The CBM SIS100 program for hadronic observables

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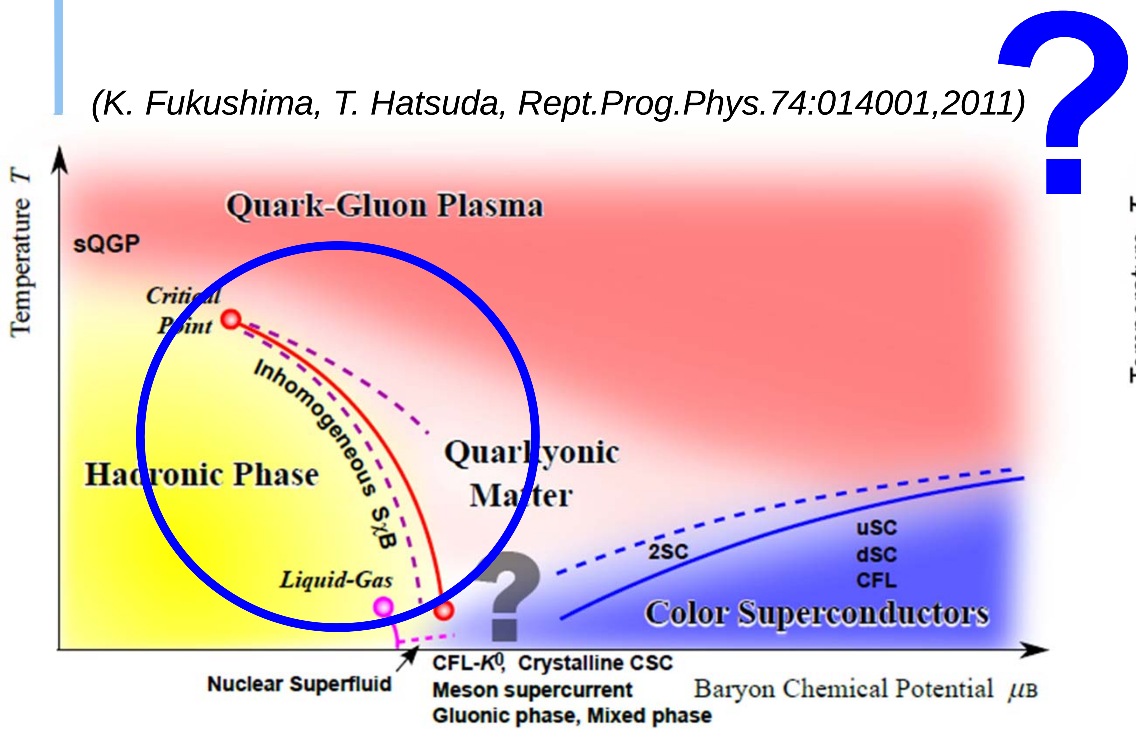
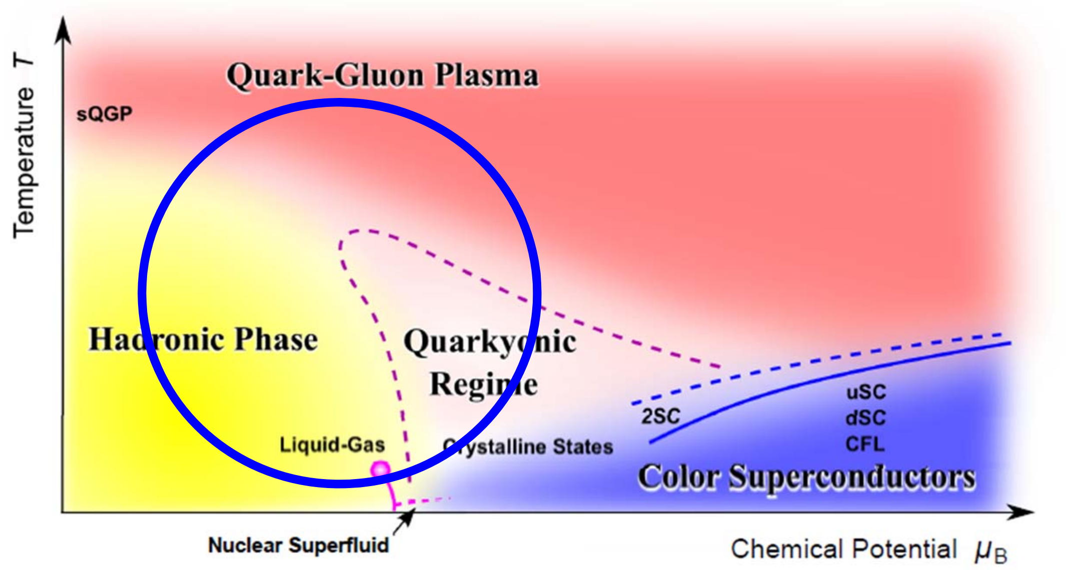
Claudia Höhne, Universität Giessen & GSI

QCD phase diagram

(K. Fukushima, T. Hatsuda, Rept.Prog.Phys.74:014001,2011)





Field driven by experimental data!

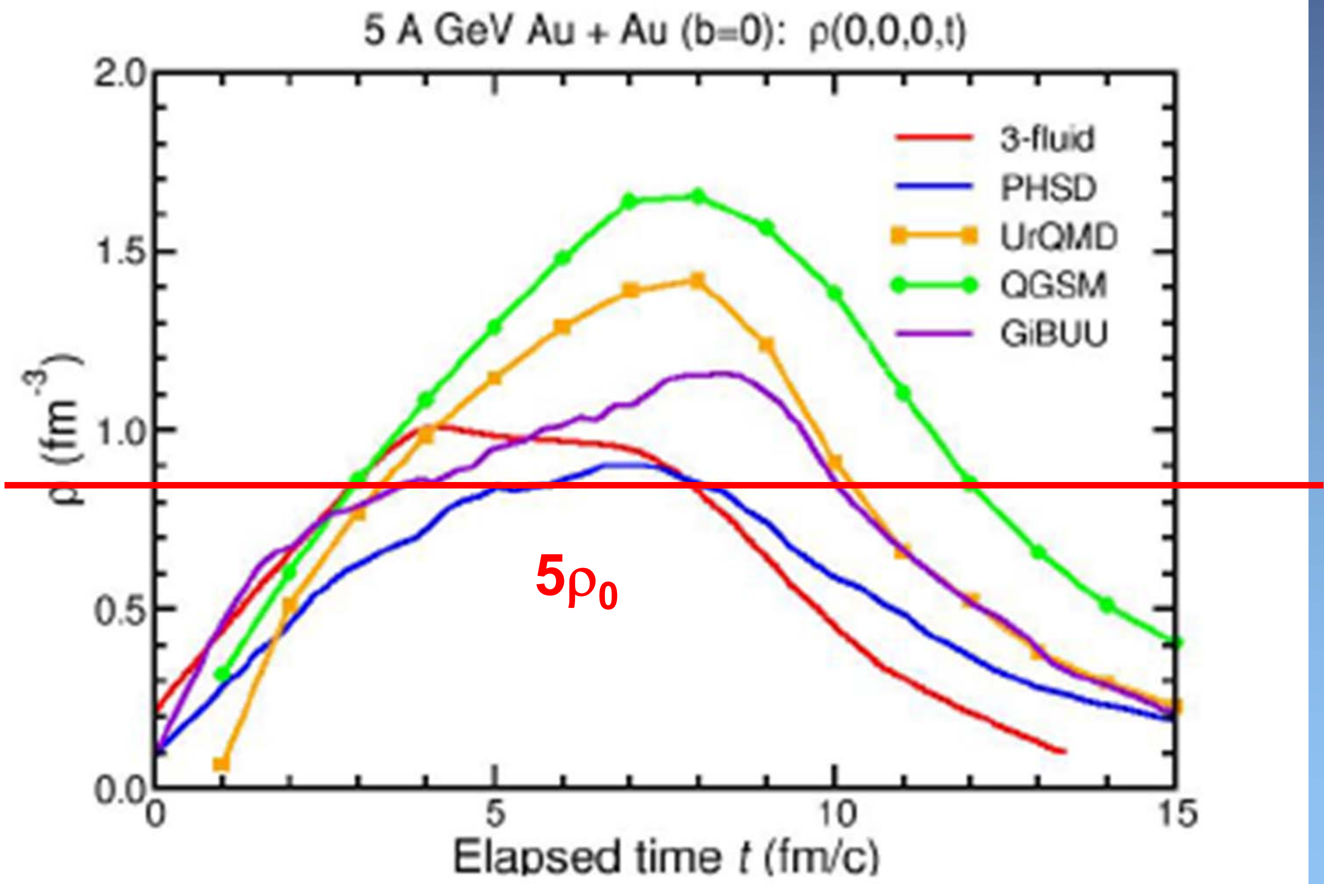
Need: ~ 2-40 AGeV beam energies

Outline:

- QCD phase diagram
- Hadronic probes in heavy-ion collisions (SIS 100)
  - → Thermalization, Multi-s-Baryons, Flow, Fluctuations
  - → kaonic clusters, hypernuclei
- Strategy of CBM
- Conclusion

Baryon density

- SIS 100 beam energy range for Au: up to 11 AGeV ($\sqrt{s_{NN}}$=4.7 GeV)
- High baryon-densities can be probed at SIS 100
- Expected to persist for a few fm/c
- Characteristics of matter created?



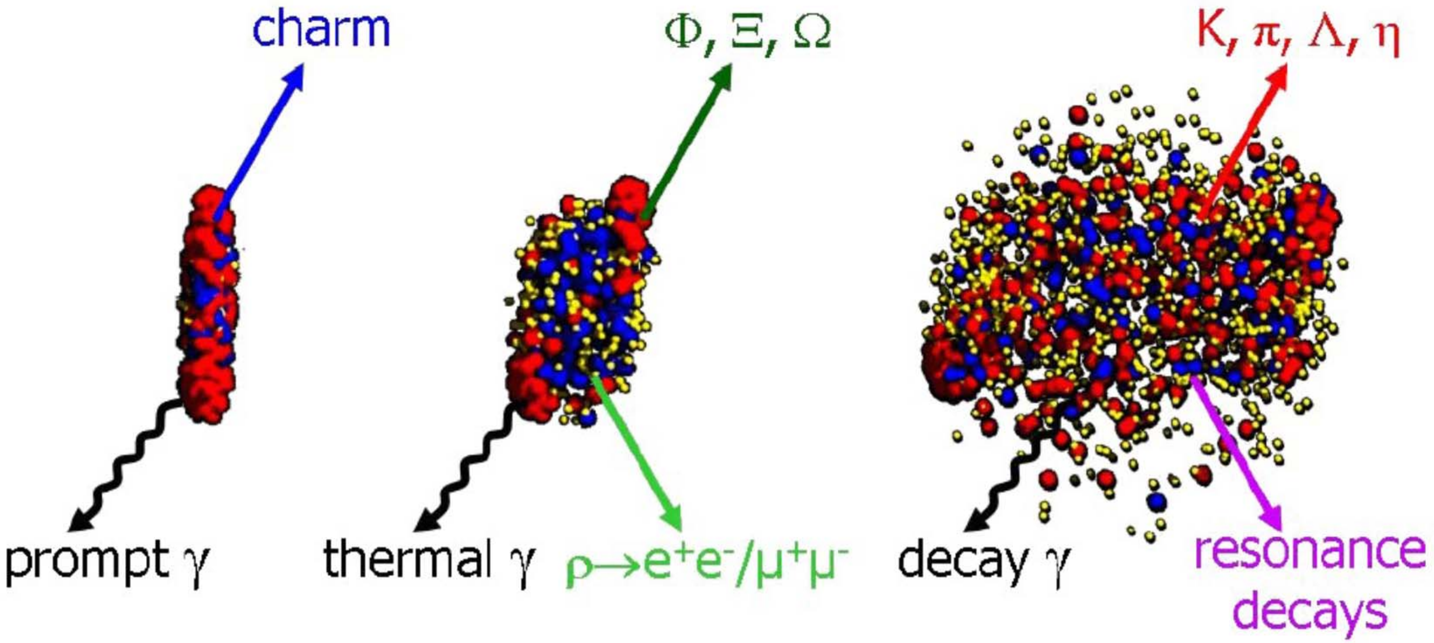
[CBM Physics Book]

Heavy – Ion Collisions

Hadrons:

- In final state: thermalized?
- From „before“: relicts from high density phase still carrying information?

Penetrating probes: *… not this talk …*



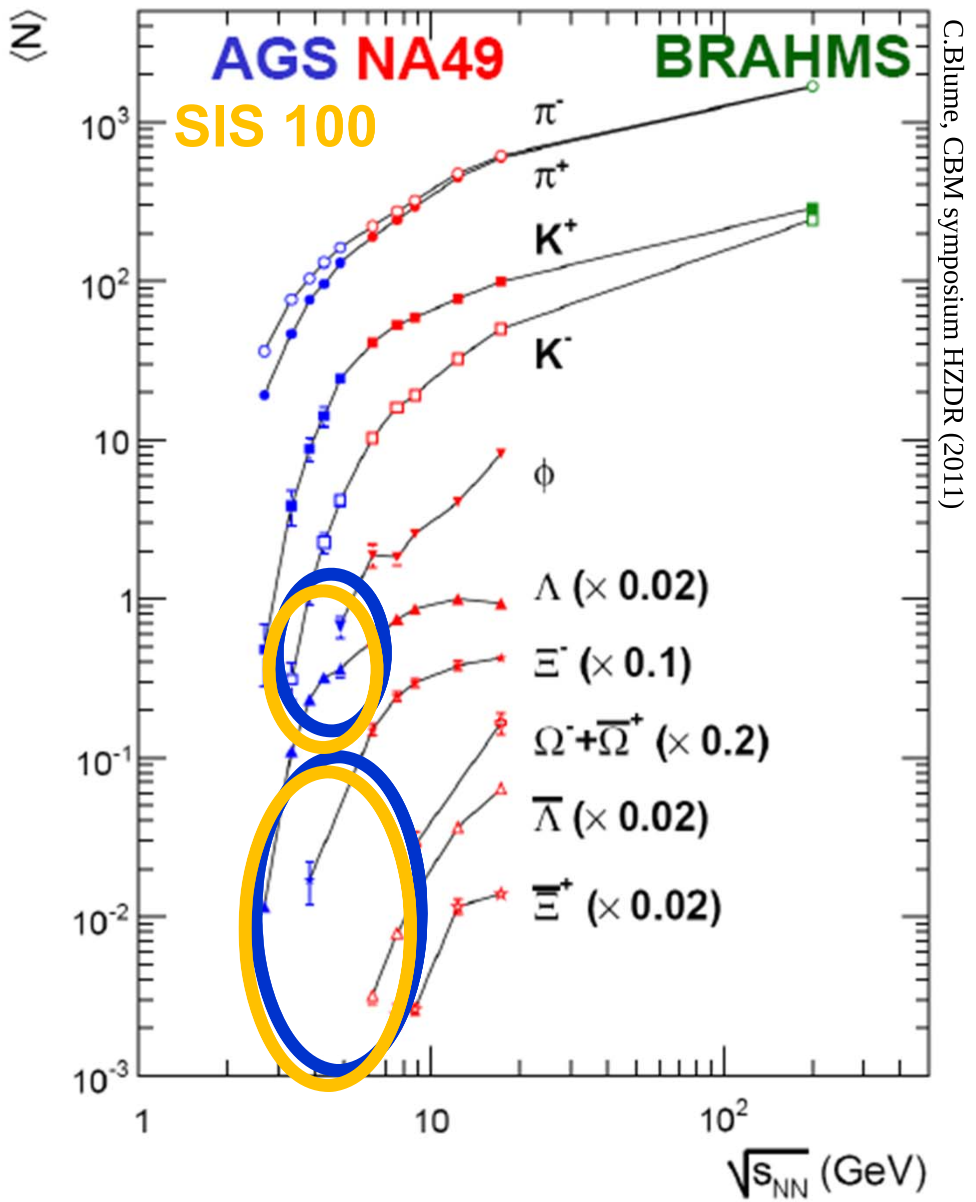
Hard probes
(initial state)

Penetrating probes
(integrate over collision history)
“Relicts”
(produced in dense phase)

Freeze-out
(final state particles)

Thermalized (?) hadrons

Final state particle abundance



Particle yields from central Au+Au/ Pb+Pb collisions

Knowledge about strange (anti-)baryons in FAIR energy range is rather limited

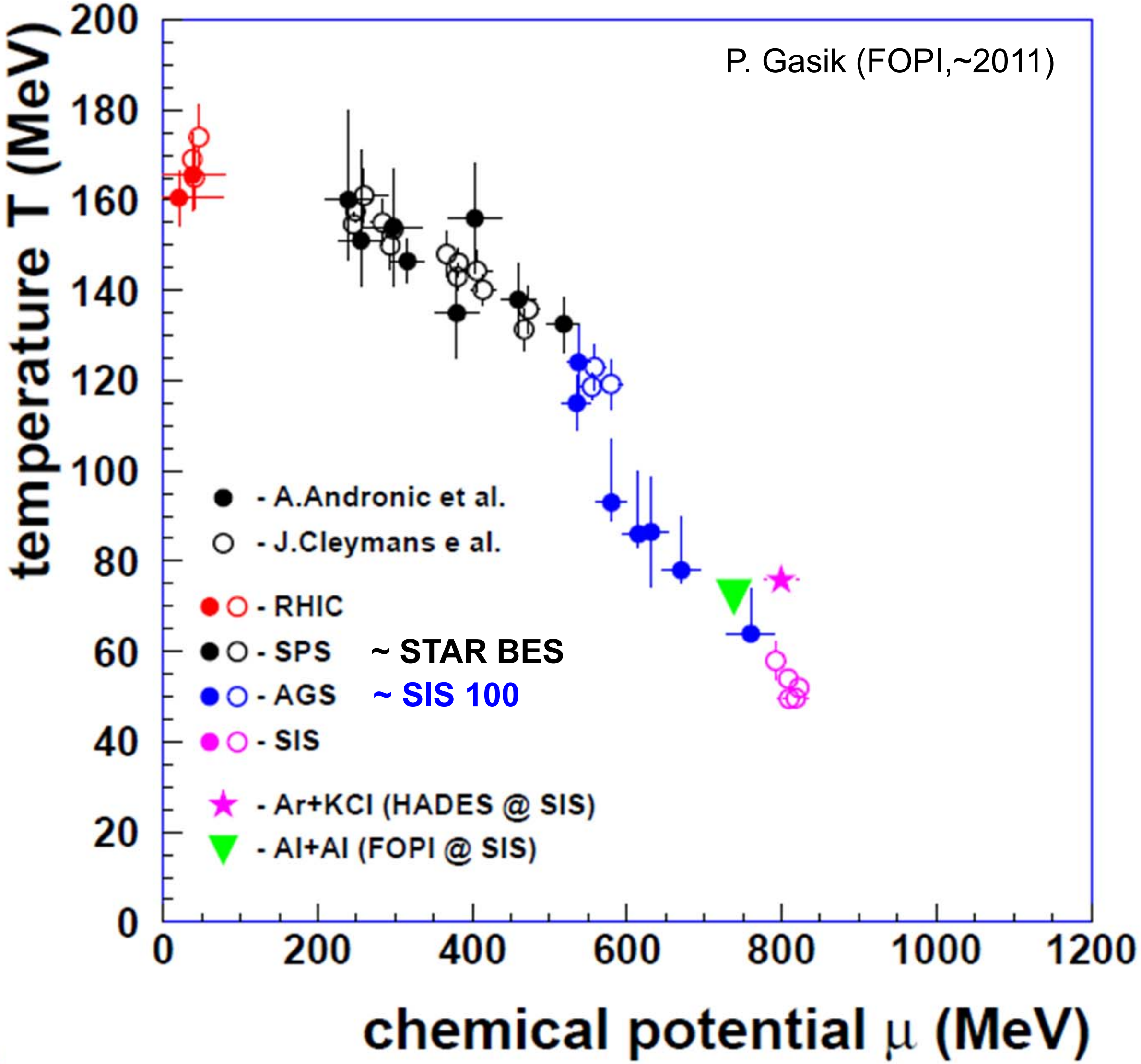
Validity of thermal model for low energies?

Note:

Direct multi-strange hyperon production:

$pp \rightarrow \Xi^- K^+ K^+ p$ (E_{thr} = 3.7 GeV)
$pp \rightarrow \Omega^- K^+ K^+ K^0 p$ (E_{thr} = 7.0 GeV)

Chemical Freeze-out data



Assumption:
thermodynamic equilibrium
(Canonical ensemble at lower energies)

Equilibrium as signature for phase transition?
Multi-strange Baryons?
ϕ-meson?

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

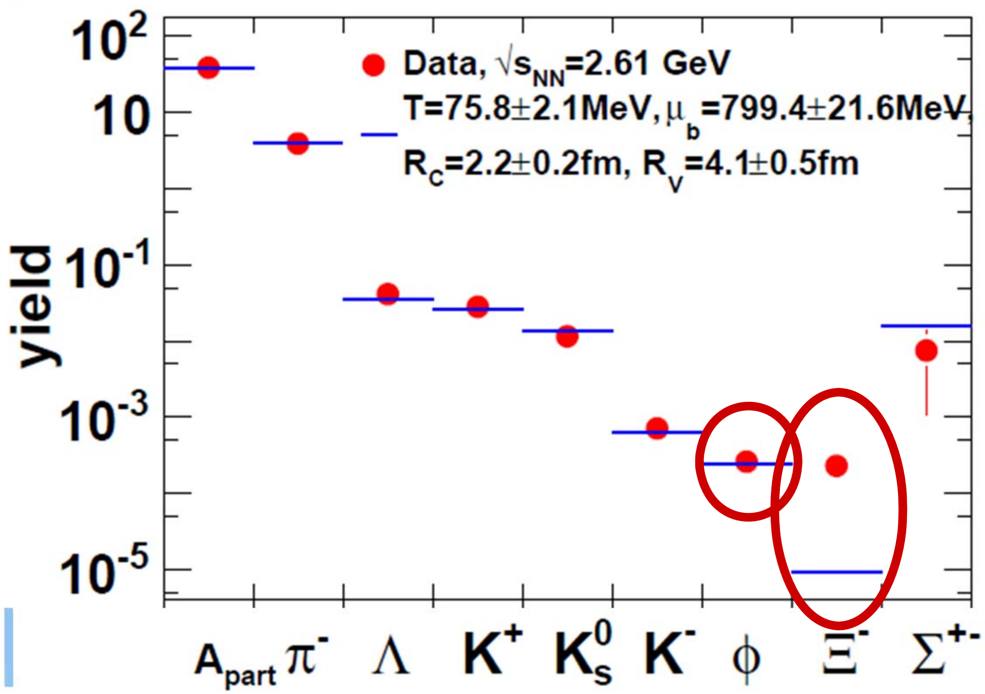
G. Agakishiev et al. (HADES), Eur. Phys.J. A47 (2011) 21

Errors include systematic errors (if given)

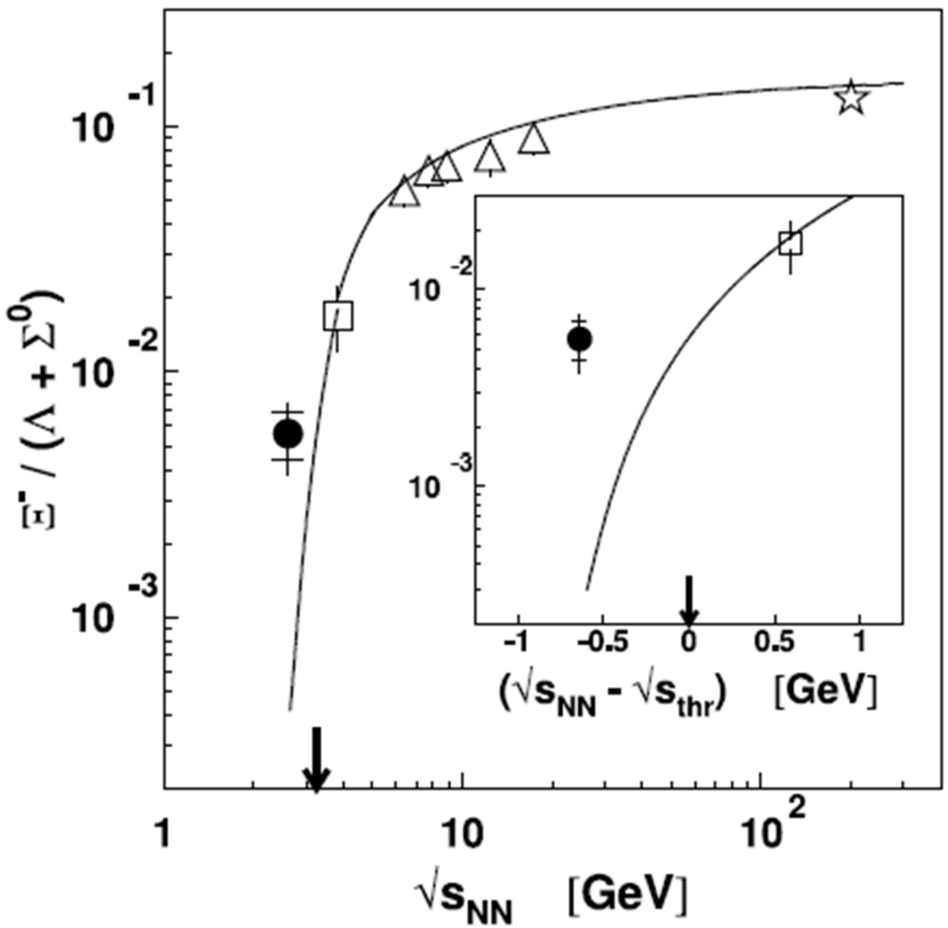
HADES: Sub-threshold Ξ^- - production

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) ?
- ϕ fitted perfectly well ….

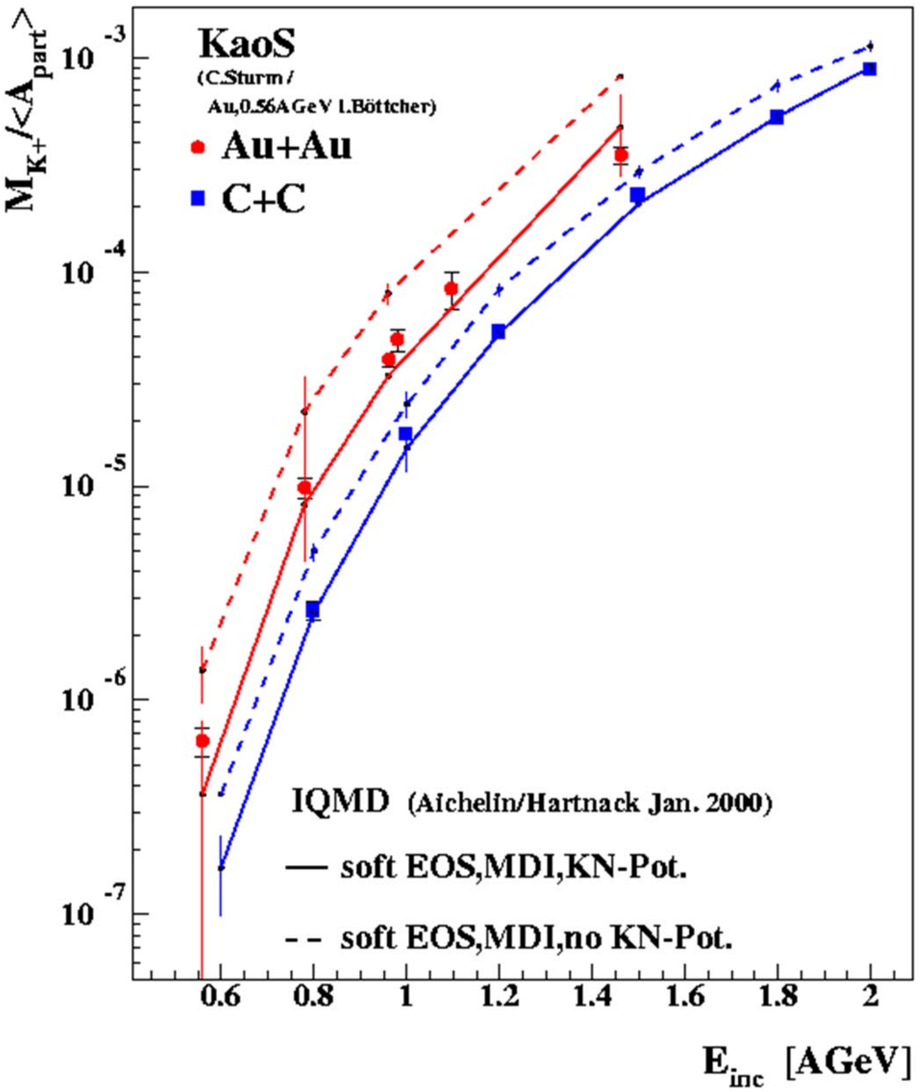


G. Agakishiev et al. (HADES), PRL103, 132301, (2009)



Reminder: Subthreshold Kaons (KAOS)

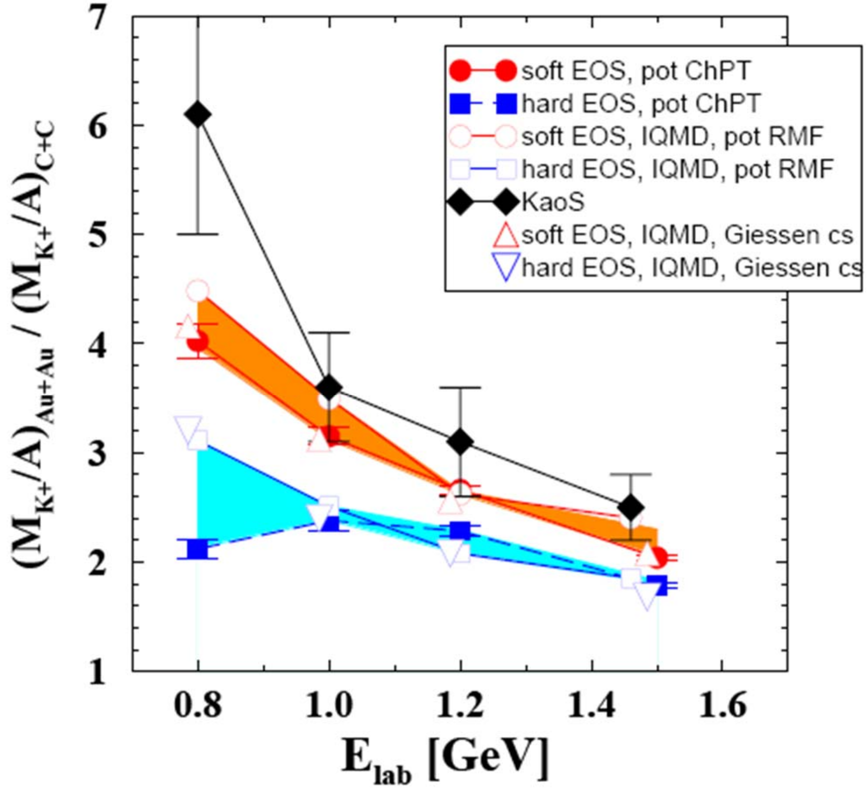
C.Sturm et al. (KaoS), PRL 86 (2001) 39



Strong sensitivity to EOS due to multistep production (formation of nucleon resonances)

=> soft EOS (K=200)

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

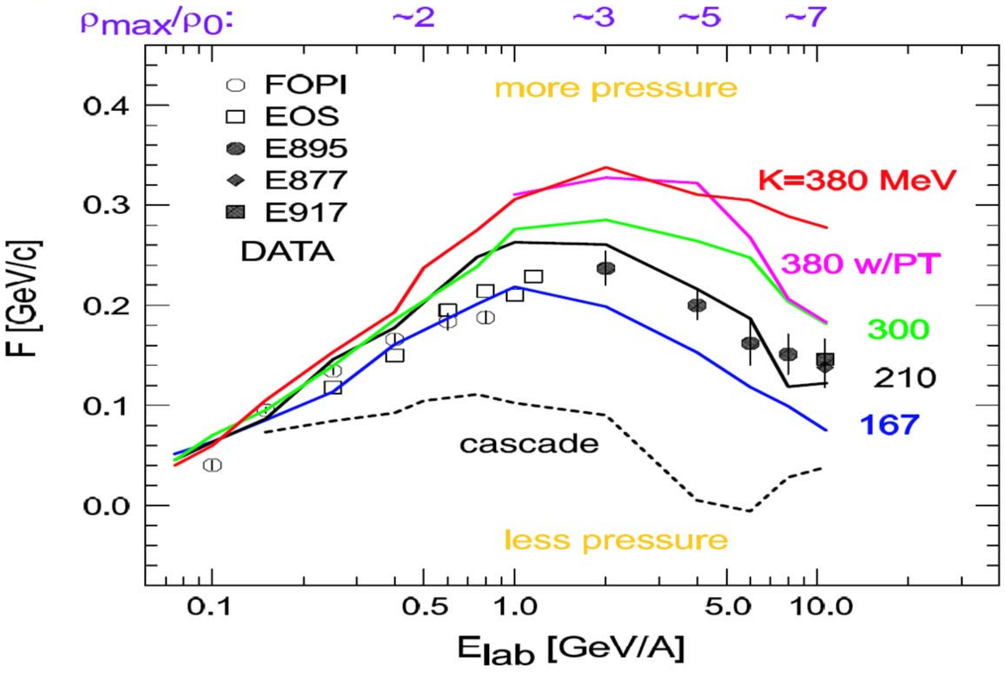


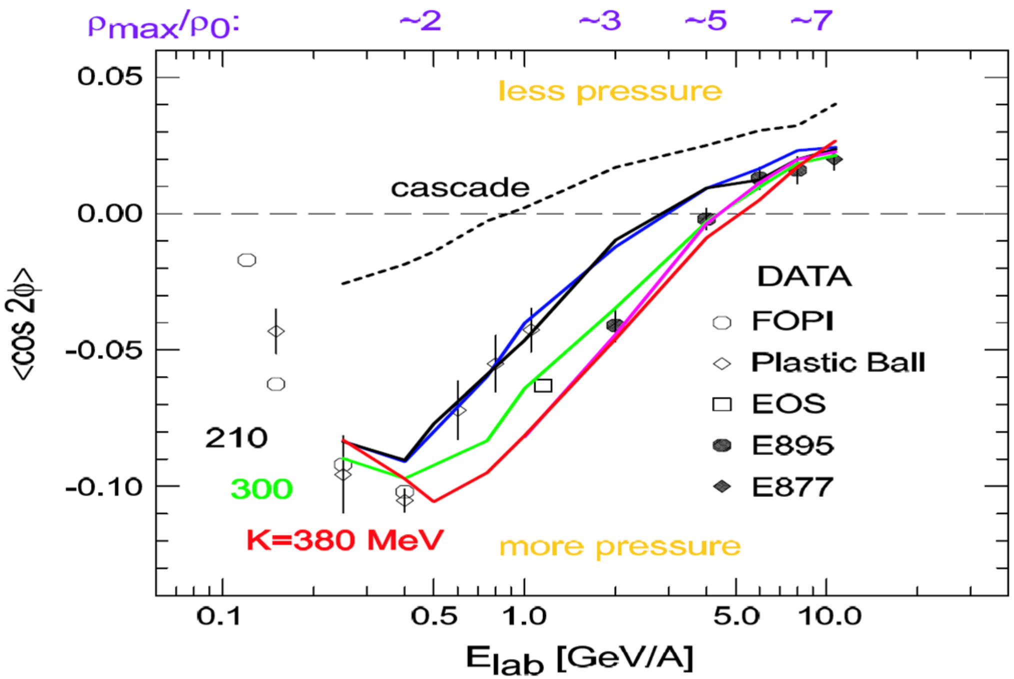
Sensitivity of multi-s baryons to μ_B, EOS?

Excitation function of flow variables (protons)

$$F = \frac{d\langle p_x / A\rangle}{d(y / y_{cm})}$$ = slope of v_1 at y_{CM}

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





Flow of protons as "classical" EOS variable:

- Protons represent only minor part of matter at low energies: deuterons, clusters?
- No consistent model description available so far
- Uncertainty in data at 1 GeV/A corresponds to uncertainty in K of 150 MeV
- Largest sensitivity to model parameters (EOS) in energy range 2 – 5 AGeV

Flow of charged kaons

Properties of mesons in matter?

Indications from kaon flow:
K^+ repulsive potential
K^- attractive potential

Sensitivity seen, however: Statistics limited!

Transport here use potentials with linear density dependence:

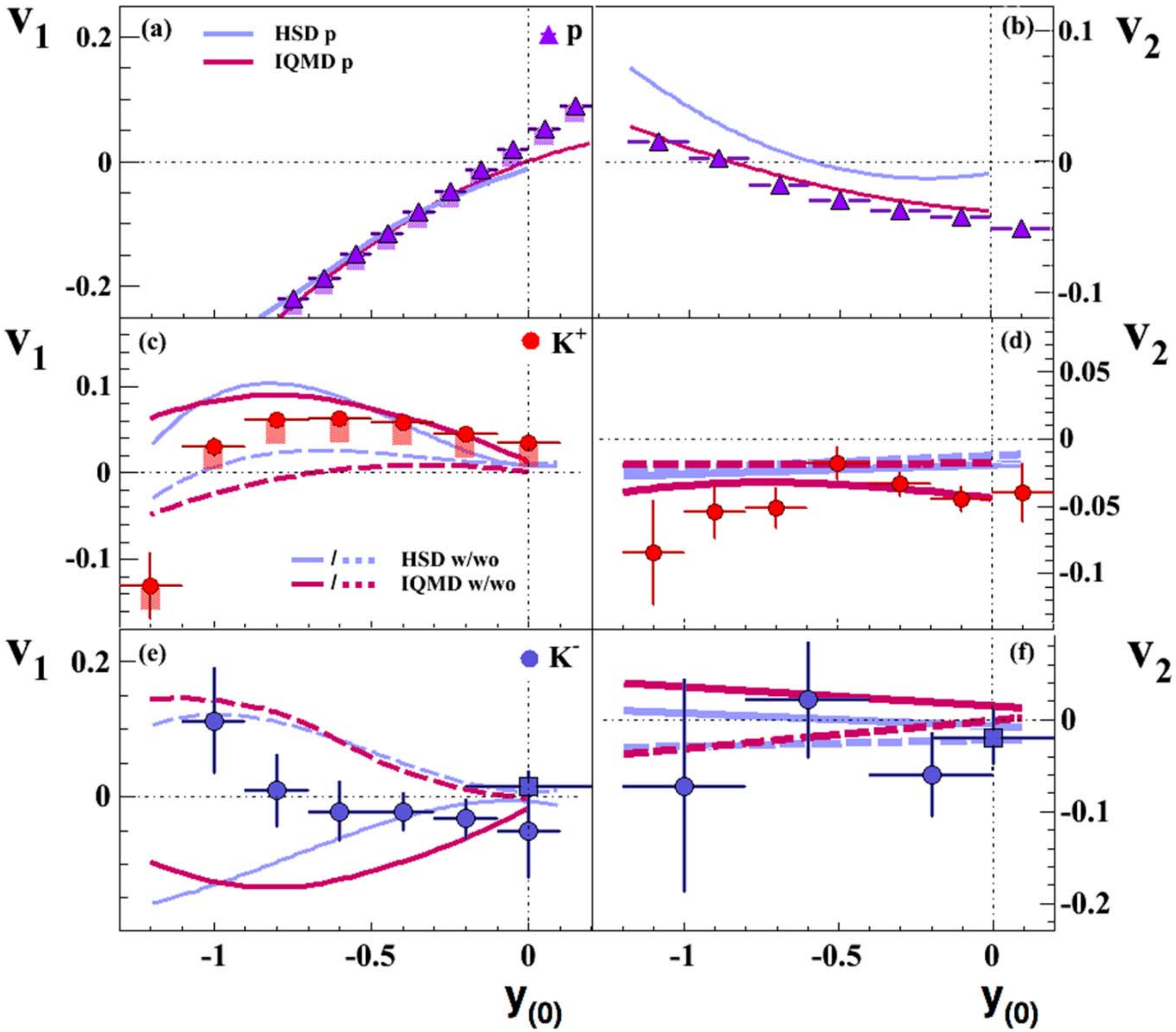
At $\rho=\rho_0$:

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

Ni+Ni at 1.91 AGeV

V.Zinyuk et al. (FOPI)
PRC 90 (2014) 025210

Models with FOPI acceptance filter



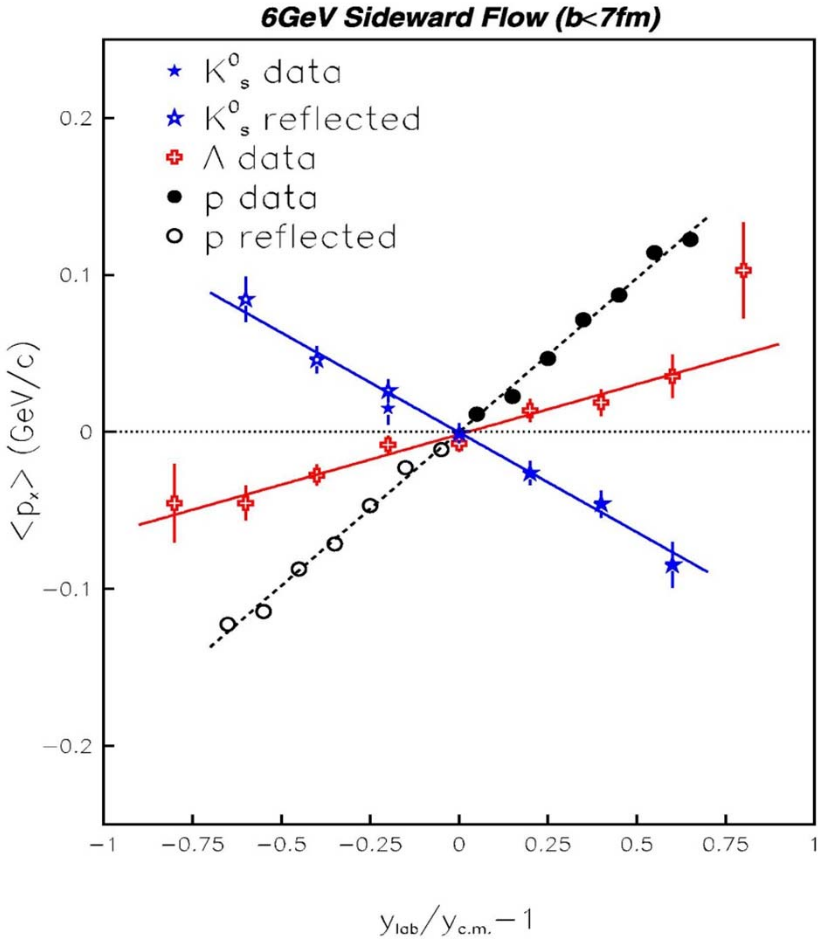
AGS: K^0 – flow

Kaons show large flow at AGS energies!

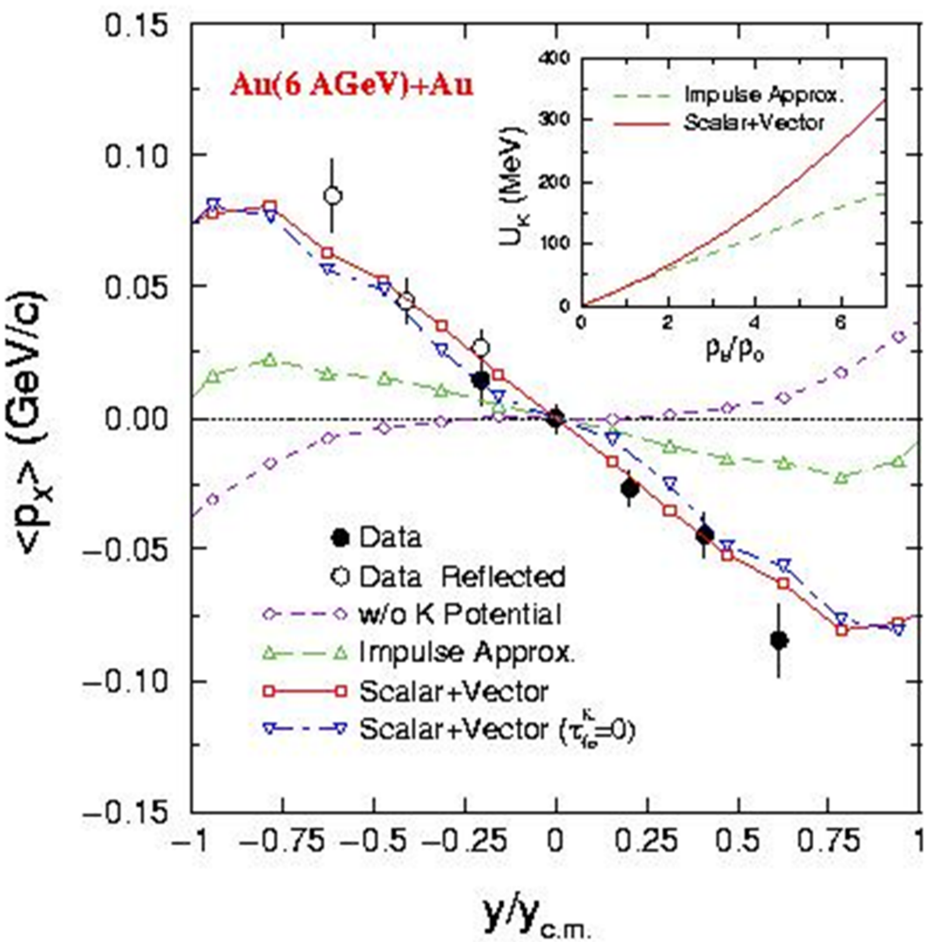
→ Kaon flow as barometer in HI collisions?

→ Calibrate probe by systematic measurements! centrality, system size, $\sqrt{s_{NN}}$

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



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



Fluctuations and critical point

Net-Proton Fluctuations in BES (STAR)

'Low' energy data limited by statistics

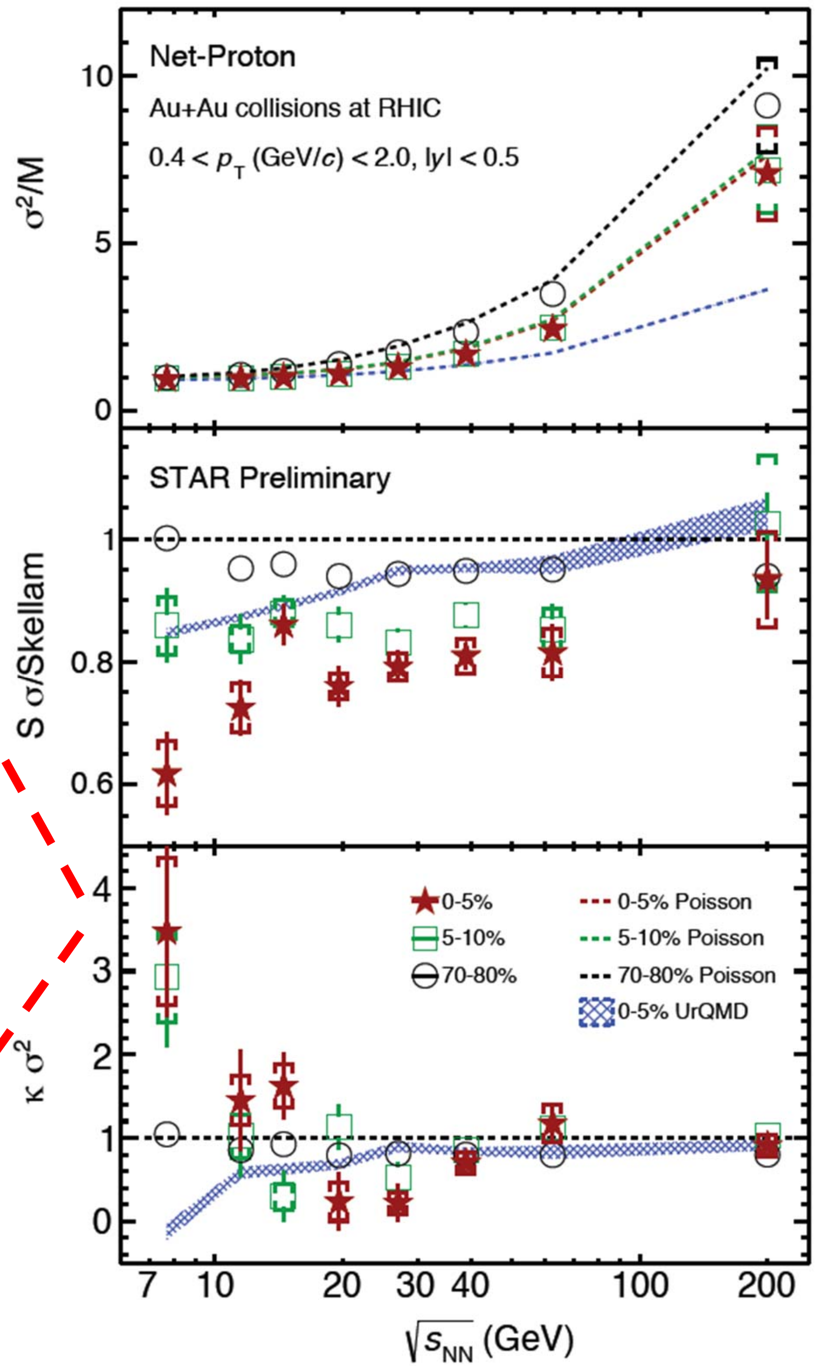
Fluctuations for energies $\sqrt{s_{NN}} < 7$ GeV ?

$$\delta N = N - \langle N \rangle$$

$$\left\langle (\delta N)^2 \right\rangle \approx \xi^2, \left\langle (\delta N)^3 \right\rangle \approx \xi^{4.5}, \left\langle (\delta N)^4 \right\rangle \approx \xi^7$$

$$S\sigma \approx \frac{\chi_B^3}{\chi_B^2}, \qquad \kappa\sigma^2 \approx \frac{\chi_B^4}{\chi_B^2}$$

?



L. Adamczyk et al. (STAR Collaboration), Phys. Rev. Lett. 112, 032302 (2014)
J. Thaeder, QM2015

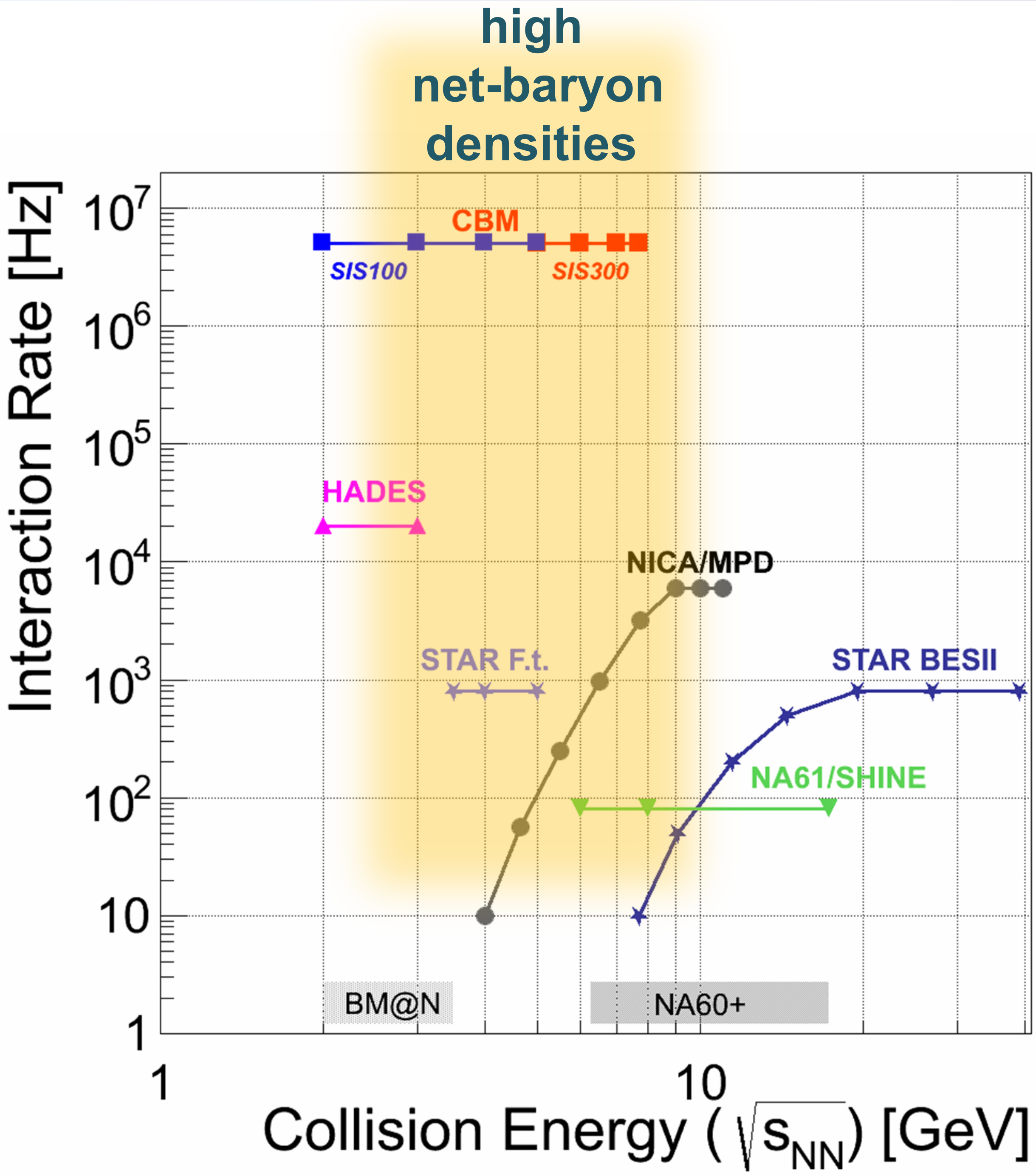
Experiments exploring dense QCD matter

CBM:
high rate experiment!

→ Opens up new possibilities!

- High statistics and good systematics on hadronic observables shown before:
  multi-s baryons, flow, fluctuations

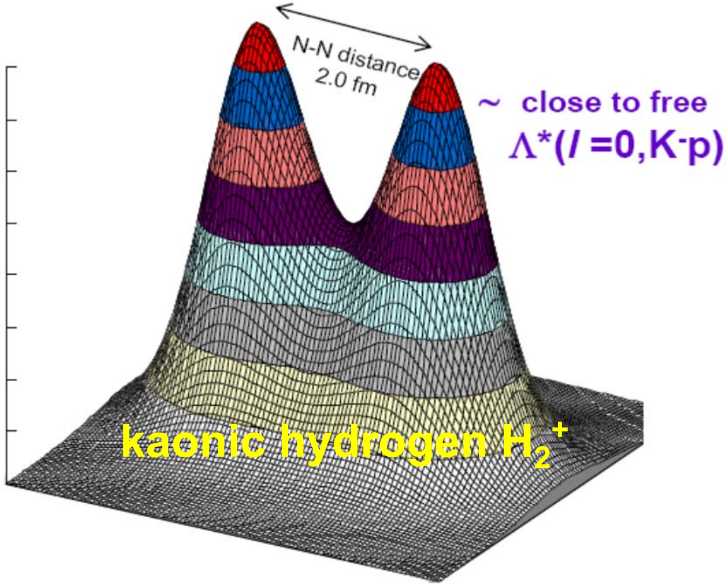
- New (exotic) observables:
  kaonic clusters, hypernuclei



Relicts of high density phase(?)

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)



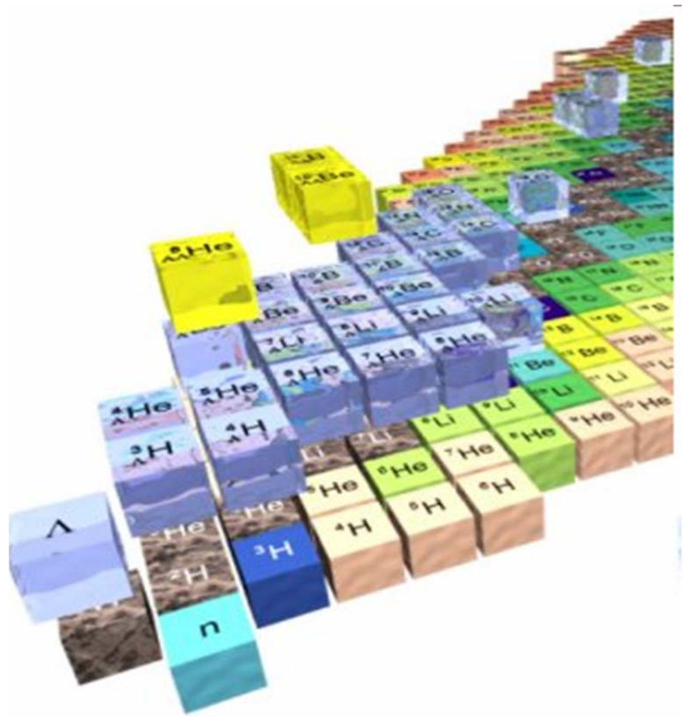
$$\Psi = \phi_a + \phi_b$$

Decay by strong interaction $\left(ppK^-\right) \to \Lambda + p$

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

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

Hypernuclei



Decay by weak interaction

Production in HI – collisions?
Recently: STAR, ALICE

Double strange hypernuclei??

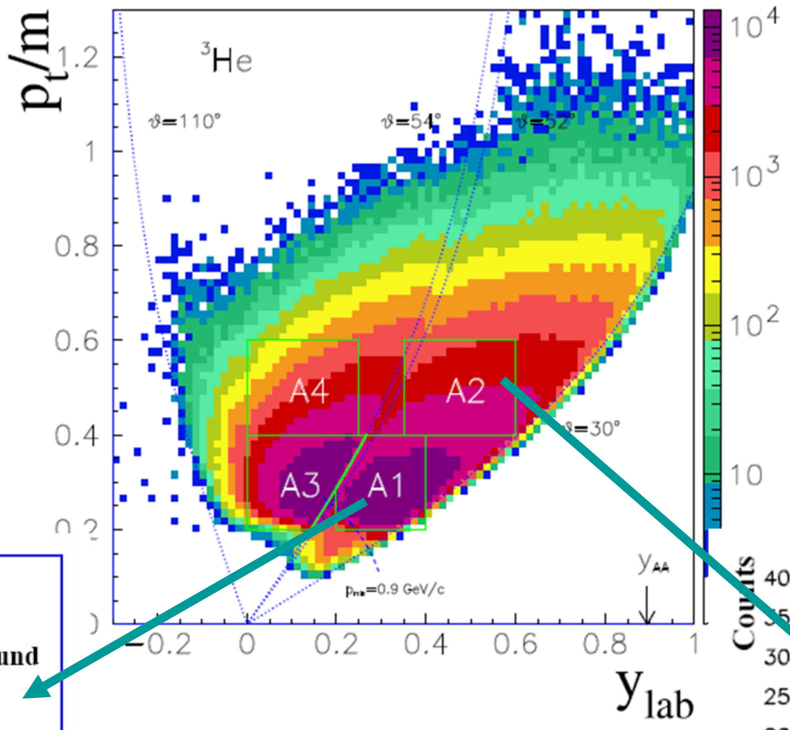
Hypertriton production in Ni+Ni at 2 AGeV

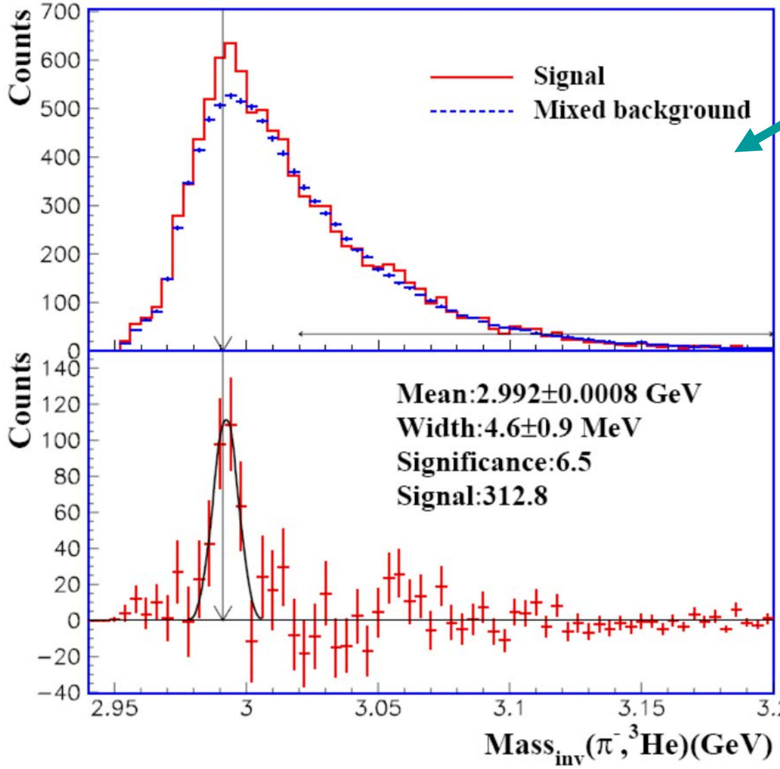
$$_{\Lambda}t \rightarrow {}^{3}He + \pi^{-}$$

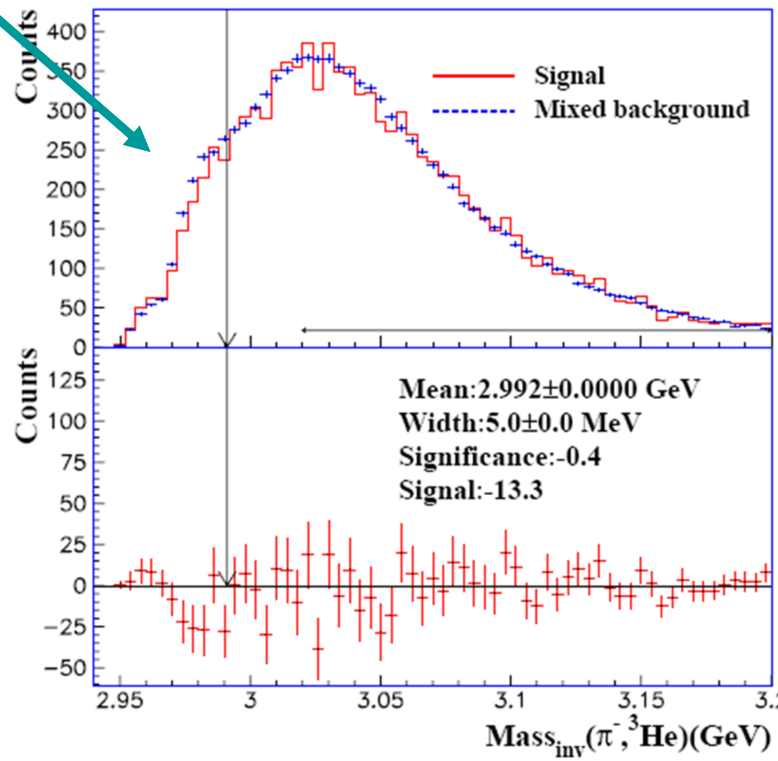
Y.P. Zhang, PhD thesis, Heidelberg

50 M events,

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







Excess over combinatorial background only in Phase space region A1

…. just an indication that something might go on …..

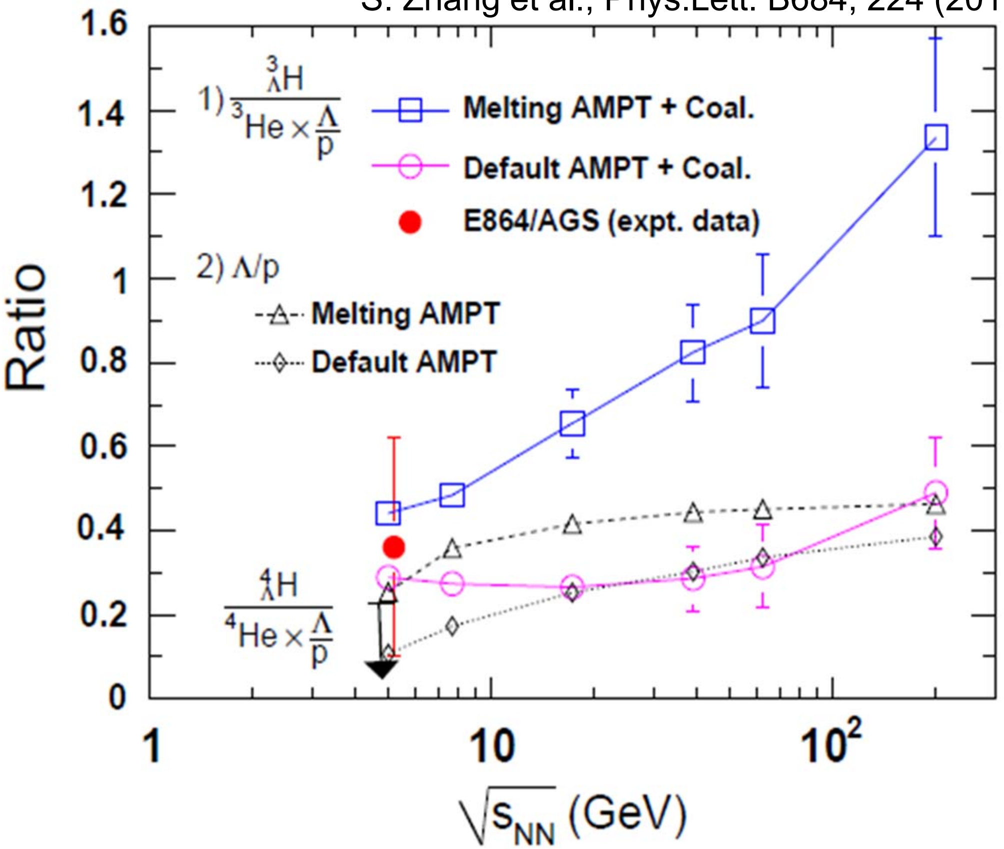
Baryon – Strangeness – Correlation

…. If becoming reality:

Proposal: Observable being sensitive to deconfinement!

Compare ${}_{\Lambda}t/{}^{3}He$ production to Λ/p: Local correlation between baryon number and strangeness

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



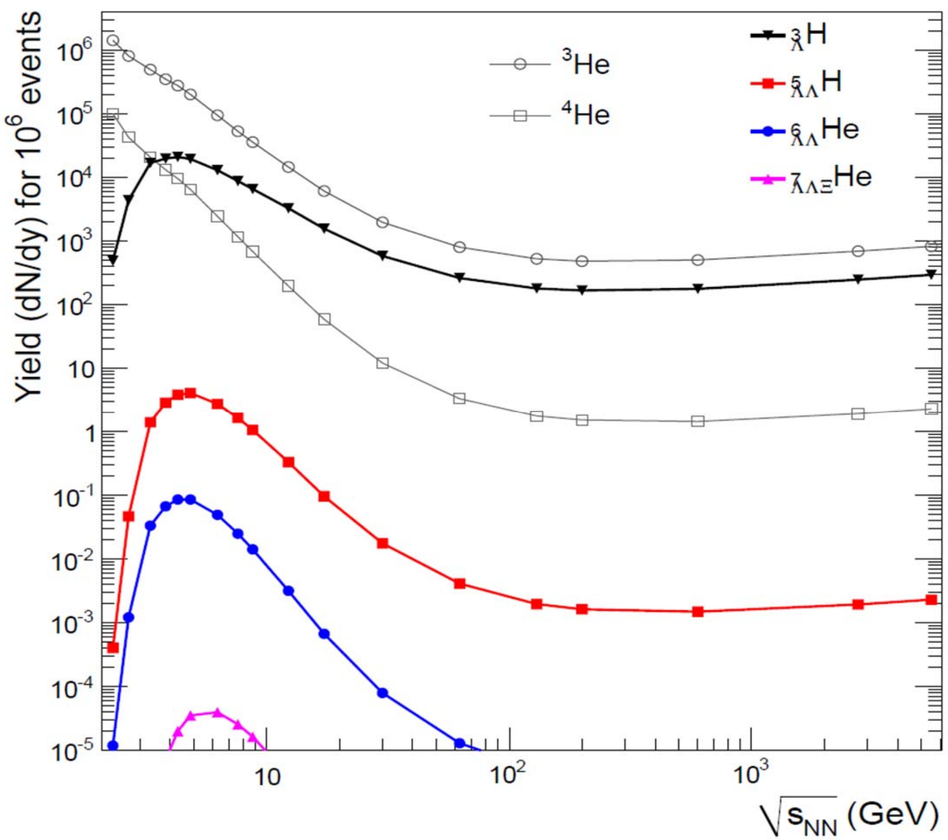
	Region A1	Region A2
${}_{\Lambda}t/{}^{3}He$	0.029 +/- 0.002	<0.003 +/- 0.002
Λ/p	0.0020 +/- 0.0005	0.0028 +/- 0.0005
${}_{\Lambda}t/{}^{3}He$ / Λ/p	10 +/- 3	< 0.95 +/- 0.6

Strange baryonic bound states

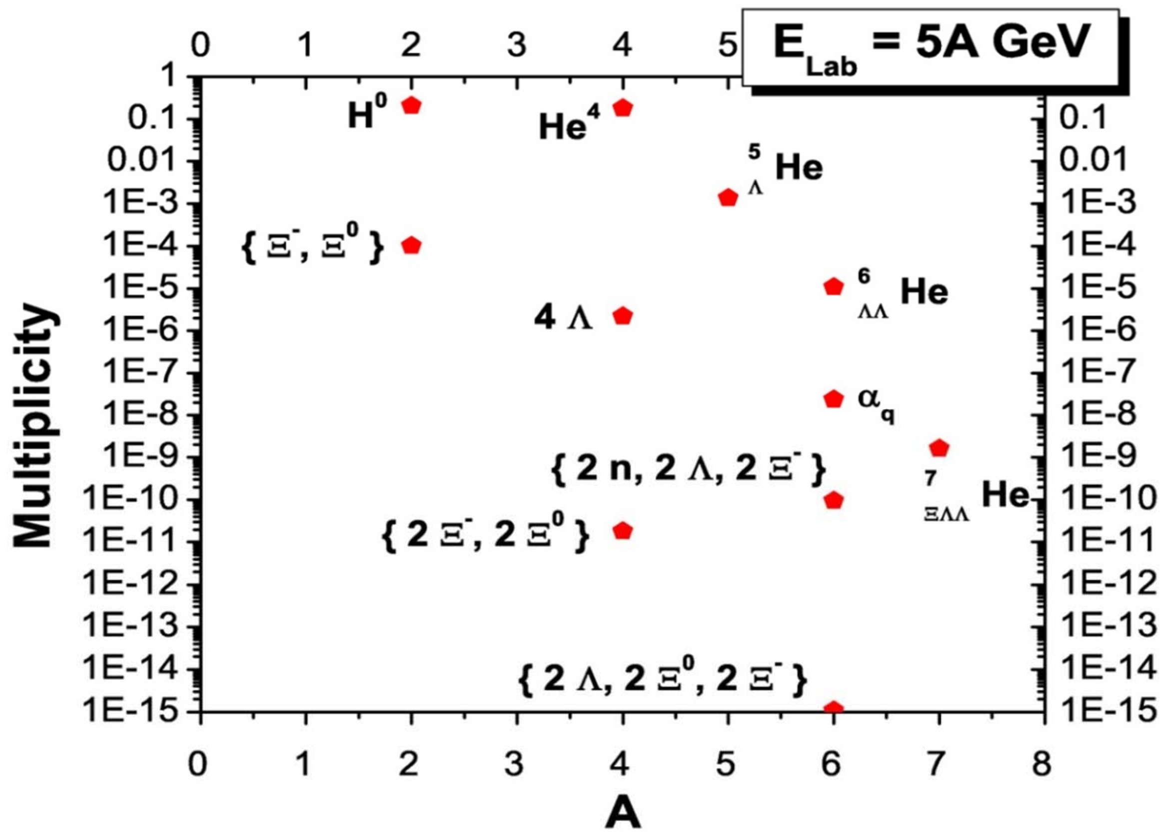
Whole range of predictions/ proposals well accessible at SIS 100 energies:

- Single and double strange hypernuclei in heavy ion collisions
- 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



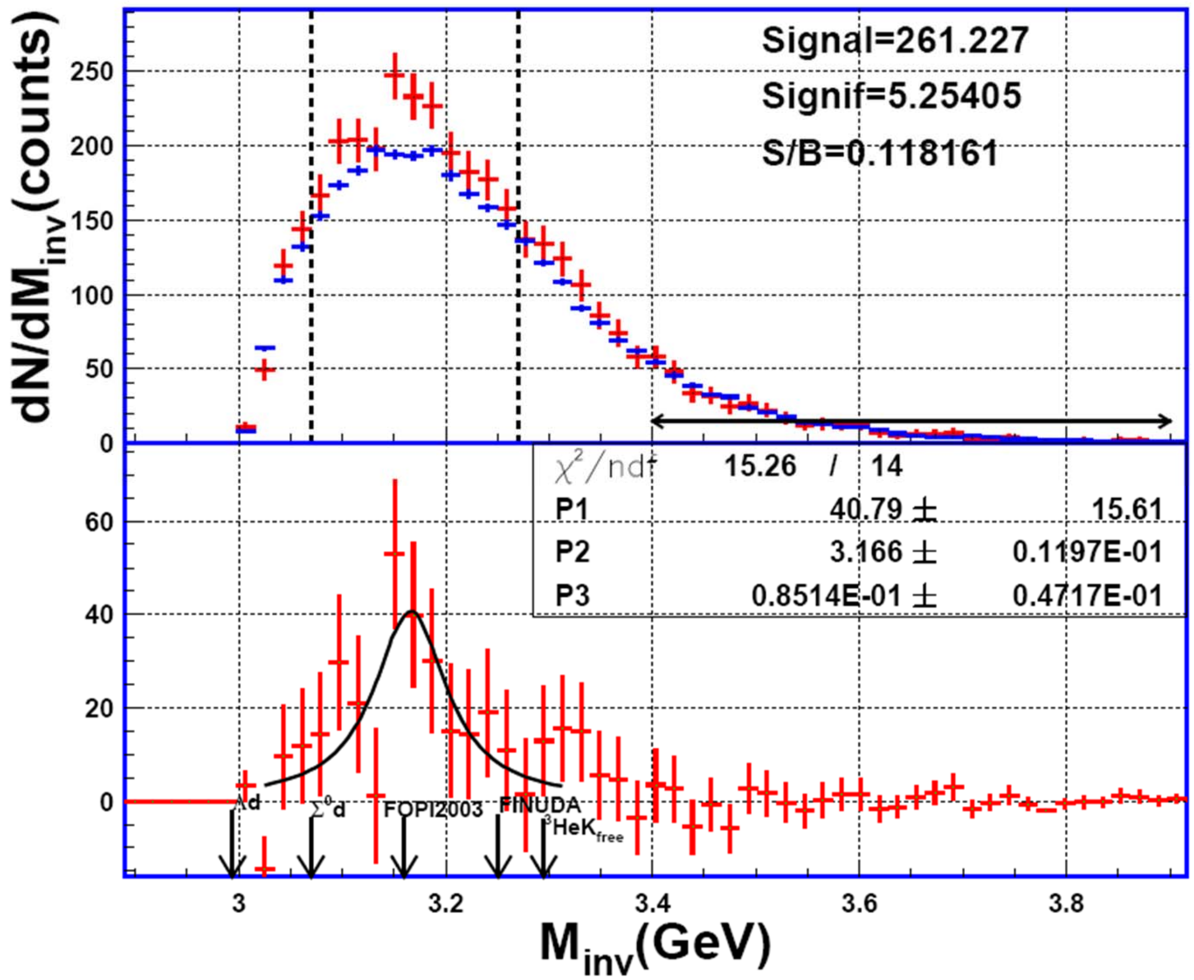
H. Stöcker et al., Nucl. Phys. A 827 (2009) 624c

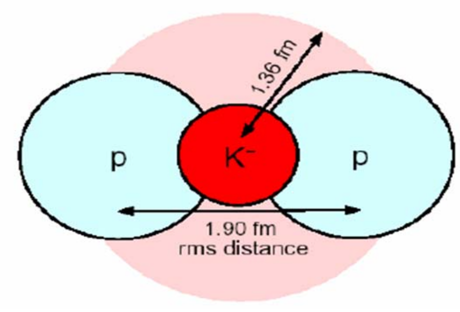


Λd – correlations

Ni+Ni at 1.91 AGeV

(FOPI, unpublished)





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

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

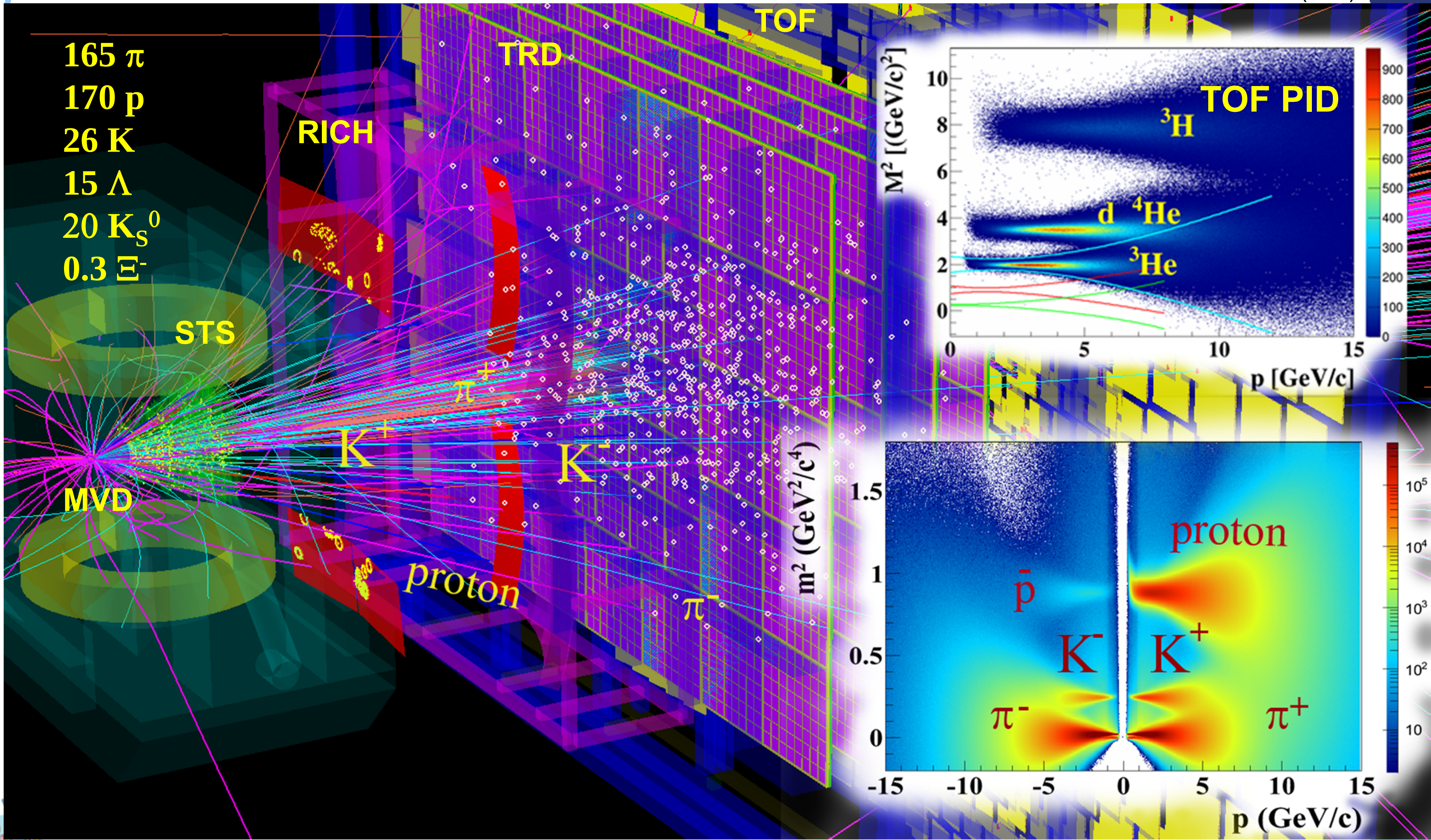
Significance does not include
LEE – Look elsewhere effect (?)

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

Signal found consistently in FOPI 2003 and 2008 data.
Inconsistent with cusp (Σ – d – threshold) and FINUDA.

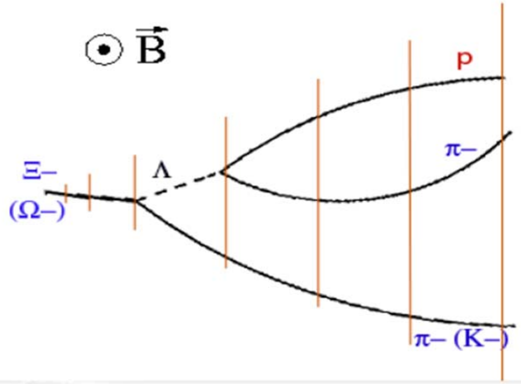
CBM: PID with ToF particle ID: Au+Au @ 10AGeV

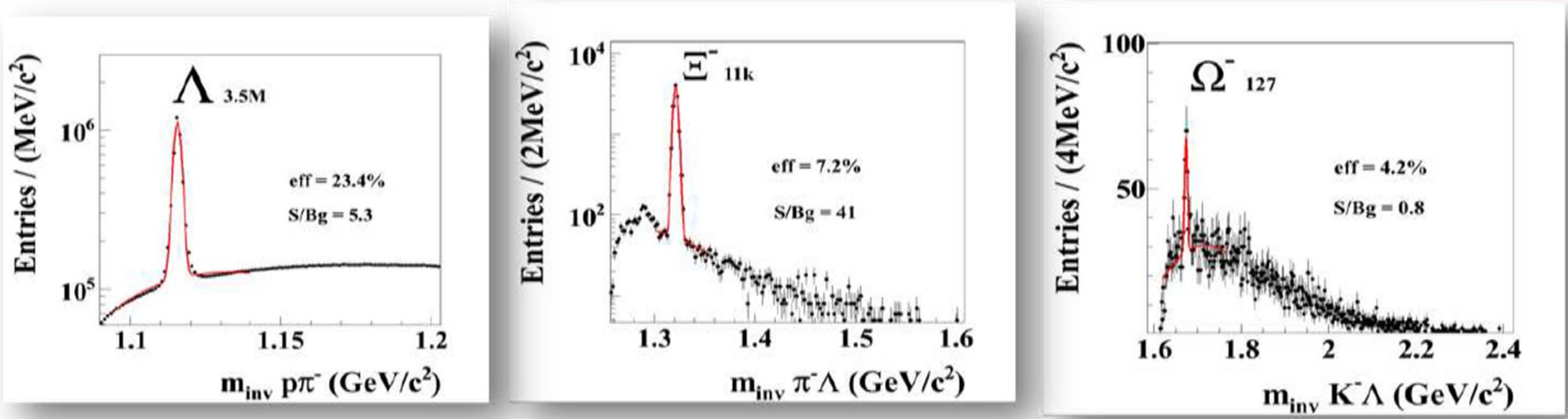
Y.Vasiliev (GSI)



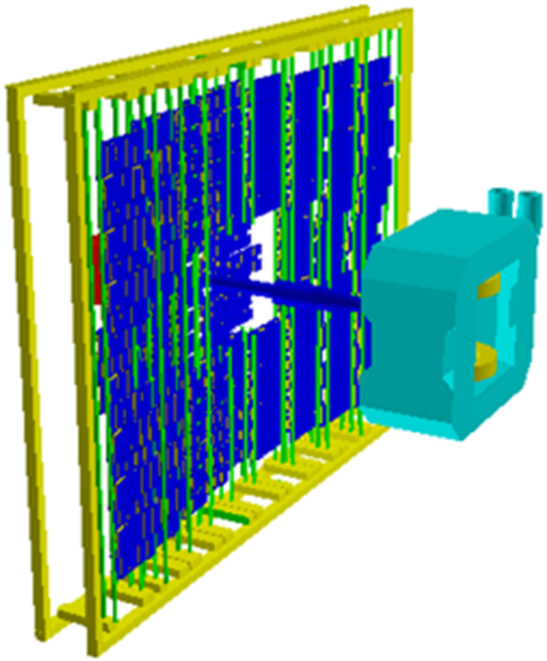
SIS 100- Hyperons

- CBM: Silicon Tracking system for fast and high resolution tracking
- Simulation: 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, …
  - → strange hypernuclei?





Generic anti-particle selection: $\bar{p}$ - candidates



Central Au+Au at 10 AGeV from UrQMD
current global track – TofHit matching performance

total efficiency: $\varepsilon = 0.36$

contamination: $\kappa = 4.$

Event selection rate: $\mathrm{R{=}R}_{ev} \cdot f_{cen} \cdot \mathrm{P}_{probe} \cdot \varepsilon \cdot (1+\kappa)$

@10MHz: $\mathrm{R{=}}10^7 \cdot 0.1 \cdot 7 \cdot 10^{-3} \cdot 0.36 \cdot 5.\mathrm{Hz}$

$= 12.6\ \mathrm{kHz}$

$\Delta T(10^5\,\bar{p}) \quad = 40\ s$ **time on target to archive 100.000 $\bar{p}$.**

Run time in 10 MHz mode:

Extrapolation to central Au+Au at 4 AGeV:

total efficiency: $\varepsilon = 0.55$

contamination: $\kappa = 1000.$

background scaled with total multiplicity

Event selection rate: $\mathrm{R{=}R}_{ev} \cdot f_{cen} \cdot \mathrm{P}_{probe} \cdot \varepsilon \cdot (1+\kappa)$

@10MHz: $\mathrm{R{=}}10^7 \cdot 0.1 \cdot 1.5 \cdot 10^{-5} \cdot 0.55 \cdot 1.10^3\,\mathrm{Hz} = 8.2\ \mathrm{kHz}$

$\Delta T(10^5\,\bar{p}) \quad = 3.5\ h$

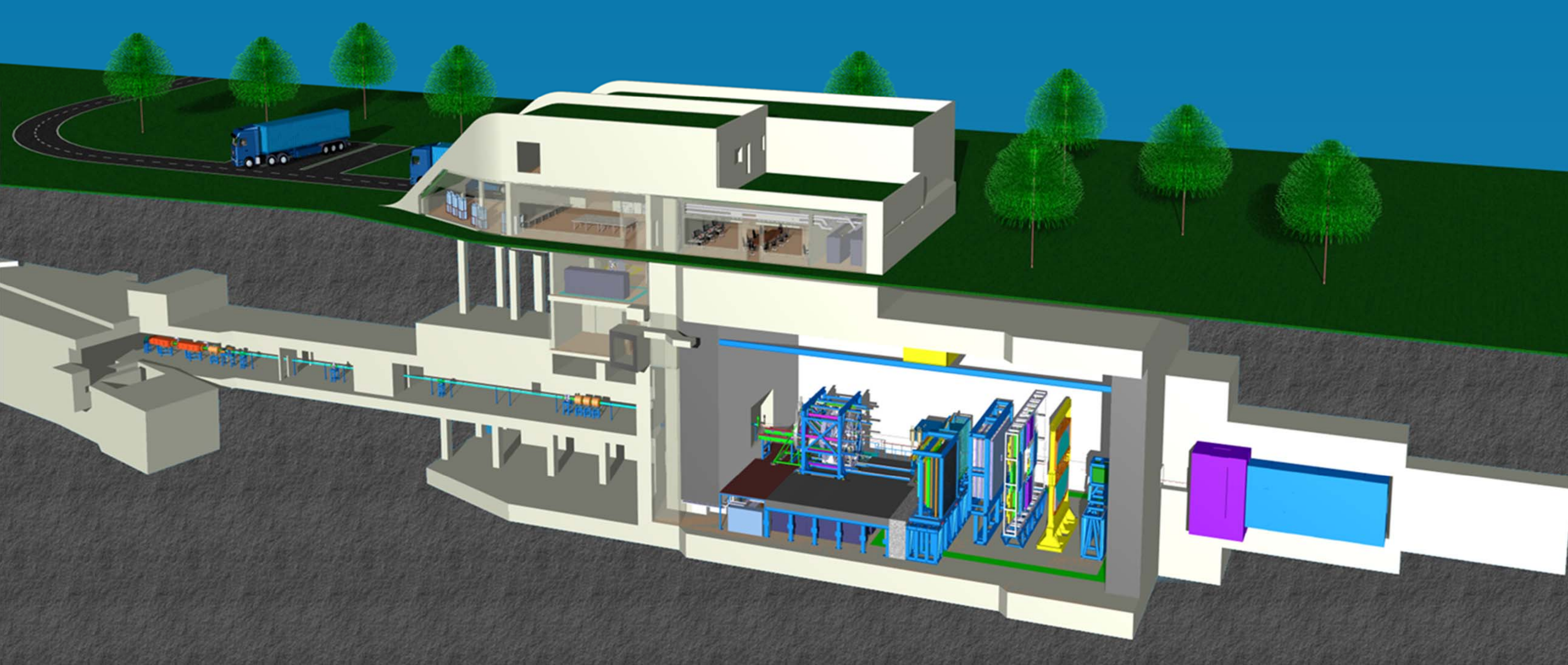
Run time in 100 kHz mode:

@100kHz: $\mathrm{R{=}}10^5 \cdot 0.1 \cdot 1.5 \cdot 10^{-5} \cdot 0.55\mathrm{Hz} = 8\ \mathrm{Hz}$

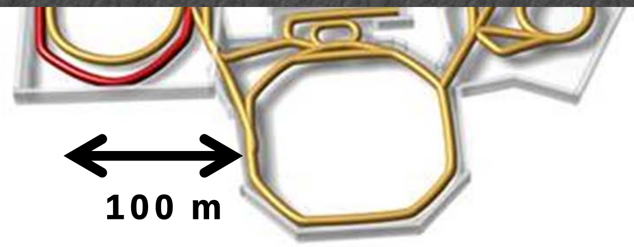
$\Delta T(10^5\,\bar{p}) \quad = 350\ h = 14\ d$

Facility for Antiproton & Ion research

Building application for SIS 100 handed in end of 2015
Submission of building application for CBM cave will follow this year



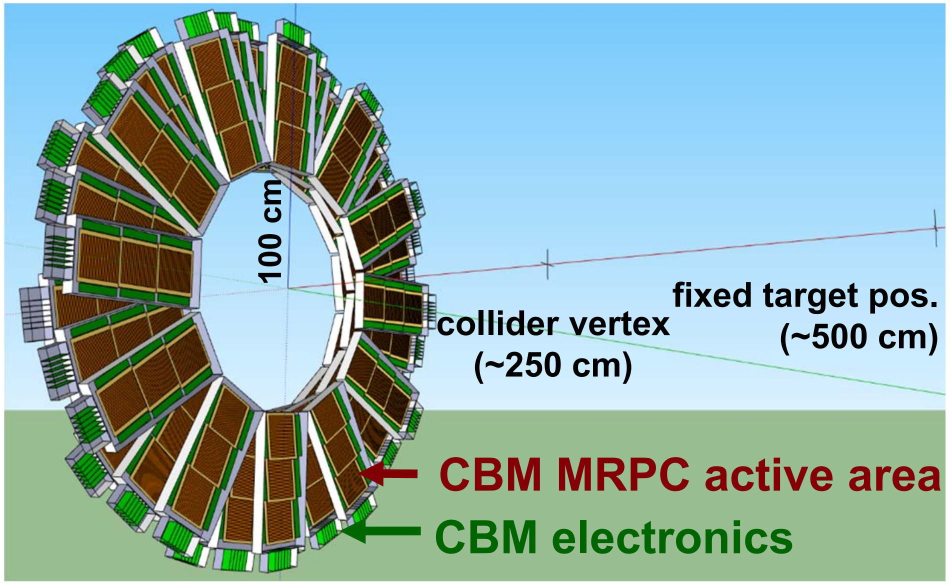
- 10^9/s Au up to 11 GeV/u
- 10^9/s C, Ca, ... up to 14 GeV/u
- 10^{11}/s p up to 29 GeV

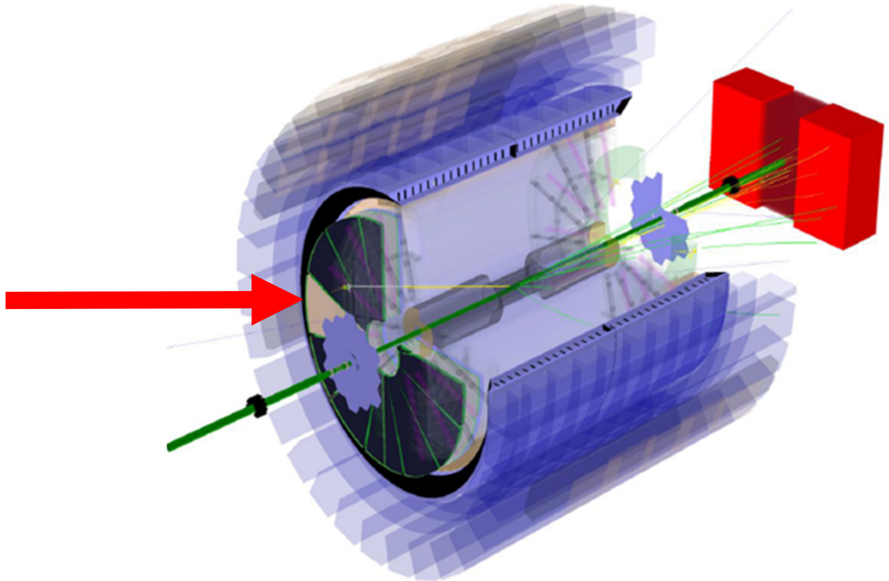


FAIR phase 1
FAIR phase 2

Strategy in view of FAIR delay

Install, commission and use 10% of the CBM TOF modules including read-out chain at STAR/RHIC





Participation in STAR Beam Energy Scan (BES II) in 2019/2020

Operation of ~30 CBM TOF modules and electronics (A~10m^2 , ~10.000 channels)

Benefits

- Get experience with detector system, develop online calibration and monitoring tools
- Develop TOF analysis strategies for particle ID under experimental conditions
- Participate in physics analysis (e.g. baryon and strangeness fluctuations)
- Complementary to CBM: low rate, high energy, $7.7\ \mathrm{GeV} < \sqrt{s_{NN}} < 20\ \mathrm{GeV}$

CBM physics program at SIS 100

Hadronic observables

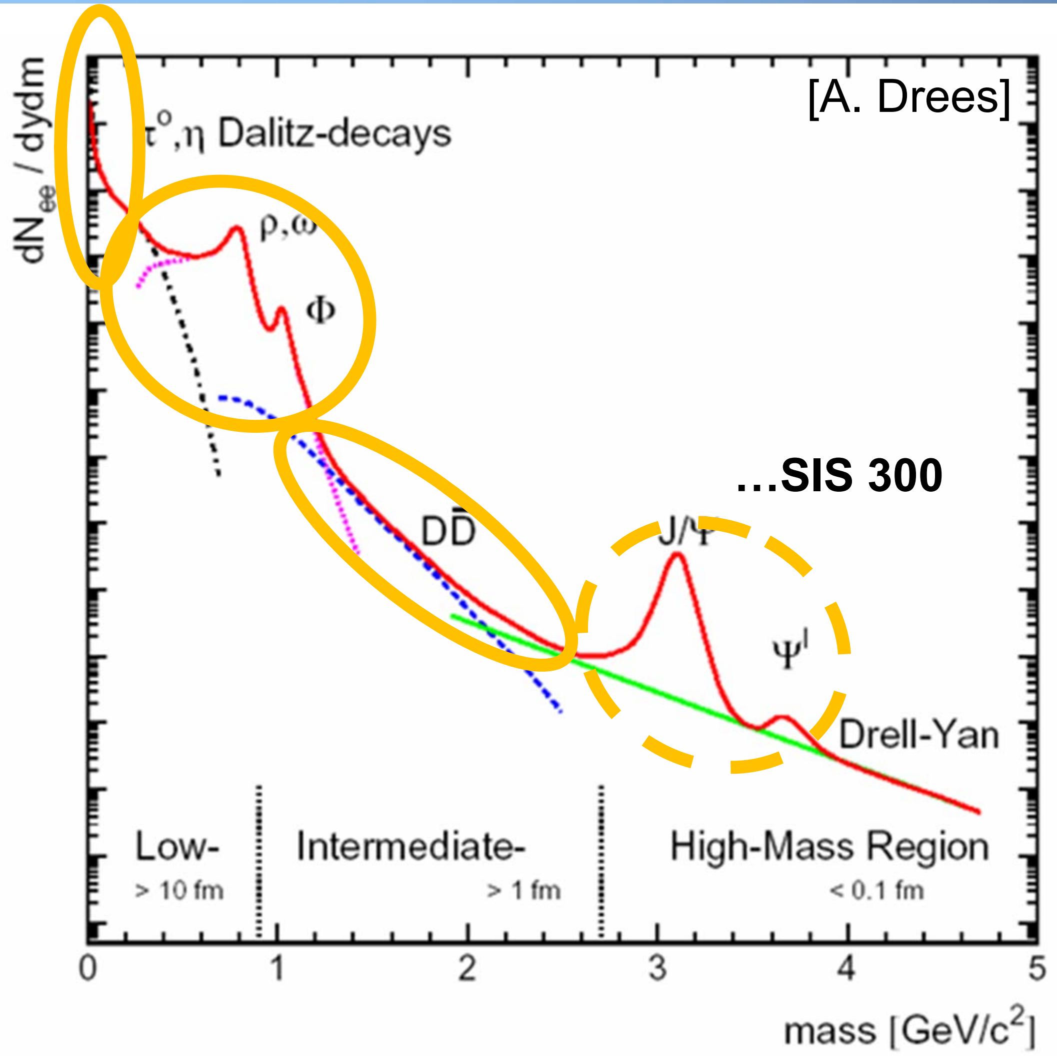
- ***Multi-strange Baryons, (ϕ-meson)***
  → thermalization?
  → sensitivity to EOS, baryon density, QCD phase
- ***Flow***
  → sensitivity to EOS
  → extend to strangeness sector!
- ***Fluctuations*** of baryons, strangeness, net-charge, ….
  → sensitivity to phase transition, CP?
- ***Exotic strange objects:*** hypernuclei, kaonic molecules

Di-leptons (penetrating probes) – *not covered here*

- Photons, low-mass vector mesons, Charm sector
  → electromagnetic radiation from baryon dense phase
  QCD phase, phase transition, baryon dynamics in medium, …?

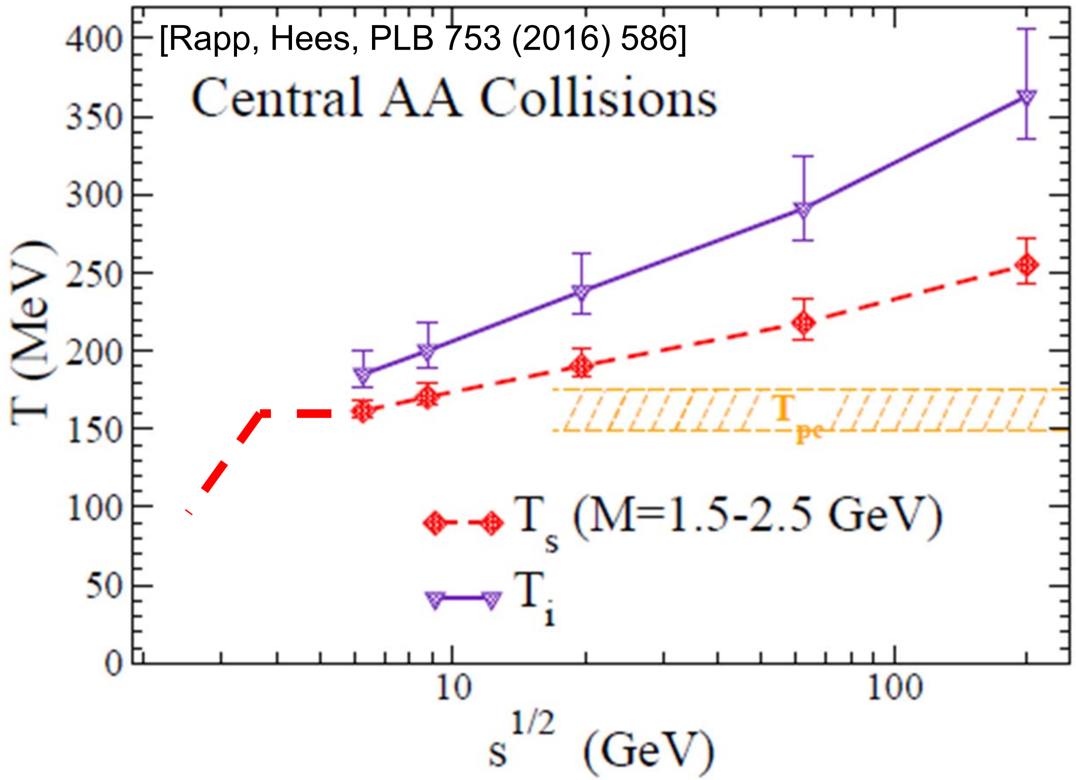
CBM: high statistics, systematic measurements (centrality, system size, $\sqrt{s_{NN}}$)

Dileptons at CBM



- Photons: access to early temperatures
  → excitation function?
- Low-mass vector mesons: in-medium properties of ρ
  → strength due to coupling to baryons (see HADES)
  → go to real dense matter!
- Intermediate range: acces to fireball radiation (see NA60): QGP, 4π- or ρ-a_1 chiral mixing
  → quarkyonic phase?
- J/ψ: charm as a probe for dense baryonic / partonic matter
  → propagation of charm?
  → distribution amongst hadrons?

Dileptons at CBM



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Summary / Conclusion

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

- QCD matter 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
      phase transition to quarkyonic matter (?)
    substantial discovery potential at SIS100 / 300
    significant contribution to STAR BESII run

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

- CBM status
    well advanced with respect to overall FAIR timeline.

The CBM collaboration

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

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Univ. Bucharest

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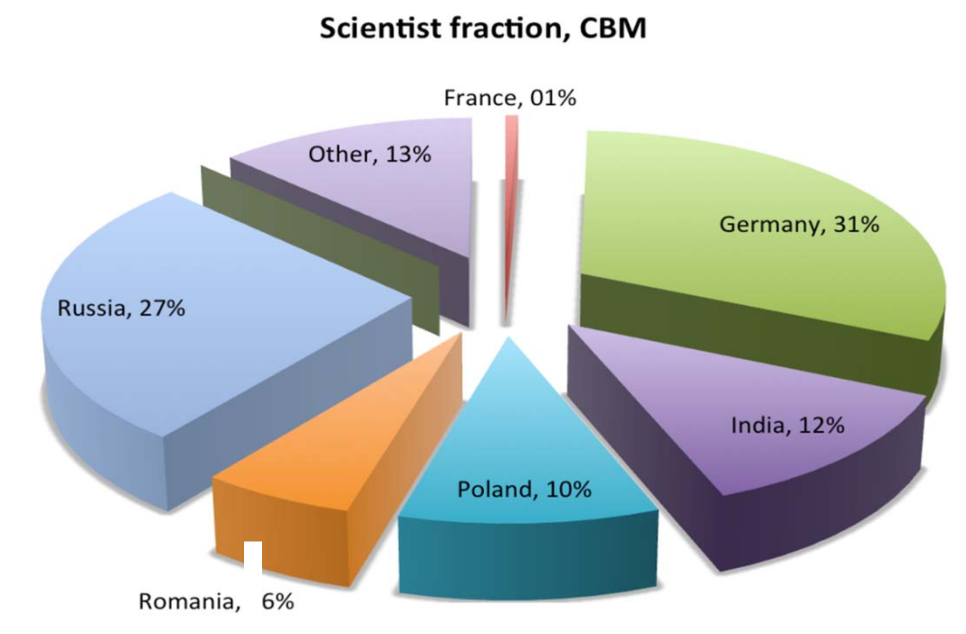
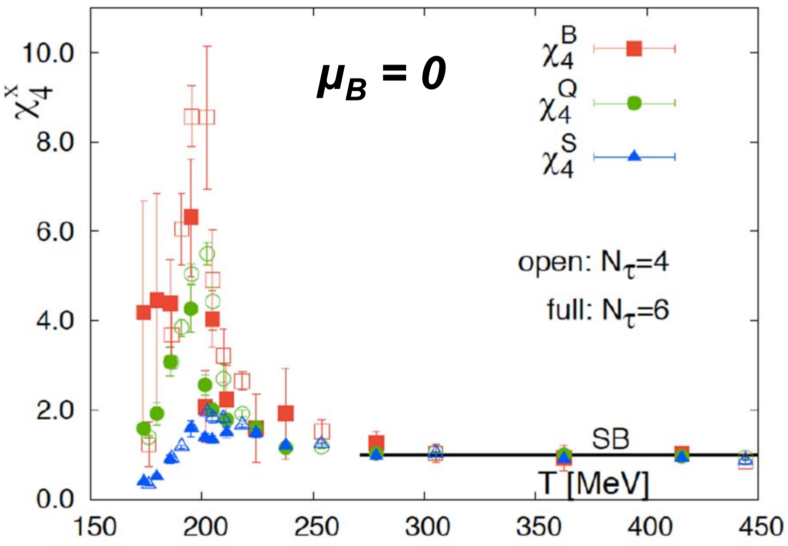
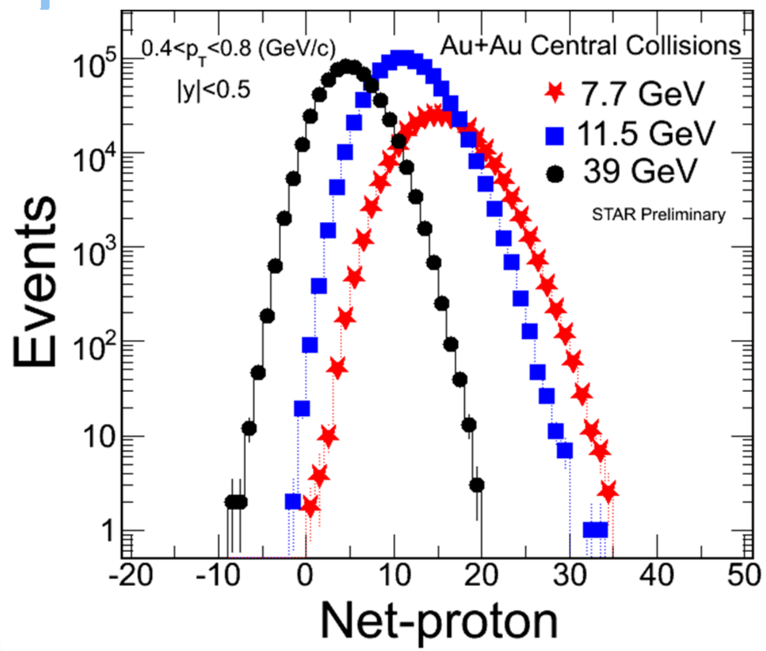
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.
Ioffe Phys.-Tech. Inst. St. Pb.

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



Fluctuations and critical point





Event-by-event fluctuations of conserved quantities like strangeness, baryons, and net-charge are related to susceptibilities χ and correlation length ξ .

$$\delta N = N - \langle N \rangle$$

$$\left\langle (\delta N)^2 \right\rangle \approx \xi^2, \left\langle (\delta N)^3 \right\rangle \approx \xi^{4.5}, \left\langle (\delta N)^4 \right\rangle \approx \xi^7$$

$$S\sigma \approx \frac{\chi_B^3}{\chi_B^2}, \qquad \kappa\sigma^2 \approx \frac{\chi_B^4}{\chi_B^2}$$

Sensitive to tails of multiplicity distributions (centrality selection, detector biases, …)

References:

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- A. Bazavov et al., PRL109, 192302(12) // S. Borsanyi et al., PRL111, 062005(13) // V. Skokov et al., PRC88, 034901(13)