Lecture 3: detectors
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No natural background

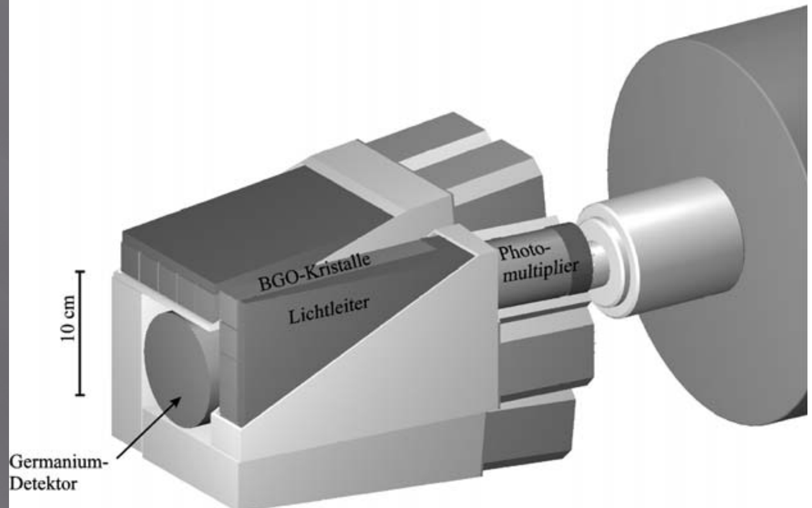
Radiative captures reactions

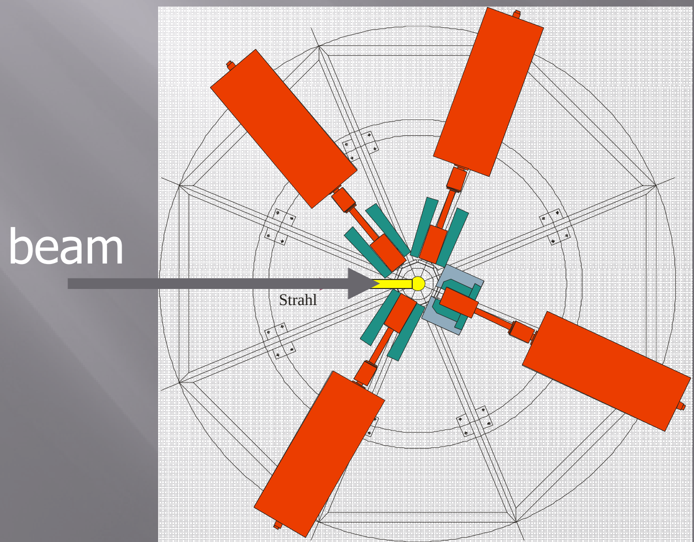
as an example: X(α,γ)Y

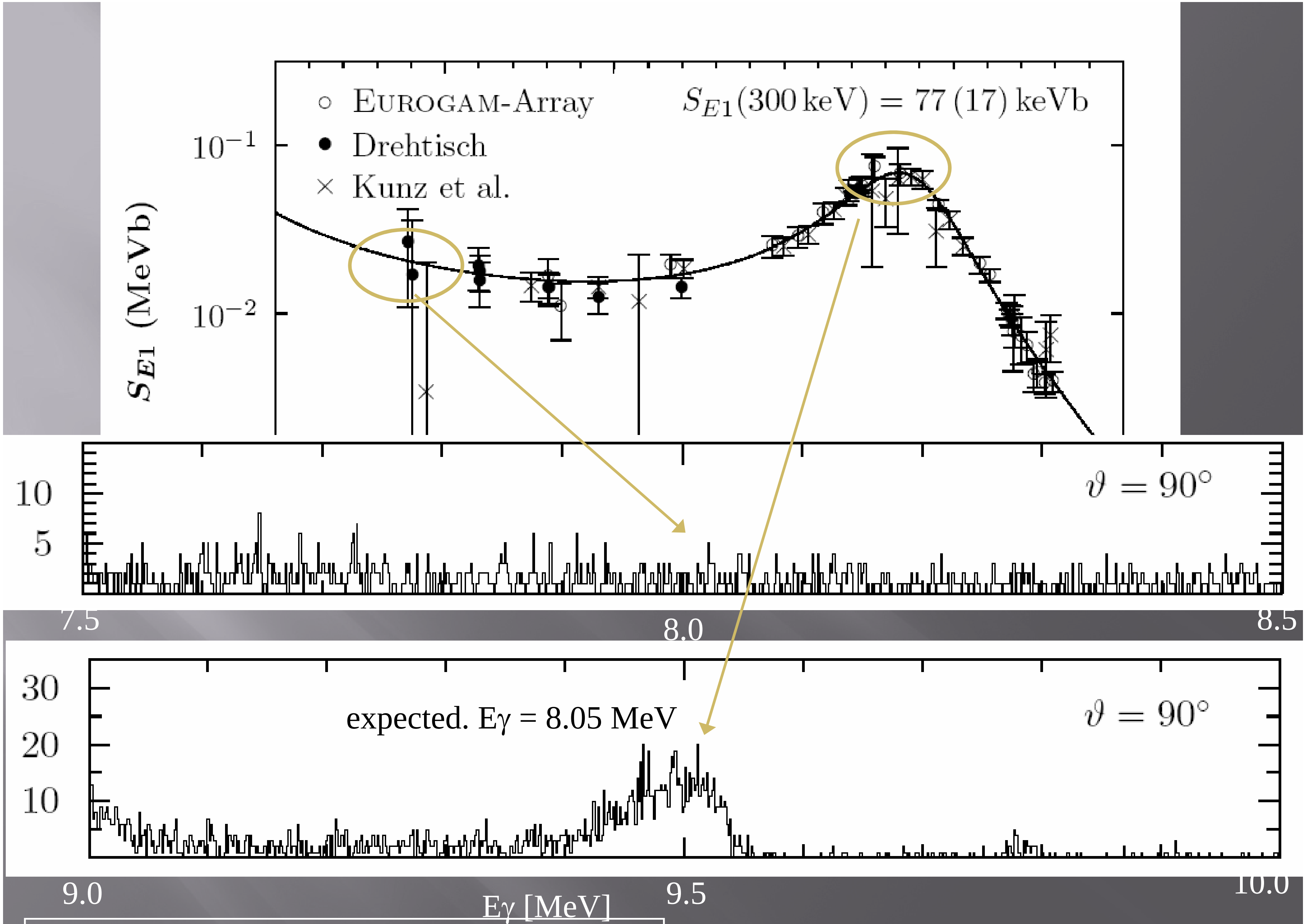
Cosmic background
Natural radioactivity

$^{12}C(^4He,\gamma)\,^{16}O$ Stuttgart

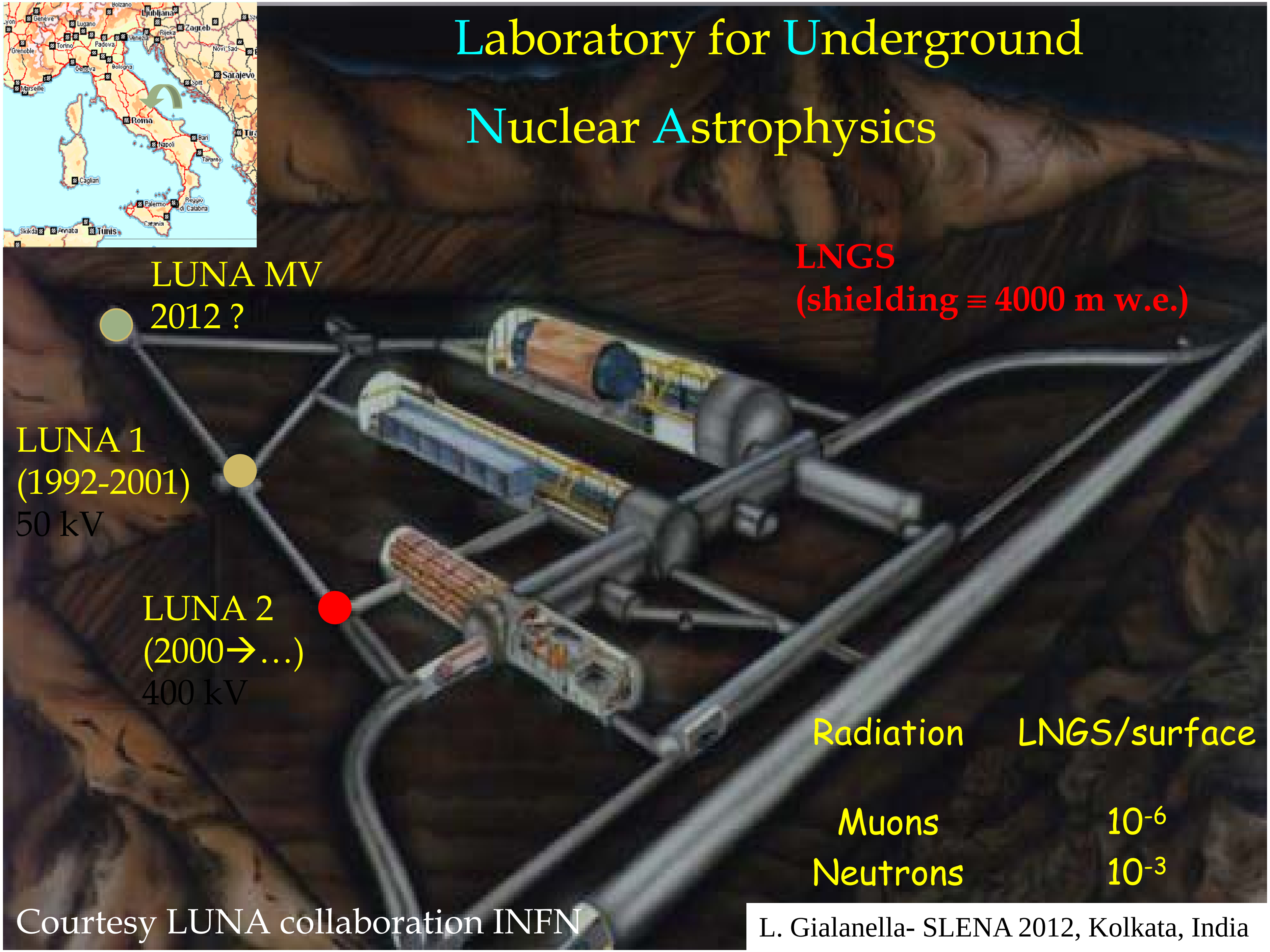
- ^4He beam on ^{12}C solid target
- Targets: (low-energy) ion beam implantation
  - $^{12}C/^{13}C$ separation of accelerated ions
- Array of Ge detectors
  - Eurogam
  - Ge surrounded by BGO crystals (active shielding)
    - Compton suppression
    - Cosmic ray suppression



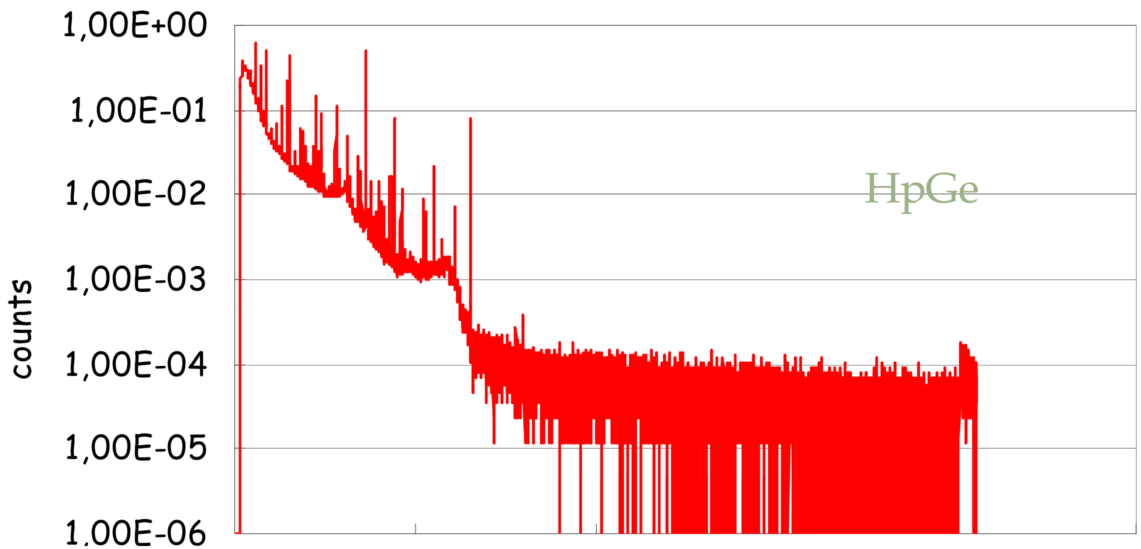




M. Fey, PHD Thesis and Assuncao et al.

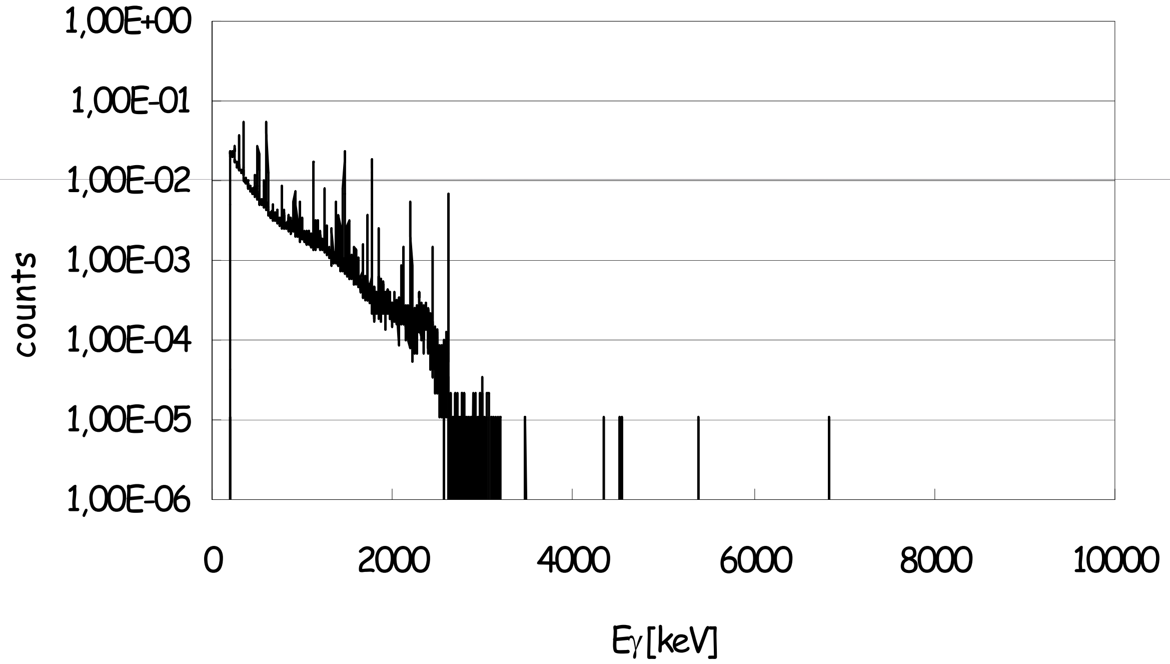


Laboratory for Underground
Nuclear Astrophysics
LNGS
(shielding ≡ 4000 m w.e.)
LUNA MV
2012 ?
LUNA 1
(1992-2001)
50 kV
LUNA 2
(2000→…)
400 kV
Radiation LNGS/surface
Muons 10^{-6}
Neutrons 10^{-3}
Courtesy LUNA collaboration INFN



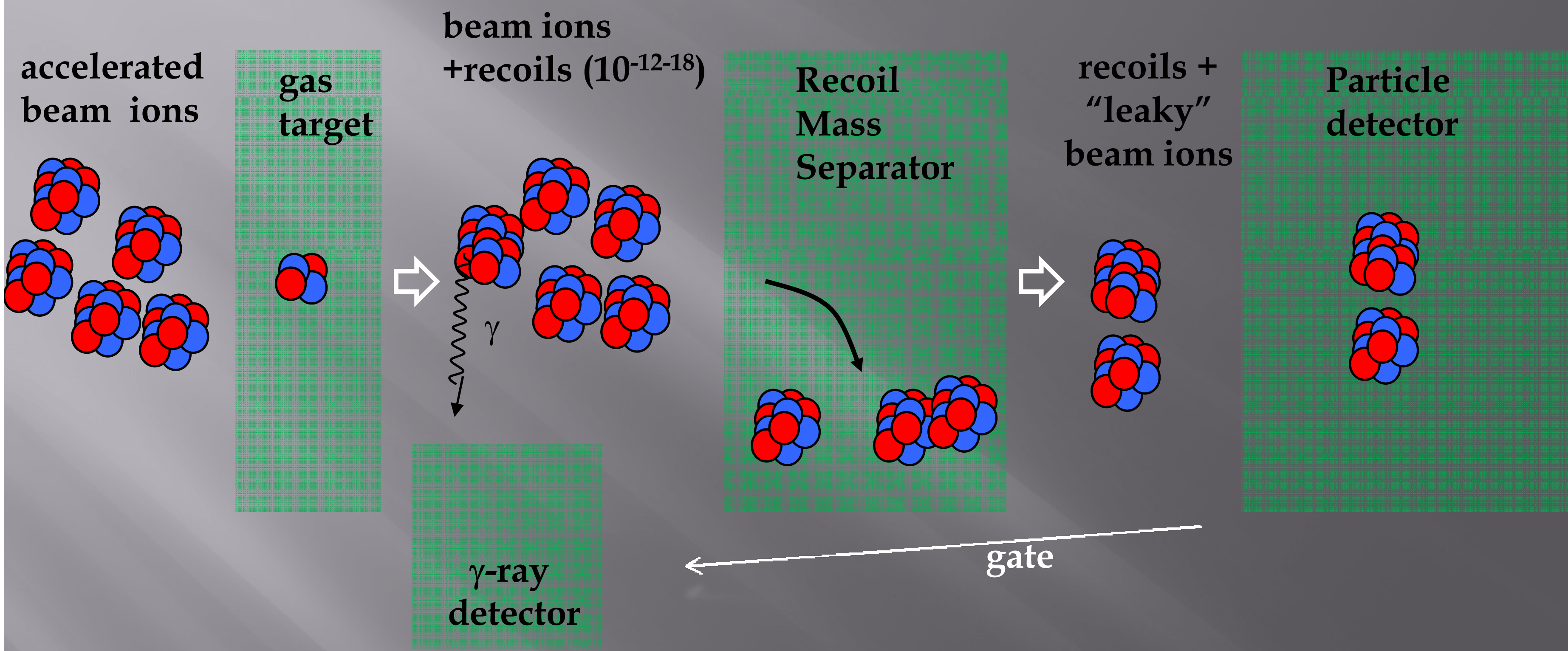
3MeV < Eγ < 8MeV:
0.5 Counts/s

GOING
UNDERGROUND



3MeV < Eγ < 8MeV
0.0002 Counts/s

RMS : working principle



$$N_{recoils} = N_{projectiles} \times n_{target} \times \sigma \times T_{ERNA} \times \Phi_q \times \varepsilon_{part}$$

$$N_{gamma} = N_{recoils} \times \varepsilon_g$$

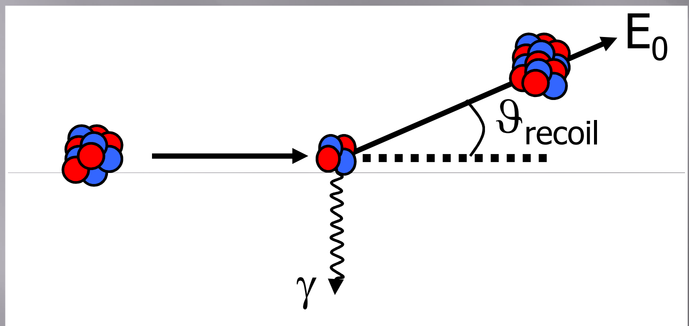
Recoil Separators
basic principles

Angular and energy broadening by γ-ray emission

$p_\gamma = E_\gamma / c$

$\vartheta_\gamma = 90°$

Full angular broadening



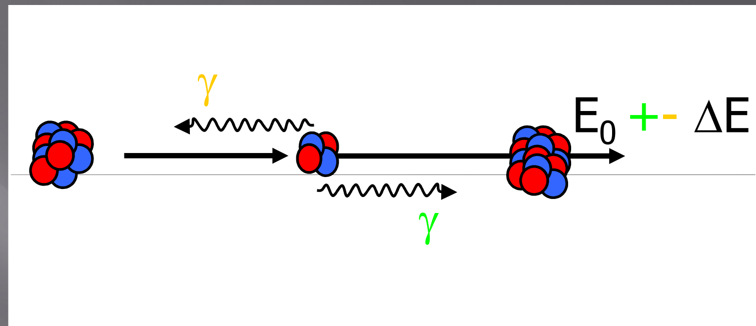
$$\vartheta_{recoil} \approx \tan^{-1}(\Delta p/p) = \tan^{-1}\left(\frac{E\gamma/c}{p_{recoil}}\right)$$

$\vartheta\gamma_{max}$ = 26mrad

-> ø52 mm after 1 m !

$\vartheta_\gamma = 0° / 180°$

Full energy broadening



$$\Delta E/E_0 \approx 2\,\Delta p/p = 2\,\frac{E\gamma/c}{p_{recoil}}$$

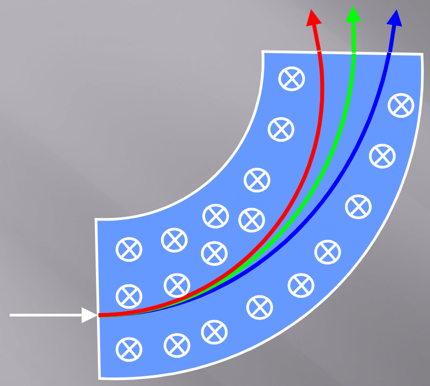
ΔE ~ ±185 keV

E0 = 3.6 MeV

Example $^{12}C(\alpha,\gamma)^{16}O$
E_{cm}=1.2 MeV
$E\gamma$ = 8.4 MeV

courtesy D. Schuermann

Recoil Separators
basic separation principles

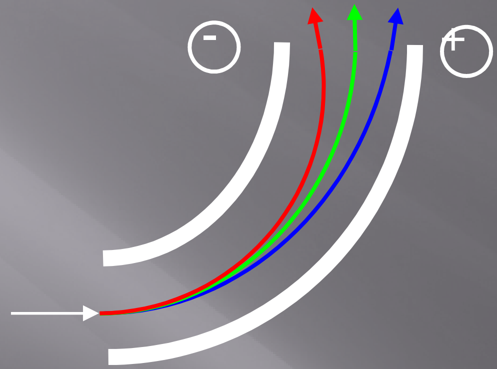


magnetic dipole

$F_z = F_L$

$$\frac{p}{q} = r \times B = \text{const}$$

Momentum filter

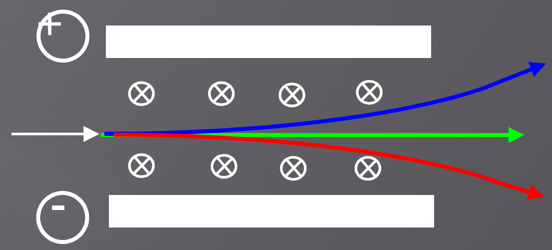


electric dipole

$F_z = F_e$

$$\frac{E}{q} = \frac{r \times U}{2 \times d} = \text{const}$$

Energy filter



Wien filter

$|F_e| = |F_L|$

$$v = \frac{U}{B \times d} = \text{const}$$

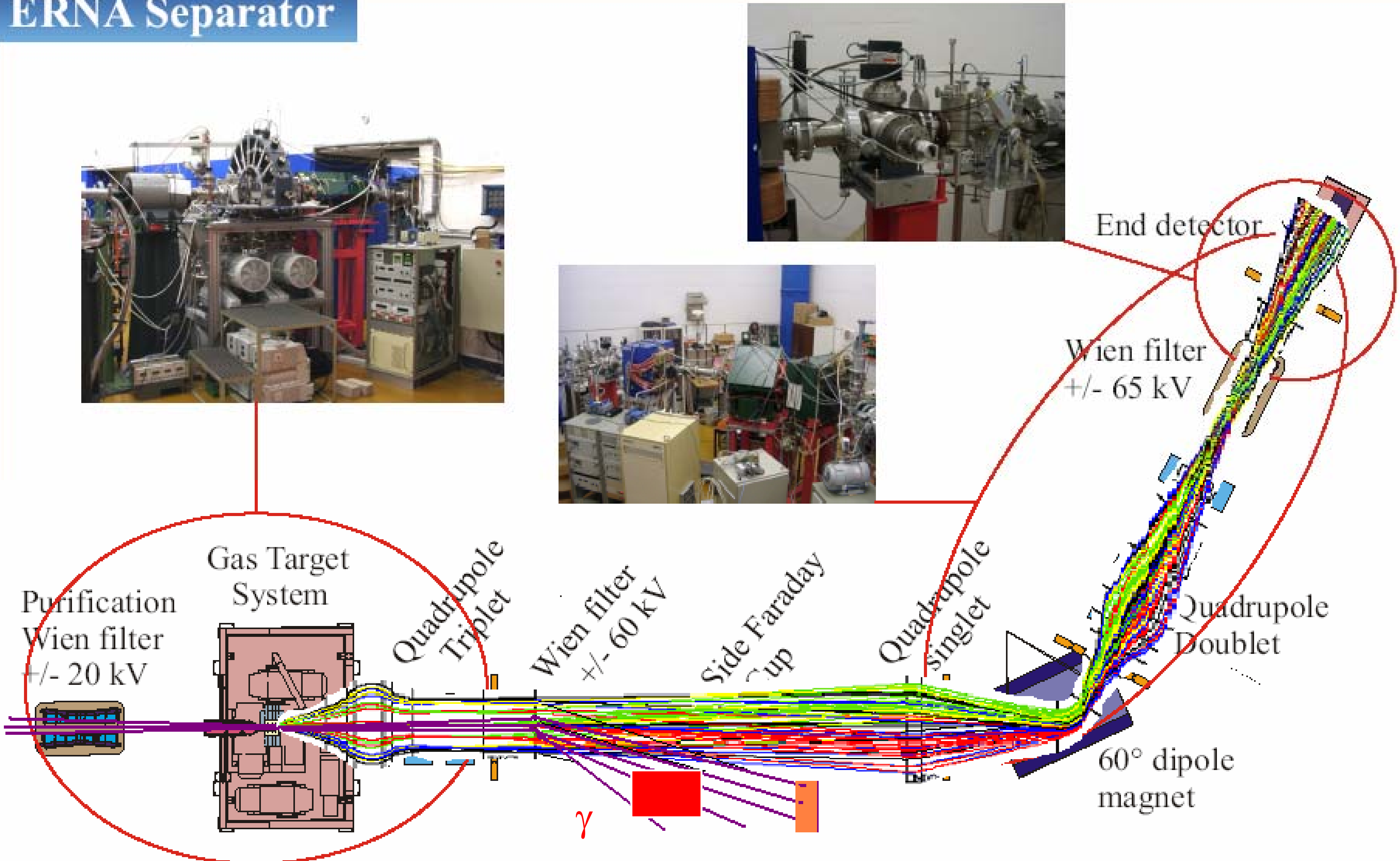
Velocity filter

Charge insensitive for $v=v_0$
Variable analyzing power

Combine to $\frac{m}{q}$ filtering

courtesy D. Schuermann

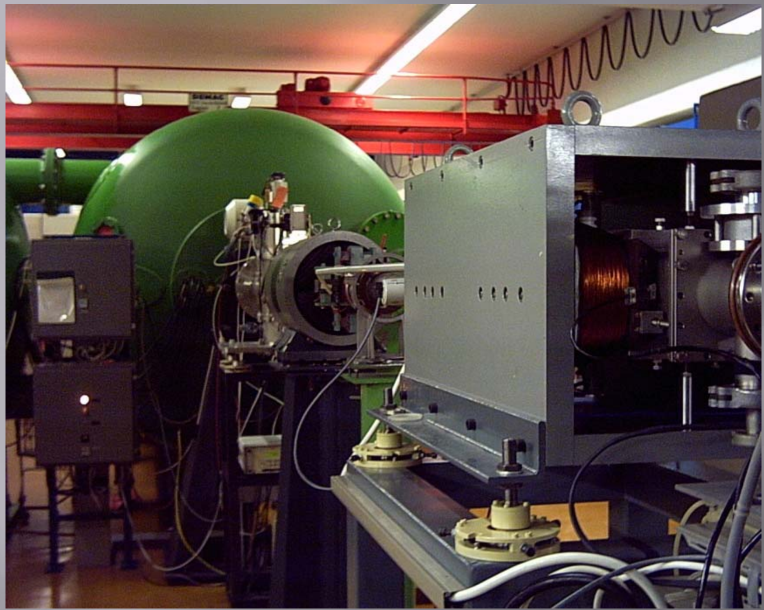
ERNA Separator

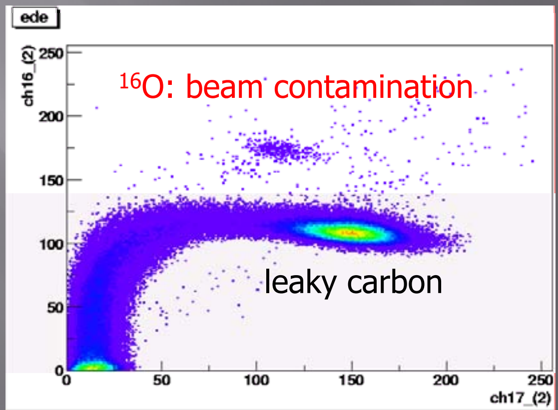


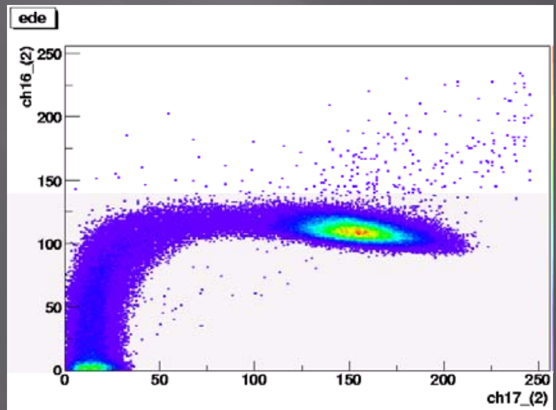
Cosy Infinity M. Berz MSU

Beam purification system

Wien-Filters

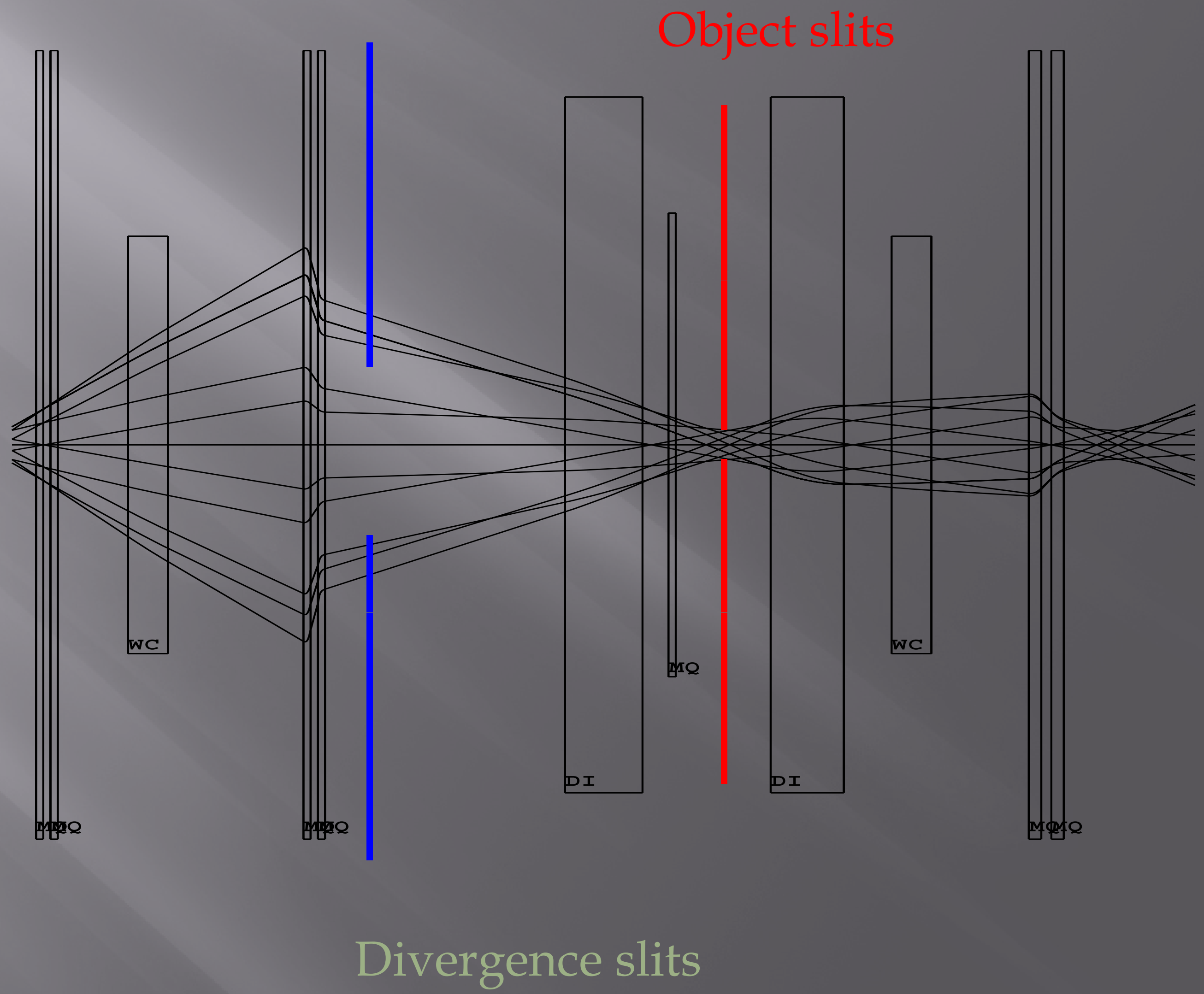




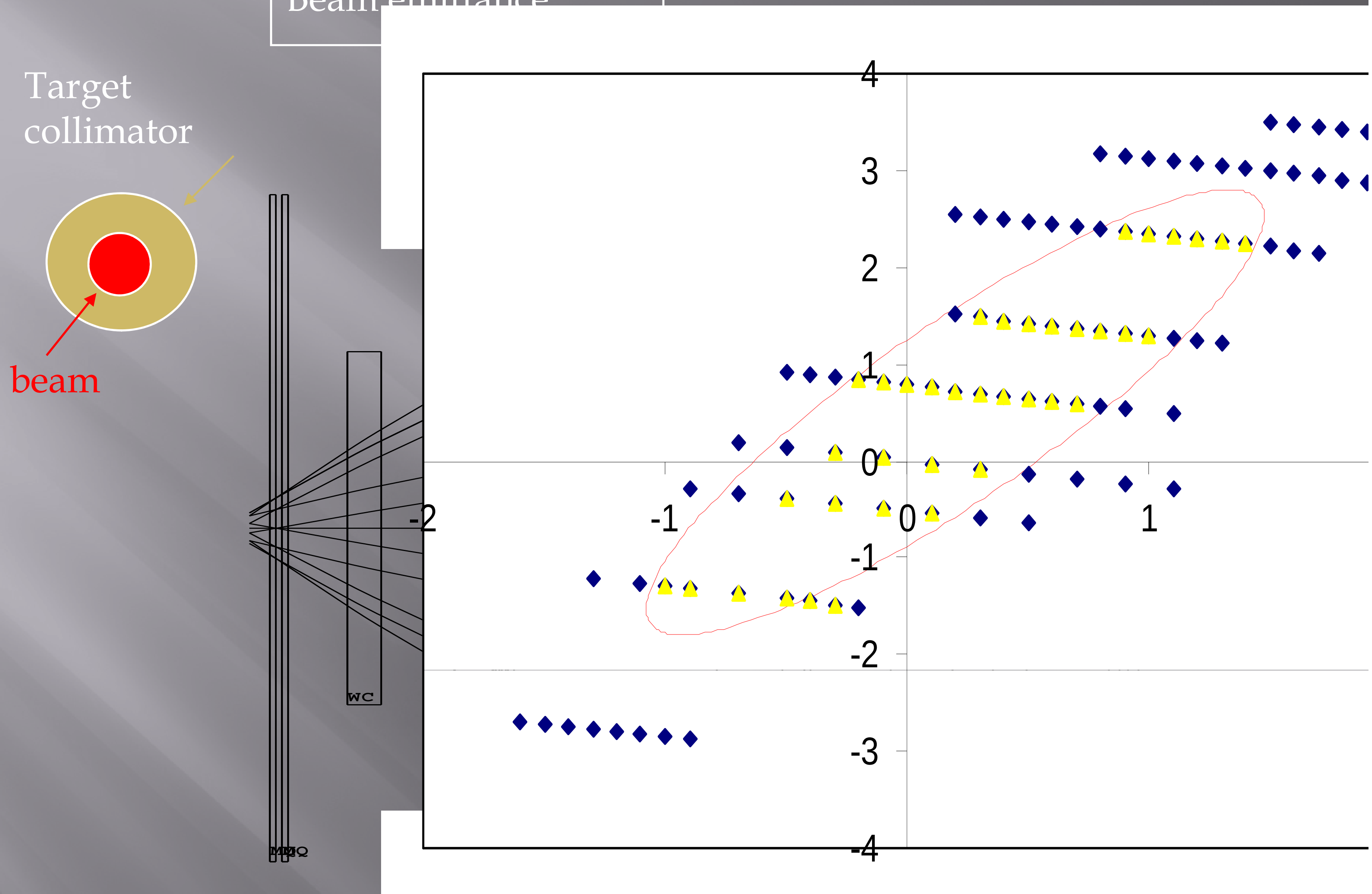


Separator set to Oxygen

Beam emittance



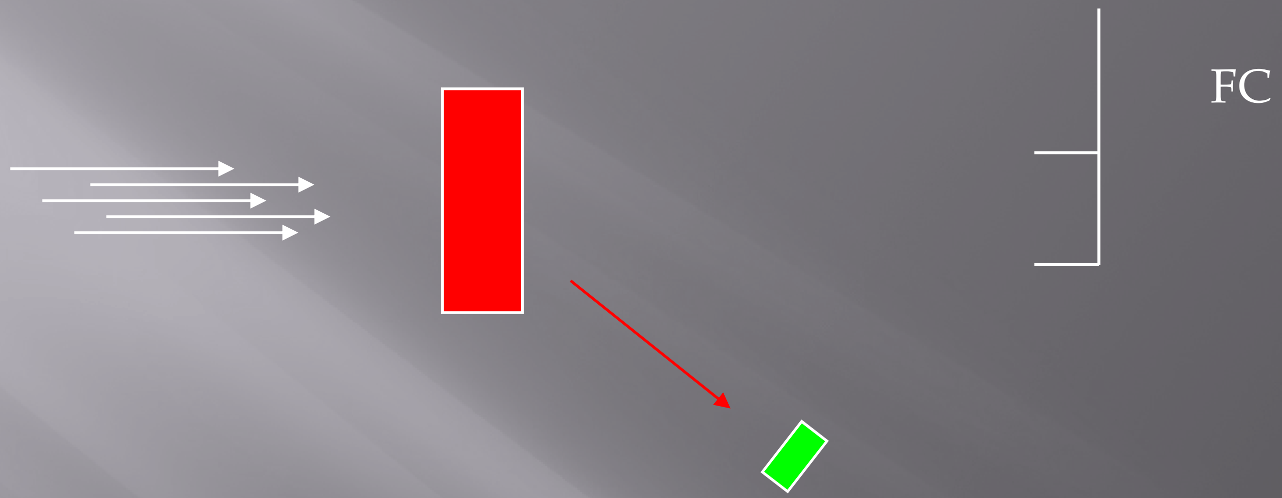
Beam emittance



Divergence slits

Beam intensityt reduction by about 15%

$N_{projectile}$

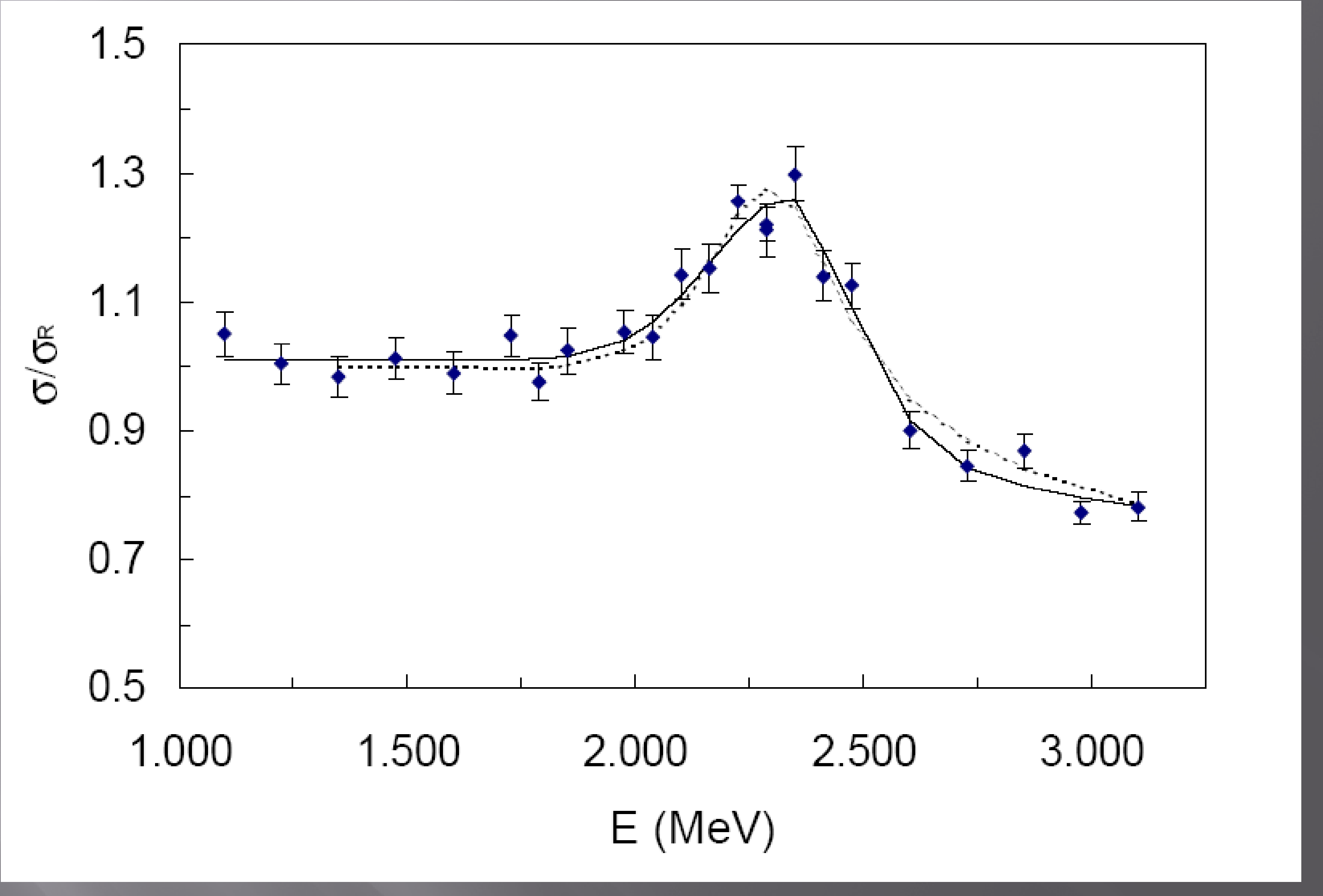


$$N_{elastic} = N_{projectiles} \times d\sigma_{el}(\theta,E)/d\Omega \times \delta n_{target} \times \Delta\Omega \times \varepsilon_{el}$$

Current measurement at FC (without target)

Or altenatively

Deviation from Rutherford using a mixture: $^{12}C(\alpha,\gamma)^{16}O$ at 75°

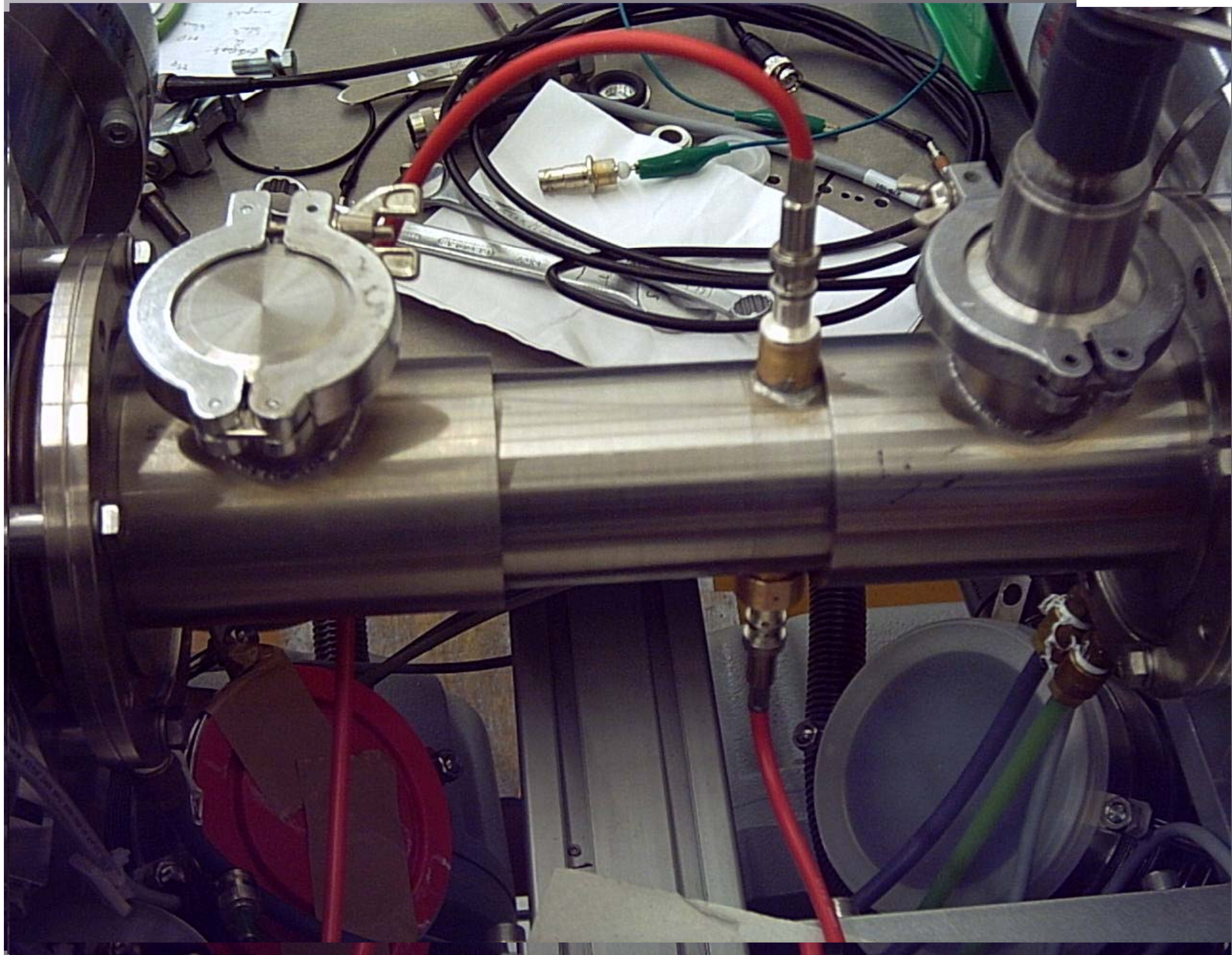


+ normalization to get an absolute scale, e.g. $^{1}H(^{19}F,\alpha\gamma)^{16}O$ $E_{r,cm}$=323 keV

Angular acceptance along the gas target

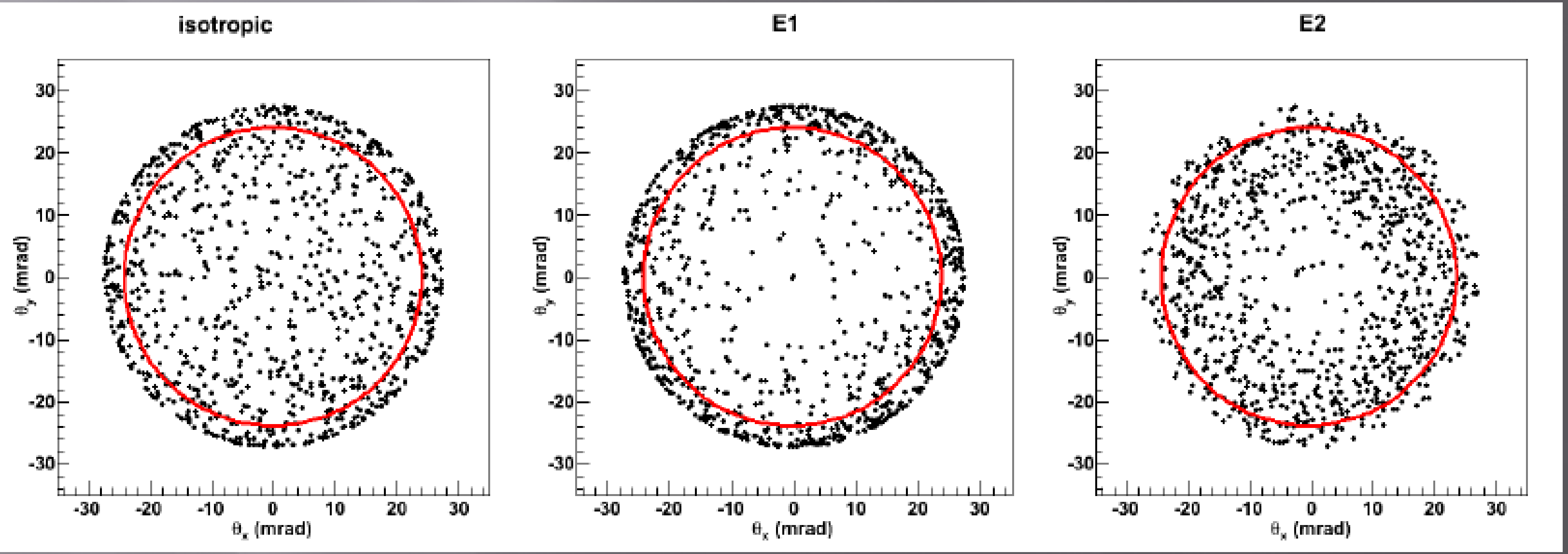
Energy acceptance

+ beam energy variation



Why is acceptance so important? An example: $^{12}C(\alpha,\gamma)^{16}O$ at E_{cm}=1 MeV

Required acceptance:27 mrad
Actual acceptance: 24 mrad

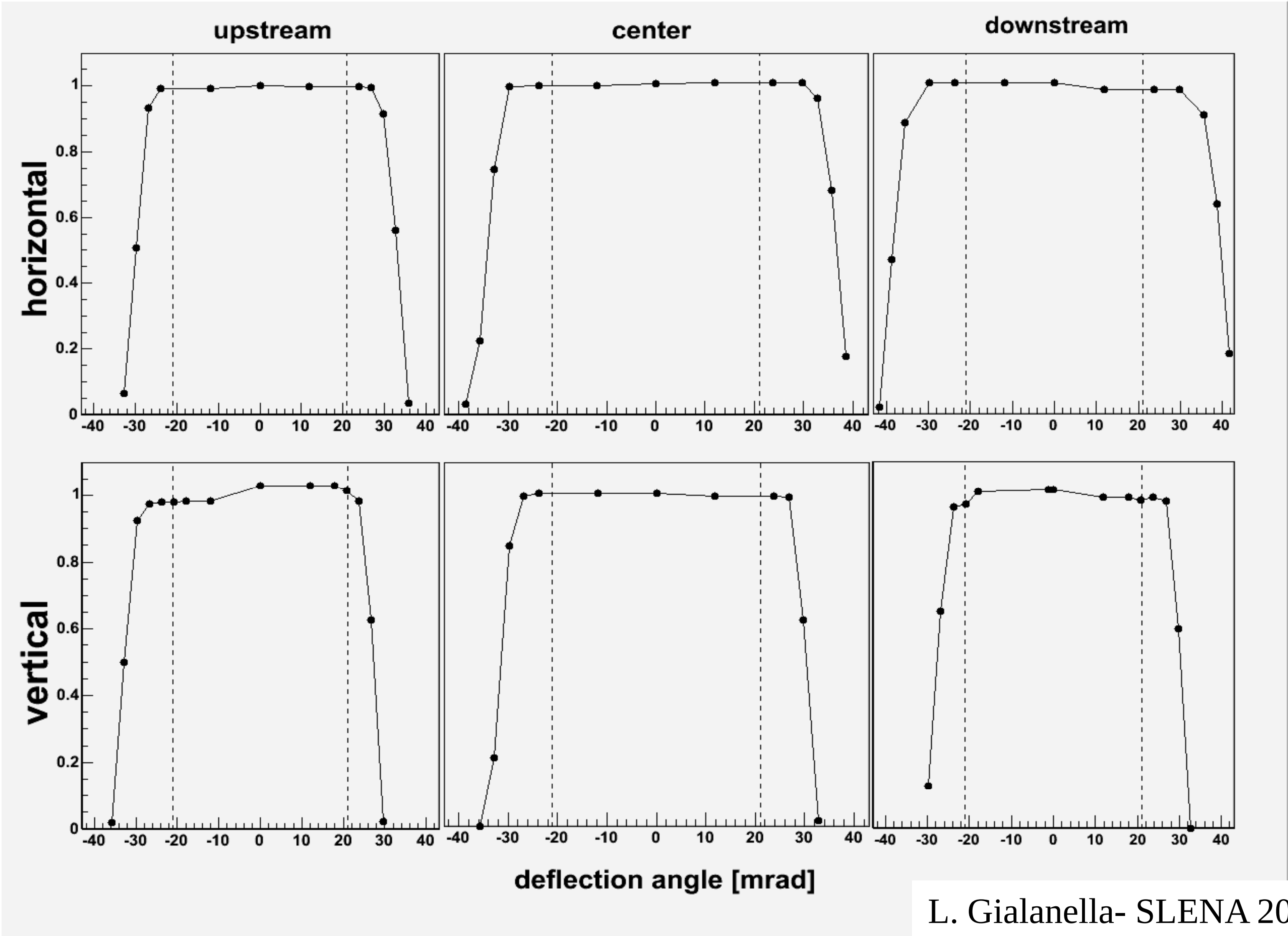


Recoils Loss	47%	66%	23%

(beam and target effects not included)

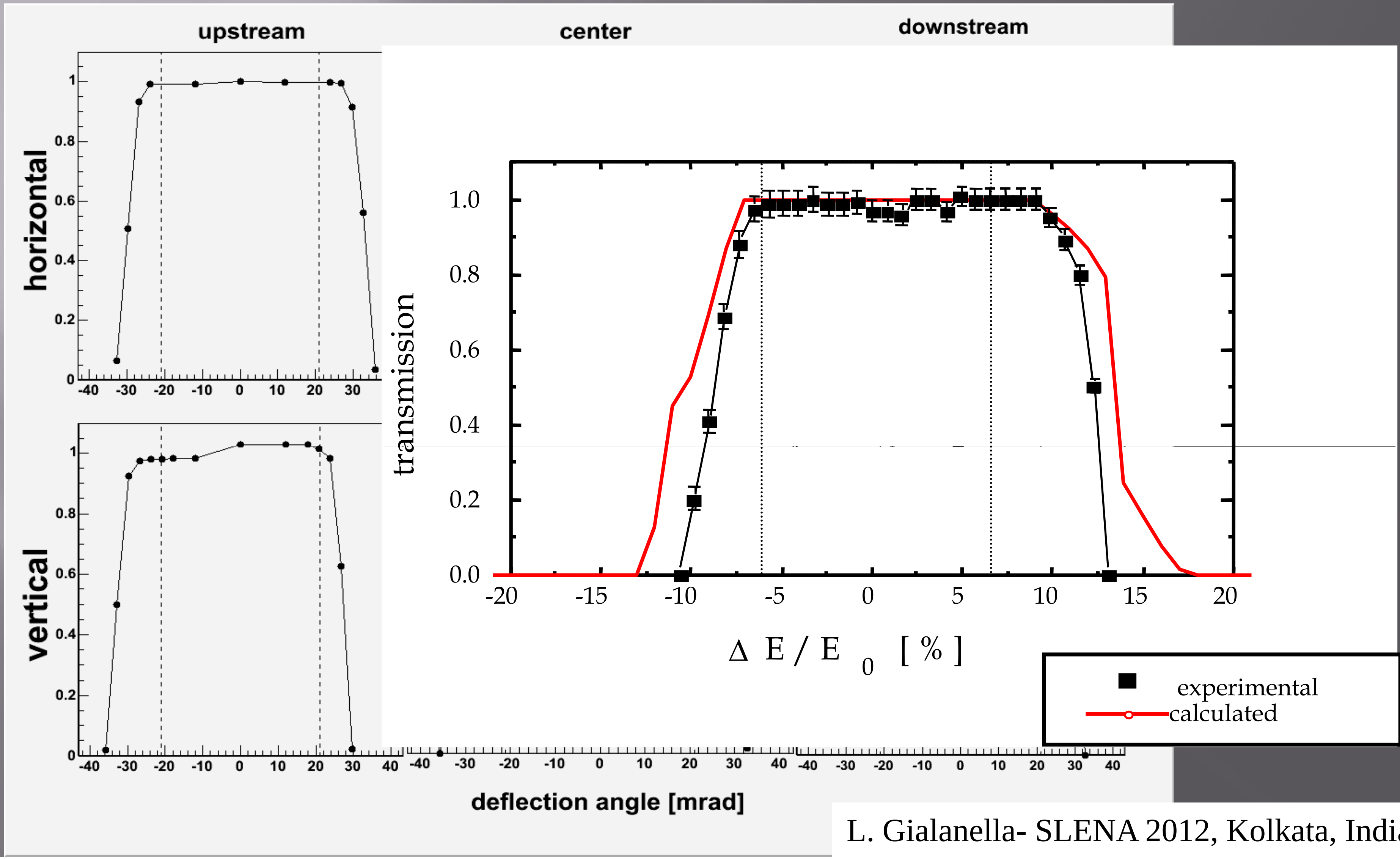
L. Gialanella and D. Schuermann *ENA VI* – POS 2011

Angular acceptance - experimental

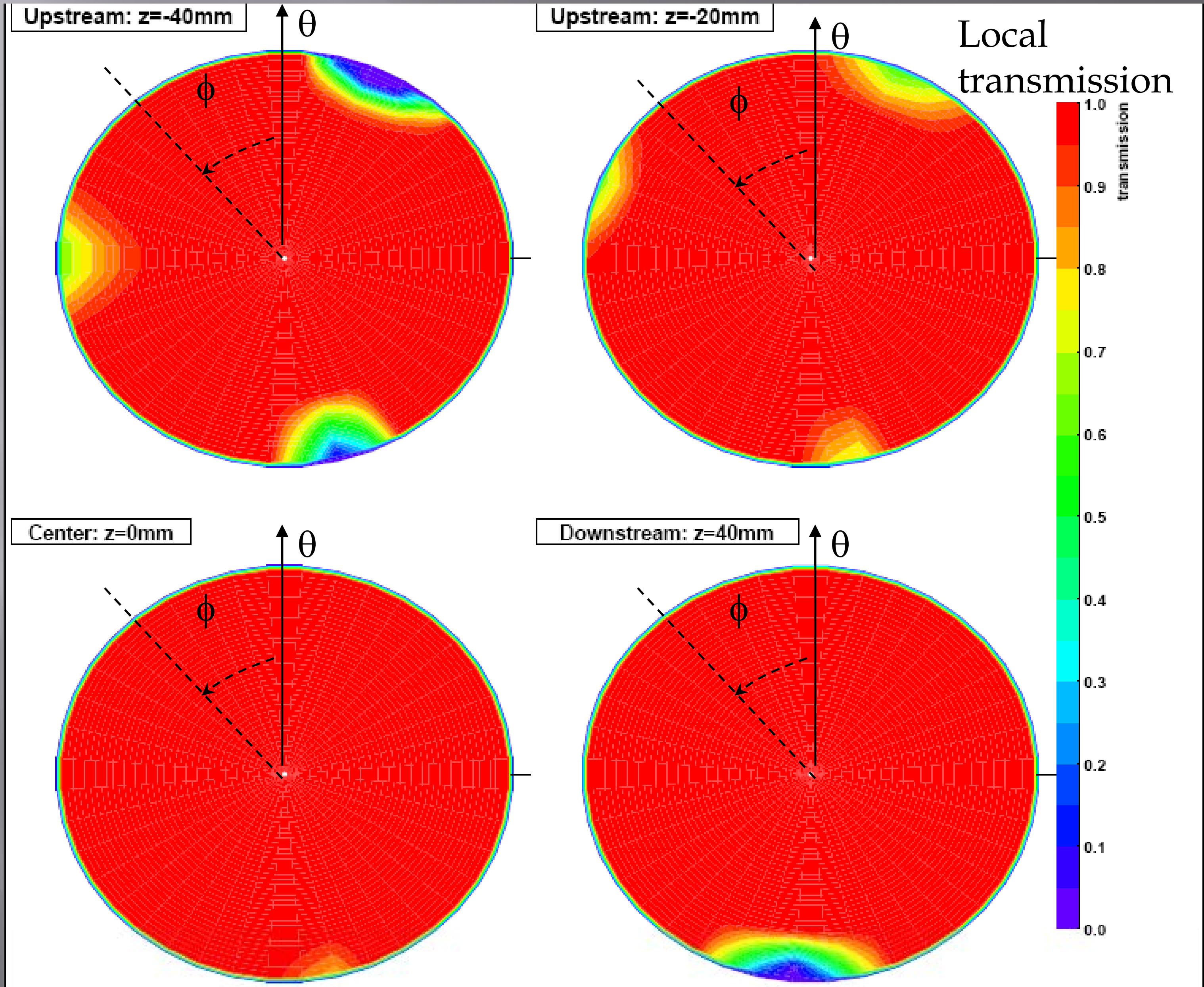


L. Gialanella- SLENA 2012, Kolkata, India

Angular acceptance - experimental
Energy acceptance - experimental



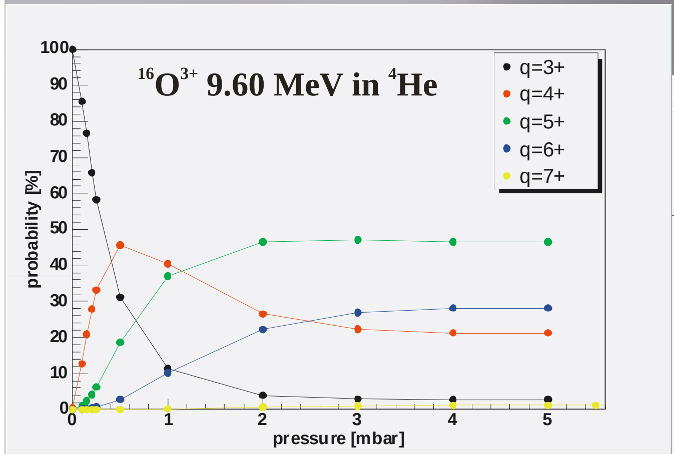
$^{3}He(\alpha,\gamma)^{7}Be$ E_{cm}=700keV



Integrated transmission > 99%

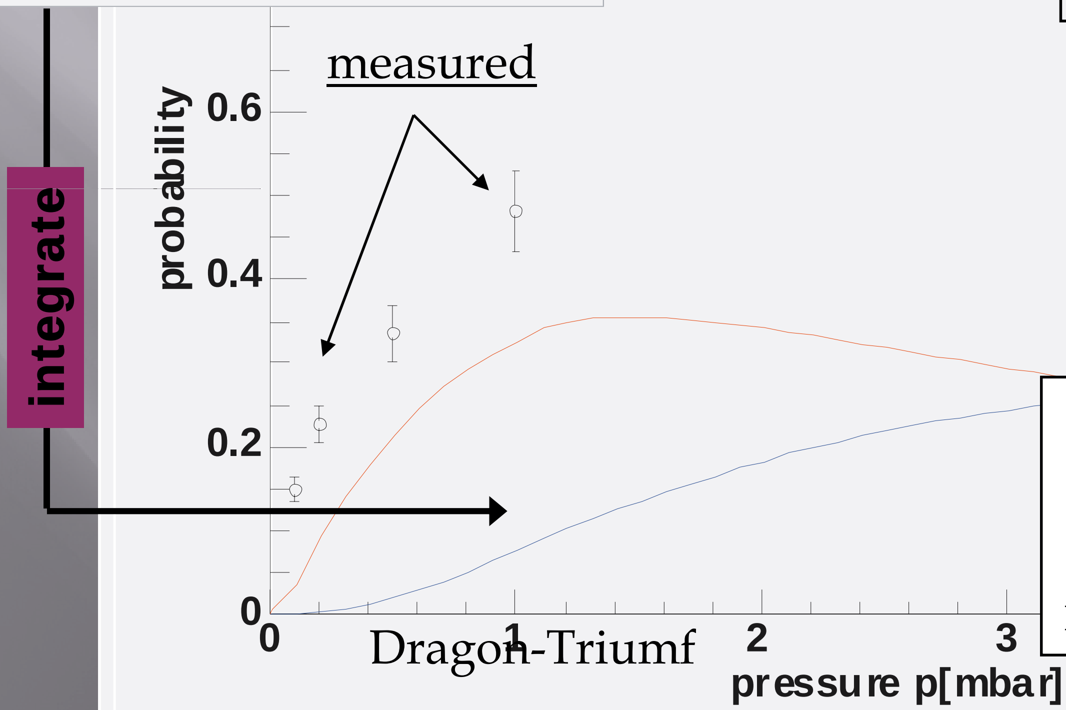
Charge state distribution

measured using the charge state sensitivity of ERNA
(measurement of currents, not single ions!)



$^{12}C^{3+} \rightarrow {}^{16}O^{6+}$

Ecm=3.2 MeV



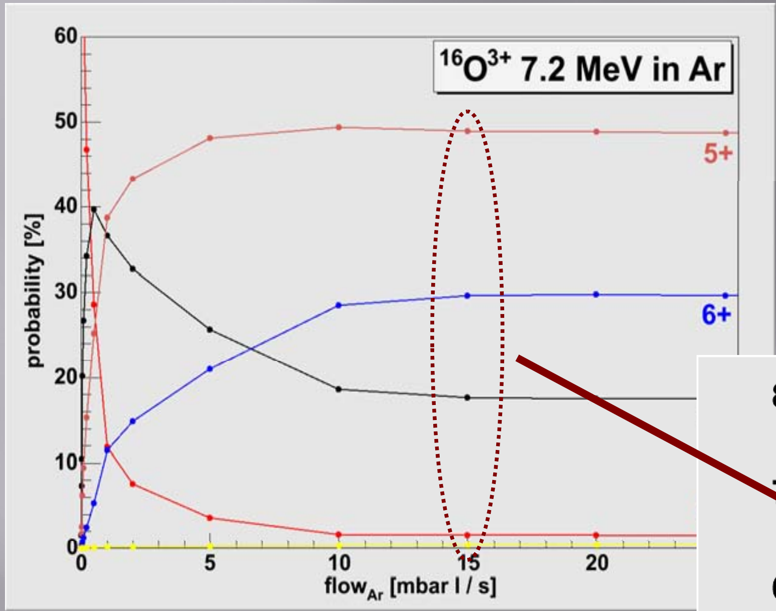
calculated

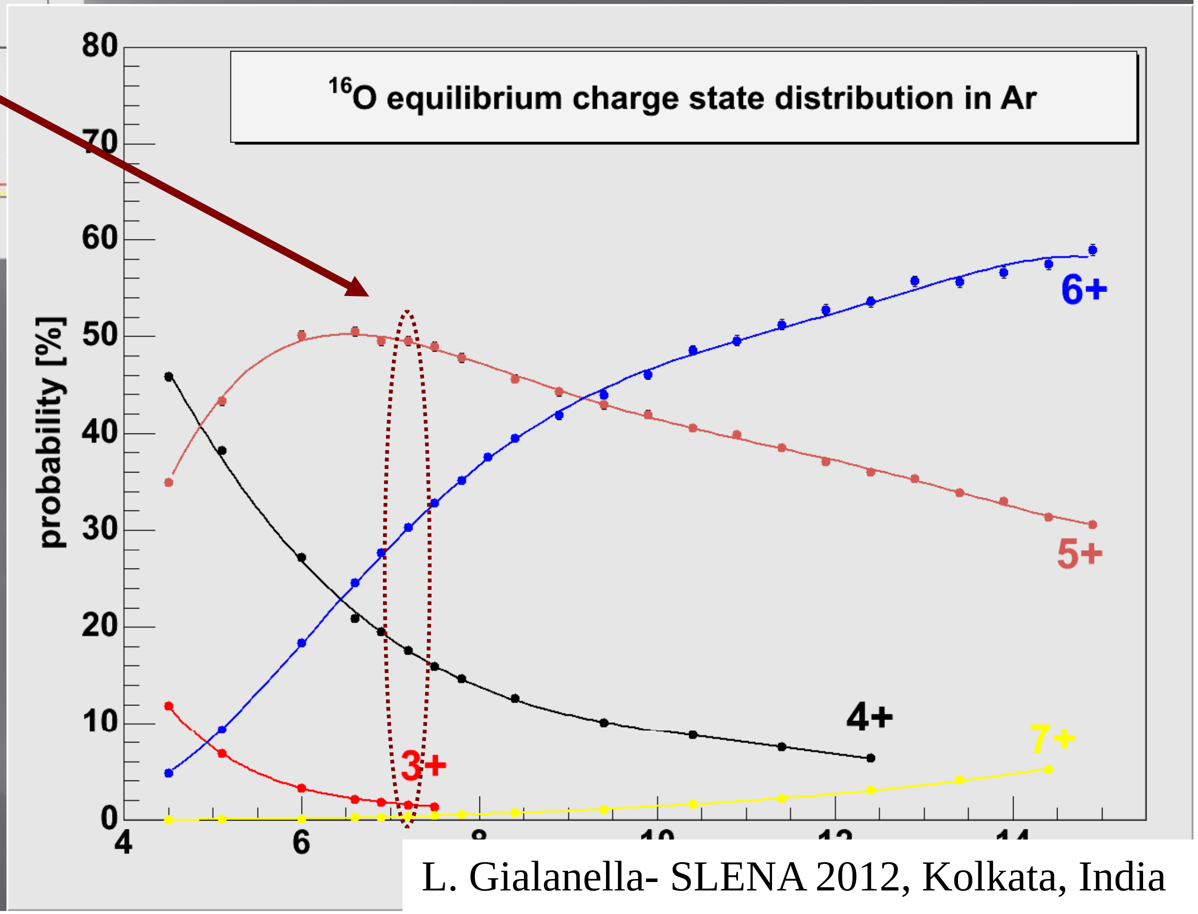
$q_{recoil} = q_{carbon}$

$q_{recoil} = q_{carbon} + 2$

Solution:
post-target stripper
or, when possible
measurement in all charge states

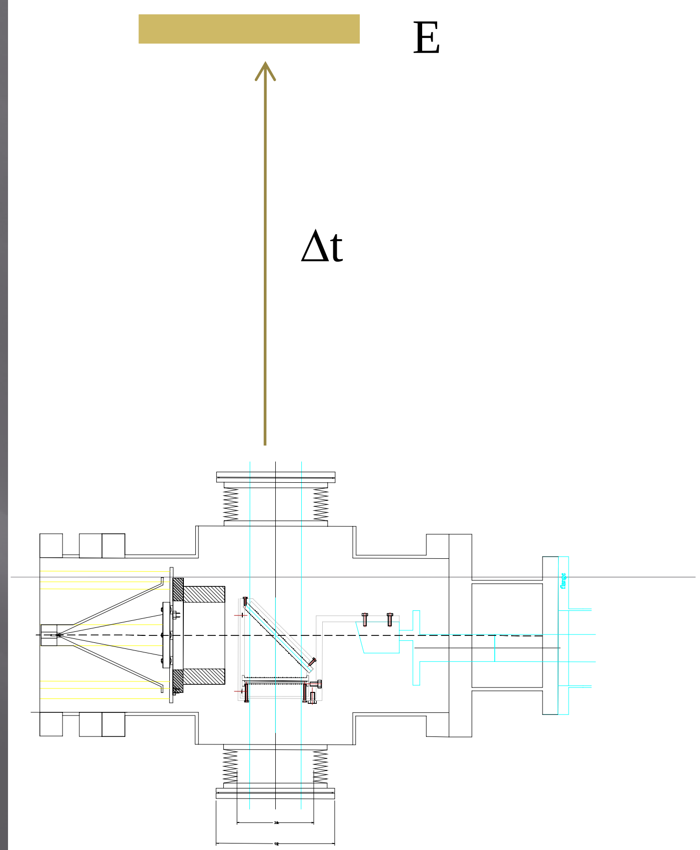
^{16}O in Ar post stripper





Recoil detection and identification

Mass identification



$\Delta t = L\,(m/2E)^{1/2}$

Charge identification

ΔE

E_{res}

$\Delta E \cdot E \propto MZ^2$

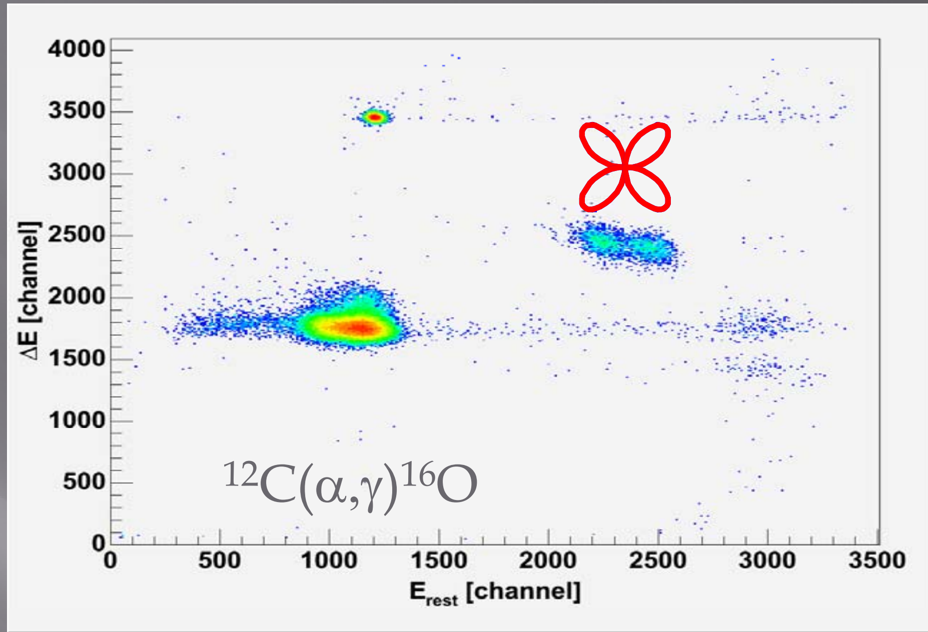
Recoil detection

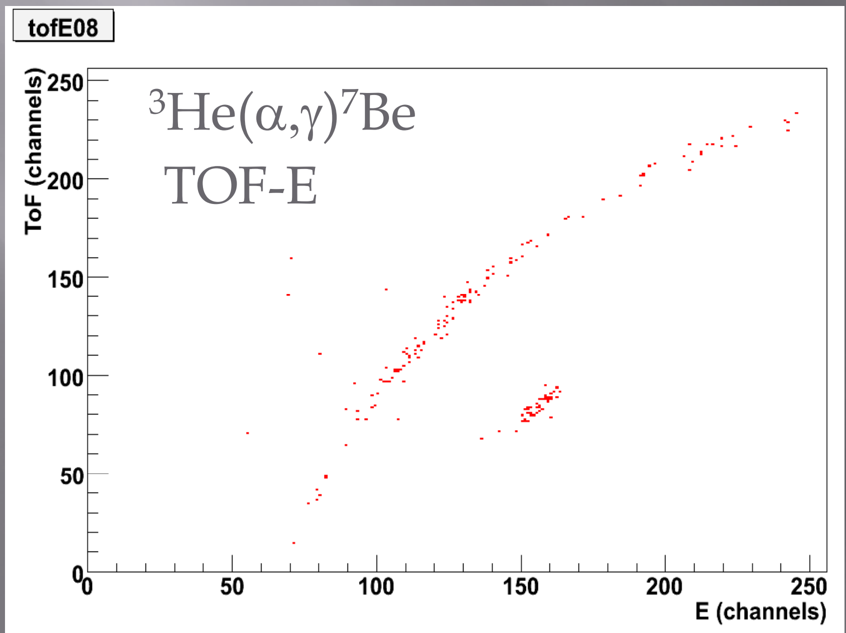
<u>Full acceptance</u>

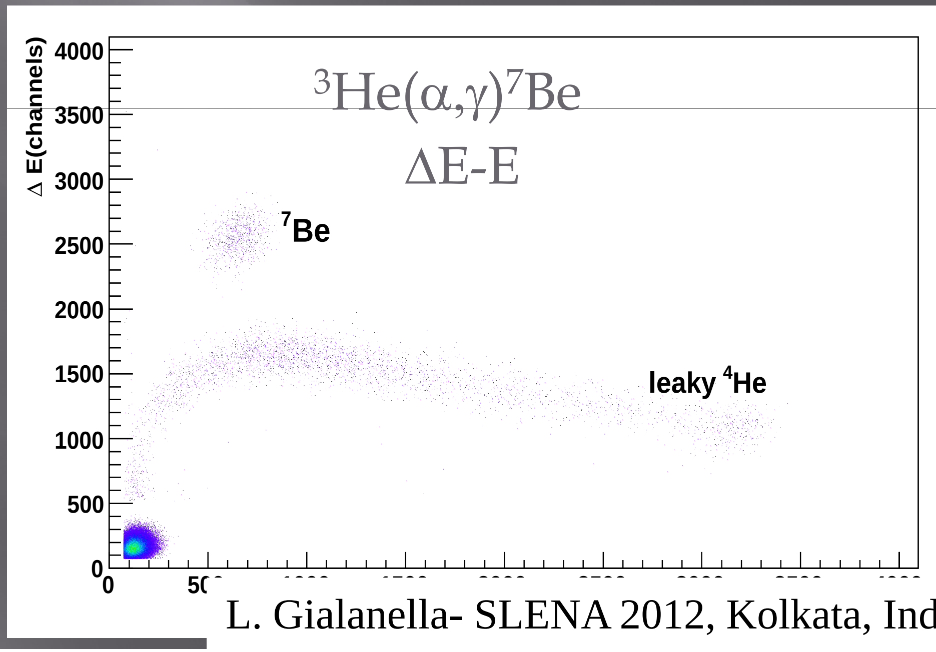
<u>Suppression</u>

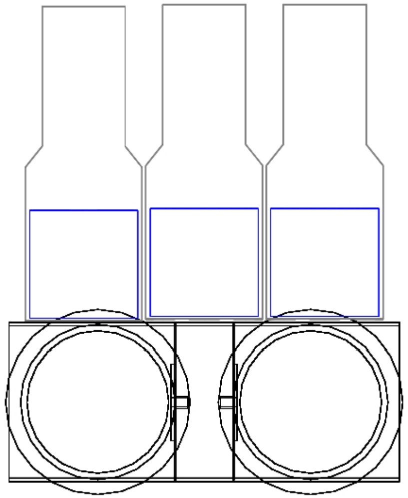
Separator: 10^{-10}-10^{-11}

Detector : 10^{-3}-10^{-6}

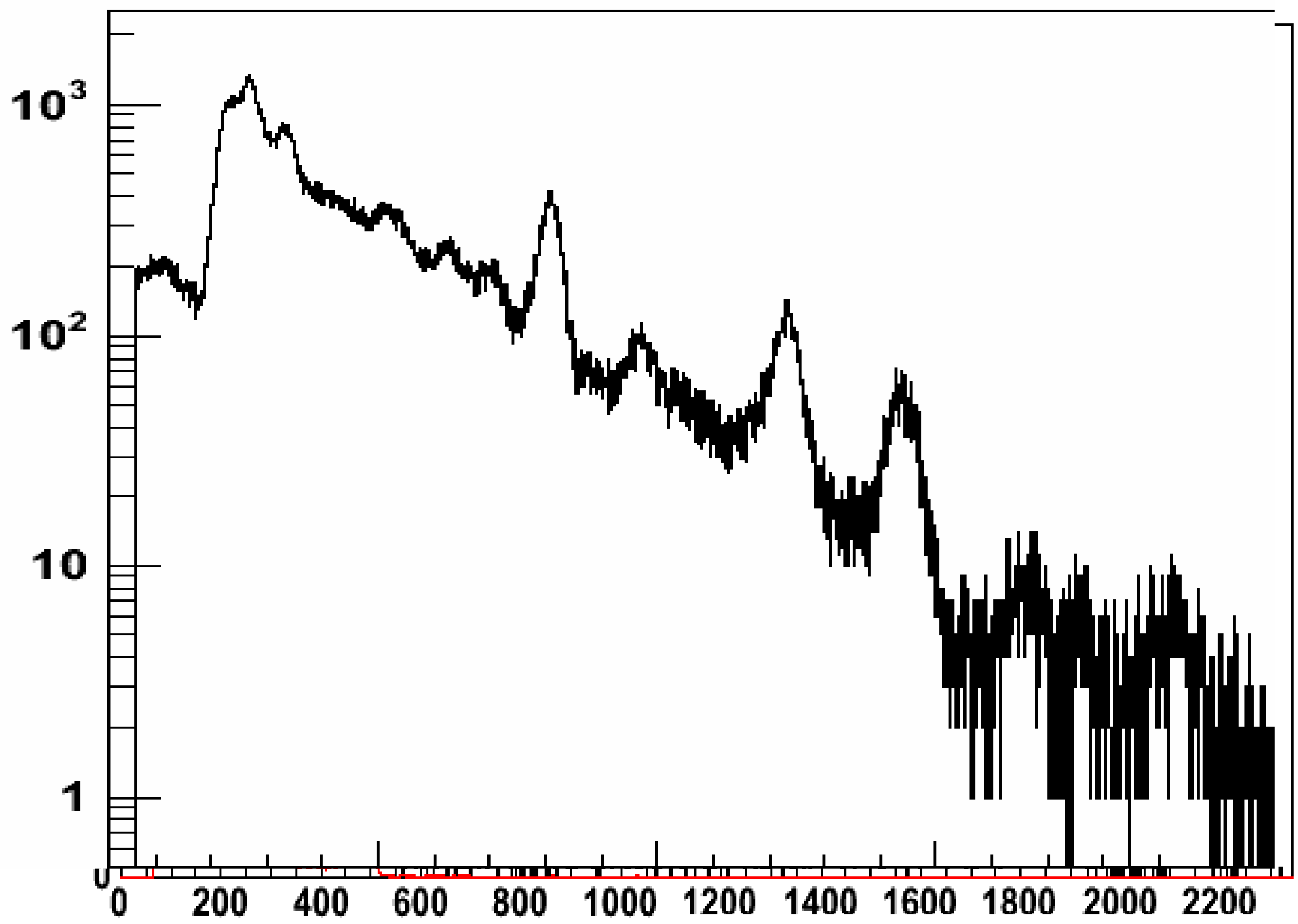




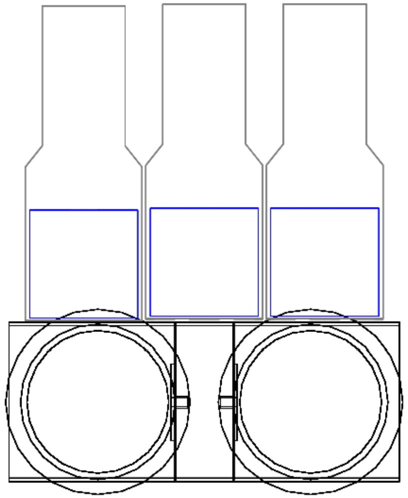


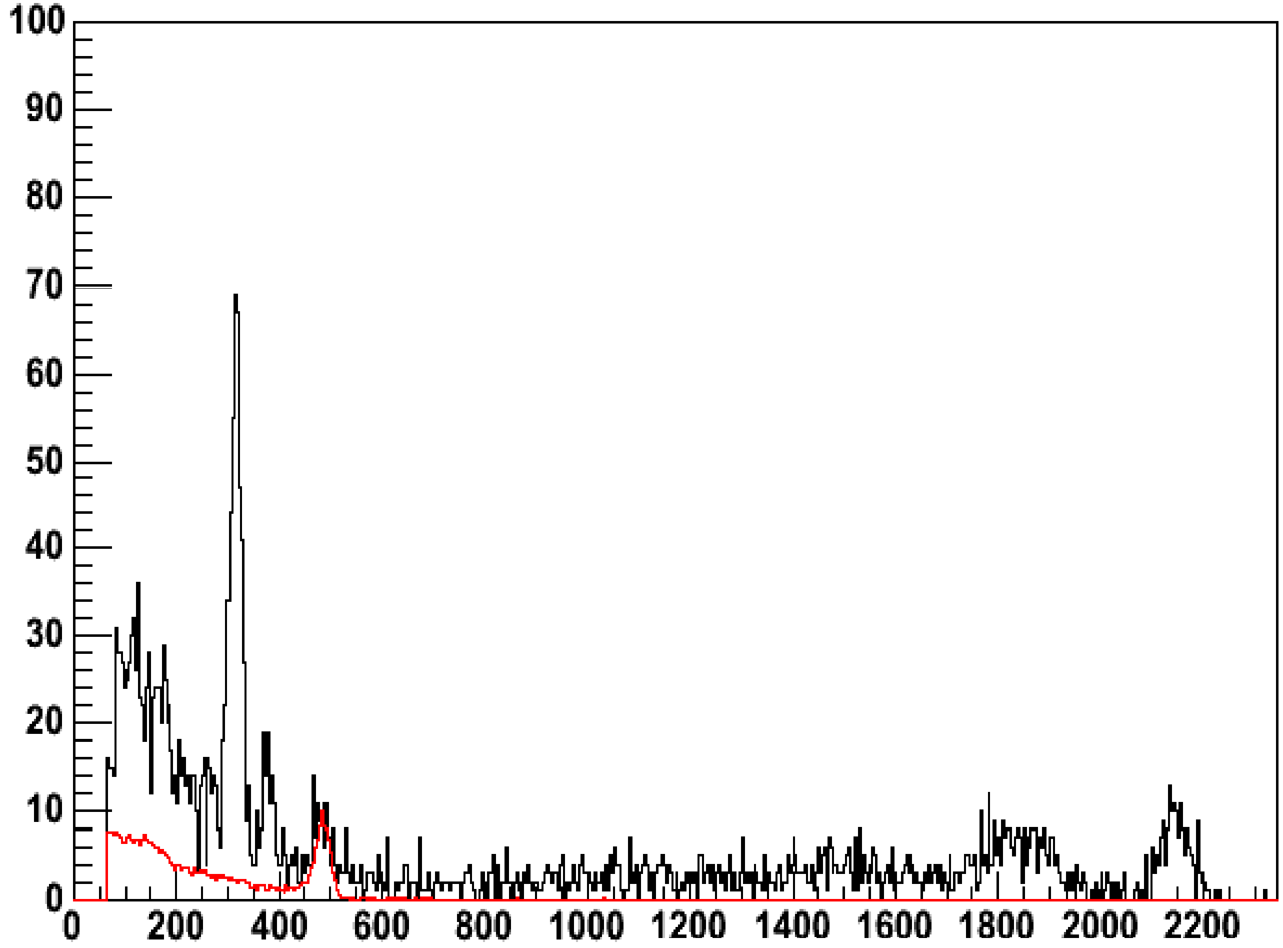


$^{3}He(\alpha,\gamma)^{7}Be$ – γ measurements

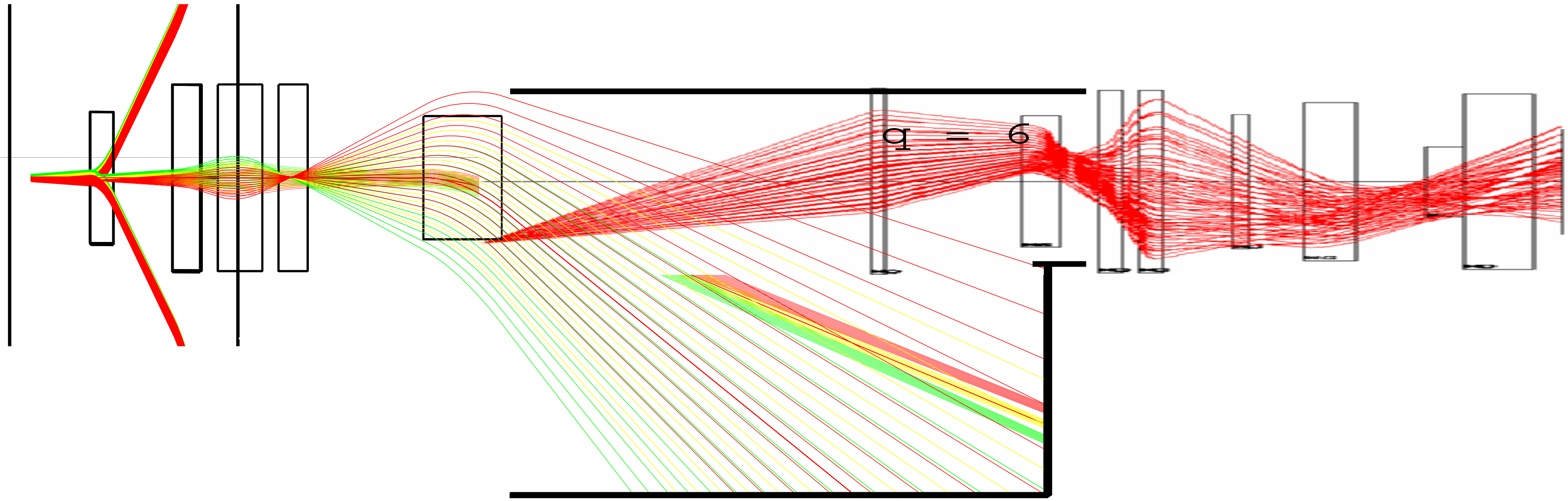


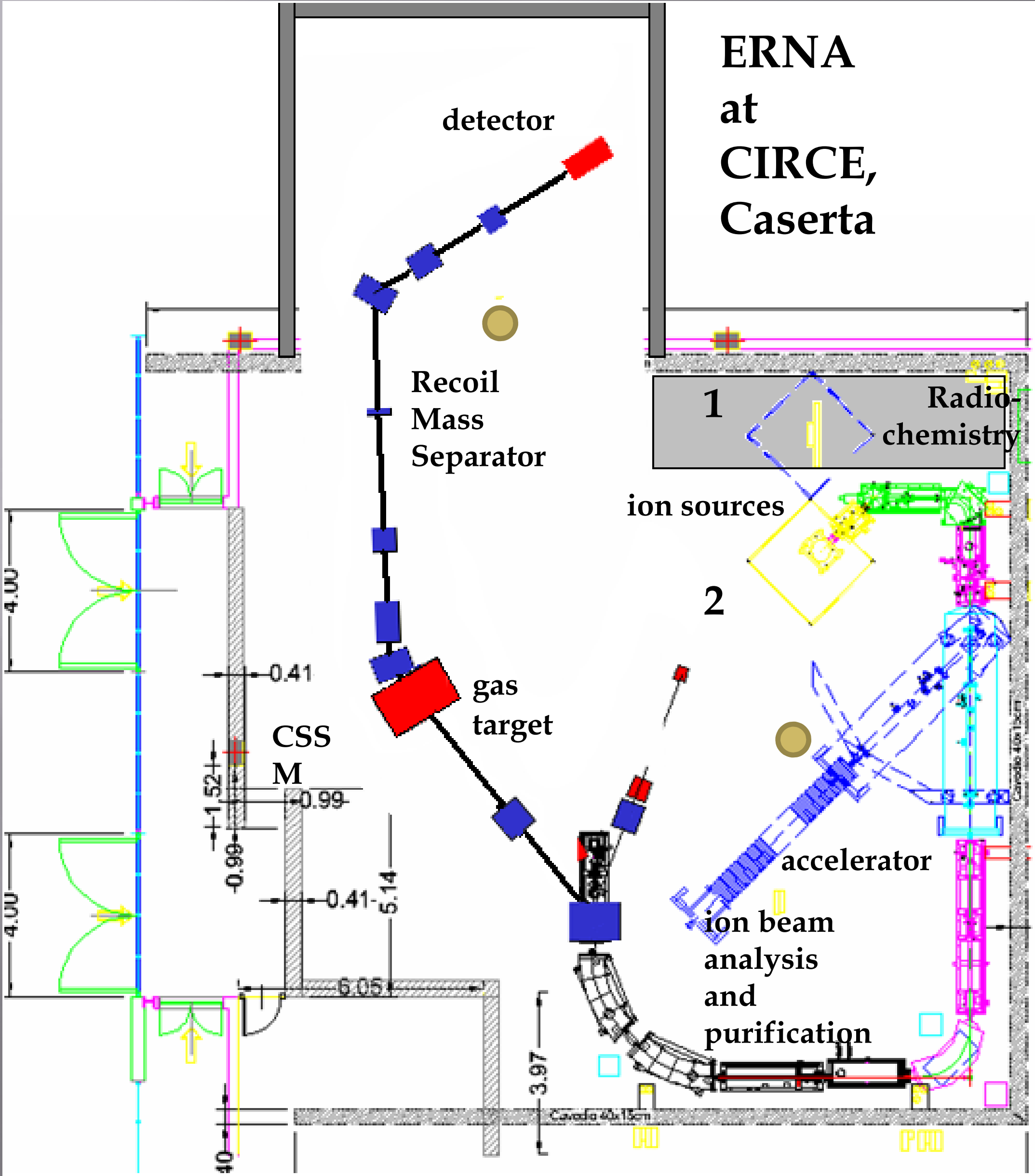
$^3He(\alpha,\gamma)^7Be$ – γ measurements





Background and leaky beams





ERNA at CIRCE, Caserta

3MV Pelletron
High intensity stable and radioactive ($^{7,10}Be$) ion beams (possible ^{26}Al)

Plans:
- $^{7}Be(p,\gamma)^{8}B$
- $^{12}C(\alpha,\gamma)^{16}O$
- $^{16}O(\alpha,\gamma)^{20}Ne$
- $^{33}S(p,\gamma)^{34}Cl$
- $^{14,15}N(\alpha,\gamma)^{18,19}F$
- SHE in nature