Perspectives for Heavy-Ion Physics With the CBM Experiment

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Zimányi 2010 Winter School, Budapest

The FAIR project

Facility for Anti-Proton and Ion Research

At GSI, Darmstadt

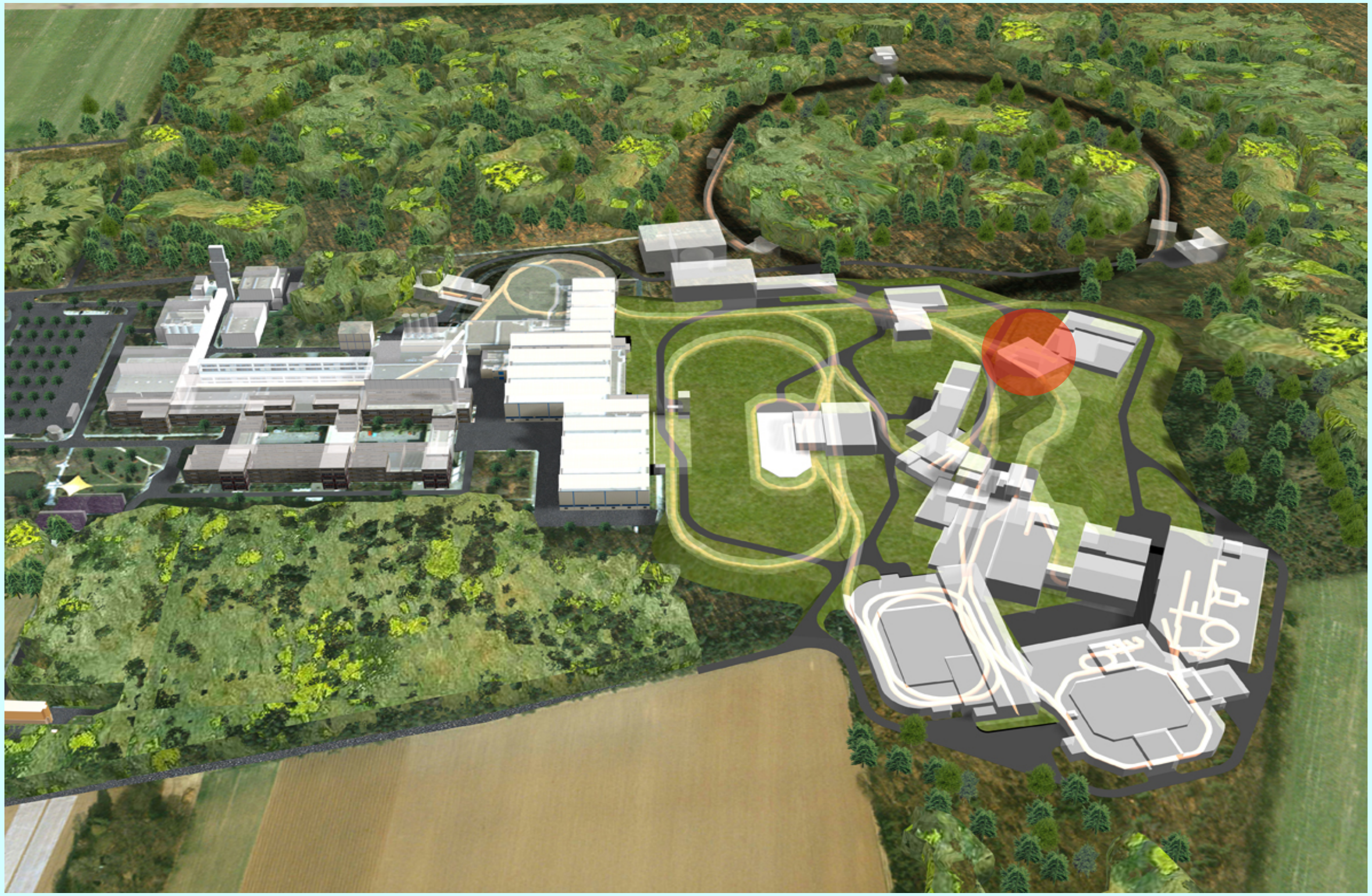
Hadron physics with anti-proton beams

Nuclear structure physics with rare isotope beams

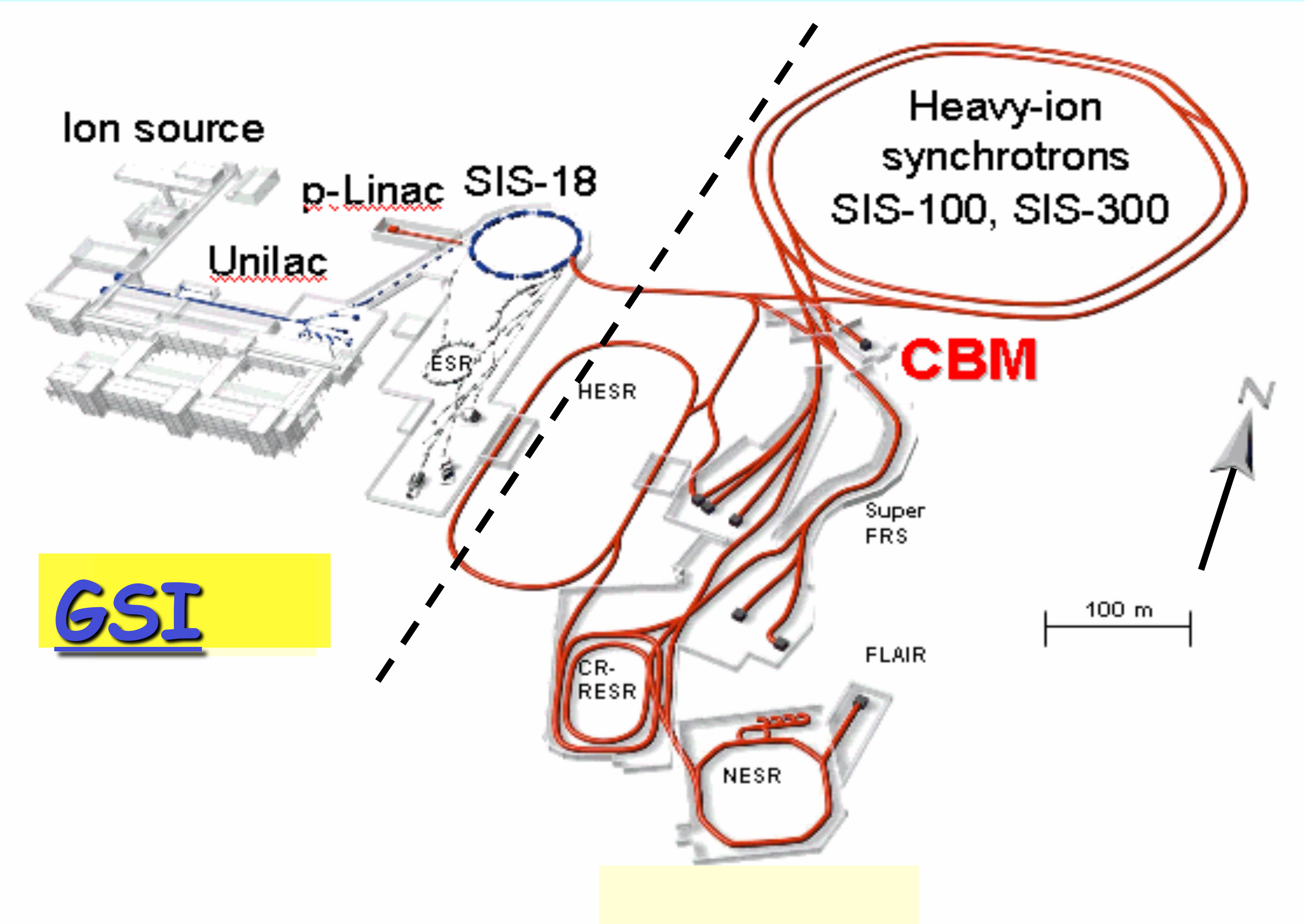
Plasma physics with short-pulsed heavy-ion beams

Atomic physics with highly charged ions and low-energy anti-protons

Nuclear collisions:
CBM
Ion beams 10^9/s
10 – 45 AGeV



FAIR schematically



SIS-100/300:

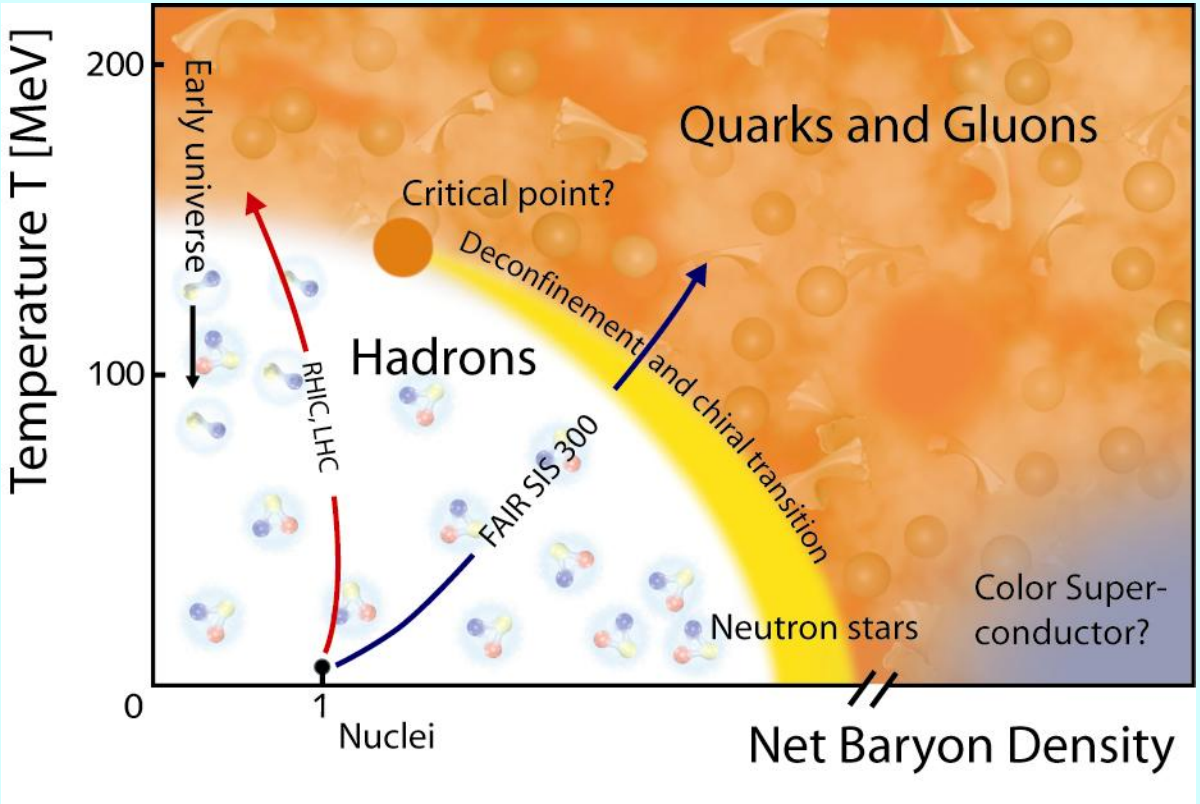
protons:
max: 90 GeV

ions:
max. 45 GeV
up to Z/A=0.5
(35 AGeV Au)

intensities:
up to 10^9 ions per second at CBM

The Landscape - schematically

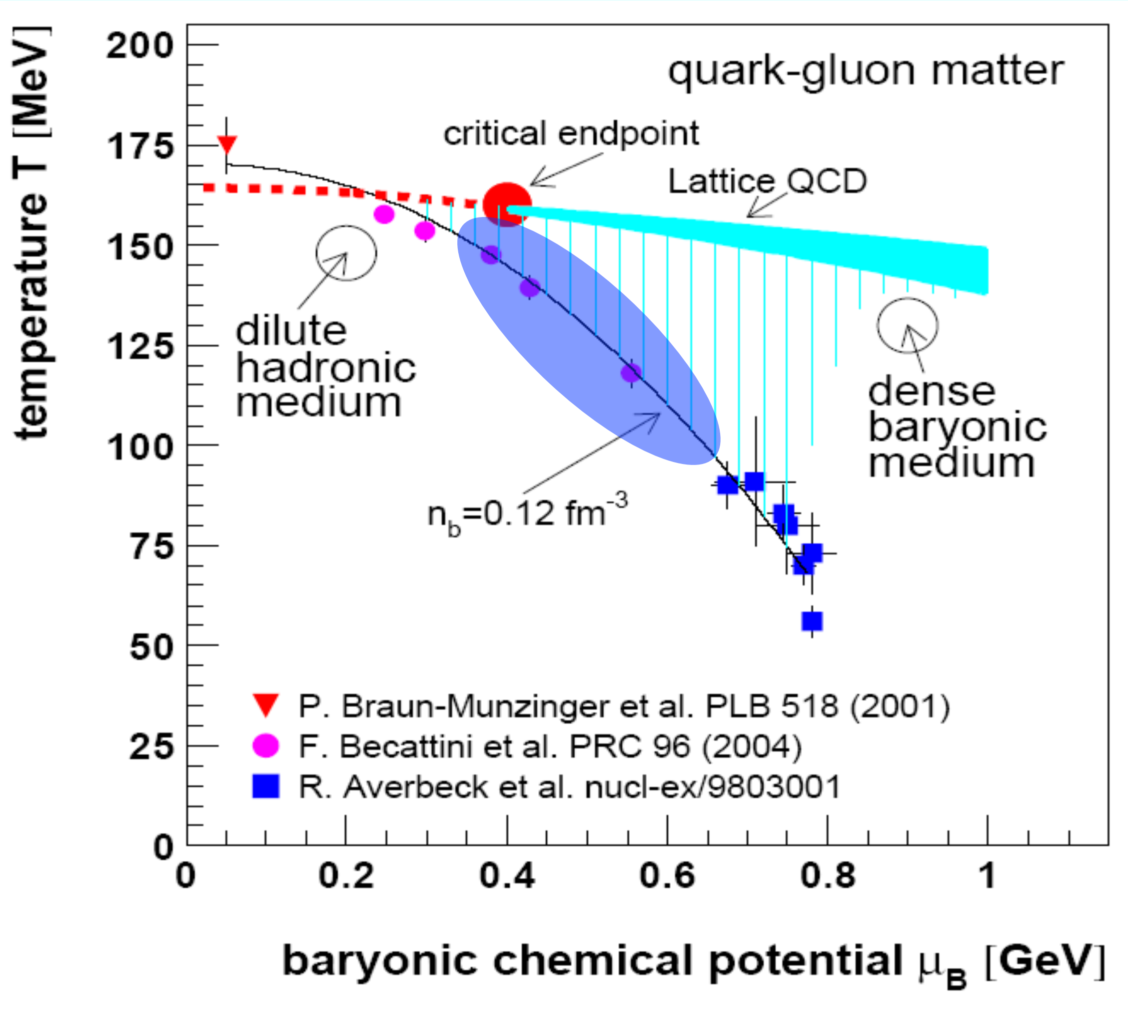
Phase diagram of strongly interacting matter



Features:

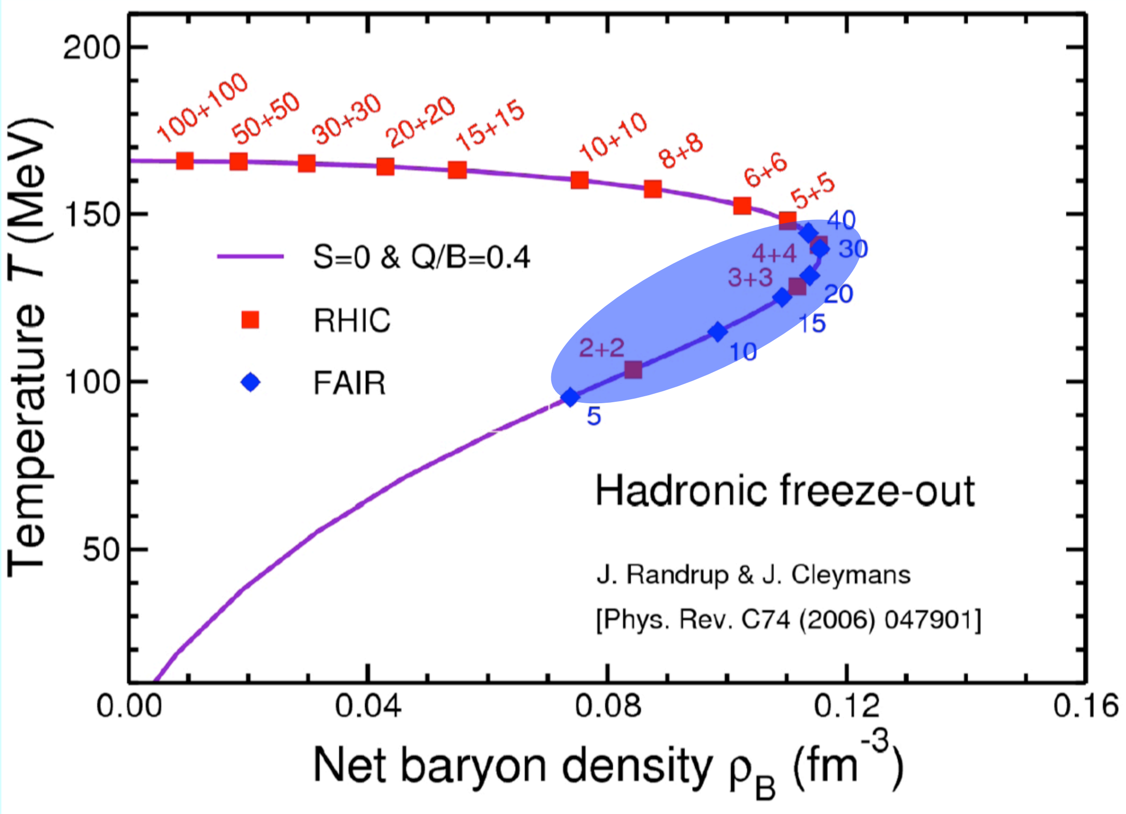
- Cross-over at small net-baryon densities
- First-order PT (deconfinement, chiral symmetry) at larger baryon densities
- Critical point
- Exotic phases

The Landscape - Experiment and Theory



- Freeze-out points lie on a smooth curve: different collision energies explore different region of the phase diagram
- lQCD:
  - extended to μ_B>0
  - large uncertainties in position of critical point
- small μ_B: freeze-out coincides with PT
- not true for large μ_B

Strongly interacting matter at highest densities



Maximal density for ≈ 30A GeV beam on target ($\sqrt{s_{NN}}$ ≈ 8 GeV)

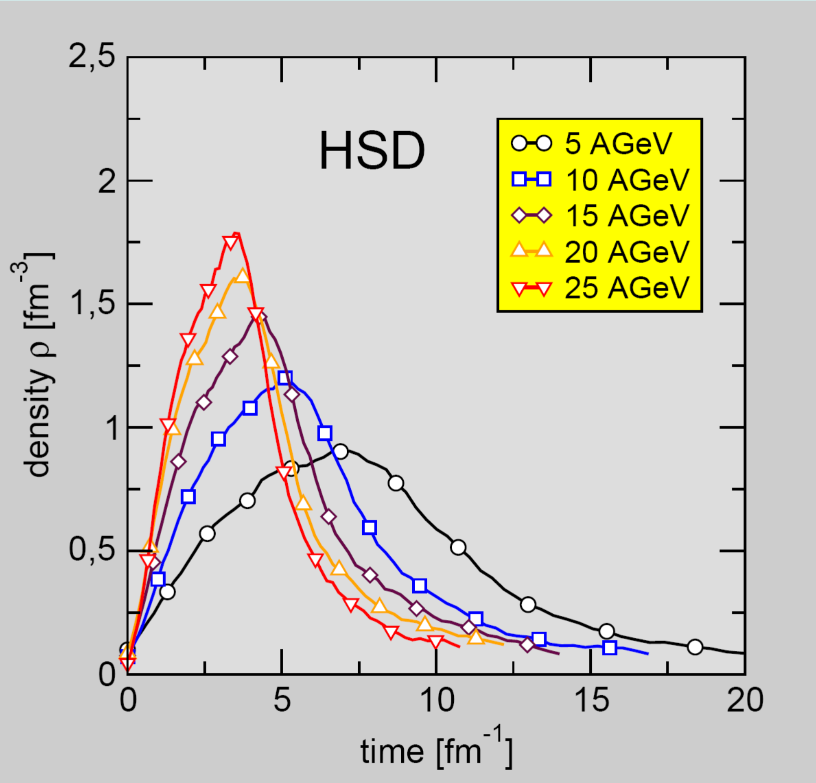
[caveat: excluded volume not included in calculation]

Basic questions

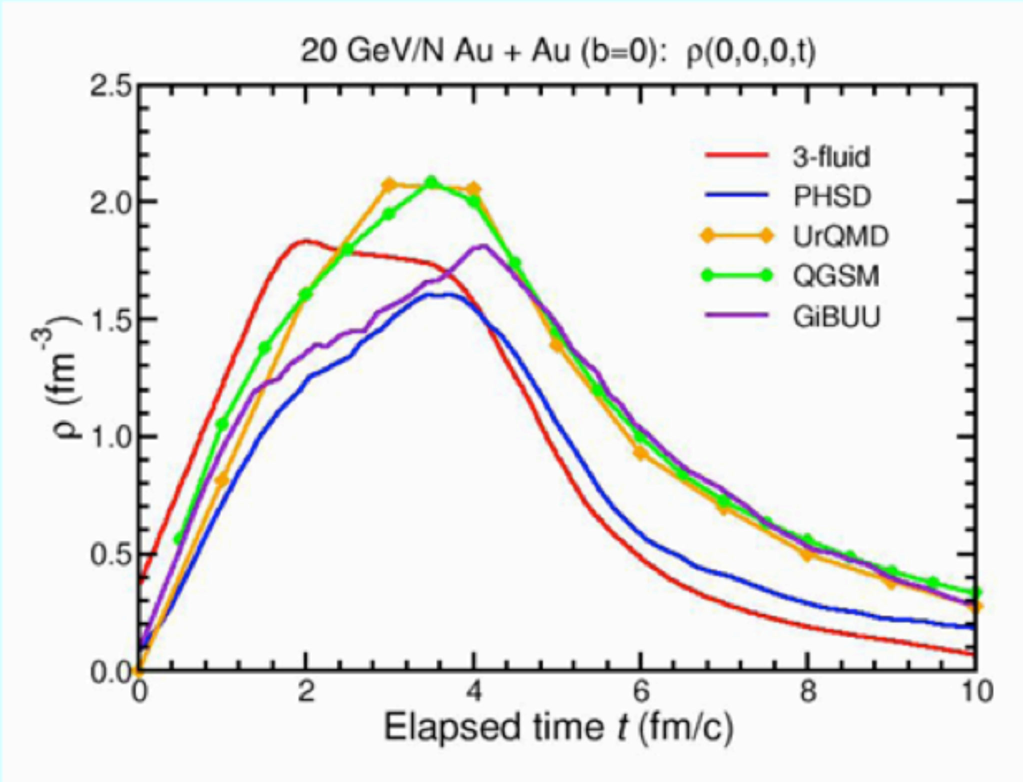
What is the equation of state at high net-baryon densities?
What are the properties of hadrons in a dense environment?
Where and of which type is the deconfinement phase transition?
Is there a critical point, and if yes, where?

The course of the collisions

E. Bratkovskaya, W. Cassing



from CBM Physics Book

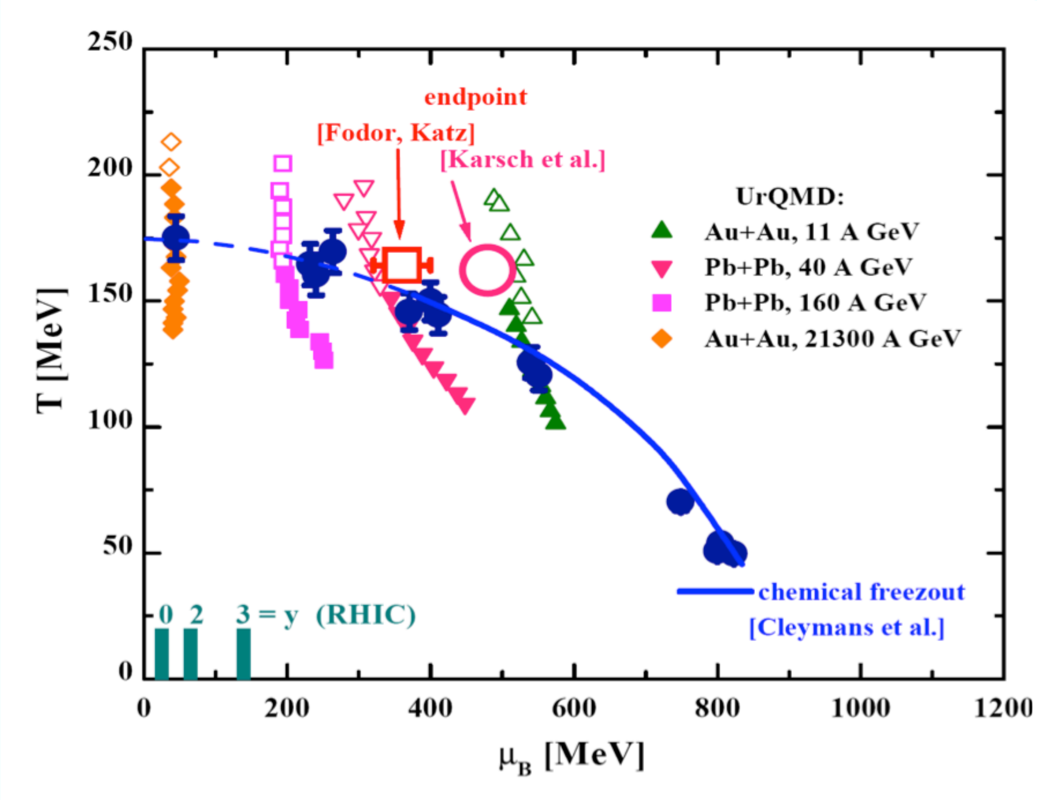


Transport models predict high densities for moderate collisions energies

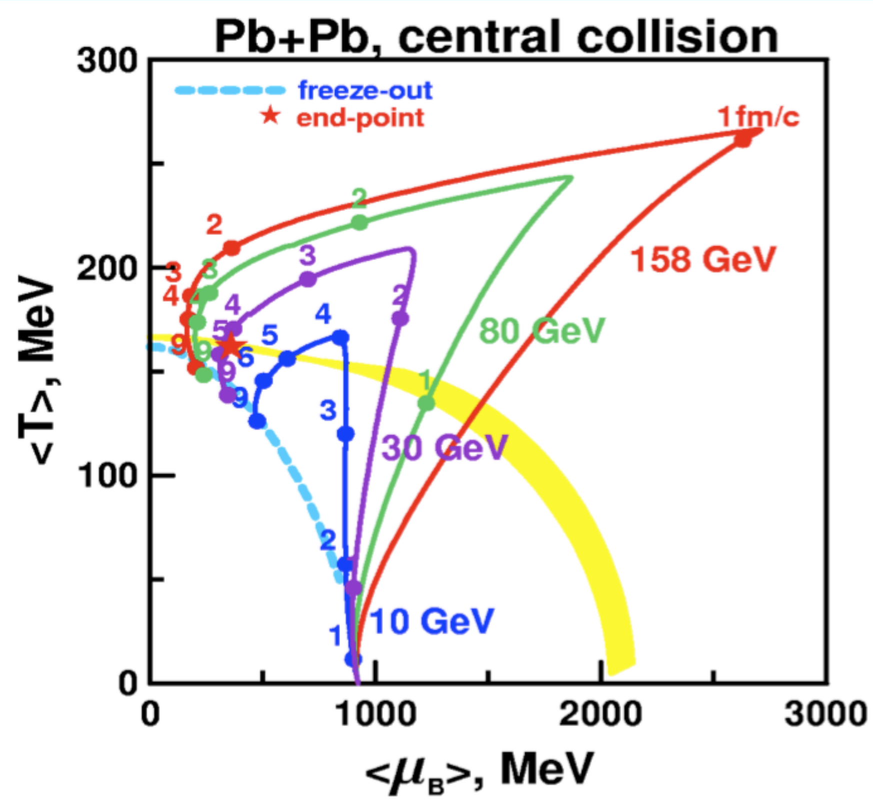
Different models agree qualitatively

Trajectories in the phase diagram

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

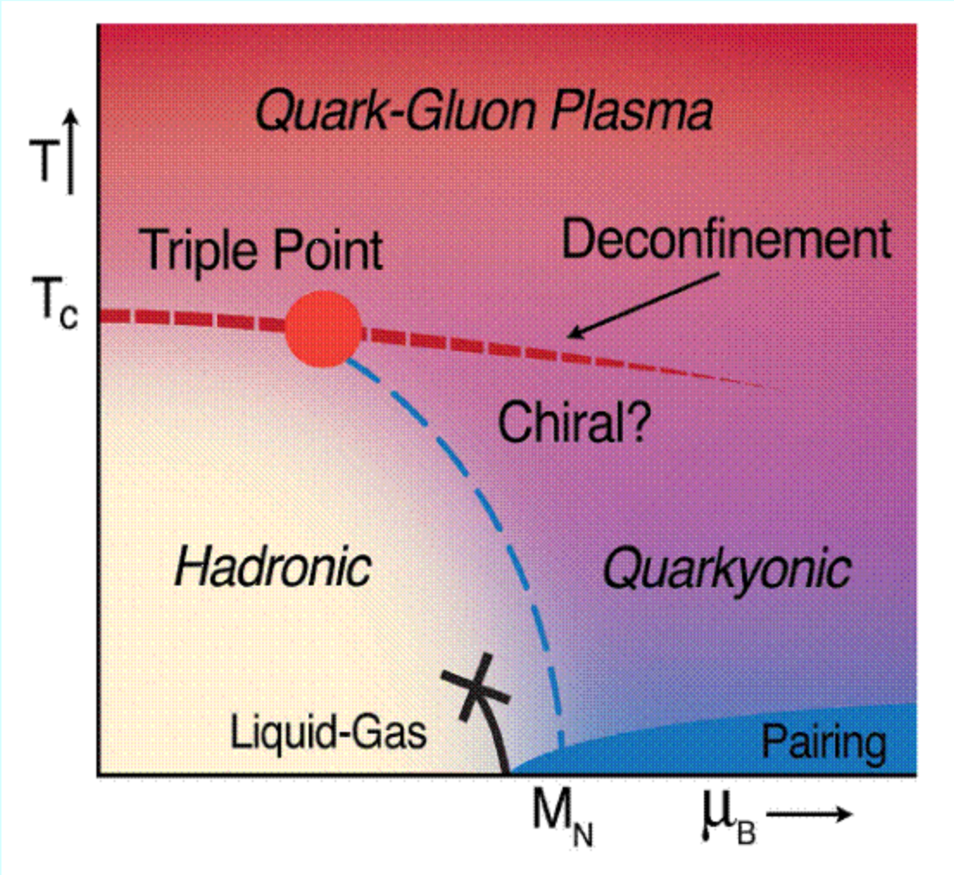


Y. Ivanov, V. Russkikh, V. Toneev,
Phys. Rev. C73 (2006) 044904



Nuclear collisions from 10 to 40 AGeV are the tools to look for the onset of deconfinement (and the critical point?)

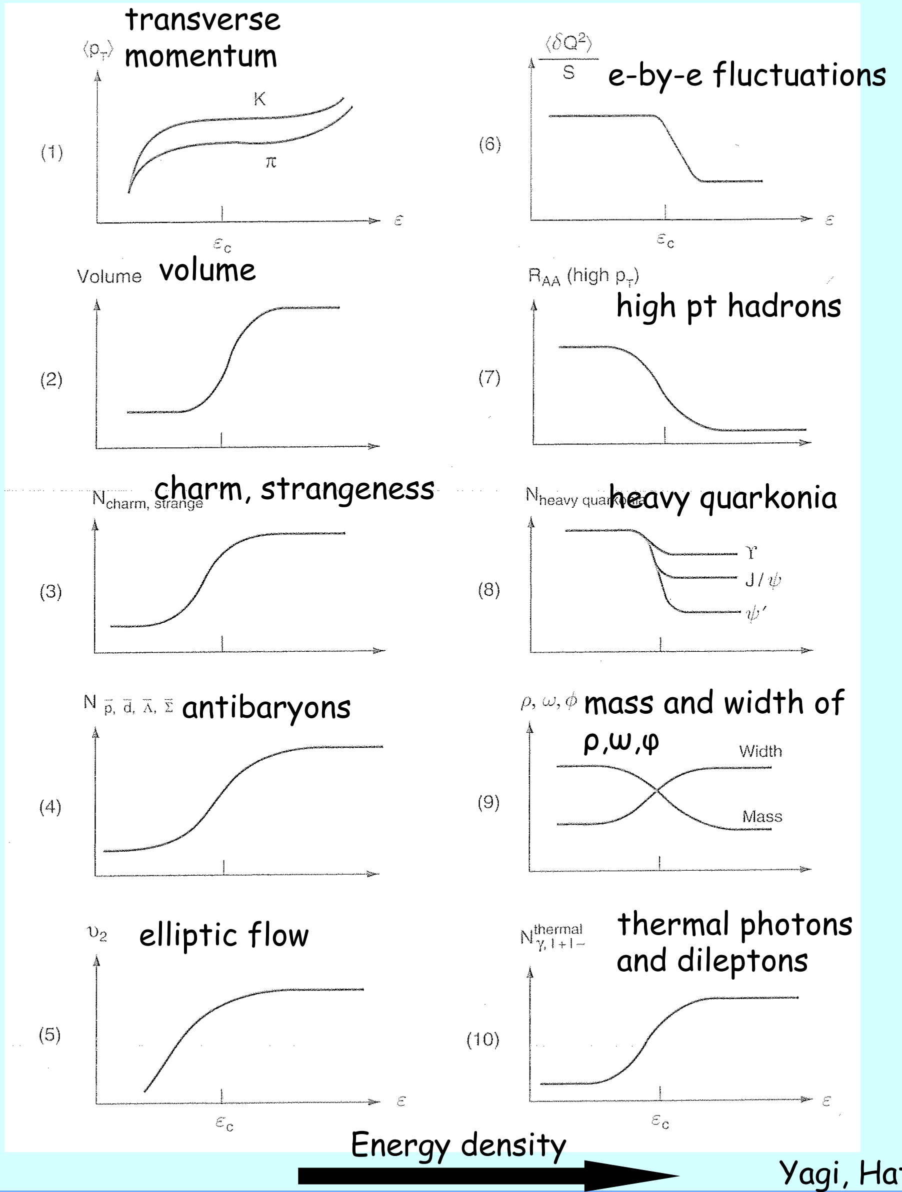
Mission and Programmes



- study of QCD matter at the highest net baryon densities achievable in the laboratory
- search for the 1st order phase transition from confined to deconfined matter
- search for restoration of chiral symmetry
- search for the critical endpoint of the QCD phase diagram

- RHIC BES: search for CP, collider, bulk observables
- SPS-NA61: search for CP, fixed target, bulk observables
- NICA-MPD: explore mixed phase, collider, bulk observables
- FAIR-CBM: scan phase diagram for PT and CP, fixed target, bulk and rare observables

The Strategy

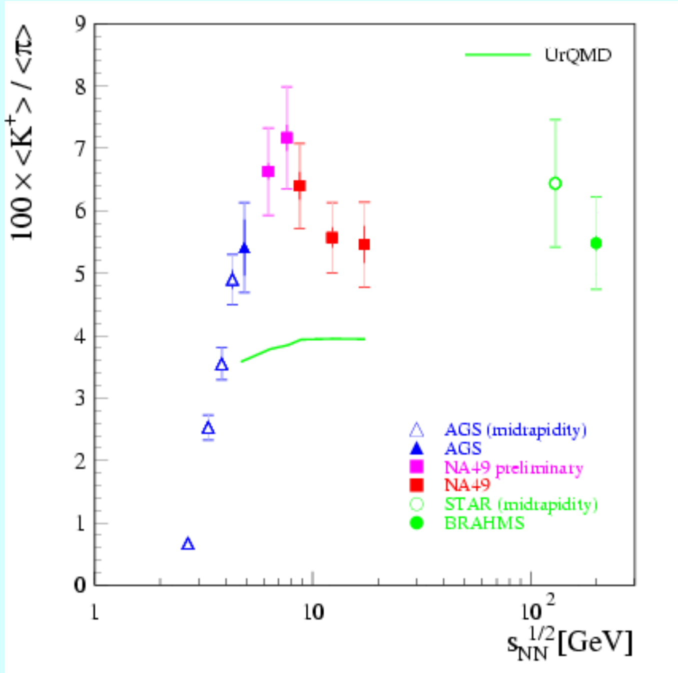


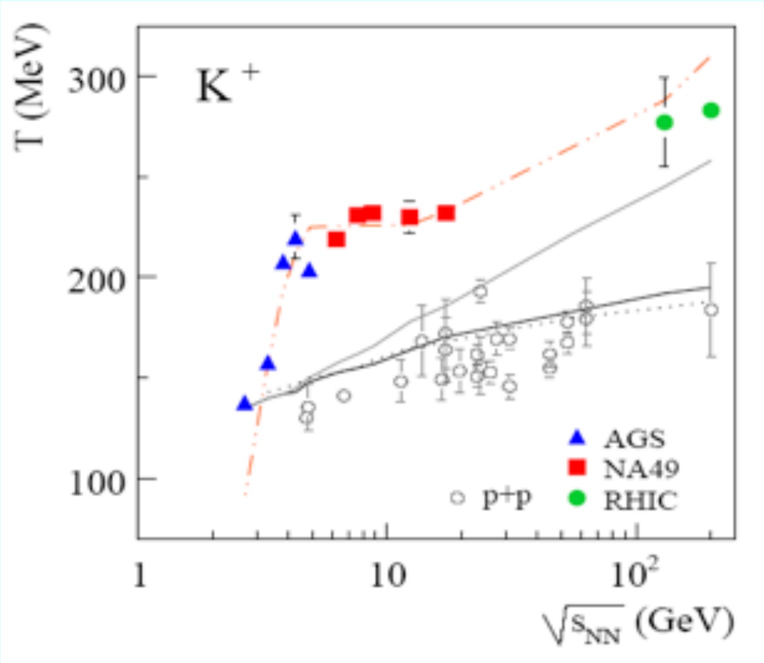
Yagi, Hatsuda, Miake: Quark-Gluon Plasma (2006)

- Phase transitions will show up in non-monotonic behaviour of observables as function of collision energy
- Measure excitation functions of yields, spectral shapes, flow, fluctuations, ...
- In particular: look for appearance / disappearance of QGP signals (large flow, quark-number scaling, high p_t suppression)

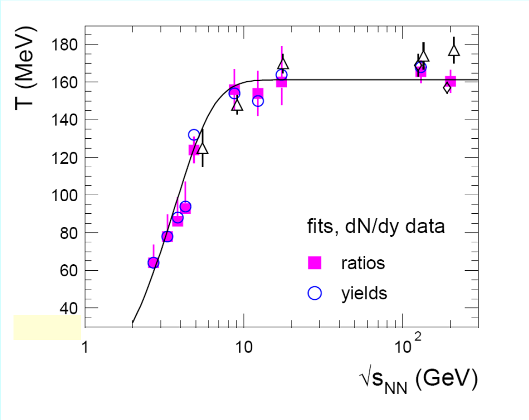
Some examples that we know already

NA49 data



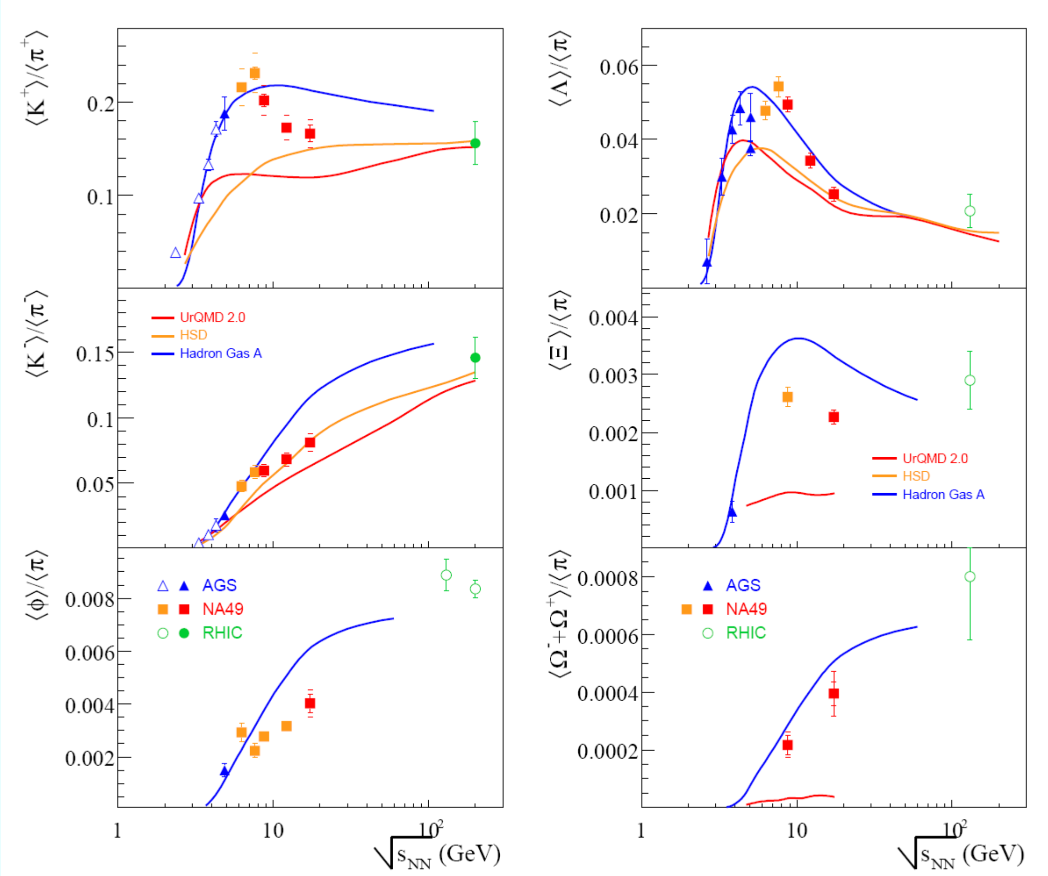


- „horn“: maximum in strangeness / non-strangeness
- „step“ in slope parameter / mean p_t
- much debated: described in statistical model?
- interesting energy range!



Observables: Strangeness

Compilation by C. Blume

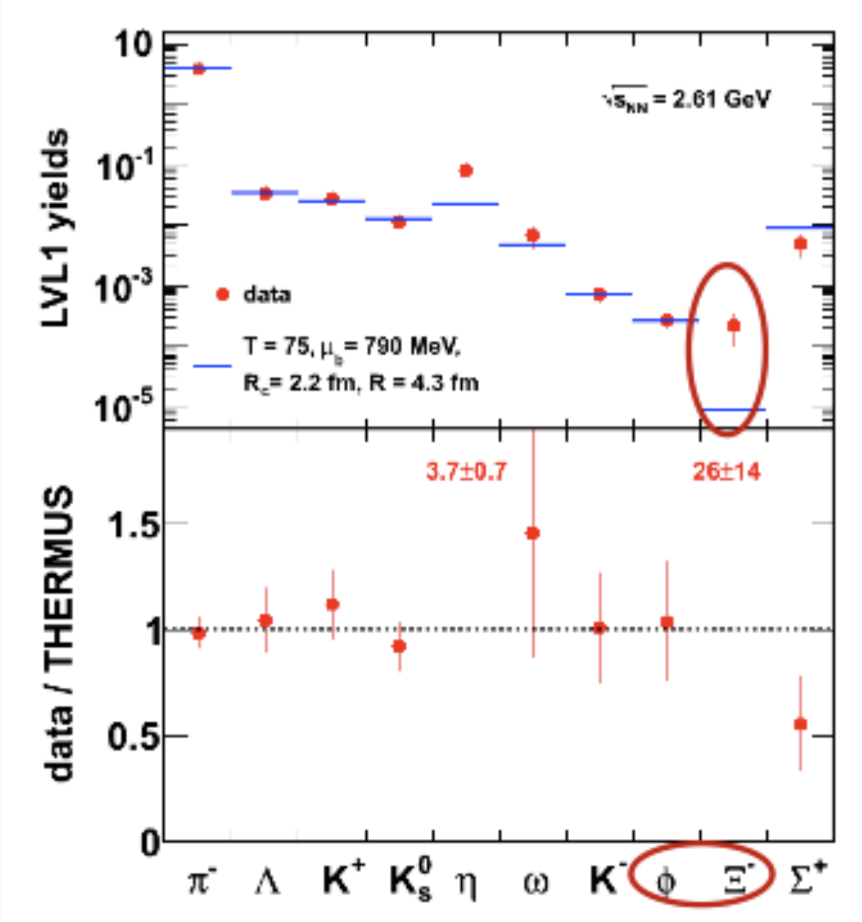


- originally thought sensitive to QGP
- but: reasonable description by statistical model (?)
- some features at lower SPS energies debated
- lack of precision measurements, in particular for multi-strange baryons

CBM: Complete characterisation of strangeness production, including flow, in 4π, also for multi-strange hyperons

Observables: Strangeness

A. Rustamov (HADES), CPOD 2010



- Is everything described by the statistical model, even at low energies?
- If yes: why? Is the transition from „quarkyonic" to hadronic the thermaliser?
- If no: what are the driving mechanisms?

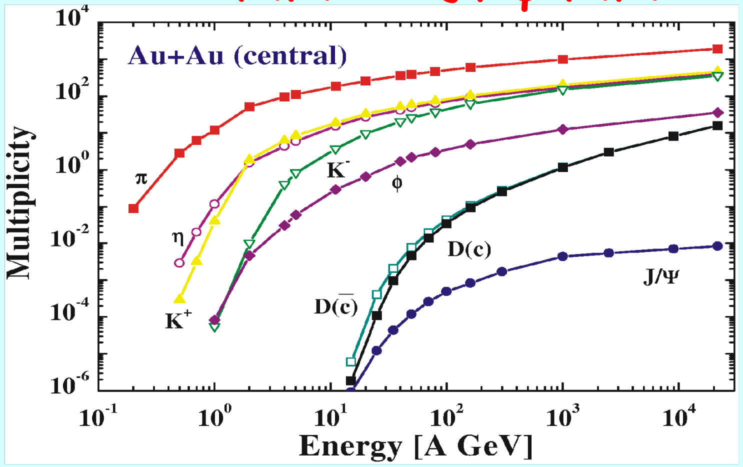
Observables: Open Charm

HSD

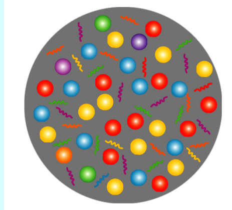
$NN \rightarrow D \Lambda_c N$

$NN \rightarrow D\bar{D} NN$

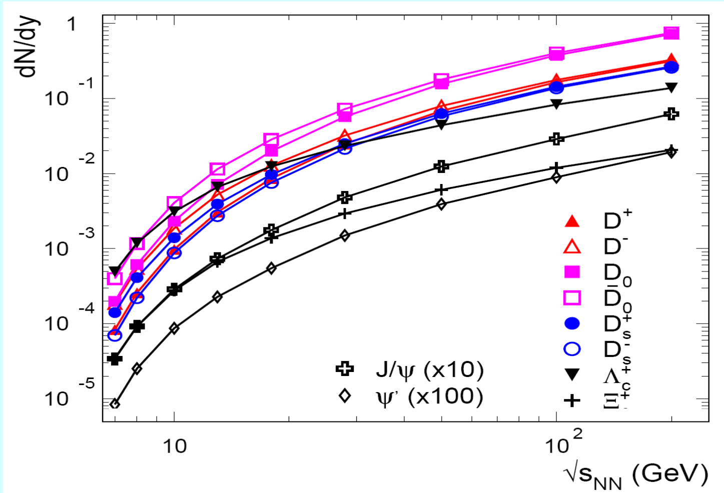
$NN \rightarrow J/\psi NN$



W. Cassing et al., Nucl. Phys. A 691 (2001) 753



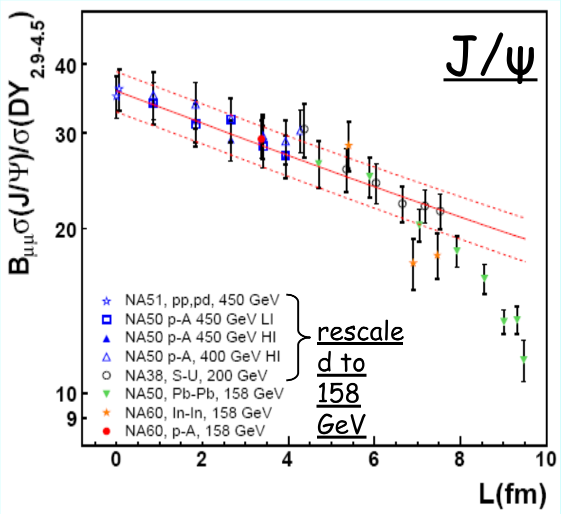
SHM

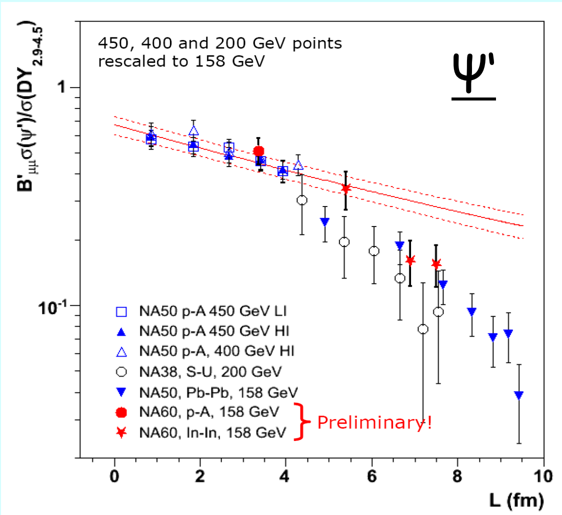


A. Andronic et al., arXiv:0708.1488

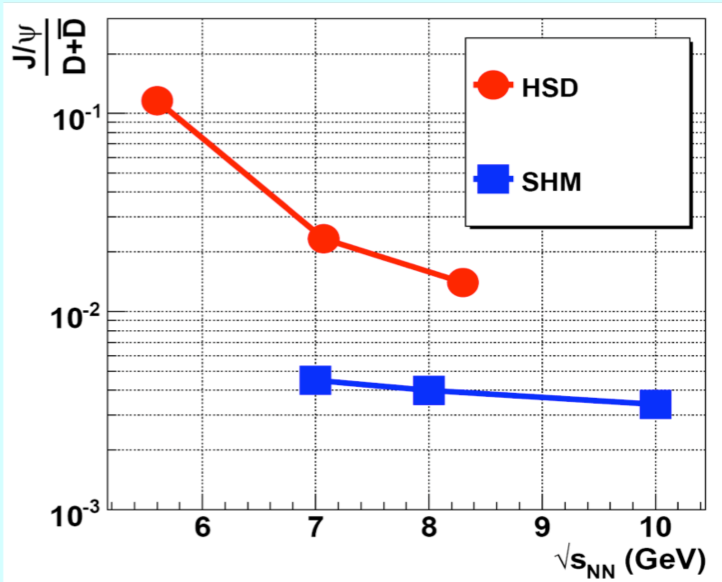
- charm is produced in first hard collisions: carries informations on all stages of the collision
- different predictions of open charm yield in hadronic (HSD) or partonic (pQCD + statistical hadronisation) pictures
- no measurements in heavy-ion collisions below RHIC energy (scarce data even in p+p)
- very rare probe at FAIR energies!

Observables: Charmonium

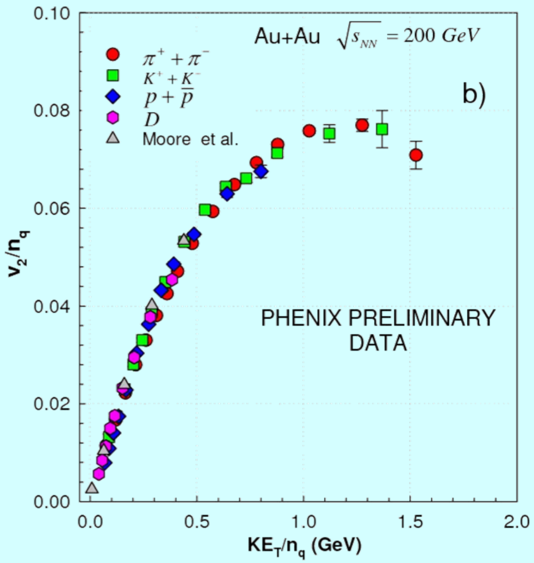




- (sequential) charmonium suppression predicted for QGP (Debye screening)
- observations by NA50/NA60 and PHENIX, but interpretation debated
- no measurements below top SPS energy
- ratio hidden / open charm very sensitive to charm production mechanism



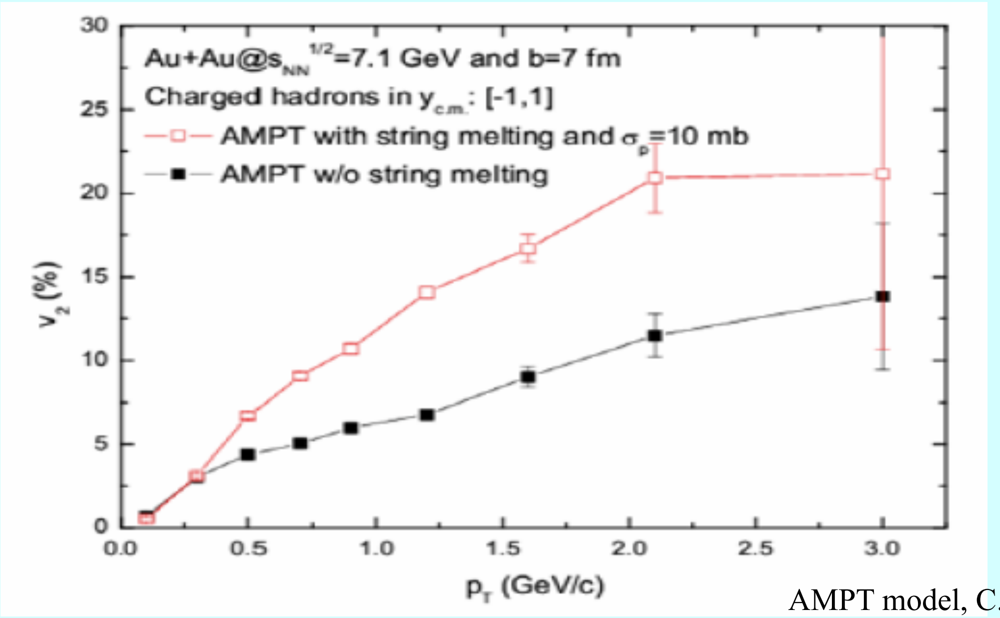
Observables: Elliptic flow

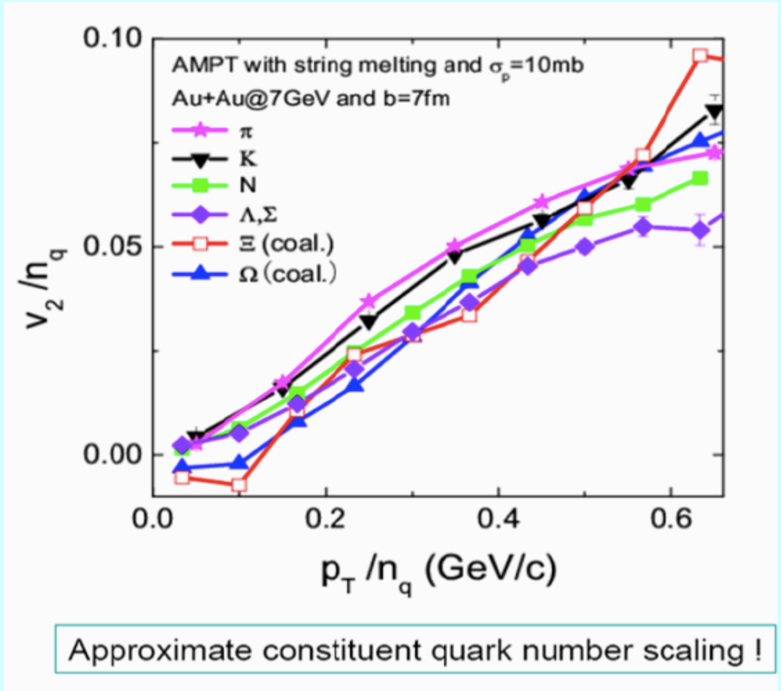


Lessons from RHIC: large flow, constituent quark number scaling indicates partonic origin

At CBM energies (AMPT): Partonic phase expected to show up in increased flow and quark number scaling

Onset of these phenomena? Flow excitation function!

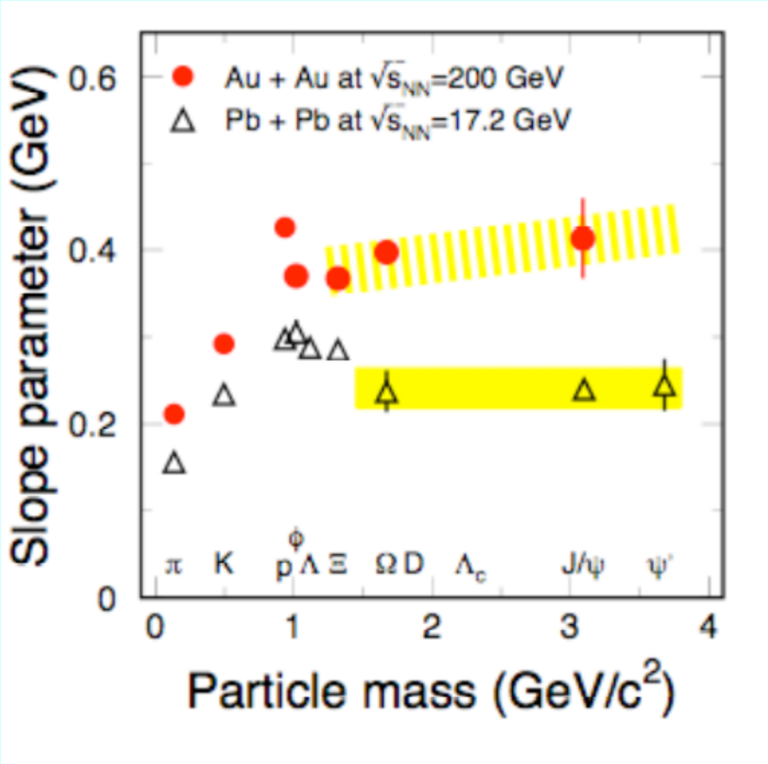




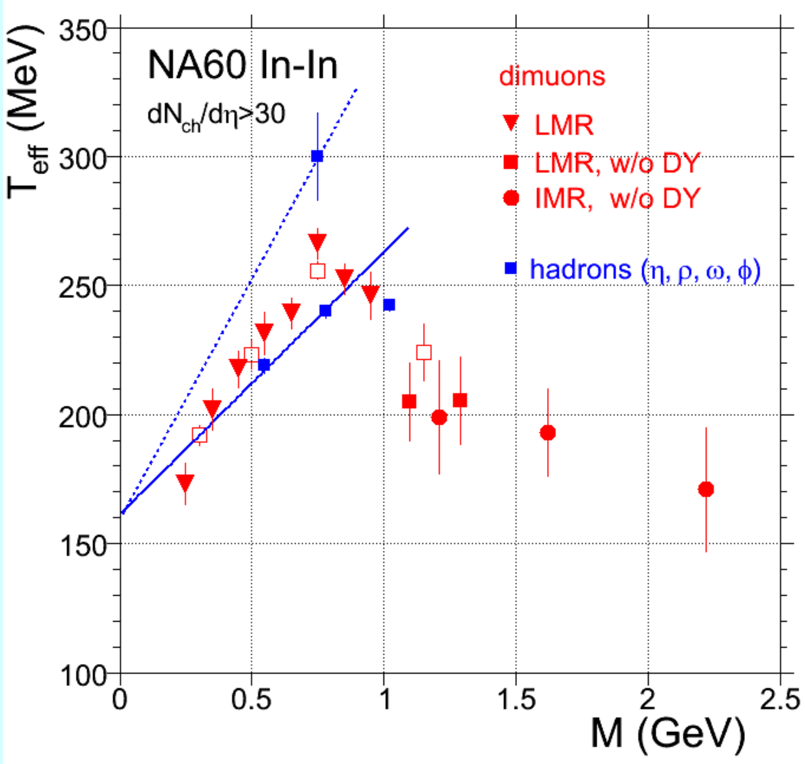
AMPT model, C. Ko et al.

Observables: Radial Flow

N. Xu, Int. J. Mod. Phys. E16 (2007) 715

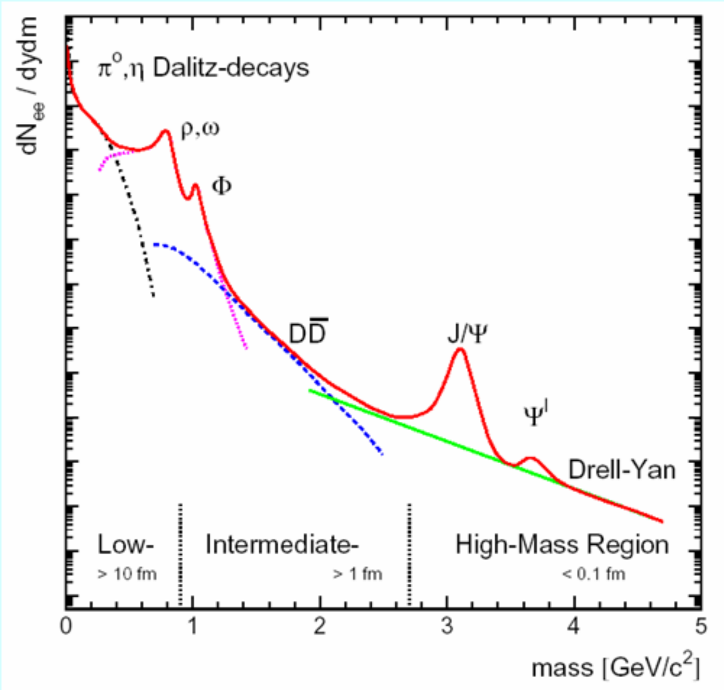


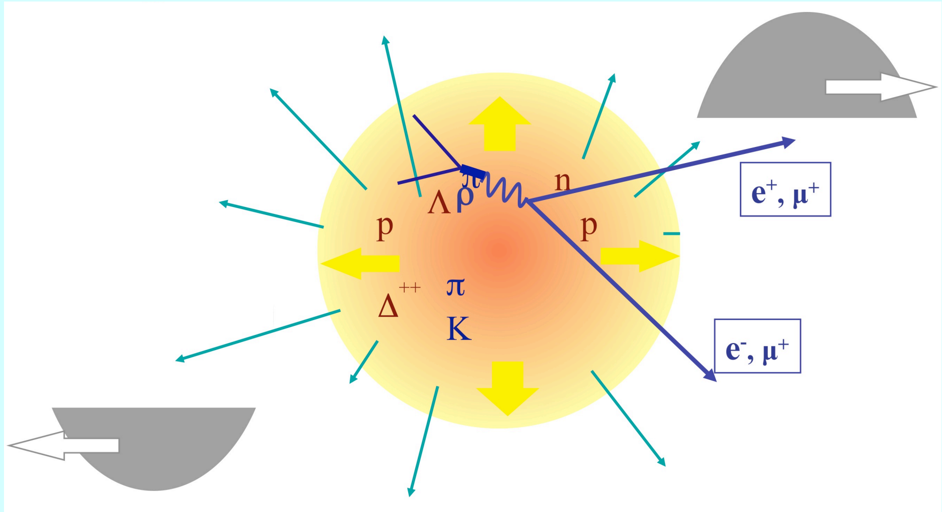
R. Arnaldi et al., (NA60), PRL 100 (2008) 022302



Do heavy particles participate in radial flow? If yes, explanation is that flow originates in partonic stage

Observables: Low-mass di-leptons





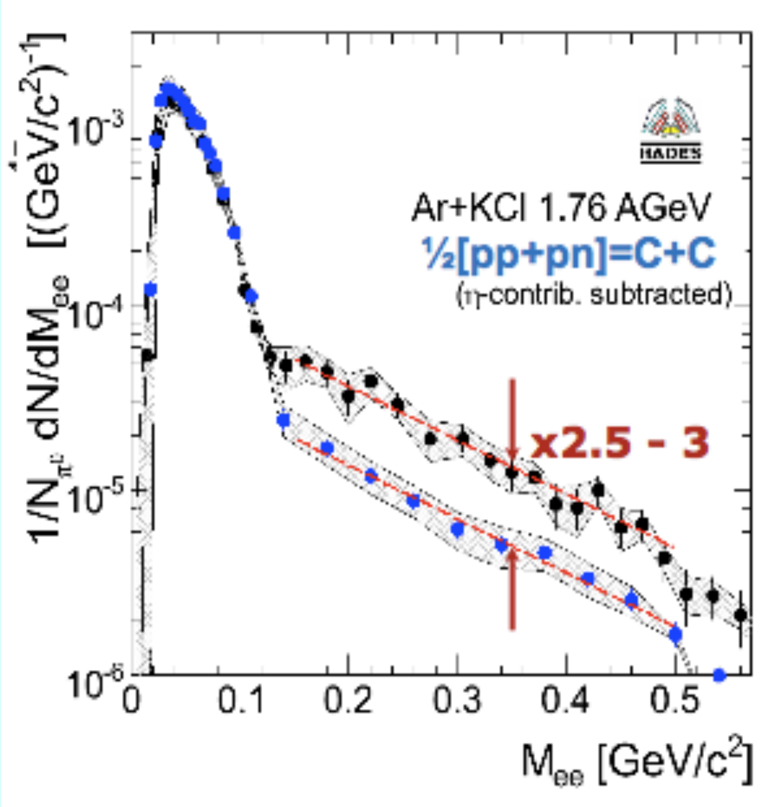
A penetrating probe:

low-mass vector vesons decaying inside the fireball into lepton pairs

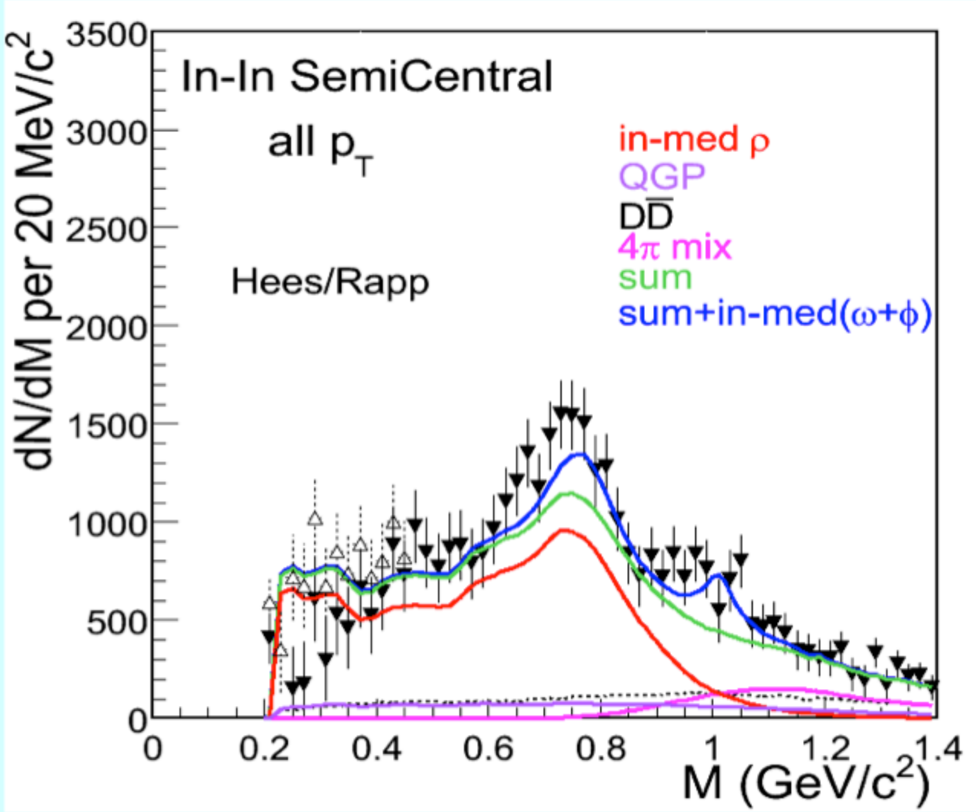
Access to in-medium properties of hadrons: chiral symmetry restoration

Observables: Low-mass di-leptons

A. Rustamov (HADES), CPOD 2010

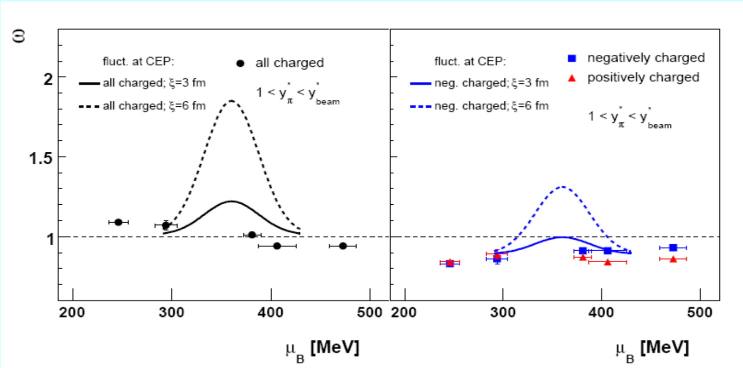


NA60, calc. by v. Hees / Rapp

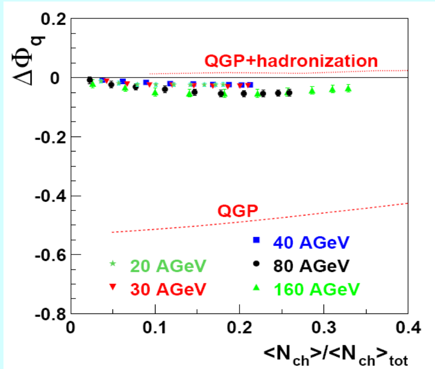


Do we understand the observed excess?
Can we observe an onset of chiral restoration?
We need data between 2 and 40 AGeV, and for heavy ions!

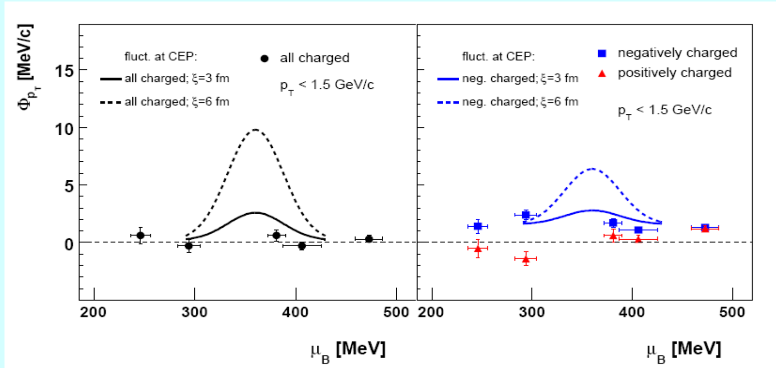
Observables: Fluctuations



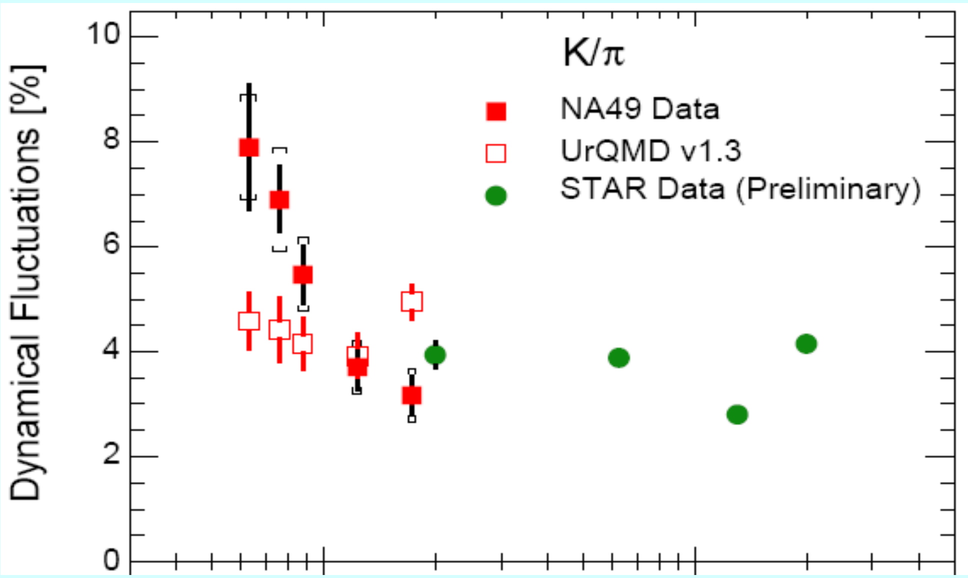
multiplicity



net charge



mean p_t



- results on multiplicity, net charge, mean p_t so far null or in line with hadronic transport
- deviation from transport seen in K/π
- finite volume / lifetime of fireball possibly suppresses fluctuations
- role of hadronic rescattering?

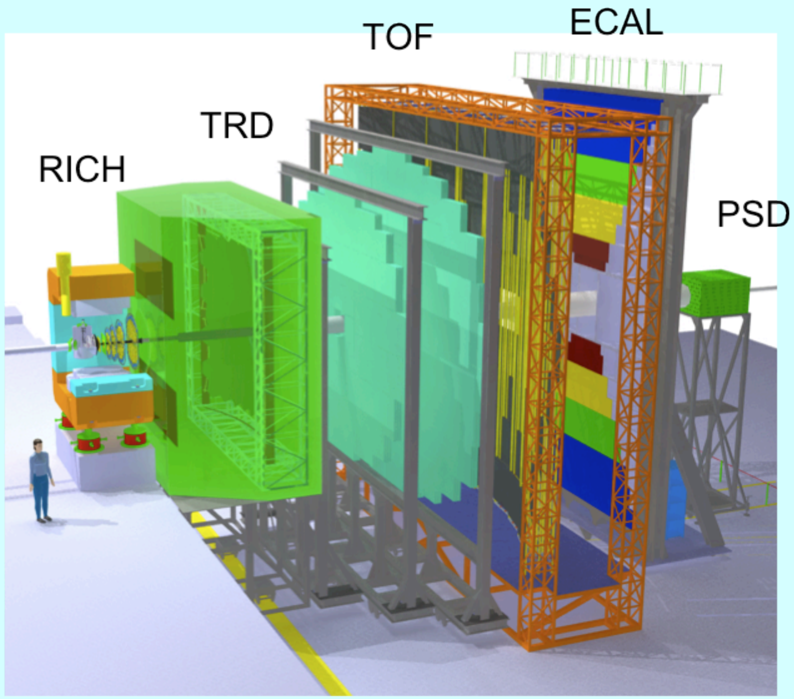
What do we need?

- Identification of hadrons: time of flight
- Identification of electrons: RICH, TRD
- Identification of muons: absorber system
- Measurement of neutrals: calorimeter
- Micro-vertex capabilities for open charm
- High rates for rare observables (charm, multi-strange hyperons)
- Large acceptance (forward rapidity, low and high pt coverage)

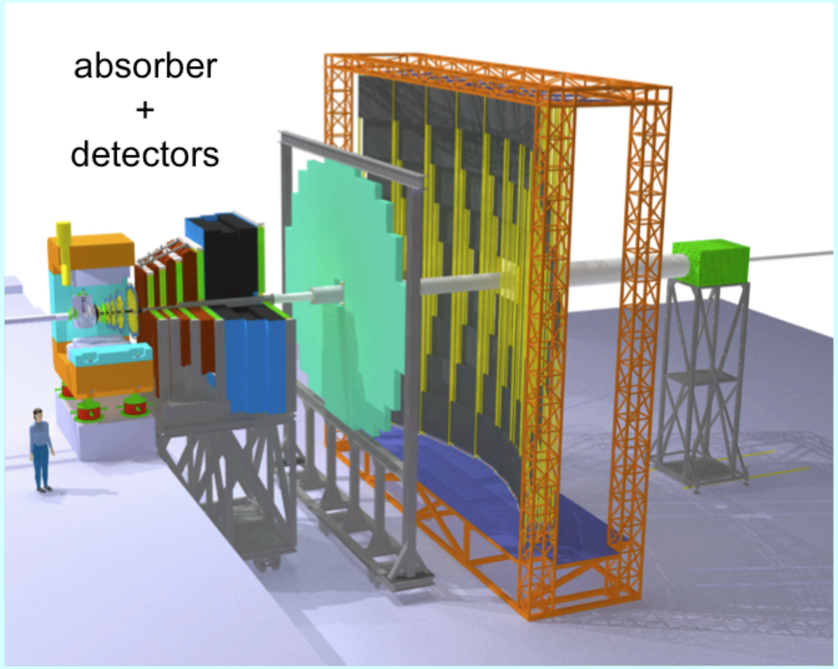
The challenge: heavy-ion reaction at rates up to 10 MHz!

The CBM Experiment

electron + hadron setup



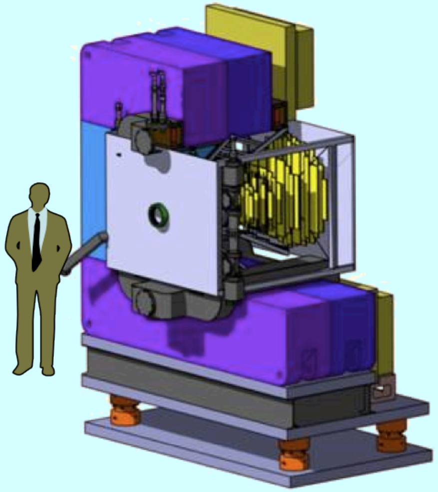
muon setup

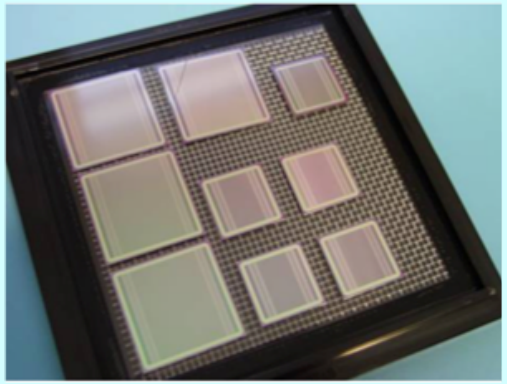


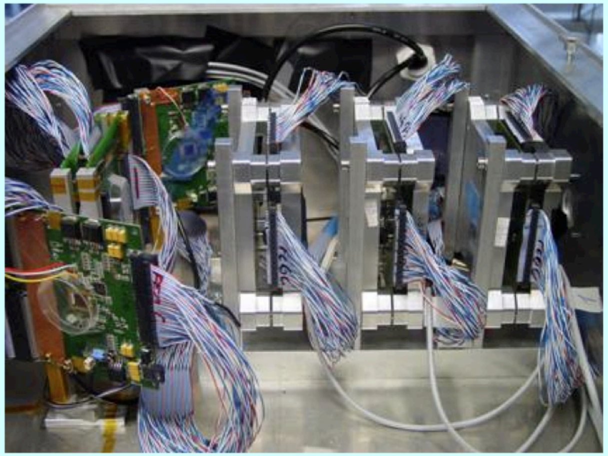
- Basic design consolidated
- Feasibility of the measurement of main observables shown
- Collaboration established (currently about 400 members)
- Activities now shifted to development of detectors: in most cases, no off-the-shelf solution possible (rate capability, speed, material budget, radiation tolerance)

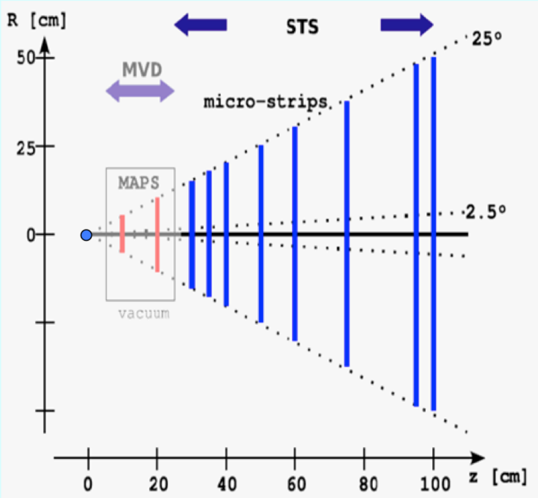
Silicon Tracking System

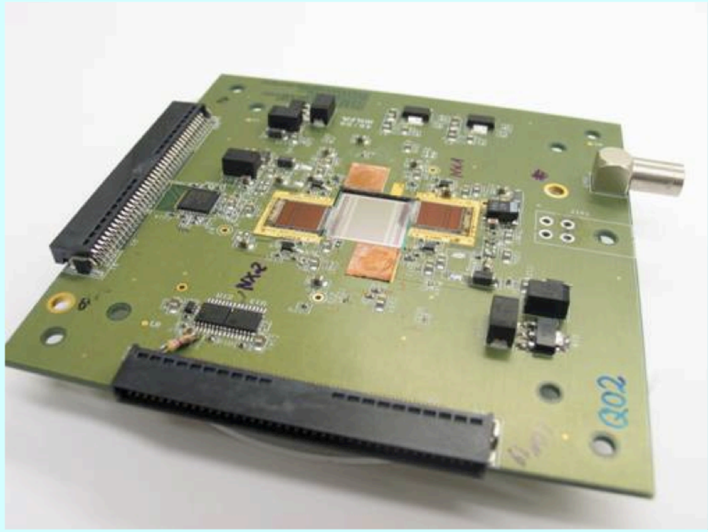
From first design to demonstrators, prototypes and beam tests
Challenge: Low mass, high rates, double-sided Si strip, r/o outside acceptance

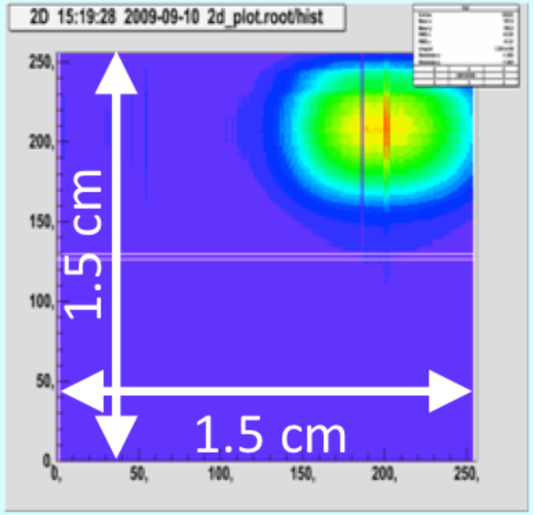






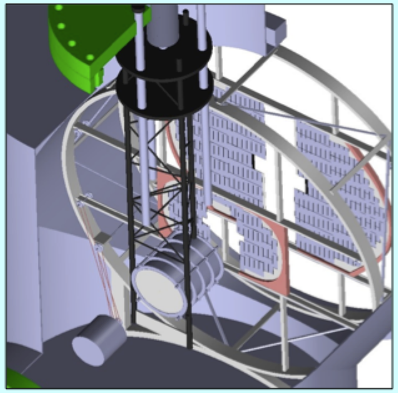


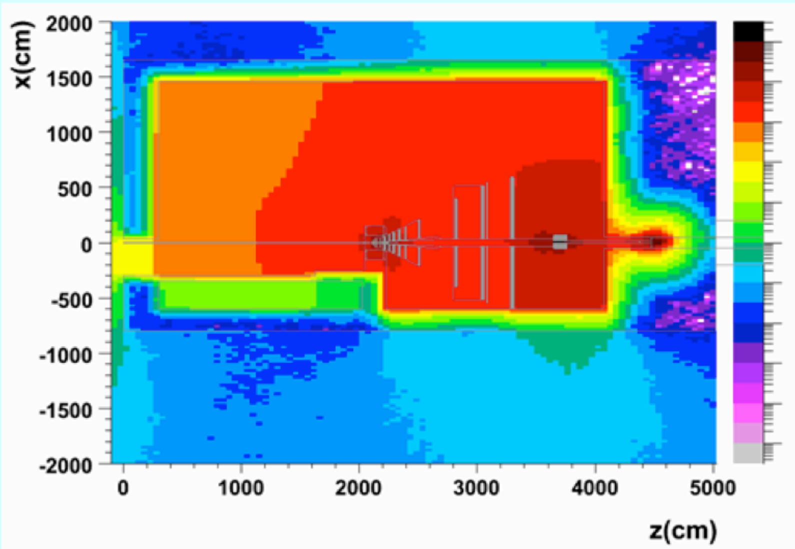




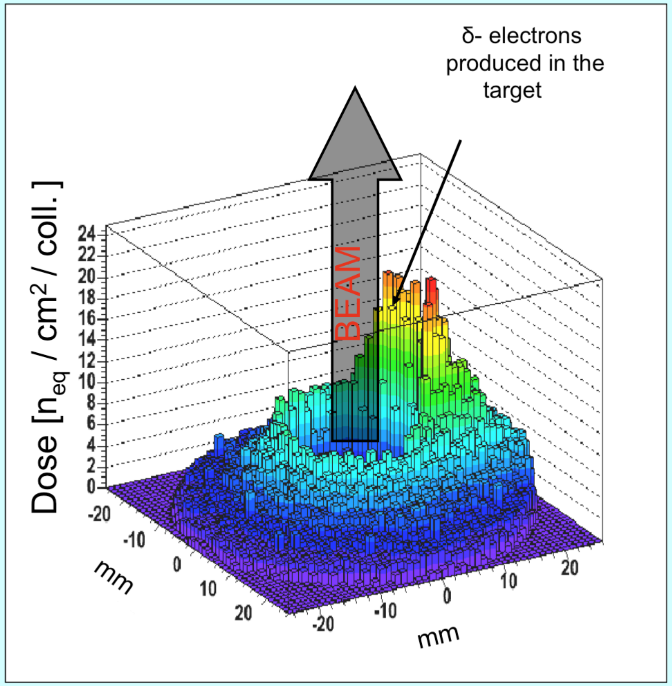
Micro Vertex Detector: The extreme challenge

- for open charm detection: very close to target; must be precise (low mass), fast (high rates) and stand the radiation environment

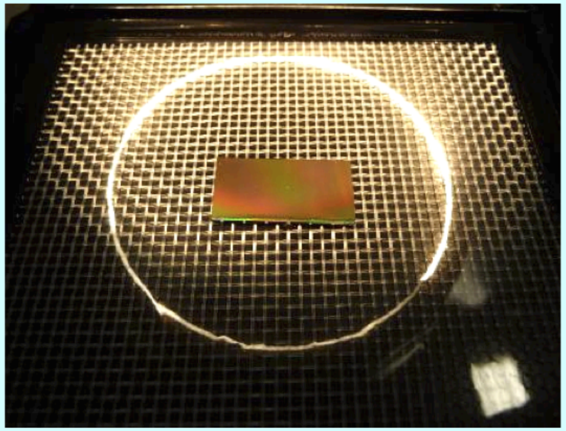


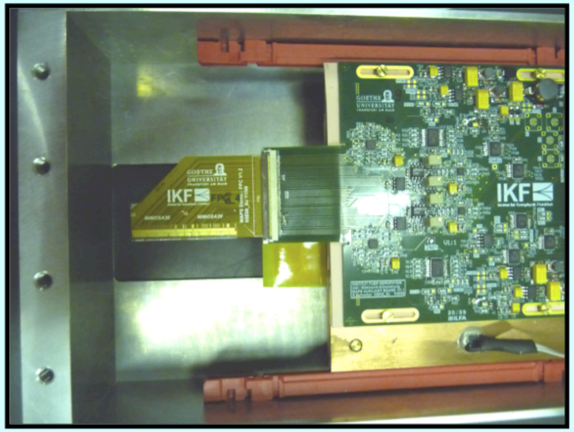


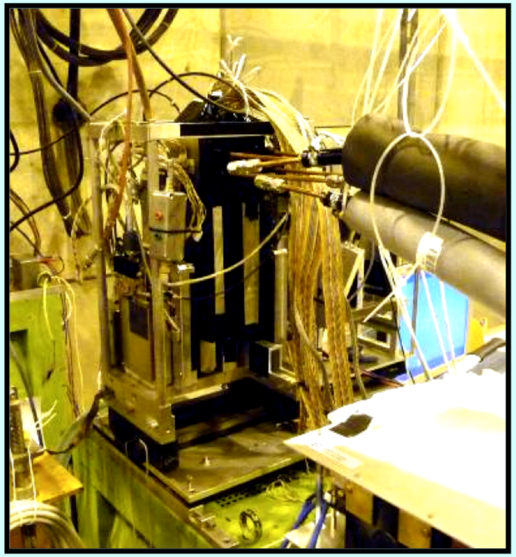
10^{13} - 10^{15} $n_{eq}/cm^2/year$



MVD: MAPS developments



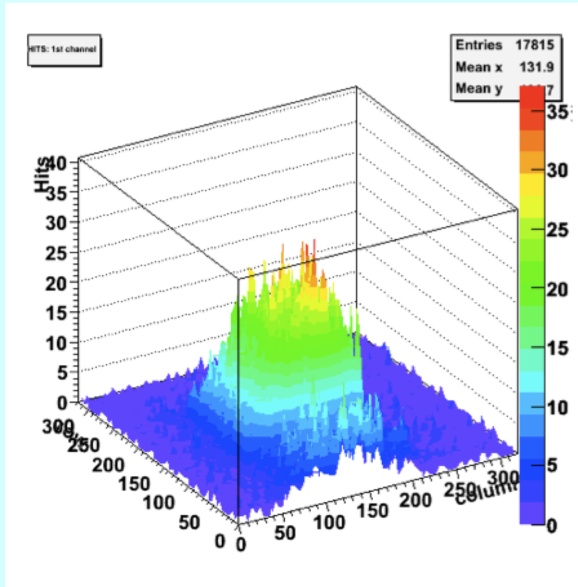




Monolithic Active Pixel Sensor:

- MimoSis 1 chip: 20 x 7.7mm^2
- pixels: 16 μm pitch
- rad tolerant: < $3\times10^{12} n_{eq}/cm^2$
- 0-suppressed readout in 40μs

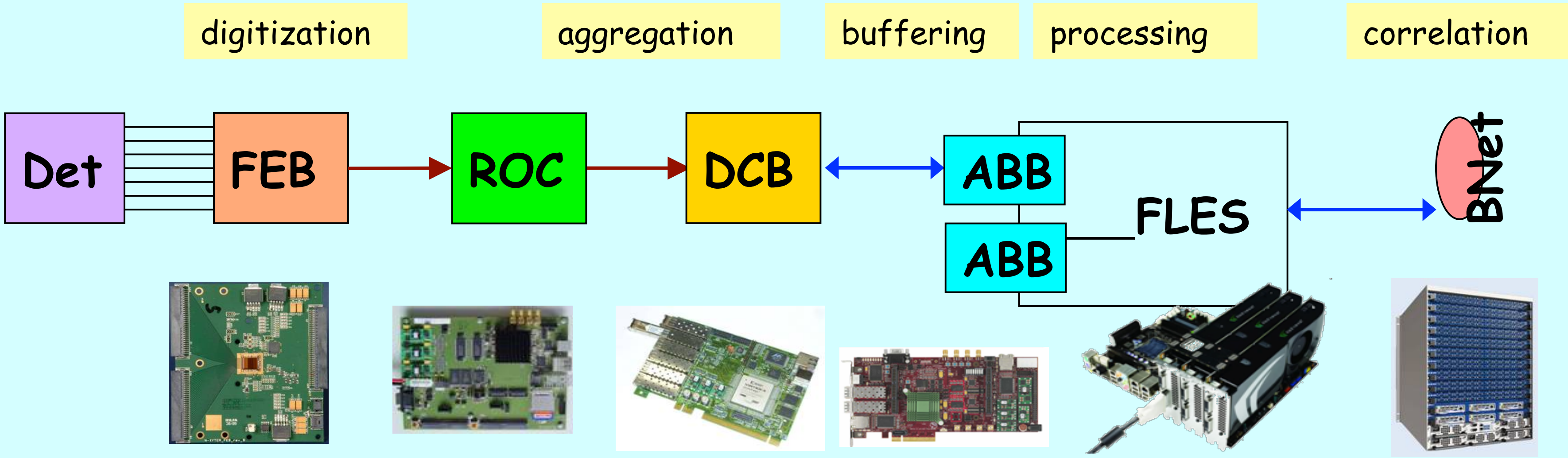
Chip thinned to 50 μm
Module: $\Rightarrow$ 0.3 % X_0



Huge improvement in r/o spead and rad. tolerance
Now close to specifications
First demonstrator successfully operated in beam

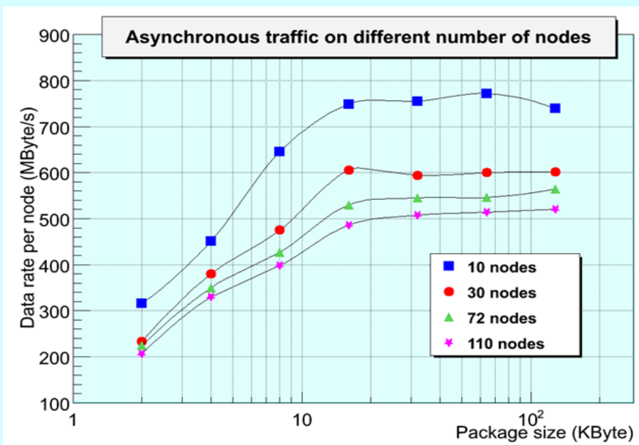
DAQ: a new paradigm

R&D challenge: High speed data transport and event building (1 TB/s)

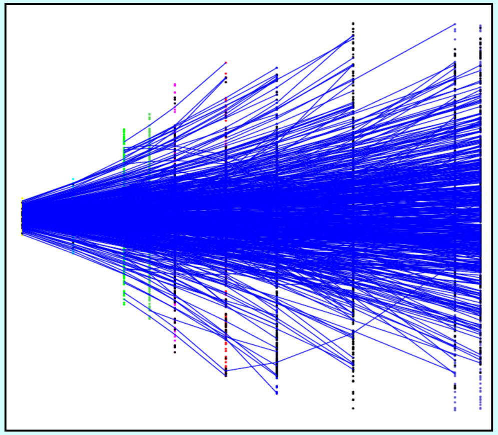


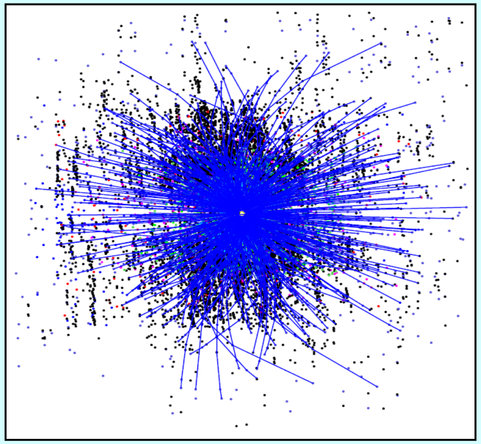
Ship 1 TB/s from front-ends
No conventional trigger: self-triggered FEE
Event association, (partial) reconstruction and selection in FLES

DAQ chain components developed and tested in-beam; operation successful



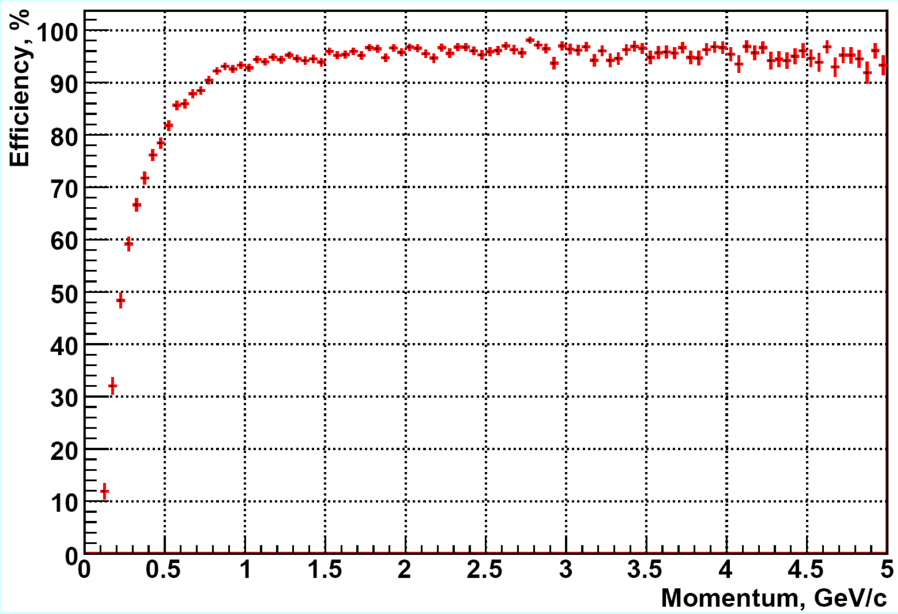
STS track reconstruction: Cellular Automaton



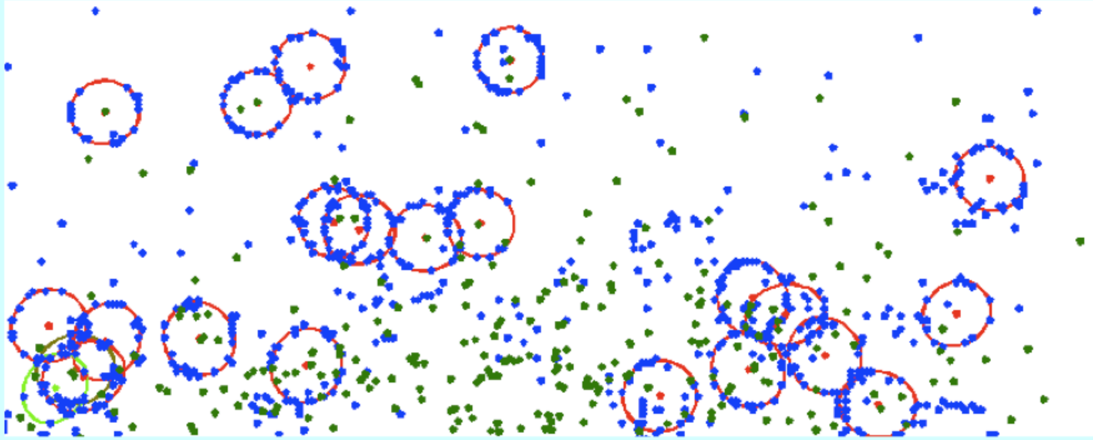


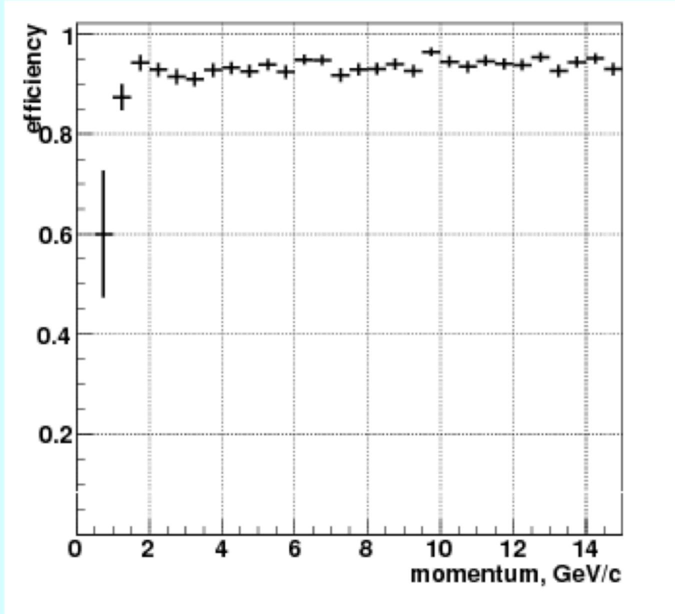
UrQMD, central Au+Au @ 25 AGeV

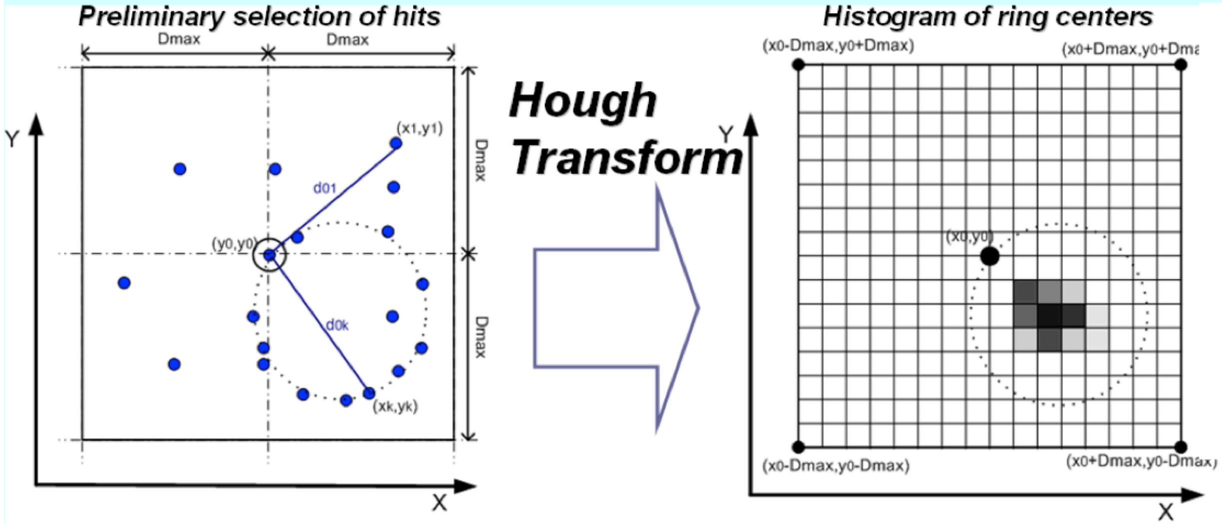
Track category	**Efficiency, %**
Reference set (>1 GeV/c)	95.2
All set (≥4 hits,>100 MeV/c)	89.8
Extra set (<1 GeV/c)	78.6
Clone	2.8
Ghost	6.6
MC tracks/ev found	672
Speed, s/ev	0.8

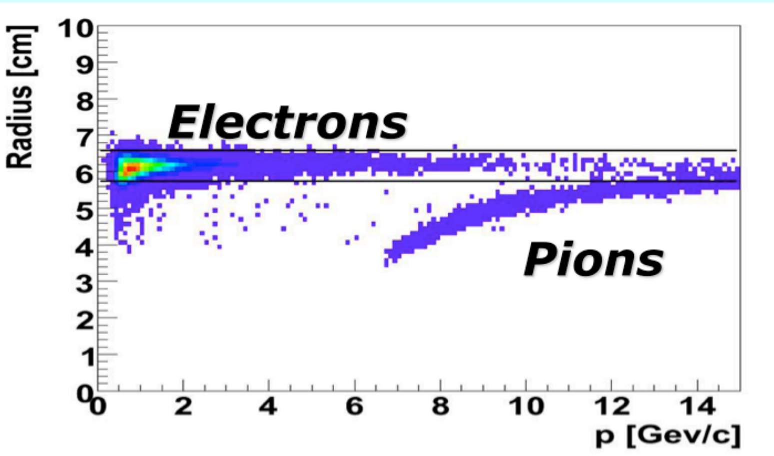


Reconstruction: RICH





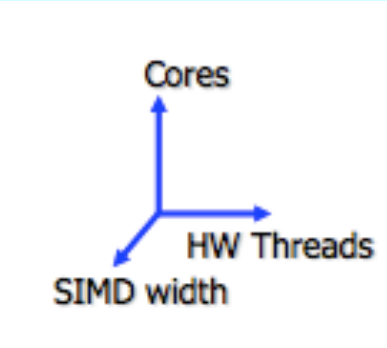




CBM: Running modes

- Untriggered: ≈ 10^4 events/s, 1 GB/s from FEE, 1 GB/s to archiv
  - pion, kaon, proton, hyperon yields, spectra and flow
  - low-mass dielectrons
- Medium rate: 10^5 – 10^6 events/s, < 100 GB/s from FEE, 1 GB/s to archiv
  - low-mass dimuons
  - open charm (limited by MAPS)
  - online event reduction 10 - 100
- High rate: 10^7 events/s, 1 TB/s from FEE, 1 GB/s to archiv
  - charmonium (electron or muon channel)
  - online event reduction 10^3

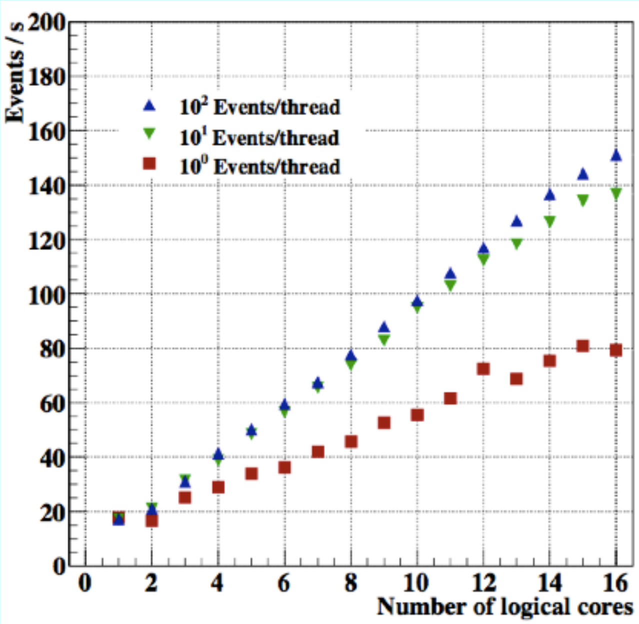
The challenge: fast online reconstruction



Make use of modern computer architectures:

- vector processing
- multithreading
- many core

CA track finder

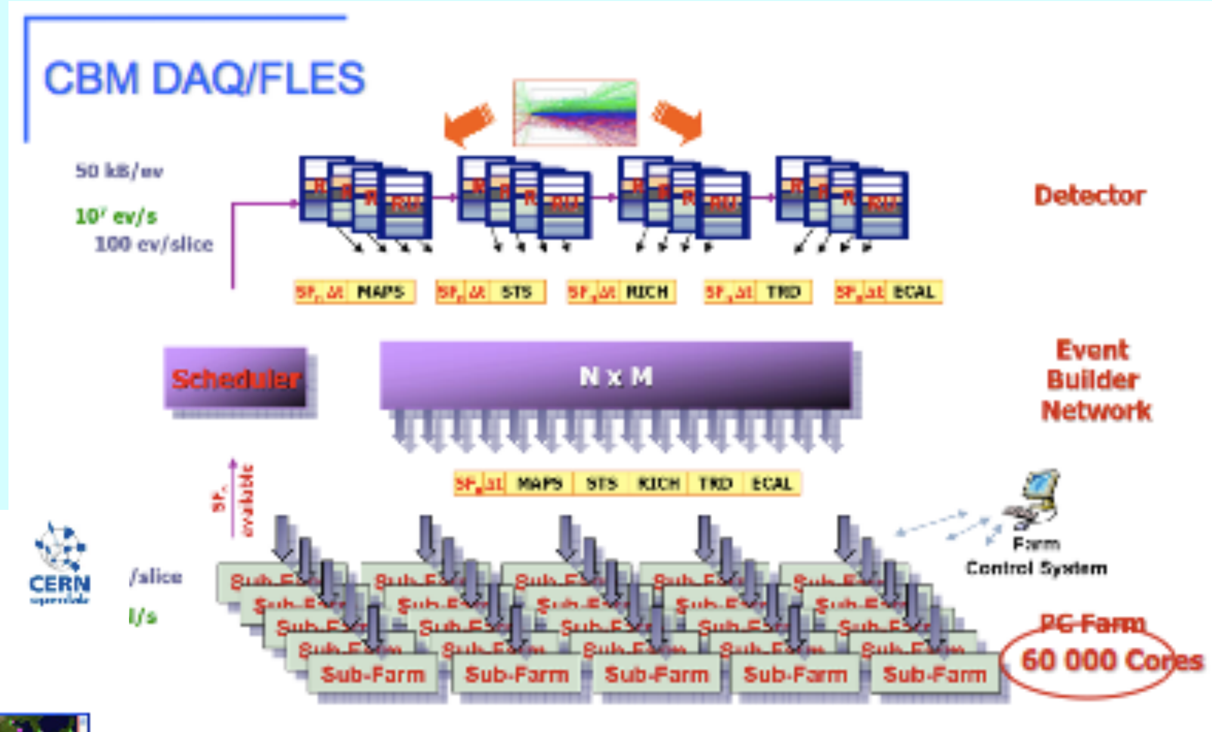


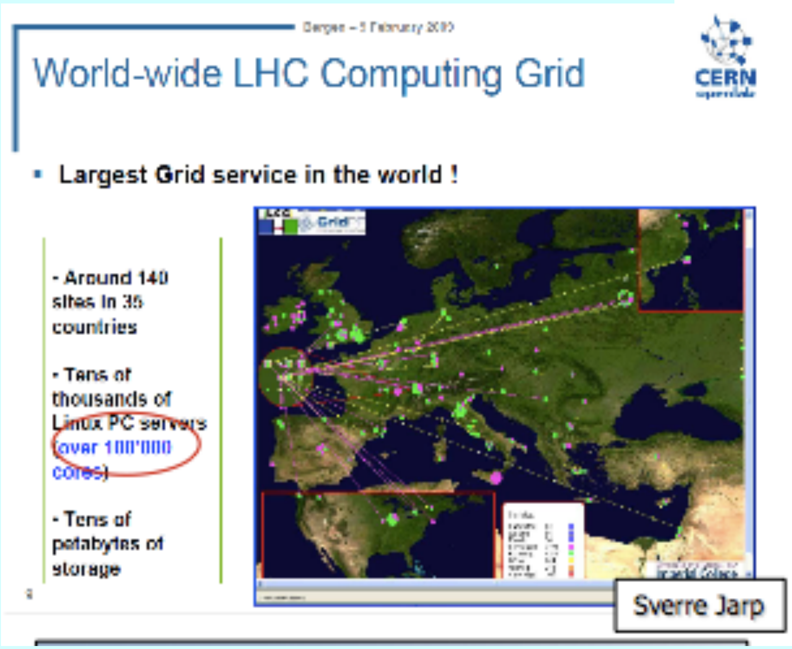
KF track fitter

	Stage	Description	Time/track	Speedup
		Initial scalar version	12 ms	–
Intel P4	1	Approximation of the magnetic field	240 μs	50
Intel P4	2	Optimization of the algorithm	7.2 μs	35
Intel P4	3	Vectorization	1.6 μs	4.5
Cell	4	Porting to SPE	1.1 μs	1.5
Cell	5	Parallelization on 16 SPEs	0.1 μs	10
		Final simdized version	0.1 μs	120000

Similar activities ongoing for RICH, TRD and MUCH reco

FLES farm: estimates and ideas



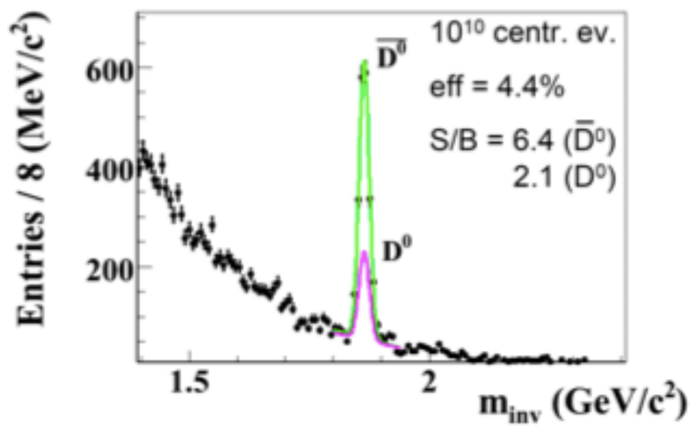


Online processing on/near experiment at GSI (new HPC centre)

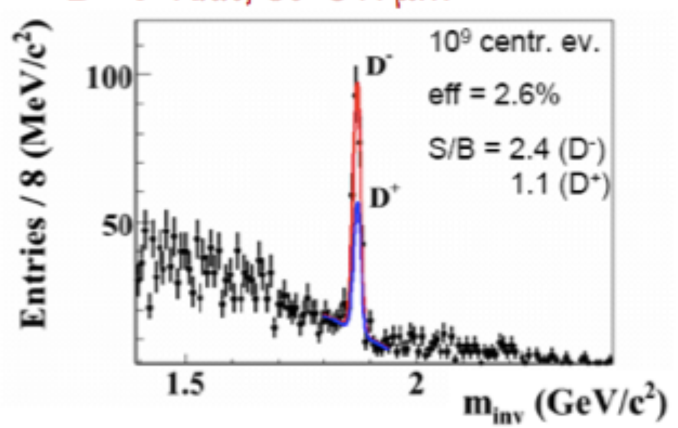
Performance (Au+Au, 25 AGeV)

open charm

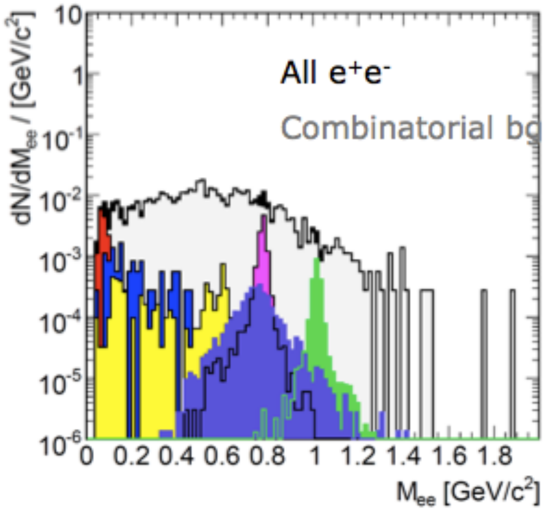
$D^0 \rightarrow K\pi$, $c\tau$=123μm



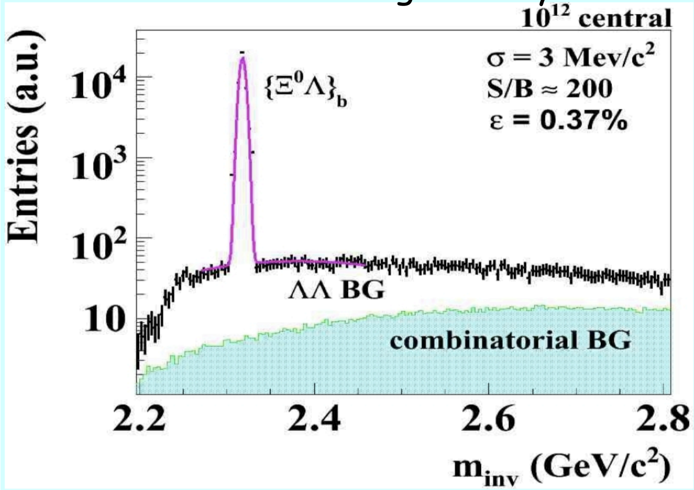
$D^{\pm} \rightarrow K\pi\pi$, $c\tau$=317μm



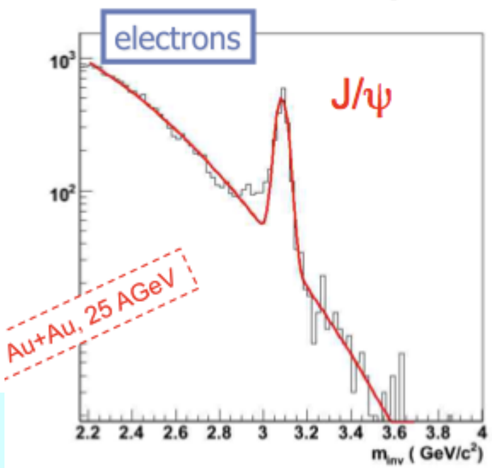
low-mass dielectrons

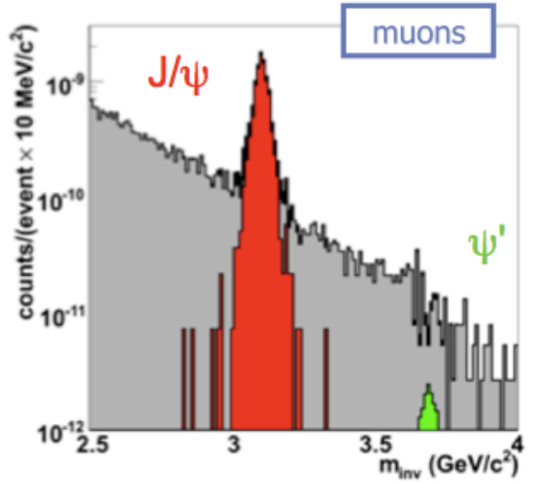


multi-strange dibaryons



charmonium





FAIR modules

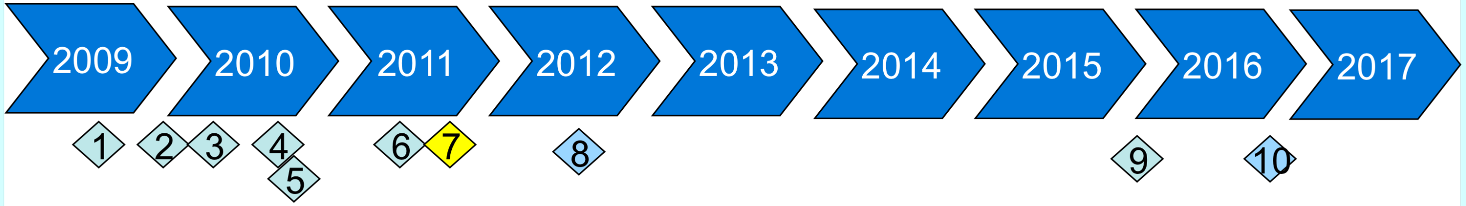
2003	**Recommendation by WissenschaftsRat – FAIR Realisation in three stages**						
2005	**Entire Facility** **Baseline Technical Report**						
2007	**Phase A**						**Phase B** SIS300
2009	**Module 0** SIS100	**Module 1** expt areas CBM/HADES and APPA	**Module 2** Super-FRS fixed target area NuSTAR	**Module 3** pbar facility, incl. CR for PANDA, options for NuSTAR	**Module 4** LEB for NuSTAR, NESR for NuSTAR and APPA, FLAIR for APPA	**Module 5** RESR nominal intensity for PANDA & parallel operation with NuSTAR and APPA SIS18 Proton Beamline	**Module 6** SIS300 HESR **Cooler** ER

Modularized Start Version (Modules 0–3)

B. Sharkov, director (des.) FAIR

FAIR roadmap

Road Map FAIR Site & Buildings

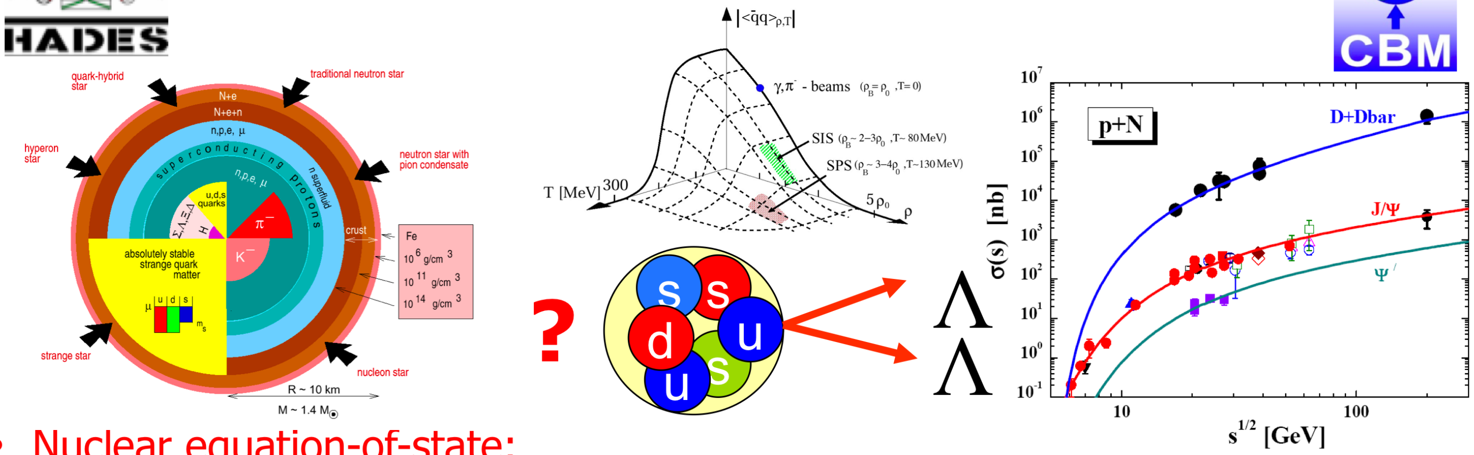


1. Handing in of preplanning documents to hbm
2. Clarification of user requirements Modularized Start Version (MSV)
3. Start revised preplanning for MSV
4. Expected approval of revised planning for MSV
5. Preparation of documents for building permit
6. Expected approval for (partial) building permit
7. Start site preparation (clearing trees)
8. Award contracts on civil construction work lot 1 … 4
9. Completion of civil construction work lot 1 … 4
10. Start installation of accelerators and detectors

B. Sharkov, director (des.) FAIR

CBM @ SIS-100

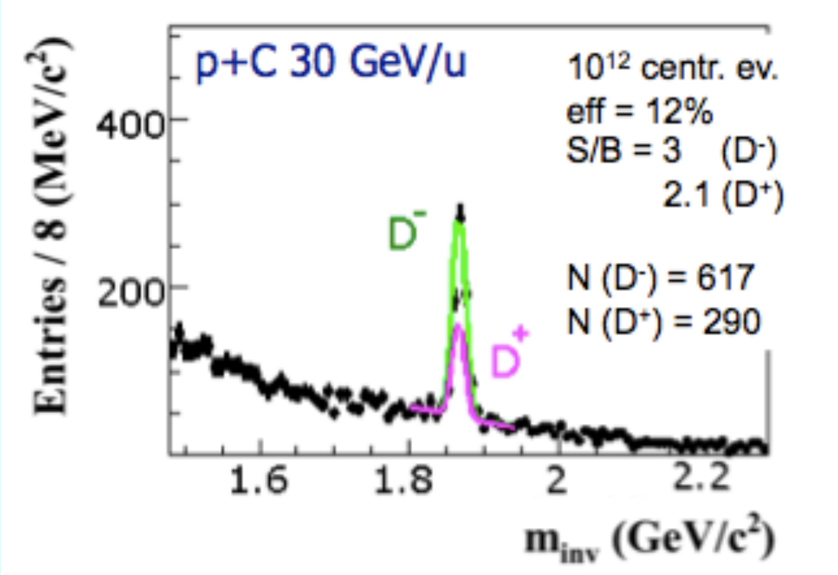
CBM physics at SIS100

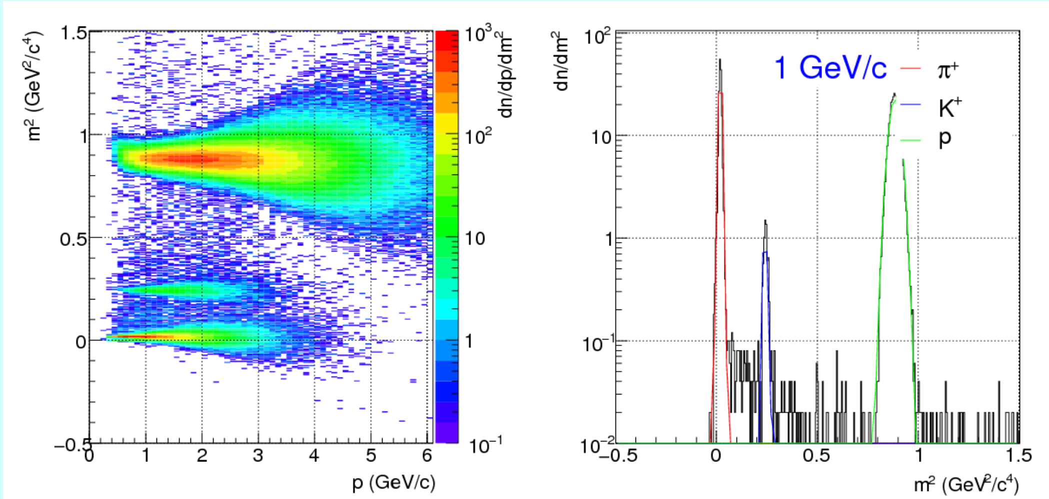


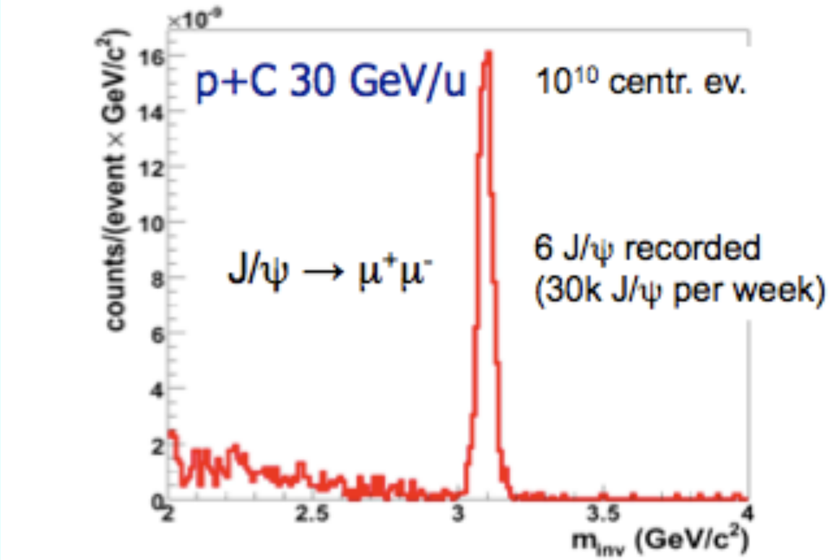
- Nuclear equation-of-state:
  What are the properties and the degrees-of-freedom of nuclear matter at neutron star core densities?
- Hadrons in dense matter:
  What are the in-medium properties of hadrons?
  Is chiral symmetry restored at very high baryon densities?
- Strange matter:
  Does strange matter exist in the form of heavy multi-strange objects?
- Heavy flavor physics:
  How ist charm produced at low beam energies, and how does it propagate in cold nuclear matter?

P. Senger

Performance at SIS-100







Simulations ongoing
First results: not much degradation of physics performance at lower beam energies

Summary

- CBM transited from the design / simulation phase to detector R&D and prototyping
- Progress in all major subdetector systems
- With simulations continuously adjusted to new insights on detector layout and detailed design: key observables demonstarted to be feasible
- Promising activties and first results towards fast algorithms for online event selection
- Will be ready for beam at SIS-100; valid (start) physics programme there identifiable
- Full physics to come with SIS-300

Progress towards SIS-300

R&D on SC magnets with curved coils

Ansaldo Superconduttori

INFN Istituto Nazionale di Fisica Nucleare

SIS-300 pre-consortium founded, March 2009, Protvino