The honor of the last speaker:

Many many thanks
to Elena, Marcus and Jörg !

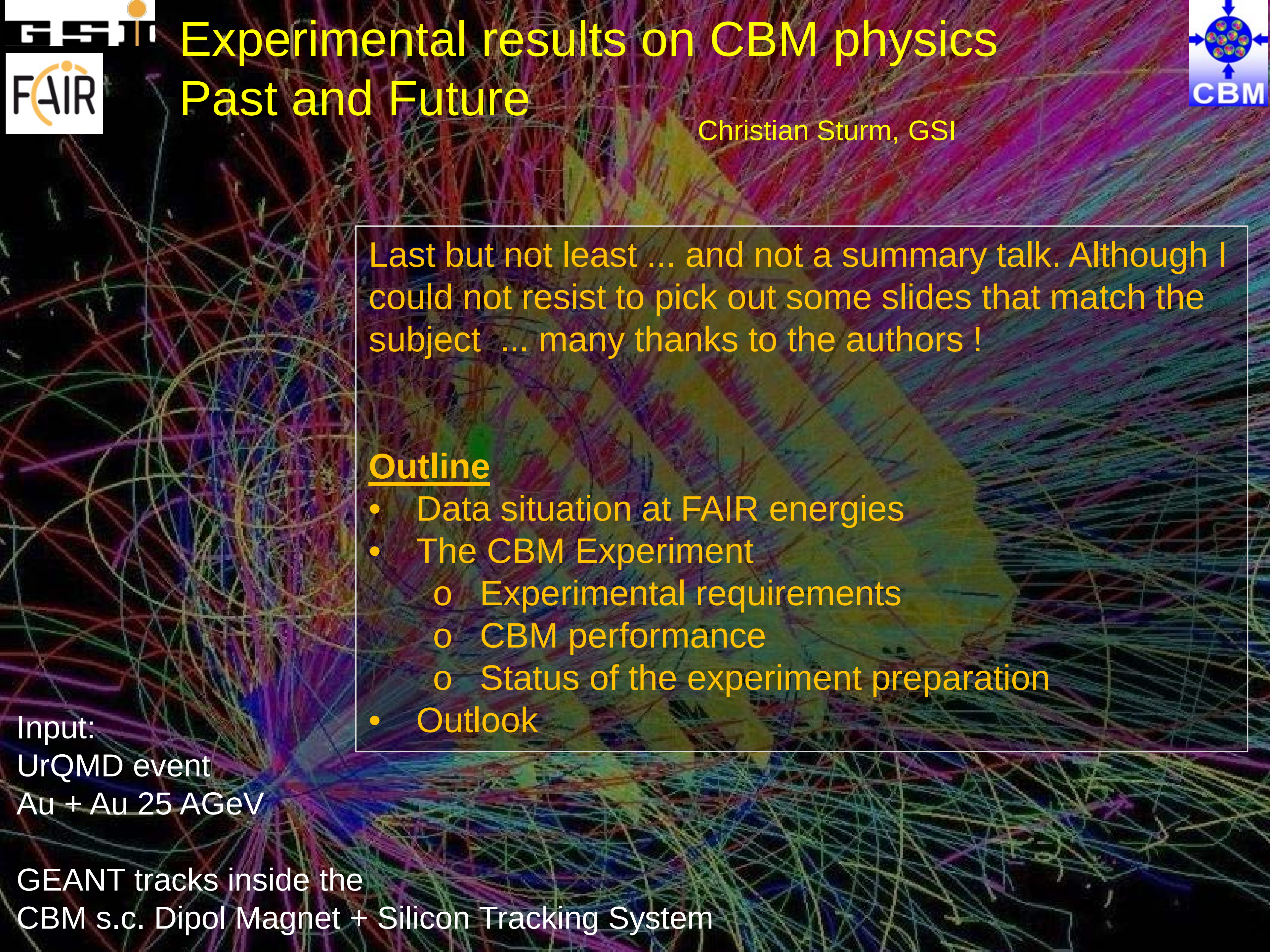
<u>My personal conclusion:</u>

- a purely scientific, non political meeting in a small circle,
- an extremely fruitful atmosphere in an inspiring environment,
- I have learned a lot (... with a special thanks to both lecturers)

→ **Fantastic !!! Please do it again !!!**

Experimental results on CBM physics
Past and Future

Christian Sturm, GSI



Last but not least ... and not a summary talk. Although I could not resist to pick out some slides that match the subject ... many thanks to the authors !

Outline

- Data situation at FAIR energies
- The CBM Experiment
  - Experimental requirements
  - CBM performance
  - Status of the experiment preparation
- Outlook

Input:
UrQMD event
Au + Au 25 AGeV

GEANT tracks inside the
CBM s.c. Dipol Magnet + Silicon Tracking System

The existence of a quark gluon plasma and the kind of transition towards the hadronic world

has been predicted by lattice gauge calculations
has been claimed to be seen in experiments (Science)

Why this is still a topic ?

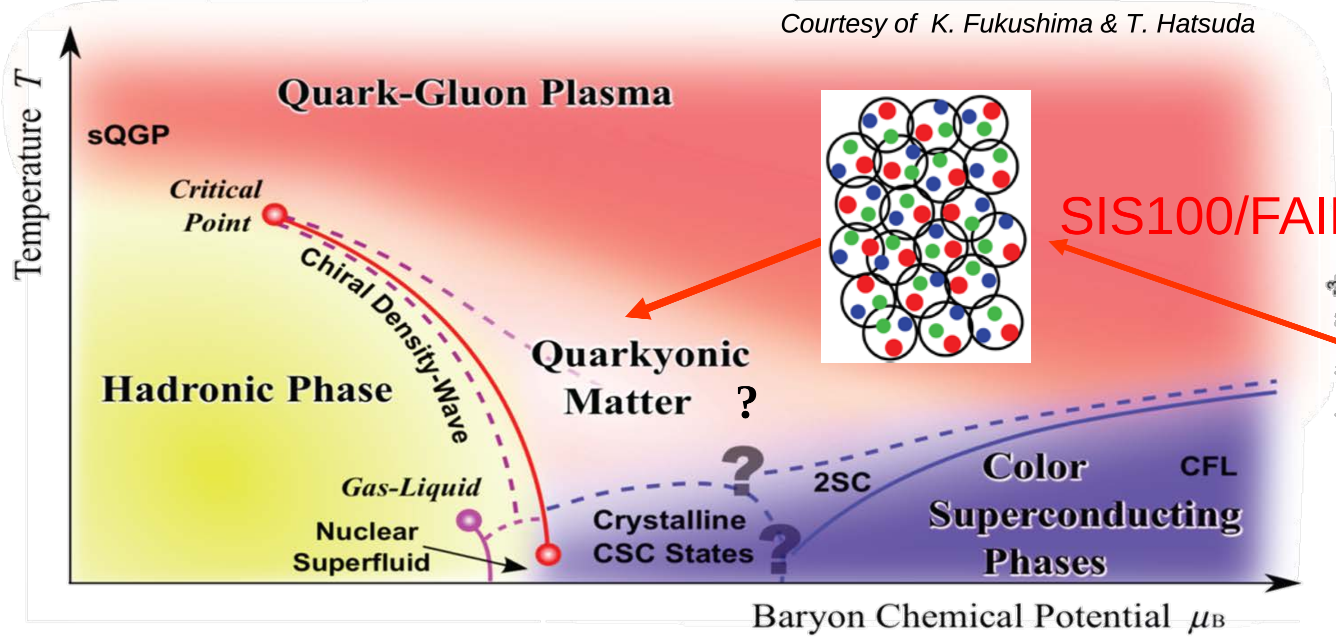
- because every result is at most circumstantial evidence of its existence

  a life time of 10^{-24} of seconds
  a size of at most 15 fm
  an expansion velocity of 0.85 c
  and certainly not in a global thermal equilibrium

- because the multiplicity of almost all observed hadrons can be perfectly described by assuming a gas of T = 158 MeV

  Hadronic rescattering spoils spectra

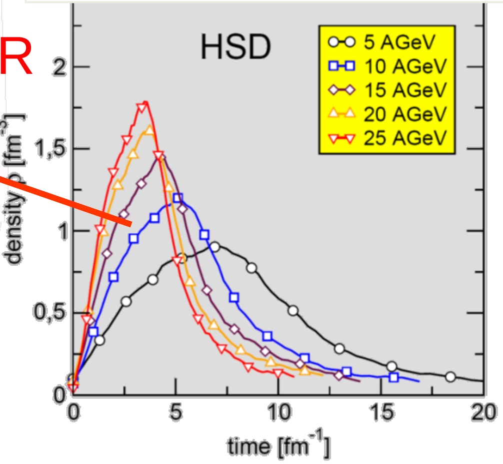
Exploring the QCD phase diagram



Courtesy of K. Fukushima & T. Hatsuda

SIS100/FAIR

Baryon density in central Au+Au collisions (HSD transport code)



Open questions at high net baryon densities:

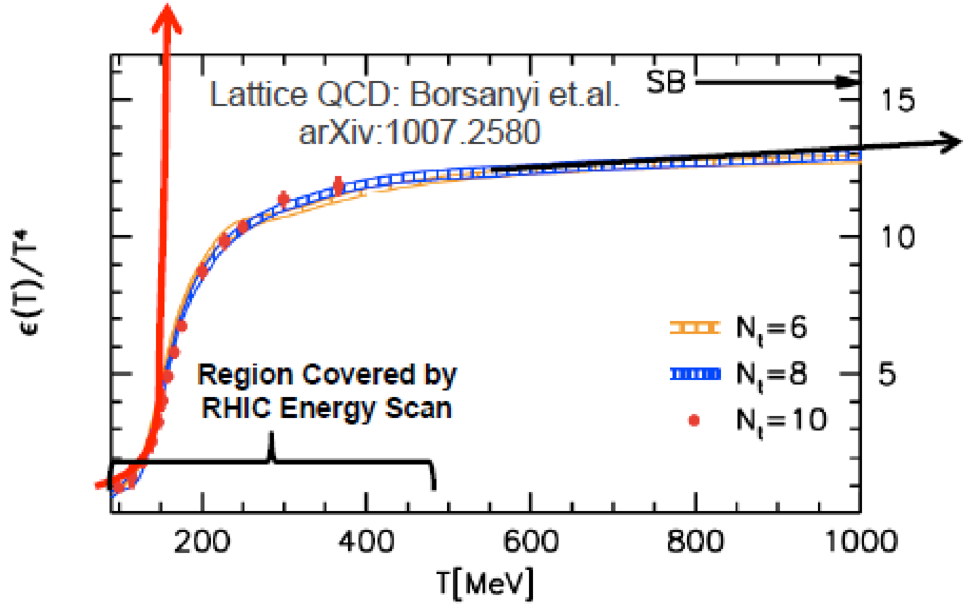
- Phase transition from hadronic matter to quarkyonic or partonic matter ?
- Chiral phase transition ? Chiral restoration ?
- In-medium modification of hadrons ?
- Nuclear Equation-of-State at neutron star core densities ?

→ **substantial discovery potential with CBM at FAIR**

Field driven by experimental data !

Thermodynamics of QCD

Quantum Chromodynamics shows a rapid crossover to QGP: ε/T^4 ($\propto$ # degrees-of-freedom) plateaus when quarks and gluons start to become the relevant degrees of freedom



Hadron Gas:
maximum T

QGP: no maximum
adding energy increases T, instead of creating heavier hadrons

The QCD phase transition that occurred at one μ-sec after the Big Bang is accessible in lab experiments today

Only very special probes are sensitive to the plasma properties

they include:

- jets
- collective features (Elena, Marcus)

  azimuthal distribution

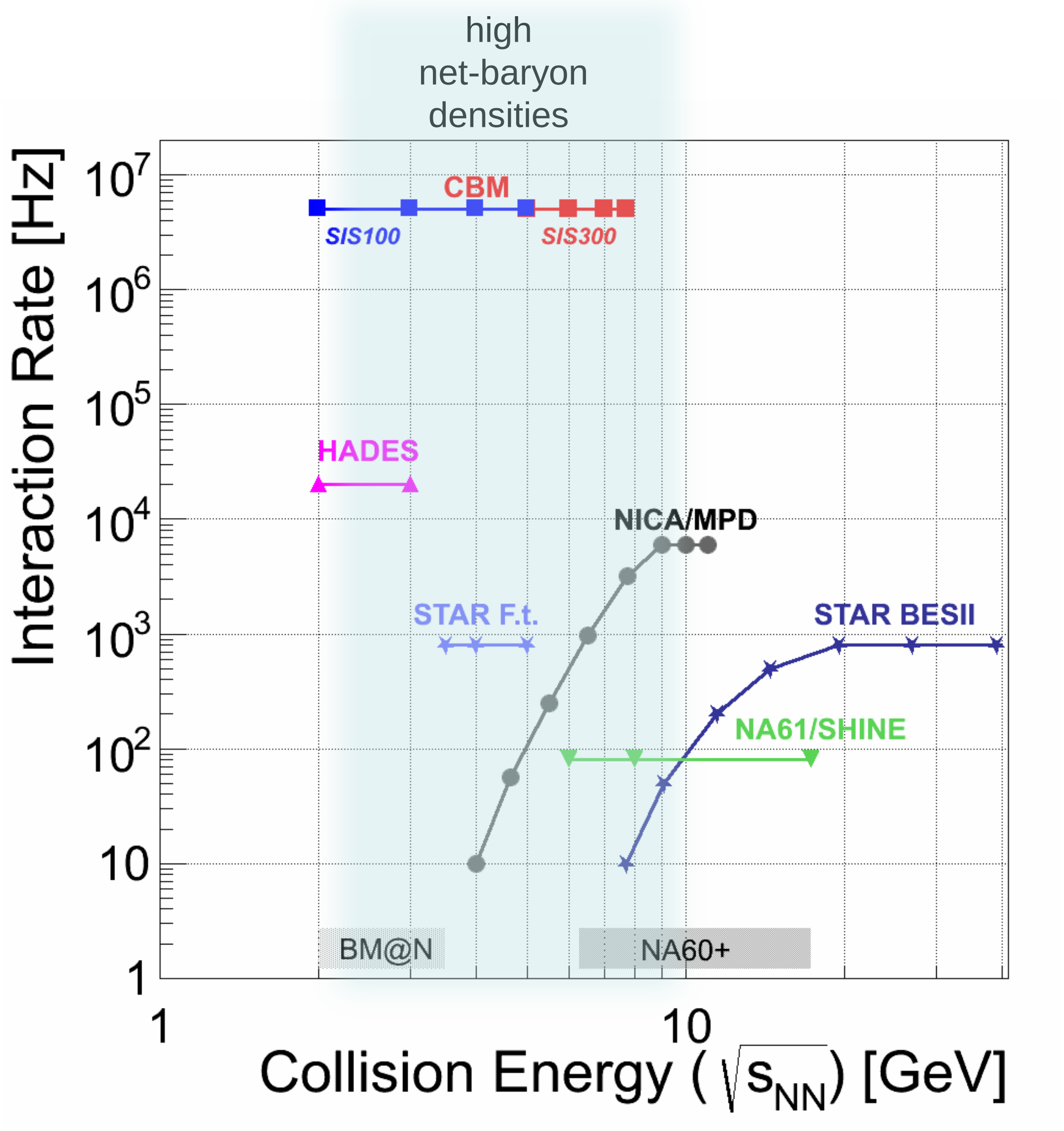
$$\frac{dN}{d\Phi} = \frac{1}{2\pi}(1 + 2v_1 \cos\Phi + 2v_2 \cos 2\Phi \ldots.)$$

- Photons
- Dileptons
- J/psi or psi' or Y (1S)... Y(3S)
- heavy quarks -> heavy mesons

These particles do not come to an equilibrium with the plasma

Experiments exploring dense QCD matter

Rate capabilities



FAIR energies
(Au ions)

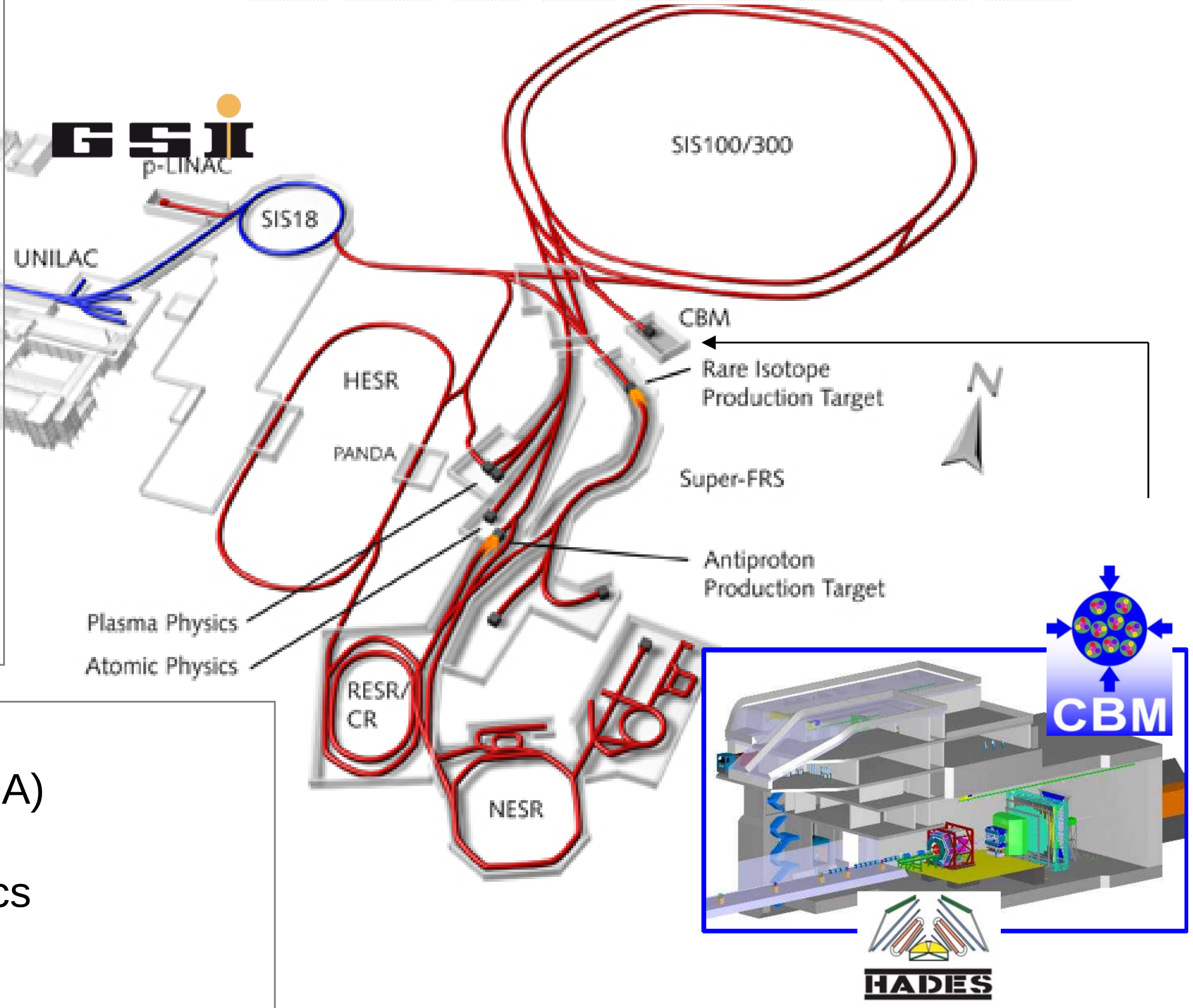
E_{kin}^{lab} [A·GeV]	$\sqrt{s_{NN}}$ [GeV]
2	2.7
11	4.9
14 (Ca @ SIS100) 29 (p @ SIS100)	5.5 7.6
30	7.7
35	8.3
44 (Ca @ SIS300) 89 (p @ SIS300)	9.3 13.0

The Facility for Antiproton and Ion Research

Using beams from two synchrotrons for parallel operation :

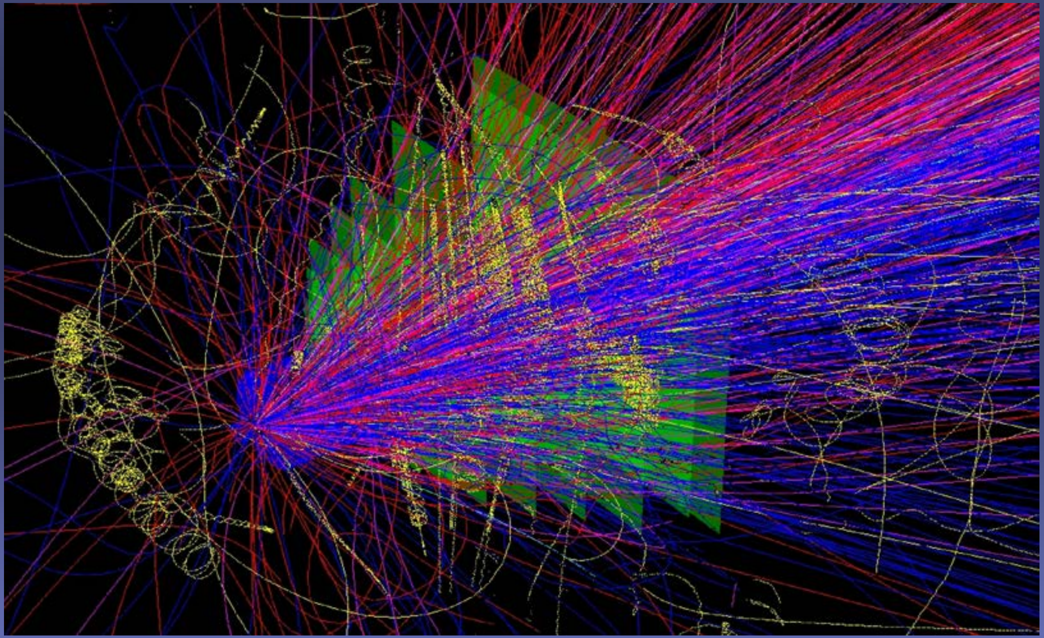
SIS100 (100Tm,4T/s):
2-29 GeV (protons)
2-14 A GeV (Ca)
2-11 A GeV (Au)

SIS300 (300 Tm):
2-89 GeV (protons)
2-44 A GeV (Ca)
2-35 A GeV (Au)

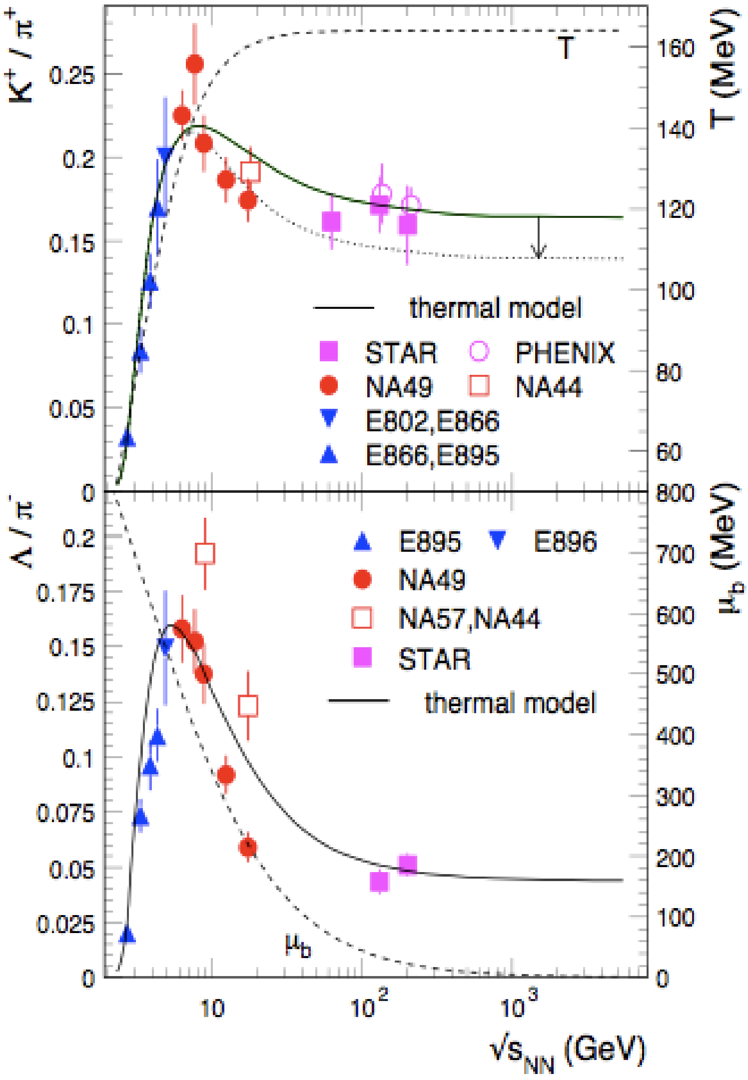


- Hadron spectroscopy with anti-protons (PANDA)
- Rare Isotope beams
- Atomic & Plasma Physics
- Nuclear Matter Physics **CBM & HADES**

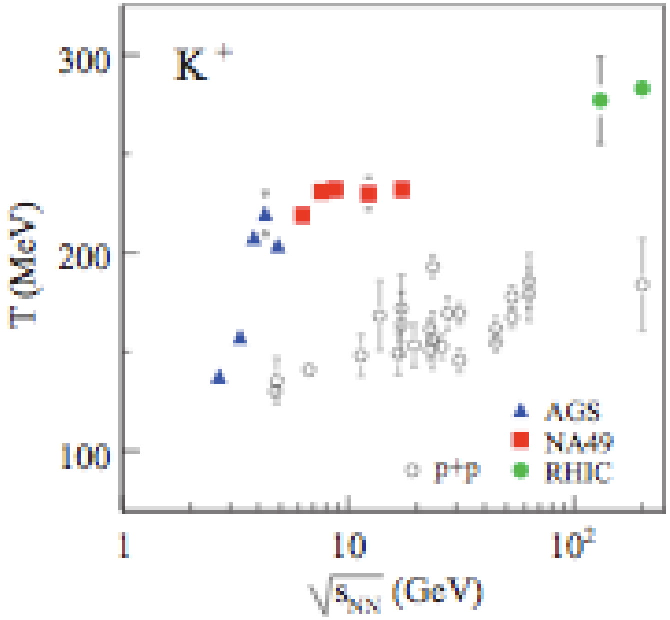
Data situation at FAIR energies (not complete)



Strangeness – particle yields

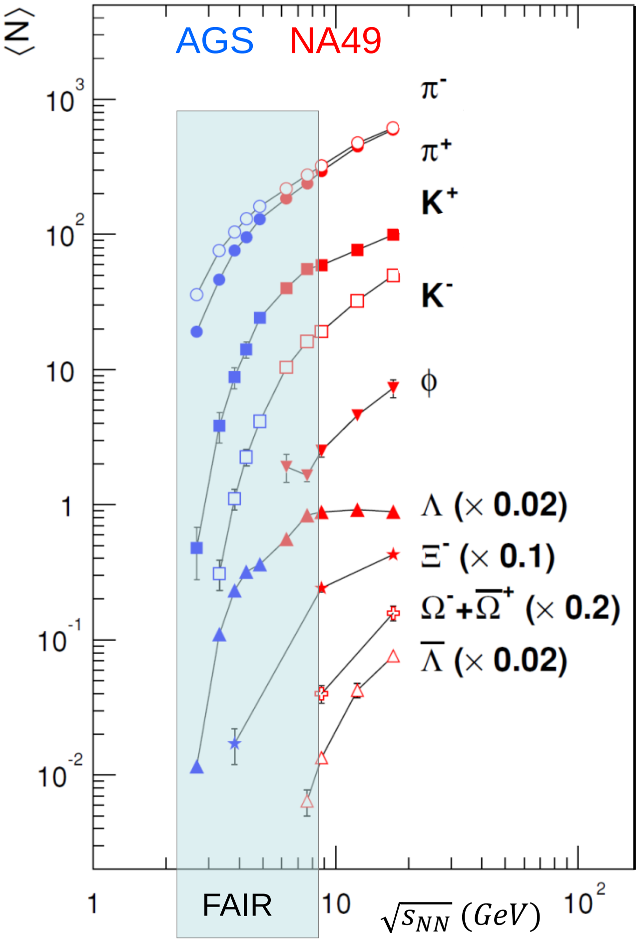


Maximum in K/pi at 30 AGeV
explained by statistical model (?)



Plateau in apparent temperature above 30 AGeV
indicative of 1st order phase transition (latent heat) ?

Strangeness – particle yields



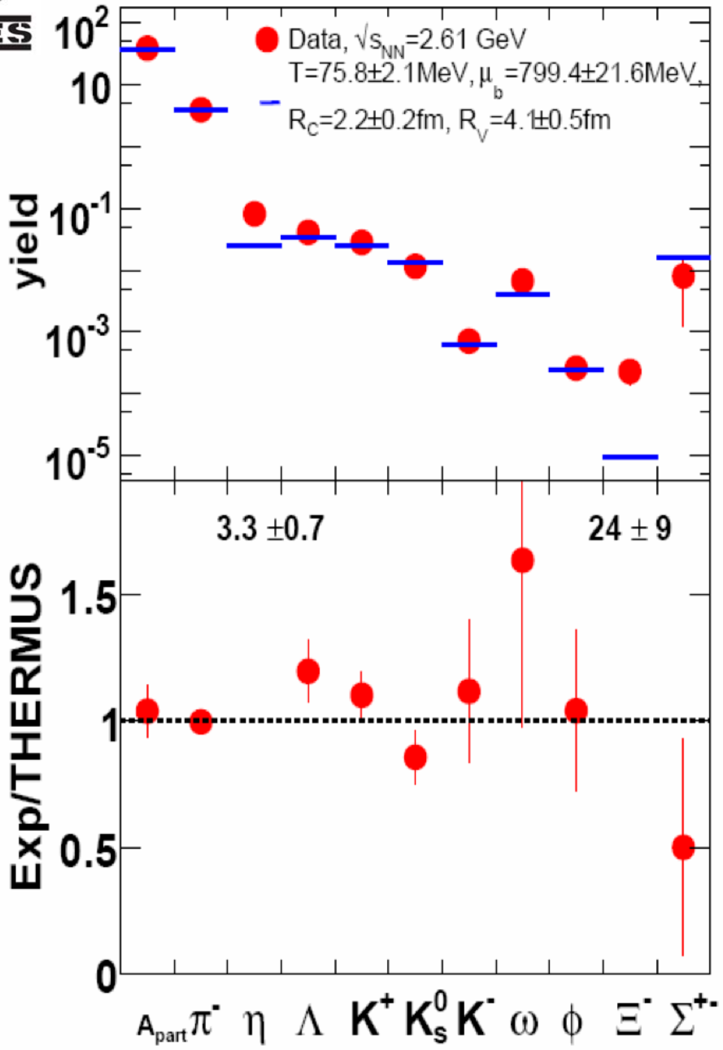
Ξ and Ω production threshold in pp collisions:
pp → $\Xi^- K^+K^+p$, E_{thr}=3.7 GeV
pp → $\Omega^- K^+ K^+ K^0 p$, E_{thr}=7.0 GeV

Knowledge about **multi-strange hyperons** at energies < 10 AGeV very limited

→ multi-step production ?
→ production via strangeness exchange channels ?
→ enhanced production in dense medium ?

Strangeness – particle yields

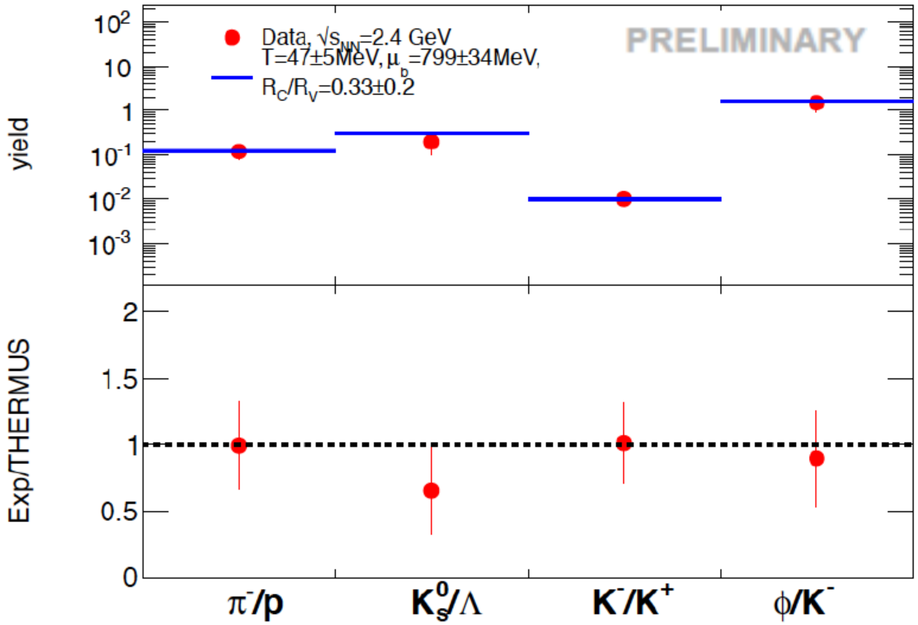
Ar + KCl 1.76 AGeV



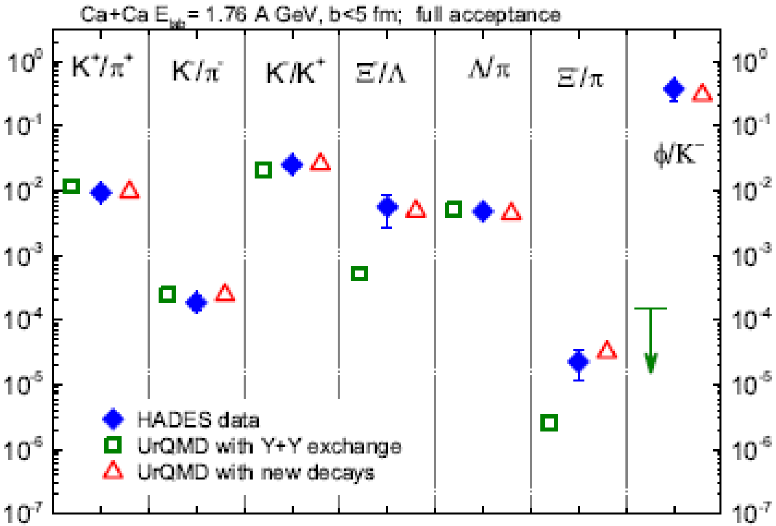
HADES data :
Ar + KCl 1.76 A GeV / Phys. Rev. Lett. 103 (2009) 132301

Statistical model:
S. Wheaton and J. Cleymans, Comp. Phys. Comm. 180 (2009) 84

Au + Au 1.23 AGeV



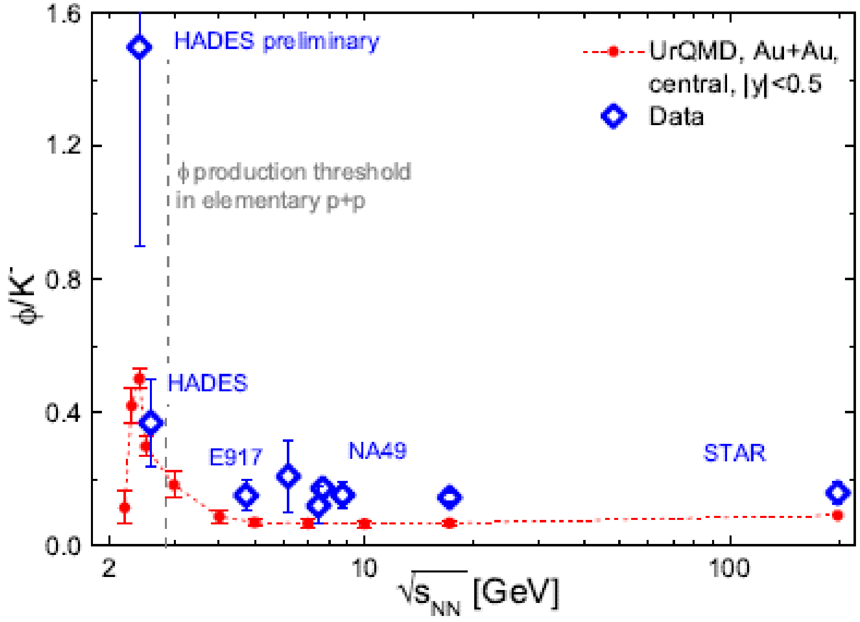
Ξ^- production in nuclear collisions below the p+p threshold



- Ξ^- yield in Ar+KCl collisions is nicely reproduced
- Consistent with the p+Nb data.
- Indication for Ξ production from non-thermal 'tails' of particle production.
- All other strange particle ratios are also in line with experiment

ϕ production in nuclear collisions below the p+p threshold

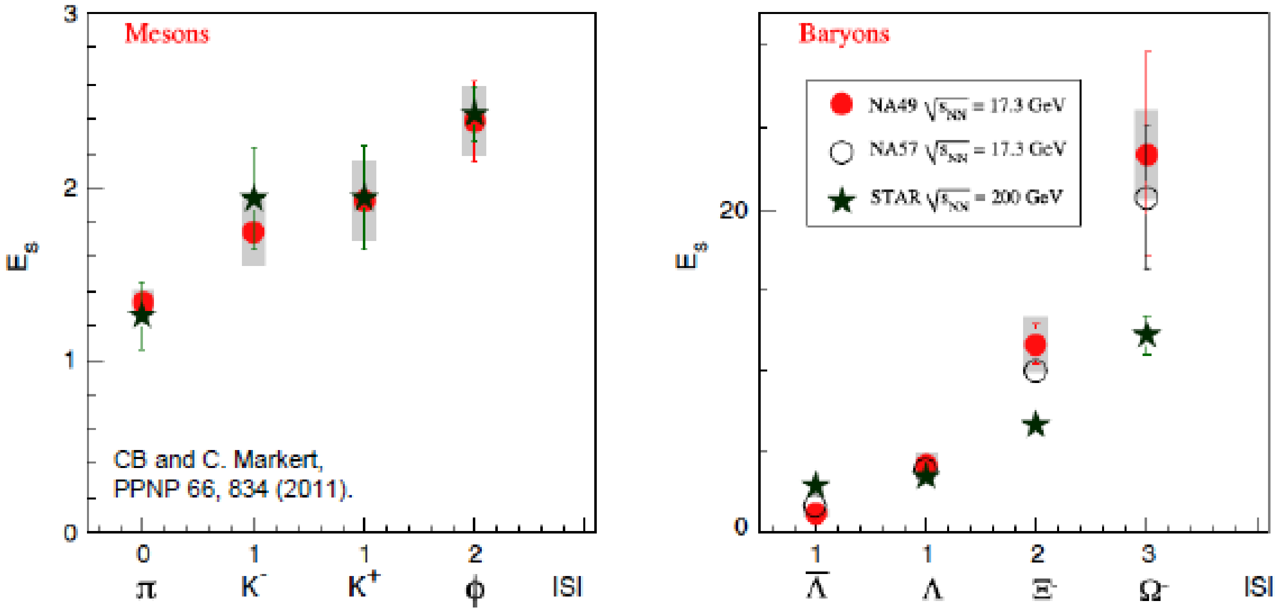
When applied to nuclear collisions:



- Qualitative behavior nicely reproduced
- Predicted maximum at 1.25 A GeV
- High energies: too low due to string production
- HADES preliminary results (1.23 A GeV) still much higher

Strangeness Enhancement

SPS and RHIC Compared



CB and C. Markert, PPNP 66, 834 (2011).

Enhancement factor

As function of the number of strange valence quarks |*S*|

E_s similar for mesons and Λ, large difference for Ξ and Ω
Opposite trend for $\bar{\Lambda}$

Christoph Blume, NeD 2015, September 3

Baryon-Meson Ratios

Ω/ϕ-Ratio vs p_T at RHIC and LHC

Only strange quarks

Baryon (sss) and meson ($s\bar{s}$)

Small hadronic cross section
⇒ partonic phase

Ratio Ω/ϕ

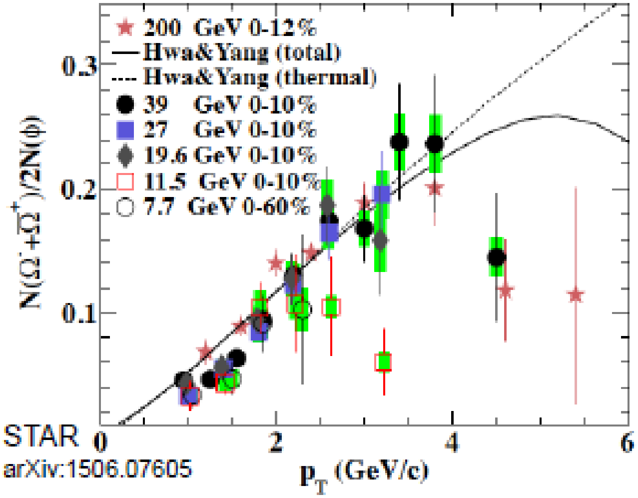
Rising up to $p_T \approx 4$ GeV/c

Consistent with quark coalescence model up to $p_T \approx 4$ GeV/c
Maximum at different position

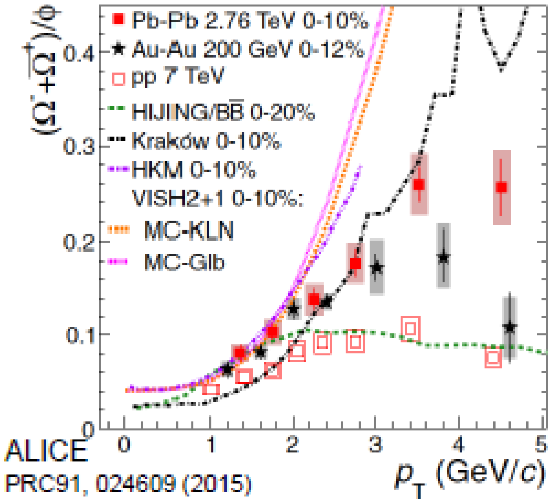
p_T dependence not described by any model

Ω/ϕ(LHC) > Ω/ϕ(RHIC, 200 GeV) for $p_T > 3$ GeV/c

Also deviation at $\sqrt{s_{NN}} = 11.5$ GeV



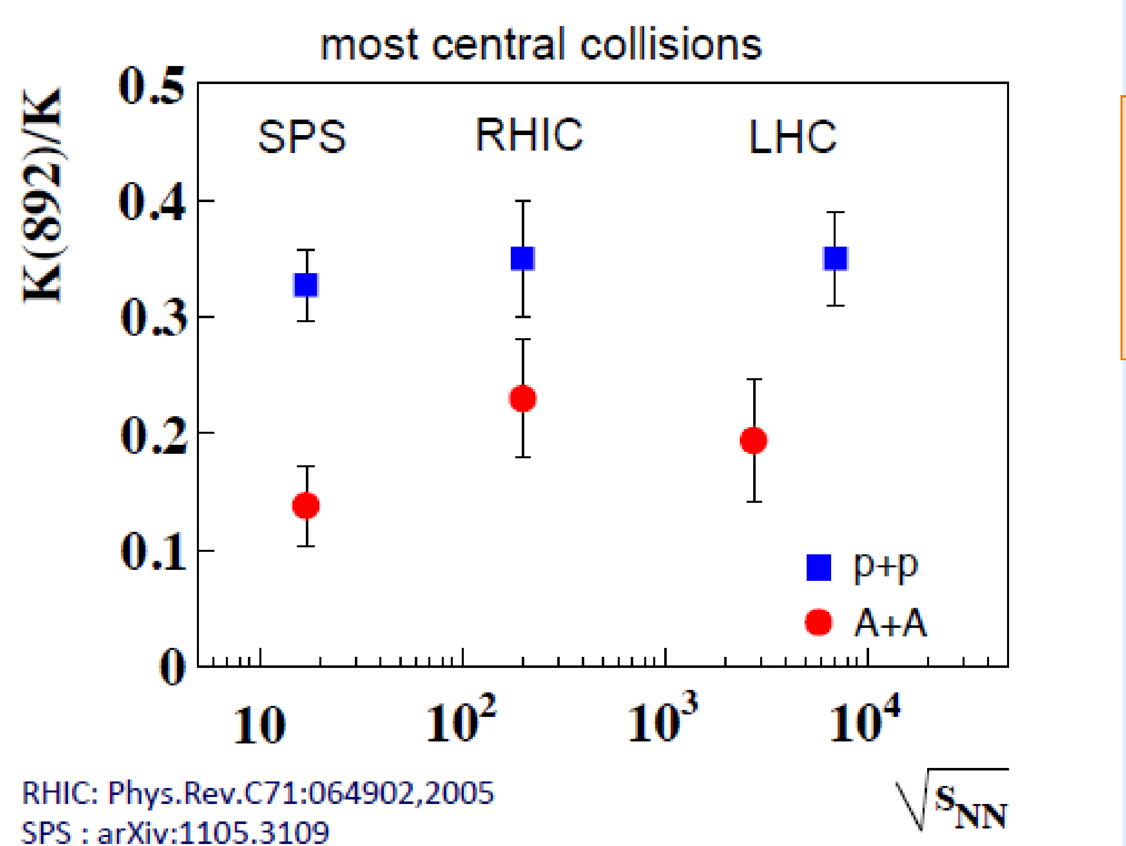
STAR
arXiv:1506.07605



ALICE
PRC91, 024609 (2015)

Christoph Blume, NeD 2015, September 3

Resonance ratios (K*/K) vs energy



RHIC: Phys.Rev.C71:064902,2005
SPS : arXiv:1105.3109

RHIC: Hadronic lifetime > 4-5 fm/c
(in central collisions)
Fireball lifetime ~ 10 fm/c
→partonic lifetime ~ 5 fm/c
CM, G. Torrieri and J. Rafelski,
hep-ph/0206260

Larger resonance suppression at SPS and LHC
(More re-scattering)

Christina Markert, NeD 2015, September 2

Strangeness - elliptic flow

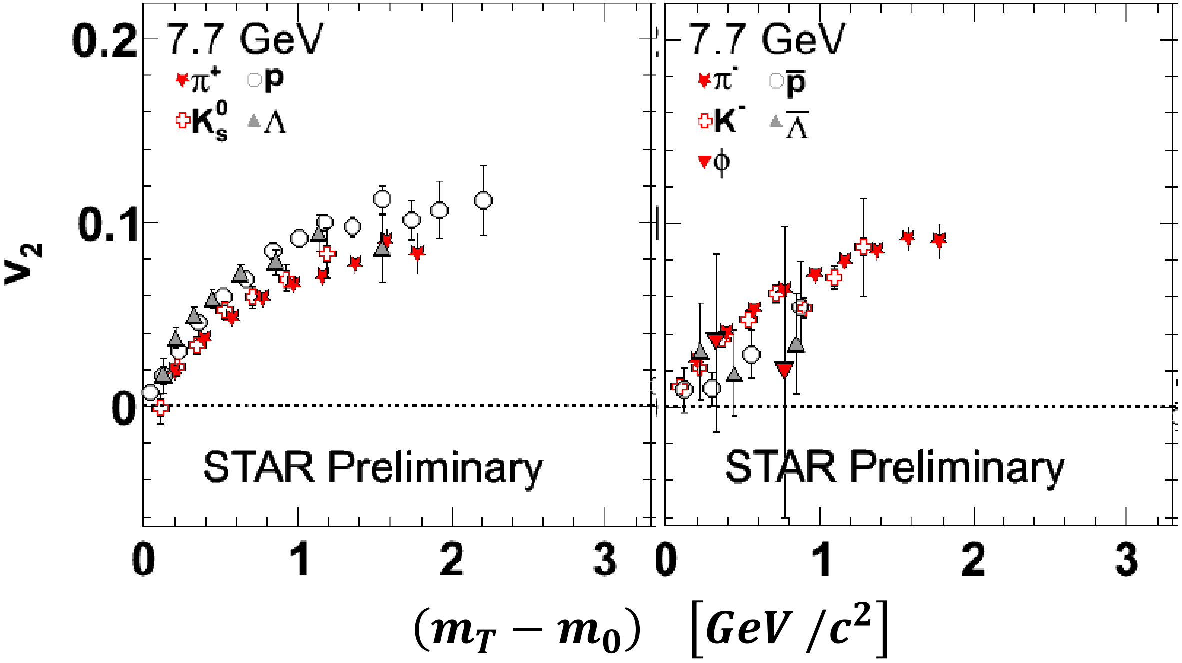
Fourier expansion of the azimuthal distribution dN/dϕ

$$\frac{dN}{d\phi} \sim [1 + 2v_1 \cdot \cos(\phi) + 2v_2 \cdot \cos(2\phi)]$$

the coefficients quantify :

- v_1 the in-plane and
- v_2 the elliptic emission pattern

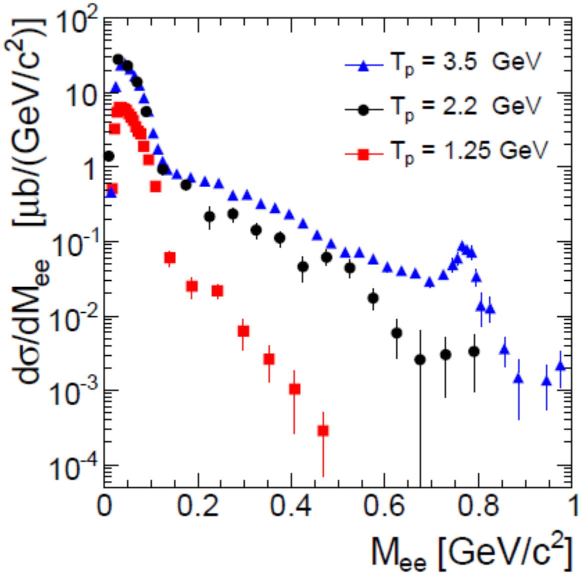
RHIC beam energy scan



few data
at FAIR energies

Dileptons
Excess yield at SIS18

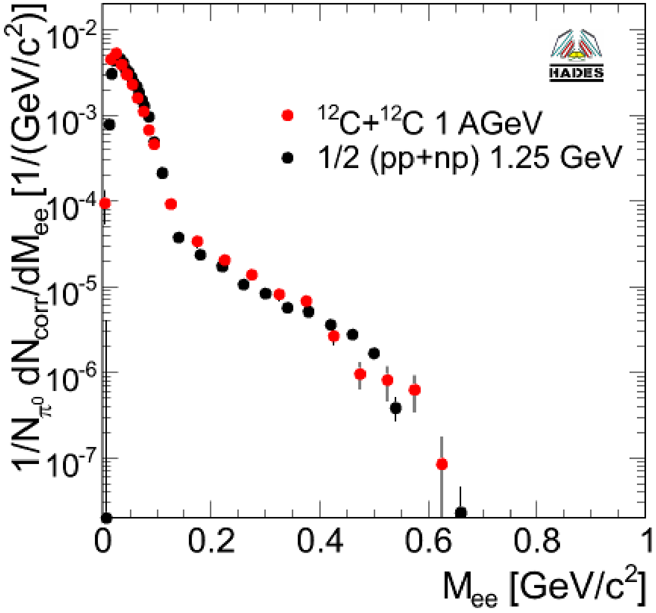
HADES@SIS18

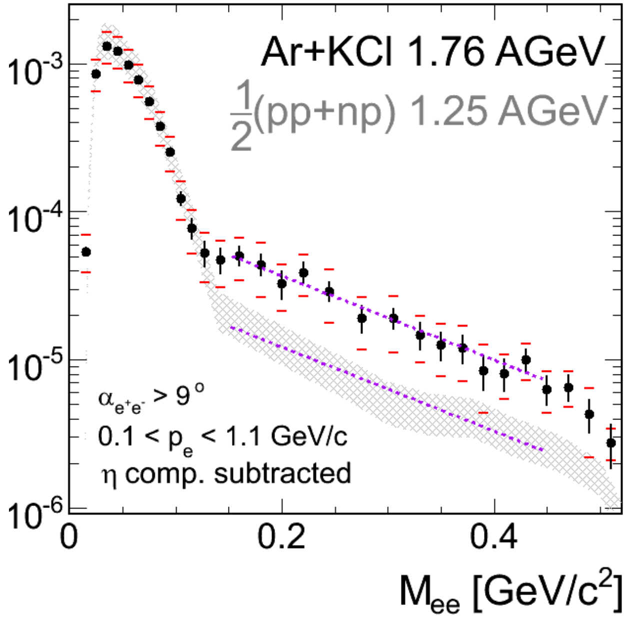


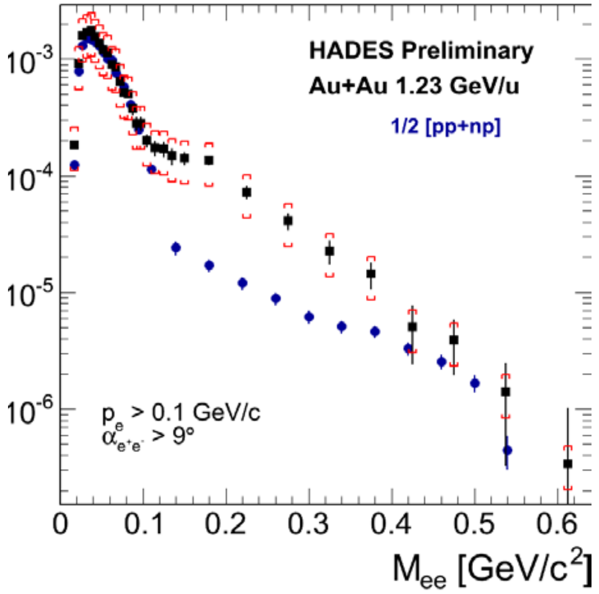
Ar+KCl:
G. Agakishiev et al.PRC 84 (2011) 014902

Au+Au:
preliminary, QM2014

QM 2014

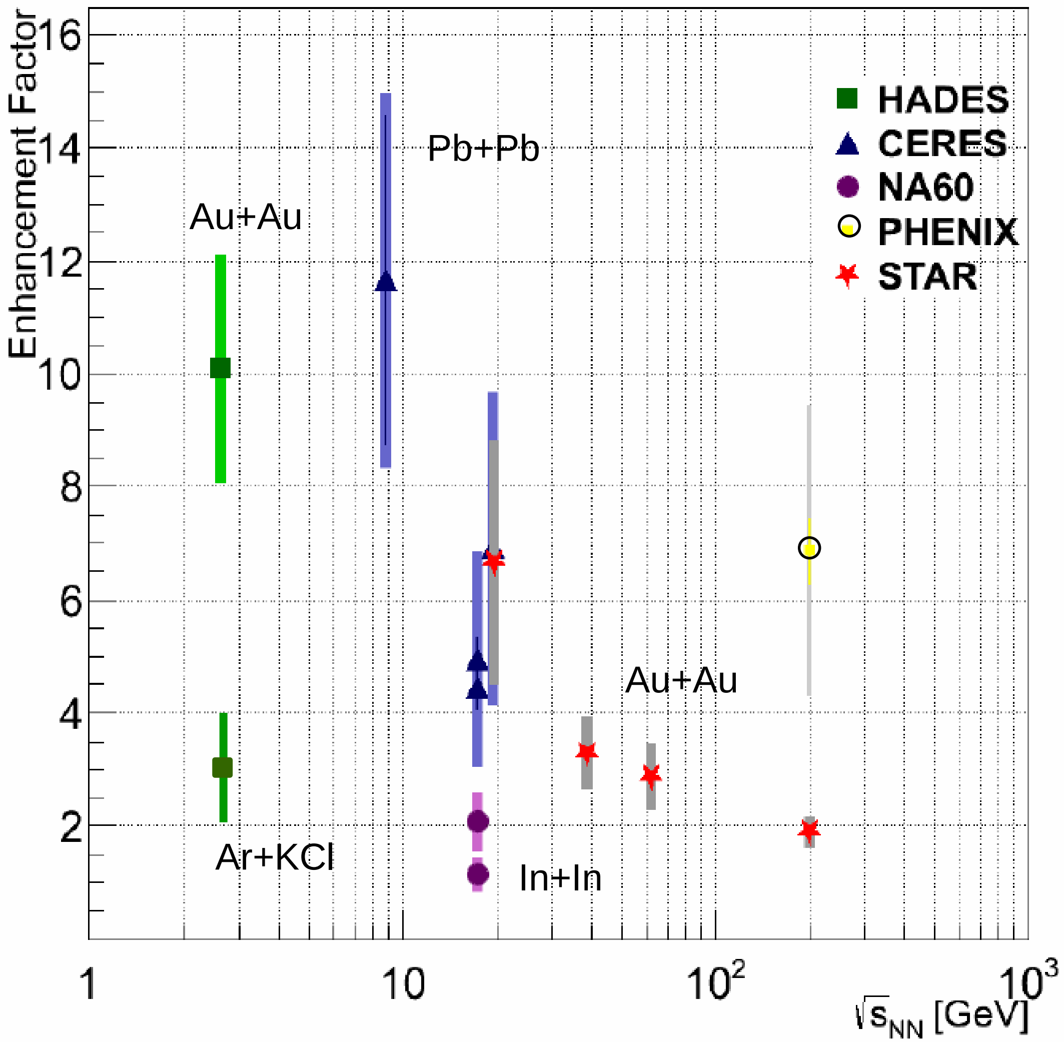






Dileptons

Excess yield



compilation by T. Galatyuk

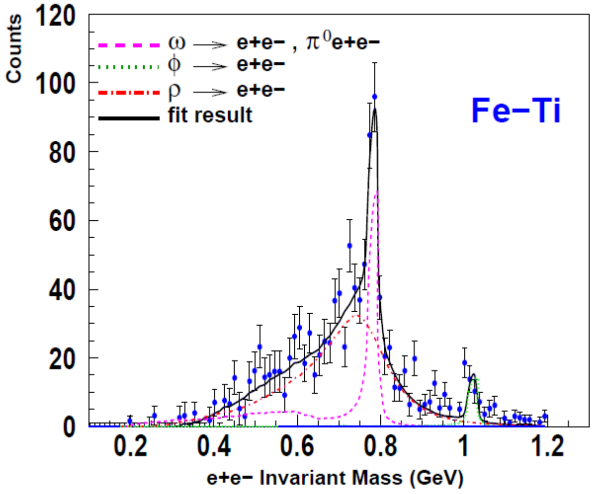
Excess yield observed

- at SIS18 by HADES (in Au+Au, Ar+KCl but not in C+C).
- at SPS by CERES and NA60
- at RHIC by STAR and PHENIX

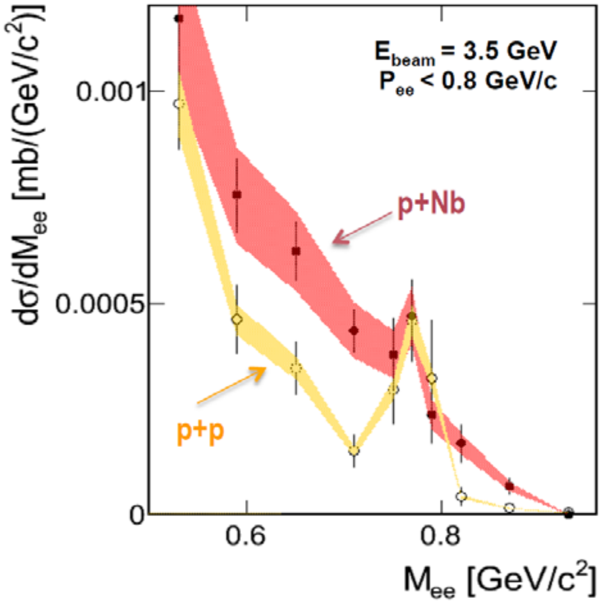
No dilepton data between SIS18 and SPS available !

Dileptons
The melting of the ρ meson

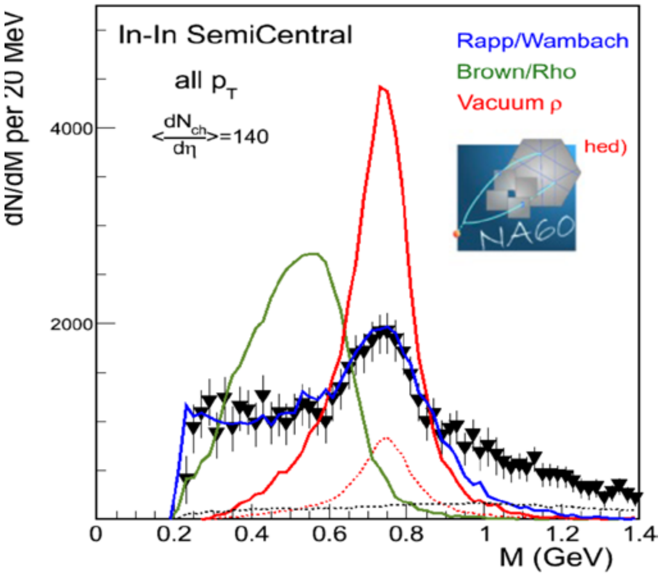
CLAS@JLab
γA
Phys.Rev. C78 (2008) 015201



HADES@SIS18
p+Nb, 3.5 GeV
Phys.Lett. B715 (2012)

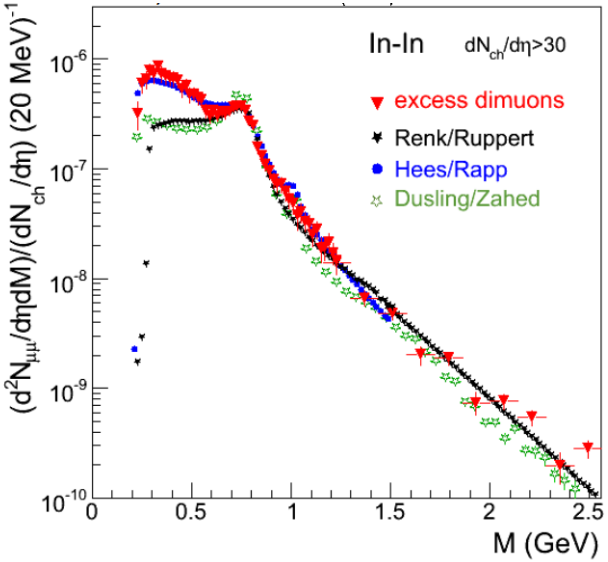


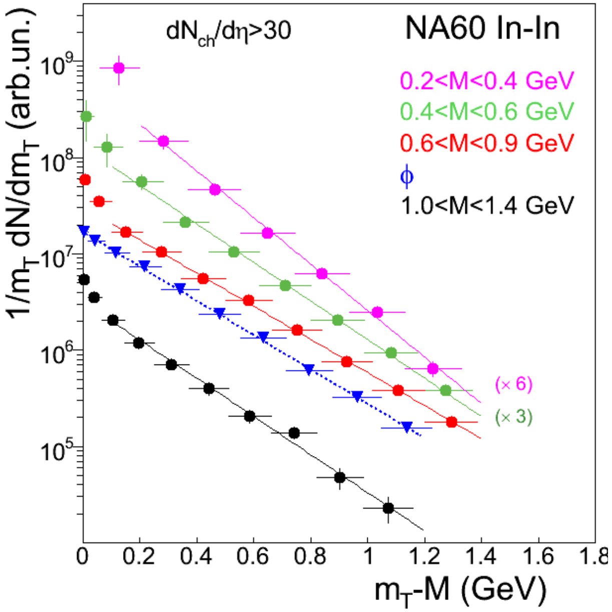
NA60@SPS
In+In, 158 AGeV
Phys. Rev. Lett. 96 (2006) 162302



consistent with broadening (melting) of the ρ meson

Dileptons
The intermediate mass region





Between ϕ and J/ψ:
no hadronic sources

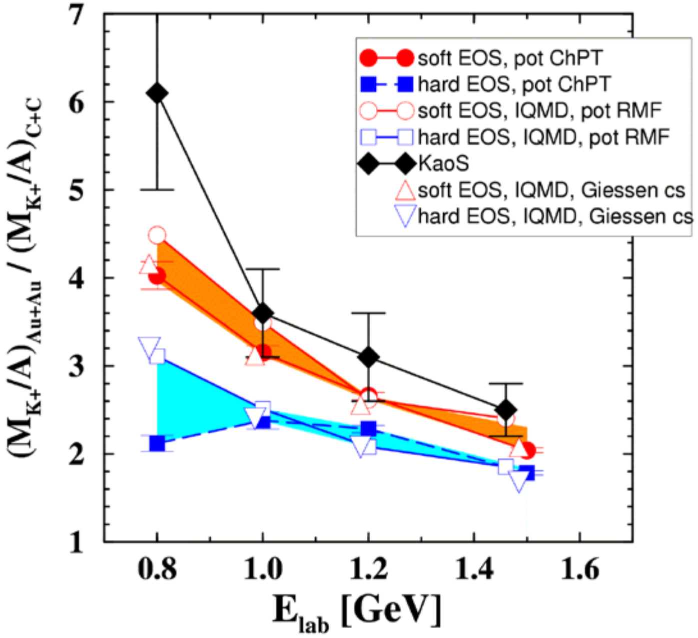
processes:
- Drell-Yan
- thermal radiation
  (QGP / hadron gas)

Temperature of excess yield as function of mass M:
M < 1 GeV: **rise of T(M)**
→ hadronic sources, radial flow
M > 1 GeV: **T ≈ constant**
→ early source, small flow
→ direct radiation from the QGP?

Calls for systematic investigation at lower energies!

Nuclear equation-of-state – data situation at FAIR energies

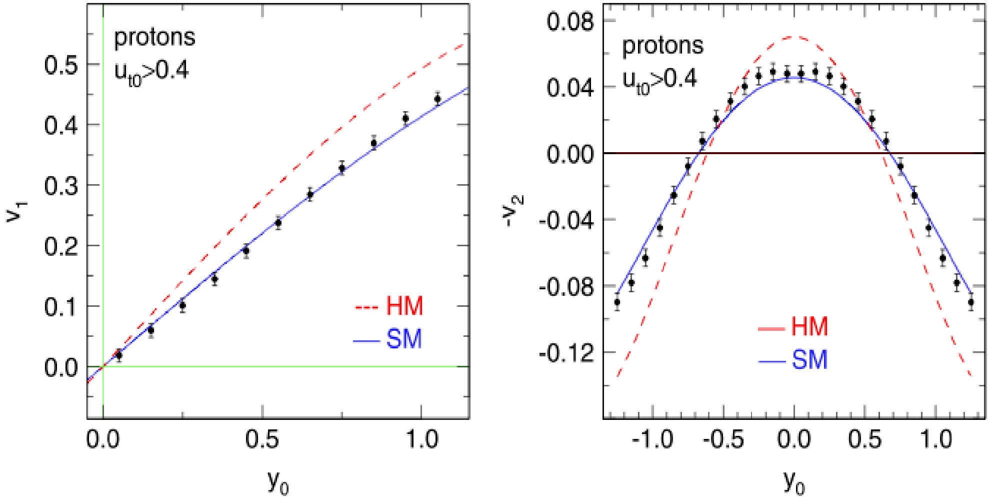
Experiment: CS et al., Phys. Rev. Lett. 86 (2001) 39
Theory: RQMD C. Fuchs et al., Phys. Rev. Lett. 86 (2001) 1974
IQMD Ch. Hartnack, J. Aichelin, J. Phys. G 28 (2002) 1649

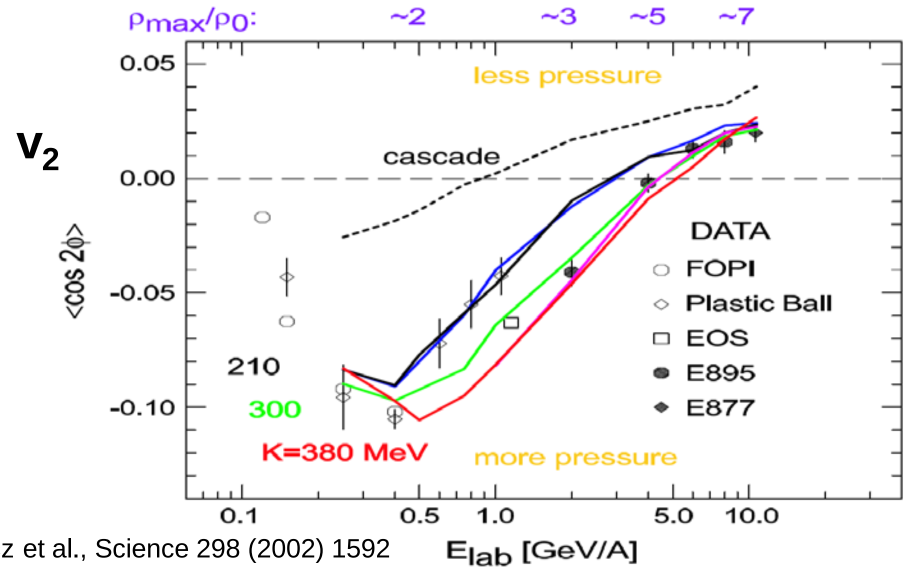


FOPI

Au+Au 1.5 AGeV

W. Reisdorf et al. (FOPI), Nucl. Phys. A 876 (2012) 1



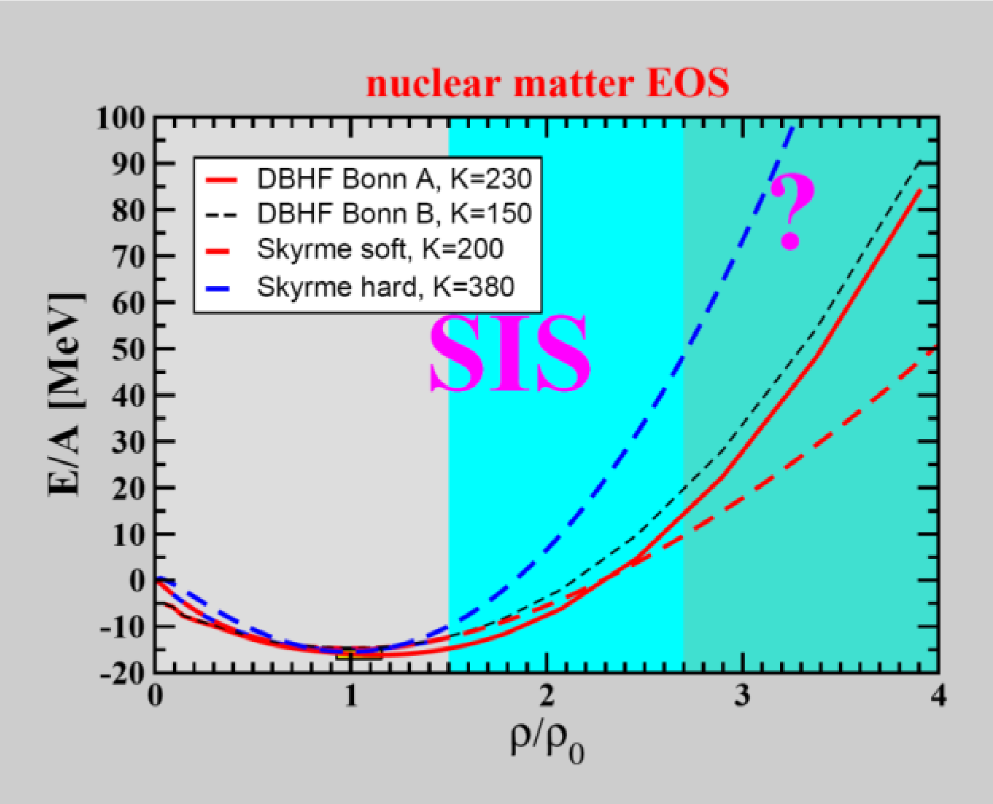


P. Danielewicz et al., Science 298 (2002) 1592

consistent picture at
SIS18 energies (1.5 < ρ / ρ_0 < 3.0)

inconclusive at AGS energies

Nuclear equation-of-State – data situation at FAIR energies



equation-of-state
at
neutron star core densities ?

→ (sub-threshold) production
of $\Omega^+(\bar{s}\bar{s}\bar{s})$ at FAIR energies
- refined to the high-density phase
- small final-state interaction

DBHF: E. N. E. van Dalen, C. Fuchs, A. Faessler
EPJ. A 31,29 (2007)

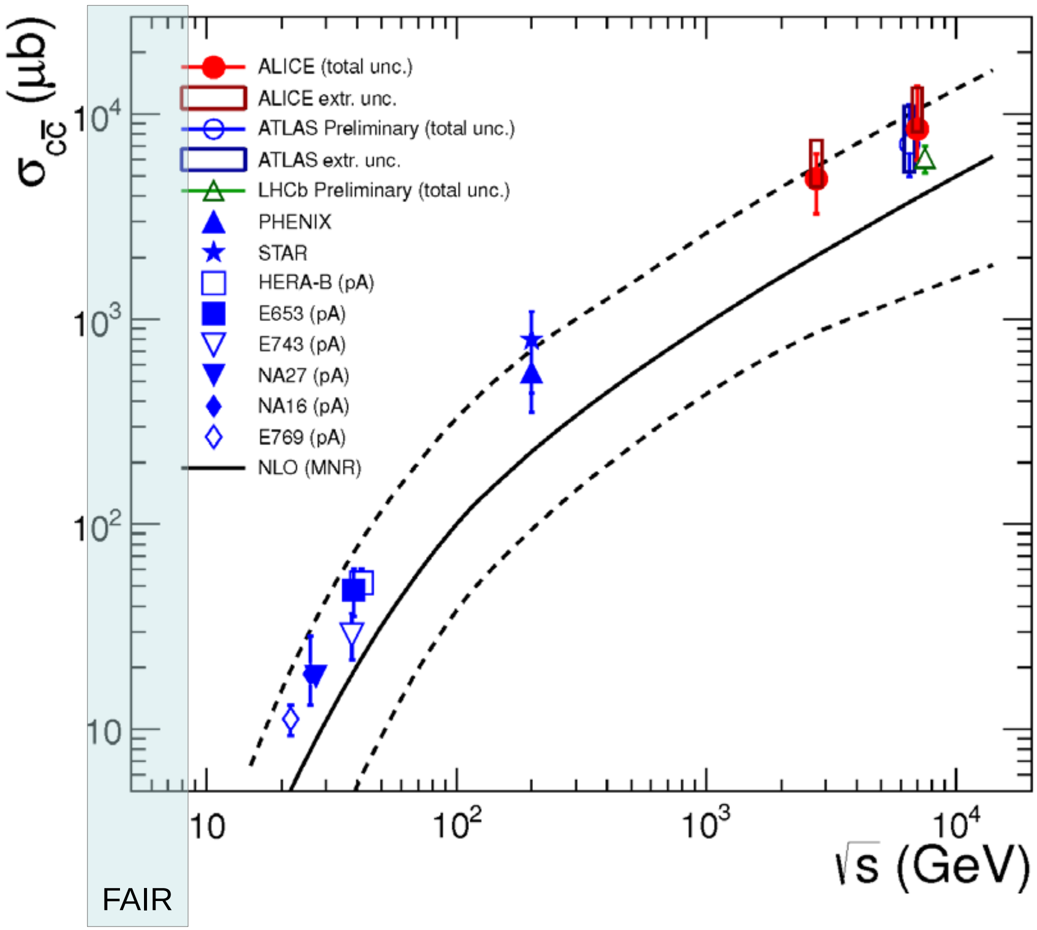
Open and hidden charm

Observables

Cross sections and phase-space distributions in p+p , p+A , A+A collisions

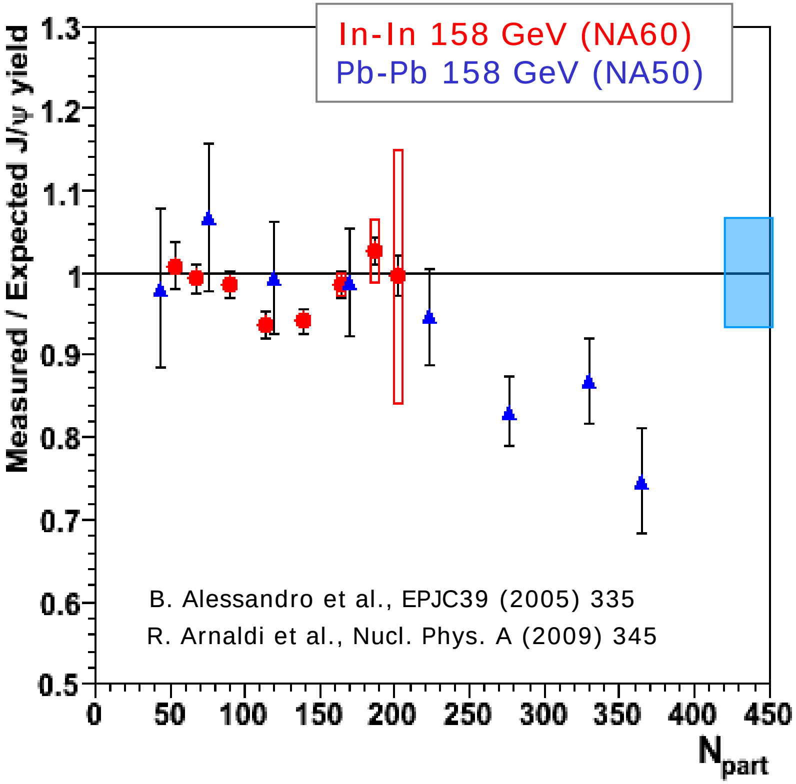
Physics case

- Charm production at threshold energies
- Charm production in cold nuclear matter
- Charm propagation in dense QCD matter



no charm data at FAIR energies

Charmonium (J/ψ)



B. Alessandro et al., EPJC39 (2005) 335
R. Arnaldi et al., Nucl. Phys. A (2009) 345

“J/ψ summary plot from SPS”

No data available below top SPS energies !

Excitation function of J/ψ production at SIS100/300 energies
→ production mechanism ?
→ J/ψ suppression ?

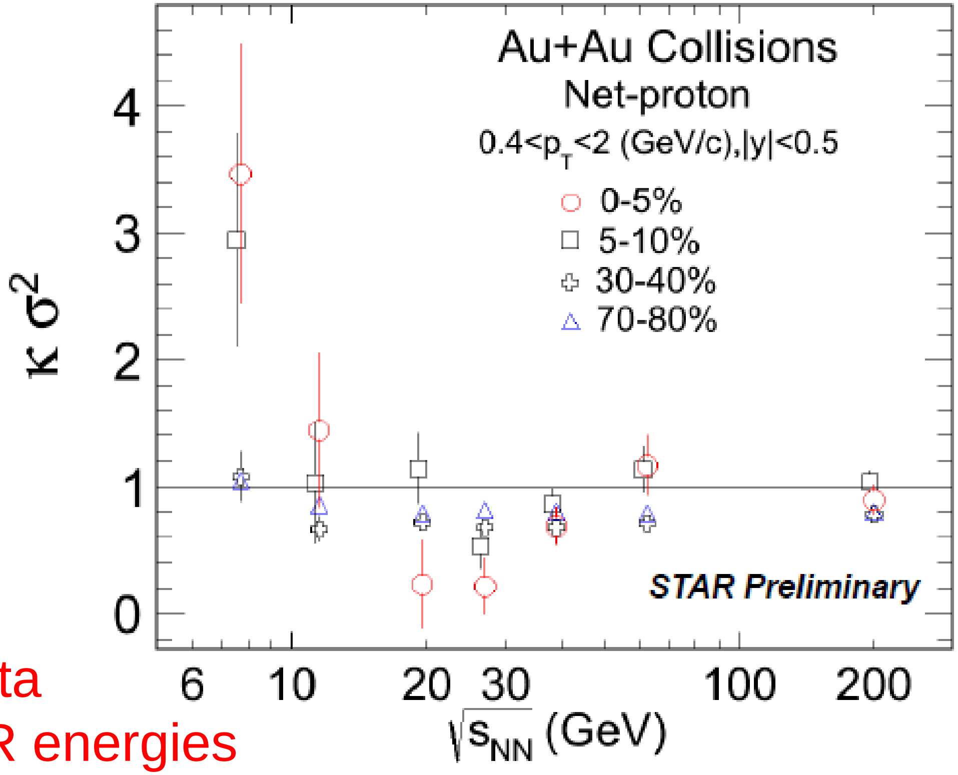
Collective flow, correlations, fluctuations

Observables

- Excitation function of flow of identified particles
- Enhanced production of composite particles, multi-particle correlations (spinodal amplification of density fluctuations)
- Higher moments of net-baryon and net-charge multiplicity distributions

Physics case

- Equation-of-state
- Phase coexistence
- Phase transition
- Critical point

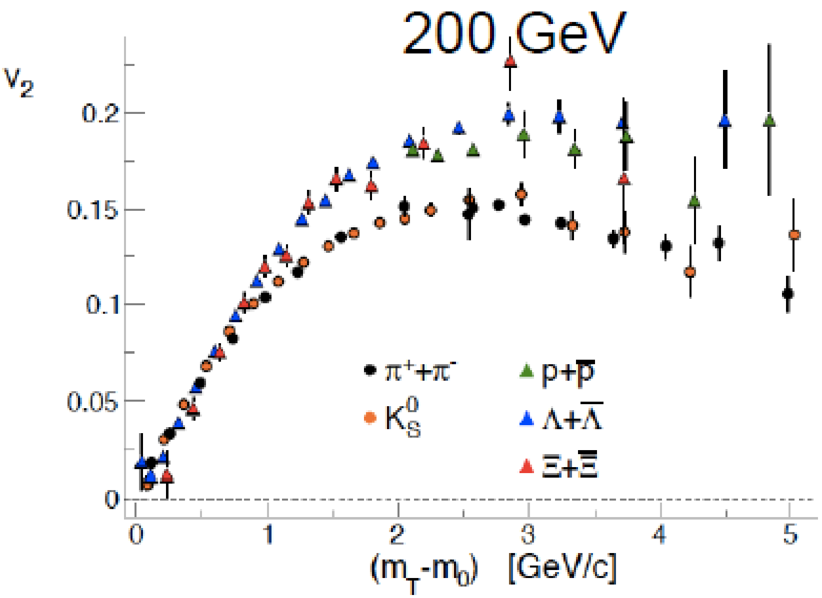


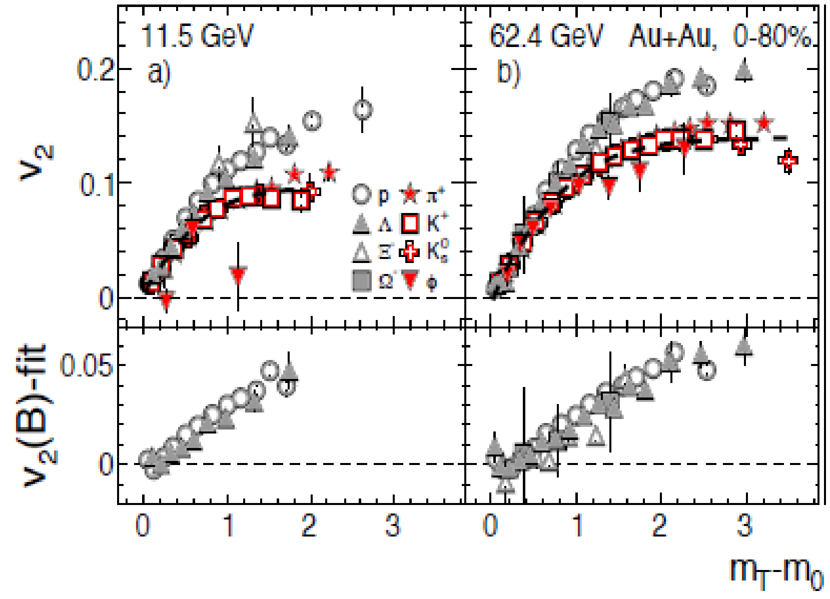
few data
at FAIR energies

v_2 from 2.76 TeV down to 7.7 GeV

elliptic asymmetry depends on quark number: thought to be a signal of a hadron formation from a quark-gluon plasma

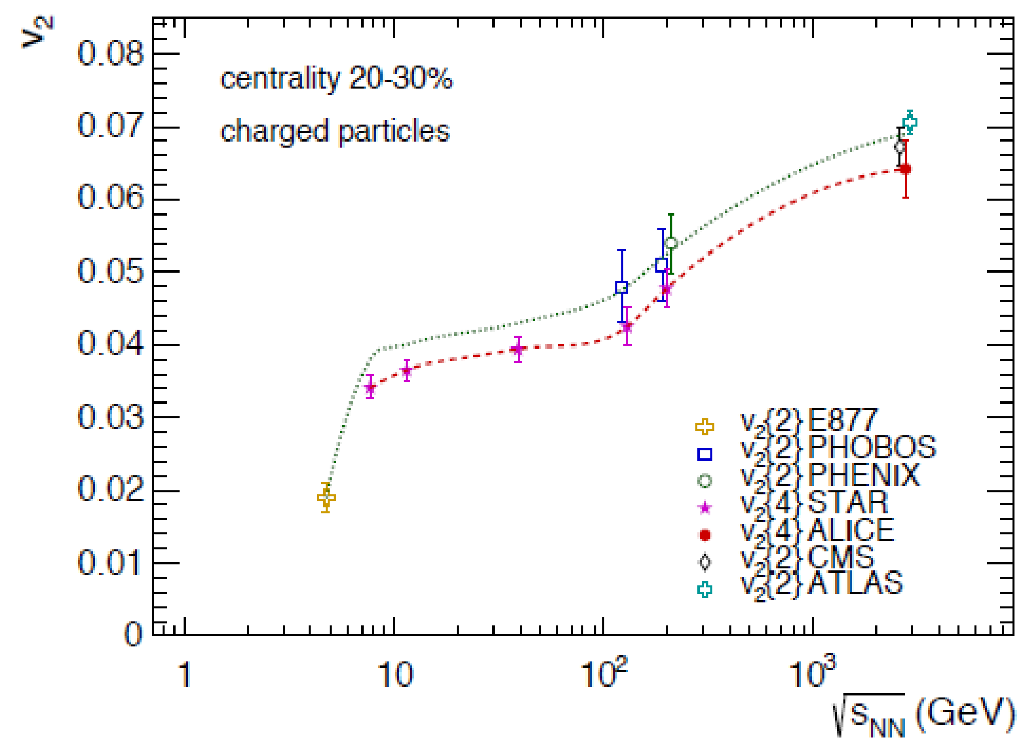
$$\rho_B \sim \rho_q^3; \qquad \rho_M \sim \rho_q^2;$$





The baryon-meson quark number grouping persists to the lowest energies

Integrated v_2



collision energy dependence of the elliptic flow
shows indication of changing slope

Raymond Snellings, NeD 2015, August 31

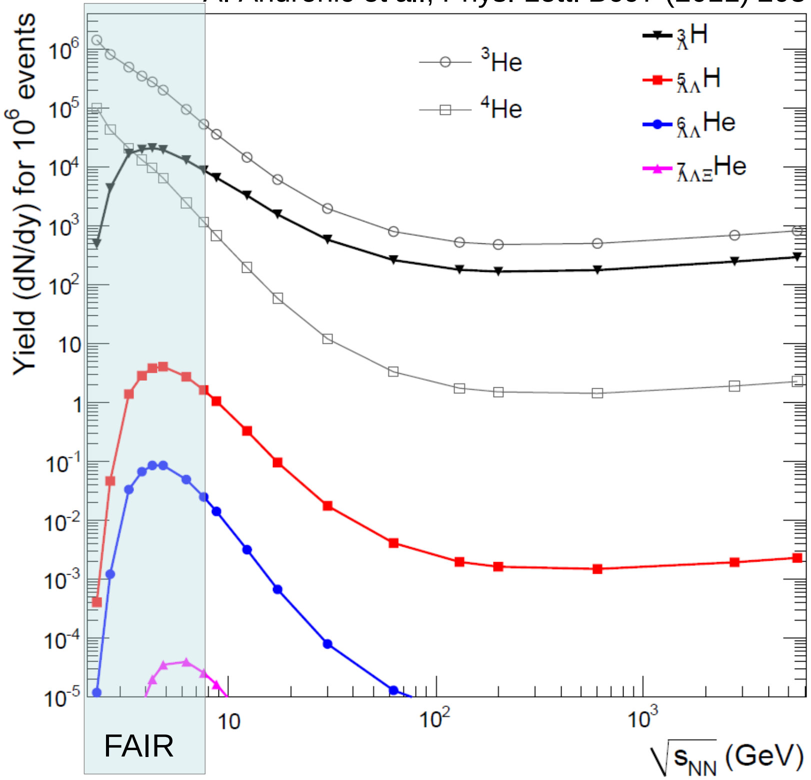
Strange Matter

Observables

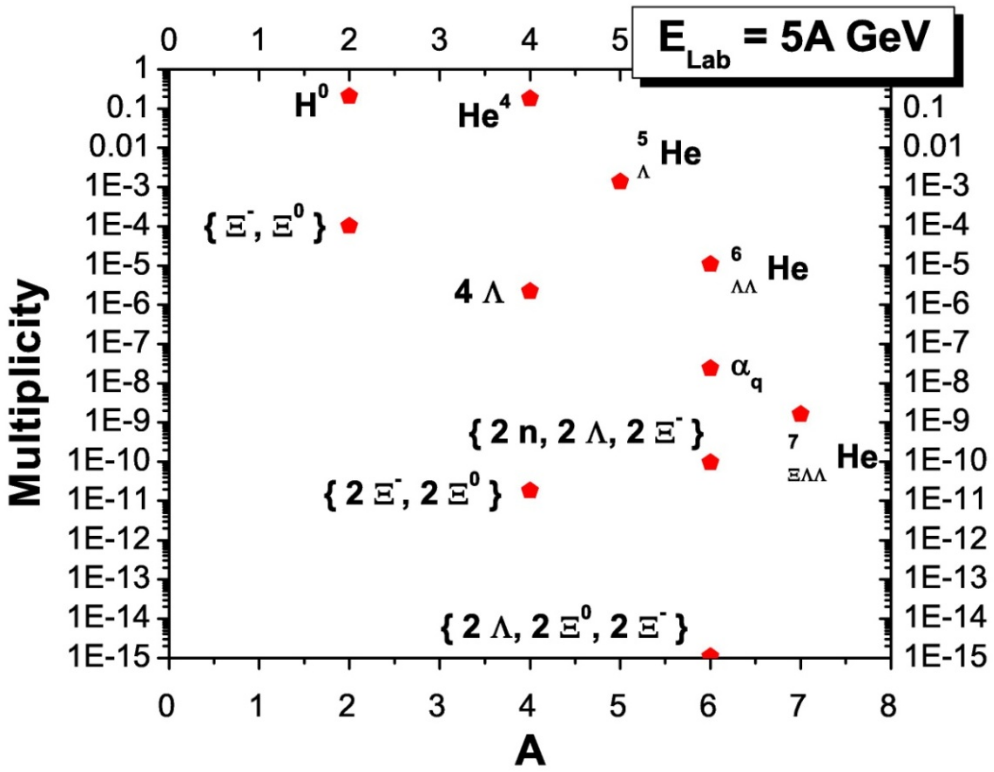
Hypernuclei, strange dibaryons and massive strange objects

no data at FAIR energies

A. Andronic et al., Phys. Lett. B697 (2011) 203



H. Stöcker et al., Nucl. Phys. A 827 (2009) 624c



The CBM physics program

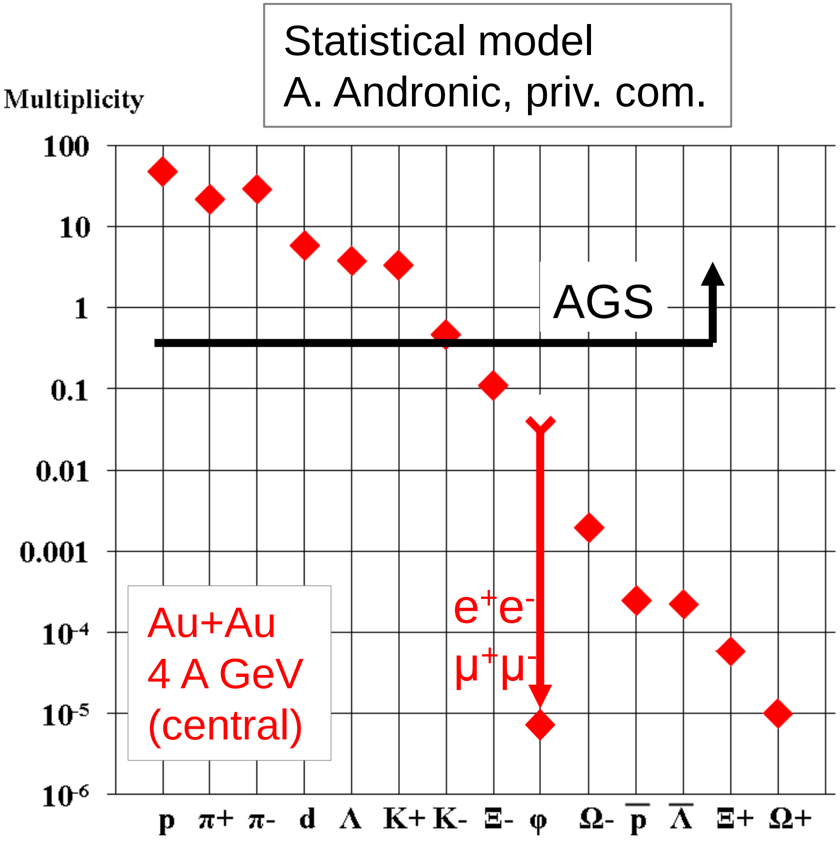
Physics case

- Nuclear matter equation-of-state at high net-baryon densities
- Strangeness in nuclear matter and (multi-) strange objects
- Search for quarkyonic matter or for phase coexistence
- In-medium modifications of hadrons
- Exploring chiral symmetry restoration
- Charm production and propagation in cold nuclear matter and in dense QCD matter

Observables

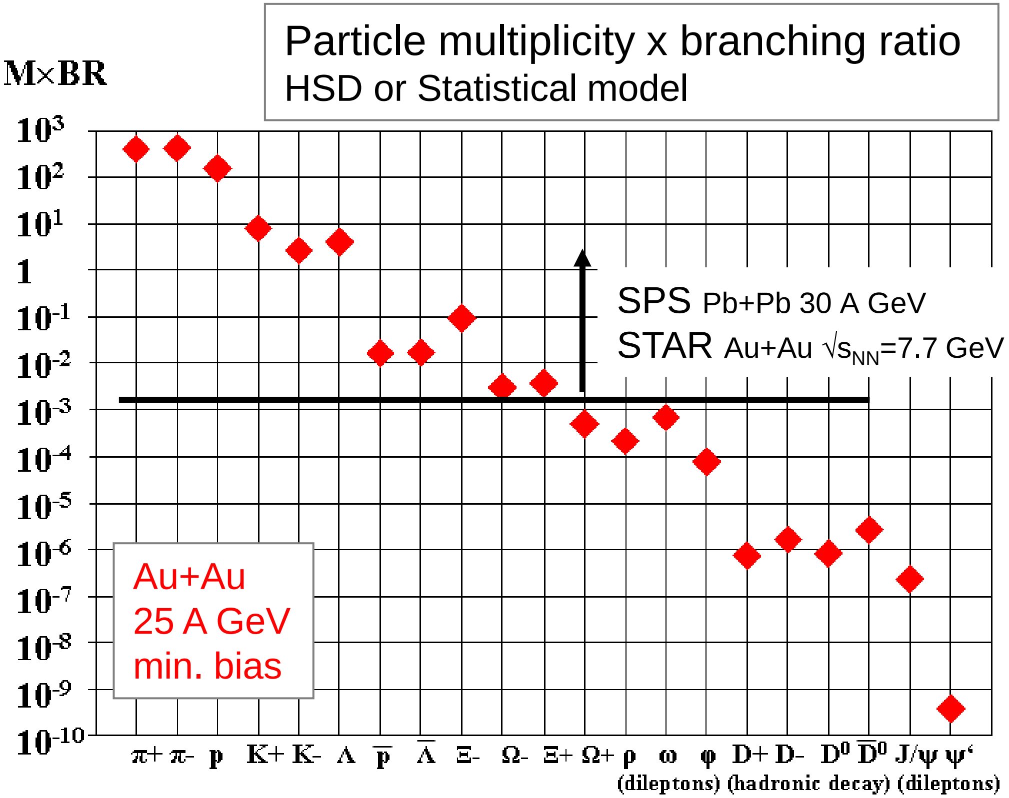
- Strangeness
- Dileptons
- Collective flow, correlations, fluctuations
- Charm
- Hypernuclei

Experimental challenges



Statistical model
A. Andronic, priv. com.

Au+Au
4 A GeV
(central)



Particle multiplicity x branching ratio
HSD or Statistical model

SPS Pb+Pb 30 A GeV
STAR Au+Au $\sqrt{s_{NN}}$=7.7 GeV

Au+Au
25 A GeV
min. bias

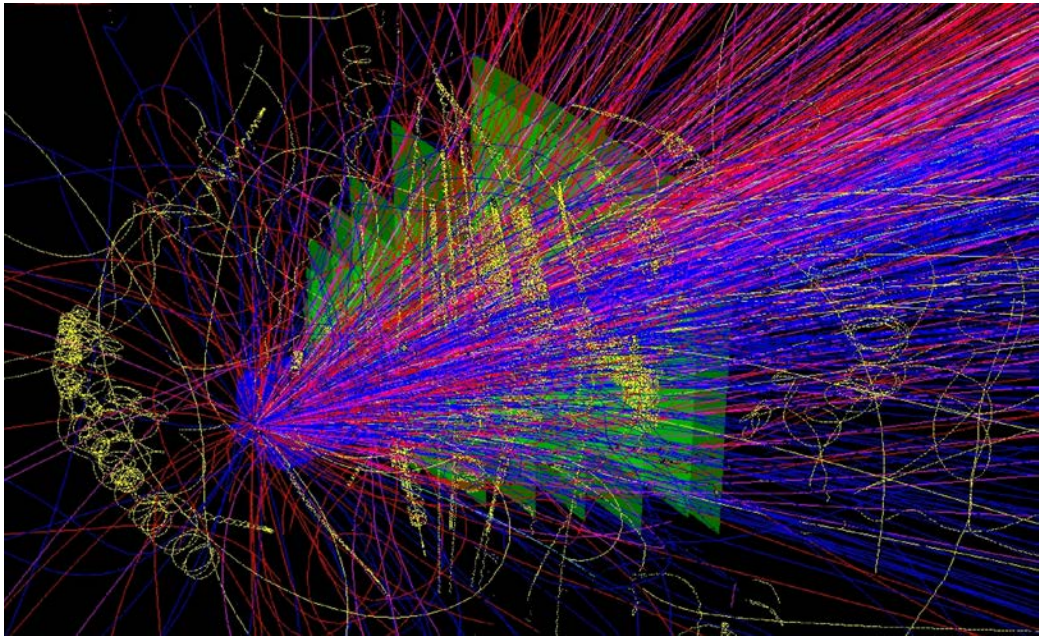
rare probes → extremely high interaction rates required !

Experimental challenges

Perform measurements at unprecedented reaction rates

10^5 - 10^7 Au+Au reactions/sec

→ fast and radiation tollerant detectors
→ free-streaming read-out electronics
→ high speed data acquisition and
high performance computer farm for online event selection



Central Au+Au at 25 A GeV / UrQMD+GEANT4
160 p, 450 $\pi^+ + \pi^-$, 44 K^+, 13 K^-

Identification
of leptons and hadrons

Determination of
(displaced) vertices ($\sigma \approx 50\ \mu m$)

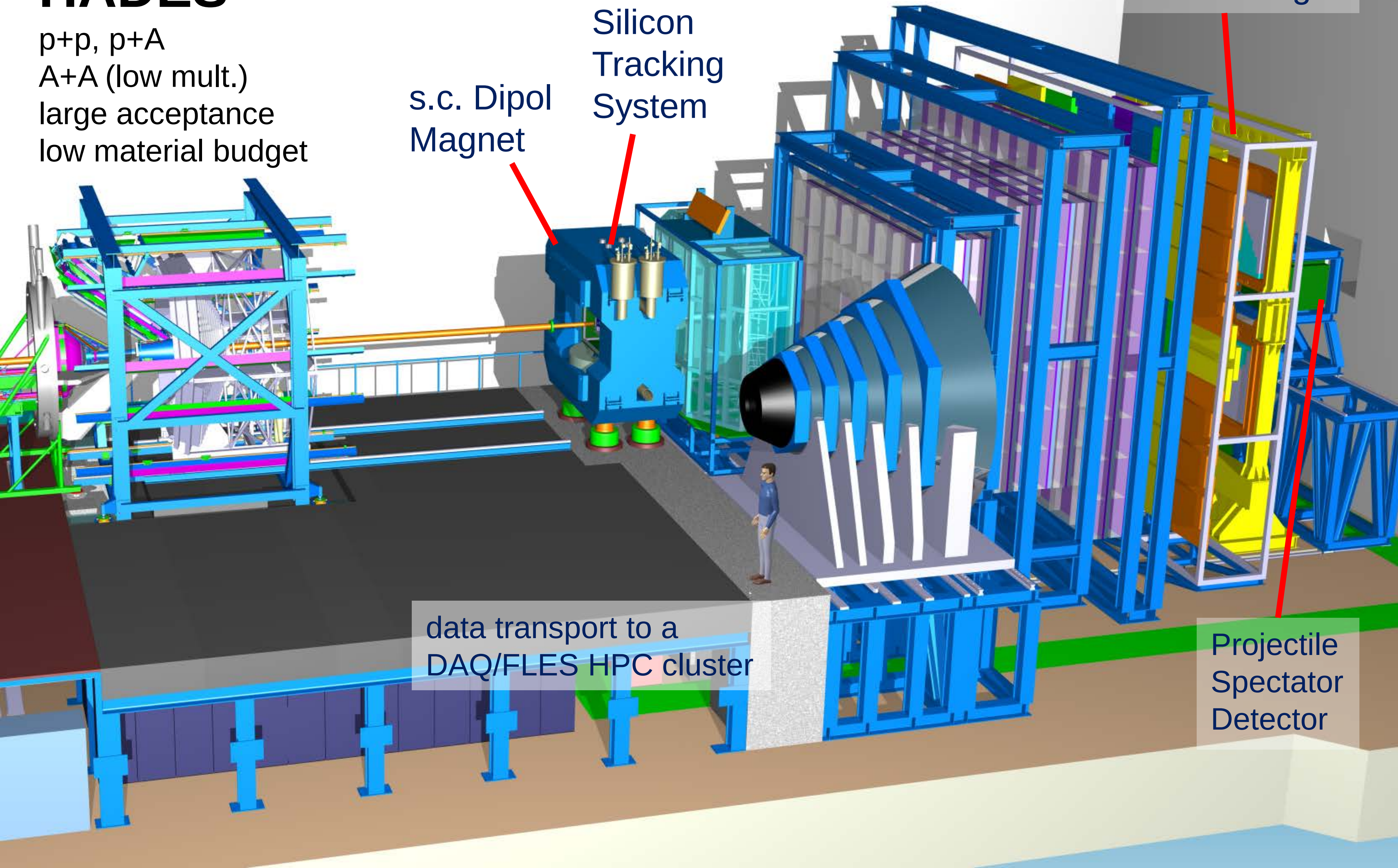
momentum resolution
$\delta p / p \cong 1\%$

HADES

p+p, p+A
A+A (low mult.)
large acceptance
low material budget

CBM

hadrons



s.c. Dipol Magnet

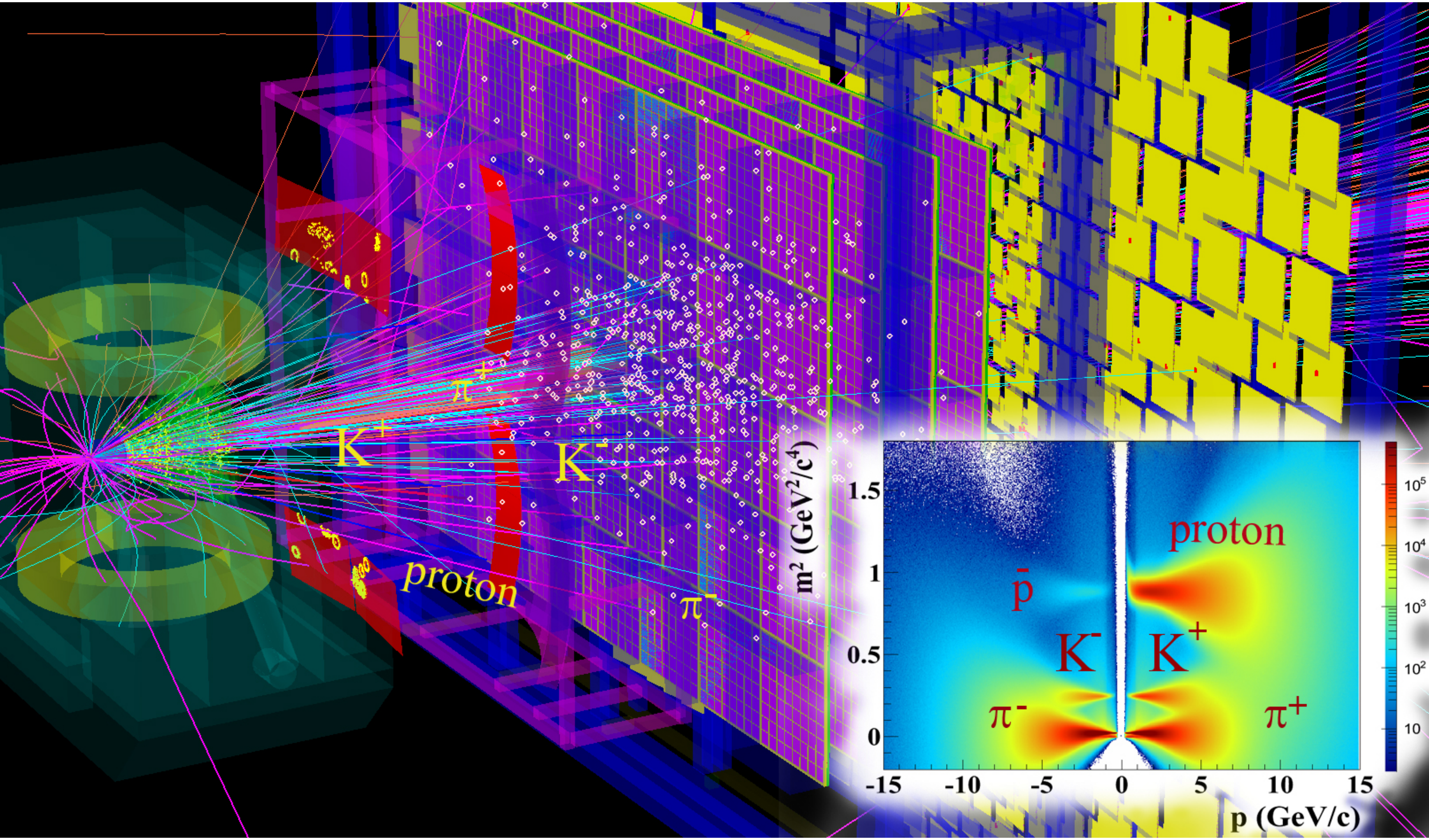
Silicon Tracking System

Time of Flight

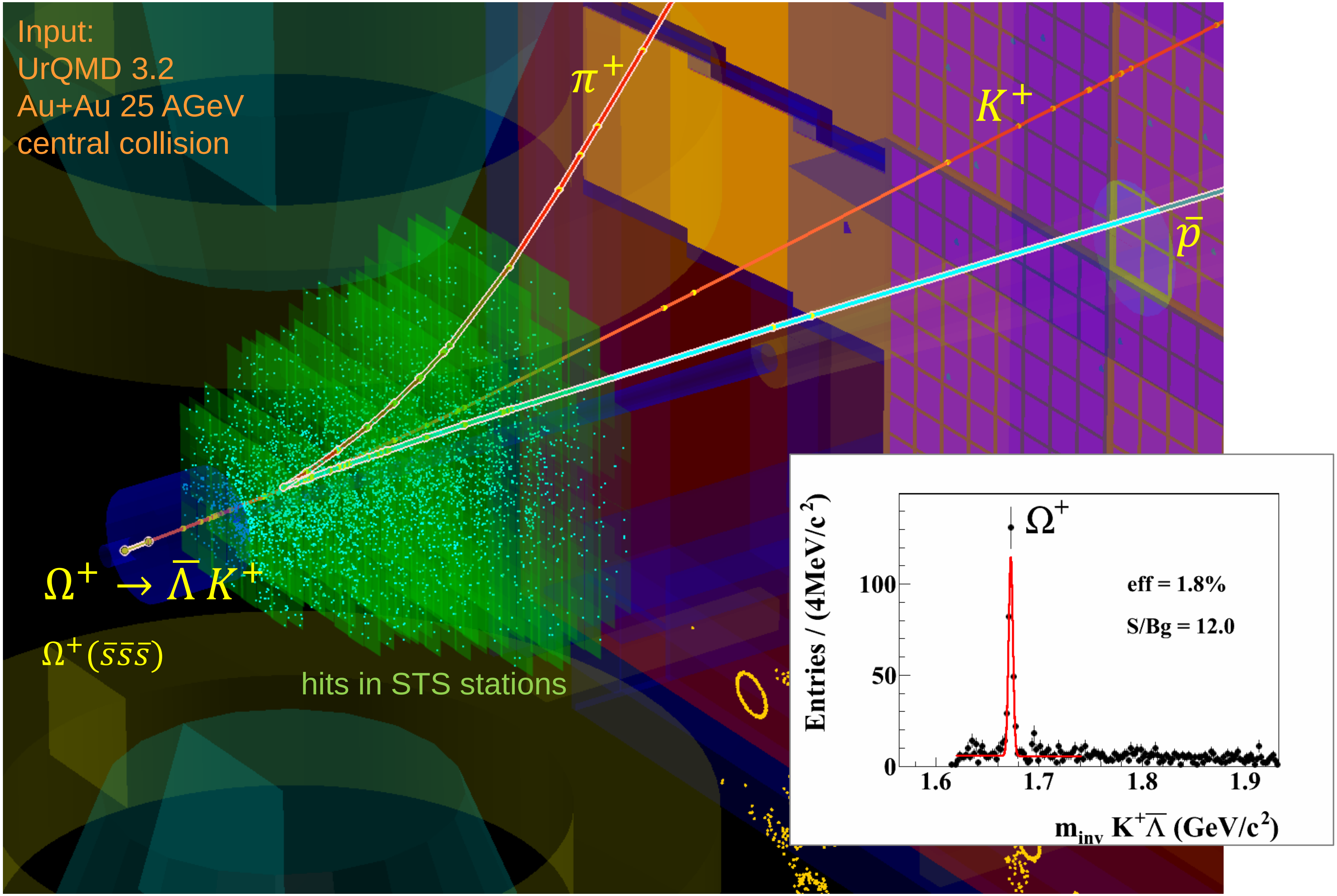
data transport to a DAQ/FLES HPC cluster

Projectile Spectator Detector

Particle identification



Anti-hyperon reconstruction



Input:
UrQMD 3.2
Au+Au 25 AGeV
central collision

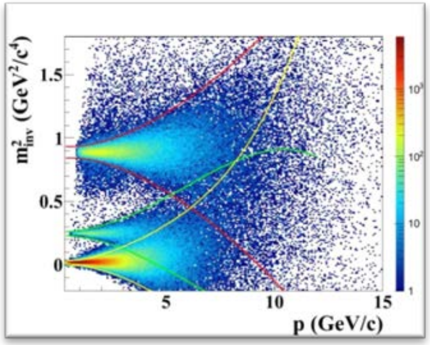
$\Omega^+ \rightarrow \bar{\Lambda} K^+$

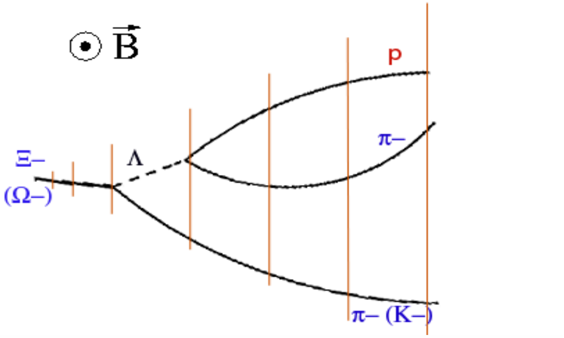
$\Omega^+(\bar{s}\bar{s}\bar{s})$

Performance of hyperon identification

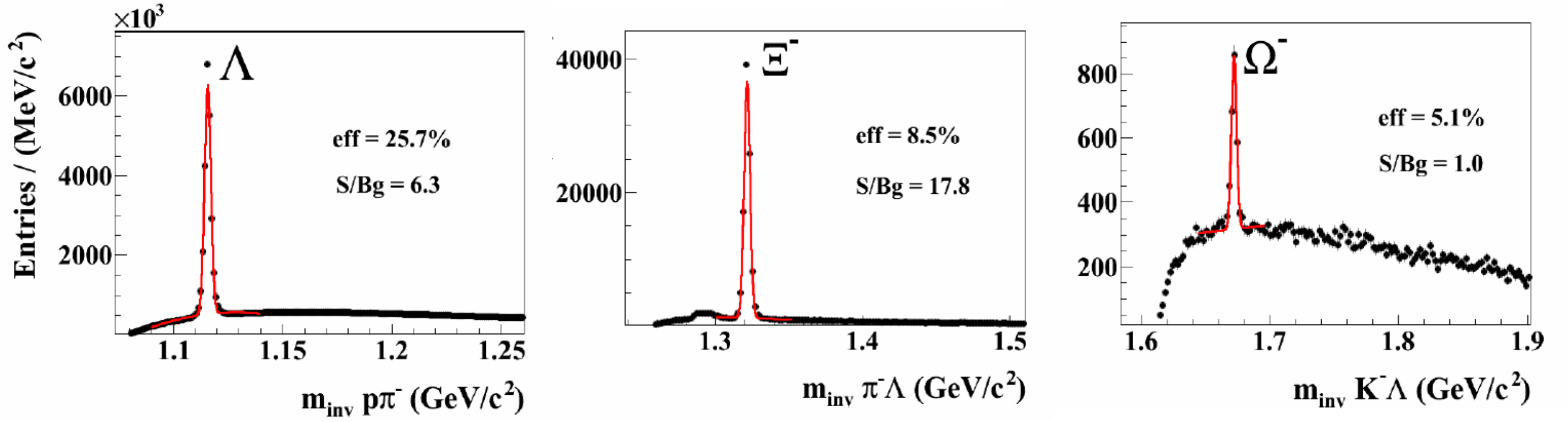
Simulations:

- STS with realistic geometry, material budget, and detector response
- TOF at 10 m, time resolution 80 ps

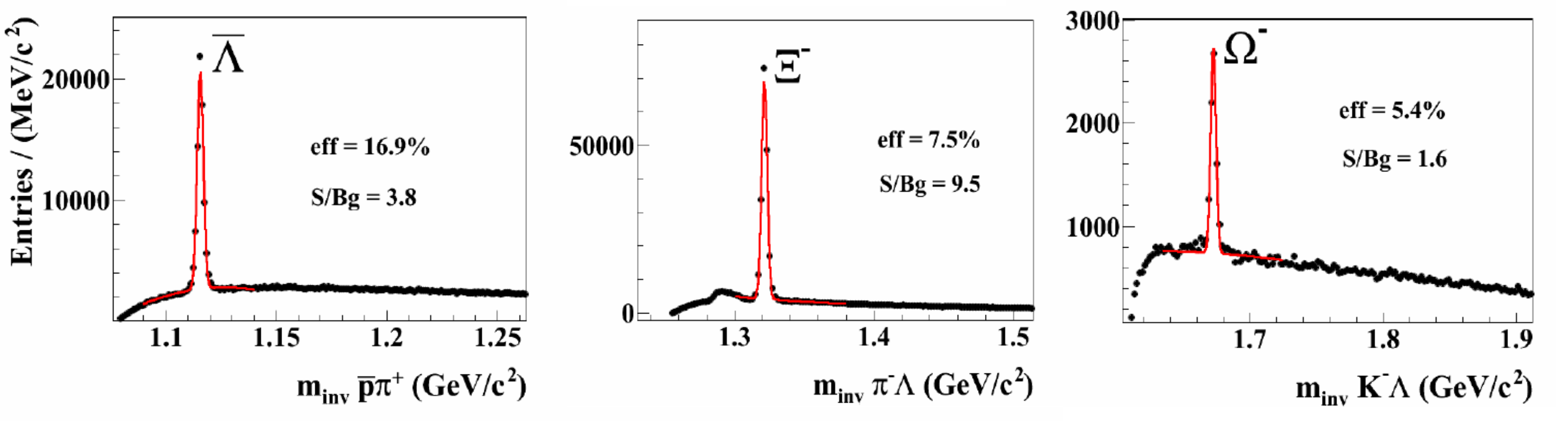




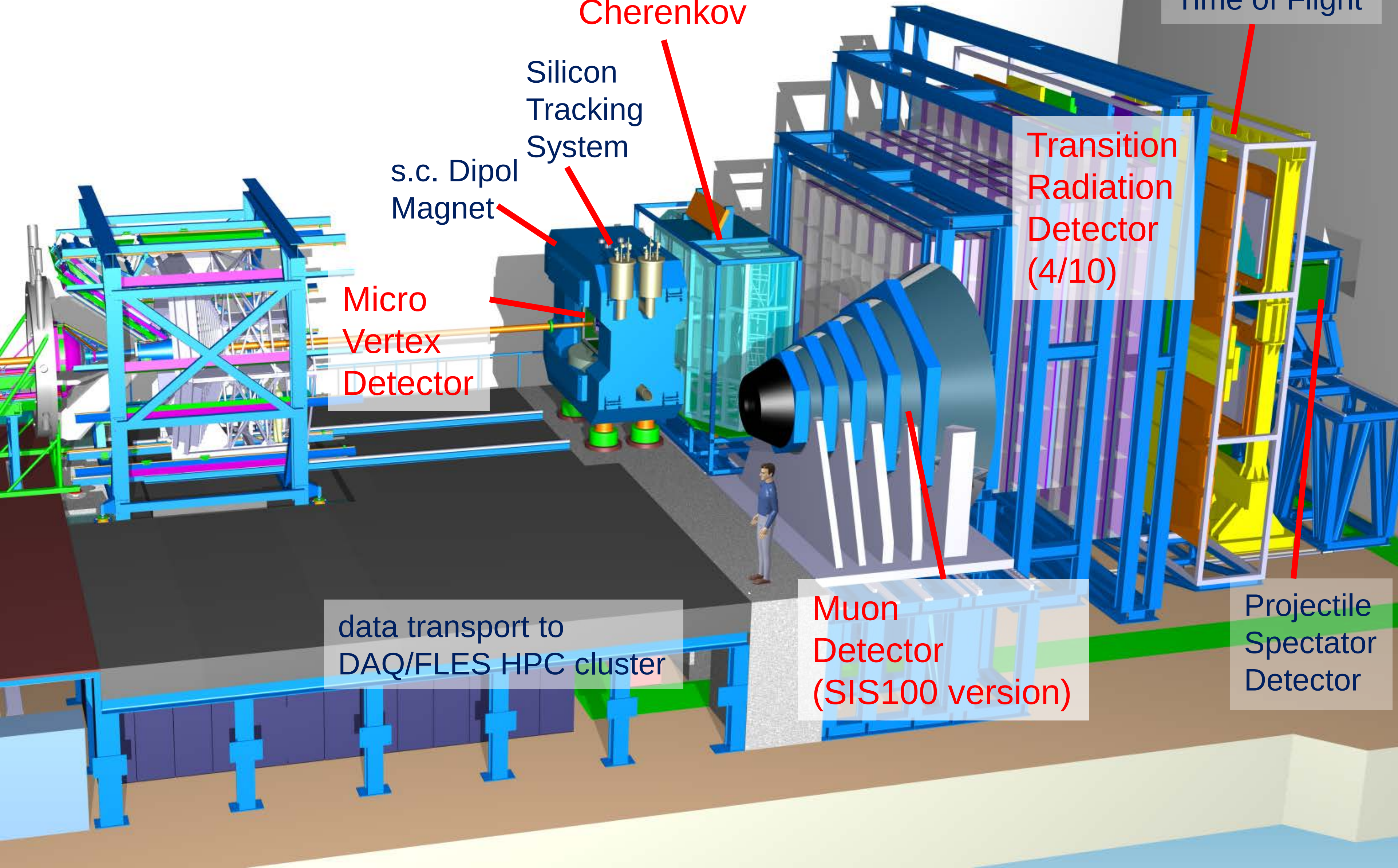
5·10^6 Au+Au central **10 AGeV**



5·10^6 Au+Au central **25 AGeV**



CBM
dileptons



Ring Imaging Cherenkov

Silicon Tracking System

s.c. Dipol Magnet

Micro Vertex Detector

Time of Flight

Transition Radiation Detector (4/10)

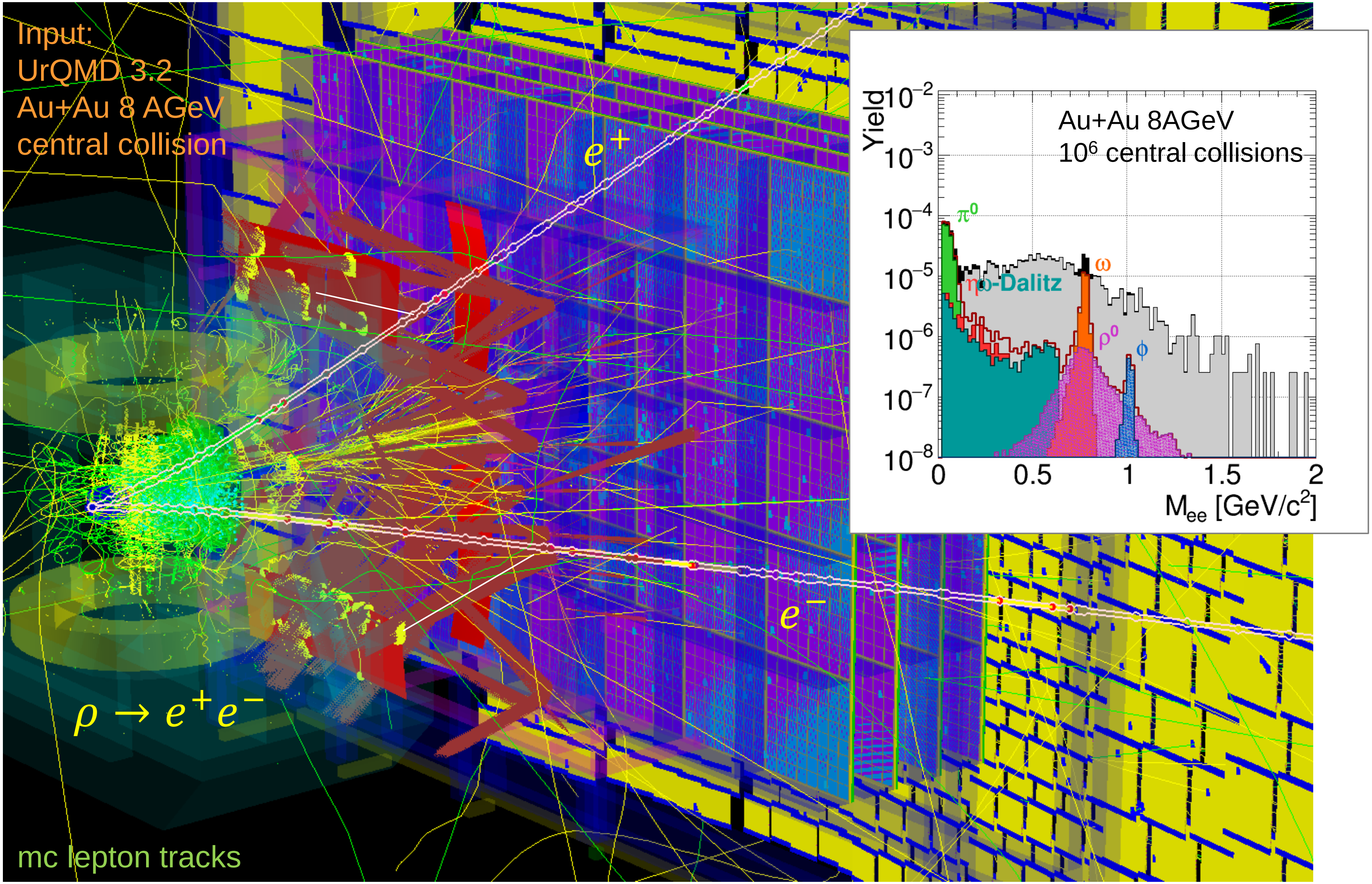
Muon Detector (SIS100 version)

Projectile Spectator Detector

data transport to DAQ/FLES HPC cluster

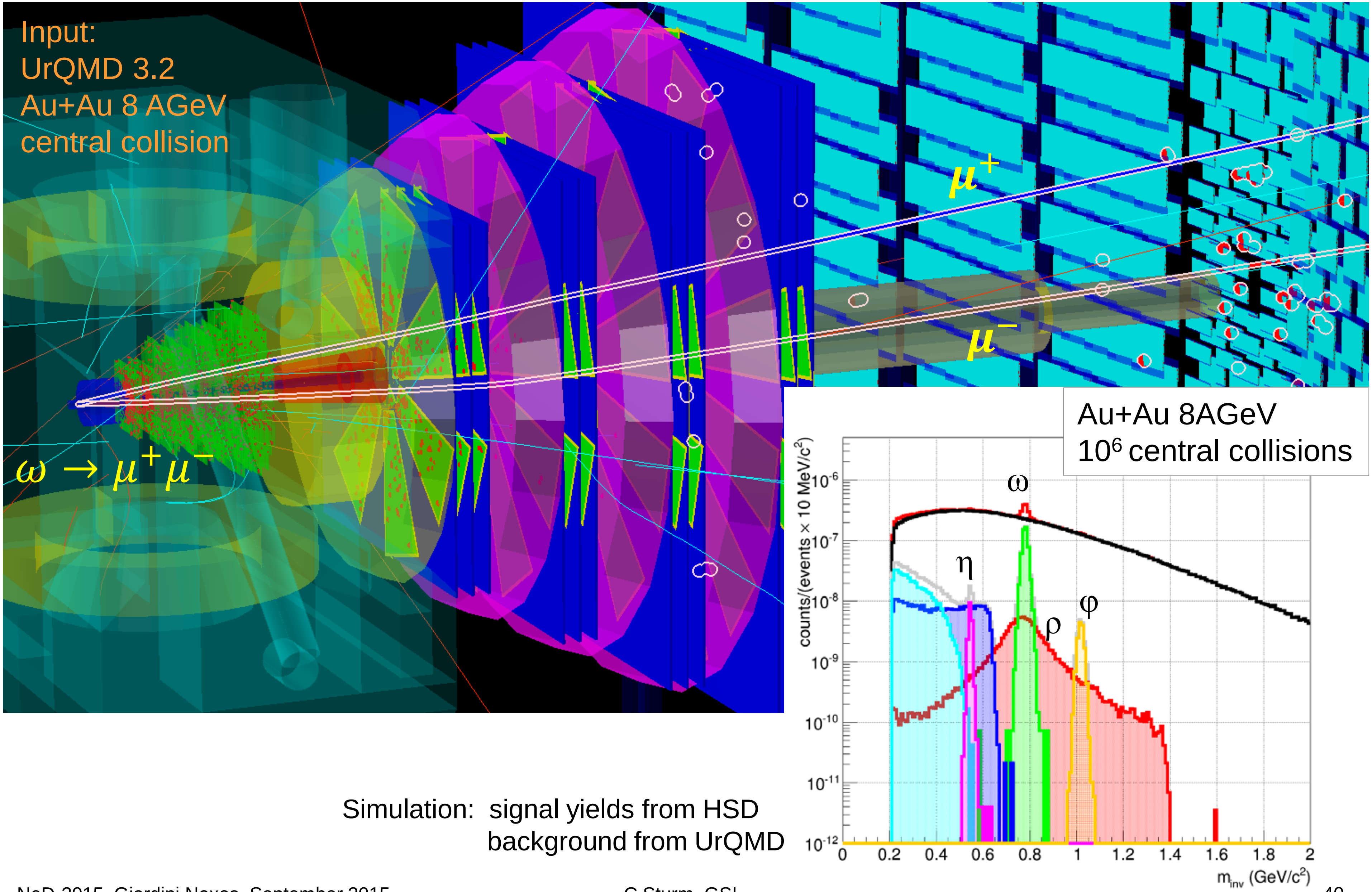
Di-electron reconstruction

Input:
UrQMD 3.2
Au+Au 8 AGeV
central collision



mc lepton tracks

Di-muon reconstruction



Input:
UrQMD 3.2
Au+Au 8 AGeV
central collision

$\omega \rightarrow \mu^+\mu^-$

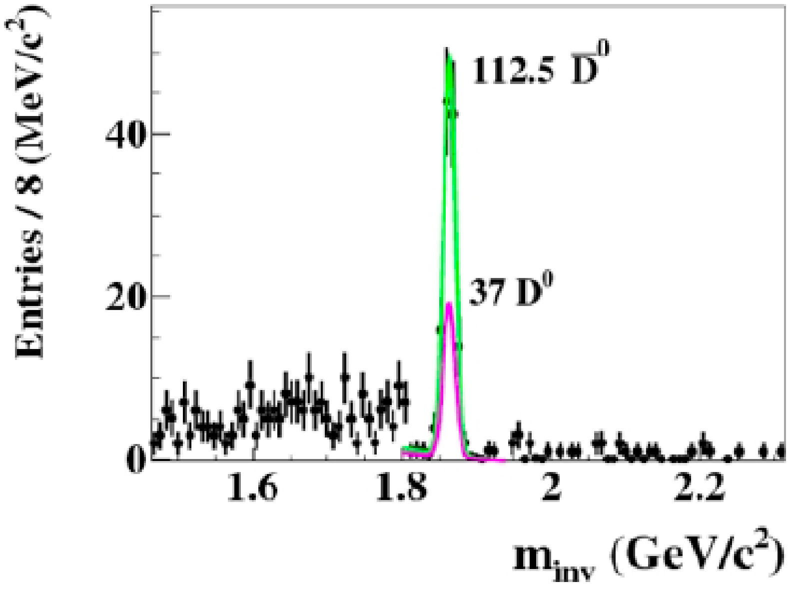
Simulation: signal yields from HSD
background from UrQMD

Open charm in CBM at SIS100

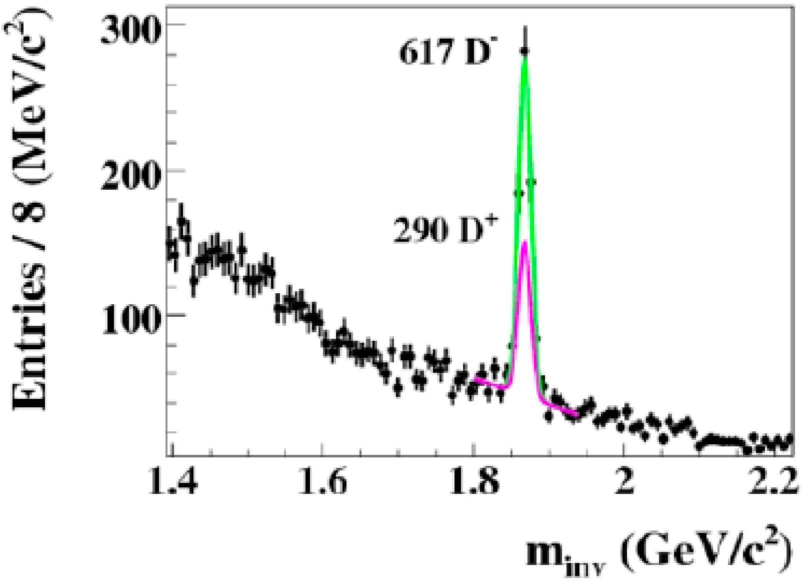
- ► Charm production cross sections at threshold energies
- ► Charm production in cold nuclear matter

Open charm reconstruction in p+C 30GeV :

$D^0 \rightarrow K\pi\pi\pi$



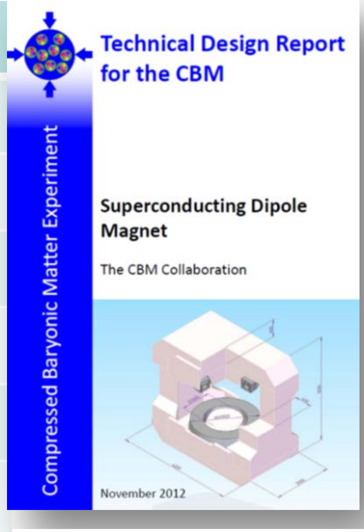
$D^\pm \rightarrow K\pi\pi$



Status of the experiment preparation

Technical Design Reports

#	Project	TDR Status
1	**Magnet**	approved
2	**STS**	approved
3	**RICH**	approved
4	**TOF**	approved
5	**MuCh**	approved
6	**HADES ECAL**	approved
7	**PSD**	approved
8	**MVD**	submission in 2015
9	**DAQ/FLES**	submission in 2015
10	**TRD**	submission in 2015
11	**ECAL**	submission in 2015

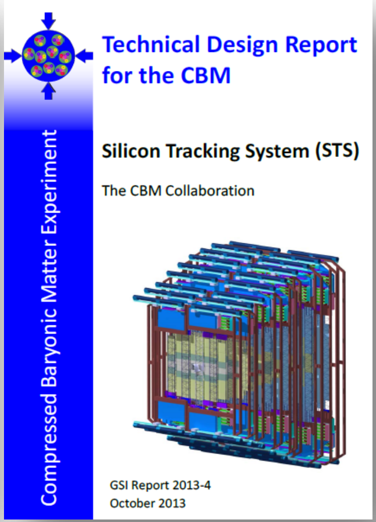

Technical Design Report for the CBM

Superconducting Dipole Magnet

The CBM Collaboration

November 2012

Compressed Baryonic Matter Experiment


Technical Design Report for the CBM

Silicon Tracking System (STS)

The CBM Collaboration

GSI Report 2013-4
October 2013

Compressed Baryonic Matter Experiment


Technical Design Report for the CBM

Ring Imaging Cherenkov (RICH) Detector

The CBM Collaboration

April 2013

Compressed Baryonic Matter Experiment

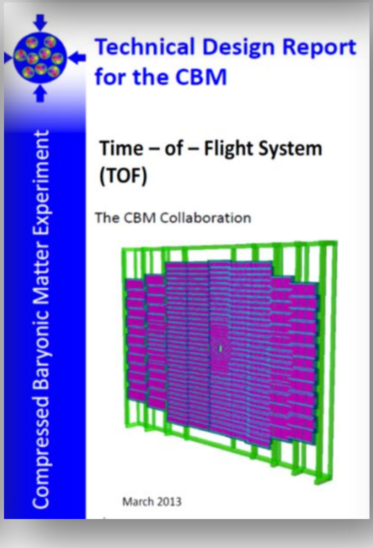

Technical Design Report for the CBM

Projectile Spectator Detector (PSD)

The CBM Collaboration

March 2013

Compressed Baryonic Matter Experiment


Technical Design Report for the CBM

Time – of – Flight System (TOF)

The CBM Collaboration

March 2013

Compressed Baryonic Matter Experiment


Technical Design Report for the CBM

Muon Chamber (MUCH)

The CBM Collaboration

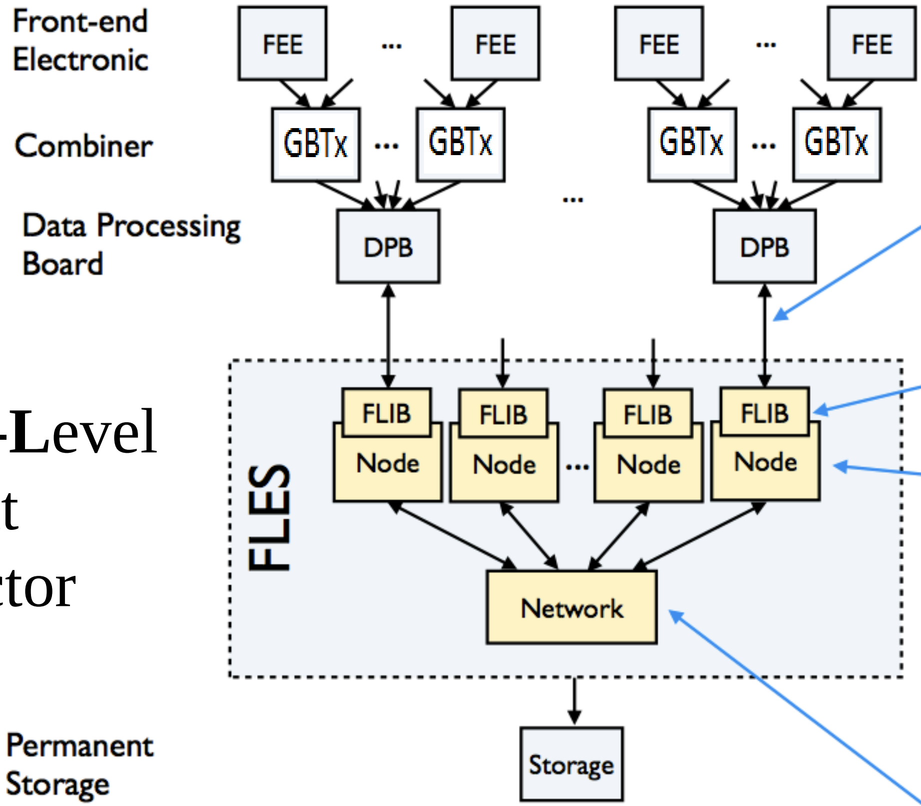
December 2013

Compressed Baryonic Matter Experiment

Ongoing R&D:
Development of CMOS sensors (MVD), read-out ASIC for STS, and DAQ/FLES

CBM online data flow

First-Level Event Selector



Self-triggered front-end
All hits shipped to FLES

1 TByte/s Total Input Data Rate
- 1000 links

FLES Interface Board
- FPGA based
- Optical input links
- Fast PCIe interface
- Large buffer memory

Event selection in FLES processor farm
- High-throughput online analysis
- **full event reconstruction**
- **10^7 Events/s**
- Vectorization and many-core architectures
- **~ 60.000 Cores**

High-throughput interval building
- InfiniBand

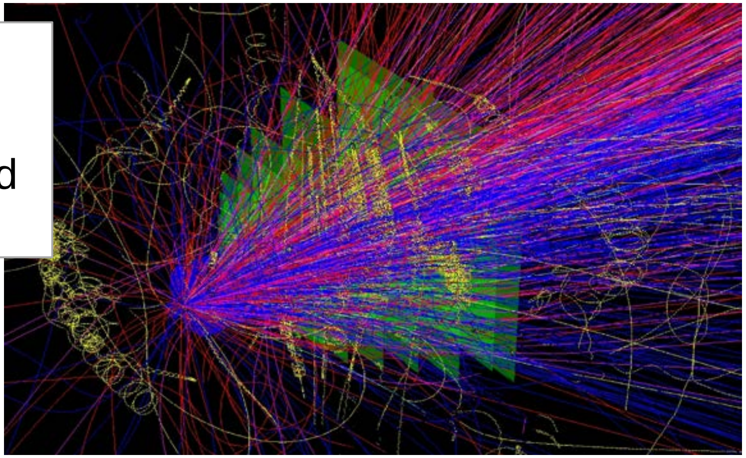
Potential CBM running scenario at SIS100 (preliminary)

Collision system	**Projectile** (intensity [s^{-1}])	**Observable**	**CBM configuration of detector subsystems**	**Request [weeks]**
A + A (C, Au) at 4, 6, 8, 11, (14) AGeV	C (10^8), Au (10^7)	▪ Hadrons ▪ Hypernuclei ▪ Di-electrons	MVD, STS, TOF, PSD, & RICH, TRD	6
p + A (C, Au) at 4, 6, 8, 11, 14 GeV	p ($5x10^8$)	▪ Hadrons ▪ Di-electrons	MVD, STS, TOF, (PSD) & RICH, TRD	6
p + p & p + A (C, Au) at 14, 20, 25, 29 GeV	p ($5x10^8$)	▪ Open charm	MVD, STS, TOF, (PSD) & RICH, TRD	12
A + A (C, Au) at 4, 8, 11, (14) AGeV	C (10^9), Au (10^9)	▪ Anti-baryons ▪ Multistrange (anti-)particles	STS, TOF, PSD	12
A + A (C, Ca, Au) at 4, 8, 11, (14) AGeV p + p & p + A (C, Ca, Au) at 14, 20, 25, 29 GeV	C (10^9), Ca (10^9), Au (10^9), p ($5x10^{10}$)	▪ Di-muons (incl. J/ψ)	STS, TOF & MUCH	12

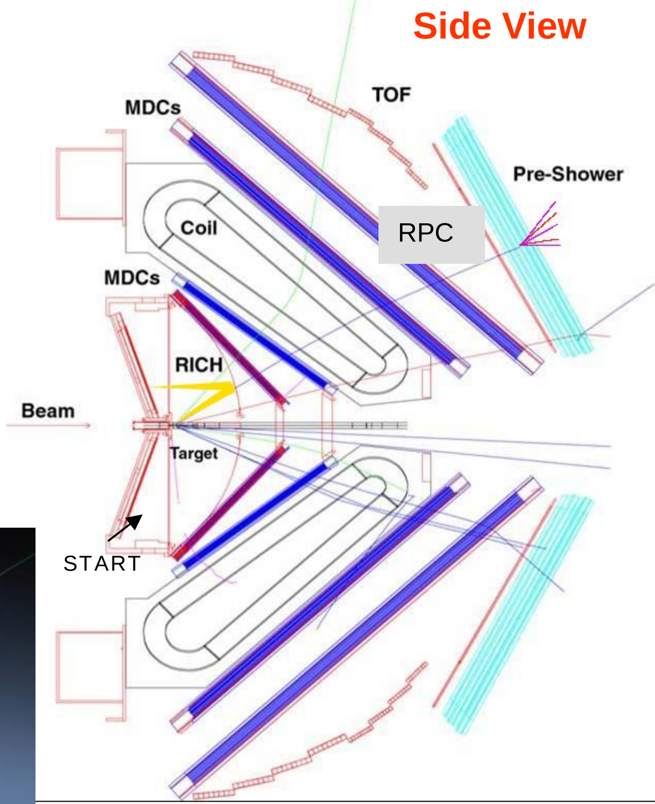
preliminary estimations !

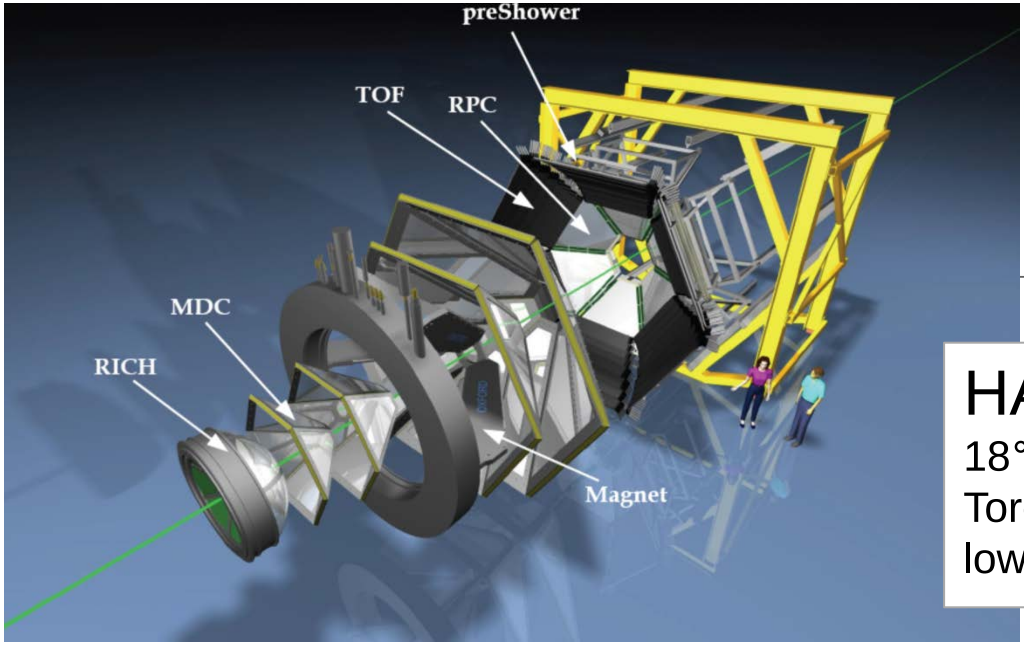
CBM & HADES: Complementary experiments

CBM
3° - 25°
Dipole field
high rate



Side View





HADES
18° - 85°
Toroidal field
low mass; high res

Potential HADES running scenario at SIS100 (preliminary)

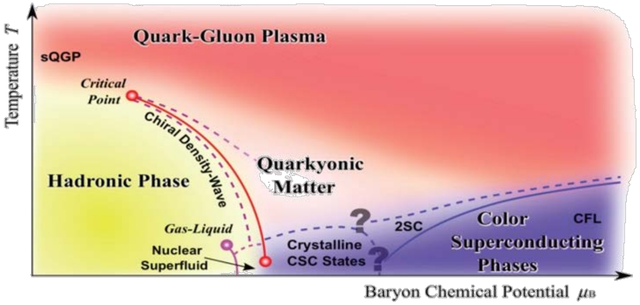
Collision system	**Projectile** (intensity [s^{-1}])	**Observable**	**Request [weeks]**
Phase I :			
p + p & p + A (C, Ca, Nb, Au) at 2, 3.5, 6, 8, 11, 14, 20 GeV	p (5×10^6)	▪ Di-electrons ▪ Strangeness	12
A + A (C, Nb, Au) at 1.5, 2, 3, 4, 6 AGeV	C (5×10^6), Nb (2×10^6), Au (10^6)	▪ Di-electrons ▪ Strangeness	12

Beam request: 1x 4 week block per year

Phase II :			
π + p & π + A (C, Nb, Au)	N (10^{11}) at 14 AGeV	▪ Di-electrons ▪ Strangeness	16

Pion beam campaign: taking full statistics in 2 years

preliminary estimations !



Open questions at high net baryon densities:
- Phase transition from hadronic matter to quarkyonic or partonic matter ?
- Chiral phase transition ? Chiral restoration ?
- In-medium modification of hadrons ?
- Nuclear Equation-of-State at neutron star core densities ?

→ **substantial discovery potential with CBM at FAIR**

Field driven by experimental data ... **but how to interpret ? How to link fundamental properties of QCD with nucleus-nucleus data ?**

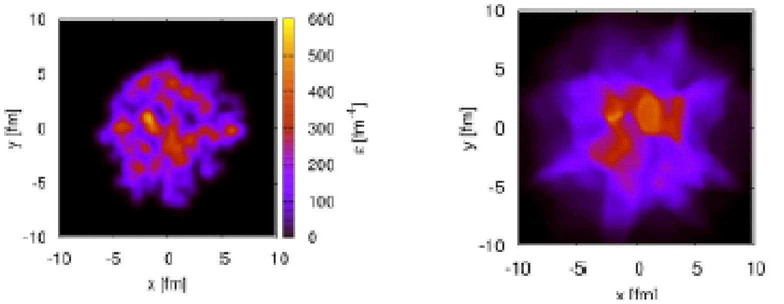
Microscopic approaches to describe the highest net-baryon densities
- Off-shell transport
- Hybrid transport approaches (Hydro at FAIR energies ?)

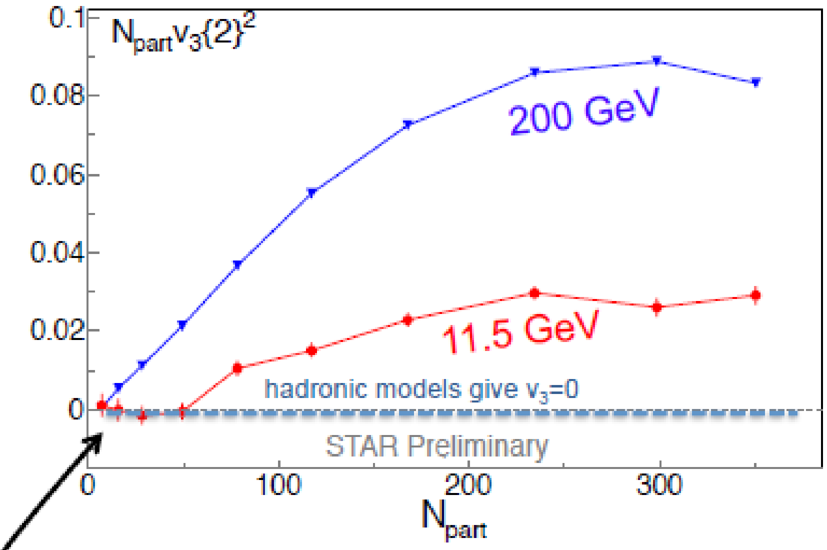
Elementary collisions & small collision systems to “gauge” effective approaches
- p+p , p+A , C+C
- π+p , π+A

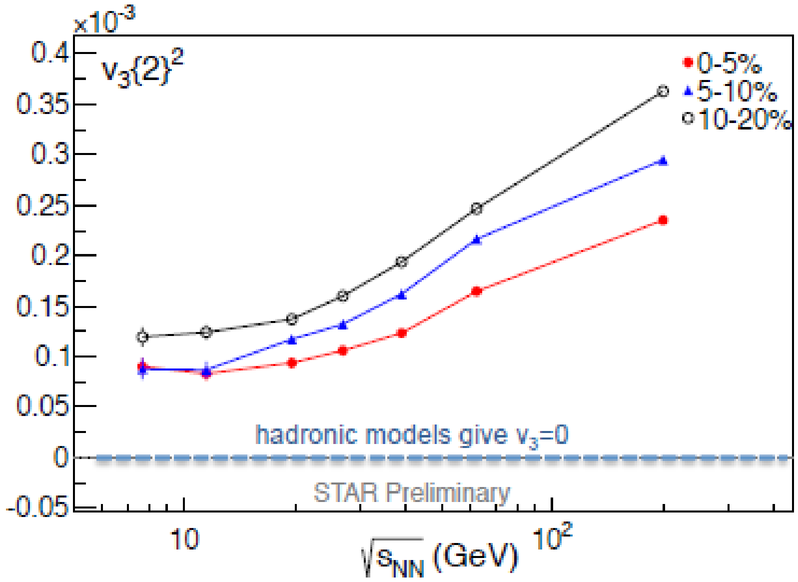
Turning off the QGP

v_3: low η/s plasma transfers fluctuations from the initial overlap density into final-state

requires early QGP phase







QGP signatures go away in smaller/less dense collisions

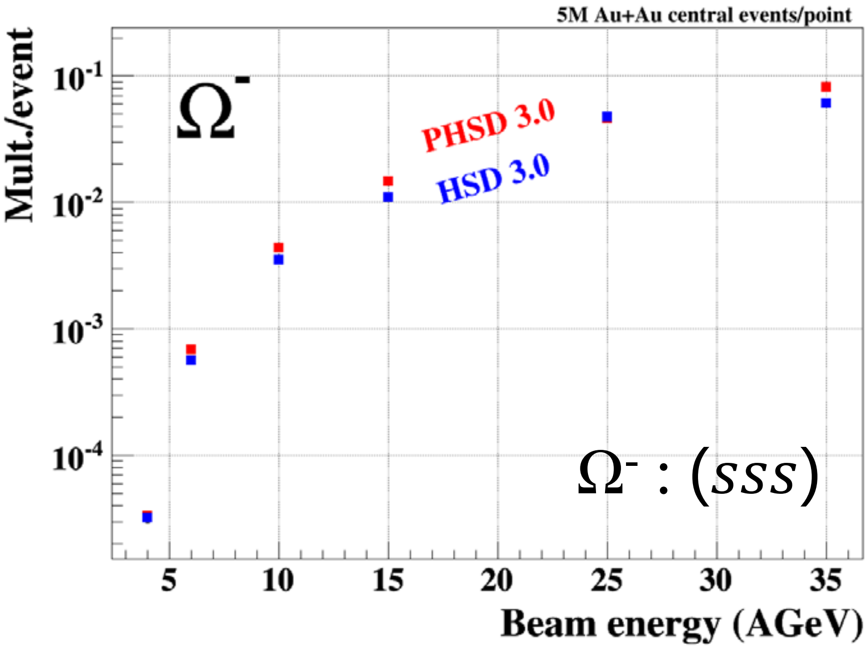
Large system exhibits QGP behavior even at the lowest energies

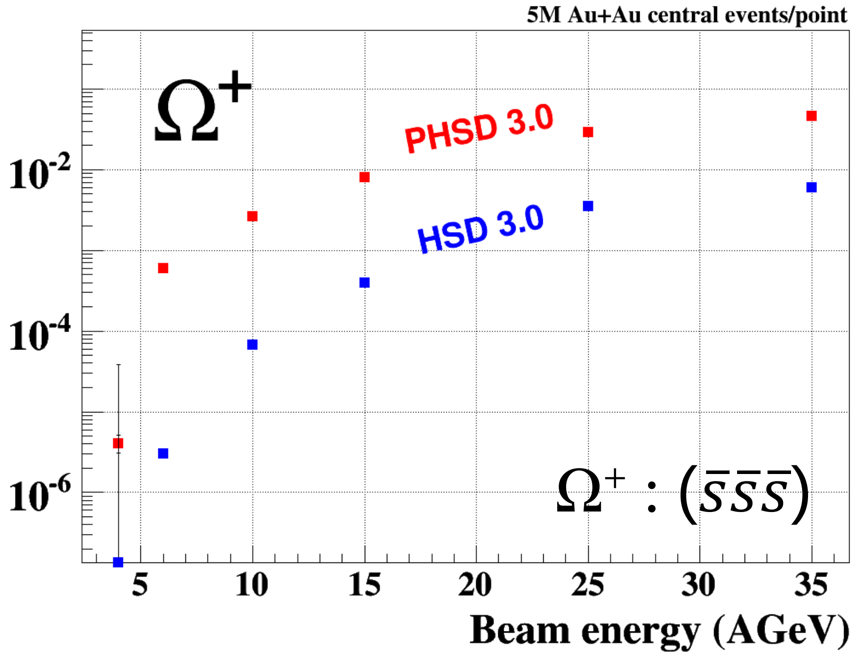
Paul Sorensen, NeD 2015, September 4

CBM physics observables

Multi-strange (anti-) hyperons

PHSD: Hadronic transport code with partonic phase (ε > 1 GeV/fm^3)
HSD: Hadronic transport code

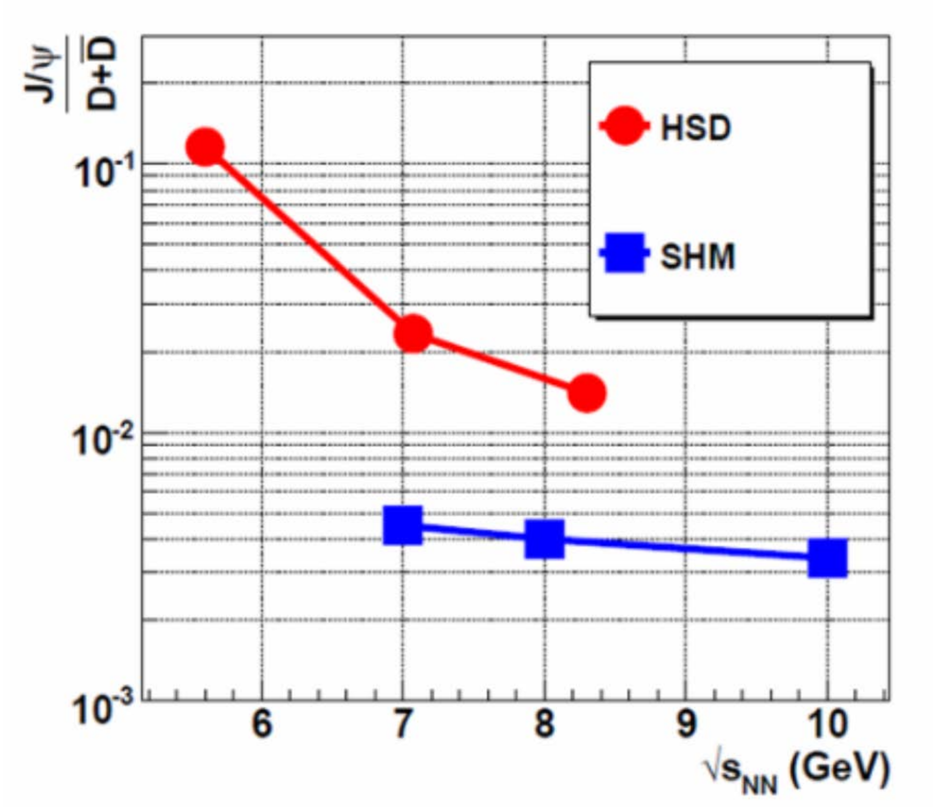




I. Vassiliev, E. Bratkovskaya, preliminary results

CBM physics observables

Charmonium (J/ψ) and open charm ($D\bar{D}$) production



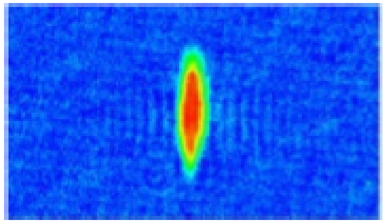
HSD “hadronic”
O. Linnyk et al.,
Int.J.Mod.Phys. E17, 1367 (2008)

SHM “partonic”
A. Andronic et al.,
Phys. Lett. B 659 (2008) 149

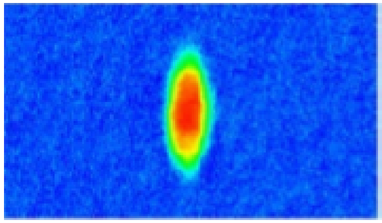
Anisotropic expansion

- ultracold Fermi gas released from deformed trapping potential

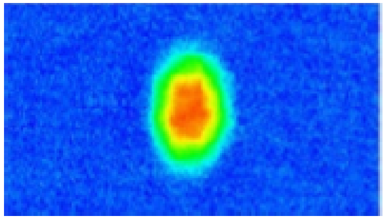
K.M. O'Hara et al., Science **298** (2002)



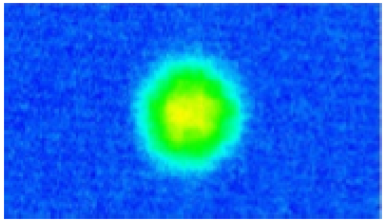
$t = 100\ \mu s$



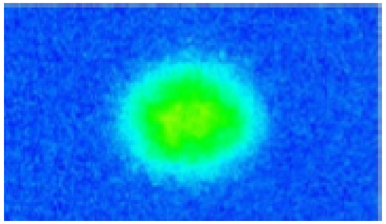
$t = 200\ \mu s$



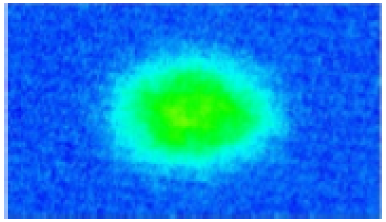
$t = 400\ \mu s$



$t = 600\ \mu s$



$t = 800\ \mu s$



$t = 1000\ \mu s$

→ observe fluid dynamical behavior (elliptic flow)

- coordinate-space anisotropy converted to momentum-space anisotropy
- perfect to study shear viscosity η and bulk viscosity ζ

Ultra-cold Fermi gases - a playground to study strongly coupled systems ?

Scientific output after first years of CBM / HADES running

Au+Au collisions, 4 – 11 A GeV

- ► Yield, p_T spectra and flow excitation functions of identified particles incl. multi-strange hyperons
- ► Excitation function of event-by-event fluctuations
- ► (Double-) hypernuclei produced (discovered)
- ► Heavy strange objects discovered or excluded
- ► In-medium properties of light vector mesons at different fireball densities and temperatures
- ► Excitation function of the fireball temperature
- ► Flow of dileptons as function of p_T and m_{inv}

p+p and p+A collisions, 5 – 29 GeV

- ► Charm production and propagation in hadronic matter

Moon Plates

by Anjali Chandrasekhar, Pratt

Agnes Mocsy, NeD 2015, September 2

The CBM Collaboration

China:
Tsinghua Univ., Beijing
CCNU Wuhan
USTC Hefei

Croatia:
University of Split

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IPHC Strasbourg

Hungaria:
Wigner IPNP, Budapest
Eötvös Univ. Budapest

Germany:
TU Darmstadt
Univ. Gießen
Univ. Heidelberg, Phys. Inst.
Univ. Heidelberg, ZITI
Univ. Frankfurt
FIAS Frankfurt
Univ. Münster
FZ Rossendorf
GSI Darmstadt
FAIR Darmstadt
Univ. Tübingen
Univ. Wuppertal

India:
Aligarh Muslim Univ., Aligarh
IOP Bhubaneswar
Panjab Univ., Chandigarh
Gauhati Univ., Guwahati
Univ. Rajasthan, Jaipur
Univ. Jammu, Jammu
IIT Kharagpur
SAHA Kolkata
Univ Calcutta, Kolkata
VECC Kolkata
Univ. Kashmir, Srinagar
Banaras Hindu Univ., Varanasi
Inst. of Tech., Indore, India

Korea:
Pusan National Univ.

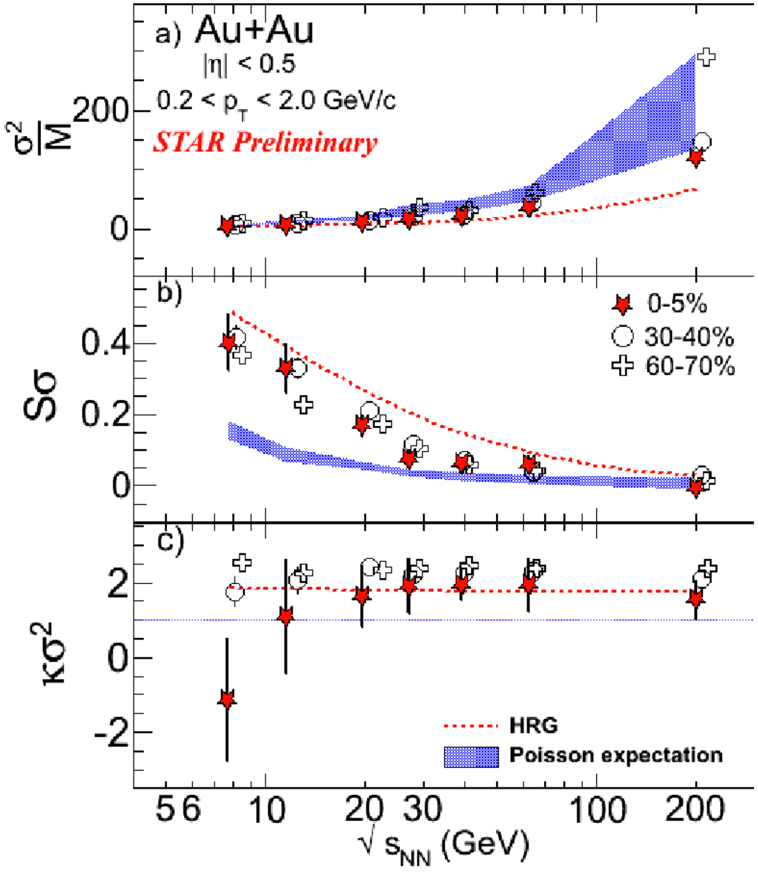

Krakow, Sep. 2014

56 institutions

> 500 members

Backup

The Search for the Critical Point



Criticality would express in non-statistical event-by-event fluctuation of conserved quantities: e.g., net charge, net baryon

STAR data: no conclusive indication of a critical point yet

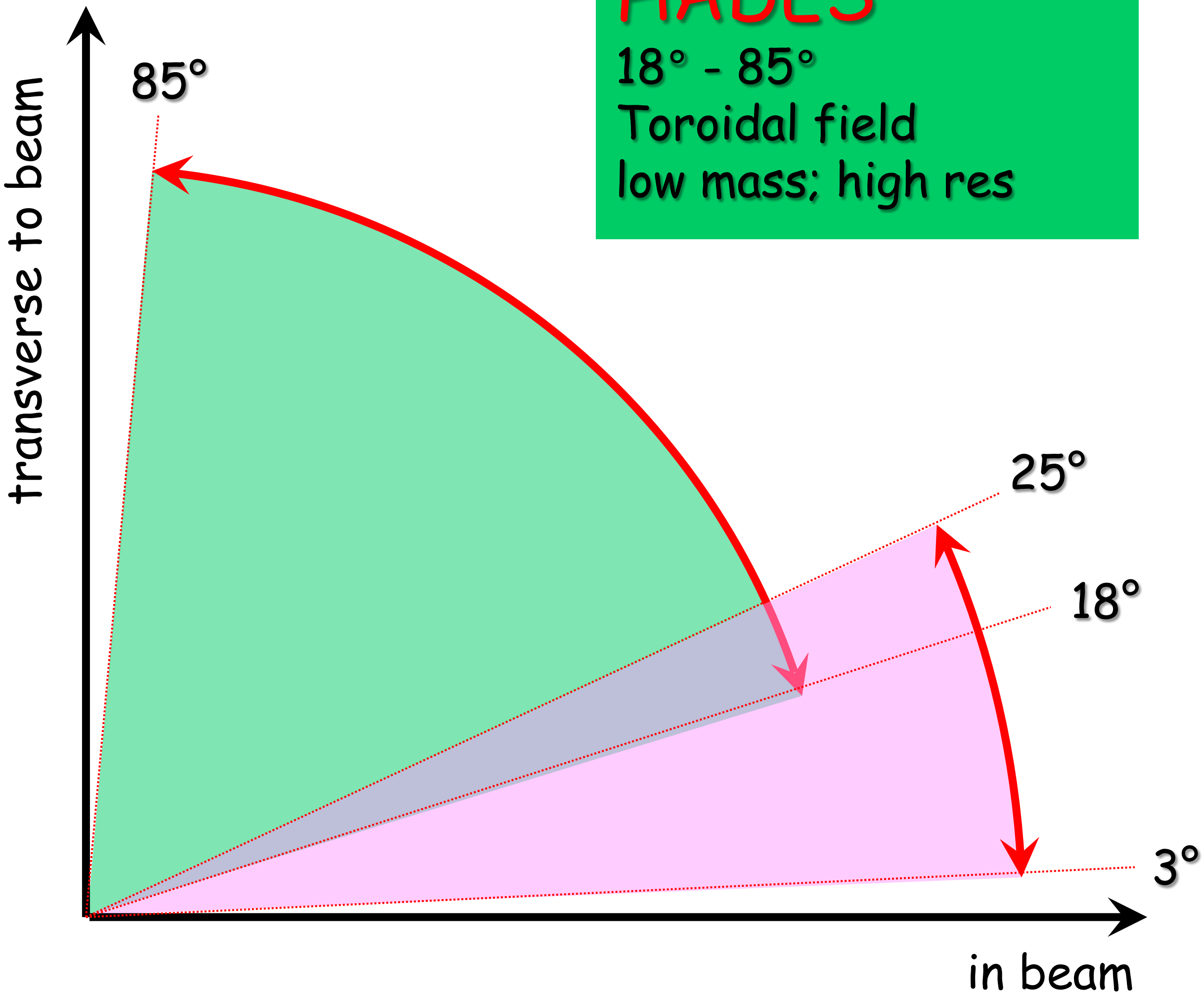
- theory gives little guidance how close to the critical point fluctuations should be observable

  finite size and lifetime of system

- data at lower energies suffer from low statistics

  improvement to be expected from BES phase II (improved beam, detector upgrade)

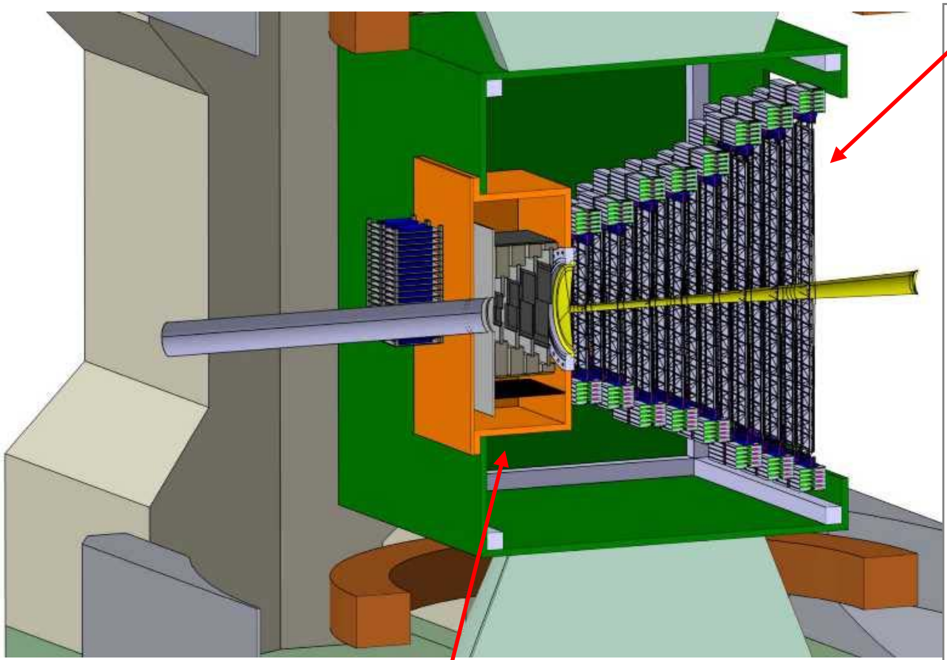
CBM & HADES: Complementary Experiments



HADES
18° - 85°
Toroidal field
low mass; high res

CBM
3° - 25°
Dipole field
high rate

STS & MVD – the heart of CBM



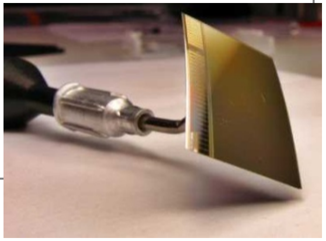
<u>STS – Silicon Tracking System</u>

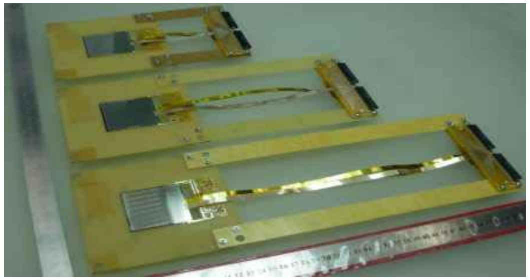
- Track reconstruction inside magnetic field
- Momentum resolution $\Delta p/p \approx 1\%$
  (p=1 GeV/c , B=1.0T)

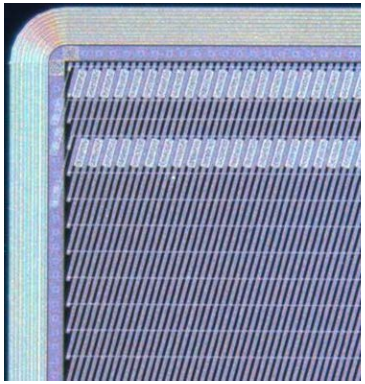
- Double-sided silicon strip sensors
  (58 μm pitch, 300 μm thickness)
- ~ 1300 sensors
  8 stations (0.2 – 0.8 m^2) , > 2 mio. channels
- CO_2 cooling system for FEE
  thermal enclosure (-5°C)
- low-mass carbon structures

<u>MVD – Micro Vertex Detector</u>

- Primary & secondary vertex reconstruction
  5 μm & 60 μm resolution (open charm !)
- Monolithic Active Pixel Sensors (MAPS)
  CMOS, radiation-hard
- MIMOSA-26
  single-point resolution 4μm

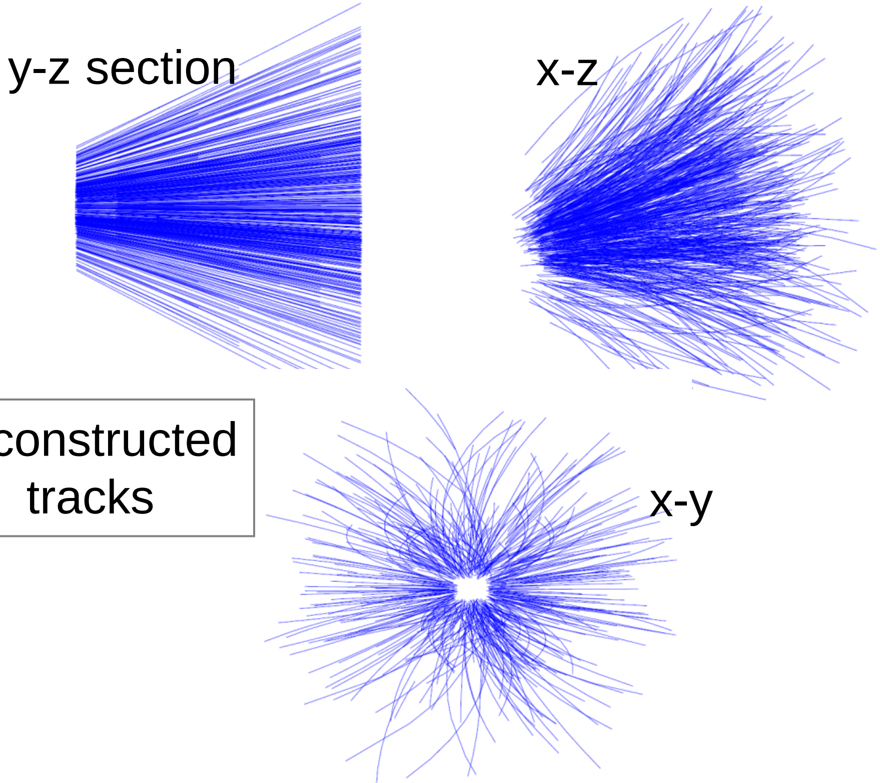






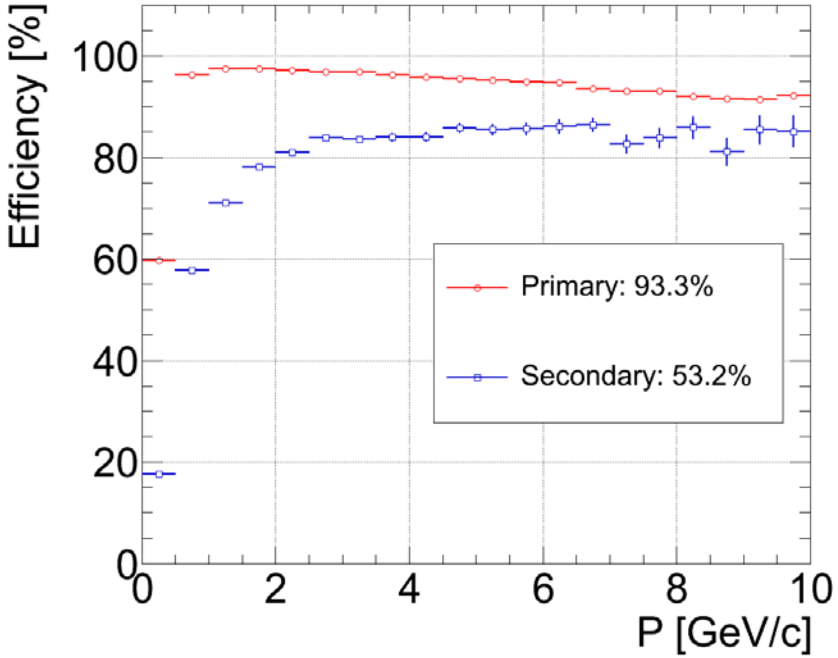
STS tracking performance in central Au+Au collisions at 25 A GeV

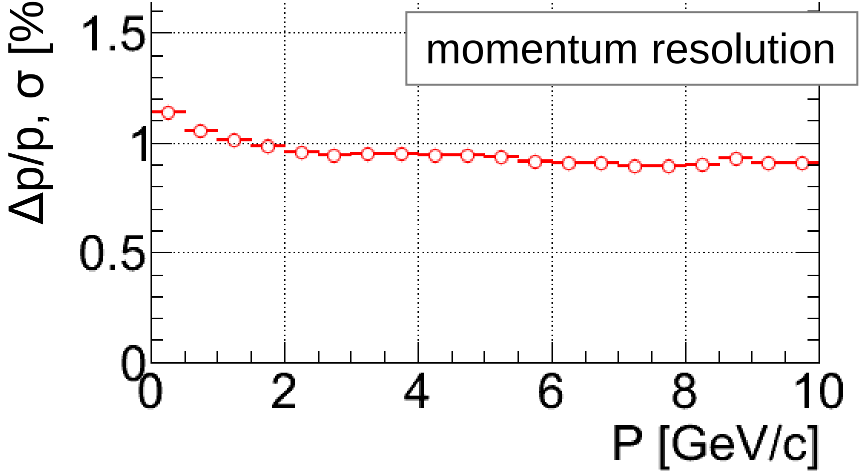
- Realistic material budget
- Track finding - Cellular Automaton
- Track and vertex fitting - Kalman filter
- Running on many-core CPUs



Reconstructed tracks

central Au+Au collisions, 25 A GeV



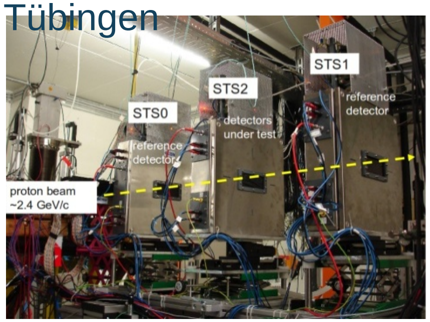


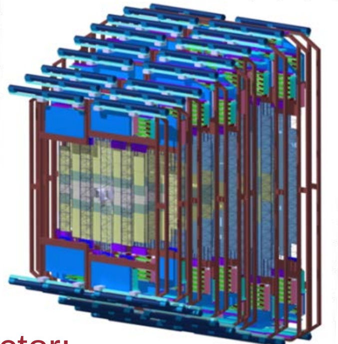
CBM Technical Developments

SC Magnet: JINR Dubna

Micro-Vertex Detector: Frankfurt, Strasbourg

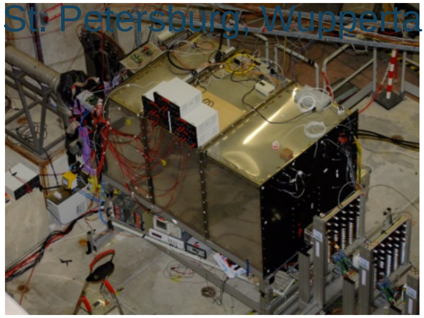
Silicon Tracking System: Darmstadt, Dubna, Krakow, Kiev, Kharkov, Moscow, St. Petersburg, Tübingen



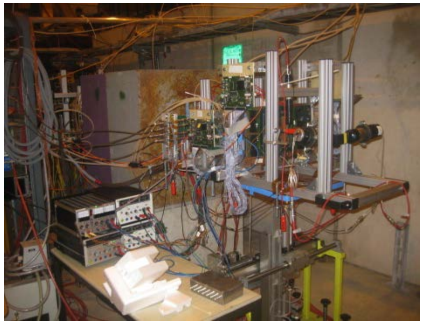


MRPC ToF Wall: Beijing, Bucharest, Darmstadt, Frankfurt, Hefei, Heidelberg, Moscow, Rossendorf, Wuhan

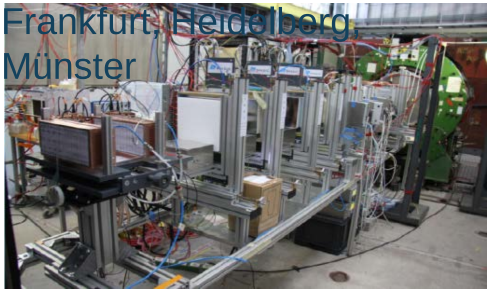
RICH Detector: Darmstadt, Giessen, Pusan, St. Petersburg, Wuppertal



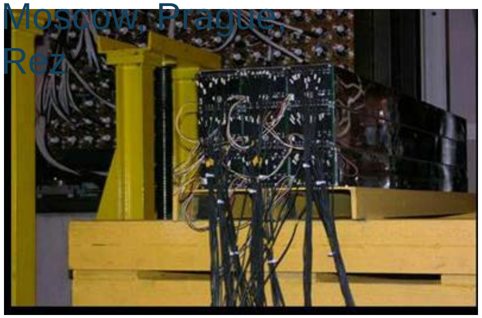
Muon detector: Kolkata + 13 Indian Inst., Gatchina, Dubna



Transition Radiation Detector: Bucharest, Dubna, Frankfurt, Heidelberg, Münster



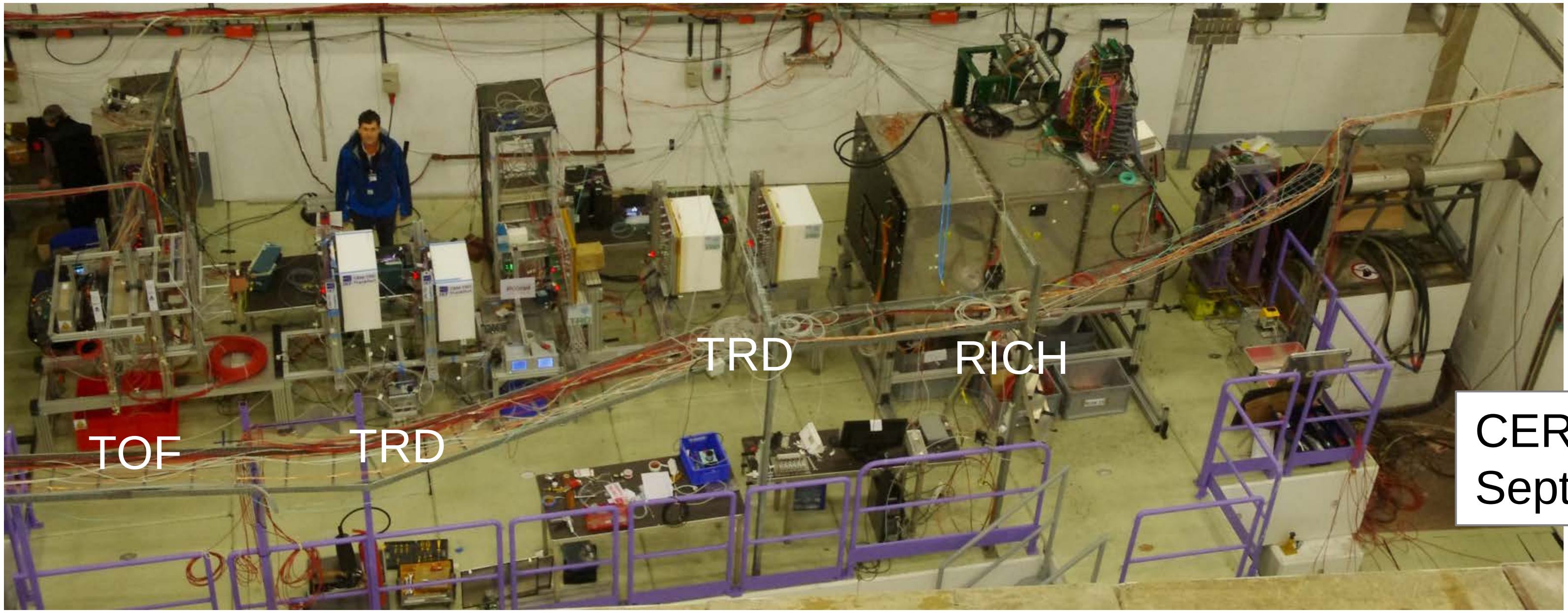
Forward calorimeter: Moscow, Prague, Rez



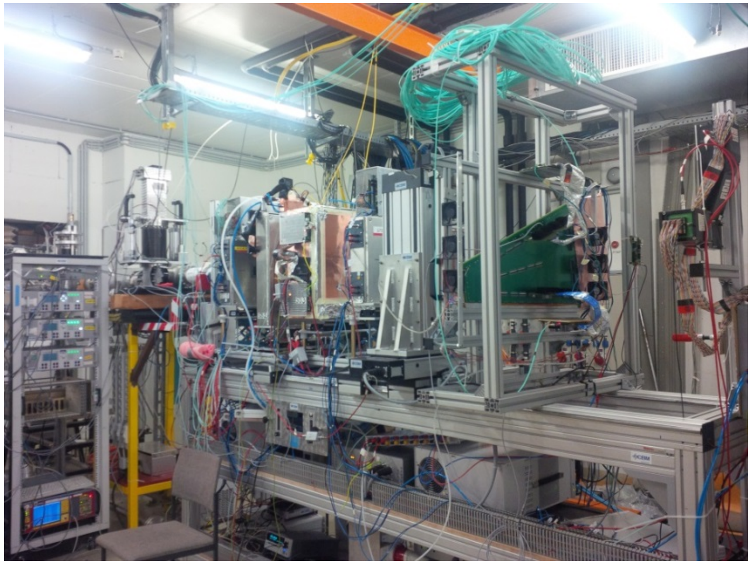
DAQ and online event selection: Darmstadt, Frankfurt, Heidelberg, Kharagpur, Warsaw

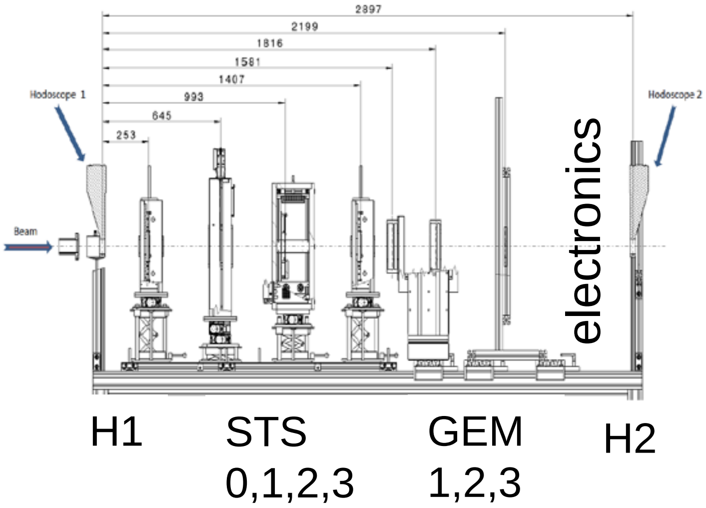
Status of the experiment preparation

In-beam tests of detector prototypes



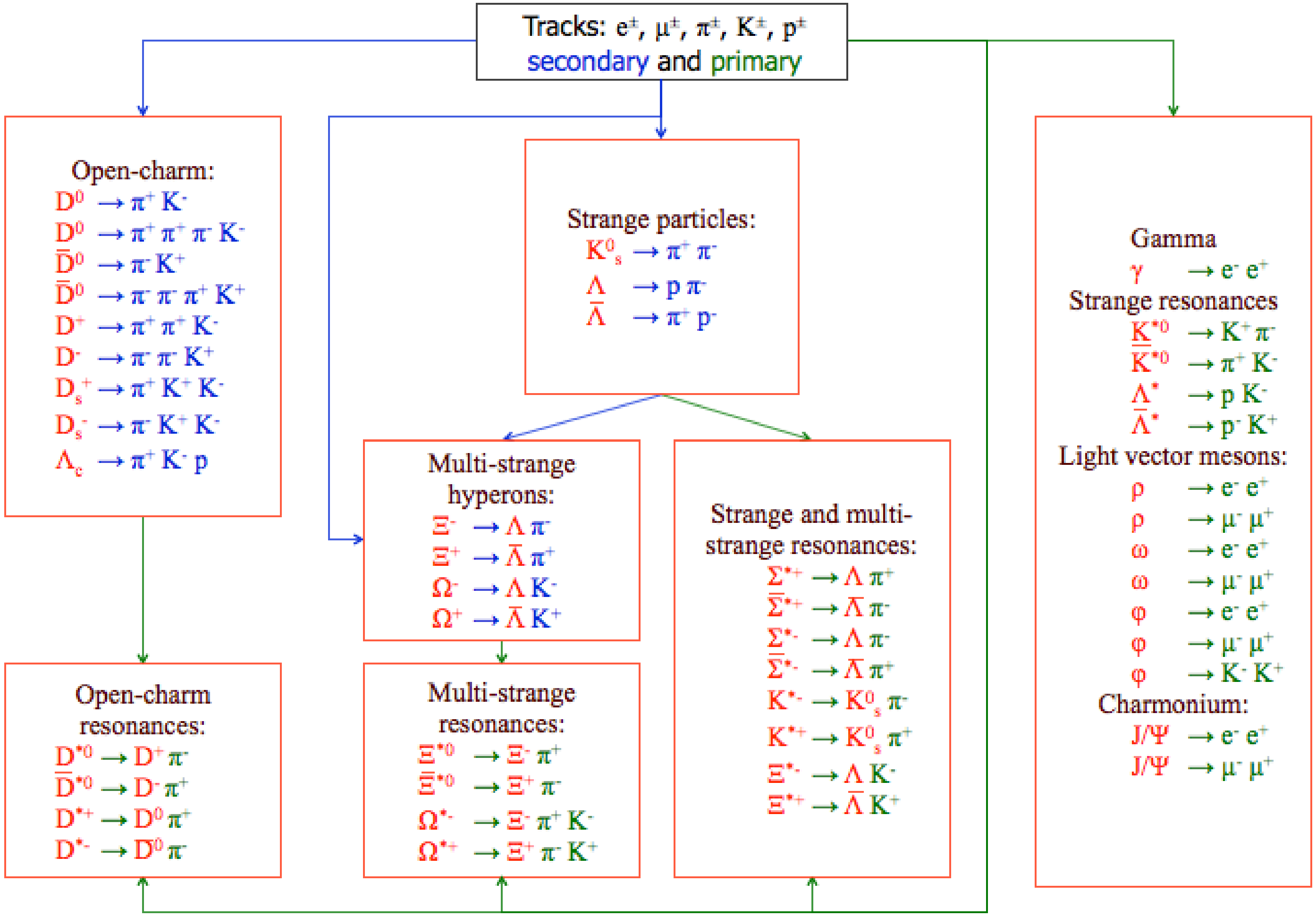
CERN PS
September 2014





FZJülich / COSY
December 2014

Particle finder



Tracks: $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$
secondary and primary

Open-charm:
$D^0 \rightarrow \pi^+ K^-$
$D^0 \rightarrow \pi^+ \pi^+ \pi^- K^-$
$\bar{D}^0 \rightarrow \pi^- K^+$
$\bar{D}^0 \rightarrow \pi^- \pi^- \pi^+ K^+$
$D^+ \rightarrow \pi^+ \pi^+ K^-$
$D^- \rightarrow \pi^- \pi^- K^+$
$D_s^+ \rightarrow \pi^+ K^+ K^-$
$D_s^- \rightarrow \pi^- K^+ K^-$
$\Lambda_c \rightarrow \pi^+ K^- p$

Strange particles:
$K^0_s \rightarrow \pi^+ \pi^-$
$\Lambda \rightarrow p\, \pi^-$
$\bar{\Lambda} \rightarrow \pi^+ p^-$

Gamma
$\gamma \rightarrow e^- e^+$
Strange resonances
$K^{*0} \rightarrow K^+ \pi^-$
$\bar{K}^{*0} \rightarrow \pi^+ K^-$
$\Lambda^* \rightarrow p\, K^-$
$\bar{\Lambda}^* \rightarrow p^- K^+$
Light vector mesons:
$\rho \rightarrow e^- e^+$
$\rho \rightarrow \mu^- \mu^+$
$\omega \rightarrow e^- e^+$
$\omega \rightarrow \mu^- \mu^+$
$\varphi \rightarrow e^- e^+$
$\varphi \rightarrow \mu^- \mu^+$
$\varphi \rightarrow K^- K^+$
Charmonium:
$J/\Psi \rightarrow e^- e^+$
$J/\Psi \rightarrow \mu^- \mu^+$

Multi-strange hyperons:
$\Xi^- \rightarrow \Lambda\, \pi^-$
$\Xi^+ \rightarrow \bar{\Lambda}\, \pi^+$
$\Omega^- \rightarrow \Lambda\, K^-$
$\Omega^+ \rightarrow \bar{\Lambda}\, K^+$

Strange and multi-strange resonances:
$\Sigma^{*+} \rightarrow \Lambda\, \pi^+$
$\bar{\Sigma}^{*+} \rightarrow \bar{\Lambda}\, \pi^-$
$\Sigma^{*-} \rightarrow \Lambda\, \pi^-$
$\bar{\Sigma}^{*-} \rightarrow \bar{\Lambda}\, \pi^+$
$K^{*-} \rightarrow K^0_s\, \pi^-$
$K^{*+} \rightarrow K^0_s\, \pi^+$
$\Xi^{*-} \rightarrow \Lambda\, K^-$
$\Xi^{*+} \rightarrow \bar{\Lambda}\, K^+$

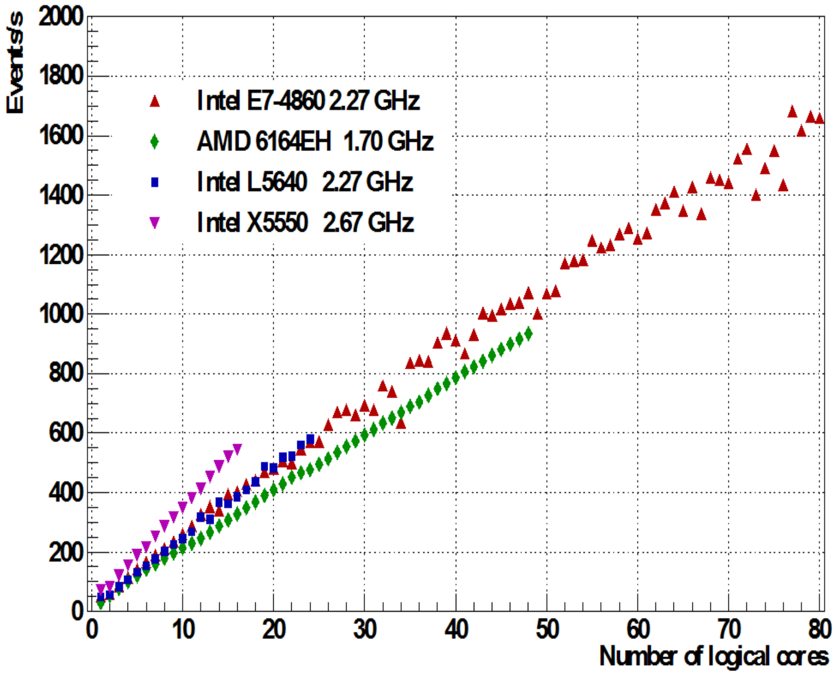
Open-charm resonances:
$D^{*0} \rightarrow D^+ \pi^-$
$\bar{D}^{*0} \rightarrow D^- \pi^+$
$D^{*+} \rightarrow D^0 \pi^+$
$D^{*-} \rightarrow \bar{D}^0 \pi^-$

Multi-strange resonances:
$\Xi^{*0} \rightarrow \Xi^- \pi^+$
$\bar{\Xi}^{*0} \rightarrow \Xi^+ \pi^-$
$\Omega^{*-} \rightarrow \Xi^- \pi^+ K^-$
$\Omega^{*+} \rightarrow \Xi^+ \pi^- K^+$

Parallelization of event reconstruction

On “event” level:

- reconstruction with independent processes
- Exploit many-core systems with multi-threading: 1 thread per logical core, 1000 events per core.



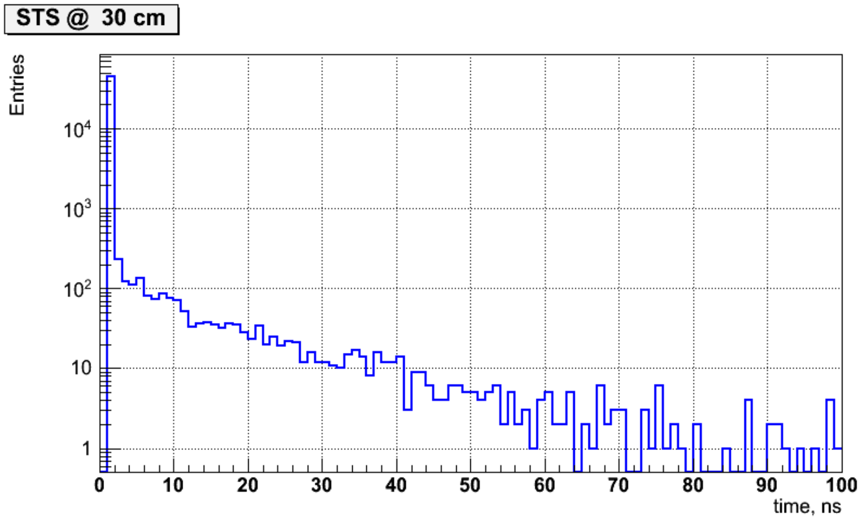
On “task” level:

- digitizer, finder, fitter, analysis tasks: current readiness of parallelization
- employing different computing techniques and architectures

Algorithm	Vector SIMD	Multi Threading	CUDA	OpenCL CPU/GPU
Digitizers				
STS KF Track Fit	✓	✓	✓	✓/✓
STS CA Track Finder	✓	✓		
MuCh Track Finder	✓	✓	✓	
TRD Track Finder	✓	✓	✓	
RICH Ring Finder	✓	✓		✓/✓
Vertexing (KF Particle)	✓	✓		
Off-line Physics Analysis	✓			
FLES Analysis and Selection	✓	✓		

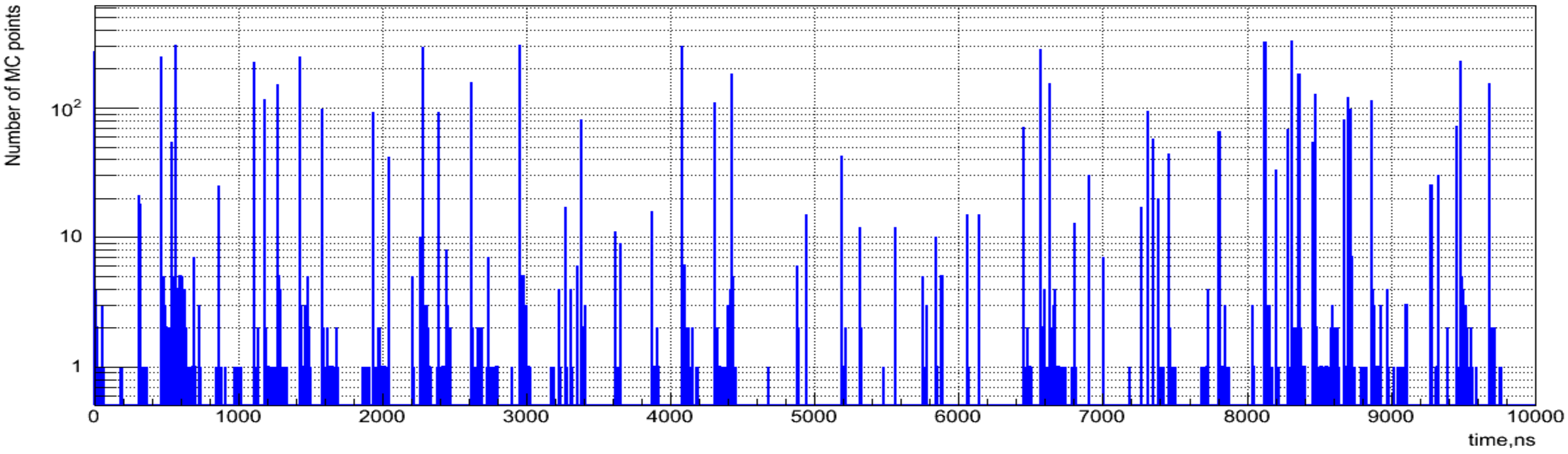
Time based simulation:
Hit distribution at high rates

MC hit time relative to event start



10^7 events/s (Poisson distr.)

MC hit absolute time (STS only)

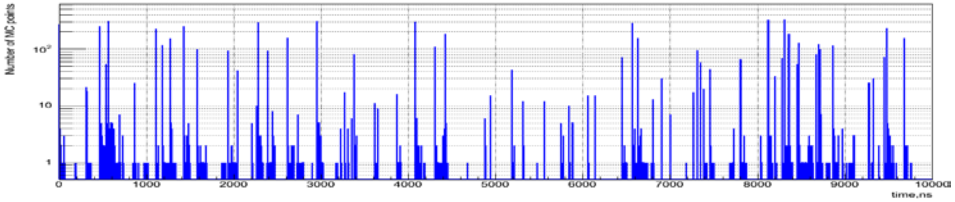


On-line event reconstruction

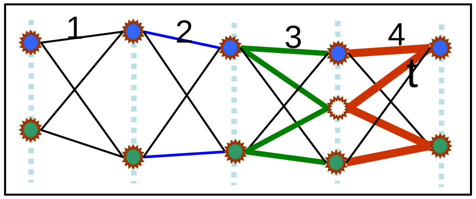
- There is no a-priori event definition possible:
  - events may overlap in time
  - free-streaming FEE shipping time-stamped data
  - in general, data from all detectors come asynchronously
- The classical DAQ task of „event building“ is now rather a „time-slice building“. Physical events are defined later in software.
- Data reduction is shifted entirely to software:
  - Complex signatures involve secondary decay vertices; difficult to implement in hardware.
  - maximum flexibility w.r.t. physics.
- The system is limited only by the throughput capacity and by the rejection power of the on-line computing farm.

Steps of event reconstruction

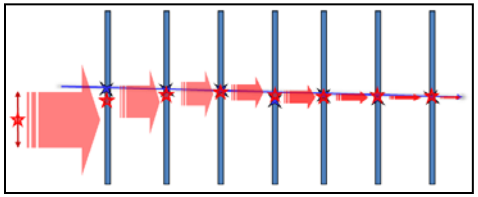
1. Time-slice sorting of detector hits:
   First step in "pre-event" definition.



2. Track finding – Cellular Automaton:
   Which hits in the detector layers belong to the same track?
   - large combinatorial problem
   - well to be parallelized
   - applicable to many-core CPU/GPU systems

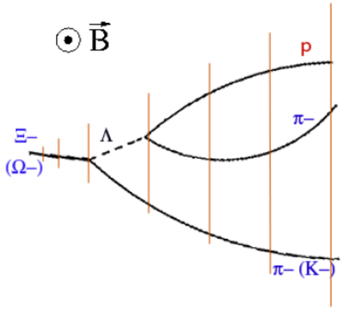


3. Track fitting – Kalman Filter:
   Optimization of the track parameters.
   - recursive least squares method, fast

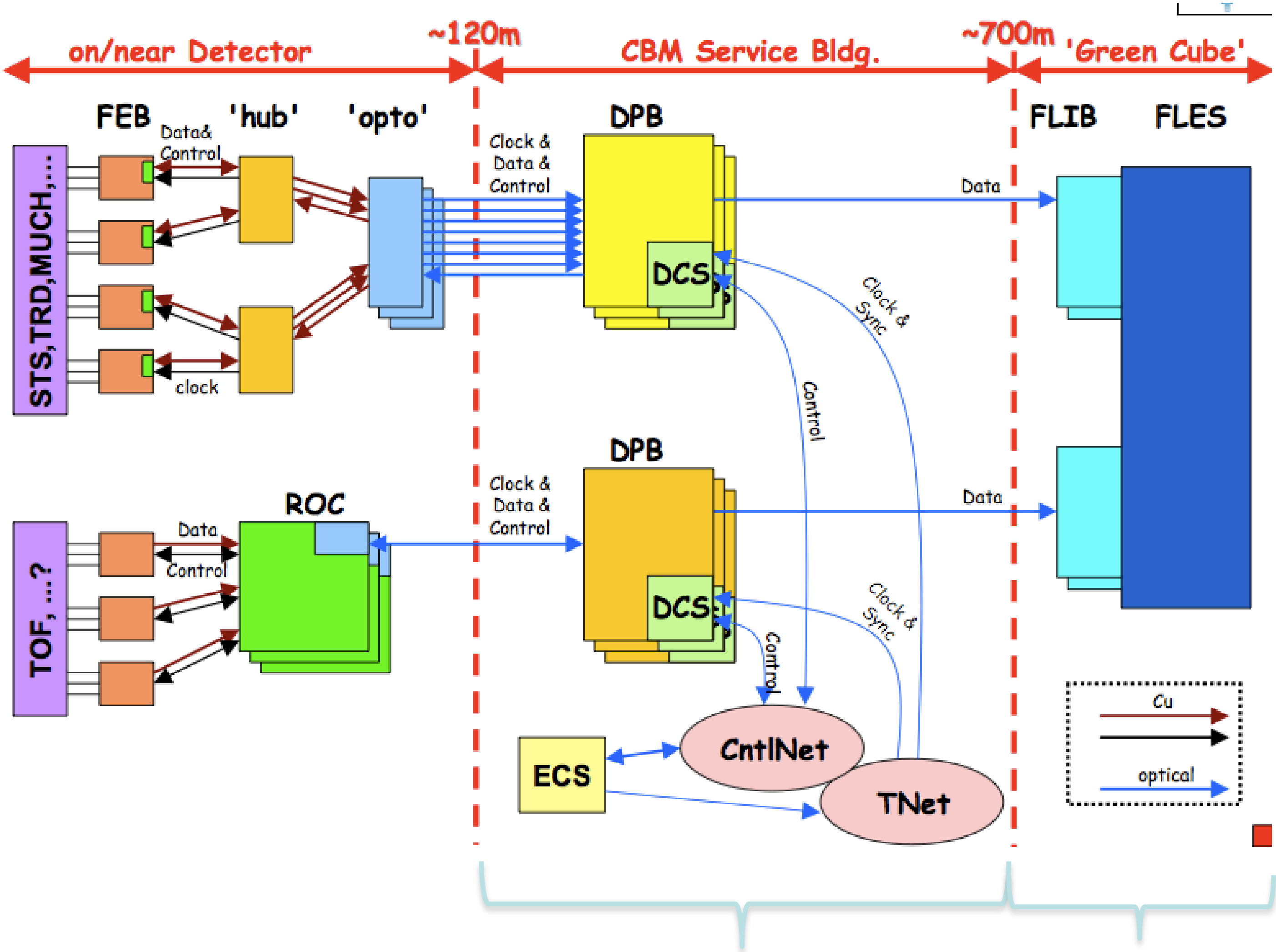


4. Event determination
   Which tracks belong to same interaction?

5. Particle finding:
   Identify decay topologies and other signatures.



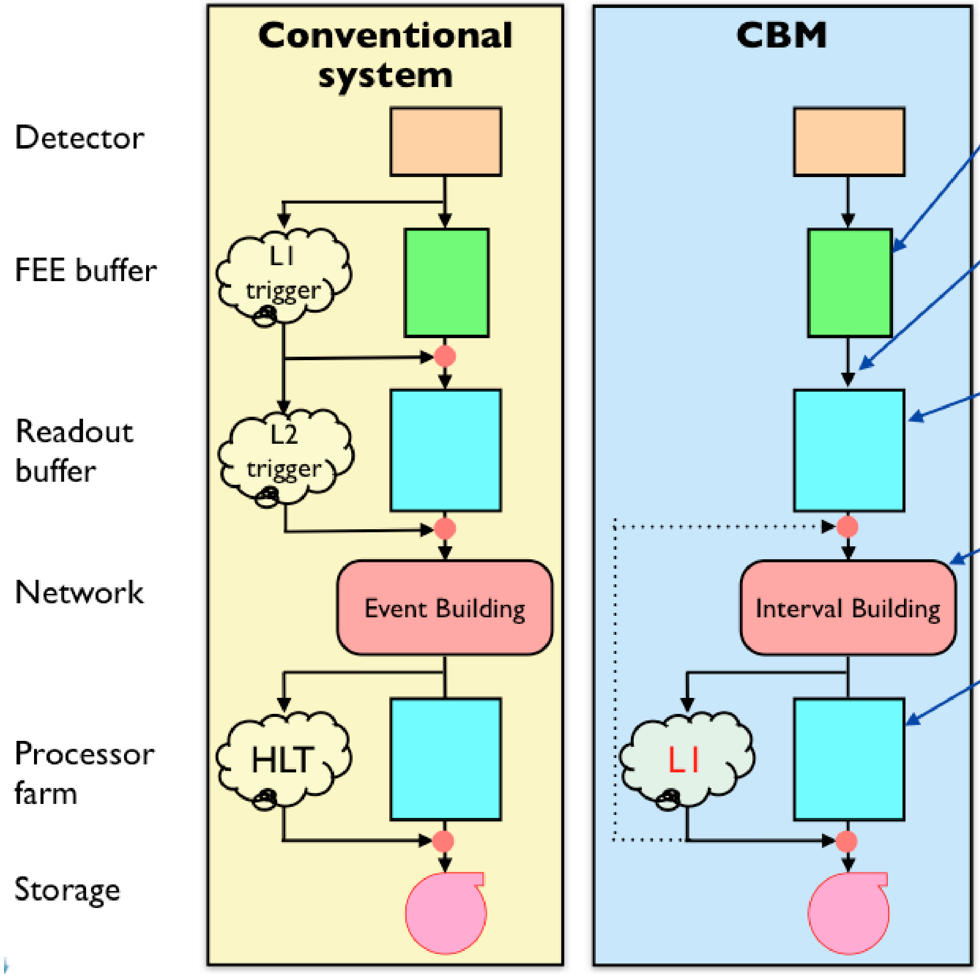
CBM Readout Architecture



DAQ: data aggregration
time-slice building
(pre-processing?)

FLES: event
reconstruction
and selection

CBM Readout Concept



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

Fast FEE links

Readout buffer outside radiation area, many GByte
Allows L1 decision times up to 100-1000 ms

High-throughput network

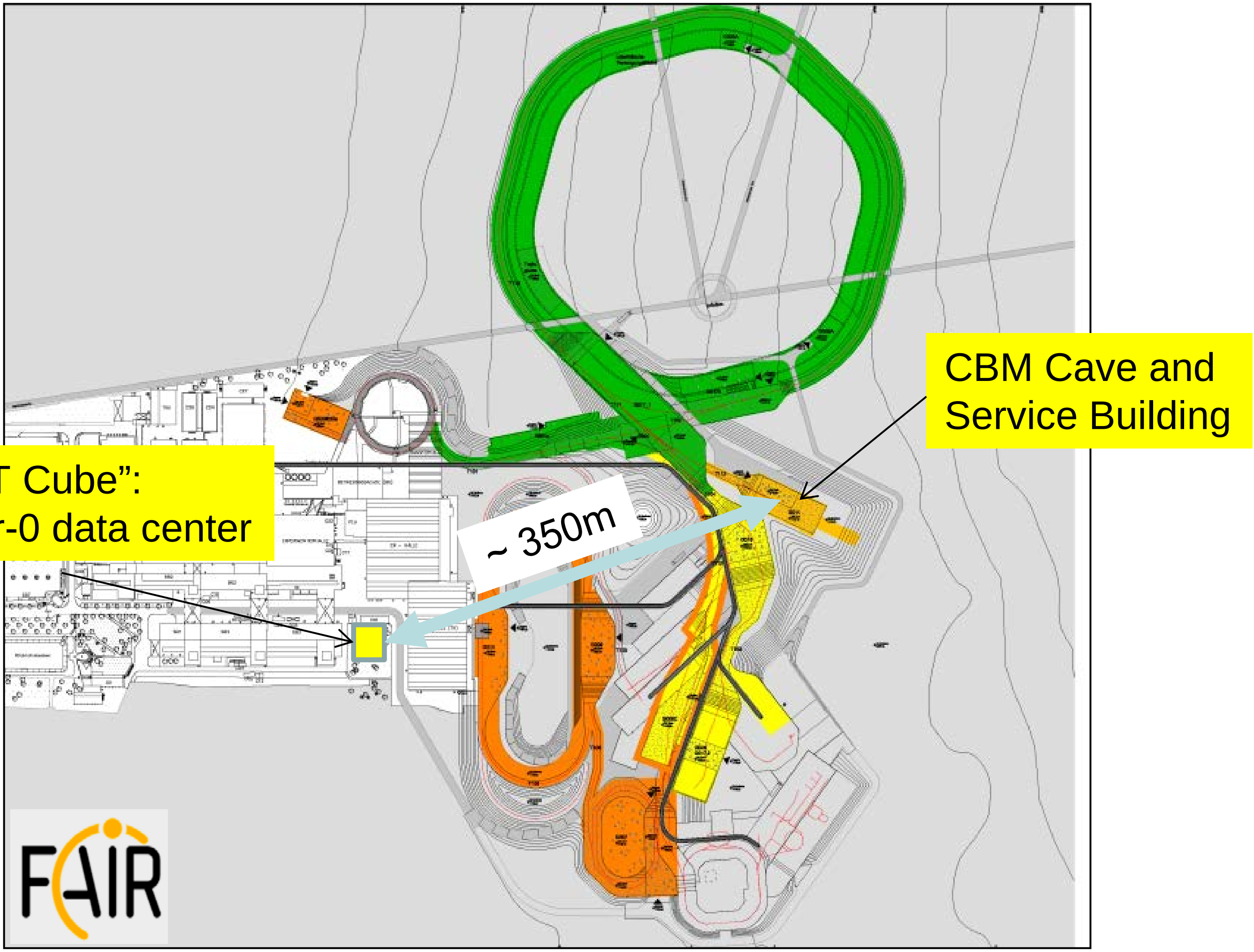
First event selection performed in processor farm

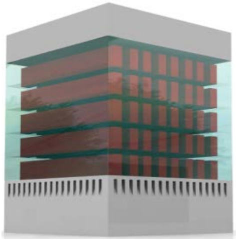
Typical Parameters:
1% occupancy, 10^7 int./s
100 kHz channel hit rate
1 MByte/s per channel
whole CBM: ~ **1 TByte/s**

Finite-size FEE buffer: latency limited

throughput limited

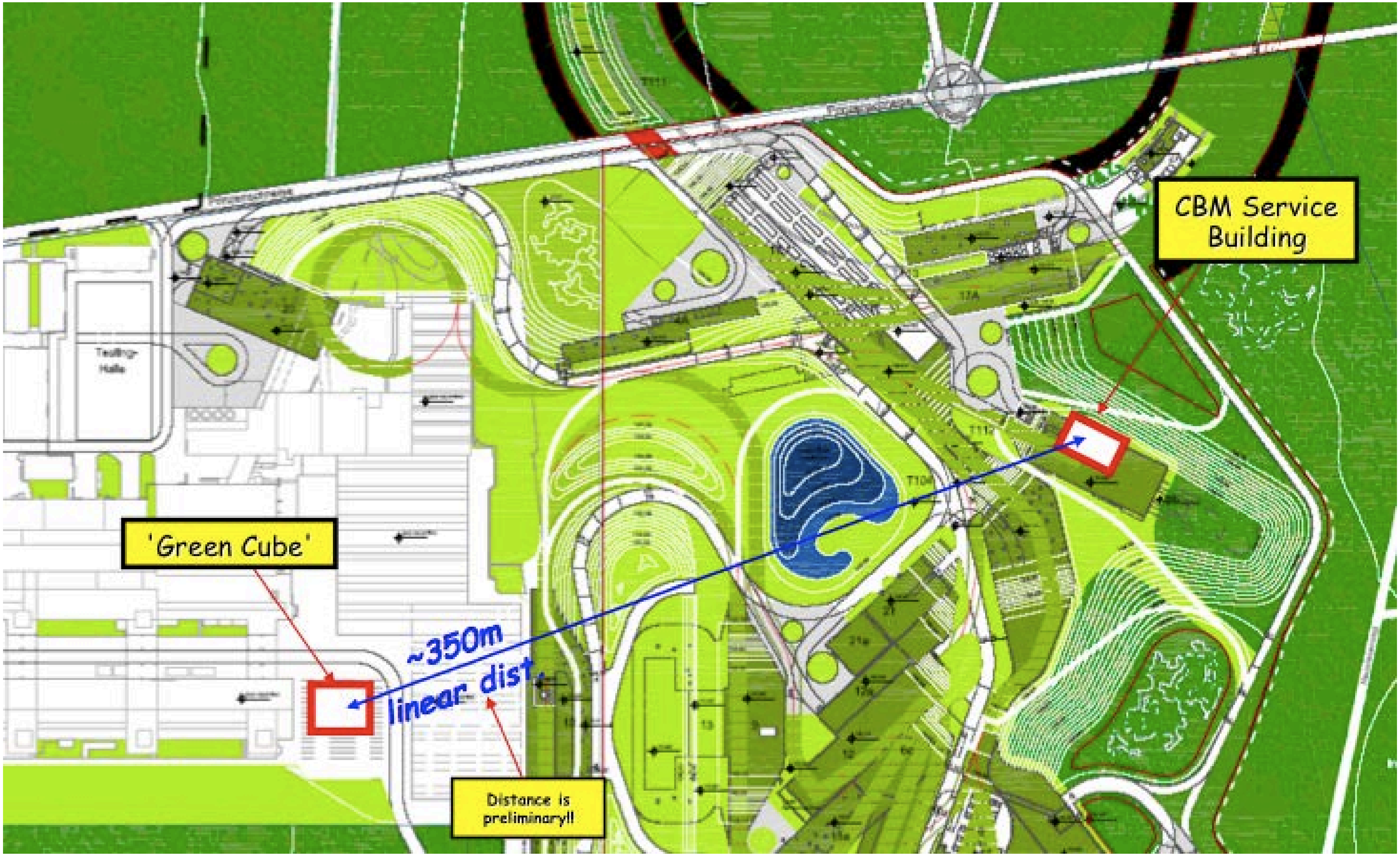
CBM cave and FLES location





CBM cores:
~ 100.000

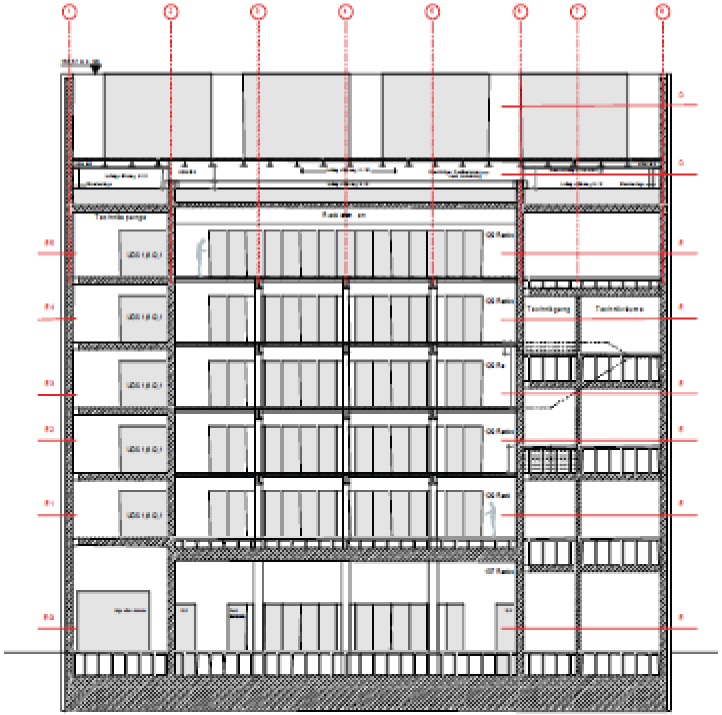
FLES location



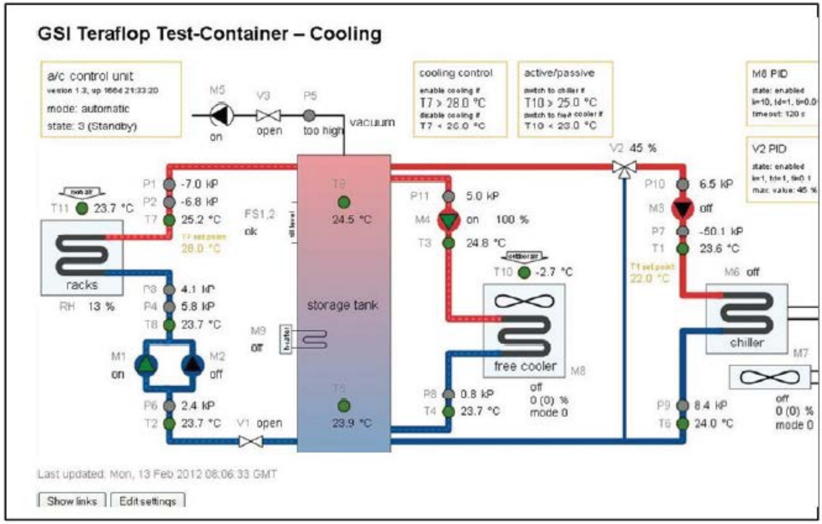
New computing centers

GreenIT Cube

forthcoming FAIR Tier-0 data center



Prototype for a new data center at GSI: “Mini Cube”



GSI Teraflop Test-Container – Cooling

a/c control unit
version 1.3, up 1664 21:33:20
mode: automatic
state: 3 (Standby)

cooling control
enable cooling if
T7 > 28.0 °C
disable cooling if
T7 < 26.0 °C

active/passive
switch to chiller if
T10 > 25.0 °C
switch to free cooler if
T10 < 23.0 °C

M8 PID
state: enabled
k=10, td=1, ti=0.0
timeout: 120 s

V2 PID
state: enabled
k=1, td=1, ti=0.1
max value: 45 %

Last updated: Mon, 13 Feb 2012 08:06:33 GMT

Parallelization of event reconstruction

On “event” level:

- reconstruction with independent processes
- Exploit many-core systems with multi-threading:
  1 thread per logical core, 1000 events per core.