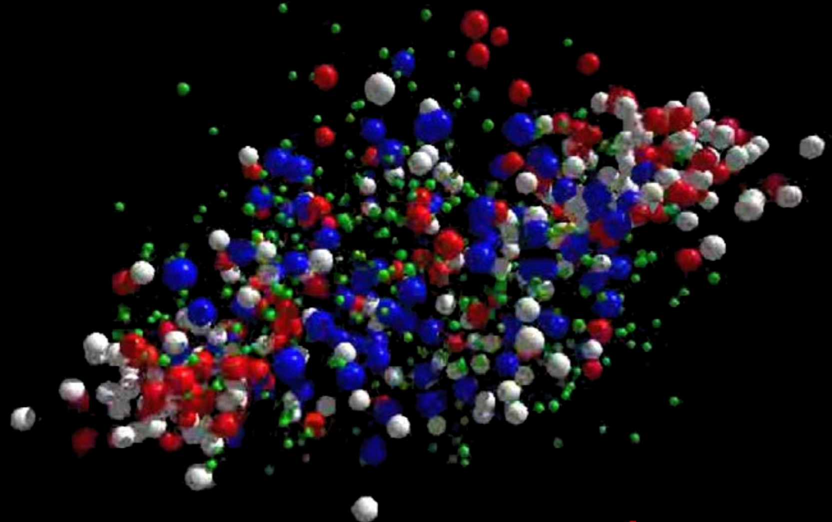


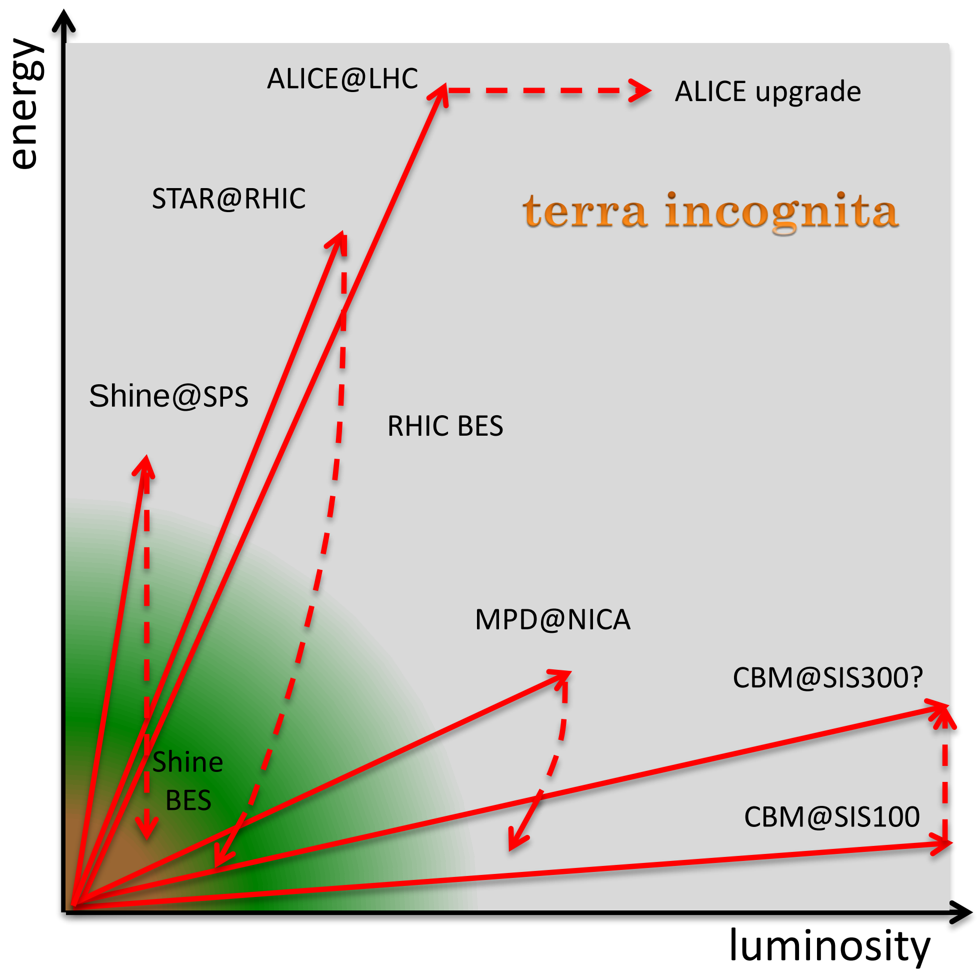
Hyperon Production at CBM-FAIR & Detector Requirements

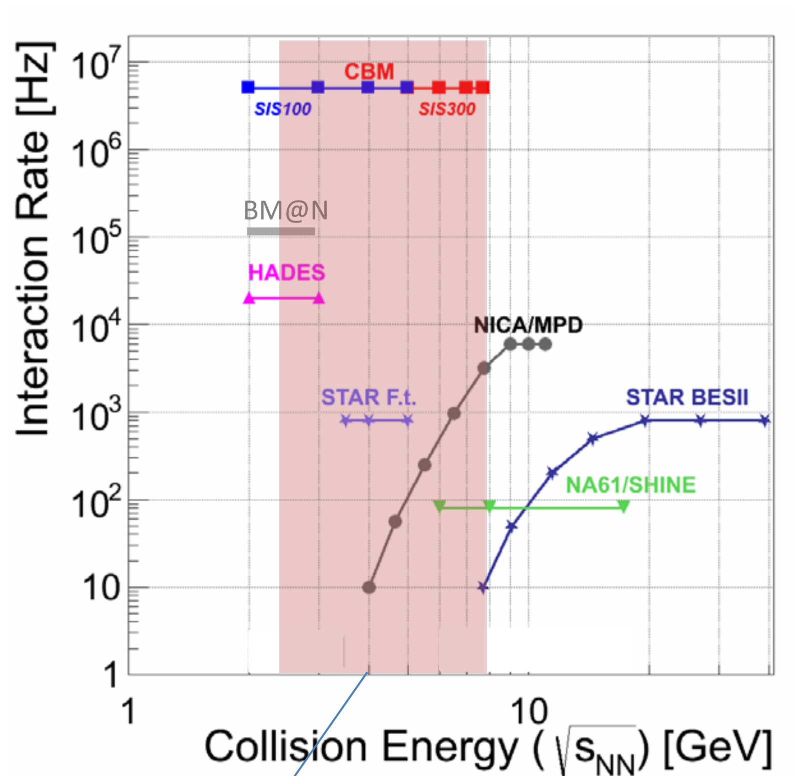
32nd Winter Workshop on Nuclear Dynamics

February 28th-March 5th, 2016

Guadeloupe, France

Landscape of Discovery in Super-Dense Matter Physics



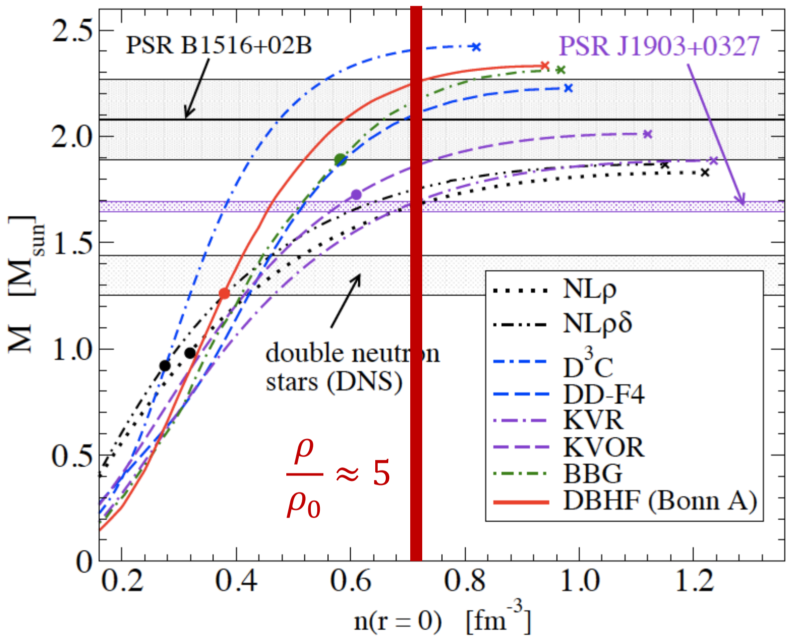


highest net-baryon densities

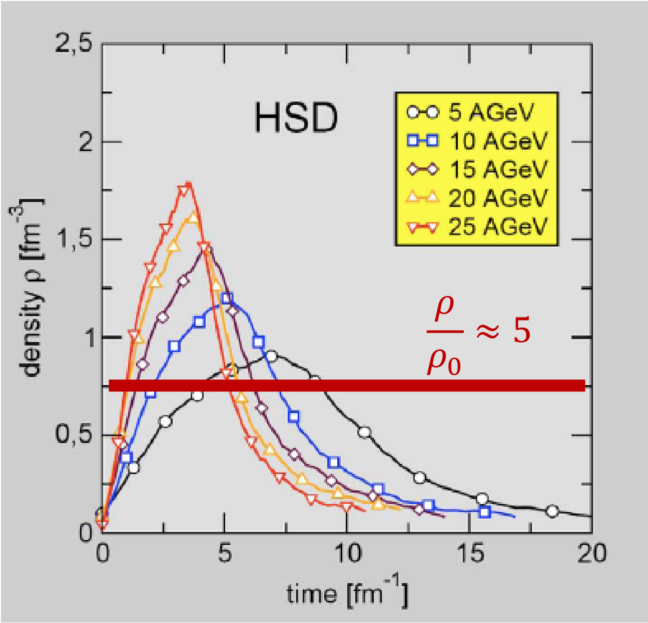
note: at CBM energies
$1min$ CBM ~ $1\ y$ STAR@RHIC

Densities in Neutron Stars and in Nuclear Collisions

NS: Mass vs density



HI: density vs. time



W. Cassing, E.L. Bratkovskaya, Phys. Rep. 308, 65 (1999)

experimental prerequisites to understand NS in the laboratory:

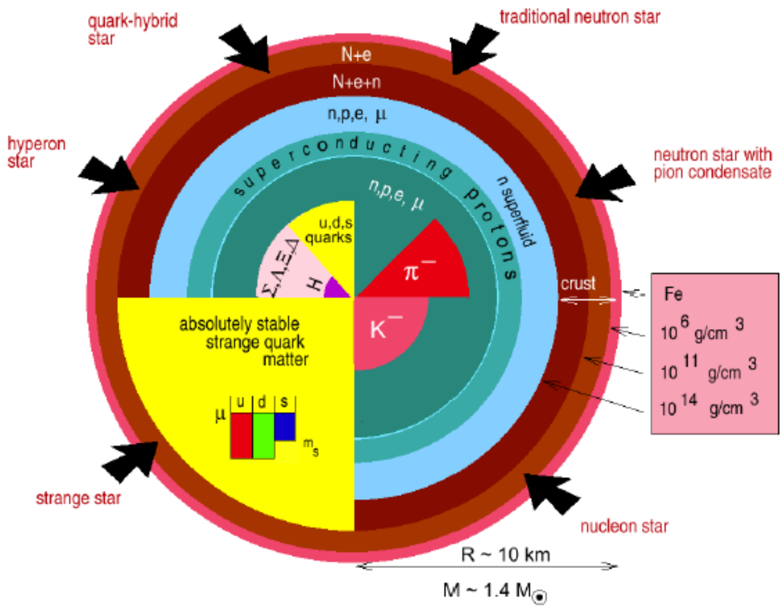
- high, long-lived baryonic densities ⇒ reached in AuAu collision around 10 AGeV
- probes of high density phase (are „traditional" nuclear flow measurements suffient?)

what do we want to learn from HI-collisions for NS?

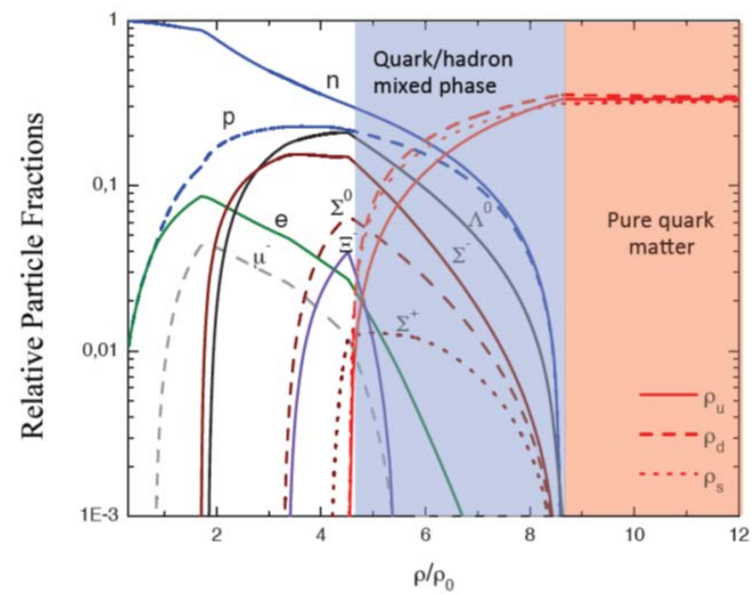
Structure of Neutron Stars

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)



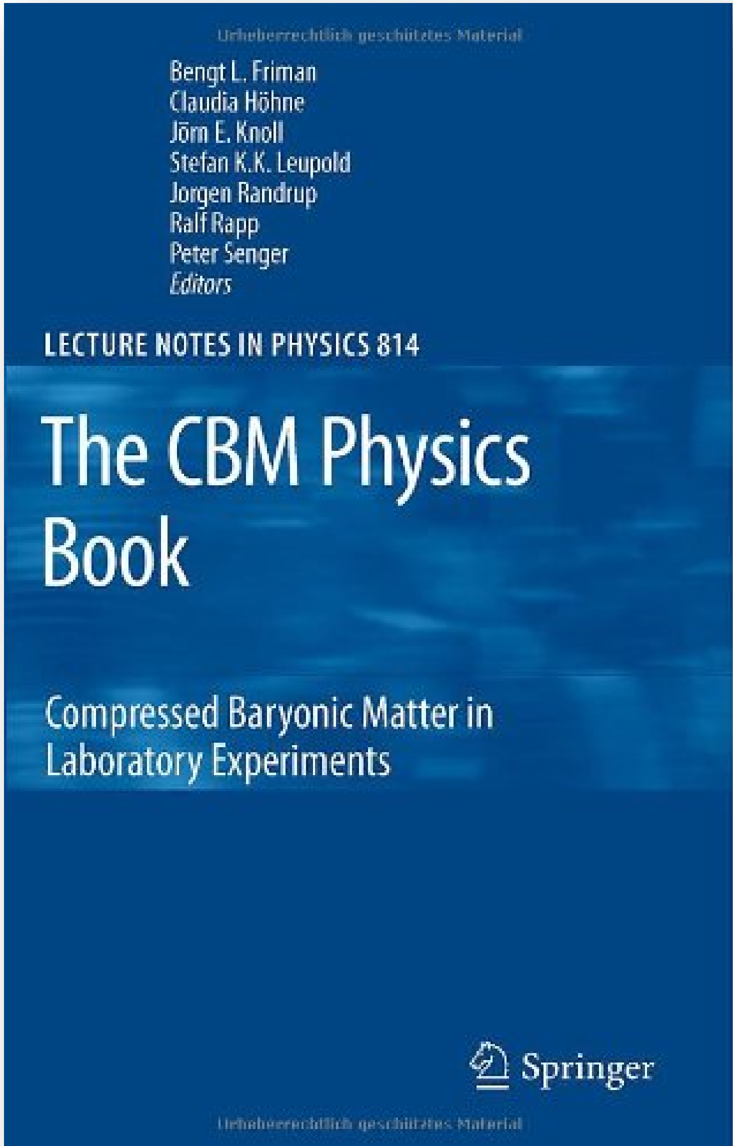
recent observation of a $\frac{M}{M_\odot} \approx 2$ Neutron Star → hyperon puzzle

- not stable against gravitational collaps with soft EOS, i.e., a $2M_\odot$ NS should not exist!
- stable Neutron Star with quark-hadron mixed phase incl. hyperons possible (?)
  - EoS of hybrid matter (soft, hard ?)
  - important: knowledge of NY & YY interactions $(Y = \Lambda, \Sigma, \Xi, \Omega)$ → couplings

Outline

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

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



The CBM Physics Book

Foreword by Frank Wilczek

Springer Series:
Lecture Notes in Physics, Vol. 814
1st Edition., 2011, 960 p., Hardcover
ISBN: 978-3-642-13292-6

Electronic Authors version:
http://www.gsi.de/documents/DOC-2009-Sep-120-1.pdf

Nuclear Matter Flow

Experimental Investigation von of flow observables

$$v_1 = \left\langle \frac{P_x}{P_T} \right\rangle \sim F_y = \frac{d\langle p_x/A \rangle}{dy}\bigg|_{y=y_{mid}}$$

$$v_2 = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle \sim \langle \cos 2\phi \rangle$$

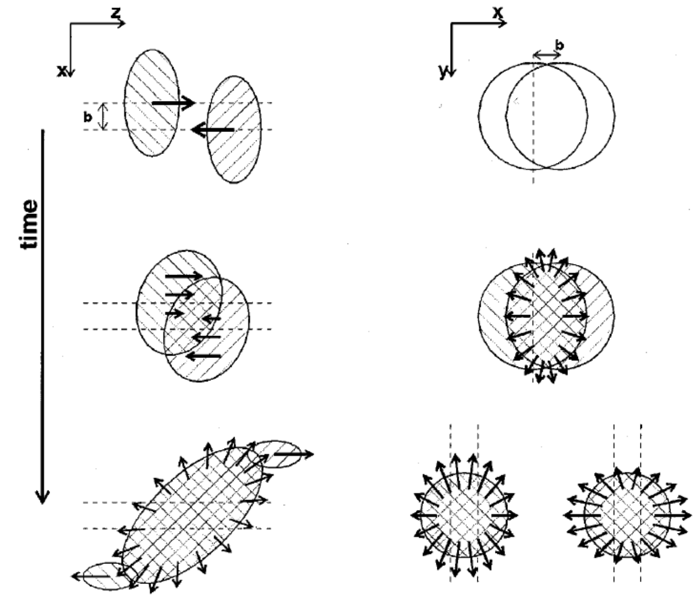
in the energy range

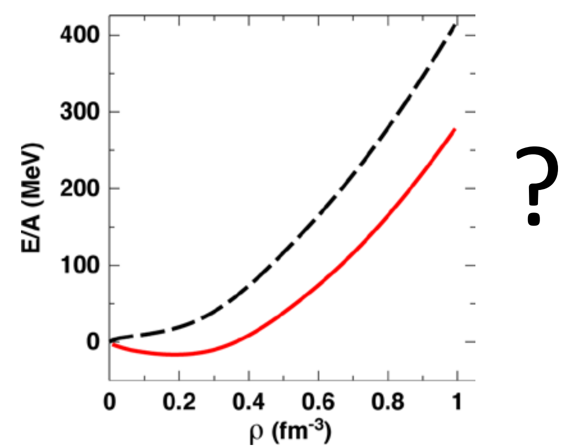
$$1 AGeV < E_{lab} < 10\ AGeV$$

has essentially stopped in the last century with the decommissioning FOPI (GSI-SIS18) & E877/895 (BNL-AGS) experiments!

What are the results?

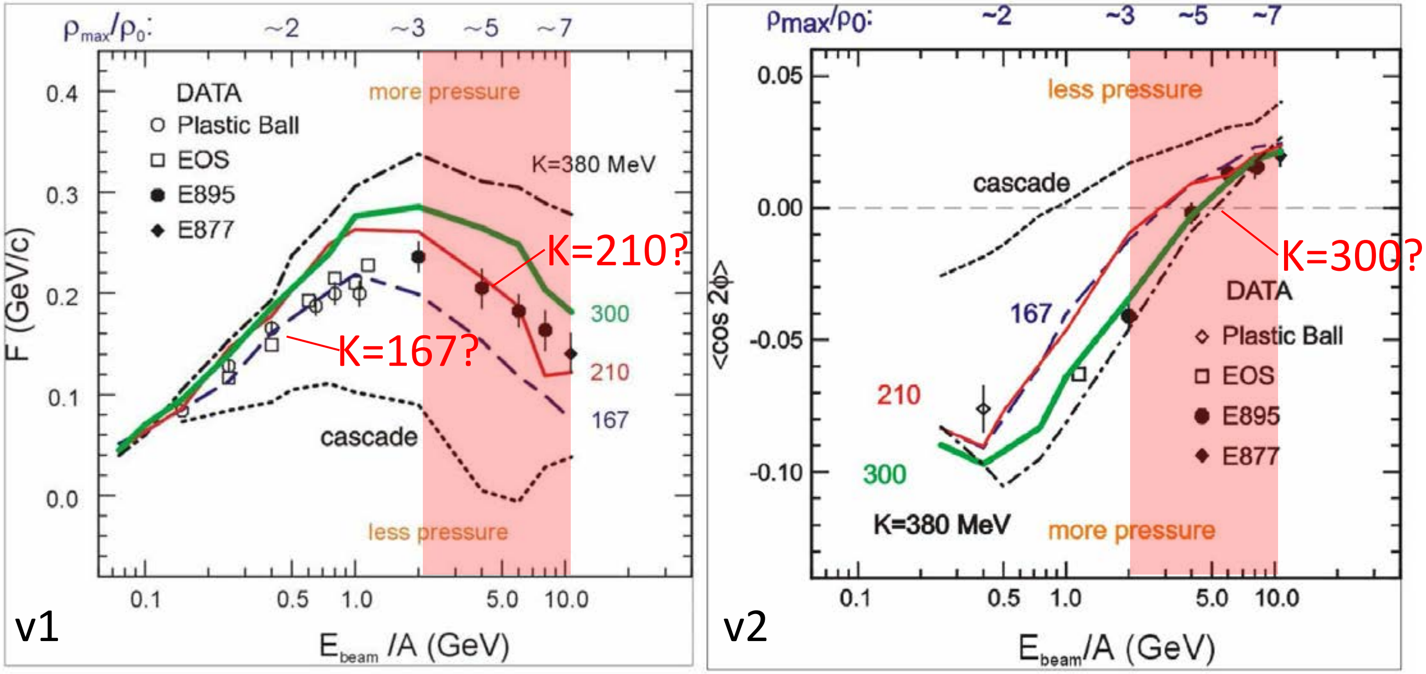
Do we know the Equation of State (EoS) of nuclear matter in all its facets?





Excitation Function of Proton Flow

P. Danielewicz, arxiv.org/abs/nucl-th/0112006 (2001)



- comparison of data and theory inconclusive!
- no single EOS allows for a simultaneous description of both types of anisotropies at all energies.
- uncertainty in data maps to uncertainty of in K of 150 MeV!

but:

- protons represent only small part of flowing species: clusters, (heavy) meson, hyperons, …
- largest sensitivity to model parameters of EOS in CBM energy range

Reminder: Flow of Charged Kaons (FOPI-Experiment)

Properties of mesons in matter?

flow observable is sensitive to sign of in-medium potential

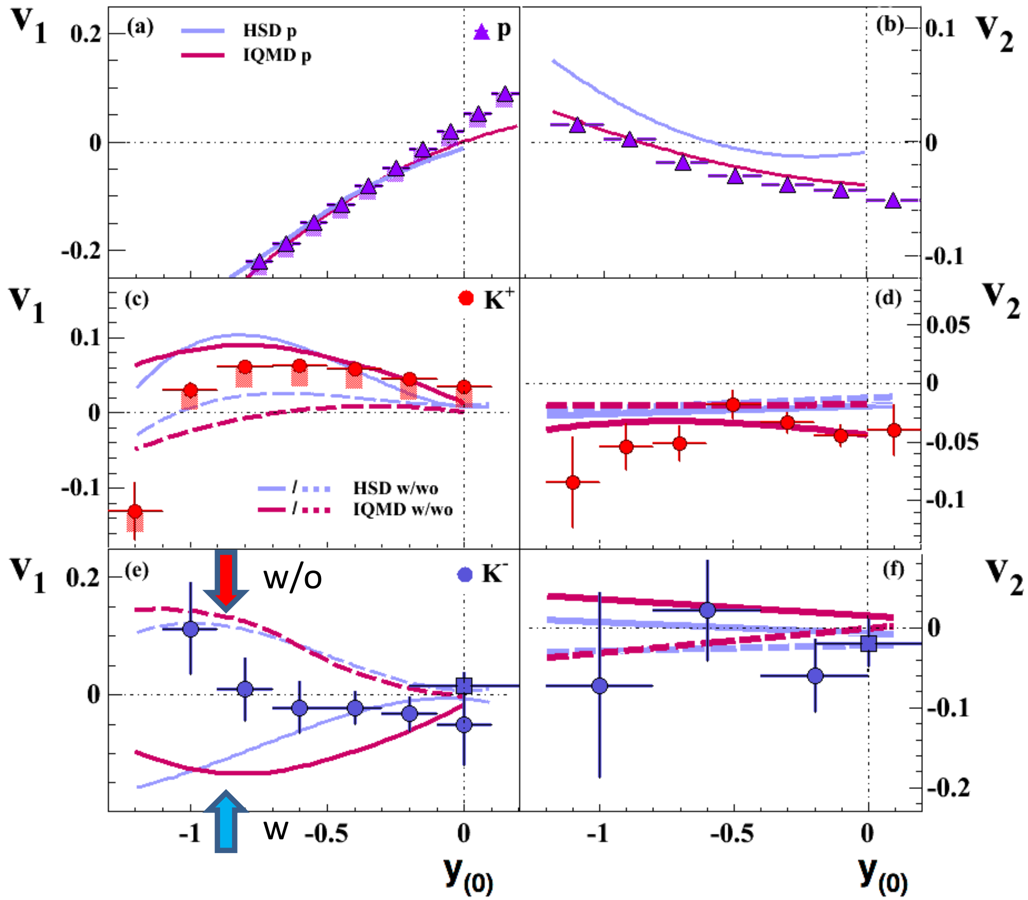
Indications from kaon flow:
K^+ repulsive potential
K^- attractive potential

<u>However:</u> Statistics limited for kaon production close to threshold!

Ni+Ni at 1.91 AGeV

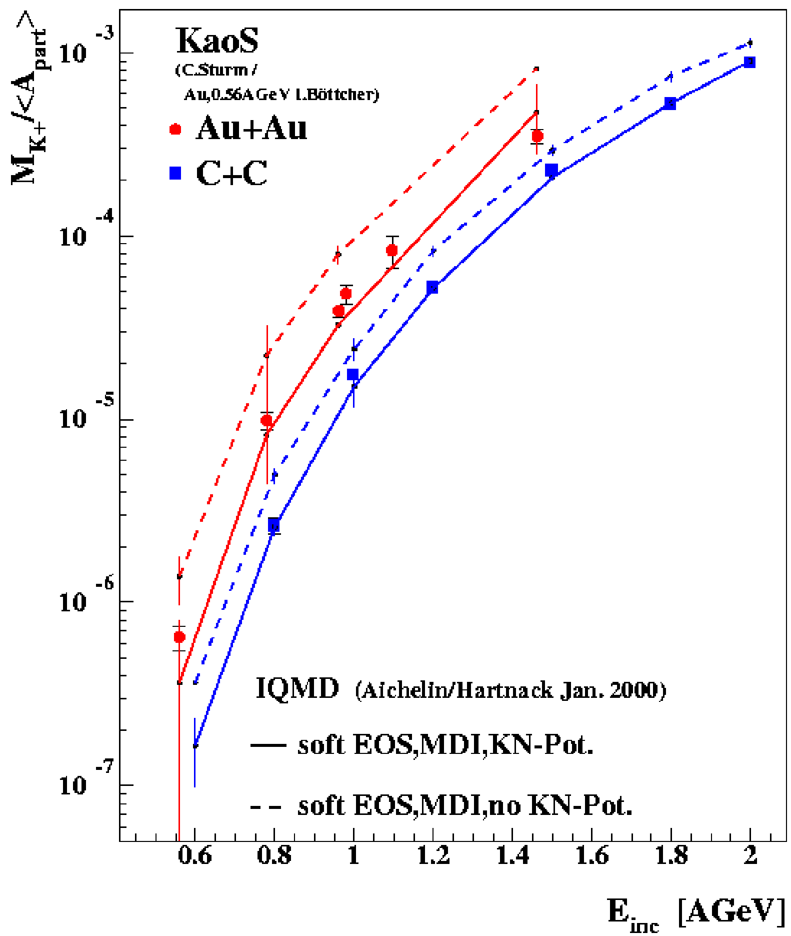
V.Zinyuk et al. (FOPI)
PRC 90 (2014) 025210

Models with FOPI acceptance filter



Reminder: Subthreshold Kaons (KAOS-Experiment)

C.Sturm et al. (KaoS), PRL 86 (2001) 39



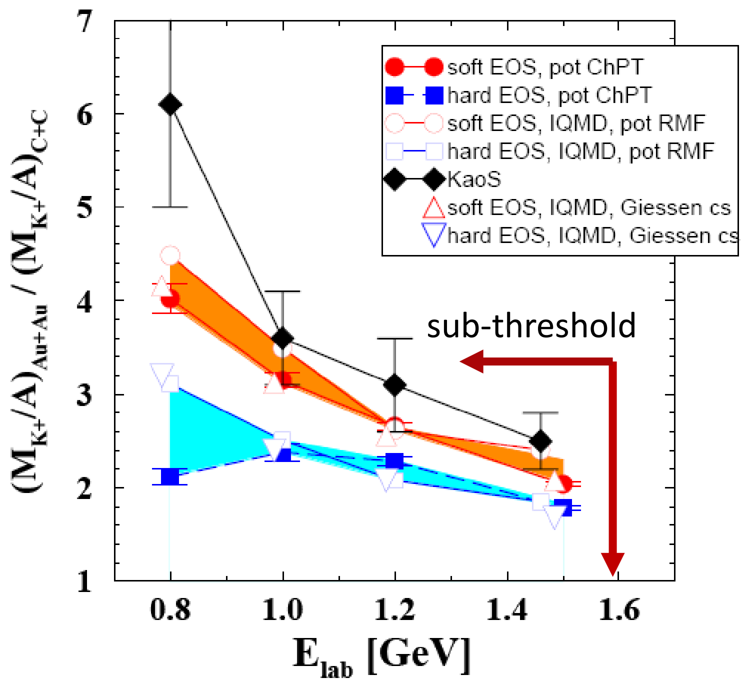
$pp \rightarrow K^+ \Lambda p \;\; E^{beam}_{thresh} = 1.6\ AGeV$

production via multiple collison: $NN \rightarrow N\Delta \rightarrow \cdots \rightarrow K^+ N$

⇒ sensitivity to density ⇒ soft EOS (K=200 MeV)

Fuchs, Aichelin, Hartnack, ….

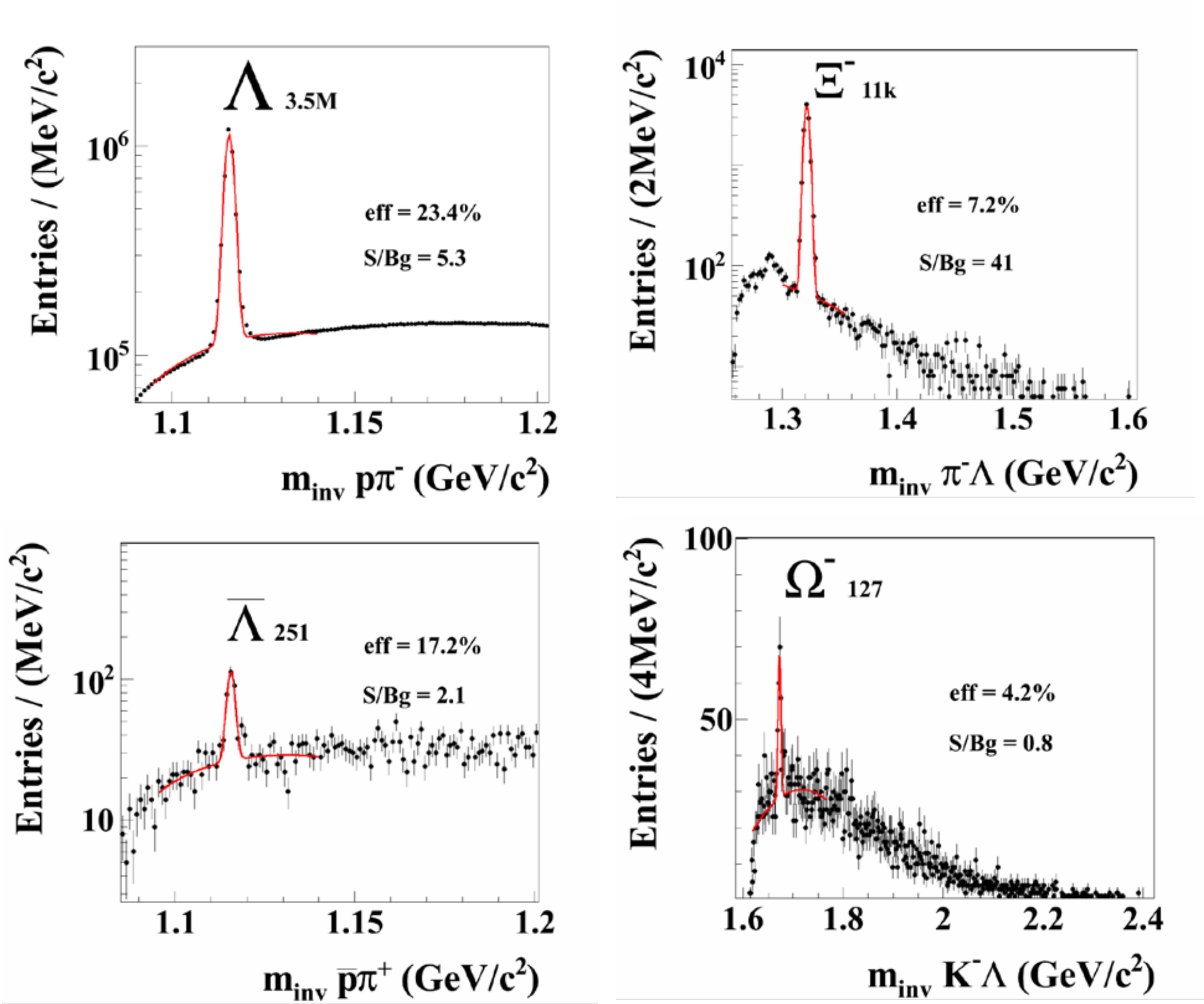
C. Fuchs et al., PRL 86 (2001) 1974



Similary: Sensitivity of hyperons to μ_B & EOS?

Hyperons in CBM at SIS100

Simulations: Au+Au at 8 A GeV, 10^6 central collisions
promise and challange of CBM: data taking of a few seconds at 10^7 Hz



In addition: kaons and baryon resonances (K*,Λ*,Σ*,Ξ*)

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

yield/week

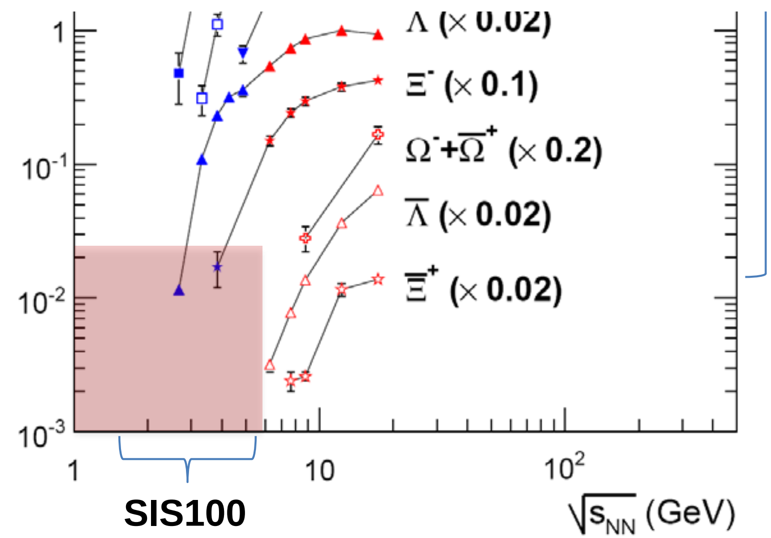
Beam energy	Ξ^-	Ω^-	$\overline{\Lambda}$	$\overline{\Xi}^+$	$\overline{\Omega}^+$
$4.0A$ GeV	$9.0 \cdot 10^6$	$1.8 \cdot 10^5$	$3.6 \cdot 10^3$	$5.3 \cdot 10^3$	$9.0 \cdot 10^2$
$6.0A$ GeV	$2.6 \cdot 10^7$	$5.0 \cdot 10^5$	$2.4 \cdot 10^5$	$1.4 \cdot 10^4$	$2.8 \cdot 10^3$
$8.0A$ GeV	$4.0 \cdot 10^7$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

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

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

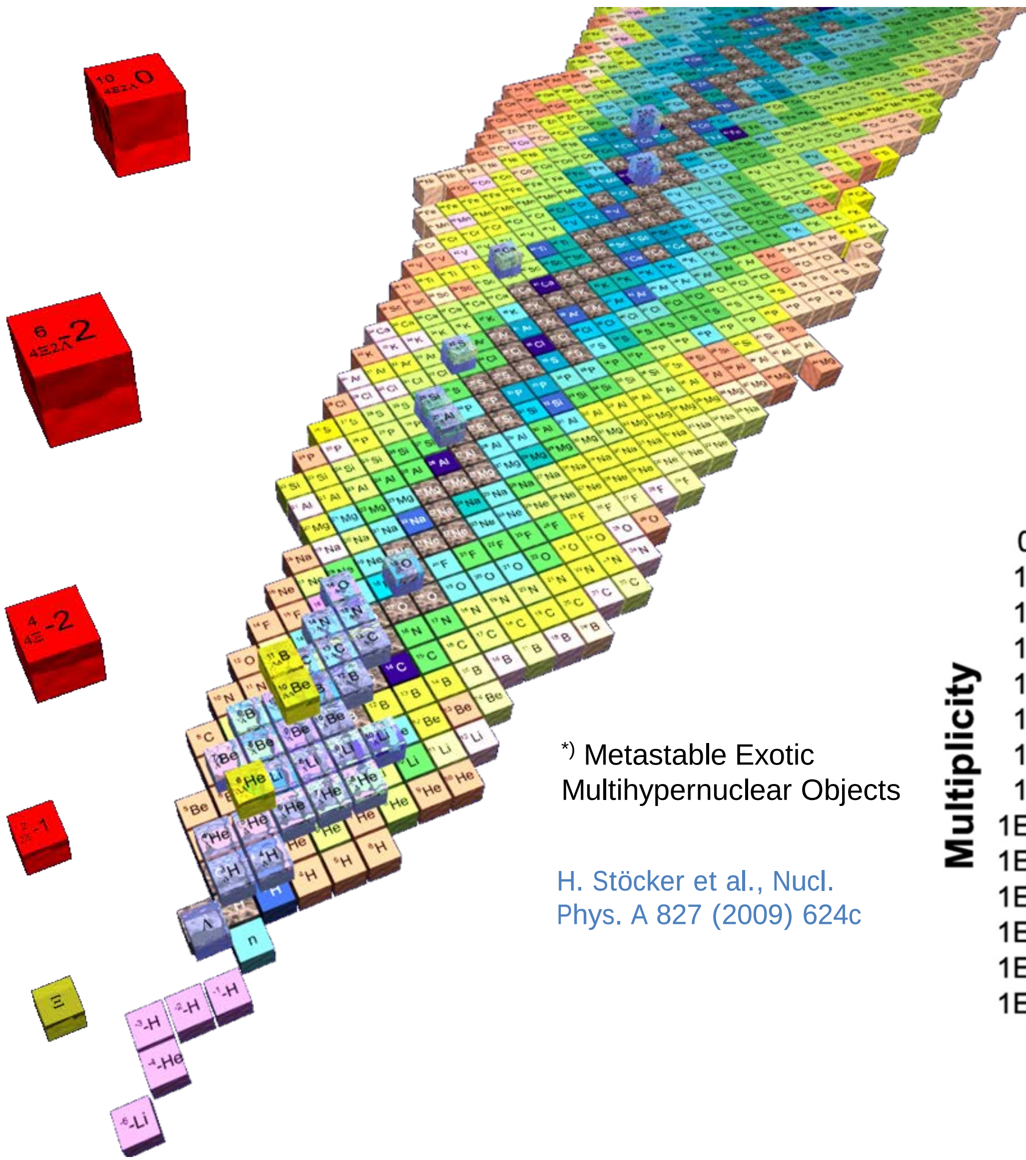
sub-threshold production cross section of Ξ^-, Ω^- probes dense, baryonic matter….

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

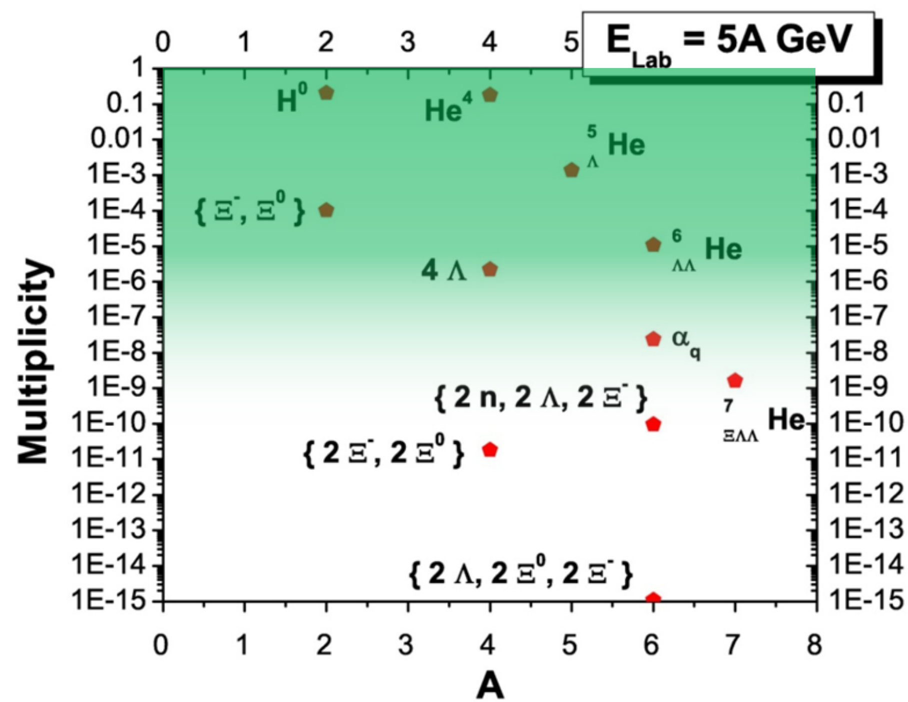


*) P. Chung et al, E895 Coll. PLR 91.202301(2003)
G. Agakishiev et al, Hades Coll, PRL 103, 132301 (2009)

Multi-Strangeness



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



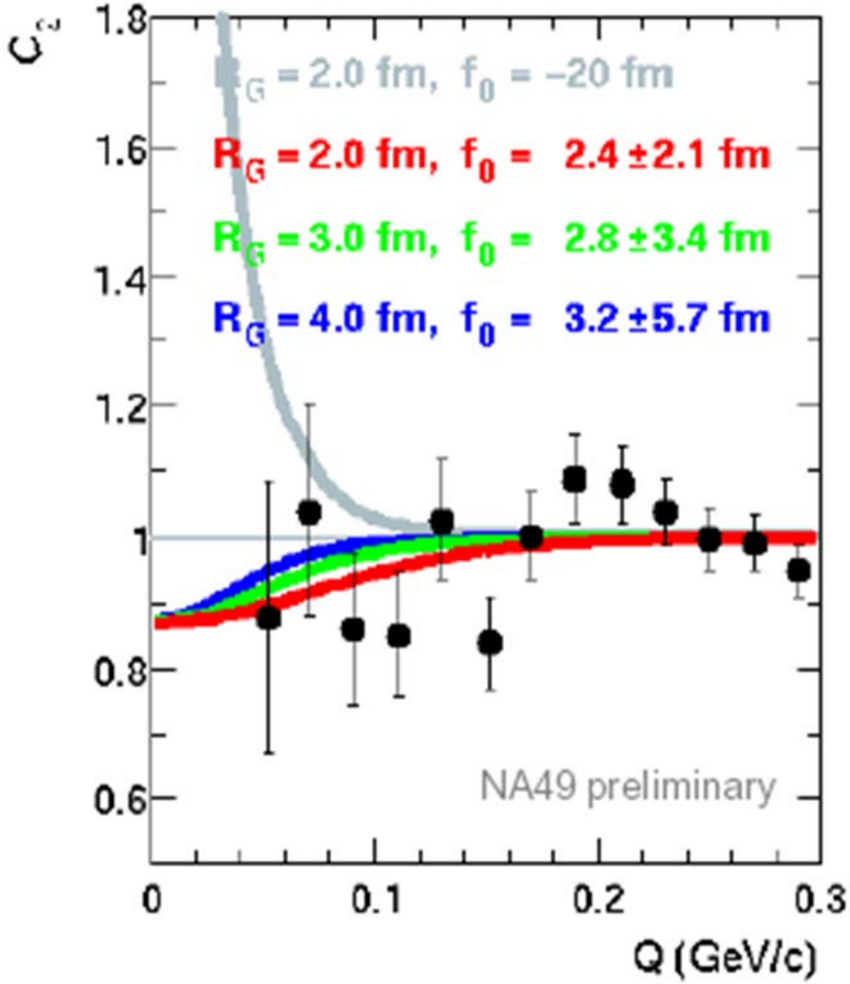
*) Metastable Exotic Multihypernuclear Objects

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

Hyperons (ΛΛ) Correlations at the SPS

$Pb + Pb\ 158\ AGeV$

Blume et al. Nucl. Phys. A715 (2003) 55

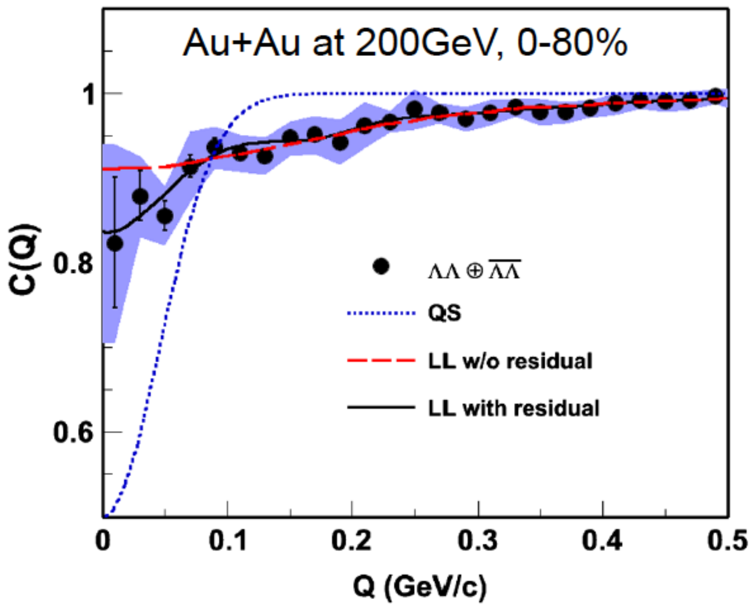


NA49

- 3500 $\Lambda\Lambda$ pairs with $Q < 0.3\,\frac{GeV}{c}$
- fit done with fixed R_G and λ, scattering length f_0 varied
- scattering length related to $\Lambda\Lambda$ - potential
- inconclusive due to low statistics

Hyperons ($\Lambda\Lambda$) Correlations at RHIC/STAR

STAR Col. Phys. Rev. Lett. 114, 022301(2015)

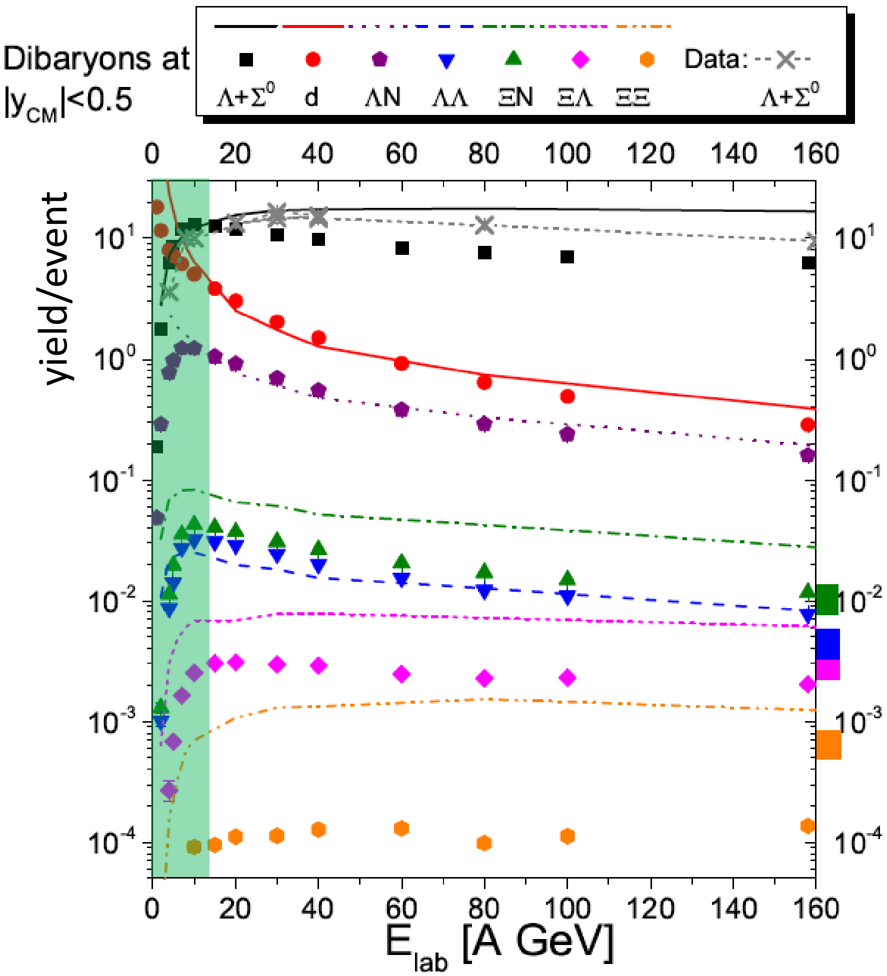


- $\sim 8 \times 10^8$ events analyzed
- fit to data with Lednicky-Lyuboshitz model w and w/o residual $\Lambda\Lambda$ interaction:
- $CF(Q = 0) > \mathrm{CF_{QS}}(\mathrm{Q} = 0) \Rightarrow$ attractive interaction?
  - no correction from feed down, i.e. residual correlation (only 45% of $\Lambda's$ are primary)
- scattering length $a_{\Lambda\Lambda} = -1.0 \pm 0.38^{+0.96}_{-0.02}\ fm$
- effective range $r_{\Lambda\Lambda} = 8.52 \pm 2.56^{+2.09}_{-0.74} fm$
- firm conclusion on sign of potential is model dependent and limited by statistics

substantial feed down: $\Lambda's$ from $\Sigma^0\Lambda$, $\Sigma^0\Sigma^0$, and $\Xi^-\Xi^-$.

Jinhui Chen @ SQM 2015

Di-Baryons and Hyperons Correlations at FAIR/CBM?



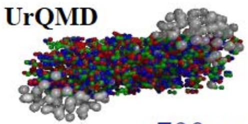
lines: UrQMD + thermal hydrodynamics
symbols: DCM + coalescence

J. Steinheimer, K. Gudima, A. Botvina, I. Mishustin, M. Bleicher, H. Stöcker, Phys. Lett B714 (2012) 85

PHSD

~700 π
174 p
42 K
30 Λ
24 K_S^0
2.4 Ξ^-
0.005 Ω^-

UrQMD



~700 π
160 p
53 K
32 Λ
27 K_S^0
0.44 Ξ^-
0.018 Ω^-

copious production of hyperons (due to high rate) and favorable phase space make CBM@FAIR a:

- di-baryon factory ☺

…but will at least provide good stat. correlation data (→ hyperon couplings)

Double-strange hypernuclei

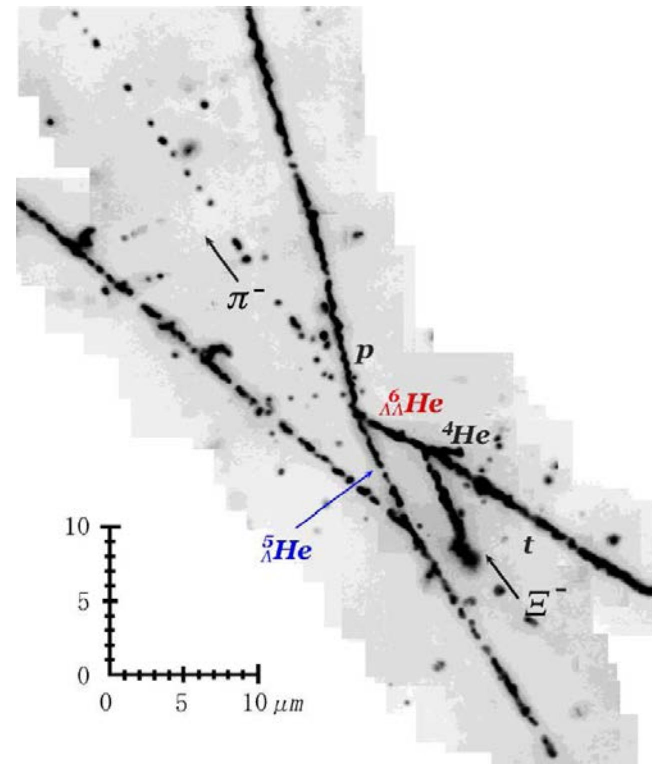
VOLUME 87, NUMBER 21 PHYSICAL REVIEW LETTERS 19 NOVEMBER 2001

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]

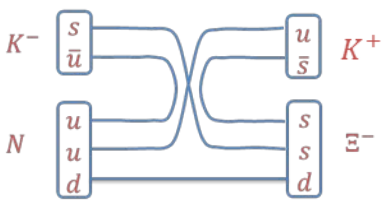
Observed ΛΛ hypernuclei:

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)



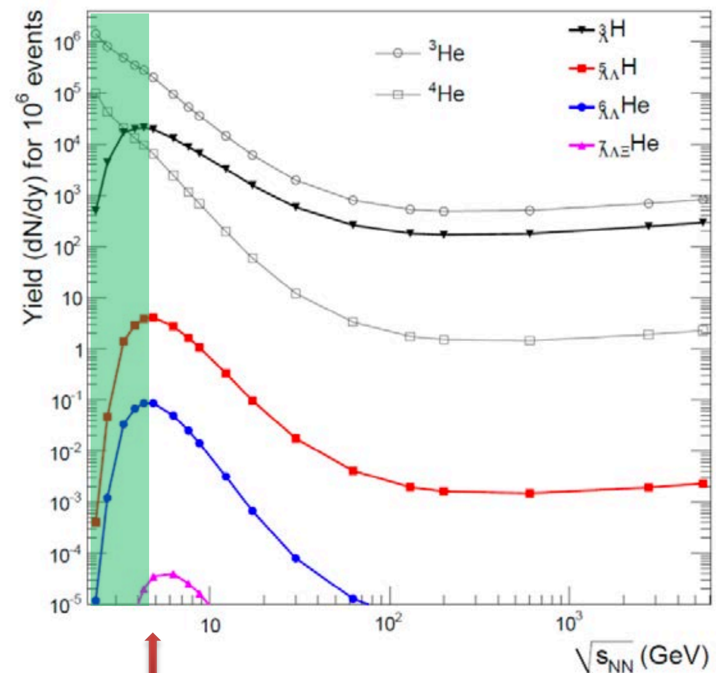
Search for Double Hypernuclei

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



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

<u>heavy collisions:</u>

production via coalescence of Λ with light fragments

40 AGeV: 50 $\Lambda's$/central Au+Au collision
10 AGeV: 15 $\Lambda's$/central Au+Au collision

yield: $10^{-6}\,{}^{5}_{\Lambda\Lambda}H, 3\cdot10^{-8}\,{}^{6}_{\Lambda\Lambda}He$ /central collision

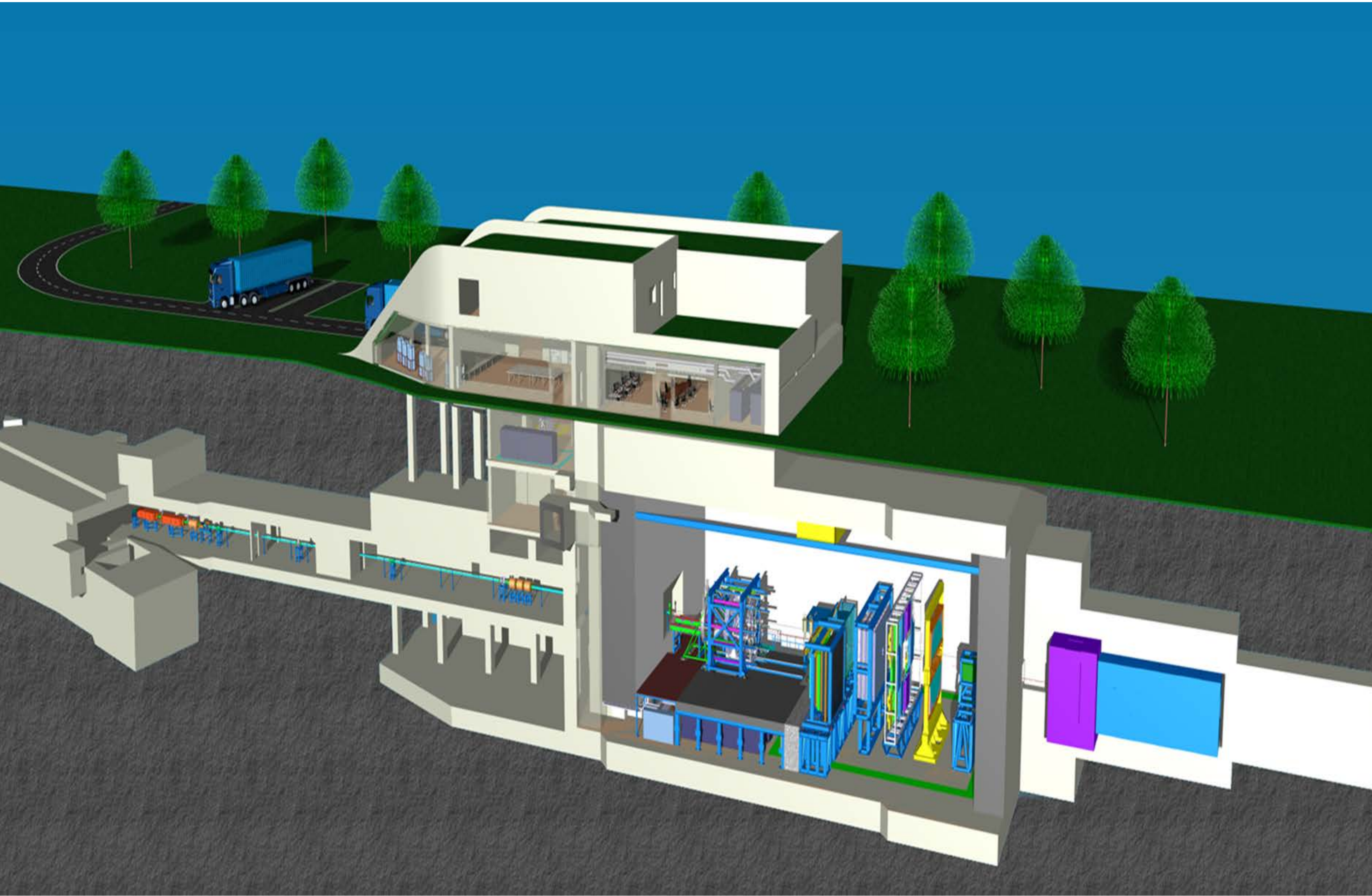
120/week 3.6/week

*) Takahashi et al, PRL 87 (2001)

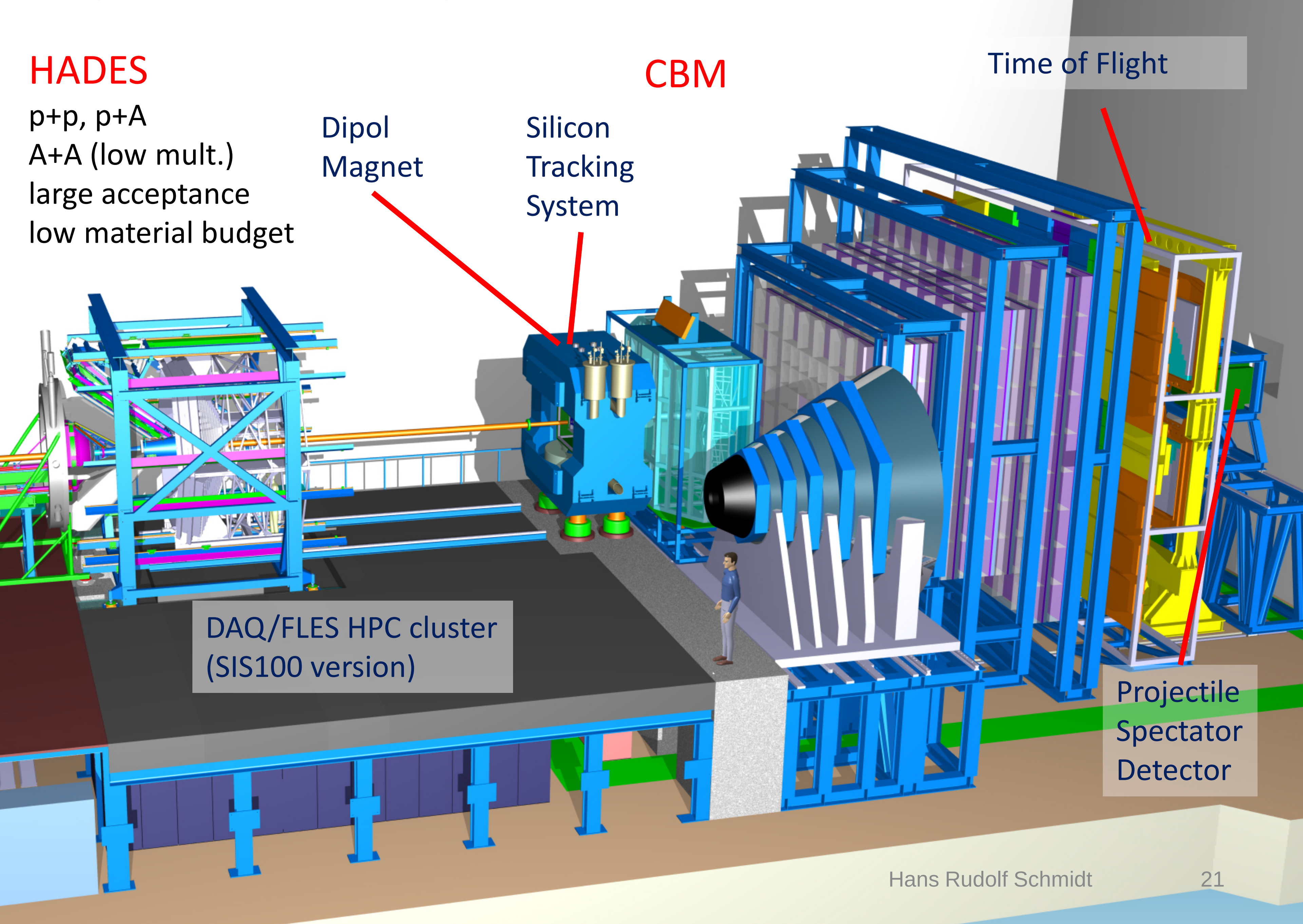
Experimental Requirements

- 10^5 - 10^7 Au+Au reactions/sec
- determination of displaced vertices ($\sigma \approx 50\ \mu m$)
- 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

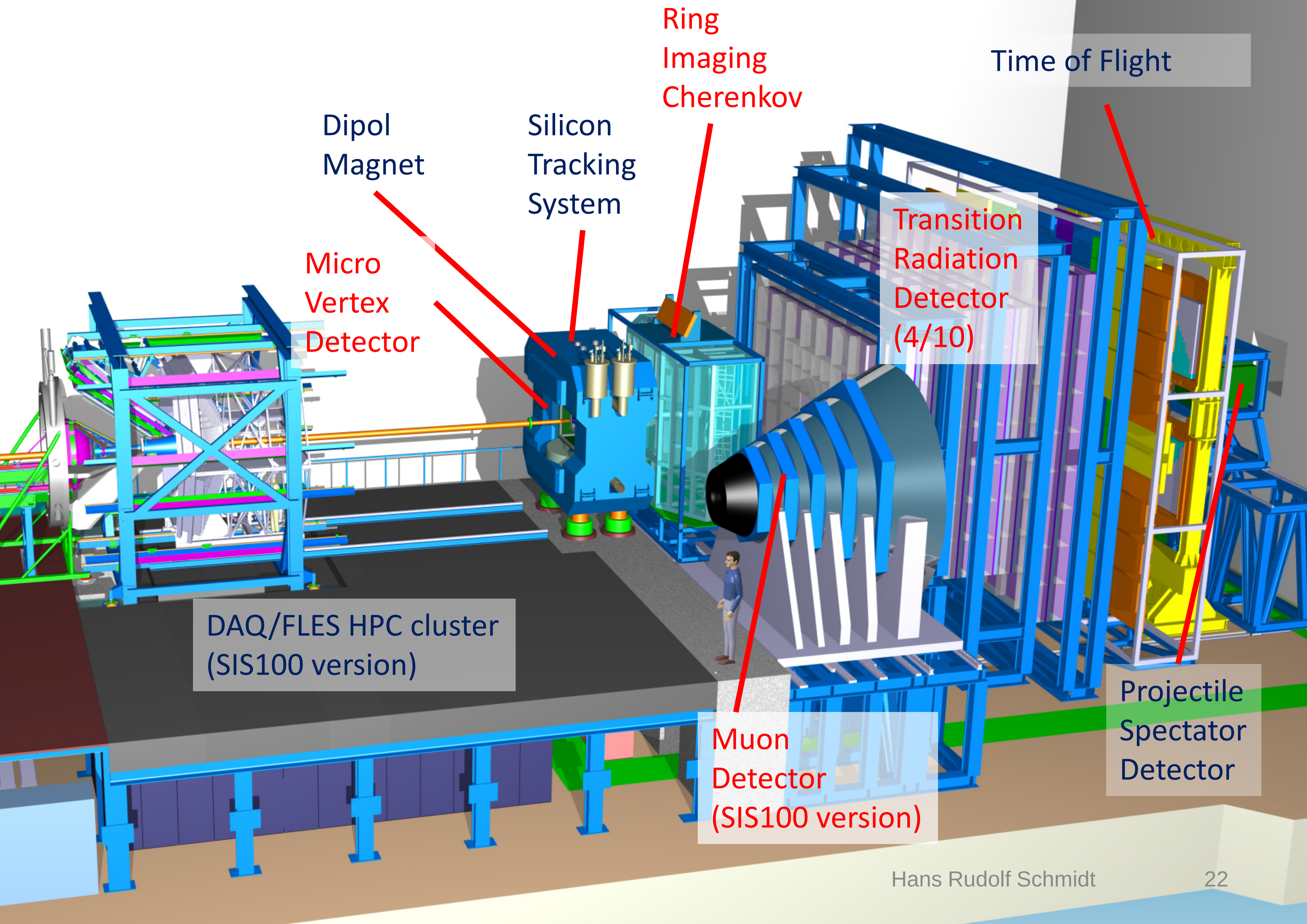
Facility for Antiproton & Ion research



Experimental Requirements: Hadrons

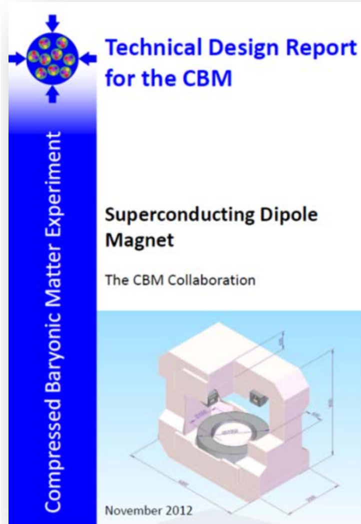


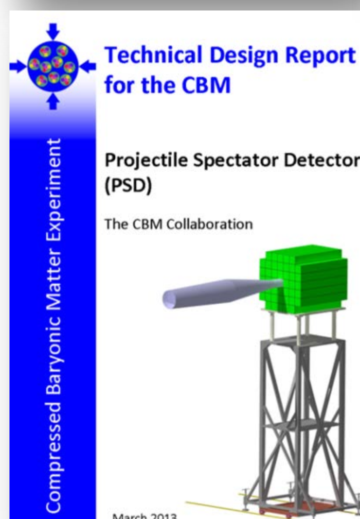
Experimental Requirements: Leptons

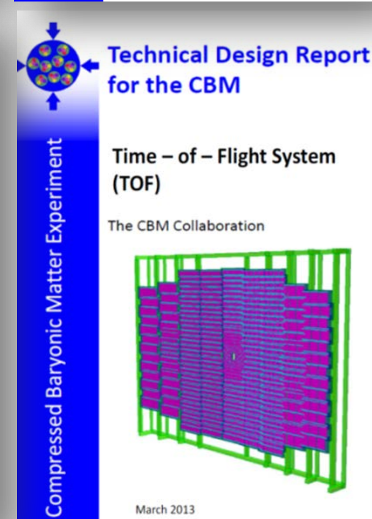


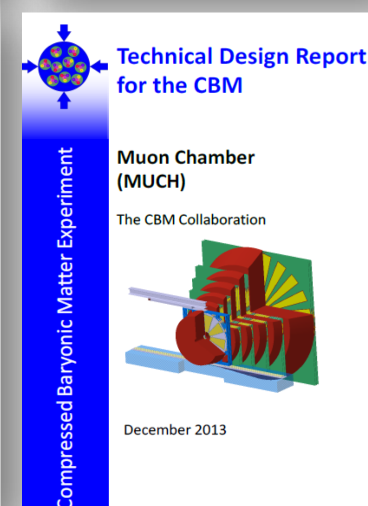
CBM Technical Design Reports

#	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 2016
9	DAQ/FLES	submission 2017
10	TRD	submission 2016

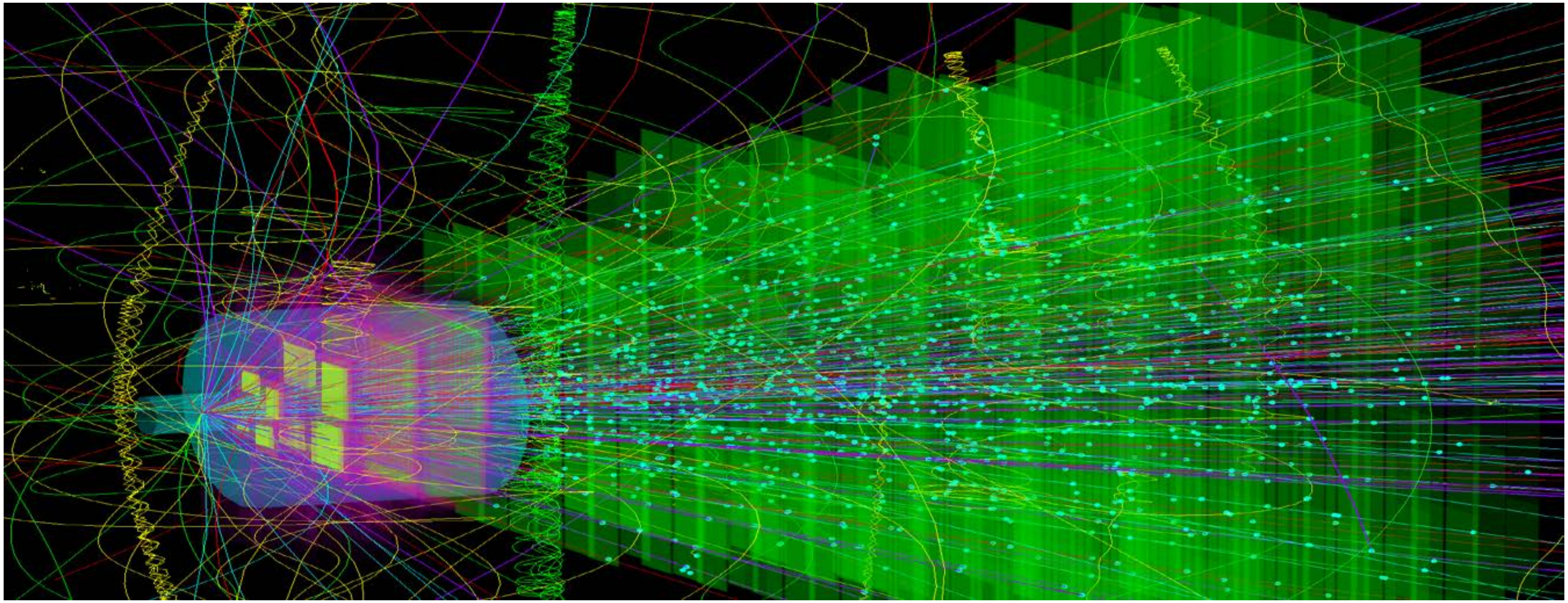








Ongoing R&D:
Development of CMOS sensors (MVD), read-out ASIC for STS, and DAQ/FLES



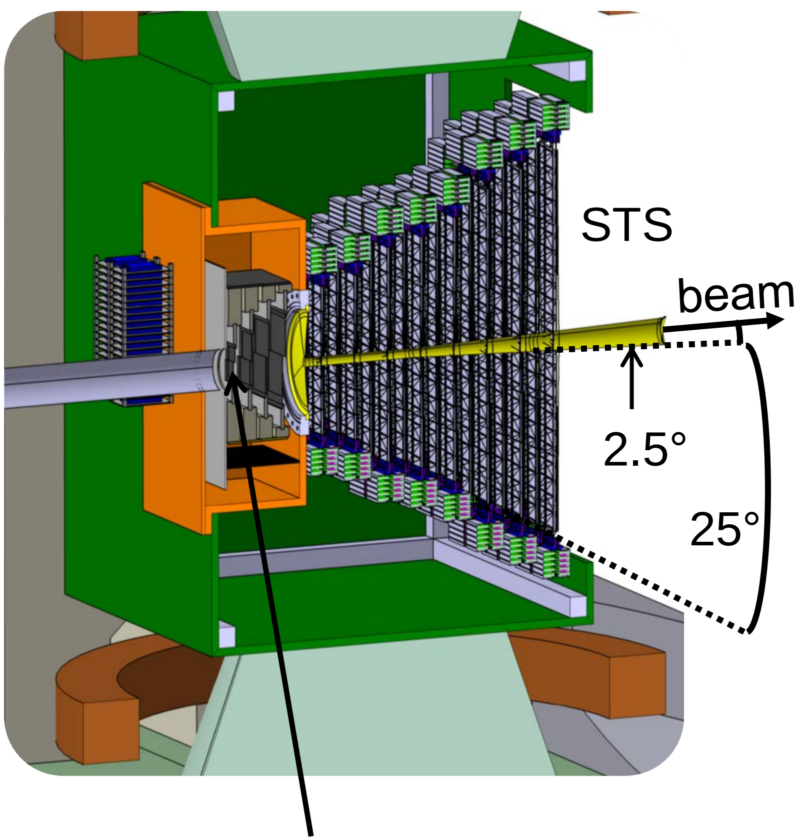
can a 3D-Silicon Tracking System meet the ambitious CBM requirements?

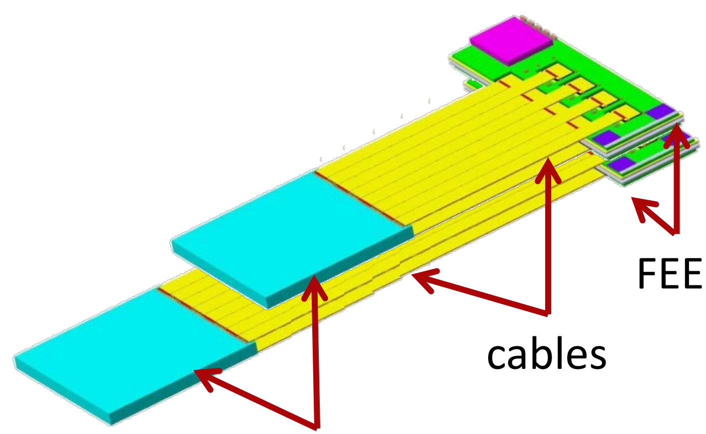
I. very good momentum resolution ($\Delta p/p \approx 1.5\%$) at lower momenta (<10 GeV/c) ⇔ very low material budget
II. excellent secondary vertex resolution (MicroVertexDetector)
III. simultaneous tracking of several hundred particles ⇔ granularity
IV. high collisions rate of up to 10 MHz ⇔ readout and rad. hardness

Momentum Resolution & Material Budget

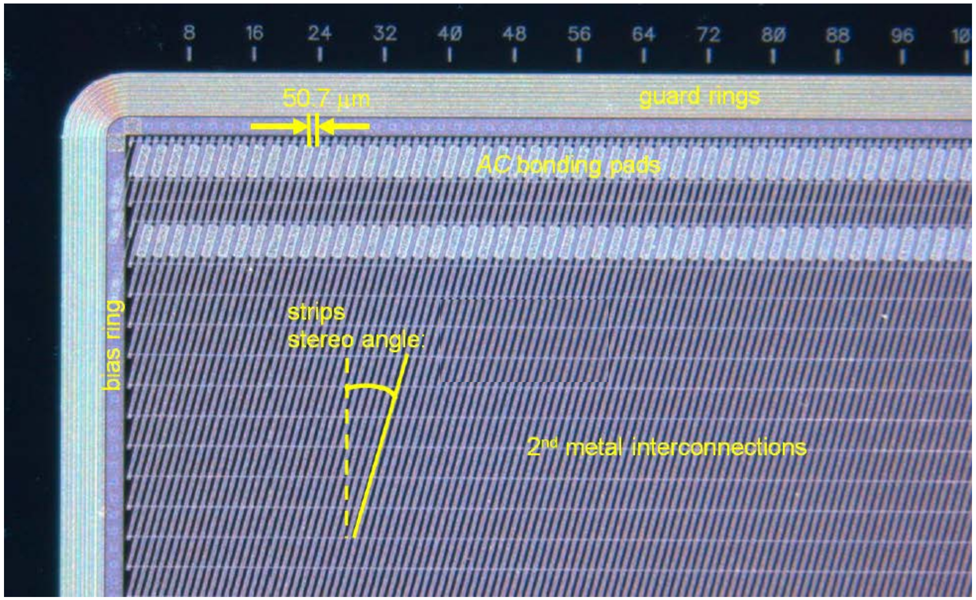
At SIS-energies (and design spatial resolution < 25 µm) the momentum resolution is dominated by multiple scattering, i.e., for good momentum resolution the active area has to be practically massless….

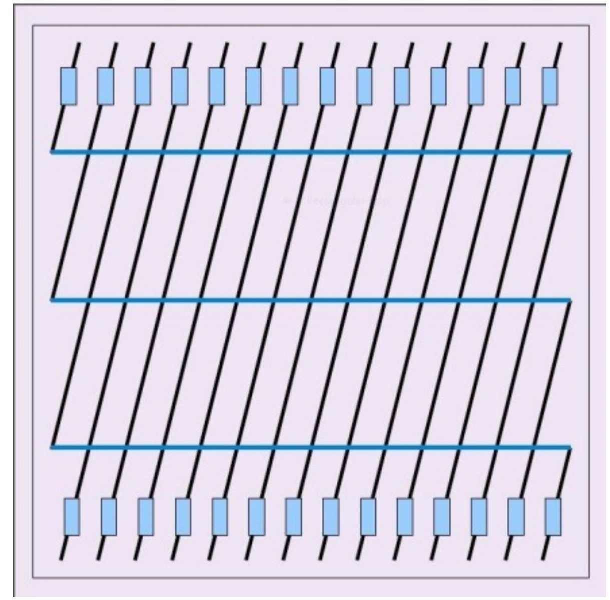
- readout electronics outside of active area
  - ultra-thin readout cables
- ultra light support structure
  - carbon fiber
- 300 µm sensor with double sided readout





Sensors





sensor:

- n-type silicon
- 300 µm thickness
- double sided readout
- metal interconnect between strips

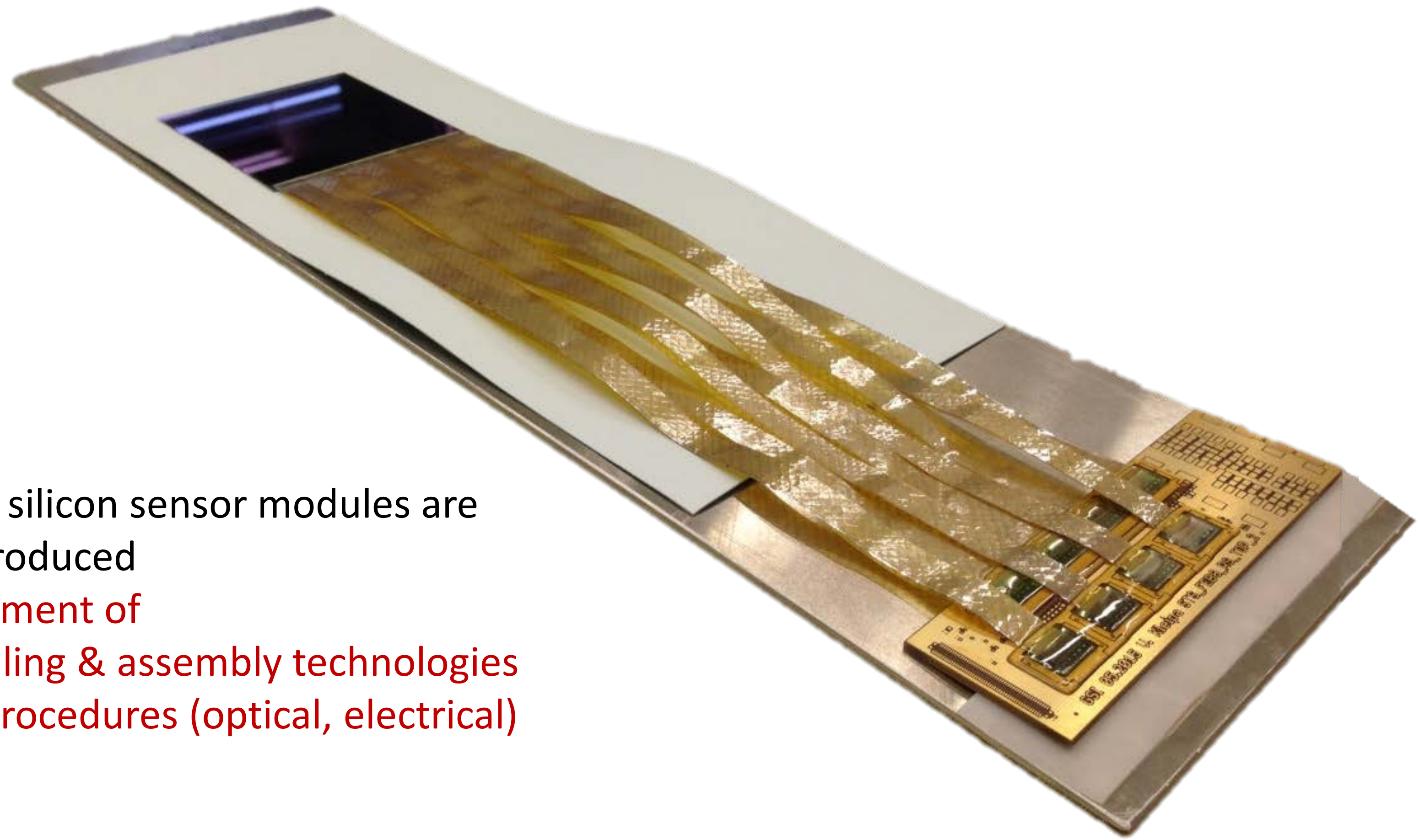
(300 µm thickness, double sided readout) } X/X_0 !

} large number of masks, complicated production, yield?

granularity and space point resolution:

- strip pitch: 58 µm
- stereo angle between font and back strips: 7.5 °
- strip length: 2.2, 4.2, 6.2, 12.4 (?) cm

STS-Modules Prototypes



first STS silicon sensor modules are being produced

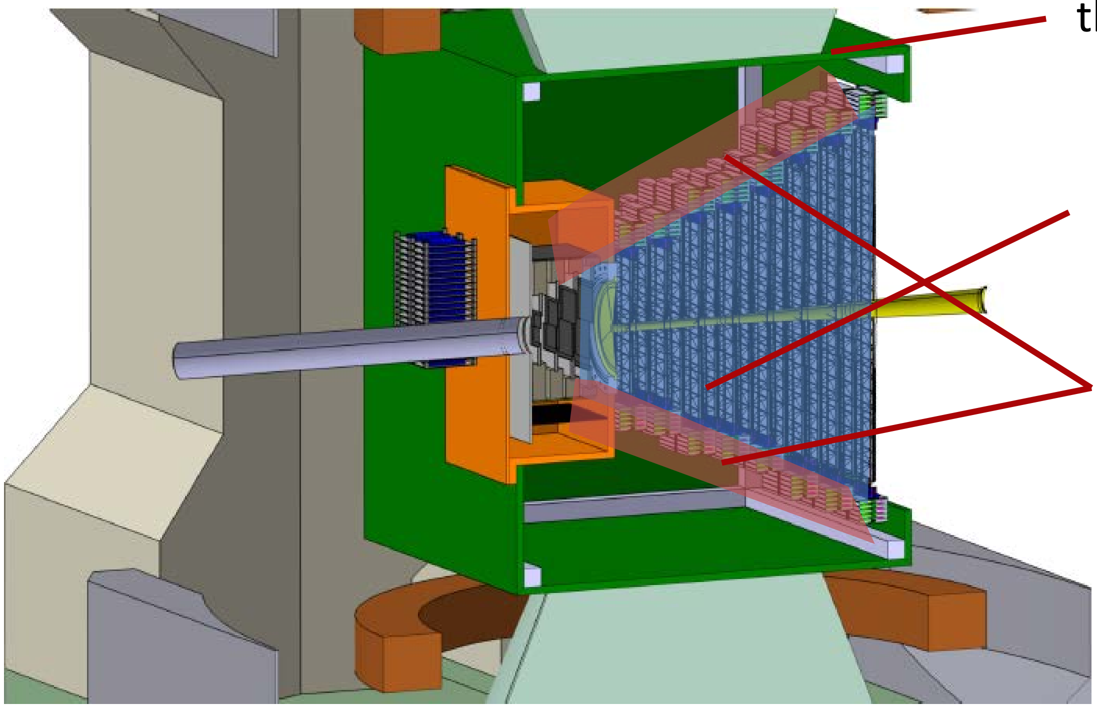
development of

- handling & assembly technologies
- QA procedures (optical, electrical)

Cooling Requirements

the radiation environment requires that the sensers are kept at $-5°C$ all the time

caveat: fast readout electronics produces 40 kW thermal power within insulation volume



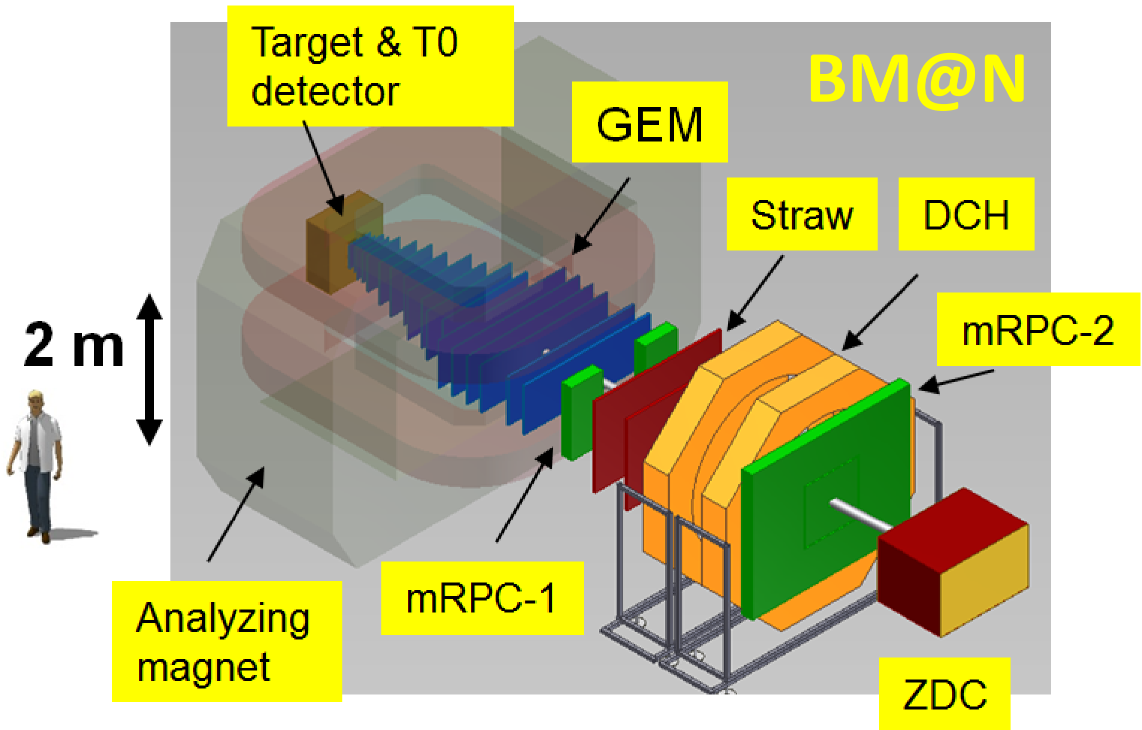
Very efficient high power CO_2 cooling system under development to neutralize 40 kW thermal power from r/o electronics!

for comparison: CMS develops a 15 kW CO_2 cooling system for sLHC

Strategy in view of FAIR delay: CBM-STS at Nuclotron (BM@N Dubna)

I. A+A collisions:
strangeness production at threshold

II. *p+p, p+n, p+A* collisions:
hadron production in elementary reactions and ‚cold' nuclear matter

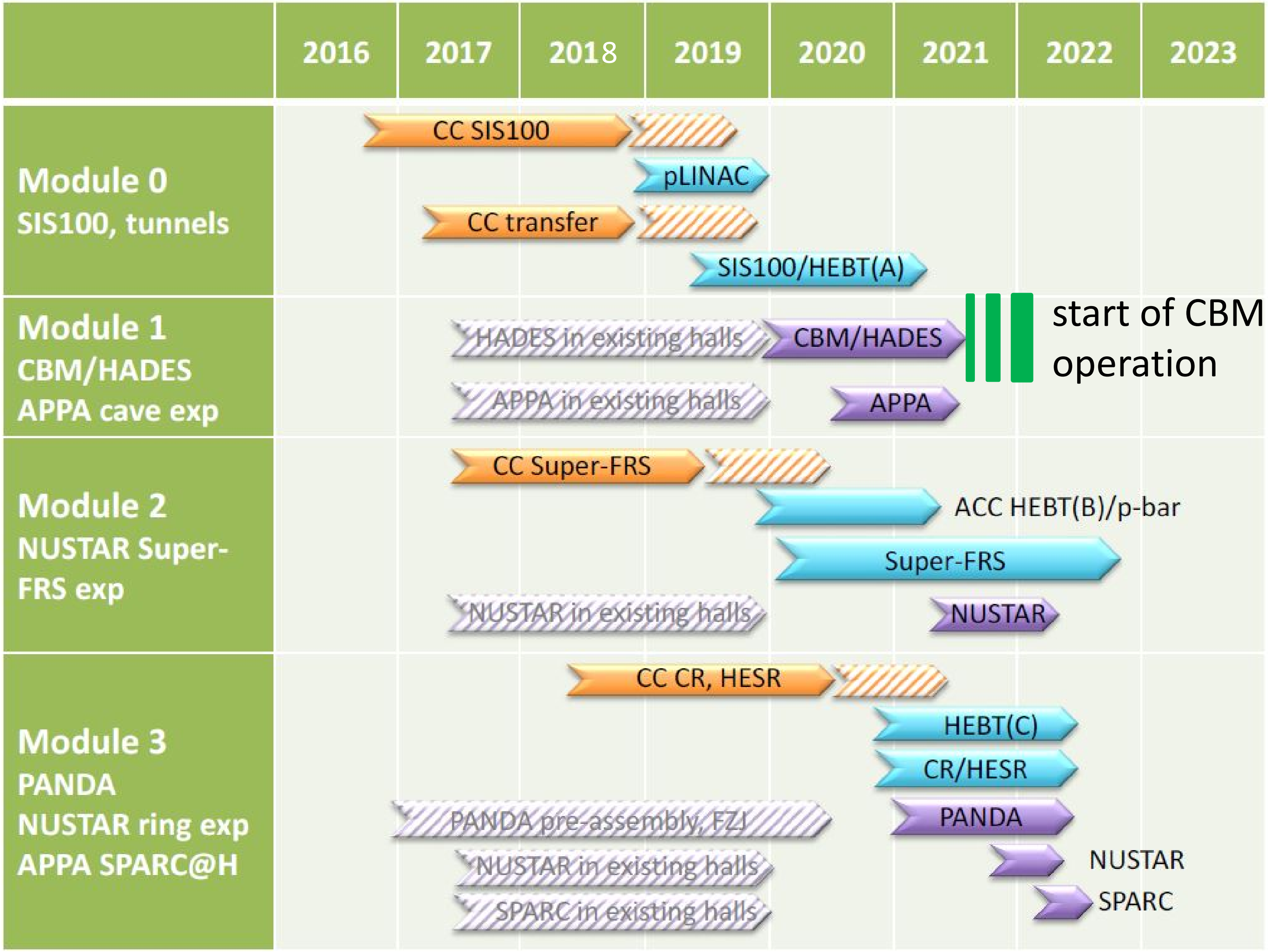


high intensity Au-beams in 2018/19 at $E_{lab} = 4\ AGeV$

CBM-type fixed target experiment
<u>but:</u>
silicon tracker replaced by 12 layers of GEM's

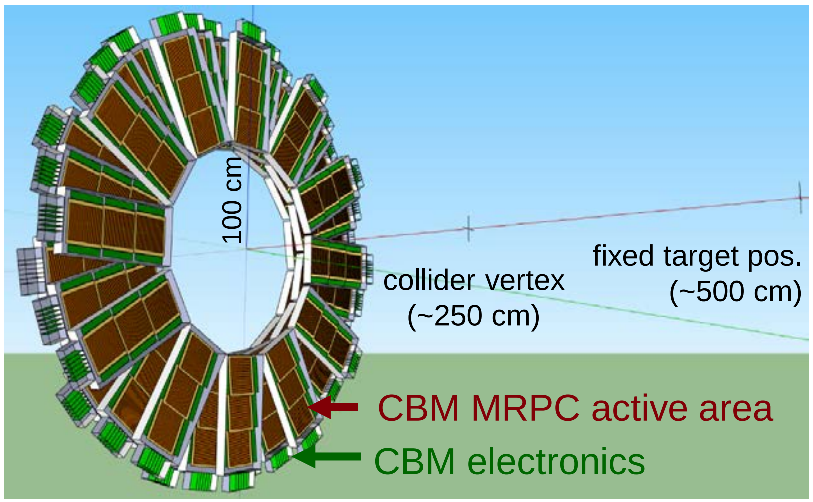
<u>proposal:</u> use serveral STS-tpye silicon stations at high track density regions

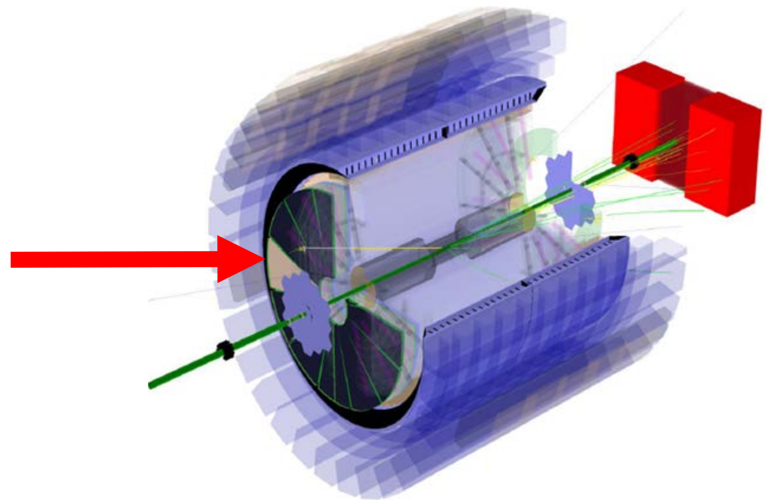
High Level Schedule of the Modularized Start Version (MSV)



Strategy in view of FAIR delay: CBM-TOF@RHIC

Install, commission and use 10% of the CBM TOF modules including read-out chain at STAR/RHIC





Participation in STAR Beam Energy Scan (BES II) in 2019/2020

- Operation of ~30 CBM TOF modules and electronics (A~10m^2 , ~10.000 channels)

Benefits

- Get experience with detector system, develop online calibration and monitoring tools
- Develop TOF analysis strategies for particle ID under experimental conditions
- Participate in physics analysis (e.g. baryon and strangeness fluctuations)
- Complementary to CBM: low rate, high energy, $7.7\ \mathrm{GeV} < \sqrt{s_{NN}} < 20\ \mathrm{GeV}$

Summary

- Unique measurements of rare diagnostic probes with CBM:
  – high-precision multi-differential measurements of hadrons incl. multistrange hyperons and dileptons for different beam energies and collision systems → terra incognita.

- Open Questions:
  - Are the yield, flow, spectra of multi-strange (anti-) hyperons sensitive to the dense phase of the collision?
  - I
  - s collective flow at high beam energies sensitive to the EOS?
  - …

- Key experimental requirements:
  – high-rate capability of detectors and DAQ, online event reconstruction and selection → Unrivaled feature of CBM

- Status for SIS100:
  – FAIR built “along beam line”,
  – first beams for CBM in 2021/22 (first day experiment)