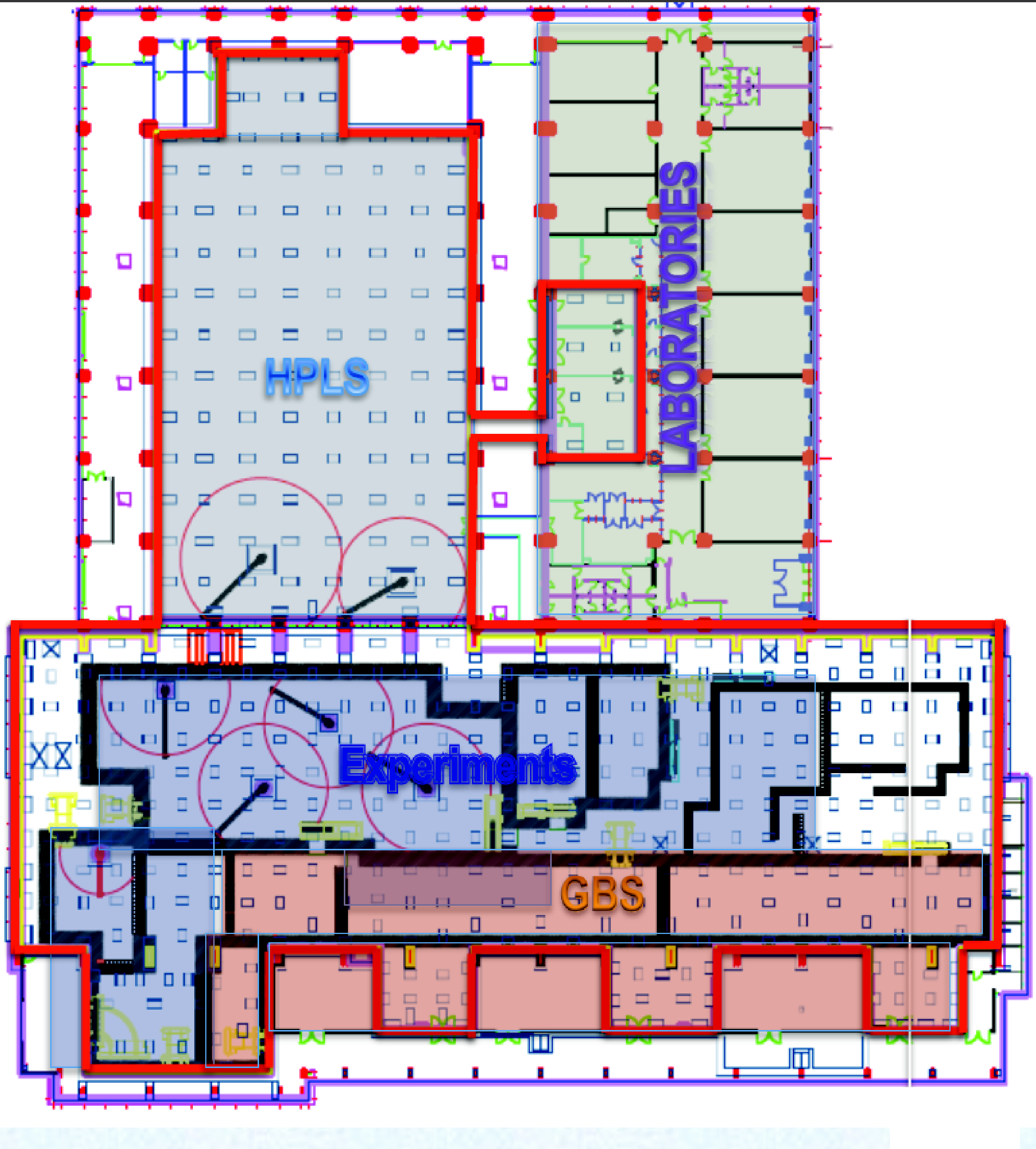
The Cryogenic Stopping Cell of the IGISOL facility at ELI-NP

Paul Constantin

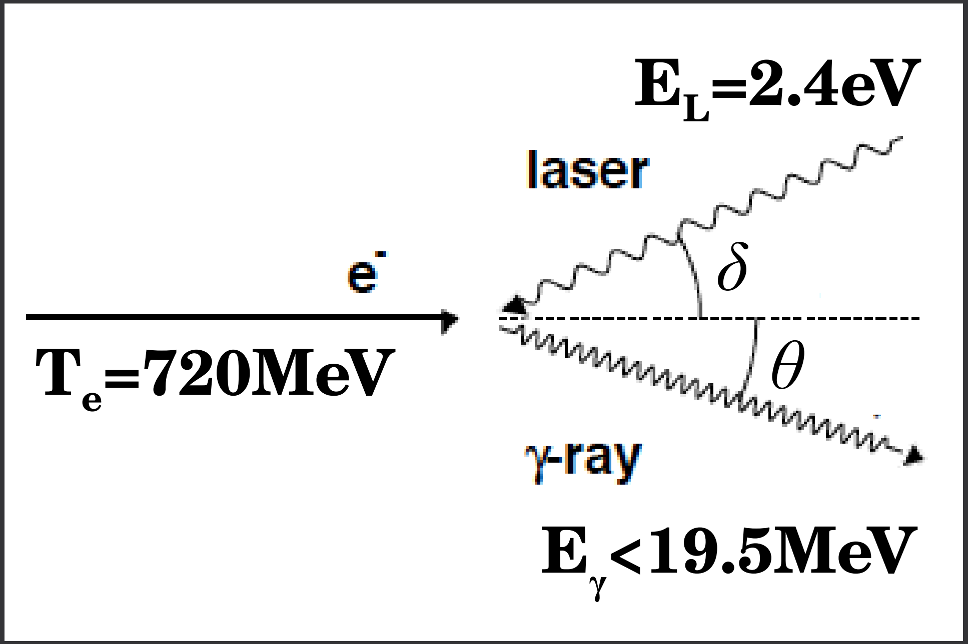
ELI-NP / IFIN-HH



High Power Laser System (HPLS)
- built by **Thales**
- 2 arms, 6 outputs
- 2 x 0.1 PW, 10 Hz
- 2 x 1 PW, 1 Hz
- 2 x 10 PW, 0.1 Hz

Gamma Beam System (GBS)
- built by **EuroGammaS**
- spectral density 0.8-4·10^4 γ/(s·eV)
- narrow bandwidth 0.3-0.5%
- energy range 0.2-19.5 MeV
- linear polarization >99%

The ELI-NP Gamma Beam



$$E_\gamma(\theta, T_e) = \frac{4\gamma_e^2 E_L}{(1 + \delta^2/4 + a_{0p}^2/2) + \gamma_e^2\theta^2}$$

$$\gamma_e = 1 + T_e/m_e c^2$$

$$E_\gamma^{max} = 9.55\, eV \cdot \gamma_e^2$$

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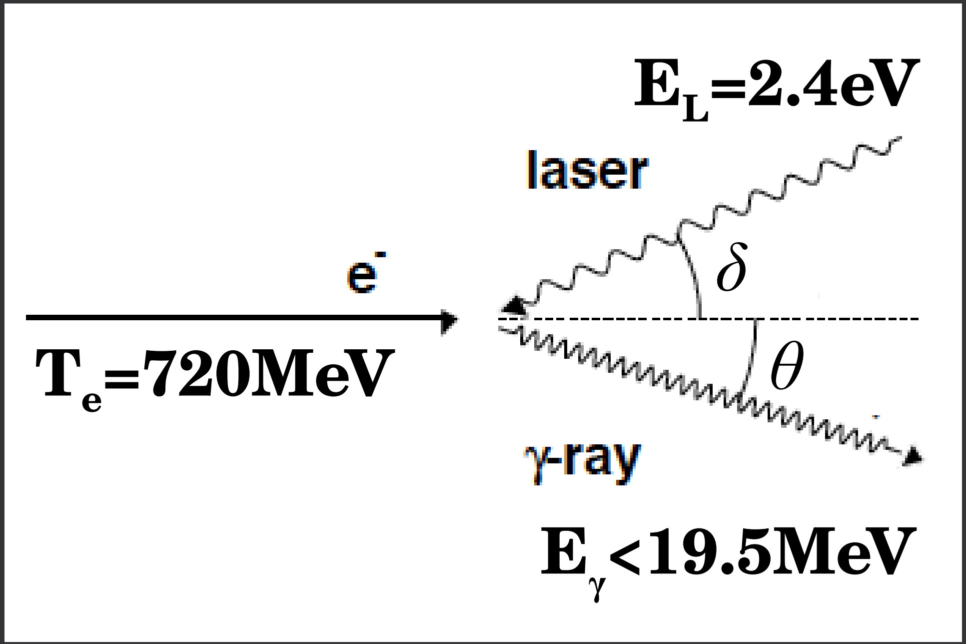

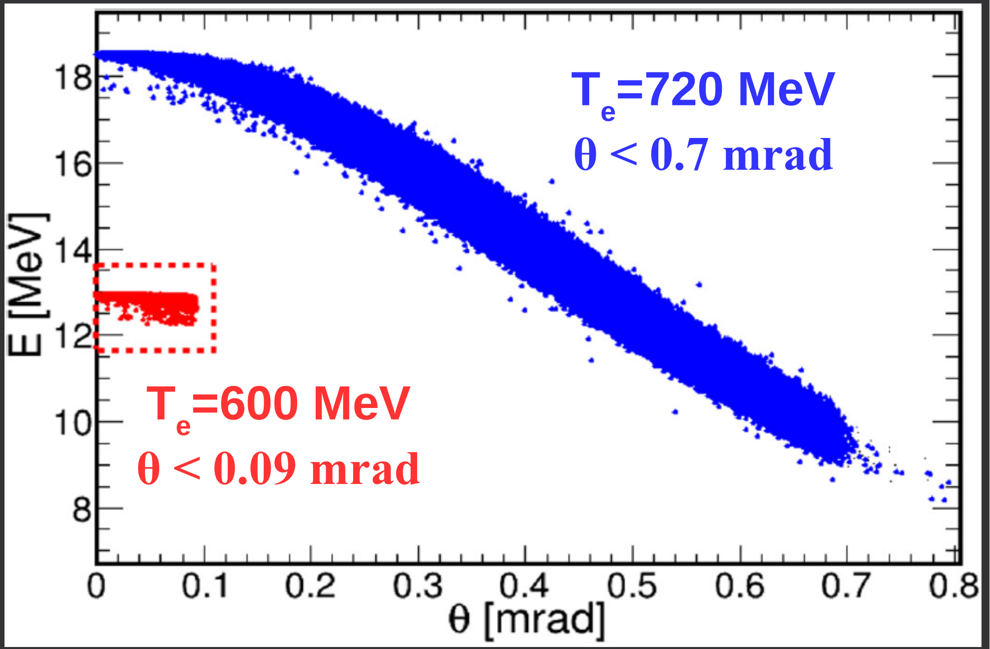

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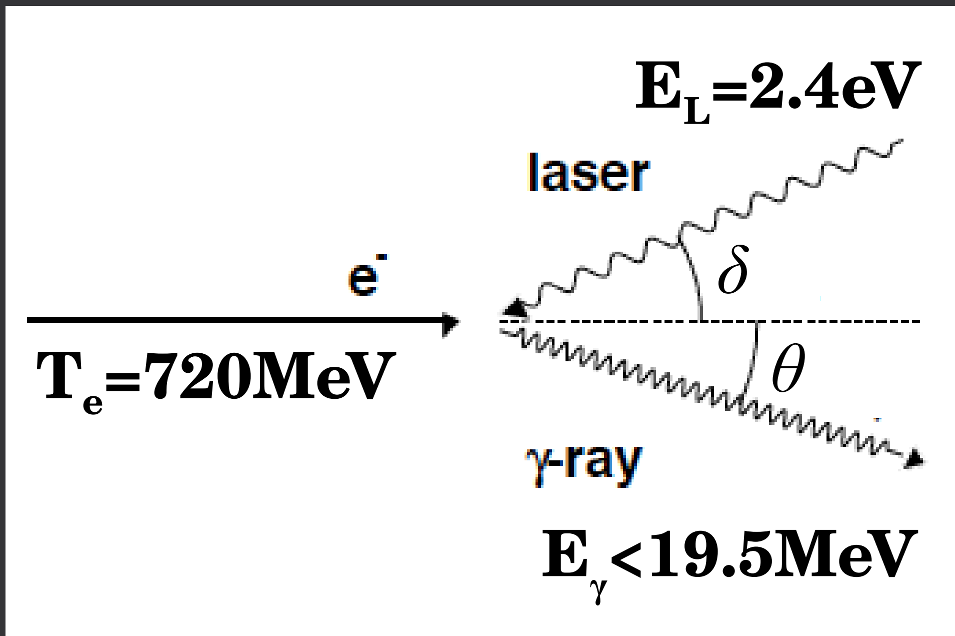

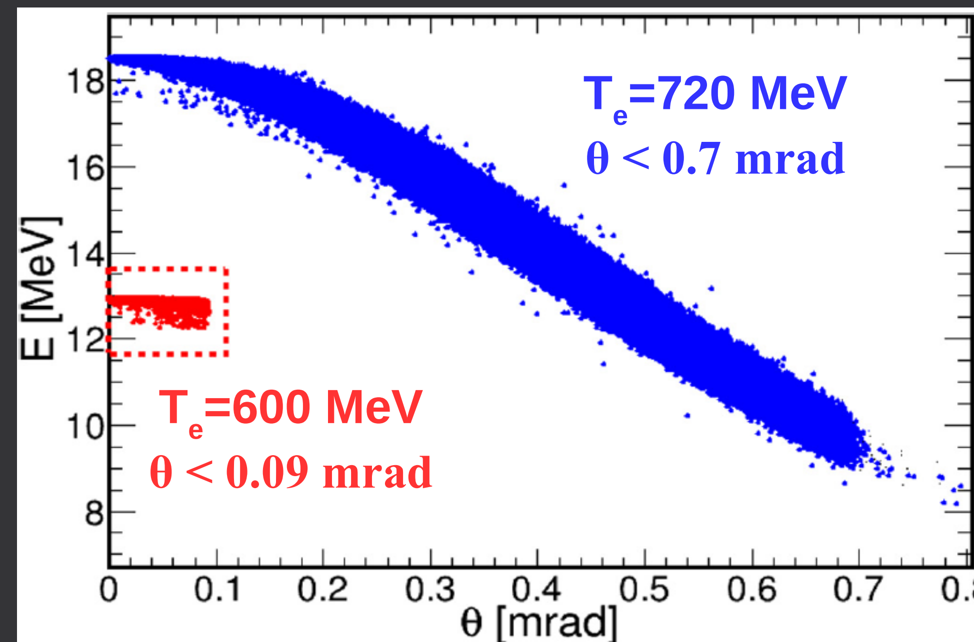

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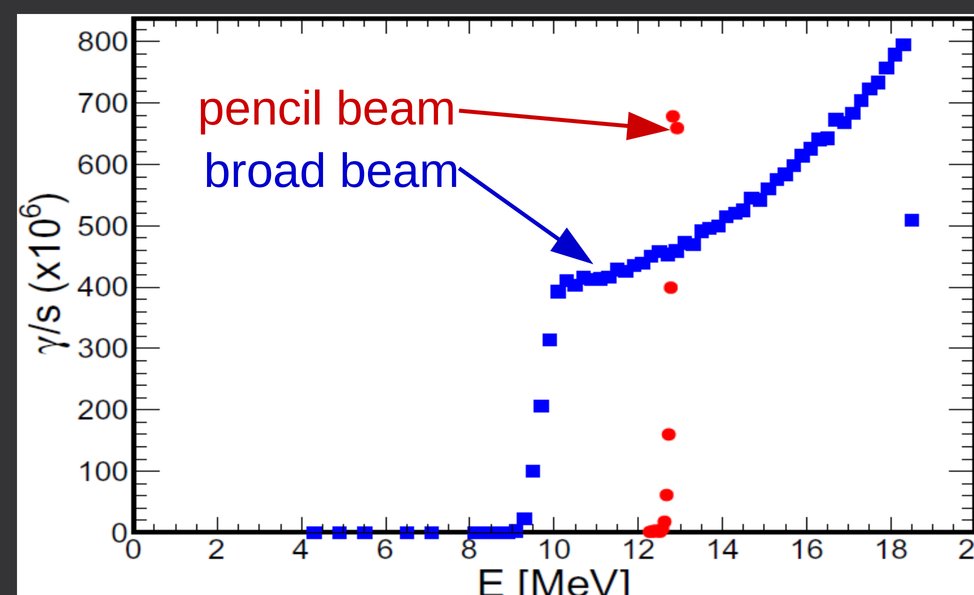
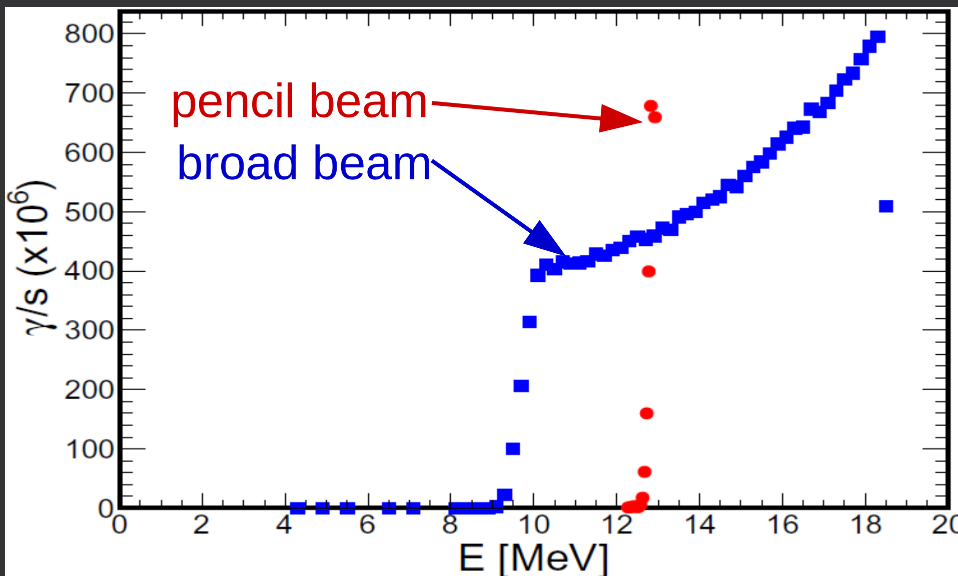
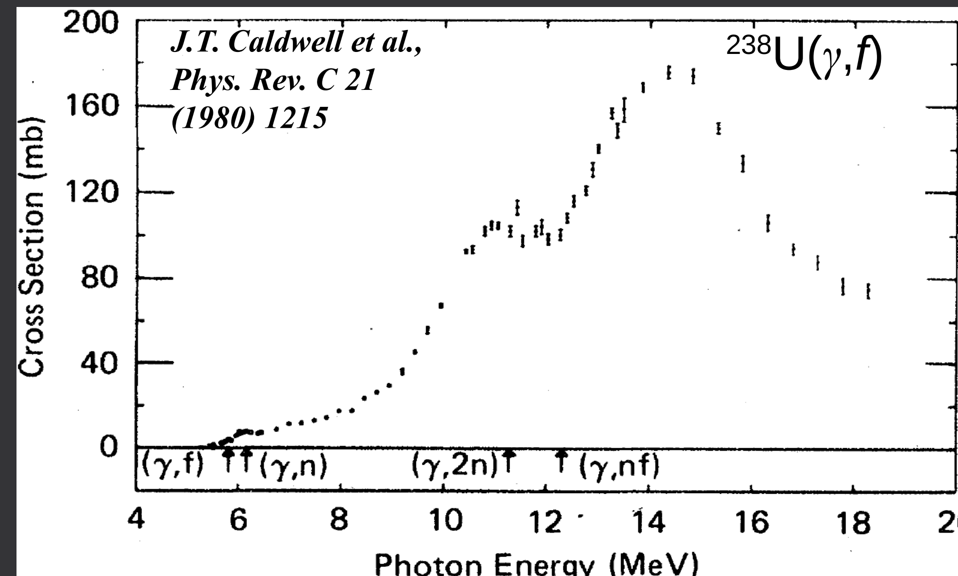


Radioactive Ion Beams with the Gamma Beam

Beam energy range up to ~19 MeV covers the GDR: RIB via photofission in an actinide thick target





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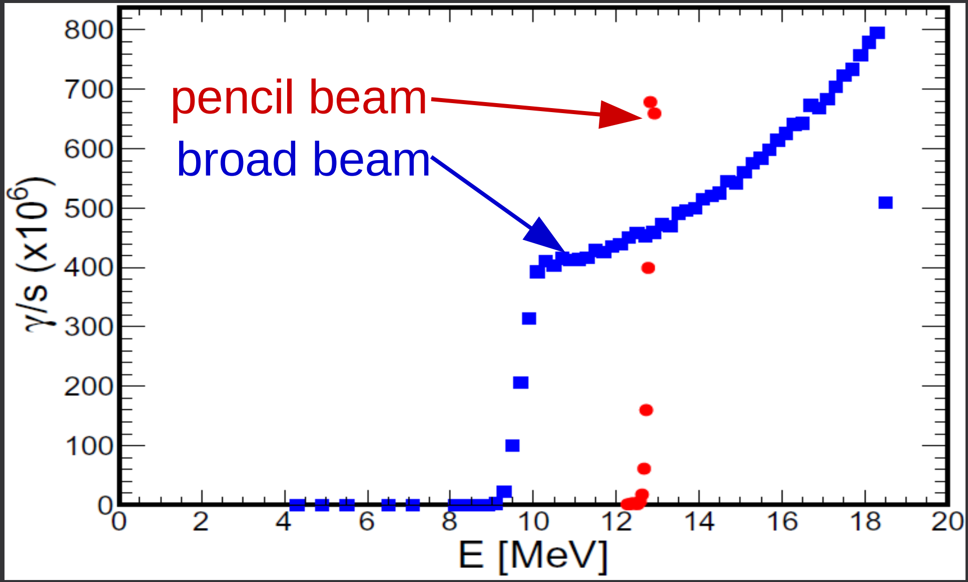
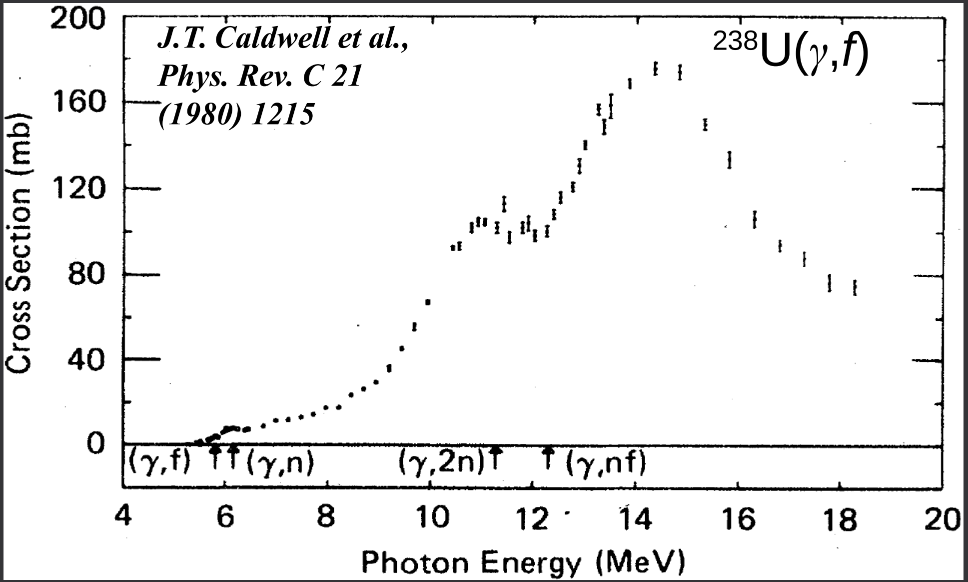
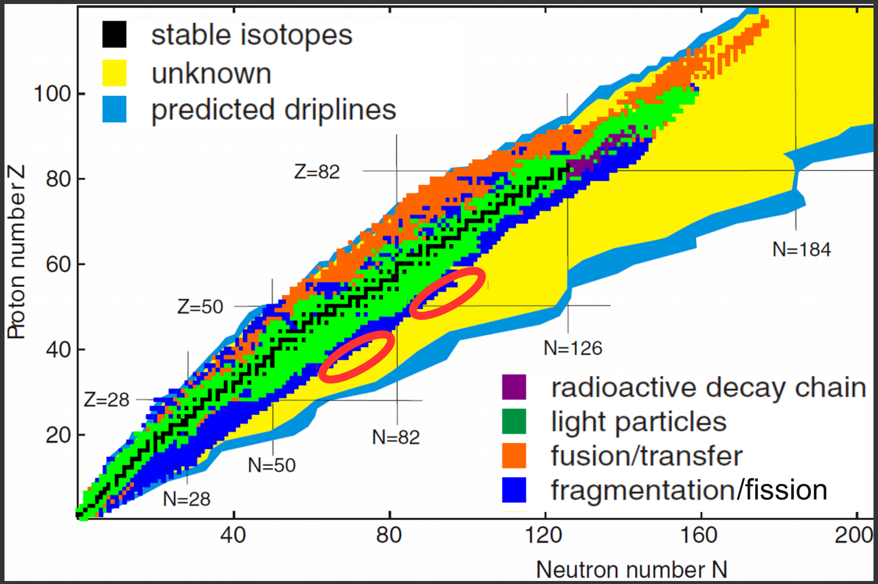




M. Thoennessen, Rep. Prog. Phys. 76 (2013) 056301



IGISOL beamline: Exotic Neutron-Rich Isotopes

Production of exotic neutron-rich fission fragments
Refractory elements: light region Zr-Mo-Rh and heavy rare-earths region around Ce

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- tilted foils:
  (1) avoid hitting neighboring foils
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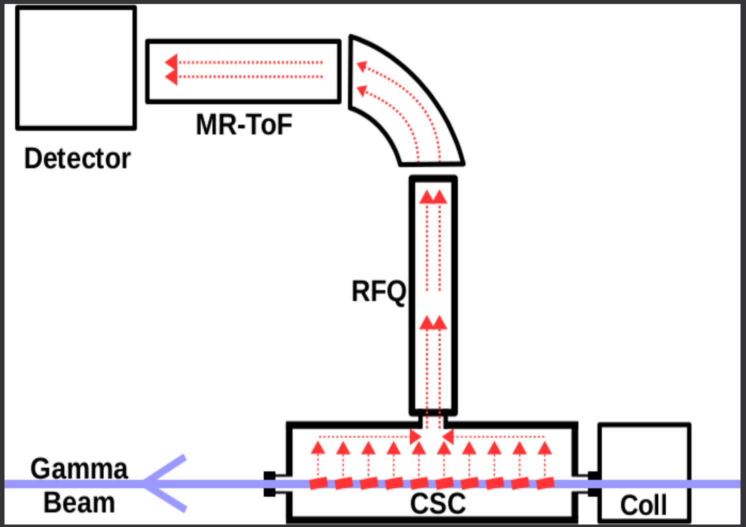

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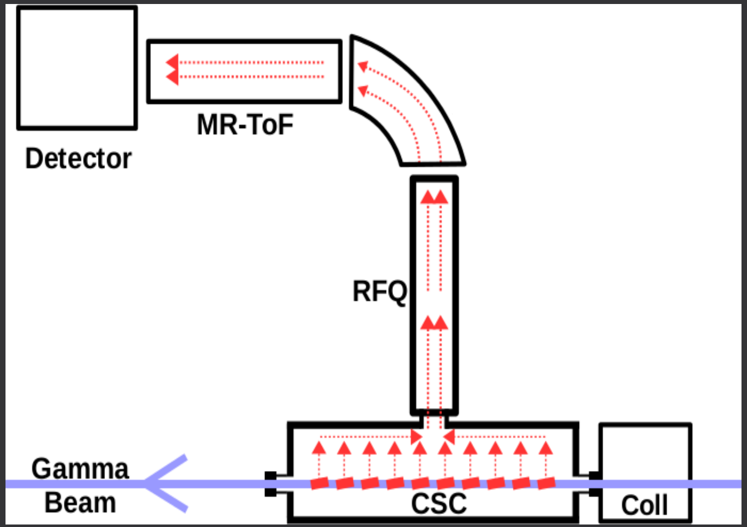

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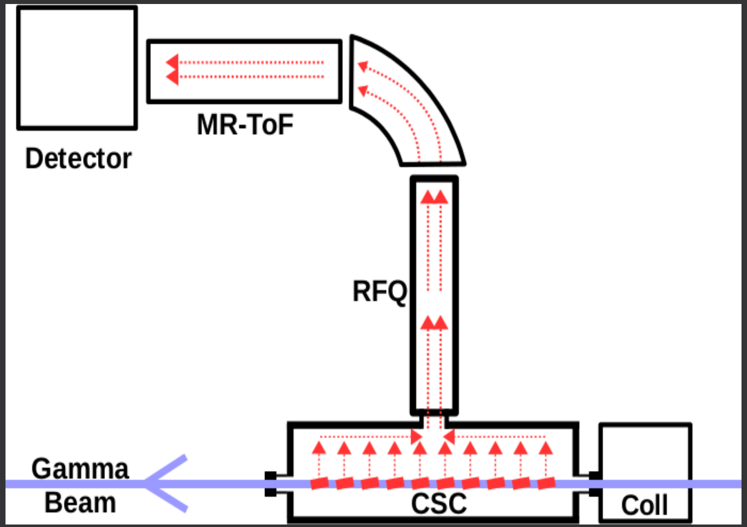

T. Dickel et al., NIM B 376 (2016) 216

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Phase I
1) Cryogenic Stopping Cell (orthogonal extraction)
2) RFQ (Radio Frequency Quadrupole)
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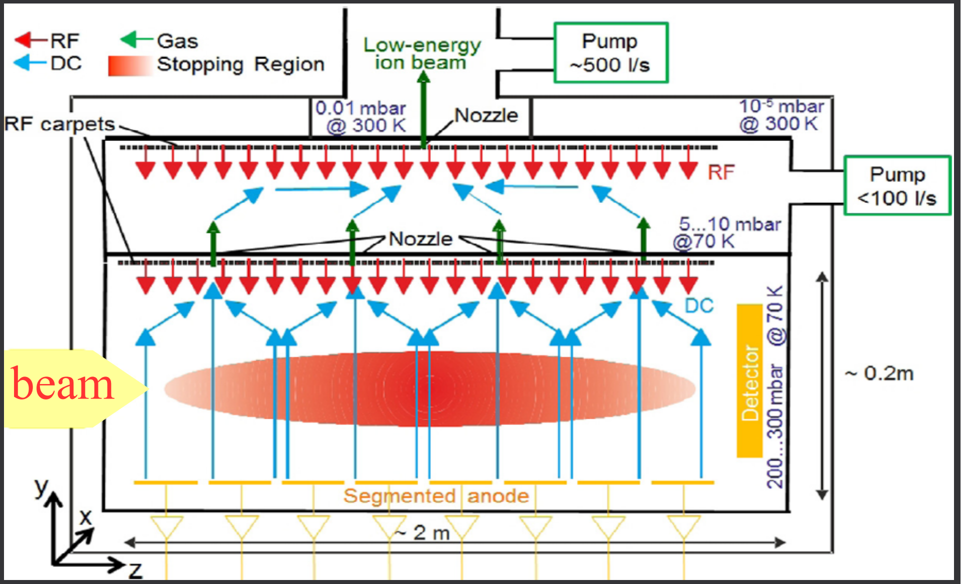

Nuclear Physics

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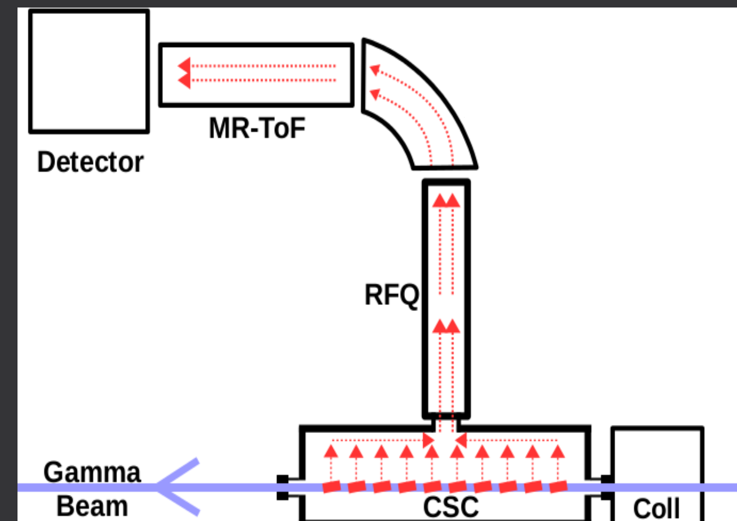

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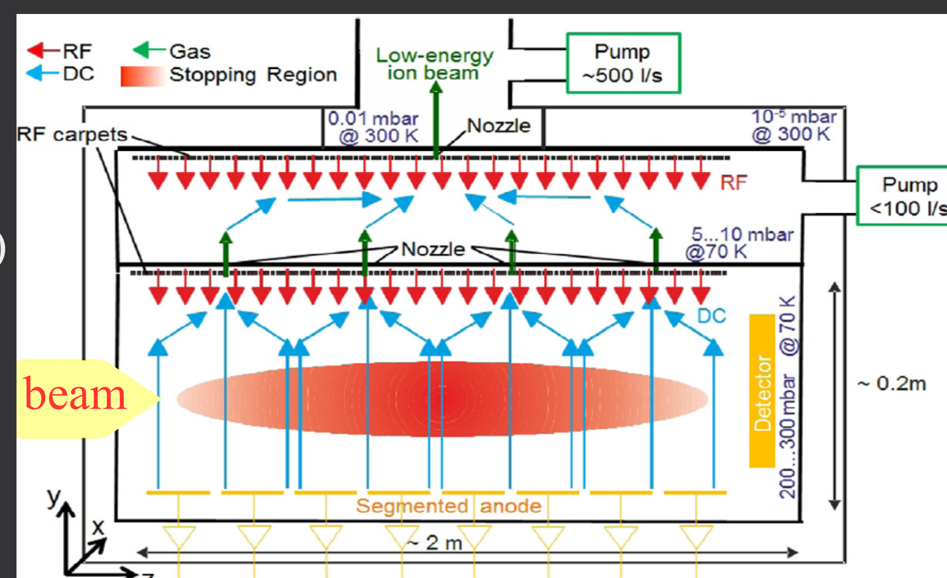
Phase II
1) β-decay station: HPGe detectors, tape station
2) collinear laser spectroscopy station



Fission fragment release rates

Geant4 photofission implementation
Target foils: 3μm UF_4 with 0.5μm graphite backing

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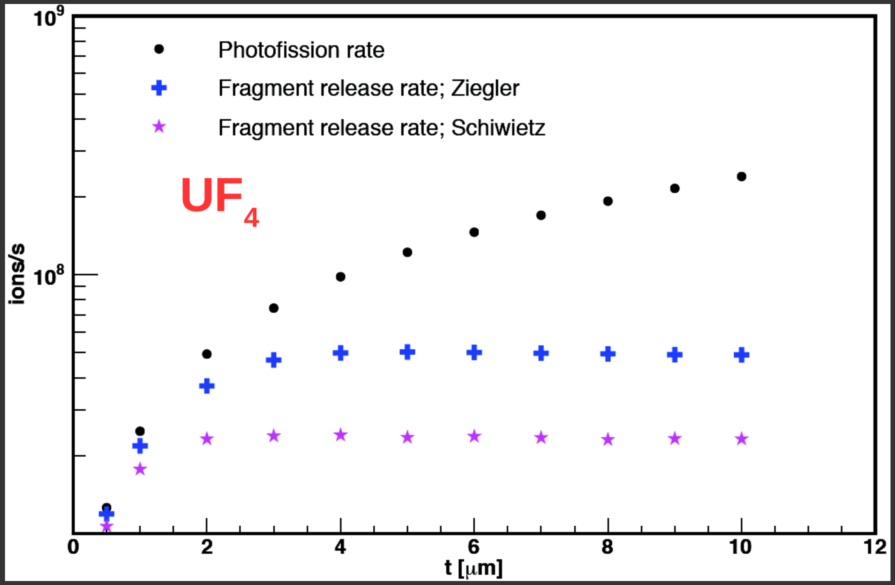

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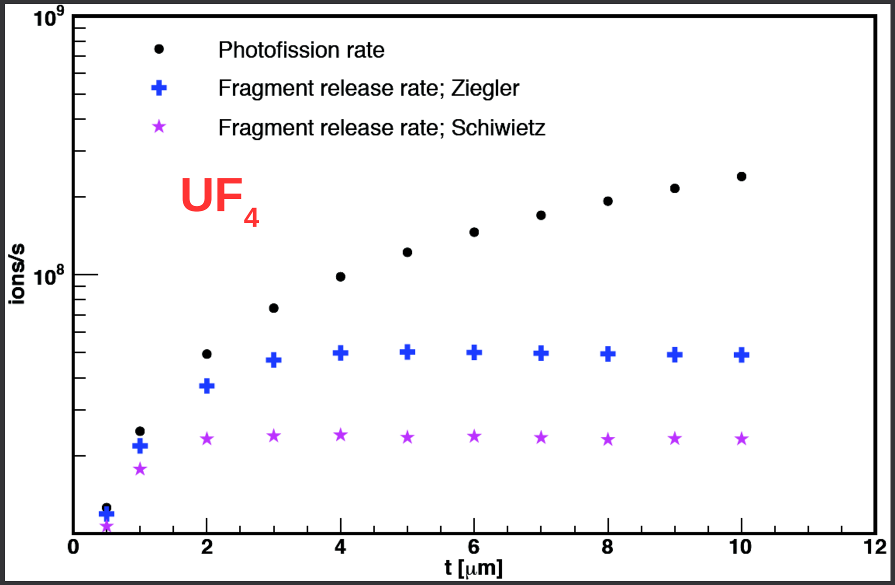

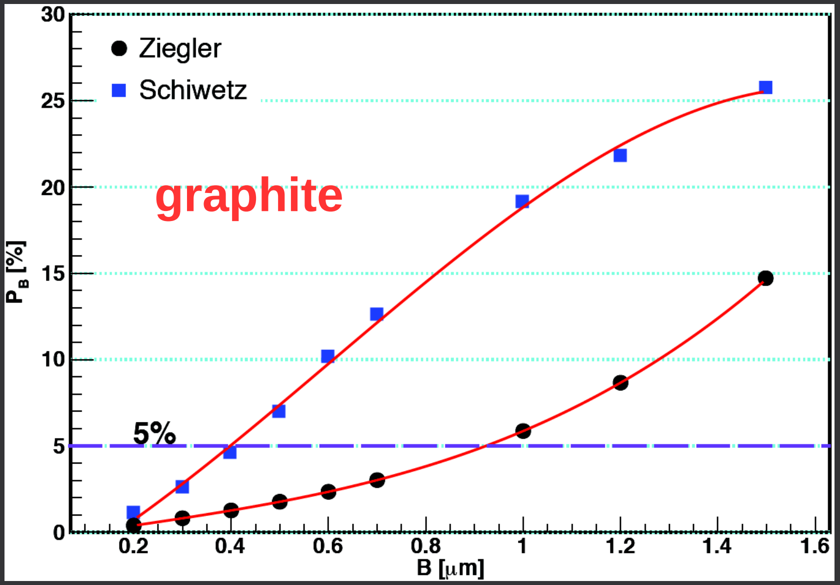

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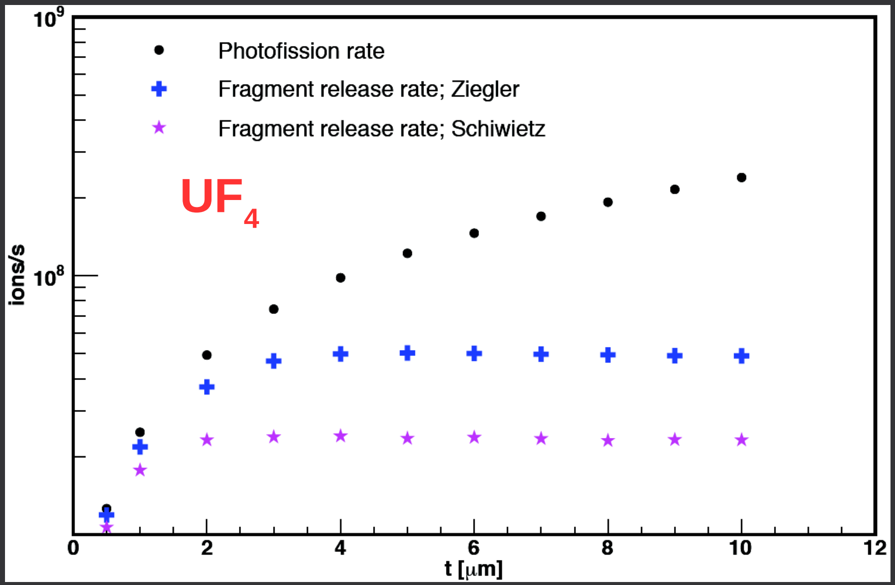
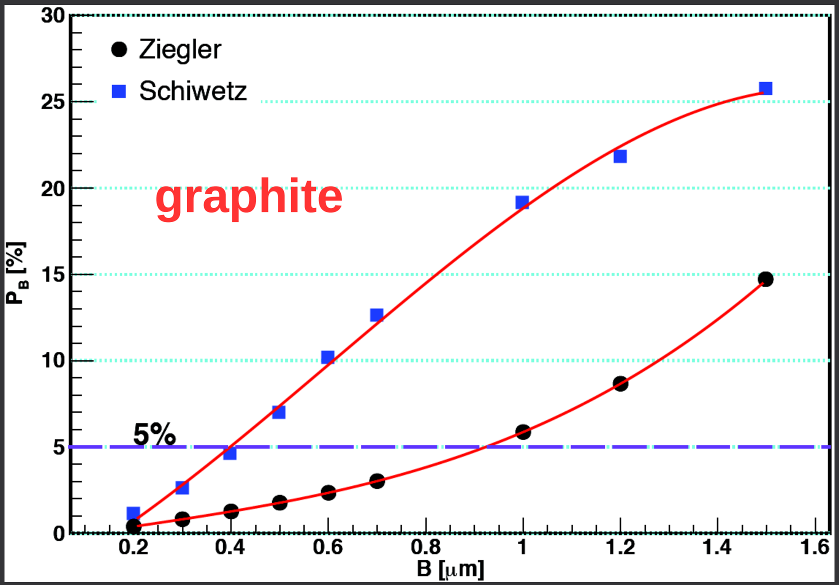
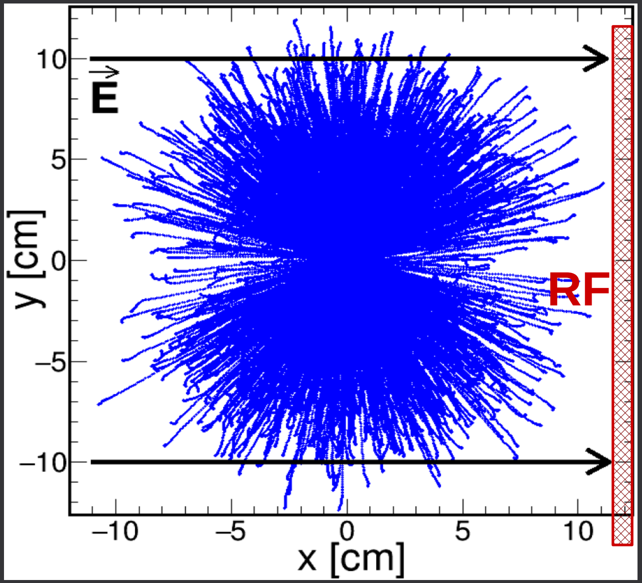




For beam rate $10^{12}\gamma$/s: **$4\cdot10^7$ frag/s**

Fragment Slowing Down in Gas

Geant4: He, T=70K, p=300mbar (ρ=0.206mg/cm^3)
>95% of fragments stop in 11.3cm → **width~24cm**



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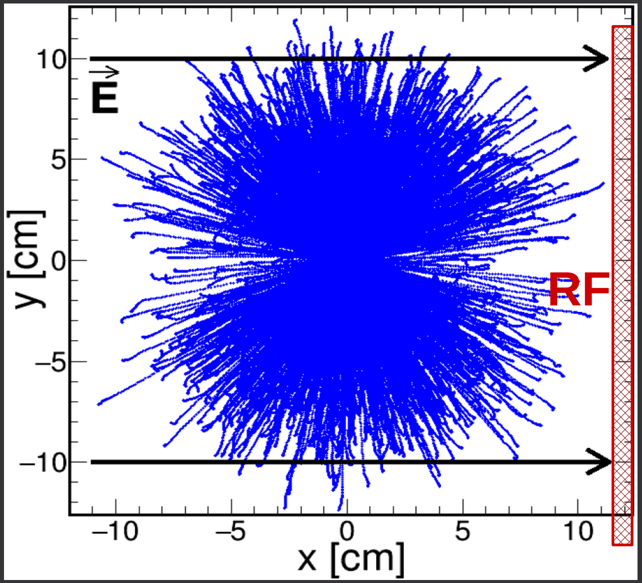
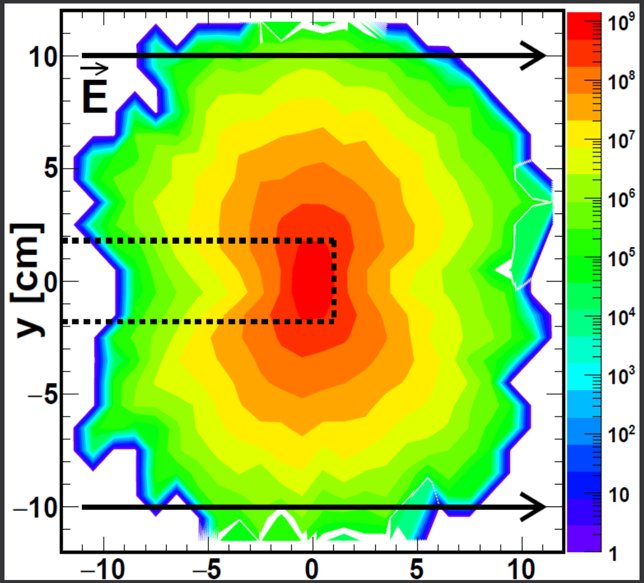
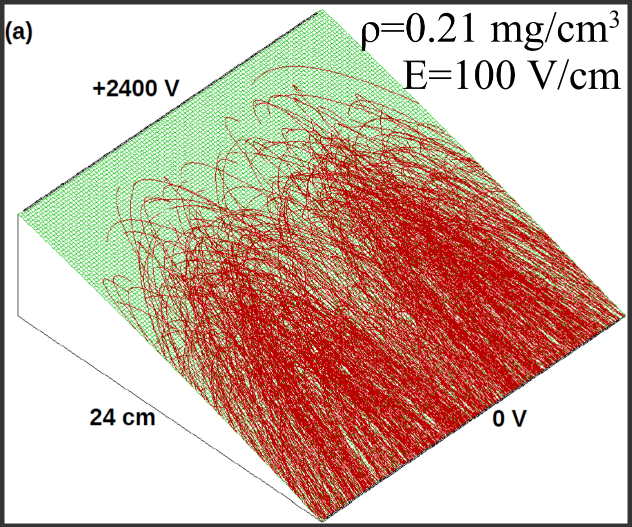


Space charge = He^+ cloud created by fragment (>90%) and e^+/e^- (<10%) induced ionization of He gas
Above a certain **charge density rate Q**: field saturation, strong e-ion recombination, weak plasma.

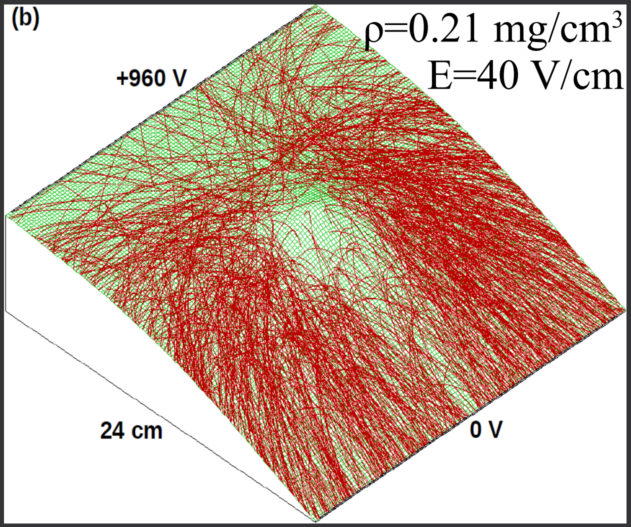


Fragment extraction – space charge effect

SIMION 8.1: solve Poisson equation dynamically (PIC simulation) with ionic charge distribution from GEANT4 as input → **extraction efficiency ε and time τ**

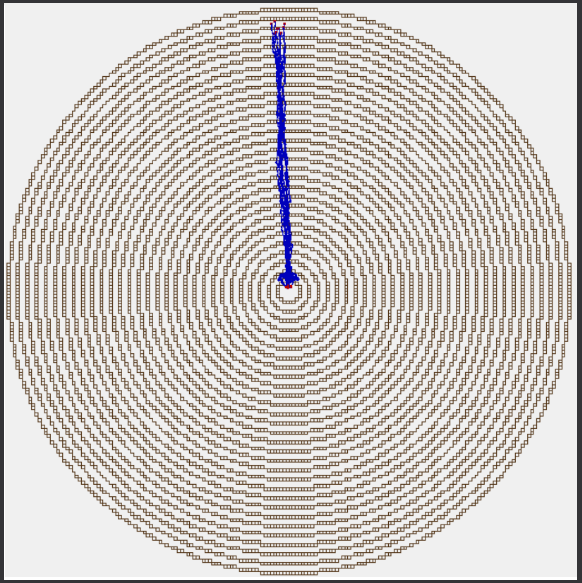


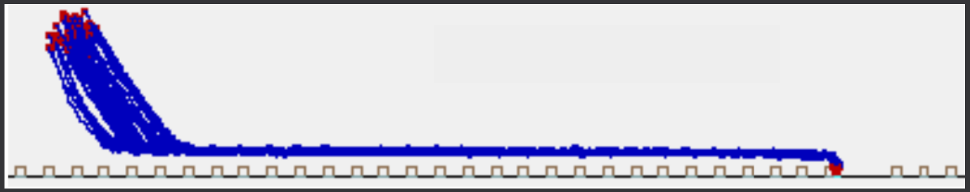
ε = 89% <τ> = 6.8ms



ε = 67% <τ> = 17ms

Fragment extraction – RF carpet transport





$$V(t) = V_{DC} + V_{RF} \sin(2\pi \nu_{RF} t)$$

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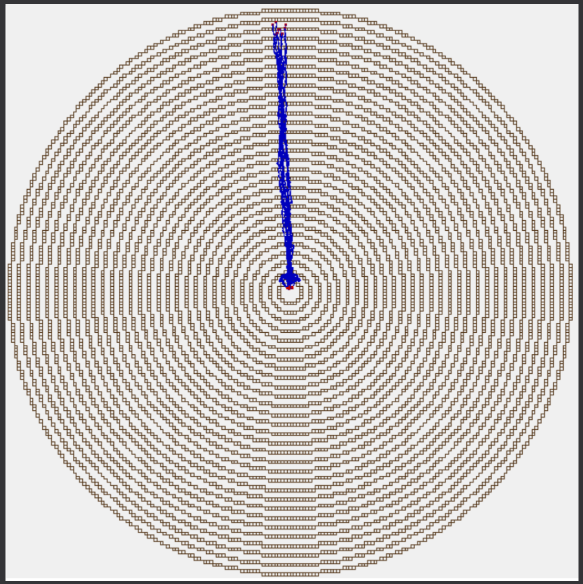

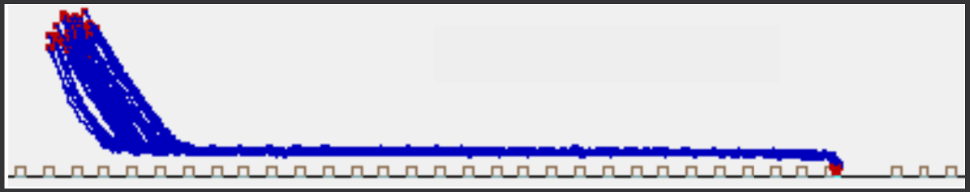

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V_{DC}=180V , V_{RF}=150V , ν_{RF}=6MHz , r_0=125μm , ρ=0.12mg/cm^3

Optimal density ρ: large for fragment stopping, small for carpet repulsion
Optimal U_{DC}, U_{RF}, ν_{RF}, r_0 for best ε and τ → ε>90% and τ≈10ms are obtained

Current developments

Design of the main CSC components:
– target system
– gas recirculation and purification system
– cryogenic system
– electrode system (RF carpets) for ion drift

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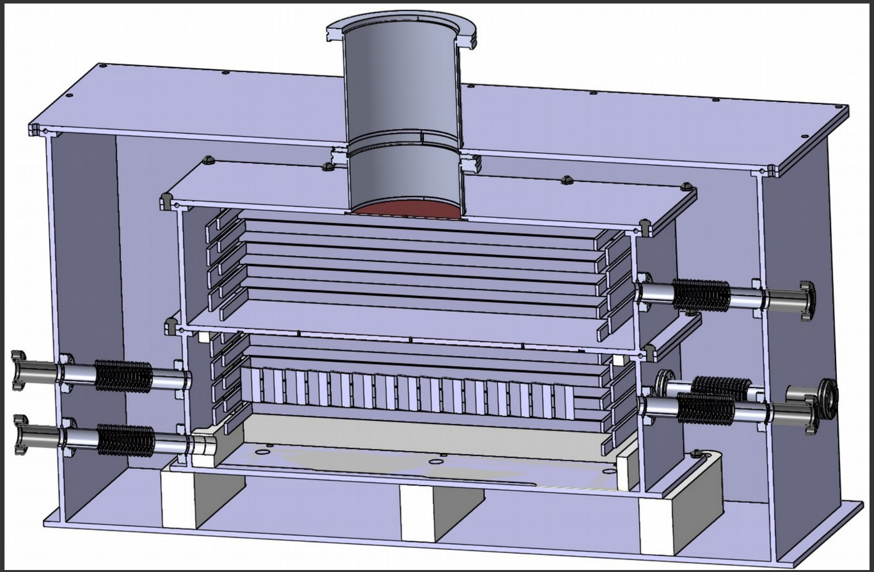

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– visualize and optimize gas flow
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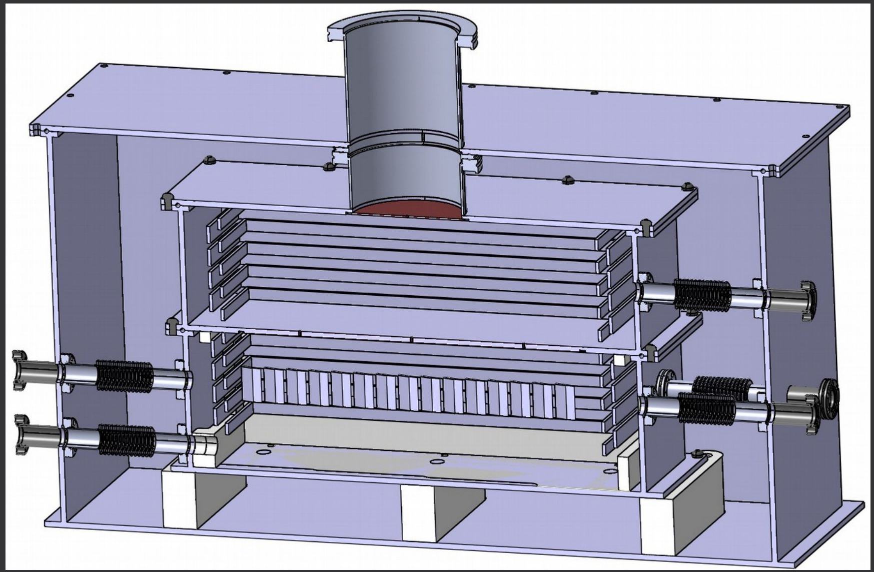

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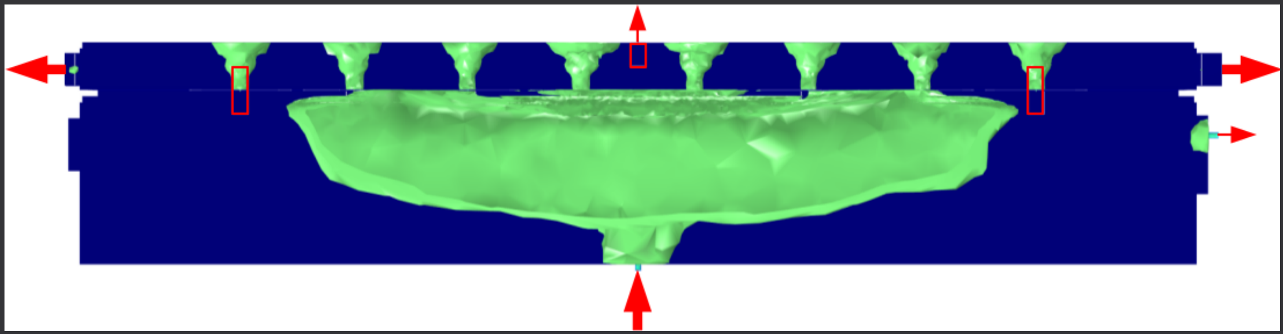
CFD + heat transfer simulations (COMSOL)
→ gas jet optimization



Summary

- a two-phased IGISOL RIB facility will be built at ELI-NP

- its main characteristics are expected to be:
  - very low backgrounds (space charge)
  - high extraction efficiency (70-90%) and low extraction time (~25 ms)
  - very high mass selectivity ($\Delta m/m \sim 10^6$): isomeric beams
  - large range of measuring capabilities: mass, $\alpha/\beta/\gamma$ spectroscopy, nuclear moments and radii
  - emphasis on refractory isotopes

- the design of the gas cell is in final stages; a demonstrator cell will be ready next year

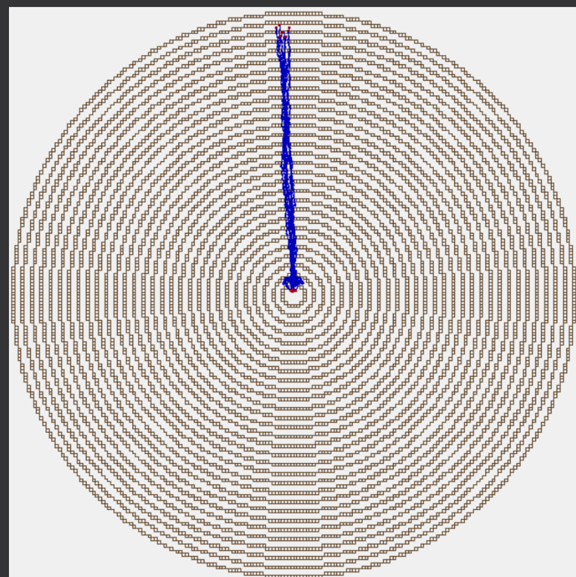
Extreme Light Infrastructure - Nuclear Physics

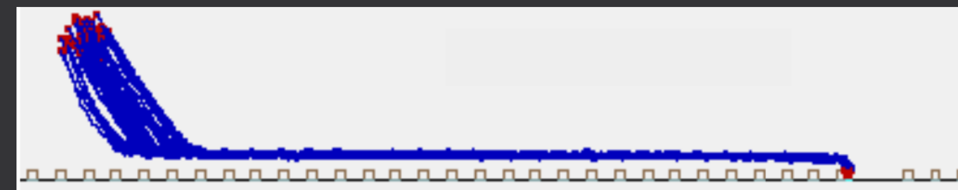
(ELI-NP) - Phase I

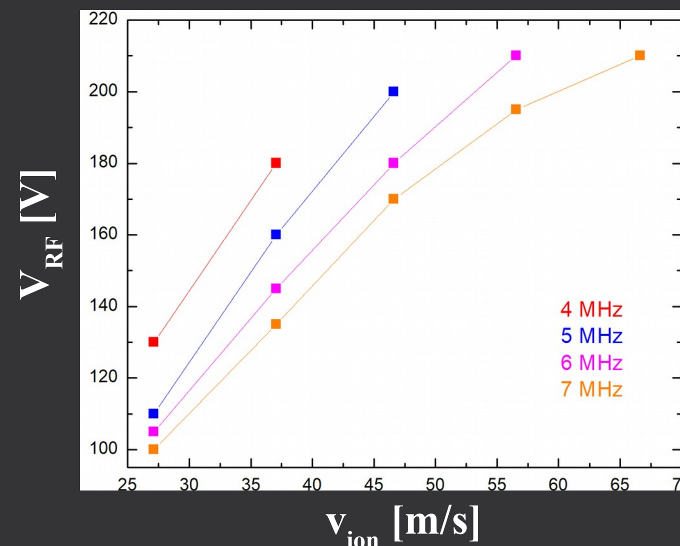
www.eli-np.ro

Project co-financed by the European Regional Development Fund

Fragment extraction – RF carpet transport







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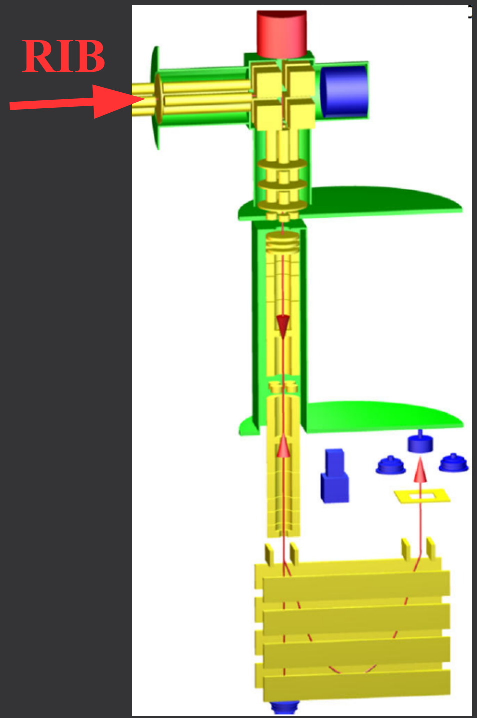
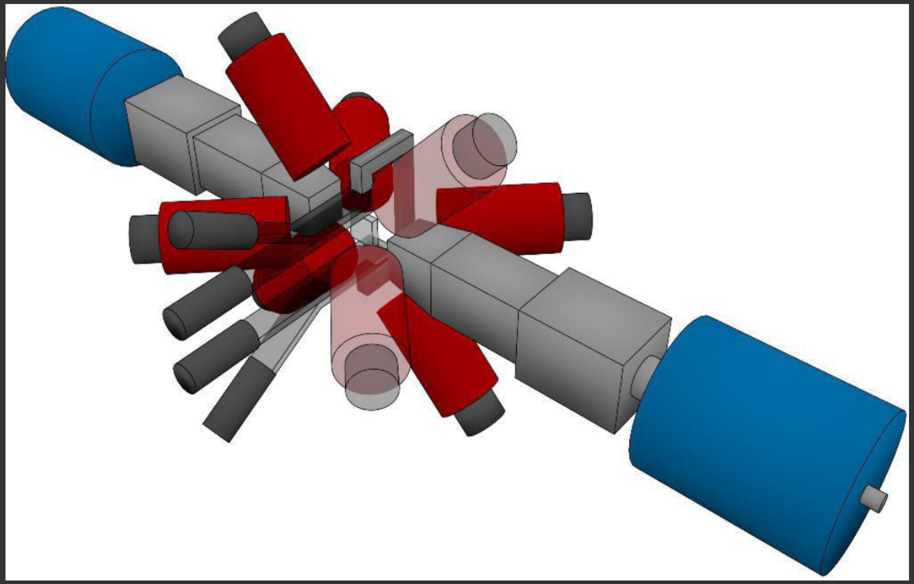
Exotic nuclei selection and measurement

- ions extracted from the CSC are formed into a RIB by the RFQ: cooling, bunching, mass selection (m/Δm~200), CID
- high resolution (m/Δm~10^6) mass selection and measurement by the MR-ToF
- β-decay station: β and γ decays and coincidences





Fragment Stopping in Target (I)

Geant4 stopping power: J.F. Ziegler and J.M. Manoyan, NIM B 35 (1988) 215

$S_{ion} = (\gamma Z)^2 S_p$, S_p = proton stopping (Bethe-Bloch)

$\gamma = q(1+s.c.)$ = ion effective charge, $q \equiv Q/Z$, s.c. = screening correction (Brant-Kitagawa)

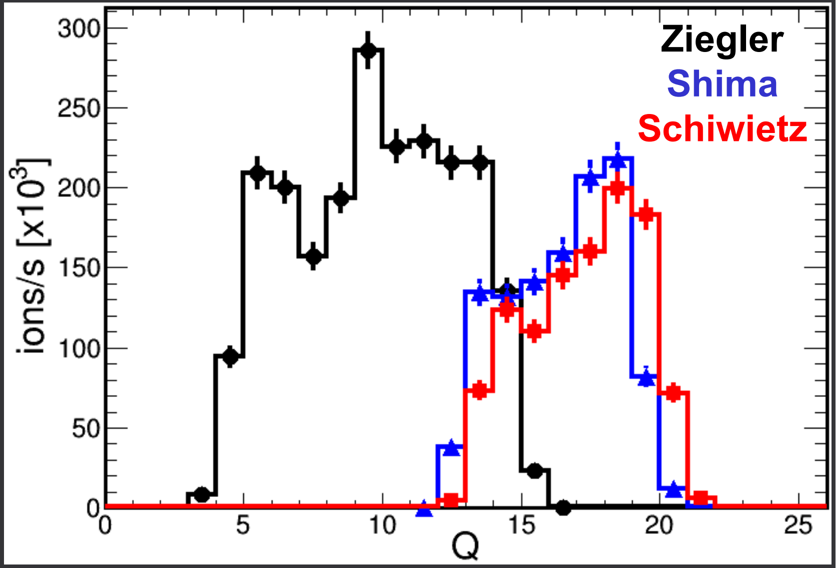
$q \equiv Q/Z \sim 1 - \exp(-v/v_B \cdot Z^{-2/3})$ = ion charge state (Bohr approx)

$\gamma \approx q \approx 1$ for light ions (Z~1), high velocity ($v \gg v_B$=25 keV/u)

Significant for fission fragments: Z=30-60, KE~0.3-1.5 MeV/u

$q(v, Z, Z_{targ})$ measurement parameterizations:

1) Ziegler (1988): Geant4
2) Shima (1982): older, specific for slower heavy ions
3) Schiwietz (2001): newest (largest data set), differentiated for solid/gas targets



LOHENGRIN (ILL Grenoble): (n_{th},f) of ^{235}U, $^{239,241}Pu$

$\langle Q \rangle$ = 20-22, σ_Q = 2.0-2.4

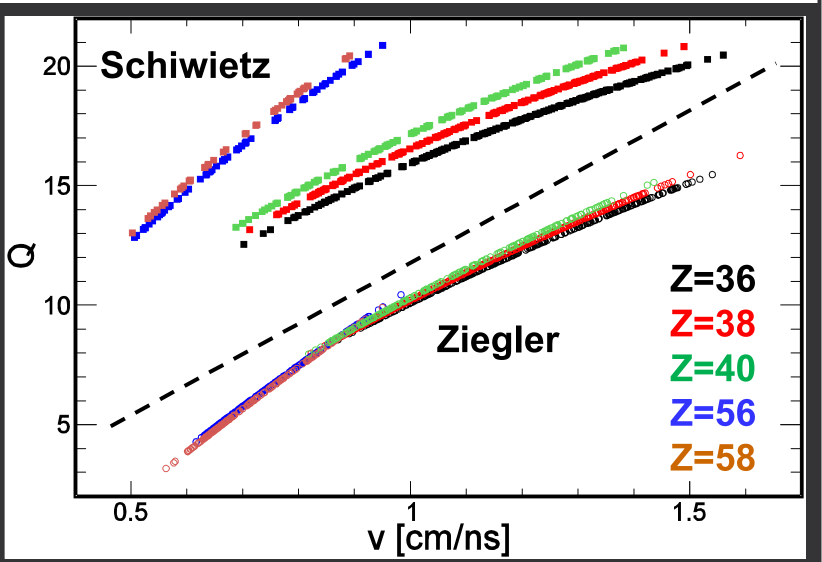
Ziegler: $\langle Q \rangle$ = 9.8, σ_Q = 3.0

Shima: $\langle Q \rangle$ = 16.5, σ_Q = 2.0

Schiwietz: $\langle Q \rangle$ = 17.3, σ_Q = 2.1

Schiwietz&Shima:

- describe better data
- larger ionic charge
- stronger Z dependence
- smaller release efficiency



Release efficiency UF_4