Physics with the CBM Experiment

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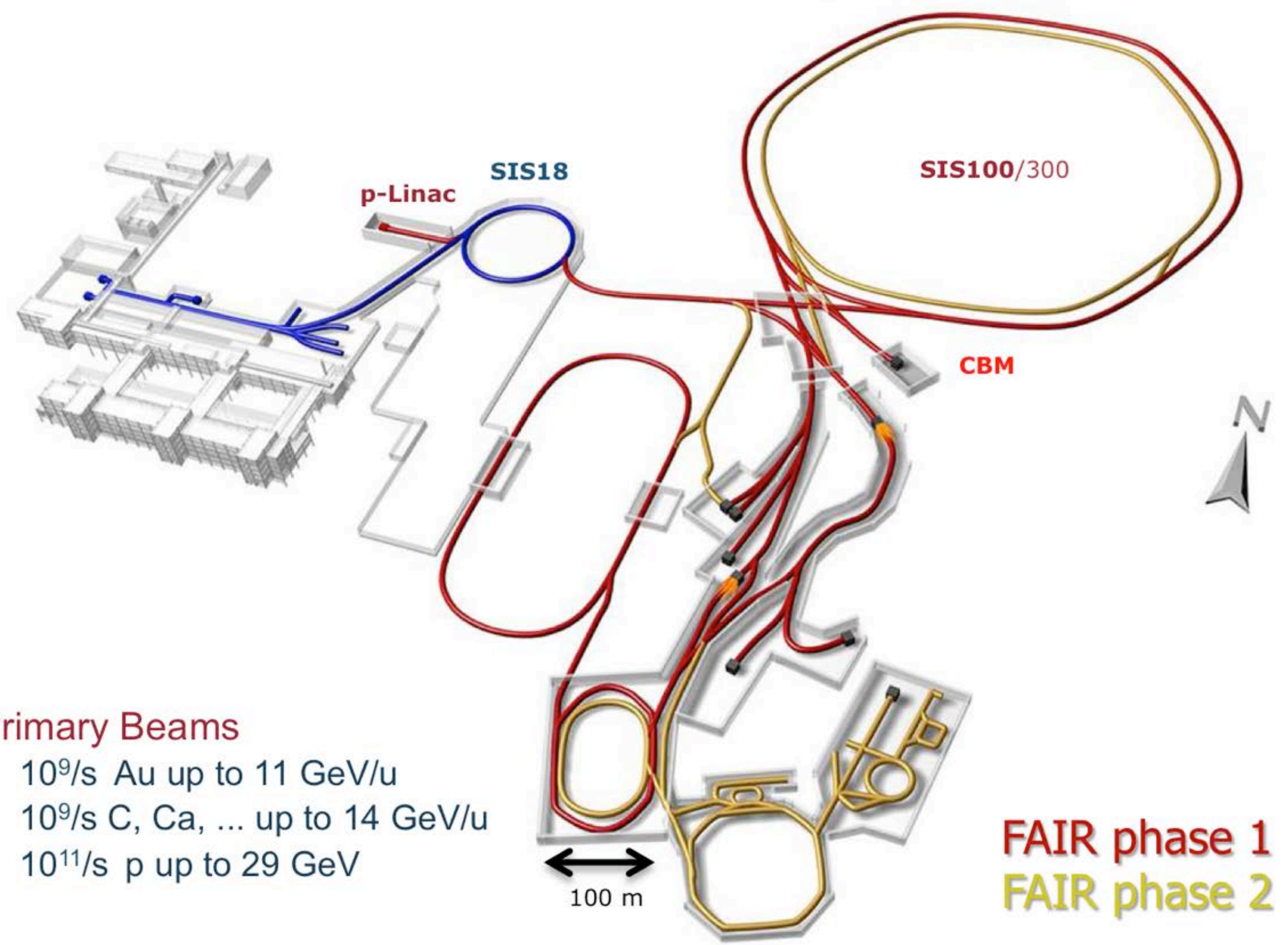
on behalf of the CBM Collaboration

ICNFP 2017, Kolymbari, 25 August 2017

FAIR Accelerator Complex



Primary Beams

- 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 Accelerator Complex and CBM

Primary Beams

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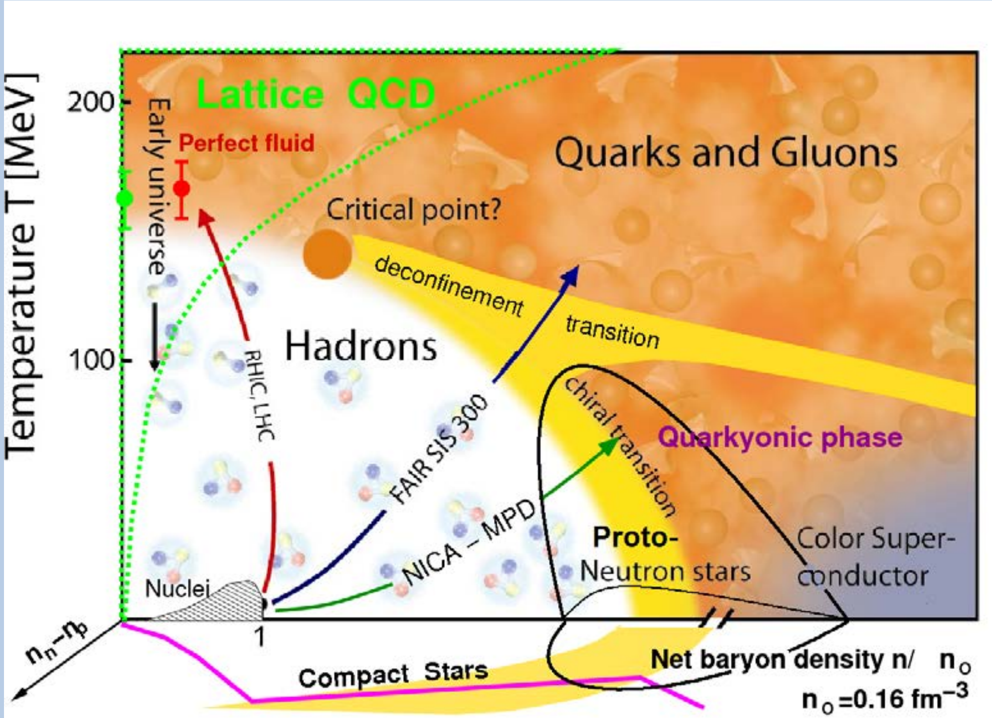
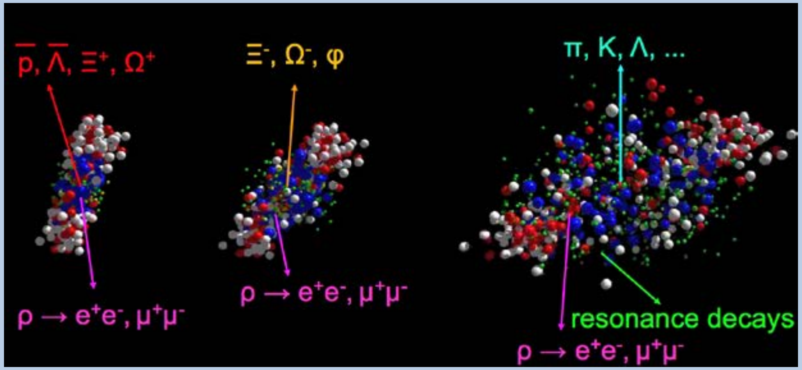
What We Are After





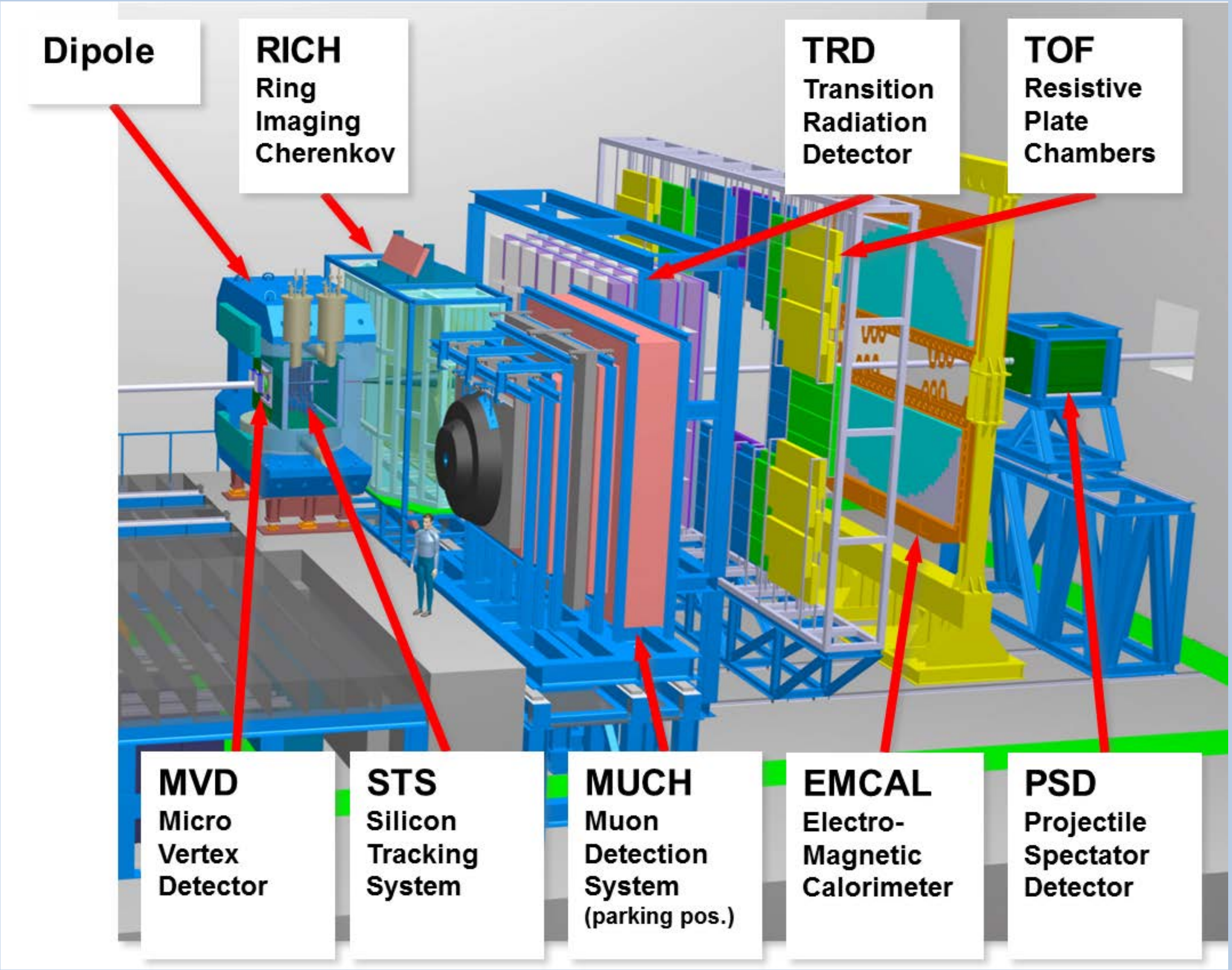
Theory, models

The quest: study 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

General experimental strategy: stay as open and flexible as possible; measure as many observables as you reasonably can.

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

SIS-100 and SIS-300

- SIS-100 and CBM are part of the FAIR Modularised Start Version (MSV)
- SIS-300 is agreed-on part of FAIR, but not of the start version; timeline is unclear
- we concentrate here on CBM@SIS-100
  - Au: 2A – 11A GeV
  - Ni: 2A – 15A GeV
  - p: up to 30 GeV
- staying open for SIS-300 as later upgrade

CBM Physics: Strangeness

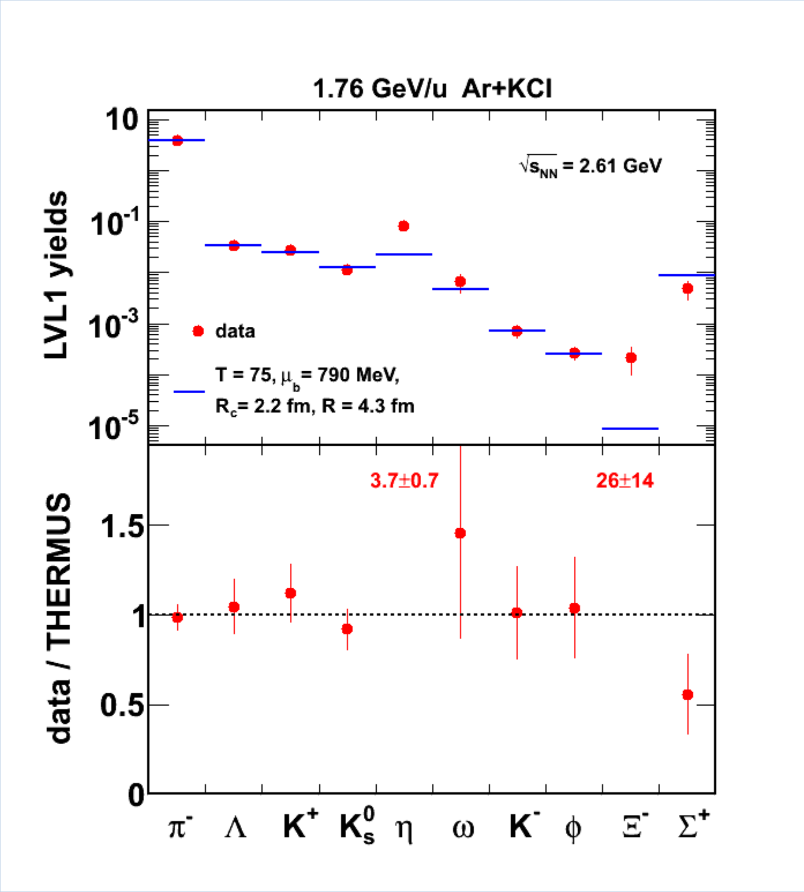
- One of the ”classical” observables: strangeness enhancement / canonical suppression
- Strangeness yields from are well described by the statistical model: strong argument for phase transition (no hadronic mechanism to equilibrate e.g. Omega)
- Model fits describe data at lower SPS and at AGS
  - But with a limited amount of particle species
  - Data on multi-strange baryons are scarce
- Following this: measuring strange baryon abundances at lower energies.
  - Down to which collision energies does the hadron gas model hold?

Breakdown of strangeness thermalisation?

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

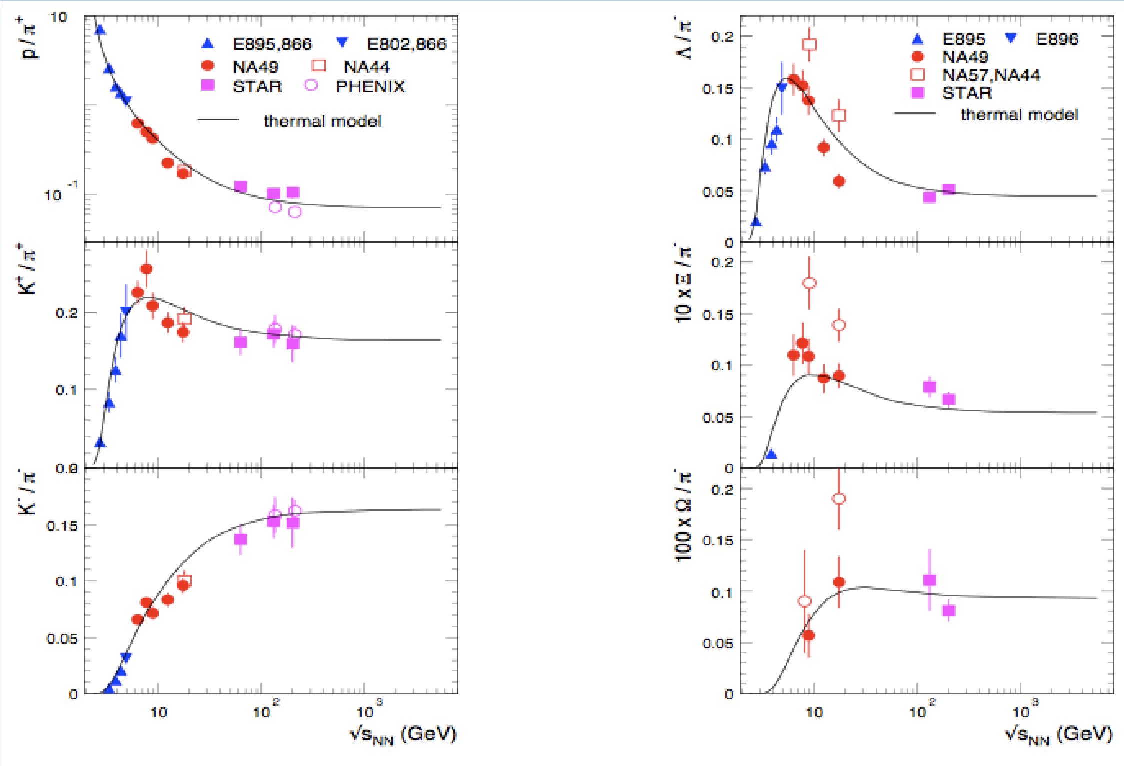
N.b.: This is deep sub-threshold. Production through multi-step processes

$$\Lambda K \rightarrow \Xi\pi \quad \Lambda\Lambda \rightarrow \Xi^- p \quad \Xi K \rightarrow \Omega\pi$$



R. Holzmann, CBM Physics Workshop, April 2010

The need for data on multi-strange baryons

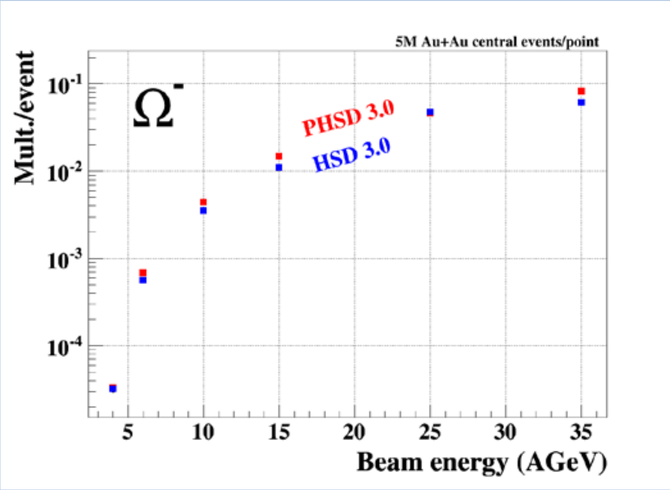


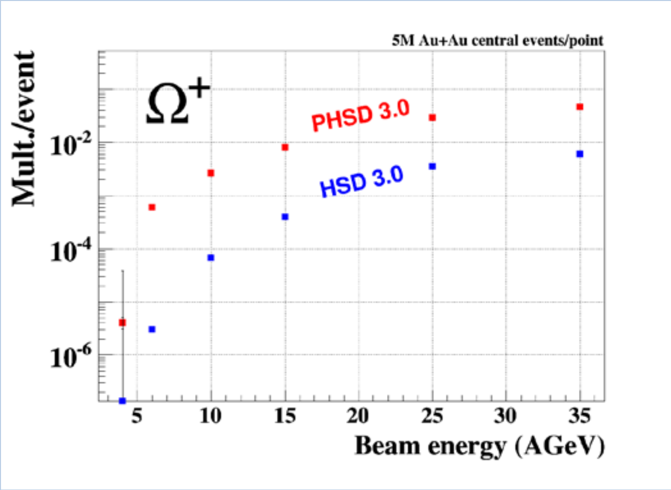
A long-lasting debate: pure hadronic description or signal of drastic change in matter properties?

Data on multi-strange baryons will be decisive!

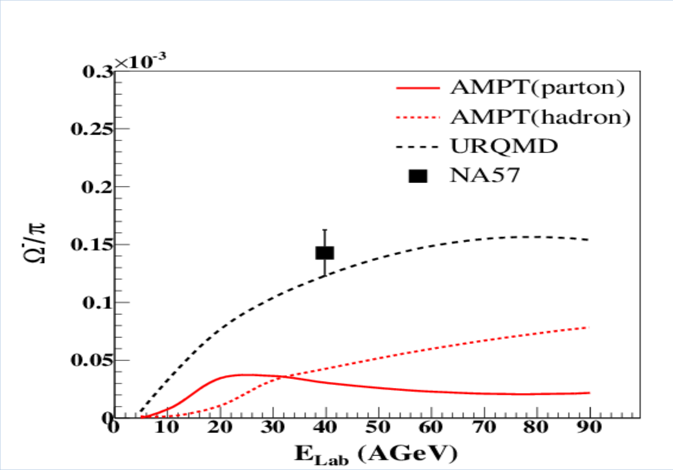
- “Onset” scenario: effect is due to increase in strangeness; sharp maximum at same location as K/pi; size of peak increases with strangeness content
- Hadron Gas Model: effect is due to net-baryon density; broad maximum; size of maximum decreases with strangeness content; position of maximum shifts

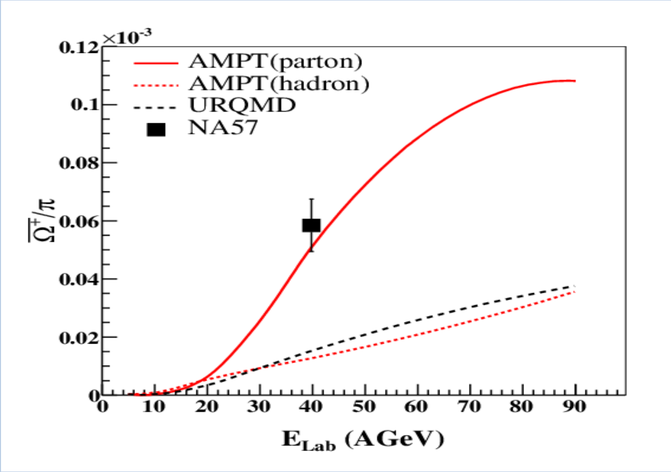
Strange anti-baryons at FAIR/NICA energies





HSD / pHSD

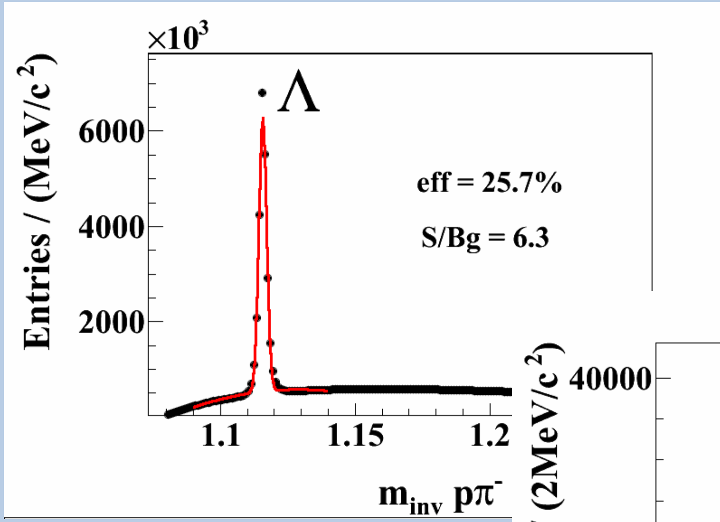


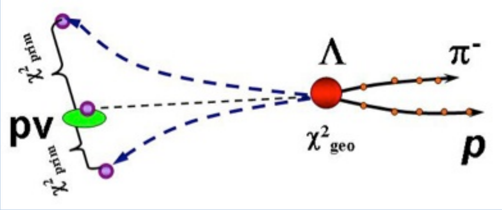


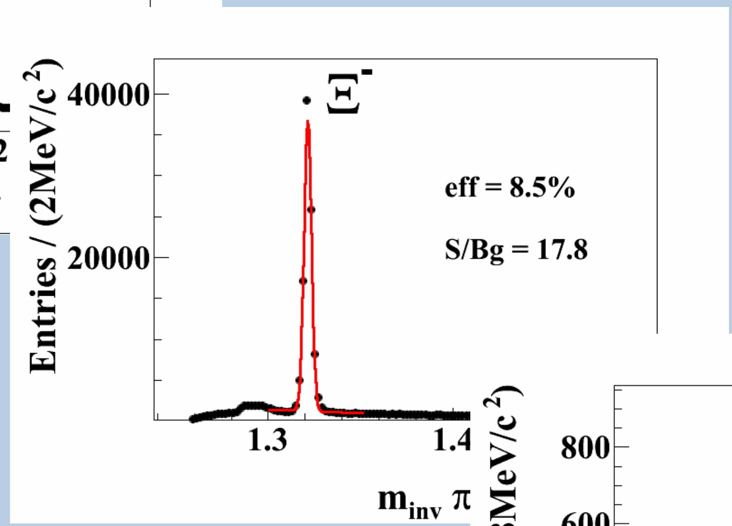
AMPT

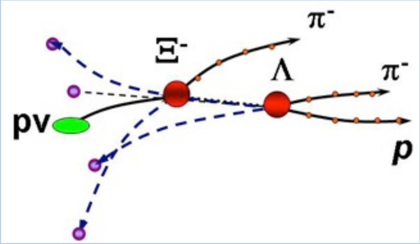
Microscopic models (including partonic production) predict the anti-hyperons to be very sensitive to partonic production mechanisms (hyperons much less)

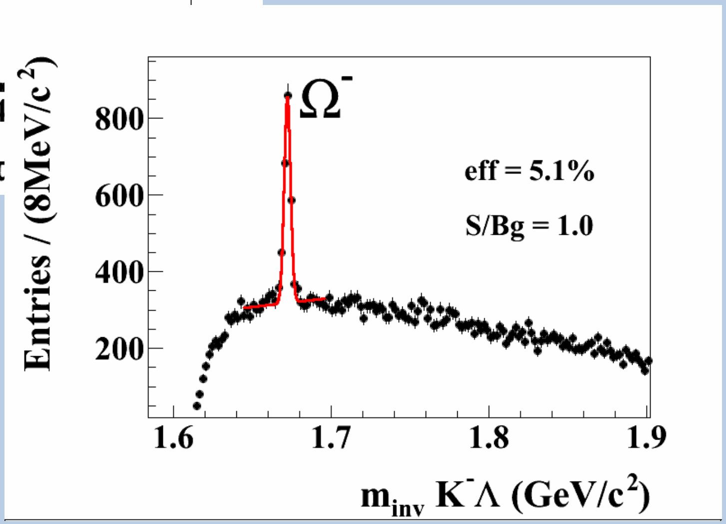
CBM Performance for Hyperons





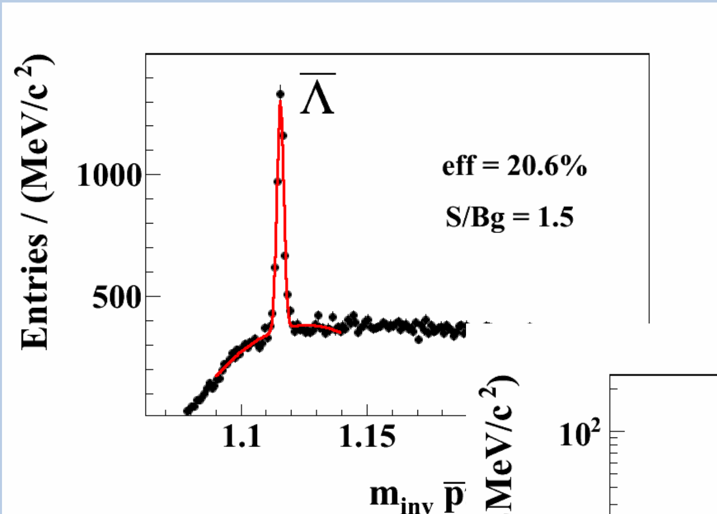




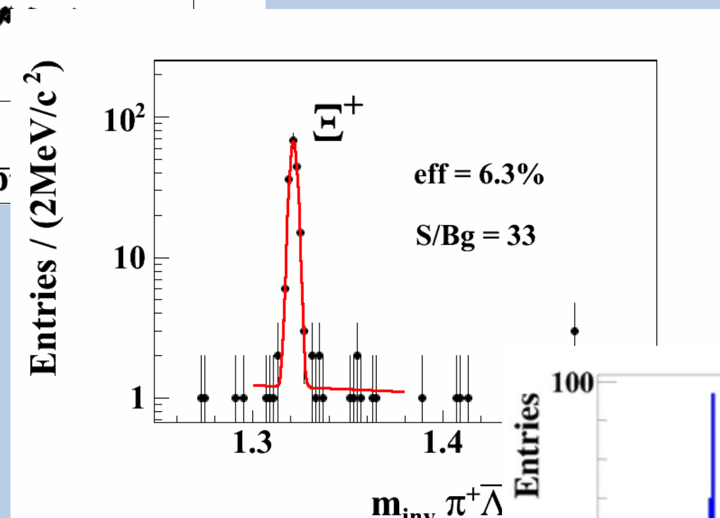


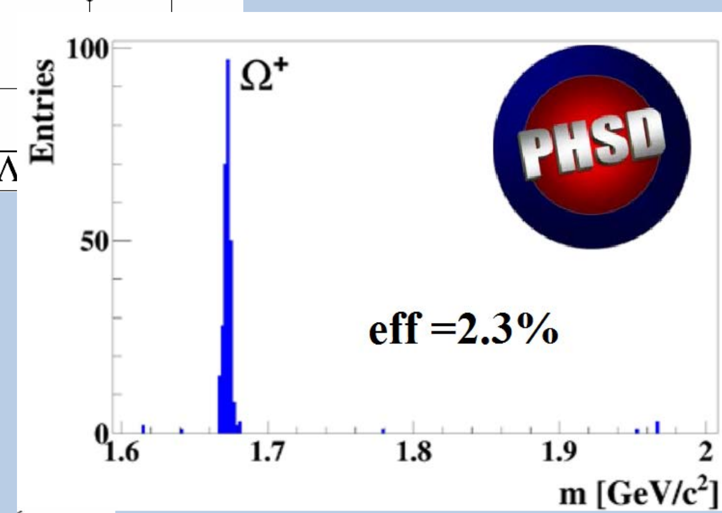
Input: UrQMD, central Au+Au, 10A GeV
Reconstruction from fully simulated detector response

CBM Performance: Anti-Hyperons



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





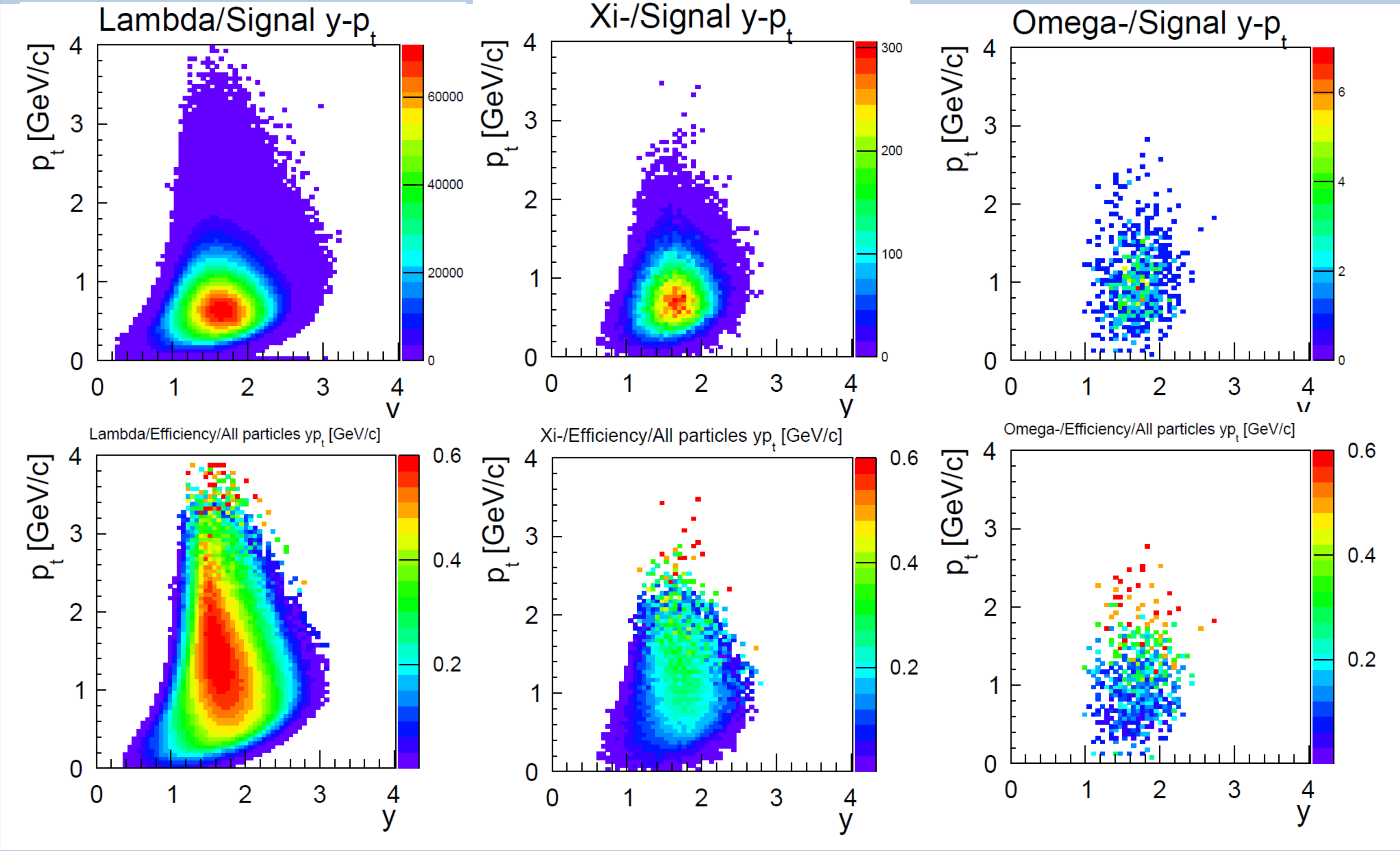
Very rare probes; require high interaction rates and online selection!

Hyperons: Expected Statistics

Au+Au 10 AGeV	Λ	Ξ^-	Ω^-	Ω^+
decay channel	$p\,\pi^-$	$\pi^- p\,\pi^-$	$K^- p\,\pi^-$	$K^+ \bar{p}\,\pi^+$
$M_{UrQMD\ 3.3}$	17.4	0.22	5.5E-3	6.7E-5
BR(%)	63.9	~100	67.8	67.8
total eff. (%)	**25.7**	**8.5**	**5.4**	**2.3**
$S/B_{2\sigma}$	**.3**	**17.8**	**1.0**	**~10**
Reco yield/sec. ~ 1MHz	**4.5M**	**20k**	**280**	**1.5**

Will allow systematic, differential studies also of rare particles!

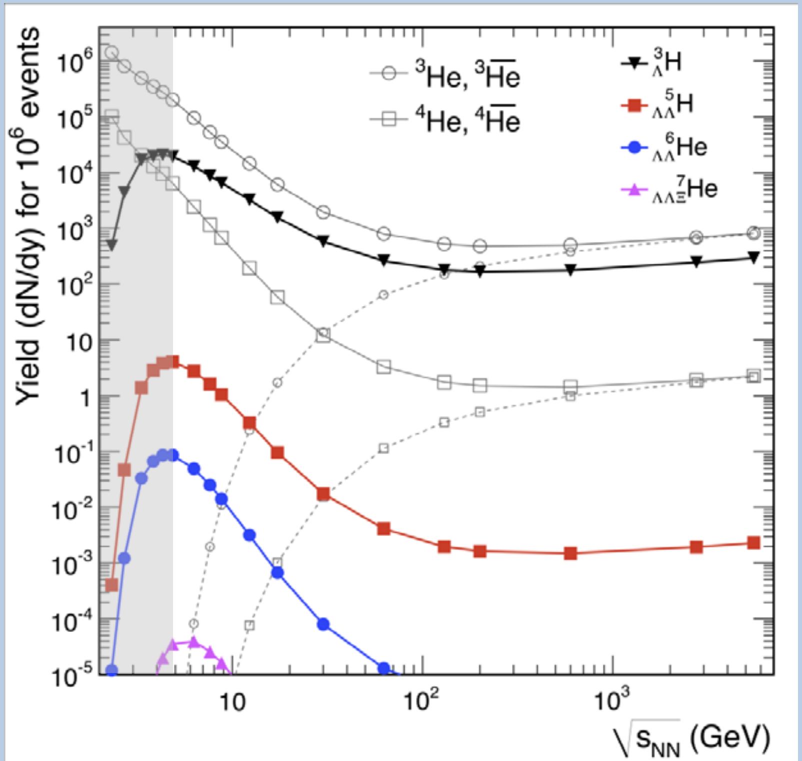
Hyperons: Acceptance and Efficiency



CBM Physics: Hyper-Matter

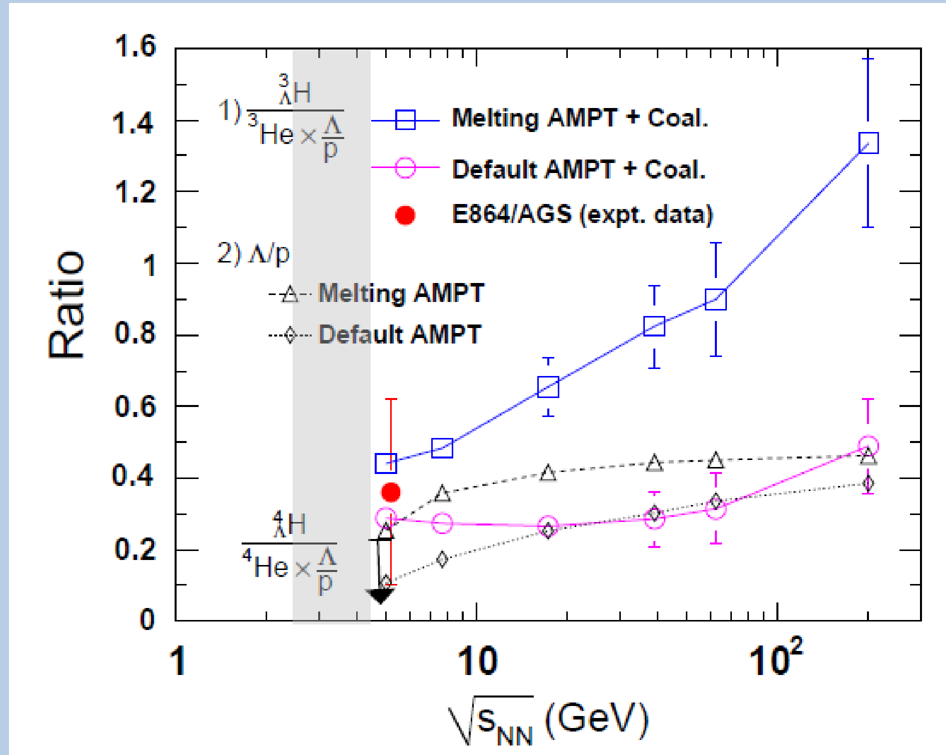
In heavy-ion collisions: produced through capture of Λ in light nuclei

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



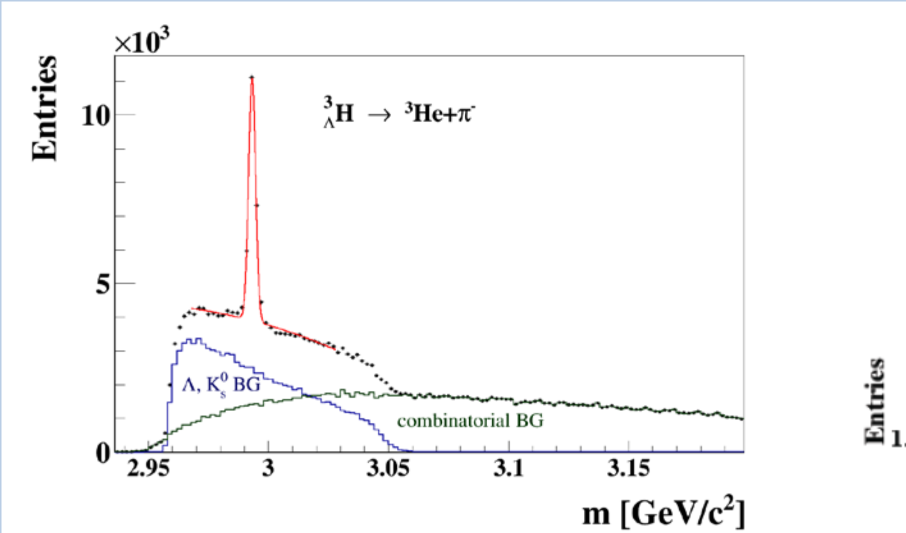
Thermal model: maximum production at CBM energies

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

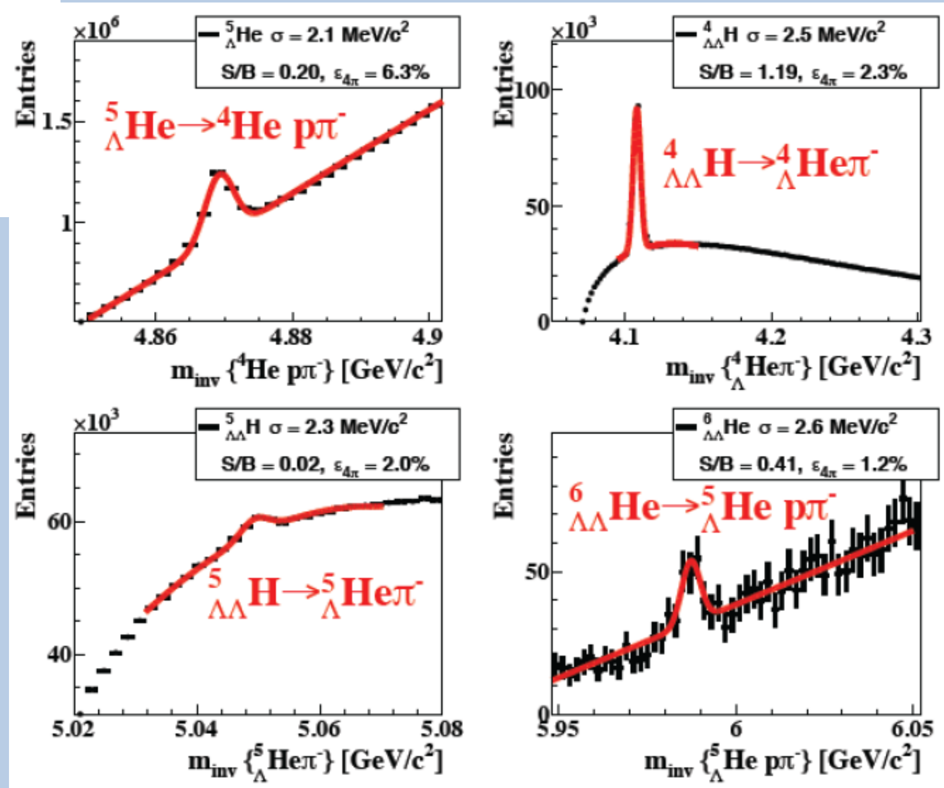


Transport: sensitive to medium properties (correlation of strangeness and baryon number)

CBM Physics: Hyper-Matter

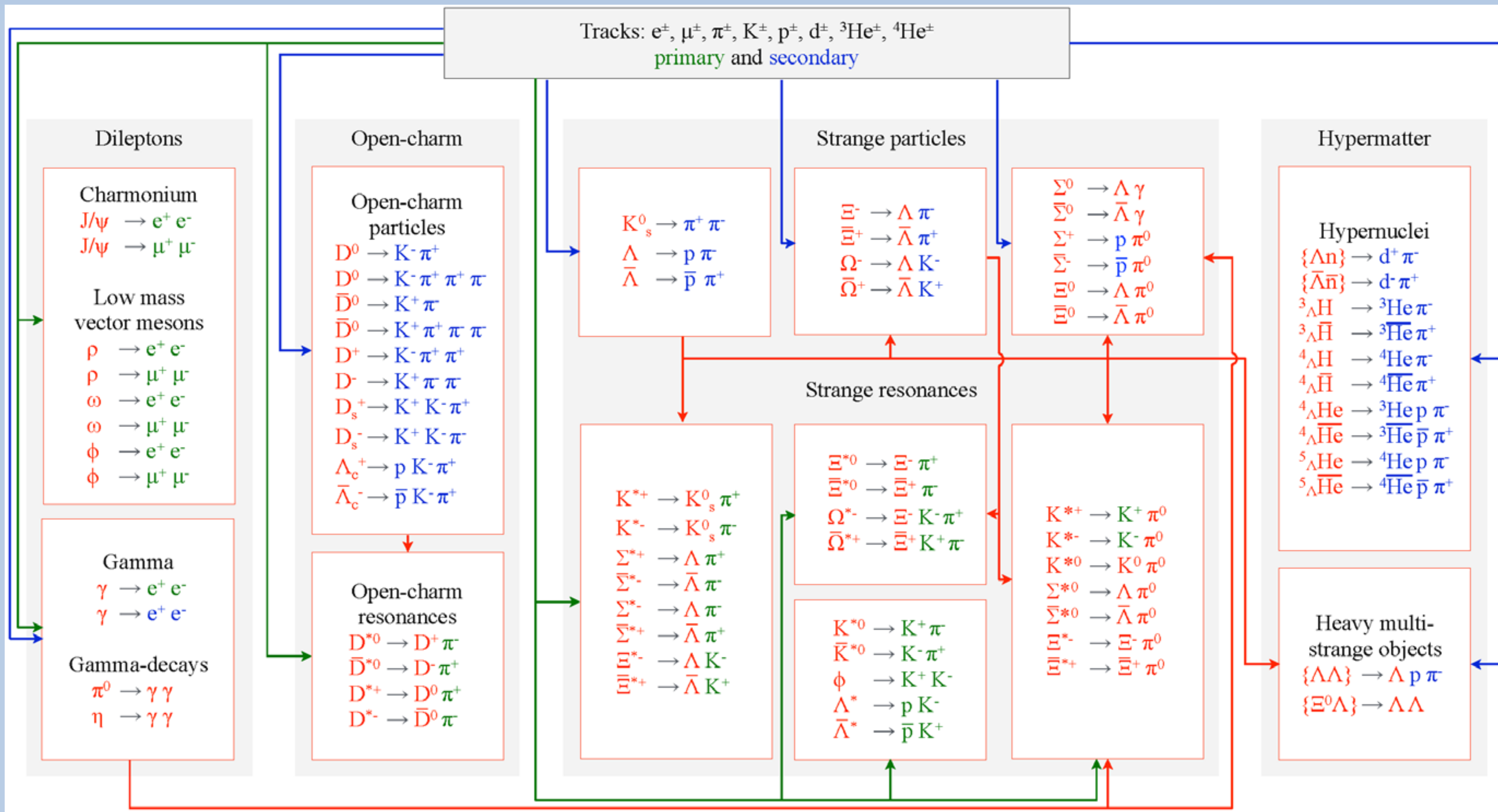


CBM Simulation
central Au+Au, 10A GeV
10^{12} events (3 weeks beamtime)



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

Particle reconstruction in real-time



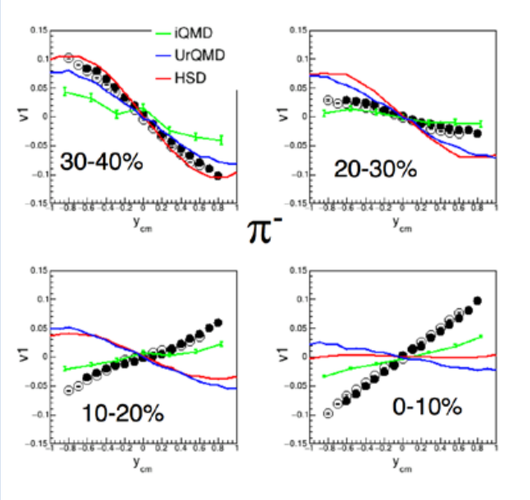
A multitude of particles will become accessible.

Real-time reconstruction allows online selection of rare probes.

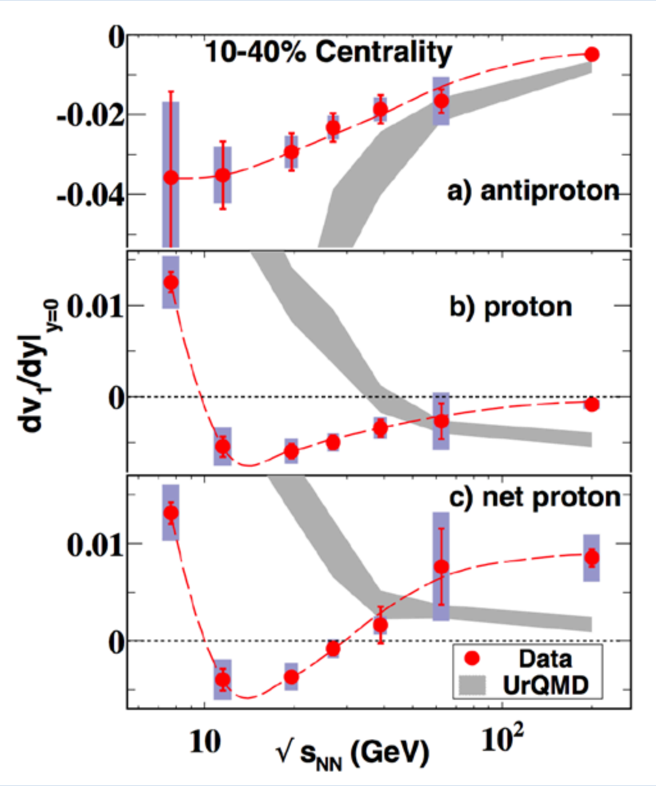
Software becomes the key to the physics output.

CBM Physics: Flow

- The prime tool to study the equation-of-state
- Results at lower energies not understood in terms of transport models



A. Kugler, this conference



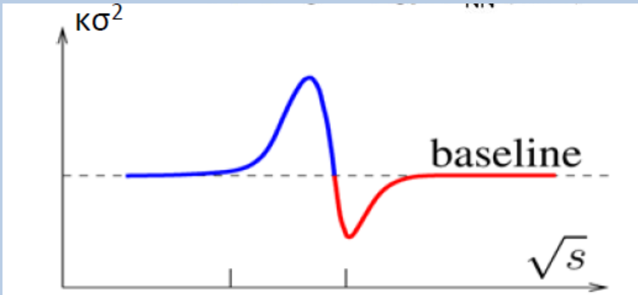
STAR, PRL 112 (2014) 162301

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

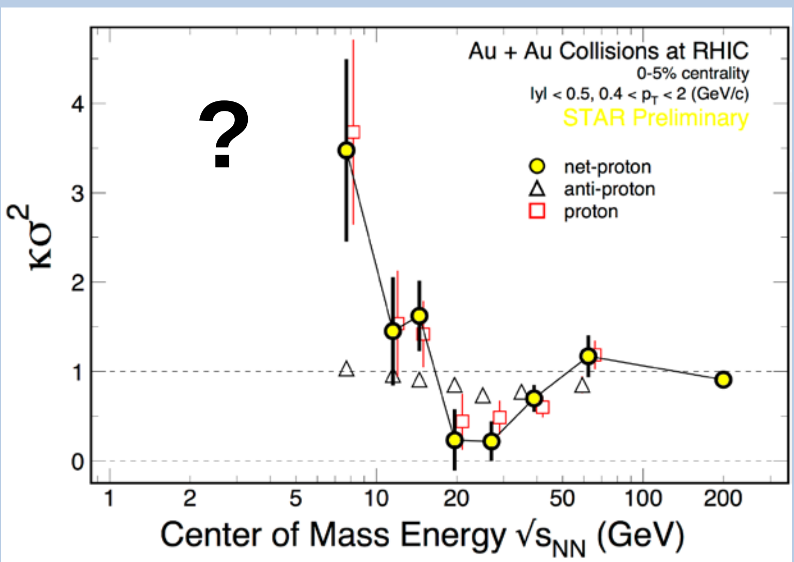
CBM Physics: Fluctuations

Should signal the critical point…

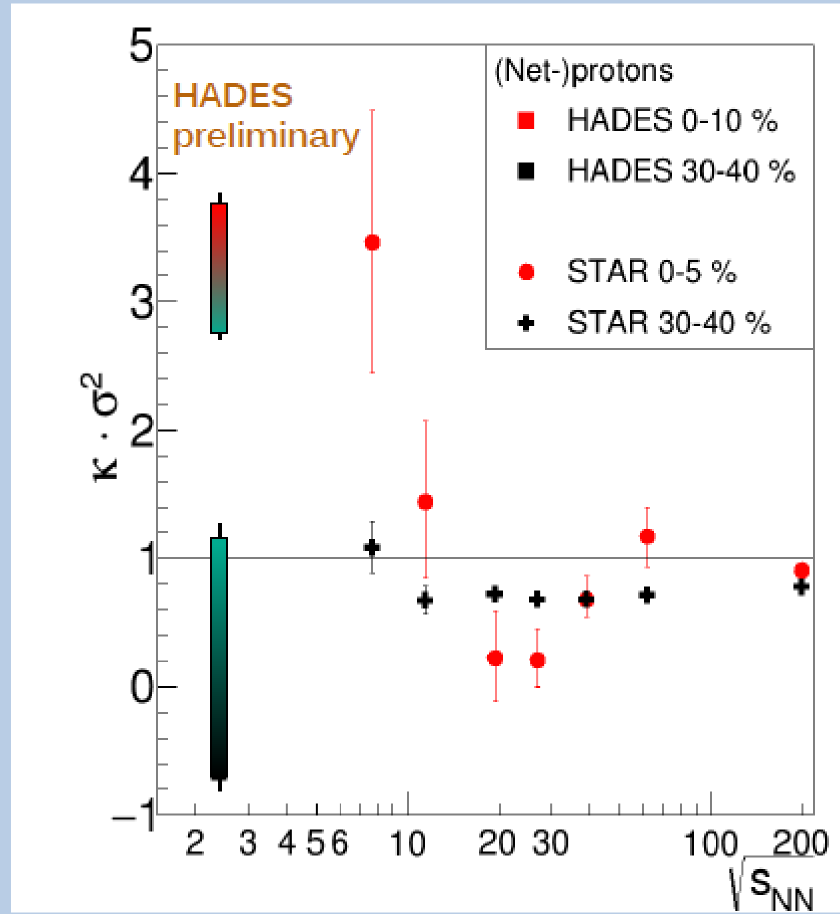
M. Lorentz, QM 2017



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



STAR, NPA 956 (2016) 320c



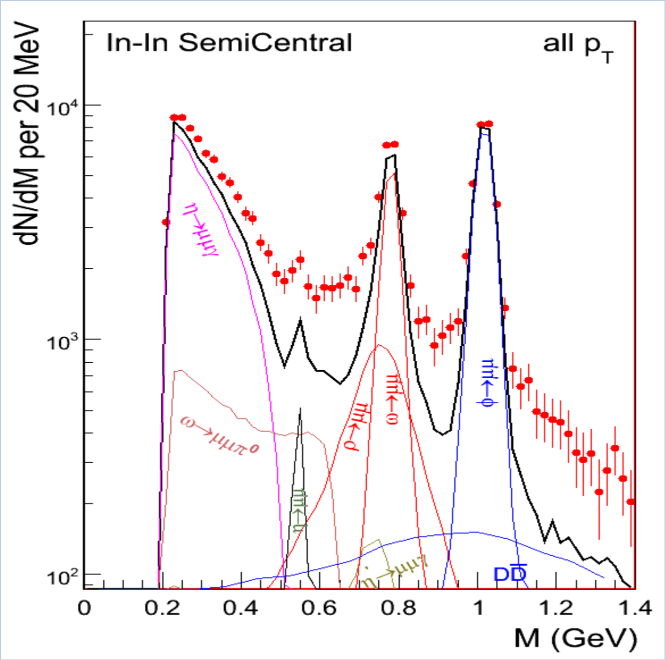
…or spinodial decomposition of a mixed phase?

CBM Physics: 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.

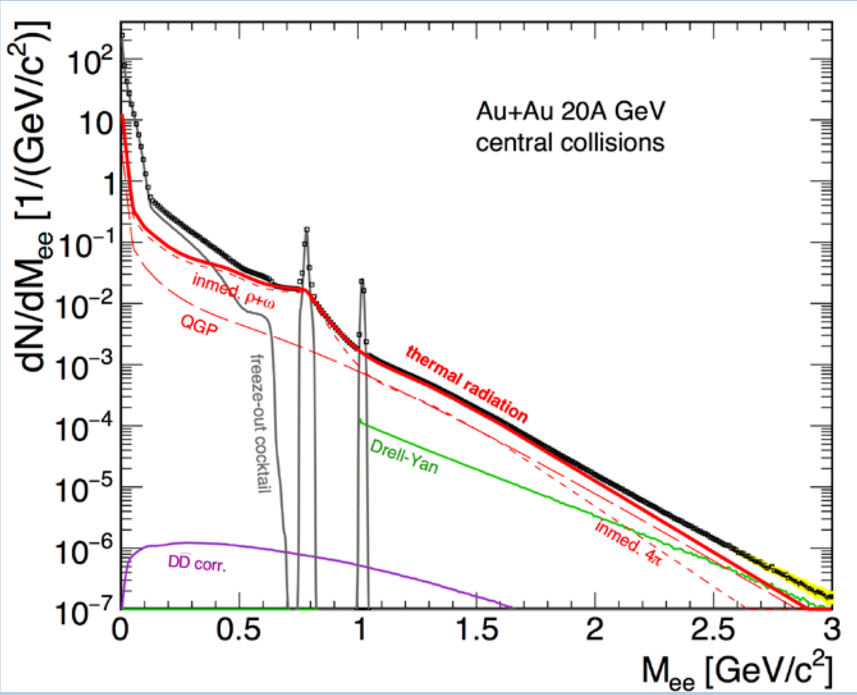


NA60, EPJC 59 (2009) 607

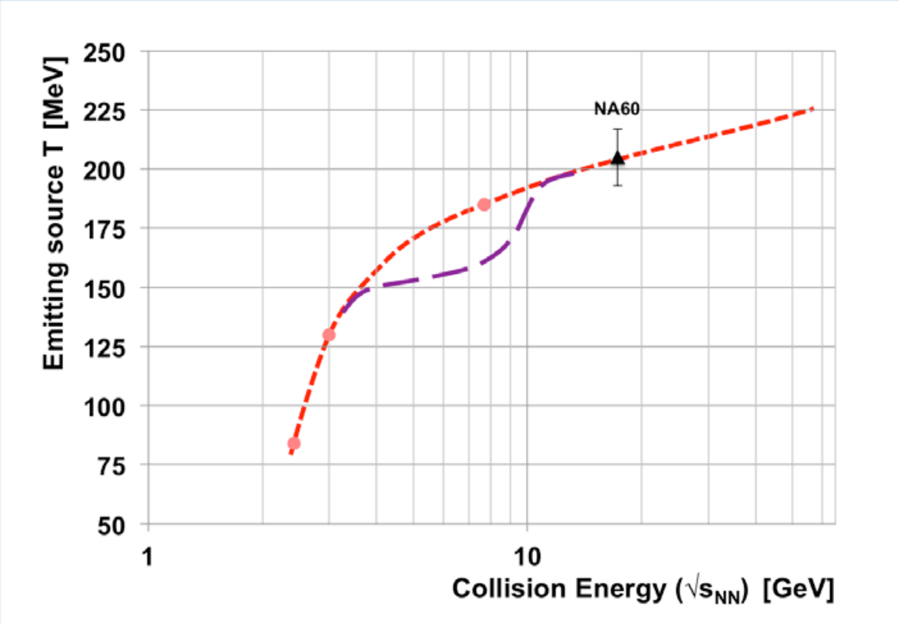
CBM Physics: Lepton Pairs

No di-lepton data exist between HADES and NA60!

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



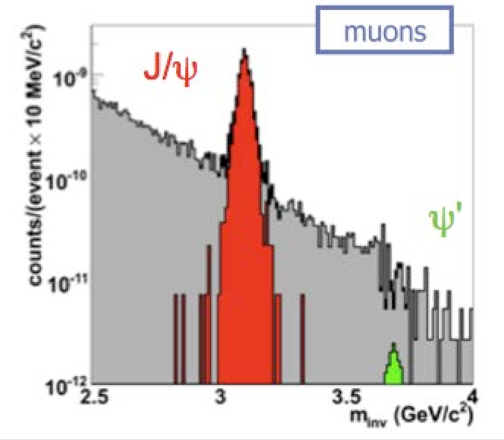
CBM Simulation



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

CBM Physics: 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

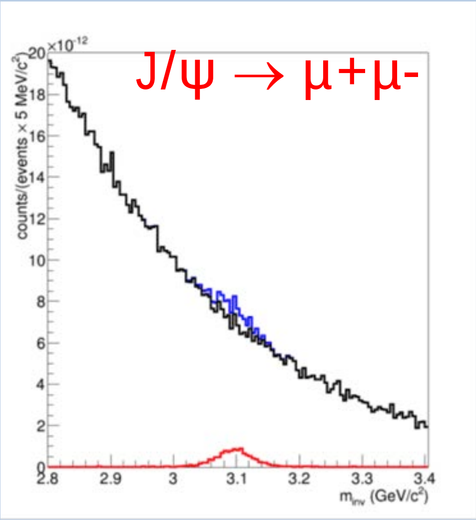


CBM Simulation, Au+Au @ 25A GeV

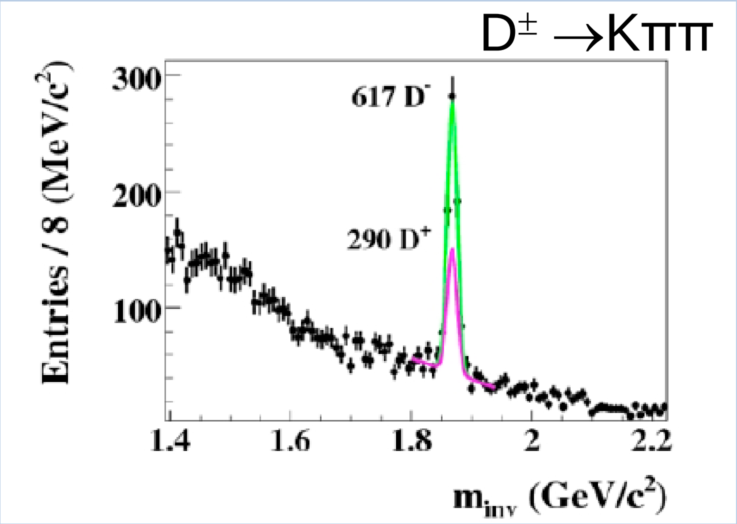
CBM Physics: Charm at SIS-100

- The CBM charm programme is tailored for SIS-300 energies
- At SIS-100:
  - charmonium at top energy: Au+Au, 10A 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)

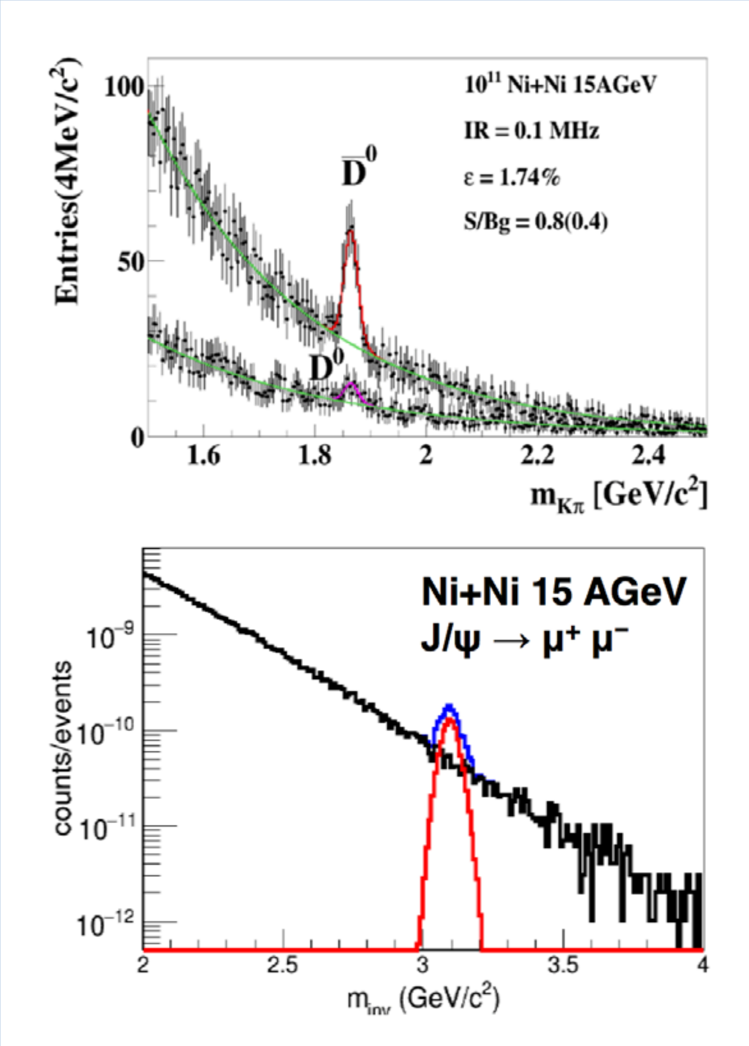
central Au + Au, 10A GeV



p + C, 30 GeV



CBM Physics: Open Charm at SIS-100



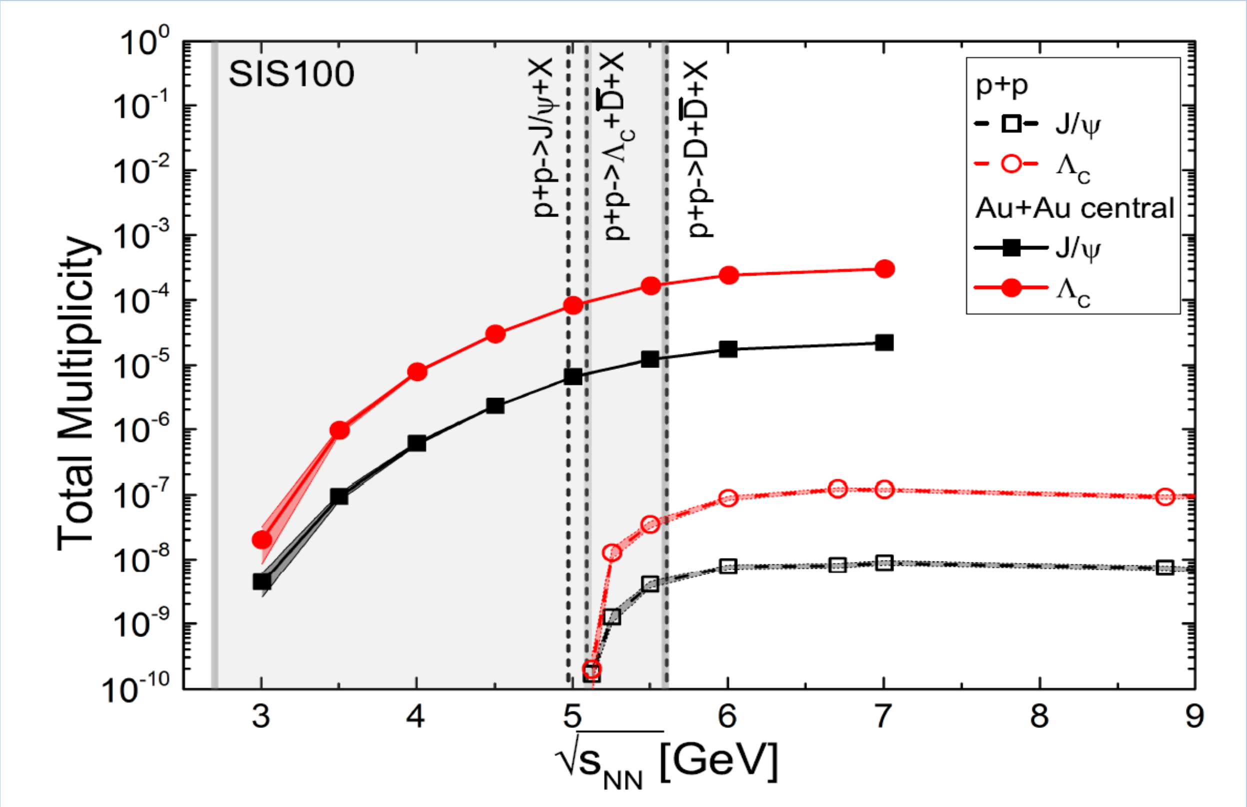
D mesons:
Interaction rate 0.1 MHz
260 $\overline{D}^0$ and 45 D^0 in 2 weeks

Acceptance down to zero p_t

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

Open Charm: Maybe There Is More Subthreshold

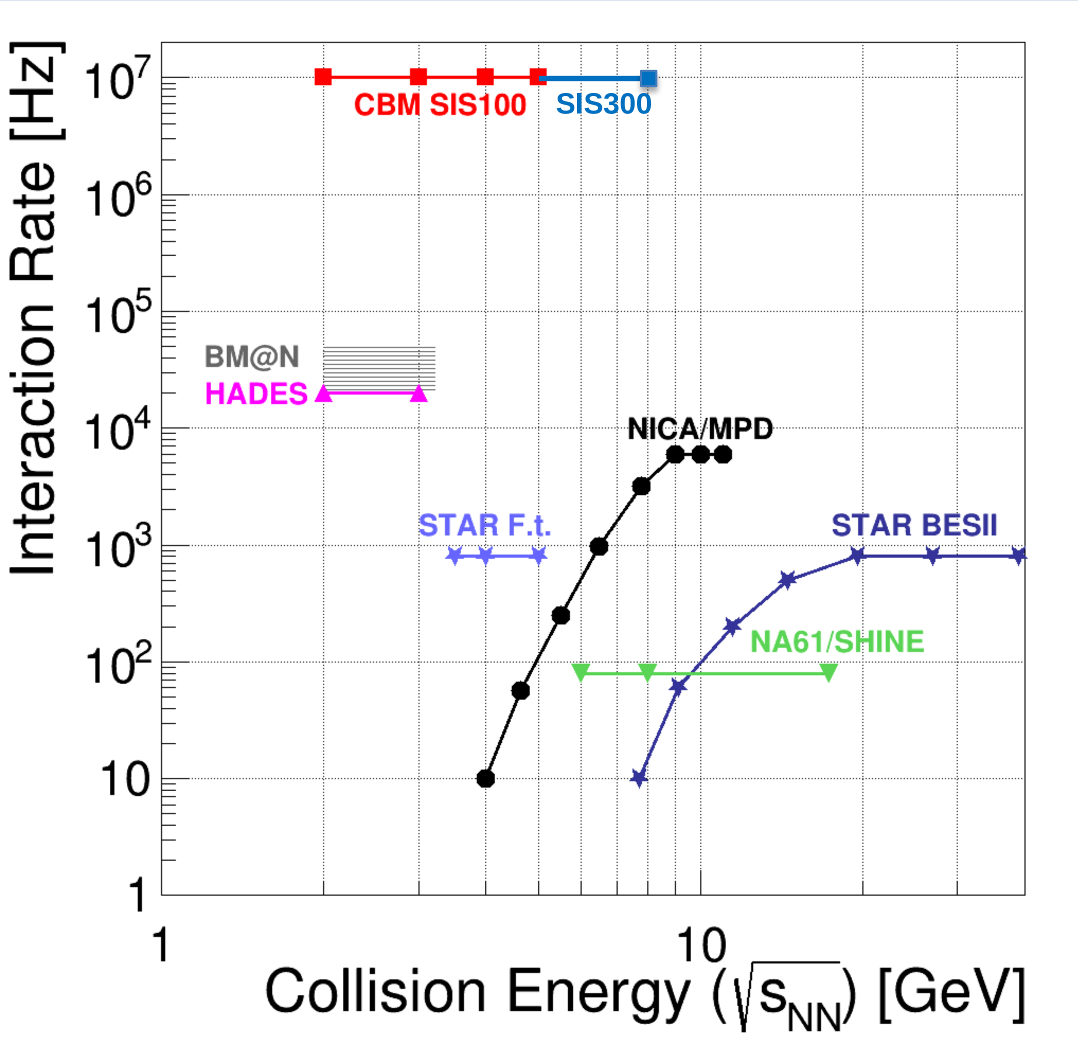
J. Steinheimer et al., PRC 95 (2017) 014911



Sub-threshold production through heavy baryonic resonances:

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

CBM and MPD



CBM: fixed-target
Extreme rates (large range of observables) but restructed energy range (in particular in the first years)

MPD: collider
Larger energy range
Limited in rate

A lot of complementarity;
Some competition where physics programmes overlap.

Summary

- The ambitious design of CBM, combining very high interaction rates with large acceptance and precision reconstruction, will allow the measurement of a multitude of particles originating from heavy-ion collision
  - At SIS-100 (AGS energy range) up to 10A GeV from 2024 on
  - After the installation of the second (booster) synchrotron up to 35A GeV (45 for symmetric nuclei)
- Systematic measurements (collision energy, system size) will address the nature of QCD matter at high net-baryon density:
  - Particle yields and spectra
  - Flow
  - Fluctuations
  - Lepton pairs
  - Charm