CBM Physics at SIS-100

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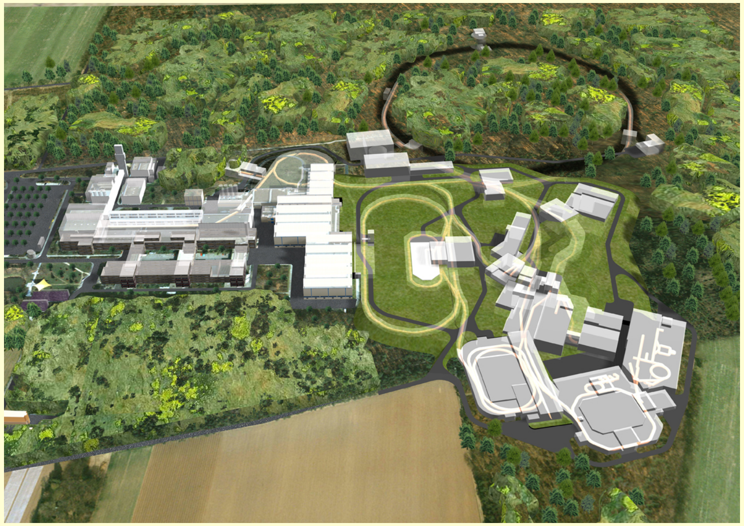
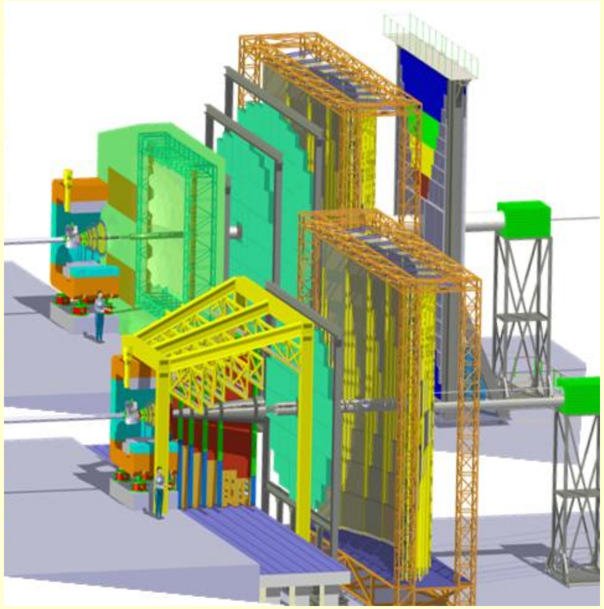
GSI

NICA/JINR-FAIR Bilateral Workshop
„Matter at highest baryon densities in the laboratory and in space“
Frankfurt, 2 April 2012

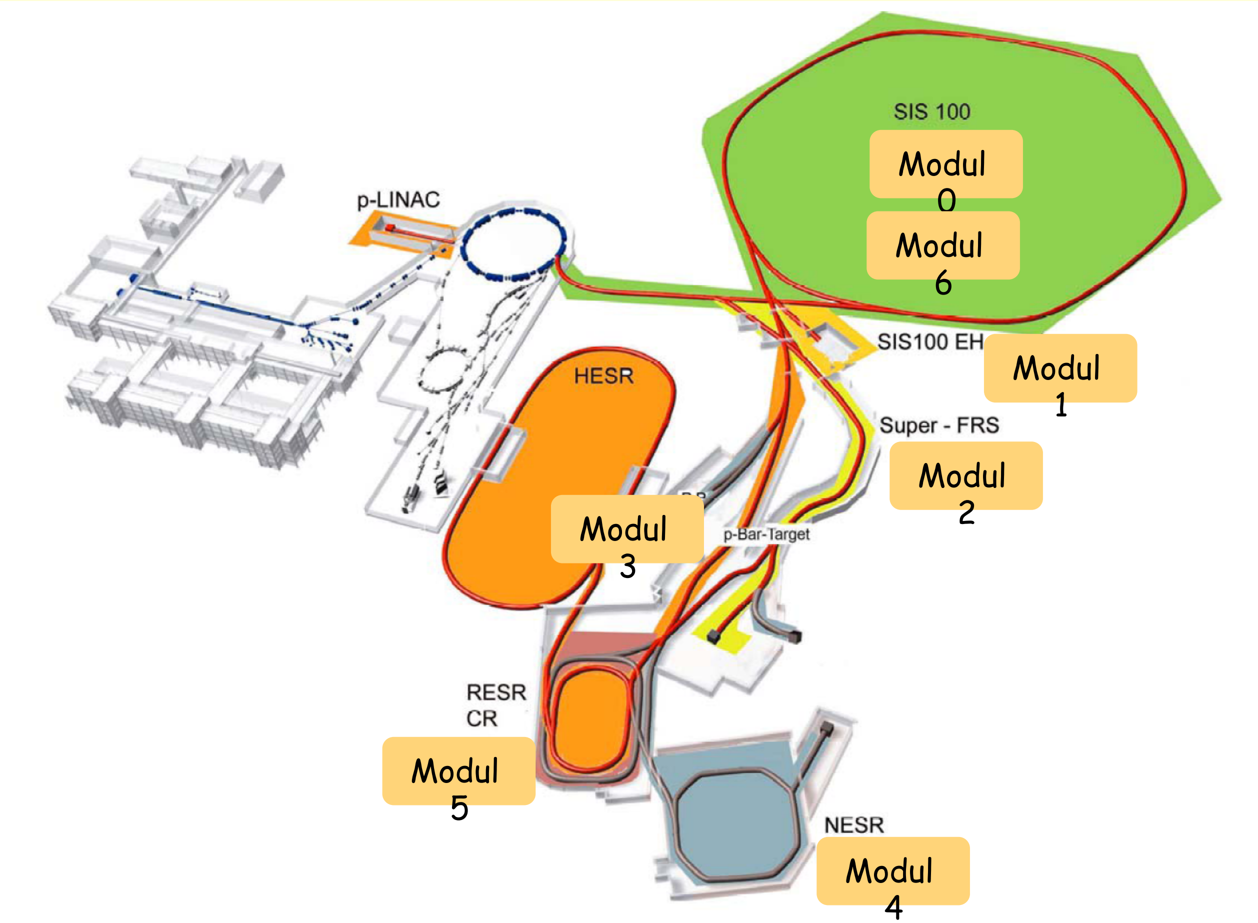
CBM @ FAIR: Tour de force





- Heavy-ion experiment with large acceptance at SIS-100/300
- External beams:
  - up to 35 AGeV (heavy ions)
  - up to 45 AGeV (light ions)
  - up to 90 GeV (protons)
- Investigate strongly interacting matter at high baryon densities: equation of state, 1st order phase transition, critical point
- Identification of hadrons, leptons and photons
- Setups:
  - hadron + electron
  - muon
- Uniqueness: extreme rate capability, rare observables

FAIR: Modularised Start Version



Module 0: SIS-100

Module 1: CBM cave, APPA hall

Module 2: Super-FRS and R3B

Module 3: Anti-proton facility

MSV

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

CBM @ SIS-100

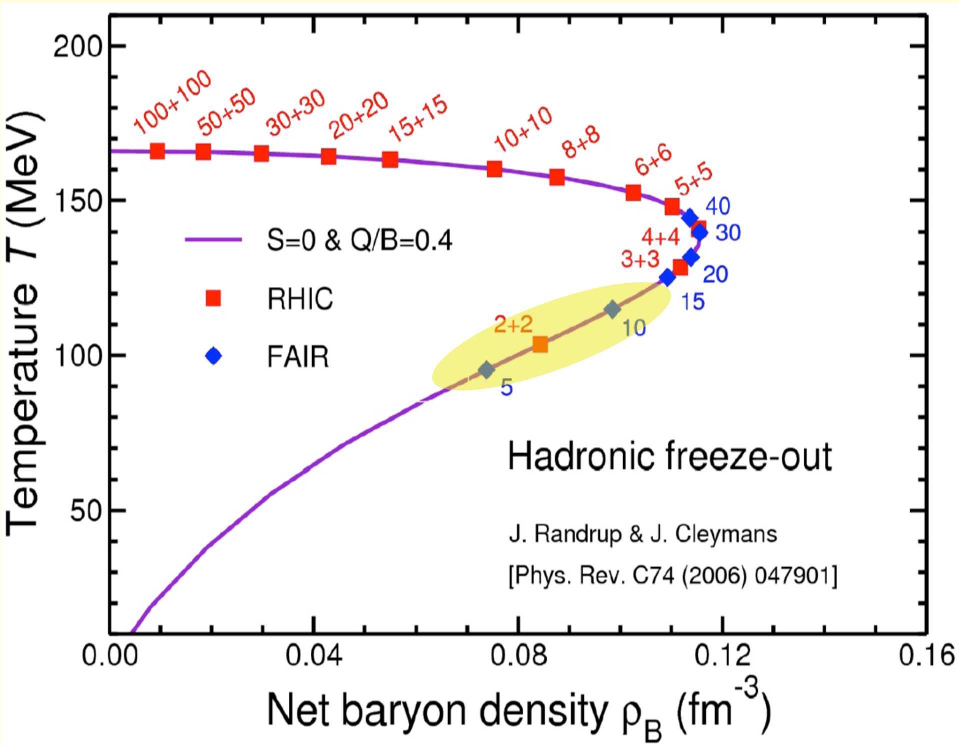
The first years of CBM operation will be at SIS-100 with a start setup.

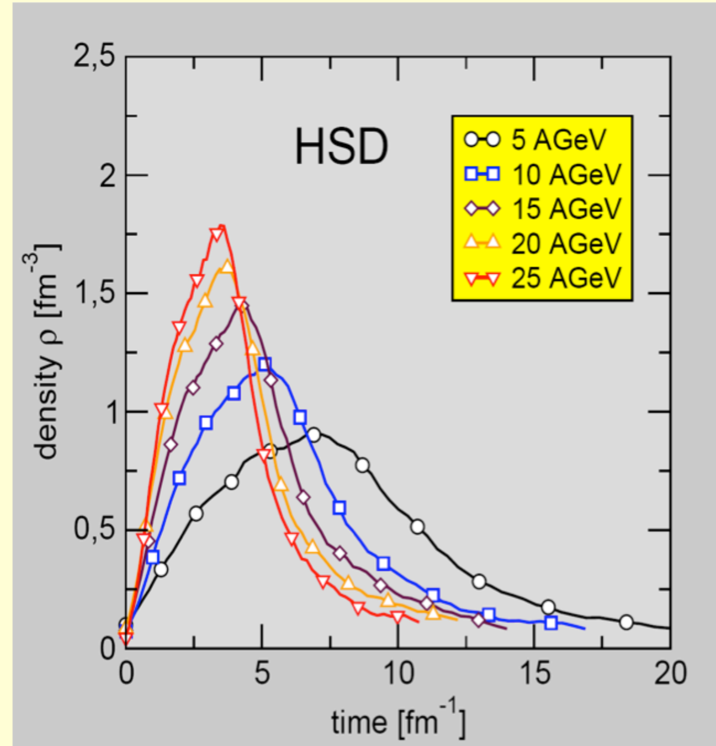
Beam	$p_{lab, max}$	$\sqrt{s_{NN, max}}$
heavy ions (Au)	11A GeV	4,7 GeV
light ions (Z/A = 0.5)	14A GeV	5,3 GeV
protones	29 GeV	7,5 GeV

Physics case at SIS-100:

- What are the equation of state and the degrees of freedom of strongly interacting matter at densities as present in the cores of neutron stars?
- What are the properties of hadrons in dense matter? Is chiral symmetry restored?
- Does strangeness exist in form of heavy, meta-stable objects?
- How is charm produced close to the threshold, and how does it propagate in cold nuclear matter?

Dense matter



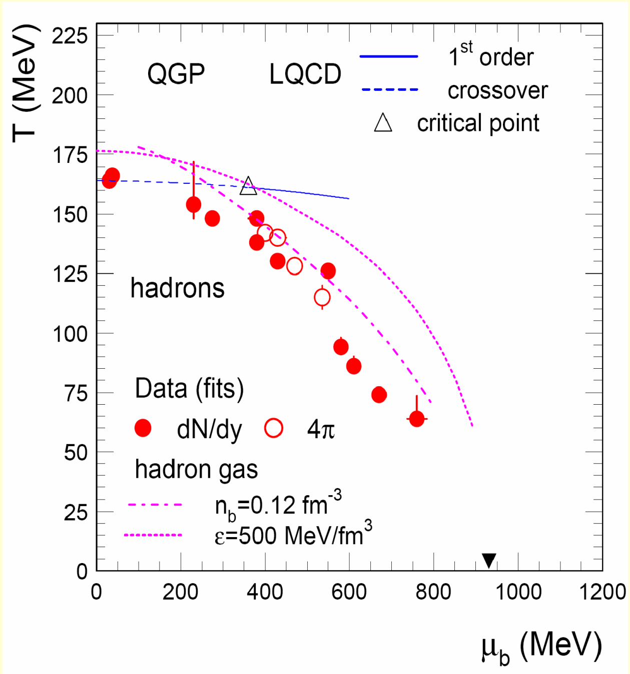


E. Bratkovskaya, W. Cassing

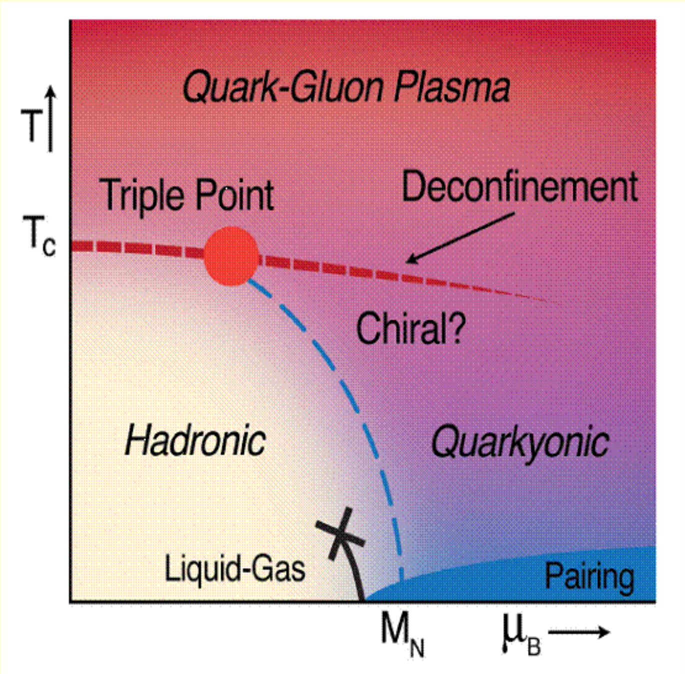
At SIS-100 energies, the density in the centre of nucleus-nucleus collisions exceeds ground state density by factors, for a considerable period of time.

The QCD phase diagram at high baryon densities

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



A. Andronic et al., Nucl. Phys. A 837 (2010) 65



Statistical models describe hadronic final state: thermalisation

At low μ_b: hadronisation coincides with deconfinement phase transition

Relaxation mechanism at lower temperature / high density?

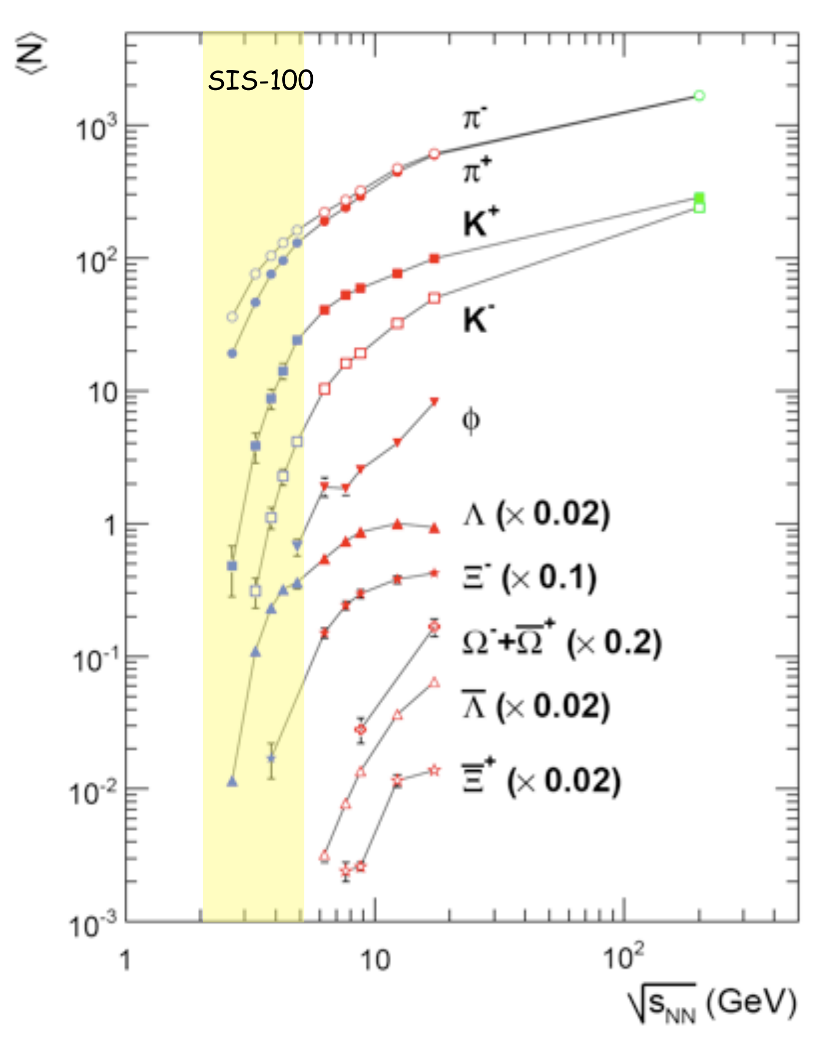
„Quarkyonic Phase“: confinement, but (partial) chiral symmetry

Phase transition quarkyonic – hadronic could act as „thermaliser“ at high μ_b

Hadrochemistry of the final state

- At AGS- und SIS18 energies: small number of measured species; low quality of thermal fits
- Desideratum: characterisation of the hadronic final state in 4π with a large number of hadron species
- Systematic measurements in terms of collision energy and system size; measurement also with collisions of heavy nuclei

C. Blume, J. Phys. G 31 (2005) S57

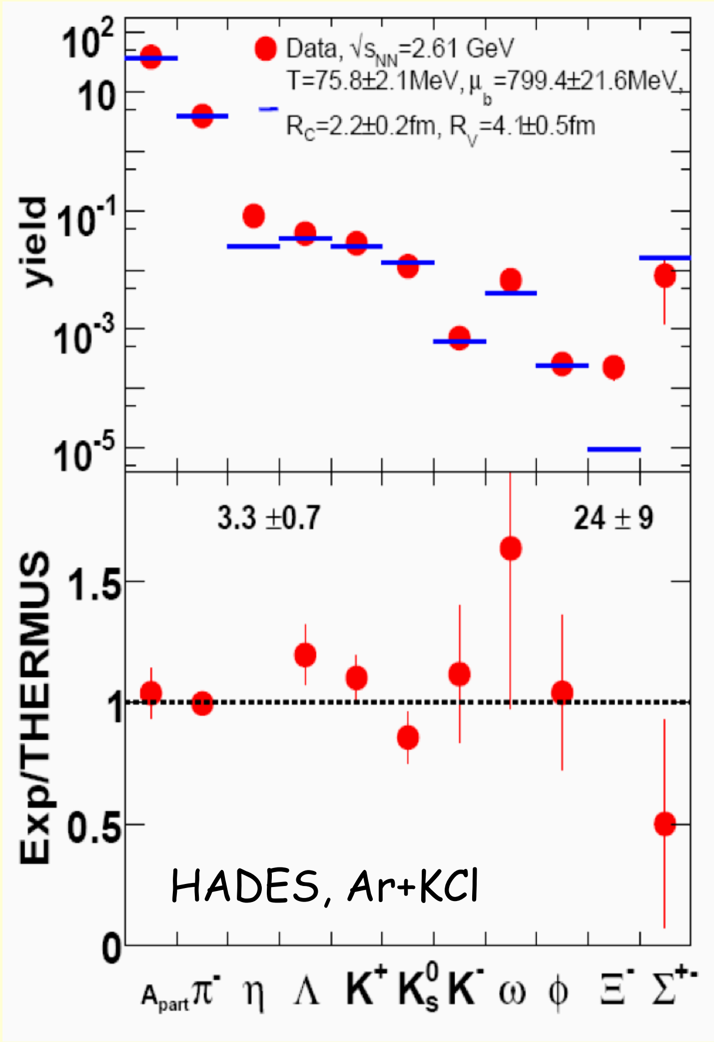


Multi-strange hyperons

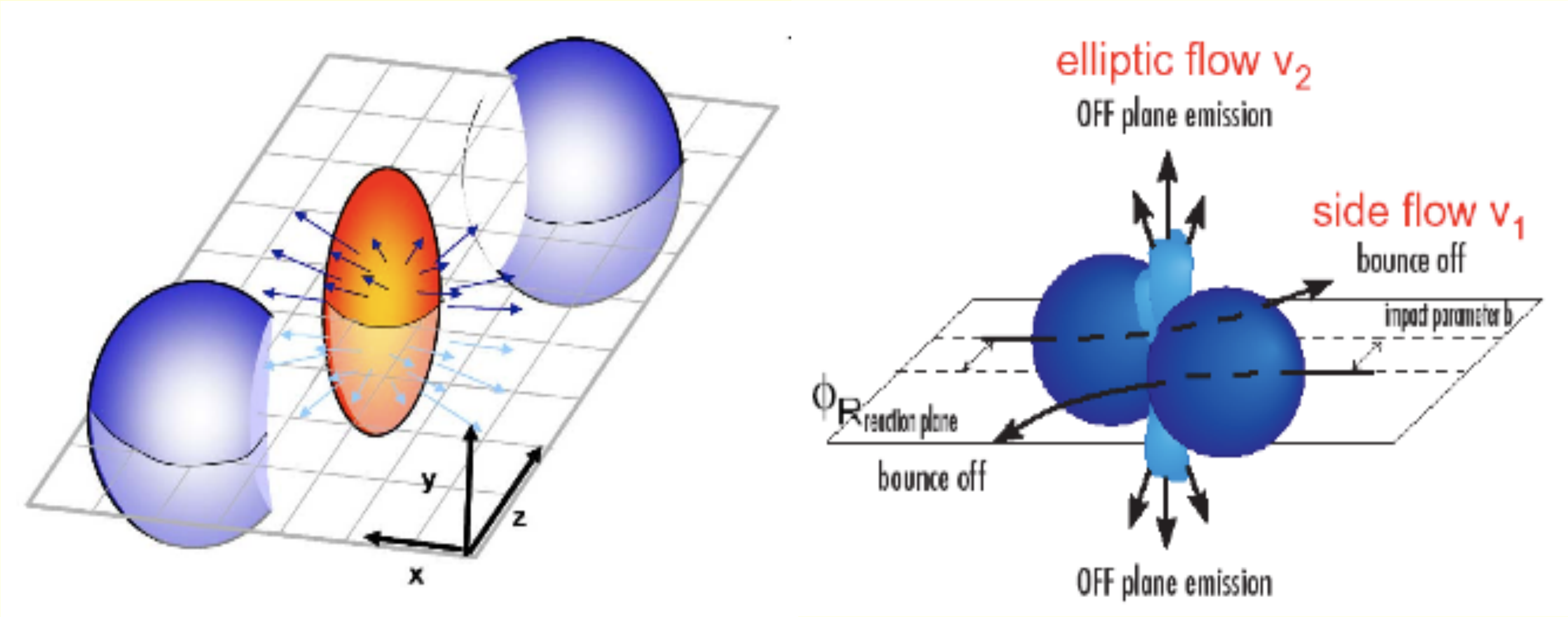
- Hyperon production threshold in p+p
  - Ξ: 3,7 GeV
  - Ω: 7,0 GeV
- Production below threshold in heavy-ion collisions:
  - multi-step processes (strangeness exchange)

    $\Lambda K \rightarrow \Xi\pi \quad \Lambda\Lambda \rightarrow \Xi^- p \quad \Xi K \rightarrow \Omega\pi$
  - Multi-particle collisions involving K or Λ
- sensitive to both baryon density and strangeness
- test of thermalisation!
  - HADES: Ξ in Ar+KCl not described by SHM

S. Wheaton and J. Cleymans, Comp. Phys. Comm. 180 (2009) 84



Flow and the equation of state

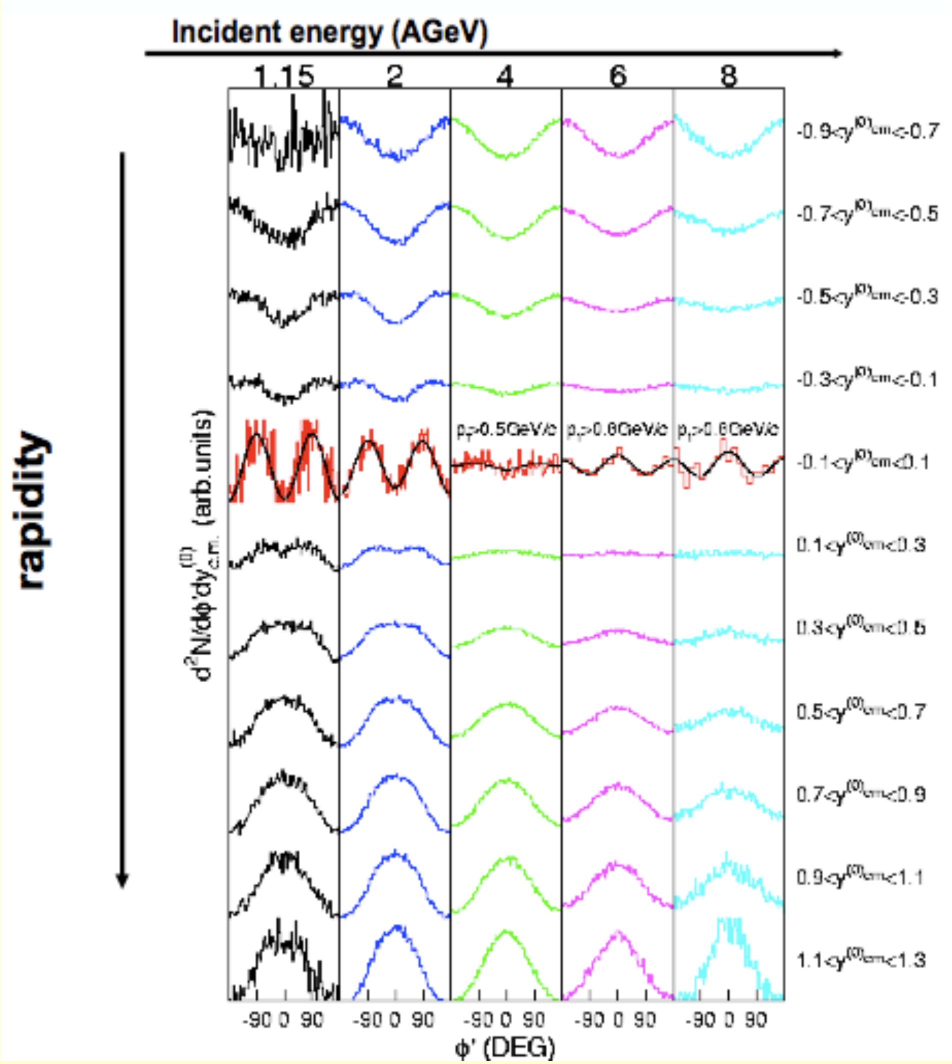


density gradient -> pressure -> collective flow

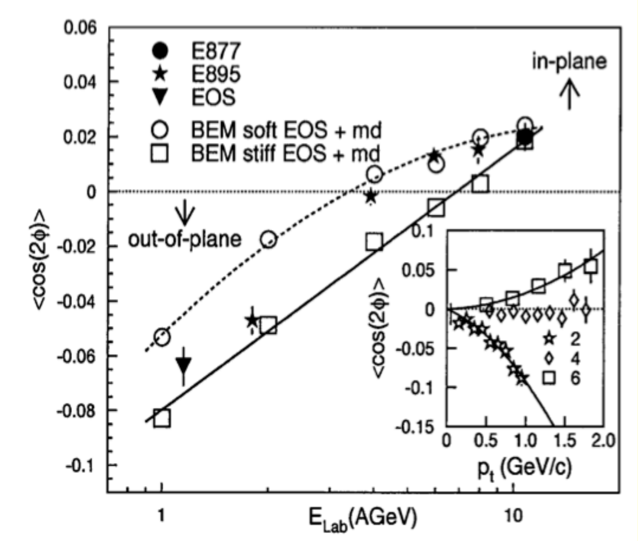
provides access to the equation of state of strongly interacting matter

AGS: Softest point in EOS at 4A GeV?

C. Pinkenburg et al. (E895), Phys. Rev. Lett. 83 (1999) 1295



protons in mid-central Au+Au

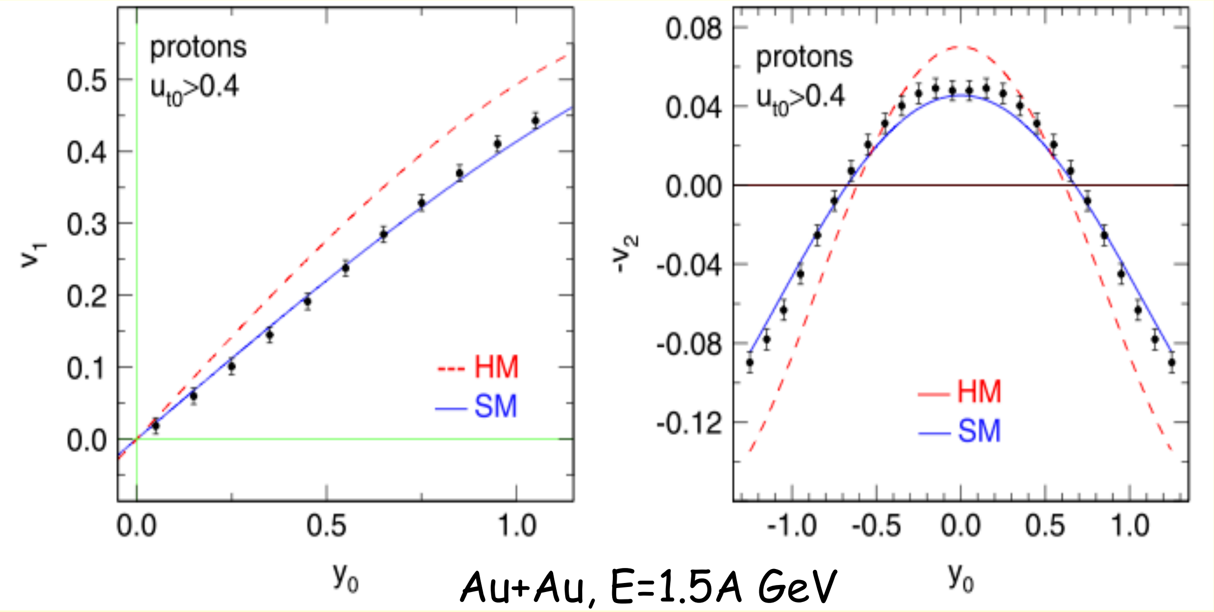


Transition from stiff to soft EOS at 4A GeV

Indication of phase transition?

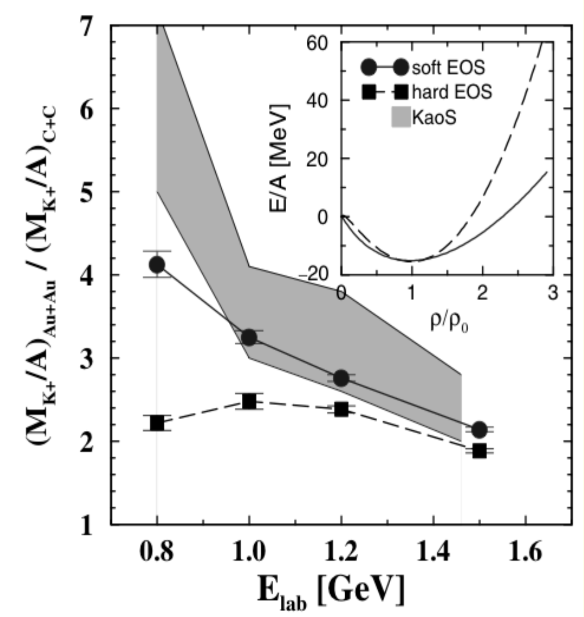
Flow: open questions

W. Reisdorf et al. (FOPI), Nucl. Phys. A 876 (2012) 1



Au+Au, E=1.5A GeV

C. Fuchs, A. Faessler and E. Zabrodin, Phys. Rev. Lett. 86 (2001) 1974

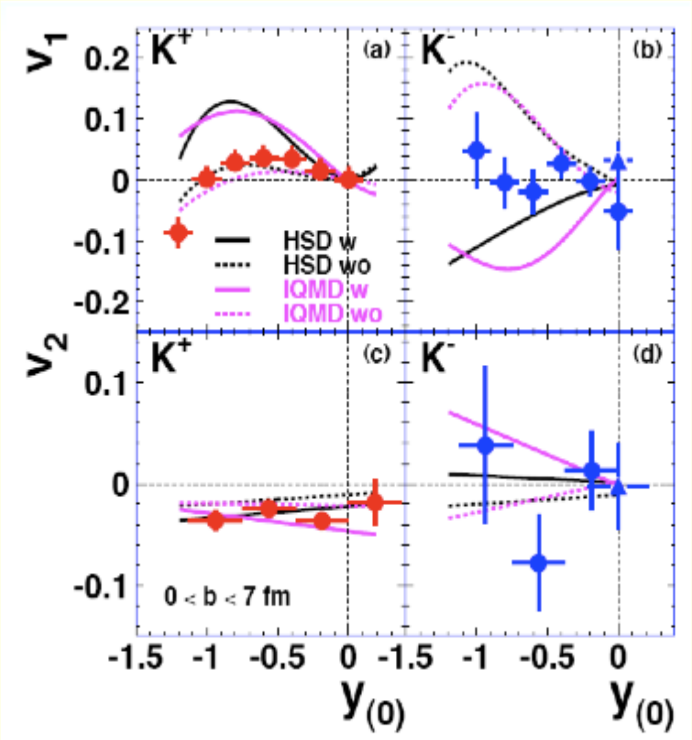


Flow data from FOPI prefer soft EOS at 1.5A GeV and below

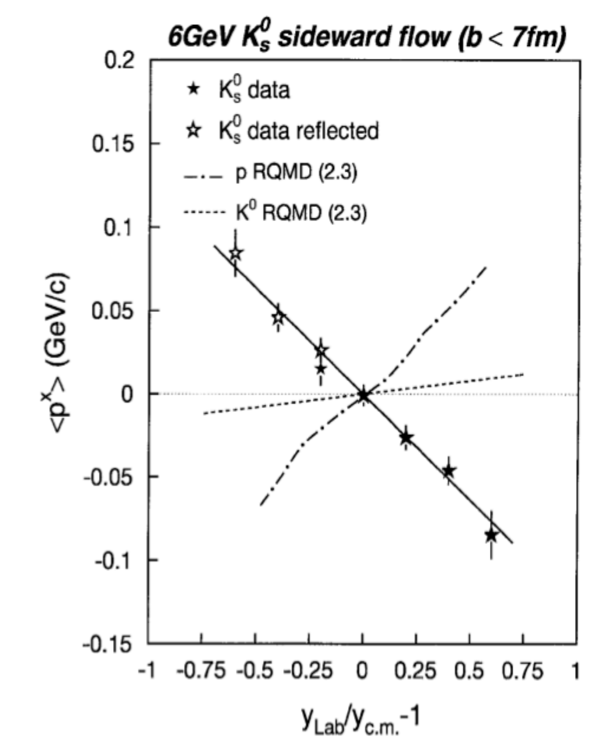
Consistent with K^+ production in Au+Au (KaoS)

Flow of strange particles

N. Herrmann (FOPI), Ni+Ni, 1.91A GeV



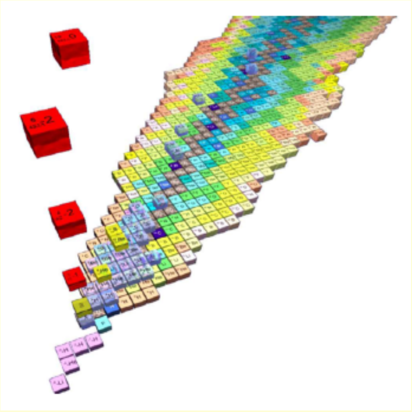
P.Chung et al. (E895), Phys. Rev. Lett 85 (2000) 940



- Strange particle flow is sensitive to EOS and in-medium potential
- Pioneering measurements at SIS-18 (FOPI) und AGS (E895): lack description by models (transport)

Systematic, multi-differential flow measurements (systematic as function of collision energy and system size) are prerequisites for further understanding.

Hypernuclei



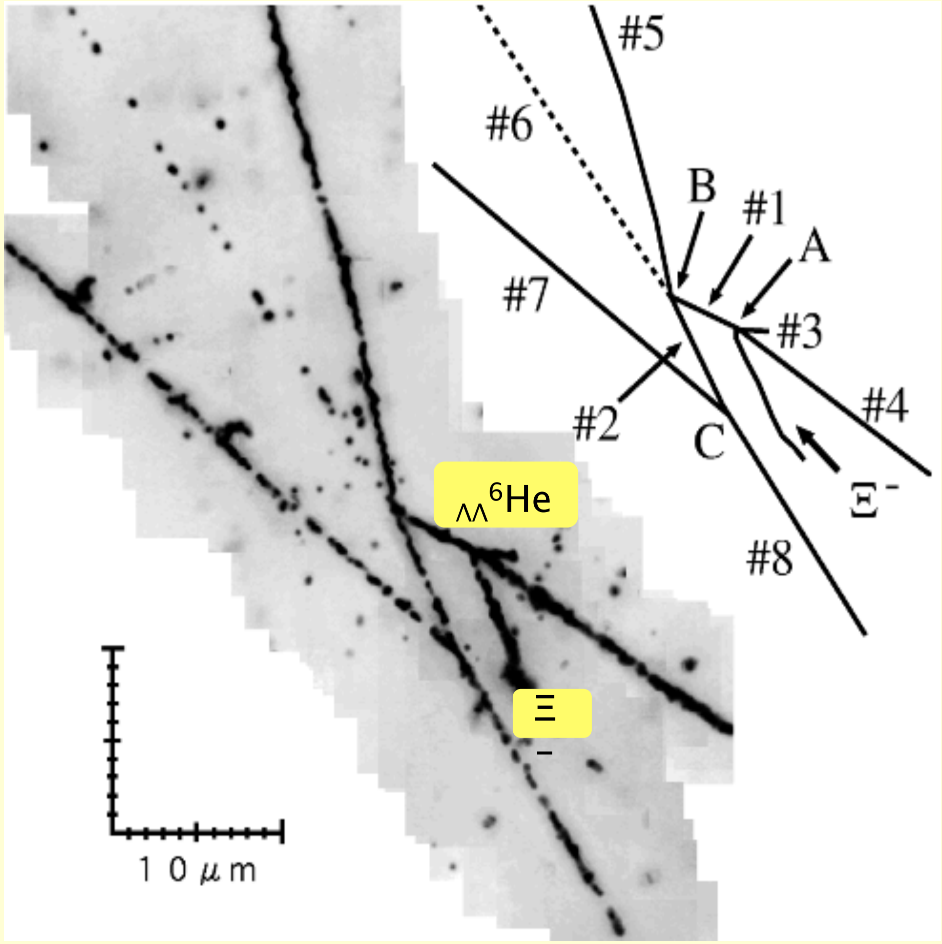
- nuclei containing one (or more) hyperons
- give access to hyperon-nucleon and hyperon-hyperon potential
- observation in in K^- + A collisions (emulsions):

$$K^- + n \rightarrow \Xi^- + \pi^- + K^+$$

$$\Xi^- + A \rightarrow {}^{6}_{\Lambda\Lambda}He$$

- only few double hypernuclei observed so far

H. Takahashi et al., Phys. Rev. Lett. 87 (2001) 212502

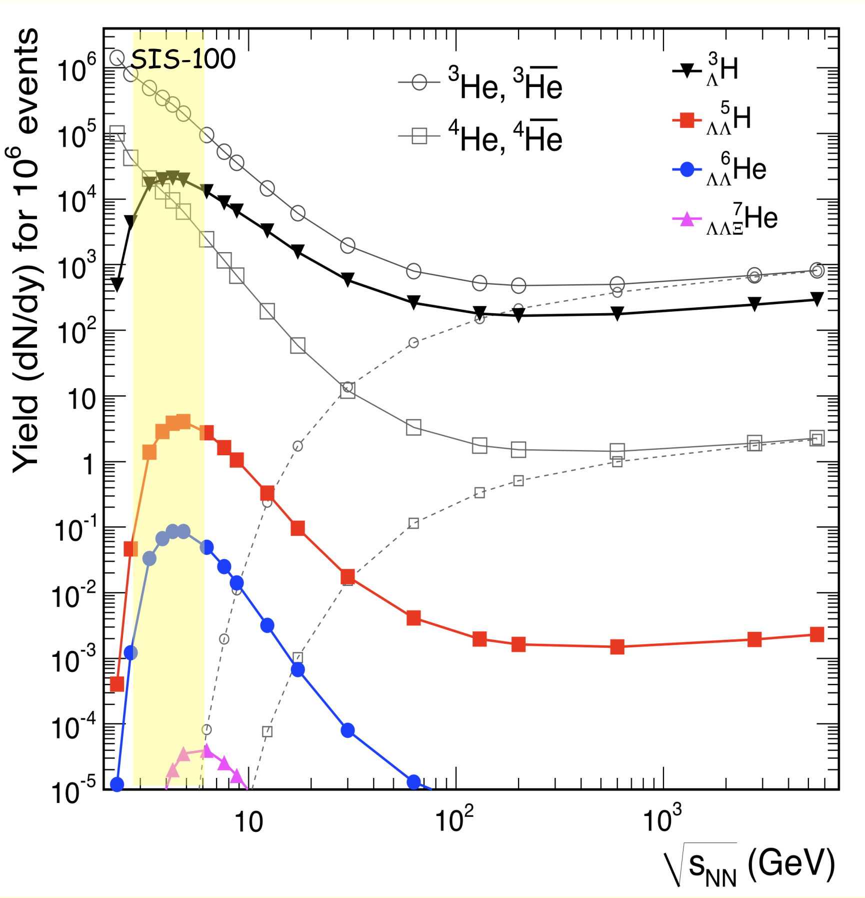


Hypernuclei in heavy-ion reactions

- production through coalescence of Λ (Ξ) with nucleons or light fragments
- interplay of
  - Λ production: increasing with energy (up to ≈ 40A GeV)
  - fragment production: strongly decreasing with energy
- maximum of hypernuclei production predicted for 7A – 11A GeV (statistical model)
- detection through decay chain, e.g.

$$ {}^{5}_{\Lambda\Lambda}H \rightarrow {}^{5}_{\Lambda}He + \pi^{-} \rightarrow {}^{4}He + p + \pi^{-} + \pi^{-} $$

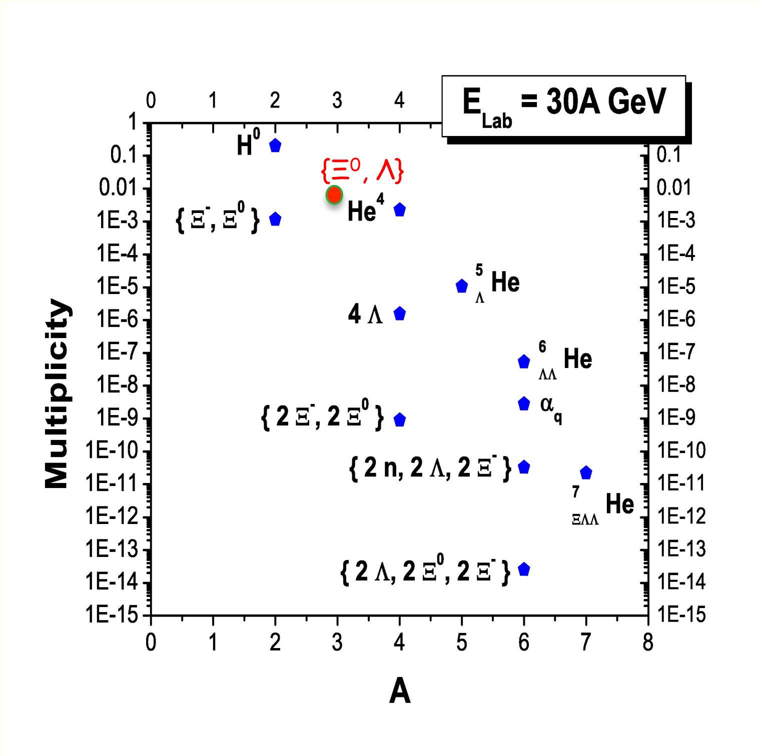
A. Andronic et al., Phys. Lett. B 697 (2011) 203



needs measurement of decay topology and identification of fragments

Exotic states

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



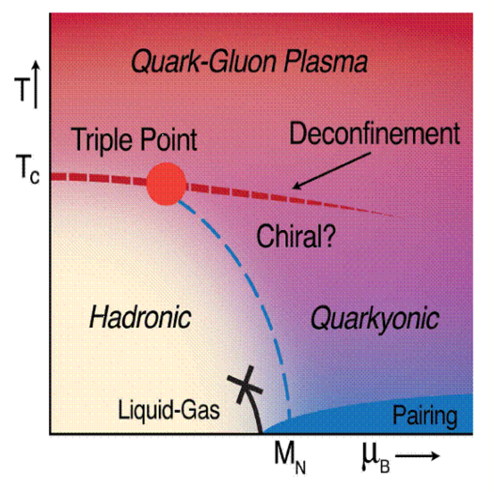
$$H \rightarrow \Lambda + p + \pi^-$$

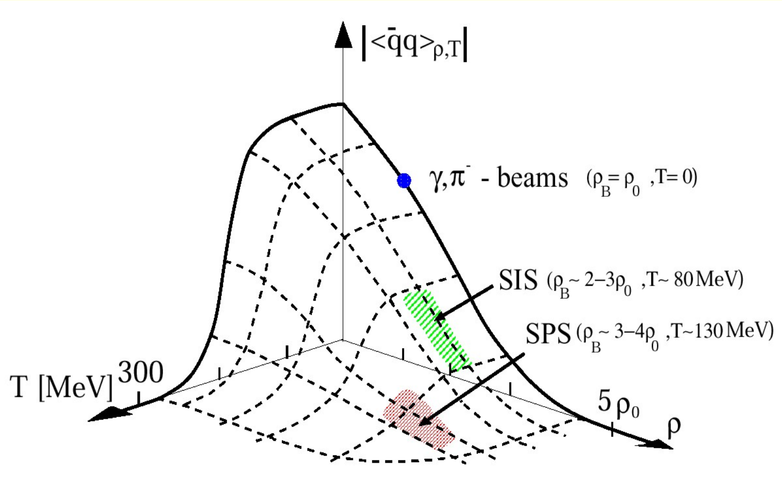
$$(\Xi^0 p)_b \rightarrow p + \Lambda$$

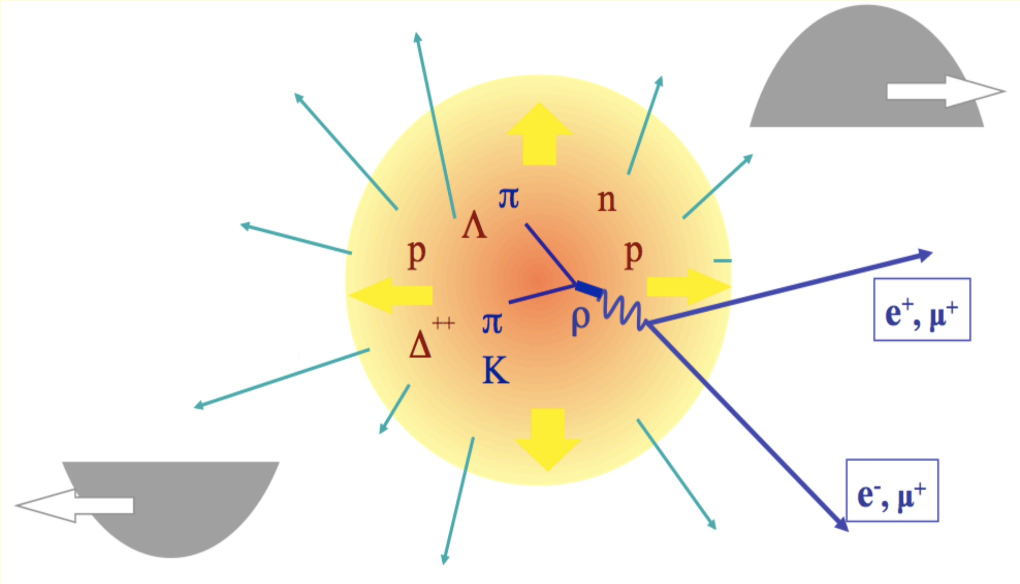
$$(\Xi^0 \Lambda)_b \rightarrow \Lambda\Lambda$$

- dibaryons proposed since long: „collapsed nuclei“, B > 1
- existence or non-existence gives insight into QCD quark dynamics (one-gluon exchange)
- Lightest state: H (uuddss); recently found in in lQCD
  - NPLQCD, PRL 106 (2011) 162001; HALQCD, PRL 106 (2011) 162002
- No experimental evidence so far
- In heavy-ion reactions: production through ΛΛ or Ξ^-p coalescence
- multiplicity: prediction by SHM (30A GeV)
- Measurement through weak decay topology; life time some cm
- Search at SIS-100 with precise measurement of decay vertex and high rates looks promising

Vector mesons in dense matter



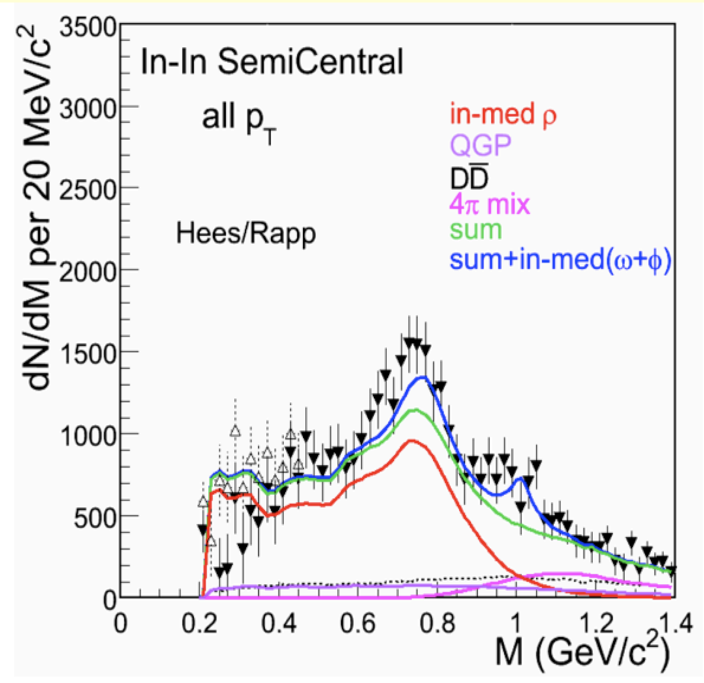




- Are the hadron properties influenced by the dense medium?
- Can we see an onset of chiral symmetry restoration?
- Measure short-lived vector mesons: decay in dense phase of collisions
- decay into lepton pairs: no interaction with medium

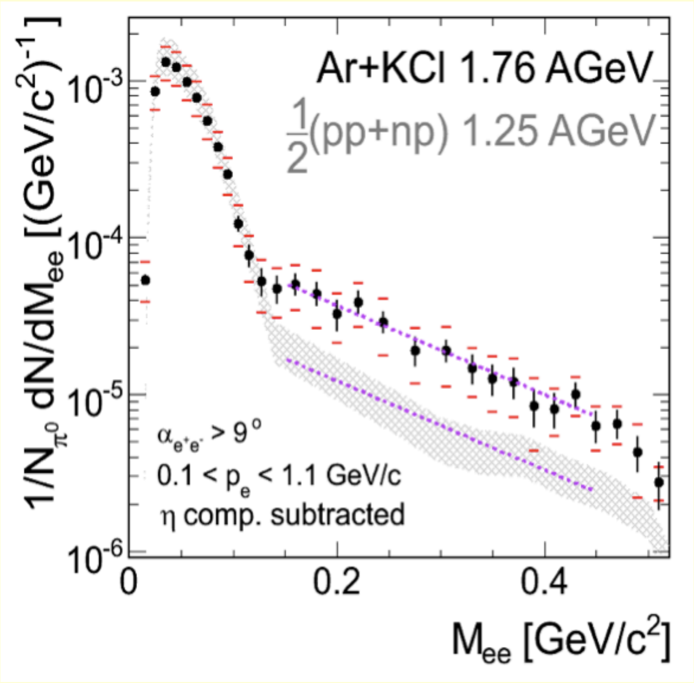
Vector Mesons: SPS and SIS-18

S. Damjanovic et al. (NA60), Nucl. Phys. A 774 (2006) 715



NA60 (Pb+Pb, 158A GeV): excess yield described by broadening of ρ

G. Agakishiev et al. (HADES), arXiv:1103.0876v2 [nucl-ex]



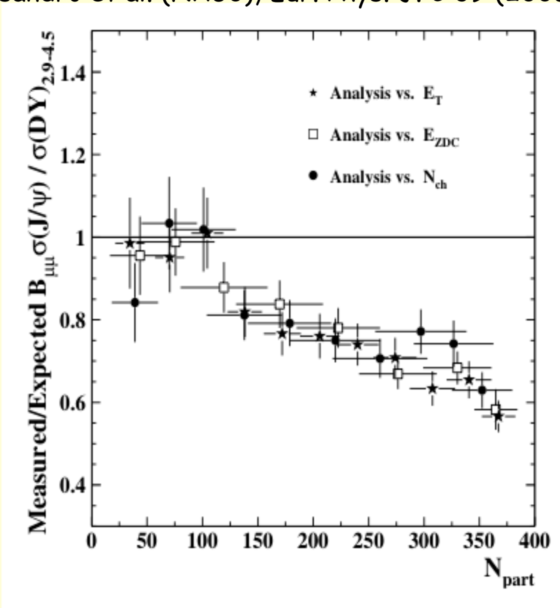
HADES: excess yield already observed in Ar+KCl at 1,76A GeV (but not in C+C)

No experimental data between SIS-18 and SPS, where baryon density is highest.

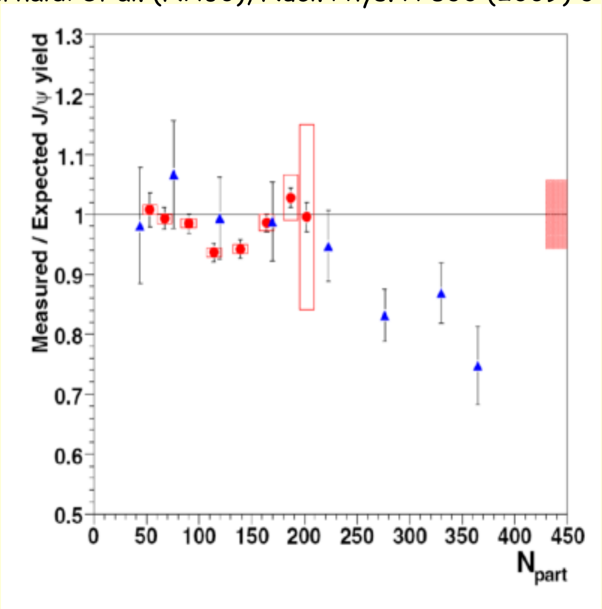
Extension of the HADES programme to larger systems and higher energies at SIS-100: HADES@SIS-100 and CBM

Charm production

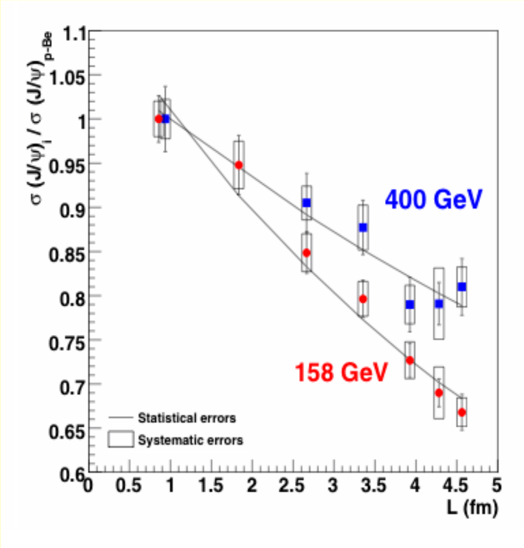
B. Alessandro et al. (NA50), Eur. Phys. J. C 39 (2005) 335



R. Arnaldi et al. (NA60), Nucl. Phys. A 830 (2009) 345c

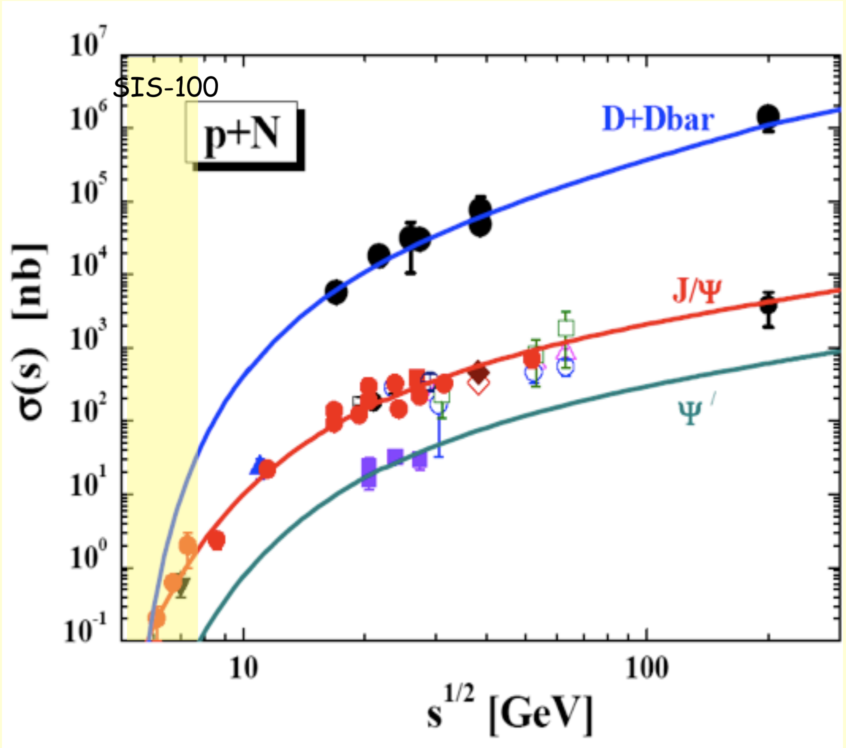


- probe of early collision stage
- absorption of charmonium as QGP signal
- experience from SPS: need to understand absorption in cold nuclear matter for interpretation of A+A



Charm in p+A at SIS-100

O. Lynnek et al., Nucl. Phys. A 786 (2007) 183

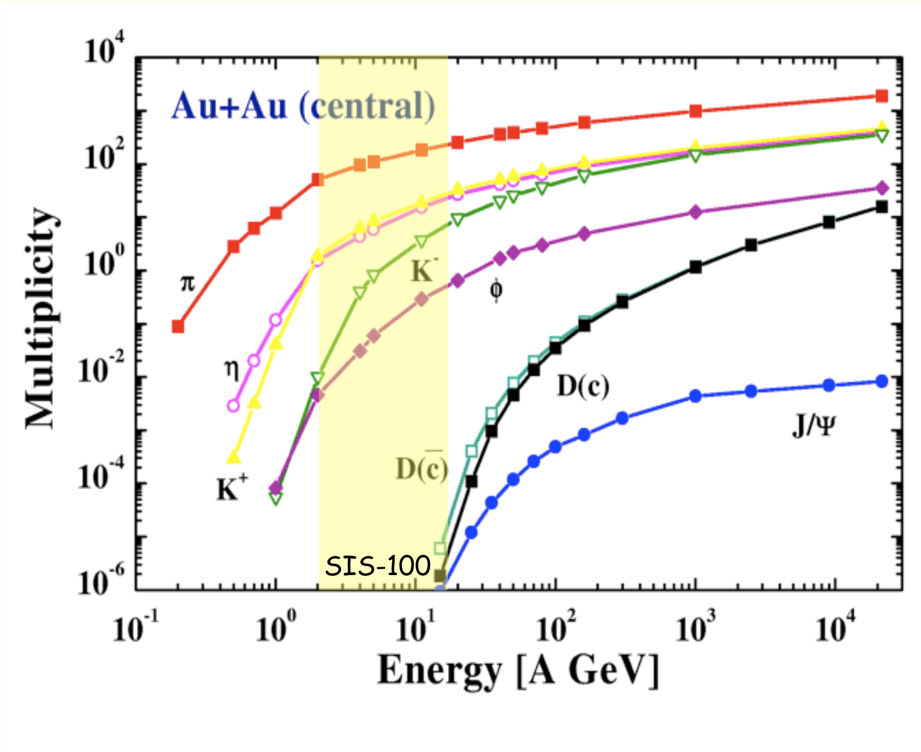


- charm production cross section near threshold unknown
- pQCD calculations with large uncertainties
- important input for models (transport, SHM)

Measurement of both open charm (D mesons) and hidden charm (charmonium) in p+A collisions at SIS-100 (up to 29 GeV)

Requires micro-vertexing and extreme rates!

Charm in A+A at SIS-100 (?)



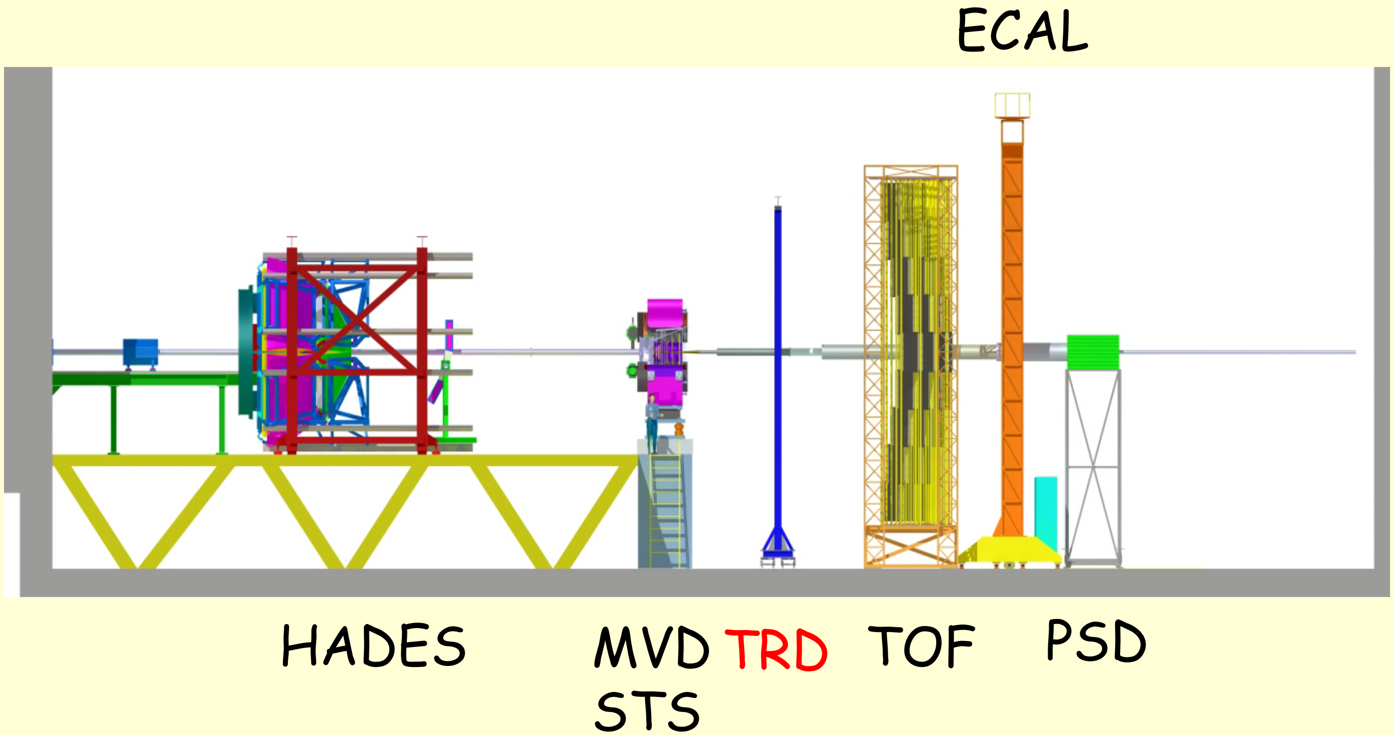
- charm in A+A at / near threshold: terra incognita
- high discovery potential, e.g. in-medium modifications of D mesons
- threshold energies:

$p+p \rightarrow J/\psi + p + p$	11.2 GeV
$p+n \rightarrow \Lambda_c + D^- + p$	12.0 GeV
$p+p \rightarrow D^+ + D^- + p + p$	14.9 GeV

Thresholds for J/ψ, Λ_c und D^- reachable at SIS-100 with light / medium-sized nuclei (Z/A = 0.5)

Very low multiplicities, extremely challenging measurement

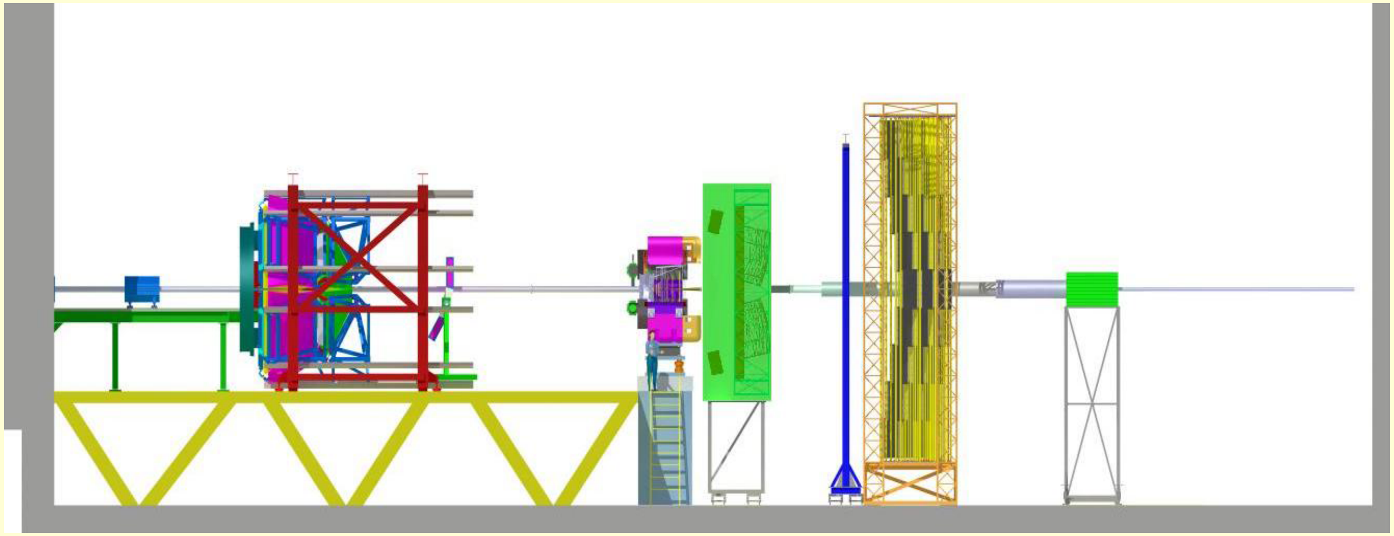
CBM setup at SIS-100



Direct hadrons, hyperons, dibaryons, D mesons, photonic decays of vector mesons
HADES: di-electrons (up to Ni+Ni, 8A GeV)

TRD: start version, only tracking, no electron identification by TR

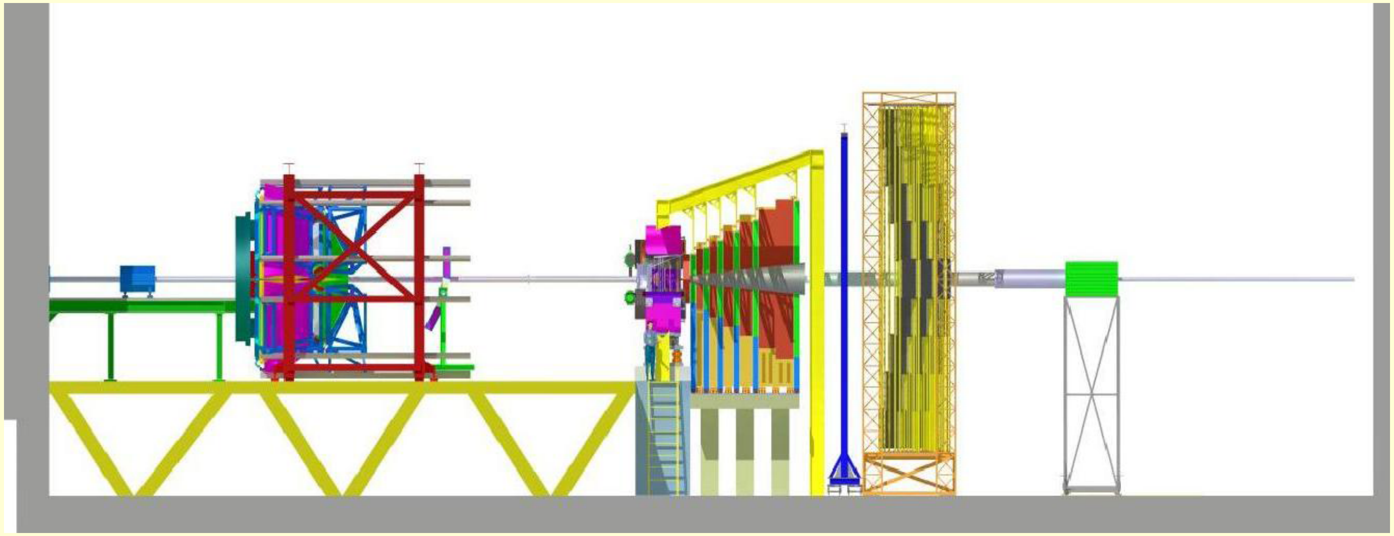
CBM setup at SIS-100



Di-electrons from light vector mesons

CBM setup at SIS-100

MUCH



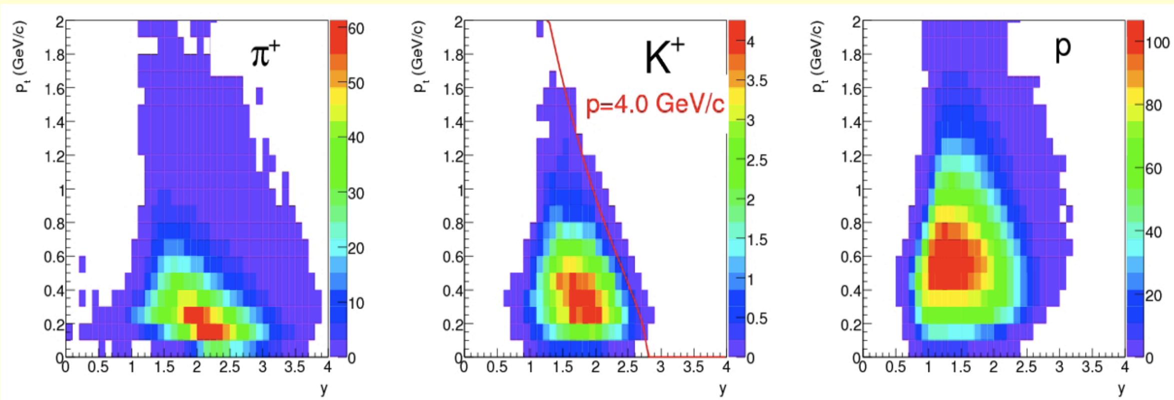
HADES STS TOF PSD

Charmomium

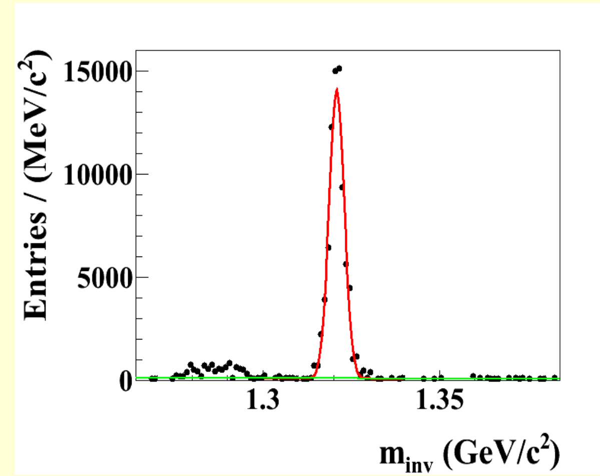
MUCH: start version, 3 x 3 detector layers

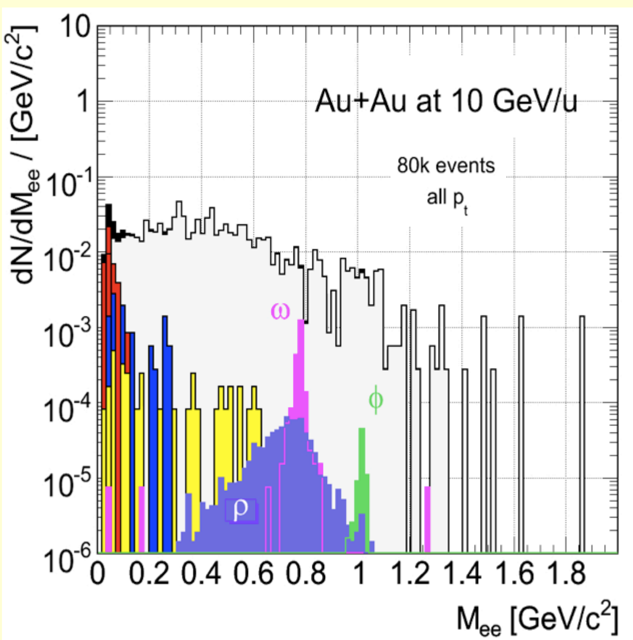
CBM sensitivity at SIS-100 energies

TOF acceptance, 6A GeV

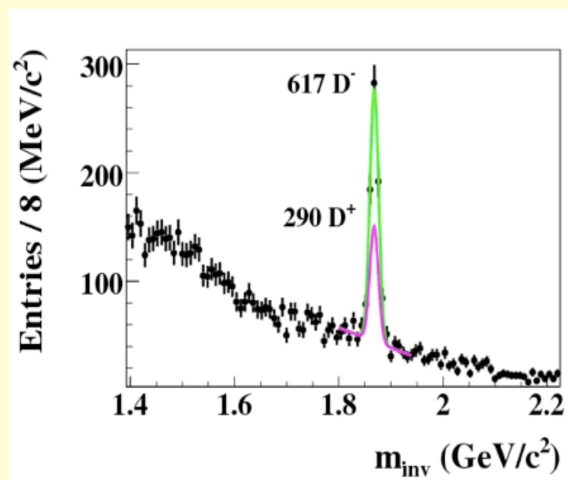


Ξ-, 10^8 Au+Au, 4A GeV

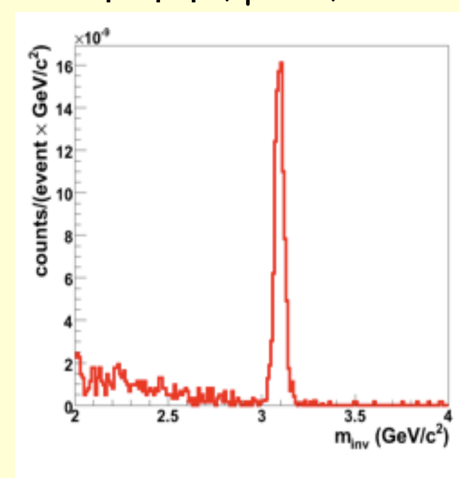




D mesons, p+C, 30 GeV

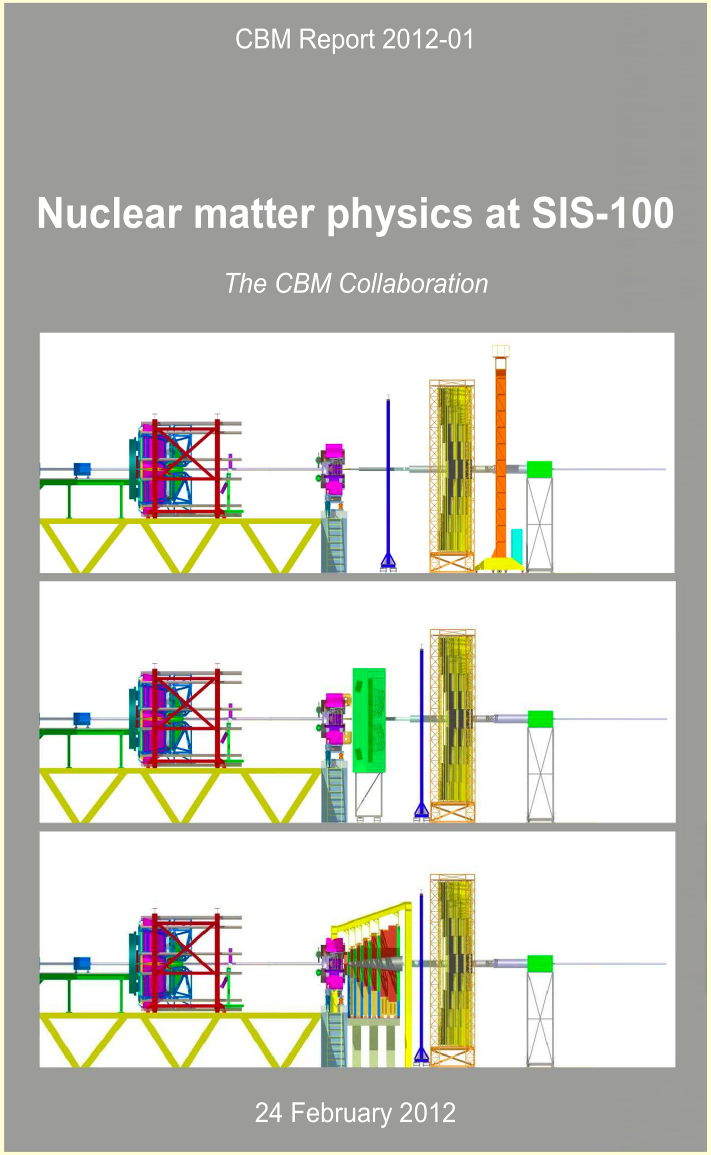


J/ψ->μ+μ-, p+Au, 25 GeV



Summary

- The CBM physics programme starts 2018 at SIS-100 with a start version of the experimental setup
- The SIS-100 energy range allows an exiting and competitive experimental programme:
  - hadrons, hyperons, hypernuclei, dibayrons in A+A up to 11A/14A GeV
  - e^+e^- from light vector mesons in A+A up to 11A/14A GeV, together with HADES
  - D mesons und charmonium in p+A up to 29 GeV
- with large acceptance and high interaction rates
- The full CBM physics potential will be realised at a later stage with operation at SIS-300.



https://www.gsi.de/documents/DOC-2011-Aug-29.html

CBM100 and BM@N

- The nuclotron covers the lower half of the SIS-100 energy range, but will be ready for operation soon.
- With a moderate experimental setup, some parts of the CBM physics can be started with BM@N:
  - High precision tracking device: hyperons, hypernuclei, dibaryons
  - TOF will add charged kaons and increase the sensitivity for rare weak decays
  - Some device for centrality determination (PSD)
  - Reaction plane determination will give access to flow
- Di-electron spectroscopy requires detectors for electron identification
  - Think of HADES operation at Nuclotron? This would extend the physics range of fixed-target nuclotron experiments.