Imaging in Decay Spectroscopy

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Decay Spectroscopy: Production

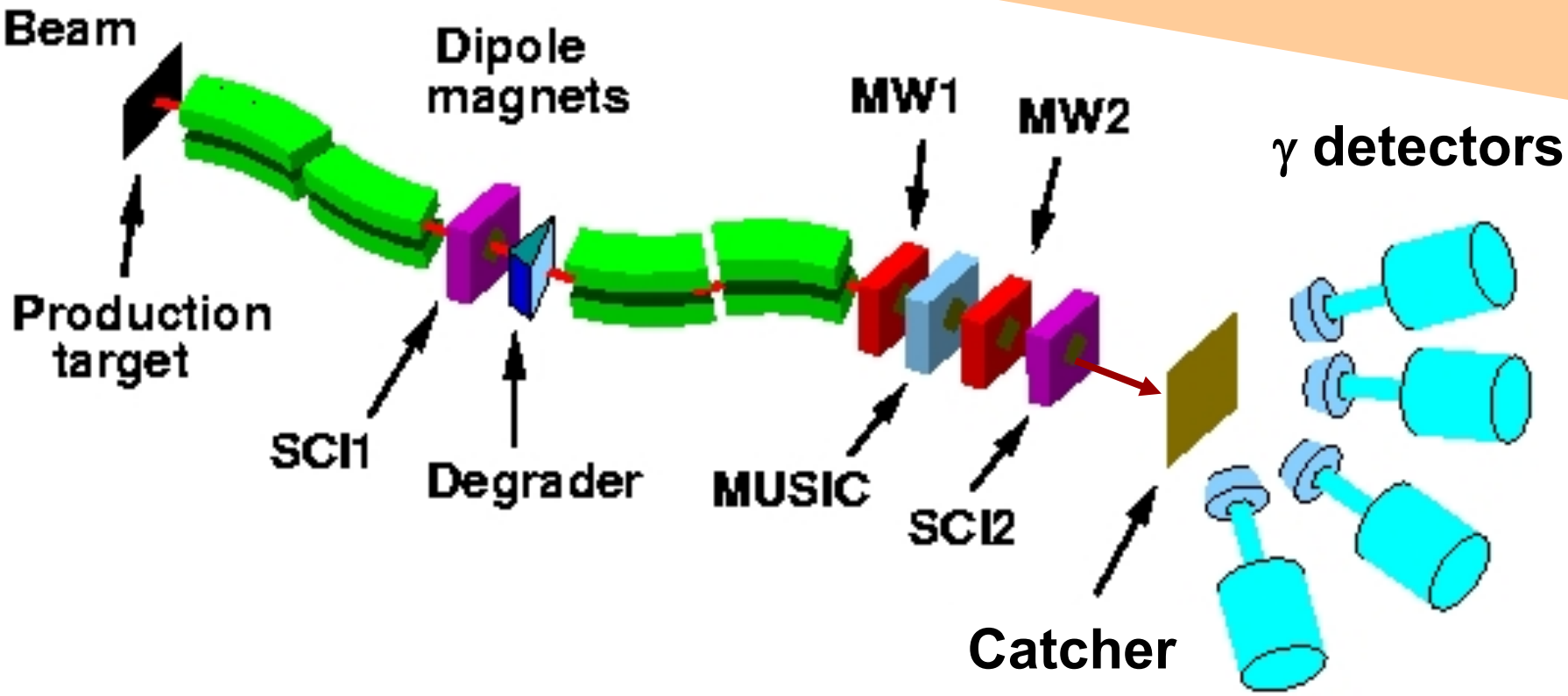
production

selection

identification

spectroscopy

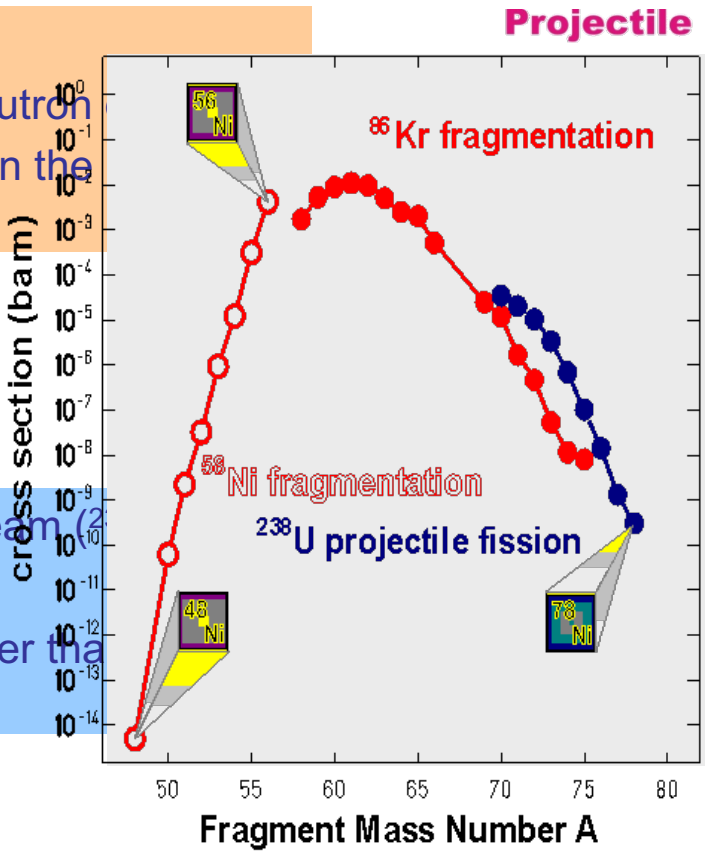
implantation

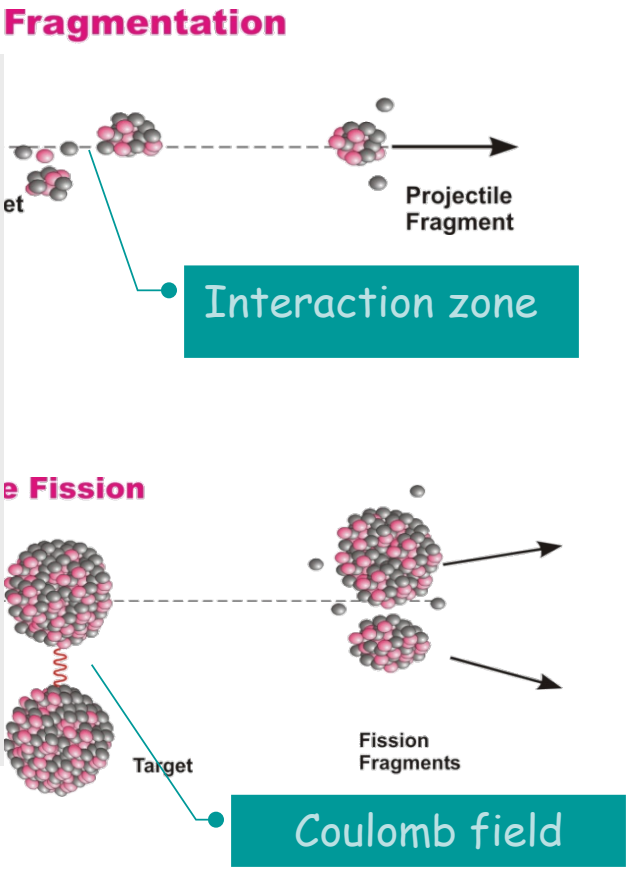


Projectile fragmentation or fission in radioactive isotopes production ?

- ^{9}Be target
- exotic nuclei (also neutron
- fragments nearly retain the direction and velocity

- ^{208}Pb target, heavy beam (2
- neutron rich nuclei
- fragments can be faster tha projectile





Decay Spectroscopy: Selection

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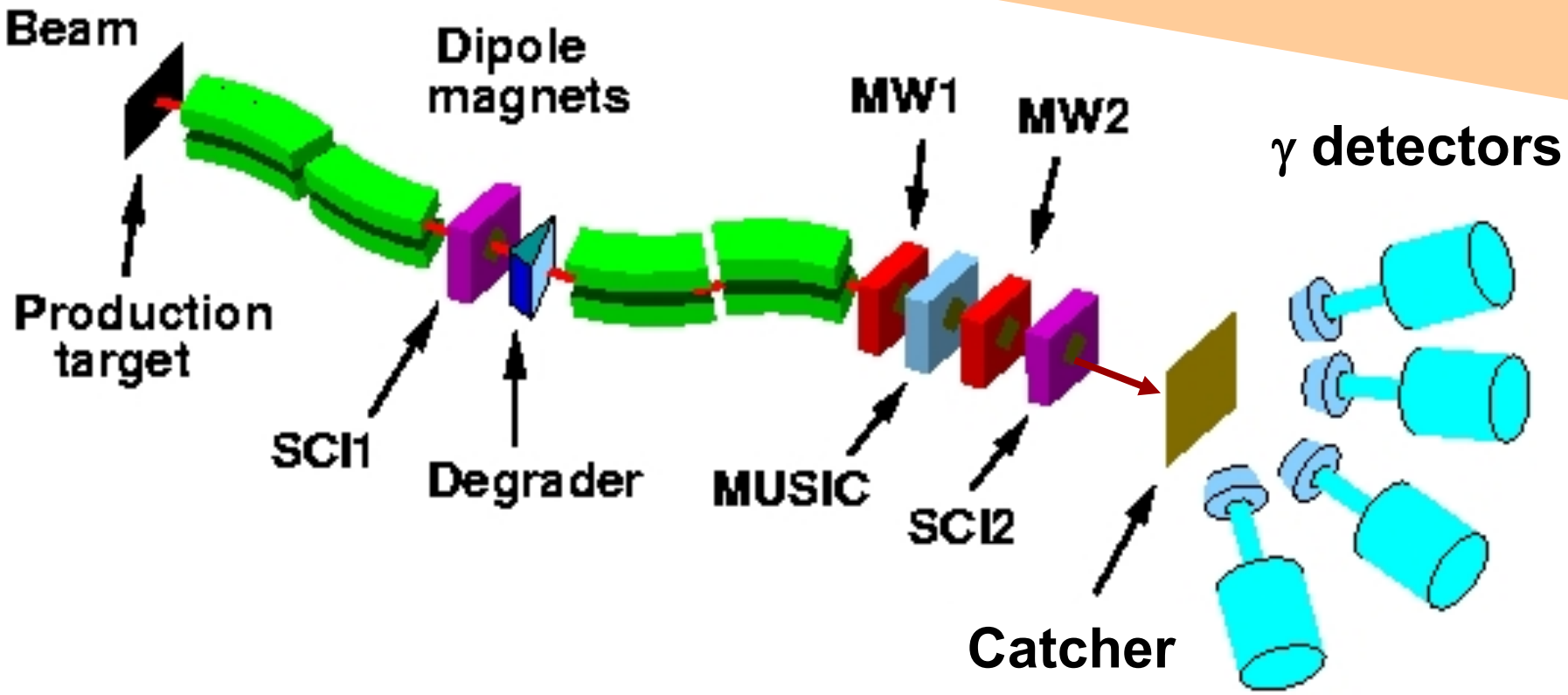
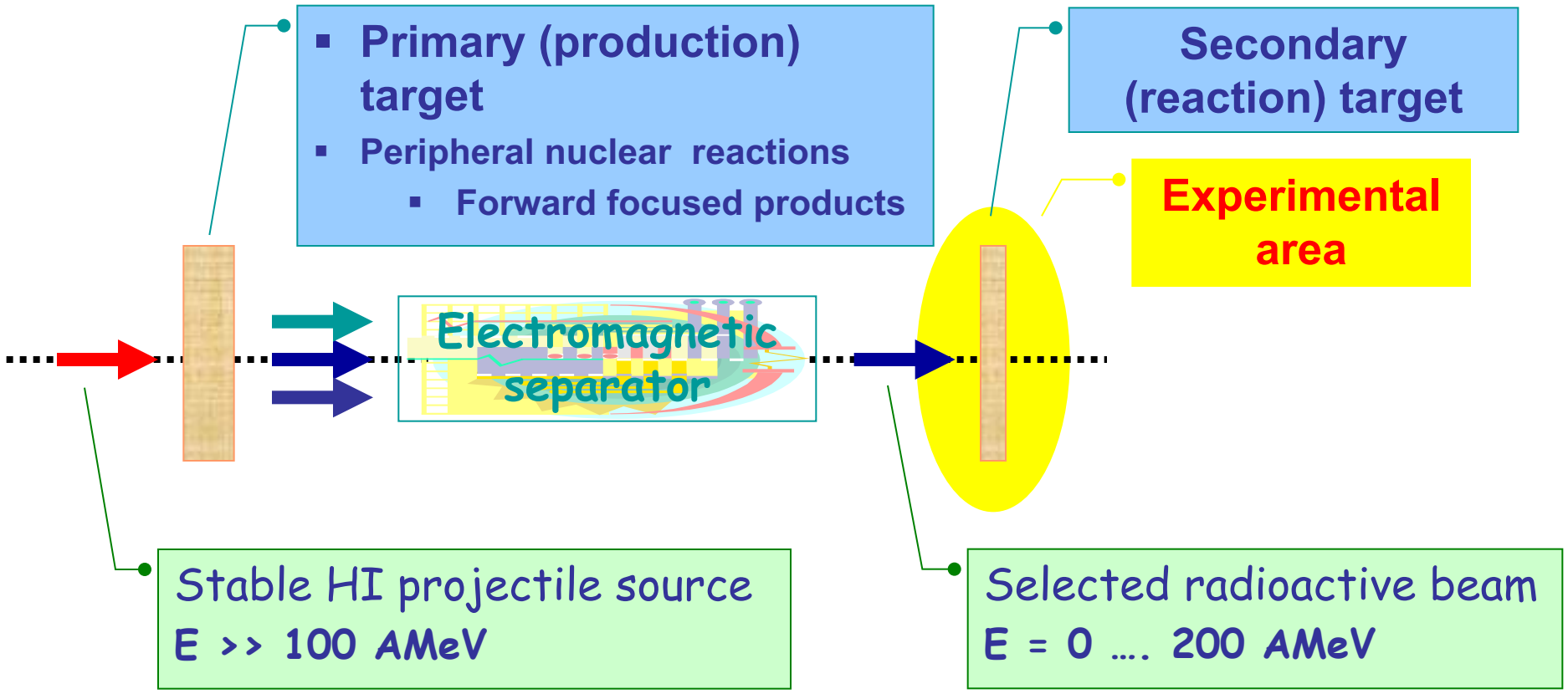
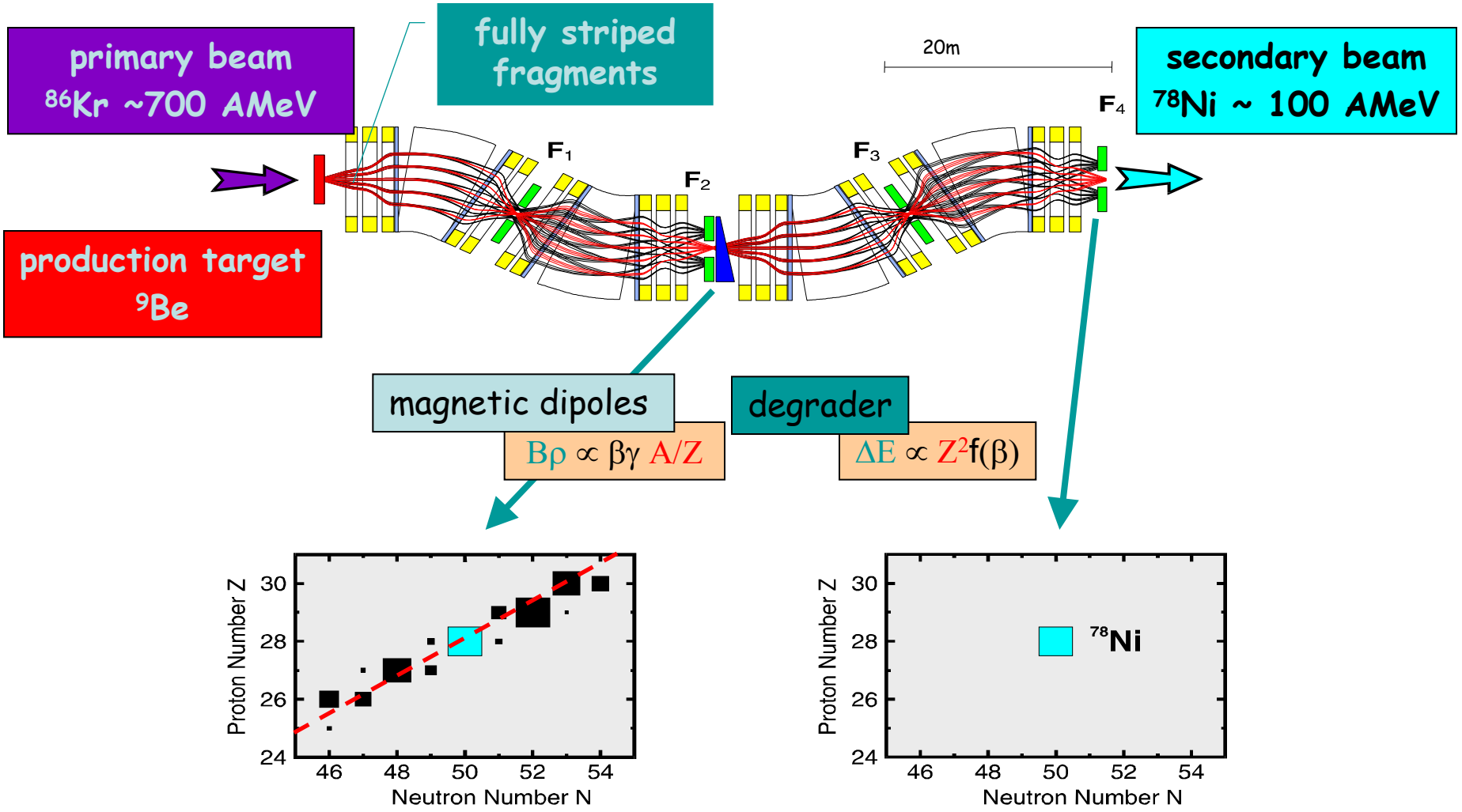


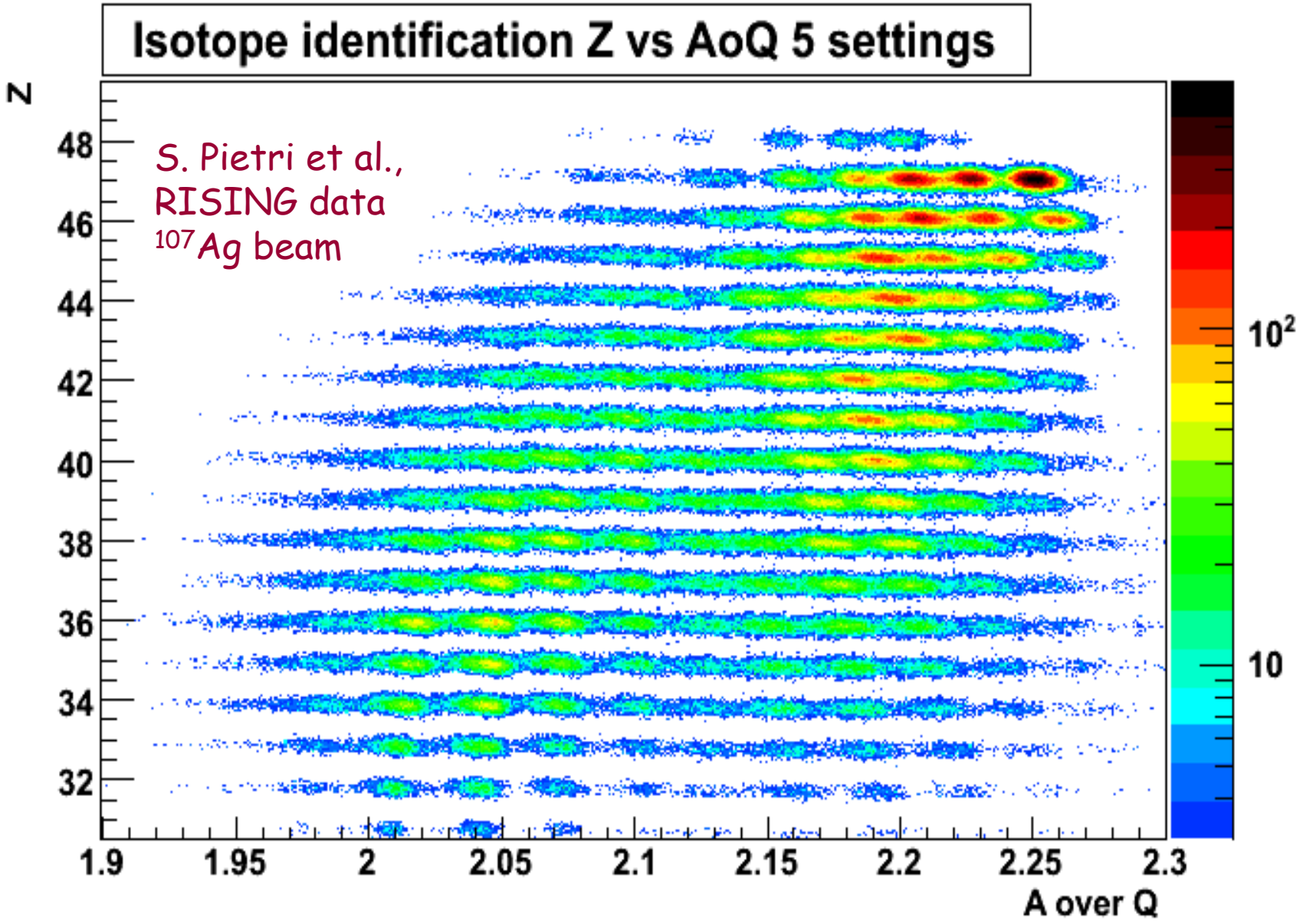
In-flight separation of Rare Isotope Beams



Radioactive isotope selection at FRS (Bρ–ΔE–Bρ technique)



Isotope identification



Decay Spectroscopy: Implantation

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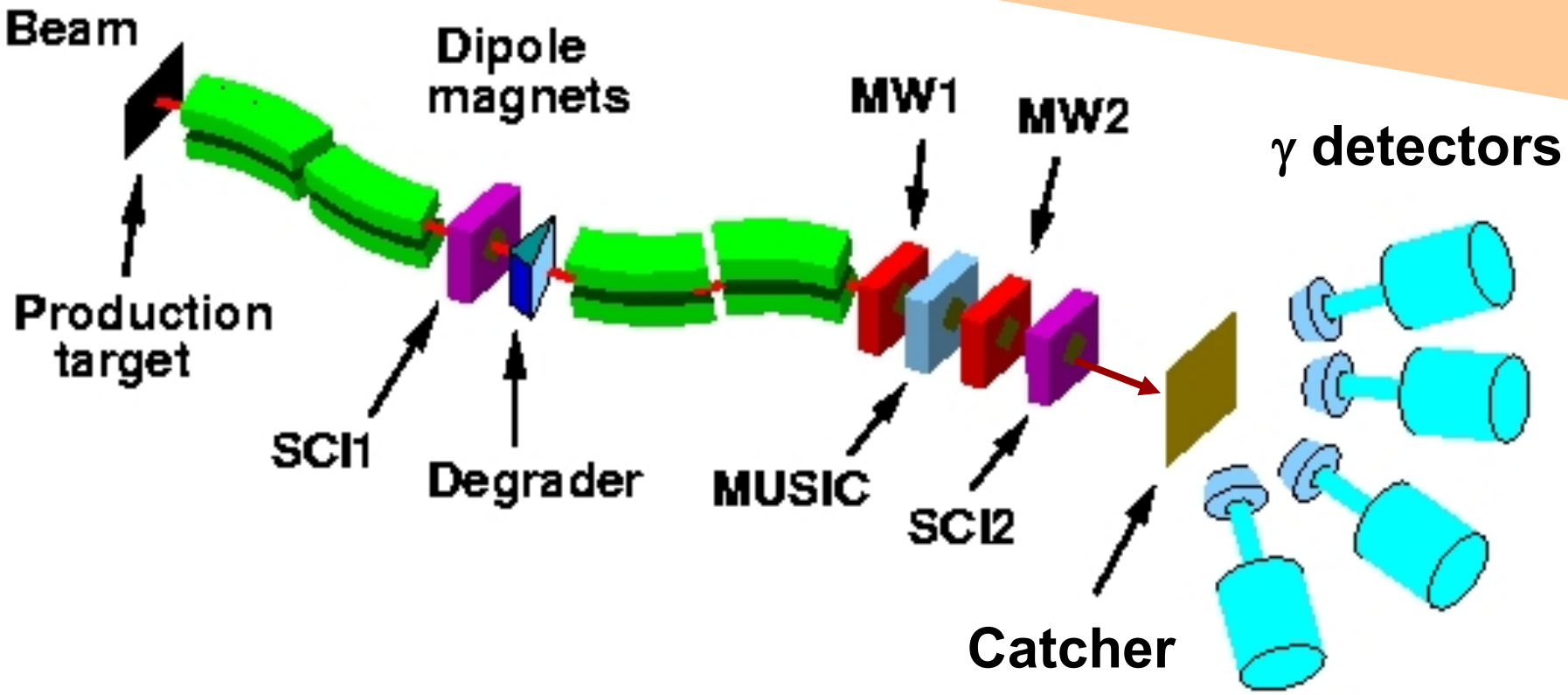
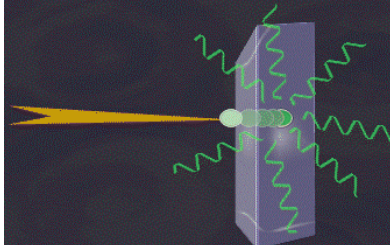


Atomic Background Radiation
Bremsstrahlung



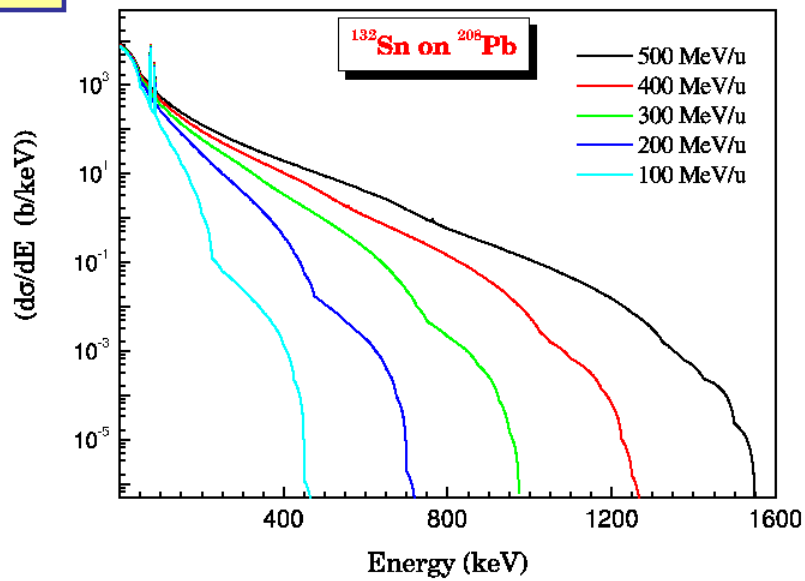
➢Radiative electron capture (REC)
capture of target electrons into bound states of the projectile:

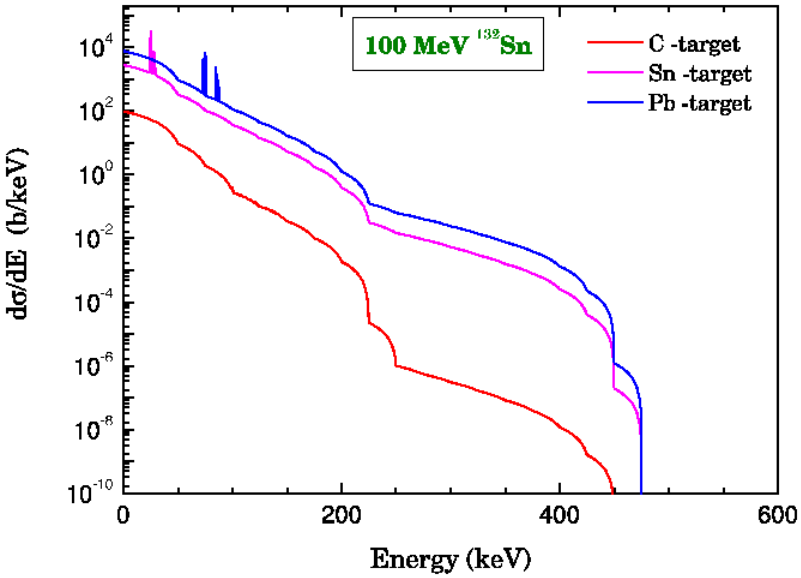
$$\sigma \sim Z_p^2 \cdot Z_t$$

➢Primary Bremsstrahlung (PB)
capture of target electrons into continuum states of the projectile:

$$\sigma \sim Z_p^2 \cdot Z_t$$

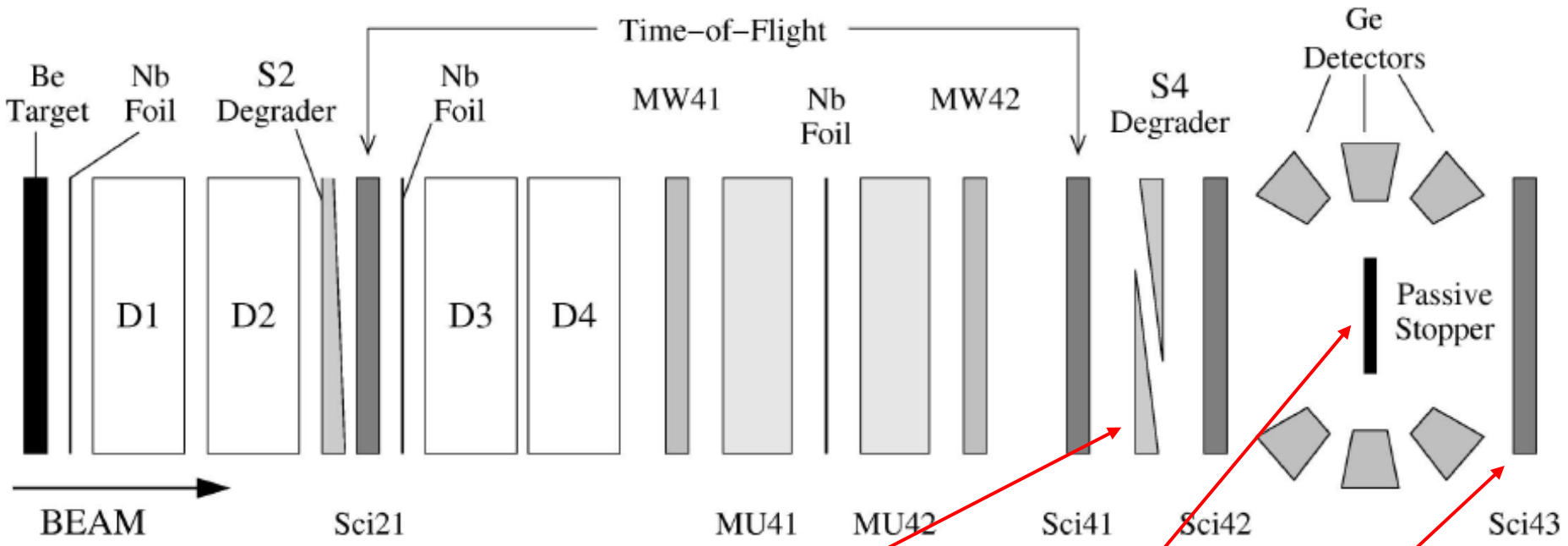
➢Secondary Bremsstrahlung (SB)
Stopping of high energy electrons in the target: $\sigma \sim Z_p^2 \cdot Z_t^2$





Low Z catcher
High granularity γ detector

Passive Stopper



Beam particle energy reduction

5 mm plastic or 2 mm aluminum catcher

Veto detector for secondary reactions

Decay Spectroscopy: γ detection

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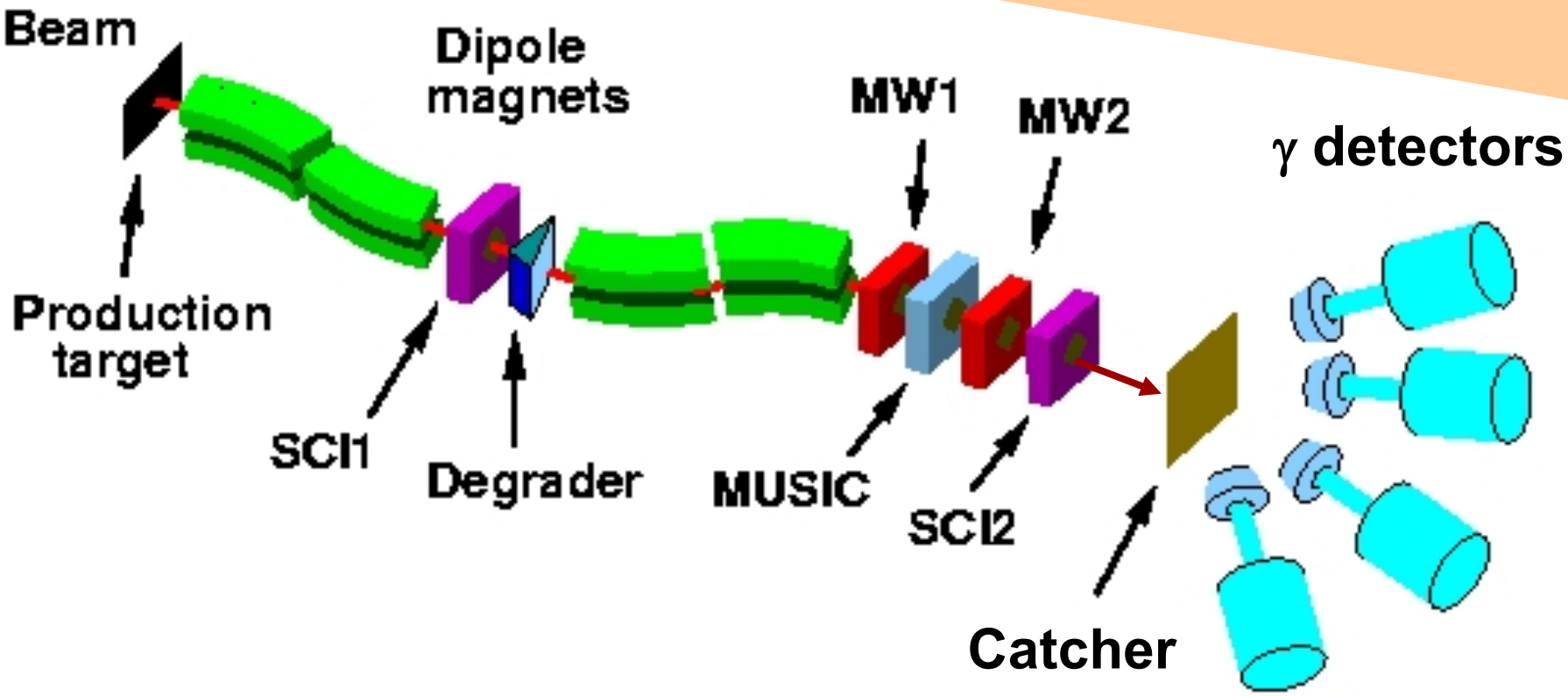
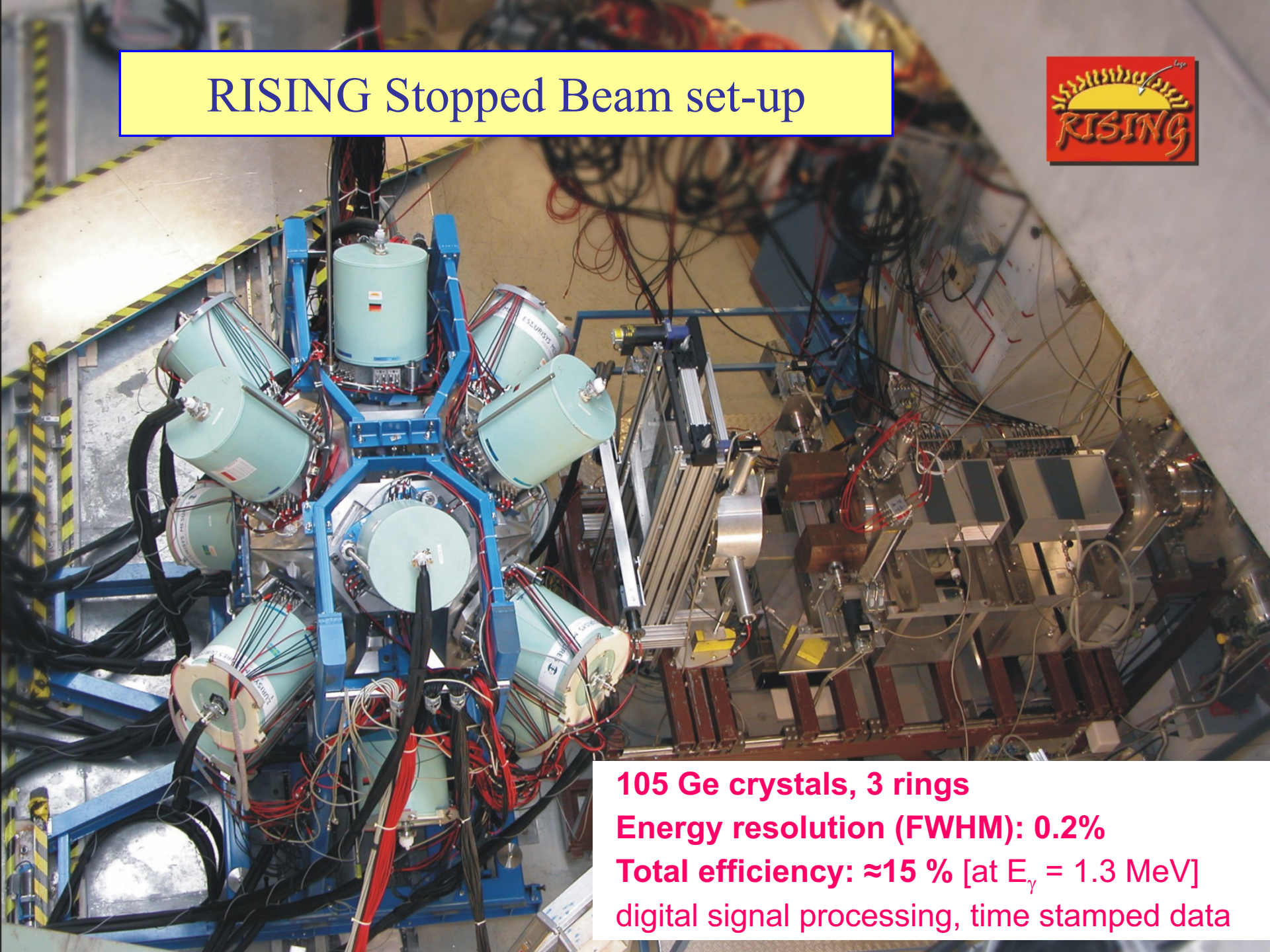


RISING Stopped Beam set-up



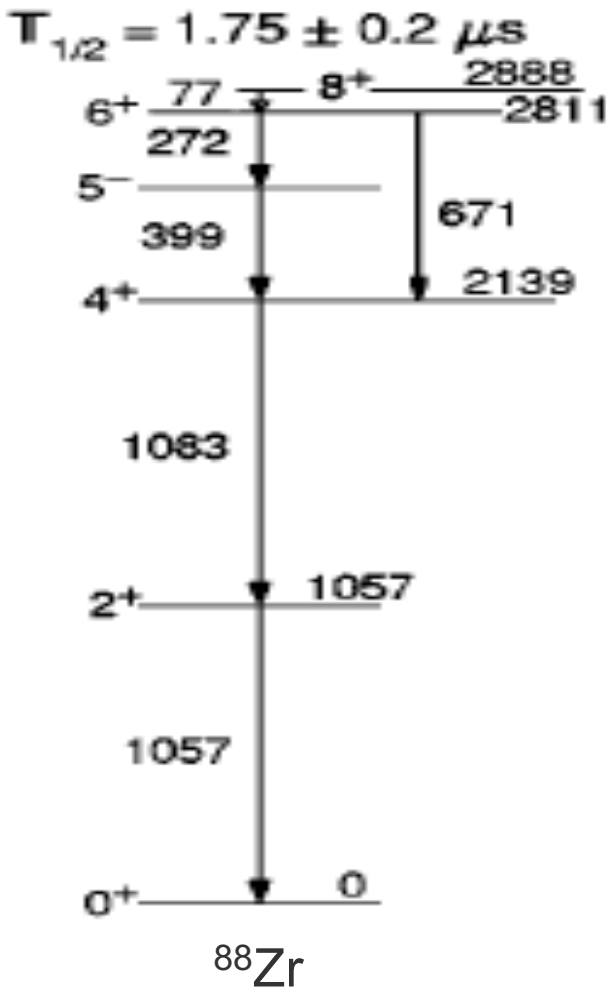
105 Ge crystals, 3 rings

Energy resolution (FWHM): 0.2%

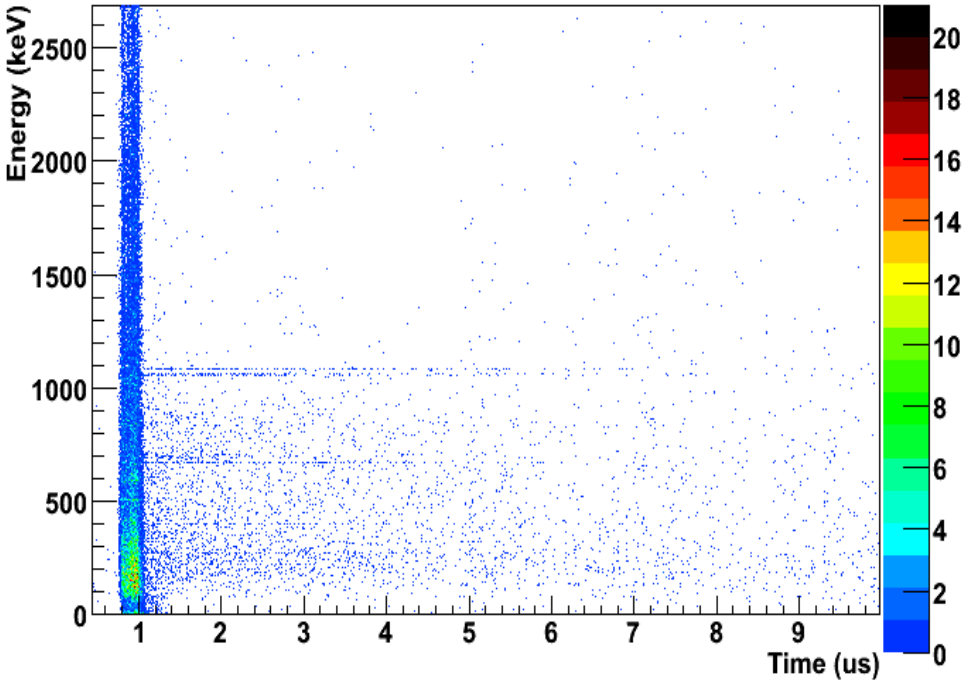
Total efficiency: ≈15 % [at E_γ = 1.3 MeV]

digital signal processing, time stamped data

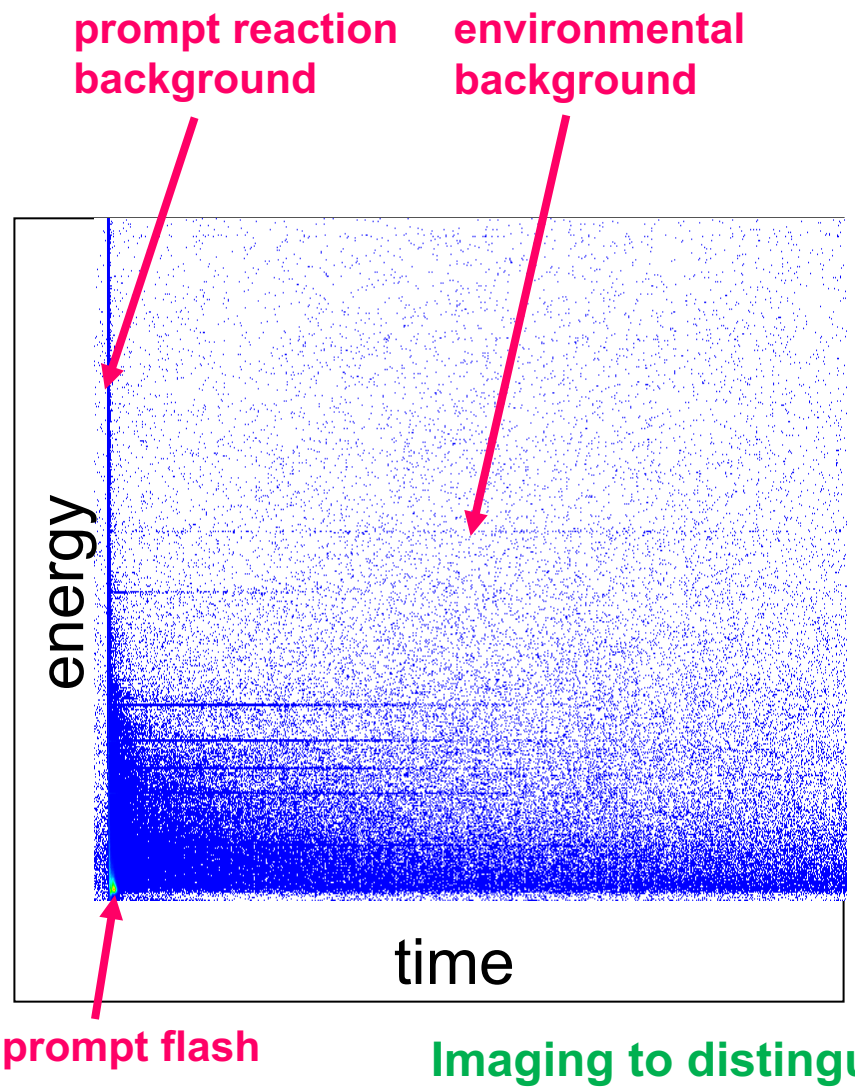
^{88}Zr E_γ - t_γ correlation

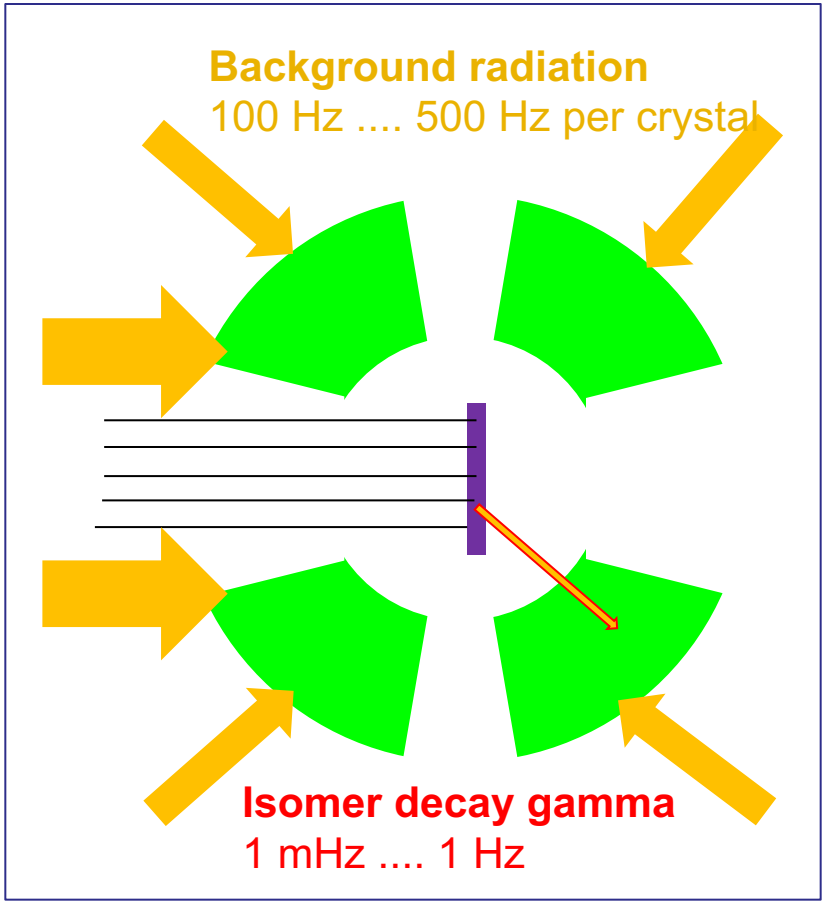


^{88}Zr



Challenge: background suppression

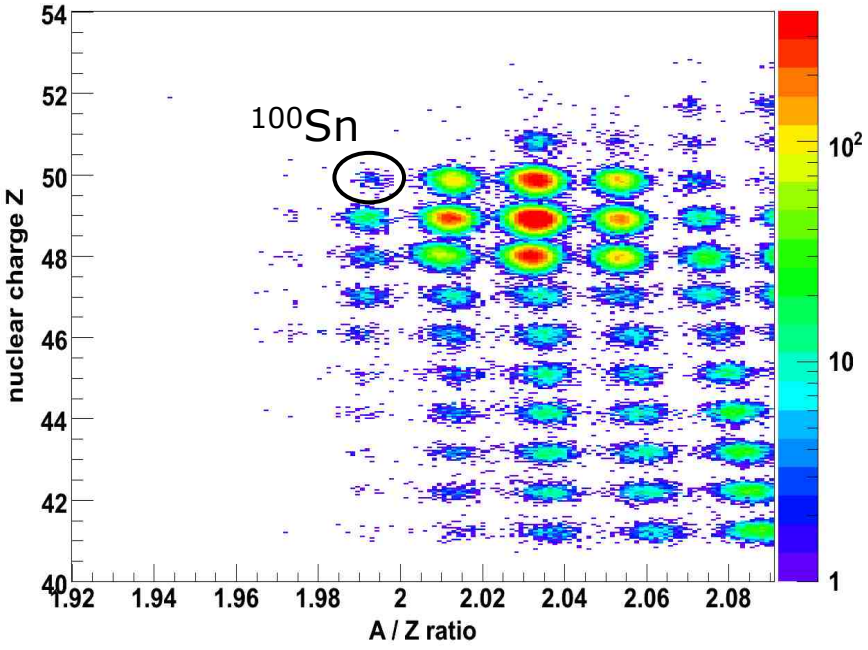




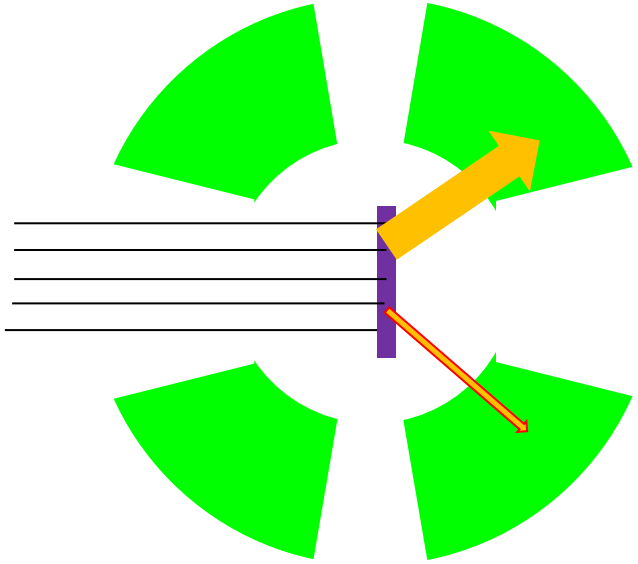
Imaging to distinguish isomeric from environmental γ rays

Challenge: background suppression

background from unwanted isotopes



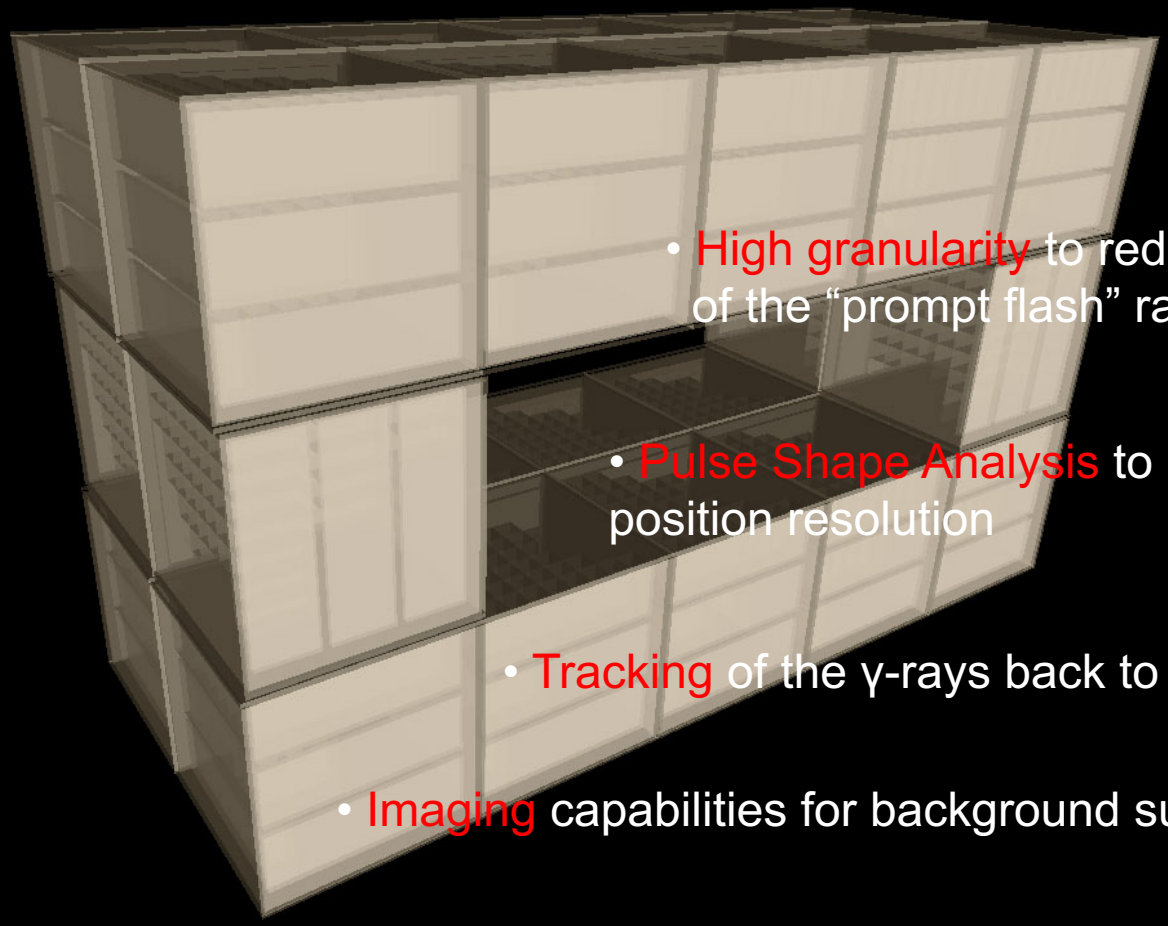
Implantation rate
0.1 kHz .... 50 kHz



weak decay channel
1 mHz .... 1 Hz

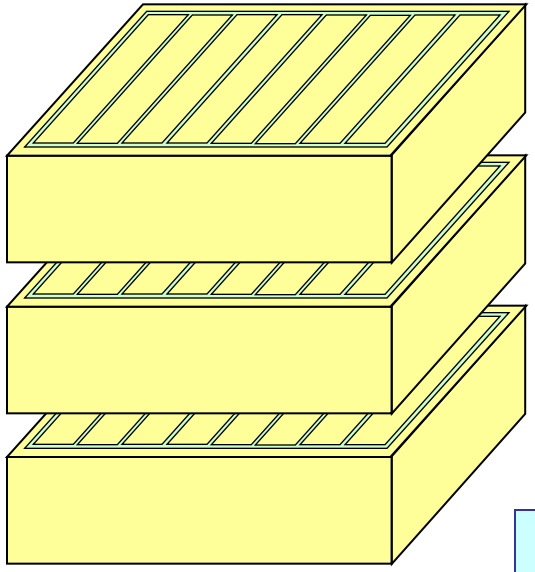
Imaging to localize the respective implantation points

DESPEC γ-tracking/imaging array



- High granularity to reduce the effect of the "prompt flash" radiation
- Pulse Shape Analysis to improve the position resolution
- Tracking of the γ-rays back to the origin
- Imaging capabilities for background suppression
- Polarization sensitivity

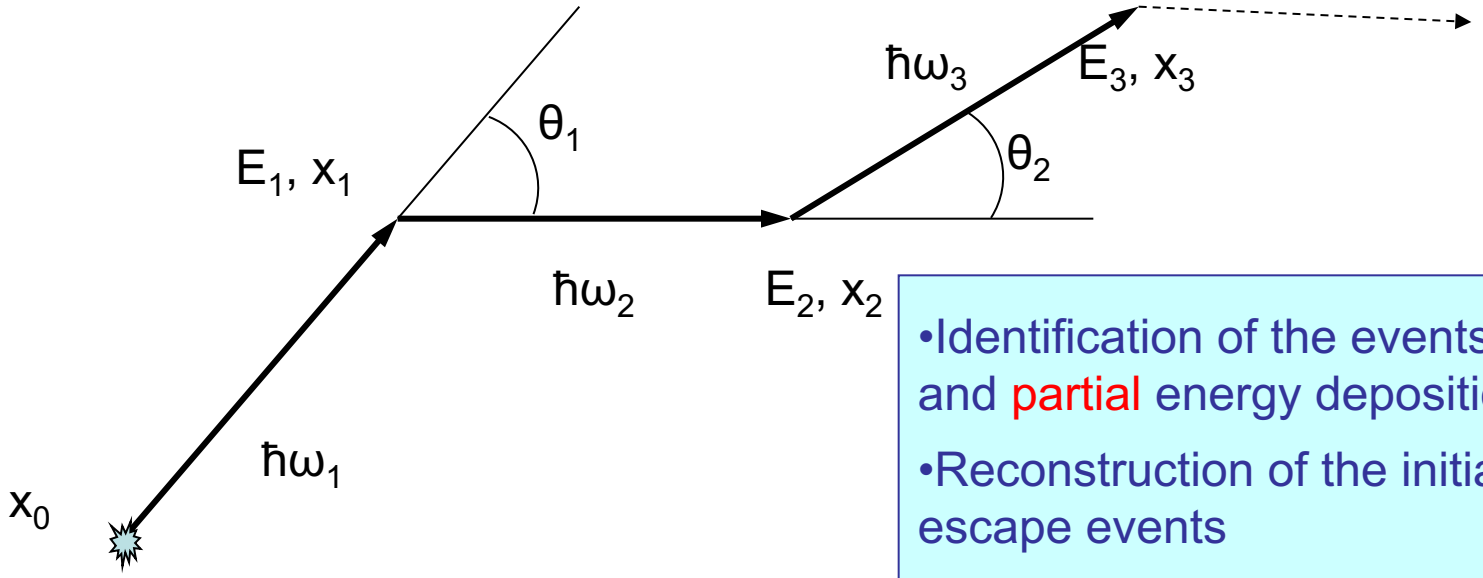
Early ideas for a detector module



- Stack of 3 planar 2D stripe Ge detectors
- $68mm^2$ x $68mm^2$ x $20mm^2$ + 2mm guard ring
- 6mm gap between crystals
- 8x8 segmentation
- 1 – 3 mm 3D position resolution with PSA
- Energy resolution: 0.2%

- Increase of correlation time range between implantation and decay for isomers
- Distinction of gamma events from background sources
- localization of implantation point
- Suppression of Compton escape background (software anti-Compton shield)
- Increase of absolute efficiency by reconstruction of incomplete events

Tracking algorithm TANGO*



- Identification of the events with total and partial energy depositions
- Reconstruction of the initial energy for escape events
- Rejection of events from background sources

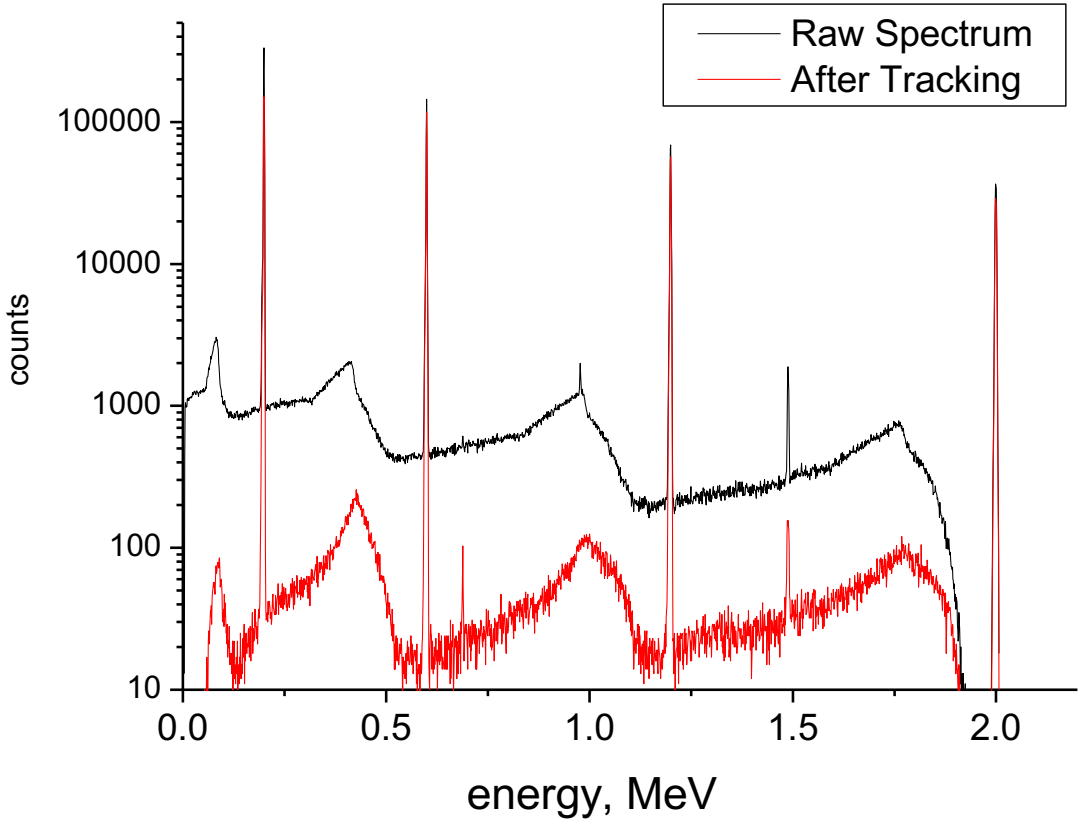
Construction of a "Figure of Merit"

- for each possible order of interactions
- for the case of total and partial energy deposition
- probing the origin of the γ ray

Selecting the case with the maximum Figure of Merit

*S. Tashenov, J. Gerl, NIM A622 (2010) 592

Results of tracking:
events, identified as total energy deposition

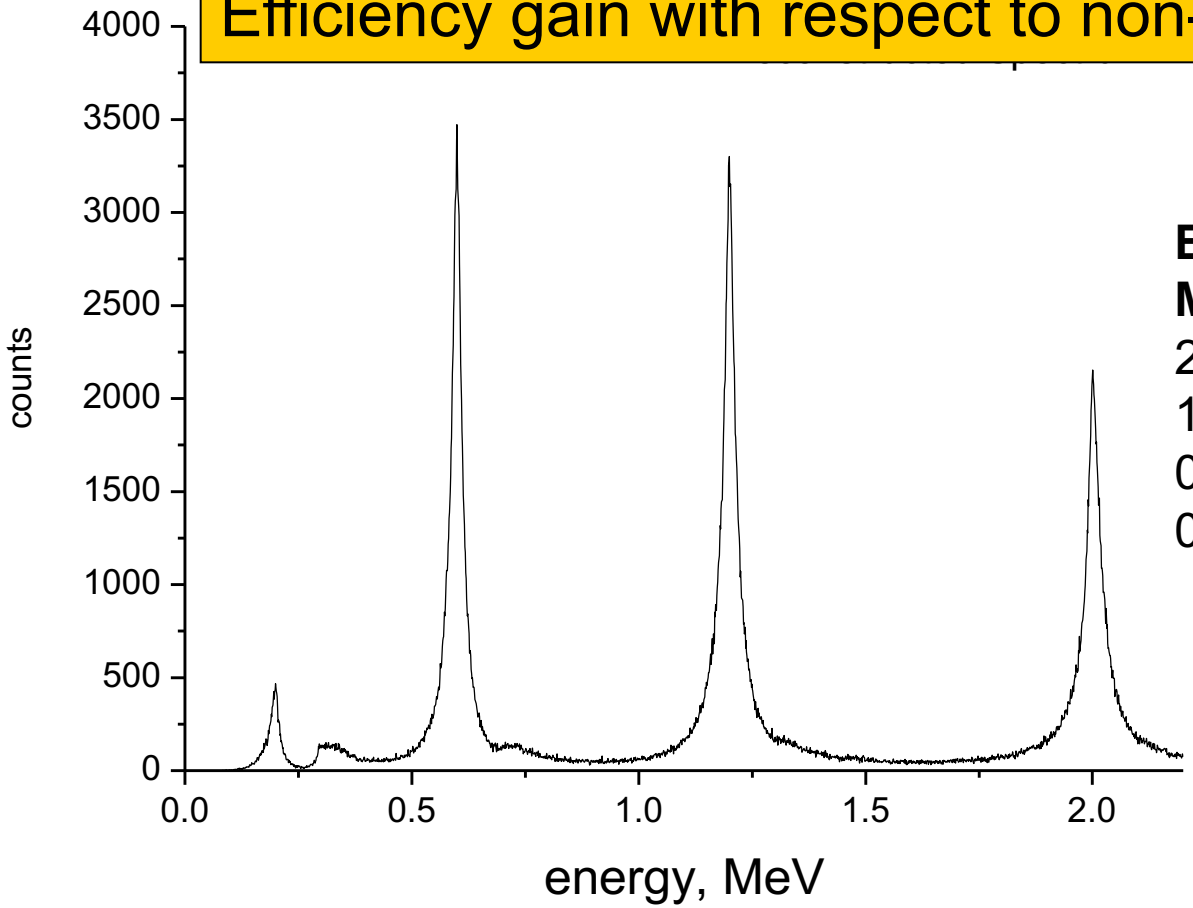


Energy MeV	Tracking Efficiency	Compton Background Suppression
2	0.79	7.5
1.2	0.81	13
0.6	0.82	13
0.2	0.51	57

GEANT4 simulation

Results of tracking: events, identified as partial energy deposition (escapes)

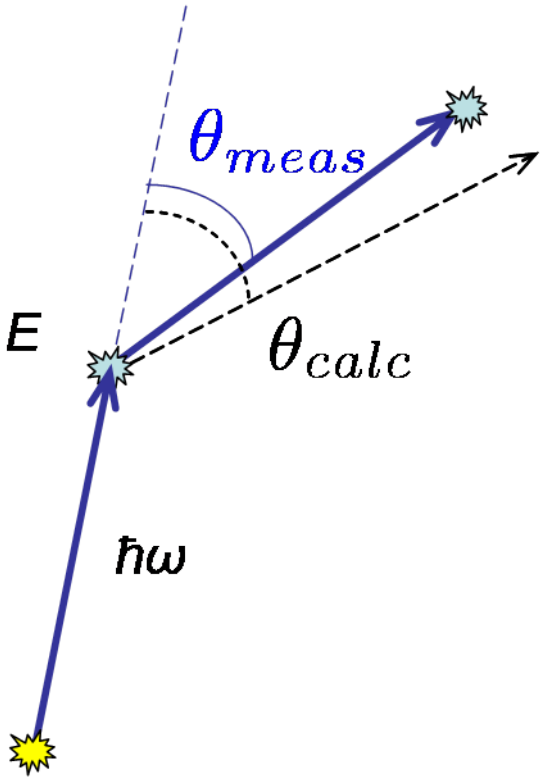
Efficiency gain with respect to non-tracking detectors

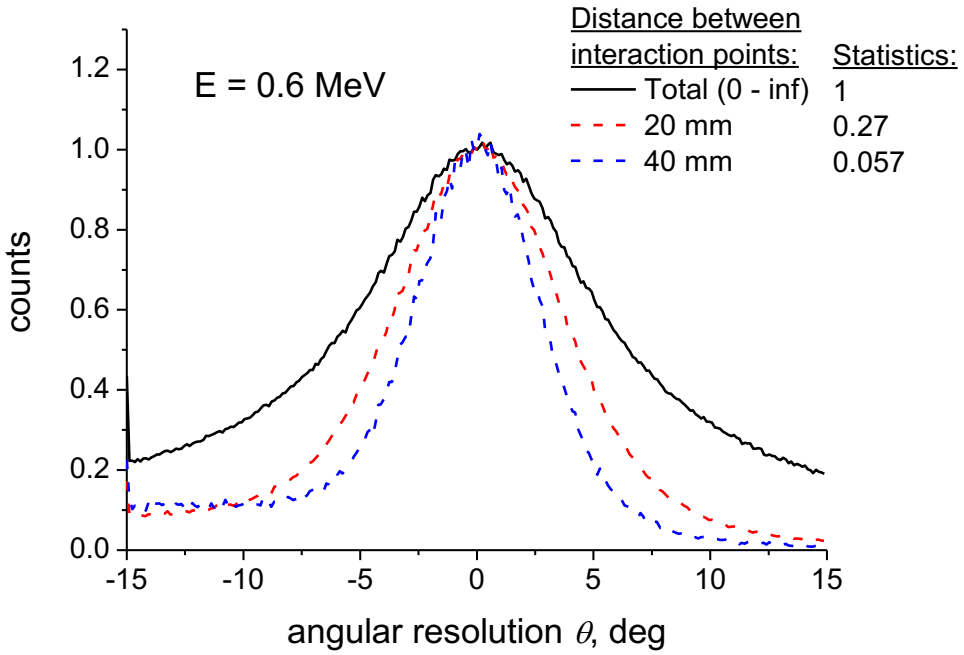


Energy MeV	Tracking Efficiency (escape)	Tracking Efficiency (total)
2	0.7	1.5
1.2	0.65	1.5
0.6	0.35	1.2
0.2	0.02	0.5

Energy Resolution:
FWHM: ~1.5%
Lorentzian Profile

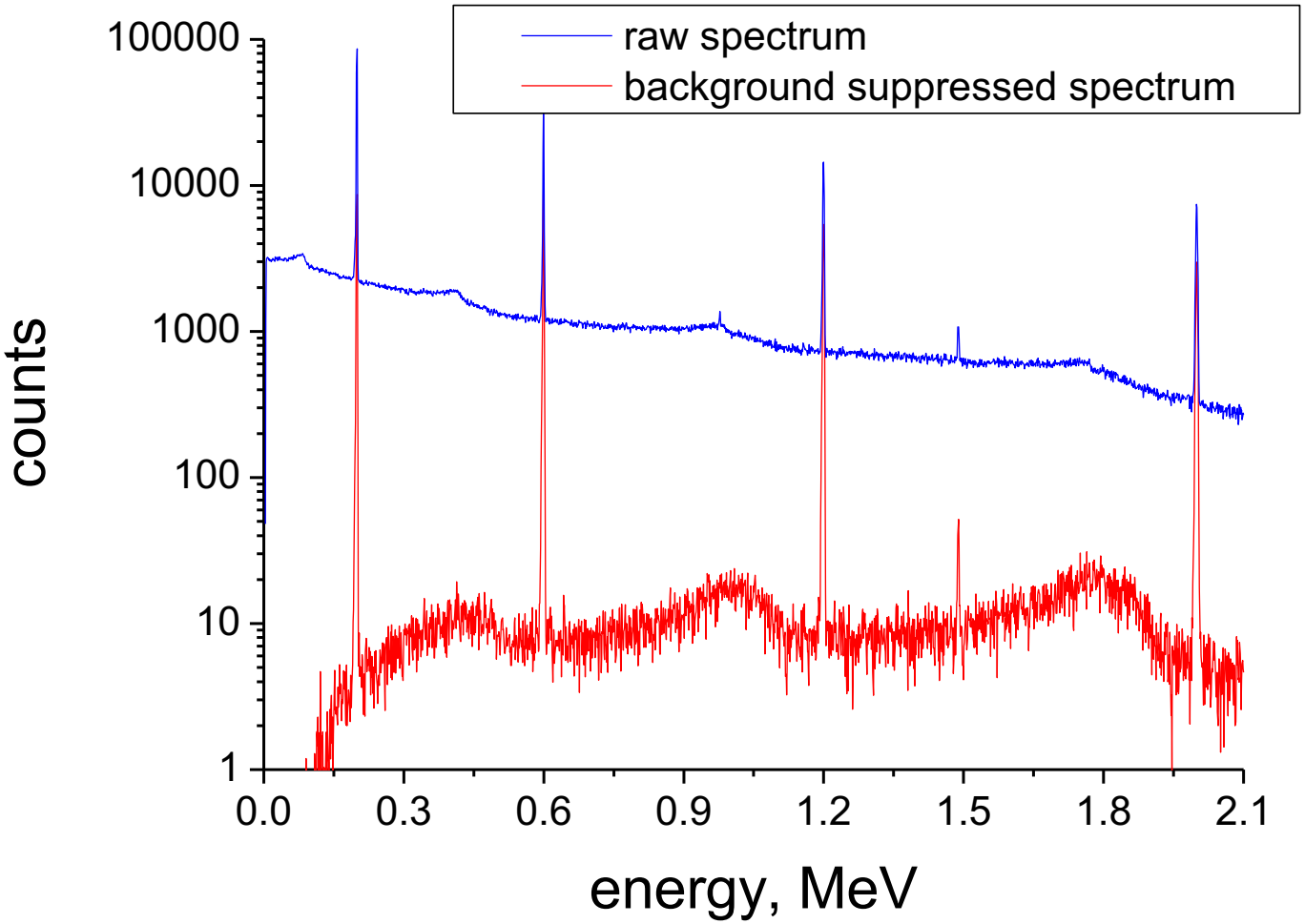
Background suppression via Imaging





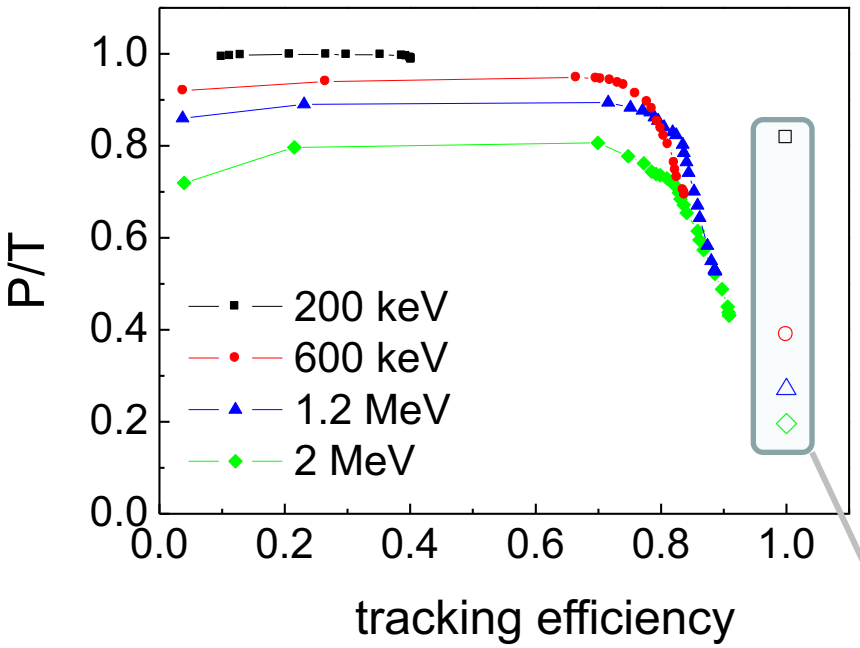
$$\Delta\theta = \theta_{meas} - \theta_{calc}$$

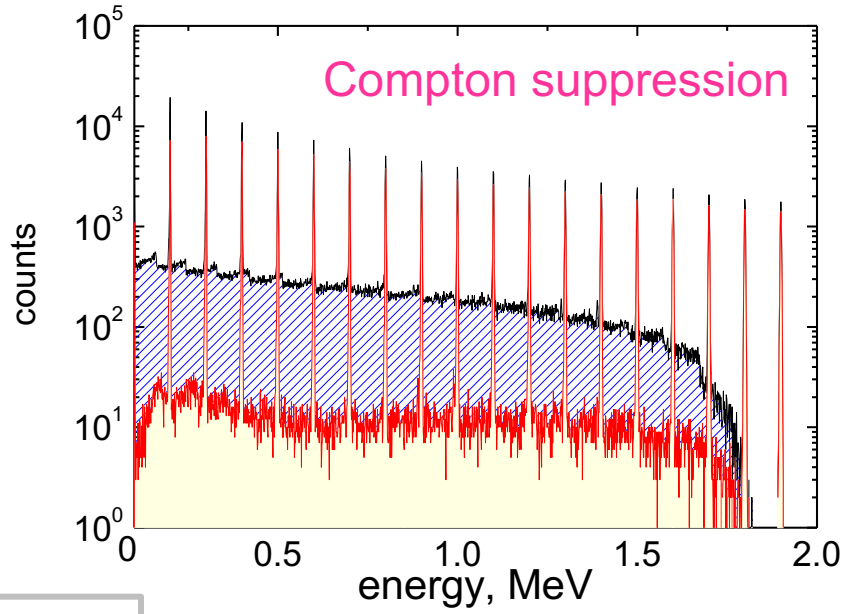
Environmental background suppression



"Ideal" (100% efficient) tracking was assumed for simulations

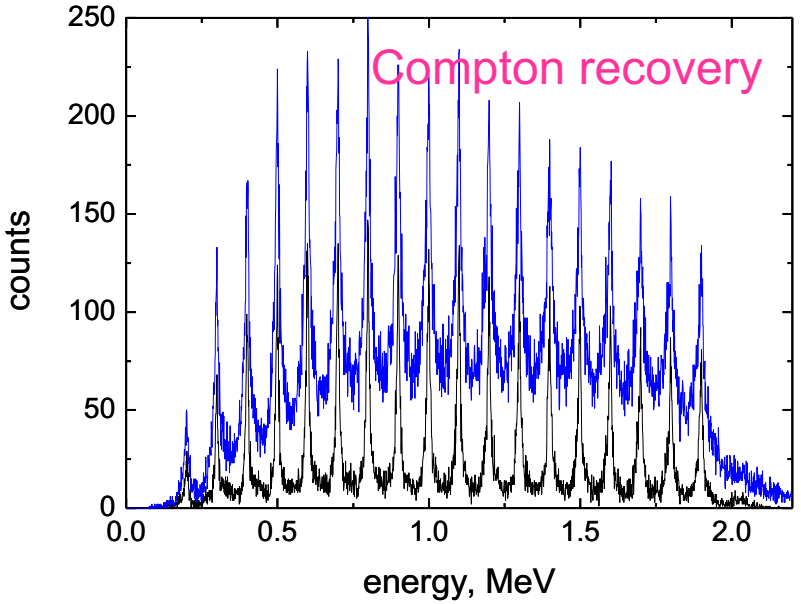
Tracking performance (@ 1mm res.)



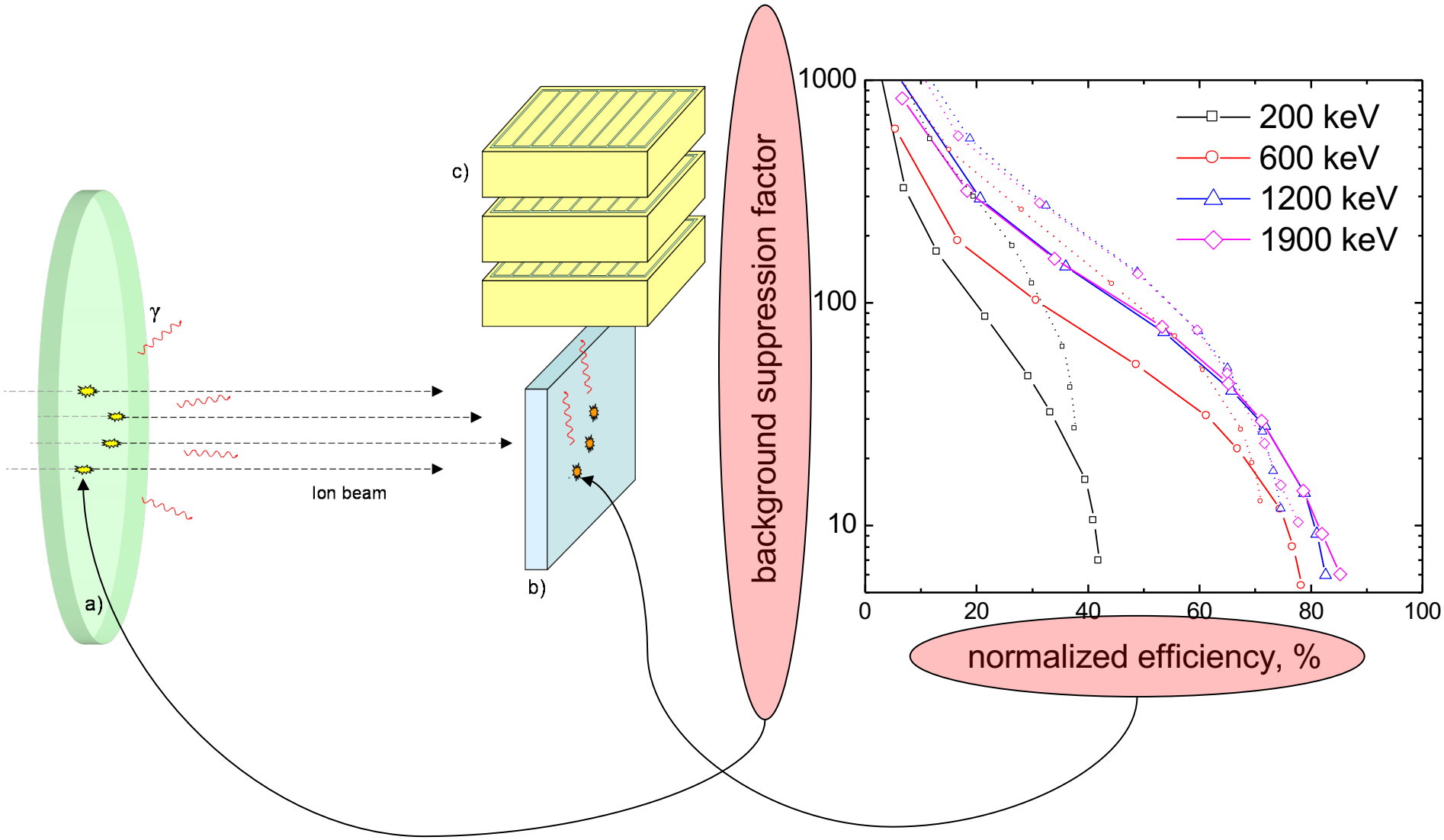


Energy	**normalized** tracking efficiency		
MeV	full-energy	escapes	total
0.2	0.4	0.02	0.42
0.6	0.75	0.35	1.1
1.2	0.8	0.65	1.45
2	0.8	0.7	1.5

!!!



Background suppression by γ imaging



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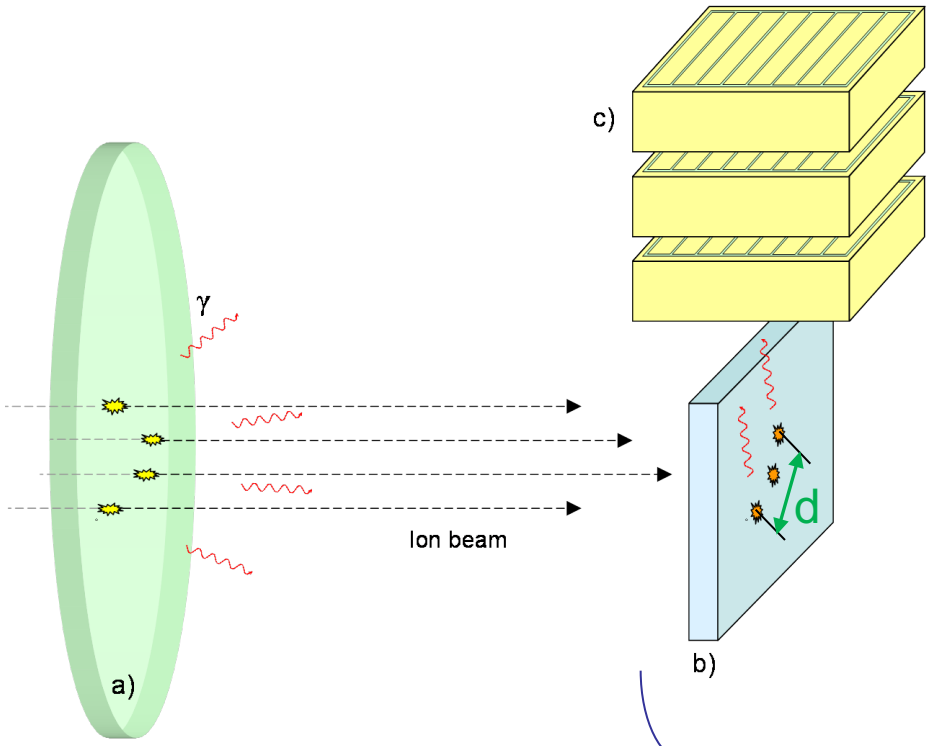

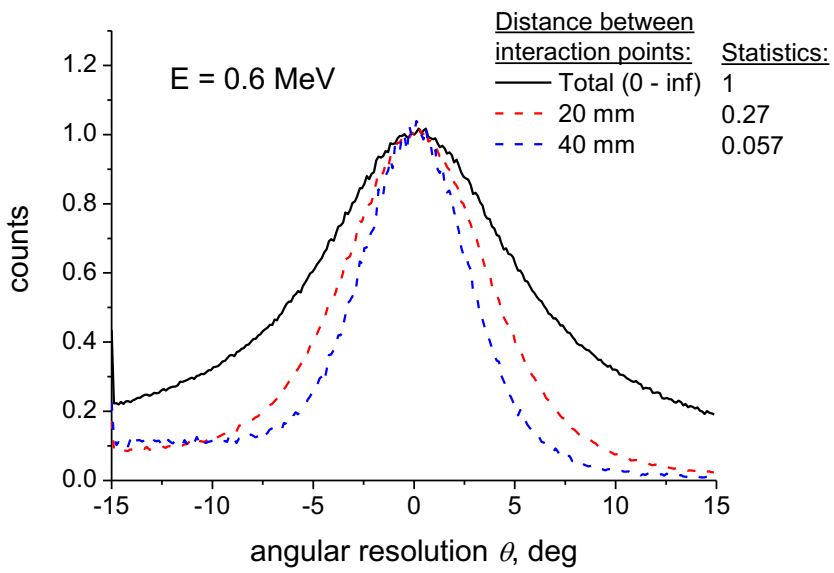

d ≈ 1-2 cm

Conclusion

- γ tracking/imaging is essential to reduce the huge background in rare decay experiments
- Environmental background reduction of up to three orders of magnitude seems possible
- The attainable angular resolution may enable distinction of decaying nuclei 1-2 cm apart of each other
- Efficient γ detector set-up need to be developed