The CBM Physics Programme

Volker Friese
GSI Darmstadt

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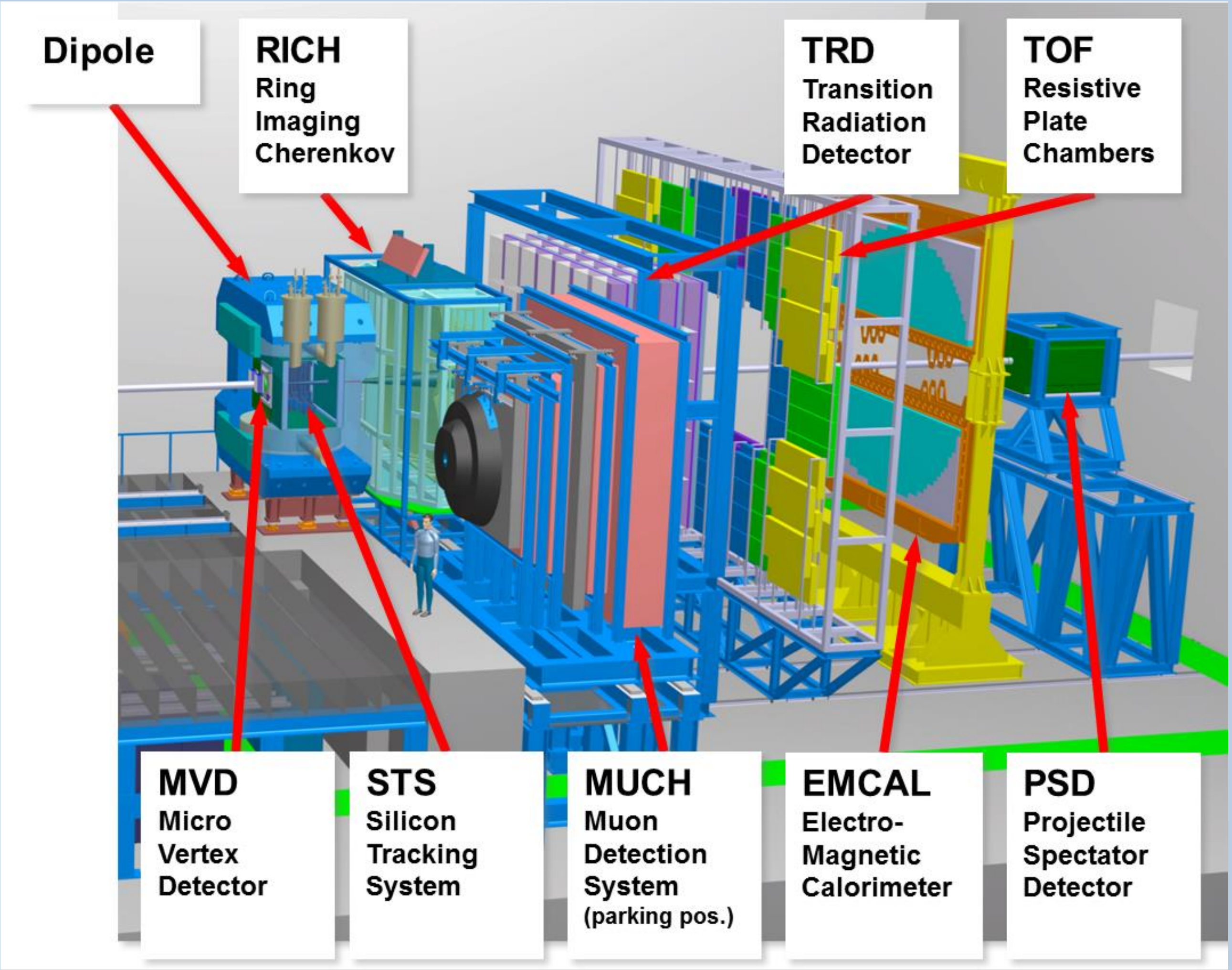
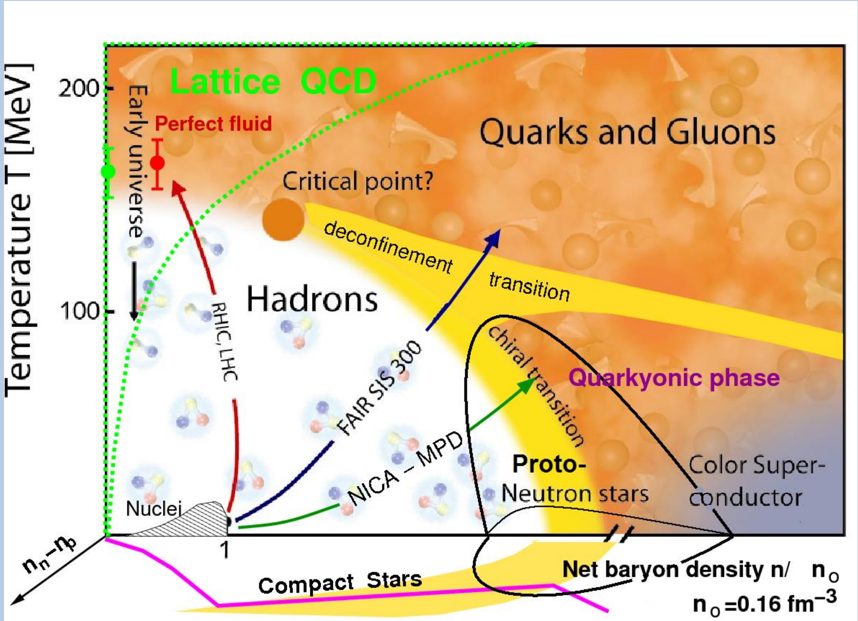
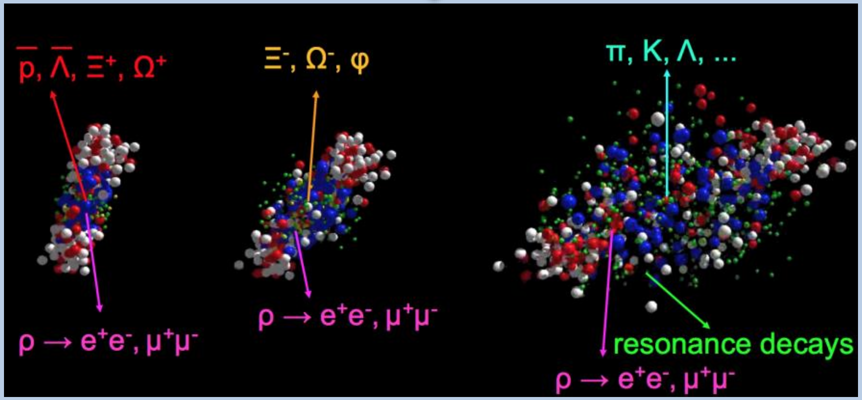
CBM: Experiment Systems



- Large acceptance: 2.5° – 25°
- Identify:
  - Hadrons (TOF)
  - Electrons (RICH, TRD)
  - Muon (MUCH)
  - Neutral probes (ECAL)
  - Open charm (MVD)
- High rates: up to 10^7 events/s

The Grand Picture



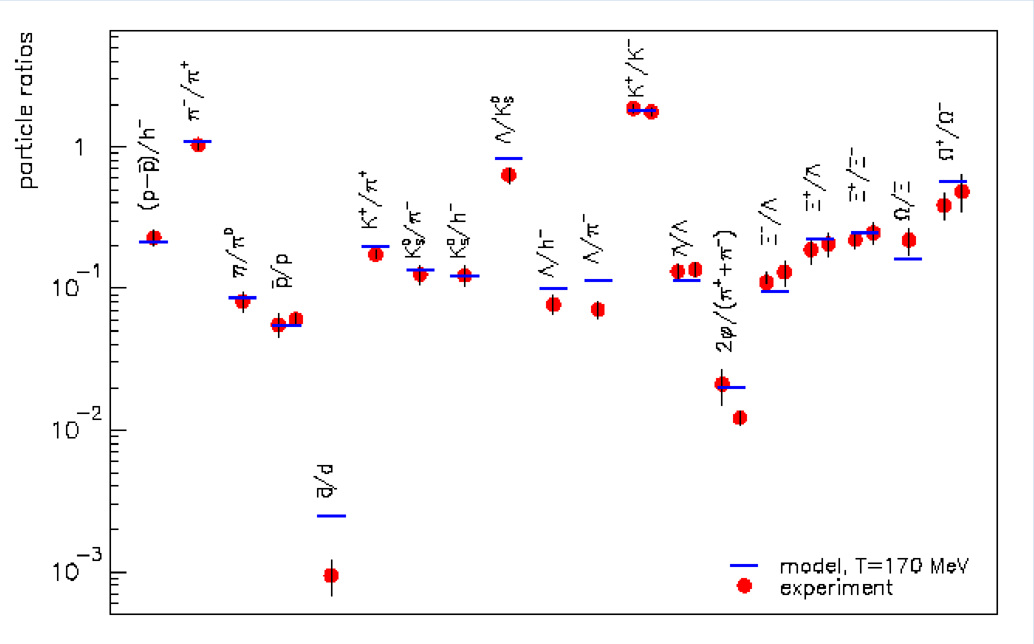


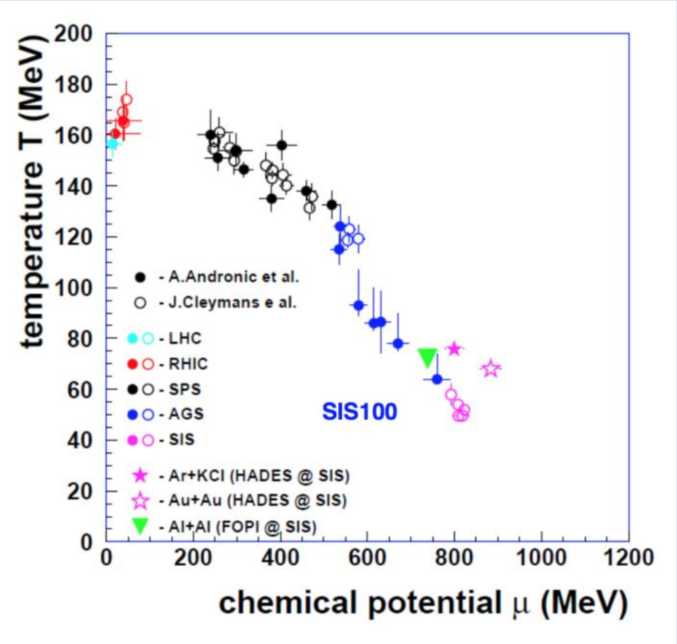
The quest: study the properties of QCD matter at high net-baryon densities:

- Equation-of-state
- Onset of deconfinement / chiral restoration
- Nature of transition (first-order?)
- Critical end-point

- Study collisions of heavy nuclei systematically as function of collision energy.
- Characterise the final state as completely as possible.

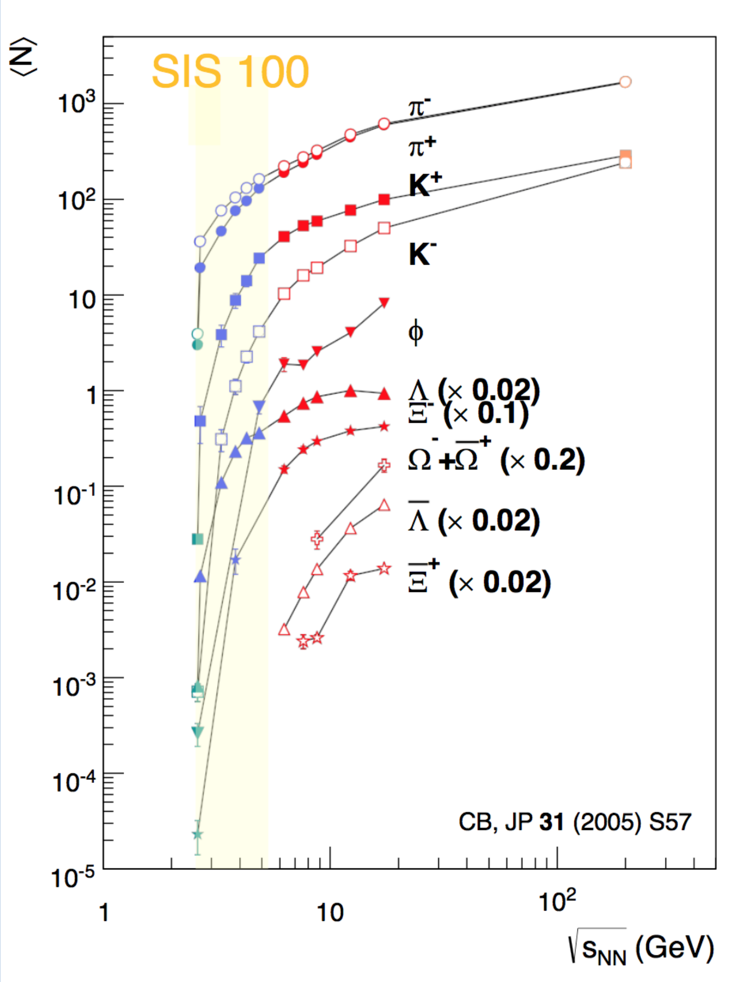
Hadron Abundances and Chemical Freeze-Out

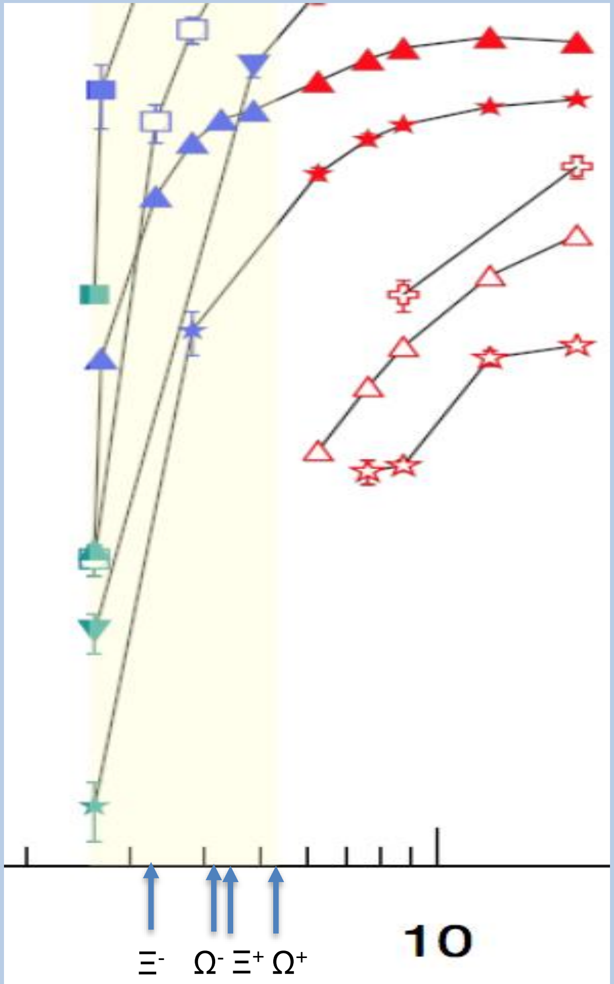




- Equilibrium at high energies is interpreted as signature transition to the QGP.
- Equilibrium seems to hold also at lower energies and smaller collision systems.
- Indicative to a phase boundary to Quarkyonic matter? Or to thermalisation due to a longer-lived fireball?

Limited Datasets





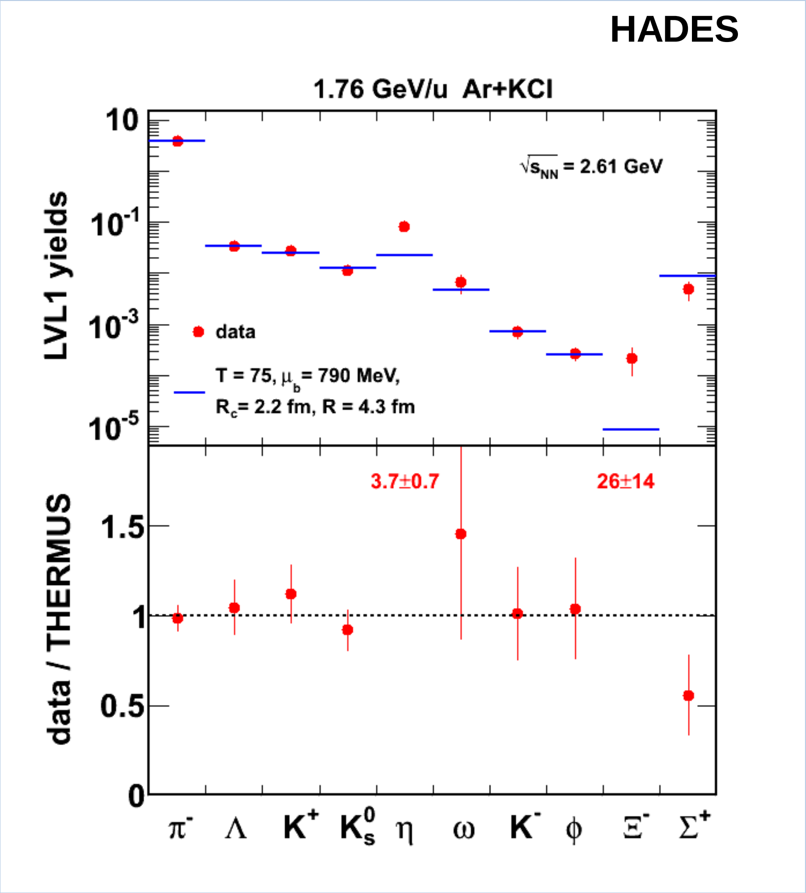
- At low energies, the number of measured particle species is small.
- In particular, no or scarce data on multi-strange hyperons in the SIS-100 energy range (near or below threshold).

Sub-threshold Ξ Production

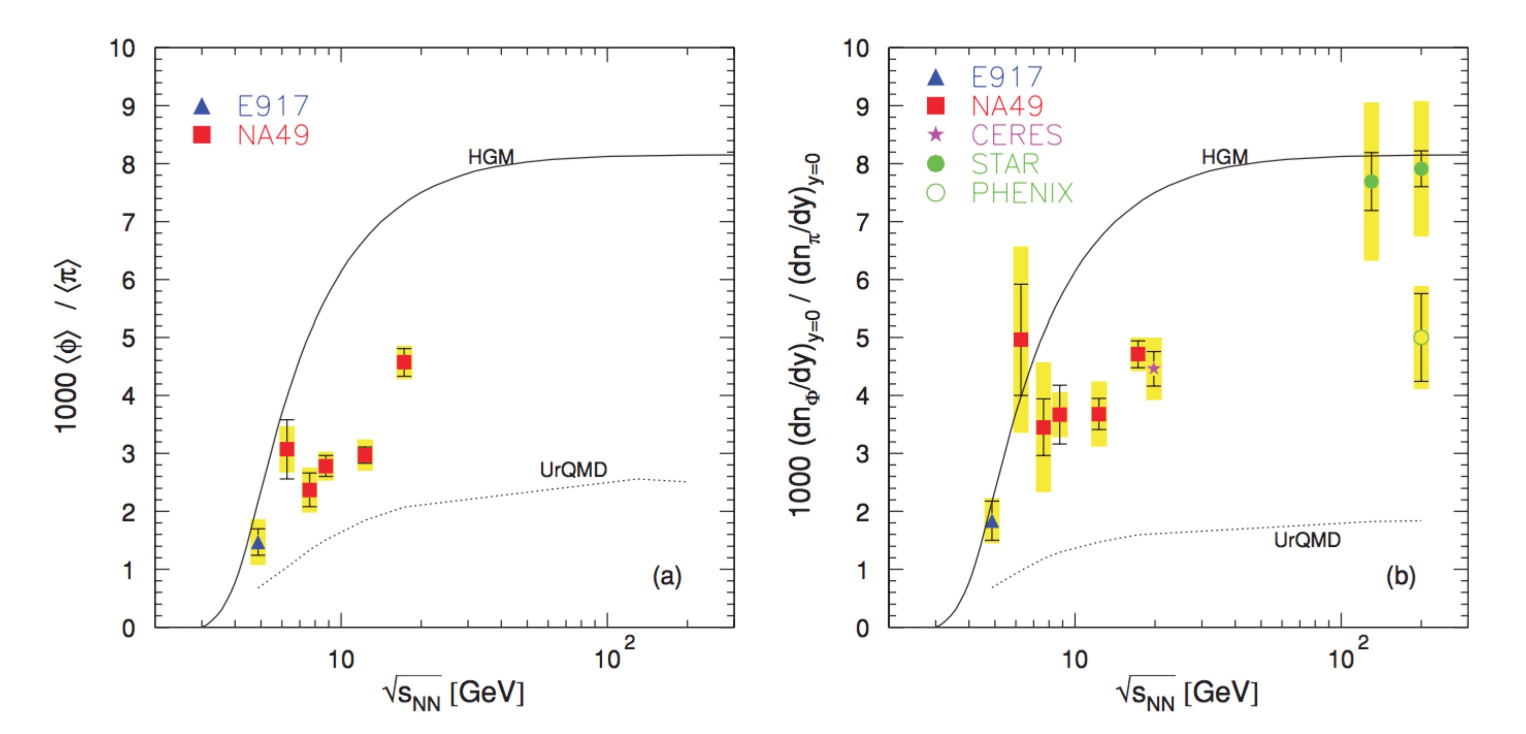
HADES result for Xi$^-$ at SIS-18 (1.76A GeV): Xi$^-$ yield is off by more than an order of magnitude from the statistical model.

First gross discrepancy with the thermal yields observed in nuclear collisions.

N.b.: This is deep sub-threshold. Production through multi-step processes: $\Lambda K \rightarrow \Xi\pi \qquad \Lambda\Lambda \rightarrow \Xi^- p$



Phi Meson Production

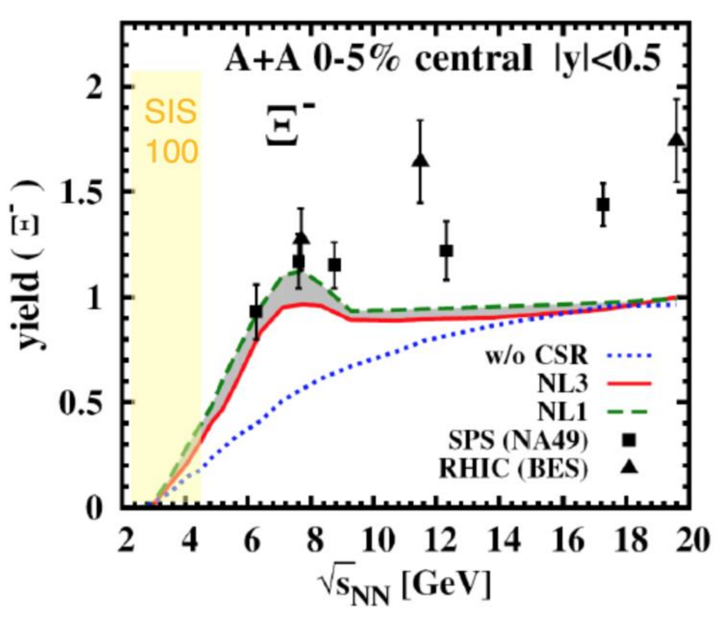


- No satisfactory description by the statistical model at SPS - but at AGS and RHIC.
- Transport models give a fair description at SPS, but not at lower energies.

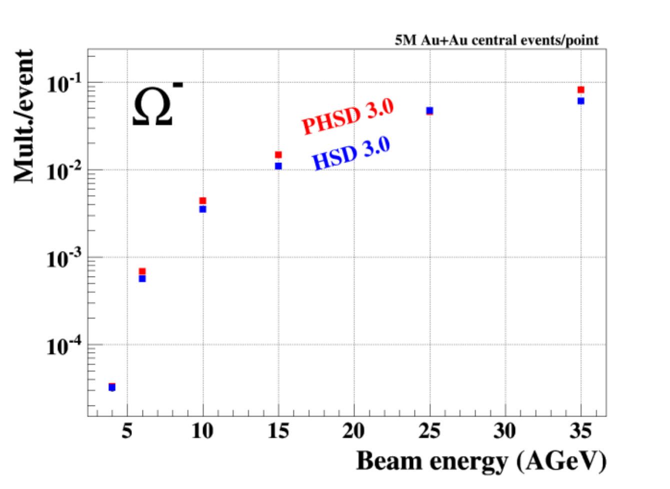
Hyperons: The Microscopic View

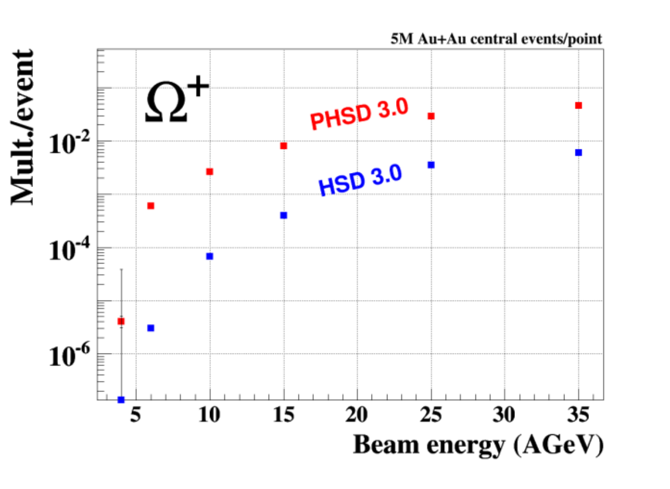
Near or below threshold: production through multi-step processes -> sensitive to both the equation-of-state and the strangeness content of the medium.

pHSD also predicts sensitivity to chiral symmetry restoration (through modified s quark masses).

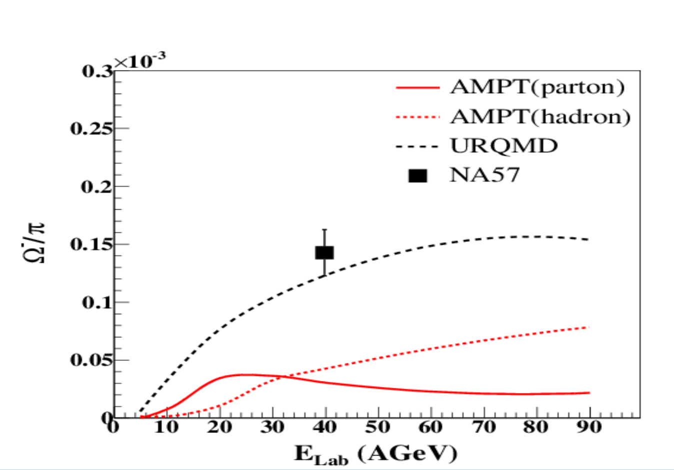


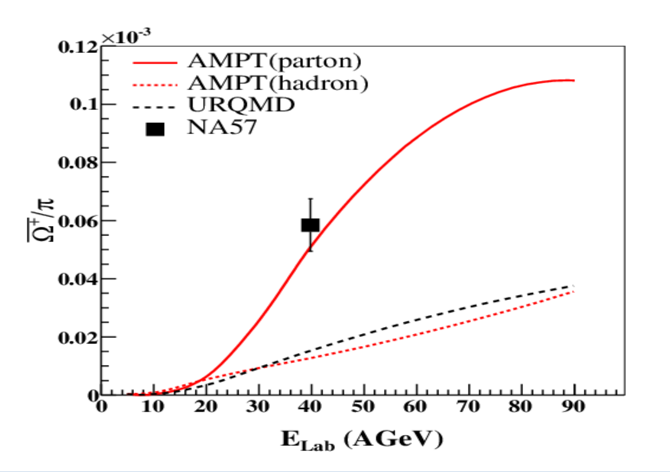
Strange anti-hyperons at FAIR energies





HSD / pHSD

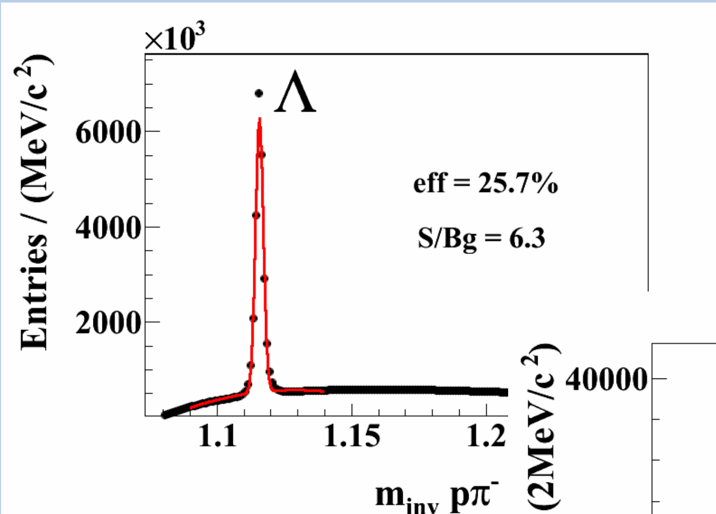


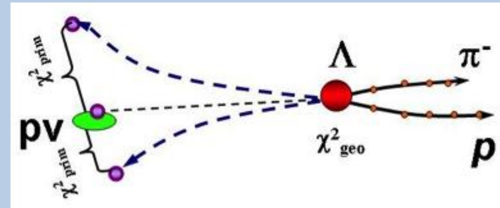


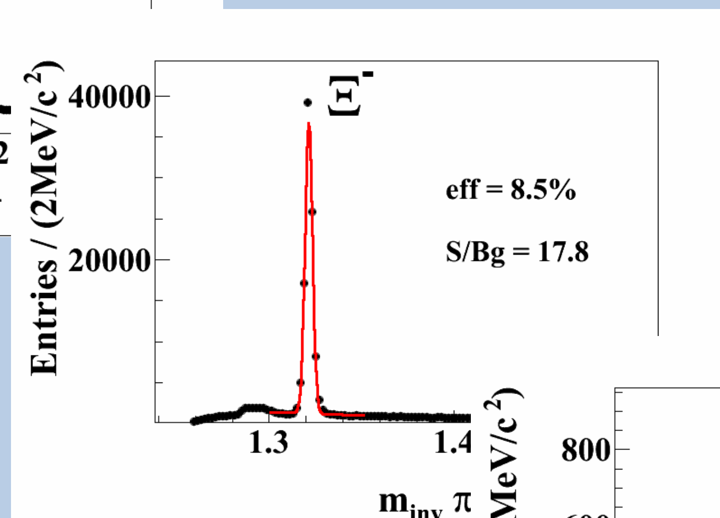
AMPT

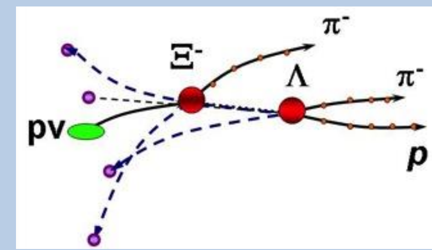
Microscopic models (including partonic production) predict the anti-hyperons to be very sensitive to partonic production mechanisms (hyperons much less).

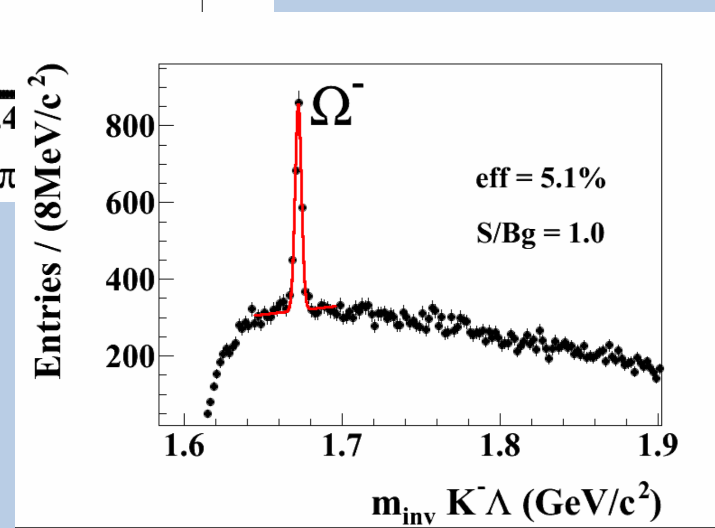
CBM Performance for Hyperons





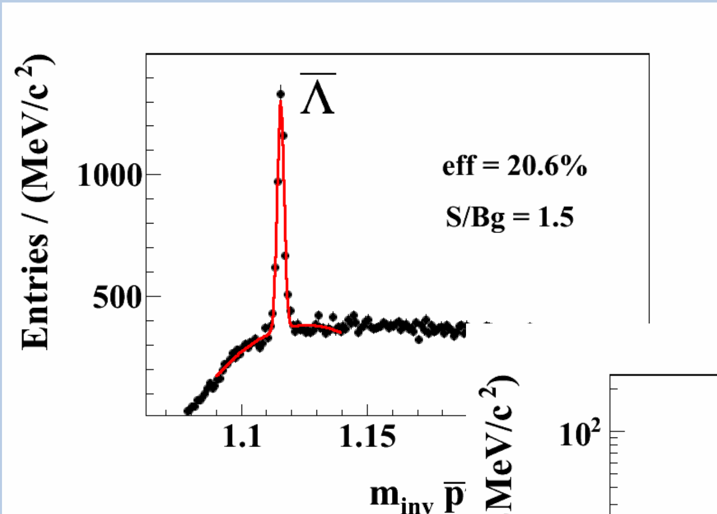


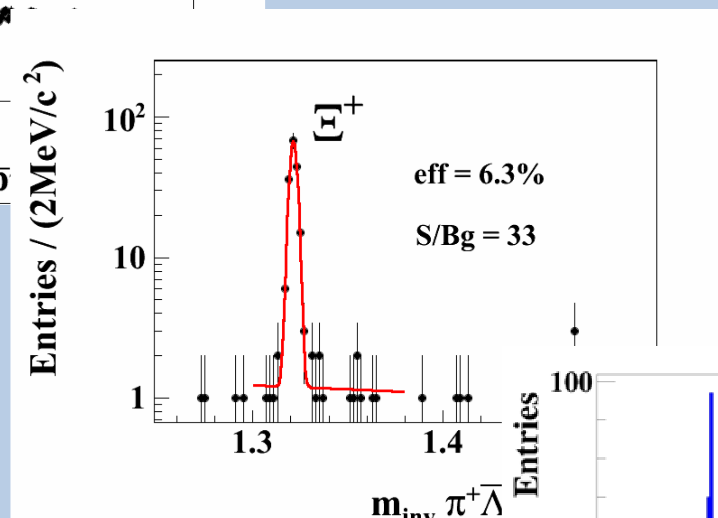


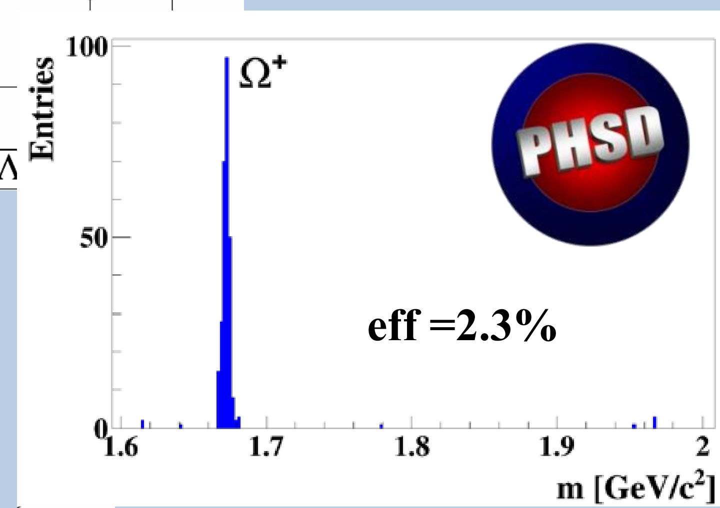


Input: UrQMD, central Au+Au, 10A GeV
Reconstruction from fully simulated detector response

CBM Performance: Anti-Hyperons



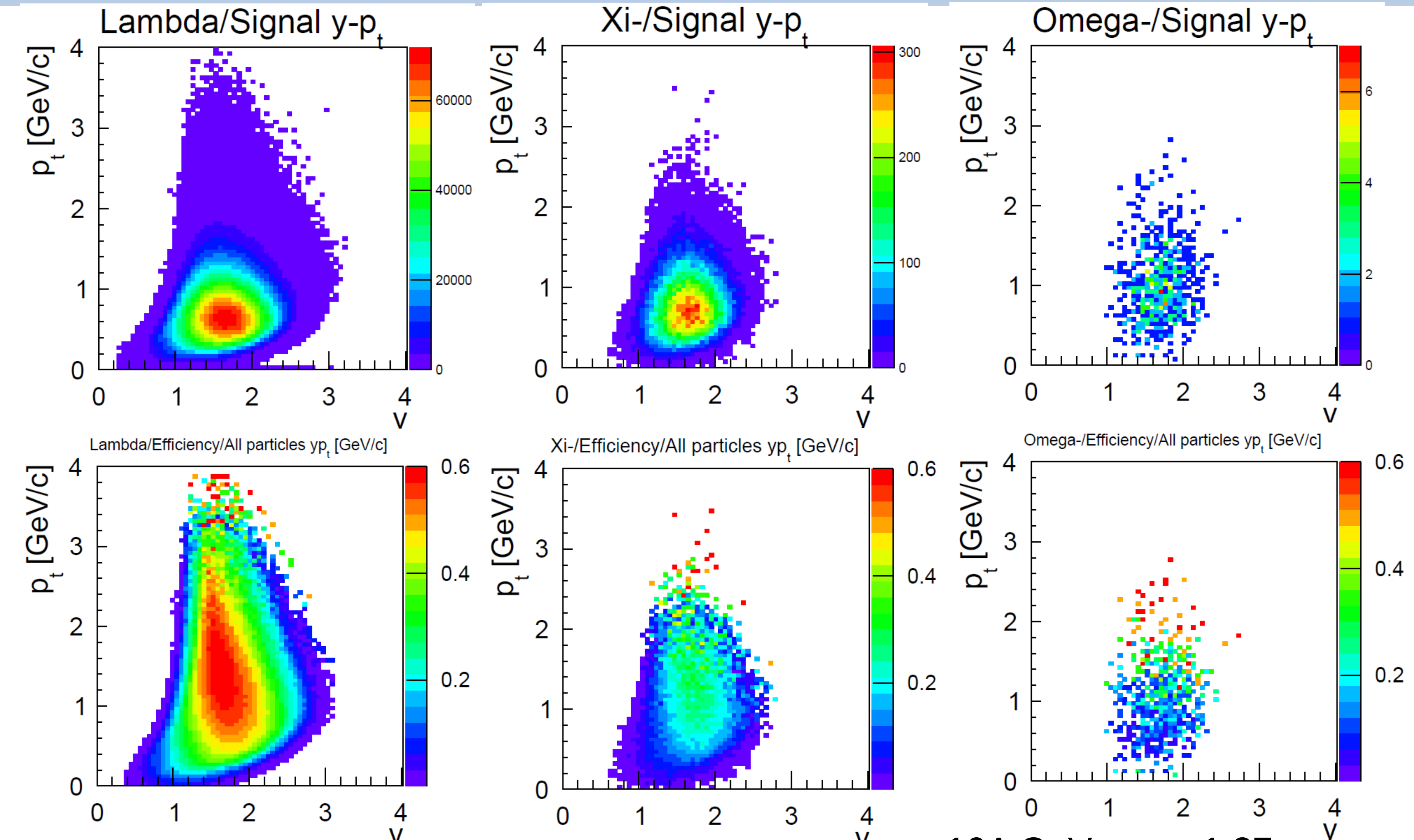




Input: central Au+Au, 10A GeV
UrQMD (PHSD for Ω^+)

Very rare probes; require high interaction rates and online selection!

Hyperons: Acceptance and Efficiency



10A GeV, y_{cm} = 1.37

Hyperon Measurement with CBM

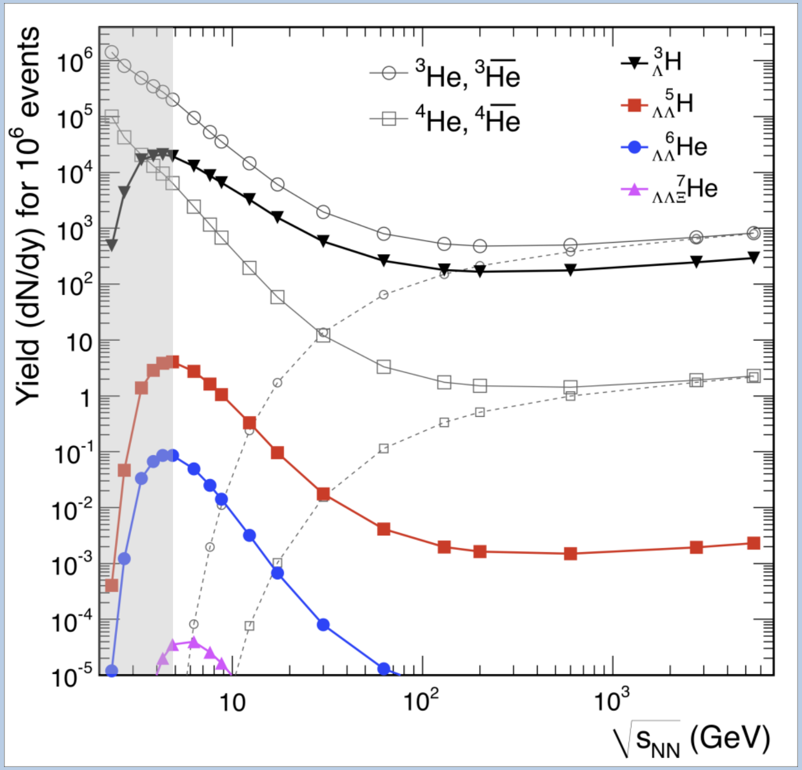
p_{beam}	<Xi>	<Omega>	<Xi_bar>	<Omega_bar>	Events	Run time
10A GeV	1.93×10^{-1}	4.43×10^{-3}	3.35×10^{-4}	3.76×10^{-5}	1.2×10^{9}	2.3 h
8A GeV	1.26×10^{-1}	2.07×10^{-3}	1.33×10^{-4}	1.26×10^{-5}	3.7×10^{9}	6.8 h
6A GeV	5.88×10^{-2}	5.47×10^{-4}	2.70×10^{-5}	2.40×10^{-6}	1.9×10^{10}	36 h
4A GeV	1.01×10^{-2}	3.16×10^{-5}	1.80×10^{-6}	2.00×10^{-7}	2.3×10^{11}	428 h

- Central Au+Au collisions; multiplicities from UrQMD
- Events: number of events required to determine the anti-Omega yield with a statistical precision of 5 %
- Run time: assuming 3×10^6 min. bias events per second and 5% centrality selection.

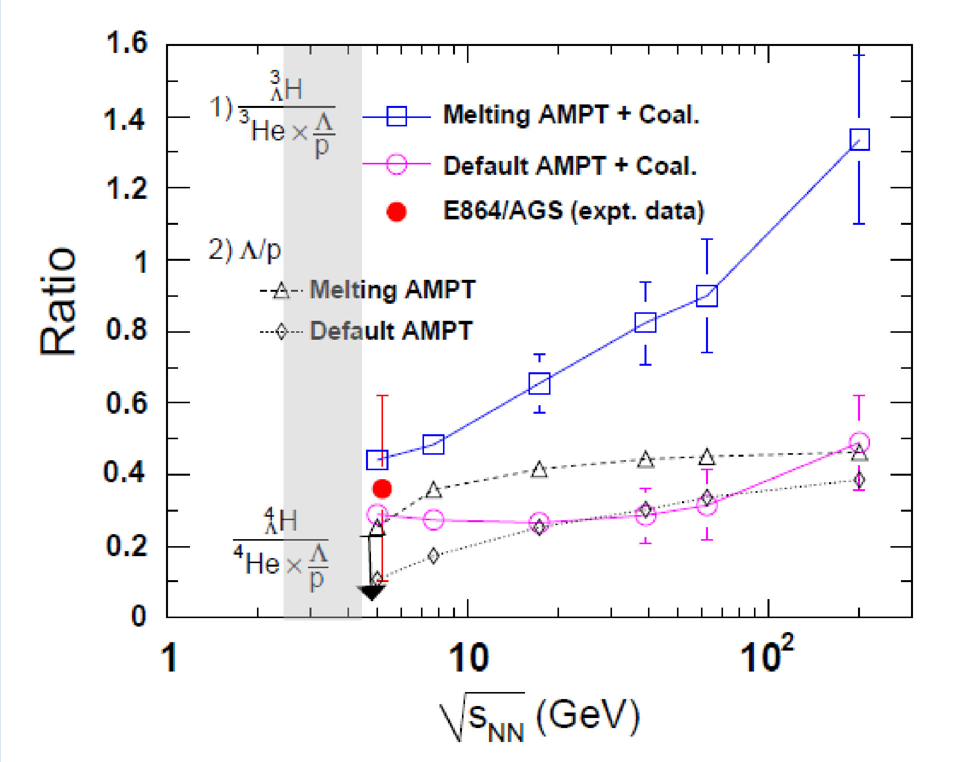
Hyper-Matter

In heavy-ion collisions: produced through capture of Λ in light nuclei

A. Andronic et al., PLB 697 (2011) 203



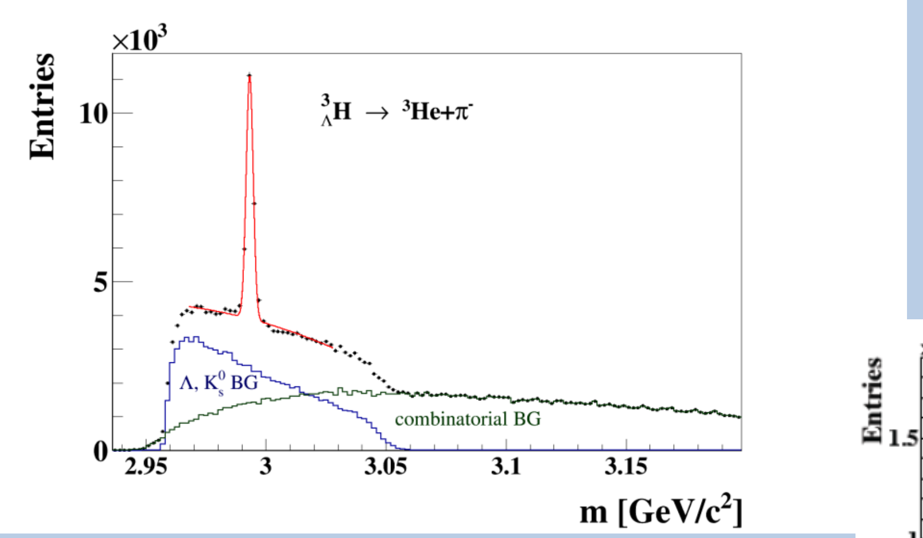
S. Zhang et al., PLB 684 (2010) 224



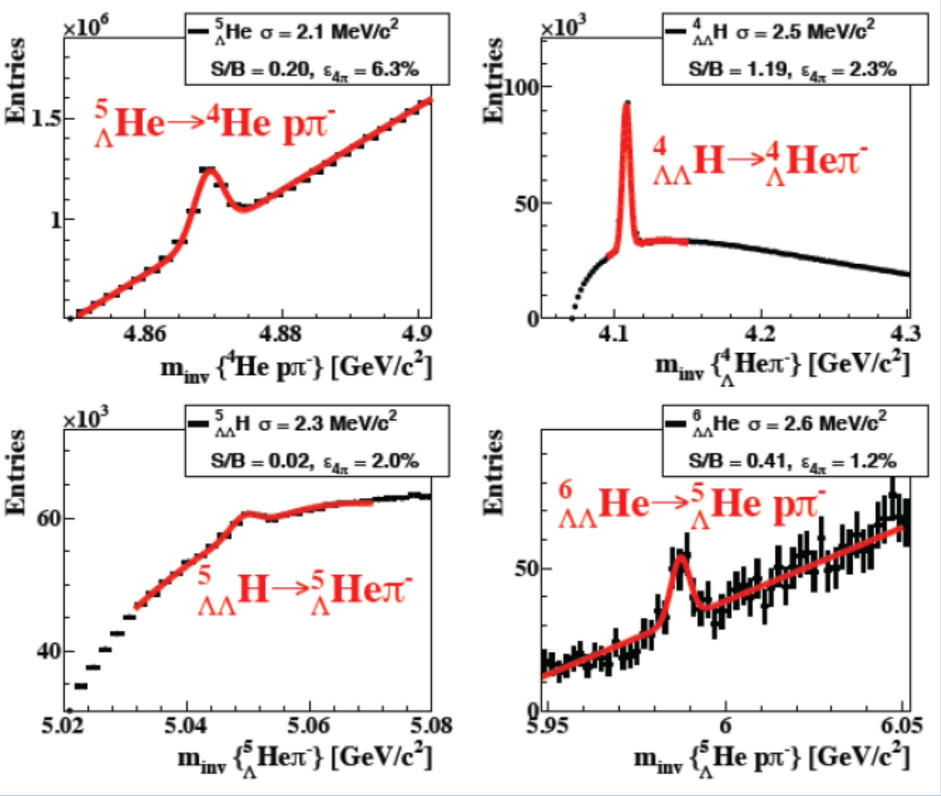
Thermal model: maximum production at CBM energies

Transport: sensitive to medium properties (correlation of strangeness and baryon number)

Hyper-Matter with CBM

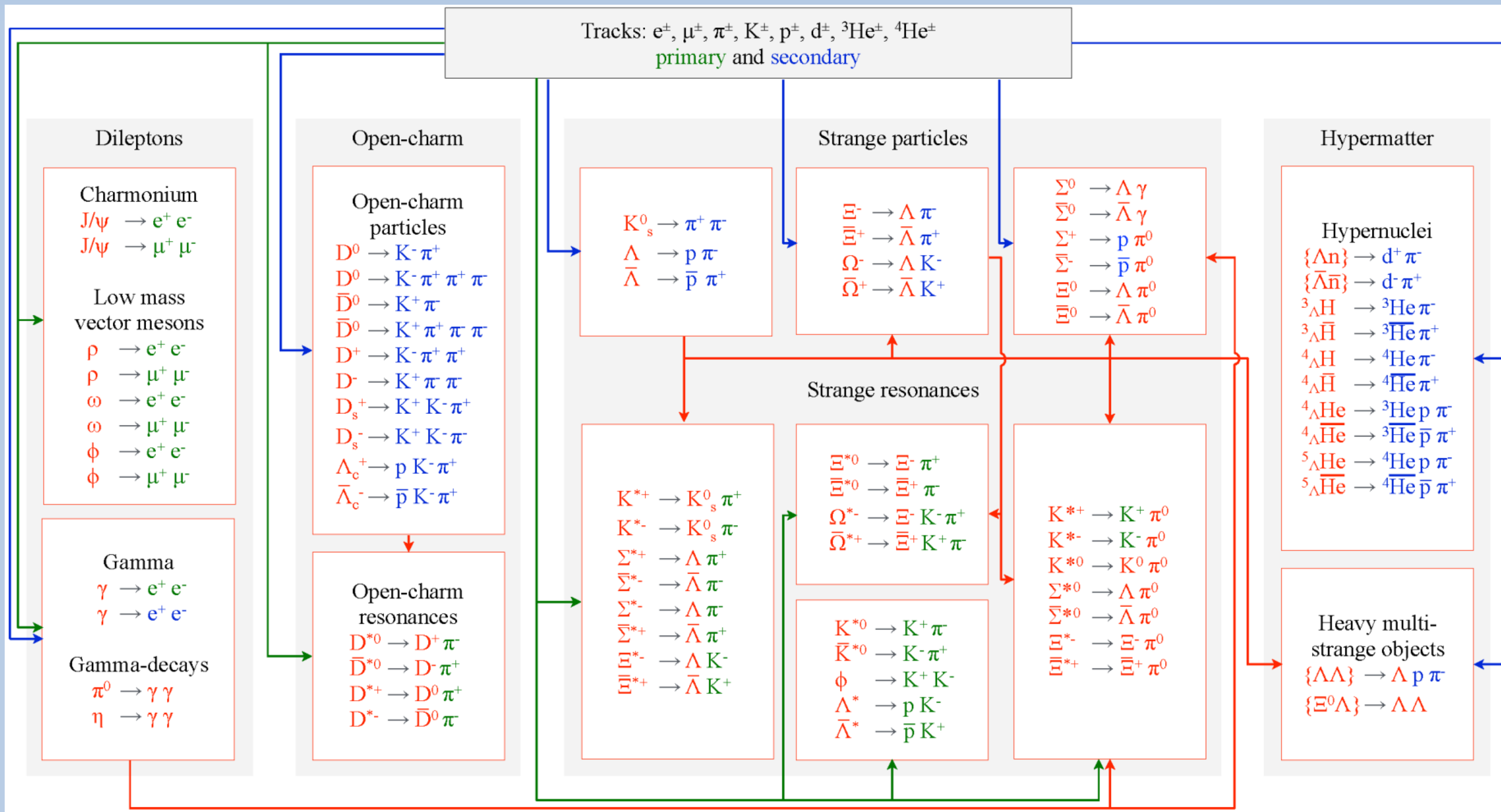


CBM Simulation
central Au+Au, 10A GeV
10^{12} events (40 days beamtime)



Prospects are good;
double-strange hyper-nuclei require
maximal interaction rate

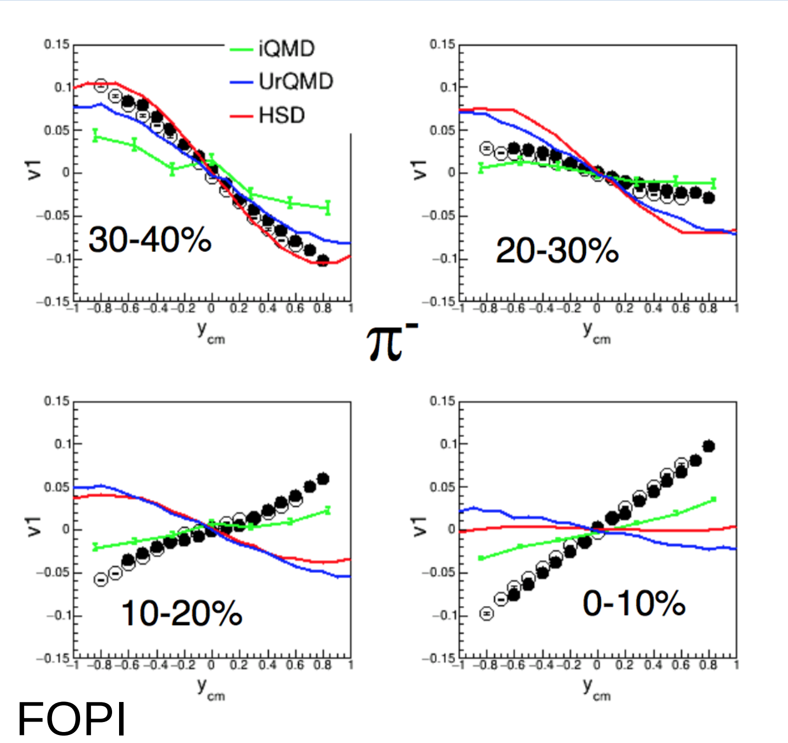
Particle reconstruction in real-time

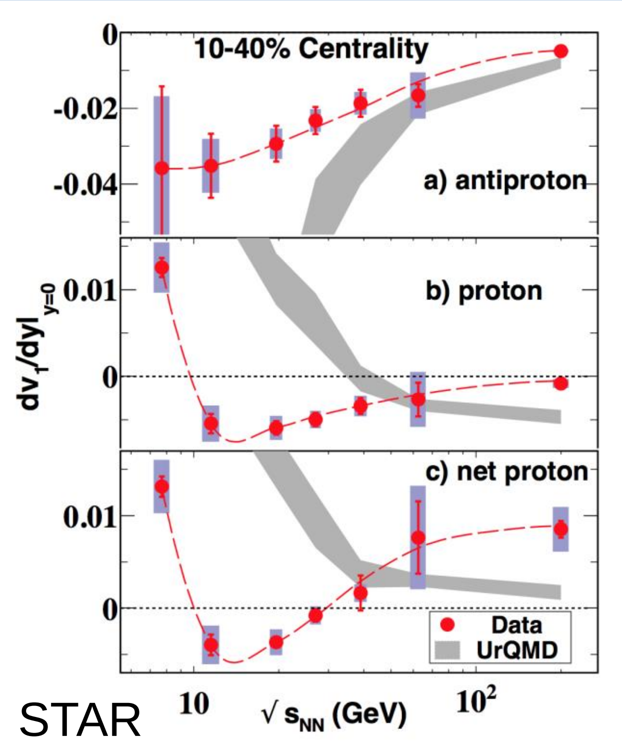


A multitude of particles will become accessible.
Real-time reconstruction allows online selection of rare probes.
Software becomes the key to the physics output.

Flow

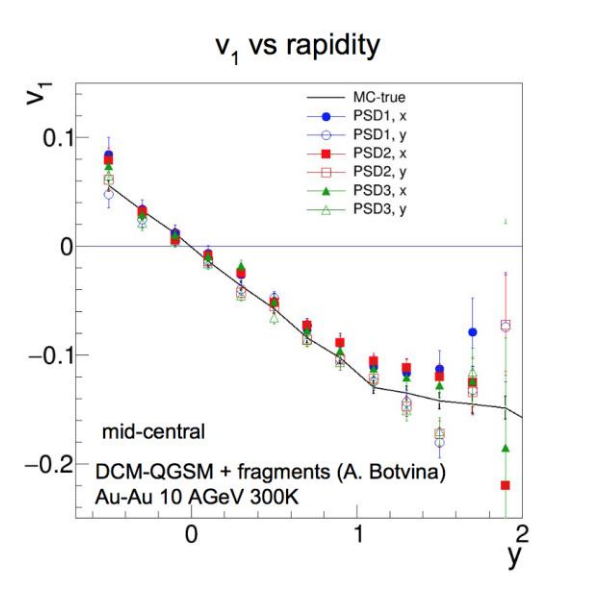
The prime tool to study the equation-of-state, but: results at lower energies not understood in terms of transport models



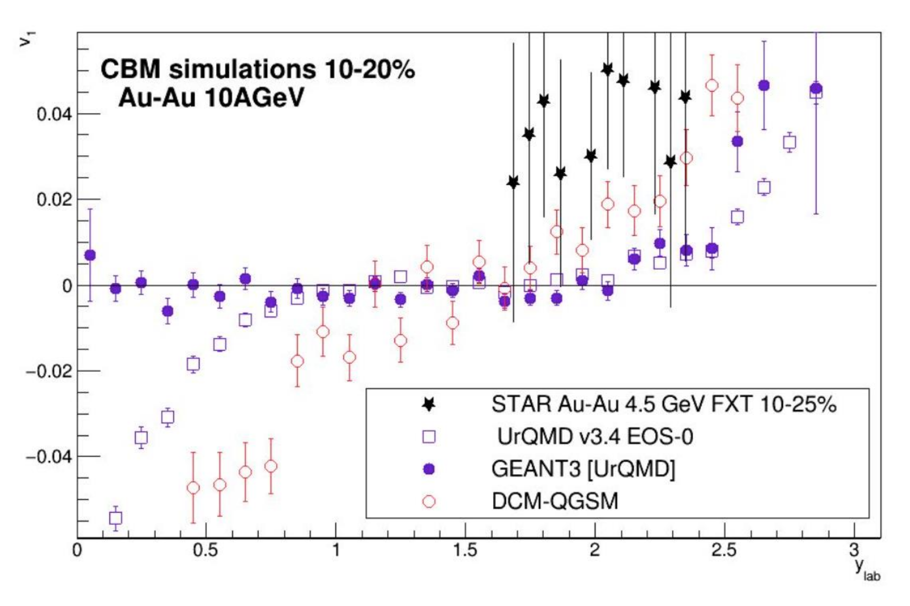


Flow with CBM

pions



Λ

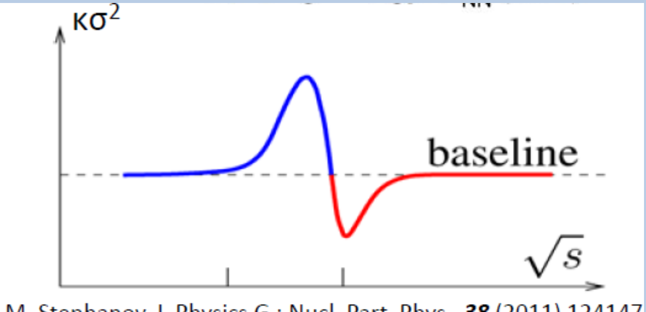


CBM will add flow data, also for weakly rescattering particles like φ or Ω

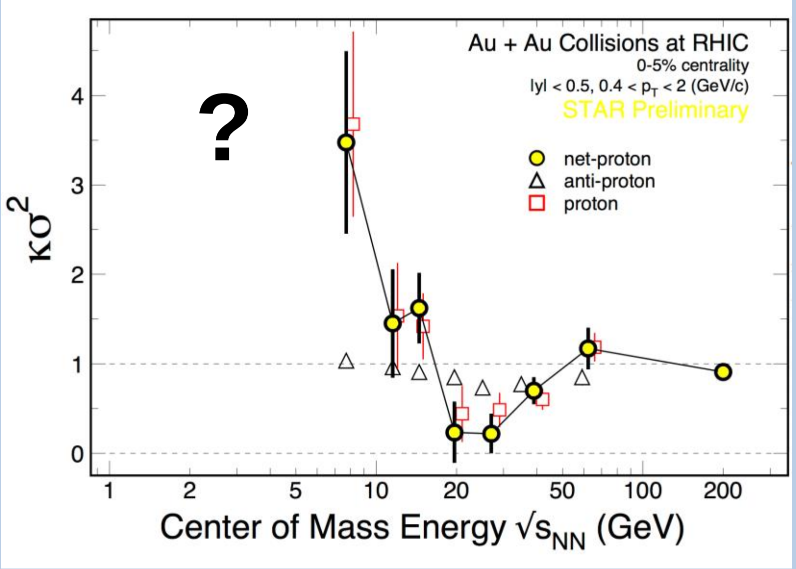
Fluctuations

Should signal the critical point...

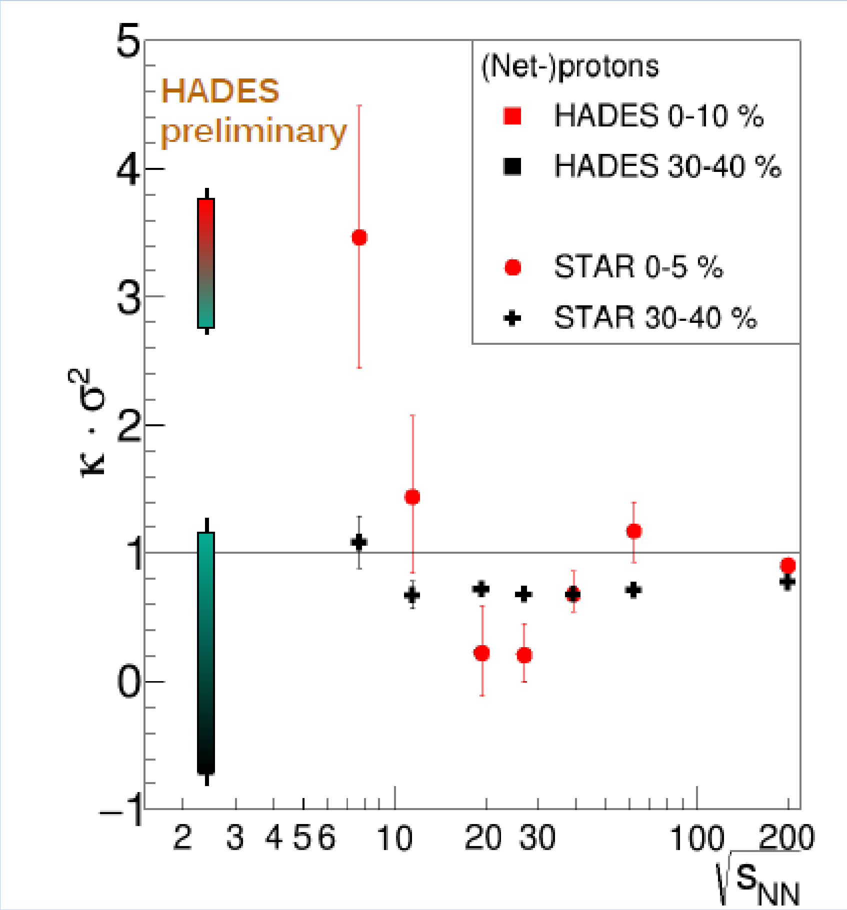
M. Lorentz, QM 2017



M. Stephanov. J. Physics G.: Nucl. Part. Phys. ***38*** (2011) 124147



STAR, NPA 956 (2016) 320c



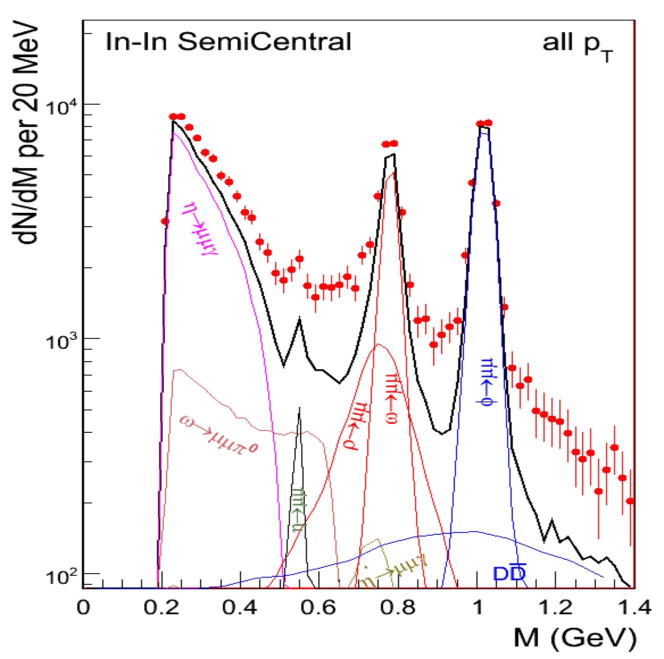
...or spinodial decomposition of a mixed phase?

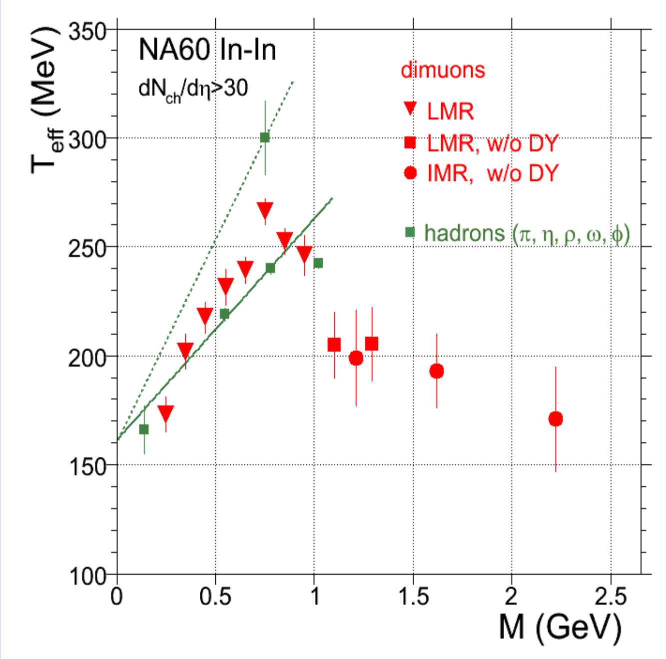
Lepton Pairs

Emitted throughout the lifetime of the fireball: probe its space-time evolution

Low mass (< 1 GeV): in-medium properties of rho meson; excess yield (over vacuum hadronic cocktail) is sensitive to the lifetime of the system

Intermediate mass (1 – 2.5 GeV): no hadronic sources; measure directly the temperature of the fireball.

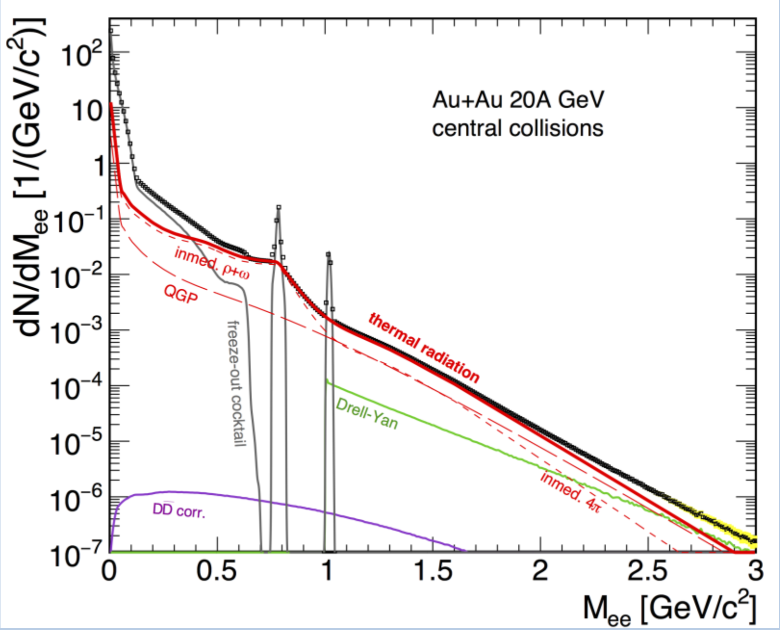




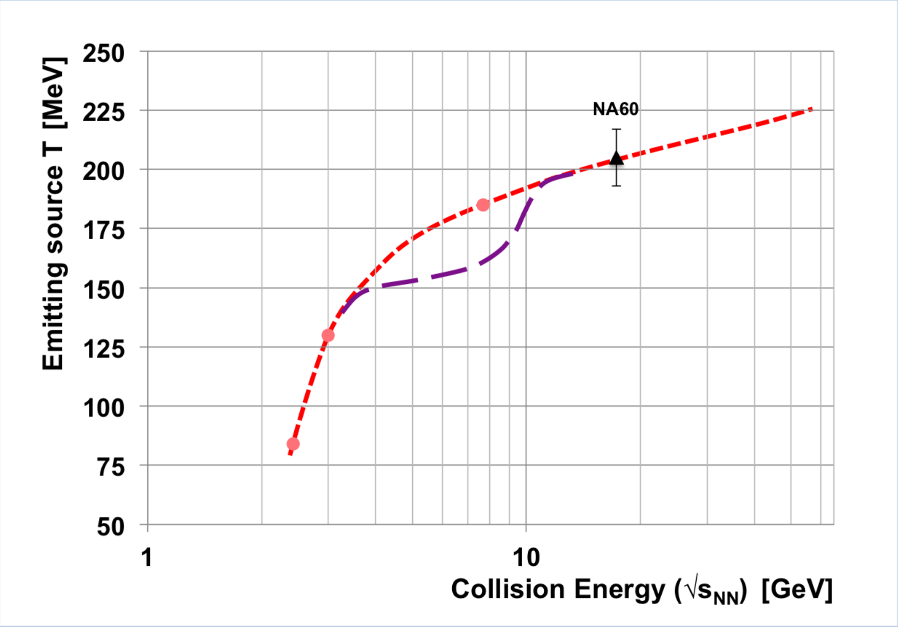
NA60, EPJC 59 (2009) 607

Lepton Pairs

CBM will provide di-lepton mass spectra and measure the caloric curve in the FAIR energy range. Interpretation almost model-independent.



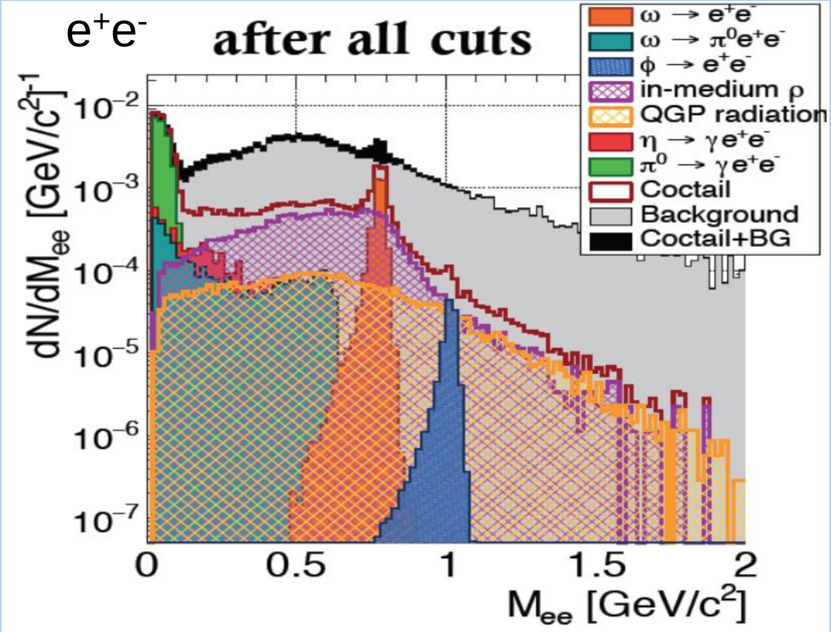
CBM Simulation

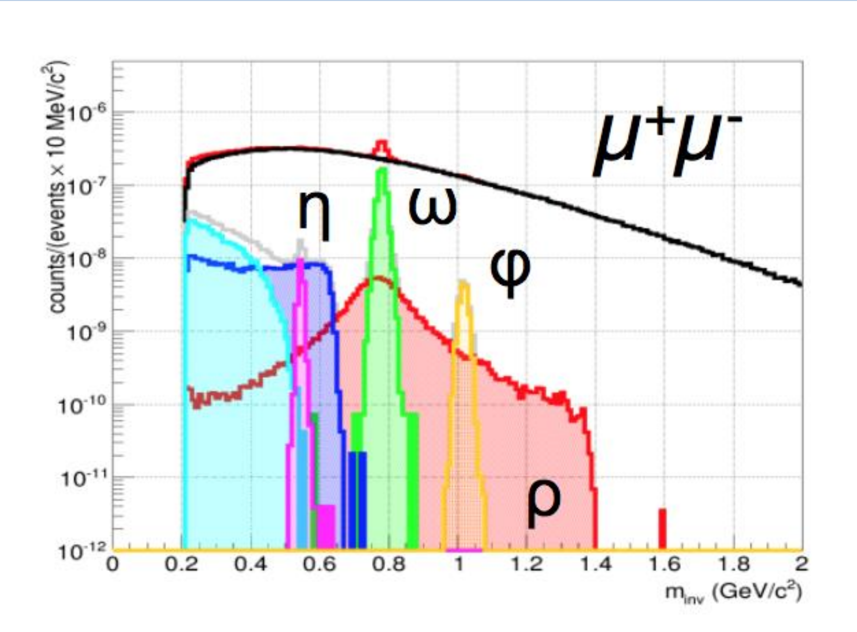


Extracted temperature at intermediate masses; violet: speculated signature of a mixed phase

Lepton Pairs: Electrons and Muons

Di-muon measurements provide a complementary measurement to electron pairs with different background and systematic errors.

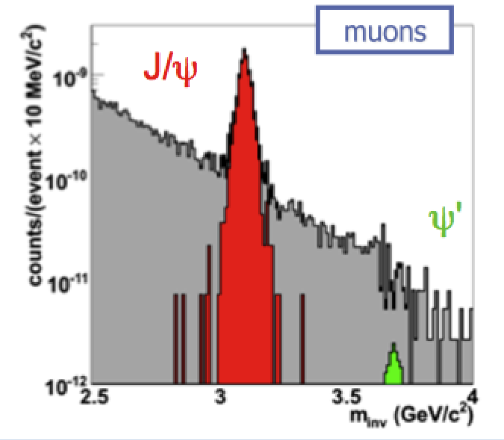




CBM Simulation, Au+Au @ 8A GeV

Charm

- Important (if not decisive) probe of the created medium
  - that holds at all energies!
- Fraction of charm hadronising in J/psi is sensitive to the medium properties (e.g. suppression in QGP)
- Particular at lower energies (below top SPS):
  - N_{ccbar} << 1 -> no regeneration, ”clean” probe
  - Softer J/psi, longer-lived fireball: charm has a chance to see the medium
- Proper interpretation of data requires the measurement of both open and hidden charm
  - Important part of the CBM physics programme

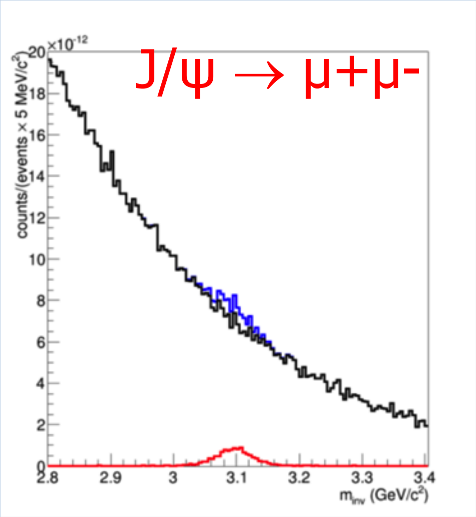


CBM Simulation, Au+Au @ 25A GeV

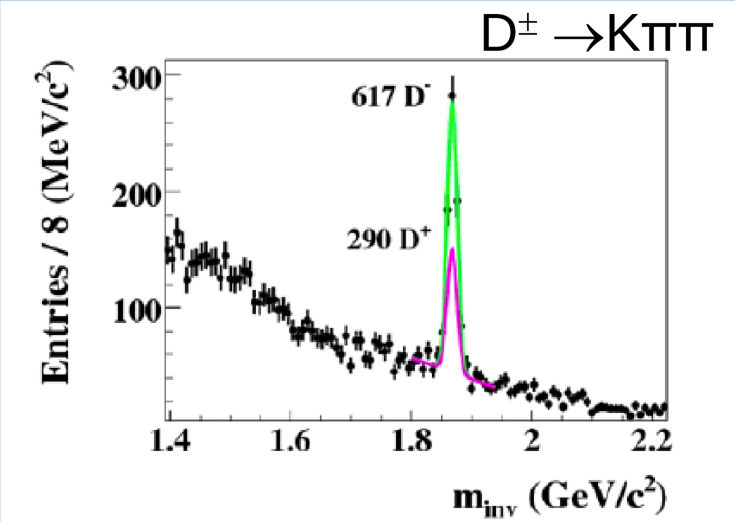
Charm at SIS-100

- The CBM charm programme is tailored for SIS-300 energies
- At SIS-100:
  - charmonium at top energy: Au+Au, 11A GeV (sub-threshold, extremely challenging)
  - Z/A = 0.5 (e.g., Ni+Ni) @ 15A GeV (slightly above threshold)
  - open and hidden charm in p+A up to 30 GeV (c-cbar cross section, cold matter effects)

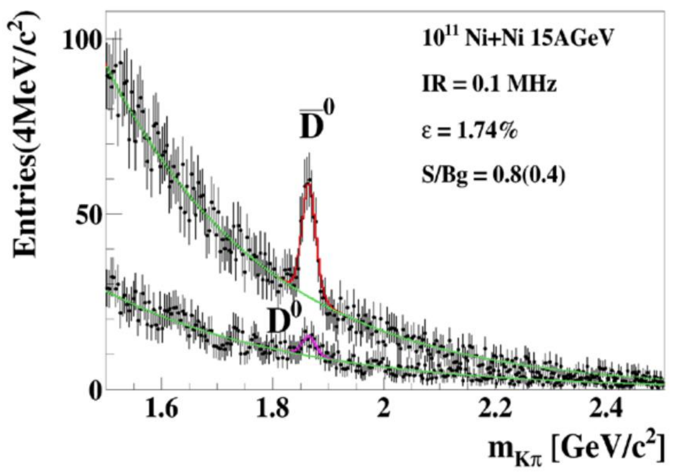
central Au + Au, 10A GeV

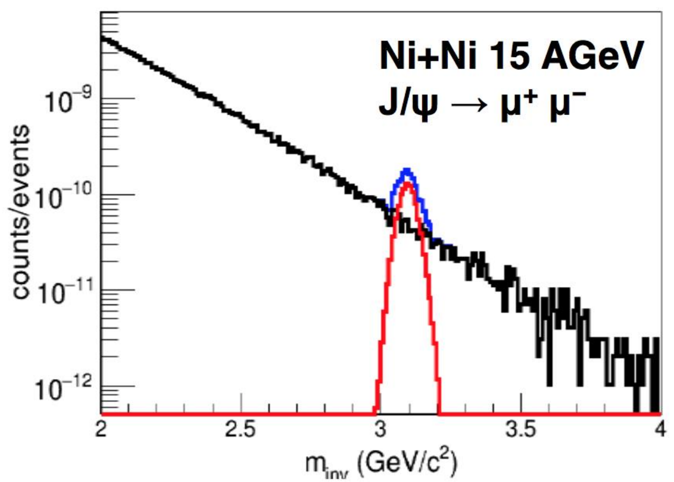


p + C, 30 GeV



Charm at SIS-100





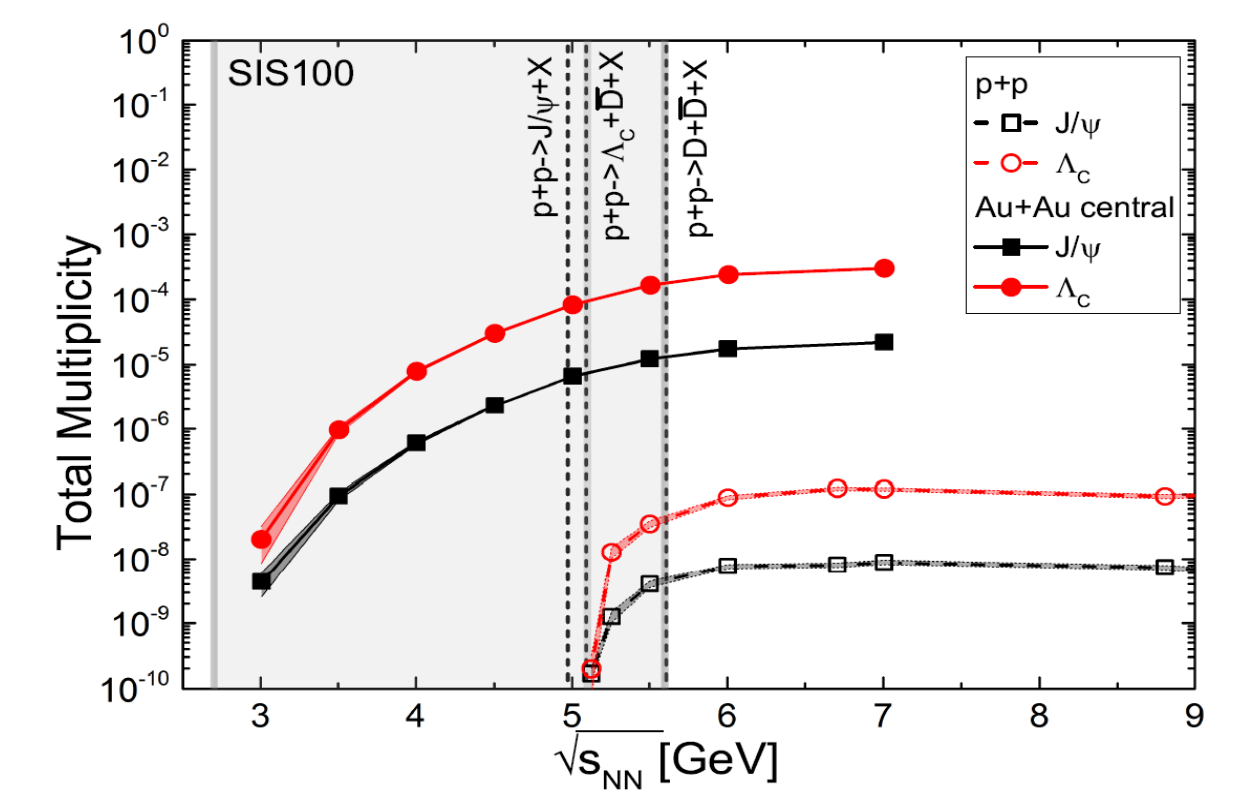
D mesons:
Interaction rate 0.1 MHz
260 $\overline{D}^0$ and 45 D^0 in 2 weeks

Acceptance down to zero p_t

Charmonium (muon channel):
Interaction 1 MHz
3300 J/Ψ in 2 weeks

Maybe There Is More Charm Sub-threshold

J. Steinheimer et al., PRC 95 (2017) 014911



Sub-threshold production through heavy baryonic resonances:

$N^* \rightarrow \Lambda_c + D$ and $N^* \rightarrow N + J/\psi$

Summary

The CBM physics programme comprises:

- Hadron yields and spectra, in particular for multi-strange hyperons and anti-hyperons,
- Hyper-nuclei and exotic strange objects,
- Directed and elliptic flow, in particular of weakly scattered particles,
- Fluctuation of conserved quantities
- Lepton pair spectra (electrons and muons),
- Charm near threshold in A+A collisions, charm in p+A collisions (both open and hidden charm)

These observables will be measured systematically as function of beam energy in the range T = 1.3A - 11.1A GeV for heavy nuclei and 29 GeV for proton beams (SIS-100).

At a later stage, the SIS-x00 (x >= 3) will open up a larger energy regime to fully exploit the CBM capabilities in particular in the charm sector.