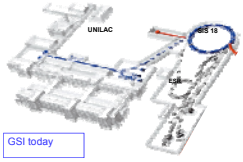
NUSTAR and the status of the R³B project at FAIR

O. Tengblad for the R3B collaboration

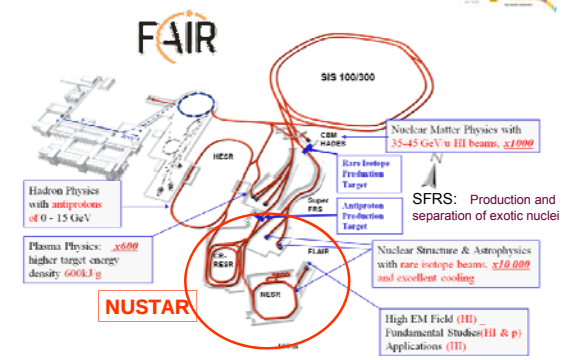
http://www.gsi.de/forschung/kp/kr/R3B_e.html ,
email: olof@iem.cfmac.csic.es

INTERNATIONAL SYMPOSIUM ON NUCLEAR PHYSICS
December 8 – 12, 2009
Bhabha Atomic Research Centre, Mumbai – 400 085, INDIA
Sponsored by the Board of Research in Nuclear Sciences, Department of Atomic Energy

FAIR - Facility for Antiproton & Ion Research @GSI Darmstadt Germany



The FAIR research community



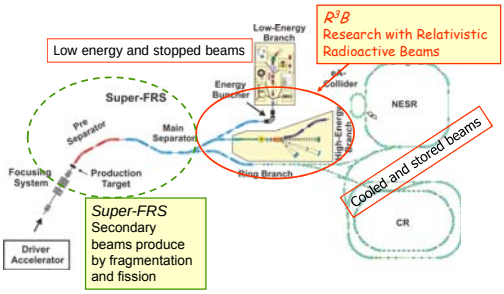
NUSTAR - a facility for NUclear STructure & Astrophysis Research

Superconducting Fragment Separator

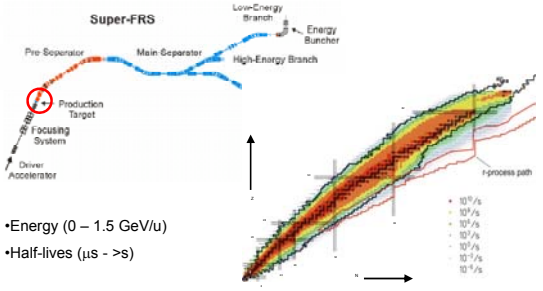
·High Energy Reaction Set-up

·Multi-Storage Rings

·Energy bunched and stopped beams



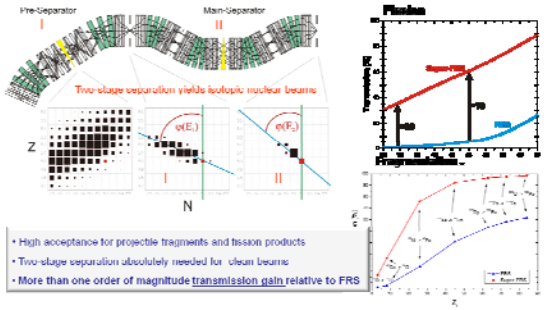
Super-FRS – radioactive beams at FAIR



- Energy (0 – 1.5 GeV/u)
- Half-lives (μs - >s)

5

The Super-FRS



6

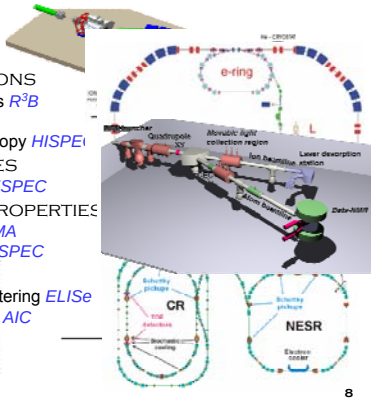
NUSTAR

> 800 members from 37 countries and 146 institutions

7

NuSTAR Experiments

- Nuclear reactions
  - Relativistic energies *R³B*
  - Cooled beams *EXL*
  - High-res. spectroscopy *HISPE*
- Decay properties
  - Stopped beams *DESPEC*
- Ground state properties
  - Masses *MATS, ILIMA*
  - Radii, momenta *LASPEC*
- New tools
  - Electron – RIB scattering *ELISe*
  - p-bar – RIB collider *AIC*



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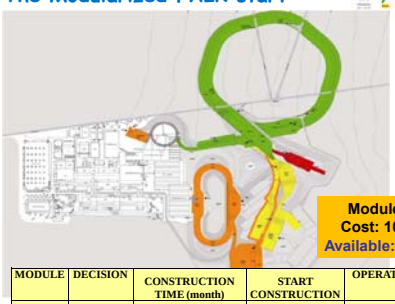
The Modularized FAIR start

- Module 0 SIS100 op. 2015/16
- Module 1 SIS100-EXP op. 2015/16
- Module 2 SFRS +R3B op. 2016
- Module 3 Antiproton, CR, HESR



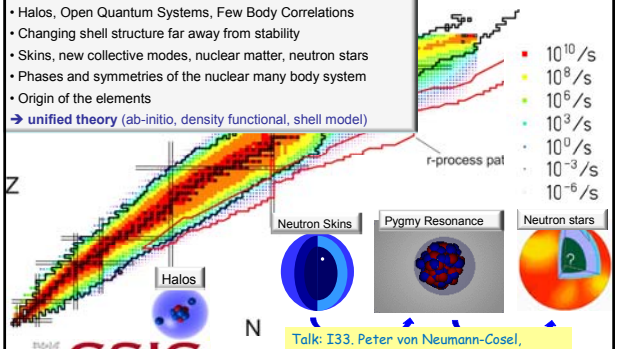
Module 0 -3
Cost: 1027 M€
Available: 1039 M€

MODULE	DECISION	CONSTRUCTION TIME (month)	START CONSTRUCTION	OPERATIONAL
0	2009	72	2010/11	2015/16
1	2009	28	2010/11	2015/16
2	2010/11	60	2012	2016
3	2010/11	60	2012	2016

Central Topics for NuSTAR at FAIR

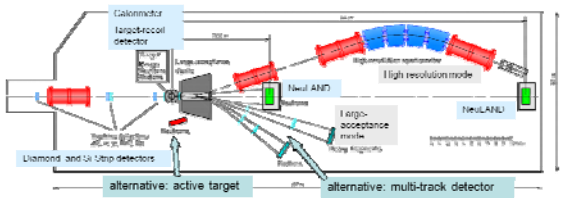
- Quest for the limits of existence
- Halos, Open Quantum Systems, Few Body Correlations
- Changing shell structure far away from stability
- Skins, new collective modes, nuclear matter, neutron stars
- Phases and symmetries of the nuclear many body system
- Origin of the elements

➔ **unified theory** (ab-initio, density functional, shell model)



Talk: I33. Peter von Neumann-Cosel, *Pygmy dipole resonance in stable nuclei*

R³B: Reactions with Relativistic Radioactive Beams



Kinematically complete measurement of reactions with high-energy secondary beams

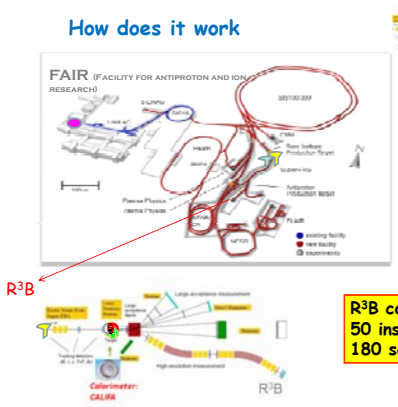
- Nuclear Astrophysics
- Structure of exotic nuclei
- Neutron-rich matter

·A universal fixed-target experiment for complete inverse-kinematics reactions with relativistic RIBs (~300 – 1500 MeV/u),

·Experiments with the most exotic (<1 ion/s) and short-lived nuclei – exploring the isospin frontier at and beyond the drip-lines –

·Concept built on existing ALADIN-LAND experiment at GSI

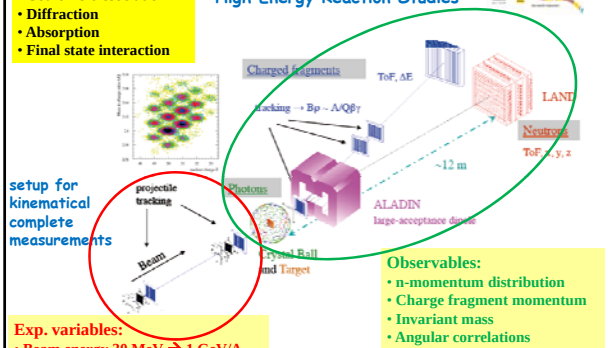
How does it work



R³B collaboration:
50 institutes
180 scientists

Reaction mechanism:
- Coulomb dissociation
- Diffraction
- Absorption
- Final state interaction

High Energy Reaction Studies



setup for kinematical complete measurements

Observables:
- n-momentum distribution
- Charge fragment momentum
- Invariant mass
- Angular correlations

Exp. variables:
- Beam energy 30 MeV → 1 GeV/A
- Target material H → Pb
- Projectile ^{6}He → ^{238}U

Light-Ion Induced Direct Reactions

- elastic scattering (p,p), (α,α), …
  nuclear matter distribution ρ(r), skins, halo structures
- inelastic scattering (p,p'), (α,α'), …
  deformation parameters, B(E2) values, transition densities, giant resonances
- charge exchange reactions (p,n), (^{3}He,t), (d, ^{2}He), …
  Gamow-Teller strength
- transfer reactions (p,d), (p,t), (p, ^{3}He), (d,p), …
  single particle structure, spectroscopic factors
  spectroscopy beyond the driplines
  neutron pair correlations
  neutron (proton) capture cross sections
- knock-out reactions (p,2p), (p,pn), (p,p ^{4}He)…
  ground state configurations, nucleon momentum distributions, cluster correlations

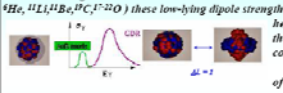
Poster D2

S. Chakraborty & U.Datta Pramanik et al,
Saha Inst of Nuclear Physics, Kolkata, India

Low-lying dipole strength of neutron-rich 'Island of inversion' nuclei around N~ 20

Low-lying dipole strength and PDR

In case of neutron rich nuclei in addition to GDR a new type of excitation mode occurs due to the collective motion of the neutron core and neutron skin. This phenomena is called pygmy resonance. Excitation energies here are much below GDR resonance energy. In neutron rich psd-shell nuclei (e.g. ^{6}He, ^{11}Li,^{11}Be,^{19}C,$^{17-22}$O) these low-lying dipole strength are single particle in nature. However, in heavier nuclei, neutron rich Sn, Sb (N ~ 82), these excitation modes are observed to be collective in nature.

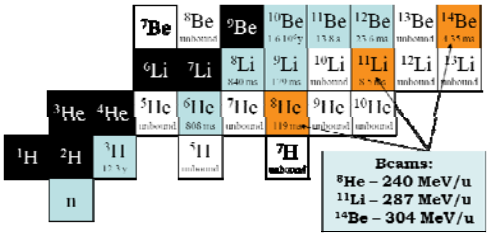


Our experiment aims at exploring the nature of Low-lying dipole strength in the neutron-rich nuclei around N~20.

Astrophysical interest

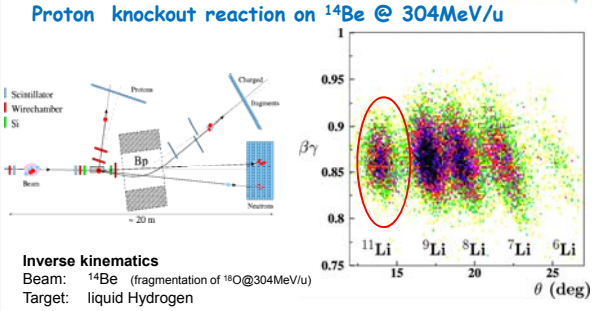
Indirect method of measurement of radiative capture cross-section of unstable neutron-rich nuclei will be useful in nucleosynthesis process . Further the unique method using RIB will help us to pin down the isospin-dependent part of Equation Of State of asymmetric nuclear matter.

S245@GSI - Unbound Light Nuclei



Beams:
^{8}He – 240 MeV/u
^{11}Li – 287 MeV/u
^{14}Be – 304 MeV/u

Proton knockout reaction on ^{14}Be @ 304MeV/u

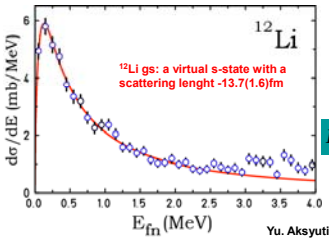


Inverse kinematics
Beam: ^{14}Be (fragmentation of ^{18}O@304MeV/u)
Target: liquid Hydrogen

Yu. Aksyutina *et al.* PLB 666(2008)430

^{1}H(^{14}Be,2pn)^{12}Li

Differential cross section as function of relative energy for ^{12}Li(^{11}Li+n) after 1p knockout from ^{14}Be



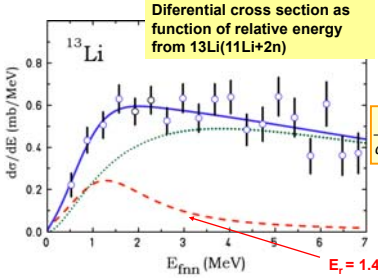
ε =1.47(19)MeV
S_{2n} = 1.26(13) MeV

$$E_{fn} = \left|\vec{P}_f + \vec{P}_n\right| - M_f - m_n$$

Yu. Aksyutina *et al.* PLB 666(2008)430

^{1}H(^{14}Be, 2p)^{13}Li

Diferential cross section as function of relative energy from 13Li(11Li+2n)



Correlated background

$$\frac{d\sigma}{dE_{f2n}} = \frac{E_{f2n}^2}{(2.21S_{2n} + E_{f2n})^{7/2}}$$

C. Forssén *et al.* NPA 673 (2008) 143

E_r = 1.47(31) MeV
three- body resonance

Yu. Aksyutina *et al.* PLB 666(2008)430

What do we gain by FAIR

Higher Primary beam energy

Higher secondary beam intensity

Thicker reaction targets
In the order of 1 g/cm^2

Reaction products
Kinematically forward focused

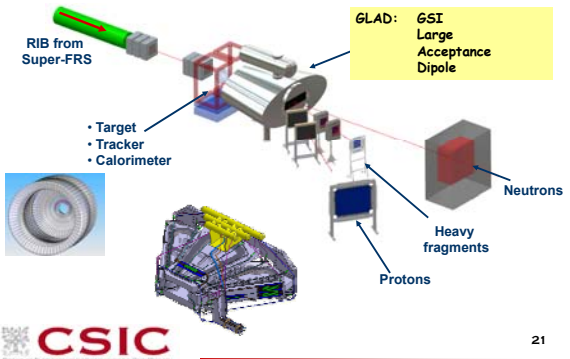
Implies an extended detection scheme with better efficiency and resolution

Possible study more exotic nuclei
efficient down to 1 ion/s, shorter halflive

Primary Beams
- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- 2(4)x10^{13}/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 35 GeV/u
- up to 90 GeV protons

Reactions with Relativistic Radioactive Beams

R³B Start version



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Neutron detector NeuLAND

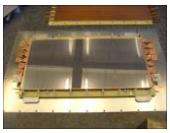
Working group coordinator: K. Boretzky (GSI)

Existing LAND detector:
- σ_t < 250 ps
- $\sigma_{x,y,z}$ ≈ 3 cm
- Size: 2 x 2 x 1 m³
- Plastic scintillator / Fe converter sandwich structure

NeuLAND design goals:
- σ_t < 100 ps
- $\sigma_{x,y,z}$ ≈ 1 cm
- Size : approx. 2 x 2 x 0.8 m³
- Efficiency > 90% for 1-n hits
- Improvement of multi-n recognition

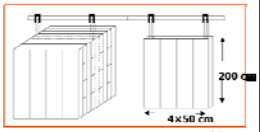
Timing RPC concept:
- Total of 140 m² RPC
- Approx. 10'000 channels
- Converter material: integrated in RPC structure

detection principle based on Resistive Plate Chambers layered with iron converters



status:
- ✓ proof of principle: RPC excellent for slow protons
- ✓ prototypes with included converter as electrodes: efficiency of 99%, time resolution ~50 ps

Strong participation by the Saha Inst of Nuclear Physics, Kolkata, India



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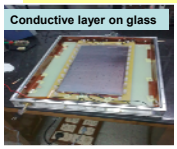
Development of RPC for NeuLand @ SINP, Kolkata:

The 1st prototype build @SINP 2nd week of Nov. Testing started with cosmic Background.

SINP Proposal submitted to DST, India for ½ NeuLAND@R3B



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U.Datta Pramanik et al, Saha Inst of Nuclear Physics, Kolkata, India

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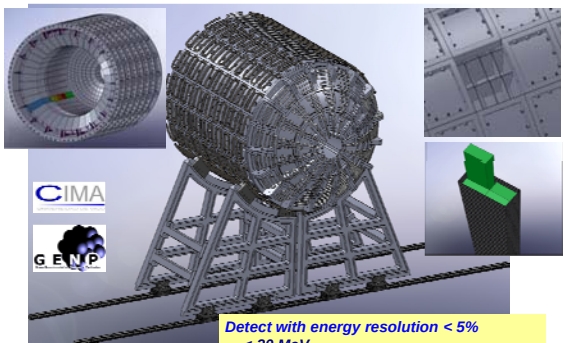
Calorimeter CALIFA@R³B R&D

Engineering design and Mechanical structure → based on carbon fibre alveolus



Detect with energy resolution < 5%
γ < 30 MeV
p < 300 MeV

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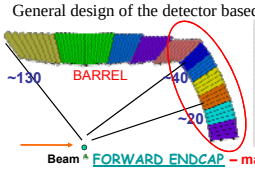
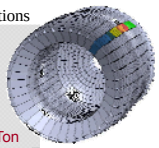
Calorimeter CALIFA@R³B R&D

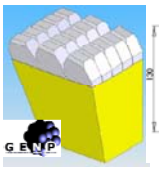
General design of the detector based on kinematical considerations

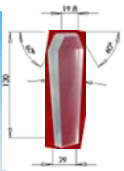


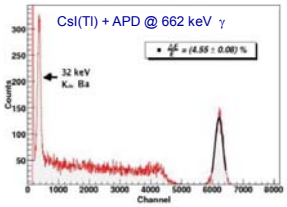
"Egg" shape
Highly segmented
Thick detection volume
Inner radius 30cm
Crystal length 13 cm
Barrel 3650 crystals = 1.6 Ton



FORWARD ENDCAP – major challenge! Phoswich LaBr/LaCl ?







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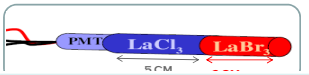
WG Coordinator: Lola Cortina, Univ. Santiago de Compostela

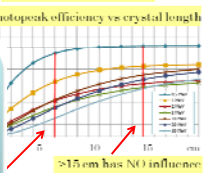
Calorimeter CALIFA@R³B R&D

Forward end cap → possible Phoswich solution

In the Forward direction the high energy combined the exponential behavior of the Lorentz boost makes a special solution needed;
Possible solution → Two high resolution & high efficiency scintillator crystals in a phoswich configuration with a common readout

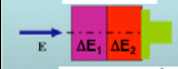


Geant 4 simulations



Phoswich: proton detection

LaBr + LaCl



$E = f(\Delta E_1) + g(\Delta E_2)$

$$\frac{dE}{dx} = K z^2 \frac{Z}{A\beta^2}\left[\frac{1}{2}\log\frac{2m_e c^2\beta^2\gamma^2 T_{max}}{I^2} - \beta^2\right]$$

>15 cm has NO influence on detection efficiency

% of incident beam is detected

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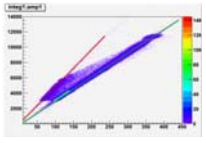
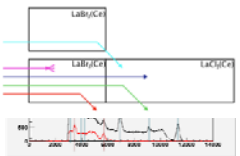
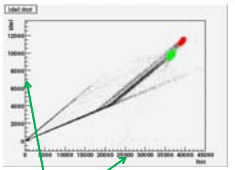
Phoswich response to gammas and protons

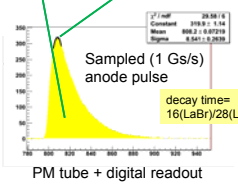
Huge dynamic range <30 MeV γ <300 MeV p



228Th gamma source
Eγ = 200 -2600 KeV







Sampled (1 Gs/s) anode pulse

decay time= 16(LaBr)/28(LaCl) ns

PM tube + digital readout

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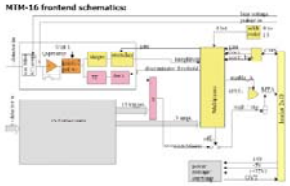
Calorimeter CALIFA R&D

Readout Electronics for APD

MTM-16 Preamp, shaper, dicriminator, multiplexer
MDI-2 VME Sequencer and ADC

2 x 256 channels
Daisy-chained
(like DRAMs)

30 € /ch



Features:

- High quality 12 bit (4k) conversion with sliding scale ADC (DNL < 1%).
- 10 M samples / s per bus.
- Up to 512 channels can be converted
- Multi event buffer
- Zero suppression with individual thresholds
- Supports different types of time stamping
- Connected frontend modules can be remote controlled (gain, threshold, polarity).
- Address modes: A24 / A32
- Data transfer modes: D16,32,64, BLT32, MBLT64, CBLT
- Multicast for event reset and timestamping start.

DLEP mesytec

Olof Tengblad ISNP 2009 MUMBAI

Alternative digital solution

Slow control

MPR16 – Preamp
Lin/Log
Temperature control
HV monitoring

HADES -development

data

trigger

16 x 40MHz 12 bit ADC
MWD – moving window deconvolution (DGF), 14 bit eff.
Internal module trigger
different algorithms in parallel
ca 50 € / channel

TRB net
Hub for 16 fibers
GBit - interface

Participation by: Prof. Vandana Nanal and Rudrajyoli Palit
Dept. of Nuclear & Atomic Physics
Tata Inst of Research, Mumbai, India

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R3B experiment Cost & commitments

Cost Estimate in 2005 €			
Magnets	Quadropoles	1.000€	
	GLAD	5.700€	7
Detectors	ToF wall	370€	
	Tracking	270€	
	CALIFA	3.200€	
	Recoil	650€	
	NeuLand	2.500€	7
Vacuum		300€	
DAQ		500€	
Infrastructure		110€	1
			15 MC

Comittments as of 2005	
GSI	3.000€
Spain	2.000€
Sweden	1.650€
Univ. Germany	1.370€
UK	1.100€
India	1.000€
France	500€
Russia	300€
Poland	200€
EU	3.500€
	15 MC

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Summary

- FAIR will become a world-class centre for major parts of the subatomic physics
  - Modularised version maintains competitiveness in all scientific domains
- NUSTAR community combines a vast number of complementary exp. facilities & methods to study the nuclear structure
  - Low Energy, High Energy and Ring Branch
    - Hispec, Despec, Mats, Ilima, R3B, Exl, Elise ...
- R³B - Reactions with relativistic radioactive beams yield unique possibilities for studies of nuclear systems at the extremes, based on a generic fixed-target set-up
  - Fully adapted to Super-FRS production method
- R&D enlarging the experimental toolbox at R³B requires cutting-edge instrumentation
  - Has to be accompanied by efficient methods for data handling and analysis

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R³B collaboration

Argonne National Laboratory, USA
ATOMKI, Debrecen, Hungary
CCLRC Daresbury Laboratory, UK
CEA Saclay, France
Chalmers Uni of Tech, Göteborg, Sweden
IFIC - CSIC, Valencia, Spain
CUPP project, Pyhaesalmi, Finland
Dep. of Phys & Astro, Univ Aarhus, Denmark
Forschungszentrum Rossendorf, Germany
GANIL, Caen, France
GSI, Darmstadt, Germany
IFJ PAN Krakow, Poland
IN2P3/IPN Orsay, France
Inst of Modern Physics, Lanzhou, China
IEM - CSIC, Madrid, Spain
Inst de Fisica, Univ de Sao Paulo, Brazil
IPN Lyon, France
IPPE Obninsk, Russia
Jagellonski University, Krakow, Poland
Johannes Gutenberg Univ, Mainz, Germany
J W Goethe Univ, Frankfurt, Germany
Joint Inst Nuclear Research, Dubna, Russia
Justus-Liebig-Univ, Giessen, Germany
Kurchatov Inst, Moscow, Russia
Max-Planck Inst Heidelberg, Germany
Michigan State Univ, East Lansing, USA
PNPI, Petersburg, Gatchina, Russia
RIKEN, Japan
Russian Academy of Sciences, Moscow, Russia
Saha Inst of Nuclear Physics, Kolkata, India
Tata Inst of Research, Mumbai, India
Technische Universität Darmstadt, Germany
Technische Universität München, Germany
Univ Santiago de Compostela, Spain
Universität zu Köln, Germany
Univerity of Bergen, Norway
University of Birmingham, UK
University of Complutense Madrid
University of Keele, UK
University of Liverpool, UK
University of Manchester, UK
University of Paisly, UK
University of Surrey, Guildford, UK
University of York, UK
Yale Univerity, USA

R³B collaboration:
50 institutes
180 scientists

CSIC

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