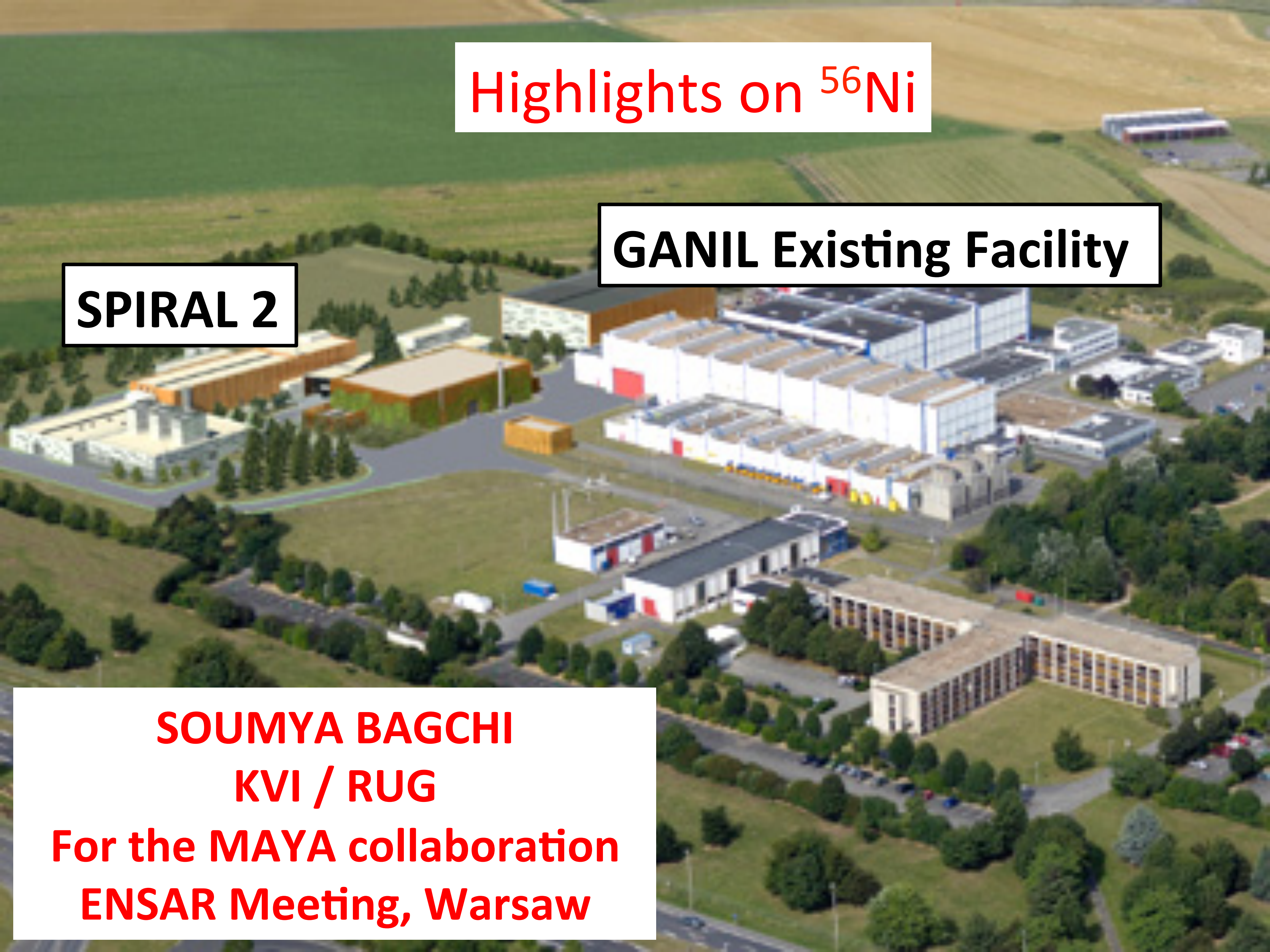
Highlights on ^{56}Ni



SOUMYA BAGCHI
KVI / RUG
For the MAYA collaboration
ENSAR Meeting, Warsaw

Outline:

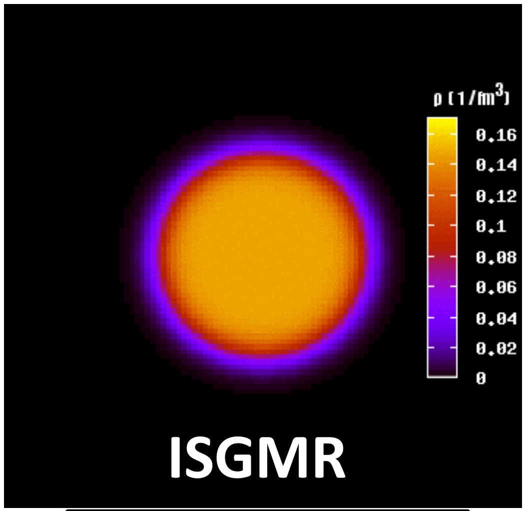
- Introduction to Giant Resonances
- Importance of compression modes in nuclei
- Experimental Setup (MAYA)
- Results
- Hint for alpha clustering (H. Akimune)
- Summary and outlook

Giant Resonances:

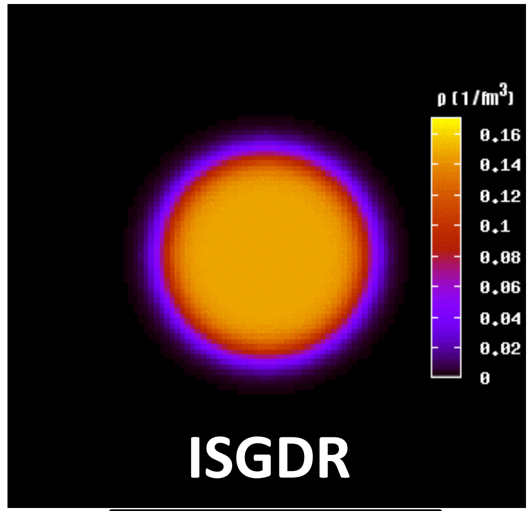
Collective oscillations of all neutrons and all protons in a nucleus

- In phase (Iso-Scalar)

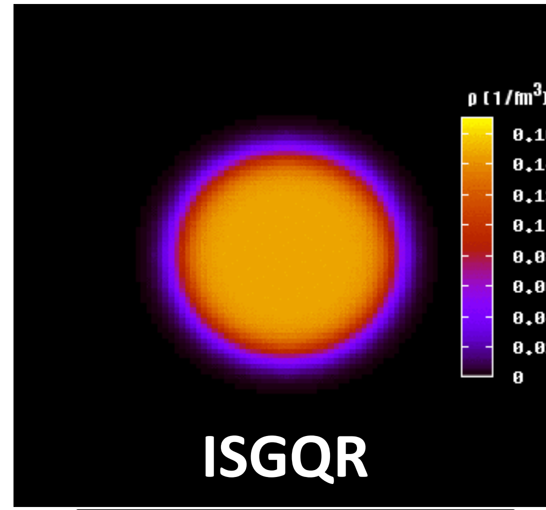
M. Itoh



Monopole, L = 0

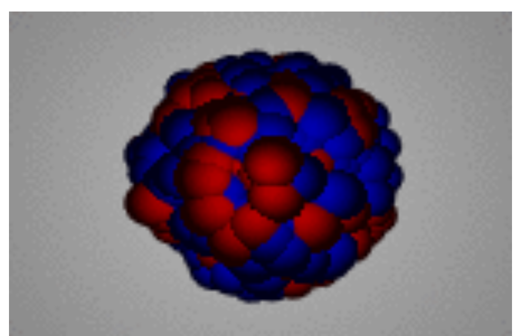


Dipole, L = 1



Quadrupole, L = 2

- Out of phase (Iso-Vector)



IVGDR

Macroscopic & Microscopic Structure

Giant resonances (collective modes)

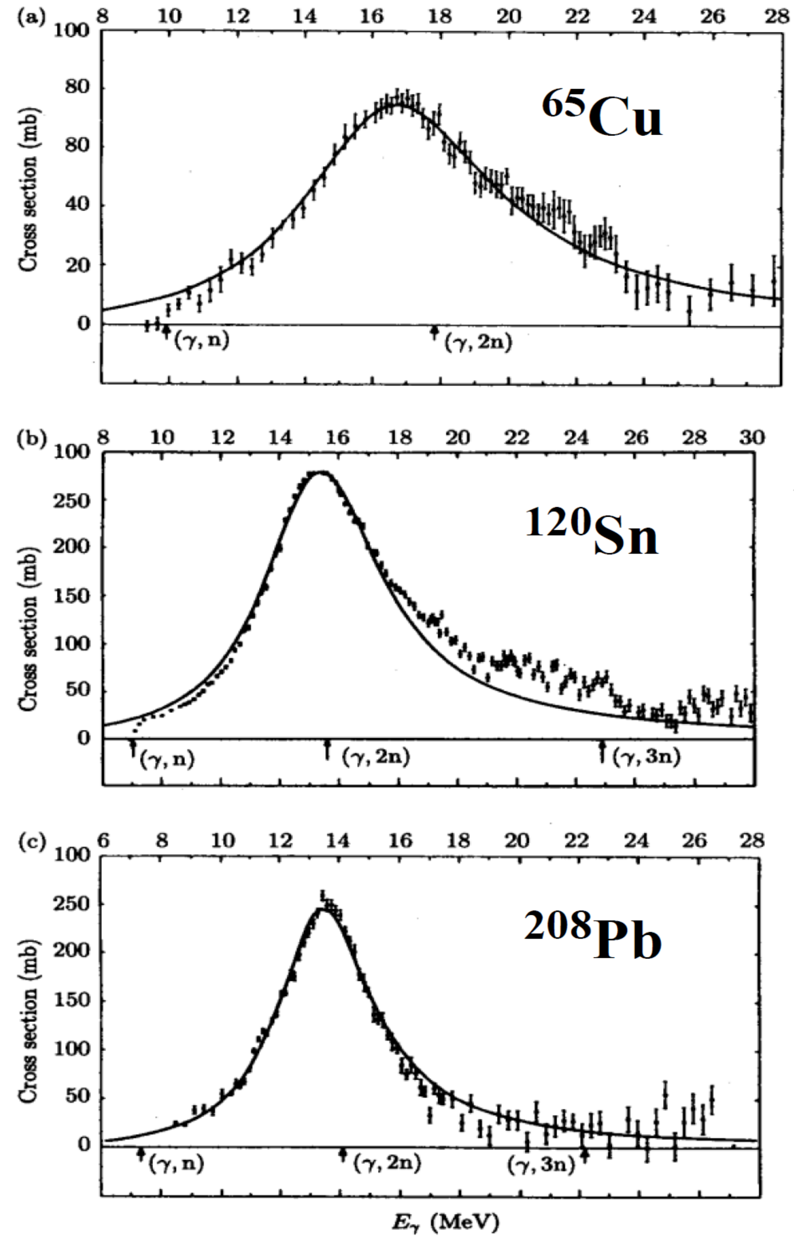
→ Width and Excitation energy

→ Coherent superposition of

1p-1h excitation

(Figure depicts IVGDR, obtained by gamma absorption in these nuclei)

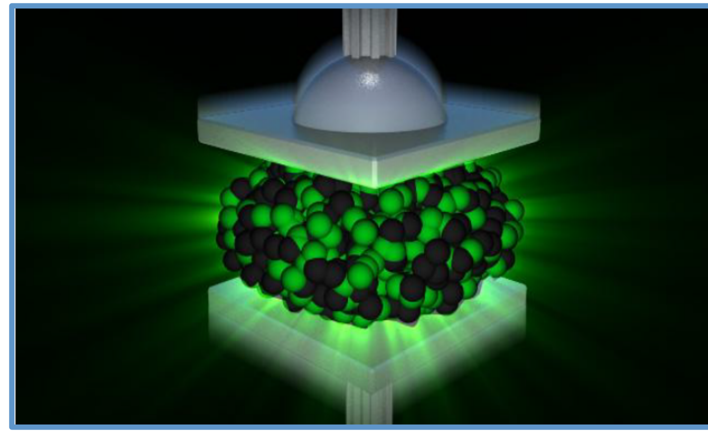
Berman and Fultz, Rev. Mod. Phys. 47 (1975)



Nuclear Incompressibility

Incompressibility → Measure of the resistance of matter to uniform compression

$$K = -V\frac{\partial P}{\partial V}$$



Adapted from M. N. Harakeh

ISGMR (T=0, L=0)

$$E_{ISGMR} = \hbar\sqrt{\frac{K_A}{m\langle r^2\rangle}}$$

ISGDR (T=0, L=1)

$$E_{ISGDR} = \hbar\sqrt{\frac{7}{3}\frac{K_A + \frac{27}{25}\varepsilon_F}{m\langle r^2\rangle}}$$

Nuclear Incompressibility

$$K_A = K_{vol} + K_{surf} A^{-1/3} + K_\tau((N-Z)/A)^2 + K_{Coul} Z^2 A^{-4/3}$$

EoS is important for studying:

- Core collapse and explosion of supernovae
- Formation of neutron stars
- Collisions of heavy ions

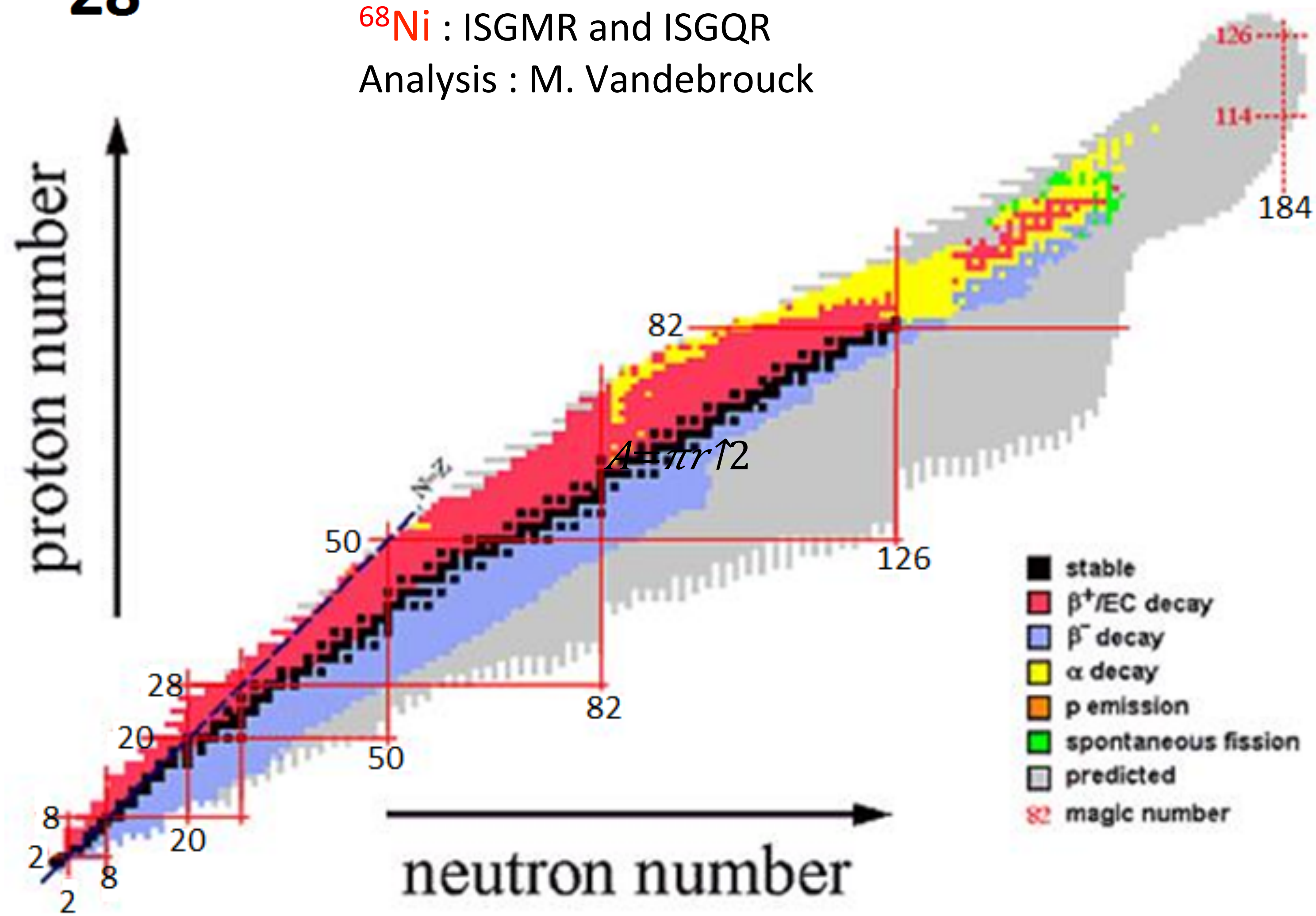
Why Ni ?

- Incompressibility value obtained for
  - Pb isotopes 240 ± 10 MeV
  - Sn and Cd isotopes 210 – 215 MeV
- Question : Why Sn and Cd are softer than Pb?
- Need of study of incompressibility for a series of isotopes of a nucleus

$^{56}_{28}Ni_{28}$

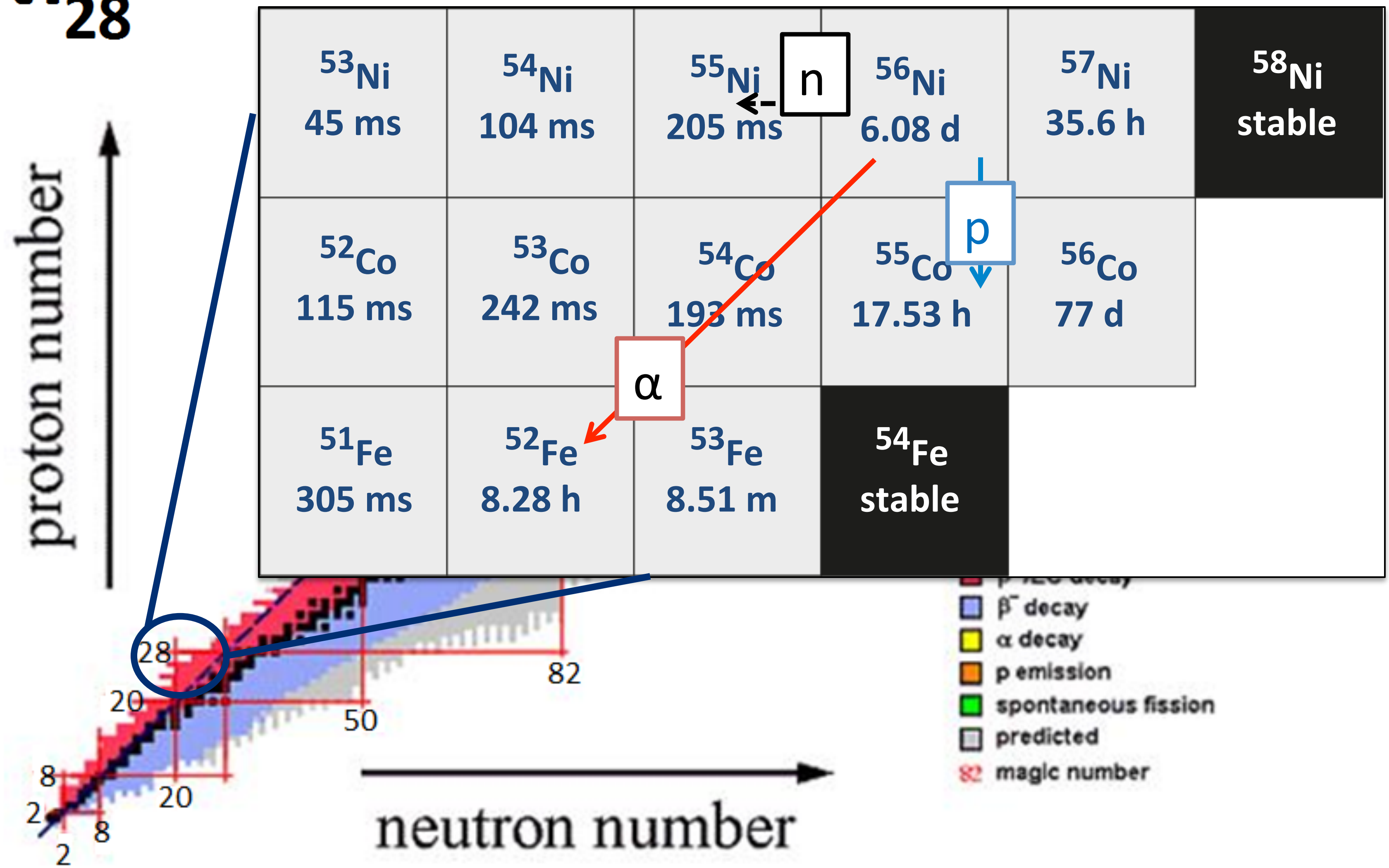
^{56}Ni : ISGMR and ISGQR
C. Monrozeau et al. , PRL 100, 042501 (2008)

^{68}Ni : ISGMR and ISGQR
Analysis : M. Vandebrouck



$$K_A = K_{vol} + K_{surf} A^{-1/3} + K_{\tau}((N-Z)/A)^2 + K_{Coul} Z^2 A^{-4/3}$$

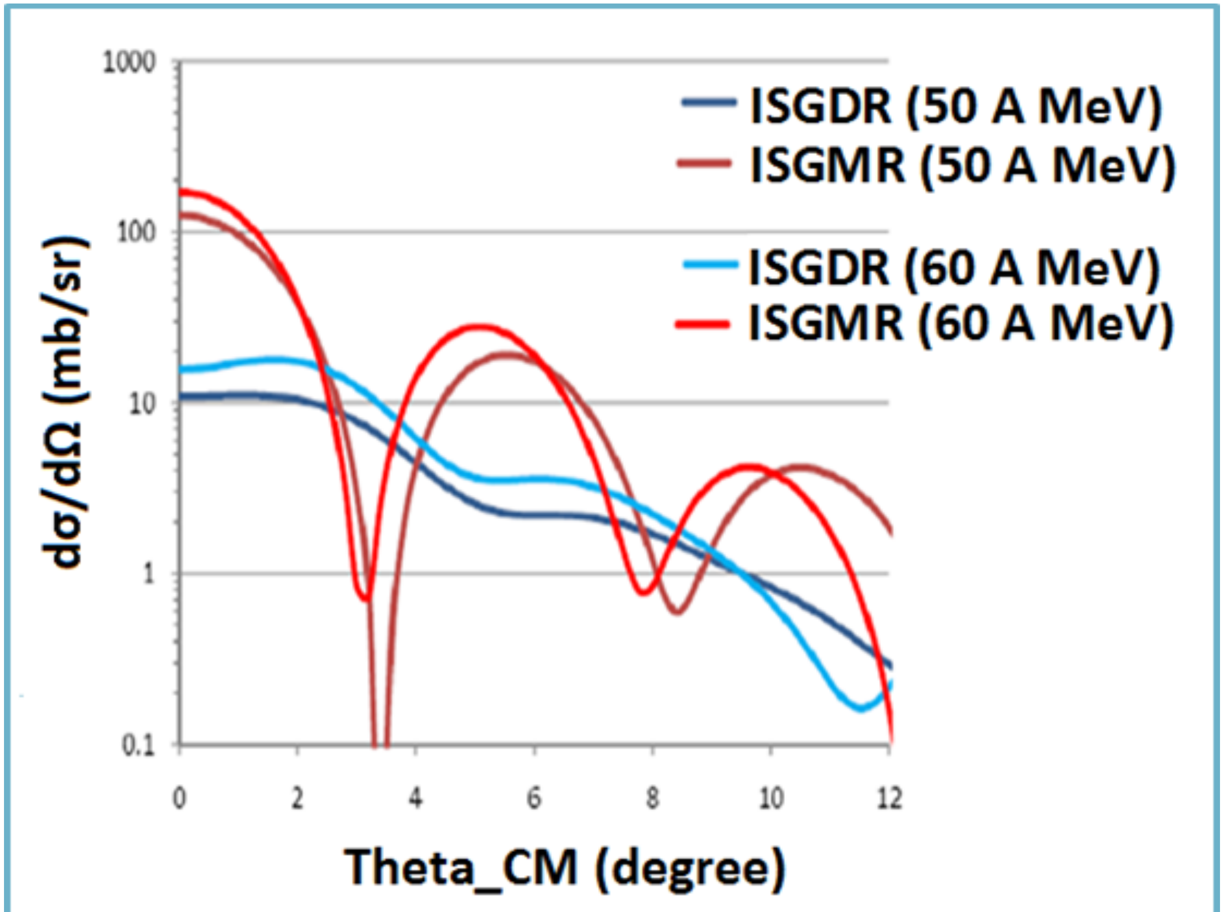
$^{56}_{28}Ni_{28}$



53Ni 45 ms
54Ni 104 ms
55Ni 205 ms
56Ni 6.08 d
57Ni 35.6 h
58Ni stable
52Co 115 ms
53Co 242 ms
54Co 193 ms
55Co 17.53 h
56Co 77 d
51Fe 305 ms
52Fe 8.28 h
53Fe 8.51 m
54Fe stable
n
p
α
proton number
neutron number
2
8
20
28
50
82
β⁻ decay
α decay
p emission
spontaneous fission
predicted
magic number

Angular Distribution of ISGMR and ISGDR

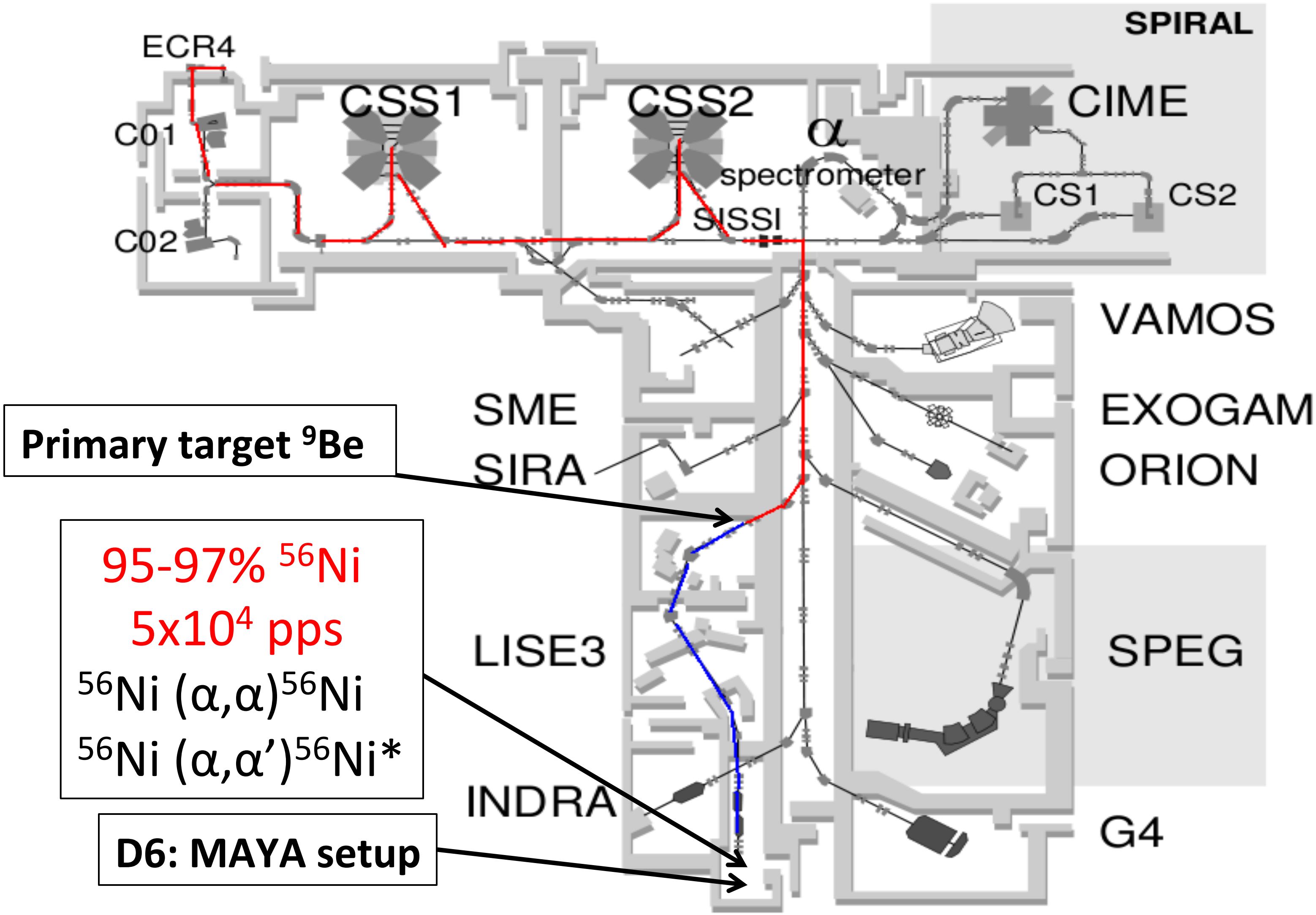
Differential cross-section in DWBA calculation for ^{56}Ni:



Primary Beam : ^{58}Ni at 75 MeV/u

Fragmentation method : Target ^{9}Be (thickness 500 μm)

Secondary Beam : ^{56}Ni at 50 MeV/u



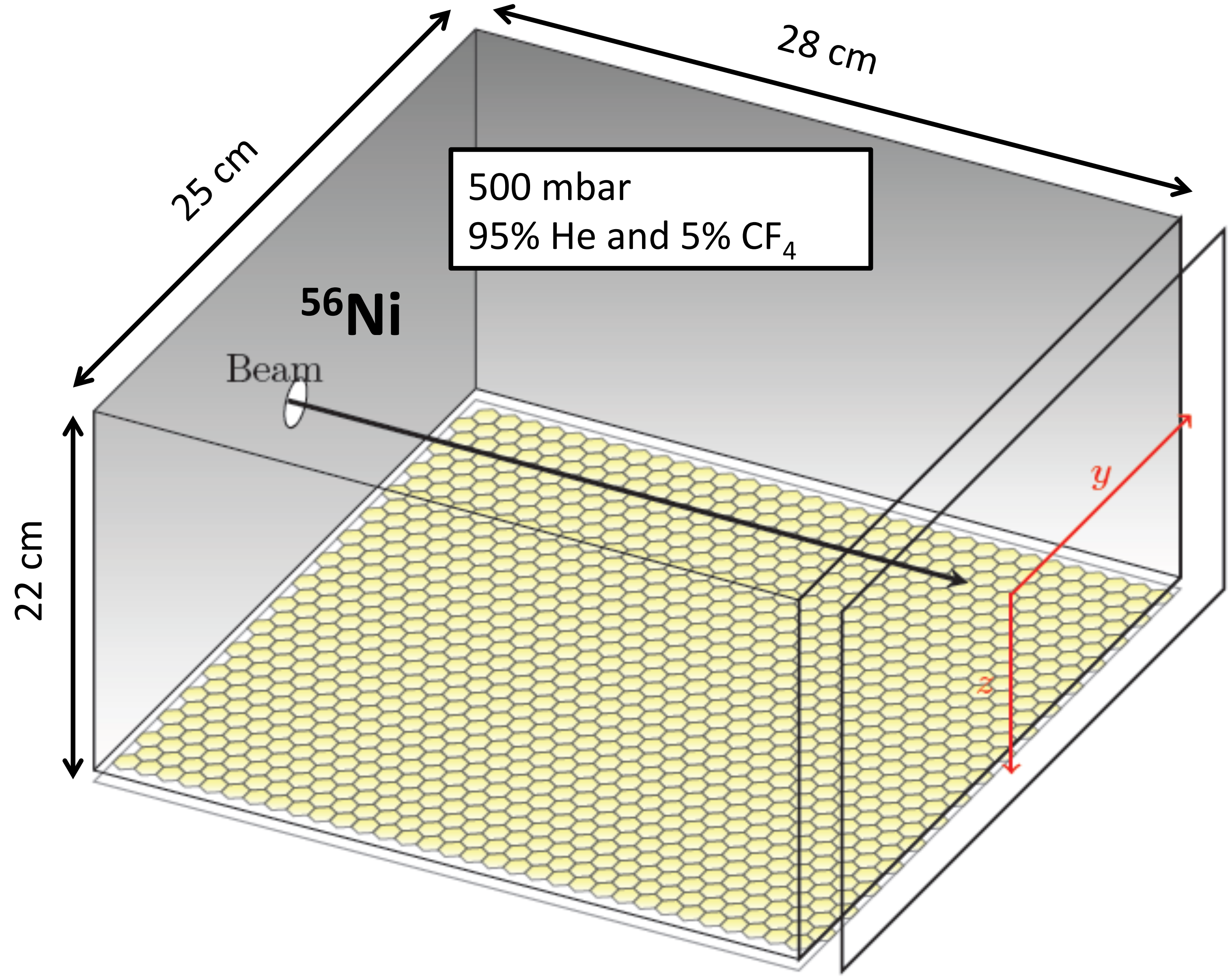
Challenges with exotic beams:

- Intensity of exotic beams is very low
- To get reasonable yields thick target is needed
- Very low energy (~ sub MeV) recoil particle will not come out of the target

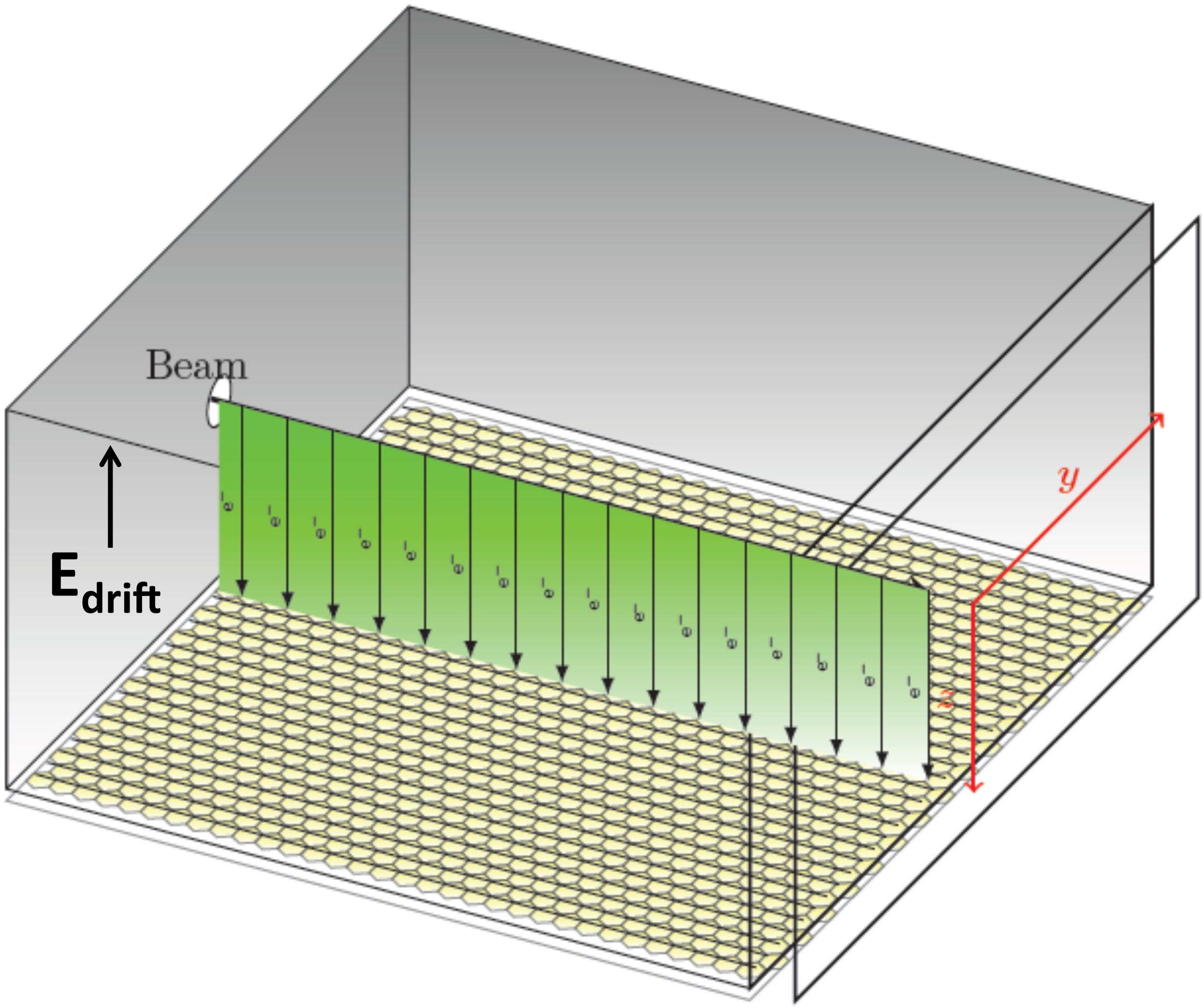
Active target: Detection takes place at every point of the target

- ➢ Good angular coverage
- ➢ Effective target thickness can be increased without much loss of resolution
- ➢ Detection of very low energy recoil particle is also possible

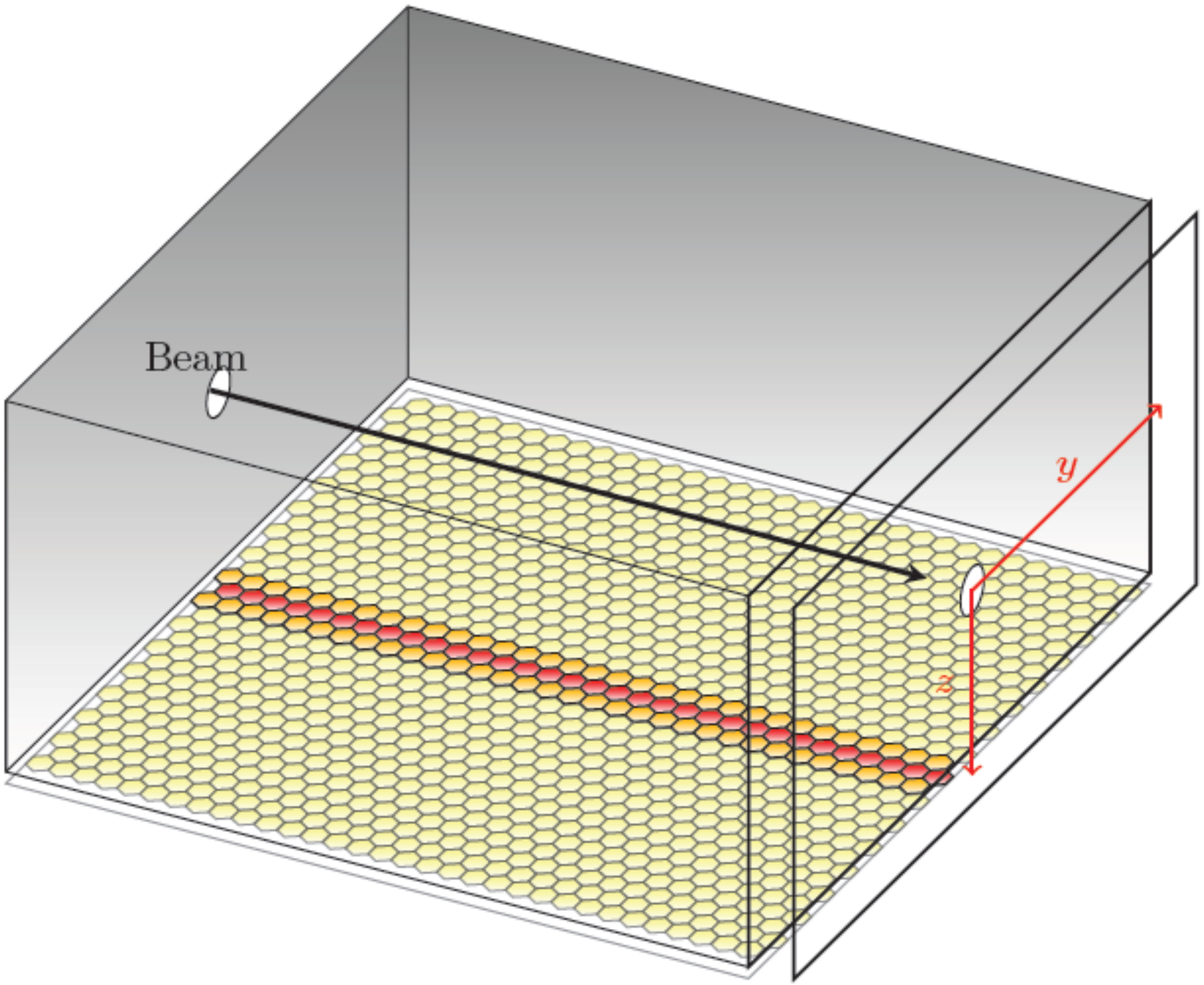
MAYA setup



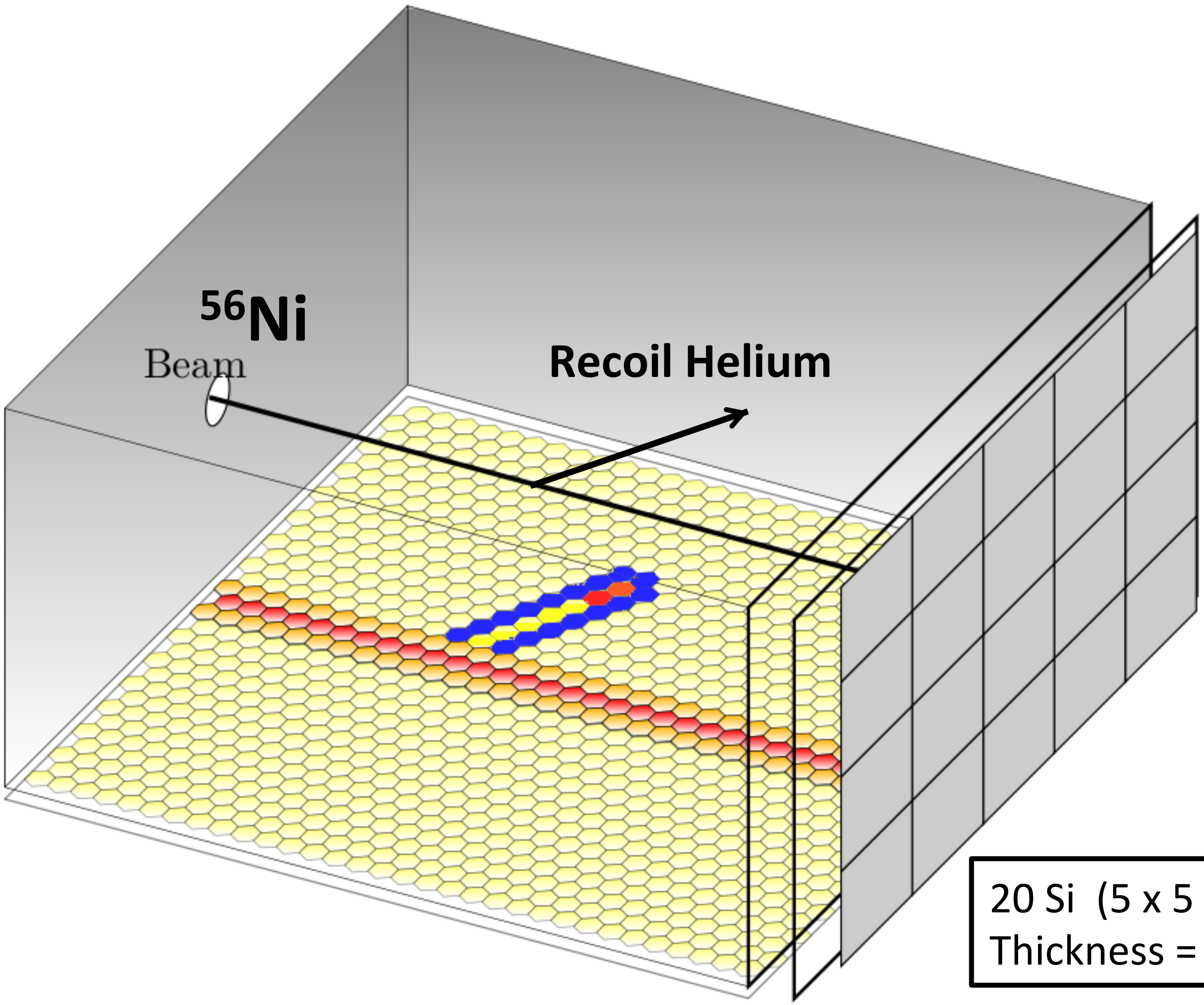
MAYA setup



MAYA setup

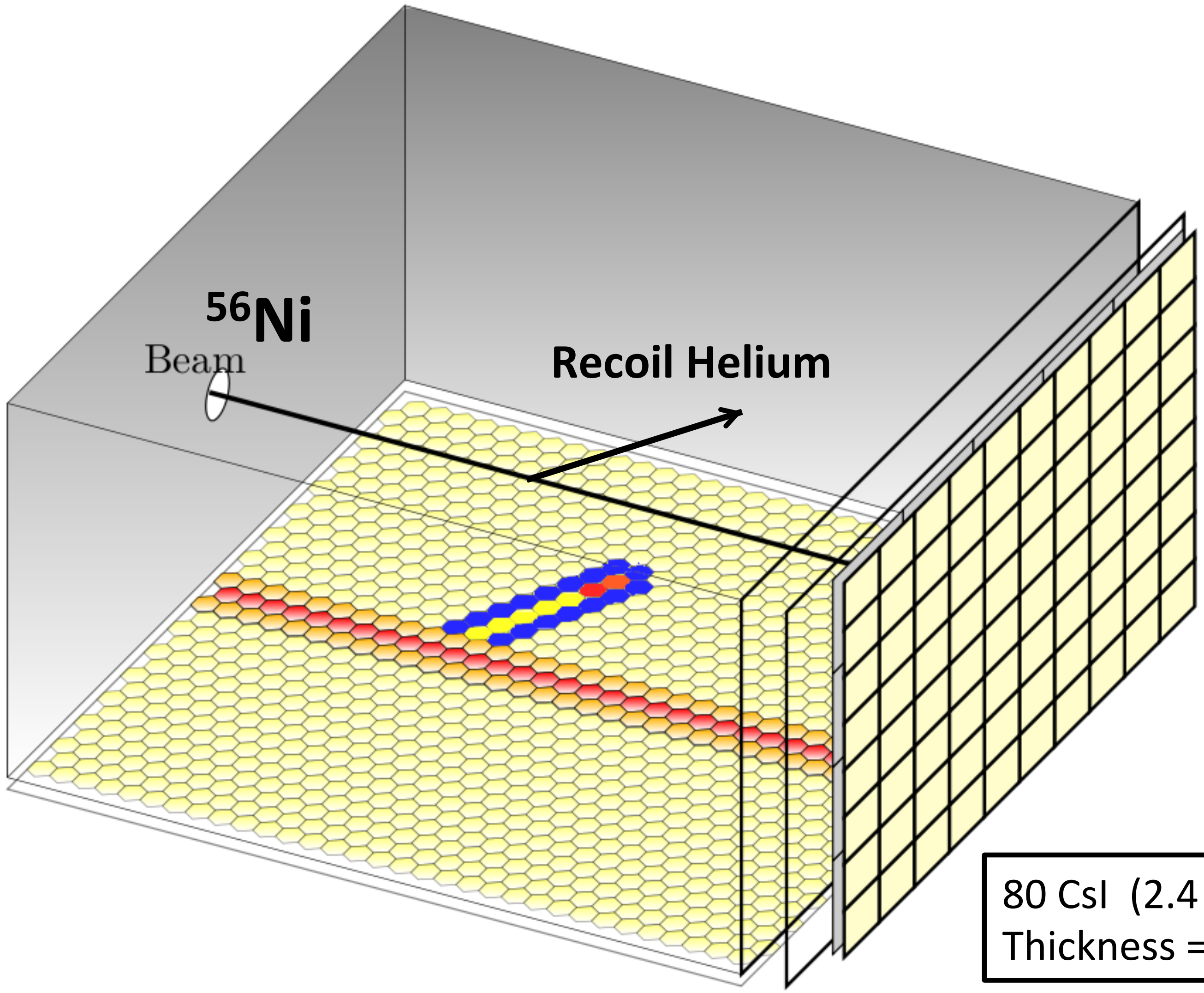


Si/CsI Telescope in MAYA



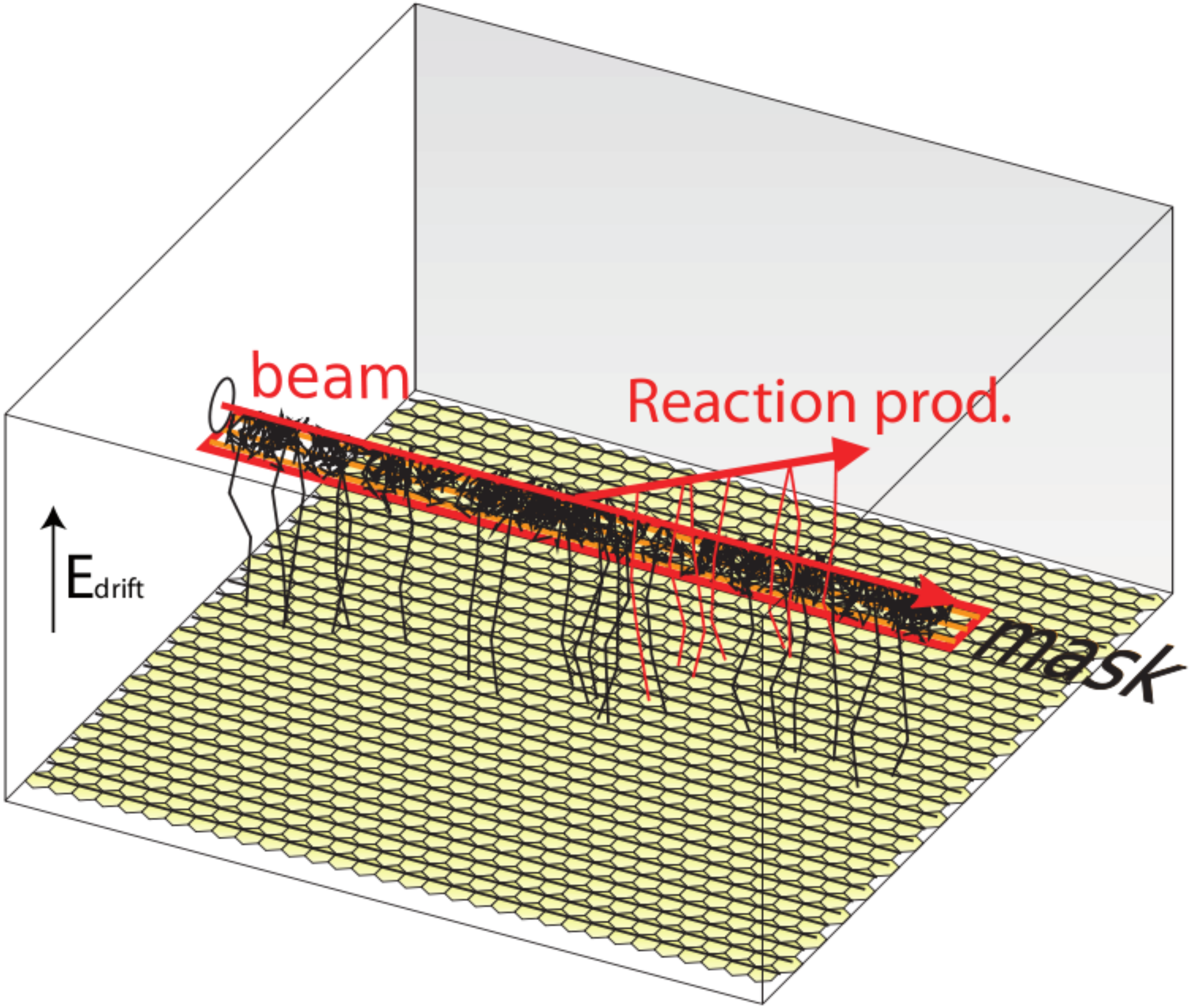
20 Si (5 x 5 cm^2)
Thickness = 700 µm

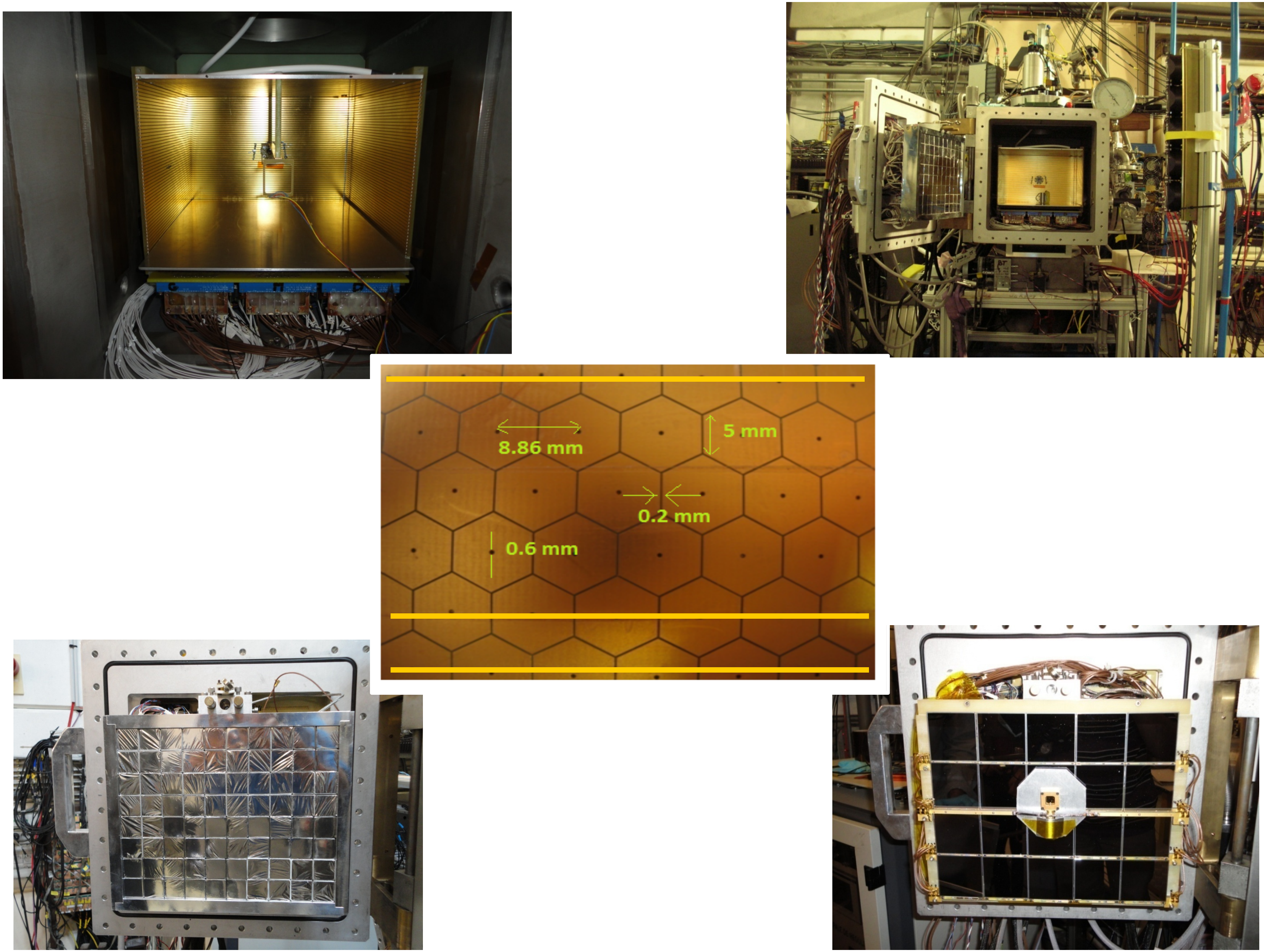
Si/CsI Telescope in MAYA



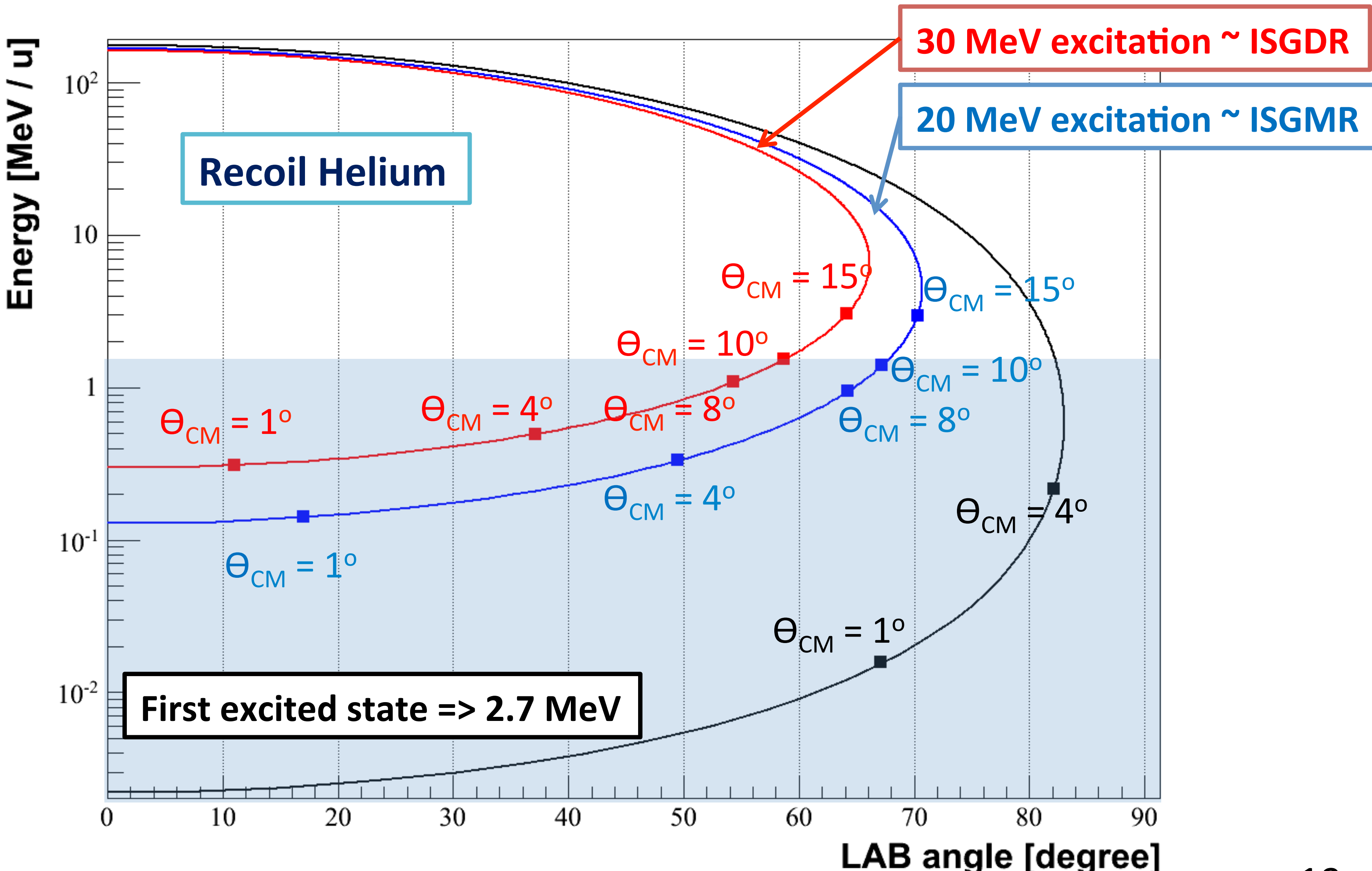
80 CsI (2.4 x 2.4 cm^2)
Thickness = 1.5 cm

Mask in MAYA

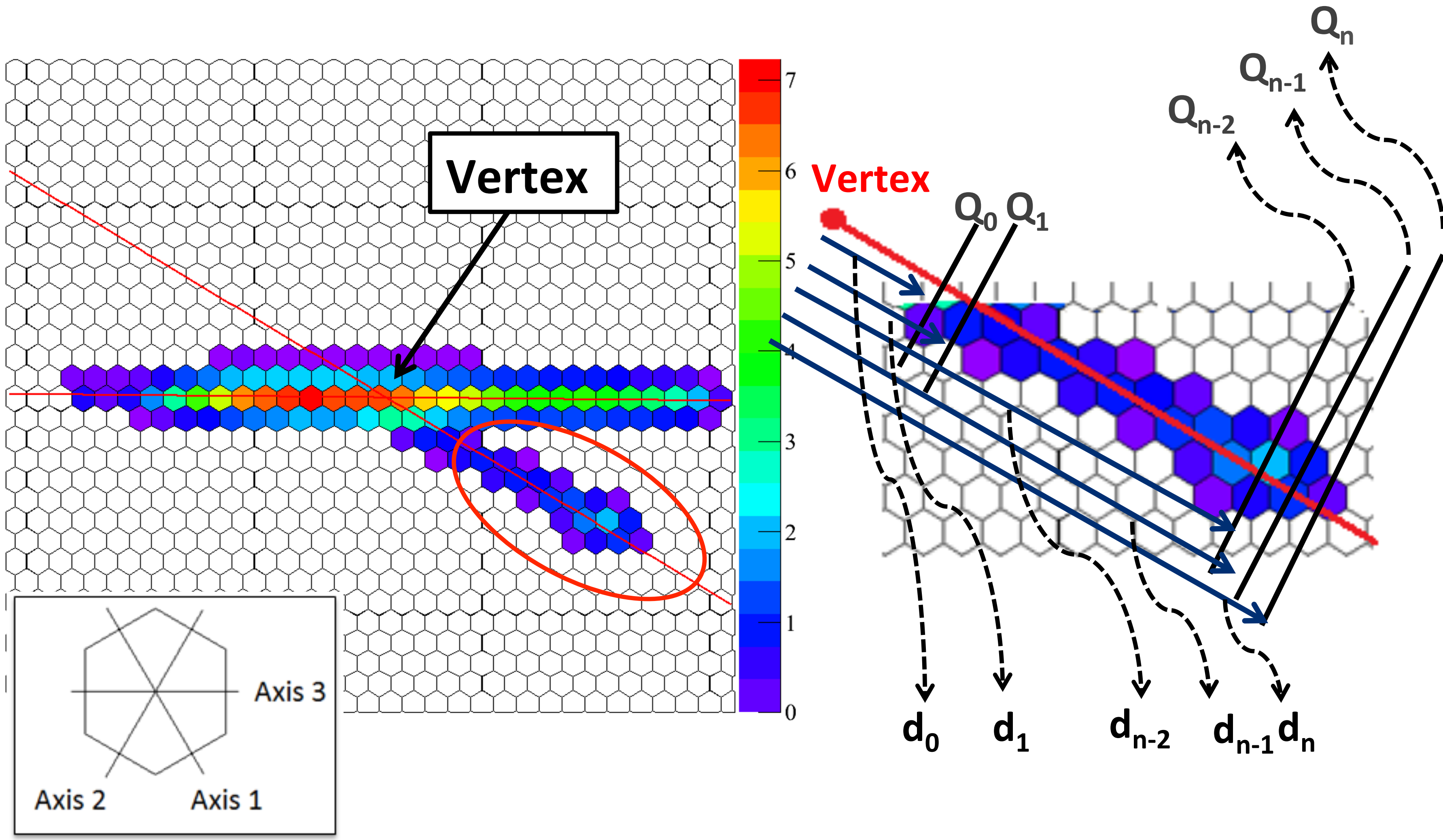



8.86 mm
5 mm
0.2 mm
0.6 mm

Kinematics curve for ^{56}Ni (α, α') ^{56}Ni* with ^{56}Ni at 50 MeV / u

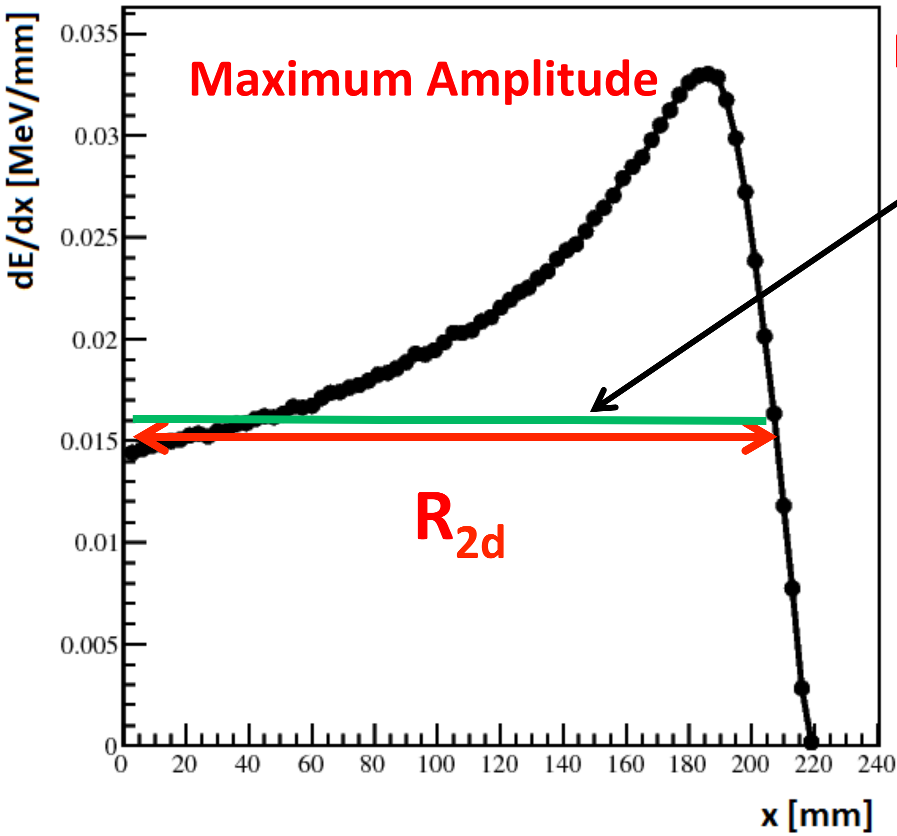


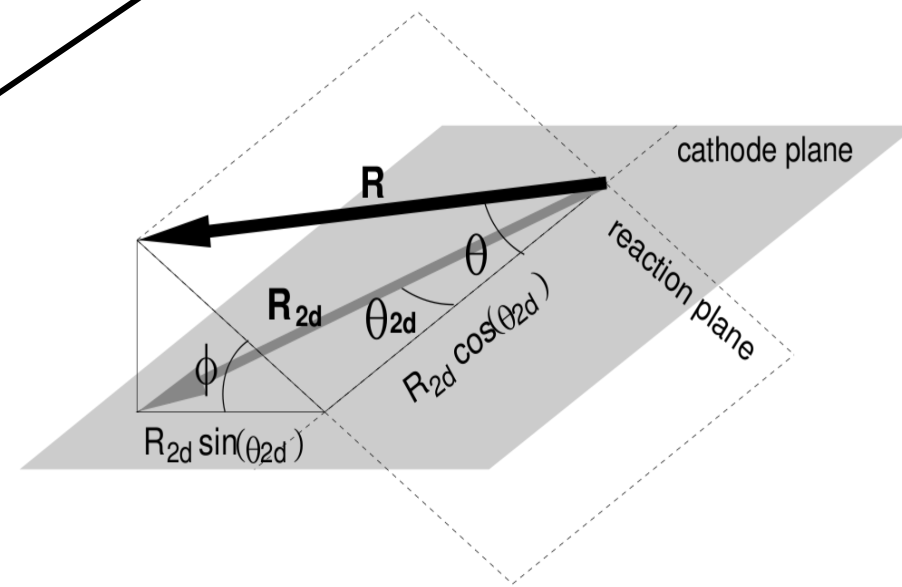
Kinematics reconstruction in MAYA



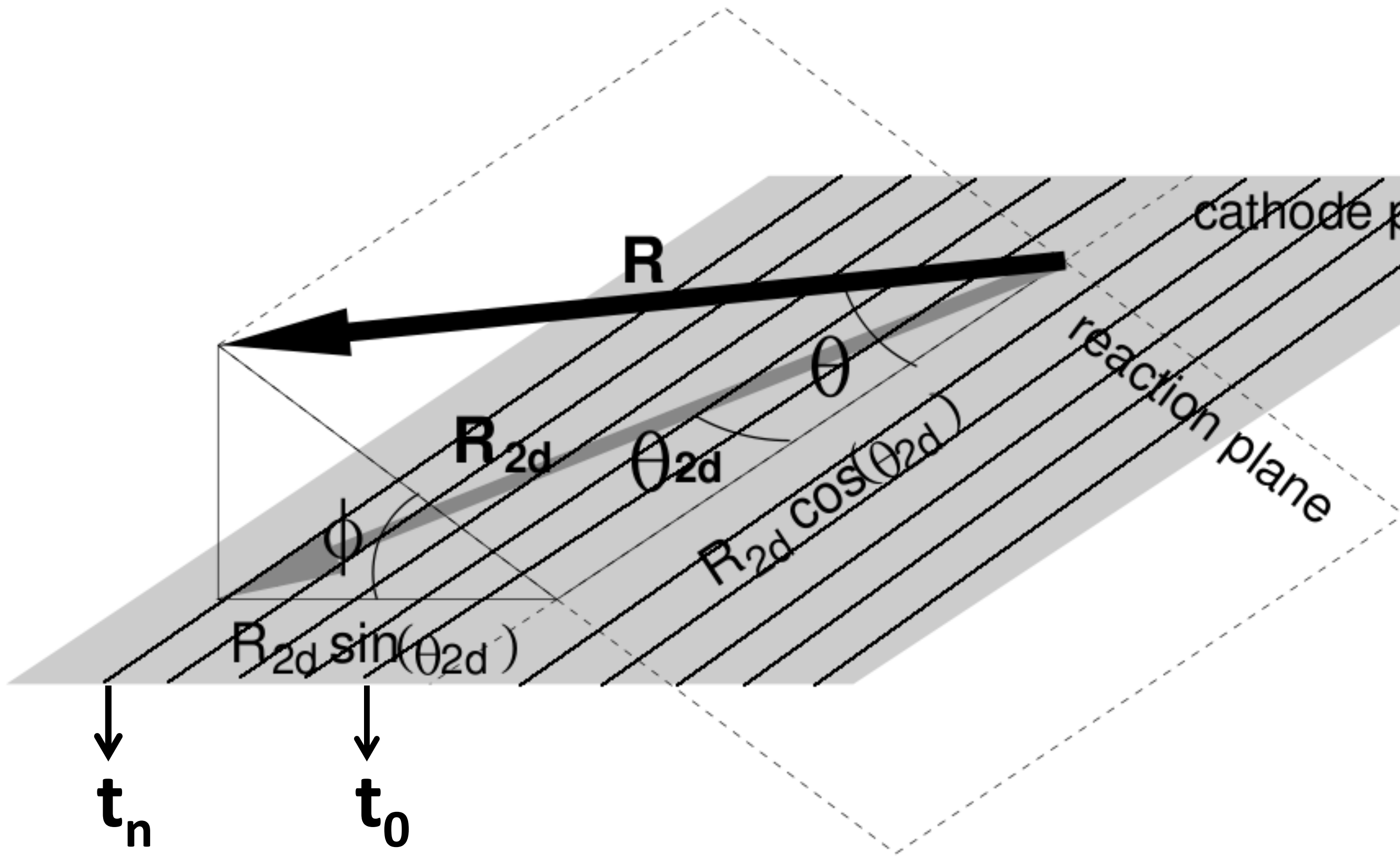
Kinematics reconstruction in MAYA

Maximum Amplitude / 2



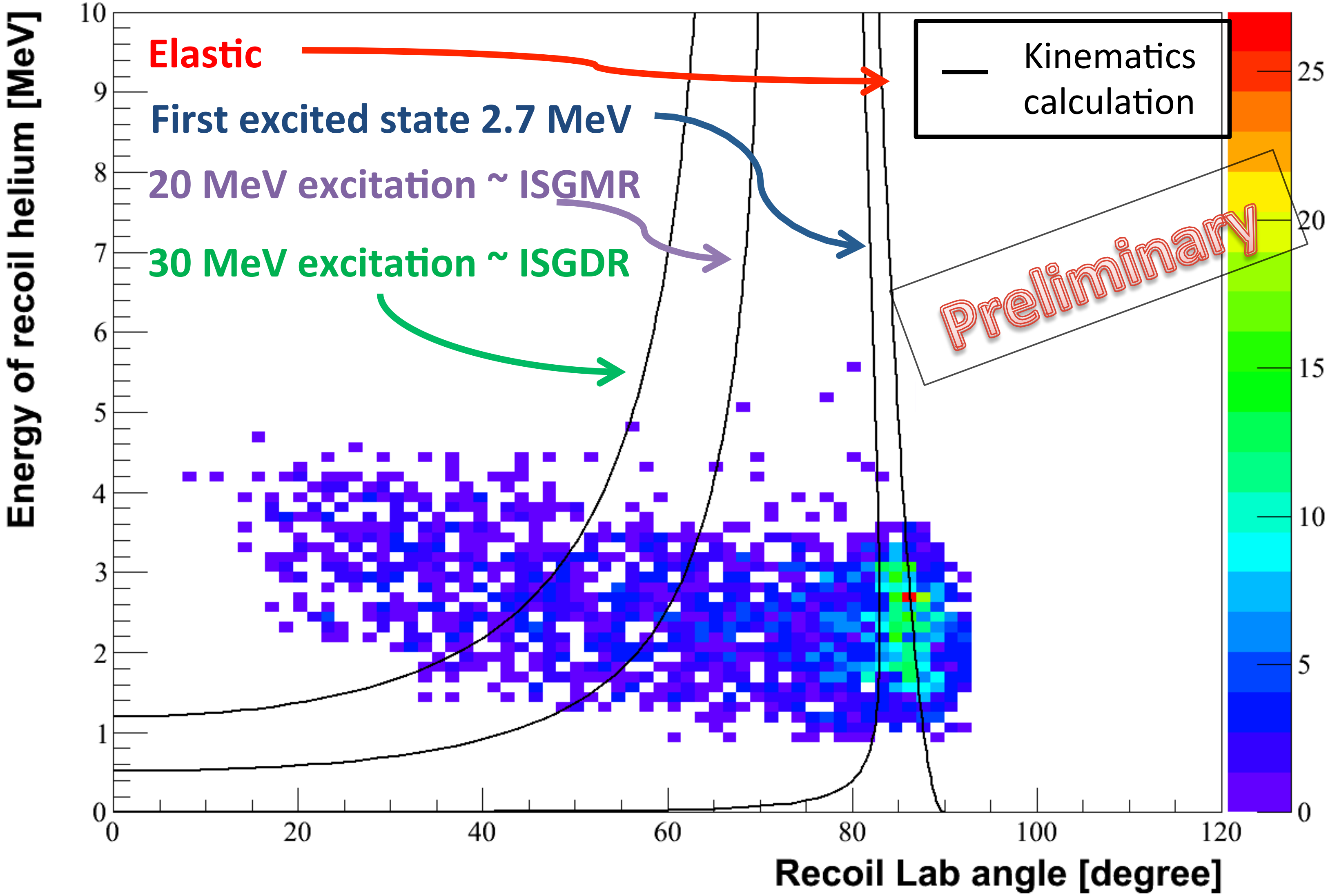


ϕ angle reconstruction

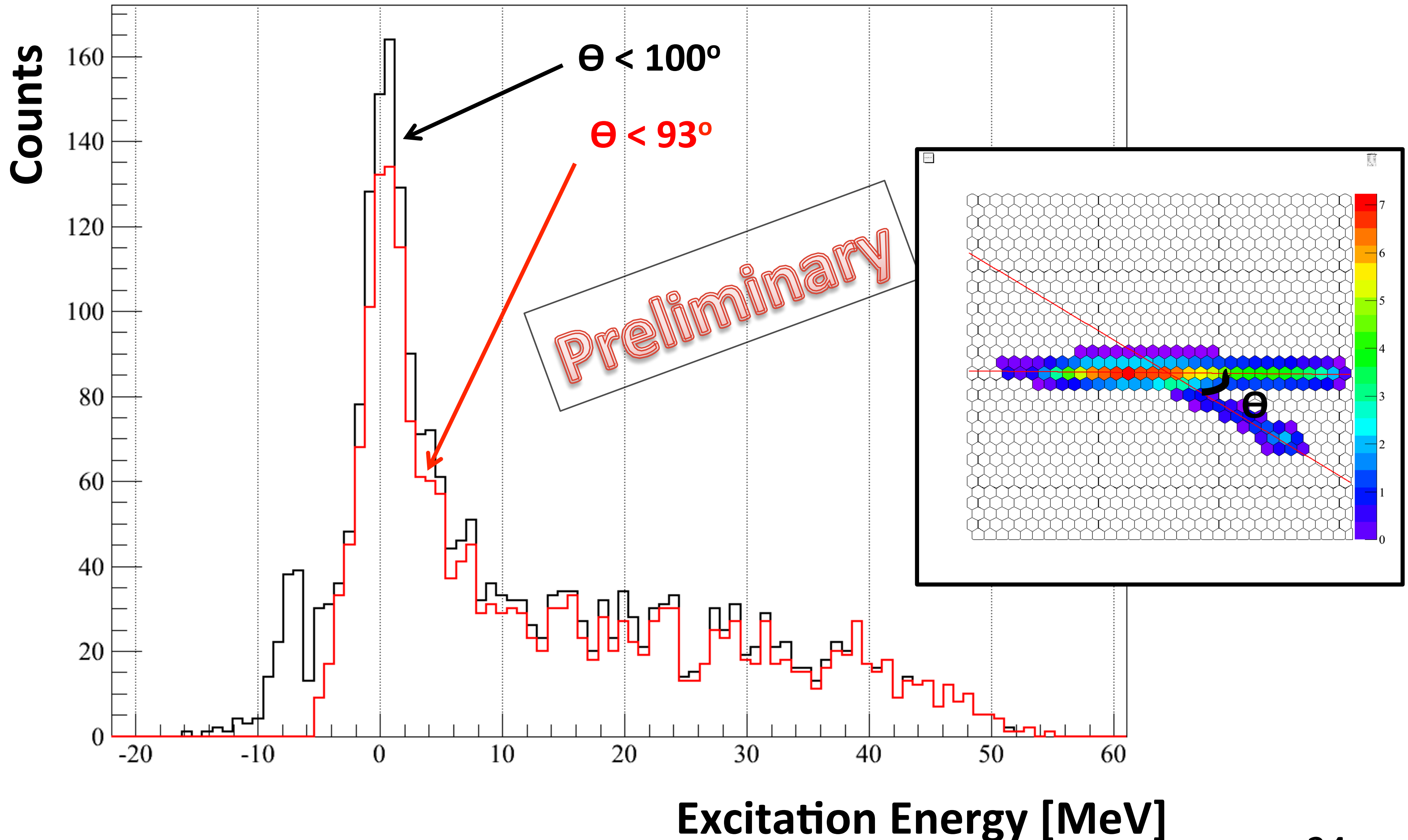


$t_n > t_0$

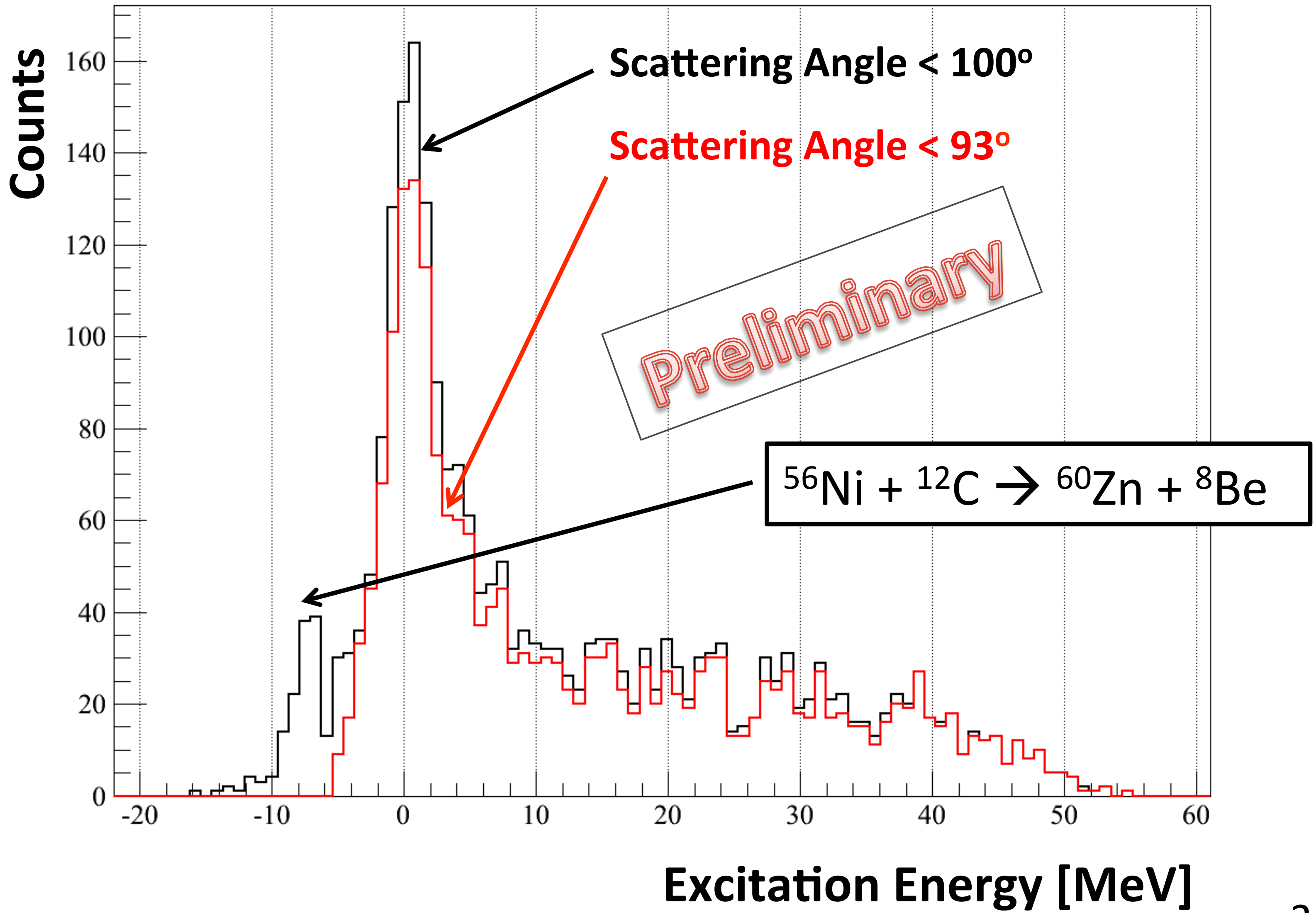
Recoil Helium



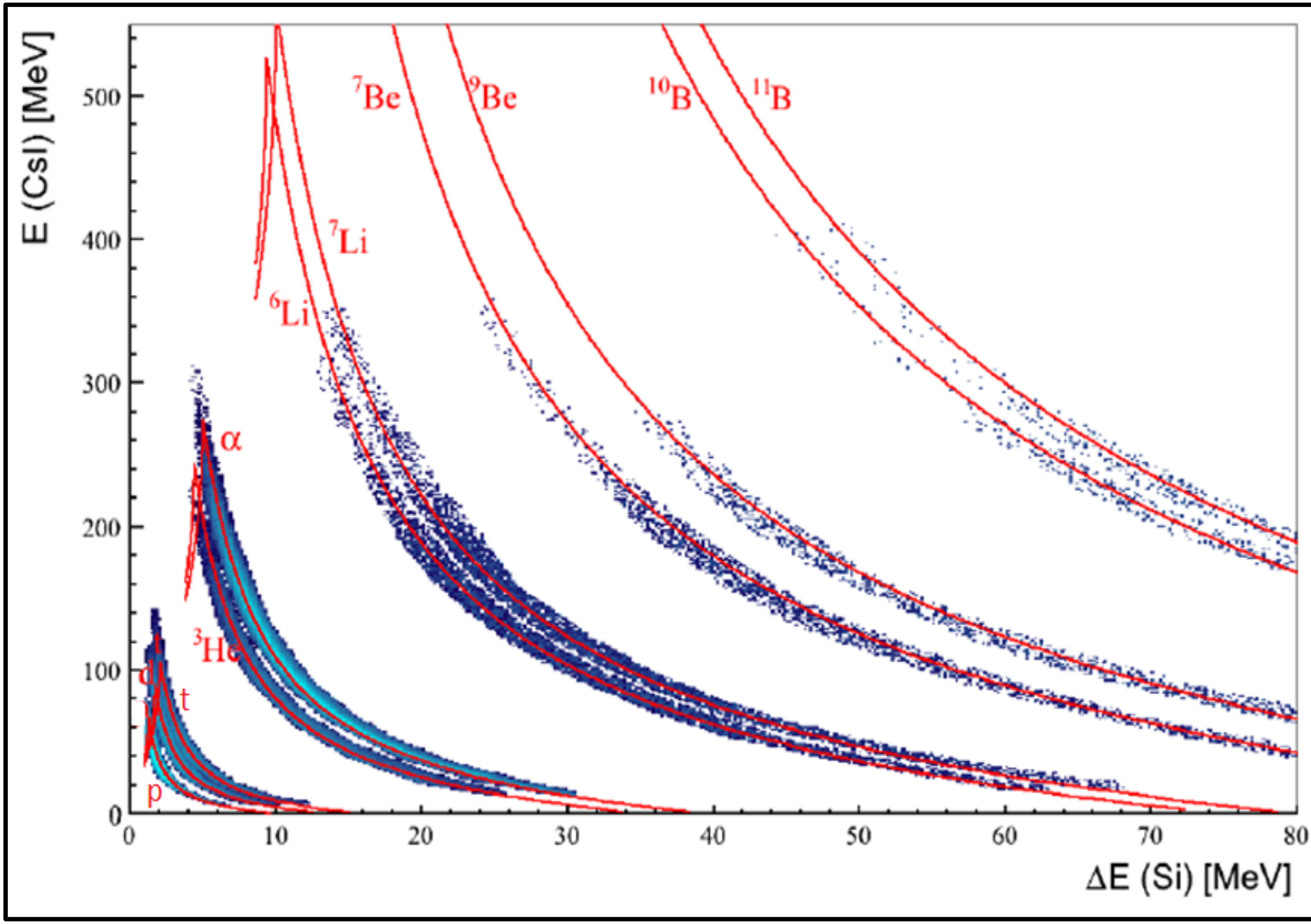
Excitation energy of ^{56}Ni



Excitation energy of ^{56}Ni



Particle Identification in forward ΔE-E telescope

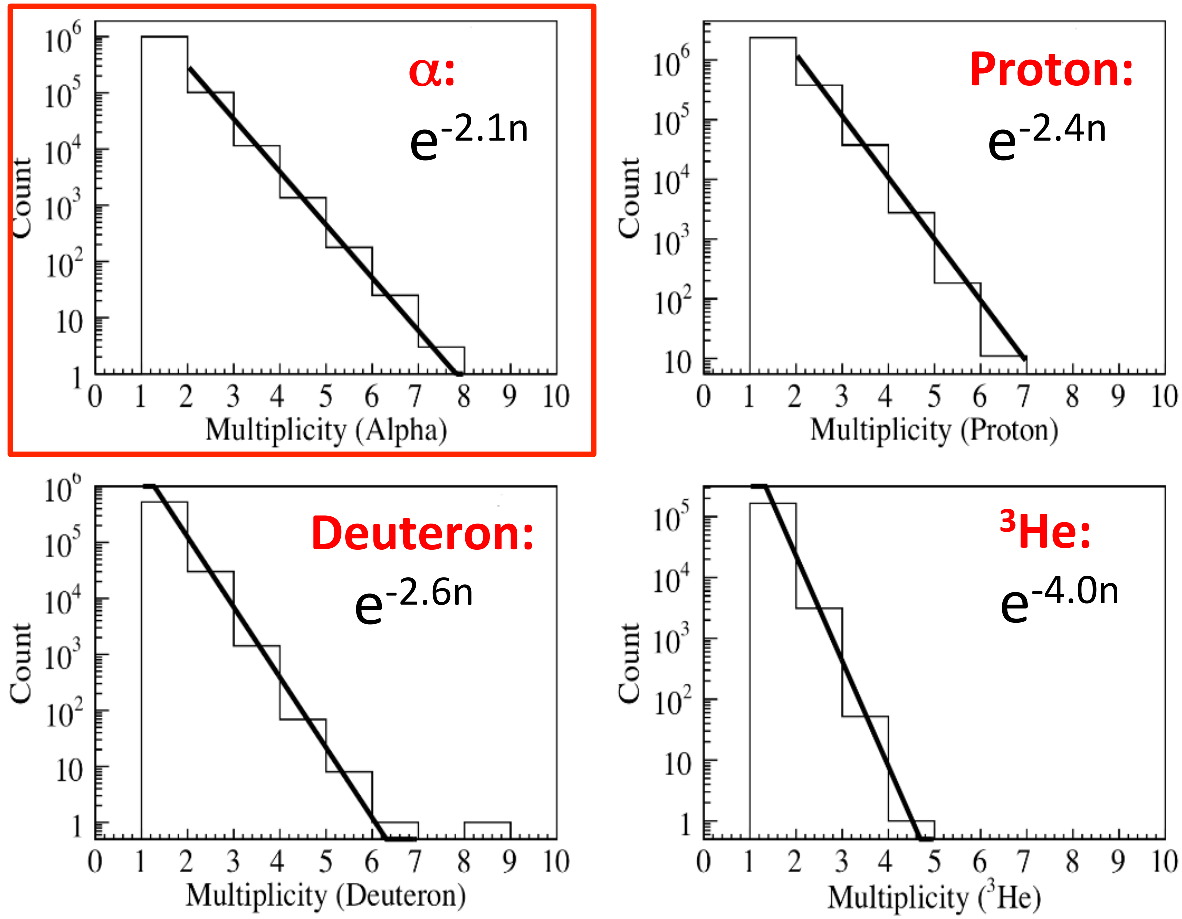


This analysis is carried out by Prof. H Akimune, Konan University, Japan

Multiplicity of decay particles

The maximum <u>multiplicity for α is 7!</u>

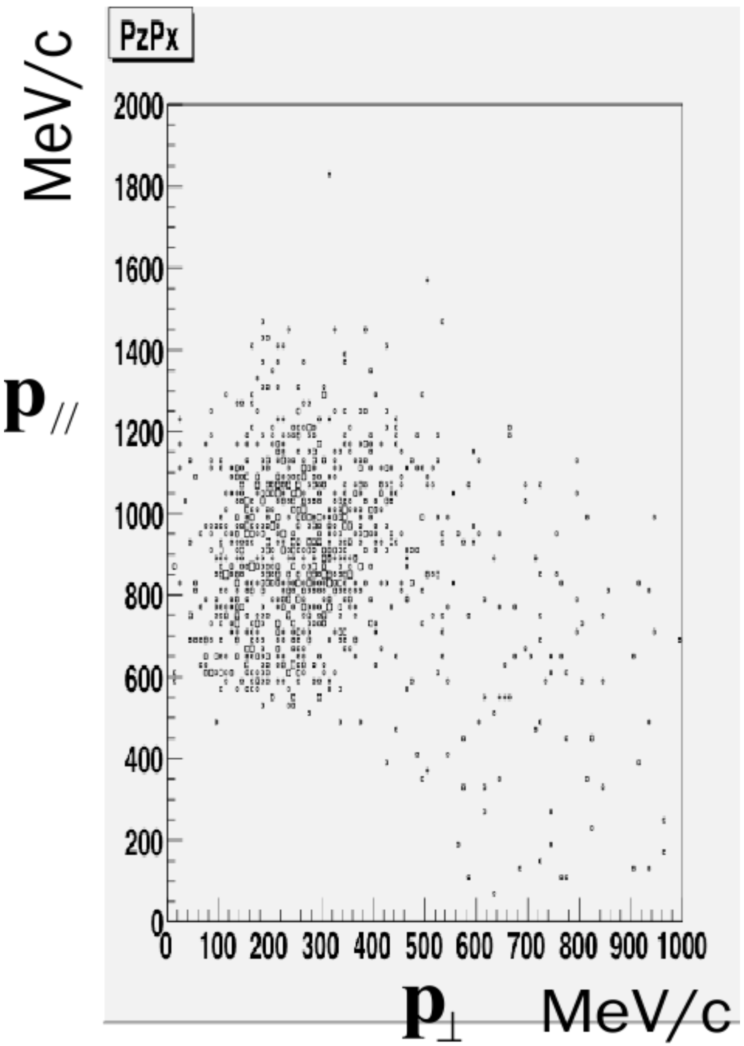
Striking enhancement of α multiplicity strongly suggests existence of α cluster state in ^{56}Ni



Momentum distribution of α

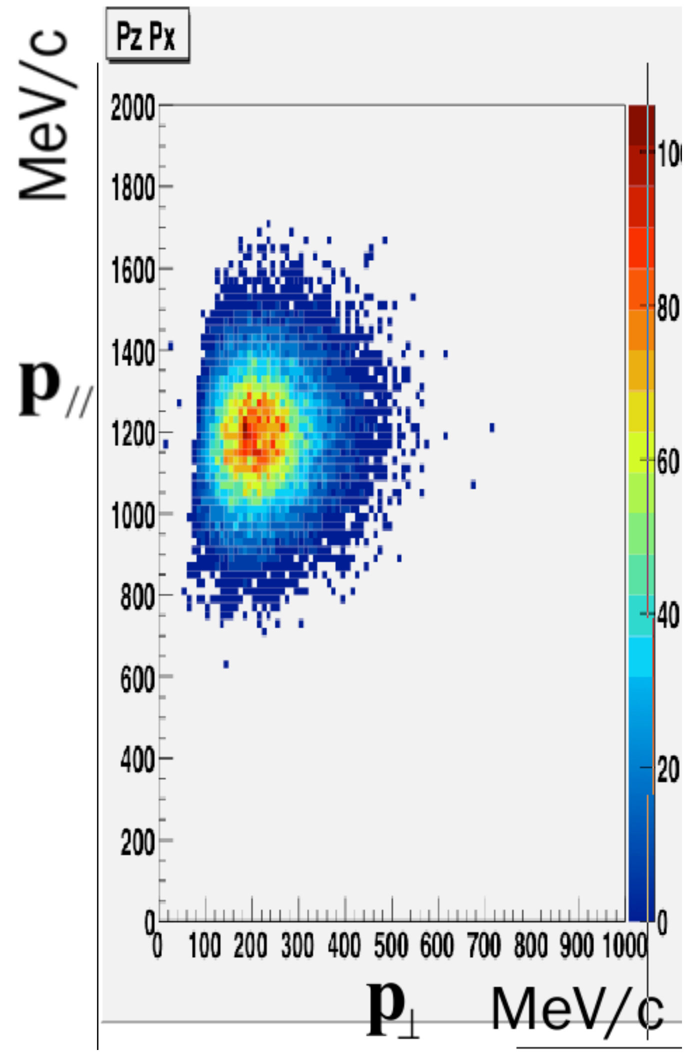
Experiment

Sum of events with M>4



Simulation for kT= 5 MeV, including the efficiency of the detector

Sum of events with M>4



Summary and Outlook

- Compression modes in ^{56}Ni have been studied.
- MAYA active target at GANIL was used.
- Excitation energy of ^{56}Ni (ongoing analysis) is shown.
- Angular distributions of ISGMR and ISGDR of ^{56}Ni have to be obtained.
- Few results of α cluster state in ^{56}Ni (ongoing analysis) are shown.

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university of groningen

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ORSAY

MTA atomki DEBRECEN

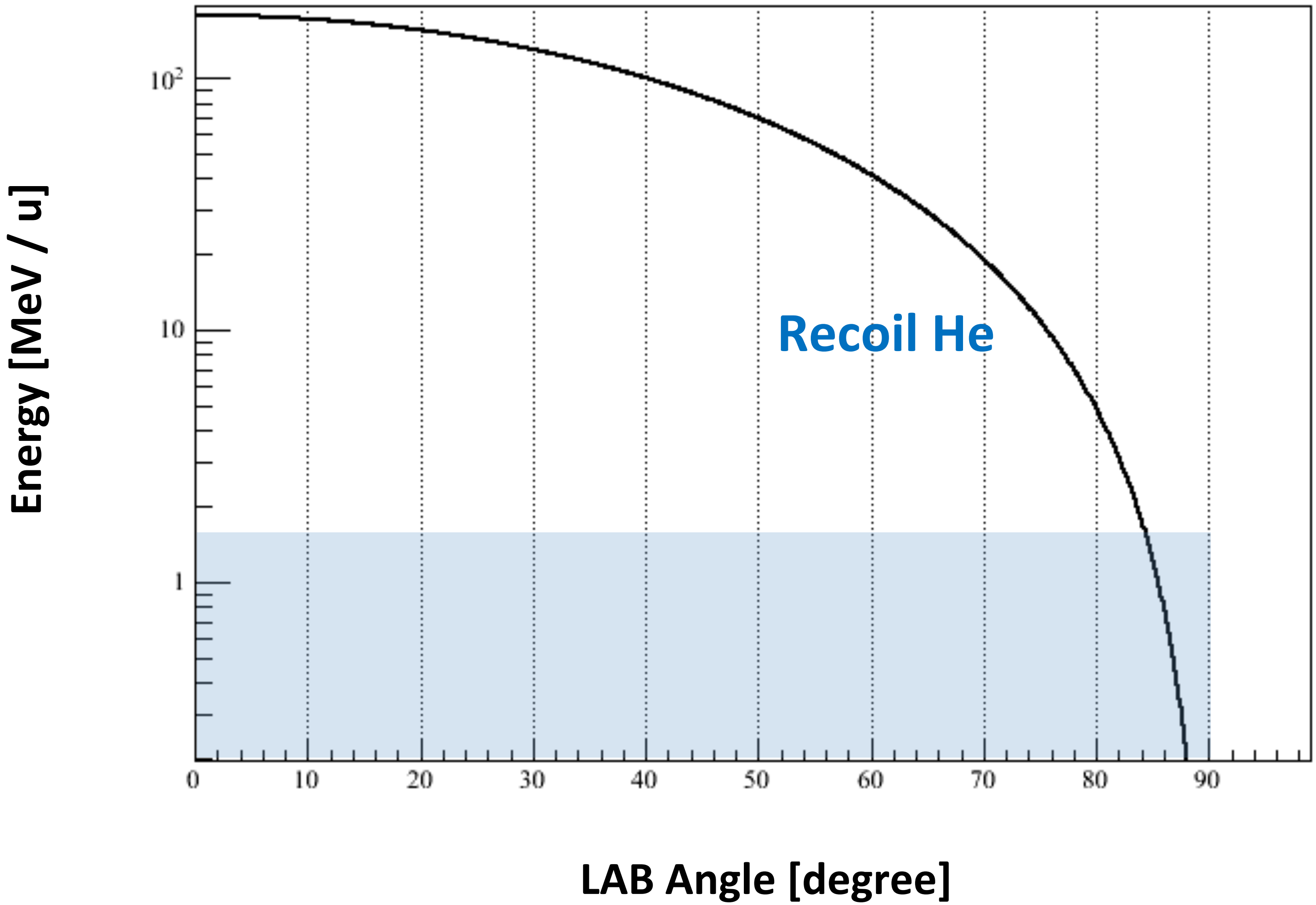
IFJ

UNIVERSITY OF NOTRE DAME

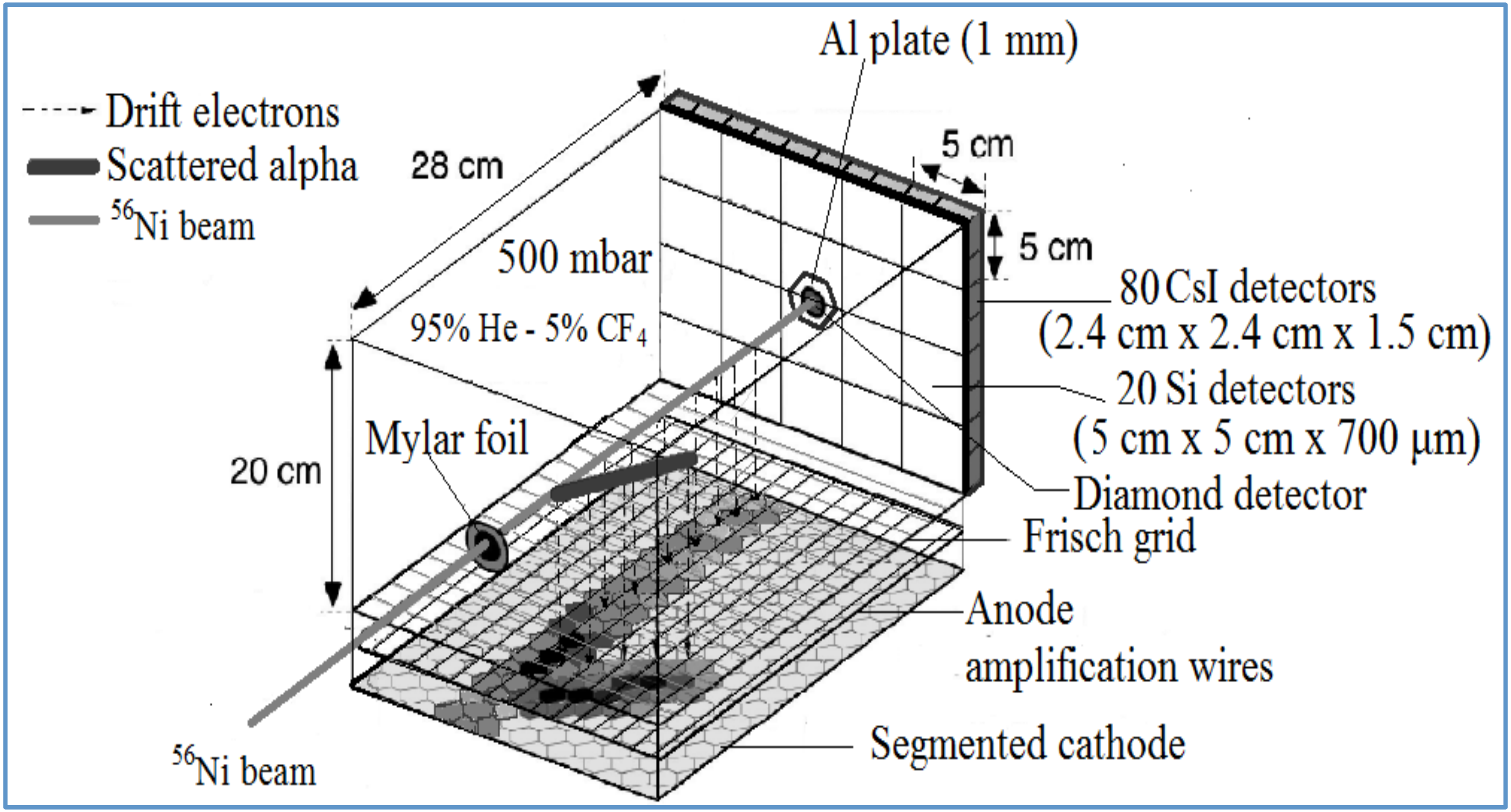
KONAN UNIVERSITY

OSAKA UNIVERSITY

Kinematics curve for ^{56}Ni (α, α) ^{56}Ni with ^{56}Ni at 50 MeV / u

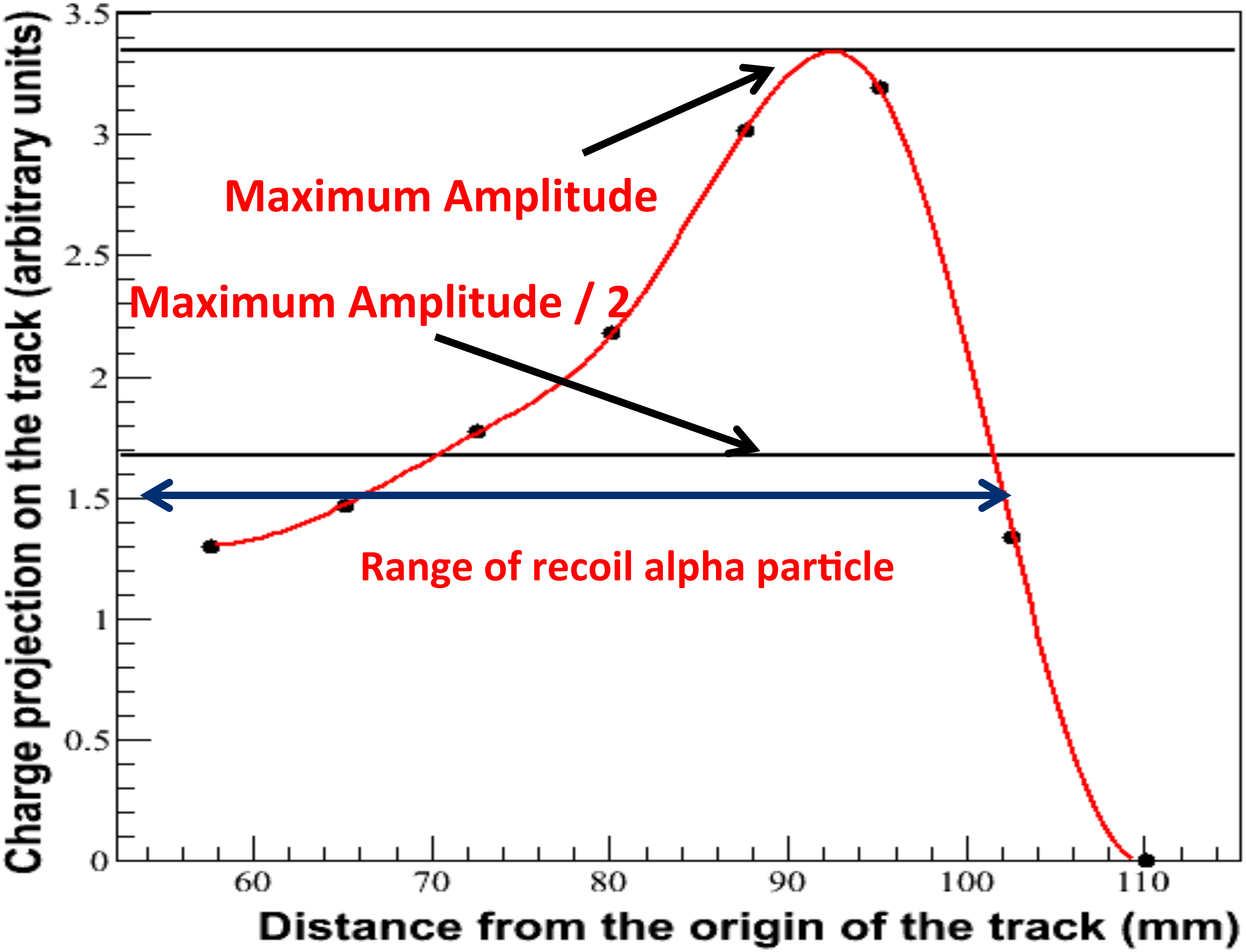


MAYA setup

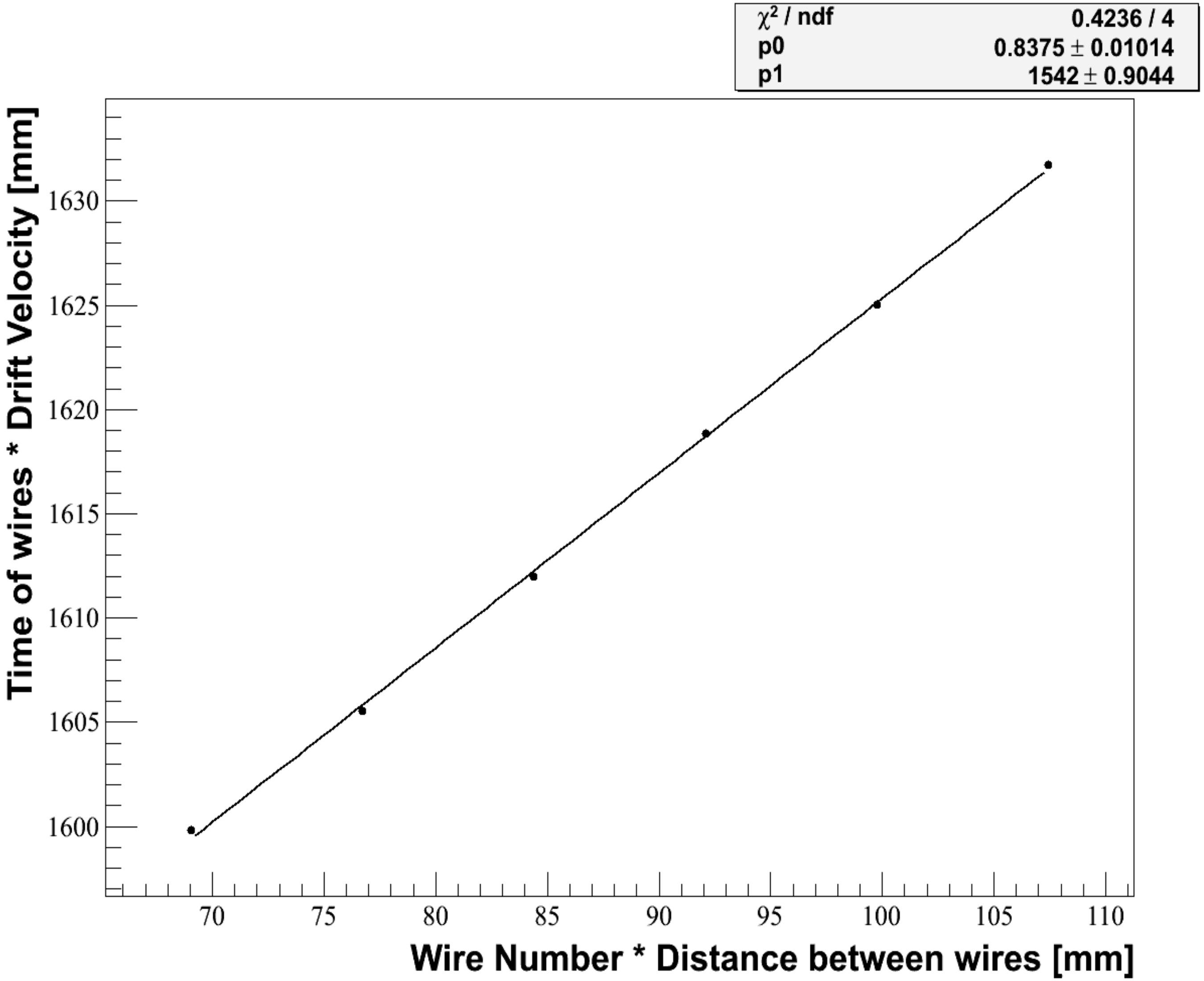


Drift electrons
Scattered alpha
56Ni beam
28 cm
500 mbar
95% He - 5% CF4
20 cm
Mylar foil
56Ni beam
Al plate (1 mm)
5 cm
5 cm
80 CsI detectors
(2.4 cm x 2.4 cm x 1.5 cm)
20 Si detectors
(5 cm x 5 cm x 700 μm)
Diamond detector
Frisch grid
Anode
amplification wires
Segmented cathode

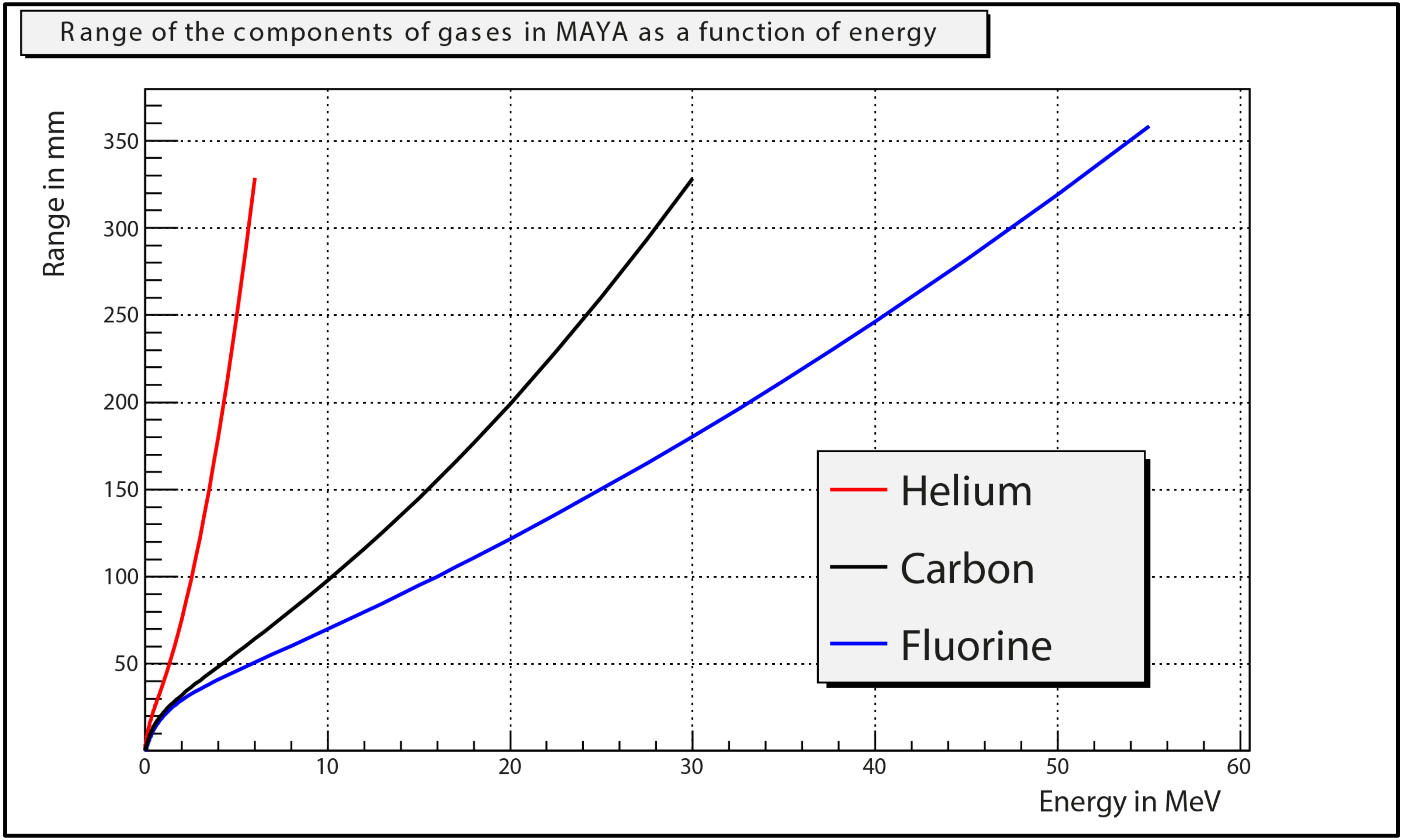
Range extraction of recoil track



Phi angle reconstruction

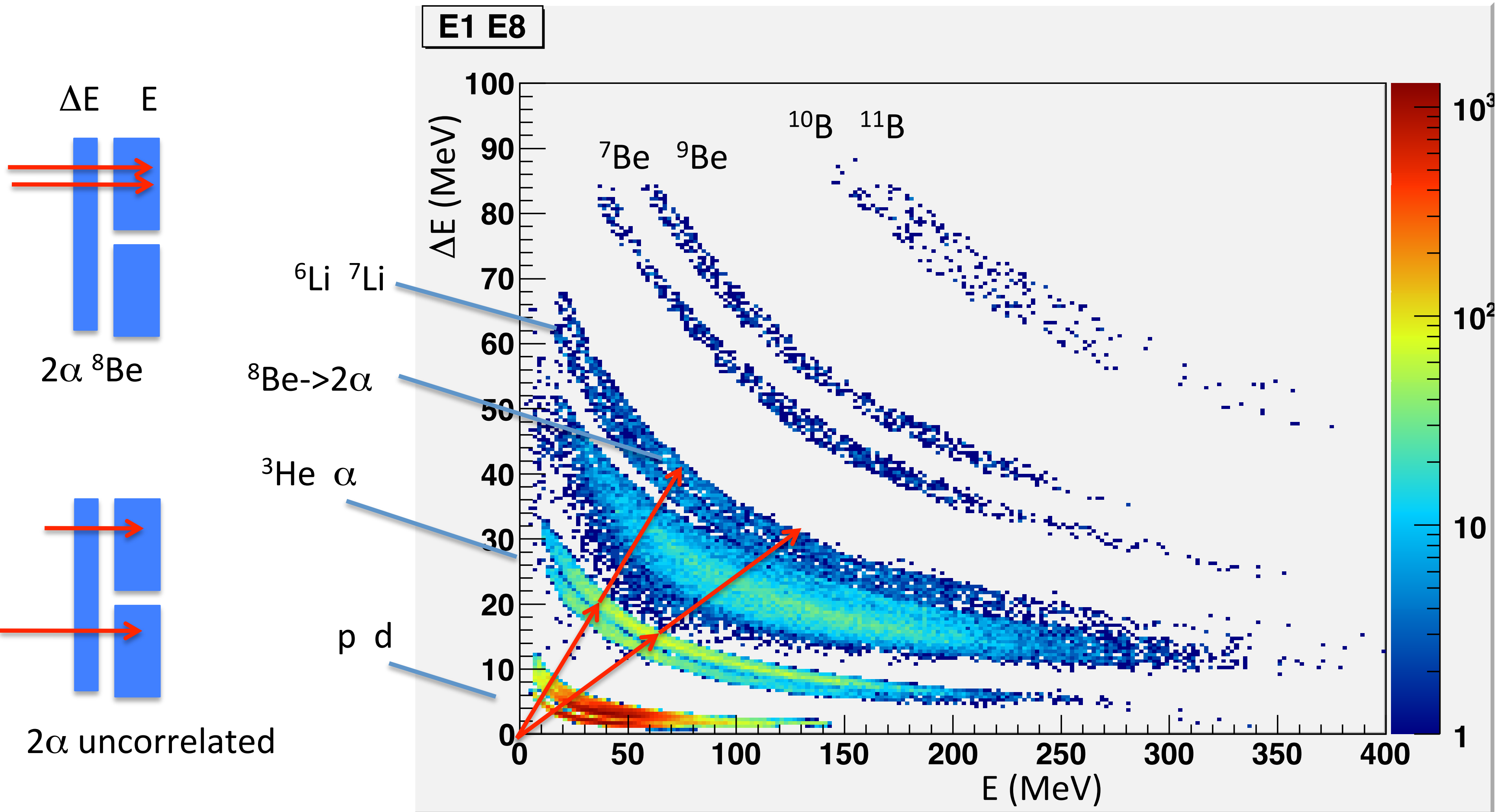


Background Subtraction-SRIM Calculation

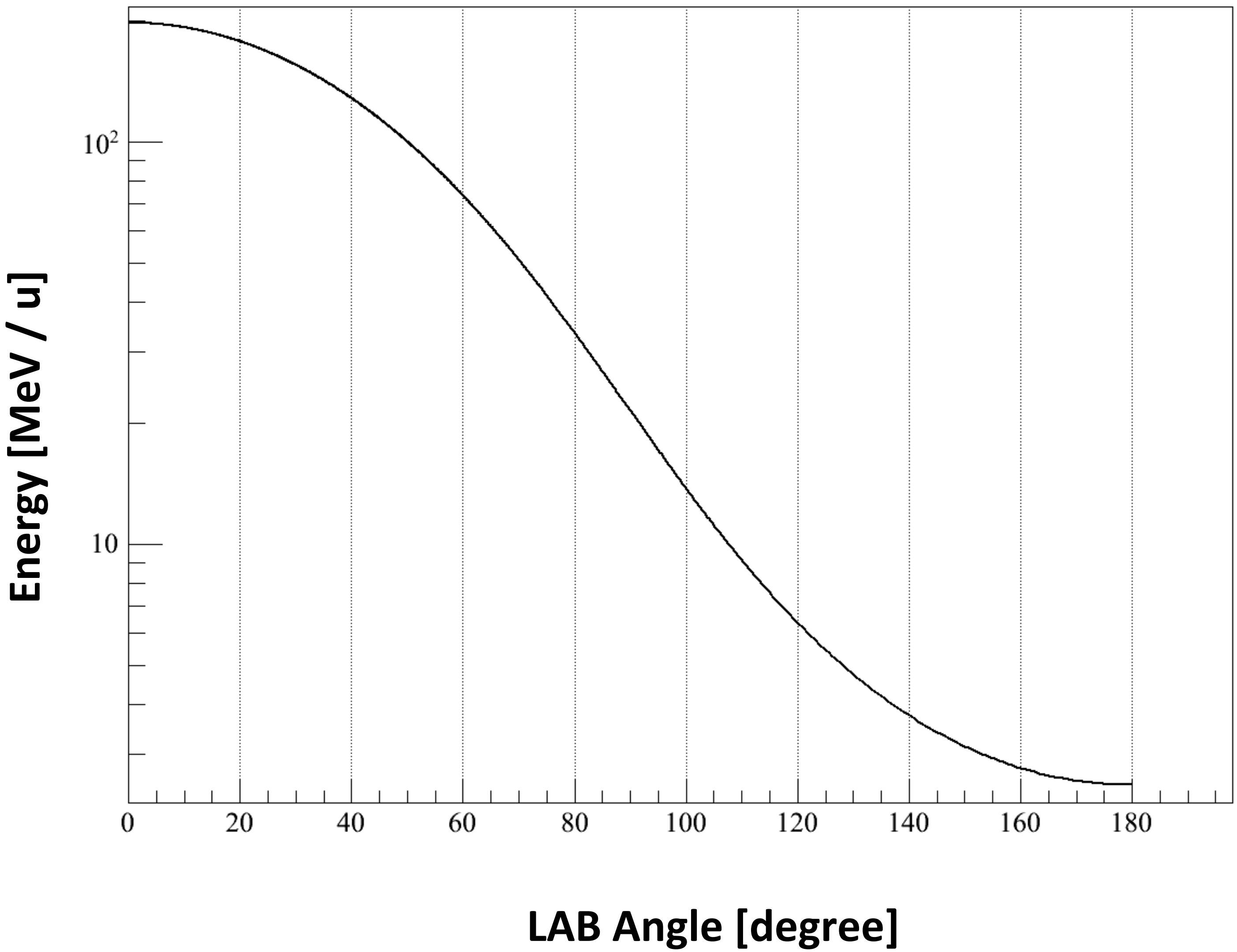


Particle identification

- number of p is the largest,
- however, as for the multiplicity, number of multi α is very large

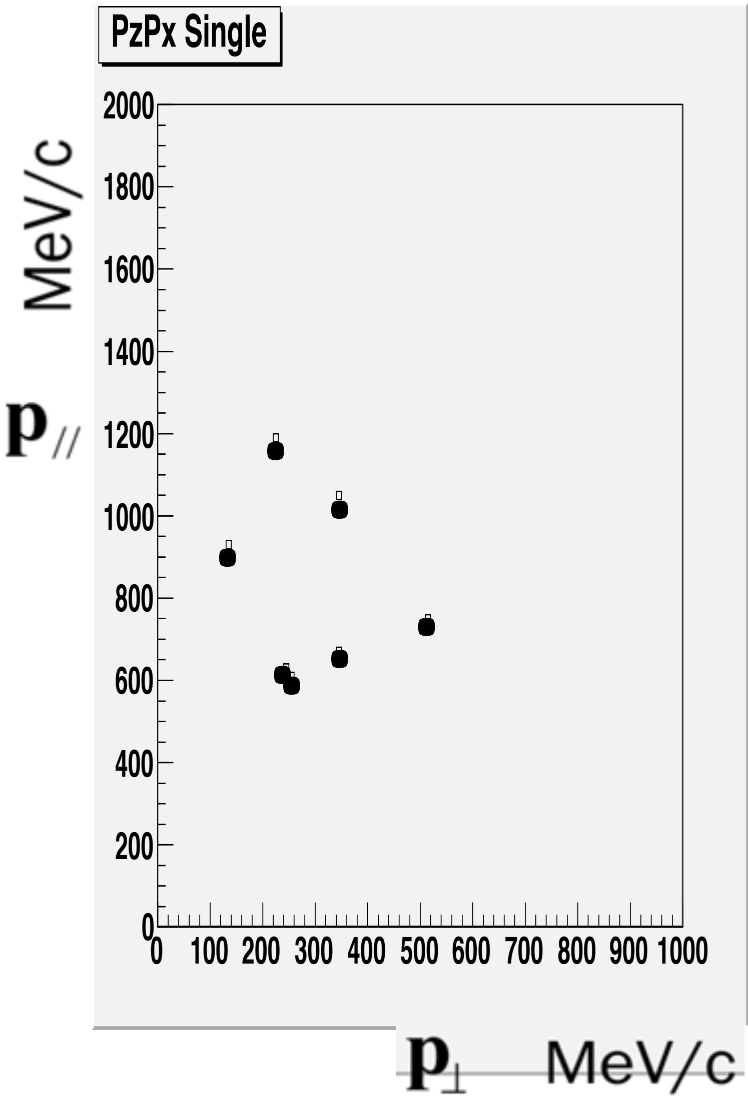


$^{56}Ni + ^{12}C \rightarrow ^{60}Zn + ^{8}Be$

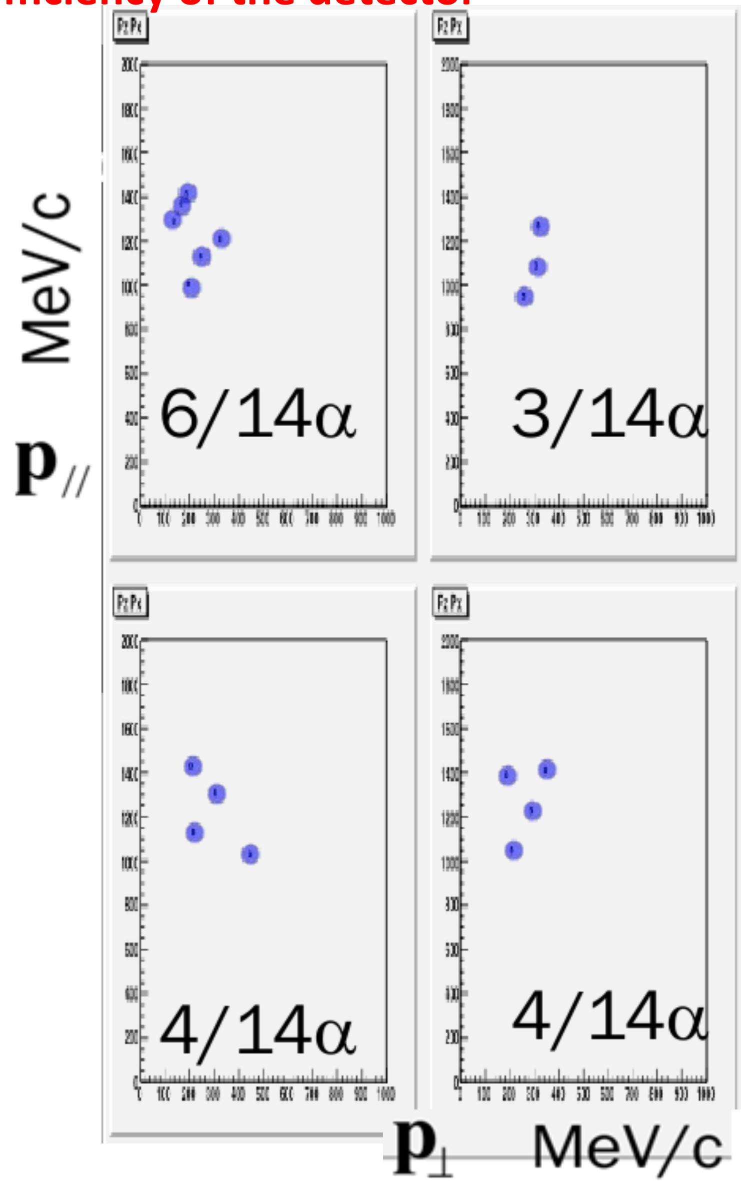


Momentum distribution of α

Experiment



Simulation for kT= 5 MeV, including the efficiency of the detector



$$K_A = \left[r^2 (d^2(E/A)/dr^2) \right]_{r=R_0}$$

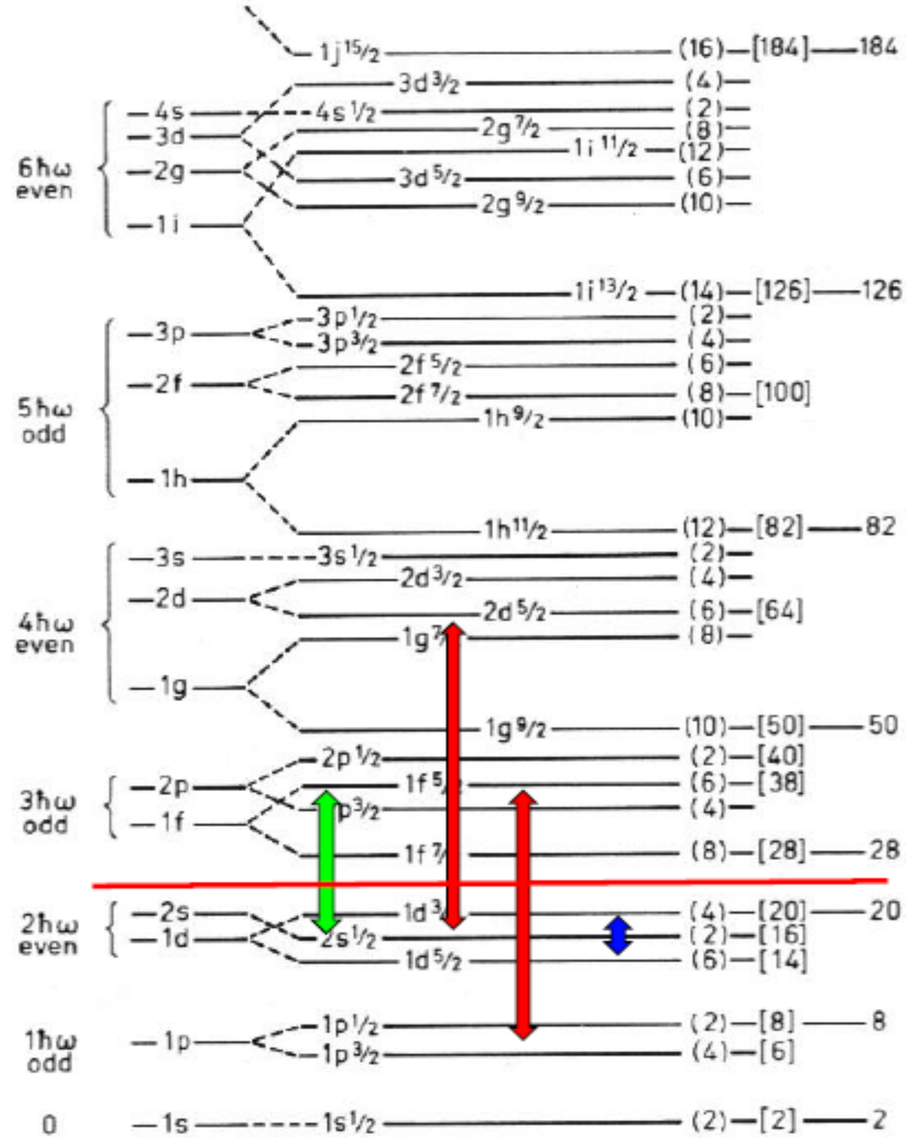
J.P. Blaizot, Phys. Rep. 64 (1980) 171

ISGMR, ISGDR $\Rightarrow$ Incompressibility, symmetry energy

$$K_A = K_{vol} + K_{surf} A^{-1/3} + K_{sym}((N-Z)/A)^2 + K_{Coul} Z^2 A^{-4/3}$$

$\Delta N = 1$ E1 (IVGDR)

$\Delta N = 2$ E2 (ISGQR) & $\Delta N = 0$ E0 (ISGMR)



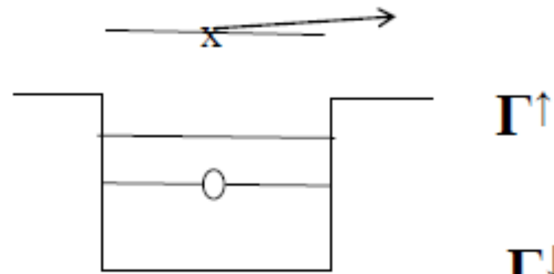
Decay of giant resonances

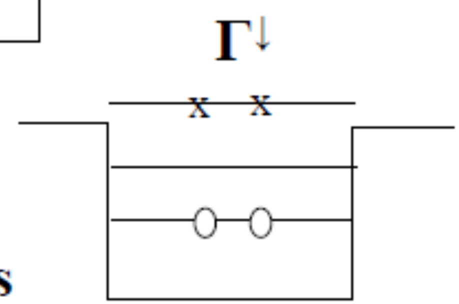
- **Width of resonance**

  $\Gamma, \Gamma^{\uparrow}, \ \Gamma^{\downarrow} \ (\Gamma^{\downarrow\uparrow}, \Gamma^{\downarrow\downarrow})$

  - **$\Gamma^{\uparrow}$: direct or escape width**
  - **$\Gamma^{\downarrow}$: spreading width**

    $\Gamma^{\downarrow\uparrow}$: pre-equilibrium, $\Gamma^{\downarrow\downarrow}$: compound

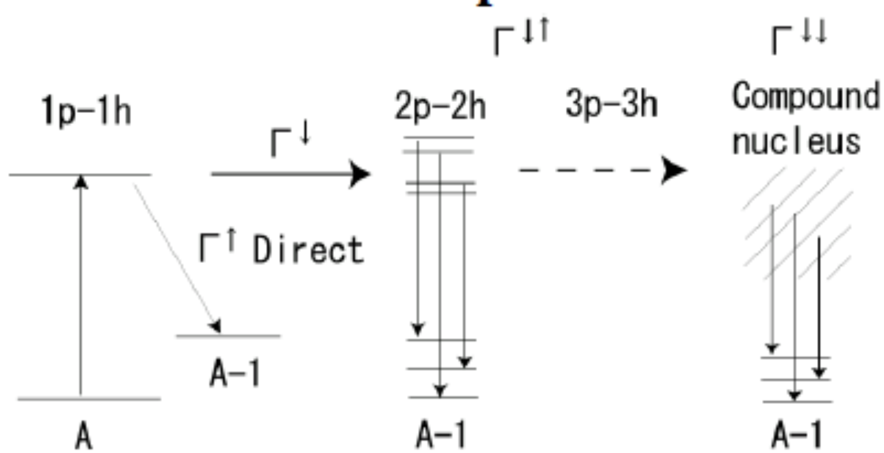




- **Decay measurements**

  $\Rightarrow$ Direct reflection of damping processes

  Allows detailed comparison with theoretical calculations

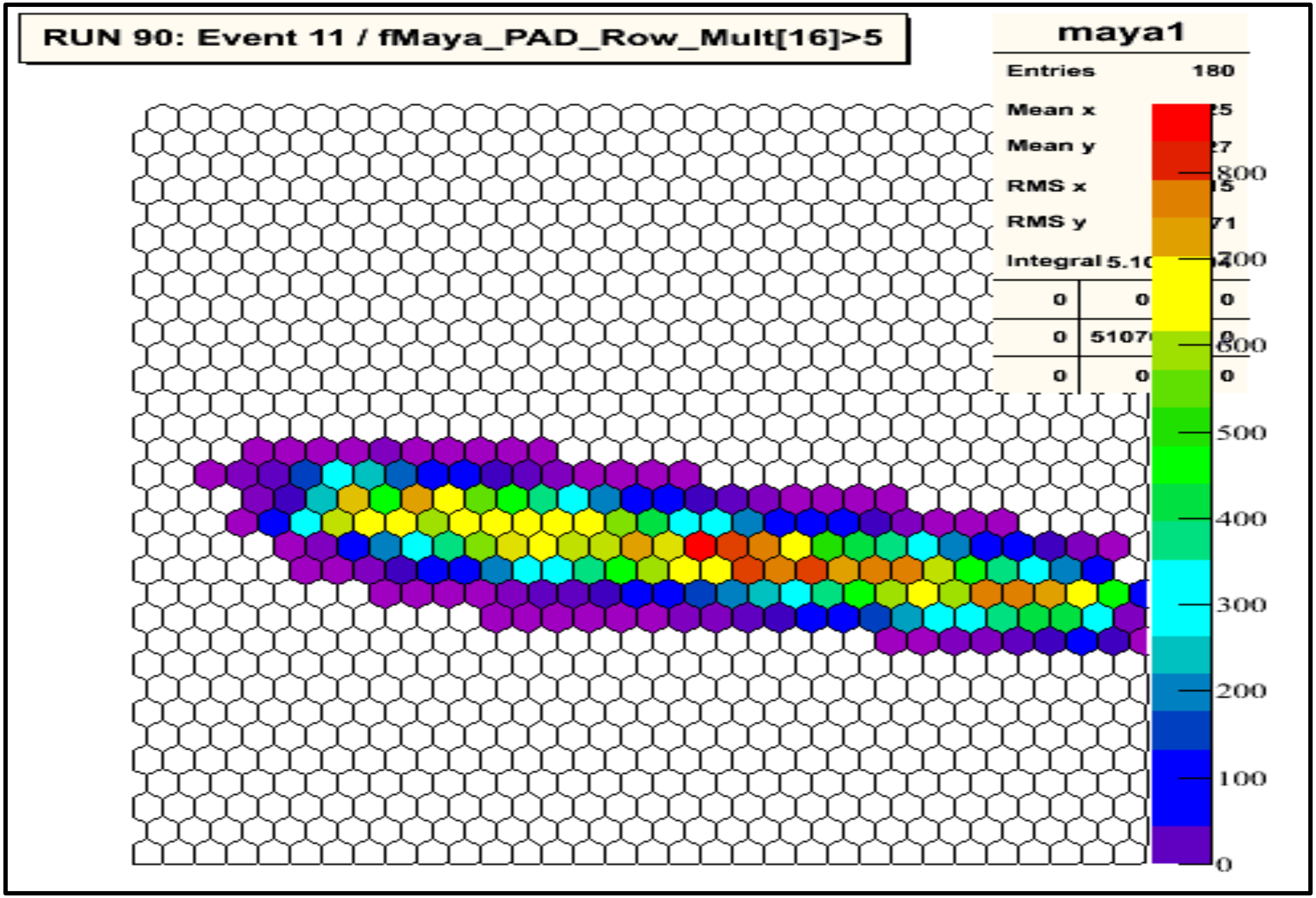


Microscopic picture:

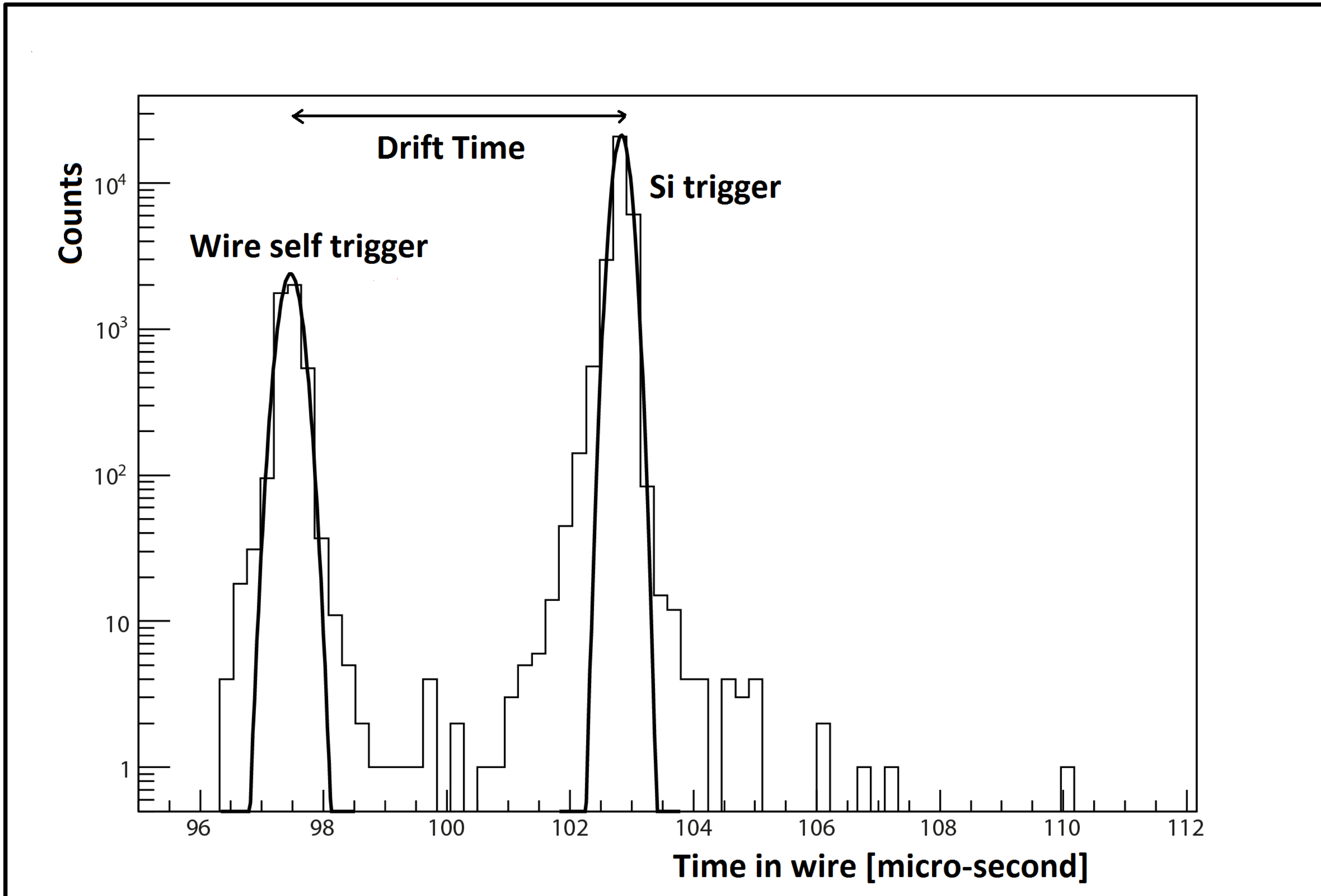
GRs are coherent superposition of 1p-1h excitations induced by the single particle opeartors

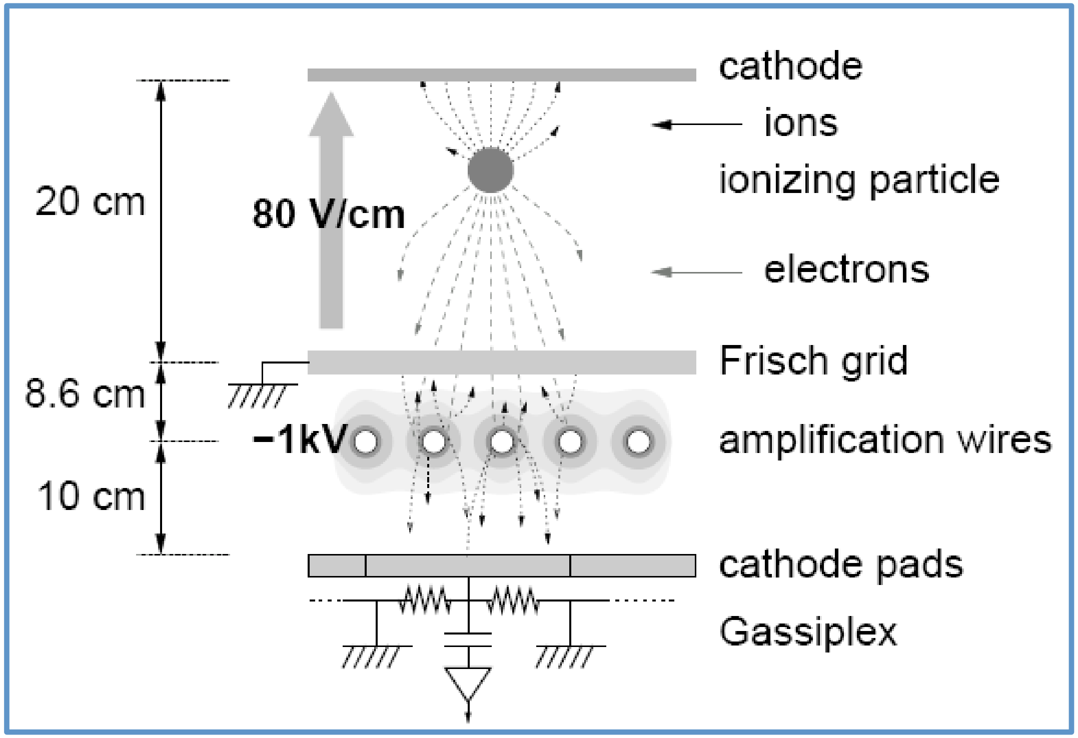
- Excitation energy depends on:
  - Multipole L (L$\hbar\omega$, since the radial operator ∝ r^L; except for ISGMR and ISGDR, $2\hbar\omega$ and $3\hbar\omega$ respectively)
  - Strength of effective interaction
  - Collectivity
- Exhausts appreciable % of EWSR
- Acquires a width due to coupling to continuum and to the underlying 2p-2h…. configurations

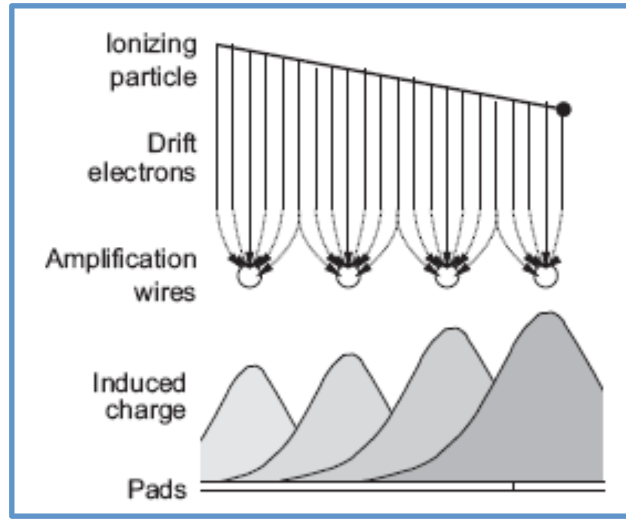
Drift time measurement



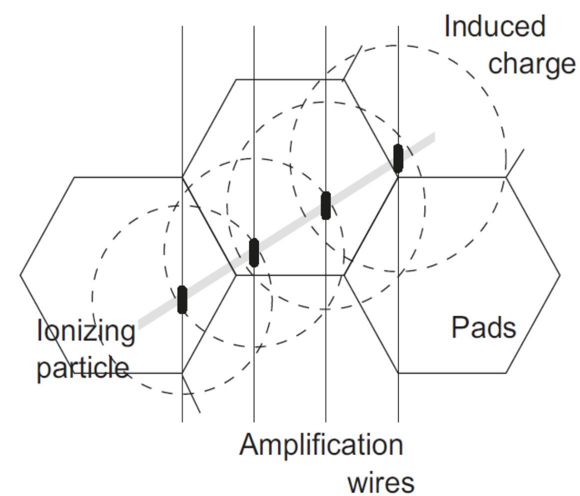
Drift time measurement

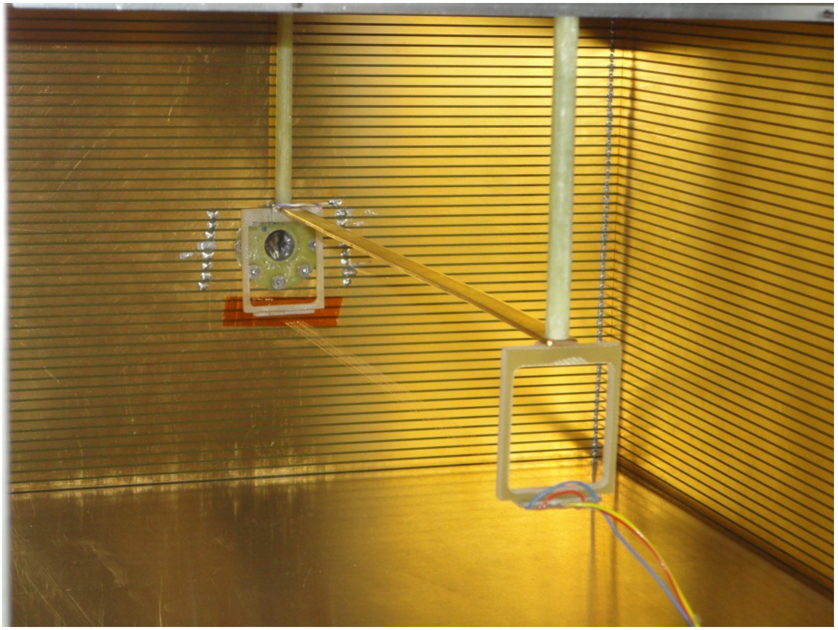


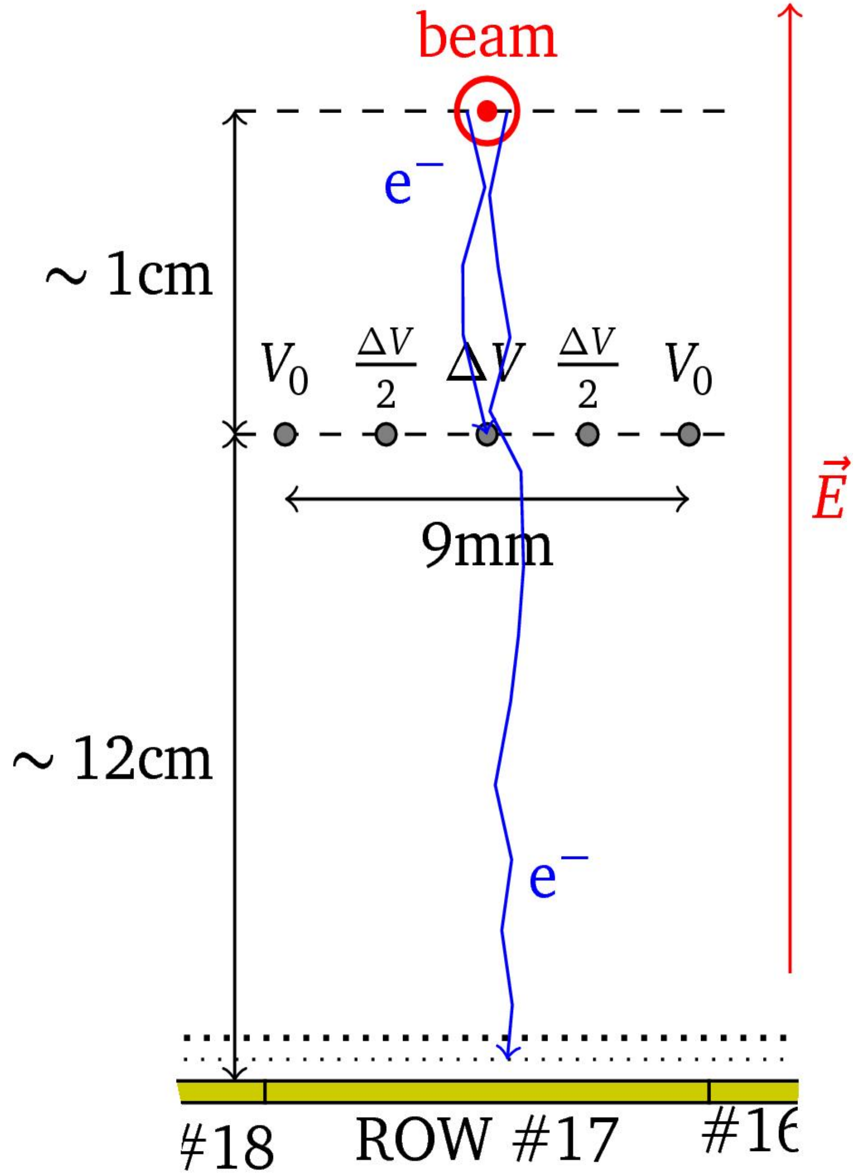


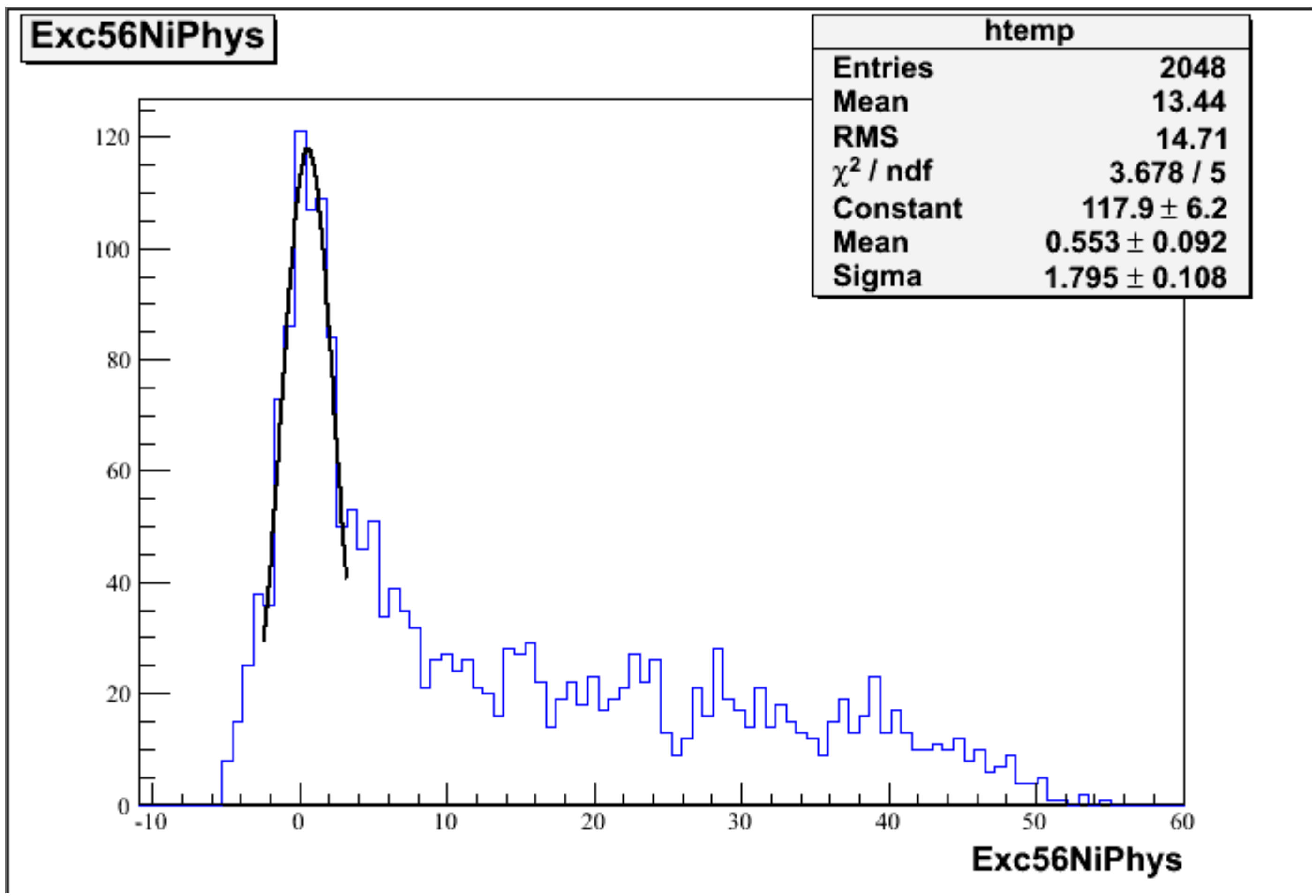


$$\sigma(x,y)=\frac{-Q}{2\pi}\sum_{n=0}^{\infty}\frac{(2n+1)L}{[(2n+1)^2L^2+x^2+y^2]^{3/2}}$$






beam
e−
~ 1cm
V_0
$\frac{\Delta V}{2}$
ΔV
$\frac{\Delta V}{2}$
V_0
9mm
~ 12cm
e−
$\vec{E}$
#18
ROW #17
#16


Exc56NiPhys
htemp
Entries 2048
Mean 13.44
RMS 14.71
χ² / ndf 3.678 / 5
Constant 117.9 ± 6.2
Mean 0.553 ± 0.092
Sigma 1.795 ± 0.108
120
100
80
60
40
20
0
-10
0
10
20
30
40
50
60
Exc56NiPhys

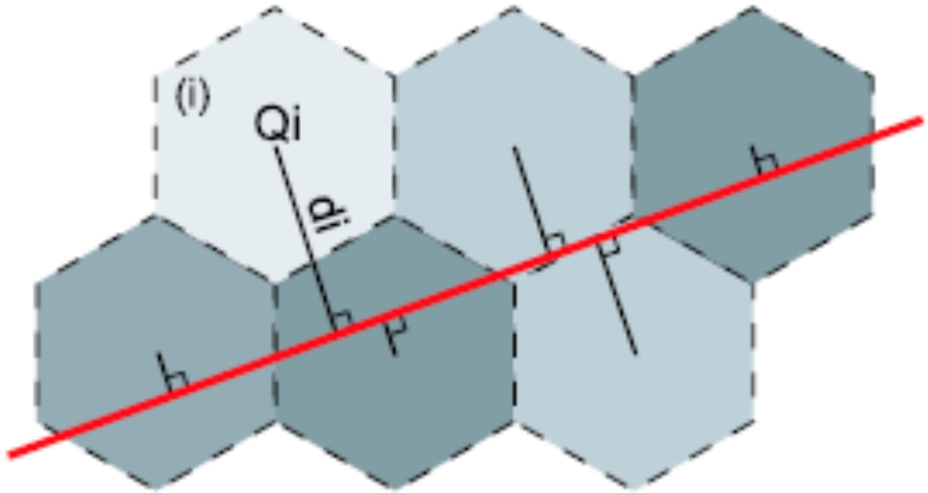


Fig. 9. Principle of the *Global Fitting method*. The orthogonal distance of the center of the pads to the straight line, weighted by their charge is minimized.

$$\chi^2 = \sum_{n=0}^{N} Q_n \frac{(a_0 x_n + a_1 - y_n)^2}{a_0^2 + 1}$$

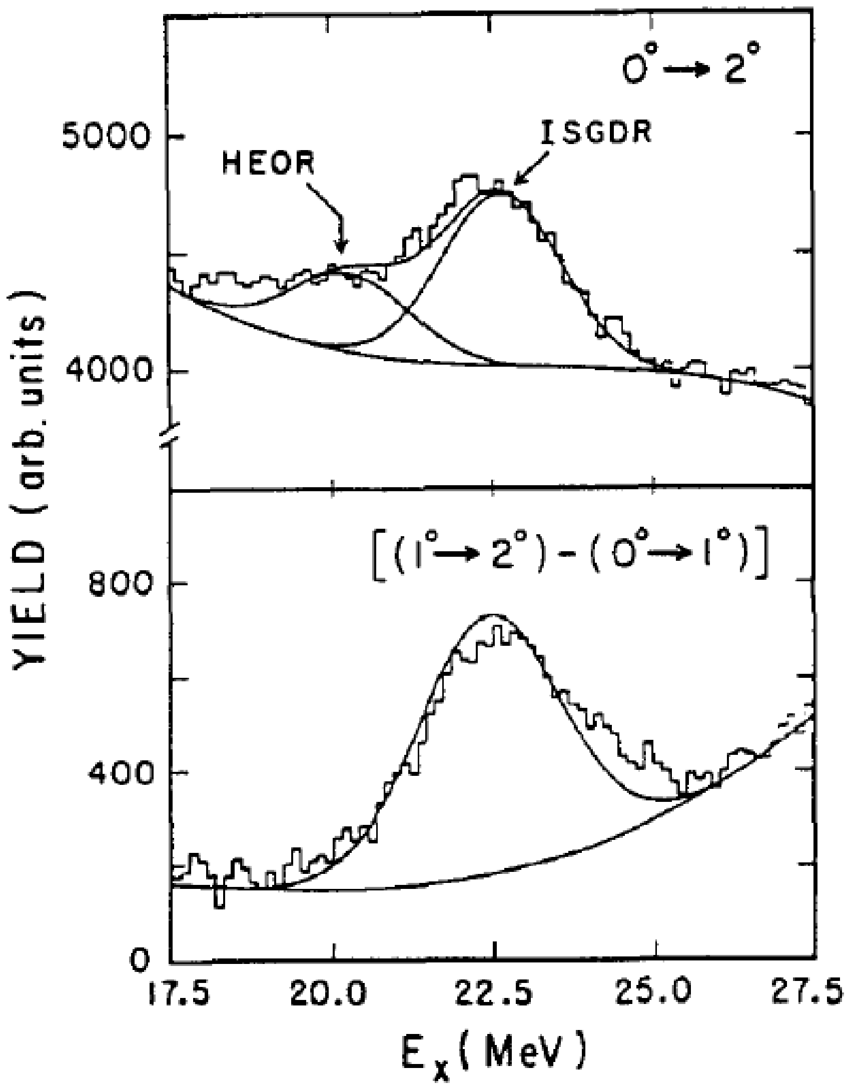


Figure 1. 200 MeV inelastic α-scattering spectra for ^{208}Pb for $(0 \rightarrow 2)^\circ$ (upper panel) and the "difference" spectrum (lower panel). Simultaneous 2-peak + polynomial-background fits to the two spectra are shown superimposed.