RIB production at the Gamma Factory

1) GF beam as RIB driver

2) Ion catcher cell: HADO-CSC

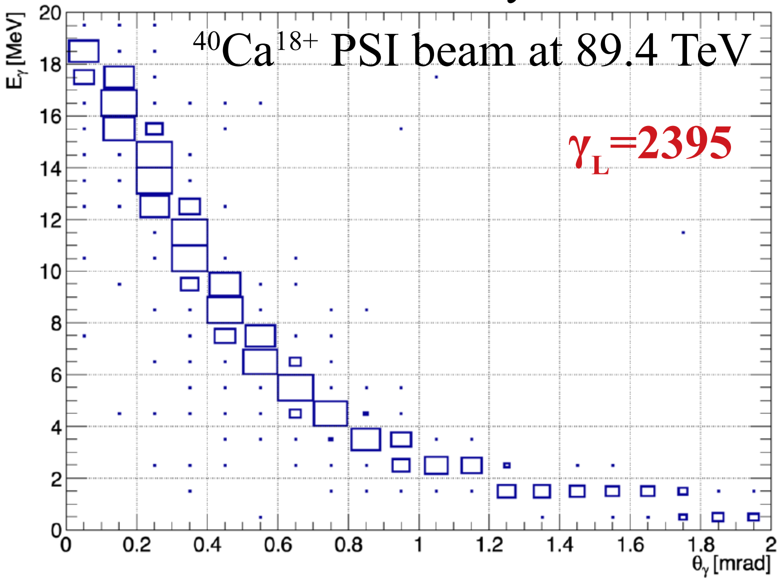
3) Extraction challenges: space charge

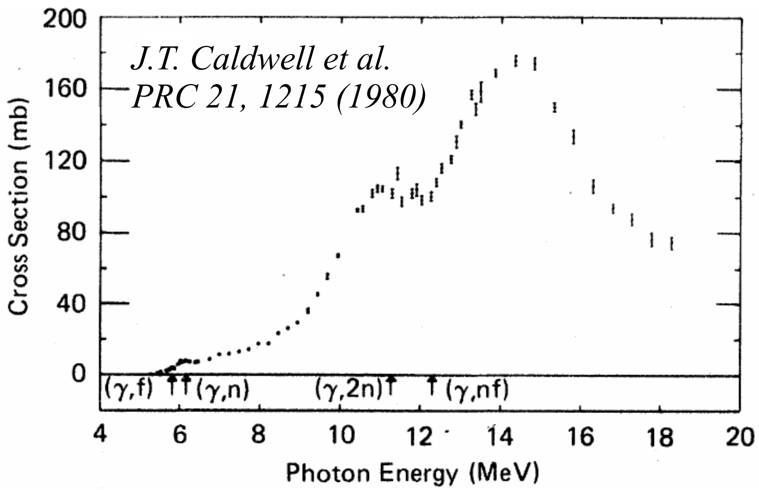
4) Production rates and comparisons

D. Nichita et al., arXiv:2105.13058 (submitted to Annalen der Physik)

GF beam as RIB driver

GF-CAIN simulation by **W. Placzek**





Energy – angle correlation:

$$E_\gamma = \frac{4\gamma_L^2 E_l}{1+\gamma_L^2\theta_\gamma^2} \longrightarrow E_\gamma^{max} = 4\gamma_L^2 E_l$$

Divergence: $\sigma \sim 1/\gamma_L \longrightarrow \sigma \sim 0.3\ mrad$

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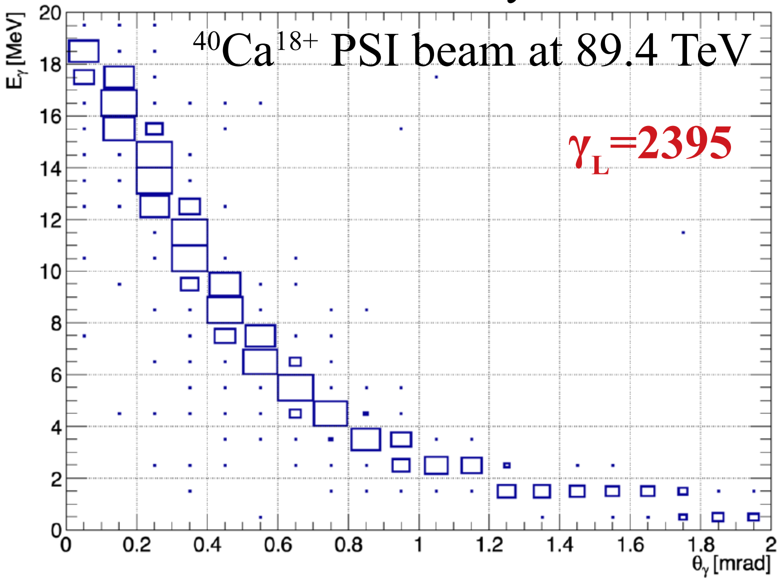

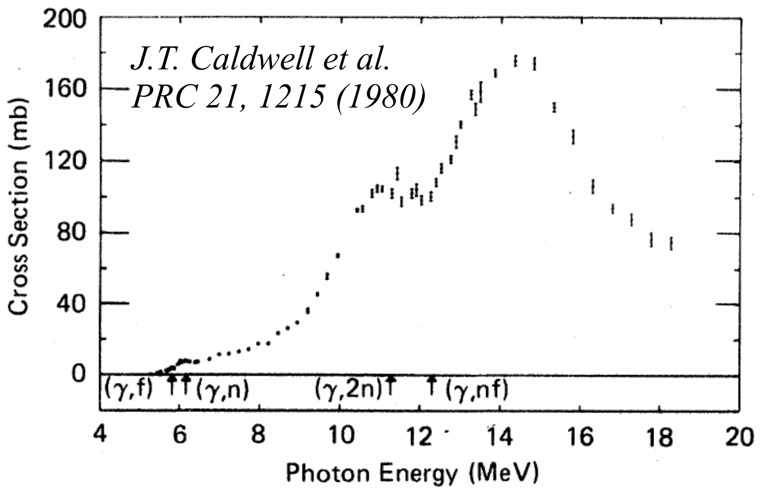

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Energy interval tunable by θ_{max} and E_{beam} choice.

PSI γ beams almost identical to LCB γ beams except:
– huge intensity difference: σ~1b → σ~Gb
– huge primary beam energy difference: γ_L=E/M → $M_{ion}/M_e \sim 10^5$

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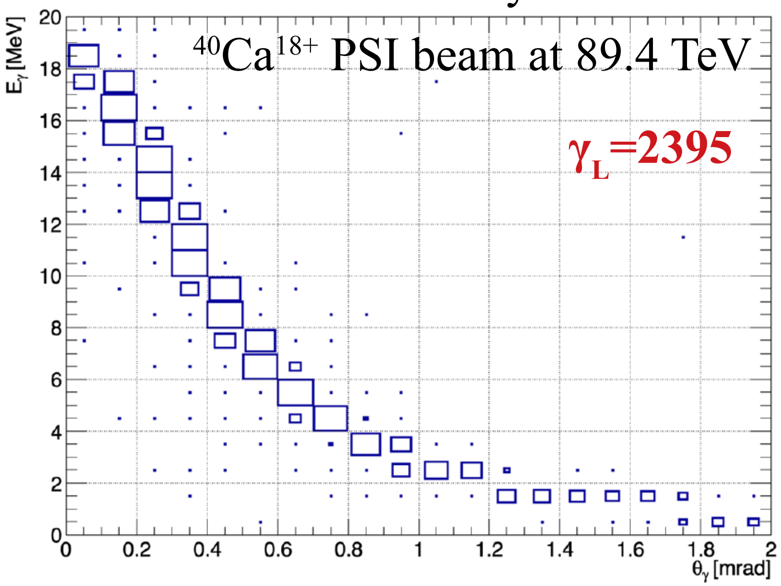

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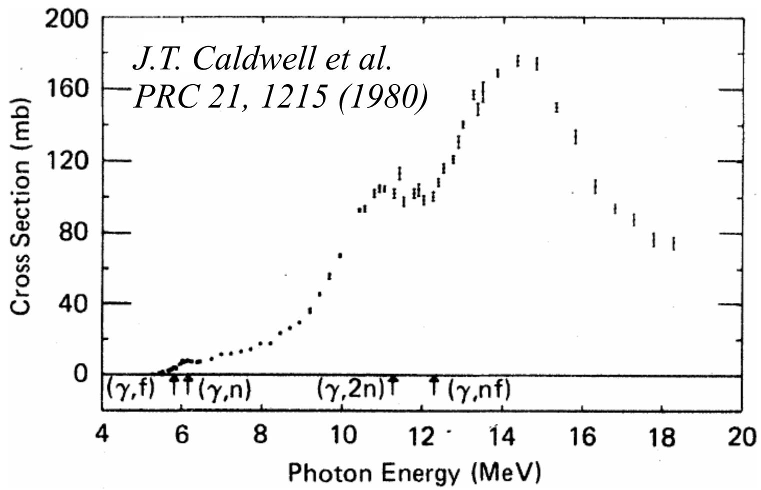
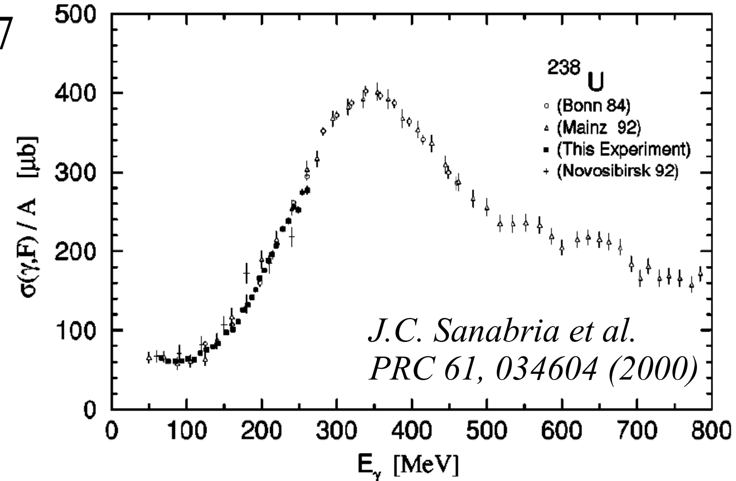


$^{207}Pb^{80+}$ PSI beam to γ_L = 2887
and laser with λ = 104.4 nm
→ E_γ^{max} = 396 MeV
→ from GDR to Δ resonance



RIB production at the Gamma Factory

HADO-CSC ion catcher gas cell

Target system:

– $\sigma_{\gamma f}(^{238}U) \approx 1b$ → thick target; fast extraction, refractory → thin target

– many (~50) thin targets: 3µm thick UO_2 with 0.5µm graphite backing, tilted ~10° wrt beam

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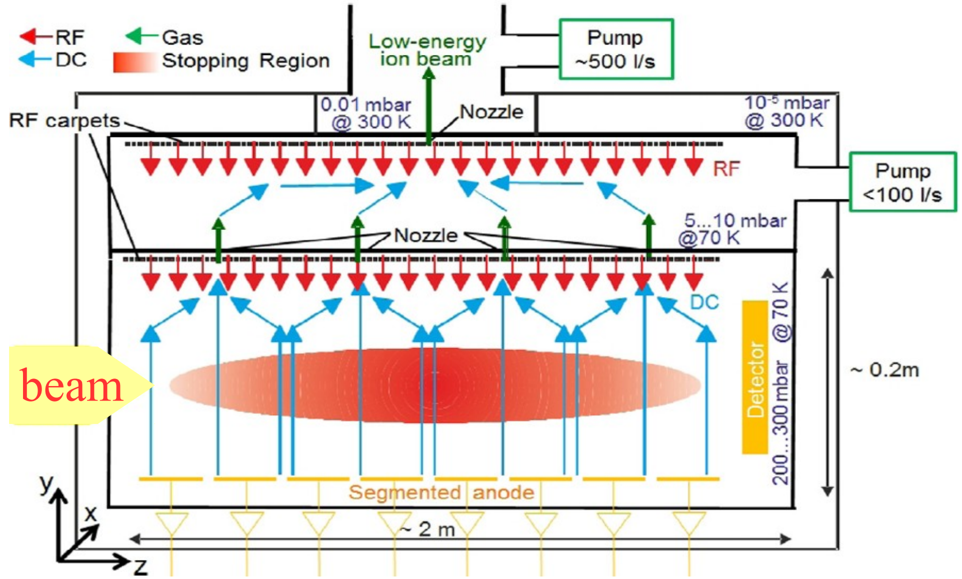
HADO-CSC gas cell:
collaboration **GSI, Giessen Univ, ELI-NP, SOREQ, Jyvaskyla Univ**
– fast (~ few ms), broadband extraction → electric transport
– cryogenic He operation → avoid neutralization, broadband
– orthogonal DC field → fast transport; higher rate capability
– wall transport with RF carpets

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

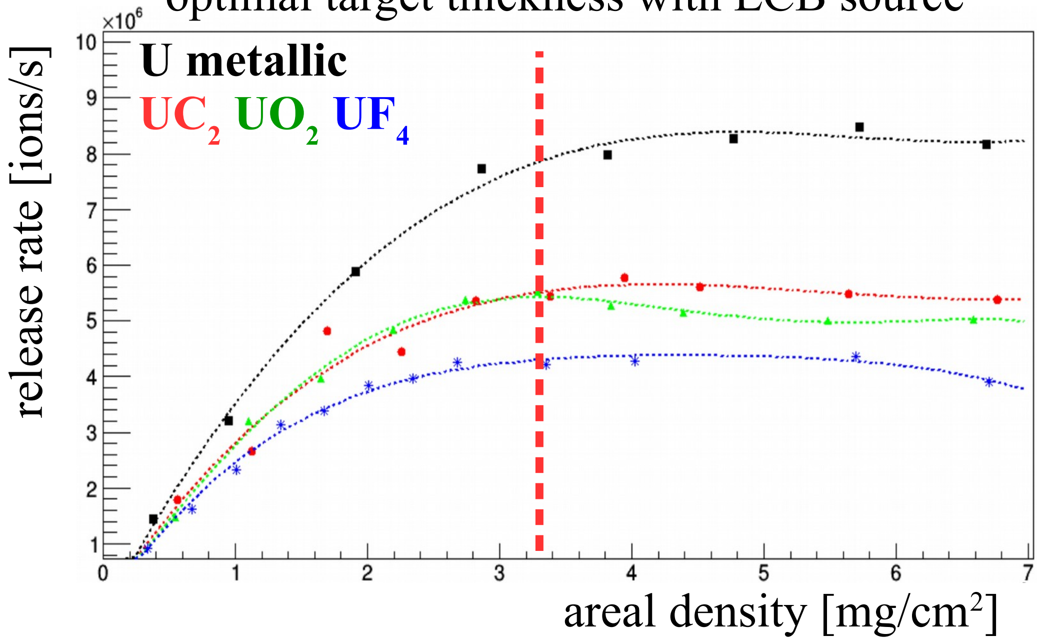


Production simulation with Geant4

GEANT4: fission + target E-loss + gas thermalization

P. Constantin et al., NIM B 397 (2017) 1-10

optimal target thickness with LCB source



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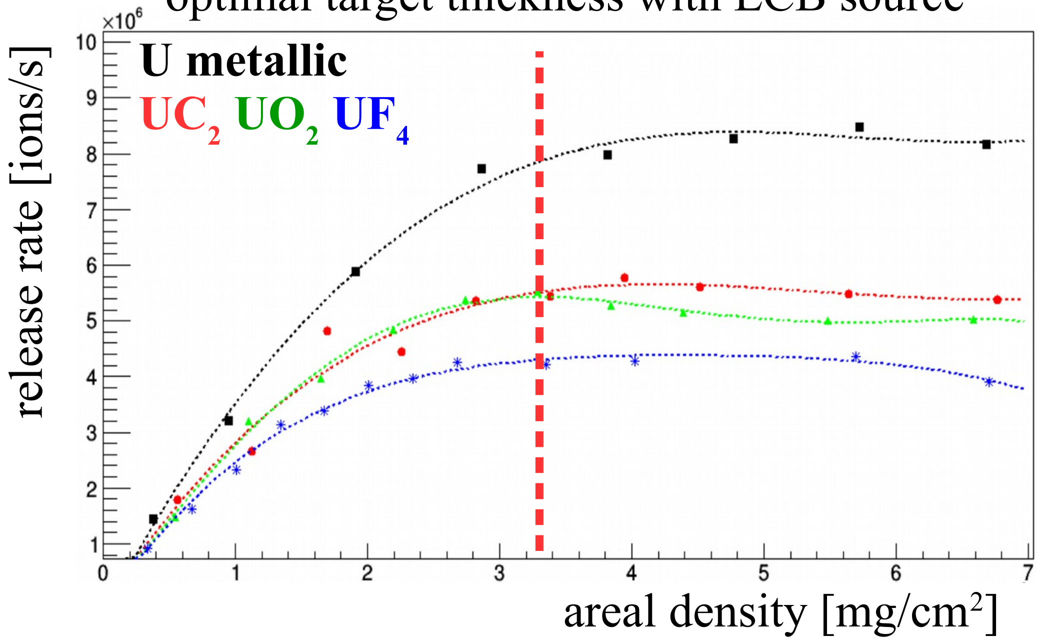
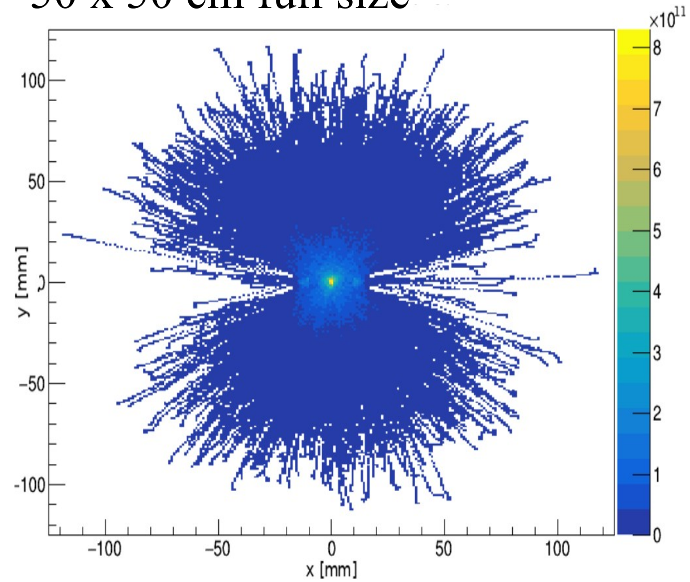


optimal gas cell transversal size:
25 x 25 cm at 300 mbar & 75 K (He)
50 x 50 cm full size



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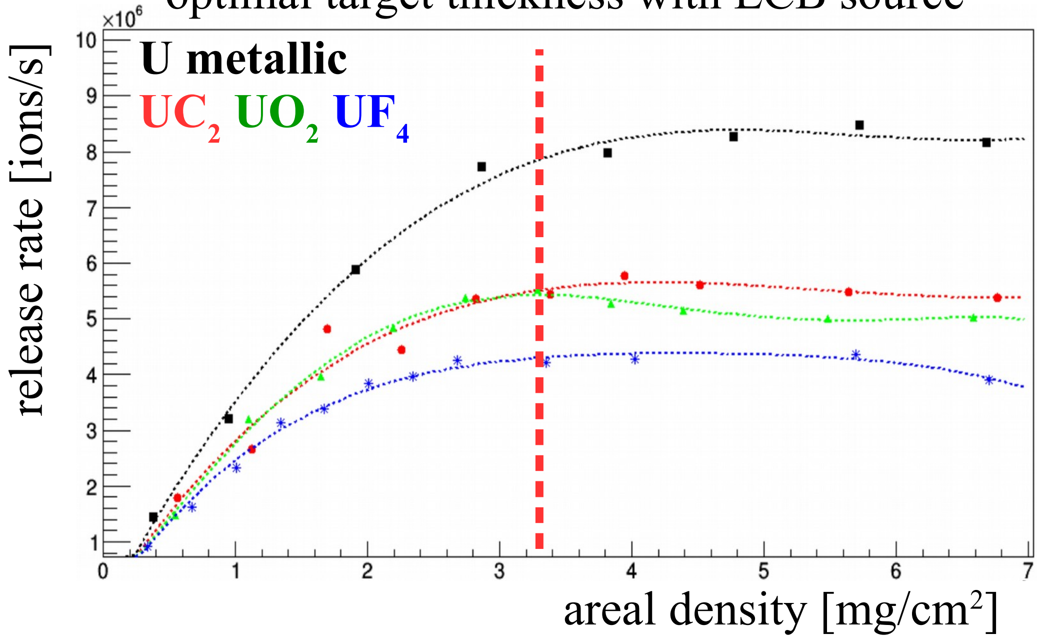

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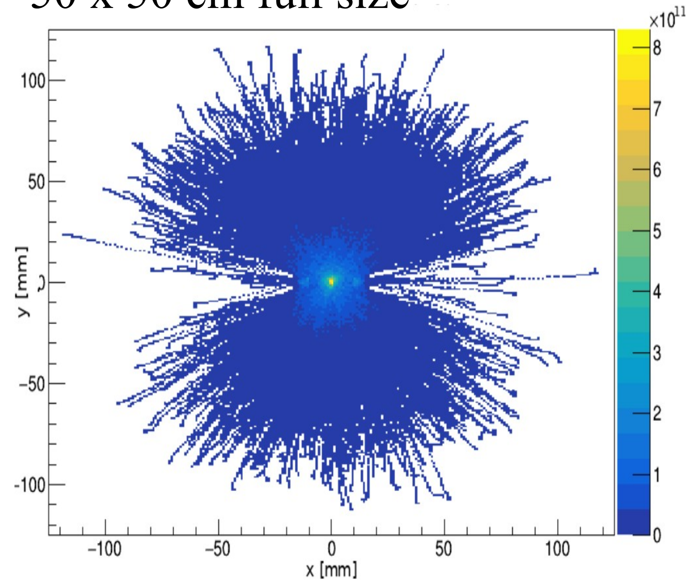

For a beam intensity of 10^{17} γ/s and a distance IP-target of 100 m:
3% on targets, **10^{12} FF/s** released from targets

Space charge effects

– during their stopping, FFs create a cloud of He_3^+ ions

– when induced electric field ≈ external electric field → large drop in extraction efficiency

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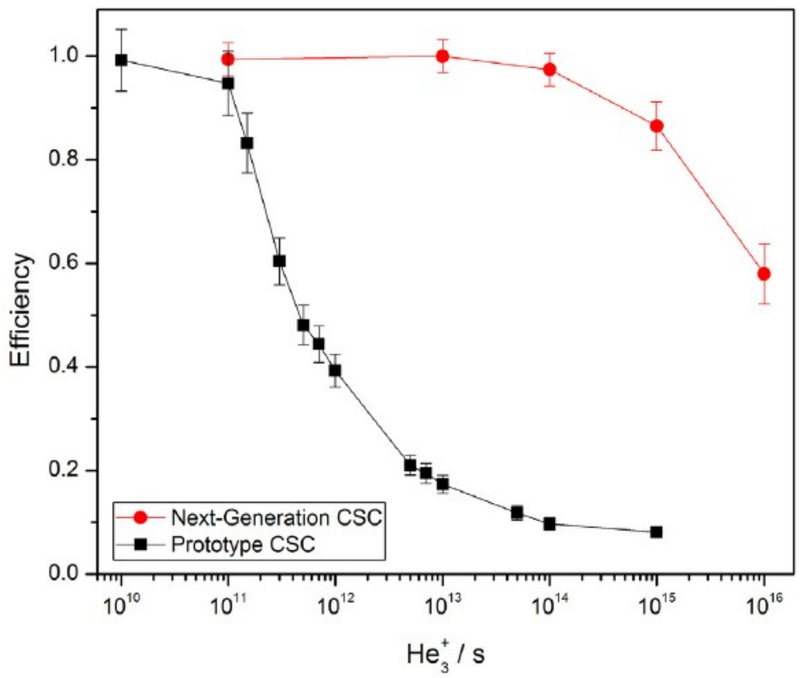

RIB production at the Gamma Factory

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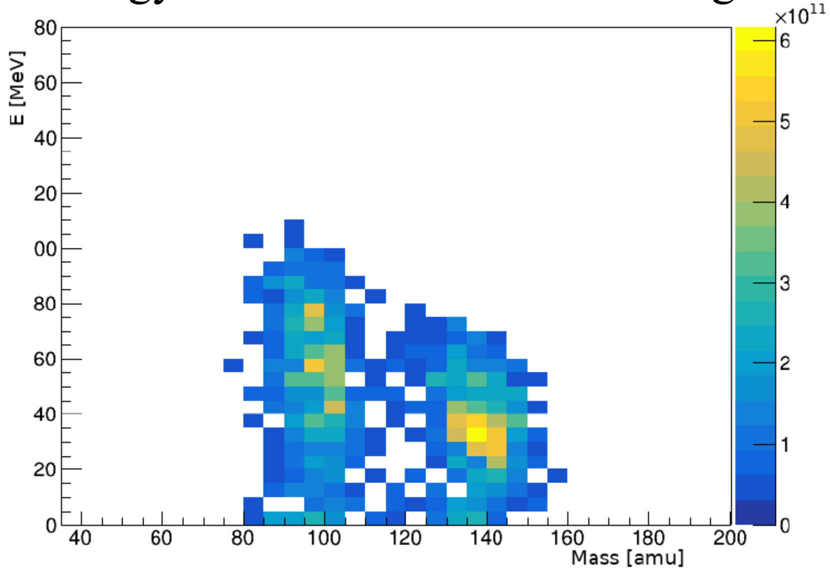
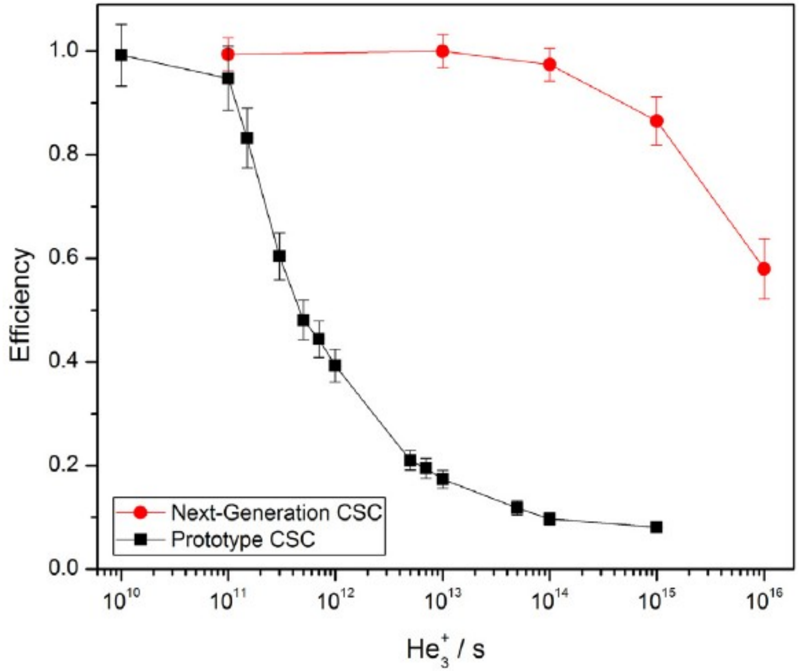
Energy vs. mass at release from targets





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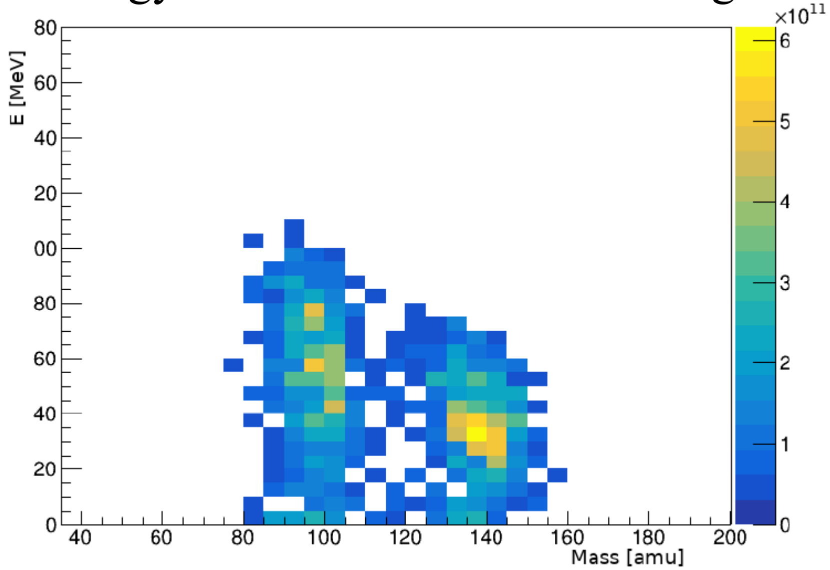
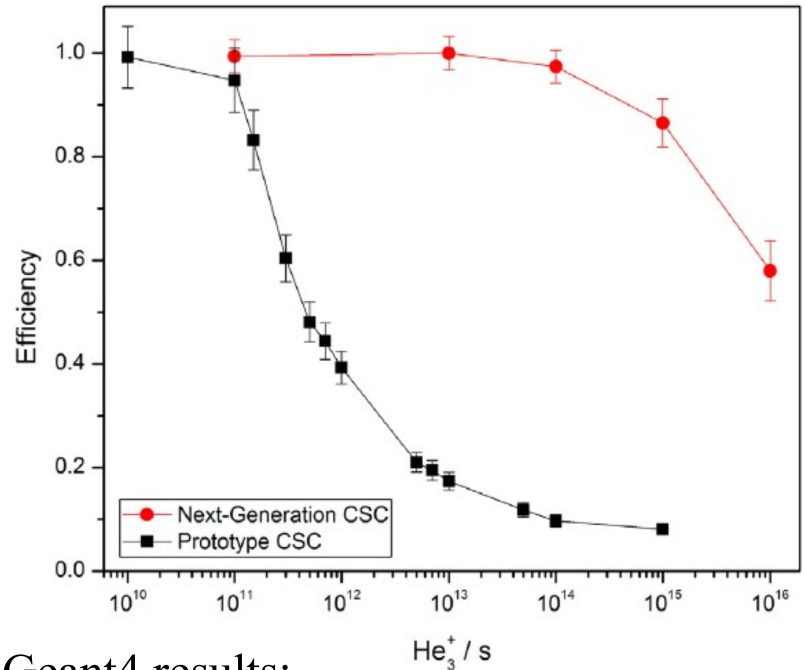
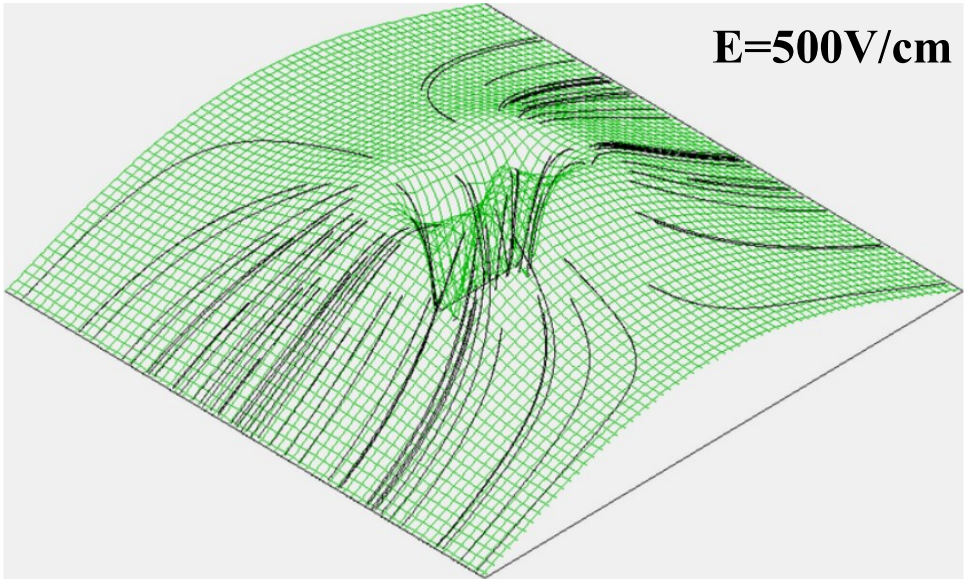




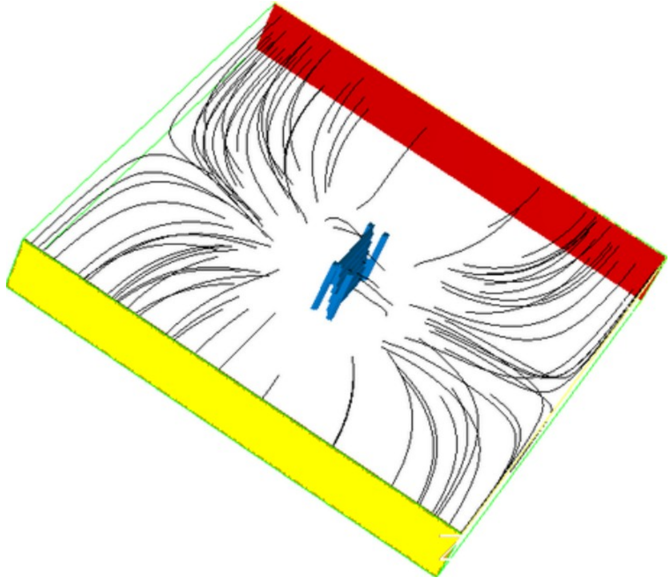
A full PIC simulation needed with input from Geant4 results:
map of charge by ionization + collection of thermalized heavy ions

Extraction simulation with SimIon

Initial state of PIC simulation with SimIon from Geant4



PIC simulation for 1 target



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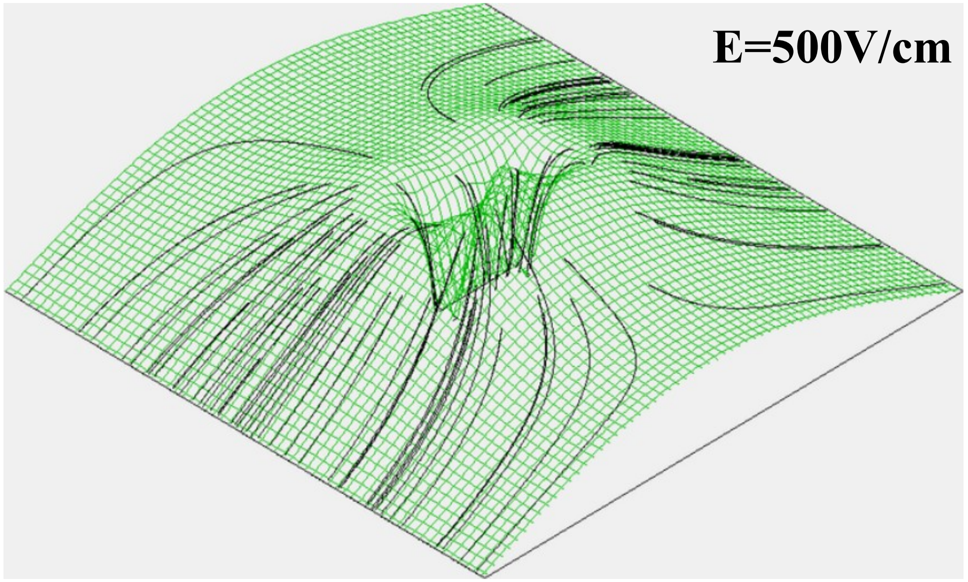

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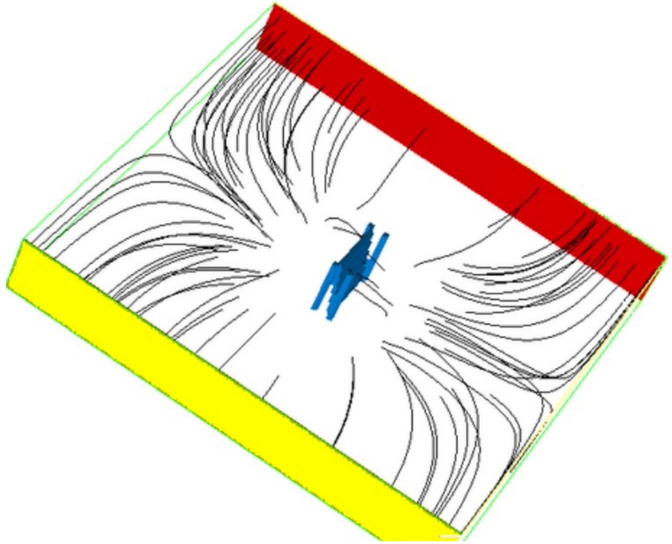

Heavy ions are extracted if they reach the
RF carpet with velocity v<50m/s: in our case **ε≈0**.
10^{17} ions ≈ 10 mC → huge velocities (~km/s)!

Extraction simulation with SimIon

However, the large induced electric fields generate also small extraction times **τ≈1ms**.

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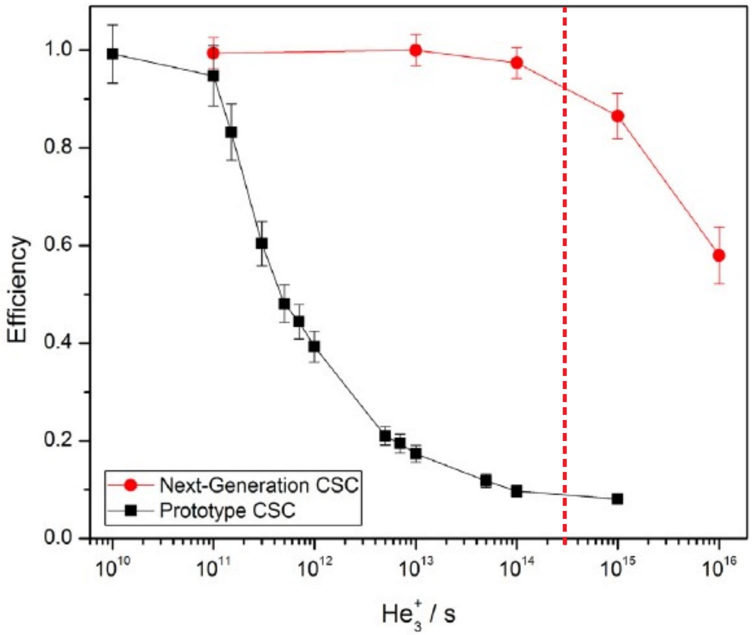
→ release $5 \cdot 10^{11}$ FF/s (half), but accumulate $3 \cdot 10^{14}$ He_3^+/s (0.1%)



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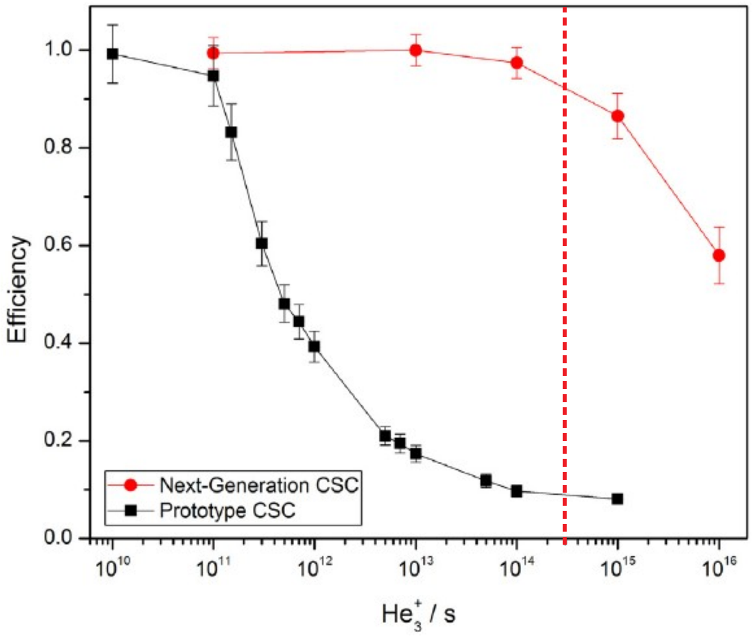
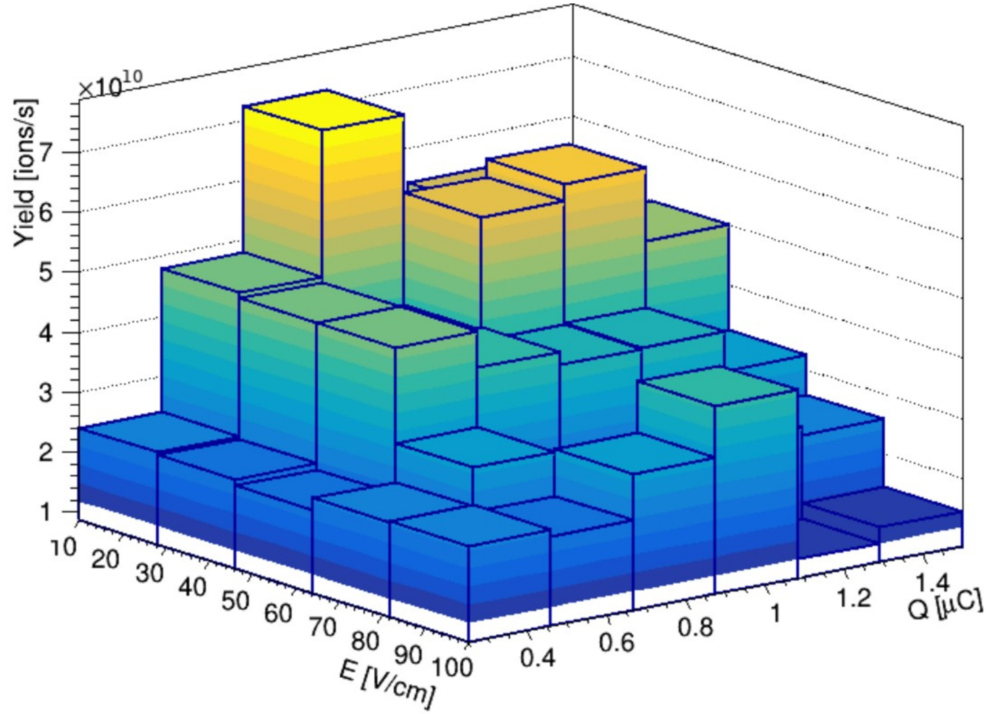
→ maximum extracted yield **~$7\cdot10^{10}$ FF/s**, hence **ε≈14%**, for E≈10V/cm and Q≈0.8μC





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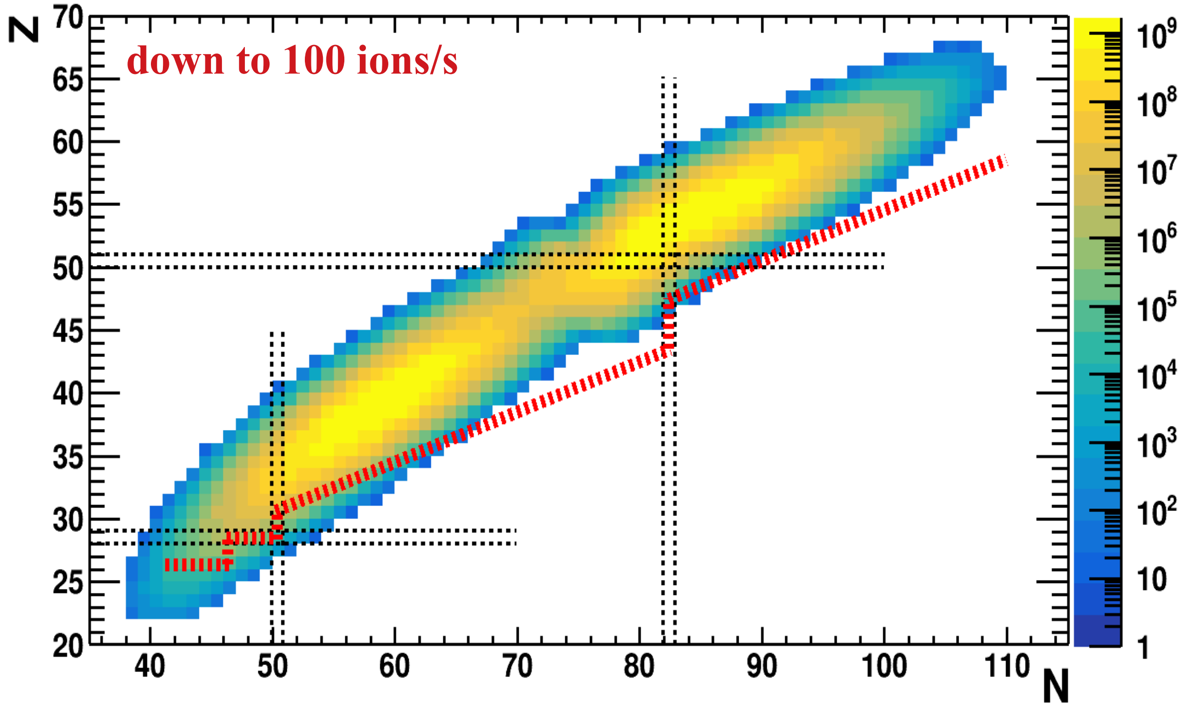

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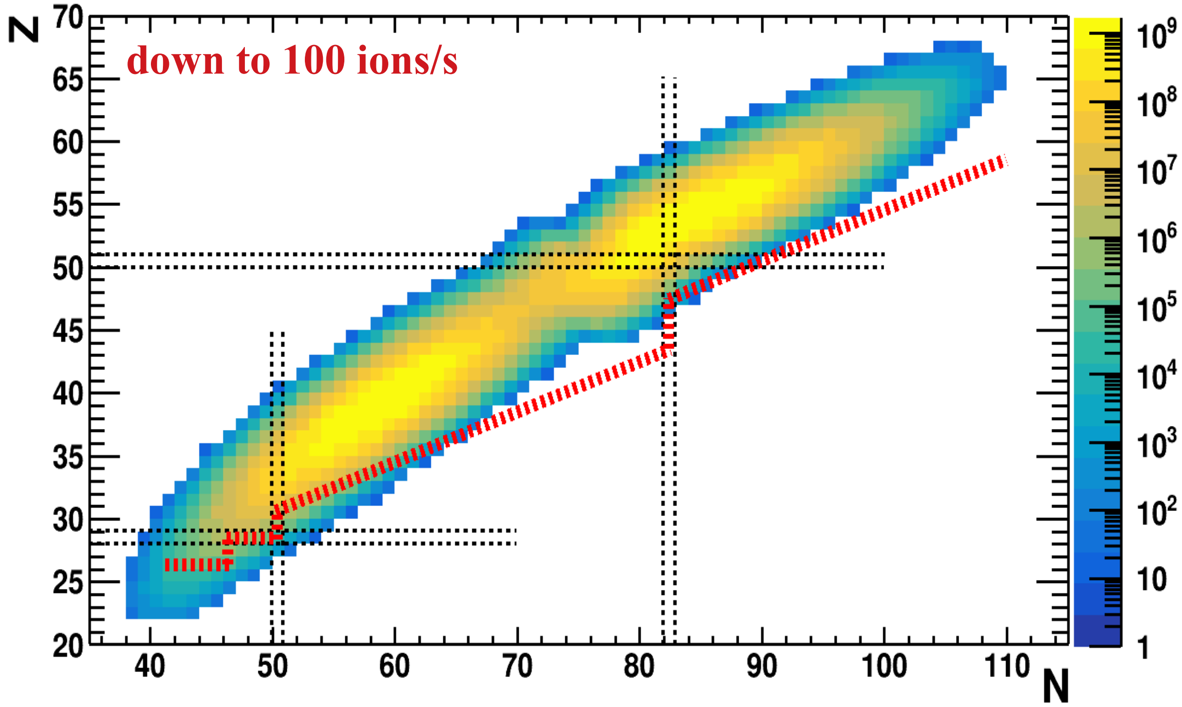

	76Co	78Ni	90Zr	110Zr	132Sn	136Sn	160Ce
(Z,N)	(27,49)	(28,50)	(40,50)	(40,70)	(50,82)	(50,86)	(58,102)
GF [i/s]	$8\cdot10^3$	$3\cdot10^4$	15	178	$7\cdot10^7$	$9\cdot10^4$	238
ISOLDE [i/µC]	NA(55-57)	NA(56-70)	NP	NP	$3\cdot10^8$	$4\cdot10^3$	NA(133)
FRIB [i/s]	0.1	7	$8\cdot10^9$	36	$1\cdot10^6$	29	0.1
CARIBU [i/s]	NP	NP	NA(97-105)	NA(97-105)	$2.4\cdot10^3$	NA(126-134)	NA(143-153)

ISOLDE: *http://isoyields-classic.web.cern.ch/query_tgt.htm*
FRIB: “Ultimate yields for stopped beams” *https://groups.nscl.msu.edu/frib/rates/fribrates.html*
CARIBU: “Low energy” *https://www.anl.gov/atlas/caribu-beams*

Conclusions

– continuous 10^{17} γ/s and distance 100 m: 10^{12} FF/s released, $3 \cdot 10^{17}$ He_3^+/s space charge → ε≈0
– same beam, but chopped 1 ms ON/OFF: $5 \cdot 10^{11}$ FF/s released, $3 \cdot 10^{14}$ He_3^+/s space charge → ε≈14%
– extracted RIB rate: ~$7 \cdot 10^{10}$ FF/s, quite competitive even on long-term future
– drift time very short: ~1 ms

BUT:
– this is in simulations…
– this operational regime for gas cells with electric transport has never been done
– a small scale prototype to test extraction in such space charge conditions
– instrumentation after the cell, like RF quadrupoles, would also need to be tested

Thank you!