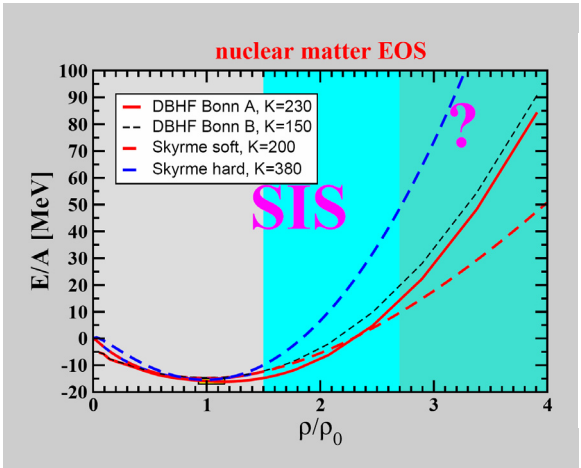
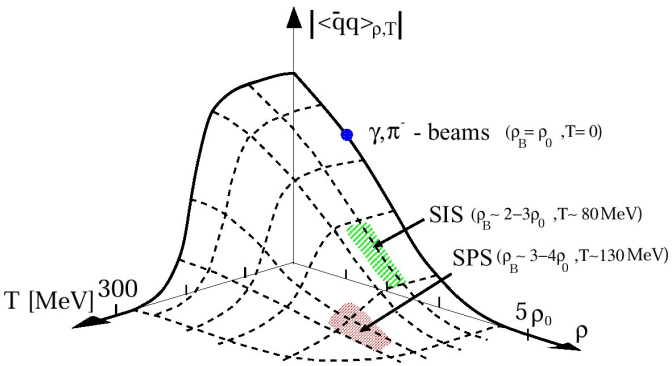
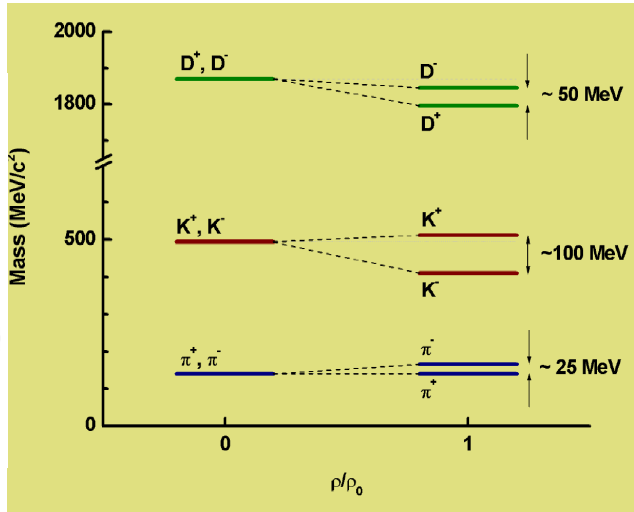
Nuclear Matter Physics at SIS100

P. Senger

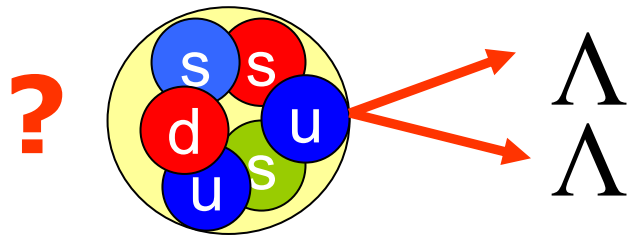






Outline

- FAIR planning
- Results from AGS
- Multi-strange hyperons and the nuclear matter EOS
- Hadrons in dense nuclear matter: Dilepton spectroscopy
- Heavy flavor physics: production and propagation of charm
- Search for (short-lived) strange matter

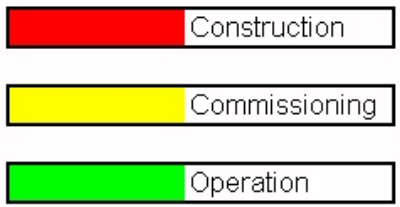


FAIR start version as of Nov. 2007 (940 Mio €)

FAIR Realization	Start Version	Phase B
Accelerator systems		
Super-FRS	X	
CR	X	
NESR	X	
Proton-linac	X	
SIS 100	X	
SIS 100 RF Phase B		X
Antiproton-target and separator	X	
RESR	X	
HESR		
no electron-cooling	X	
electron-cooler		X
SIS 300		X
electron-ring (incl. electron-linac)		X
Basis experiments		
PANDA	X	
CBM	X	
NUSTAR	X	
APPA (Applied, Atomic and Plasma Physics	X	

FAIR Realization	Start Version	Phase B
Beam Lines		
from SIS18 to SIS100/300	X	
from SIS 18 to HESR		X
from SIS18 to plasma physics cave		X
from SIS18 to NESR	X	
from SIS 100 to Super-FRS	X	
from SIS100 to antiproton target	X	
from SIS100 to CBM	X	
from SIS100 to plasma physics	X	
from SIS300 to caves		X
from SIS100/300 to high-energy atomic physics		X
from Super-FRS to CR	X	
from CR to RESR/NESR	X	
from RESR to HESR	X	
from Super-FRS to NUSTAR Experiments	X	
from NESR to SPARC/FLAIR-Experiments	X	

FAIR accelerator schedule



Beams available for experiments:

<u>SIS100 in 2014:</u>

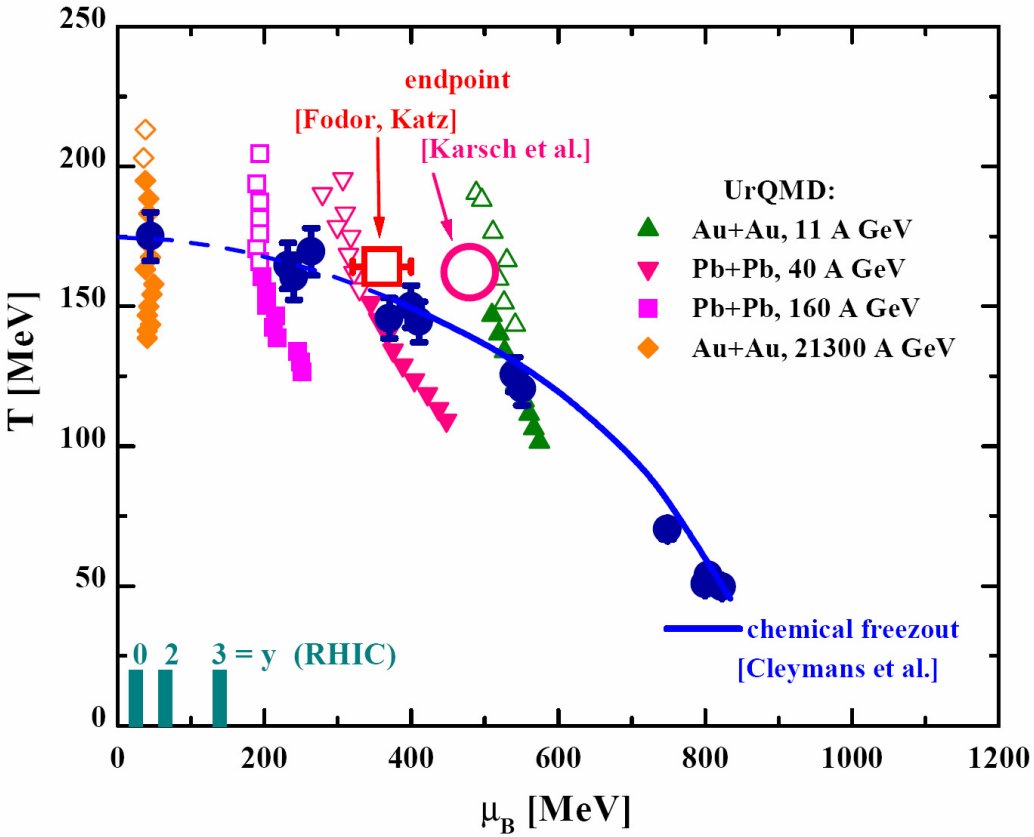
- nuclei up to 14 (11) A GeV, Z/A=0.5 (0.4)
- protons up to 29 GeV

<u>SIS300 in 2016-2017:</u>

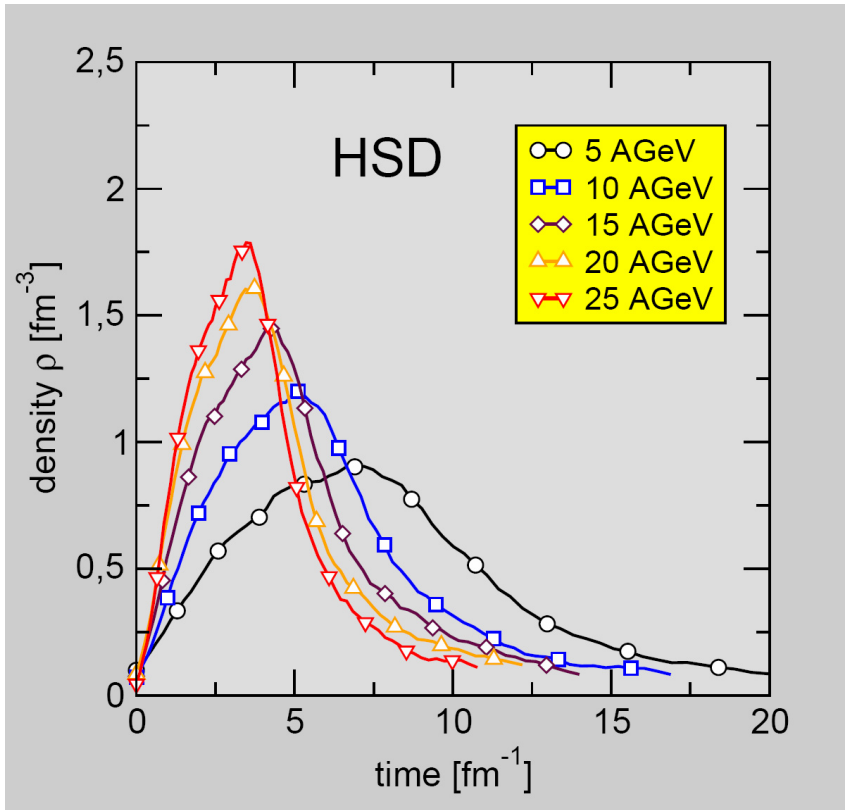
- nuclei up to 44 (34) A GeV, Z/A=0.5 (0.4)
- protons up to 89 GeV

Heavy-ion collisions at SIS100: Transport model predictions

UrQMD: L.V. Bravina et al., Phys. Rev. C60 (1999) 044905

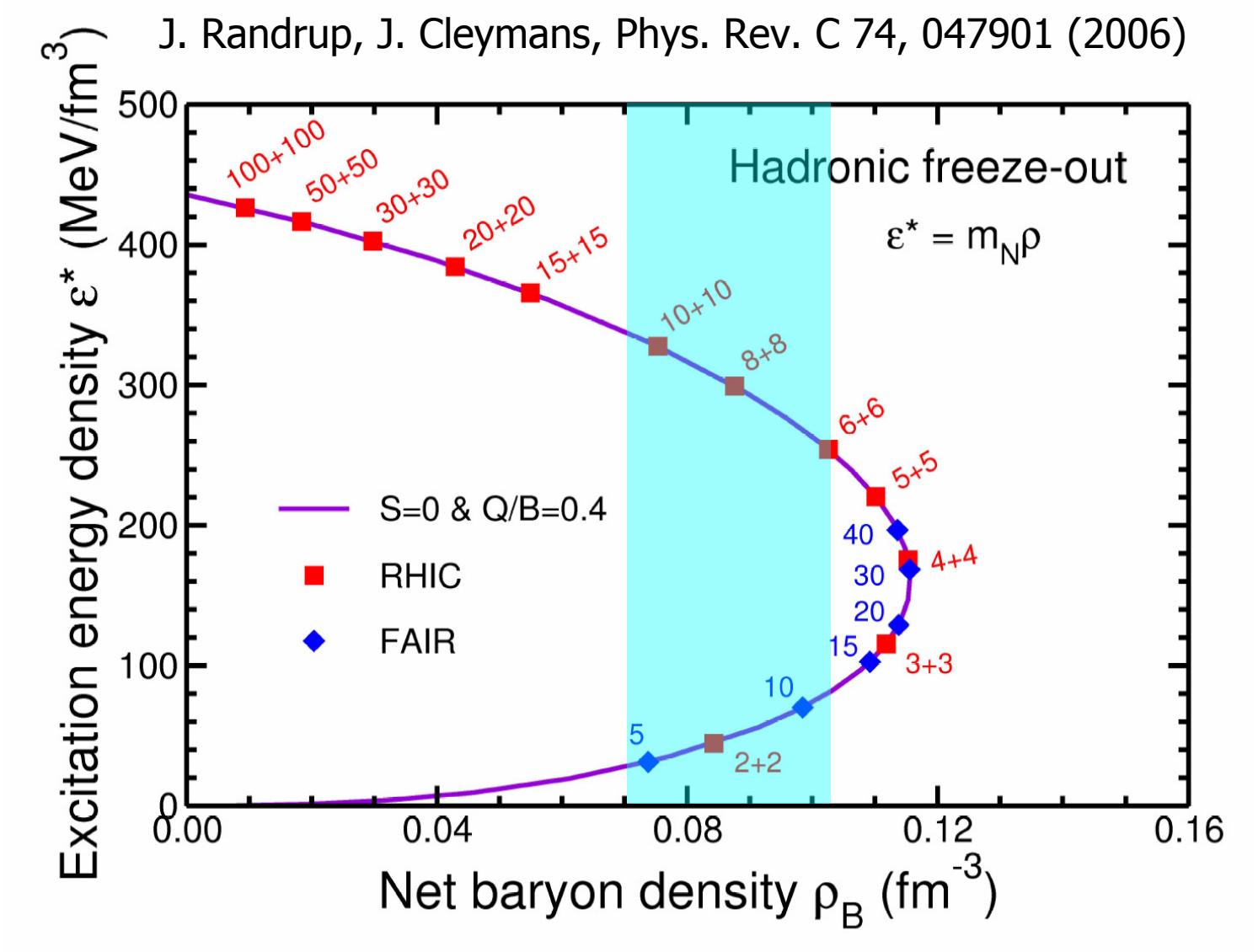


E. Bratkovskaya, W. Cassing



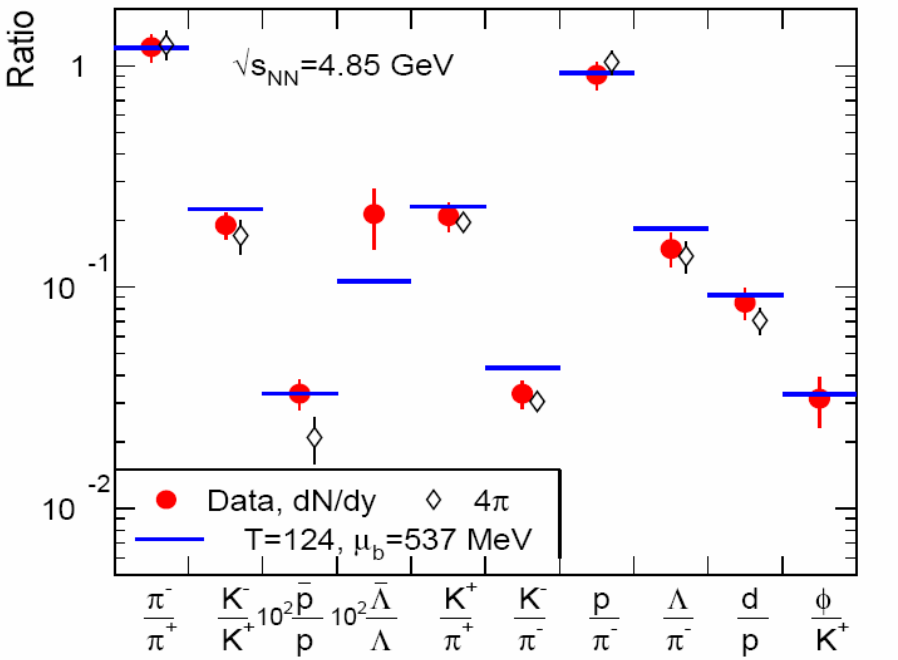
Au+Au collisions up to 11 AGeV: exploring properties of dense hadronic (resonance) matter in the vicinity of the phase transition

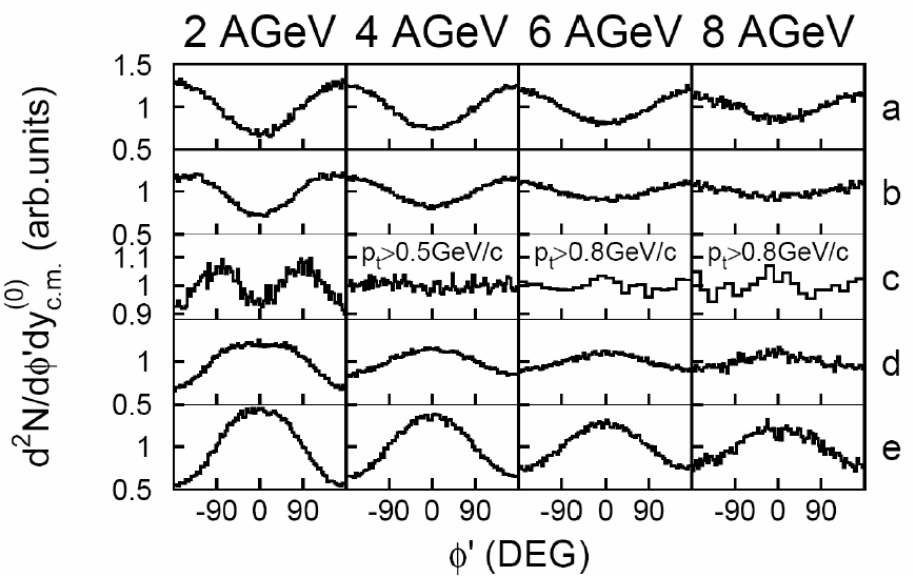
Chemical freeze-out: a different view



Results from AGS (1988-1999)

Exhaustive measurements of global observables such as basic hadronic spectra, kaon and lambda production, collective flow and HBT.





No measurements of rare probes such as hadronic resonances, multistrange hyperons (except one point at 6 AGeV), lepton pairs and charmed particles. No fluctuation studies.

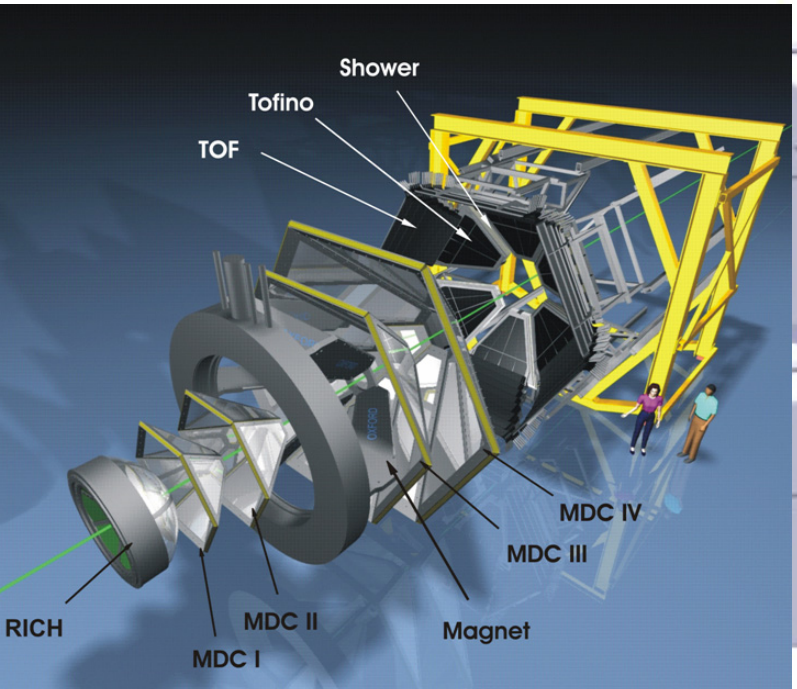
Detector setups at FAIR

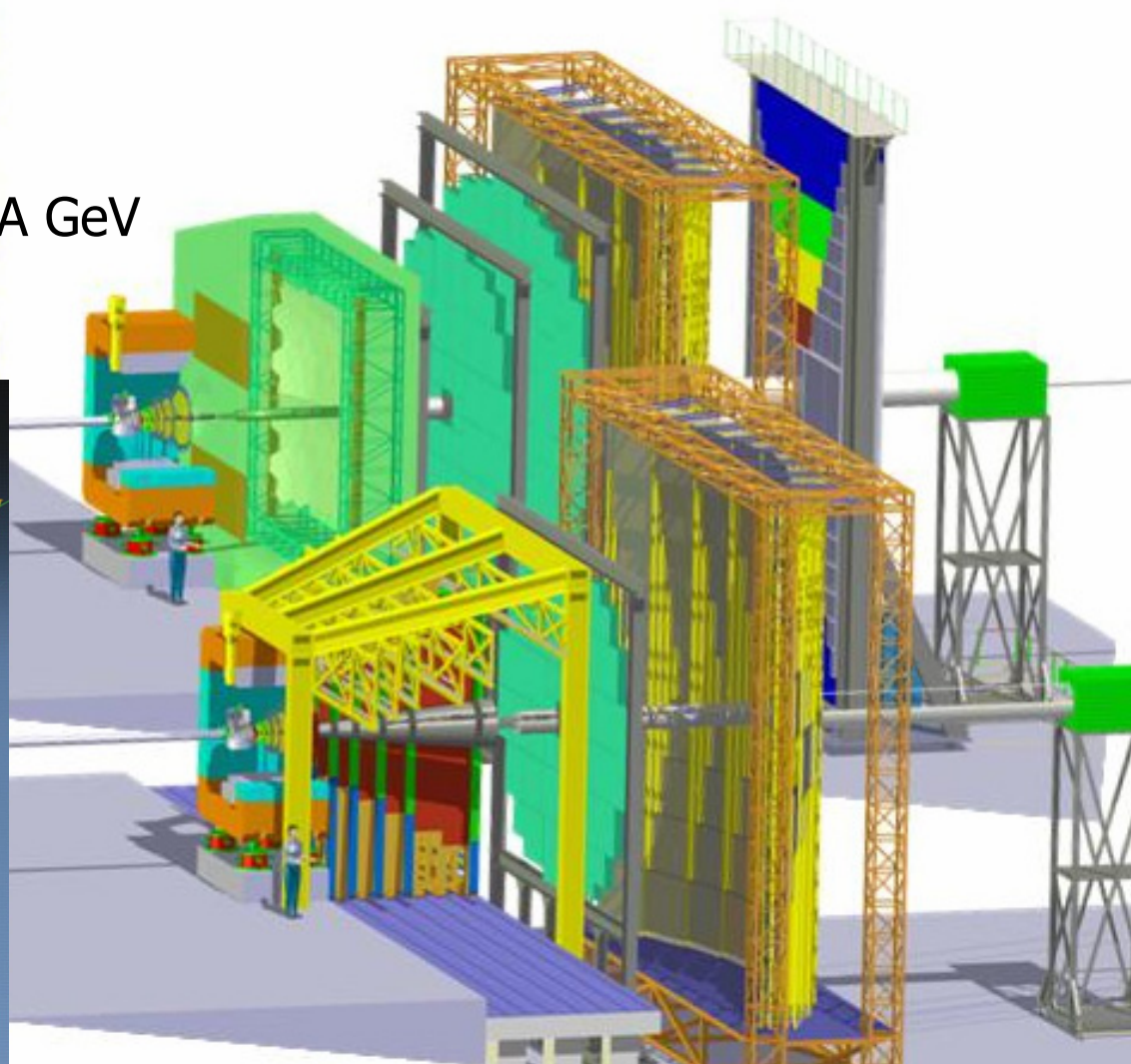
CBM at SIS100/300:

- Electrons, muons, charm, hadrons, photons, exotica
- Nuclear collisions from 4 - 45 A GeV

HADES at SIS100:

- Electrons. hadrons, (photons)
- Nuclear collisions from 1 - 10 A GeV





The CBM physics program at SIS300

The equation-of-state at high ρ_B

- collective flow of hadrons
- particle production at threshold energies (multistrange hyperons, open charm?)

Deconfinement phase transition at high ρ_B

- excitation function and flow of strangeness (K, Λ, Σ, Ξ, Ω)
- excitation function and flow of charm (J/ψ, ψ', D^0, $D^{\pm}$, Λ_c) (e.g. melting of J/ψ and ψ')
- excitation function of low-mass lepton pairs
- disappearance of quark-number scaling of elliptic flow

QCD critical endpoint

- excitation function of event-by-event fluctuations (K/π,...)

Onset of chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$, D)

The equation-of-state of (symmetric) nuclear matter

Equation of state:

$P = \delta E/\delta V \big|_{T=const}$

$V = A/\rho$

$\delta V/\delta\rho = -A/\rho^2$

$P = \rho^2\ \delta(E/A)/\delta\rho \big|_{T=const}$

T=0: $E/A = 1/\rho \int U(\rho) d\rho$

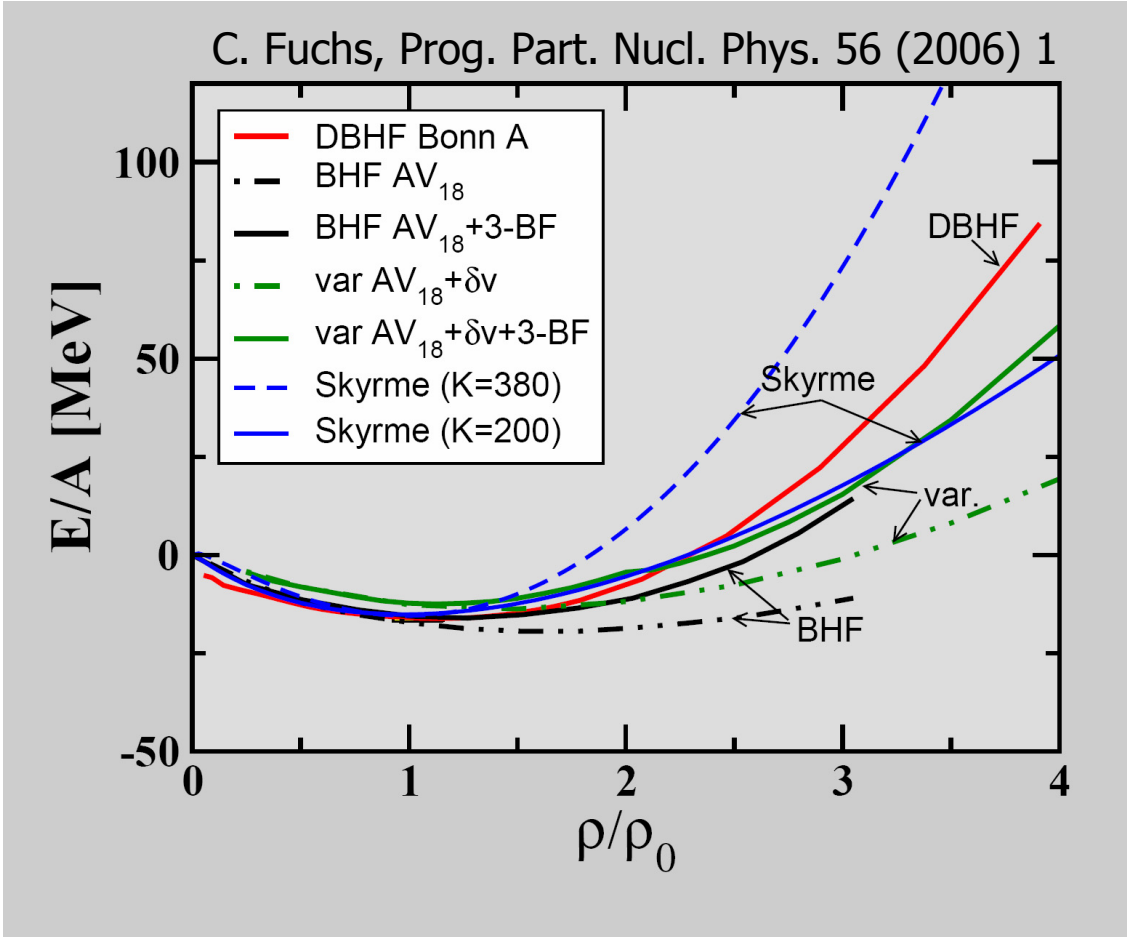
Effective NN-potential:

$U(\rho)=\alpha\rho+\beta\rho^{\gamma}$

$E/A(\rho_o) = -16$ MeV

- $\delta(E/A)(\rho_o)/\delta\rho = 0$
- Compressibility:

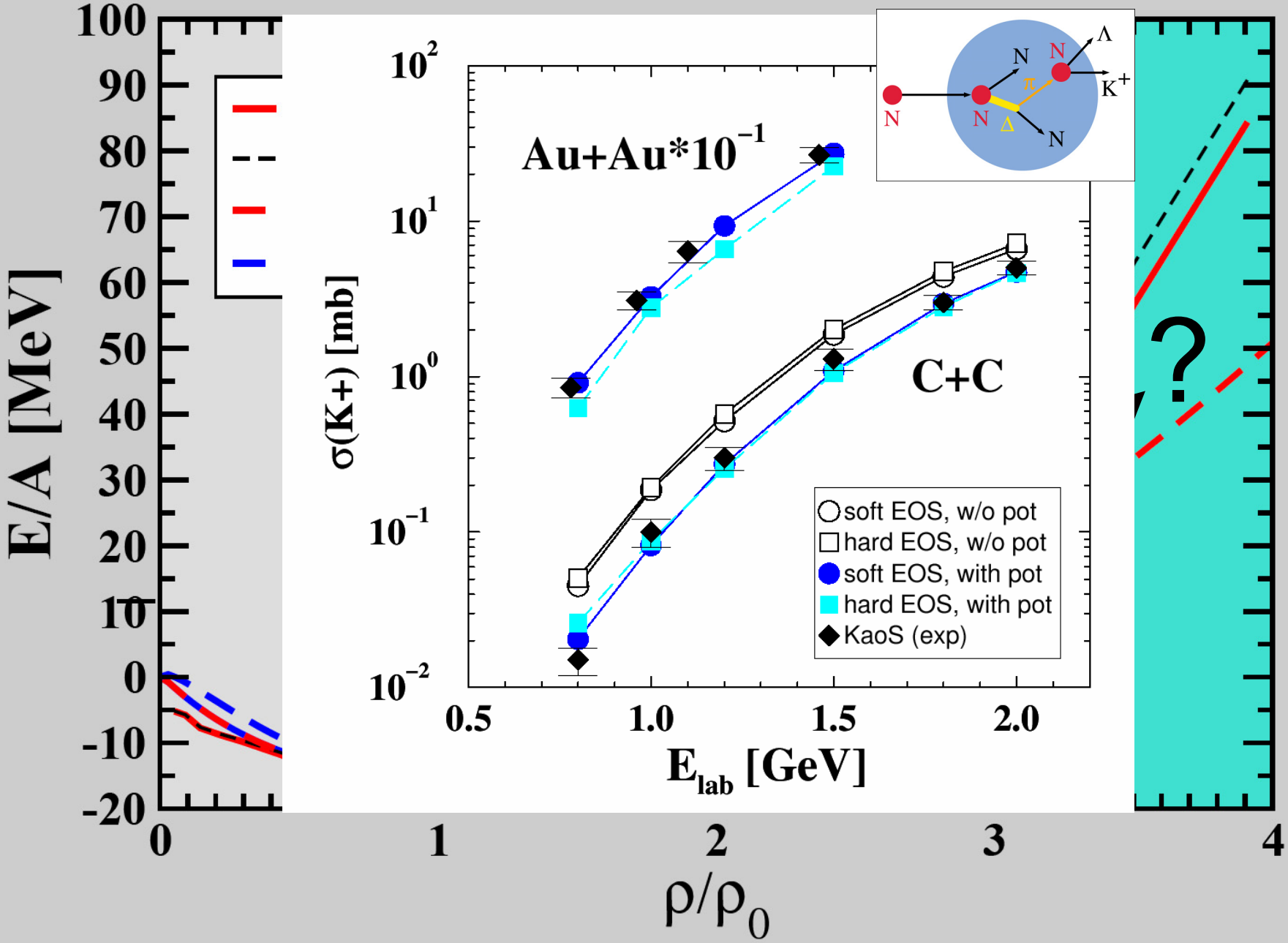
$\kappa = 9\rho^2\ \delta^2(E/A)/\ \delta\rho^2$



κ = 200 MeV: "soft" EOS

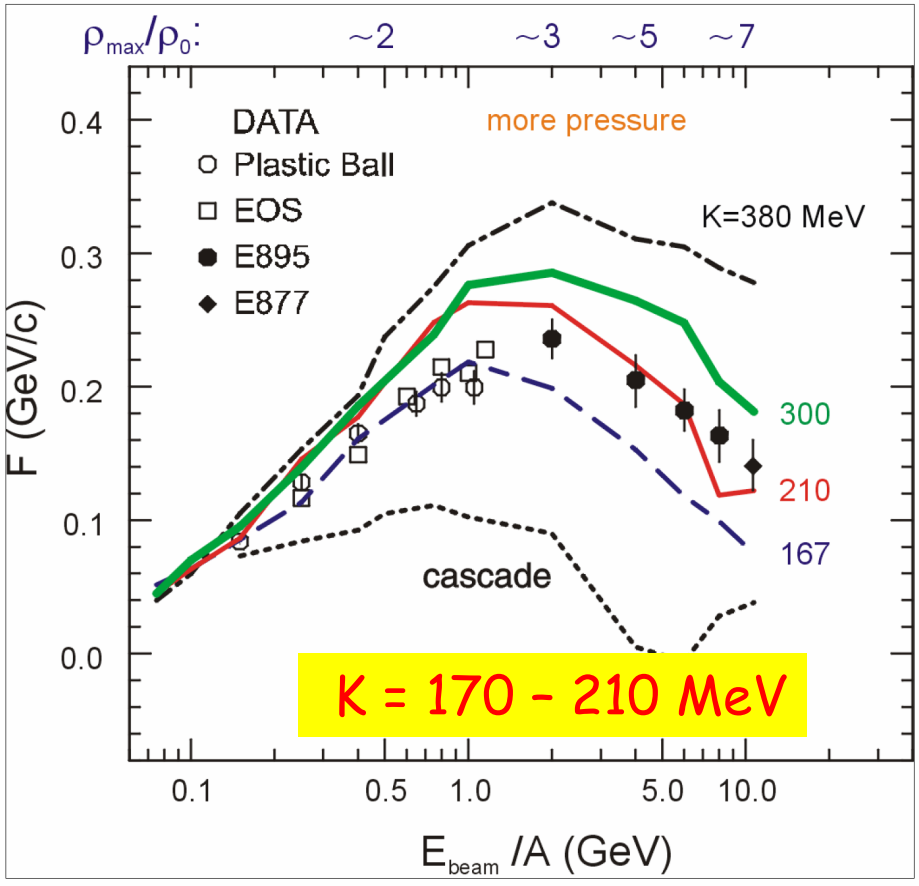
κ = 380 MeV: "stiff" EOS

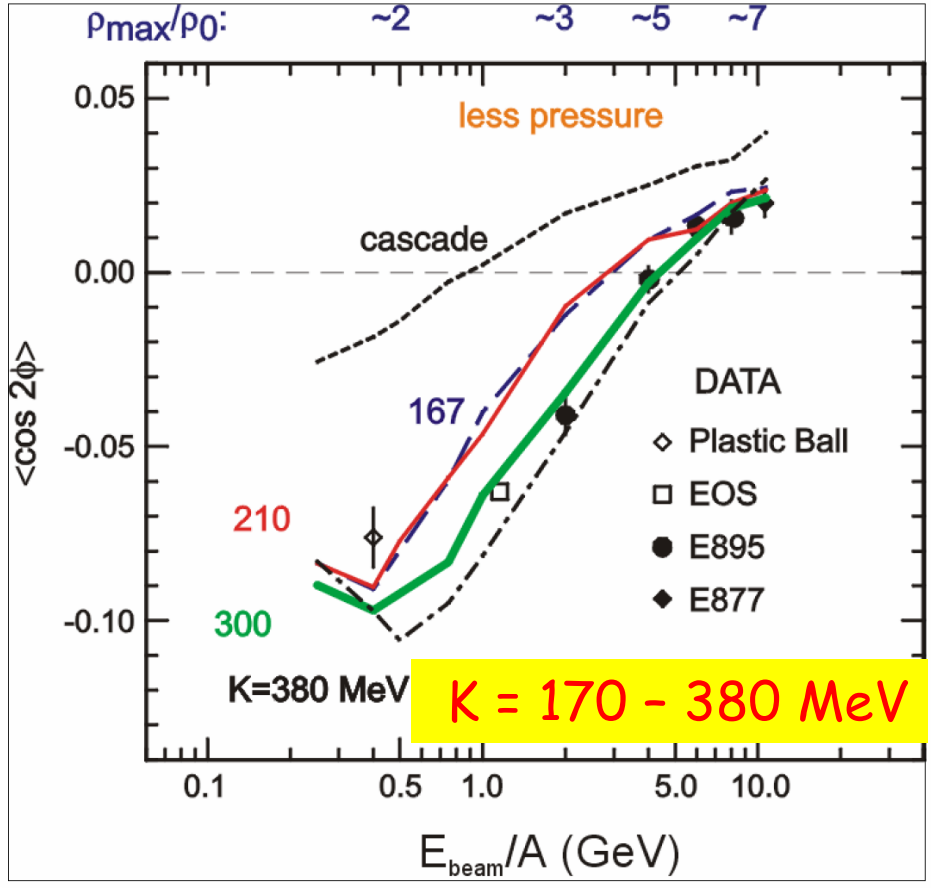
nuclear matter EOS



Probing the nuclear equation-of-state: proton collective flow

P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592





Within microscopic transport models the collective flow is sensitive to:

- The nuclear matter equation of state
- In-medium nucleon-nucleon cross sections
- Momentum dependent interactions

Exploring the "nuclear" EOS at $3\rho_0 < \rho < 7\rho_0$ with (sub)threshold production of multistrange hyperons

Measure the excitation function of (multi-strange) hyperon production in heavy-ion collisions from 2 - 15 AGeV:

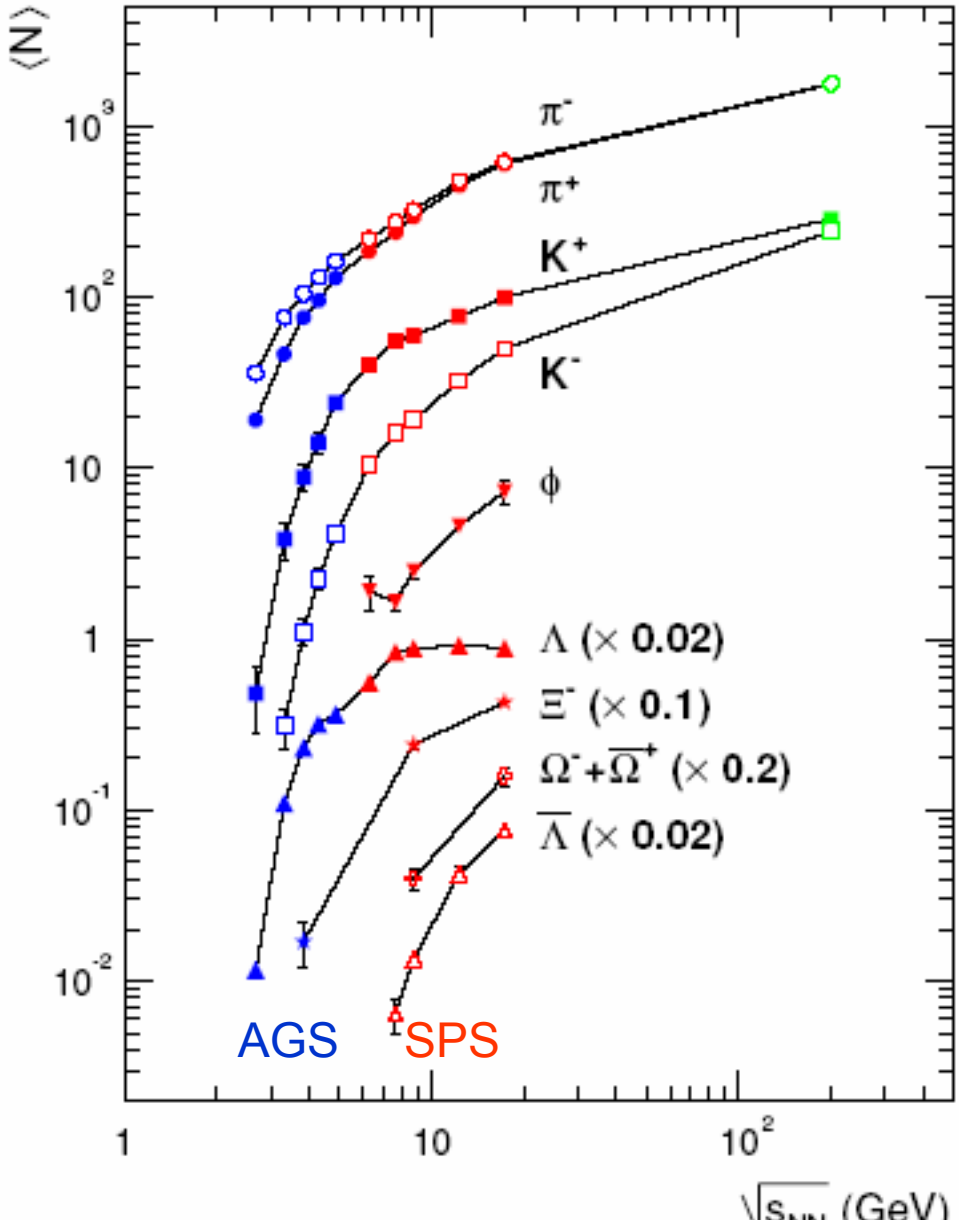
<u>Direct production:</u>

$NN \rightarrow \Lambda^0\overline{\Lambda}^0\, NN$ (E_{thr} = 7.1 GeV)
$NN \rightarrow \Xi^+\, \Xi^-\, NN$ (E_{thr} = 9.0 GeV)
$NN \rightarrow \Omega^+\, \Omega^-\, NN$ (E_{thr} = 12.7 GeV)

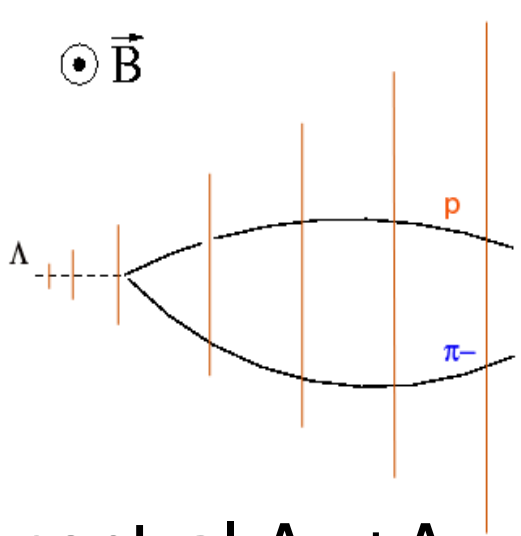
<u>Production via multiple collisions:</u>

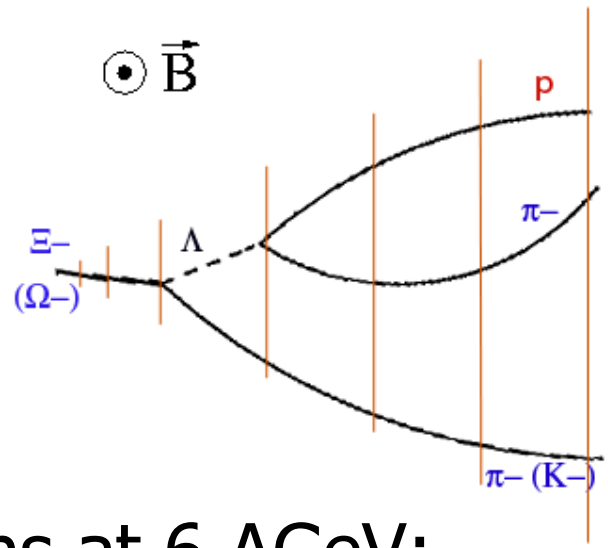
Hyperons (s quarks):
1. $NN \rightarrow K^+\Lambda^0 N$, $NN \rightarrow K^+K^-NN$,
2. $\Lambda^0 K^- \rightarrow \Xi^-\pi^0$,
3. $\Xi^- K^- \rightarrow \Omega^-\pi^-$

Antihyperons (anti-s quarks):
1. $\overline{\Lambda}^0 K^+ \rightarrow \Xi^+\pi^0$,
2. $\Xi^+ K^+ \rightarrow \Omega^+\pi^+$.

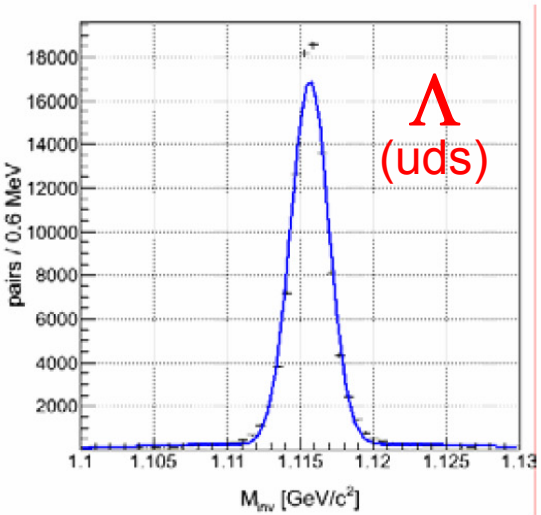


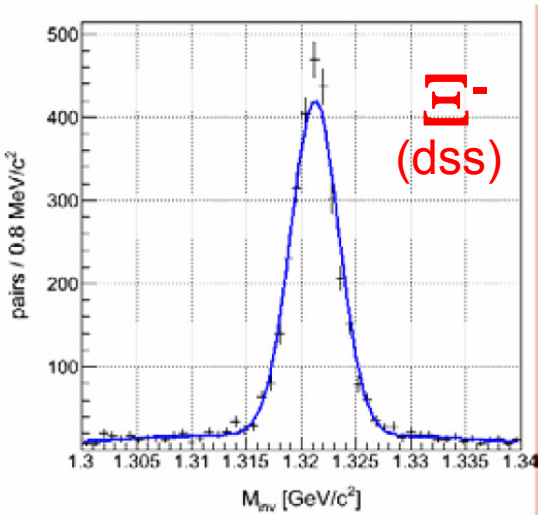
Identification of hyperons in heavy-ion collisions with the CBM Silicon Tracker via decay topology (no PID)

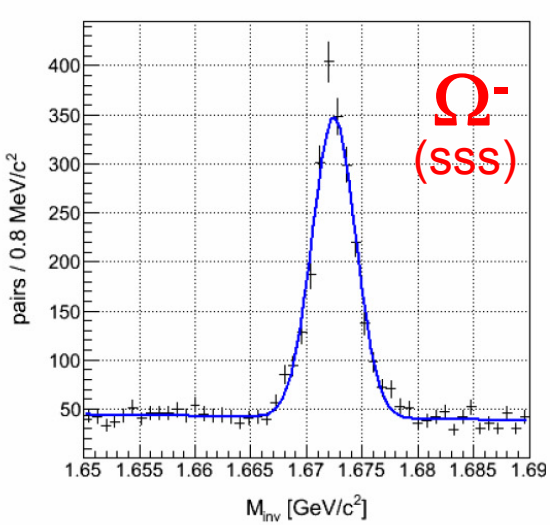




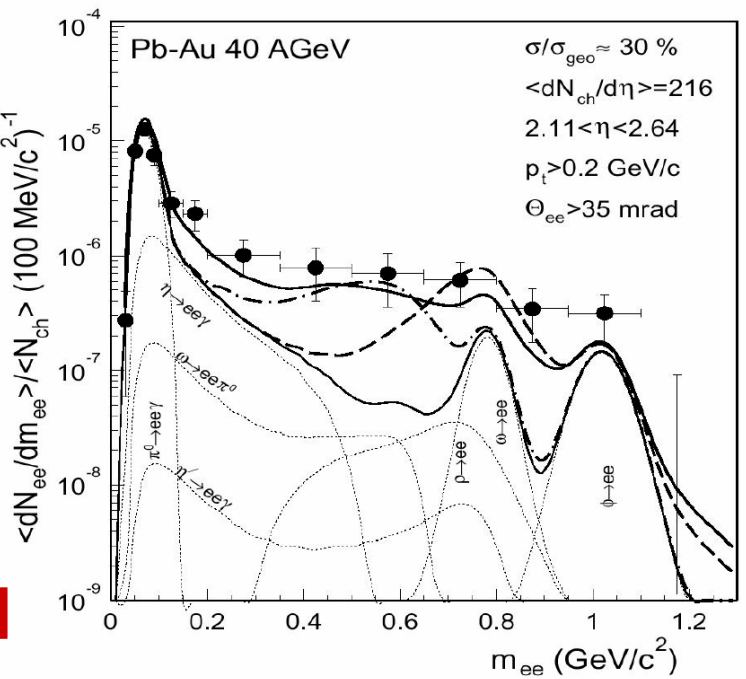
central Au+Au collisions at 6 AGeV:

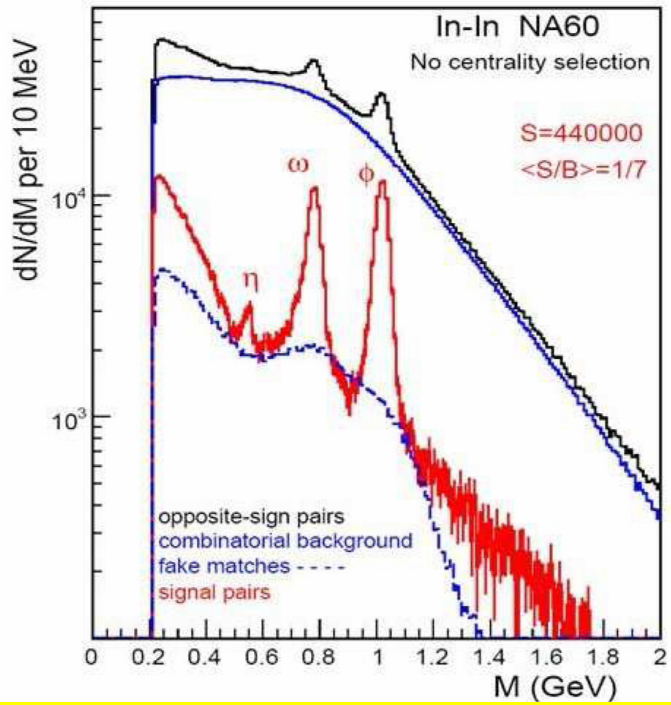






Looking into the fireball using penetrating probes: Dilepton measurements in heavy-ion collisions





no dilepton data between 2 and 40 A GeV
no dilepton data from heavy systems below 40 A GeV

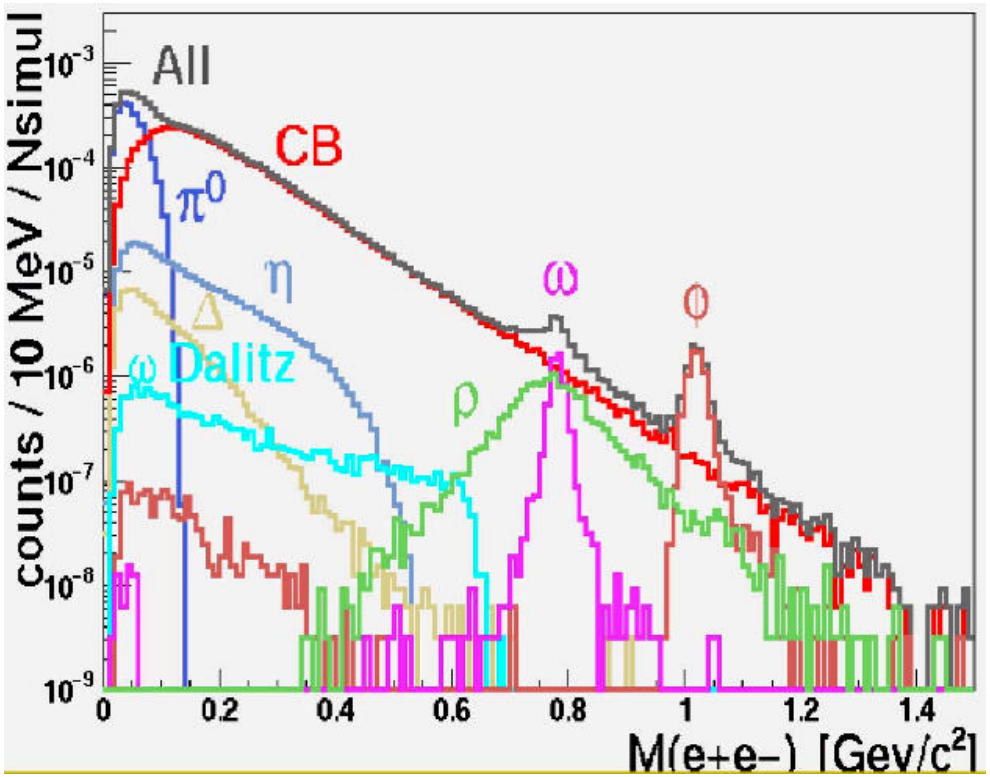
<u>Information needed in addition to dileptons from A+A:</u>

- π, K, p, Λ, … to constrain the fireball evolution
- ρ → π π, φ → KK to measure the freeze-out contributions
- p+A collisions to determine the contribution of primordial ρ's

Dileptons from central Au+Au collisions at 8A GeV

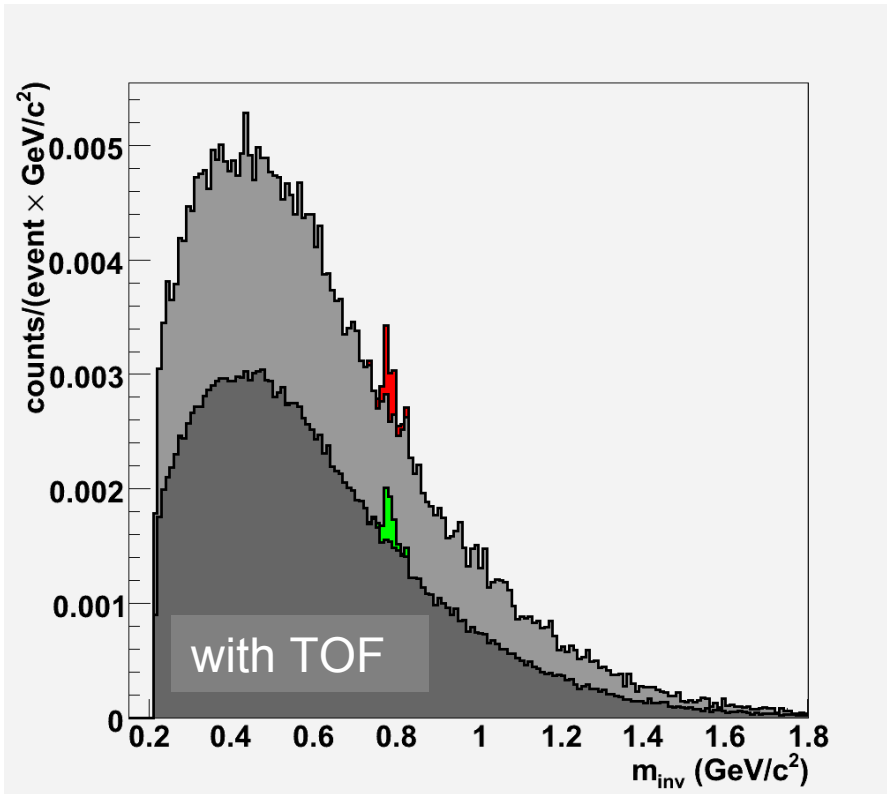
HADES

Monte Carlo simulation:
Dielectron invariant mass spectrum



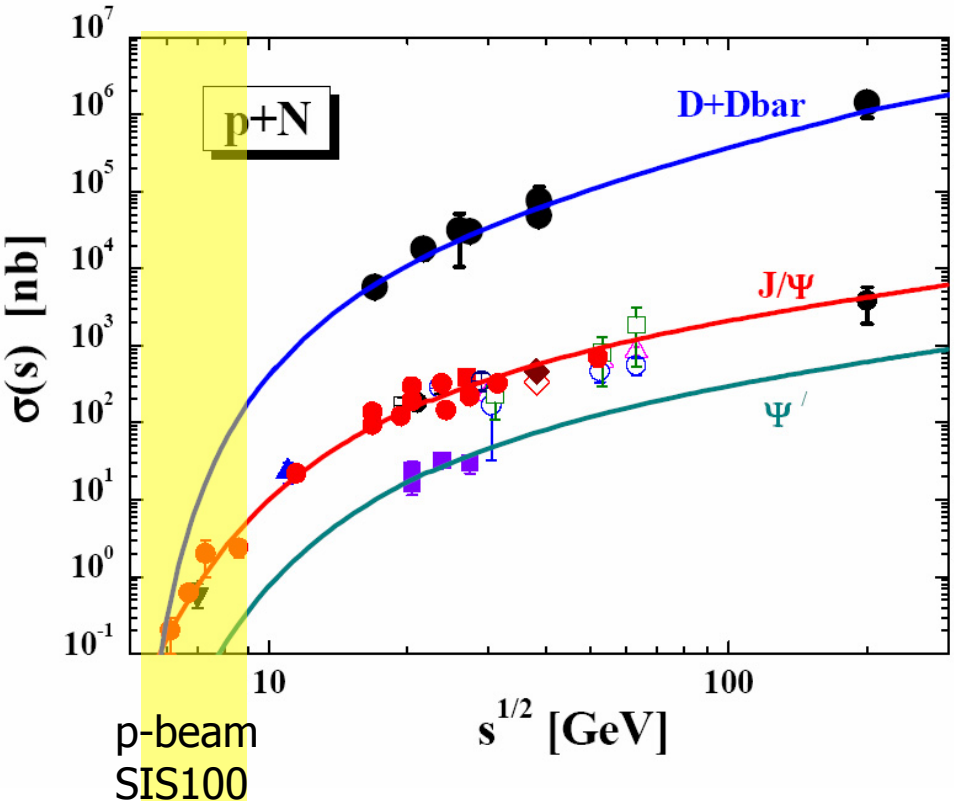
CBM

Full event reconstruction:
Dimuon invariant mass spectrum
(Only ω meson as signal)

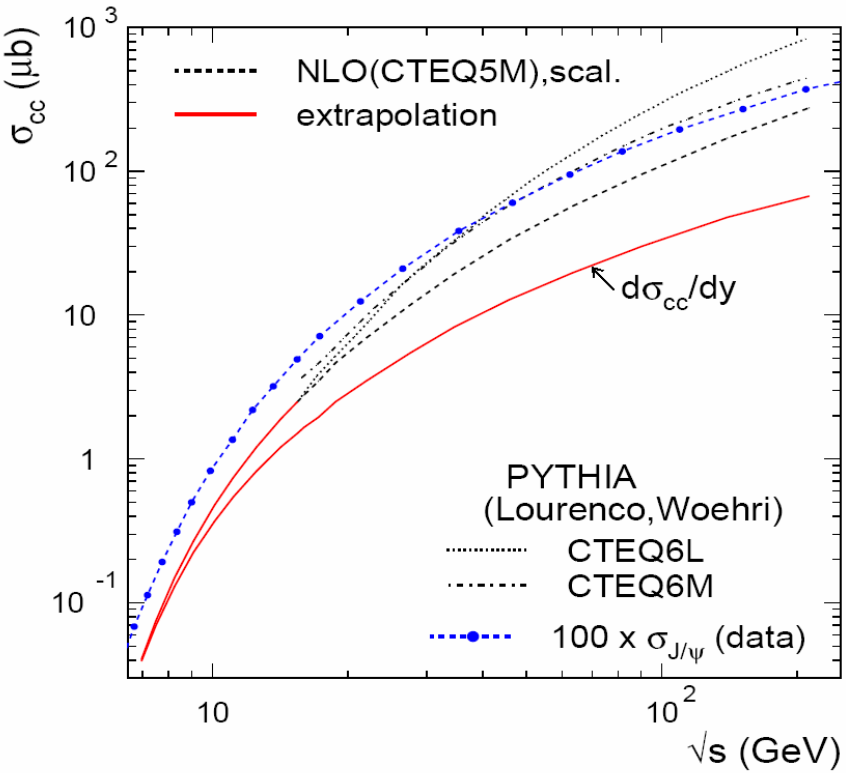


Heavy flavor physics I: Charm production at threshold energies

Input to hadronic transport models (HSD):
Parameterization of measured cross sections
O. Linnyk et al., Nucl. Phys. A786 (2007) 183



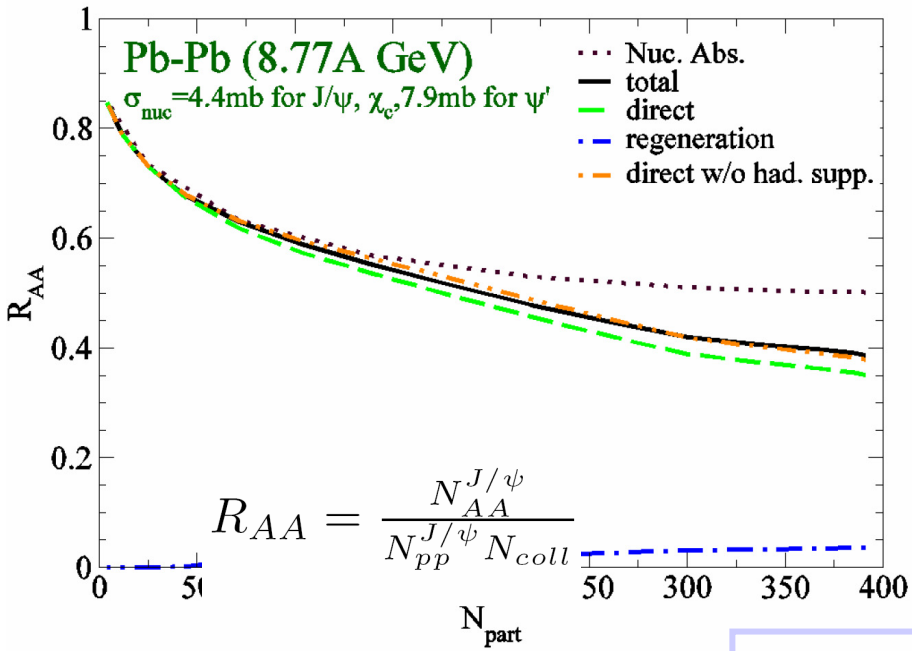
Input to Statistical Hadronization Model
A. Andronic et al.,
Phys. Lett. B659 (2008) 149



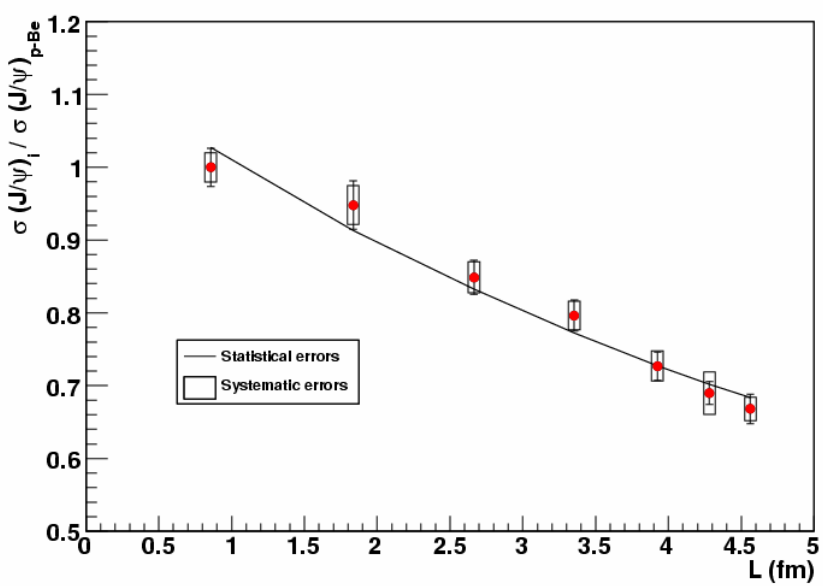
Measure: p+A → D+X, p+A → J/ψ+X, p+ A → ψ'+X

Heavy flavor physics II: Charmonium propagation in nuclear matter

J/ψ suppression at FAIR energies dominated by nuclear absorption (Xingbo Zhao and Ralf Rapp)



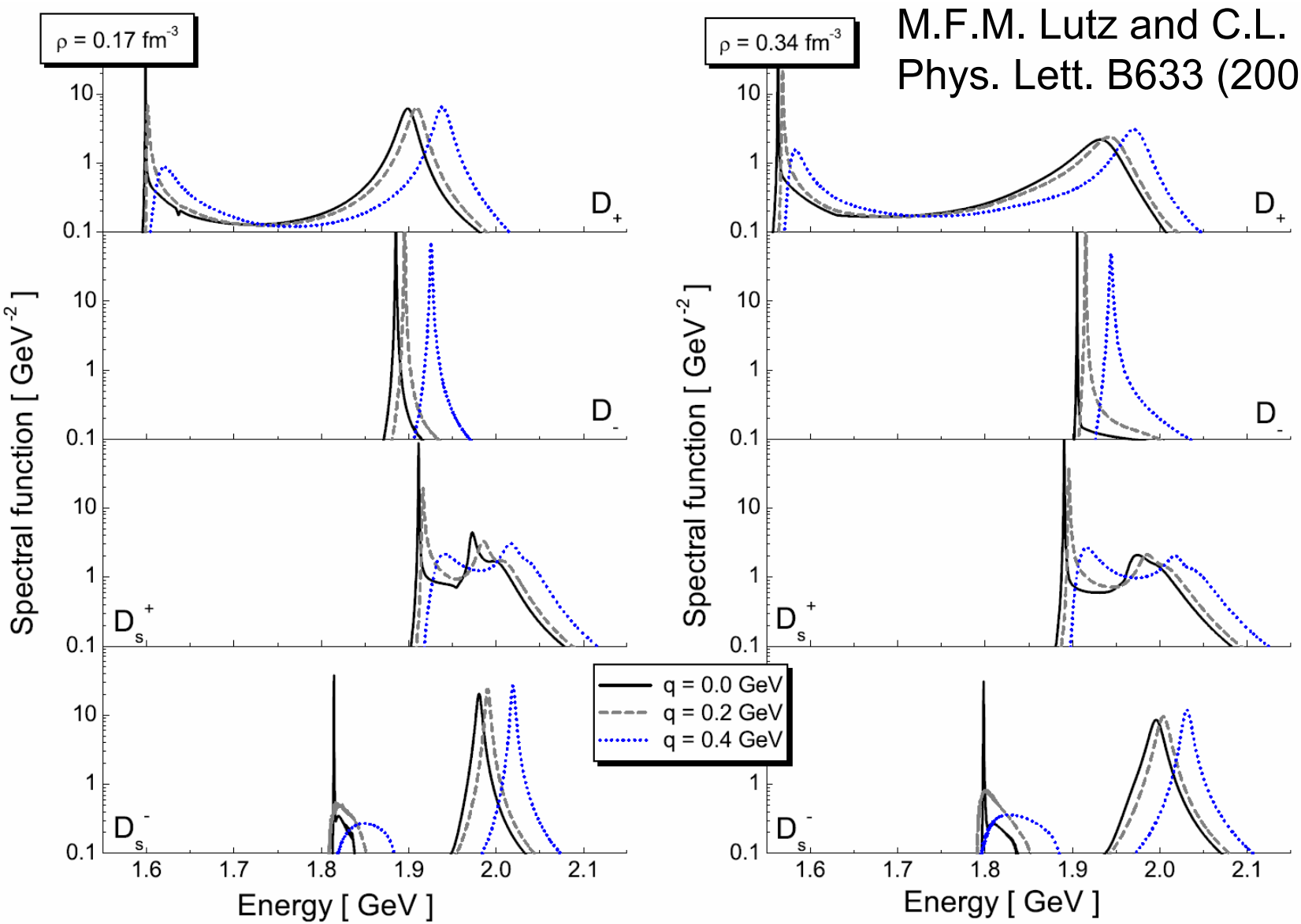
new NA60 data: 158 GeV p+A
E. Scomparin, QM2009



$\sigma_{abs}^{J/\psi}$ (158 GeV) = 7.6 ± 0.7 ± 0.6 mb
$\sigma_{abs}^{J/\psi}$ (400 GeV) = 4.3 ± 0.8 ± 0.6 mb

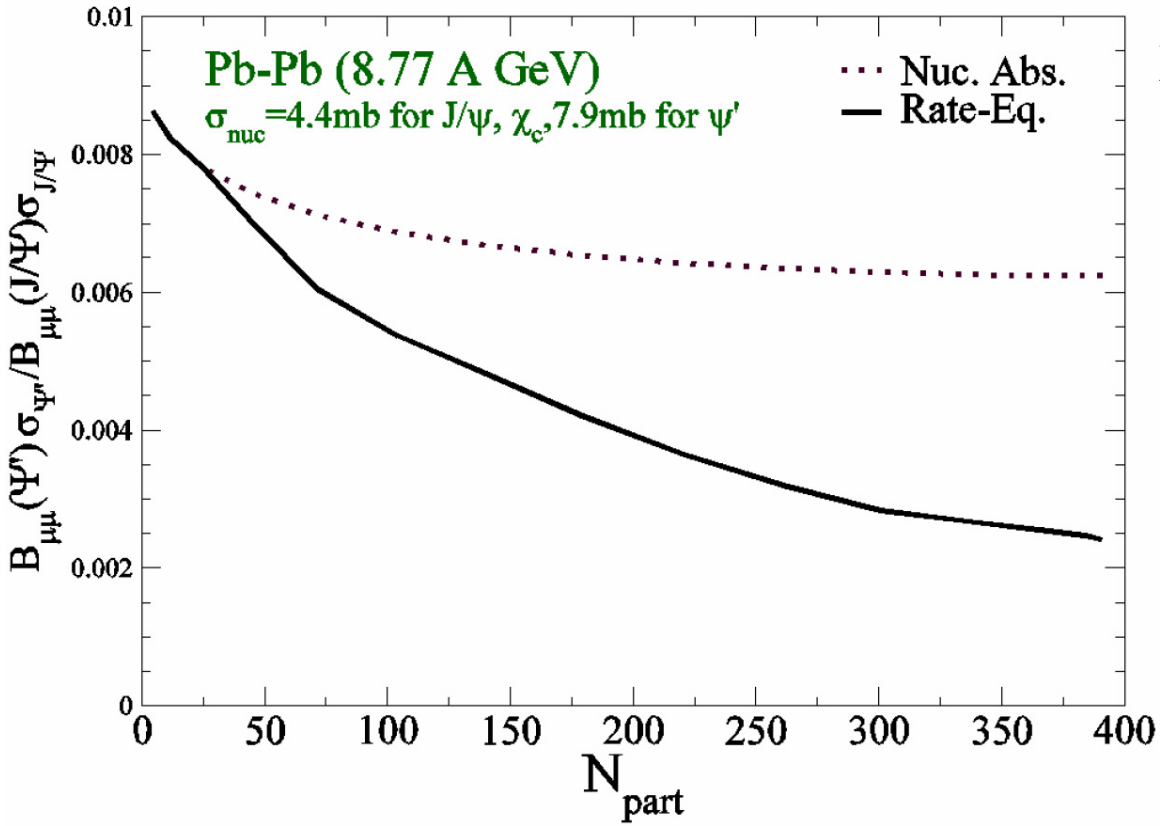
Measure: p + C (..... Au) → J/ψ + X

Heavy flavor physics III: Open charm propagation in nuclear matter



M.F.M. Lutz and C.L. Korpa, Phys. Lett. B633 (2006) 43

Heavy flavor physics IV: In-medium properties of D-mesons



Xingbo Zhao and Ralf Rapp

D meson mass modification affects the ψ'/(J/ψ) ratio

New absorption mechanism in nuclear medium if D meson mass reduced: $\psi' \rightarrow D^+D^-$

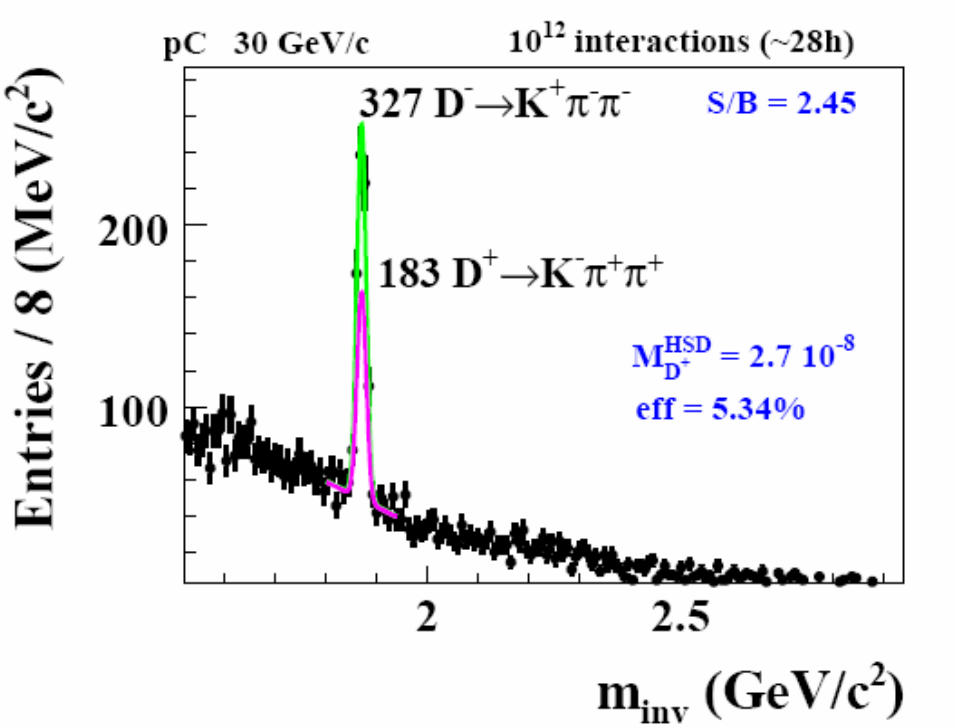
Not possible in vacuum: ψ'(3686 MeV) < D^+D^-(3738 MeV)

Measure: p + C (..... Au) → J/ψ, ψ'

CBM: Charm production in 30 GeV p+C collisions

$p+C \rightarrow D^{\pm} + X$

$D^{\pm} \rightarrow K\pi\pi$



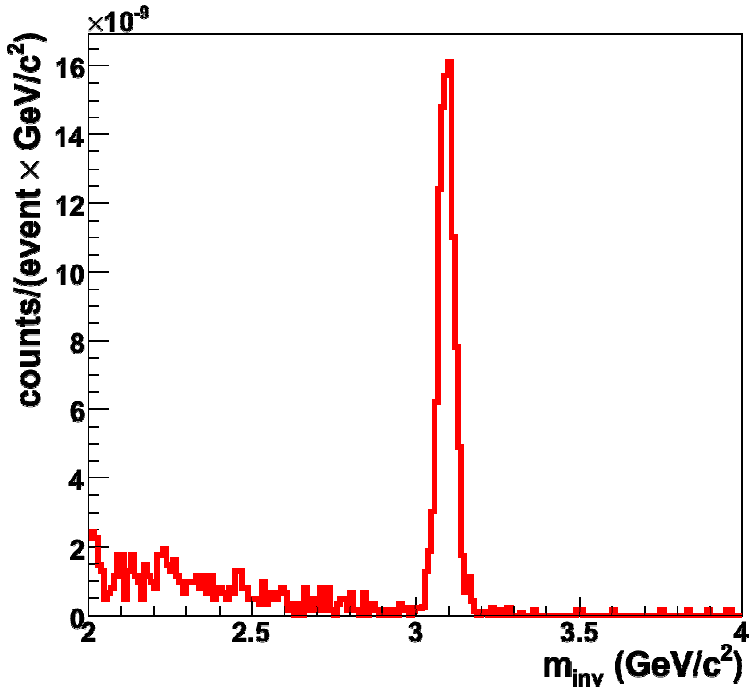
STS with 10 microstrip stations

St.1-2: strip pitch 25 μm, strip length 10 mm

St.3-8: strip pitch 60 μm, strip length 20-60 mm

$p+C \rightarrow J/\psi + X$

$J/\psi \rightarrow \mu^+\mu^-$



6 J/ψ recorded in 10^{10} events (b=0)

($3 \cdot 10^4$ J/ψ per week)

Being prepared for exotica: experimental reconstruction of a multistrange di-baryon

Signal: strange dibaryon

$(\Xi^0\Lambda)_b \rightarrow \Lambda\Lambda$ (cτ=3cm)

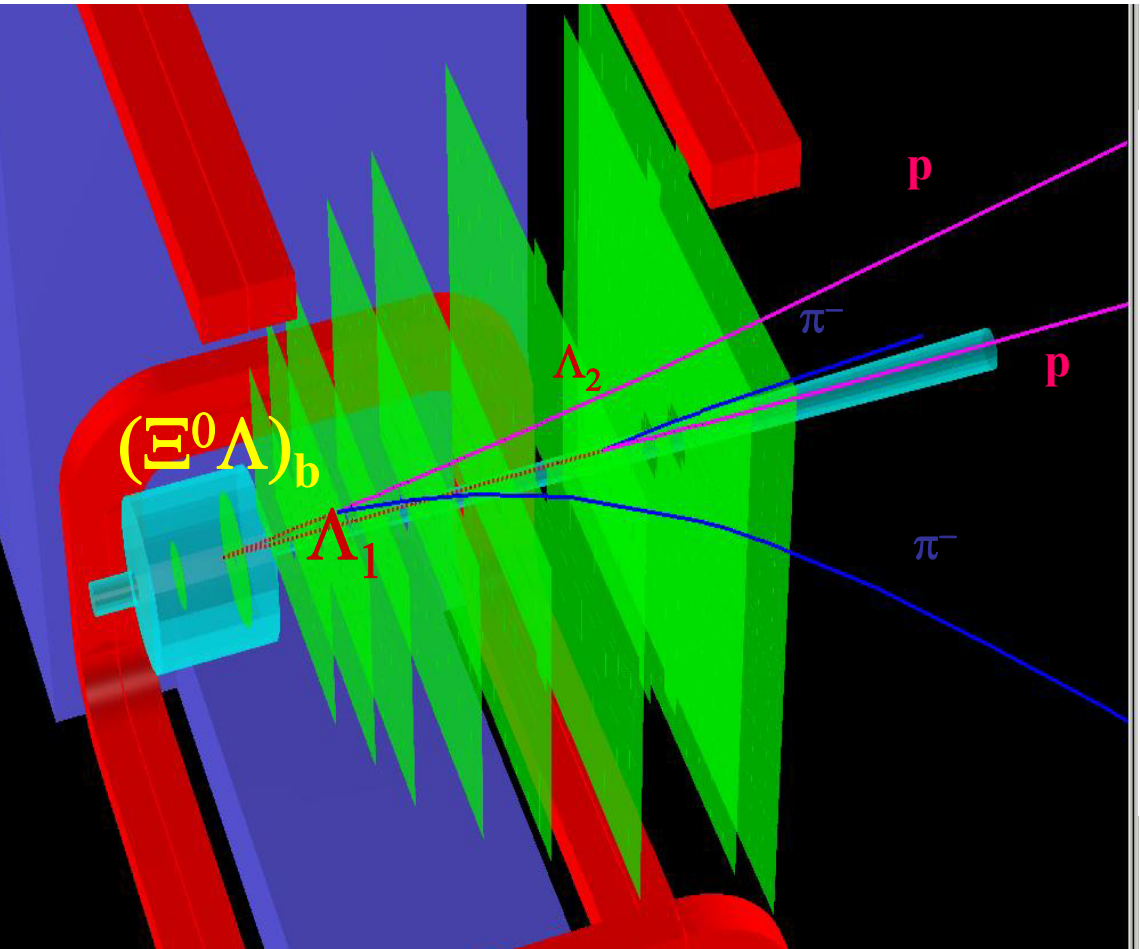
M= 10^{-6}, BR = 5%

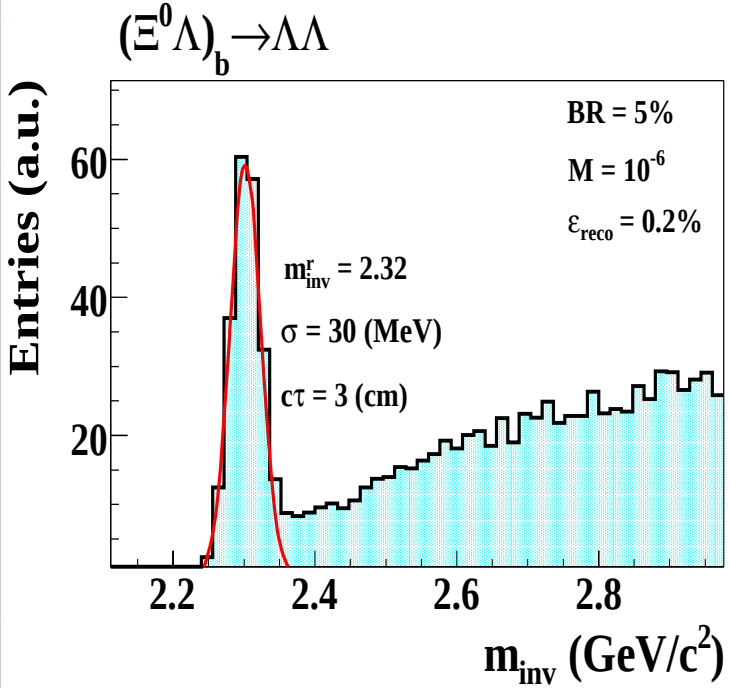
Background:

Au+Au @ 25 AGeV

32 Λ per central event

11 Λ reconstructable

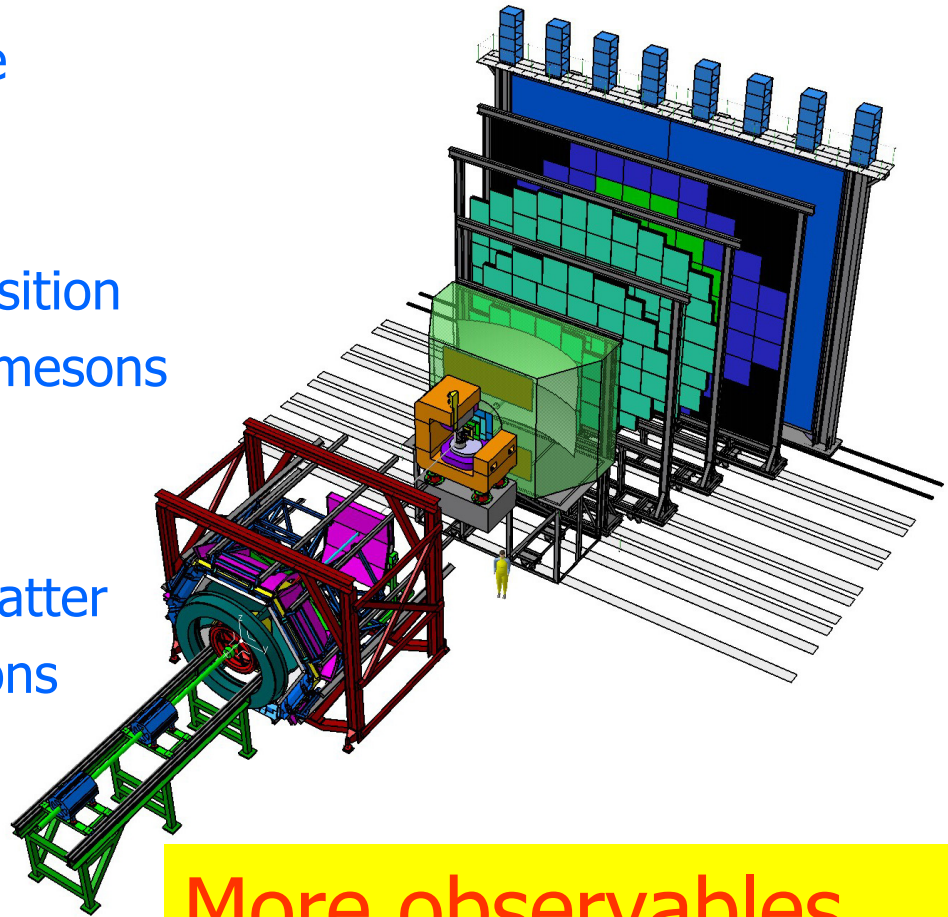




Summary: nuclear matter physics at SIS100

Physics case:

- Nuclear matter equation-of-state
  at baryon densities up to 6 ρ_0
- Properties of resonance matter
  in the vicinity of the phase transition
- In-medium properties of vector mesons
- Charm production mechanisms
  at threshold beam energies
- Charm propagation in nuclear matter
- In-medium properties of D mesons
- Multi-strange objects



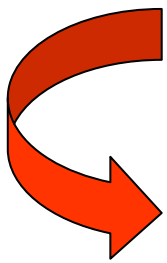
Observables:

- hadrons (incl. collective flow)
- Multi-strange hyperons
- Dilepton pairs
- D-mesons and charmonium in p+p and p+A collisions

More observables
to be discussed today

Goals of the workshop

- Define physics program
- Propose diagnostic probes
- Review theoretical concepts
- Identify experimental requirements
- Compare physics performance of HADES and CBM



Input for documentation

Physics case	Observables	Setup
EOS at high density	Elliptic flow, multistrange hyperons in heavy ion collisions up to Au+Au	CBM: STS +TOF
In-medium properties of vector mesons	Dileptons from heavy ion collisions up to Au+Au	HADES, CBM ?
Multistrange objects, kaonic clusters, Multistrange hyperons, in p+A and A+A	Hyperons, kaons, hadrons	CBM: STS +TOF, HADES?
Velocity of sound, shockwaves	Protons, fragments	CBM?
Charm production in p+A	D-mesons, Charmonium	CBM:MVD+STS, Much
Charm propagation in p+A, In-medium properties of D mesons	D mesons, Charmonium	CBM:MVD+STS, Much