# The Compressed Baryonic Matter Experiment at FAIR

Physics Program, Challenges and Status

# Landscape of Discovery in Super-Dense Matter Physics

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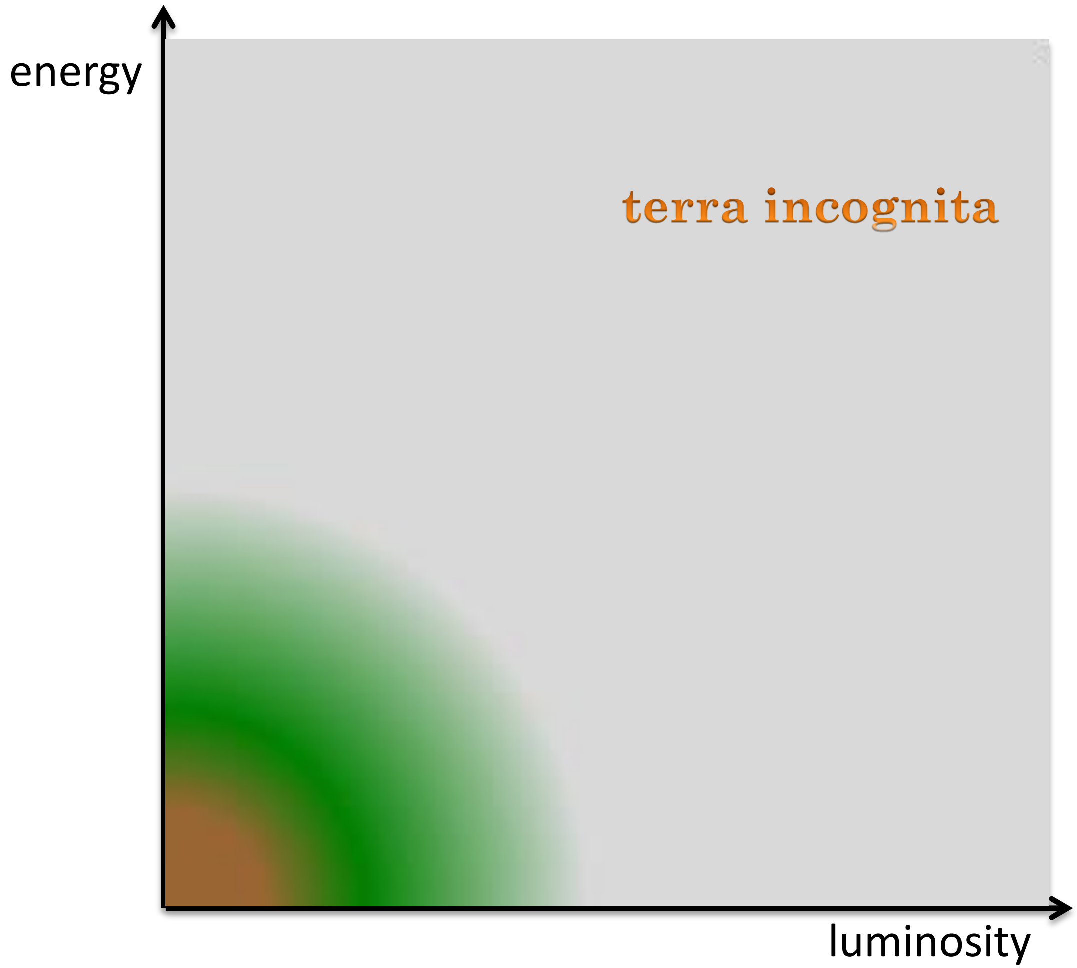

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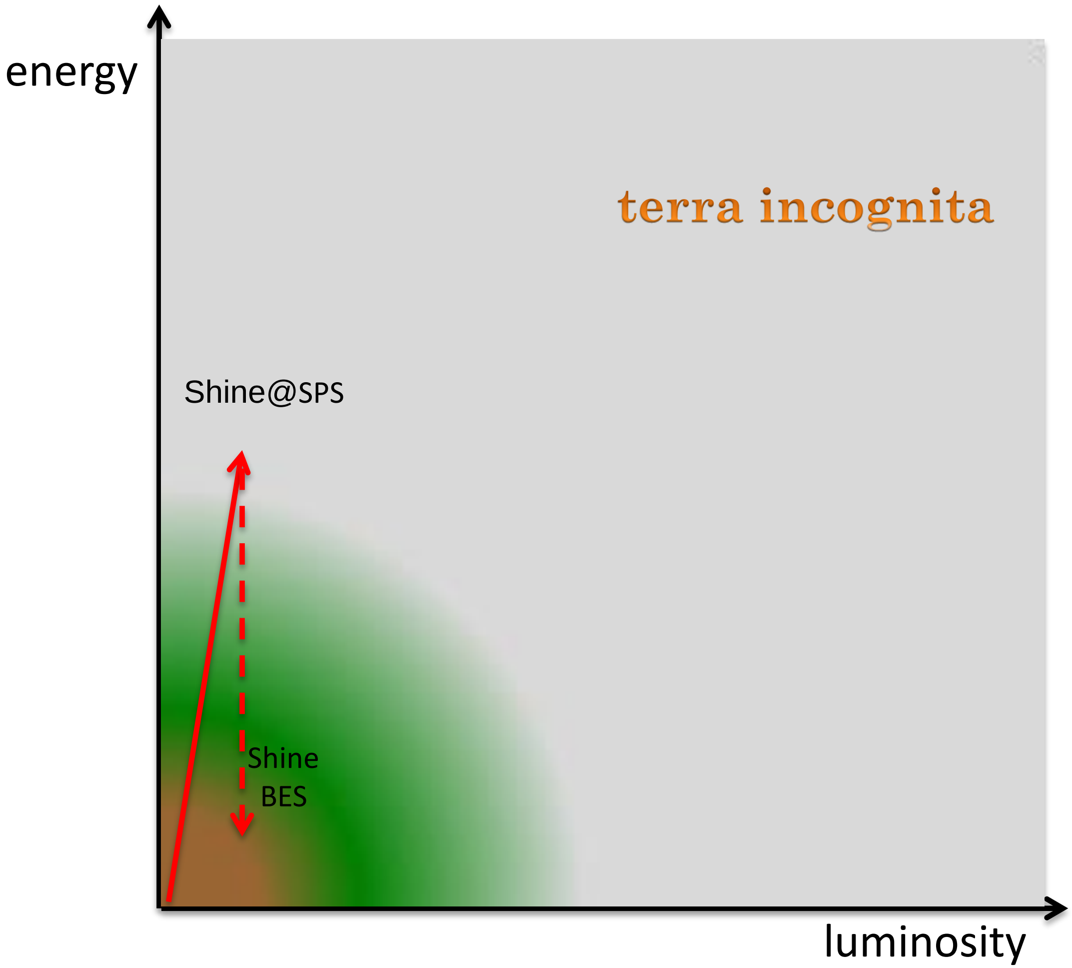

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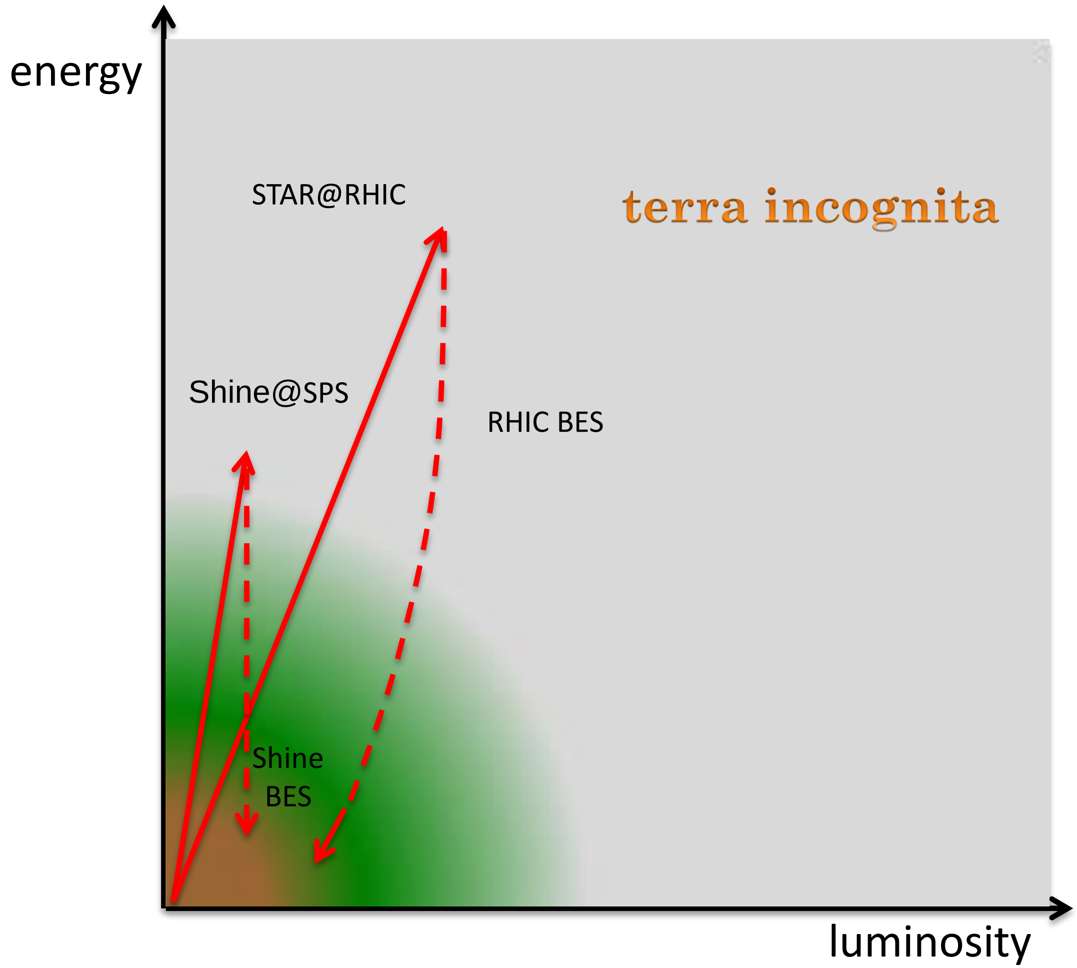

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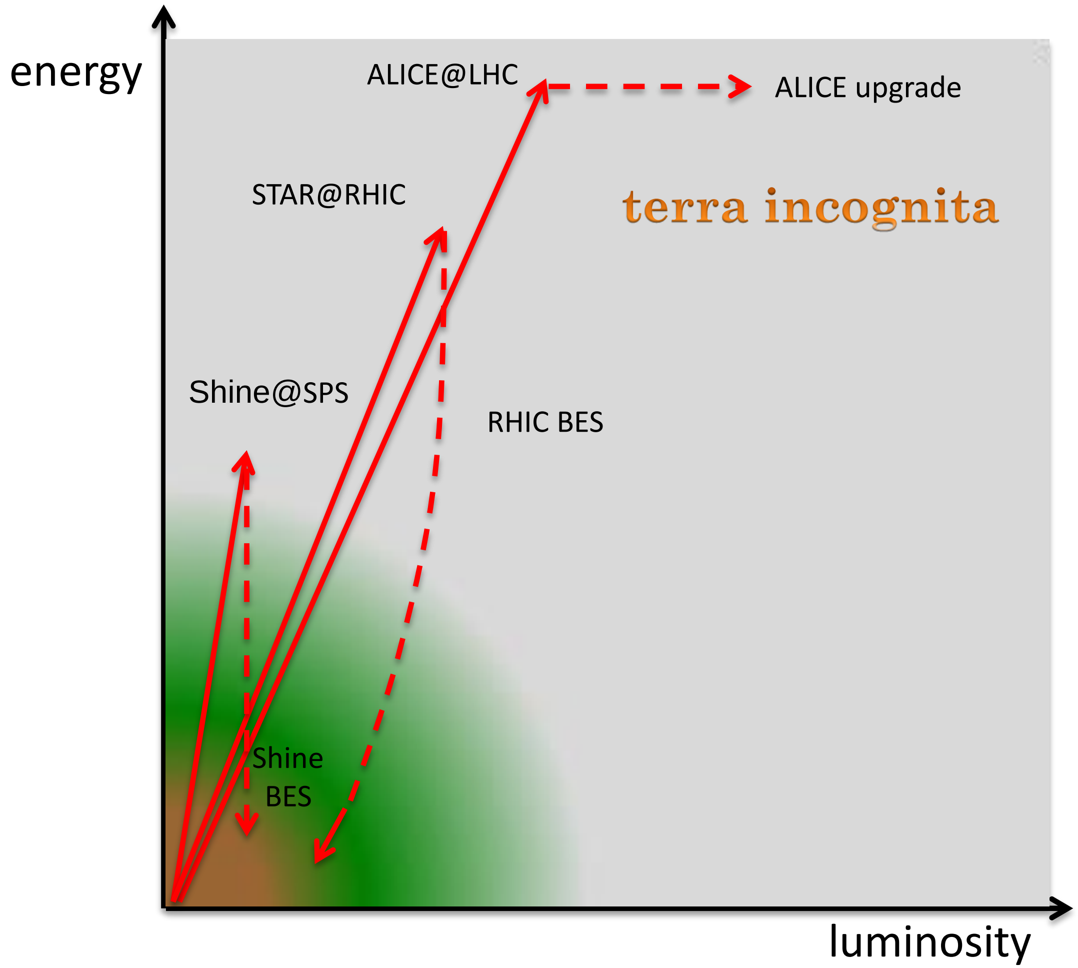

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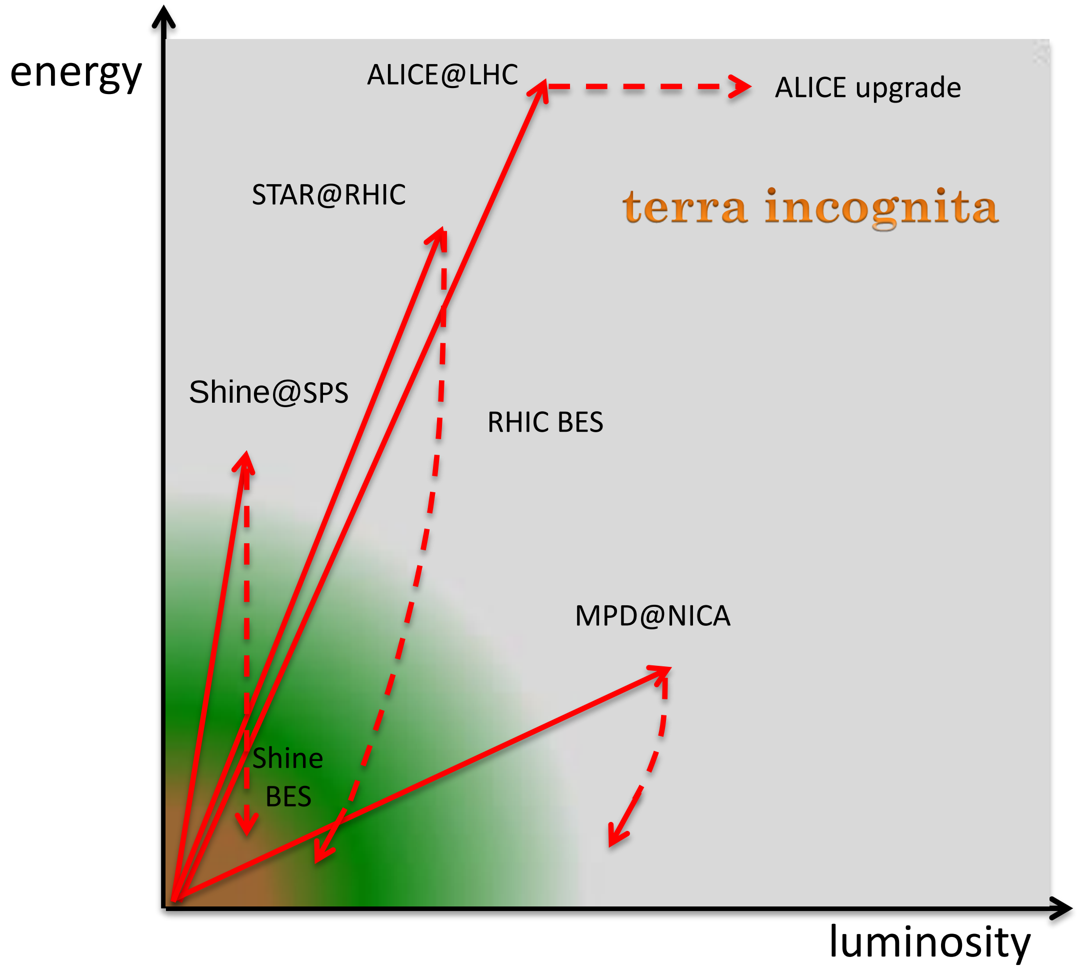

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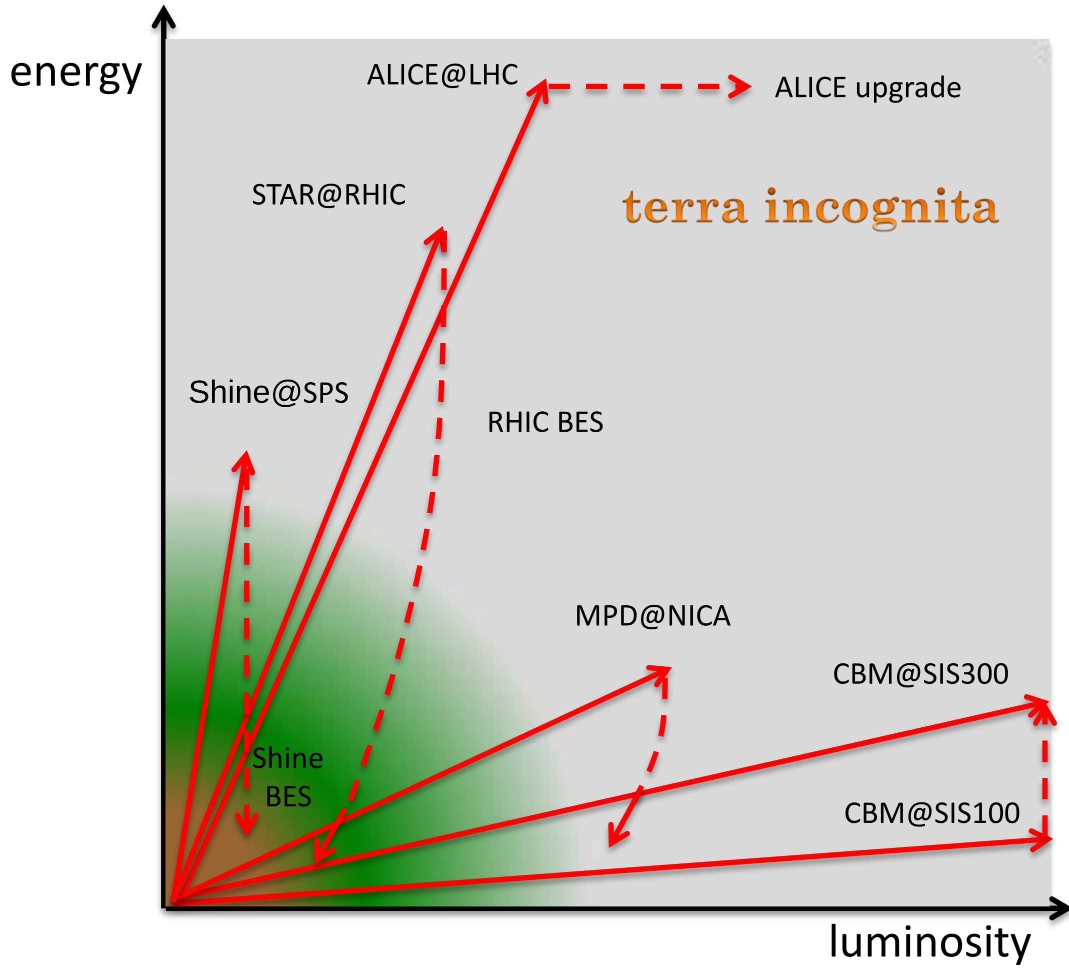
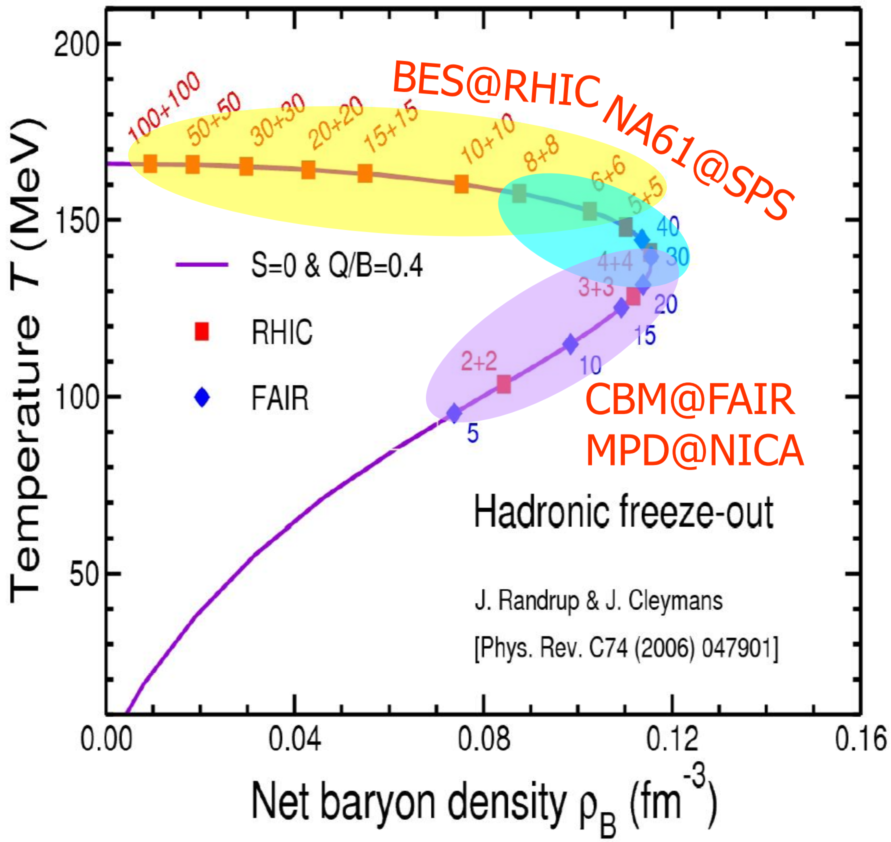
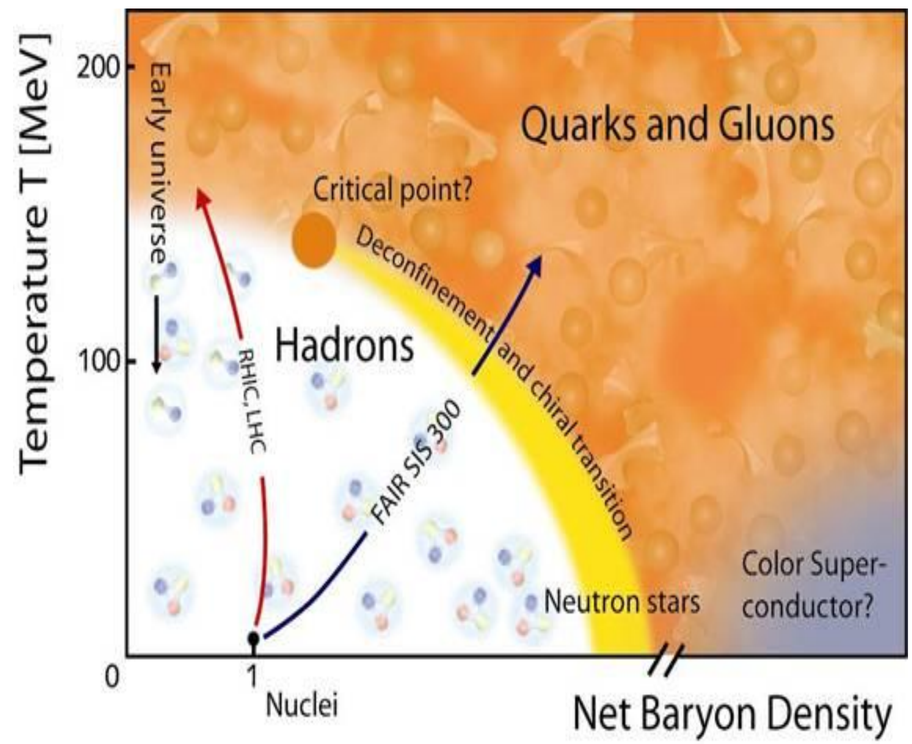



$R_{int} = 10^5 - 10^7$ Hz
(limitation by present detector technology)

# Covering the High Baryon Density Regime




Maximal net-baryon density (from hadron gas model): $E_{beam} \approx 30A$ GeV ($\sqrt{s_{NN}} \approx 8$ GeV)

# Experiments on Superdense Nuclear Matter

| Experiment | Observables for beam energies below $\sqrt{s_{NN}}$ = 12 GeV (high baryon density region) | | | |
|---|---|---|---|---|
| | hadrons | correlations, fluctuations | dileptons | multi-strange, charm |
| STAR@RHIC BNL | yes | yes | no | no |
| NA61@SPS CERN | yes | yes | no | no |
| MPD@NICA Dubna | yes | yes | yes | no |
| CBM@FAIR Darmstadt | yes | yes | yes | yes |

rare probes (dileptons; multi-strange, charm)

# Outline

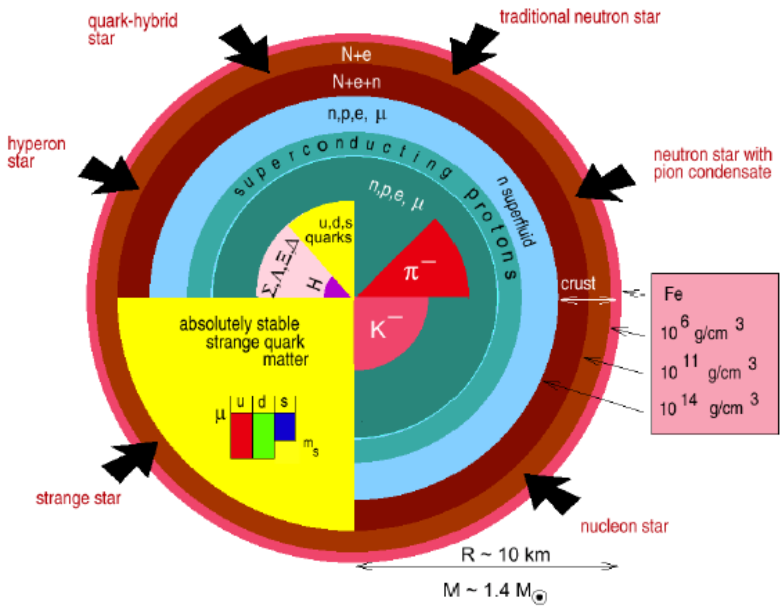
- Focus of this talk
  - Exploration of Dense Matter  with new, rare probes
    - (sub)threshold production of multi-strange hyperons
    - hyper-nuclei
  - Experimental Challenges & Status of CBM

- No covered (because of time constraints)
  - bulk observables
    - flow, fluctuations, correlations, ….
  - Hadrons in Dense Matter
    - low mass vector mesons
    - charm & open charm

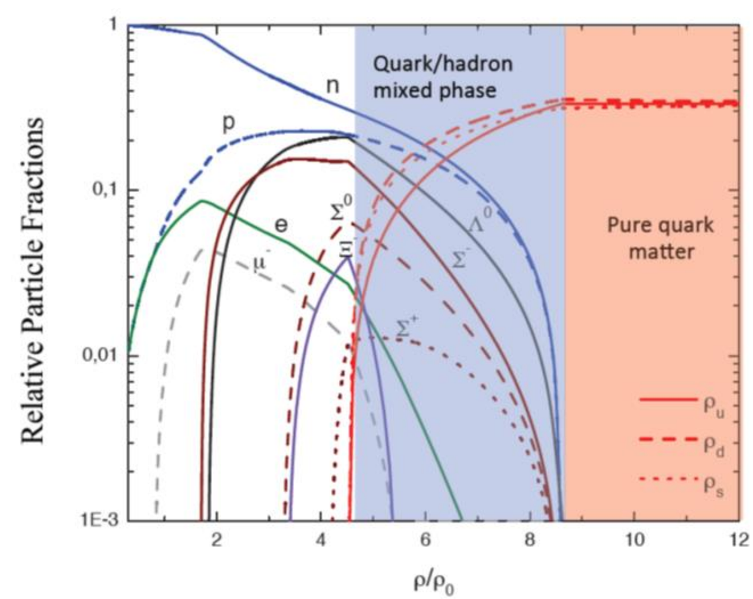
# Structure of Neutron Stars

Each arrow indicates a different model for the neutron star

Each model represents a different EoS




M. Orsaria, H. Rodrigues, F. Weber, G.A. Contrera
Phys. Rev. D 87, 023001 (2013)




recent observation of a $\frac{M}{M_{\odot}} \approx 2$ Neutron Star

- no stable against gravitational collaps with soft EOS (e.g. quark matter EOS)
- stable Neutron Star with quark-hadron mixed phase incl. hyperons
  - important: knowledge hyperon-hyperon interaction
- **experimental prerequisites:**
  - probes of high density phase (are traditional flow measurements suffient?)

# Exploring the EOS at $3\rho_0 < \rho < 7\rho_0$ with (Sub)-Threshold Production of Multi-Strange Hyperons

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CBM

Direct production:

$pp \rightarrow \Xi^- K^+ K^+ p \quad (E_{thresh} = 3.7\ GeV)$

$pp \rightarrow \Omega^- K^+ K^+ K^0 p \ (E_{thresh} = 7.0\ GeV)$

Production via multiple collisions*):

$\mathrm{pp} \rightarrow \mathrm{K}^+ \Lambda p \quad (E_{thresh} = 1.6\ GeV)$

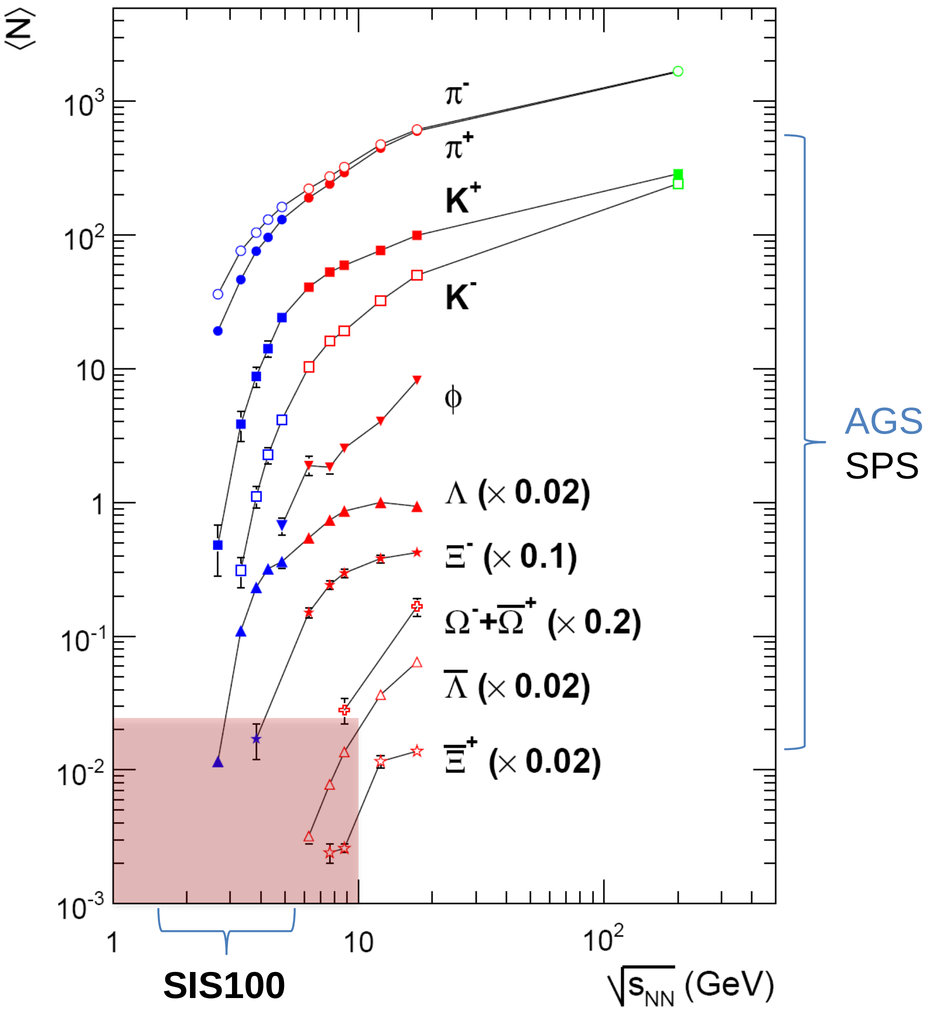
$\mathrm{pp} \rightarrow \mathrm{K}^+ \mathrm{K}^- pp \quad (E_{thresh} = 2.5 GeV)$

$\Lambda\Lambda \rightarrow \Xi^- p \qquad \Lambda\Xi^- \rightarrow \Omega^- n,$

$\Lambda \mathrm{K}^- \rightarrow \Xi^- \pi^0 \qquad \Xi^- K^- \rightarrow \Omega^- \pi^-$

sub-threshold production cross section of $\Xi^-$, $\Omega^-$ probes dense, baryonic matter….

- AGS physics revisited with new probes
- measure excitation functions for multi-strange hyperons in light and heavy collision system




*) P. Chung et al, E895 Coll. PLR 91.202301(2003)
G. Agakishiev et al, Hades Coll, PRL 103, 132301 (2009)

# Exploring the EOS at $3\rho_0 < \rho < 7\rho_0$ with (Sub)-Threshold Production of Multi-Strange Hyperons

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yield/week

| Beam energy | $\Xi^-$ | $\Omega^-$ | $\bar{\Lambda}$ | $\bar{\Xi}^+$ | $\bar{\Omega}^+$ |
|---|---|---|---|---|---|
| 4.0A GeV | $9.0 \cdot 10^6$ | $1.8 \cdot 10^5$ | $3.6 \cdot 10^3$ | $5.3 \cdot 10^3$ | $9.0 \cdot 10^2$ |
| 6.0A GeV | $2.6 \cdot 10^7$ | $5.0 \cdot 10^5$ | $2.4 \cdot 10^5$ | $1.4 \cdot 10^4$ | $2.8 \cdot 10^3$ |
| 8.0A GeV | $4.0 \cdot 10^7$ | $1.4 \cdot 10^6$ | $3.6 \cdot 10^6$ | $2.0 \cdot 10^5$ | $6.0 \cdot 10^4$ |
| 10.7A GeV | $5.4 \cdot 10^8$ | $2.2 \cdot 10^6$ | $6.8 \cdot 10^6$ | $3.8 \cdot 10^5$ | $1.2 \cdot 10^4$ |

$\Lambda\Lambda \to \Xi^- p \qquad \Lambda\Xi^- \to \Omega^- n,$

$\Lambda K^- \to \Xi^- \pi^0 \qquad \Xi^- K^- \to \Omega^- \pi^-$

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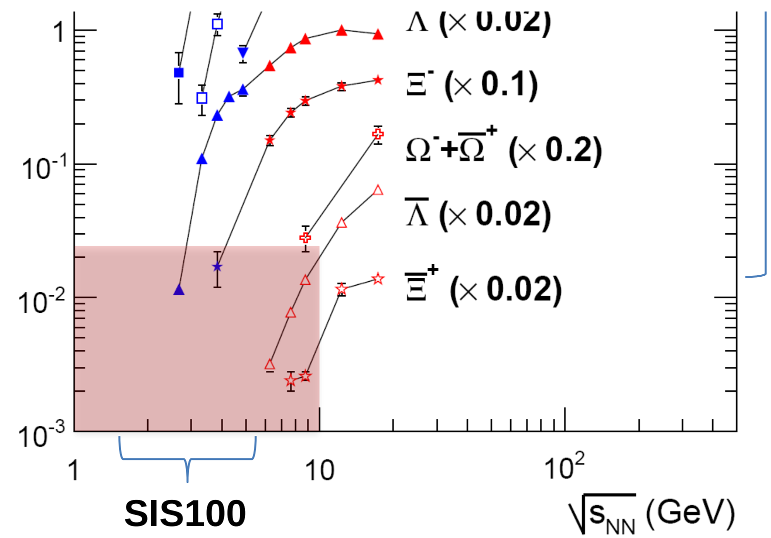


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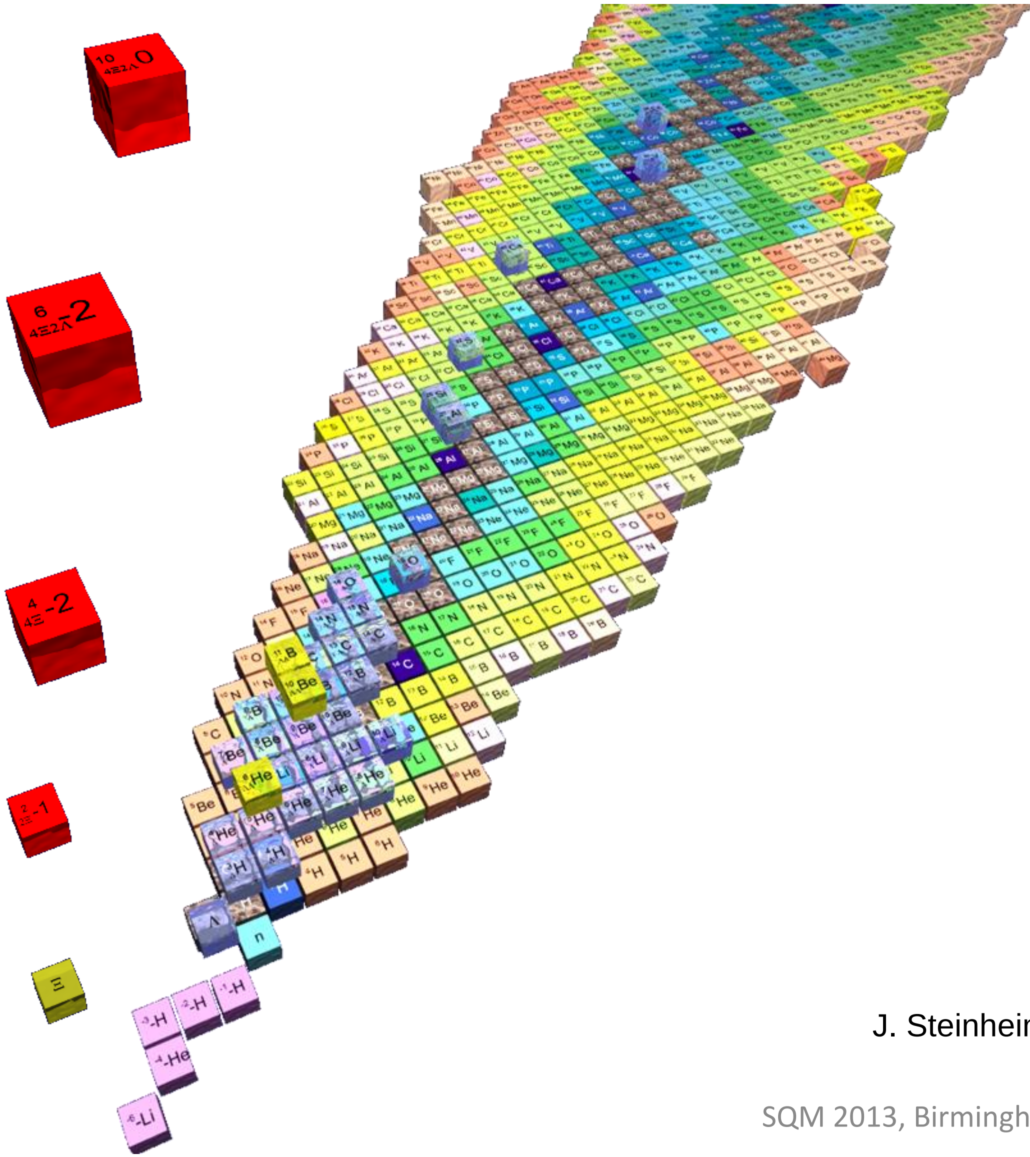
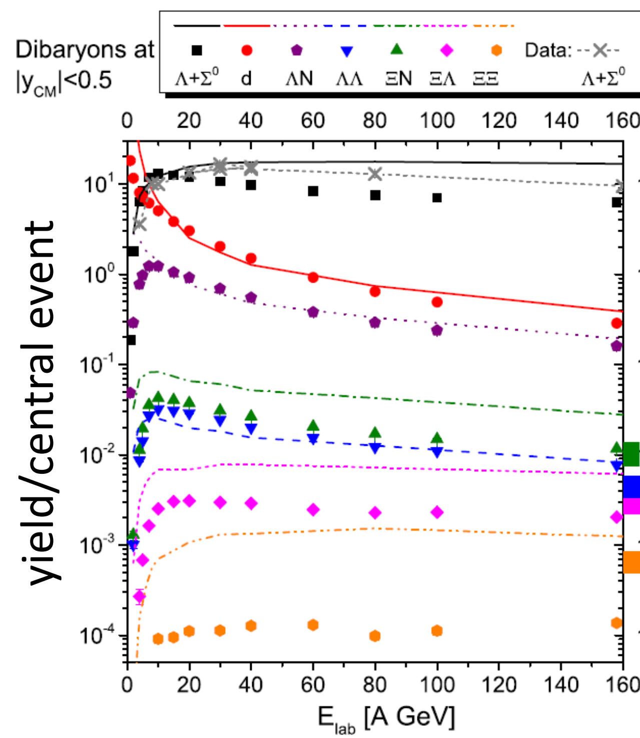
# Multi-Strangeness



search for
- double hyper-nuclei
  - ✓ ${}^{5}_{\Lambda\Lambda}H, {}^{6}_{\Lambda\Lambda}He$
- MEMOS[*)]
  - ✓ $(\Xi^0\Xi^-)_b, (\Xi^0\Lambda)_b, \ldots$




J. Steinheimer et al. / Physics Letters B 714 (2012) 85–91

*) Metastable Exotic Multihypernuclear Objects

# Double-strange hypernuclei

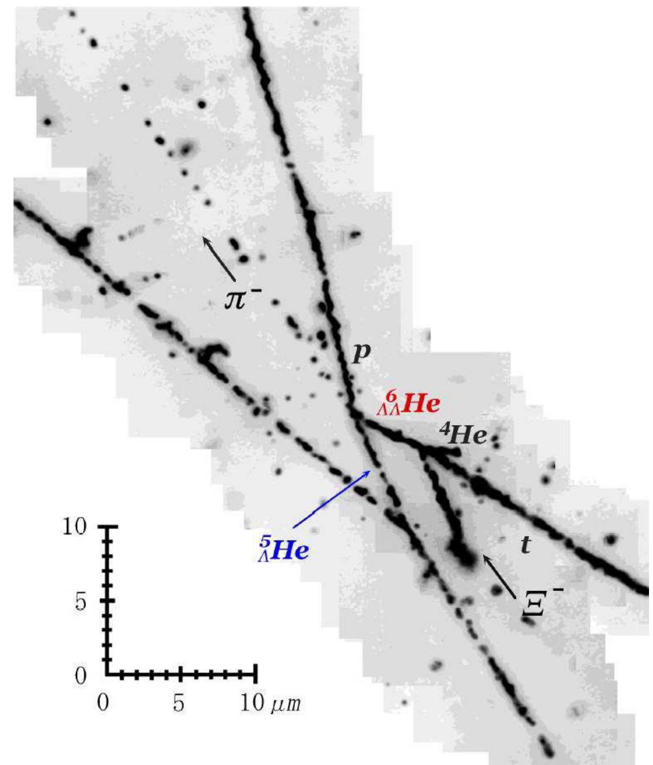
VOLUME 87, NUMBER 21 PHYSICAL REVIEW LETTERS 19 NOVEMBER 2001

**Observation of a ${}_{\Lambda\Lambda}^{6}$He Double Hypernucleus**

H. Takahashi,[1,*] J. K. Ahn,[1,†] H. Akikawa,[1] S. Aoki,[2] K. Arai,[3] S. Y. Bahk,[4] K. M. Baik,[5] B. Bassalleck,[6] J. H. Chung,[7]

## Observed ΛΛ hypernuclei:

1963: ${}_{\Lambda\Lambda}^{10}$Be (Danysz et al.)
1966: ${}_{\Lambda\Lambda}^{6}$He (Prowse et al.)
1991: ${}_{\Lambda\Lambda}^{10}$Be or ${}_{\Lambda\Lambda}^{10}$Be (KEK-E176)
2001: ${}_{\Lambda\Lambda}^{4}$H (BNL-E906)
2001: ${}_{\Lambda\Lambda}^{6}$He (KEK-E373)
2001: ${}_{\Lambda\Lambda}^{10}$Be (KEK-E373)



# Search for Double Hypernuclei

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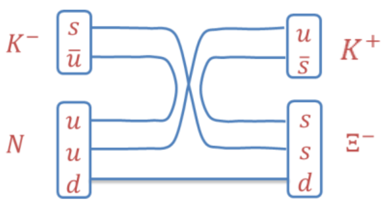
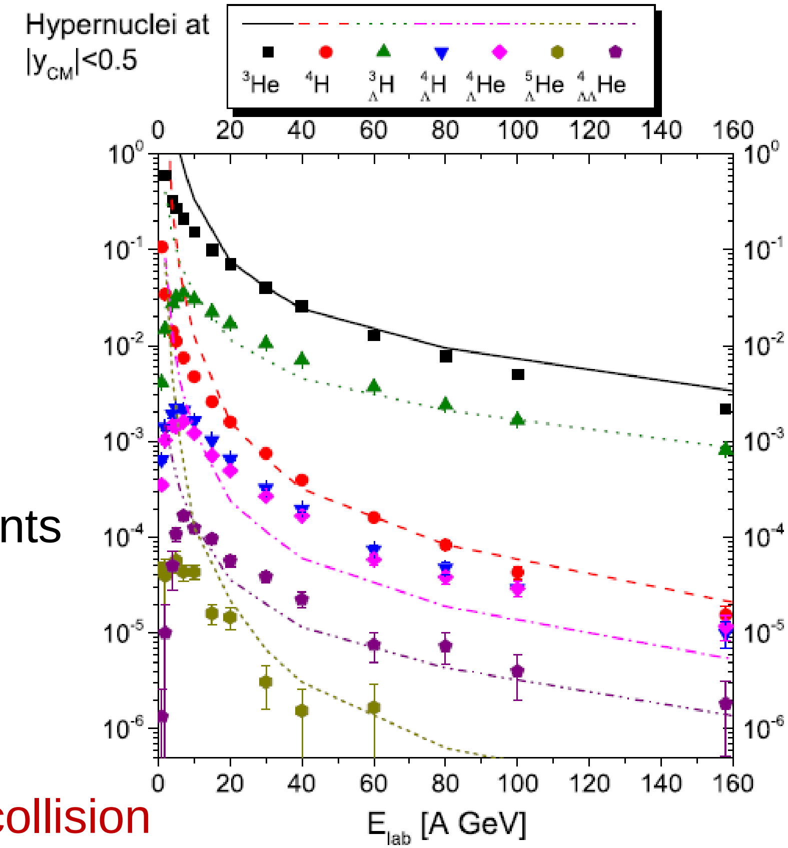
conventional production mechanism*):




$+$

$$\Xi^- + {}^{12}C \rightarrow {}^{6}_{\Lambda\Lambda}He + {}^{4}He + t$$

J. Steinheimer et al. / Physics Letters B 714 (2012) 85–91




<u>heavy collisions:</u>

production via coalescence of $\Lambda$ with light fragments

40 AGeV: 50 $\Lambda's$/central Au+Au collision

10 AGeV: 15 $\Lambda's$/central Au+Au collision

yield: $10^{-4}\,{}^{4}_{\Lambda\Lambda}He, 10^{-6}\,{}^{5}_{\Lambda\Lambda}H, 3\cdot 10^{-8}\,{}^{6}_{\Lambda\Lambda}He$ /central collision

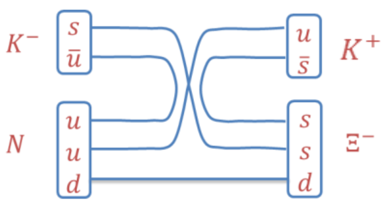
>10[4]/week 120/week 3.6/week



*) Takahashi et al, PRL 87 (2001)

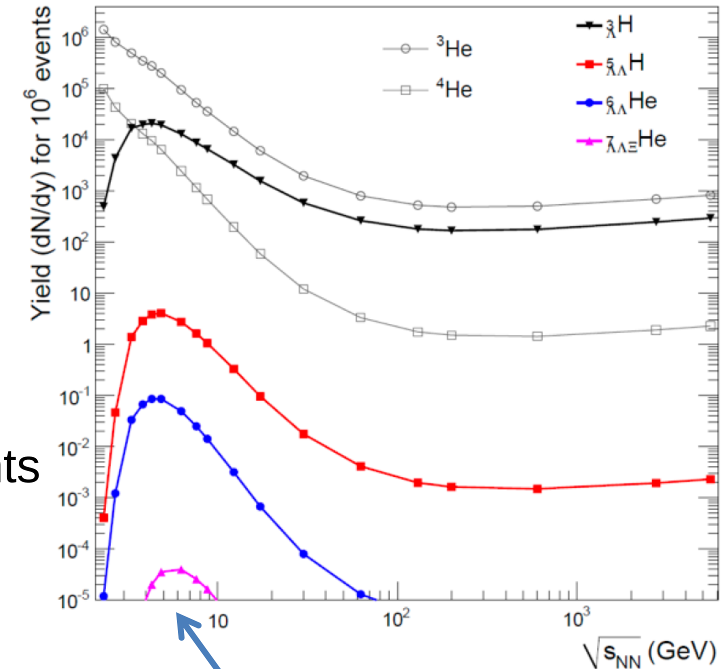
# Search for Double Hypernuclei

conventional production mechanism*):




$+$ $\Xi^- + {}^{12}C \rightarrow {}^{6}_{\Lambda\Lambda}He + {}^{4}He + t$

A. Andronic, P. Braun-Munzinger, J. Stachel, H. Stöcker , PL B697 (2011) 204

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>10⁴/week 120/week 3.6/week

coalecense probability has maximum at $\sqrt{s_{NN}} = 4 - 5\ GeV$



*) Takahashi et al, PRL 87 (2001)

# Being prepared for exotica: Experimental Reconstruction of a Multistrange Di-Baryon

**Signal: strange dibaryon**

$(\Xi^0\Lambda)_b \rightarrow \Lambda\Lambda$ (cτ=3cm)

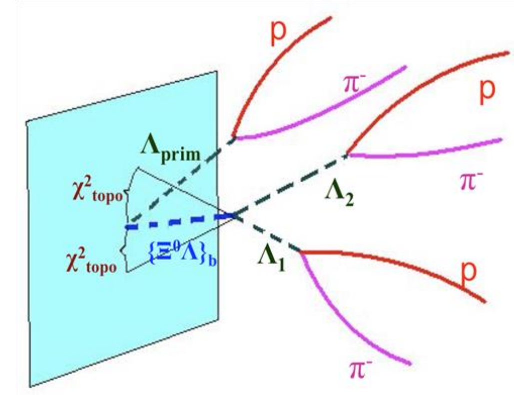
M= $10^{-6}$, BR = 5%

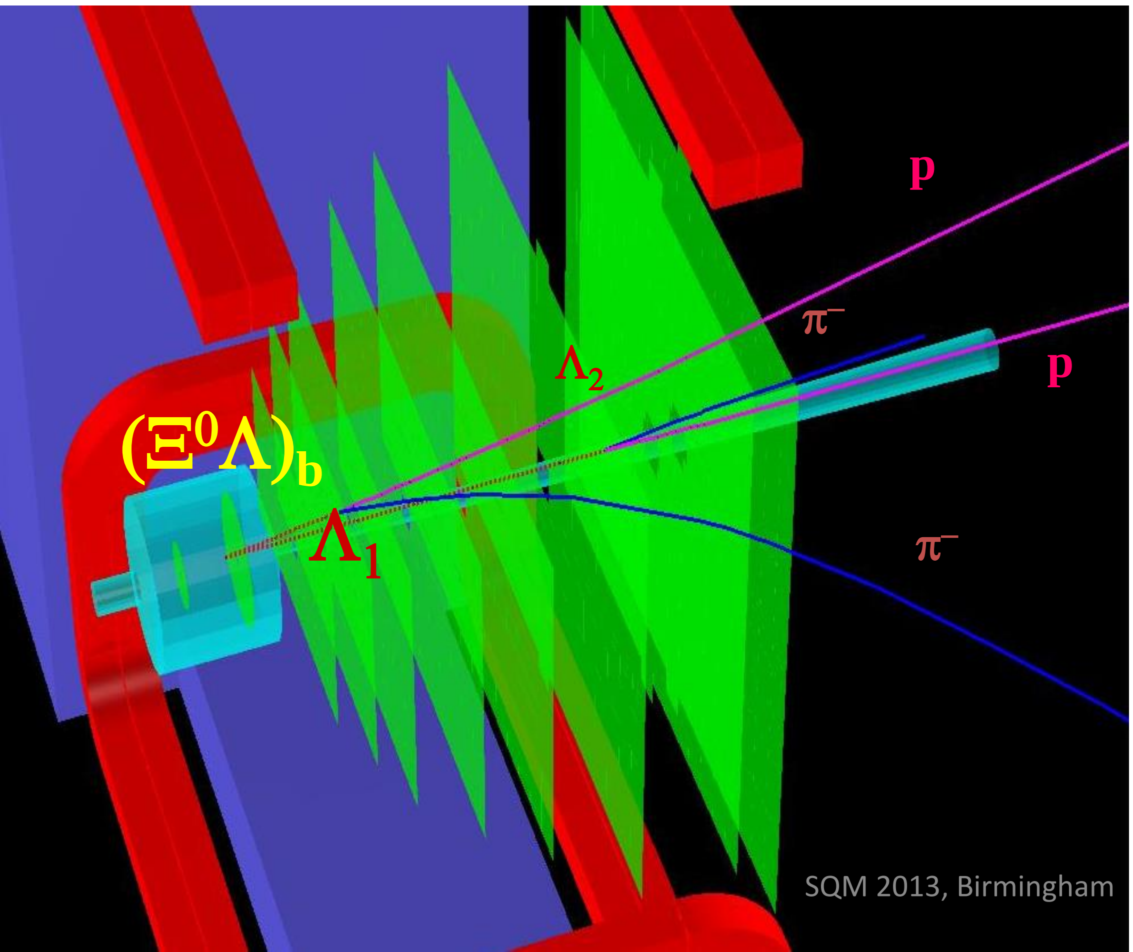
**Background:**

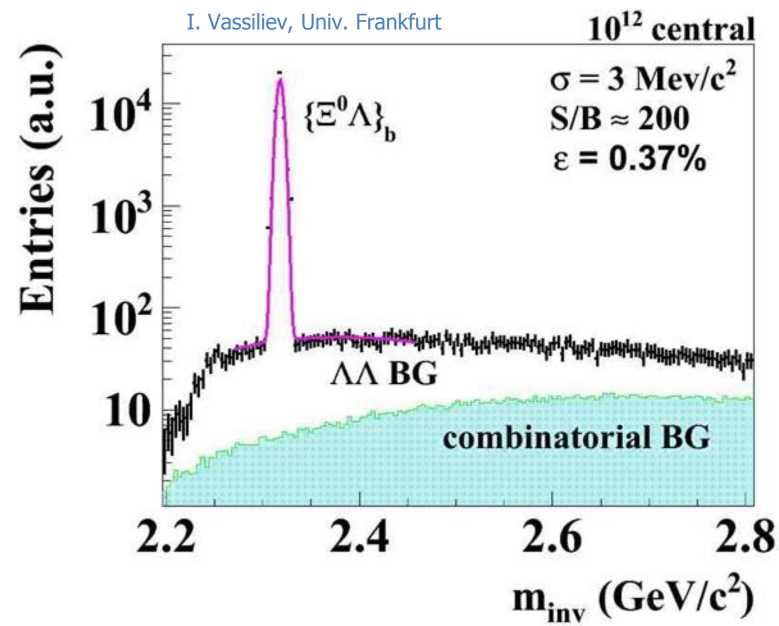
Au+Au @ 25 AGeV

32 Λ per central event

11 Λ reconstructable



# CBM @ FAIR

## FAIR Modules 0-3 (SIS100):

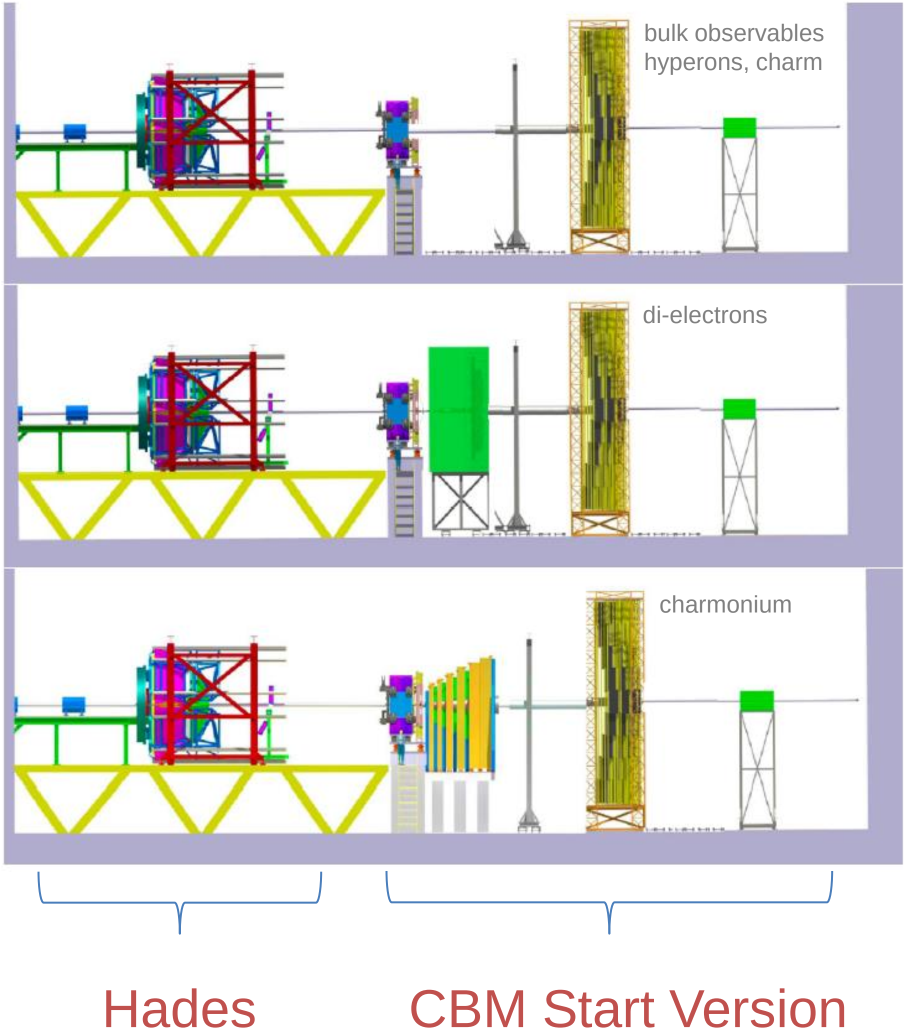
- protons up to 29 GeV
- Au+Au 11 AGeV,
- Ca+Ca 14 AGeV

→ HADES + CBM Start Version

## FAIR Module 6 (SIS300):

- protons up to 89 GeV
- Au+Au 35 AGeV,
- Ca+Ca 44 AGeV

→ CBM



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- 

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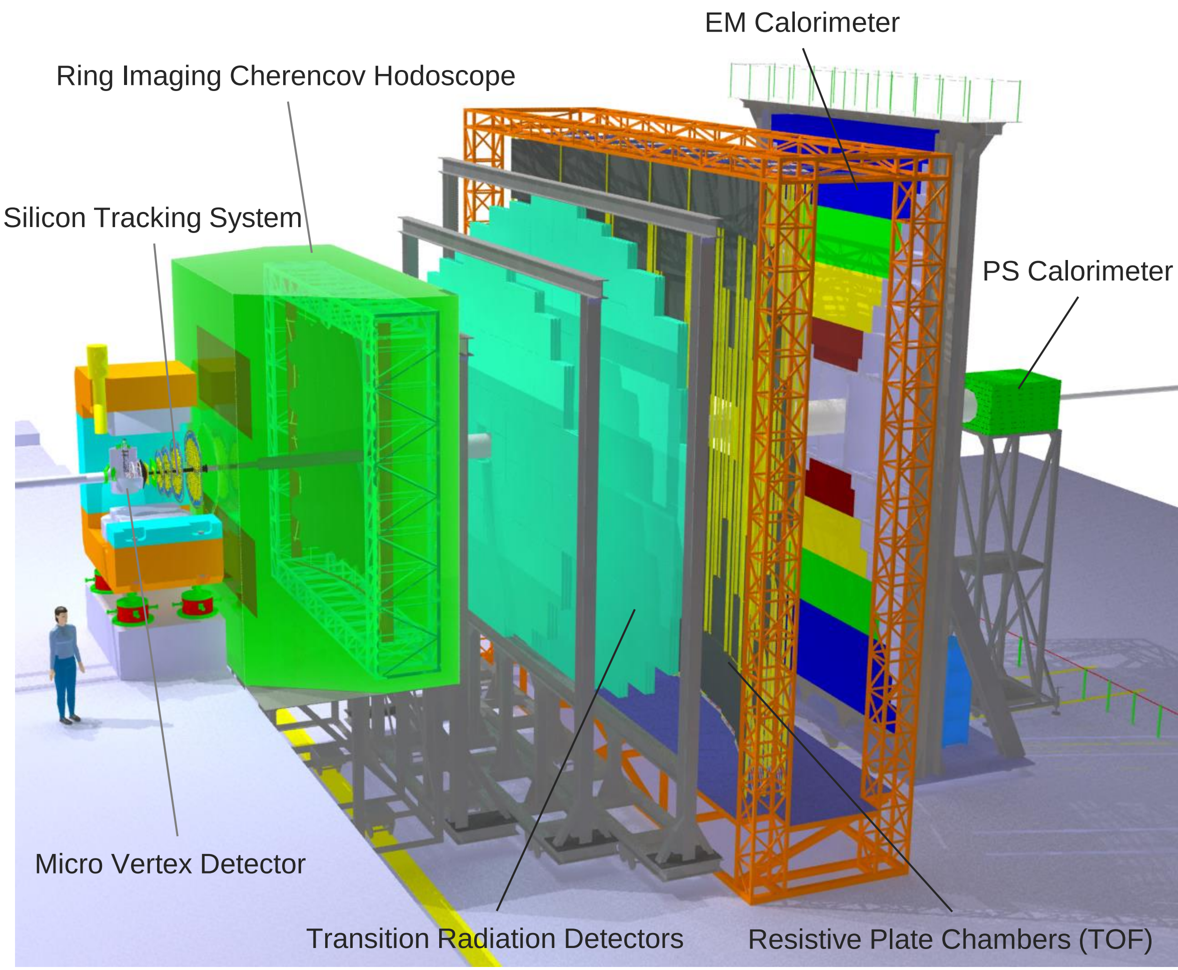


CBM Full Version

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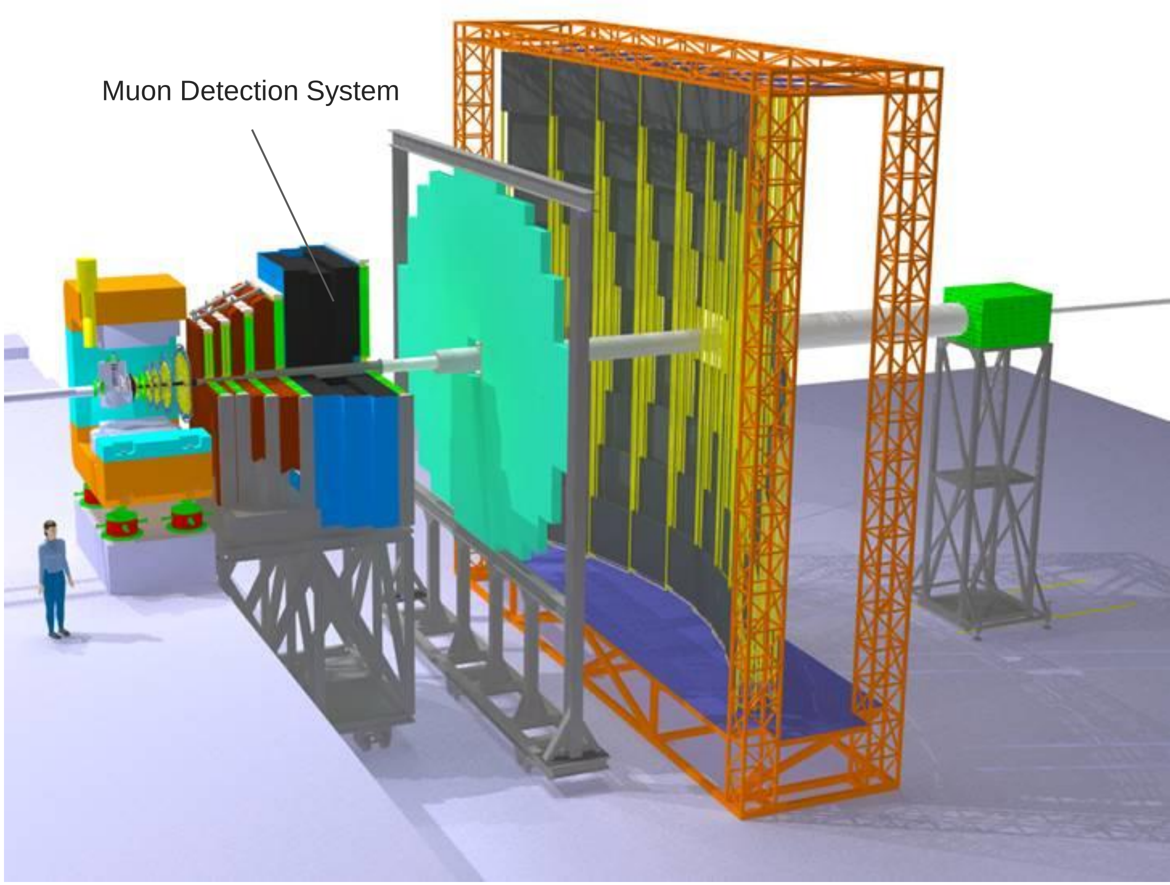



CBM Full Version

# Rare Probes, High Rates

- Requirement for a high rate expiment:
  - fast and rate-capable detectors
  - fast read-out electronics
  - radiation-hard detectors and electronics
  - high-throughput data acquisition and efficient online data selection

⇒ new territory from a detector, electronics, trigger/computing point of view!

# Detector systems

- Main tracking device: STS
  - low-mass silicon strip detectors in magnetic diplole field
  - tracking efficiency > 90 %
  - momentum resolution ≈ 1%
- Micro-vertex detector for open charm: MVD
  - low-mass silicon pixel detector close to the target
  - high precision (resolution ≈ 3 µm)
- Electron identication: RICH and TRD
  - RICH with $C0_2$ radiator, two focal planes and MAPMT photo detection
  - several layers of thin TRDs with MWPC readout
- Hadron identification: TOF
  - RPC wall at 10 m flight distance, resolution <≈ 80 ps
- Muon identification: active absorber system
  - several absorber / GEM detector layers
- ECAL for photon and electron identification
  - lead/scinitillator sandwich
- Event characterisation: PSD
  - compensated forward calorimeter

low mass, radiation hard!

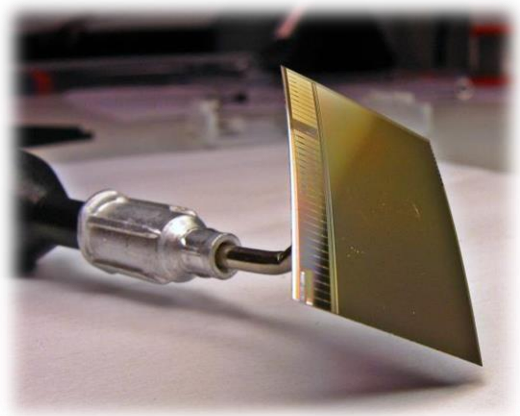
new technology: high rate & resolution MAPS !

new technology: fast TRD!

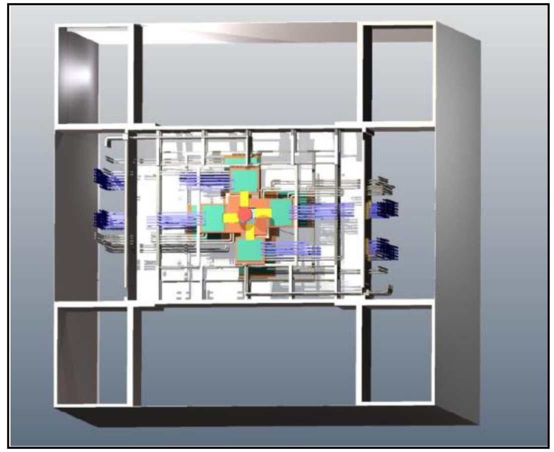
new technology: high rate & resolution RPC !

new technology: GEM instrumented absorber!

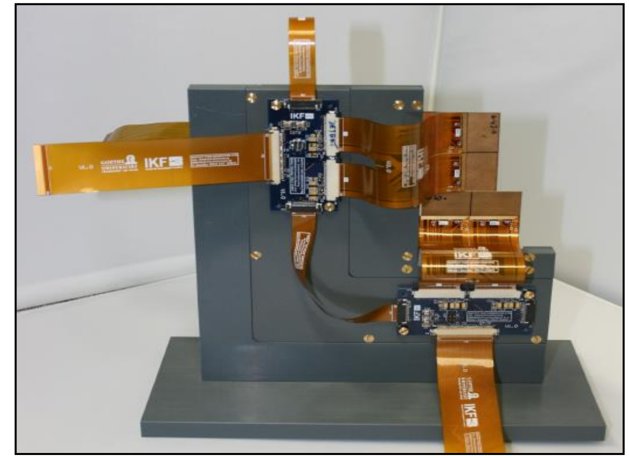
# CBM Start-Version: Micro-Vertex Detector



MIMOSA 26



station design



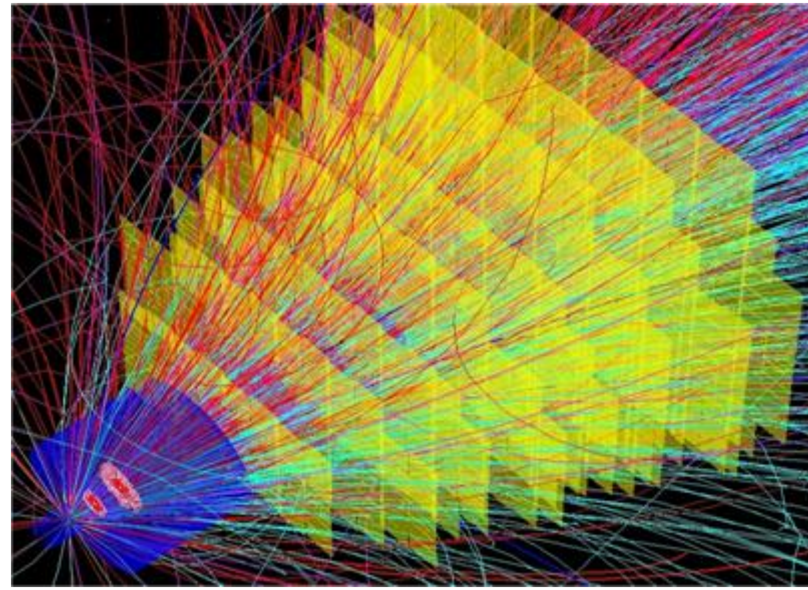
prototype

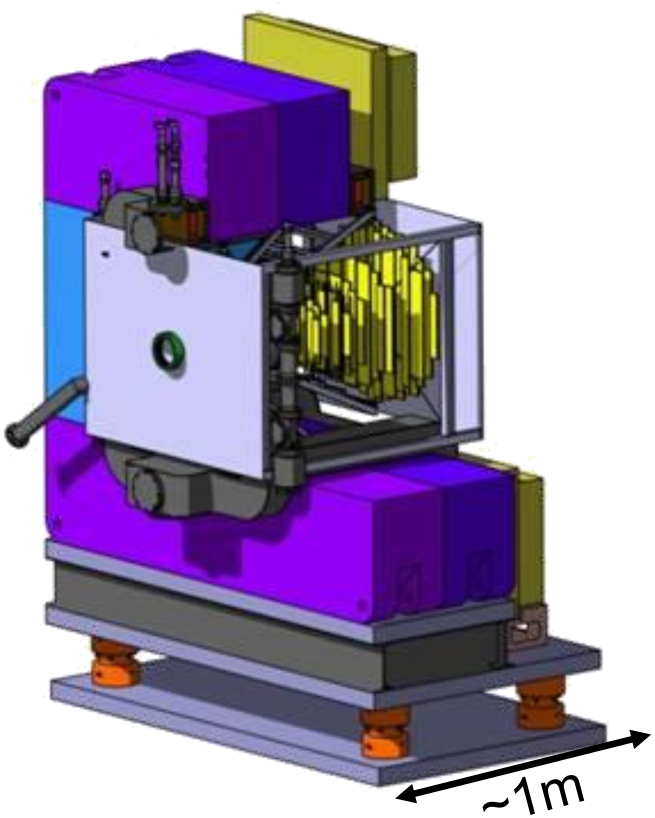
The key to open charm is a high-precision, ultra low-mass vertex detector

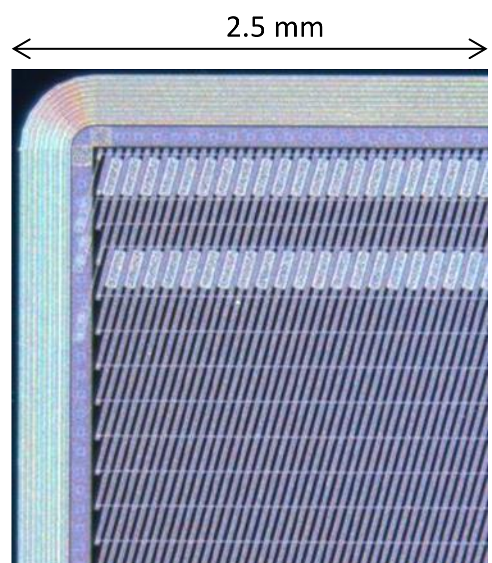
- MAPS: integrated electronics, very low material budget, very precise (3 µm)
- Not intrisically fast and radiation hard, but tremendeous progress: 40 µs r/o frame, stands up to $10^{13}$ $n_{eq}/cm^2$
- now almost „state of the art“ (STAR, ALICE, NA61 upgrades)

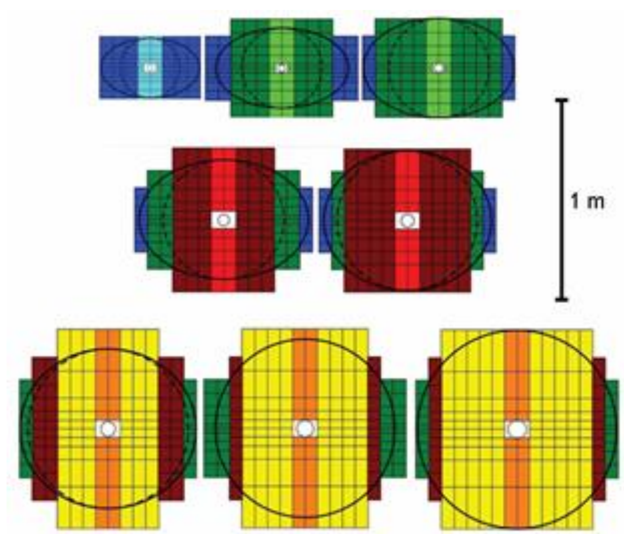
# CBM Start-Version: Silicon Tracking System

double sided silicon microstrip detector 15° stereo angle, 60 µm pitch, 300 µm thick, bonded to ultra-thin micro-cables, radiation hardness





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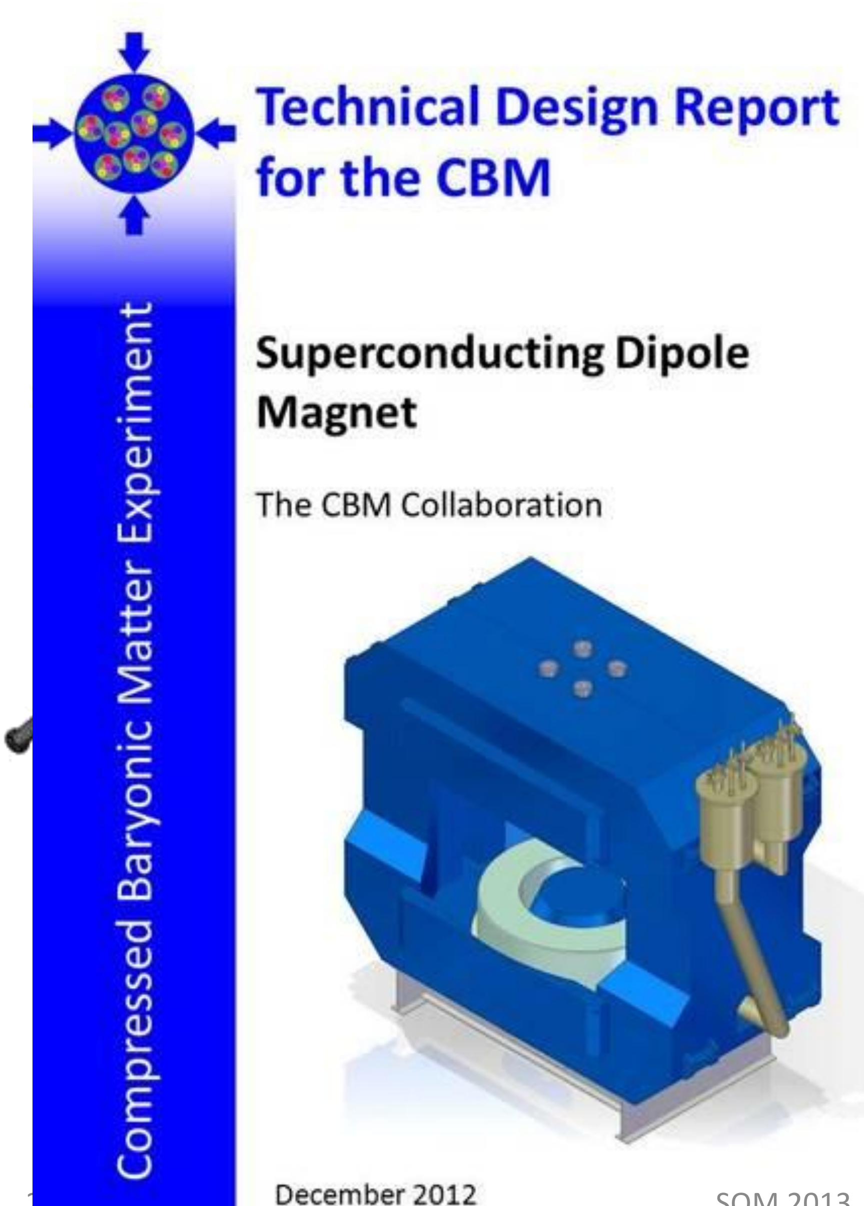


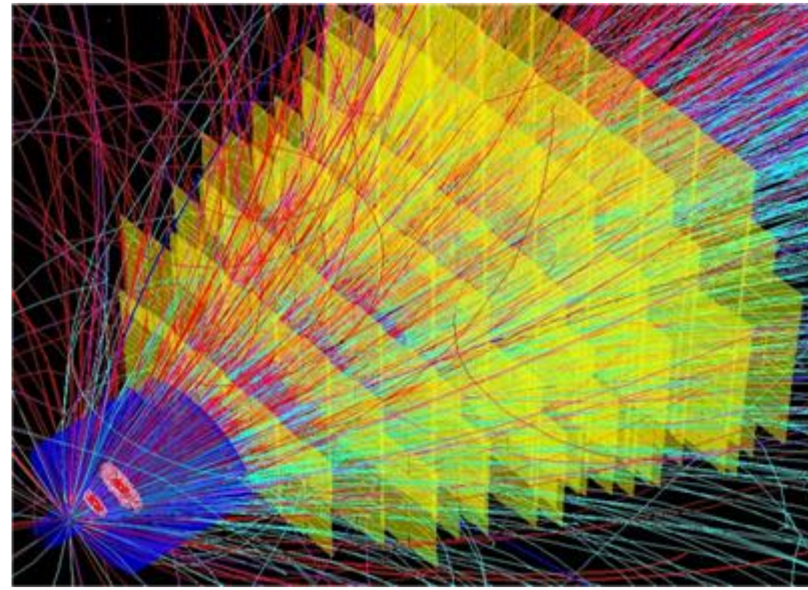

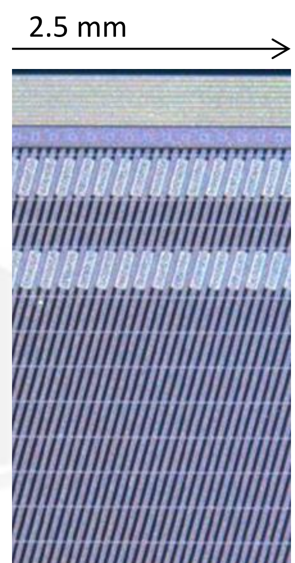


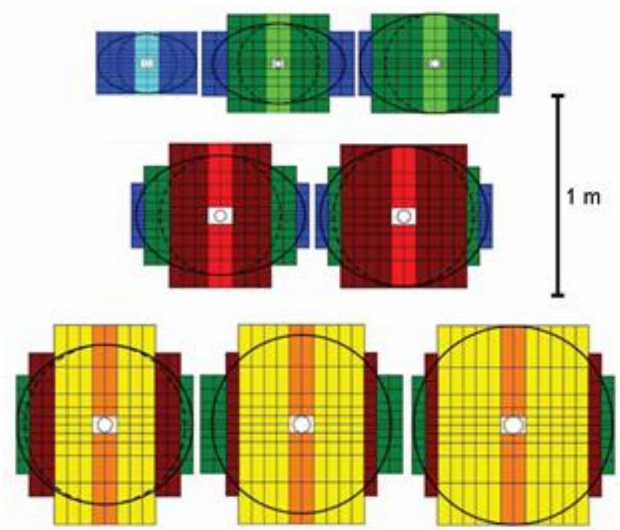

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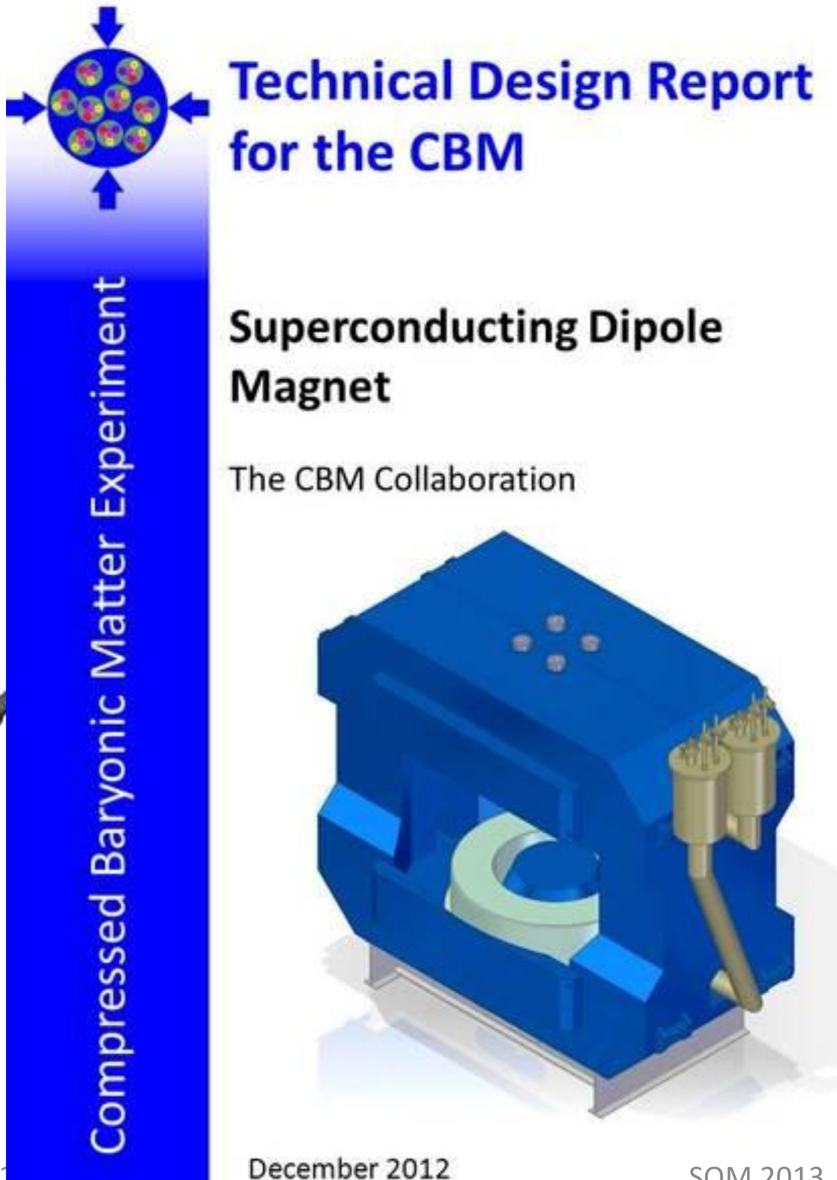
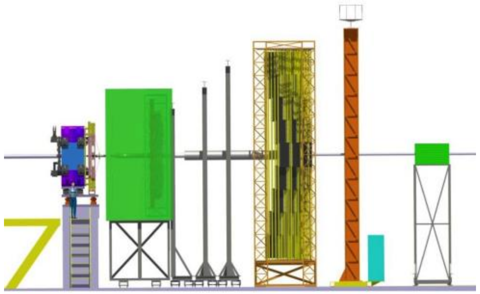



# The Big Challenge: Data Reduction



CBM FEE

At 10 MHz, online data reduction by ≈ 1000 is mandatory

Trigger signatures are complex (open charm) and require partial event reconstruction

1 TB/s

free steaming data flow

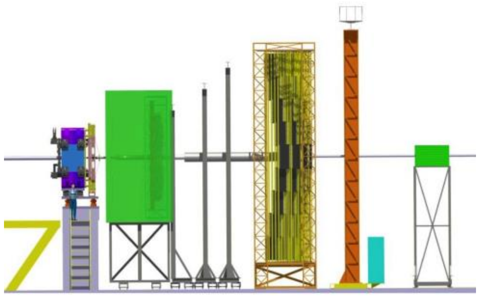
Online Data Processing

1 GB/s

Mass Storage

- No a-priori association of signals to physical events!
- „Event building“ becomes non-trivial at high rates
- Need extremely fast reconstruction algorithms!

# The Big Challenge: Data Reduction



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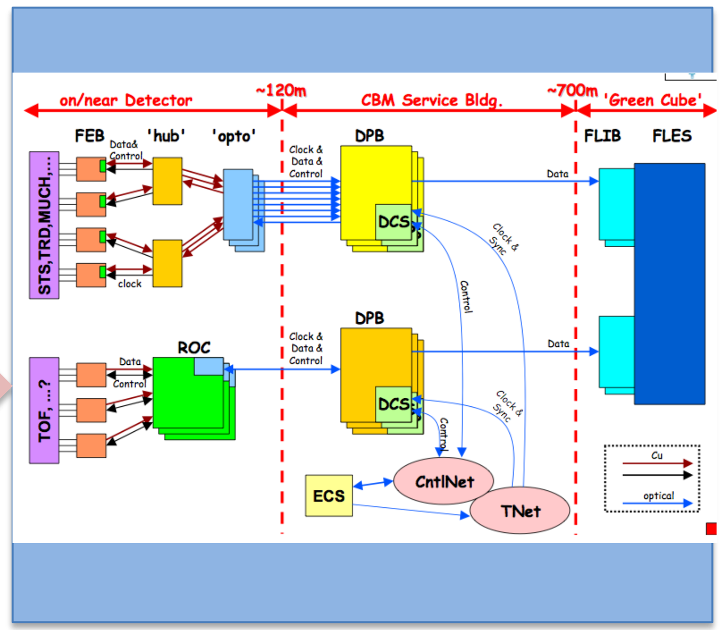


1 GB/s

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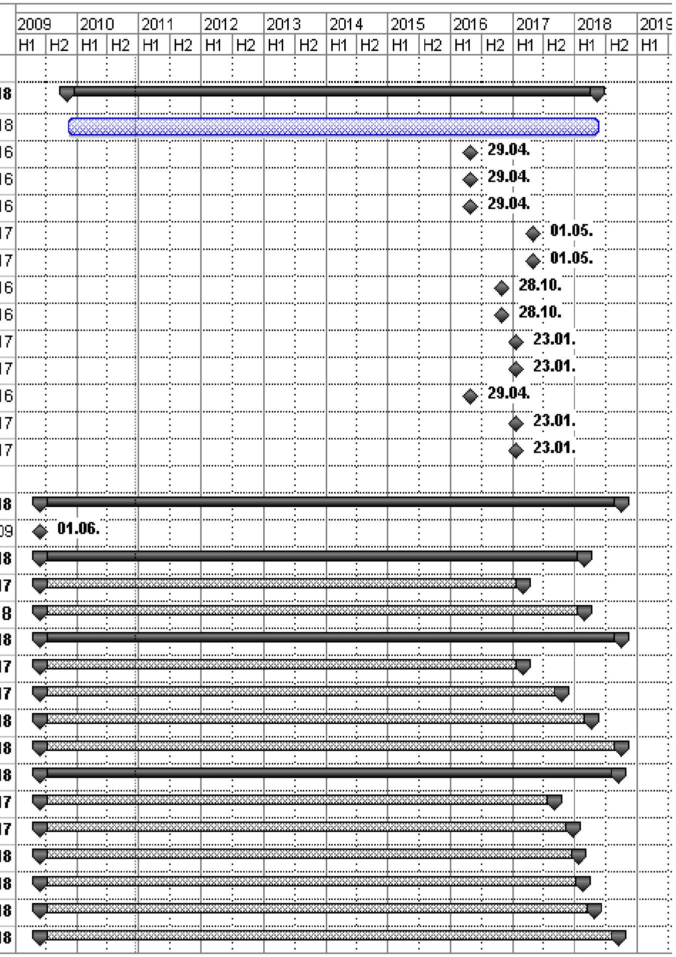
# CBM Time Line

| Nr. | | Vorgangsname | Anfang | Ende |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | **FAIR Civil Construction** | **Fr 06.11.09** | **Mi 09.05.18** |
| 3 | | Planning, Tendering, Construction of Site and Buildings | Fr 06.11.09 | Mi 09.05.18 |
| 4 | | Ready to move in HEBT Connection SIS18- SIS100 | Fr 29.04.16 | Fr 29.04.16 |
| 5 | | Ready to move in HEBT SIS100 | Fr 29.04.16 | Fr 29.04.16 |
| 6 | | Ready to move in SIS100 | Fr 29.04.16 | Fr 29.04.16 |
| 7 | | Ready to move in HEBT - T1X1... | Mo 01.05.17 | Mo 01.05.17 |
| 8 | | Ready to move in Multifunction Caves (CBM, HADES) | Mo 01.05.17 | Mo 01.05.17 |
| 9 | | Ready to move in HEBT -T1F1... | Fr 28.10.16 | Fr 28.10.16 |
| 10 | | Ready to move in Super-FRS | Fr 28.10.16 | Fr 28.10.16 |
| 11 | | Ready to move in HEBT TAP1 ... | Mo 23.01.17 | Mo 23.01.17 |
| 12 | | Ready to move in p-bar Target | Mo 23.01.17 | Mo 23.01.17 |
| 13 | | Ready to move in p-LINAC | Fr 29.04.16 | Fr 29.04.16 |
| 14 | | Ready to move in CR | Mo 23.01.17 | Mo 23.01.17 |
| 15 | | Ready to move in HESR | Mo 23.01.17 | Mo 23.01.17 |
| 16 | | | | |
| 17 | | **FAIR Accelerator for Set-Up Phase** | **Mo 01.06.09** | **Fr 28.09.18** |
| 18 | | **Module 0 - 3** | Mo 01.06.09 | Mo 01.06.09 |
| 19 | | **Systems Block 1 of Mod 0-3** | **Mo 01.06.09** | **Do 22.02.18** |
| 20 | | **HEBT Connection SIS18 - SIS100 (T1S1, T1S2, T1S3, T1S4)** | **Mo 01.06.09** | **Mi 01.03.17** |
| 103 | | **Super FRS** | **Mo 01.06.09** | **Do 22.02.18** |
| 188 | | **Systems Block 2 of Mod 0 - 3** | **Mo 01.06.09** | **Fr 28.09.18** |
| 189 | | **HEBT-SIS100 (T8DU)** | **Mo 01.06.09** | **Mi 01.03.17** |
| 271 | | **SIS100** | **Mo 01.06.09** | **Fr 13.10.17** |
| 372 | | **HEBT - T1X1, T1C1,T1D1-T1C2,TNC1 - T1X2,TXL1,TXL2,TXL3,TXL4,TPP1,T** | **Mo 01.06.09** | **Di 03.04.18** |
| 453 | | **Multifunction Caves (CBM HADES)** | **Mo 01.06.09** | **Fr 28.09.18** |
| 533 | | **Systems Block 3 of Mod 0 - 3** | **Mo 01.06.09** | **Fr 14.09.18** |
| 534 | | **HEBT - T1F1,T1F2,TFF1, TSX1, TSF1, FRF, TFC1** | **Mo 01.06.09** | **Di 29.08.17** |
| 614 | | **HEBT - TAP1, TAP2, TCR1, THS1** | **Mo 01.06.09** | **Do 21.12.17** |
| 694 | | **p-bar Target** | **Mo 01.06.09** | **Mi 17.01.18** |
| 774 | | **p-LINAC** | **Mo 01.06.09** | **Do 15.02.18** |
| 855 | | **CR** | **Mo 01.06.09** | **Mi 25.04.18** |
| 935 | | **HESR** | **Mo 01.06.09** | **Fr 14.09.18** |



# CBM Time Line

| Nr. | Vorgangsname | Anfang | Ende | 2009–2019 |
|---|---|---|---|---|
| 1 | | | | |
| 2 | **FAIR Civil Construction** | **Fr 06.11.09** | **Mi 09.05.18** | |
| 3 | Planning, Tendering, Construction of Site and Buildings | Fr 06.11.09 | Mi 09.05.18 | |
| 4 | Ready to move in HEBT Connection SIS18- SIS100 | Fr 29.04.16 | Fr 29.04.16 | 29.04. |
| 5 | Ready to move in HEBT SIS100 | Fr 29.04.16 | Fr 29.04.16 | 29.04. |
| 6 | Ready to move in SIS100 | Fr 29.04.16 | Fr 29.04.16 | 29.04. |
| 7 | Ready to move in HEBT - T1X1 ... | Mo 01.05.17 | Mo 01.05.17 | 01.05. |
| 8 | Ready to move in Multifunction Caves (CBM, HADES) | Mo 01.05.17 | Mo 01.05.17 | 01.05. |
| 9 | Ready to move in HEBT -T1F1 ... | Fr 28.10.16 | Fr 28.10.16 | 28.10. |
| 10 | Ready to move in Super-FRS | Fr 28.10.16 | Fr 28.10.16 | 28.10. |
| 11 | Ready to move in HEBT TAP1 ... | Mo 23.01.17 | Mo 23.01.17 | 23.01. |
| 12 | Ready to move in p-bar Target | Mo 23.01.17 | Mo 23.01.17 | 23.01. |
| 13 | Ready to move in p-LINAC | | | 29.04. |
| 14 | Ready to move in CR | | | 23.01. |
| 15 | Ready to move in HESR | | | 23.01. |
| 16 | | | | |
| 17 | **FAIR Accelerator for Set-Up Phase** | **Mo 01.06.09** | **Fr 28.09.18** | |
| 18 | **Module 0 - 3** | Mo 01.06.09 | Mo 01.06.09 | 01.06. |
| 19 | **Systems Block 1 of Mod 0-3** | **Mo 01.06.09** | **Do 22.02.18** | |
| 20 | **HEBT Connection SIS18 - SIS100 (T1S1, T1S2, T1S3, T1S4)** | **Mo 01.06.09** | **Mi 01.03.17** | |
| 103 | **Super FRS** | **Mo 01.06.09** | **Do 22.02.18** | |
| 188 | **Systems Block 2 of Mod 0 - 3** | **Mo 01.06.09** | **Fr 28.09.18** | |
| 189 | **HEBT-SIS100 (T8DU)** | **Mo 01.06.09** | **Mi 01.03.17** | |
| 271 | **SIS100** | **Mo 01.06.09** | **Fr 13.10.17** | |
| 372 | **HEBT - T1X1, T1C1,T1D1-T1C2,TNC1 - T1X2,TXL1,TXL2,TXL3,TXL4,TPP1,T** | **Mo 01.06.09** | **Di 03.04.18** | |
| 453 | **Multifunction Caves (CBM HADES)** | **Mo 01.06.09** | **Fr 28.09.18** | |
| 533 | **Systems Block 3 of Mod 0 - 3** | **Mo 01.06.09** | **Fr 14.09.18** | |
| 534 | **HEBT - T1F1,T1F2,TFF1, TSX1, TSF1, FRF, TFC1** | | | |
| 614 | **HEBT - TAP1, TAP2, TCR1, THS1** | | | |
| 694 | **p-bar Target** | | | |
| 774 | **p-LINAC** | **Mo 01.06.09** | **Do 15.02.18** | |
| 855 | **CR** | **Mo 01.06.09** | **Mi 25.04.18** | |

CBM cave ready: May 1, 2017

SIS100 ready: Oct. 13, 2017

| 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| R&D detectors & read-out systems | | | construction detectors & read-out systems | | | | installation, commissioning | | first data taking | |

# CBM Collaboration (55 Labs, 400 People)

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

**Croatia:**
RBI, Zagreb
Split Univ.

**China:**
CCNU Wuhan
Tsinghua Univ.
USTC Hefei

**Czech Republic:**
CAS, Rez
Techn. Univ.Prague

**France:**
IPHC Strasbourg

**Hungaria:**
KFKI Budapest
Budapest Univ.

**Norway:**
Univ. Bergen

**Germany:**
Frankfurt Univ. IKF
Frankfurt Univ. FIAS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. KIP
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
Münster Univ.
Tübingen Univ.
Wuppertal Univ.

**Korea:**
Korea Univ. Seoul
Pusan Nat. Univ.

**Romania:**
NIPNE Bucharest
Univ. Bucharest

**India:**
Aligarh Muslim Univ.
Panjab Univ.
Rajasthan Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
SAHA Kolkata
IOP Bhubaneswar
IIT Kharagpur
Gauhati Univ.

**Poland:**
AGH Krakow
Jag. Univ. Krakow
Silesia Univ. Katowice
Warsaw Univ.

**Russia:**
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP MSU, Moscow
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Kiev Inst. Nucl. Research