Fragmentation Cross Section Database

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Database Project History

- Early 1990's situation: sparse data on GCR-like ions except for extensive measurements by Webber et al.
- Webber's group measured several ions and energies on He, C, and CH_2 targets, using subtraction to get results for H targets for GCR propagation models.

Schimmerling/Miller Group

- Formed in 1991 to make systematic fragmentation measurements at the LBL Bevalac using many beam ions, energies, and targets.
  - Standard target list: C, CH_2, Al, Cu, Sn, Pb
- Ran twice – mostly hardware debugging – and then Bevalac closed in spring 1992.
- Fall 1995, AGS radiation biology program started runs with 1 GeV/amu ^{56}Fe.

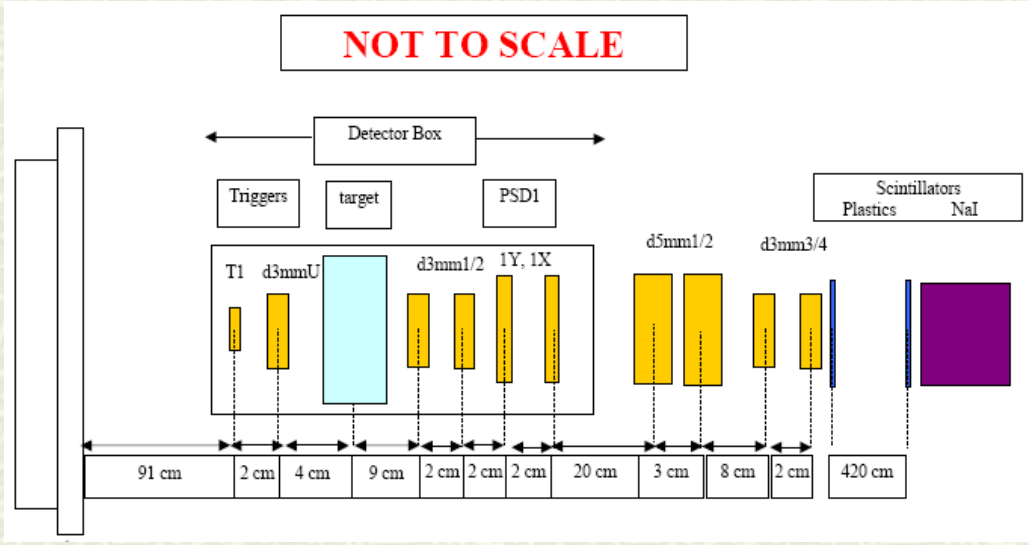
HIMAC and NSRL

- AGS cave difficult to work in, beam tuned for radiation biology experiments (large spot, high intensity, lots of spill structure).
- HIMAC experiments started 1997 – just 1 week/yr, but many beams available, $E_{beam} \leq 800$ MeV/amu.
  - Superb beam → high quality data, easy analysis.
  - Last (?) run February 2007.
- First NSRL physics runs in October 2003.
  - Much better than AGS (not yet as good as HIMAC).
  - Last run September 2006.

AGS Revisited

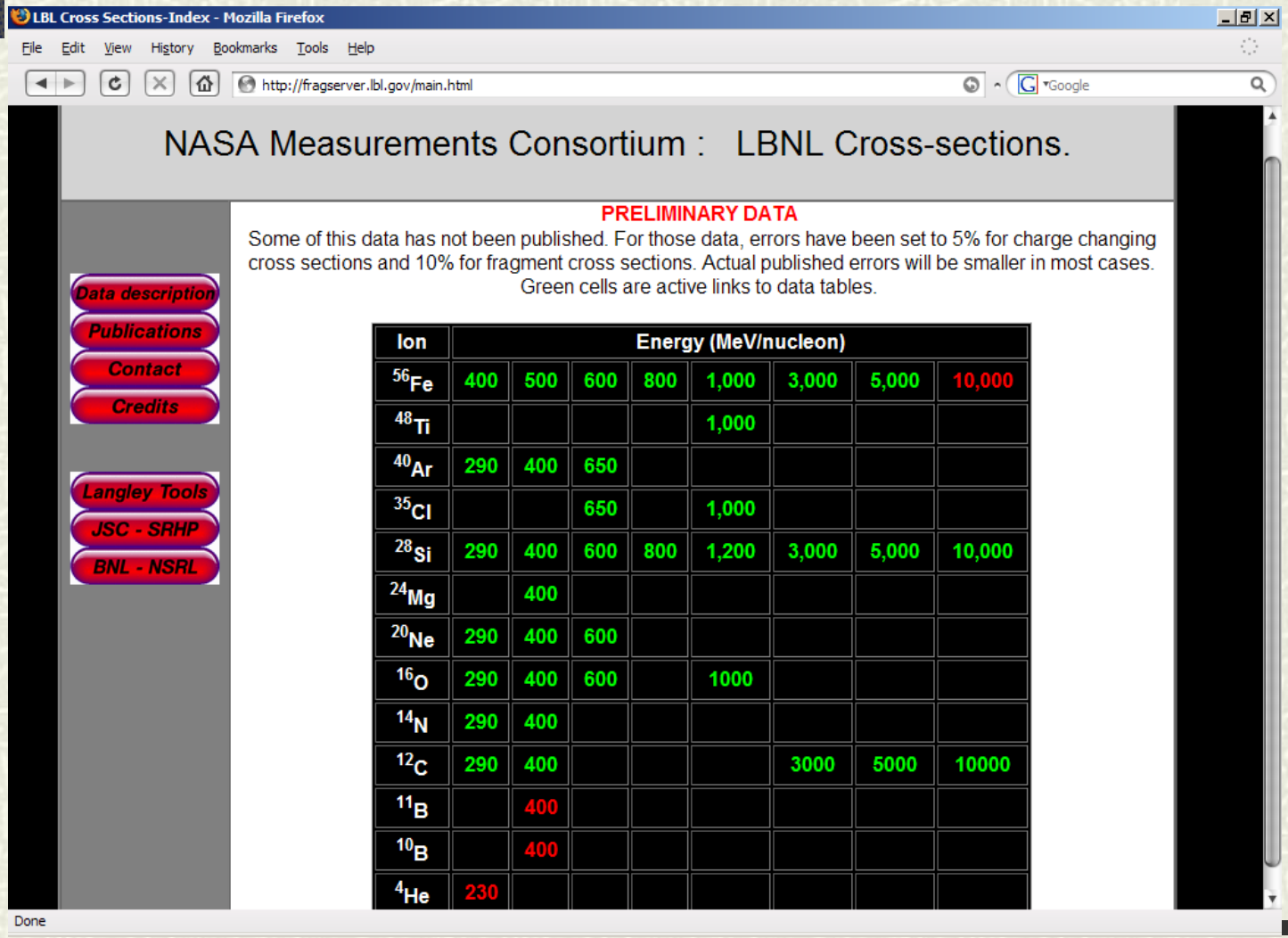
- Last physics experiment at AGS in 2005 to measure C, Si, and Fe ions at 3 high-energy points each (3, 5, and 10 GeV/amu).
- LBL 0º experiment plus 3 off-axis systems: high-energy neutron counters, ZDDS (Christl and Kuznetsov, MSFC), and SSDs (Pinsky et al., UH).
  - 3 separate data acquisition systems, tricky to merge in off-line analysis, but UH group has succeeded.

Typical Setup



- Different approach from typical experiments: measure "light" fragments with $Z < Z_{beam}/2$.
- Most experiments report $Z > Z_{beam}/2$ only.
- To get low Z, need detectors far from target and data need model-dependent corrections for angular distribution losses. (Or could use highly segmented detectors).

Present Status



Ion	Energy (MeV/nucleon)							
^{56}Fe	400	500	600	800	1,000	3,000	5,000	10,000
^{48}Ti					1,000			
^{40}Ar	290	400	650					
^{35}Cl			650		1,000			
^{28}Si	290	400	600	800	1,200	3,000	5,000	10,000
^{24}Mg		400						
^{20}Ne	290	400	600					
^{16}O	290	400	600		1000			
^{14}N	290	400						
^{12}C	290	400				3000	5000	10000
^{11}B		400						
^{10}B		400						
^{4}He	230							

Published Cross Section Data

- Older: ^{56}Fe at 1 GeV/amu, ^{20}Ne at 600 MeV/amu.
- Newer: ^{28}Si at 290, 400, 600, 800, 1200 MeV/amu, and ^{12}C at 290, 400 MeV/amu.
- Almost done: ^{35}Cl at 650 and 1000 MeV/amu, ^{40}Ar at 290, 400, and 650 MeV/amu, and ^{48}Ti at 1000 MeV/amu.
- Next: AGS 2005 data with 9 sets of cross sections.

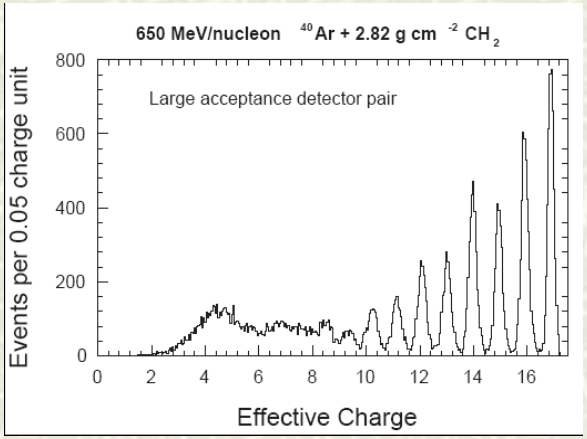
Selling Points

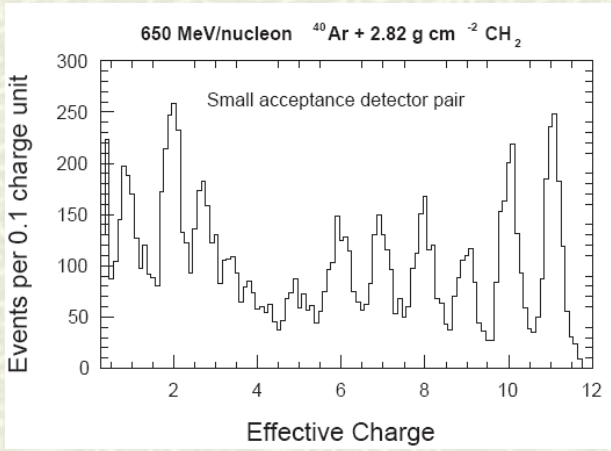
- Range of targets spans the period chart from H to Pb.
  - Scaling from H target cross sections to targets heavier than H is dubious.
- Light fragment cross sections are available.
  - Few previous data for modelers to work with.
  - It’s more complicated than simple models predict.
- Careful & conservative evaluation of systematic errors in measurement (often underestimated).
- Large number of data points: ~ 200 charge-changing and 2000 fragment production cross sections.

Cl – Ar – Ti Paper (In Progress)

- Comparison of different ions and energies in a narrow range of projectile mass (35 to 48).
- Demonstrates all the main points: light fragments, model tests, differences between H and other target materials, neutron-excess dependence of the fragment cross sections.

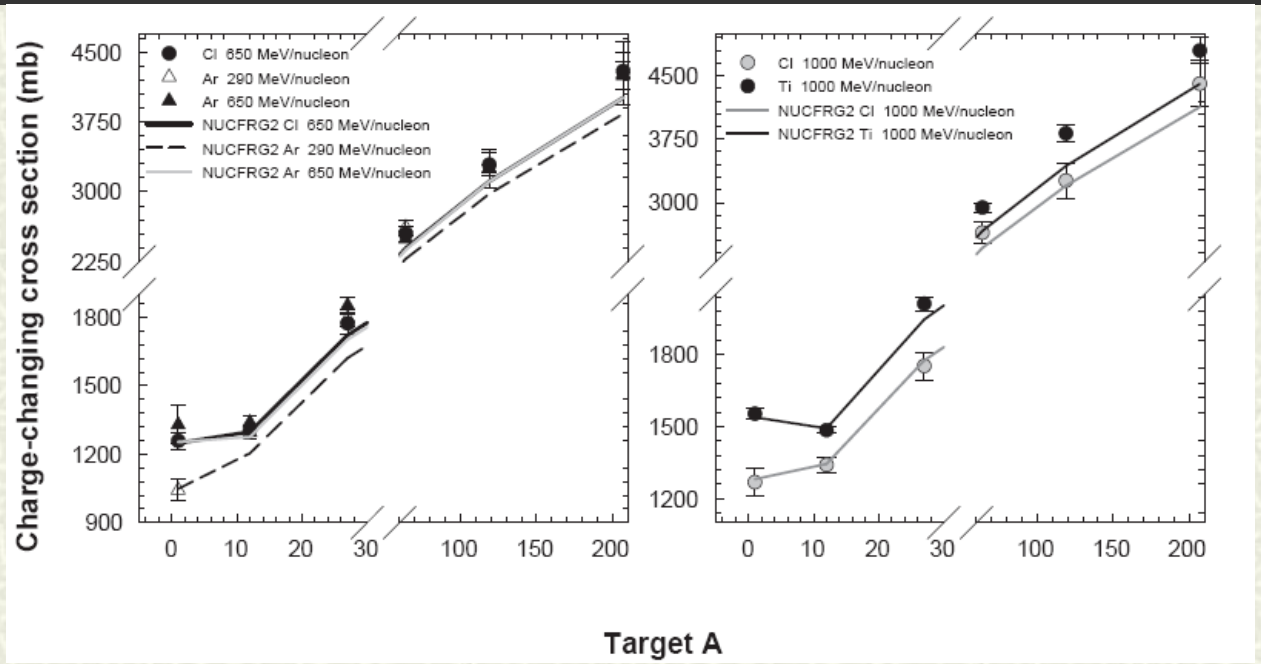
Fragments from ^{40}Ar (Z = 18)





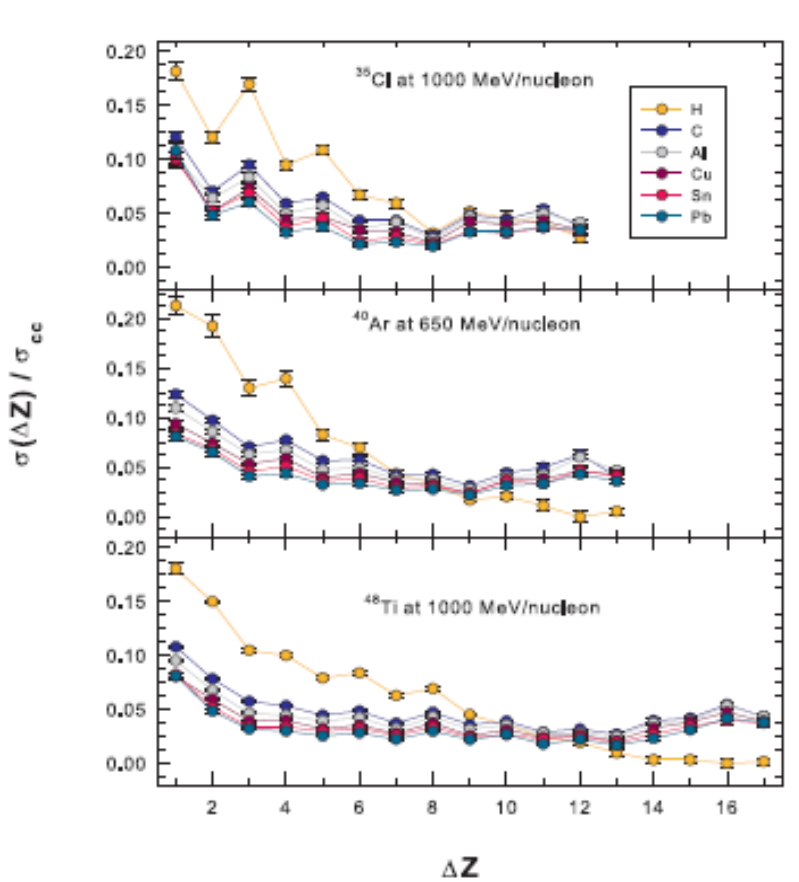
- Large acceptance spectrum is typical, hard to distinguish peaks below charge 10, impossible below charge 8.
- Small acceptance spectrum shows peaks for all species and some combinations, e.g., Z ~ 3.5 corresponding to 3 He fragments in coincidence.

Charge-changing Cross Sections



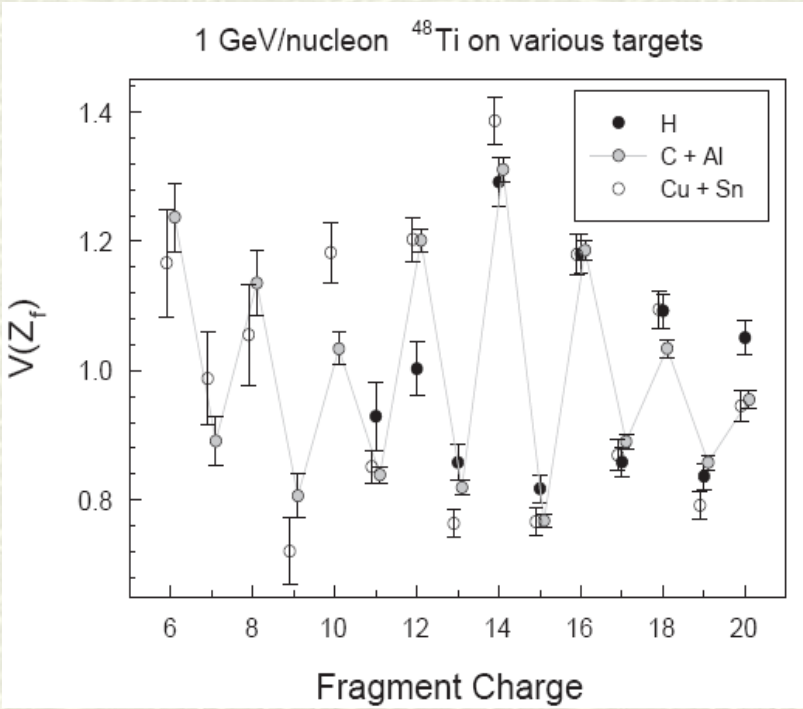
- NUCFRG2 (and PHITS, not shown) do well for Cl beams but are systematically off 5-10% for Al and heavier targets for Ar and Ti beams.
- Was NUCFRG2 tuned to Webber et al. H and C target data?
  - NUCFRG2 σ_{cc} matches H target data very well. (PHITS off 10-15% for H.)
  - We don't always agree w/Webber (e.g., ^{28}Si data).

Fragment Cross Sections



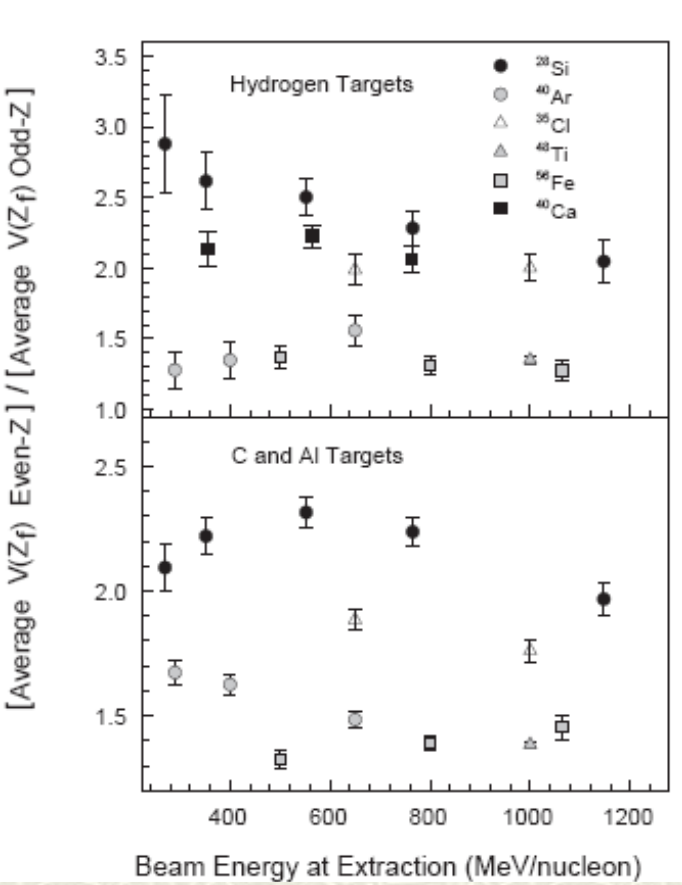
- Normalizing to σ_{cc} allows data for all targets to be plotted on the same scale.
- Curves are similar for all targets except H.
- Cross section for F production (Z = 9) is always minimum for non-H targets.
  - This would not be apparent if we only measured $Z > Z_{beam}/2$.
- Bigger odd-even effect for ^{35}Cl beam than for others.

Odd-Even Effect



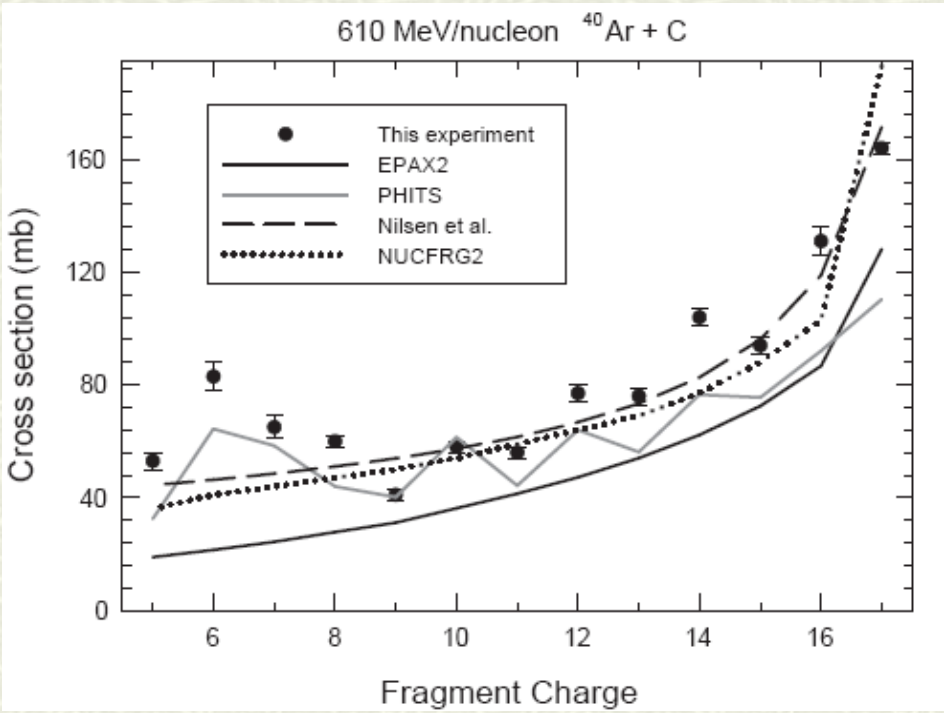
- Previously reported by many.
- Depends on neutron excess.
  - Stronger effect seen for $T_z = 0$ than for $T_z = -2$.
- Iancu et al. defined $V(Z_f)$ to measure the effect.
  - They find weak target dependence; we agree.
- We go further: lump all odd-Z V's together into an average, do same for even-Z V's, take ratio.
  - Excessively reductionist, but…

Excessive Reductionism Pays Off



- Include other data sets – ^{28}Si from our recent paper and ^{40}Ca from Chen et al.
- Effect strongest for $T_z = 0$ projectiles, weaker but not negligible for $T_z = -2$.
- For H targets, there seems to be energy dependence for $T_z = 0$, not for $T_z = -2$.
  - Note ^{35}Cl has $T_z = -1/2$.
- Hard to see trend for C+Al data; possibly differing trends for Ar, Fe beams.

Fragment Cross Sections vs. Models



- Most models are over-simplified and this appears in two ways.
  - Lack of odd-even effect.
  - Cross sections decrease monotonically with increasing ΔZ.
- Contrast with PHITS: on average. not much closer to the data than others, but it predicts the odd-even effect and cross sections increase below Z = 9.

Conclusions

- Many data available, with occasional updates, at http://fragserver.lbl.gov/main.html
  - Trying to get cross sections into NNDC at Brookhaven.
- Links to tables of cross sections and our articles, including neutron cross section papers by Lawrence Heilbronn et al.
  - Lawrence and Prof. Nakamura of Tohuko Univ. have also published a handbook of neutron cross section data.
- We plan to publish as much charged particle data as possible – maybe not much given that support → 0.
- More could be mined from existing data, but…