# Comparison of $(\gamma,f)$ & $(p,X)$ $^{238}U$ Yields and Light Nuclide Yields from Photofission

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# Outline

- **Calculation of $^{238}U(p,X)$ Yield Estimates for a 100 μA $p^+$ driver (ISAC)**
- **Comparison of Yield Estimates to Observed $^{238}U(p,X)$ Yields**
- **Comparison of Yield Estimates to $^{238}U(\gamma,f)$ Yield Estimates for a 25 MeV/50 kW $e^-$ driver**

**"Mom, if I got a bicycle for Christmas, I could ride to the store for you"**

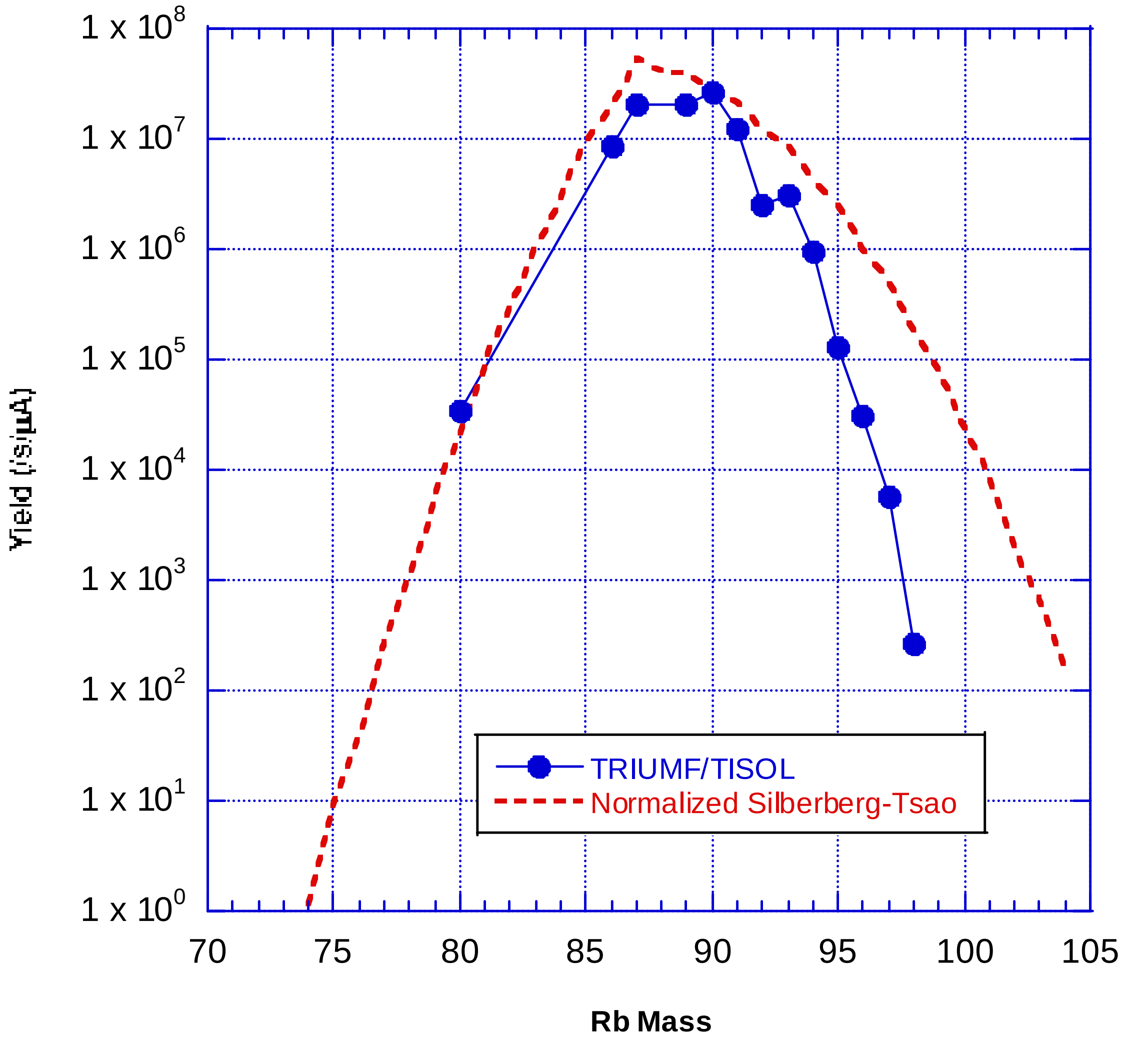
- **Light Nuclei from $^{238}U(\gamma,f)$**
- **Light Nuclei from (γ,p) reactions ($^{8}Li$ for a β-NMR facility)**

# $^{238}U(p,X)$ Yield Estimates

- Yield = $\sigma \Phi_{p+} N_t$
- Proton Flux ($\Phi_{p+}$) = 100 μA
- Target Thickness ($N_t$) = 30 g $^{238}U/cm^2$ (proposed HRIBF target)
- Cross sections ($\sigma$) from from Silberberg & Tsao, *Astrophys. J. Suppl. 25 (1973) 315*
  - S-T cross section calculations are based on experimental measurements

# Comparison of $^{238}U(p,X)$ Mass Yield Curves to Measured TISOL Yields

- **TISOL $^{238}U(p,X)$ yields (/s/μA) for 500 MeV $p^+$**
- **S-T estimates normalized to highest TISOL yield**



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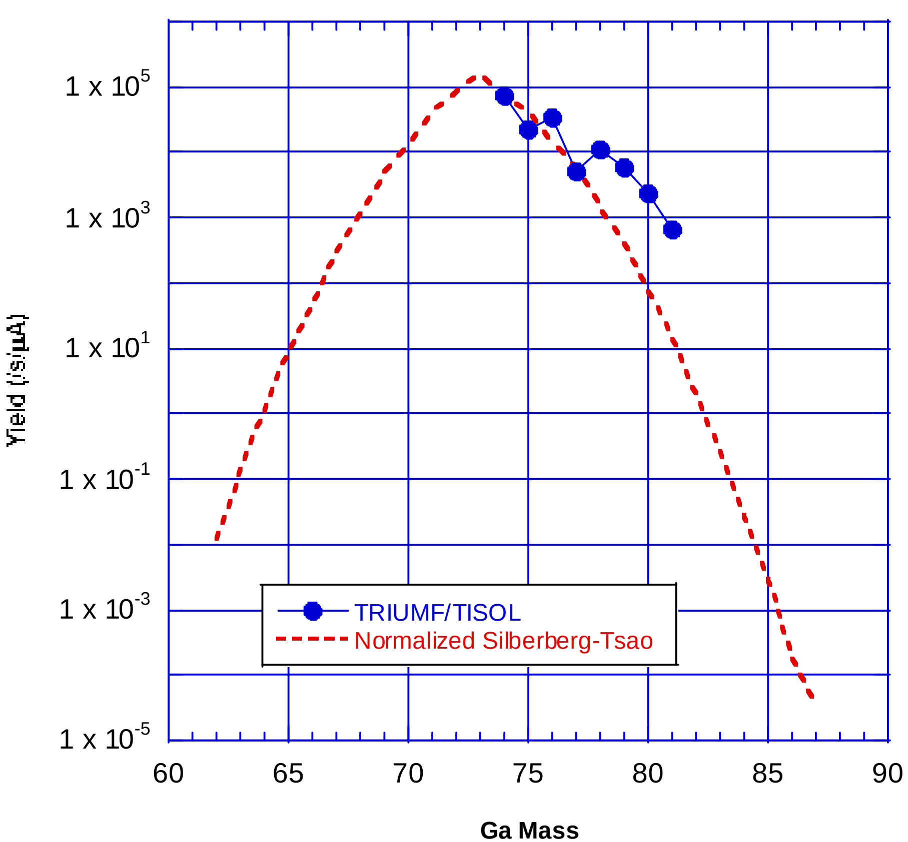
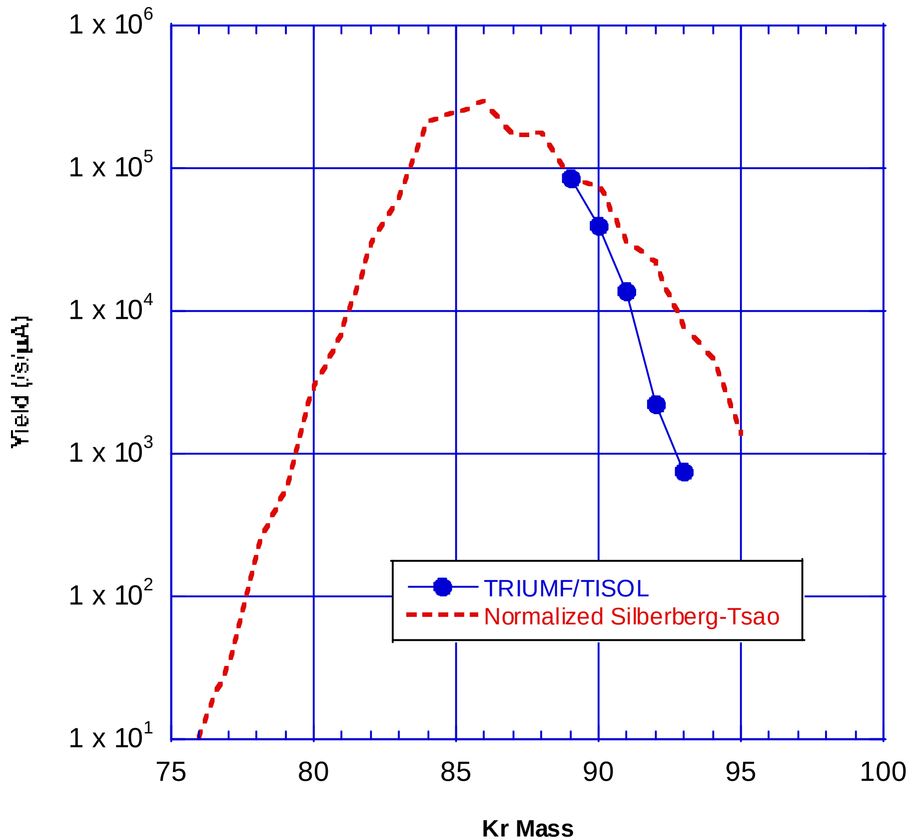
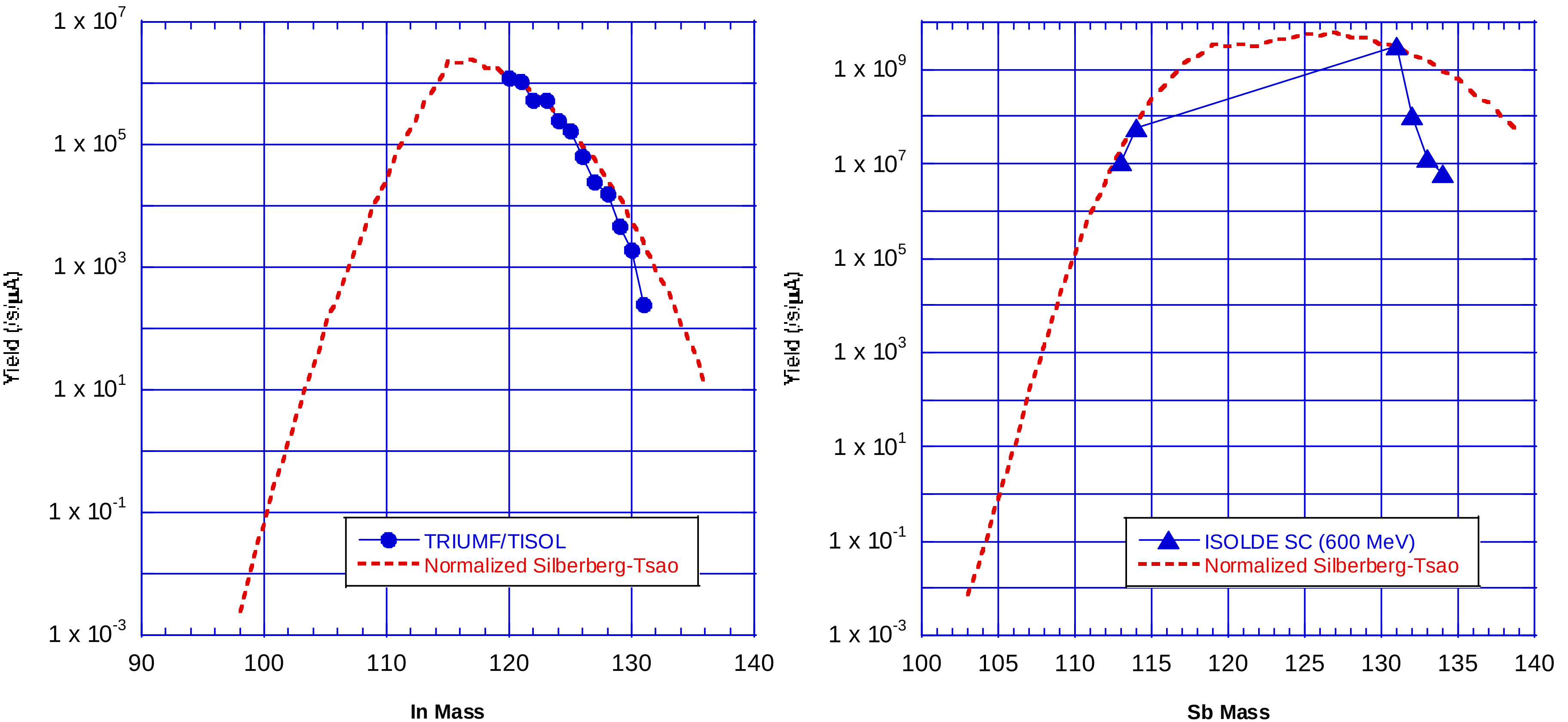


# Comparison of $^{238}U(p,X)$ Mass Yield Curves to Measured TISOL Yields & ISOLDE Yields



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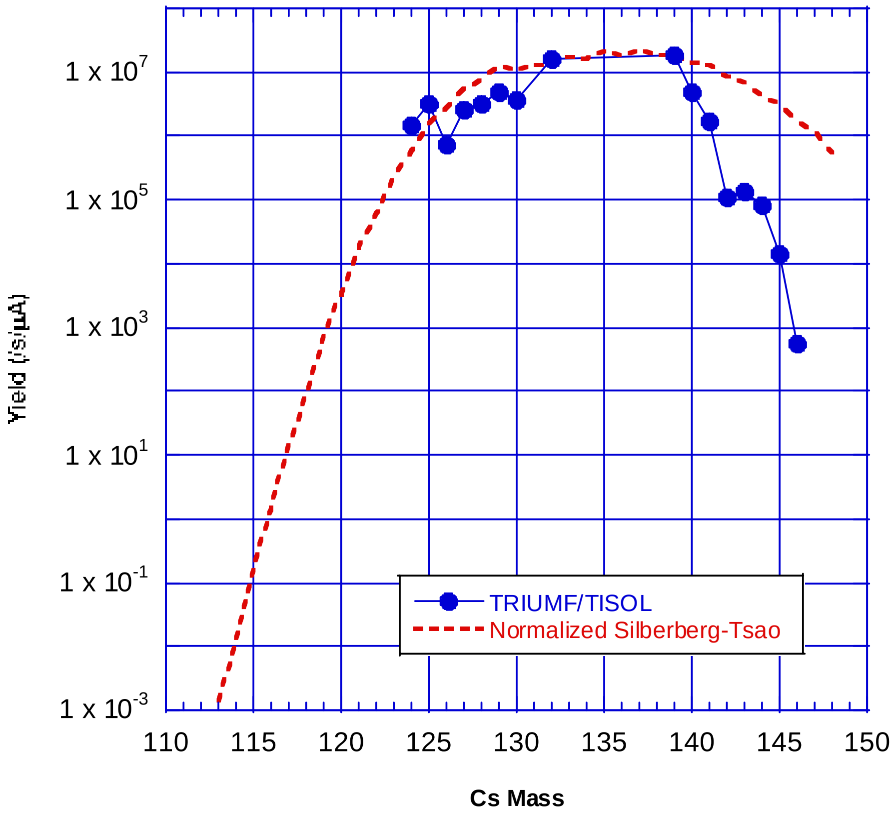


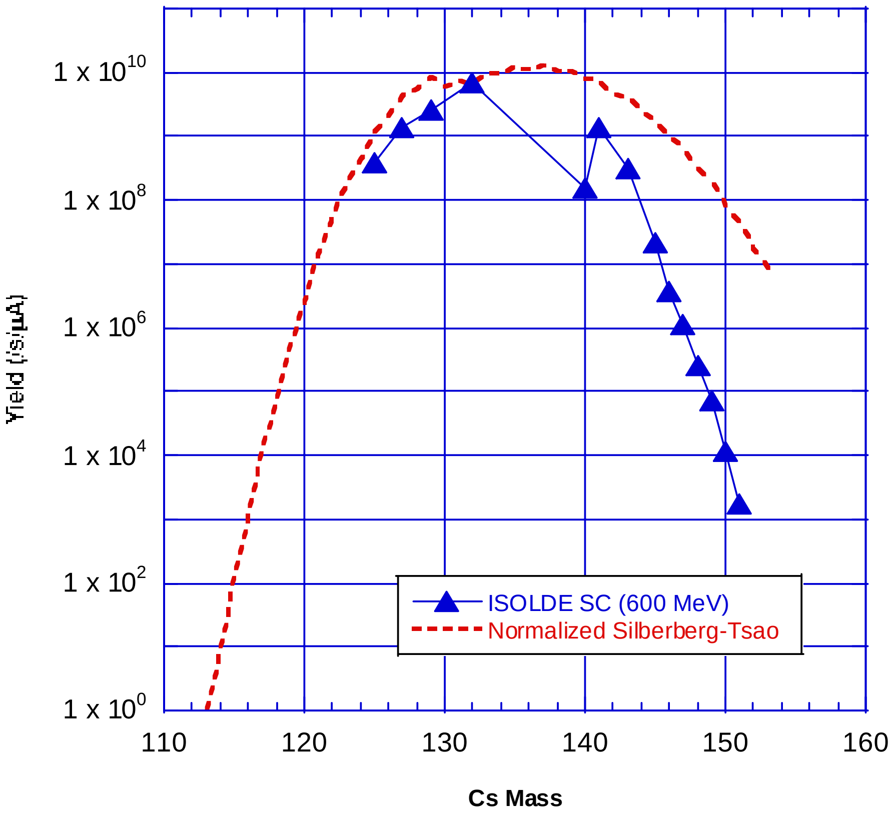

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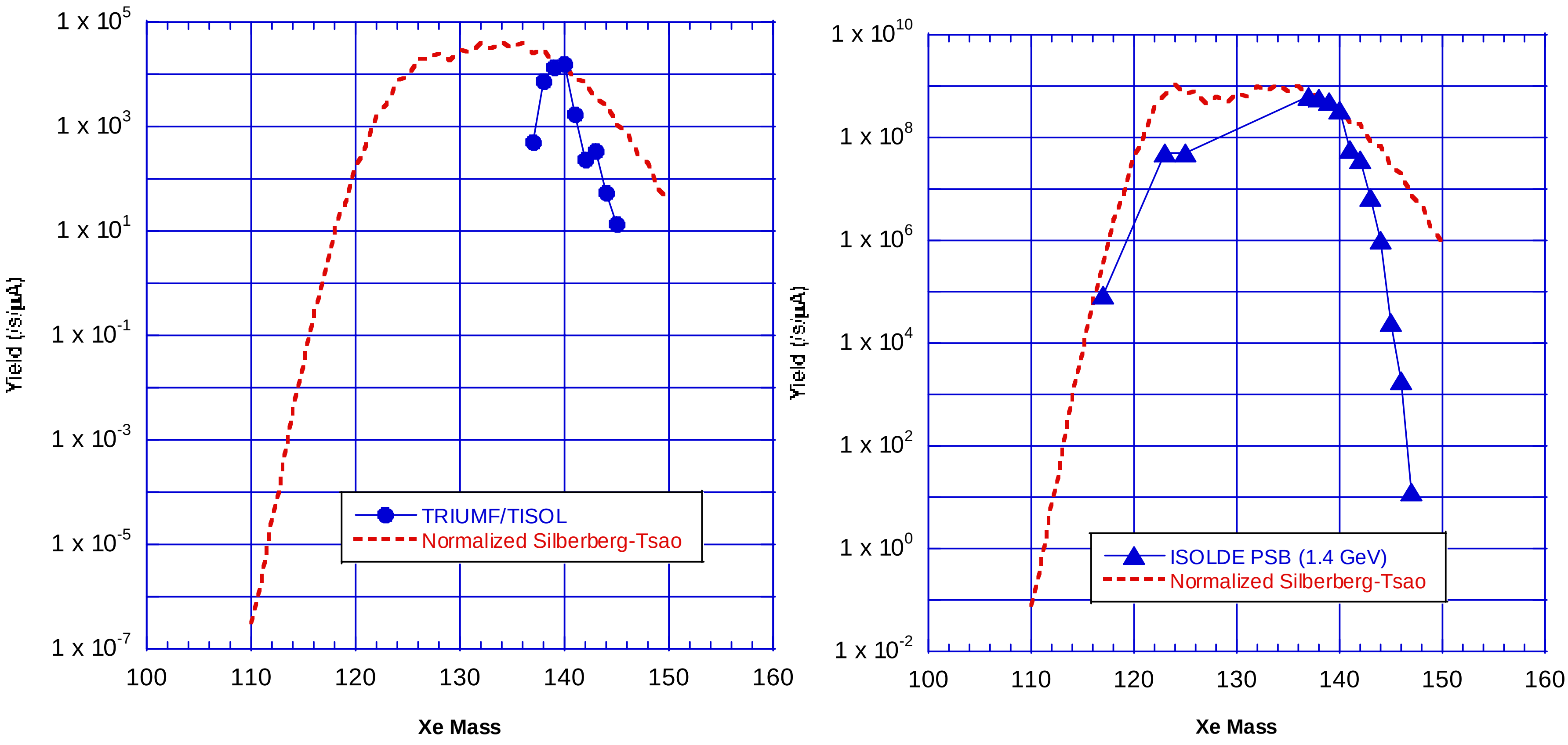


# Experimental $^{238}U(\gamma,f)$ Yields

- **Nuclear Physics Laboratory in Ghent, Belgium:**
  - **bremsstrahlung from 12–70 MeV electrons.**
  - **cumulative chain yields**
    **(% fission events that result in a specific product mass)**
  - **fractional independent chain yields**
    **(fractional yield of a specific isotope in an isobaric chain)**
  - **Additionally, element isotopic distributions can be calculated based on an assumed Gaussian charge distribution and the Zp value (the most probable charge) for an isobar chain.**

**<u>Phys. Rev. C</u>**: **13** (1976) 1536, **14** (1976) 1058, **19** (1979) 422,
**20** (1979) 2249, **21** (1980) 237, **21** (1980) 629, **26** (1982) 1356,
**29** (1984) 1777 & **29** (1984) 1908

# Experimental $^{238}U(\gamma,f)$ Yields

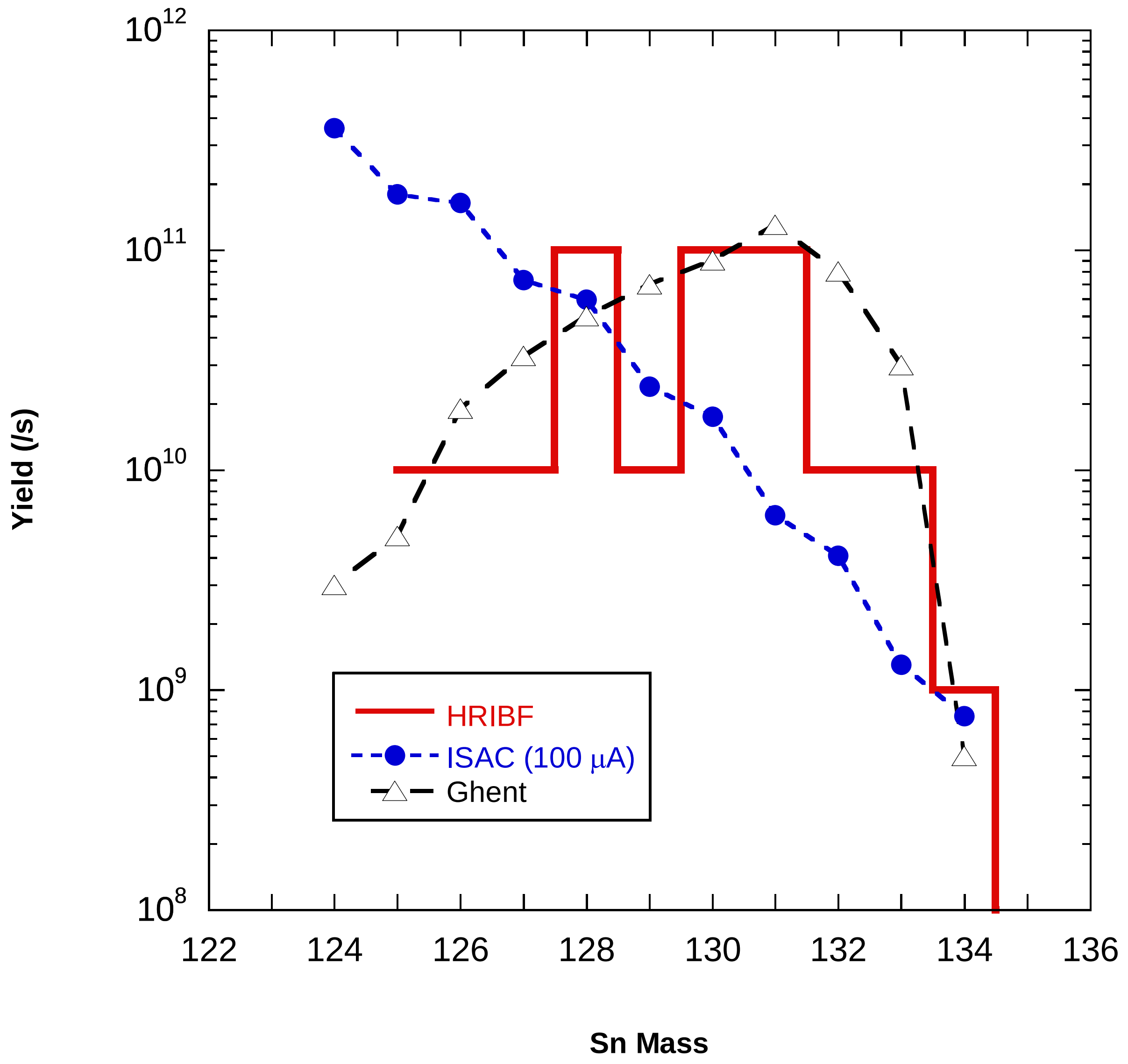
- **JINR, Dubna group :**
  - **bremsstrahlung from 25 MeV electrons**
  - **fractional independent chain yields for Kr and Xe isotopes**
    - **used in conjunction with the Ghent cumulative chain yields to estimate absolute yields for Kr and Xe at $10^{13}$ fissions/s.**

Yu.P. Gangrsky, V.I. Zhemenik, N.Yu. Maslova, G.V. Mishinsky, Yu.E. Penionzhkevich & O. Szöllös, Phys. Atomic Nuclei, **66** (2003) 1211

# For In-Target Yield Comparisons

- **Extract elemental yields (as possible) from the Ghent & Dubna data for $10^{13}$ f/s**
- **Use order-of-magnitude yield estimates for same elements from HRIBF proposal**
- **Calculate ISAC 100 μA in-target yields for same elements as above on the proposed HRIBF target**
- **No scaling for release, ionization or transport efficiencies**

# Comparison of in-target (γ,f) & (p,X) $^{238}$U Yield Estimates



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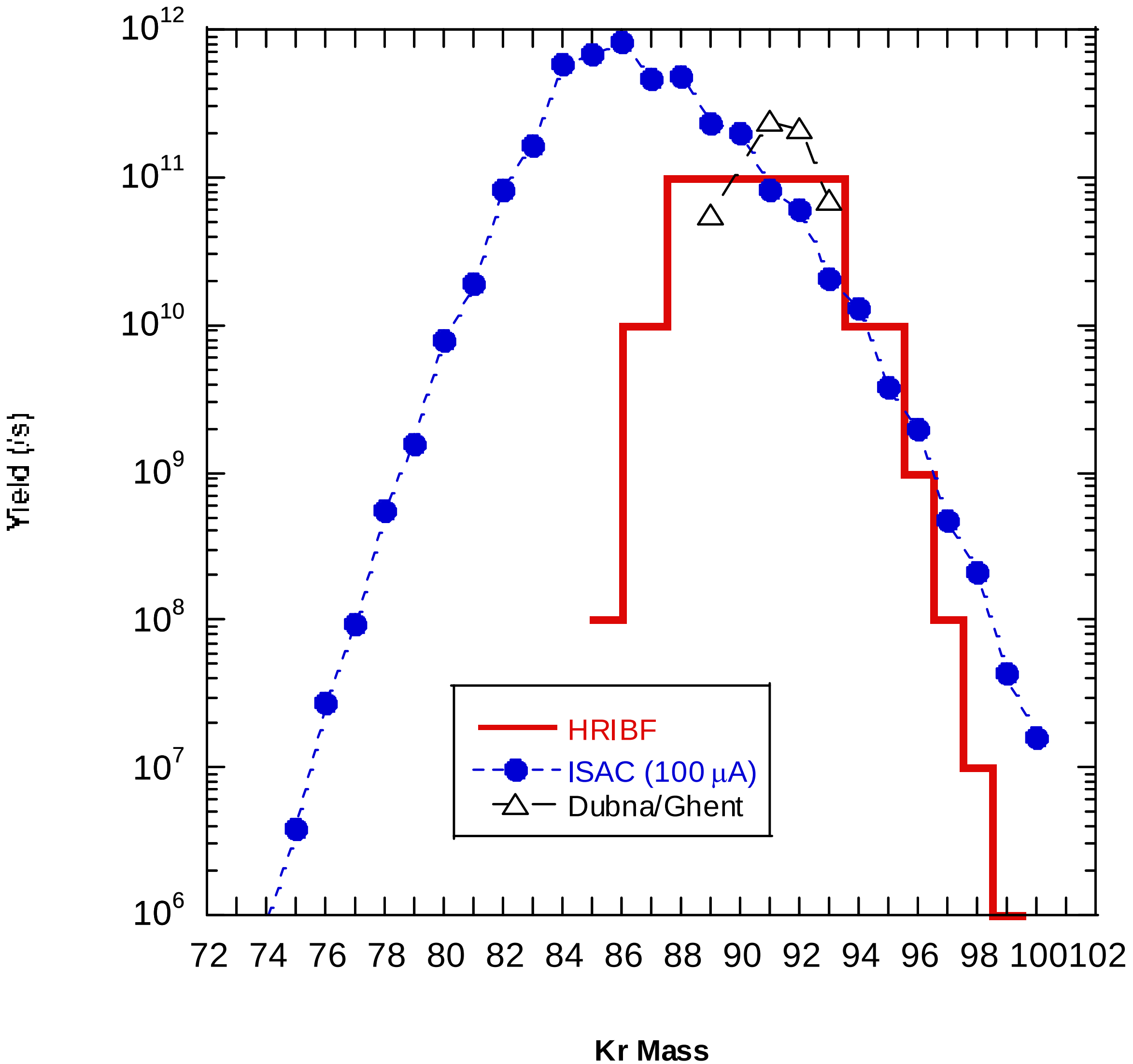

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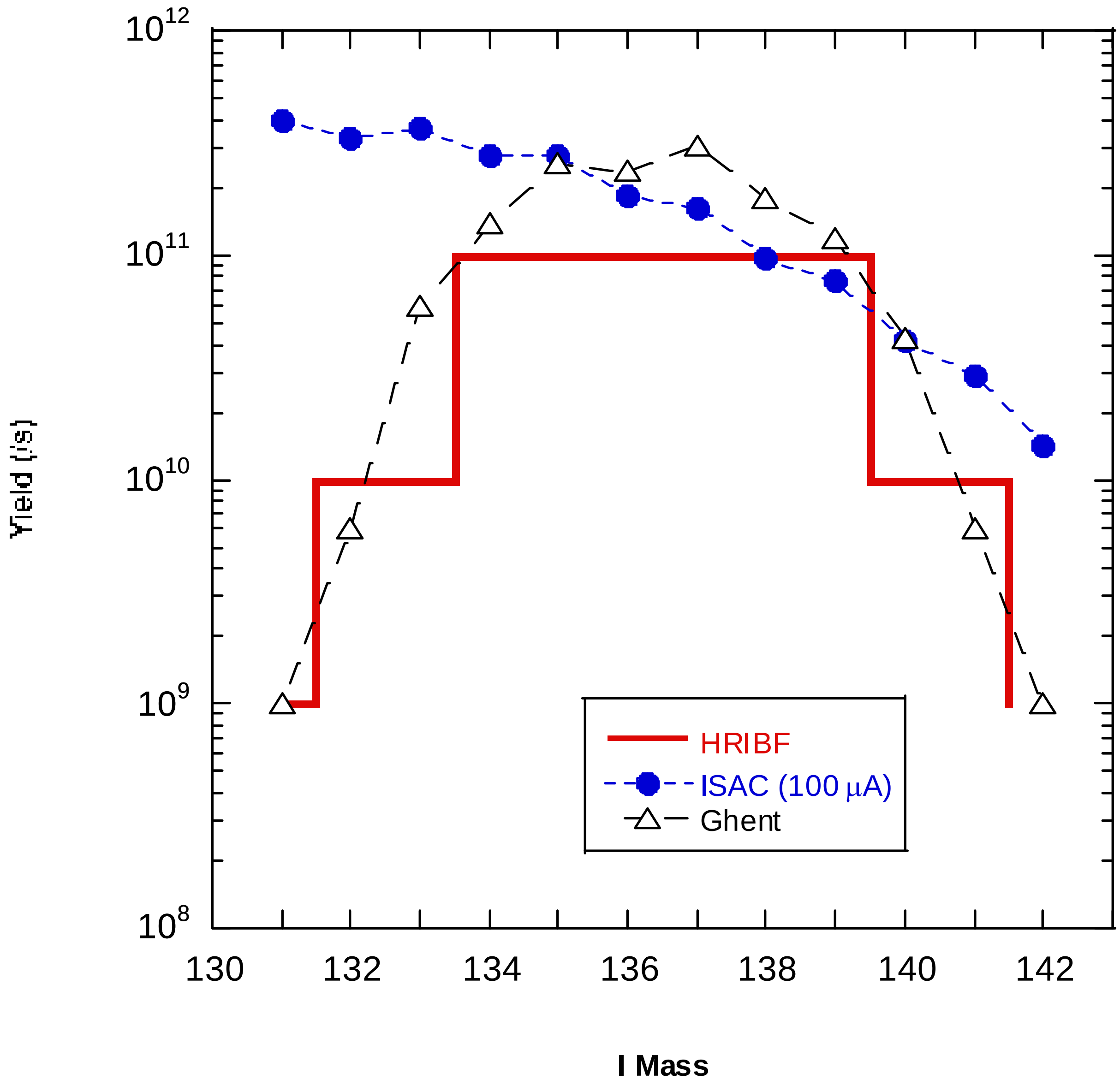

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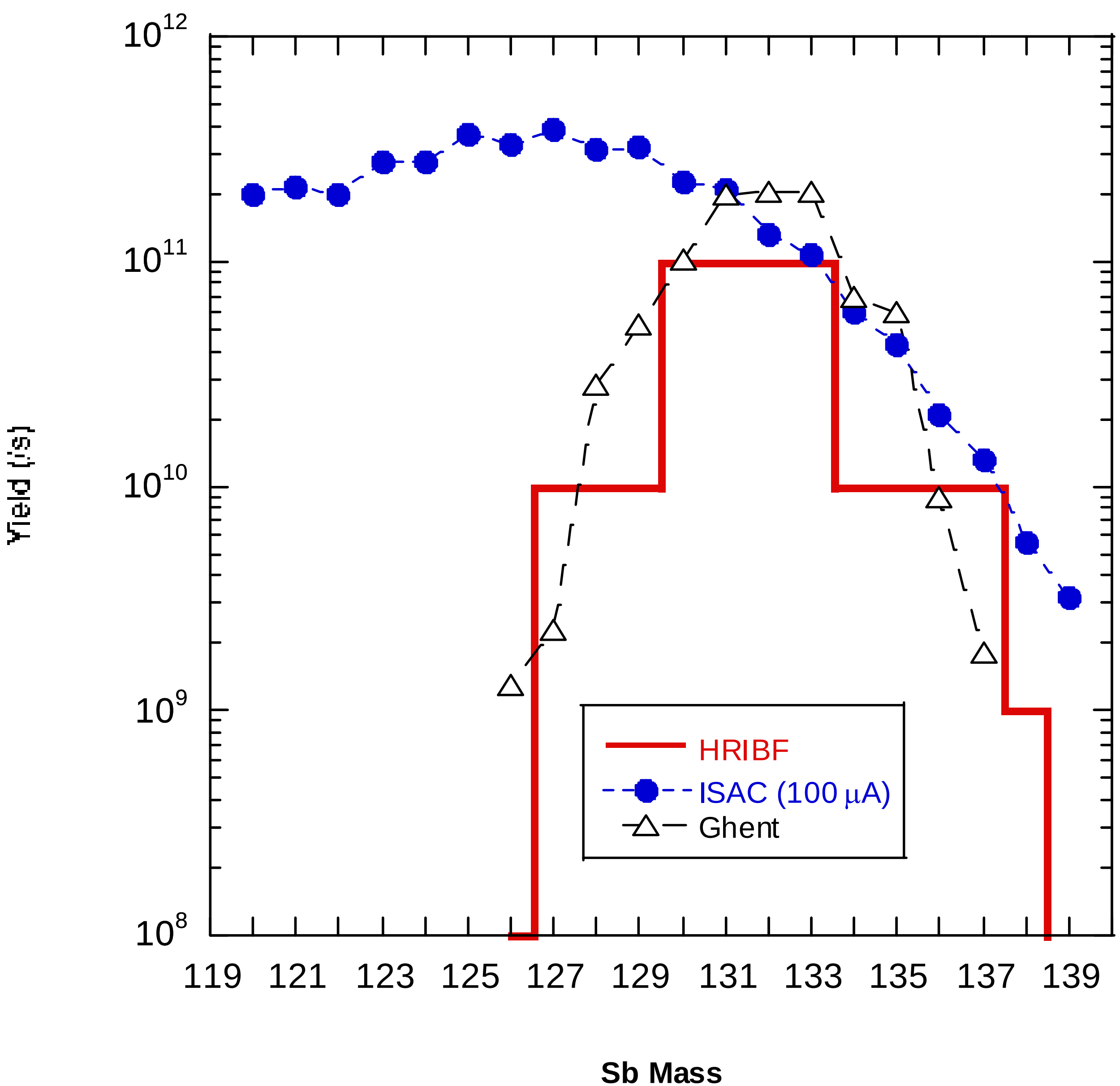

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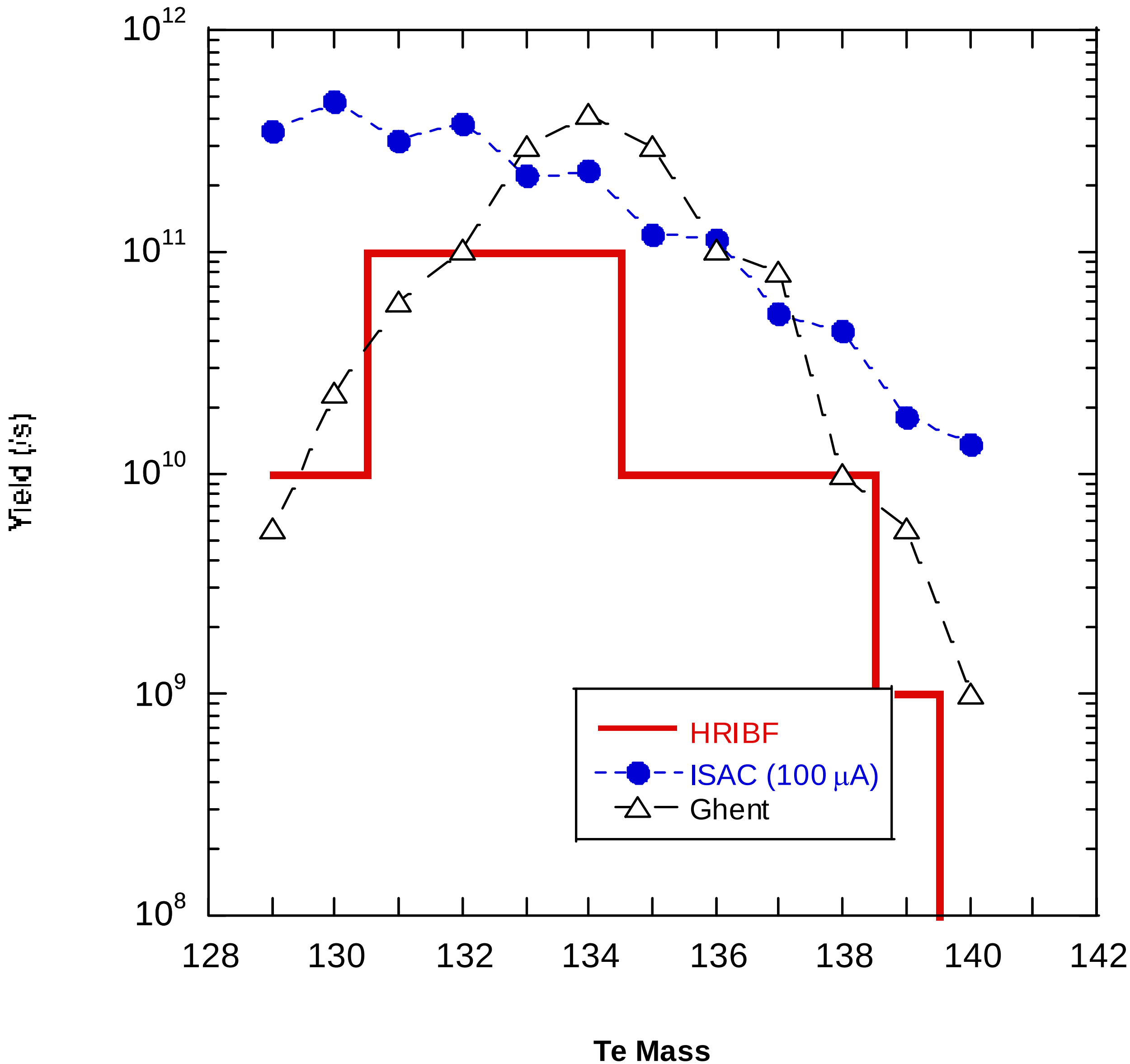

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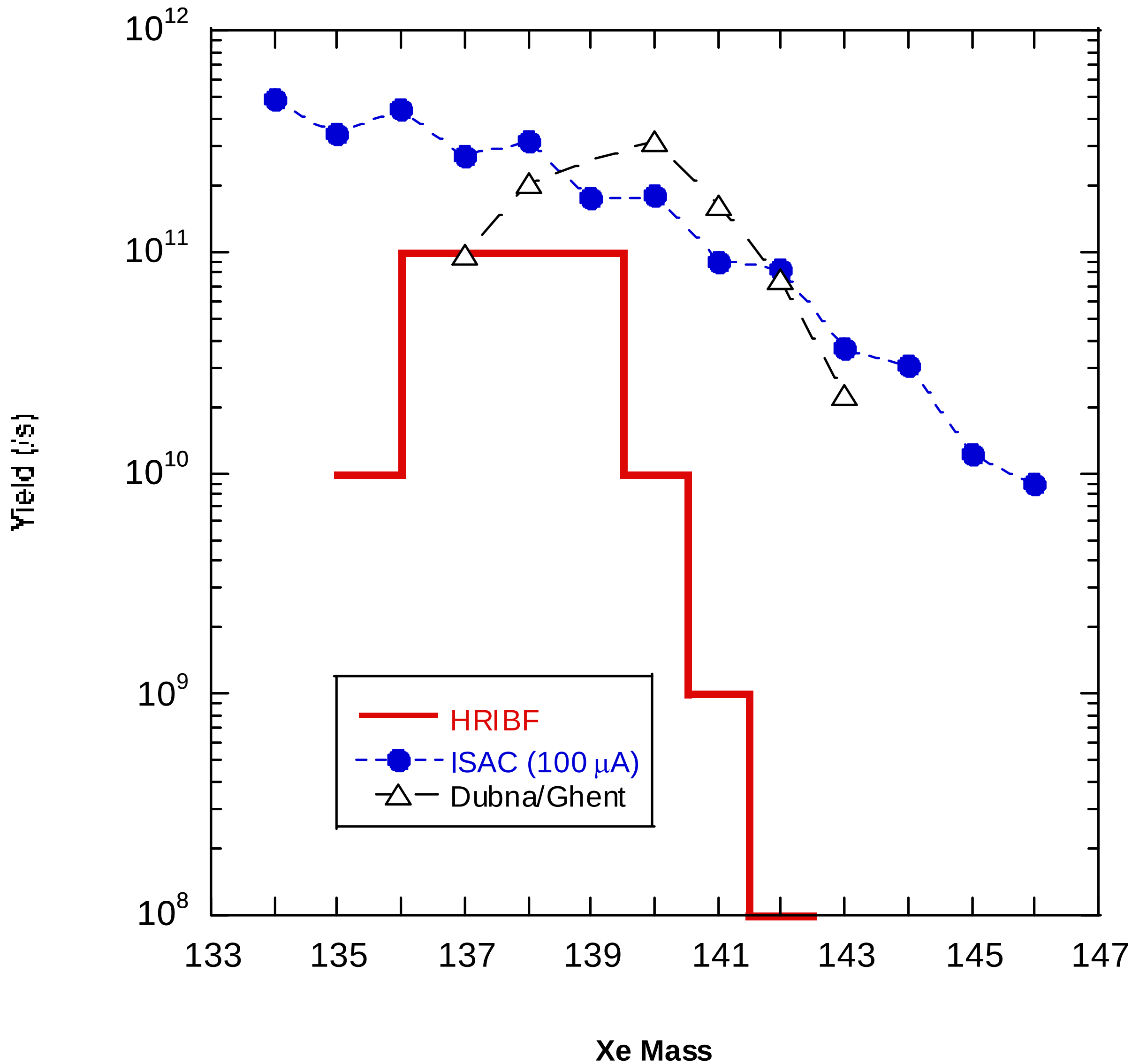

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# Conclusions

- **100 μA 500 MeV $p^+$ driver vs 25 MeV/50 kW $e^-$ driver:**
  - **In-target production yields about the same order**
  - **$p^+$ driver also produces $n^0$-deficient nuclides**
  - **Not clear if (γ,f) will have same release rates as (p,X)**
    - **Radiation enhanced diffusion with (γ,f) ?**
  - **For (γ,f) to be a clear winner, need > $10^{13}$ f/s**

# Light Nuclei from $^{238}U(\gamma,f)$ (Value Added?)

- Ternary fission:
  - 3-body breakup with 2 fission fragments proper + 1 light fragment
  - $\sim 10^{-3}$ probability of binary fission
  - 97% of ternary fragments are H (7%) & He (90%)

- Ternary fission yields from $^{241}Pu(n_{th},f)$ relative to $^{4}He$
  - $^{4}He$ yield $= 1.86 \times 10^{-3}$/binary fission

    U. Köster et al., Nucl. Phys. A 652 (1999) 371

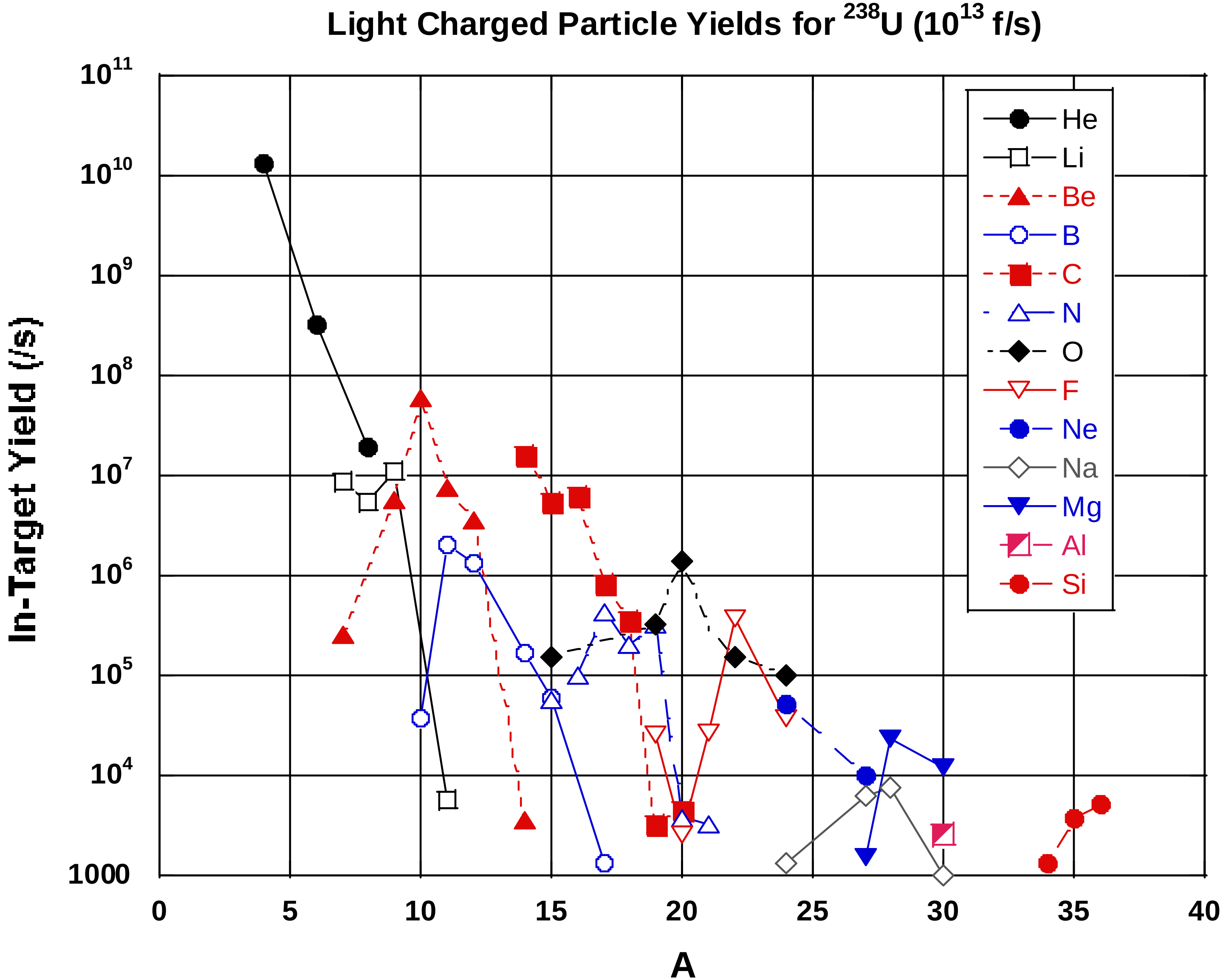
- $^{238}U(\gamma,f)$ $^{4}He$ yield $= 1.28 \times 10^{-3}$/binary fission

  Sinha, Nadkarni & Mehta, Pramãna-J. Phys. 33 (1989) 85

- $^{238}U(\gamma,f)$ $^{4}He$ yield $= 1.37 \times 10^{-3}$/binary fission

  Verboven, Jacobs & De Frenne, Phys. Rev. C 49 (1994) 991

# Ternary Fission Yield Estimates from $^{238}U(\gamma,f)$



# $^{8}$Li for a β-NMR facility

- **$^{8}$Li @ ~ 5 × 10$^{6}$/s required for reasonable experiment times (according to ISAC β-NMR group)**
- **~ 25% transmission through ISAC polarizer line (according to Phil Levy)**
- **~1% $^{8}$Li released from ISAC Ta foil targets**
  **~0.2% $^{8}$Li released from ISAC SiC targets**
- **Requires $^{8}$Li @ ~ 1 × 10$^{10}$/s in-target production**
  - **BUT $^{238}$U(γ,f) @ 10$^{13}$ f/s yield ~ 5 × 10$^{6}$/s**

# However, All is not lost

- (γ,p) cross sections in the GDR region are HIGH

## So try another target material:

- $^{9}Be(\gamma,p)^{8}Li$ integrated cross section to ≤ 26 MeV = 13 Mev·mb
  Haslam, Katz, Crosby,Summers-Gill & Cameron,
  Can. J. Phys. 31 (1953) 210

- $^{9}Be(\gamma,p)^{8}Li$ integrated cross section to ≤ 25 MeV = 13 Mev·mb
  Clikeman, Bureau & Stewart,
  Phys. Rev. C 126 (1962) 1822

# $^9Be(\gamma,p)^8Li$ for a β-NMR facility

- **Assume:**
  - **60% dense BeO target, same volume as HRIBF proposal**
    $N_t = 1.6 \times 10^{24}$ /cm$^2$
  - **1 γ/2 $e^-$ on converter (according to Pierre Bricault)**
  - **45% of ≤ 25 MeV γ on target (according to Pierre Bricault)**
    $\Phi_\gamma = 3 \times 10^{15}$/s
  - $\sigma = 5 \times 10^{28}$ cm$^2$

  - **Then:**
    - **$^8$Li in-target production ~ 1 × $10^{12}$/s for 25 MeV $e^-$ driver**
      **100 times higher than required!**

    - **Could be ~ 3 × $10^{13}$/s for 50 MeV/1MW $e^-$ driver**

# Final Conclusions

- 25 MeV/50 kW $e^-$ driver good idea for HRIBF
- 25 MeV/50 kW $e^-$ driver probably won't improve ISAC capabilities
- Higher power (50 MeV/1MW) $e^-$ driver required for ISAC
- Ternary $^{238}U(\gamma,f)$ may produce some usable yields of light nuclides ($^{6,8}He$) but not enough $^{8}Li$ for β-NMR
- $^{9}Be(\gamma,p)^{8}Li$ with 25 MeV/50 kW $e^-$ driver could more than sustain a β-NMR materials science facility
- $^{7}Li(\gamma,p)^{6}He$ could also produce high yields

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**Thanks to John Behr for Light Nuclei from $^{238}U(\gamma,f)$ &**

**$^{9}Be(\gamma,p)^{8}Li$ ideas**