

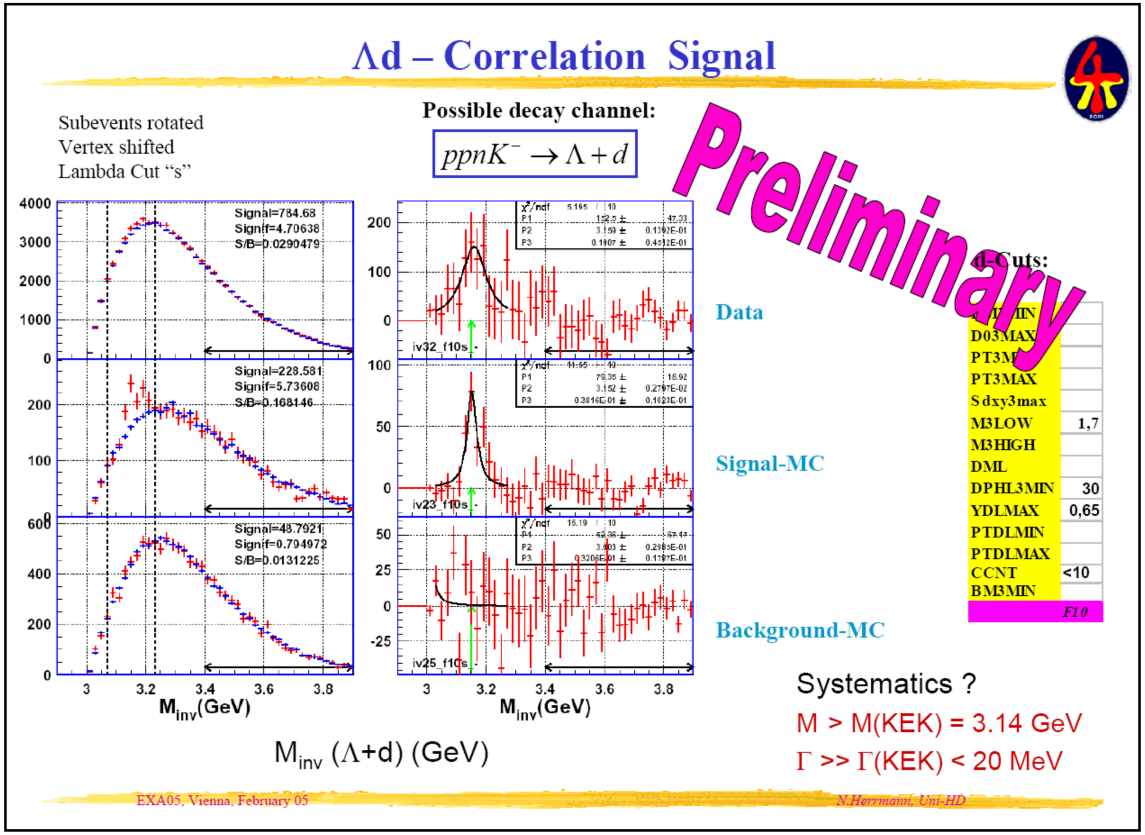


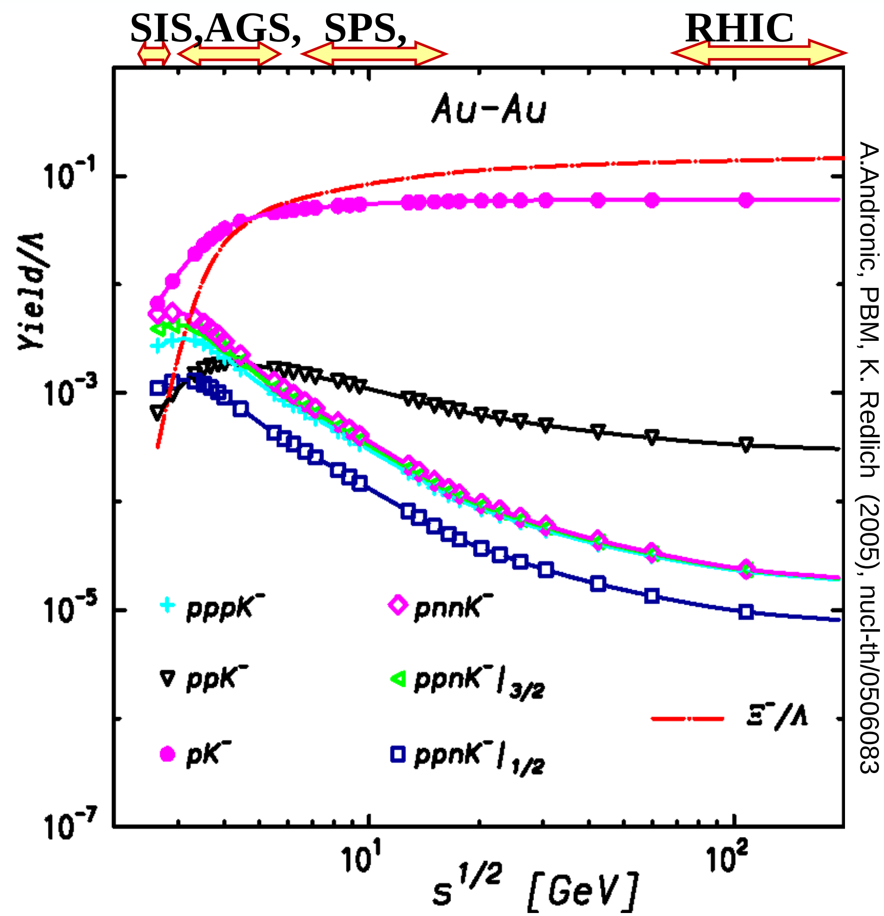
Calc.: K. Piasecki (THERMUS)

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

Strange Cluster search in HI - collisions

since 2003: ppnK⁻ ??



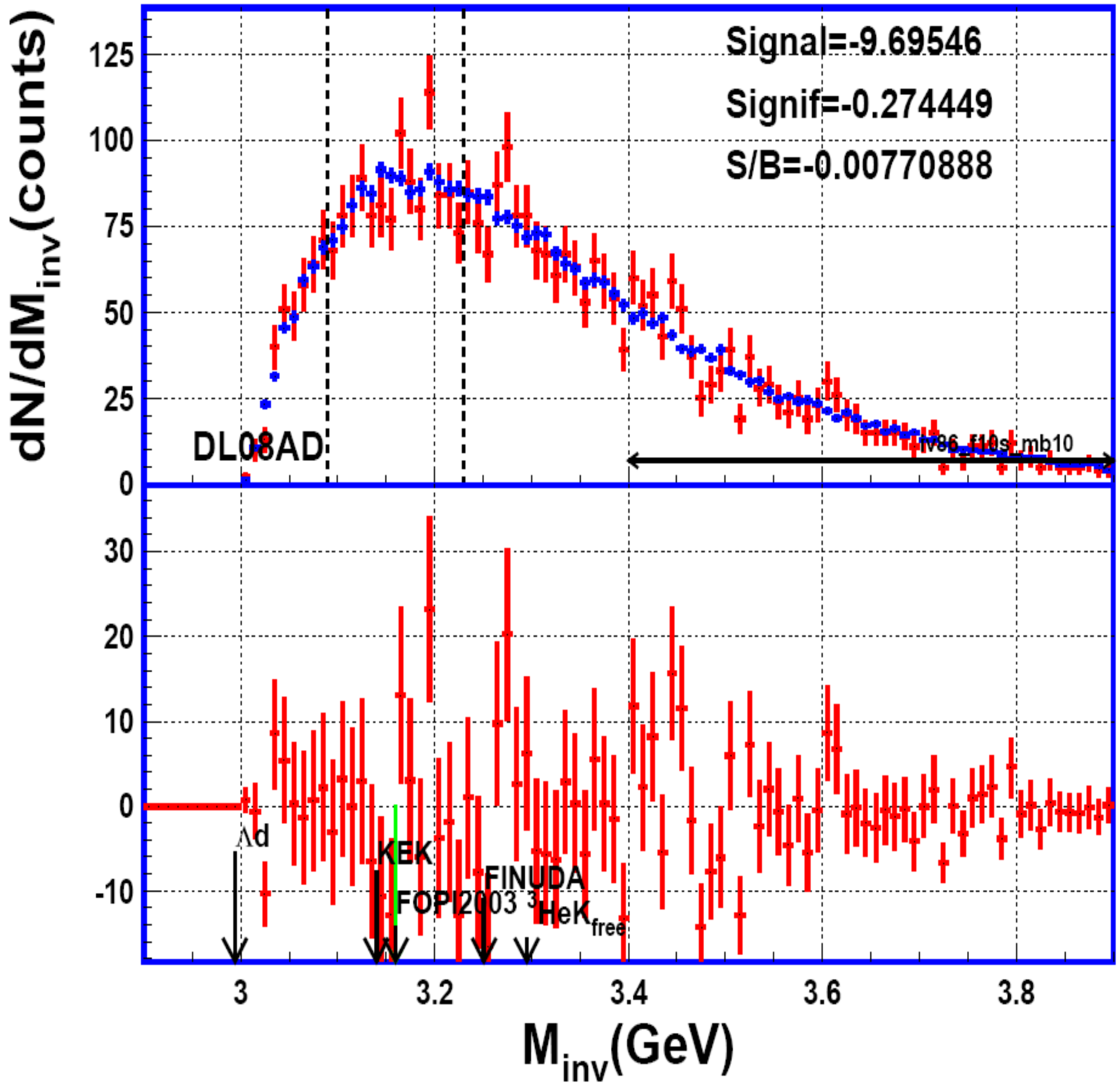


Yield of single strange clusters per Λ predicted to peak at lowest beam energies

Abundance larger than Ξ – baryon

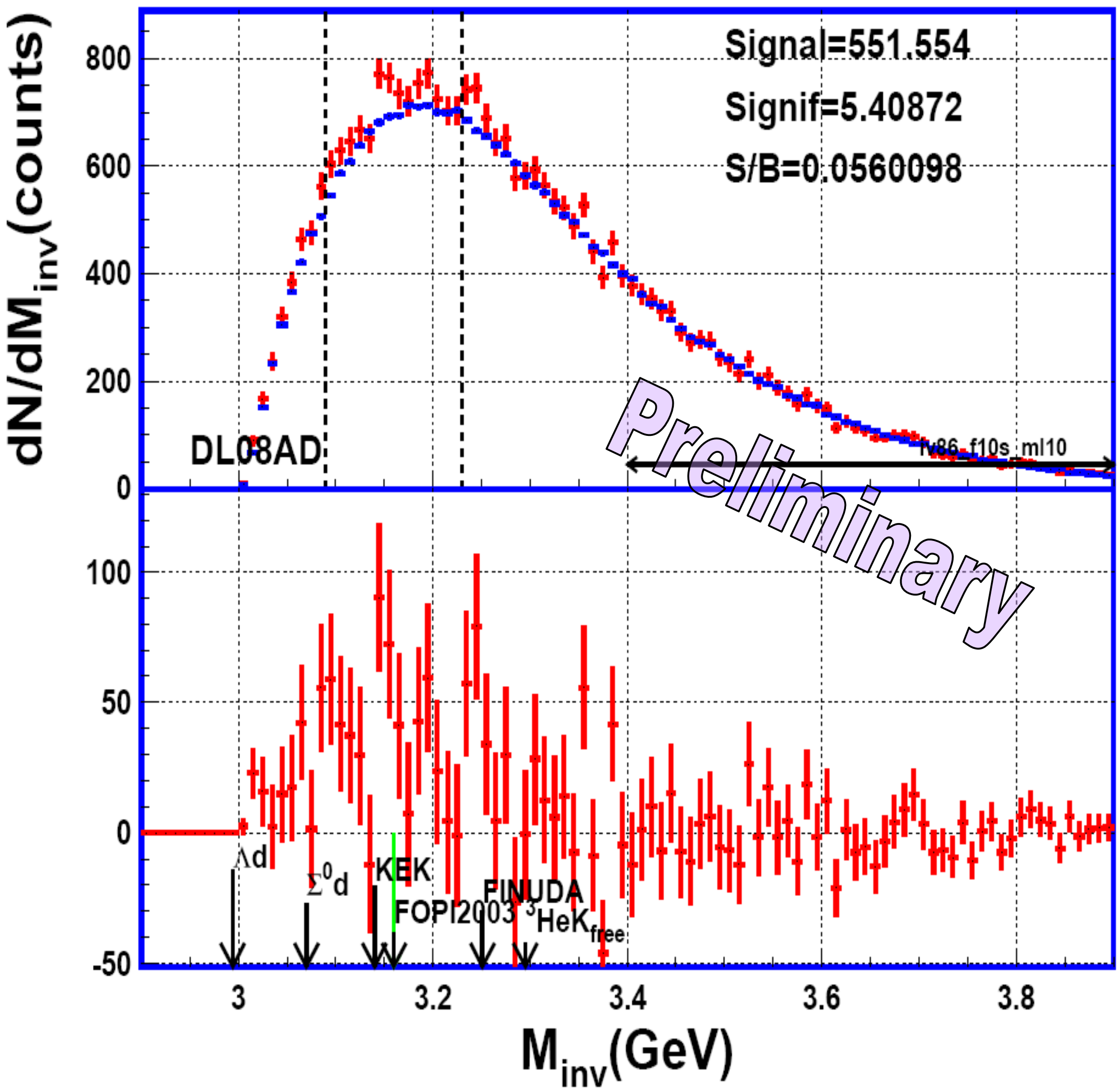
More data are needed …

Λd – correlation (2008 – data)



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

Λd – correlation (2008 – data)



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

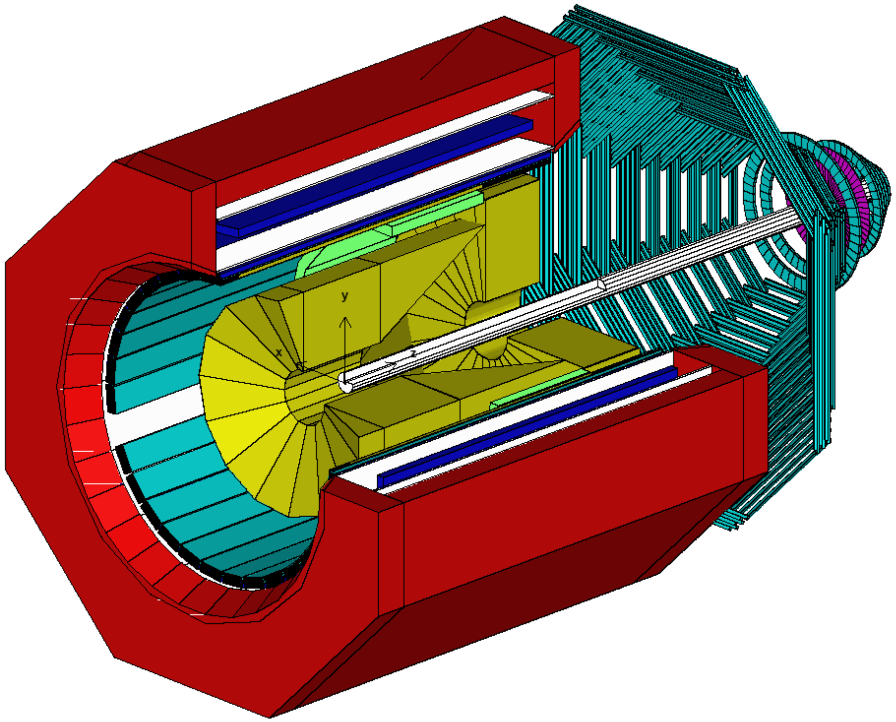
Excess statistically consistent with 2003 – data.

Statistics not enough to resolve narrow structures.

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

Significantly more data needed → new experiment

Strange baryon program with FOPI @ GSI



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

Objectives:

Strangeness in

HI collision

pion induced reactions

proton-proton collisions

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

Further talks:

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

Summary / Conclusion

Strangeness production close to threshold is still not understood.

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

New data from FOPI at SIS18

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

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

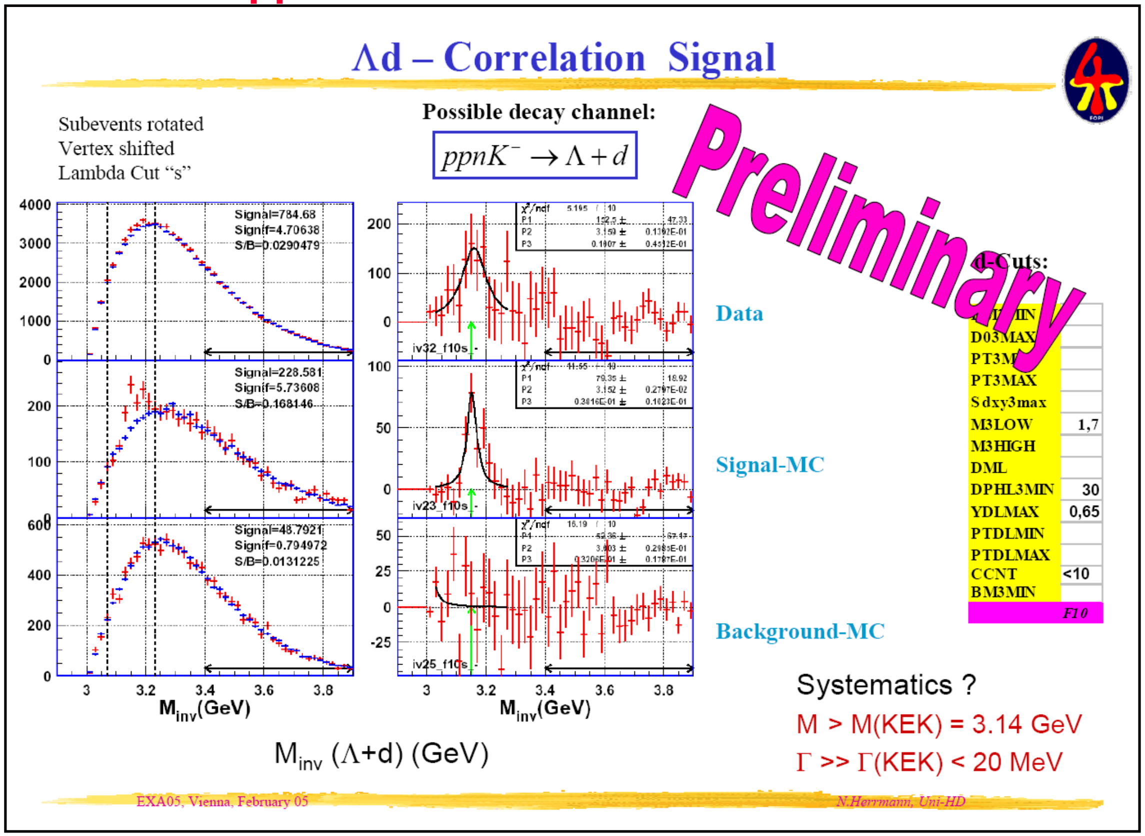
Serious theoretical effort necessary to interpret available and coming data.

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

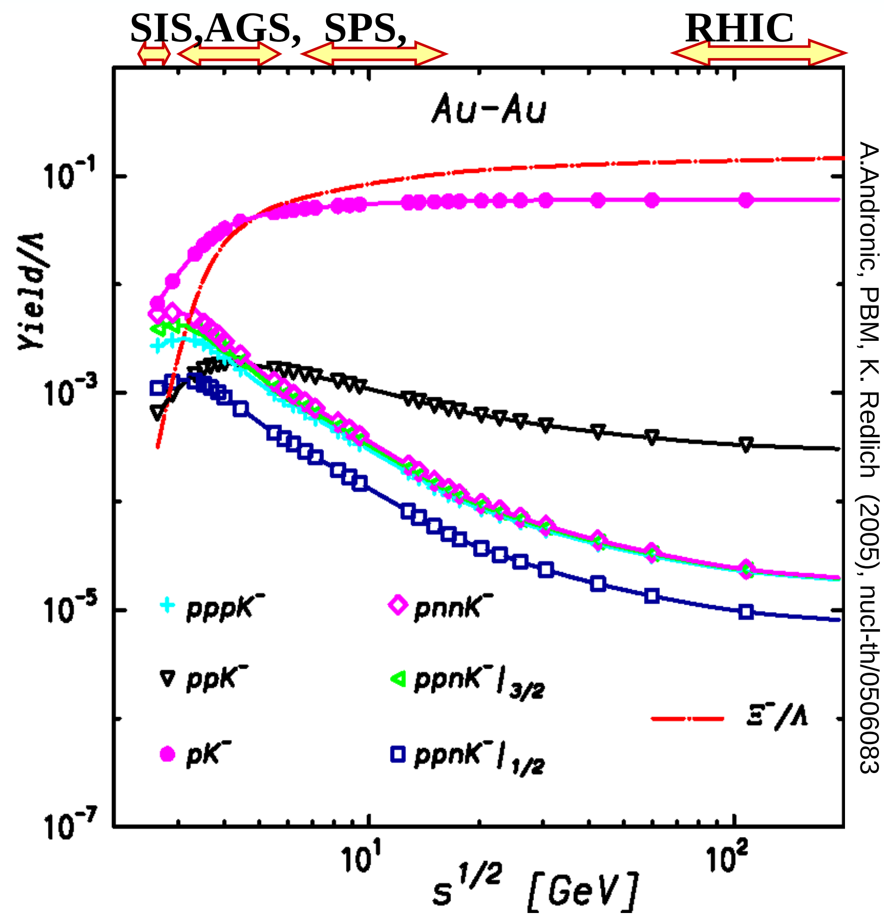
Strangeness physics from 2-10 AGeV must be continued/ revisited with high statistics!
=> FOPI(?)/HADES@SIS18/GSI => HADES/CBM @ SIS100/FAIR

Strange cluster search in HI - collisions

since 2003: $ppnK^-$??



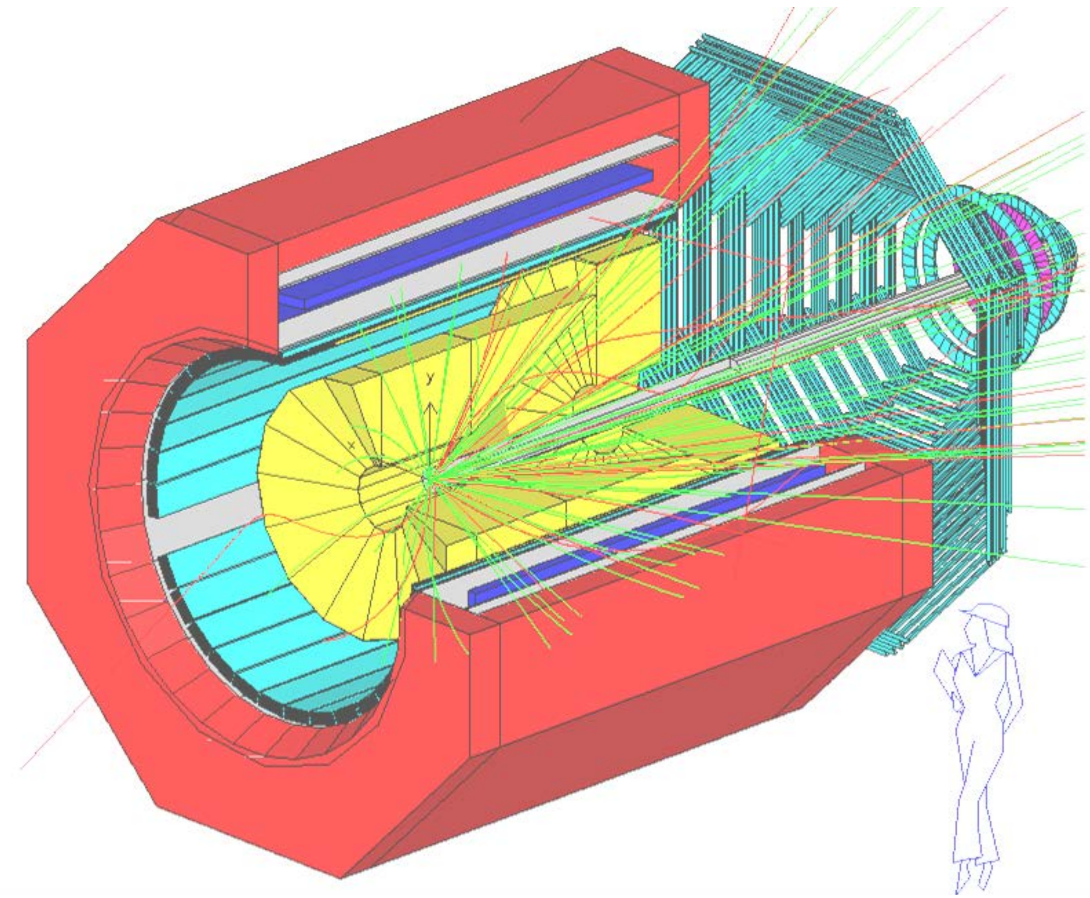
NH, proceedings EXA05, ÖAdW, 73 (2005), ISBN 3-7001-3616-1



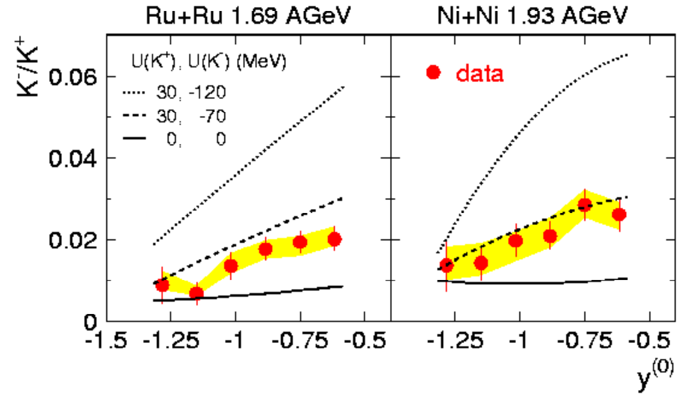
Rapidity constraint necessary for statistical significance,
Width much larger than early predictions,
Abundance larger than Ξ – baryon (consistent with Statistical Hadronisation Model).

More data are needed …

Status ~ 2002

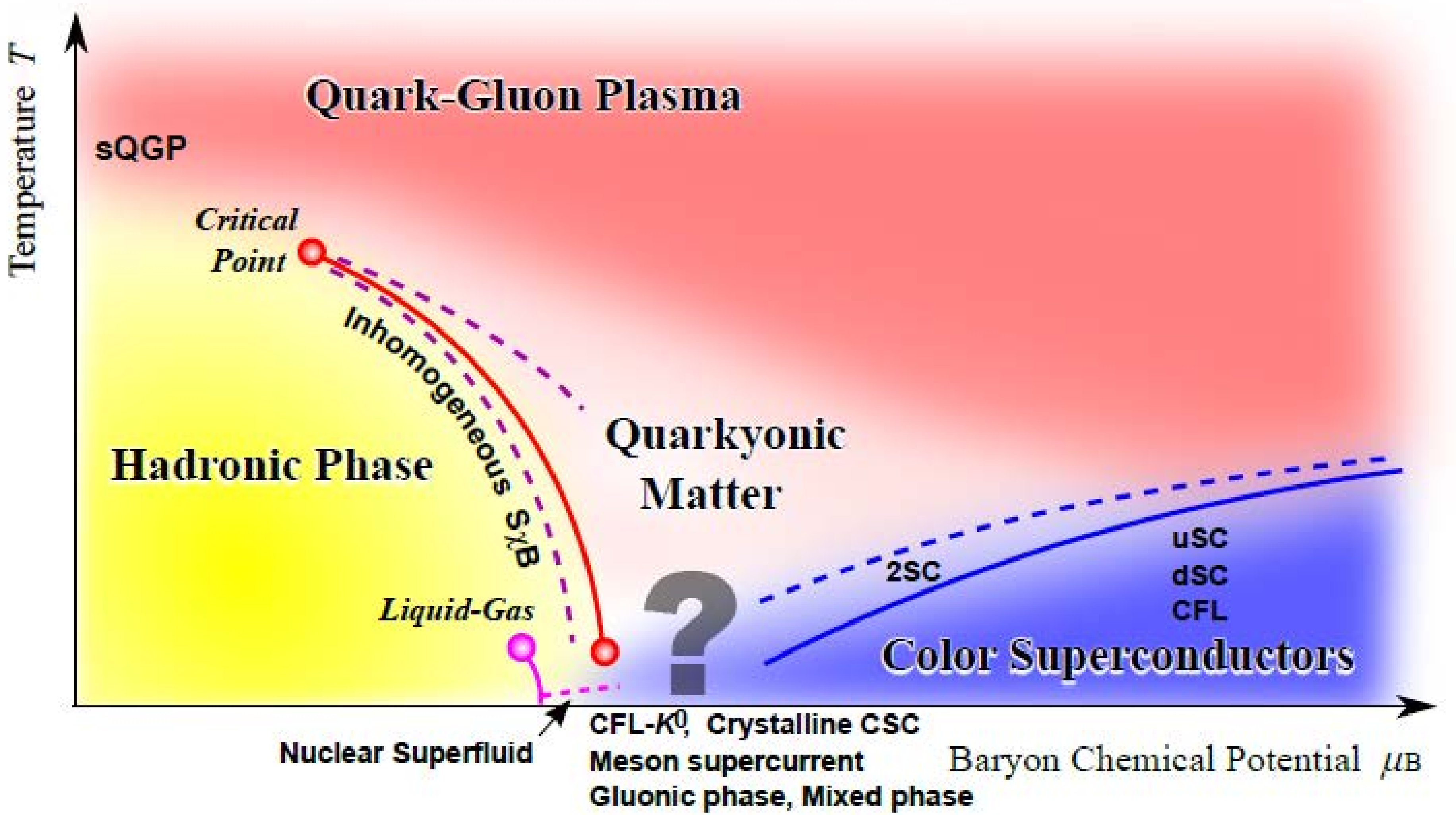


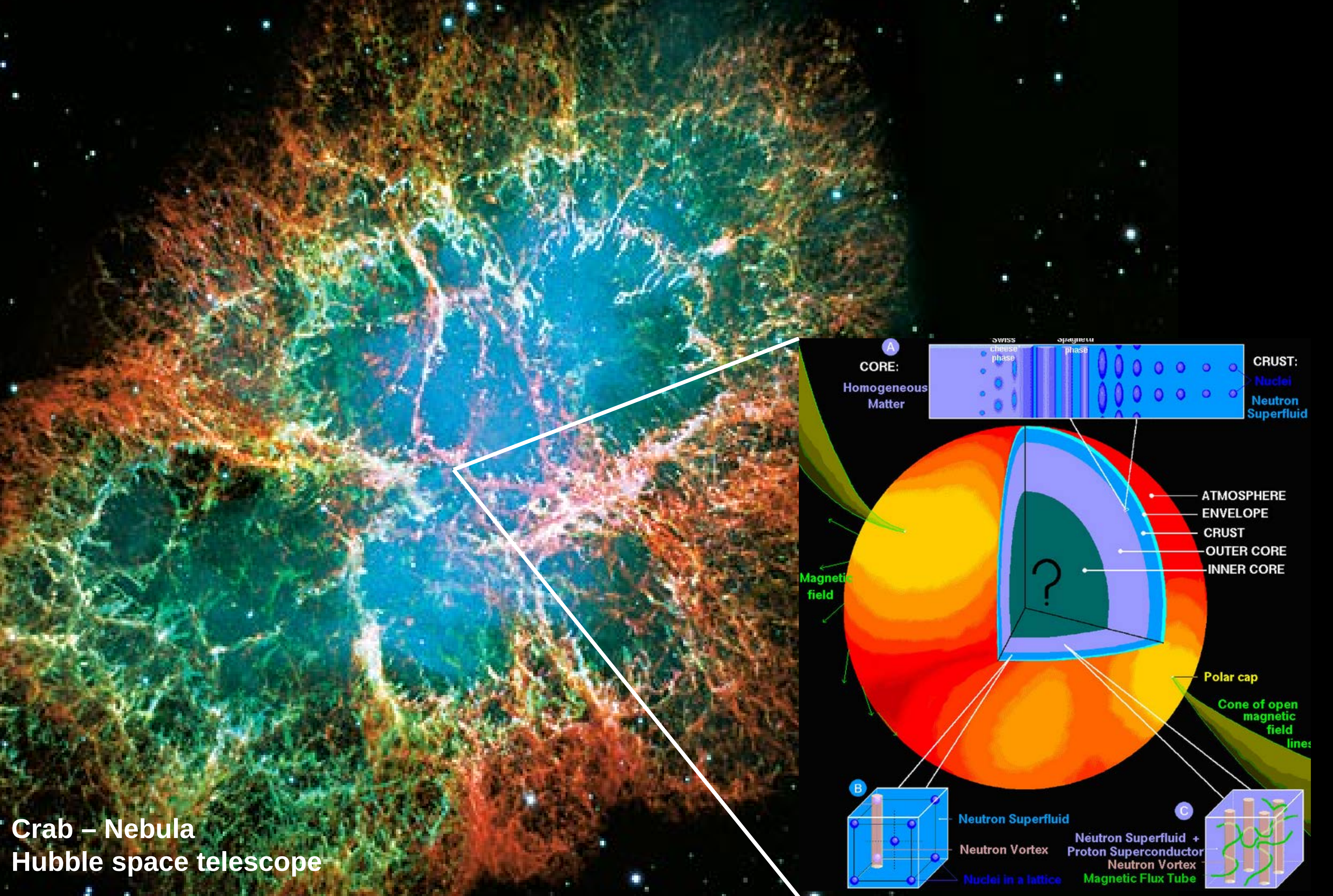
Evidence for attractive Kaon potential



Y.J. Kim, FOPI (GSI)

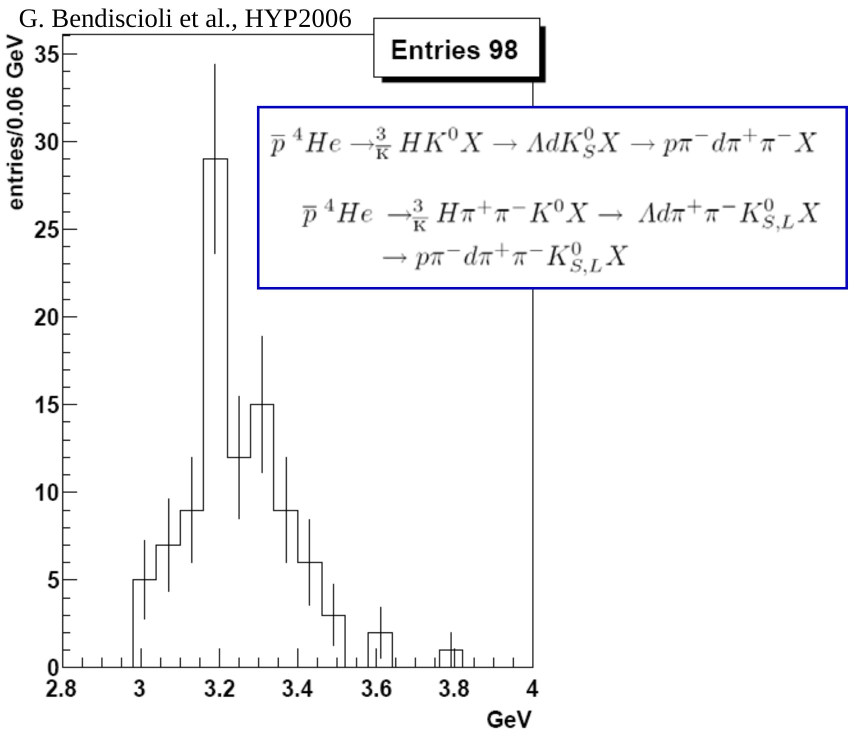
QCD – phase diagram

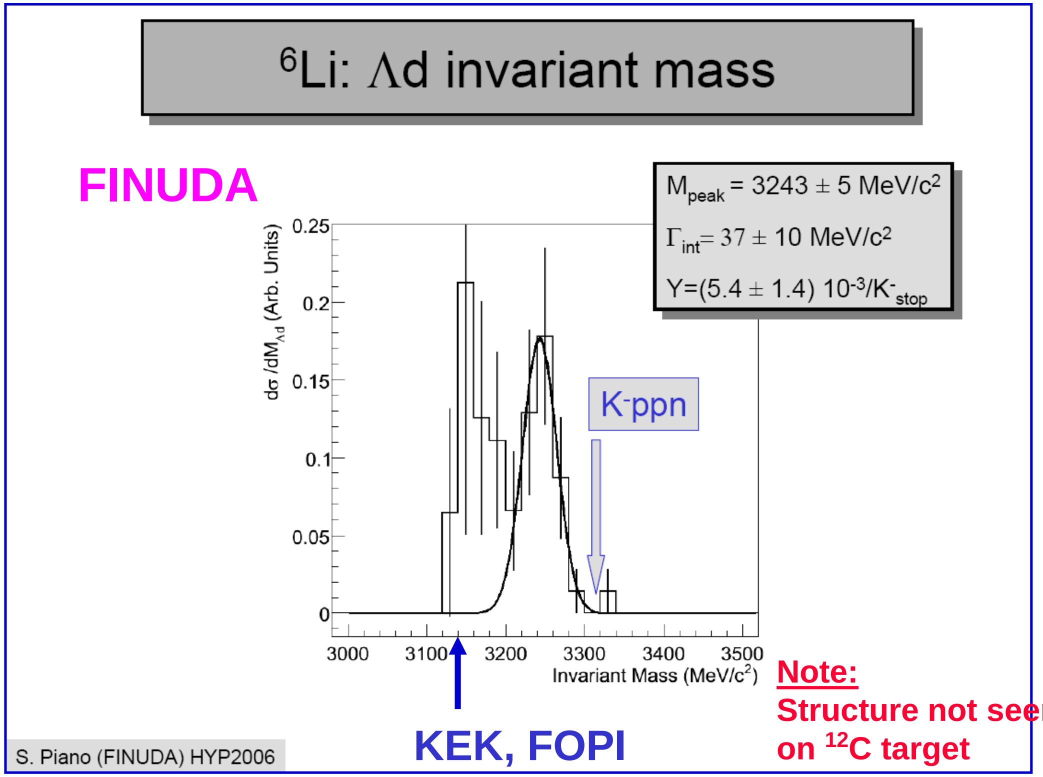



Crab – Nebula
Hubble space telescope
A
CORE:
Homogeneous Matter
CRUST:
Nuclei
Neutron Superfluid
ATMOSPHERE
ENVELOPE
CRUST
OUTER CORE
INNER CORE
?
Magnetic field
Polar cap
Cone of open magnetic field lines
B
Neutron Superfluid
Neutron Vortex
Nuclei in a lattice
C
Neutron Superfluid + Proton Superconductor
Neutron Vortex
Magnetic Flux Tube

Status of ppnK$^-$ $\rightarrow$ Λd - search

OBELIX





Note:
Structure not seen on ^{12}C target

		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