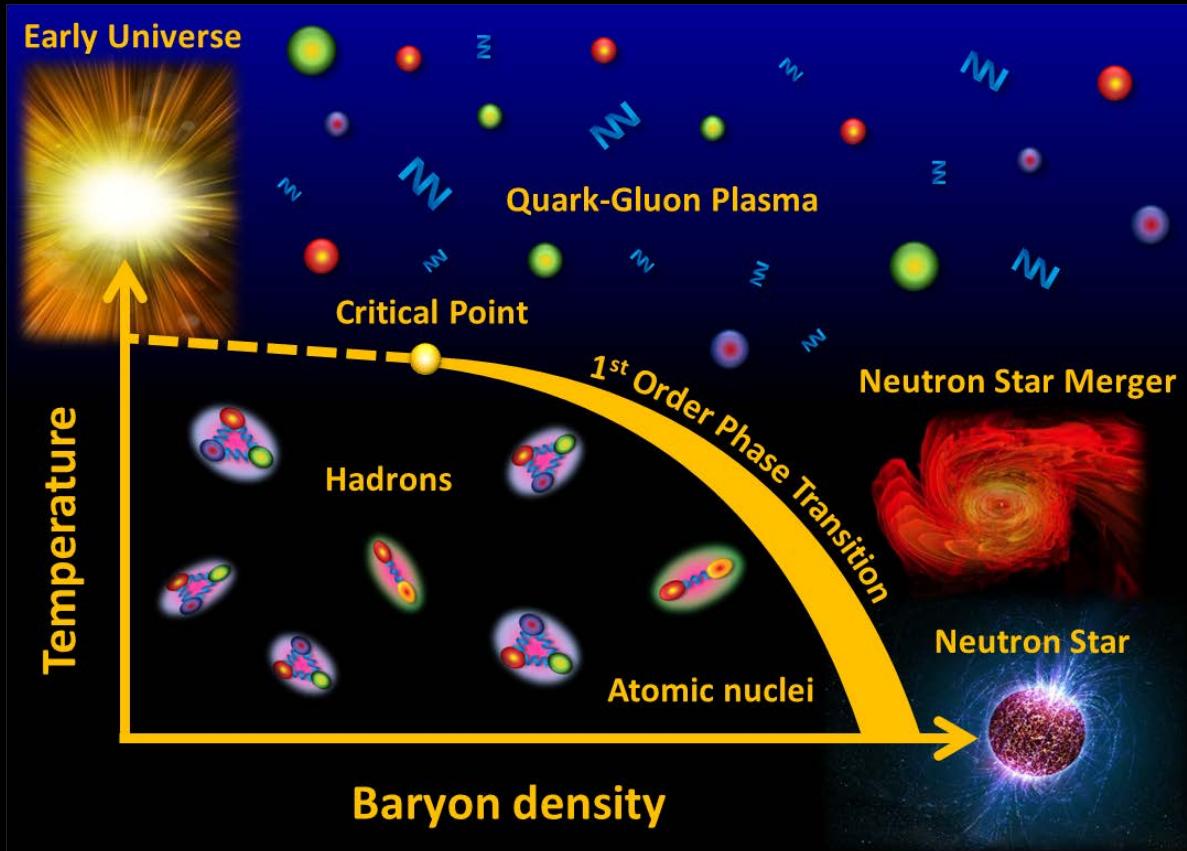


# Cosmic Matter in the Laboratory – The Compressed Baryonic Matter experiment at FAIR

Peter Senger

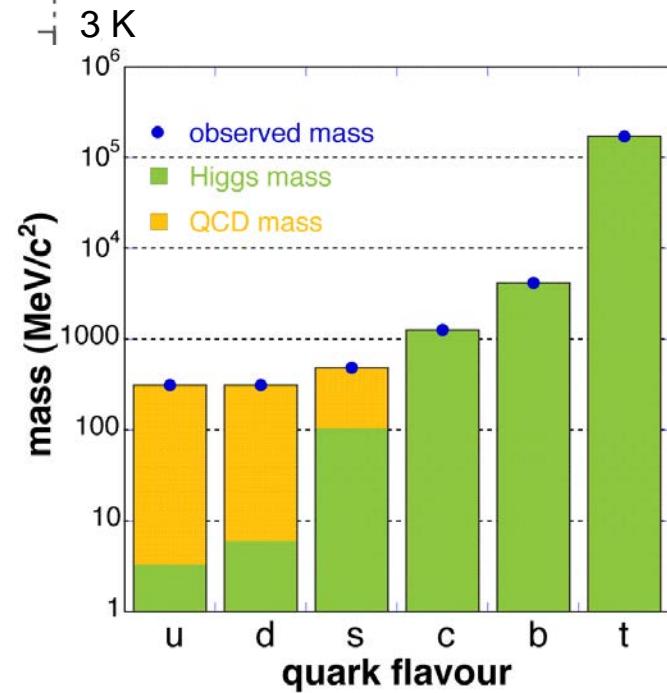
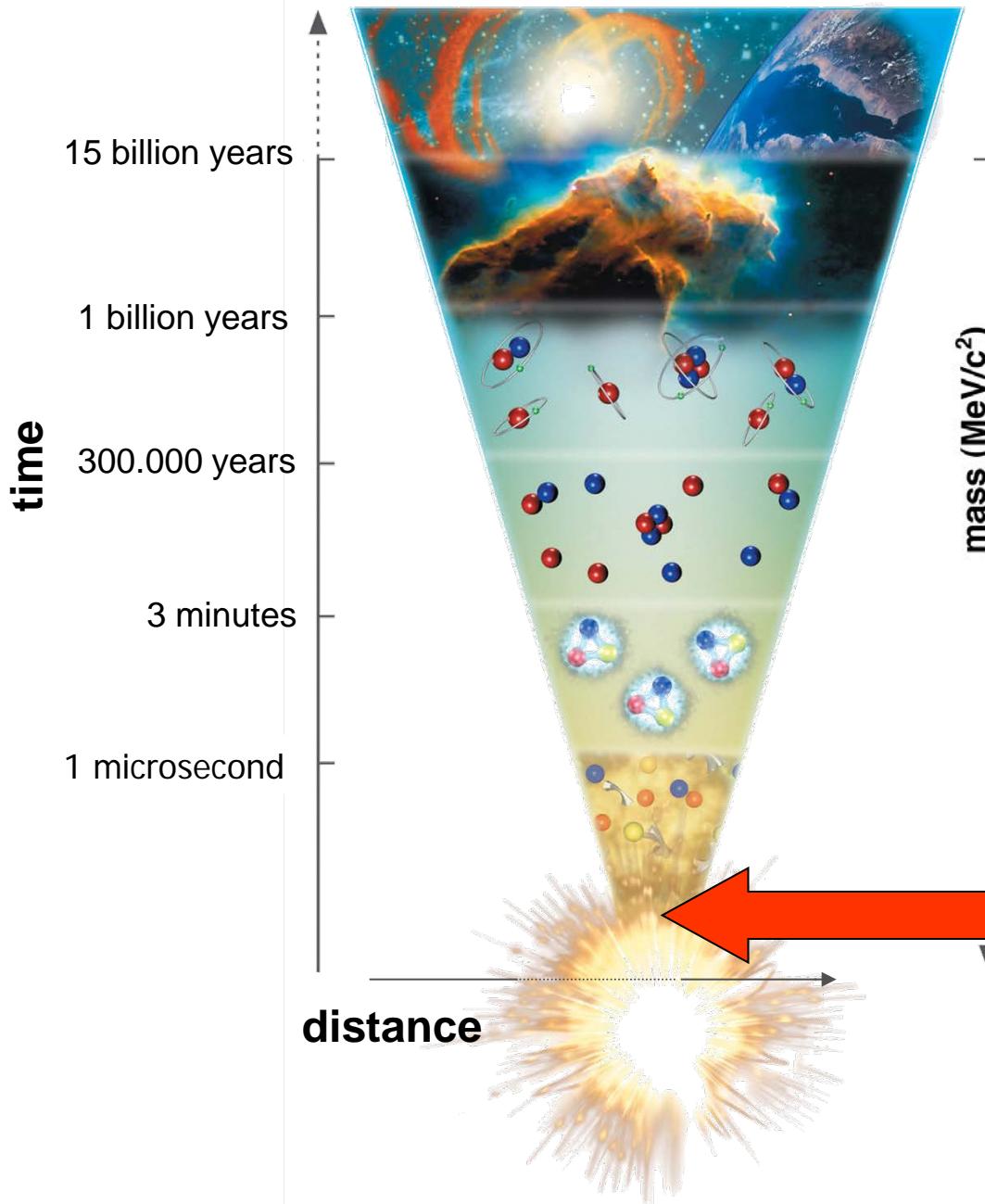
GSI and Univ. Frankfurt



## Outline:

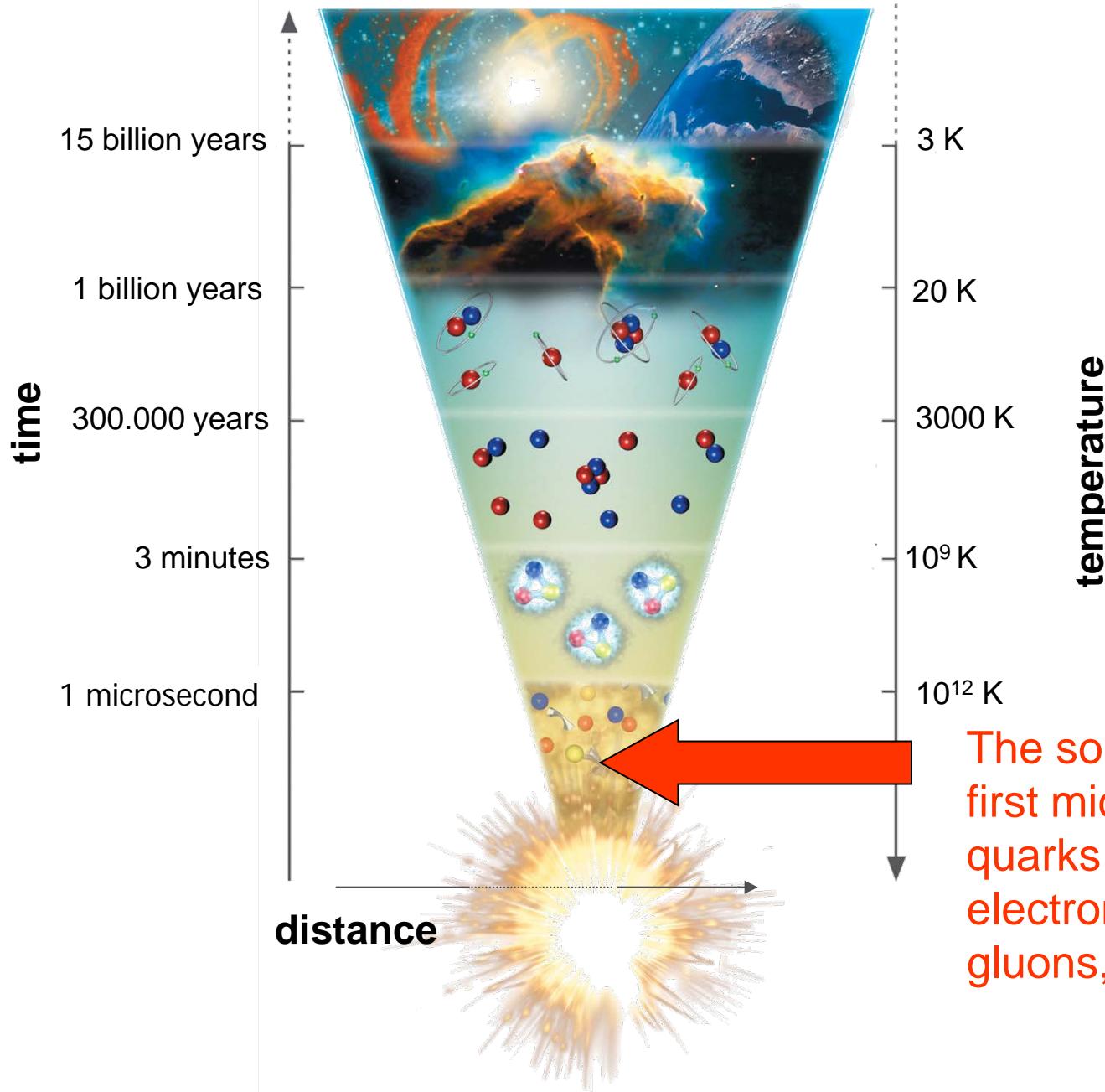
- Cosmic matter
- The Facility of Antiproton and Ion Research
- The Compressed Baryonic Matter experiment

# The evolution of matter in the universe

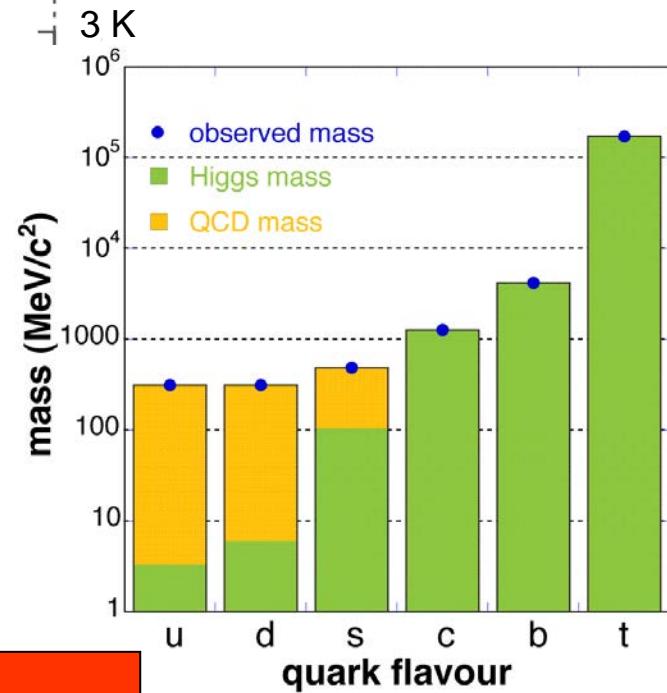
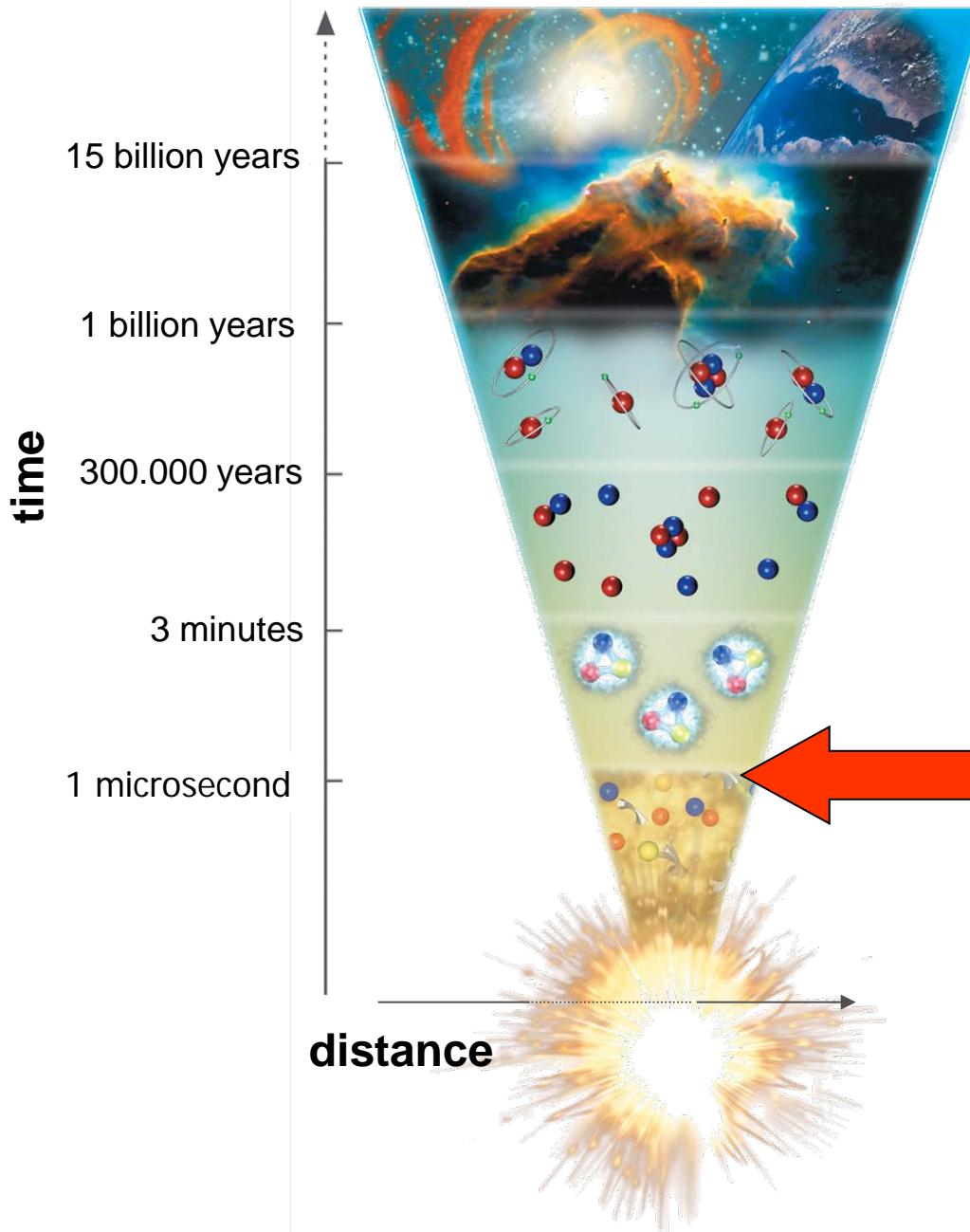


Explicit breaking  
of Chiral Symmetry  
(Higgs mechanism)  
 $m_u \approx 5 \text{ MeV}$ ,  
 $m_d \approx 10 \text{ MeV}$ ,  
 $m_s \approx 150 \text{ MeV}$

# The evolution of matter in the universe

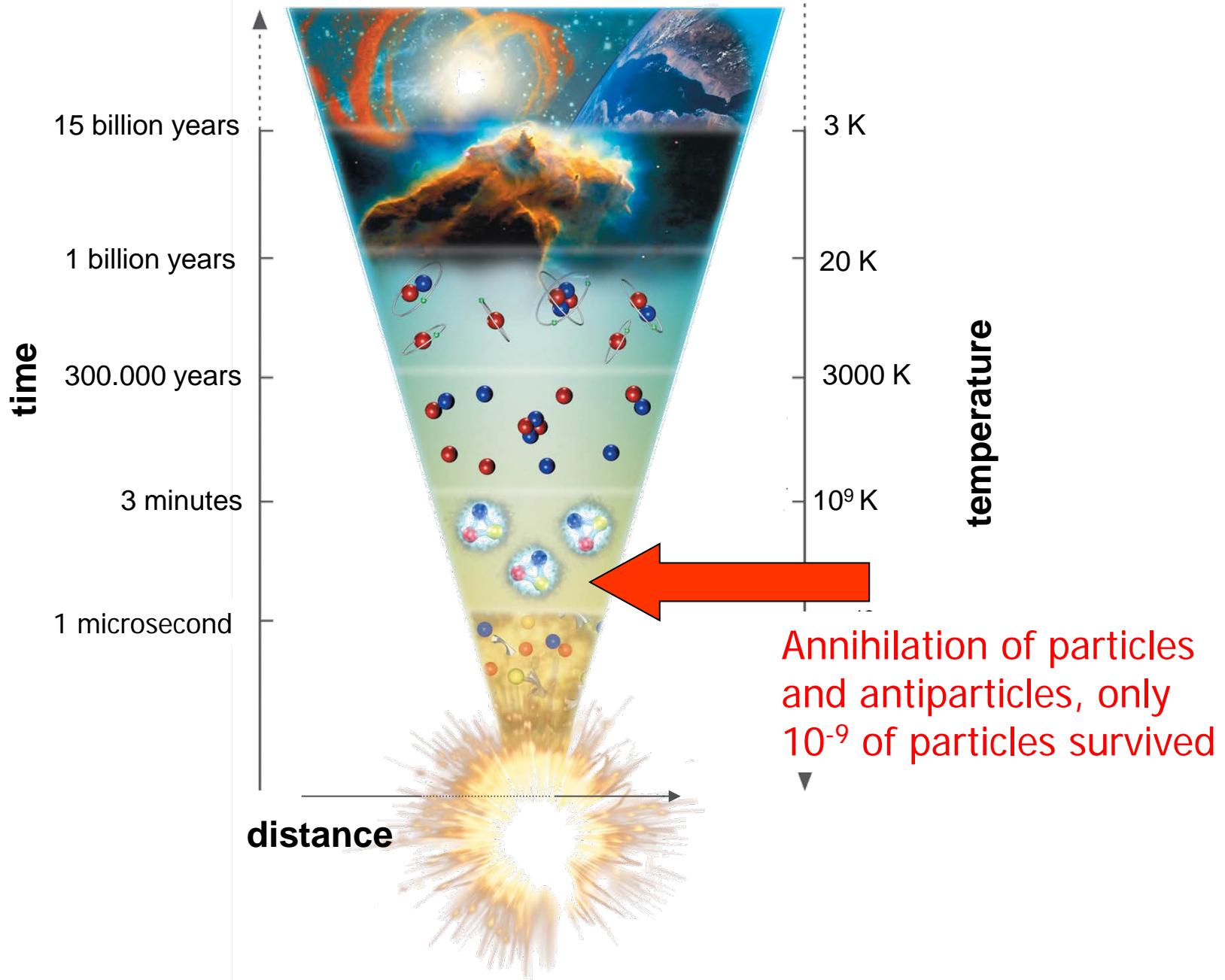


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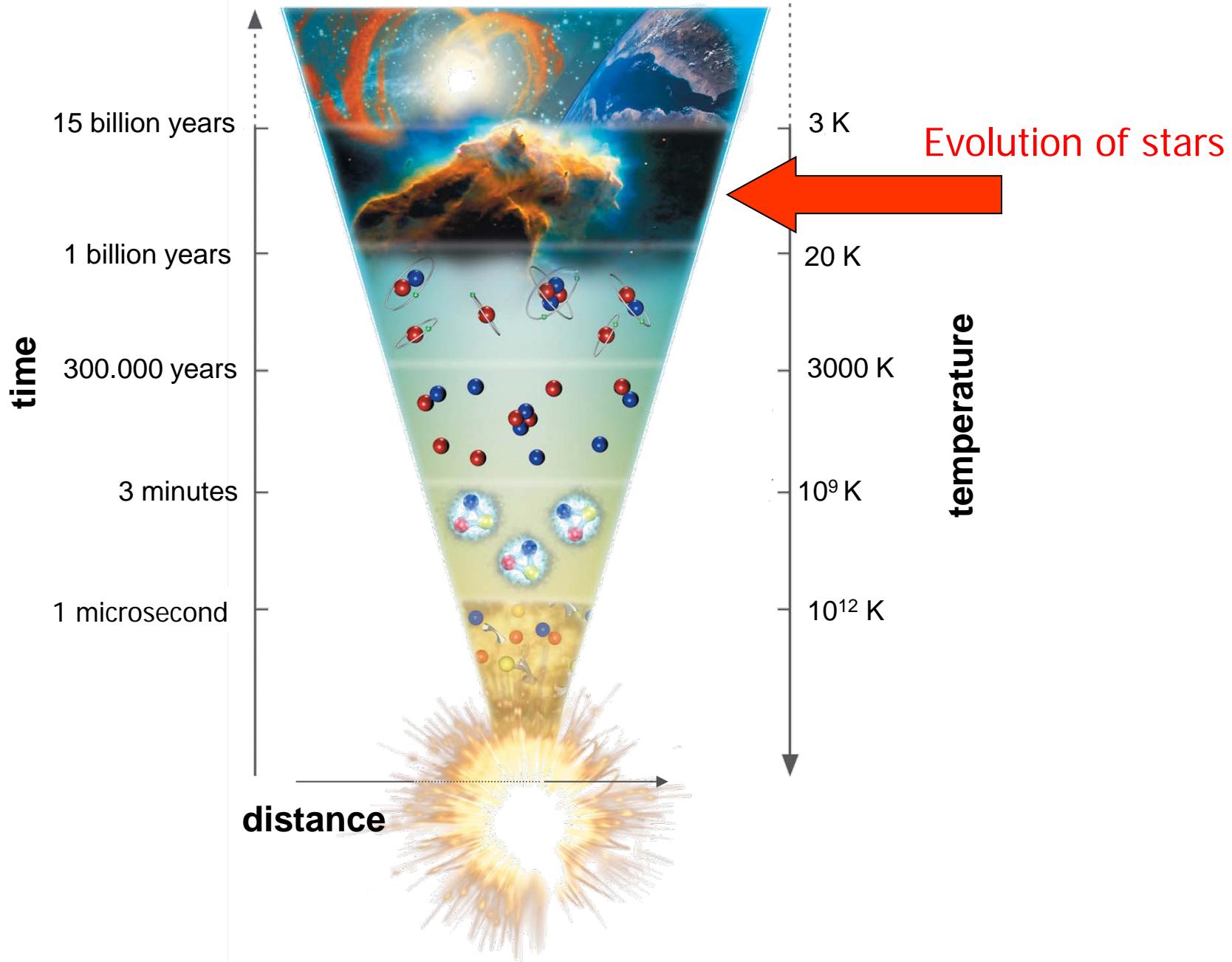


Spontaneous/dynamical Chiral Symmetry breaking:  
Hadrons acquire mass by coupling to the virtual quark-antiquark pairs of the chiral condensate

# The evolution of matter in the universe

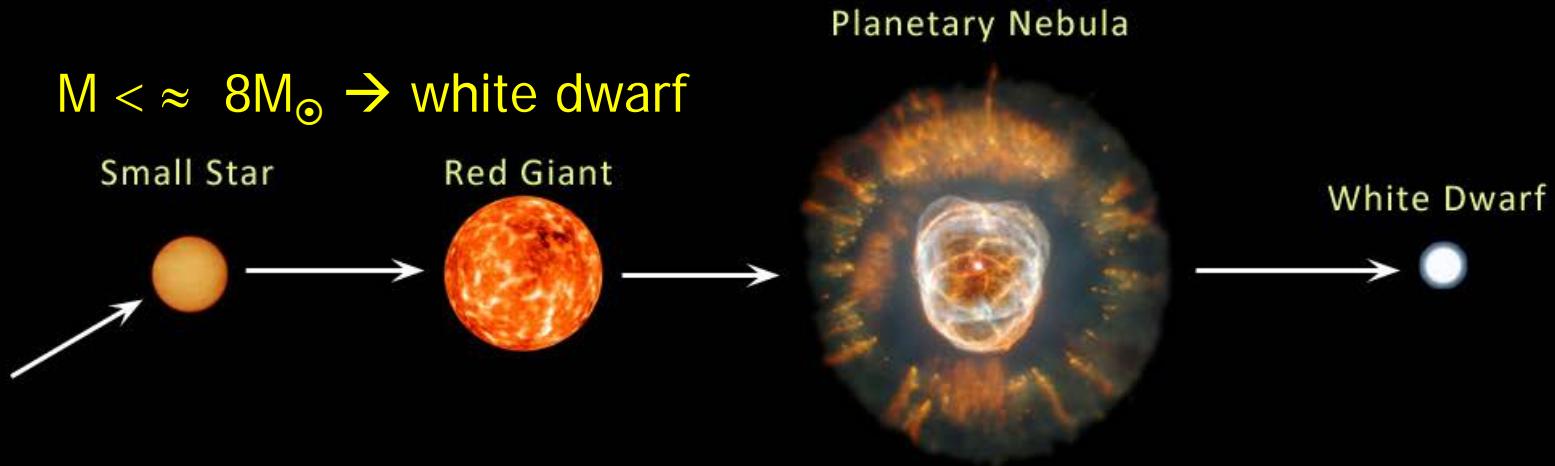


# The evolution of matter in the universe

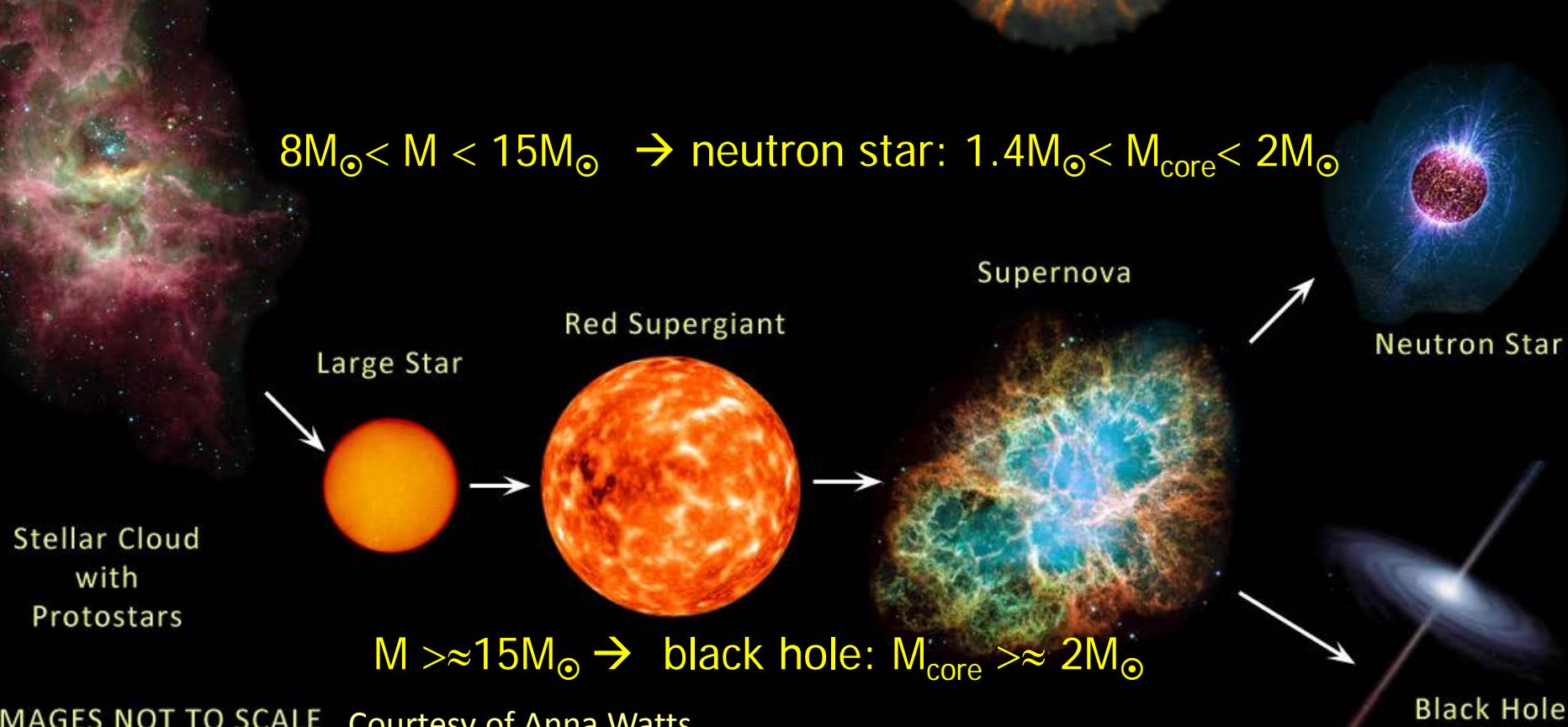


# The evolution of stars

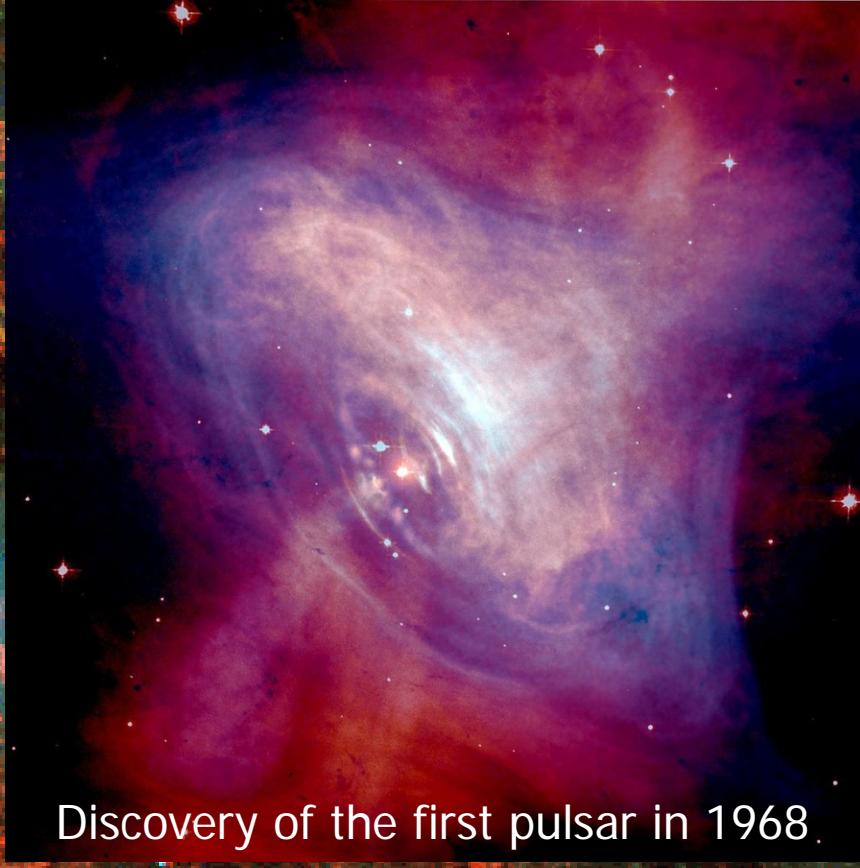
$M < \approx 8M_{\odot}$  → white dwarf



$8M_{\odot} < M < 15M_{\odot}$  → neutron star:  $1.4M_{\odot} < M_{\text{core}} < 2M_{\odot}$



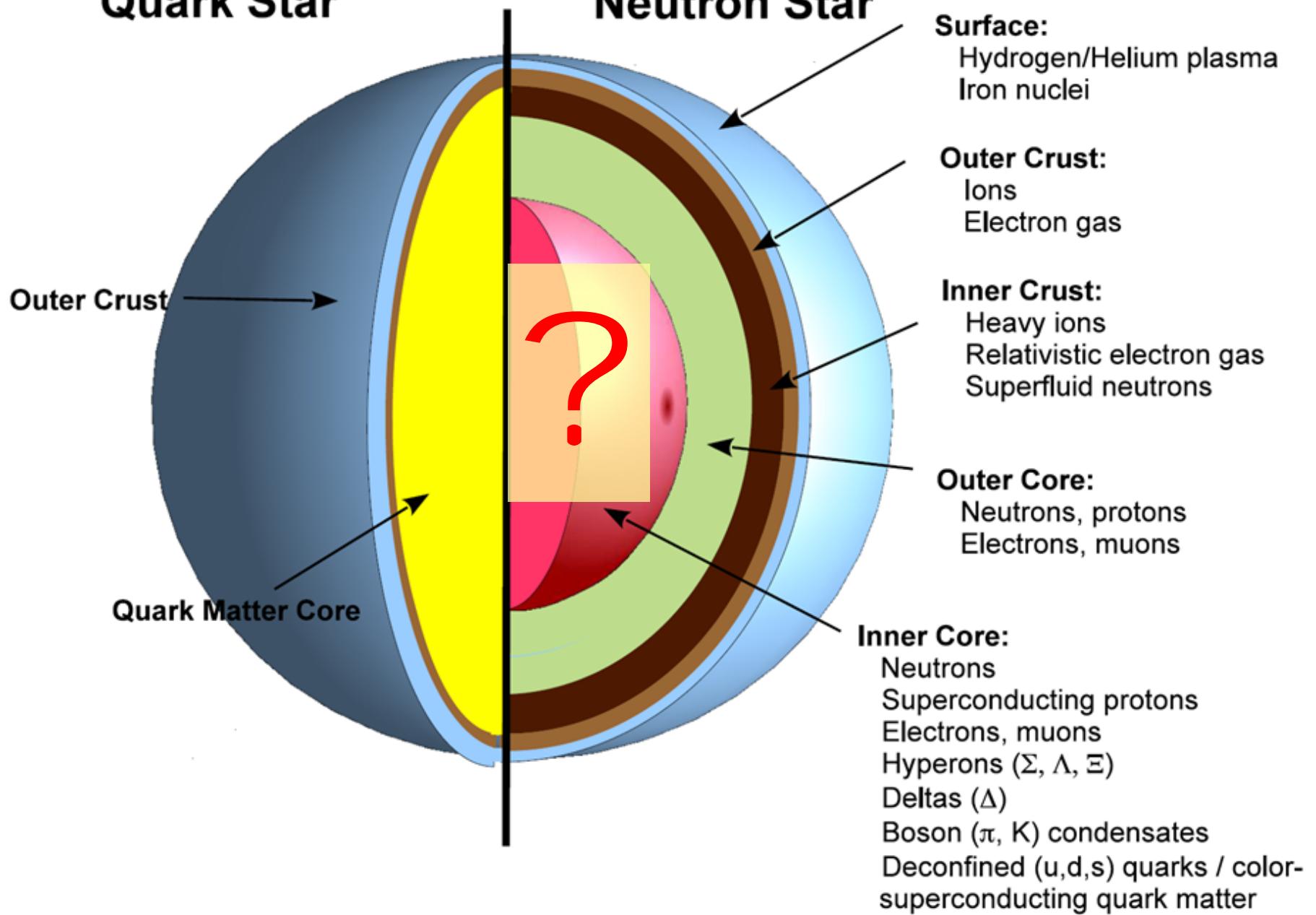
$M > \approx 15M_{\odot}$  → black hole:  $M_{\text{core}} > \approx 2M_{\odot}$



Discovery of the first pulsar in 1968

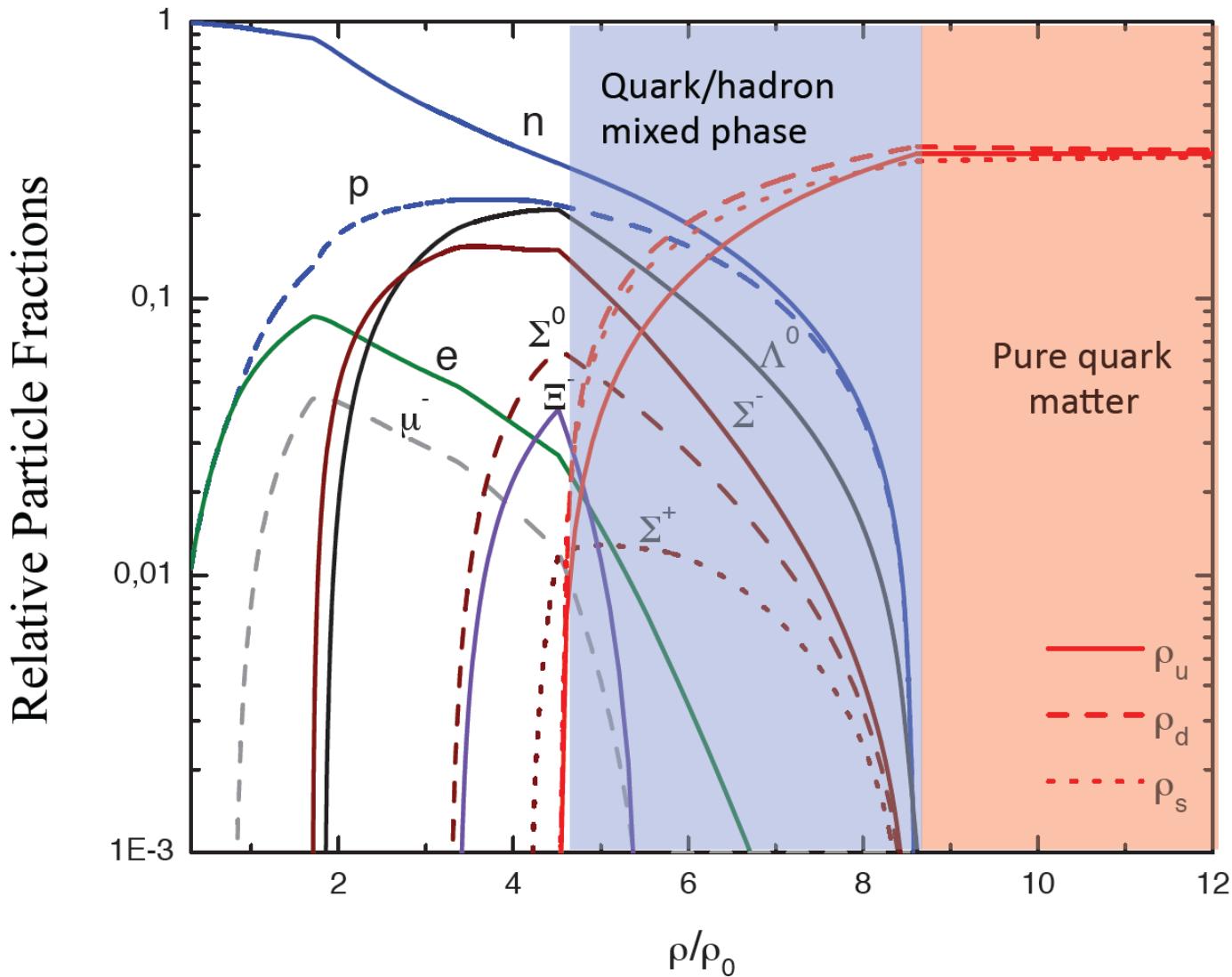
Crab nebula:  
ashes of a core collapse supernova observed in 1054 by Chinese astronomers.  
The “visiting star” was as bright as the Venus for more than 20 days.

# Quark Star



# Quark matter in massive neutron stars?

M. Orsaria, H. Rodrigues, F. Weber, G.A. Contrera, arXiv:1308.1657  
Phys. Rev. C 89, 015806, 2014



# Fundamental questions

What is the origin of the mass of the universe?

What is the origin of the elements ?

What is the structure of neutron stars?

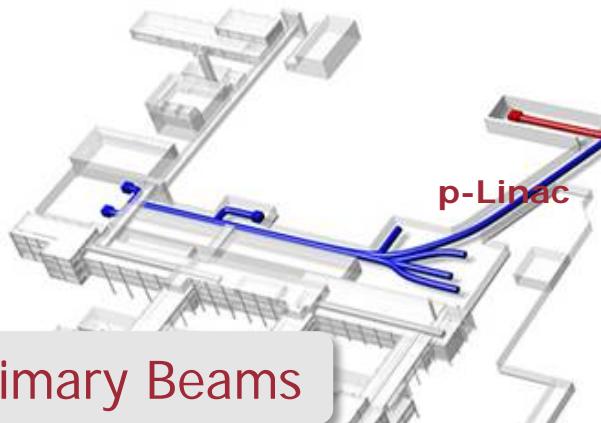
Can we ignite the solar fire on earth ?

Does matter differ from antimatter ?

Why do we not observe individual quarks ?

→ to be explored at the future international Facility for Antiproton and Ion Research (FAIR)

# Facility for Antiproton & Ion Research



## Primary Beams

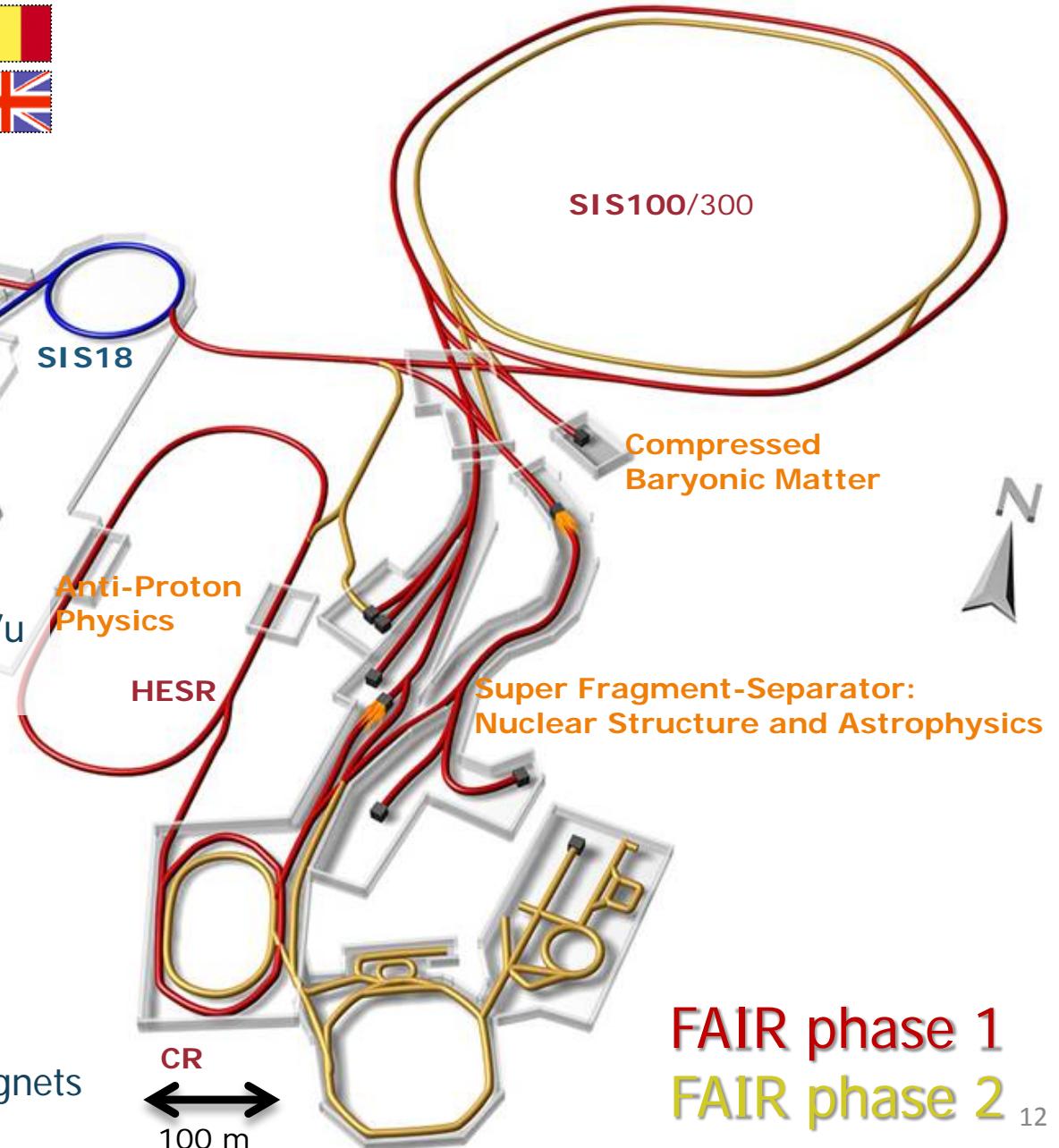
- $10^{12}/\text{s}$ ; 1.5 GeV/u;  $^{238}\text{U}^{28+}$
- $10^{10}/\text{s}$   $^{238}\text{U}^{92+}$  up to 11 (35) GeV/u
- $3 \times 10^{13}/\text{s}$  30 (90) GeV protons

## Secondary Beams

- radioactive beams up to 1.5 - 2 GeV/u;
- $10^{11}$  antiprotons 1.5 - 15 GeV/c

## Technical Challenges

- rapid cycling superconducting magnets
- dynamical vacuum



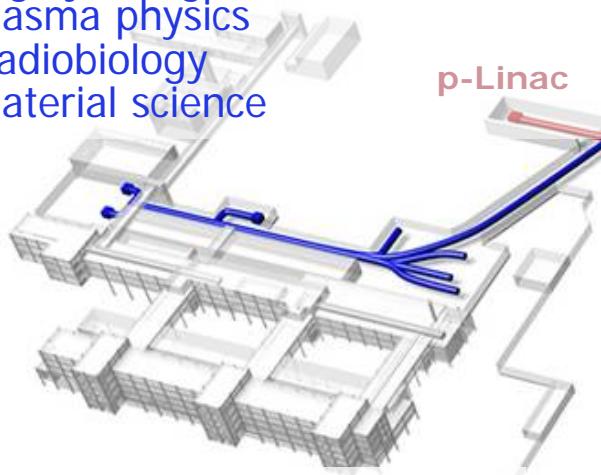
FAIR phase 1  
FAIR phase 2

# Facility for Antiproton & Ion Research

## Experimental programs:

### APPA: Atomic & Plasma Physics & Applications

- Highly charged atoms
- Plasma physics
- Radiobiology
- Material science



SIS100/300

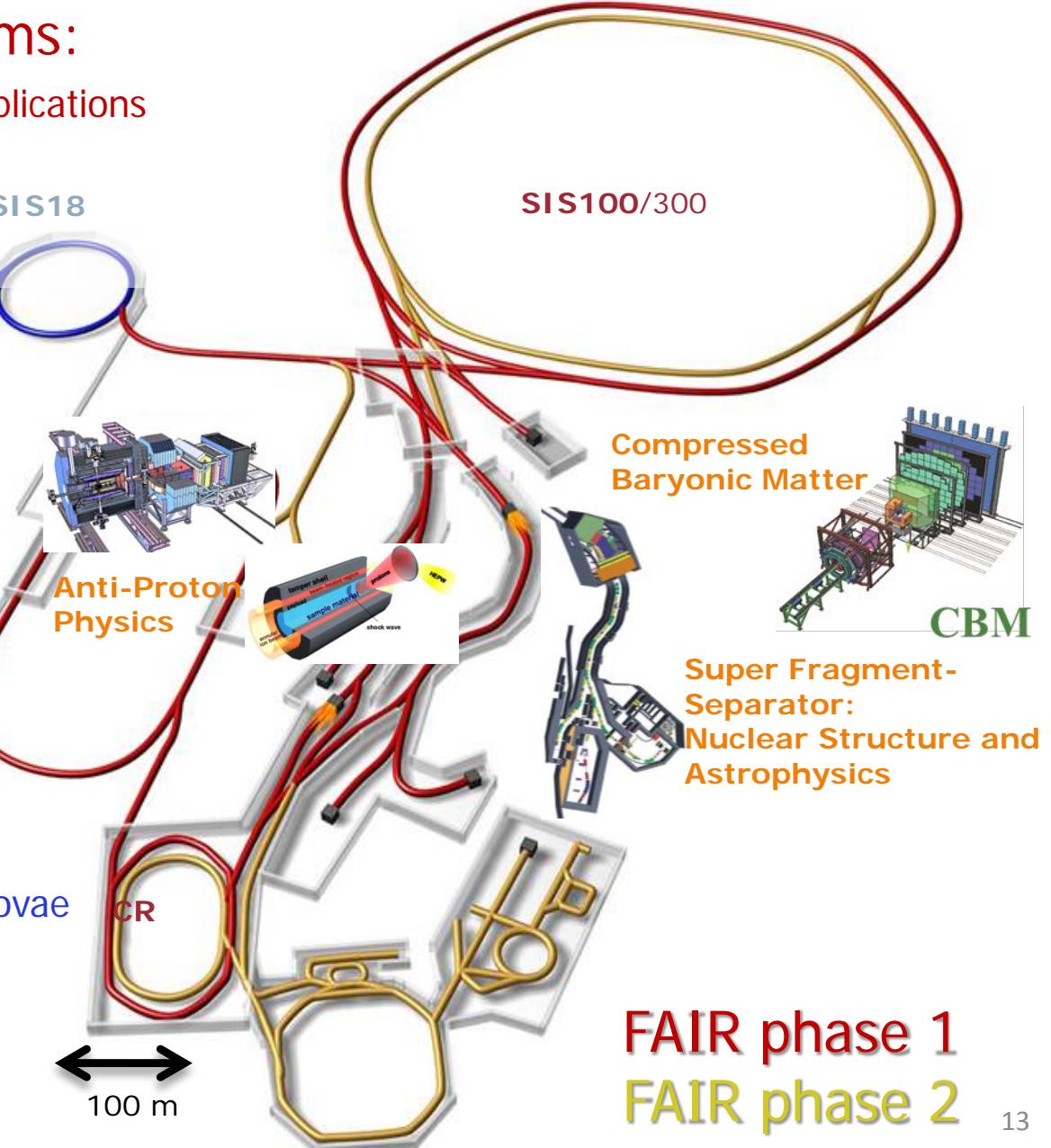
Compressed  
Baryonic Matter

CBM

Super Fragment-  
Separator:  
Nuclear Structure and  
Astrophysics

### CBM: Nucleus-nucleus collisions

- Nuclear matter at neutron star core densities
- Phase transitions from hadrons to quarks



FAIR phase 1  
FAIR phase 2

### NUSTAR: Rare Isotope beams

- Nuclear structure far off stability
- Nucleosynthesis in stars and supernovae

### PANDA: Antiproton-proton collisions:

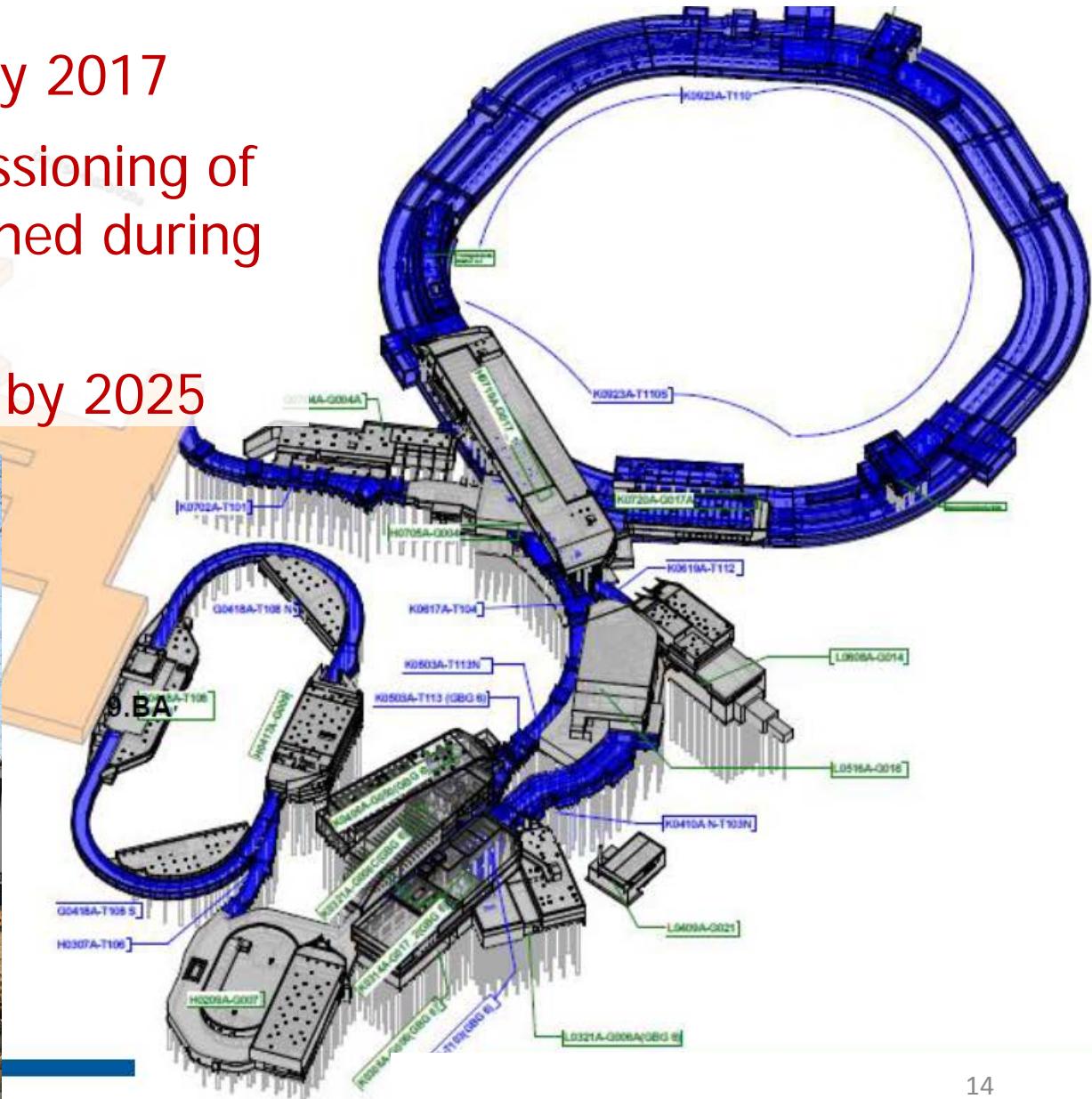
- Charmed hadrons (XYZ)
- Gluonic matter and hybrids
- Hadron structure
- Double Lambda hypernuclei

# Status of FAIR

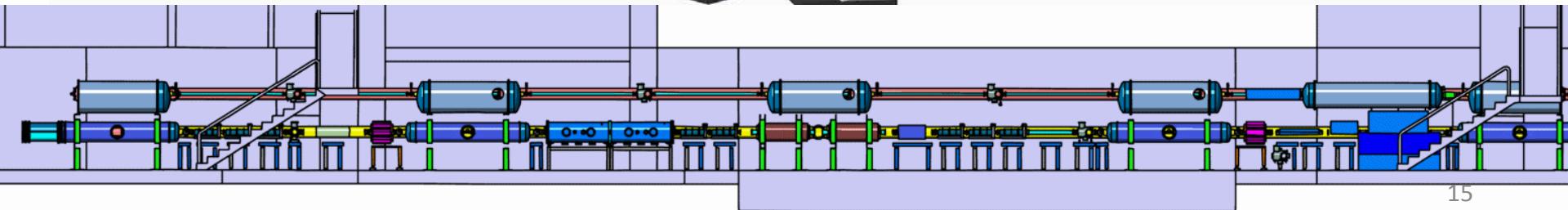
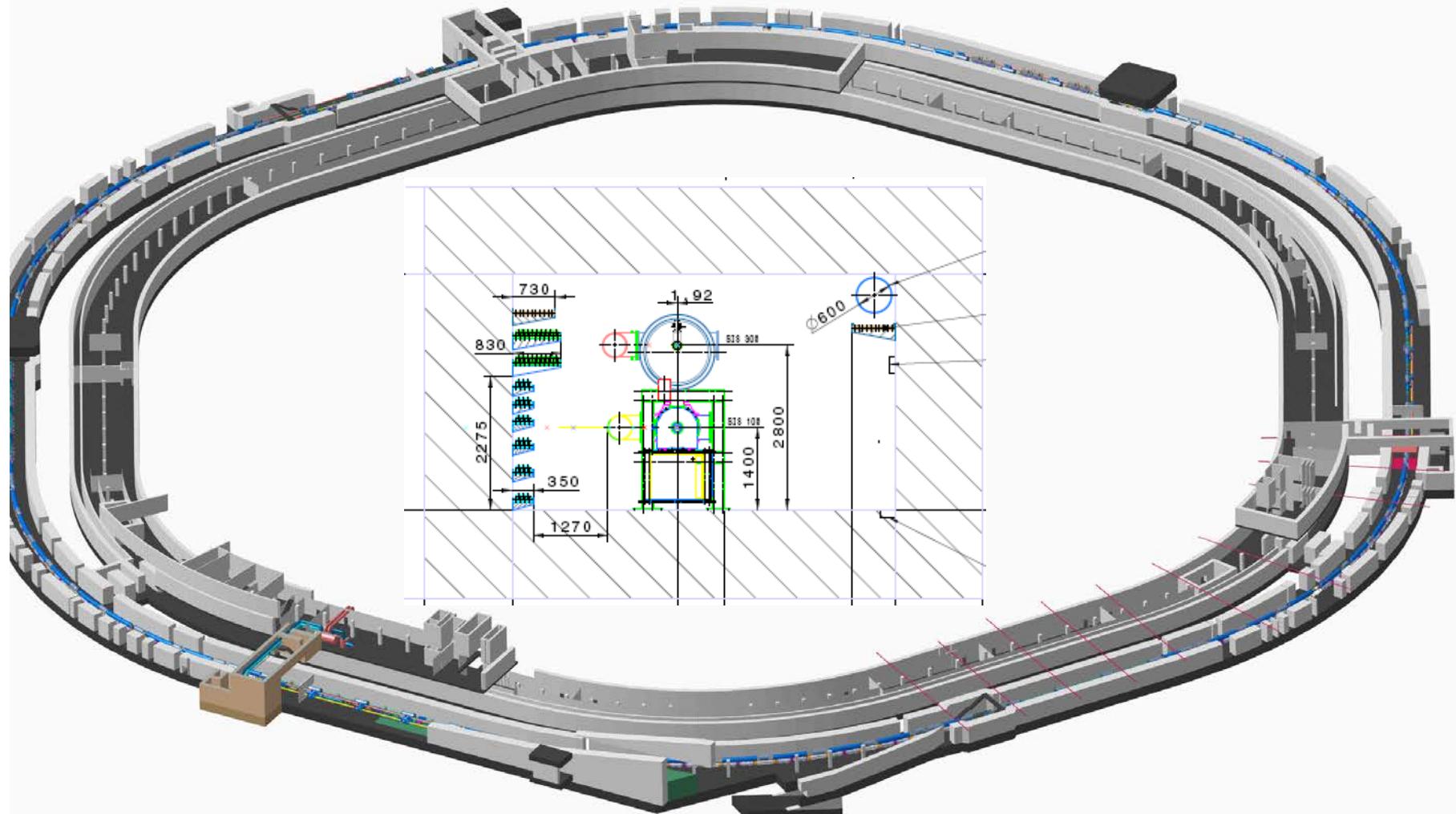
Construction started July 2017

Installation incl. commissioning of  
the experiments is planned during  
2021-2024

Full completion of FAIR by 2025



# Tunnel for SIS100/300







**FAIR** Groundbreaking  
4 July 2017 Darmstadt



# Status FAIR civil construction as of August 25, 2017

SIS18 – adaptation works for FAIR



# Status FAIR civil construction as of August 25, 2017

SIS18 – adaptation works for FAIR



# Status FAIR civil construction as of August 25, 2017

Preparatory works for excavation

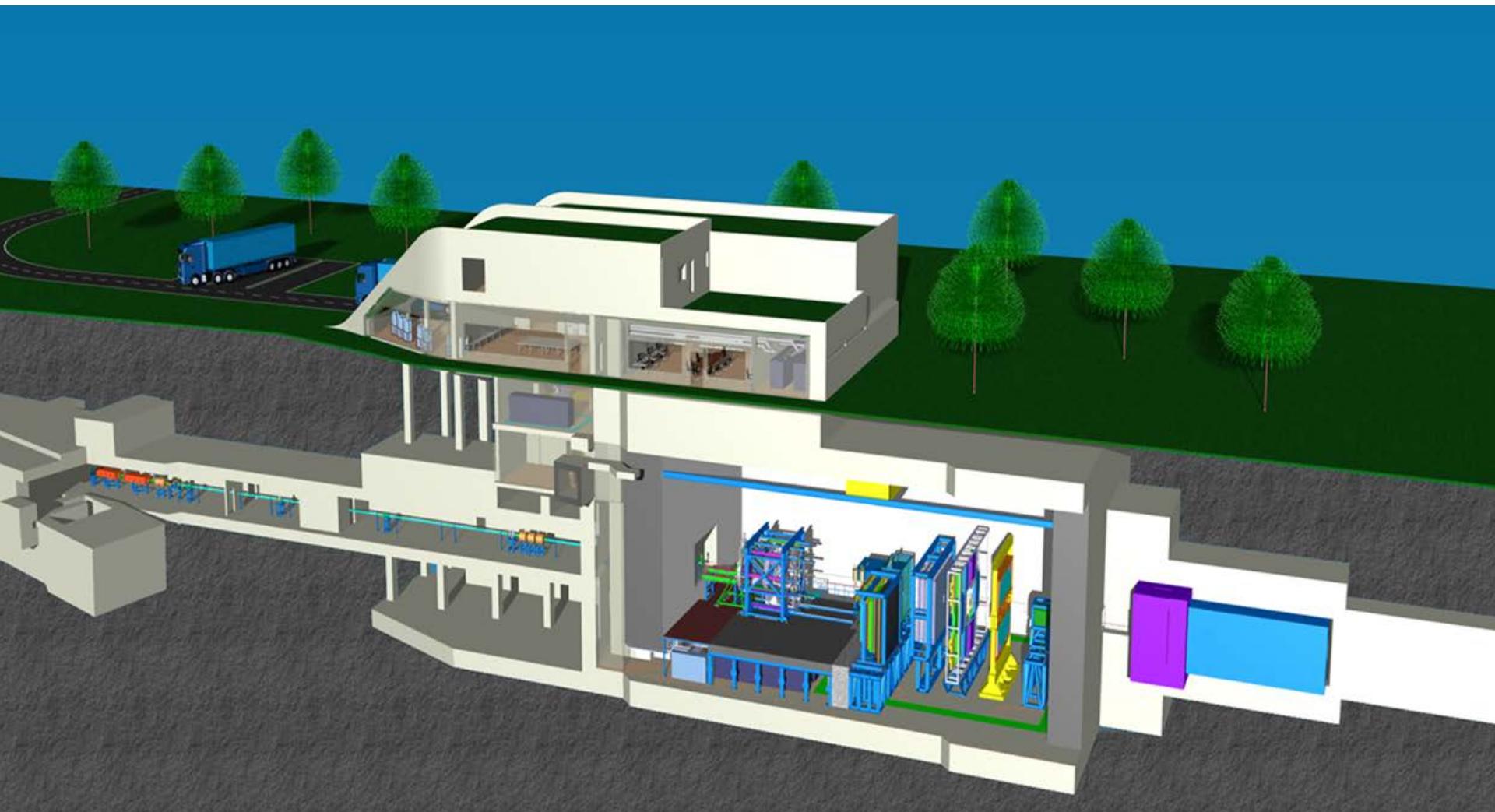


# Status FAIR civil construction as of August 25, 2017

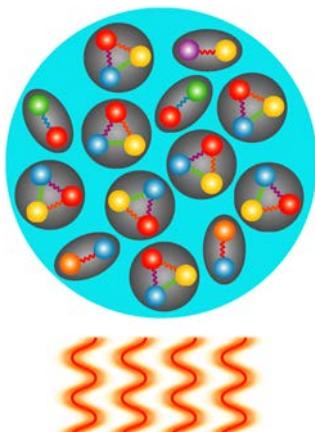
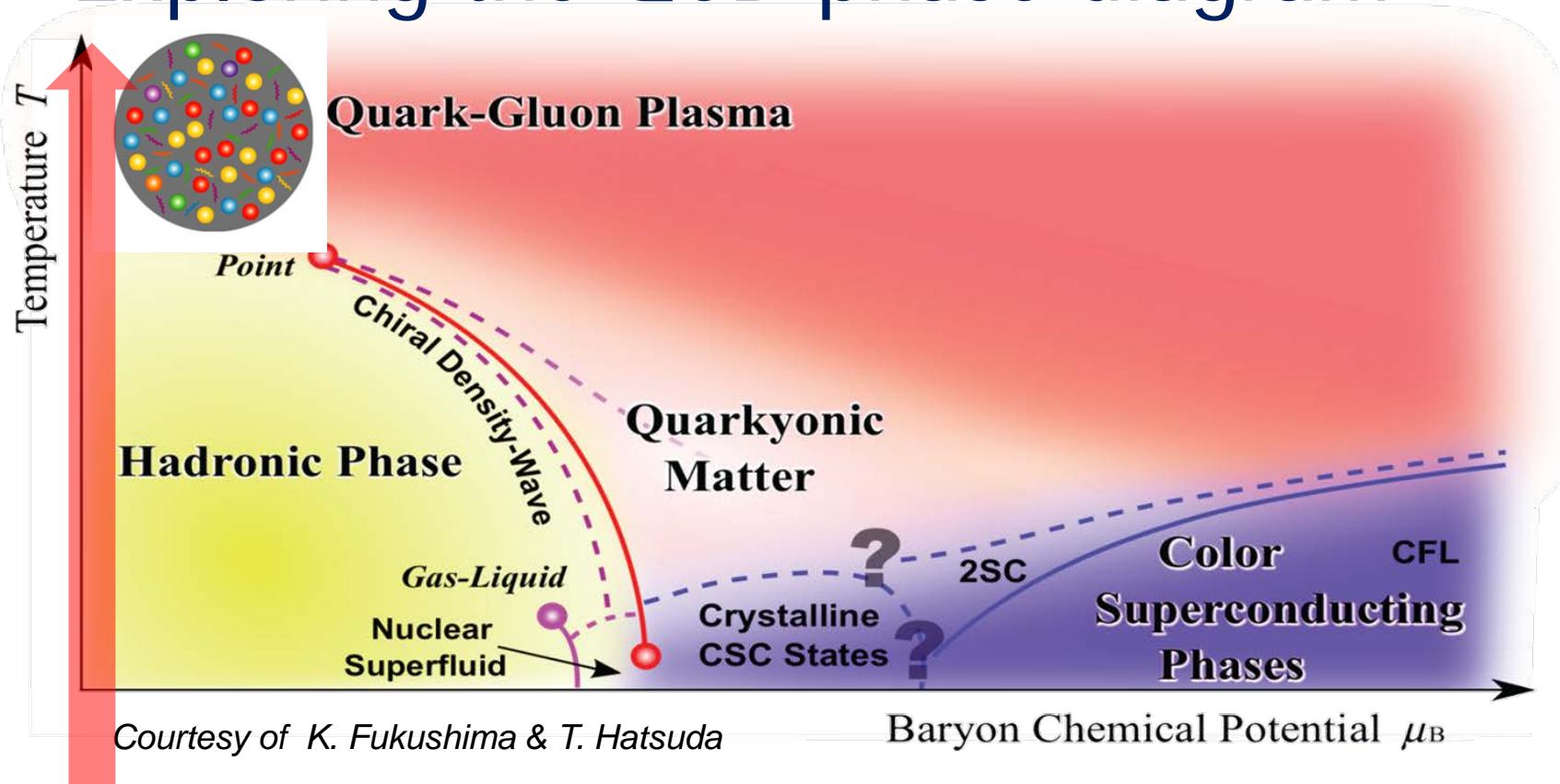
Piping for ventilation and ground water lowering



# The Compressed Baryonic Matter (CBM) experiment



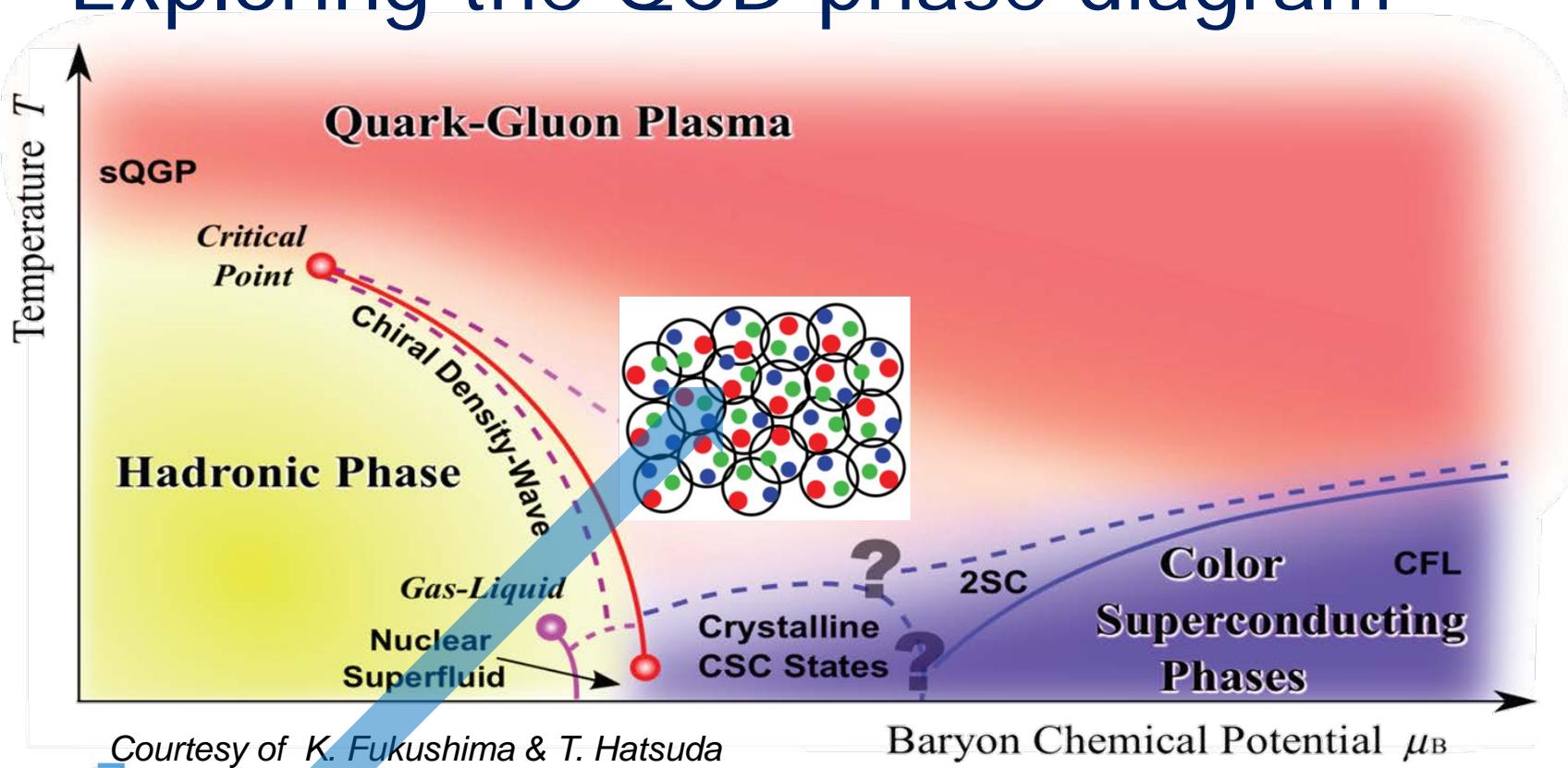
# Exploring the QCD phase diagram



At very high temperature:

- N of baryons  $\approx$  N of antibaryons  
Situation similar to early universe
- L-QCD finds crossover transition between hadronic matter and Quark-Gluon Plasma
- Experiments: **ALICE, ATLAS, CMS at LHC**  
**STAR, PHENIX at RHIC**

# Exploring the QCD phase diagram



At high baryon density:

- $N$  of baryons  $\gg N$  of antibaryons  
Densities like in neutron star cores
- L-QCD not (yet) applicable
- Models predict first order phase transition with mixed or exotic phases
- Experiments: BES at RHIC, NA61 at CERN SPS, CBM at FAIR, NICA at JINR, J-PARC

# Density estimates

## Atomic nucleus:

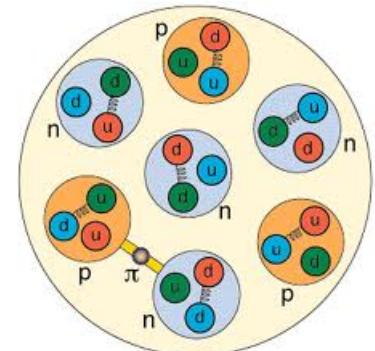
Radius  $R = 1.2 \text{ fm } A^{1/3}$  ( $\sigma_{\text{reac}} = \pi R^2$ )

Volume  $V = 4/3 \pi R^3 = 4/3 \pi 1.2^3 A \text{ fm}^3$

Nucleon density  $\rho_0 = A/V = 3/(4 \pi 1.2^3) \text{ fm}^{-3} \approx 0.14 \text{ fm}^{-3}$

Mass of nucleon  $m = 1.67 \cdot 10^{-24} \text{ g}$

Mass density of cold nuclear matter  $\rho_0 \cdot m \approx 270 \text{ Mio t/cm}^3$



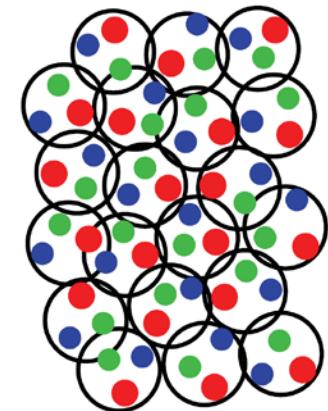
## Limits of nucleon density:

Au-nucleus:  $R \approx 7 \text{ fm}, V \approx 1400 \text{ fm}^3$

Nucleon:  $R \approx 0.8 \text{ fm}, V \approx 2 \text{ fm}^3$

200 Nucleons:  $V \approx 400 \text{ fm}^3$

At  $3 - 4 \rho^0$ : nucleons overlap, Fermi see of quarks?



## Neutron star:

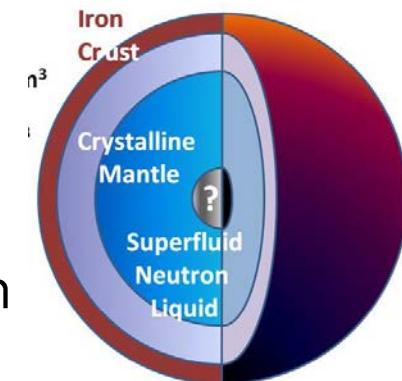
Radius  $R \approx 10 \text{ km}$ ,

Volume  $V \approx 4200 \text{ km}^3$

Mass  $M \approx 2 \text{ solar masses} = 2 \cdot 2 \cdot 10^{33} \text{ g}$

Average mass density  $\rho = M/V \approx 1000 \text{ Mio t/cm}^3 \approx 3.6 \rho^0 \cdot m$

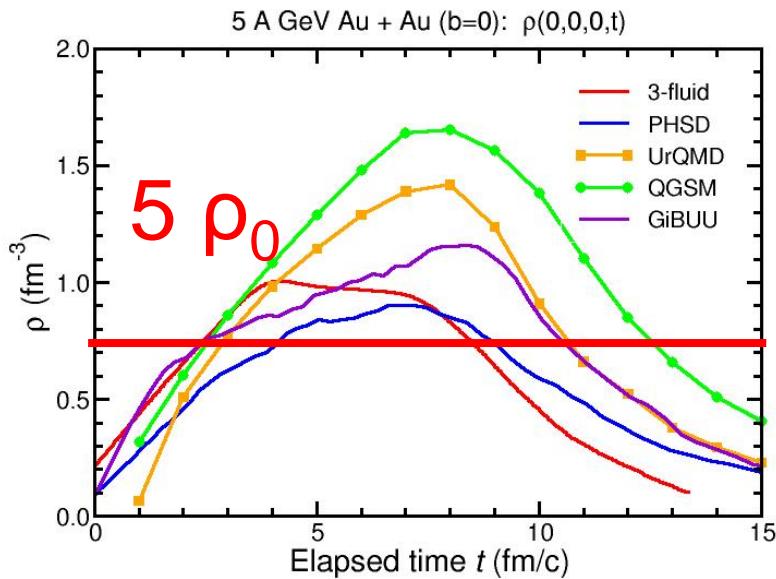
Core density 5 – 10 times nuclear density



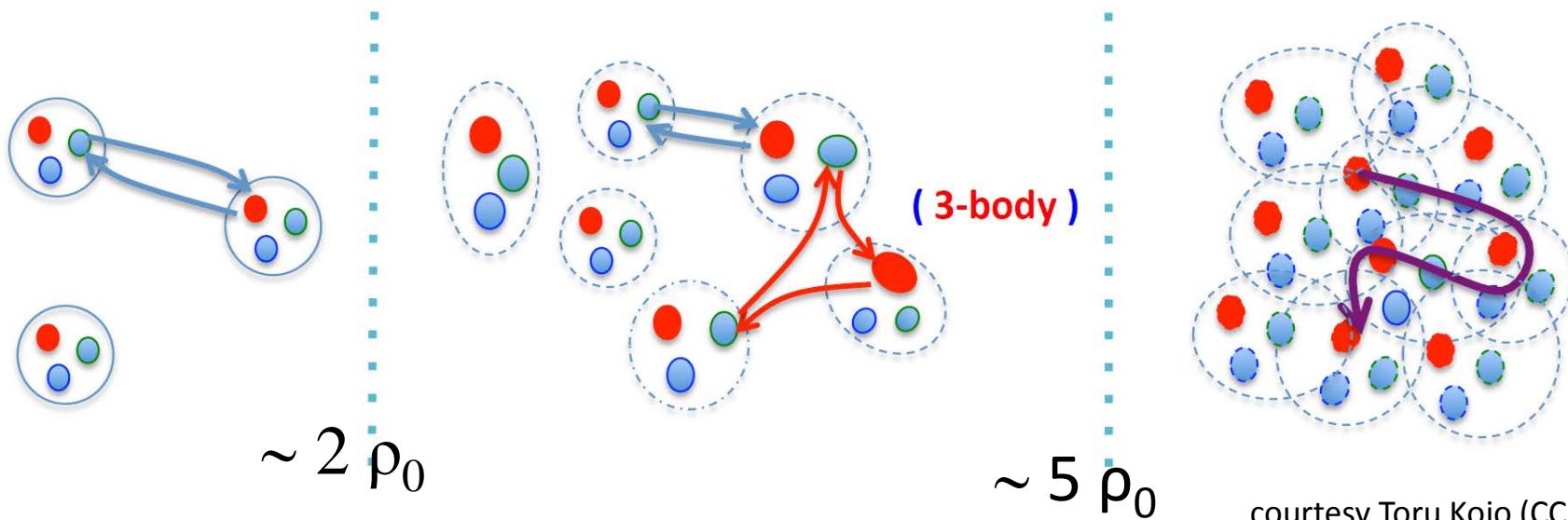
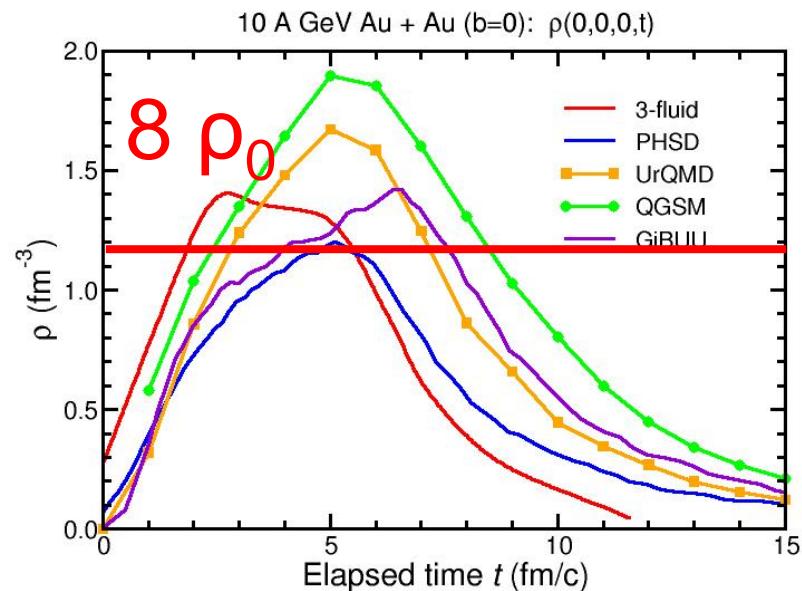
# Baryon densities in central Au+Au collisions

I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

**5 A GeV**



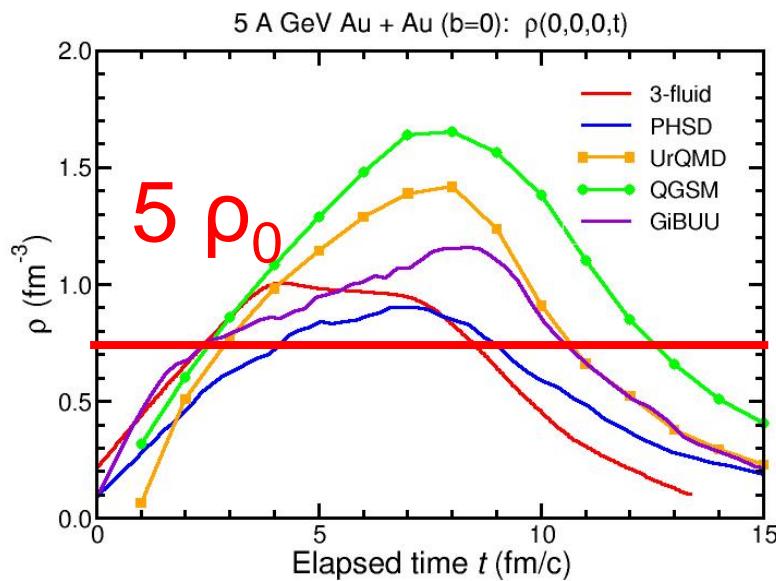
**10 A GeV**



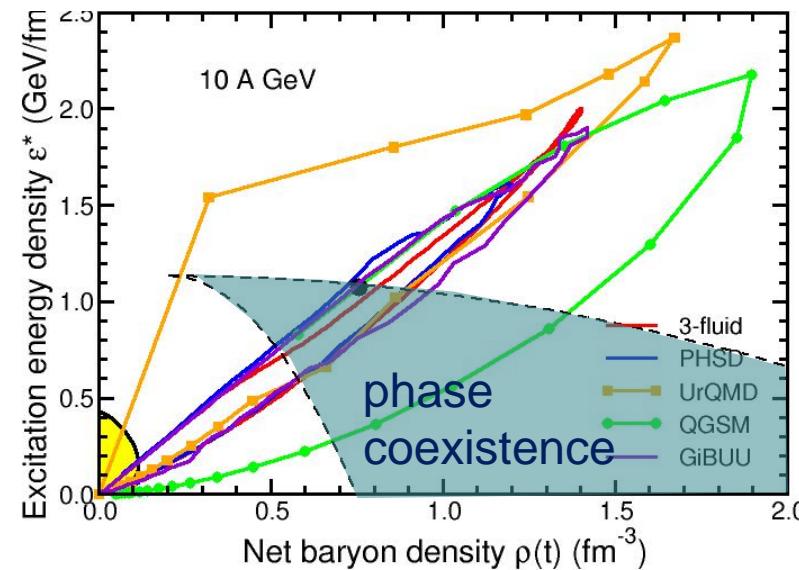
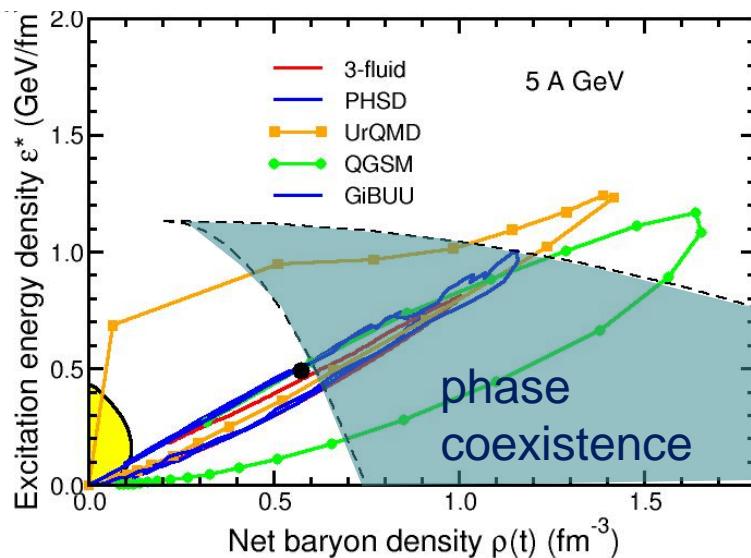
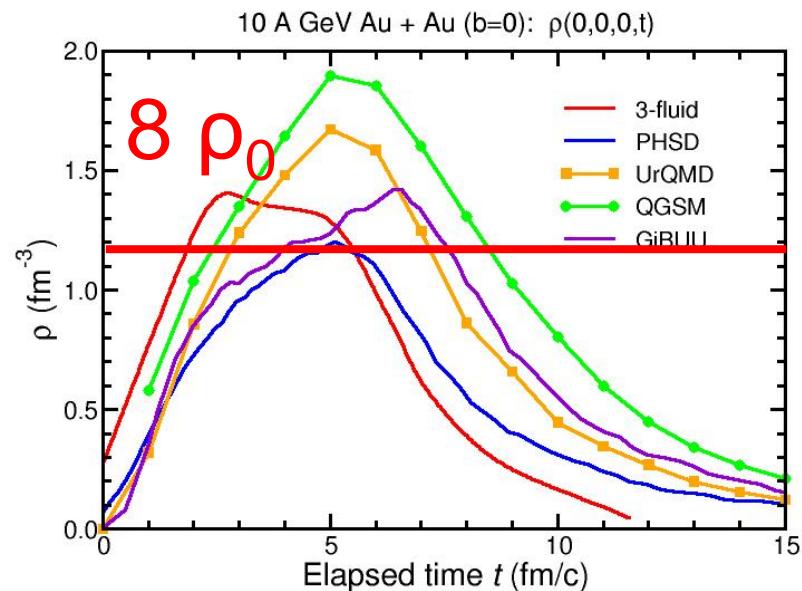
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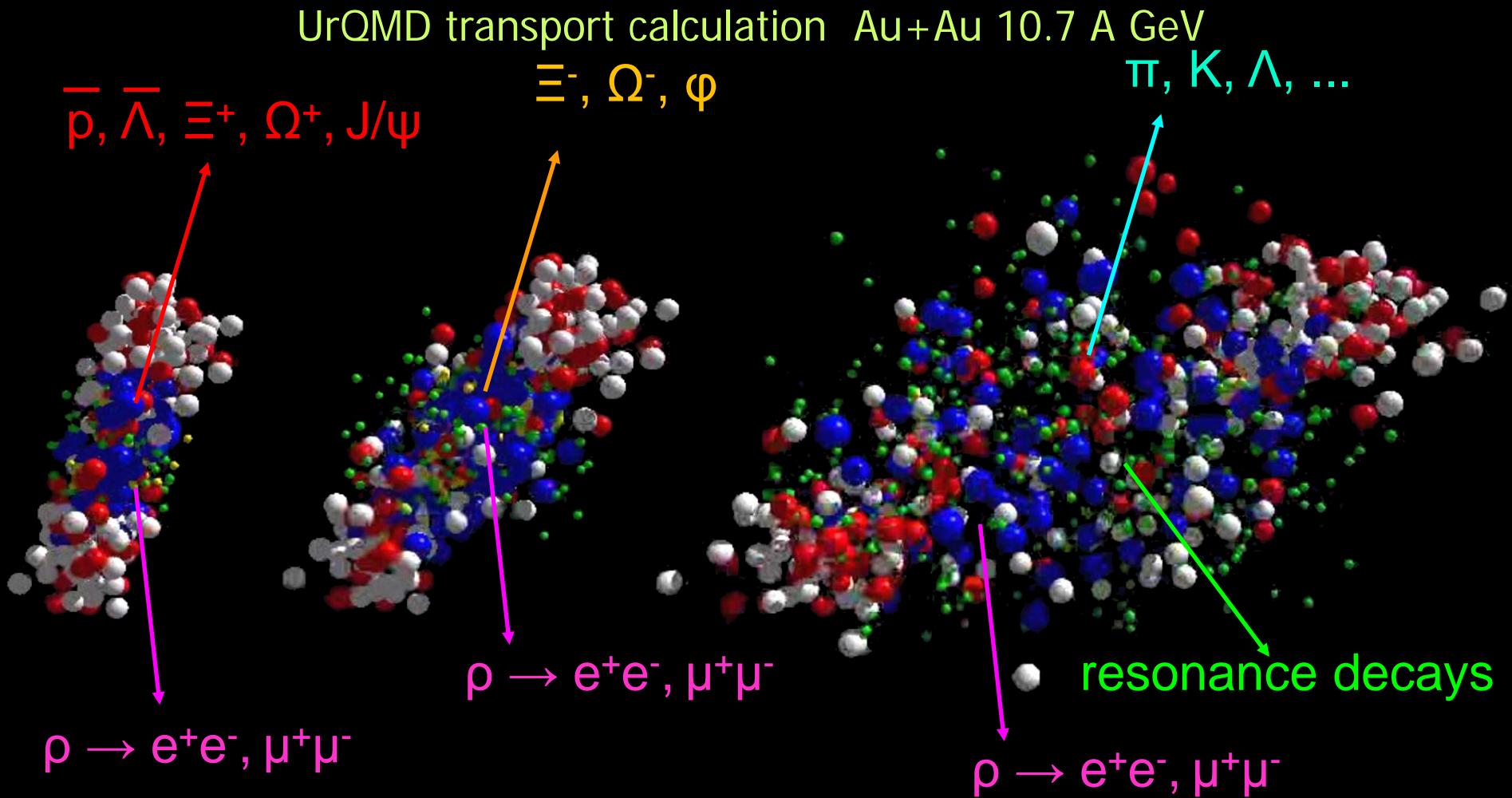
**5 A GeV**



**10 A GeV**



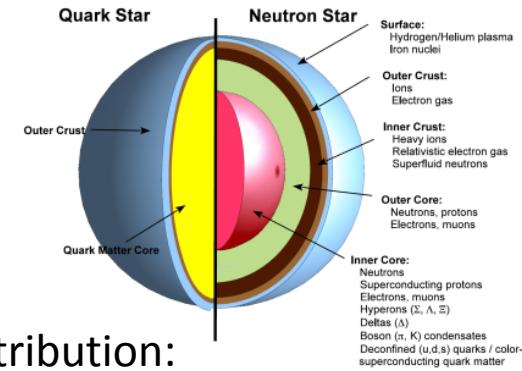
# Messengers from the dense fireball: CBM at FAIR



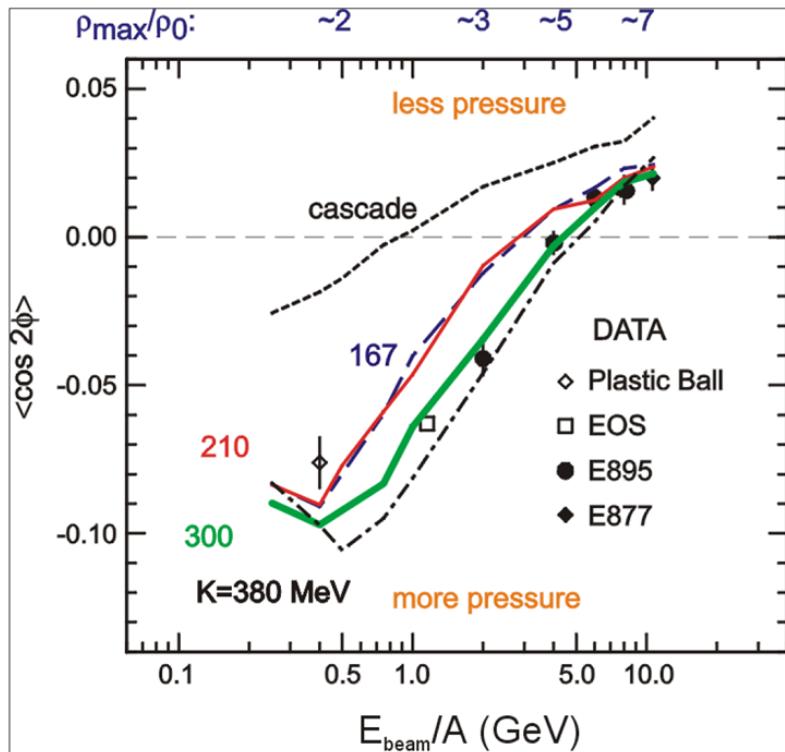
# CBM physics case and observables

The QCD matter equation-of-state at neutron star core densities

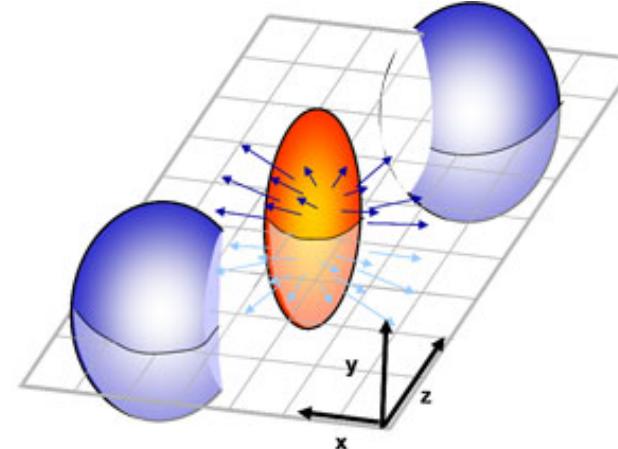
- collective flow of identified particles ( $\pi, K, p, \Lambda, \Xi, \Omega, \dots$ ) driven by the pressure gradient in the early fireball



AGS: proton flow in Au+Au collisions



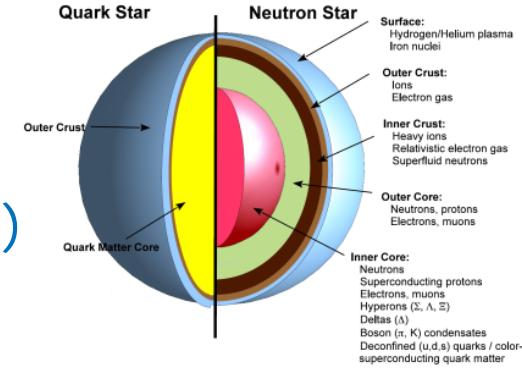
Azimuthal angle distribution:  
 $dN/d\phi = C (1 + v_1 \cos(\phi) + v_2 \cos(2\phi) + \dots)$



# CBM physics case and observables

The QCD matter equation-of-state at neutron star core densities

- collective flow of identified particles ( $\pi, K, p, \Lambda, \Xi, \Omega, \dots$ ) driven by the pressure gradient in the early fireball
- particle production at (sub)threshold energies via multi-step processes (multi-strange hyperons, charm)



Direct multi-strange hyperon production:

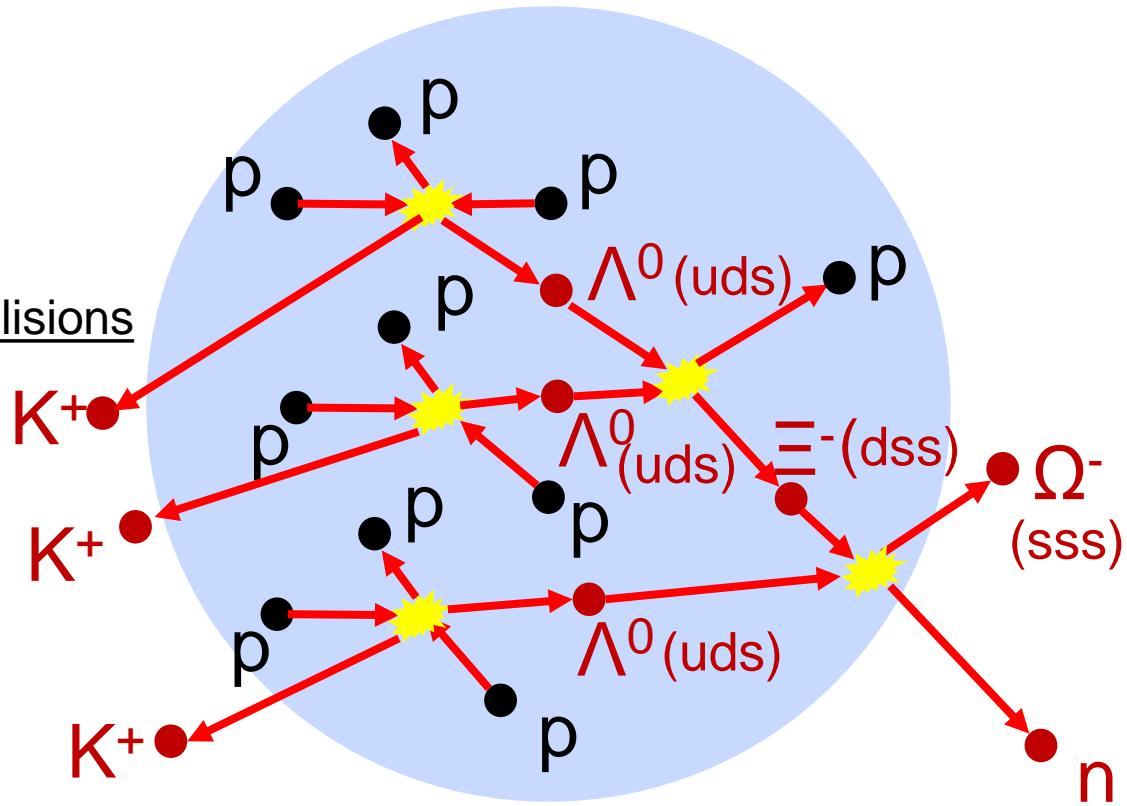
$$\begin{aligned} pp &\rightarrow \Xi^- K^+ K^+ p \quad (E_{\text{thr}} = 3.7 \text{ GeV}) \\ pp &\rightarrow \Omega^- K^+ K^+ K^+ n \quad (E_{\text{thr}} = 7.0 \text{ GeV}) \\ pp &\rightarrow \Lambda^0 \bar{\Lambda}^0 pp \quad (E_{\text{thr}} = 7.1 \text{ GeV}) \\ pp &\rightarrow \Xi^+ \Xi^- pp \quad (E_{\text{thr}} = 9.0 \text{ GeV}) \\ pp &\rightarrow \Omega^+ \Omega^- pp \quad (E_{\text{thr}} = 12.7 \text{ GeV}) \end{aligned}$$

Hyperon production via multiple collisions

1.  $pp \rightarrow K^+ \Lambda^0 p, \quad pp \rightarrow K^+ K^- pp,$
2.  $p \Lambda^0 \rightarrow K^+ \Xi^- p, \quad \pi \Lambda^0 \rightarrow K^+ \Xi^- \pi, \quad \Lambda^0 \Lambda^0 \rightarrow \Xi^- p, \quad \Lambda^0 K^- \rightarrow \Xi^- \pi^0$
3.  $\Lambda^0 \Xi^- \rightarrow \Omega^- n, \quad \Xi^- K^- \rightarrow \Omega^- \pi^-$

Antihyperons

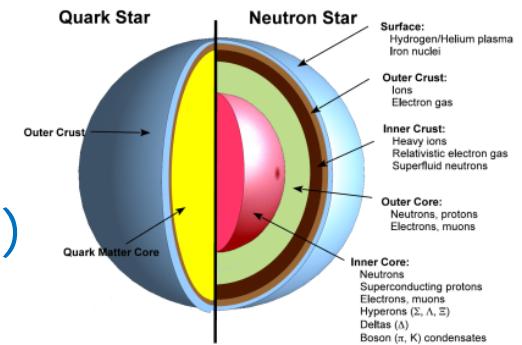
1.  $\bar{\Lambda}^0 K^+ \rightarrow \Xi^+ \pi^0, \quad \Xi^+ K^+ \rightarrow \Omega^+ \pi^+$
2.  $\Xi^- K^+ \rightarrow \Omega^- \pi^-$



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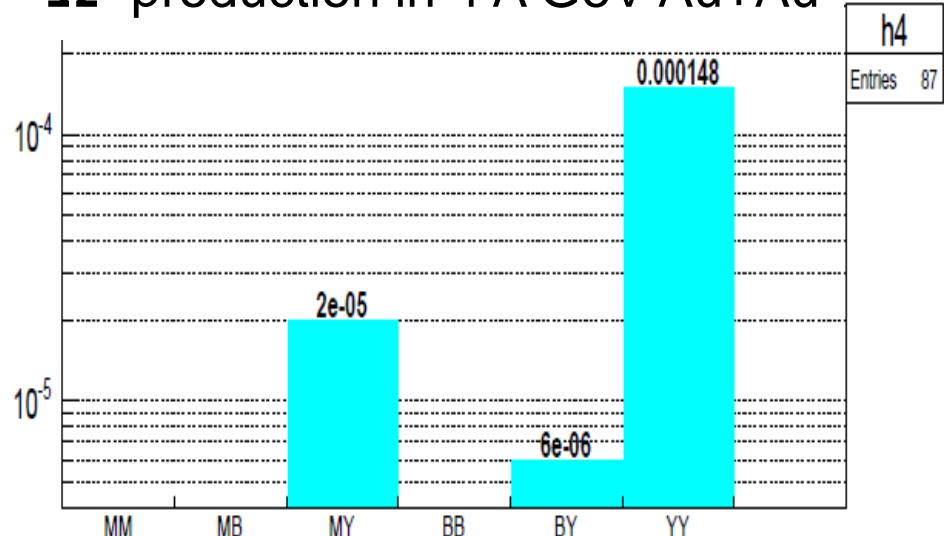
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Antihyperons

1.  $\bar{\Lambda}^0 K^+ \rightarrow \Xi^+ \pi^0$ ,
2.  $\Xi^+ K^+ \rightarrow \Omega^+ \pi^+$ .

$\Omega^-$  production in 4 A GeV Au+Au

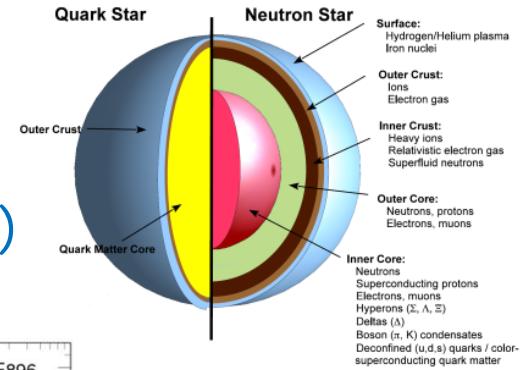


HYPQGSM calculations , K. Gudima et al.

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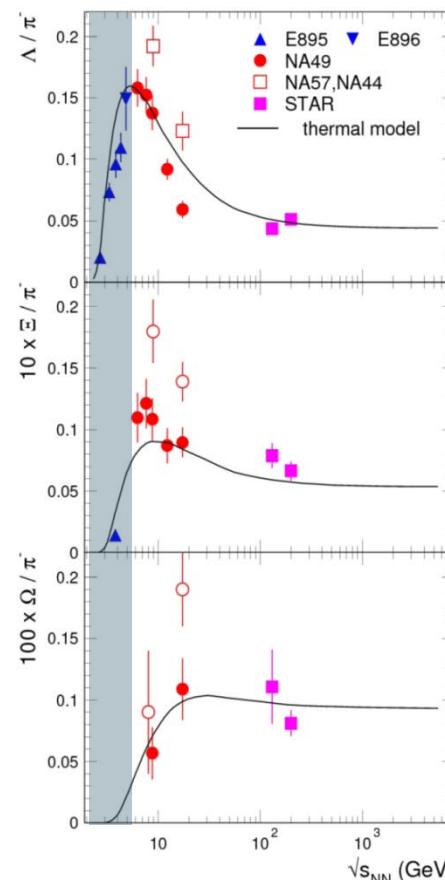
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Antihyperons

1.  $\bar{\Lambda}^0 K^+ \rightarrow \Xi^+ \pi^0$ ,
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Very few data  
at FAIR energies

# CBM physics case and observables

Phase transitions from partonic to hadronic matter

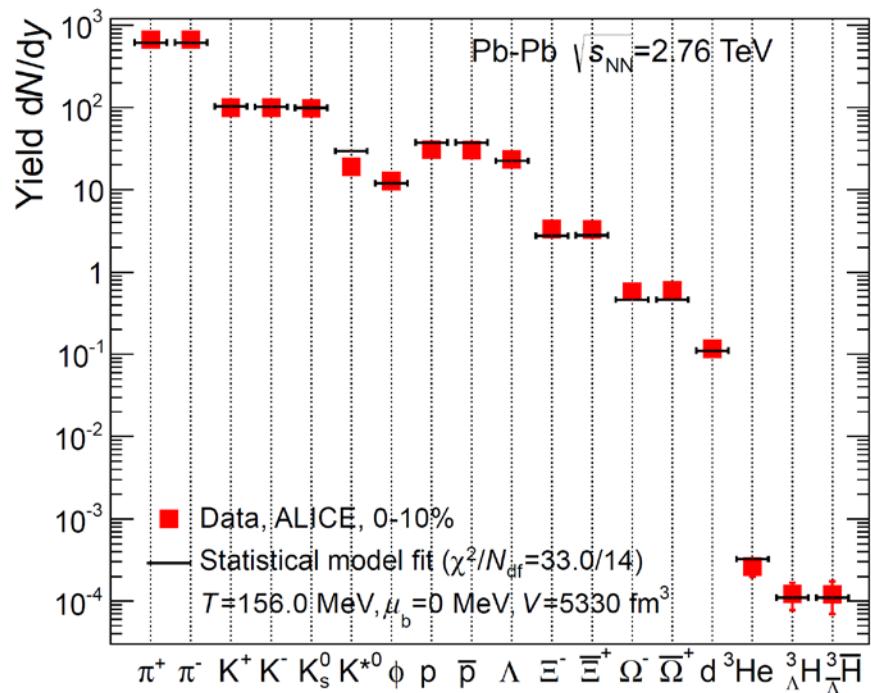
- excitation function of strangeness:  $\Xi^-(dss), \Xi^+(\bar{d}\bar{s}s), \Omega^-(sss), \Omega^+(\bar{s}\bar{s}s)$   
 → chemical equilibration at the phase boundary

Particle yields and thermal model fits

$$n_i = N_i/V = -\frac{T}{V} \frac{\partial \ln Z_i}{\partial \mu} = \frac{g_i}{2\pi^2} \int_0^\infty \frac{p^2 dp}{\exp[(E_i - \mu_i)/T] \pm 1}$$

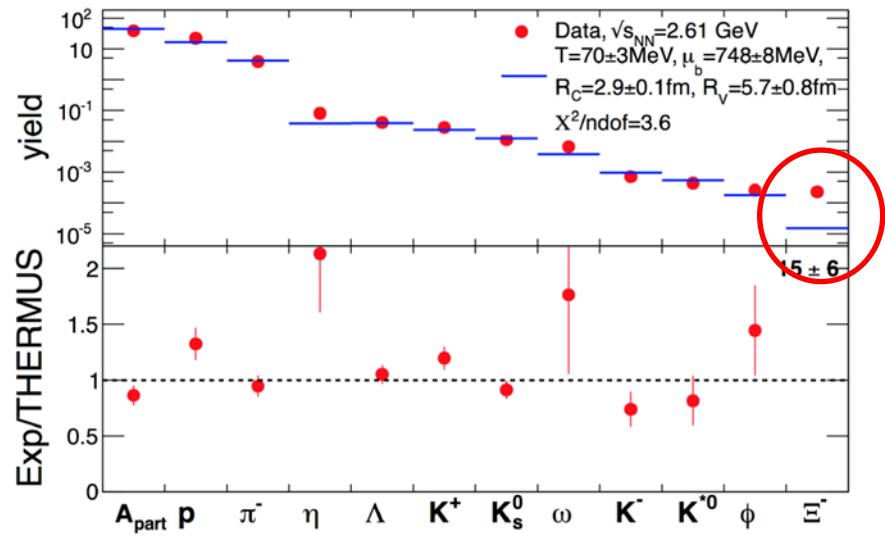
Very few data  
at FAIR energies

A. Andronic et al., Jour. Phys. G38 (2011)



HADES: Ar + KCl 1.76 A GeV

G. Agakishiev et al., arXiv:1512.07070



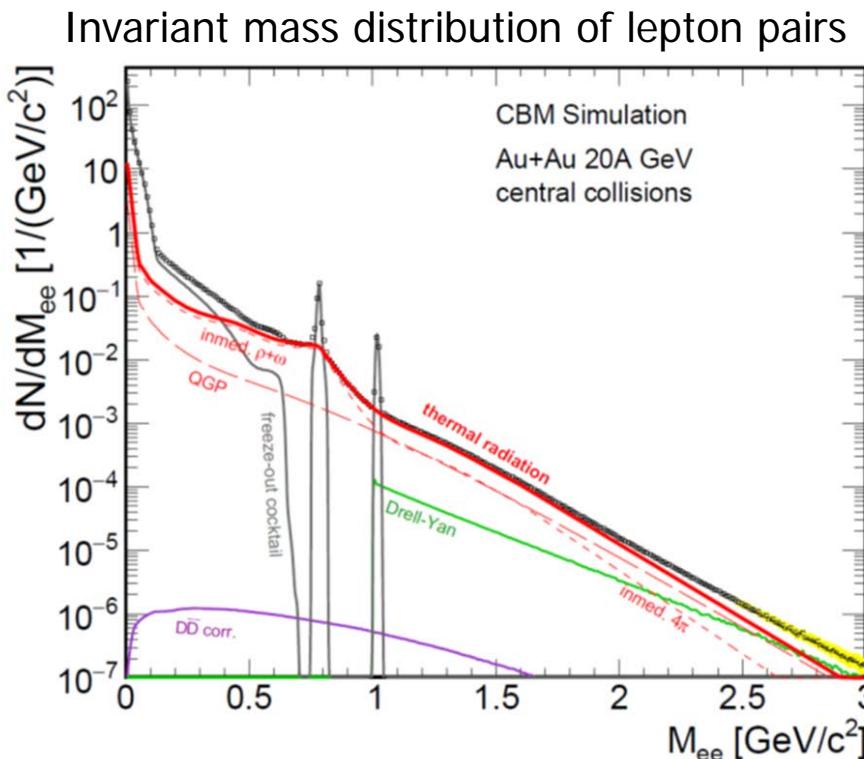
# CBM physics case and observables

Phase transitions from partonic to hadronic matter

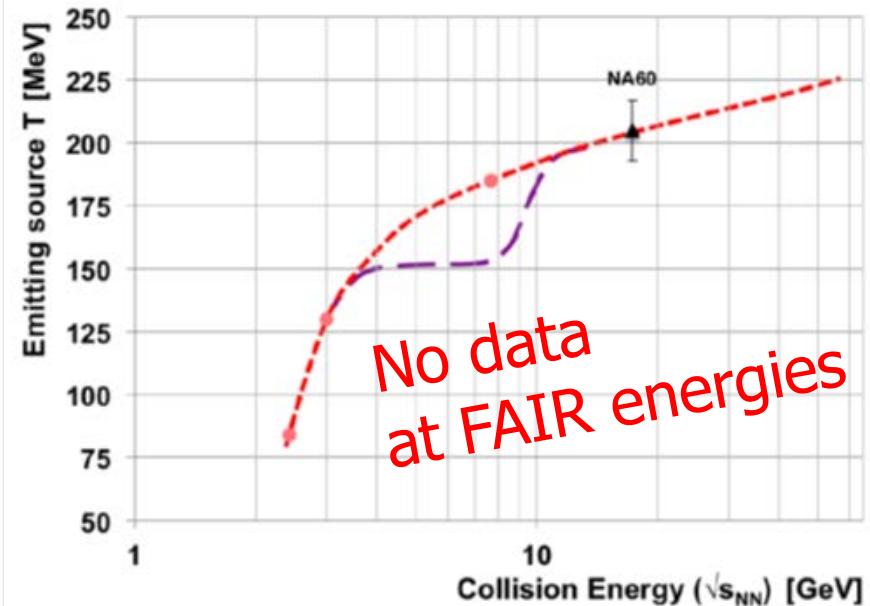
- excitation function of strangeness:  $\Xi^-(dss), \Xi^+(\bar{d}\bar{s}s), \Omega^-(sss), \Omega^+(\bar{s}\bar{s}s)$   
→ chemical equilibration at the phase boundary

Phase coexistence

- excitation function (invariant mass) of lepton pairs:  
thermal radiation from QGP, caloric curve



Slope of dilepton invariant mass spectrum  
 $1 \text{ GeV}/c^2 < M_{\text{inv}} < 2.5 \text{ GeV}/c^2$



# CBM physics case and observables

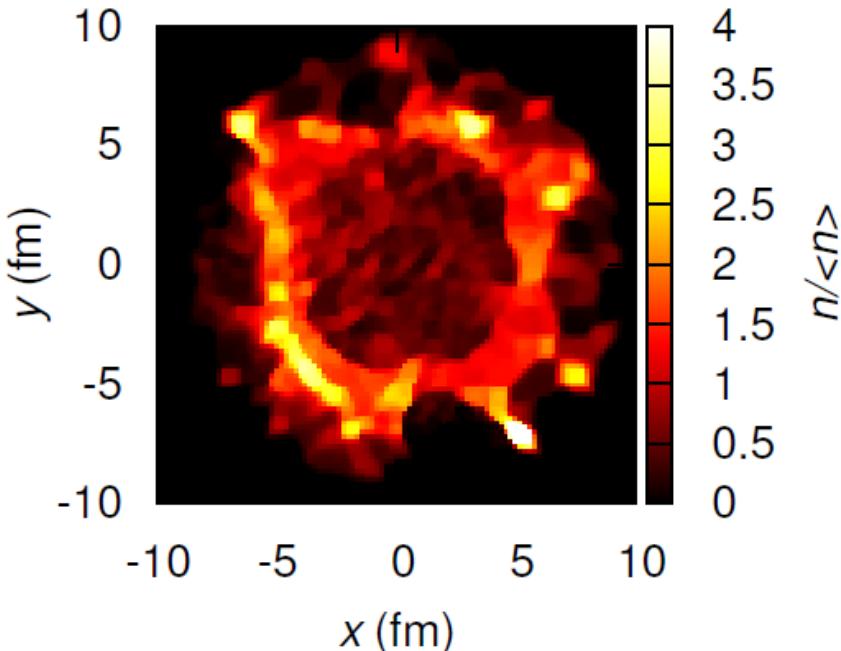
Phase transitions from partonic to hadronic matter

- excitation function of strangeness:  $\Xi^-(dss), \Xi^+(\bar{d}\bar{s}s), \Omega^-(sss), \Omega^+(\bar{s}\bar{s}s)$   
→ chemical equilibration at the phase boundary

Phase coexistence

- excitation function (invariant mass) of lepton pairs:  
thermal radiation from QGP, caloric curve
- anisotropic azimuthal angle distributions: “spinodal decomposition”

Spinodal decomposition of the mixed phase: net baryon number density fluctuations



C. Herold, M. Nahrgang, I. Mishustin, M. Bleicher  
Nuclear Physics A 925 (2014) 14

Jan Steinheimer, Jorgen Randrup  
Phys. Rev. C 87, 054903 (2013)  
Eur. Phys. J. A (2016) 52: 239

# CBM physics case and observables

Phase transitions from partonic to hadronic matter

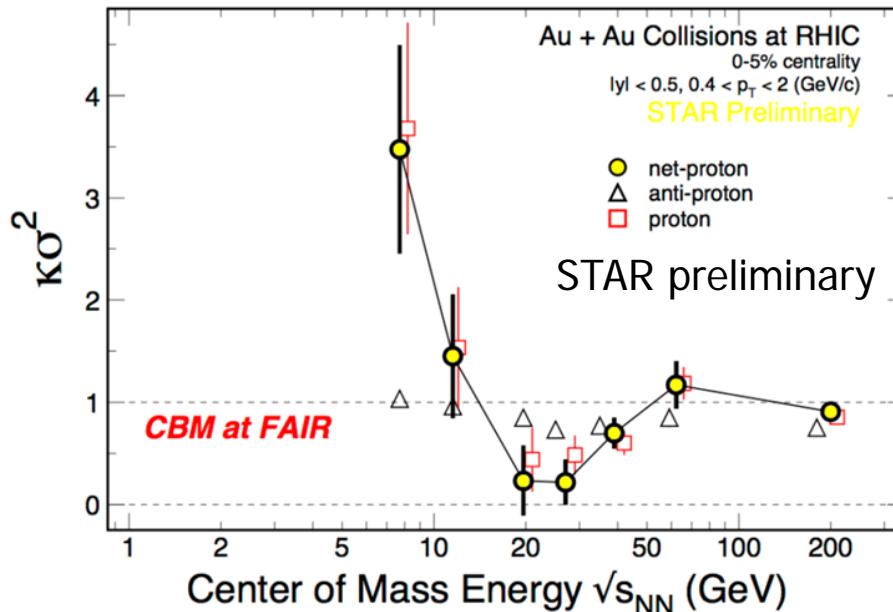
- excitation function of strangeness:  $\Xi^-(dss), \Xi^+(dss), \Omega^-(sss), \Omega^+(sss)$   
→ chemical equilibration at the phase boundary

Phase coexistence

- excitation function (invariant mass) of lepton pairs:  
thermal radiation from QGP, caloric curve
- anisotropic azimuthal angle distributions: "spinodal decomposition"

Critical point

- event-by-event fluctuations of conserved quantities (B,S,Q)  
"critical opalescence"



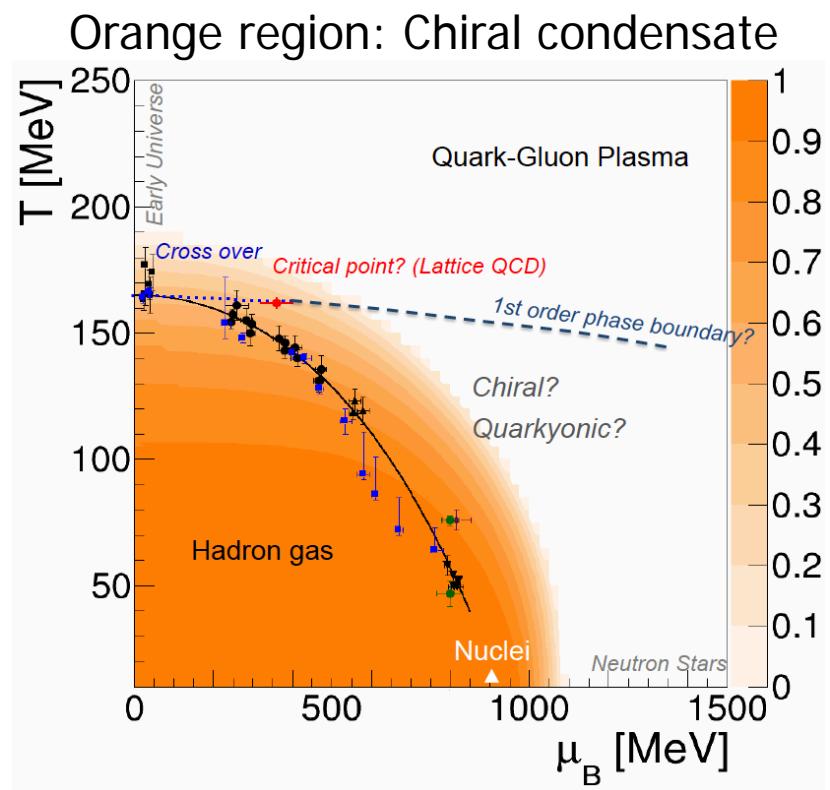
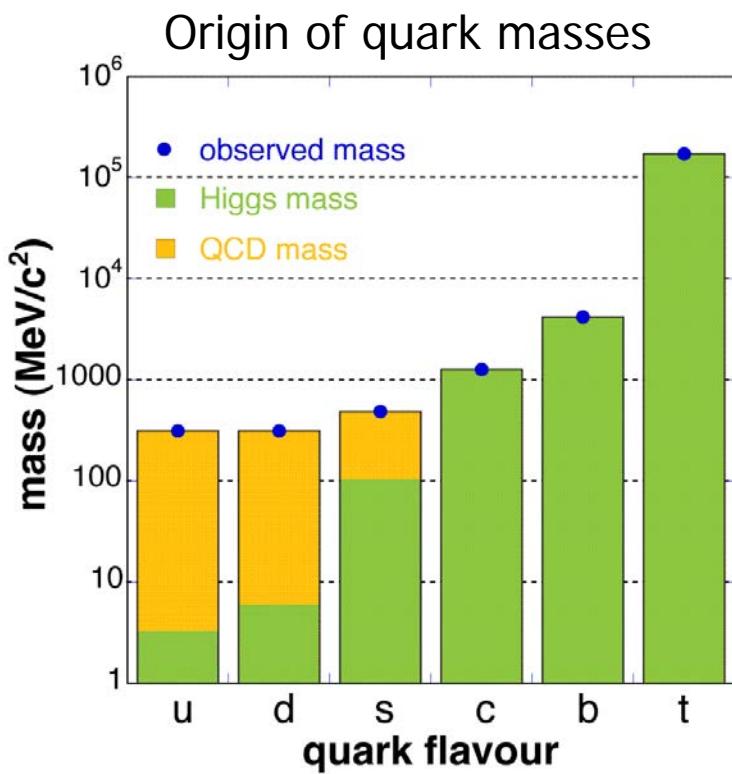
4<sup>th</sup> moment of net-proton  
multiplicity distribution:  
critical fluctuations

No data  
at FAIR energies

# CBM physics case and observables

Onset of chiral symmetry restoration at high  $\rho_B$

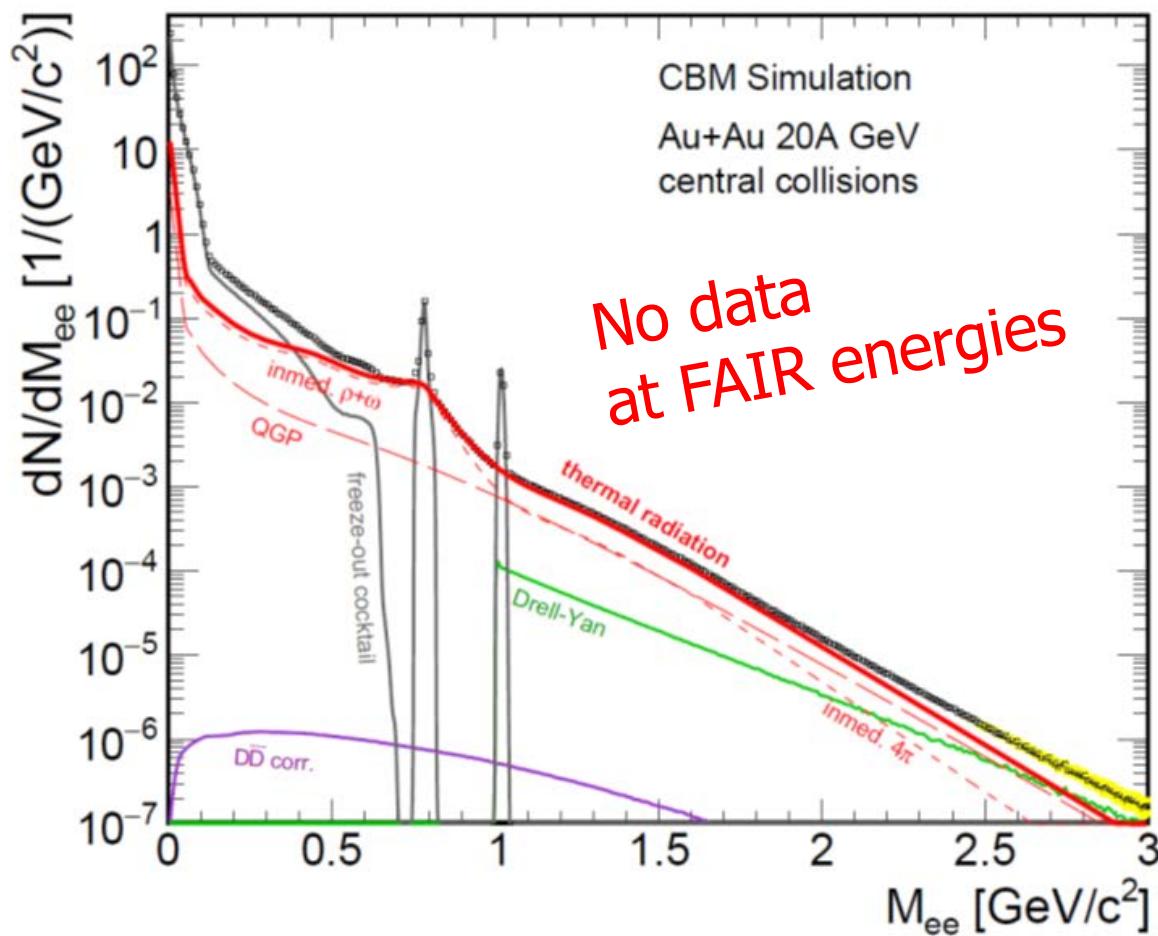
- in-medium modifications of hadrons:  $\rho, \omega, \phi \rightarrow e^+e^- (\mu^+\mu^-)$
- dileptons at intermediate invariant masses:  $4\pi \rightarrow \rho\text{-}a_1$  chiral mixing



# CBM physics case and observables

Onset of chiral symmetry restoration at high  $p_B$

- in-medium modifications of hadrons:  $\rho, \omega, \phi \rightarrow e^+e^- (\mu^+\mu^-)$
- dileptons at intermediate invariant masses:  $4\pi \rightarrow \rho - a_1$  chiral mixing

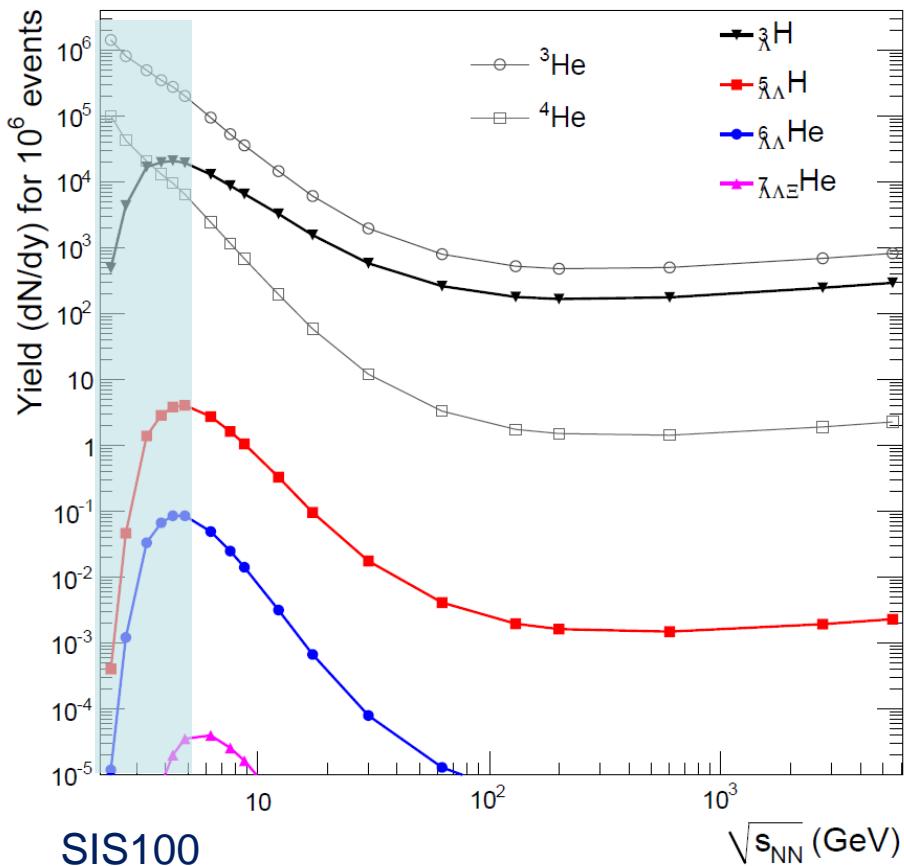


# CBM physics case and observables

N- $\Lambda$ ,  $\Lambda$ - $\Lambda$  interaction, strange matter?

- (double-) lambda hypernuclei
- meta-stable objects (e.g. strange dibaryons)

No data  
at FAIR energies



Double lambda hypernuclei production  
in central Au+Au collisions at 10 A GeV:

	Multiplicity	Yield in 1 week
$^5\Lambda\Lambda H$	$5 \cdot 10^{-6}$	3000
$^6\Lambda\Lambda He$	$1 \cdot 10^{-7}$	60

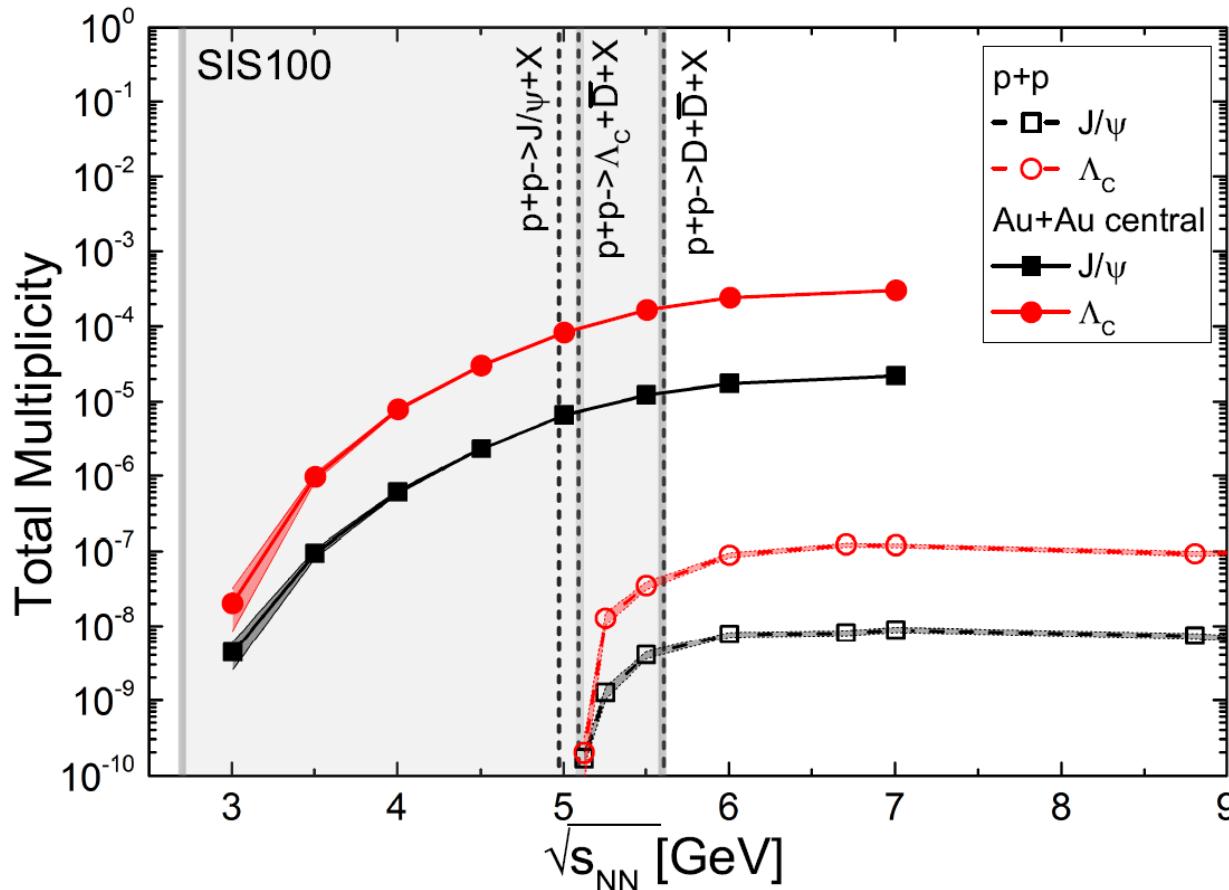
Assumption for yield calculation:  
Reaction Rate 1 MHz  
BR 10% (2 sequential weak decays)  
Efficiency 1%

# CBM physics case and observables

Charm production at threshold energies in cold and dense matter

➤ excitation function of charm production in p+A and A+A (J/ $\psi$ , D<sup>0</sup>, D<sup>±</sup>)

UrQMD calculation including subthreshold charm production via  
 $N^* \rightarrow \Lambda_c + D$  and  $N^* \rightarrow N + J/\psi$

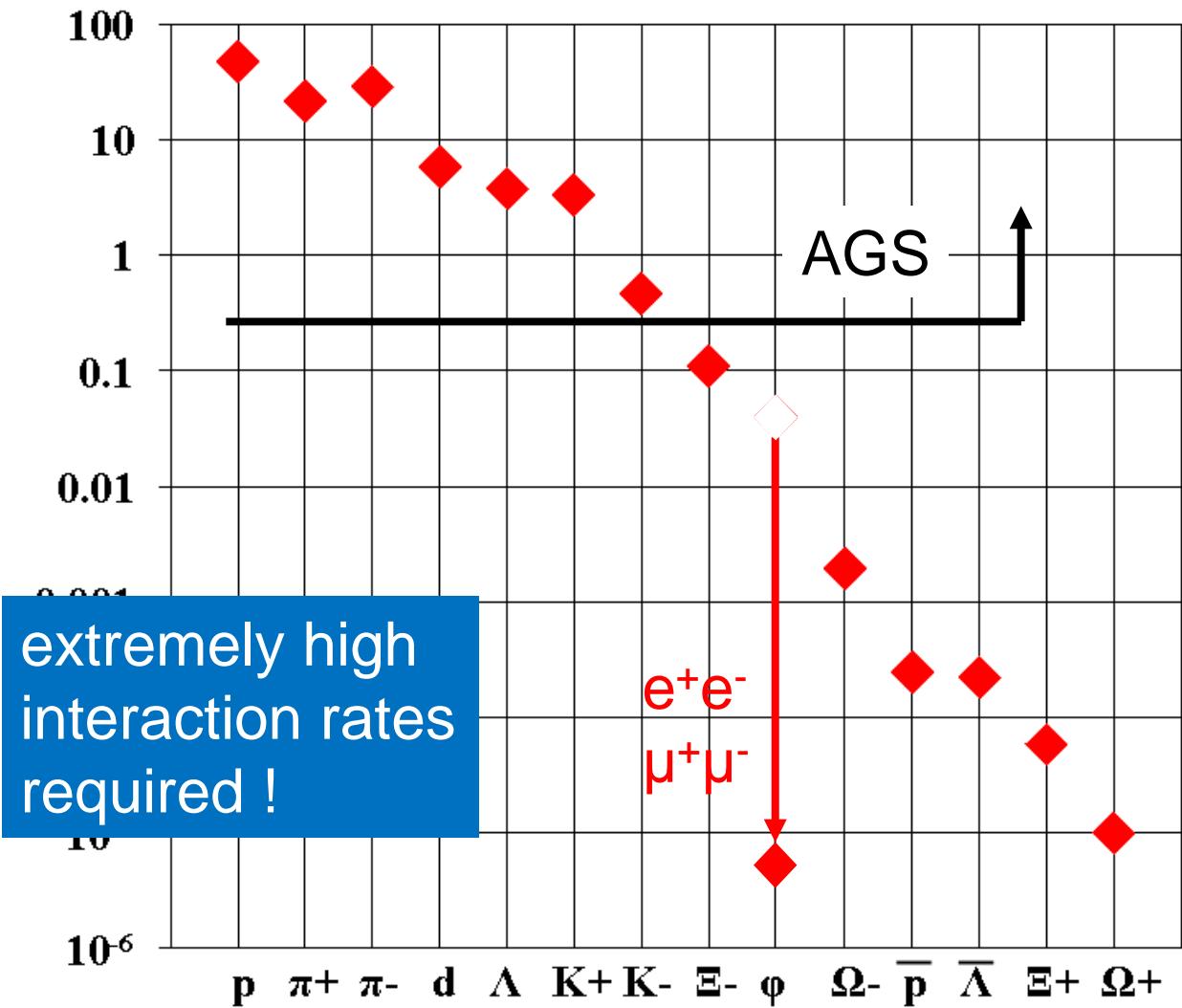


No data  
at FAIR energies

# Experimental challenges

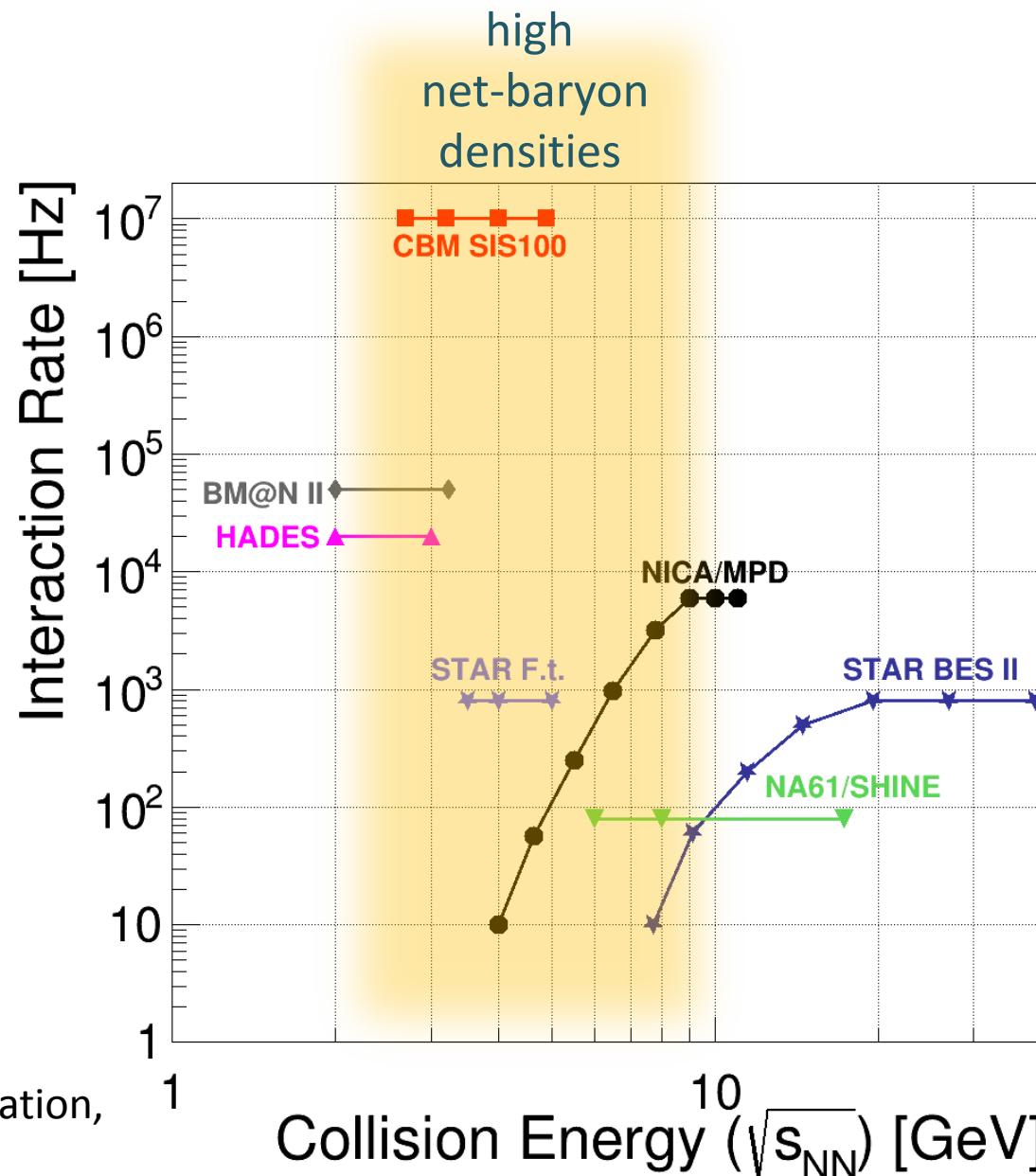
## Particle yields in central Au+Au 4 A GeV

Multiplicity    Statistical model, A. Andronic, priv. com.



extremely high  
interaction rates  
required !

# Experiments exploring dense QCD matter



# Experimental requirements

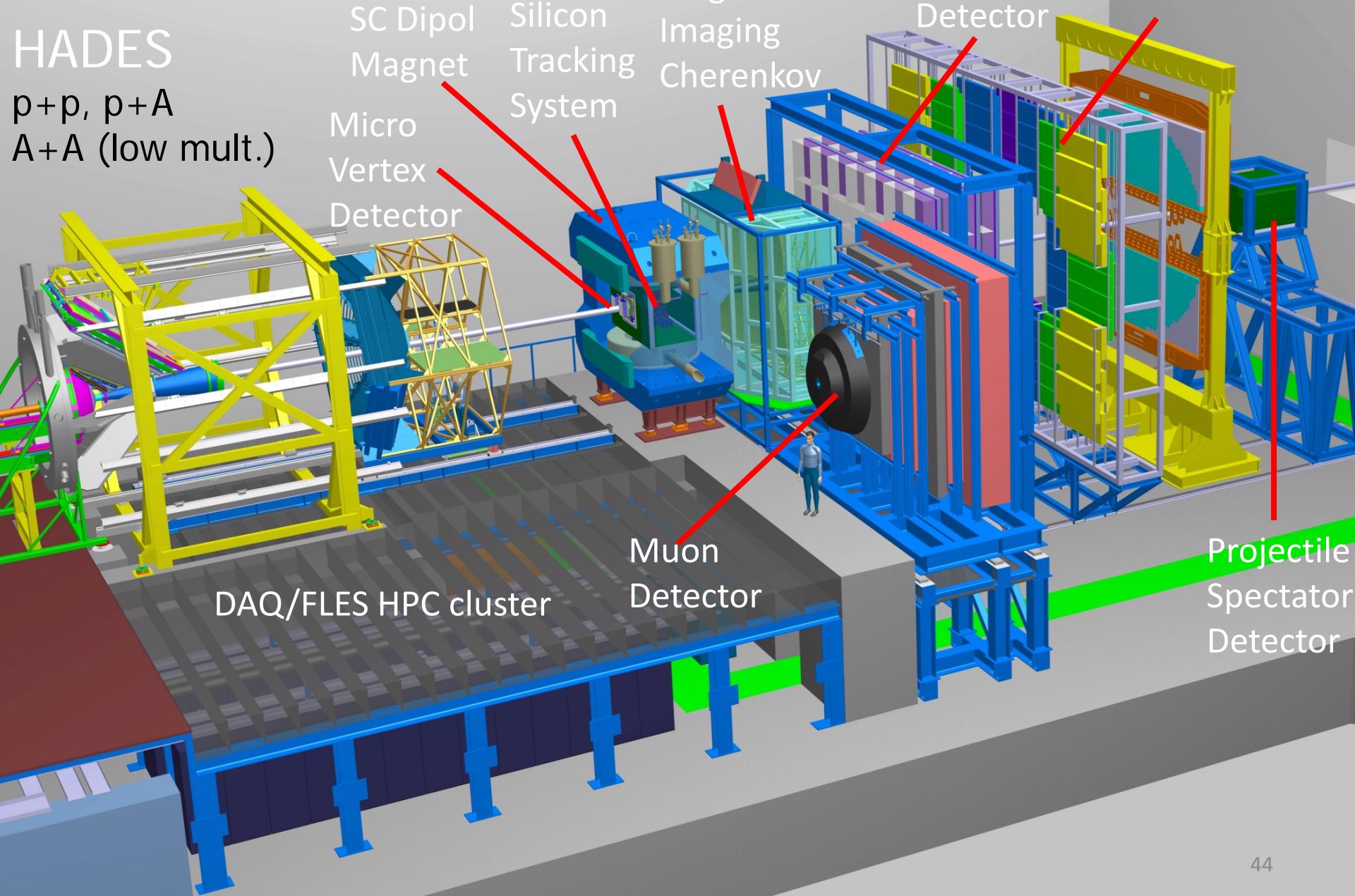
- $10^5 - 10^7$  Au+Au reactions/sec
- determination of displaced vertices ( $\sigma \approx 50 \mu\text{m}$ )
- identification of leptons and hadrons
- fast and radiation hard detectors and FEE
- free-streaming readout electronics
- high speed data acquisition and high performance computer farm for online event selection
- 4-D event reconstruction

# Experimental requirements

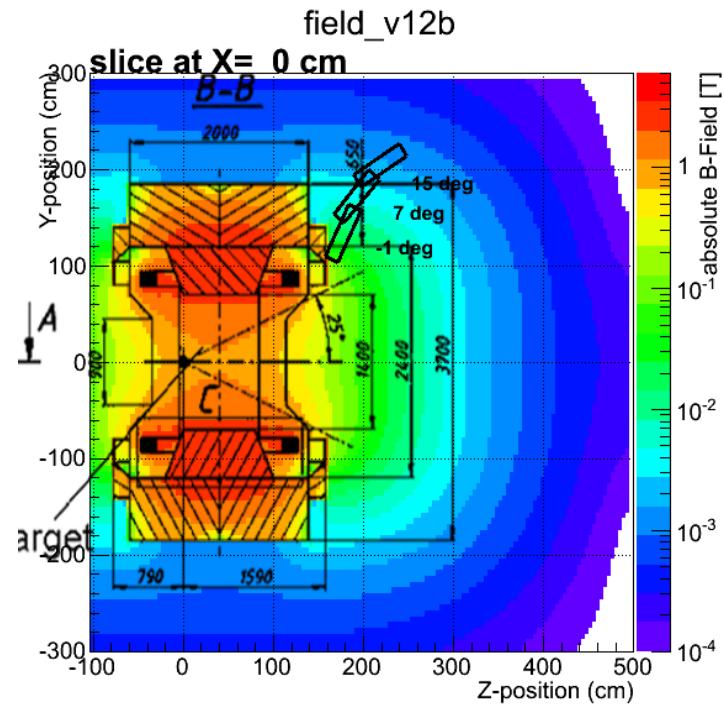
HADES

p+p, p+A

A+A (low mult.)



# Superconducting Dipole Magnet



Large-acceptance superconducting dipole magnet.

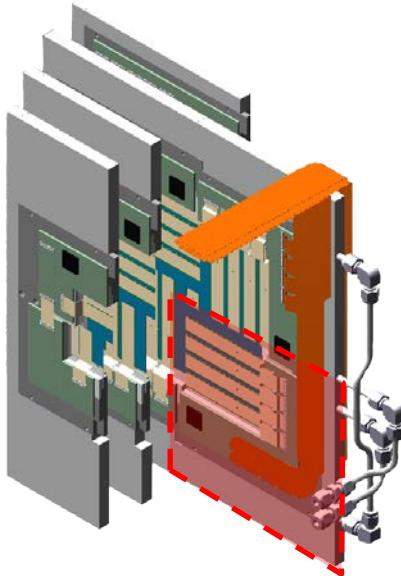
The pole gap is 144 cm, the bending power 1 Tm.

Participating institutes:

Design by INR Dubna and GSI, under construction at BINP  
Novosibirsk

# Micro Vertex Detector

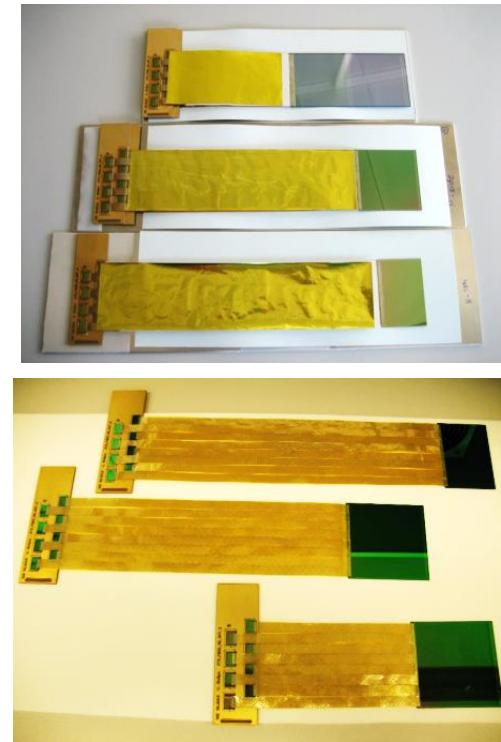
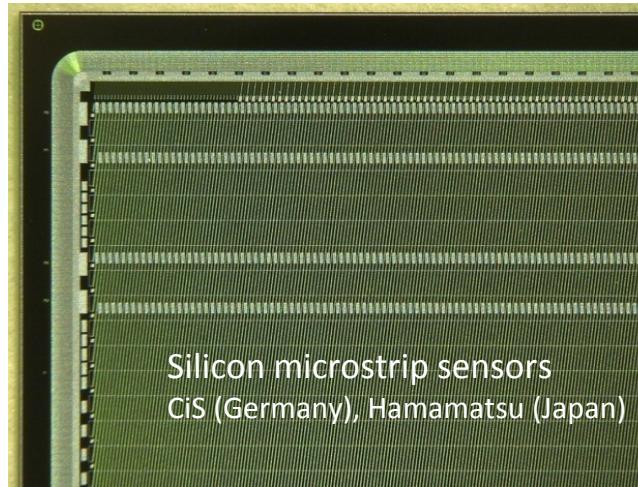
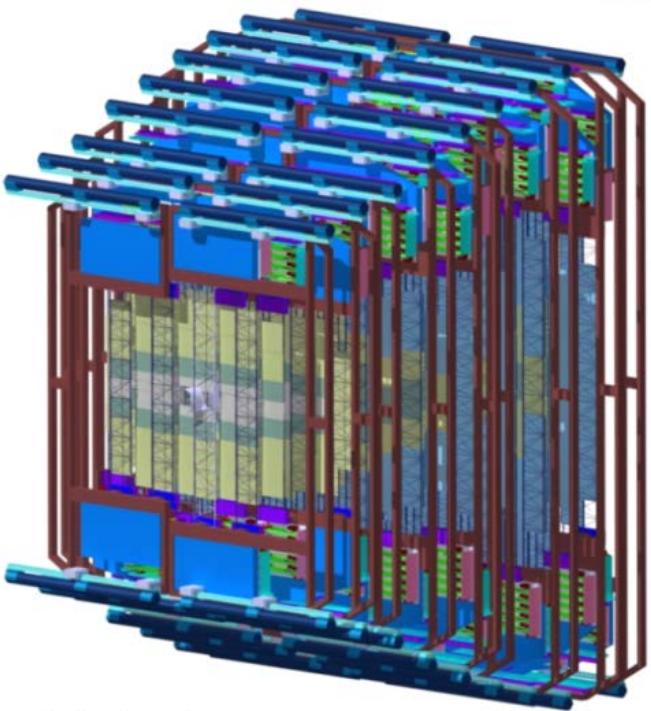
- Background suppression for di-electron measurements
- Determination of secondary vertices of open charm decays ( $\tau = 10^{-12}\text{-}10^{-13}$  s)
- Improved tracking for hyperon-ID



The MVD consists of highly granulated Monolithic Active Pixel Sensors (MAPS) arranged in four ultra-thin detector arrays positioned close to the target. Determination of secondary vertices with high precision which is required for the identification of charmed mesons.

Participating institutes: [Univ. Frankfurt](#), [IPHC Strasbourg](#)

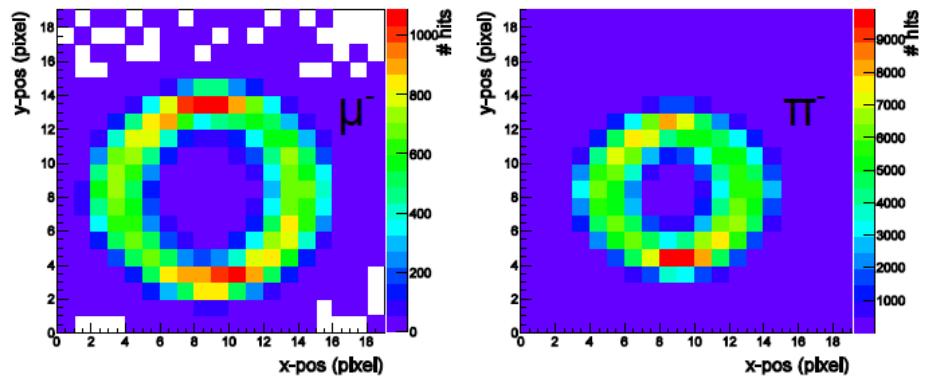
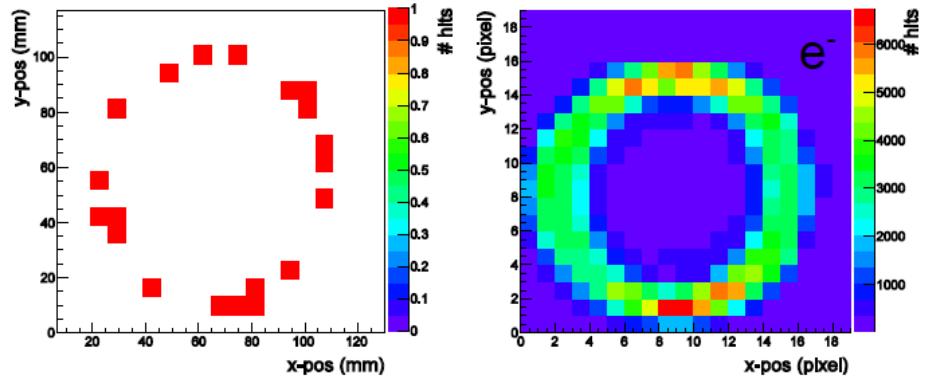
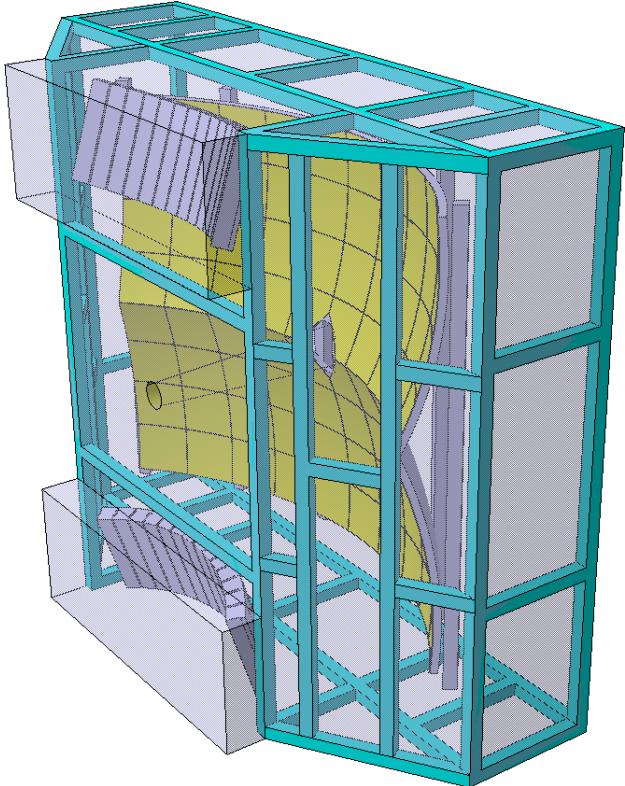
# Silicon Tracking System



The STS consists of about 1000 double-sided silicon micro-strip sensors arranged in 8 detector arrays located inside the dipole magnet. The detector provides track reconstruction and momentum determination for up to 1000 particles per event. The detector is operated at about -10°C, heat dissipation of the front-end electronics 40 kW, bi-phase CO<sub>2</sub> cooling system

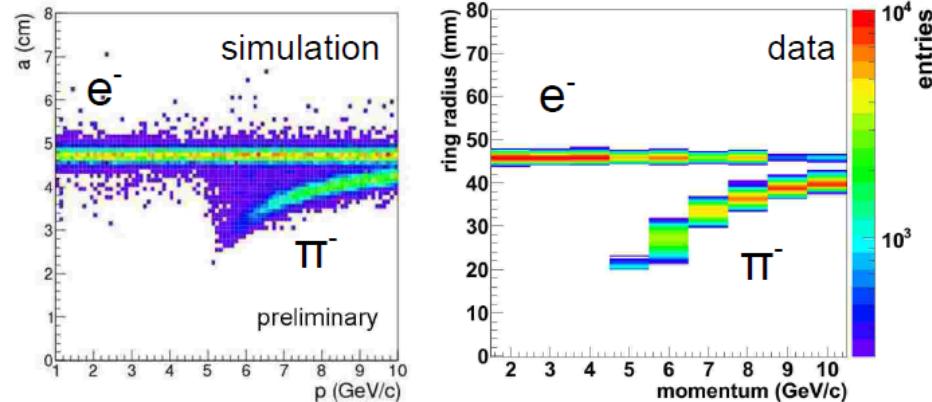
Participating institutes: [GSI](#), Darmstadt, JINR Dubna, KIT, INR Kiev, AGH and UJ Krakow, Univ. Tübingen, Warsaw UT

# Ring-Imaging Cherenkov (RICH) Detector

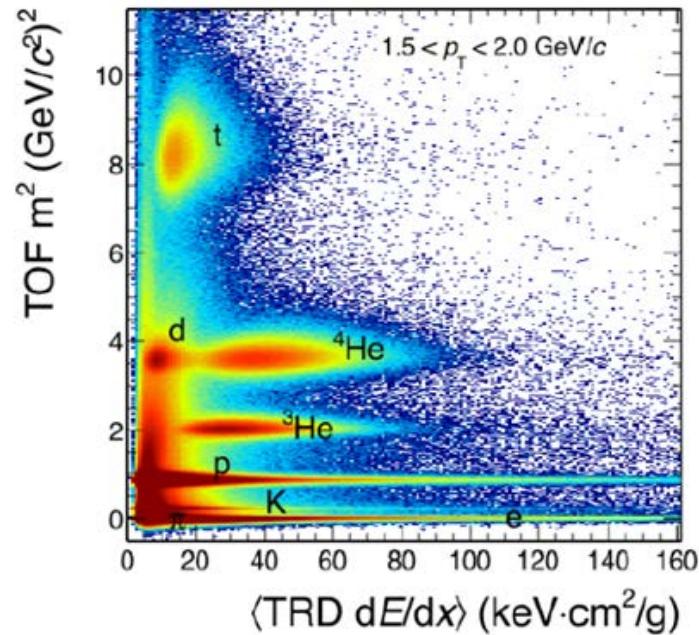
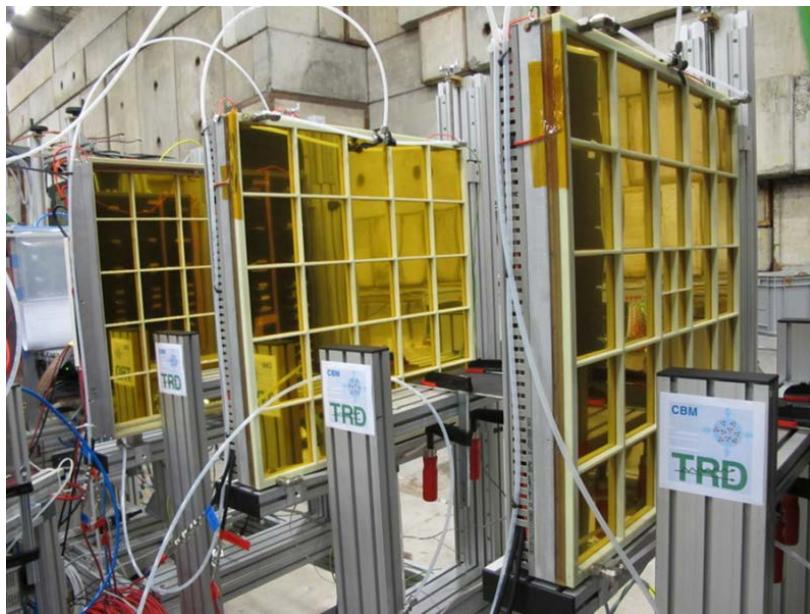


The RICH is used for the identification of electrons with momenta below 8 GeV/c (pion suppression factor of more than 500).

Participating institutes:  
[Univ. Gießen](#), [Univ. Wuppertal](#), [PNPI Gatchina](#),



# Transition Radiation Detector (TRD)

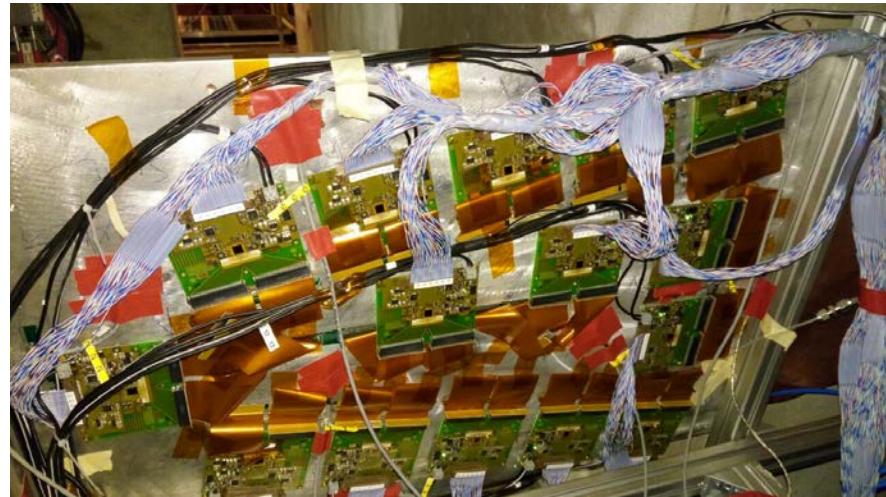
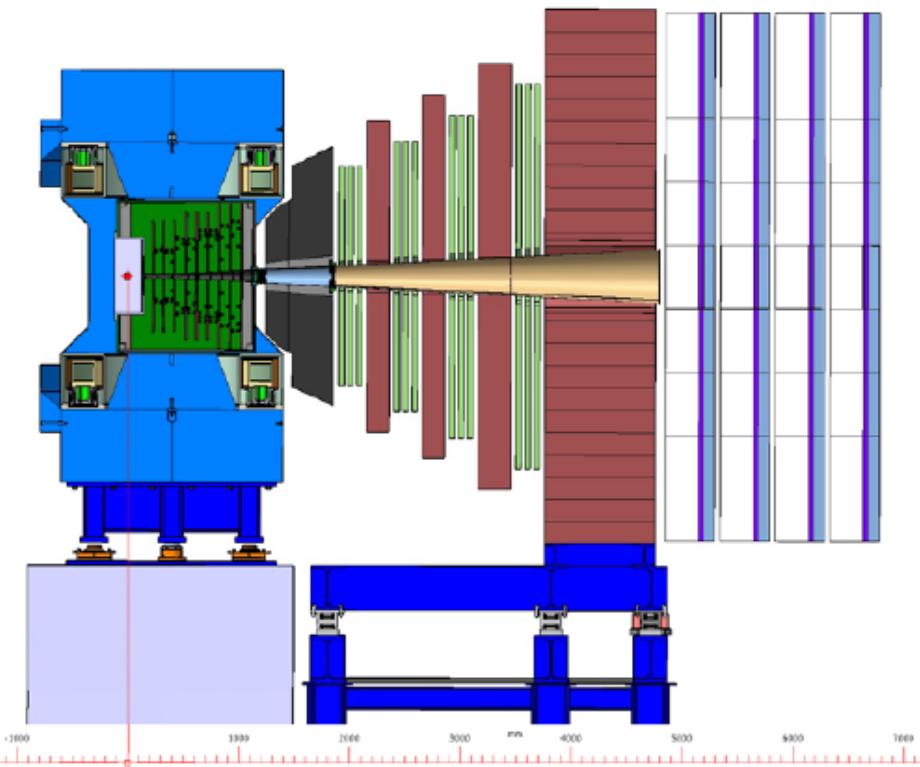


Challenge:  $\varepsilon(e^\pm) = 90\%$ ,  $\varepsilon(\pi) = 7.5\%$  at 100 kHz/cm<sup>2</sup>

The TRD consists of 4 detectors layers. It provides identification of electrons with momenta above 1.5 GeV/c, and an energy-loss measurement  
Participating institutes:

NIPNE Bucharest, JINR Dubna, Univ. Frankfurt, Univ. Heidelberg,  
Univ. Münster

# Muon Chamber (MuCh) System



Full size GEM detectors tested with free-streaming read-out electronics at the CERN-SPS Nov.-Dec. 2016

The MuCh consists of a combination of 15 detector stations sandwiched between one carbon and 4 iron absorber layers for hadron suppression. The MuCh provides the identification of muons with momenta above 1.5 GeV/c.

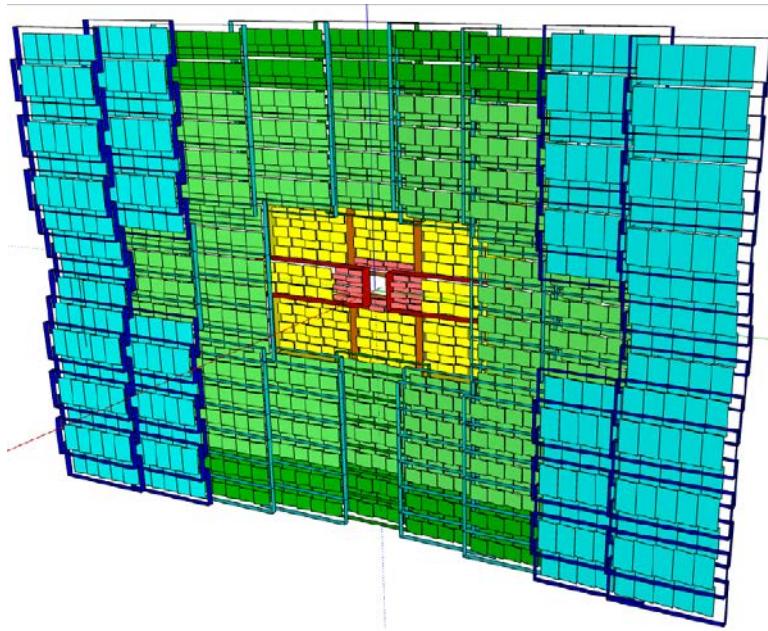
Tracking station 1+2: Two Gas-Electron-Multiplier (GEM) detector triplets

Tracking station 3+4: two low-resistivity Bakelite trigger RPC triplets

Tracking station 5: four Transition Radiator Detectors (used only as trackers)

Participating institutes: [VECC Kolkata](#) + 12 Indian Inst., PNPI Gatchina 50

# The high-rate MRPC TOF wall

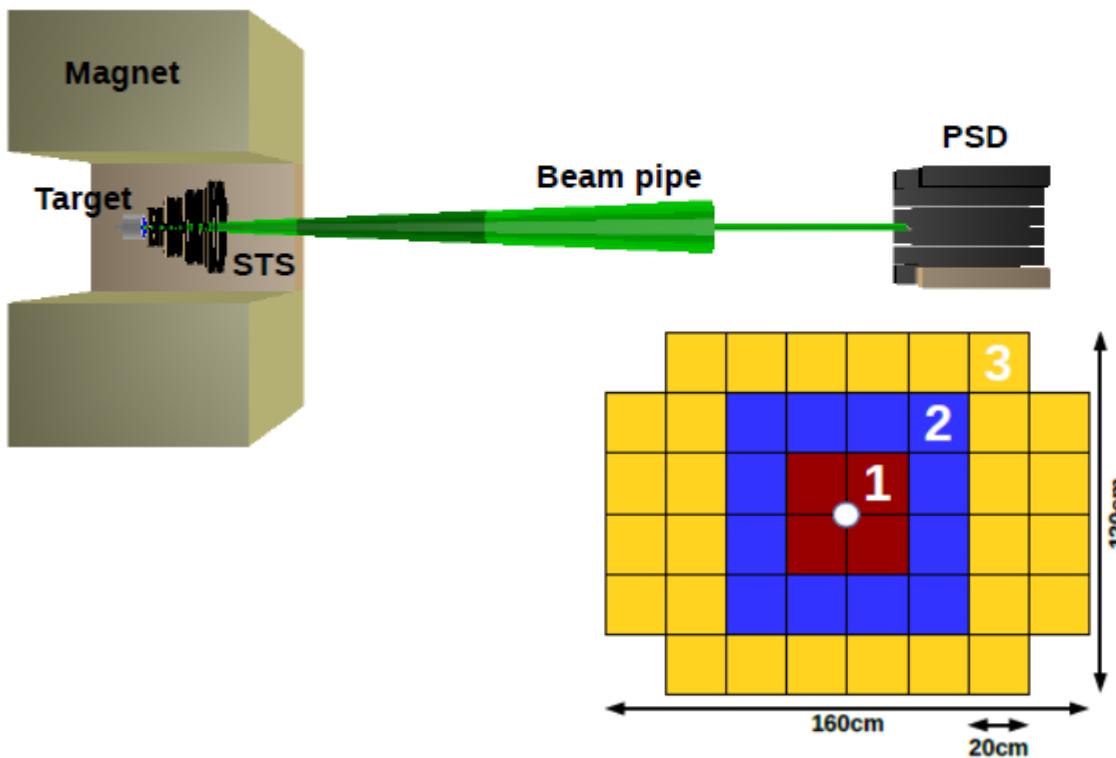


ToF MRPC detectors tested with free-streaming read-out electronics at the CERN-SPS Nov.-Dec. 2016

Multigap Resistive Plate Chambers (MRCP) provide the time-of-flight measurement for hadron identification. Challenge: Time resolution of 60 ps at rates of  $25 \text{ kHz/cm}^2$ , inner part low-resistivity glass electrodes, area  $100 \text{ m}^2$

Participating institutes: [THU Beijing](#), [NIPNE Bucharest](#), [GSI Darmstadt](#), [TU Darmstadt](#), [IfI Frankfurt](#), [USTC Hefei](#), [Univ. Heidelberg](#), [ITEP Moscow](#), [HZDR Rossendorf](#), [CCNU Wuhan](#)

# Projectile Spectator Detector

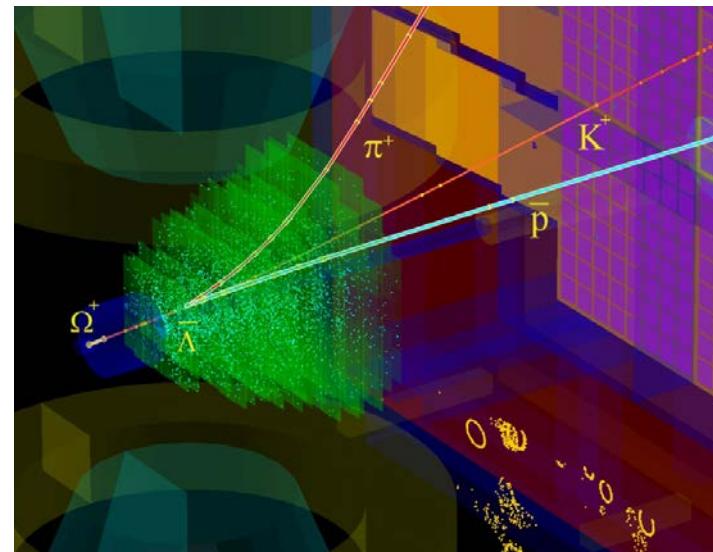
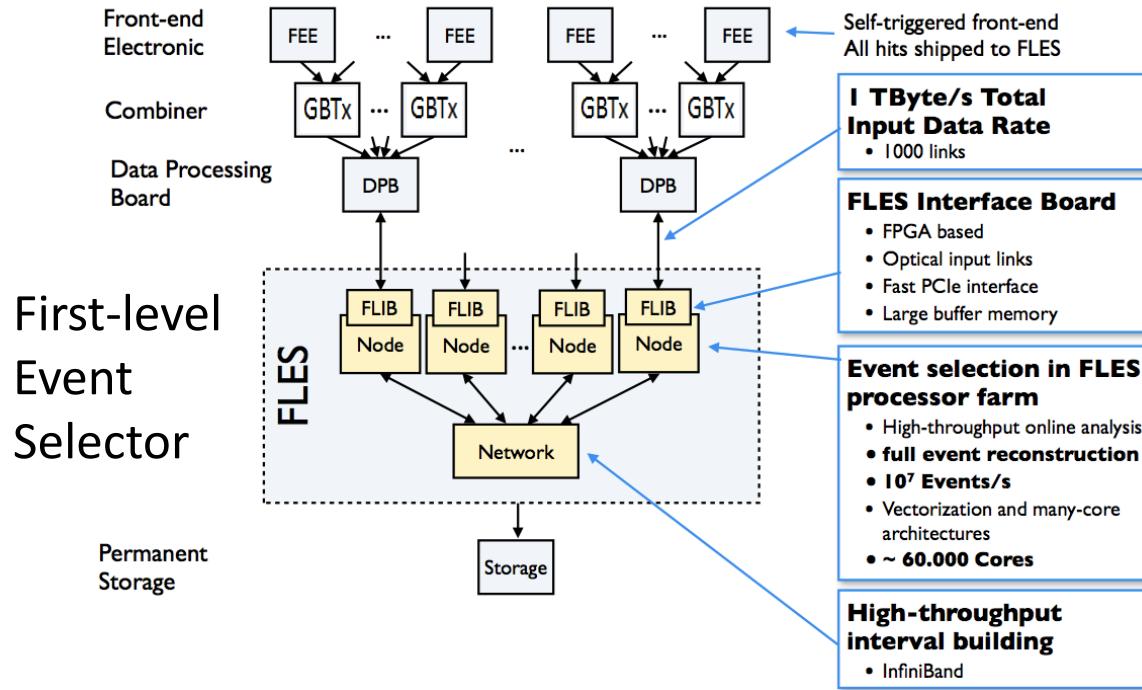


The PSD is a lead-scintillator calorimeter and is used for the determination of the collision centrality and the orientation of the reaction plane.

Participating institutes:

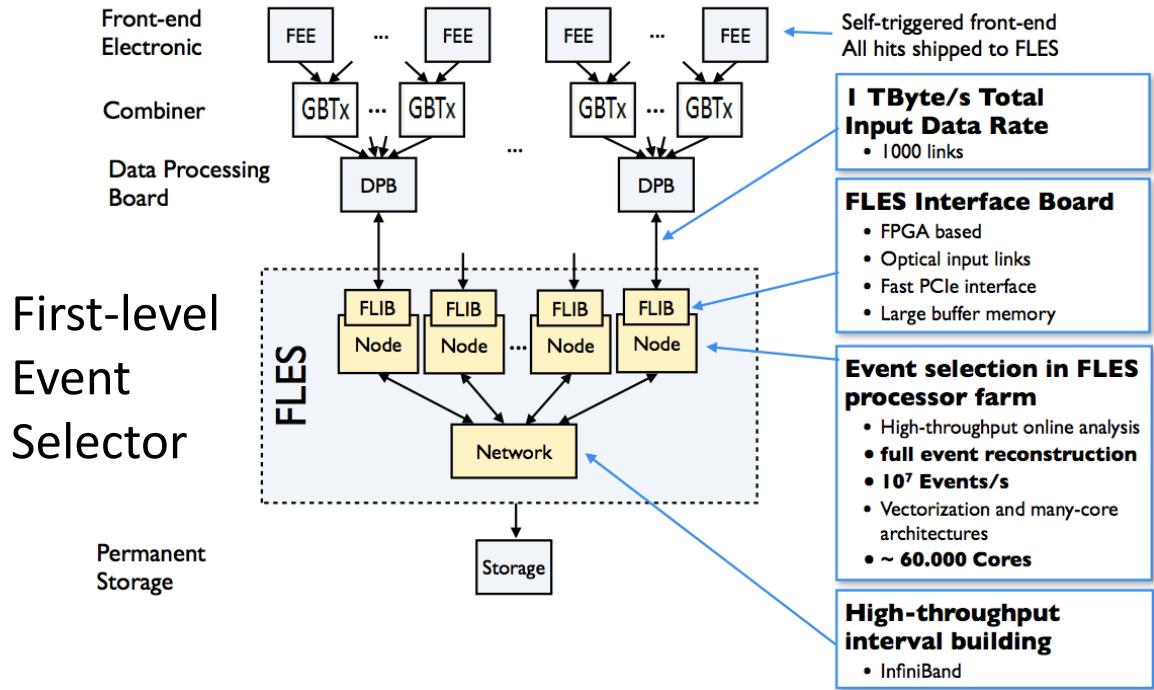
[INR Moscow](#), Prague, Rez, TU Darmstadt

# CBM DAQ and online event selection



Novel readout system: no hardware trigger on events, detector hits with time stamps, full online 4-D track and event reconstruction.

# CBM DAQ and online event selection



Novel readout system: no hardware trigger on events, detector hits with time stamps, full online 4-D track and event reconstruction.

# Test beams at CERN

- Prototype TOF, GEM, TRD and diamond detectors with common free-streaming readout system and DAQ successfully tested.
- Pb+Pb collisions with energies of 13, 30 and 160 A GeV.
- Teams from China, Germany, India, Romania

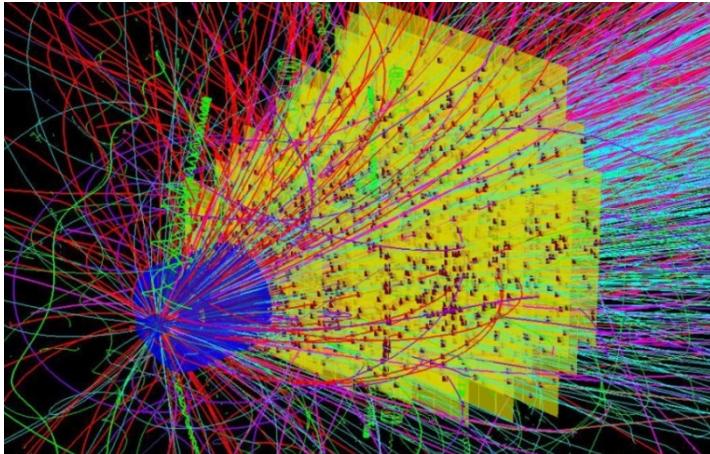


# Simulation and reconstruction

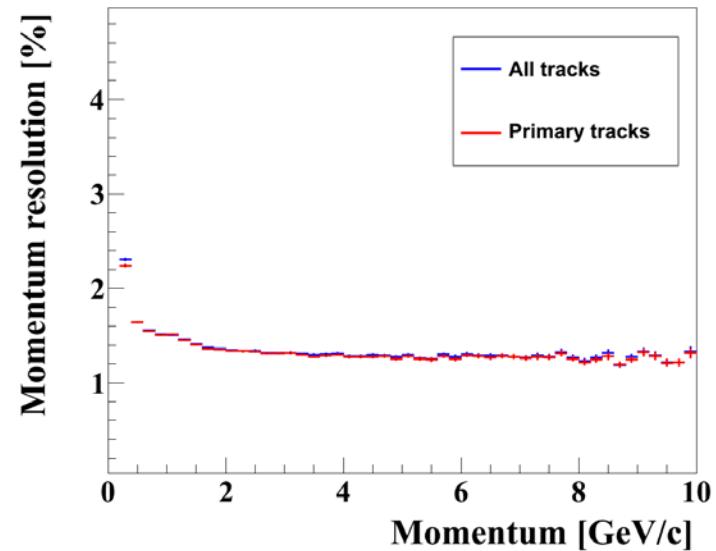
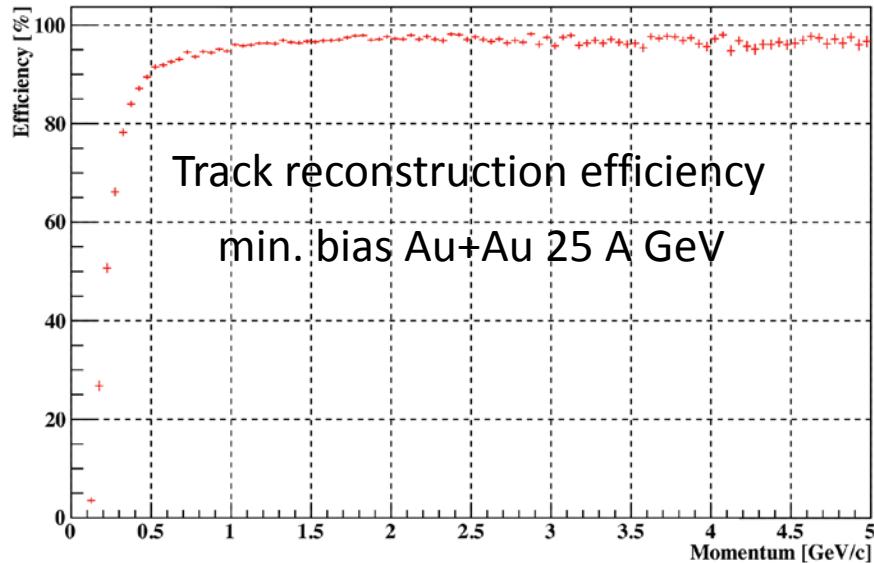
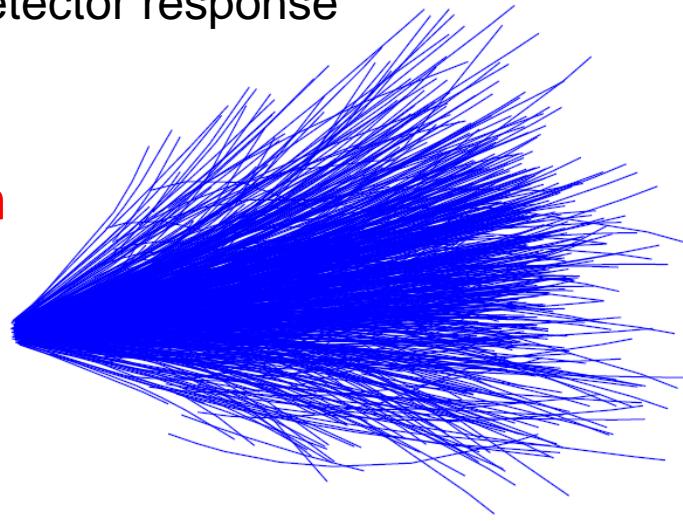
Event generators UrQMD 3.3

Transport code GEANT3, FLUKA

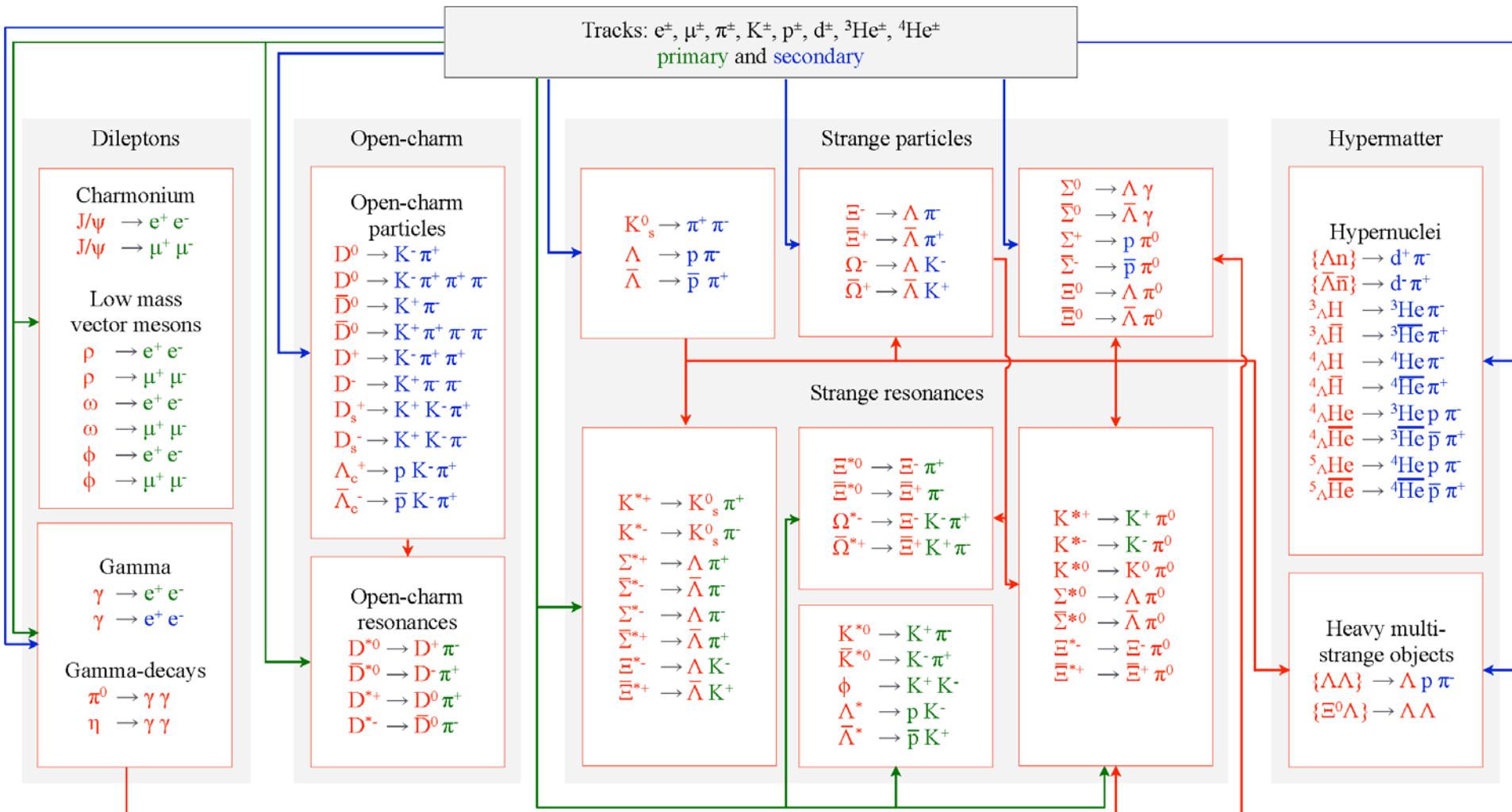
Realistic detector geometries, material budget and detector response



reconstruction



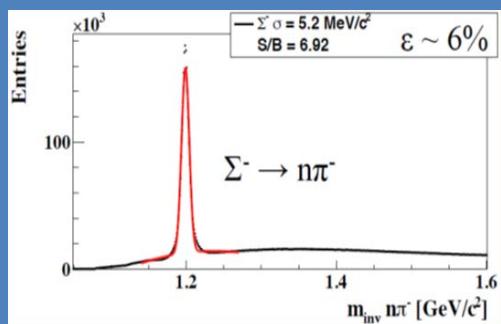
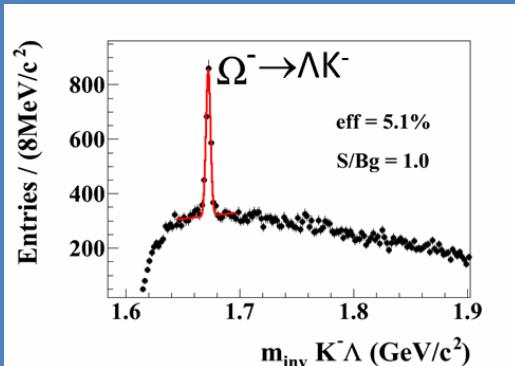
# Online particle identification in CBM: The KF Particle Finder



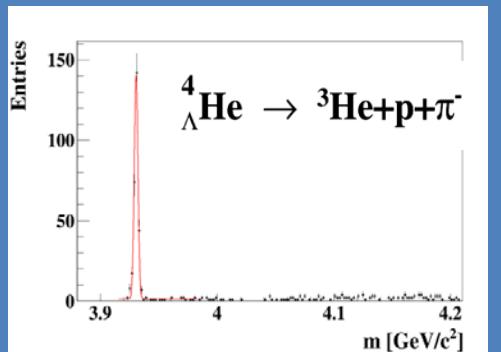
successfully used online in the STAR experiment

# Simulations: central Au+Au collisions at 8A GeV and 10A GeV

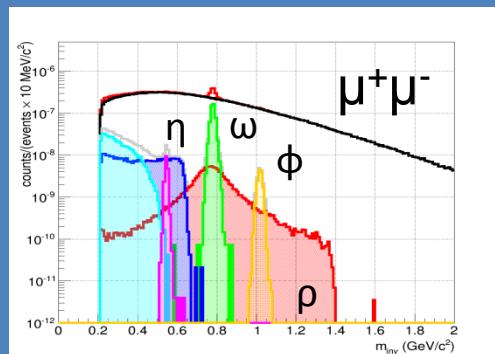
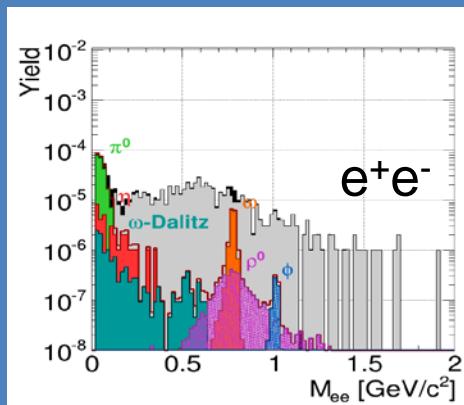
## Hyperons at 10 A GeV



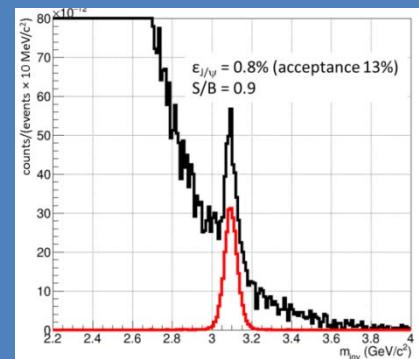
## Hypernuclei at 10 A GeV



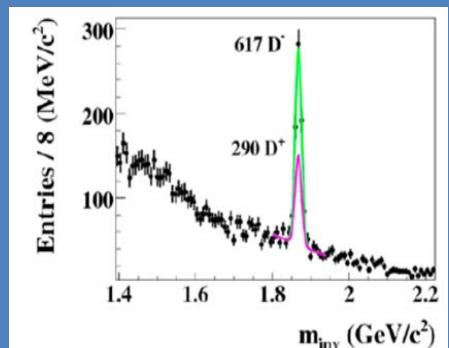
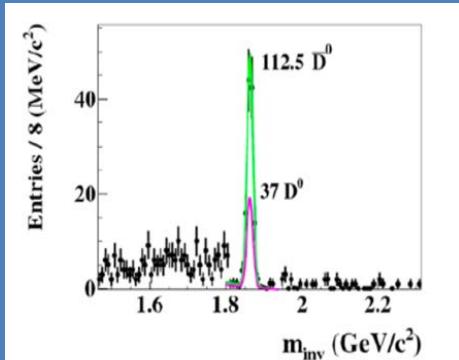
## Dileptons 8A GeV



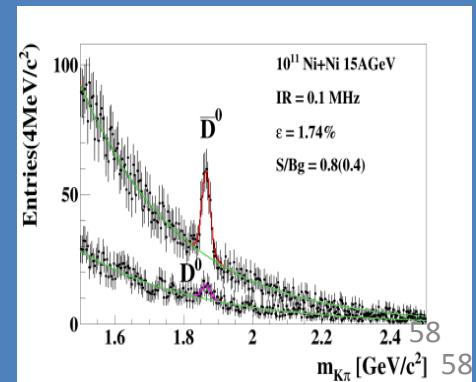
## Charmonium at 10 A GeV



## D mesons 30 GeV p+Au

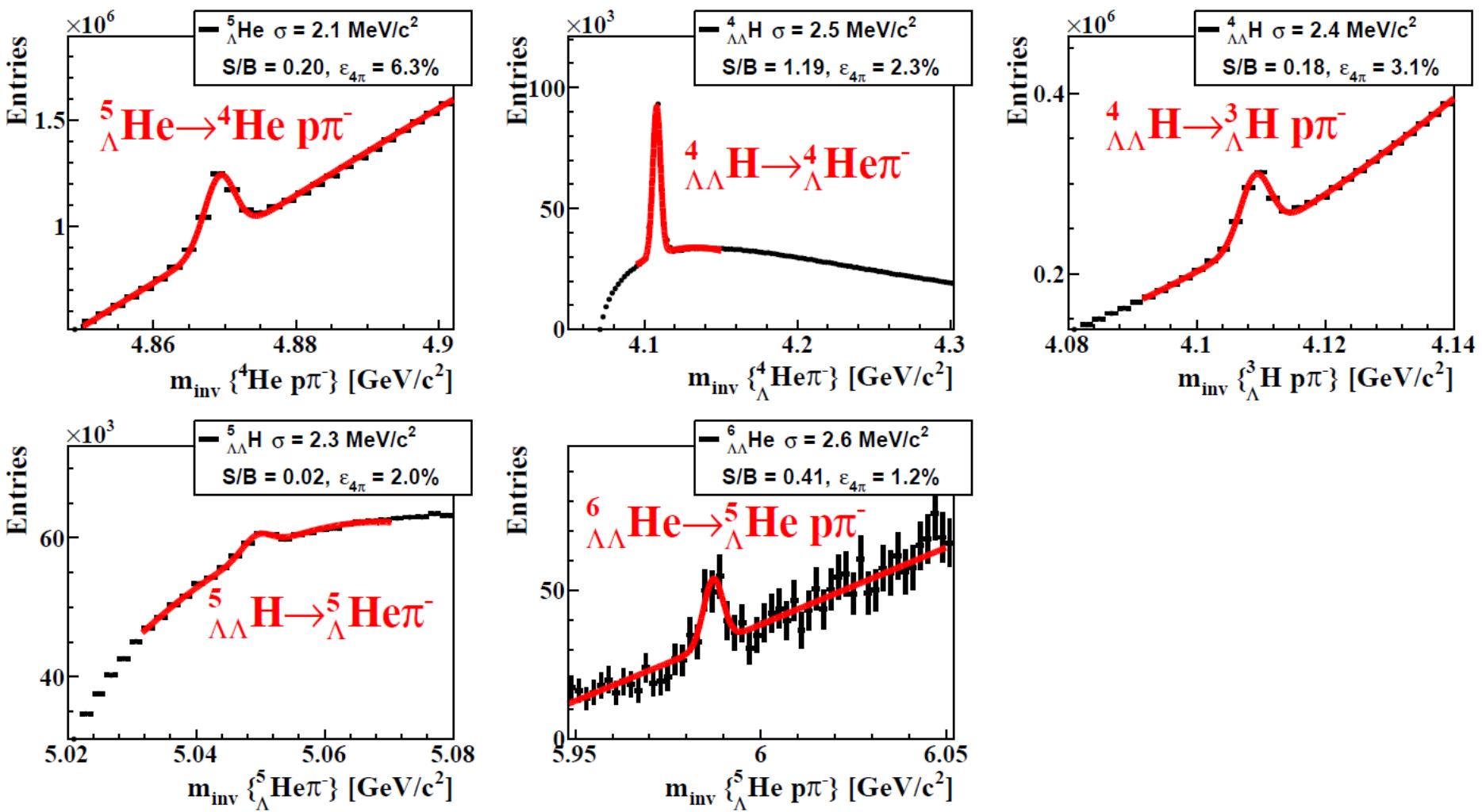


## D mesons Ni+Ni 15A GeV



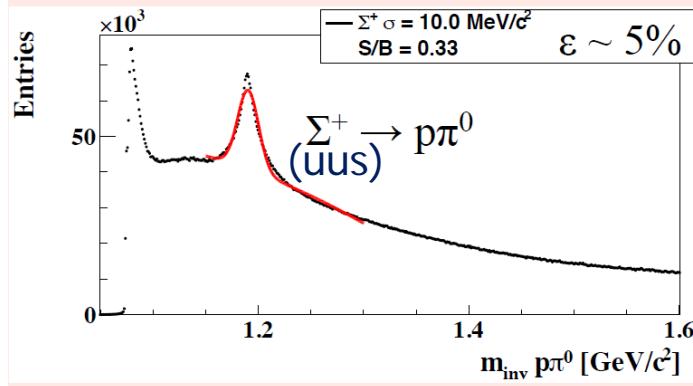
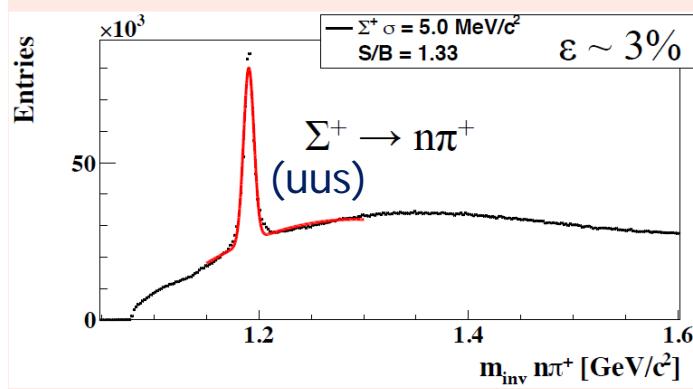
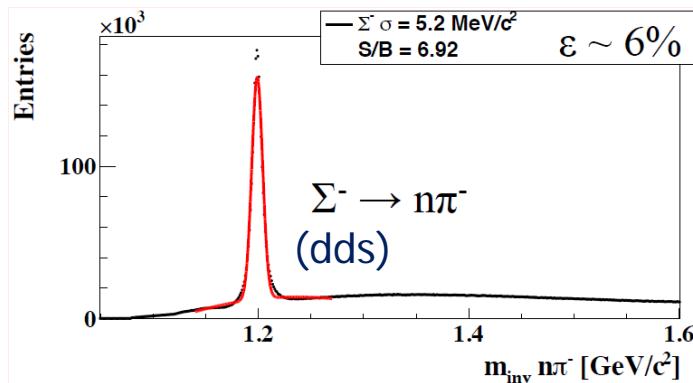
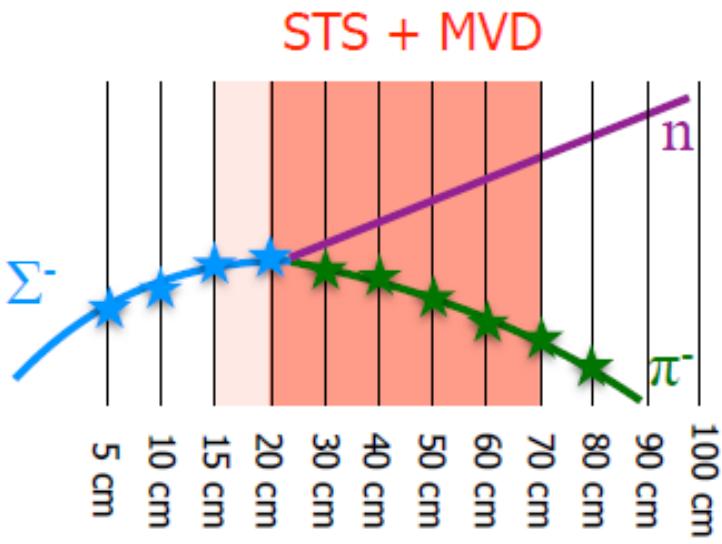
# Simulation and reconstruction

## Hypernuclei in central Au+Au 10 AGeV



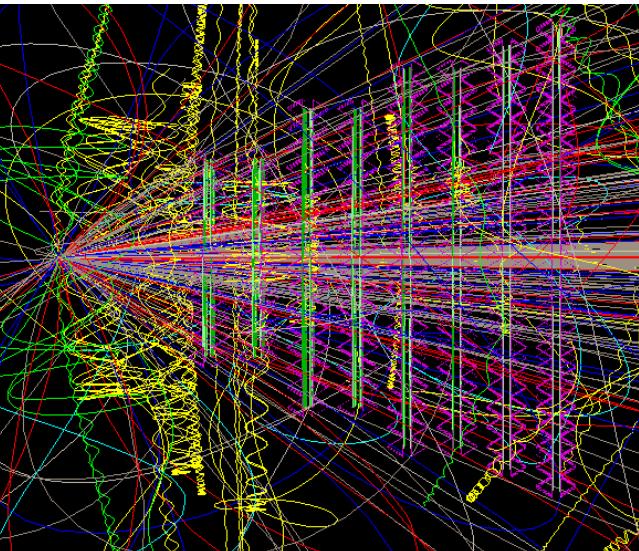
# Simulation and reconstruction

## Hyperons in Au+Au 10 AGeV missing mass analysis

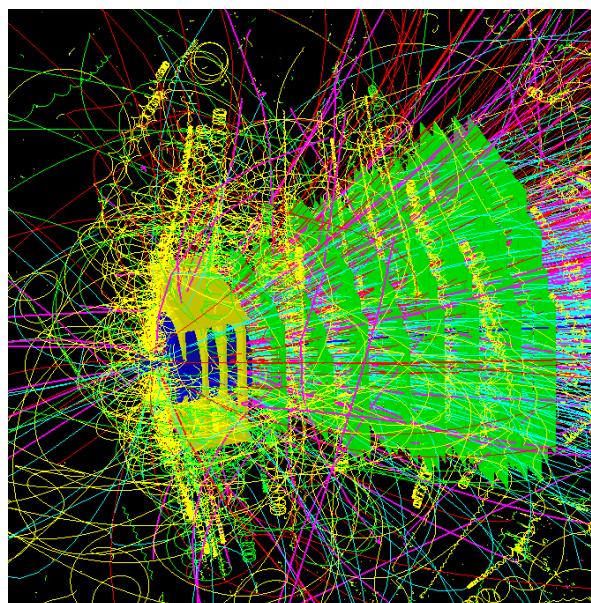


# 4D reconstruction

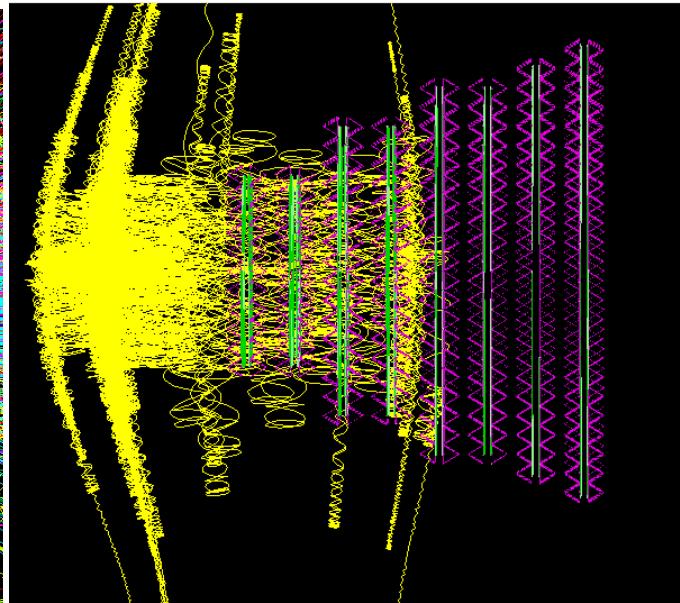
Au+Au 8 A GeV  
peripheral collision  
UrQMD + GEANT3



Au+Au 8 A GeV  
central collision  
UrQMD + GEANT3

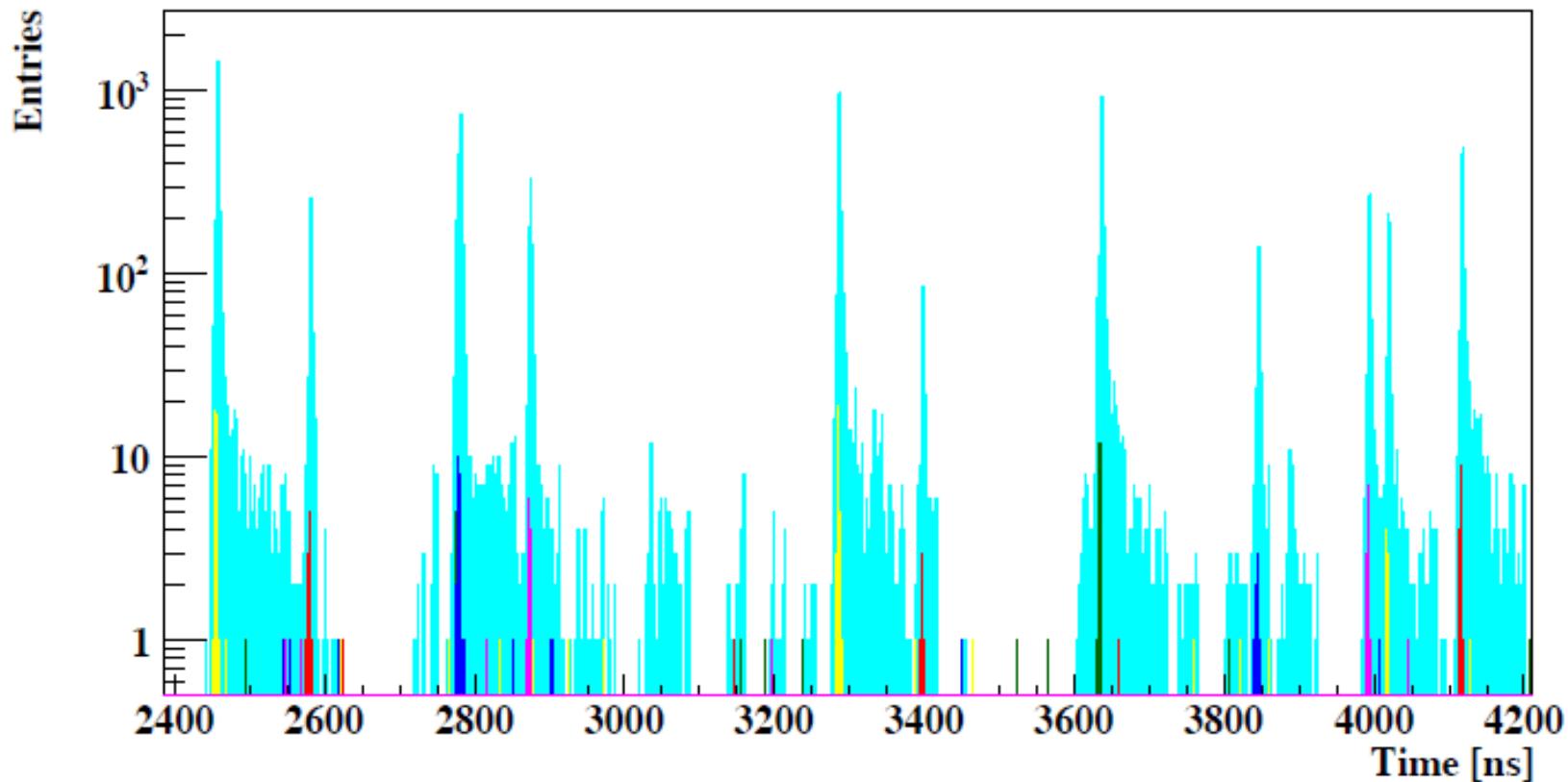


Au beam 8 A GeV  
one single ion  
passing the target  
FairIon + GEANT3



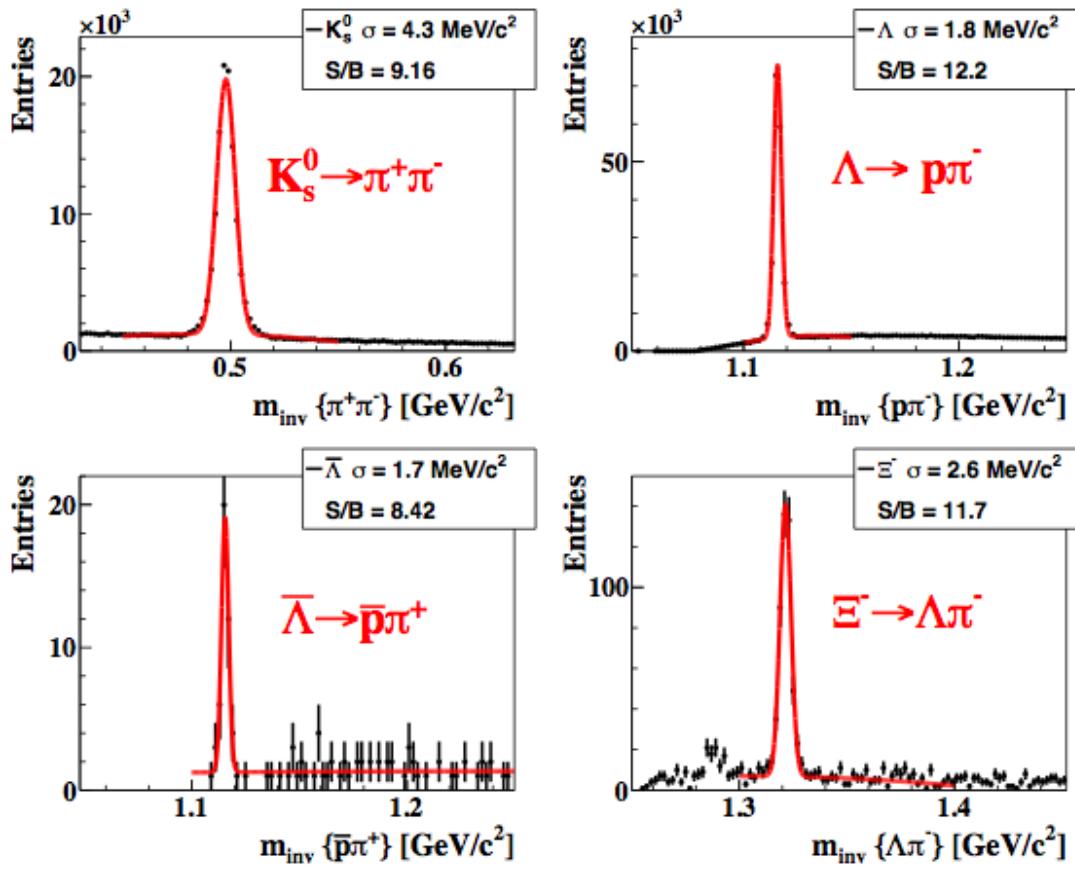
# 4D reconstruction

Hit and track time distribution for  
Au+Au 10 AGeV mbias events at 10 MHz (UrQMD)



# 4D reconstruction

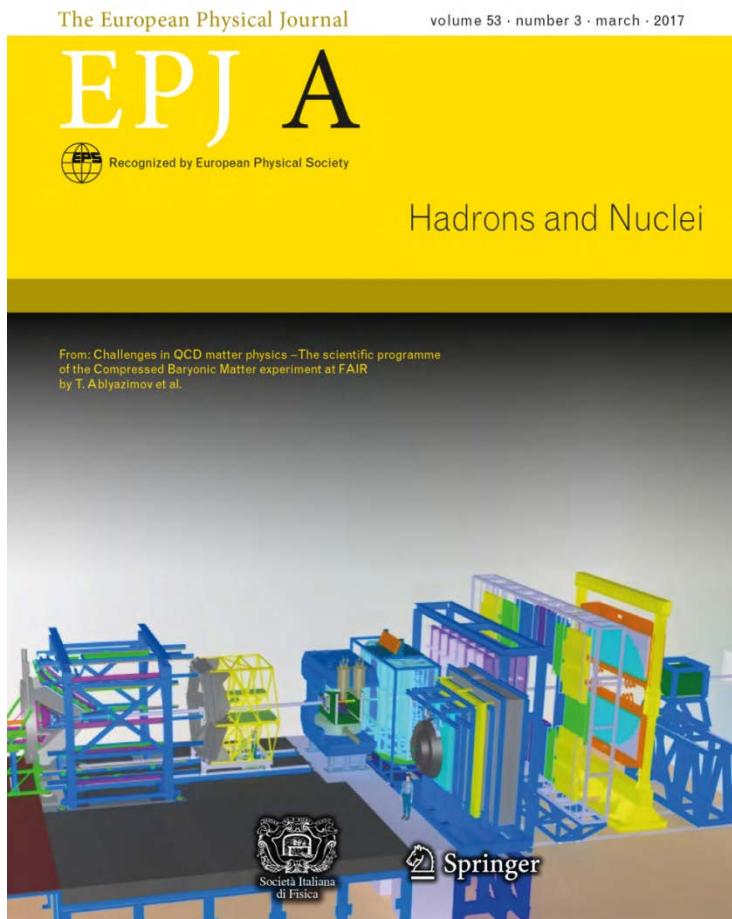
10 MHz Au+Au, 10 AGeV,  
300k mbias UrQMD events, ideal PID



		$K_s^0$	$\Lambda$	$\bar{\Lambda}$	$\Xi^-$
$\epsilon_{\text{method}}, \%$	$K_s^0$	68.6	61.2	67	46.7
	$\Lambda$	20.7	19.4	28	10.5
S/B	$K_s^0$	10.6	23.7	12.7	21.8
	$\Lambda$	68.5	62.0	62	45.2
$\epsilon_{\text{method}}, \%$	$\bar{\Lambda}$	21.1	20.6	32	11.7
	$\Xi^-$	9.8	12.9	10	14.2
S/B	$\bar{\Lambda}$	67.5	60.9	59	46.0
	$\Xi^-$	19.4	18.7	26	10.6
$\epsilon_{\text{method}}, \%$	$\Xi^-$	9.3	12.5	10	12.3
	$K_s^0$	66.8	60.0	64	41.8
S/B	$\Xi^-$	17.6	16.7	28	8.2
	$K_s^0$	9.2	12.2	8	11.7

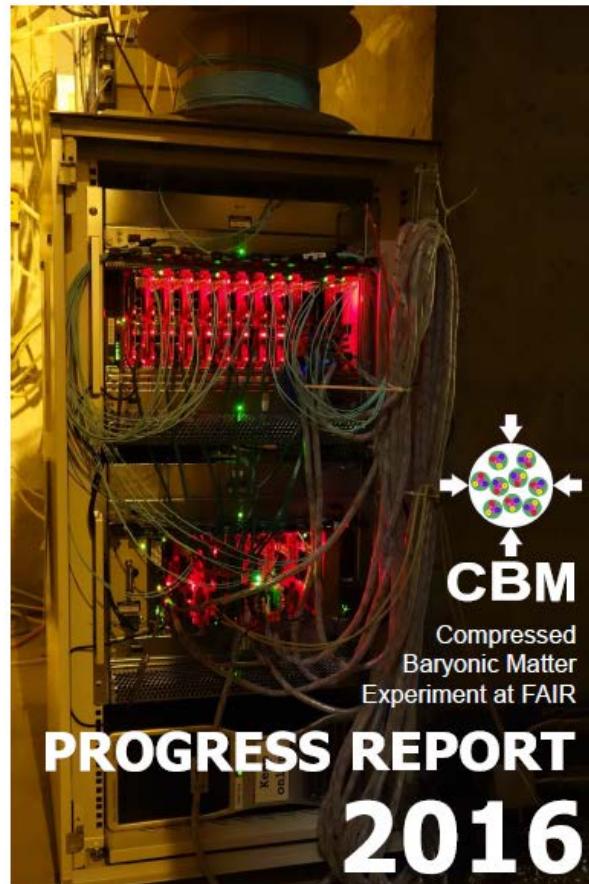
all mother particles emitted from one primary vertex

# For further reading ...



“Challenges in QCD Matter Physics – the scientific programme of the Compressed Baryonic Matter Experiment at FAIR”

Ablyazimov, T. et al. Eur. Phys. J. A (2017) 53: 60. doi:10.1140/epja/i2017-12248-y

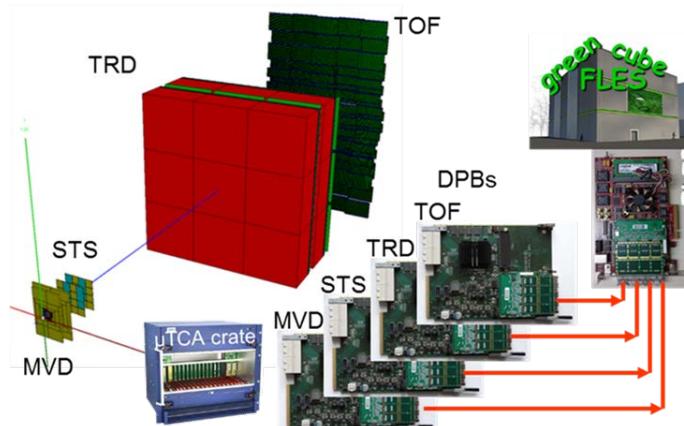
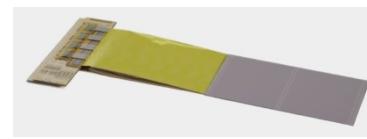
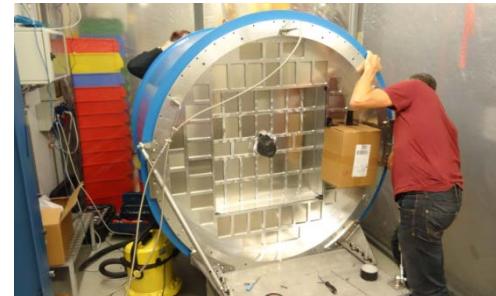


135 contributions, 220 pages  
ISBN 978-3-9815227-4-7.

[https://repository.gsi.de/record/186952/  
files/CBM-PR-2015%20\[pdf\].pdf](https://repository.gsi.de/record/186952/files/CBM-PR-2015%20[pdf].pdf)

# FAIR phase 0 experiments on dense QCD matter

1. Install, commission and use 430 out of 1100 CBM RICH multi-anode photo-multipliers (MAPMT) in HADES RICH photon detector
2. Install, commission and use 10% of the CBM TOF modules including read-out chain at STAR/RHIC (BES II 2019/2020)
3. Install, commission and use 4 Silicon Tracking Stations and the Project Spectator Detector in the BM@N experiment at the Nuclotron in JINR/Dubna (start 2019 with Au-beams up to 4.5 A GeV)
4. Build miniCBM at GSI/SIS18 for a full system test with high-rate nucleus-nucleus collisions from 2018 - 2021



# The CBM Collaboration: 55 institutions, 460 members

## China:

CCNU Wuhan  
Tsinghua Univ.  
USTC Hefei  
CTGU Yichang

## Czech Republic:

CAS, Rez  
Techn. Univ. Prague

## France:

IPHC Strasbourg

## Hungary:

KFKI Budapest  
Eötvös Univ.

## Germany:

Darmstadt TU  
FAIR  
Frankfurt Univ. IKF  
Frankfurt Univ. FIAS  
Frankfurt Univ. ICS  
GSI Darmstadt  
Giessen Univ.  
Heidelberg Univ. P.I.  
Heidelberg Univ. ZITI  
HZ Dresden-Rossendorf  
KIT Karlsruhe  
Münster Univ.  
Tübingen Univ.  
Wuppertal Univ.  
ZIB Berlin

## India:

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Bose Inst. Kolkata  
Panjab Univ.  
Rajasthan Univ.  
Univ. of Jammu  
Univ. of Kashmir  
Univ. of Calcutta  
B.H. Univ. Varanasi  
VECC Kolkata  
IOP Bhubaneswar  
IIT Kharagpur  
IIT Indore  
Gauhati Univ.

## Korea:

Pusan Nat. Univ.

## Poland:

AGH Krakow  
Jag. Univ. Krakow  
Warsaw Univ.  
Warsaw TU

## Romania:

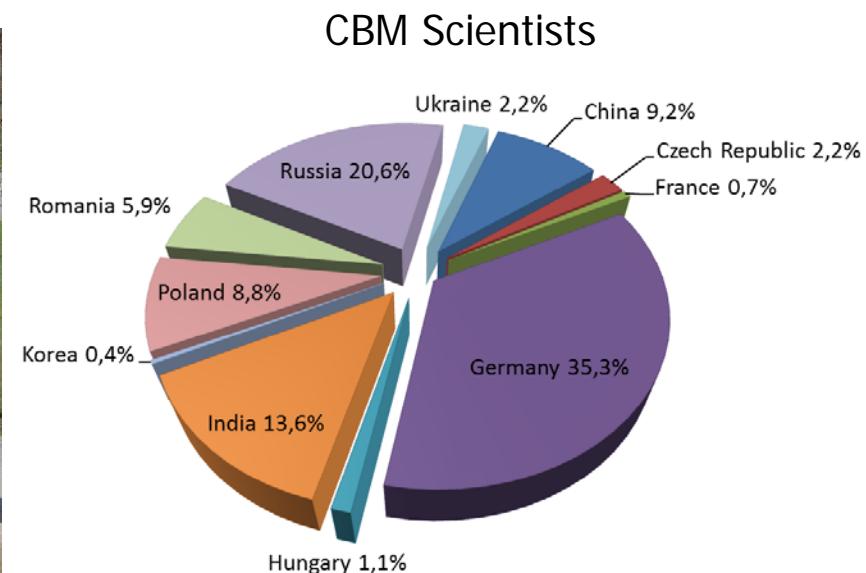
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## Russia:

IHEP Protvino  
INR Troitzk  
ITEP Moscow  
Kurchatov Inst., Moscow  
VBLHEP, JINR Dubna  
LIT, JINR Dubna  
MEPHI Moscow  
PNPI Gatchina  
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## Ukraine:

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Kiev Inst. Nucl. Research



# Summary

- FAIR: Forefront research in nuclear, hadron, atomic, plasma and applied physics. Construction started, full operational in 2025. Installation/commissioning of experiments planned 2021-2024.
- CBM scientific program at SIS100: Exploration of the QCD phase diagram in the region of neutron star core densities → large discovery potential.
- CBM concept: High-rate detectors combined with free streaming data readout and online event selection enable high-precision multi-differential measurements of hadrons incl. multistrange hyperons, hypernuclei and dileptons for different beam energies and collision systems → terra incognita.
- Status of experiment preparation: Prototype detectors fulfill CBM requirements. Mass production starts in 2018
- FAIR Phase 0: HADES experiments with CBM RICH photon detector, use CBM detectors at STAR/BNL and BM@N/JINR,  
• and miniCBM at GSI