Fluorine nucleosynthesis: measurement of $^{15}N(\alpha,\gamma)^{19}F$

A. Di Leva for the ERNA Collaboration

Origin of ^{19}F: a long standing issue

three the possible **astrophysical sites** proposed:

1. **type II Supernovae:** via spallation of ^{20}Ne by ν_μ and ν_τ
3. **Wolf Rayet stars:** massive stars experiencing large mass loss episodes, where the material exposed to the He burning can be ejected before the fluorine destruction occurs via the ^{19}F(α,*p*)^{22}Ne reaction
5. **Asymptotic Giant Branch (AGB)** stars via the chains
   ^{14}N(n,p)^{14}C(α,γ)^{18}O(p,α)^{15}N(α,γ)^{19}F
   ^{14}N(α,γ)^{18}F(β+)^{18}O(p,α)^{15}N(α,γ)^{19}F
   neutrons from ^{13}C(α,n)^{16}O, protons from ^{14}N(n,p)^{14}C

in the convective zones generated by recurring He-burning thermonuclear runaways (thermal pulses). **Most promising:** observational evidence of ^{19}F in outer envelope

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Sensitivity to nuclear inputs

Updated nuclear network cross sections, models computed with FUNS.
Main uncertainty related to $^{13}C(\alpha,n)^{16}O$ and $^{14}N(p,\gamma)^{15}O$

However, playing a little with unlikely options:

Table 3. Scaling factors *sf* of the computed tests with the corresponding ^{19}F and F/⟨s⟩ surface ratios with respect to the reference case.

Reaction rate	*sf*	$R(^{19}F)$	$R(F/\langle s \rangle)$
$^{13}C(\alpha,n)^{16}O$	0.01	4.70	2.80
$^{13}C(\alpha,n)^{16}O$	100	0.62	0.67
$^{14}C(\alpha,\gamma)^{18}O$	0.01	1.03	1.59
$^{14}C(\alpha,\gamma)^{18}O$	100	1.04	1.61
$^{14}N(\alpha,\gamma)^{18}F$	0.01	3.03	5.14
$^{14}N(\alpha,\gamma)^{18}F$	100	0.64	1.10
$^{15}N(\alpha,\gamma)^{19}F$	0.01	0.11	0.12
$^{15}N(\alpha,\gamma)^{19}F$	100	0.96	1.50
$^{18}O(\alpha,\gamma)^{22}Ne$	0.01	2.21	2.01
$^{18}O(\alpha,\gamma)^{22}Ne$	100	0.52	0.52
$^{19}F(\alpha,p)^{22}Ne$	0.01	1.05	1.19
$^{19}F(\alpha,p)^{22}Ne$	100	0.08	0.14

$^{14}C(\alpha,\gamma)^{18}O$
$^{18}O(\alpha,\gamma)^{22}Ne$ → No variation

$^{14}N(\alpha,\gamma)^{18}F$
$^{13}C(\alpha,n)^{16}O$ → Small variation

$^{15}N(\alpha,\gamma)^{19}F$
$^{19}F(\alpha,p)^{22}Ne$ → Large variation

Cristallo et al. A&A 570, A46 (2014) Effects of nuclear cross sections on ^{19}F nucleosynthesis at low metallicities (RN)

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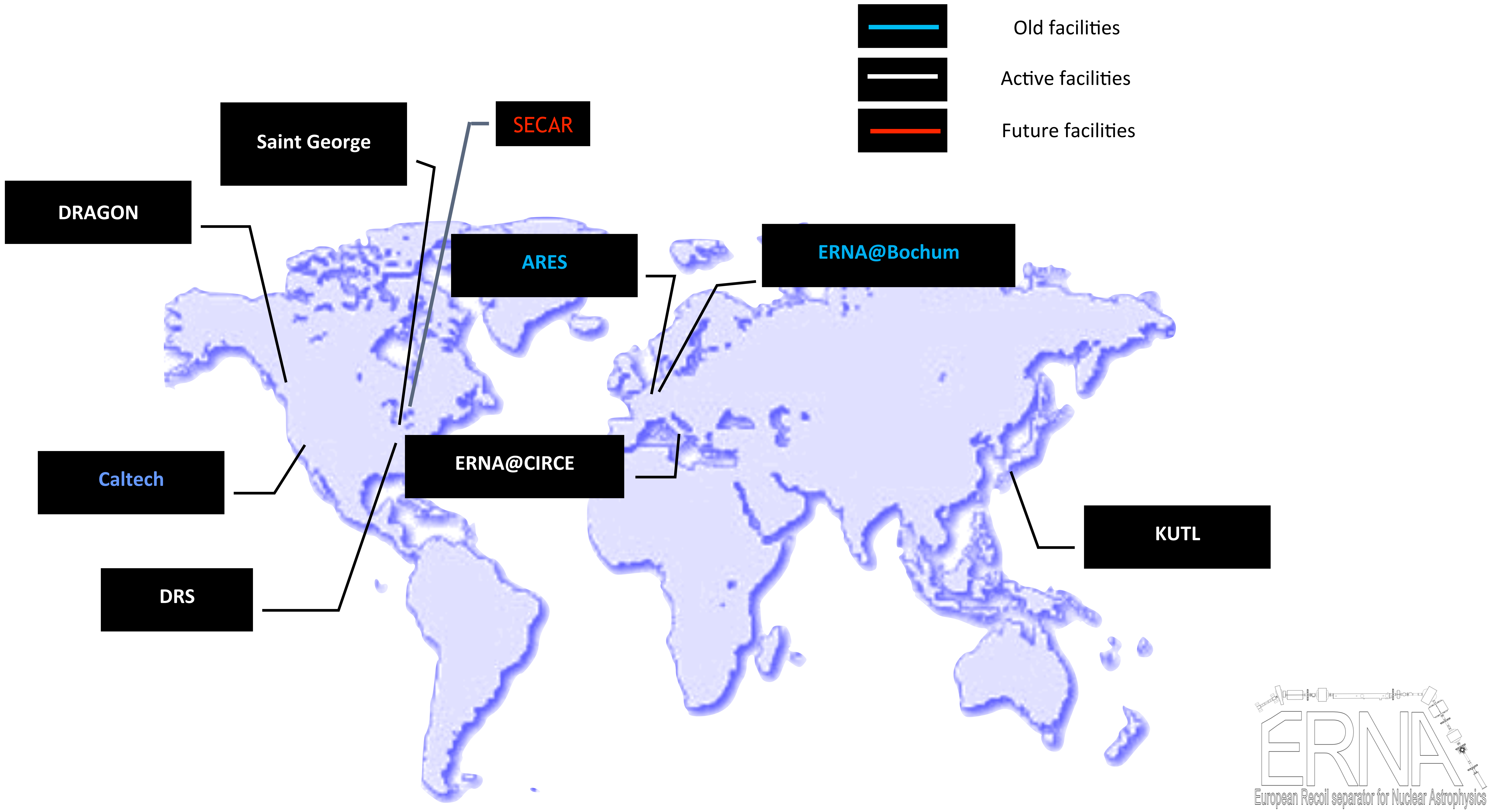
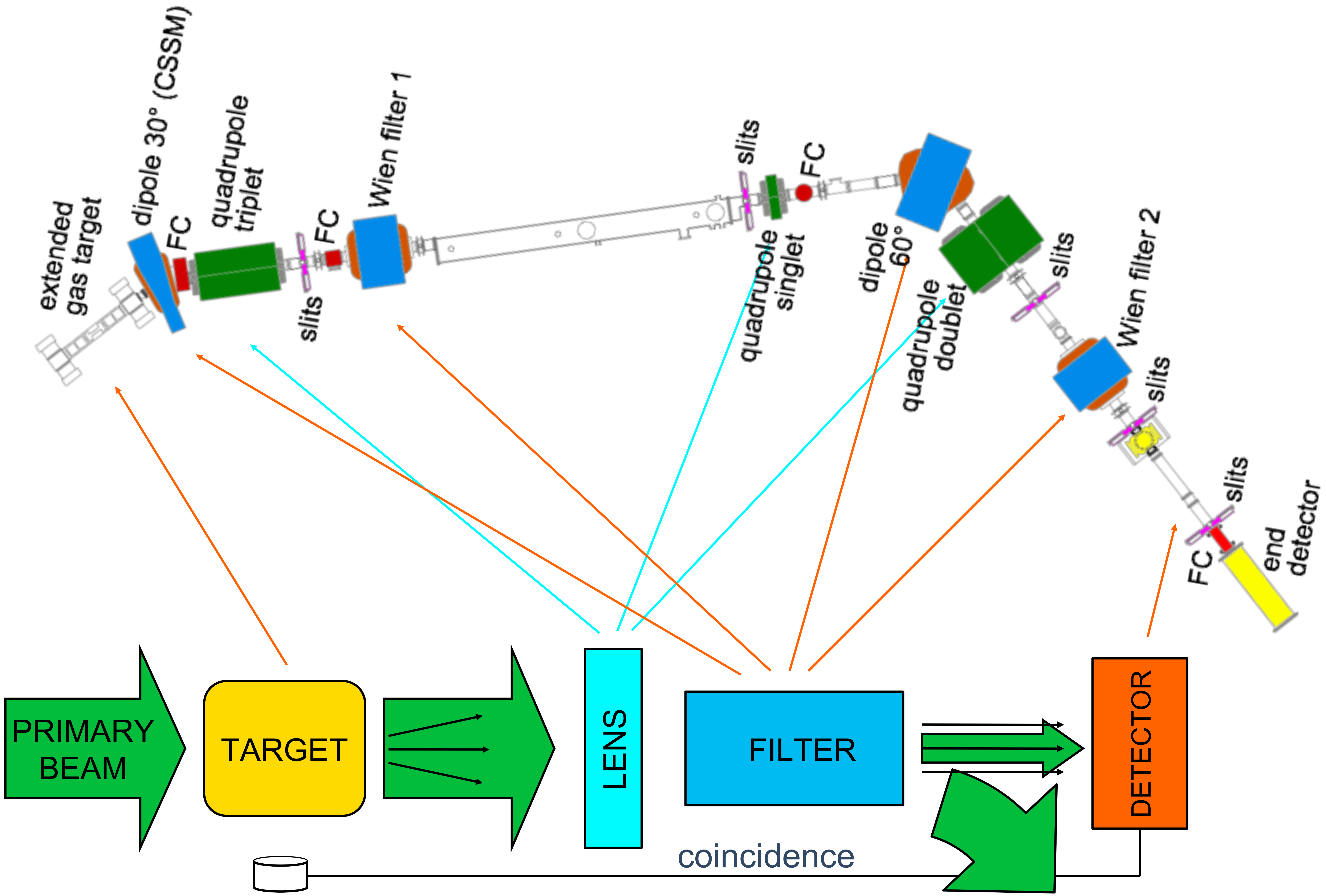
Recoil separators for Nuclear Astrophysics



Recoil Mass Separator ERNA



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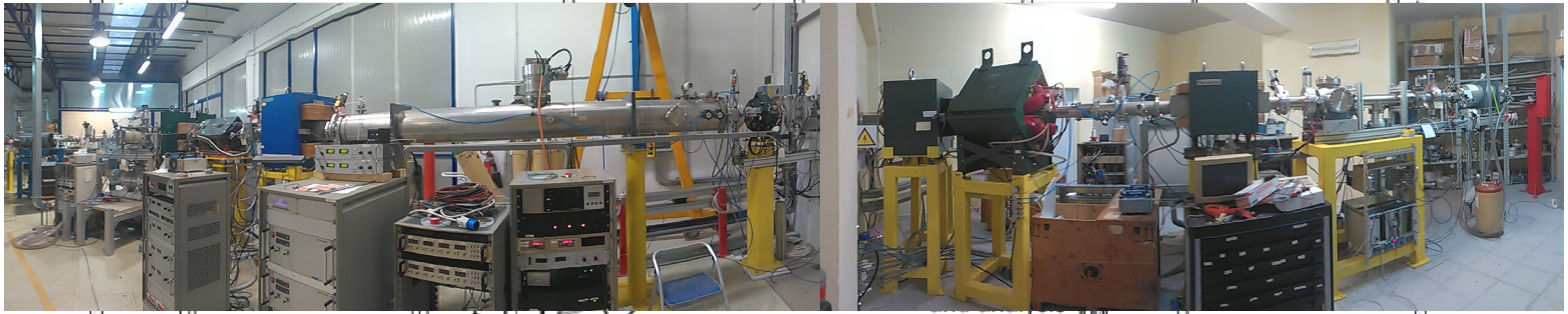
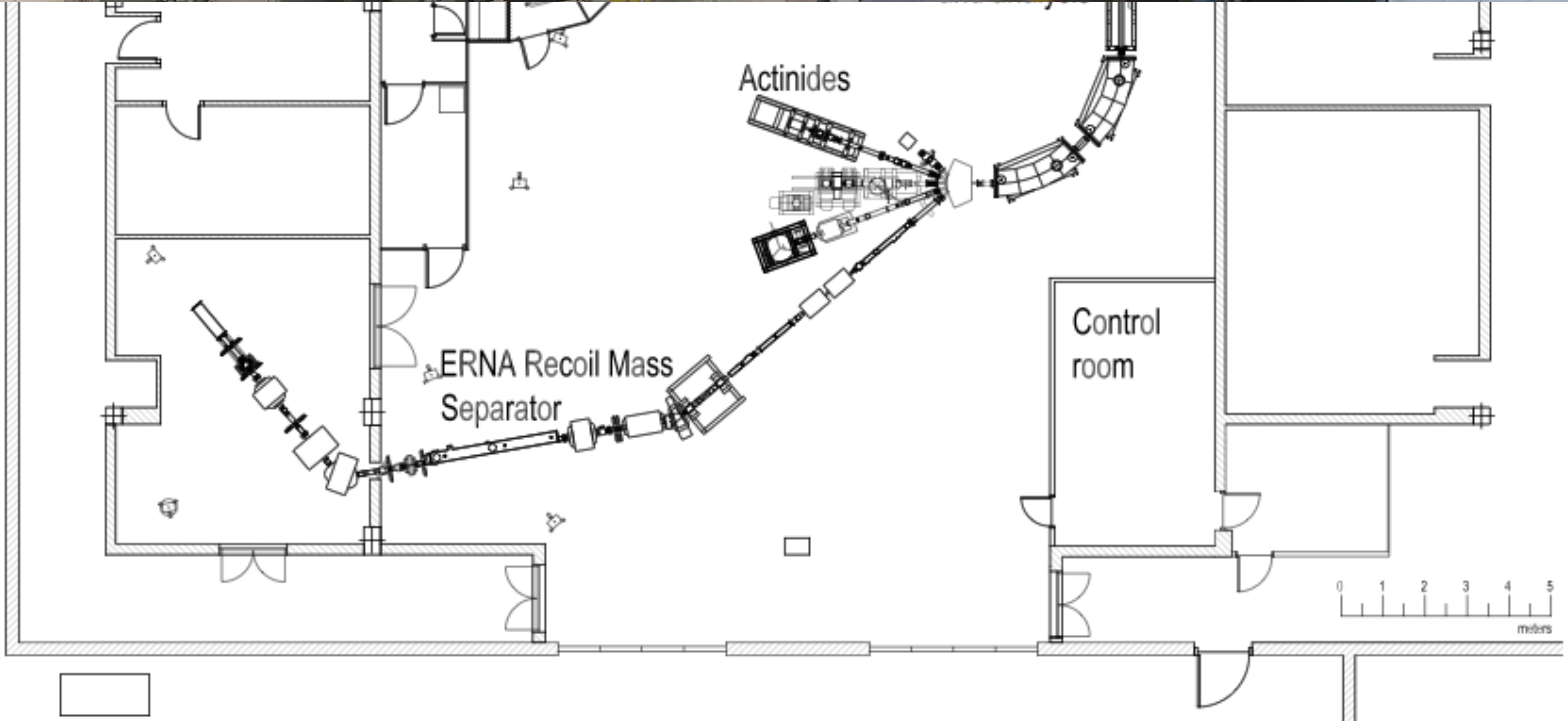
ERNA at CIRCE





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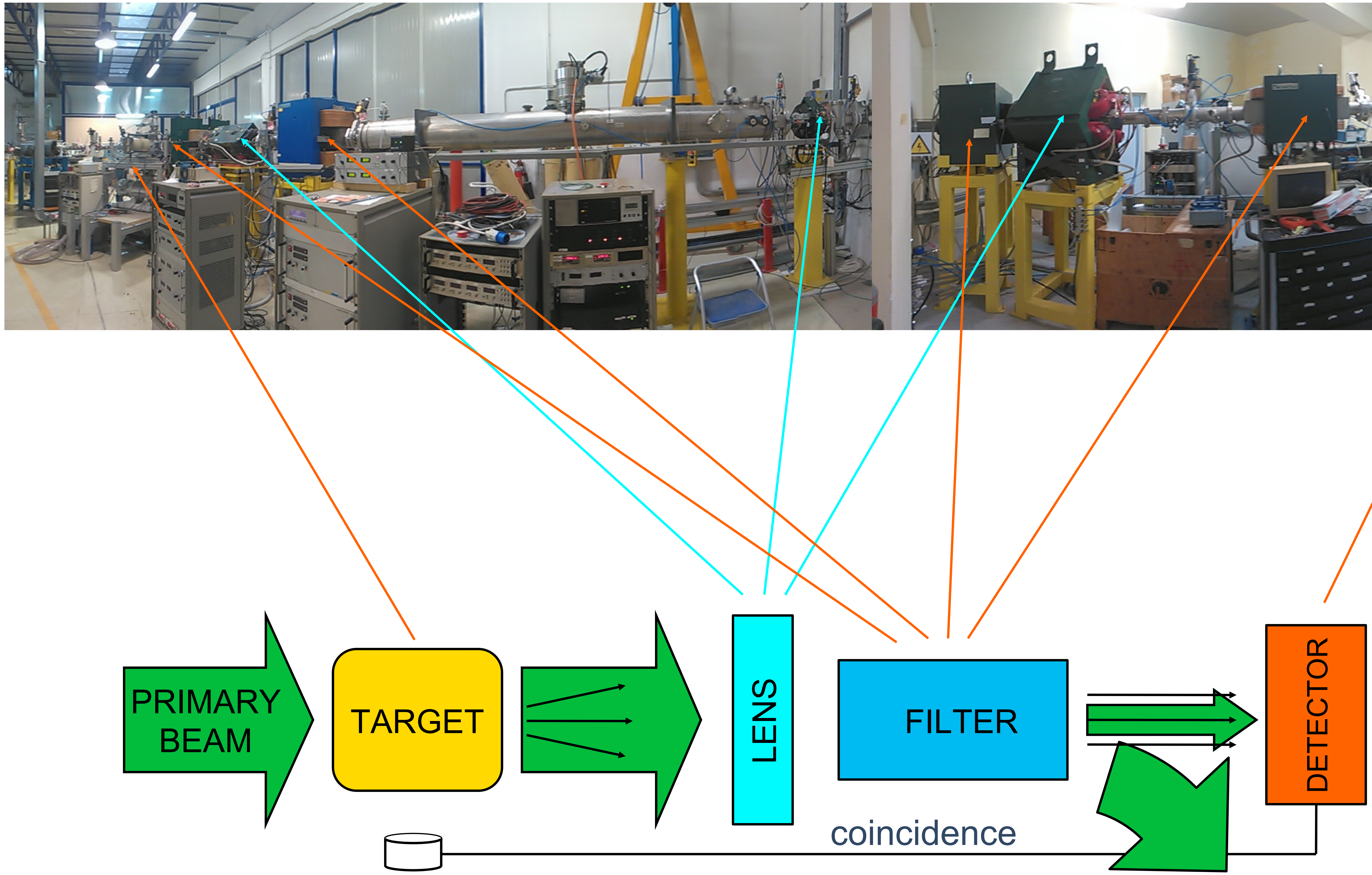
ERNA at CIRCE



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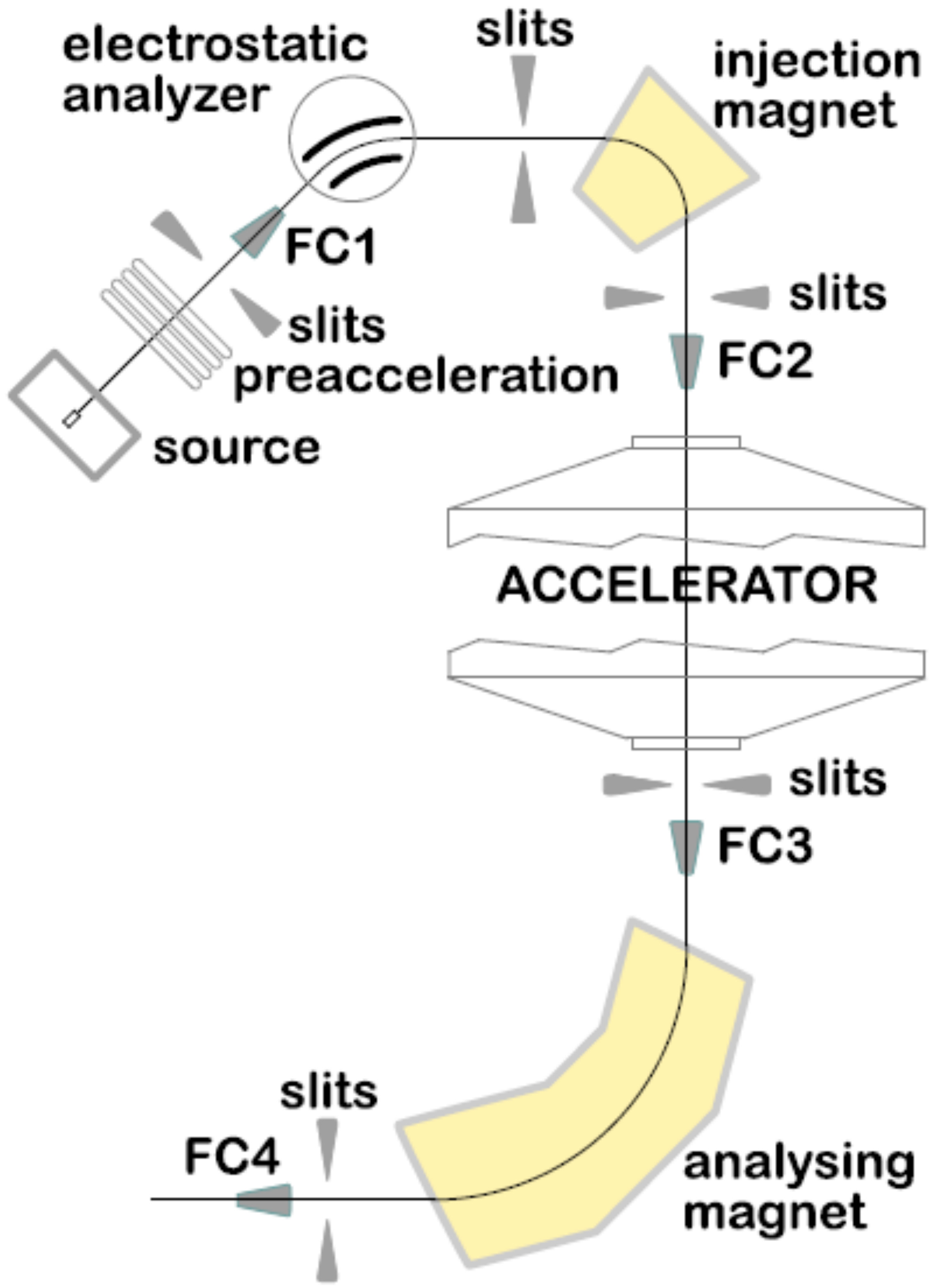
Cross section determination

$$\sigma(E) = \frac{1}{T_q\,\phi_q(E)\varepsilon N_{\mathrm{target}} N_{\mathrm{projectiles}}} Y\left(R^{q+}\right)$$

		typical uncertainty
T_q	transmission to end detector (acceptance)	1%
$\phi_q(E)$	charge state probability	3%
ε	detection efficiency	0.5-2%
N_{target}	number of target atoms	5%
$N_{\mathrm{projectiles}}$	number of projectiles	1%
$Y(R^{q+})$	number of detected recoils	2%

Intense N ion beam production

Nitrogen ion beam generation with a source of negative ions by cesium sputtering (**SNICS**) suffers difficulties connected with its low electron negativity, which hampers the formation of a stable negative ion.



material	Mass injected	I_{FC02} [μA]	I_{FC04} [pμA]
BN + C + Ag	26	7.7	2.1 ± 0.5
BN + C + Ag	25	2.5	0.7
$Fe_3K(CN)_6$	26	14.0	4.0 ± 0.5
KSCN	26	11.0	3.5 ± 0.6
$KSC^{15}N$	27	10.0	3.2
Polypyrrole	26	6.0	1.3
NaN_3 + C	26	10.0	2.8
Eumelanin	26	7.0	1.7
Nitroaniline	26	0.3	
BN	25	2.7	0.8
$NaNO_3$	30	0.4	
NH_4NO_3	30	0.03	

Di Leva et al. NIMA 689(2012)98

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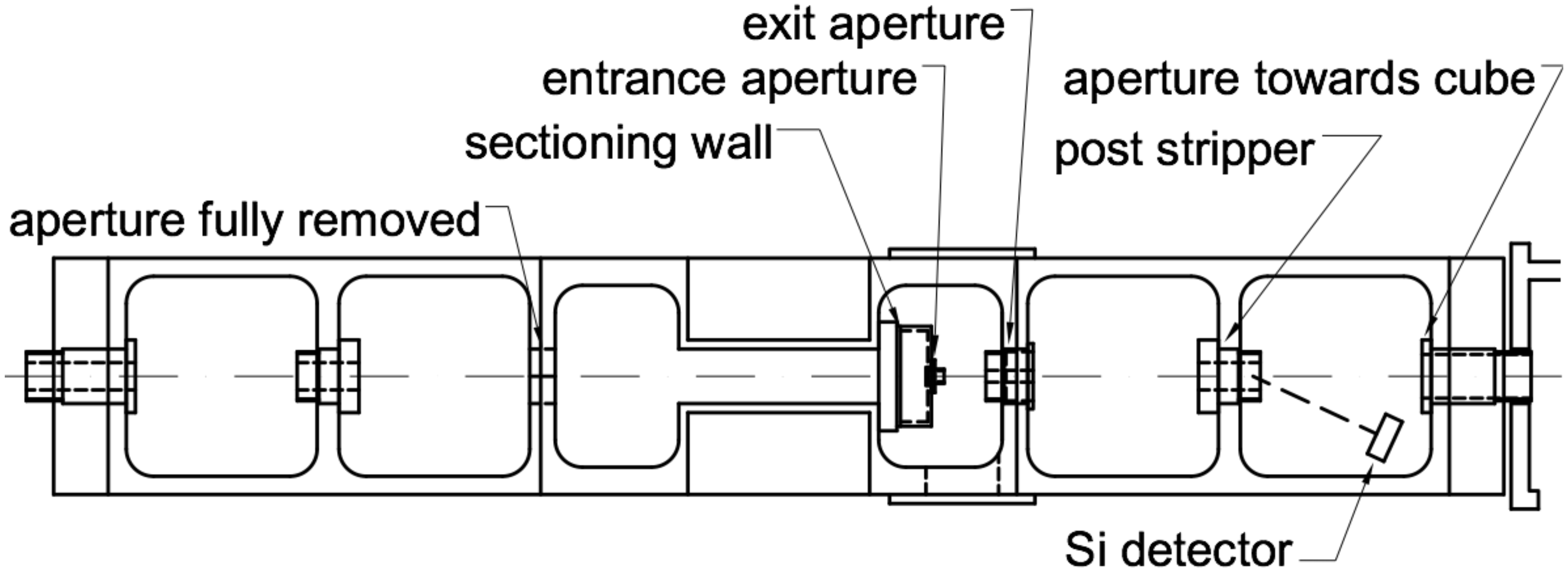
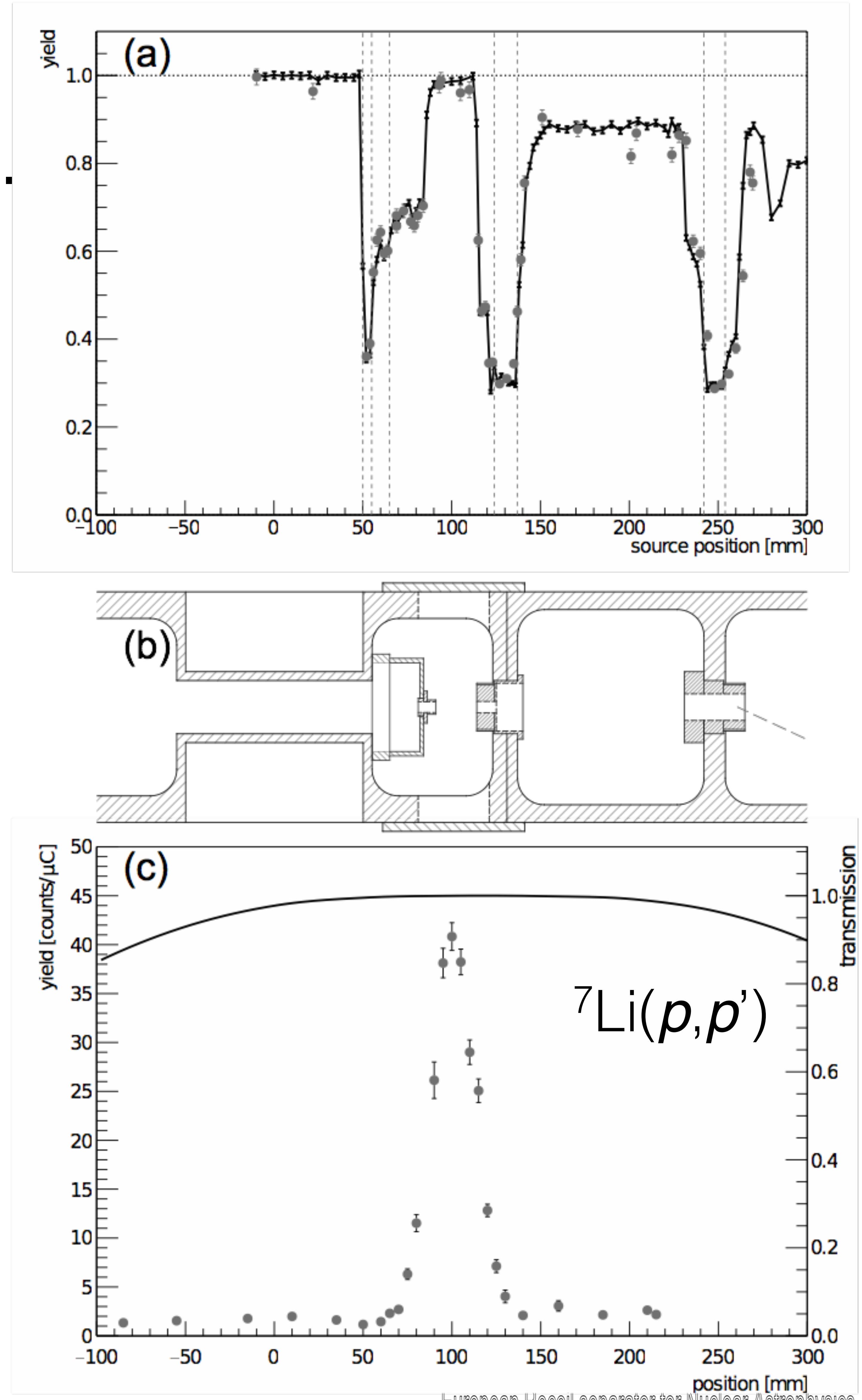
^{4}He extended gas target

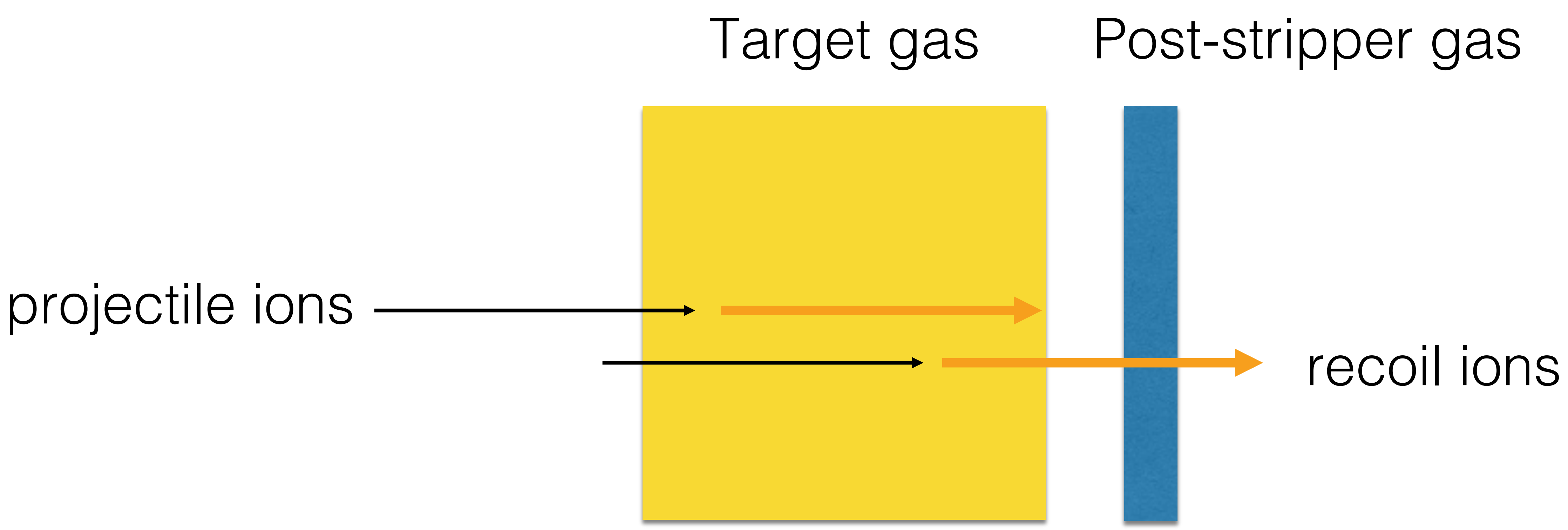
Measurements overlapped with ^{7}Be(p,γ)^{8}B, target chamber was adapted for a shorter gas cell. Target fully characterized.



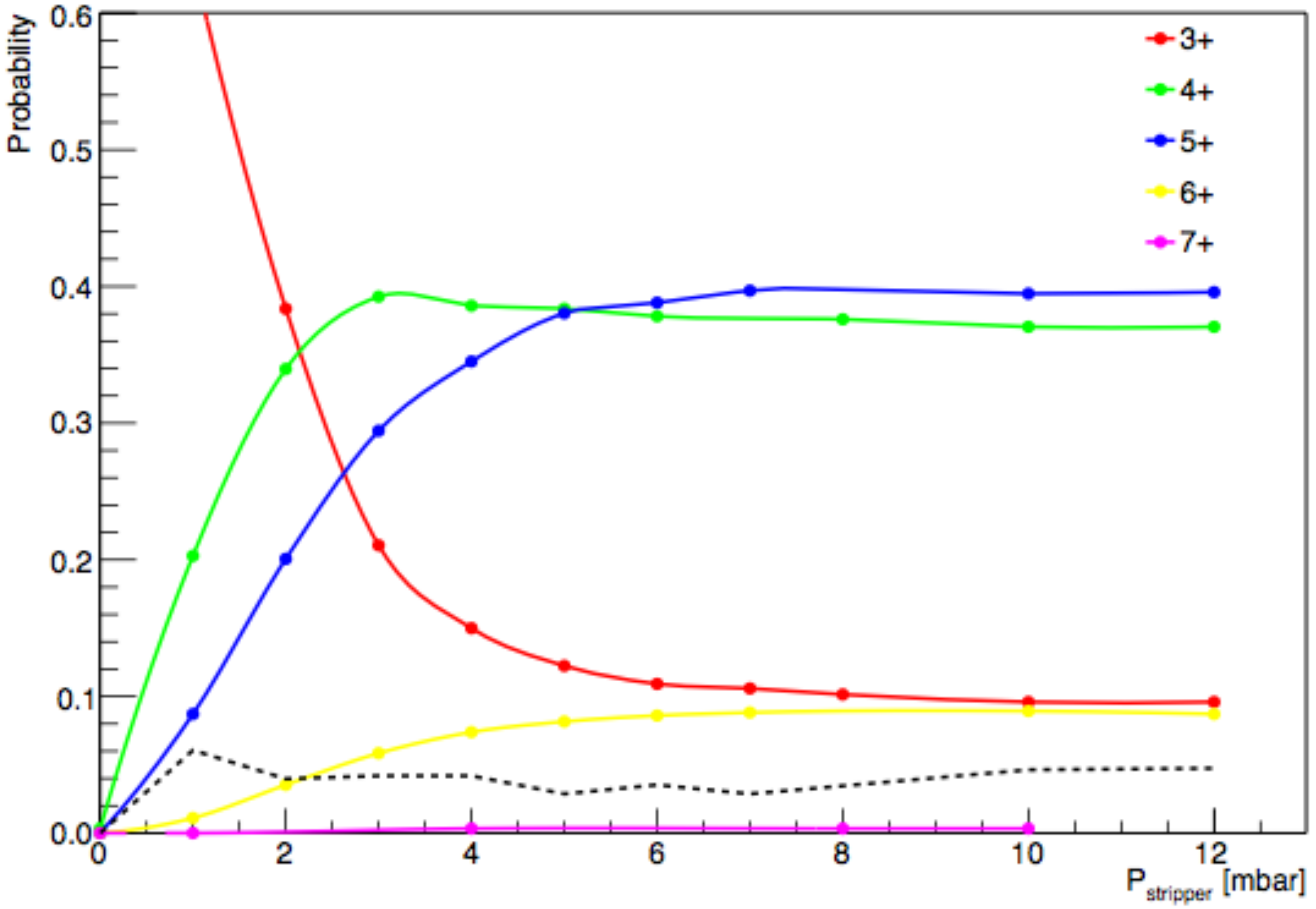
$P_{4He:}$ 4 mbar
Effective length: …
Thickness: (0.54±0.03)atoms/cm^2

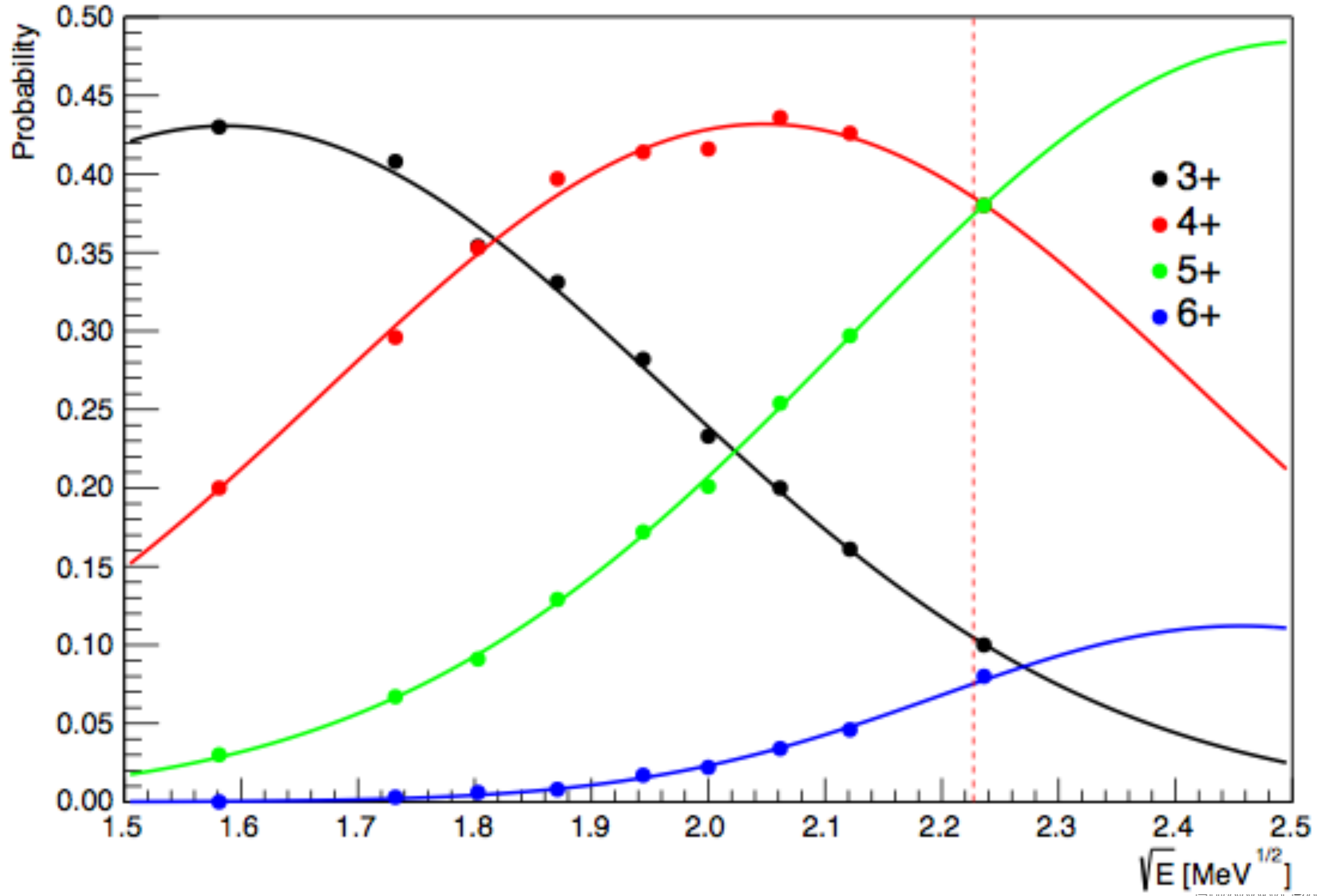


^{19}F recoils charge state



The use of an additional layer of a different gas can make charge state independent of reaction coordinate within the target





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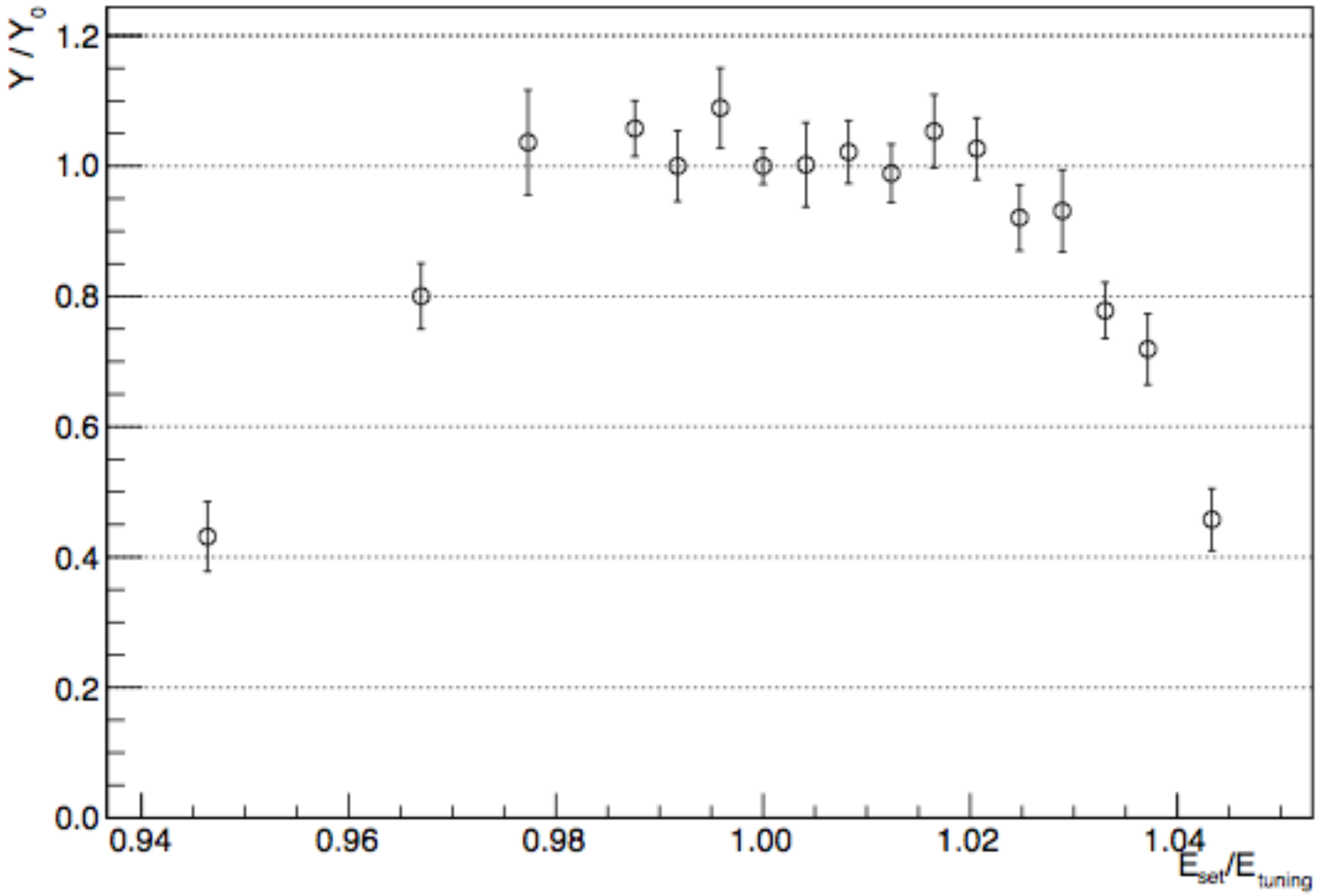
Separator acceptance



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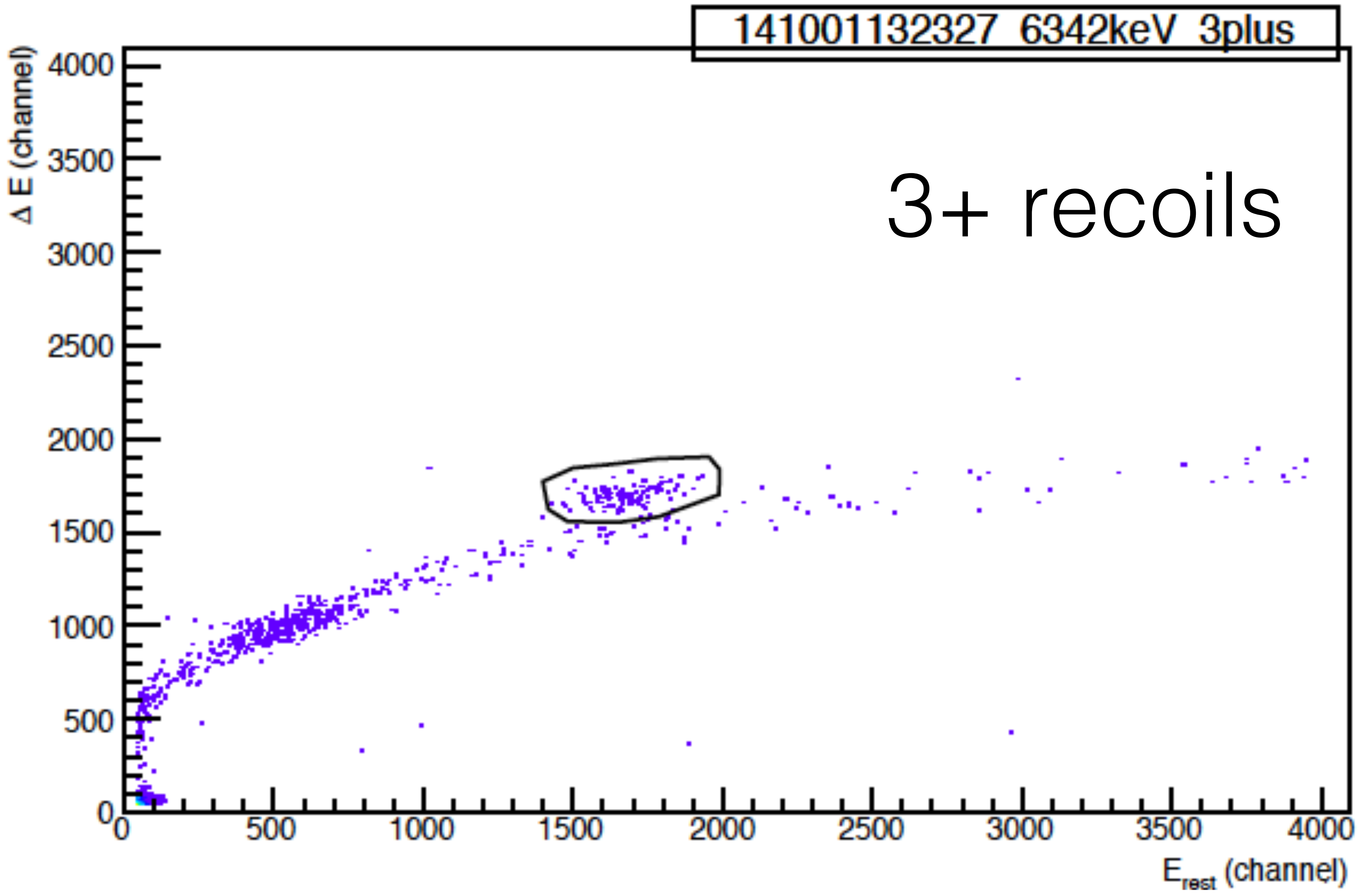
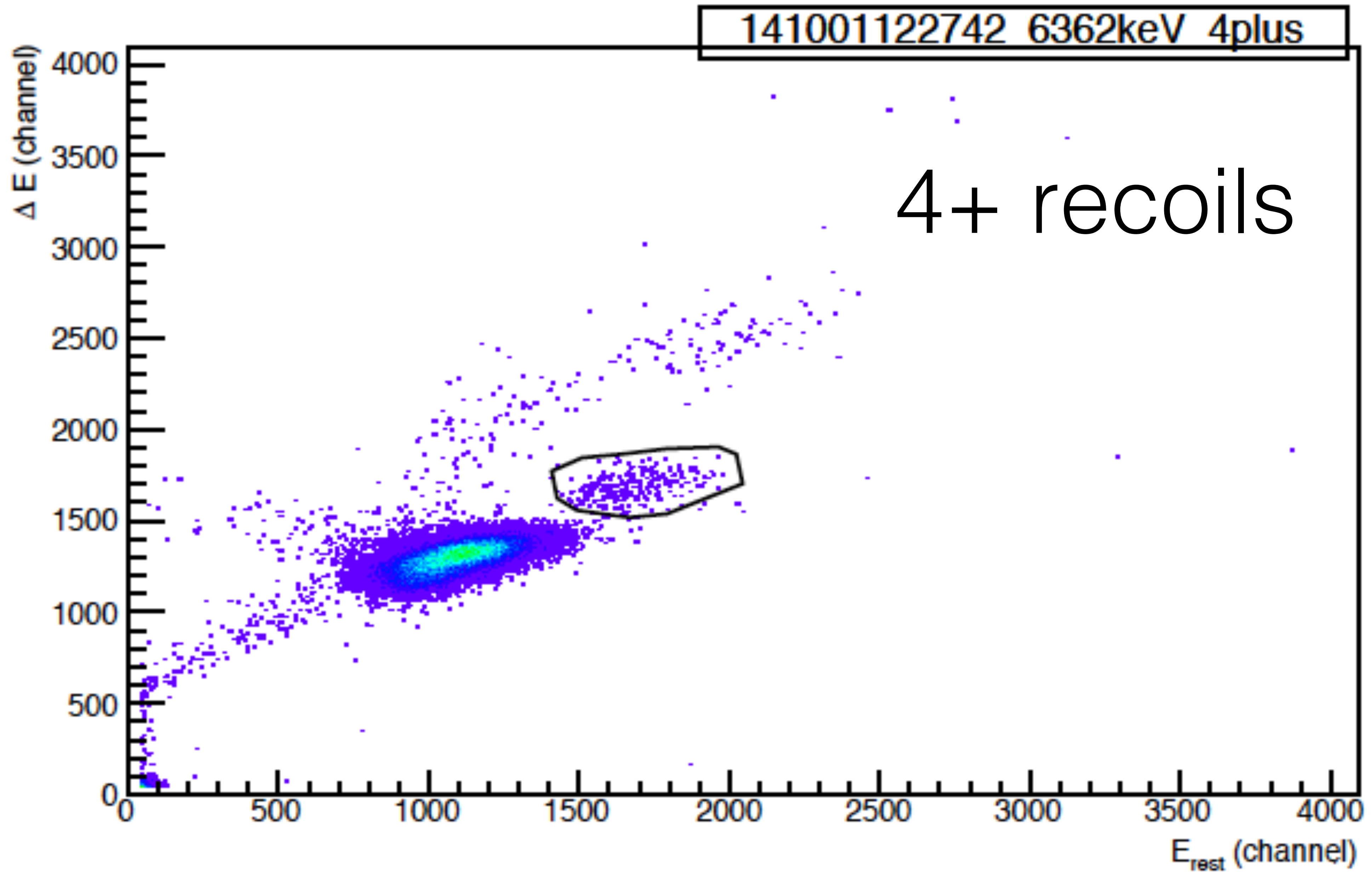
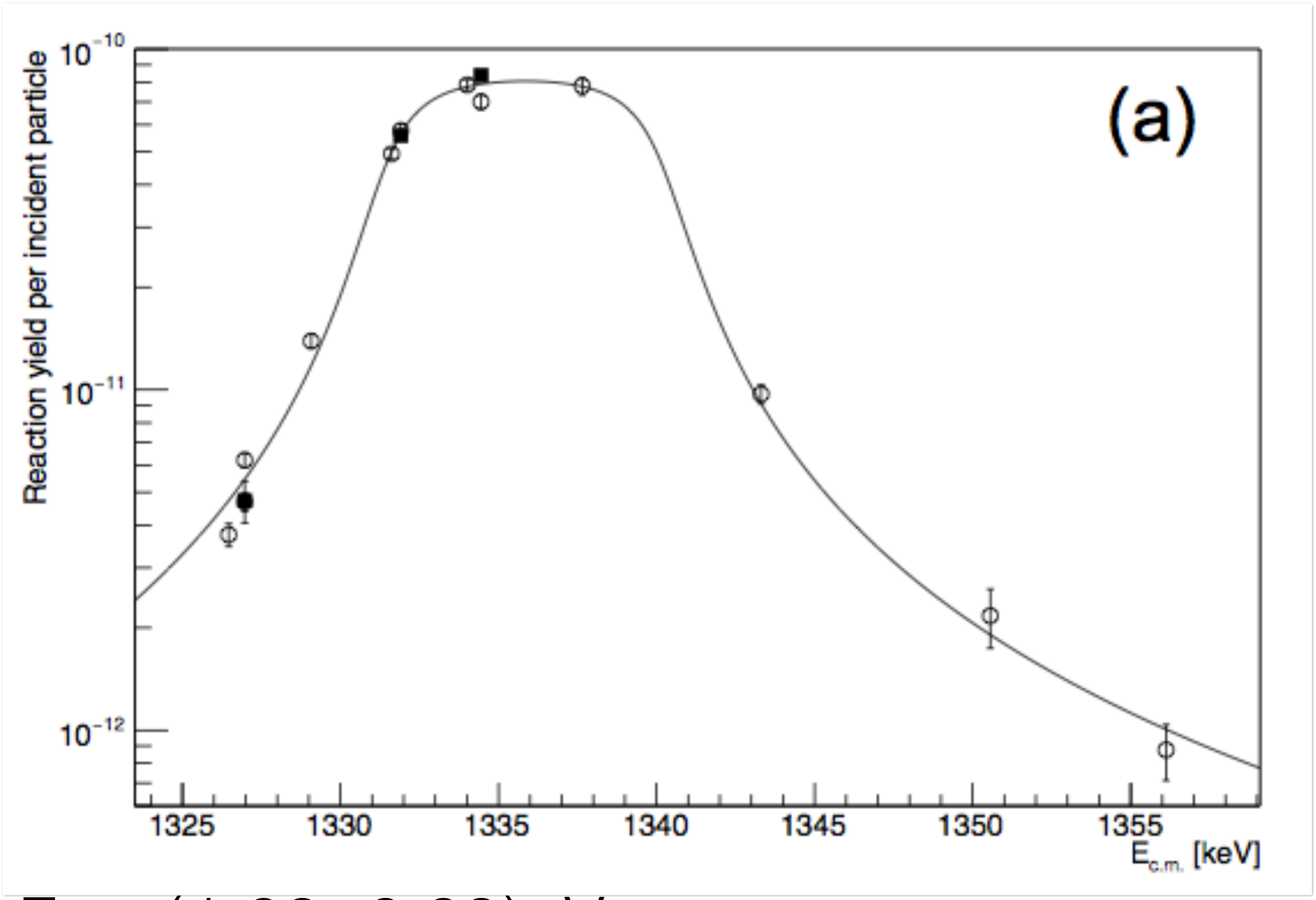
1323keV resonance







Γ_γ = (1.62±0.09)eV

Γ_α = (2.51±0.10)keV

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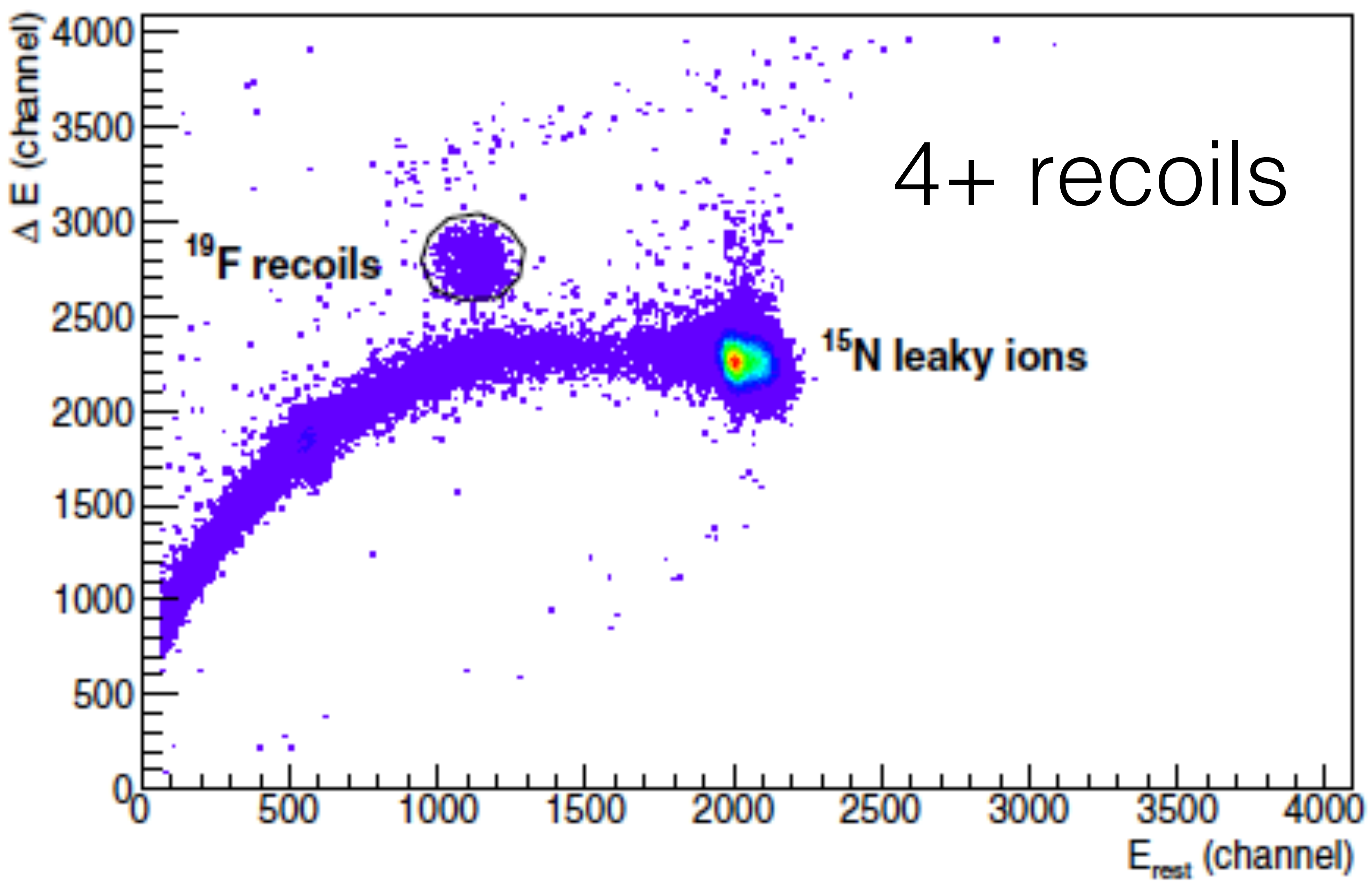
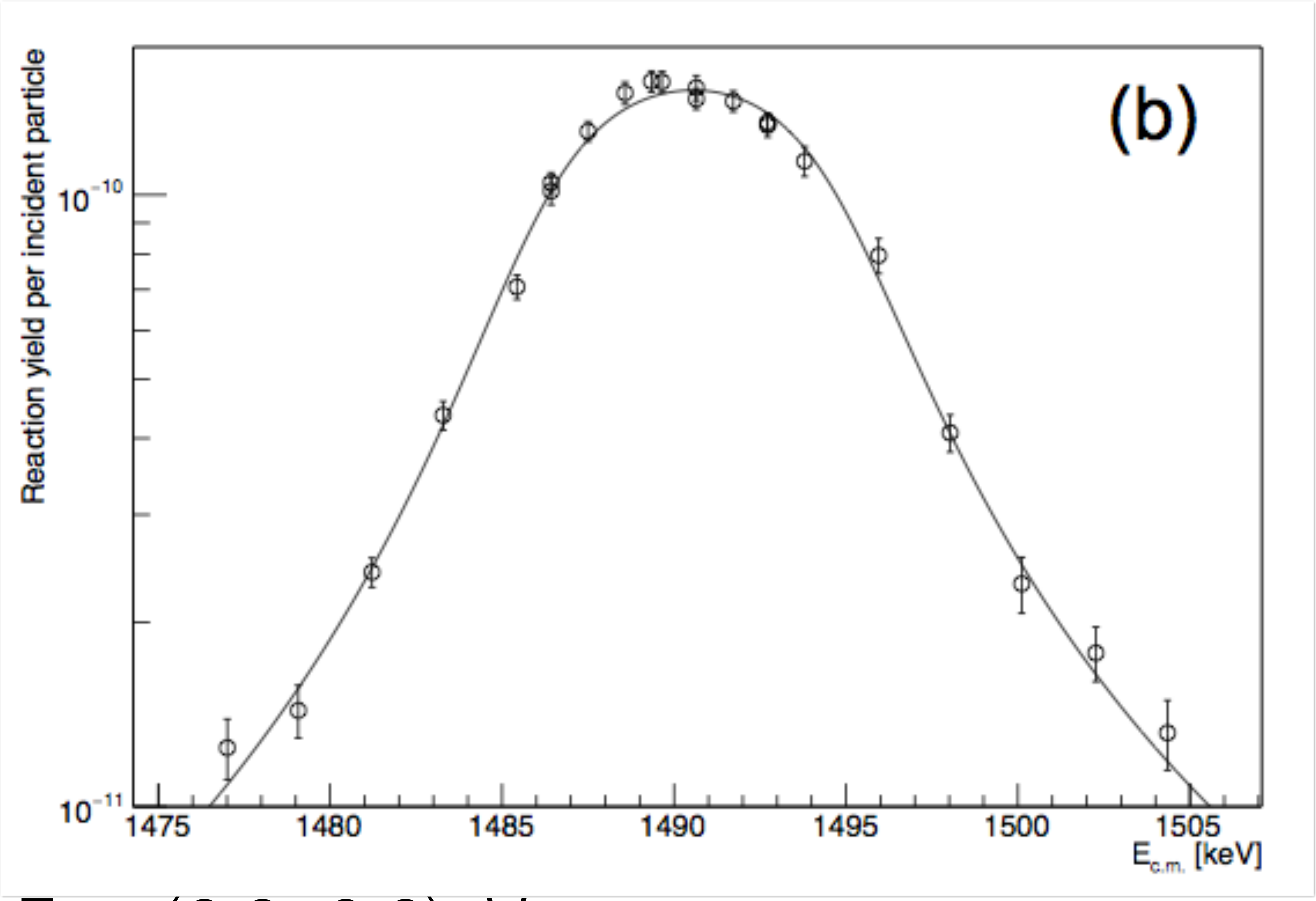
1487keV resonance





$\Gamma_\gamma = (2.2 \pm 0.2)$eV

$\Gamma_\alpha = (6.0 \pm 0.3)$keV

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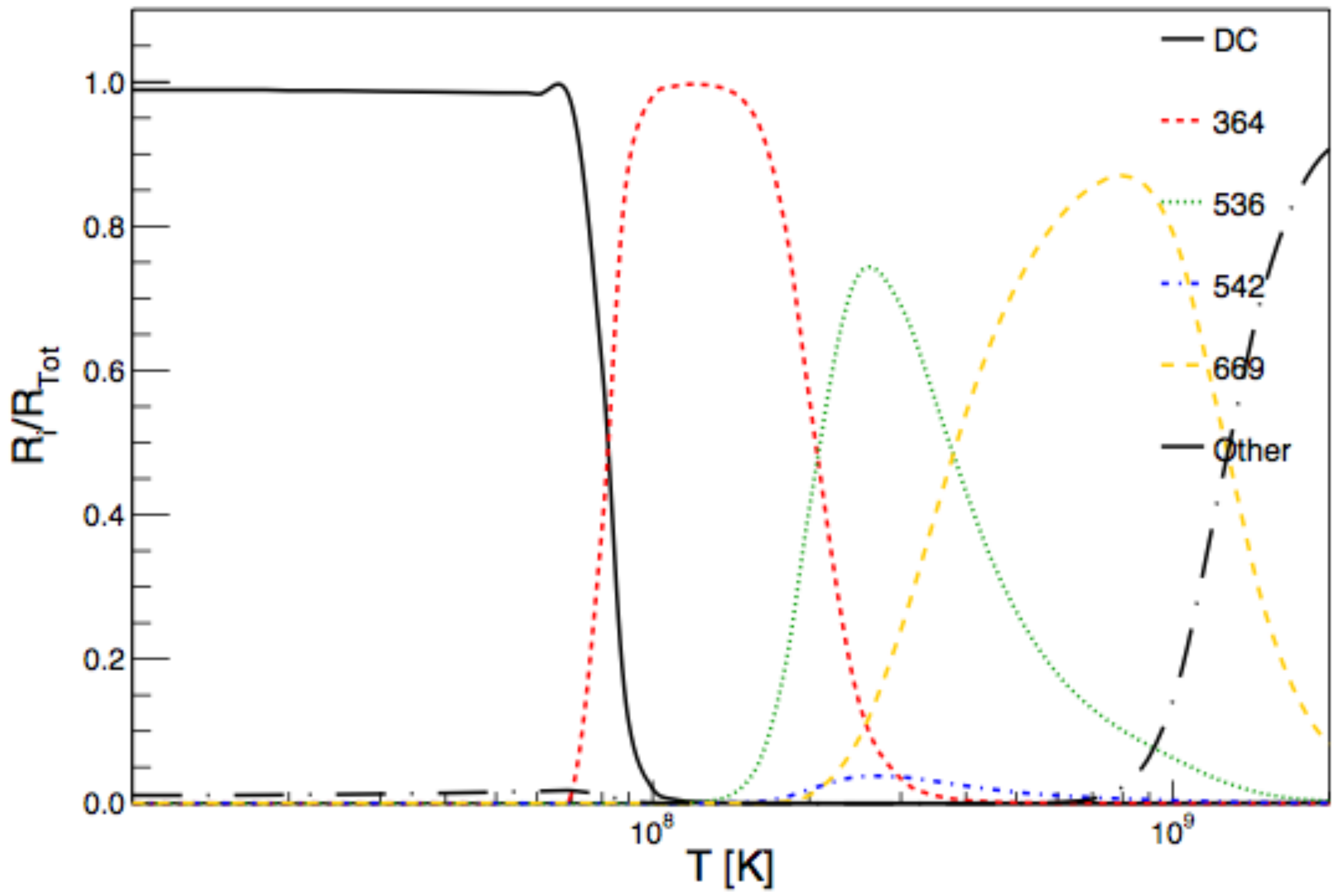
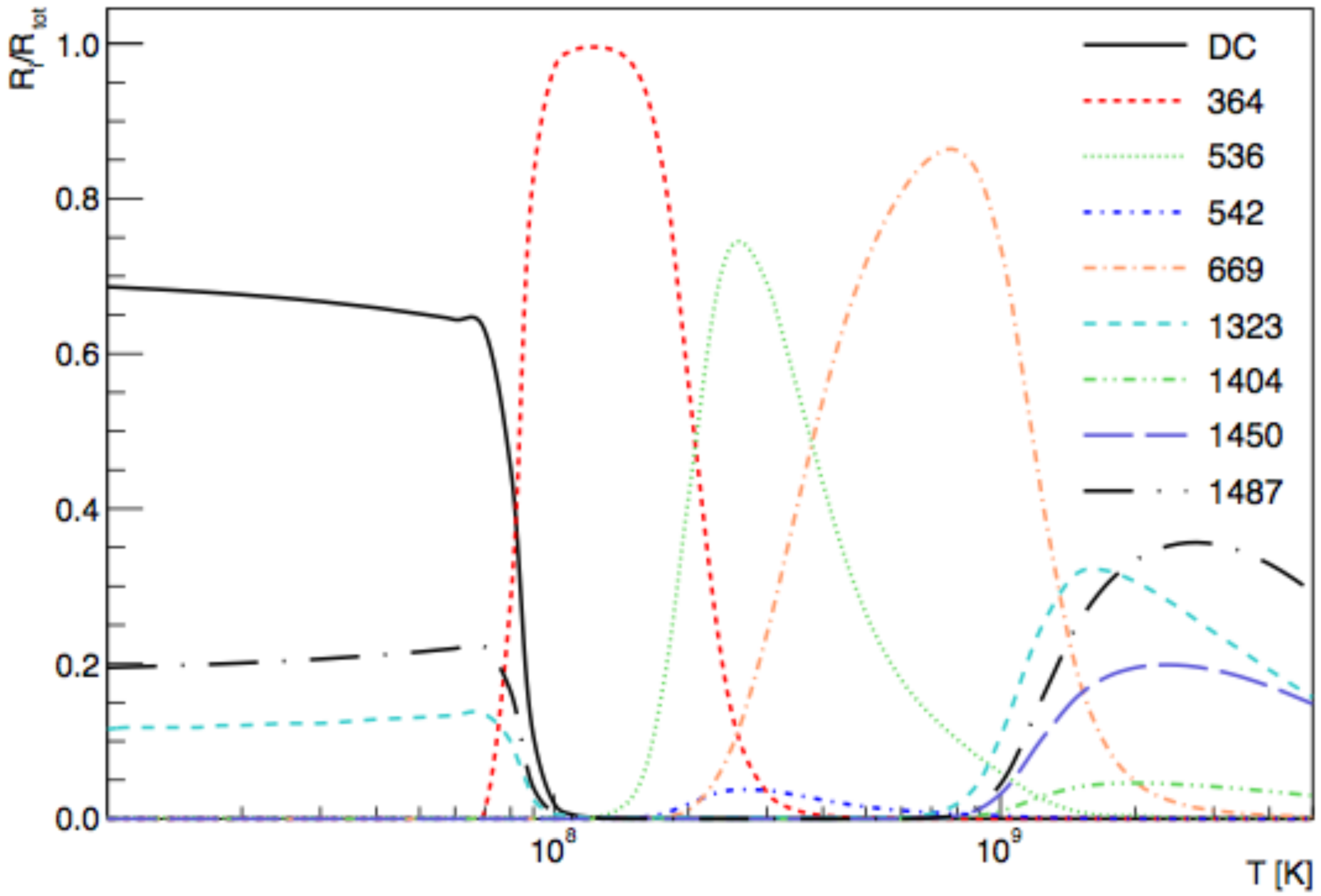
Influence on reaction rate

Before



After



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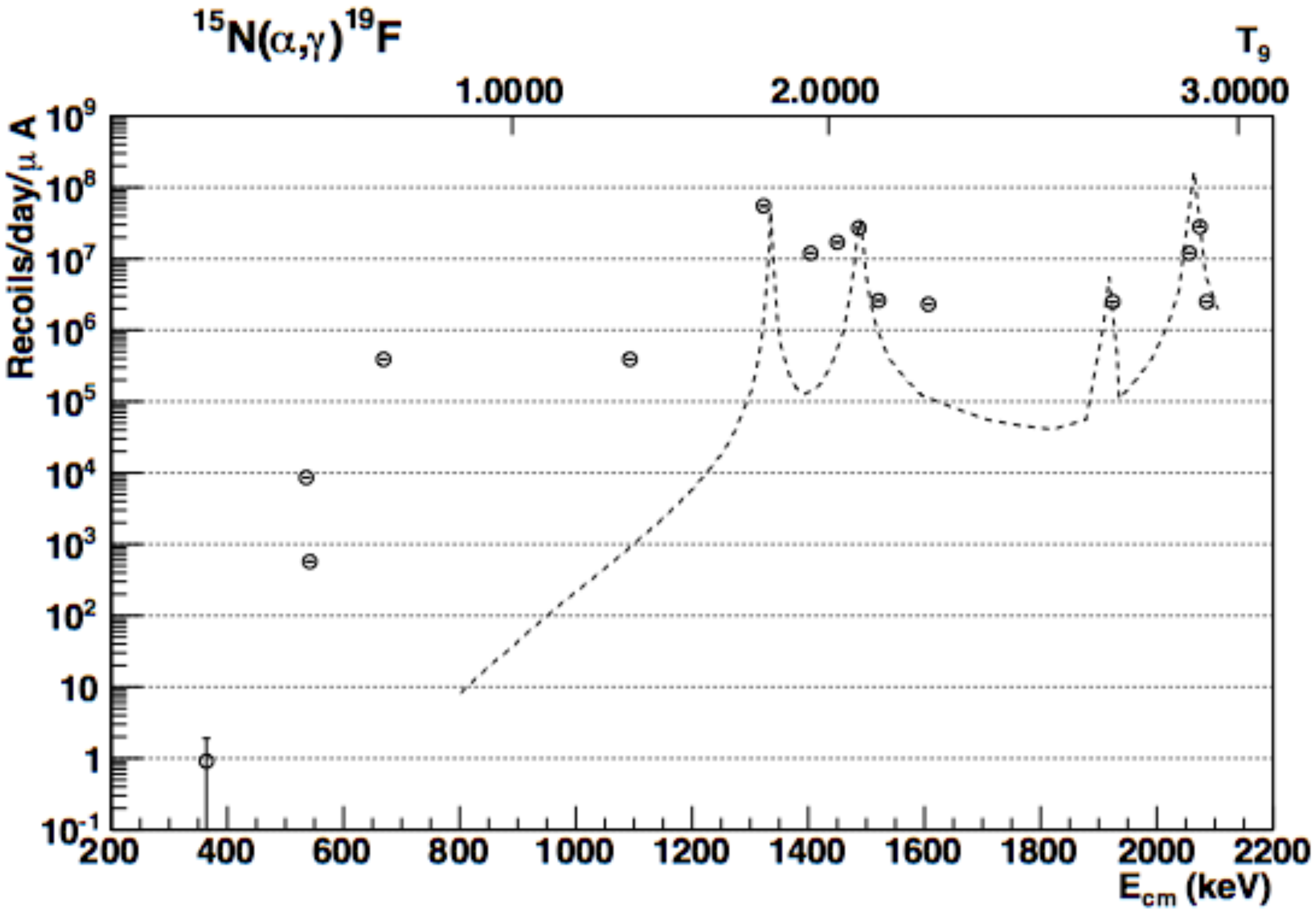
Outlook



Using values from:
Wilmes et al., Phys.Rev. C 66 (2002) 065802
De Olivera et al., Phys.Rev. C 55 (1997) 3149

need:

- end detector with lower detection threshold: ToF-E (see poster J.G. Duarte #…);
- ^{4}He jet gas target (see poster D. Rapagnani #…);

aim:

- measurement of narrow resonances E_{cm} = 536keV÷1093keV (not difficult)
- measurement of non resonant component (DC) (challenging)
- measurement of 365keV resonance (very challenging)

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Thank you for your attention

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