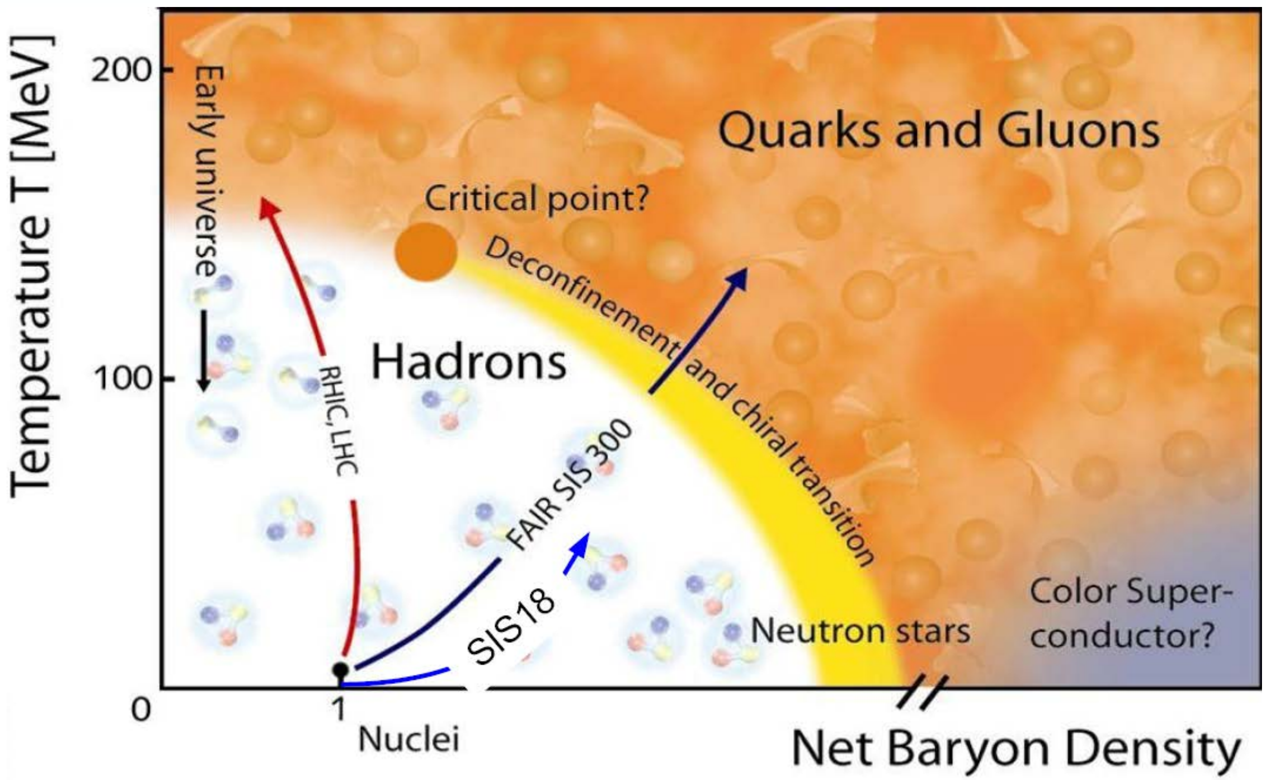
Compressed Baryonic Matter: CBM @ FAIR



Outline

- **CBM / FAIR – status**
- **CBM detector concept**
- **Observables at SIS100**
  - **Hypernuclei**
  - **(Multi) strange baryon production**
  - **Flow**
- **Detector performance**

GSI / FAIR

SIS18:

In operation since 1989

E_{beam} < 2 AGeV

SIS100/300:

Proposal 2003

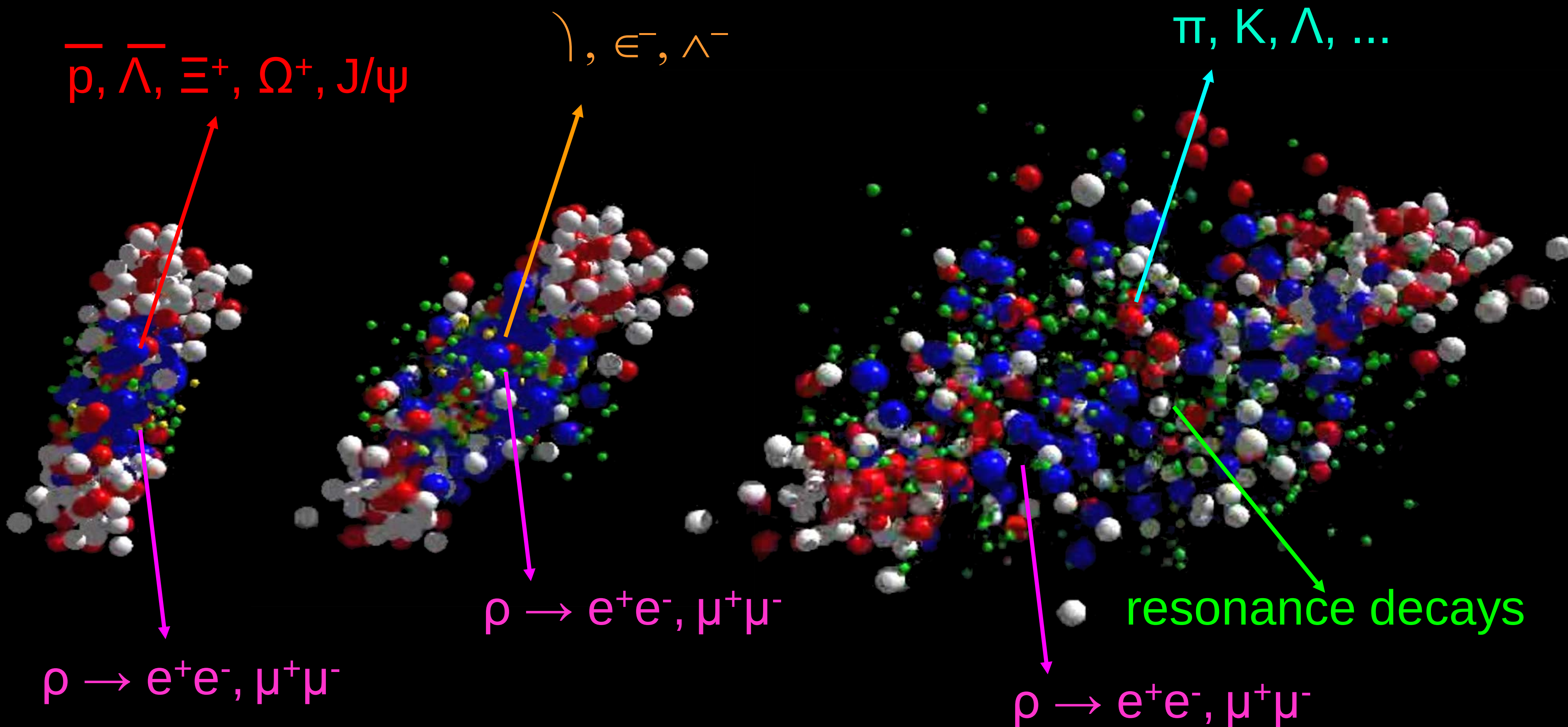
Start 2018++

E_{beam} < 14 / 45 AGeV (Ca)

< 11 / 35 AGeV (Au)

Messengers from the dense fireball: CBM at SIS100

UrQMD transport calculation Au+Au 10.7 A GeV



CBM – detector concept

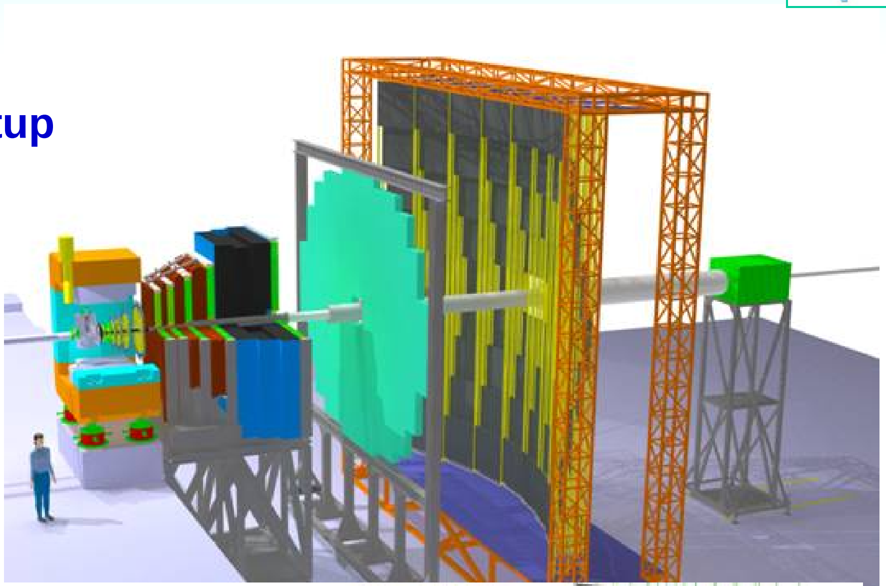
Different detector setups for muon & electron measurements:

0) Core elements
- dipole magnet
- STS – silicon tracking system
- PSD – projectile spectator detector
- DAQ – data acquisition
- FLES – first level event selection

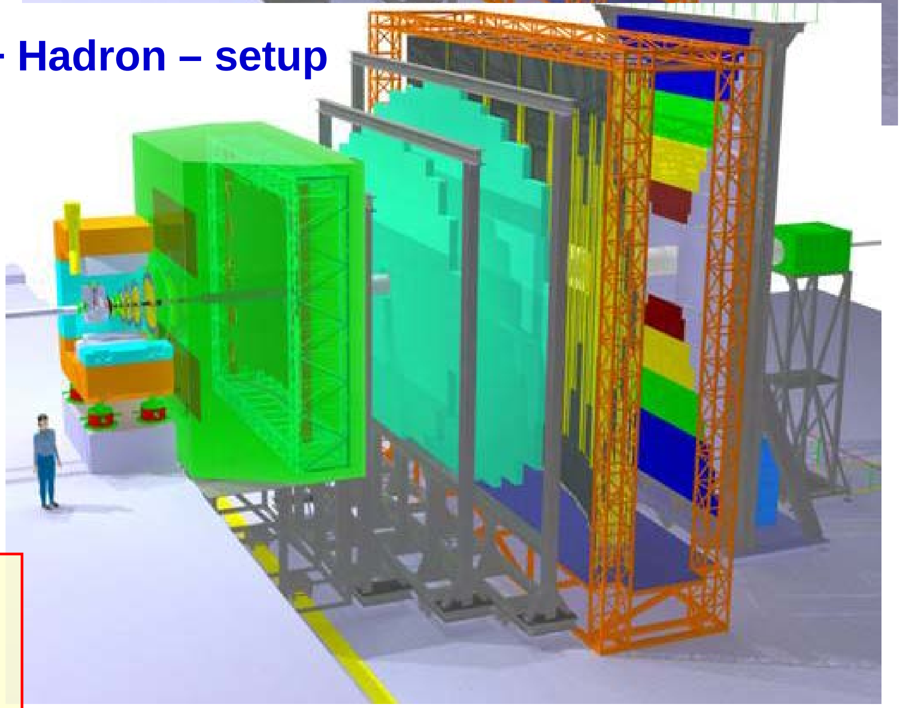
1) Muon setup
- MUCH – Muon detection system (active absorber)
- TRD – tracking station
- TOF – MRPC time-of-flight detector

2) Electron/Hadron setup
- MVD – Micro vertex detector
- TRD – Transistion radidation detector
- TOF – MRPC time-of-flight detector
- ECAL – Electromagnetic calorimeter

1) Muon – setup



2) Electron + Hadron – setup



Concept for high rates (up to 10 MHz Au+Au reactions):
Self triggered detectors and
free running DAQ with sufficient bandwidth!

CBM - collaboration

China:
Tsinghua Univ., Beijing
CCNU Wuhan
USTC Hefei

Croatia:
University of Split
RBI, Zagreb

Cyprus:
Nikosia Univ.

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IPHC Strasbourg

Germany:
Univ. Gießen
Univ. Heidelberg, Phys. Inst.
Univ. HD, Kirchhoff Inst.
Univ. Frankfurt
Univ. Mannheim
Univ. Münster
FZ Rossendorf
GSI Darmstadt
Univ. Tübingen
Univ. Wuppertal

Hungaria:
KFKI Budapest
Eötvös Univ. Budapest

India:
Aligarh Muslim Univ., Aligarh
IOP Bhubaneswar
Panjab Univ., Chandigarh
Gauhati Univ., Guwahati
Univ. Rajasthan, Jaipur
Univ. Jammu, Jammu
IIT Kharagpur
SAHA Kolkata
Univ Calcutta, Kolkata
VECC Kolkata
Univ. Kashmir, Srinagar
Banaras Hindu Univ., Varanasi

Korea:
Pusan National Univ.

Poland:
Krakow Univ.
Warsaw Univ.
Silesia Univ. Katowice
Nucl. Phys. Inst. Krakow

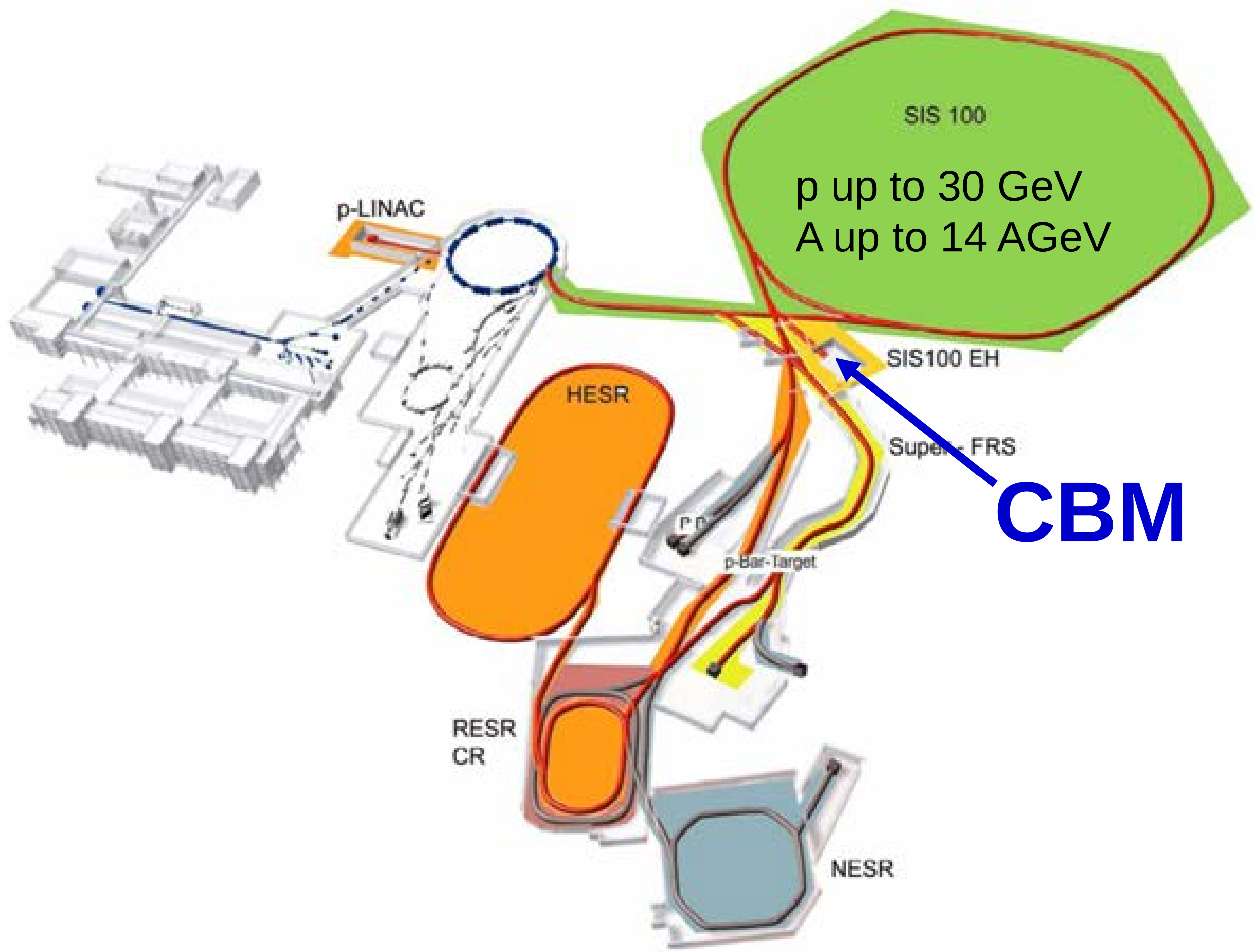
Romania:
NIPNE Bucharest
Bucharest University

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst. Moscow
LHE, JINR Dubna
LPP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP, Moscow State Univ.
St. Petersburg Polytec. U.

Ukraine:
INR, Kiev
Shevchenko Univ. , Kiev

52 institutions, > 400 members

FAIR: Modularized Start Version



Module 0: SIS-100

Module 1: CBM cave, APPA hall

Module 2: Super-FRS and R3B

Module 3: Anti-proton facility

Module 4: LE-NuSTAR, NESR, FLAIR

Module 5: RESR

Module 6: SIS-300

Modules 0 – 3:
Start of construction 2011, completion until 2017

Modules 4-6:
Start and completion of construction not fixed

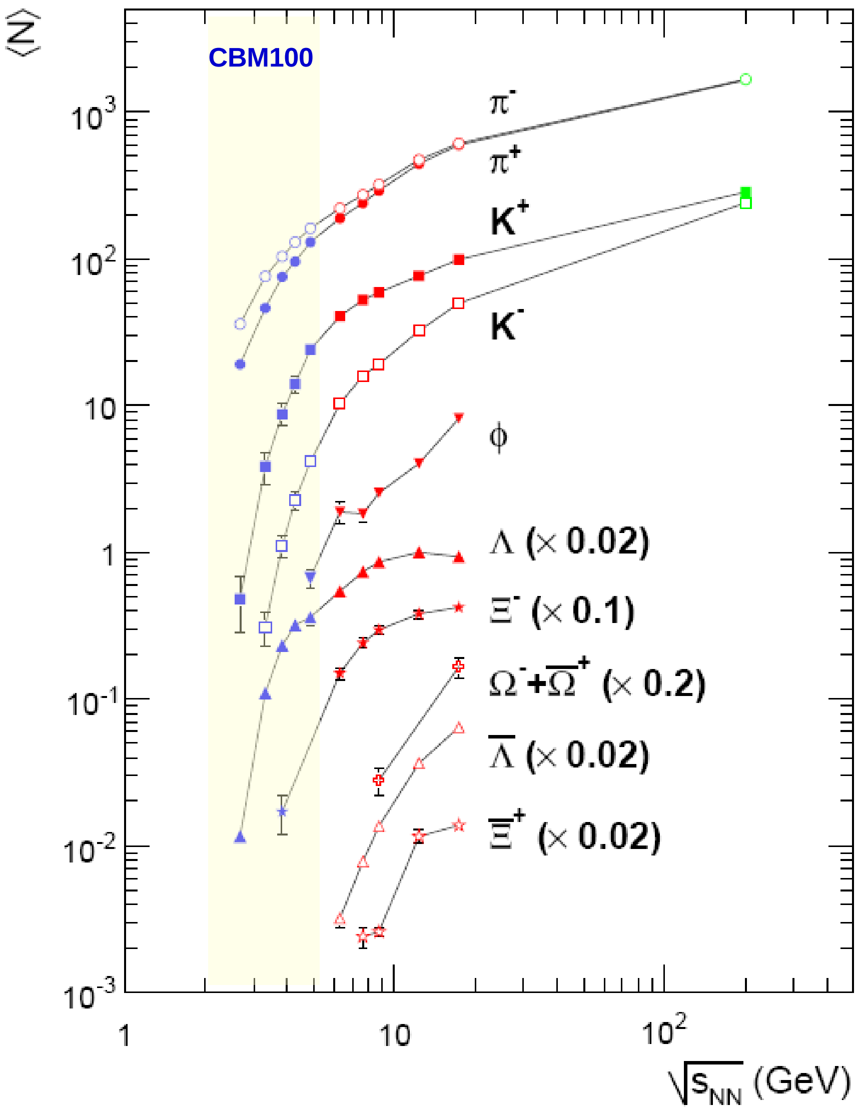
FAIR construction site

May 2012

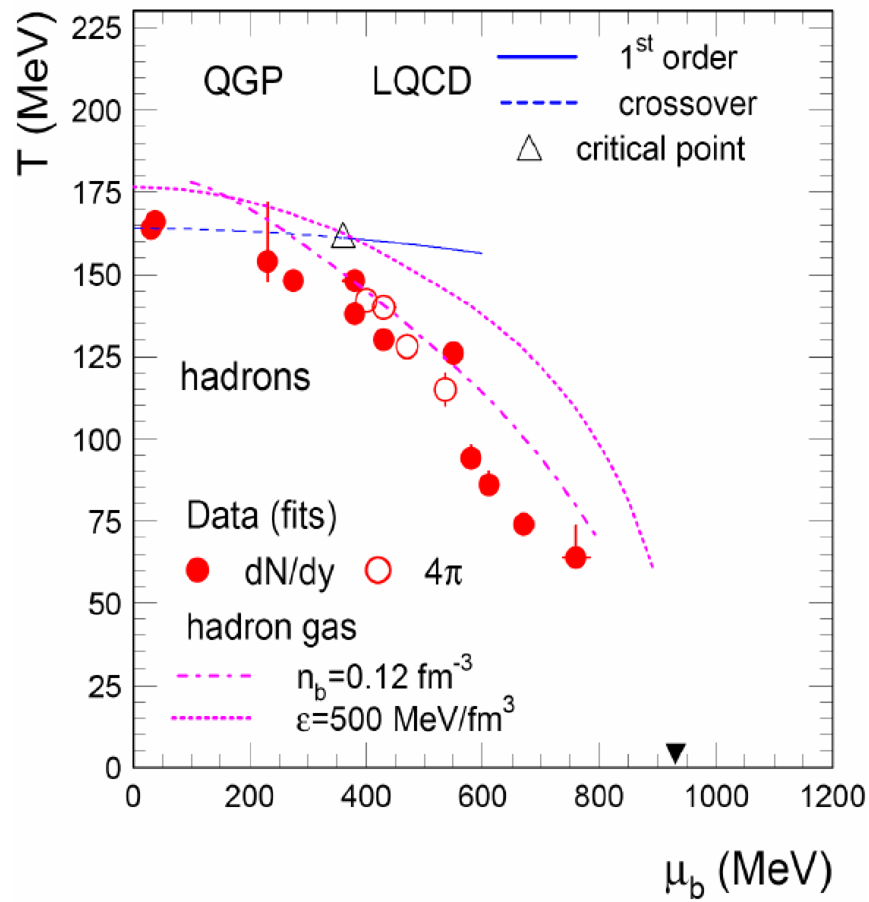
Yields and Thermal Model

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

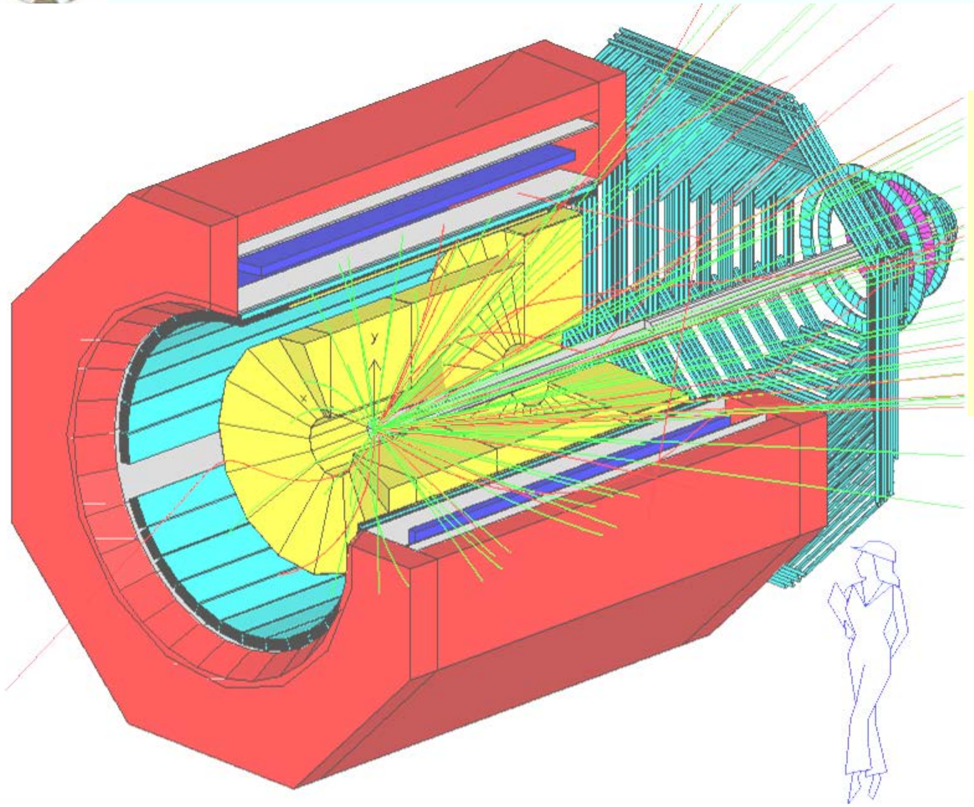
C. Blume, J. Phys. G 31 (2005) 57



A. Andronic et al., Phys. Lett. B 673 (2009).



Hadron Detektor FOPI @ GSI Darmstadt



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
+ SMI Vienna, Austria
+ TUM Munich, Germany

A. Andronic, R. Averbeck, Z. Basrak, N. Bastid, M.L. Benabderramahne, M.Berger, P. Bühler, R. Caplar, M. Cargnelli, M. Ciobanu, P. Crochet, I. Deppner, P. Dupieux, M. Dzelalija, L. Fabbietti, J. Fruehauf, 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, A. LeFevre, P.-A. Loizeau, X. Lopez, J. Marton, M. Merschmeyer, 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, V. Zinyuk, J. Zmeskal

… still running … (1990 – 2012) …

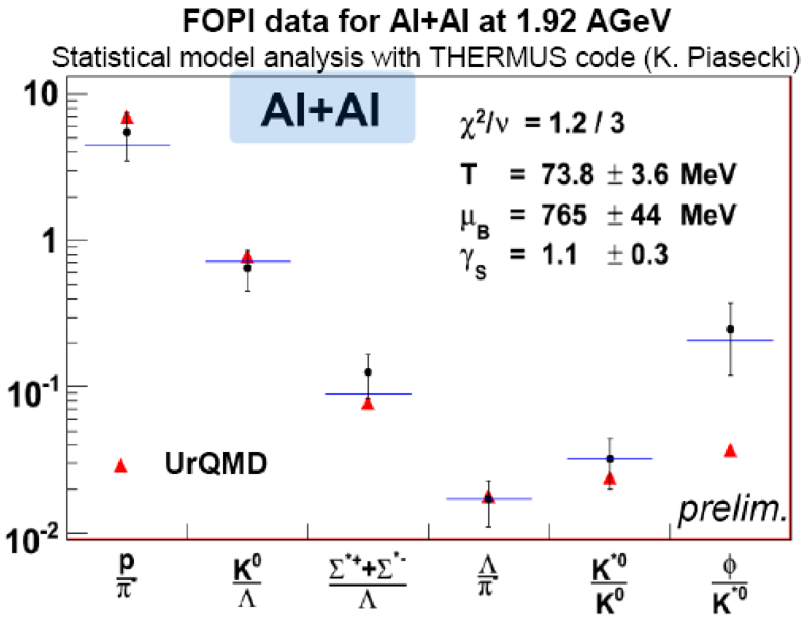
Scientific Program:

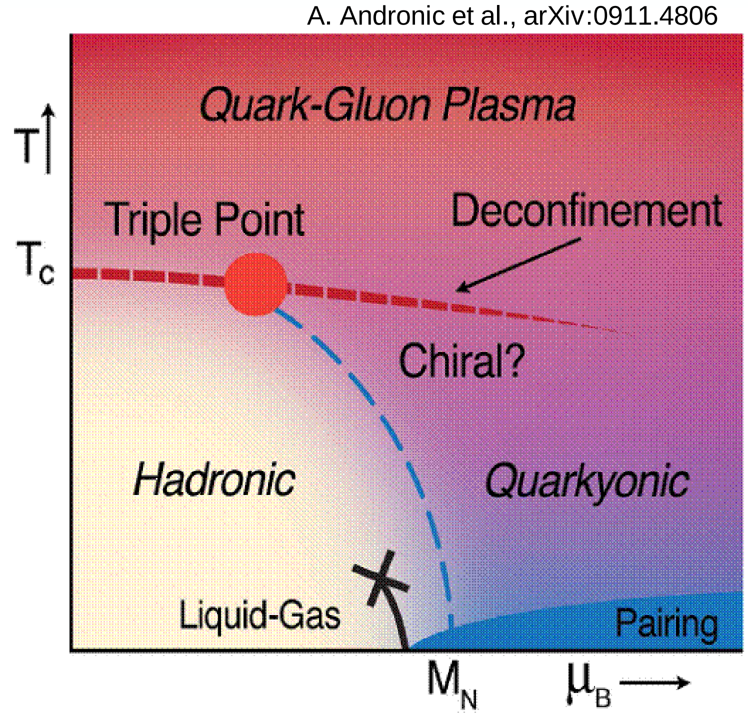
Equation – of – State

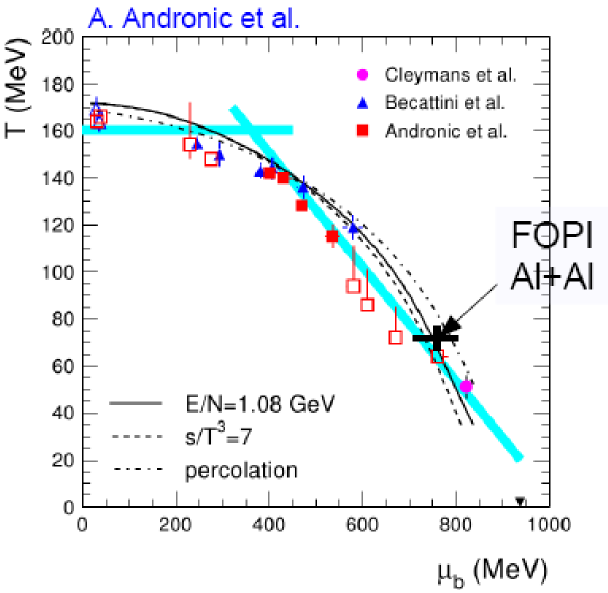
In - medium – modifications of strange hadrons

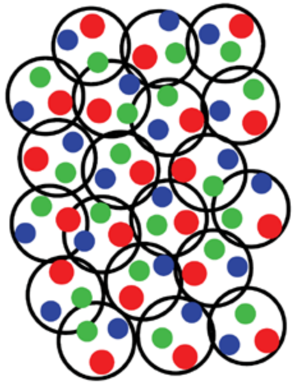
Search for bound states with strangeness

Phases of QCD?









Quarkyonic matter:

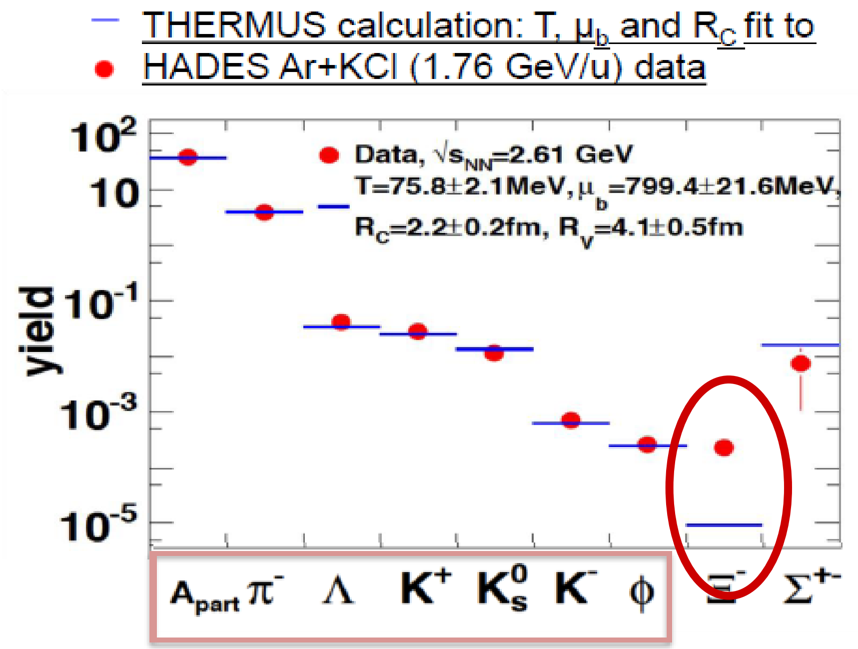
confined matter
χ – sym. restored (?)

HADES: Sub-threshold Ξ^- production

Ar+KCl reactions at 1.76A GeV

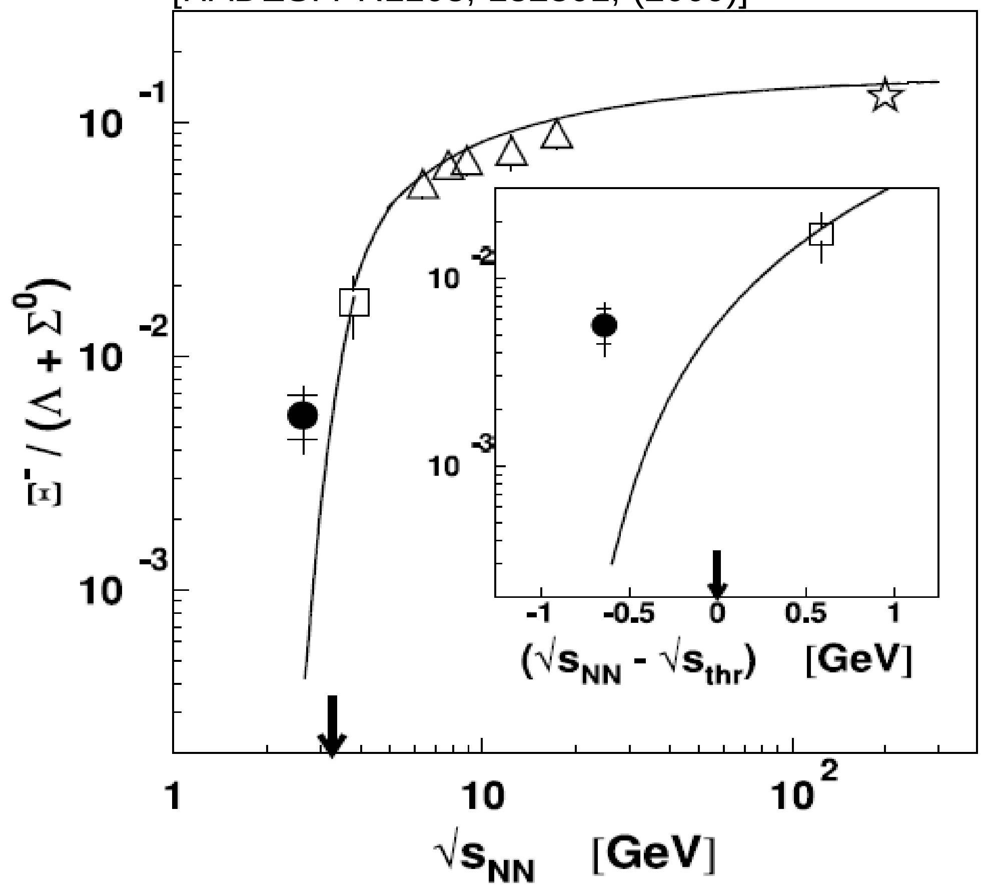
- Ξ^- yield by appr. factor 25 higher than thermal yield
- strangeness exchange reactions like

$$\bar{K}Y \rightarrow \pi\Xi \text{ (Y=}\Lambda,\Sigma) \text{ ?}$$



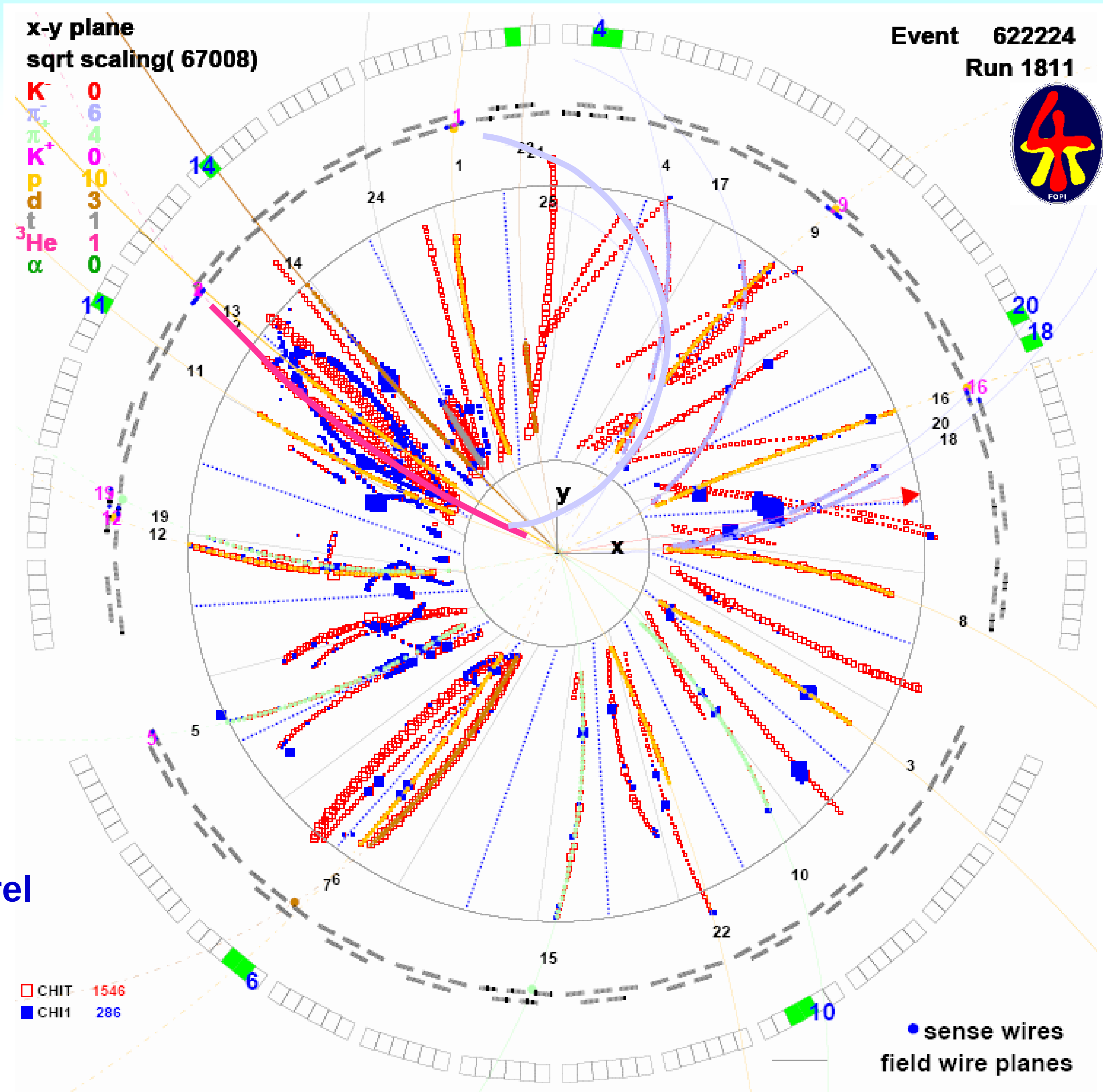
THERMUS fit: J.Cleymans, J.Phys.G31(2005)S1069
HADES: Eur. Phys. J. A 47:21, 2011.

[HADES: PRL103, 132301, (2009)]



hypernuclei

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

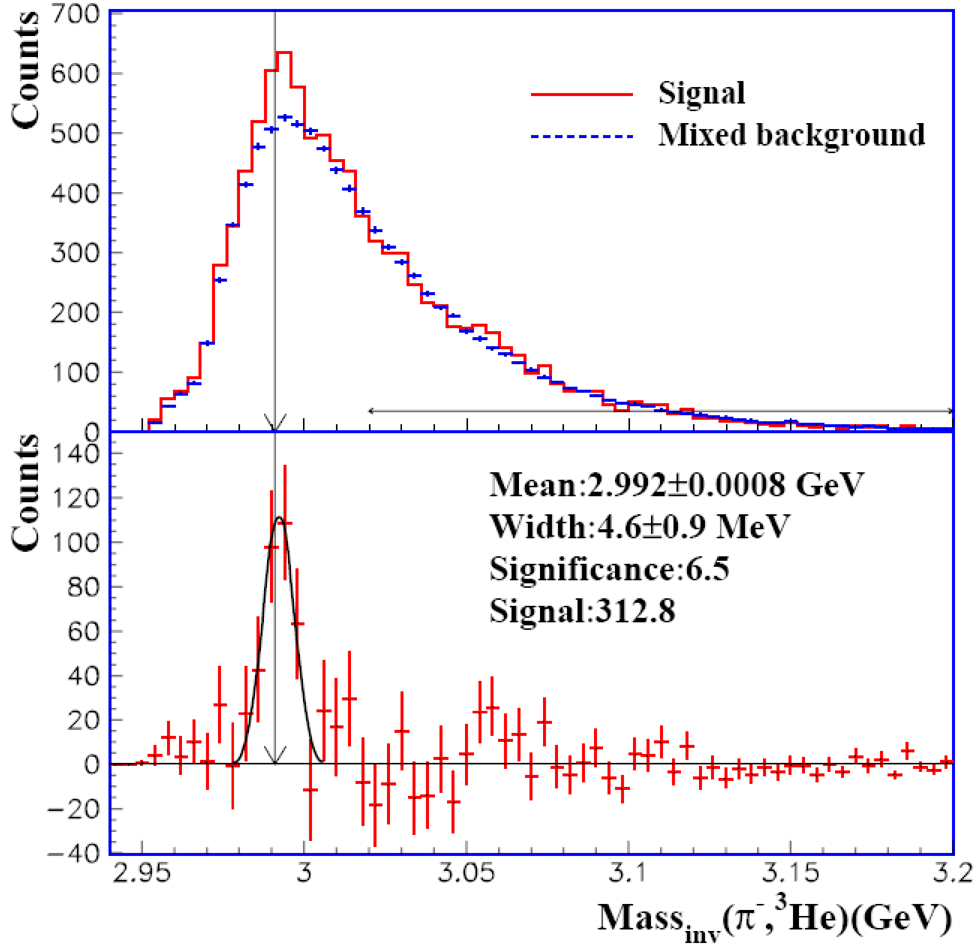


Matching with RPC – barrel essential for ^{3}He - identification

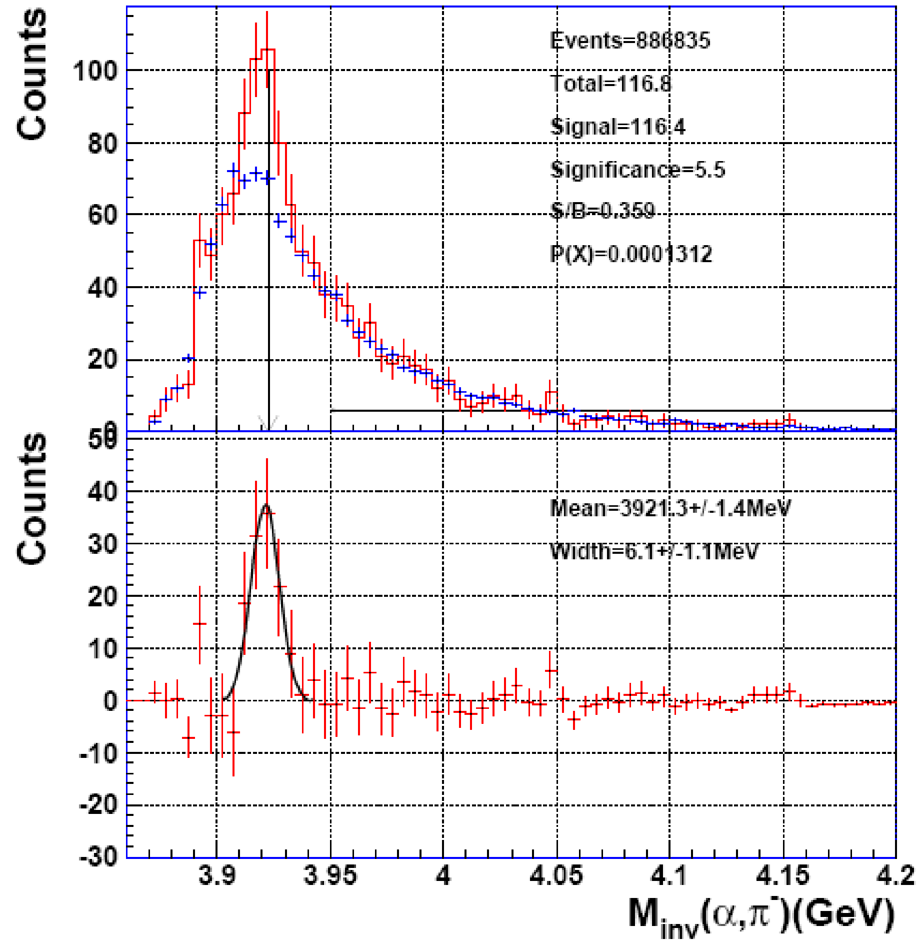
Hypernuclei production in Ni+Ni (S325e)

Y. Zhang, Heidelberg

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



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

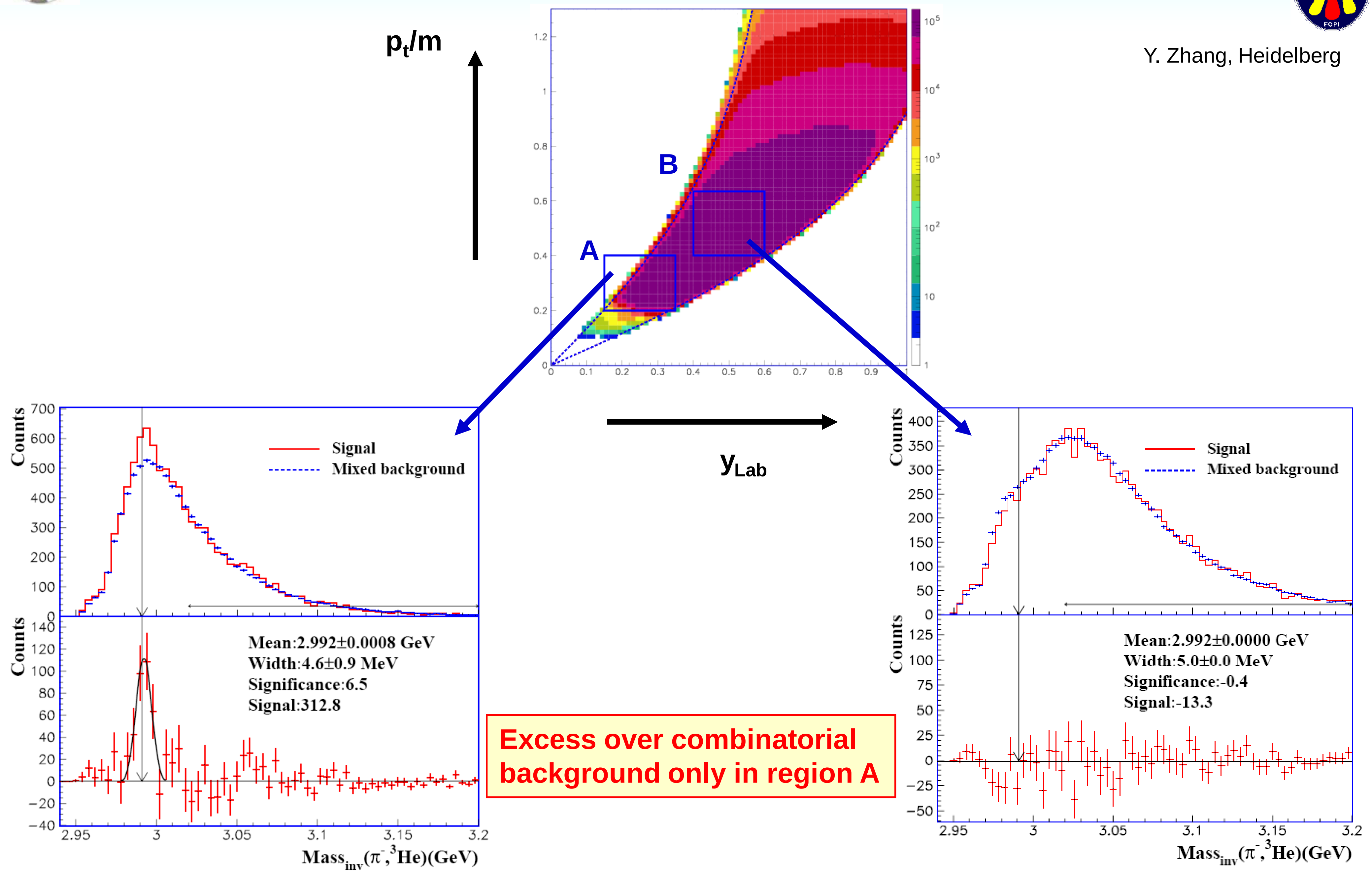


Reconstruction probability: **300 (100) candidates in 55 · 10^6 events, $P_{rec} \sim 10^{-4}$**

Measurement time: FOPI: 10 days → CBM: 10 sec !

Hypertriton production in Ni+Ni (S325e)

Y. Zhang, Heidelberg



Excess over combinatorial background only in region A

Particle yields and production mechanism

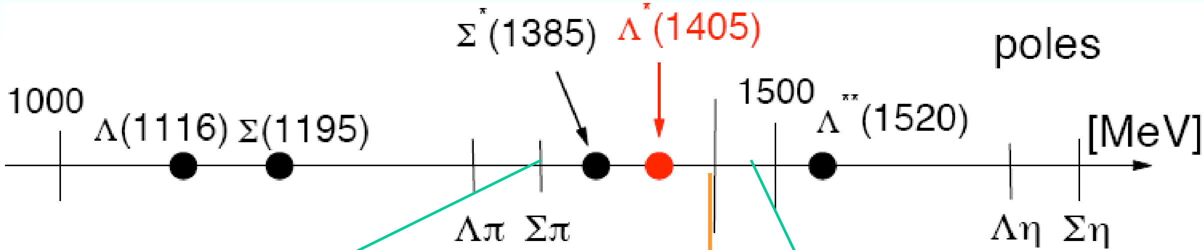
Ni + Ni @ 1.93 AGeV (S325e)

Efficiency corrected yield ratios:

	Region A	Region B	Thermal model (T=60MeV, μ_B=783 MeV)
$_{\Lambda}t/^{3}He$	0.029 +/- 0.002	<0.003 +/- 0.002	0.002
$t/^{3}He$	1.45 +/- 0.01	0.93 +/- 0.01	1.1
Λ/d	0.0046 +/- 0.0005	0.0138 +/- 0.0005	0.031

Particle ratios incompatible with
- **Thermal model**
- **Naïve coalescence hypothesis**

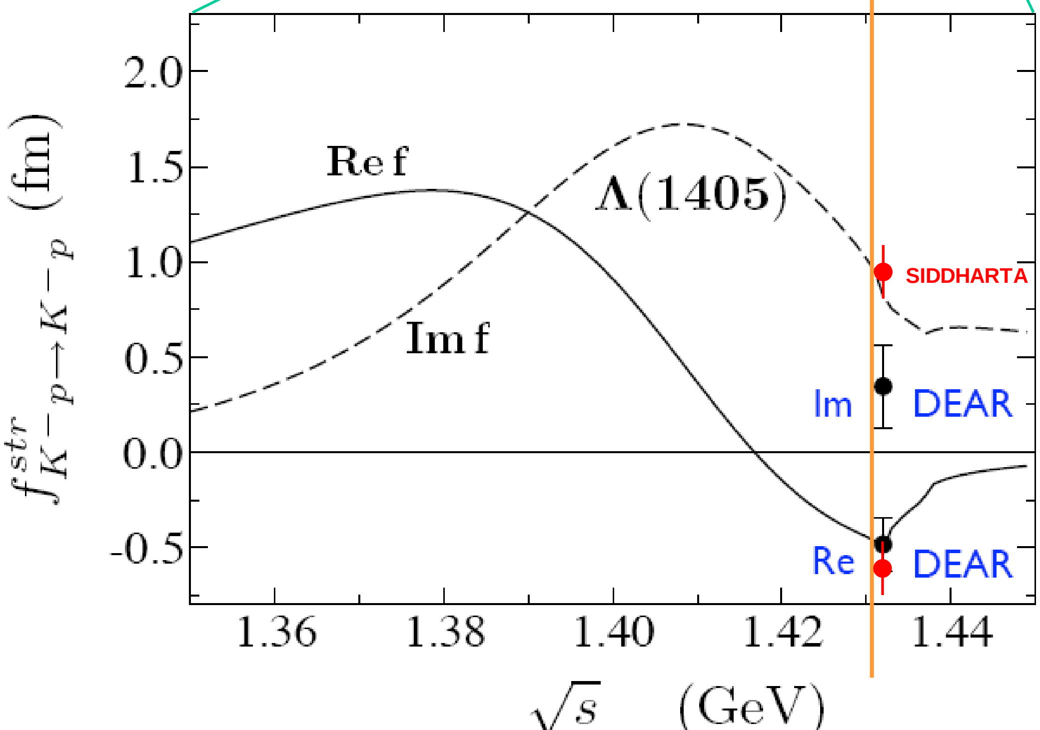
$\bar{K}$N – interaction



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

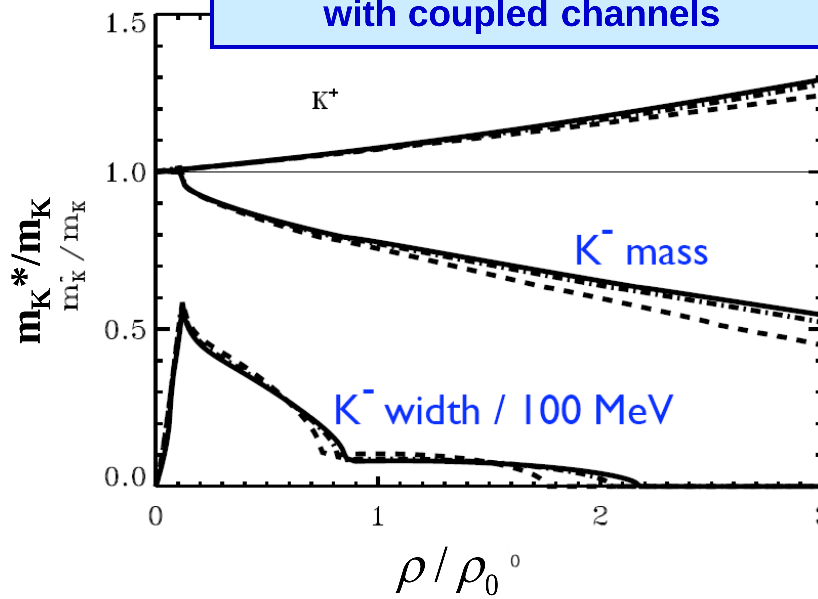
↑ $\bar{K}$ – energy

Scattering amplitude f



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

Motivation of high density kaonic clusters

NN- interaction:

Repulsive at small distances

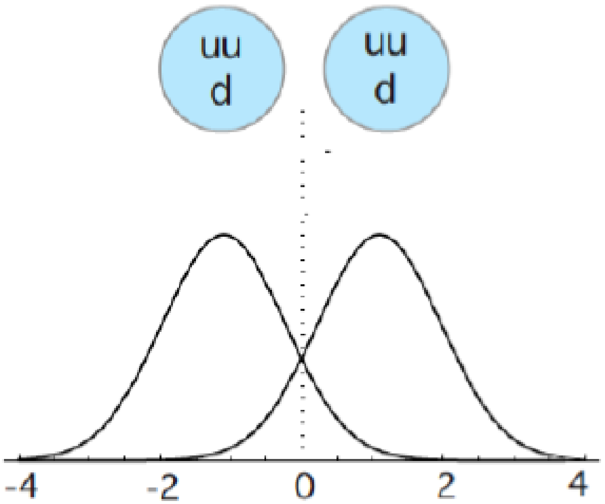
Pauli-blocking on quark level

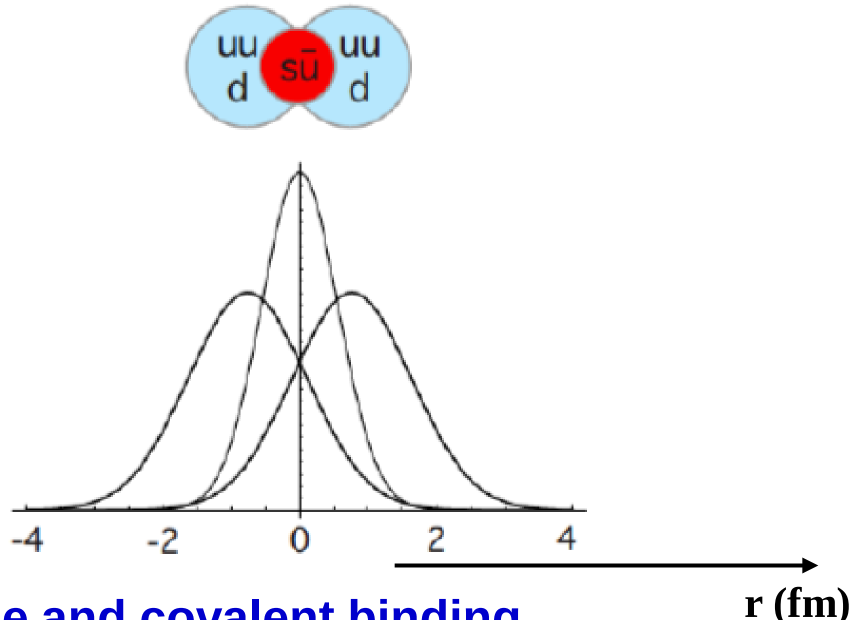
ppK^- - molecule:

$K^- = (\bar{u},s)$, no u,d quark

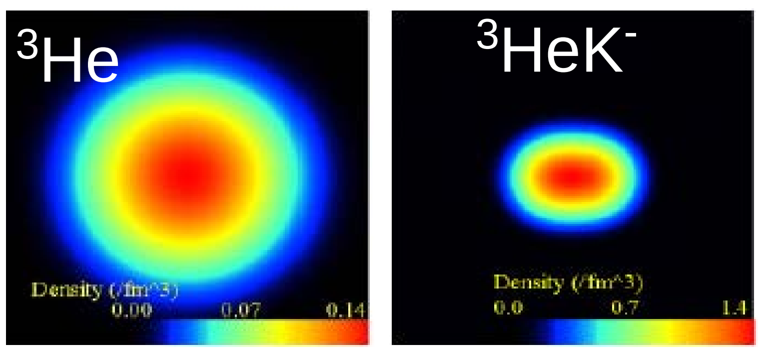
No Pauli repulsion

Strong attraction between $u\bar{u}$ and $d\bar{d}$





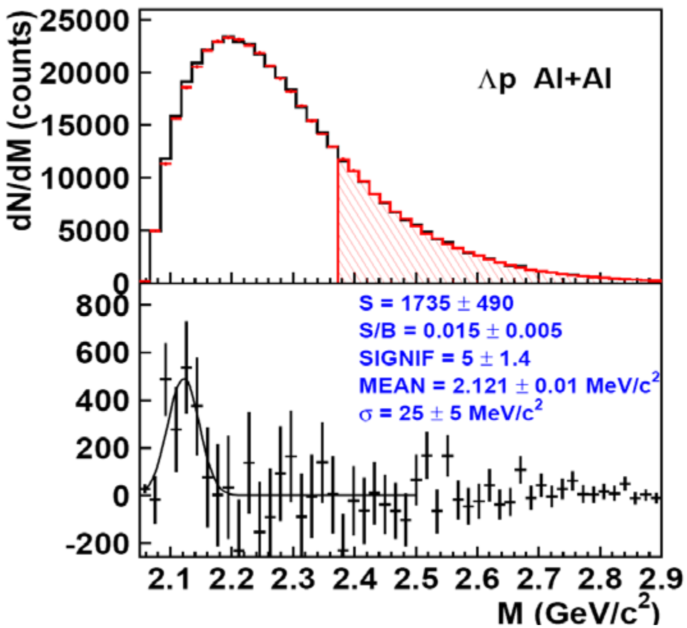
Analogy to H_2^+ - molecule and covalent binding

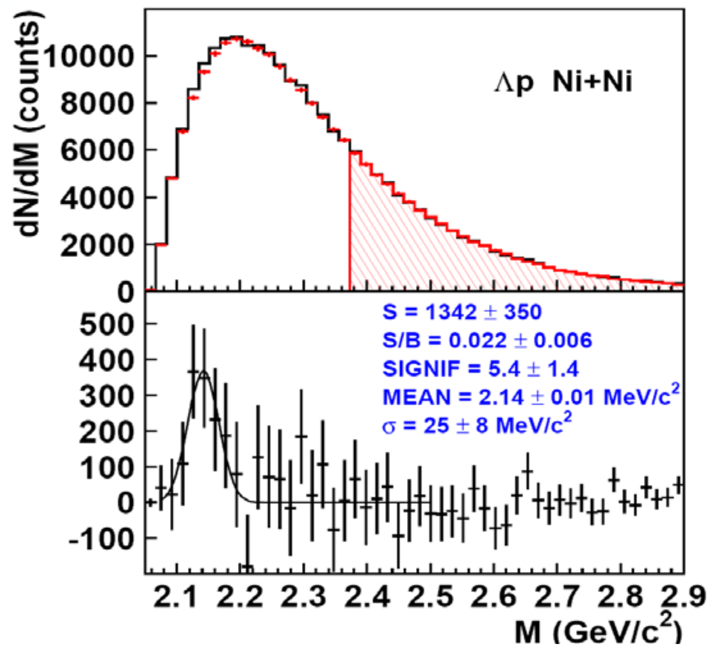


Y. Akaishi, T.Yamazaki, Phys.Rev.C65, 044005 (2002)
T.Yamazaki and Y. Akaishi, Phys.Lett.B535, (2002)

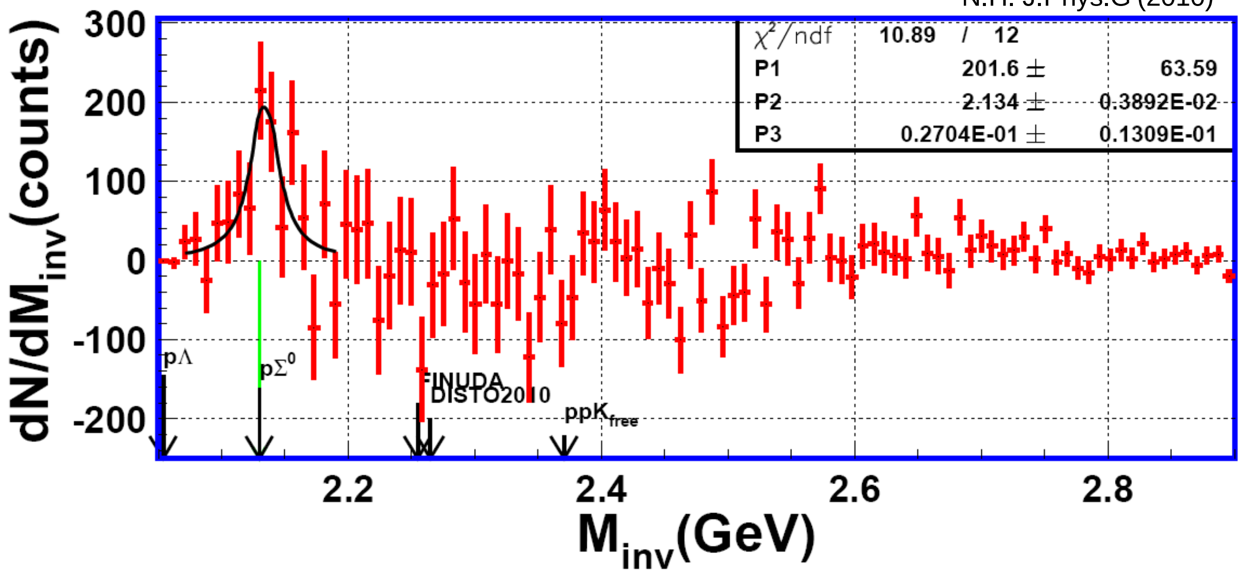
Λp – correlation

X.Lopez, HYP2006





N.H. J.Phys.G (2010)



M = 2.134+/-0.004 GeV

Γ= 26 +/-14 MeV

(statistical errors)

Λp – Interpretation?

Cusp (?) in pp – reactions:

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

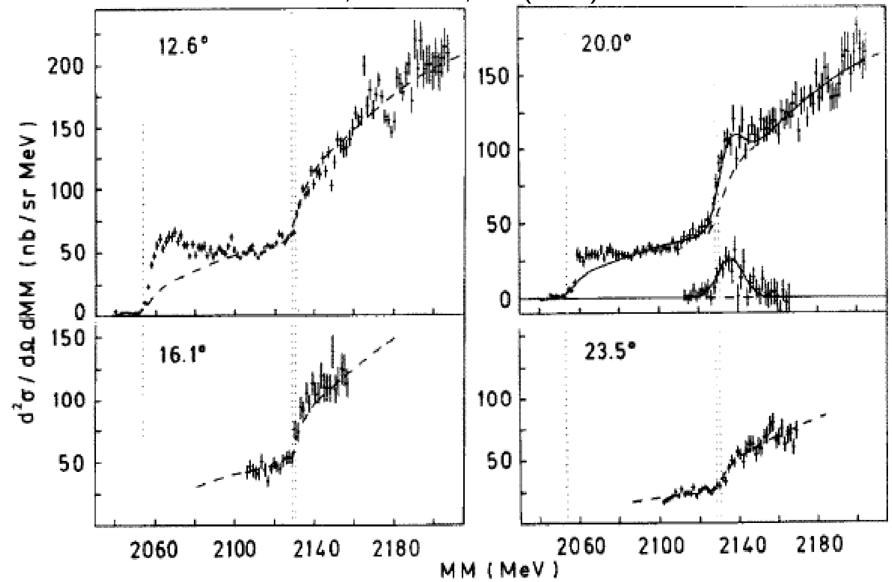
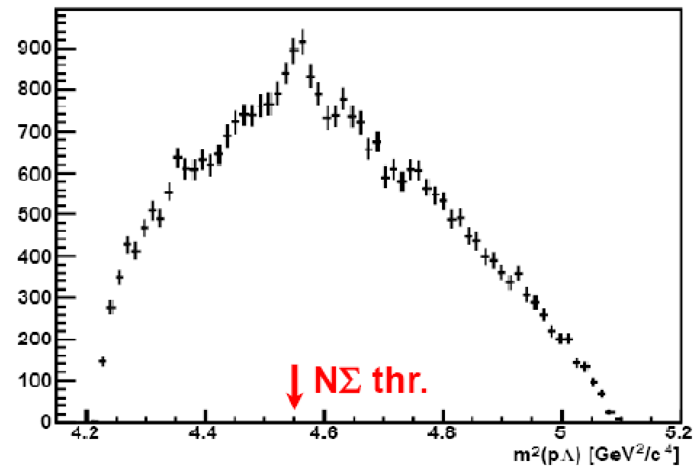


Fig. 6. Inclusive missing mass spectra for pp → K⁺X at 2.7 GeV incident energy. The kaon laboratory scattering angles are 12.6°, 16.1°, 20.0° and 23.5°. The bins are 1.5 MeV wide. The resolutions (FWHM) are approximately 3 MeV (12.6°), 4 MeV (16.1°), 3.5 MeV (20.0°) and 5 MeV (23.5°). The dashed lines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

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



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

Peak position consistent with p+p scattering data: M=2.315 ± 0.004GeV

Suggested interpretation: D_t (q4 x q2 structure)

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

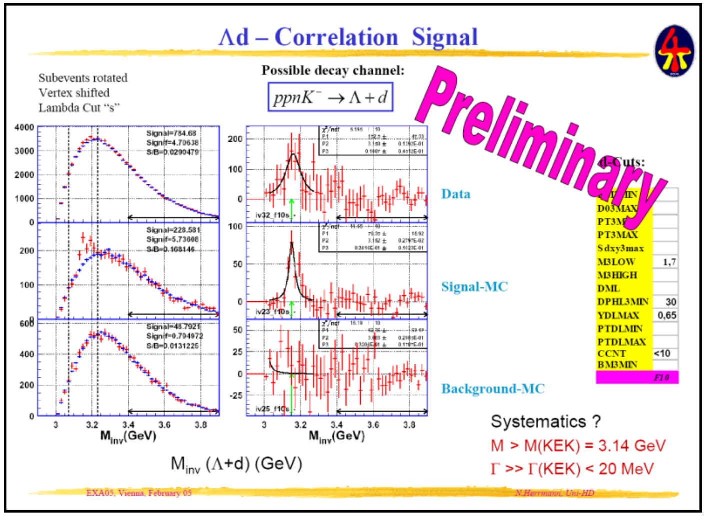
Object also seen in K^- + d → $\Lambda p \pi^-$ (O. Braun et al., NPB 124,45 (1977))

Interpretation: ΣN – bound state H(2129)

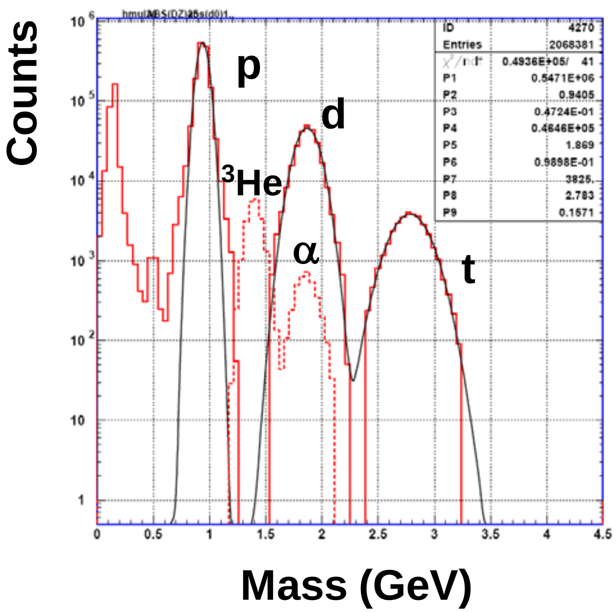
Λd – correlations

K. Wisniewski

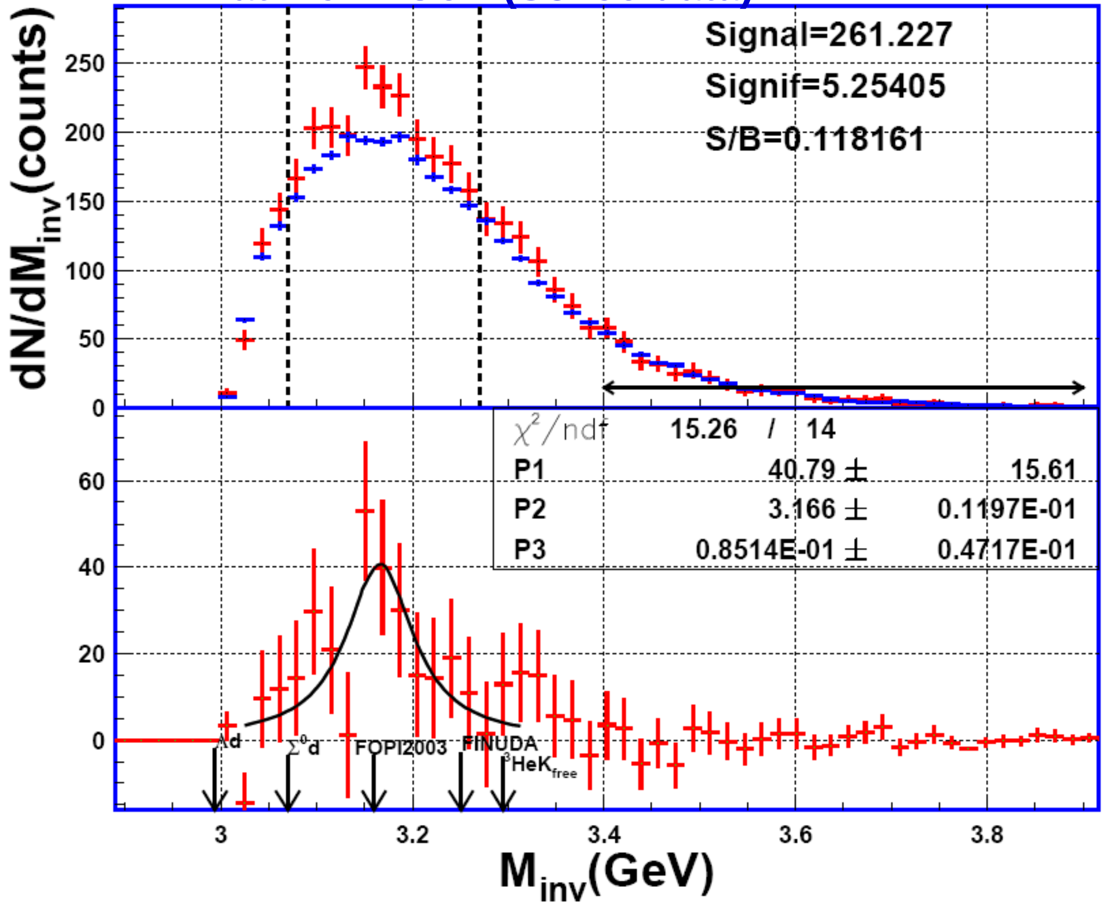
N. Herrmann, EXA2005



Improvement (2003→2008): PID



Ni+Ni at 1.91 AGeV (S325e data)

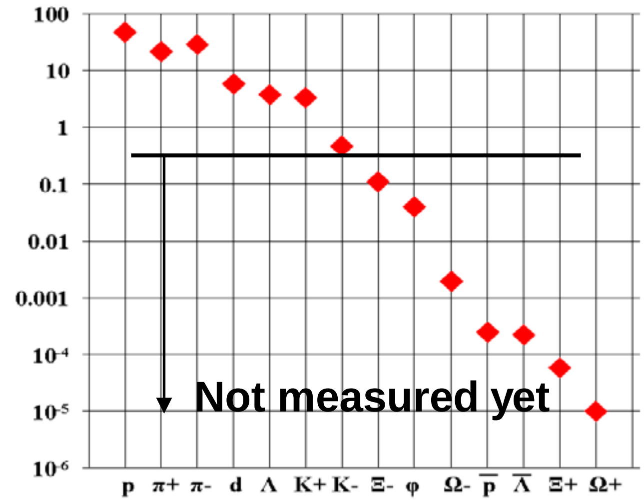


FOPI 2003 and 2008 data are consistent,
Inconsistent with cusp (Σ – d – threshold) and FINUDA.

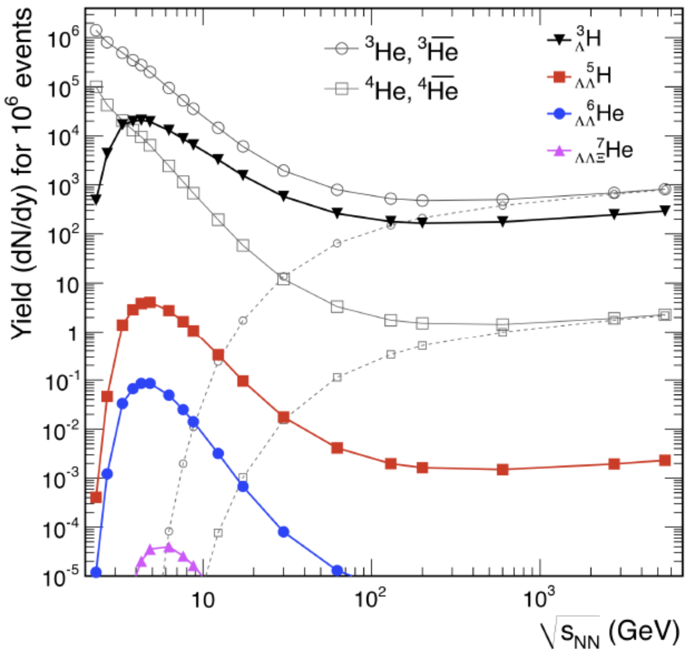
Strange objects to be measured by CBM

Standard hadrons

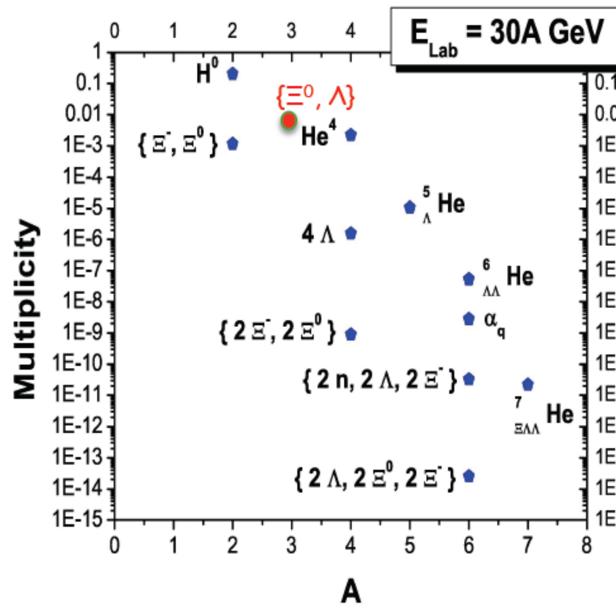
Au+Au 4 A GeV (statistical model)



Hypernuclei



Exotic states



Note:
World data of ΛΛ-hypernuclei: 4 emulsion events

CBM @ SIS100

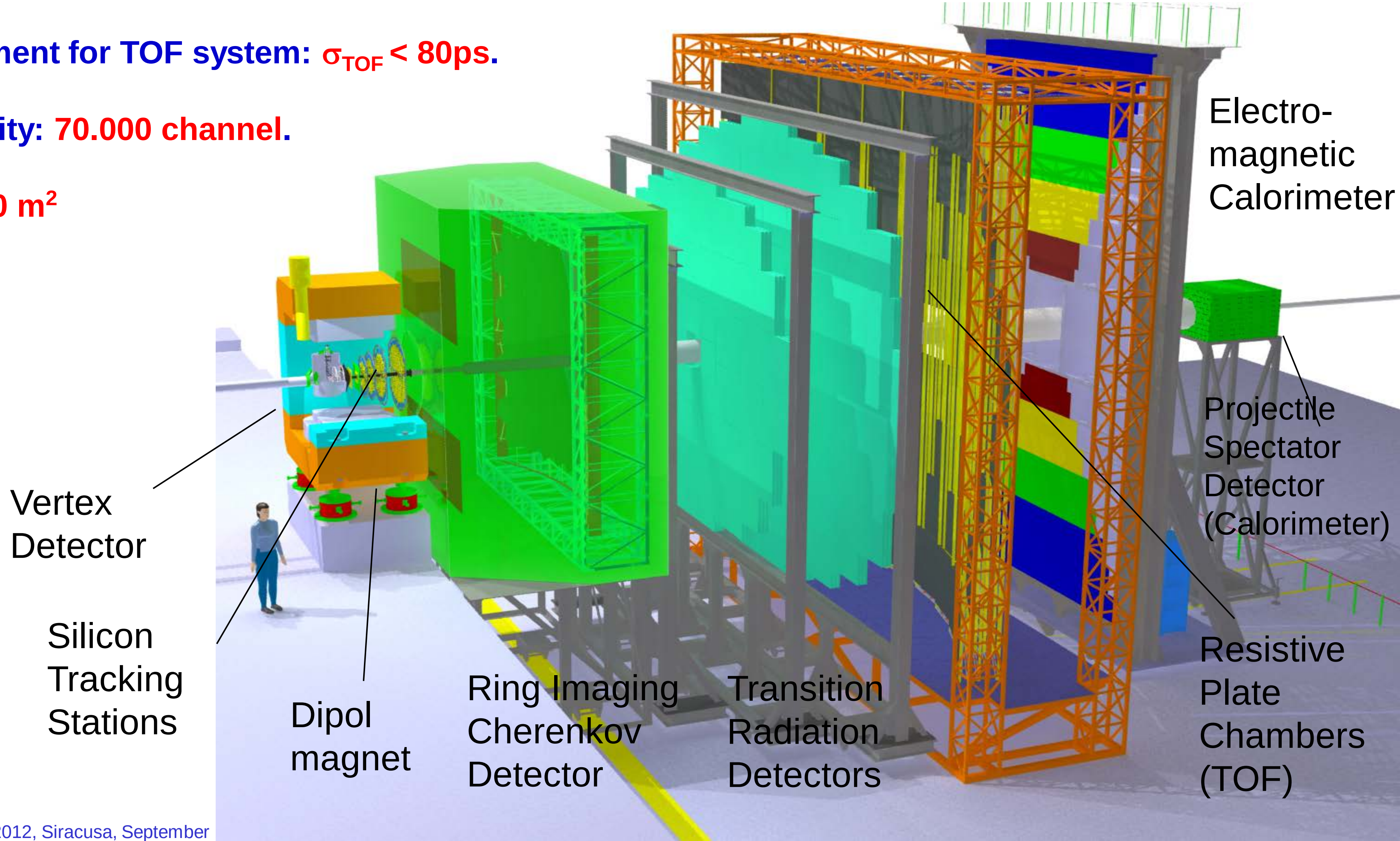
All components designed to run without trigger at 10 MHz interaction rate (free streaming readout).

RPCs at small angles are exposed to rates R=20 kHz/cm^2.

Requirement for TOF system: σ_{TOF} < 80ps.

Granularity: 70.000 channel.

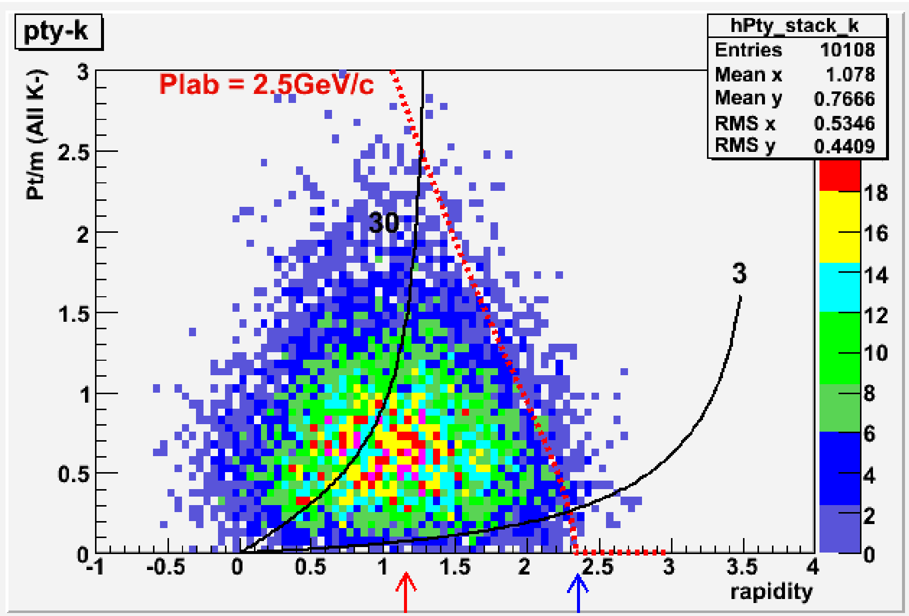
Area: 120 m^2

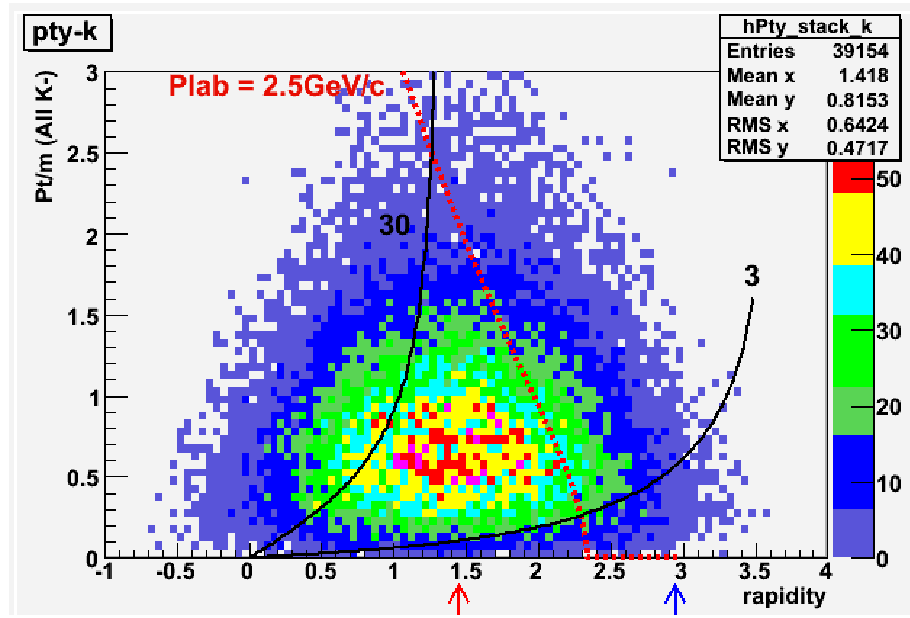


Kaon acceptance for CBM @ SIS100

URQMD acceptance simulations:

4AGeV **8AGeV**





Charged Kaon acceptance with 3σ – TOF separation:

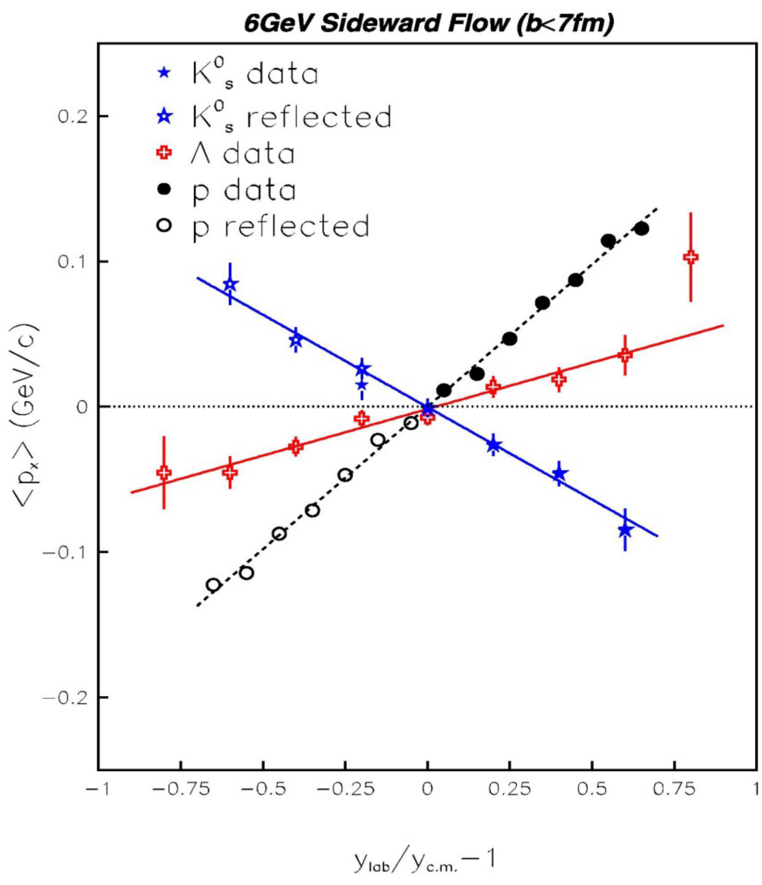
E_{lab} (AGeV)	4	6	8
ε	77%	64%	55%

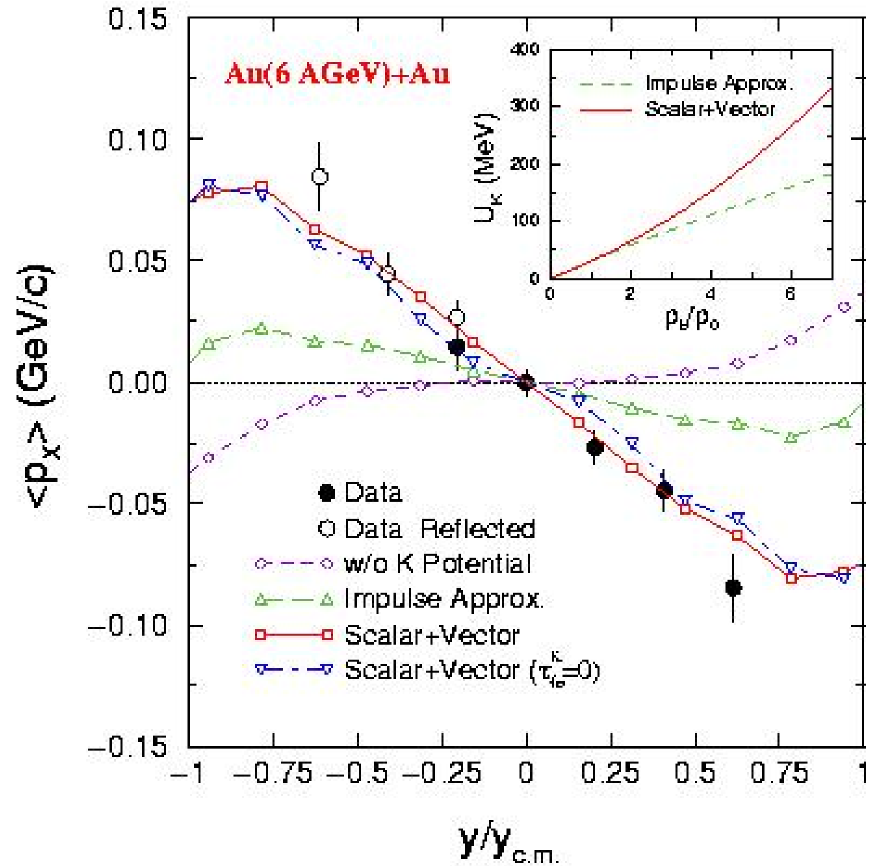
Coverage of low – p_t range of the spectrum !
K^+ - multiplicity selection (FLES) possible → enrichment of strangeness in interaction region.
However: Limited p_t acceptance at midrapidity (e.g. for $v_2(p_t)$) for E_{beam} < 4 AGeV

Kaon/Lambda sideflow at 6AGeV

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

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



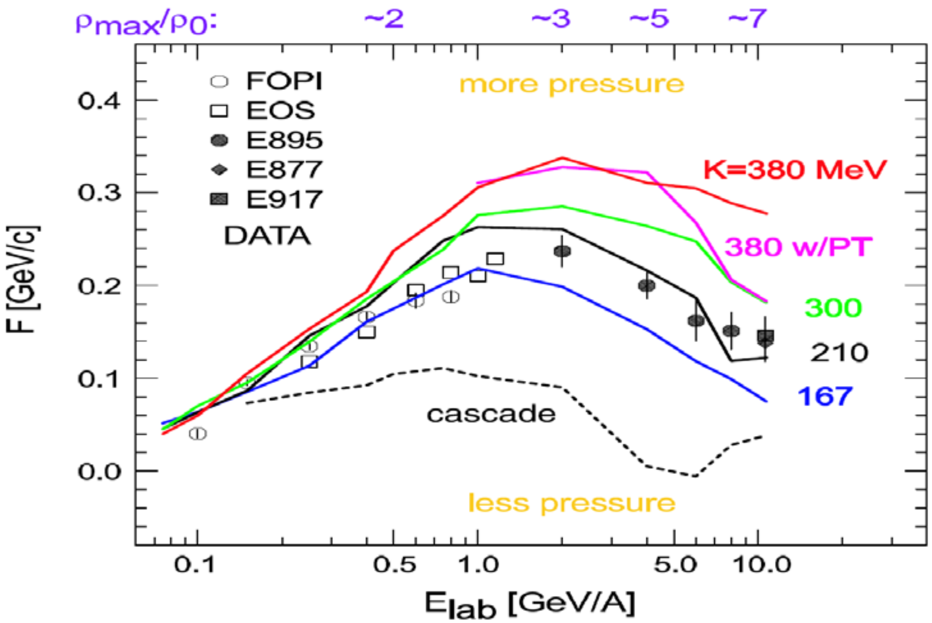


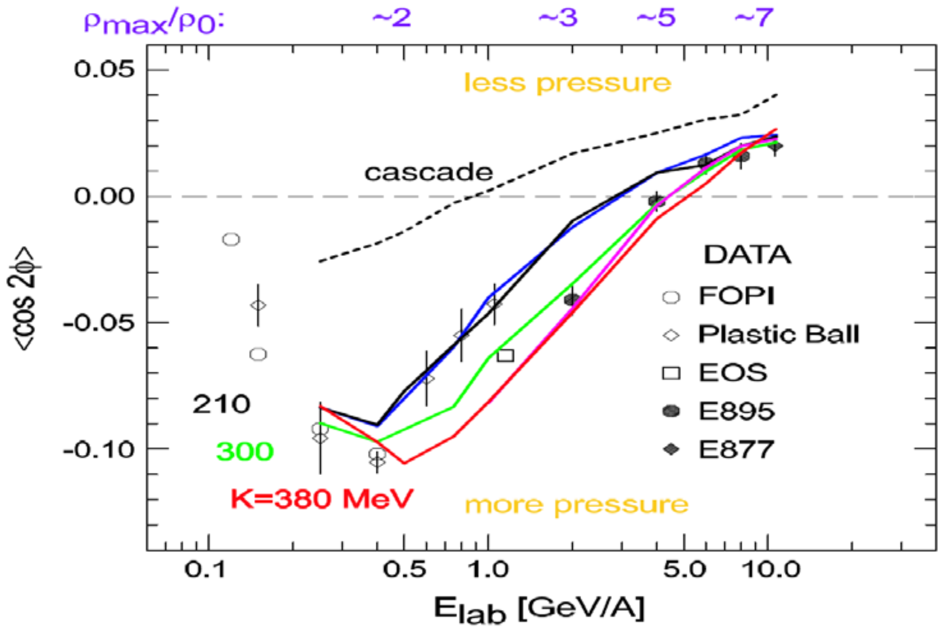
Very strong kaon antiflow signal, as big as proton flow (opposite sign)!

Excitation function of flow variables

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

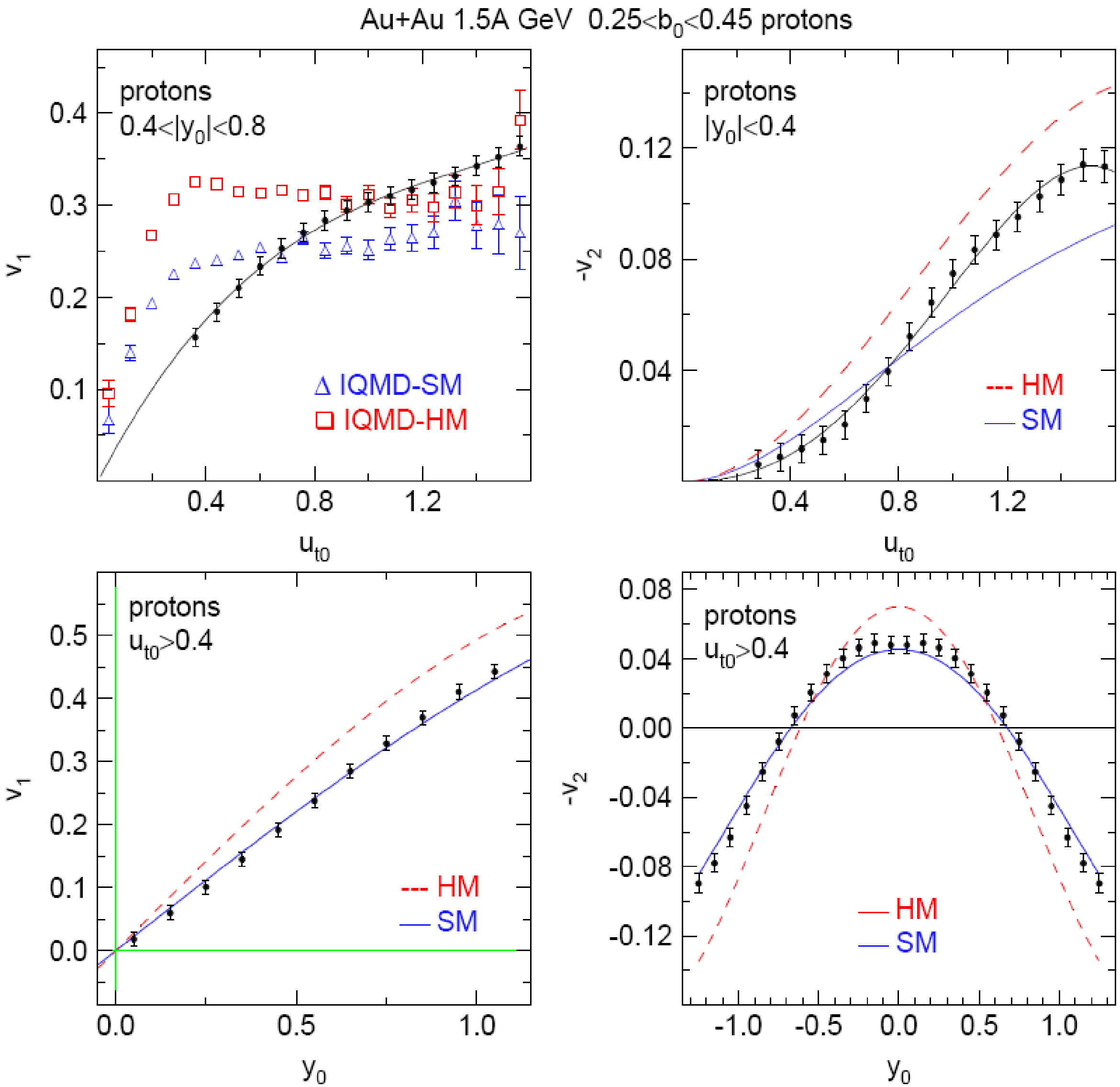
P. Danielewicz et al.
nucl-th/0112006 (2001),
Science 298, 1592 (2002)





- Mean field effects clearly visible by difference to 'cascade' calculations.
- None of the model calculations describes all the available data.
- 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.

Detailed model comparison at 1.5 AGeV

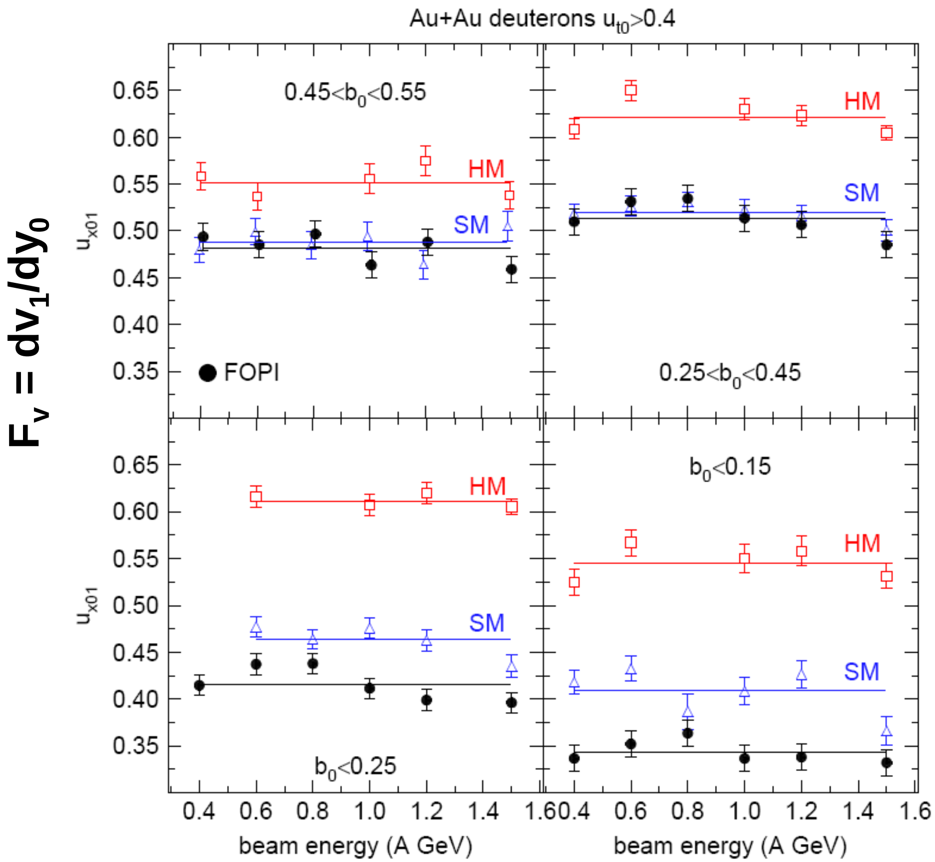


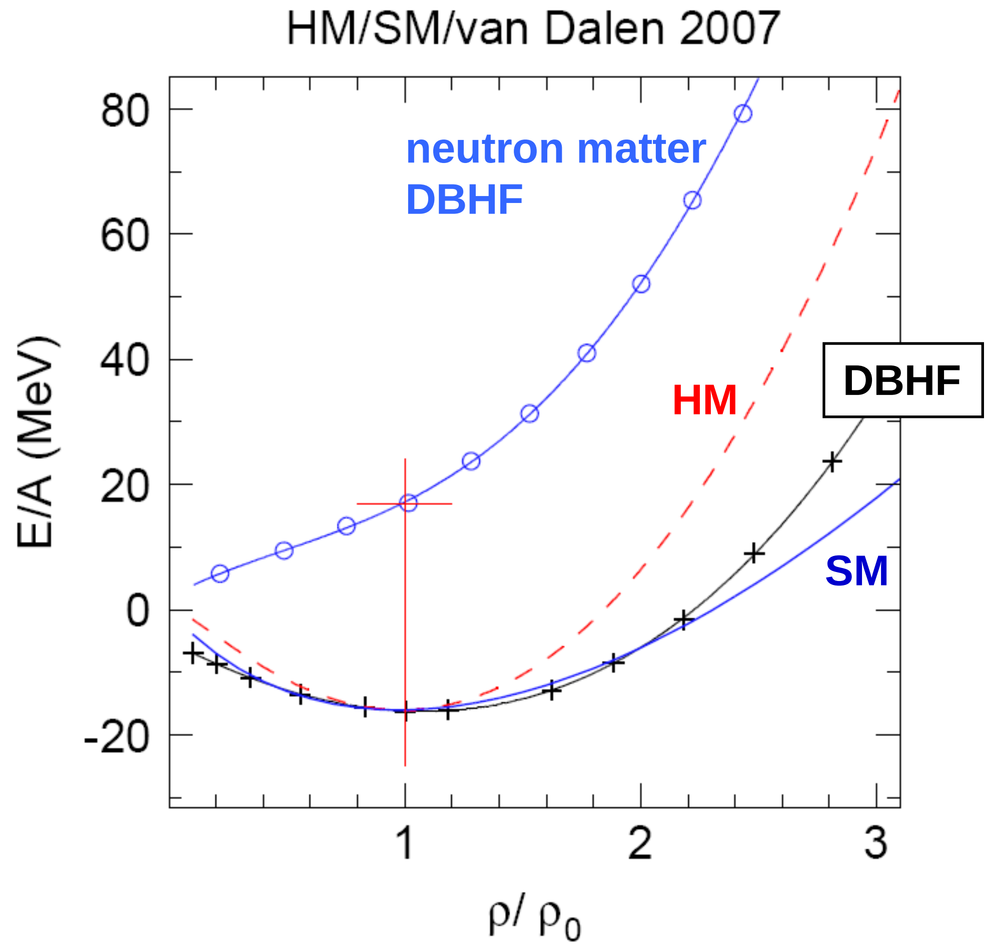
W. Reisdorf et al. (FOPI), NPA 876,1 (2012)
see also
W. Reisdorf et al. (FOPI), NPA 848, 366 (2010),
W. Reisdorf et al. (FOPI), NPA 781, 459 (2007)

Strong preference for SM even at E_{beam}=1.5 AGeV

Transverse momentum dependence of azimuthal asymmetry not reproduced by model

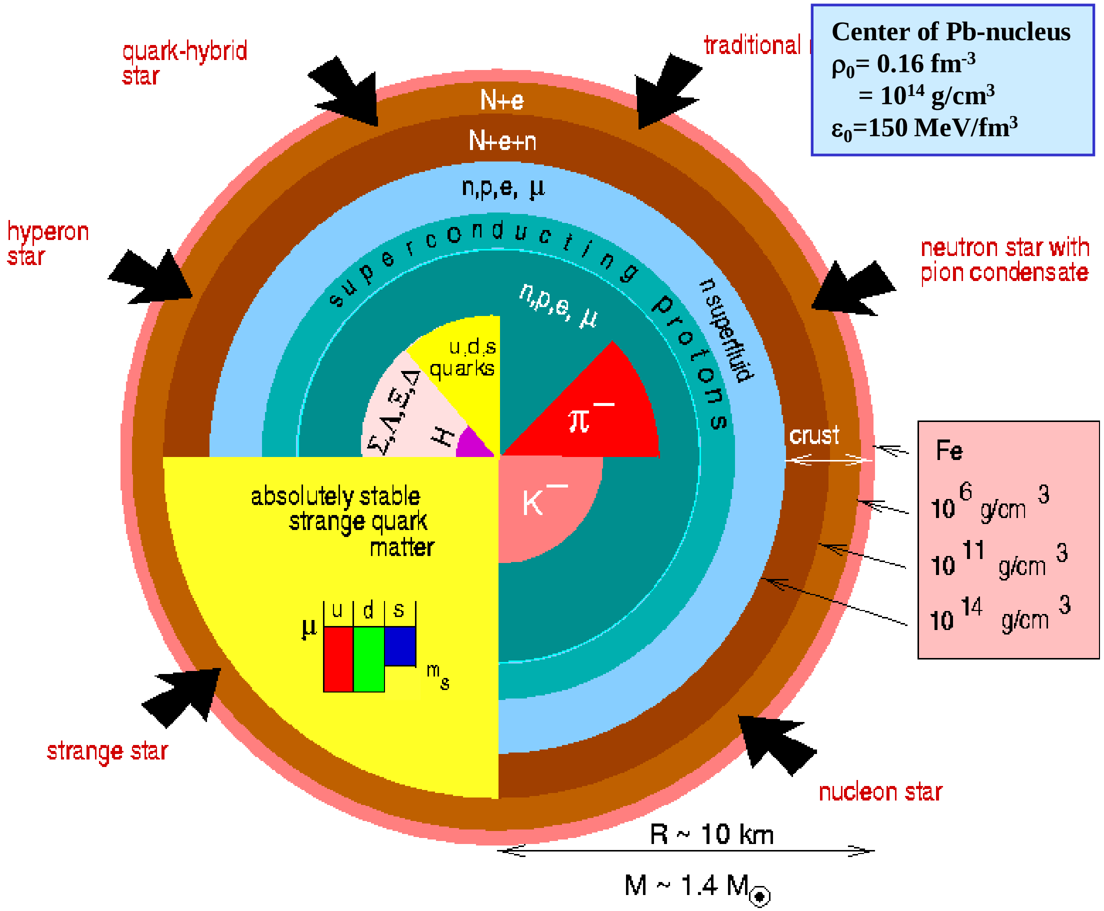
Equation – of – state





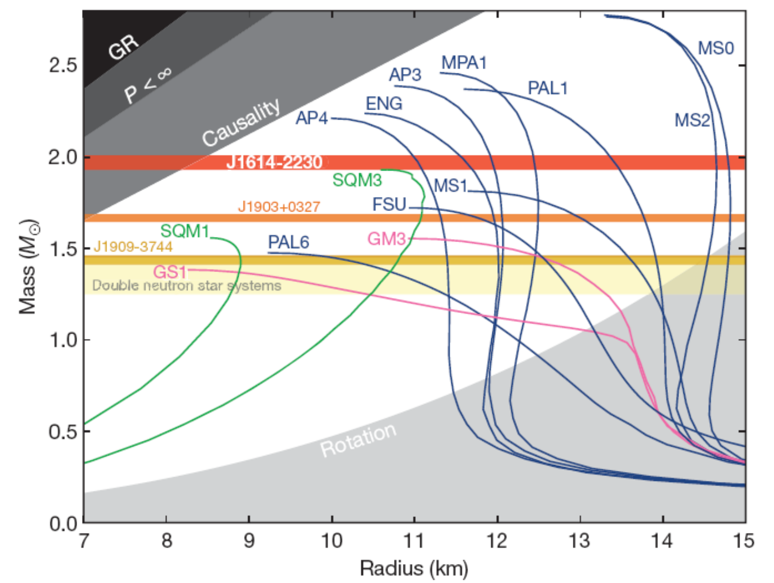
In the density range accessible at SIS18
SM agrees with many body theory (Dirac Brueckner Hartree Fock)

Inner structure of neutronstars



Recent developments:
2-solar-mass neutron star → stiff EOS

P.B. Demorest et al.,nature09466 (2010)



All EOS with kaon and hyperon condensates are excluded.
Stiffening of EOS will occur at densities accessible at SIS100.

F.Weber, LBL, Berkeley
Pulsars as Astrophysical Laboratories for Nuclear and Particle Physics
IOP Publishing, Bristol, Great Britain, 1999

Flow of charged kaons

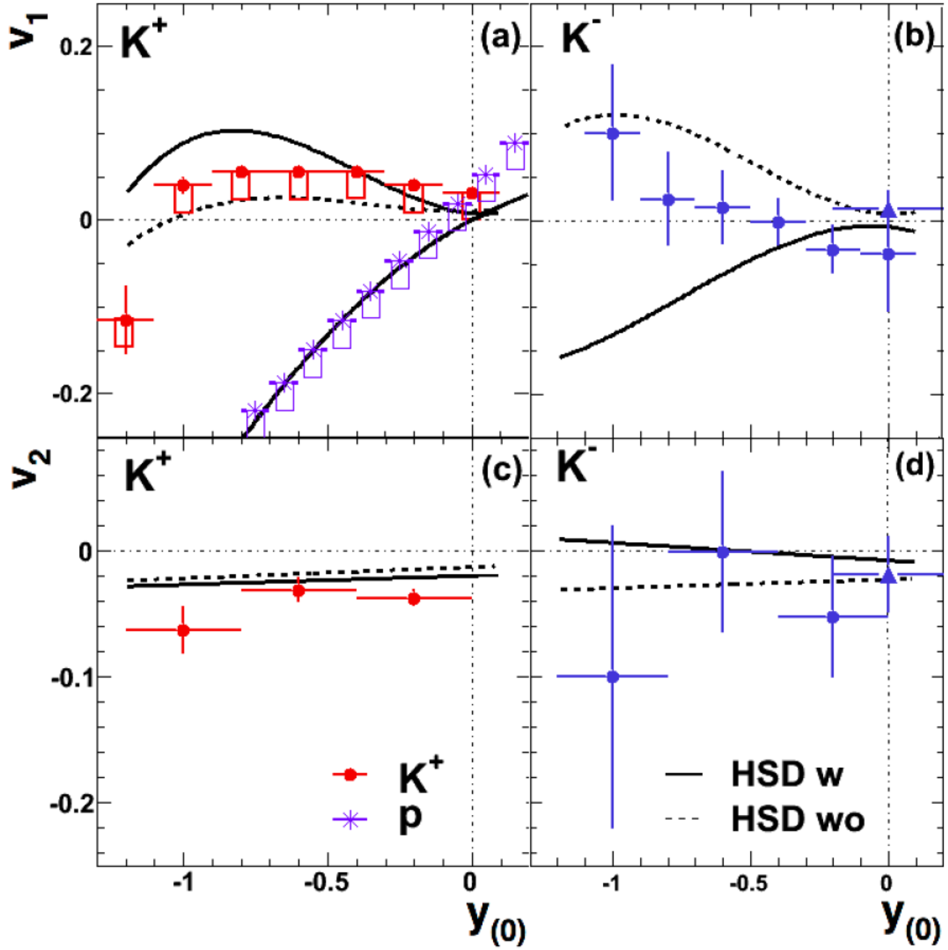
T.I.Kang, V.Zinyuk

Ni+Ni at 1.91 AGeV
(S325 + S325e data)
σ = 1.5 b
(b_{geo}= 7 fm)

Models with FOPI acceptance filter

Potentials with linear density dependence.

At $\rho=\rho_0$:
$U_{HSD}(K^+)$ +20 MeV
$U_{HSD}(K^-)$ - 50 MeV



K+ sideflow much smaller than expectation from model calculations.
K- sideflow compatible with zero, in variance with model expectiations.
K+ - elliptic flow negativ ⟶ out of plane emission.
K- - elliptic flow consistent with zero.

Summary / Conclusion

CBM has a very interesting physics program at SIS100 :

- **EOS**
- **hypernuclei**
- **strange baryons**
- **partial restoration of chiral symmetry (vector mesons)**
- **charm production in pA – collisions**

→ GSI – report 2012-1 (http://www-alt.gsi.de/documents/DOC-2011-Aug-29.html).

Detector development ongoing to achieve interaction rate of 10 MHz (Au + Au @ 25 AGeV).

CBM - TDRs are being prepared

Magnet	**Dec. 2012**
STS	**Dec. 2012**
TOF	**Dec. 2013**

Isospin effect have not been considered so far, suggestions are welcome.

Epilog

X. Lopez et al. (FOPI), Phys. Rev. C 75, 011901(R) (2007)

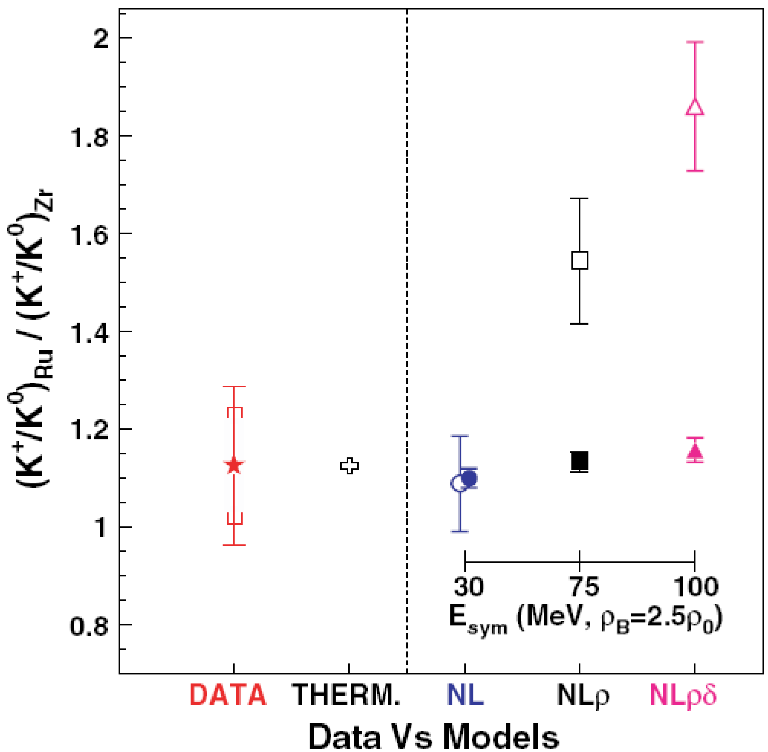


FIG. 3. (Color online) Experimental ratio $(K^+/K^0)_{\mathrm{Ru}}/(K^+/K^0)_{\mathrm{Zr}}$ (star) and theoretical predictions of the thermal model (cross) and the transport model with three different assumptions on the symmetry energy: NL (circles), NLρ (squares), and NL$\rho\delta$ (triangles), for two sets of calculations: INM (open symbols) and HIC (full symbols) (see text for more details). Statistic and systematic errors are represented by vertical bars and brackets, respectively.

Difference in production yield might be measurable with CBM.

Experimental errors can be reduced by ~ 100!

Is N/Z equilibration theoretically under control?