FIRST Meeting 21-22/11 2013

ToF-Wall calibration check

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Overview

What are we studying?

In order to check the validity of ToF-Wall calibration we started a study on ^{12}C.
We examined, using production runs:

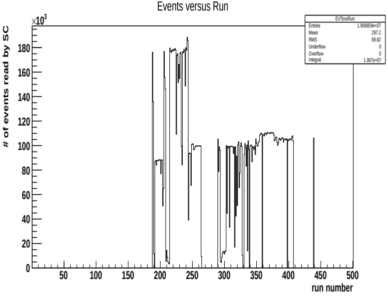
- the statistic of ^{12}C impinging on the Target;
- the statistic of non interacting ^{12}C;
- the statistic of ^{12}C scattered at small angles by single Coulomb scattering and multiple scattering and their angular distribution on ToF-Wall.

Moreover, we also considered the statistic of fragmented events.

^{12}C impinging on the Target

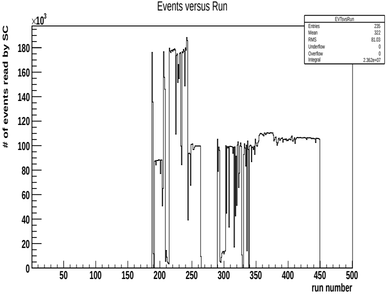
- Selection of events: SC trigger only
  - if $(!(trraw\_hit->Pattern()\&0x1))$ continue;
    // 0x1 masks pattern bits except SC

- v 60; runs 188-264,290-407,449



N of events from SC $= 19.07 * 10^6$

- v 62; runs 188-264, 290-449

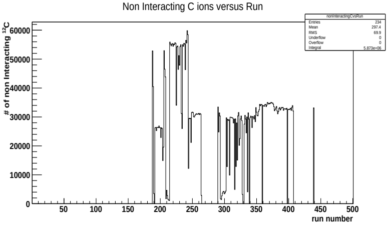


N of events from SC $= 23.62 * 10^6$

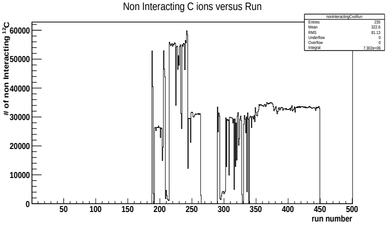
Non Interacting – Transmitted ^{12}C

- Selection of events:
  - considering events with SC trigger only;
  - selecting exclusively carbon hits with Samuel's Zid;
  - only 1 carbon hit in slats 152-153-154 in the RW;
  - no hit in the FW

- v 60; runs 188-264,290-407,449



- v 62; runs 188-264, 290-449



N of transmitted $^{12}C = 5.9 * 10^6$:36% of the total

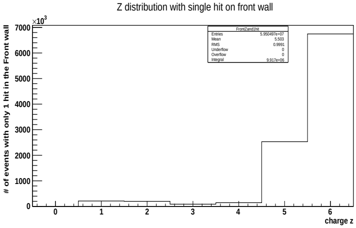
N of transmitted $^{12}C = 7.3 * 10^6$:32% of the total

Too few (beam width is ≈1.25 cm and the transmitted beam should pass entirely in the Front-Wall hole):
expected $> 95\%$ of the total

Scattered ^{12}C

- Selection of events:
  - considering events with SC trigger only;
  - selecting hit charge with Samuel's Zid;
  - only 1 hit in the Front Wall;
- in a histogram we count the number of single hit events (FW only) for each Z; the event number for Z=6 is the number of scattered ^{12}C

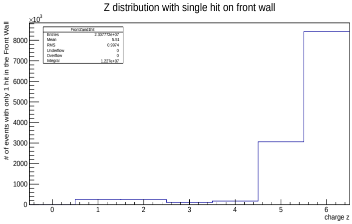
- v 60; runs 188-264,290-407,449



N of scattered $^{12}C = 6.7 * 10^6$

^{12}C is the dominant component

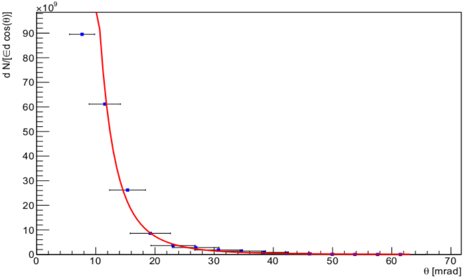
- v 62; runs 188-264, 290-449



N of scattered $^{12}C = 8.422 * 10^6$

Theoretical previsions and experimental results

Distribution of ^{12}C over the solid angle Ω with error evaluation



Comparison with Rutherford model (red line):

- θ_{min}=5.8 mrad; $\theta_{max} = \pi$
- very low angles: Multiple Scattering (MS)
- larger angles: Single Coulomb Scattering (SCS)

Rutherford cross section:

$$\sigma_R = \int_{4\pi} \frac{d\sigma}{d\Omega} d\Omega = \int_{4\pi} d\Omega \left(\frac{Z_p Z_t e^2}{8\pi\epsilon_0 m v_0^2}\right)^2 \frac{1}{sin(\theta/2)^4} = 151\ mb$$

Expected percentage of SCS (Rutherford) ^{12}C:

$\frac{I_R}{I_{SC}} = \frac{\sigma_R}{\sigma_R+\sigma_F}\left(1 - e^{-\frac{\rho N_A}{A}(\sigma_R+\sigma_F)w}\right)$ with w=0.8 mm: target thickness

- σ_F: fragmentation cross section not known; assumed as 0
- $\frac{I_R}{I_{SC}} = 1.34\%$ if $\rho = 2.1\ g/cm^3$; $\frac{I_R}{I_{SC}} = 2.7\%$ if $\rho = 4.5\ g/cm^3$
- different from the experimental value: $\frac{I_R}{I_{SC}} = 53\%$

Clue: Multiple Scattering?

At small angles

- mean deflection angle for MS: $< \theta_{MS} >= 2.24\ mrad$
- MS contributes with a Gaussian to the ^{12}C distribution and broadens the incident beam (decreases transmitted beam).
  Calculations to evaluate the beam spread are in progress.
- the MS contribution (to be evaluated) has to be subtracted from SCS counts.

A picture of hit configurations on TW

In order to understand the configurations of hits on ToF-Wall, we define for each event a string:

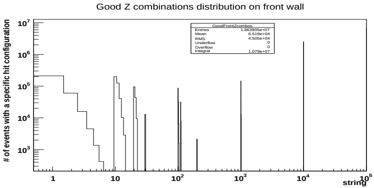
# C	# B	# Be	# Li	# He	# H
# 10^5	# 10^4	# 10^3	# 10^2	# 10^1	# 10^0

- e.g. (001001) means 1 Be & 1 H; (000020) means 2 He
- for each event, the string allows us to understand the configuration of hits on the ToF-Wall
- the string allows a maximum of 9 hit (enough) for each charge (z_f)
- we display all the configurations in 1D histograms:
  # of events with a specific hit configuration vs string
  distinguishing between
  - good configurations: $\Sigma z_f <= 6$;
  - bad configurations: $\Sigma z_f > 6$;

Fragmented Events in FW: good configurations

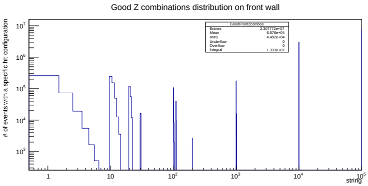
- Selection of events:
  - considering events with SC trigger only;
  - selecting hit charge with Samuel's Zid;
  - we consider the good configurations ($\Sigma z_f <= 6$) obtained with the strings
- The counts of fragmented events come from the total integral of the good configuration histogram, excluding C events.

- version 60; production runs 188-264, 290-407, 449



N of fragmented events $= 4.04 * 10^6$

- version 62; production runs 188-264, 290-449



N of fragmented events $= 4.9 * 10^6$

Fragmented Events in FW v 62: good configurations ZOOM

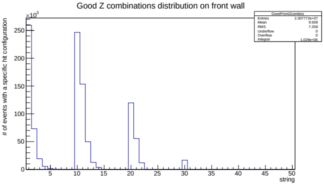


Figure: Hit configurations for H & He

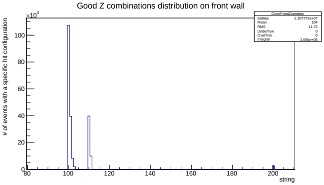


Figure: Hit configurations for Li

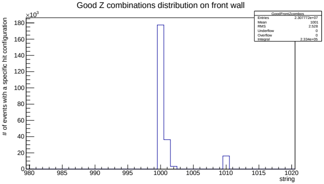


Figure: Hit configurations for Be

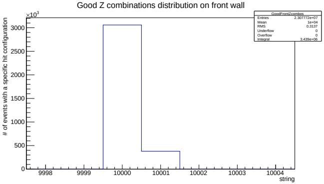


Figure: Hit configurations for Boron

Bad configurations in FW v 62

- We noticed a number of bad cases in which $\Sigma z_f > 6$.

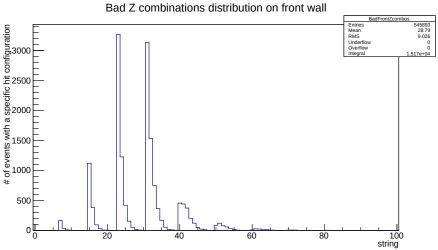


Figure: Hit configurations for H & He

Bad configurations in FW v 62

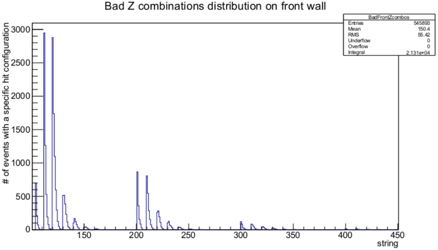


Figure: Hit configurations for Li

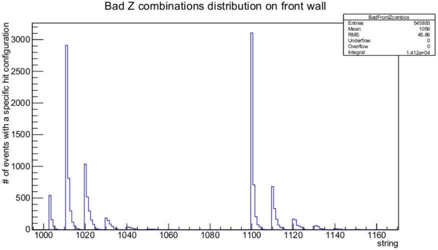


Figure: Hit configurations for Be

Bad configurations in FW v 62

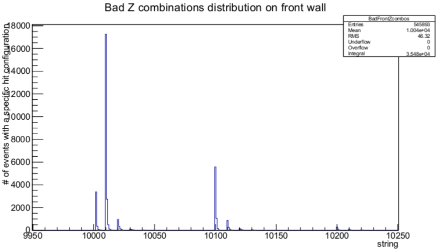


Figure: Hit configurations for B

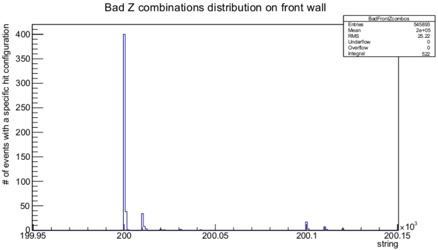


Figure: Hit configurations for C

The counts of bad events come from the total integral of the bad configuration histogram.

We counted: N of bad events $= 0.54 * 10^6$

Bad event number is more than two orders of magnitude smaller then the total number of events from SC

Number of fragmented events at large angles (not in TW)

In the good configuration histogram for FW, the column of string (0,0,0,0,0,0) was present:

v 60
we counted: N of (0,0,0,0,0,0) events $= 7.8 * 10^6$

v 62
we counted: N of (0,0,0,0,0,0) events $= 9.7 * 10^6$

This column represents those events that don't fall onto the FW i.e.:

- non interacting ^{12}C;
- fragments at large angles (not in TW) or in bad slats

Subtracting the non interacting ^{12}C number to the number of events that don't fall onto the FW,
the number of fragmented events at large angles can be obtained:

v 60
we counted: N of large angle fragmented events $= 1.9 * 10^6$

v 62
we counted: N of large angle fragmented events $= 2.4 * 10^6$

Summarizing:

v 60

Event Type	Counts (10^6)
not interacting C	5.9
S.C.S.	6.7 F
FRAGMENTATION	4.04 F
BAD	0.4 F
N of events not on F: large angle Fragments	1.9
Event from SC	19

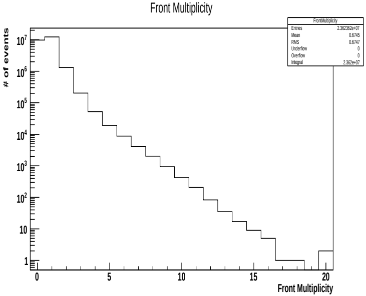
v 62

Event Type	Counts (10^6)
not interacting C	7.3
S.C.S.	8.4 F
FRAGMENTATION	4.9 F
BAD	0.54 F
N of events not on F: large angle Fragments	2.4
Event from SC	23.6

Hit Multiplicity on FW v62

Considering the hit multiplicity on the Front Wall:

Events with number of hit:	Counts (10^6)
0	9.7
1	12
2	1.1
3	0.19
4	0.04
>4	0.035



- Sum of events with number of hit $>0 = 13.36 * 10^6$;
  - if we subtract the number of scattered ^{12}C: $8.42 * 10^6$;
  - we obtain $4.94 * 10^6 \approx$ number of fragmented events.

Counts and energies on FW

To understand better what happens in the ToF-Wall
(i.e. the configurations of hits on ToF-Wall),
we also performed a study on:

- counts of scattered ^{12}C;
- counts of fragments under particular constraints;
- kinetic energies (calculated starting from the hit energy loss) of scattered ^{12}C and fragments.

Single hit event analysis on FW: counts

We started analyzing the multiplicity of events with a single hit in the Front Wall:
for each hit we read the assigned hit charge Z from 1 to 6 and we counted the frequency for each Z.

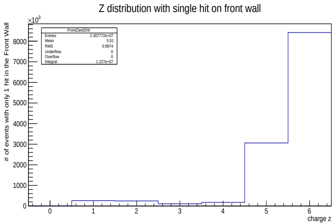


Figure: Z multiplicity distribution for events with single hit in Front Wall

Z	Multiplicity (10^6)
1	0.259
2	0.246
3	0.107
4	0.18
5	3
6	8

- ^{12}C is dominant (SCS and multiple scattering)
- ^{11}B dominant fragment in the forward direction
  - ^{11}B number (as for the other fragments) can also be higher because here we see only 1 hit events

Single hit event analysis on FW: kinetic energies

We calculated the initial kinetic energy for each hit.

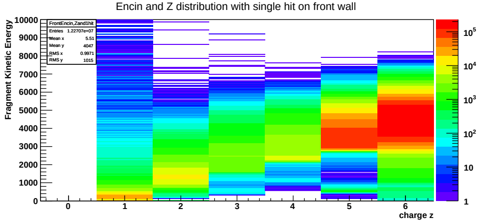


Figure: Kinetic Energy vs Z

Isotopes	Equivalent Ek (MeV)	Ek Peak (MeV)	Ekmin (MeV)	Ekmax (MeV)	Expected Ekin (MeV)	Counts (10^6)
1H		220	40	950	1183	0.259
2H	1183					
3H	1182					
3He	2980					
4He		1310	450	2540	1600	0.246
5Li	2705					
6Li	2400					
7Li		2490	1580	3600	2140	0.107
7Be	1260					
8Be	3200					
9Be		2340	2145	4850	2936	0.18
9B	4300					
10B	4000					
11B		3100	2800	5400	3730	3
10C	5400					
11C	5100					
12C		4300	2600	6300	4800	8

$E_k < 4800 MeV$ at the peak, because hit number=1 and we miss the coupled fragment E_k

- For fragments: differences in loss of energy due to ionization, isotopes, approximations in E_k measurements, errors in Z id.
- For ^{12}C: differences in energy loss are due to the same phenomena of fragments with the Coulomb scattering addition.

Double hit event analysis on FW: counts

In a second step we analyzed those events with 2 hits in the Front Wall.
For each pair of hits, we identified the elements that form the couple.
Then we calculated the frequency of events in which one particle (Z1; impinging on the Front Wall) is a proton and the other (Z2) could be any (from Z=1 to Z=6).
We did the same for all the possible charges (Z1=2,3,4,5,6).

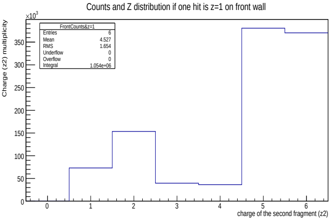


Figure: Charge (Z2) multiplicity distribution of the second fragment when 2 fragments are on FW and Z1=1

- total number of pairs (Z1=1, Z2=1,2,...,6) = $1.054 * 10^6$;
- 1 proton on Front Wall is mostly coupled to ^{11}B $(0.38 * 10^6)$ and ^4He $(0.15 * 10^6)$;
- a number $(0.37 * 10^6)$ of ^{12}C is coupled to 1 proton, due to:
  - wrong Z id;
  - proton can be spurious (^{12}C scattered beam).

Double hit event analysis on FW: kinetic energies sum $E_k(\text{hit1})+E_k(\text{hit2})$

We calculated the initial kinetic energy for each hit and the kinetic energy of the pair.

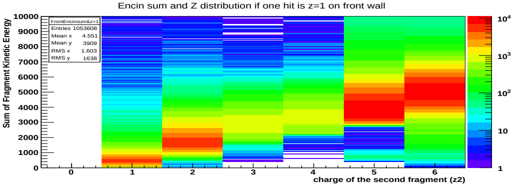


Figure: Sum of Ek vs Z2 for double hit events in FW with Z1=1

Considering Z1=1 and Z2=6: # of events $= 0.37 * 10^6$

- the kinetic energy sum of Z1&Z2 ranges between 3500 and 6700 with peak at 5100 MeV: higher than single ^{12}C;
- the spurious proton (for Z1=1) hypothesis implies that this ^{12}C is scattered beam: this energy sum is compatible with the energy ranges of single ^{12}C, with the addition of some energy assigned to the spurious p;
- it is also possible that the spurious proton is coupled with a C isotope: e.g. ^{11}C.

Double hit event analysis on FW: kinetic energies of the "second" fragment E_k(hit2)

We calculated the initial kinetic energy only for the "second" fragment.

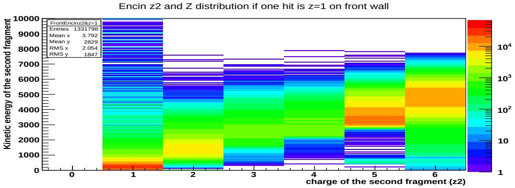


Figure: Ek of the "second" fragment vs Z2 for double hit events in FW with Z1=1

Considering Z1=1 and Z2=6:

- the kinetic energy of the "second" fragment (Z2) ranges between 3500 and 5800 with peak at 4800 MeV: similar to the expected one for single ^{12}C;
- the hypothesis of a spurious proton (for Z1=1) coupled with a ^{12}C or one of its isotopes e.g. ^{11}C can be confirmed; the statistic of this hit configuration (# of events $= 0.37 * 10^6$) has to be added to the scattered ^{12}C statistic.

Conclusions

After TW calibration, we can detect for each hit on TW:

- position (x,y): for tracking and multiplicity;
- ToF: for Z id, β calculations and energy evaluation x-check;
- energy loss: for energy evaluation and Z id.

General remarks, after a first insight on $23 * 10^6$ events:

a) $7.3 * 10^6$ ^{12}C ions impinging on the RW in slats 152-153-154: these are non interacting ^{12}C events;

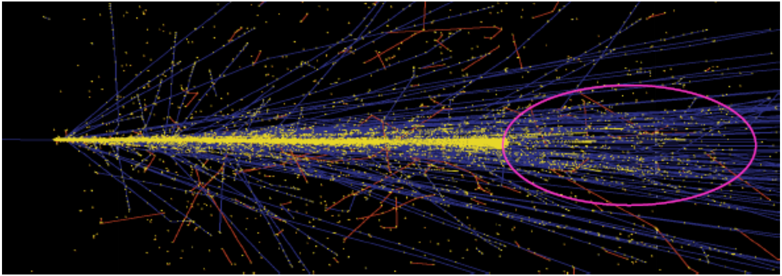
b) $8.4 * 10^6$ (single hit) ^{12}C ions impinging on FW (slats 37-68)
   - their distribution follows the Rutherford theoretical curve: σ_R: these are SCS ^{12}C event candidates;
   - at lower angles, their distribution is compatible with the MS distribution too: a raw evaluation of the mean deflection angle for MS is: $< \theta_{MS} >= 2.24\ mrad$, to be improved;
     - the MS contribution (to be evaluated) has to be subtracted from SCS counts: otherwise theoretical $\frac{I_R}{I_{SC}}$ doesn't agree with data

c) $4.9 * 10^6$ events contain more than 1 hit in FW: fragment candidates (energies are compatible with this hypothesis);

d) $2.4 * 10^6$ events are missing on FW: large-angle fragment candidates; expected to be seen in KENTROS and VERTEX.

THE END

Thanks for your attention



Fragmented Eventsin FW v 60: good configurations ZOOM

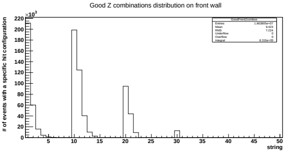


Figure: Hit configurations including Hydrogen and Helium

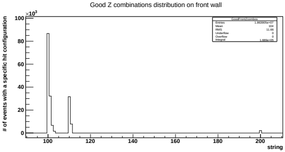


Figure: Hit configurations including Litium

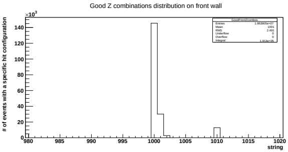


Figure: Hit configurations including Berillium

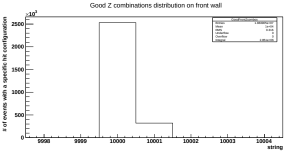


Figure: Hit configurations including Boron

Bad configurations in FW v 60

- We noticed a number of bad cases in which $\Sigma z_f > 6$.

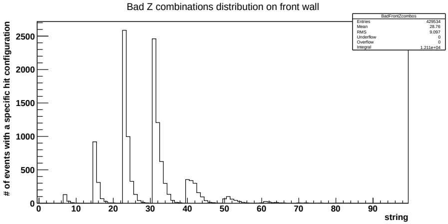


Figure: Hit configurations including Hydrogen and Helium

Bad configurations in FW v 60

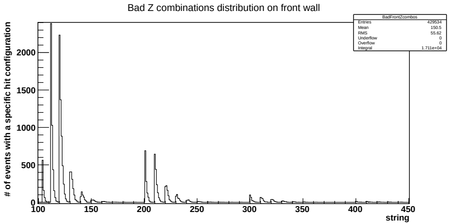


Figure: Hit configurations including Litium

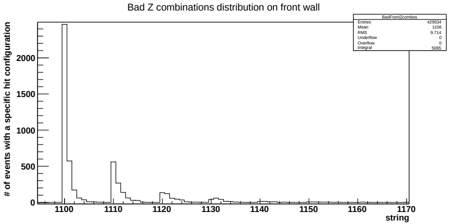


Figure: Hit configurations including Berillium

Bad configurations in FW v 60

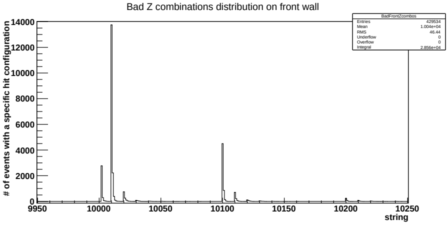


Figure: Hit configurations including Boron

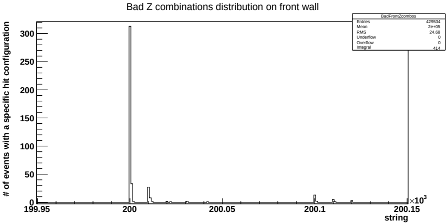


Figure: Hit configurations including Carbon

The counts of bad events come from the total integral of the bad configuration histogram.

We counted: N of bad events $= 0.4 * 10^6$

Summarizing:

- v 60
- v 62

Before SC: beam	SC	KENTROS VERTEX	TW F	TW R non central	TW R (152-153-154)	In Target	z	n fragments	Counts (10^6)
12C	yes	K no; V yes	no	no	yes	no interaction	6	0	5.9
12C	yes	K no; V yes	yes	yes	no	S.C.S.	6	0	6.7 F
12C	yes	K yes/no; V yes	yes /no	yes/no	no	FRAGMENTATION	Σzf <=6	nf	4.04 F
12C	yes	?	yes /no	yes/no	yes/no	BAD	Σzf >6	nf	0.4 F
N of events not on F	7.8*10^6	Includes: non interacting C and large angle fragments							
N of C from SC	19*10^6								

Before SC: beam	SC	KENTROS VERTEX	TW F	TW R non central	TW R (152-153-154)	In Target	z	n fragments	Counts (10^6)
12C	yes	K no; V yes	no	no	yes	no interaction	6	0	7.3
12C	yes	K no; V yes	yes	yes	no	S.C.S.	6	0	8.422 F
12C	yes	K yes/no; V yes	yes /no	yes/no	no	FRAGMENTATION	Σzf <=6	nf	4.9 F
12C	yes	?	yes /no	yes/no	yes/no	BAD	Σzf >6	nf	0.54 F
N of events not on F	9.7*10^6	Includes: non interacting C and large angle fragments							
N of C from SC	23.62* 10^6								