RIKEN
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Overview of in-beam γ-ray spectroscopy at the RIBF

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ピーター　ドルネンバル

RIKEN NiSHiNA CENTER

Outline

- Workshop aims
  - Physics case/proposals
  - Strengthen SUNFLOWER collaboration
- In-beam γ setup
  - BigRIPS/ZeroDegree
  - DALI2
- Atomic background
- Inelastic scattering and Coulomb excitation

Workshop Aims

- Present our facility/method to researchers abroad
  - MINOS, DALI2, GRAPE
  - BRS, ZDS
- Present and discuss the problems of the method and points to consider
- Present the status of performed experiments and achievements
- **Discuss potential experiments for the next NP-PAC and later NP-PACs**
  - Possibility of merging towards sub-projects defined by certain regions of the nuclear chart

Discussion Part

- The near future
  - Physics case/individual proposals
  - Next NP-PAC meeting is Dec. 13-14, 2013
  - Proposal dead-line mid/end of October
  - Assistance
    - LISE++/GEANT4
      GEANT4:
      `http://ribf.riken.jp/~pieter/shogun/`
- 2014 beam time
  - MINOS
  - Large Volume $LaBr_3$
- Please let me know if there is anything else

SUNFLOWER

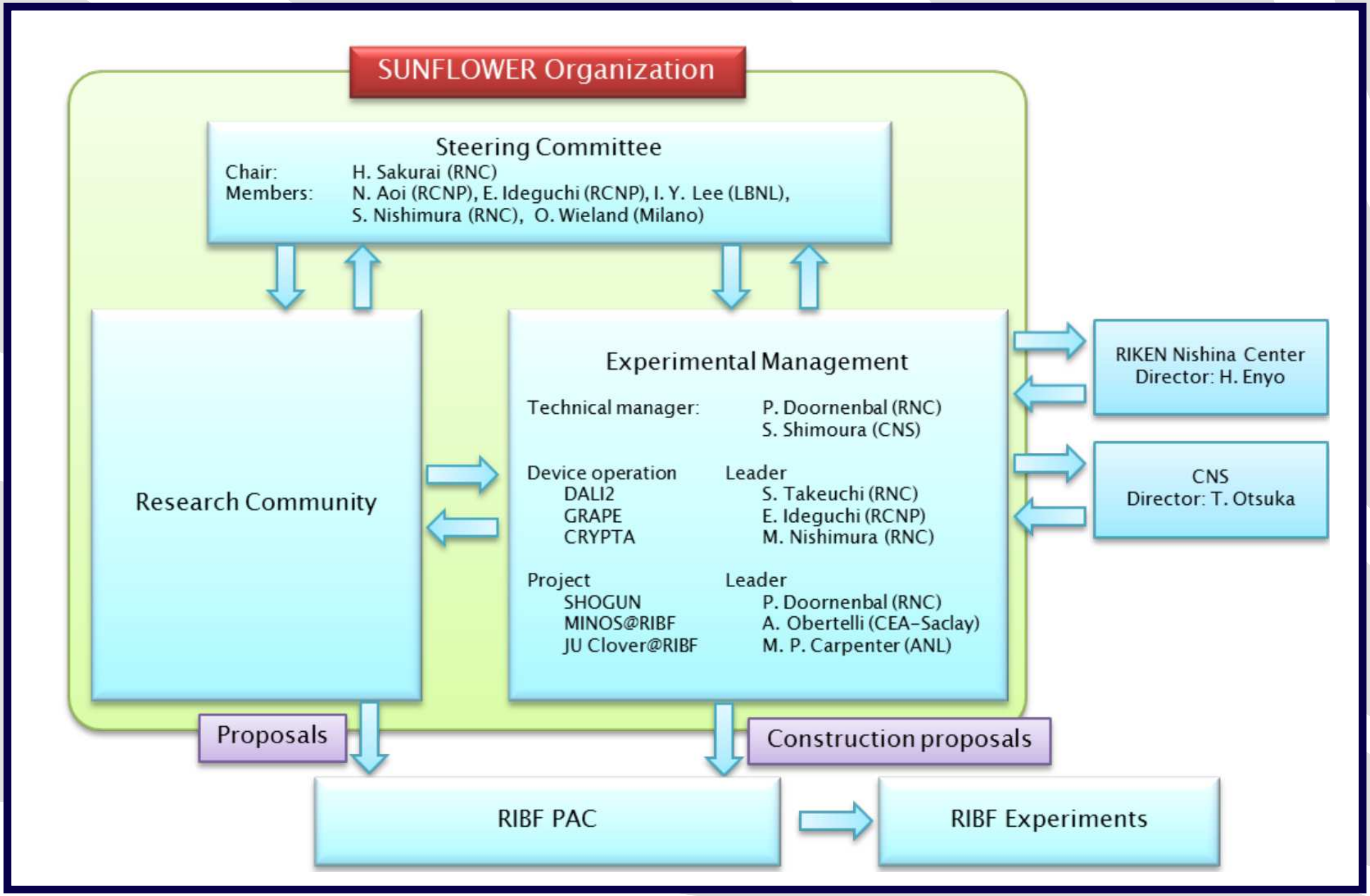
SUNFLOWER: Spectroscopy of Unstable Nuclei with Fast and sLOW beam Experiments at the RIBF

- The SUNFLOWER collaboration was launched in 2012 to enhance activities of the in-beam γ-ray spectroscopy at RI Beam Factory (RIBF)
- SUNFLOWER stands for "Spectroscopy of Unstable Nuclei with Fast and sLOW beam Experiments at the RIBF"
- Framework to coordinate researchers in the field of nuclear structure studies of unstable nuclei using fast and decelerated RI beams at RIBF by means of γ-ray measurements
- See `http://www.nishina.riken.jp/collaboration/SUNFLOWER` and register

Function

- Offer a forum for discussion and information exchanges. Proposals may be amended after consulting with SUNFLOWER members in advance of PAC meetings
- Arrange the tasks and resources necessary to accomplish experiments. The spokespersons of proposed experiments may ask members of SUNFLOWER to collaborate
- Provide technical information and consults regarding the utilization of non-standard detectors.
- Coordinate research programs and equipment use. Arranges experimental campaigns. Mediates between conflicting experiments when similar subjects are proposed
- Discusses the strategy of detector developments

Organization



Organization II

- The **Steering Committee** conducts the activities described above receiving technical support by the Experimental Management.
- The **Experimental Management** is in charge of operating existing devices and pursuing projects. The information on the devices and the project should be updated to allow for sharing among the SUNFLOWER members.
- The board members would be changed if necessary after discussion among the members. Election is considered. The items listed in the Device and Project will be added or removed in order to reflect reality.

Mailing Lists

sunflower@ribf.riken.jp

- SUNFLOWER Collaboration members

sunflower-contact@ribf.riken.jp

- Send us any question or suggestion

sunflower-sc@ribf.riken.jp

- SUNFLOWER Steering Committee members

sunflower-em@ribf.riken.jp

- SUNFLOWER Experimental Management members

Status of In-Beam γ-Ray Spectroscopy

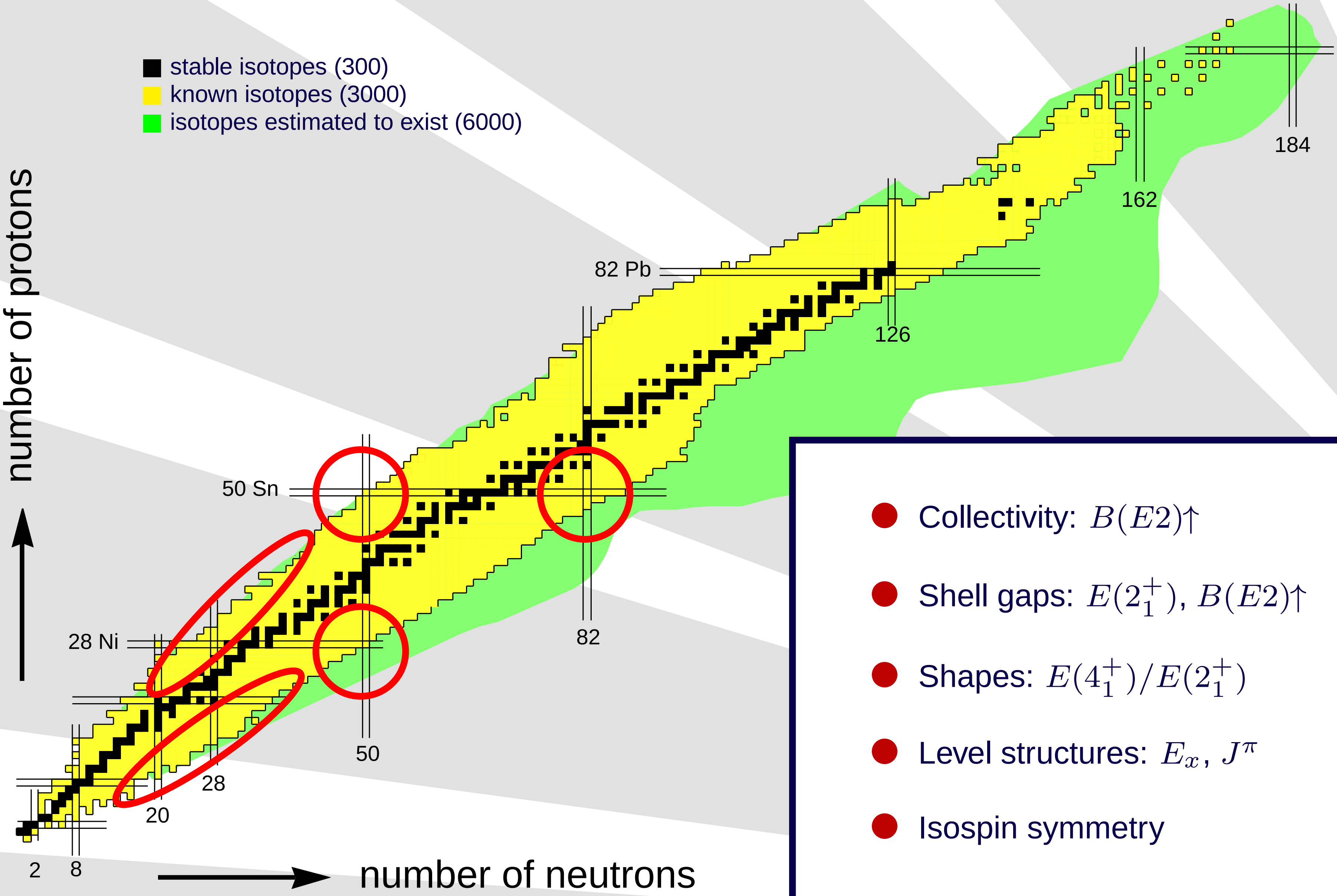
Approved Experiments (Including also DALI2 as "Ancillary" Detector)

Experiment	Spokesperson	Primary Beam	Devices	Approved Days	Completed Days
NP1306-RIBF107	Werner	^{70}Zn	DALI2+MINOS	–	
NP1306-RIBF108	Cerizza	^{124}Xe	DALI2	–	
NP1306-RIBF109	Corsi	^{70}Zn	DALI2+MINOS	–	
NP1306-RIBF110	Doornenbal	^{70}Zn	DALI2	–	
NP1306-RIBF111	Lee	^{70}Zn	DALI2+MINOS	3	
NP1306-RIBF31R1	Aoi,Wang	^{238}U	DALI2	4	
NP1306-RIBF98R1	Jungclaus, Doornenbal	^{238}U	DALI2	3	
NP1112-RIBF94	Korten, Doornenbal	^{78}Kr	DALI2,EURICA	8	
NP1112-RIBF93	De Angelis, Algora, Recchia, Rubio	^{78}Kr	DALI2,EURICA	5	
NP1112-SAMURAI10	Lee	^{18}O	SAMURAI+DALI2	0.5	DONE
NP1112-SAMURAI08R1	Otsu	^{18}O	SAMURAI+DALI2	3	DONE
NP1112-SAMURAI07	Nakamura	^{18}O	SAMURAI+DALI2	6	
NP1106-SAMURAI04	Orr, Gibelin	^{48}Ca	SAMURAI+DALI2	4	DONE?
NP1106-SAMURAI03	Nakamura	^{48}Ca	SAMURAI+DALI2	8.5	DONE?
NP1106-RIBF75	Corsi	^{238}U	GRAPE	5	
NP1106-RIBF74	Obertelli, Doornenbal	^{124}Xe	DALI2	2	DONE
NP1106-RIBF73	Steppenbeck, Takeuchi	^{70}Zn	DALI2	3	DONE
NP1012-RIBF61	Aumann	^{238}U	DALI2+$LaBr_3$	8	
NP1012-RIBF53	Bäck, Ideguchi	^{238}U	GRAPE,EURICA	(7)	
NP1012-RIBF51	Wieland	^{76}Ge	DALI2+$LaBr_3$	4	
NP1012-RIBF49R1	de Angelis	^{238}U	DALI2	焼鳥	DONE
NP1012-RIBF46	Dombradi, Sohler	^{238}U	DALI2	(4)	
NP1012-SHARAQ07	Shimbara	^{40}Ar	DALI2+SHARAQ	(6)	
NP1012-SHARAQ06	Shimoura	^{18}O,^{15}N	DALI2+SHARAQ	14	DONE

Approved Experiments (Including also DALI2 as "Ancillary" Detector)

Experiment	Spokesperson	Primary Beam	Devices	Approved Days	Completed Days
NP0912-RIBF01	Nakamura	^{48}Ca	DALI2+mom.	3.5	
NP0912-RIBF22	Steppenbeck	^{76}Ge	DALI2	5	
NP0906-RIBF02	Bazin	^{48}Ca	DALI2+mom.	4	DONE
NP0906-RIBF03	Fallon	^{48}Ca	DALI2	3	1
NP0906-RIBF07	Ideguchi	^{76}Ge	GRAPE+DALI2	4	
NP0906-RIBF12	Dombradi	^{238}U	DALI2	3	
NP0906-RIBF13	Trache	^{20}Ne	DALI2+mom.	3	
NP0906-SHARAQ01	Sasamoto	^{14}N	DALI2+SHARAQ	6.5	DONE
NP0906-SHARAQ02	Noji	^{14}N	DALI2+SHARAQ	6.5	DONE
NP0811-RIBF70R1	Doornenbal	^{124}Xe	DALI2	4	DONE
NP0802-RIBF55	Nakamura	^{48}Ca	DALI2	7	DONE
NP0802-RIBF56	Baba	^{48}Ca	BaF2+BGO	10	
NP0802-RIBF58	Sohler, Elekes	^{86}Kr	DALI2	4	
NP0702-RIBF28	Takeuchi	^{48}Ca	DALI2	6	DONE
NP0702-RIBF30	Yoneda	^{238}U	DALI2	10	DONE
NP0702-RIBF31	Aoi	^{238}U	DALI2	10(3)	DONE
NP0702-RIBF32	Scheit	^{48}Ca	DALI2	10	3.5

Regions of Interest



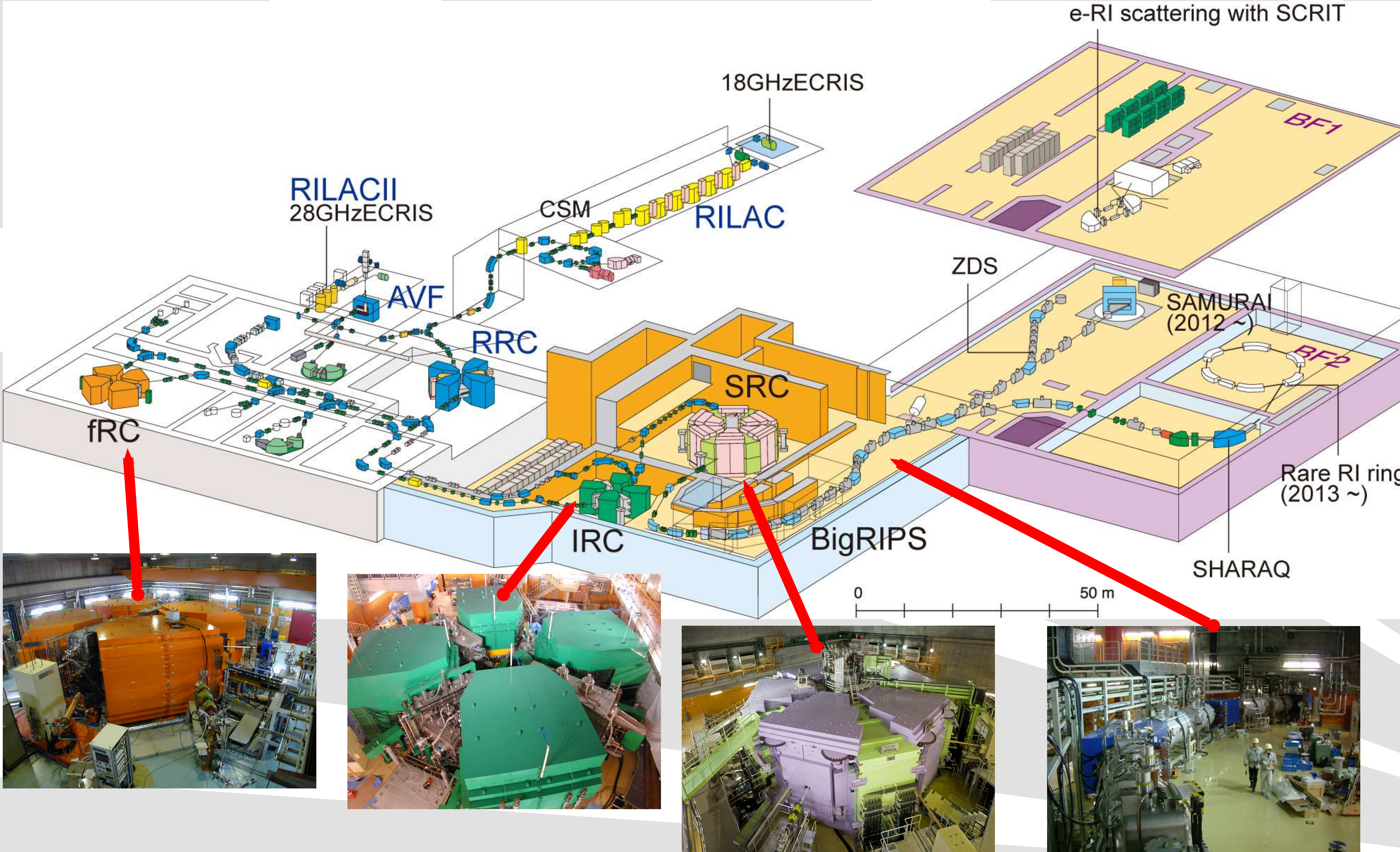
- Collectivity: $B(E2)\uparrow$
- Shell gaps: $E(2_1^+)$, $B(E2)\uparrow$
- Shapes: $E(4_1^+)/E(2_1^+)$
- Level structures: E_x, J^π
- Isospin symmetry

Performed Experiments

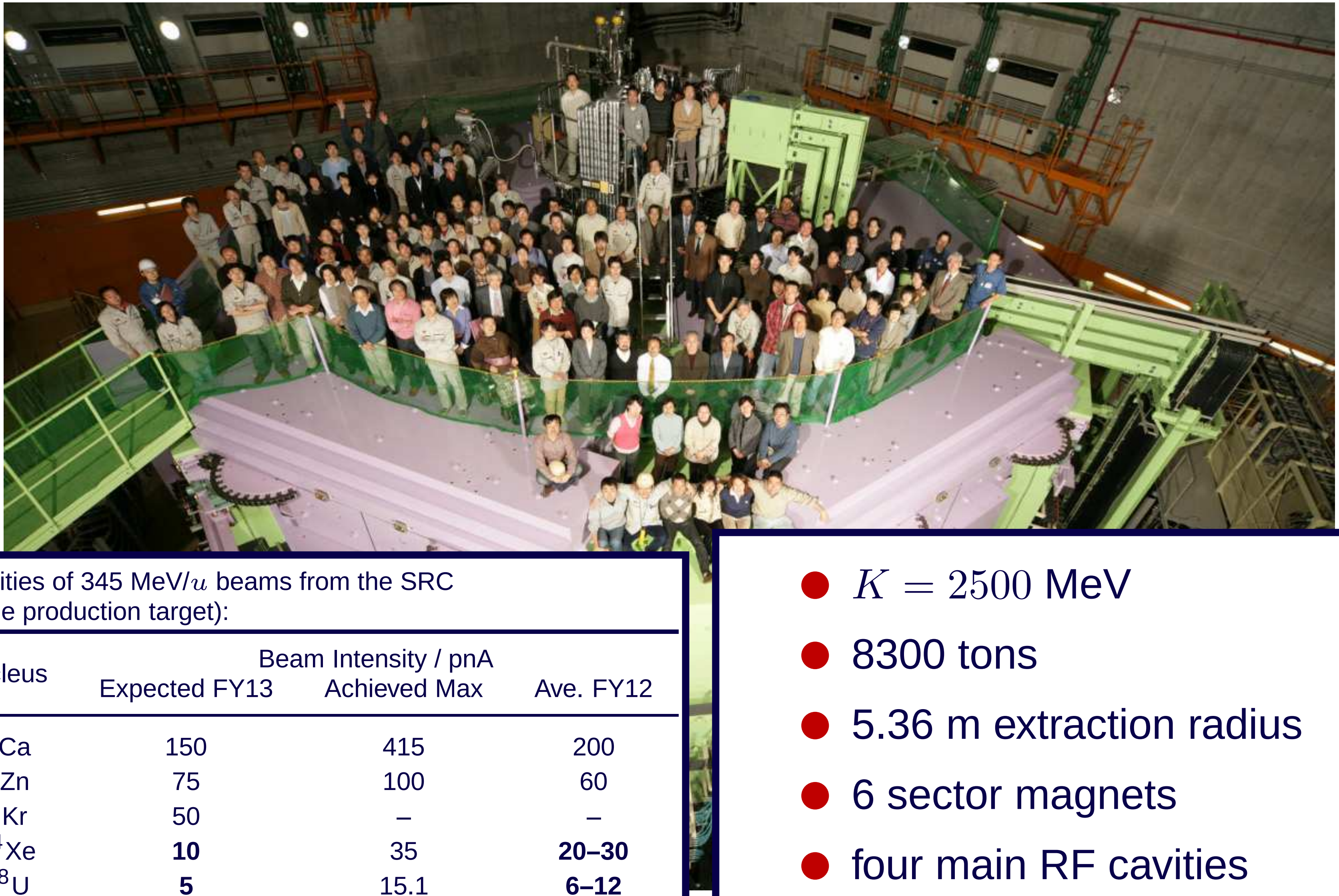
- **December 2008, Dayone, ^{32}Ne**
- December 2009, Test with ^{238}U
- **December 2010 ^{48}Ca**
  - **S. Takeuchi *et al.*, ^{38,40,42}Si**
  - **H. Scheit *et al.*, ^{36,38}Mg**
  - D. Bazin *et al.*, ^{33}Mg
  - P. Fallon *et al.*, ^{40}Mg test
- November/December 2011, ^{238}U
  - K. Yoneda *et al.*, ^{78}Ni
  - **N. Aoi *et al.*, Around ^{132}Sn**
- July 2012, ^{124}Xe and ^{70}Zn
  - **A. Obertelli, P. Doornenbal *et al.*, ^{10x}Sn**
  - **D. Steppenbeck *et al.*, ^{54}Ca**
- May 2013, ^{238}U
  - **G. de Angelis *et al.*, $^{73–75}$Ni**

The RIBF

RIBF Overview



Superconducting Ring Cyclotron (SRC)

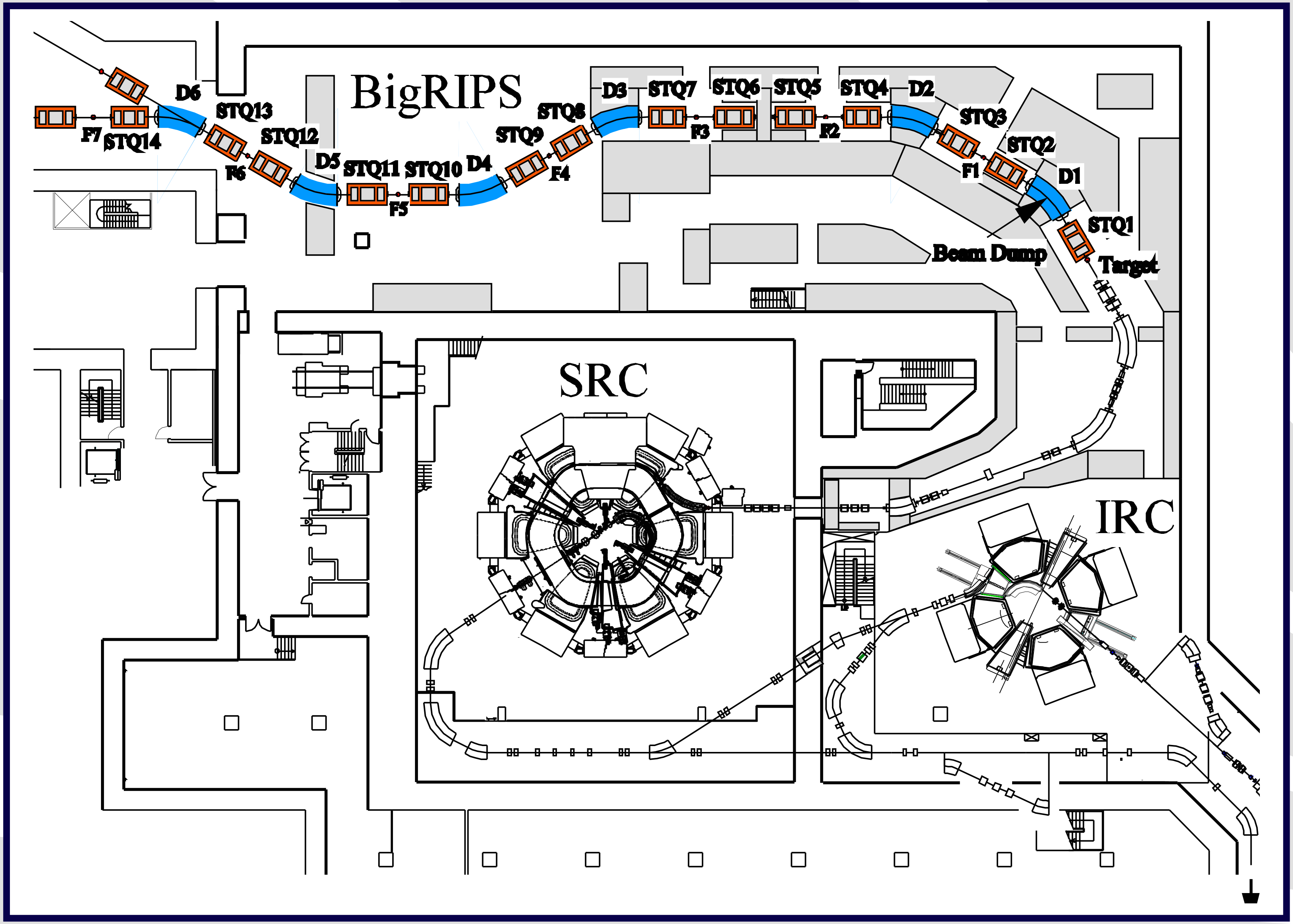


Intensities of 345 MeV/u beams from the SRC
(On the production target):

Nucleus	Beam Intensity / pnA Expected FY13	Achieved Max	Ave. FY12
^{48}Ca	150	415	200
^{70}Zn	75	100	60
^{78}Kr	50	–	–
^{124}Xe	**10**	35	**20–30**
^{238}U	**5**	15.1	**6–12**

- $K = 2500$ MeV
- 8300 tons
- 5.36 m extraction radius
- 6 sector magnets
- four main RF cavities

BigRIPS Overview



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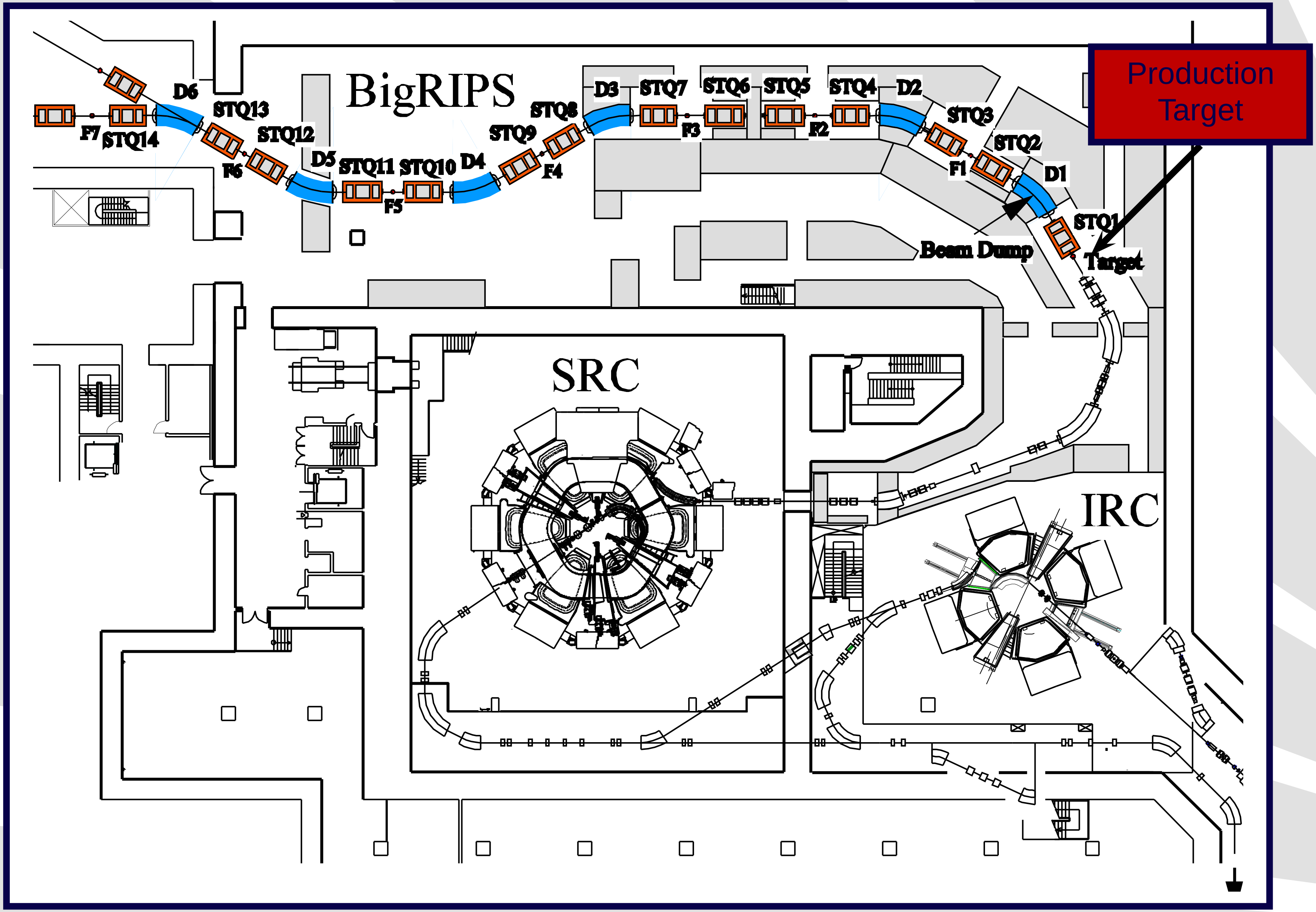
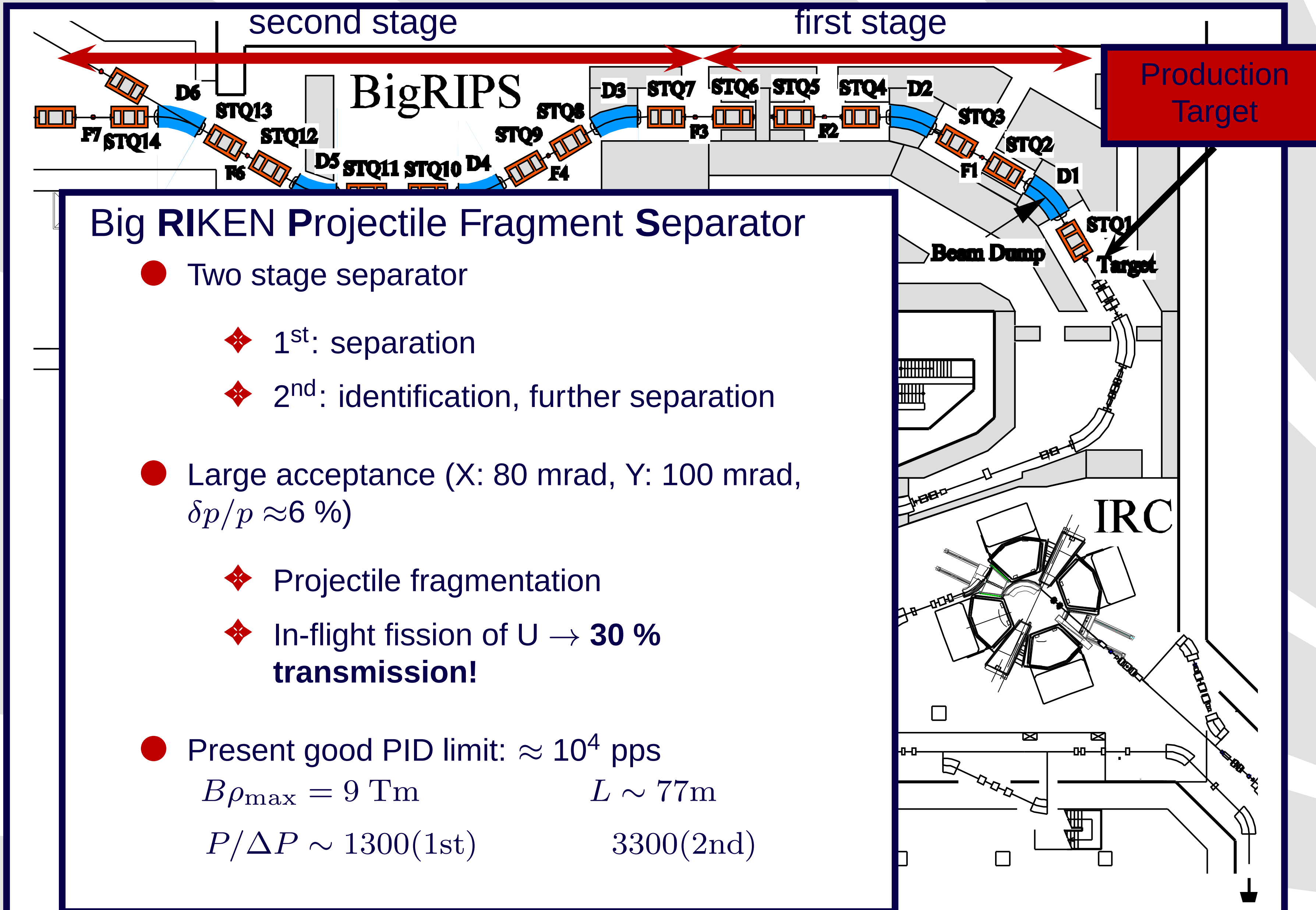


BigRIPS Overview



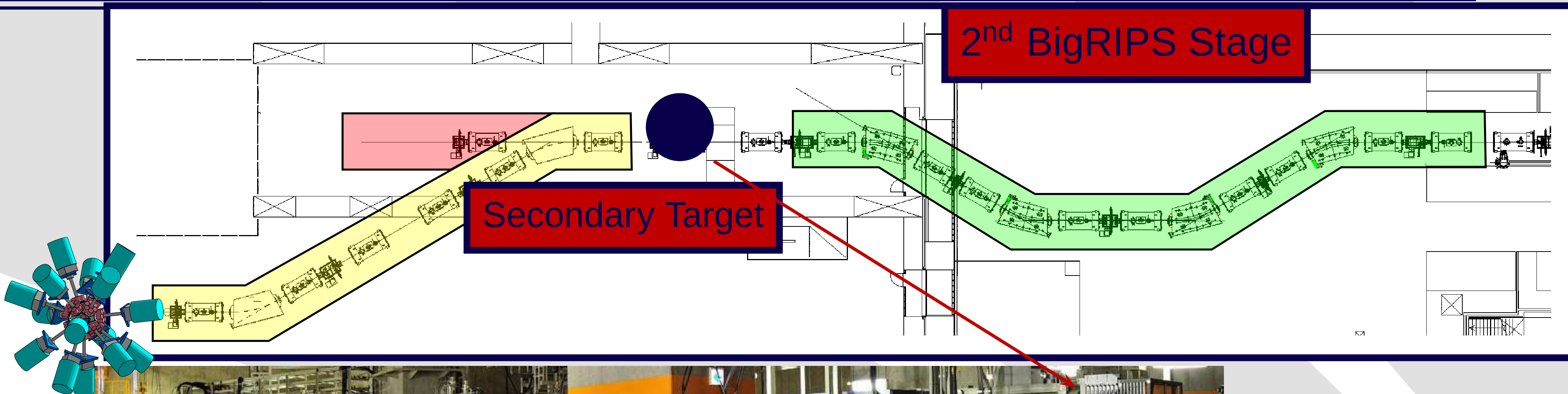
Big **RI**KEN **P**rojectile Fragment **S**eparator

- Two stage separator
  - 1^{st}: separation
  - 2^{nd}: identification, further separation
- Large acceptance (X: 80 mrad, Y: 100 mrad, $\delta p/p$ ≈6 %)
  - Projectile fragmentation
  - In-flight fission of U $\rightarrow$ **30 % transmission!**
- Present good PID limit: $\approx 10^4$ pps

$B\rho_{\max} = 9\ \mathrm{Tm}$ $\qquad L \sim 77\mathrm{m}$

$P/\Delta P \sim 1300(1\mathrm{st}) \qquad 3300(2\mathrm{nd})$

ZeroDegree Spectrometer



~ 3 m between Q-poles

- DALI2 array, 186 NaI(Tl)
- GRAPE HPGe array
- $E_{\mathrm{beam}} \sim 100 - 250$ MeV/u

0° Spectrometer ZeroDegree

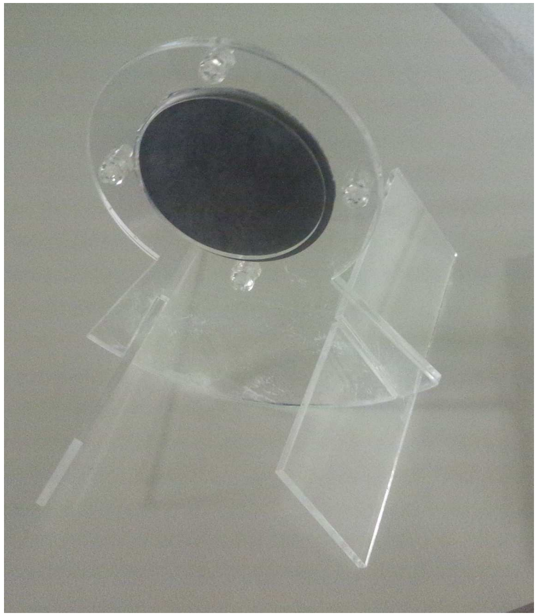
- **Particle ID** after secondary target
- Fragment momentum distribution
- Various modes of operation

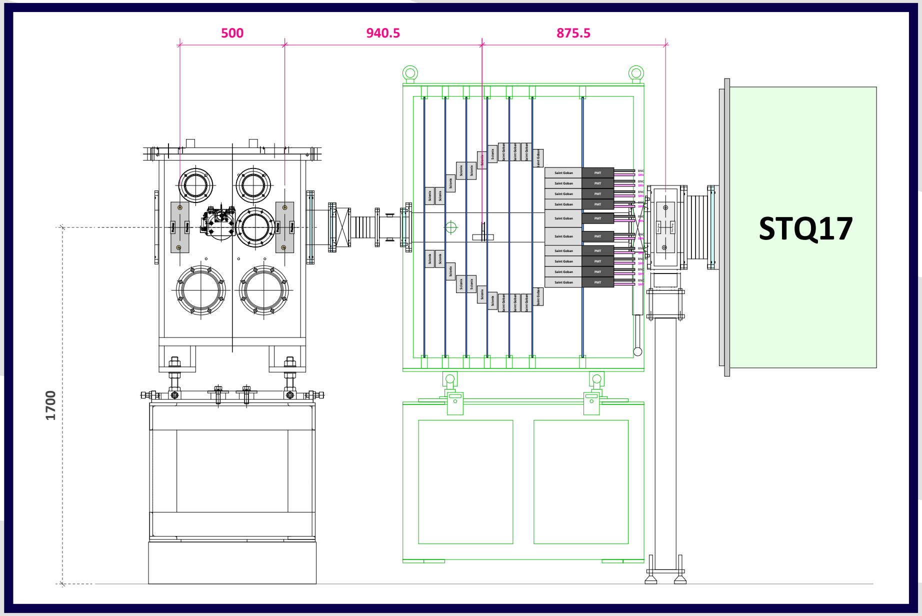
mode	$p/\Delta p$	Δp	Ang. Accep.
Large Accep.	**1240**	**±3%**	**±45 mrad(H) ±30 mra**
High res.(achrom)	2120	±3%	±20 mrad(H) ±30 mrad(V)
Dispersive	4130	±2%	±20 mrad(H) ±30 mrad(V)

F8 Area

Secondary Target Area

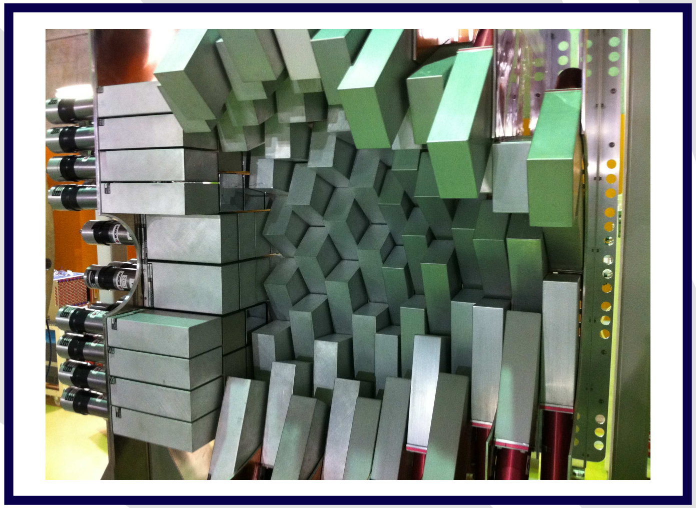
- 2 double PPACs in front of reaction target
- 1 double PPAC behind reaction target
- Secondary beam spot size ≈ 5 mm (σ)
- Scattering angle reconstruction ≈ 5 mrad (σ)
- Open Beam pipe to change reaction target
- Target diameters 30–40 mm
- Target thicknesses of several g/cm^2

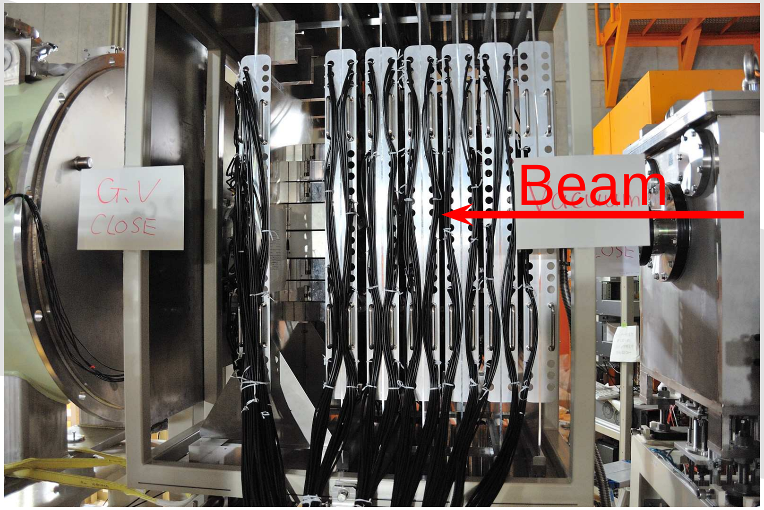


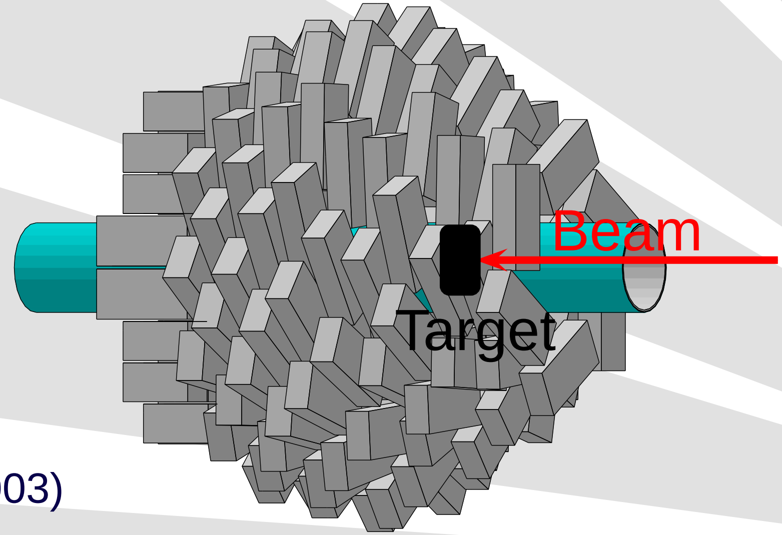


DALI2 (2010–to Present)

- Forward-wall configuration
- 186 NaI(Tl) detectors
- ϑ coverage 11° to 165°
- 7 % intrinsic resolution at 1 MeV
- $\Delta E/E \approx$**10(11) % at 100(250) MeV/**u
- $\approx$ **20% FEP efficiency at 1 MeV**
- Simplified target holder and beam pipe
- 1mm Pb (+1mm Sn) shielding







S. Takeuchi *et al.*, RIKEN Pr. Rep. 36, 148 (2003)

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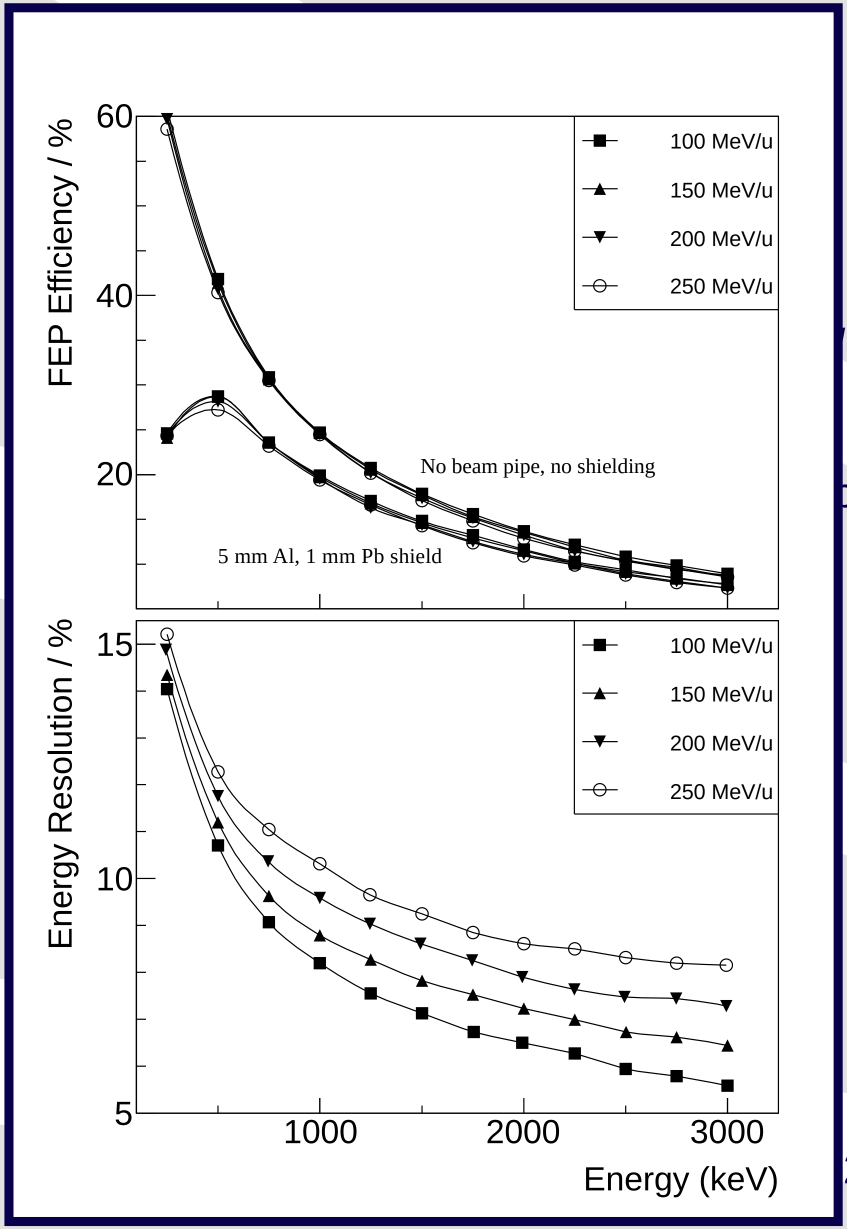
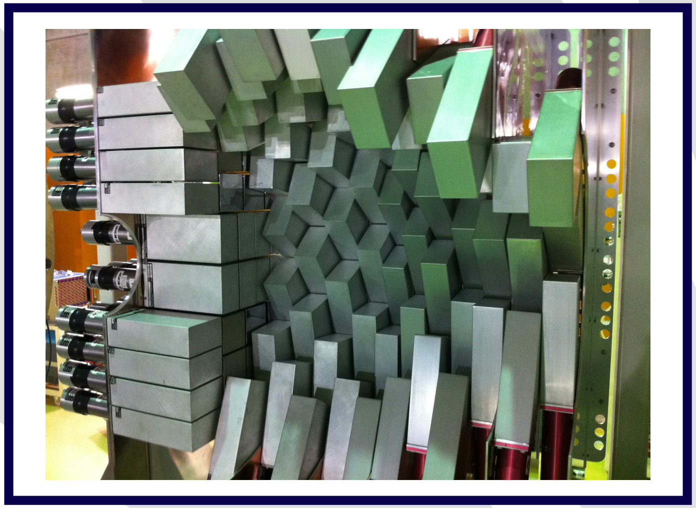
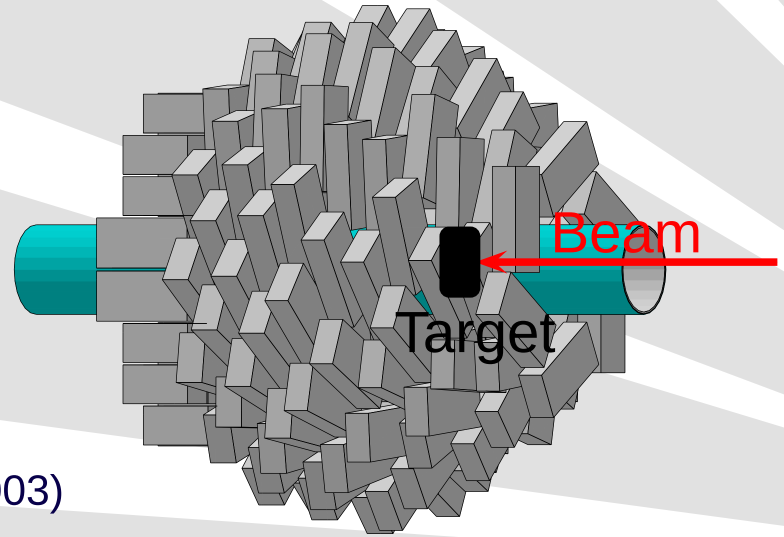






Atomic Background

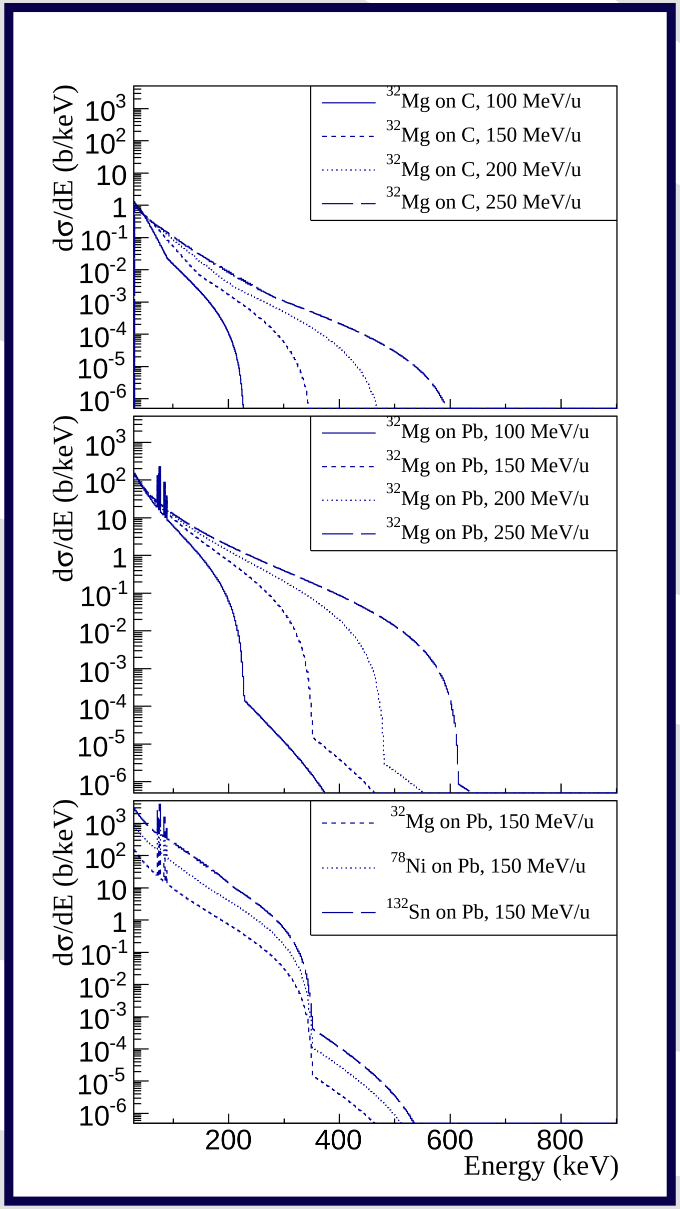
Atomic Background

- target electrons scattering off heavy projectile
- maximum electron energy:

$$E^{e^-}_{\max} = \frac{1}{500} E/A \qquad (\beta \to 2\beta, \quad m \to \frac{1}{2000} m)$$

- Components of radiation
  - Radiative electron capture (Capture of target e^- into bound states of the projectile)
    $\sigma \propto Z_p^2 Z_t$ $W(\theta)$ in proj. frame
  - Primary bremsstrahlung (Capture of target e^- into continuum states of the projectile)
    $\sigma \propto Z_p^2 Z_t$ $W(\theta)$ in proj. frame
  - Secondary (electron) bremsstrahlung (**SEB**)
    (Stopping of high energy electrons in the target)
    $\sigma \propto Z_p^2 Z_t^2$ isotropic in lab. frame
- Most important for high-Z targets

Atomic Background



R. Holzmann *et al.*, GSI Annual Report 1992, 48 (1993).

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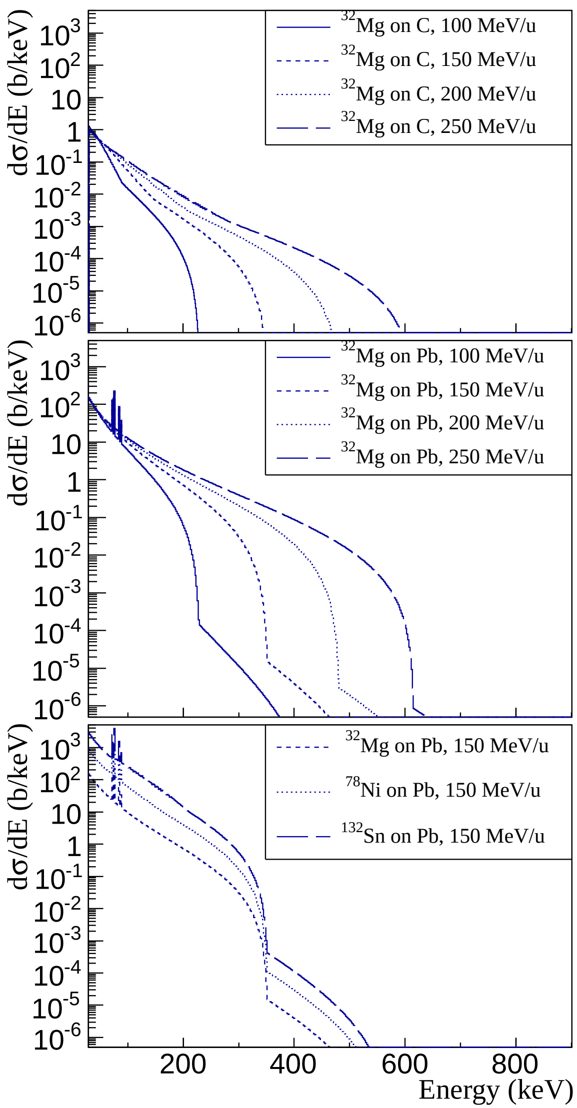

Projectile	Target	Thickness / gcm^{-2}	Energy / MeV/u	Produced γ-rays >30 keV
^{36}Mg	C	2.54	221	3.68
^{36}Mg	Pb	3.37	216	44.1
^{112}Sn	C	0.370	150	16.65
^{112}Sn	Pb	0.557	150	135.7

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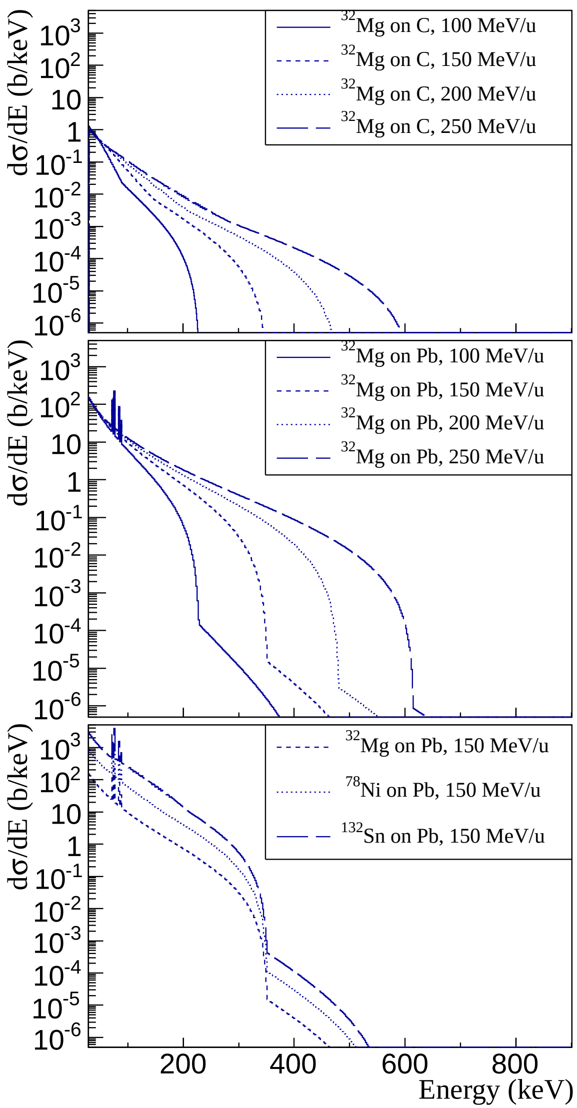

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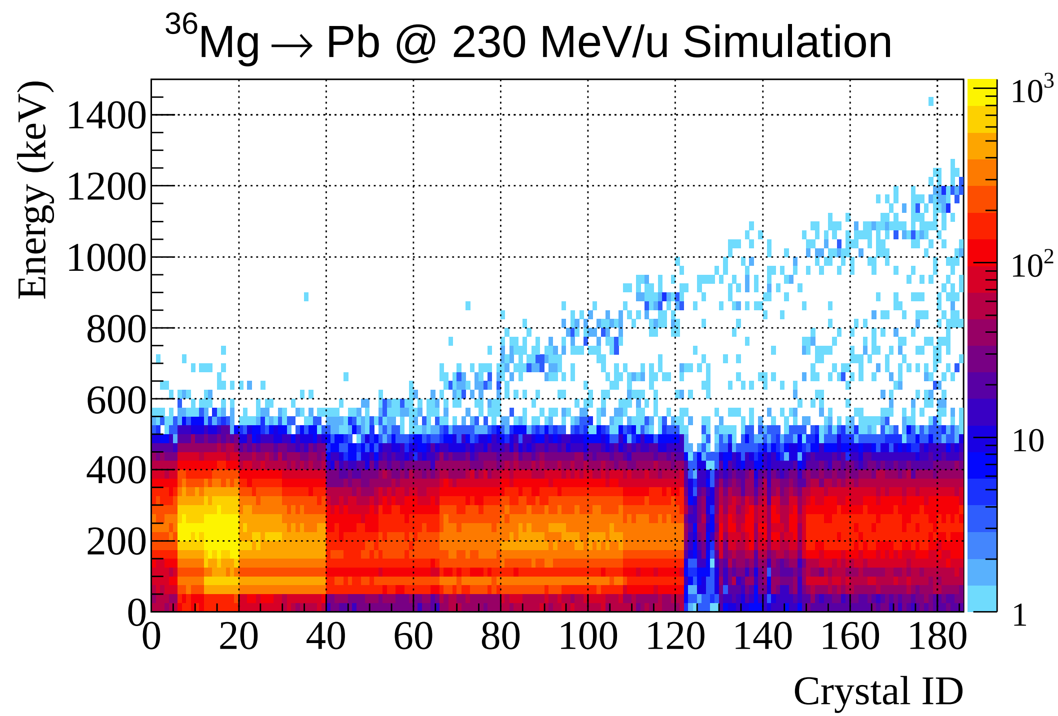

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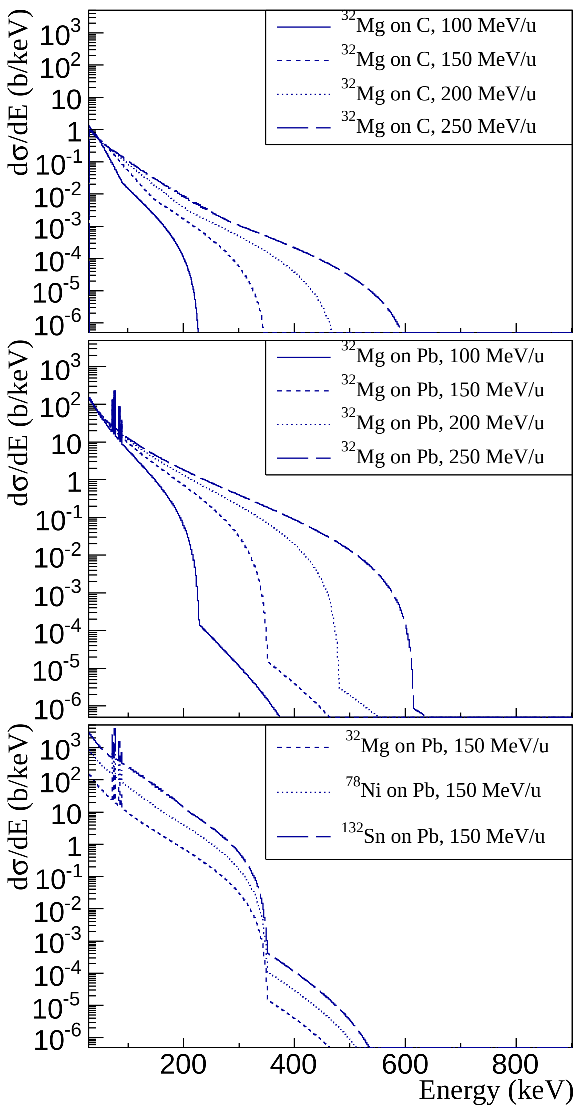

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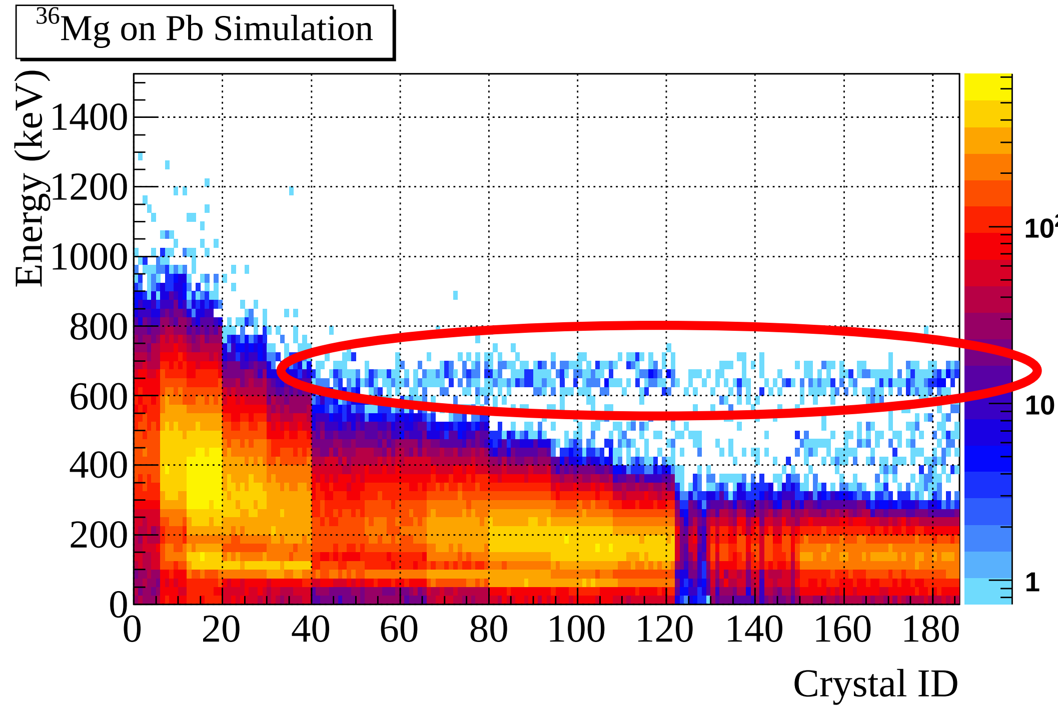

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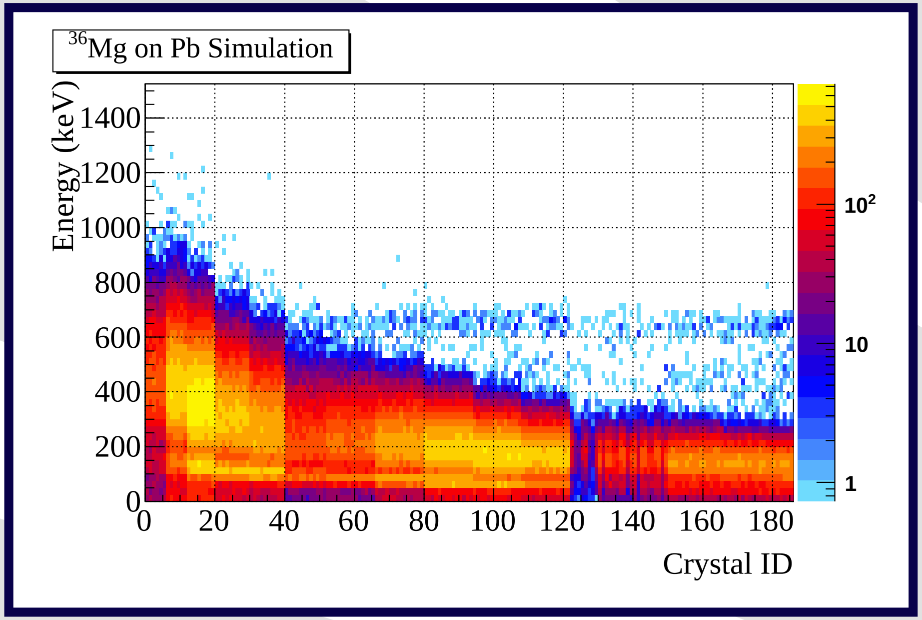
Atomic Background Comparison to Experiment – ^{36}Mg on Pb @ 230 MeV/u



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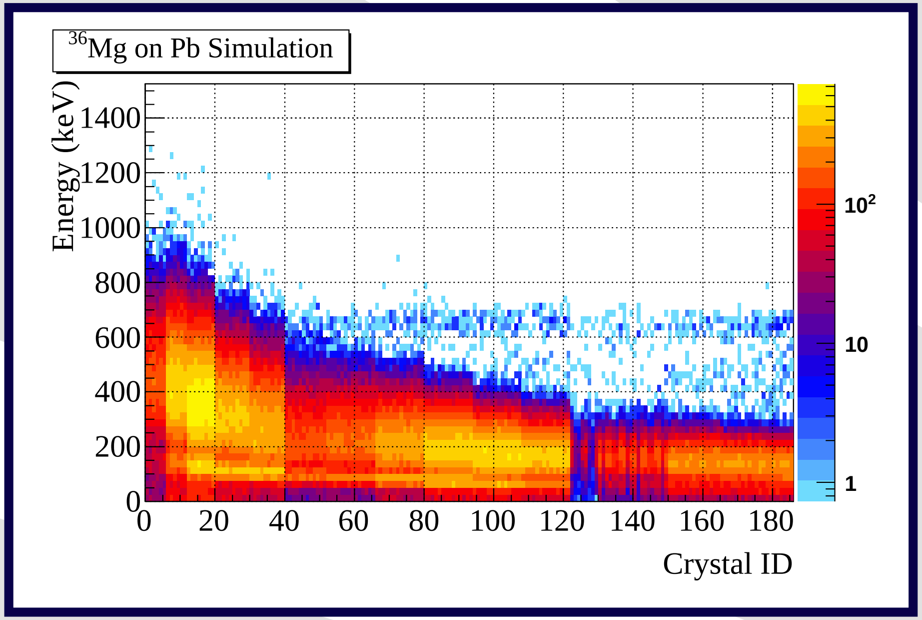

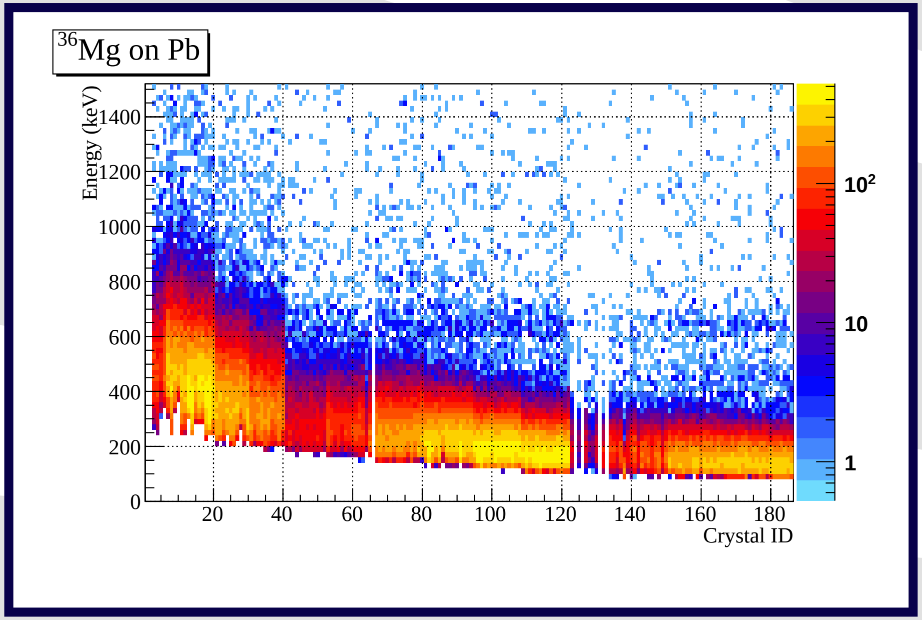

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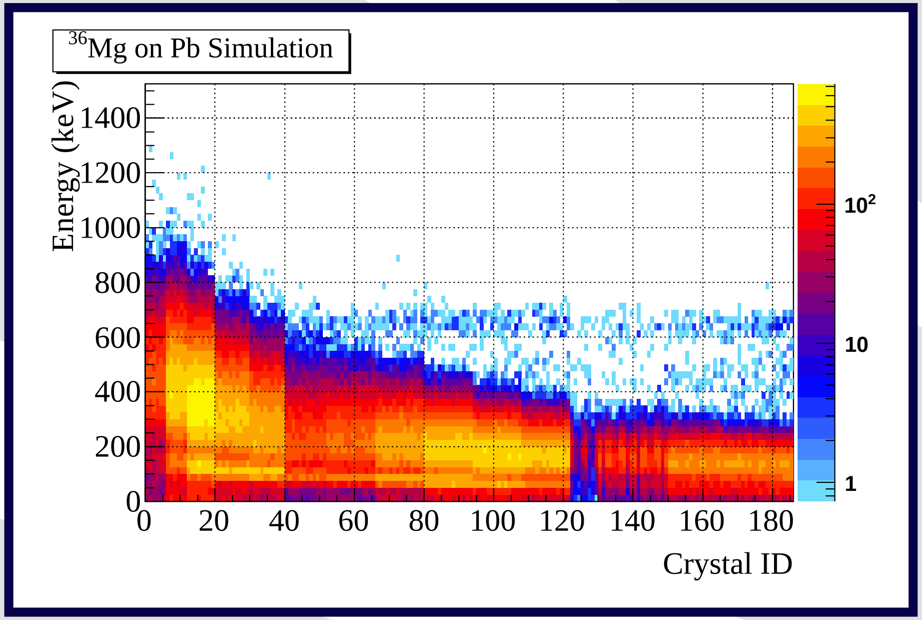
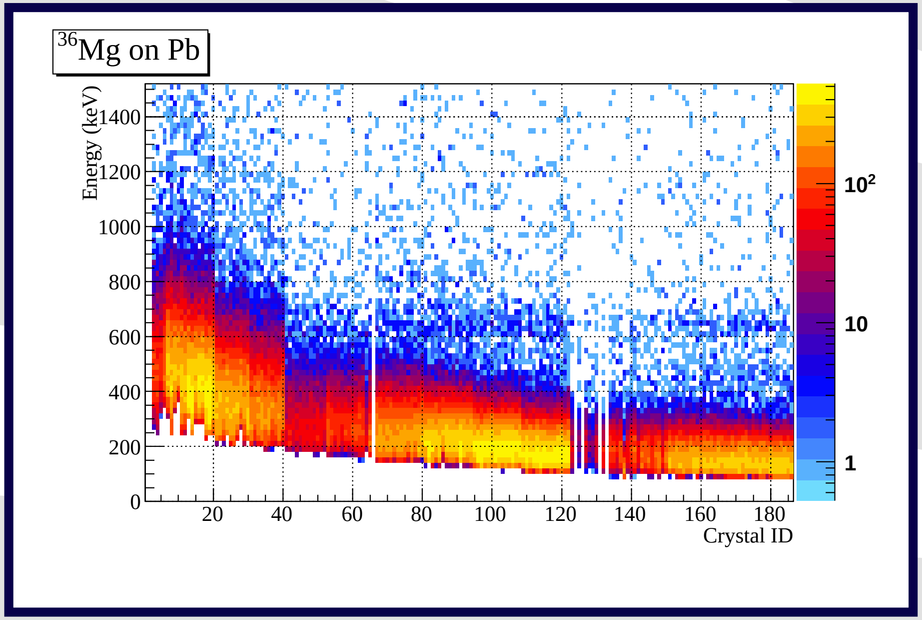
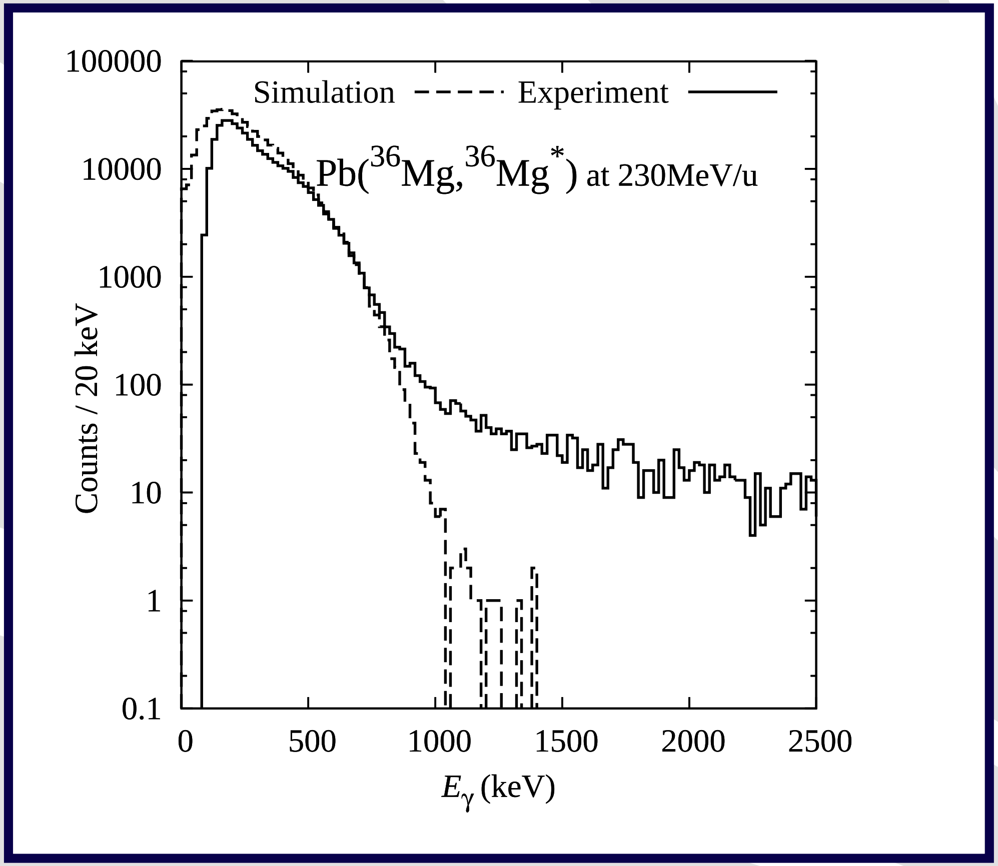






Intermediate-Energy Coulomb Excitation

Considerations for Intermediate-Energy Coulex

- Want to measure at higher energies
  - Thicker targets
  - Higher secondary beam yield
  - Higher ZDS acceptance
  - Charge states
- Want to measure at lower energies
  - Higher Coulomb excitation cross-section
  - Larger scattering angle
  - Less atomic background

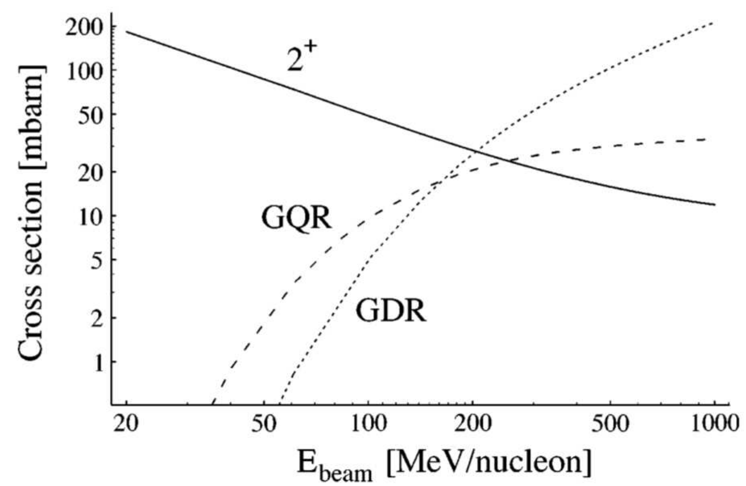
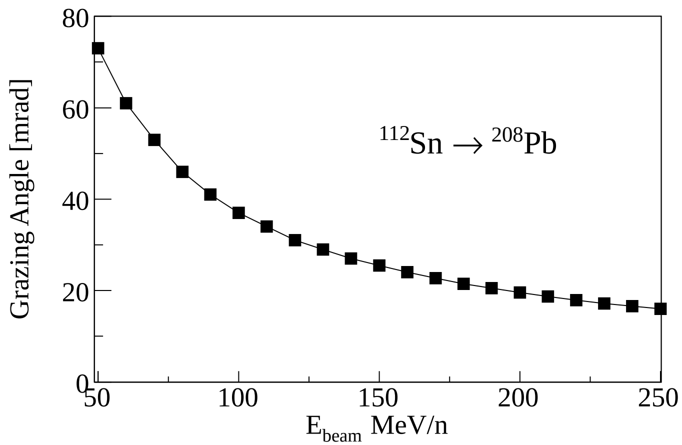
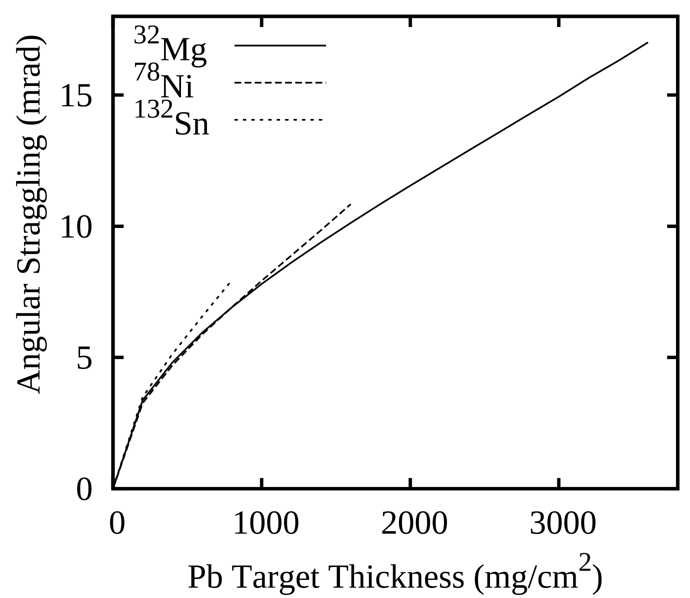


Figure 1 Cross sections for Coulomb excitation of the first excited state (2^+), the giant dipole





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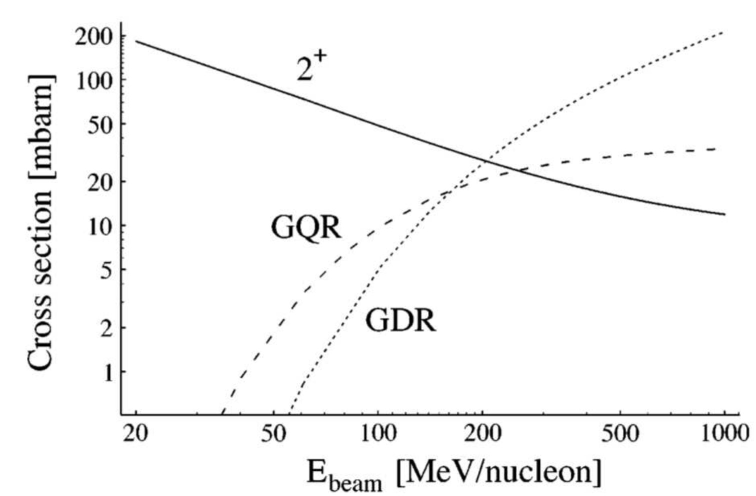
- $\approx$150 MeV/u for ^{104,112}Sn
- $\approx$215 MeV/u for ^{36}Mg



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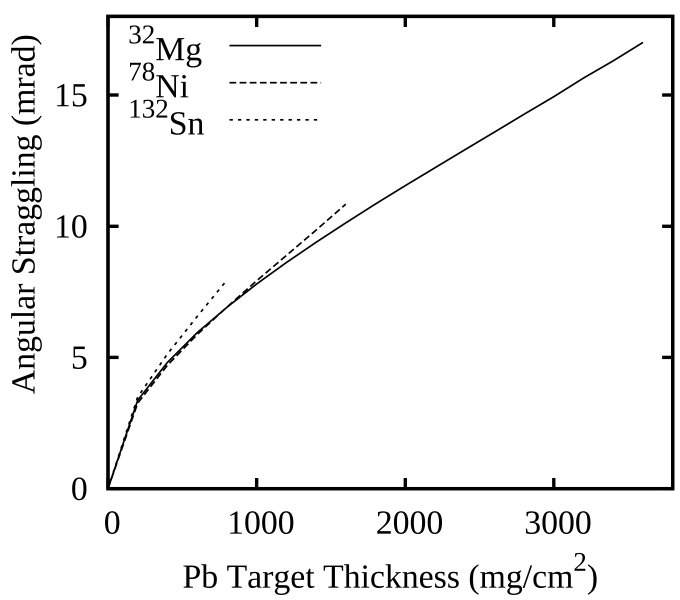

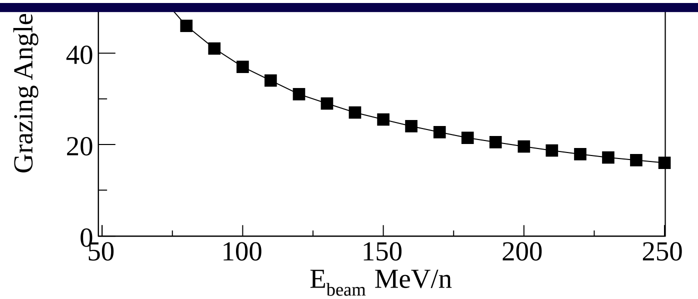

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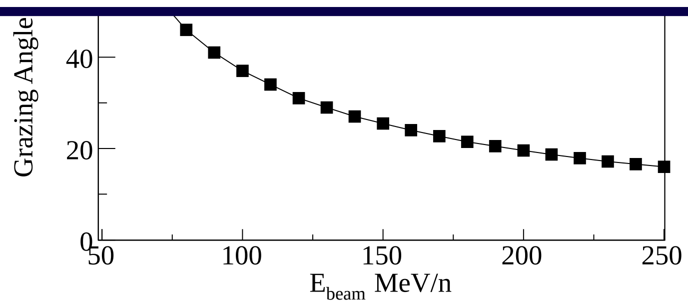
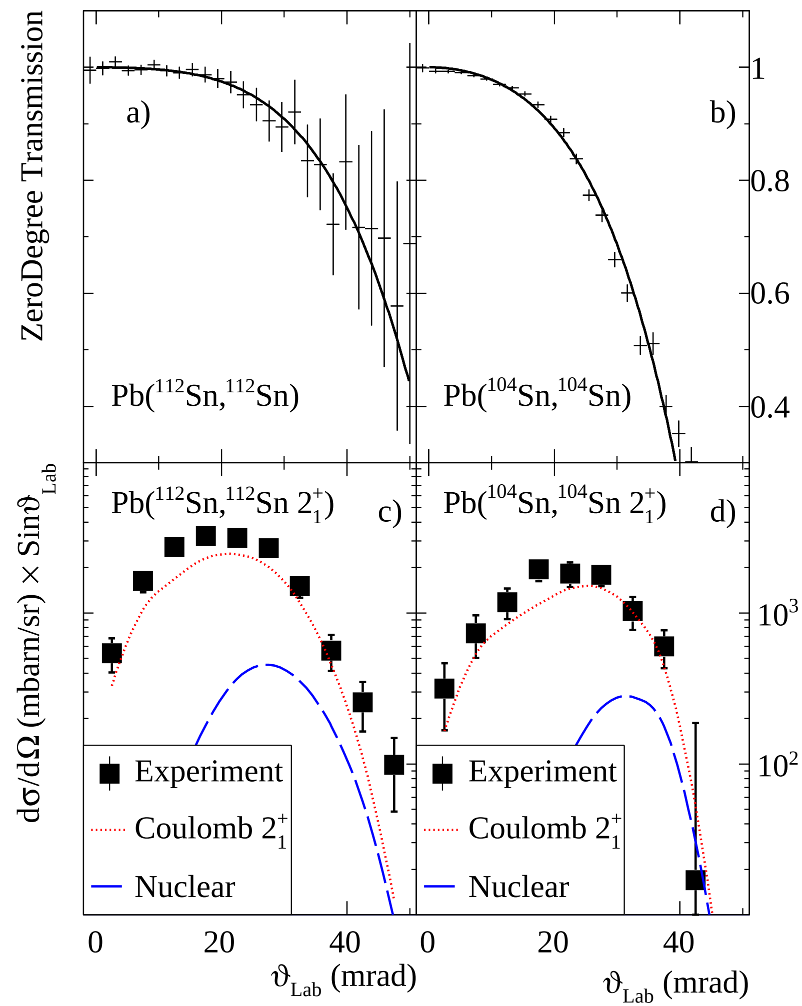
- $\approx$215 MeV/u for ^{36}Mg





Summary and Outlook

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- Many experiments are already proposed
- Experimental data obtained so far very promising, as we will see...
- Regarding method:
  - All aspects well understood
  - Atomic background described quantitatively in simulations
    - Other components from target excitations (not shown today)
  - Absolute cross-sections

THE END

Backup slides from now