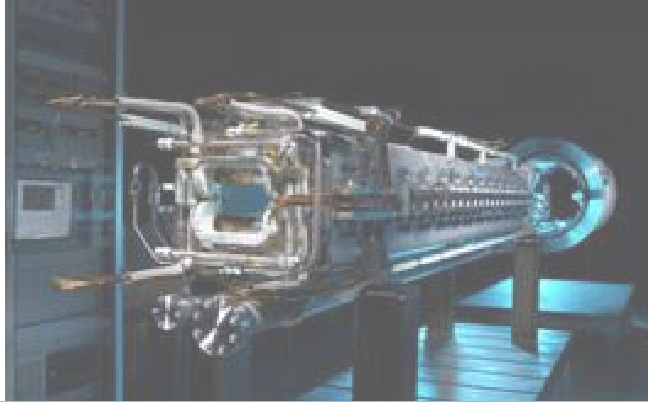


FAIR – Facility for Antiproton and Ion Research

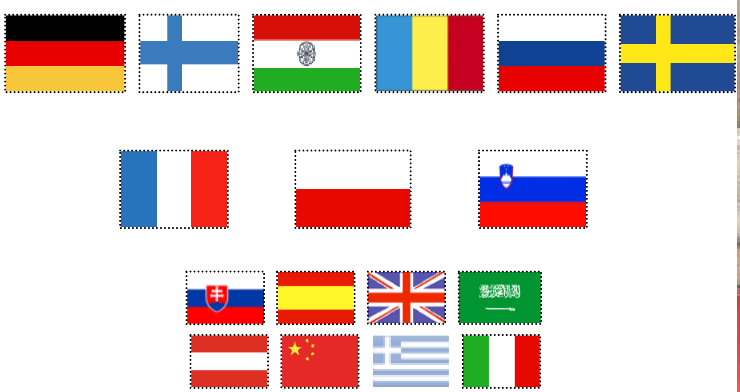
Thomas Nilsson
FAIR-NUSTAR BR chair/spokesperson
Board of FAIR Collaborations

16th Lomonosov Conference on Elementary Particle Physics –
Moscow State University 2013-08-23

FAIR

Oct 4th 2010 – a FAIR (GmbH) is born

Signing of the **FAIR Convention** by representatives of the founding countries **Finland, France, Germany, India, Poland, Romania, Russia, Slovenia, Sweden** in Wiesbaden



Facility for Antiproton & Ion Research

Nuclear Structure & Astrophysics
(Rare-isotope beams)

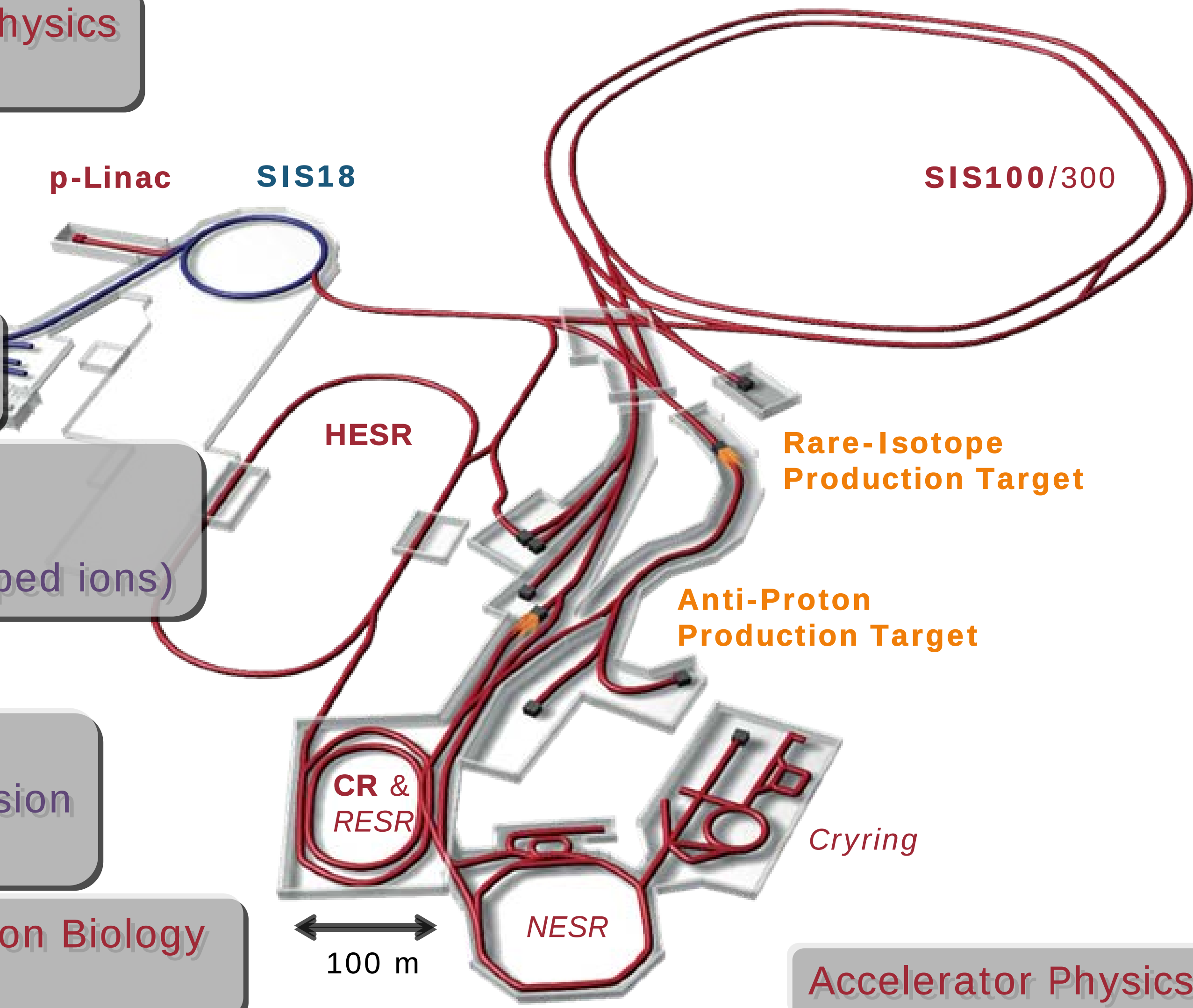
Hadron Physics
(Stored and cooled
14 GeV/c anti-protons)

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)

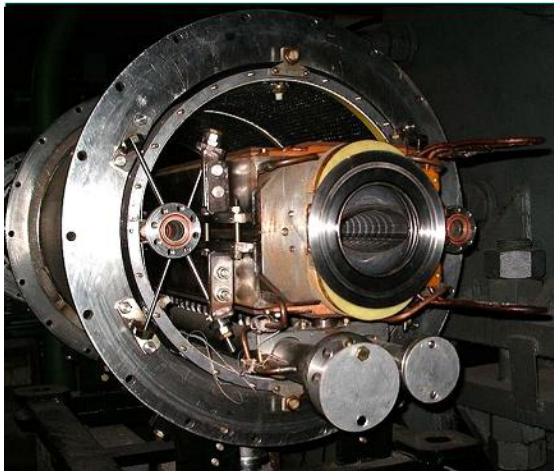
Materials Science & Radiation Biology
(Ion & antiproton beams)



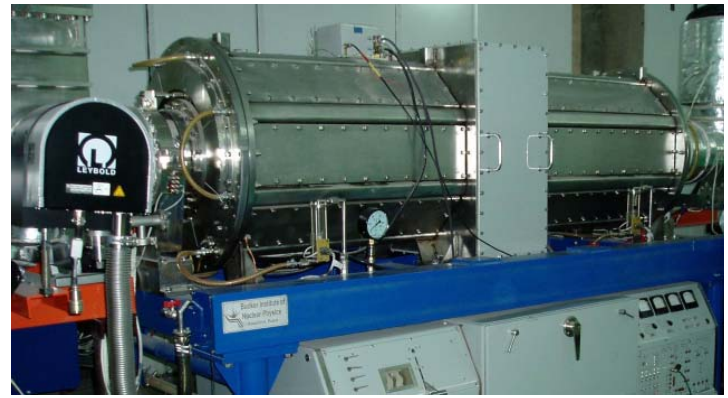
Accelerator Physics

Accelerator Challenges

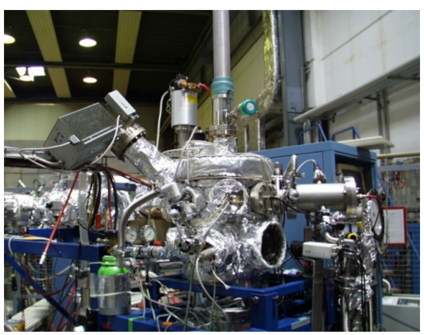
Compact & cost effective accelerators
Fast cycling superconducting magnets
dB/dt ~ 4T/s



Fast acceleration
High gradient, variable frequency
Ferrite & MA loaded cavities



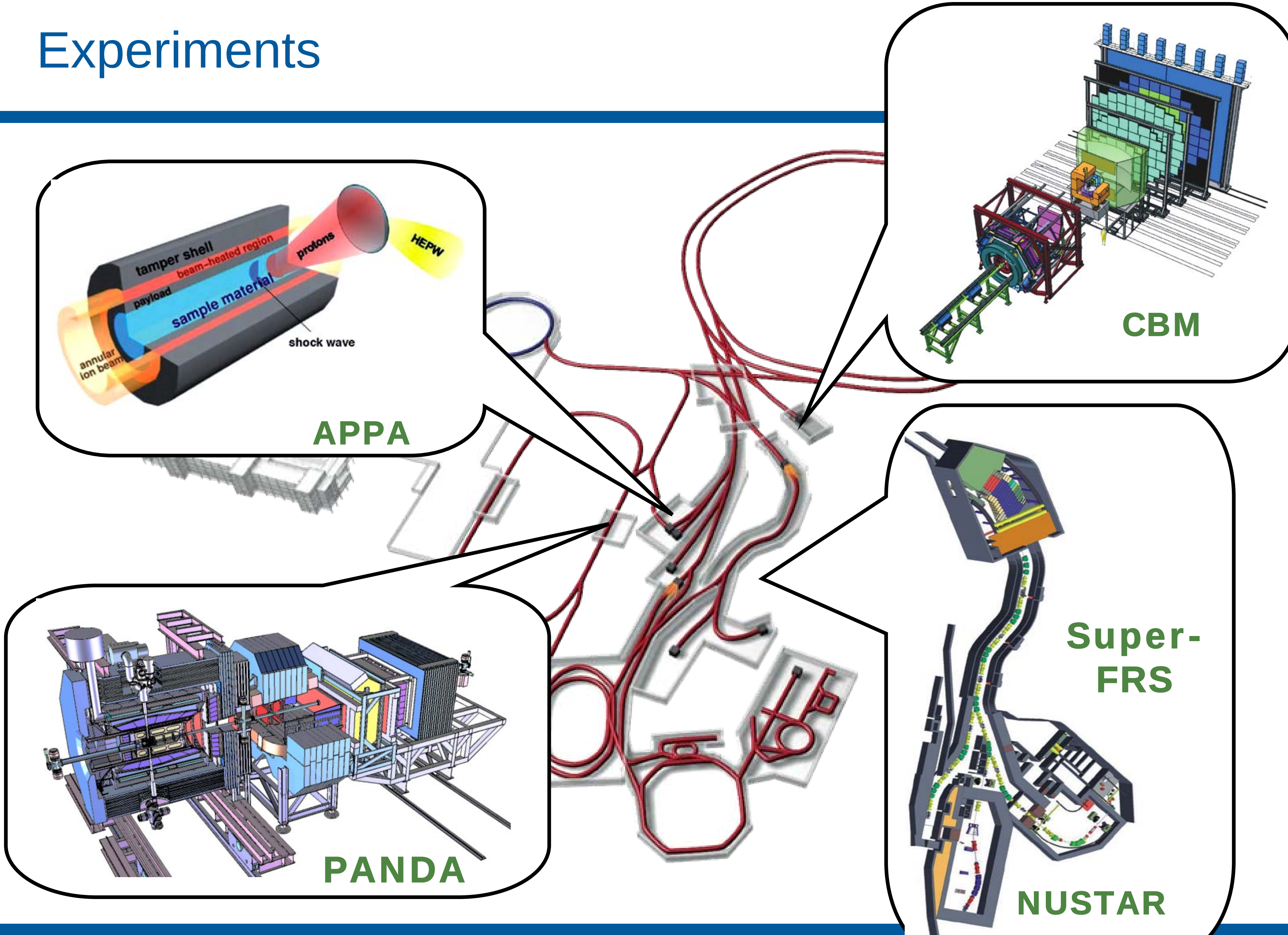
XHV @ high beam intensities
Extremely high vacuum ~10^{-12} mbar



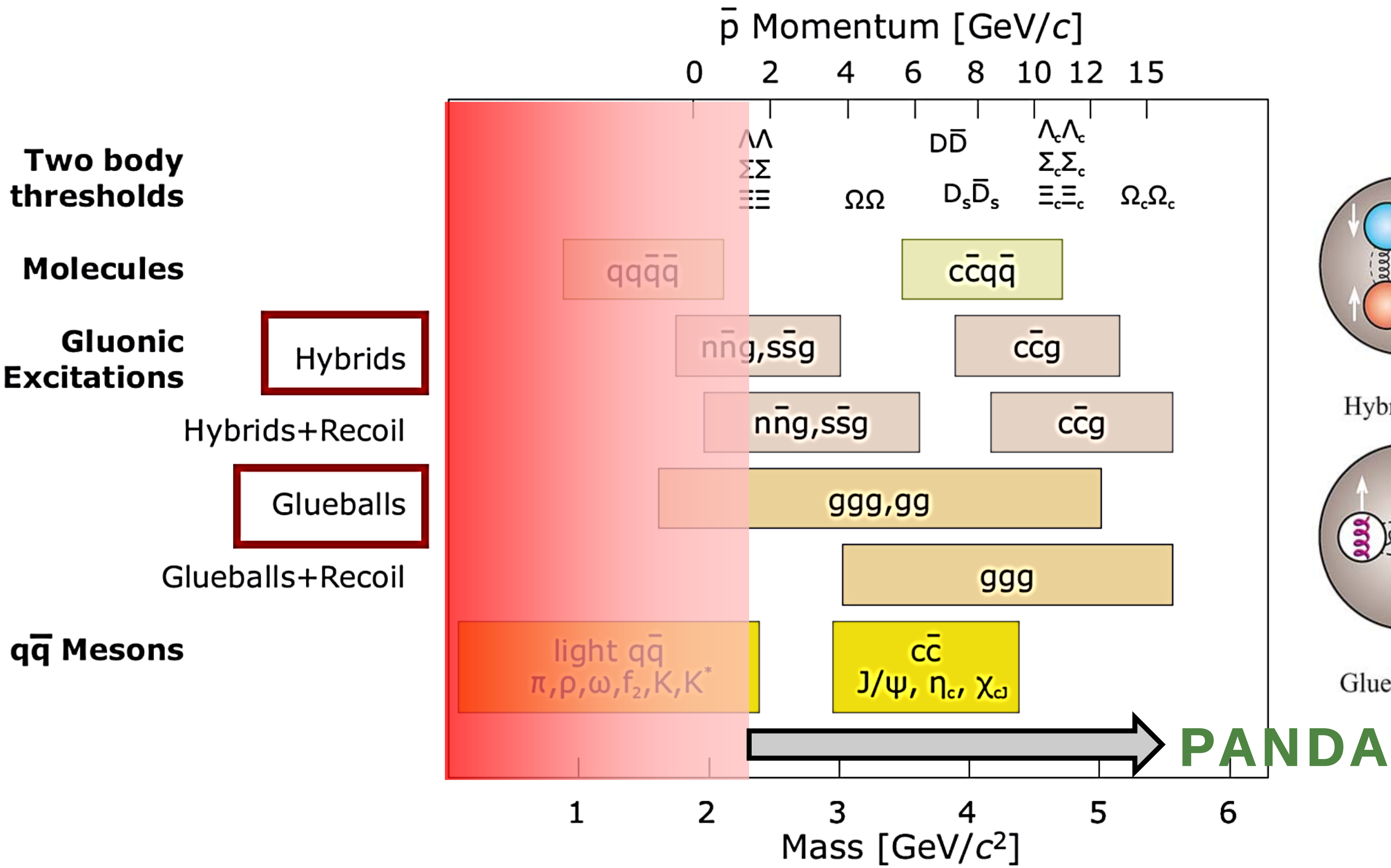
Precision beams
Electron & stochastic cooling

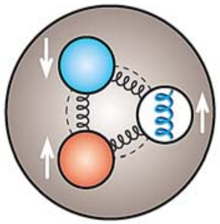
Major contributions by Russian laboratories (JINR, BINP, …)

Experiments

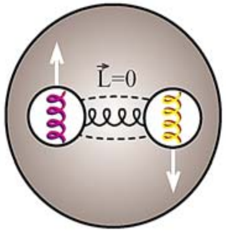


Anti-Proton Annihilation @ DA





Hybrid ($q\bar{q}g$)



Glueball (gg)

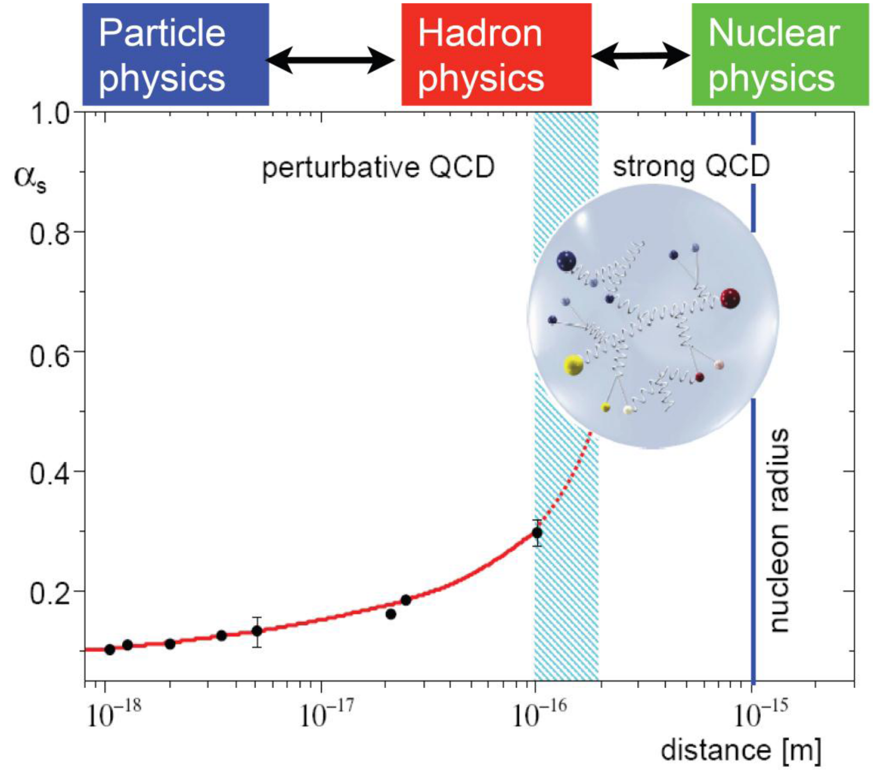
Hadron Physics with PANDA

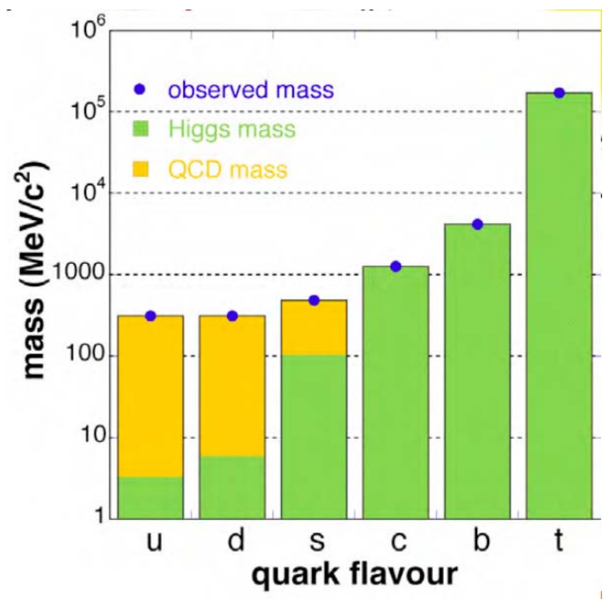
Courtesy J. Ritman

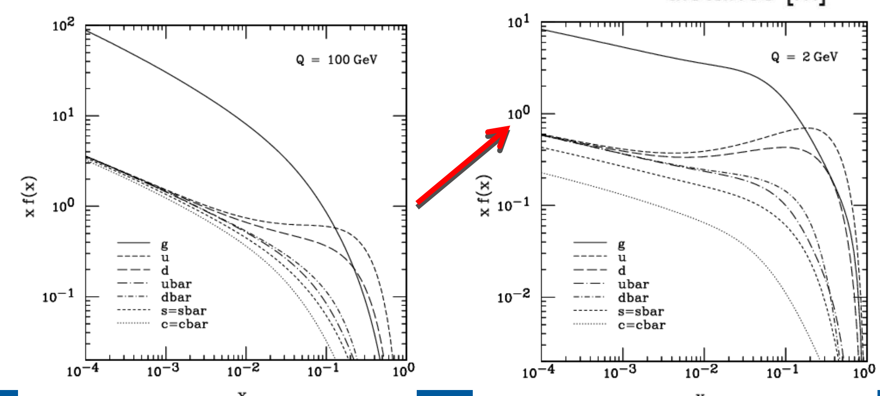
QCD well understood at high Q^2
Emergence of eff. DoF at low Q^2

Study of the *strong interaction* in the transition region

Phenomena appear that are hard to predict from QCD:
e.g. confinement, nature of hadrons, hadronic masses…





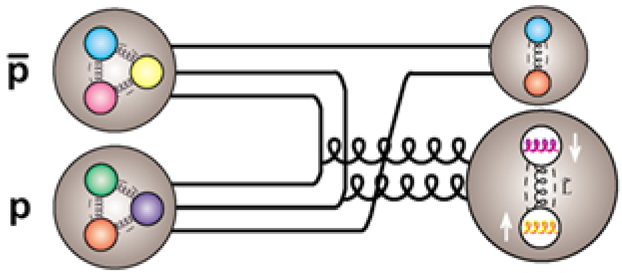


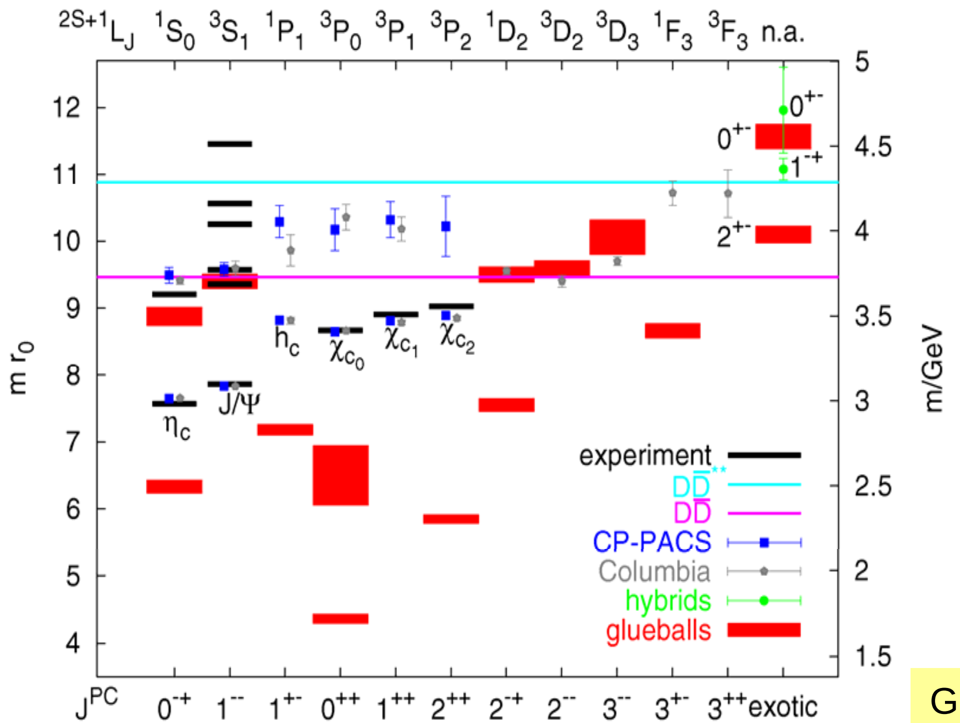
J. Pumplin et al., JHEP 0207 (2002) 012

Exotics production in $\bar{p}p$ collisions

Courtesy J. Ritman

Production: all J^{PC} accessible





Hybrids

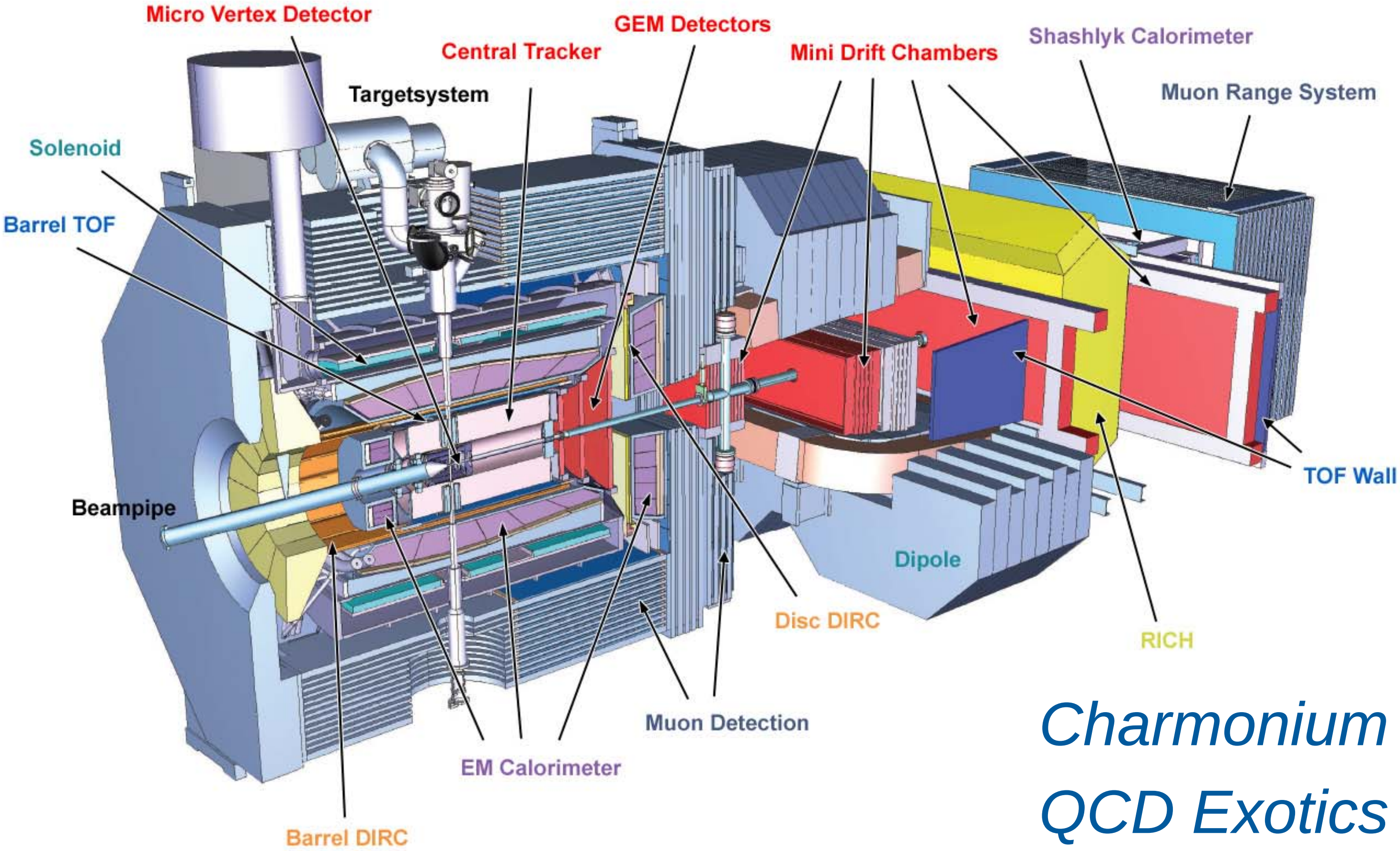
Gluon	1^{-+}	1^{+-}
$^1S_0$, 0^{-+}	1^{++}	1^{--}
$^3S_1$, 1^{--}	0^{+-}	0^{-+}
	1^{+-}	1^{-+}
	2^{+-}	2^{-+}

J^{PC} exotic

Exotic J^{PC} would be clear signal

G.Bali, EPJA 1 (2004) 1 (PS)

Panda



Charmonium Spectroscopy

QCD Exotics

Hypernuclear physics

Charm in nuclear matter

The PANDA Collaboration

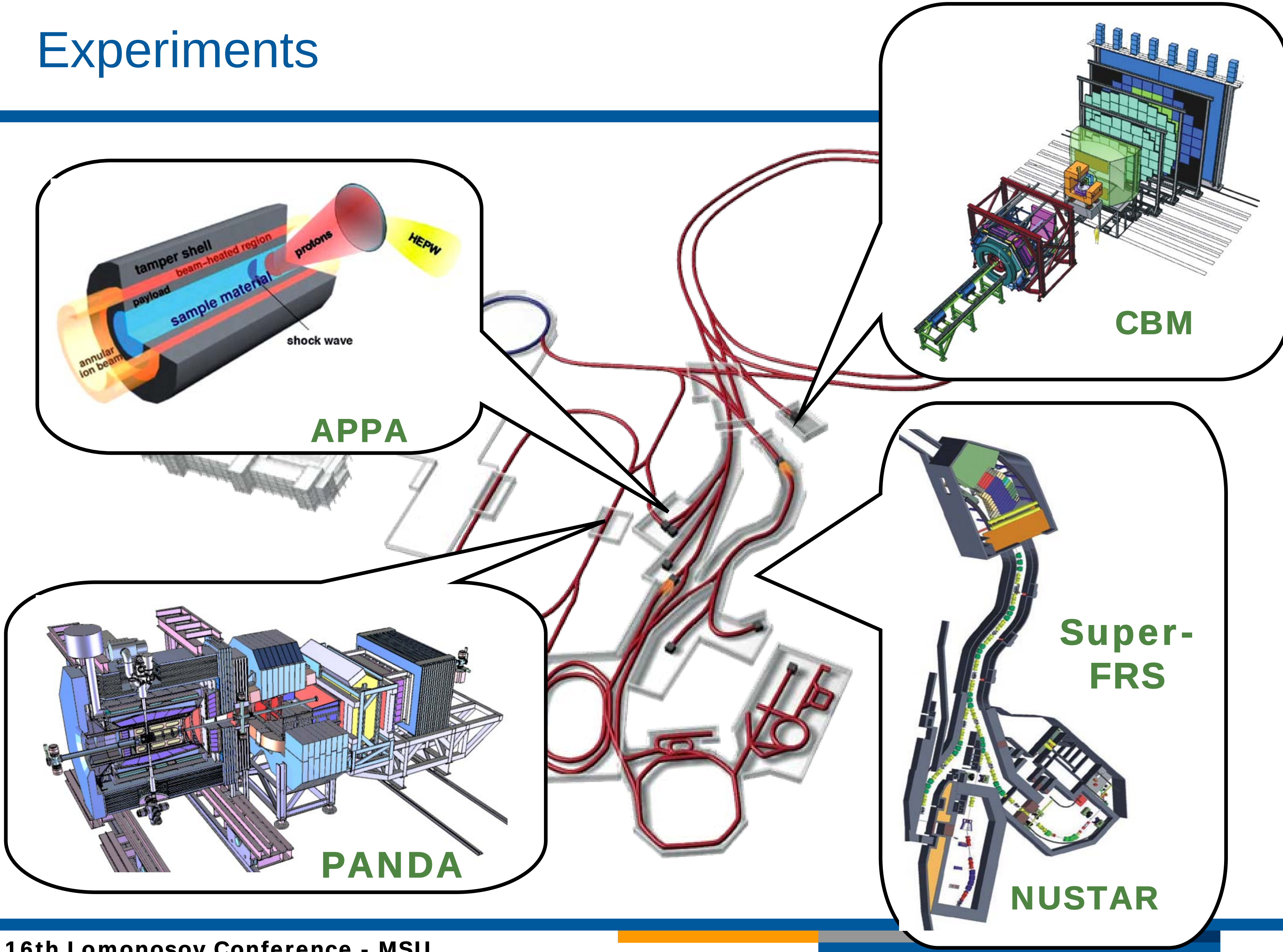
517 Members from

67 Institutes

18 Countries

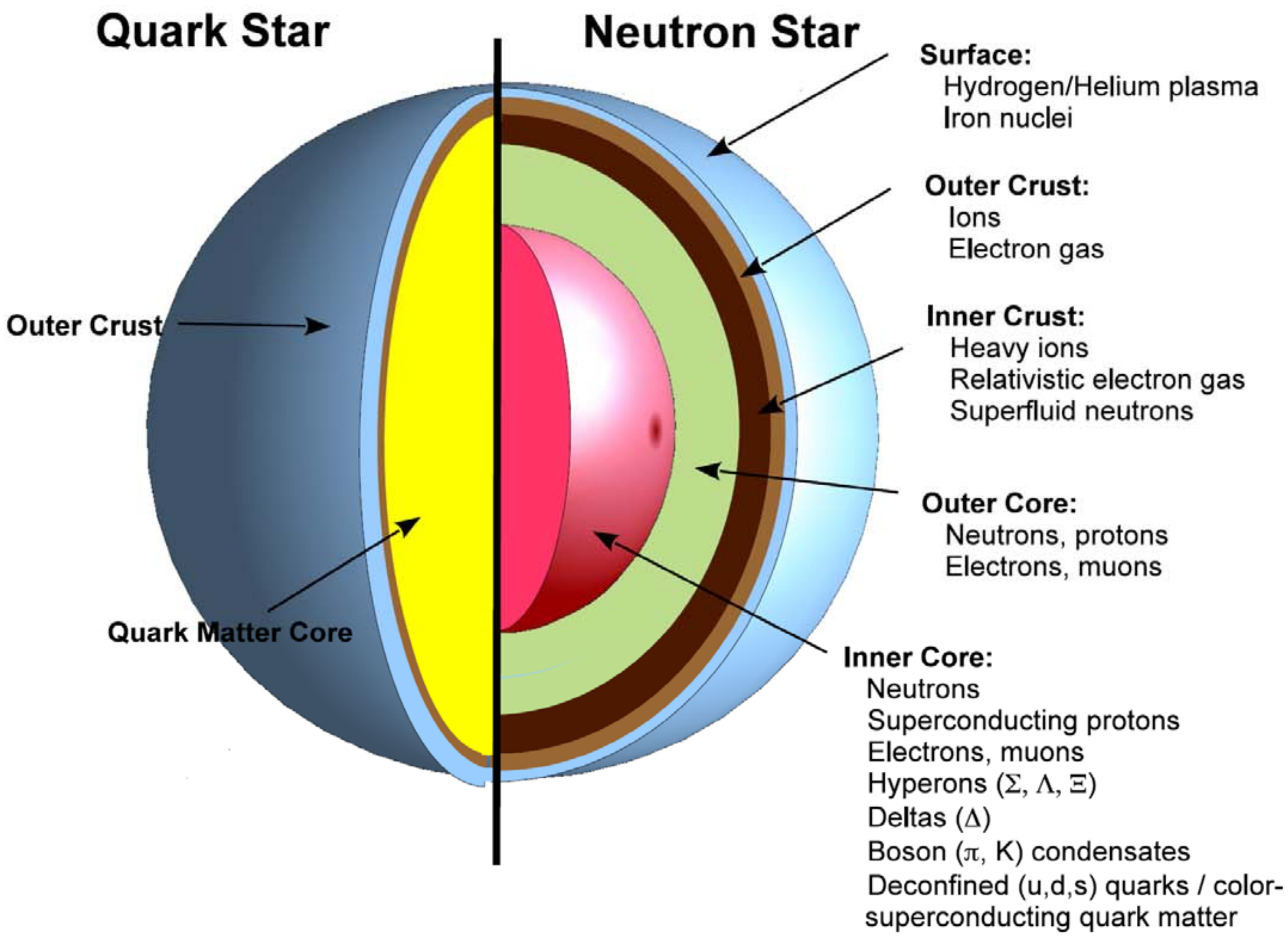
Australia, Austria, Belarus, China, France, Germany, India, Italy, Poland, Romania, Russia, Spain, Sweden, Switzerland, Thailand, The Netherlands, USA, UK

Experiments



Fundamental Questions of (QCD-) Physics

- What is the structure of compact stars?



Fundamental Questions of (QCD-) Physics

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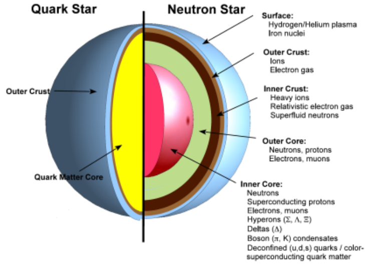
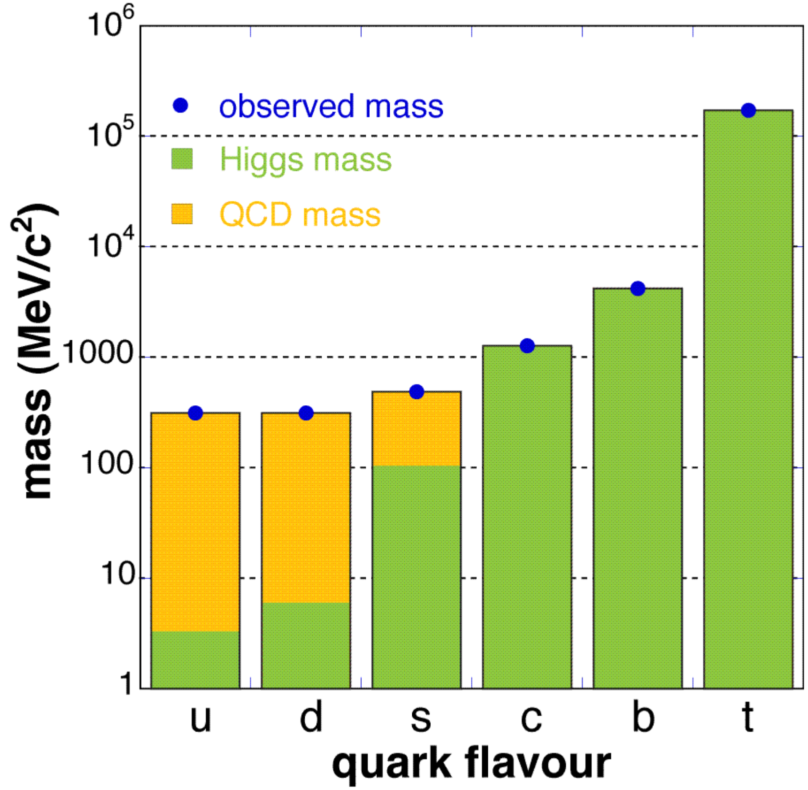


- What is the origin of the mass of the hadrons which determine the visible mass of the universe?



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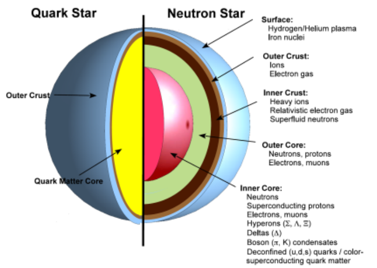

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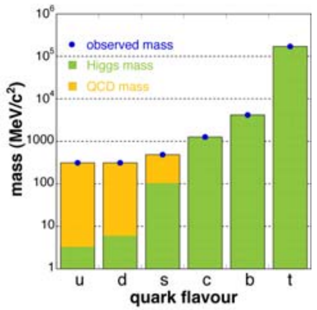

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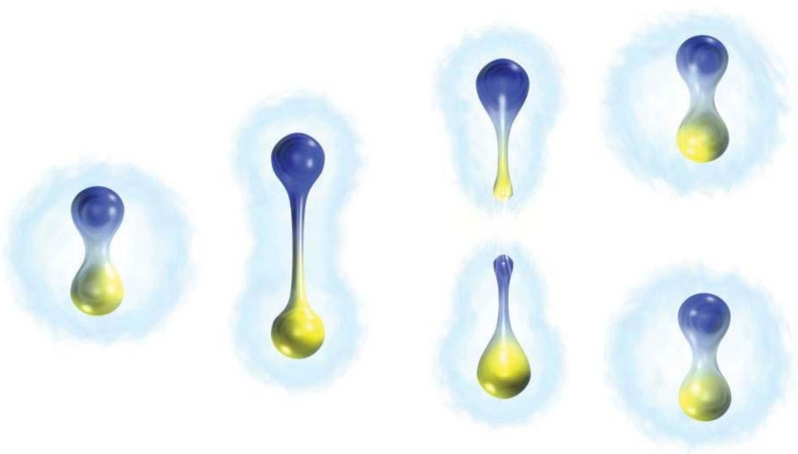
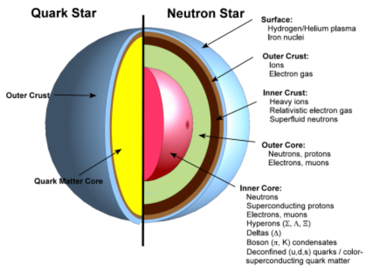
- Why do we not observe individual quarks, the elementary building blocks of matter?



Fundamental Questions of (QCD-) Physics

- What is the structure of compact stars?



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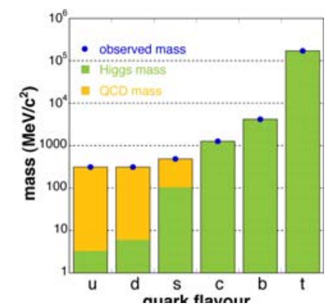

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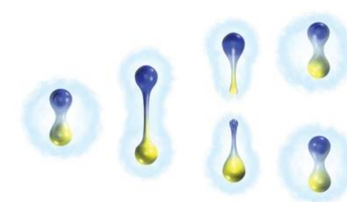
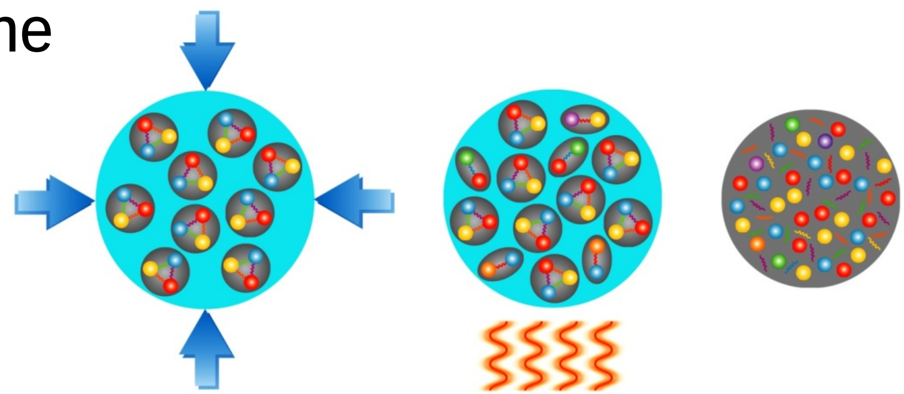
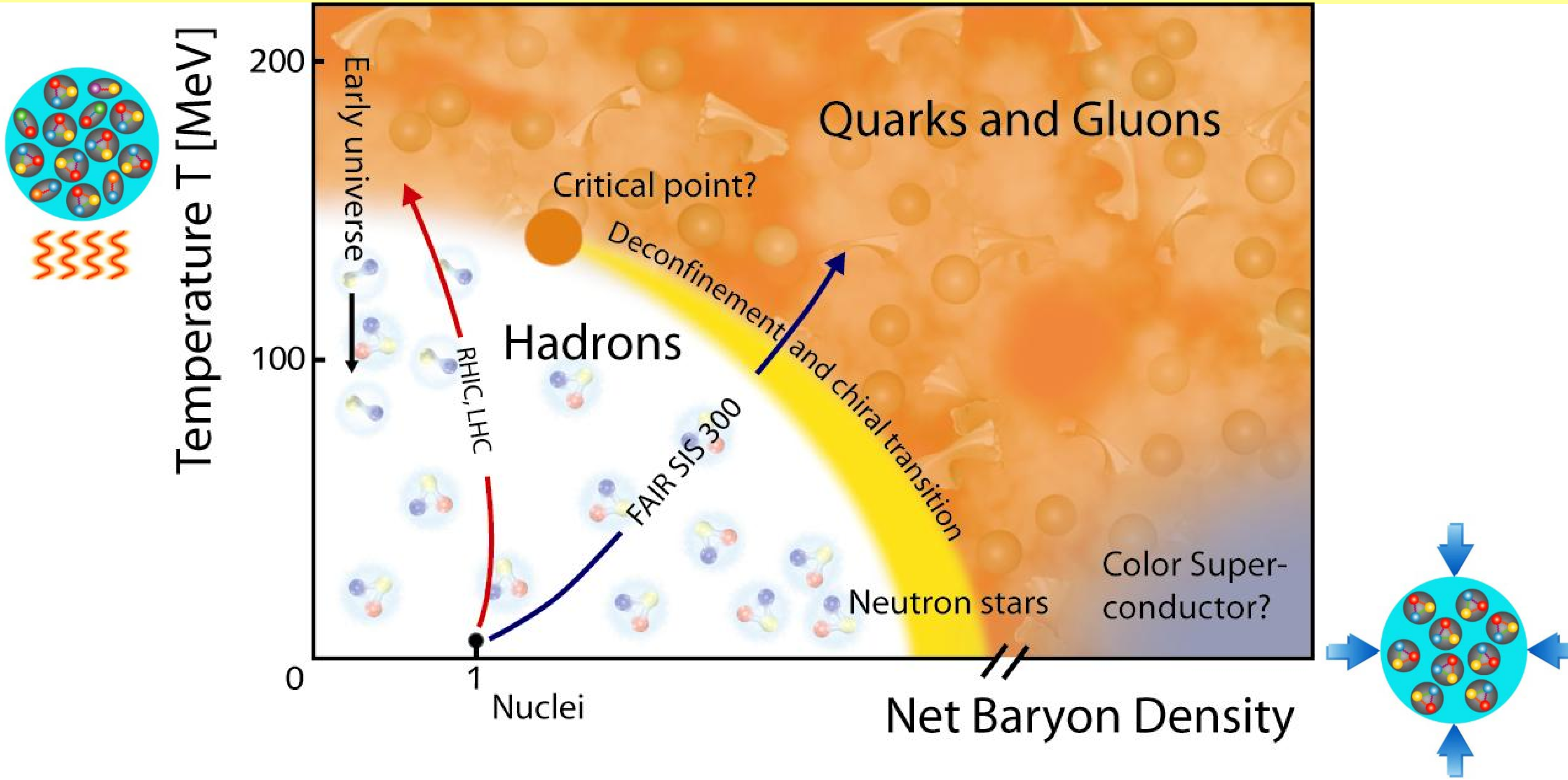


- What are the properties and the degrees-of-freedom of nuclear matter under extreme conditions (high temperature and/or high density)?



Courtesy P. Senger

Exploring the QCD phase diagram

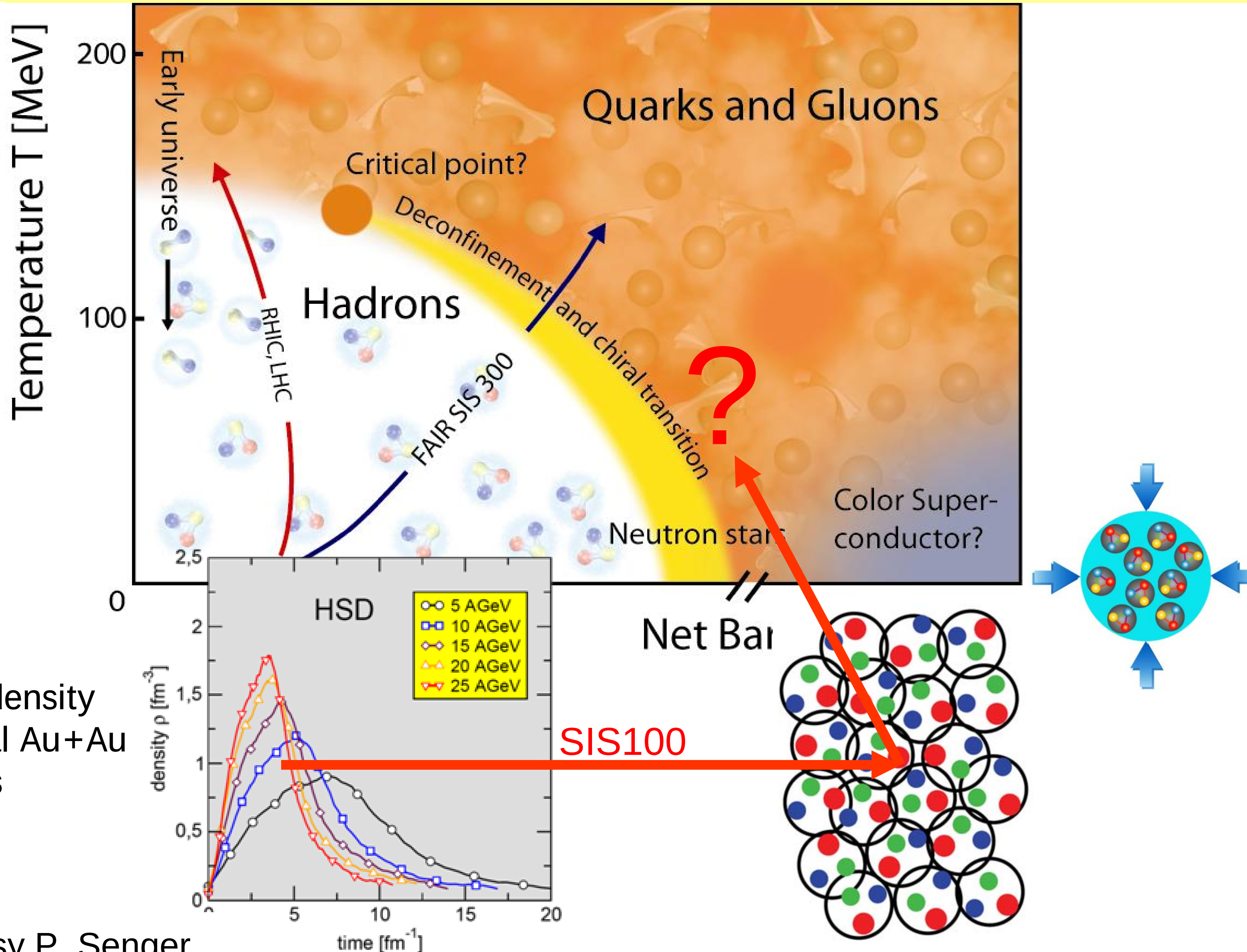


Probing the QCD diagram at very high T and $\rho_B \sim 0$ (early universe):
ALICE, ATLAS, CMS at LHC
STAR, PHENIX at top RHIC energies

Previous talk

Probing the QCD diagram at moderate T and very high ρ_B:
Beam energy scan at RHIC, NA61 at CERN SPS, CBM at FAIR, MPD at NICA

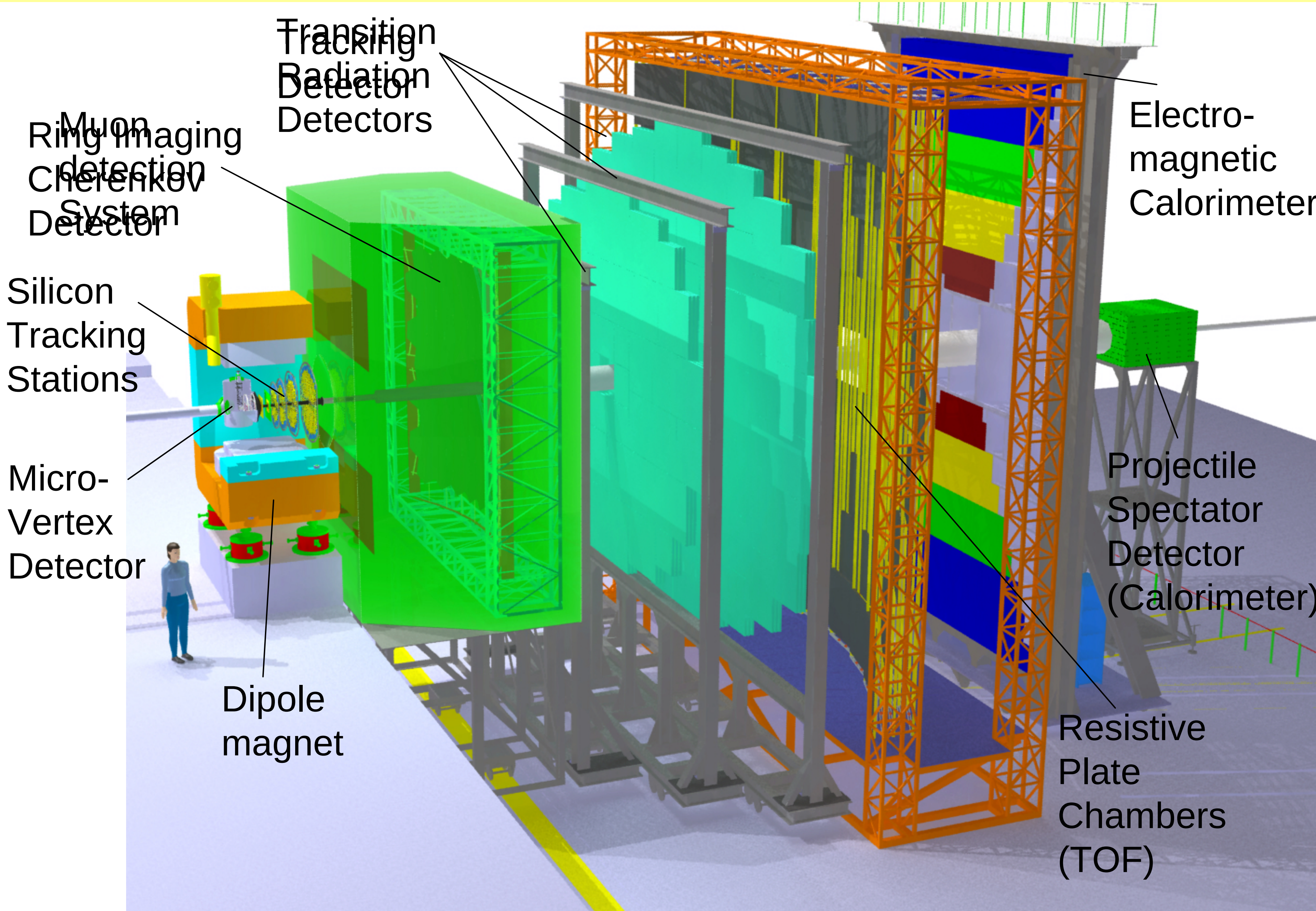
Exploring the QCD phase diagram



Baryon density
in central Au+Au
collisions

Courtesy P. Senger

The Compressed Baryonic Matter Experiment



The CBM Collaboration: 58 institutions, 500 members

Croatia:
RBI Zagreb
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei

Czech Republic:
CAS, Rez
Techn. Univ.Prague

France:
IPHC Strasbourg

Hungary:
KFKI Budapest
Budapest Univ.

Germany:
Darmstadt TU
FAIR
Frankfurt Univ. IKF
Frankfurt Univ. FIAS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
Münster Univ.
Tübingen Univ.
Wuppertal Univ.

India:
Aligarh Muslim Univ.
Bose Inst. Kolkata
Panjab Univ.
Rajasthan Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
SAHA Kolkata
IOP Bhubaneswar
IIT Kharagpur
Gauhati Univ.

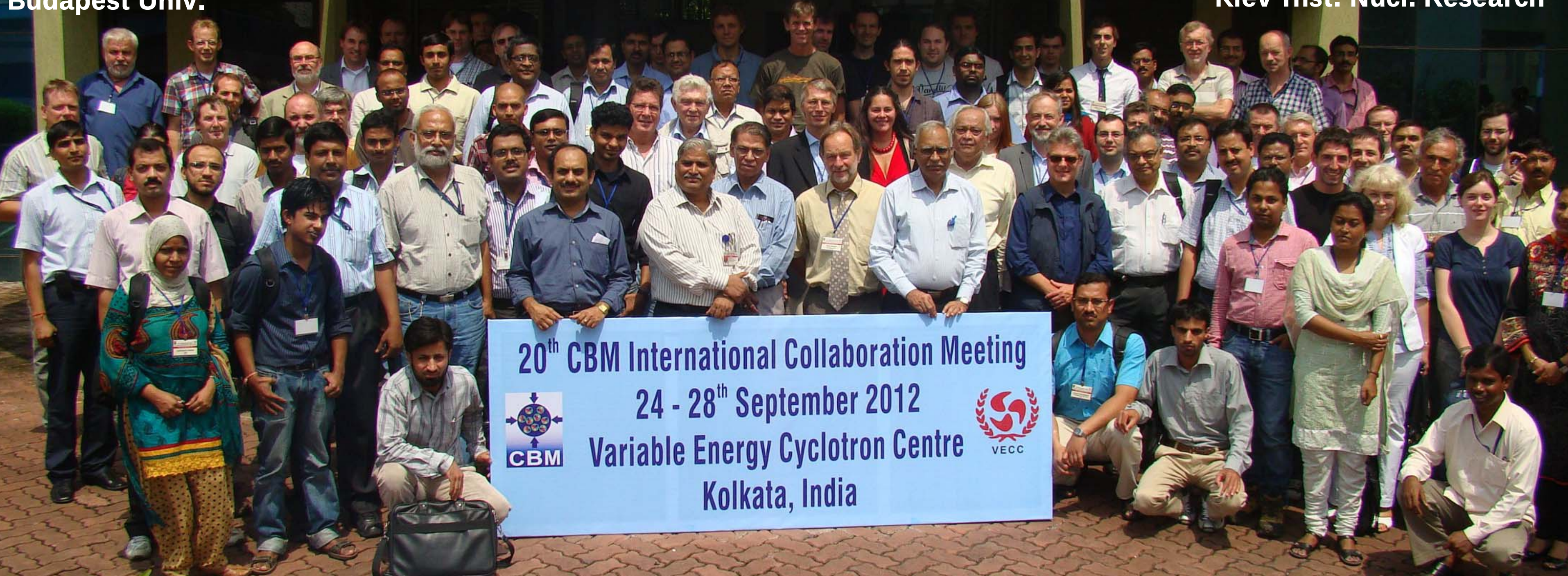
Korea:
Korea Univ. Seoul
Pusan Nat. Univ.

Romania:
NIPNE Bucharest
Univ. Bucharest

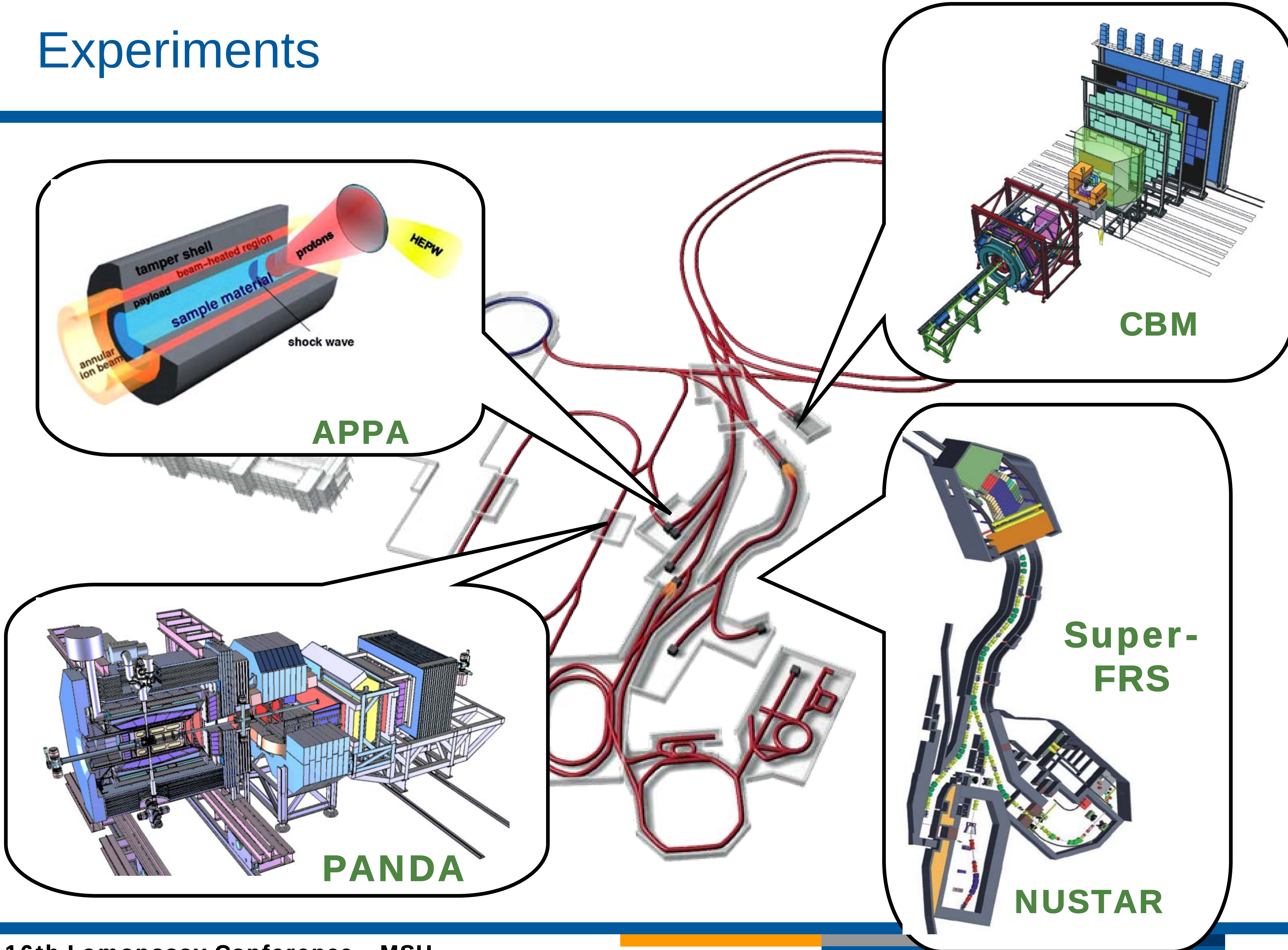
Poland:
AGH Krakow
Jag. Univ. Krakow
Silesia Univ. Katowice
Warsaw Univ.
Warsaw TU

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.

Ukraine:
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research



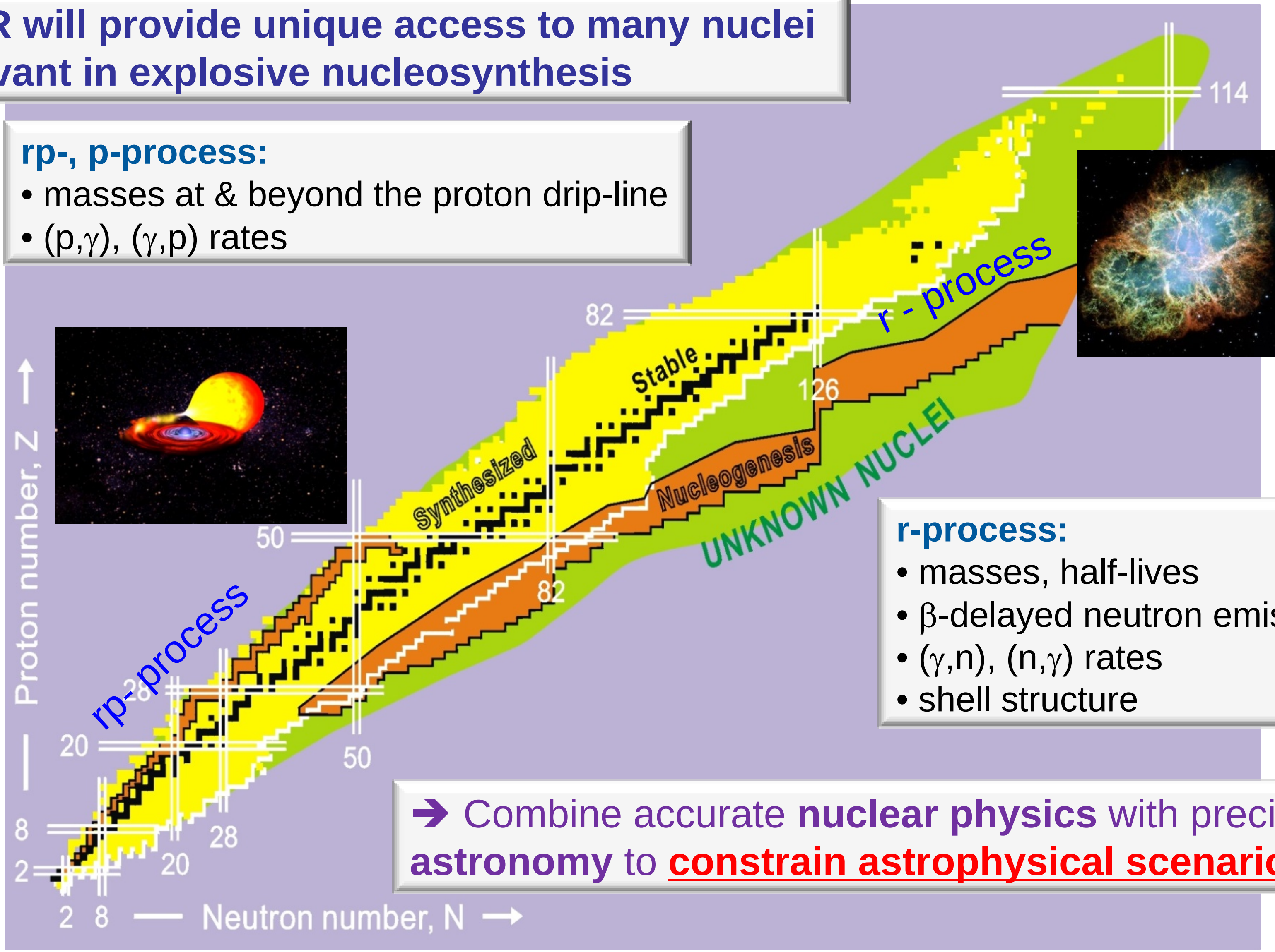
Experiments



Which are the nuclei relevant for astrophysical processes and what are their properties?

FAIR will provide unique access to many nuclei relevant in explosive nucleosynthesis

rp-, p-process:
- masses at & beyond the proton drip-line
- (p,γ), (γ,p) rates

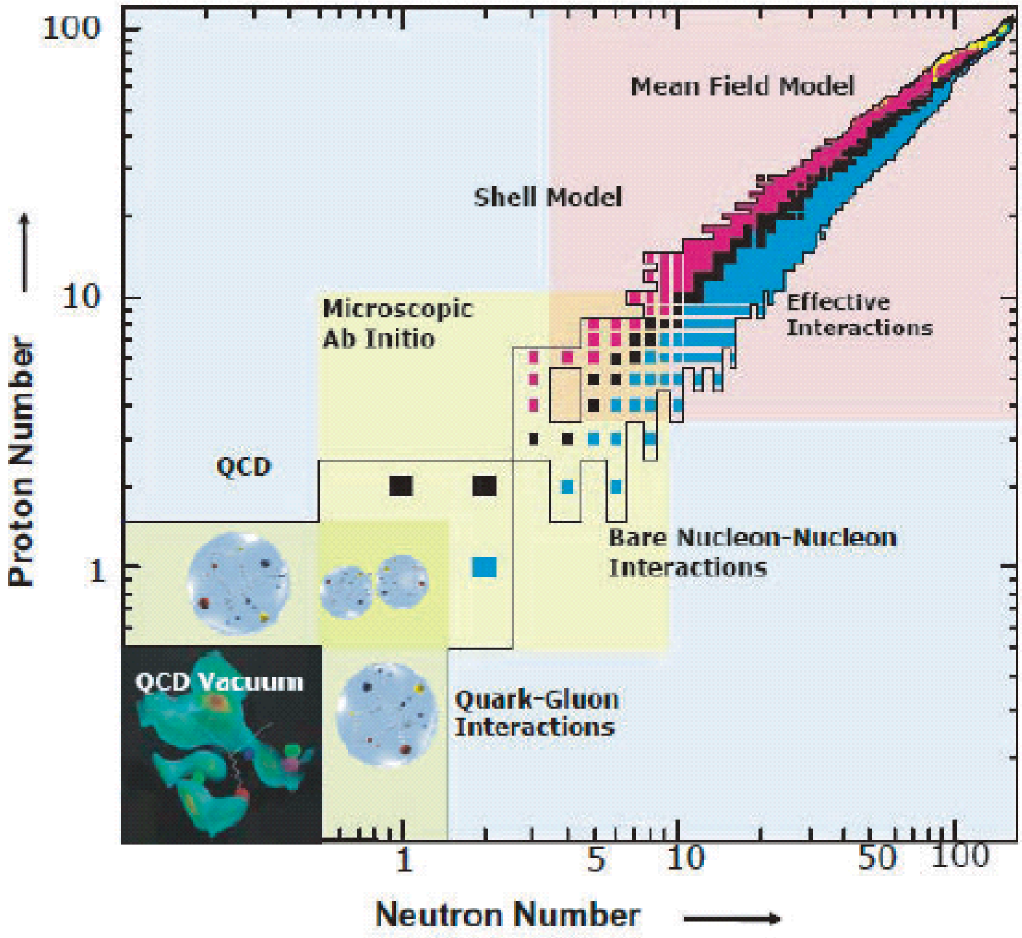


r-process:
- masses, half-lives
- β-delayed neutron emission
- (γ,n), (n,γ) rates
- shell structure

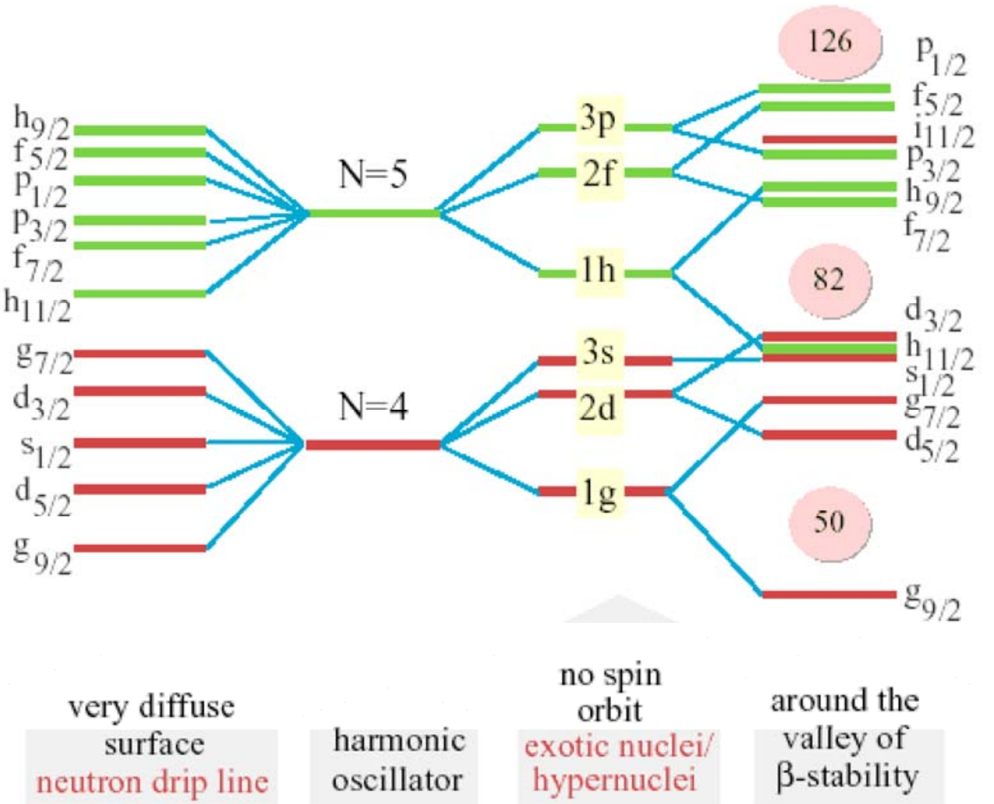
➔ Combine accurate **nuclear physics** with precision **astronomy** to <u>**constrain astrophysical scenarios**</u>

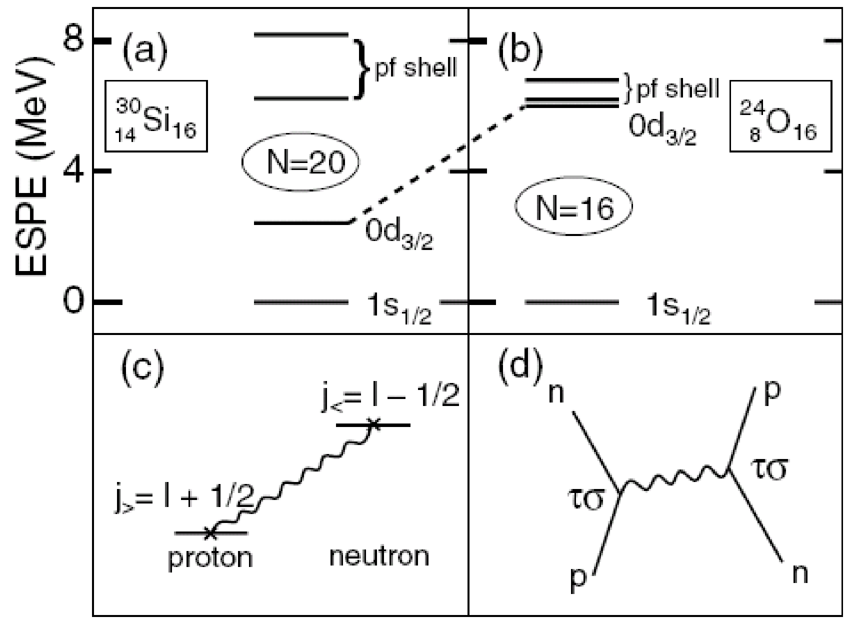
Open questions

- **What are the limits for existence of nuclei?**
  - **Where are the proton and neutron drip lines situated?**
  - **Where does the nuclear chart end?**
- **How are complex nuclei built from their basic constituents?**
  - **What is the effective nucleon-nucleon interaction?**
  - **How does QCD constrain its parameters?**



How does the nuclear force depend on varying proton-to-neutron ratios?





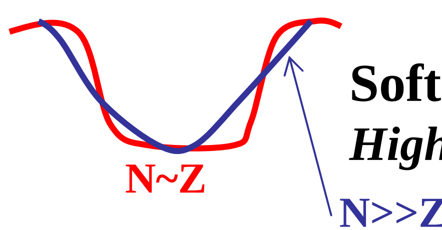
A. Ozawa et al. PRL 84 (2000) 5493

T. Otsuka et al., PRL 87(2001)082502

Shell quenching and reordering:

Transition from SO gaps (50,82,126)

to HO gaps (40,70,112)



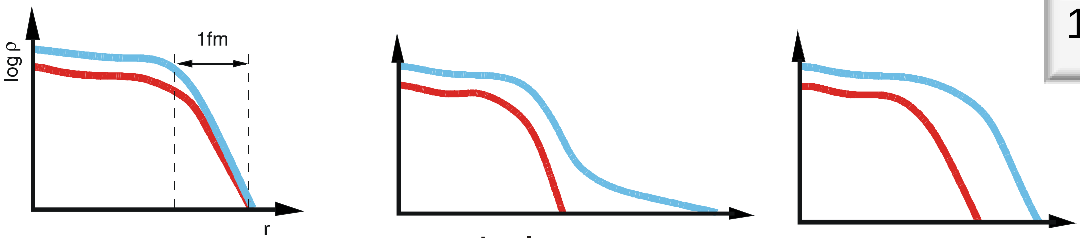
Softening of the nuclear potential:

High-l pushed upward and

Spin-Orbit splitting reduced

How to explain collective phenomena from individual motion?

stable



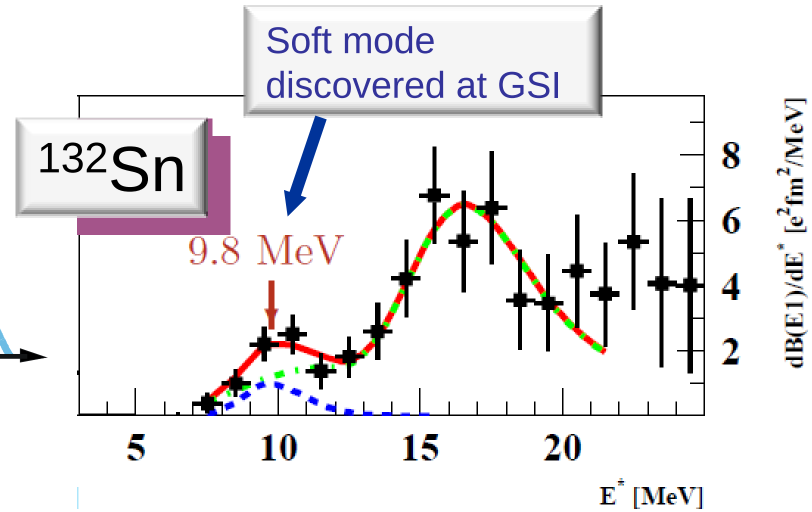
$r_p = r_n, \quad \rho_0 = 0.17\text{fm}^{-3}$
$d_p = d_n = \text{const} \approx 1\text{fm}$

halo

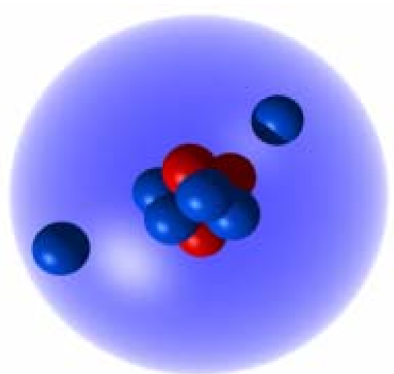
$r_p \neq r_n$
$d_p \neq d_n$

skin

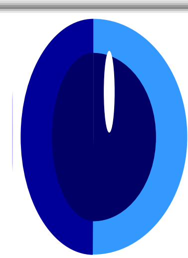
$r_p \neq r_n$
$d_p = d_n$



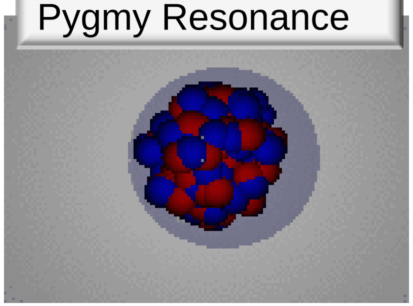
Halos



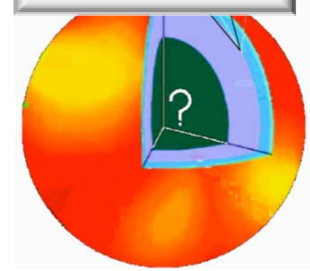
Neutron Skins



Pygmy Resonance



Neutron stars



EOS

NUSTAR - The Project

Super-FRS	RIB production, identification and high resolution spectroscopy
DESPEC	γ-, β-, α-, p-, n-decay spectroscopy
HISPEC	in-beam spectroscopy at low and intermediate energy
ILIMA	masses and lifetimes of nuclei in ground and isomeric states
LASPEC	Laser spectroscopy
MATS	in-trap mass measurements and decay studies
R³B	kinematically complete reactions at high beam energy
ELISE	elastic, inelastic, and quasi-free e–A scattering
EXL	light-ion scattering reactions in inverse kinematics

The Approach

Complementary measurements leading to consistent answers

The Collaboration

> 800 scientists

146 institutes

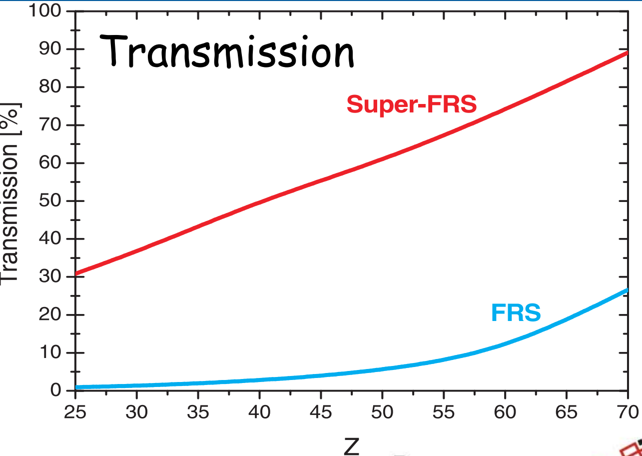
38 countries

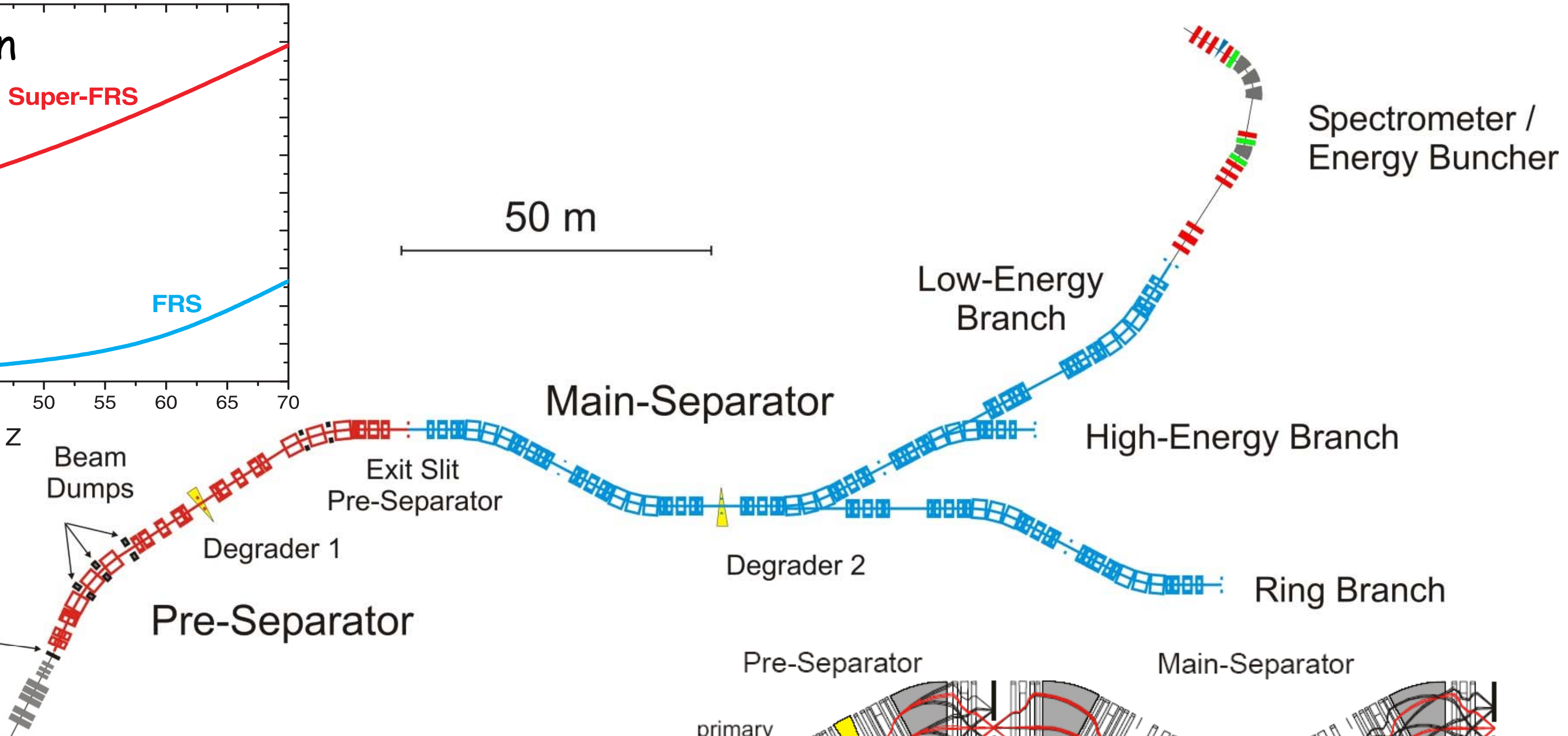
The Investment

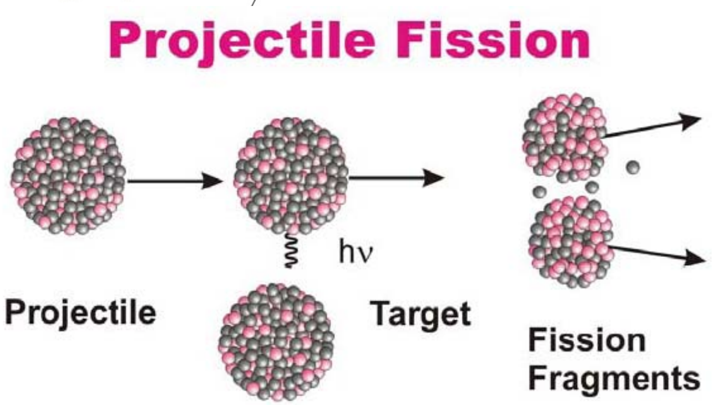
82 M€ Super-FRS

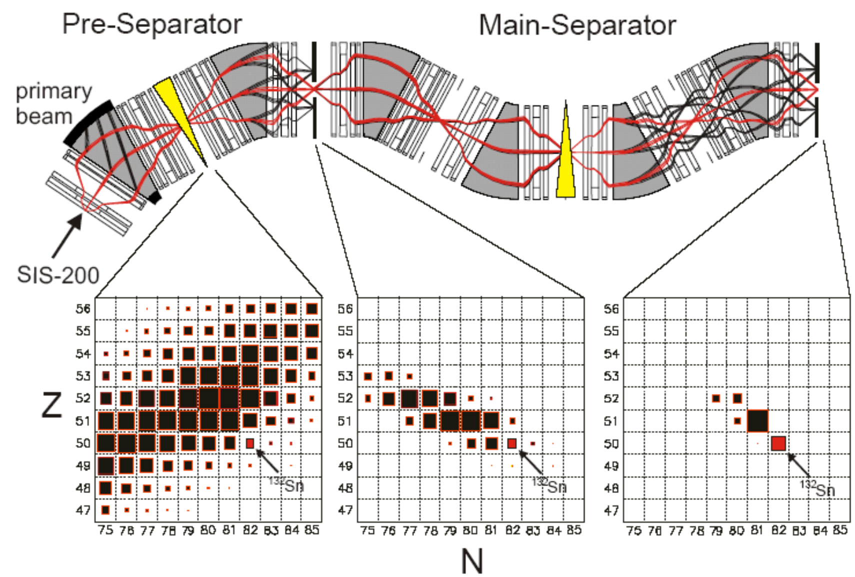
73 M€ Experiments

SUPERconducting FRagment Separator



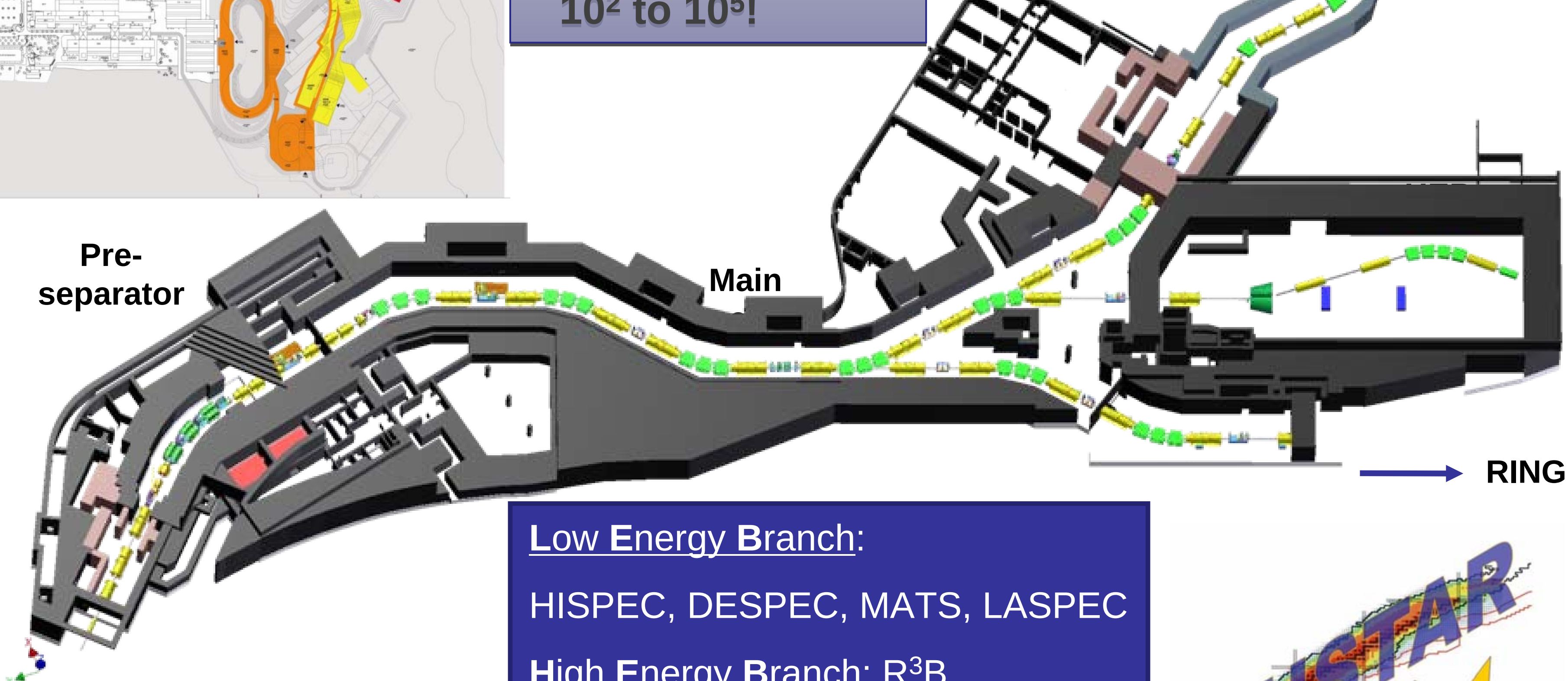






NUSTAR - The Facility

Beam intensity improvement FRS –Super-FRS: 10^2 to 10^5!



<u>**L**ow **E**nergy **B**ranch</u>:

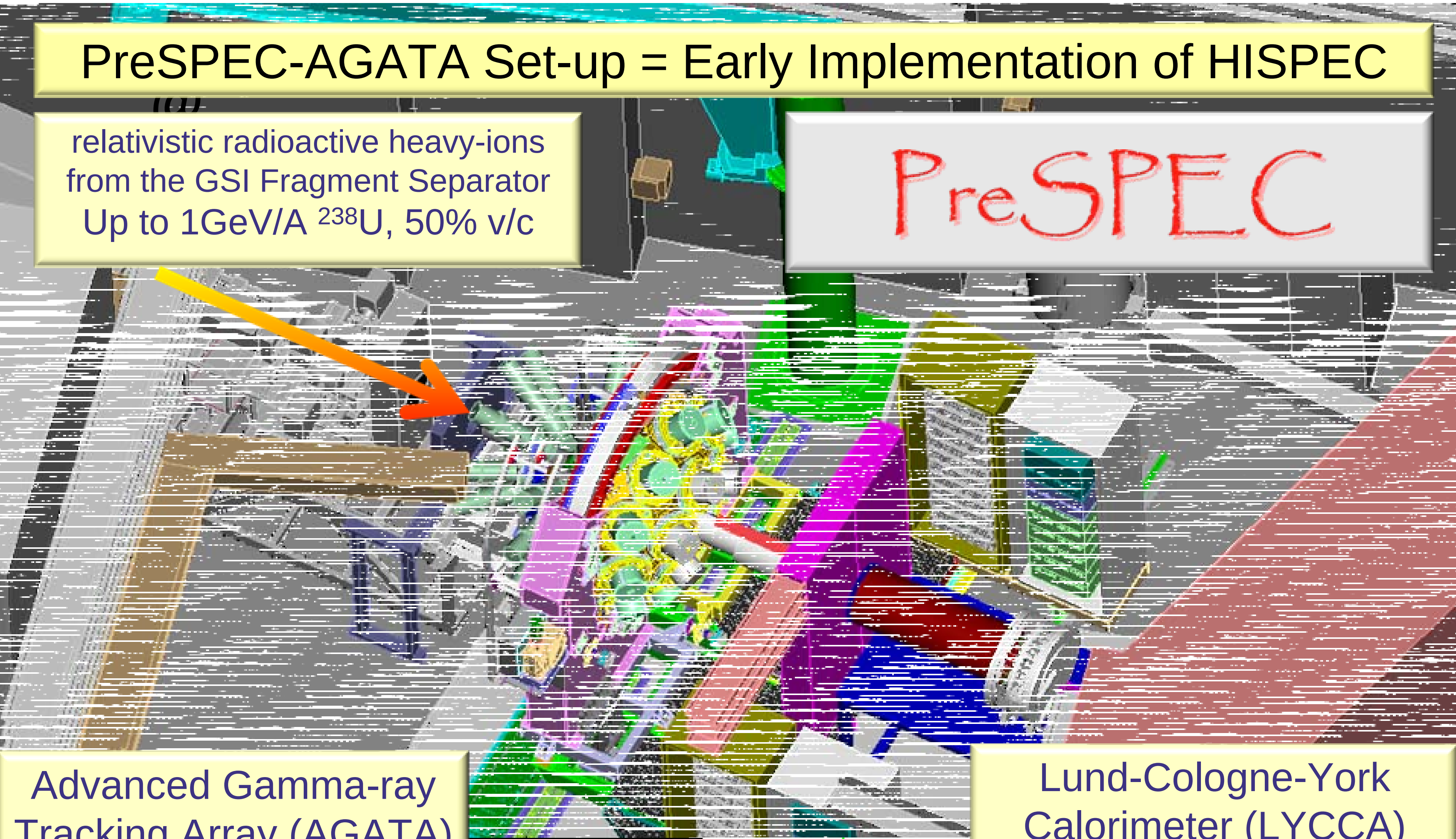
HISPEC, DESPEC, MATS, LASPEC

<u>**H**igh **E**nergy **B**ranch</u>: R^3B

<u>**Ring** Branch</u>: EXL, ILIMA, ELISE

PreSPEC-AGATA Set-up = Early Implementation of HISPEC

relativistic radioactive heavy-ions
from the GSI Fragment Separator
Up to 1GeV/A ^{238}U, 50% v/c



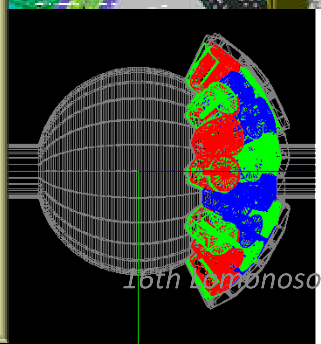
Advanced Gamma-ray Tracking Array (AGATA)

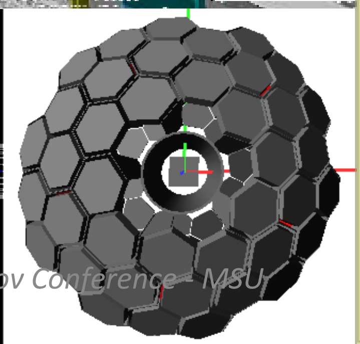
up to 5 x 2+10 x 3 = 40
segmented HP Ge-crystals

d ~ 20 cm

$\varepsilon_{Ph} \approx 17\%$

$\Delta E \approx 0.4\%$

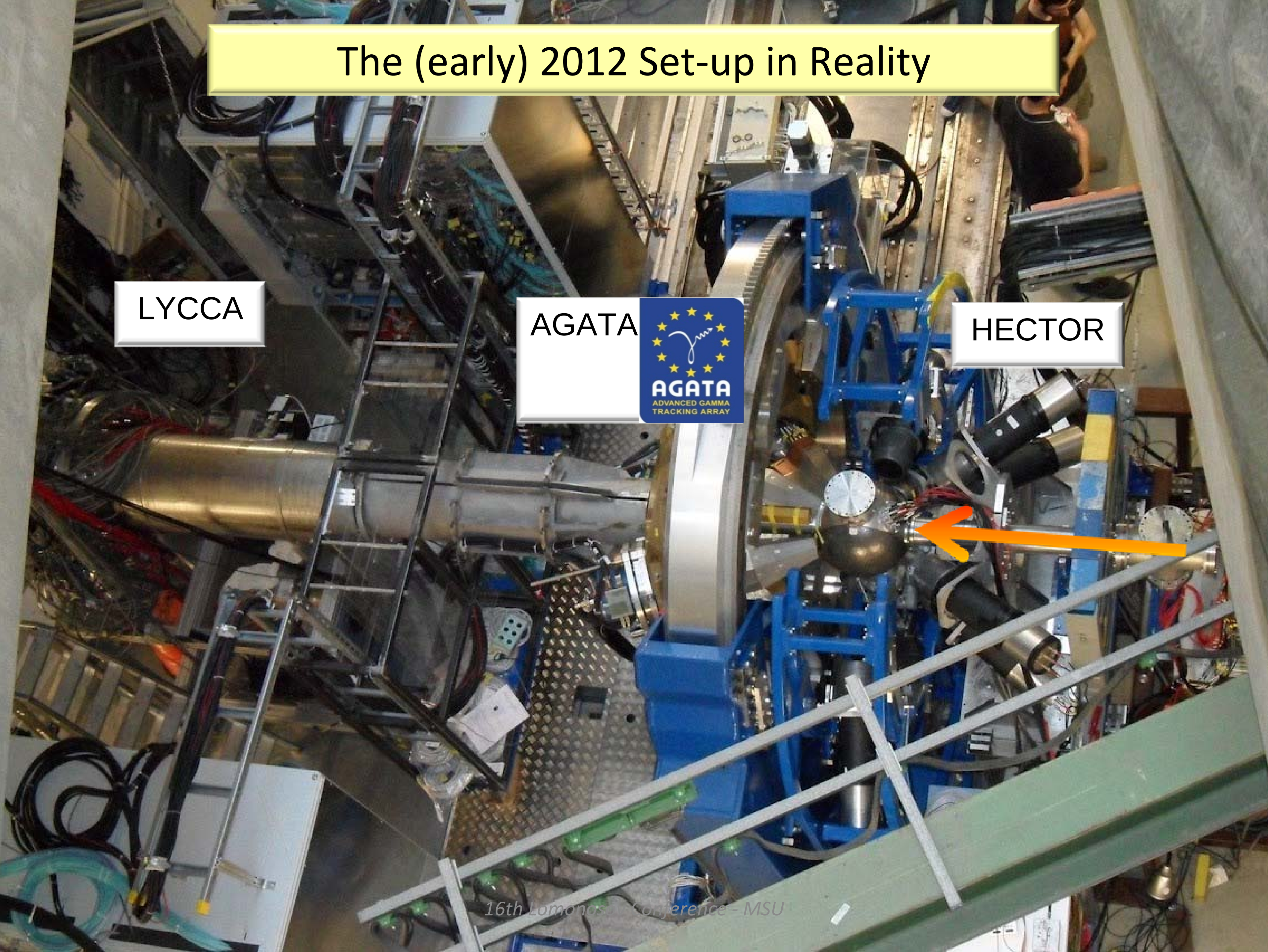




Lund-Cologne-York Calorimeter (LYCCA)

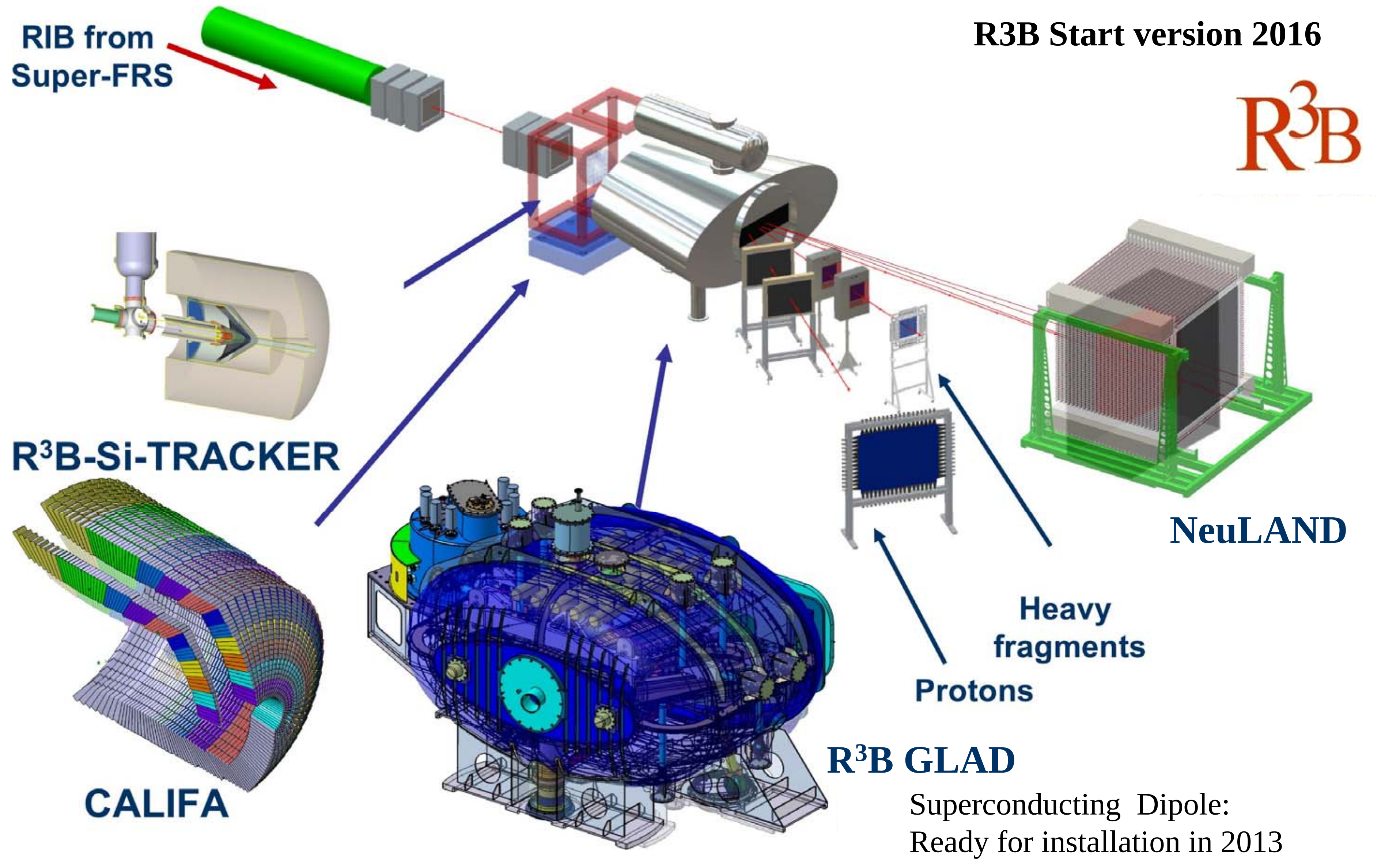
A and *Z* particle-ID after secondary target by means of
- x,y tracking
- ΔE-E (Si-CsI)
- Δt (plastic)

The (early) 2012 Set-up in Reality



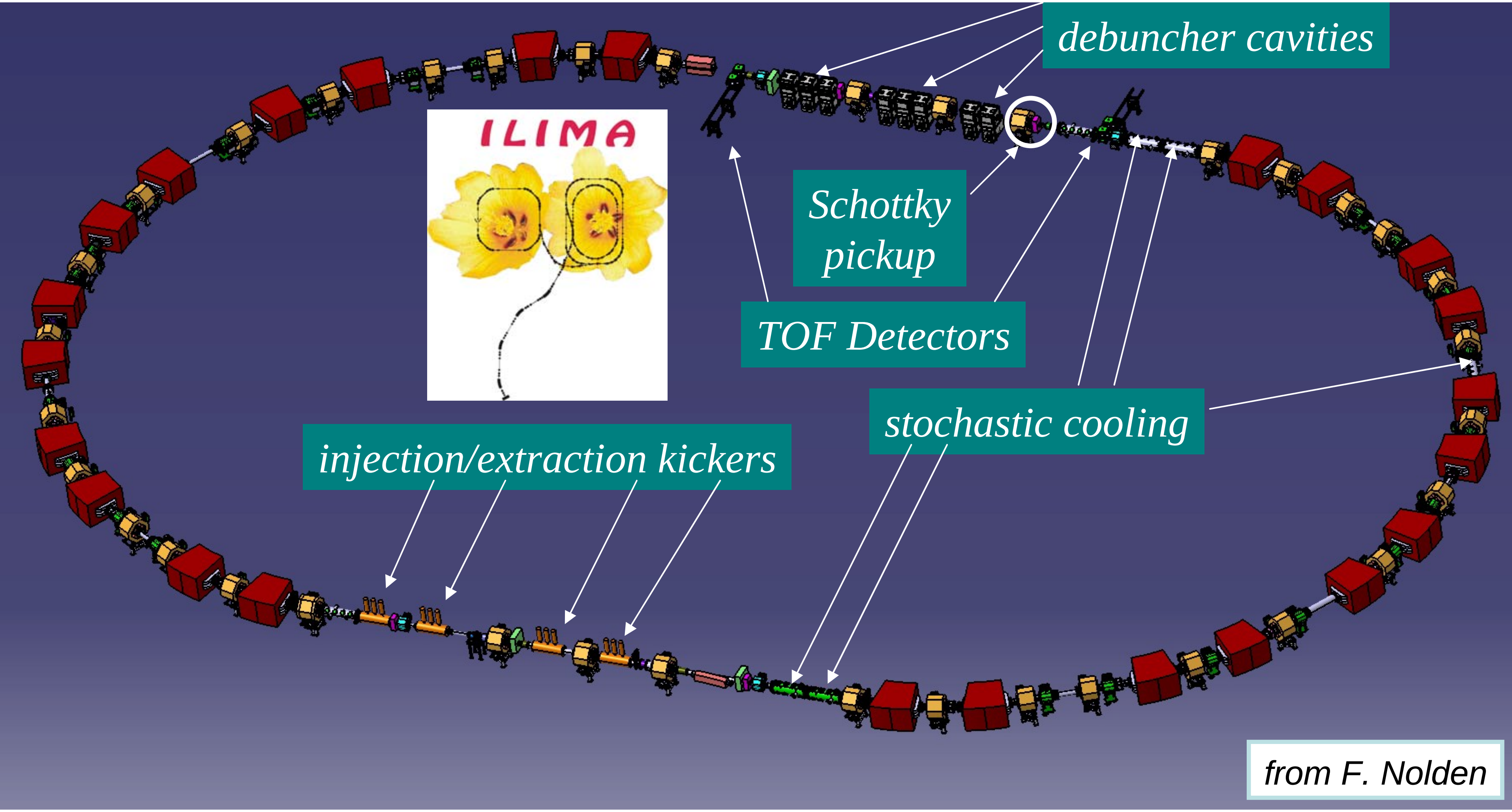
Reactions with Relativistic Radioactive Beams

R3B Start version 2016

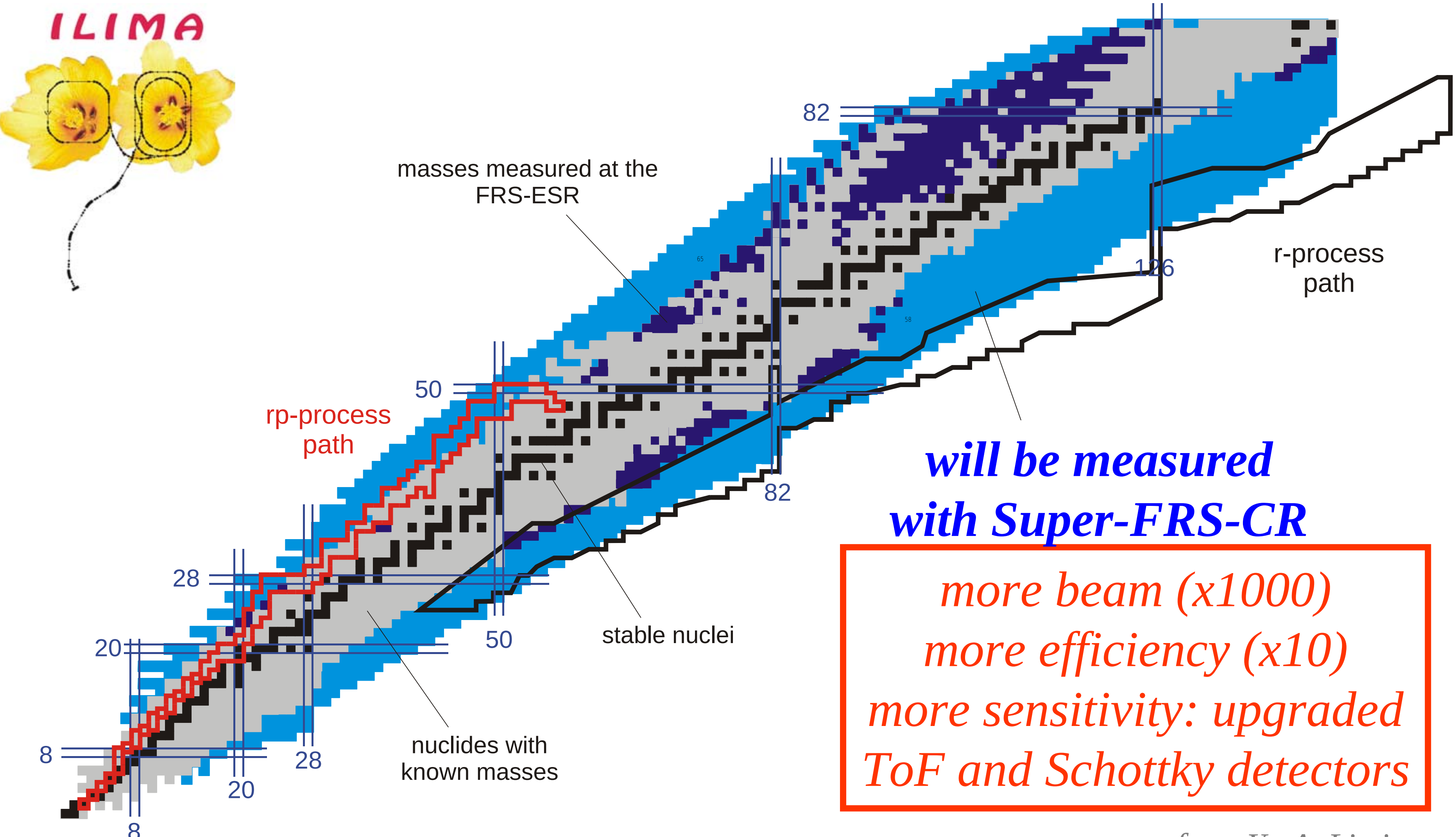


Superconducting Dipole:
Ready for installation in 2013
Construction by CEA Saclay

CR perspective view



Potential for new masses with ILIMA



will be measured with Super-FRS-CR

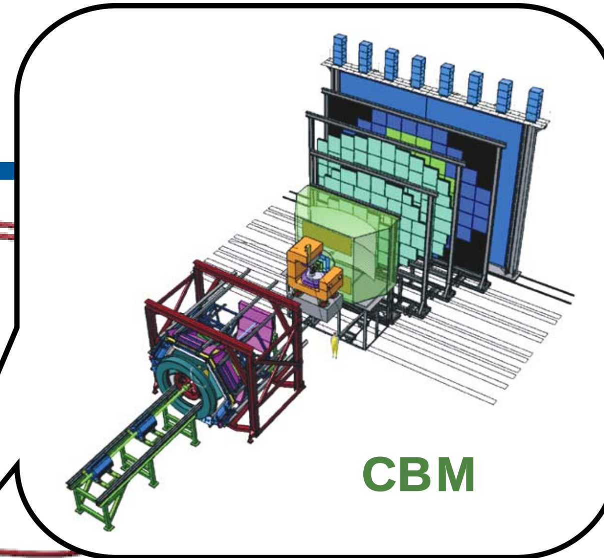
more beam (x1000)
more efficiency (x10)
more sensitivity: upgraded ToF and Schottky detectors

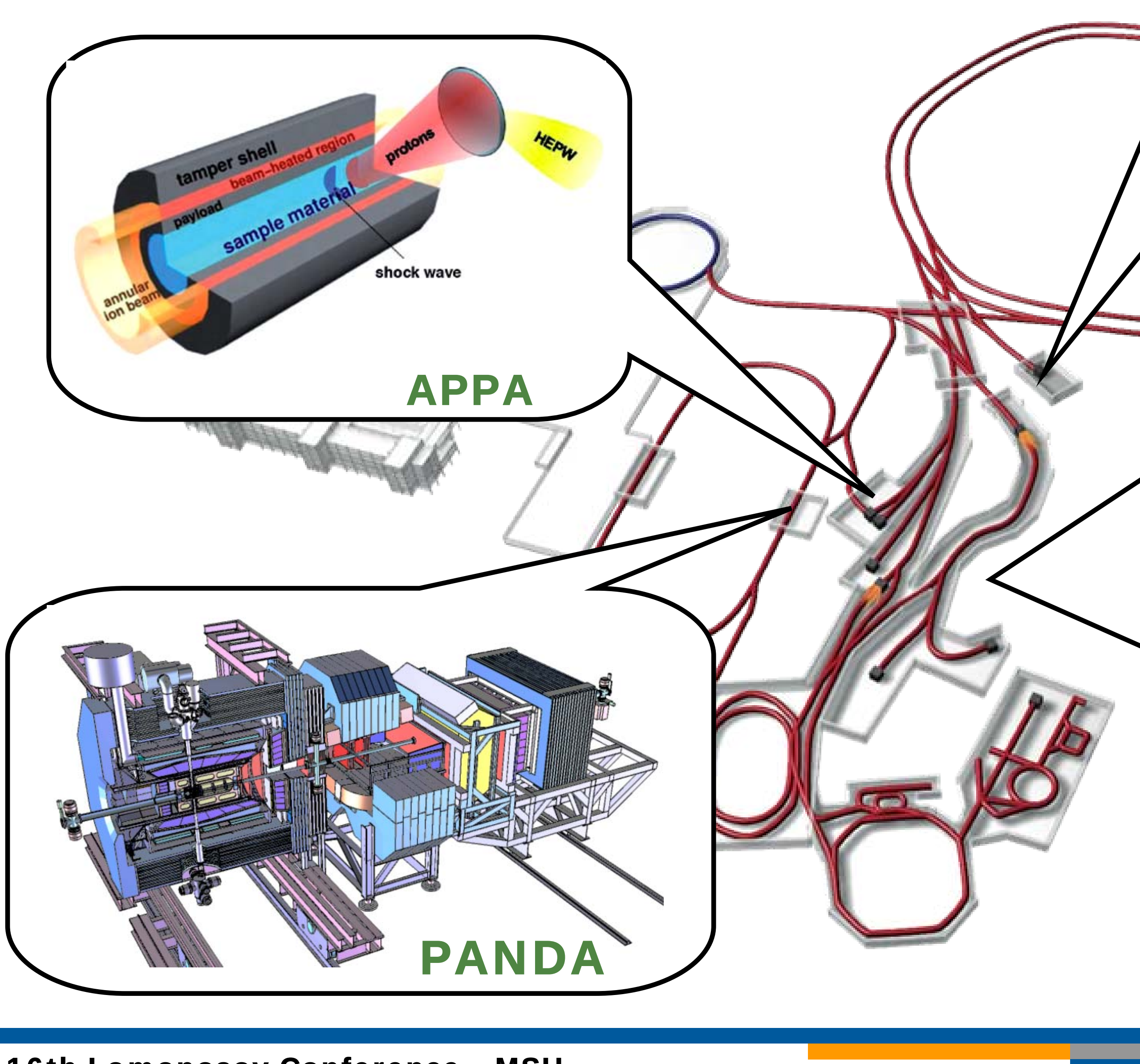
from Yu.A. Litvinov

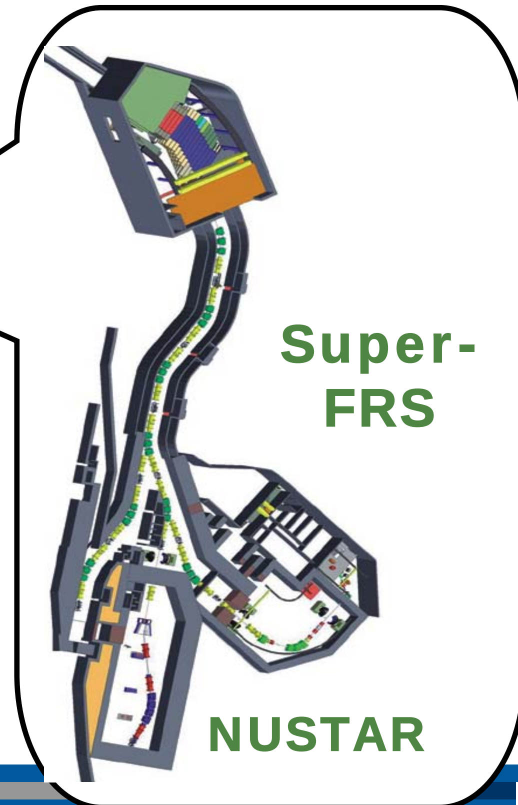
NUSTAR Week Kolkata Oct 2012

> 800 scientists
146 institutes
38 countries

Experiments







Atomic Physics, Plasma Physics, Bio Physics and Materials Research

Research Focus

Matter under Extreme Conditions
&
Extreme States of Matter

• **Highest Charge States**	***Extreme Static Fields***
• **Relativistic Energies**	***Extreme Dynamical Fields and Ultrashort Pulses***
• **High Intensities**	***Very High Energy Densities and Pressures***
• **High Charge at Low Velocity**	***Large Energy Deposition***
• **Low-Energy Anti-Protons**	***Antimatter Research***

Atomic Physics, Plasma Physics, Bio Physics and Materials Research

APPA

- > 500 scientists
- > 90 institutions
- > 30 countries

SPARC

SP: R. Schuch

- 302 scientists
- 83 institutions
- 26 countries

FLAIR

SP: K. Blaum

- 144 scientists
- 49 institutions
- 15 countries

HEDgeHOB

SP: D. Varentsov

- 175 scientists
- 43 institutions
- 14 countries

BIOMAT

SP: M. Durante
C. Trautmann

- 136 scientists
- 70 institutions
- 20 countries

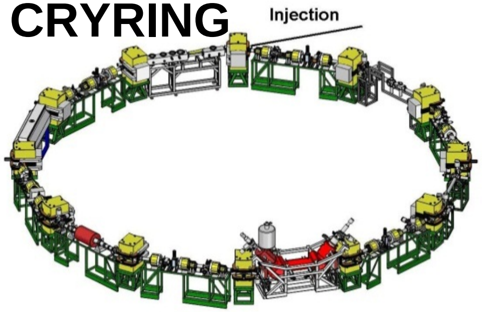
WDM

SP: F. Rosmej

- 71 scientists
- 24 institutions
- 8 countries

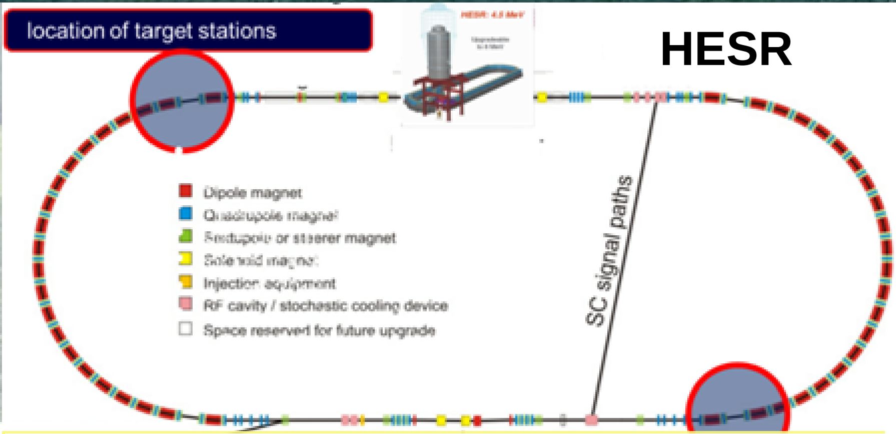
MSV for APPA (Status 2012): The Facilities

CRYRING



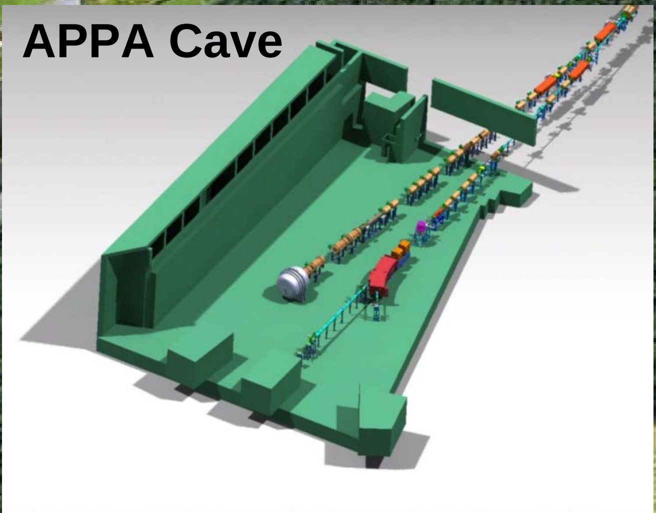
Cold Low-Energy Heavy Ions and Anti-Protons

HESR



Cold Relativistic Heavy Ions

APPA Cave



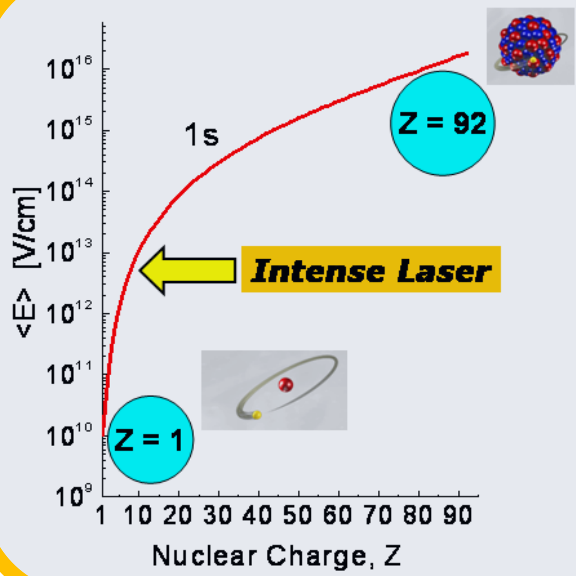
Unique physics opportunities !!! ☺

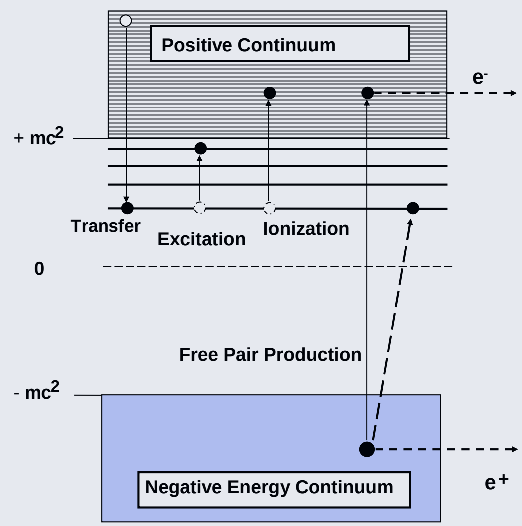
Atomic & Fundamental Physics

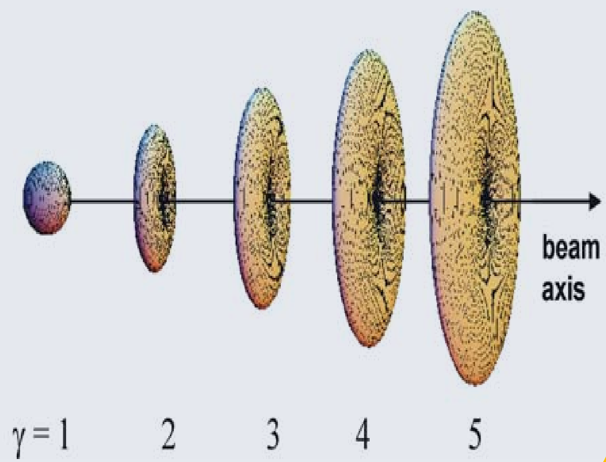
SPARC — Stored Particles Atomic Physics Research Collaboration

FLAIR — Facility for Low-energy Antiproton and Ion Research

QED in the non-perturbative regime
Correlated multi-body dynamics for atoms and ions
Precision determination of fundamental constants
Influence of atomic structure on nuclear decay properties
Fundamental physics and antimatter

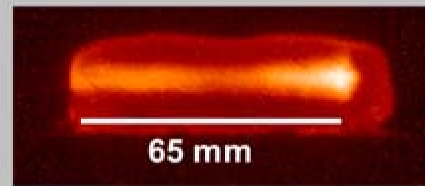






Courtesy Th. Stöhlker

Plasma Physics at FAIR



Ne^{10+} 300 MeV/u; Kr crystal

Interaction of ions and photons with plasmas
Equation of state, phase transitions, transport phenomena
Matter under high pressure
Coupling of intense light with matter

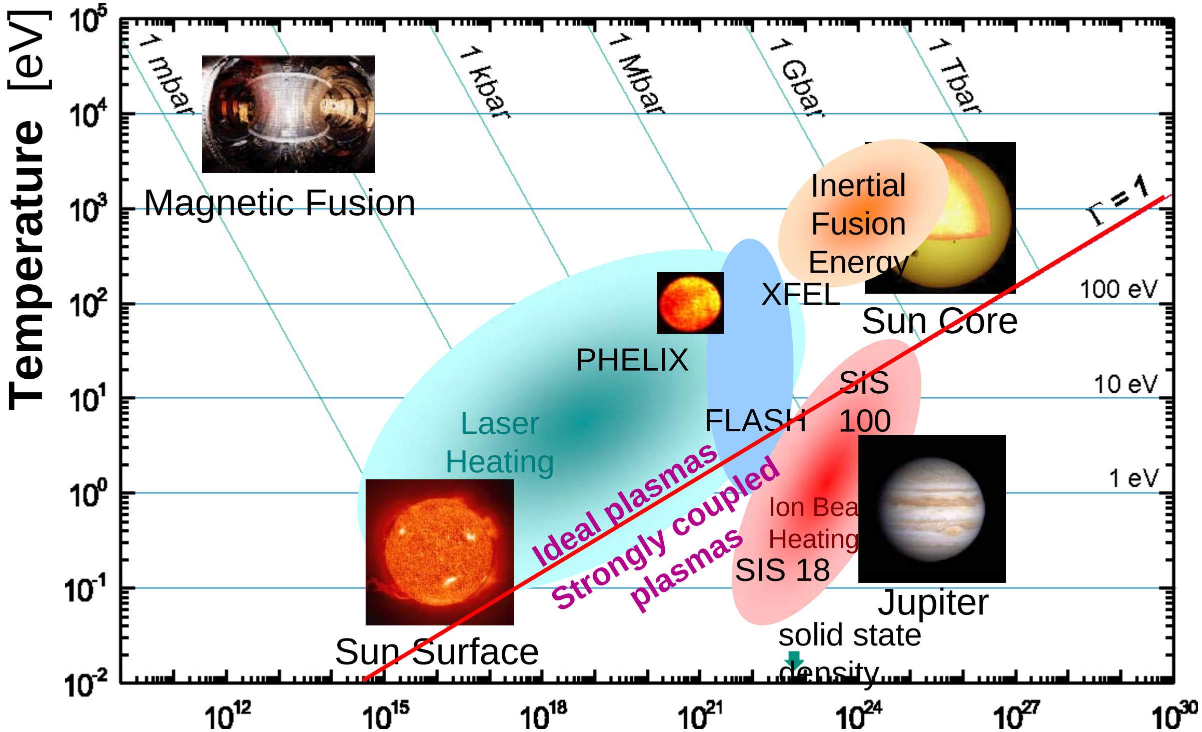
- large volume of sample (mm^3)
- fairly uniform physical conditions
- high entropy @ high densities
- high rep. rate and reproducibility
- any target material

Courtesy Th. Stöhlker

Plasma Physics with Intense Ion Beams

Relevant for astrophysics, planetary science, inertial confinement fusion research, research on materials under extreme conditions

Measurements are required for guidance of theoretical models



Density [cm^{-3}]

Degeneracy

E_{KIN}=kT ≈ E_{Fermi}

Strongly coupled plasmas, $\Gamma = E_C / E_{KIN} > 1$

Courtesy Th. Stöhlker

Staging

Start Version Phase A (SIS100)						**Phase B** (SIS300)
Modularised Start Version						
Module **0**	Module **1**	Module **2**	Module **3**	Module **4**	Module **5**	
SIS100	**Exp. halls** *CBM & APPA*	**Super-FRS** *NuSTAR*	**Antiproton Facility** *PANDA & options NuSTAR*	**LEB, NESR, FLAIR** *NuSTAR & APPA*	**RESR** *PANDA, NuSTAR & APPA*	

2018

Costs

Accelerators and personnel (including Super-FRS)	502 M€
Civil construction (excluding site related costs)	400 M€
FAIR contribution to experimental end stations *	78 M€
FAIR GmbH personnel & running until 2018 (>8 years)	47 M€
Grand Total MSV, Modules 0 - 3	1027 M€

in 2005 €

(inflation escalation until 2018: ca. **+50%**)

* Total experimental end stations (excluding Super-FRS): ca. 210 M€ (2005) = 315 M€ (2018)

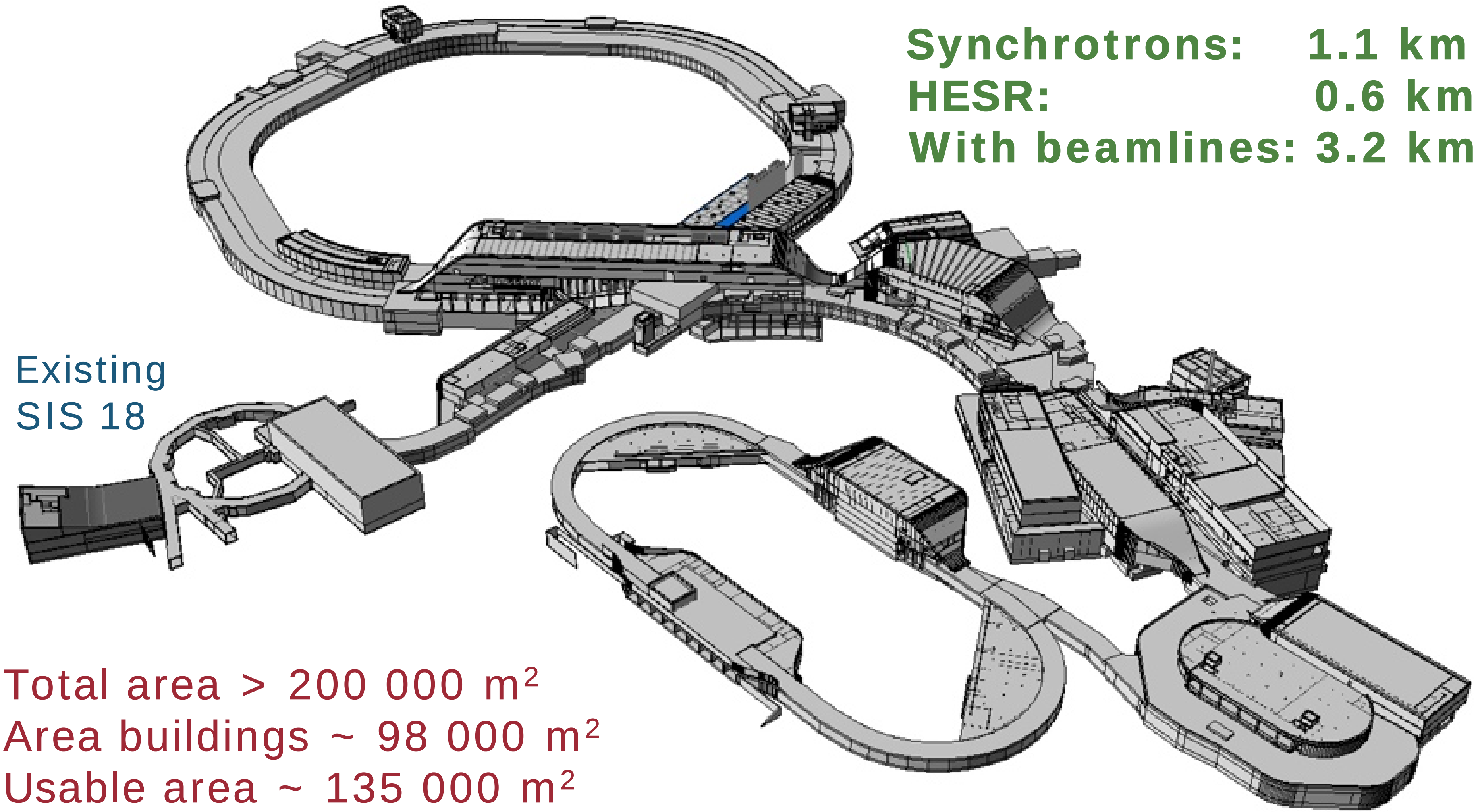
FAIR Member States

Contracting Party	Contribution (in 2005 M€)
Finland	5.00
France	27.00
Germany	705.00
India	36.00
Poland	23.74
Romania	11.87
Russia	178.05
Slovenia	12.00
Sweden	10.00
Total	**1.008,66**

- **All numbers in 2005 €** (escalation until 2018 ca. **+50%**)
- UK Associate Member since 3/5/13
- Spain expected to join soon as a full member
- Talks with China on Associate FAIR Member status
- Talks with Italy
- Additional contributions to experiments by many countries

Civil Construction

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



Existing
SIS 18

Total area > 200 000 m^2
Area buildings ~ 98 000 m^2
Usable area ~ 135 000 m^2
Volume of buildings ~ 1 049 000 m^3
Substructure: ~ 1500 pillars, up to 65 m deep

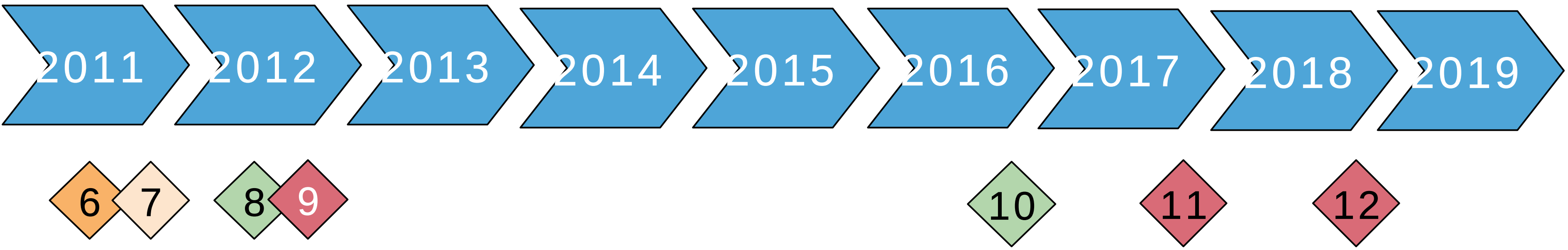
Bird’s View

Courtesy G. Rosner

...closing in

Courtesy G. Rosner

Timeline



6 Submission building permits

7 Site preparation

8 Civil construction contracts

9 Building of accelerator & detector components

10 Completion of civil construction work

11 Installation & commissioning of accelerators and detectors

12 Start data taking

Courtesy G. Rosner

Conclusions

- The FAIR facility is that will offer world-wide unique research opportunities
  - plasma, atomic, nuclear and subnuclear physics
  - a truly international infrastructure
- Construction of the start version has commenced
  - Excellent potential for going to the full version and beyond

Thanks to:
Günther Rosner – FAIR Scientific director
James Ritman – PANDA
Peter Senger – CBM
Thomas Stöhlker – APPA
and numerous NUSTAR colleagues
for providing slides