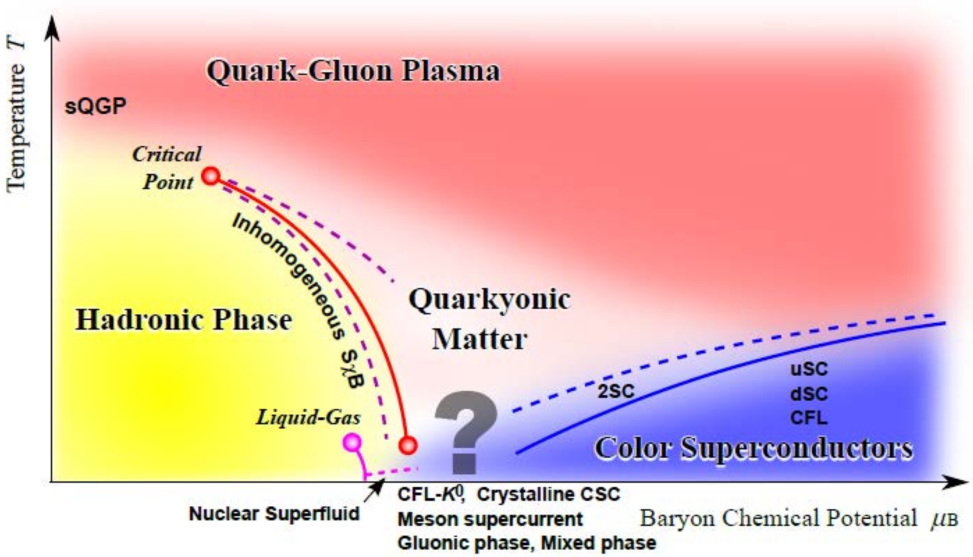
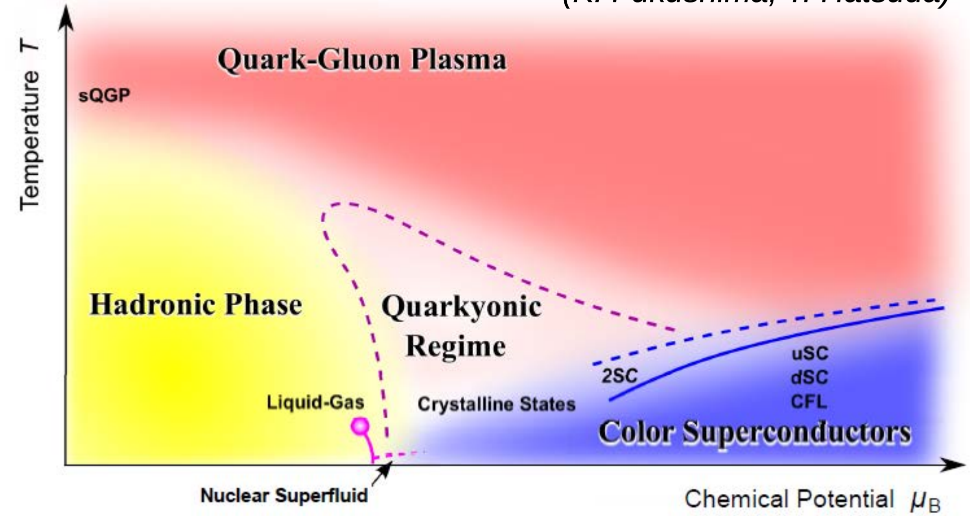
HI – physics at High Net-Baryon Density

EMMI workshop: Prospects and Challenges for Future Experiments in Heavy Ion Collisions



(K. Fukushima, T. Hatsuda)



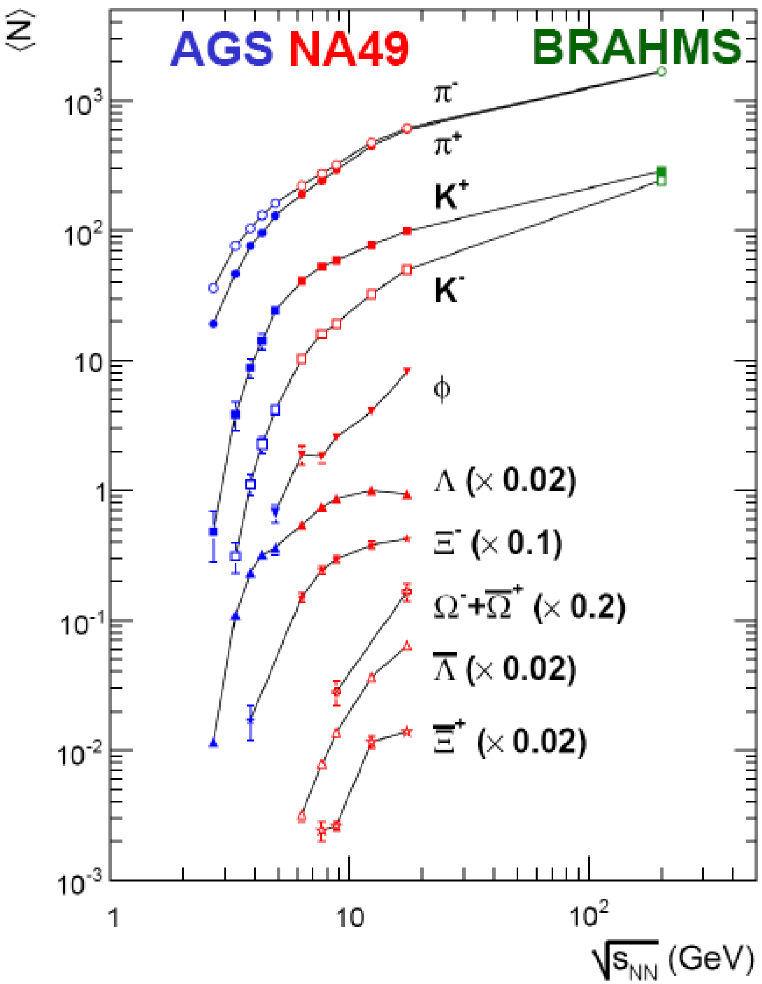
Outline:

Freeze-out data	
Equation – Of – State	(SIS18 / AGS)
In-medium modifications of hadrons	(SIS18 / AGS)
Dense matter observables at ‘low energies’	(SIS18 / SIS100)
Experimental strategy	(SIS18 – SIS 300)
Conclusion	

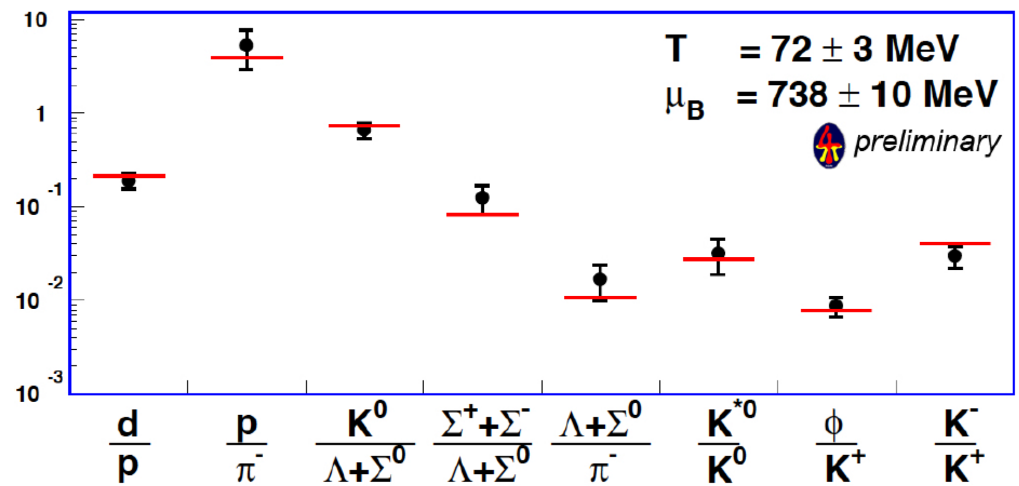
Excitation function of particle production

Central Au+Au collisions
4π yields

C.Blume, CBM symposium HZDR (2011)



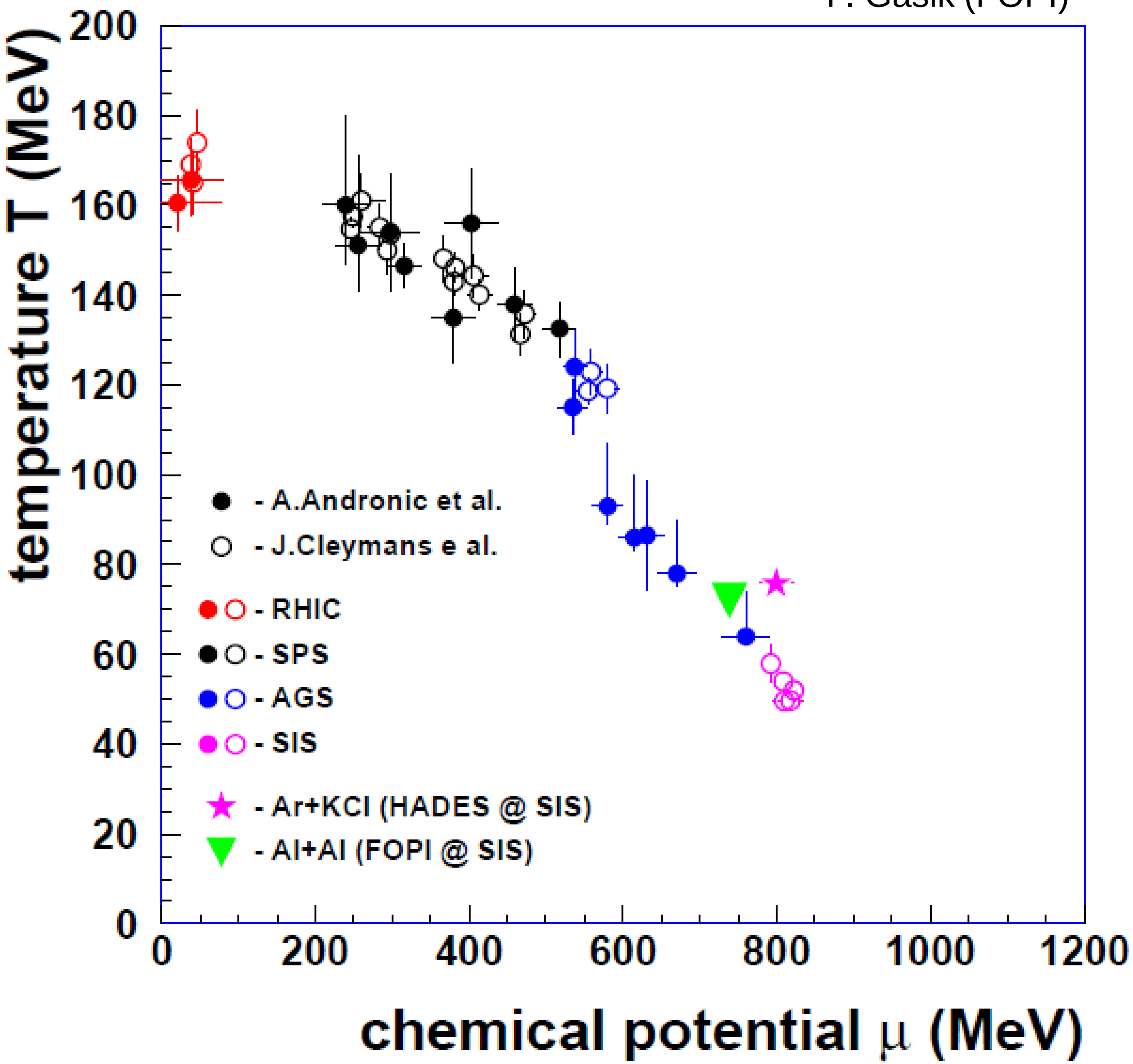
Low energies (SIS18): light systems only
Al + Al at 1.91 AGeV



Knowledge about multi-strange baryons at energies below 10 AGeV very limited.

Chemical Freeze-out data

P. Gasik (FOPI)



Errors include systematic errors (when given).

Data sources:

A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772 (2006) 167

J. Cleymans, H. Oeschler, K. Redlich, S. Wheaton, Phys. Rev. C73 (2006) 034905

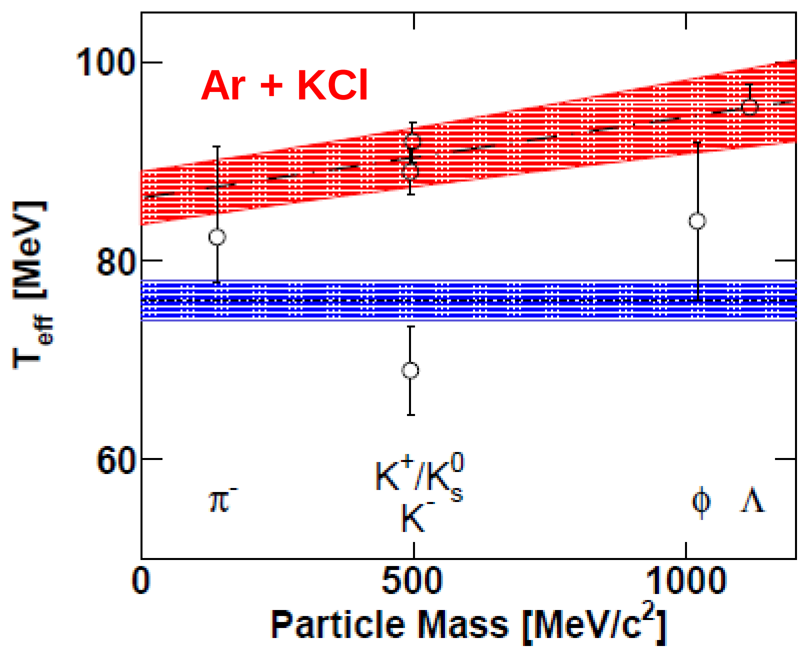
G. Agakishiev et al. (HADES), Eur. Phys.J. A47 (2011) 21

At lower energies canonical ensemble has to be used.

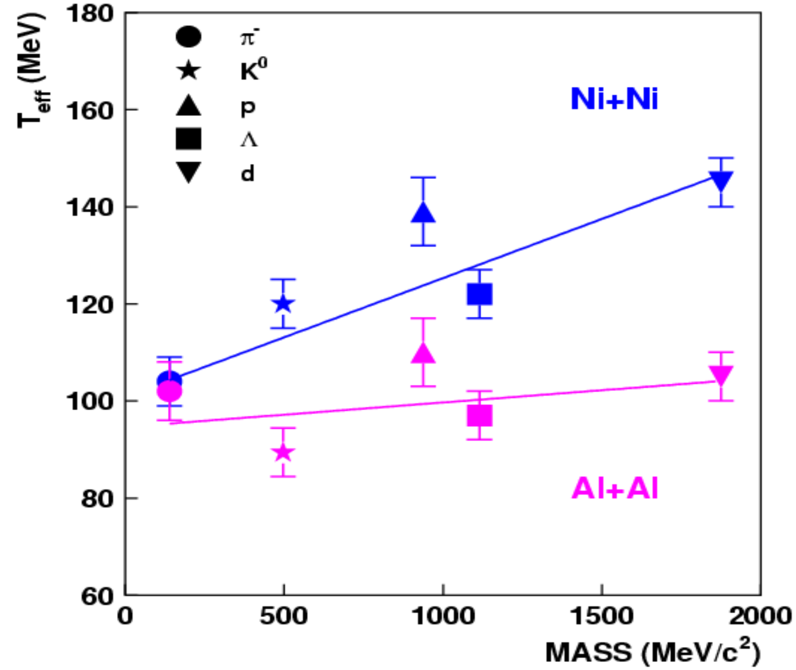
Equilibrium as signature for phase transition?

Kinetic freeze out

G. Agakishiev et al.(HADES),EPJ A47 (2011) 21



K. Piasecki et al.(FOPI), Act.Phys.Pol. B41 (2010) 405



T_{kin} > 90 MeV > T_{chem} ≈ 75 MeV

Ordering counter intuitive for equilibrated systems.

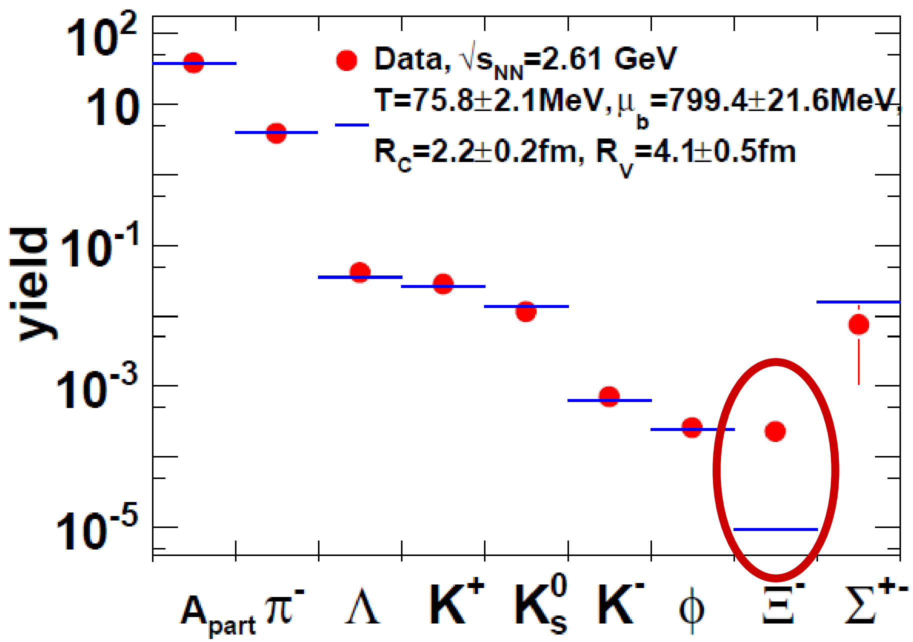
No thermal equilibrium? -> Stochastic particle production
(Hadronic Unruh radiation?)
-> Non – equilibrium off-shell scattering (?)

HADES: Sub-threshold Ξ^- production

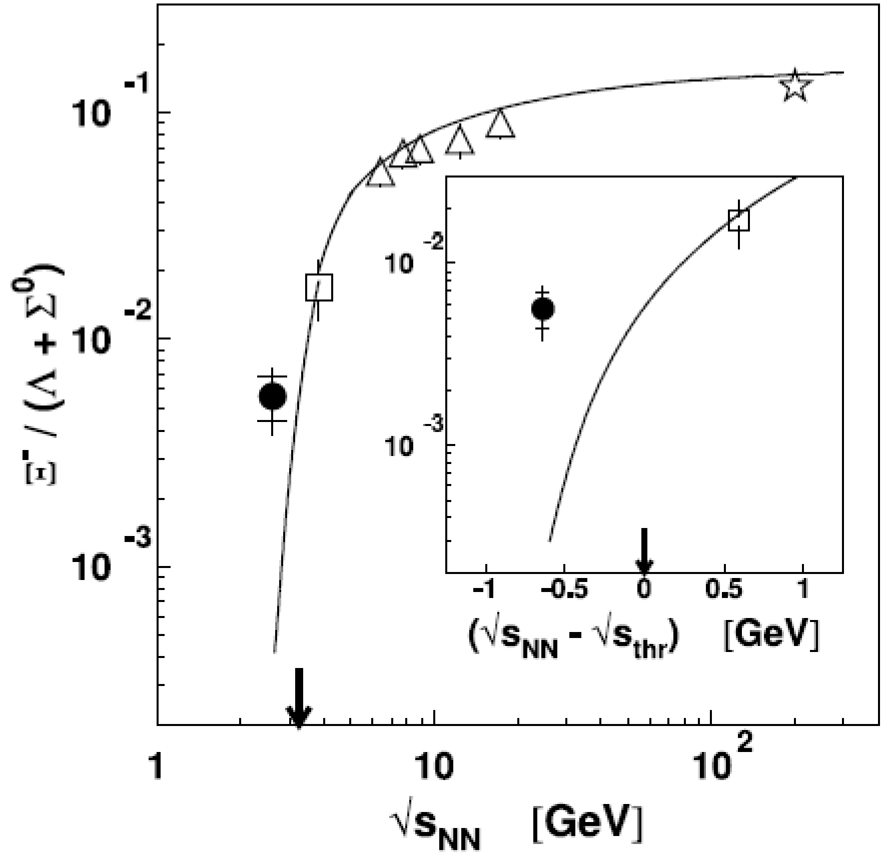
Ar+KCl reactions at 1.76A GeV

- Ξ^- yield by appr. factor 25 higher than thermal yield
- strangeness exchange reactions like

$\bar{K}Y \rightarrow \pi\Xi$ (Y=Λ,Σ) ?



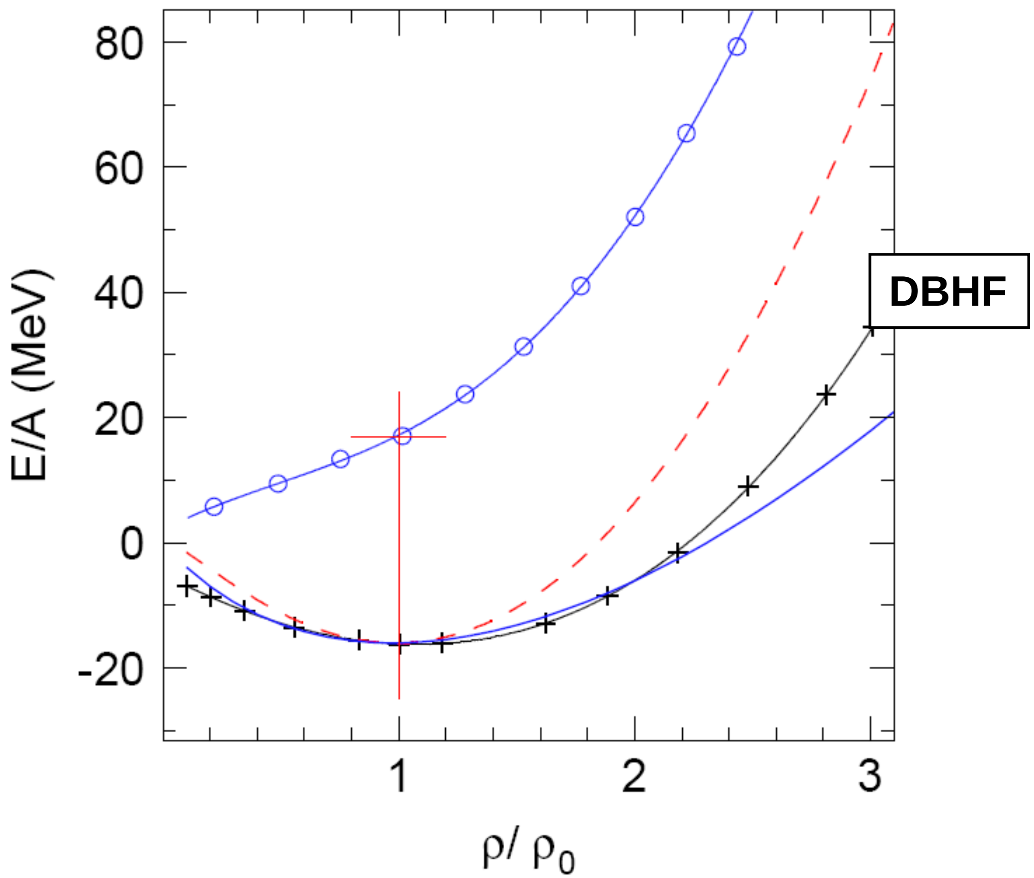
G. Agakishiev et al. (HADES), PRL103, 132301, (2009)



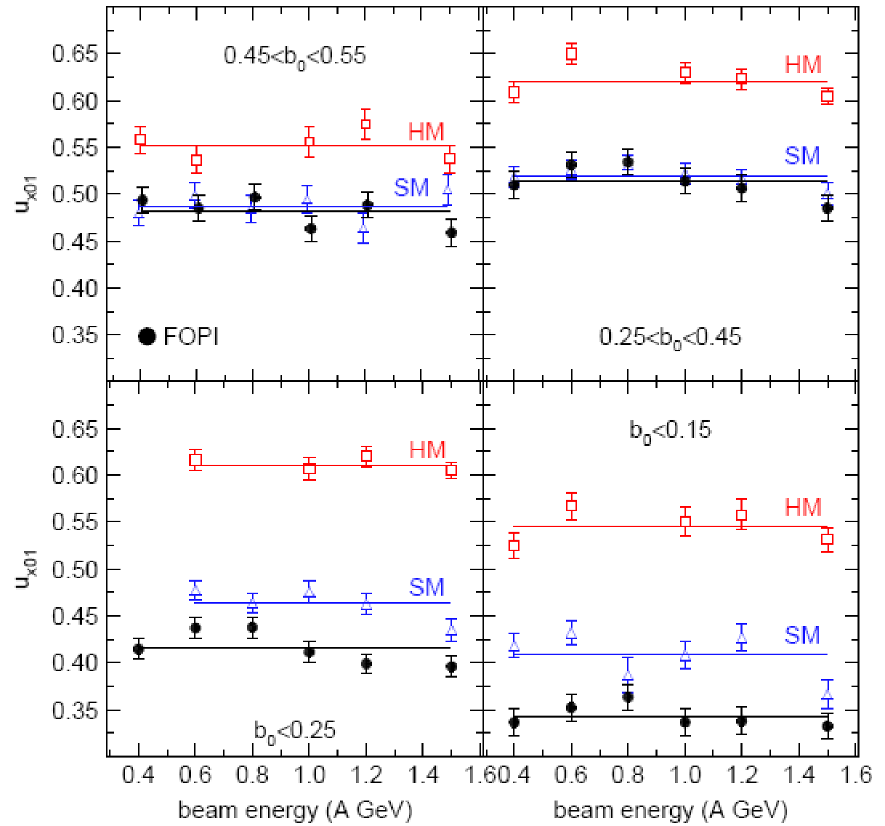
Equation – Of – State

Excitation function of deuteron sideflow

DBHF: E. N. E. van Dalen, C. Fuchs, A. Faessler, EPJ. A 31,29 (2007)



W. Reisdorf et al. (FOPI), NPA 876, 1 (2012)



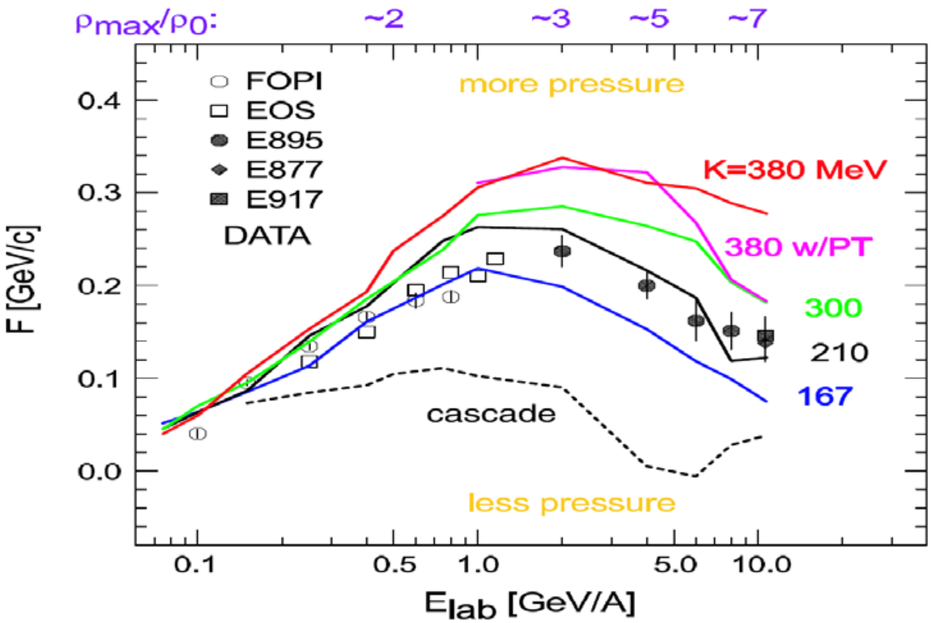
The EOS is soft up to E_{beam}=1.5 AGeV (ρ_{max} = 2 – 2.5 ρ_0).

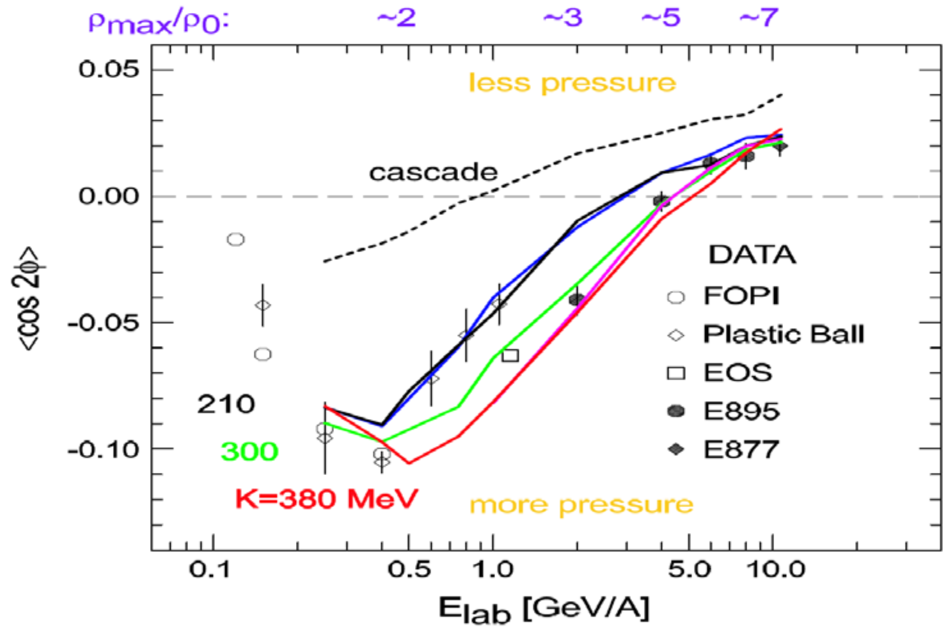
Soft EOS does not support neutron stars with $M_{NS}=2M_{\odot}$

Excitation function of flow variables

$$F = \frac{d\langle p_x / A\rangle}{d(y / y_{cm})}$$

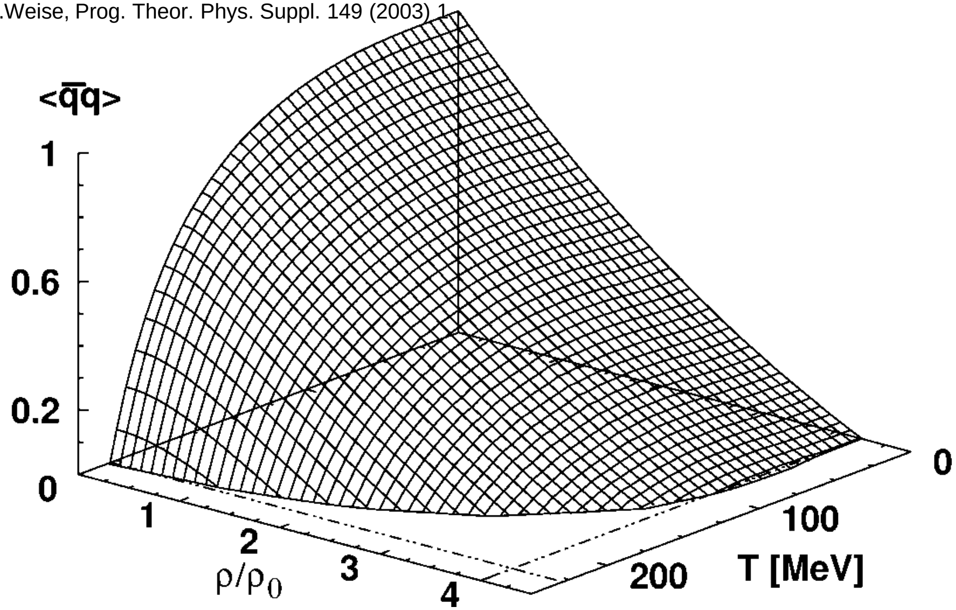
P. Danielewicz et al.
nucl-th/0112006 (2001),
Science 298, 1592 (2002)





- **No consistent model description available so far.**
- **Largest sensitivity to model parameters (EOS) in energy range 2 – 5 AGeV.**
- **Uncertainty in data at 1 GeV/A corresponds to uncertainty in K of 150 MeV.**

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

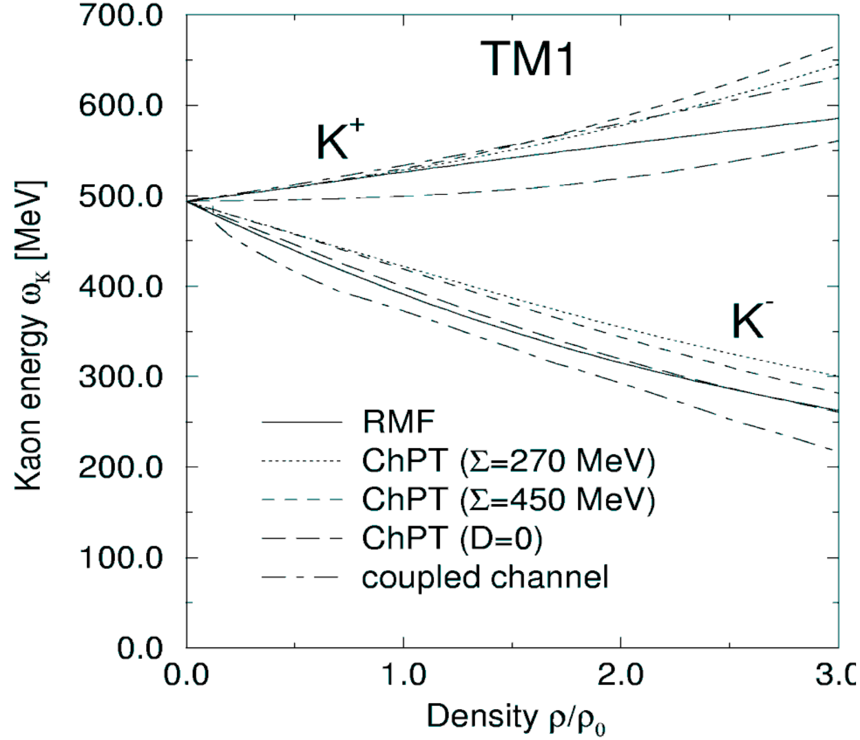


Modified properties of hadrons in dense baryonic matter?

$M^*(\rho)$	(mass)
$\Gamma^*(\rho)$	(width)
$\sigma^*(\rho)$	(cross section)

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

in-medium kaon energy



In-medium effects in finite systems:

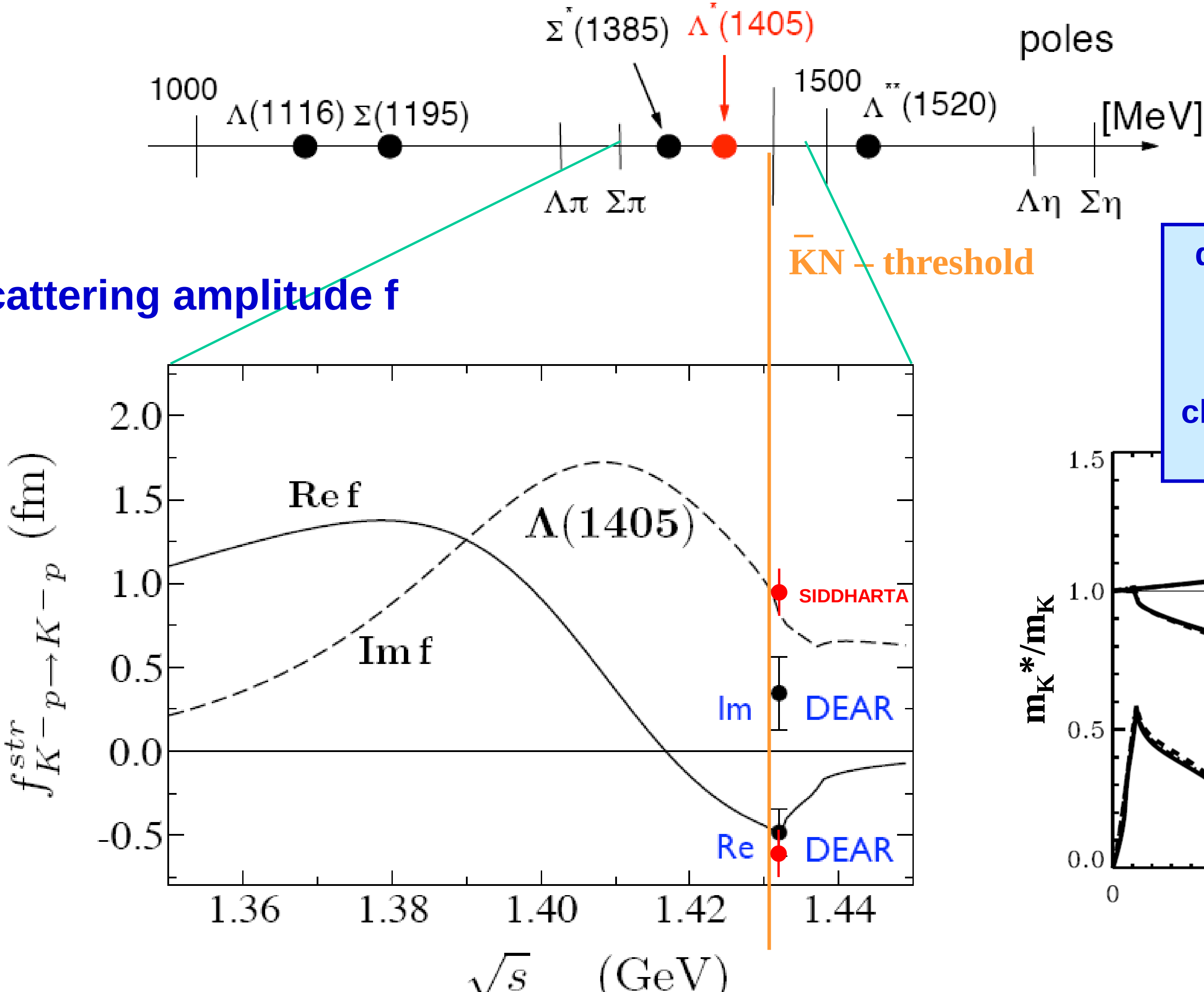
'Trivial'

- Fermi motion
- Pauli blocking
- Collisional broadening

'Non-trivial'

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

$\bar{K}N$ – interaction

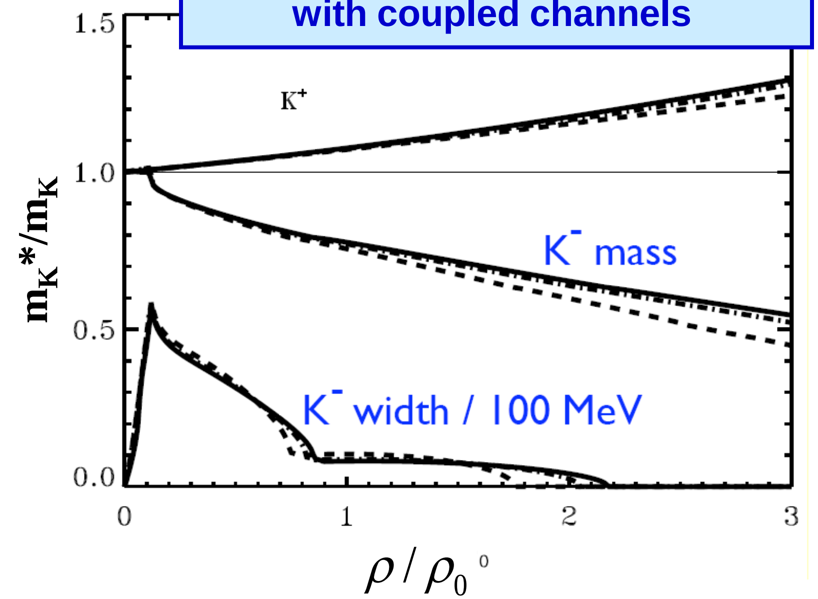


$$\sqrt{s} = \omega + m_N$$

↑ $\bar{K}$ – energy

W.Weise et al.: PLB 379, 34 (1996), PRL 94, 213401 (2005)
Y.Ikeda et al. arXiV:1109:3005

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
Experimental signatures: flow of kaons
bound baryonic states

Flow of charged kaons

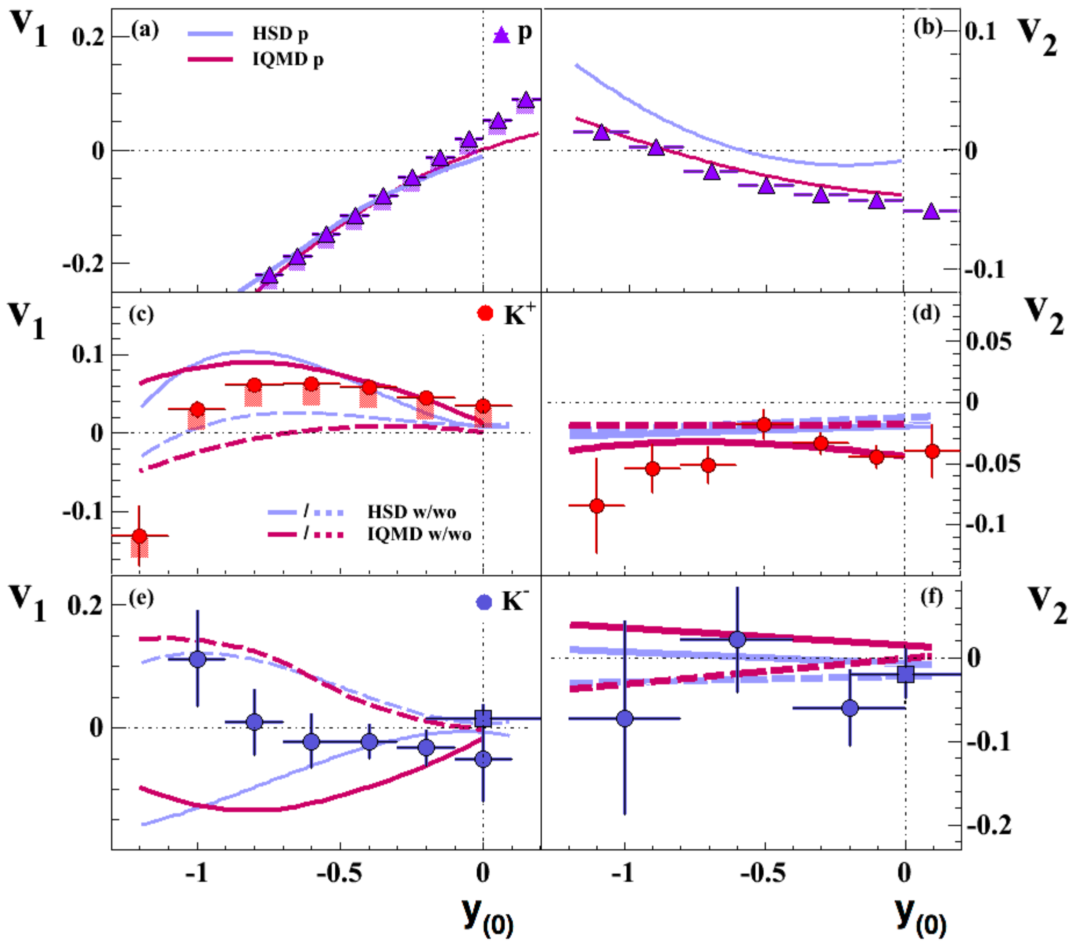
Ni+Ni at 1.91 AGeV
(S325 + S325e data)
σ = 1.5 b

Models with FOPI acceptance filter

Potentials with linear density dependence.

At $\rho=\rho_0$:

$U_{HSD}(K^+)$	20 MeV
$U_{IQMD}(K^+)$	40 MeV
$U_{HSD}(K^-)$	-50 MeV
$U_{IQMD}(K^-)$	-90 MeV



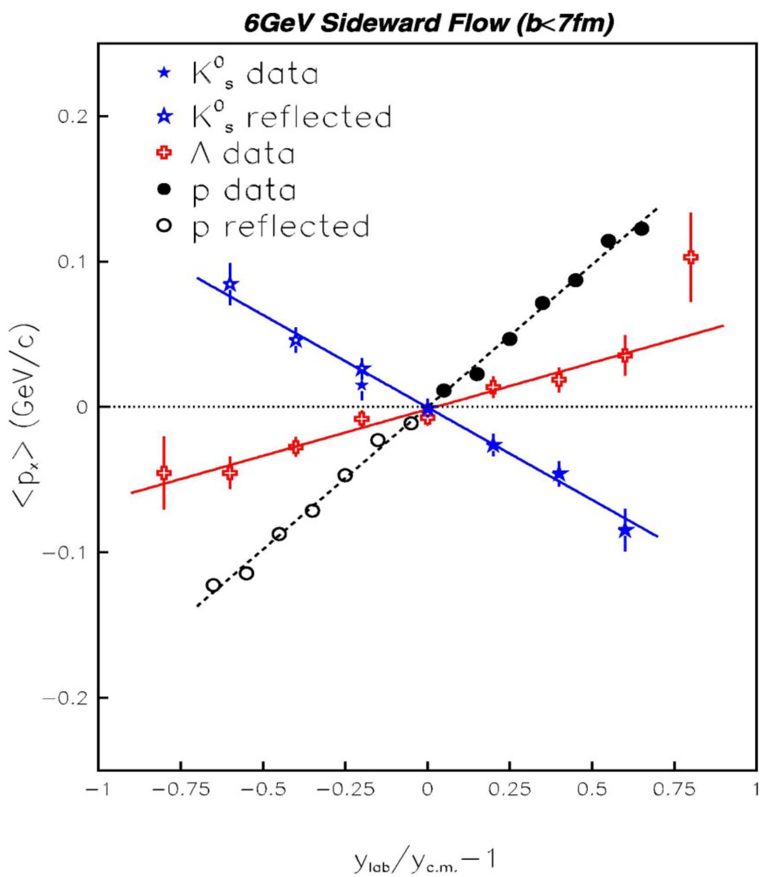
V.Zinyuk et al. (FOPI) submitted to PRL

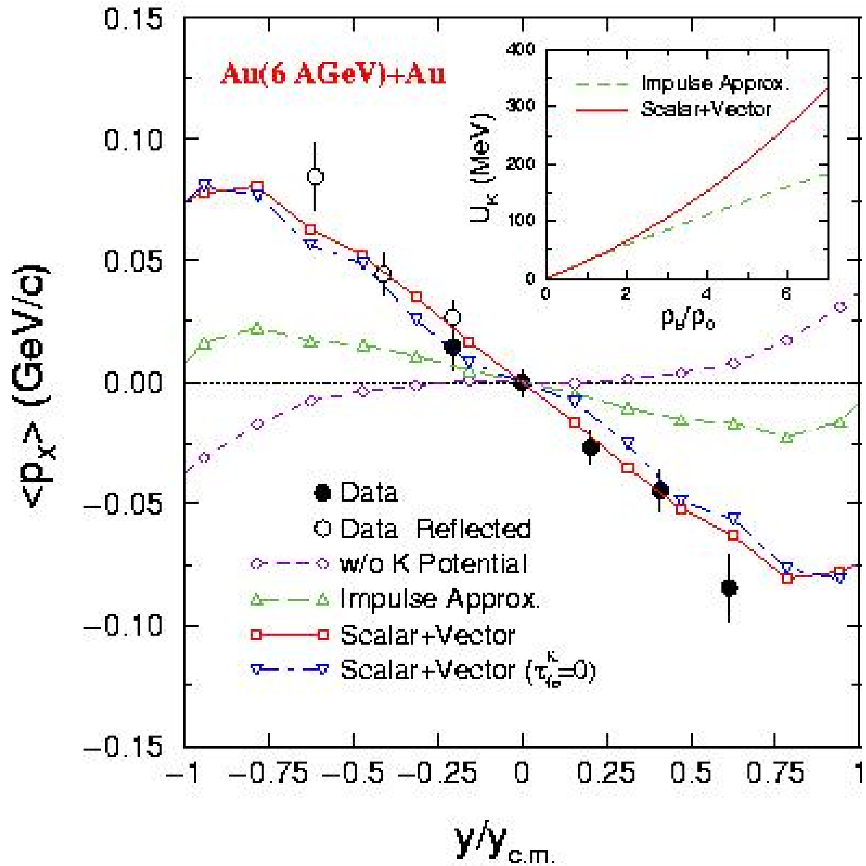
K^+ sideflow indicative for repulsive potential.
K^- sideflow indicative for attractive potential.
Transport model calculations need to be refined.

AGS: K^0 – flow

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

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





Kaon flow as barometer in HI collisions?
Calibrate probe by systematic measurements

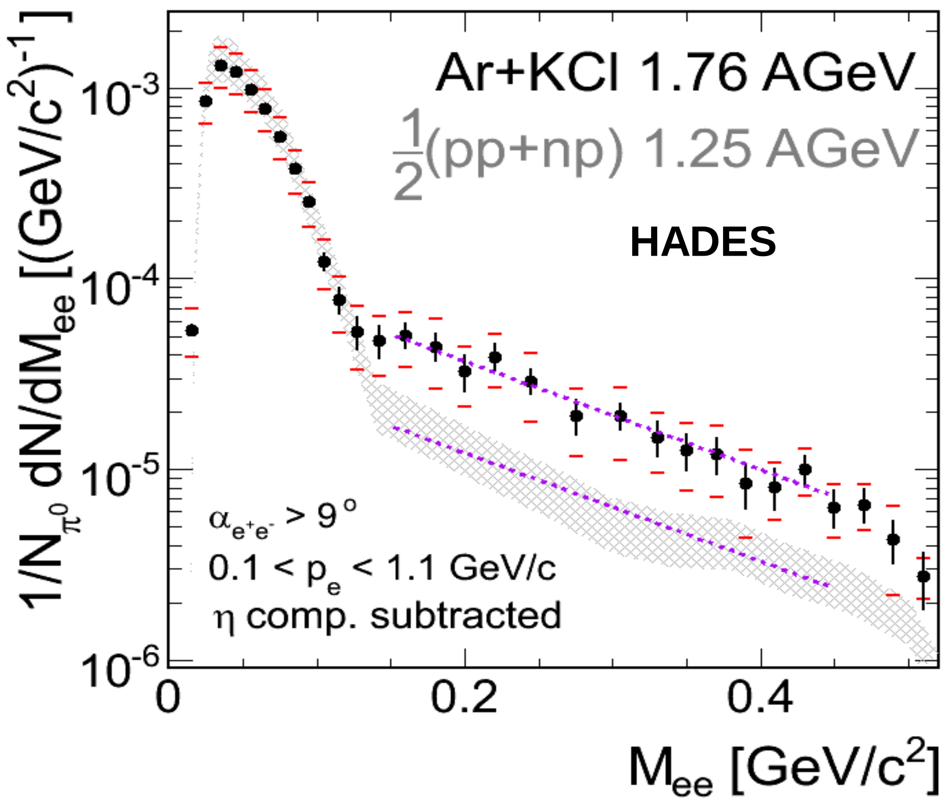
- **centrality**
- **system size**
- **incident energy**

Light vector mesons

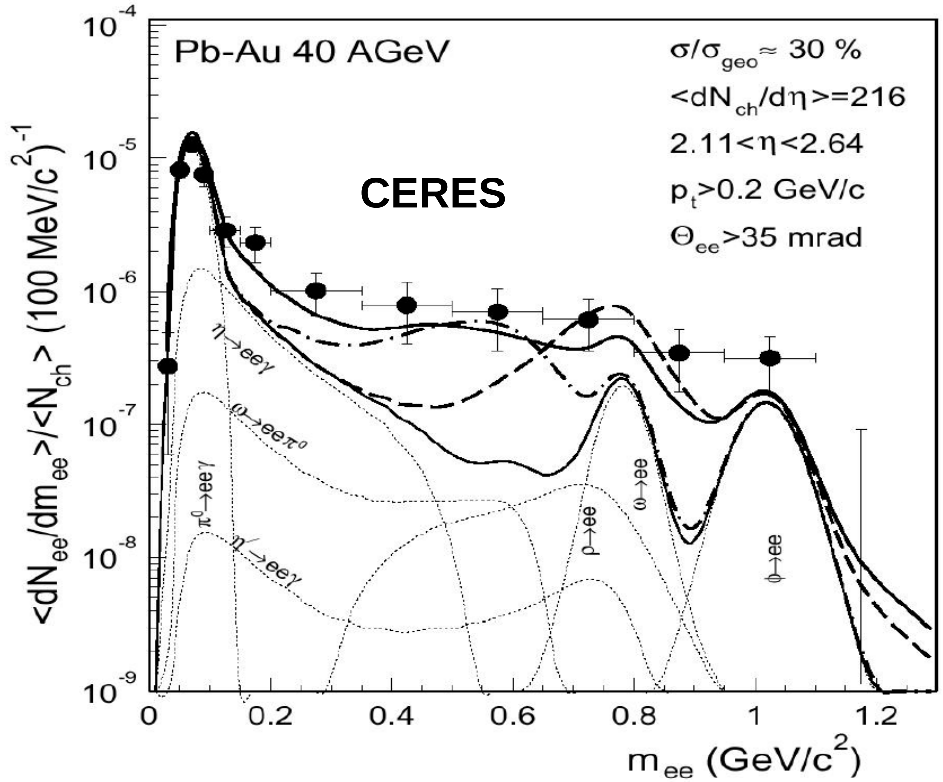
Integrating probe:

In-medium mass distributions of light vector mesons

G. Agakishiev et al., Phys. Rev. C 84 (2011) 014902



D. Adamova et al., Phys. Rev. Lett. 91 (2003) 042301

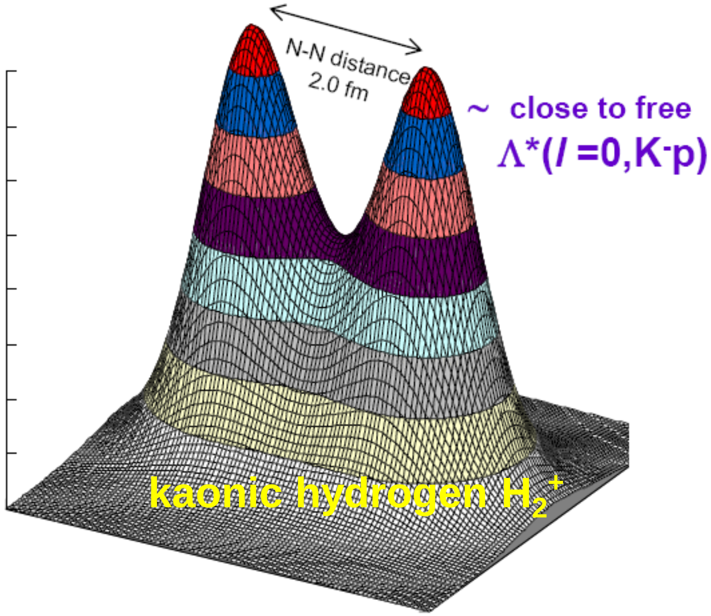


No data available in SIS100 / SIS300 energy range

Do strange baryon bound states exist?

Kaonic molecules

T.Yamazaki and Y. Akaishi, Phys. Rev. C76 (2007) 045201
Y. Akaishi, T.Yamazaki, Phys.Rev.C65, 044005 (2002)
T.Yamazaki and Y. Akaishi, Phys.Lett.B535, 70 (2002)



$$\Psi = \phi_a + \phi_b$$

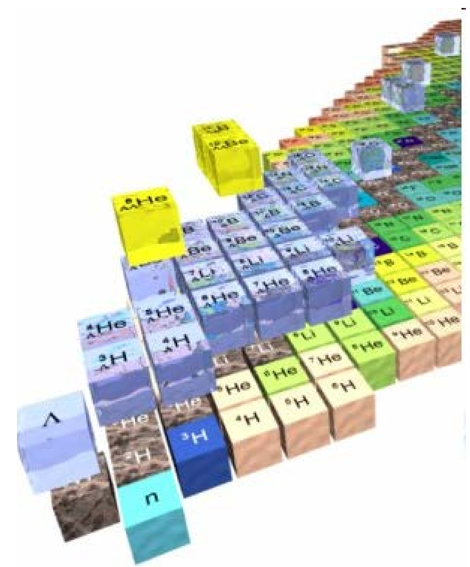
Decay by strong interaction

(ppK⁻): $$\left(ppK^-\right) \rightarrow \Lambda + p$$

FINUDA M=2255±9 MeV, Γ=64±14 MeV
DISTO M=2265±2 MeV, Γ=118±8 MeV

Heavier clusters, e.g.: $$\left(ppnK^-\right) \rightarrow \Lambda + d$$

Hypernuclei



Decay by weak interaction

Production in HI – collisions?
Recently: STAR, ALICE

Double strange hypernuclei??

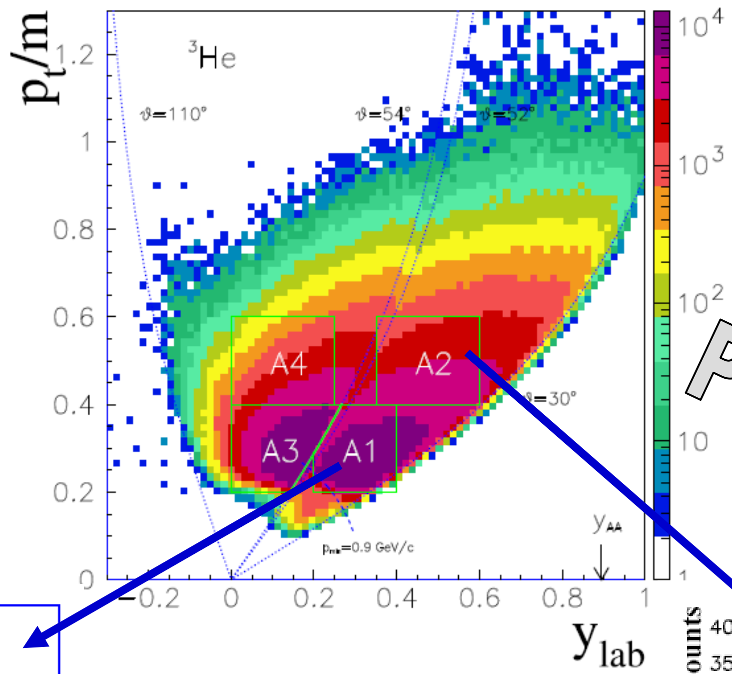
Hypertriton production in Ni+Ni at 2 AGeV

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

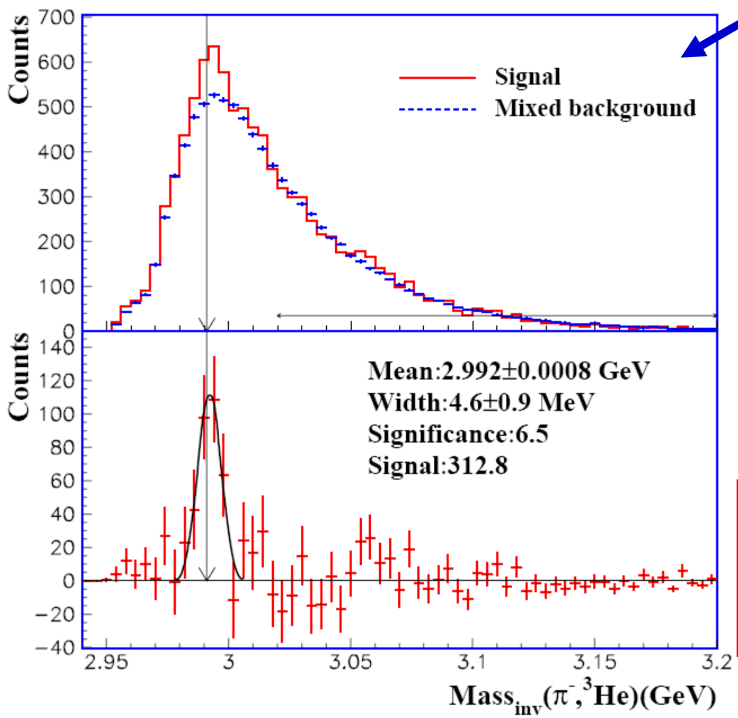
50 M events,

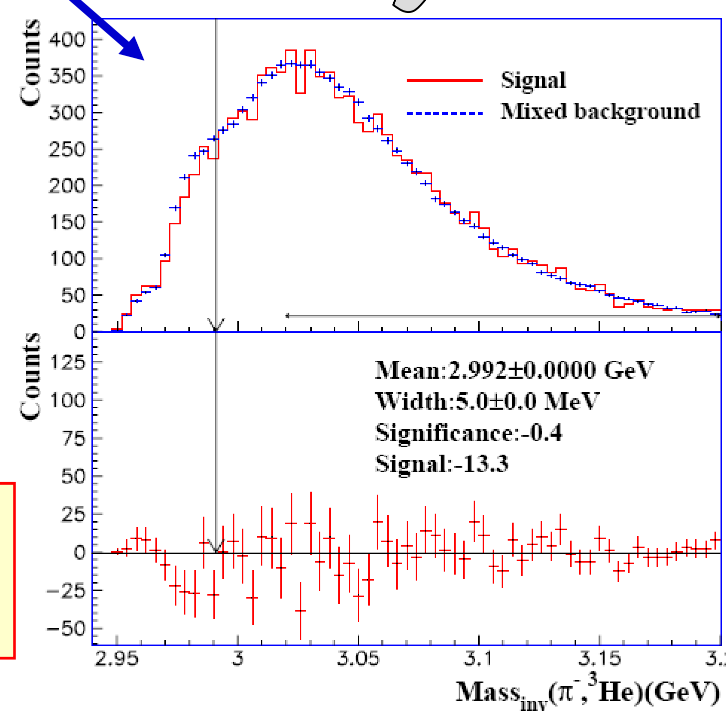
$\sigma_{triggered}$ = 0.5 . $\sigma_{reaction}$

Y. Zhang, PhD thesis, Heidelberg



Preliminary

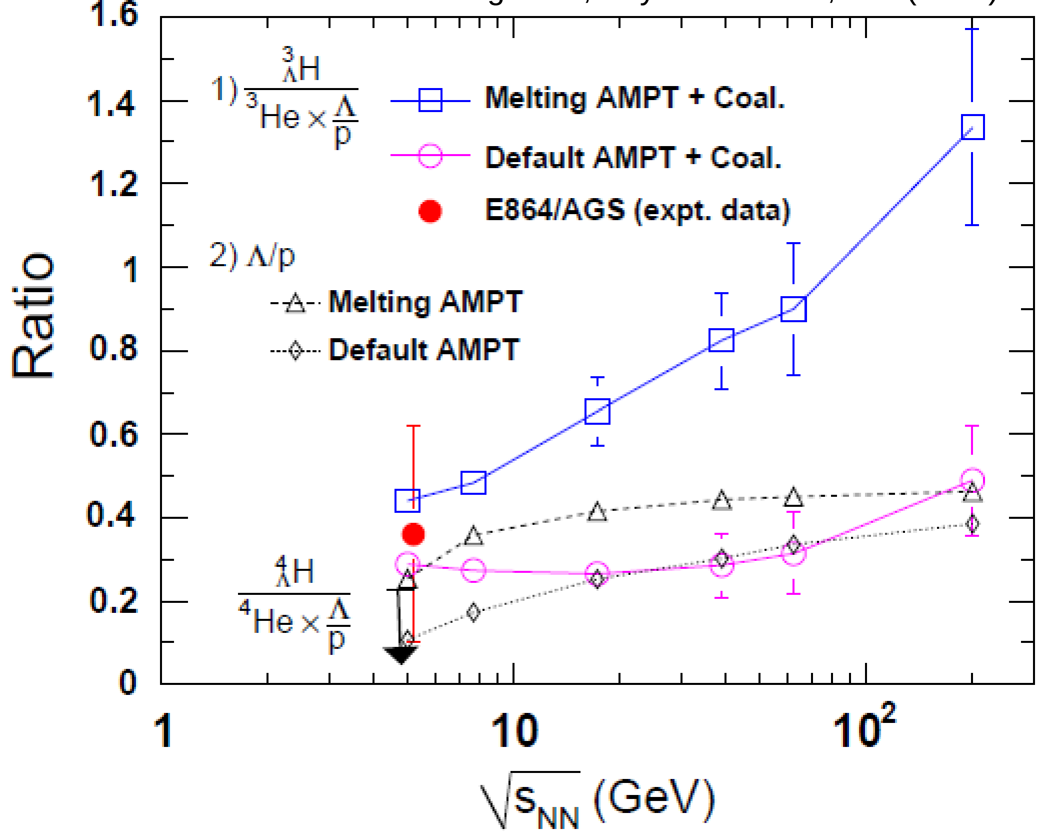




Excess over combinatorial background only in Phase space region A1

Baryon – Strangeness – Correlation

S. Zhang et al., Phys.Lett. B684, 224 (2010)

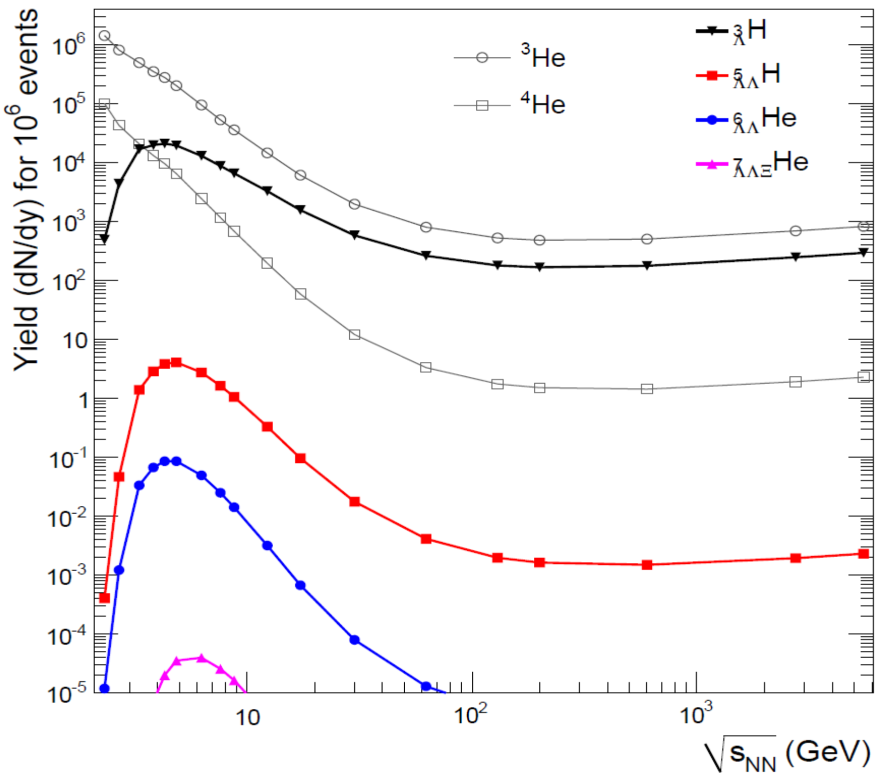


	Region A1	Region A2
$_{\Lambda}t/^{3}He$	0.029 +/- 0.002	<0.003 +/- 0.002
Λ/p	0.0020 +/- 0.0005	0.0028 +/- 0.0005
$_{\Lambda}t/^{3}He$ / Λ/p	10 +/- 3	< 0.95 +/- 0.6

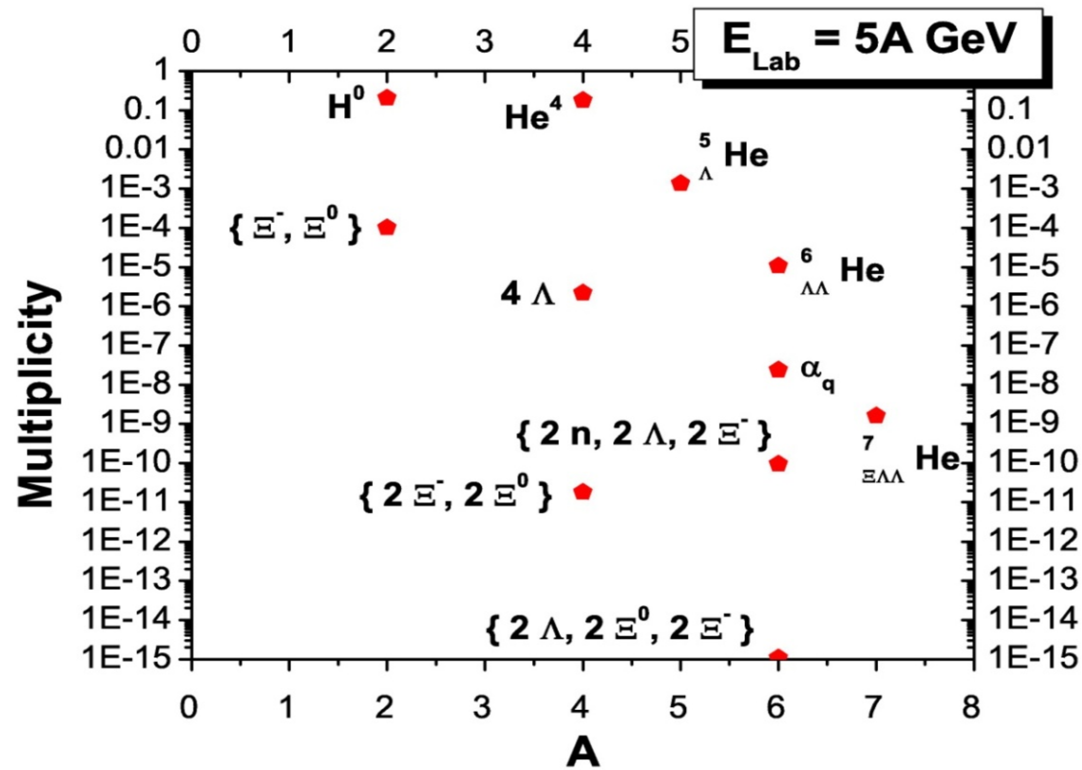
Strange baryonic bound states

- Single and double strange hypernuclei in heavy ion collisions at SIS100
- Search for strange matter in the form of strange dibaryons and heavy multi-strange short-lived objects.

A. Andronic, P. Braun-Munzinger, J. Stachel, H. Stöcker, Phys. Lett. B697 (2011) 203



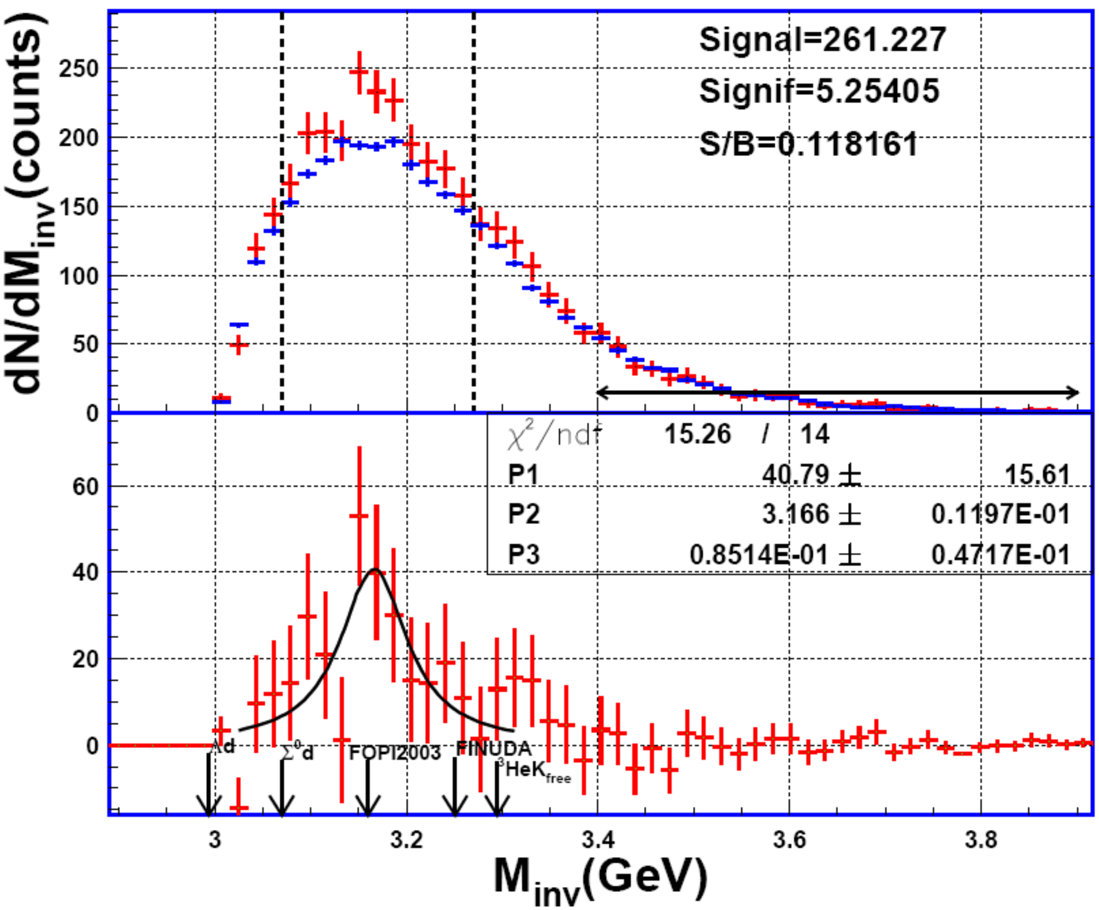
H. Stöcker et al., Nucl. Phys. A 827 (2009) 624c

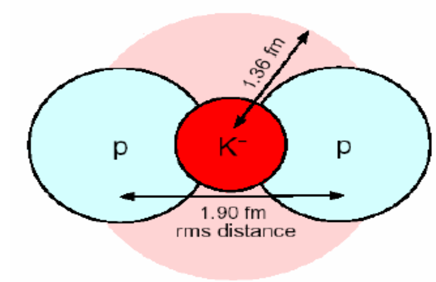


Λd – correlations

(FOPI, work in progress)

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





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

FOPI 2003 and 2008 data are consistent,
Inconsistent with cusp (Σ – d – threshold) and FINUDA.

Current 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
LEE – Look elsewhere effect (?)

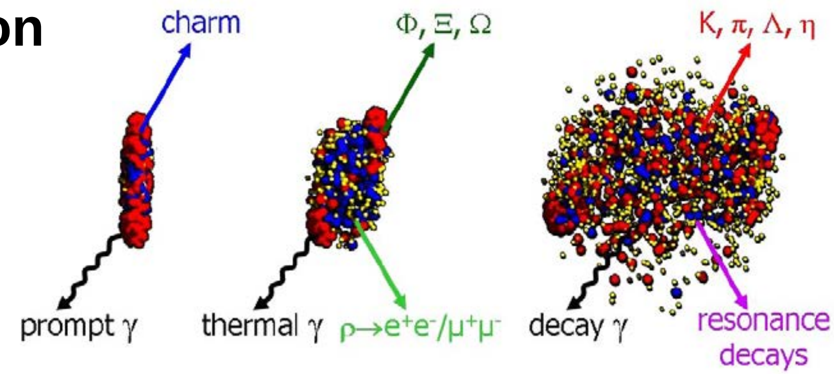
Needed :

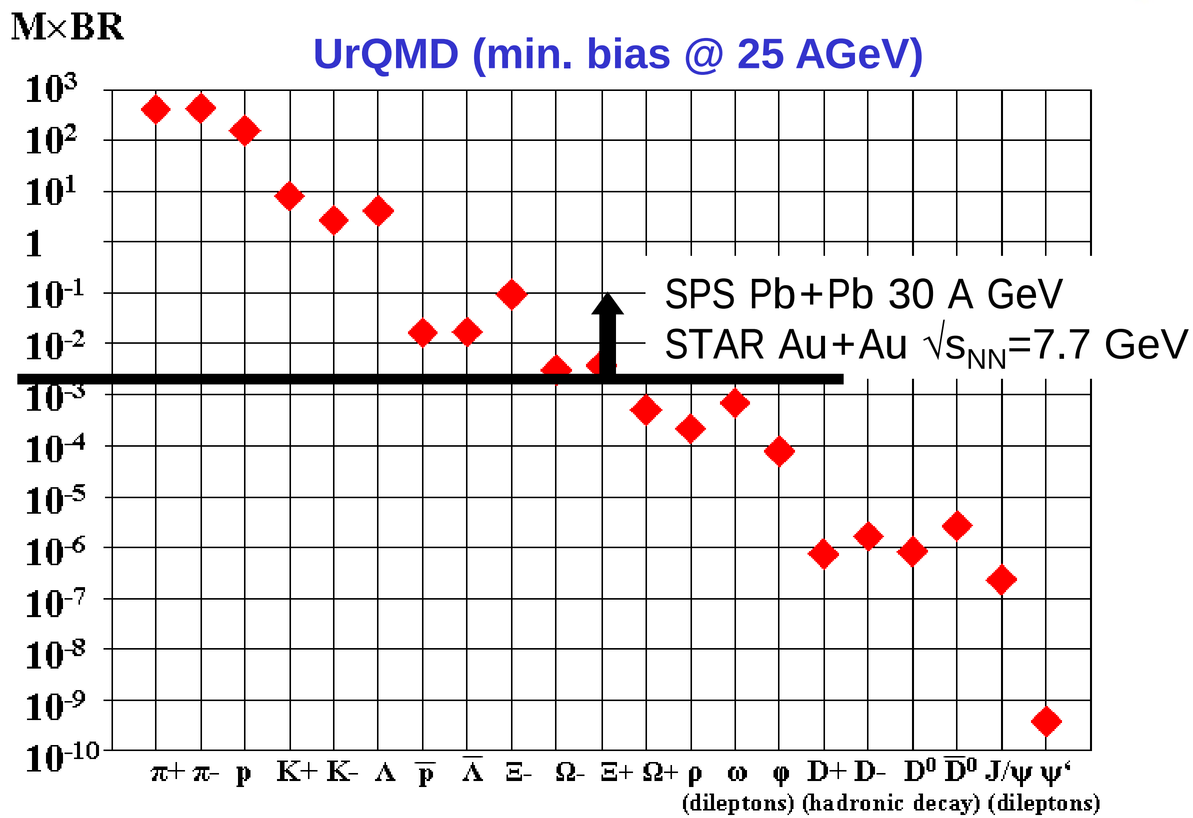
Sensitivity at level P ~ 10^{-6}
Significant increase of
DAQ rate

CBM - strategy

Systematic measurement of excitation function of <u>rare</u> probes with full event characterisation

- **Multiple strange hadrons**
- **Low mass vector mesons via dileptons**
- **Open charm**
- **Charmonia**



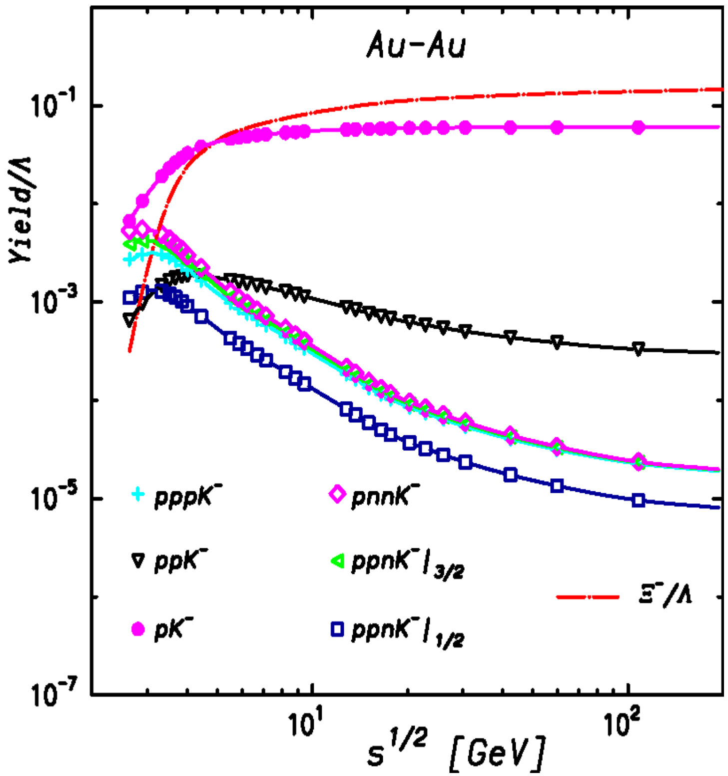


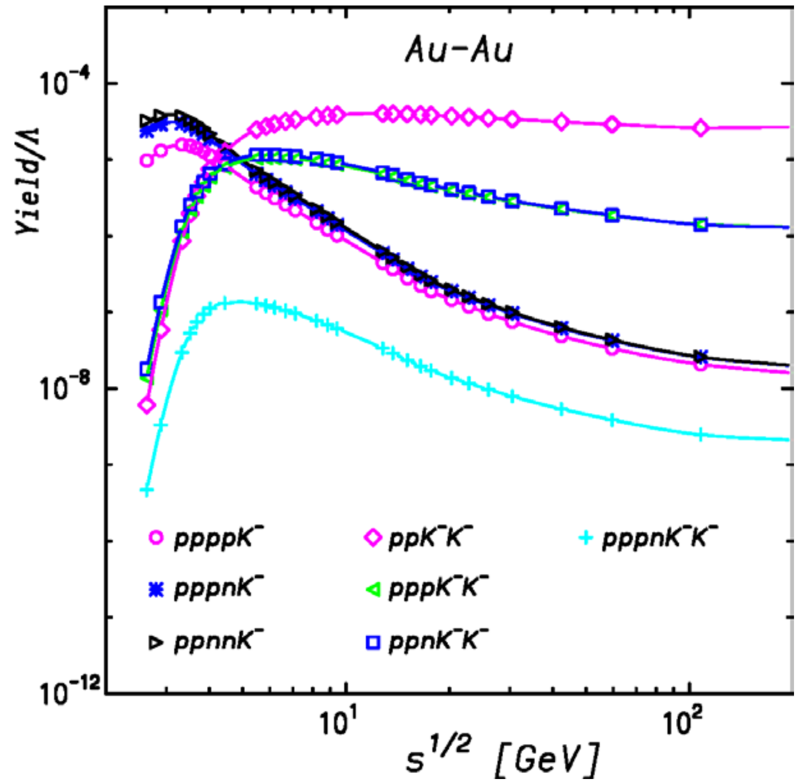
with min. bias event Inspection rate of

10 MHz (!)

by realizing free streaming DAQ concept.

Experimental strategy towards strange bound states





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

Experimental strategy at beam energies < 10 AGeV:

- allow for large event samples (P ~ 10^{-8}, N_{signal} > 1000 => $N_{event} > 10^{11}$
- 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

CBM – Detector Concept

Different detector setups for muon & electron measurements:

0) Core elements

- dipole magnet
- STS – silicon tracking system
- PSD – projectile spectator detector
- TOF – MRPC time-of-flight detector
- DAQ – data acquisition
- FLES – first level event selection

1) Muon setup

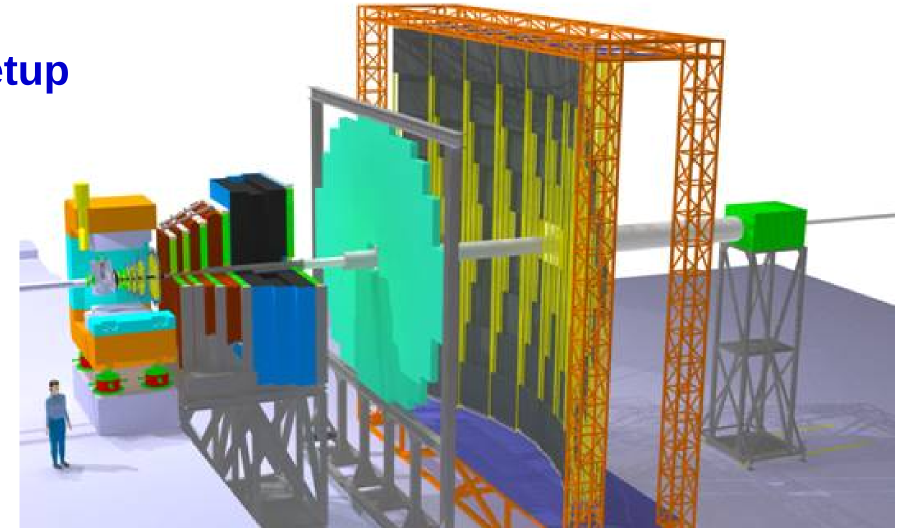
- MUCH – Muon detection system (active absorber)
- TRD – tracking station

2) Electron/Hadron setup

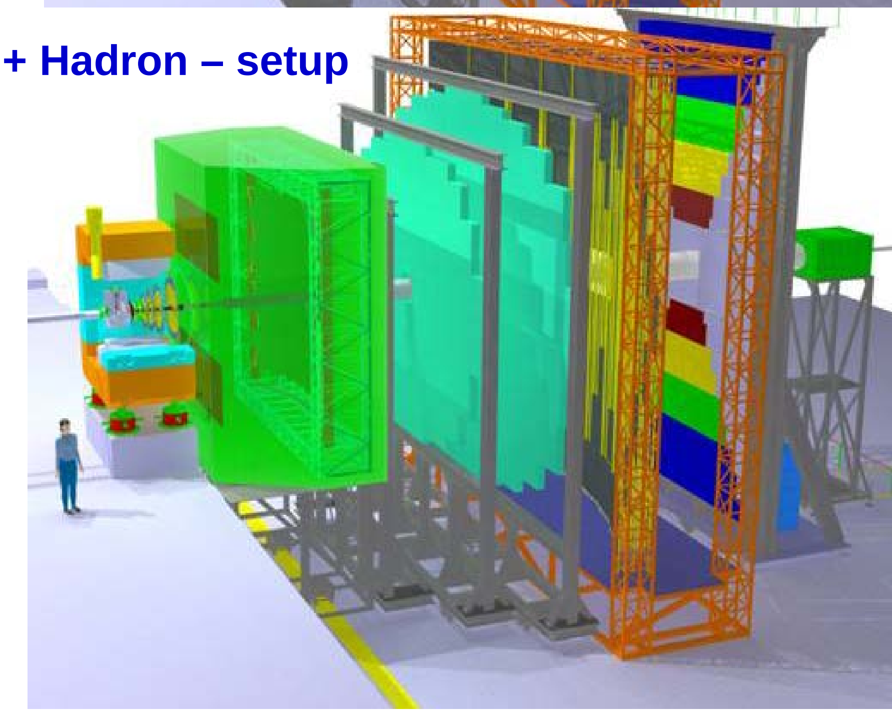
- MVD – Micro vertex detector
- TRD – Transistion radidation detector
- ECAL – Electromagnetic calorimeter

All core components designed with self triggered FEE and free running DAQ for 10 MHz interaction rate.

1) Muon – setup



2) Electron + Hadron – setup



Schedule

Nr.	Vorgangsname	Anfang	Ende
1			
2	**FAIR Civil Construction**	**Fr 06.11.09**	**Mi 09.05.18**
3	Planning, Tendering, Construction of Site and Buildings	Fr 06.11.09	Mi 09.05.18
4	Ready to move in HEBT Connection SIS18- SIS100		
5	Ready to move in HEBT SIS100		
6	Ready to move in SIS100		
7		Mo 01.05.17	Mo 01.05.17
8	ES)	Mo 01.05.17	Mo 01.05.17
9		Fr 28.10.16	Fr 28.10.16
10			
11			
12			
13			
14			
15			
16			
17	FAIR Accelerator for Set-Up Phase	**Mo 01.06.09**	**Fr 28.09.18**
18	**Module 0 - 3**	Mo 01.06.09	Mo 01.06.09
19	**Systems Block 1 of Mod 0-3**	**Mo 01.06.09**	**Do 22.02.18**
20	**HEBT Connection SIS18 - SIS100 (T1S1, T1S2, T1S3, T1S4)**		
103	**Super FRS**		
188	**Systems Block 2 of Mod 0 - 3**		
189	**HEBT-SIS100 (T8DU)**	**Mo 01.06.09**	**Mi 01.03.17**
271	**SIS100**	**Mo 01.06.09**	**Fr 13.10.17**
372	**HEBT - T1X1, T1C1,T1D1-T1C2,TNC1 - T1X2,TXL1,TXL2,TXL3,TXL4,TPP1,T**	**Mo 01.06.09**	**Di 03.04.18**
453	**Multifunction Caves (CBM HADES)**	**Mo 01.06.09**	**Fr 28.09.18**
533	**Systems Block 3 of Mod 0 - 3**	**Mo 01.06.09**	**Fr 14.09.18**
534	**HEBT - T1F1,T1F2,TFF1, TSX1, TSF1, FRF, TFC1**	**Mo 01.06.09**	**Di 29.08.17**
614	**HEBT - TAP1, TAP2, TCR1, THS1**	**Mo 01.06.09**	**Do 21.12.17**
694	**p-bar Target**	**Mo 01.06.09**	**Mi 17.01.18**
774	**p-LINAC**	**Mo 01.06.09**	**Do 15.02.18**
855	**CR**	**Mo 01.06.09**	**Mi 25.04.18**
935	**HESR**	**Mo 01.06.09**	**Fr 14.09.18**

CBM cave ready: May 1, 2017

SIS100 ready: Oct. 13, 2017

CBM time line

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
R&D detectors & read-out systems			construction detectors & read-out systems				installation, commissioning		first data taking	

Summary / Conclusion

Phase structure of QCD will not be revealed by a single measurement or experiment.

QCD 'bulk' or 'many body' physics needs a facility for systematic studies. and a third generation experiment -> CBM

rate capability: 10 MHz interaction rate

CBM physics program

many open physics questions

- **EOS**
- **in-medium modifications of hadrons**
- **quarkyonic matter (?)**

substantial discovery potential at SIS100 / 300

CBM strategy

systematic measurement of multi-dimensional observables of (rare) probes,
use detector components as tool kit.