CZECH PARTICIPATION AT FACILITY FOR ANTIPROTON AND ION RESEARCH (FAIR-CZ)

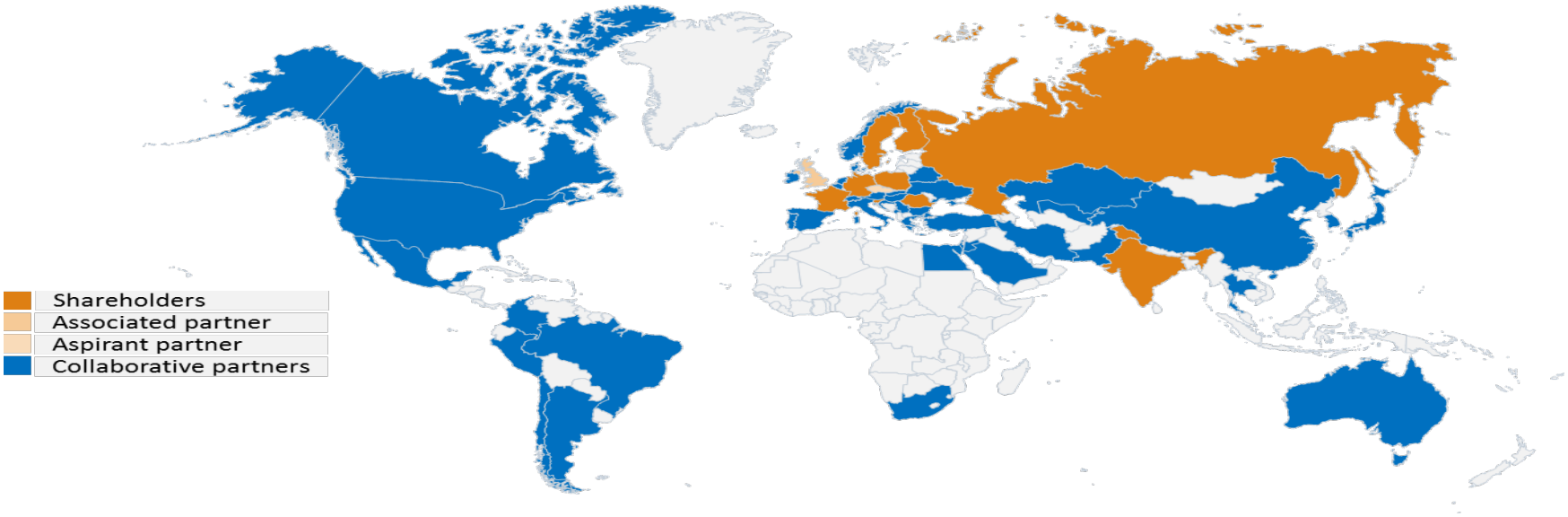
RNDr. Andrej Kugler, CSc.
Coordinator of FAIR-CZ
Nuclear Physics Institute, CAS

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Facility for Antiproton and Ion Research

– new international research laboratory <u>under construction</u> at GSI (Germany) to explore the nature and evolution of matter in the Universe

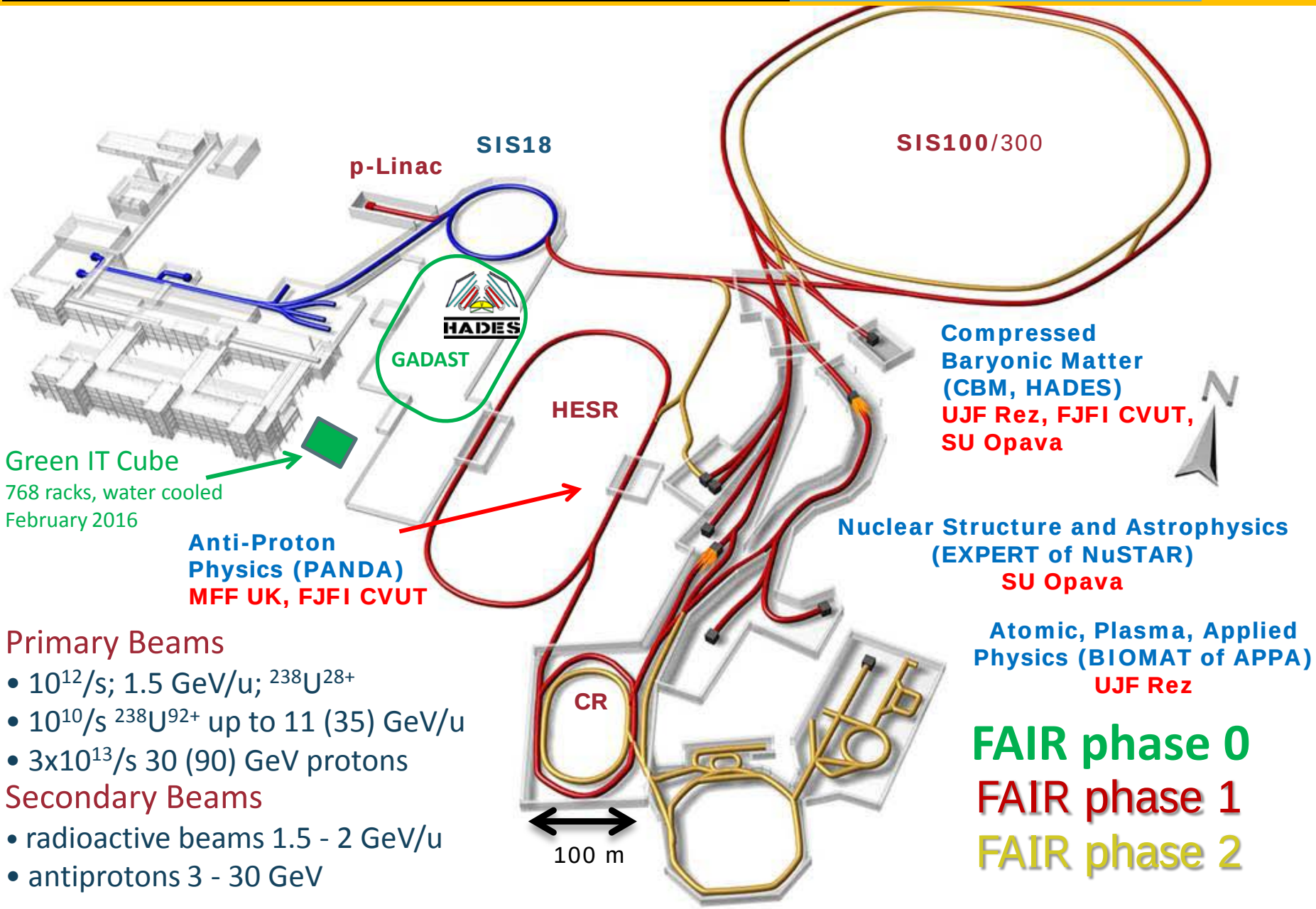


- FAIR governed by international convention
  - 9 shareholders + 1 assoc. partner +1 aspirant partner
- Scientists from all over the world are engaged
  - More than 200 institutions from 53 countries are involved with their scientists (orange + blue) → FAIR community growing
- FAIR is included in ESFRI road map since 2006

Finland France Germany India Poland Romania Russia Slovenia Sweden United Kingdom Czech Republic

FACILITY FOR ANTIPROTON AND ION RESEARCH

Participation of the Czech Republic http://fair.ujf.cas.cz



Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- 10^{10}/s $^{238}U^{92+}$ up to 11 (35) GeV/u
- $3x10^{13}$/s 30 (90) GeV protons

Secondary Beams

- radioactive beams 1.5 - 2 GeV/u
- antiprotons 3 - 30 GeV

FAIR Civil Construction

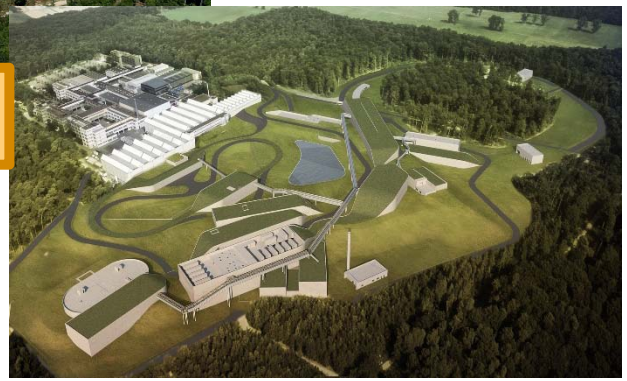
https://www.gsi.de/forschungbeschleuniger/fair/bau_von_fair/bilder_und_videos.htm

2018

2019

2020

2025



4th July 2017

SIS100 tunnel July 2020

CBM cave August 2020

The FAIR science: Evolution of Matter in the Universe

15 billion years

1 billion years

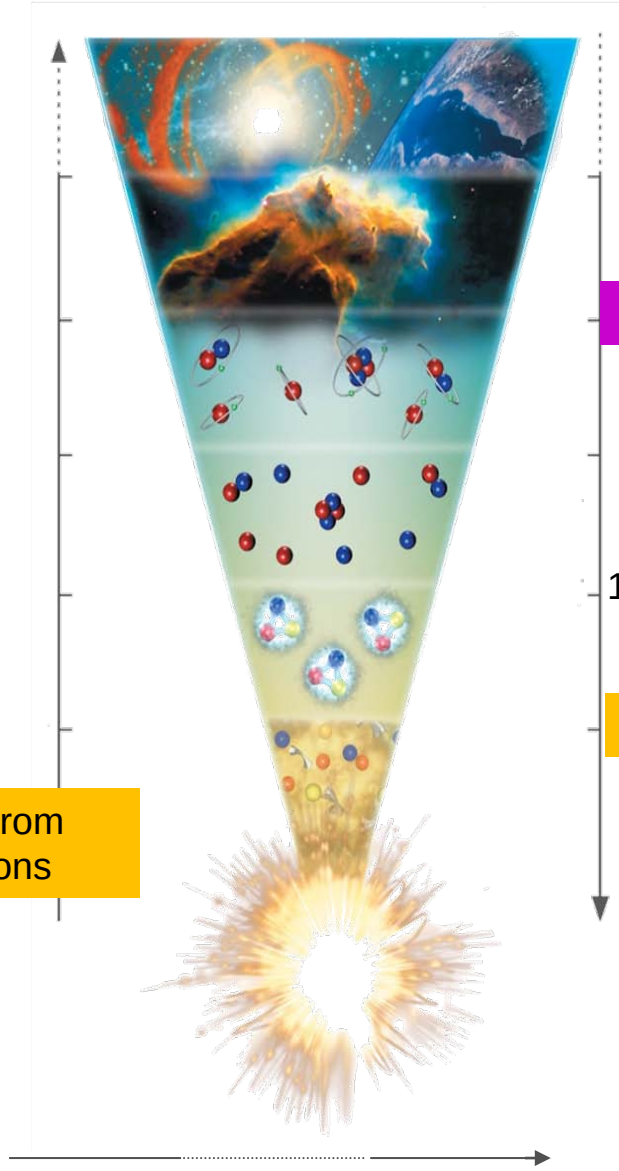
300.000 years

3 minutes

1 microsecond

Phase transitions from quarks to hadrons

time



distance

3 K

20 K

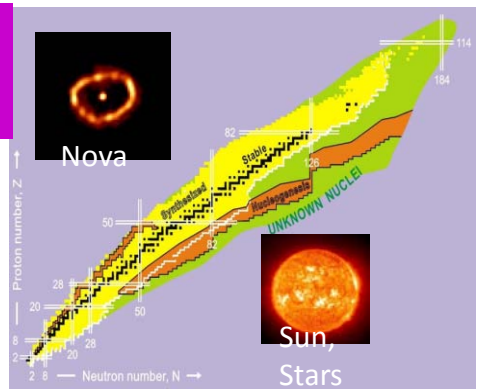
3000 K

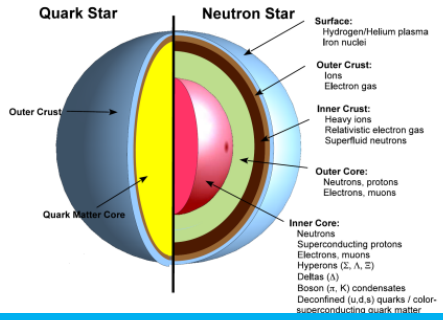
10^9 K

10^{12} K

temperature

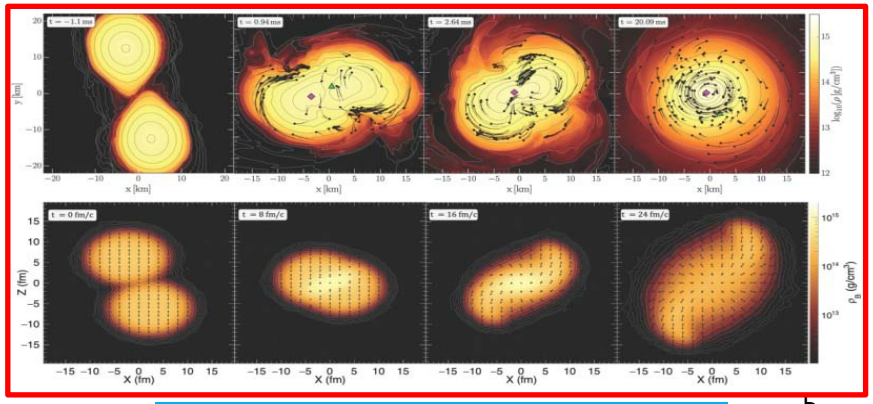
Origin of elements in current Universe





Baryonic matter at neutron star densities

Simulation of neutron stars merger



Simulation of heavy ion collisions

The FAIR science: four pillars

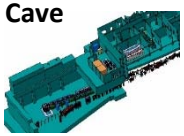
Participation of Czech scientist

Atomic & Plasma Physics & Applied Sciences

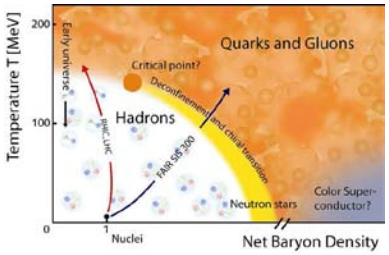
APPA

- Highly charged atoms (SPARC@FAIR)
- Plasma physics (HED@FAIR)
- Radiobiology (BIOMAT@FAIR)
- Space radiation protection (ESA)
- Material science (BIOMAT@FAIR)

APPA Cave



CRYRING

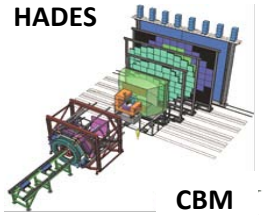


Compressed Baryonic Matter

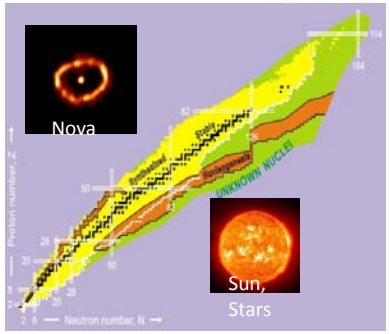
CBM

- Phase transitions from hadrons to quarks
- Equation-of-state of matter
- Electro-magnetic radiation from the dense fireball
- Chiral symmetry restoration in dense baryonic matter
- Hypernuclei: Λ-N, Λ-Λ interaction

HADES



CBM

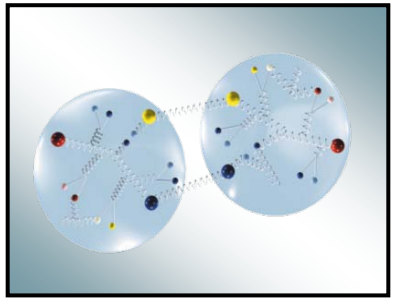


Nuclear structure and nuclear astrophysics

- r-process nucleosynthesis
- nuclear landscape beyond driplines
- Super heavy elements
- Exotic nuclei

NuSTAR

Super-FRS



Hadron structure and dynamics

- Exotic particles
- Gluonic matter and hybrids
- Hadron structure
- Hadrons in matter
- Double Lambda hypernuclei

PANDA

PANDA -> Anti-Proton ANnihilation at Darmstadt

Antiproton Annihilation

* Gluon rich process
* 2 GeV for free
* High mass (width) resolution (<100 keV)

Unique oportunity to study

* Production of high spin charmonia
* Line shape of narrow XYZ states, like X(3872).....
* Production of multistrangeness baryons
* Search for exotic particles
* Search for Gluonic Excitations

Nucleon Structure

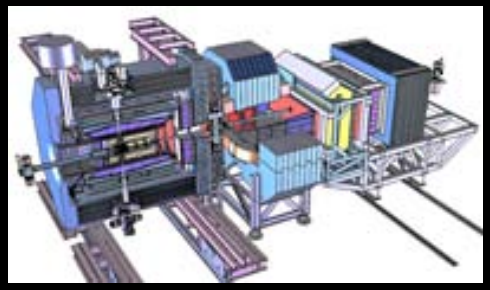
* Generalized Parton Distributions
* Time-like Form Factor of the Proton

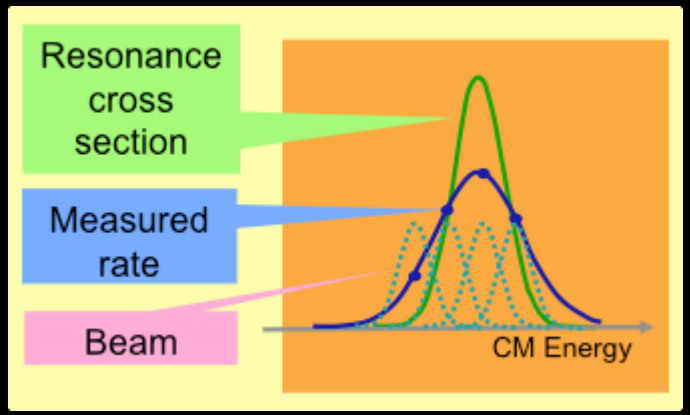
Hadrons in Matter

* Study in-medium effects of hadronic particles

Hypernuclei

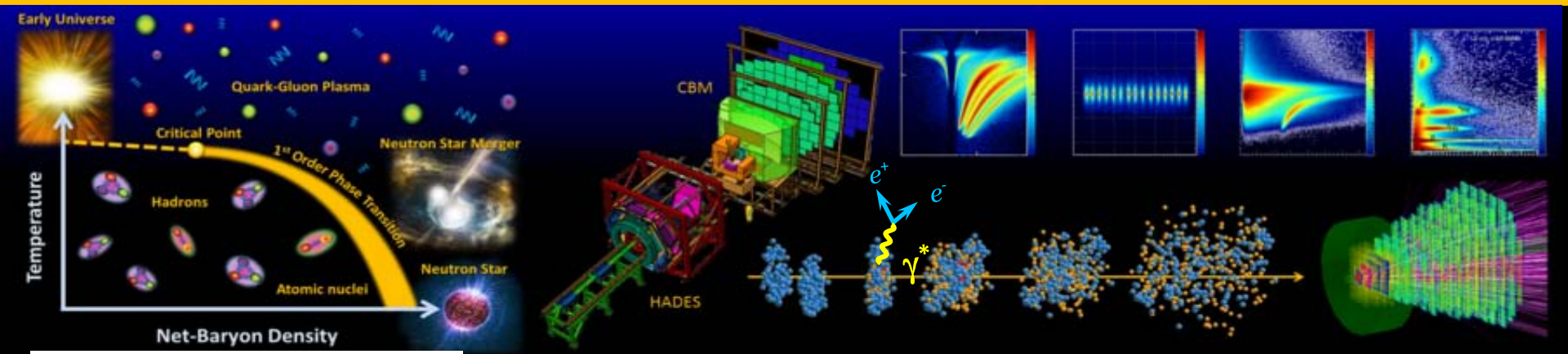
* Measurement of nuclear properties with an additional strangeness degree of freedom

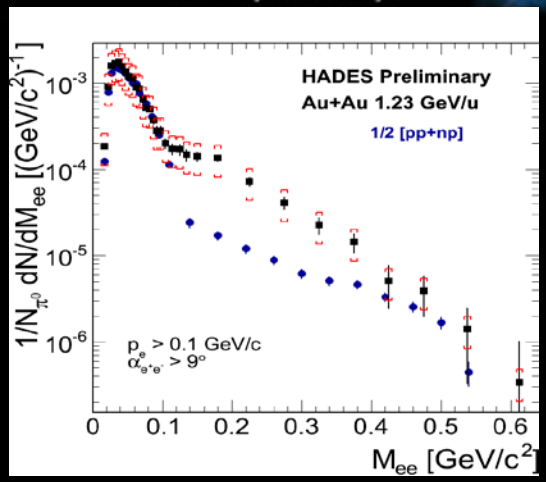


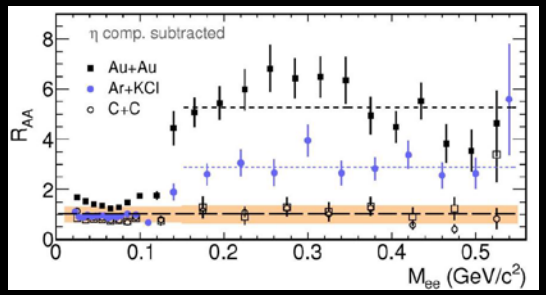


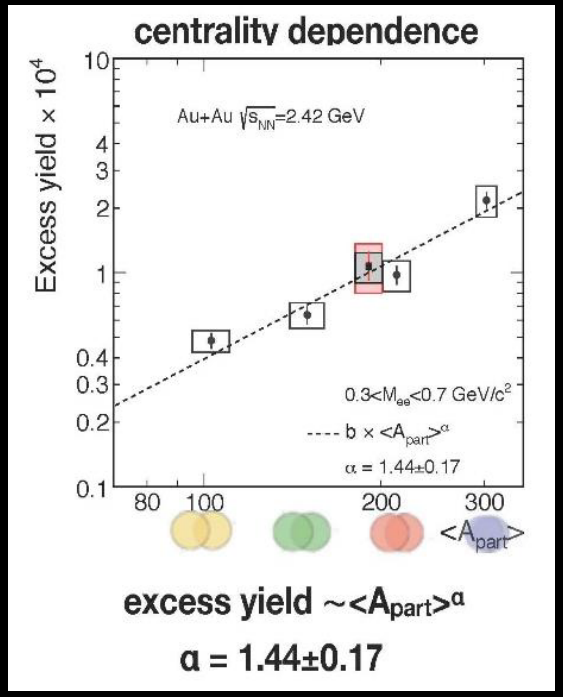
Emission of e^+e^- from Compressed Baryonic Matter

HADES results

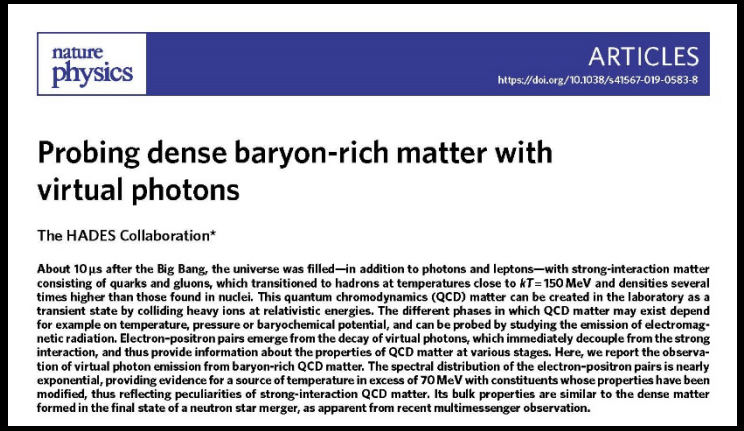








HADES Nature Physics 15 (2019) 1040



nature physics — ARTICLES

https://doi.org/10.1038/s41567-019-0583-8

Probing dense baryon-rich matter with virtual photons

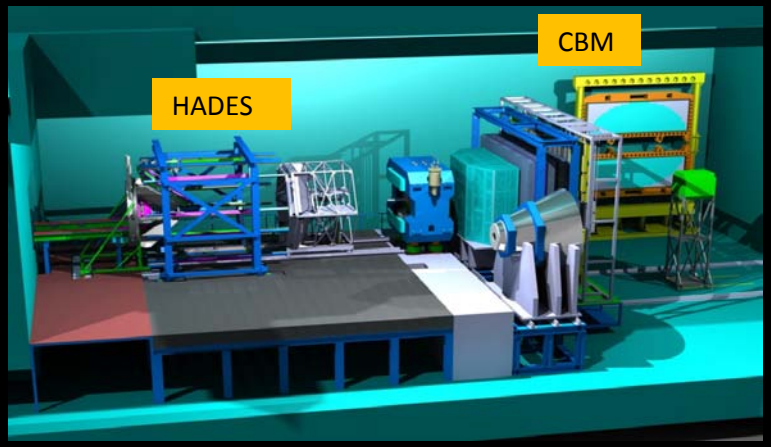
The HADES Collaboration*

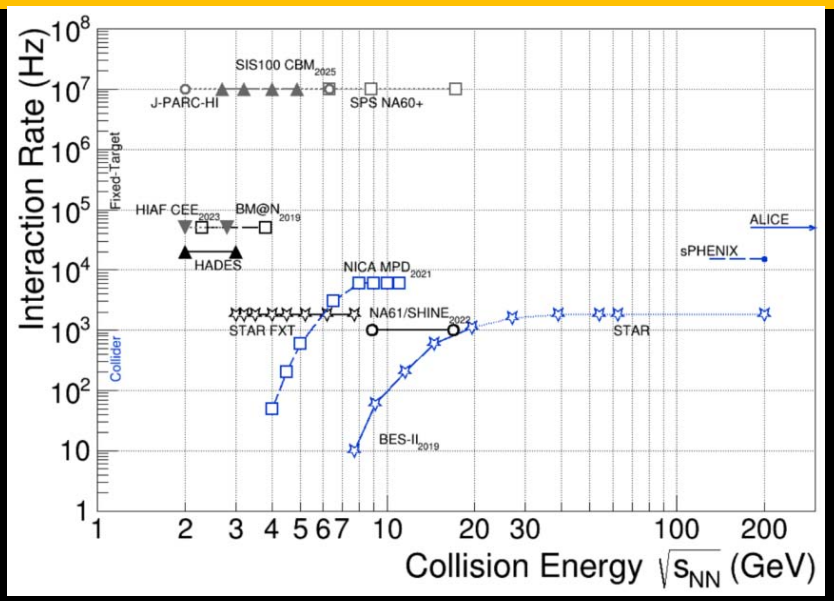
About 10 μs after the Big Bang, the universe was filled—in addition to photons and leptons—with strong-interaction matter consisting of quarks and gluons, which transitioned to hadrons at temperatures close to kT = 150 MeV and densities several times higher than those found in nuclei. This quantum chromodynamics (QCD) matter can be created in the laboratory as a transient state by colliding heavy ions at relativistic energies. The different phases in which QCD matter may exist depend for example on temperature, pressure or baryochemical potential, and can be probed by studying the emission of electromagnetic radiation. Electron–positron pairs emerge from the decay of virtual photons, which immediately decouple from the strong interaction, and thus provide information about the properties of QCD matter at various stages. Here, we report the observation of virtual photon emission from baryon-rich QCD matter. The spectral distribution of the electron–positron pairs is nearly exponential, providing evidence for a source of temperature in excess of 70 MeV with constituents whose properties have been modified, thus reflecting peculiarities of strong-interaction QCD matter. Its bulk properties are similar to the dense matter formed in the final state of a neutron star merger, as apparent from recent multimessenger observation.

Study of Compressed Baryonic Matter @ FAIR

HADES, CBM

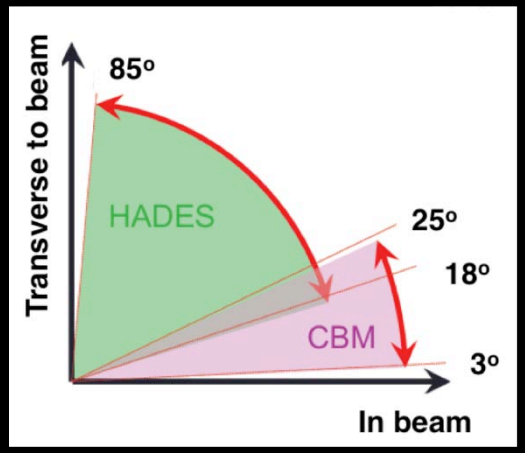
CBM cave

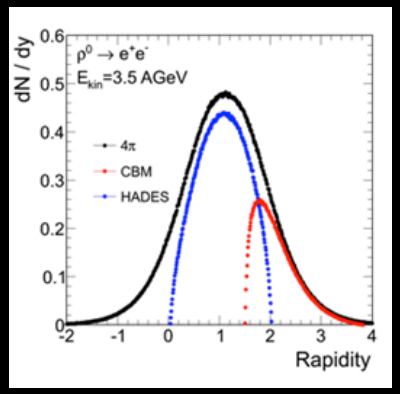




Phase space coverage (acceptance, reconstruction efficiency, secondary vertex cuts)

- $\sqrt{s_{NN}}$ = 2 - 4 GeV:
  - → BM@N, STAR FXT, NICA, J-PARC HADES and CBM



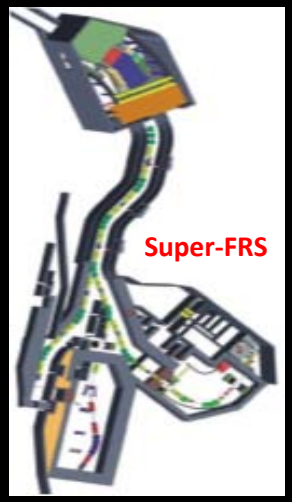


EPJ A v.53 N3 (2017)

Nuclear STructure, Astrophysics and Reactions (NuSTAR)

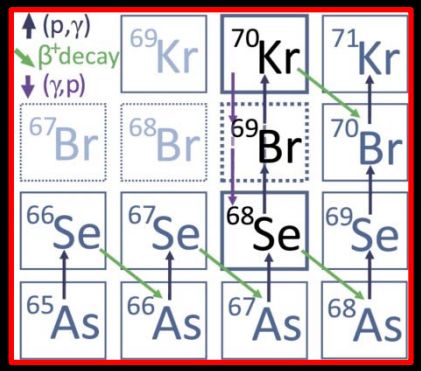
EXPERT: part of SuperFRS project

Experimental studies will be exploiting unique beams of radioactive nuclei provided at FAIR. Particularly, scientist will concentrate to studies of nuclear reactions between unstable nuclei which occur inside stars during synthesis of elements in current Universe



main goals of the EXPERT scientific program

- new types of radioactivity
- investigation of 2p radioactivity
- search for 4p, 2n, 4n radioactivity
- p, 2p, 4p, n, 2n, 4n resonance decays



Part of scenario of synthesis of elements in Universe, *i.e.* the *rp*-process around the waiting point ^{68}Se

Atomic, Plasma Physics and Applied Sciences (APPA)
Dosimetry and microdosimetry for BIOMAT experiments

Objective of the planned research: optimization of ion cancer therapy

Different passive and active detectors (mainly track etched detectors, silicon detectors, Timepix, …) will be applied to describe dosimetry and microdosimetry characteristics of ion beams (distributions of particle fluence, LET spectra, absorbed dose,…)

Own research topics:

- Influence of metallic orthopedic and dental implants on LET spectra and dose distributions
- Application of radioactive beam ^{11}C in cancer radiotherapy

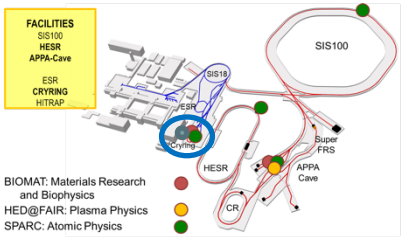
Schedule for FAIR Science

- Working towards the completion of FAIR by 2025
- Major thrust is on construction of FAIR accelerators and experiments.
- At the same time ***staged approach to FAIR science is applied to educate young scientist and to progressive commissioning of accelerators and detectors***:

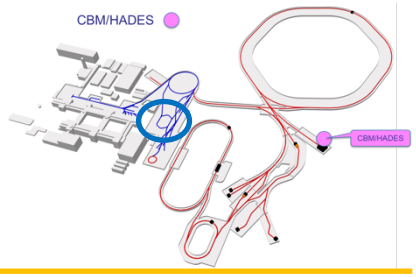
- ***FAIR phase 0: started in 2018/2019***
- FAIR day 1 configurations/ phase 1 experiments with FAIR accelerators progressively approaching design parameters → 2024/25 …
- Full FAIR operation 2025+

FAIR Phase 0 Research Program

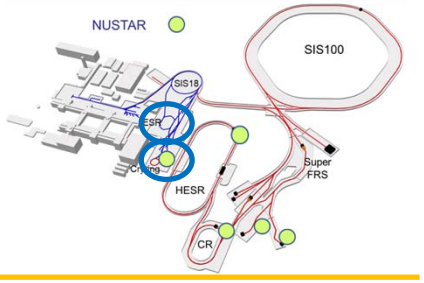
APPA



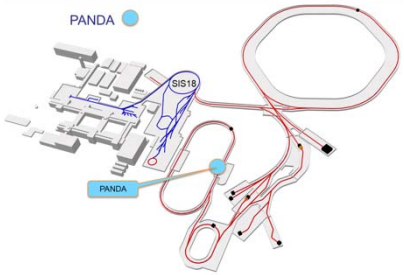
CBM



NUSTAR

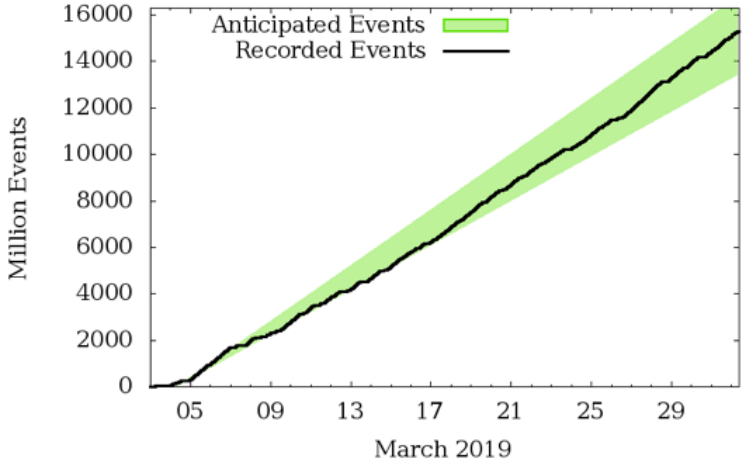


PANDA



HADES during FAIR Phase-0

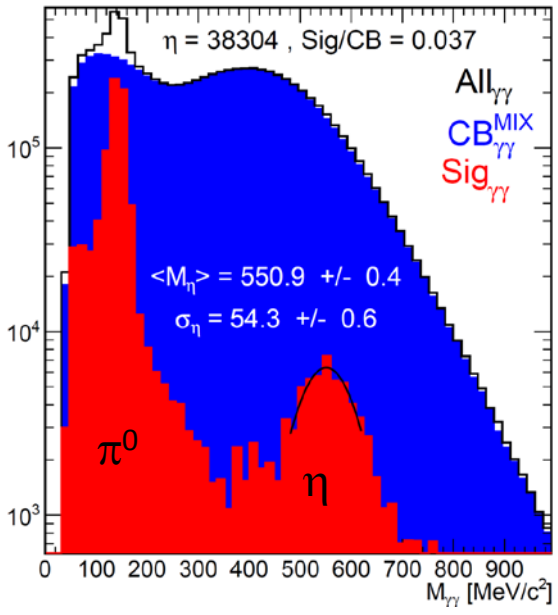
Ag+Ag 1.58 AGeV experiment March 2019

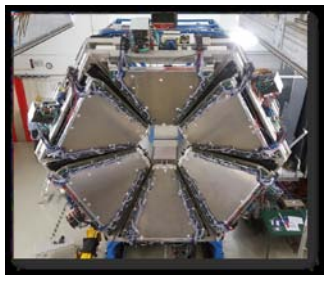


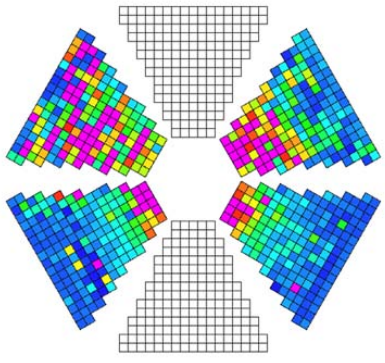
HADES ECAL Czech in-kind contribution

- Based on lead glass recycled from OPAL and read out with HADES TRB3
- PADIWA system based on commodity hardware (cell phones, FPGAs)
- Four sectors equipped for 2019 run. Will be completed in 2020.

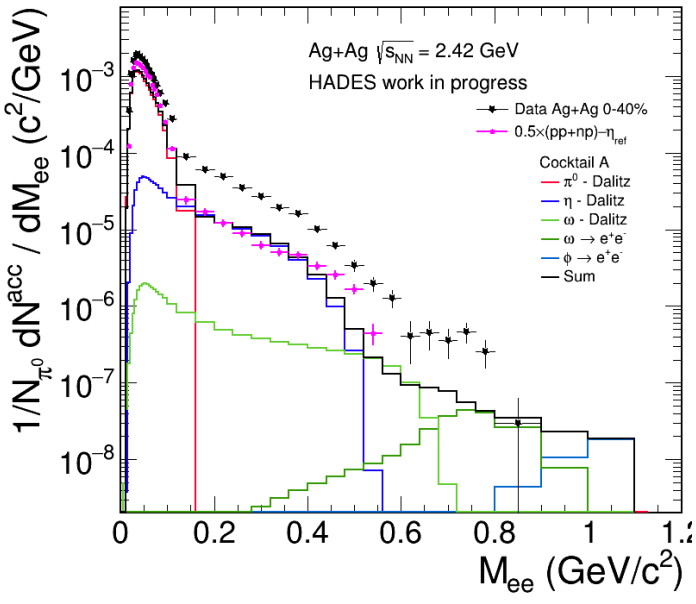
Diphotons, E>400 MeV, work in progress





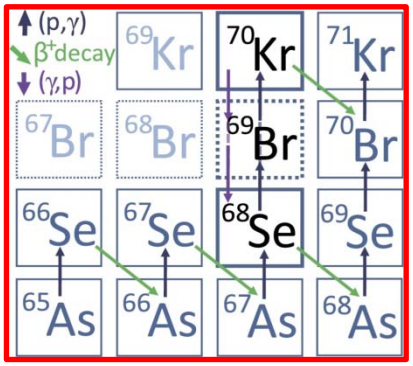


Dileptons, work in progress



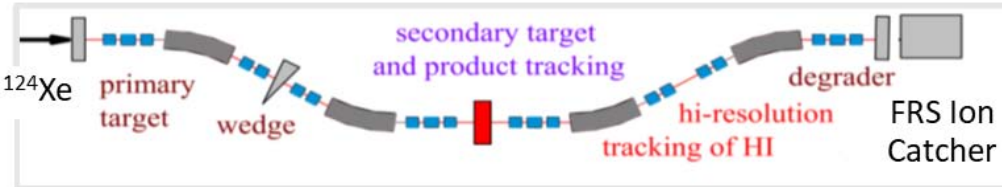
EXPERT experiments S459 and S443 combined with S472 March 2020

- combined 3-day experiment of two detector setups at FRS using primary ^{124}Xe beam
- EXPERT experiments S459 (V. Chudoba, Opava), and S443 (I. Mukha, GSI) combined with FRS Ion Catcher
- Secondary beams of ^{70}Br and ^{74}Rb hit $^{nat.}$Be target where occurred one-neutron removal populating the nuclei of interest.



Part of scenario of synthesis of elements in Universe, *i.e.* the *rp*-process around the waiting point ^{68}Se

Layout of the FRS with the EXPERT experimental setup



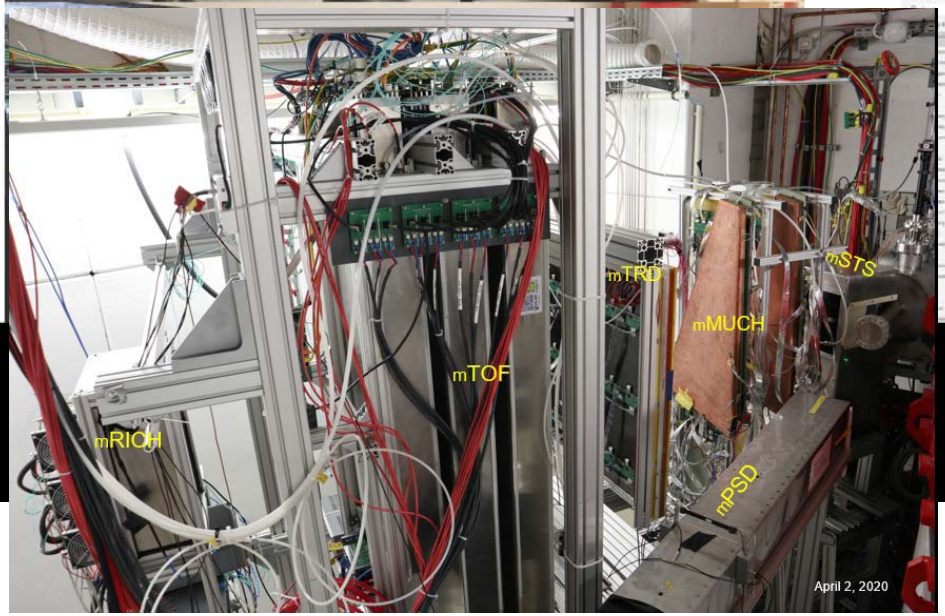
- Properties of ^{69}Br,^{73}Rb investigated:
  - interest for understanding of synthesis of elements in Universe (*rp*-process);
  - both isotopes located in the vicinity of waiting points;
  - Information on 1p-decay is relevant for population of heavier isotopes (e.g. from ^{68}Se);
- Registered ~80 and ~40 events of 1*p*-decays in-flight of ^{69}Br and ^{73}Rb, respectively.
- The life-times of ^{69}Br,^{73}Rb isotopes produced in secondary reactions were determined.
- Successful testing and running of custom FRS ion optics, and FRS and EXPERT detectors.
- The results of the above two isotopes give good chances for two publications at least.

mCBM commissioning campaign in Spring 2020

Frequent runs between March 27 and May 24, 2020.

COVID-19 measures:

- Strongly reduced on-site crew
- Remote participation of experts from around the world
- Excellent operation via VNC, communication via Vibe
- Very important program executed



Czech Republic joins FAIR as “Aspirant Partner” 25.3.2019

- “Aspirant Partner”, a new type of participation, is offered to new countries interested in being part of FAIR a progressive path to membership. FAIR Council, the shareholders' meeting of FAIR GmbH, has created it in 2017 and decided in December 2018 to recognize the Czech Republic as the first FAIR “Aspirant Partner”.
- The contract has been signed by the managing directors of GSI and FAIR, Professor Paolo Giubellino, Ursula Weyrich and Jörg Blaurock, as well as by Dr. Petr Lukáš, Director of the NPI. Czech partners in FAIR-CZ consortium – represented by Prof. Vojtěch Petráček, Rector of the Czech Technical University in Prague, Prof. Gabriel Török, Vice-Rector of the Silesian University in Opava, Prof. Jan Kratochvíl, Dean of the Faculty of mathematics and physics, Charles University (FMP CU), Prof. Vladimír Baumruk, Vice-Dean of the FMP CU, and Dr. Andrej Kugler, FAIR-CZ coordinator – took part at the signing as well.
- Czech Republic has thus been an aspirant member of the FAIR Large European Infrastructure since 2019 and it has the corresponding representation in the FAIR institutions including the FAIR Council (A.Kugler and M.Vyšinka)

FACILITY FOR ANTIPROTON AND ION RESEARCH

Participation of the Czech Republic http://fair.ujf.cas.cz

Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- 10^{10}/s $^{238}U^{92+}$ up to 11 (35) GeV/u
- $3x10^{13}$/s 30 (90) GeV protons

Secondary Beams

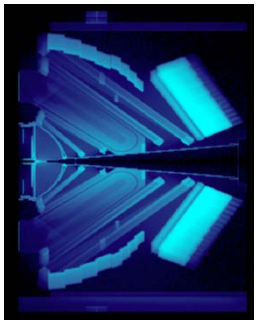
- radioactive beams 1.5 - 2 GeV/u
- antiprotons 3 - 30 GeV

Compressed Baryonic Matter: Czech contributions

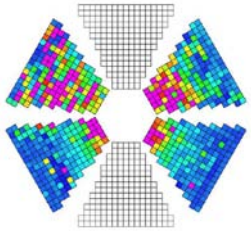
High Acceptance DiElectron Spectrometer @FAIR

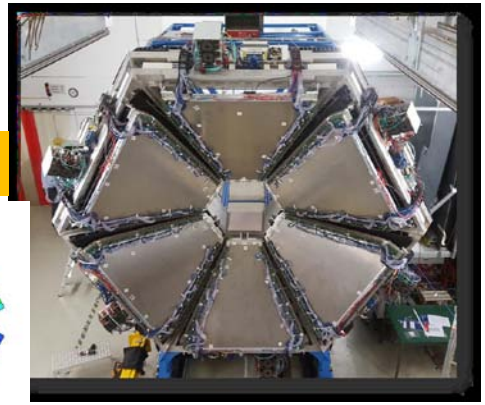
Electromagnetic Calorimeter (ECAL)

- 978 modules of lead glass + photomultiplier

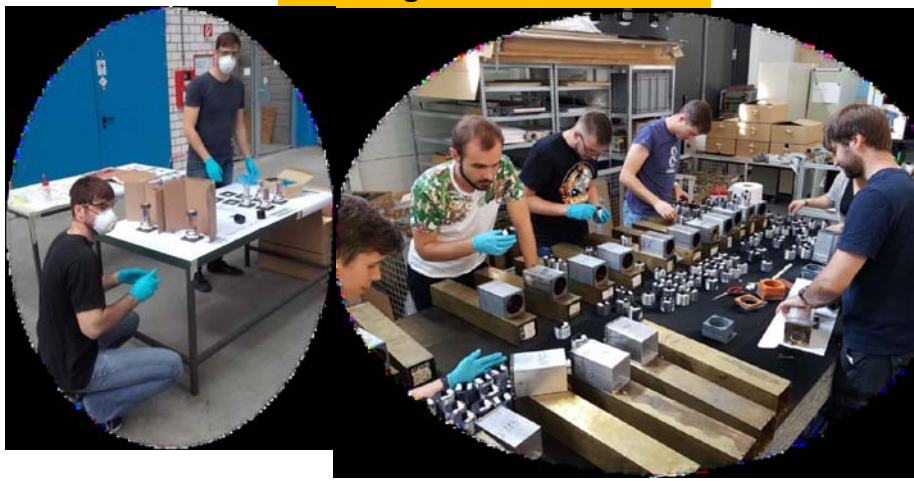


March 2019





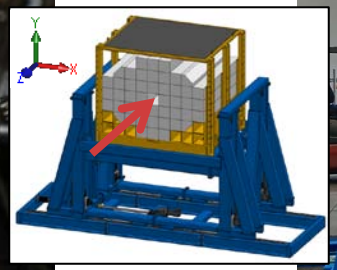
Building HADES ECAL



Compressed Baryonic Matter @ FAIR

Projectile Spectator Detector (PSD)

- 60 sandwiches in one module
- 45 modules of 20 x 20 x 120 cm^3
- Read out by Avalanche Photodiodes
- Total weight ~ 22 tons, 8 m from target
- for intensity up to 10^9 ions/sec



Testing PSD photodiodes at NPI

Building Projectile Spectator Detector (PSD)

Electromagnetic Calorimeter @ PANDA

based on high-quality PWO-II crystals: Czech contribution

Barrel of Electromagnetic Calorimeter (EMC)
8 500 $PbWO_4$ crystals , operated at -25°C, read-out by APD
Crystals to be produced in CRYTUR

- physical goals of PANDA require further development

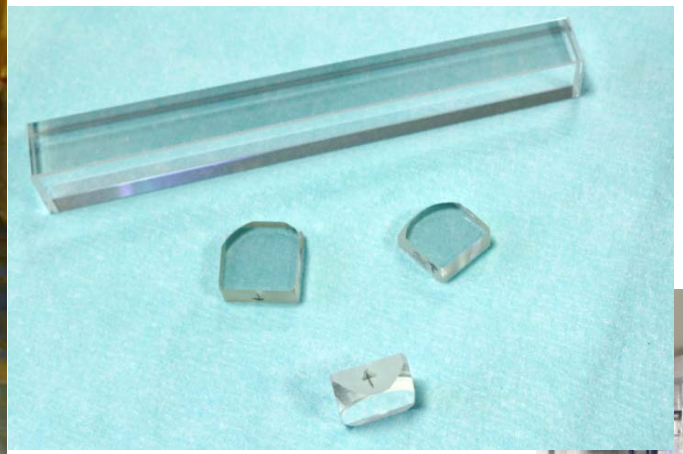
	PWO-I (CMS)	PWO-II (PANDA)
luminescence maximum, nm	420	420
La, Y concentration level, ppm	100	40
expected energy range of EMC	150MeV - 1TeV	10MeV - 10GeV
light yield, phe/MeV at room temperature	8-12	17-22
EMC operating temperature, °C	+18	-25
energy resolution of EMC at 1GeV, %	3,4	2,0

Test of radiation hardness of ingots @ Microtron Lab of NPI

- **irradiation of samples from the top and bottom part of the ingot by Bremstrahlung due to electrons from Microtron (5.5 MeV < E_e < 16.6 MeV)**
- **Samples are provided by CRYTUR**

MT25 Facility at Prague

- **homogeneous** illumination of the (rotated) sample
- **integral beam intensity** adjusted to irradiation γ-rays from ^{60}Co source (30Gy)
- illumination for 5-10 minutes
- immediate measurements of the **optical transmission** before and after irradiation (sample thickness ~ 10mm)



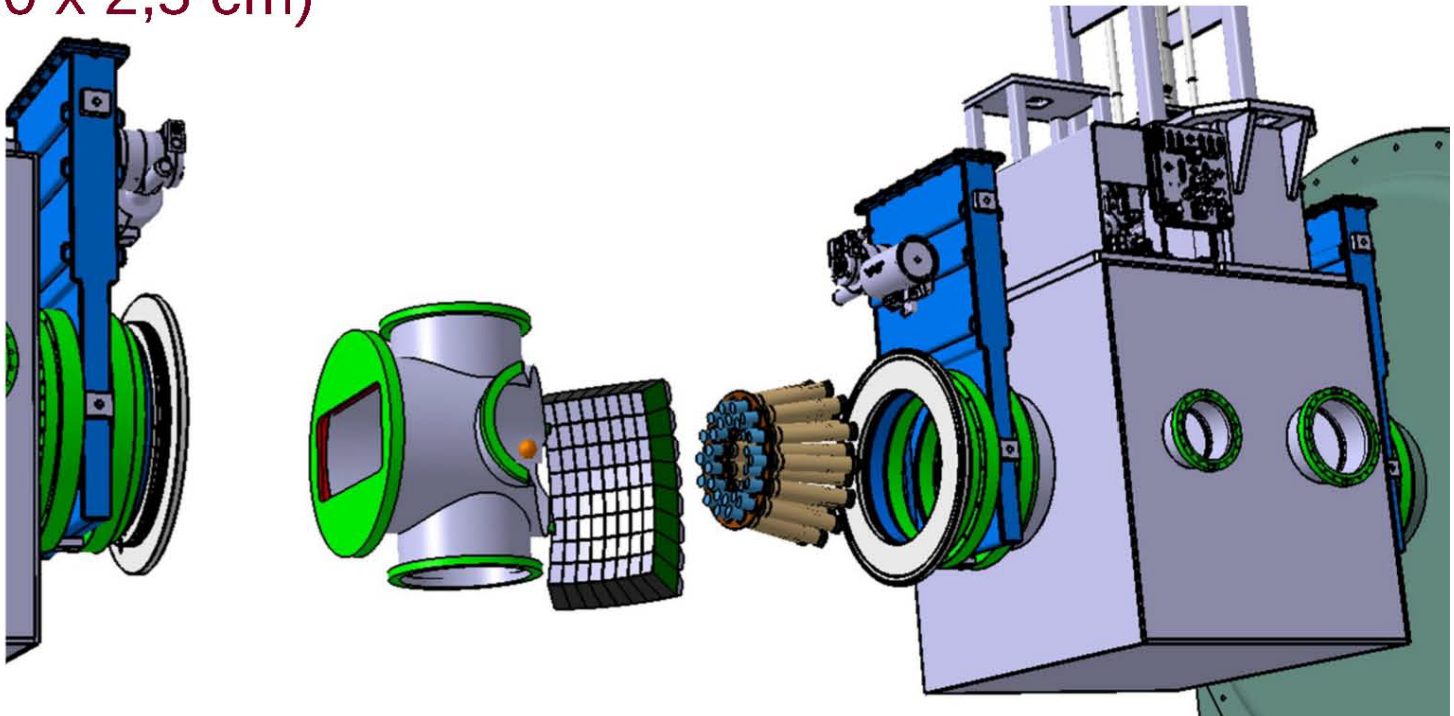
fast response for immediate reactions of CRYTUR

GADAST@EXPERT: Czech contributions

- tagging of gammas from 2p-radioactivity
- E_g ~ 100 keV – 2 MeV
- trapezoidal CsI(Tl) crystals (4.1 x 7.6 x 15 cm)
- cylindrical $LaBr_3$(Ce) crystals (10 x 2,5 cm)

in the middle of SuperFRS in FMF2

128 modules CsI(Tl)
32 modules $LaBr_3$(Ce)



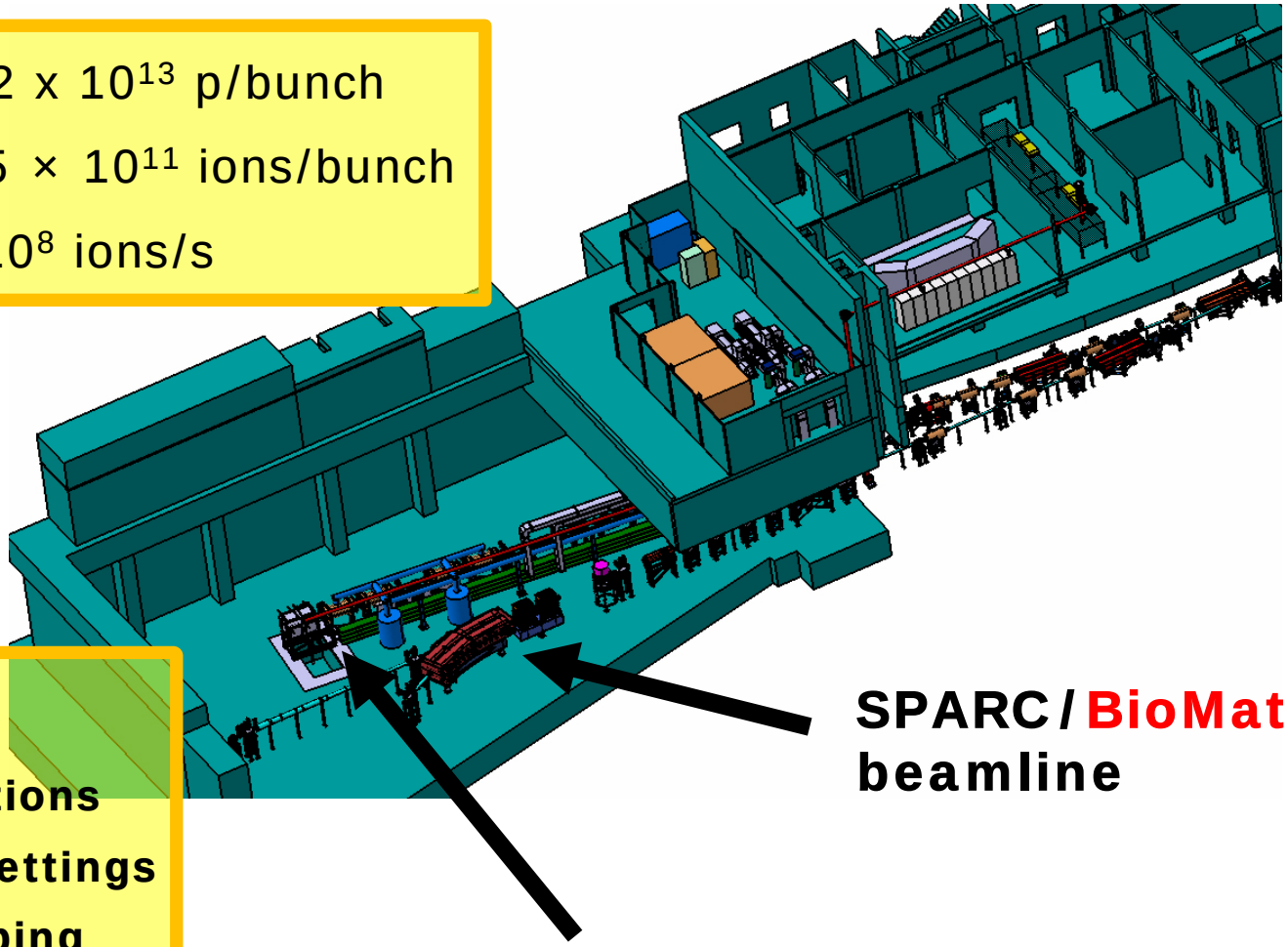
Atomic, Plasma Physics and Applied Sciences

Vacuum stations for beam line in APPA Cave: Czech contributions

protons (10 GeV): 2 x 10^{13} p/bunch

U^{28+} (2 GeV/u): 5 × 10^{11} ions/bunch

U^{92+} (10 GeV/u): 10^{8} ions/s



- **user facility**
- **several target stations**
- **flexible detector settings**
- **flexible beam shaping**
- **external drivers**

Participation of the Czech Republic in FAIR
Current status

FAIR-CZ, Czech Research Infrastructure (RI) (included in the Roadmap of Large Infrastructures for Research, Experimental Development and Innovation of the Czech Republic for the years 2016 - 2022) addresses the approach of the Czech Republic to FAIR in general, and access of the Czech communities in nuclear and hadron physics (CBM, HADES, PANDA and NUSTAR), biophysics and radiobiology (APPA), in particular.

Hosting institution: *Nuclear Physics Institute Czech Academy of Sciences (NPI)*
Partner institutions: *Charles University (CUNI), Czech Technical University in Prague (CTU), Silesian University in Opava (SUO)*
Futher participating: *University of West Bohemia in Pilsen (UWB), Technical University in Brno*
LOI: *PPI CAS Prague*

Support by MEYS
2016-2019 OP VVV+LM2015049
2020-2022 OP VVV+LM2018112
2017-2021 LTT17003 (research activities of NPI+SUO)

Period: 2016-2019

FAIR-CZ OP(CZ.02.1.01/0.0/0.0/16_013/0001677)+LM2015049

Monitoring system of HADES ECAL	NPI
High voltage power source system of HADES ECAL	NPI
High voltage dividers, mechanics and shielding of PMT's for HADES ECAL	NPI
3" photomultipliers for HADES ECAL (122 pieces)	NPI
PbWO4 scintillators for PANDA EMC Barrel (71 pieces)	CU
Modules for EXPERT GADAST based on 4 LaBr and 10 LYSO scintillators	SUO
Support Platform of CBM PSD	CTU

Period: 2020-2022

investment from FAIR-CZ-OPII (CZ.02.1.01/0.0/0.0/18_046/0016066)
operation from LM2018112

HADES platform at SIS100	NPI
Modules of PMTs with dividers and mechanics for two sectors of HADES ECAL	NPI
3 vacuum stations for BIOMAT beam line	NPI
Carbon beam pipe for PSD CBM	CTU
200 PbWO4 scintilators for PANDA EMC Barrel	CU
32 GADAST scintillation modules for EXPERT	SUO
Local infrastructure at Czech Republic (cooling system for NPI microtron)	NPI...

Conclusion

During 2016-2019 period we successfully carried out R@D activities related to FAIR. HADES experiment with significant czech contribution was successfully carried out in 2019, another experiment was carried out in 2020 as part of NuSTAR physics. Both experiments are part of FAIR Phase 0 activities. Two new institutions (UWB Pilsen and IPP Prague) became involved in FAIR related activities. The Technical University in Brno will join EXPERT (NuSTAR) activity since 2020. The CTU partner included into FAIR related activities colleagues from new faculty (FMP). Czech Republic became Aspirant member of the FAIR in 2019.

For the future, it is planned to continue to develop and manufacture the cutting-edge scientific equipment necessary to complete the FAIR infrastructure. This will include, in particular, the completion of the remaining two sectors of the ECAL detector for the HADES experiment, the completion of the PSD detector (support structures, read-out diode tests and beampipe made of composite materials). For the PANDA detector, silicon tracking detectors will be completed and made ready for mass production. In addition, mass production in the Czech company CRYTUR and testing of $PbWO_4$ crystals at the NPI CAS microtron for electromagnetic calorimeter for the PANDA experiment will take place. Additional scintillation detector modules will be acquired and installed for the GADAST detector from EXPERT (NUSTAR) and the BIOMAT (APPA) experiment will be supported by the supply of vacuum components.

THANK YOU