Prospects for the study of baryon-rich matter at new facilities

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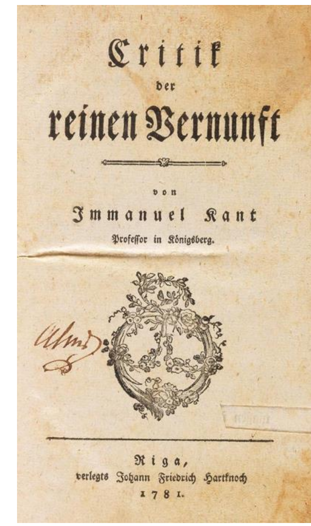
CPOD 2018
Corfu, 27 September 2018

Metaphysics

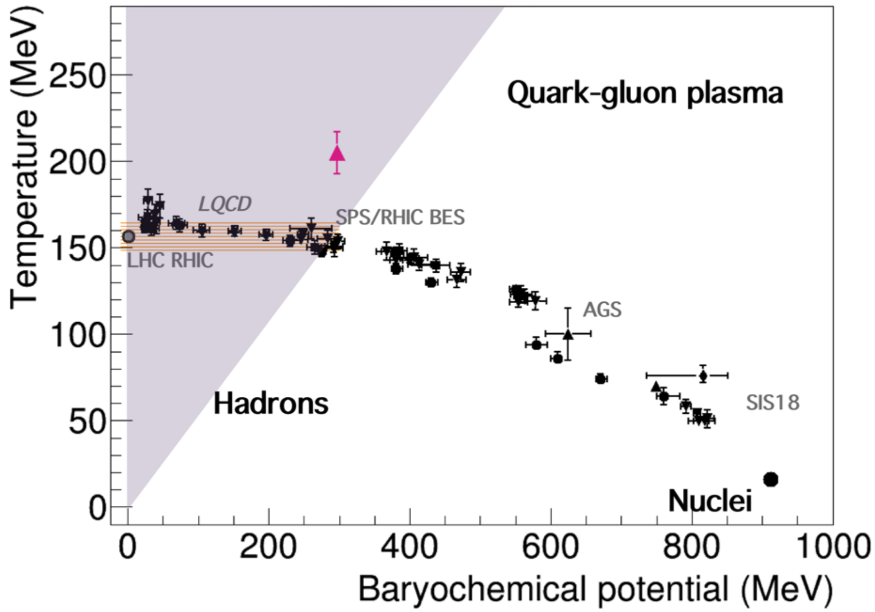
I. What can we know?


Critik
der
reinen Vernunft
von
Immanuel Kant
Professor in Königsberg.
Riga,
verlegts Johann Friedrich Hartknoch
1781.

Current research centres in high-density heavy-ion physics

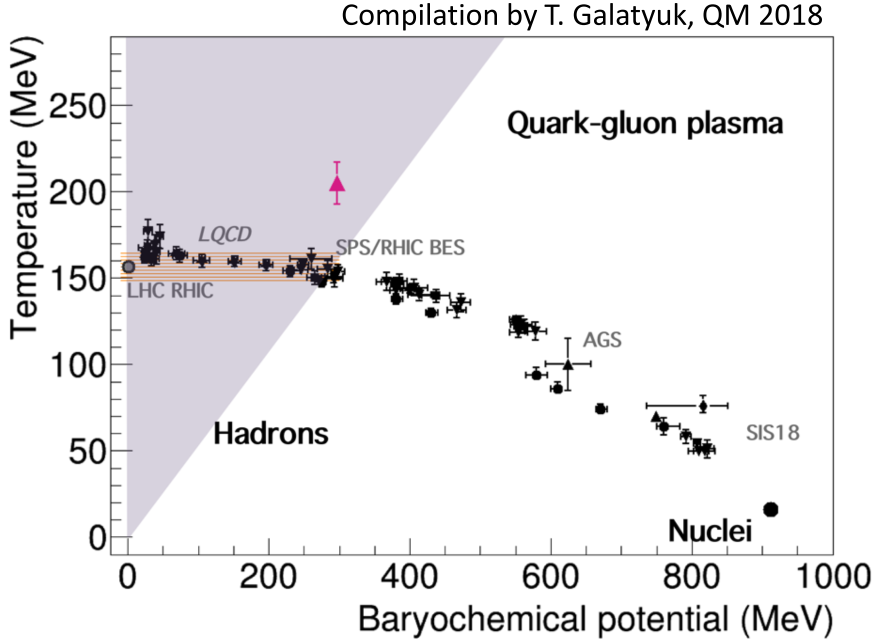
Current research centres in high-density heavy-ion physics

Compilation by T. Galatyuk, QM 2018



- We try to probe QCD matter with heavy-ion collisions.
- The main control parameter is the collision energy.
- Systematic investigations ("scans"): NA49 (1999-2002), STAR (2010-today), NA61
- An impressive plenitude of data was obtained, but basic questions remain to be solved:
  - Is there a critical point?
  - Is there a chiral / deconfinement phase transition?
  - What is the nuclear equation of state?

Current research centres in high-density heavy-ion physics



- These questions will be addressed by running experiments - but also by new, dedicated facilities and experiments.
- Punch line is, coverage of the entire energy range - and statistics:
  - precision measurements;
  - systematic measurements;
  - extending the menu of currently addressable observables.

Ethics

II. What shall we do?

Kritik
der praktischen Vernunft.

Von

Immanuel Kant.

Text der Ausgabe 1788, (A)
unter Berücksichtigung der 2. Ausgabe 1792 (B) und der
4. Ausgabe 1797 (D).

Herausgegeben
von
Karl Kehrbach.

Leipzig.

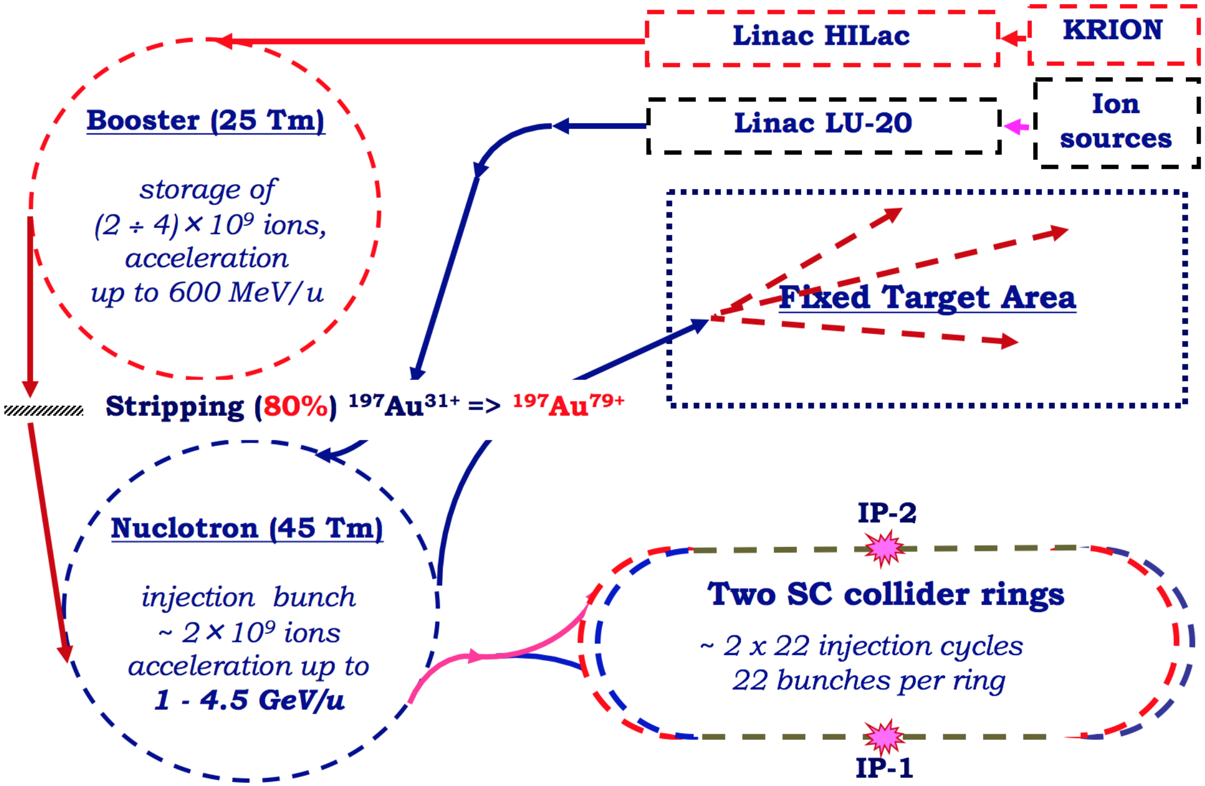
Druck und Verlag von Philipp Reclam jun.

Future research centres in high-density heavy-ion physics

NICA

Nuclotron-based Ion Collider Facility, Dubna, Russia

NICA - acceleration scheme

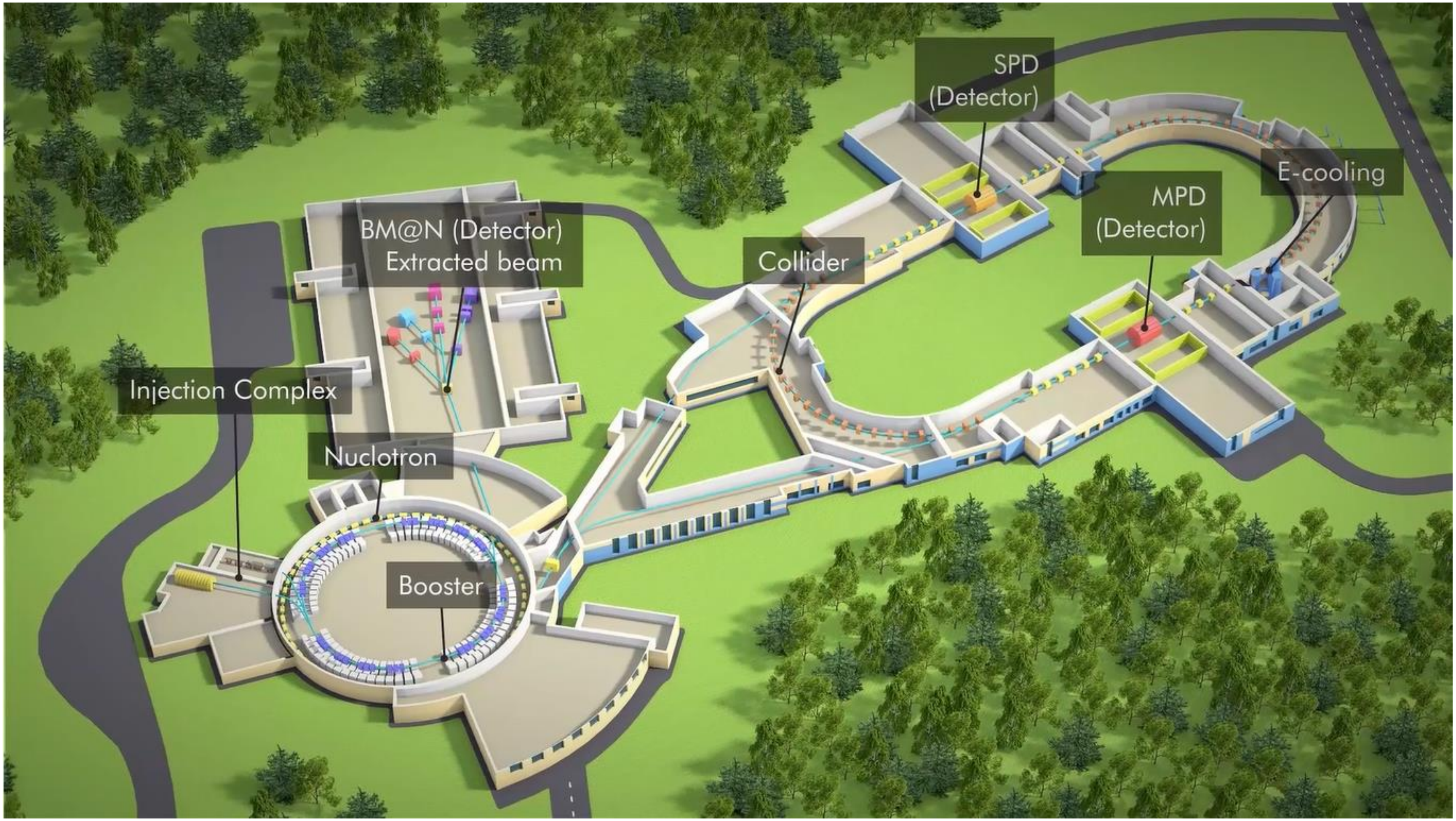


New: LINAC, booster, collider (U = 500 m)

- Slow extraction to fixed-target:
  $E_{beam,\,kin}$ = 1 - 4.5 GeV/u (Au)
  Intensity 10^9 ions/spill
- Collider:
  - up to 5.5 + 5.5 GeV (Au + Au)
  - luminosity 10^{27} cm^{-2} s^{-1} at top energy

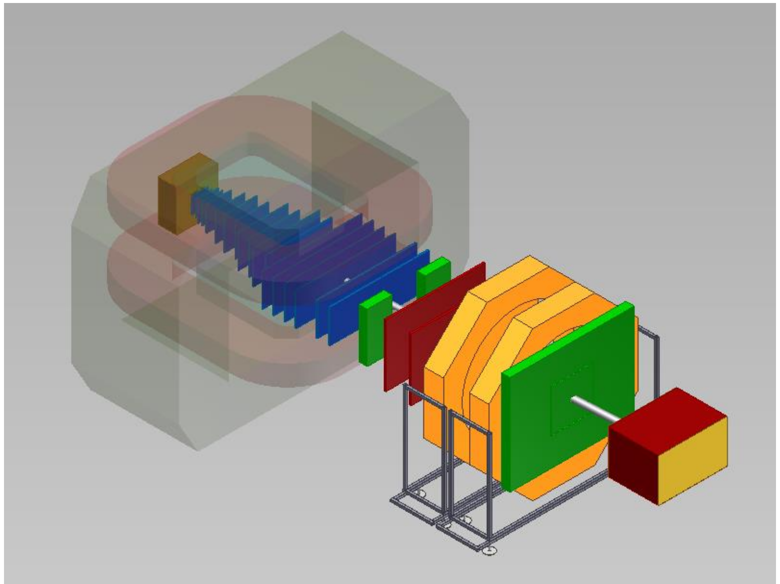
V. Kekelidze, QM 2018

NICA

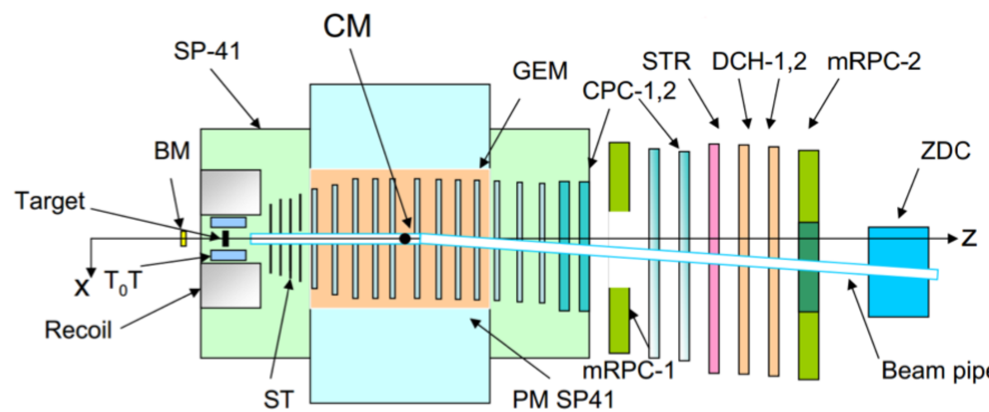


V. Kekelidze, QM 2018

BM@N



Baryonic Matter @ Nuclotron

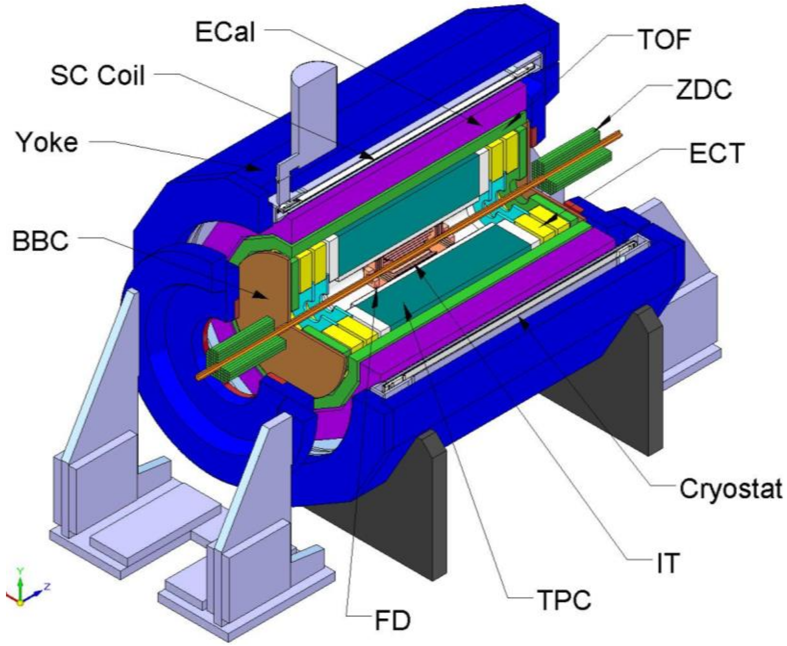


courtesy M. Kapishin

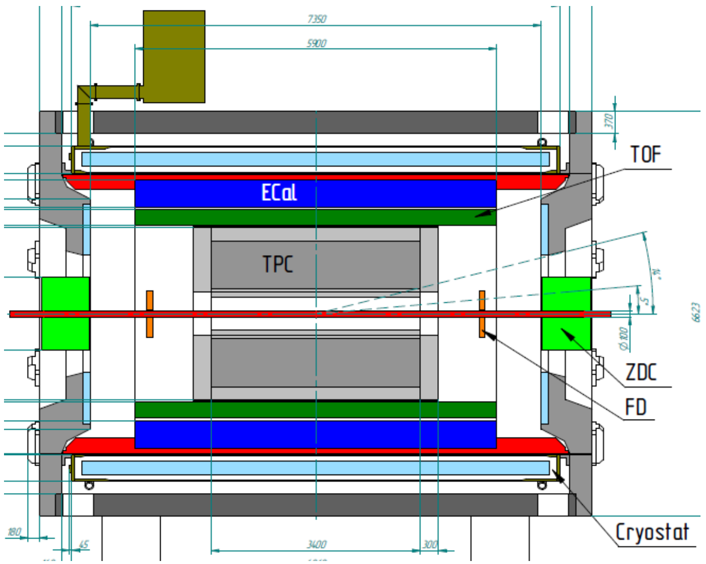
- Fixed-target, forward hadron spectrometer
- Large-aperture magnet filled with radiation-hard tracking devices (GEM / Si)
- Hadron ID by time-of-flight (RPC)
- Forward calorimeter

- Already in operation with light beams (up to Kr^{26+})
- Au + Au in 2020 with 10 kHz interaction rate
- 2021: upgrade with Si trackers (CBM); increase interaction rate to 50 kHz

The MPD experiment



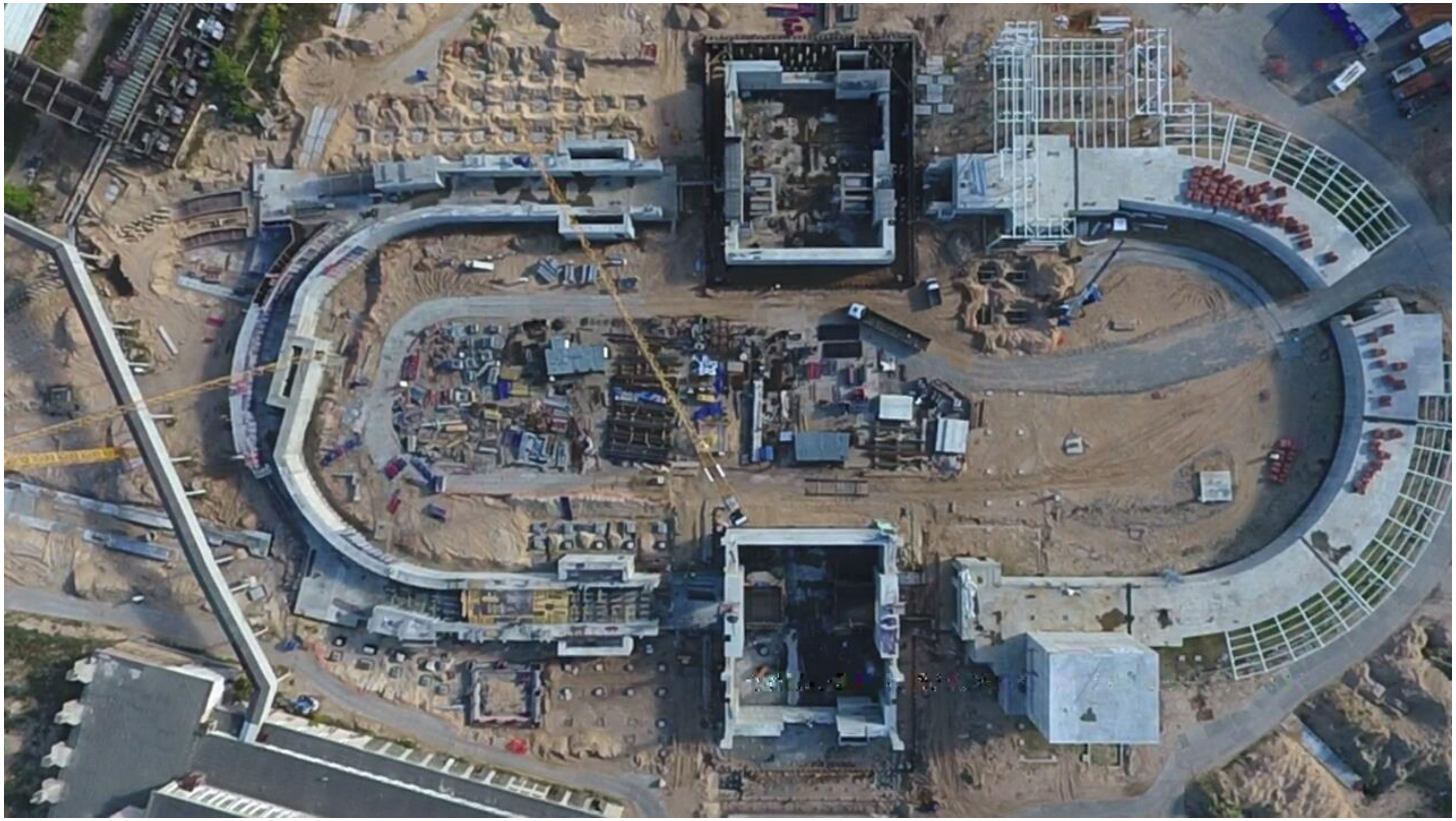
Multi Purpose Detector



V. Kekelidze, QM 2018

- Stage 1 (2020):
  - barrel-type collider experiment ($|\eta| < 1.2$ for TPC+TOF)
  - hadron + electron identification, calorimetry
  - forward calorimeter for centrality and event plane
- Stage 2 (2023):
  - endcap (increase acceptance)
  - Inner tracking system (charm)

NICA: status



courtesy M. Kapishin

- Civil construction well progressed and in schedule
- MPD hall ready for installation in 2019
- MPD detectors in production
- Start of data taking 2021

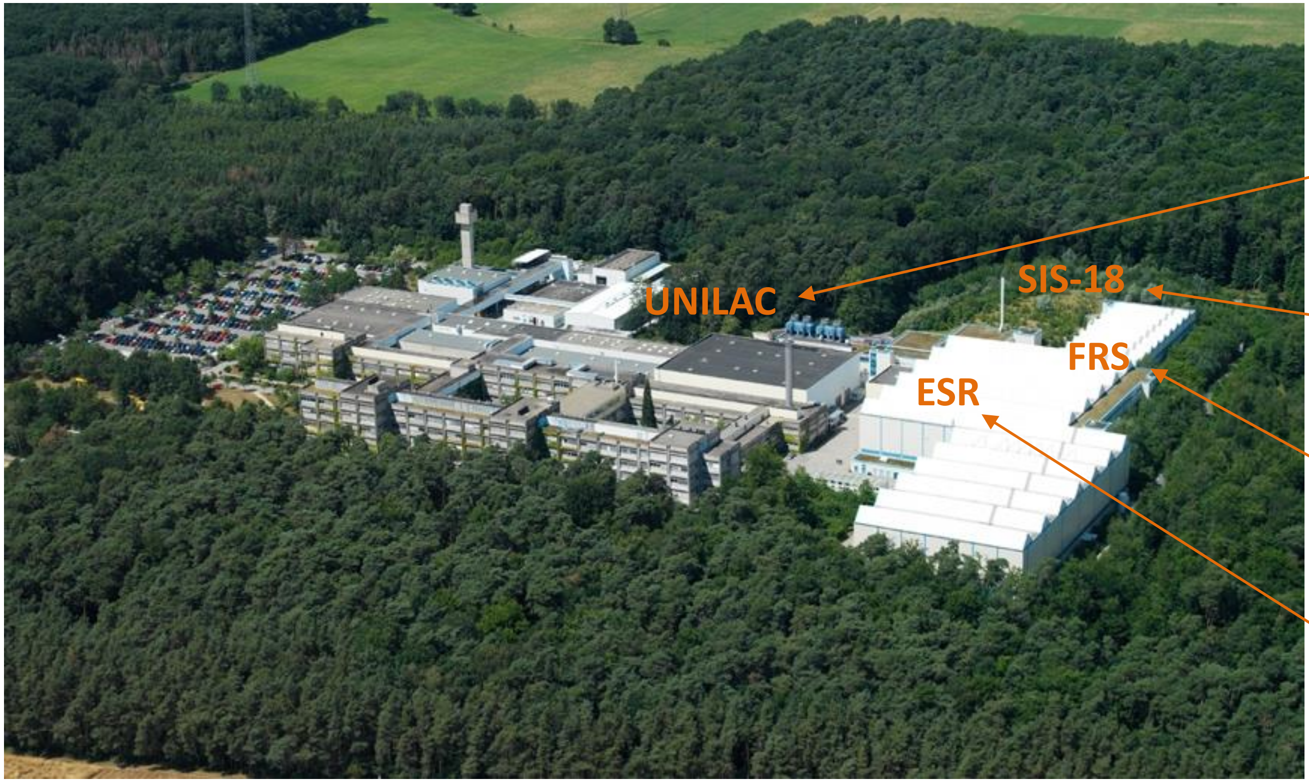
NICA

For more details, see talk by M. Kapishin, today, 11:00

FAIR

Facility for Anti-Proton and Ion Research, Darmstadt, Germany

GSI



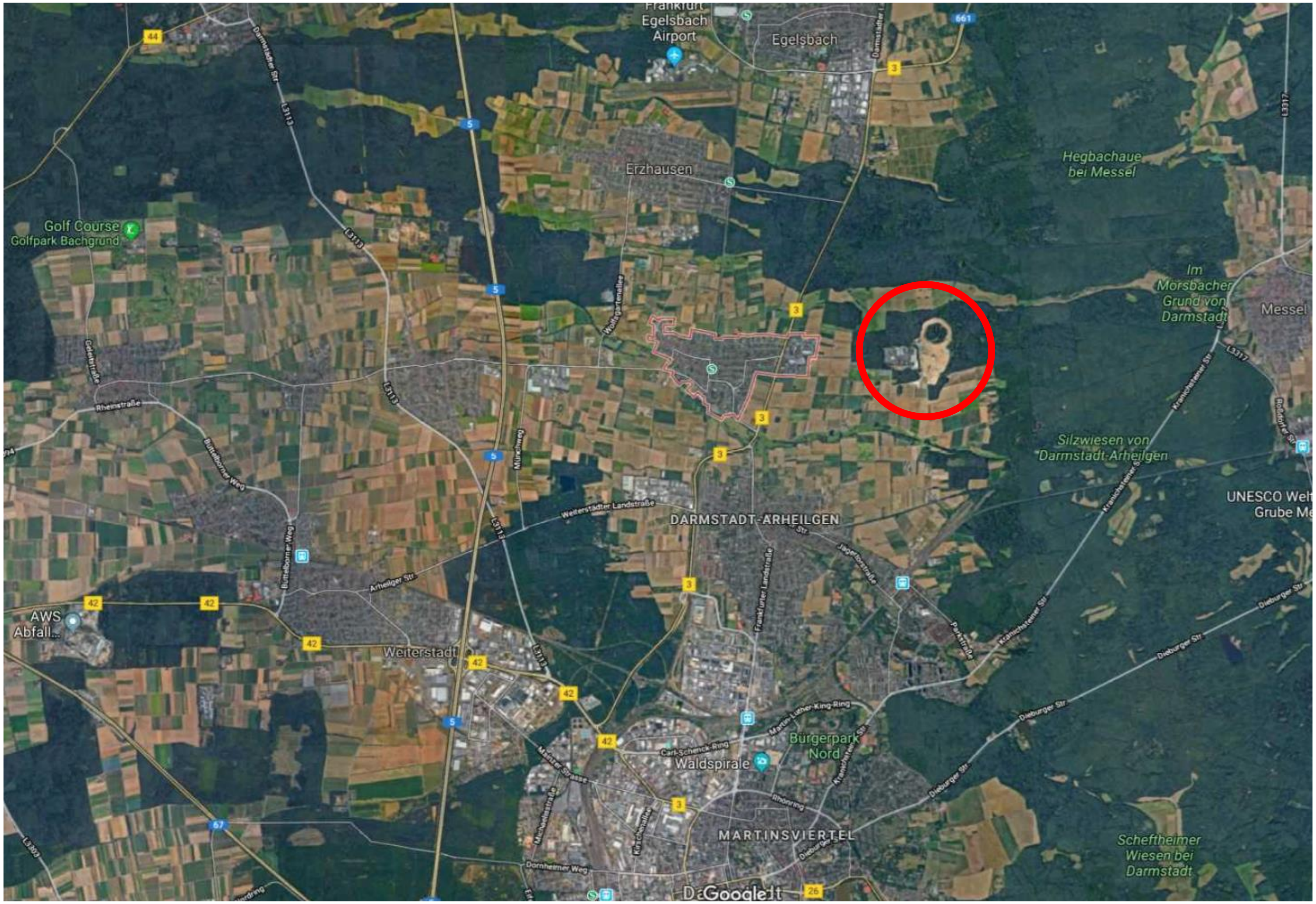
Main Facilities:

- Linear Accelerator
- Heavy-Ion Synchrotron
- Fragment Separator
- Experimental Storage Ring

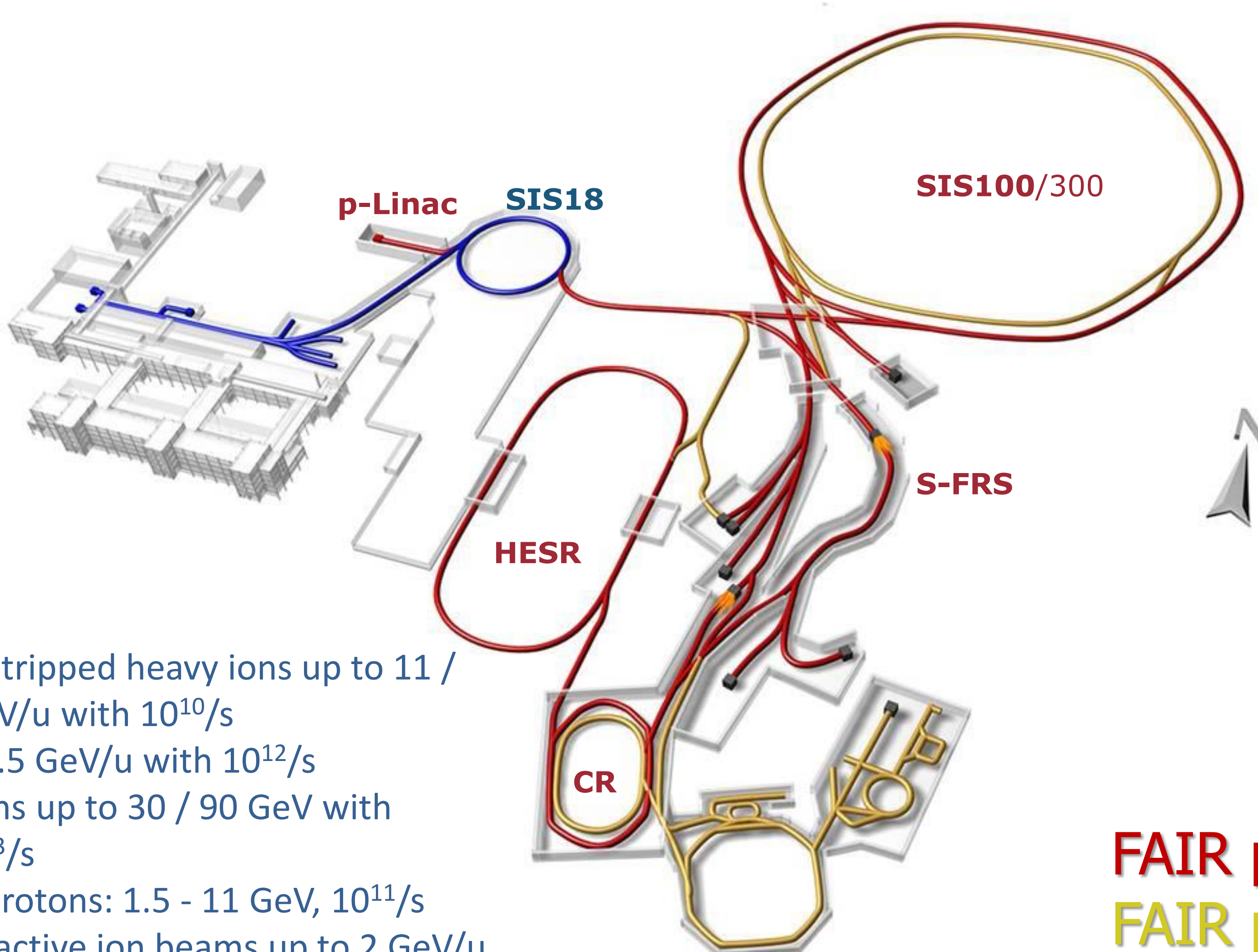
- GSI Helmholtzzentrum für Schwerionenforschung mbH
- Founded 1969
- About 1,400 employees (750 scientific staff)
- About 1,200 external scientists

- Heavy-ion Physics
- Super-heavy elements
- Particle cancer therapy

Location


Frankfurt Egelsbach Airport
Egelsbach
Erzhausen
Hegbachaue bei Messel
Golf Course Golfpark Bachgrund
Im Morsbacher Grund von Darmstadt
Messel
Silzwiesen von Darmstadt-Arheilgen
DARMSTADT-ARHEILGEN
UNESCO Welt Grube Me
AWS Abfall...
Weiterstadt
Bürgerpark Nord
Waldspirale
MARTINSVIERTEL
Scheftheimer Wiesen bei Darmstadt
Google

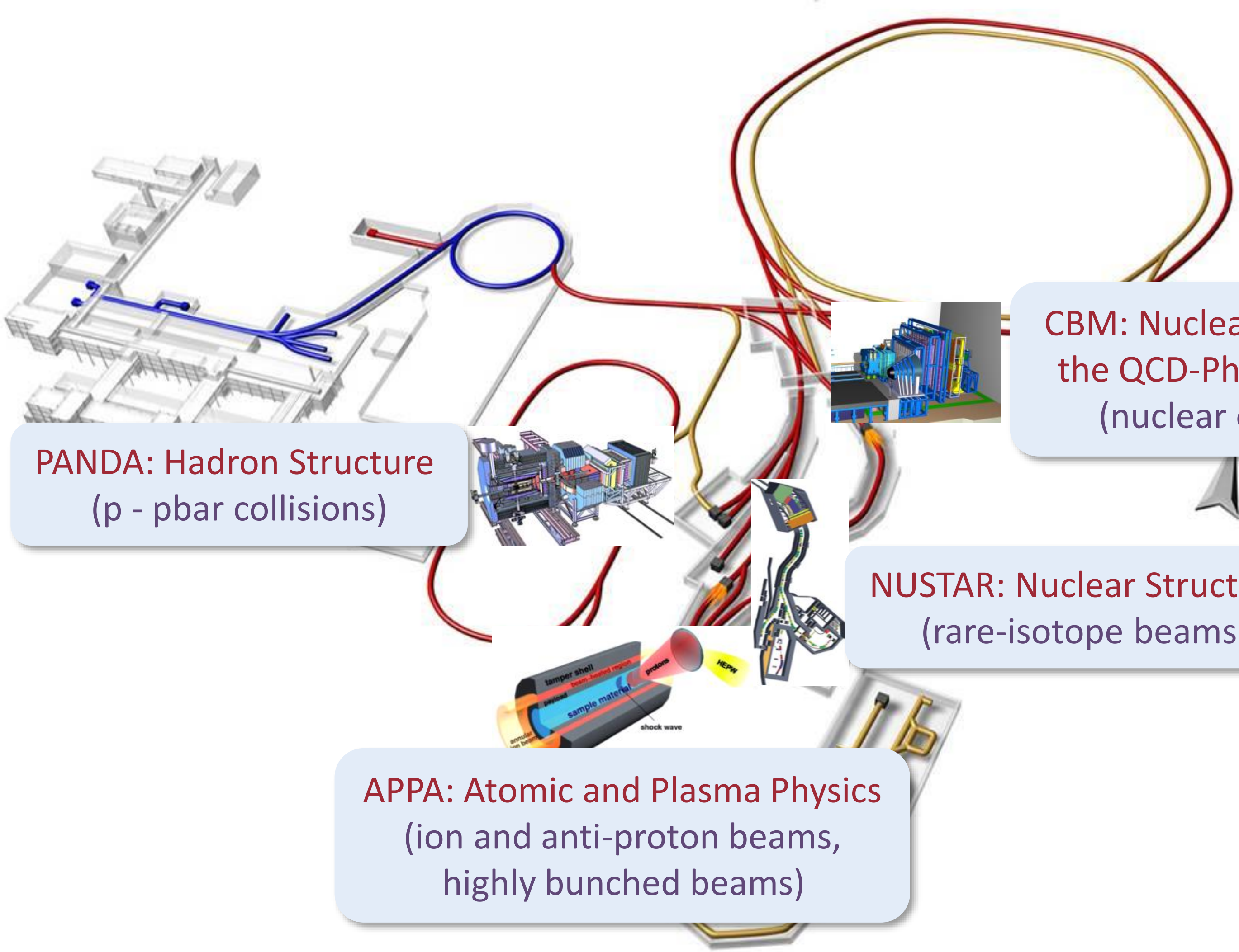
FAIR schematically



- Fully stripped heavy ions up to 11 / 35 GeV/u with 10^{10}/s
- U^{28+} 1.5 GeV/u with 10^{12}/s
- Protons up to 30 / 90 GeV with 3×10^{13}/s
- Anti-protons: 1.5 - 11 GeV, 10^{11}/s
- Radioactive ion beams up to 2 GeV/u

FAIR phase 1
FAIR phase 2

FAIR: Research Programmes



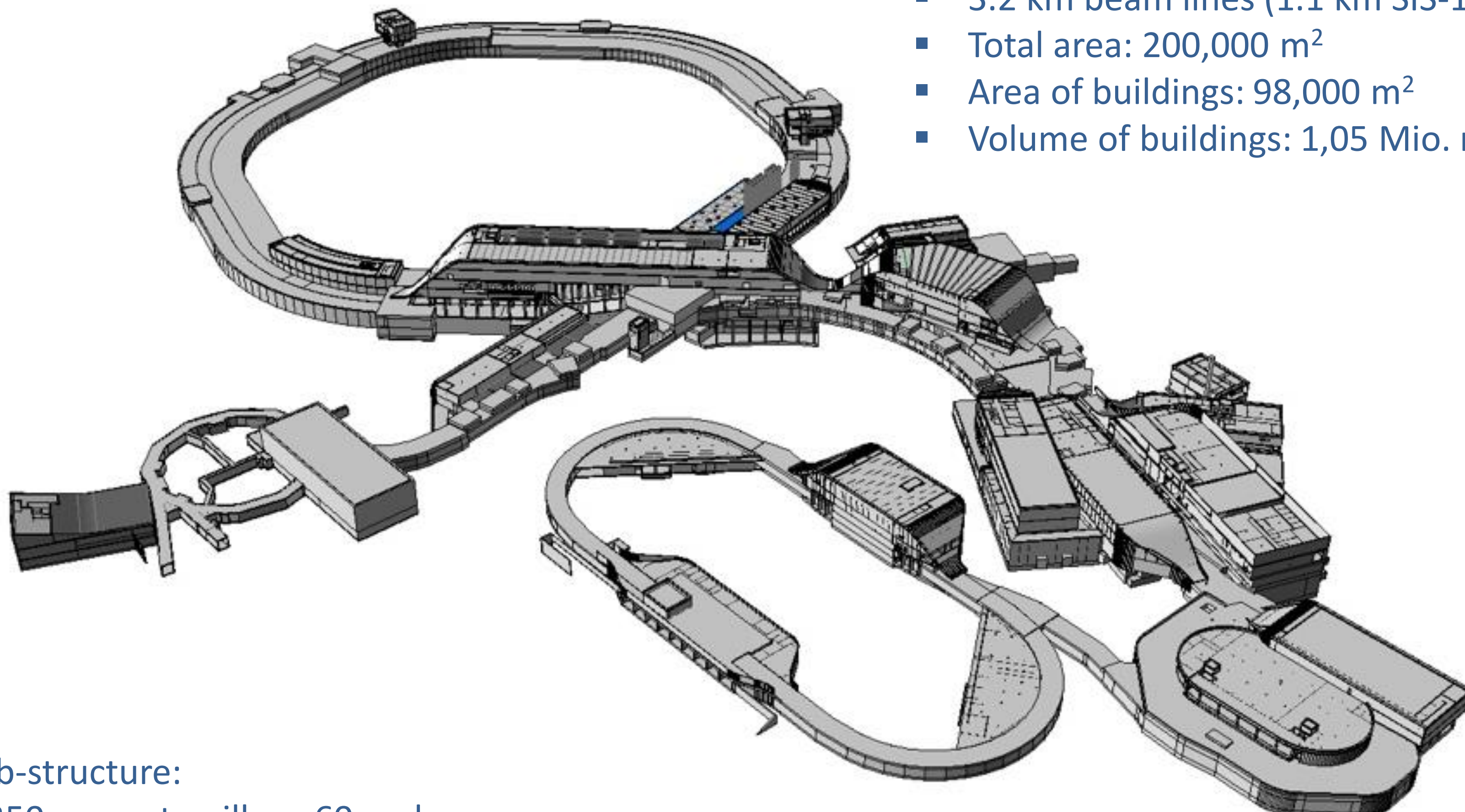
CBM: Nuclear Matter and the QCD-Phase Diagram (nuclear collisions)

PANDA: Hadron Structure (p - pbar collisions)

NUSTAR: Nuclear Structure (rare-isotope beams)

APPA: Atomic and Plasma Physics (ion and anti-proton beams, highly bunched beams)

FAIR: Civil Construction

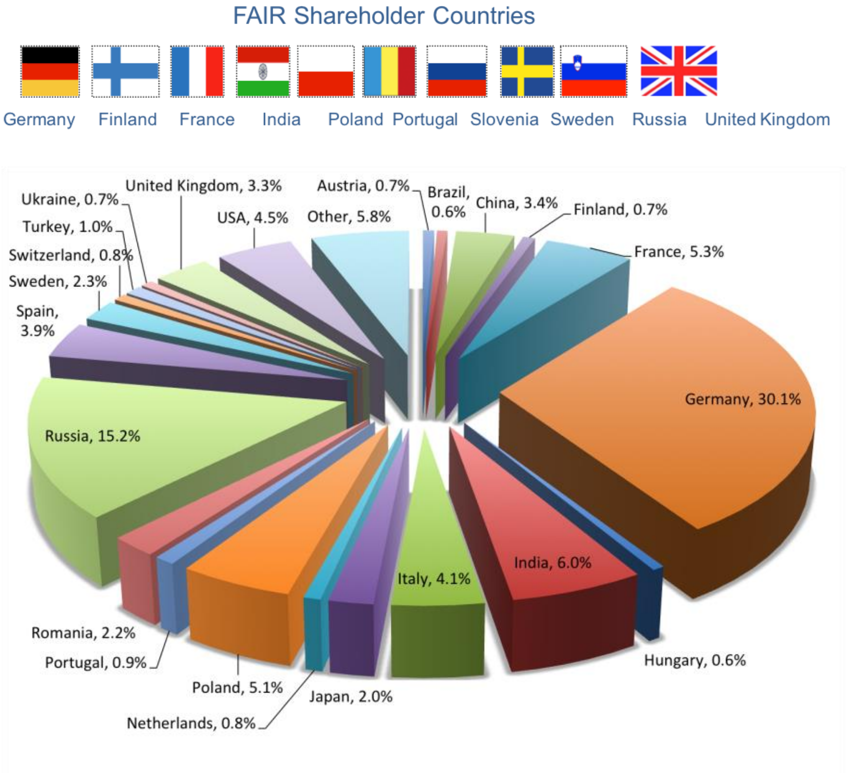


- 3.2 km beam lines (1.1 km SIS-100)
- Total area: 200,000 m^2
- Area of buildings: 98,000 m^2
- Volume of buildings: 1,05 Mio. m^3

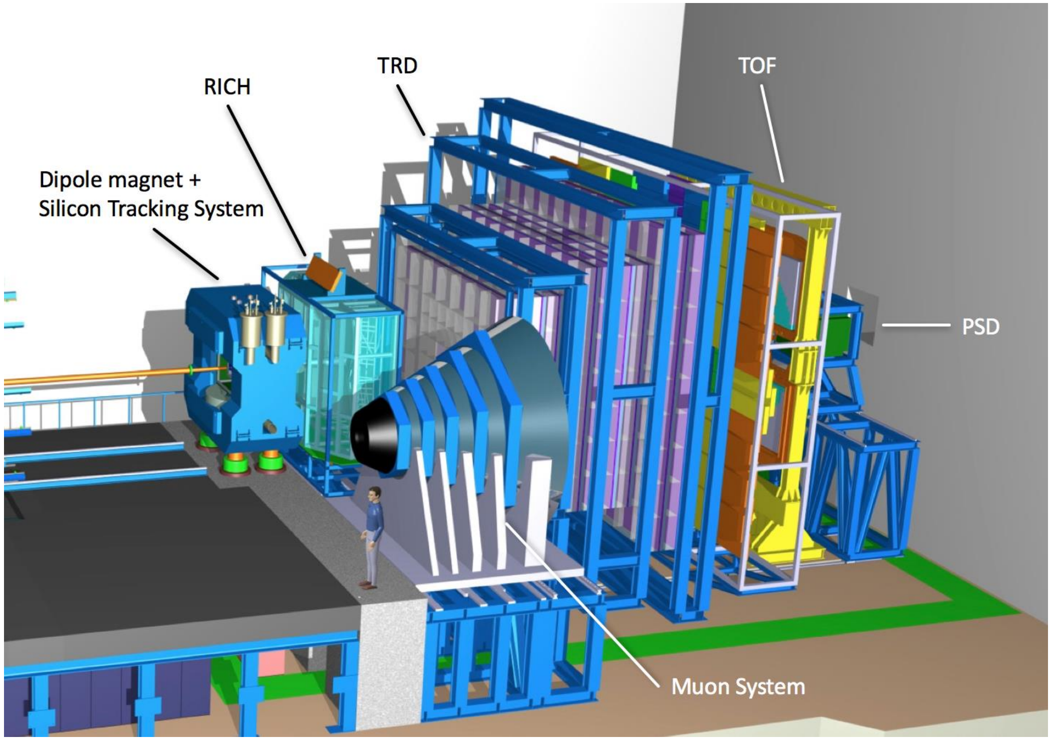
Sub-structure:
1,350 concrete pillars, 60 m deep

FAIR: some facts

- largest current project in fundamental science in Germany
- forefront research in nuclear, hadron, atomic, anti-matter, plasma and applied physics.
- about 2,500 users
- full completion by 2025
- total costs: 1.7 Mrd. €
- financing:
  – FR Germany 60%
  – State of Hessen 10%
  – International Partners 30%



The CBM experiment at FAIR



- Fixed-target spectrometer
- Hadron, electron and muon ID
- Large (central to forward) acceptance
- Tracking in dipole field
- Electron ID after tracking
- Extreme rate capability: up to 10^7 / s
- Trigger-less readout
- Event building and selection on CPU in real-time

Now under construction;
Full-system test (mCBM) February 2019

2024 commissioning with SIS-100 beam

FAIR Timeline

- July 2017: Start of excavation and trench sheeting
- January 2018: Civil construction north area awarded (SIS tunnel, CBM building)
- July 2018: Start of shell construction
- 2022: Buildings completed
- 2025: Completion of full facility and start of operations

Work in Progress

HIAF

Heavy-Ion Accelerator Facility, Huizhou, China

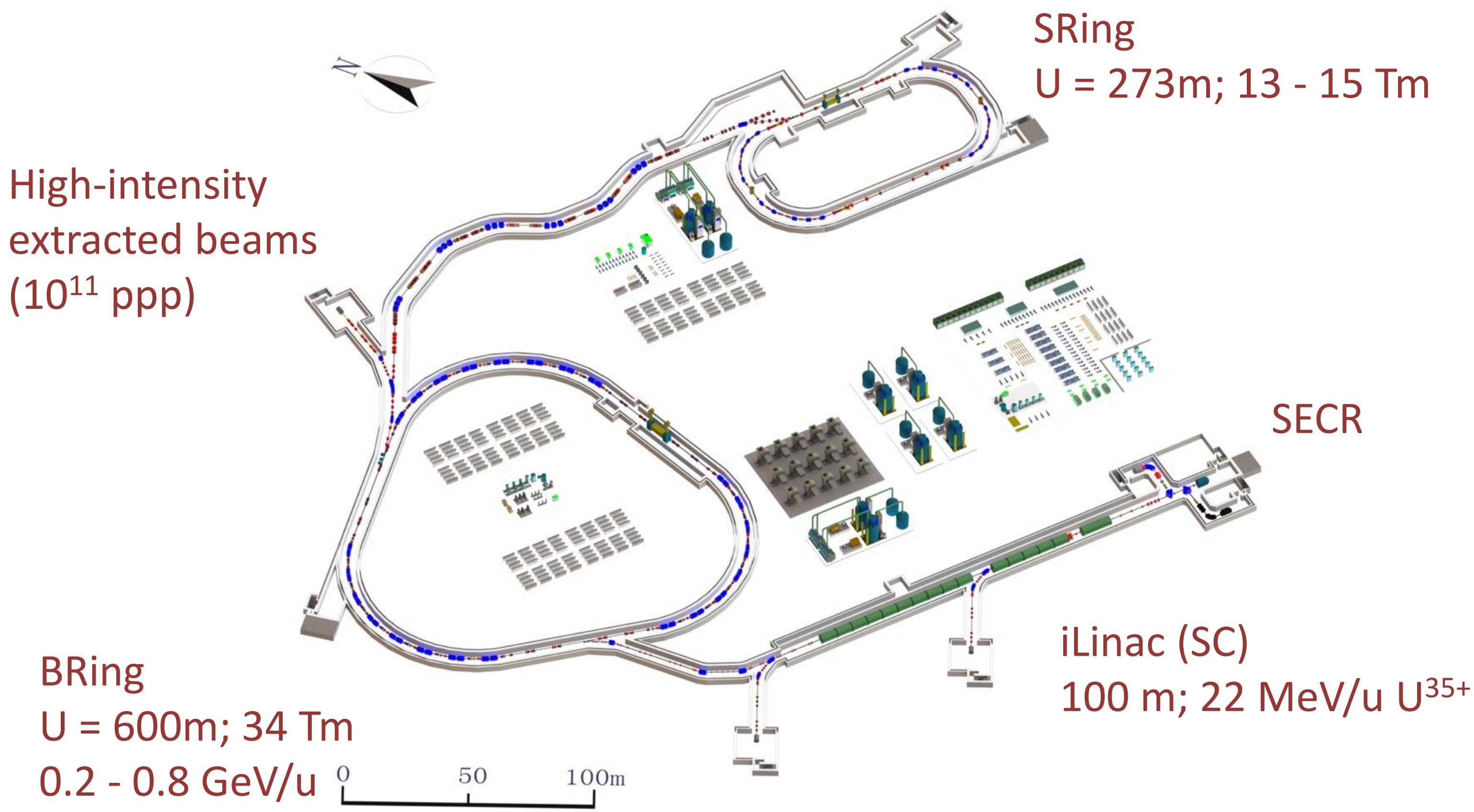
HIAF

Heavy-Ion Accelerator Facility, Huizhou, China

courtesy N. Xu

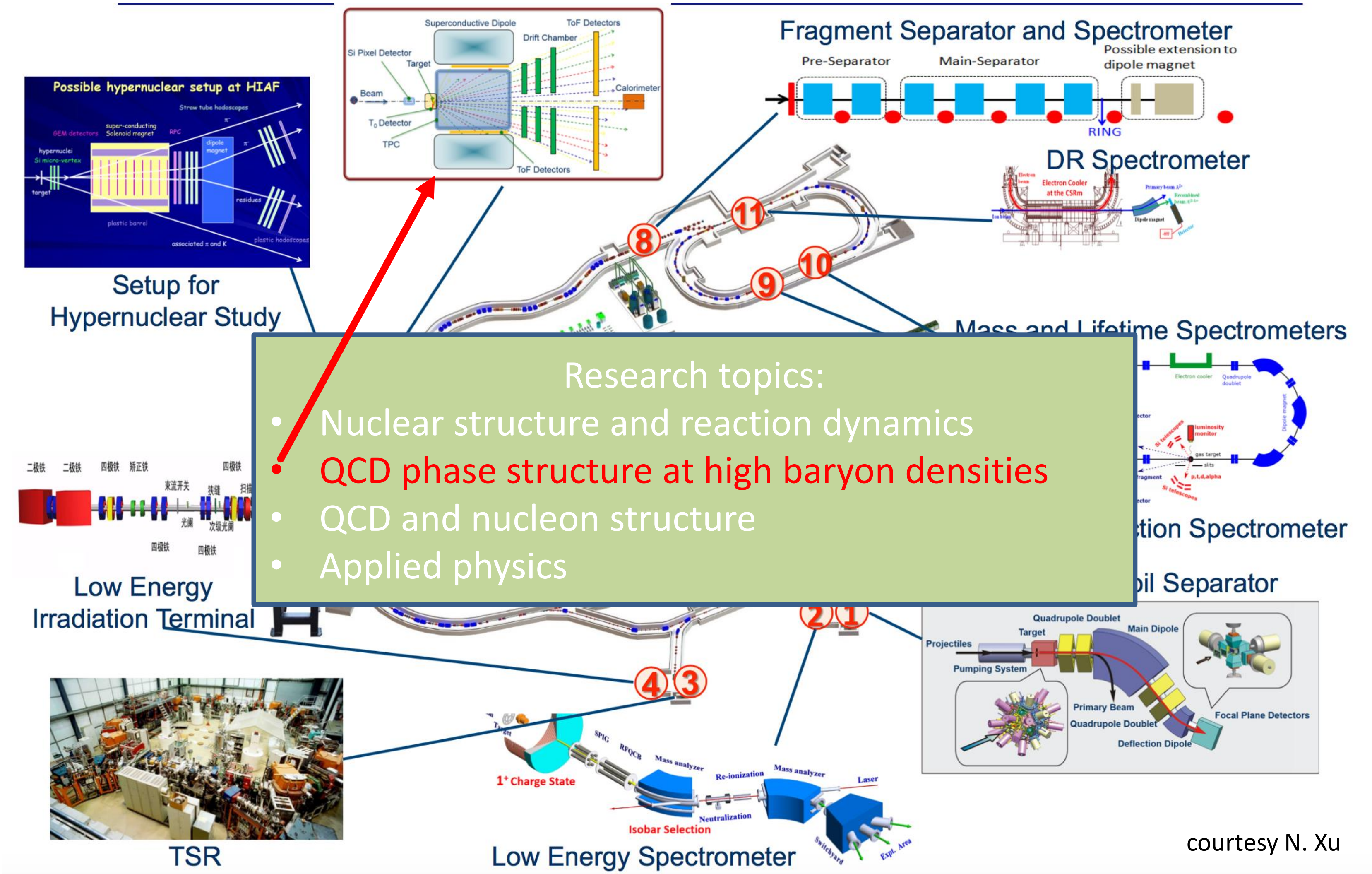
- One of the large-scale research facilities in China to boost basic science in the 12th 5-years-plan (2011-2015)
- Approved 2015
- Budget: 2.6 B CNY (320 M €)
- Start of construction 2018
- Start of operation 2024

HIAF



Imp.cas.cn

HIAF

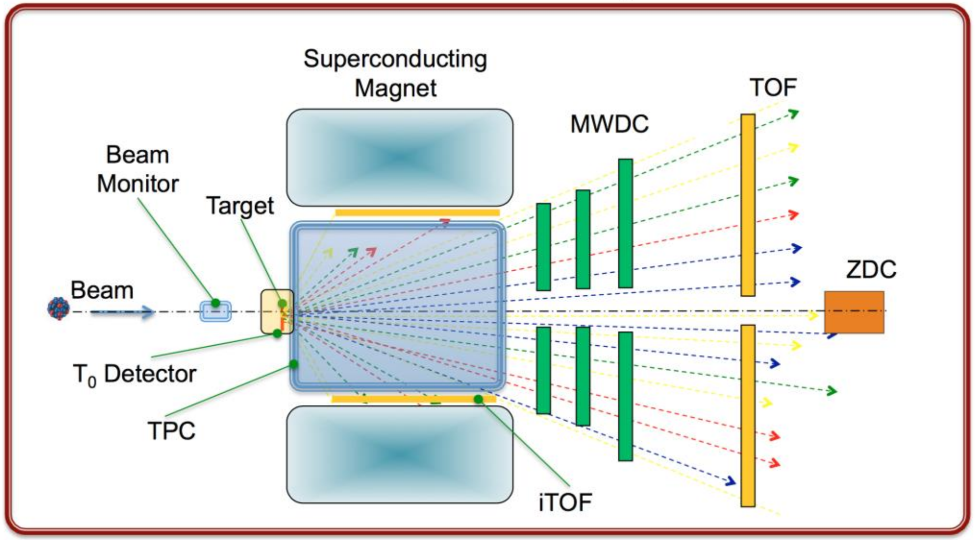


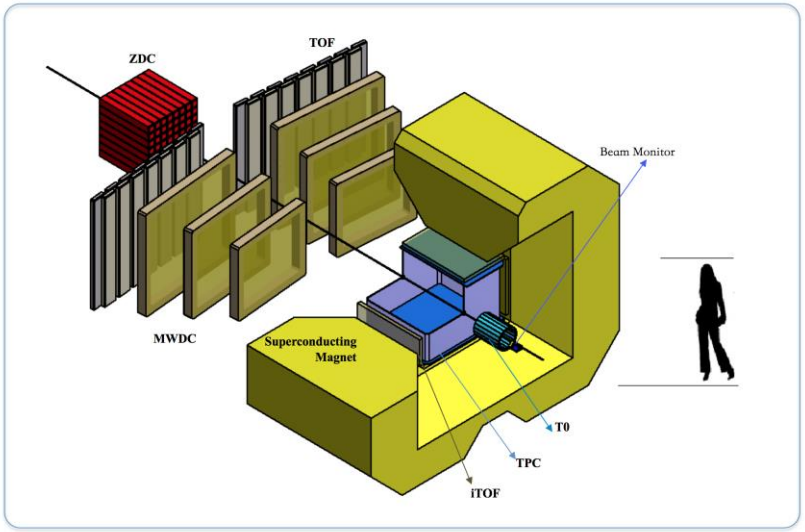
Research topics:

- Nuclear structure and reaction dynamics
- QCD phase structure at high baryon densities
- QCD and nucleon structure
- Applied physics

The CEE experiment at HIAF

CSR External-Target Experiment





courtesy N. Xu

Hadron spectrometer (proton and pion ID)

- QCD critical point (proton fluctuations)
- Directed flow
- Symmetry energy (proton flow, π^-/π^+

Interaction rates: > 100 kHz

Large acceptance

Triggerless DAQ

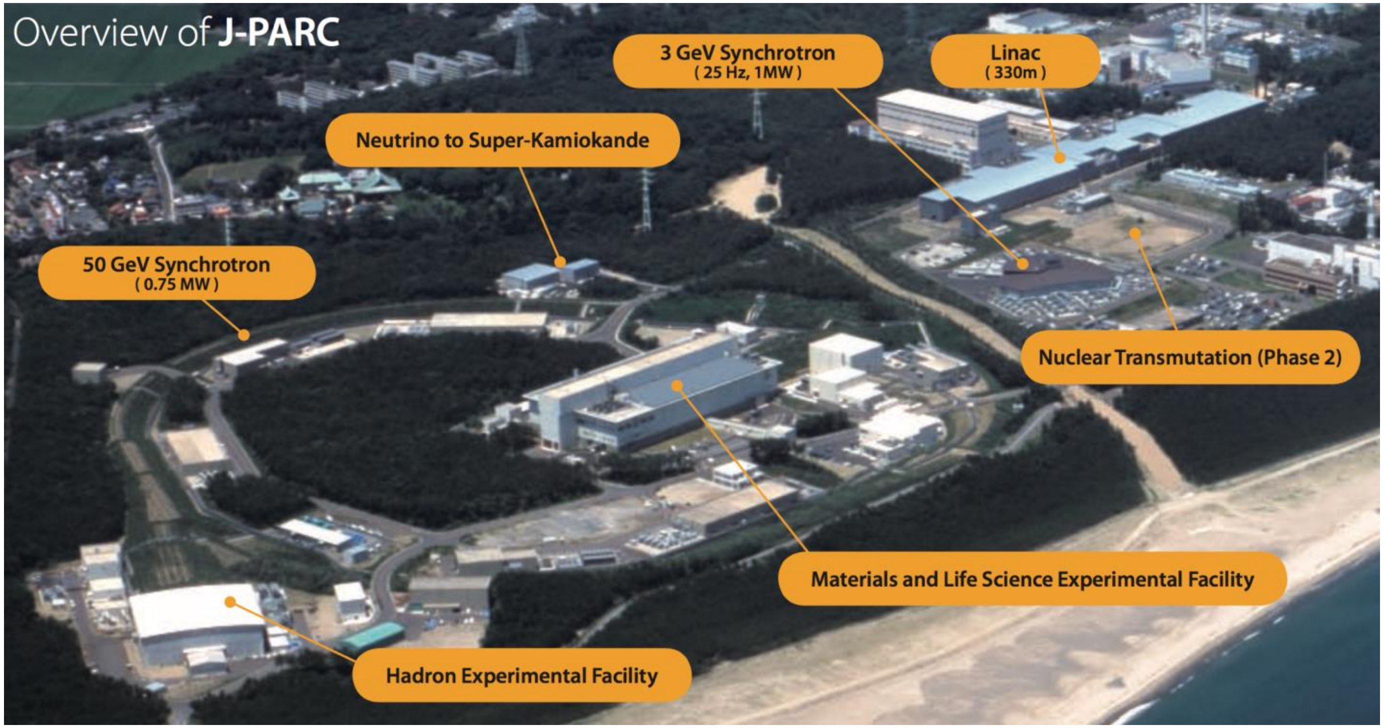
HIAF in 2024

courtesy N. Xu

J-PARC-HI

J-PARC Heavy-Ion Program, Tokai, Japan (Proposed)

J-PARC today

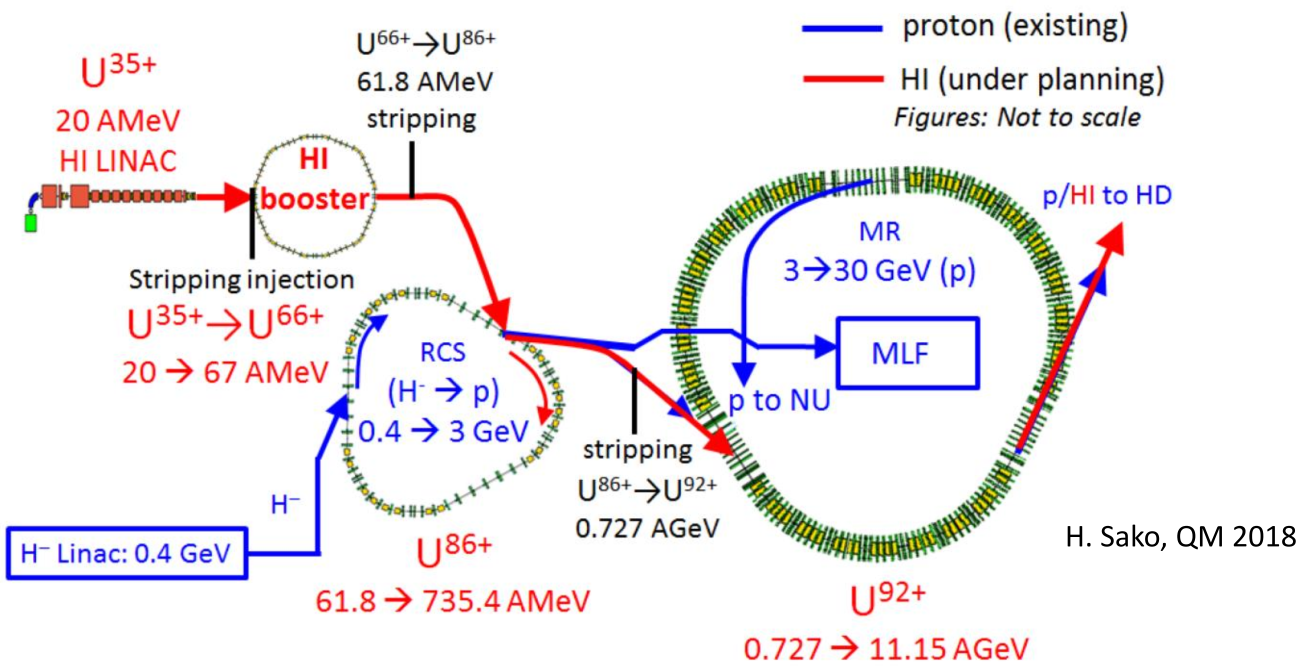


j-parc.jp

Proton acceleration facility for very intense proton beams (50 GeV)

Research with secondary beams (π, K, anti-p)

J-PARC-HI



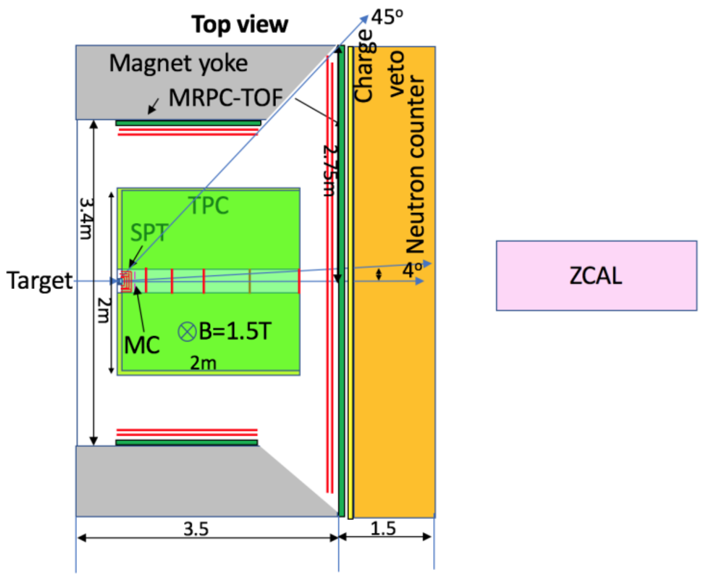
H. Sako, QM 2018

Proposal: Add a heavy-ion injection branch (LINAC, booster) to the existing proton accelerator complex

Slow extraction of extremely intense beams (10^{11} / s)

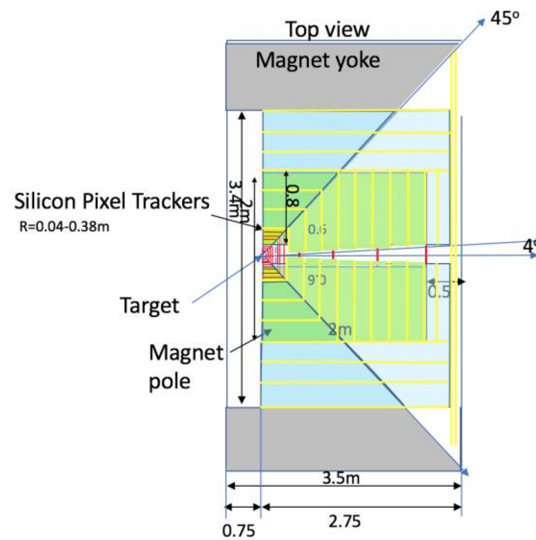
Beam energy range: 1 - 19 GeV/u

Proposed experiments at J-PARC-HI



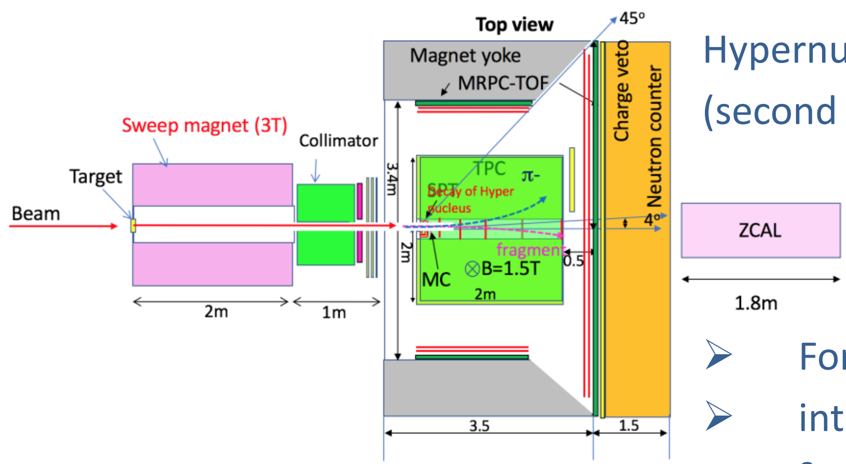
Hadron spectrometer (SPT, TPC + TOF)

- 4π acceptance
- interaction rate < 10^6 / s
- neutron counter



Muon spectrometer (SPT, absorbers + GEM trackers)

- 4π acceptance
- interaction rate 10^7 / s



Hypernuclei spectrometer (second magnet)

- Forward rapidity
- interaction rate 10^8 / s

H. Sako, QM 2018

J-PARC-HI

For more details, see talk by T. Sakaguchi, today, 11:45

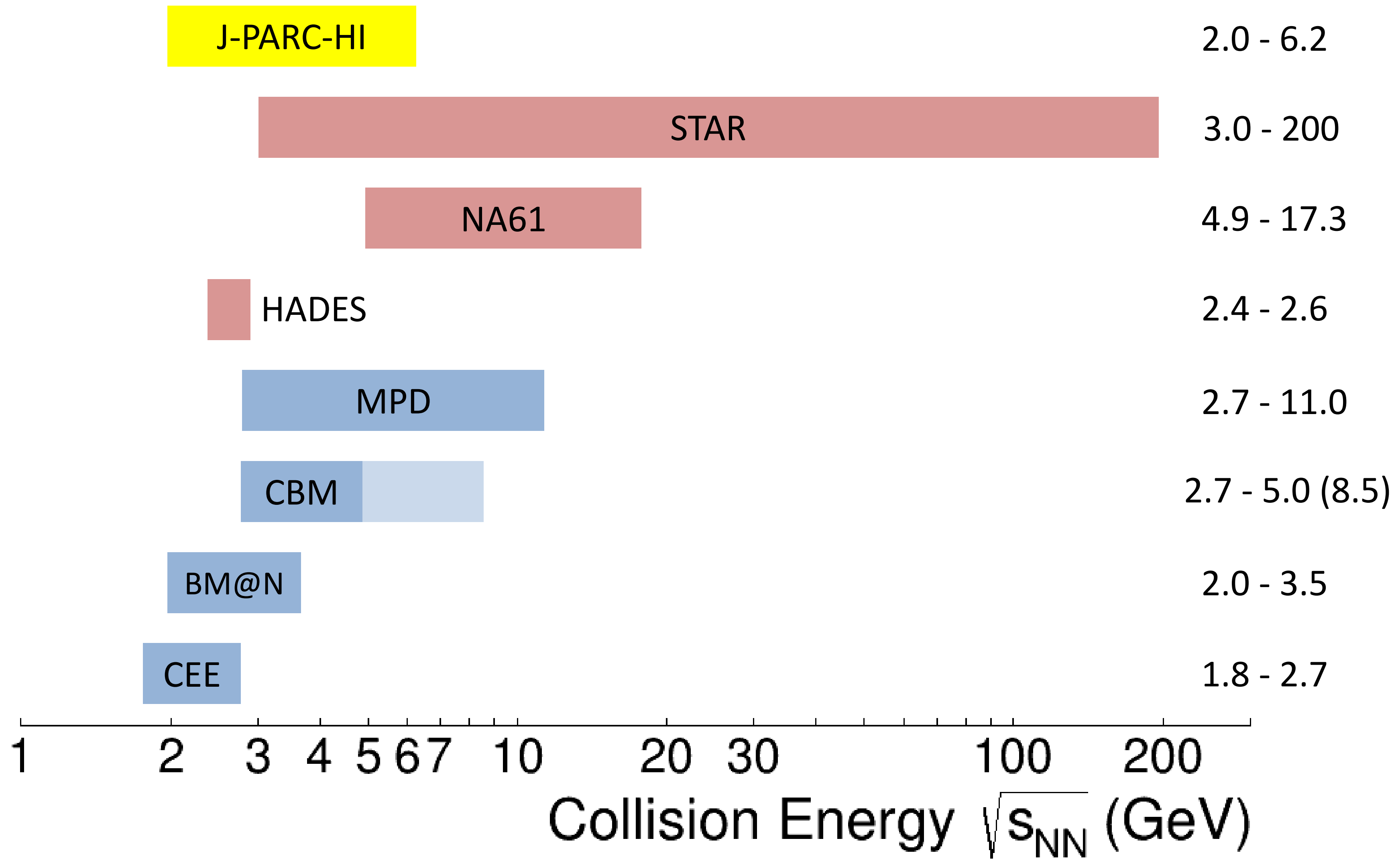
Theology

III. What may we hope?

Critik
der
Urtheilskraft
von
Immanuel Kant.

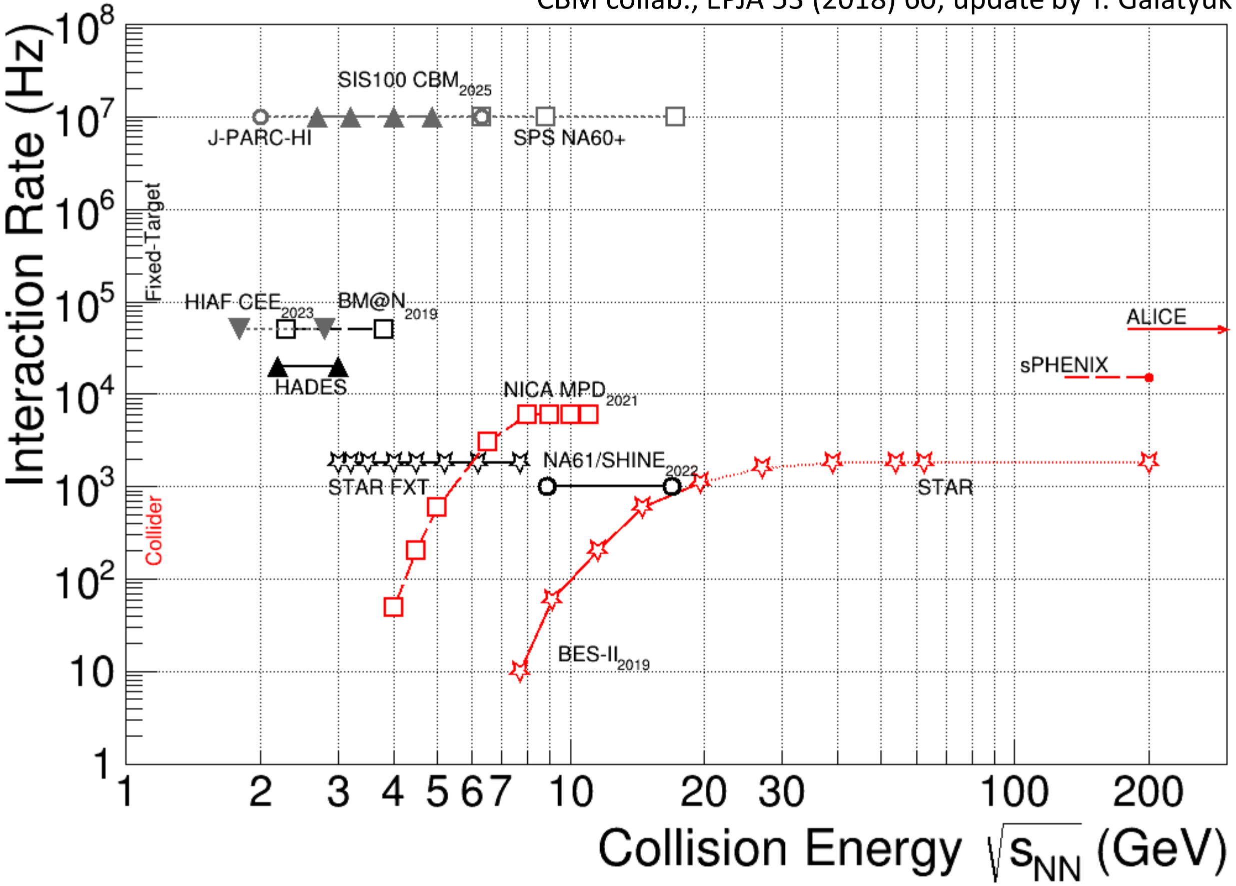
Berlin und Libau,
bey Lagarde und Friederich
1790.

Collision energy



Interaction rates

CBM collab., EPJA 53 (2018) 60; update by T. Galatyuk



running
approved / under constr.
proposed

Availability

- CBM @ FAIR: many research programmes; competition for beam
  - however: parallel operation to storage-ring experiments, e.g. PANDA
  - machine operation 9 months/year; estimated 3 months/year for CBM
- MPD @ NICA: sole user of collider ring (later shared only with SPD)
- CEE @ HIAF: competition with other research programmes (similar to CBM)
- BM@N @ NICA: at the moment only user of extracted beams

Mode: fixed-target vs. collider

- Fixed-target experiments:
  - Lower energy, potentially higher interaction rate (limit not by accelerator but by detector capacity)
  - Easier coverage of forward rapidity region
  - Acceptance changes with energy (can be partially compensated by magnetic field)
  - Projectile spectators are hard to measure
- Collider experiments:
  - Larger energy range
  - Interaction rate usually limited by the accelerators; beam quality deteriorates when running below maximum energy
  - Harder to measure spectators (beam hole), but possible on both sides
  - Acceptance stays approximately constant with energy.

Pros and cons: good to have both even at the same energy!

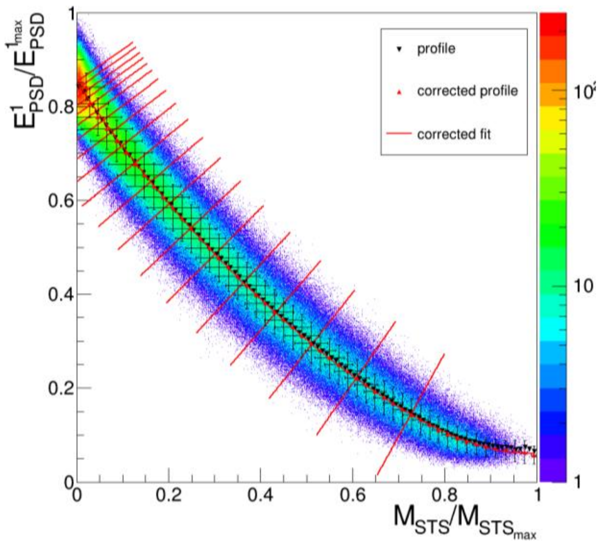
Coverage

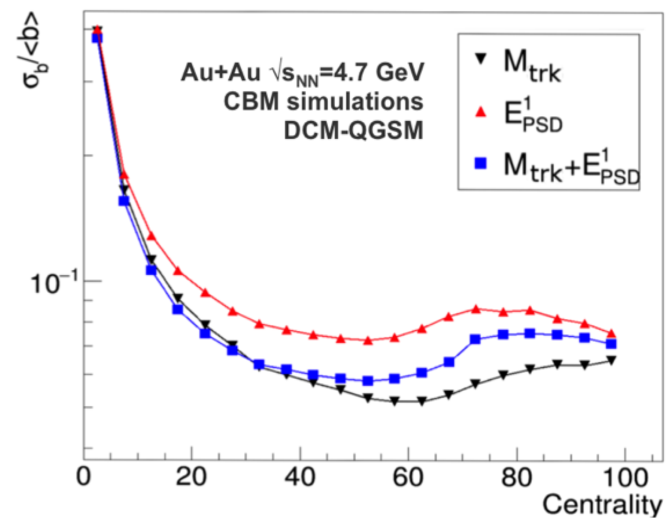
	CEE	BM@N	CBM	MPD	HADES	NA61	STAR	J-PARC
hadrons								
fluctuations								
electrons								
muons								
charm								

Performance: event centrality

CBM

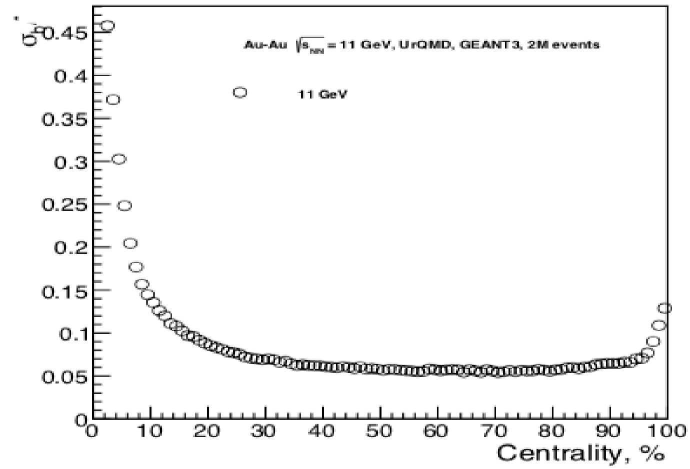
- Energy in forward calorimeter
- Charged-track multiplicity in main tracker





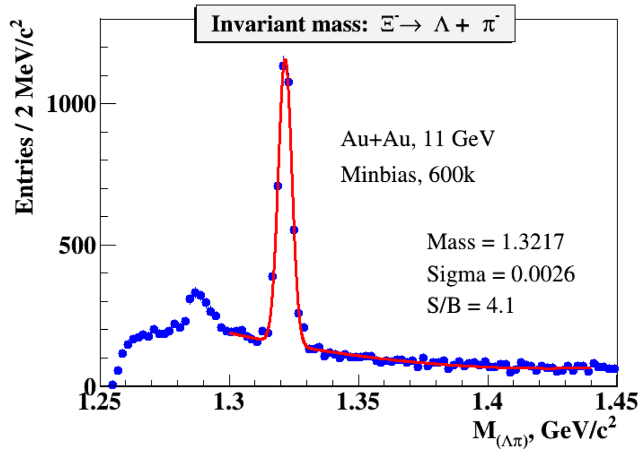
MPD

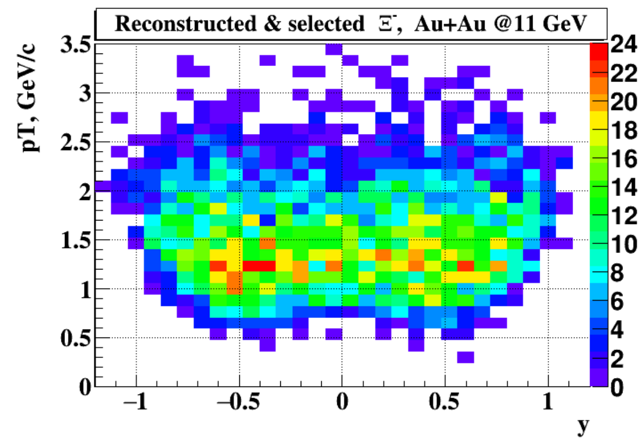
- Energy in 2 forward calorimeters



Performance: (anti-) hyperons

MPD



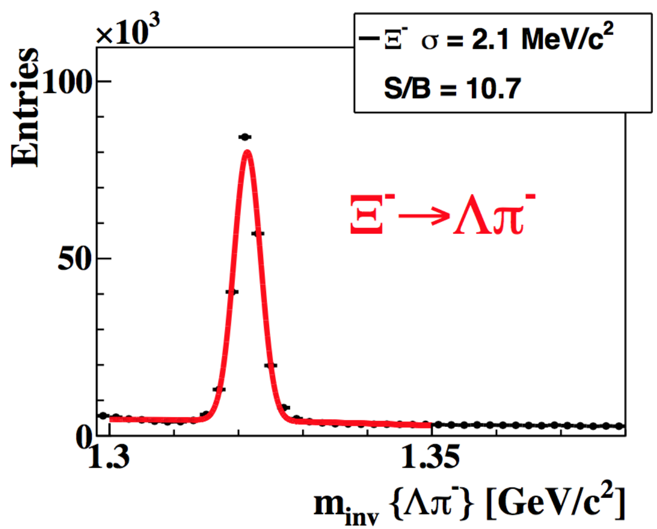


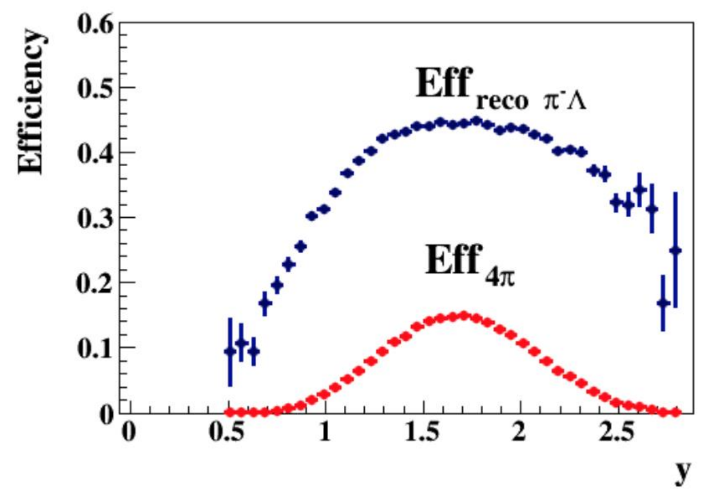
V. Kekelidze, QM 2018

CBM

Au+Au, p_{beam} = 10A GeV

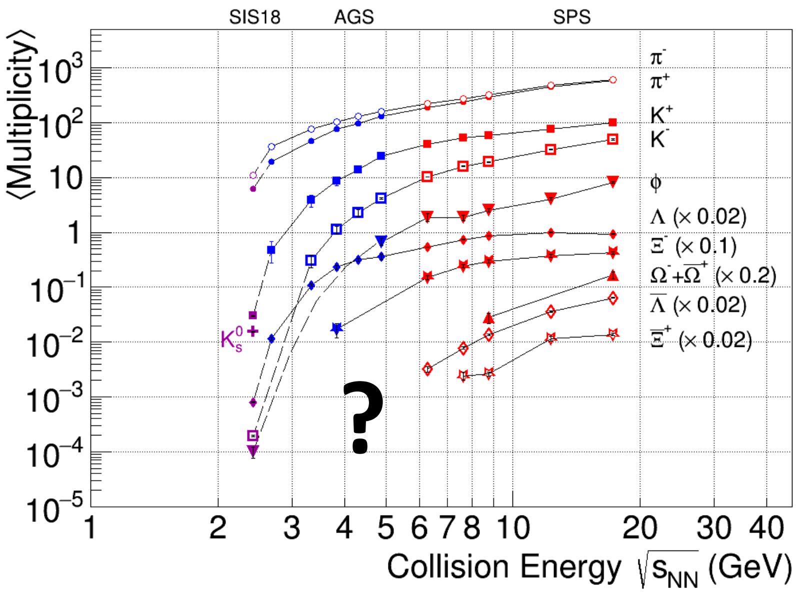
(sqrt(s_{NN}) = 4.7 GeV)





I. Vassiliev, QM 2018

Performance: (anti-) hyperons



Compilation by C. Blume. C. Markert, T. Galatyuk

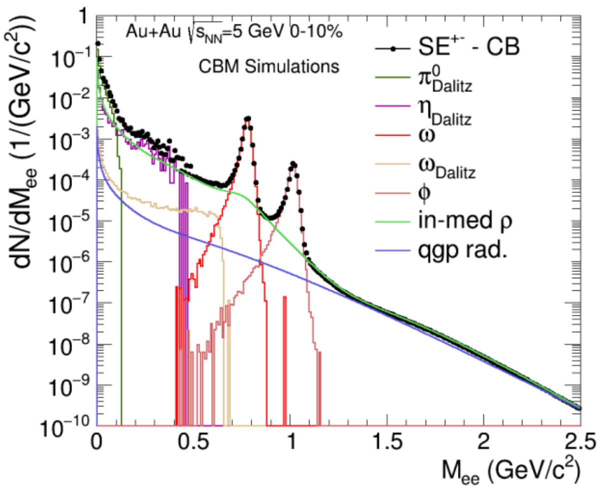
Both MPD and CBM will allow precision measurements for multi-strange hyperons (spectra flow).

CBM will also be able to address anti-Omega.

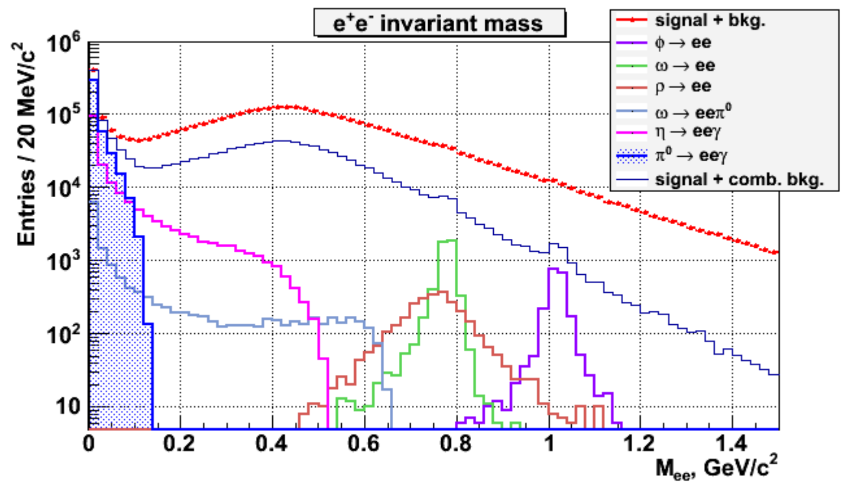
	sqrt(s_{NN})	Run time	Event rate	Ξ^-	Ξ^+	Ω^-
HADES	2.6 GeV	4 w	10 kHz	2.5 x 10^3		
MPD (s1)	11 GeV	10 wk	5 kHz	1.5 x 10^6	8 x 10^4	1.5 x 10^4
CBM	3.8 GeV	1 wk	10 Mhz	4 x 10^9	5 x 10^6	3.3 x 10^5

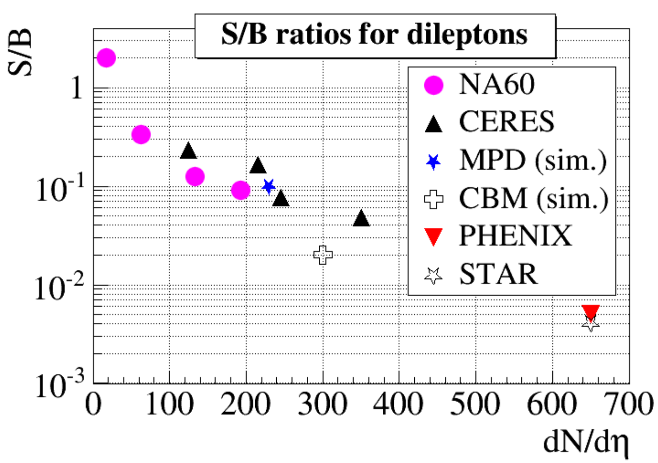
Performance: electron pairs

CBM, Au+Au, sqrt(s_{NN}) = 5 GeV



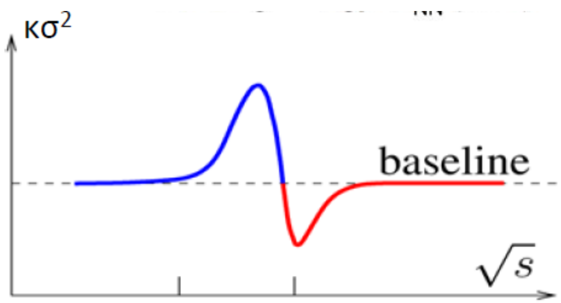
MPD, Au+Au, sqrt(s_{NN}) = 8 GeV



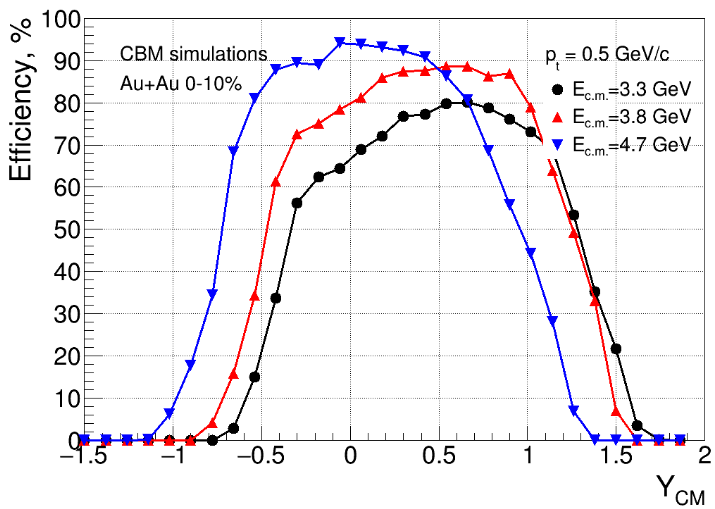


Performances of CBM and MPD are competitive to dedicated lepton-pair experiments.

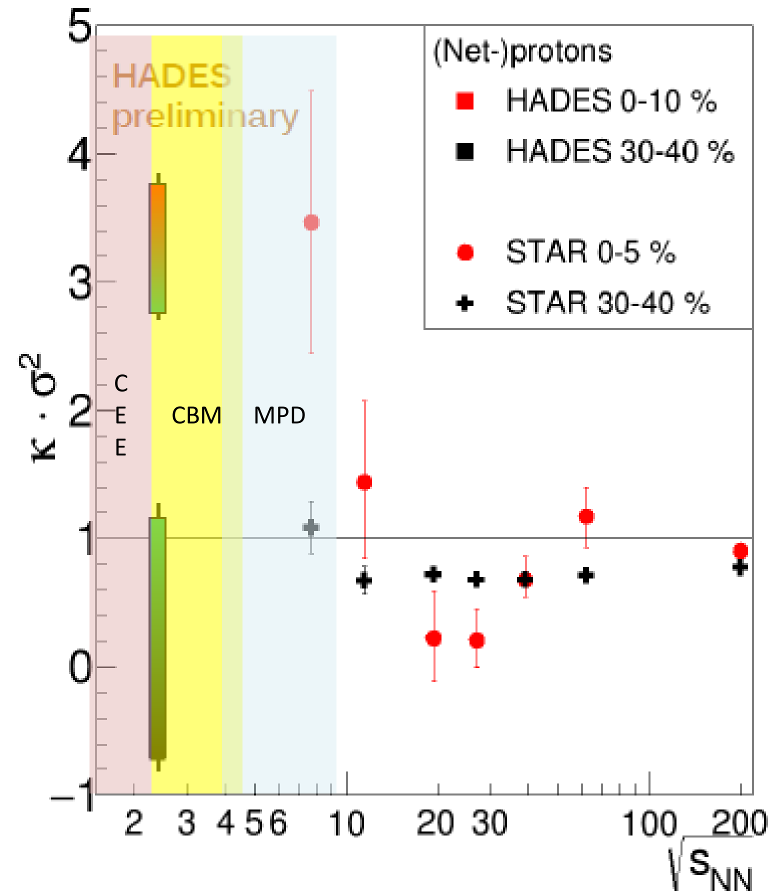
Fluctuations



M. Stephanov. J. Physics G.: Nucl. Part. Phys. ***38*** (2011) 124147

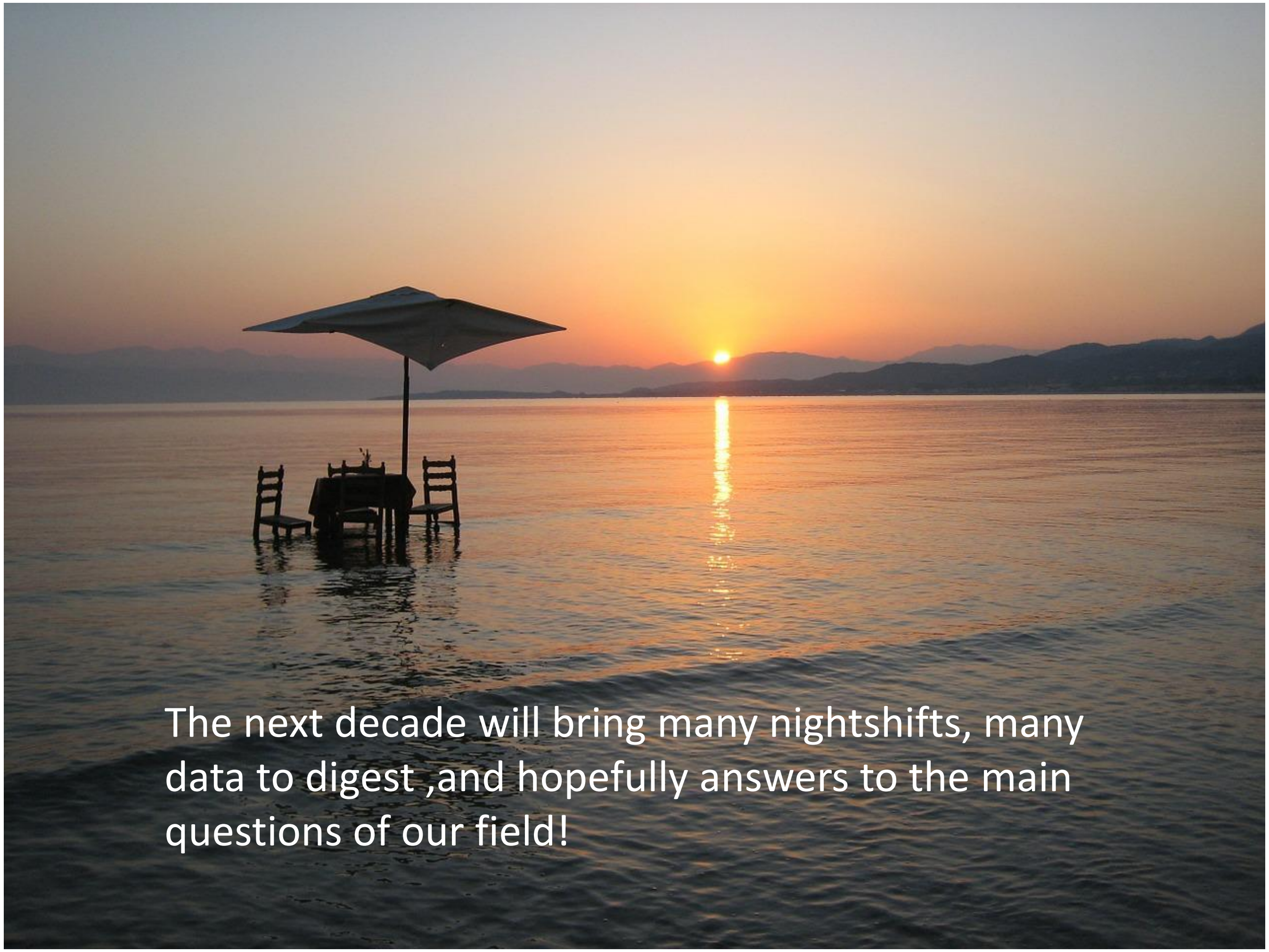


M. Lorentz, QM 2017



Current and future experiments will continue the excitation function:
Critical point? Phase transition?

Conclusions



Thanks to M. Kapishin, T. Sakaguchi, N. Xu and T. Galatyuk for providing information and materials!