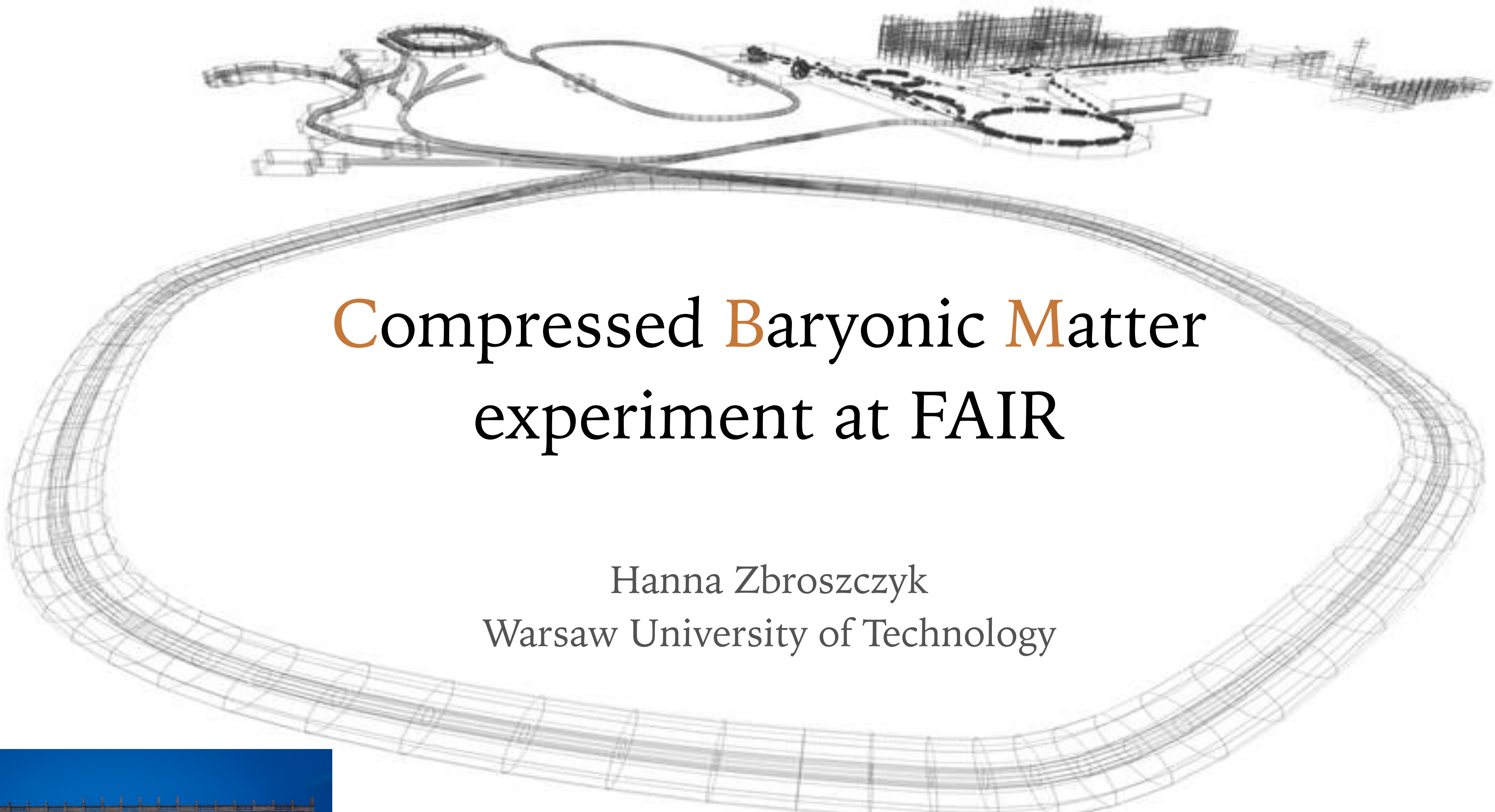


Compressed Baryonic Matter experiment at FAIR

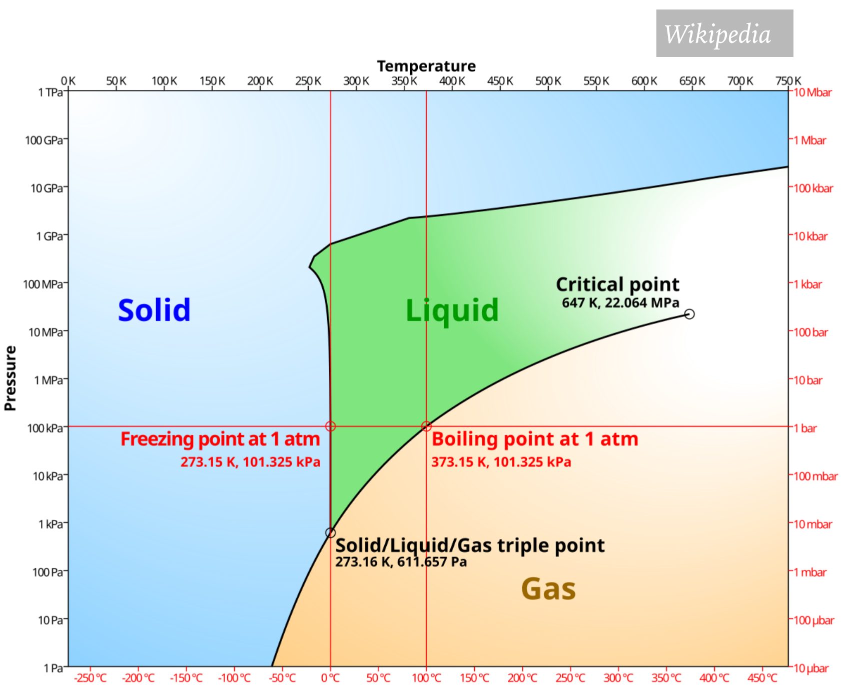
Hanna Zbroszczyk
Warsaw University of Technology

Road map

What are we pursuing and why? ⟹ **Physics motivation**

Water phase diagram

A **phase diagram** in physical chemistry, engineering, mineralogy, and materials science is a type of chart used to show conditions (pressure, temperature, etc.) at which thermodynamically distinct phases (such as solid, liquid or gaseous states) occur and coexist at equilibrium.



Lines of equilibrium or *phase boundaries*: lines that mark conditions under which multiple phases can coexist at equilibrium.

Phase transitions occur along lines of equilibrium.

Triple points are points on phase diagrams where lines of equilibrium intersect.

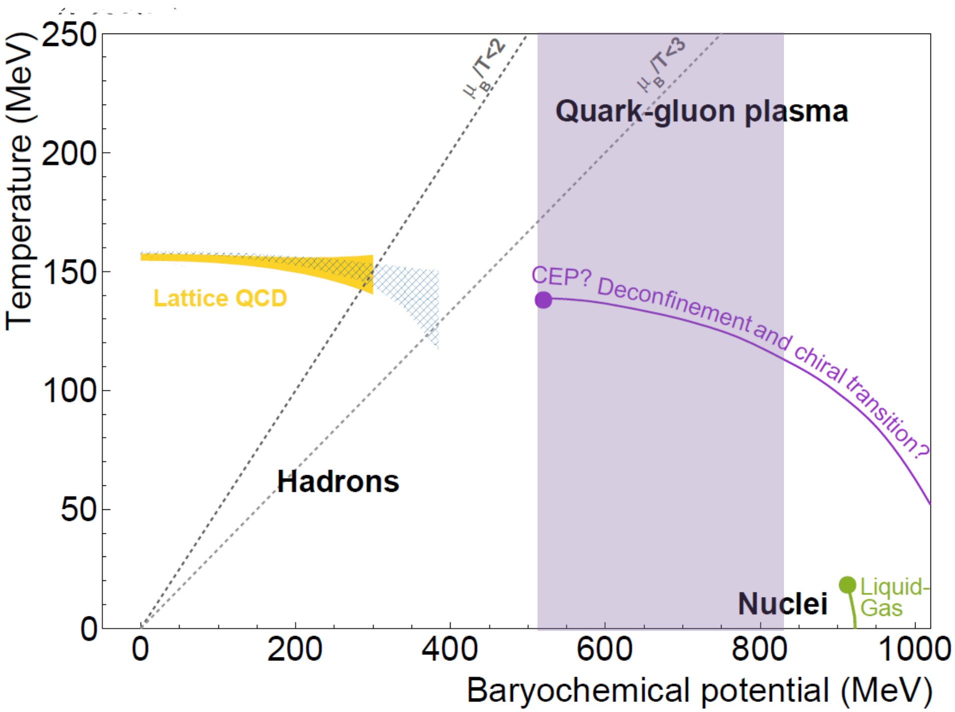
They mark conditions at which three different phases can coexist.

Water phase diagram has a triple point corresponding to the single temperature and pressure at which solid, liquid, and gaseous water can coexist in a stable equilibrium (273.16 K and a partial vapor pressure of 611.657 Pa).

QCD phase diagram

Low μ_B, hight T:

- **Cross-over** transition from hadronic to quark matter - comprehensive studies of **QGP** properties
- No **critical point** anticipated for $\mu_B/T < 3$



High μ_B, low T:

- Unknown **phase structure** (first-order phase transition, critical point possible, mixed phases, new phases, …)
- Properties of matter to determine
- Characteristics of hadrons
- Equation of State (**EoS**) to establish
- Neutron Star (**NS**)

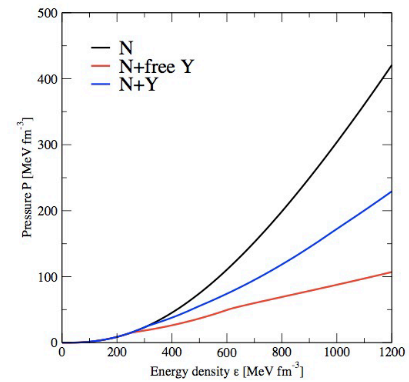
Bazavovet al.[HotQCD], PLB 795 (2019) 15-21
Dinget al., [HotQCD], PRL 123 (2019) 6, 062002
Borsanyiet al., PRL125(2020)5,052001
Isserstedt et al. PRD 100 (2019) 074011
Gao, Pawlowski, PLB 820 (2021) 136584

Ehrenfest classification*: phase transitions based on the behavior of the thermodynamic free energy as a function of other thermodynamic variables, described as the lowest derivative of the free energy that is discontinuous at the transition.*
First-order phase *transitions - exhibit a discontinuity in the first derivative of the free energy with respect to some thermodynamic variable.*
Second-order phase *transitions - continuous in the first derivative but exhibit discontinuity in a second derivative of the free energy.*

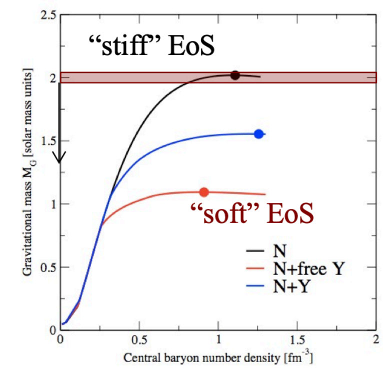
NS puzzle

$M_{NS} \approx 1 \div 2\ M_\odot$
$R \approx$ 10-12 km
$\rho \approx 3 \div 5\ \rho_0$
$\rho_0 \approx 2.8 \times 10^{14}$ g/cm³

- Observation of **NS** indicates their **mass** $\sim 2M_\odot$
  (Shapiro-delay: Post-Keplerian parameters of orbits)
- **Hyperons:** Expected in core of NS, the conversion of N into Y is energetically favorable
- **Appearance of Hyperons:** The presence of Y alleviates Fermi pressure, resulting in a EoS and a reduction in NS mass (inconsistent with observations)
  Can they still be considered as components of NS?

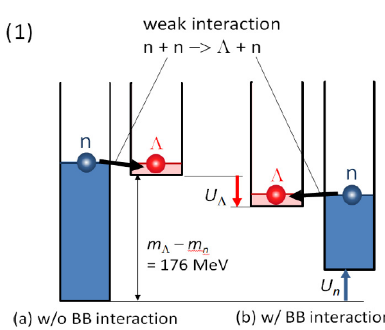


- **Proposed Solution:** A mechanism that provides additional pressure to ensure a stiffer EoS
  One emergent mechanism involves many-body interactions, such as YN, YY, NNY, NYY
  (Other: hypersonic three-body forces, Quark Matter Core - a transition to deconfined phase below hyperon threshold in density)



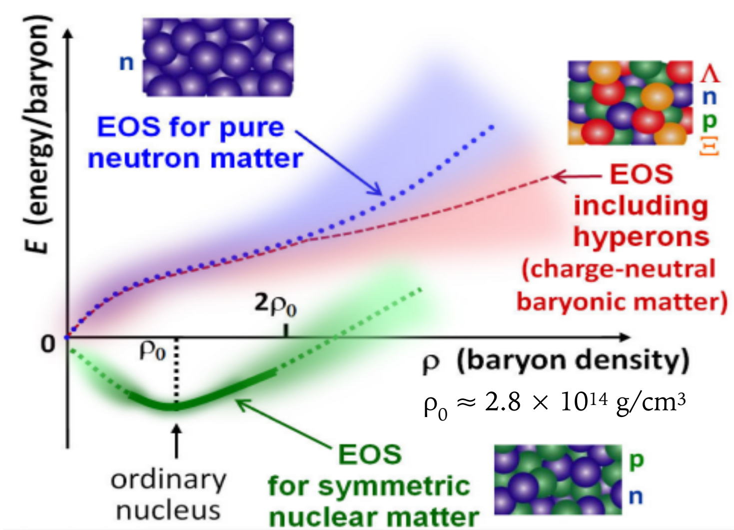
The inner core of the neutron star is totally unknown. One of the most probable scenarios is that hyperons (baryons with strange quarks) appear at a density larger than (2–3) ρ_0
Λ hyperons, being free from Pauli exclusion principle by neutrons, are allowed to stay at the bottom of the attractive nuclear potential made by neutrons. **When the kinetic energy of a neutron on the Fermi surface of the degenerate neutron matter exceeds the Λ-n mass difference of 176 MeV, it converts into a Λ hyperon via weak interaction.**

(1)

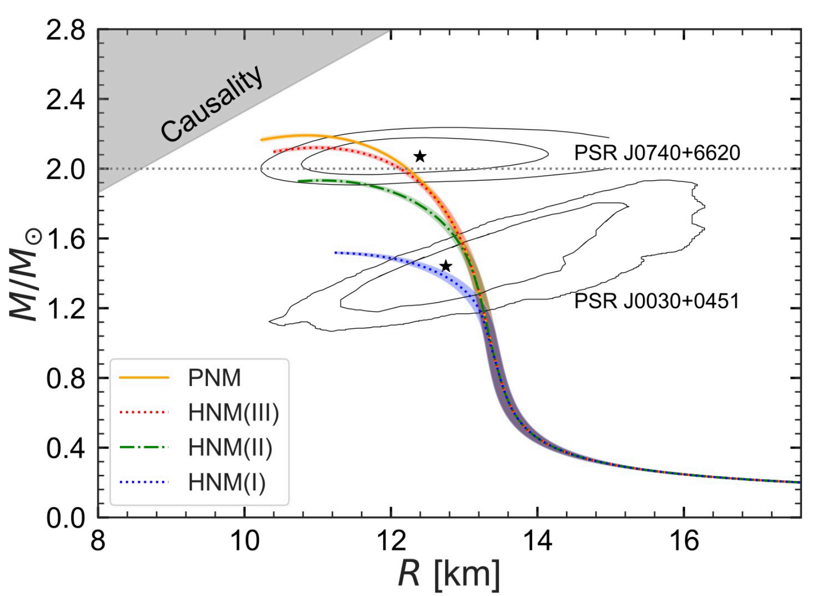


Neutron star (NS) puzzle

H.Tamura, JPS Conf. Proc. , 011003 (2014)



$\rho_0 \approx 2.8 \times 10^{14}$ g/cm^3



„To establish the EoS applicable to the neutron star has been one of the most important subjects in nuclear physics for a long time but has not been achieved yet." T. Hamura

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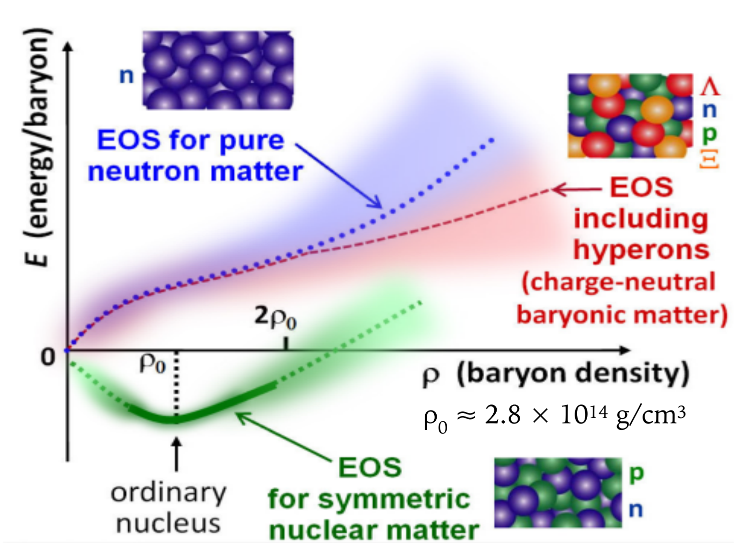
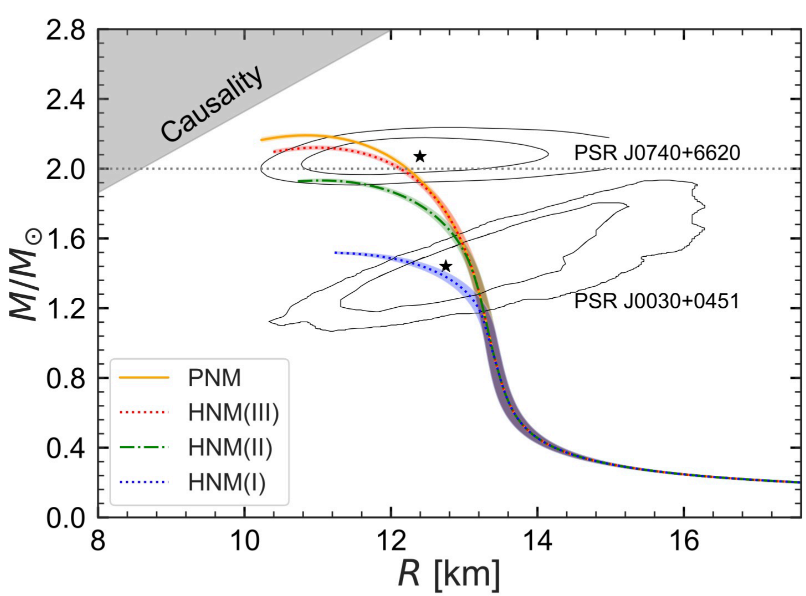
H.Tamura, JPS Conf. Proc. , 011003 (2014)





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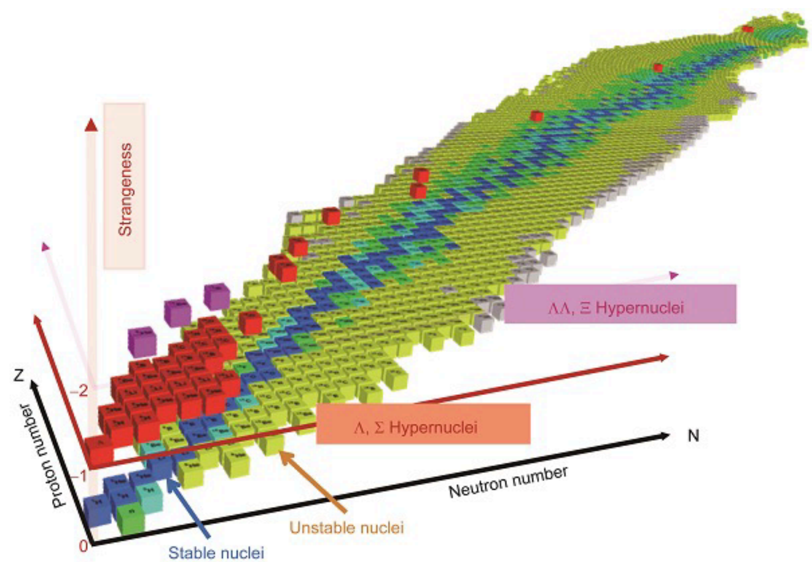


M. Kaneta, Department of Physics, Tohoku University, Japan

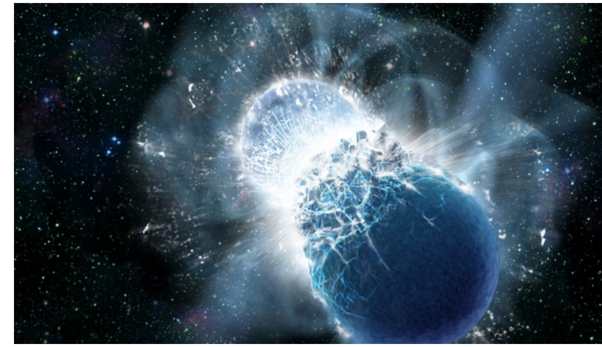
Hypernuclei are pivotal for the EoS of the NS

- How do nuclei and hyper-nuclei form?
- What are their characteristics?
- How do nuclei (N) and hyperons (Y) interact?

NSM and HIC

Top row: simulation of **NS mergers (NSM)**
2 NSs of 1.35 M⊙ each,
merging into a single object (2R ~ 10 km, $n \sim 5n_0$, $T \leq 20$ MeV).
Overlap region: $t \sim 20$ ms, $n \sim 2n_0$, $T \sim 75$ MeV

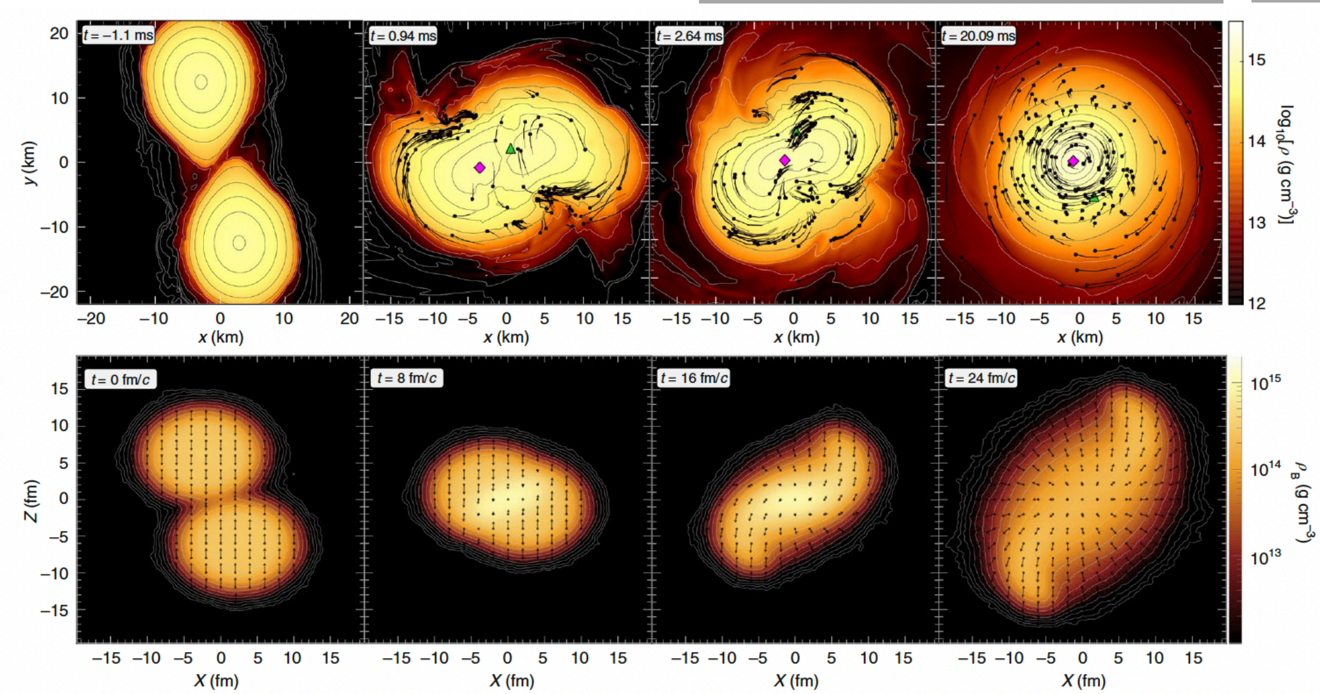
- max. temperature
- max. density



Artist's depiction of a neutron star collision after inspiral, NASA/Swift/Dana Berry

Bottom row: non-central **Au+Au collision** at $\sqrt{s_{NN}} = 2.42$ GeV
$n \simeq 3n_0$, $T \simeq 80$ MeV

HADES, Nature Phys. 15, 1040–1045 (2019)



Space and **time** scales vastly contrasting (**km**-NS / **fm**-HIC - 18 orders of magnitude; **duration** - 20 orders of magnitude)

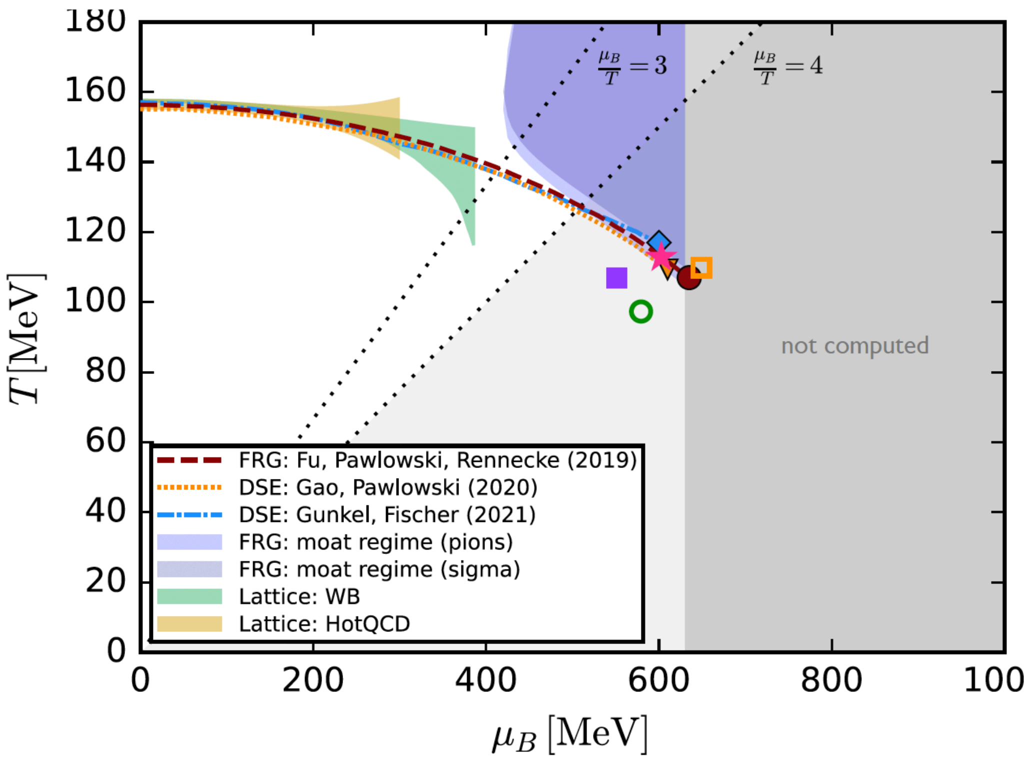
Similar **densities** and **temperatures** achieved

Road map

What are we pursuing and why? ⇒ Physics motivation

Where are we now? ⇒ **Current status**

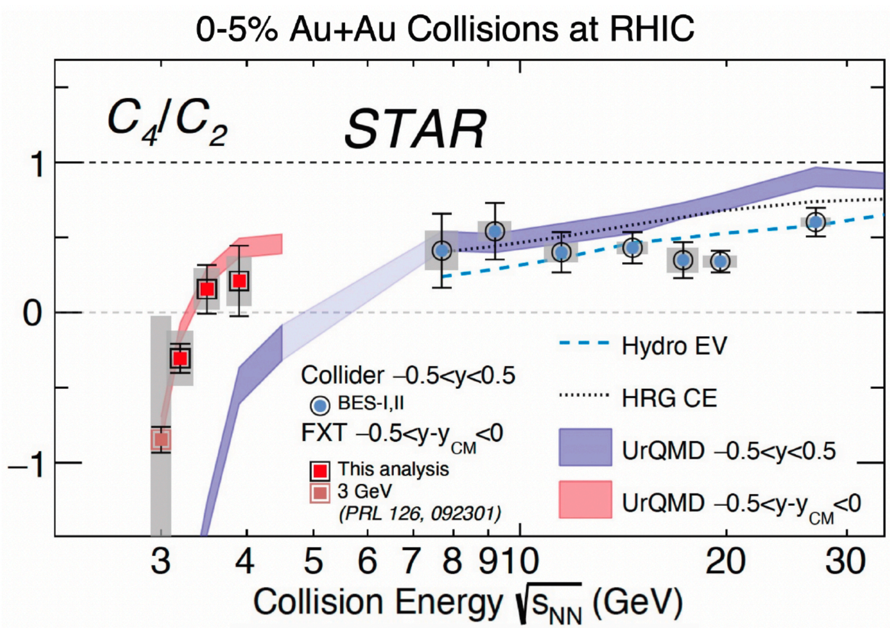
Critical point predictions



DSE: Bernhardt, Fischer and Isserstedt, PLB 841 (2023)[2]
FRG: Fu, Pawlowski, Rennecke, PRD 101, 053032 (2020)[3]
BHE: Hippert et al., arXiv:2309.00579
lQCD-Pade: Basar, arXiv:2312.06952
lQCD-Pade: Clarke et al., PoS LATTICE2023 (2024),
Bazavov et al. [HotQCD], PLB 795 (2019) 15-21
Borsanyi et al. [Wuppertal-Budapest], PRL 125 (2020)
Cuteri, Philipsen, Sciarra, JHEP 11 (2021) 141
Vovchenko et al., PRD 97, 114030 (2018)

- LQCD frowns upon the location of the critical point at $\mu_B/T < 3$
- Effective QCD and lattice-based theories estimate its location at $T \sim 90 - 120$ MeV and $\mu_B \sim 500 - 650$ MeV
- This corresponds to heavy-ion collisions at $\sqrt{s_{NN}} \sim 3 - 5$ GeV (QM 2025 states even $\sqrt{s_{NN}} \sim 3.6 - 4.1$ *Fabian Rennecke, QM25*)
- The circumstance in which the critical point does not exist is also conceivable

Critical point searches



STAR CPOD 2024,QM 2025

$$\frac{\kappa_n(N_B - N_{\bar{B}})}{VT^3} = \frac{1}{VT^3}\frac{\partial^3 ln Z(V,T,\mu_B)}{\partial(\mu_B/T)^n}$$

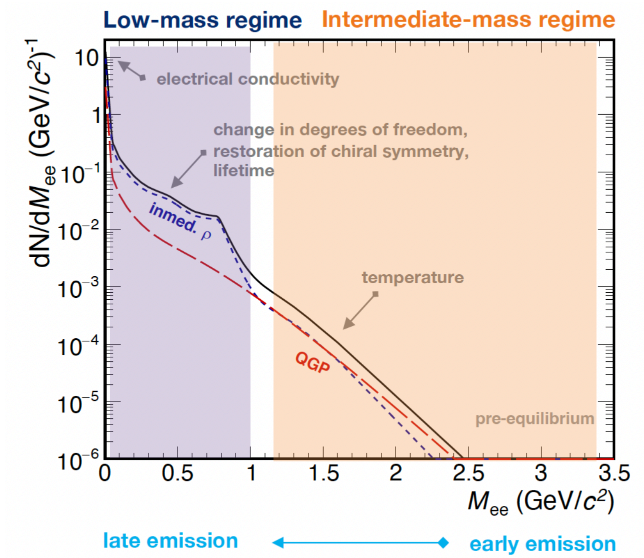
κ_n experimentally measured

$$\kappa_n(N_B - N_{\bar{B}}) = < N_B > + (-1)^n < N_{\bar{B}} > = k_n(Skellam)$$

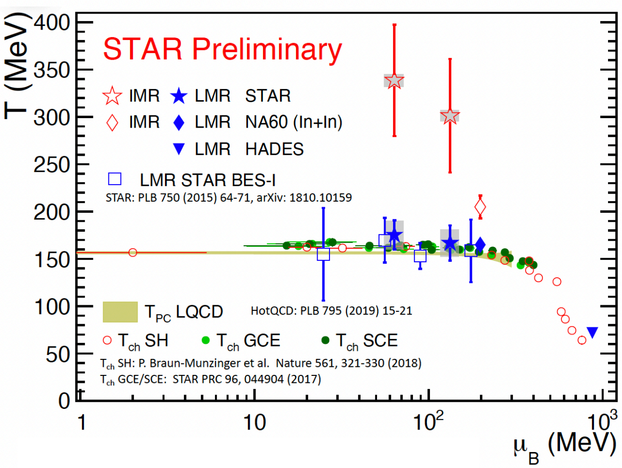
- Non-monotonic trend in κ_4/κ_2 of net-proton multiplicity distributions suggested as a **signature** of the **critical point**
- STAR collider program conducted comprehensive studies at $\sqrt{s_{NN}} > 7.7\ GeV$
- STAR fixed-target data investigation at $\sqrt{s_{NN}} > 3\ GeV$
- Sensitivity to the features of the QCD phase diagram increases with the order of the moment
- Higher-order moments requires prominent **statistics**

Detailed systematics studies indispensable

E-M probes access the whole collision



Inscribes matter properties enabling estimation:
- degrees of freedom of the medium
- fireball’s lifetime, temperature, acceleration, polarization
- transport properties
- restoration of chiral symmetry



Thermal dileptons in **LMR**:
- T close to T_{ch} and T_{pc}
- dominantly emitted around phase transition

Thermal dileptons in **IMR**:
- T is higher than T_{pc}
- Emitted fom QGP phase

Effective size-signal: $S_{eff} \sim R\frac{S}{B}$

R - interaction rate

S - signal

B- combinatorial background

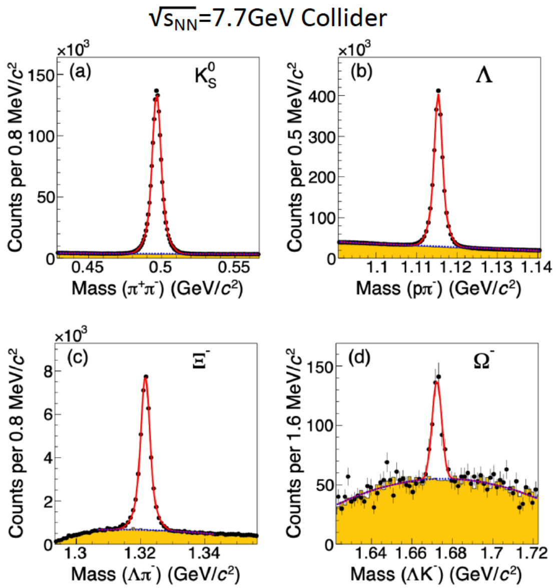
Prominent interaction rate mandatory

EPJC (2009) 59 607-623
Nature Physics 15, 1040-1045 (2019)
JPS Conf.Proc. 21 (2020) 010079

EoS to probe NS properties

EoS investigations include vast number of measurements:

- Chemistry (strangeness, charm, hyper nuclei, …)
- Collectivity
- Vorticity
- Fluctuations and correlations
- Interactions in the final states (NN, NY, YY, many-body, hyper-nuclei, …)



PRC 102 (2020) 34909 (STAR)

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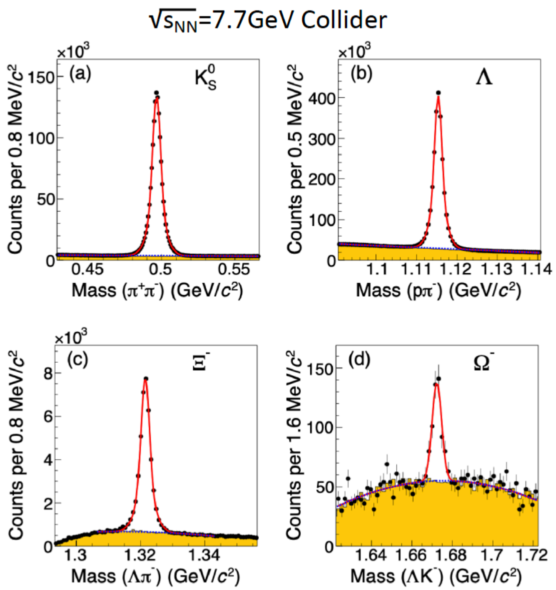

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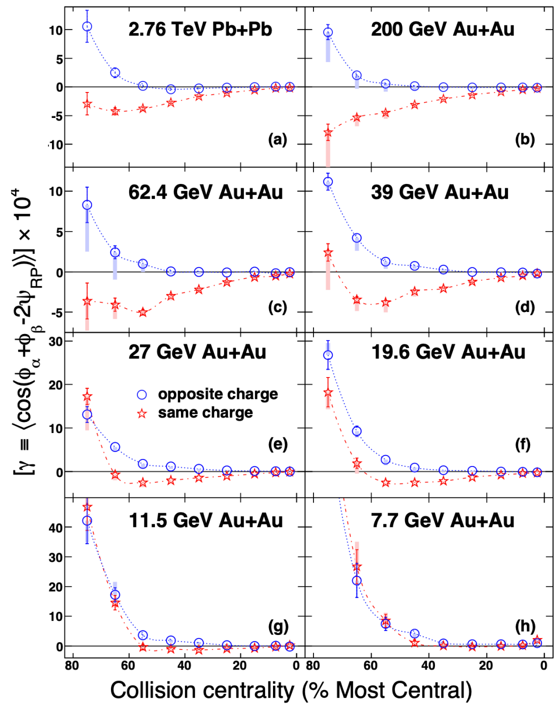

PRL 113 (2014) 52302

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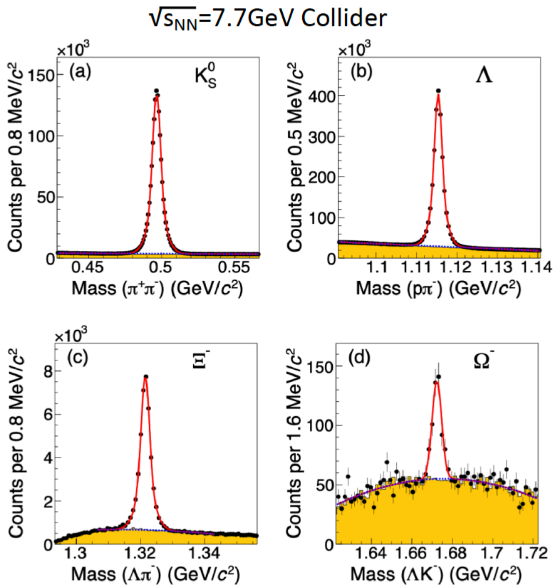

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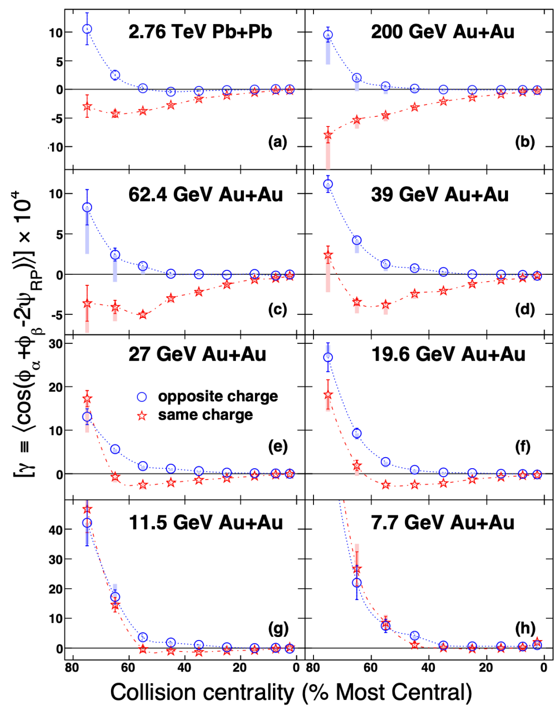
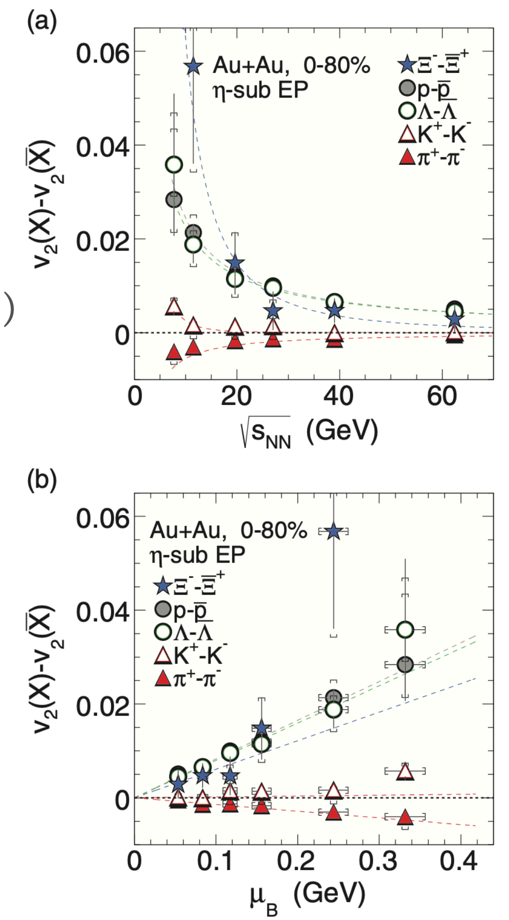


PRL 113 (2014) 52302



PRC 93 (2016) 14907 (STAR)

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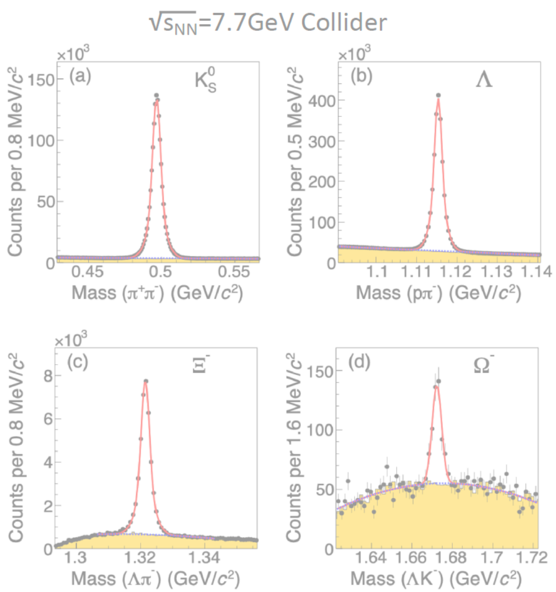

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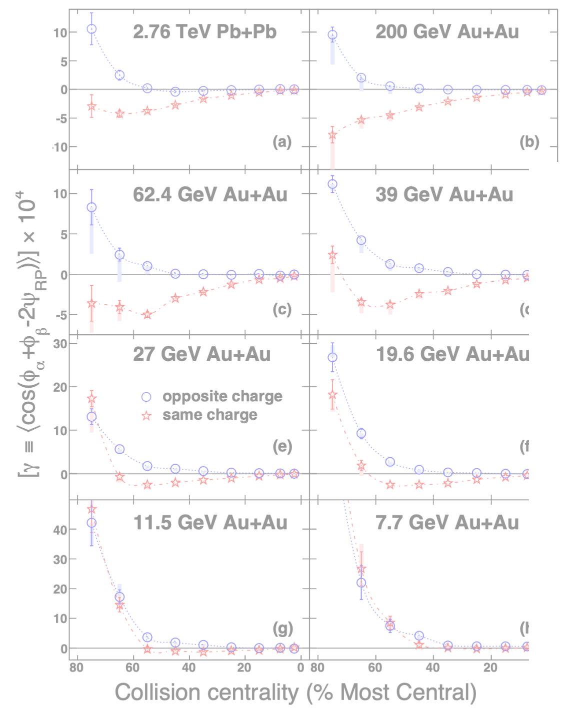
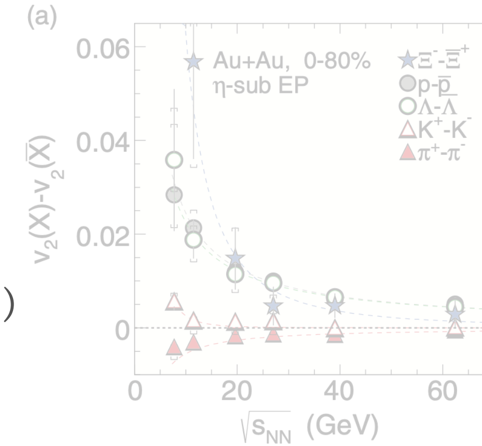
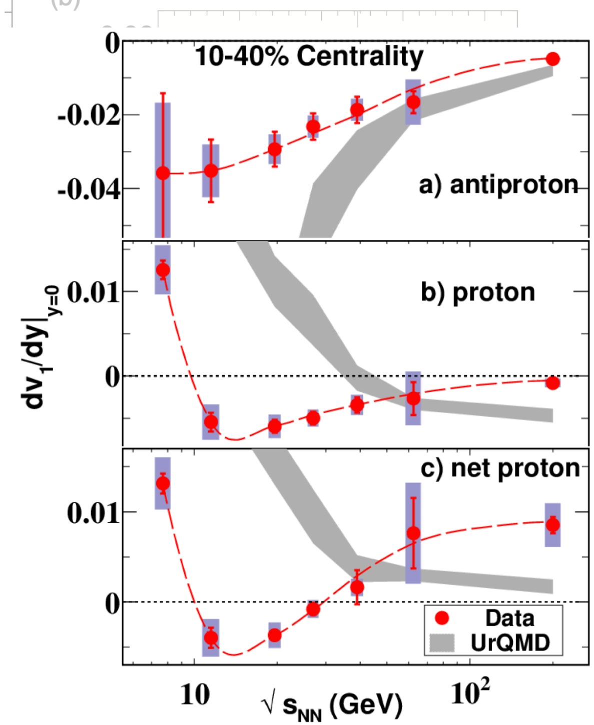


PRL 113 (2014) 52302



STAR, PRL 112, 162301 (2014)



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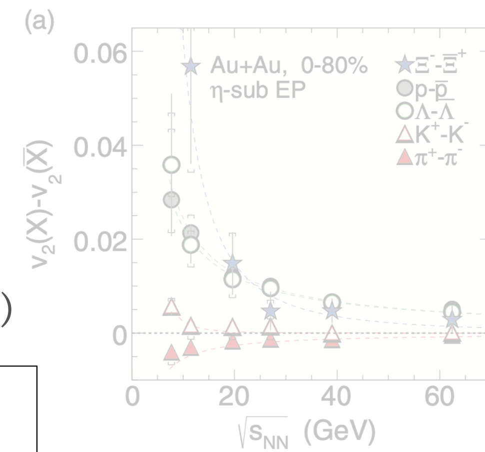

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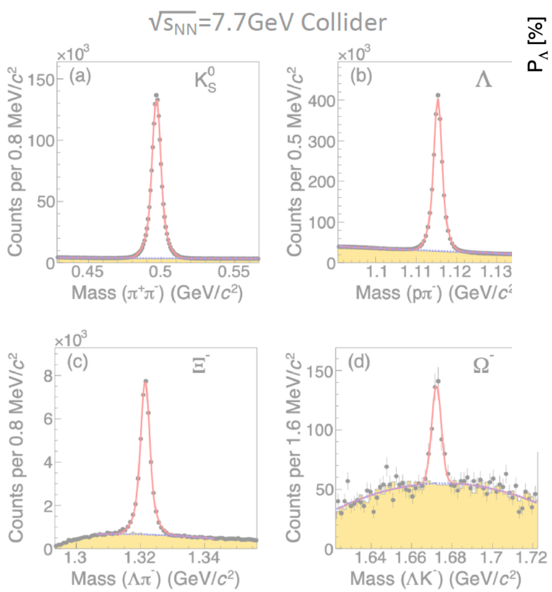

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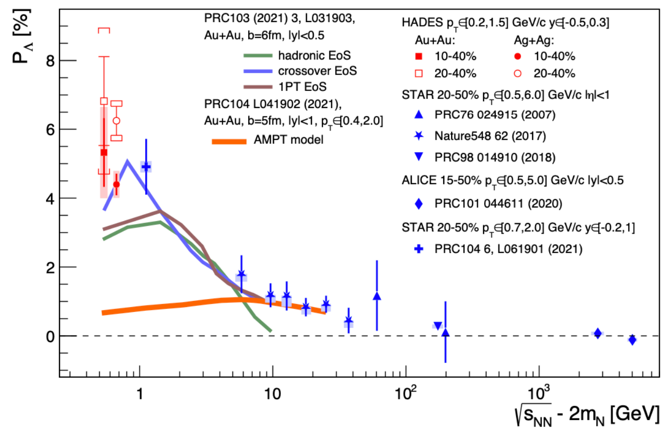
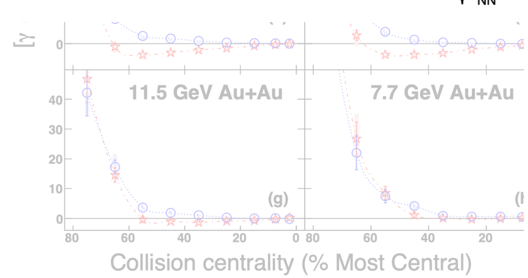
PLB 835, 137506 (2022)





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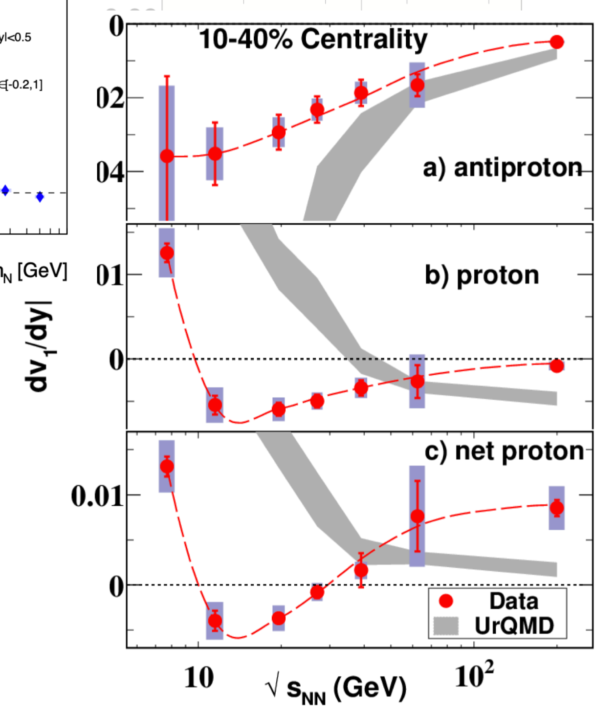

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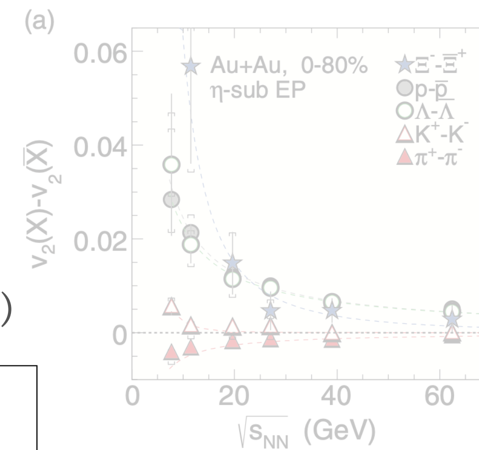

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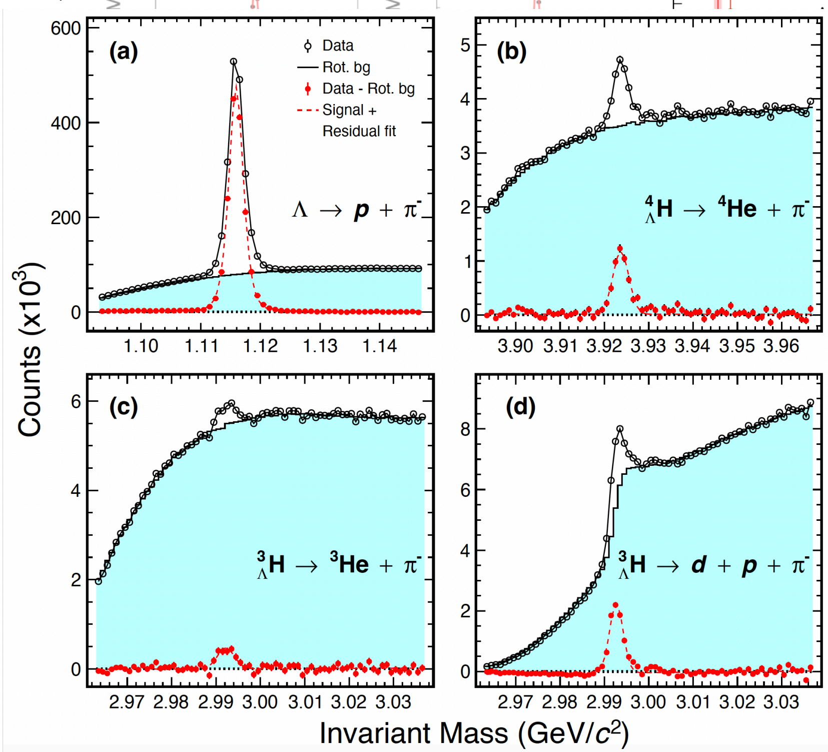
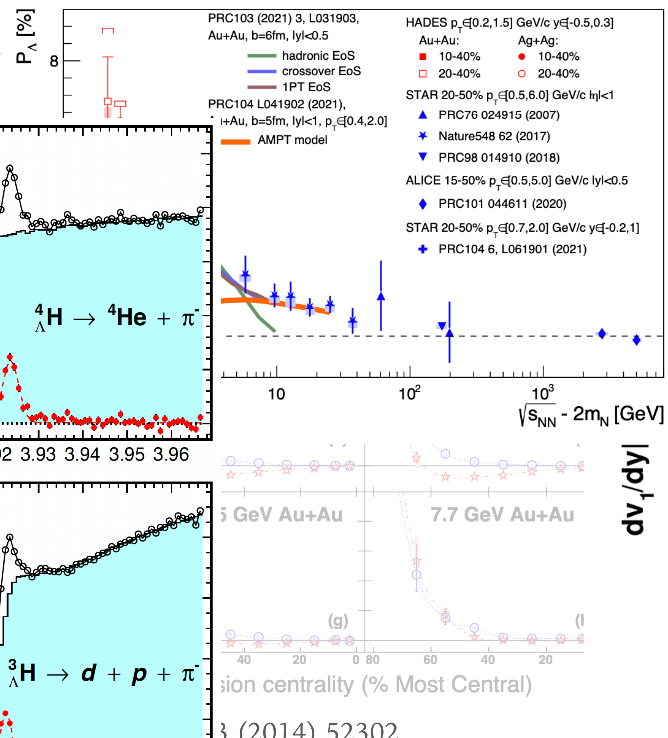
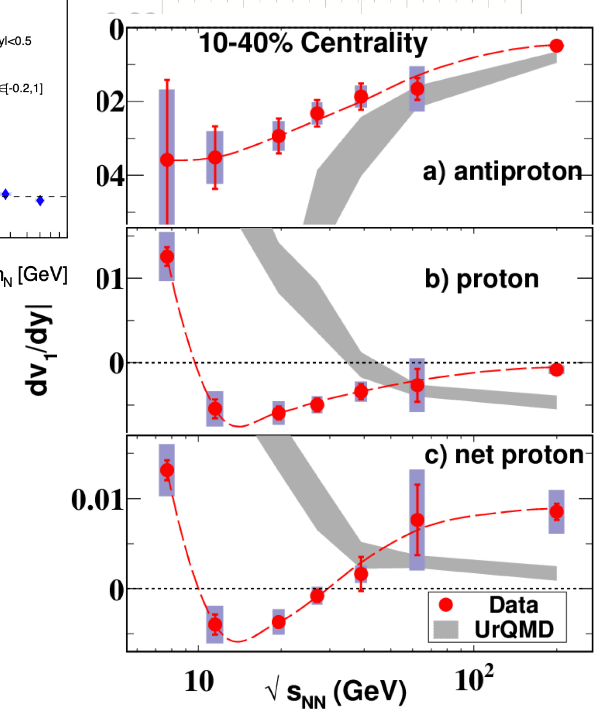
Phys. Rev. Lett. 130 (2023) 212301







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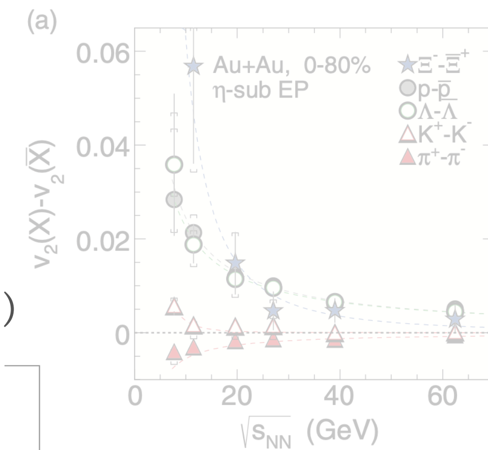

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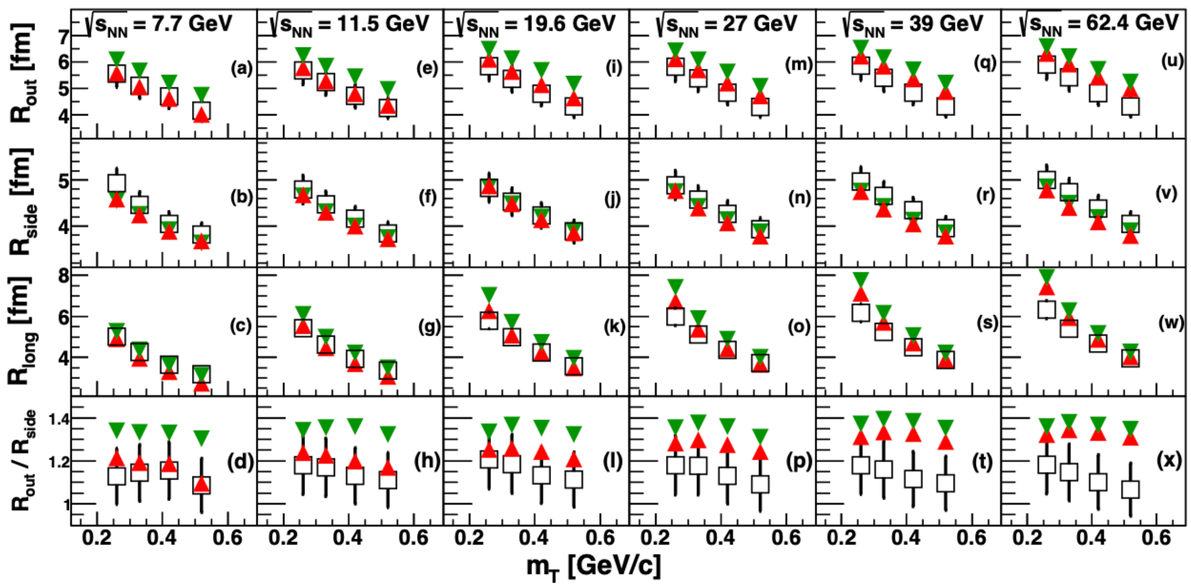
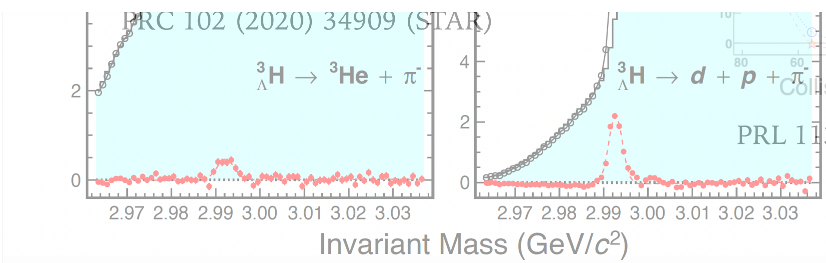
PRC 96 (2017) no.2, 024911





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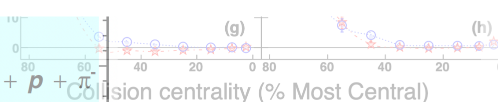

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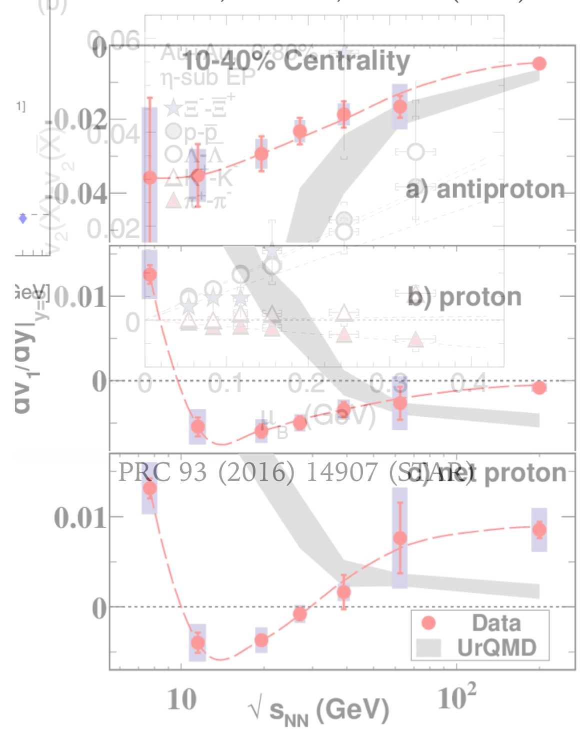

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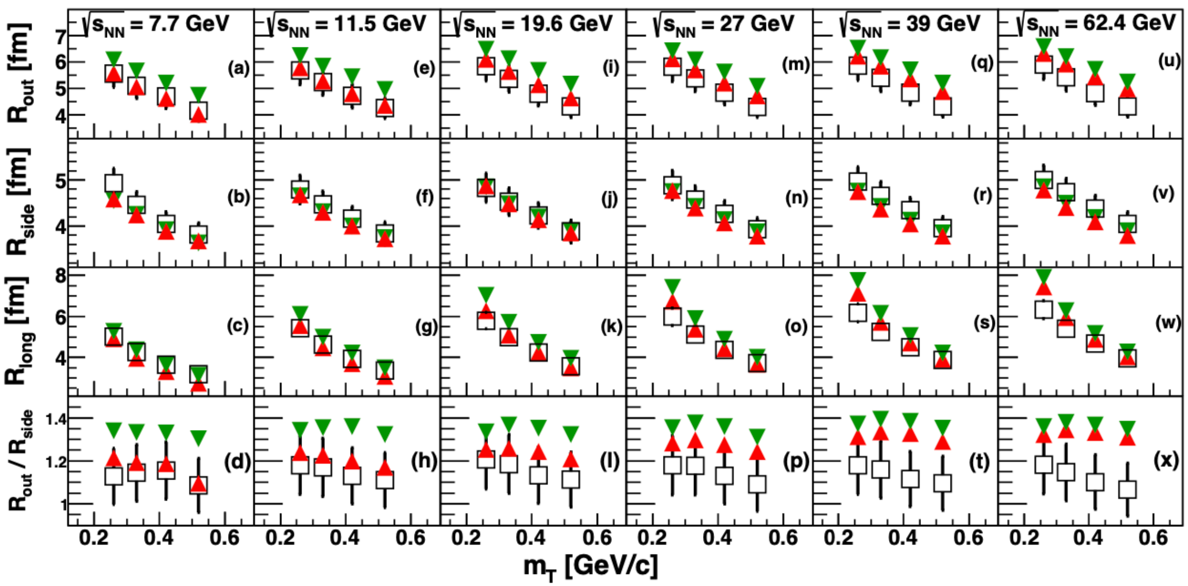
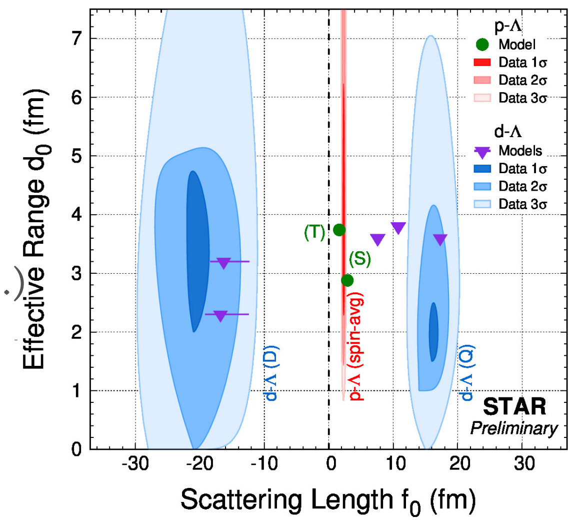
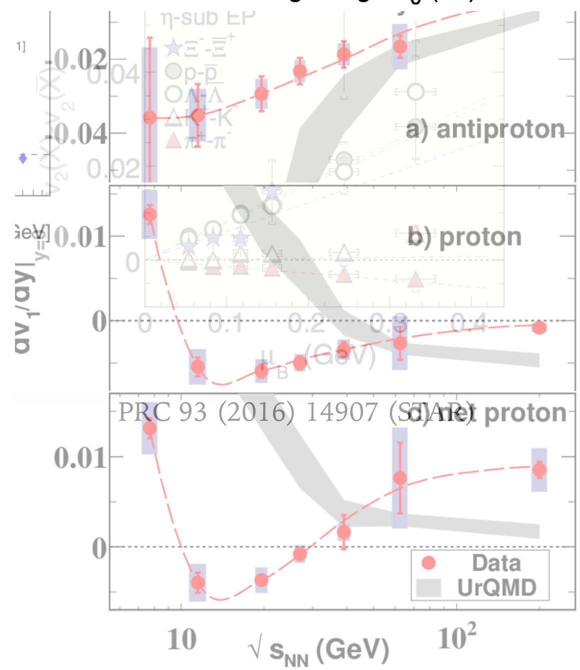
PRC 96 (2017) no.2, 024911



QM2024, Nucl. Phys. A 259, (2024)





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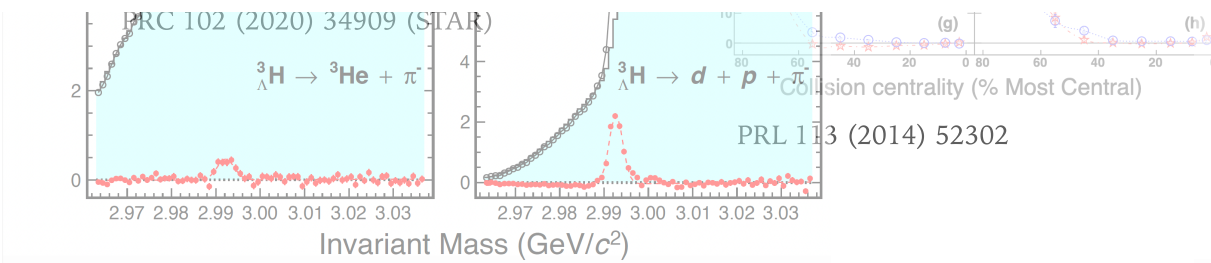

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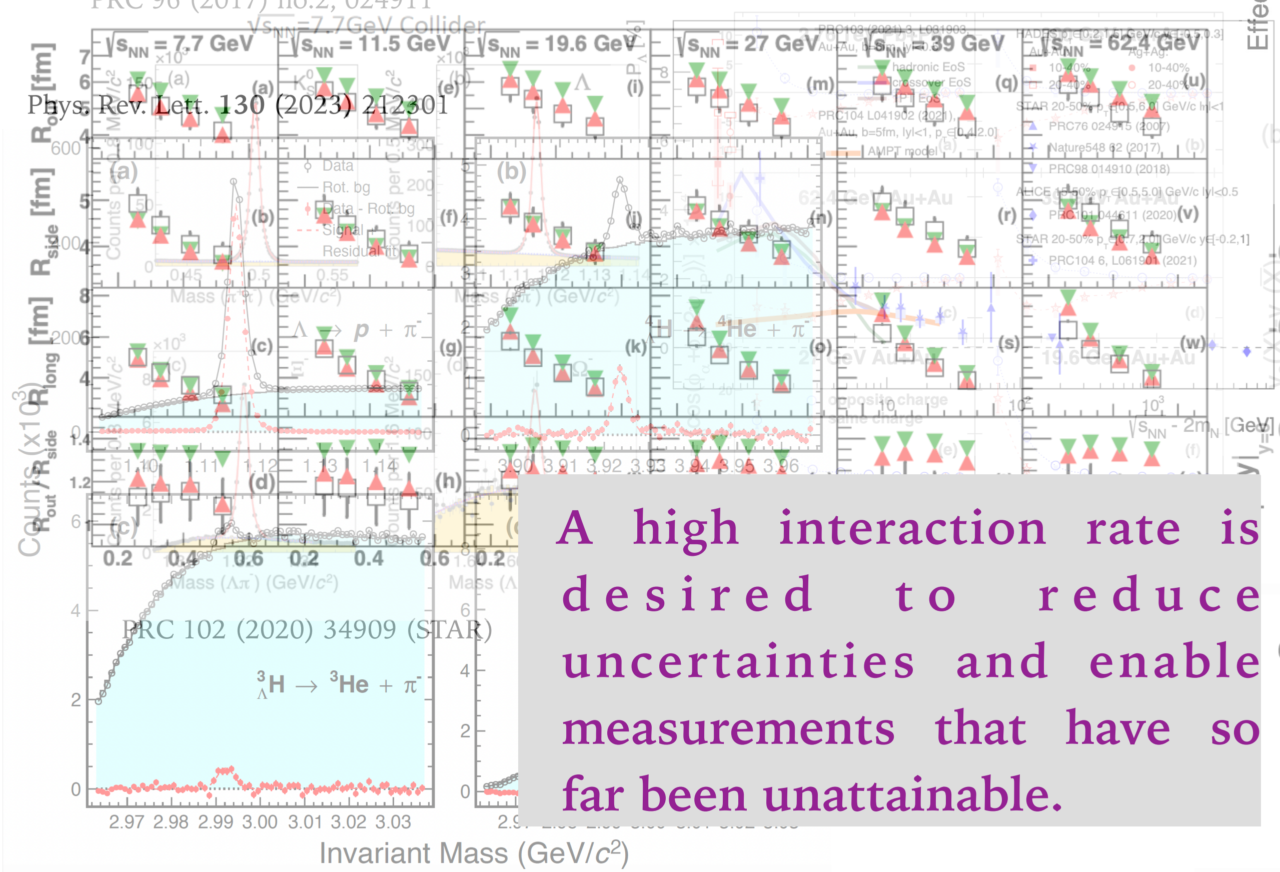

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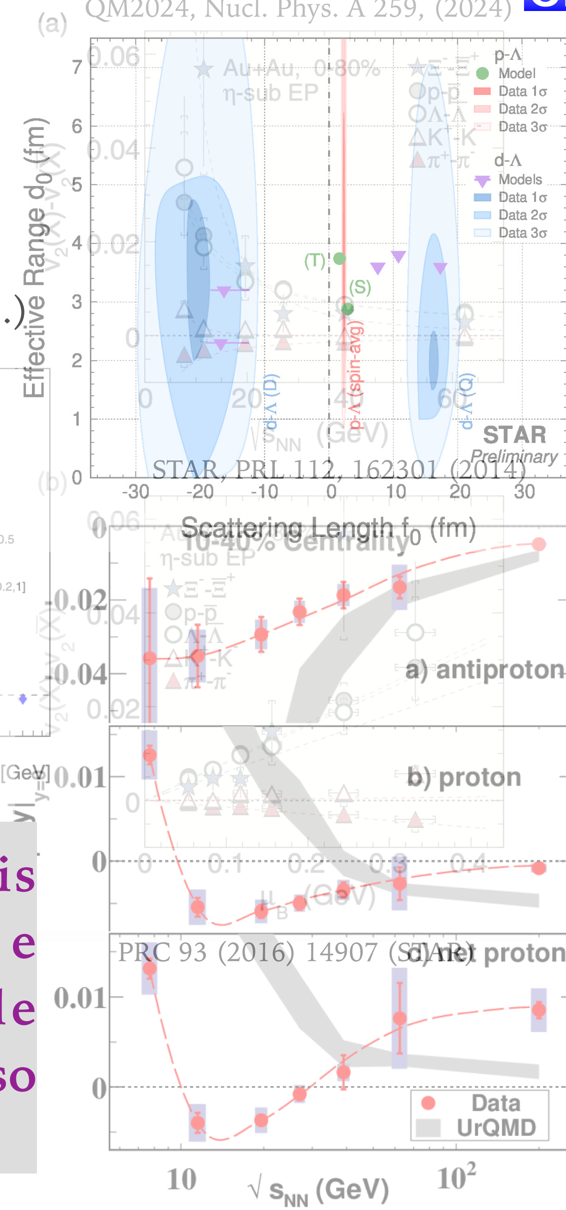
Phys. Rev. Lett. 130 (2023) 212301

PRC 102 (2020) 34909 (STAR)



QM2024, Nucl. Phys. A 259, (2024)

STAR, PRL 112, 162301 (2014)

PRC 93 (2016) 14907 (STAR)

A high interaction rate is desired to reduce uncertainties and enable measurements that have so far been unattainable.

Road map

What are we pursuing and why? ⇨ Physics motivation

Where are we now? ⇨ Current status

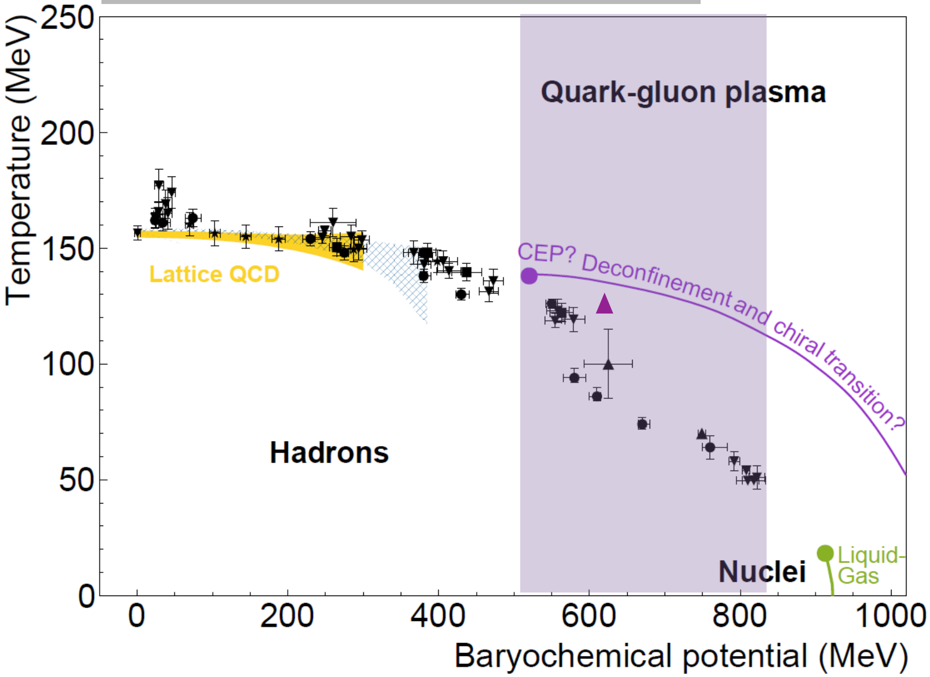
Who is involved?

⇨ **Experimental facilities**

Current coverage of the QCD phase diagram

CBM / HADES experimental exploration of the region $\mu_B \sim 520 - 830\ MeV$

HADES; Nature Physics 15 (2019) 10, 1040-1045



Bazavovet al.[HotQCD], PLB 795 (2019) 15-21
Dinget al., [HotQCD], PRL 123 (2019) 6, 062002
Borsanyiet al., PRL125(2020)5,052001
Isserstedt et al. PRD 100 (2019) 074011
Gao, Pawlowski, PLB 820 (2021) 136584

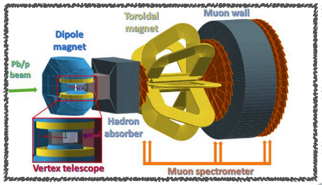
Fu et al., PRD 101 (2020), 054032
Gunkel, Fischer, PRD 104 (2021) 5, 054022

	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)
HADES@SIS18	**2-2.5**	**830-760**
CBM@SIS100	**2.3-5.3**	**785-520**
NA61/SHINE@SPS	5.1-17.3	530-220
STAR-COLL@RHIC	7.7-200	400-22
STAR-FXT@RHIC	3-13.7	700-265

A. Andronic, P. Braun- Munzinger, K. Redlich and
B. J . Stachel, Nature 561, no. 7723, 321 (2018)

High μ_B facilities

NA60@SPS(>2030)

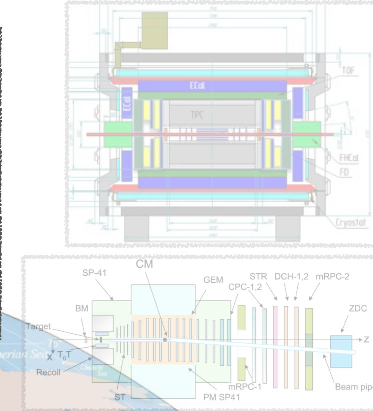


NA61/SHINE@SPS

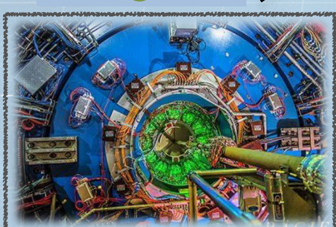
HADES@SIS18

CBM / HADES@ SIS100 (>2028)

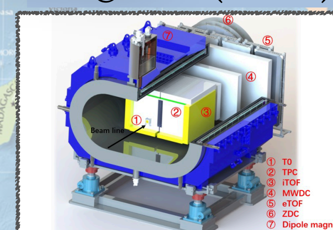
MPD, MB@N@NICA



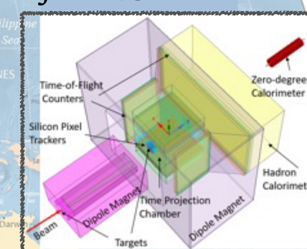
STAR@RHIC



CEE@HIAF (>2027)

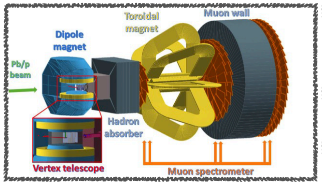


J-PARC-HI



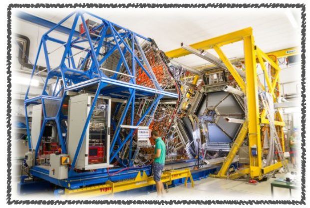
High μ_B facilities

NA60@SPS(>2030)



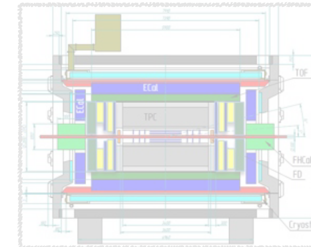
NA61/SHINE@SPS

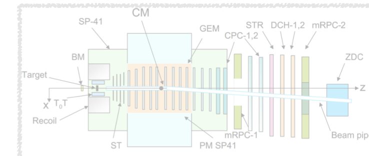
HADES@SIS18



CBM / HADES@ SIS100 (>2028)

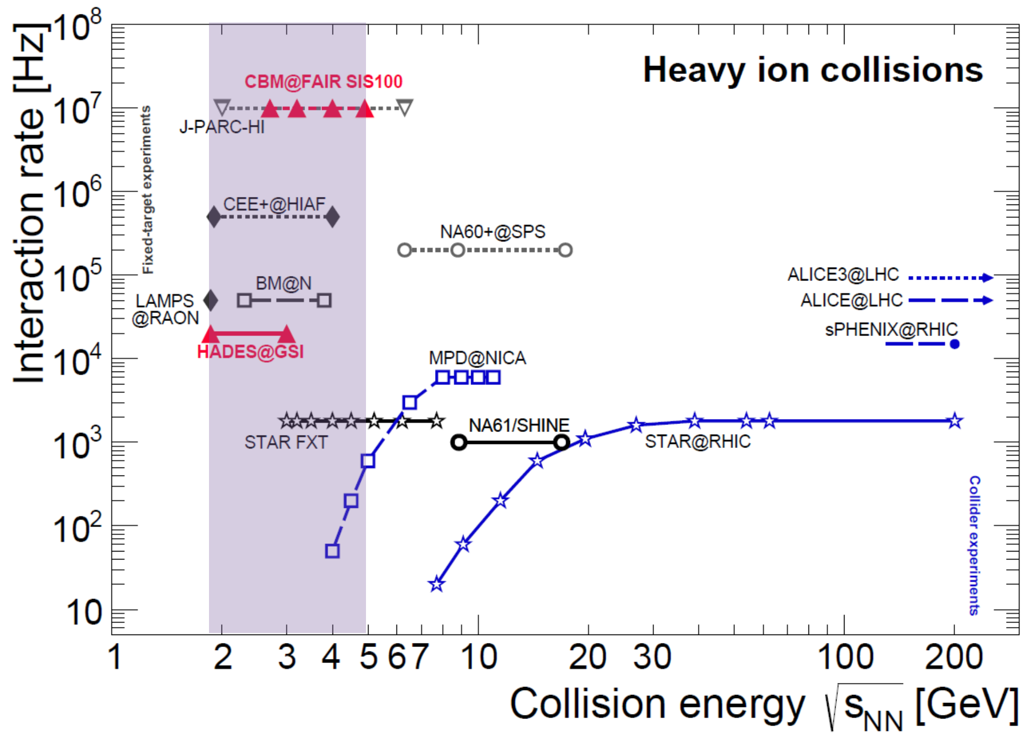
MPD, MB@N@NICA





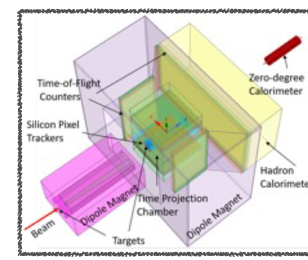
STAR@RHIC

CBM / HADES: operations at $\sqrt{s_{NN}} \sim 2 - 5\ GeV$

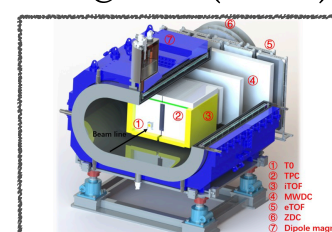


T. Galatyuk, NPA 982 (2019), update 2024 https://github.com/tgalatyuk/interaction_rate_facilities
CBM, EPJA 53 3 (2017) 60

J-PARC-HI



CEE@HIAF (>2027)



Road map

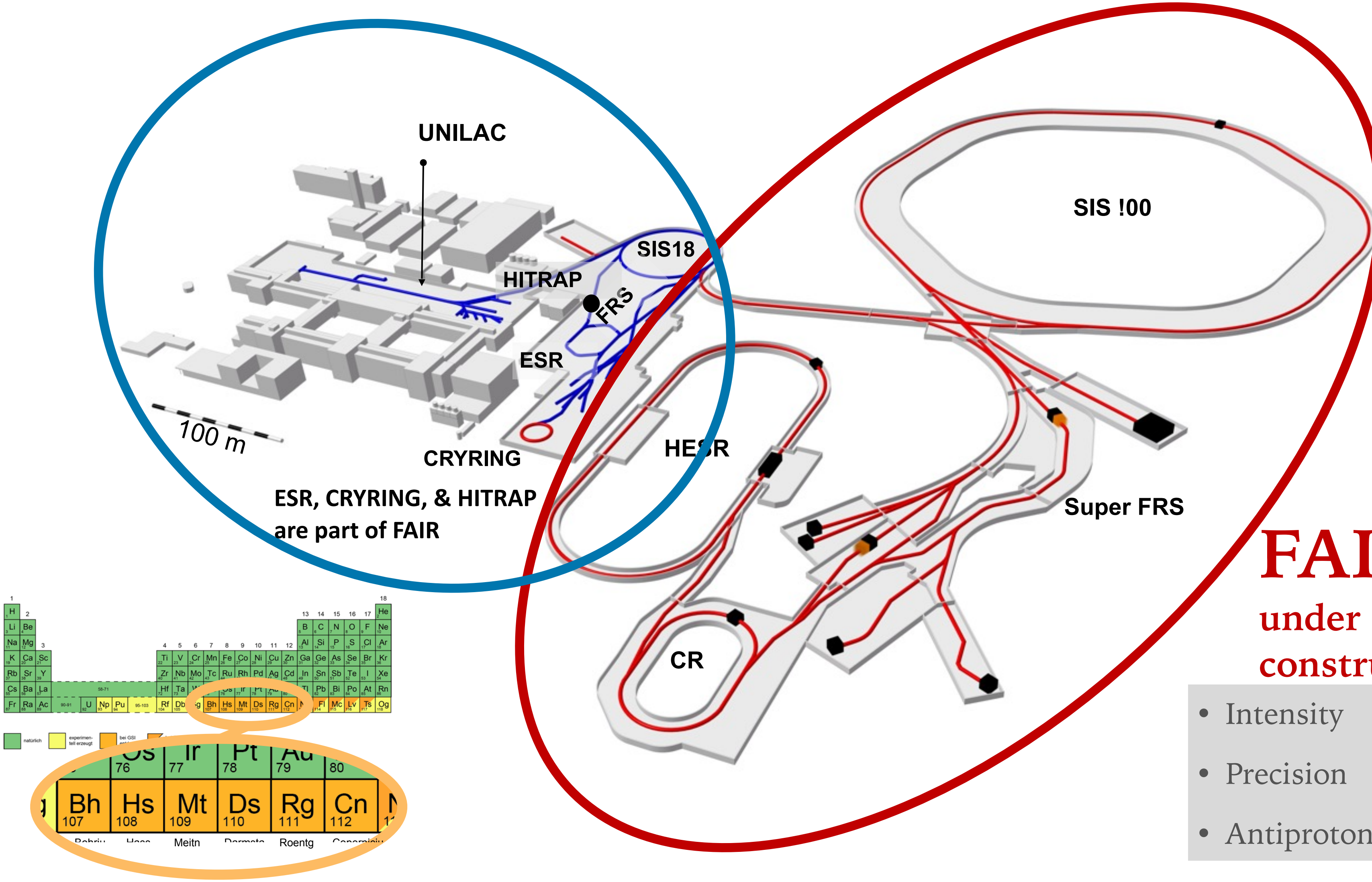
What are we pursuing and why? → Physics motivation

Where are we now? → Current status

Who is involved? → Experimental facilities

How to achieve the goal? → **Compressed Baryonic Matter**

GSI, existing (upgraded to integrate with FAIR)



FAIR, under construction

- Intensity
- Precision
- Antiproton beams

Current prospects and timeline

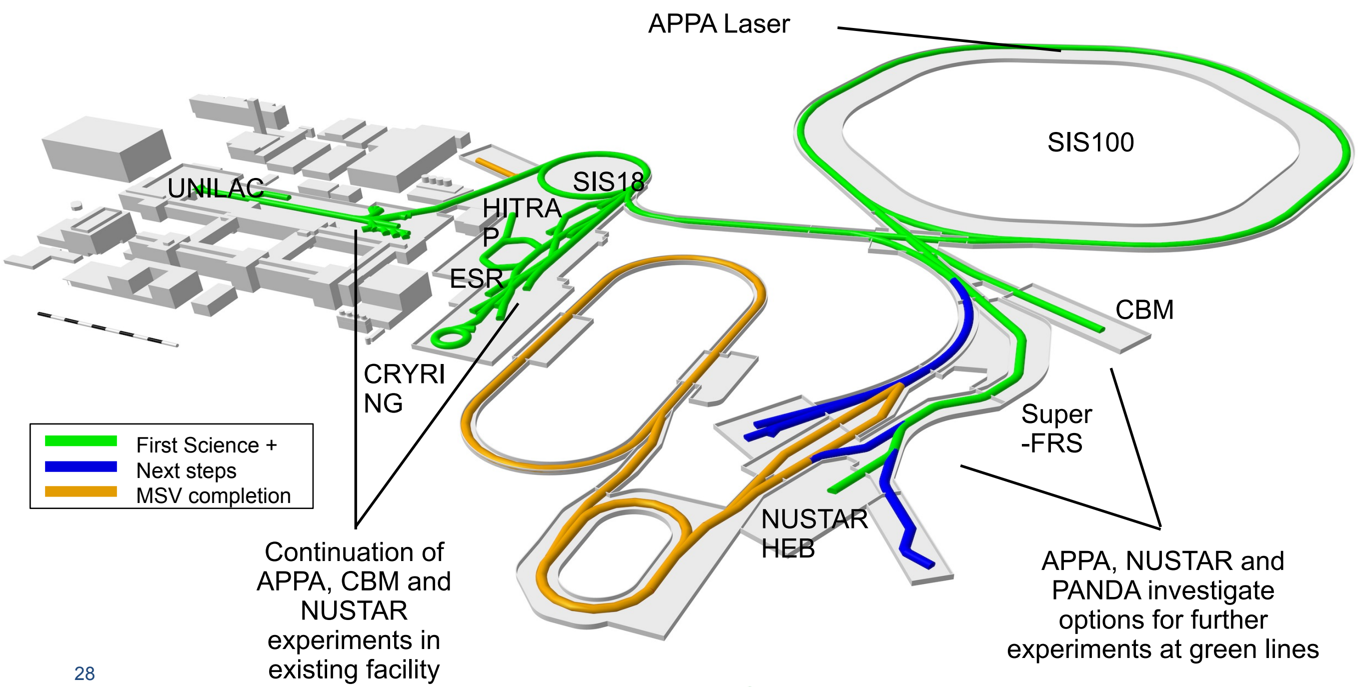
GSI

FAIR

until 2028

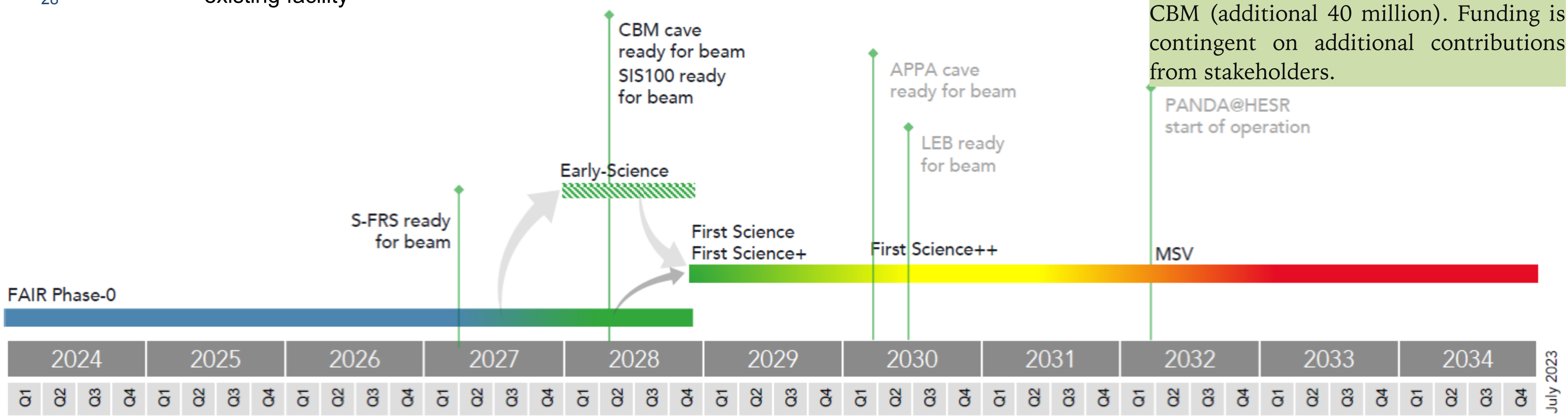
FAIR Phase-0

after 2028



Staged implementation recommended by the Heuer/Tribble Commission's report (2022) with the First Science stage endorsed by the FAIR Council as "the most appropriate starting scenario to achieve world-leading science."

A budget of 2.8 billion Euros is available (including a new contribution of 0.58 billion from Germany), enabling the implementation of First Science without CBM (additional 40 million). Funding is contingent on additional contributions from stakeholders.



Facility for Antiproton and Ion Research

Facility for Antiproton and Ion Research

SIS100 magnets,
April, 2024

CBM cave,
February, 2024

Facility for Antiproton and Ion Research

NuPECC LRP2024 Executive Summary

Introduction

https://nupecc.org/lrp2024/Draft_Executive_Summary_LRP2024.pdf

What does nuclear physics stand for?

Nuclear physics is the study of the atomic nucleus, its constituents, structure, reactions and the properties of strongly interacting matter in its various forms. It is a key basic scientific field that investigates the properties of matter at the subatomic level. This domain of research affects not only our fundamental understanding of nature but also has many peaceful applications in all areas of modern life. Nuclear physics research originally started in Europe in the late 19th century. Now, in the 21st century, Europe is still at the forefront of nuclear physics research and applications. This leading European role is due to a rich and diverse landscape of research institutions and infrastructures in all European countries.
The present Long Range Plan for European nuclear physics summarises progress in the field in the last decade, provides an outlook on expected developments in the next decades, and presents recommendations for scientific institutions, policymakers, and research funding organisations.

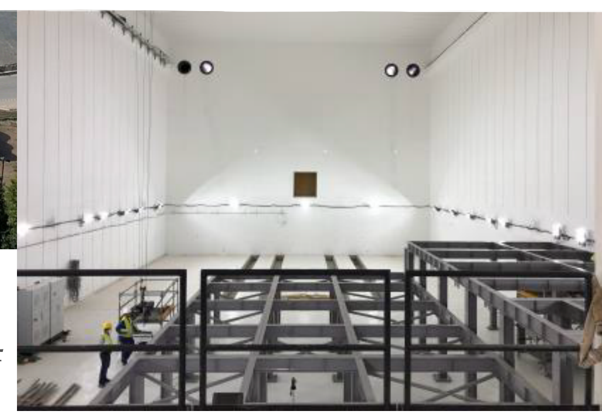
Recommendations for Nuclear Physics Infrastructures

The NuPECC Long Range Plan 2024 resulted in the following main recommendations for infrastructures of importance for nuclear physics:

- The first phase of the international **FAIR** facility is expected to be operational by 2028, facilitating experiments with SIS100 using the High-Energy Branch of the Super-FRS, the CBM cave and the current GSI facilities. Completing the full facility including the **APPA**, **CBM**, **NUSTAR** and **PANDA** programs will provide European science with world-class opportunities for decades and is highly recommended.

SIS100 magnets,
April, 2024

CBM cave,
February, 2024



Poland @ FAIR

- FAIR governed by international convention
  - 9 shareholders:
  - + 1 associated partner:
  - + 1 aspirant partner:
  - Over 3000 Scientists and Engineers from all over the world
- Scientists from More than 200 institutions from 53 countries (orange + blue)

Poland holds a 2.3% share, is represented by Jagiellonian University, coordinating Polish in-kind contributions to FAIR, funded by the Ministry of National Education (approximately 23.7 million Euros in 2005).

Over 95% of the funds allocated to in-kind contributions to research infrastructure and experiments at FAIR.
More at https://fair.uj.edu.pl/.

The National Consortium of Femtophysics comprises 12 Polish universities and research institutes (https://fair.uj.edu.pl/konsorcjum).

FAIR included in the roadmap of European and Polish research infrastructure.

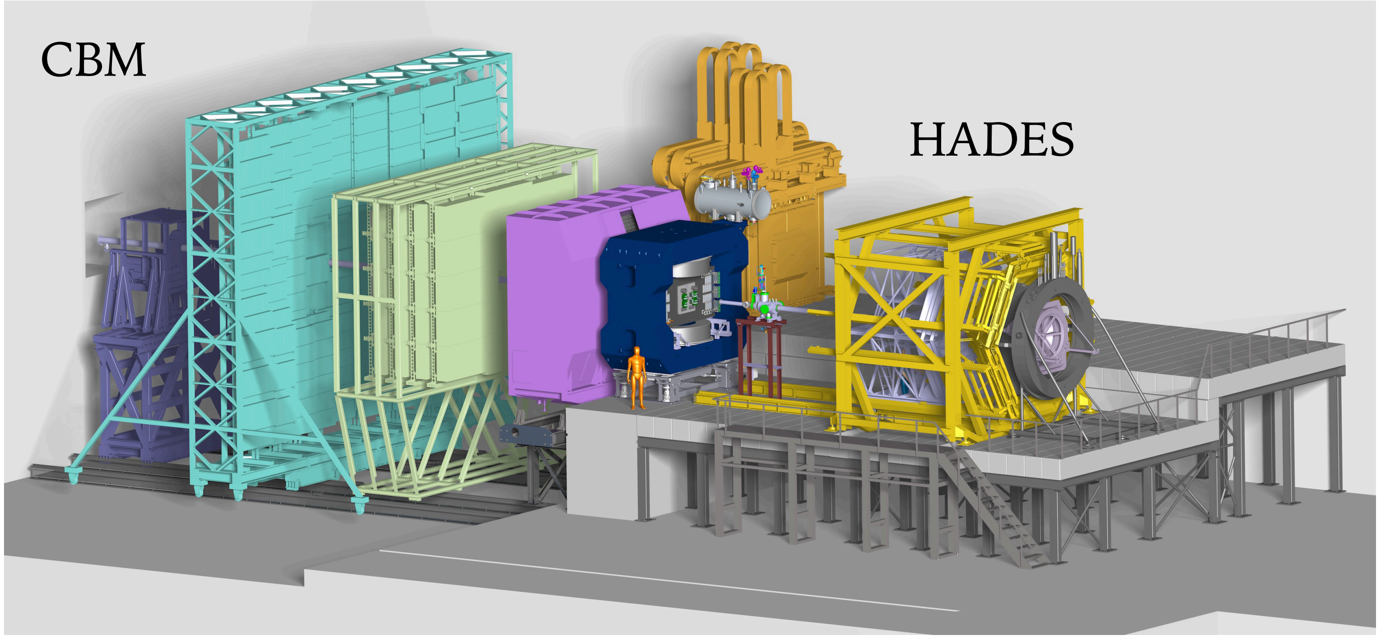
Compressed Baryonic Matter experiment

Fixed-target experiment → highest rates achievable
Versatile subsystems → tailored for the physics program
Silicon-based tracking → fast and precise
Free-streaming front-end-electronics (FEE) → minimal dead-time while data acquisition
Online event selection → advanced data taking focused on customized needs

First beams in 2028/2029

Years 1-3: first energy scan, improved statistical uncertainties of factor 10 with respect to STAR

Years 4-8: high-statistics measurements: di-lepton IMR, ultra-rare probes



315 full members from 10 countries
47 full member institutions
10 associated member institutions

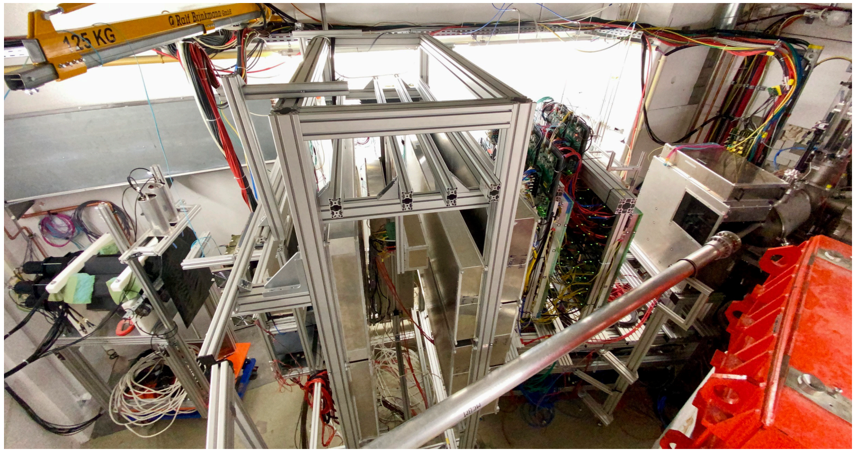
mCBM

Campaign 2024:

high-rate studies

online reconstruction and selection

Λ baryons in Ni+Ni at 1.0 - 1.93 AGeV

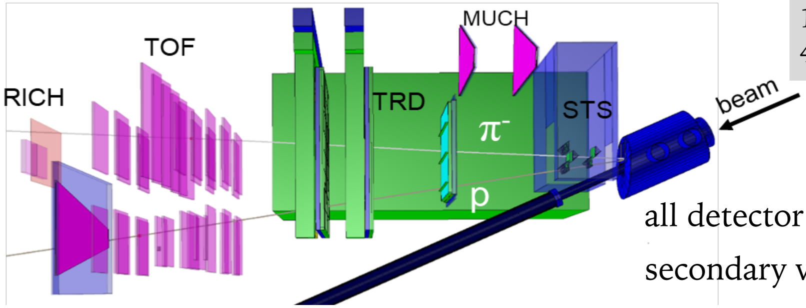


Free-streaming CBM data transport

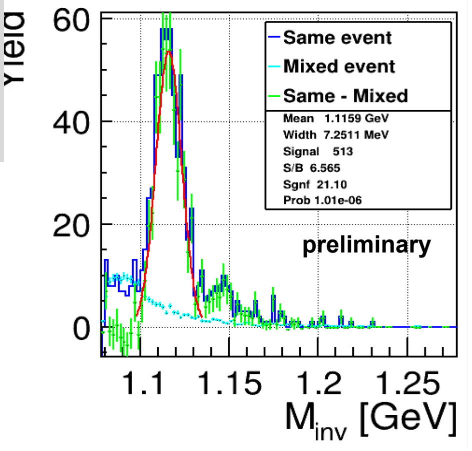
Pre-series productions of all CBM detector systems

High-rate studies up to 10 MHz coll. rate in A+A collisions

Rare signal reconstructed: $\Lambda \rightarrow p\,\pi^-$



Ni+Ni 1.93 AGeV
run 2391 (May '22):
10^9 collisions, 1:57h
400 kHz av. coll. rate



all detector systems involved

secondary vertex

velocity windows for p and π^- candidate

Road map

What are we pursuing and why? ⇒ Physics motivation

Where are we now? ⇒ Current status

Who is involved? ⇒ Experimental facilities

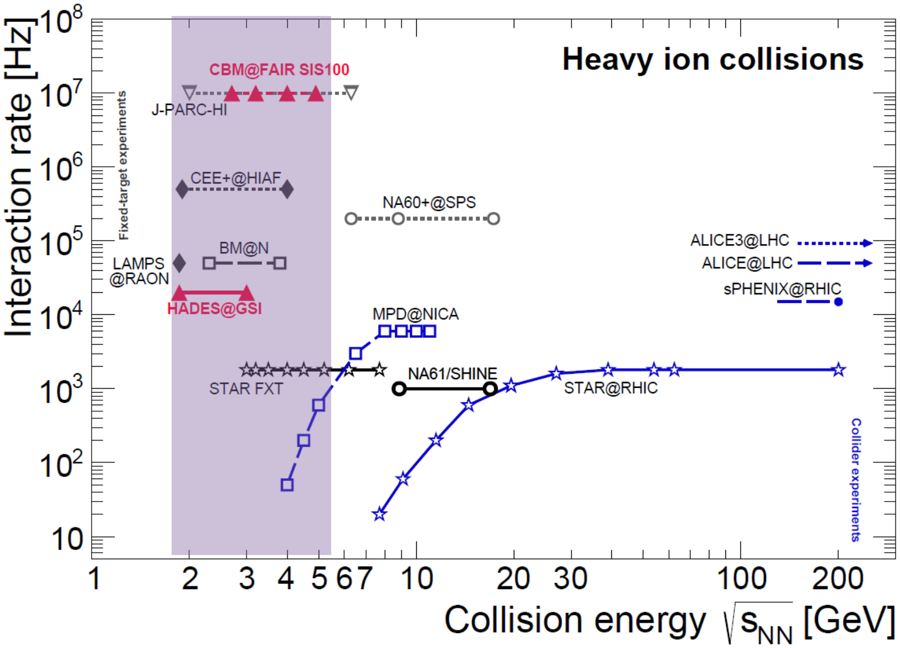
How to achieve the goal? ⇒ Compressed Baryonic Matter

What is the plan? ⇒ **Key measurements**

Key observables

Systematic measurements:

- **Fluctuations**: System alteration through first-order phase transition, critical point
- **Dileptons** : Emissivity: system's lifetime, temperature, density, in-medium characteristics
- **Hadrons (Strangeness, Charm, Hyper-nuclei, Bound states):** EOS: vorticity, collectivity, correlations: NN, YN, YY, multi-body interactions



T. Galatyuk, NPA 982 (2019), update 2023
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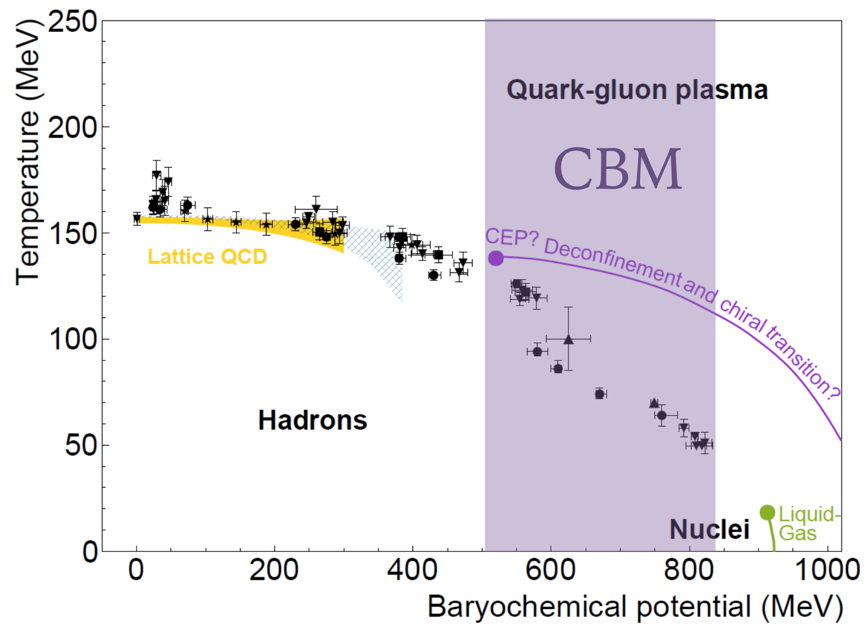
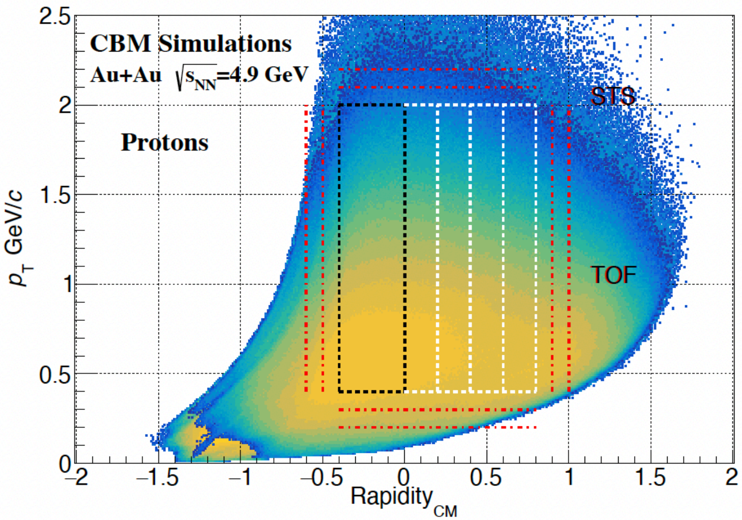


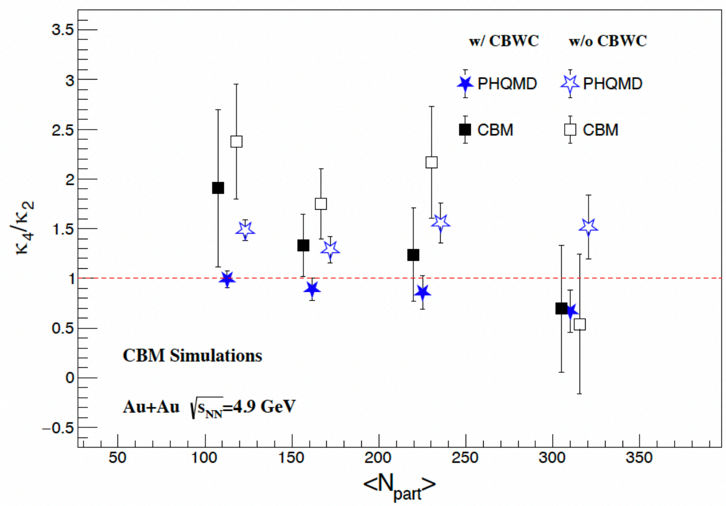
HADES; Nature Physics 15 (2019) 10, 1040-1045

Fluctuations

Corrections for volume fluctuations and conservation laws

- Event-by-event changes of efficiency
- Proper selection of $y - p_T$ interval
- (Net-)baryons vs. protons, neutrons, nuclei





Expectations after ~3 years of running

- Full coverage of κ_4(E) for protons
- First results of κ_6
- Possible addition of strangeness: $\kappa_4(\Lambda)$

Dileptons

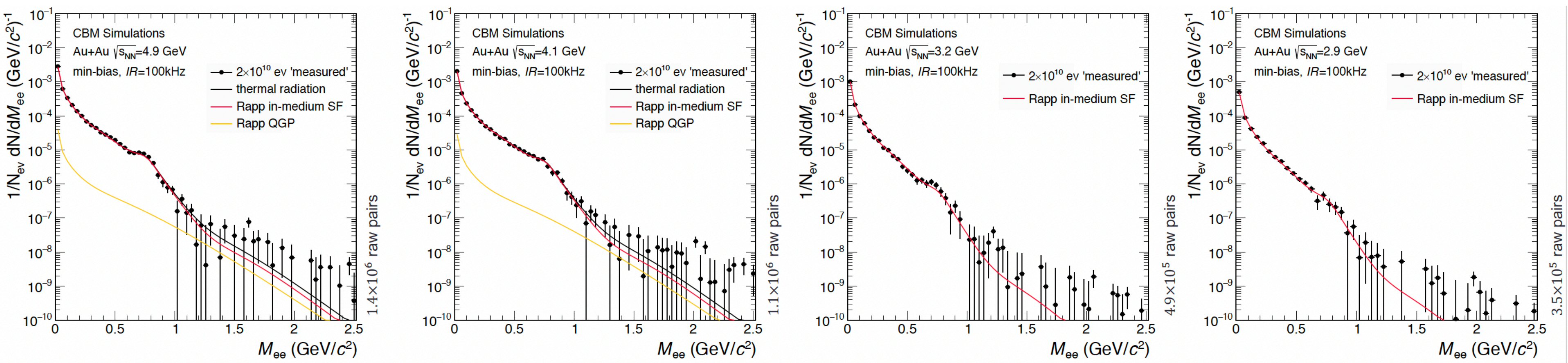
Electron thermal radiation, corrected for acceptance and efficiency,

Dominated by ρ contribution at LMR,

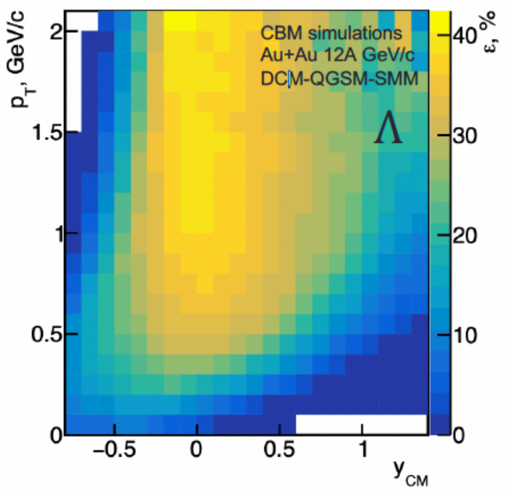
Can be reconstructed with 1.5-4.5% of precision,

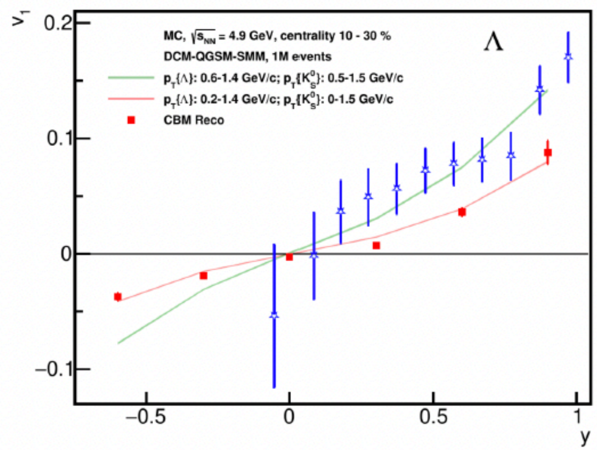
Gives access to to the fireball lifetime and electrical conductivity (transport properties)

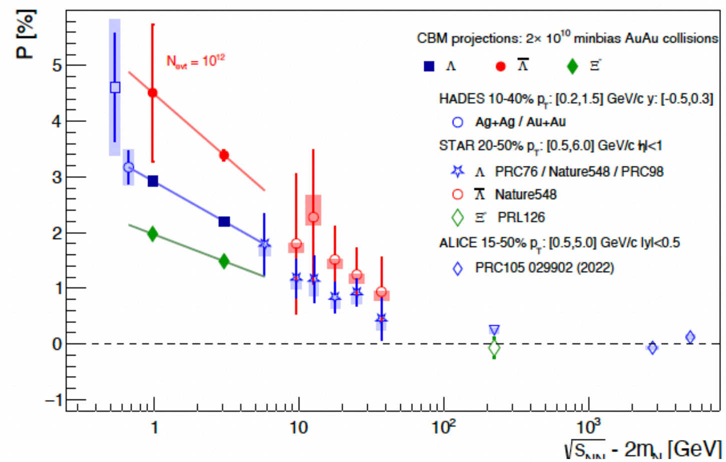
T vs. baryon density effects from partonic to hadronic fireballs



Flow, polarization, correlations

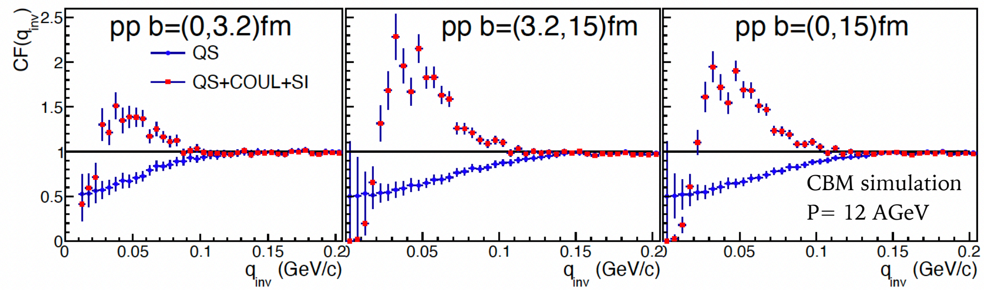




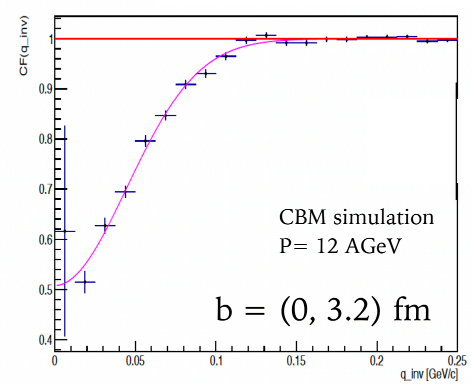


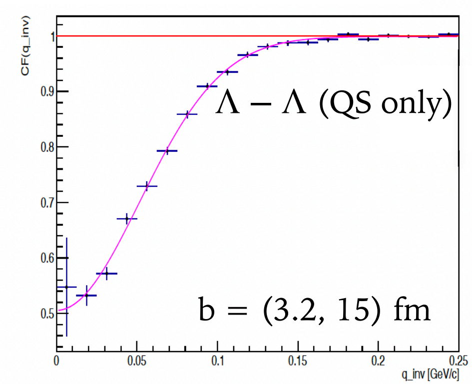
Excellent acceptance coverage

Reconstruction efficiency ~30%



- Precise measurements of flow for S=1, 2, 3
- Polarization measurement with precision of ~5%
- Thorough multi body N and Y correlations of S=1, 2, 3 achievable

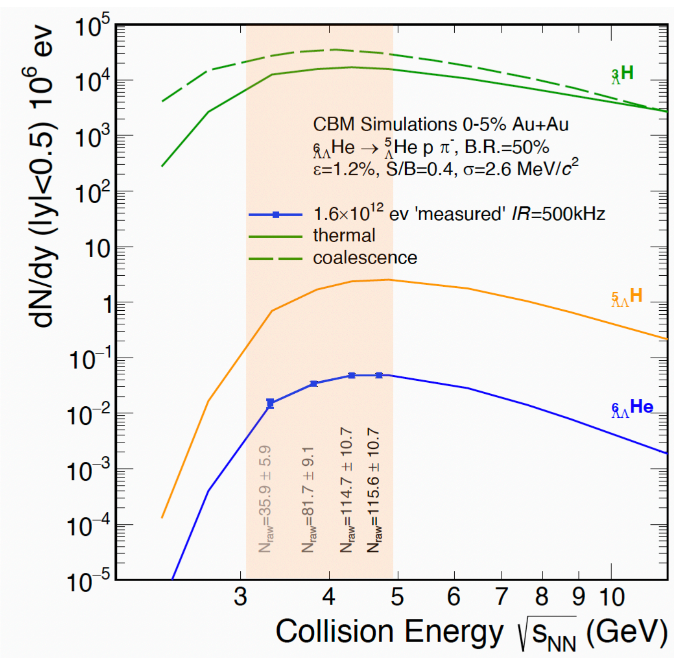


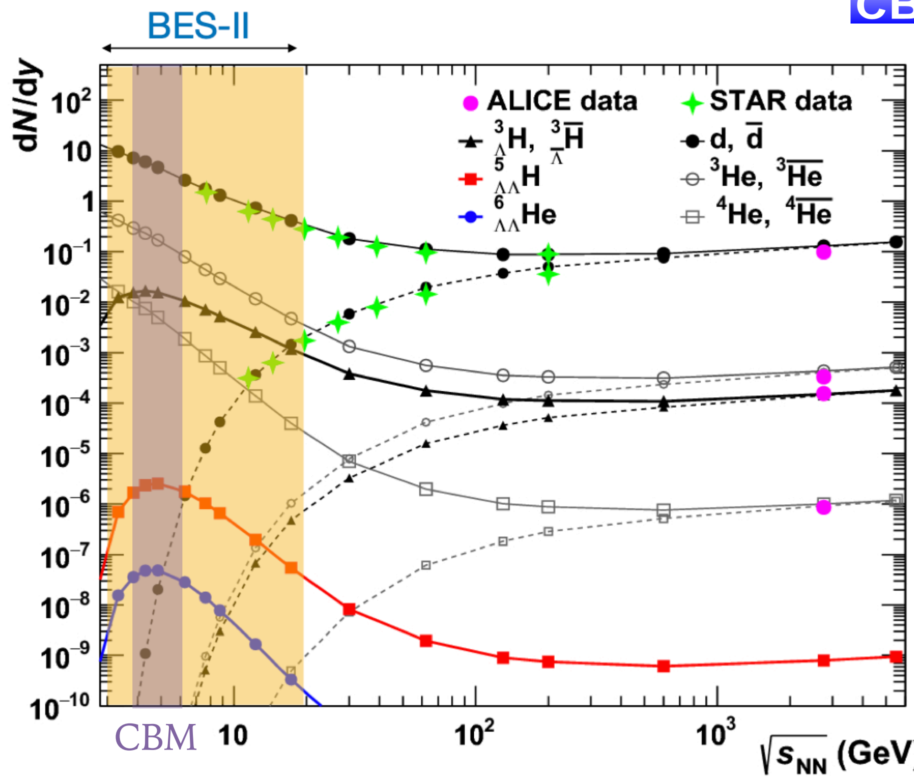


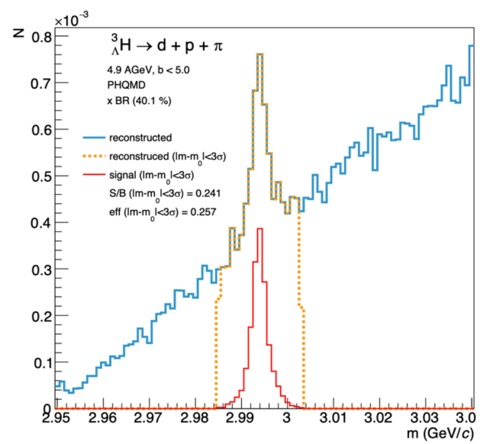
Interactions: hyper-nuclei, bound-states

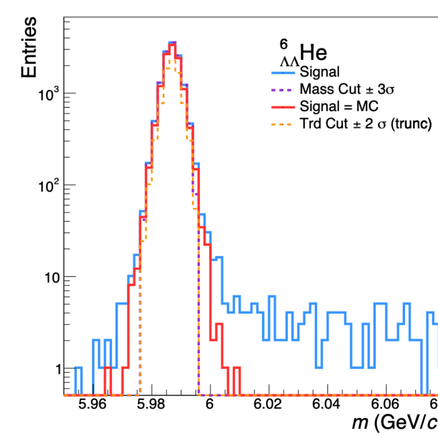
The most abundant production of hyper-nuclei anticipated at $\sqrt{s_{NN}} \sim 2-5$ GeV

Prominent interaction rates and excellent particle identification will facilitate to search for multi-strange hyper-nuclei





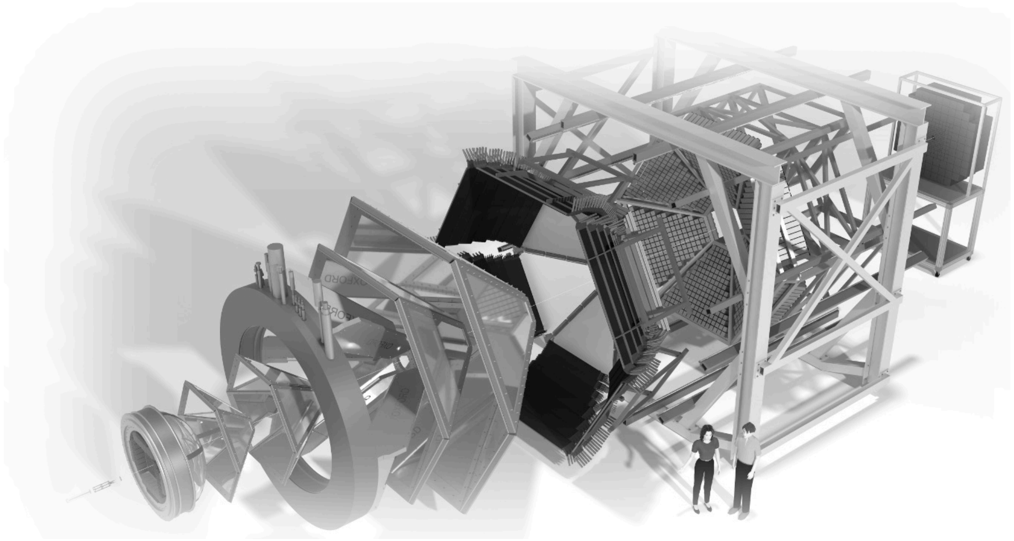




Andronic et al., PLB 697 (2011)
Steinheimer et al., PLB 714 (2012)

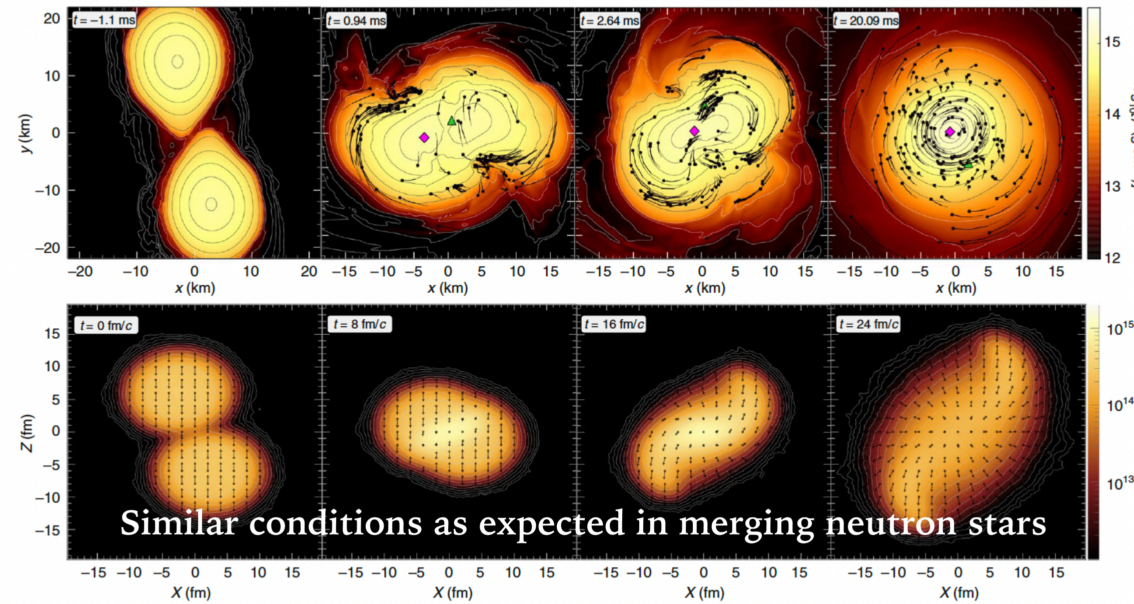
Road map

HADES FAIR Phase-0 program



Physics goals and HADES detector

HADES physics goals



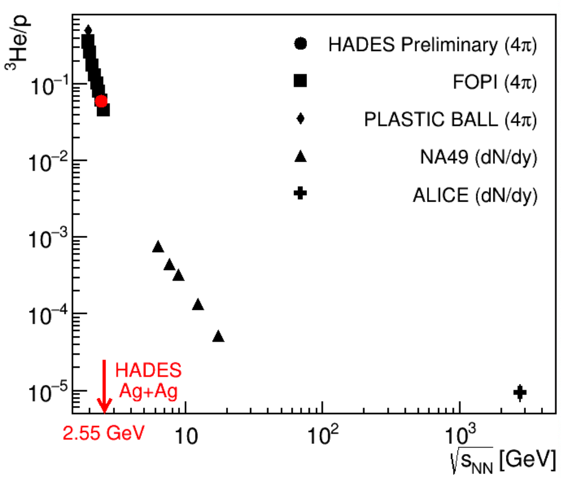
HADES, Nature Phys. 15, 1040–1045 (2019)

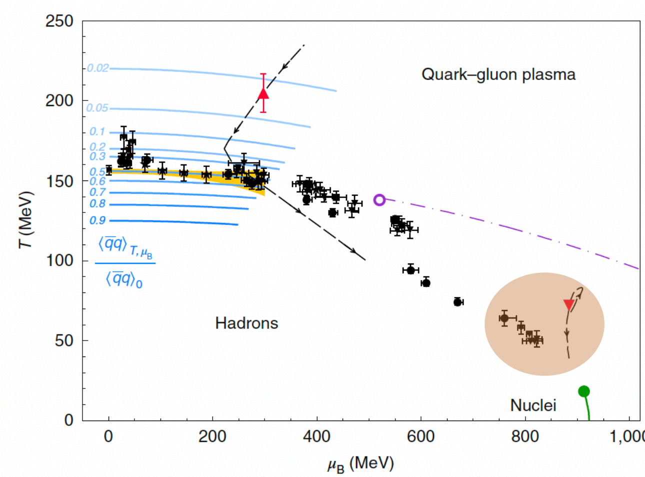
Heavy-ion collisions at $\sqrt{s_{NN}}$ up to 2.7 GeV

- Microscopic properties of baryon dominated matter
- EoS observables

π^- ($\sqrt{s}$ up to 2.35 GeV) and nucleon ($\sqrt{s}$ up to 3.46 GeV) beams:

- Reference measurements (vacuum, cold QCD matter)
- Electromagnetic structure of baryons and hyperons





High Acceptance Di-Electron Spectrometer

Fixed target experiment at **SIS-18** accelerator (**GSI**, Germany)

Magnet spectrometer

Low mass Mini-Drift-Chambers (MDCs)

Time of flight walls: RPC and TOF

RICH and ECAL for e^+/e^- and photon identification

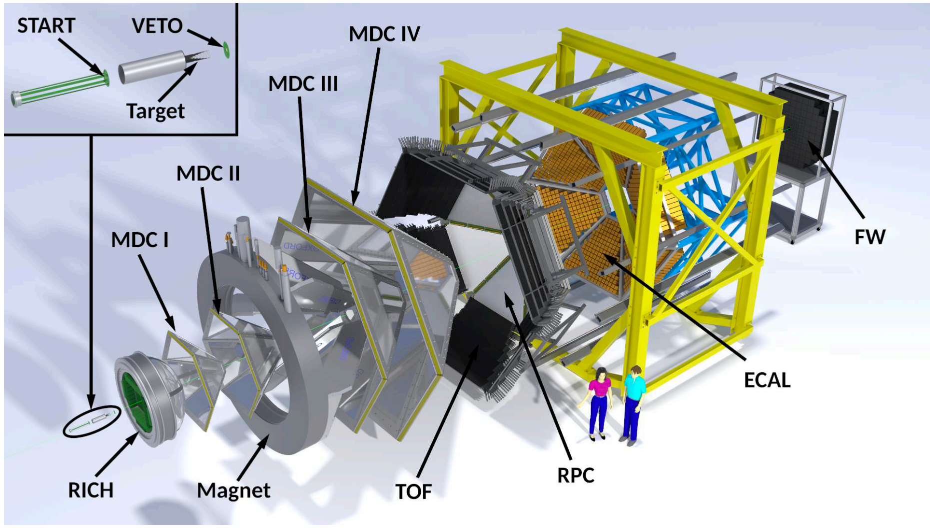
Full azimuthal angle and polar angles between 18° and 85° covered

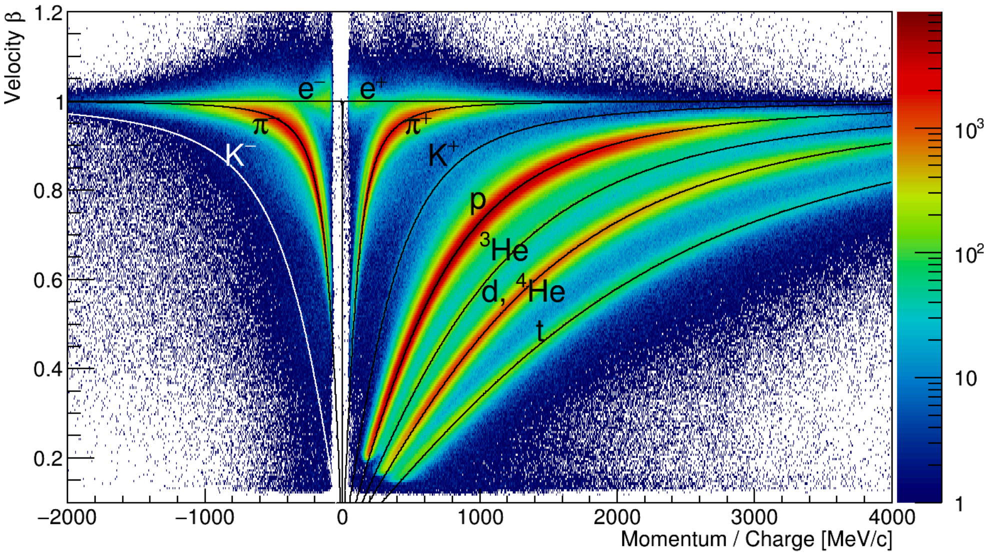
2012: Au+Au, $\sqrt{s_{NN}}$ = 2.42 GeV (7 billion)

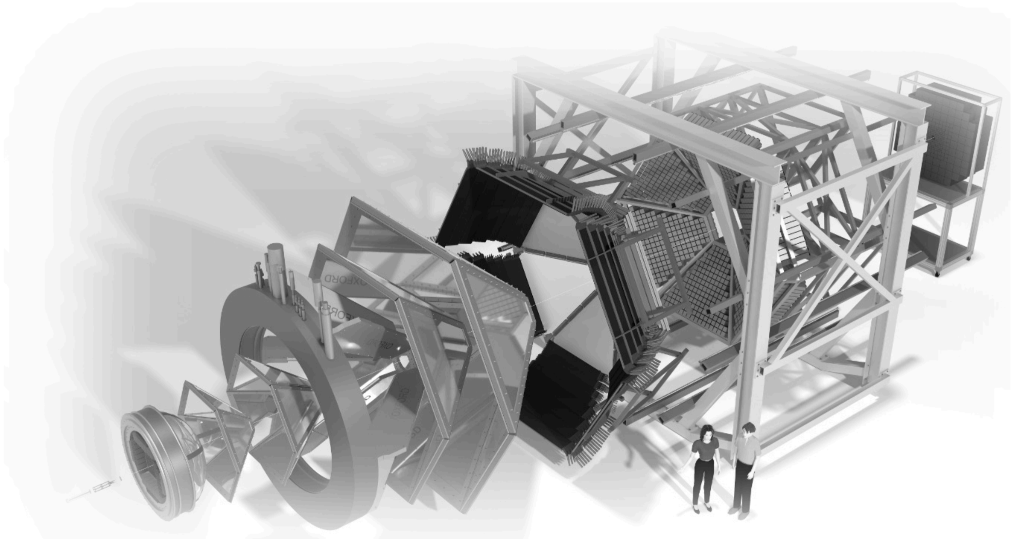
2019: Ag+Ag, $\sqrt{s_{NN}}$ = 2.55 GeV

and 2.42 GeV (14 billion)

2024: Au+Au, $\sqrt{s_{NN}}$ = 2.24 GeV (1.8 billion)







Hadrons

E-by-e fluctuations

Looking for signatures of phase transition

Higher order moments of particle yields from derivates of partition function Z w.r.t μ_B *P. Braun-Munzinger, K. Redlich, A. Rustamov, J. Stachel, JHEP 08 (2024) 113*

$$\langle N \rangle = \frac{\partial ln(Z)}{\partial(\frac{\mu}{T})}$$

$$\langle N^2 \rangle - \langle N \rangle^2 = \frac{\partial^2 ln(Z)}{\partial(\frac{\mu}{T})^2}$$

Cumulants:

$\kappa_1 = \mu$

$\kappa_2 = \sigma^2$

$\kappa_3 = \langle N^3 \rangle - 3\langle N^2 \rangle \langle N \rangle + 2\langle N \rangle^3$

$\kappa_4 = \langle N^4 \rangle - 4\langle N^3 \rangle \langle N \rangle - 3\langle N^2 \rangle^2 + 12\langle N^2 \rangle \langle N \rangle^2 - 6\langle N \rangle^4$

$\text{Skewness} = \frac{\kappa_3}{\sigma^3}$

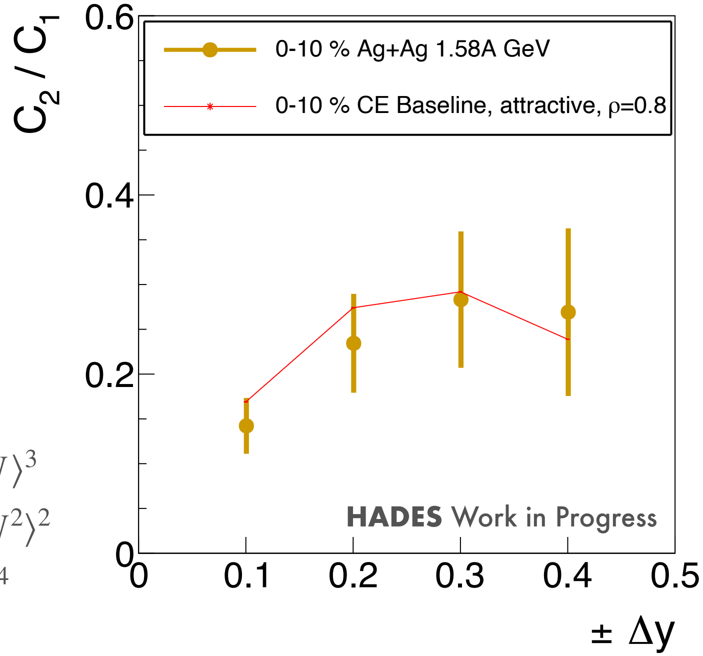
$\text{Kurtosis} = \frac{\kappa_4}{\sigma^4}$

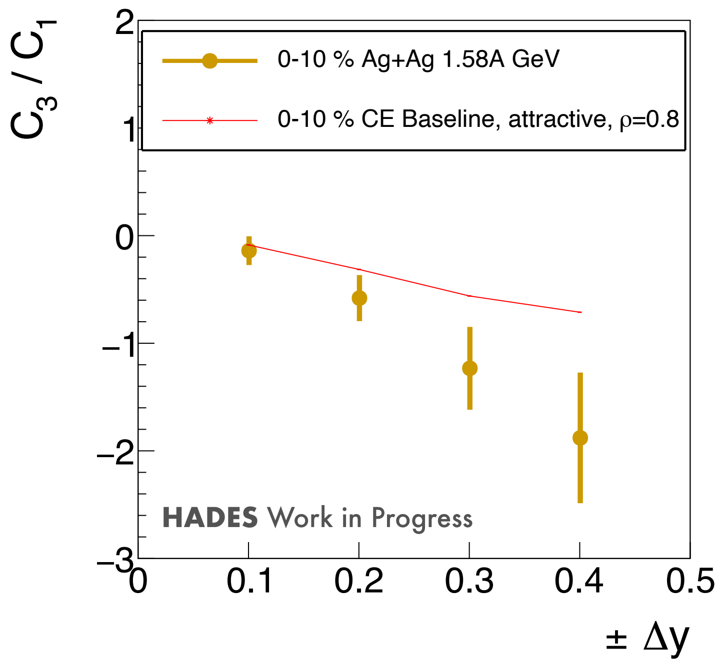
Factorial cumulants:

$C_2 = \kappa_2 - \kappa_1$

$C_3 = \kappa_3 - 3\kappa_2 + 2\kappa_1$

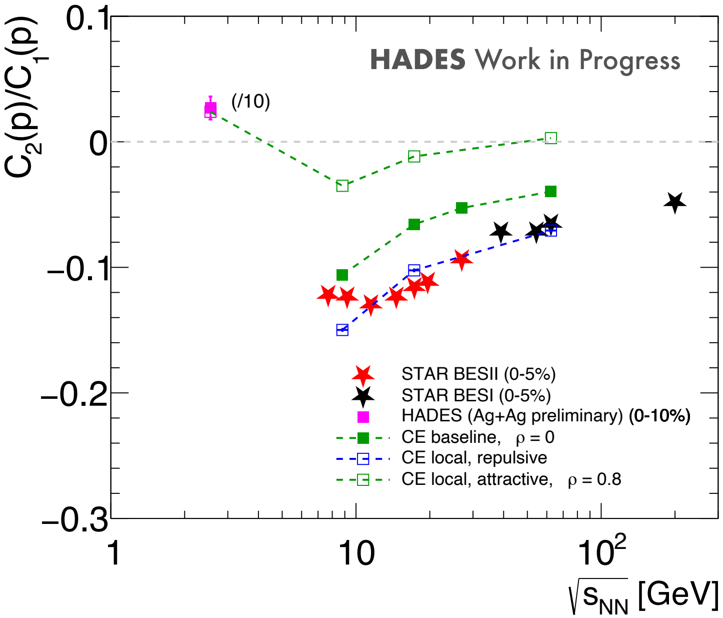
$C_4 = \kappa_4 - 6\kappa_3 + 11\kappa_2 - 6\kappa_1$

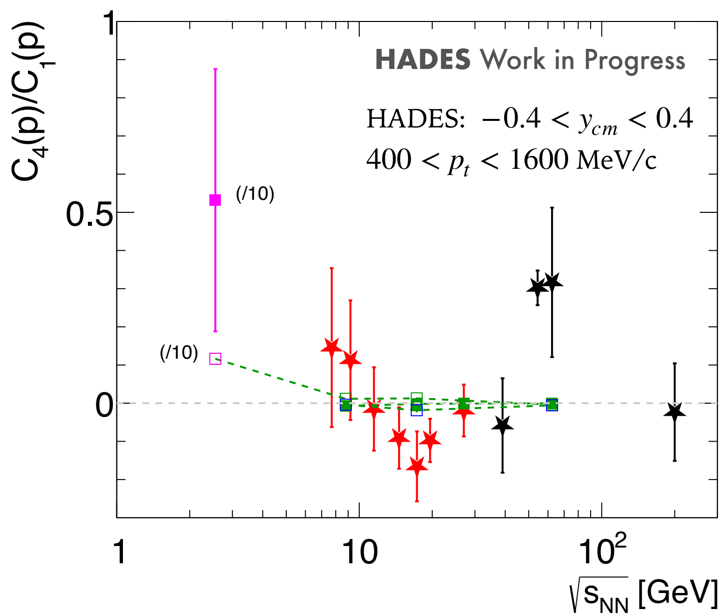




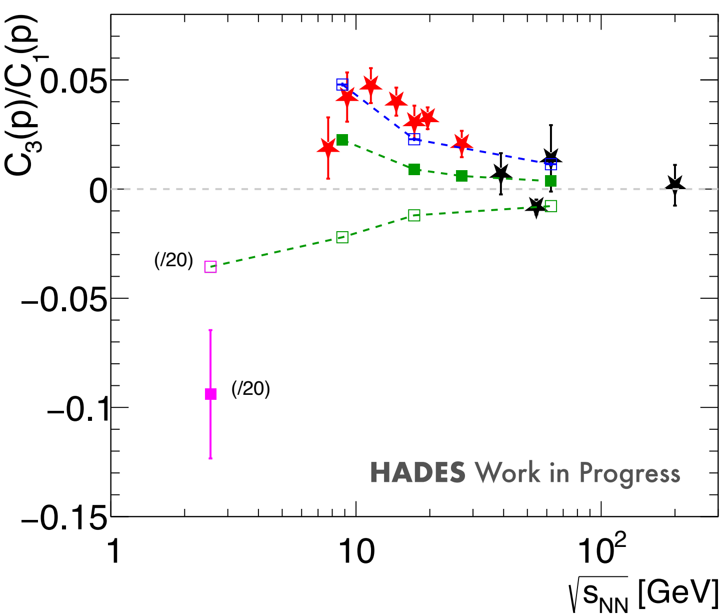
Trend of rapidity dependence of factorial cumulant ratios described by Canonical baseline considering correlations and attractive potential

Proton factorial cumulants





B. Friman, A. Rustamov, K. Redlich (in progress)



Larger factorial cumulant ratios at HADES compared to STAR

C_3/C_1 and C_4/C_1 HADES continues trend observed at STAR towards lower $\sqrt{s_{NN}}$

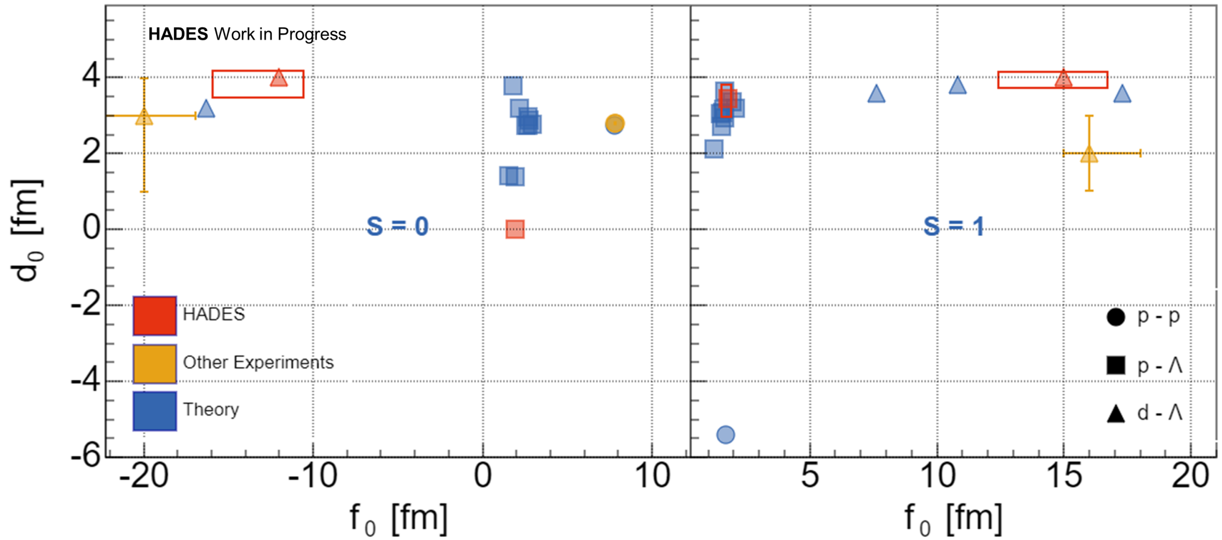
The interplay of repulsive and attractive forces between protons explains the systematic trends observed in the STAR BESII and HADES data

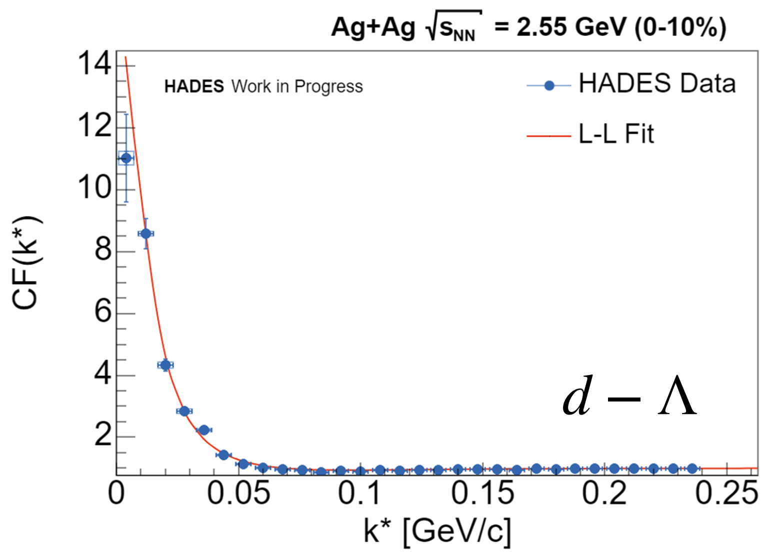
Interactions

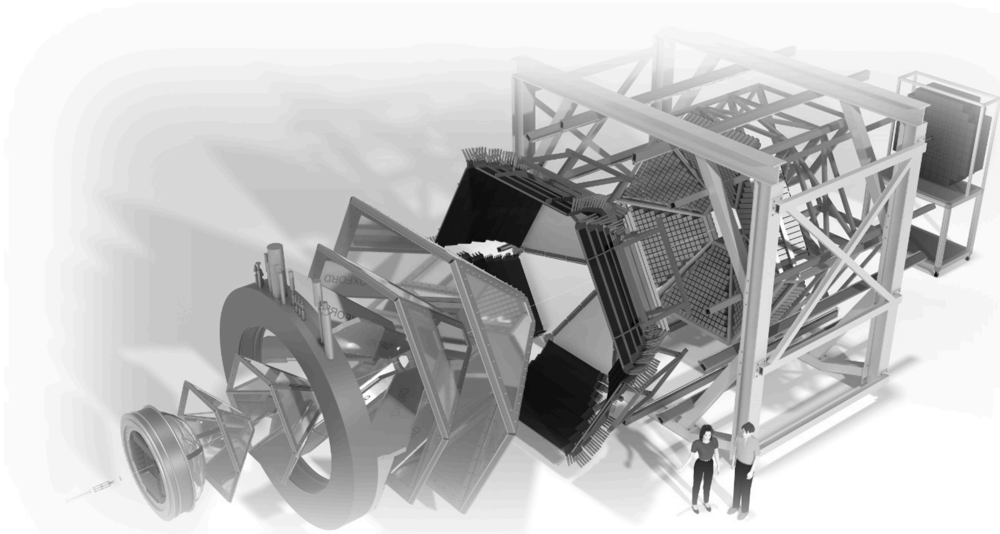
Phys. Rev. C 99.2 (2019): 024001
EPJ Web of Conferences. Vol. 296, 2024
A. Rijken, Phys. Rev. C, Nucl. Phys. 73.4 (2006): 044007
A. ES Green, M. H. MacGregor, and R. Wilson. Conf. 1967

A. Cobis, J.Phys. G 23, 401 (1997)
H.W. Hammer,Nucl. Phys. A 705, 173 (2002)
G. Alexander, Phys. Rev. 173, 1452 (1968)
T.A. Rijken, Prog. Theor. Phys. Suppl. 185, 14 (2010)

- Nucleons essentially stopped in collision zone
- HADES around the S production threshold
- Presence of Y in NS
- Impact of Y to EoS
- Modest of NN, NY, and YY interaction measurements
- Scattering length (f_0^S) and effective range (d_0^S) of p - p, p - Λ, and d - Λ interaction estimated
- Inline with the world data

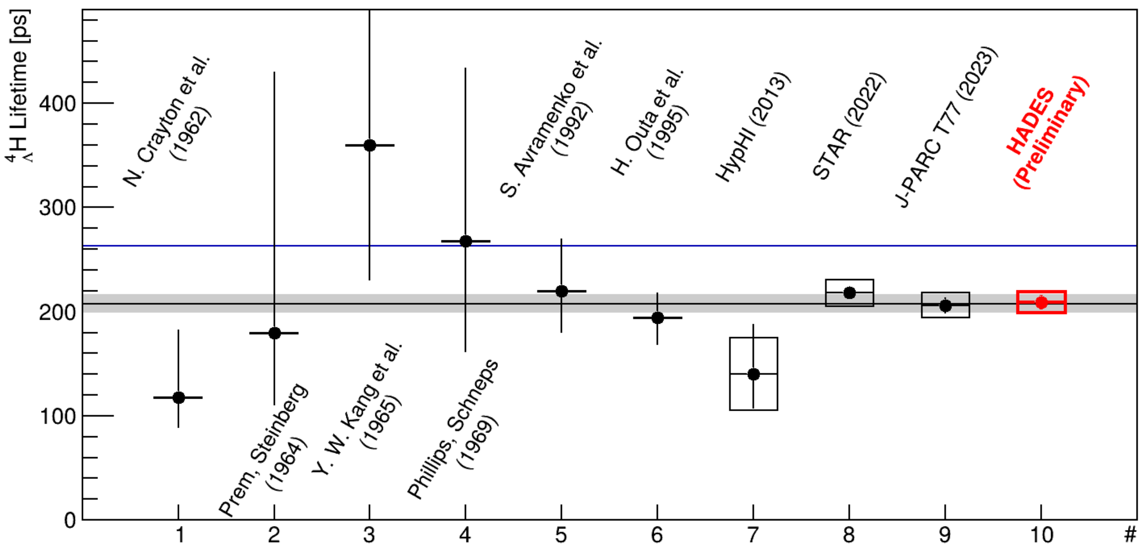






Strangeness

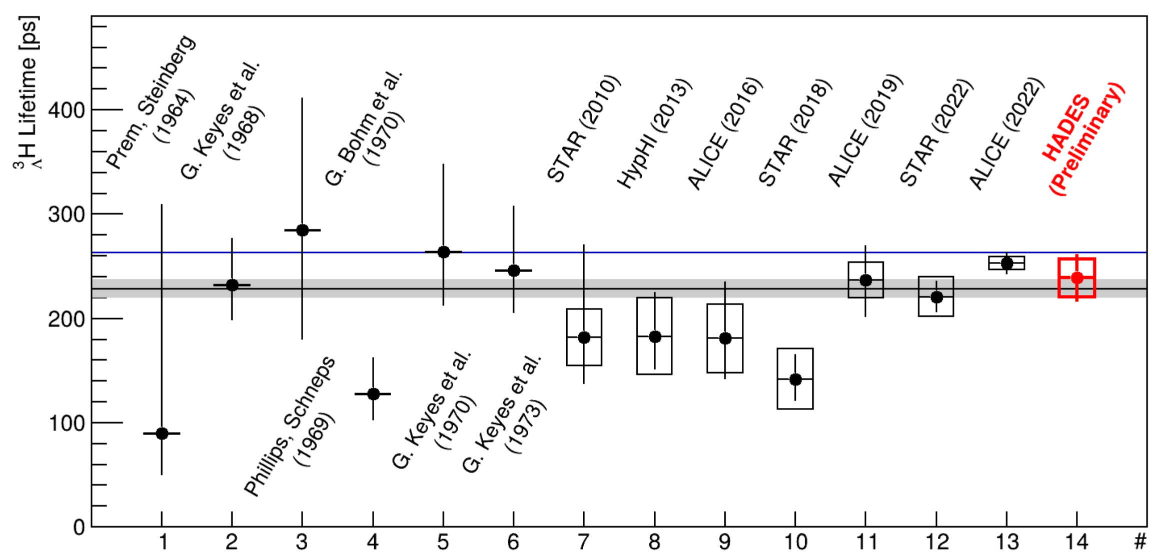
Hypernuclei - lifetime

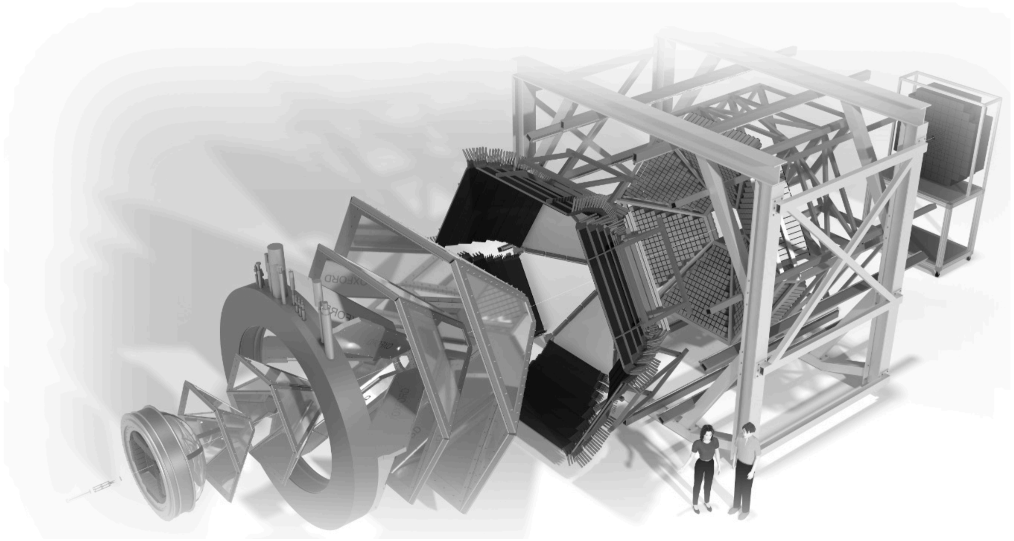


$^{3}_{\Lambda}H$ lifetime: 239 ± 23 ± 18 ps

$^{4}_{\Lambda}H$ lifetime: 209 ± 7 ± 10 ps

$^{3}_{\Lambda}H$, $^{4}_{\Lambda}H$ lifetime measurements compatible with recent data from STAR, ALICE and J-PARC





Dileptons

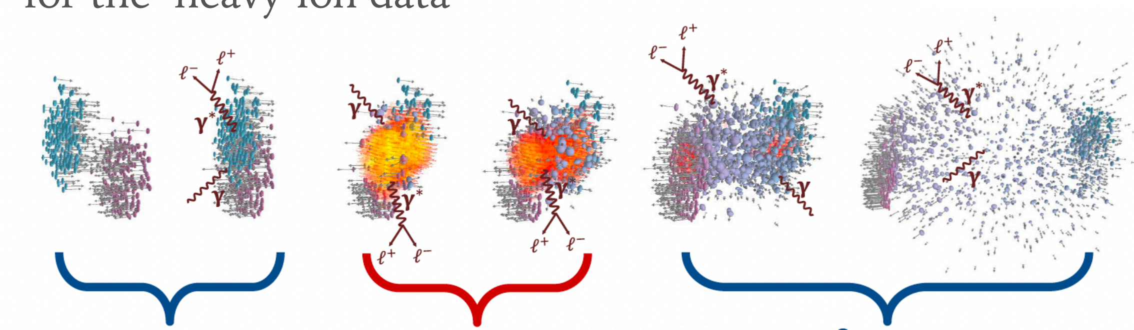
Dilepton measurements

EM probes offer direct access to all stages of heavy-ion collision

Penetrating probes unaffected by strong interactions

Possibility to extract the temperature and lifetime of the medium

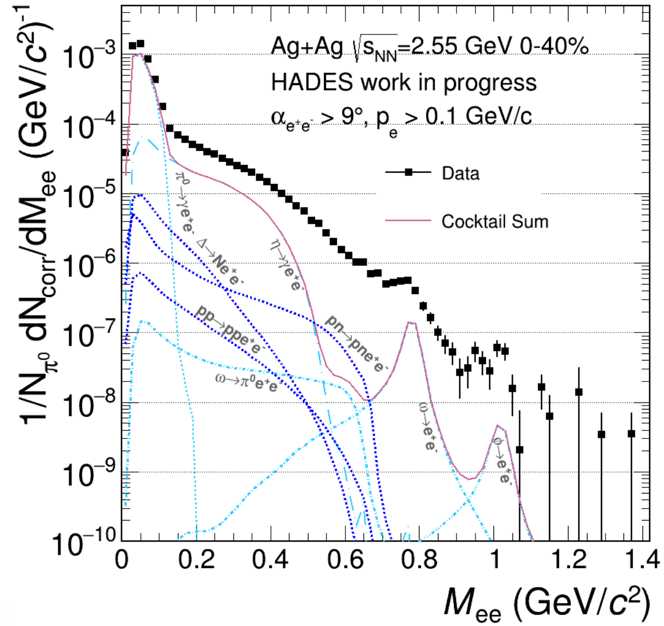
Elementary collisions serve as baseline for the heavy-ion data

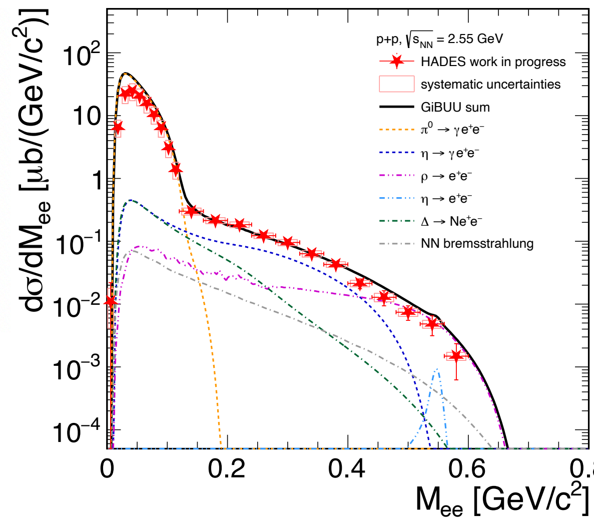


Initial NN

Thermal γ^*

$\pi^0, \eta, \ldots$



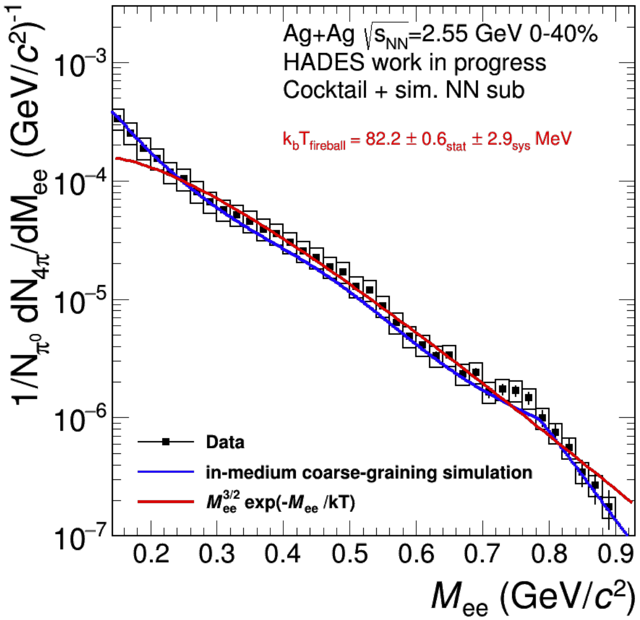


Karina Scharmann
Poster 622

Measured signal:

- Initial NN reference spectrum
- Thermal probes
- Freeze-out cocktail (π^0, η, ω, ϕ)

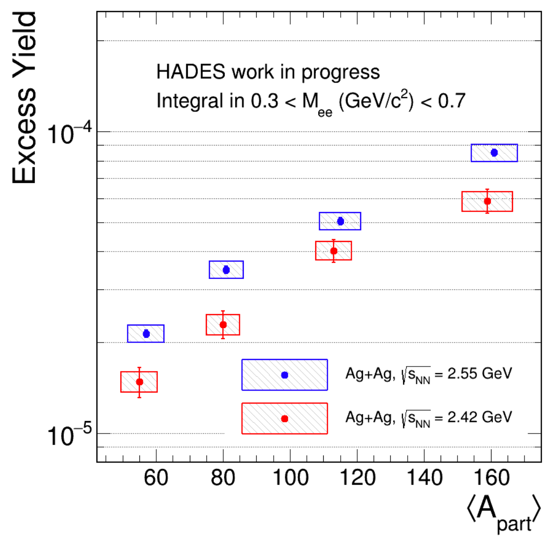
Dilepton excess



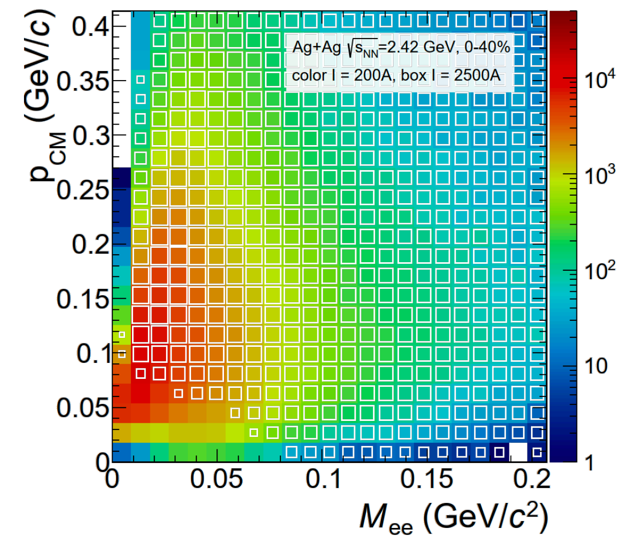
Spectra cutting low-mass of isolated dielectron pairs originating from **thermal radiation** extracted

Fireball temperature determined

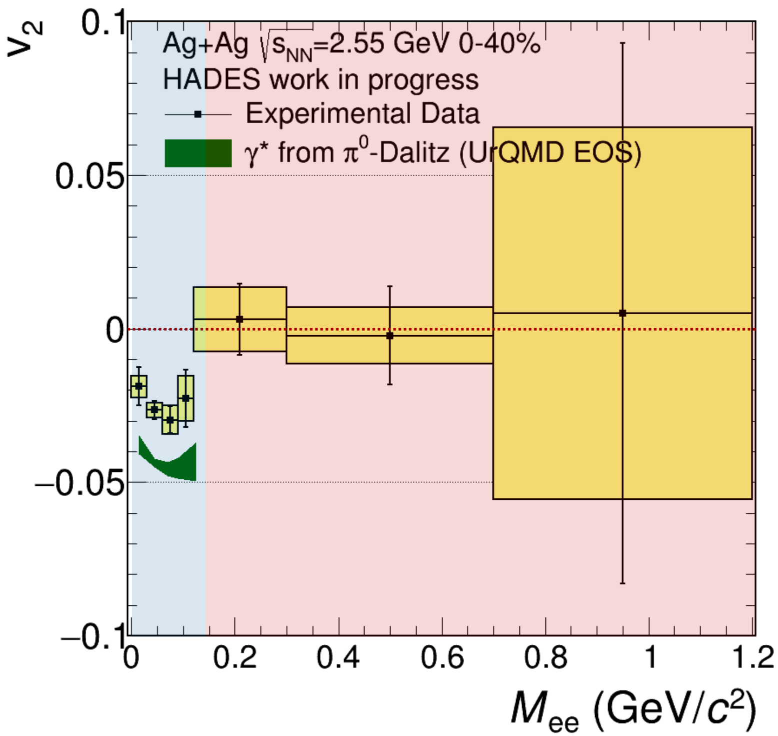
Extended lifetime of a fireball



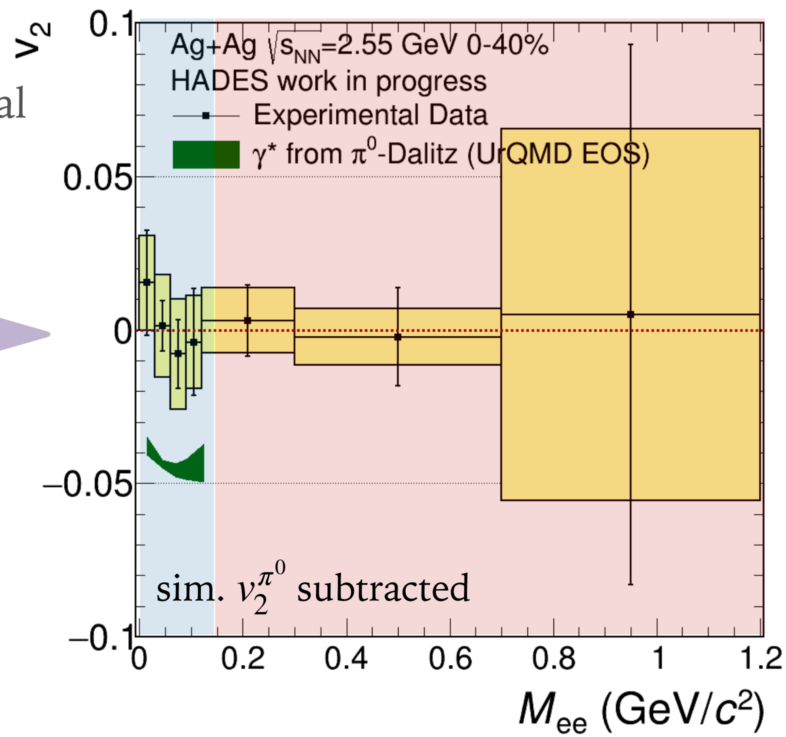
Towards extraction of electrical conductivity for QCD matter at high-density



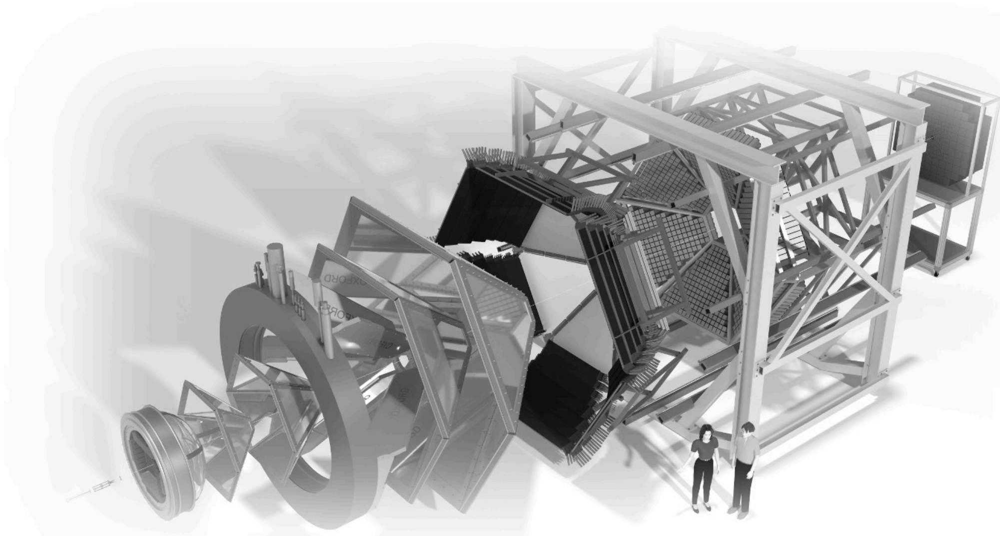
Dilepton flow



Isolating thermal contribution in di-lepton v_2



Change in v_2 in M_{ee} region dominated by π^0 **decays** **(M_{ee} < 0.12 GeV/c^2)** and dominated by **thermal radiation (M_{ee} > 0.12 GeV/c^2)**



Future

Future of HADES

In **2025** HADES continues data taking for energy scan of Au+Au collisions

Searching for critical behavior and limitations of the universal freeze-out line

Au+Au collisions at 0.2 – 0.8 AGeV ($\sqrt{s_{NN}} = 1.96 - 2.23$ GeV)

measurements of e-by-e particle correlations and fluctuations, dielectrons, strange hadrons, light nuclei (up to $Z = 3$) and their flow (up to 6^{th}order)

HADES plans to take data in **2026/27** and continue its extended ***π*-QCD** program:

Cold matter *(in-medium vector-mesons, strangeness)*

Hadron spectroscopy, structure and exotics *(baryon-meson couplings, EM couplings, exotic mesons, rare η decay)*

Effective interactions *(hyperon polarization, hypernuclei formation, hyperon-meson interaction)*

**Hadron physics possibly realized with proton beams at SIS-100 - strong interest from the community*

HADES plans to be operational at least until **2030**

In the following years HADES plans to explore high-μ_B region together with **CBM**

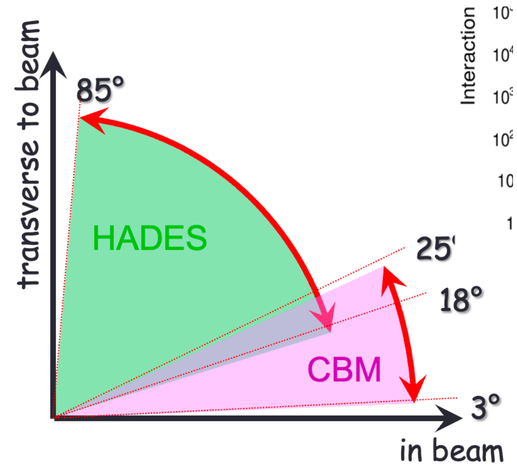
HADES and CBM experiments

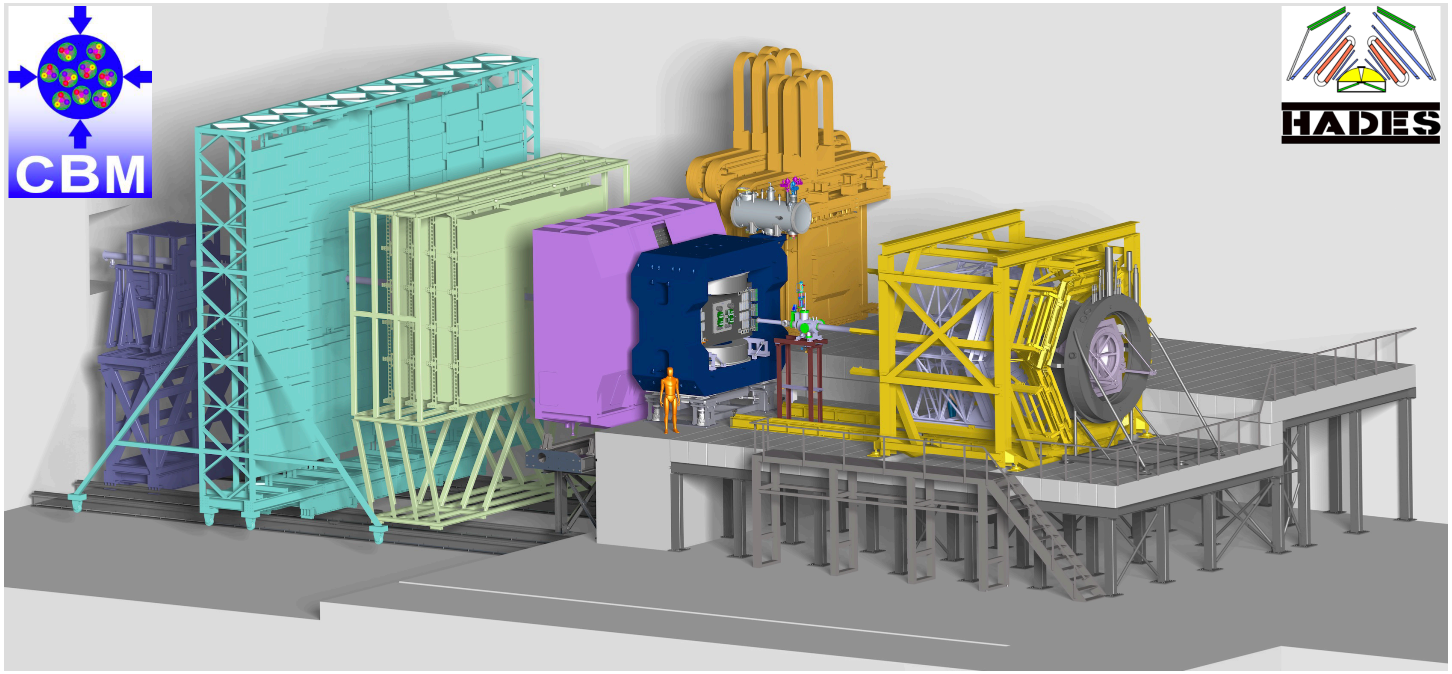
Fixed-target experiments → highest rates achievable

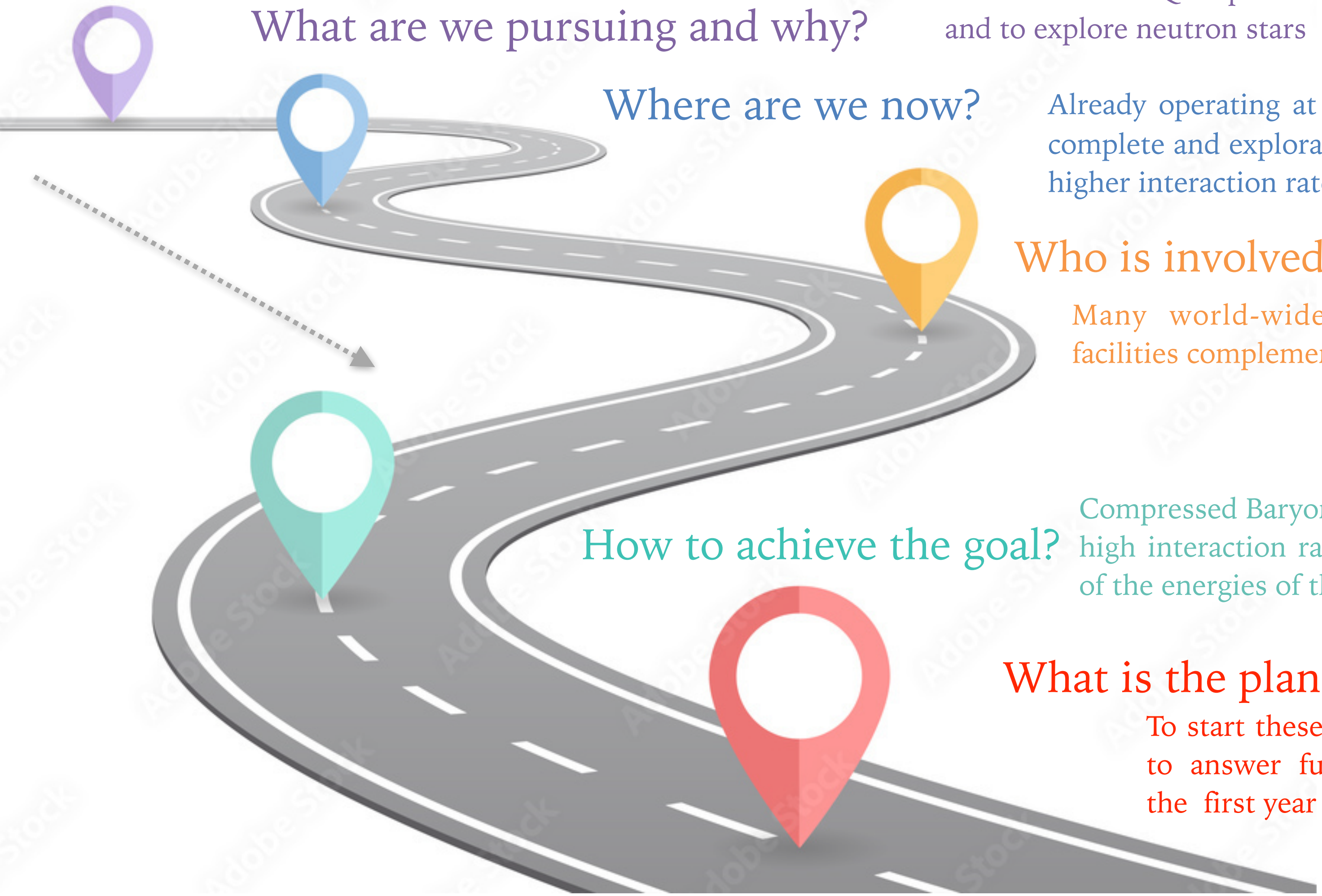
Versatile subsystems → tailored for the physics program

Angular coverage → complementary for HADES and CBM

First beams in 2028/2029







What are we pursuing and why?

To answer fundamental questions about the structure of the QCD phase diagram at high μ_B and to explore neutron stars

Where are we now?

Already operating at high μ_B experiments are complete and exploration of new physics needs higher interaction rates

Who is involved?

Many world-wide existing and planned facilities complement each other programs

How to achieve the goal?

Compressed Baryonic Matter experiment with high interaction rates will explore the region of the energies of the highest importance

What is the plan?

To start these exploration in 2028 and to answer fundamental questions in the first year of CBM running

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The Future is Bright

Be the light

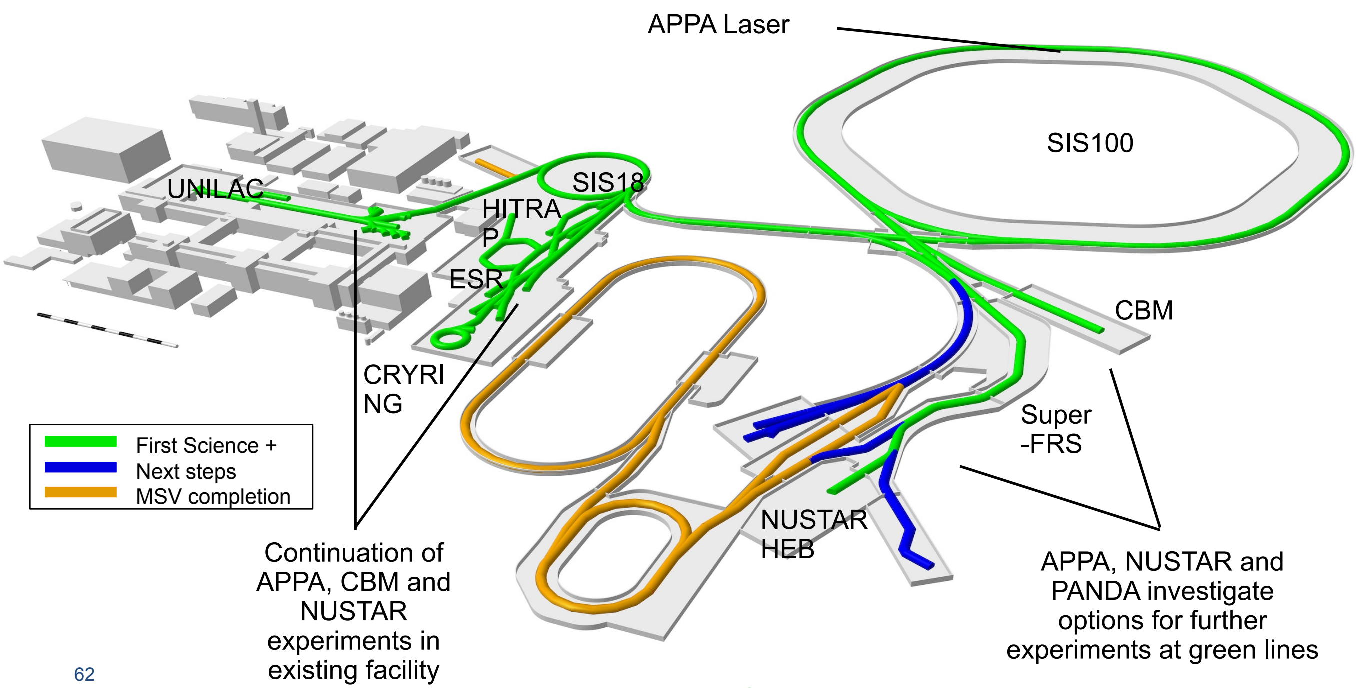
CBM is open for new participation

The Future is Bright

Be the light

CBM is open for new participation

Current prospects and timeline



until 2028

FAIR Phase-0

after 2028

Staged implementation recommended by the Heuer/Tribble Commission's report (2022) with the First Science stage endorsed by the FAIR Council as "the most appropriate starting scenario to achieve world-leading science."

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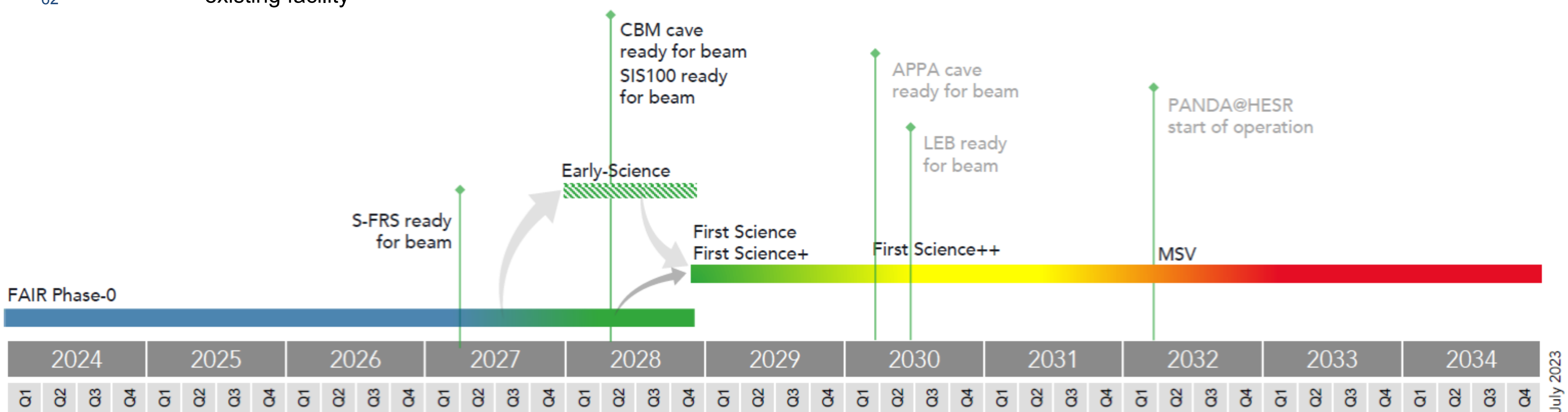


Strange hadronic matter in the inner core

The inner core of the neutron star is totally unknown. One of the most probable scenarios is that hyperons (baryons with strange quarks) appear at a density larger than (2–3) ρ_0

Λ hyperons, being free from Pauli exclusion principle by neutrons, are allowed to stay at the bottom of the attractive nuclear potential made by neutrons. **When the kinetic energy of a neutron on the Fermi surface of the degenerate neutron matter exceeds the Λ-n mass difference of 176 MeV, it converts into a Λ hyperon via weak interaction**.

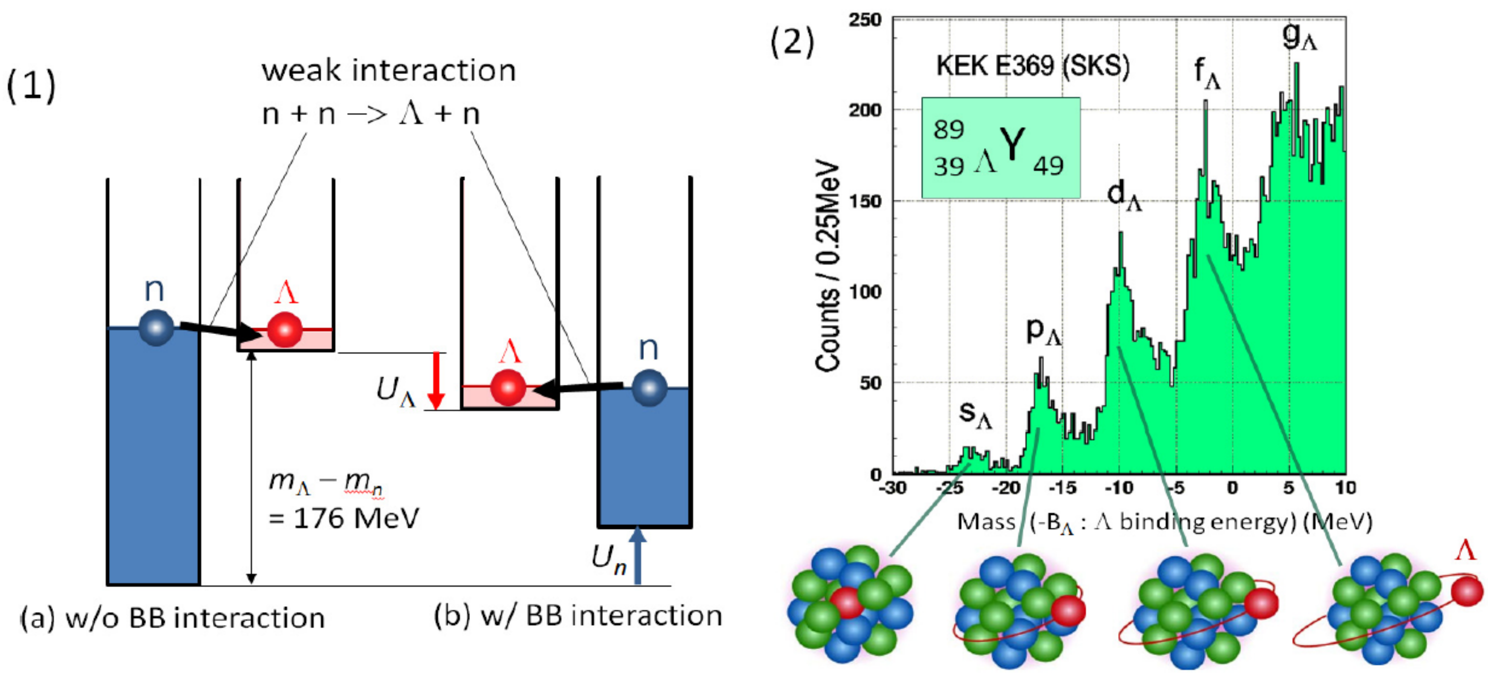
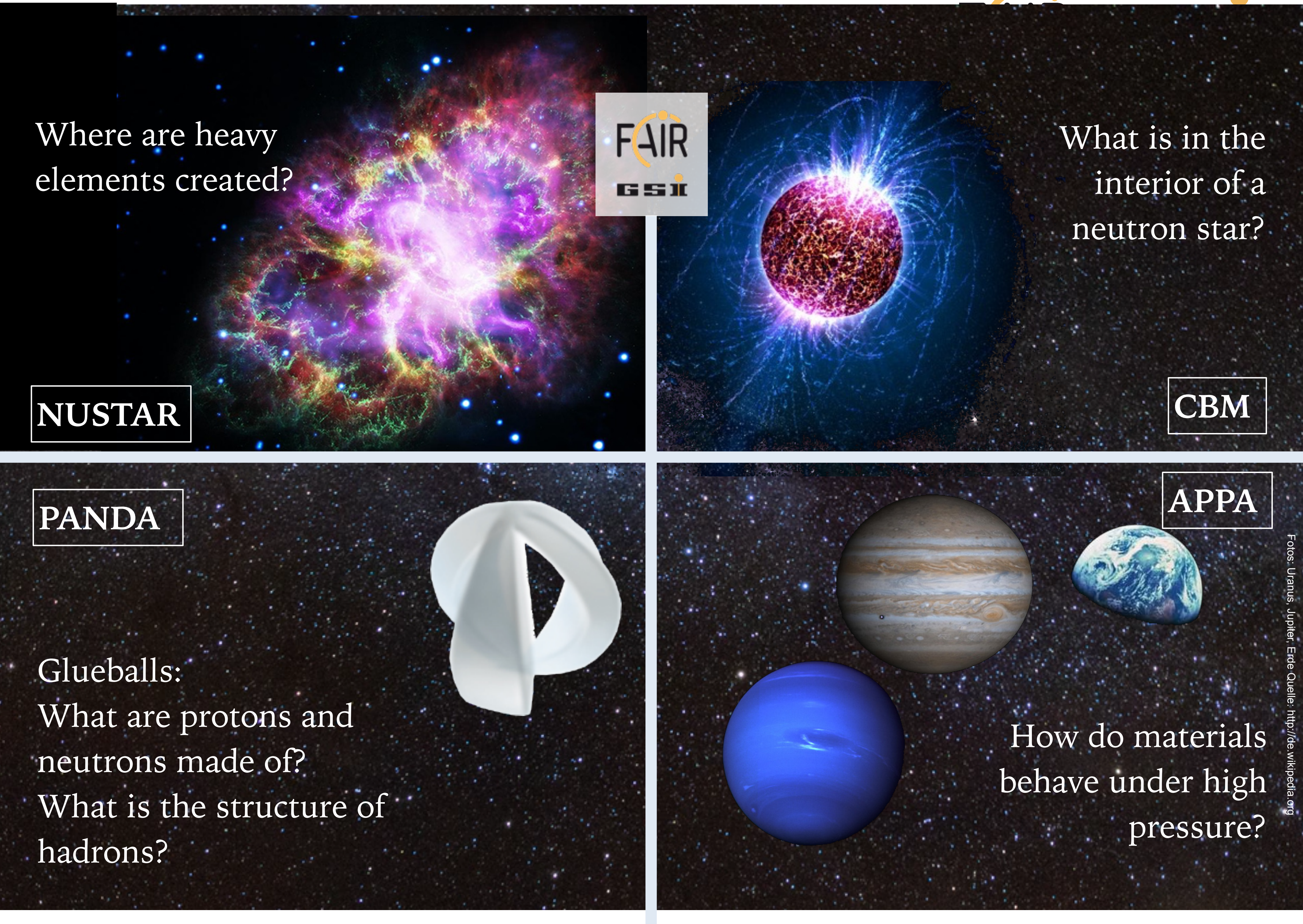


Fig. 3. (1) Energies of neutrons and Λ hyperons in high density neutron matter confined in the potential made by gravity. See text for details. (2) Excitation spectrum of a Λ hypernucleus $^{89}_{\Lambda}$Y via the (π^+,K^+) reaction on ^{89}Y target [6].

Creating extreme conditions existing in the universe with heavy ion accelerators

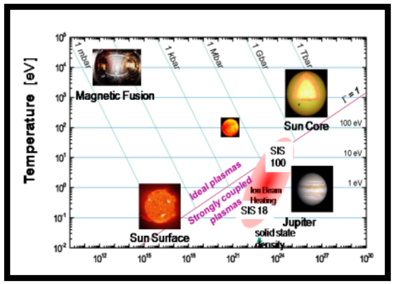
Foto: NASA, ESA, G. Dubner (IAFE, CONICET-University of Buenos Aires) et al.; A. Loll et al.; T. Temim et al.; F. Seward et al.; VLA/NRAO/AUI/NSF; Chandra/CXC; Spitzer/JPL-Caltech; XMM-Newton/ESA; and Hubble/STScI (oben), Penn State University (unten)

To find answers to fundamental questions about the Universe :
The Universe in the lab ...



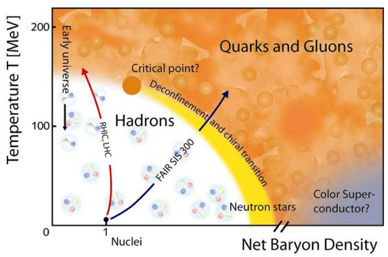
Fotos: Uranus, Jupiter, Erde Quelle: http://de.wikipedia.org

The FAIR science: four pillars



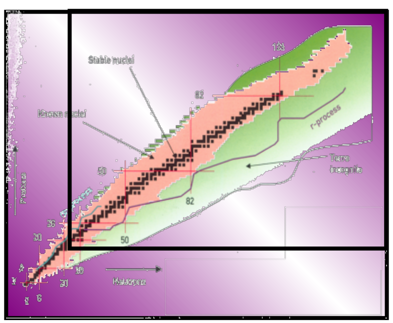
atomic physics, biophysics, plasma physics, material research

APPA



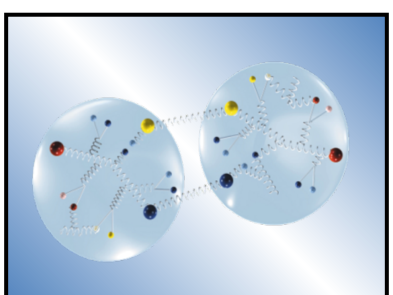
nuclear- and quark-matter

CBM



nuclear structure and nuclear astrophysics

NuSTAR

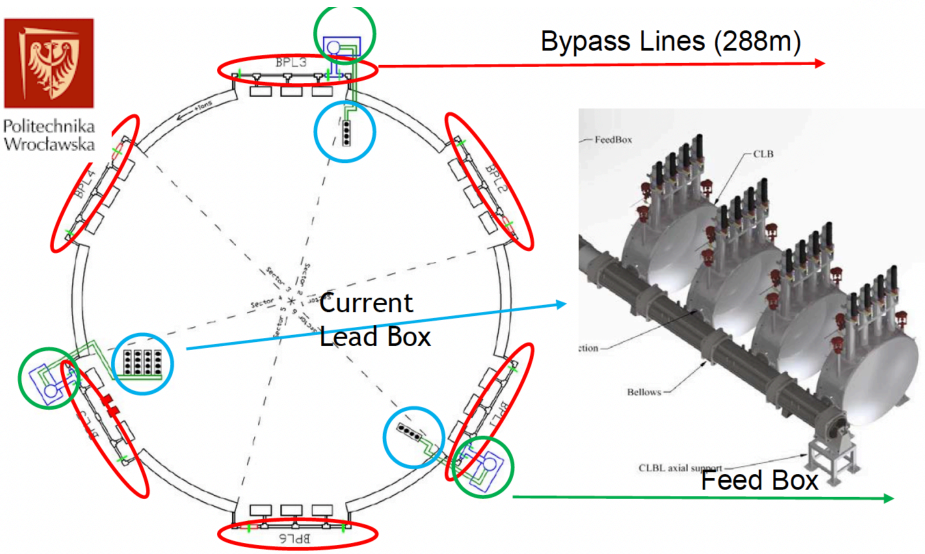


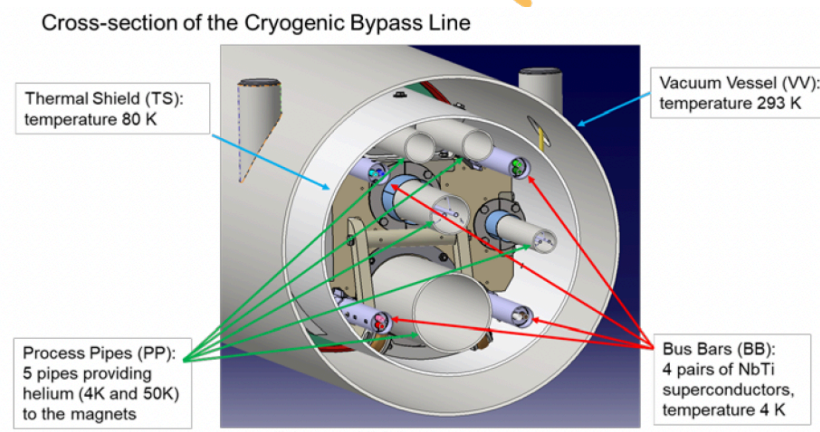
hadron structure and dynamics

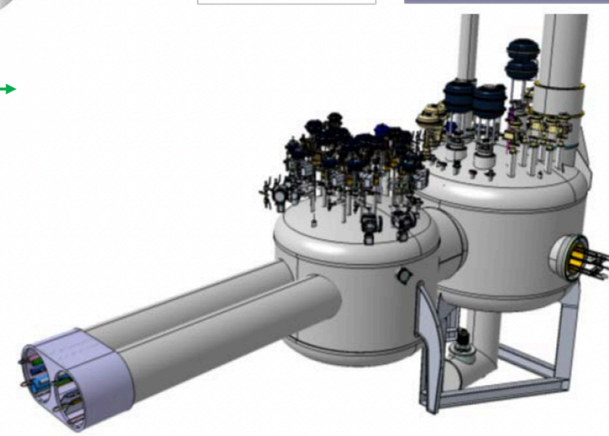
PANDA

Example of Polish in-kind contributions to SIS100

Politechnika Wrocławska







Wrocław University of Science and Technology: Design and implementation of the power (current) and cooling (He) distribution system for the SIS100 magnets. Unique competencies combining low temperatures with superconductivity (transport of helium and current in a single vacuum insulation). A crucial contribution to First Science+.

Polish in-kind contribution to SIS100 includes Bypass Lines (288m), Feed Box, and Current Lead Box.

Gdańsk University of Technology: Test system for SIS100 magnets.