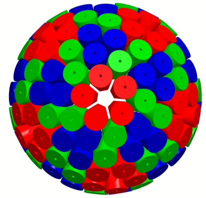
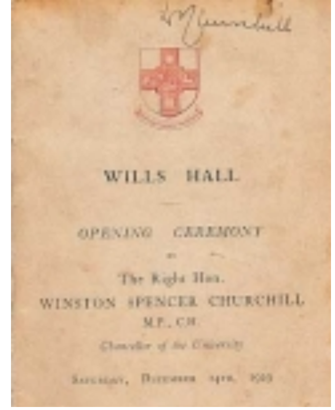
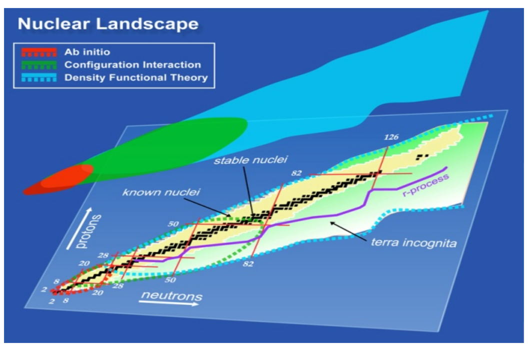
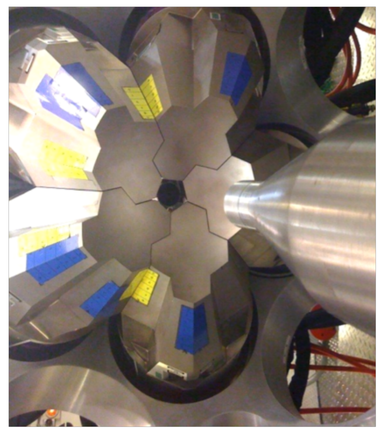
17th UK Nuclear Physics
Postgraduate Summer School
University of Bristol
27th August and 6th September 2013

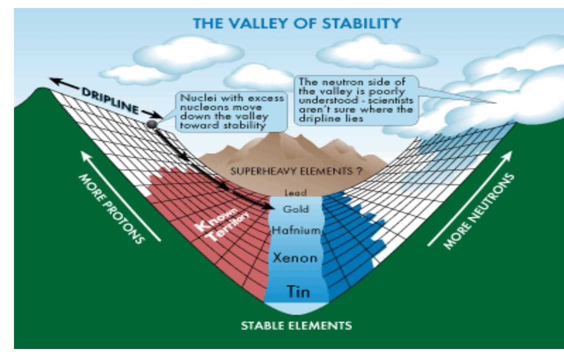




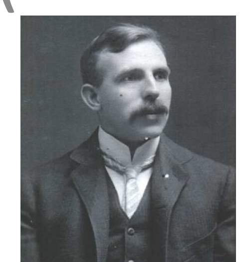
Episode 4. The Future of Gamma-Ray Spectroscopy: Gamma-Ray Tracking and the New Facilities

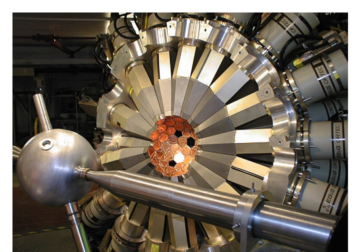


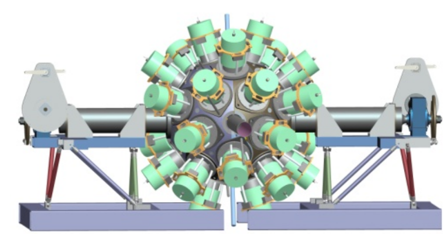




Mark Riley (Florida State University)

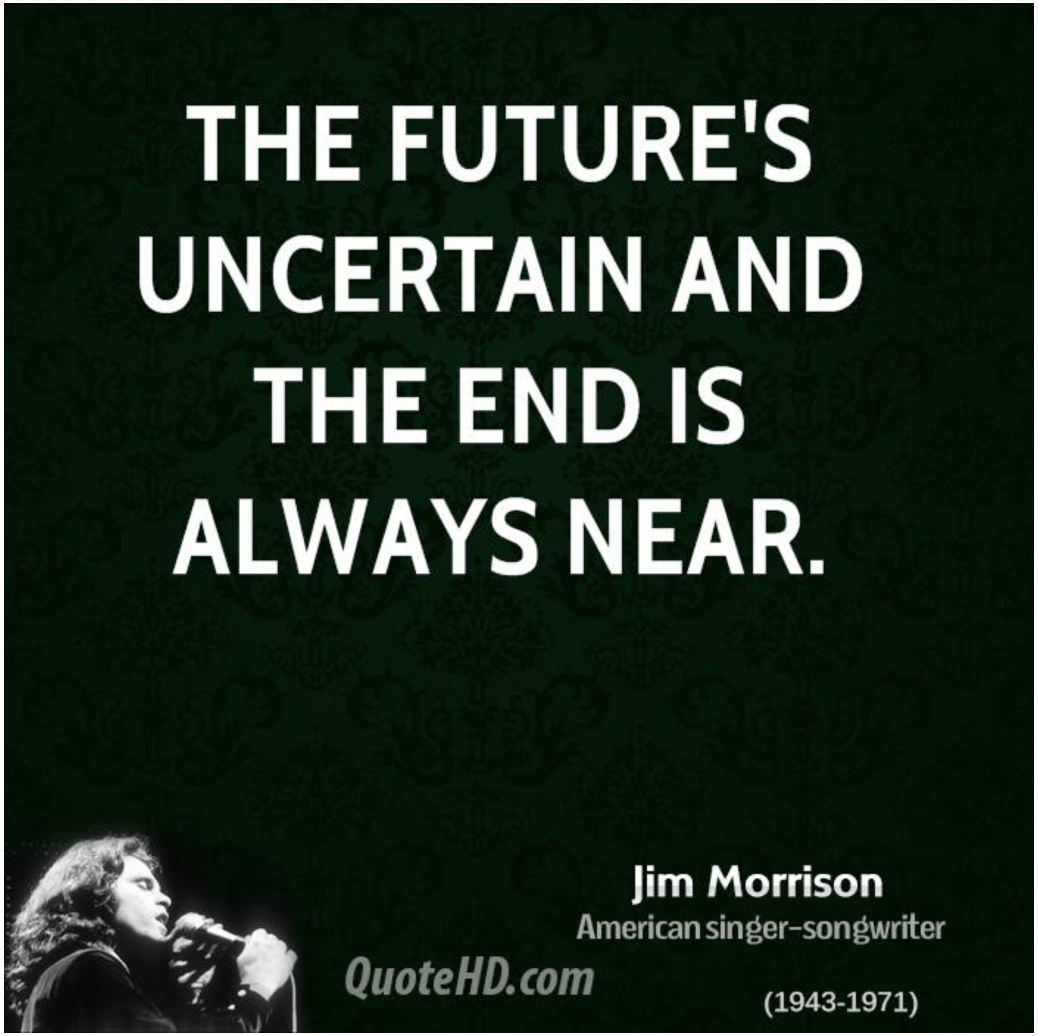






Another hero of mine: FSU alumnus, Jim Morrison

Had this to say about "The Future!"

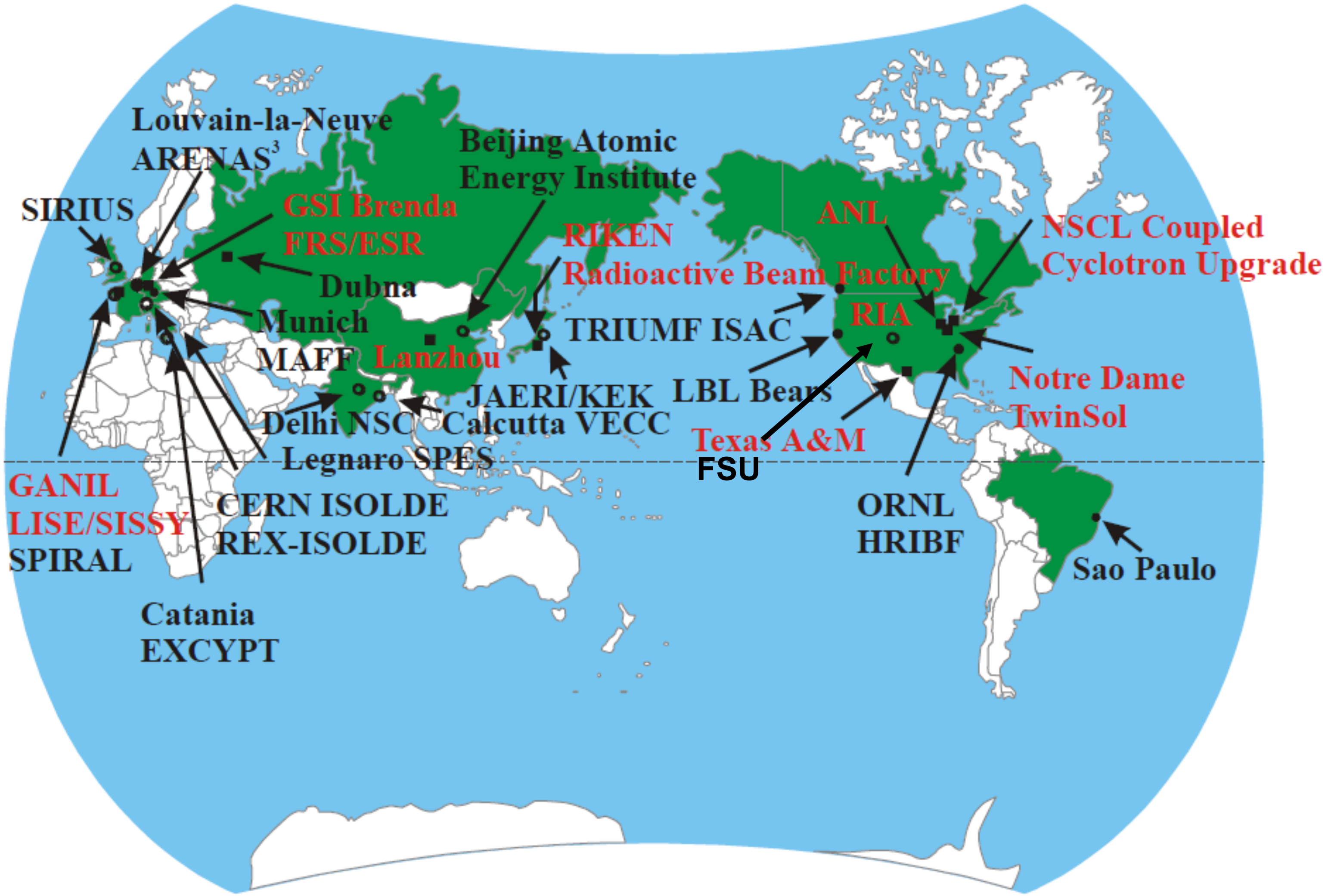


But another HERO tells us to …..

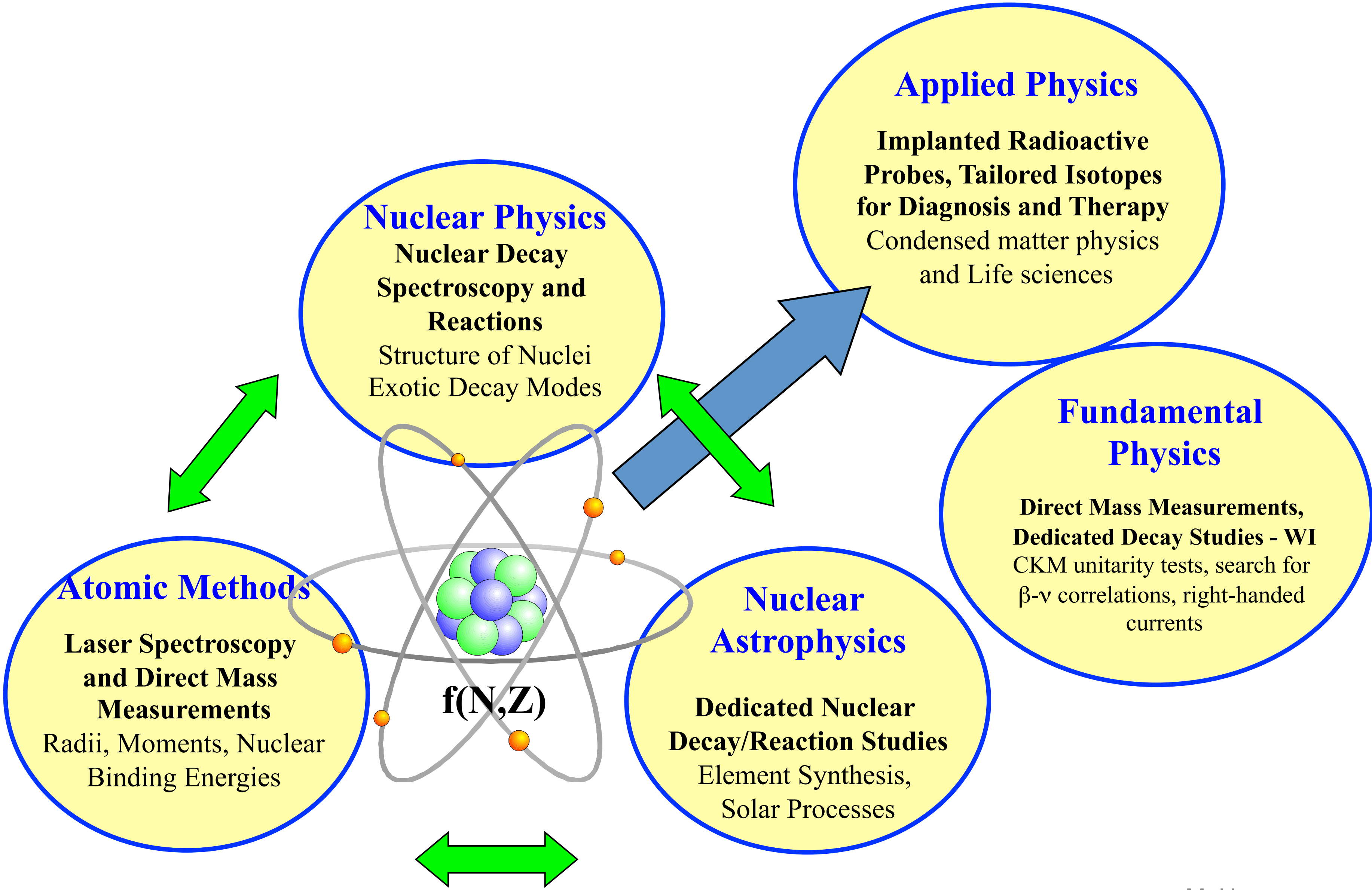
Monty Python (Life of Brian movie: MUST SEE!)

Go on give us a whistle!

Worldwide RIB Facilities

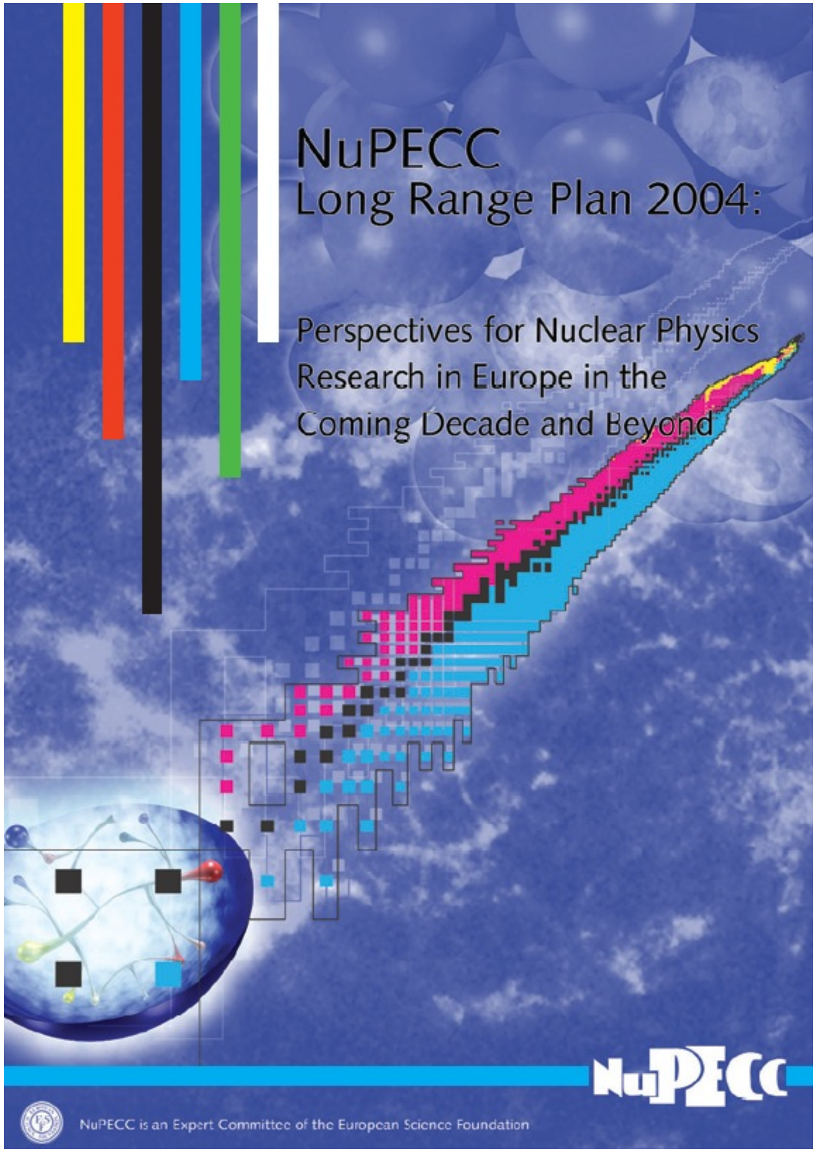


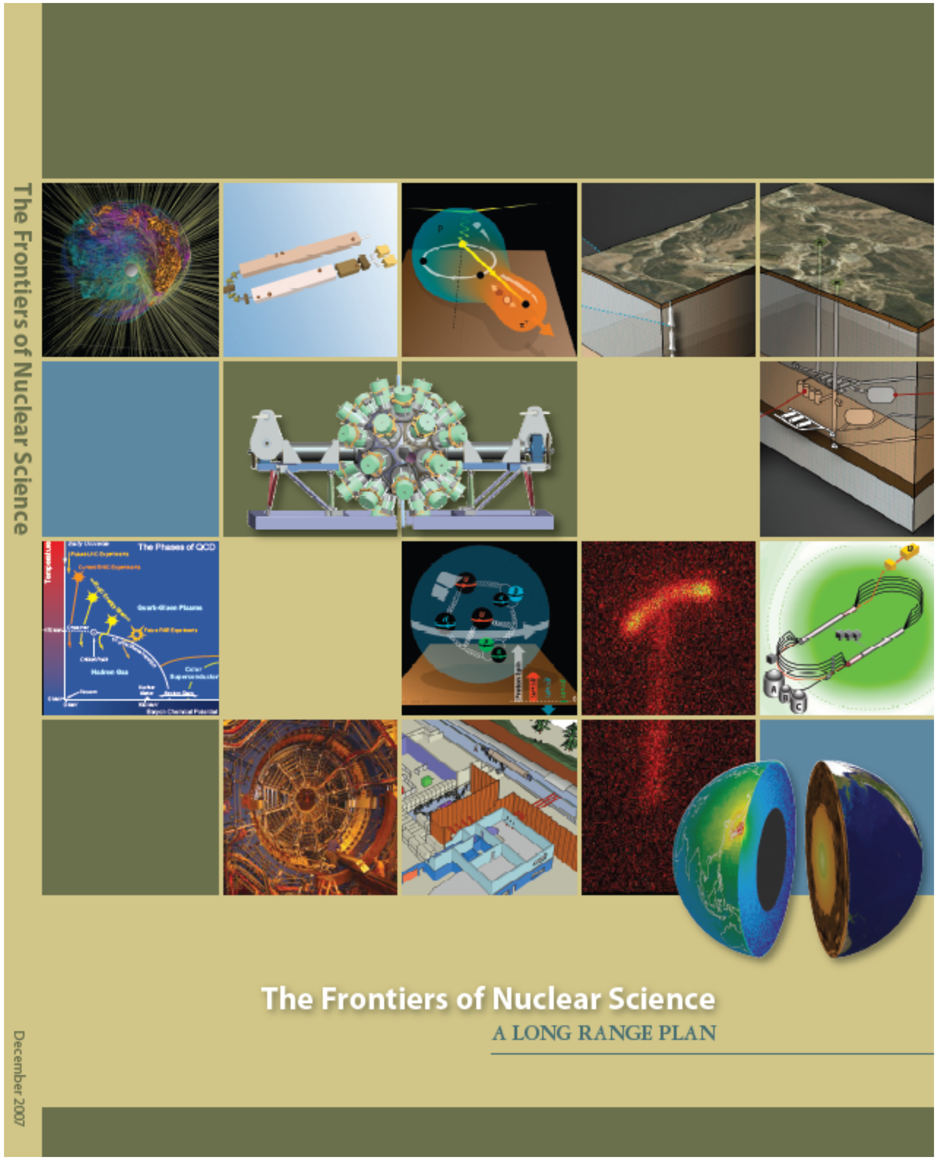
Research with Radioactive Ion Beams



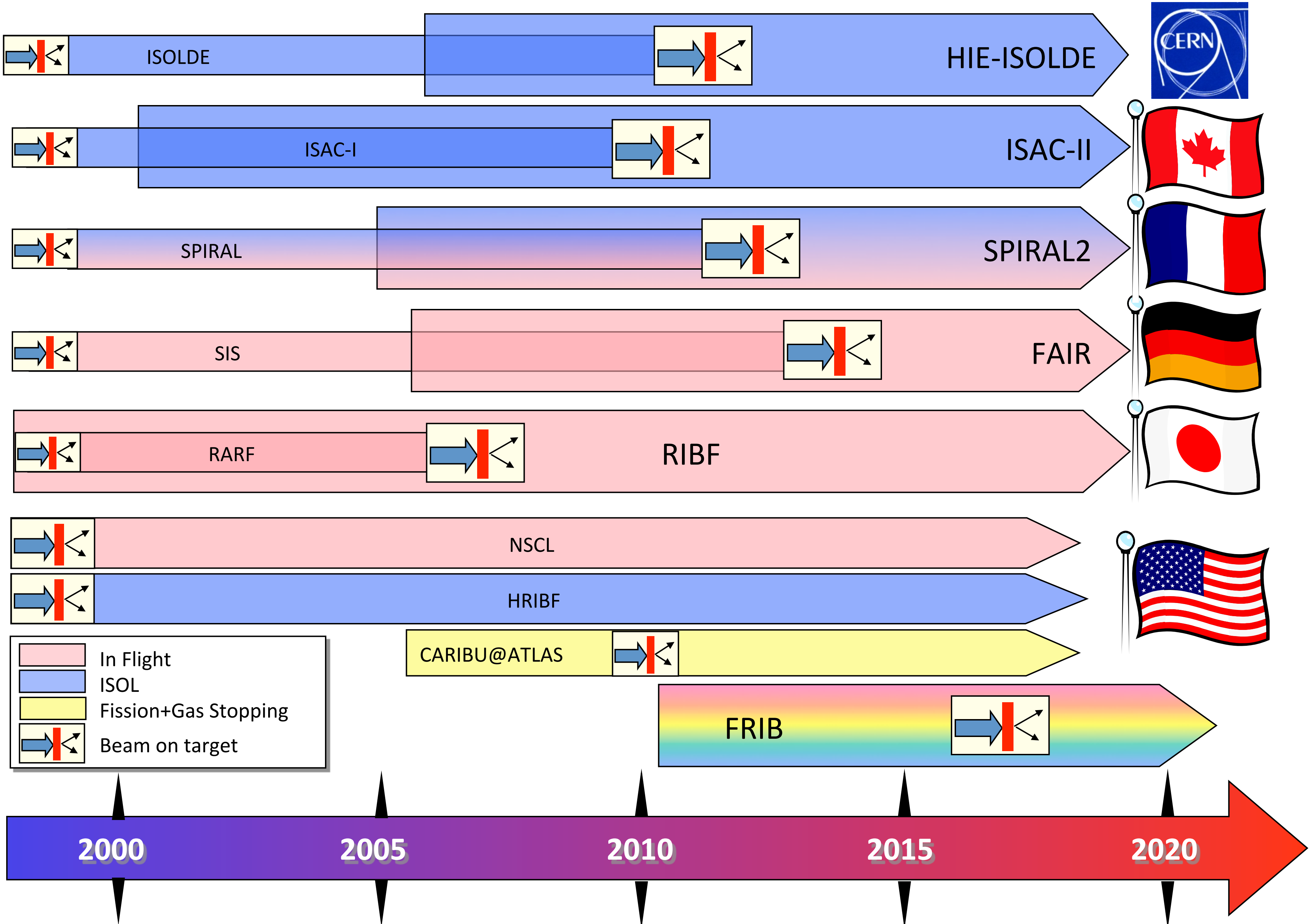
M. Huyse

NuPECC (Europe) & NSAC (USA) Long Range Plans (CHECK THEM OUT ON THE WEB!)



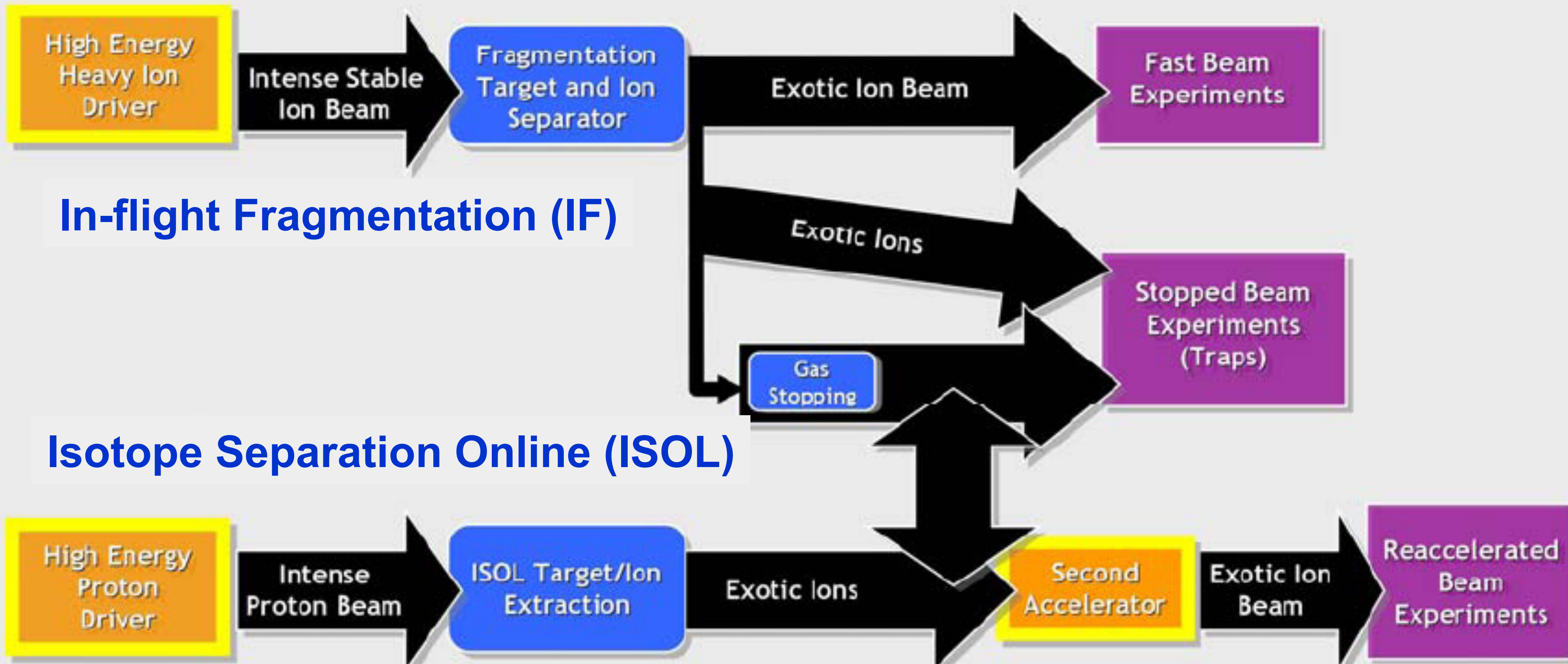


Radioactive Ion Beam Facilities Timeline



Radioactive ion production

GANIL, GSI, MSU, RIBF, *FAIR*



REX-ISOLDE, HRIBF, ISAC, SPIRAL-1,
HIE-ISOLDE, SPIRAL-2, SPES, EURISOL
FRIB

Advantages/Disadvantages of ISOL/In-Flight

In-flight:

GSI
RIKEN
NSCL
GANIL

- Provides beams with energy near that of the primary beam
  - For experiments that use high energy reaction mechanisms
  - Luminosity (intensity x target thickness) gain of 10,000
  - Individual ions can be identified
- Efficient, Fast (100 ns), chemically independent separation
- Production target is relatively simple

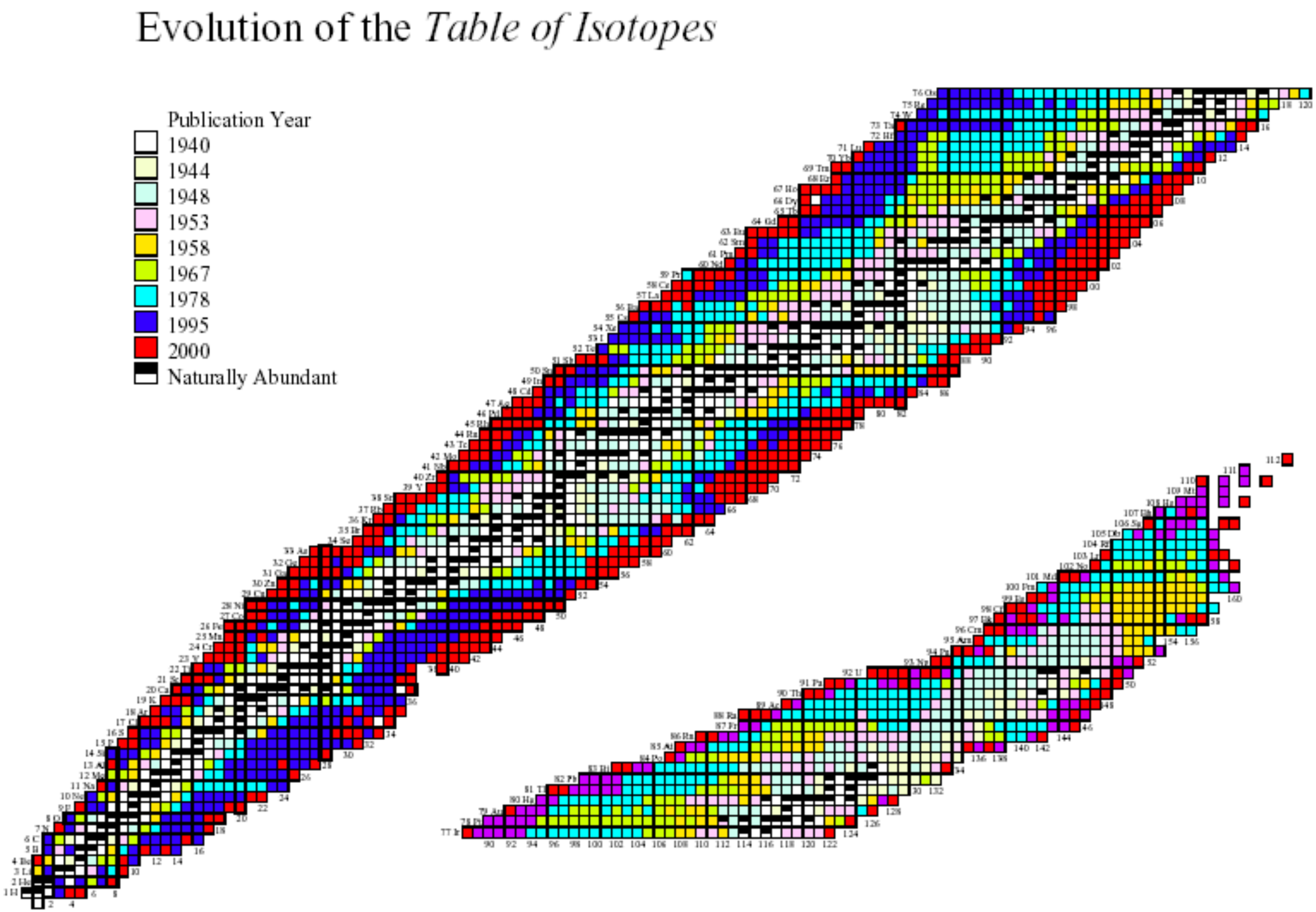
ISOL:

HRIBF
ISAC
SPIRAL
ISOLDE

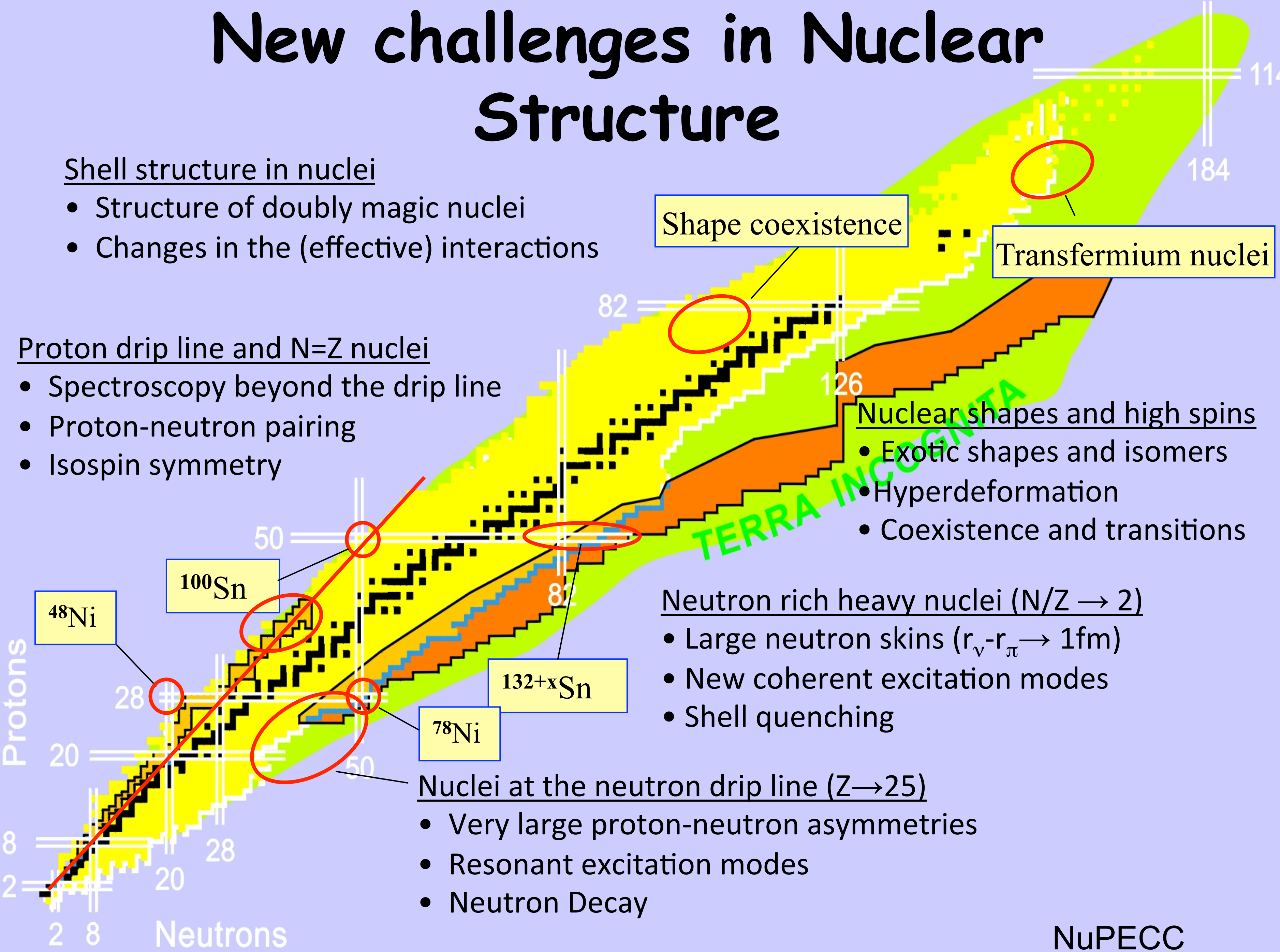
- Good Beam quality (π mm-mr vs. 30 π mm-mr transverse)
- Small beam energy spread for fusion studies
- Can use chemistry (or atomic physics) to limit the elements released
- 2-step targets provide a path to MW targets
- High beam intensity leads to 100x gain in secondary ions

400kW protons at 1 GeV is 2.4×10^{15} protons/s

More and More Isotopes



New challenges in Nuclear Structure



Shell structure in nuclei

- Structure of doubly magic nuclei
- Changes in the (effective) interactions

Proton drip line and N=Z nuclei

- Spectroscopy beyond the drip line
- Proton-neutron pairing
- Isospin symmetry

Nuclear shapes and high spins

- Exotic shapes and isomers
- Hyperdeformation
- Coexistence and transitions

Neutron rich heavy nuclei (N/Z → 2)

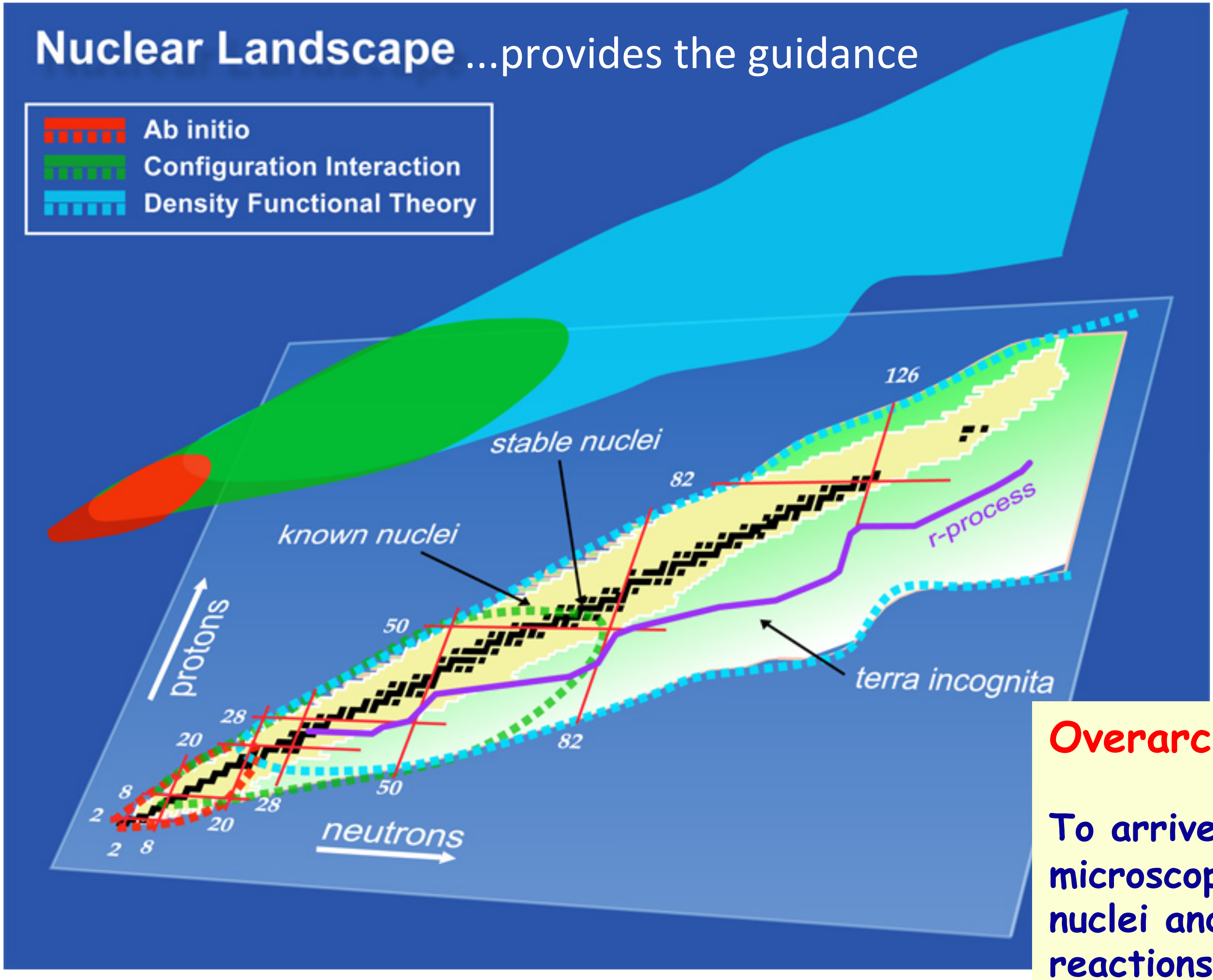
- Large neutron skins (r_ν-$r_\pi \rightarrow$ 1fm)
- New coherent excitation modes
- Shell quenching

Nuclei at the neutron drip line (Z→25)

- Very large proton-neutron asymmetries
- Resonant excitation modes
- Neutron Decay

NuPECC

Roadmap for Theory of Nuclei



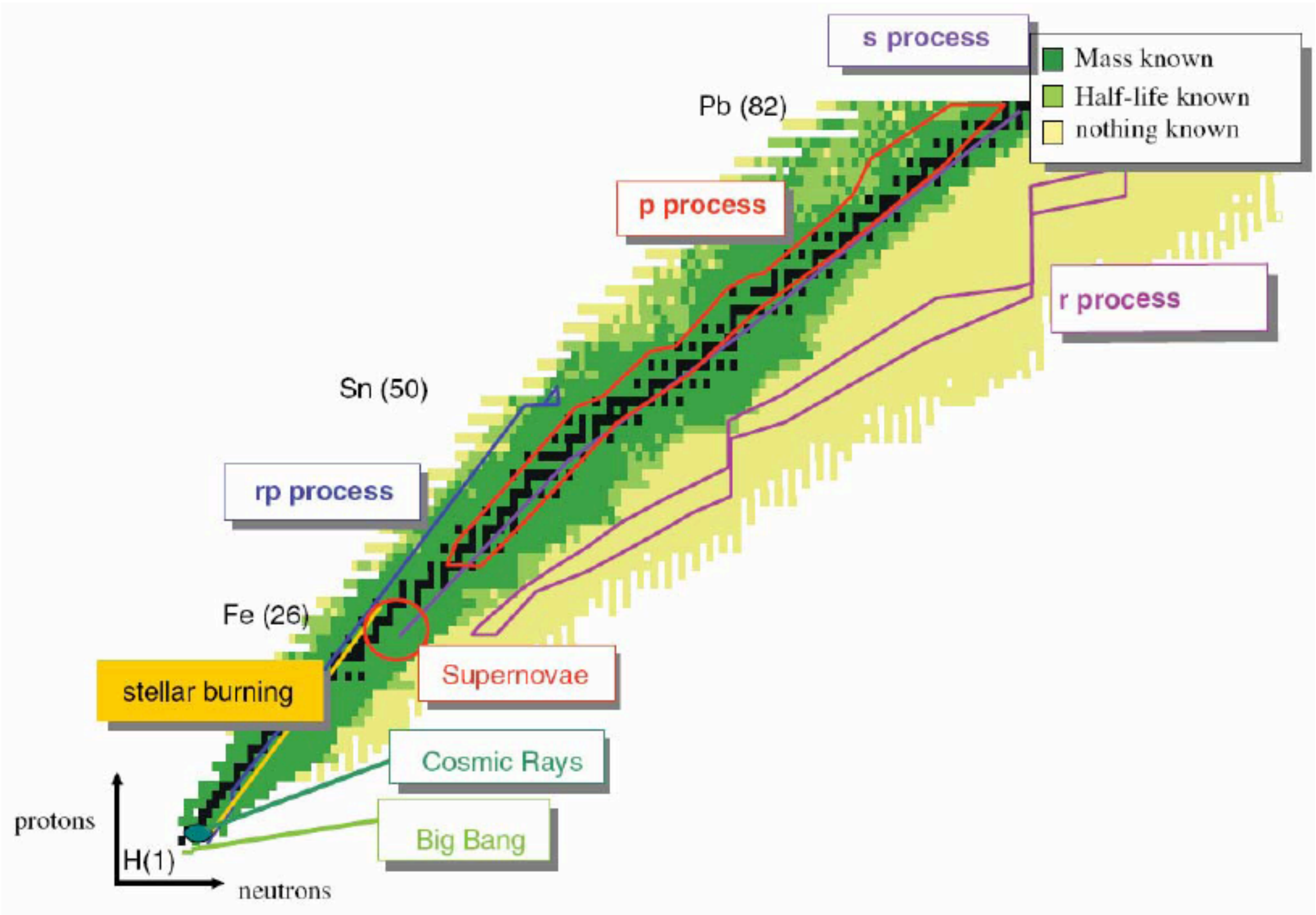
Overarching goal:

To arrive at a comprehensive microscopic description of all nuclei and low-energy reactions from the the basic interactions between the constituent nucleons

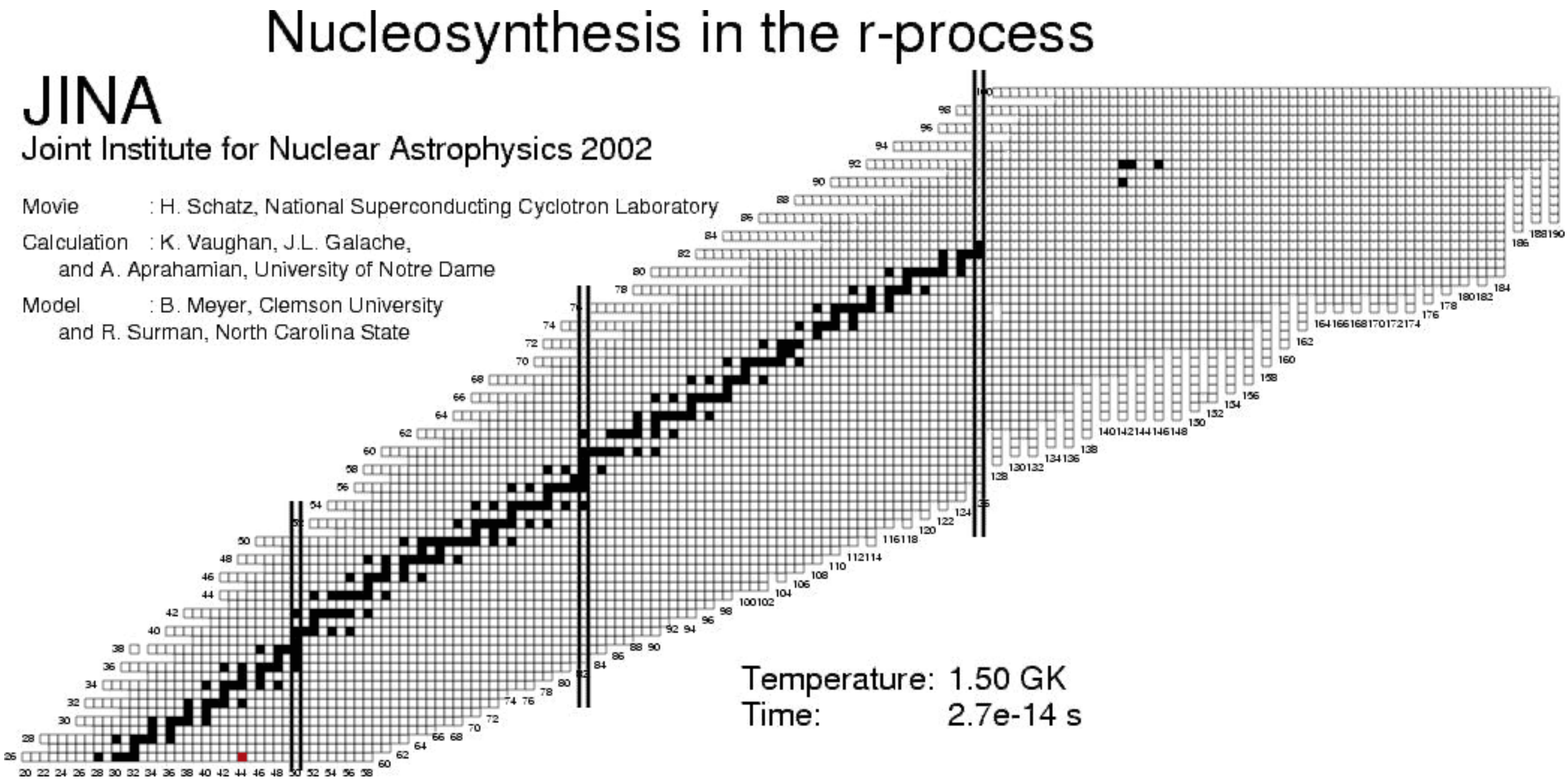
Nazarewicz

Nucleosynthesis movies : Hendrik Schatz (MSU)

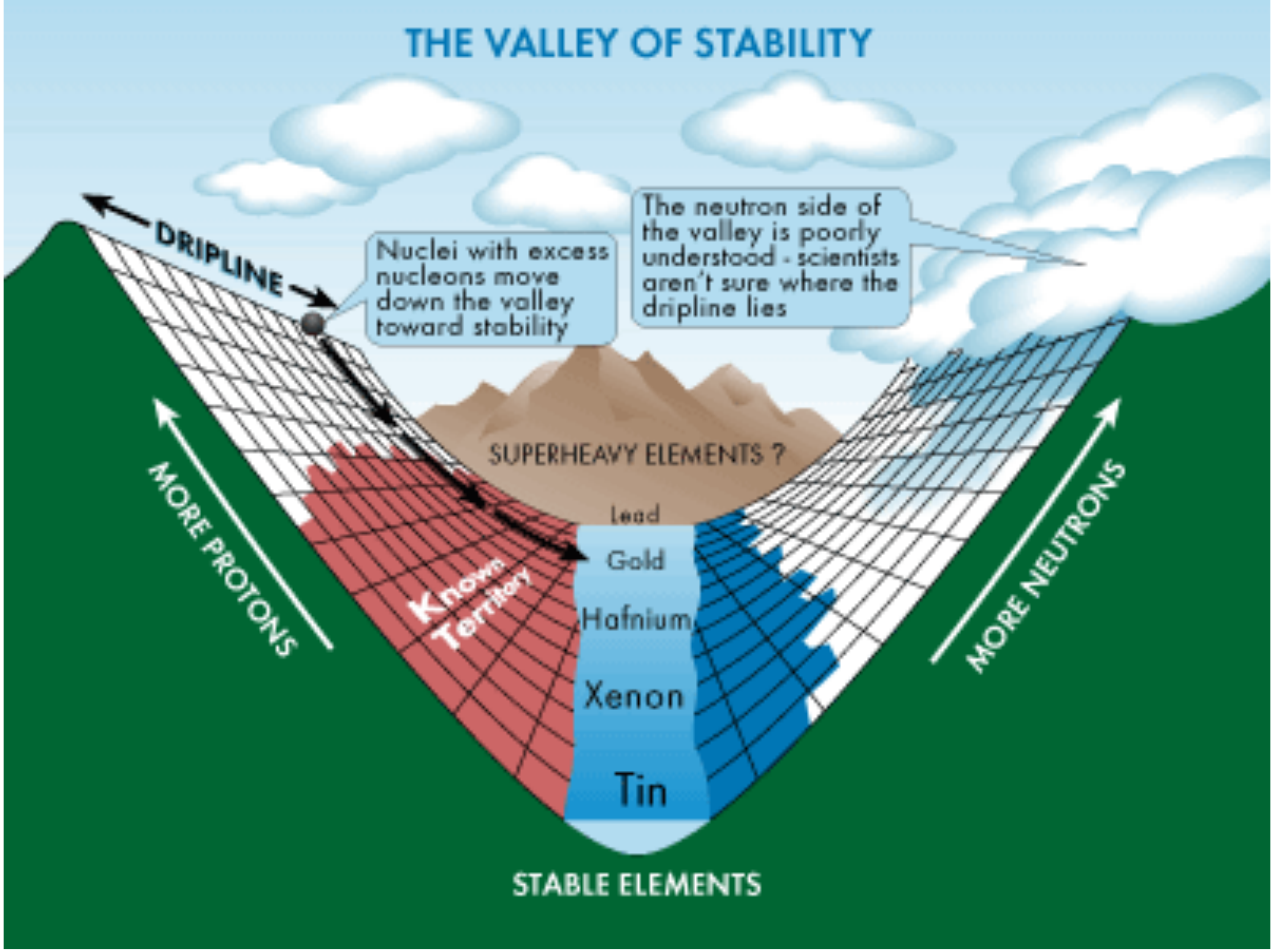
- http://www.jinaweb.org/html/movies.html



Nucleosynthesis movies : Hendrik Schatz (MSU)



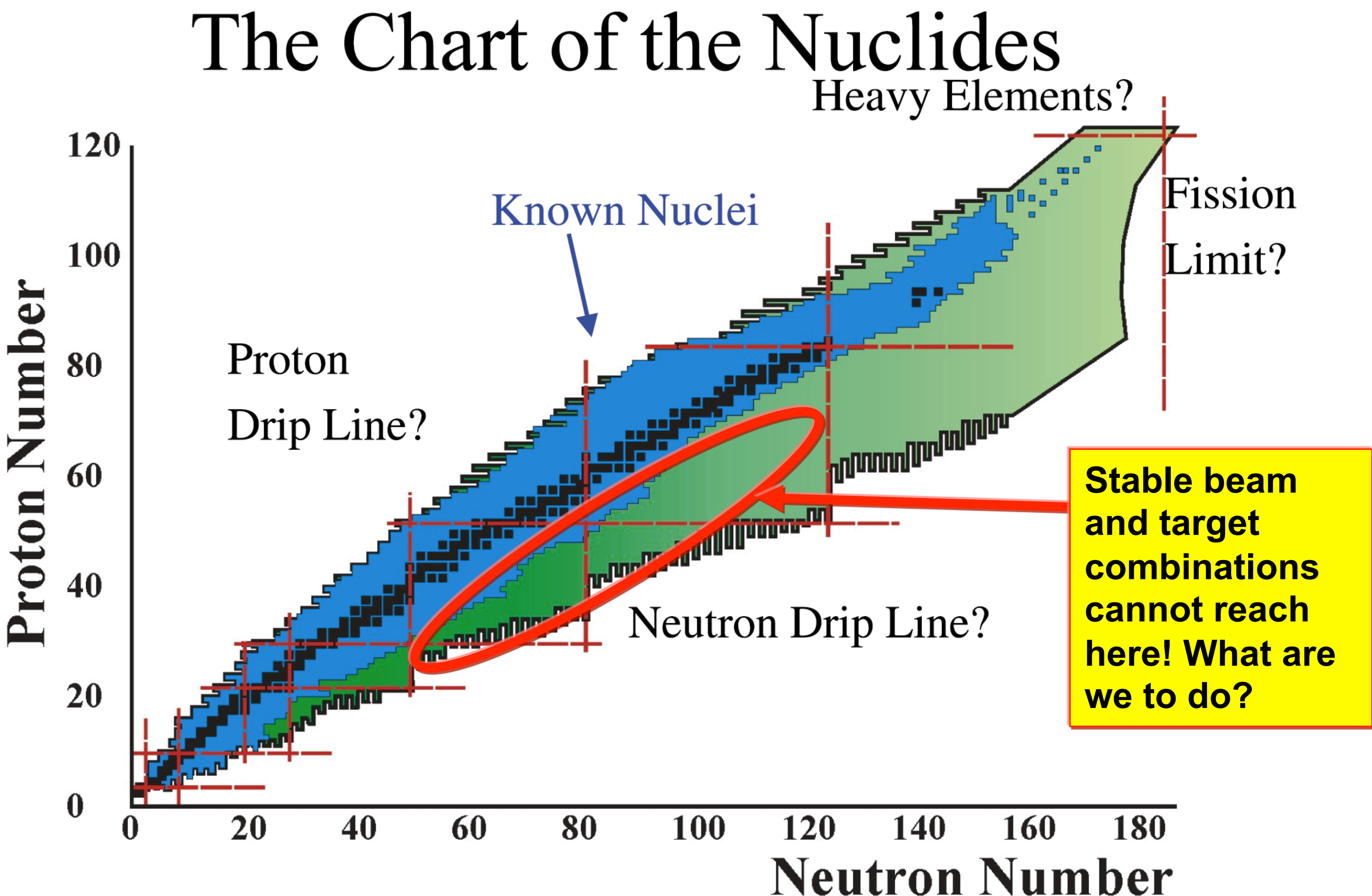
Limits of Stable Nuclei

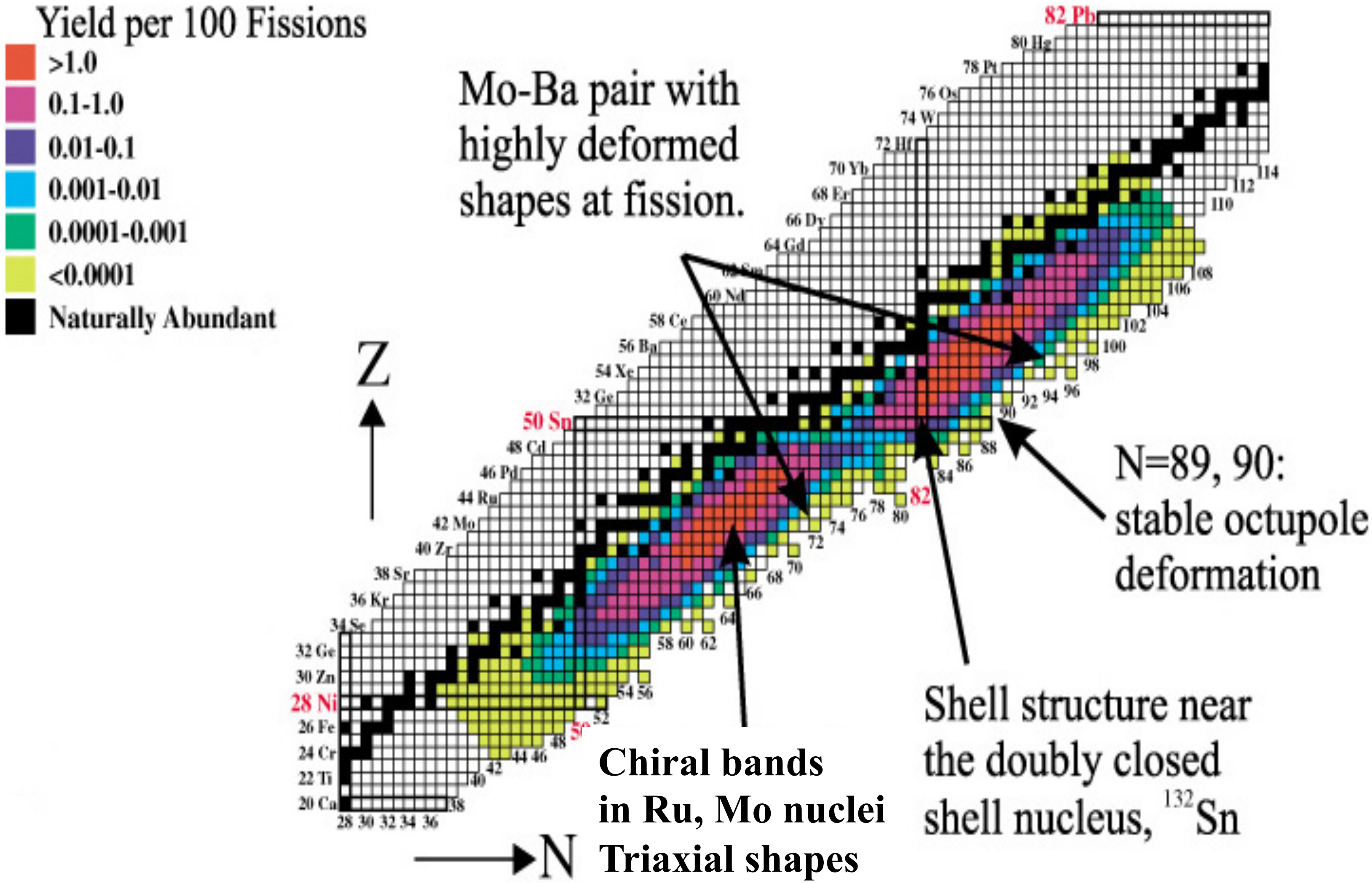


Exploring n-rich nuclei by fission using large Gamma-ray arrays

- Manchester – ANL and Vanderbilt – LBNL pioneered the spectroscopy of these exotic nuclei.
- Lots of beautiful physics.

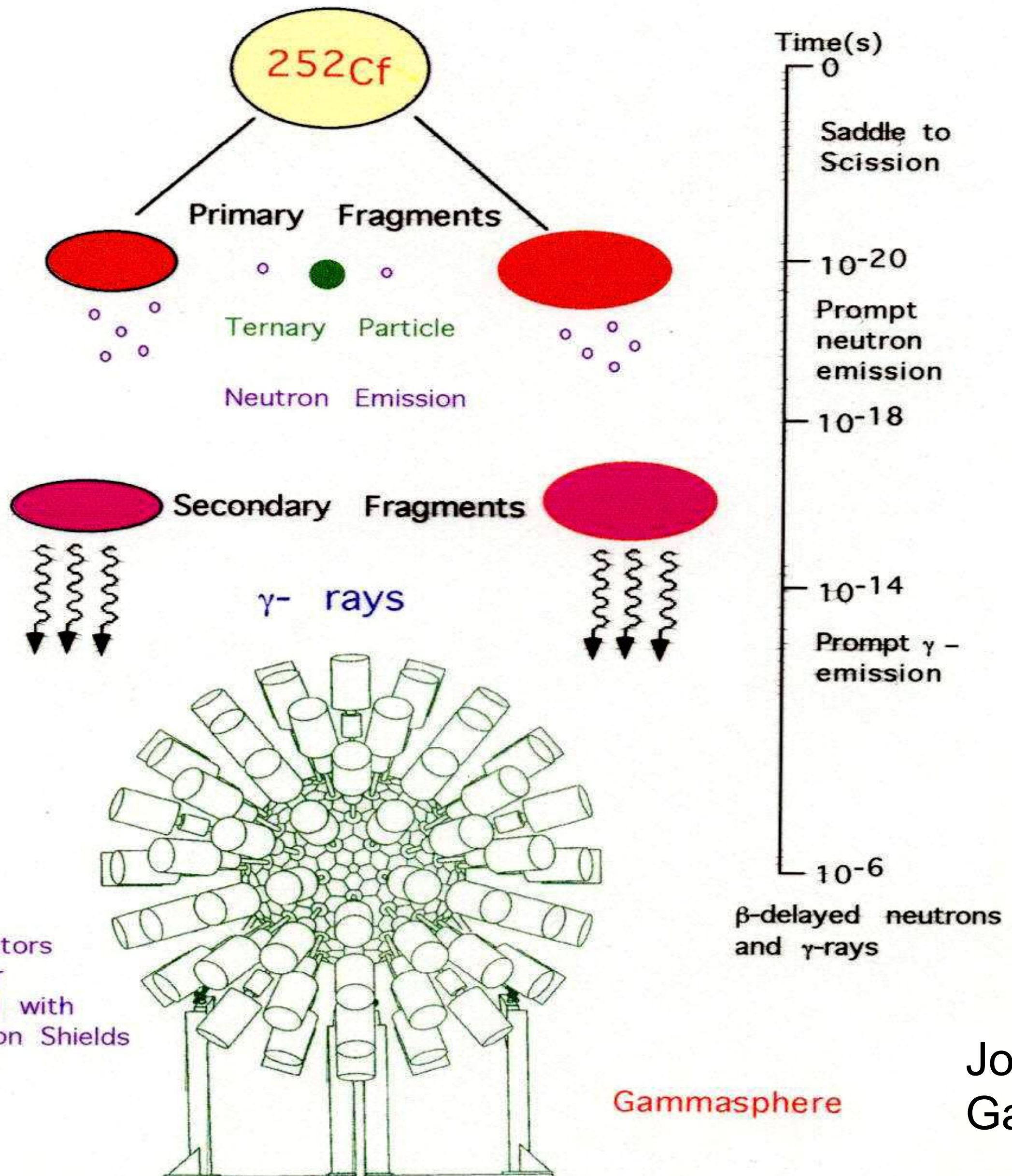
How can I populate excited states in n-rich nuclei?





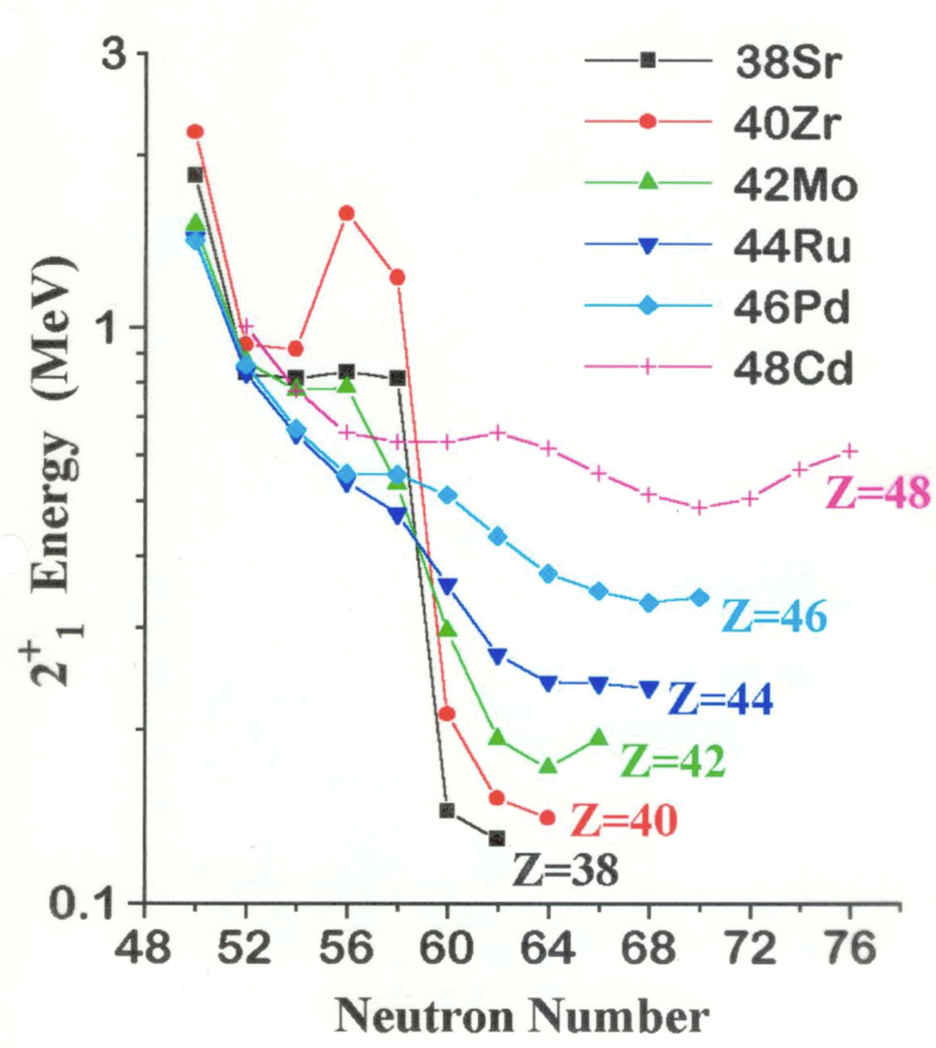
Joe Hamilton

Normal or Hot Fission



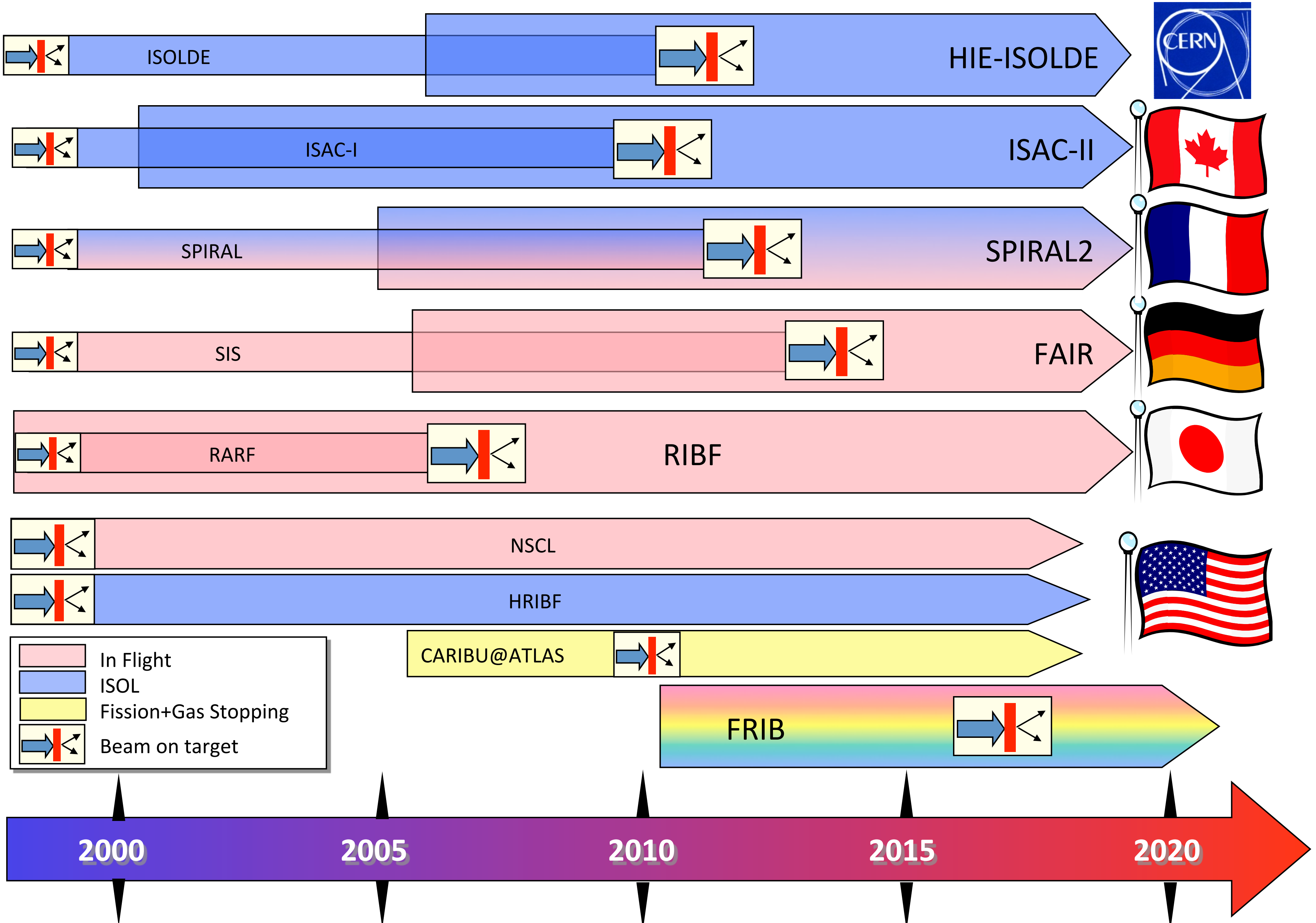
Joe Hamilton
Gavin Smith

Mapping out the deformations of n-rich nuclei.



Joe Hamilton
Vanderbilt

Radioactive Ion Beam Facilities Timeline

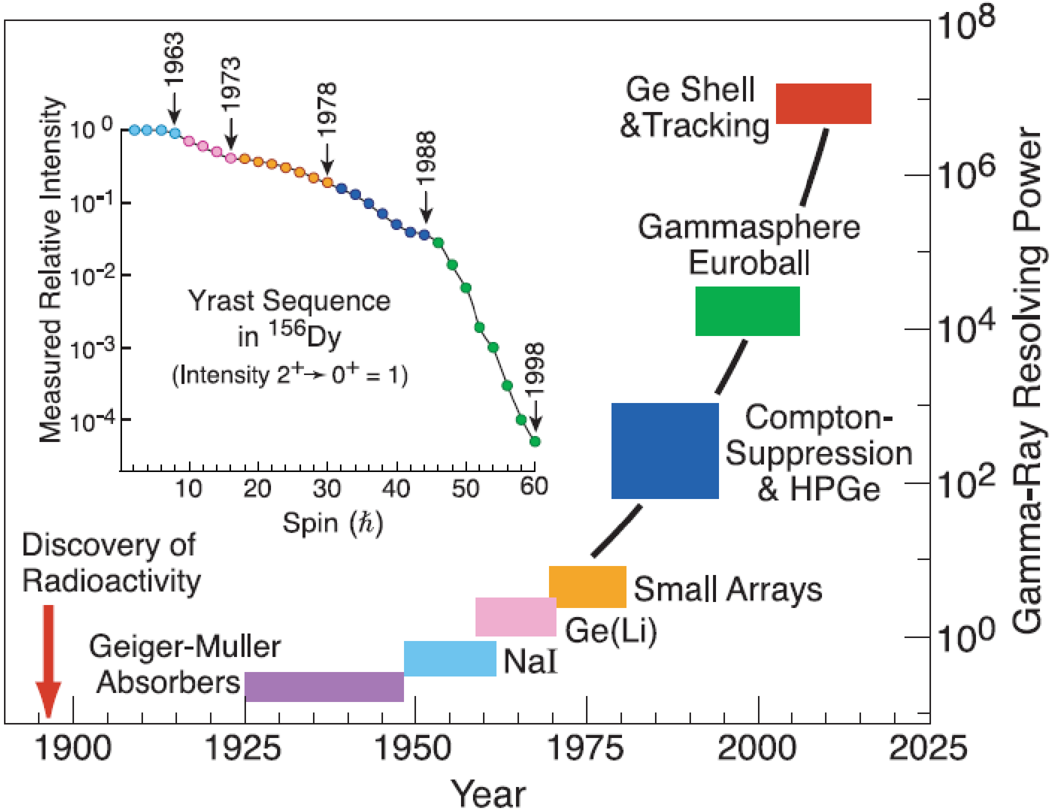


"A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty."

Winston Churchill

Instrumentation matters too!

Evolution of γ-ray detector technology

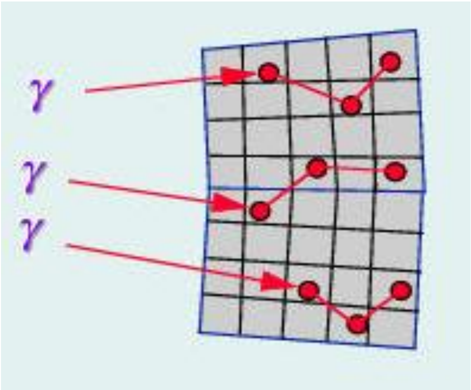


The calculated resolving power is a measure of the ability to observe faint emissions from rare and exotic nuclear states. (from 2002 LRP)

The keys to unlock wonderful new science are beams of unstable and stable nuclei + NEW INSTRUMENTATION!

Report from workshop at LBNL (98)

"…, after going through so much effort to create rare and exotic nuclear species, it only makes sense to have the best and most efficient detector systems to catch their "precious signals". It is therefore extremely exciting that, ….. revolutionary breakthroughs in gamma-ray technology seem possible."

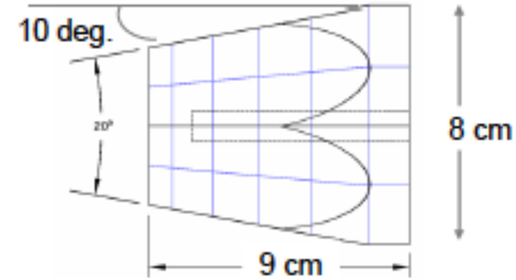


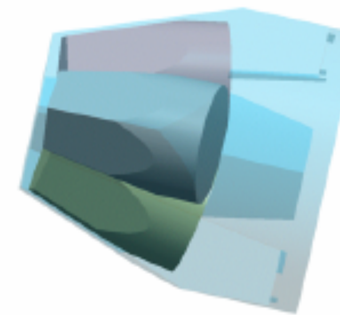
Gamma-Ray Tracking is the future!
GRETA

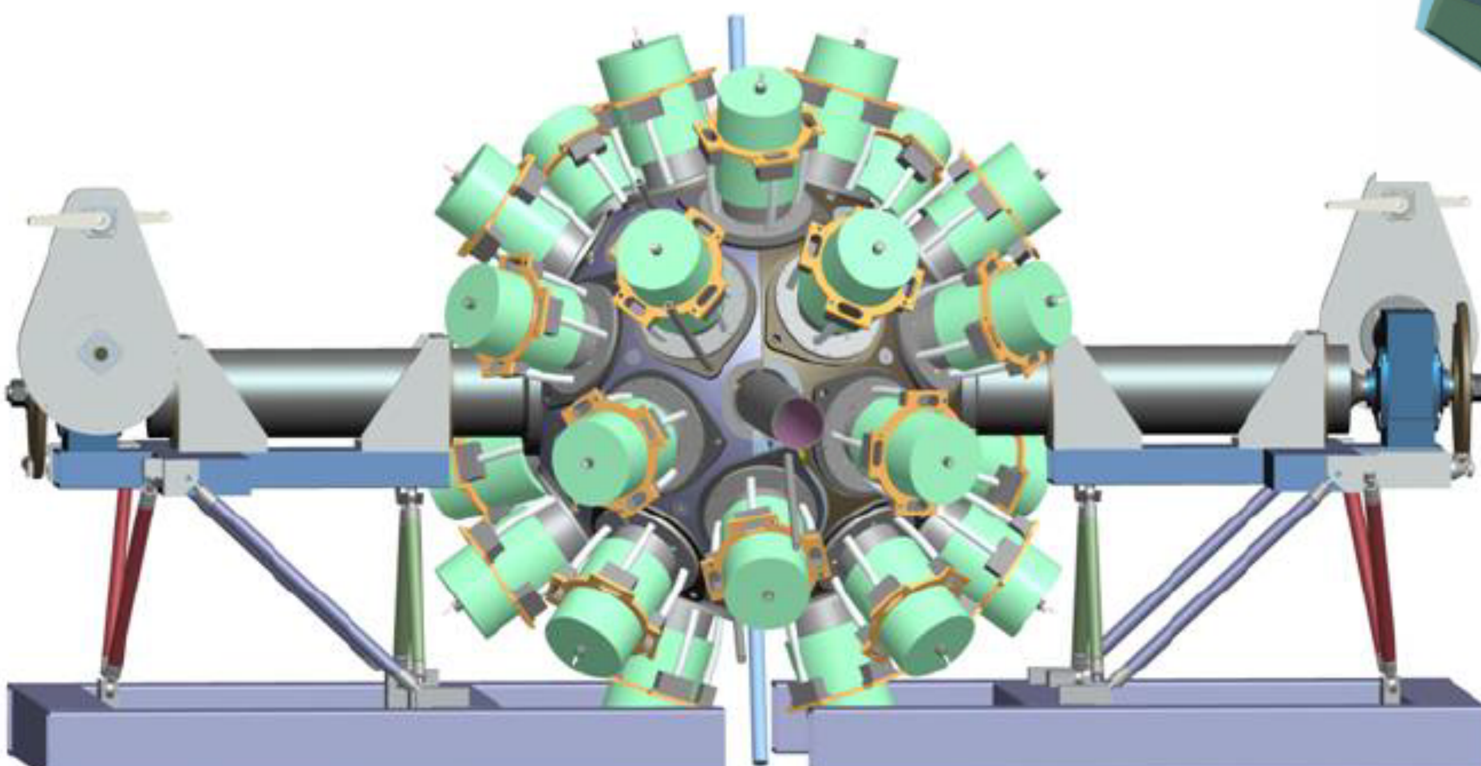
H. Spieler (LBNL) "Novel technology turns into discovery potential."

GRETA

Gamma-Ray Energy Tracking Array

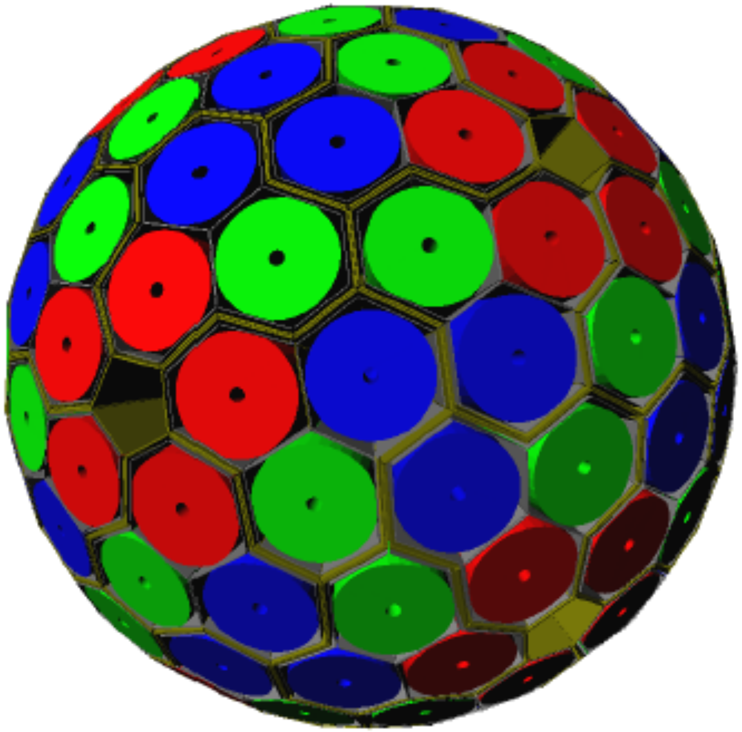






AGATA

(Advanced GAmma Tracking Array)



Efficiency: 25 - 40%

Peak/Total: 45 - 55%

Angular Resolution: ~1°

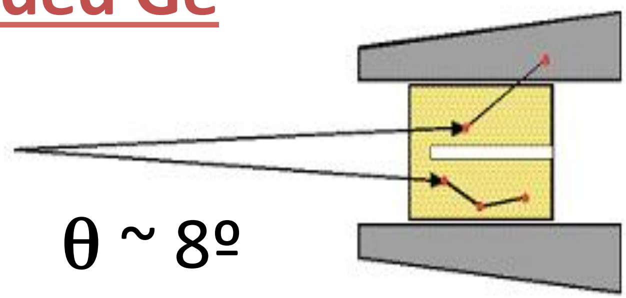
- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

Idea of γ-ray tracking

Compton Shielded Ge

ε_{ph}	~ 10%
N_{det}	~ 100

Ω ~40%



θ ~ 8º

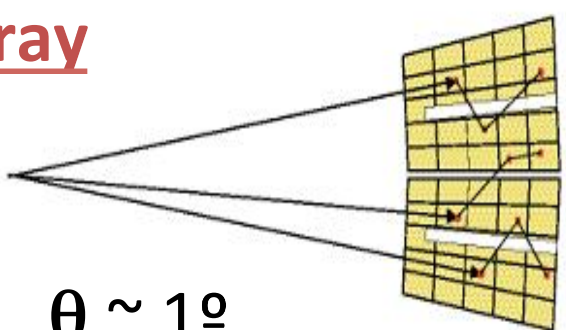
large opening angle means poor energy resolution at high recoil velocity.

Previously we had to waste scattered gammas. Technology is available now to track them.

Ge Tracking Array

ε_{ph}	~ 50%
N_{det}	~ 100

Ω ~80%

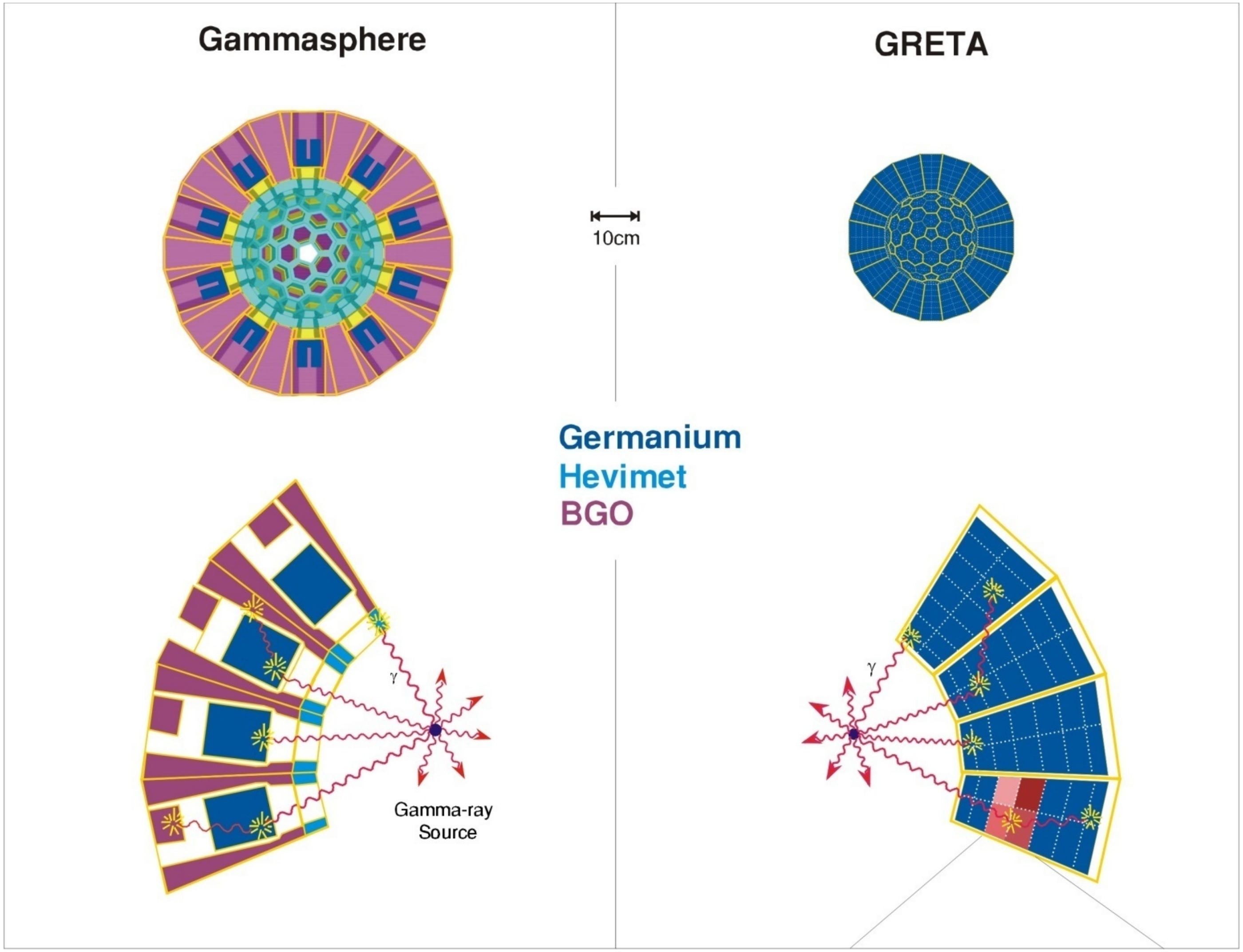


θ ~ 1º

Combination of:

- segmented detectors
- digital electronics
- pulse processing
- tracking the γ-rays

Compare GRETA with Gammasphere



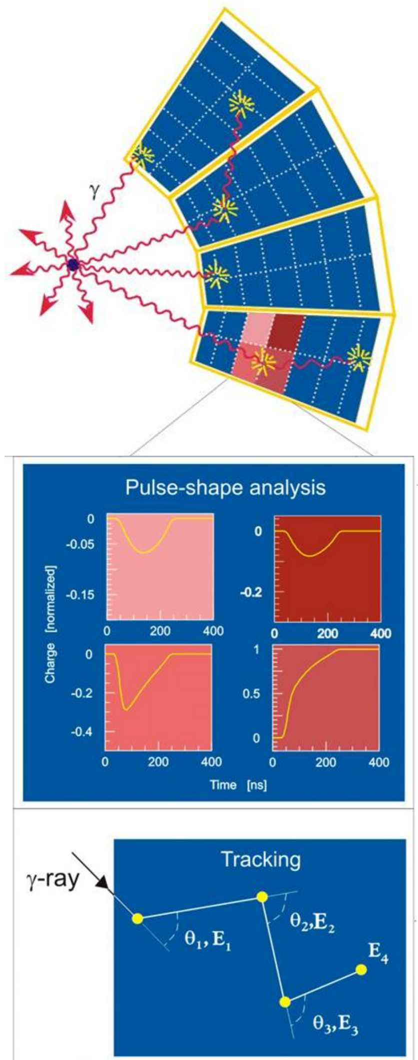
	Gammasphere	GRETA
Efficiency (1 MeV)	**8%**	**55%**
Efficiency (15 MeV)	**0.5%**	**12%**
Peak/Total (1 MeV)	**55%**	**85%**
Position resolution	**20mm**	**1 mm**

Principle and advantages of γ-ray tracking

3D position sensitive Ge detector shell

Resolve position and energy of interaction points

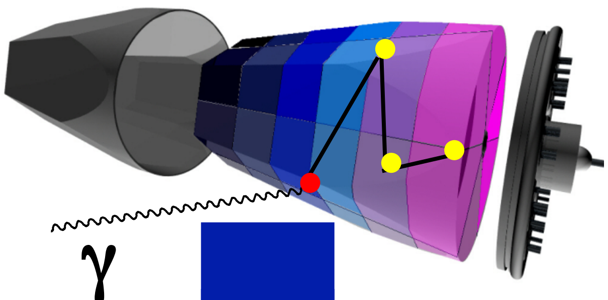
Determine scattering sequence



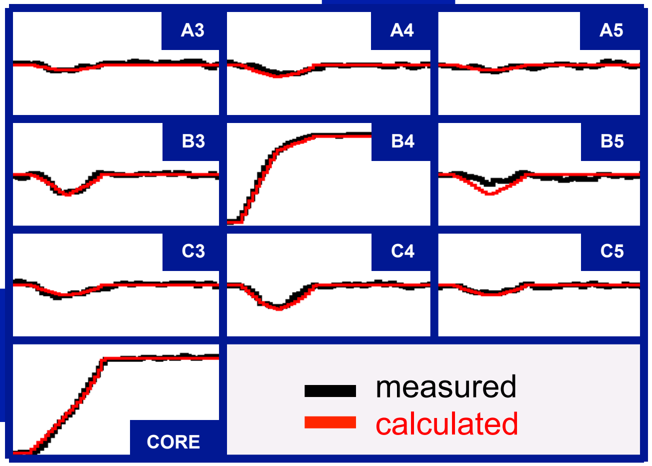
- **Efficiency (50% Ω)**
  Proper summing of scattered gamma rays, no solid angle lost to suppressors
- **Peak-to-background (60%)**
  Reject Compton events
- **Position resolution (1-2 mm)**
  Position of 1st interaction
- **Polarization**
  Angular distribution of the 1st scattering
- **Counting rate (50 kHz)**
  Many segments

γ-ray Tracking Arrays

Electrically segmented HPGe detectors



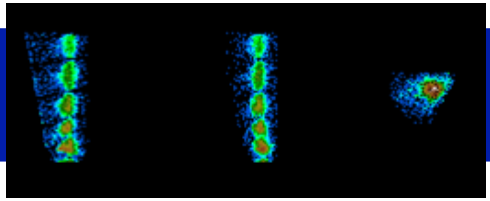
Digital electronics to record and process segment signals



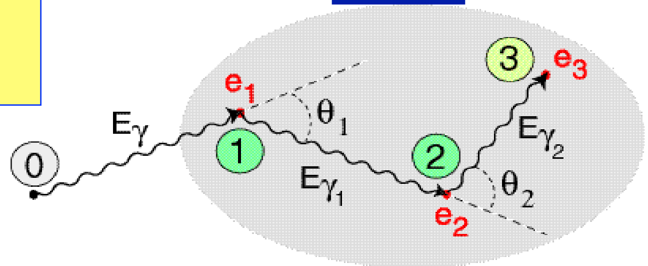
Deconvolution of the recorded waves through comparison with reference signals

Identification of the individual interaction points

$(x,y,z,E,t)_i$



Reconstruction of tracks evaluating permutations of interaction points



Energy and direction of γ-rays

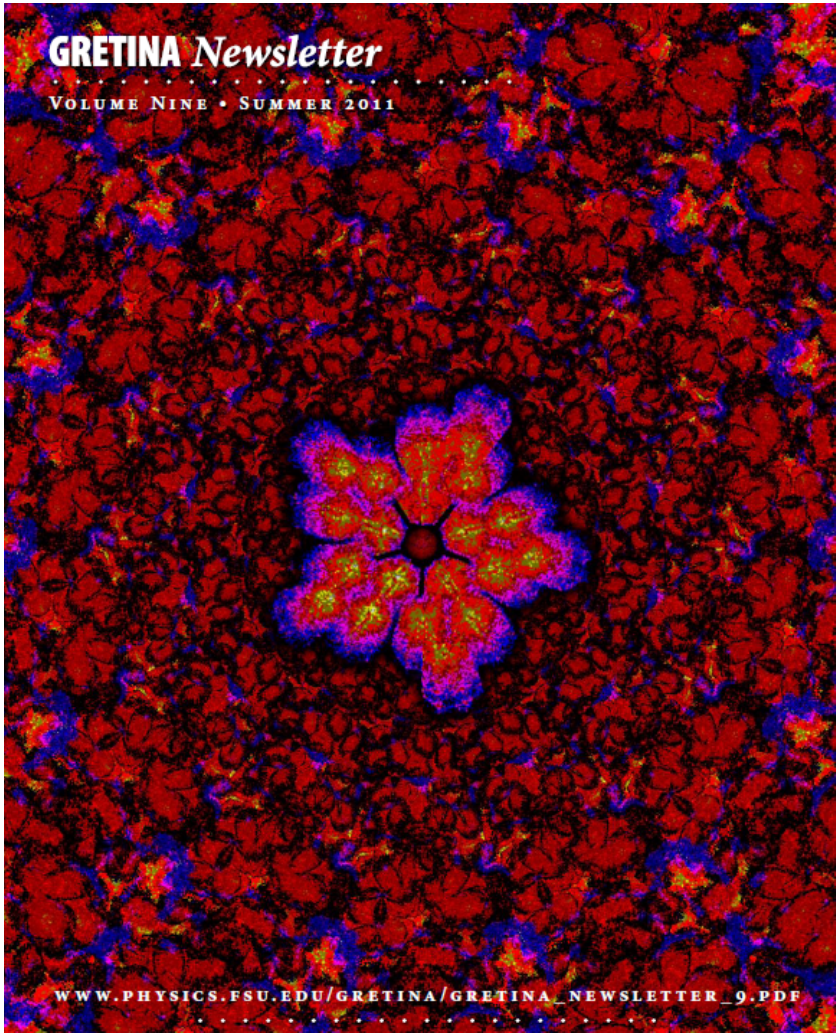
$\gamma-$ ray tracking is essential

Especially for Radioactive Beam facility (FRIB)

GRETA capabilities	Experimental conditions
• High position resolution	Large recoil velocity – Fragmentation – Inverse reaction
• High efficiency	Low beam intensity
• High P/T • High counting rate • Background rejection	High background rate Beam decay Beam impurity

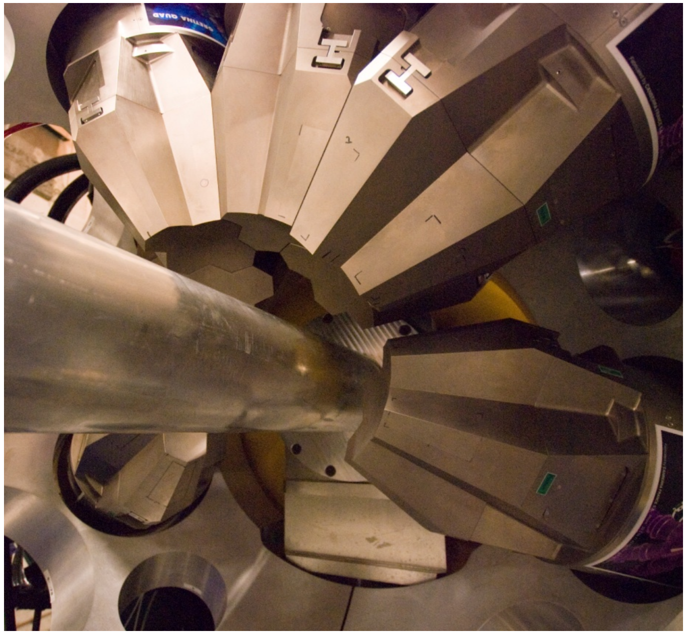
GRETINA-GRETA Webpage

- http://www.physics.fsu.edu/GRETINA.org/



Pay us a visit!

GRETINA: Summary so far and plans for the future.



M.A. Riley (FSU) with lots of help from I-Yang Lee + Augusto Macchiavelli (LBNL) + David Radford (ORNL)

and D. Weishaar (NSCL) …

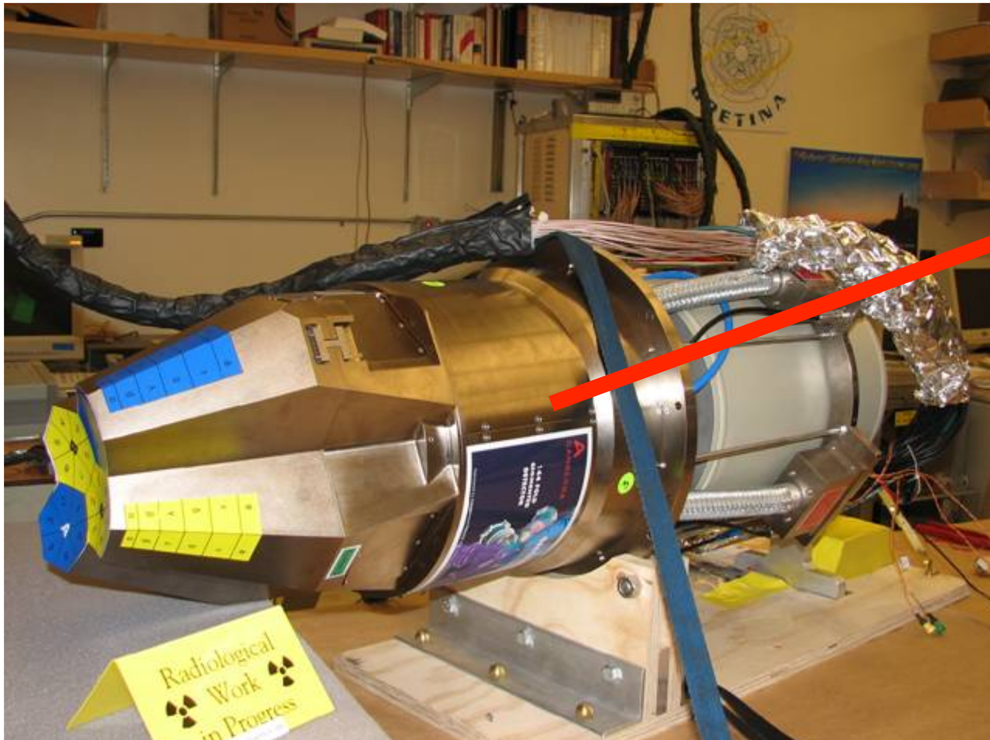
GRETINA: The first part of GRETA

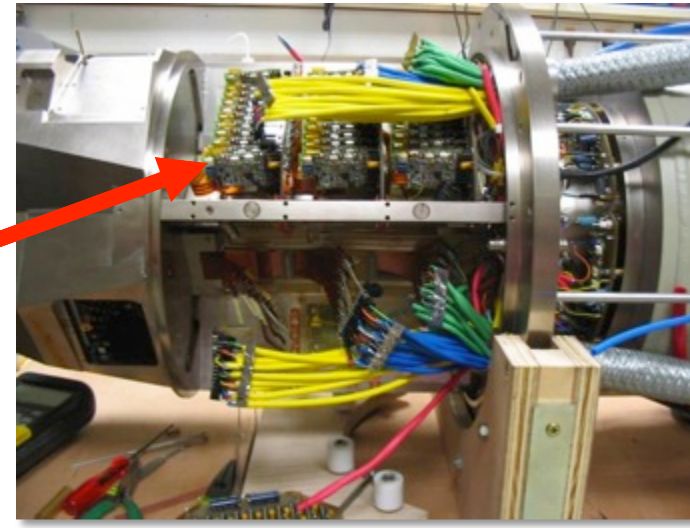
Cover ¼ of 4π solid angle
Seven 4-crystal detector modules
All the required software

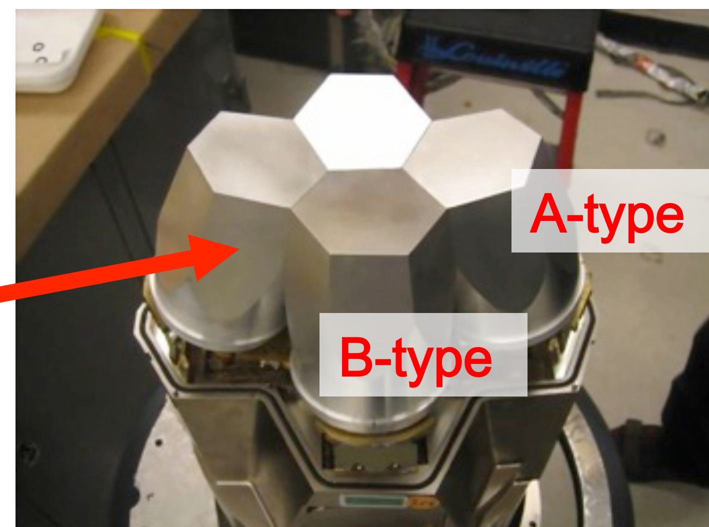
Critical Decisions

✓ CD0 : Mission need	August 2003
✓ CD1 : Preliminary Baseline Range	February 2004
✓ CD2A/CD3A : Start Construction (Long lead-time items: Ge)	June 2005
✓ CD2B/CD3B : Start Construction	October 2007
▪ CD4 : Start of Operation	February 2011

Detector Modules (Canberra/France)







36 segments/crystal
4 crystal/ module
148 signal channels /module
Cores Cold FETs
Segments Warm FETs

Computing and Data Flow

70 nodes
2 cpu / node
4 core / cpu

Data from GRETINA Detectors → *Segment events* (37 segments per detector)

Crystal Event Builder

Crystal events

Signal Decomposition

Interaction points (1-28 crystals)

Data from Auxiliary Detectors → **Global Event Builder**

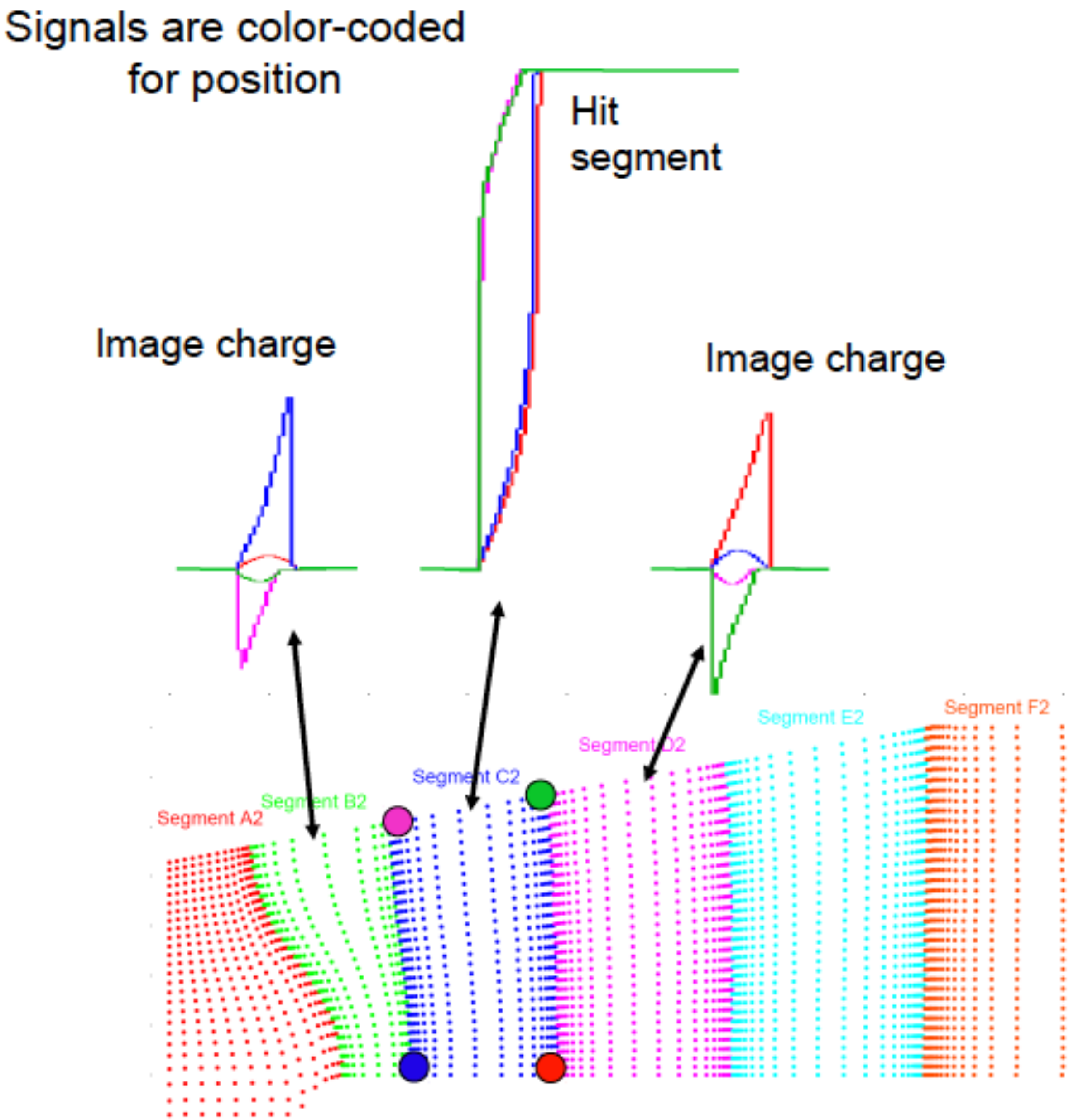
Global Events

Tracking

Analysis & Archiving

Goal:
Processing
20,000 γ /s

Calculated signals: Sensitivity to position

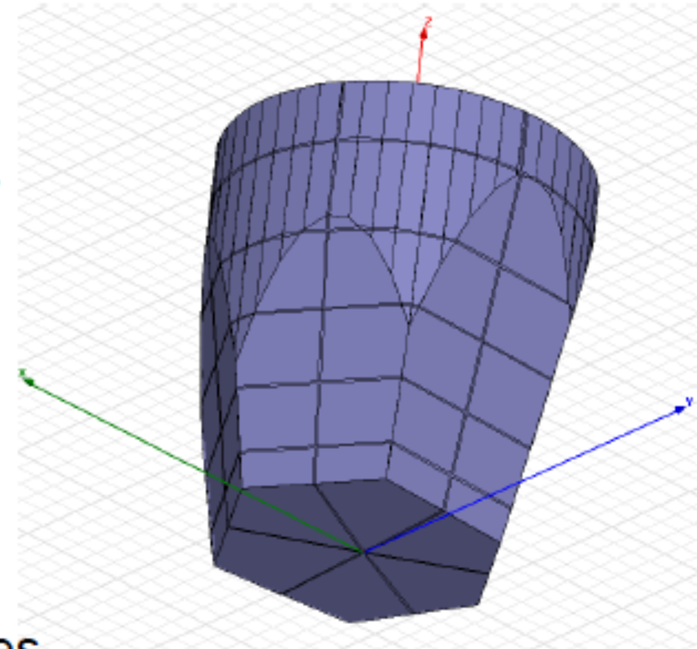


Signals are nonlinear with respect to position; a necessary condition for extracting multiple interactions

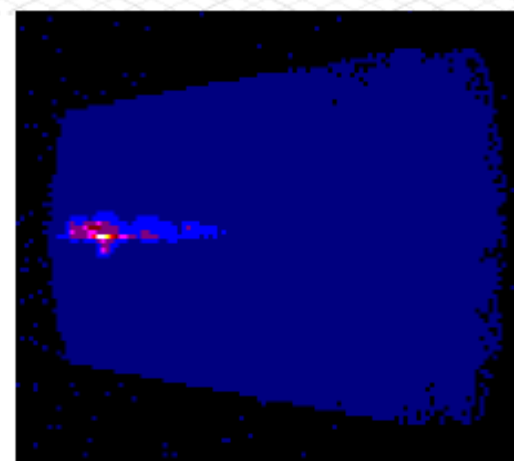
Radford

Signal Decomposition – at the heart of gamma tracking

ORNL leads the development of the GRETINA signal decomposition algorithms / codes.



- Determine, in near-real-time, the *number, positions,* and *energies* of gamma interactions in the crystal
- These interactions are required as input for gamma tracking
- Must allow for one, two, or three interactions per hit segment
- Uses data from both hit segments and image charges from neighbours
- Uses a set of pre-calculated basis pulse shapes
- *Position resolution* is crucial; dominates energy resolution, efficiency, and peak-to-total ratio
- *Speed* is also crucial; determines triggered count-rate capability of array
- Was the part of GRETINA with the largest risk



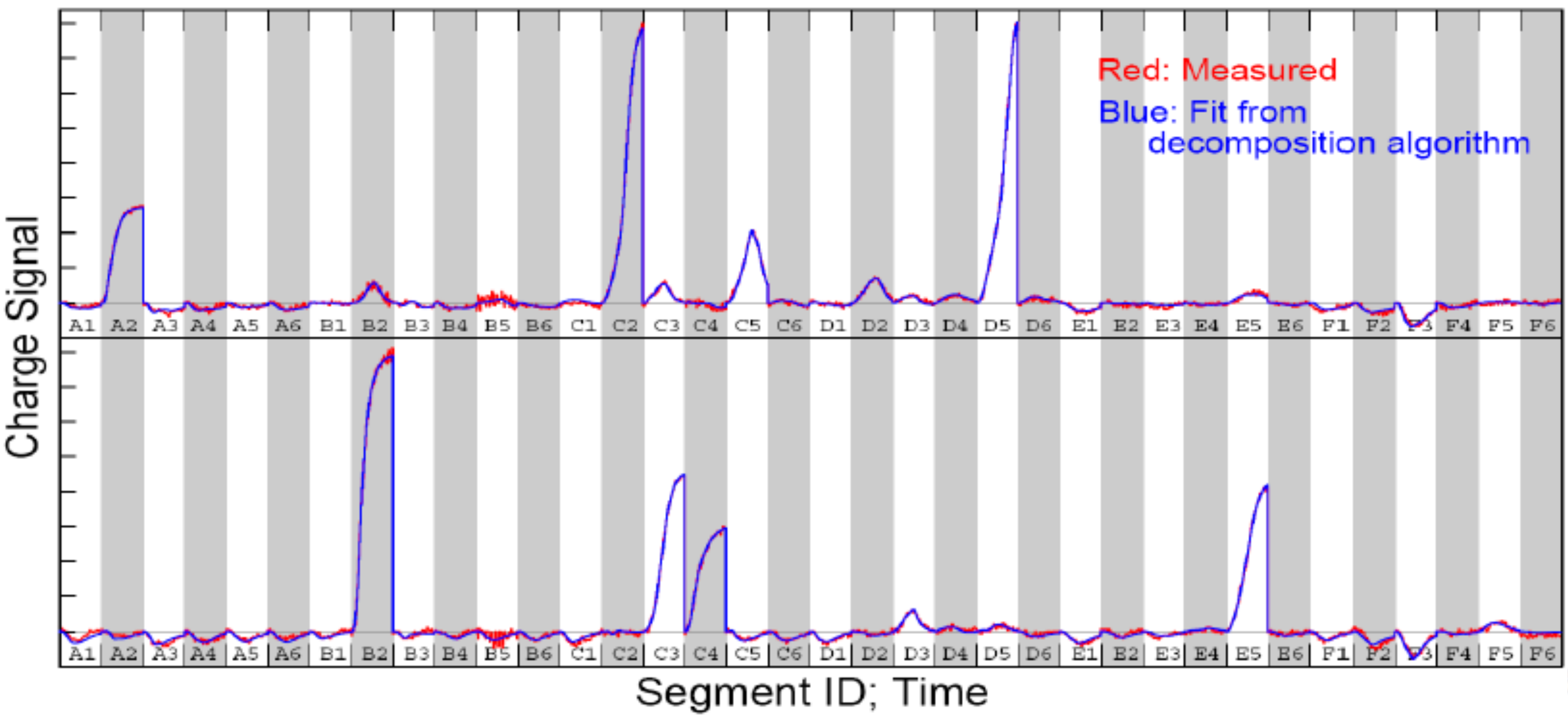
Radford

Decomposition algorithm: Fits

Radford

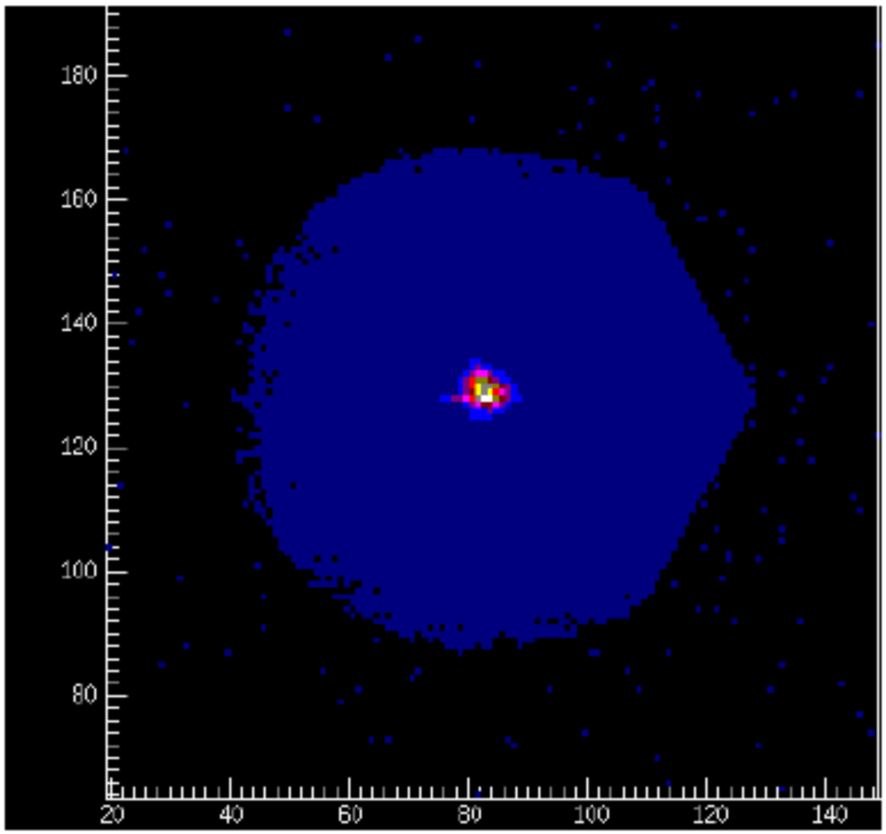
- Red: Two typical multi-segment events measured in prototype triplet cluster
  - concatenated signals from 36 segments, 500ns time range
- Blue: Fits from decomposition algorithm (linear combination of basis signals)
  - includes differential cross talk from capacitive coupling between channels

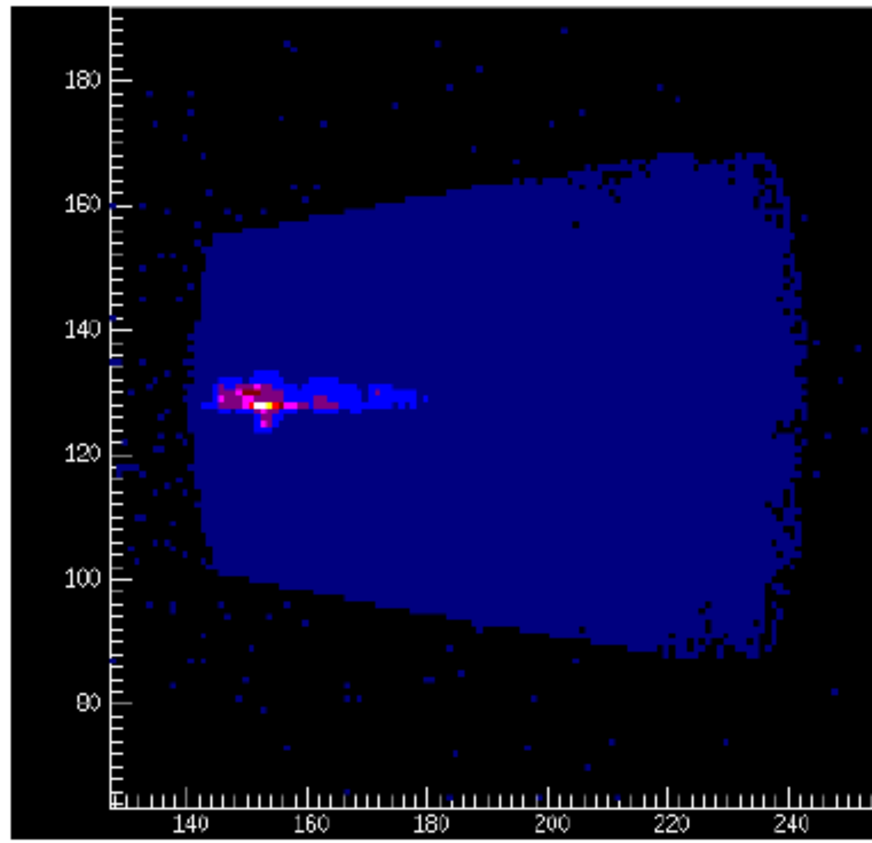
Requires excellent fidelity in basis signals!



Collimated Cs-source test

Pencil beam of 662 keV:
Distribution of deduced interactions points throughout the crystal, from decomposition plus tracking algorithms





Position resolution: σ_x = 1.5 mm; σ_y = 1.7 mm

Gamma Ray Energy Tracking In beam Nuclear Array

$20M Funded by US- DOE Nuclear Physics Office

- **A first realization of a Tracking Array**

  Optimized for fast beam experiments
- **Coverage ~ ¼ of 4π solid angle**
- **28 36-fold segmented Ge crystals (7 Modules)**
- **Mechanical support structure**
- **Data acquisition system**
- **Data processing software**

S. Paschalis, I.Y.Lee, *et al*. NIM **A709** (2013)

- Mission Need (DOE CD0) — August 2003
- Start Construction (CD2/3) — June 2005
- Start of Operation (CD4) — April 2011
- Engineering and commissioning runs at LBNL — April 2011 …. …. March 2012
- Operation at:
  - NSCL/MSU — July 2012-July 2013
  - ATLAS/ANL — Fall 2013

GRETINA Advisory Committee (D. Radford Chair)

GRETINA Users Executive Committee (P. Fallon Chair)

Working Groups: Physics, Detectors, Software, Electronics and Auxiliary Devices

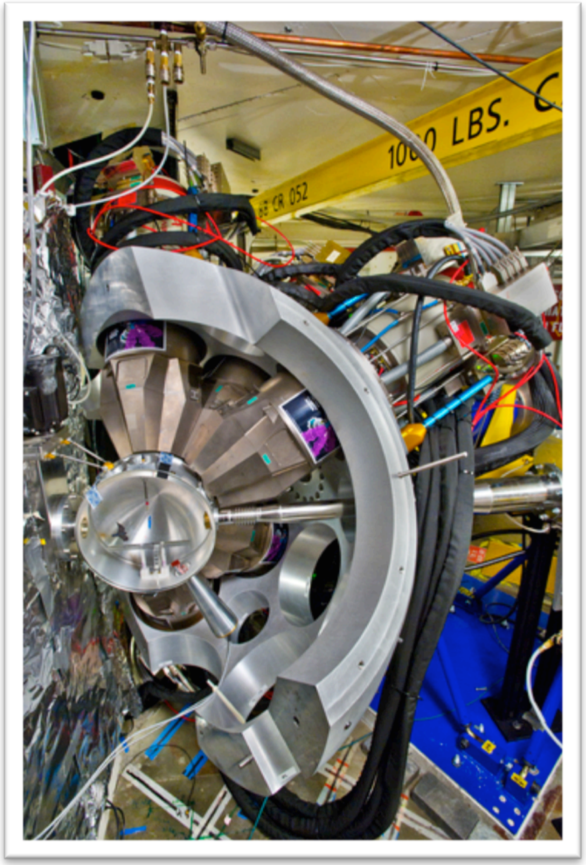
GRETINA Schedule

- Start Construction June 2005
- Start of Operation April 2011
- Engineering & commissioning at LBNL - March 2012
- Operation at NSCL/MSU July 2012 – July 2013
- Operation at ATLAS/ANL

GRETINA, was built and commissioned at LBNL.

Engineering runs **tested, characterized, and debugged** the array, showing success of decomposition and tracking.

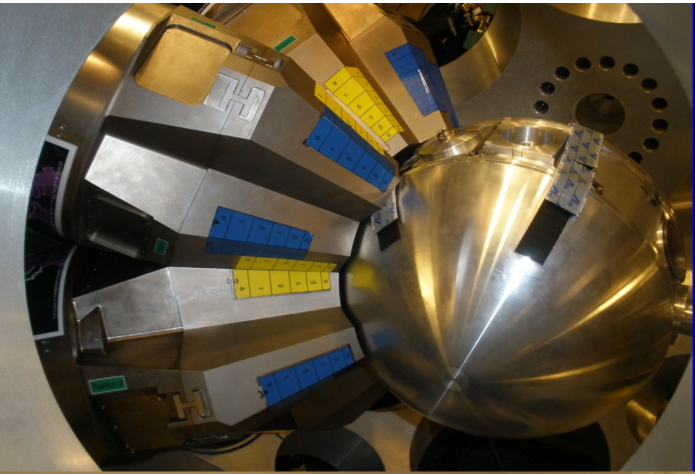
The device was **further tested, debugged and commissioned** in a campaign at the Berkeley Gas-Filled Separator, to study the heaviest elements.

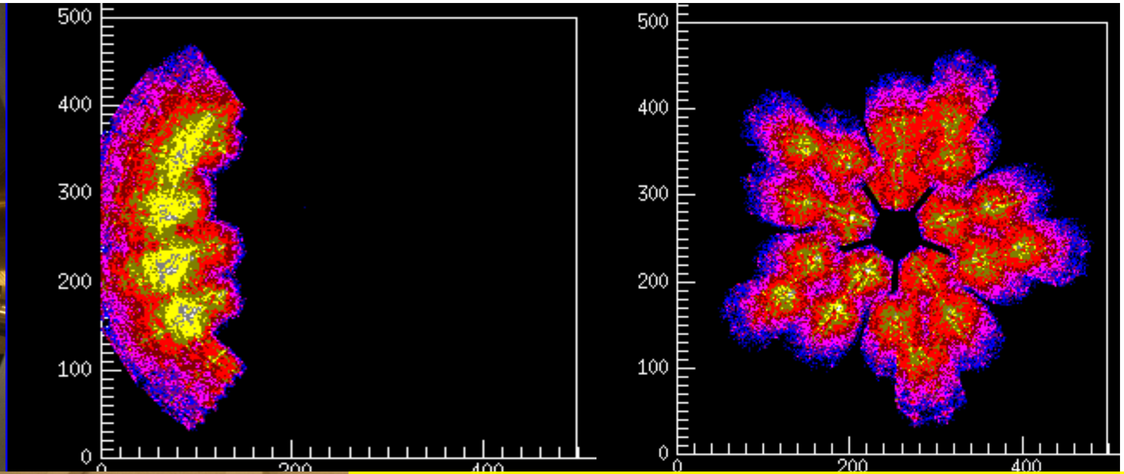


Day 1 of Engineering Run #1, April 6th, 2011

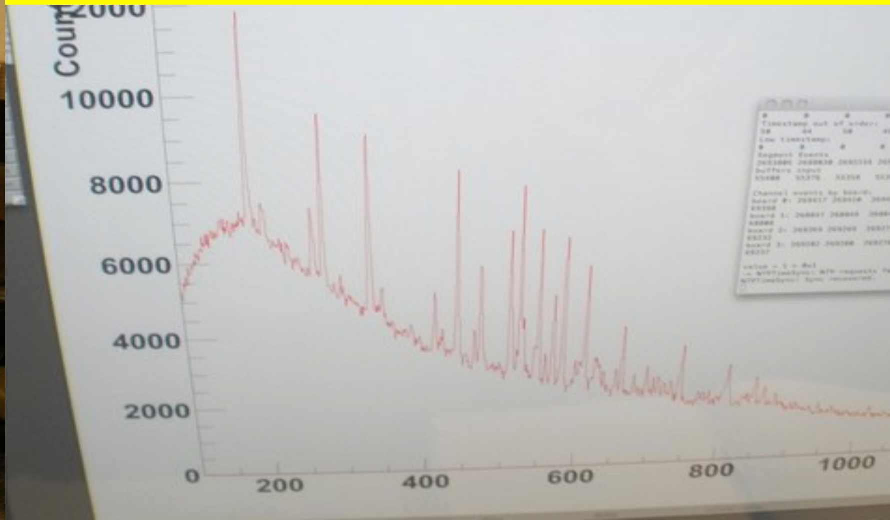
High Multiplicity Test of System

$^{40}Ar + ^{122}Sn \Rightarrow ^{158}Er^{*} + 4n$



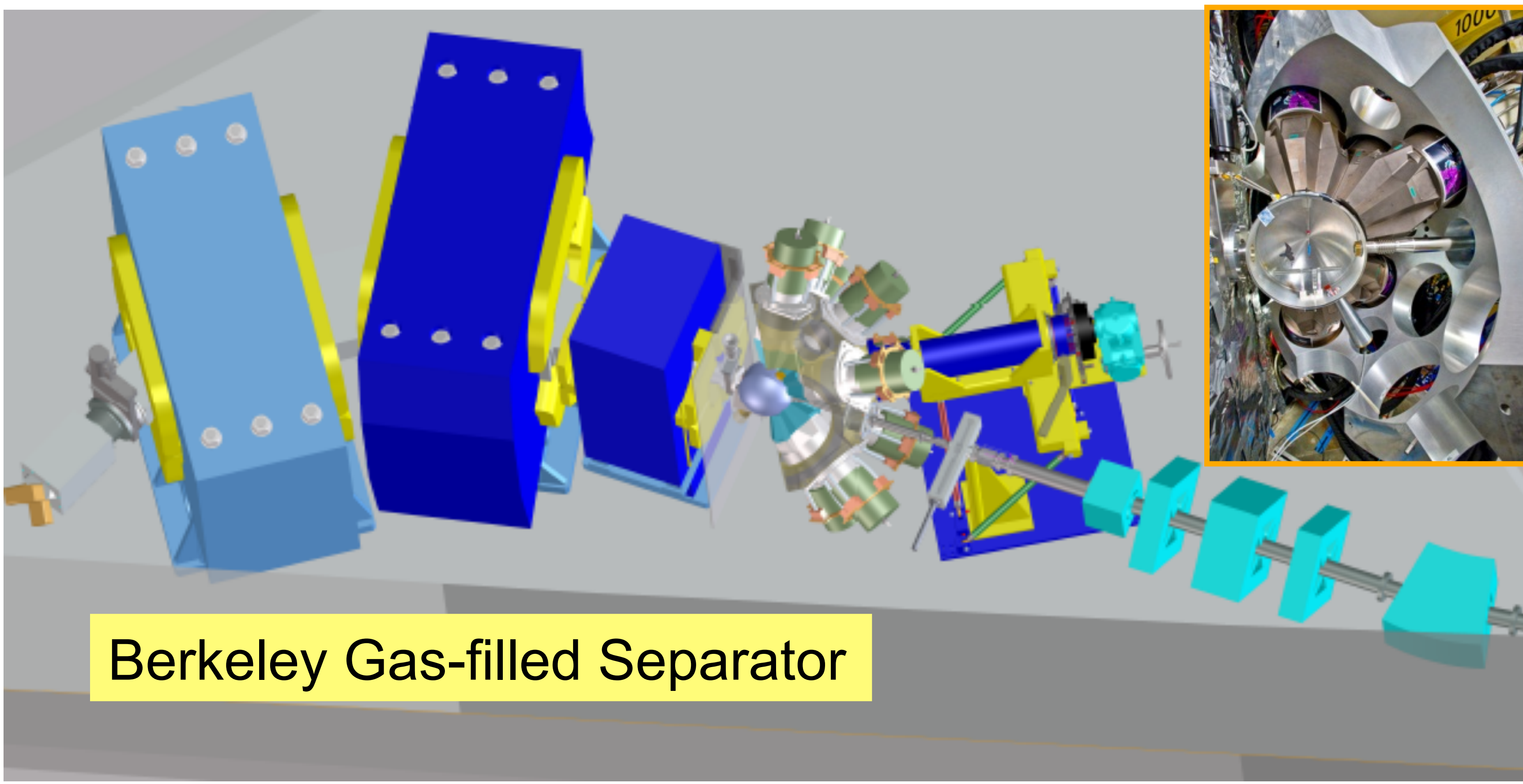


Online raw spectrum with mult>5

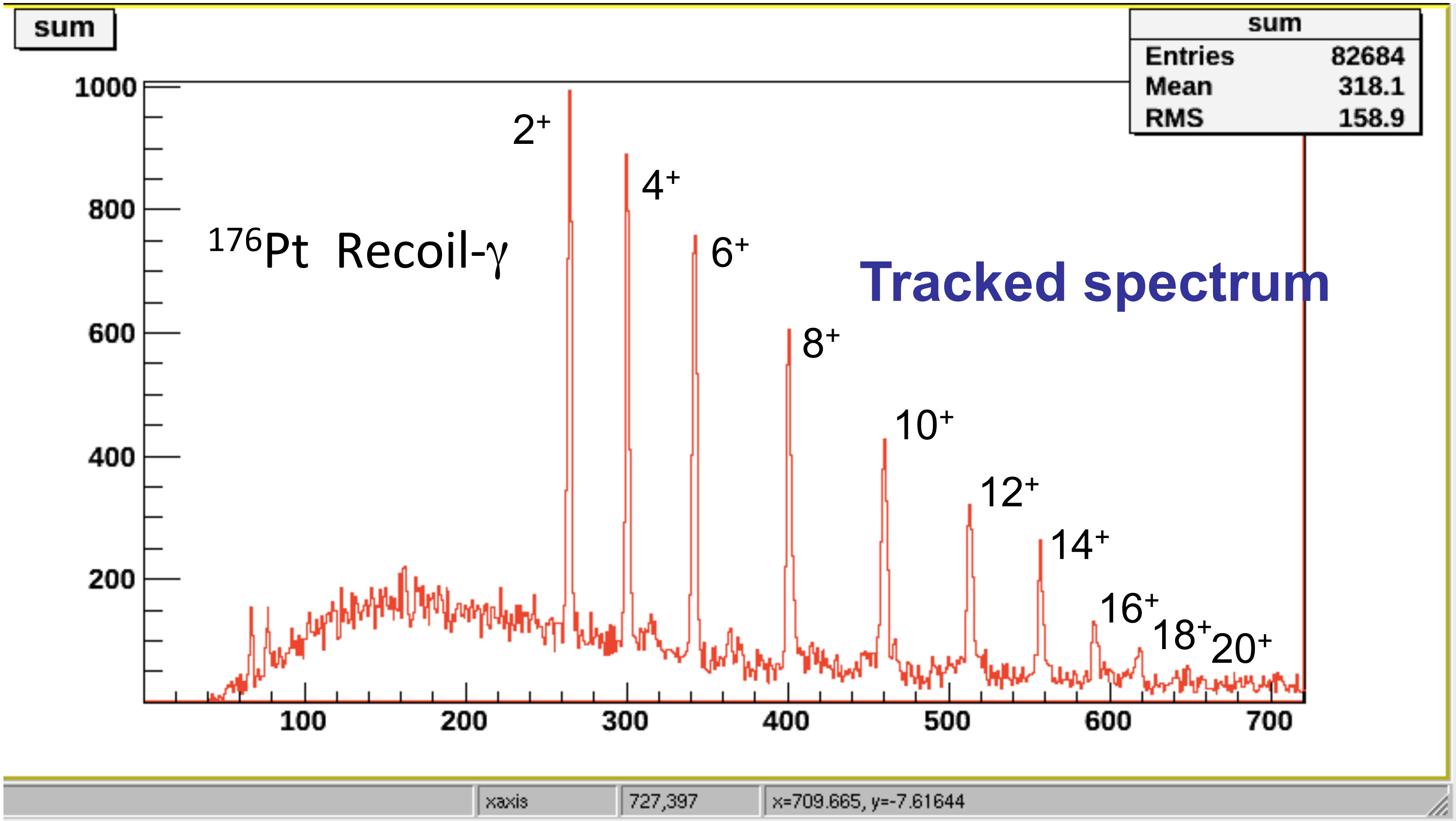


GRETINA at BGS LBNL

- GRETINA set up at BGS target position
- Experiment September 7, 2011 – March 23, 2012

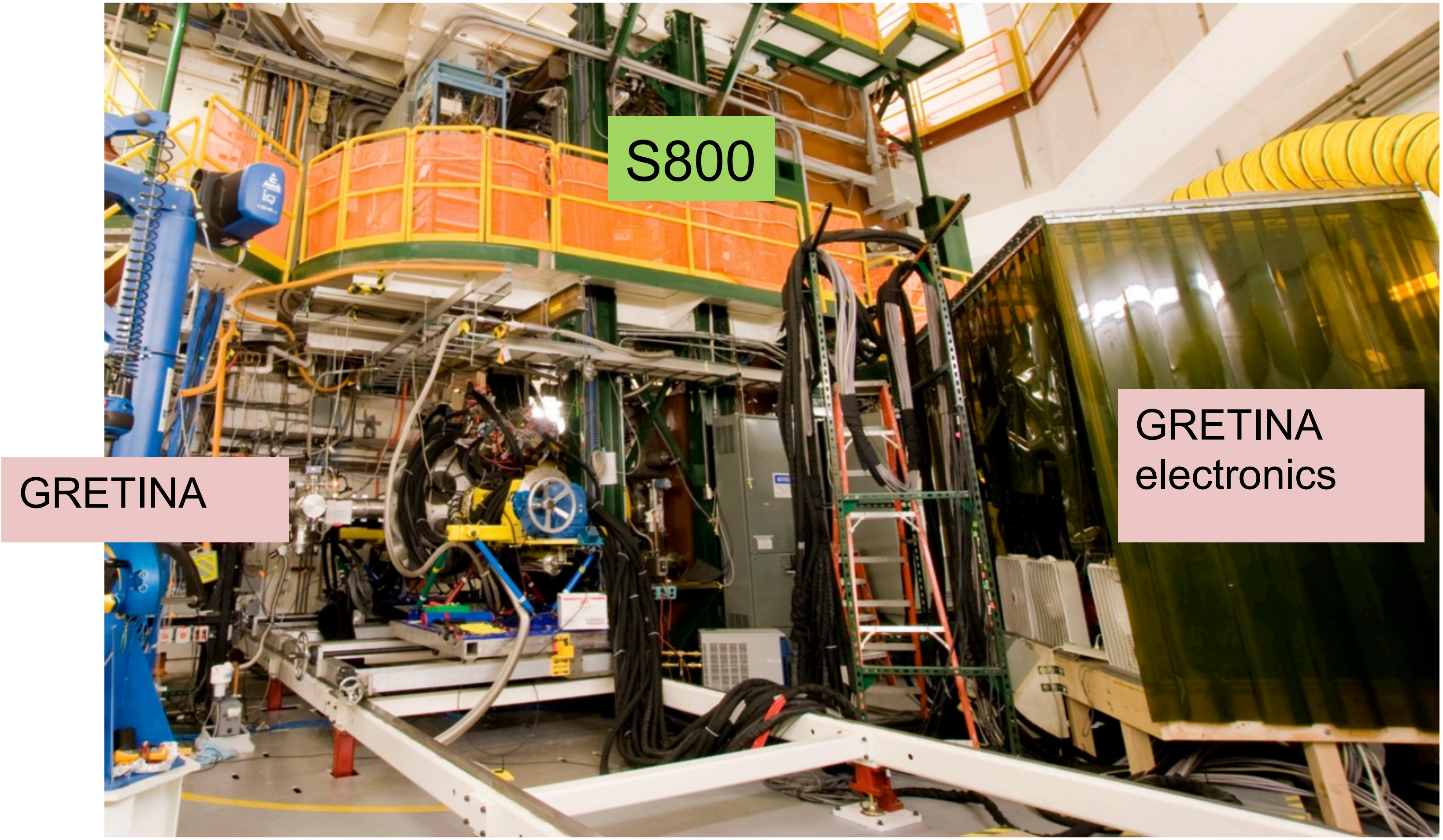


Testing Recoil-Decay Tagging Methods Using GRETINA and the BGS
$^{144}Sm(^{36}Ar, X)$ at 190MeV



Science campaign at NSCL: July 2012 – June 2013

- **23 experiments performed: 3360 hours**



GRETINA at target position of S800 spectrograph

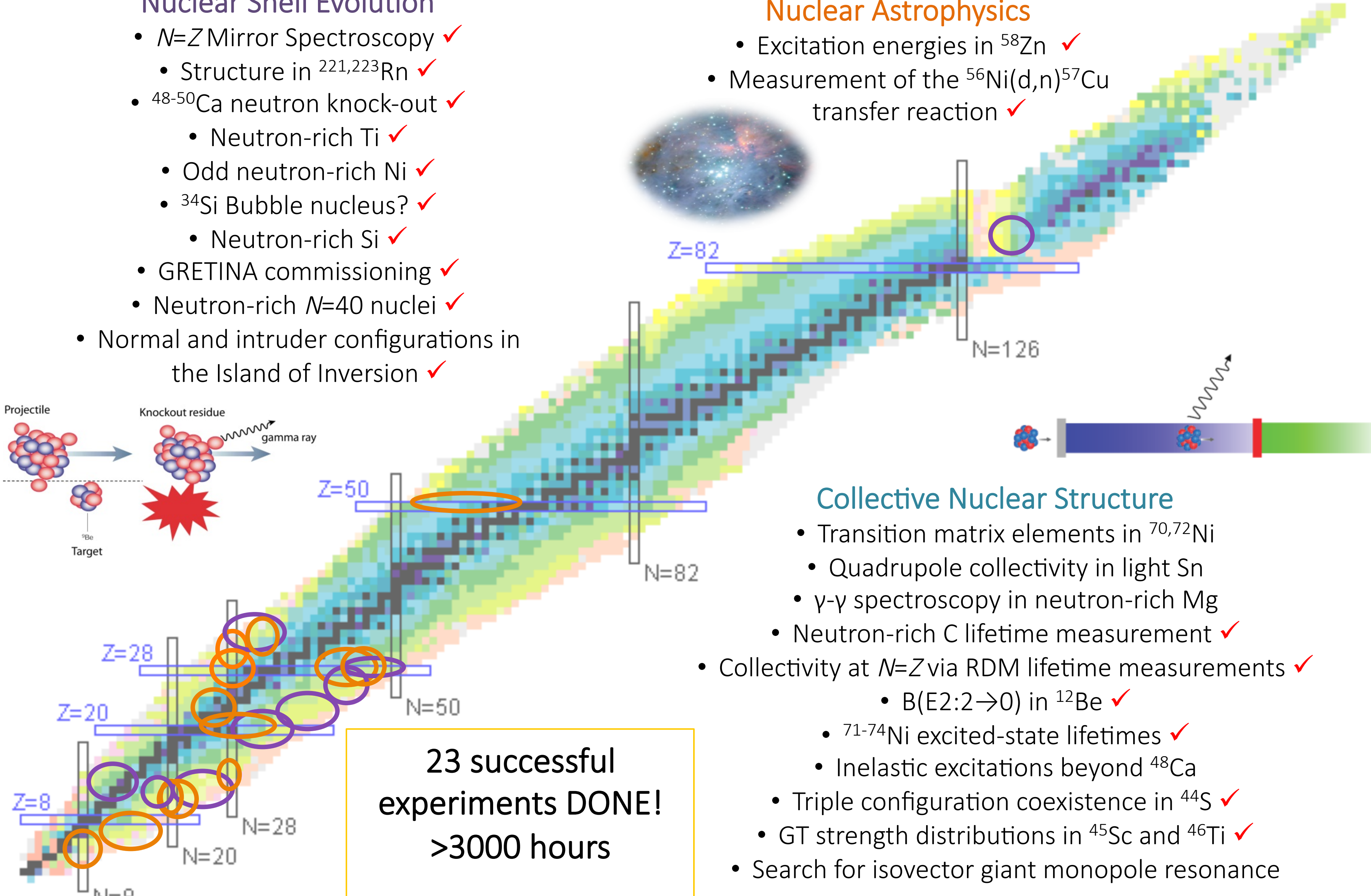
Experiments at NSCL

Nuclear Shell Evolution

- *N*=*Z* Mirror Spectroscopy ✓
- Structure in ^{221,223}Rn ✓
- $^{48\text{-}50}$Ca neutron knock-out ✓
- Neutron-rich Ti ✓
- Odd neutron-rich Ni ✓
- ^{34}Si Bubble nucleus? ✓
- Neutron-rich Si ✓
- GRETINA commissioning ✓
- Neutron-rich *N*=40 nuclei ✓
- Normal and intruder configurations in the Island of Inversion ✓

Nuclear Astrophysics

- Excitation energies in ^{58}Zn ✓
- Measurement of the ^{56}Ni(d,n)^{57}Cu transfer reaction ✓



Collective Nuclear Structure

- Transition matrix elements in ^{70,72}Ni
- Quadrupole collectivity in light Sn
- γ-γ spectroscopy in neutron-rich Mg
- Neutron-rich C lifetime measurement ✓
- Collectivity at *N*=*Z* via RDM lifetime measurements ✓
- B(E2:2→0) in ^{12}Be ✓
- $^{71\text{-}74}$Ni excited-state lifetimes ✓
- Inelastic excitations beyond ^{48}Ca
- Triple configuration coexistence in ^{44}S ✓
- GT strength distributions in ^{45}Sc and ^{46}Ti ✓
- Search for isovector giant monopole resonance

23 successful experiments DONE!
>3000 hours

Coming up next

GUEC Workshop on Future GRETINA Science Campaigns

March 2-3, 2013 – Argonne National Laboratory

https://www.phy.anl.gov/atlas/GretinaWorkshop/index.html.

ATLAS Campaign, Fall 2013 – 2104

Neutron-rich nuclei – CARIBU beams

Structure of nuclei in the ^{100}Sn region

(Super)heavy nuclei.

Second NSCL Campaign, 2015 - ……

A few words on GRETA

Complete full 4π coverage

- Unique instrument at FRIB for both fast and slow beams
- Strong community support (LRP, FRIB SAC)

A plan has been developed to complete GRETA for "day one" experiments at FRIB. The completion of GRETA requires 23 additional detector modules together with the associated electronics, computing, and mechanical support.

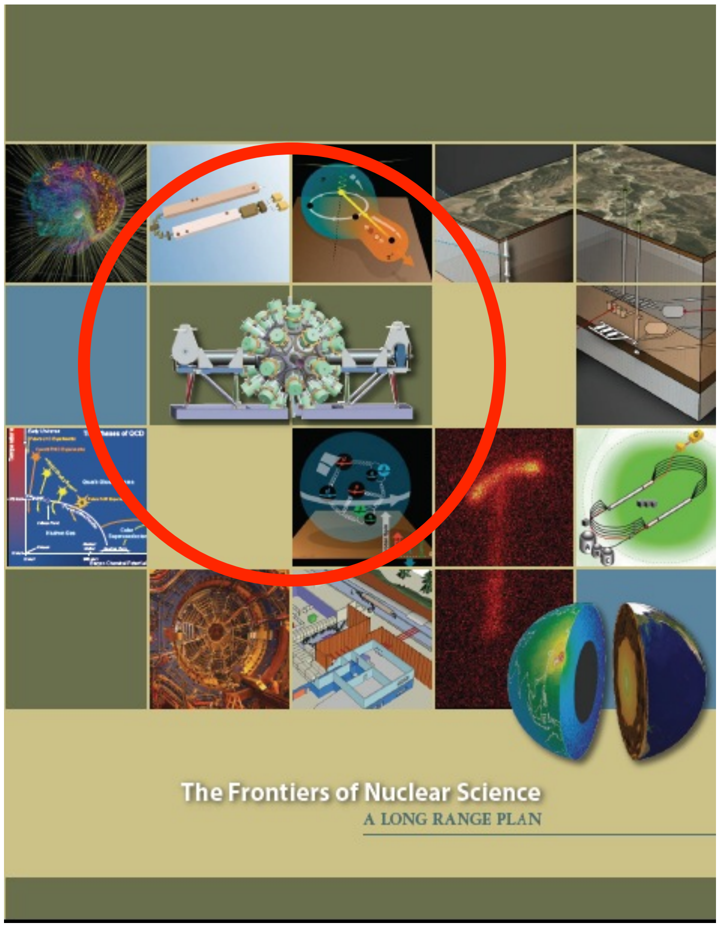
Take full advantage of technological advances while maintaining compatibility with the present system.

Detectors: new preamps, point contact, …

Electronics: new digitizers at detector, minimize use of cables

Computing: redesign of readout architecture

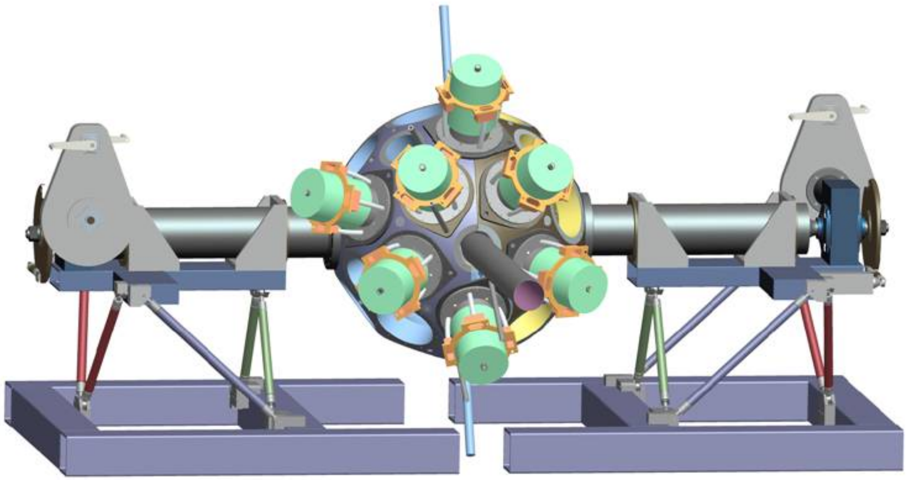
2007 Long Range Plan

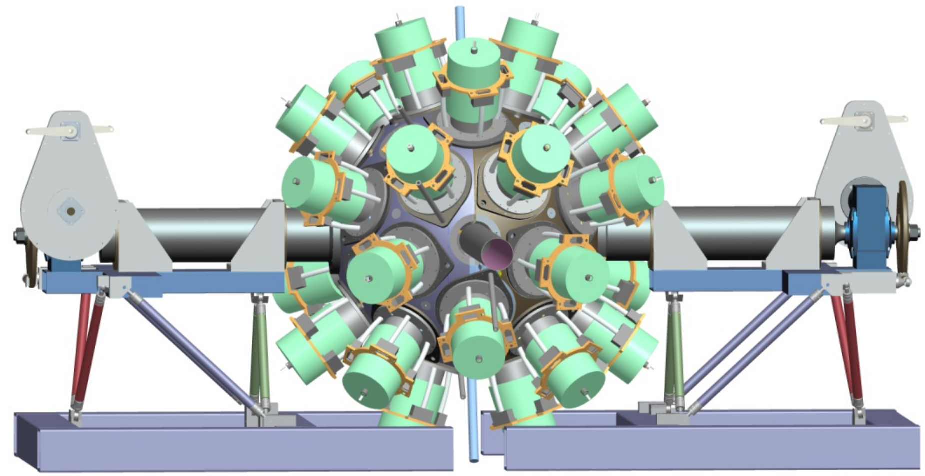


……. Thus **the construction of GRETA should begin upon successful completion of GRETINA. This gamma-ray energy tracking array will enable full exploitation of compelling science opportunities in nuclear structure, nuclear astrophysics, and weak interactions.**

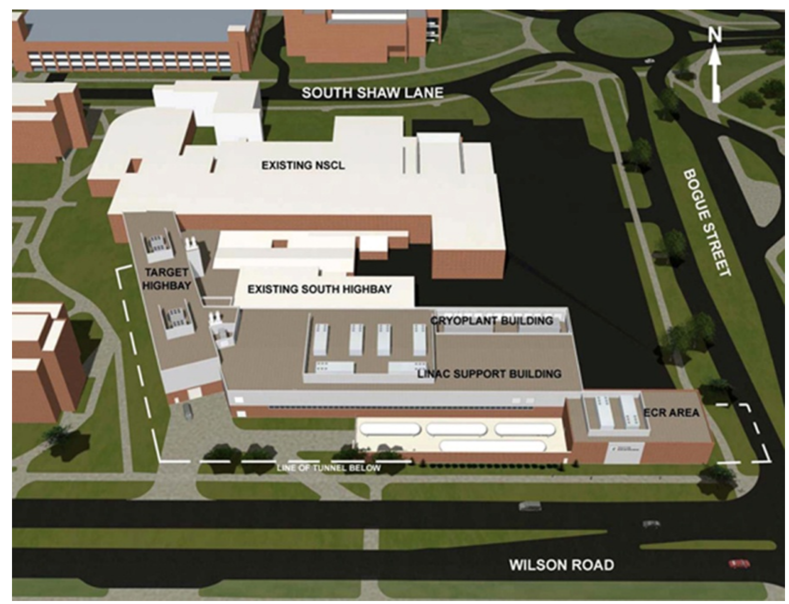
Let's keep the momentum going!

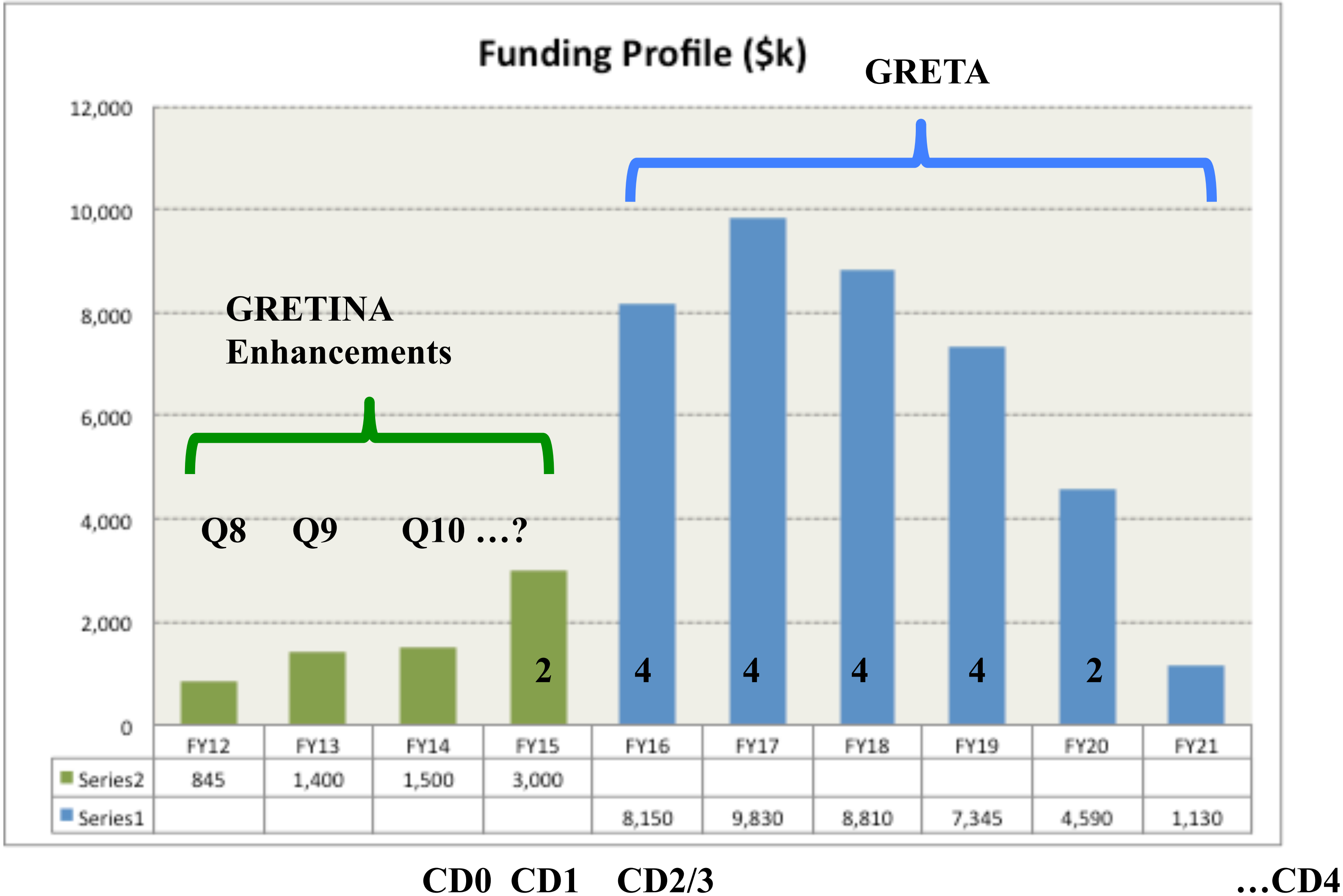
GRETINA to GRETA for FRIB





It has been called
"A jewel in the crown of FRIB"
Tim Hallman, Aug 2011:
"The importance of GRETA in the out years is understood and is part of DOE planning."



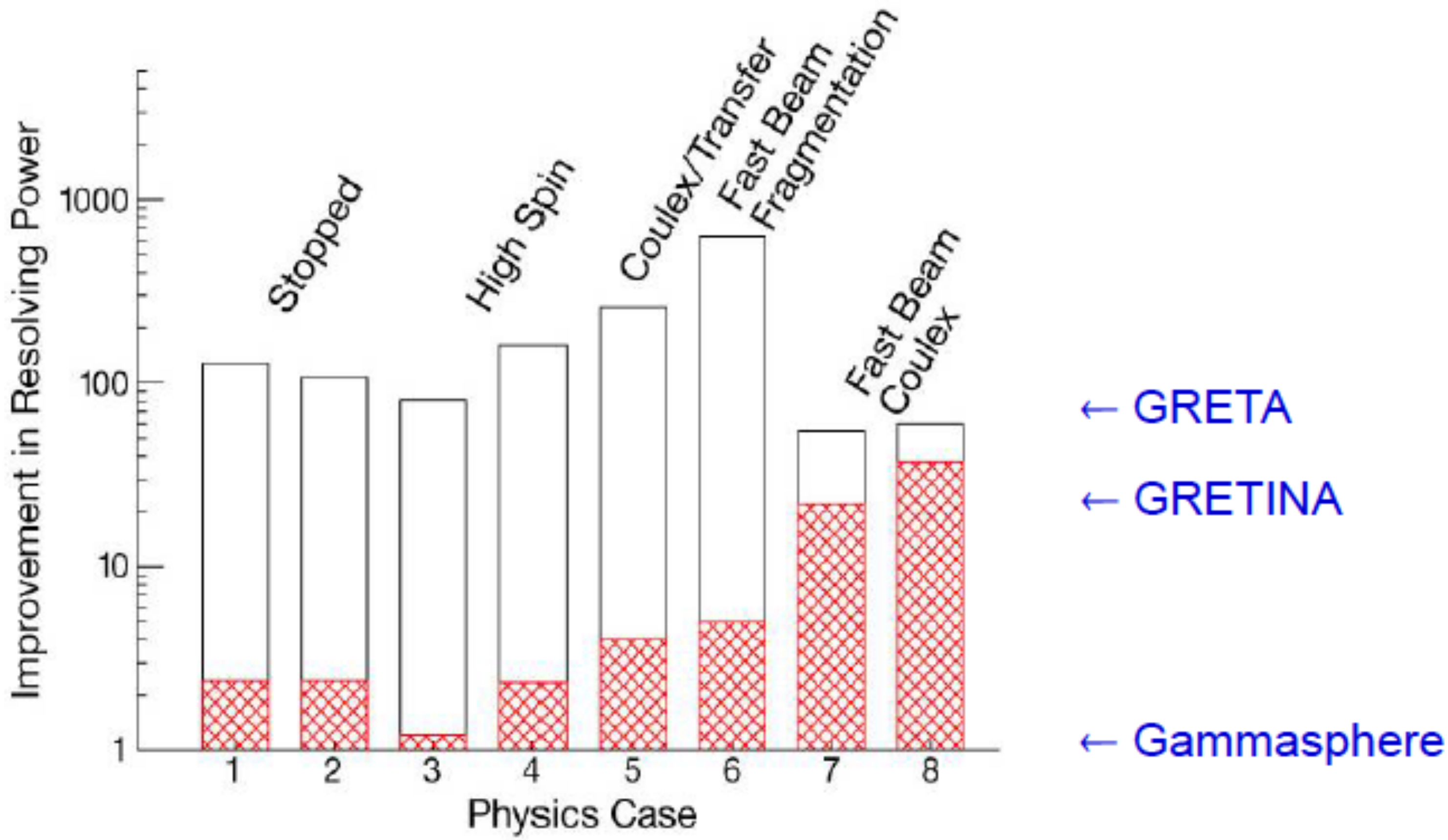


	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21
Series2	845	1,400	1,500	3,000						
Series1					8,150	9,830	8,810	7,345	4,590	1,130

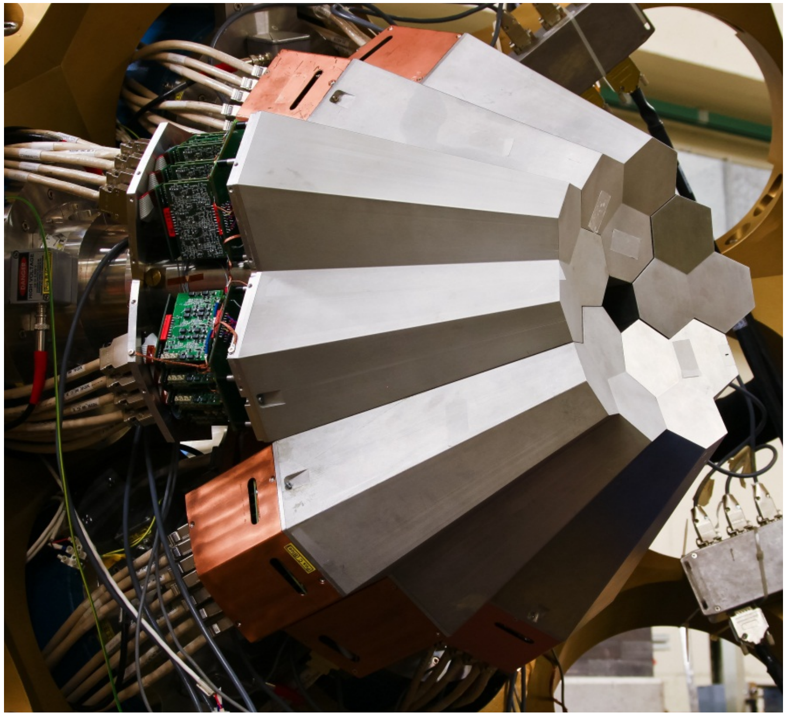
From GRETINA to GRETA

1π → 4π coverage,   28 → 120 detectors

- Greater resolving power by factors of up to 100
- GRETA is the most requested instrument at the next generation RIB facility   - RIA Facility Workshop,   March 2004



The AGATA Project; Status and Plans



John Simpson
Nuclear Physics Group
STFC Daresbury Laboratory

Why do we need AGATA?

FAIR
SPIRAL2
SPES
REX-ISOLDE
EURISOL
HI-Stable

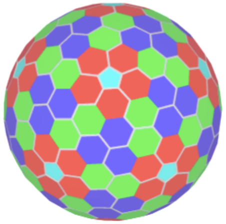
- Low intensity
- High background
- Large Doppler broadening
- High counting rates
- High γ-ray multiplicities

Harsh conditions!
Need instrumentation with

High efficiency
High sensitivity
High throughput
Ancillary detectors

Conventional arrays will not suffice!

The AGATA Collaboration



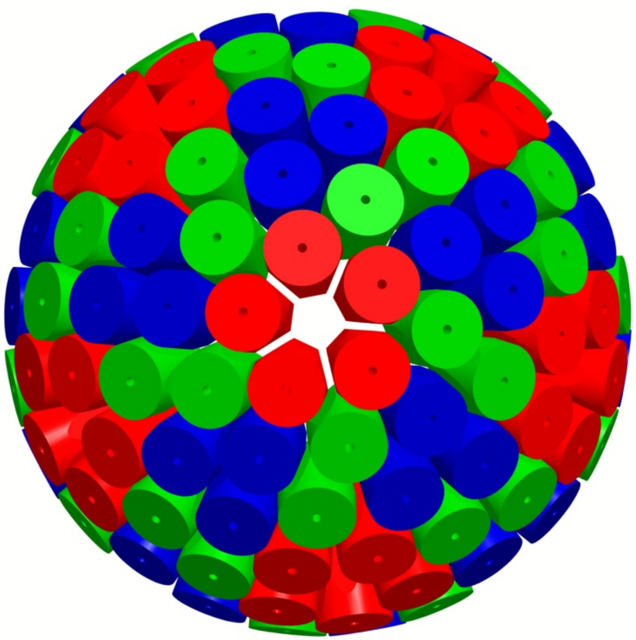
13 Countries +EU
>40 Institutions

Bulgaria:	Univ. Sofia
Denmark:	NBI Copenhagen
Finland:	Univ. Jyväskylä
France:	GANIL Caen, IPN Lyon, CSNSM Orsay, IPN Orsay, CEA-DSM-DAPNIA Saclay, IPHC Strasbourg, LPSC Grenoble
Germany:	GSI Darmstadt, TU Darmstadt, Univ. zu Köln, TU München
Hungary:	ATOMKI Debrecen
Italy:	INFN-LNL, INFN and Univ. Padova, Milano, Firenze, Genova, Napoli,
Poland:	NINP and IFJ Krakow, SINS Swierk, HIL & IEP Warsaw
Romania:	NIPNE & PU Bucharest
Sweden:	Univ. Göteborg, Lund Univ., KTH Stockholm, Uppsala Univ.
Turkey:	Univ. Ankara, Univ. Istanbul, Technical Univ. Istanbul
UK:	Univ. Brighton, STFC Daresbury, Univ. Edinburgh, Univ. Liverpool, Univ. Manchester, Univ. West of Scotland, Univ. Surrey, Univ. York

Spain: IFIC Valencia, IEM-CSIC Madrid, LRI Univ. Salamanca

AGATA
(Design and characteristics)

4π γ-array for Nuclear Physics Experiments at European accelerators providing radioactive and stable beams



Main features of AGATA

Efficiency: 43% (M_γ =1) 28% (M_γ =30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

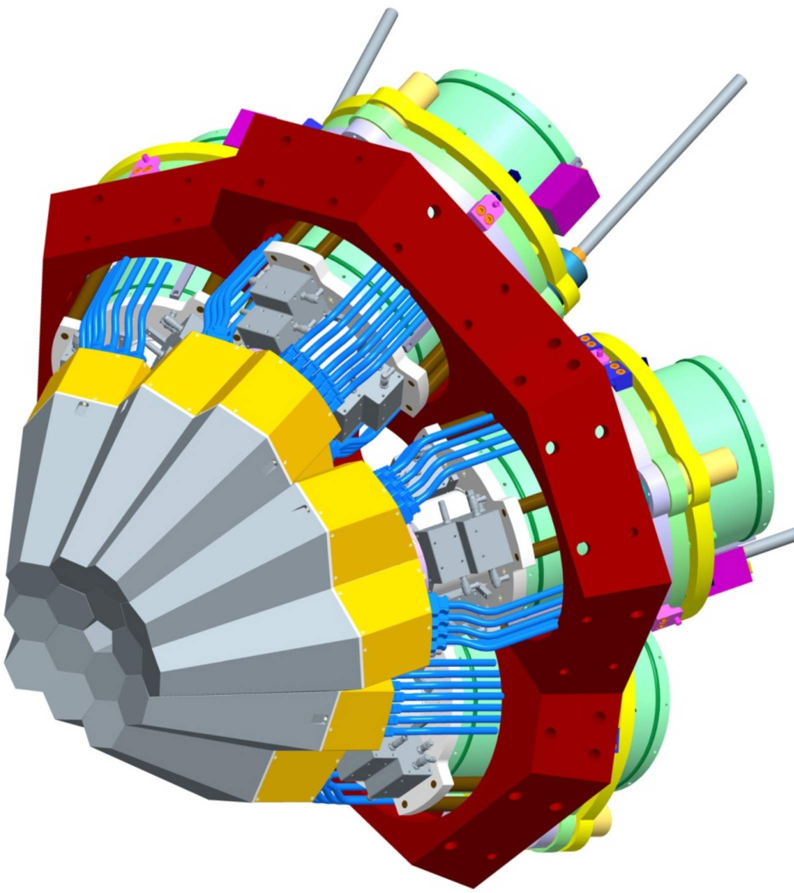
Peak/Total: 58% (M_γ=1) 49% (M_γ=30)
today ~55% 40%

Angular Resolution: ~1° →
FWHM (1 MeV, v/c=50%) ~ 6 keV !!!
today ~40 keV

Rates: 3 MHz (M_γ=1) 300 kHz (M_γ =30)
today 1 MHz 20 kHz

- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

The First Step:
The AGATA Demonstrator

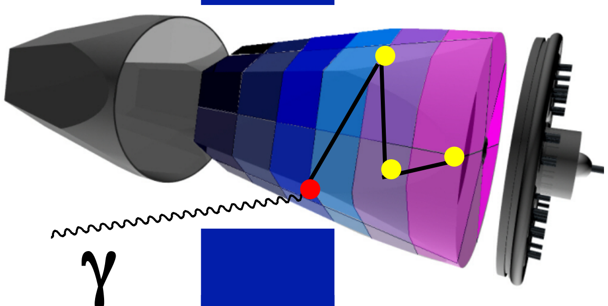


1 symmetric triple-cluster
5 asymmetric triple-clusters
36-fold segmented crystals
540 segments
555 digital-channels
Eff. 3 – 8 % @ M_γ = 1
Eff. 2 – 4 % @ M_γ = 30
Full **EDAQ**
with on line PSA and γ-ray tracking
In beam Commissioning
Technical proposal for full array

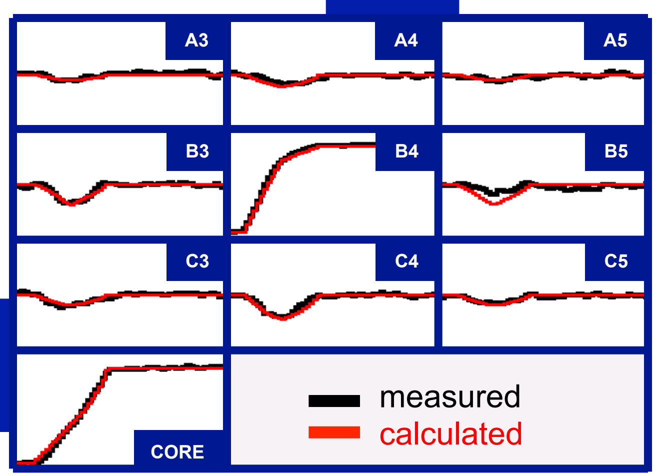
Cost 6.7 M€ Capital

γ-ray Tracking Arrays

Electrically segmented HPGe detectors



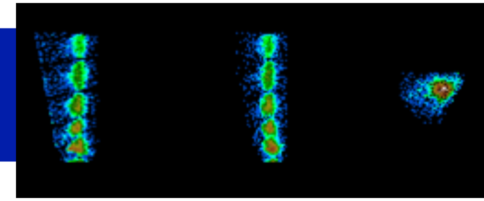
Digital electronics to record and process segment signals



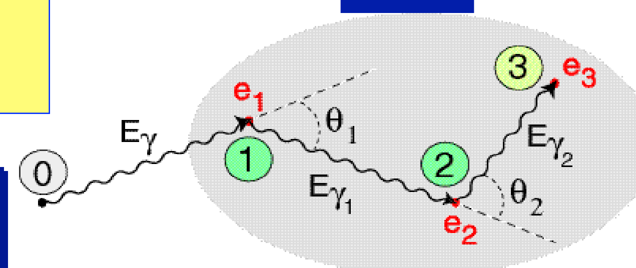
Deconvolution of the recorded waves through comparison with reference signals

Identification of the individual interaction points

$(x,y,z,E,t)_i$

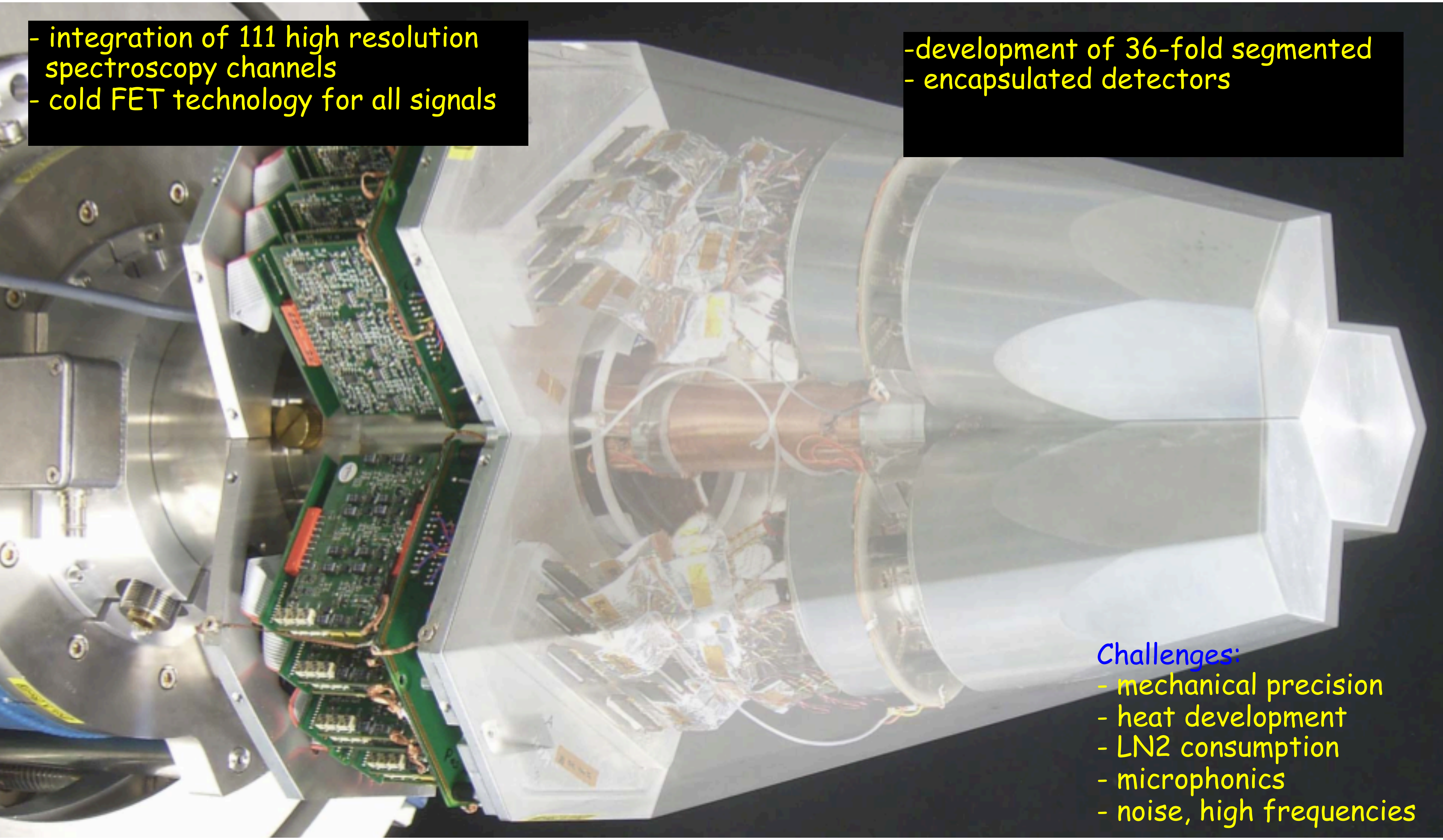


Reconstruction of tracks evaluating permutations of interaction points



Energy and direction of γ-rays

Agata Triple Cluster

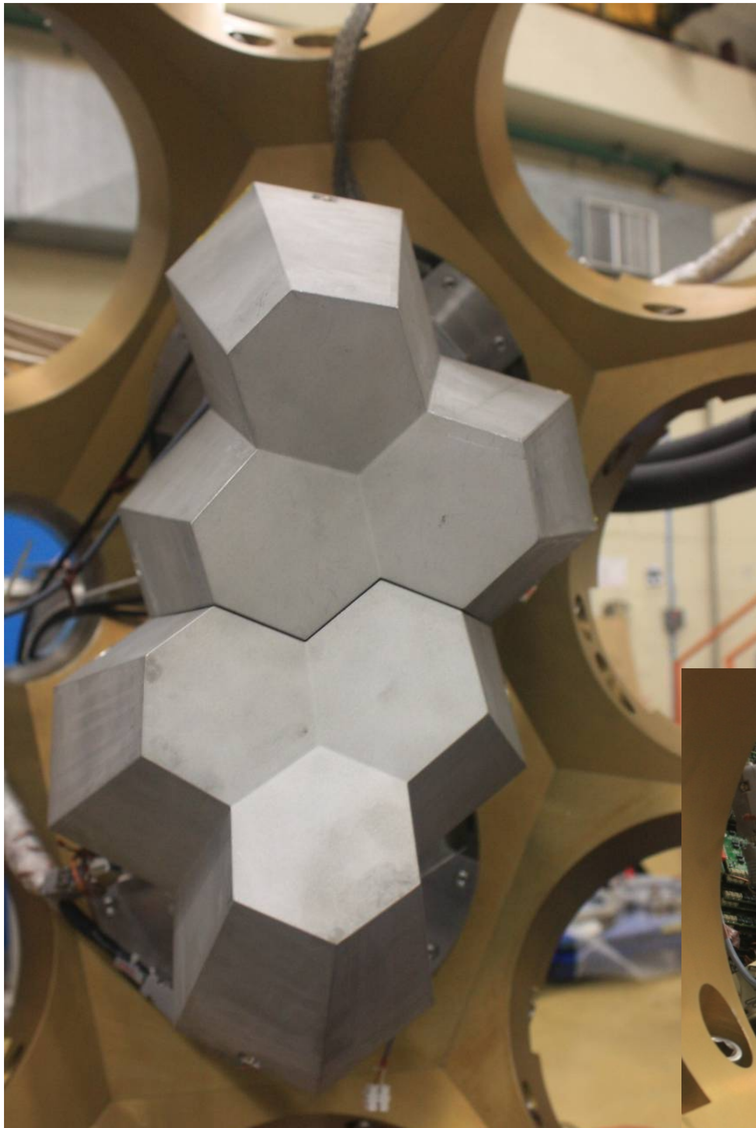


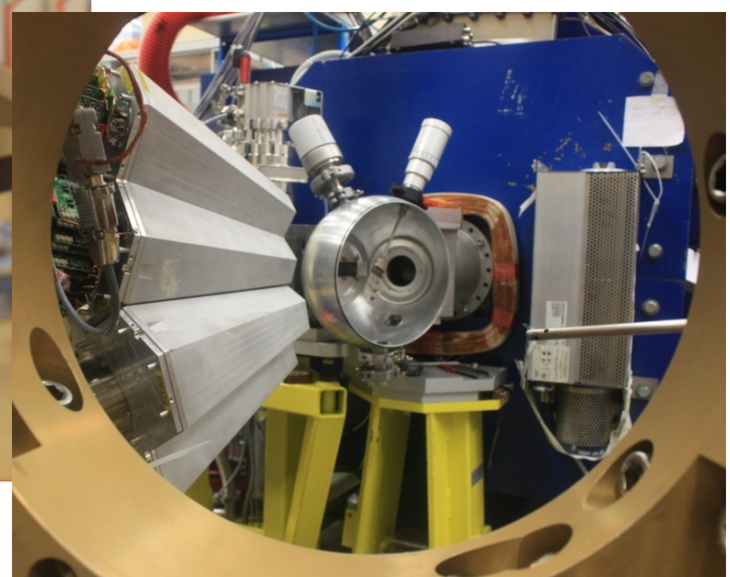
- integration of 111 high resolution spectroscopy channels
- cold FET technology for all signals

-development of 36-fold segmented
- encapsulated detectors

Challenges:
- mechanical precision
- heat development
- LN2 consumption
- microphonics
- noise, high frequencies

A. Wiens et al. NIM A 618 (2010) 223–233; D. Lersch et al. NIM A 640(2011) 133-138

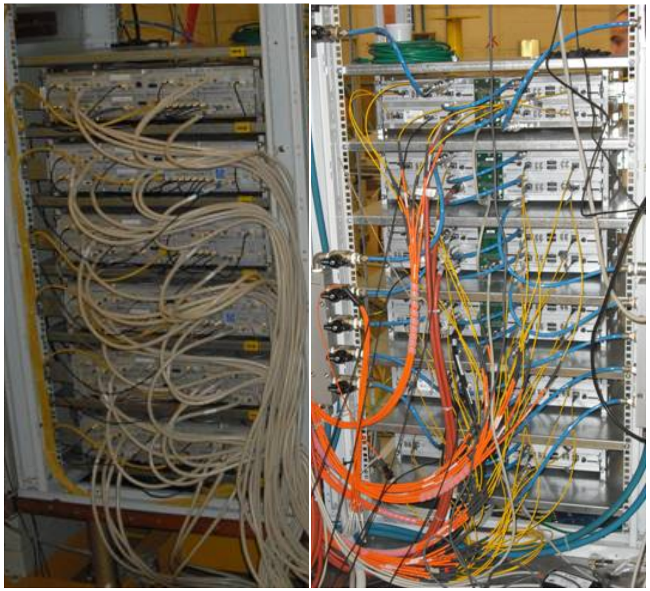




AGATA: Digital Electronics

Digitisers
in the experimental hall

10 m long MDR cables

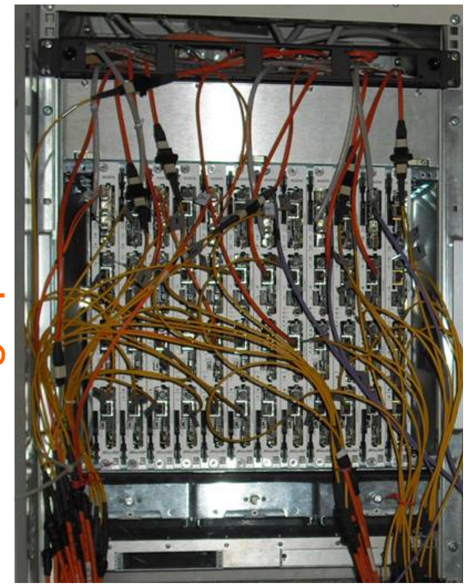


100Mhz, 14 bit
Synchronous &
continuous

80 m long optical fibers

→ (7.6GB/s/crystal)

Digital proc. electronics
in the users area

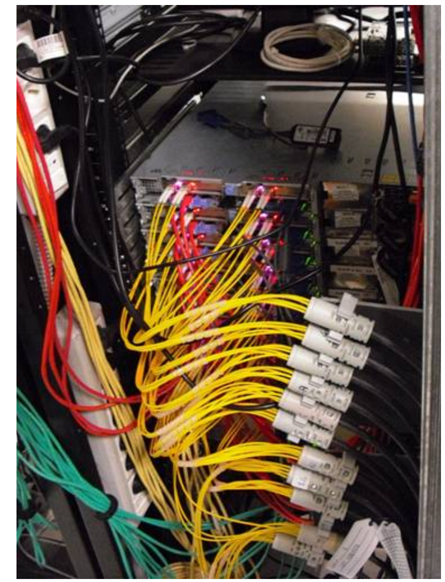


Triggering
Energy
Trace capture

20 m long optical fibers

→ (10 kB/evt/crystal)

Computer farm
in the computing room



LAN to the disk servers

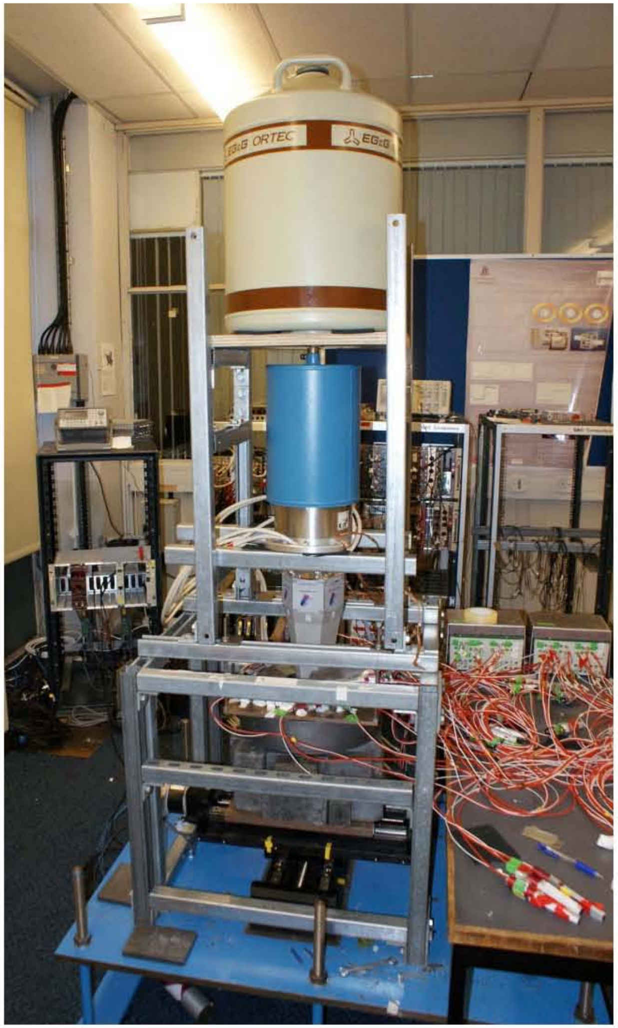
Preprocessing
PSA
Tracking

Global
Triggering
System

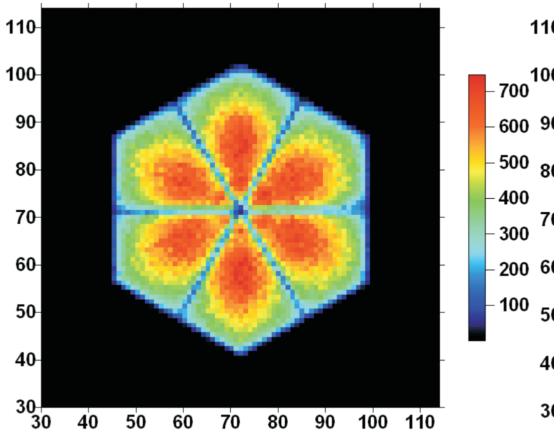
GTS

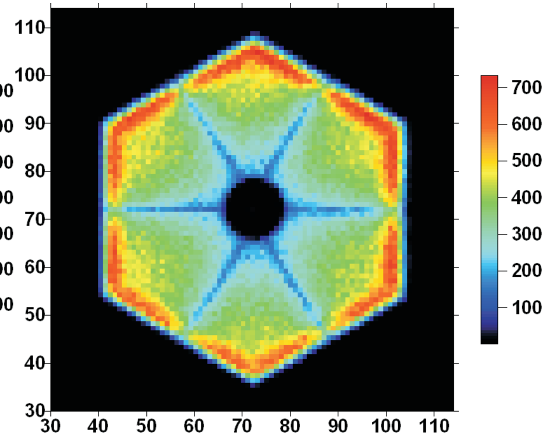
Clock &
Trigger validation

AGATA Scan Setup

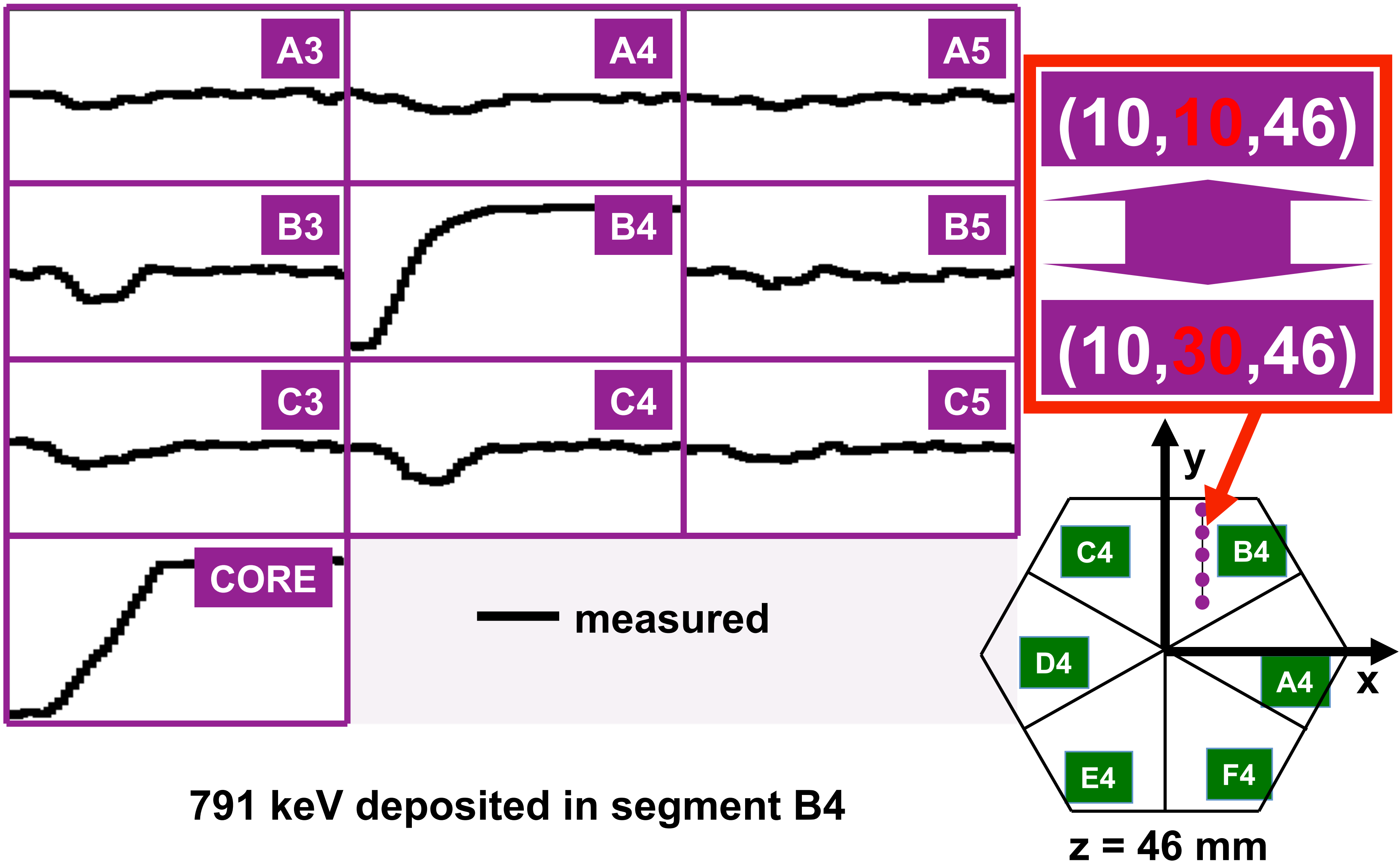


- Two symmetric and two asymmetric crystals scanned at
University of Liverpool
- Scanning systems, CSNSM Orsay, Strasbourg, GSI



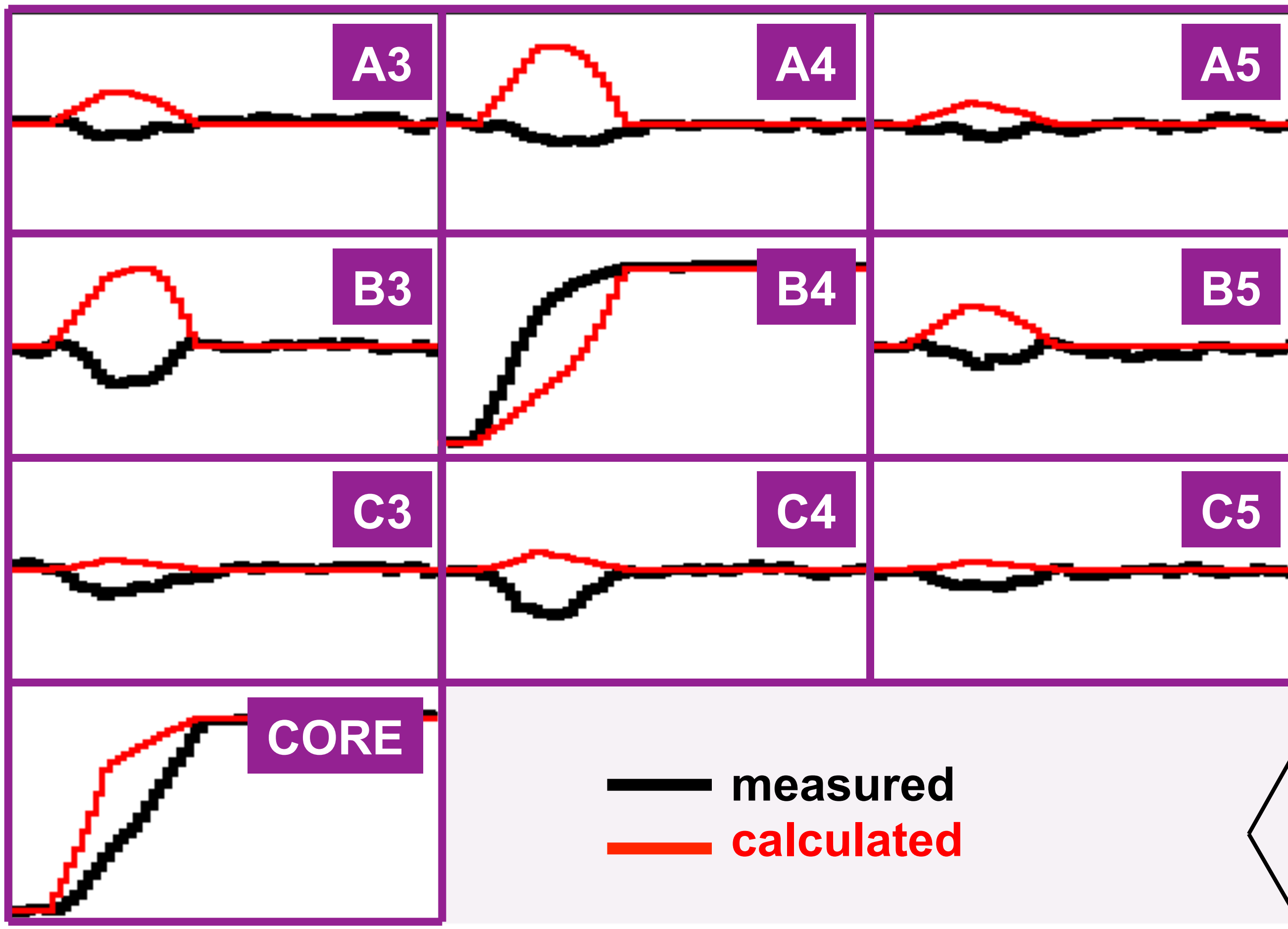


Pulse Shape Analysis concept

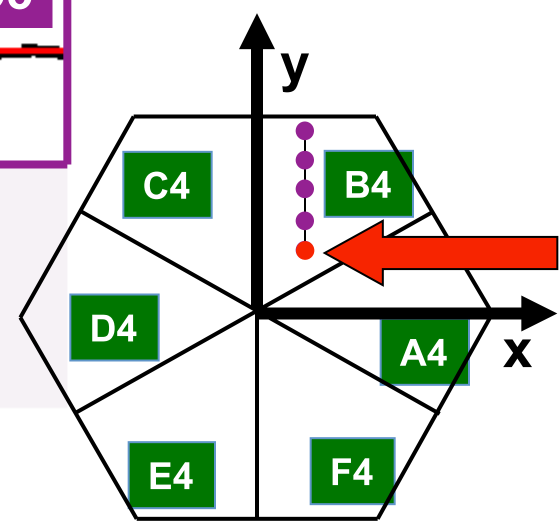


791 keV deposited in segment B4

Pulse Shape Analysis concept



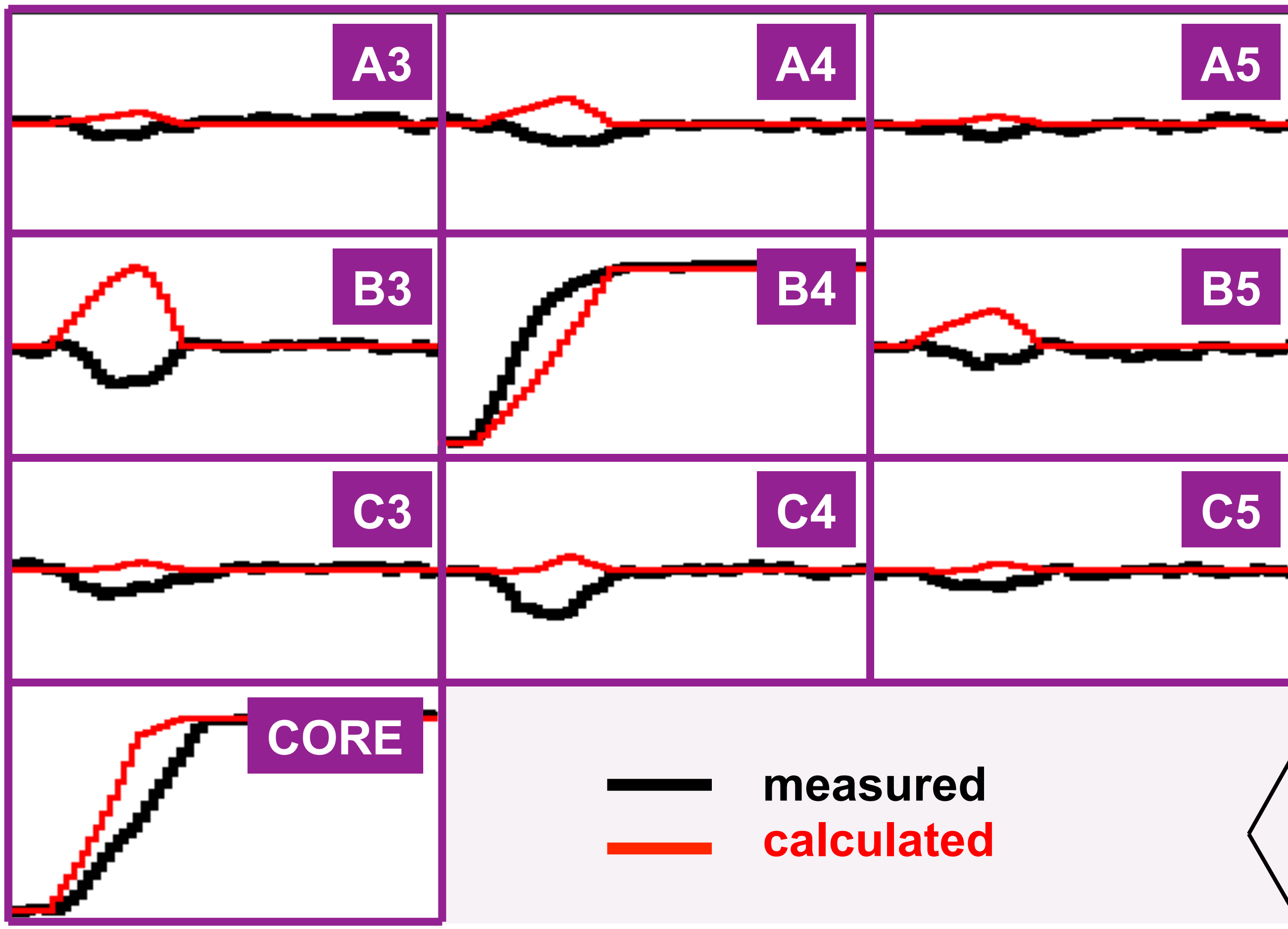
(10,10,46)

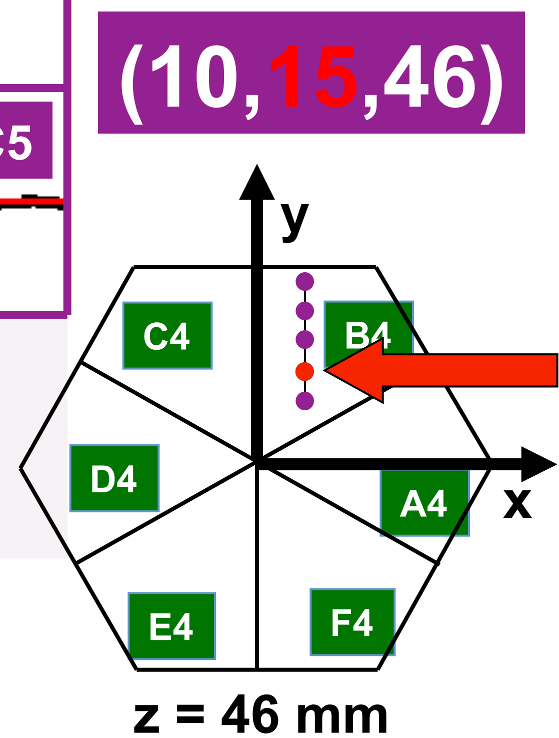


z = 46 mm

791 keV deposited in segment B4

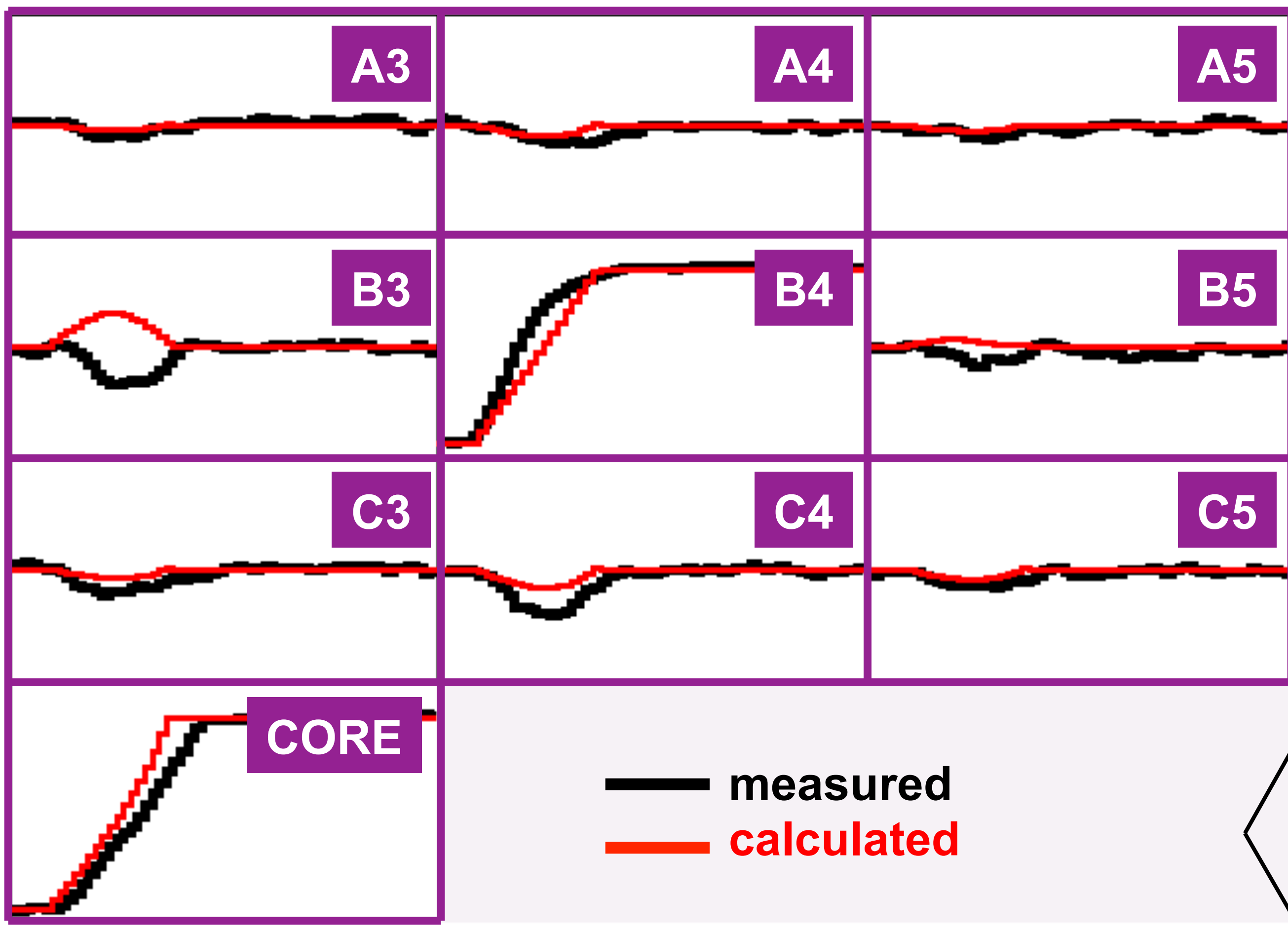
Pulse Shape Analysis concept



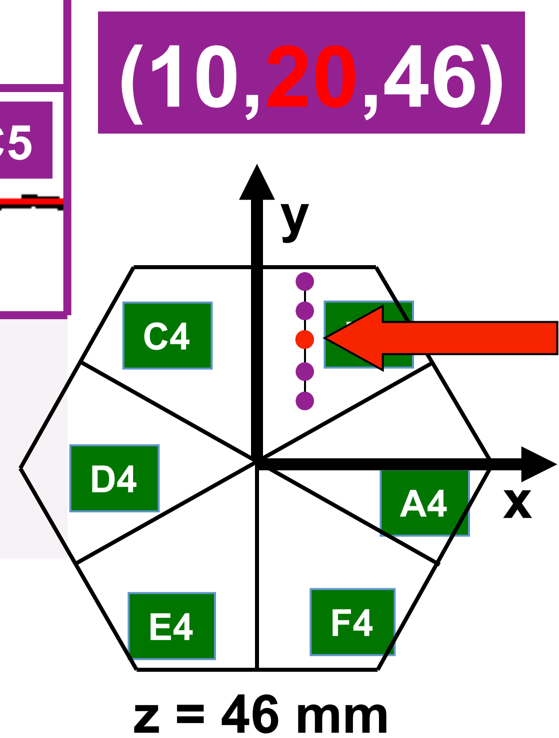


791 keV deposited in segment B4

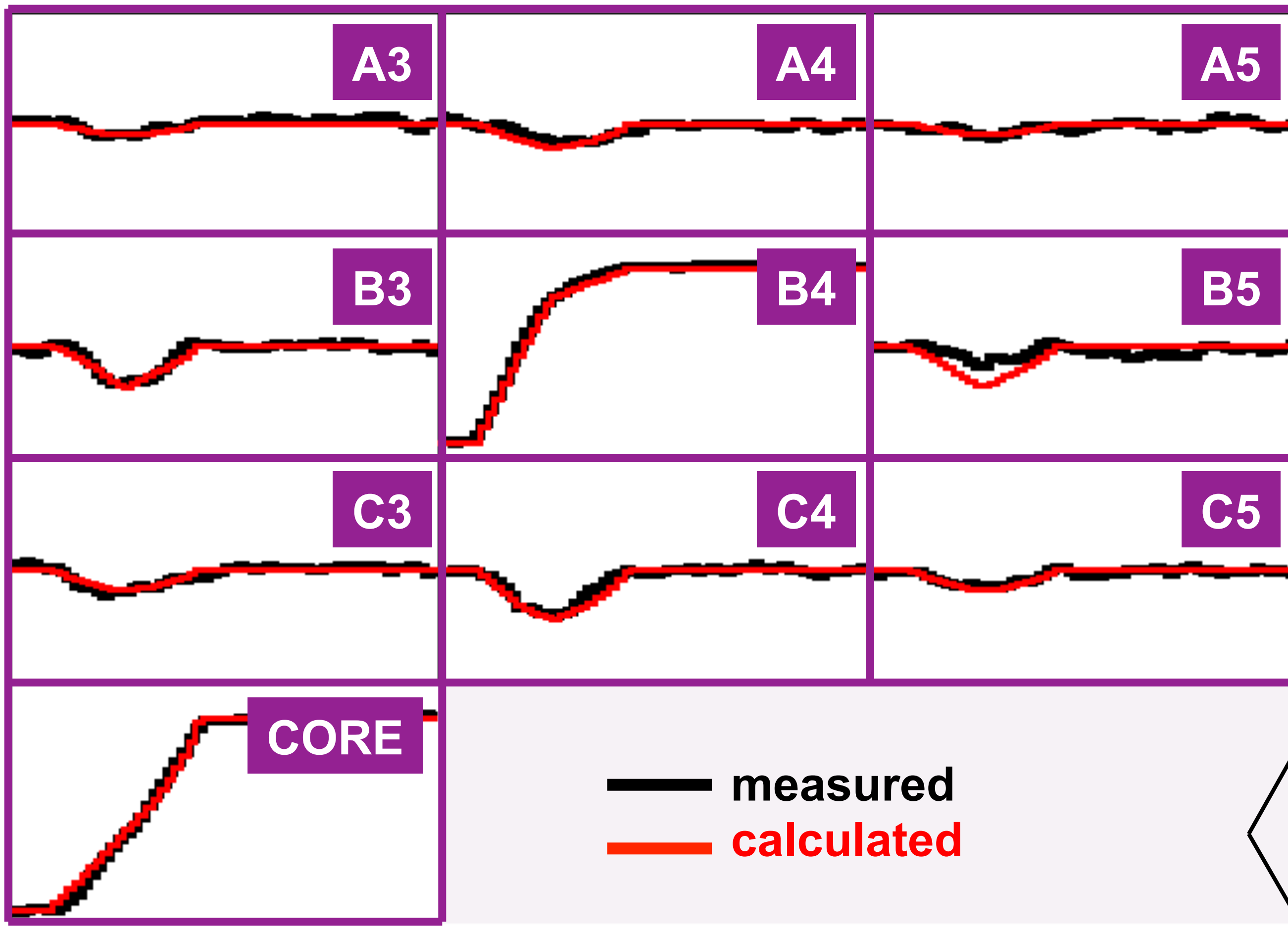
Pulse Shape Analysis concept

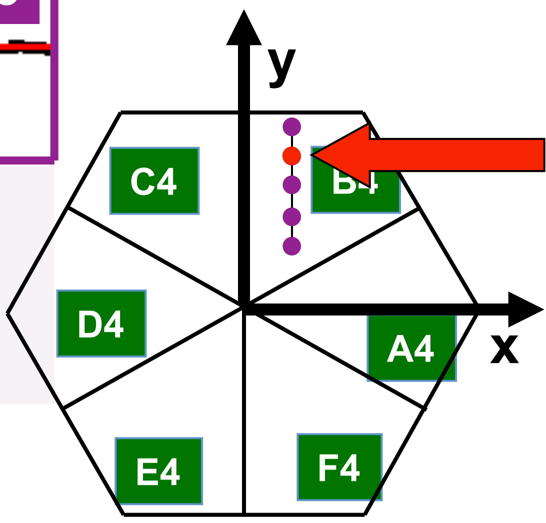


791 keV deposited in segment B4



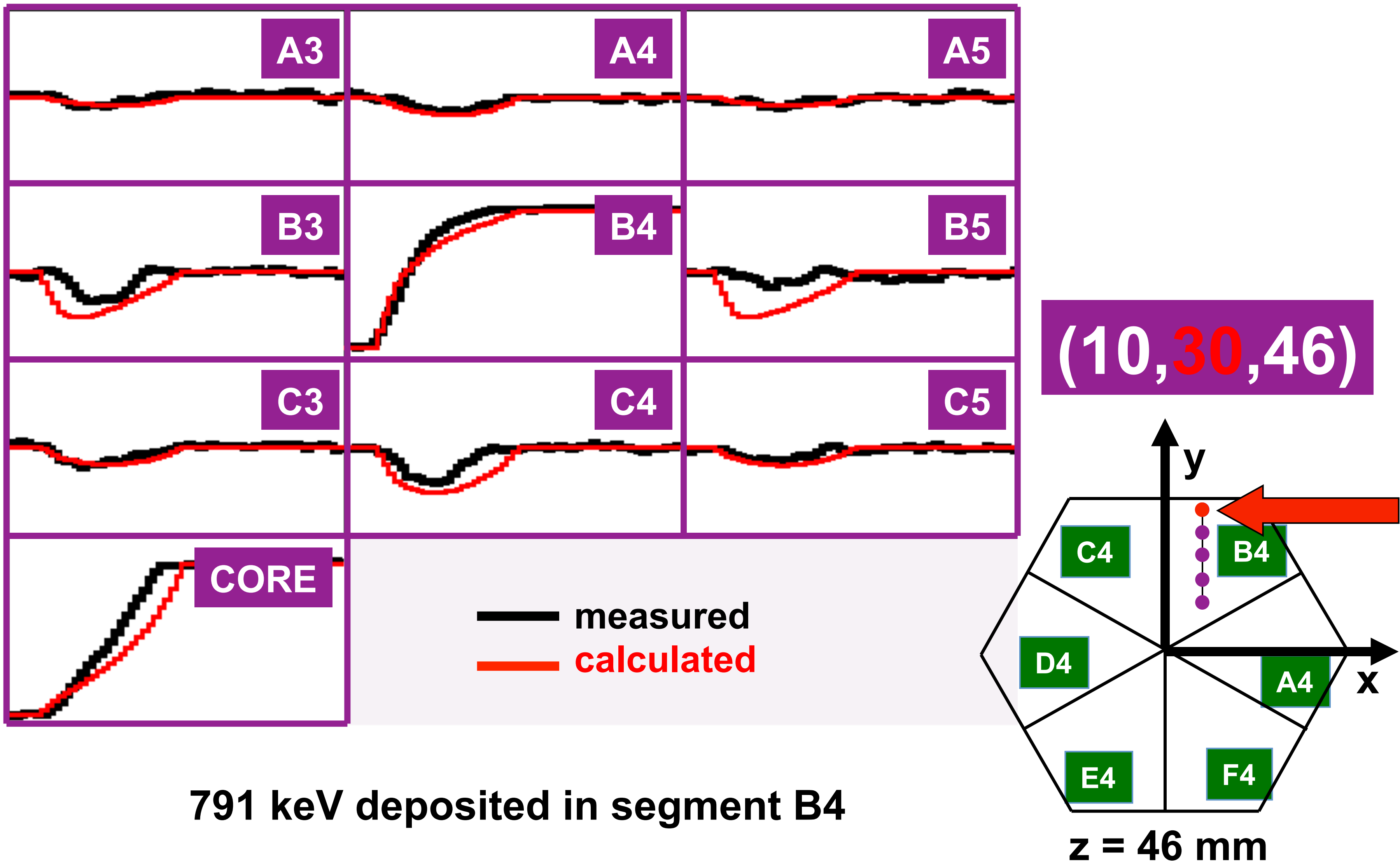
Pulse Shape Analysis concept





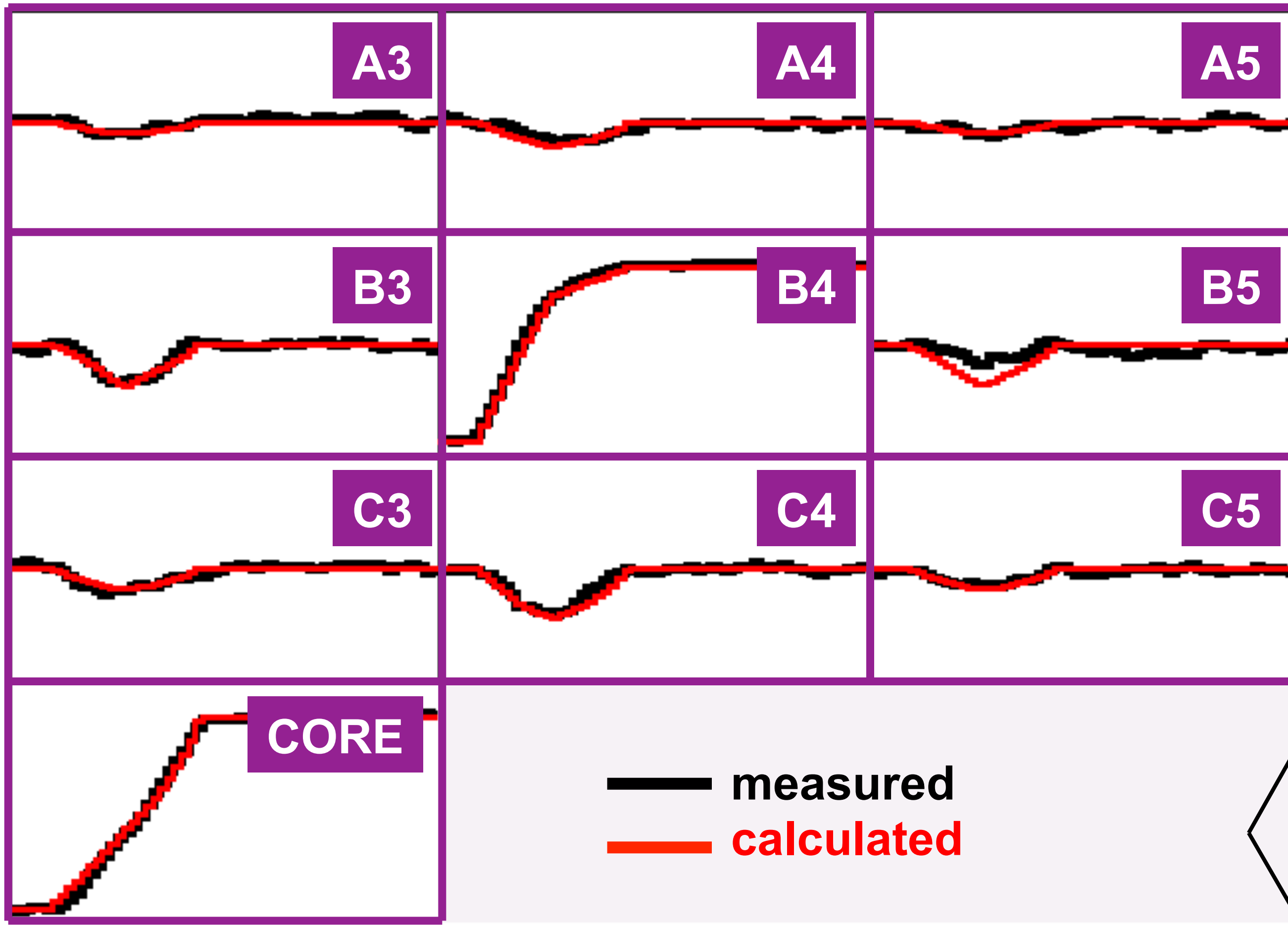
791 keV deposited in segment B4

Pulse Shape Analysis concept



791 keV deposited in segment B4

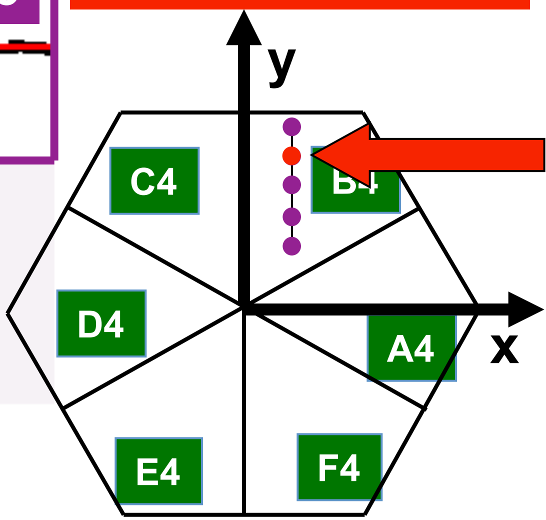
Pulse Shape Analysis concept



791 keV deposited in segment B4

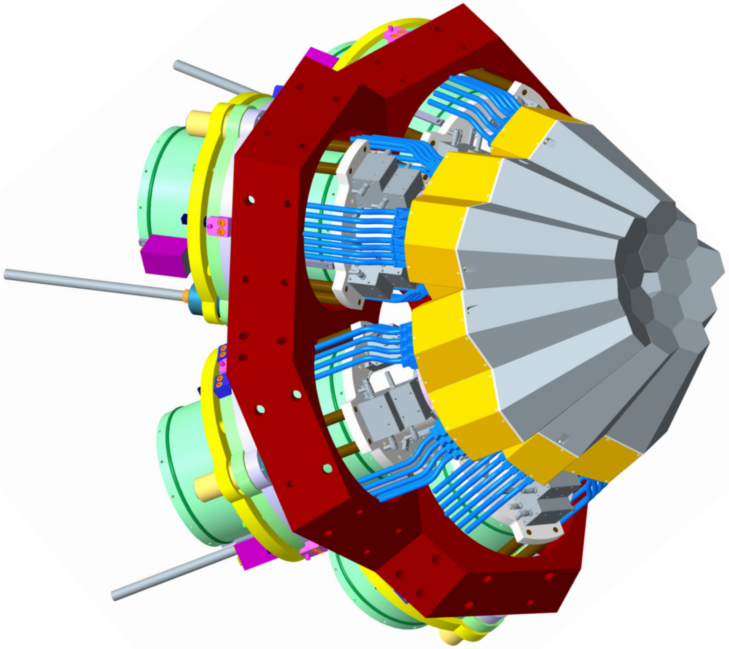
Result of *Grid Search* algorithm

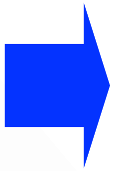
(10,25,46)

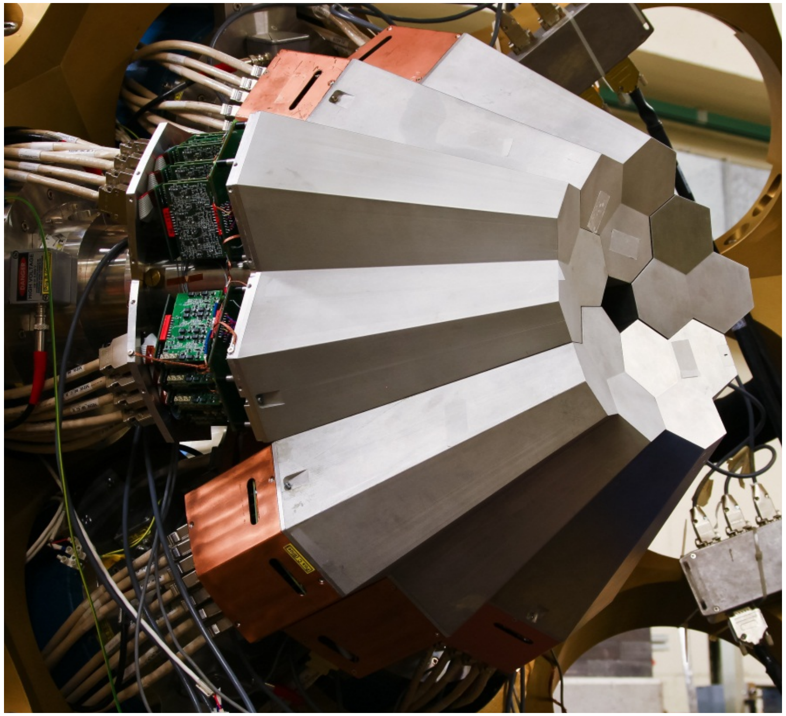


The AGATA Demonstrator

Objective of the final R&D phase 2003-2008

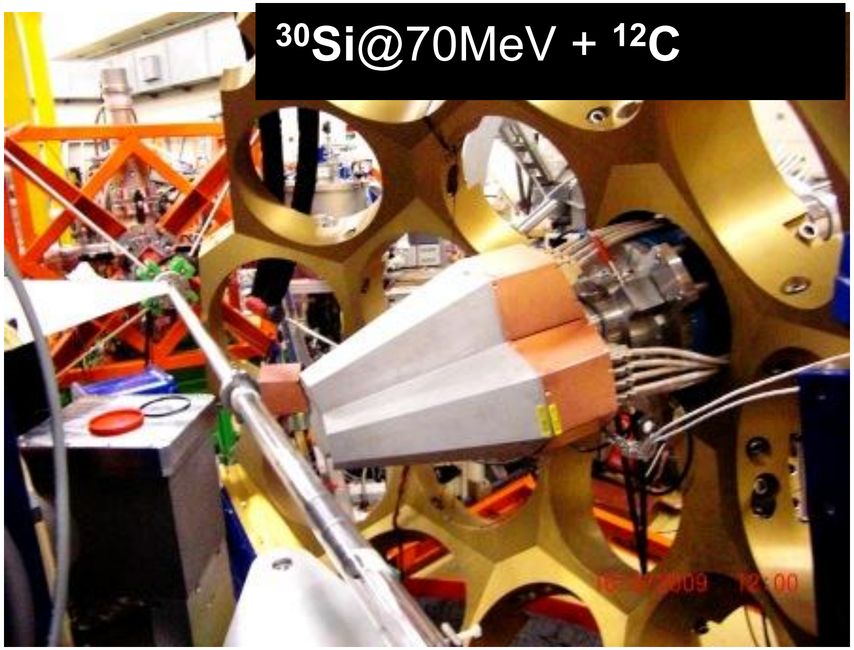


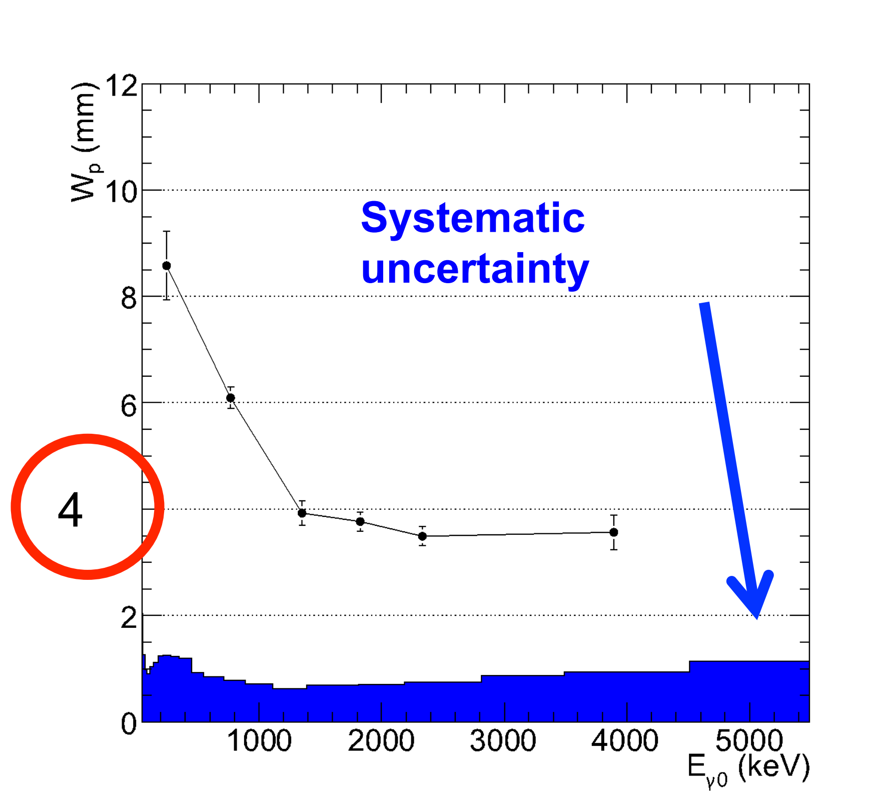




From Design to Reality

Position resolution





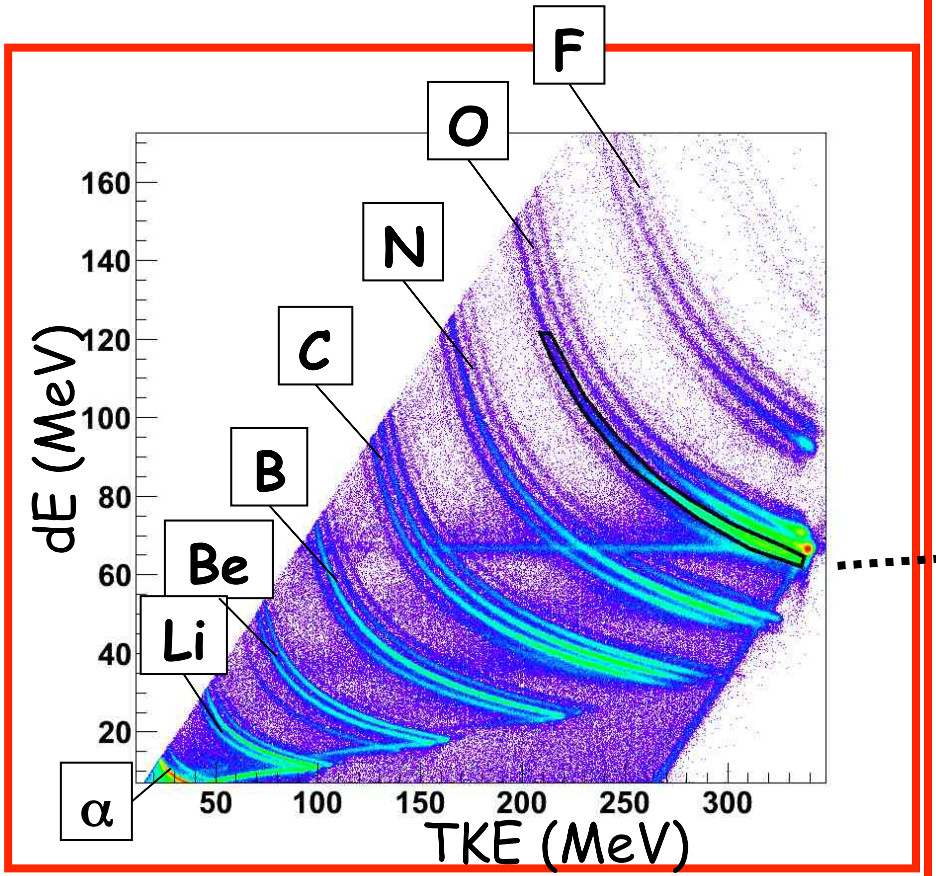
Position resolution extracted from peak FWHM values at two distances

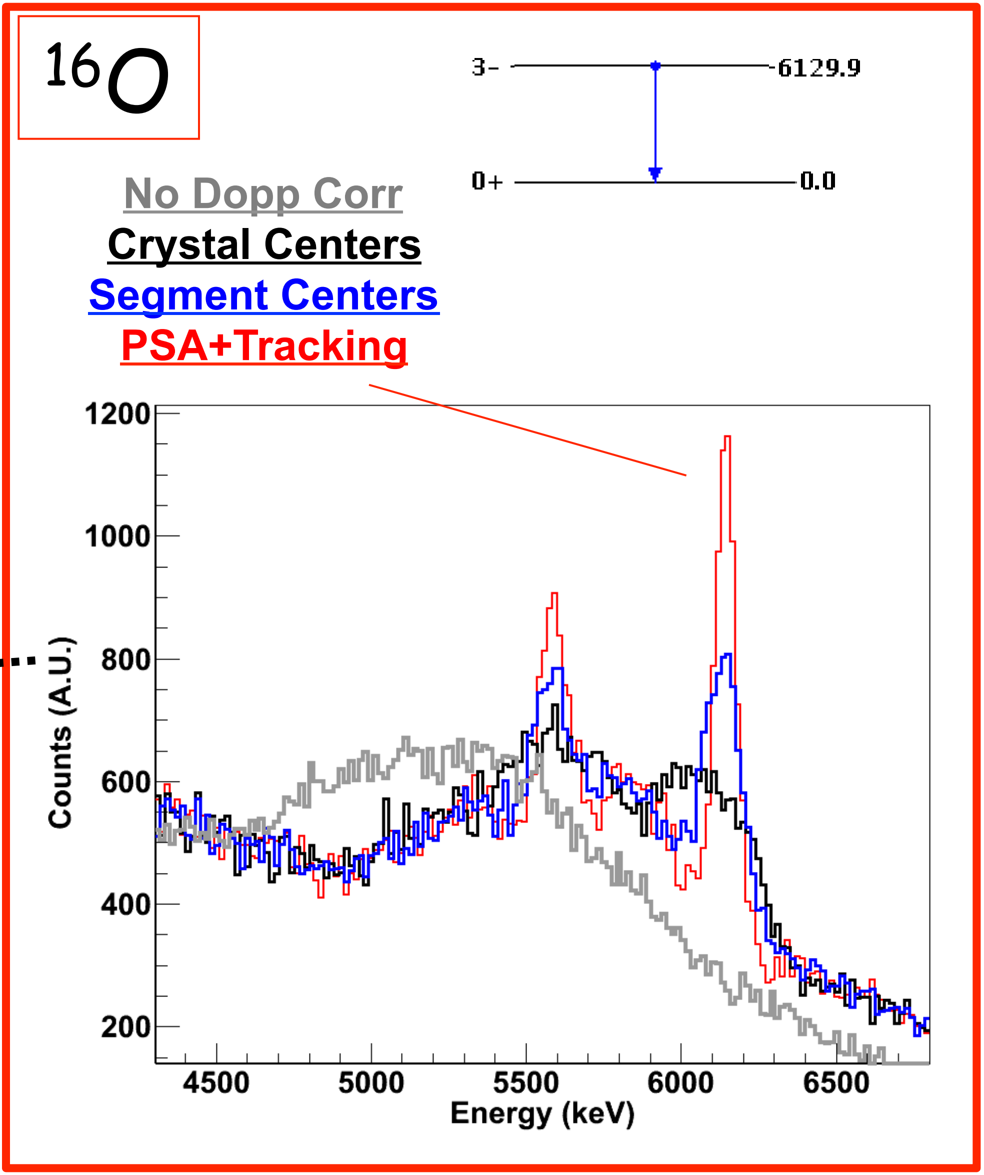
$$p^2 = \frac{1}{k^2}\left(\Delta E^2_{close} - \Delta E^2_{far}\right)\left(\frac{1}{d^2_{close}} - \frac{1}{d^2_{far}}\right)^{-1}$$

P.-A.Soderstrom, NIM A 638, 96 (2011);
F.Recchia, PhD thesis (2006)

Doppler correction capabilities

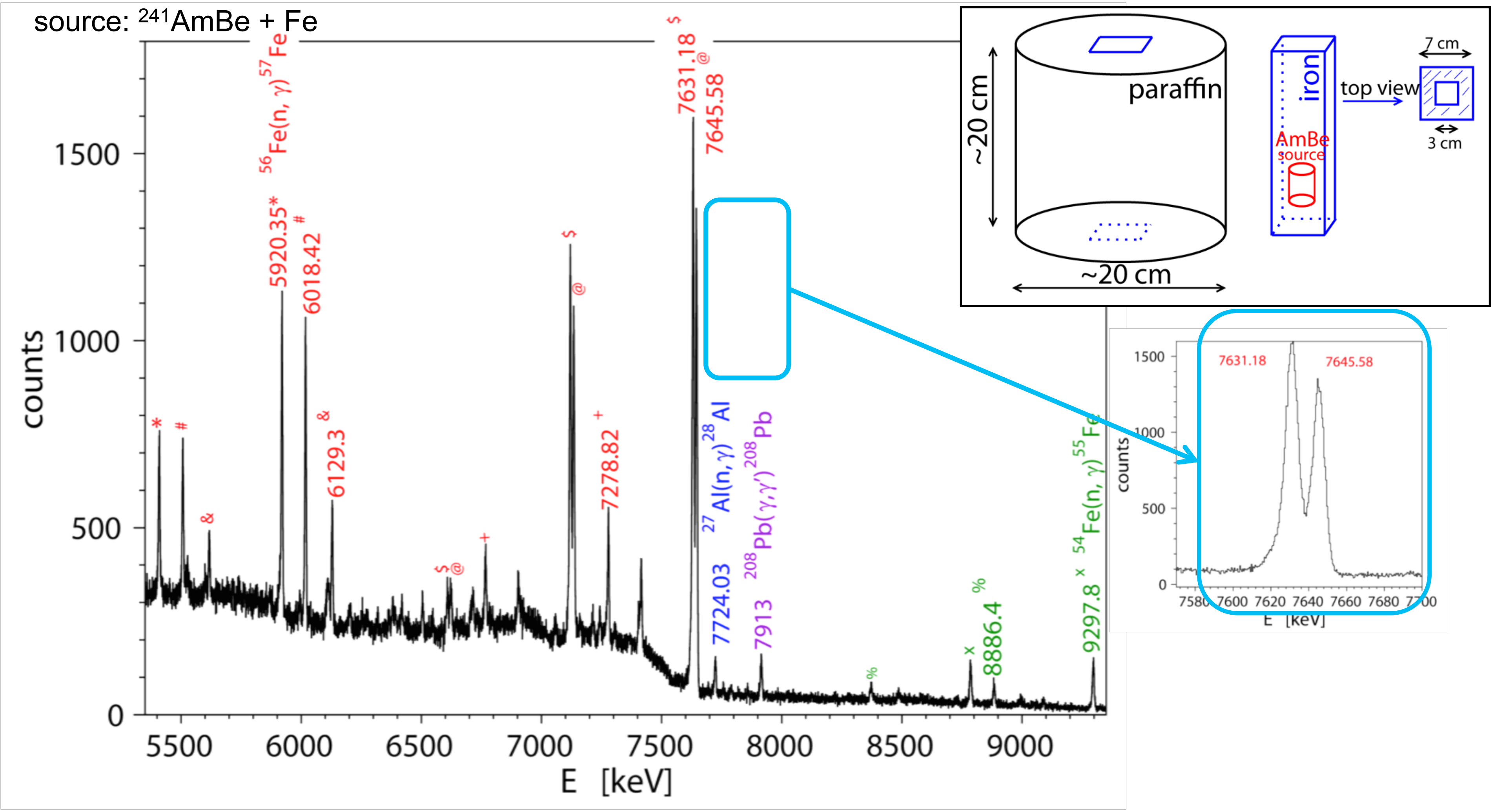
Inelastic scattering
^{17}O @ 20 MeV/u on ^{208}Pb





R.Nicolini, D.Mengoni

High-energy photons

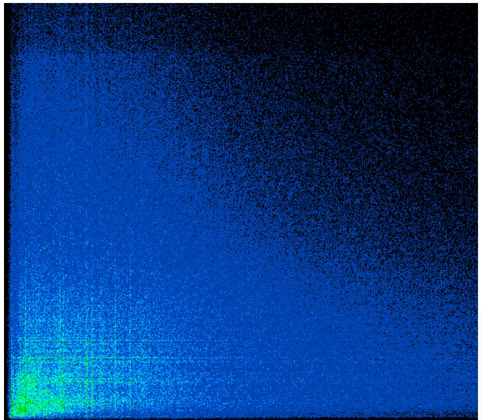


Excellent energy resolution and linerarity up to 20MeV

F.Crespi

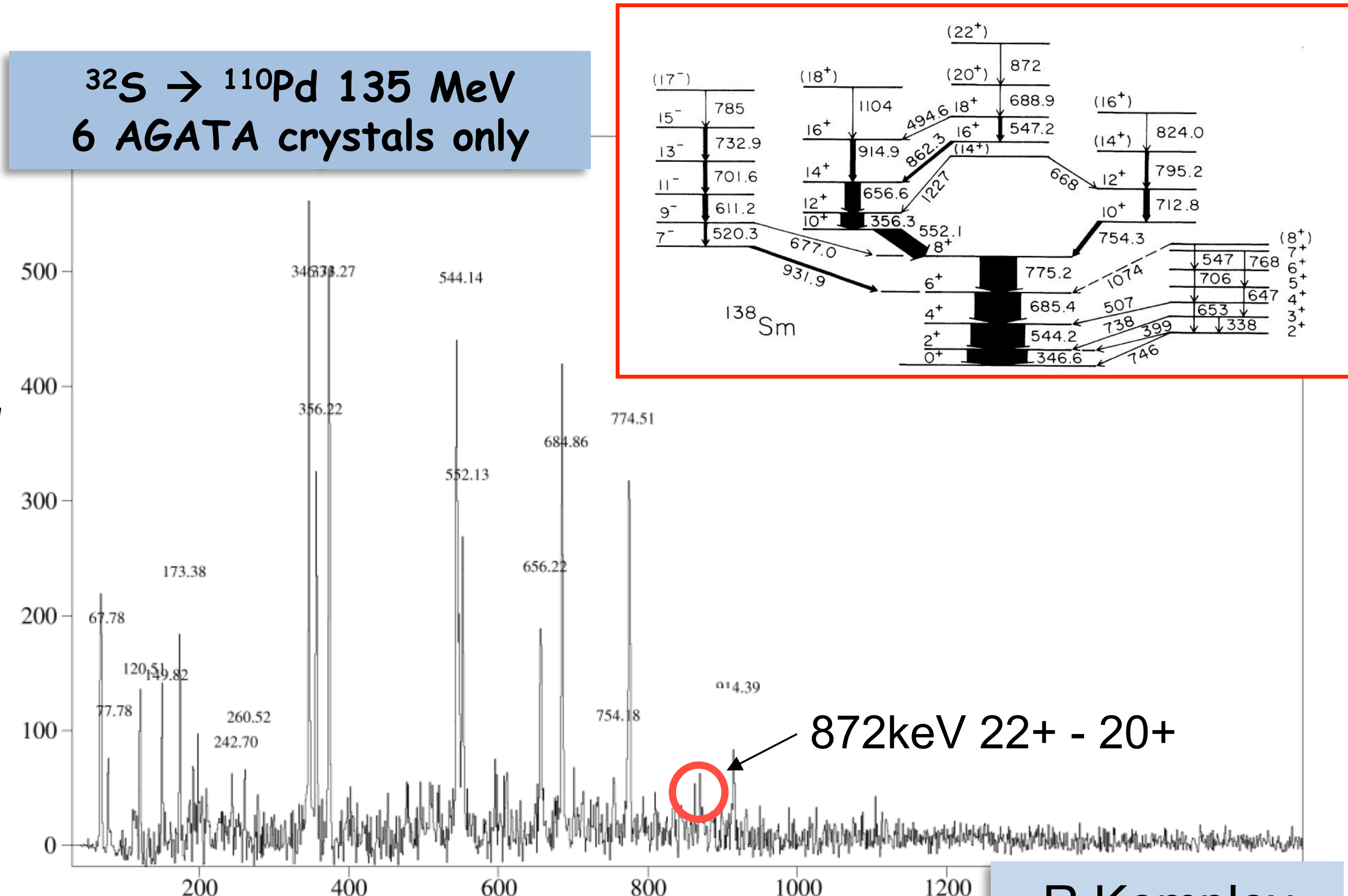
C.Michelagnoli, R.Depalo

γγ capabilities



The performance of AGATA using γ-ray tracking is comparable with conventional arrays with a much larger number of crystals

^{32}S → ^{110}Pd 135 MeV
6 AGATA crystals only

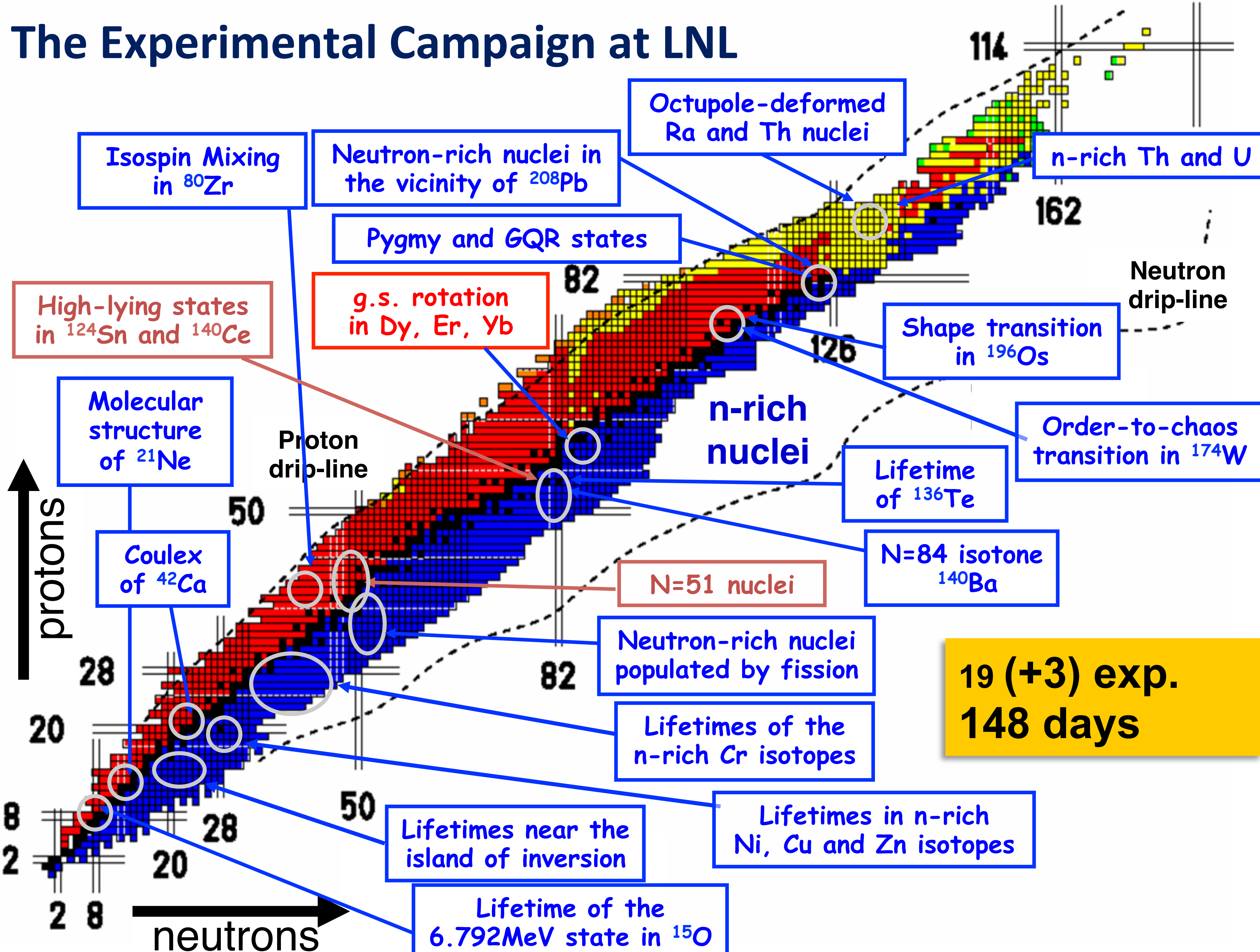


872keV 22+ - 20+

^{138}Sm
6 gates on:
347keV,545keV,
686keV,775keV,
552keV,357keV

R.Kempley

The Experimental Campaign at LNL



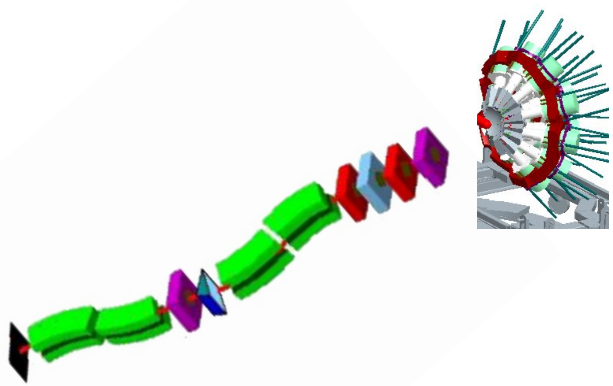
19 (+3) exp.
148 days

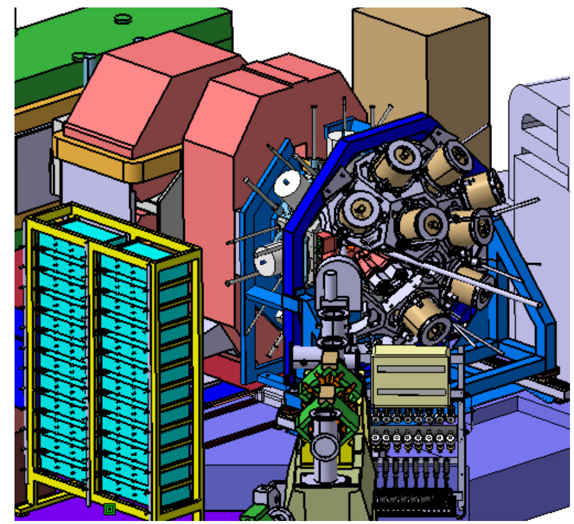
AGATA's Movements

2010- 2011
LNL
5TC

2012 → GSI/FRS
5TC+5DC

2014 → GANIL/SPIRAL2
~15TC





AGATA +PRISMA

Total Eff. ~6%

AGATA @ FRS

Total Eff. > 10%

AGATA + VAMOS
+ EXOGAM+

Total Eff. > 20%

Acknowledgements

- Huge technical achievement
- Many people and laboratories
- Ongoing
- Physics

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AGATA – Advanced Gamma Tracking Array
Nuclear Instruments and Methods in Physics Research A 668 (2012) 26–58

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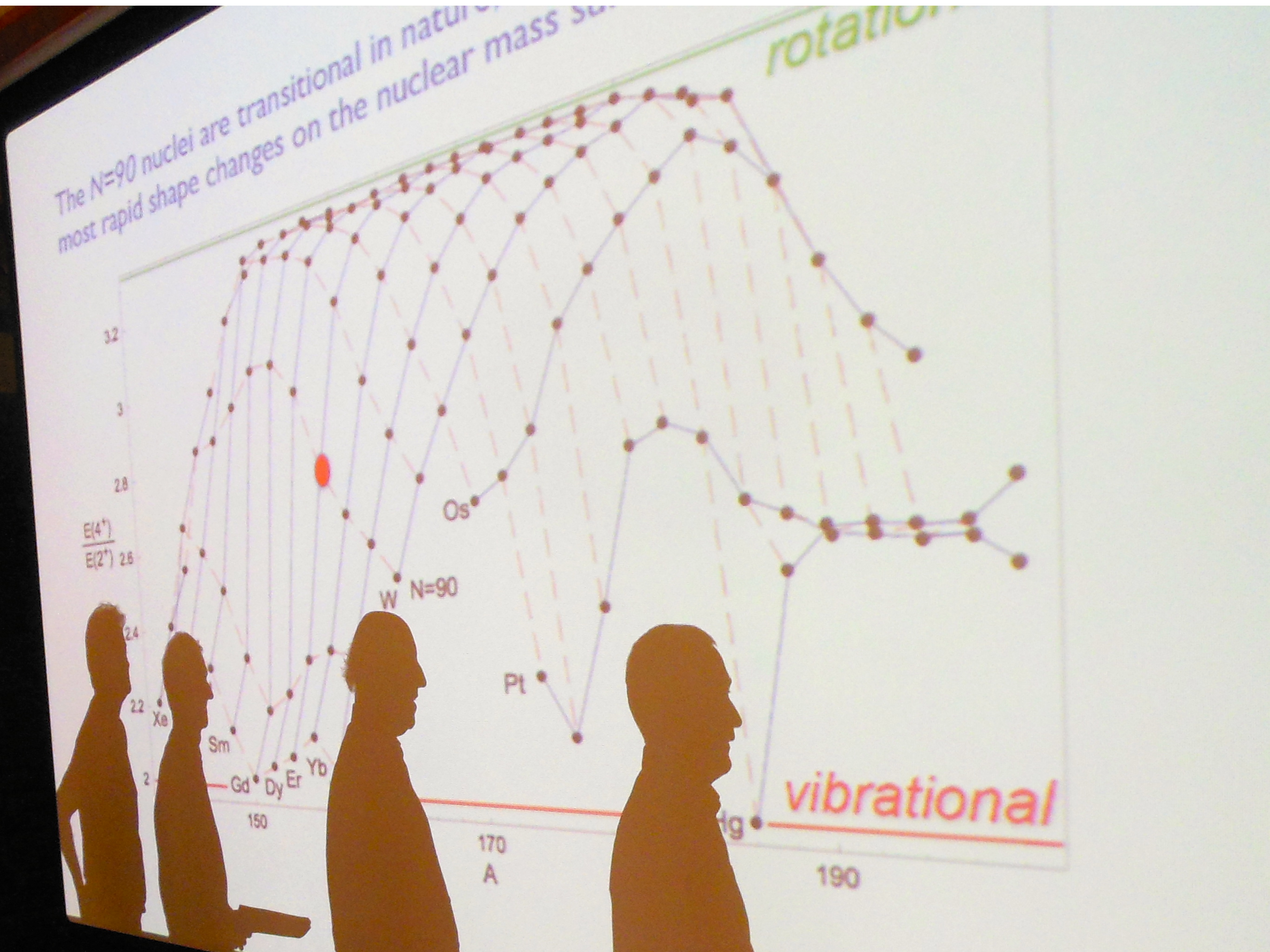
THANKS

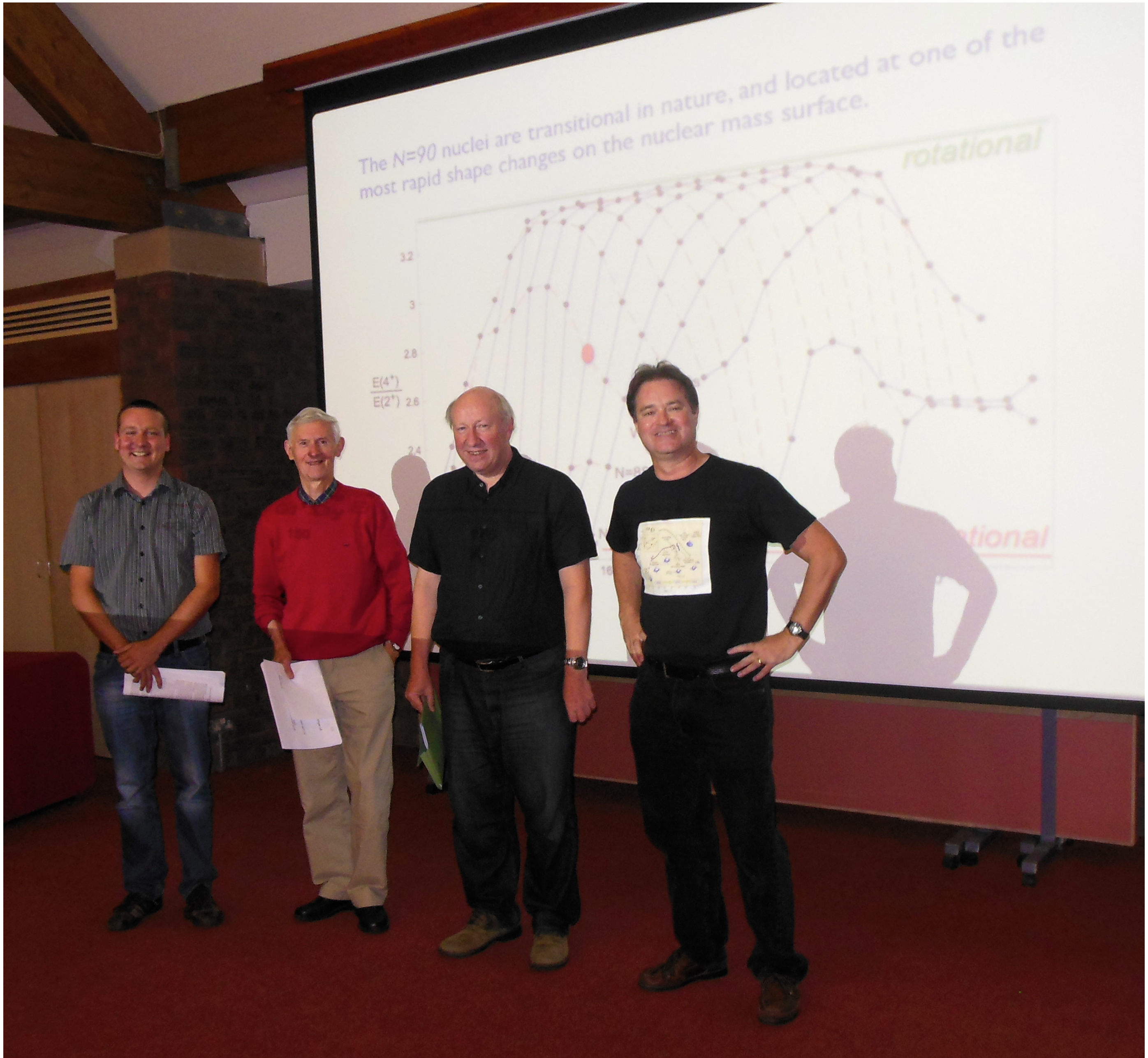
Didn’t he do brilliantly?

MEGA-THANKS ANDY!

And thanks to you for making it so much fun!

Peace, love, art, music and nuclear physics!


The N=90 nuclei are transitional in
most rapid shape changes on the nuclear mass
vibrational
E(4+)/E(2+)
3.2
3
2.8
2.6
2.4
2.2
2
150
170
190
A
Xe
Sm
Gd
Dy
Er
Yb
W
N=90
Os
Pt


The N=90 nuclei are transitional in nature, and located at one of the most rapid shape changes on the nuclear mass surface.
rotational
3.2
3
2.8
2.6
2.4
E(4+)/E(2+)

Project Overview

Brad Sherrill (MSU)

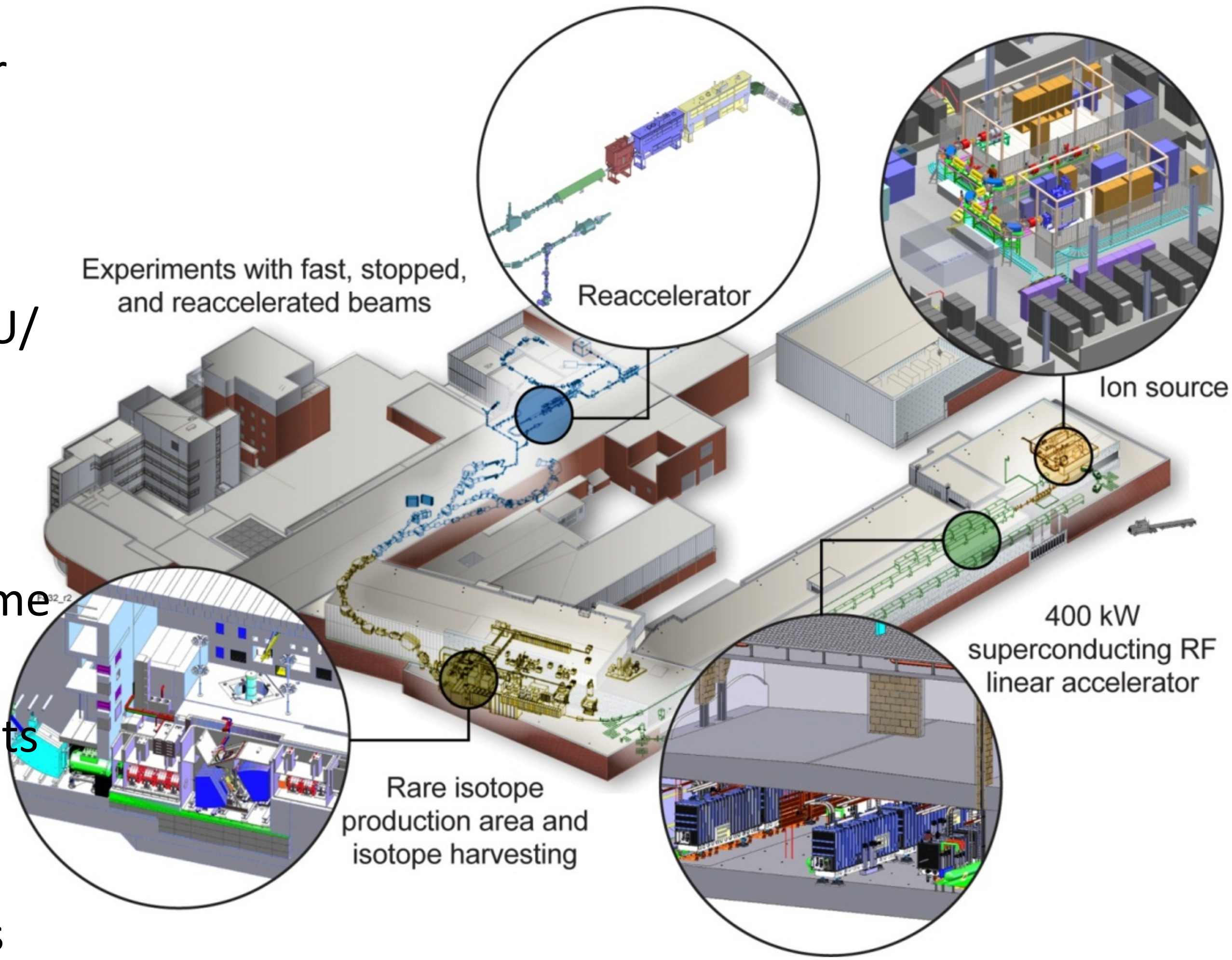
This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661.
Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

FRIB History and Progress

- 8 June 2009 – DOE-SC and MSU sign Cooperative Agreement
- Sept 2010 – Critical Decision 1 approved, DOE issues NEPA FONSI
- April 2012 – Lehman review, baseline and start of civil construction
  - Project is ready *"to establish the performance baseline when funding profile guidance from DOE is provided"*
- Oct 2012 – Lehman mini review
- 27 reviews since May 2012 (all reviews open to DOE and MSU)
  - 7 project-level peer reviews: 2 ASAC, 1 ESAC, 2 ESHAC, 1 PMAC, 1 EVMS
  - 20 technical reviews, of which six were 60% final design reviews
- February 2013 - NSAC Tribble subcommittee states "proceeds with FRIB" even in no-growth budget scenarios. DOE provides funding guidance to FRIB
- August 2013 – Critical Decision 2/3a approved (baseline & start of civil construction)
- Summer 2014 – CD-3b (technical construction)
- Nov 2021 (May 2020) – CD-4 (early completion) for civil construction start 1 October 2013

Facility for Rare Isotope Beams, FRIB

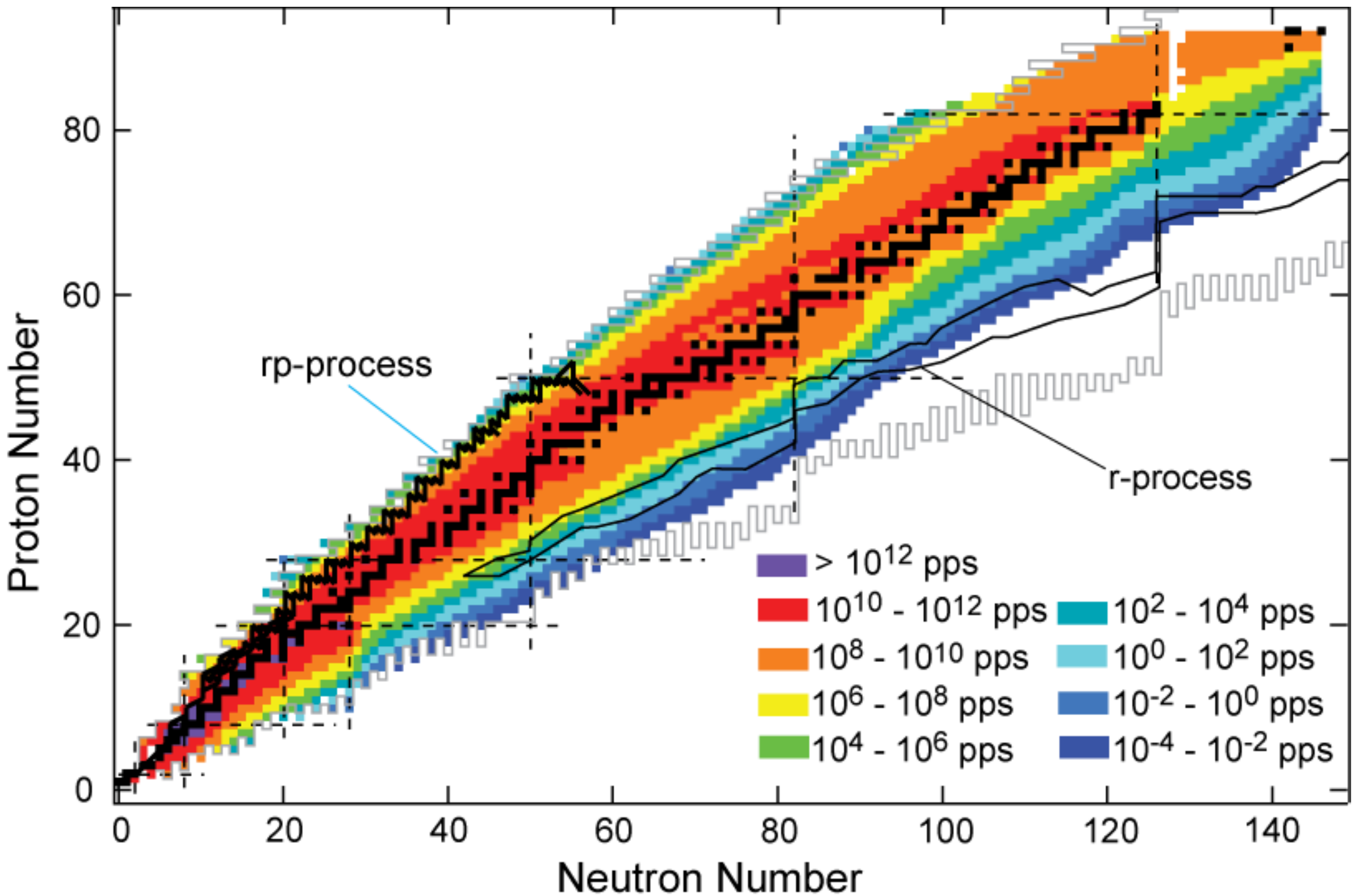
- Funded by DOE Office of Science Office of Nuclear Physics. T. Glasmacher, Project Director
- Key Feature is 400kW beam power (5 x10^{13} ^{238}U/s)
- Separation of isotopes in-flight
  - Fast development time for any isotope
  - Suited for all elements and short half-lives
  - Fast, stopped, and reaccelerated beams



Features of FRIB

- Heavy ion, superconducting linear accelerator with 400 kW beam power at 200 MeV/u
- 400 kW corresponds to a ^{136}Xe beam of $8x10^{13}$ ion/s and a sensitivity to production cross sections as low as **$2x10^{-6}$ pb**.
- ^{238}U intensity of $5x10^{13}$ ion/s
- FRIB laboratory will have beams of rare isotopes at a wide range of energies
  - Stopped beams for trapping, laser spectroscopy, etc.
  - Reaccelerated beams to 15 MeV/u (goal) with 15 – 22 MeV/u depending on A/Q)
  - Fast beams up to 250 MeV/u (used in-flight with no slowing)
- Limited multi-user capability through harvesting

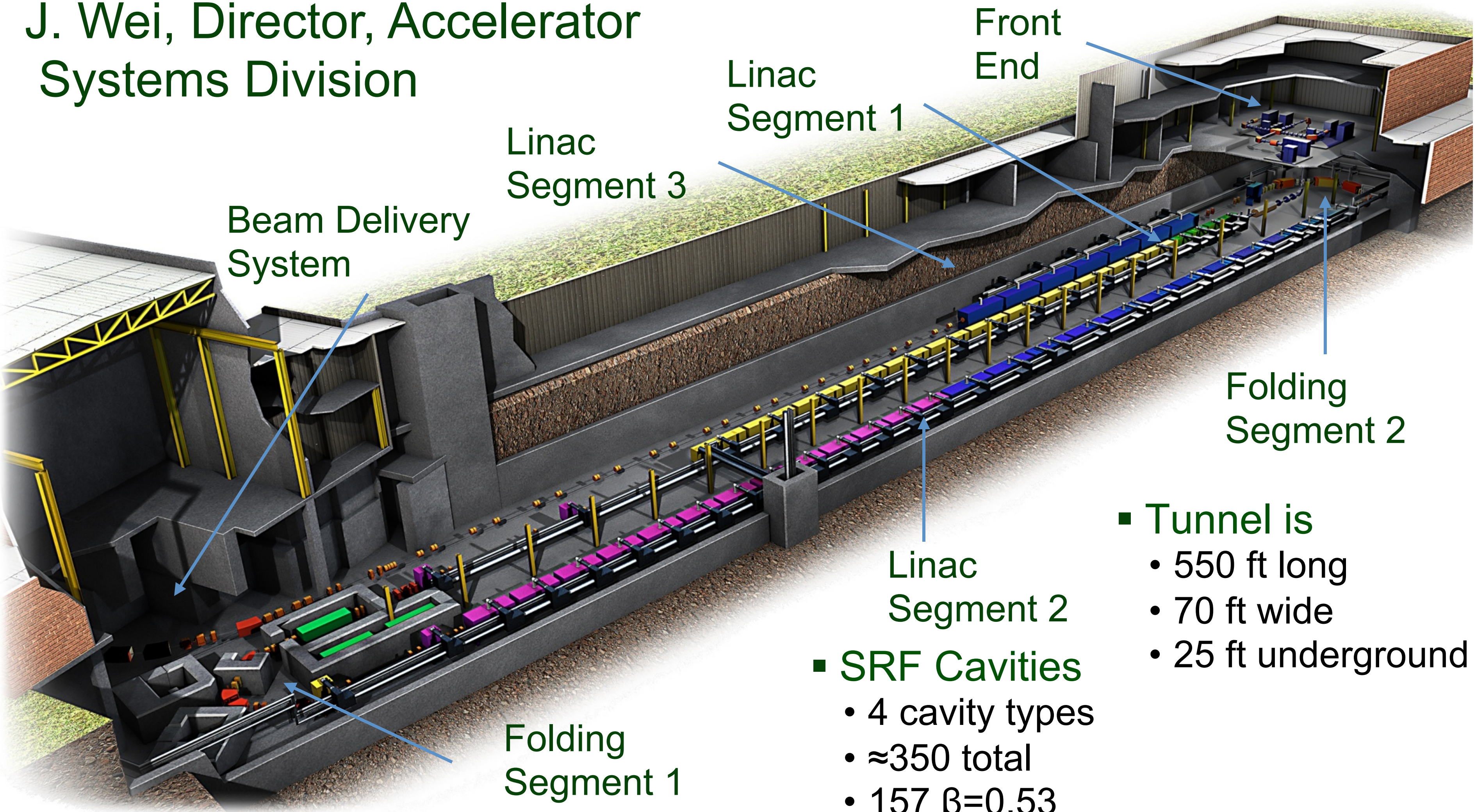
FRIB Projected Rates



Rates are available at http://groups.nscl.msu.edu/frib/rates/

FRIB Driver Linear Accelerator

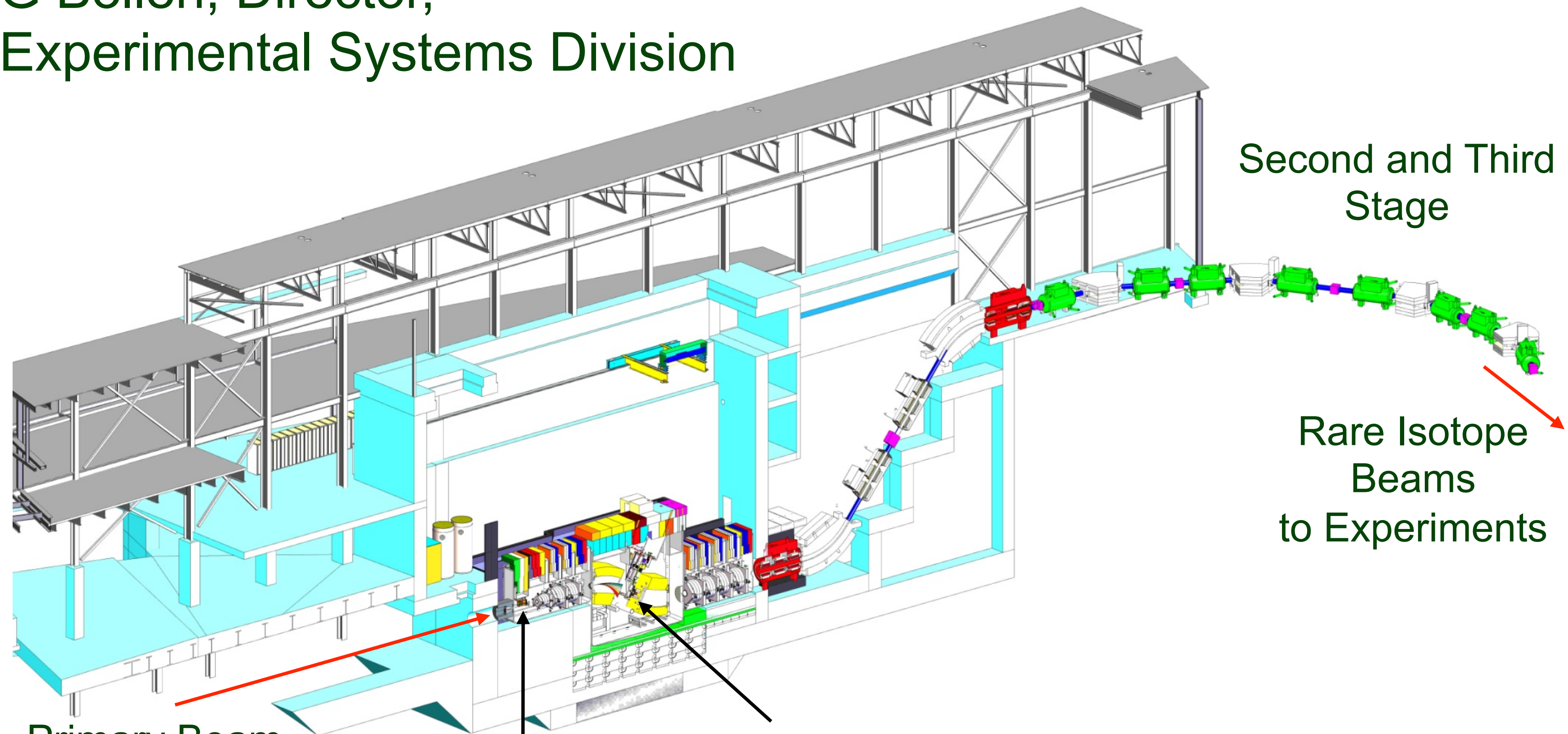
J. Wei, Director, Accelerator Systems Division



- Tunnel is
  - 550 ft long
  - 70 ft wide
  - 25 ft underground
- SRF Cavities
  - 4 cavity types
  - ≈350 total
  - 157 β=0.53

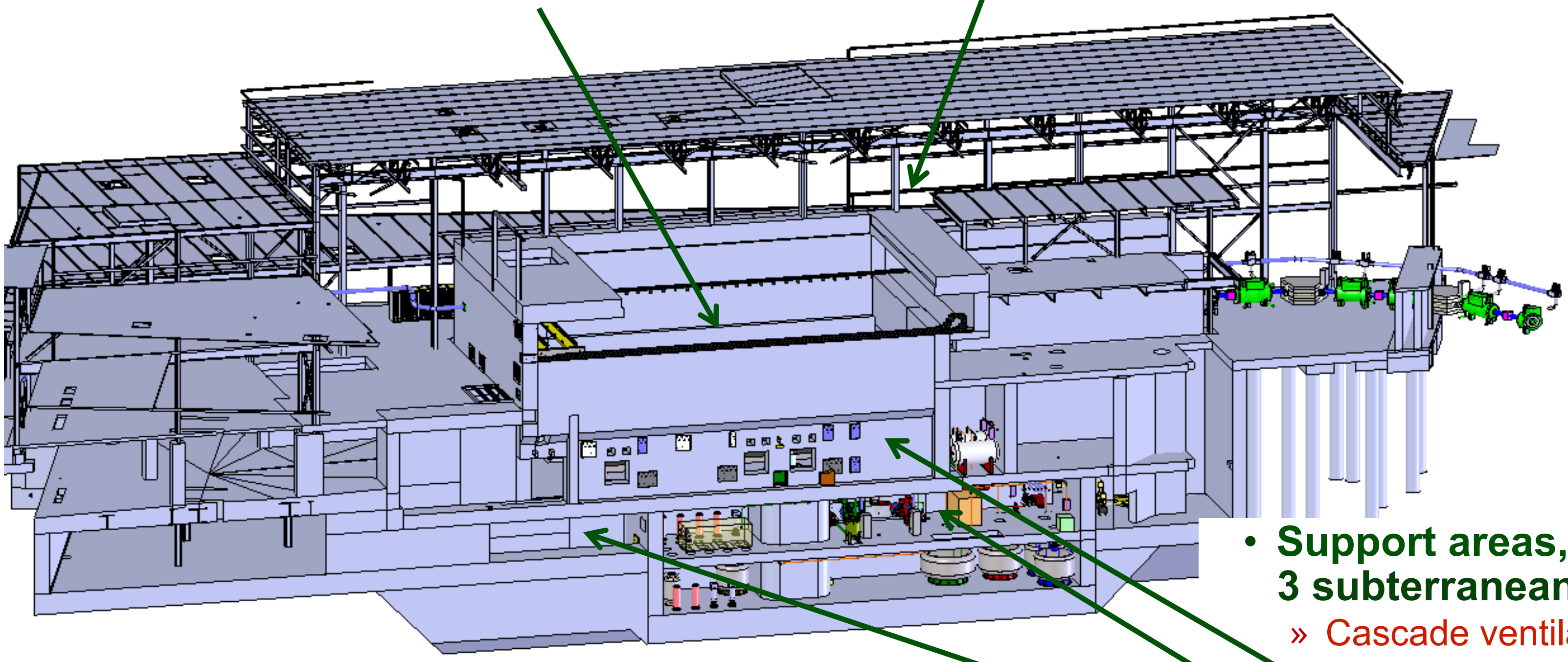
Isotope Production Area
Target and Fragment Separator

G Bollen, Director,
Experimental Systems Division



Production Area Overview

- **Target hot cell, subterranean**
  - » Production target
  - » Fragment preseparator
  - » Primary beam dump(s)
  - » Remote handling (RH) equipment
- **Target facility building high bay**
  - » Second and third stage of fragment separator
  - » 50 ton bridge crane
  - » Fragment separator power supplies

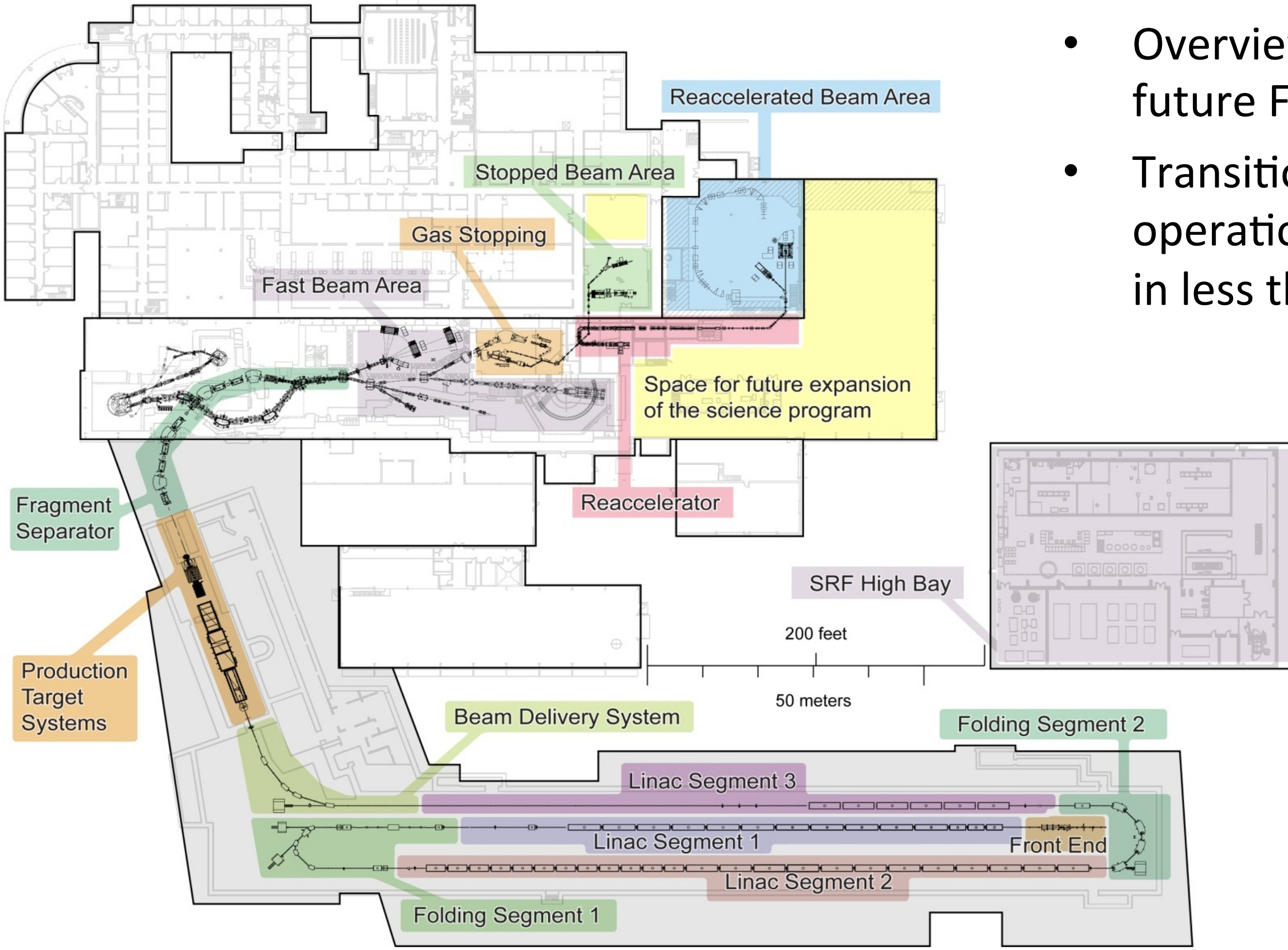


- **Support areas, 3 subterranean levels**
  - » Cascade ventilation
  - » RH Gallery & Control room
  - » Non-conventional utilities (NCU)
  - » Waste handling

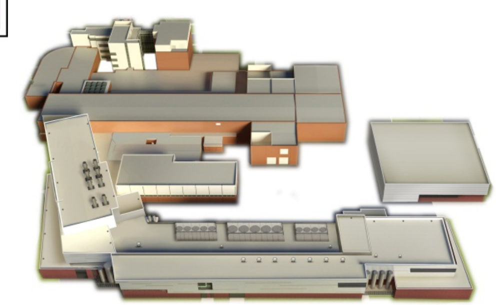
FRIB Site Ready for Civil Construction

- Ready to begin civil construction upon approval from DOE-SC
- Site preparation is complete; placement of pilings for the earth retention system is complete
- Live web cameras are linked from frib.msu.edu

NSCL-FRIB Transition Plan



- Overview of the current and future FRIB facility
- Transition from NSCL to FRIB operations can be accomplished in less than a year



FRIB Users Organization

FRIB Users Organization
FACILITY FOR RARE ISOTOPE BEAMS

fribusers.org

- Users are organized as part of the independent FRIB Users Organization
  - FRIBUO has 1350 members (92 US Colleges and Universities, 10 National Laboratories, 53 countries) as of June 2013
  - FRIBUO (M. Smith, Chair) has a Theory organization + 20 working groups on experimental equipment
- Science Advisory Committee
  - Review of equipment initiatives (Feb. 2011)
  - Review of FRIB Integrated Design (March 2012)
  - Next meeting in planning for Fall 2013
- Low-Energy Community Meeting at MSU 23-24 August, 2013.

August 2012
Joint Users Meeting
284 participants