Physik an FAIR

KET Jahrestreffen

15 November 2014

Johannes P. Wessels

für das KHuK

Universität Münster

Research Priorities

- as spelled out in the strategy document
  - construction and completion of the Facility for Antiproton and Ion Research (FAIR) in Darmstadt
  - full exploitation of existing research infrastructures for the study of the properties and structure of matter under extreme conditions
  - initiative to secure the promotion of young scientists in the field of hadron and nuclear physics

    in line with NuPECC Long-Rangle Plan for Europe

Die FAIR-Beschleunigeranlage

O. Kester

Strahlintensität:

- Primärstrahlen: x 100 – x 1.000
- Sekundärstrahlen: x 10.000

Strahlen:

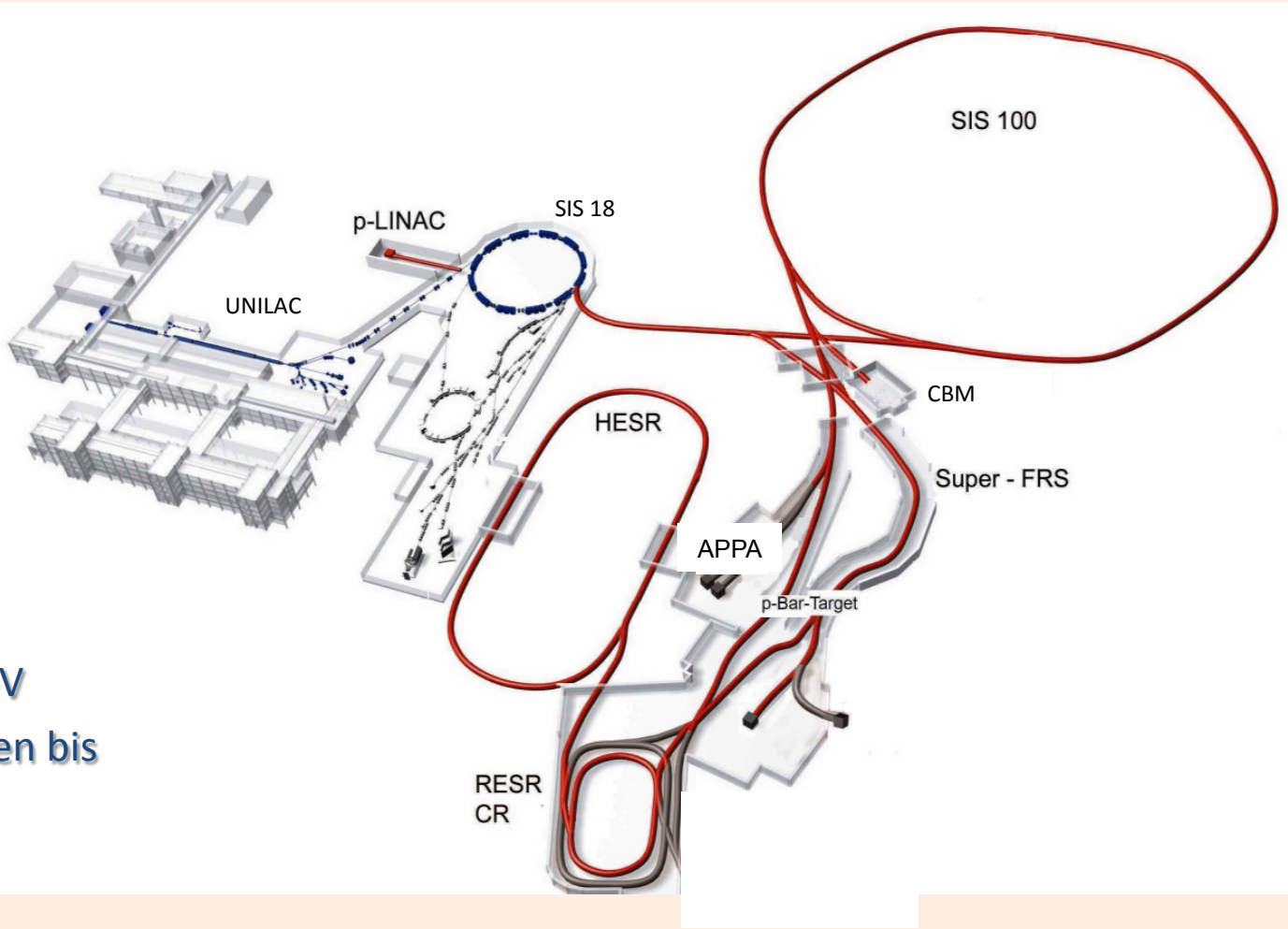
- Antiprotonen
- Protonen bis Uran
- Exotische Nuklide

Energie:

- Protonen bis 29 GeV
- Schwerionenstrahlen bis 15 GeV/u

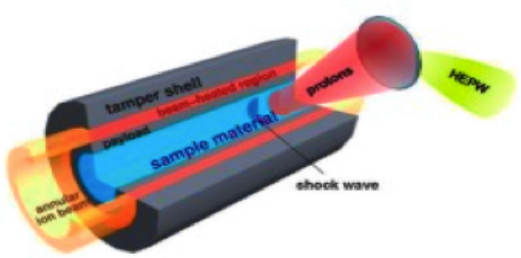
Strahlpulsstruktur:

- Extrem kurze (ns)
- bis sehr lange Pulse (s)

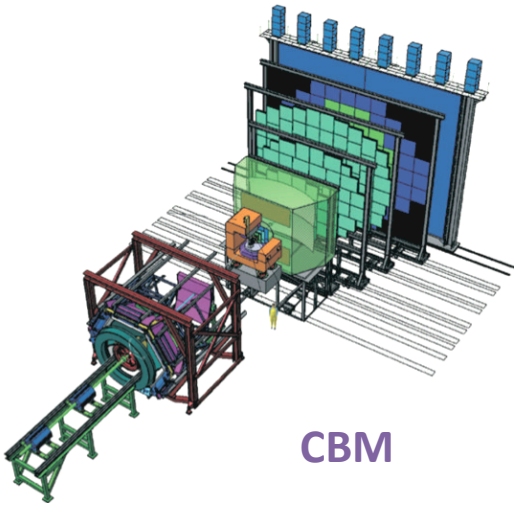


Grafik: Modularisierte Startversion (MSV) 0 - 3

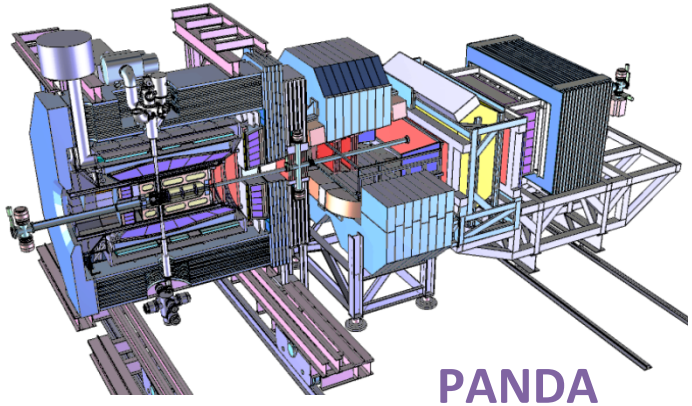
FAIR Experiments



APPA



CBM



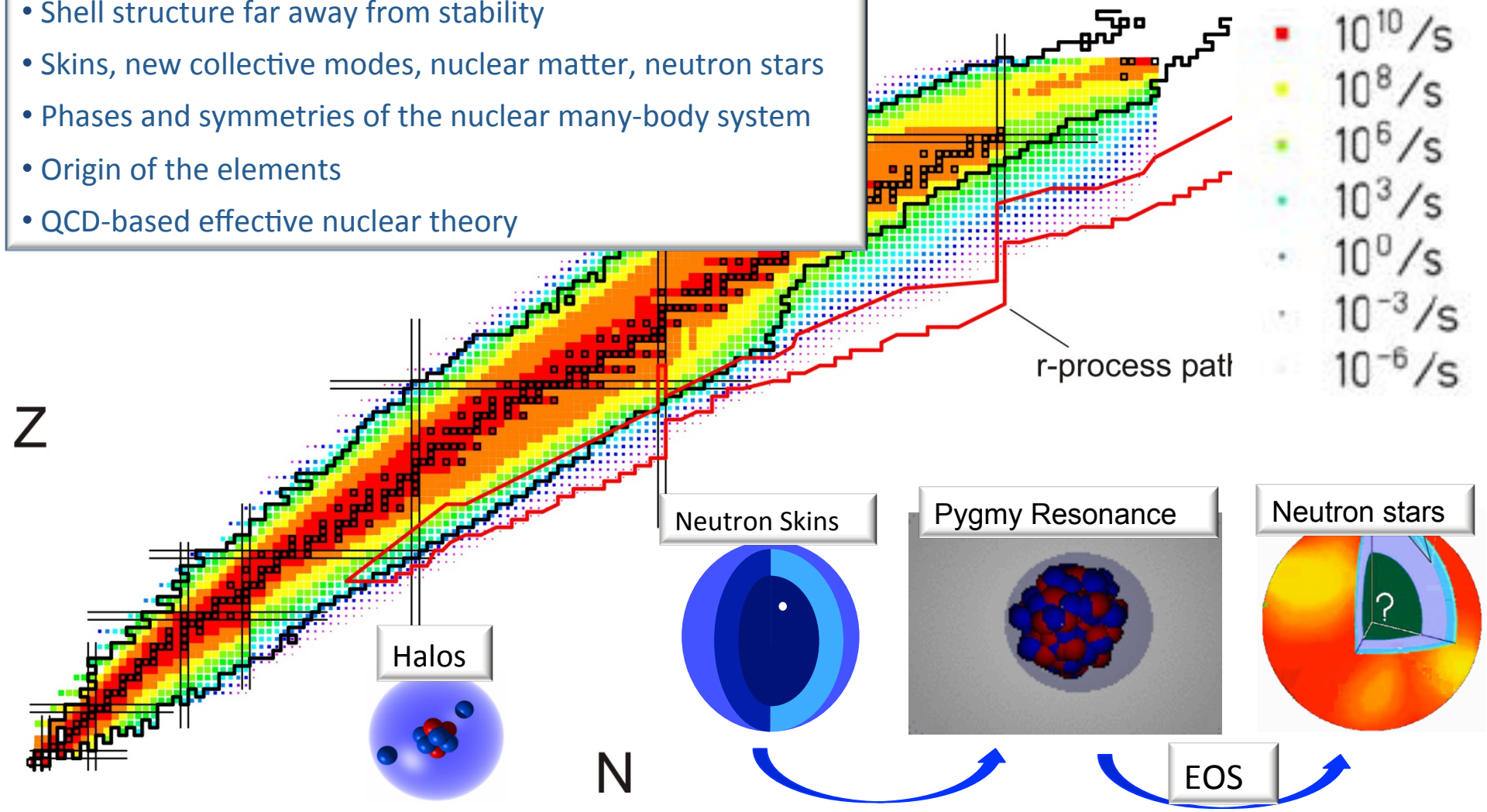
PANDA

Super-FRS

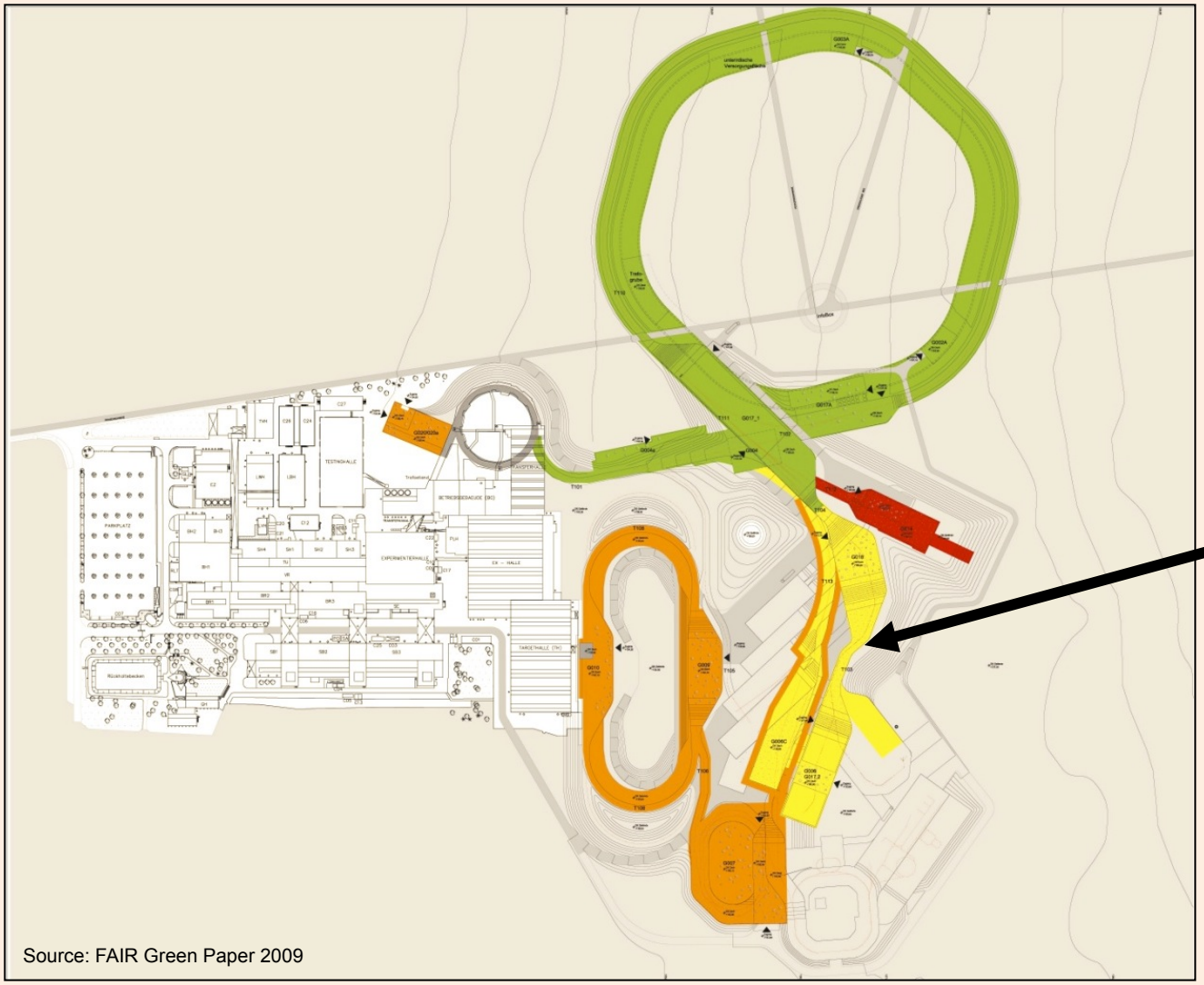
NuSTAR

NuSTAR – Nuclear STructure, Astrophysics and Reactions

- Quest for the limits of existence
- Halos, open quantum systems, few-body correlations
- Shell structure far away from stability
- Skins, new collective modes, nuclear matter, neutron stars
- Phases and symmetries of the nuclear many-body system
- Origin of the elements
- QCD-based effective nuclear theory



NUSTAR: Modularisierte Startversion MSV0-3



Source: FAIR Green Paper 2009

- Module 0: SIS 100 + connection
- Module 1: experimental areas (CBM/HADES, BIOMAT, APPA)
- Module 2: Super-FRS (wo.CR)
- Module 3: High-energy antiprotons (p-linac, antiproton target, CR, HESR)

Super-FRS

Central NUSTAR instrument: RIB generation and isotope separator with one fixed-target branch and ring branch

NUSTAR: Modularisierte Startversion MSV0-3

Nuclear STructure, Astrophysics, and Reactions

- Größte FAIR-Kollaboration ABER nicht EIN Experiment (~ 900 Wissenschaftler)
- 11 Unterkollaborationen (zahlreiche Arbeitskreise)
- Experimente mit intensiven radioaktiven Ionenstrahlen aus Fragmentation and Spaltung im Flug
- Entwicklung aus jetzigem GSI Programm am FRS
- FAIR-Investitionen werden bereits jetzt genutzt
- BMBF-FSP 302 „NUSTAR.de“

- Super-FRS
- R3B
- HISPEC/AGATA
- DeSPEC
- ILIMA
- MATS
- LaSPEC
- EXL
- SHIP/TASCA
- ELISe
- AIC

Module 0: SIS 100 + connection

Module 1: experimental areas (CBM/HADES, BIOMAT, APPA)

Module 2: Super-FRS (wo.CR)

Module 3: High-energy antiprotons (p-linac, antiproton target, CR, HESR)

Super-FRS

Central NUSTAR instrument: RIB generation and isotope separator with one fixed-target branch and ring branch

ILIMA (Isomers, LIfetimes, MAsses)

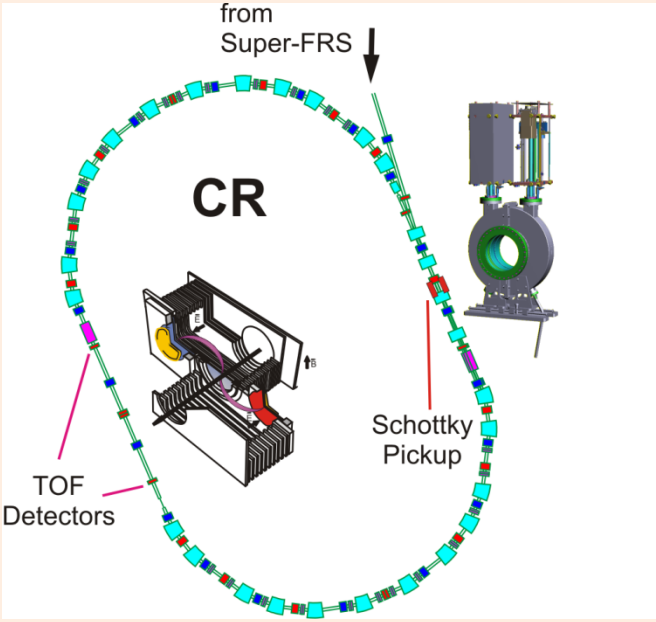
Forschungsziele

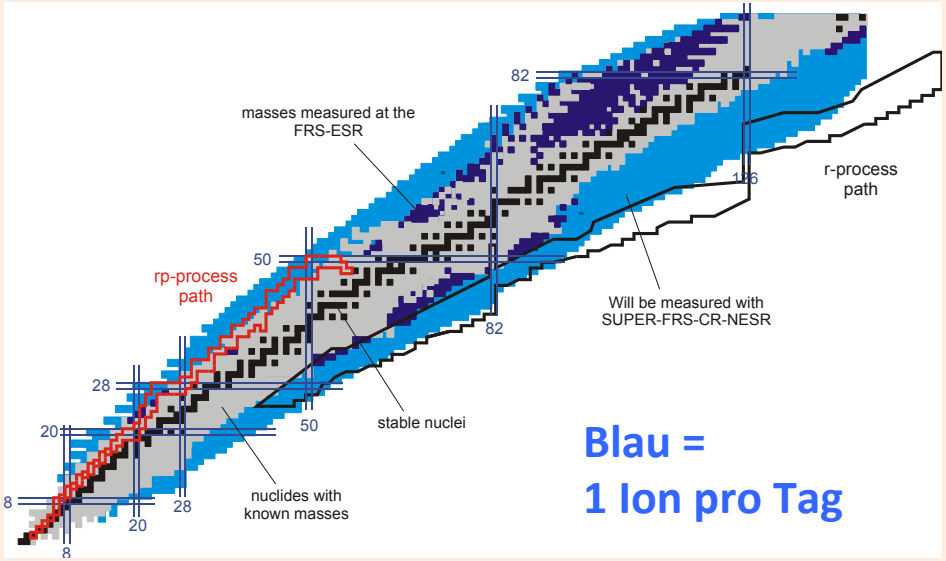
- Systematische, extensive Massenmessungen (n-/p-Abbruchkanten, Schalenabschlüsse, r-Prozess, rp-Prozess)
- Lebensdauern, Zerfallsarten von hoch-geladenen Ionen, beta-verzögerte Neutronenemissionswahrscheinlichkeiten
- Produktion und Nutzung von isomeren Strahlen

Schottky Massen-Spektrometrie (SMS)

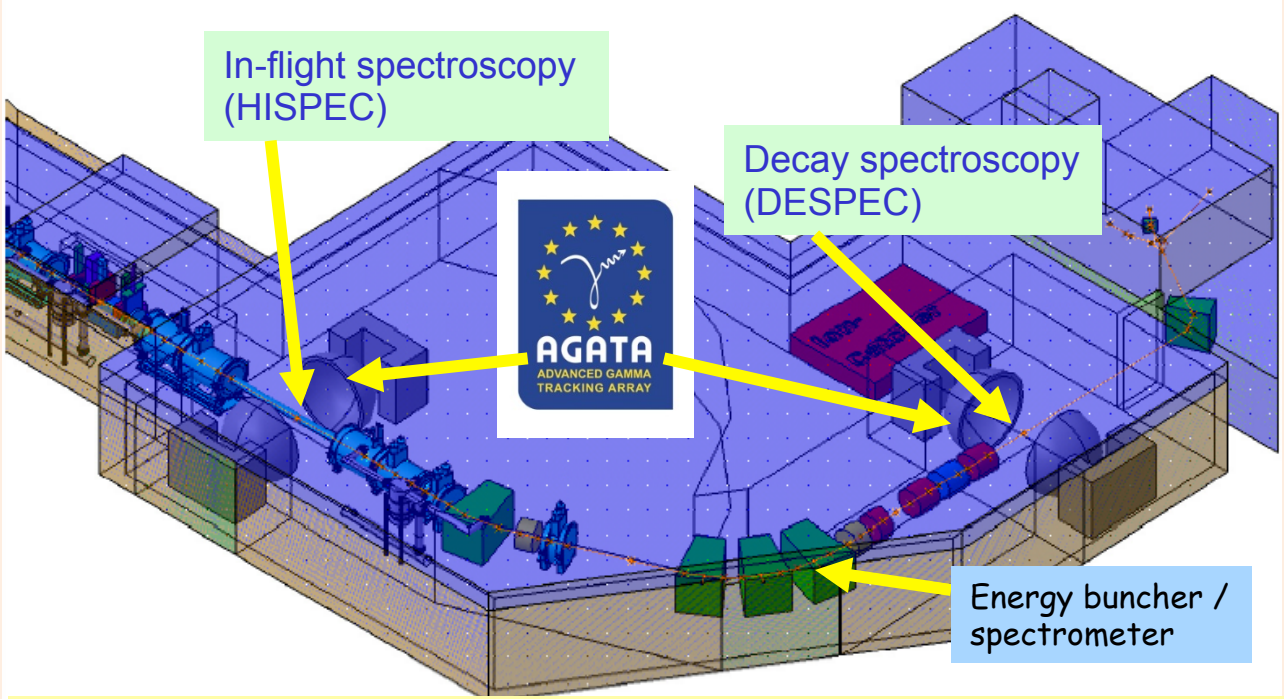
Isochrone Massen-Spektrometrie (IMS)

Day-1: Massen im r-Prozess





HISPEC/DESPEC – Hochauflösende γ-Spektroskopie mit relativistischen und gestoppten Strahlen



Set-up:

- Beam tracking and identification (LYCCA)
- Active target (AIDA)
- AGATA
- Fast timing
- HYDE particle array
- neutron arrays (MONSTER, BELEN)
- Magnetic spectrometer

Purpose:

High-resolution spectroscopy of exotic nuclei using Super-FRS RIB beams at 3 – 400 A·MeV and stopped

Reactions:

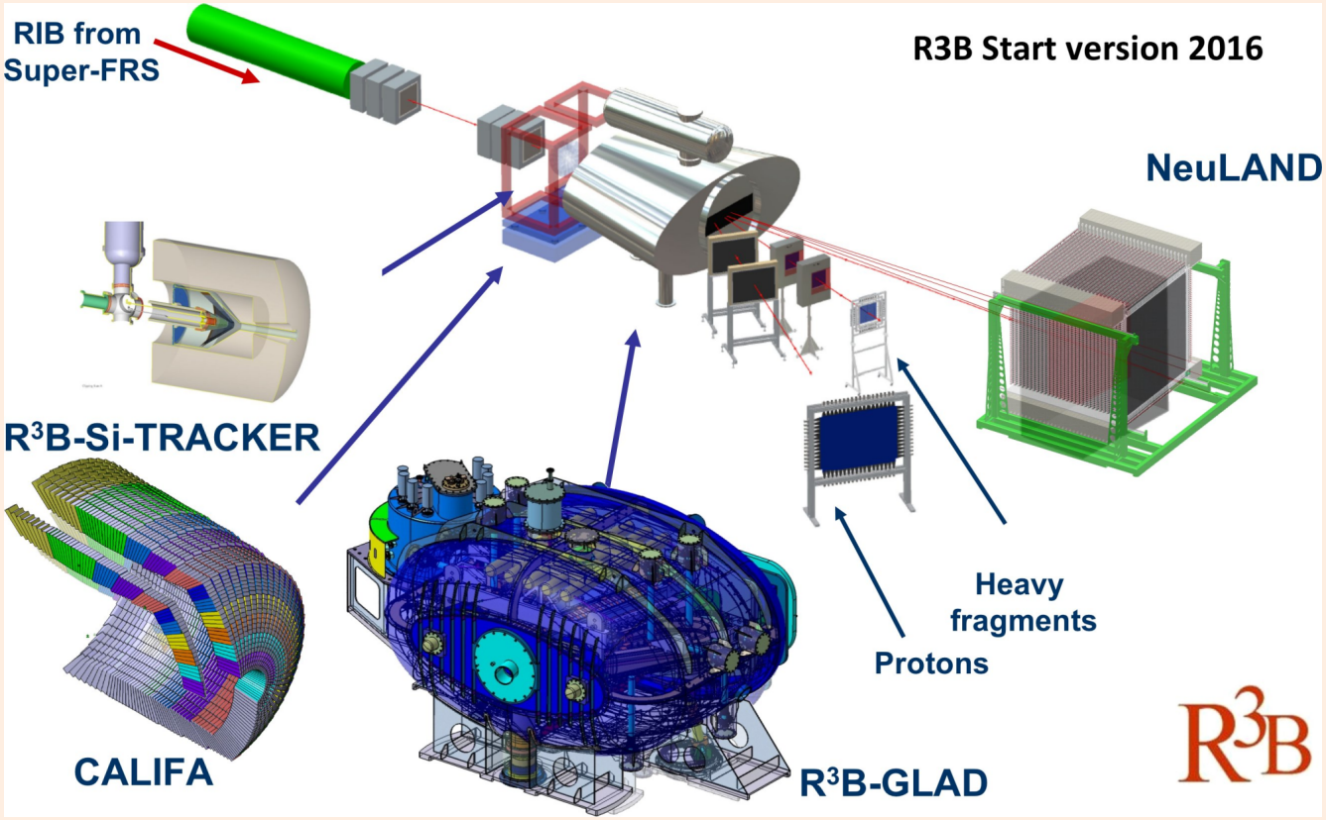
-Coulex, knock-out, fragmentation at relativistic energies, direct reactions, delayed and direct β-decay

Day-1 experiments and program:

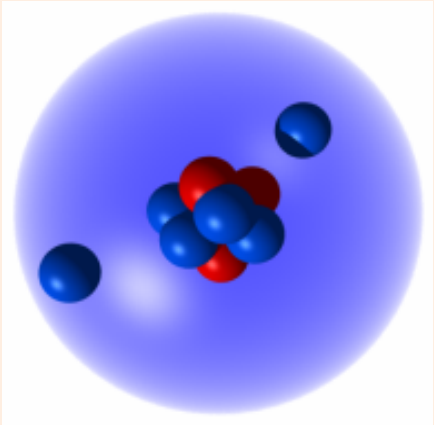
-β-delayed neutron emmission at neutron dripline, excited states of „superheavy, magic“ Sn and Pb nuclei

-high-resolution γ-spectroscopy in the r-process path, „exotic“ nuclear structures for nuclear astrophysics

R3B - Reactions with Relativistic Radioactive Beams



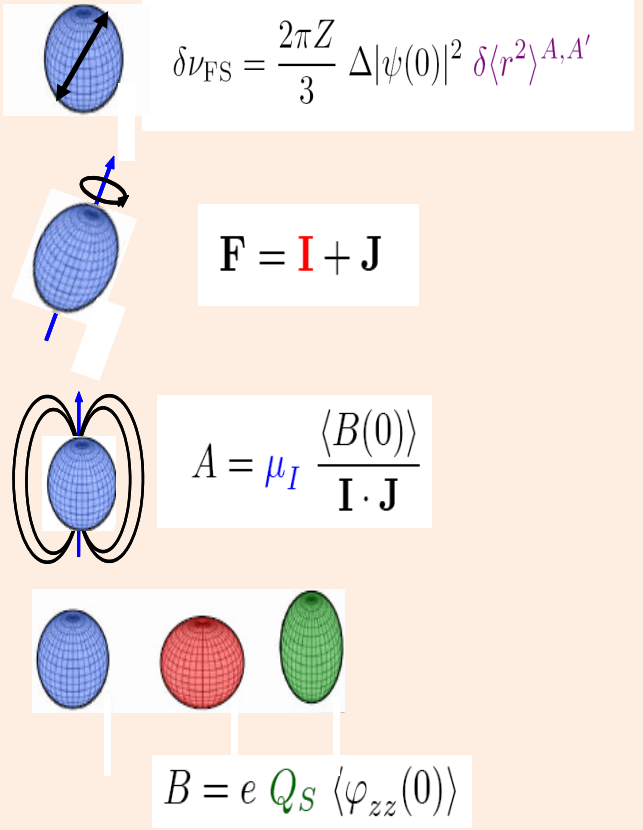
- neutron and proton halo
- 4-neutron clusters
- spectroscopic factors
- structure of most exotic nuclei



LASPEC:
Collinear Laser Spectroscopy at the Super-FRS

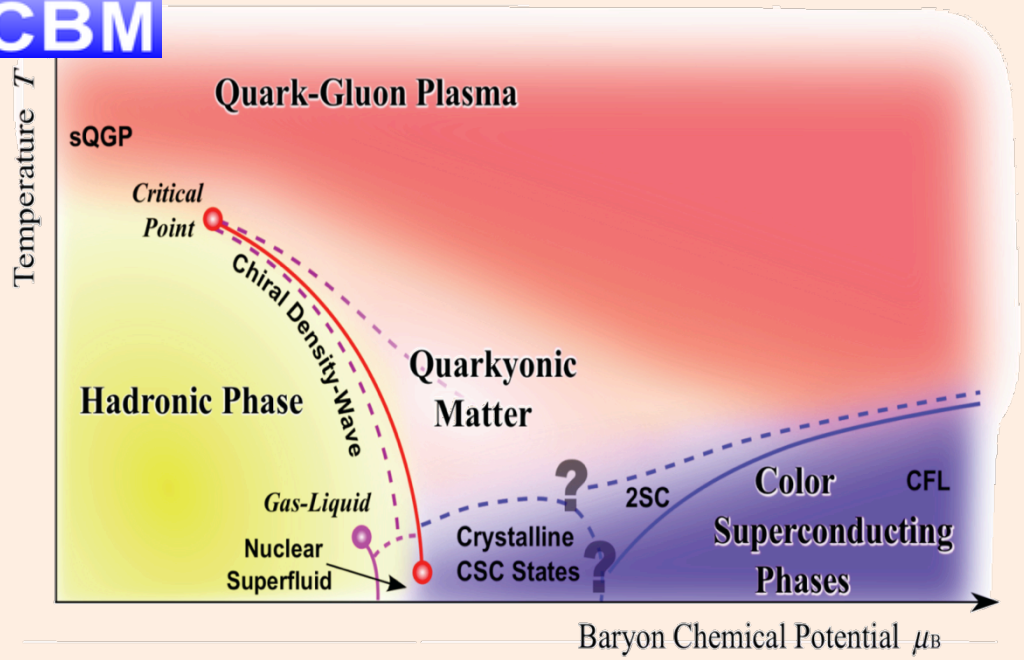
Optical spectroscopy for direct measurement of nuclear properties with very high precision independent of nuclear models

- Charge Radii
- Nuclear Spin
- Magnetic Moments
- Electric Quadrupole Moments



Prototyping (Mainz, TU Darmstadt)
Expanding the applicability of collinear spectroscopy to:
higher charge states (e.g. JYFL, TU Darmstadt), new wavelength regimes (TU Darmstadt, Mainz, ISOLDE), higher sensitivity (Leuven, TU Darmstadt, CRIS, ISOLDE, MSU), improved accuracy (TU Darmstadt, TRIUMF)…

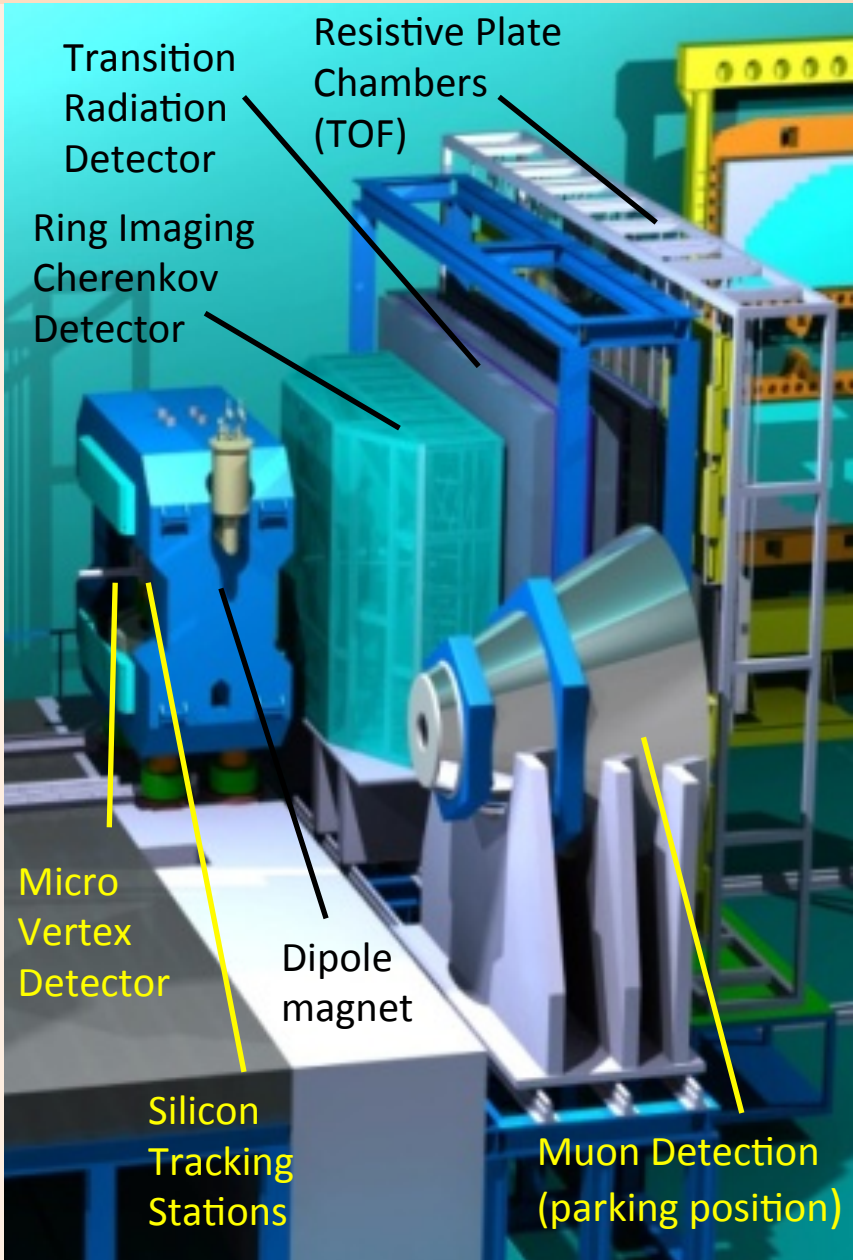
CBM – Compressed Baryonic Matter



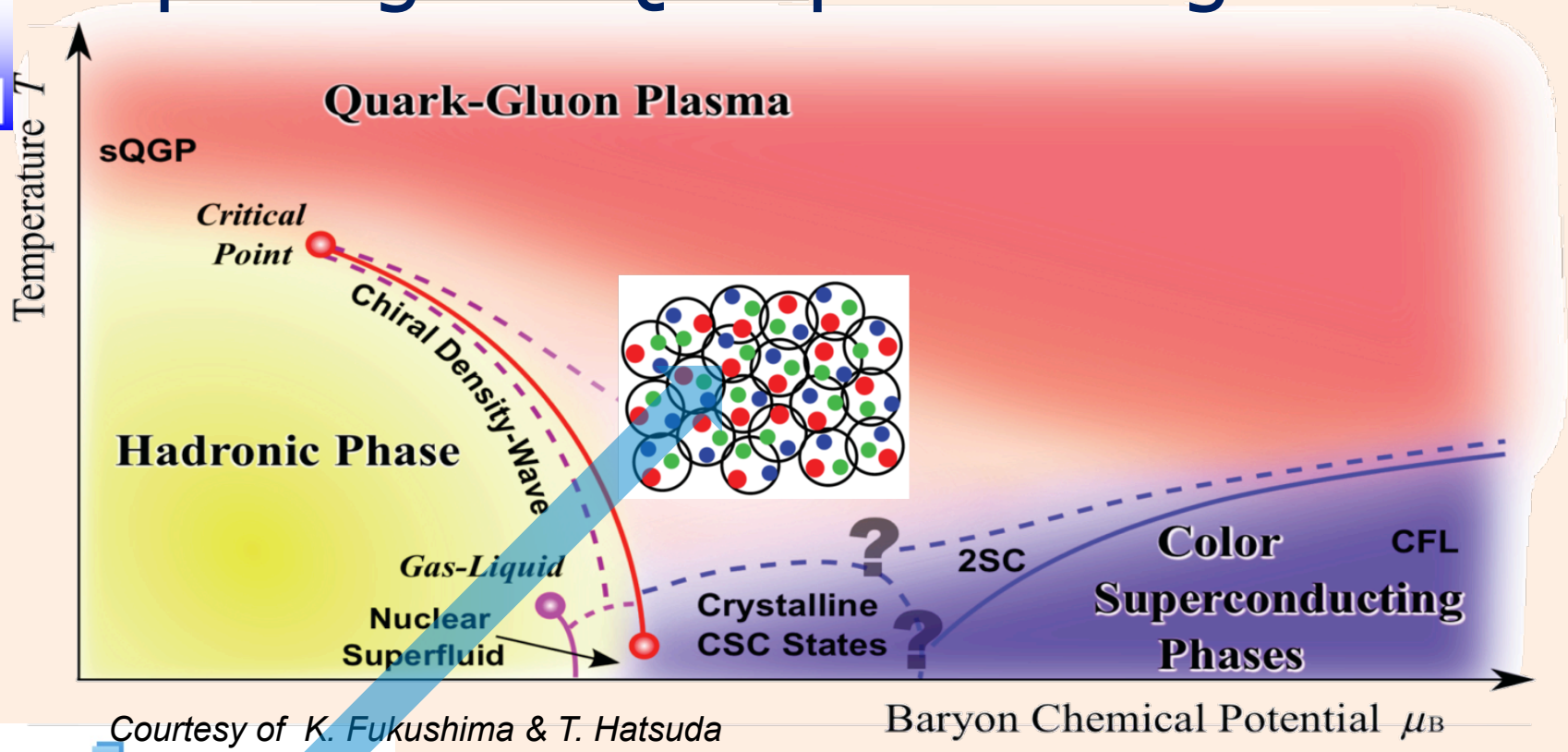
- Equation-of-state of matter at neutron star core densities.
- Phase transitions from hadronic matter to quarkyonic or partonic matter at high net-baryon densities.
- Electro-magnetic radiation from the dense fireball.
- Chiral symmetry restoration in dense baryonic matter.
- Charm production in (dense) nuclear matter an threshold energies.
- Hypernuclei, strange dibaryons, massive strange objects.

> 500 members

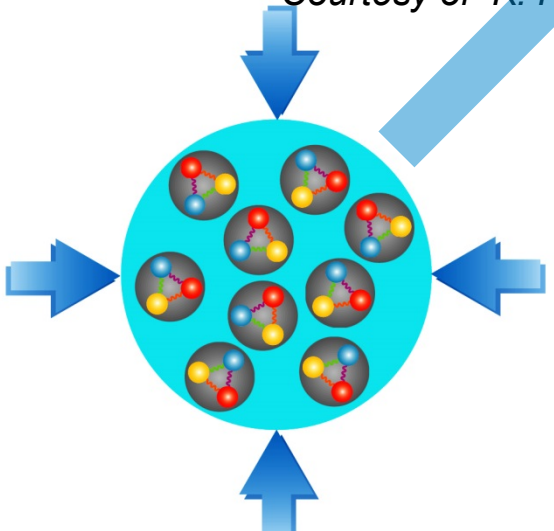
- Challenge: 10 MHz interaction rate on fixed target



Exploring the QCD phase diagram



Courtesy of K. Fukushima & T. Hatsuda



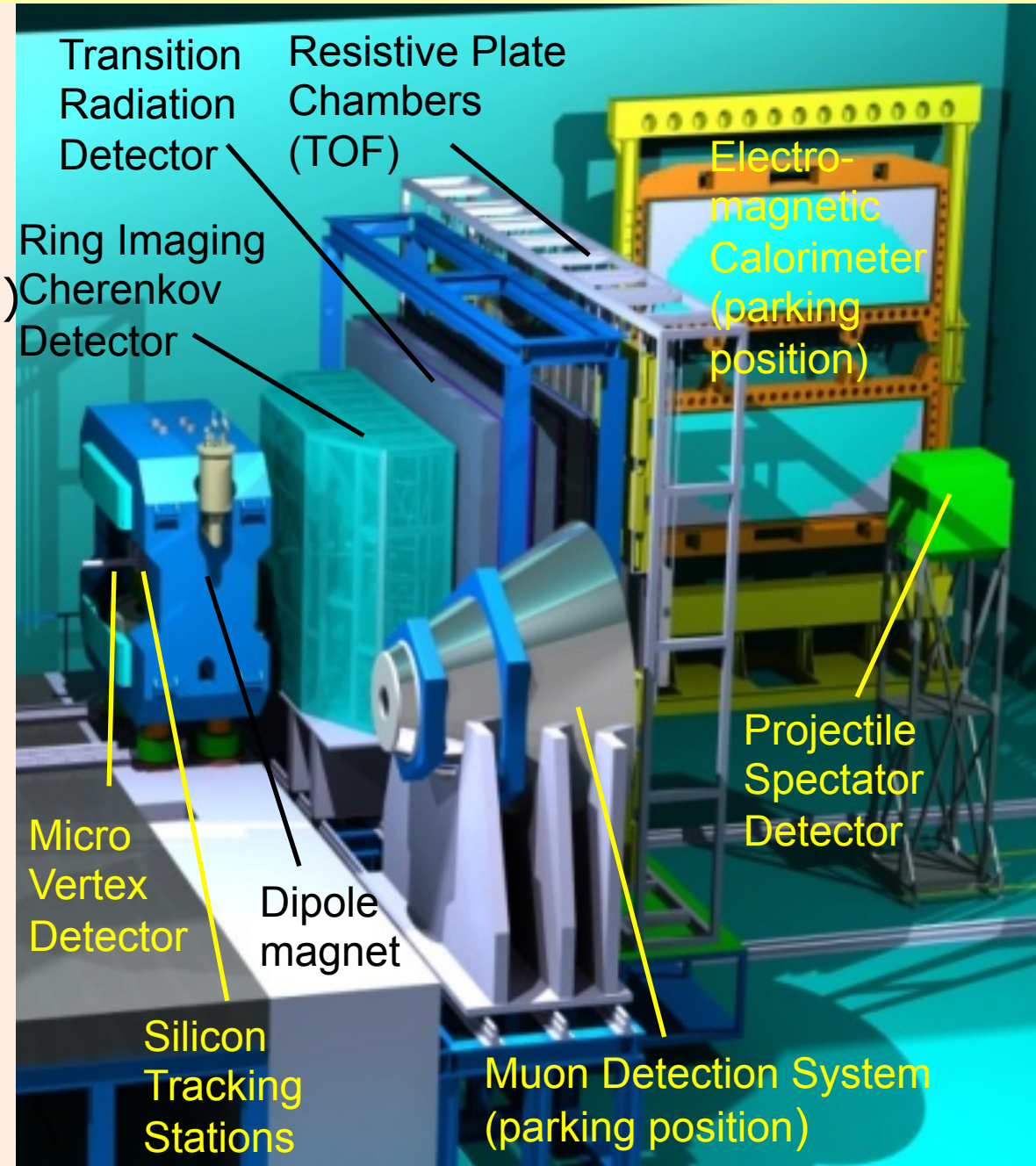
<u>At high baryon density:</u>

- N of particles >> N of antiparticles
  Densities like in neutron star cores
- L-QCD not (yet) applicable
- Models predict first order phase transition with mixed or exotic phases
- Experiments: BES at RHIC, NA61 at CERN SPS, CBM at FAIR, NICA at JINR

The Compressed Baryonic Matter Experiment

Experimental challenges:

- 10^5 - 10^7 Au+Au events/s
- determination of (displaced) vertices ($\sigma \approx 50$ μm)
- identification of leptons and hadrons
- fast and radiation-hard detectors
- free-streaming readout electronics
- high speed data acquisition and high performance computer farm for online event selection
- 4-D event reconstruction



CBM physics program – particle production

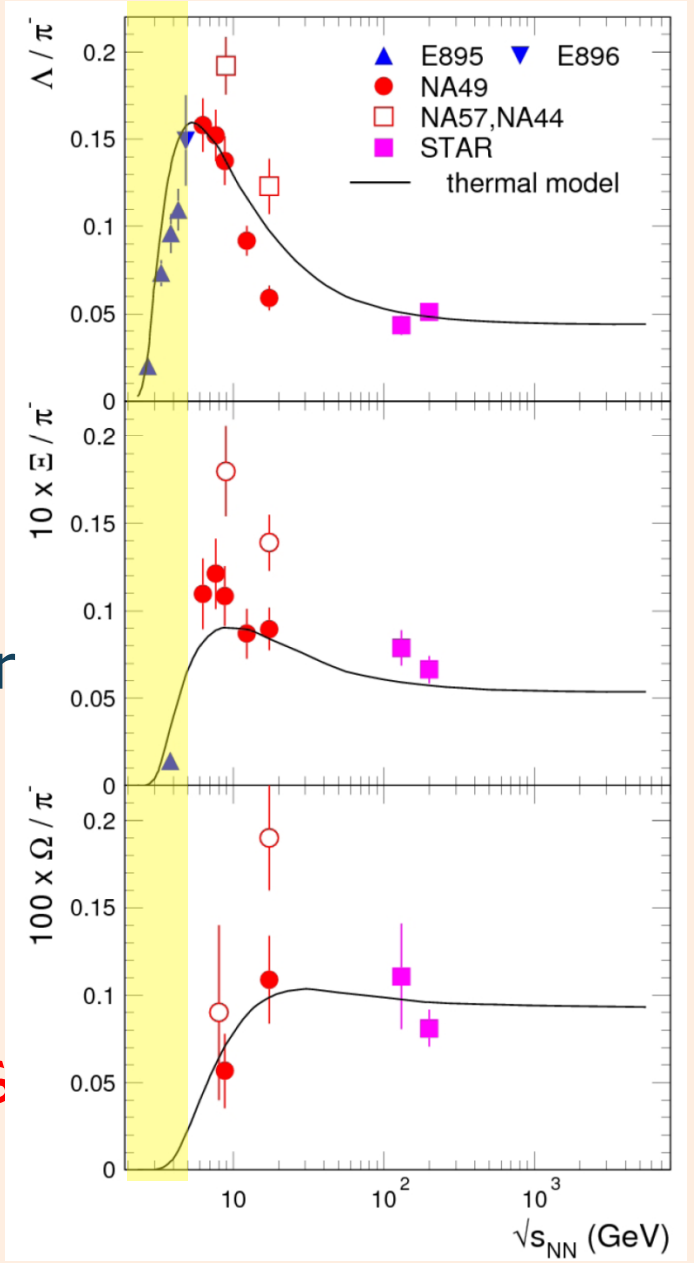
Strangeness

Excitation function of yields and phase-space distributions of multi-strange particles in heavy-ion collisions.

Physics case

- Phase transitions from hadronic matter to quarkyonic or partonic matter at high net-baryon densities
- Equation-of-state of matter at neutron star core densities

very little data at FAIR energies



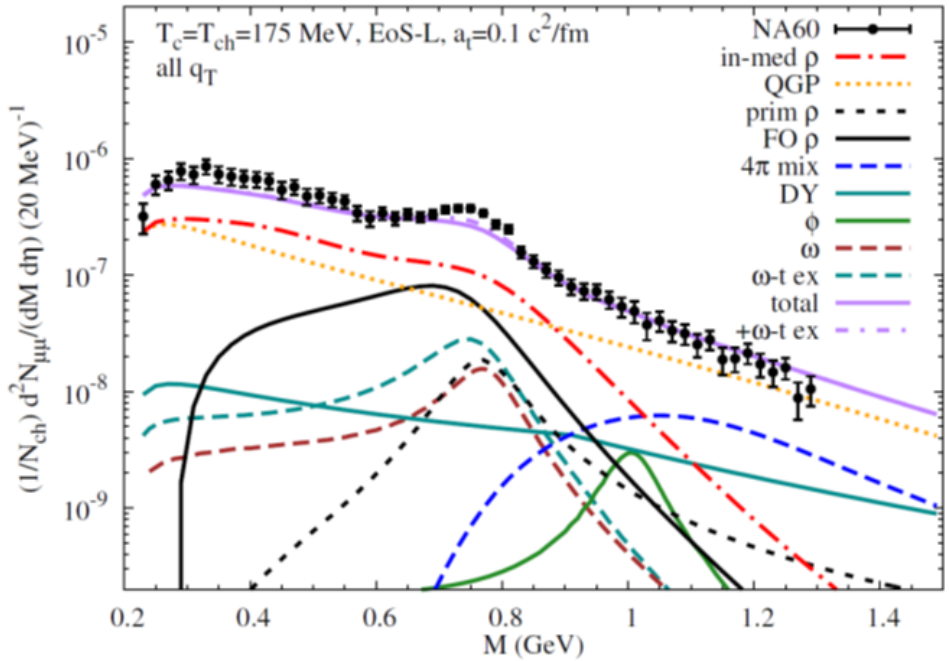
CBM physics program - dileptons

Dileptons

Excitation function of yields and phase-space distributions of lepton pairs in heavy-ion collisions.

Physics case

- Electro-magnetic radiation from the dense fireball
- Chiral symmetry restoration in dense baryonic matter



In+In 158 A GeV
Exp: NA60
Theory: R. Rapp et al.

No dilepton data at FAIR energies

CBM physics program

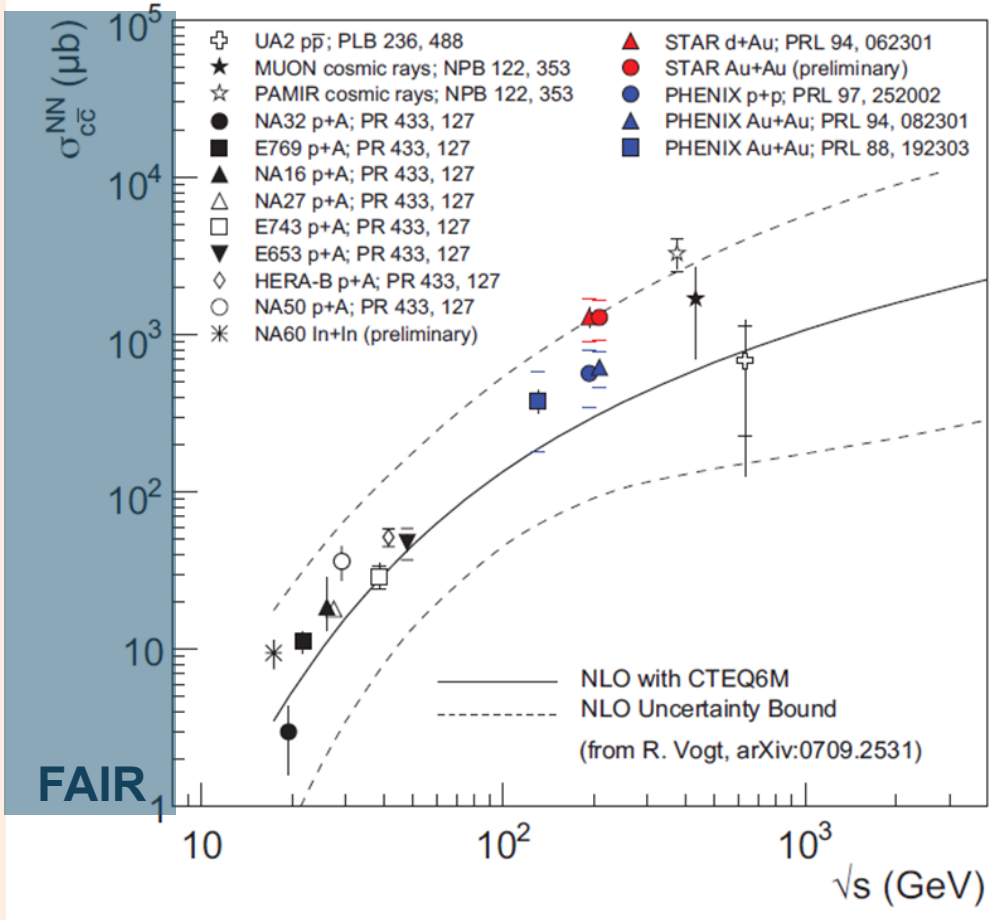
Charm

Cross sections and phase-space distributions of open and hidden charm in proton-nucleus collisions and nucleus-nucleus collisions.

Physics case

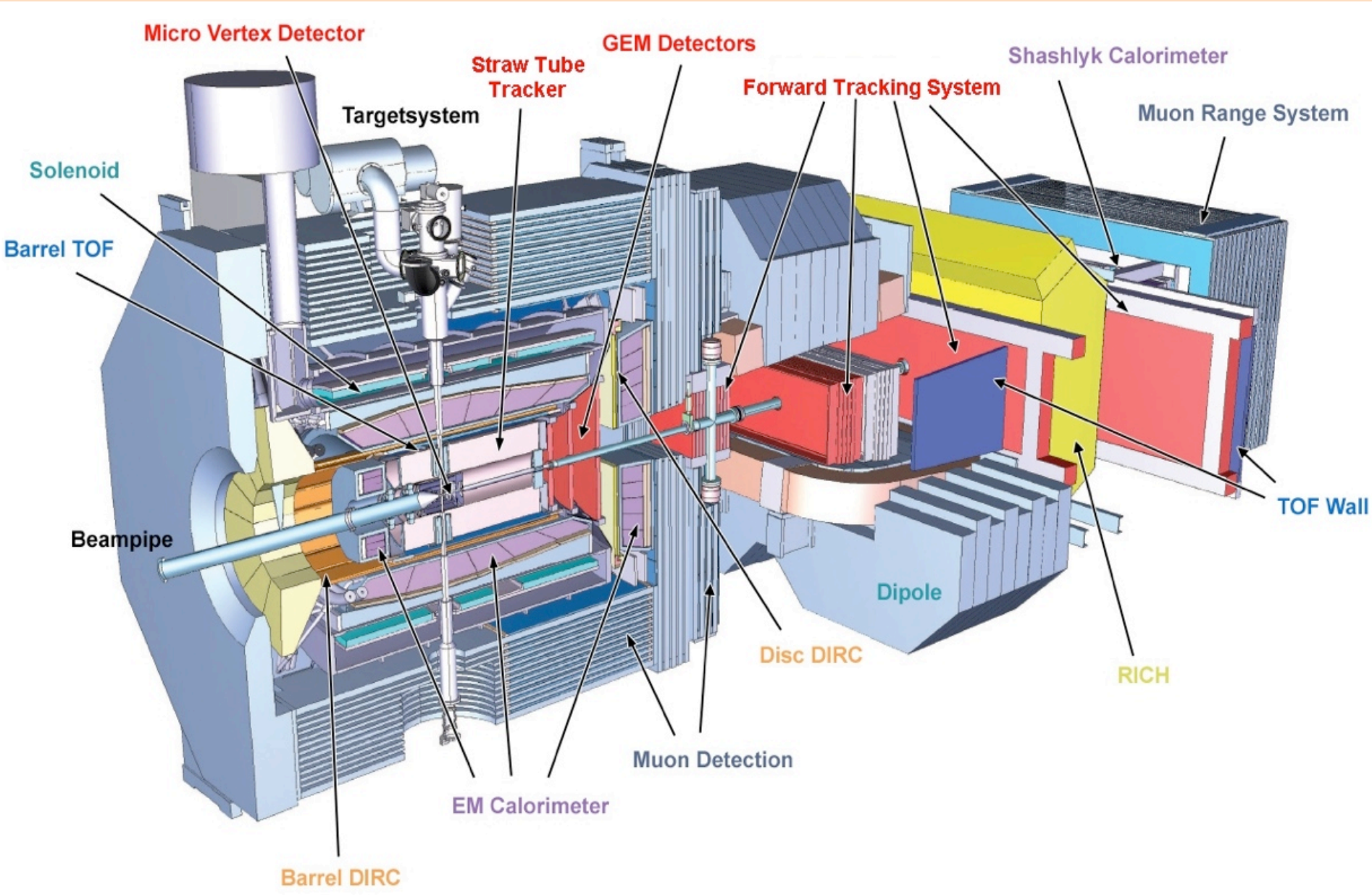
- Charm production at threshold energies
- Charm propagation in (dense) nuclear matter
- Charmonium suppression in partonic matter

No charm data at FAIR energies



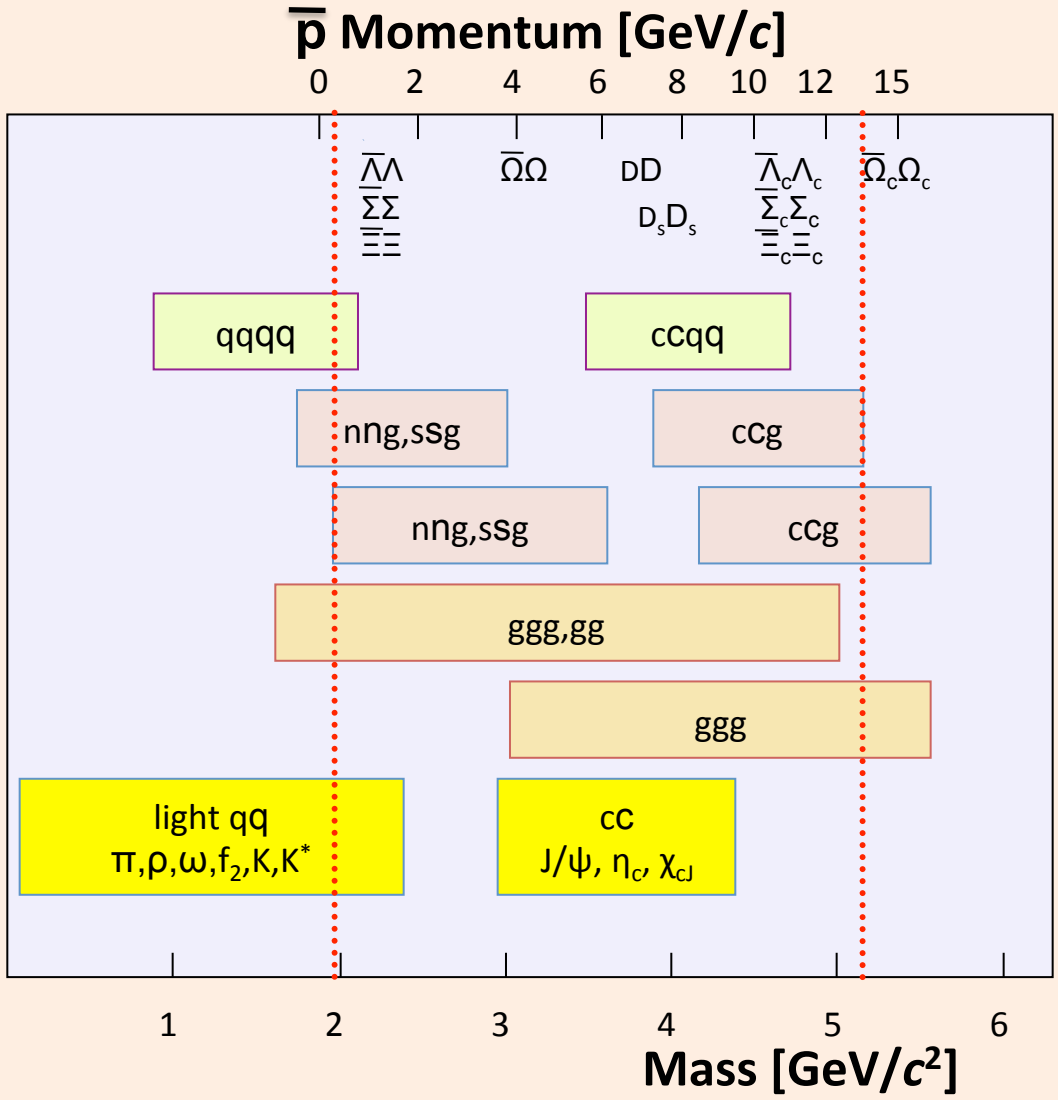
A. Frawley,T. Ulrich, R. Vogt, Phys.Rept.462:125-175,2008

PANDA – Antiproton Annihilation



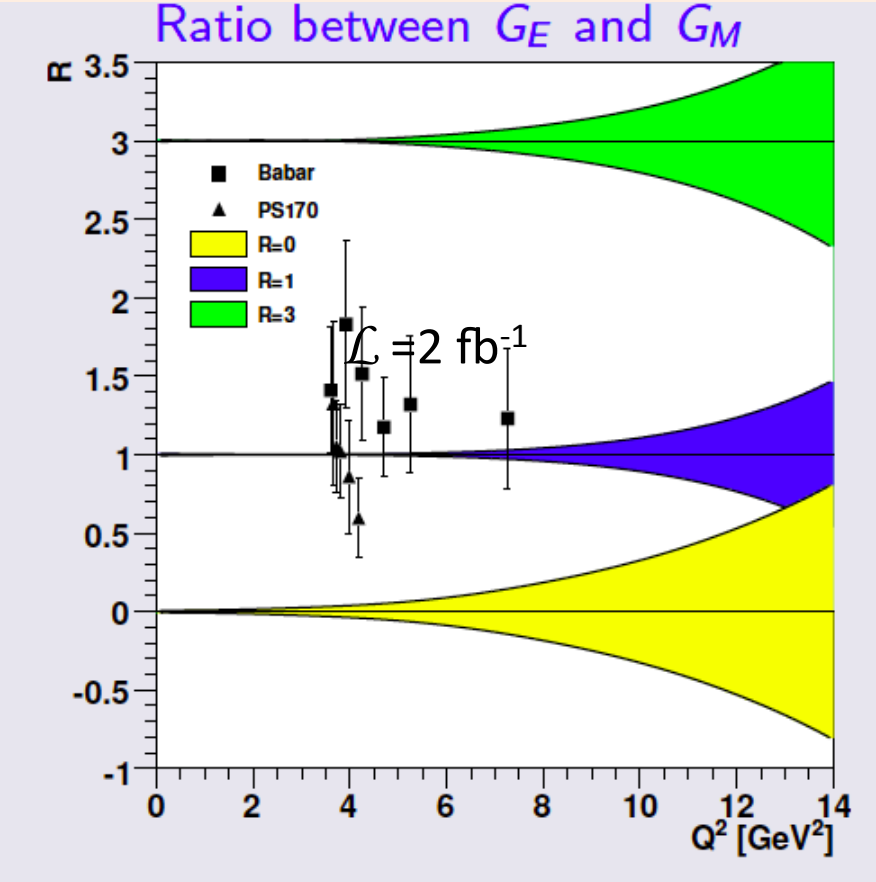
$\bar{P}$ANDA Scientific Program

- Nucleon structure
  E.M. processes
- Meson spectroscopy
  - light mesons
  - charmonium
  - exotic states
    - glueballs
    - hybrids
    - molecules/multiquarks
  - open charm
- S=2,3 and C=1 (excited)
  Baryon/antibaryon spectroscopy
- Charm in nuclei
- Strangeness physics
  - S = -2 nuclear system
    - Ξ^- nuclei
    - $\Lambda\Lambda$ hypernuclei



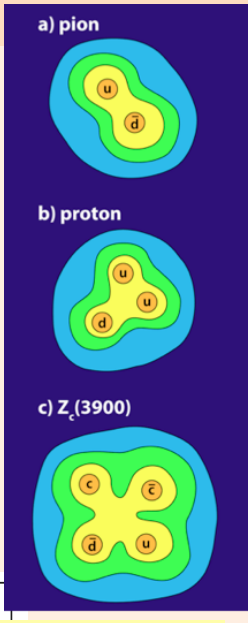
Proton G_E and G_M at "low" q^2 in time-like regime

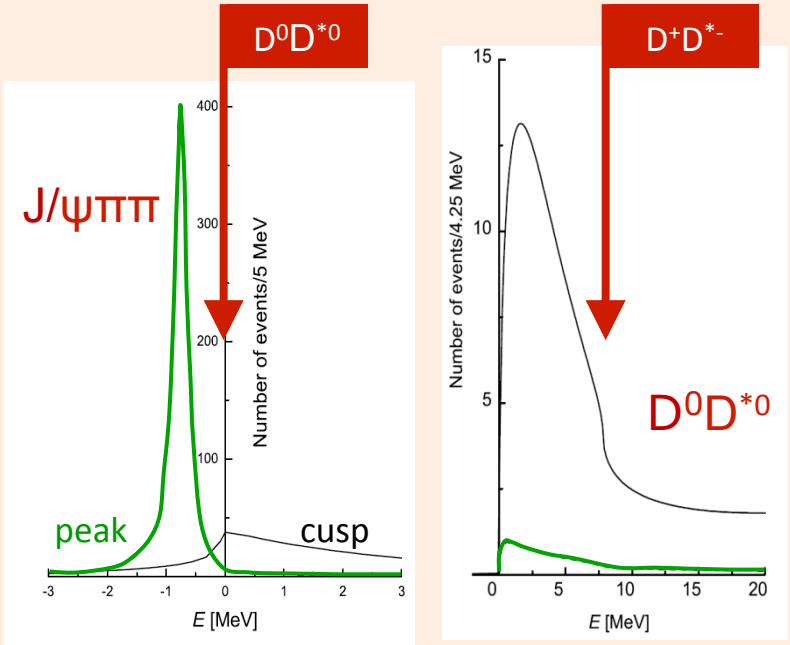
- Initial measurements allow to go to 14 GeV^2.
- Large acceptance allows G_E/G_M separation
- Backward analog to GPDs, Test of factorization possible with good background suppression
- Simulated results for 2 fb^{-1} and different assumed ratios



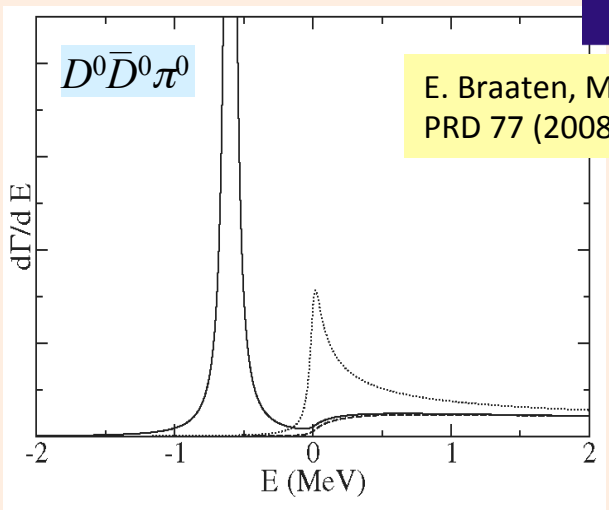
How PANDA Contributes to Exotics?

- $J/\psi\pi^+\pi^-$, $J/\psi\pi^0\pi^0$, $\chi_c\gamma \rightarrow J/\psi\gamma\gamma$, $J/\psi\gamma$, $J/\psi\eta$, $\eta_c\gamma$
- direct formation in $\bar{p}p$: line shapes !
- Exotics: compare formation with production
- d target: $\bar{p}n$ with p spectator tagging, e.g. $Z^-(3900)$





C. Hanhart *et al.*,
PRD 76 (2007) 034007



E. Braaten, M. Lu,
PRD 77 (2008) 014029

Compare lineshapes
in different final states!

Width Measurement of X(3872)

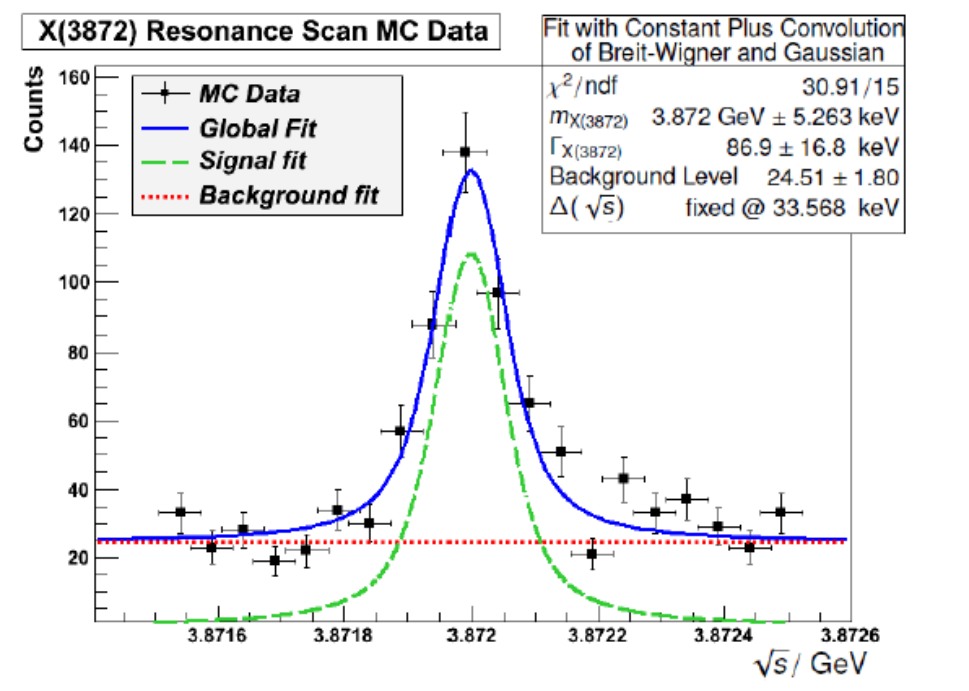
Upper limit on the branching ratio by LHCb

$BR(X \rightarrow \bar{p}p) < 0.002 * BR(X \rightarrow J/\Psi\pi^+\pi^-)$

And $BR(J/\Psi\pi^+\pi^-) > 0.026$ [pdg12] $\Gamma < 1.2$ MeV

Implies:

$\sigma(\bar{p}p \rightarrow X(3872)) \sim (67 +- ?)$ nb



Here: assume σ=50 nb

"Low lumi" – mode 2×10^{31}

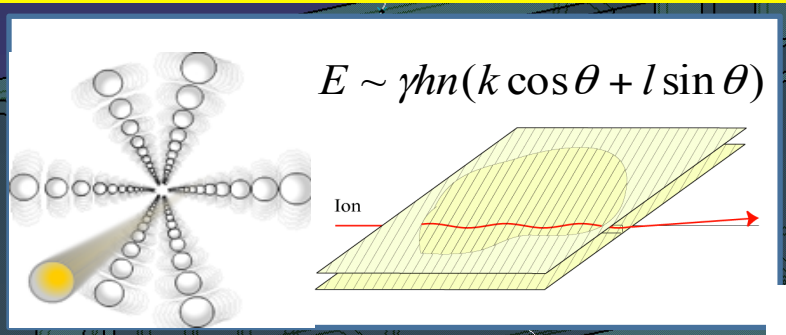
Mass resolution < 100 keV

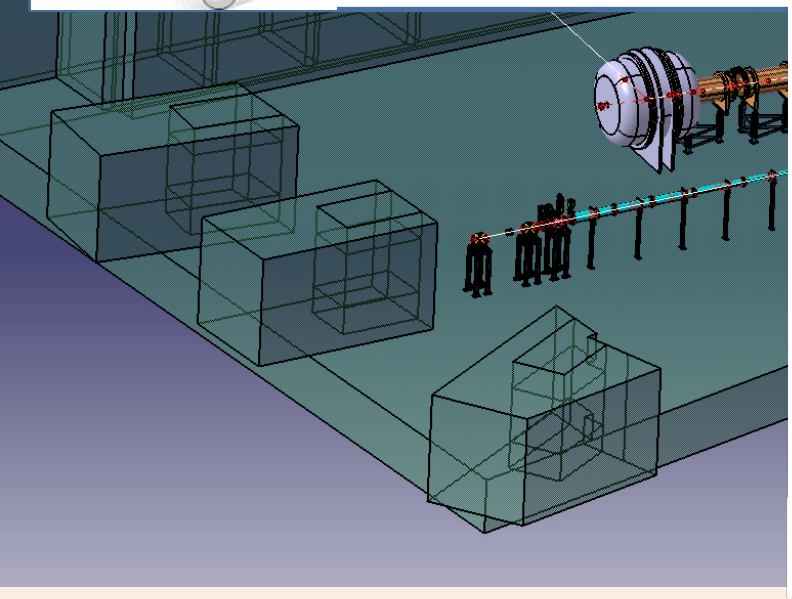
APPA – Atomic/Plasma Phyiscs & Applications

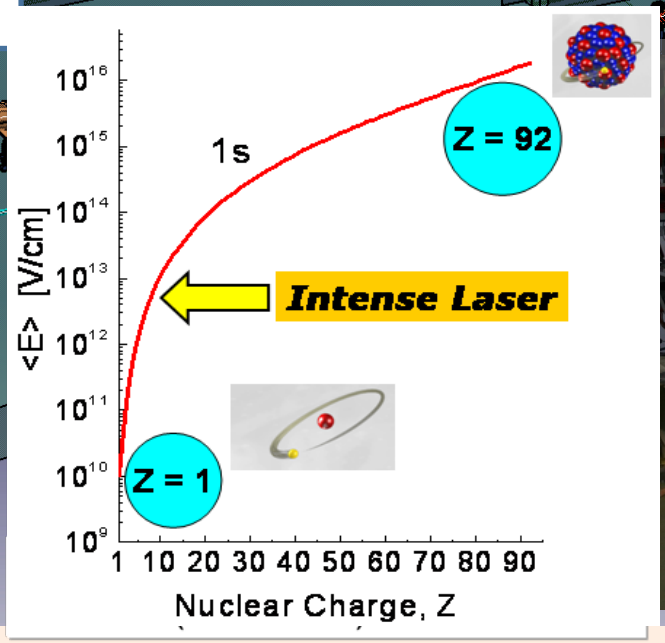
- SPARC Stored Particles Atomic physics Research Collaboration
  - QED in non-pert. regime, precision measurement of fundamental constants, influence of atomic structure on nuclear decay
- FLAIR Facility for Low-energy Antiproton Ion Research
  - tests of CPT and QED with antiprotonic atoms and anithydogen
- HEDgeHOB Plasma physics
  - heavy ion heating and expansion (uniform heating of large-volume dense target, isentropic expansion)
  - laboratory for planetary science (ring-shaped beam implodes a heavy tamper shell)
- BIOMAT
  - material science, radiation hardness
  - anti-proton therapy

Day-1: Precision Measurement of 1s Lamb Shift in H-like Uranium at High Energies

Ion channeling at relativistic energies





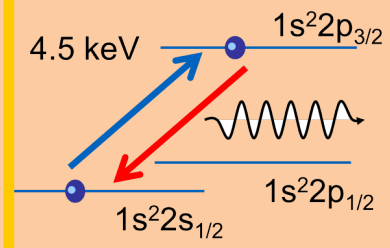


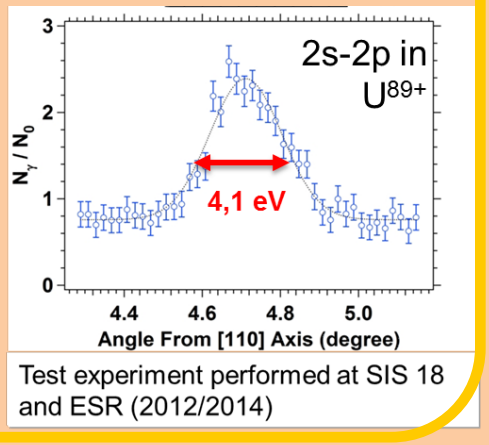
At APPA: excitation of 1s-2p in U^{91+} possible for first time !

Day-1: Precision Measurement of 1s Lamb Shift in H-like Uranium at High Energies

sparc
Stored Particles Atomic Physics Research Collaboration

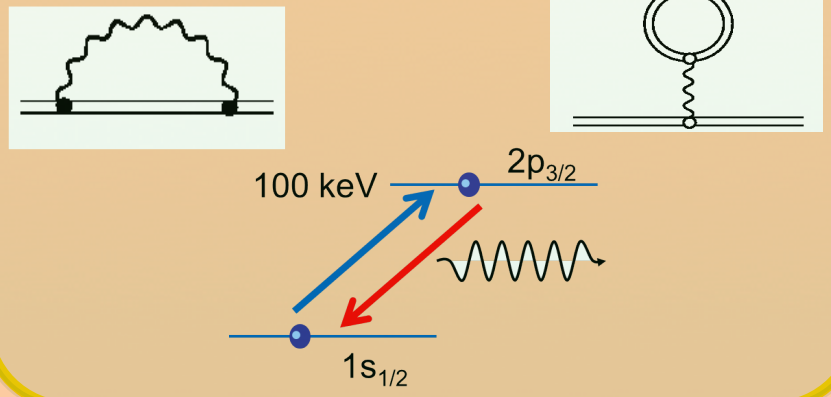
SIS18: Li-like Uranium (4.5 keV)

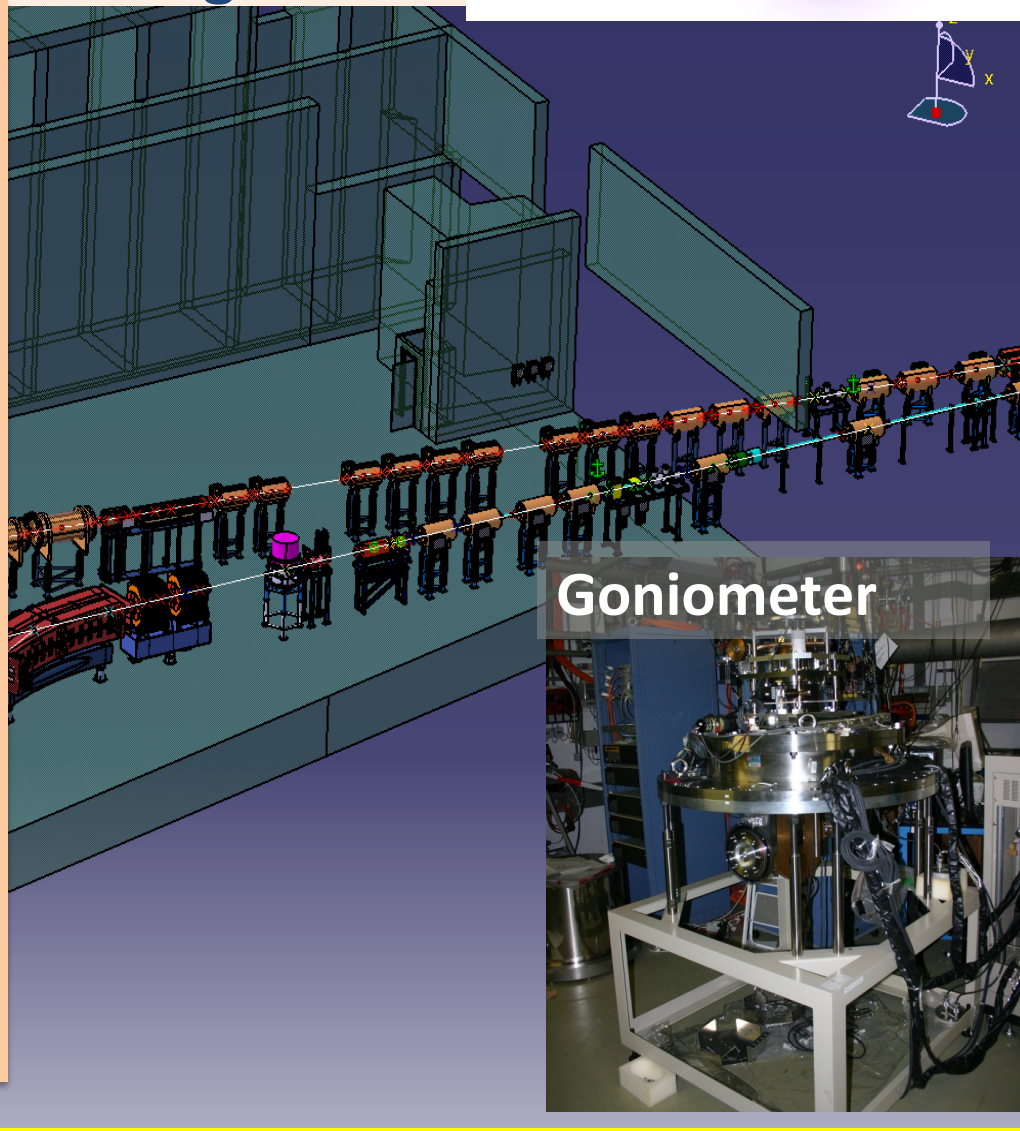




Test experiment performed at SIS 18 and ESR (2012/2014)

SIS100: H-like Uranium (100 keV)





Goniometer

At APPA: excitation of 1s-2p in U^{91+} possible for first time !

HEDgeHOB experimental frameworks

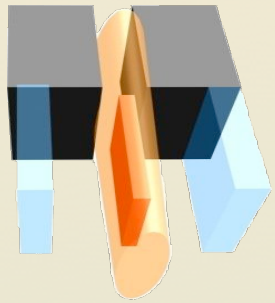
Possible with early SIS-100 some with SIS-18 beams!

HIHEX

Heavy Ion Heating and Expansion

U^{28+}, 2 AGeV, $5 \cdot 10^{11}$, SC FFS

heavy ions



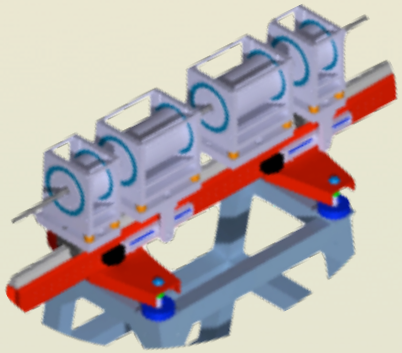
- uniform quasi-isochoric heating of a large-volume dense target and isentropic expansion
- numerous high-entropy HED states: EOS and transport properties of non-ideal plasmas / WDM for various materials

PRIOR

Proton Microscope for FAIR

p, 5–10 GeV, $2 \cdot 10^{13}$, PRIOR

protons

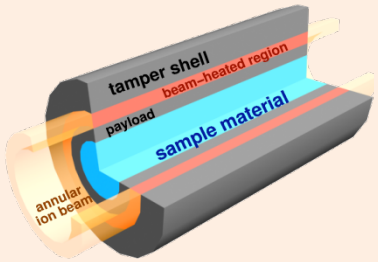


- worldwide unique high-energy proton microscopy setup with SIS-100 proton beam
- dynamic HEDP experiments and PaNTERA: unparalleled dynamic density distribution measurements and Proton Therapy and Radiography project (with BIOMAT)

LAPLAS

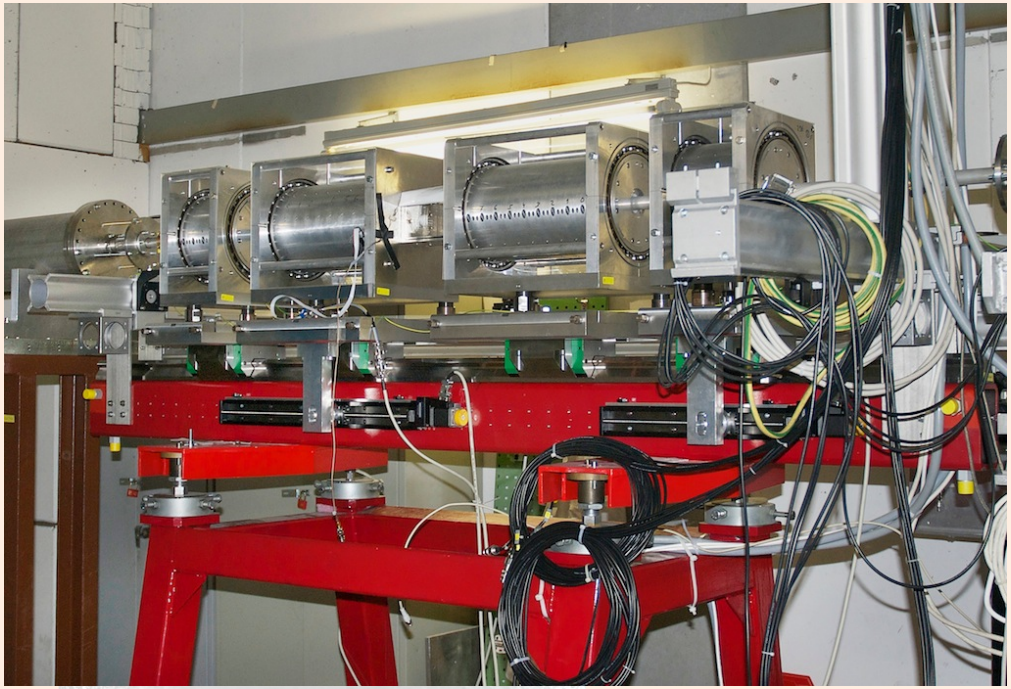
Laboratory Planetary Sciences

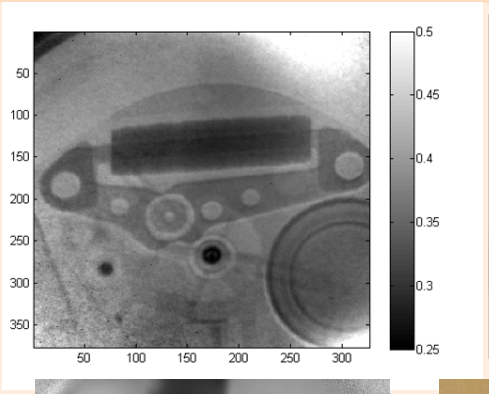
U^{28+}, 1 AGeV, $5 \cdot 10^{11}$, Wobbler

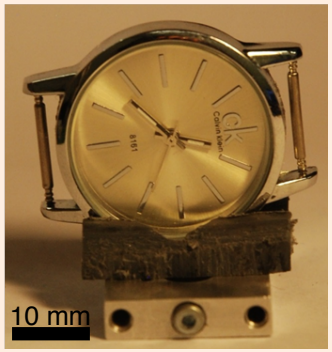


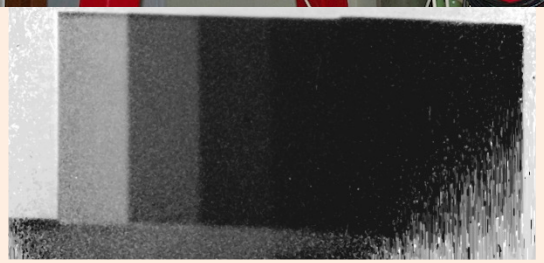
- ring-shaped beam implodes a heavy tamper shell, low-entropy compression of hydrogen
- Mbar pressures @ moderate temperatures: hydrogen metallization, interior of Jupiter, Saturn or Earth

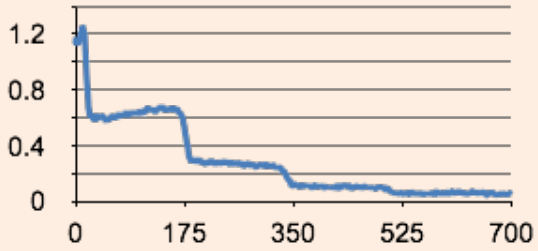
PRIOR prototype: static commissioning, April 2014











Ta calibration steps

- 25 – 40 μm spatial resolution
- remarkable density sensitivity

- installed at HHT area of GSI
- NdCo ⌀30mm PMQ lenses
- CsI and plastic detectors
- 3.5 – 4.5 GeV protons from SIS-18

Produktion SIS100 Dipolmagnete

- Die Produktion von supraleitendem Draht und die Kabelproduktion laufen
- UHV-Vakuumkammer bereit für Kalt-Test im Magneten
- Produktionsplan mit QA abgestimmt, wird ab 2. Vorseriendipol implementiert

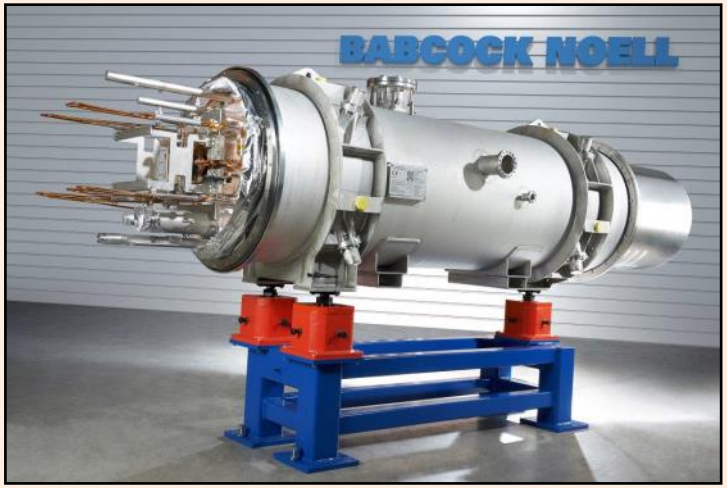


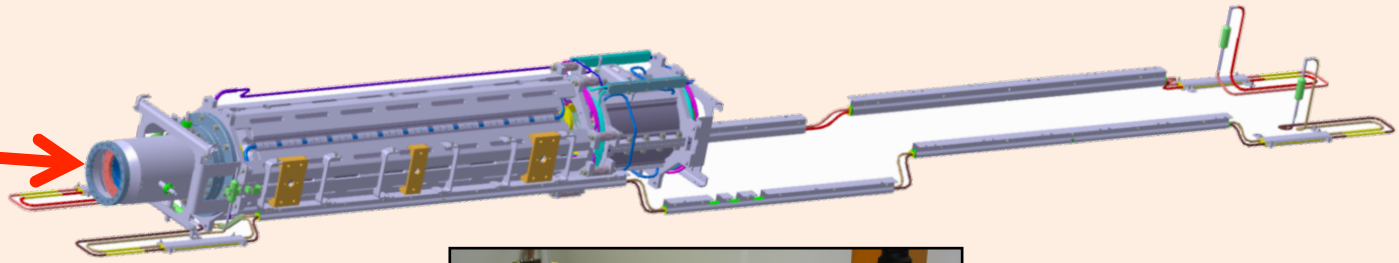
Abbildung: Vorserien-Dipolkammer

Bau der Serientestanlage

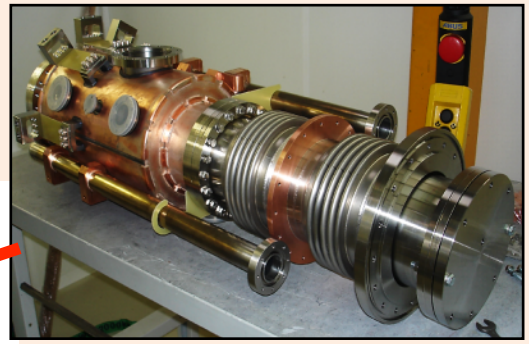
- Abschluss der Bauarbeiten an der Serientestanlage inklusive Medienversorgung im Mai 2014
- Installation und Inbetriebnahme abgeschlossen

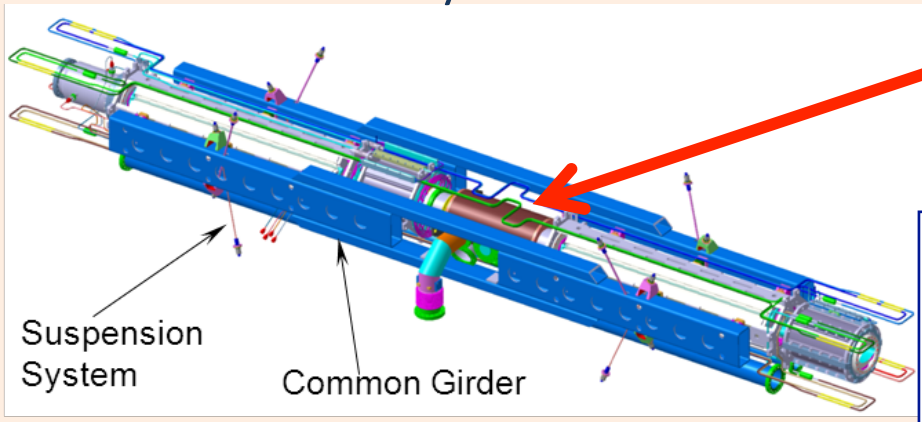
SIS100 Quadrupol Module (QDM)

Modul mit QP, chromatischen Sextupol, Beam Position Monitor

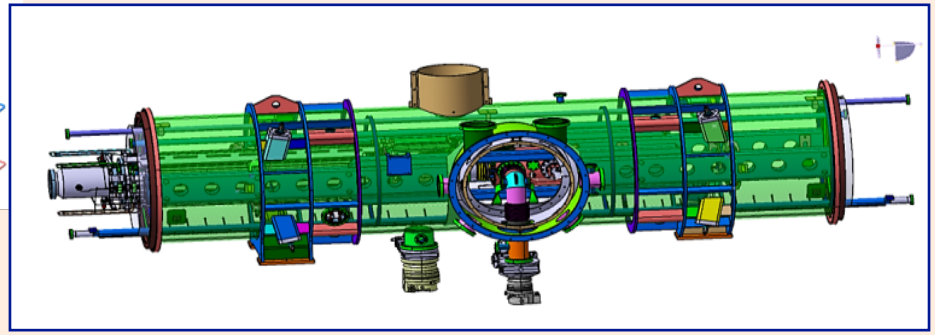


Dublette mit Cryo-Catcher





Vollständig integrierte Dublette → Pläne in Dubna

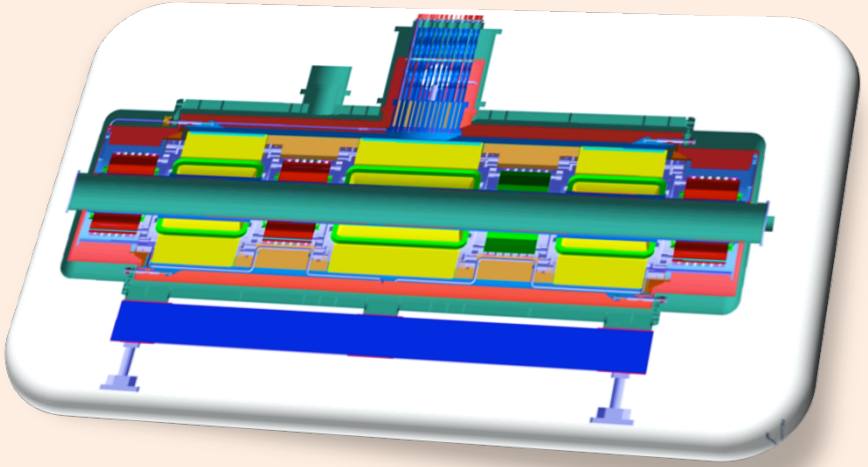


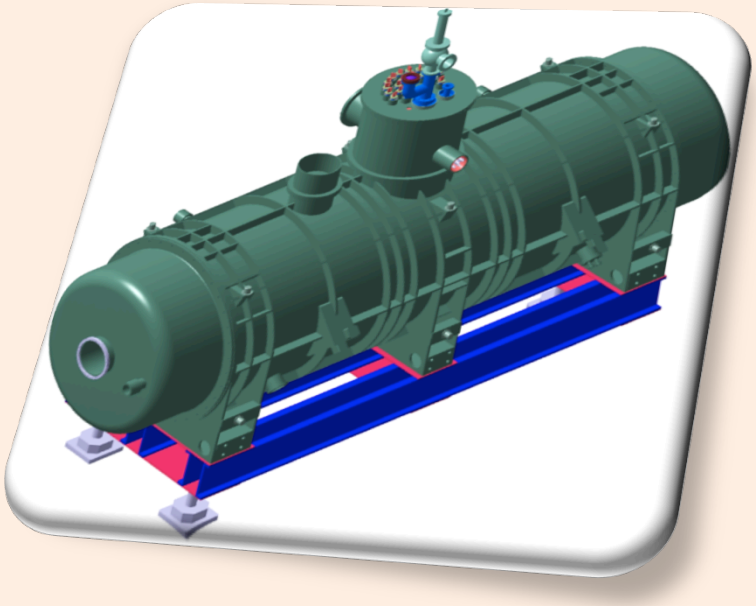
Versorgungsstrukturen auf gemeinsamen Träger

Super-FRS Multipletts

25 lange und 8 kurze Multipletts

- Spezifikationen fertiggestellt, Beschaffung läuft
- Vertragsabschluss geplant in 2014

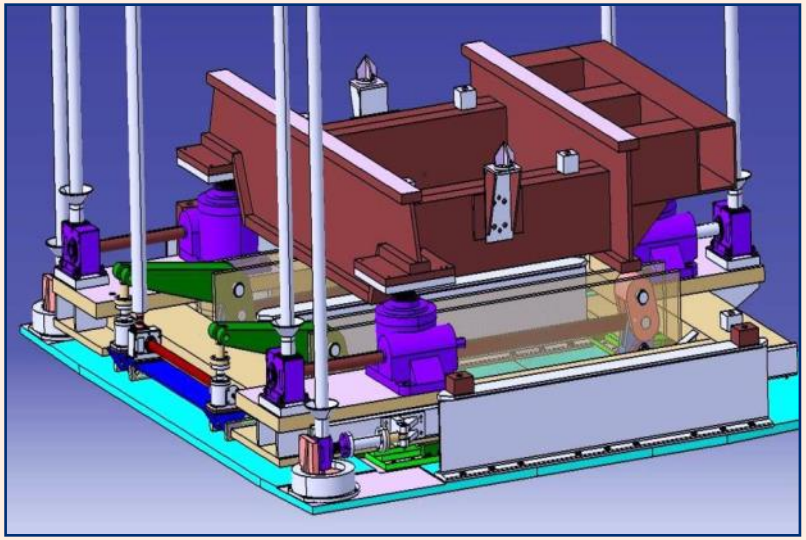




Daten zu den Multipletts

- Länge: 7 m
- Strahlachsenhöhe: 2 m
- Strahlrohr auf Raumtemperatur (38 cm Innendurchmesser)
- max. Strom < 300A

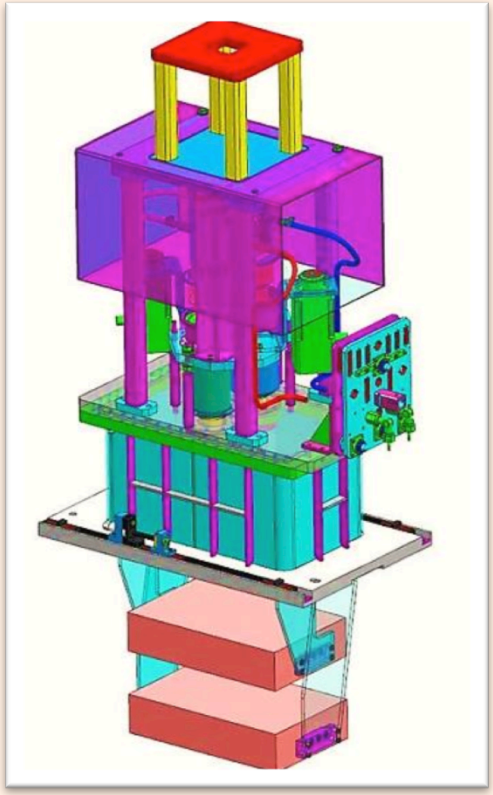
Super-FRS Entwicklungen



Strahlungsharter Dipolmagnet

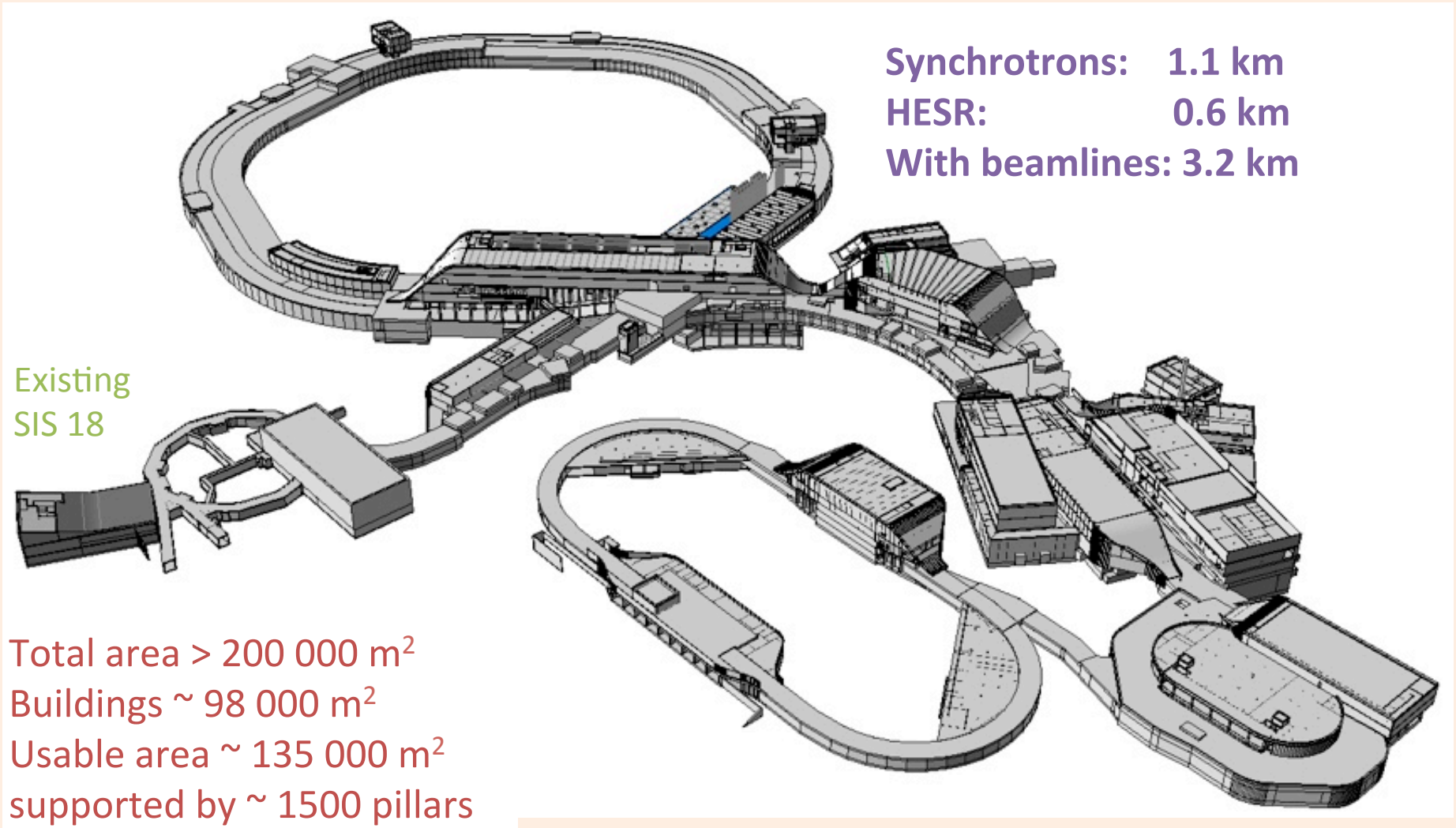
GEM TPC

Test Aufbau



Schlitzsystem:
In Zusammenarbeit mit dem KVI-CART in Groningen (NL)

FAIR – Civil Construction



Synchrotrons: 1.1 km
HESR: 0.6 km
With beamlines: 3.2 km

Existing
SIS 18

Total area > 200 000 m^2
Buildings ~ 98 000 m^2
Usable area ~ 135 000 m^2
supported by ~ 1500 pillars
up to 65 m deep

FAIR Civil Construction (May, June 2014)

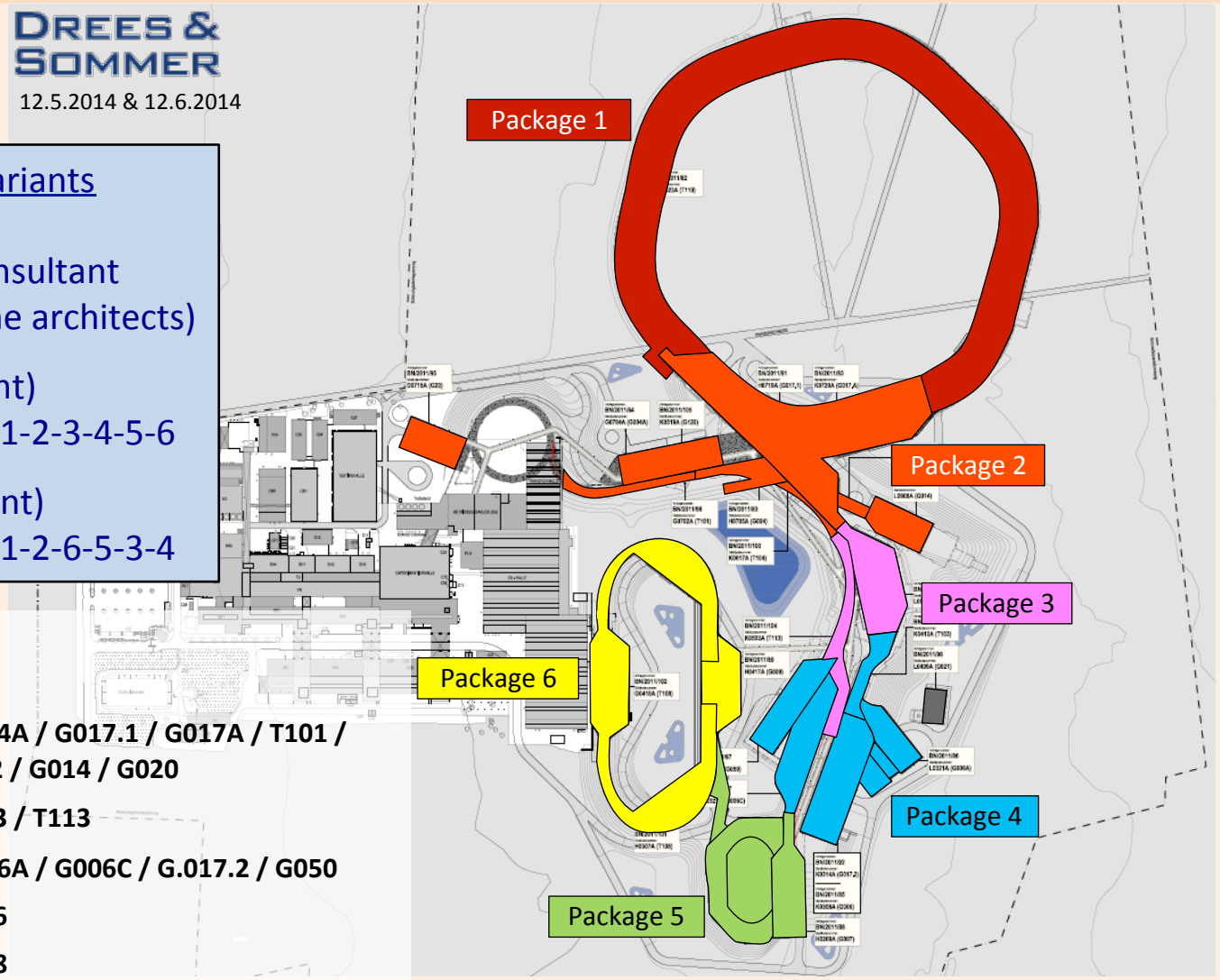
DREES & SOMMER

12.5.2014 & 12.6.2014

Civil construction variants
as suggested by the
Project Steering Consultant
(not approved by the architects)

12.5.2014 (1st variant)
Package Sequence: 1-2-3-4-5-6

12.6.2014 (2nd variant)
Package Sequence: 1-2-6-5-3-4

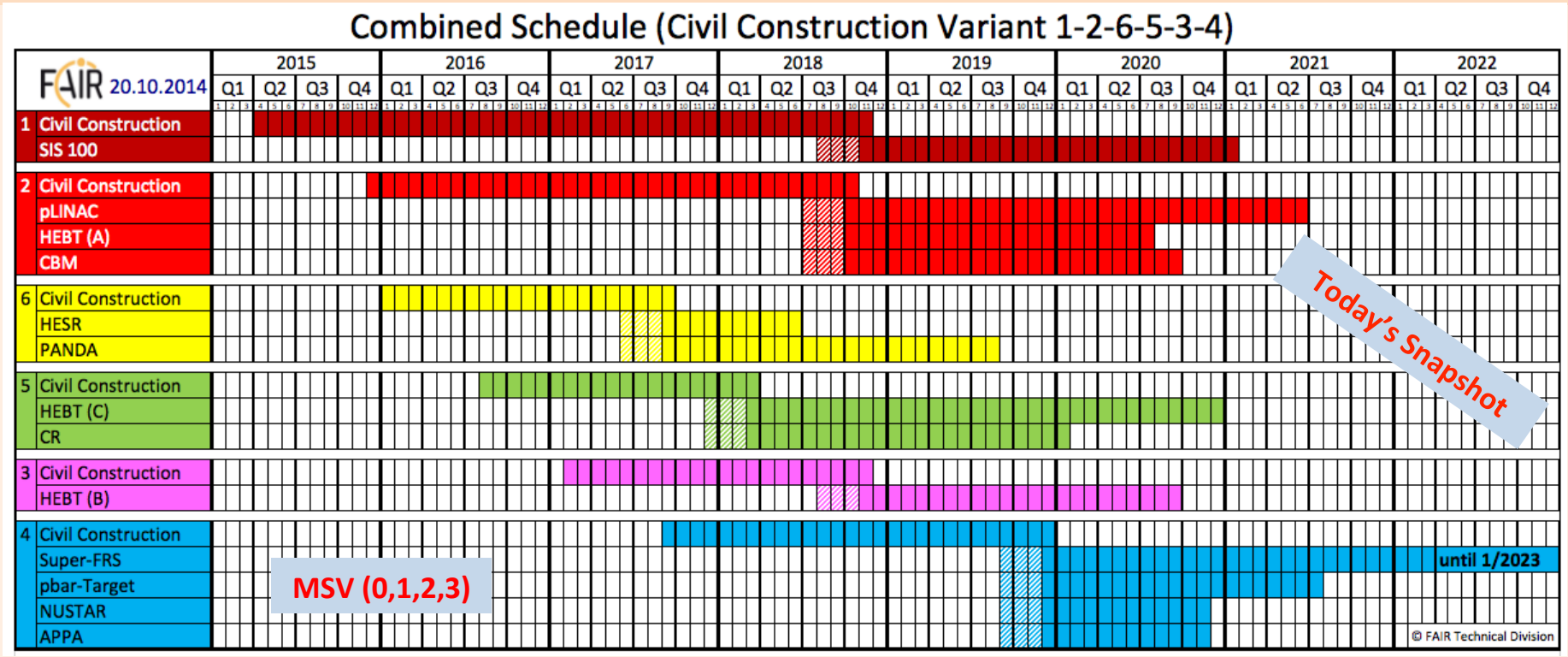


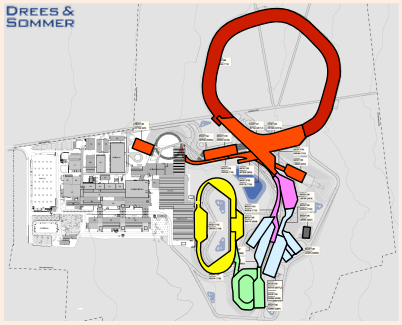
Legend:

Package 1	**T110**
Package 2	**G004 / G004A / G017.1 / G017A / T101 / T104 / T112 / G014 / G020**
Package 3	**G018 / T103 / T113**
Package 4	**G006 / G006A / G006C / G.017.2 / G050**
Package 5	**G007 / T106**
Package 6	**G009 / T108**

FAIR Combined Schedule (20.10.2014)

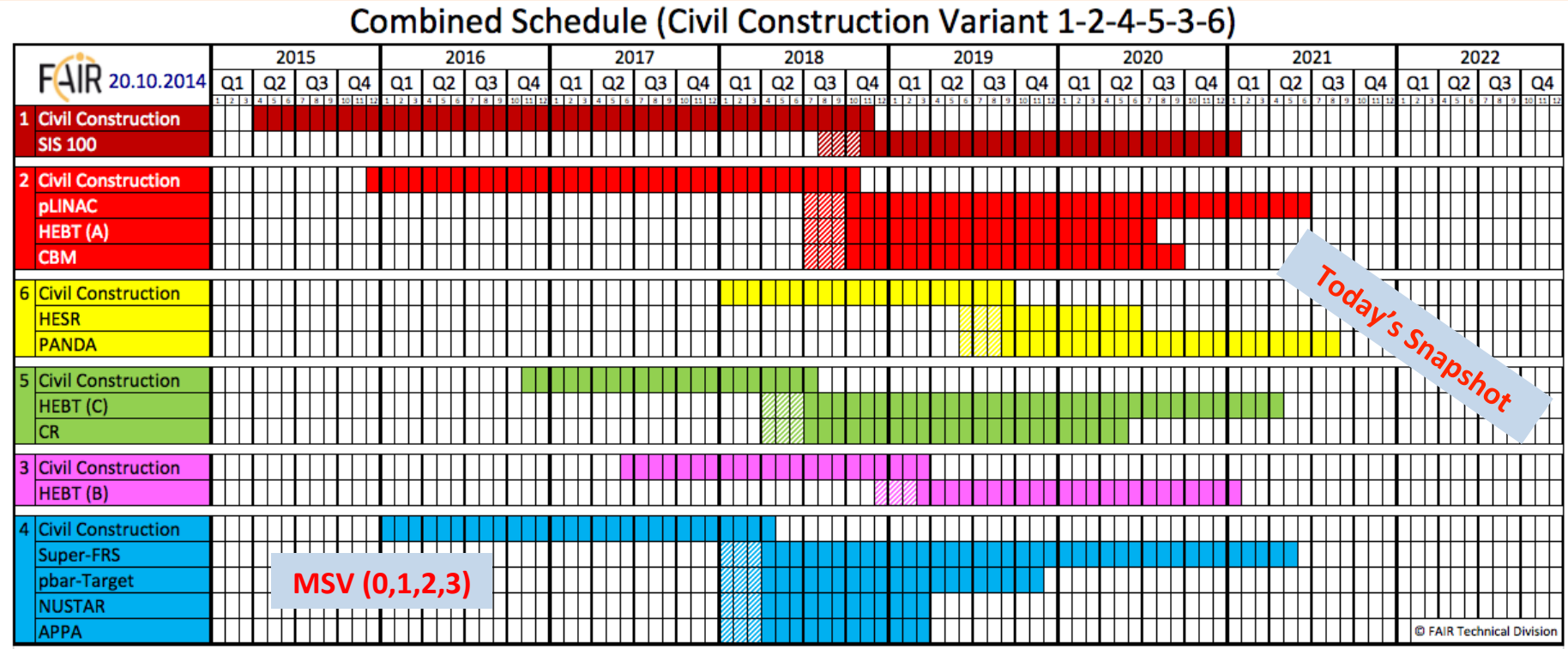
variant 2





Database/Input:	ACC (MS Project Server, 17.10.2014), CC (DreSo, 12.6.2014), HESR (FZJ, 19.9.2014), EXP (2.7.2014)
Duration CC:	Start shell construction until building acceptance
Duration ACC & EXP:	Installation time t: transport into tunnel (A110), test w/o beam (A119) until ready for beam (M11).
Basic Requirement:	**CC End: Q4/2019**

FAIR Combined Schedule (20.10.2014) variant 3



FAIR Modularised Start Version (MSV) anticipated in 09/2021, compared to 02/2023 (variant 2). ➔**Preferred solution**

Research Priorities

- as spelled out in the strategy document
  - construction and completion of the Facility for Antiproton and Ion Research (FAIR) in Darmstadt
  - full exploitation of existing research infrastructures for the study of the properties and structure of matter under extreme conditions
  - initiative to secure the promotion of young scientists in the field of hadron and nuclear physics

    in line with NuPECC Long-Rangle Plan for Europe

KHuK

Challenges in Nuclear and Hadron Physics

- Hadron Physics
  - from quarks to hadrons, masses of hadrons, spin of the nucleons, exotic bound states, matter/anti-matter asymmetry
- Heavy Ion Physics
  - exploration of the QCD phase diagram: nature of the phase transition, properties of the quark-gluon plasma at high temperature or large density, exotic phases of QCD matter
- Nuclear Structure
  - existence of super-heavy elements, properties and formation of exotic nuclei, limits of nuclear stability, formation of heavy elements in the universe, neutron matter

dedicated support for theory on related to the experimental program

FAIR – Civil Construction Progress

FAIR – Facility for Antiproton and Ion Research

Nuclear Structure & Astrophysics
Rare-isotope beams

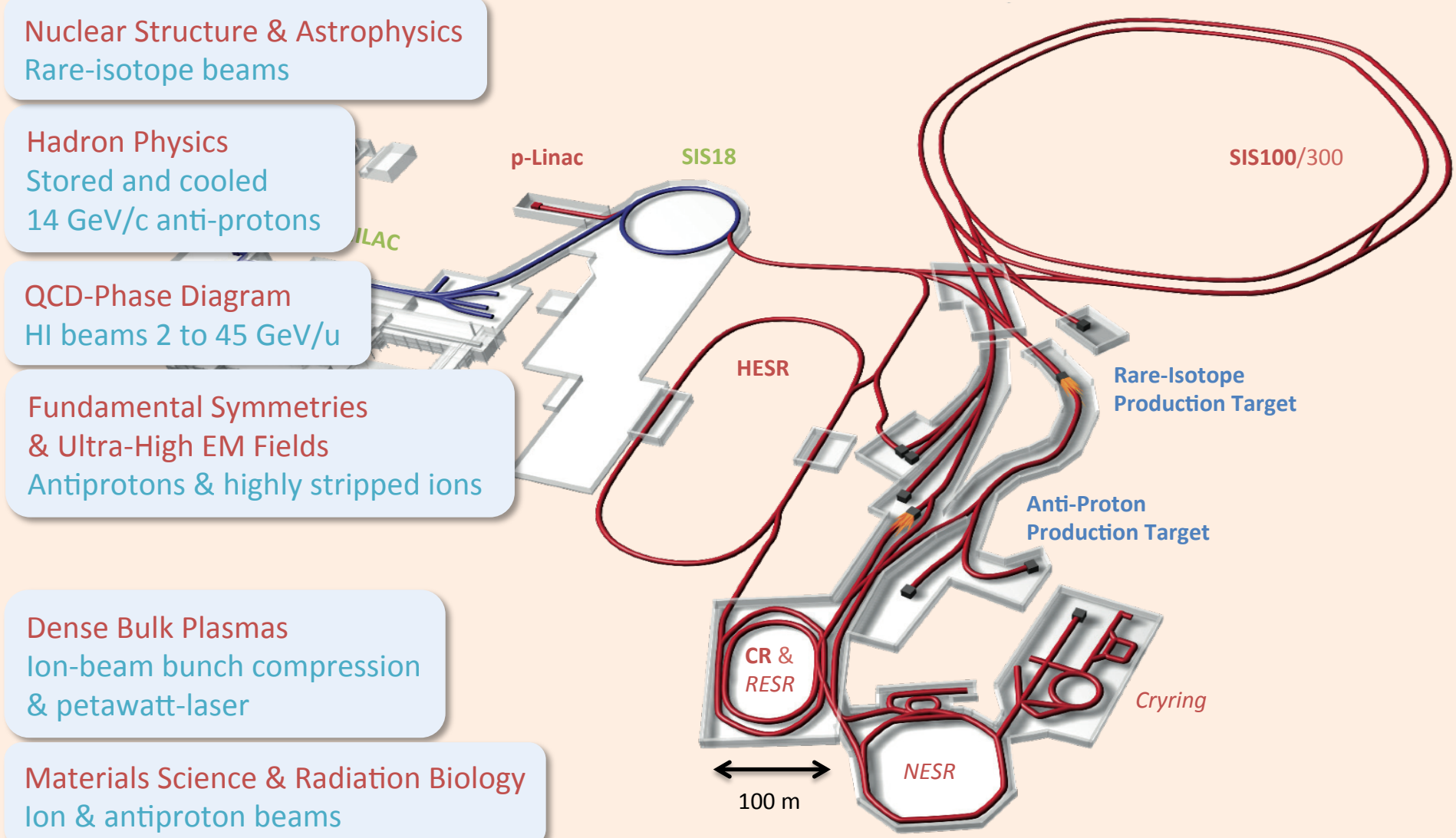
Hadron Physics
Stored and cooled
14 GeV/c anti-protons

QCD-Phase Diagram
HI beams 2 to 45 GeV/u

Fundamental Symmetries
& Ultra-High EM Fields
Antiprotons & highly stripped ions

Dense Bulk Plasmas
Ion-beam bunch compression
& petawatt-laser

Materials Science & Radiation Biology
Ion & antiproton beams



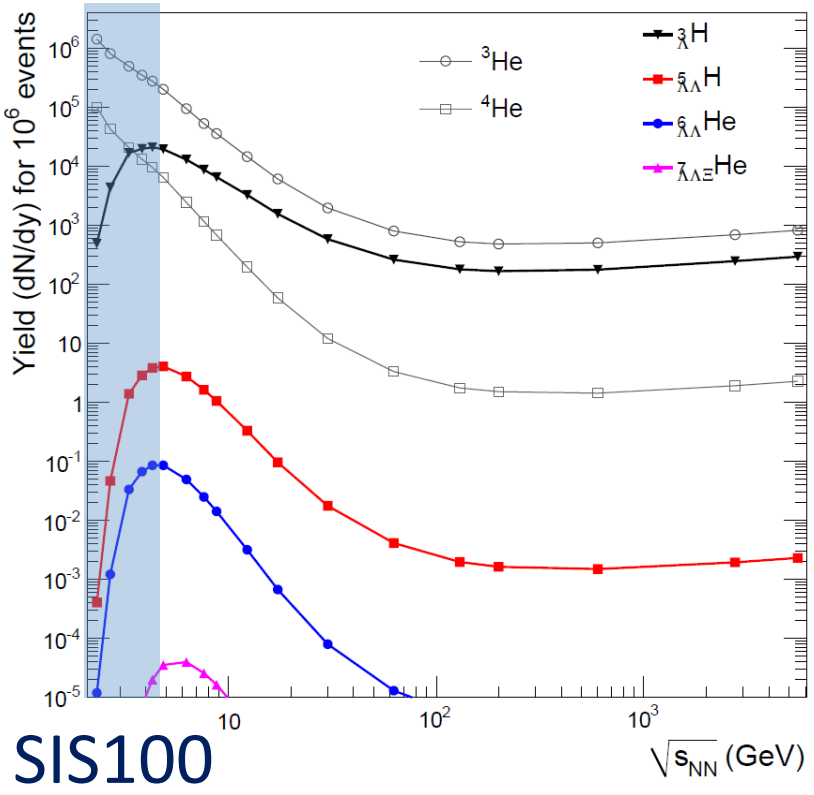
CBM physics program

Strange matter

No data at FAIR energies

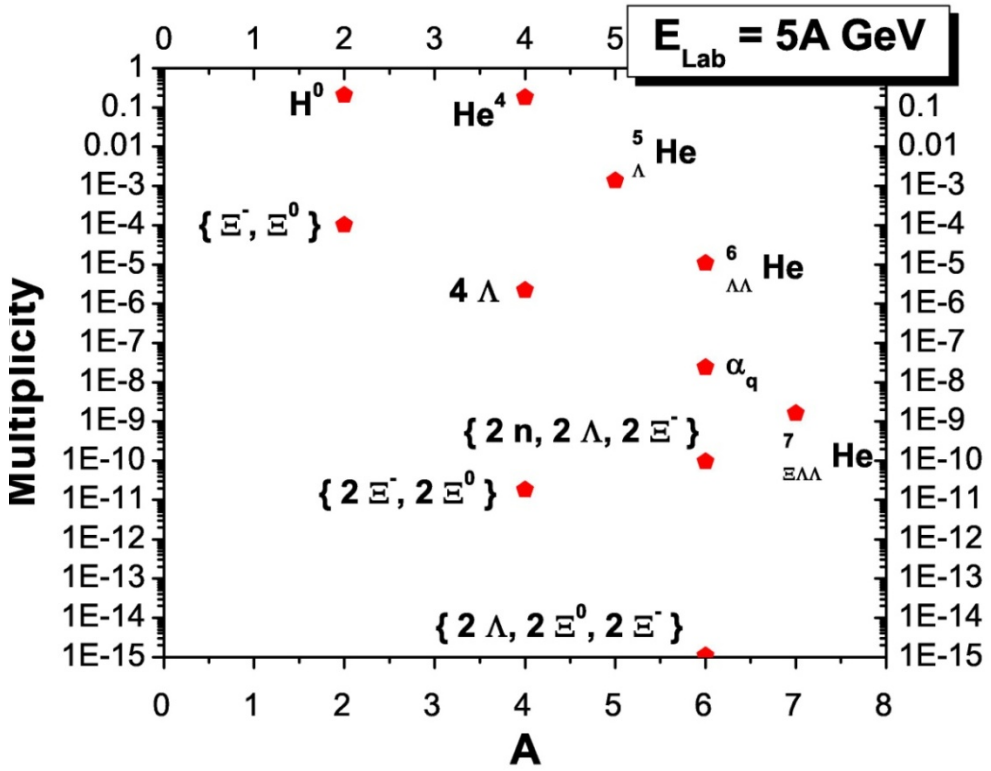
Hypernuclei, strange dibaryons and massive strange objects

Production of hypernuclei via coalescence of hyperons and light nuclei



SIS100

A. Andronic et al., Phys. Lett. B697 (2011) 203



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