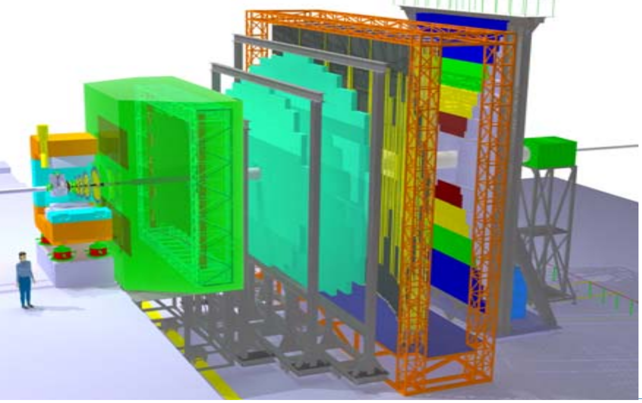
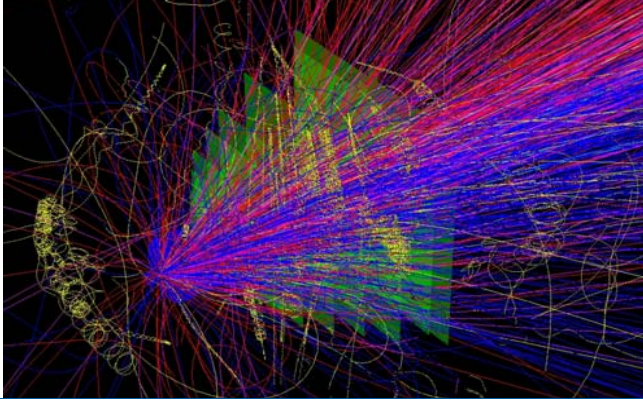




Exploration of compressed baryonic matter with the CBM experiment at FAIR

Johann M. Heuser

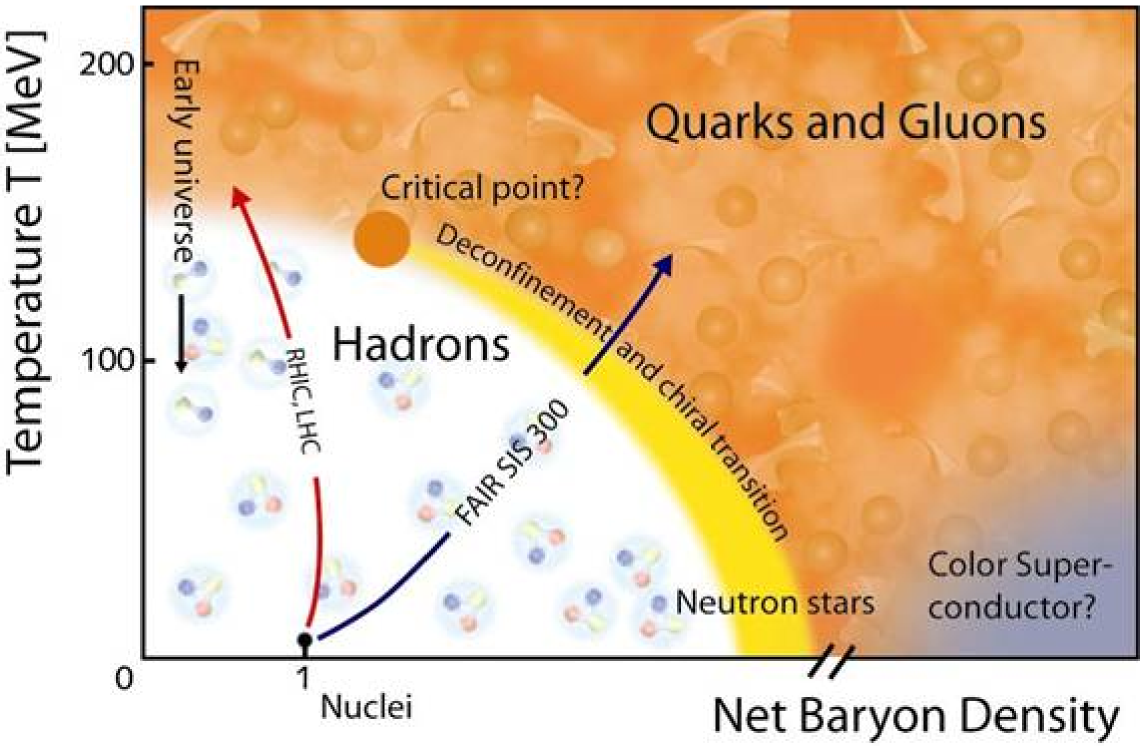
GSI, Darmstadt, Germany

HIC for FAIR Workshop

"Quarks, Gluons, and Hadronic Matter under Extreme Conditions"

March 2011, St. Goar, Germany

Physics case: Exploring the QCD phase diagram



CBM physics program:

- Equation-of-state at high ρ_B
- Deconfinement phase transition
- QCD critical endpoint
- Chiral symmetry restoration

Diagnostic probes of the high-density phase:

- open charm, charmonia
- low-mass vector mesons
- multistrange hyperons
- flow, fluctuations, correlations

Projects to explore the QCD phase diagram at large μ_B:

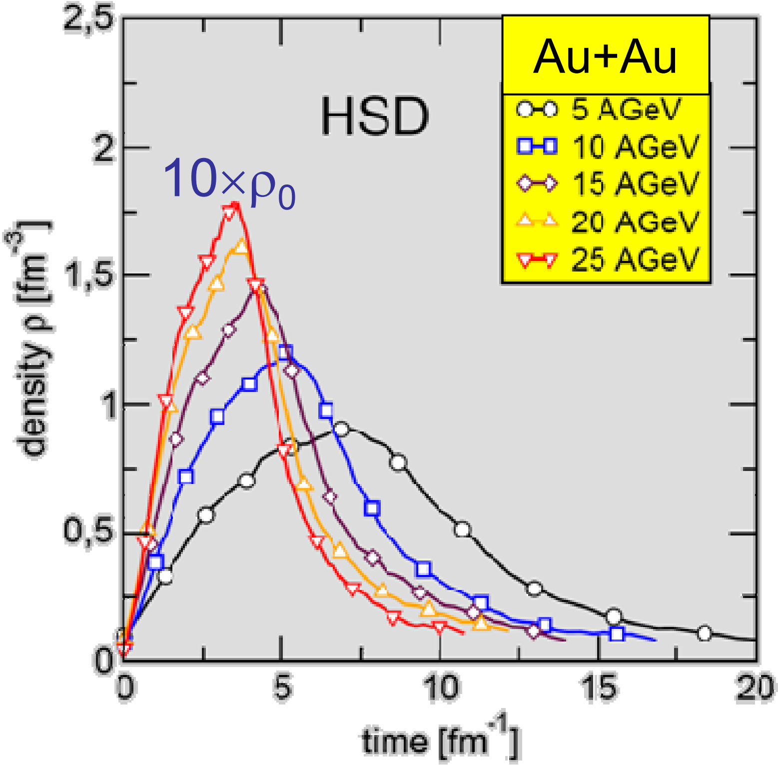
RHIC energy-scan, NA61@SPS, MPD@NICA .... bulk observables

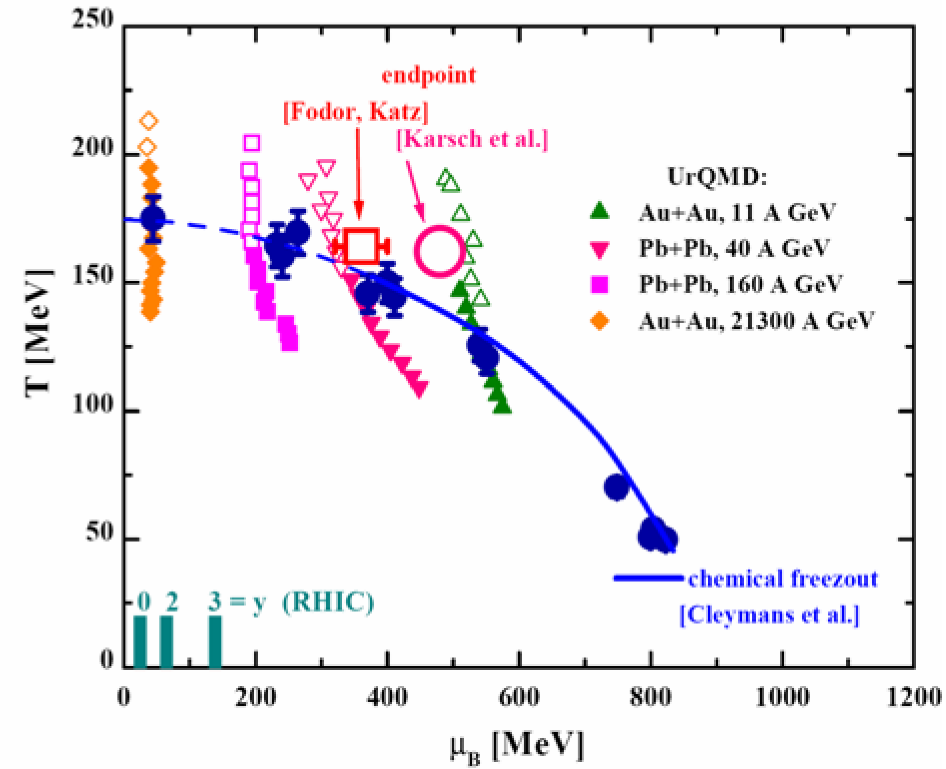
CBM@FAIR/SIS-300 .... bulk and **rare observables**

Transport model predictions

E. Bratkovskaya, W. Cassing

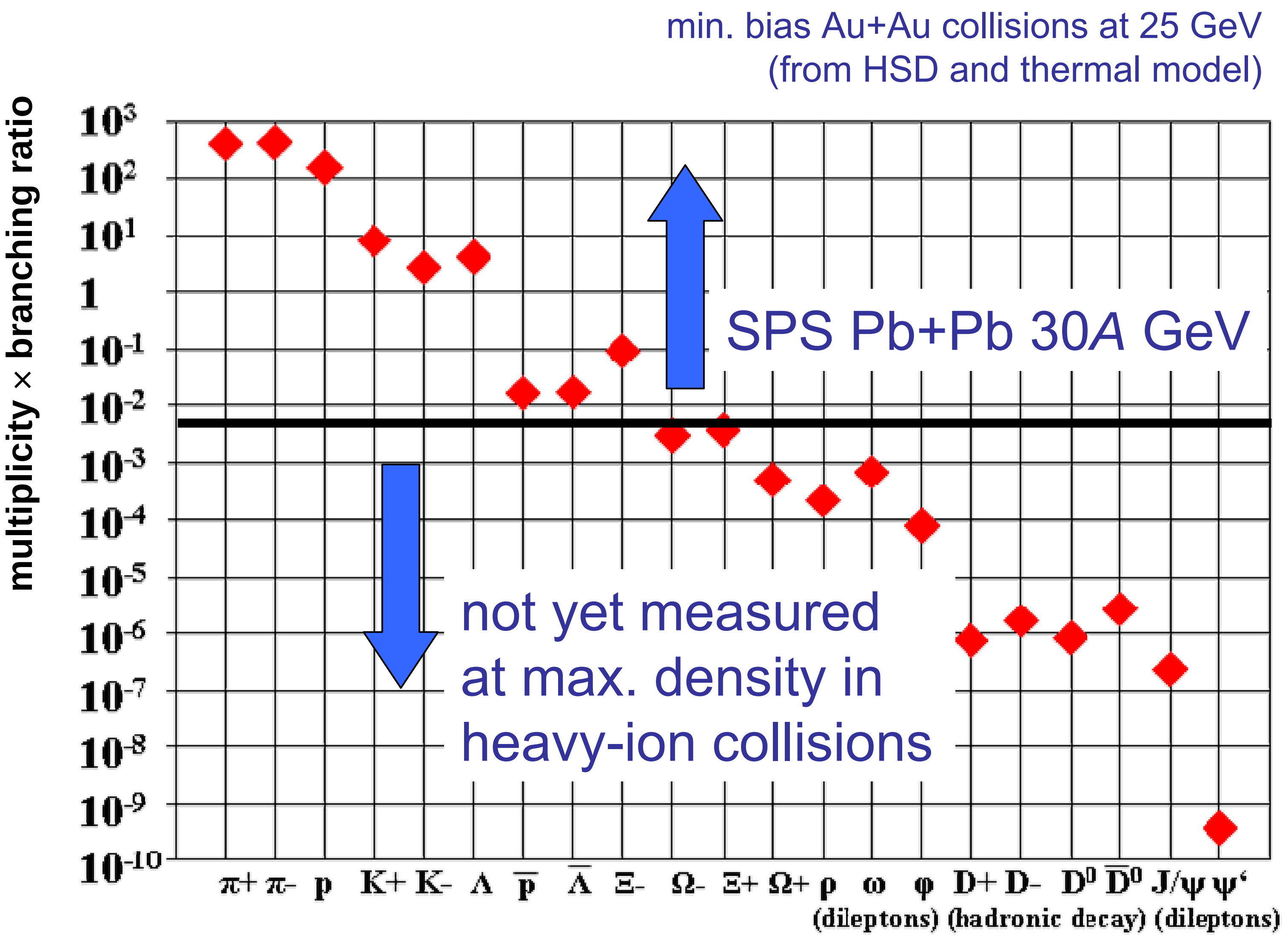
L.V. Bravina et al.



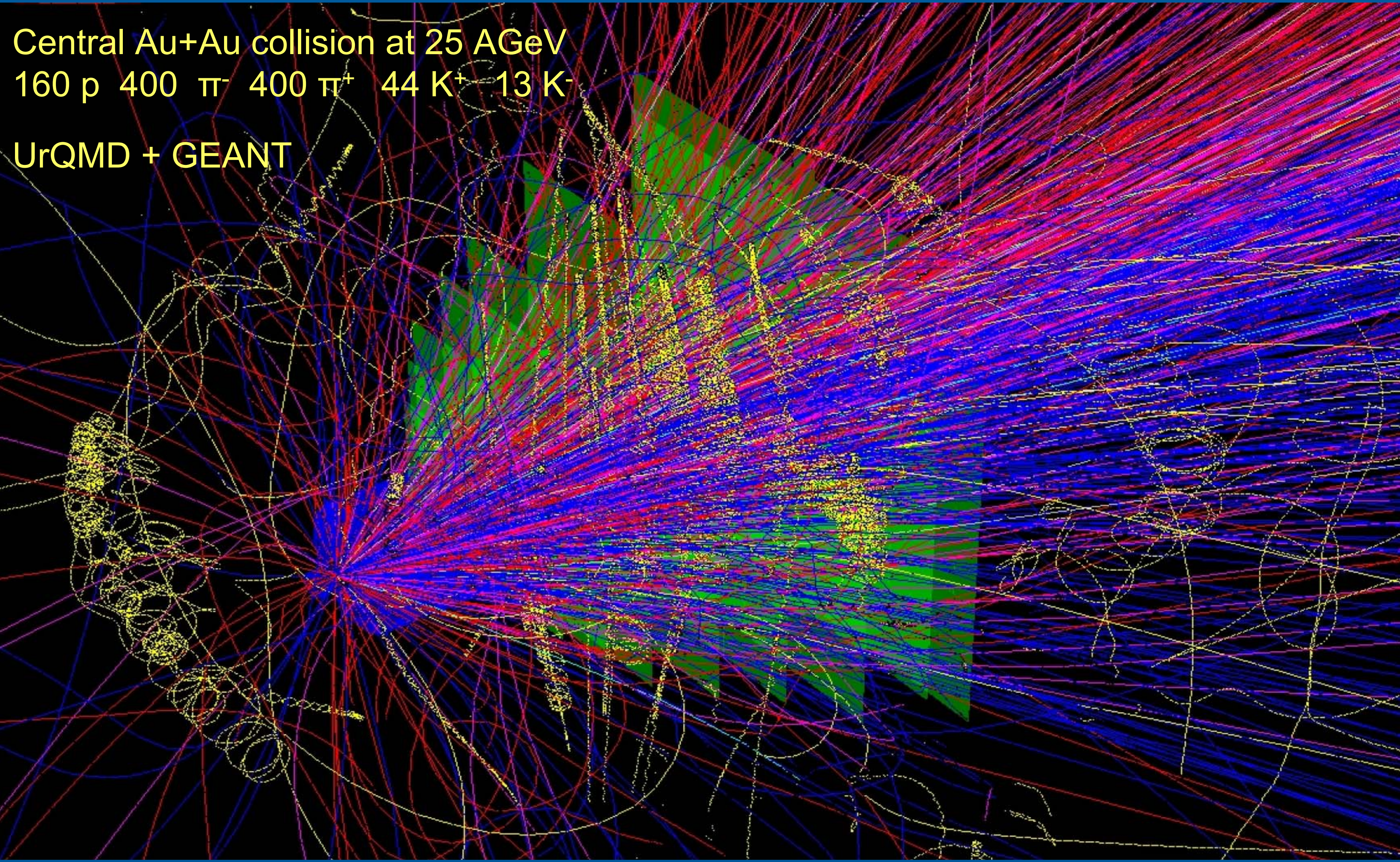


- < 11*A* GeV: dense hadronic (resonance) matter near phase transition
- ~ 30*A* GeV: maximum baryonic density, beyond phase transition

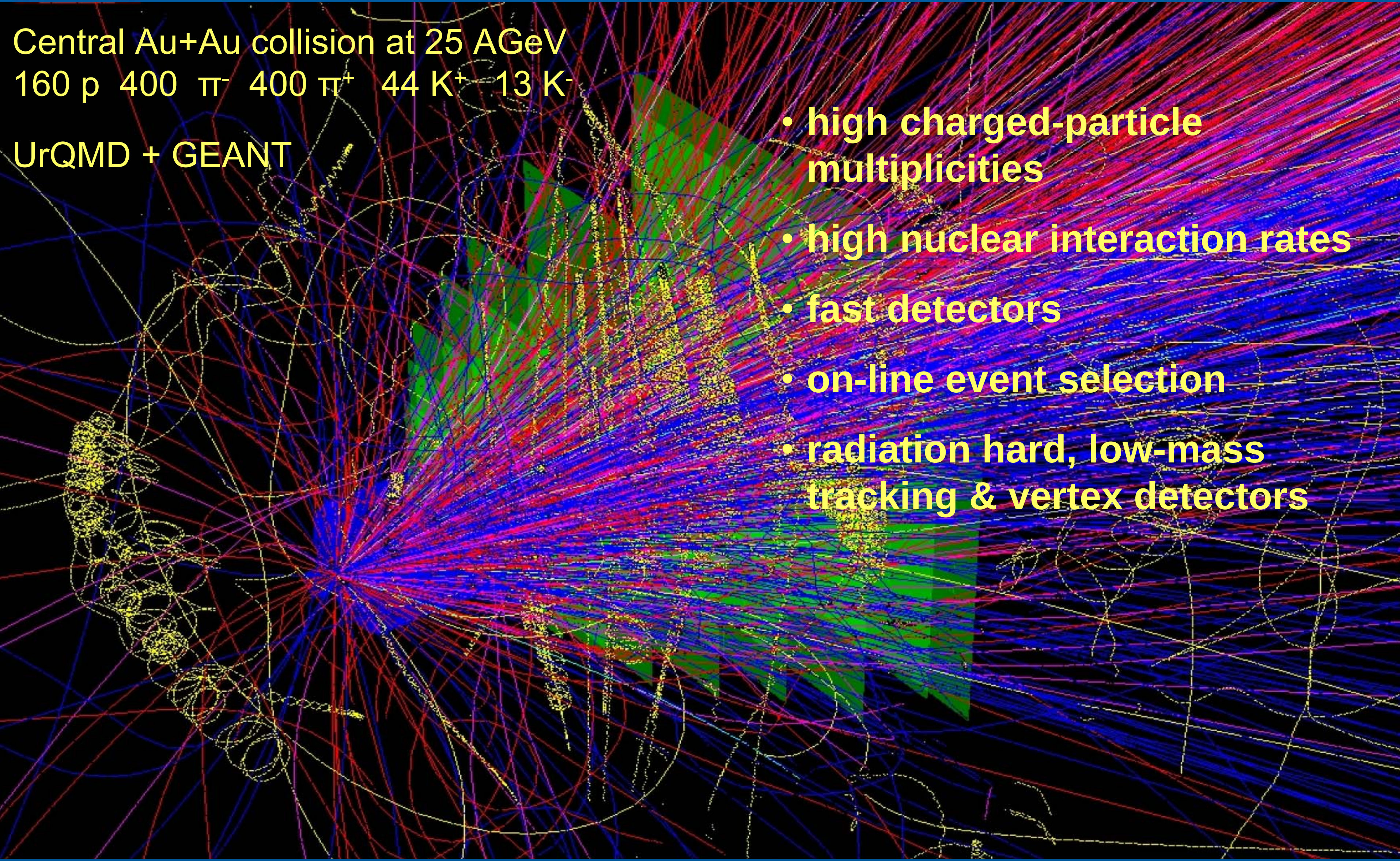
Particle multiplicities



Experimental challenges



Experimental challenges

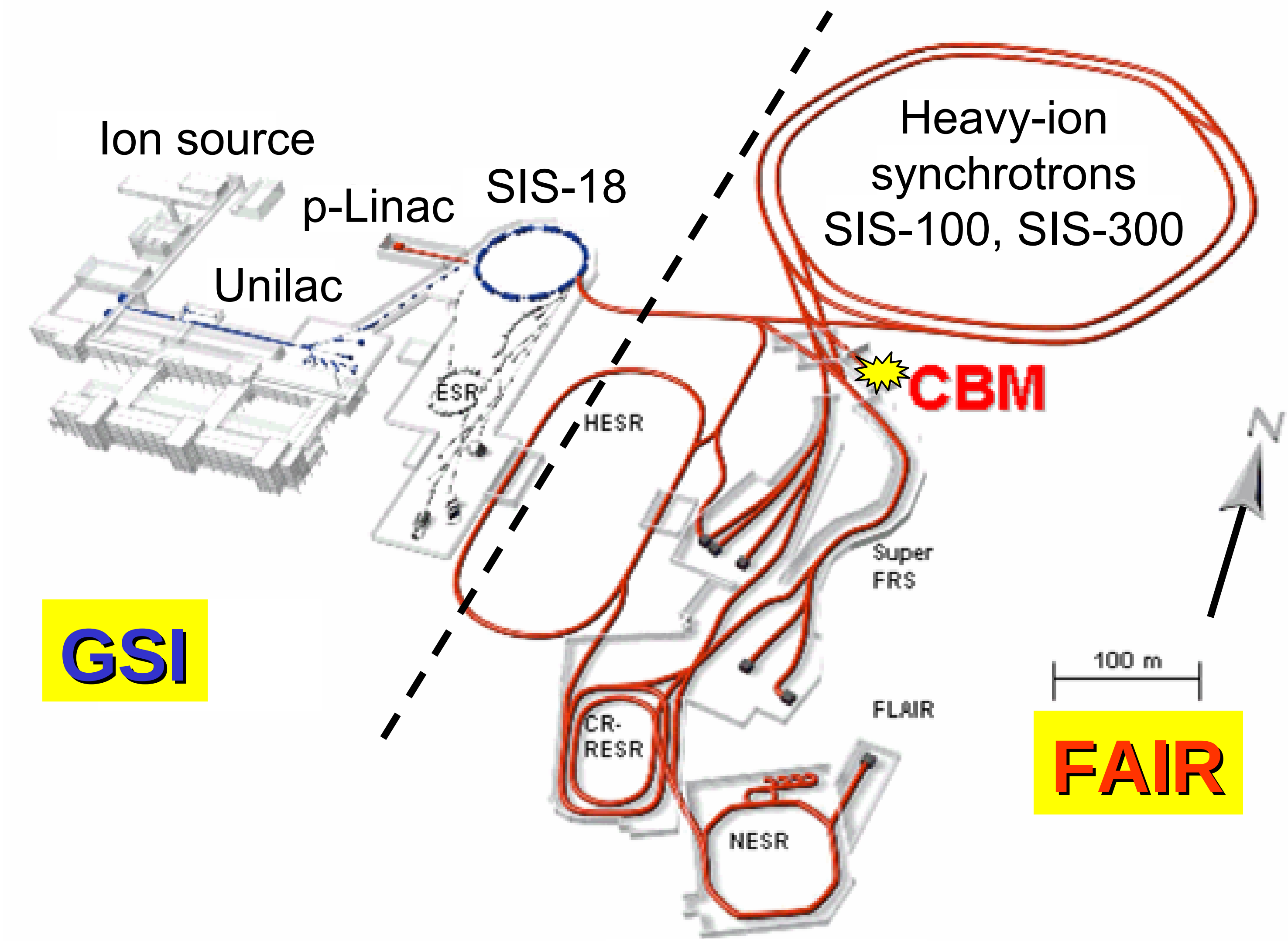


Central Au+Au collision at 25 AGeV
160 p 400 π^- 400 π^+ 44 K^+ 13 K^-

UrQMD + GEANT

- **high charged-particle multiplicities**
- **high nuclear interaction rates**
- **fast detectors**
- **on-line event selection**
- **radiation hard, low-mass tracking & vertex detectors**

Facility for Antiproton and Ion Research



High-intensity primary and secondary beams

Efficient parallel operation of up to 5 programs

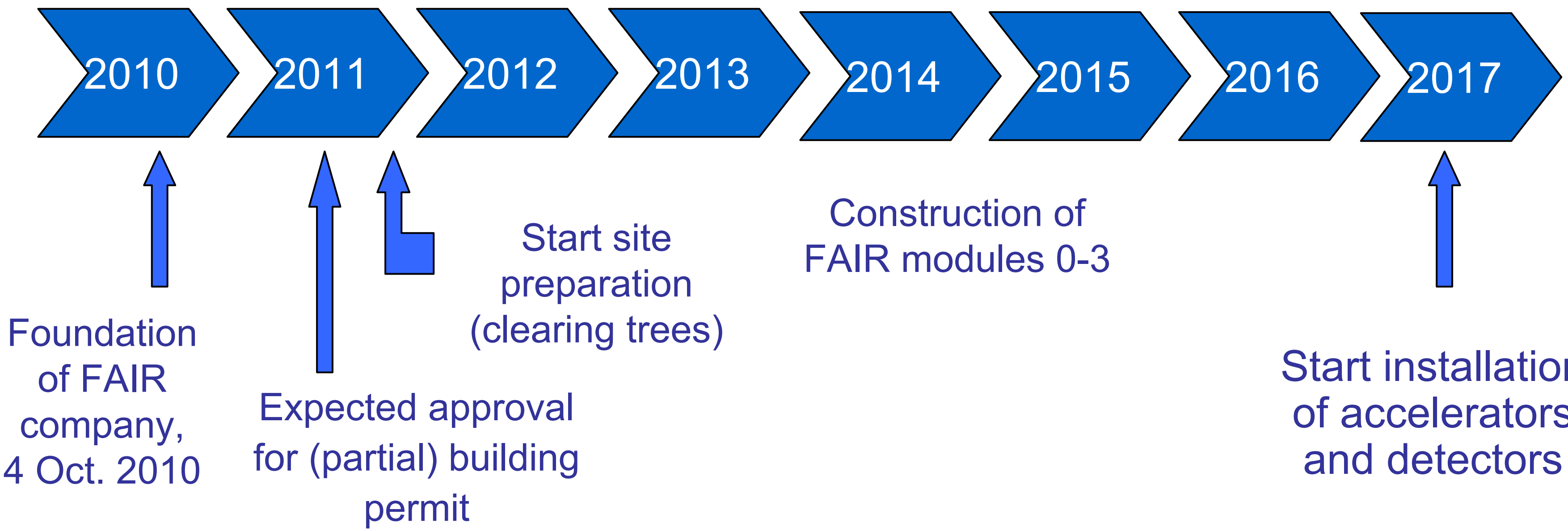
SIS-100/300:

protons:
max. 29/89 GeV

ions:
max. 14/44 GeV
up to Z/A=0.5

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

FAIR construction timeline



Phase A						Phase B SIS300
Module 0 SIS100	**Module 1** experimental areas CBM/HADES and APPA	**Module 2** Super-FRS fixed target areas and CR NuSTAR	**Module 3** pbar facility, incl. CR for PANDA, options for NuSTAR	**Module 4** LEB cave for NuSTAR, NESR for NuSTAR and APPA, FLAIR for APPA	**Module 5** RESR	**Module 6** SIS300 HESR **Cooler** ER

New buildings at GSI

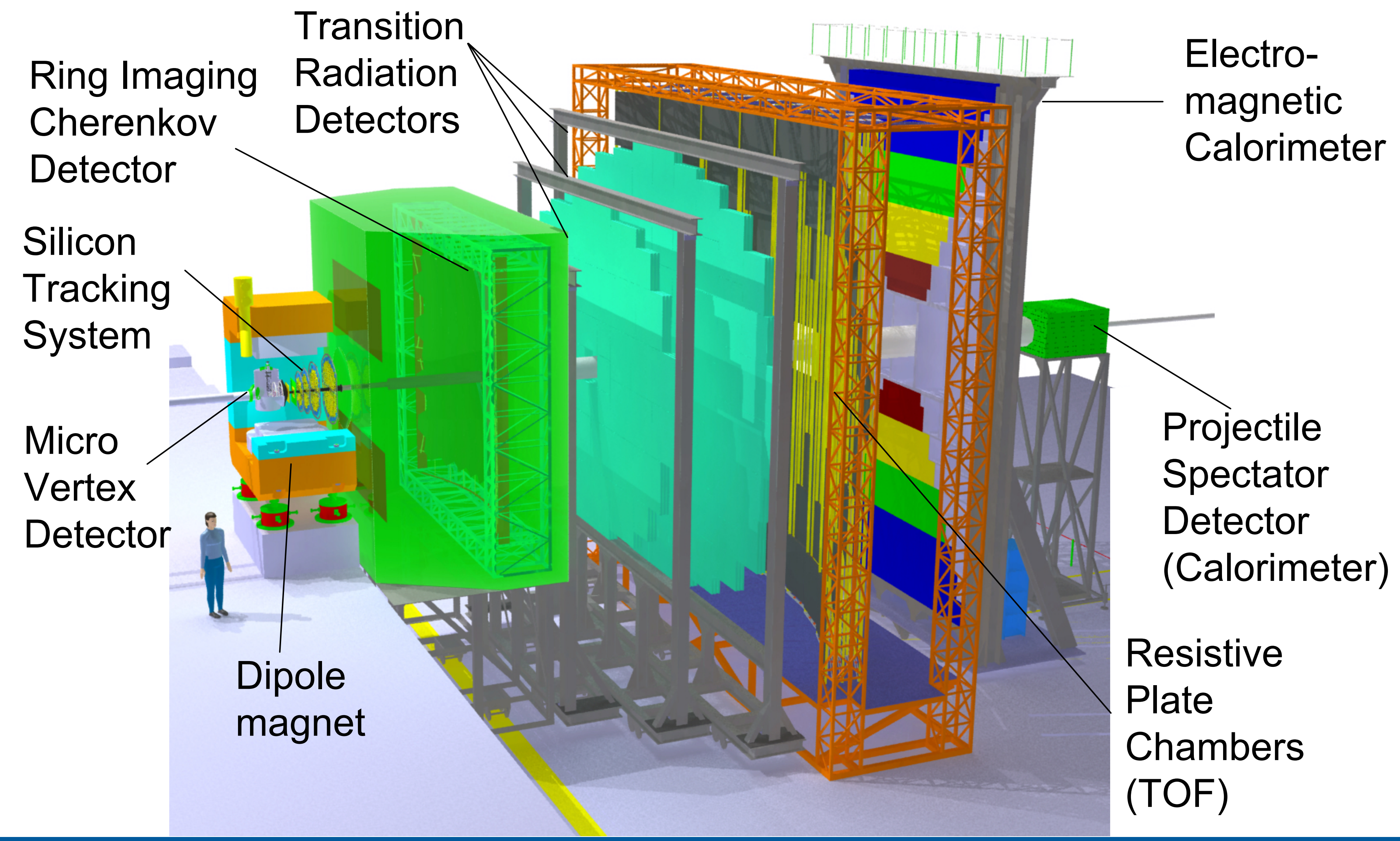
Conference & Office Building *KBW*

move-in: March 2011

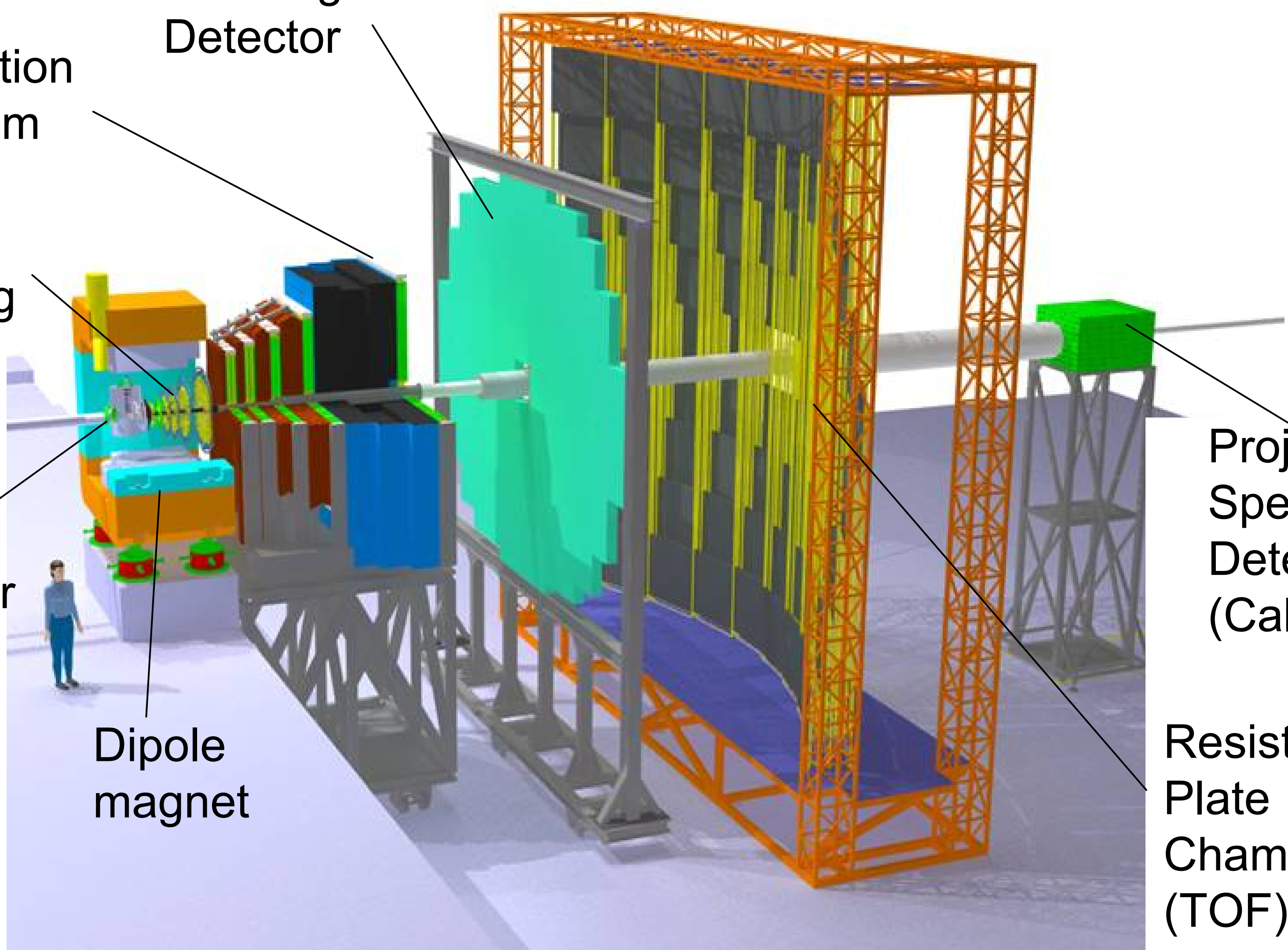
Testing Hall and Detector Laboratory

Detector Lab:
- move-in: April 2011
- two stories, ~ 600 m^2
- clean rooms, assembly areas

The Compressed Baryonic Matter Experiment



The Compressed Baryonic Matter Experiment



Realization of CBM at FAIR

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

(1) FAIR Modules 0-3:

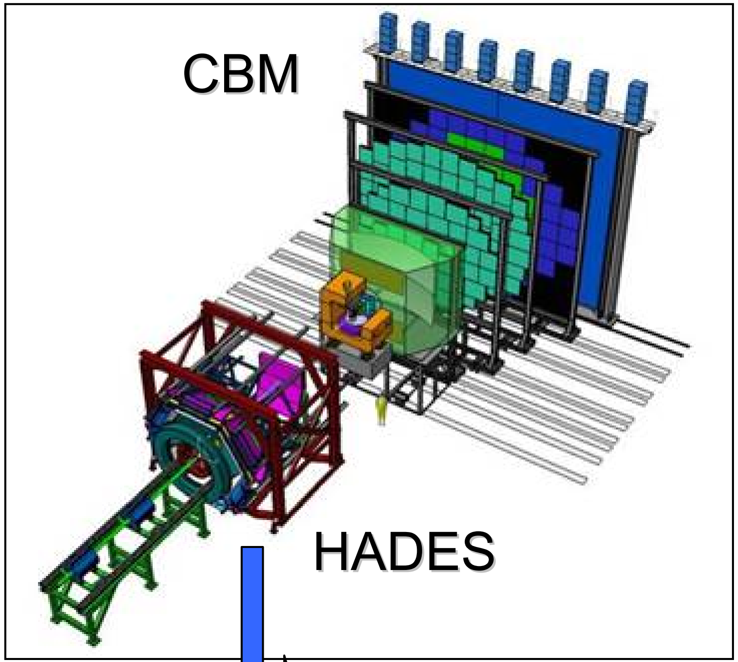
- SIS-100
- nuclei up to 14 (11) *A* GeV, Z/A=0.5 (0.4)
- protons up to 29 GeV

→ HADES + CBM

(2) FAIR Module 6:

- SIS-300
- nuclei up to 44 (34) *A* GeV, Z/A=0.5 (0.4)
- protons up to 89 GeV

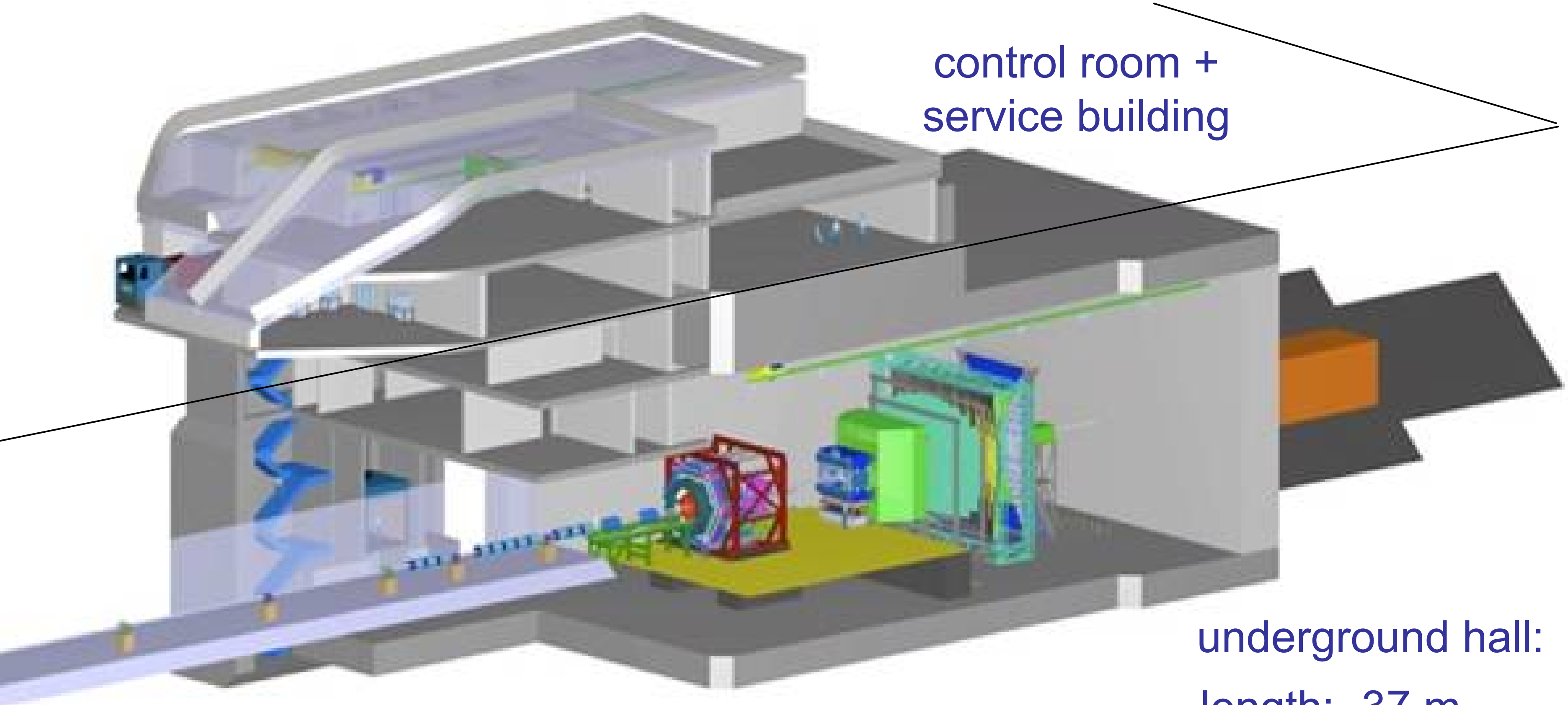
→ full CBM



High **A**cceptance
Di-**E**lectron
Spectrometer

Nuclear collisions: 1-10*A* GeV;
Electrons, hadrons, (photons).

HADES and CBM in the underground hall



control room +
service building

underground hall:

length: 37 m
width: 27 m
height: 17 m

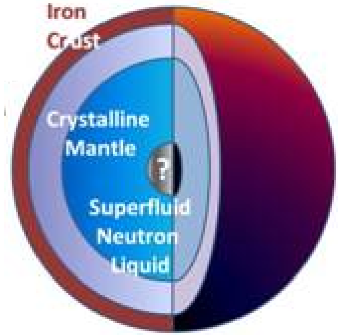
construction permit expected in summer 2011

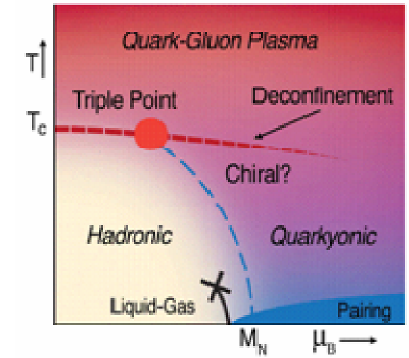
Observables for CBM physics at SIS-300

- Particles containing charm quarks (D mesons and charmonium)
  $\rightarrow$ early, dense phase of collision
- Low-mass vector mesons decaying into dilepton pairs (ρ,ω,φ)
  $\rightarrow$ hadron properties in the dense and hot fireball
- Collective flow of identified hadrons
  $\rightarrow$ information on the equation-of-state of dense matter
- Kaons, hyperons and hadronic resonances
  $\rightarrow$ strangeness sensitive to fireball evolution
- Dynamical fluctuations of particle multiplicities and momenta
  $\rightarrow$ sensitive to first order phase transition or the critical endpoint
- Photons
  $\rightarrow$ direct radiation from the early fireball
- Two-particle correlations
  $\rightarrow$ source size and time evolution of fireball + particle production

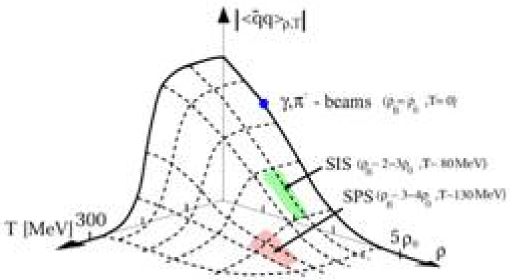
Nuclear matter physics at SIS-100 energies

- Nuclear equation-of-state, quarkyonic matter at high densities:
  What are the properties and the degrees-of-freedom of nuclear matter at neutron star core densities?

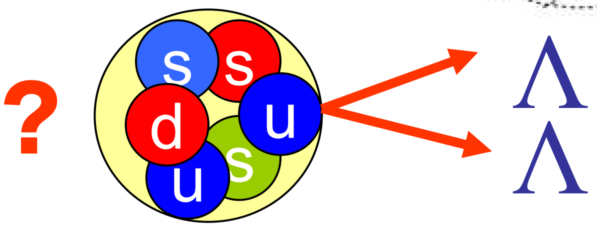




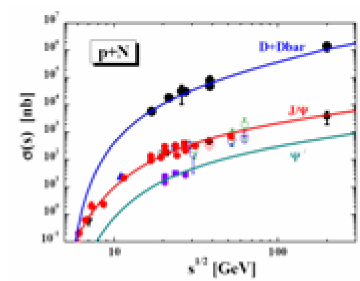
- Hadrons in dense matter:
  What are the in-medium properties of hadrons?
  Is chiral symmetry restored at very high baryon densities?



- 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?



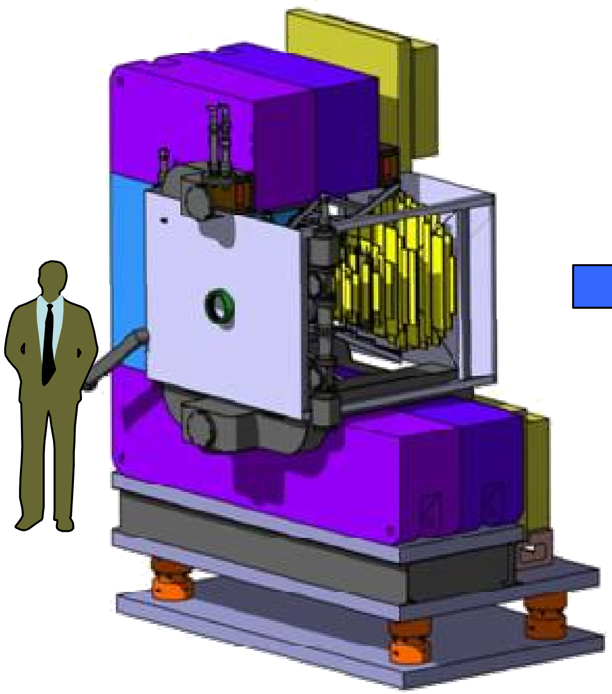
Conceptual design and feasibility studies

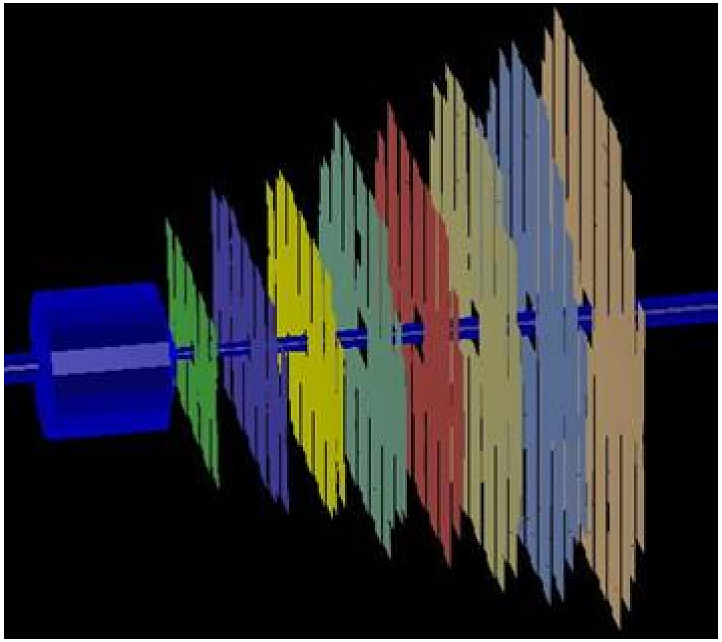
Software tools:

- Framework FAIRroot: Root + Virtual Monte Carlo
  - Transport codes GEANT 3 & 4, FLUKA
  - Event generators UrQMD, HSD, PLUTO
- Realistic detector layouts and response functions
- Fast ("SIMDized") track reconstruction algorithms for online event selection

Silicon Tracking System and Micro Vertex Detector

Silicon Tracking System, Micro Vertex Detector,
Target, Beam pipe, installed in the Superconducting Dipole Magnet





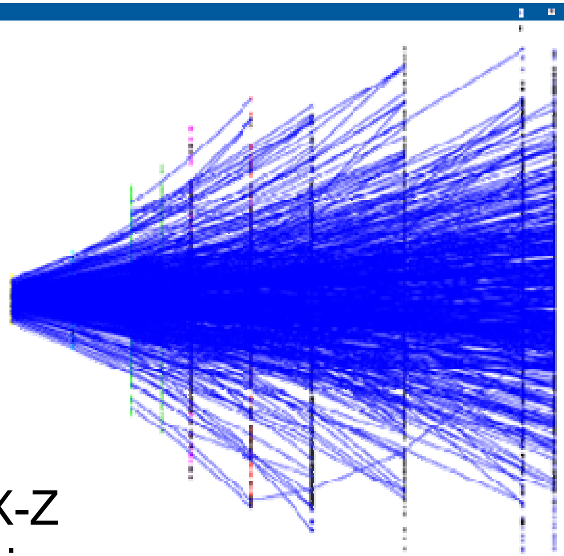
STS: ***Heart of the CBM experiment***

- silicon microstrip detectors
- 8 tracking stations in thermal enclosure

MVD:

- monolithic silicon pixel detectors
- 2 vertex stations in vacuum vessel

STS track reconstruction performance study

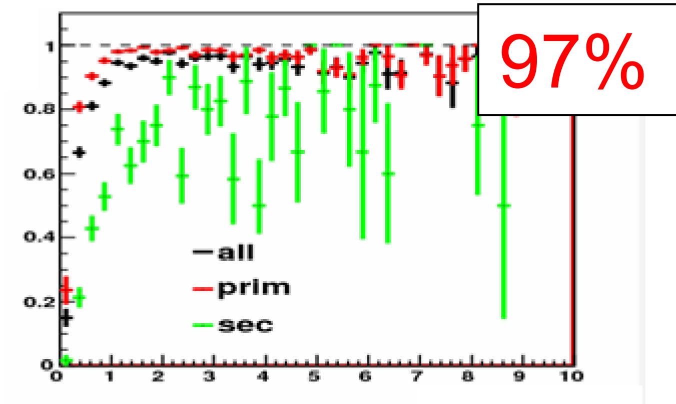


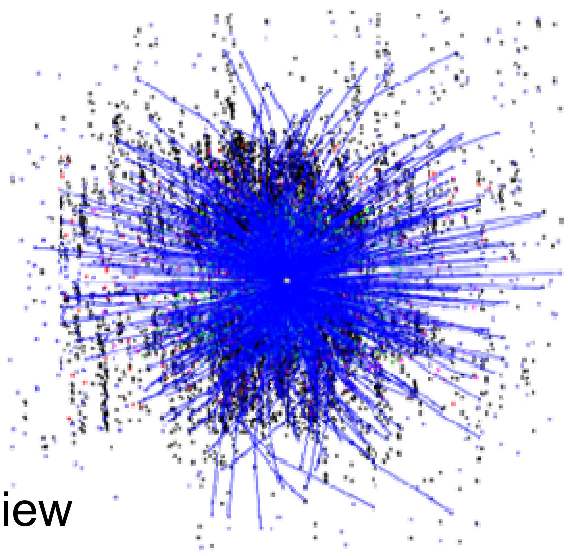
X-Z view

URQMD
central Au+Au
25*A* GeV

~ 700 tracks
Cellular Automaton
+ Kalman Filter
algorithms

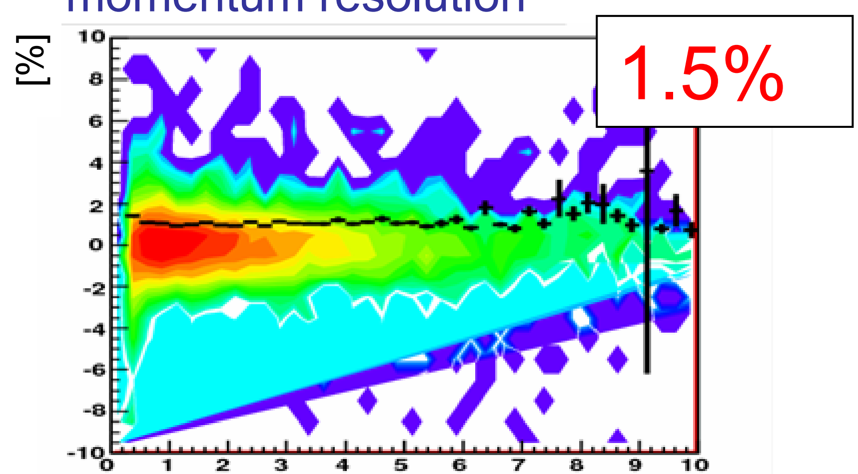
reconstruction efficiency



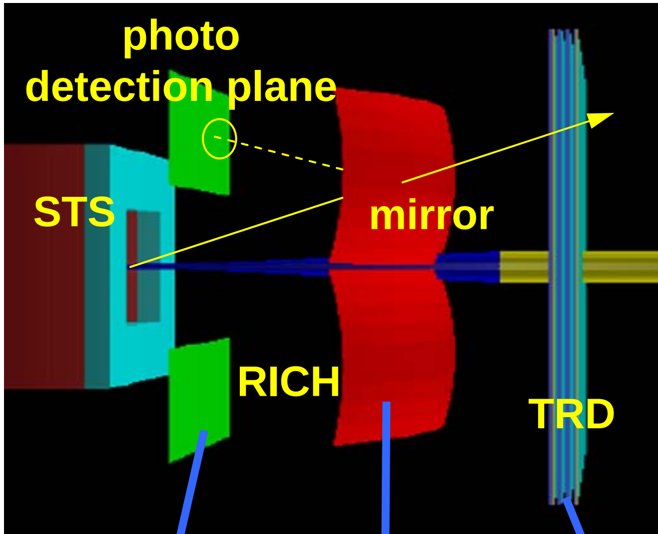


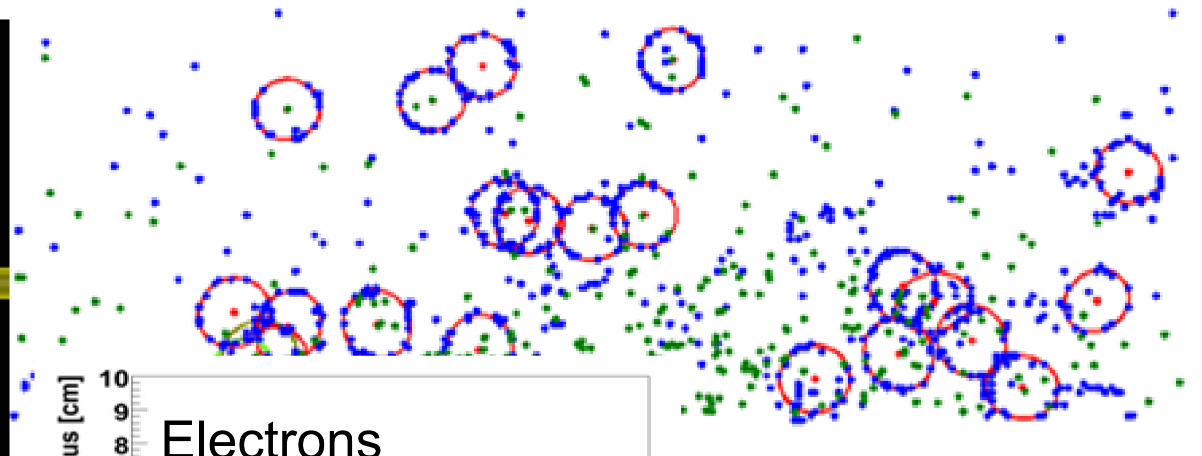
X-Y view

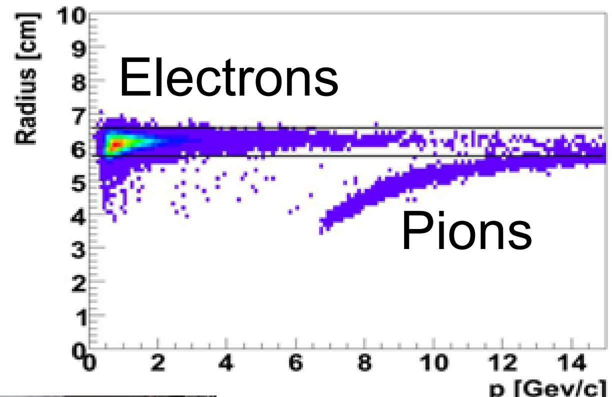
momentum resolution



Electron identification

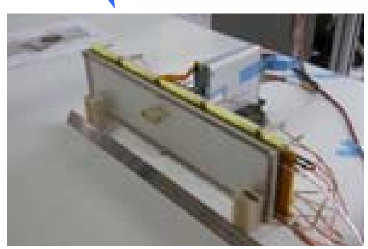






multi-anode PMT

glass mirror with $Al+MgF_2$



high-rate TRD

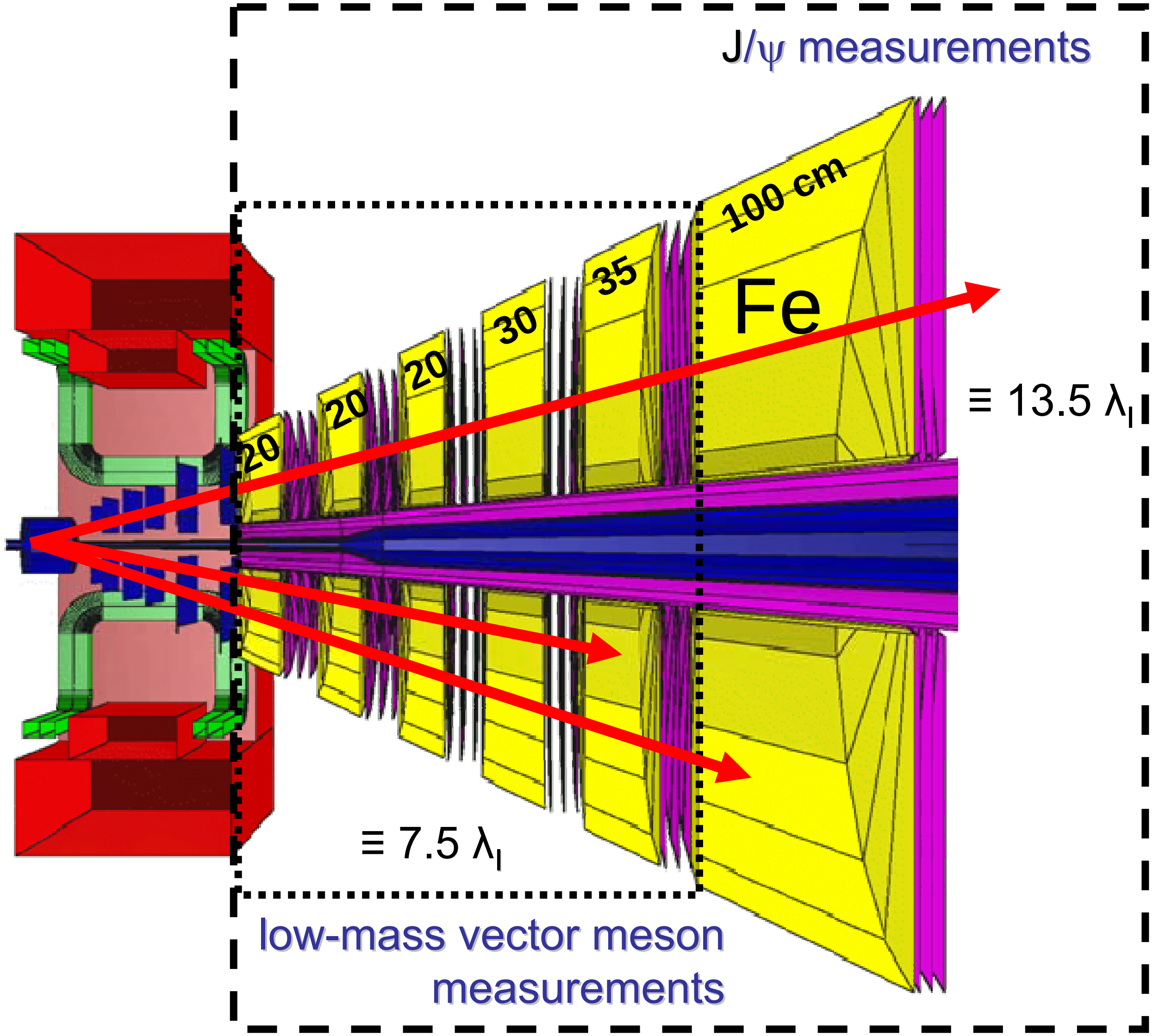
Rings:
up to 100 per event
~ 6cm diameter
~ 20 photo electrons

finding eff. **95.3%**

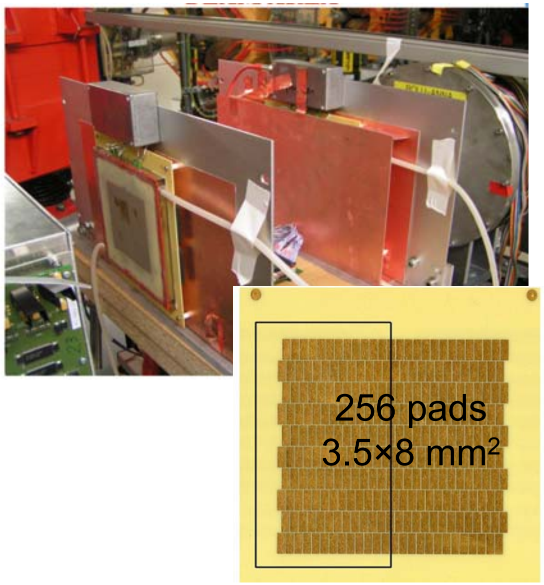
RICH + TRD:

e identification efficiency	**85 %**
π-suppression	**10^4**

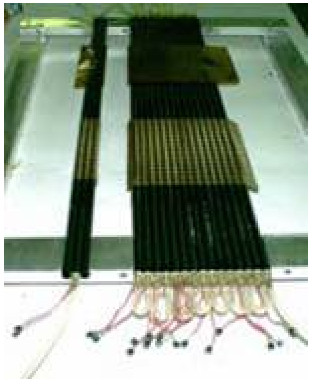
Muon detection



GEM detectors



Straw tubes



Di-lepton measurements

- Signal and background yields from physics event generators (HSD, UrQMD)
- Full event reconstruction based on realistic detector layout and response

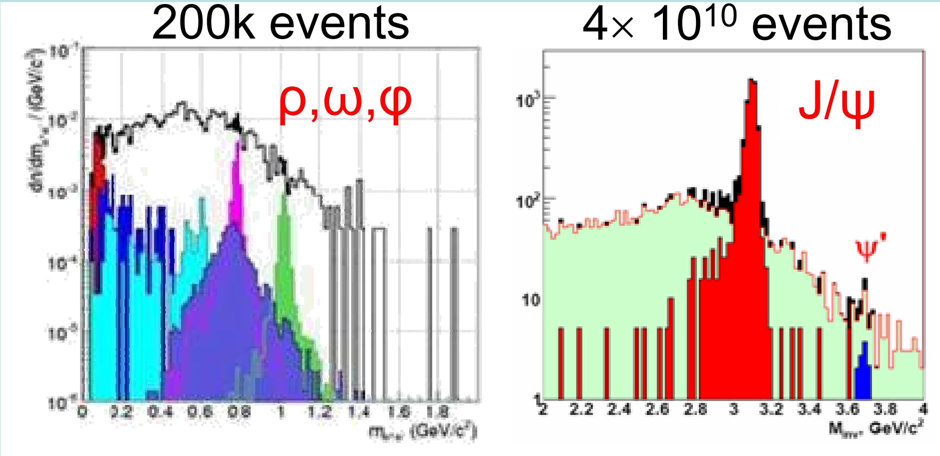
Electron id:

RICH and TRD

π suppression:

factor **10^4**

dominant background:
e from π^0 Dalitz



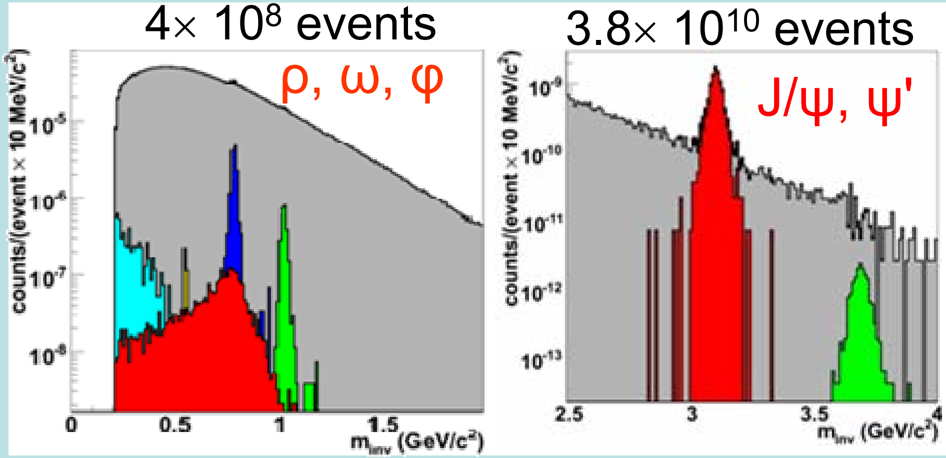
Muon id:

segmented
hadron absorber
+ tracking system

125(225) cm iron,
15(18) det. layers

125 cm Fe:
0.25 ident. μ/event

dominant background:
μ from π, K decay
(0.13/event)



Di-lepton measurements

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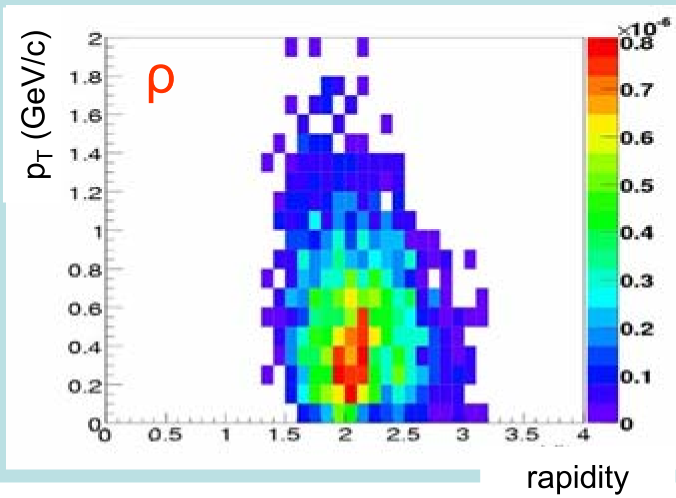
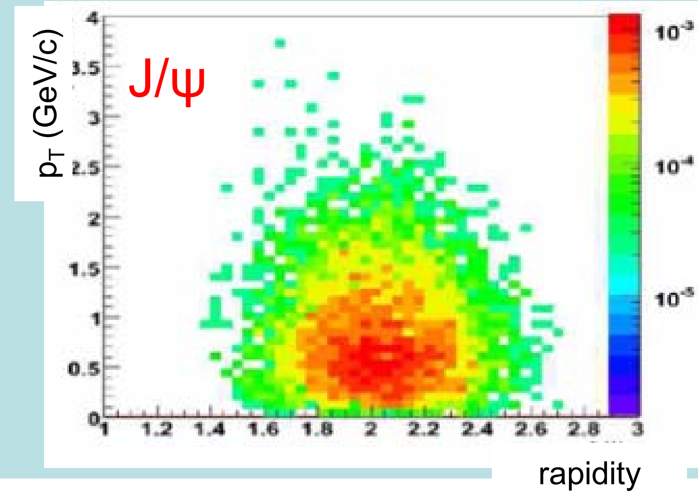
RICH and TRD

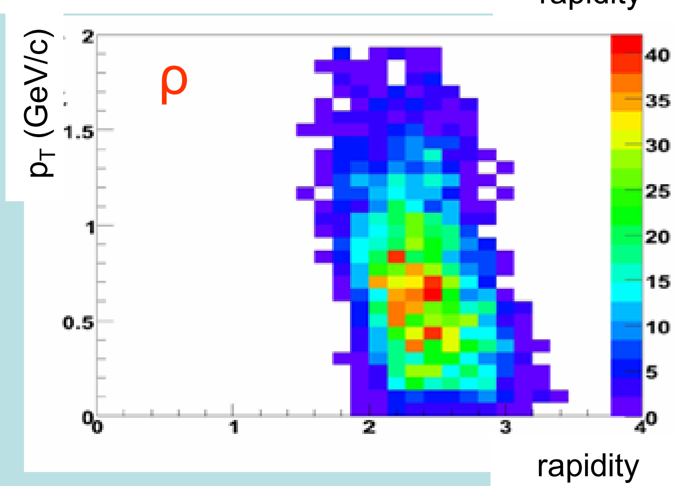


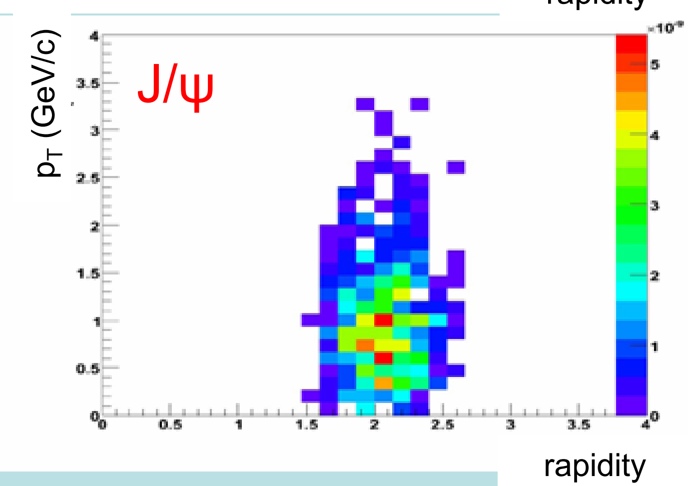


Muon id:

segmented hadron absorber + tracking system

125(225) cm iron, 15(18) det. layers

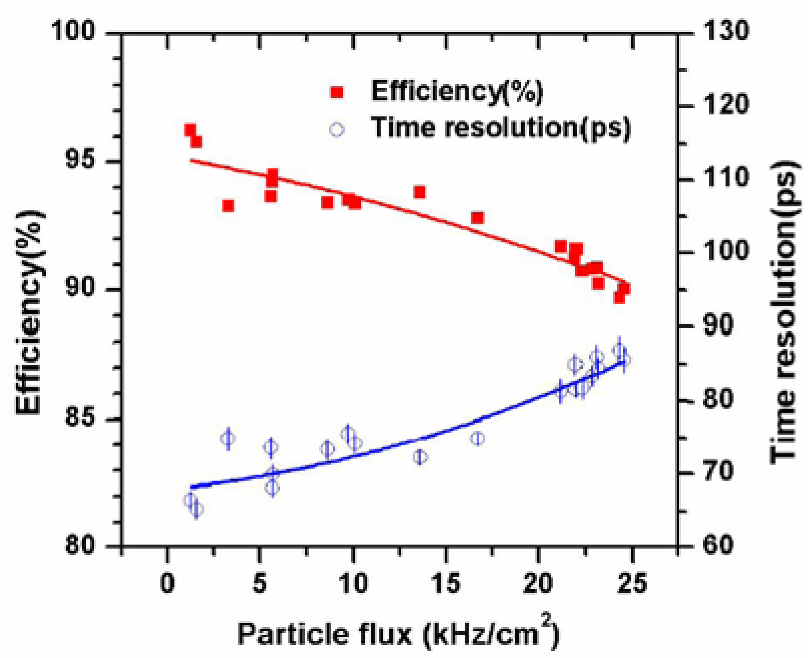




Hadron identification, Time-of-flight measurement

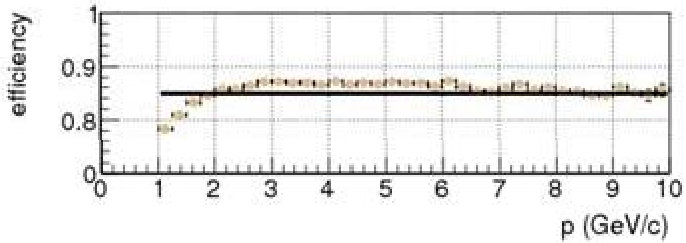
Resistive Plate Chambers

ongoing R&D:
- Ultra thin glass MRPC
- Ceramic RPC
- Differential strip RPC

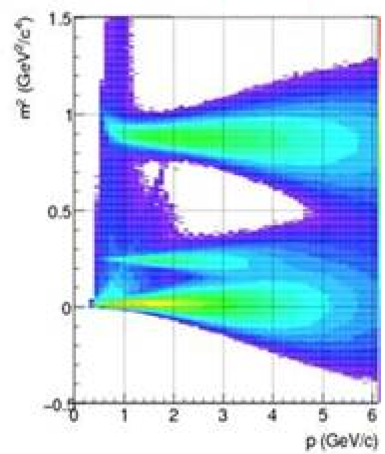


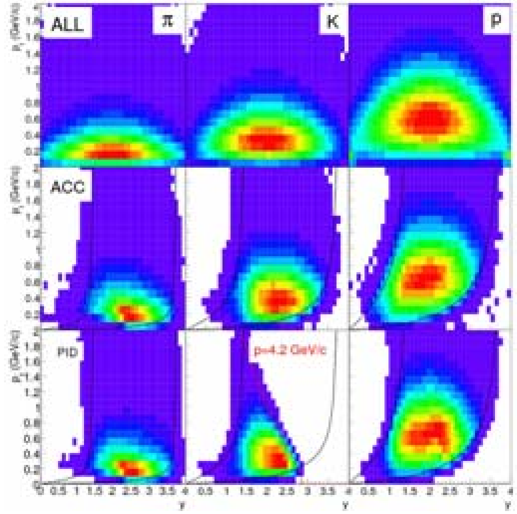
simulations:
- Segmented geometry
- Detector response, double hits
- 80ps time resolution

global tracking: STS,TRD, TOF



85 %

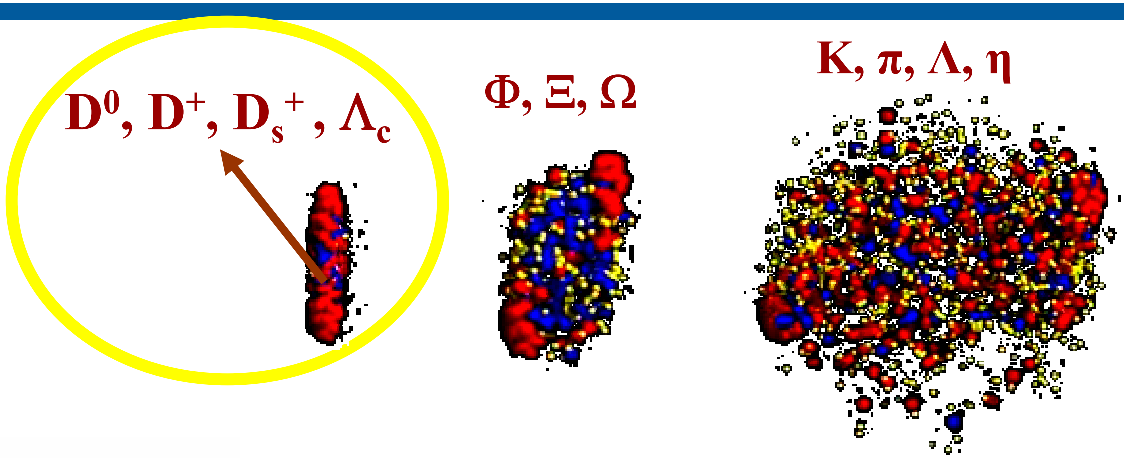




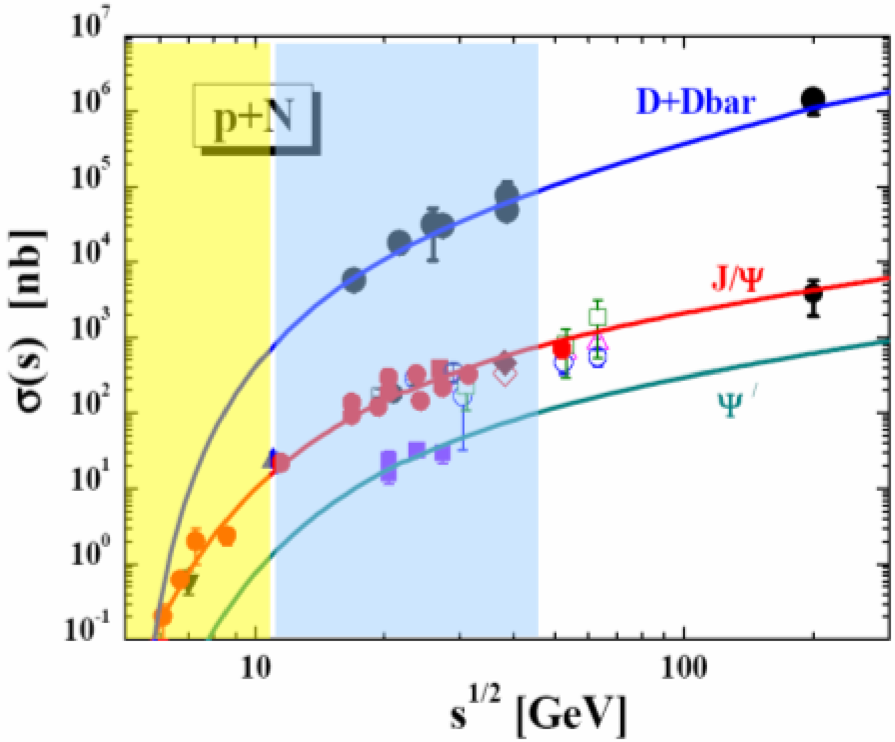
Open charm production

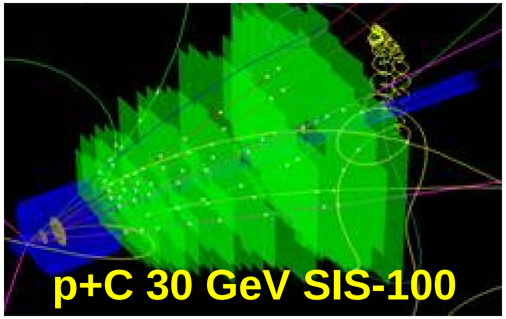
Motivation:

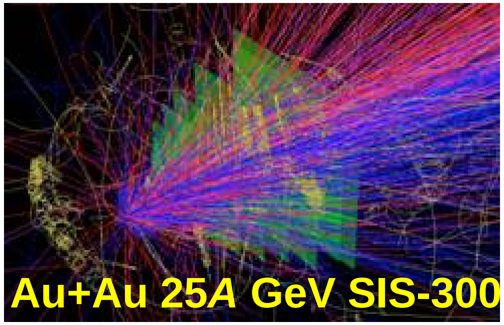
probe the dense phase



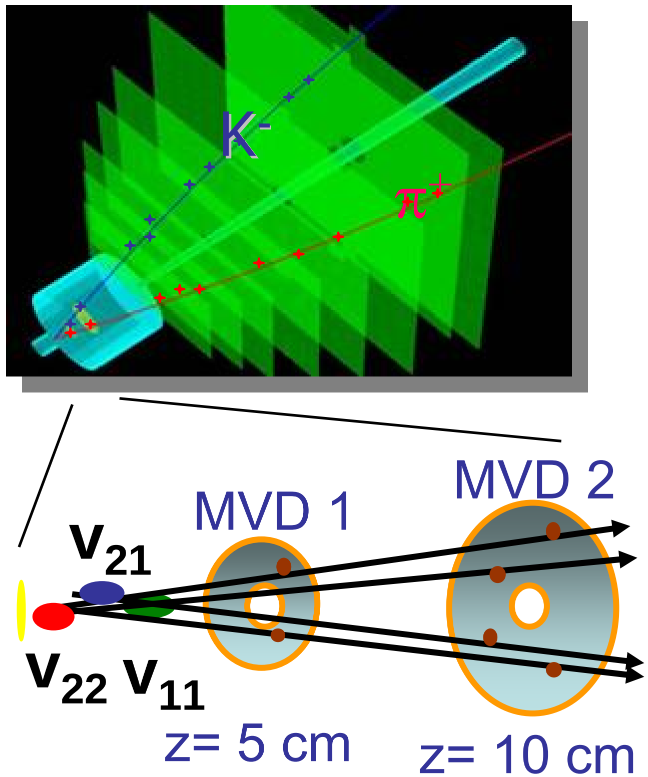
SIS-100 SIS-300



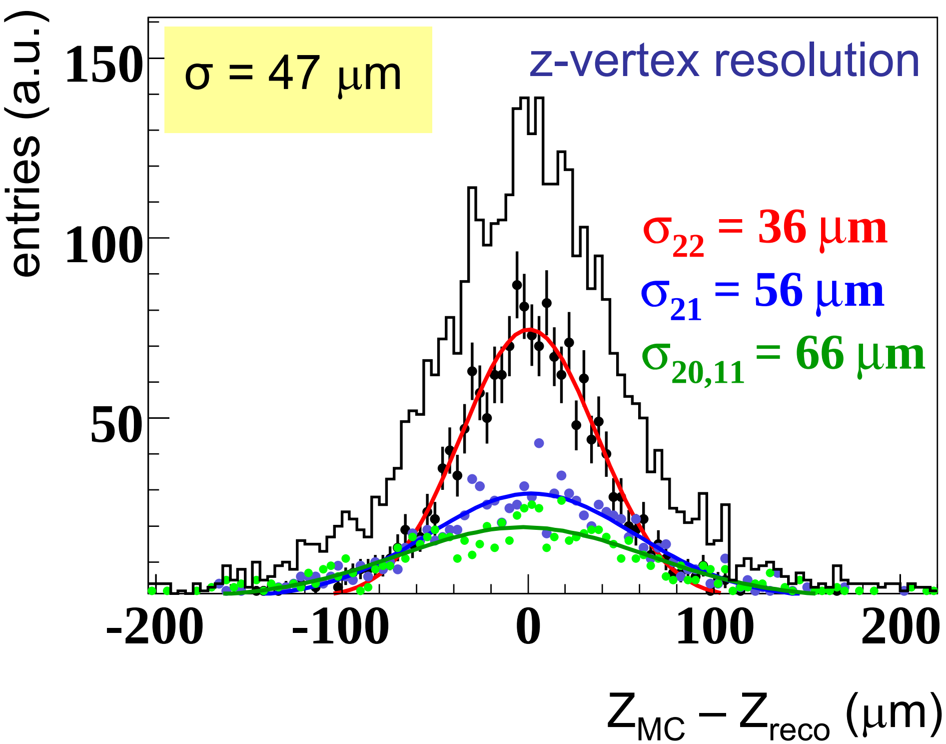




Open charm detection



e.g. $D^0 \rightarrow K^- \pi^+$



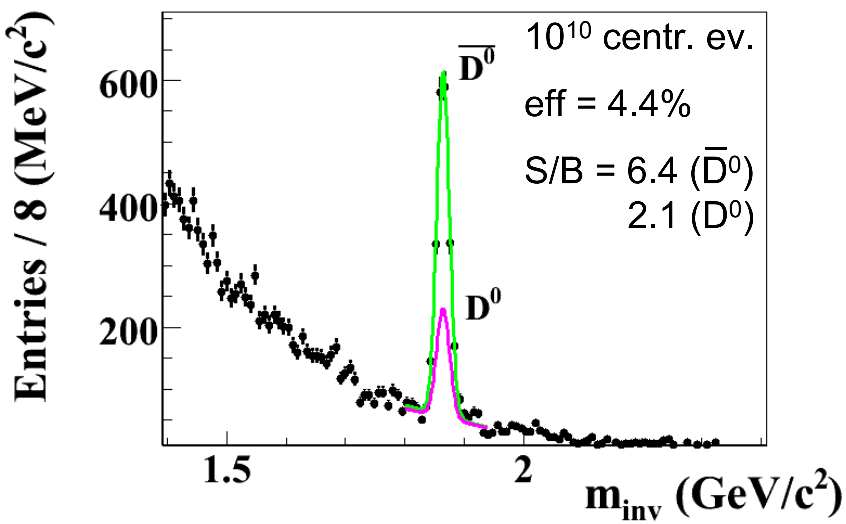
- Ultrathin Micro Vertex Detector
- Monolithic Active Pixel Sensors
- high-performance carbon supports
- material budget <0.5 % X_0 per station

Open charm measurement at SIS-300

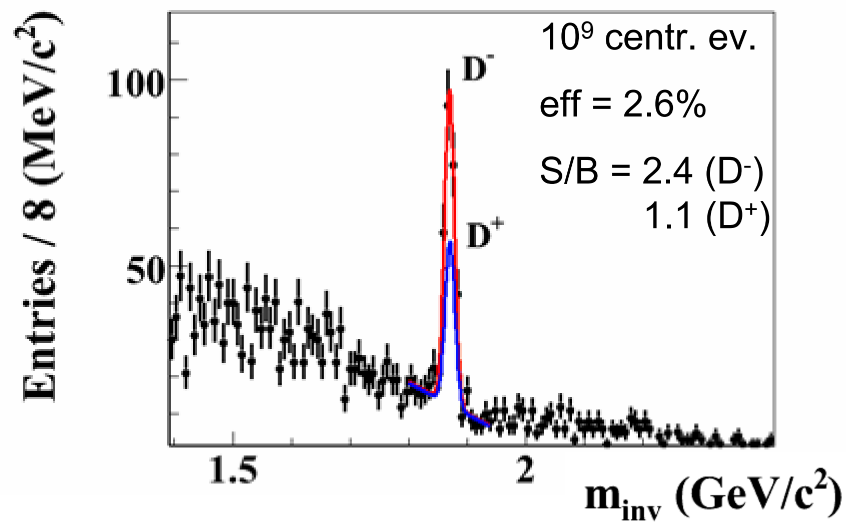
Au+Au collisions, 25*A* GeV

STS tracking**, MVD** vertexing**, proton rejection via TOF**

$D^0 \rightarrow K\,\pi$, cτ= 123 µm



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

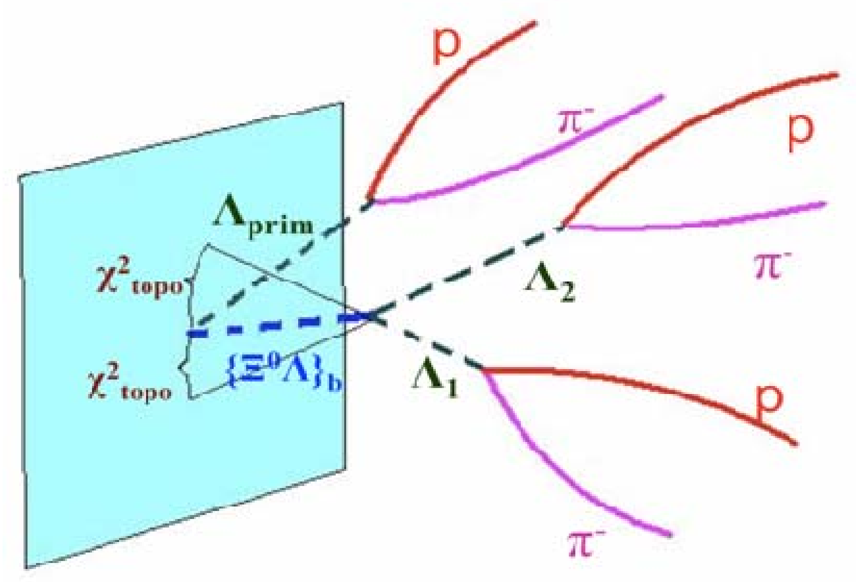


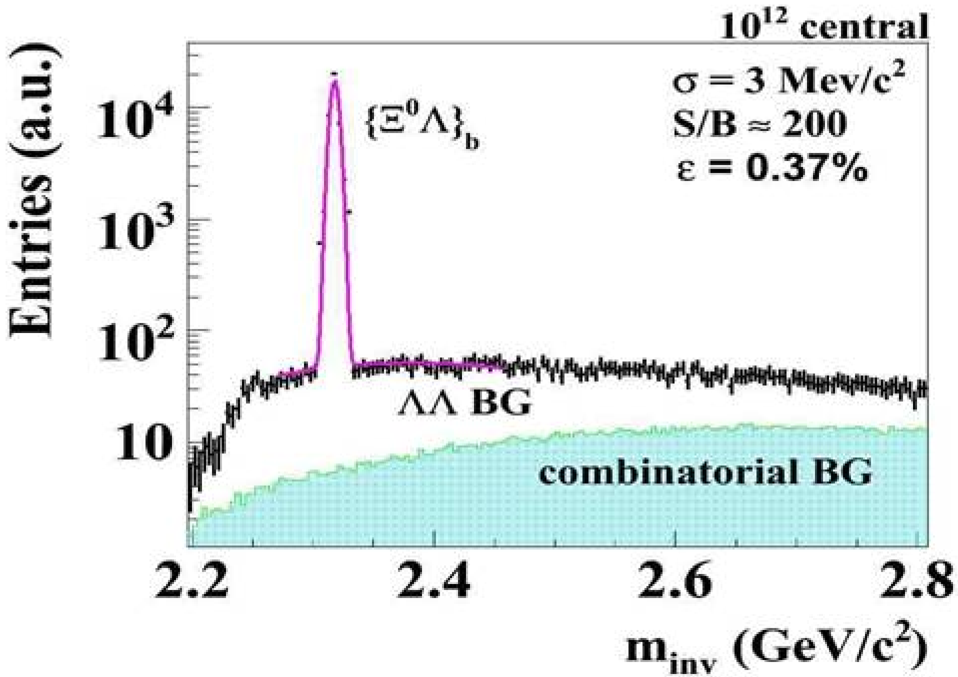
10^{12} min. bias events,
ca. 2-20 weeks @ reduced
interaction rate 10^5-10^6/s:

16k D^0 + 46k $\bar{D}^0$	and	**26k D^+ + 49k D^-**	(HSD)
87k D^0 + 251k $\bar{D}^0$	and	**52k D^+ + 98k D^-**	(SHM)

Exotica $\{\Xi^0, \Lambda\}$

Thermal multiplicity (7×10^{-3})



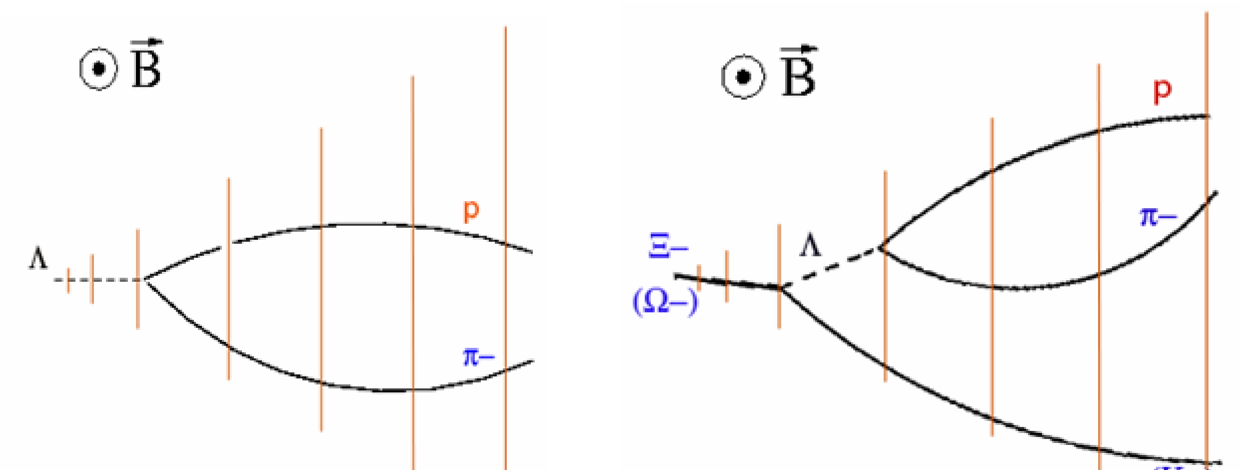


≈ 30 days of data taking at 10 MHz

CBM will see $\{\Xi^0, \Lambda\}$ with thermal yields

Even three OOM below this yield the signal will be visible above BG.

Identification of hyperons at SIS-100

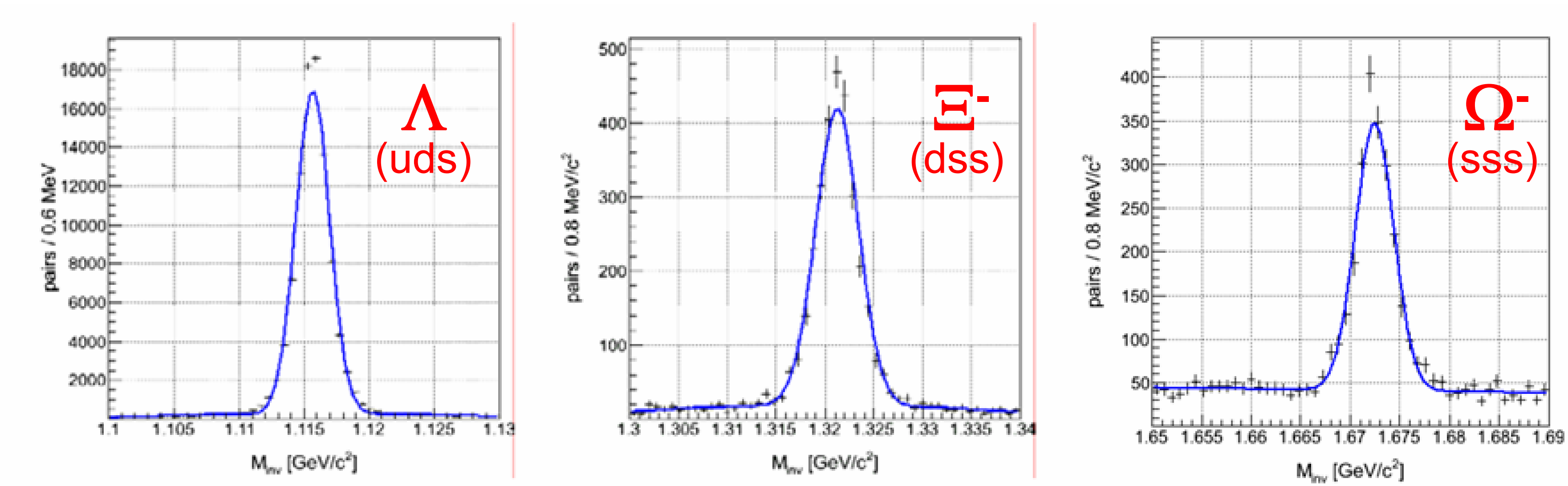


central Au+Au collisions at 6 AGeV:

Identified by decay topology in STS + inv. mass

No identification of secondaries required

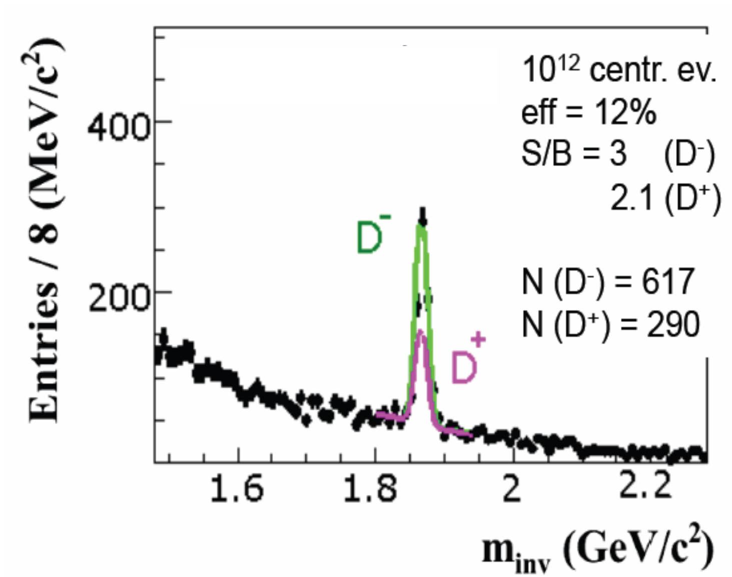
Clean signals for Λ, Ξ, Ω



Charm and charmonium production at SIS-100

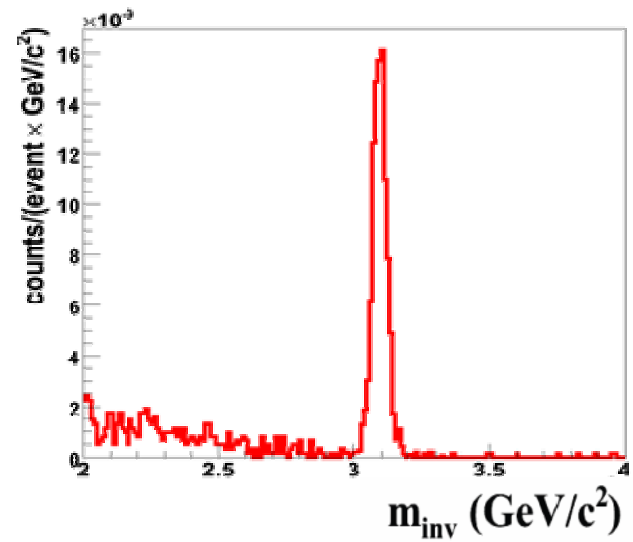
p+C collisions, 30 GeV

$D^{\pm} + X, D^{\pm} \rightarrow K\pi\pi$



- small statistics
- assuming a high-rate Micro Vertex Detector

$J/\psi + X, J/\psi \rightarrow \mu^{+}\mu^{-}$



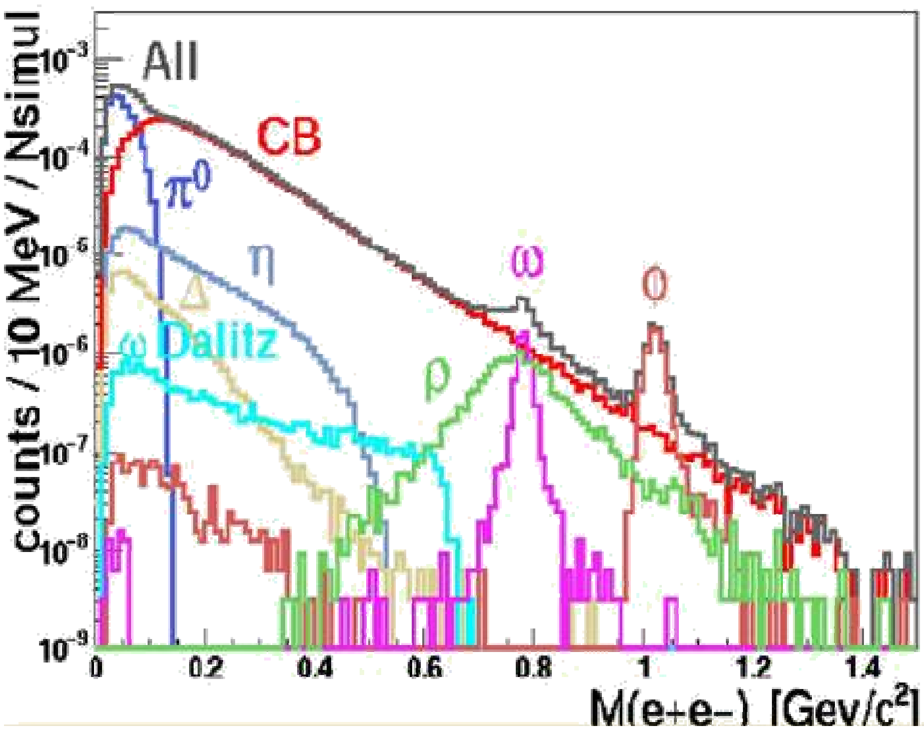
6 J/ψ recorded in 10^{10} events (b=0)
($3 \cdot 10^{4}$ J/ψ per week)

Di-lepton measurement at SIS-100

HADES

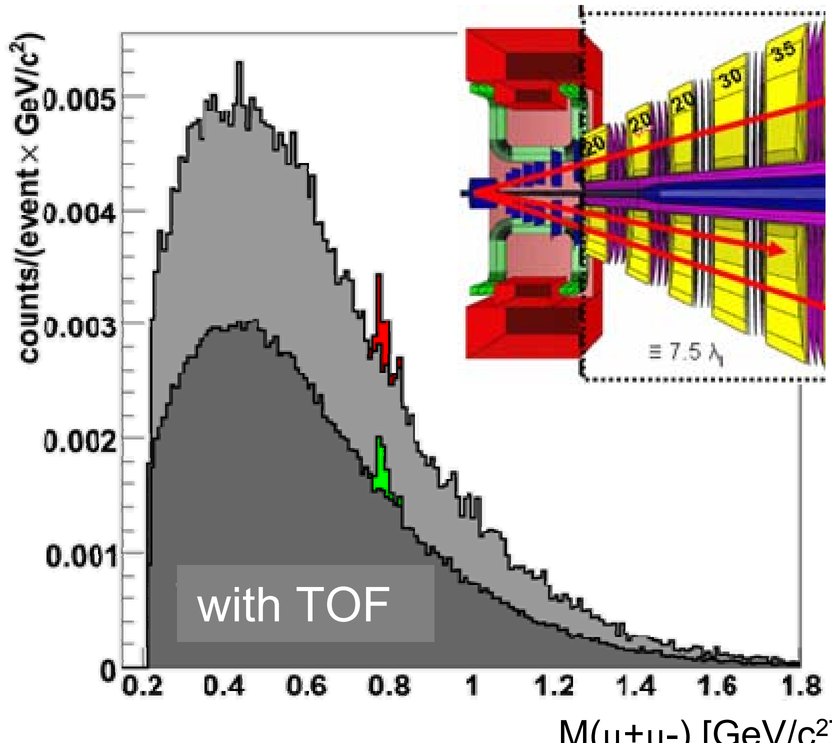
Monte Carlo simulation:
Di-electron invariant mass spectrum

central Au+Au collisions at 8*A* GeV



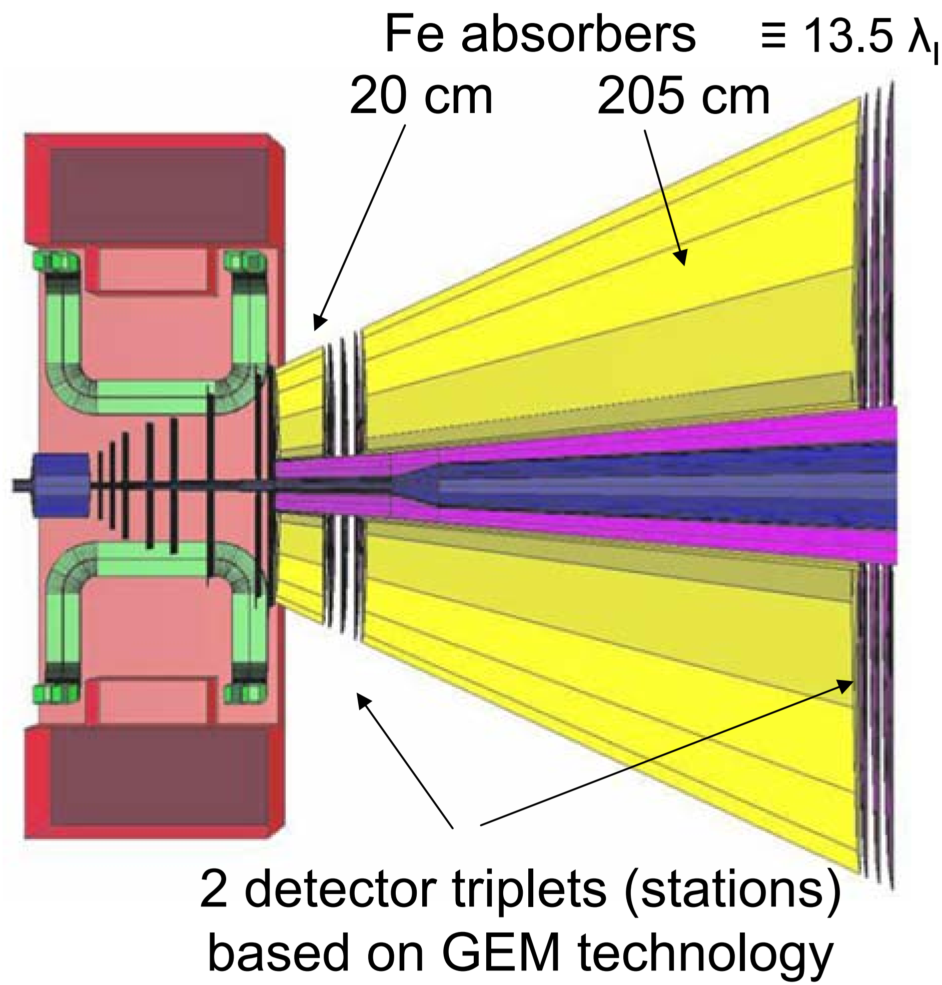
CBM

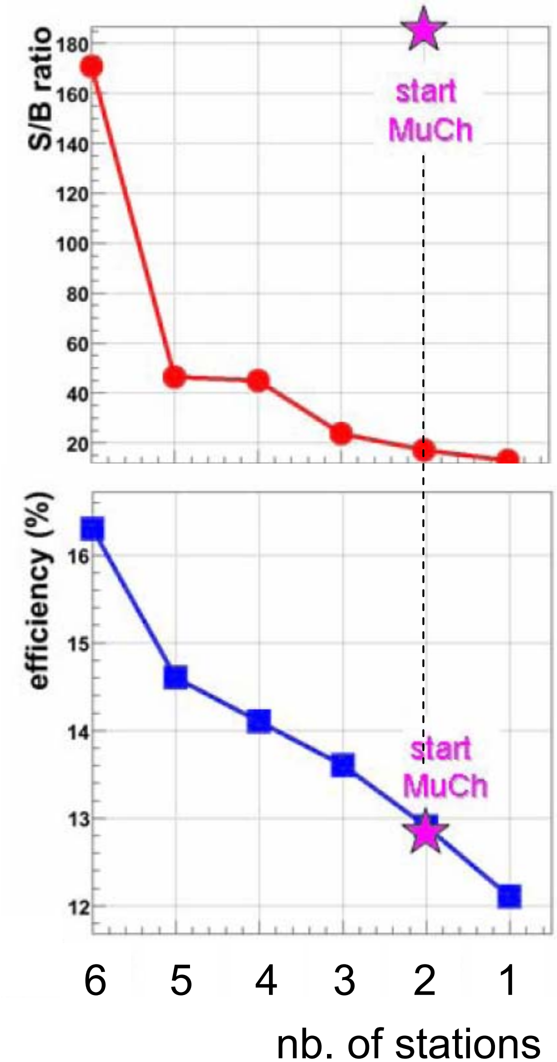
Full event reconstruction:
Di-muon invariant mass spectrum
(only ω meson as signal)



J/ψ detection via muons at SIS-100

p+Au collisions, 25 GeV





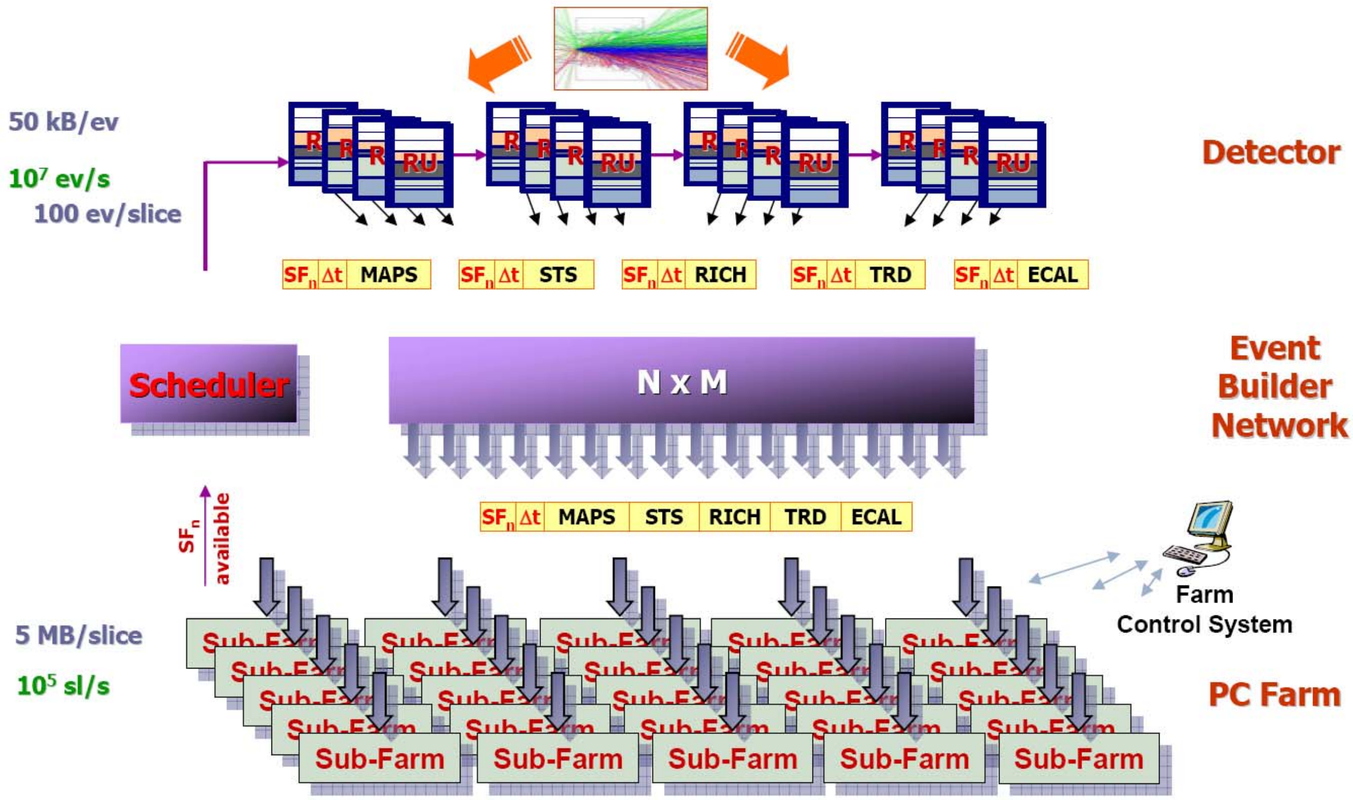
Detector developments

On-line event selection

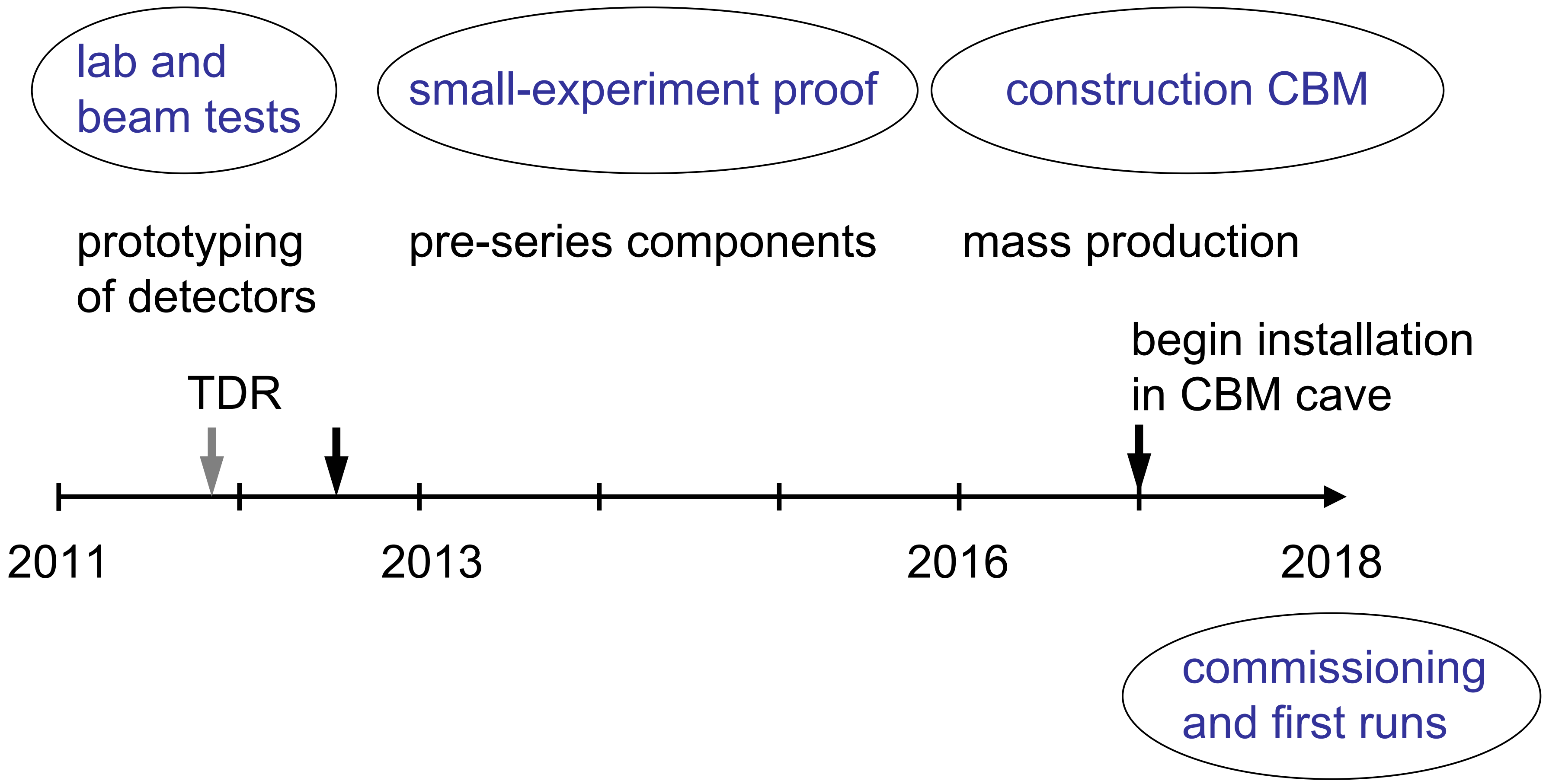
No simple trigger primitive, like high p_t, available to tag events of interest.
Open charm: The only selective signature is the detection of the decay vertex.

First level event selection in a processor farm fed with data from the event building network.

- Many-core processors
- Parallelization



Timeline towards the CBM experiment



CBM Collaboration: 55 institutions, > 400 members

15th CBM Collaboration Meeting,
April 12 - 16, 2010 at GSI

Croatia
China
Czech Republic
France
Hungary
India
Korea
Norway
Germany
Poland
Romania
Russia
Ukraine

CBM Progress Report 2010

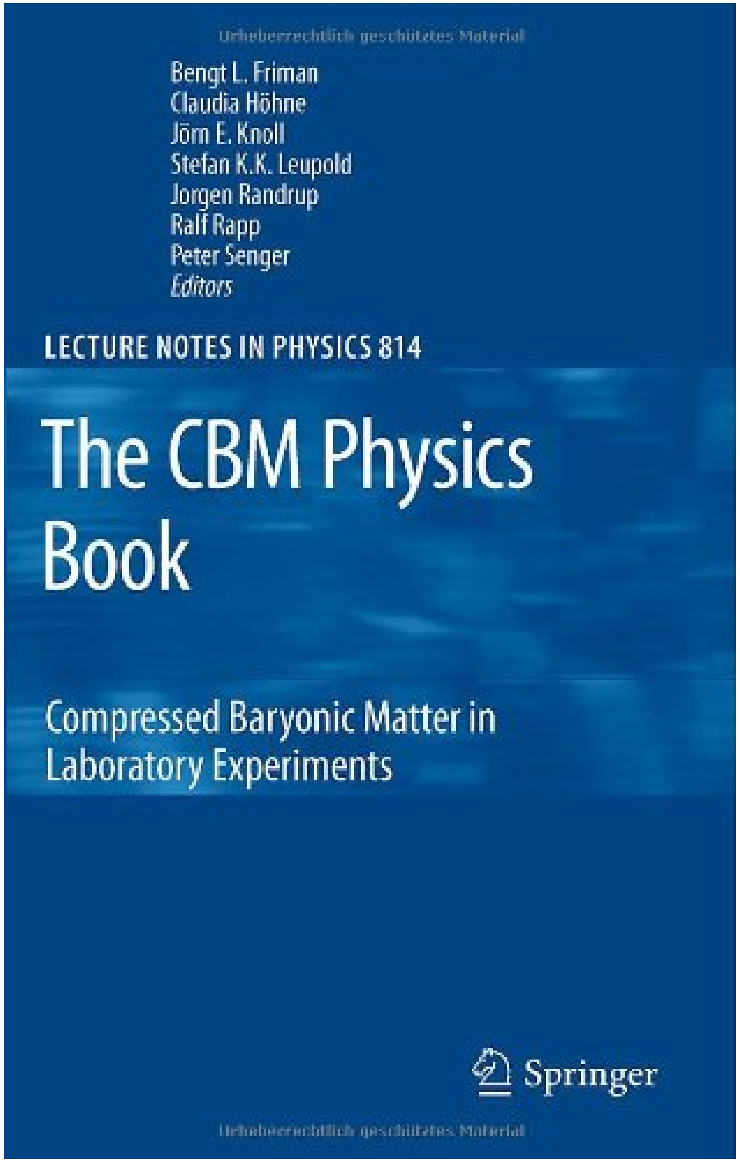
100 pages, shortly available at
www-cbm.gsi.de

Contents:

- Micro Vertex Detector
- Silicon Tracking System
- Ring Imaging Cherenkov Detector
- Muon System
- Transition Radiation Detectors
- Time-of-Flight Detectors
- Calorimeters
- Magnet
- FEE and DAQ
- Physics Performance
- Software and Algorithms

CBM Physics Book

Lecture Notes in Physics Vol. 814 (2011)
1000 pages, 400 figures, 2000 citations



General Introduction
Prelude by Frank Wilczek
Facets of Matter
Executive Summary

Part I
BULK PROPERTIES OF STRONGLY INTERACTING MATTER

Part II
IN-MEDIUM EXCITATIONS

Part III
COLLISION DYNAMICS

Part IV
OBSERVABLES AND PREDICTIONS

Part V
CBM EXPERIMENT