MAPRad

Total and partial fragmentation cross-section of 500 MeV/n Carbon ions on different targets*

F. Di Capua - 10/05/2012

esa space radiation & plasma environment monitoring ws
9 - 10 may 2012
European Space Agency

*** RESULTS FROM ESA TENDER ITT-AO5697: "Investigation and analysis of very high energy accelerators for radiation simulation"**

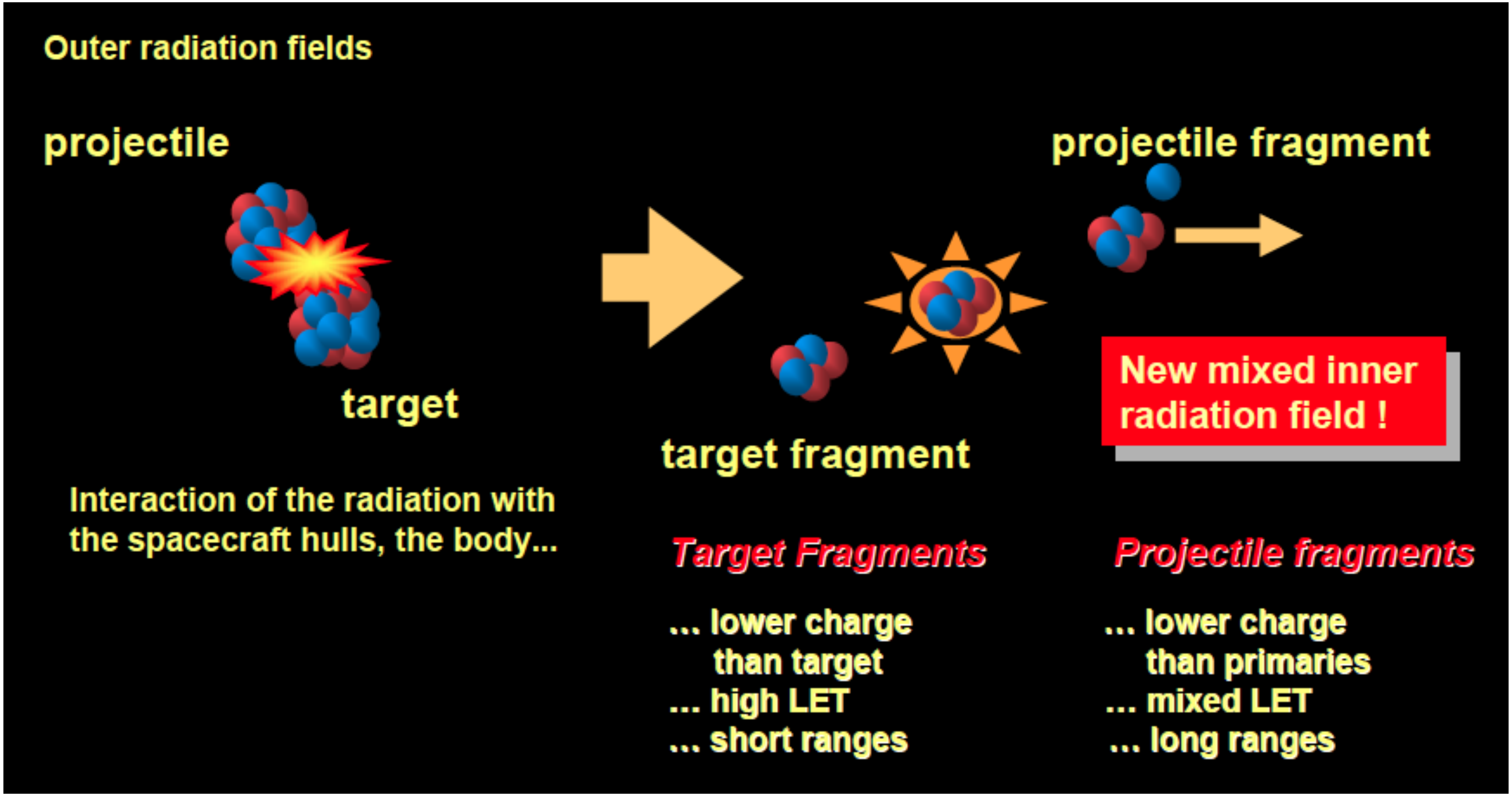
Fragmentation studies

Physics motivations

- Radiation risk estimations for humans for effect GCR (Galactic Cosmic Radiation): highly charged energetic atomic nuclei (HZE particles) not effectively shielded, for effect of fragmentation break up into lighter more penetrating pieces
- Single Event Upset in microelectronic circuits
- Cancer therapy with light ions (Z<9)

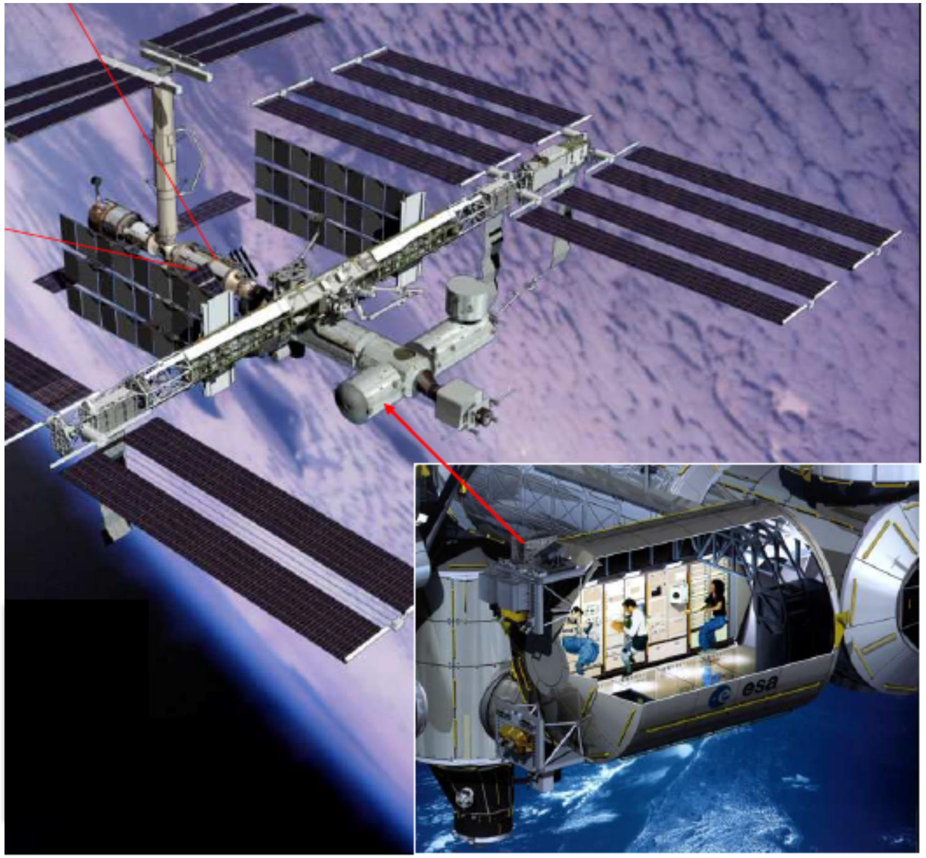
A deeper understanding of the physics process is required in both field of Space Radiation and Hadron Therapy for having a better radiation treatments and getting risk assessment in interplanetary spaceflight

The measurement of fragmentation cross sections is an important information to estimate how this process modifies dose distributions and biological effectiveness



- Attenuation of the primary beam and build up of low Z reaction products
- Long range fragments deposit dose beyond maximum range of primary beam
- Physical model, in addition to scatter and ionization, should properly account for fragmentation in order to calculate deposited dose

Mixed radiation field



- In order to estimate the radiation risk assessment on humans Dose Equivalent in critical organs has to be simulated, this means to simulate the nuclear fragmentation process
- Validation of nuclear model implemented in simulation tools is extremely important

Fraunhofer INT Institut Naturwissenschaftlich-Technische Trendanalysen

MAPRad

Total and partial fragmentation cross-section of 500 MeV/nucleon carbon ion different target materials*

B. Alpat[†] and M. Menichelli
Istituto Nazionale di Fisica Nucleare - Sezione di Perugia, Via A. Pascoli, Perugia I-06132, Italy

E. Pilicer[‡]
Department of Physics Uludag University, 16059 Bursa, Turkey

S. Blasko, D. Caraffini, F. Di Capua, A. Lucaroni, V. Postolache, G. Saltanocchi
MAPRad S.r.l., 06127 Perugia, Italy

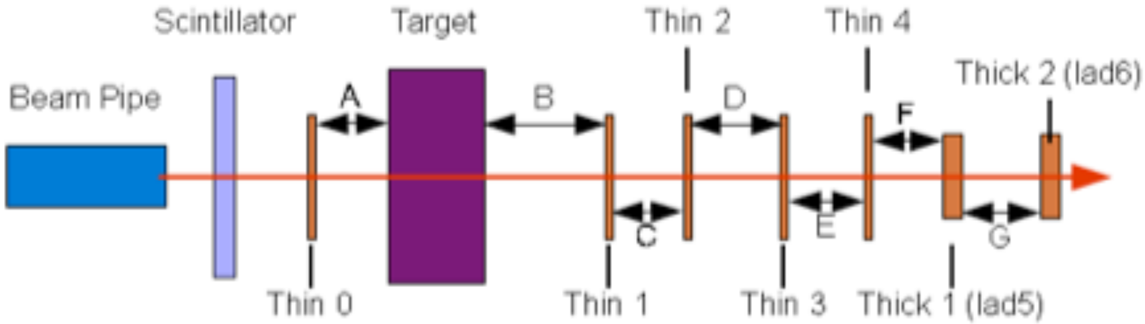
L. Desorgher
SpaceIT GmbH, 3007 Bern, Switzerland

M. Durante, R. Pleskac, C. La Tessa
GSI, Darmstadt, Germany

GSI

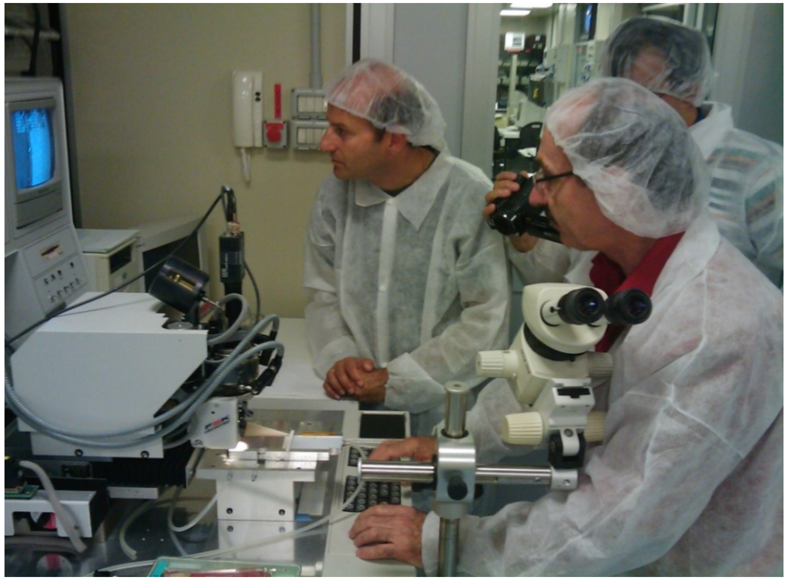
SpaceIT

Experimental setup

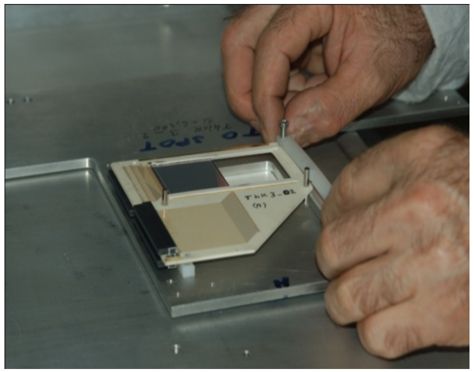


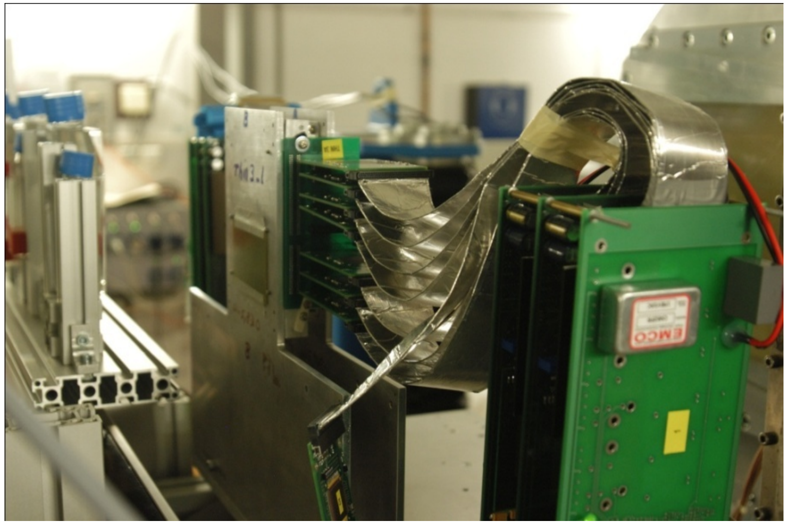
- **Double sided micro-strip silicon detectors, 1 thin sensor before the target and 4 thin sensor after, two thick sensors at end of apparatus**
- **Positions between changed**
- **Cooled dry air (2°C) blowing on sensors**

Hardware Production



- **Thin sensors**:
  - 41 X 72 X 0.31 mm3
  - Readout pitch 0.4 mm
  - 160 + 96 channels (beam session of 2009)
  - 96 + 96 channels (beam sessions of 2010)
- **Thick sensors:**
  - 35 X 35 X 1.5 mm3
  - Readout pitch 0.5 mm
  - 64 + 64 channels





Tested Materials

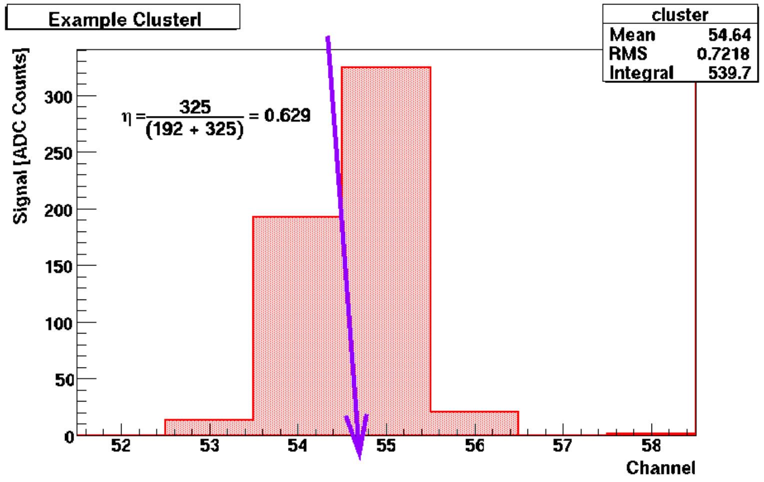
Material	Thickness (g/cm^2)
air	0.035
water	5.700
lucite	3.840
polyethylene	0.465
silicon carb.	1.580
aluminium	5.450
graphite	1.734
graphite	3.434
copper	4.628
iron	3.935
iron	6.611
tin	3.655
tin	5.848
tantalum	3.330
tantalum	6.660
lead	3.689
lead	6.810

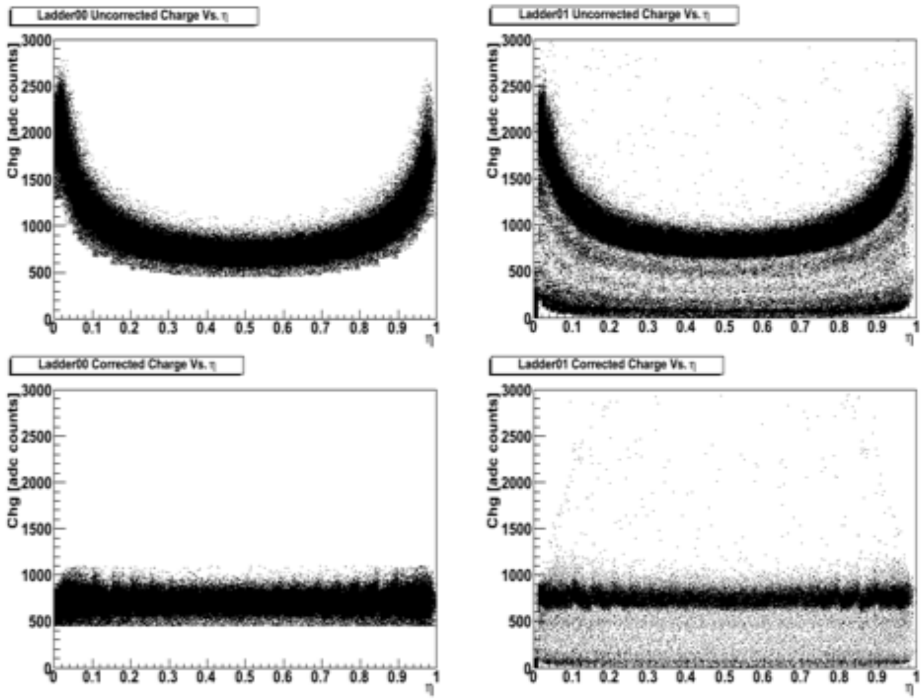
- 11 different targets
- 7 elemental: Carbon, Aluminium, Iron, Copper, Tantalum, Lead
- 4 composite targets: Water, Polyethylene, Lucite, Silicon Carbide
- same material with different thickness
- run with different sensor distances for evaluation of systematics

Charge Corrections

Basic features of the cluster:

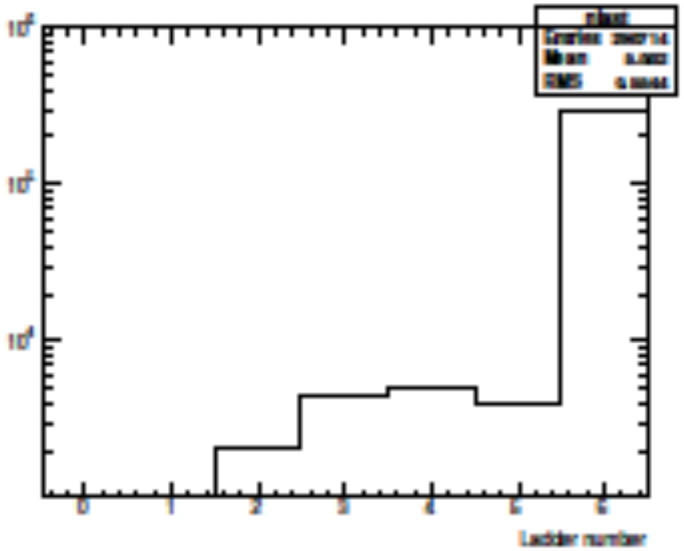
- *Collected charge (chg):* $chg = \sum_{i,j \in cluster} s_k^{ij} + q_k^{ij}$
- *Cluster identifier (clid): number of the strip containing the highest signal*
- *Position*
  - *Eta Parameter (η):* $\eta = \frac{Q_r}{Q_l + Q_r}$
  - *Center of gravity (cog):* $cog = L + \eta$

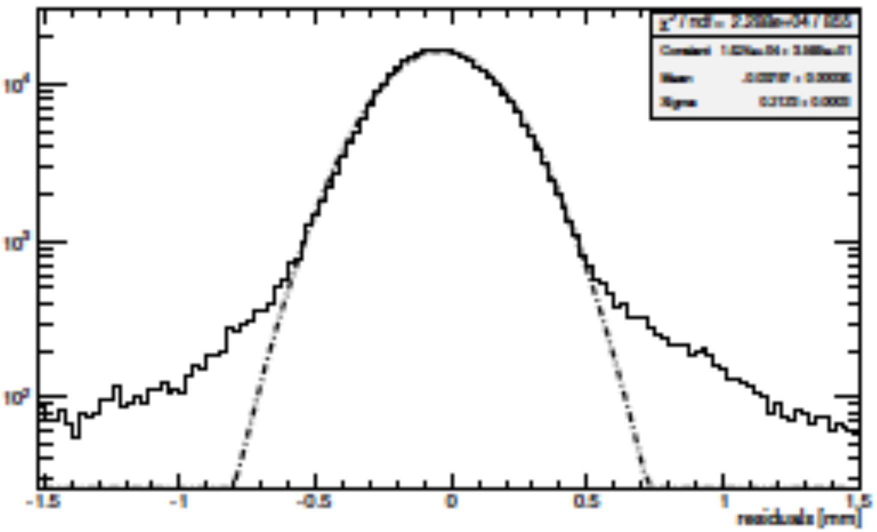


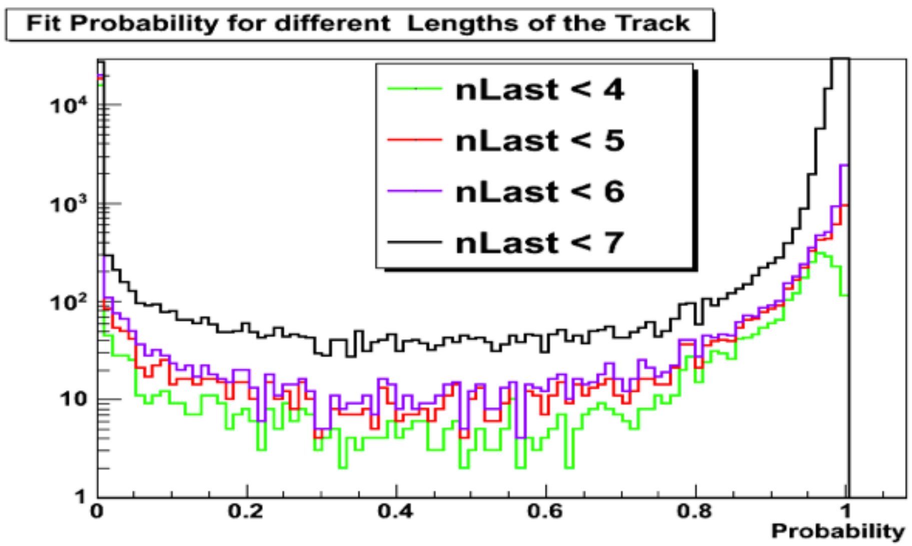


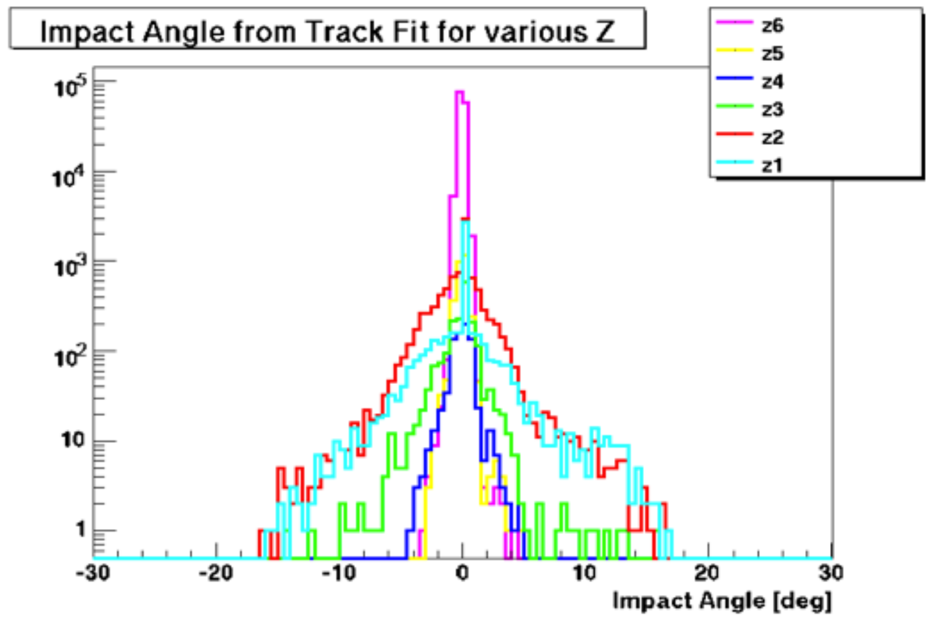
- When the hit is in the interstrip region (η=0.5) the collected charge is lower
- A correction has been implemented by using a run without target and used for all the other run

Track Fitting

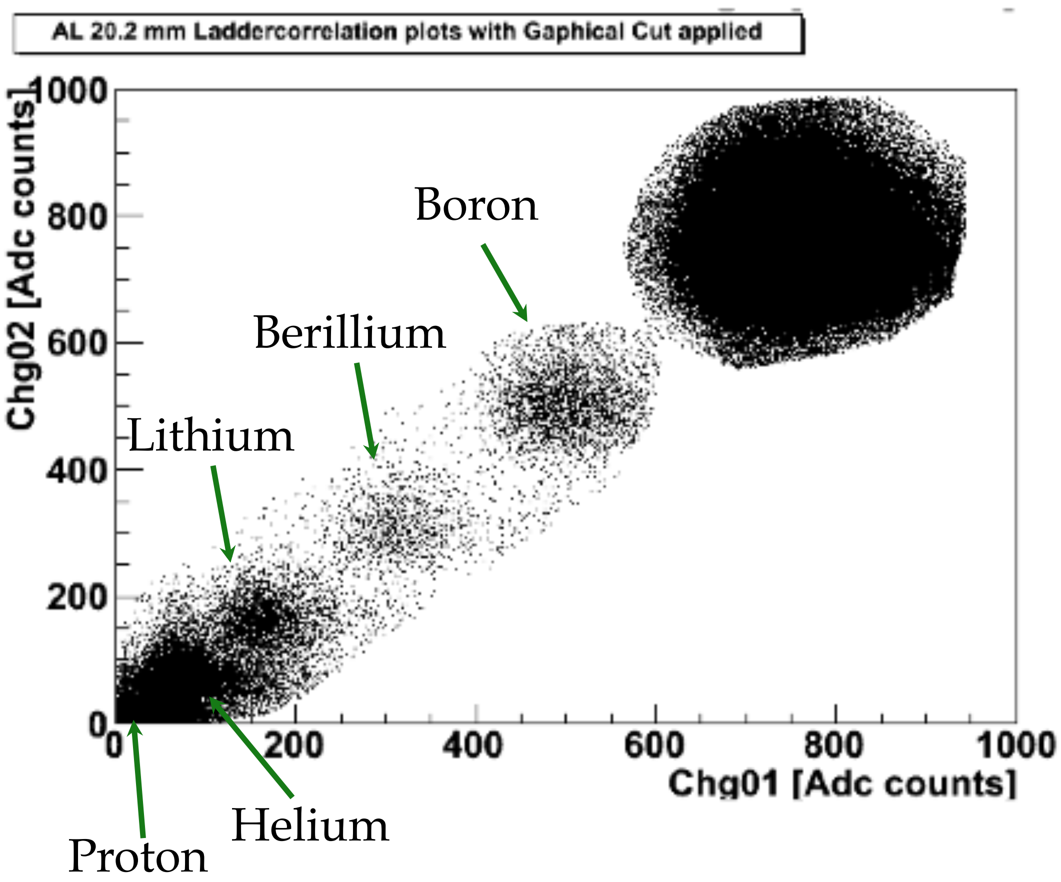






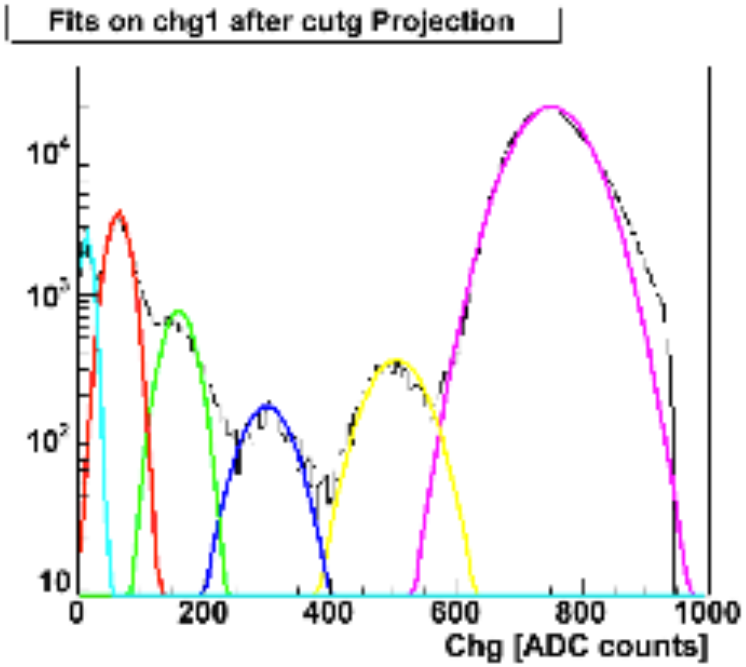


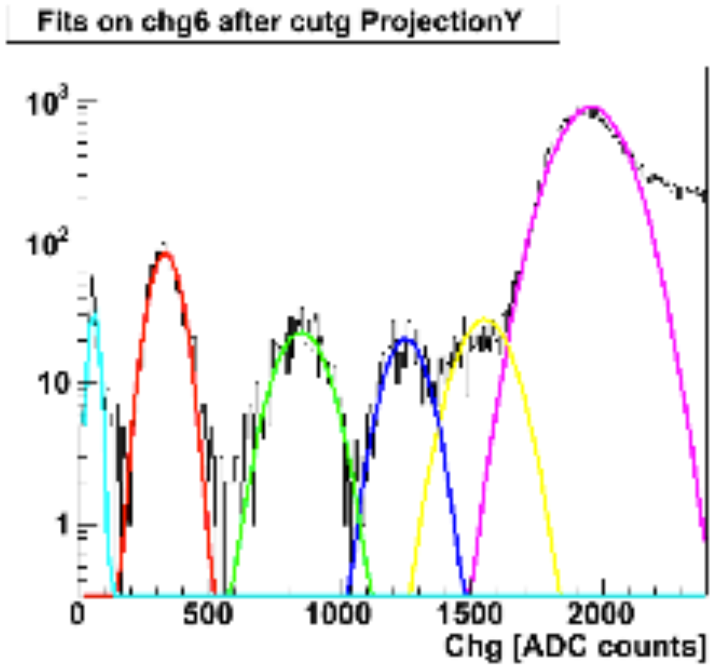
Charge correlation



- Cleaned sample due to track fitting
- Selections cuts: request to have only one cluster in ladder before the target and fit probability cut.
- Graphical cut to select peaks (the same for each target and configurations)
- Charge correlation distribution is produced for all combination of sensors
- The selection criteria are the same for any target material analysed

Charge identification





$$P_{Z_S}(x) = \frac{f_{Z_S}(x)}{\int f_{Z_S}(x)dx}$$

Probability density function

Charge scatter plot produced for all sensor combinations is projected on each sensor and used to build the p.d.f.'s for a given Z and a given sensor S

$$L(Z) = -\sum log(f_{Z_S}(x_s))$$

Likelihood

L(Z) is computed for each Z ipothesis in order to find the most probable Z

Cross section measurement

$$P(Z) = \frac{N(Z)}{\sum N(Z)}$$

survived primary events

Primary + Fragments

$$P_0(Z) = \frac{N_0(Z)}{\sum N_0(Z)}$$

obtained in run without target

Total cross section

$$\sigma_{cc} = -\frac{A\log(P_{corr}(Z_p))}{\rho d N_A}$$

$$P_{corr}(Z_p) = \frac{P(Z_p)}{P_0(Z_p)}$$

A: mass number
ρ: target density
d: target thickness
NA: Avogadro number

Partial cross section

$$\sigma_Z = \sigma_{cc}\frac{P_{corr}(Z)}{1 - P_{corr}(Z_p)}$$

$$P_{Corr}(Z) = P(Z) - P_0(Z) \cdot P_{corr}(Zp) \quad ; \qquad for\ Z \neq Zp$$

Total Cross Section

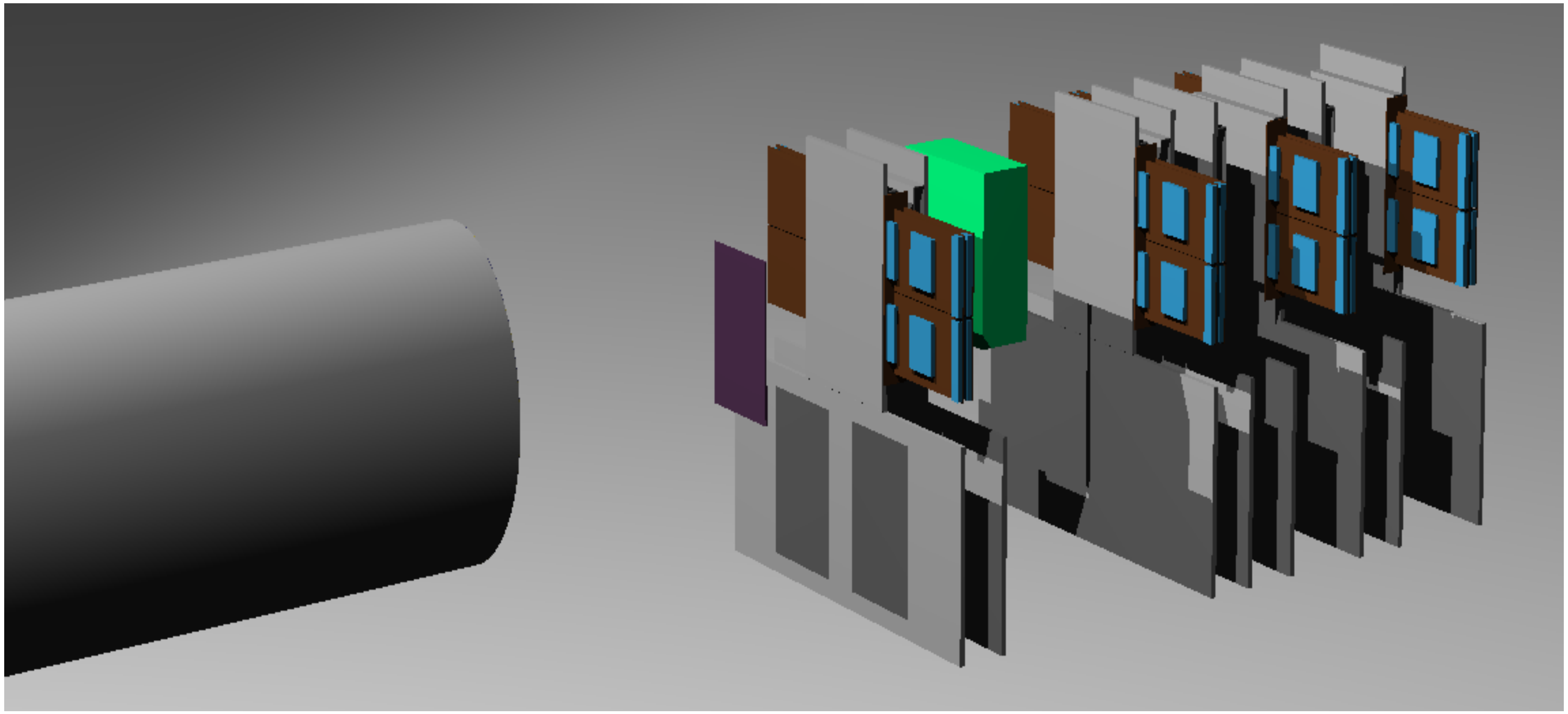
Energy (MeV/n)	Target	Cross-Section (mbarn)	Rel. Error (%)	Ref.
200	graphite	658 (7)	1.1	[17]
267	graphite	748 (19)	2.5	[18]
290	graphite	706 (7)	1.0	[19]
400	graphite	672 (7)	1.0	[17]
400	graphite	713 (11)	1.5	[21]
498	graphite	758 (15)	2.0	[18]
500	graphite	703 (18)	2.5	This exp.
192	aluminium	1179 (29)	2.5	[18]
267	aluminium	1078 (17)	1.6	[18]
290	aluminium	1155 (108)	9.3	[19]
290	aluminium	1052 (11)	1.0	[21]
400	aluminium	1011 (9)	0.9	[21]
498	aluminium	1103 (28)	2.5	[18]
500	aluminium	1095 (26)	2.5	This exp.
676	aluminium	1096 (100)	9.1	[18]
500	iron	1509 (37)	2.5	This exp.
290	copper	1625 (18)	1.1	[21]
400	copper	1557 (10)	0.6	[21]
500	copper	1598 (50)	3.1	This exp.
290	tin	2069 (18)	0.9	[21]
400	tin	2035 (21)	1.0	[21]
500	tin	2141 (79)	4.9	This exp.
500	tantalum	2936 (105)	3.6	This exp.
290	lead	2795 (15)	0.5	[21]
400	lead	2745 (45)	1.6	[21]
500	lead	2926 (116)	3.9	This exp.

Total Cross Section

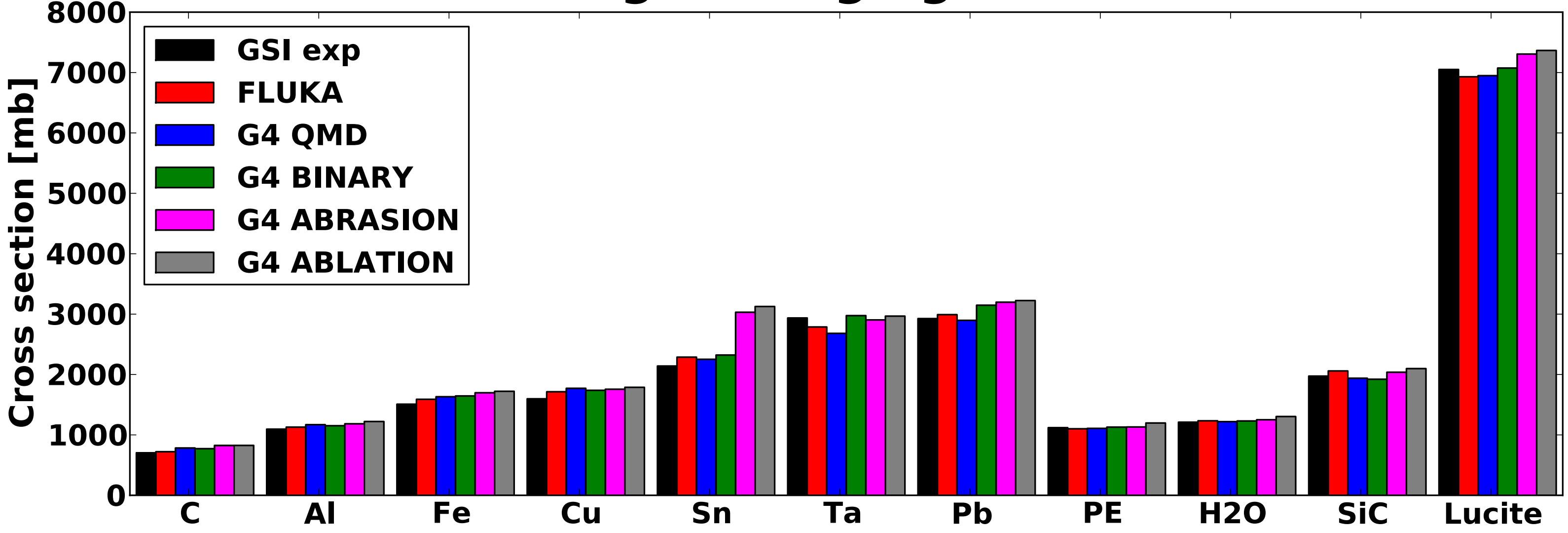
Energy (MeV/n)	Target	Cross-Section (mbarn)	Rel. Error (%)	Ref.
192	water	1264 (16)	1.3	[18]
267	water	1163 (13)	1.1	[18]
326	water	1250 (51)	4.1	[22]
352	water	1202 (47)	3.9	[22]
377	water	1253 (45)	3.6	[22]
498	water	1220 (20)	1.6	[18]
500	water	1211 (27)	2.2	This exp.
670	water	1261 (13)	1.0	[18]
192	lucite	7250 (102)	1.4	[18]
267	lucite	6733 (74)	1.1	[18]
464	lucite	7019 (112)	1.6	[18]
500	lucite	7051 (165)	2.3	This exp.
676	lucite	7170 (360)	5.0	[18]
192	polyethylene	1157 (13)	1.1	[18]
267	polyethylene	1075 (11)	1.0	[18]
498	polyethylene	1135 (15)	1.3	[18]
500	polyethylene	1120 (54)	7.0	This exp.
500	silicon carb.	1974 (91)	4.9	This exp.

MC simulation

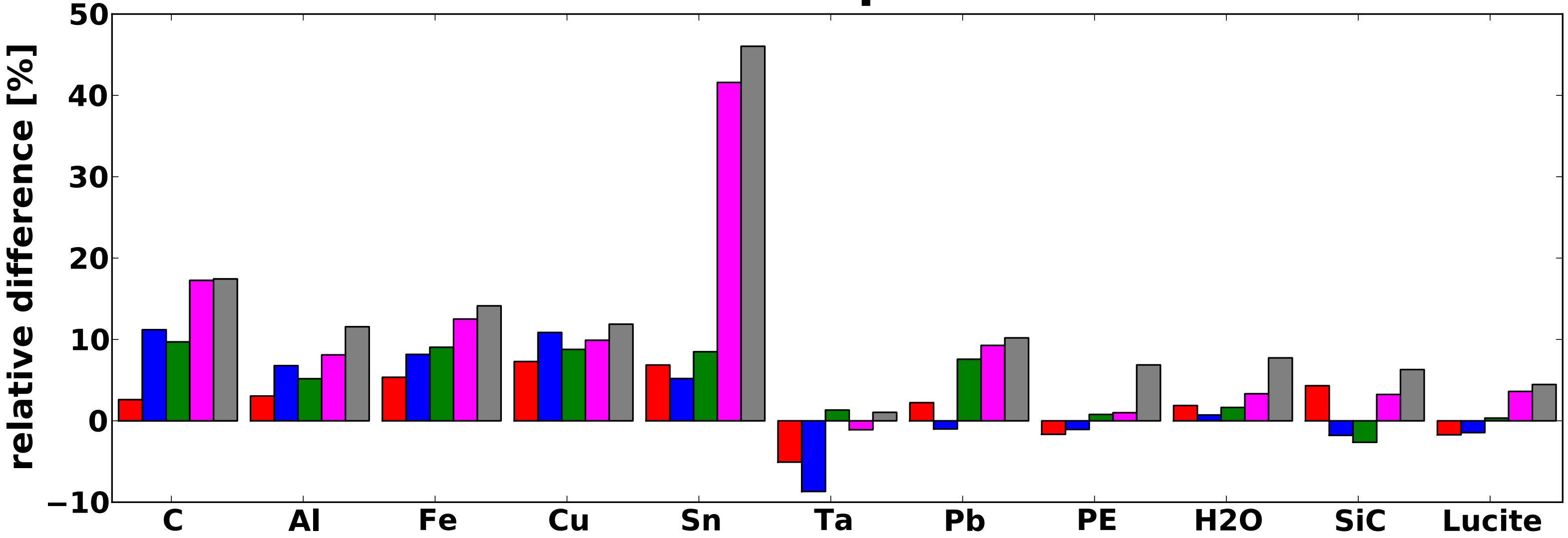
- Python based simulation software
- Input files are GDML detector descriptions
- Output in root files with Geant4 and Fluka simulation in the same tree structure



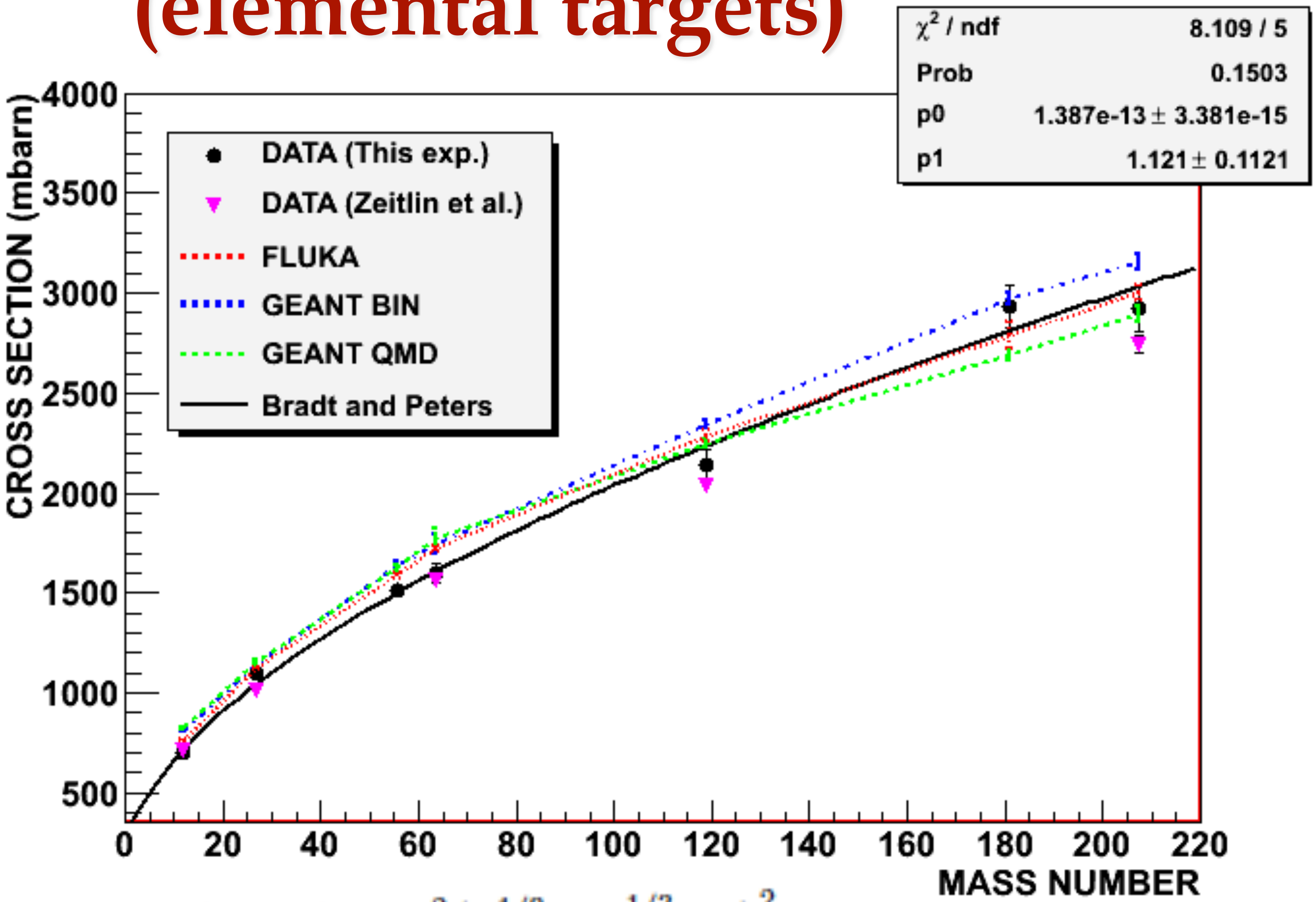
Total charge changing cross sections



Difference with experimental value



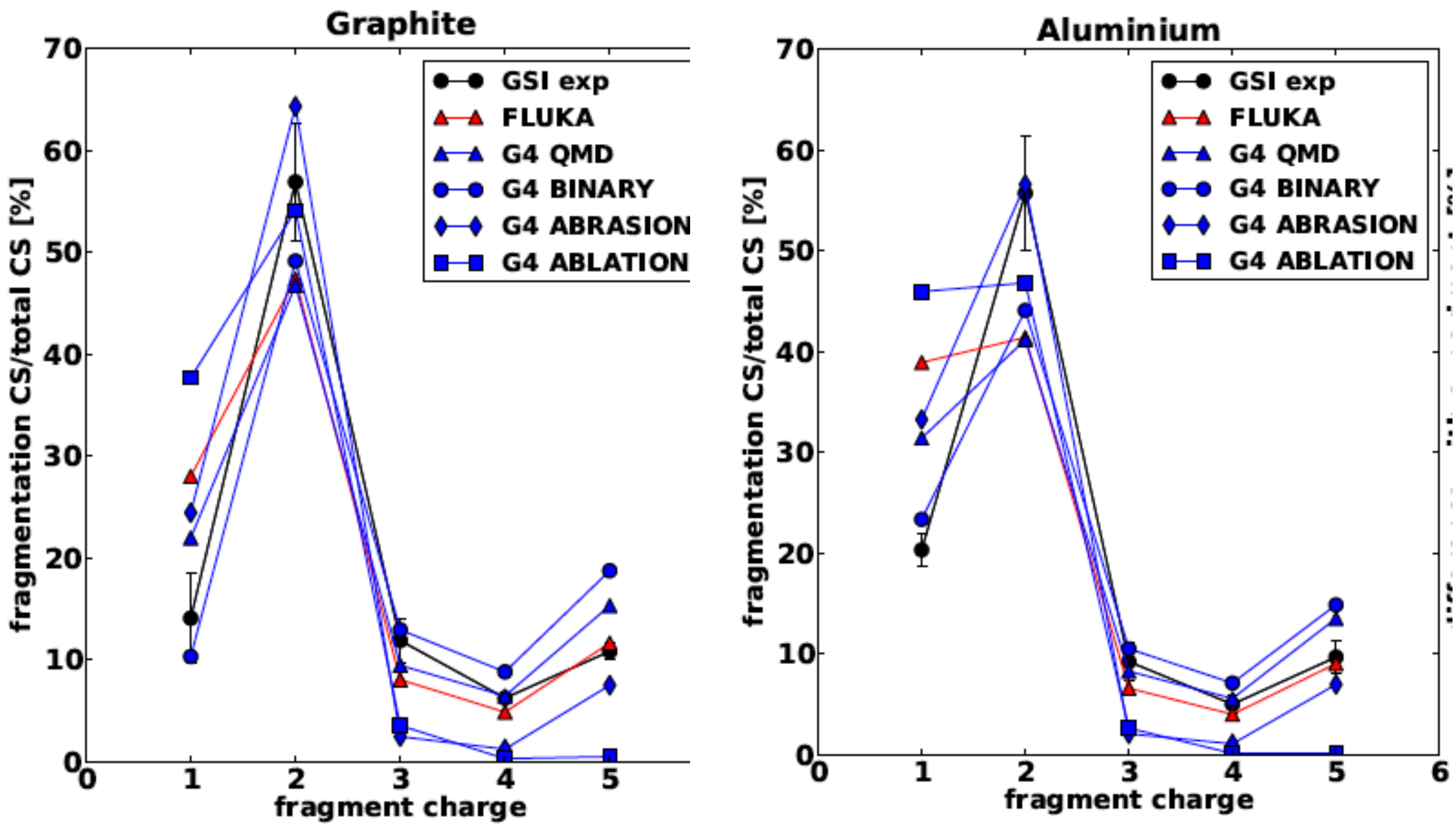
Total Cross Section (elemental targets)



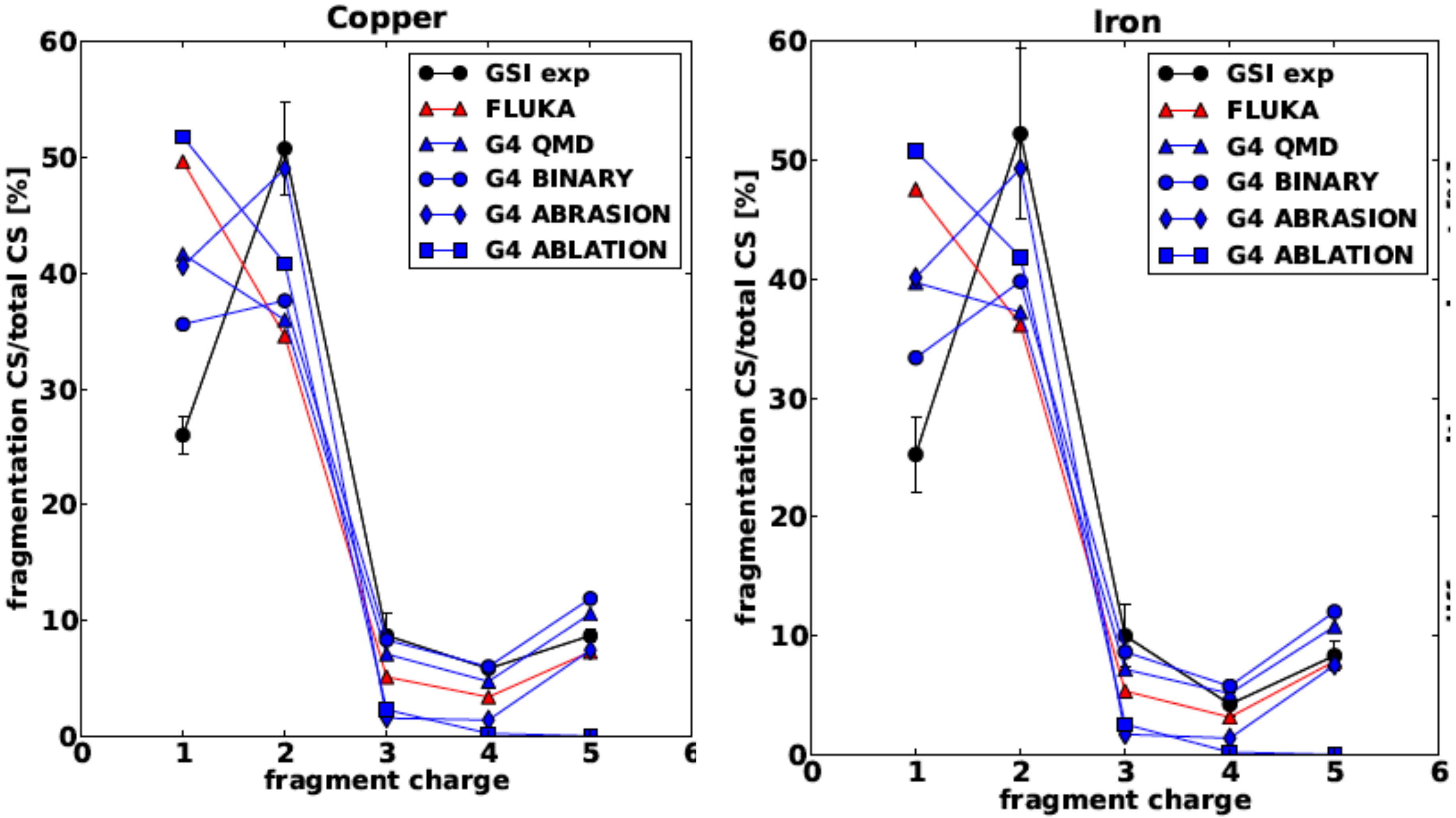
$$\sigma(A_p, A_t) = \pi r_0^2 (A_p^{1/3} + A_t^{1/3} - b)^2$$

Partial Fragments results

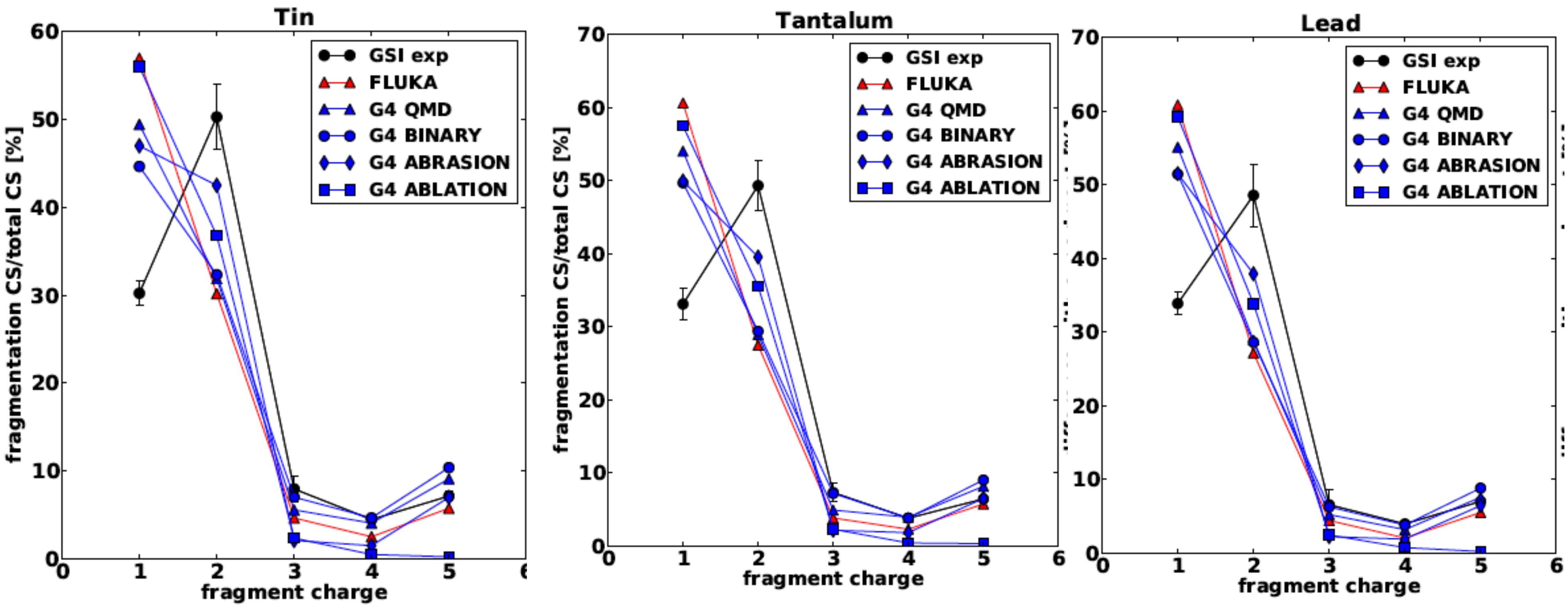
Partial Fragments



Partial Fragments

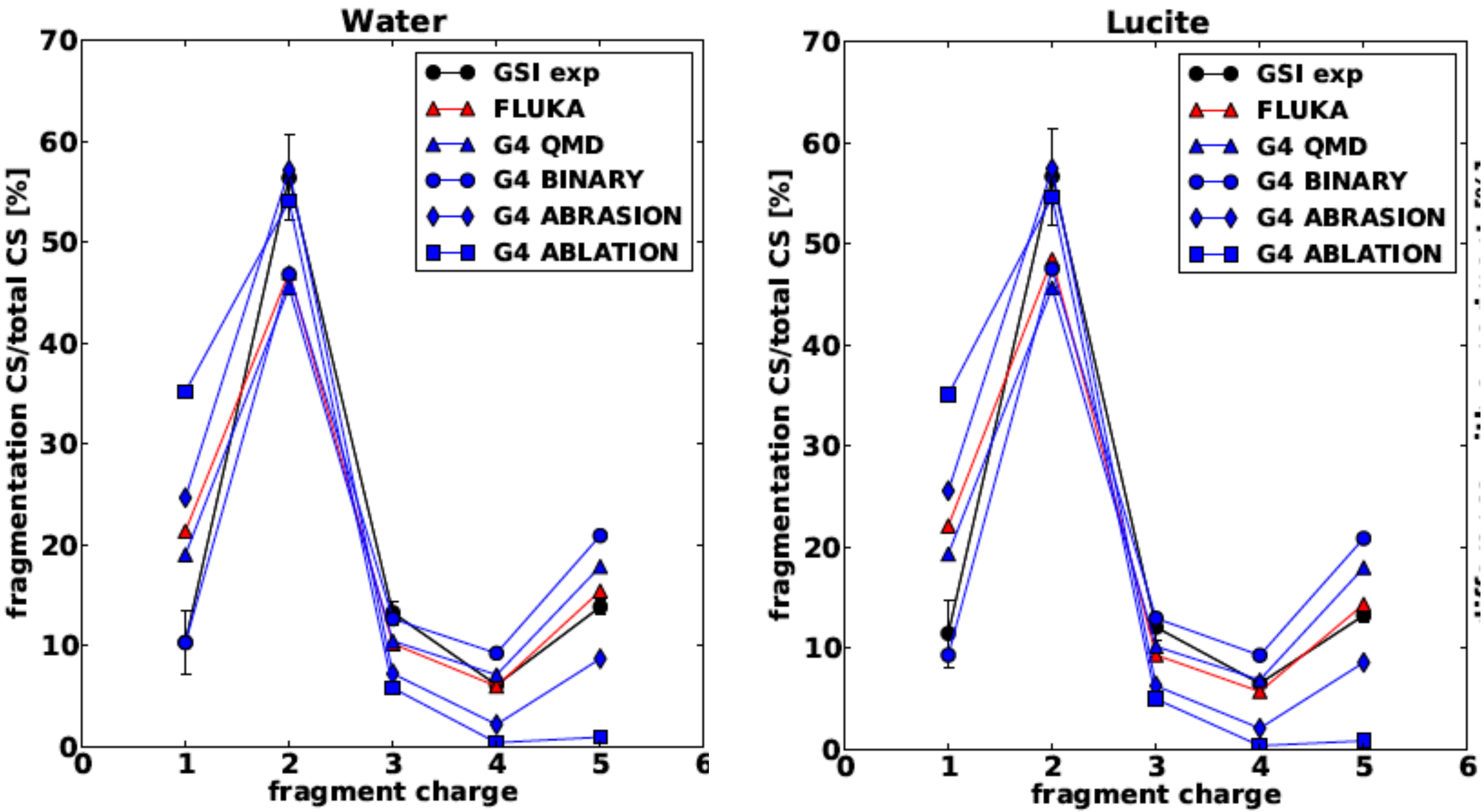


Partial Fragments

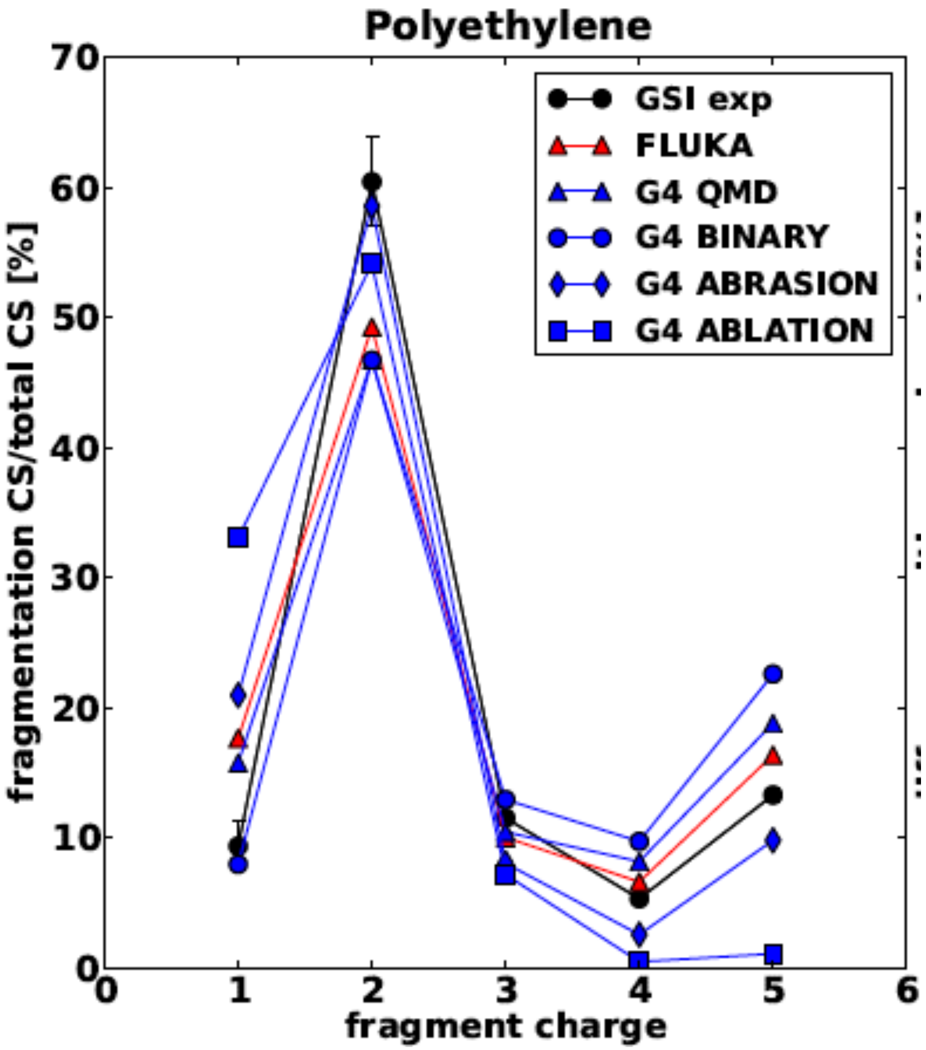


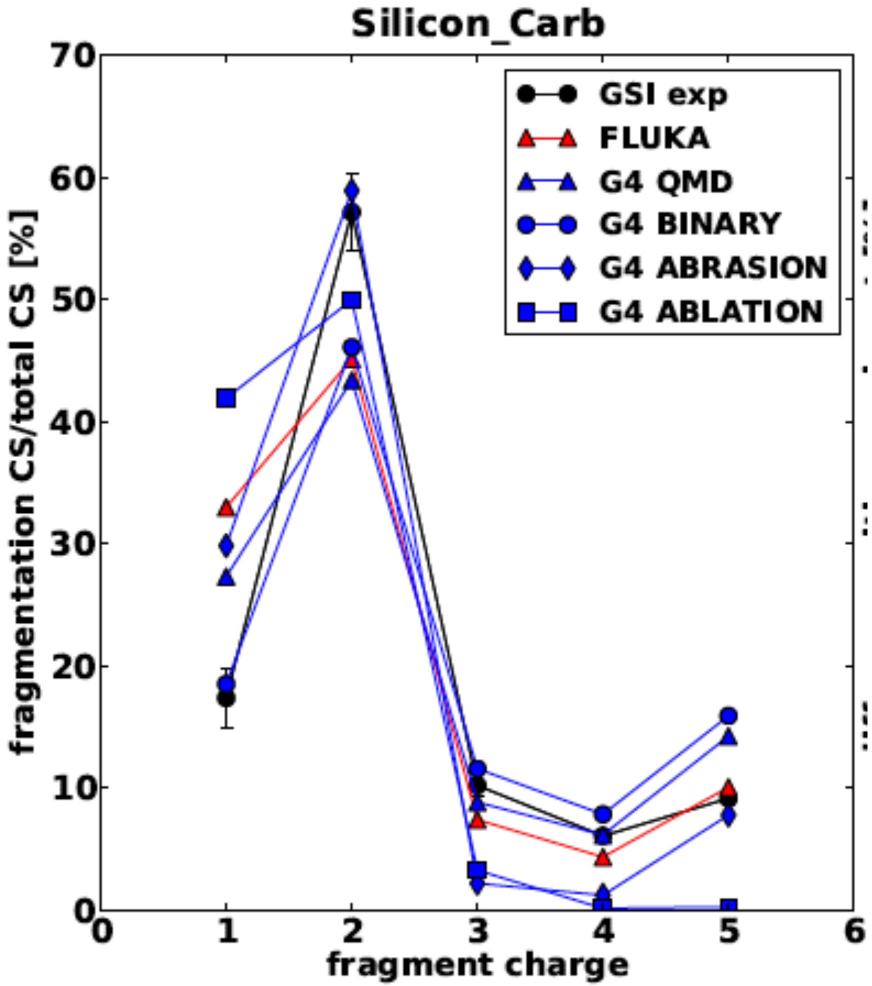
The discrepancy in light Z fragments increase in the cases of targets with high mass number

Partial Fragments



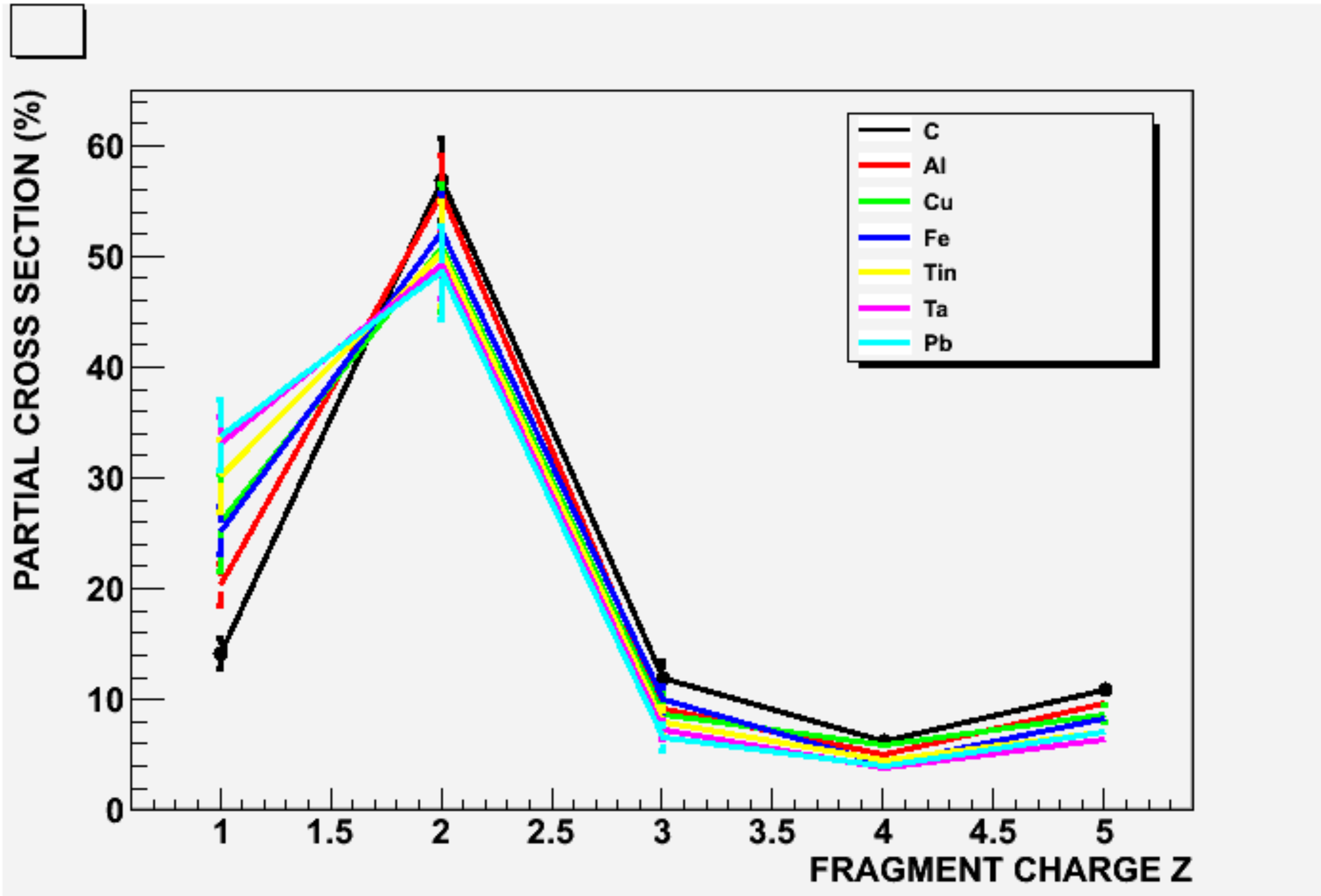
Partial Fragments



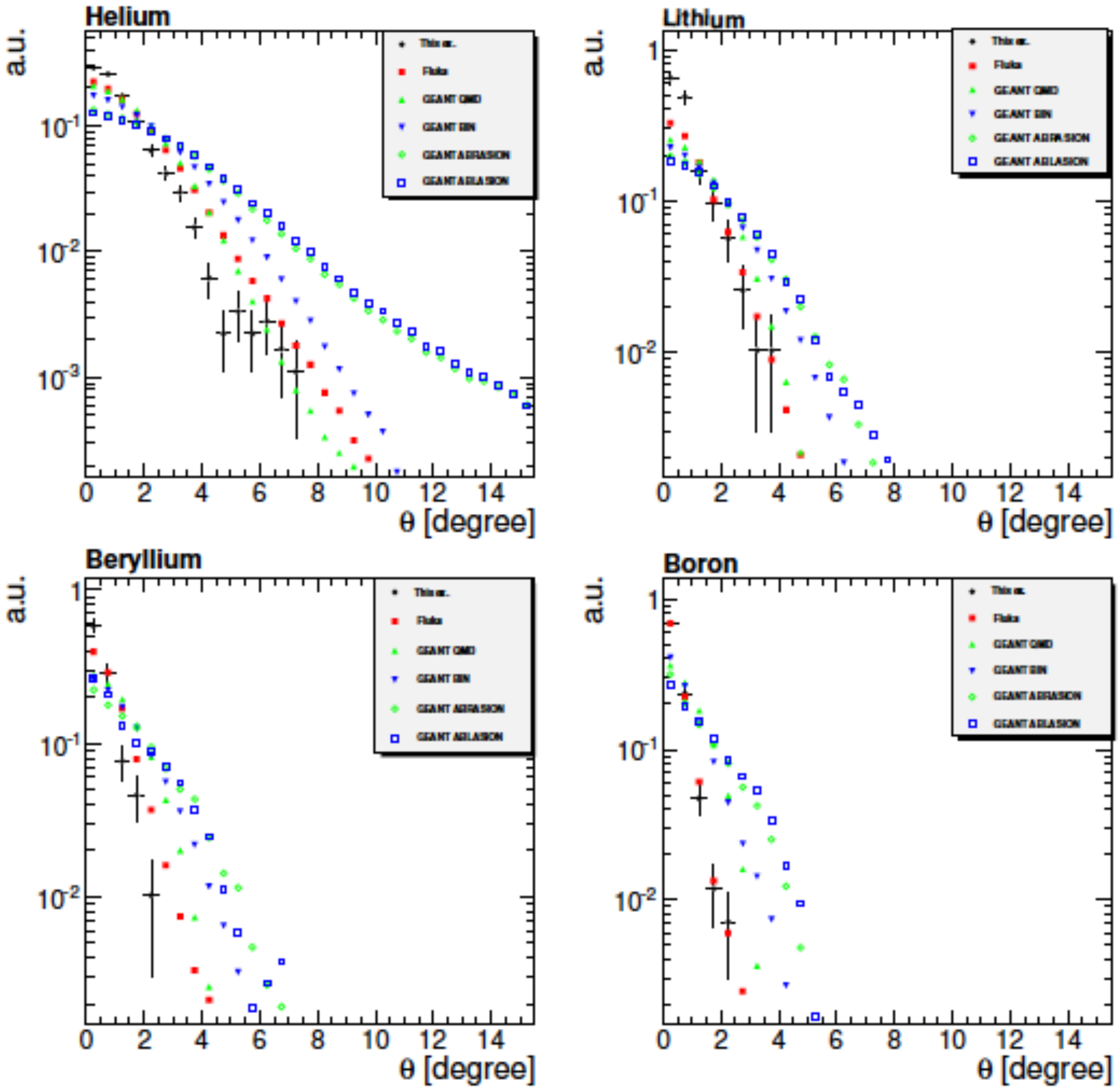


Partial Fragments

(Data summary elemental targets)



Angular distribution (Water)



Partial Fragments comparison with literature data

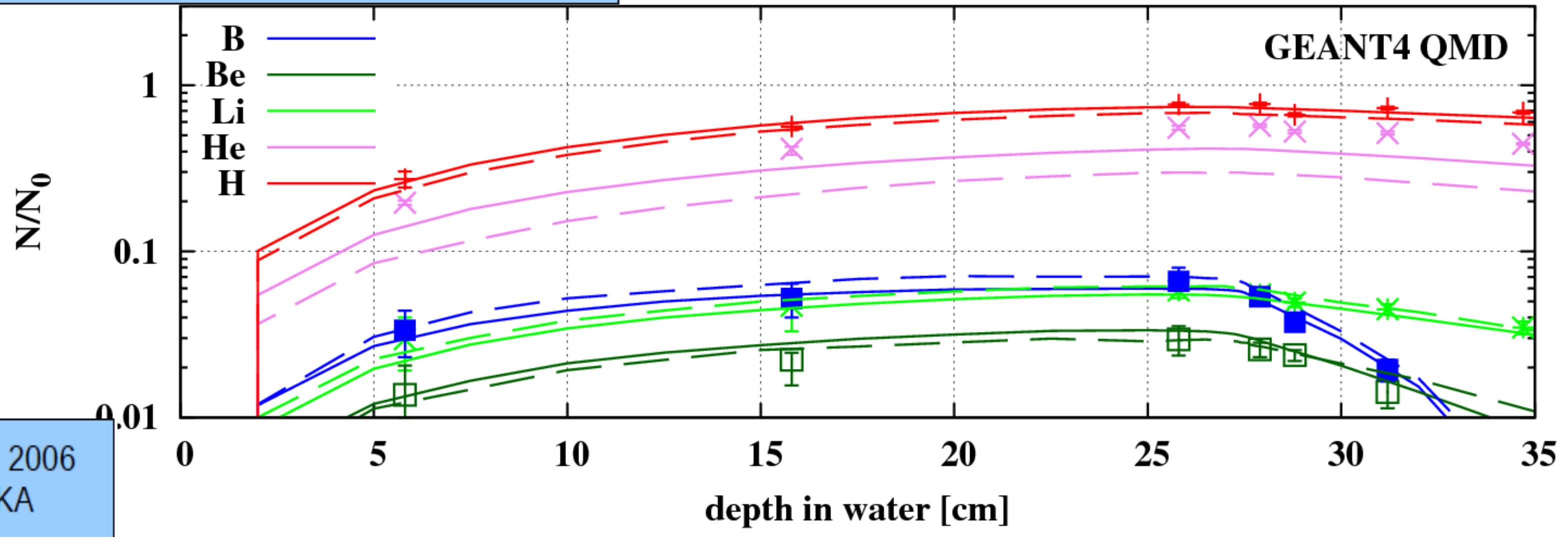
Experimental study on carbon ion fragmentation in water using GSI therapy beams

Emma Haettner

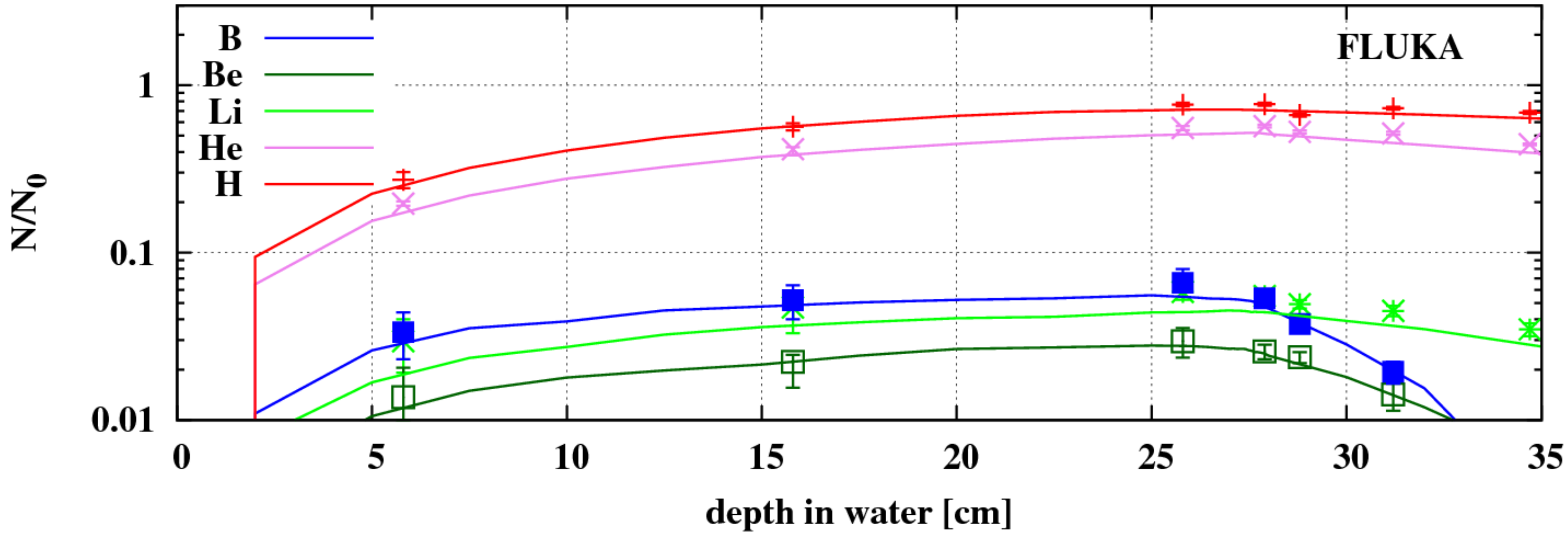
April 2006

Master of Science Thesis

Points: Haettner 2006
Dashed lines: Geant4
Solid lines: G4 with Fermi Break-Up and MultiFrag



Points: Haettner 2006
Solid lines: FLUKA



Carbon on Water data

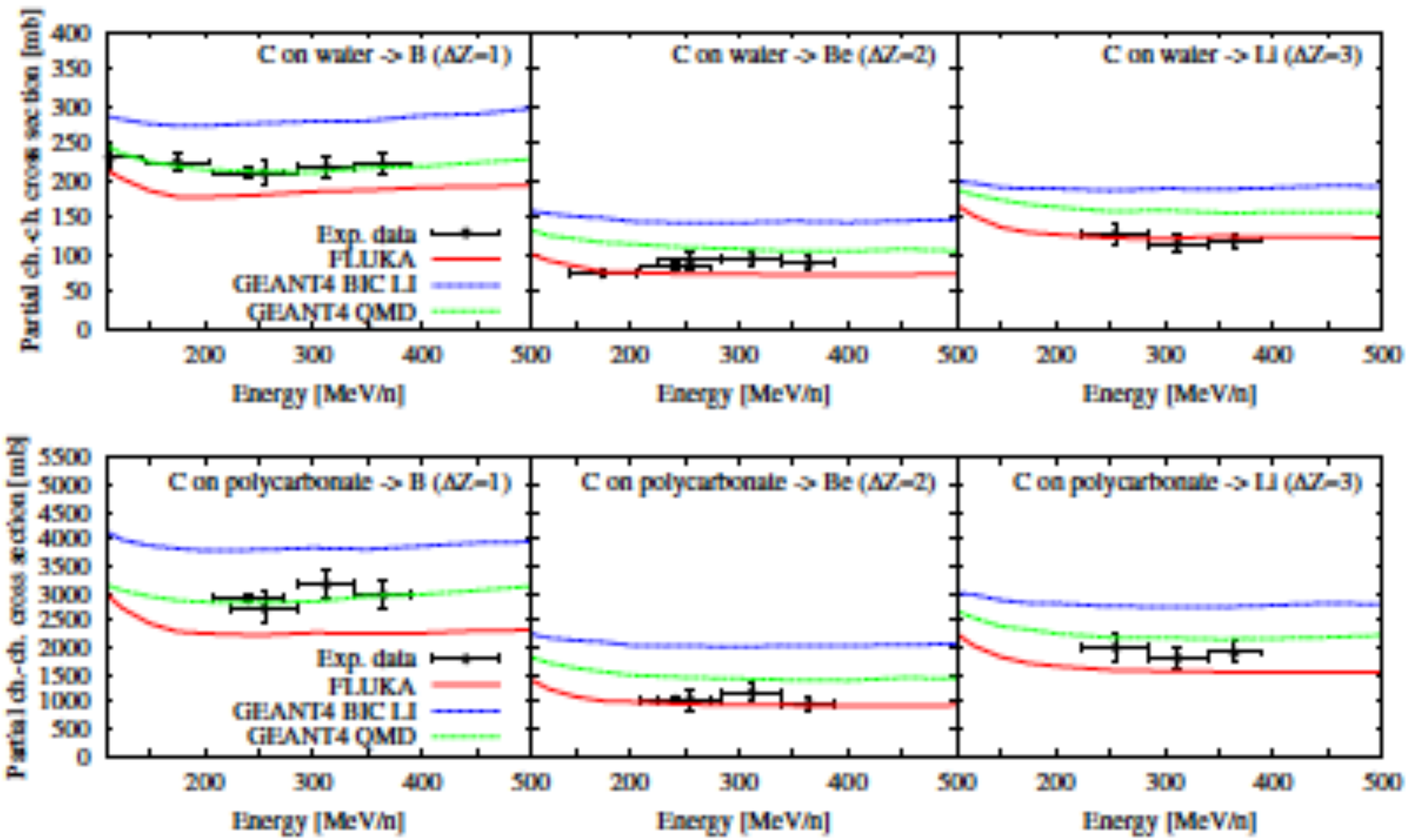
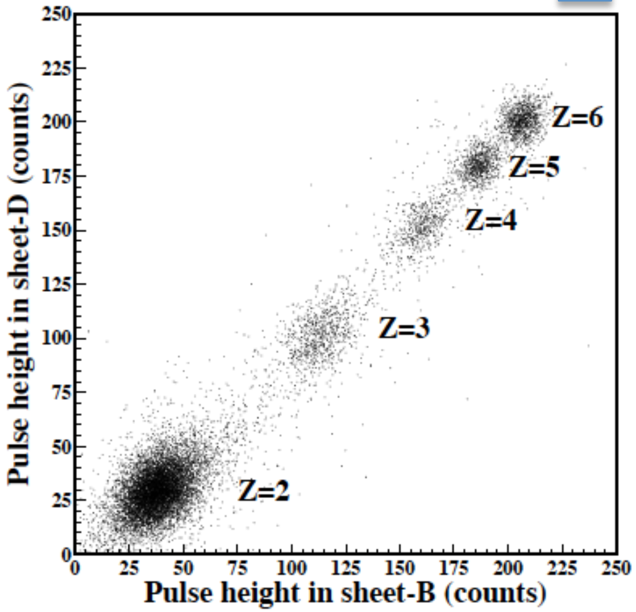


Figure 3. Partial charge-changing cross-sections for carbon ions interacting with water and with polycarbonate ($C_{16}H_{14}O_3$) for charge differences of $\Delta Z = 1, 2, 3$. Vertical error bars indicate the statistical error of the experimental data (Golovchenko *et al* 2002, Toshito *et al* 2007).

Carbon on Water



DZ	E(Mev/n)	Σ (mbarn)	Ref
1	364	221±14	Toshito et al.
	312	218±15	Toshito et al.
	255	210±18	Toshito et al.
1	200	232±21	Golovchenko et al.
1	500	168±8	This work
1	670	215±6	Schall et al.

Carbon on Water

DZ	E(Mev/n)	Σ (mbarn)	Ref.
2	364	89±9	Toshito et al.
	312	95±10	Toshito et al.
	255	93±11	Toshito et al.
2	200	115±18	Golovchenko et al.
	500	74±4	This work

DZ	E(Mev/n)	Σ (mbarn)	Ref
3	364	120±10	Toshito et al.
	312	115±11	Toshito et al.
	255	128±13	Toshito et al.
3	200	182±19	Golovchenko et al.
3	500	161±24	This work

Carbon on Lucite

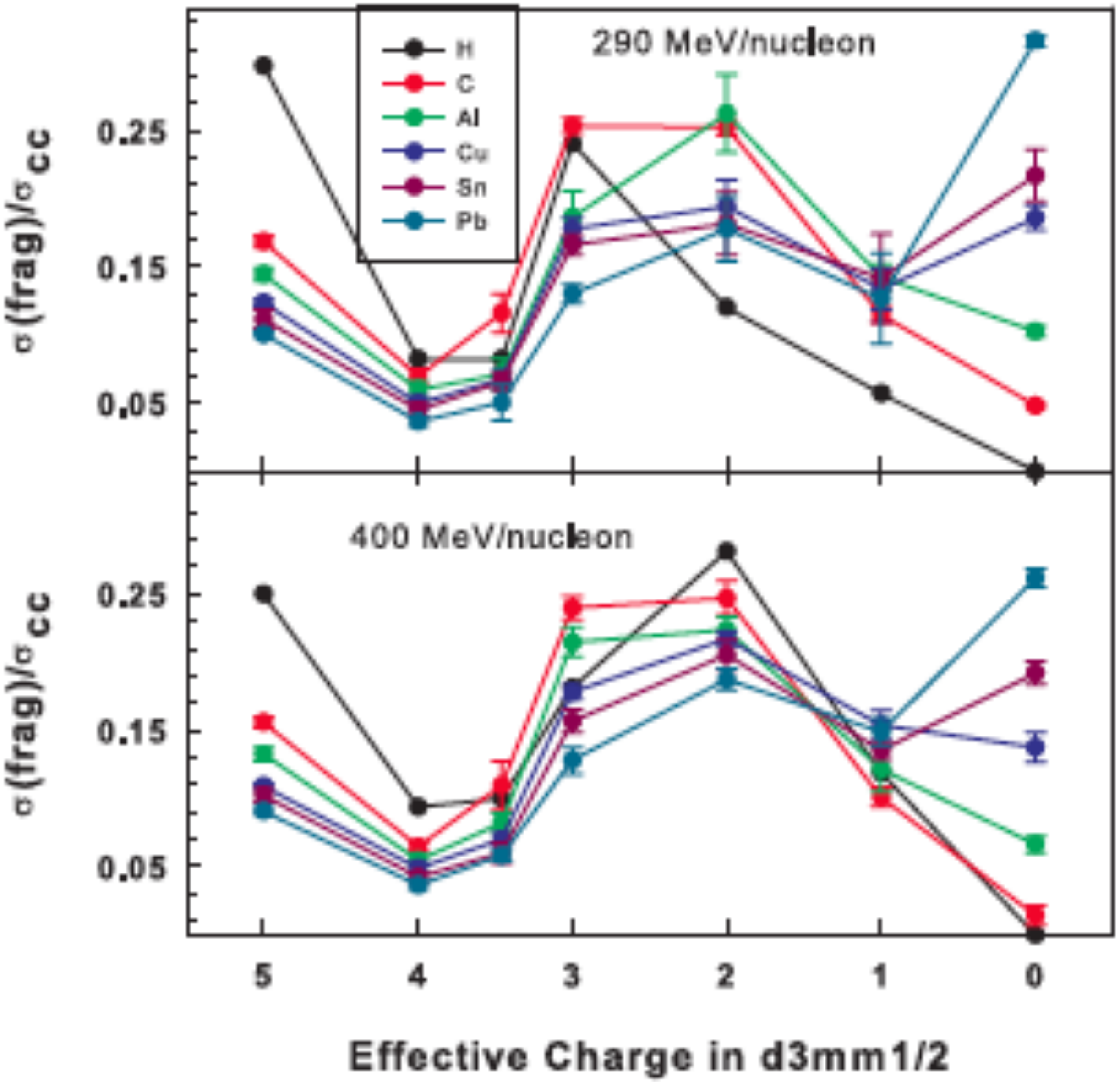
DZ	E(Mev/n)	Σ (mbarn)	Ref	E(Mev/n)	Σ (mbar)	Ref
1	225	1037±88	Golovchenko et al.	500	934±36	This work
	216	1159±74	Golovchenko et al.			
	201	1277±248	Golovchenko et al.			
2	200	462±41	Golovchenko et al.	500	460±24	This work
3	200	602±51	Golovchenko et al.	500	852±141	This work

Title:

Fragmentation Cross Sections of 290 and 400 MeV/nucleon 12C Beams on Elemental Targets

Author:

Zeitlin, C.
Guetersloh, S.
Heilbronn, L.
Miller, J.
Fukumura, A.
Iwata, Y.
Murakami, T.



Conclusions

- Measured total and partial cross-section of Carbon 500 MeV/n on Graphite, Aluminium, Iron, Copper, Tin, Tantalum, Lead, Water, Polyethylene, Lucite, Silicon Carbide
- In most of cases several thickness and setup configuration are considered in order to properly evaluate systematic
- Comparison with simulation give a good agreement (within 5%) on total CS with Geant and Fluka
- Comparison of partial CS with the simulation give a reasonable agreement also for charge changing process $\Delta Z=1$, $\Delta Z=2$, $\Delta Z=3$
- Disagreement in charge changing processes $\Delta Z=4$, $\Delta Z=5$, the disagreement increase for heavy target