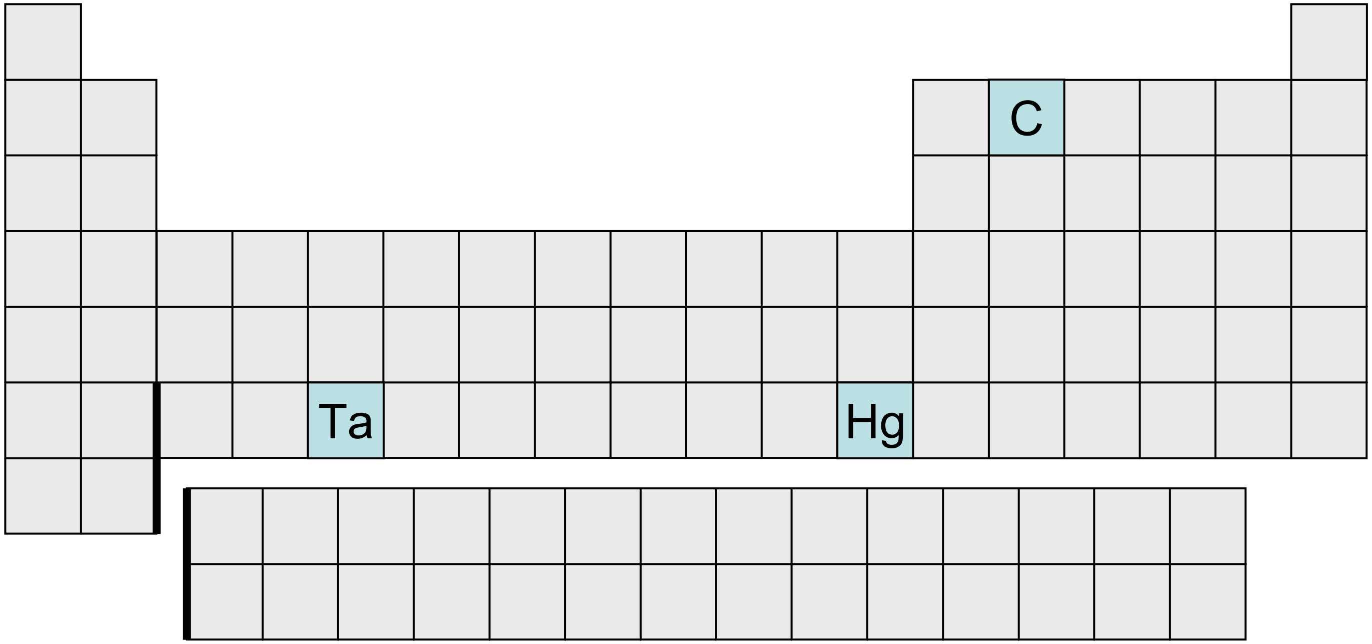
Neutrino Factory Target Yield Considerations

Click to view with less target stuff

Stephen Brooks
Scoping Study meeting, April 2006

Intermediate Z Element Needed

- Previously, results for Ta, Hg and C
- C behaviour was very different from others
- C is in P2, the others are in P6

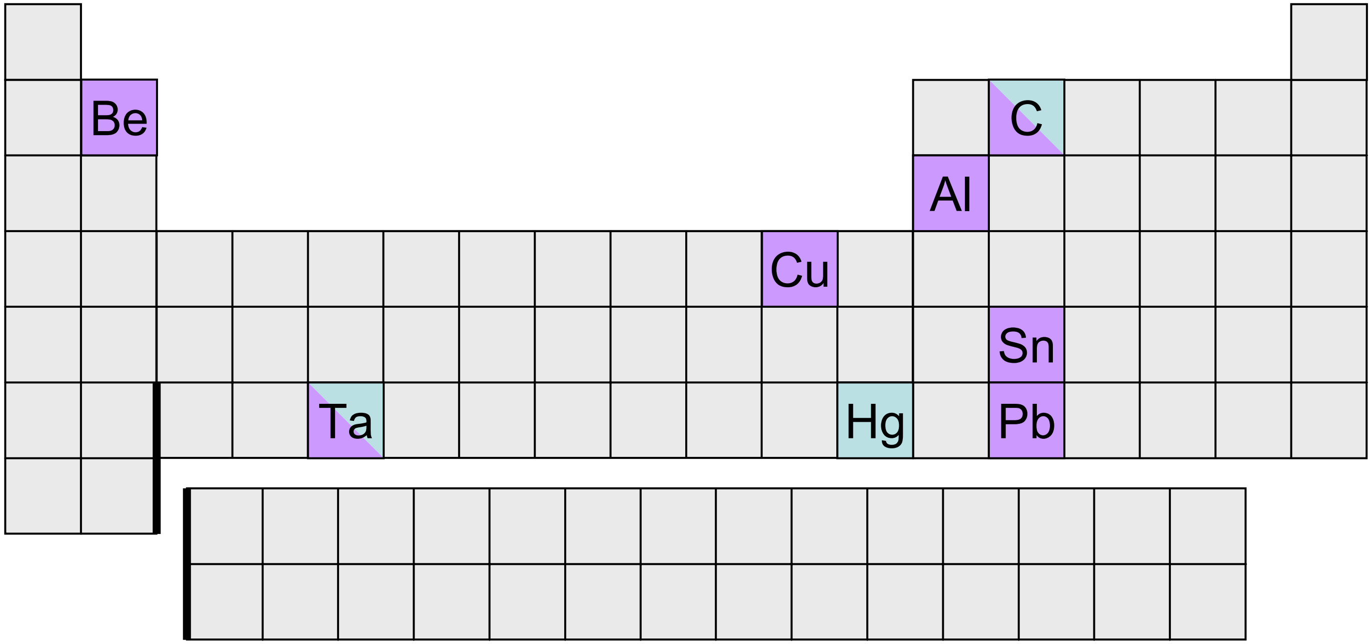


Stephen Brooks
Scoping Study meeting, April 2006

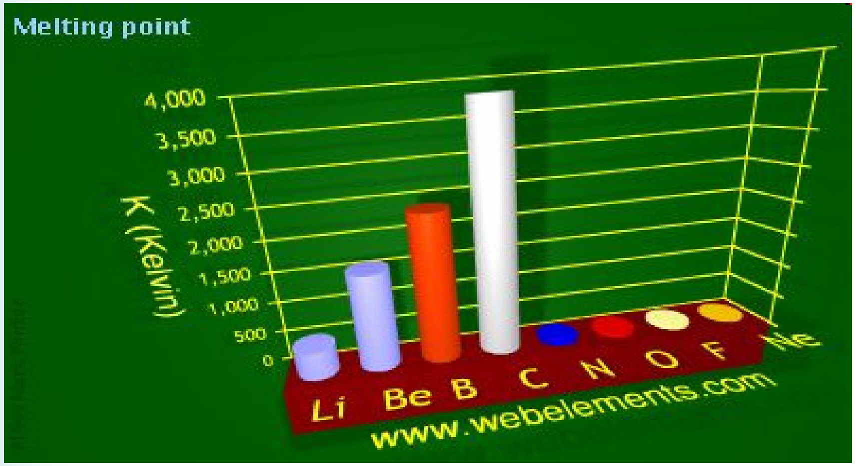
Compare: HARP Elements

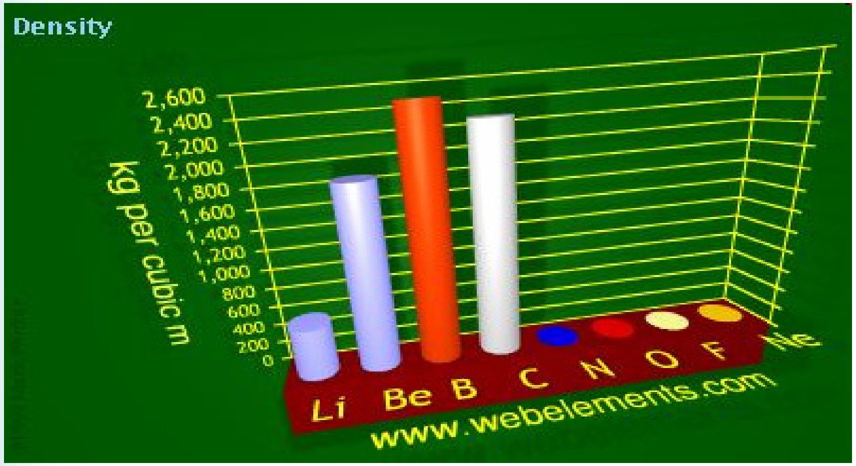
- P3: Al
- P4: Cu
- P5: Sn

- Want to compare with data
- Sensible target element
  - High melting point, density



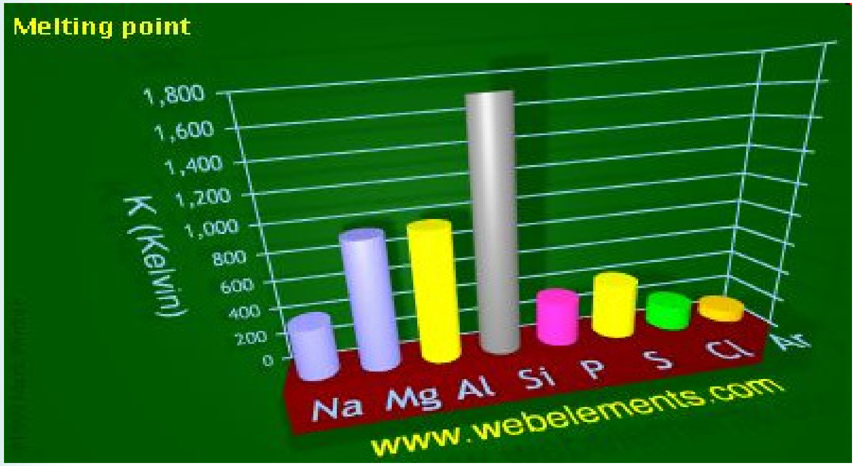
Period 2 Elements

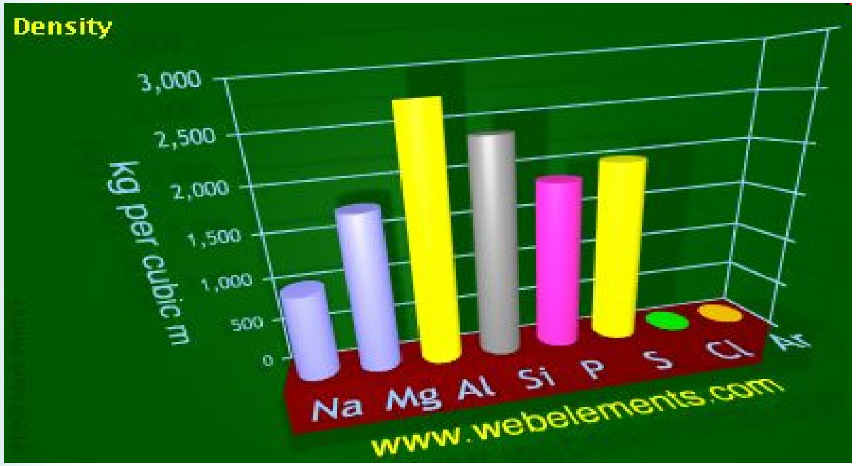




- Carbon clearly wins
- Boron and beryllium not so bad
- HARP has Be and C
- None of these densities are very high: require long targets

Period 3 Elements



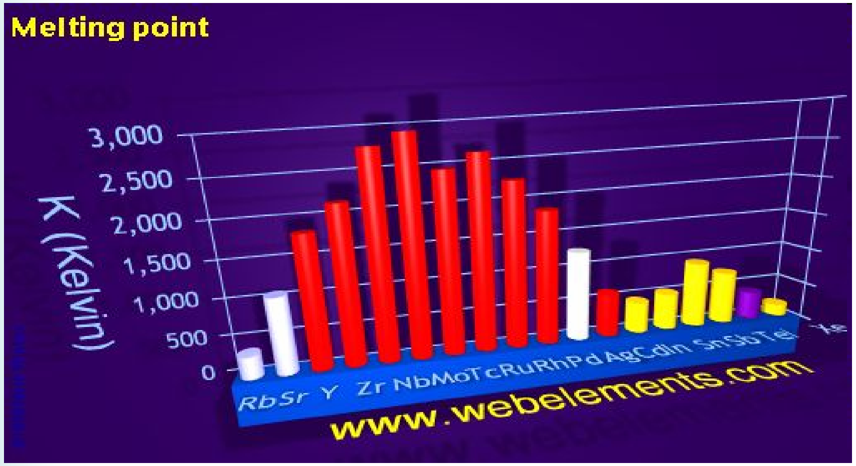


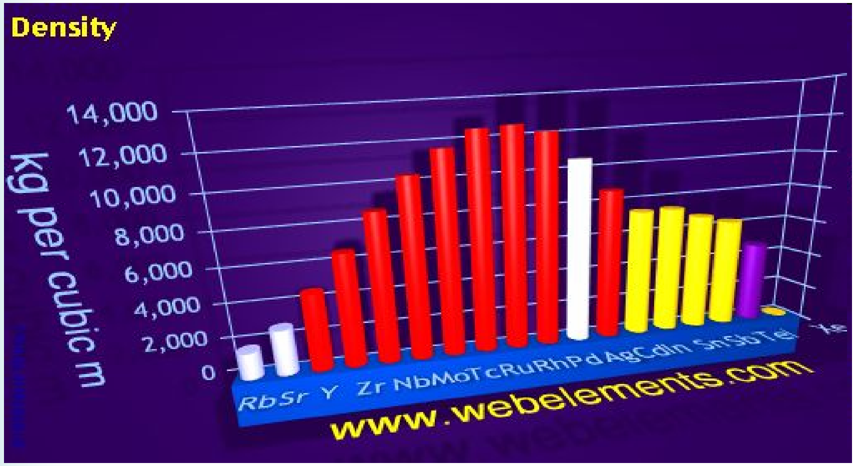
- Silicon looks best
- Everything else has a useless melting point
- HARP has aluminium
- Densities no higher than before
- I think P3 is a non-starter

Period 4 Elements

- Transition metal melting points and densities are better
- HARP's Cu has high density and moderate melting point
- Also about half-way (logarithmically) between C and Ta/Hg

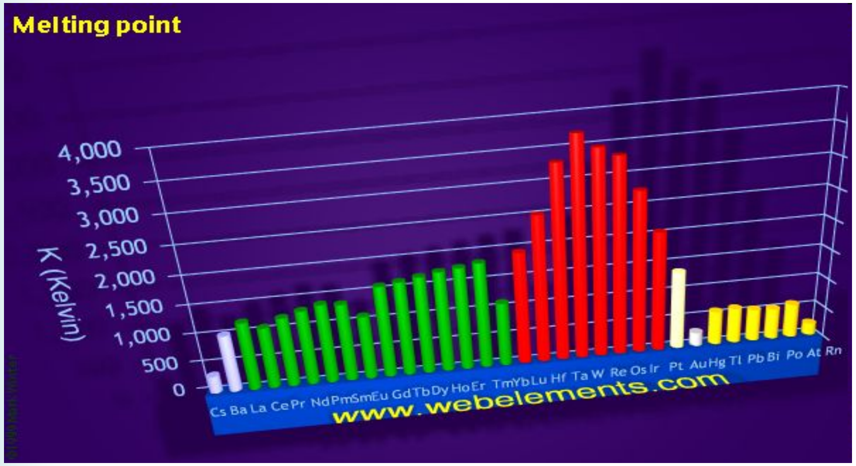
Period 5 Elements

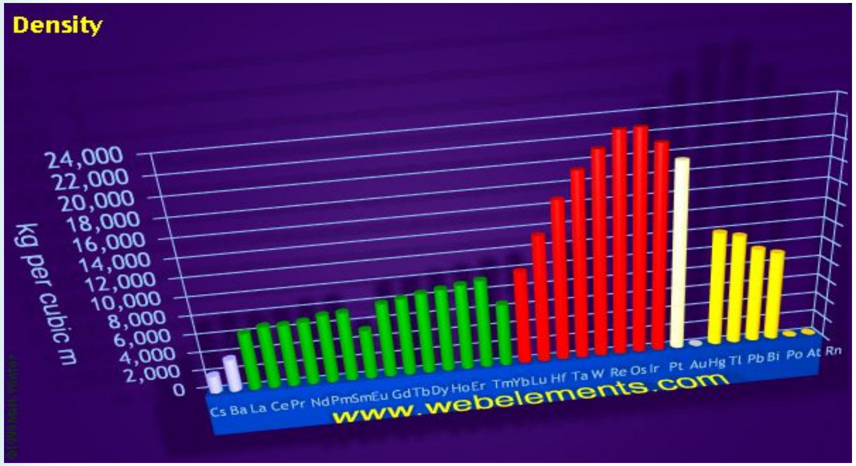




- Melting points and densities continue to increase
- HARP's tin is not good for our target!
- Plenty of workable choices in transition block, if needed

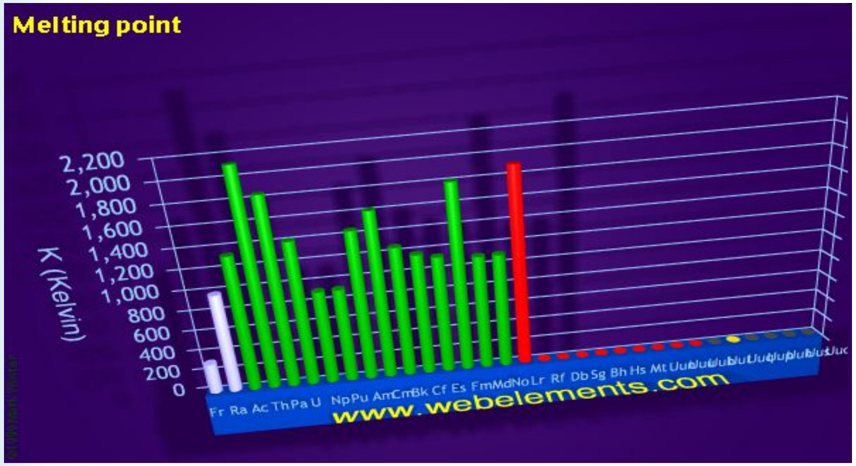
Period 6 Elements

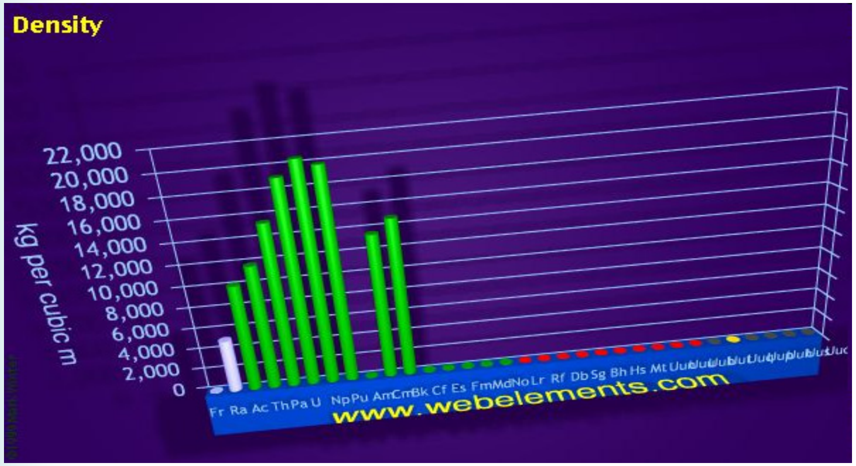




- Transition metals here have the highest values in the table
- Hence the choice of Ta in the first place
- Hg is obviously a special case

Period 7 Elements

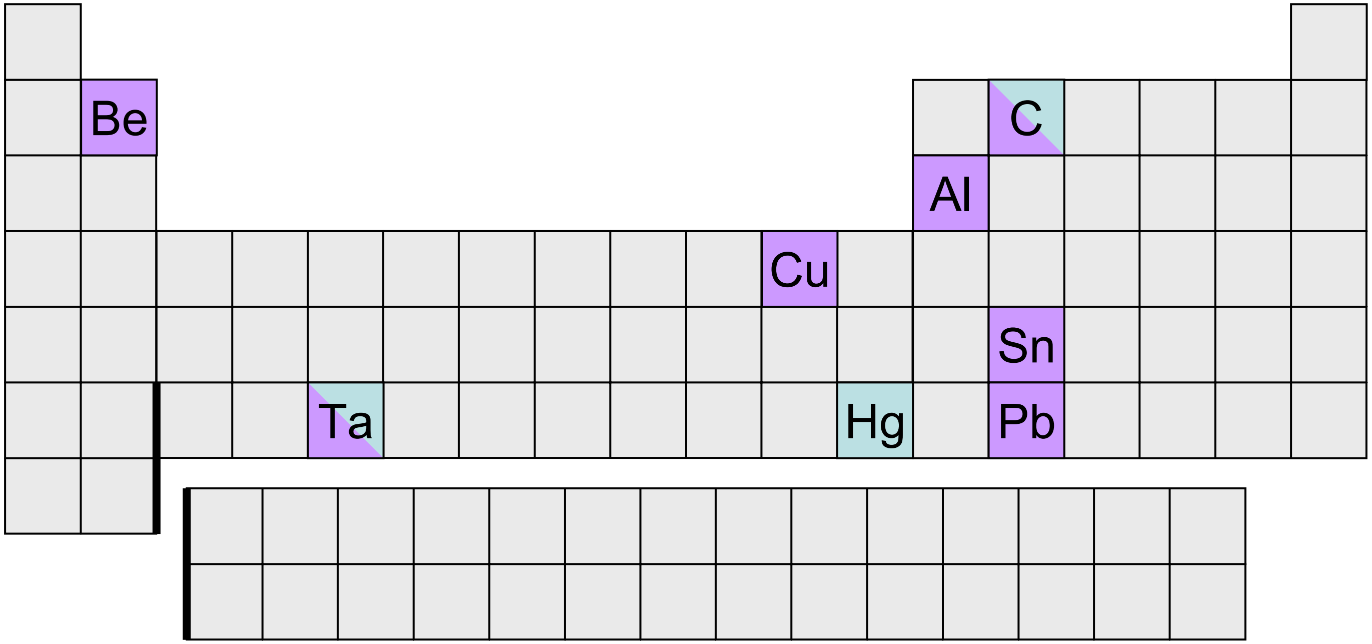




- Thorium → uranium are OK for very-high-Z if needed
- Most of the rest are radioactive

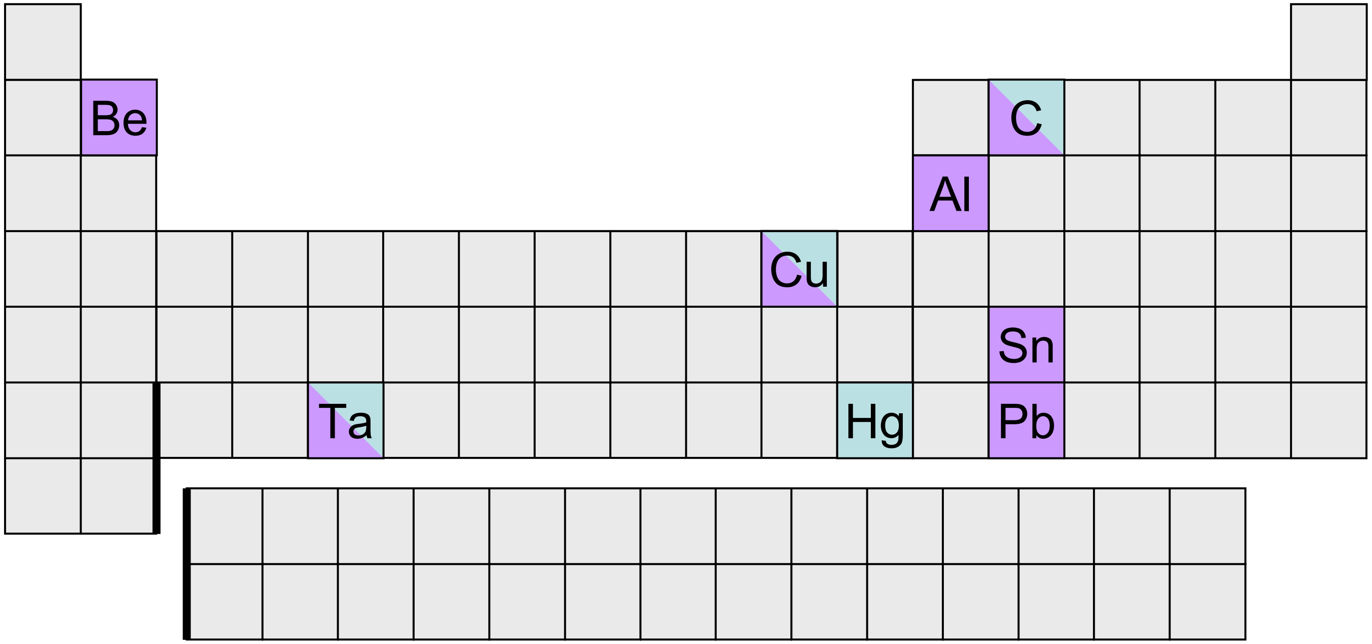
Intermediate Z Element Needed

- Previously, results for Ta, Hg and C
- C behaviour was very different from others
- Copper was chosen to represent P4



Intermediate Z Element Needed

- Previously, results for Ta, Hg and C
- C behaviour was very different from others
- Copper was chosen to represent P4



Scaling of Cylinder Length

- Proportional to hadronic interaction length

Element	Interaction length (cm)	Equivalent to 20cm Ta
Ta	11.18	20cm
Hg	13.95	25cm
C	36.92	66cm
Cu	15.16	27cm
W	9.54	17cm

Harold Kirk found ~60cm is optimal

Data from http://www.slac.stanford.edu/comp/physics/matprop.html

Summary Statistics ($\pi^{\pm}$/p.GeV)

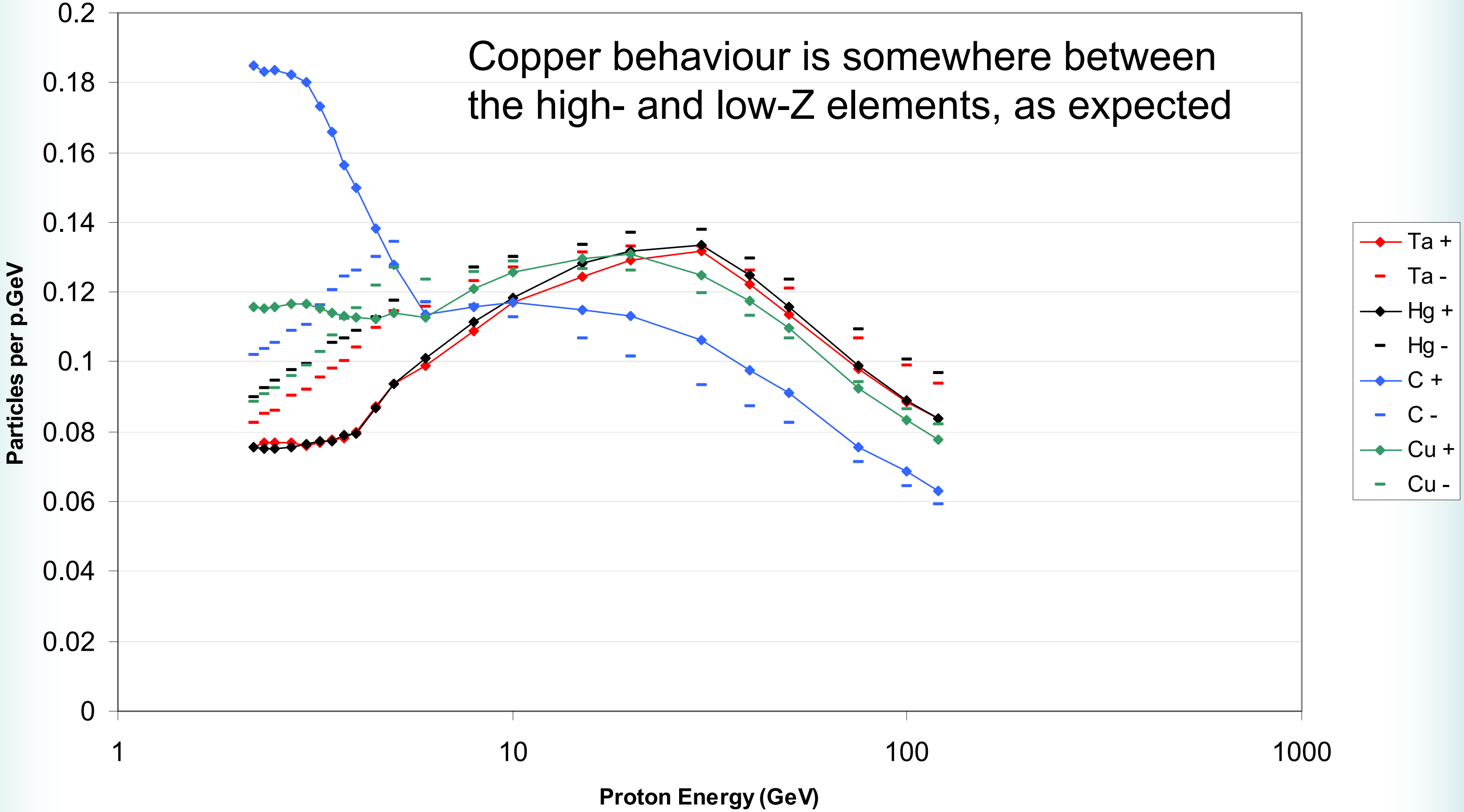
- "Total Pion Yield" = all pions (of one sign) emitted from the *rod surface*
- "Captured Yield" = these weighted by survival probability in (p_L,p_T) space
  - Survival end of (UK) phase rotation into energy band 180±23MeV of cooling ring
  - No accounting for finite rod size (e.g. ε_{long})
  - No accounting for reabsorption effects (later)

Decay modes of K^+ from PDG

- For E>3GeV, kaons add to the production
  - "A kaon is equivalent to ~1.06 pions"

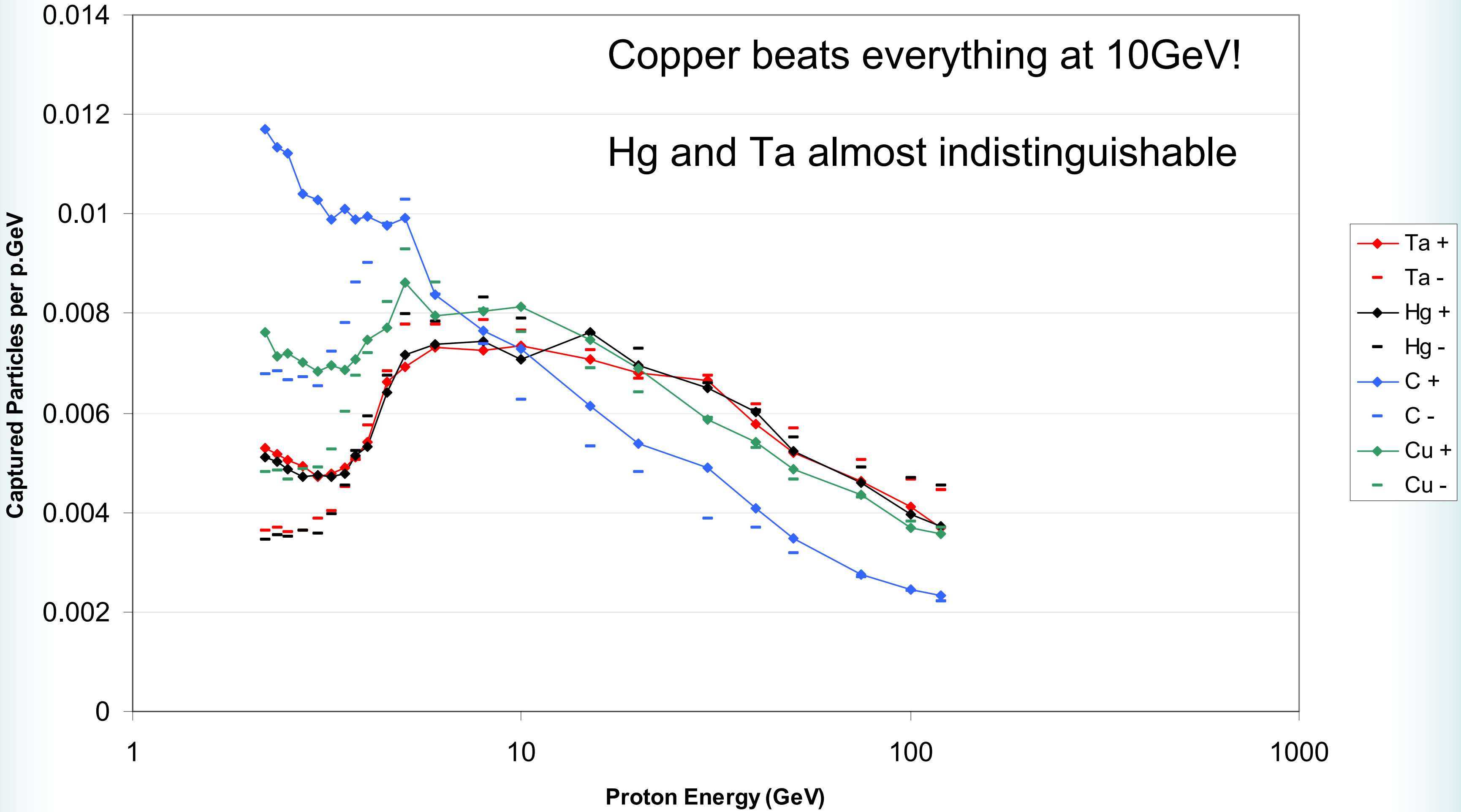
Mode	**Fraction**	**(error)**	**$\pi^\pm$ and $\mu^\pm$**	**Expected**
$\mu^+\nu_\mu$	63.39%	0.18%	1	0.6339
$\pi^0 e^+\nu_e$	4.93%	0.07%	0	0
$\pi^0\mu^+\nu_\mu$	3.30%	0.06%	1	0.033
$\pi^+\pi^0$	21.03%	0.13%	1	0.2103
$\pi^+\pi^0\pi^0$	1.76%	0.02%	1	0.01757
$\pi^+\pi^+\pi^-$	5.59%	0.05%	3	0.1677
			Mean eventual muons:	**1.06247**

Results: Total Pion Yield



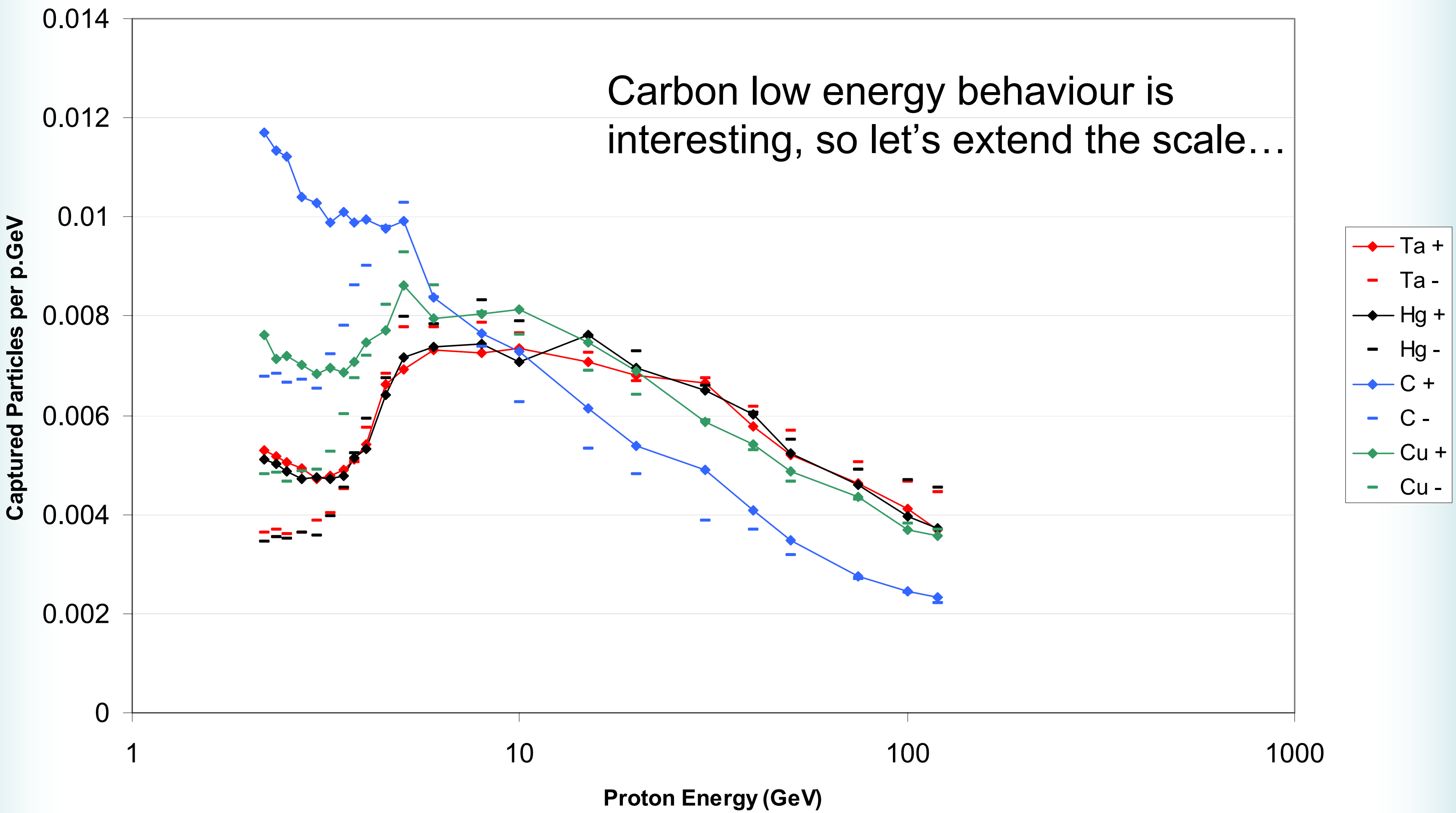
Stephen Brooks
Scoping Study meeting, April 2006

Results: Captured Yield



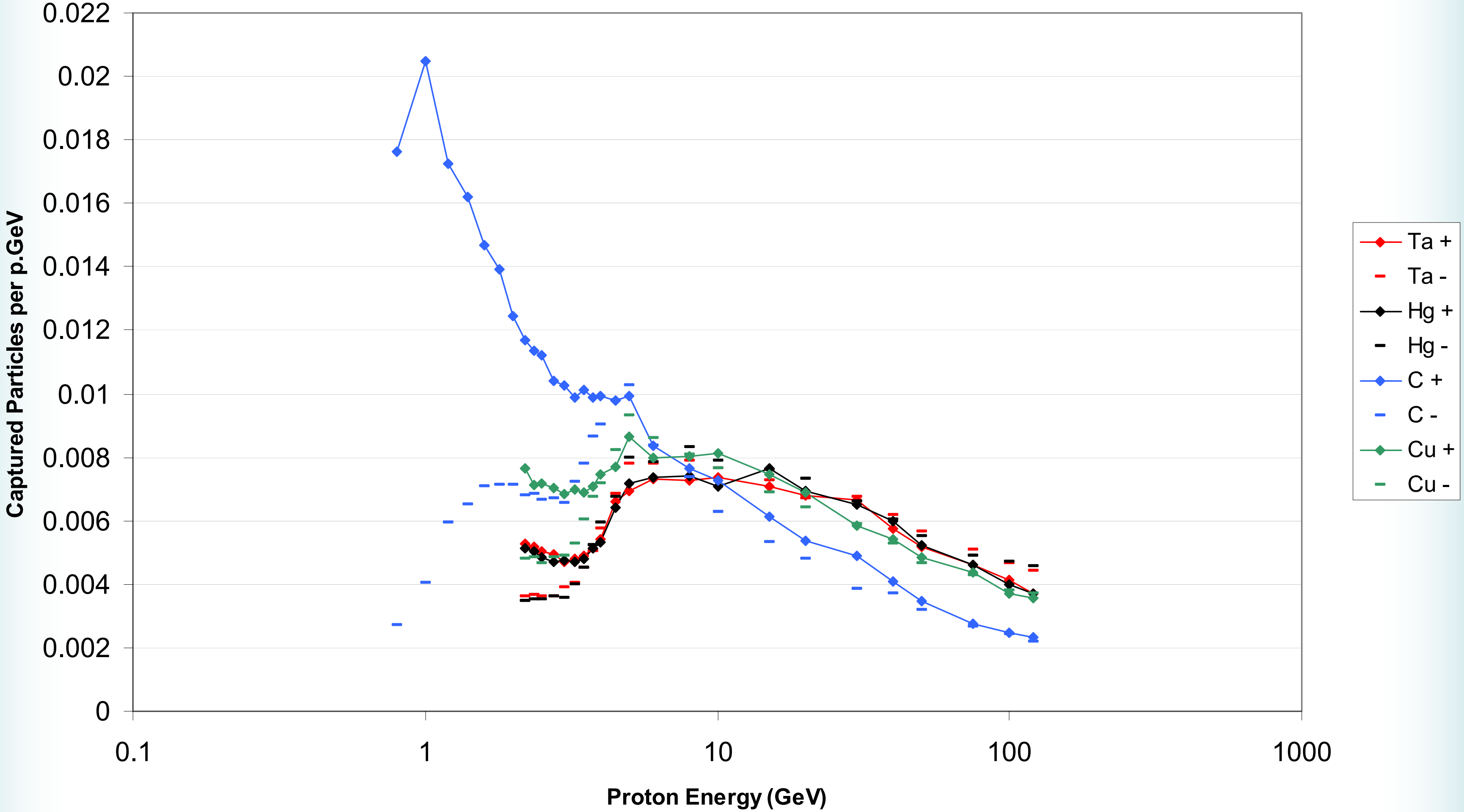
Stephen Brooks
Scoping Study meeting, April 2006

Results: Captured Yield



Stephen Brooks
Scoping Study meeting, April 2006

Results: Captured Yield

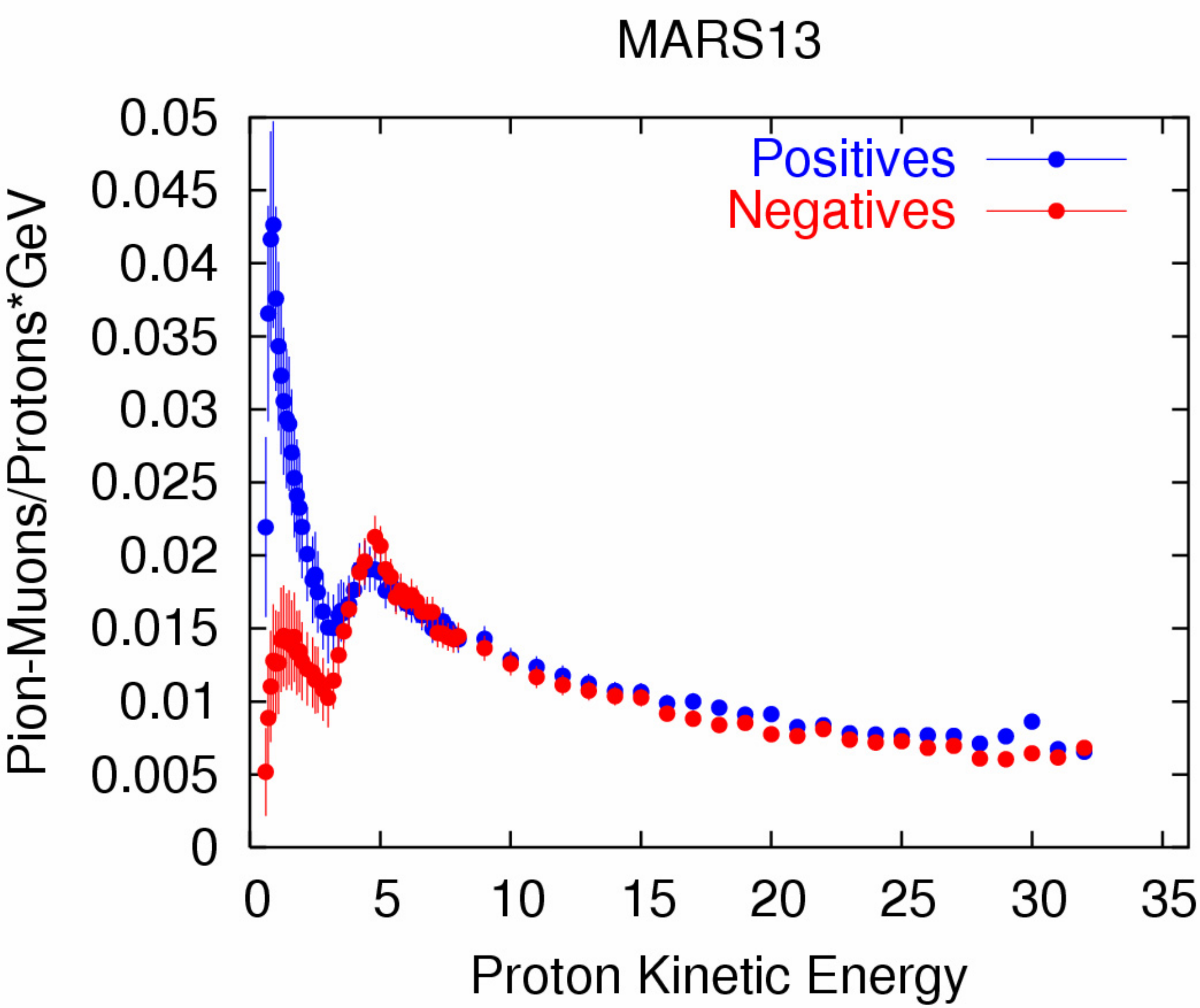


Stephen Brooks
Scoping Study meeting, April 2006

Observations

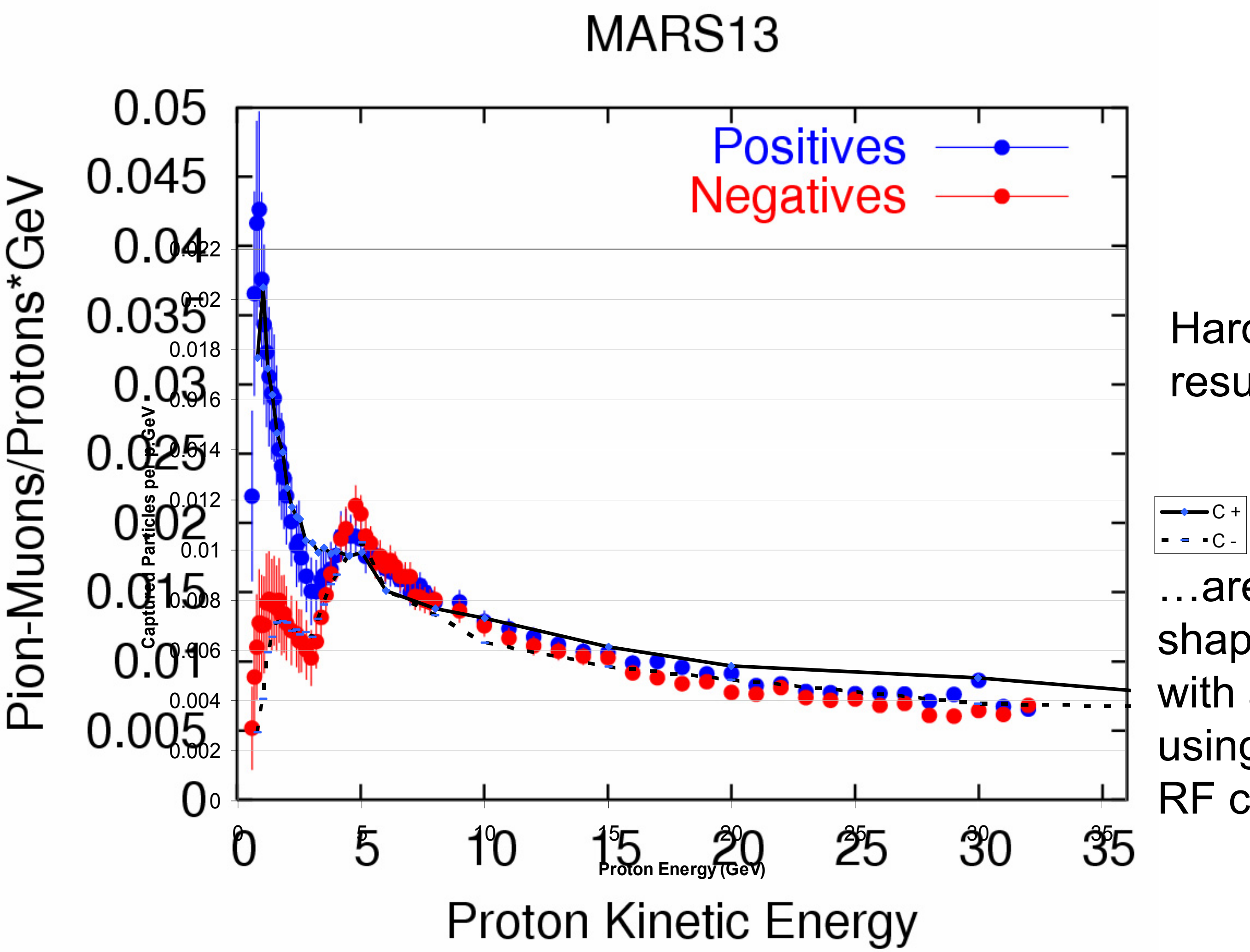
- The carbon peak at 1GeV is huge, but can you build a proton driver at that energy?
- Low energy behaviour is increasingly asymmetrical in sign for low Z
  - Proton charge manifests excess of π^+
- Carbon at 5GeV still apparently beats everything else
  - But ignoring the increased cylinder length, reabsorption and longitudinal emittance

Comparison with FS2, ICOOL



Harold Kirk's results for carbon

Comparison with FS2, ICOOL



Harold Kirk's results for carbon

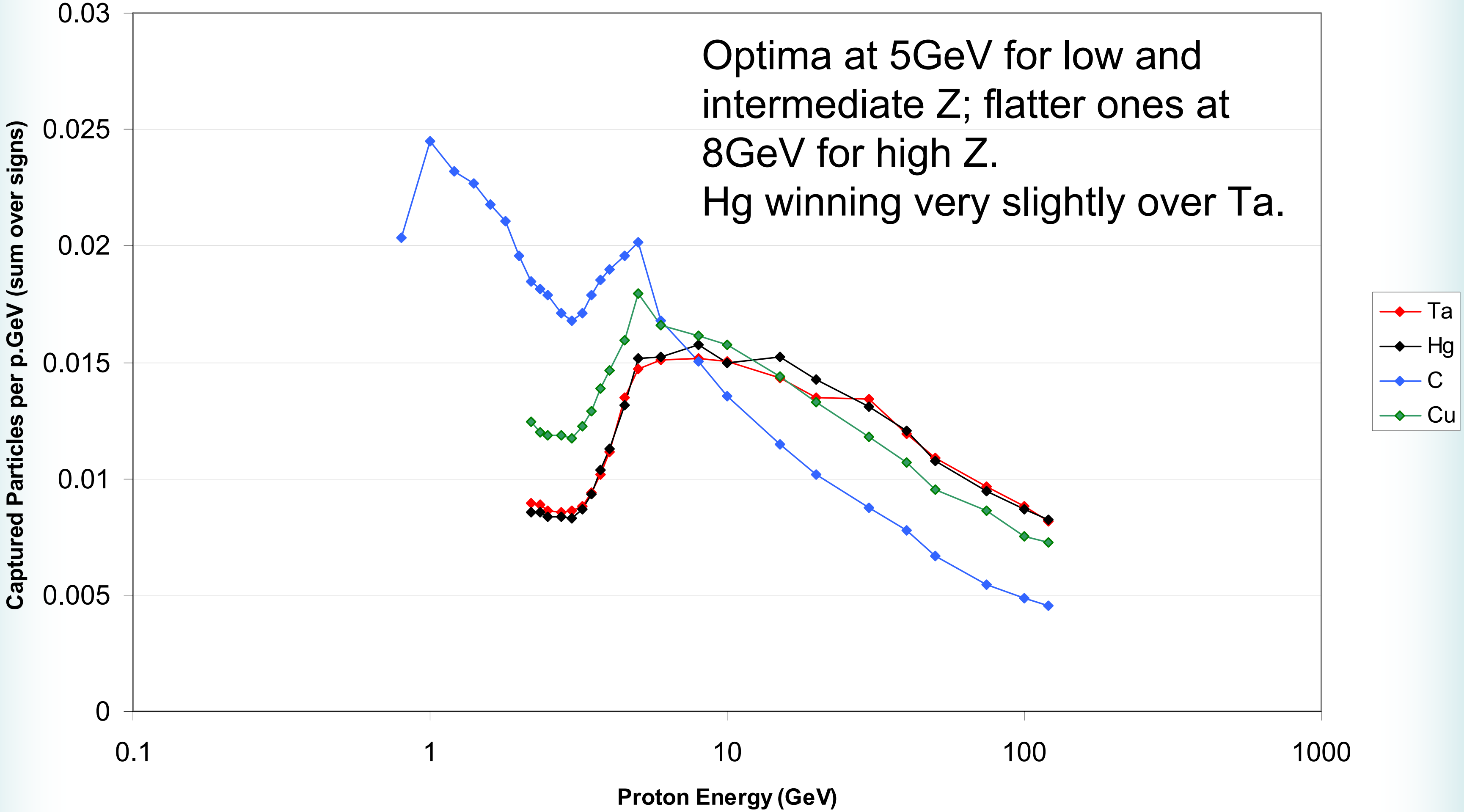
…are a similar shape to my results, with a scaling due to using more efficient RF capture

Stephen Brooks
Scoping Study meeting, April 2006

Figure of Merit: $\mu^+ + \mu^-$ or $\mu^+ \times \mu^-$?

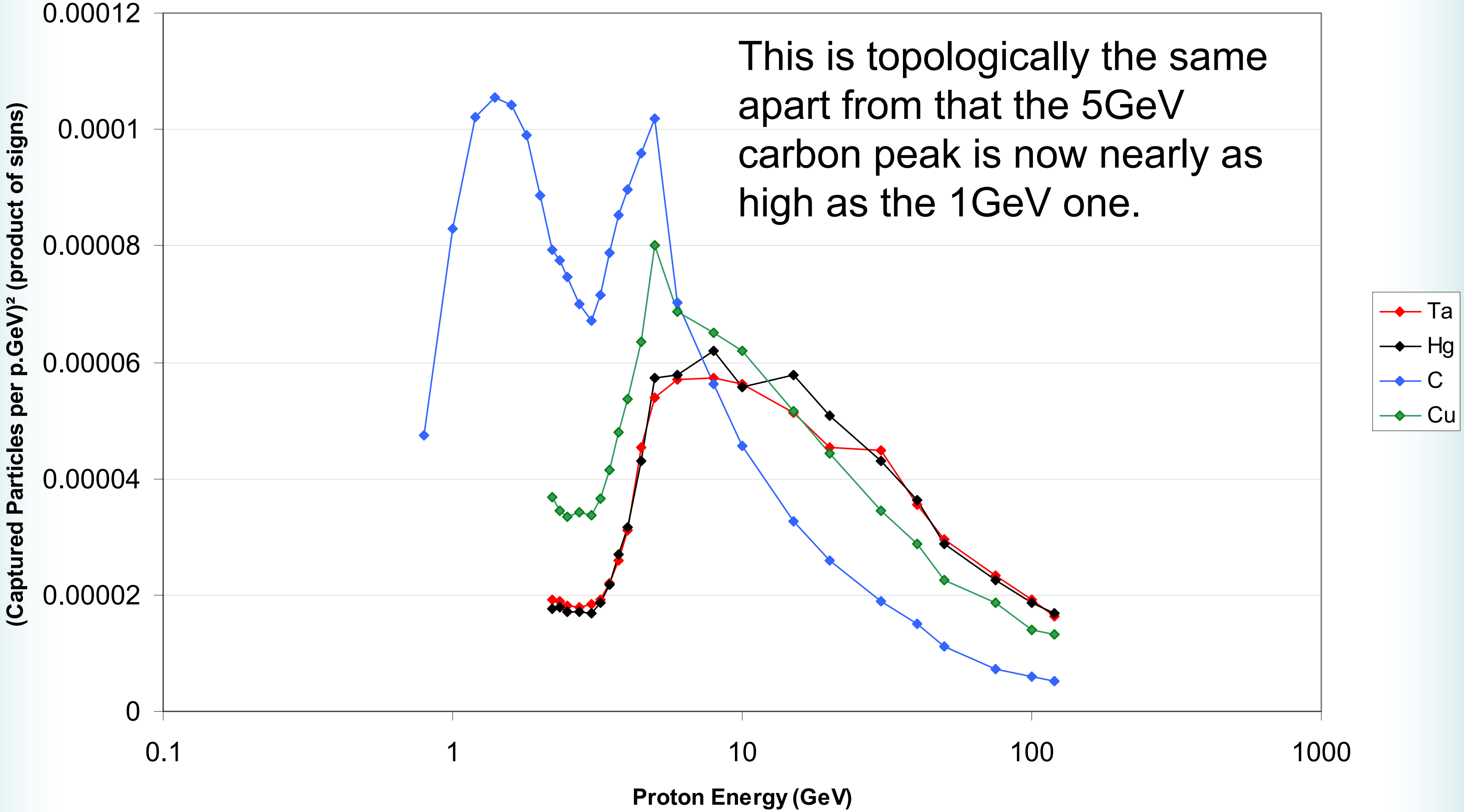
- For the muon collider they should multiply
- For the neutrino factory, it depends on the physics goals
  - Experiments that test matter-antimatter asymmetry would require both signs
  - Detectors may be more sensitive to one sign than the other, giving an asymmetric function
- I will graph both + and × cases for interest

Captured Yield Sum



Stephen Brooks
Scoping Study meeting, April 2006

Captured Yield Product



This is topologically the same apart from that the 5GeV carbon peak is now nearly as high as the 1GeV one.

Stephen Brooks
Scoping Study meeting, April 2006

Pion Reabsorption (future work)

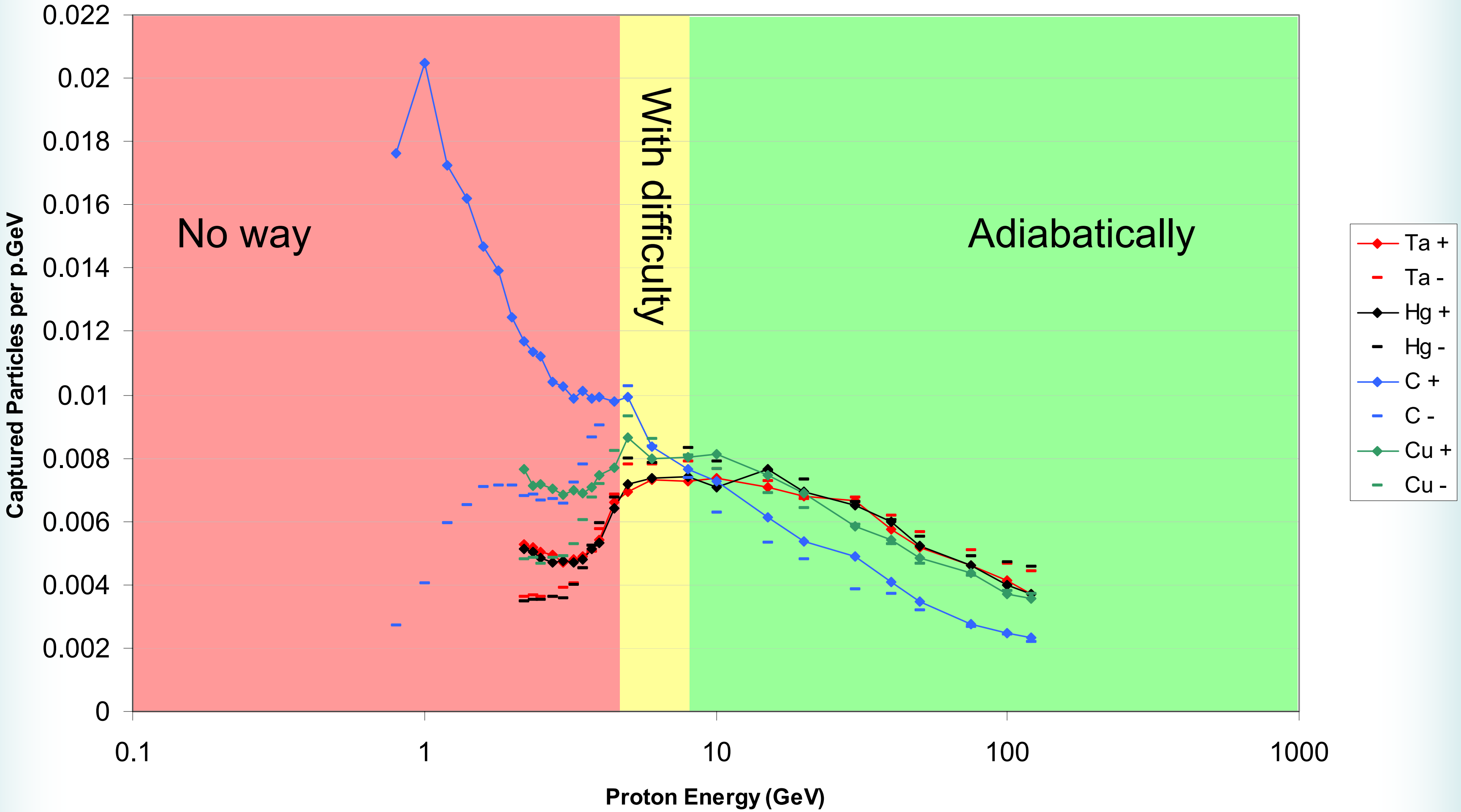
- It might be worth re-running MARS with a 20T field in the solenoid bore and collecting the pions at the endplane, to include this effect
- Could be significant in long, low-Z targets
- A rough model for manual tracking can also be obtained by extracting an "absorption length" for pions in material

Absorption Length Estimate

- MARS15 was run for pions entering a block of tantalum, surviving particles logged at various Z-planes and an exponential decay fit to the data

Energy	π^+ length	π^- length
100MeV	82mm	65mm
300MeV	107mm	106mm
1GeV	139mm	159mm

Feasibility of "1ns" Bunches



Stephen Brooks
Scoping Study meeting, April 2006

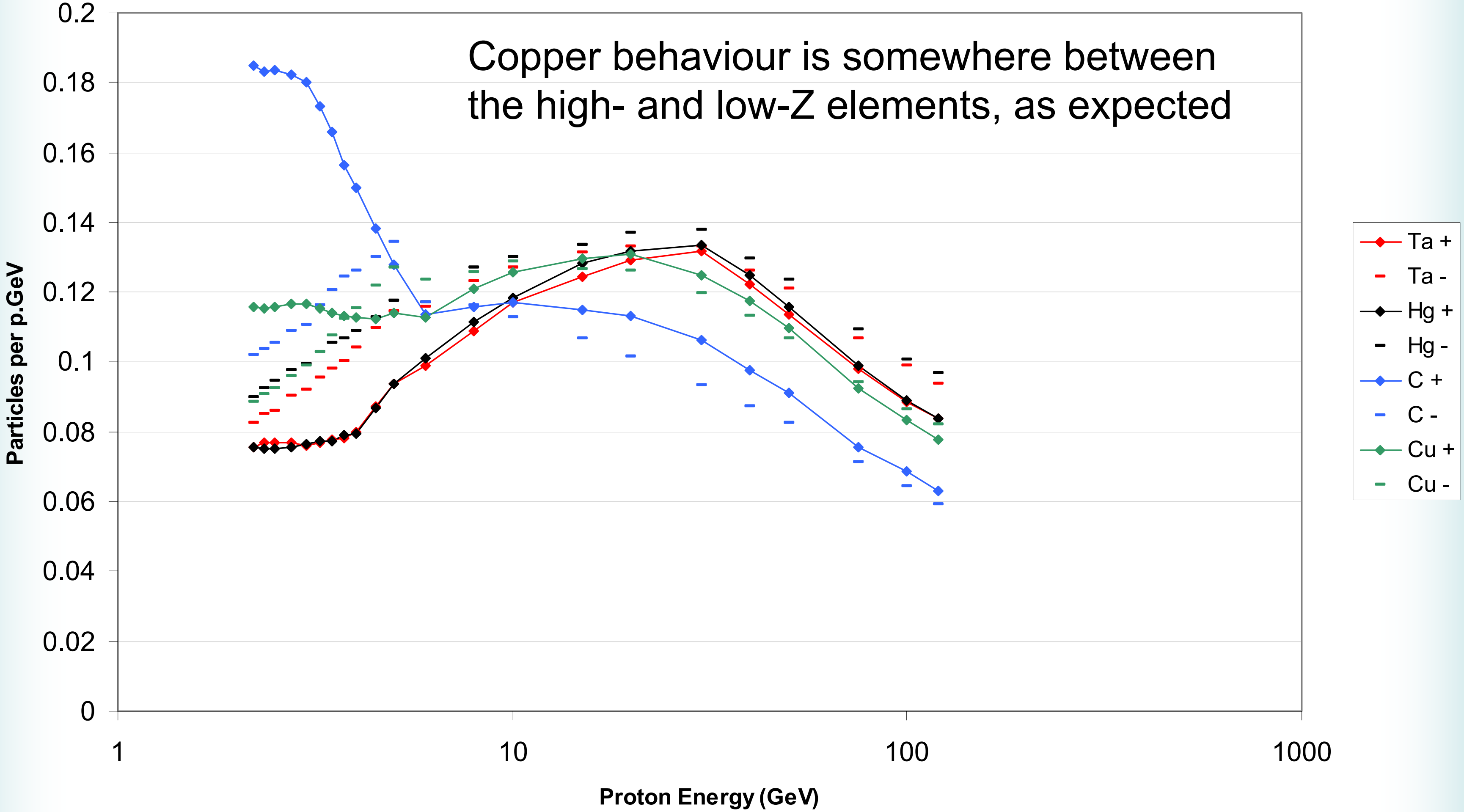
Higher Energies than 10GeV

- Going from 10GeV to 30GeV
  - Loses 10-12% yield with a high-Z target
  - Assuming fixed power (unrealistic?)
  - Re-optimising the front end for another energy tends to give small gains of order 3%
- Going from 10GeV to 50GeV
  - Loses 25-30% yield
  - This cannot be ignored so easily

Summary Statistics ($\pi^{\pm}$/p.GeV)

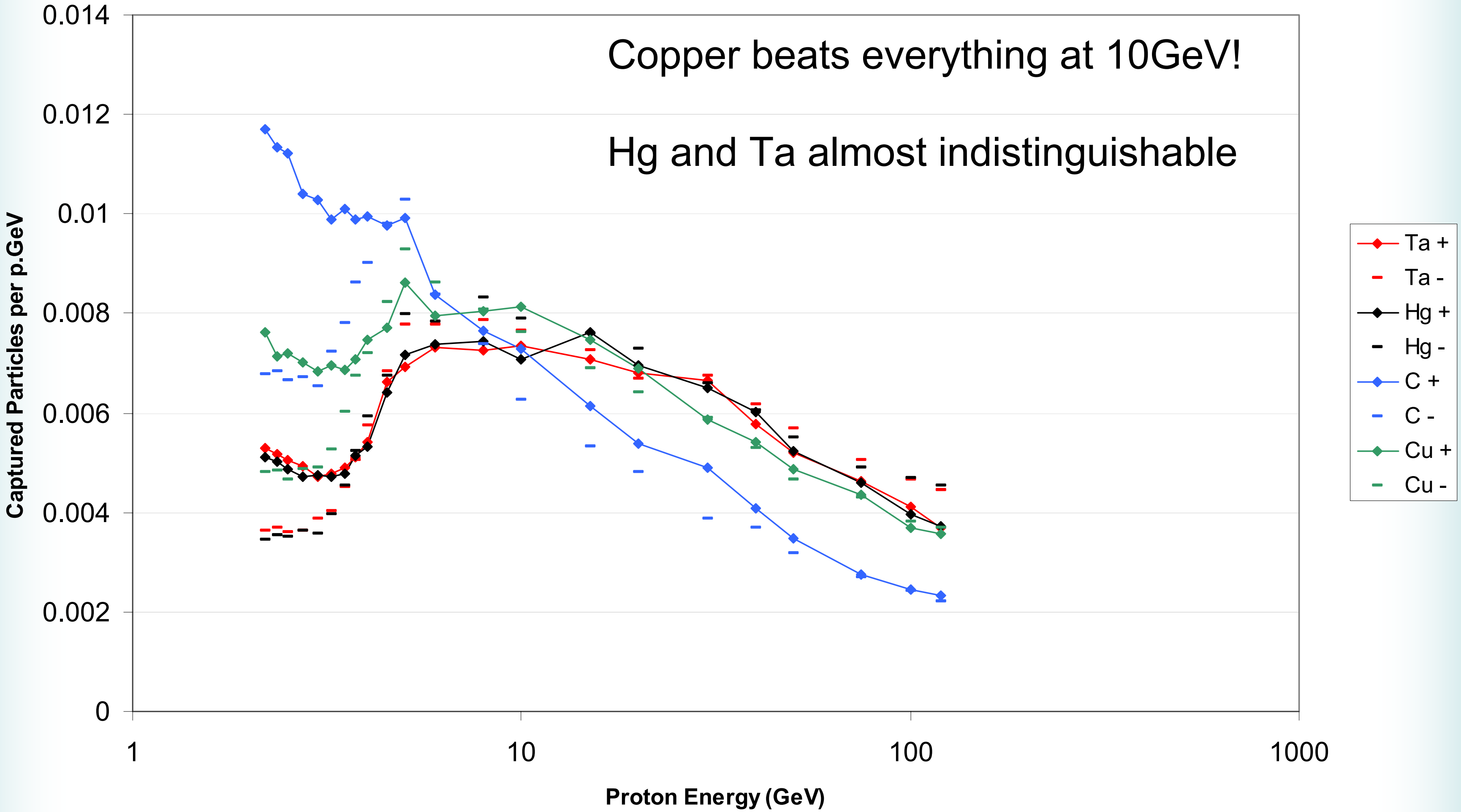
- "Total Pion Yield" = all pions (of one sign) emitted from the *rod surface*
- "Captured Yield" = these weighted by survival probability in (p_L,p_T) space
  - Survival end of (UK) phase rotation into energy band 180±23MeV of cooling ring
  - No accounting for finite rod size (e.g. ε_{long})
  - No accounting for reabsorption effects (later)

Results: Total Pion Yield



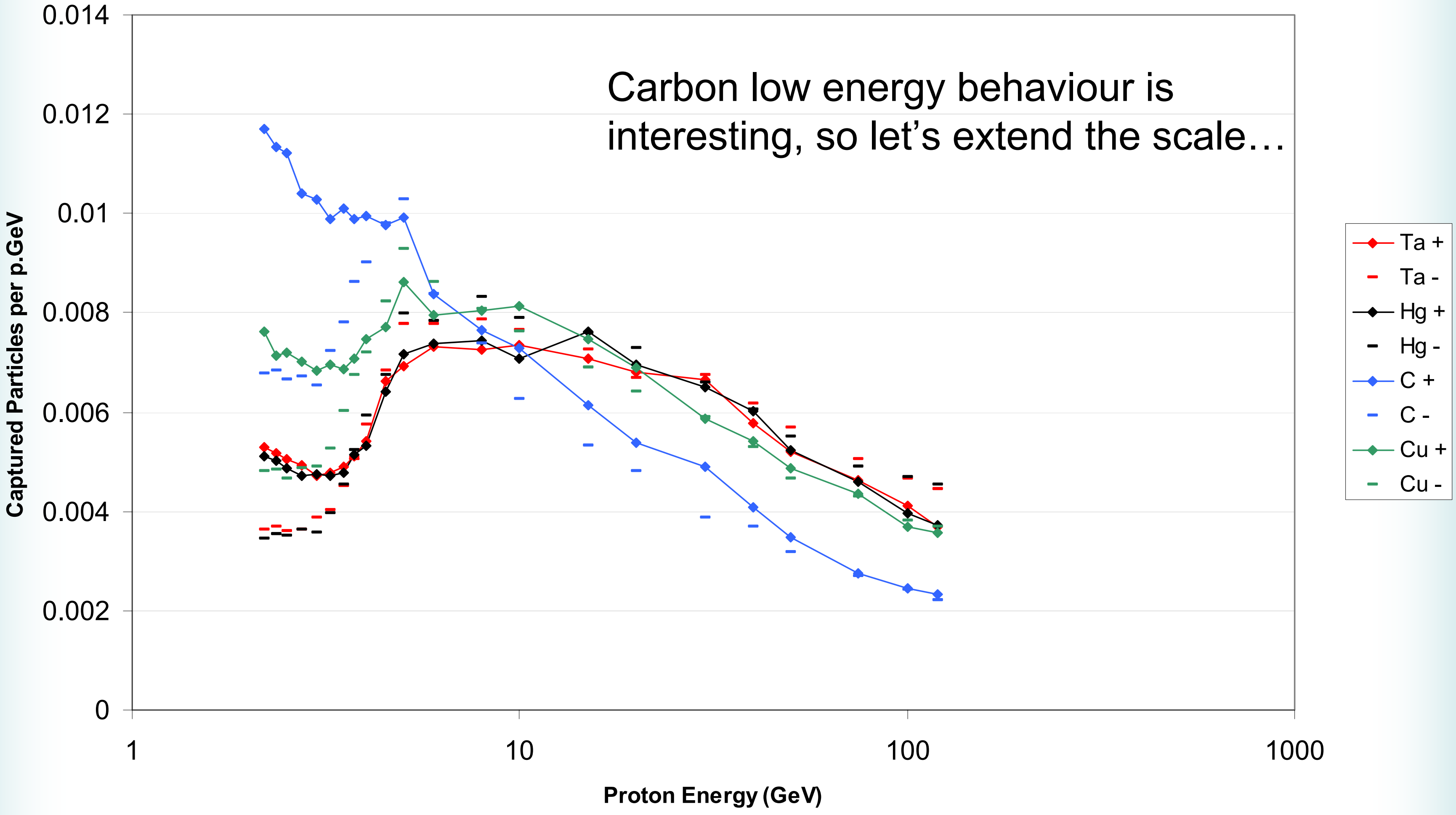
Stephen Brooks
Scoping Study meeting, April 2006

Results: Captured Yield



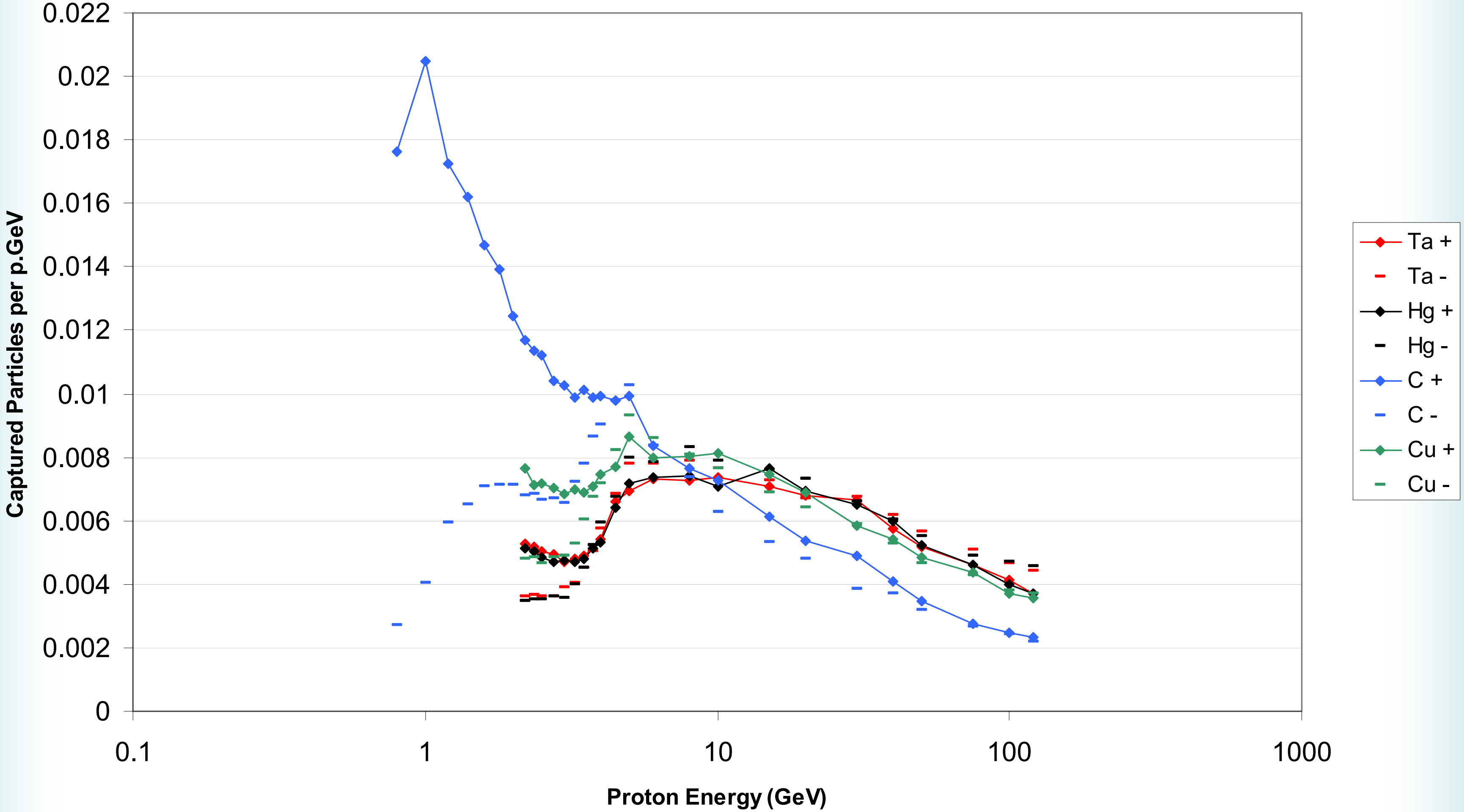
Stephen Brooks
Scoping Study meeting, April 2006

Results: Captured Yield



Stephen Brooks
Scoping Study meeting, April 2006

Results: Captured Yield



Stephen Brooks
Scoping Study meeting, April 2006

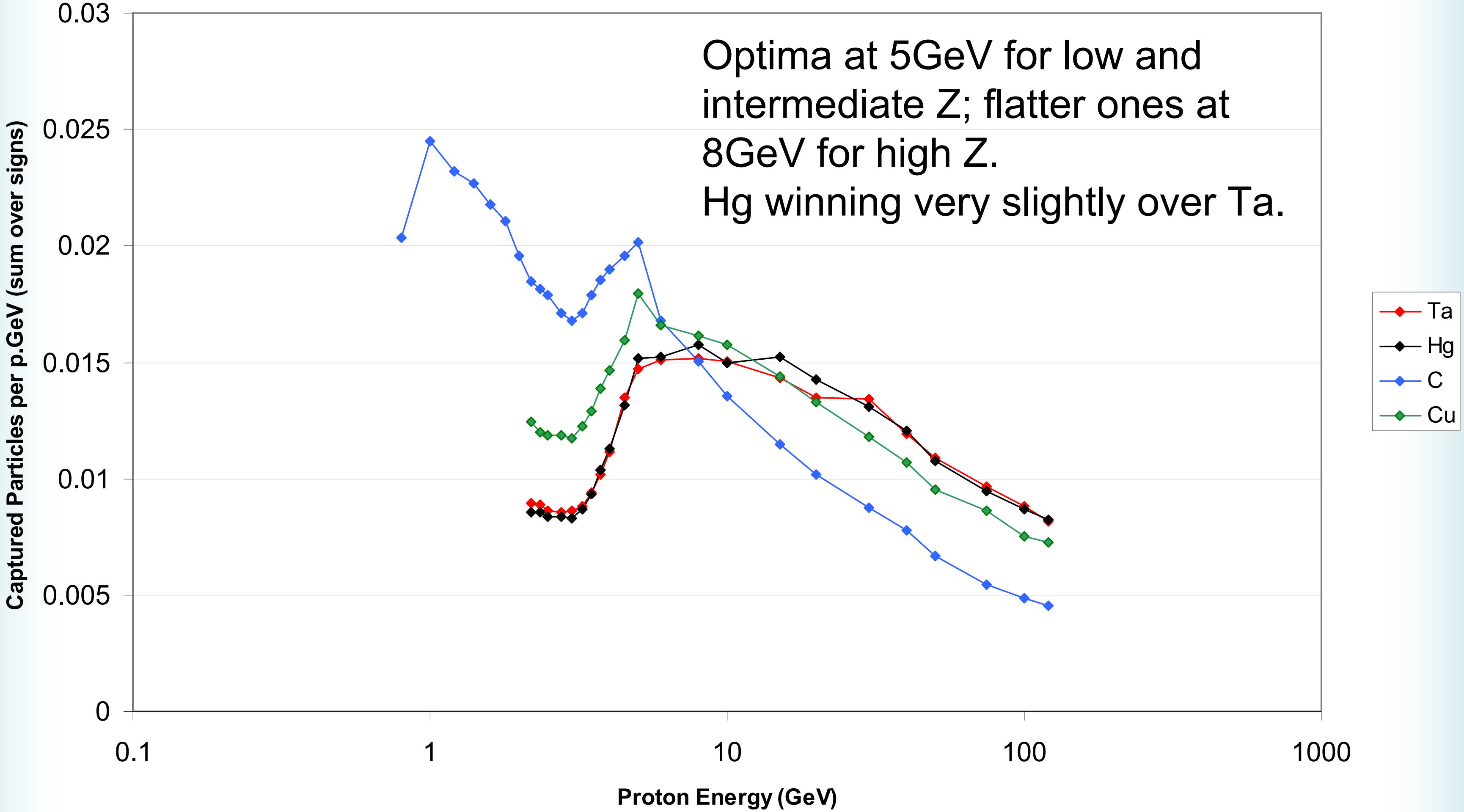
Observations

- The carbon peak at 1GeV is huge, but can you build a proton driver at that energy?
- Low energy behaviour is increasingly asymmetrical in sign for low Z
  - Proton charge manifests excess of π^+
- Carbon at 5GeV still apparently beats everything else
  - But ignoring the increased cylinder length, reabsorption and longitudinal emittance

Figure of Merit: $\mu^+ + \mu^-$ or $\mu^+ \times \mu^-$?

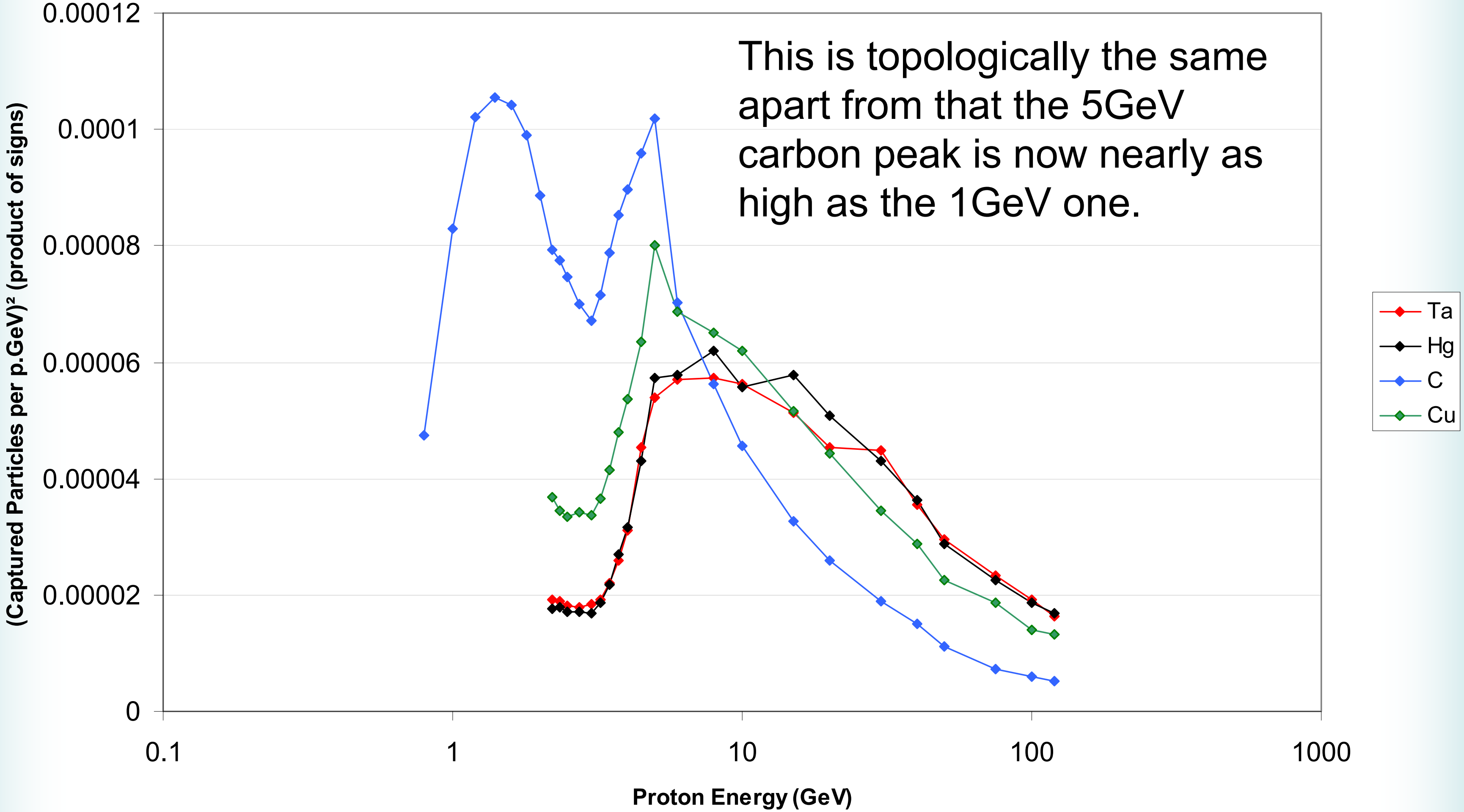
- For the muon collider they should multiply
- For the neutrino factory, it depends on the physics goals
  - Experiments that test matter-antimatter asymmetry would require both signs
  - Detectors may be more sensitive to one sign than the other, giving an asymmetric function
- I will graph both + and × cases for interest

Captured Yield Sum

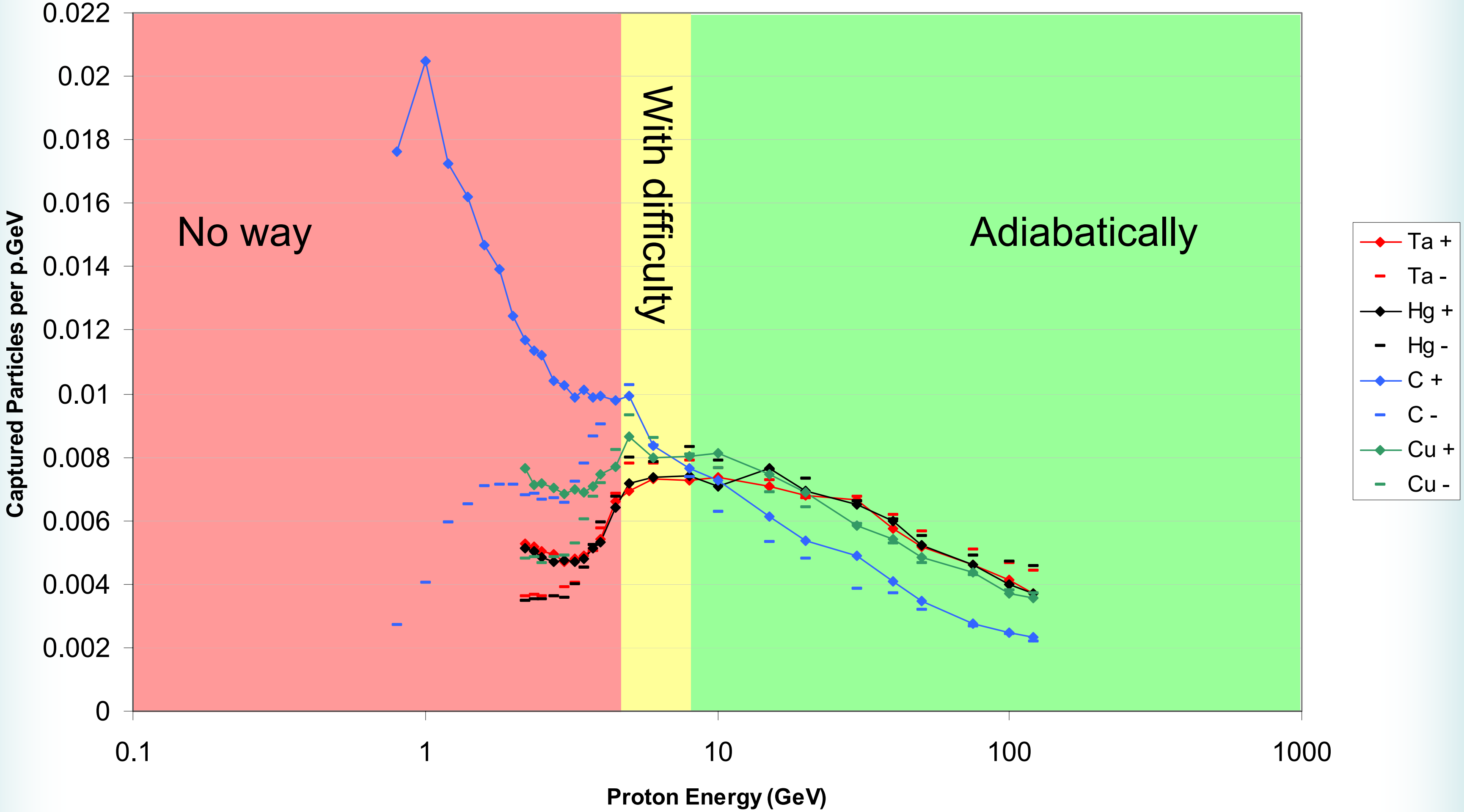


Stephen Brooks
Scoping Study meeting, April 2006

Captured Yield Product



Feasibility of “1ns” Bunches



Stephen Brooks
Scoping Study meeting, April 2006

Higher Energies than 10GeV

- Going from 10GeV to 30GeV
  - Loses 10-12% yield with a high-Z target
  - Assuming fixed power (unrealistic?)
  - Re-optimising the front end for another energy tends to give small gains of order 3%
- Going from 10GeV to 50GeV
  - Loses 25-30% yield
  - This cannot be ignored so easily