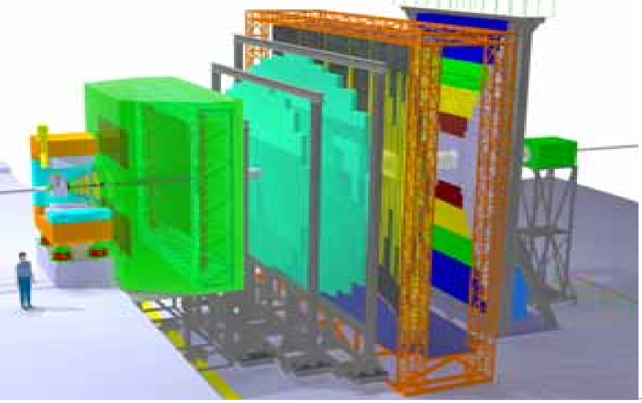
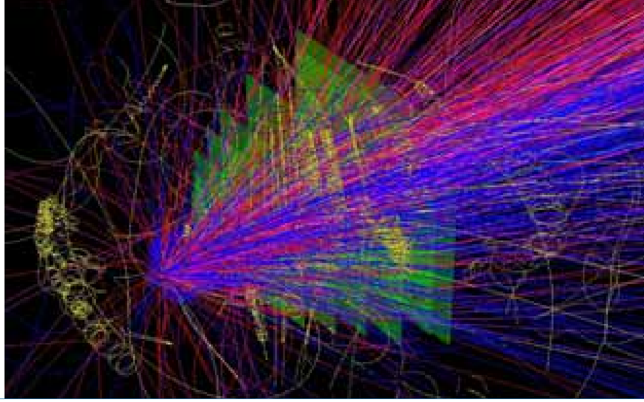


The *Compressed* ***B****aryonic* ***M****atter* *Experiment at FAIR*

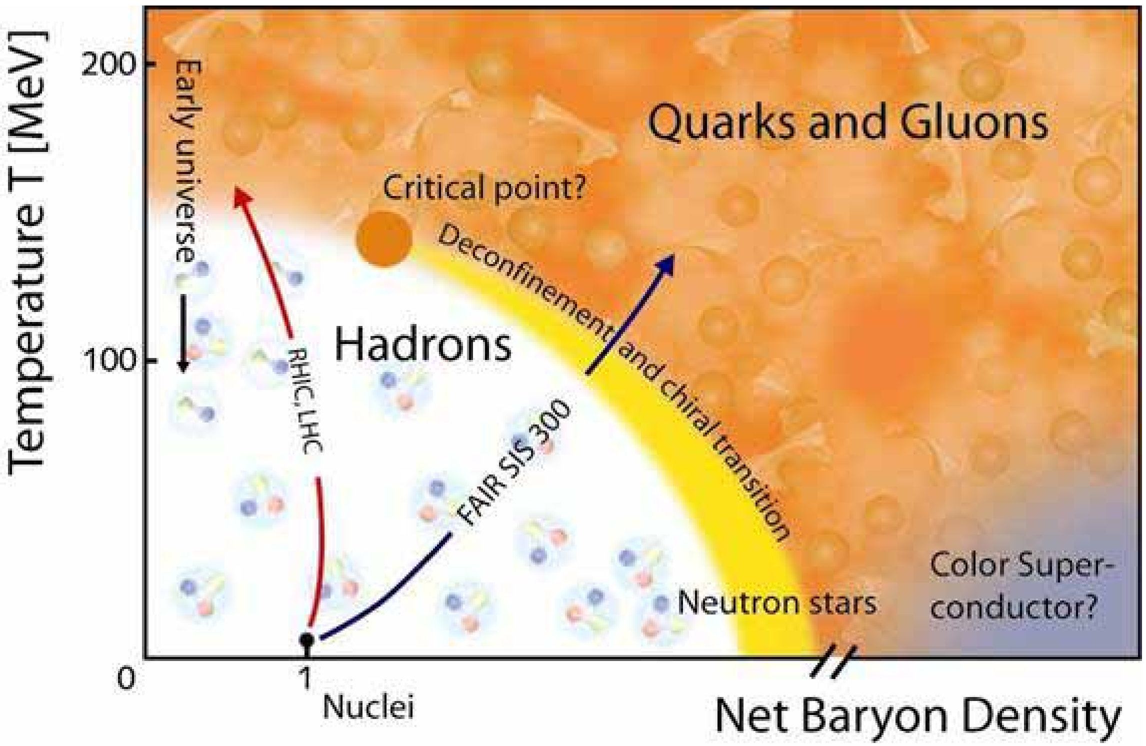
Johann M. Heuser
GSI Helmholtz Centre for Heavy Ion Research GmbH, Darmstadt, Germany

for the CBM Collaboration

International Workshop on Hot & Cold Baryonic Matter
15-20 August 2010
Budapest - Hungary

CBM FAIR GSI

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

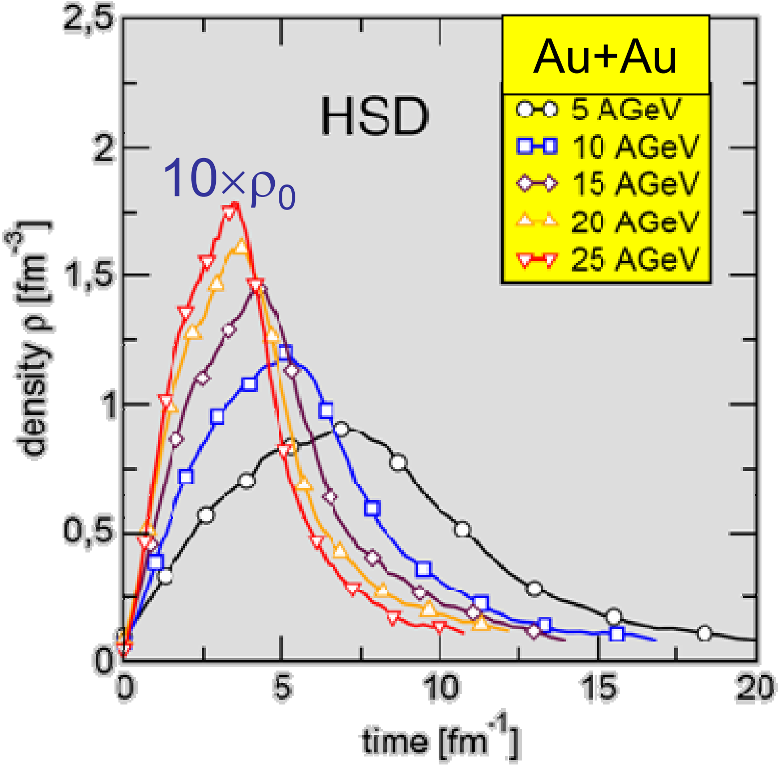
Projects to explore the QCD phase diagram at large μ_B:

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

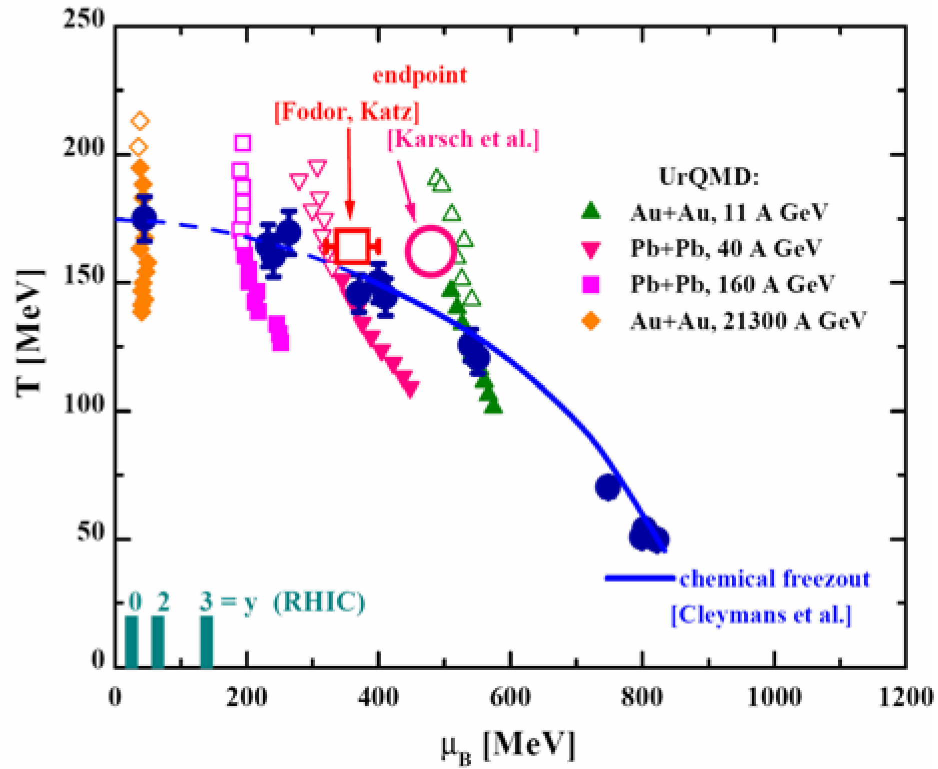
CBM@FAIR/SIS-300 .... bulk and **rare observables**

Transport model predictions

E. Bratkovskaya, W. Cassing

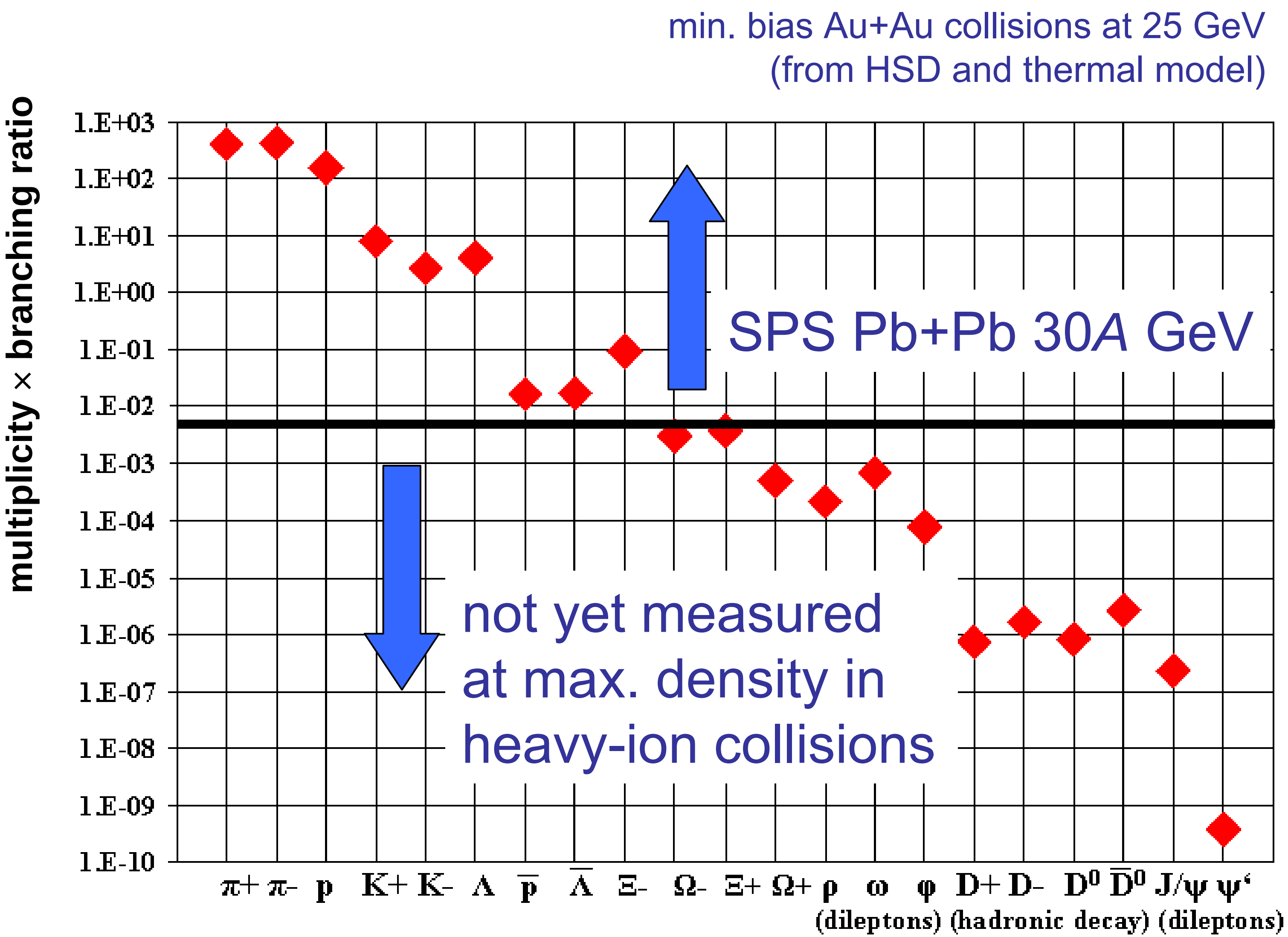


UrQMD: L.V. Bravina et al., Phys. Rev. C60 (1999) 044905



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

Particle multiplicities



B. Friman, C. Höhne,
J. Knoll, S. Leupold,
J. Randrup, R. Rapp,
P. Senger (editors)

Springer

The CBM Physics Book

Compressed Baryonic Matter
in Laboratory Experiments

1000 pages,
about 60 authors

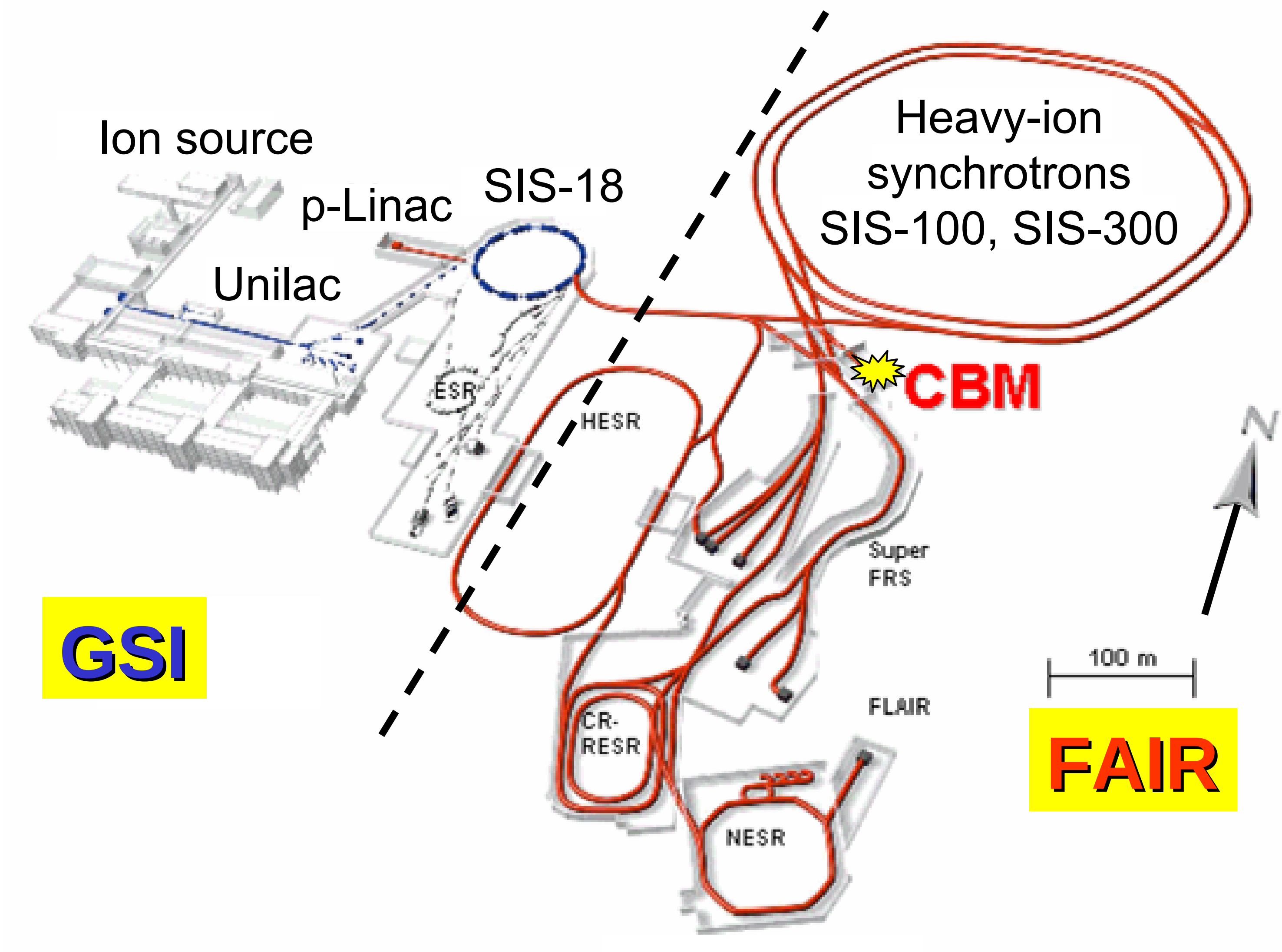
Submitted Sept. 2009
to Springer as
"Lecture Notes in Physics"

Content:

- Bulk Properties of Strongly Interacting Matter
- In-Medium Excitations
- Collision Dynamics
- Observables and Predictions
- The CBM Experiment
- Appendix: Overview on heavy-ion experiments

http://www.gsi.de/fair/experiments/CBM/PhysicsBook.html

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

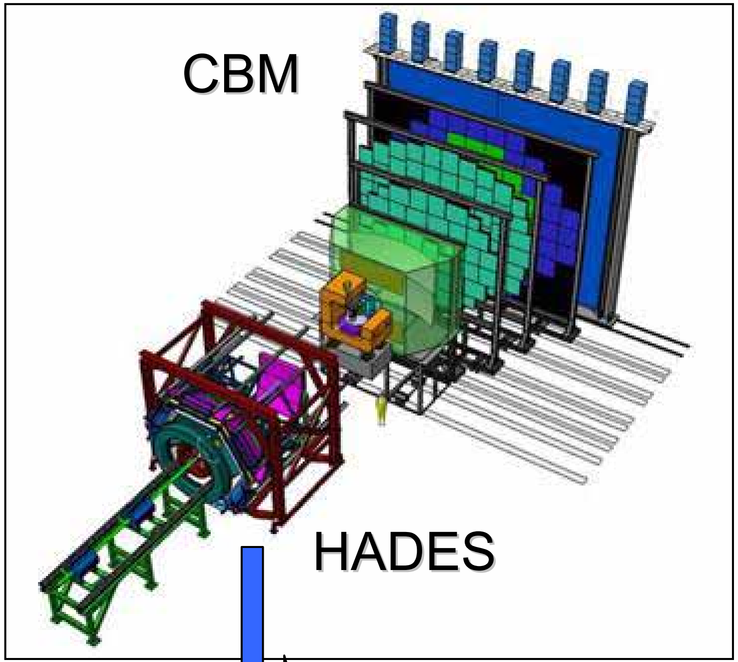
intensities:
at CBM
up to 10^9 ions per second

CBM @ FAIR

Beams available for experiments:

FAIR phase A — SIS-100 (year 2018):
- nuclei up to 14 (11) A GeV, Z/A=0.5 (0.4)
- protons up to 29 GeV

FAIR phase B — SIS-300 (in future):
- nuclei up to 44 (34) A GeV, Z/A=0.5 (0.4)
- protons up to 89 GeV



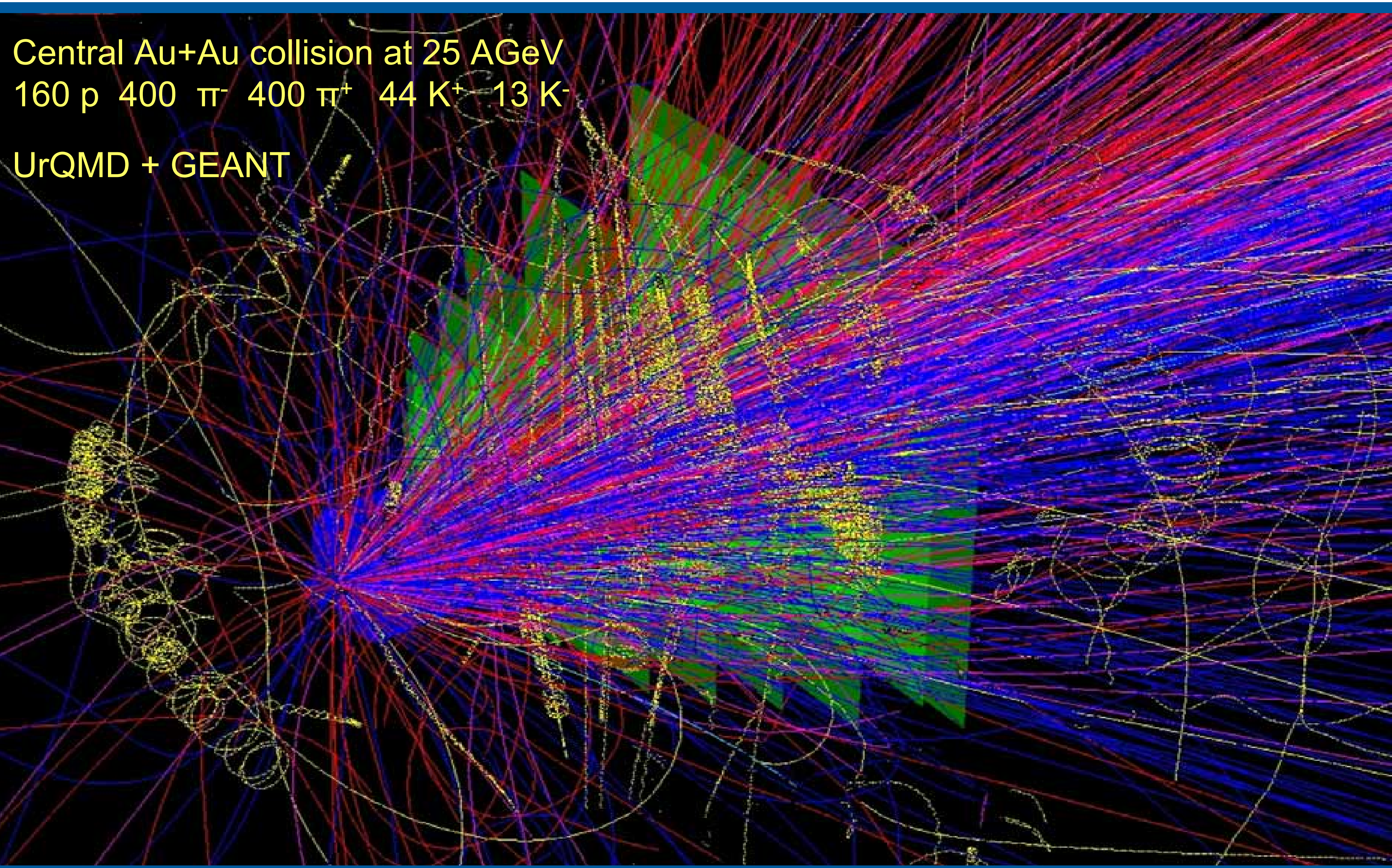
High Acceptance
Di-Electron
Spectrometer

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

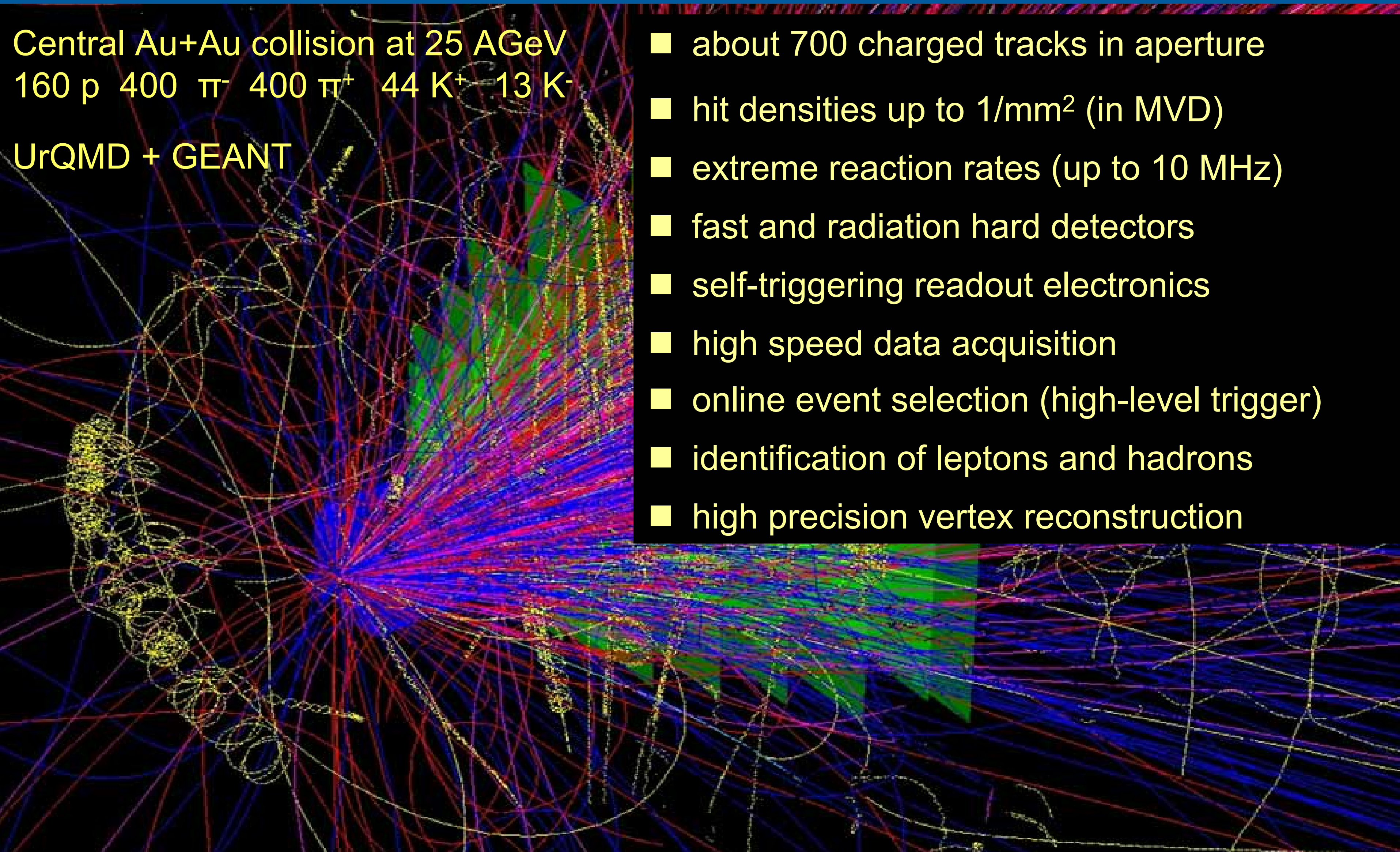
- HADES + pre-CBM at SIS-100
- full CBM at SIS-300

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

Experimental challenges

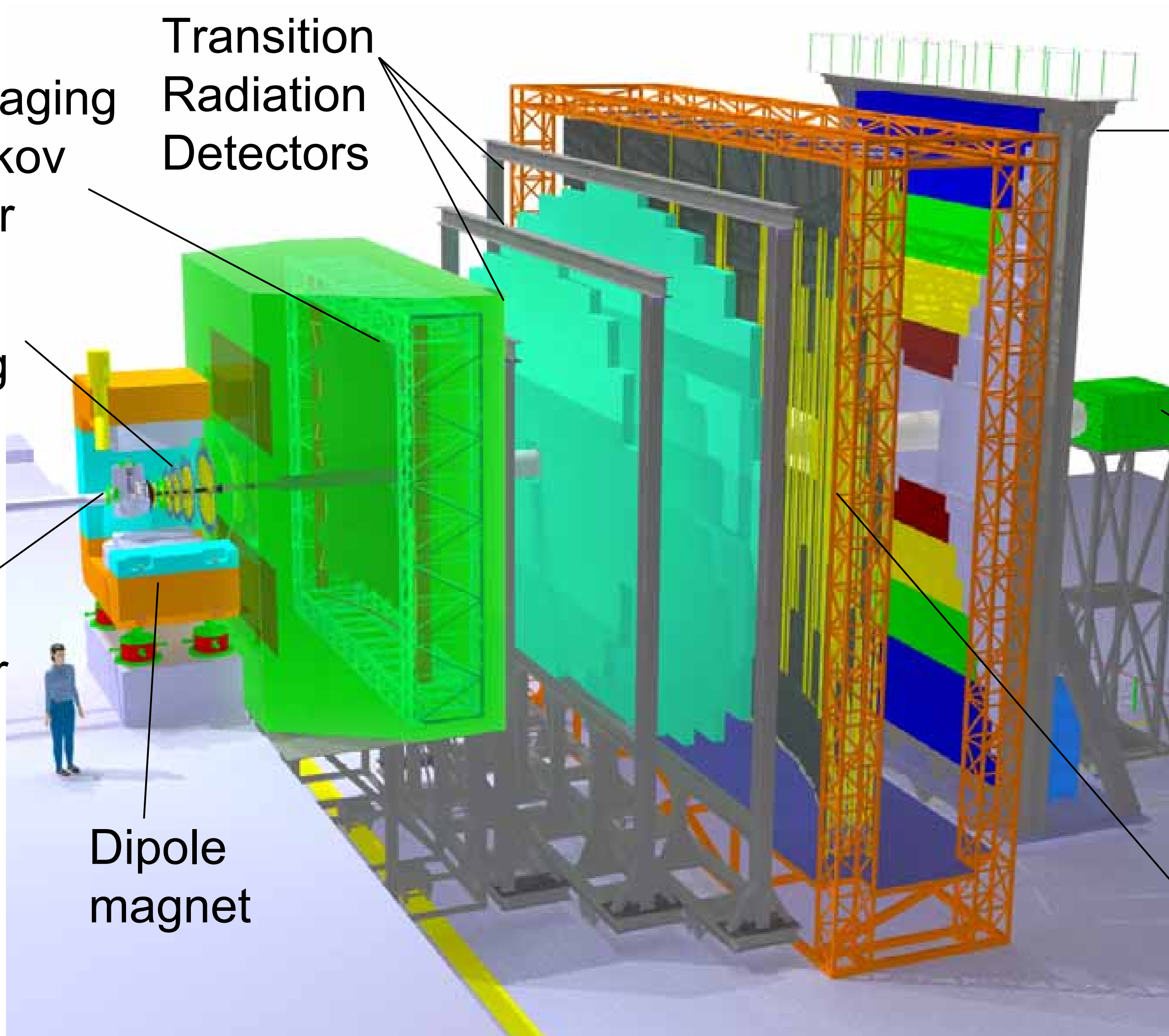


Experimental challenges

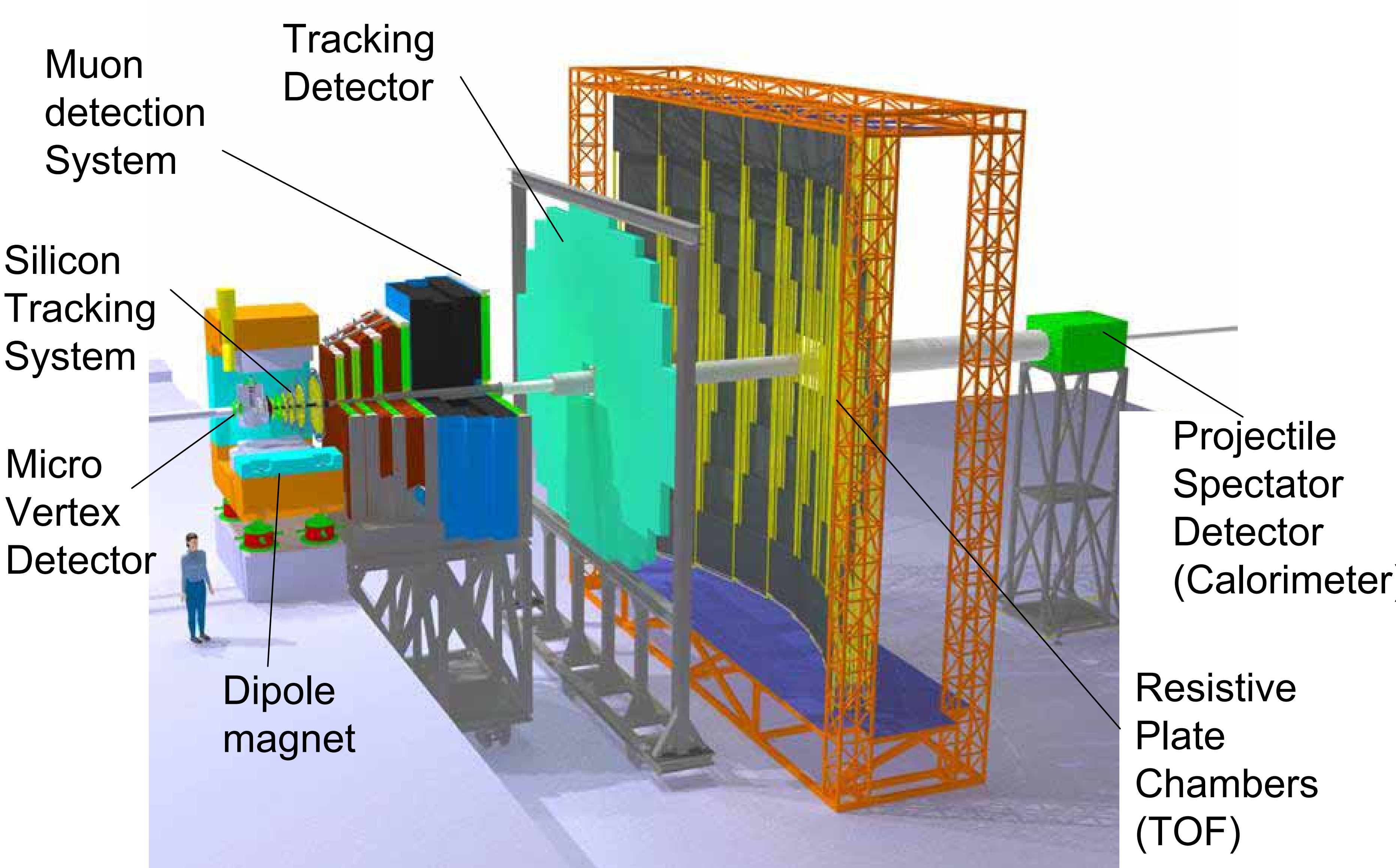


- about 700 charged tracks in aperture
- hit densities up to 1/mm^2 (in MVD)
- extreme reaction rates (up to 10 MHz)
- fast and radiation hard detectors
- self-triggering readout electronics
- high speed data acquisition
- online event selection (high-level trigger)
- identification of leptons and hadrons
- high precision vertex reconstruction

The Compressed Baryonic Matter Experiment



The Compressed Baryonic Matter Experiment



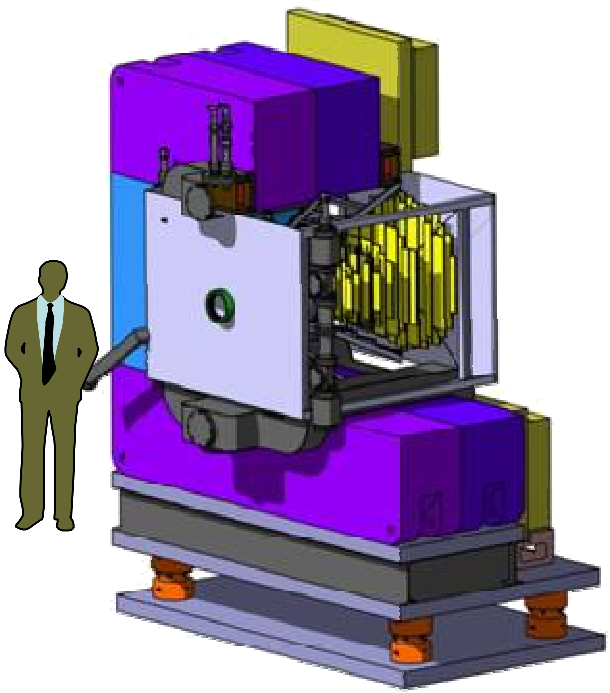
Conceptual design and feasibility studies

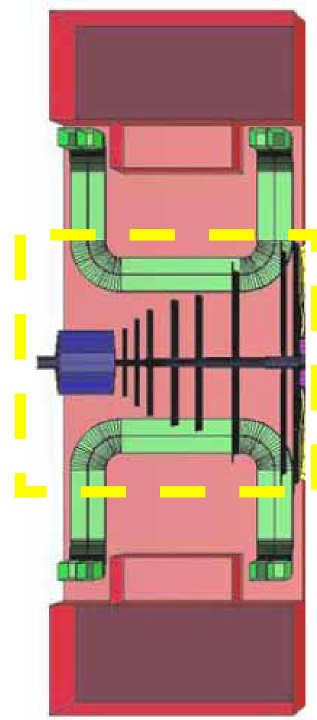
Software tools:

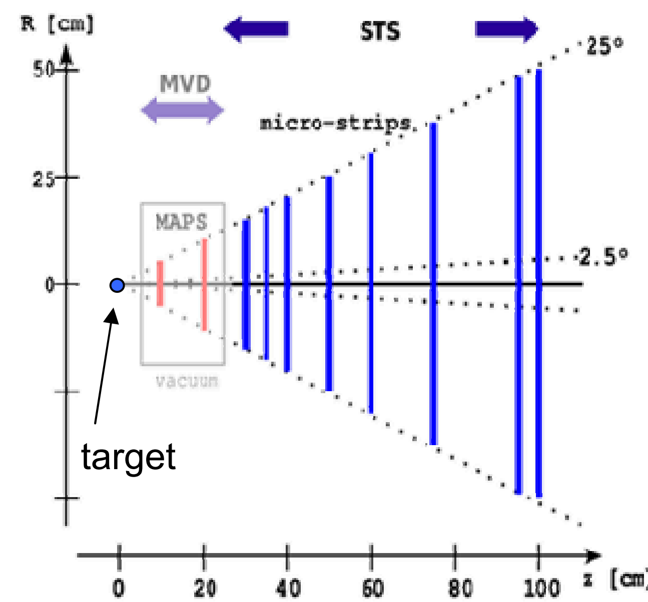
- Framework FAIRroot: Root + Virtual Monte Carlo
  - Transport codes GEANT 3 & 4, FLUKA
  - Event generators UrQMD, HSD, PLUTO
- Realistic detector layouts and response functions
- Fast ("SIMDized") track reconstruction algorithms for online event selection

CBM Target region

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







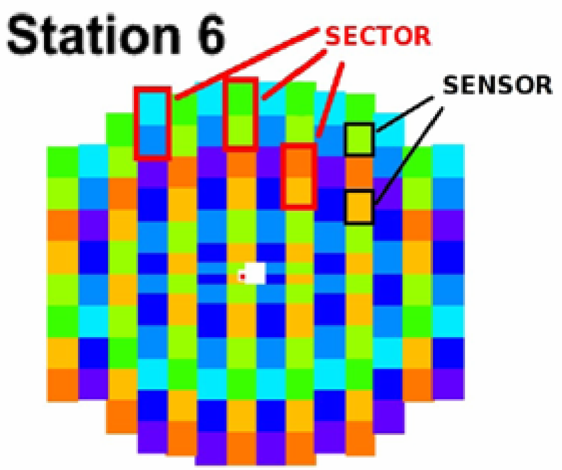
STS:
8 detectors stations
in thermal enclosure

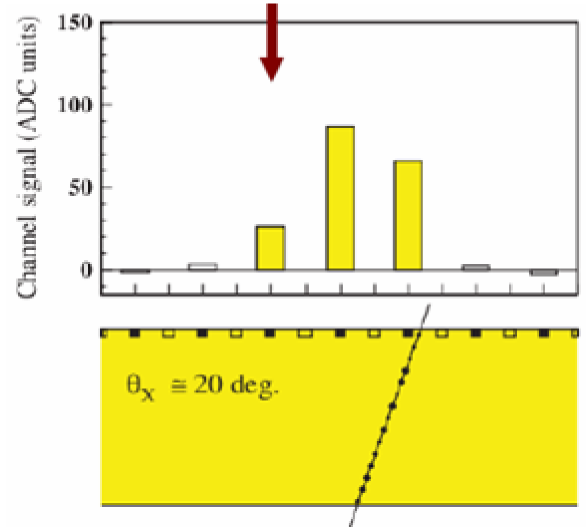
MVD:
2 detectors stations
in vacuum vessel

length: 1m
downsteam of target
aperture: 2.5° <Θ< 25°

Digitisation: Detector hits in the STS

Modular detector structure, dead zones, overlaps

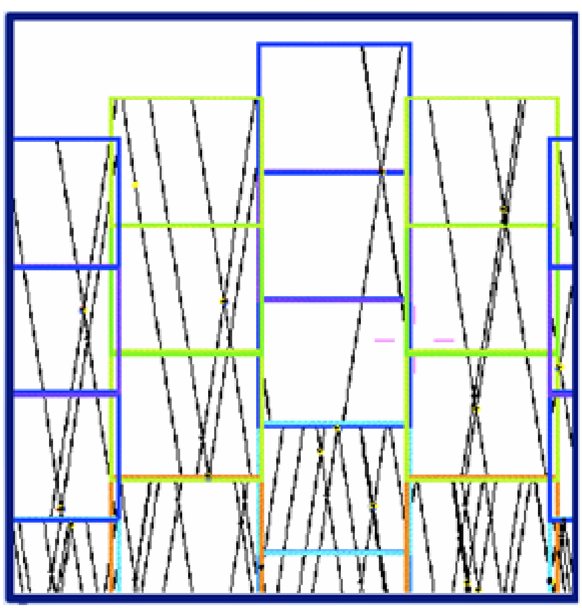


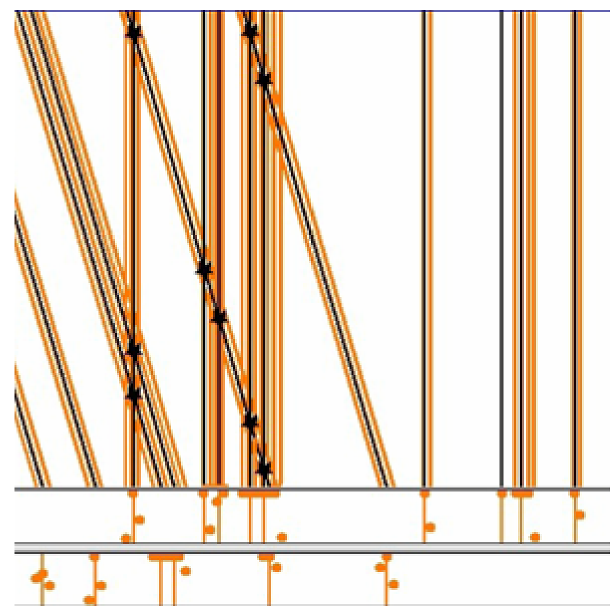


Charge sharing

Realistic sensor model

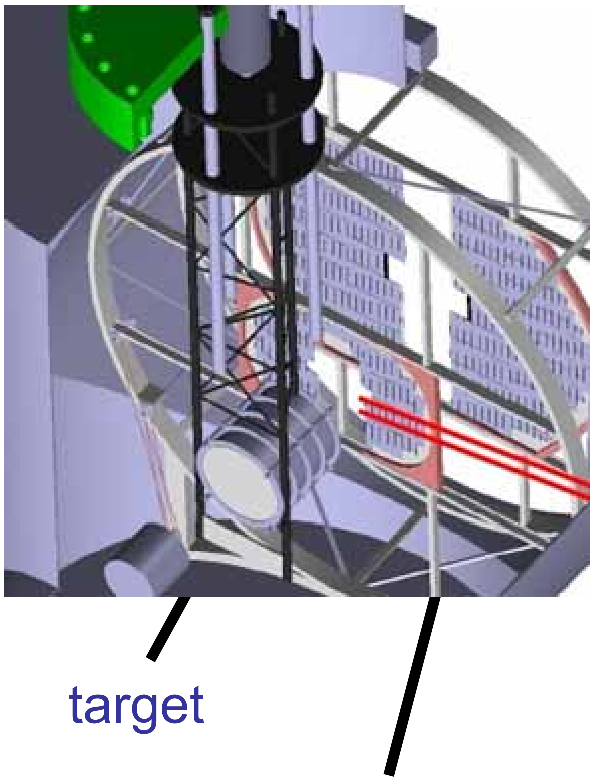
1-d cluster finding





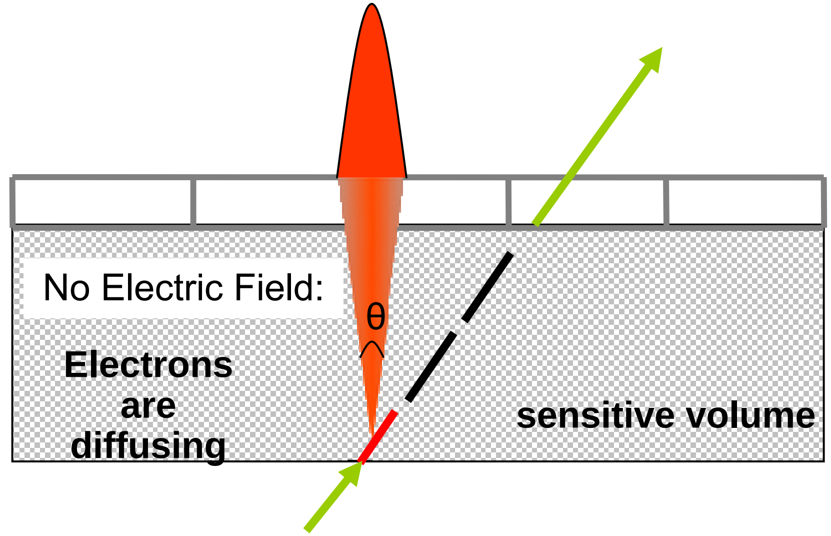
2-d hits from crossing of cluster centres

Digitisation: Detector hits in the MVD

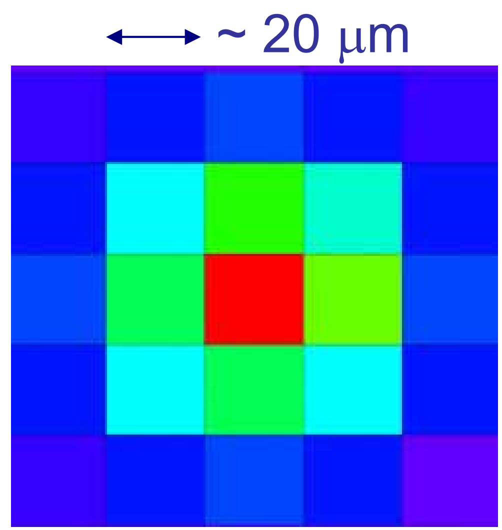


target

MVD station



Charge production and diffusion in the Monolithic Active Pixel Sensors



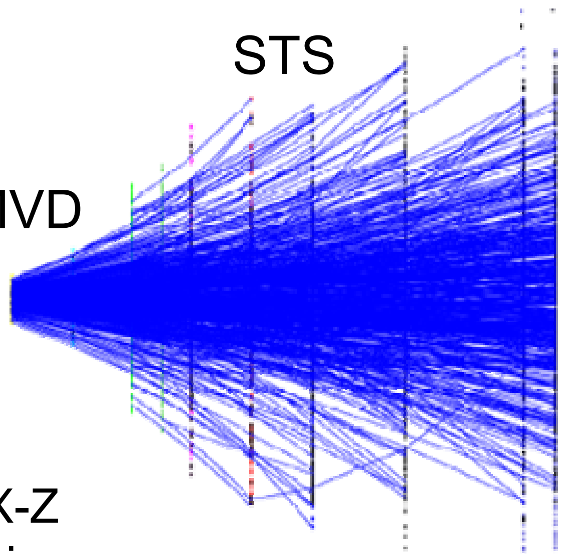
2-d charge cluster on pixels

rather slow detector:
event pile-up implemented

Charged particle tracking in the Silicon Detectors

STS

MVD



X-Z view

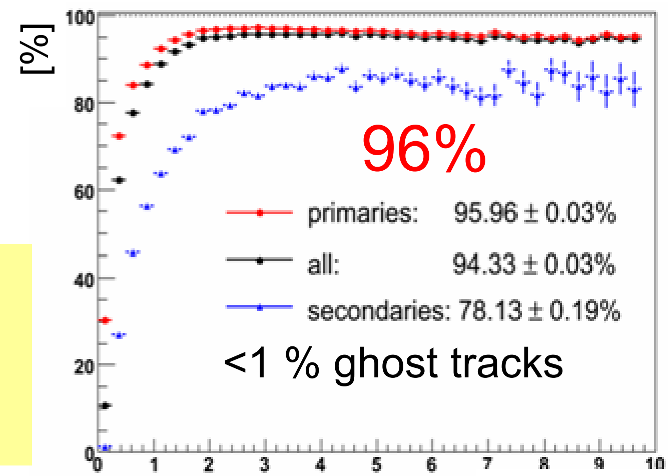
Au+Au collision
25*A* GeV, central
(UrQMD)

700 reconstr. tracks

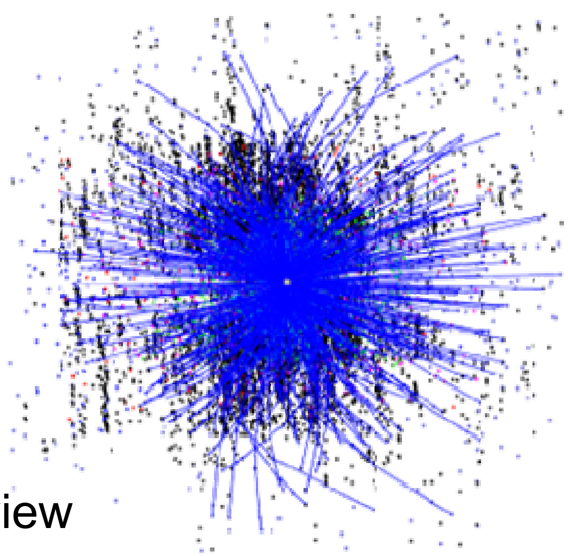
Cellular Automaton
and Kalman Filter

fast *SIMDiz*ed code

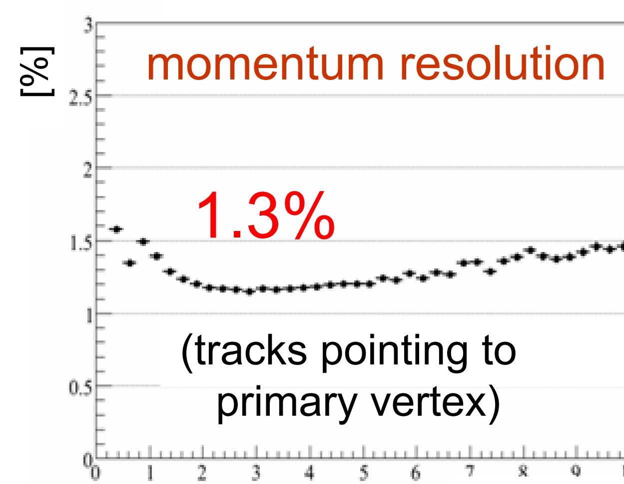
reconstruction efficiency



p [GeV/c]

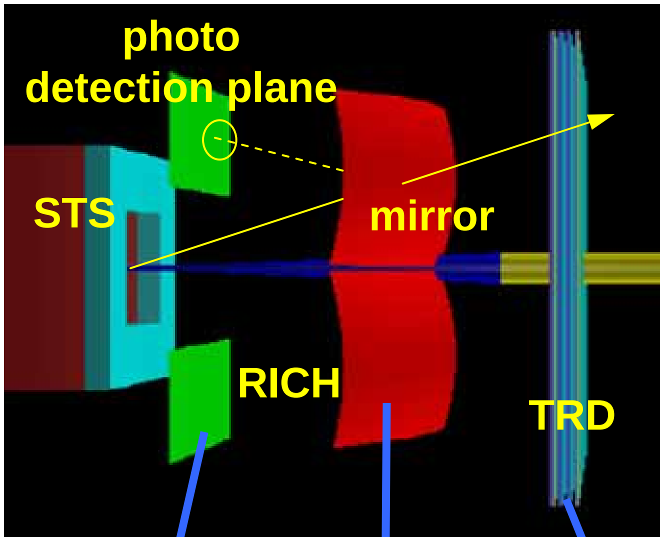


Y-X view



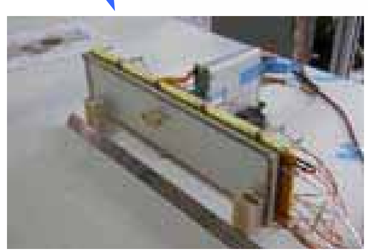
p [GeV/c]

Electron identification

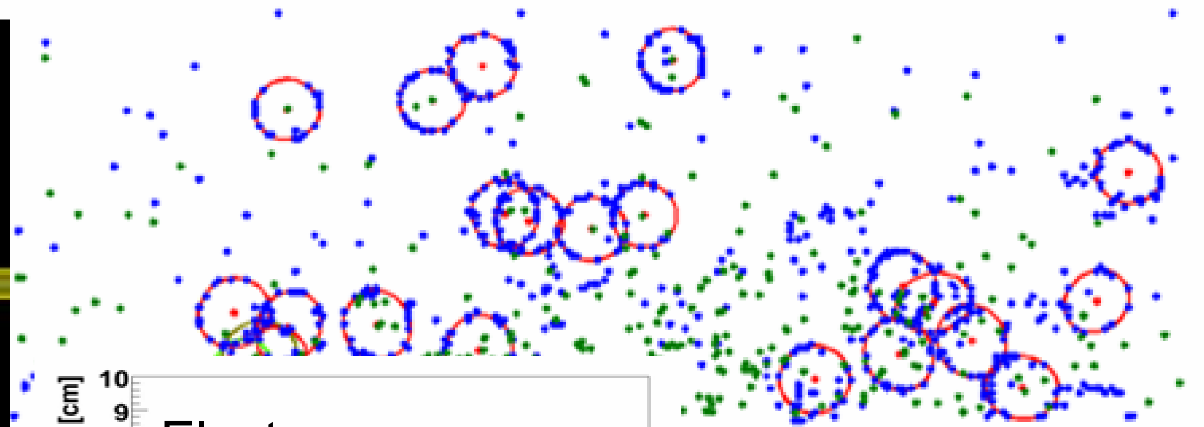


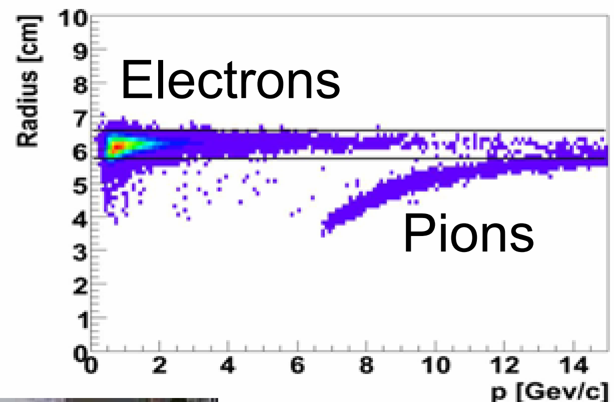
multi-anode PMT

glass mirror with Al+MgF_2



high-rate TRD





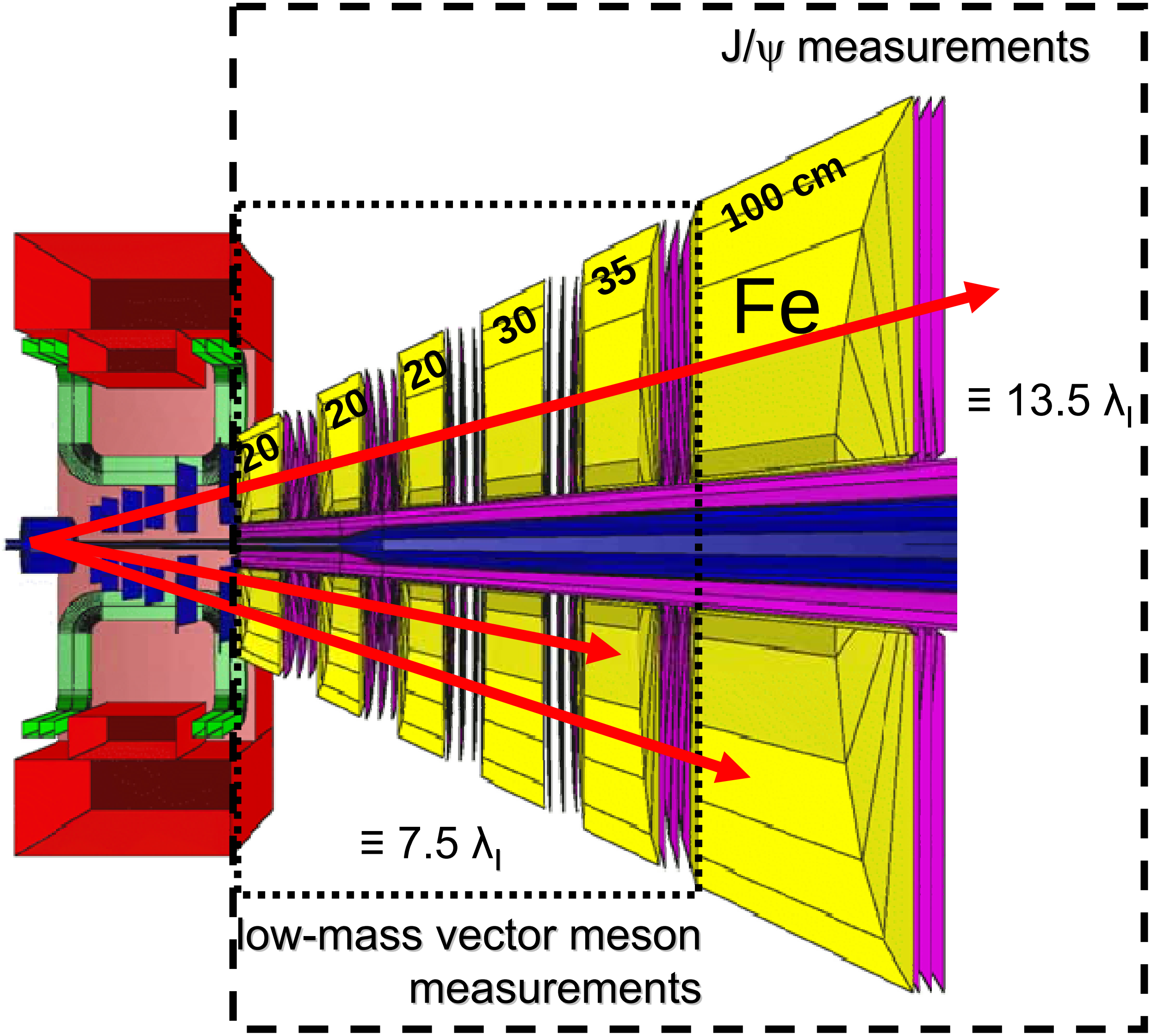
Rings:
up to 100 per event
~ 6cm diameter
~ 20 photo electrons

finding eff. **95.3%**

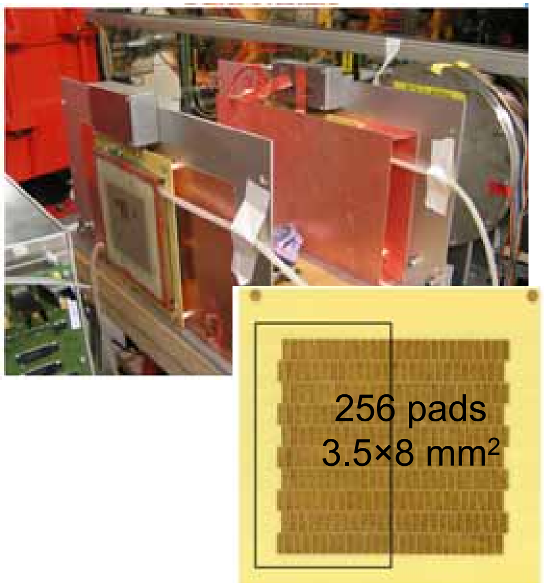
RICH + TRD:

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

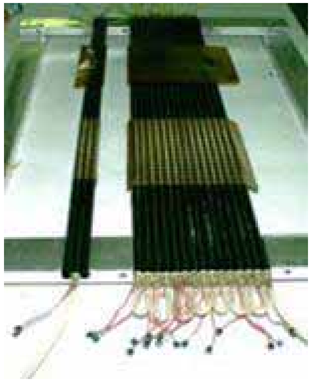
Muon Chambers (MuCh) system



GEM detectors



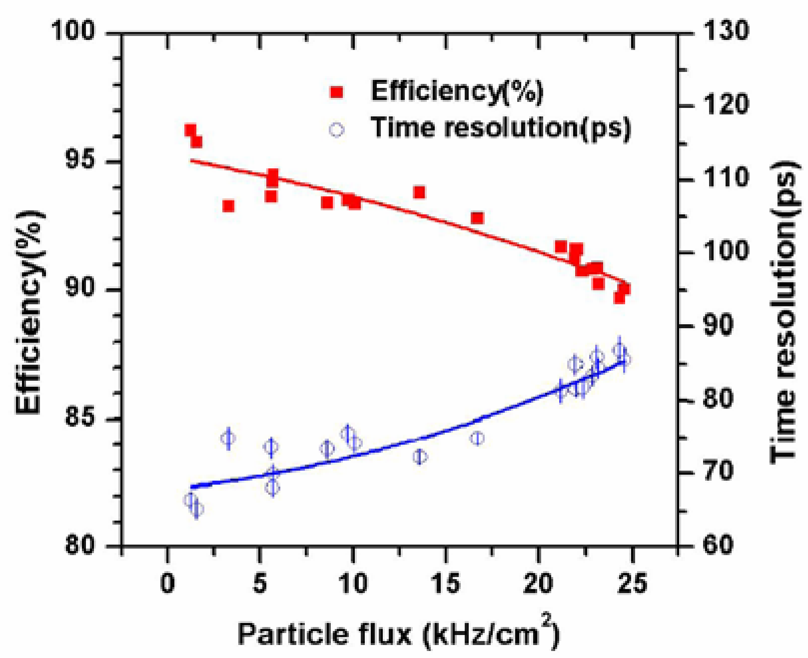
Straw tubes



Hadron identification, Time-of-flight measurement

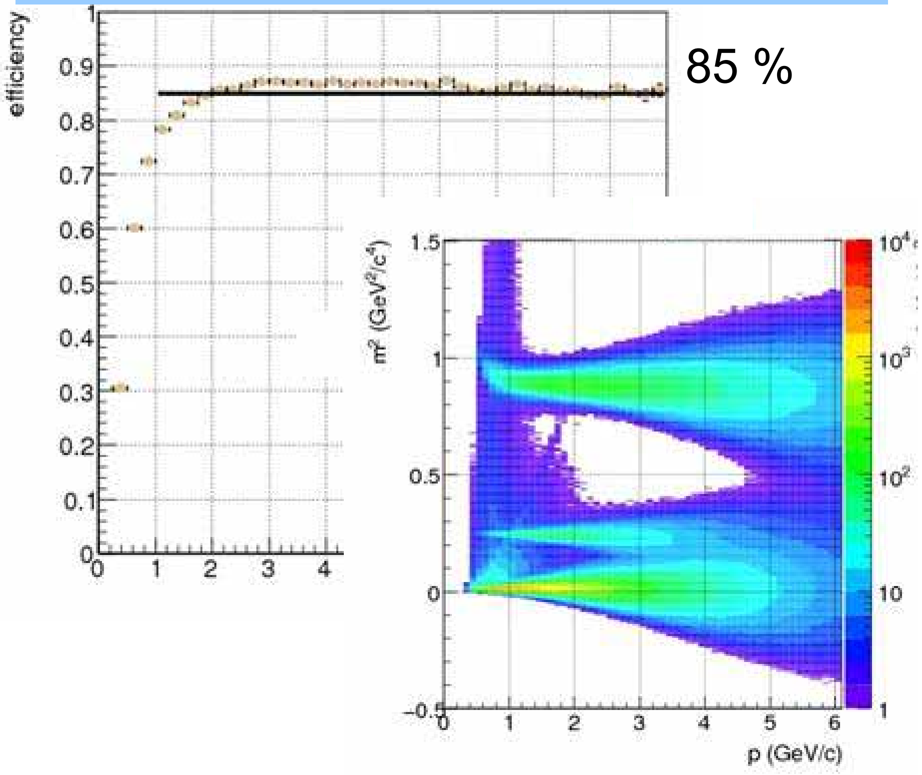
Resistive Plate Chambers

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



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

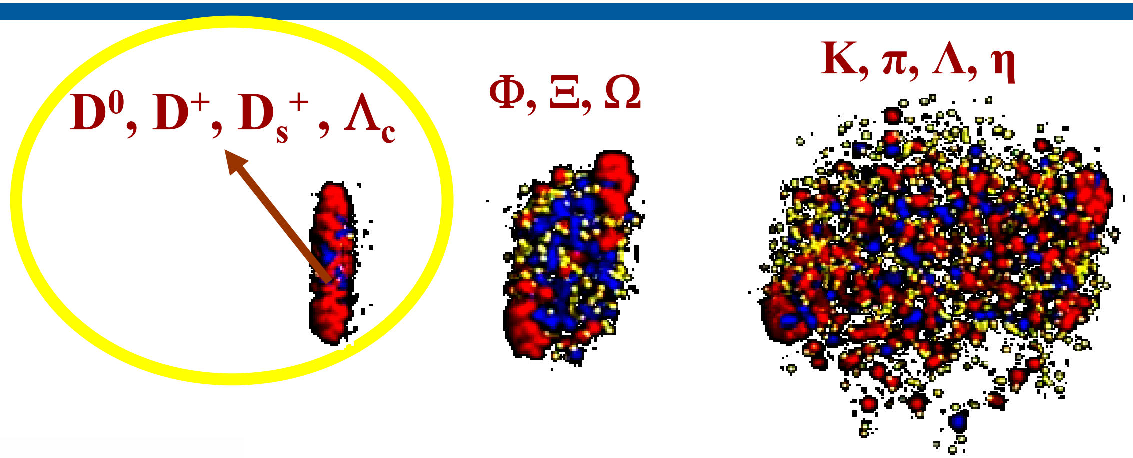
global tracking: STS,TRD, TOF

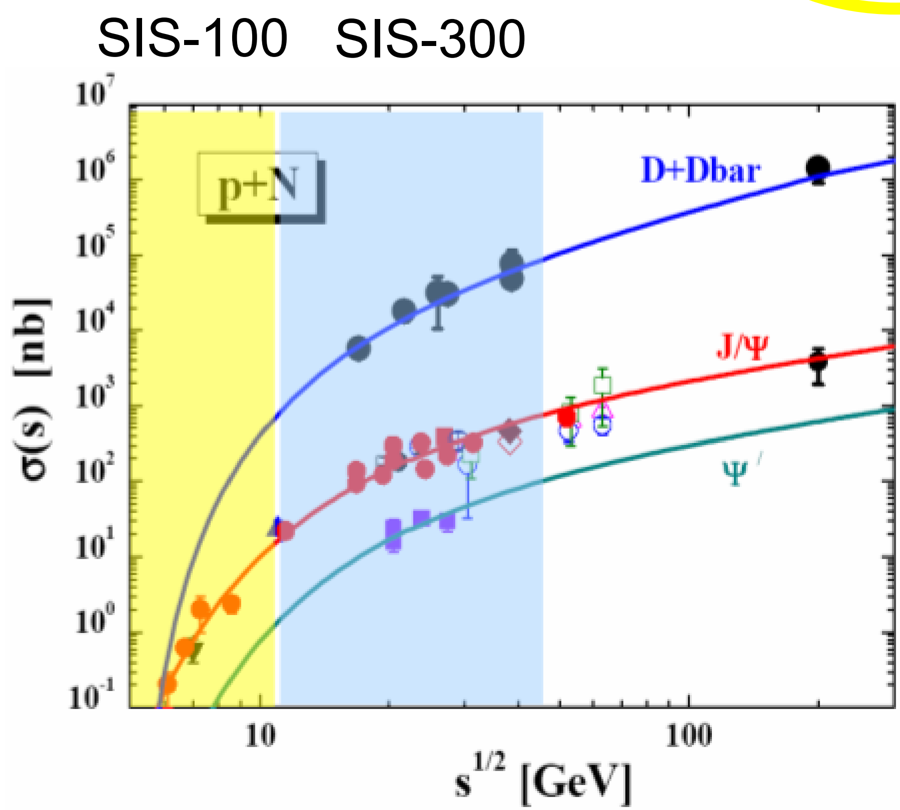


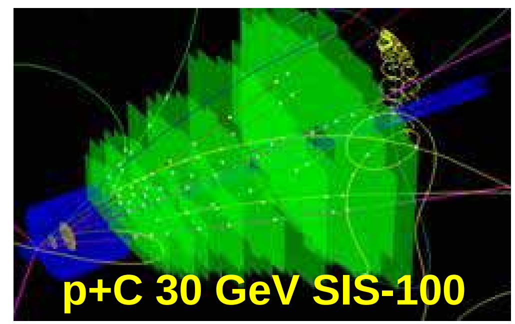
Open charm detection

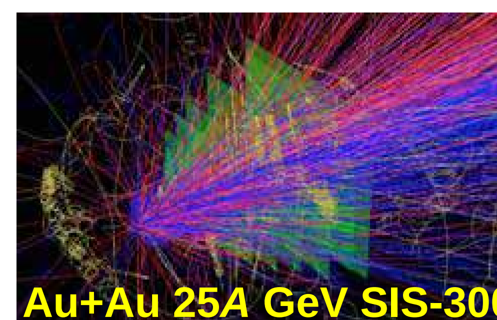
Motivation:

probe the dense phase

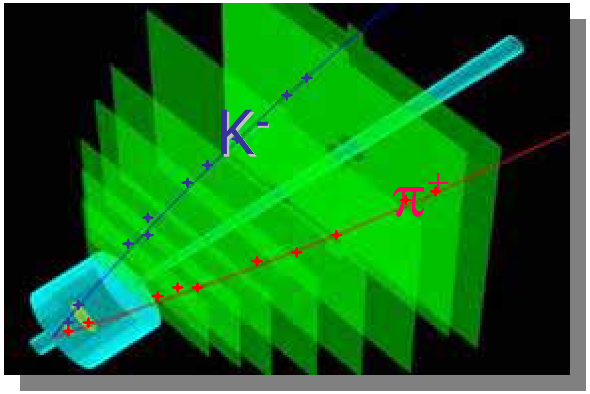


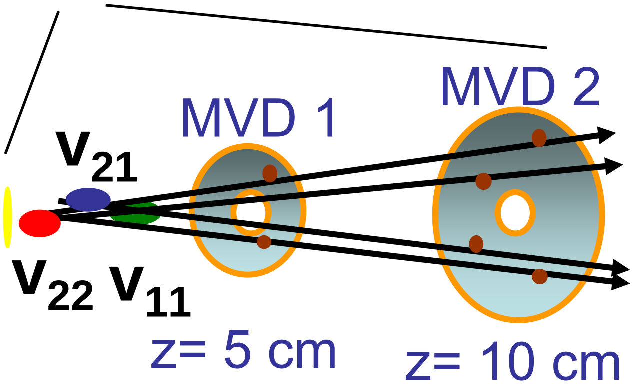






Open charm detection

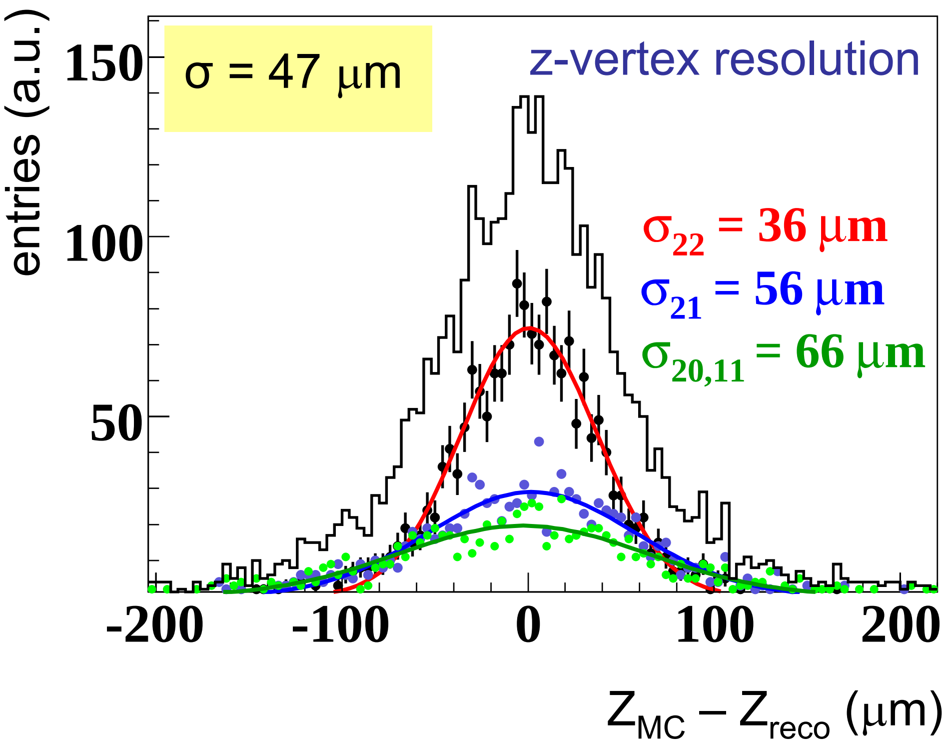




- Ultrathin Micro Vertex Detector
- Monolithic Active Pixel Sensors
- high-performance carbon supports
- material budget <0.5 % X_0 per station

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

- efficient separation of prim./sec. vertices
- requires z-vertex resolution of $\sigma \approx 50\ \mu m$

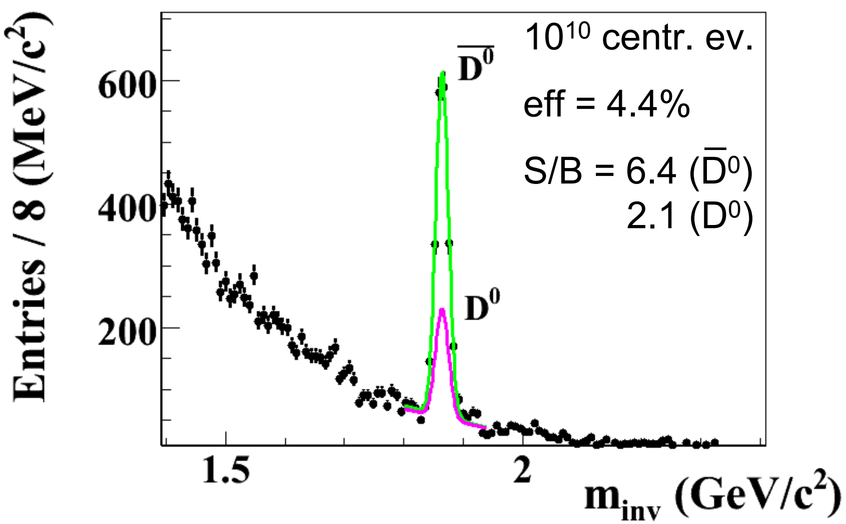


Open charm measurement at SIS-300

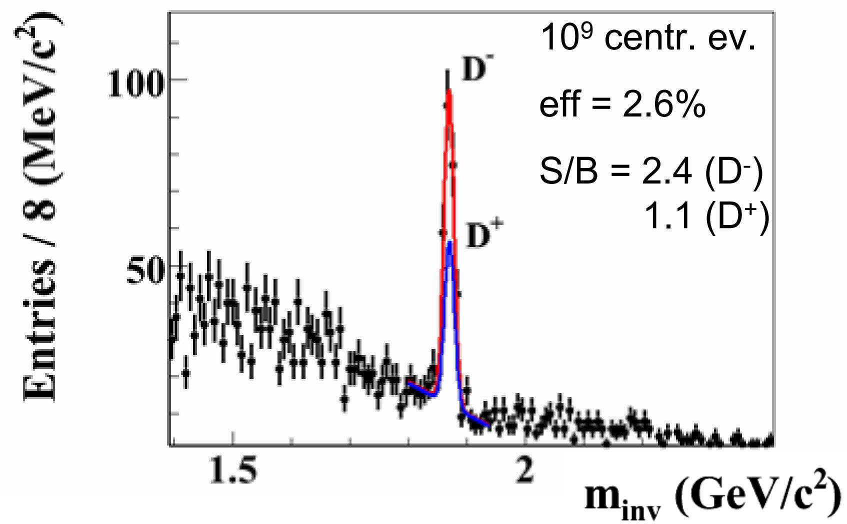
Au+Au collisions, 25*A* GeV

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

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



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

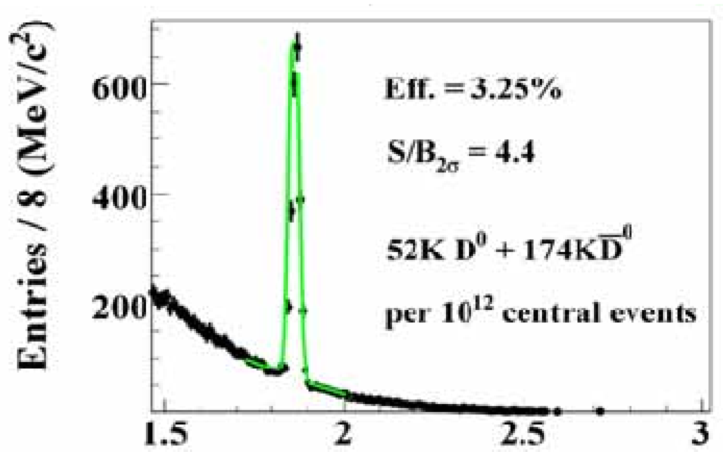


10^{12} min. bias events,
ca. 2-20 weeks @ reduced
interaction rate 10^5-10^6/s:

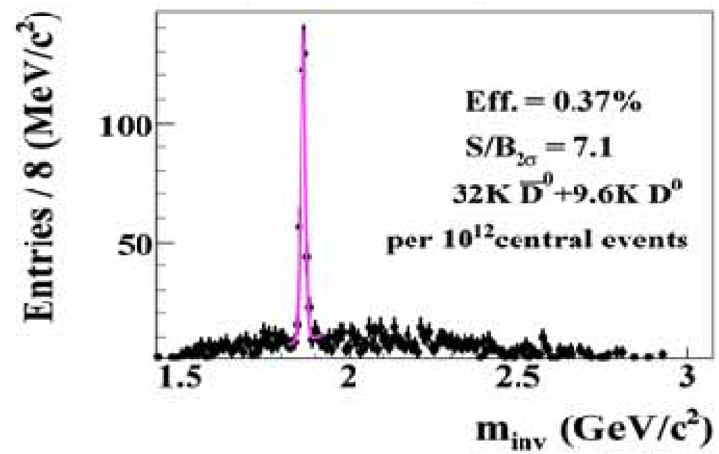
16k D^0 + 46k $\bar{D}^0$	and	**26k D^+ + 49k D^-**	(HSD)
87k D^0 + 251k $\bar{D}^0$	and	**52k D^+ + 98k D^-**	(SHM)

Open charm measurement, Other Channels

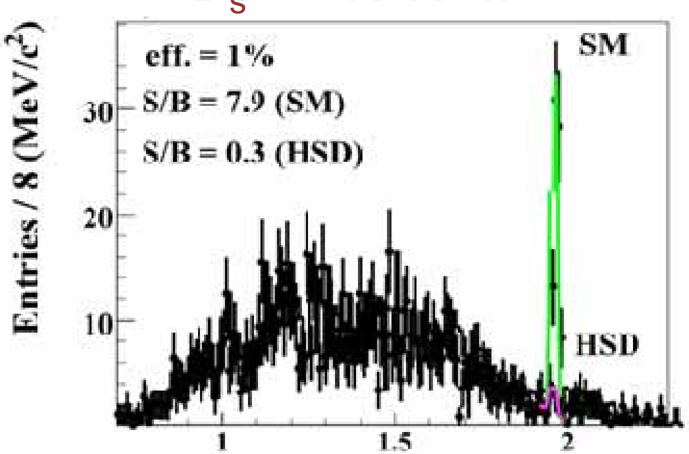
$D^0 \to K^- \pi^+$ + c.c.



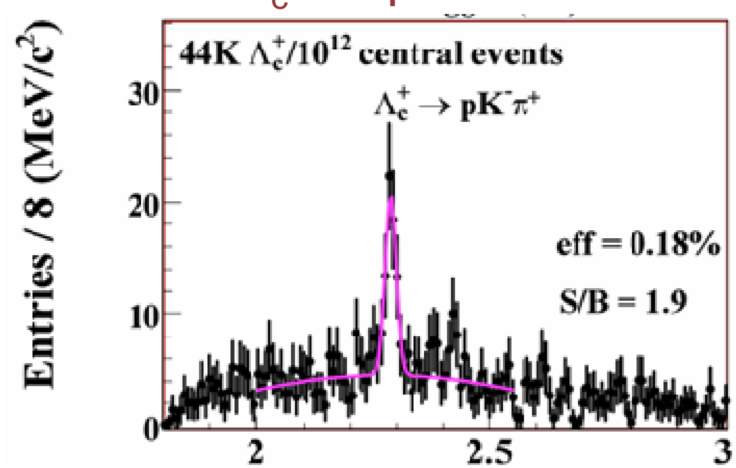
$D^0 \to K^- \pi^- \pi^+ \pi^+$



$D_s^+ \to K^- K^+ \pi^+$



$\Lambda_c^+ \to p K^- \pi^+$



Di-lepton spectroscopy

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

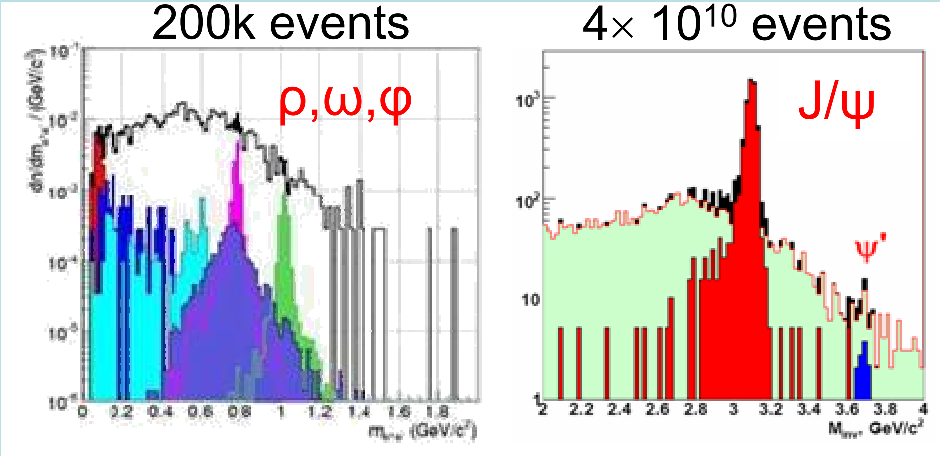
Electron id:

RICH and TRD

π suppression:

factor **10^4**

dominant background:
e from π^0 Dalitz



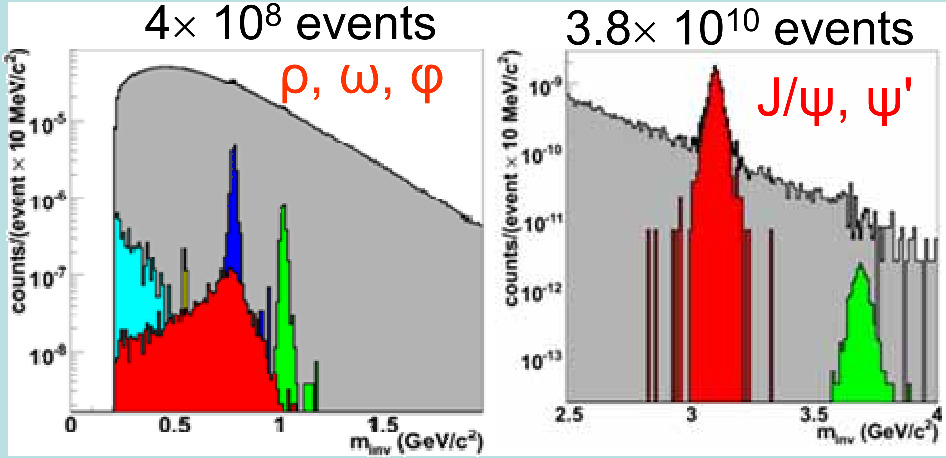
Muon id:

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)

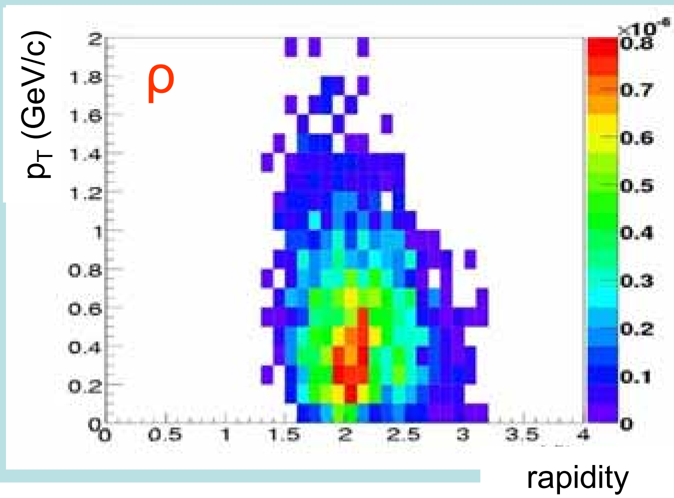


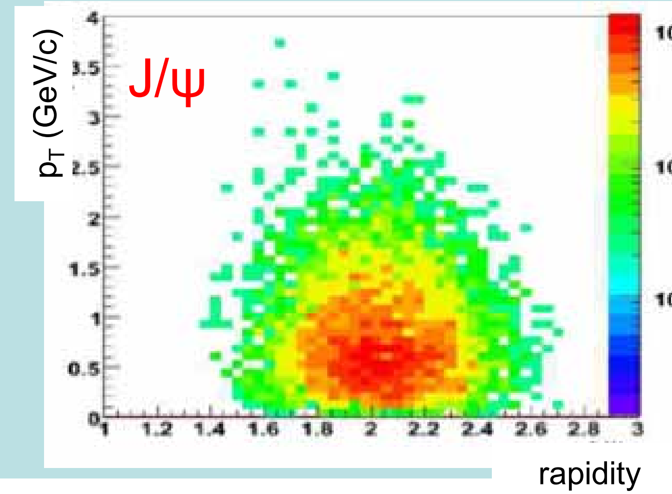
Feasibility studies for di-lepton measurements

- 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

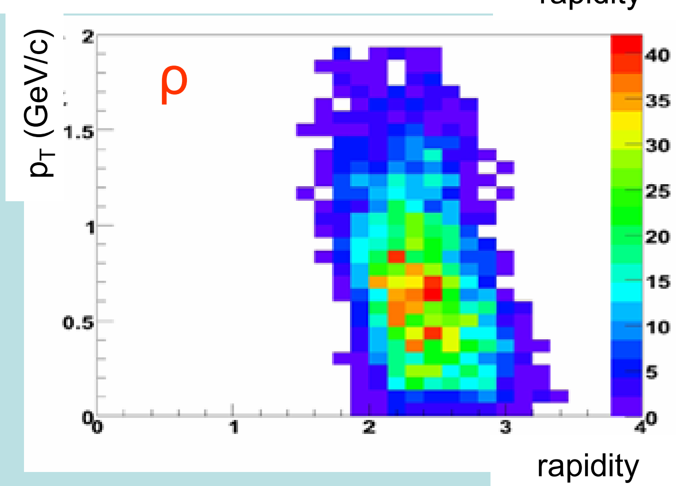


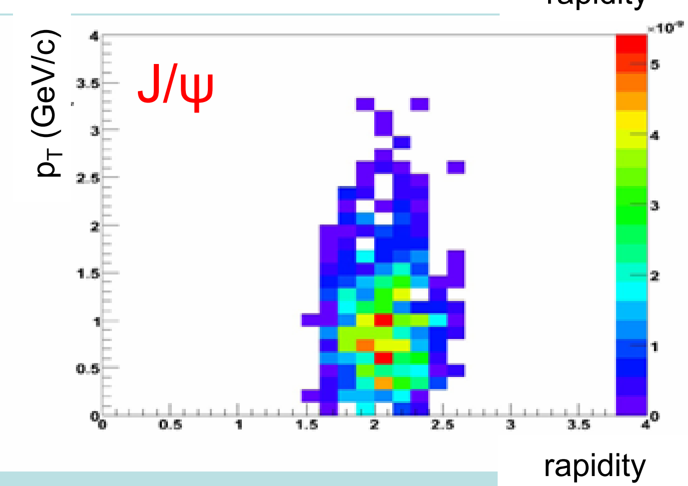


Muon id:

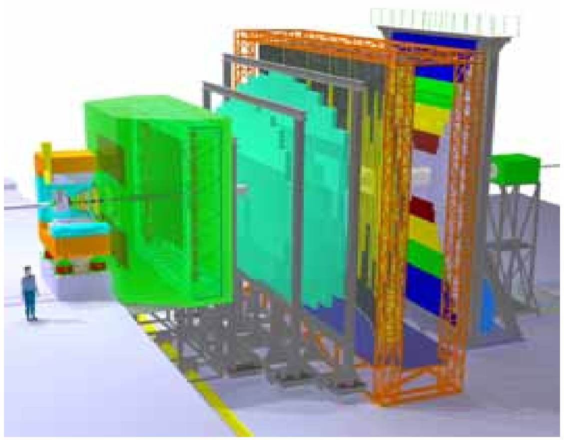
segmented
hadron absorber
+ tracking system

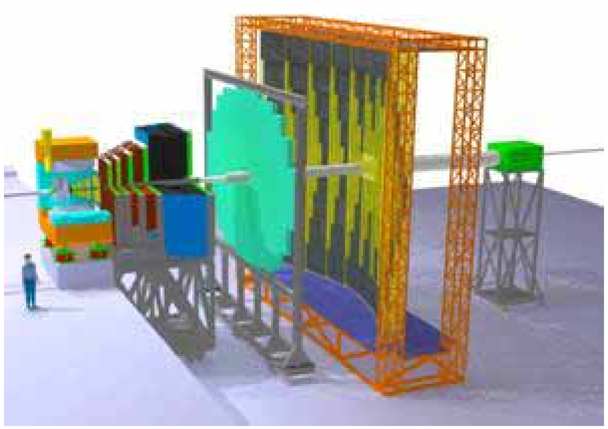
125(225) cm iron,
15(18) det. layers

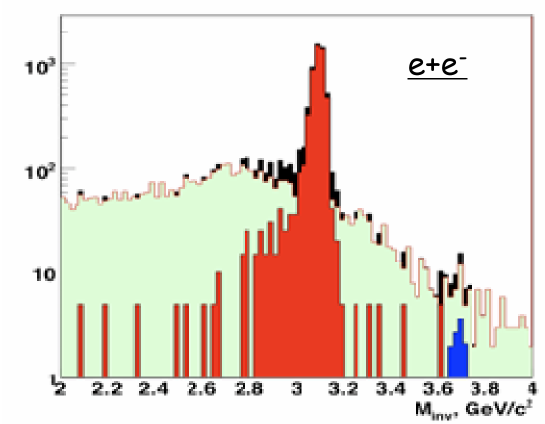


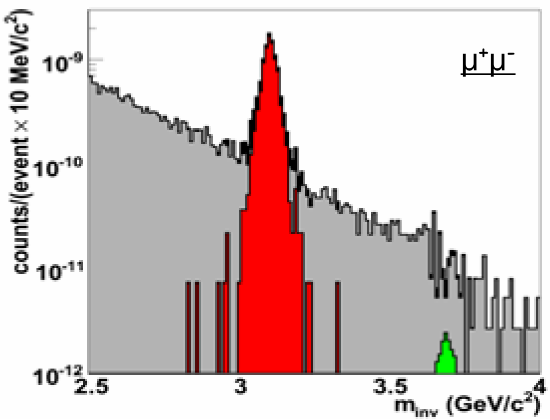


Charmonium measurement



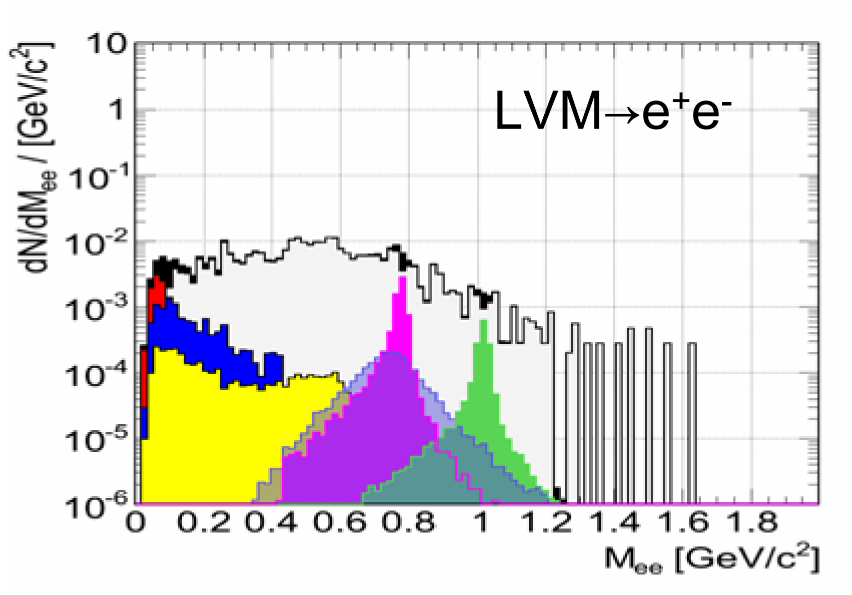


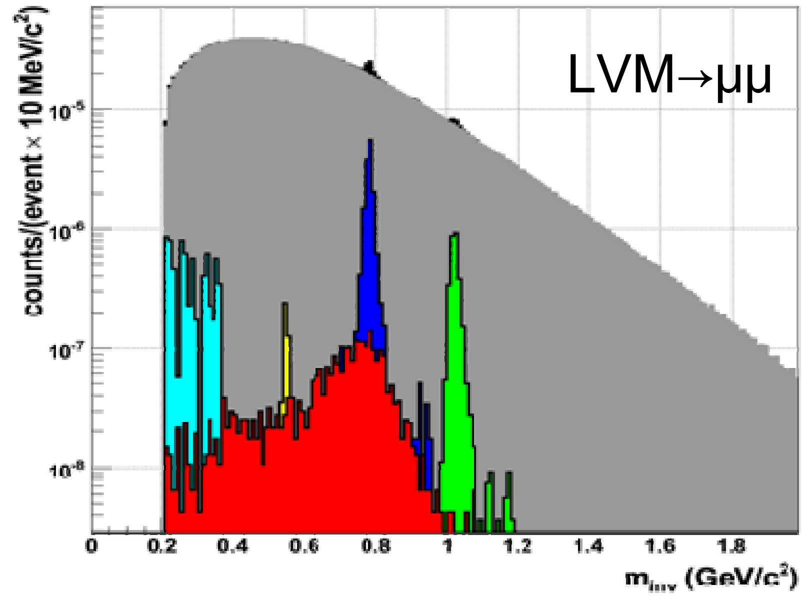




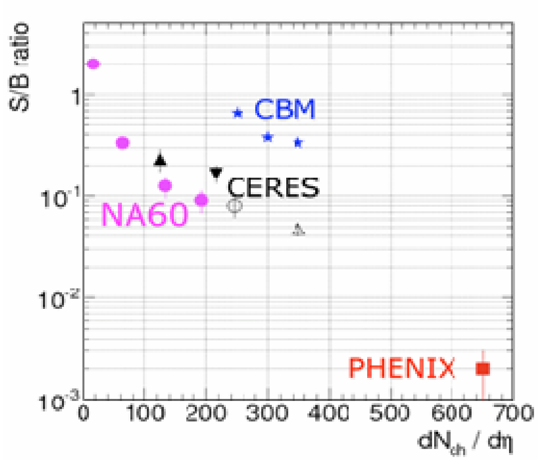
- Rarest probe for CBM: requires highest interaction rates (10 MHz)
- Measurements via electrin pairs (RICH, TRD, TOF) or muon pairs (MUCH)
- Similar performance in both channels: good S/B for J/ψ; ψ' will be difficult

Low-Mass Vector Mesons



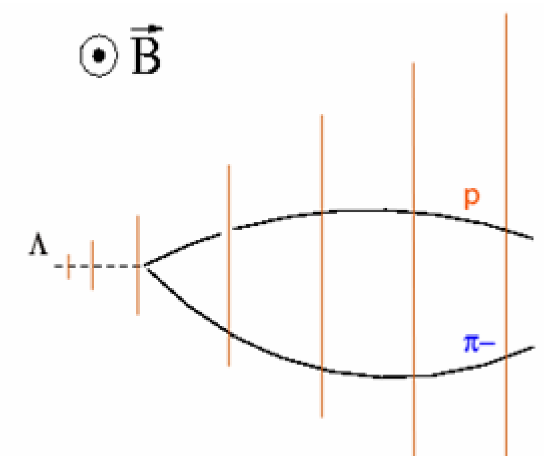


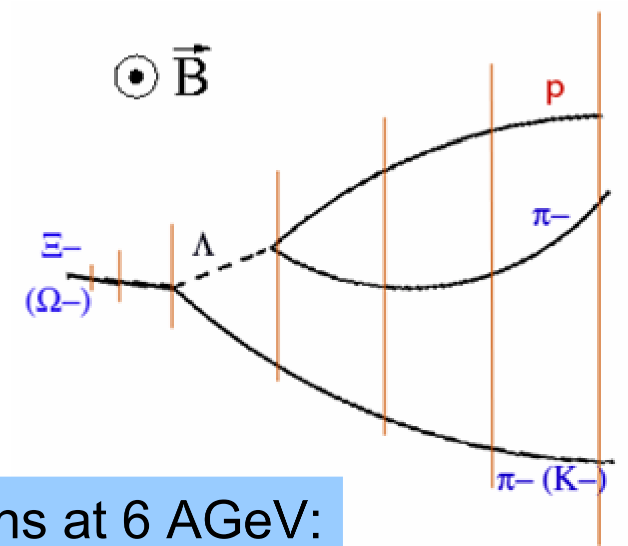
central Au+Au @ 25A GeV



- Difficult measurement, but feasible in both electron and muon channels
- S/B well above competitors

Identification of hyperons in heavy-ion collisions



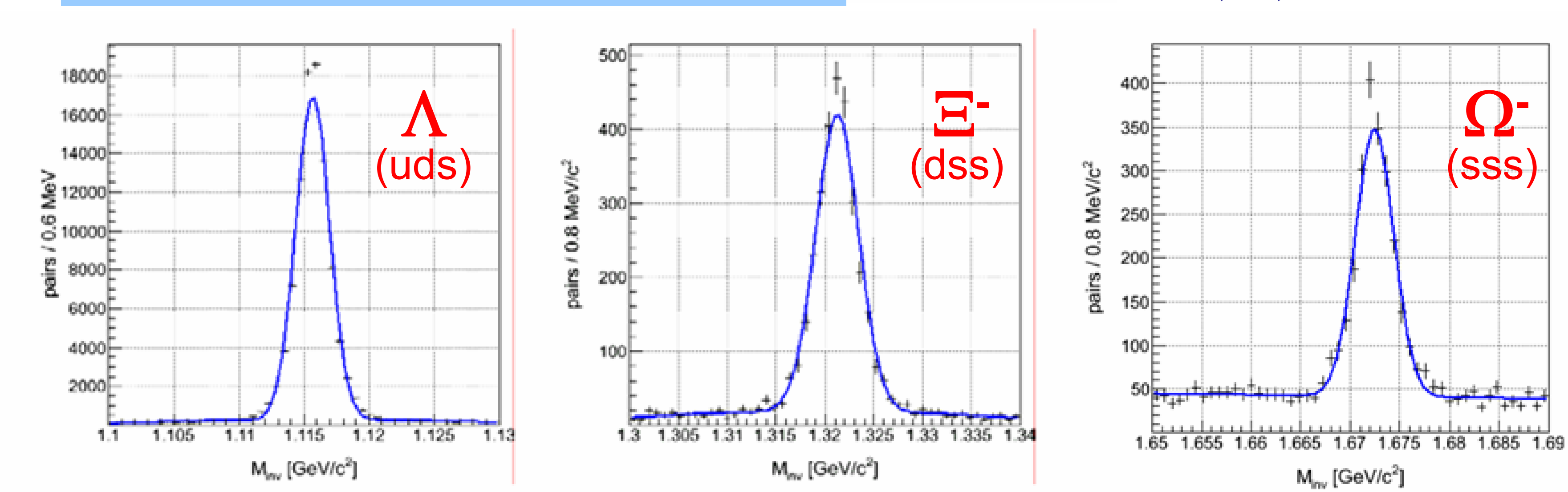


central Au+Au collisions at 6 AGeV:

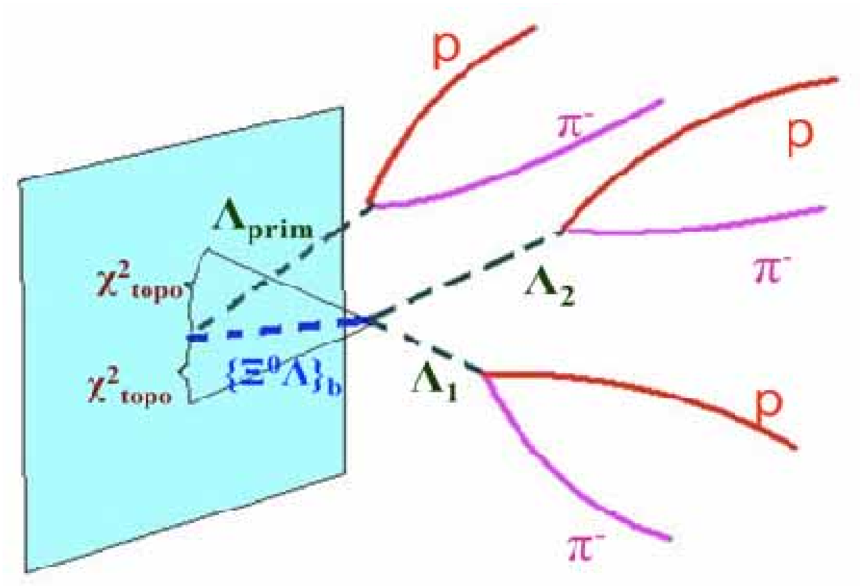
Identified by decay topology in STS + inv. mass

No identification of secondaries required

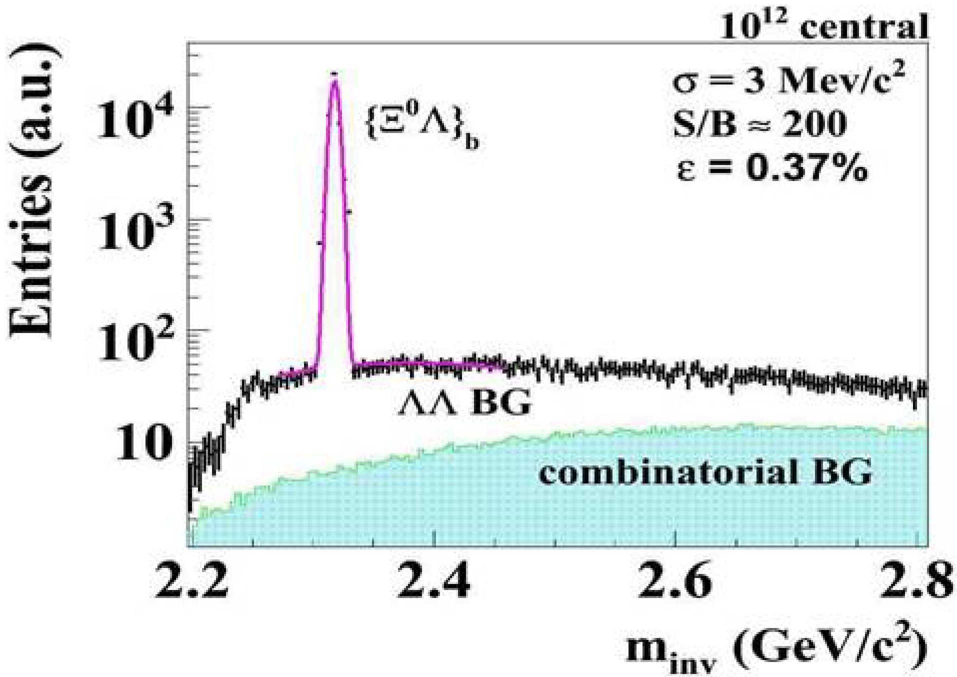
Clean signals for Λ, Ξ, Ω



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



Thermal multiplicity (7×10^{-3})



≈ 30 days of data taking at 10^7 MHz

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

Evene three OOM below the signal will be visible above BG

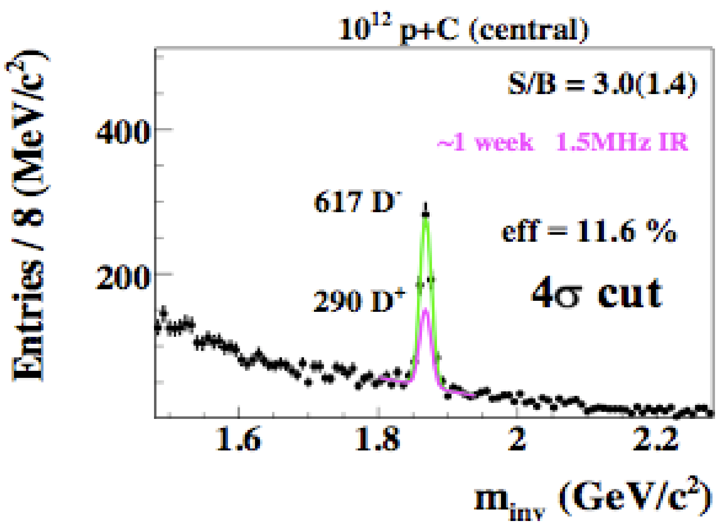
CBM at SIS-100

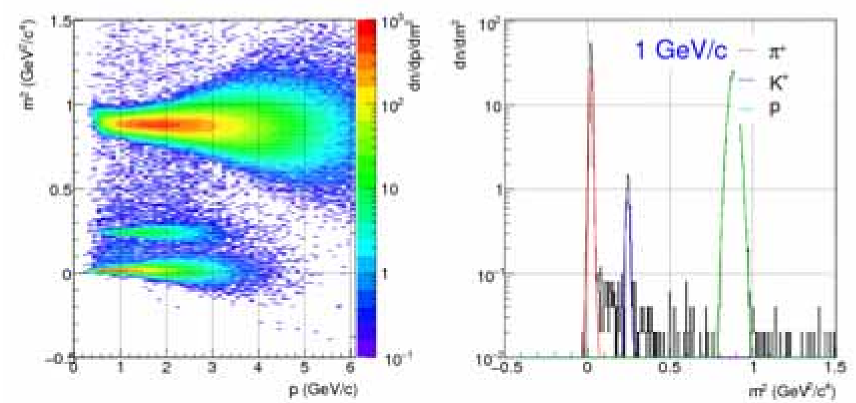
Physics programme before commissioning of SIS-300:

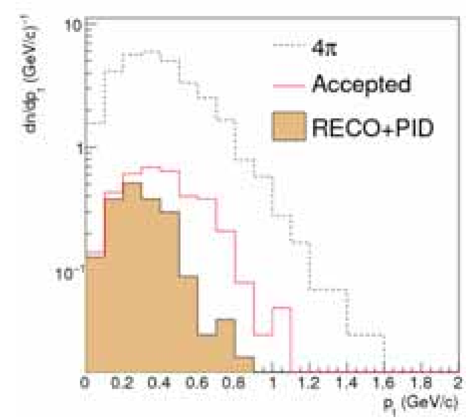
p+A up to 30 GeV: charm

A+A up to 11 GeV: strangeness, flow, low-mass vector mesons

Analysis of observables in progress



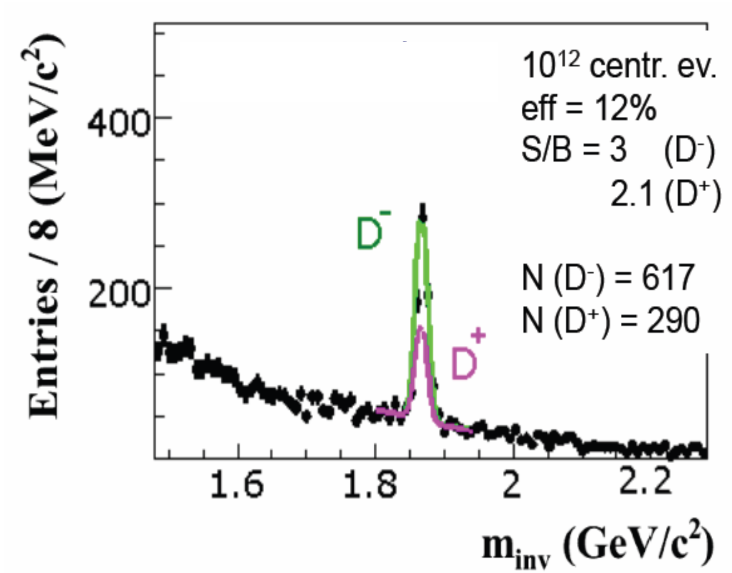




Charm and charmonium production at SIS-100

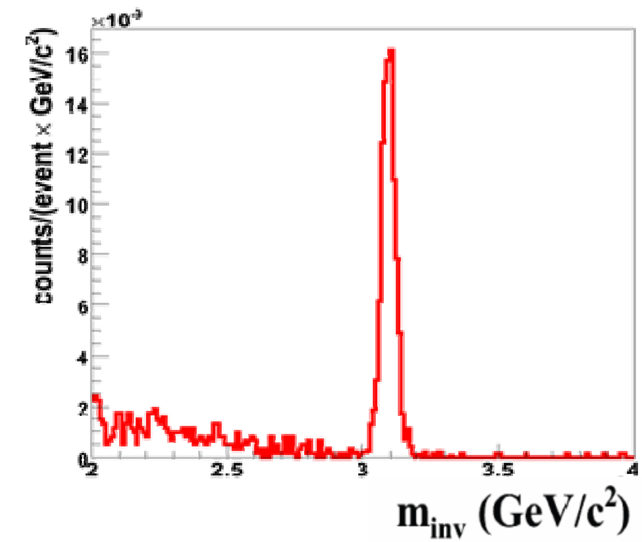
p+C collisions, 30 GeV

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



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

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



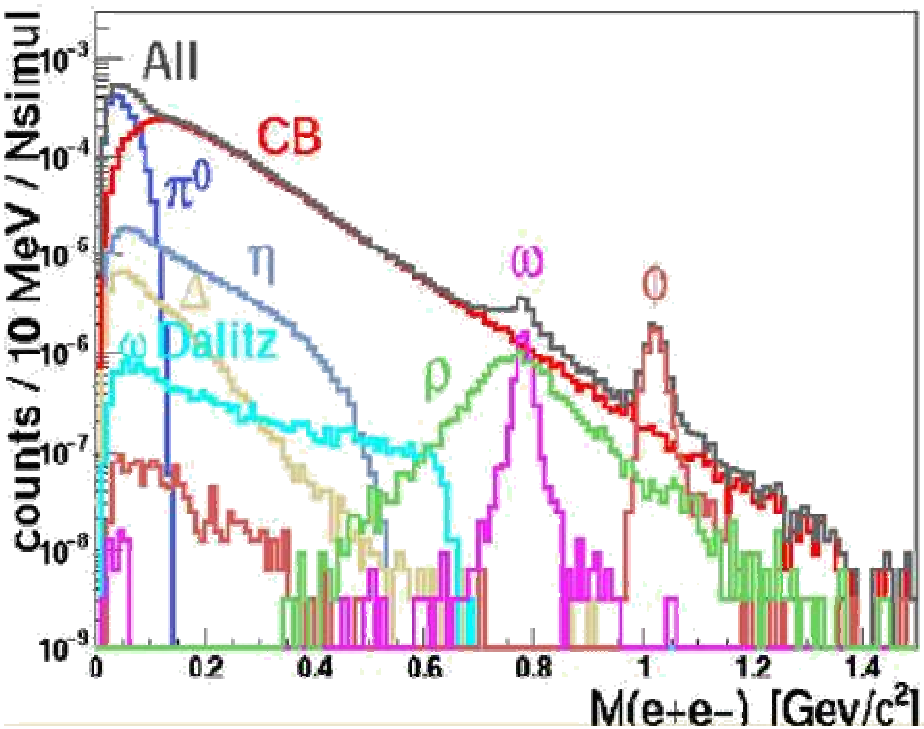
6 J/ψ recorded in 10^{10} events (b=0)
($3 \cdot 10^4$ J/ψ per week)

Di-lepton measurement at SIS-100

HADES

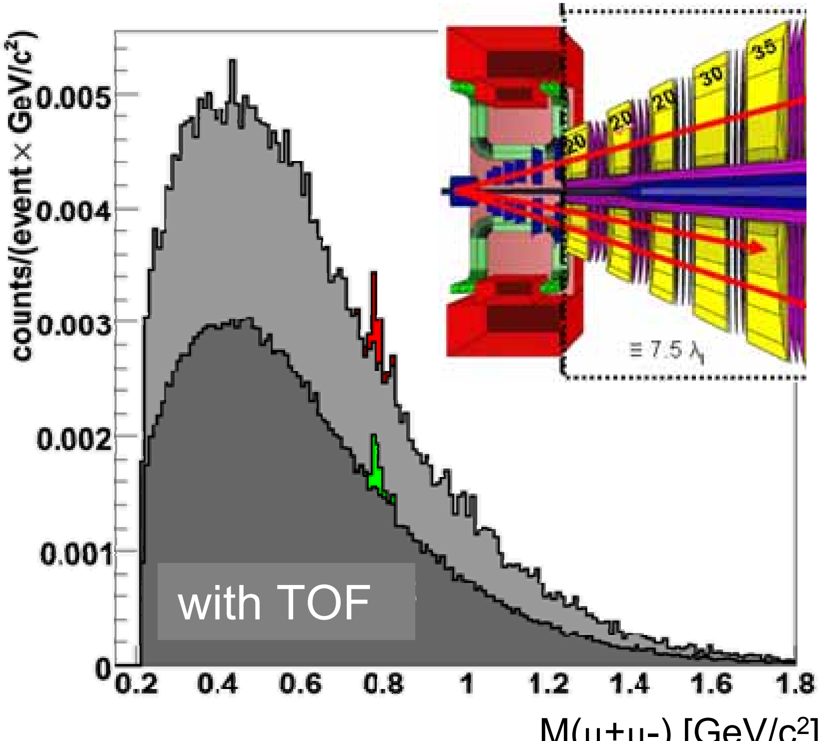
Monte Carlo simulation:
Di-electron invariant mass spectrum

central Au+Au collisions at 8*A* GeV

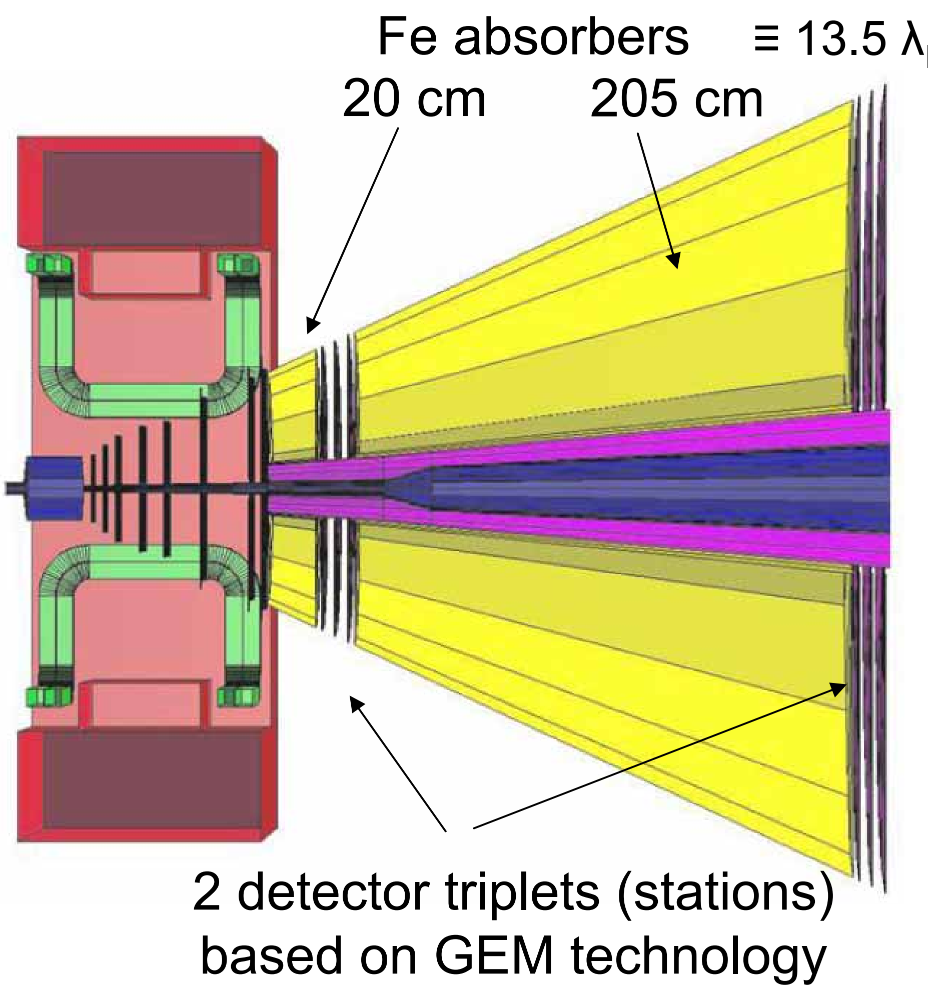


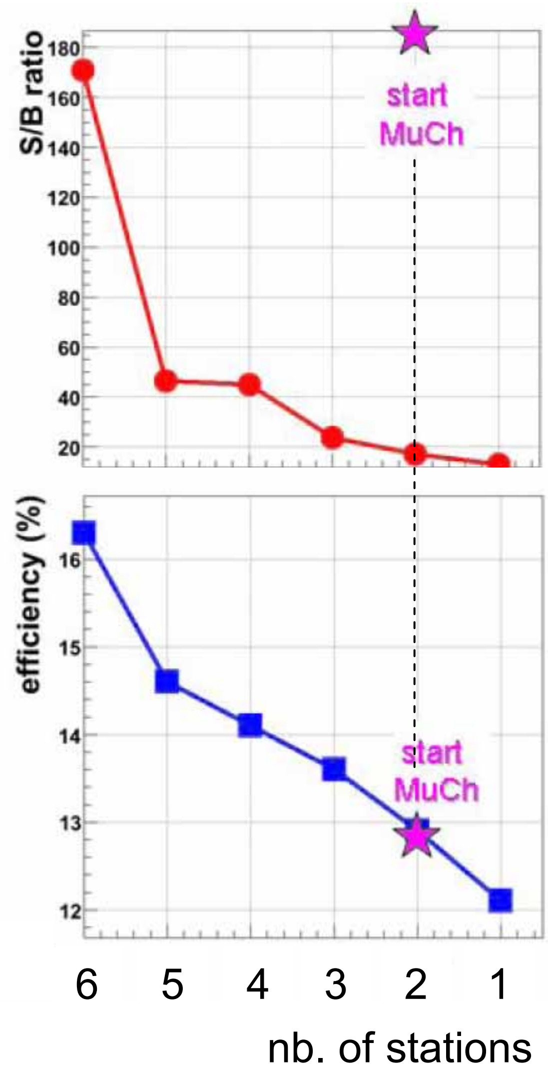
CBM

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



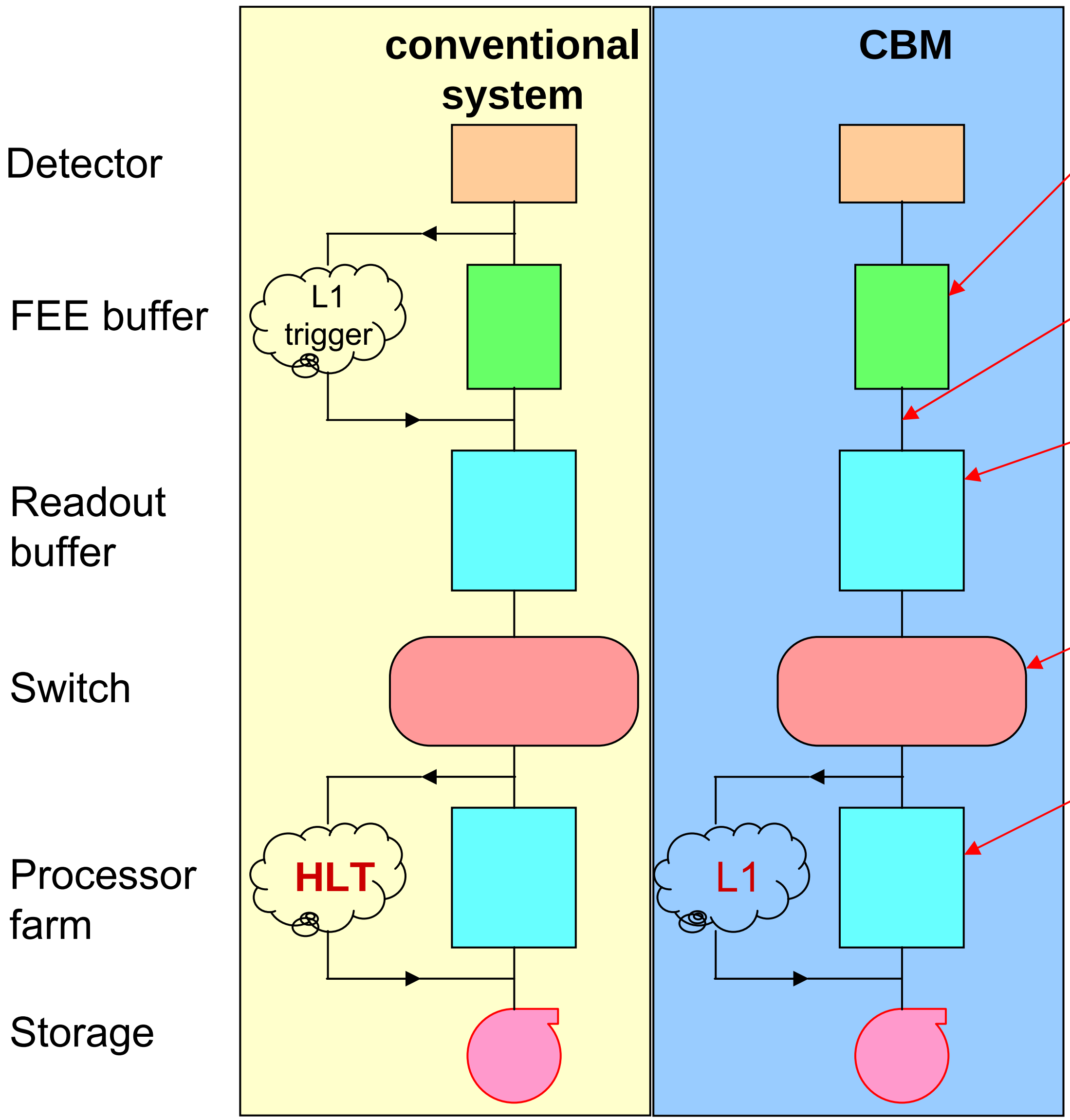
J/ψ detection via muons in p+Au collisions at 25 GeV





Detector developments

Challenge: CBM DAQ Architecture



Self-triggering Front-end; all hits shipped to DAQ. Data push architecture

Fast links

Readout buffer outside radiation area. Many Gbyte storage easily possible. Allows L1 decision times of 10-100 ms

High-throughput Event building

First event selection done in processor farm

Typical Parameters:
1% (4%) occupancy, 10^7 int./s
100 kHz channel hit rate
1 MByte/sec per channel
whole CBM: ~ 1 TByte/s

Modelling of data generation and transport into DAQ

- Classical experimental setups:

  events are defined through coincidence in time with the trigger.

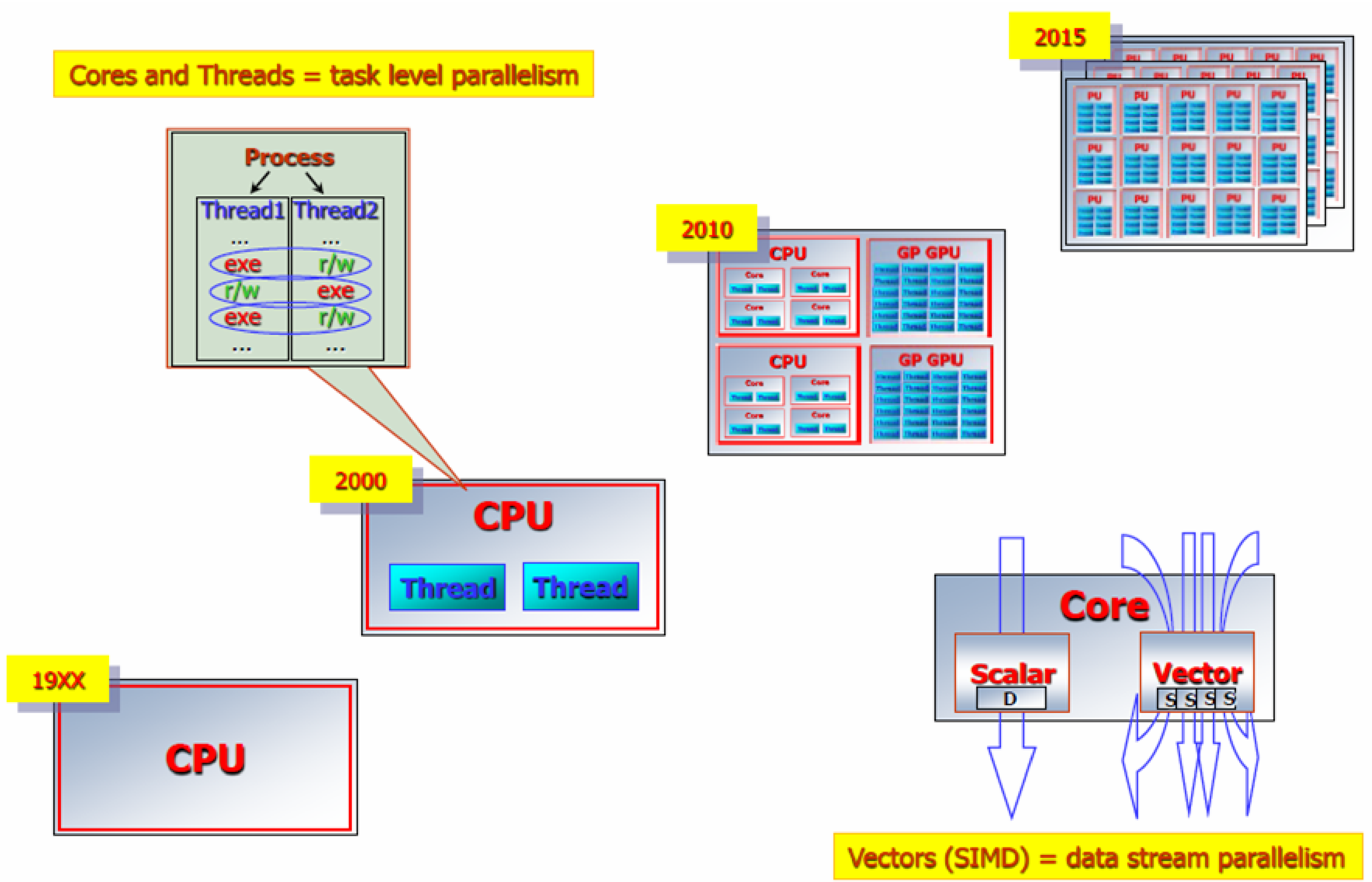
- CBM: self triggered systems with very different time resolution

  events need to be defined from the data itself through consistency in space and time out of the data volume as a whole.

On-going work:

- implement data throtteling techniques needed for overflow situations
- study how data overflow situation may be handled without compromising the quality of the data with respect to final physics analysis.
- Implement that data flow in simulation framework CbmRoot.

Many-Core High Performance Computing



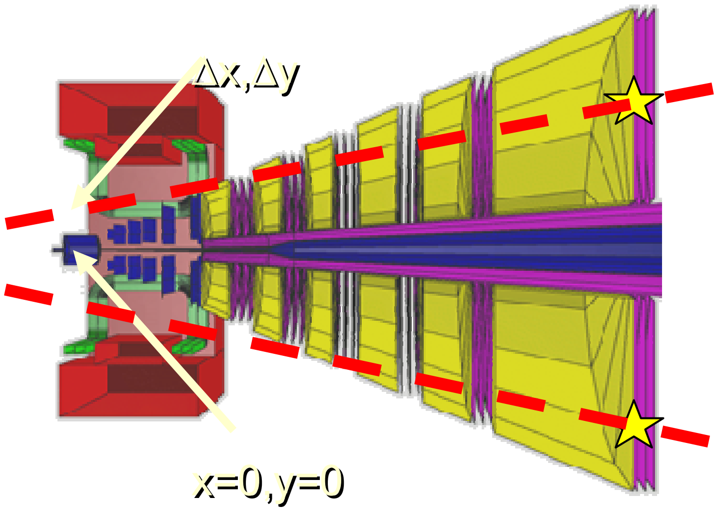
Parallelization in the CBM Reconstruction

Algorithm	Vector SIMD	Multi-Threading	NVIDIA CUDA	OpenCL	Speedup	Speed/PC
STS	+	+	+	+	10000	6.5 ms
MuCh	+	+			500*	1.5 ms
TRD	+	+			500*	1.5 ms
RICH	+	+			100**	3.0 ms
Vertexing	+				1.5***	20μs
Open Charm Analysis	+				1.5***	20μs
User Reco/Digi						
User Analysis						

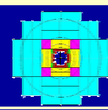
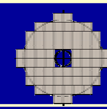
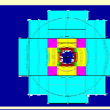
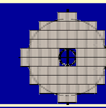
+March 2009
+October 2009

*Single hit access should be avoided
**Reformulation of the algorithm is probably necessary
***Avoid accessing the main memory –> approximation of the magnetic field map

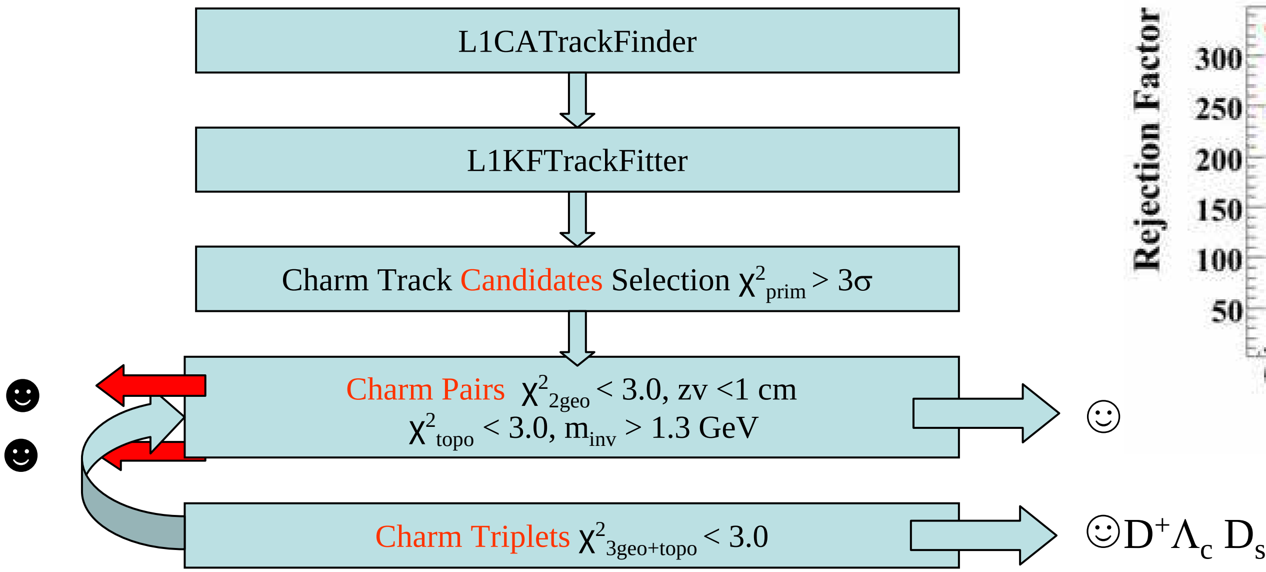
Trigger studies: charmonium ($\mu^+\mu^-$)

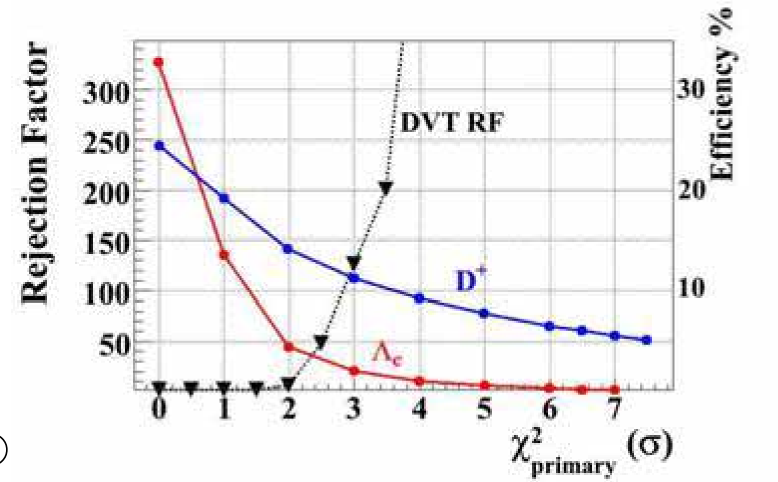


- Trigger strategy:
  - Have two tracks after last absorber
  - Fit triplet and extrapolate back to target
  - Cut on distance to target
- Requires:
  - information only from last three detector stations
- Can be improved by using TOF (2nd level?)

segmentation				
trigger	without		χ^2 $x_{z=0}$ $y_{z=0}$	
$\varepsilon_{J/\psi}^{mBias}$, %	23.4	20.3	15.5	15.2
background suppression factor (bsf) for mbias events	1	1	318	606

Trigger studies: open charm





- Trigger algorithm developed
- Rejection factors O(100) achievable w/o loss of signal (w.r.t. offline analysis)
- Requires **full STS + MVD reconstruction**, but only reduced combinatorics due to selection on single-track level

CBM Progress Report 2009

>90 pages, available at
www-cbm.gsi.de

<u>Contents:</u>

- 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 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

Hungary & CBM

Collaboration Institutes:

- Eötvös Loránd University, Budapest
- KFKI Research Institute for Particle and Nuclear Physics (KFKI-RMKI)

- linked via physics and technical interests
- NA61
- PSD detector system
- readout electronics

Excellent summer student 2009 in the CBM team at GSI !

Test of CBM Silicon Tracking Detectors in a proton beam at GSI

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Budapest, Hungary
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In August-September 2009, the CBM collaboration performed a 10 day test of several prototype detector systems in a 2.0 GeV proton beam at GSI. One of them, a demonstrator of the planned Silicon Tracking System (STS), consisted of five silicon microstrip detectors equipped with self-triggering front-end electronics. The readout was performed with the data acquisition system DABC. On-line monitoring of the data quality was made with the Go4 system. An overview of the experimental setup and the first results are shown.

1 The CBM experiment at FAIR

The Compressed Baryonic Matter (CBM) experiment will take place at the future international Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany.Its physics programme addresses the QCD phase diagram in the region of highest net baryon densities. Of particular interest is the expected first order phase transition from partonic to hadronic matter, ending in a critical point, and modifications of hadron properties in the dense medium as a signal for chiral symmetry restoration. Laid