HIT Experiment

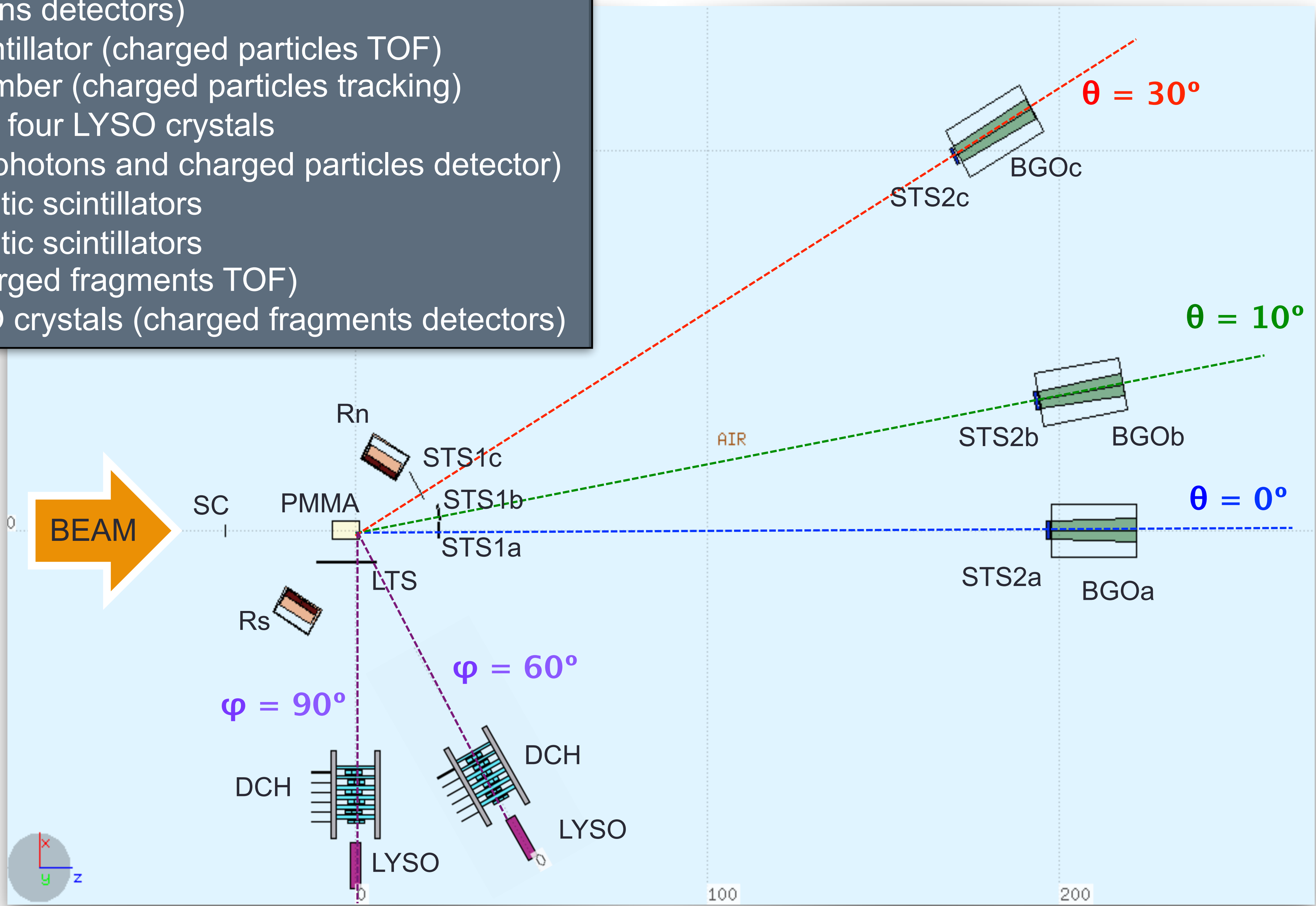
Report and Update on HIT Experiment Analysis

RDH Meeting

February, 1st 2016

Experimental Setup

SC = plastic scintillator; trigger for the DAQ
PMMA = phantom
Rn = 2 pixelated LYSO,side by side,1.6x5x5 cm^3 each
Rs = 2 pixelated LYSO,side by side,1.6x5x5 cm^3 each
(PET photons detectors)
LTS = plastic scintillator (charged particles TOF)
DCH = Drift Chamber (charged particles tracking)
LYSO = matrix of four LYSO crystals
(prompt photons and charged particles detector)
STS1a,b,c = plastic scintillators
STS2a,b,c = plastic scintillators
(charged fragments TOF)
BGOa,b,c = BGO crystals (charged fragments detectors)



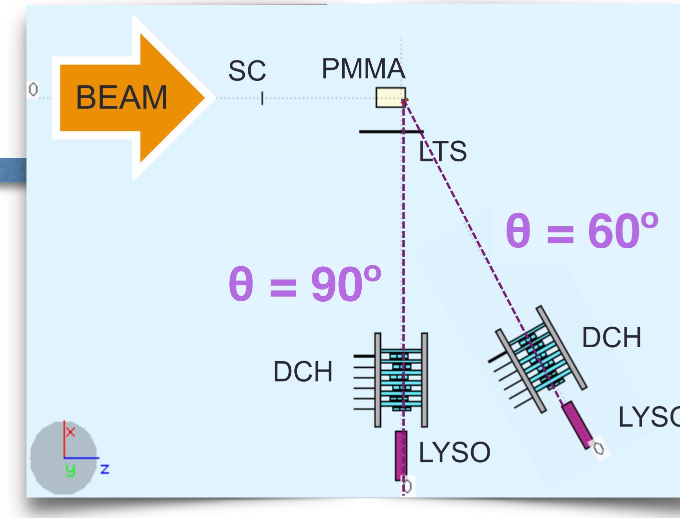
Data Taking Configurations

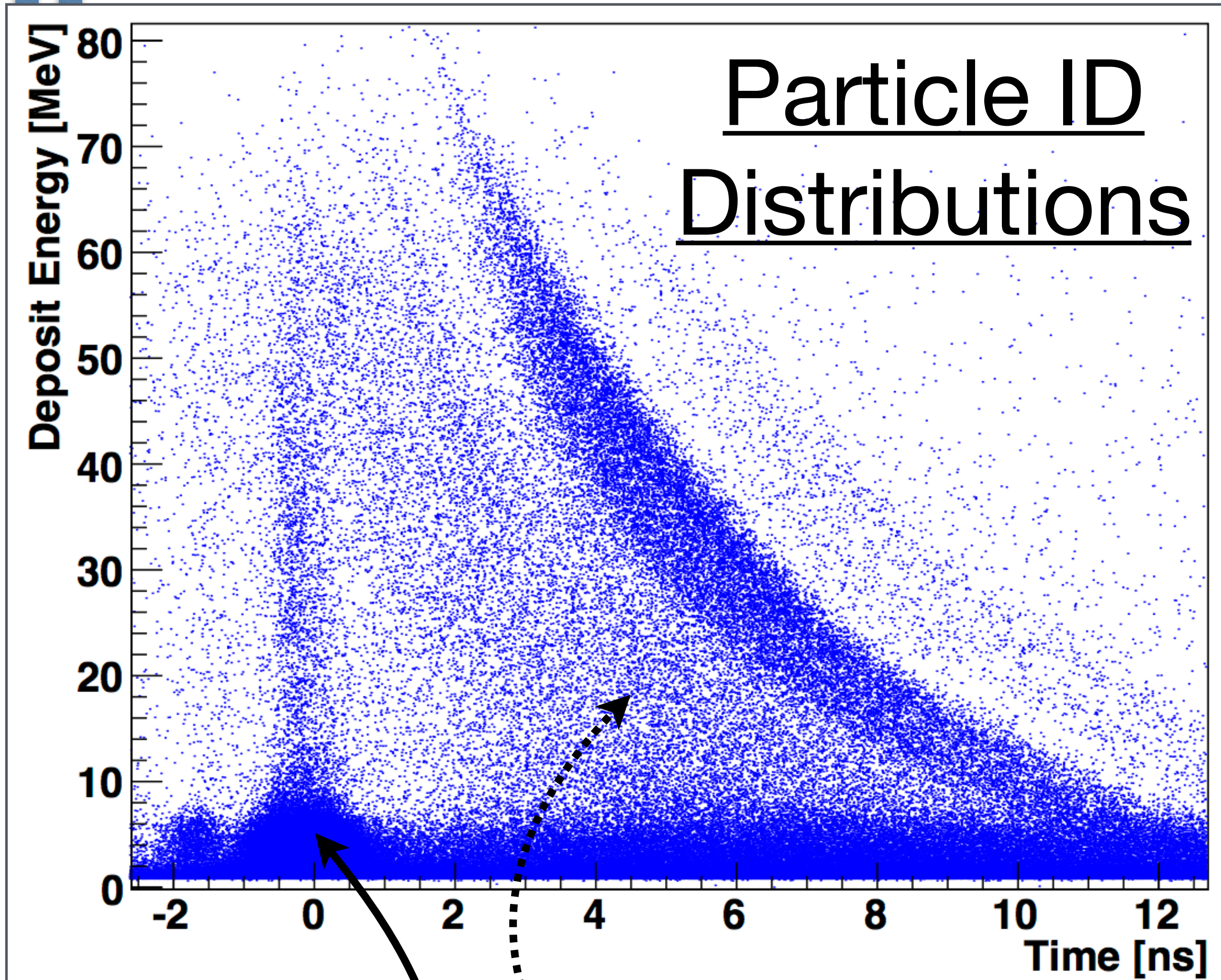
LYSO@90° BGO@0°,10°,30°	E_{beam} (MeV/u)	Range (cm)	zPMMA (cm)
^{4}He	102	6.0	7.65
^{4}He	125	8.5	10.0
^{4}He	145	11.0	12.65
^{12}C	120	2.9	10.0
^{12}C	160	4.9	10.0
^{12}C	180	6.0	10.0
^{12}C	220	8.5	10.0
^{16}O	210	6.0	7.65
^{16}O	260	8.5	10.0
^{16}O	300	11.0	12.65

LYSO@60° BGO@5°,15°,30°	E_{beam} (MeV/u)	Range (cm)	zPMMA (cm)
^{4}He	102	6.0	7.65
^{4}He	125	8.5	10.0
^{4}He	145	11.0	12.65
^{16}O	210	6.0	7.65
^{16}O	260	8.5	10.0
^{16}O	300	11.0	12.65

Prompt Photon

Paper in preparation: prompt Yield at production for He, C and O ion beams





γ

charged and neutrons

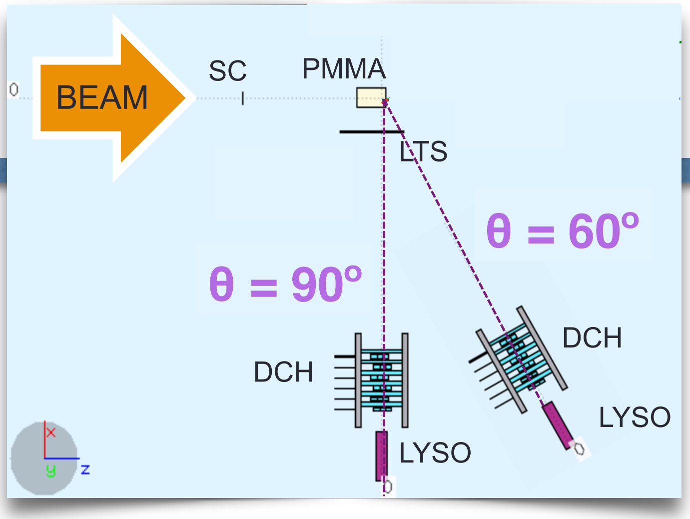
Yield at Production Measurement Φ_γ

θ	Ion	Energy (MeV/u)	Φ_γ ($10^{-3}\ sr^{-1}$)	σ_{stat} ($10^{-3}\ sr^{-1}$)	σ_{sys} ($10^{-3}\ sr^{-1}$)
90°	^{4}He	125	5.34	0.06	0.17
		145	6.53	0.07	0.17
	^{12}C	120	4.57	0.09	0.10
		160	7.66	0.13	0.10
		180	9.80	0.18	0.10
		220	12.22	0.22	0.11
	^{16}O	210	12.65	0.12	0.38
		260	16.83	0.20	0.54
		300	22.10	0.15	0.77
60°	^{4}He	102	3.70	0.08	0.11
		125	4.67	0.07	0.23
		145	6.40	0.08	0.14
	^{16}O	210	12.44	0.13	0.41
		260	17.04	0.19	0.59
		300	21.32	0.19	1.03

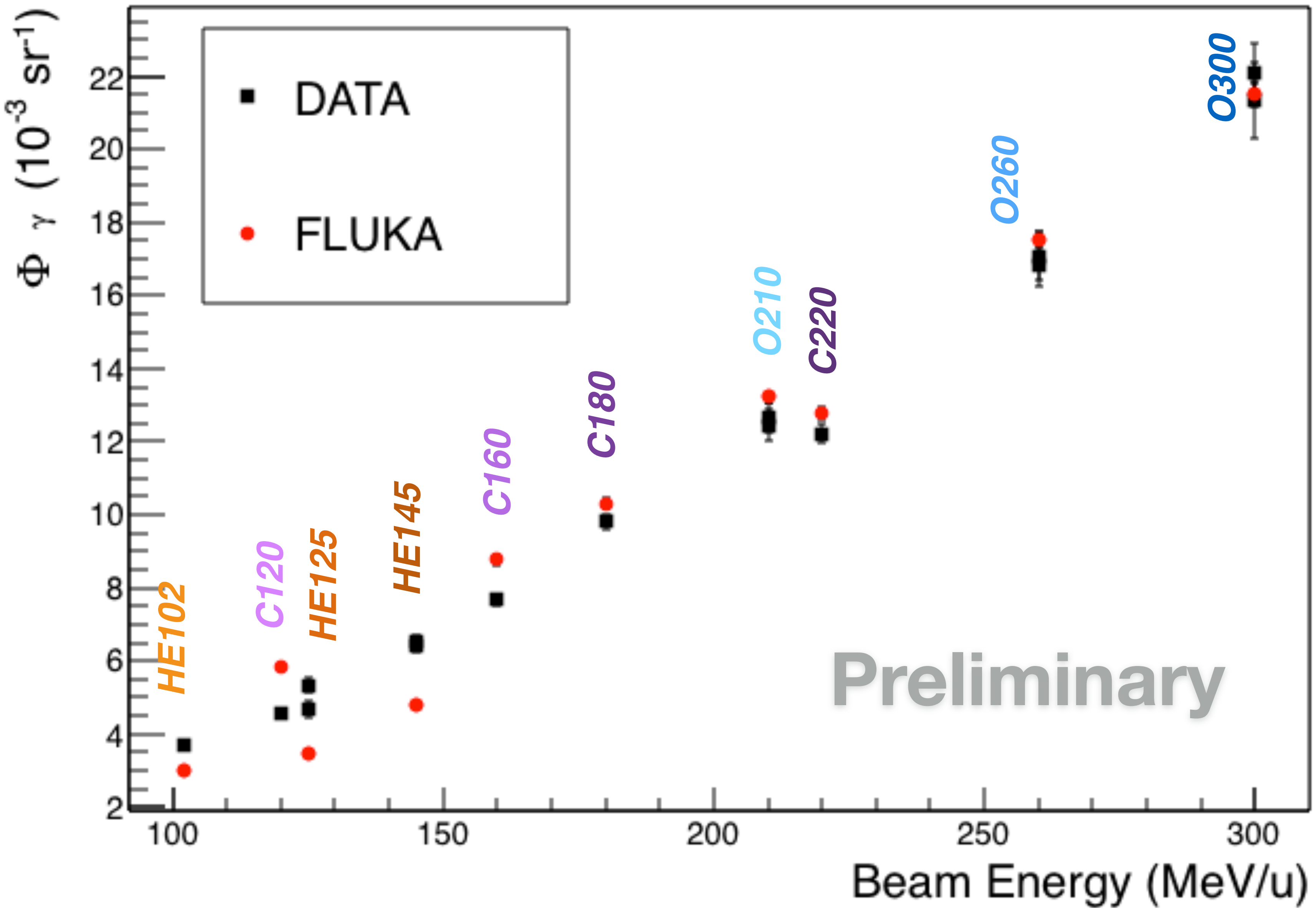
Preliminary

Prompt Photon

Paper in preparation:
prompt Yield at production
for He, C and O ion beams



Yield (at production) ϕ_γ Comparison:

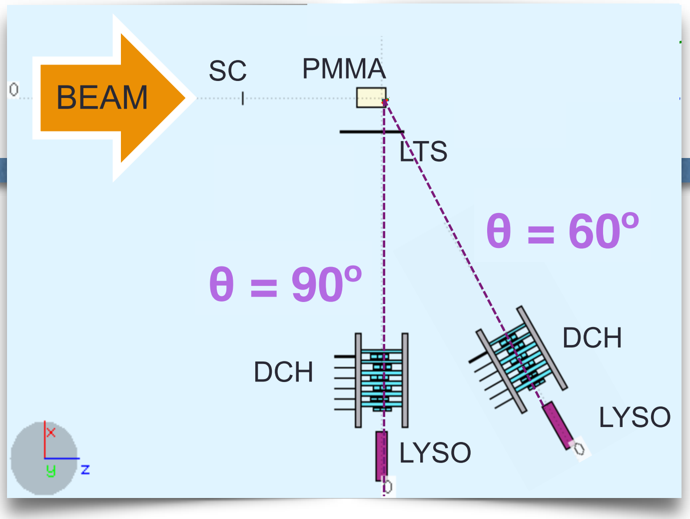


DATA - MC

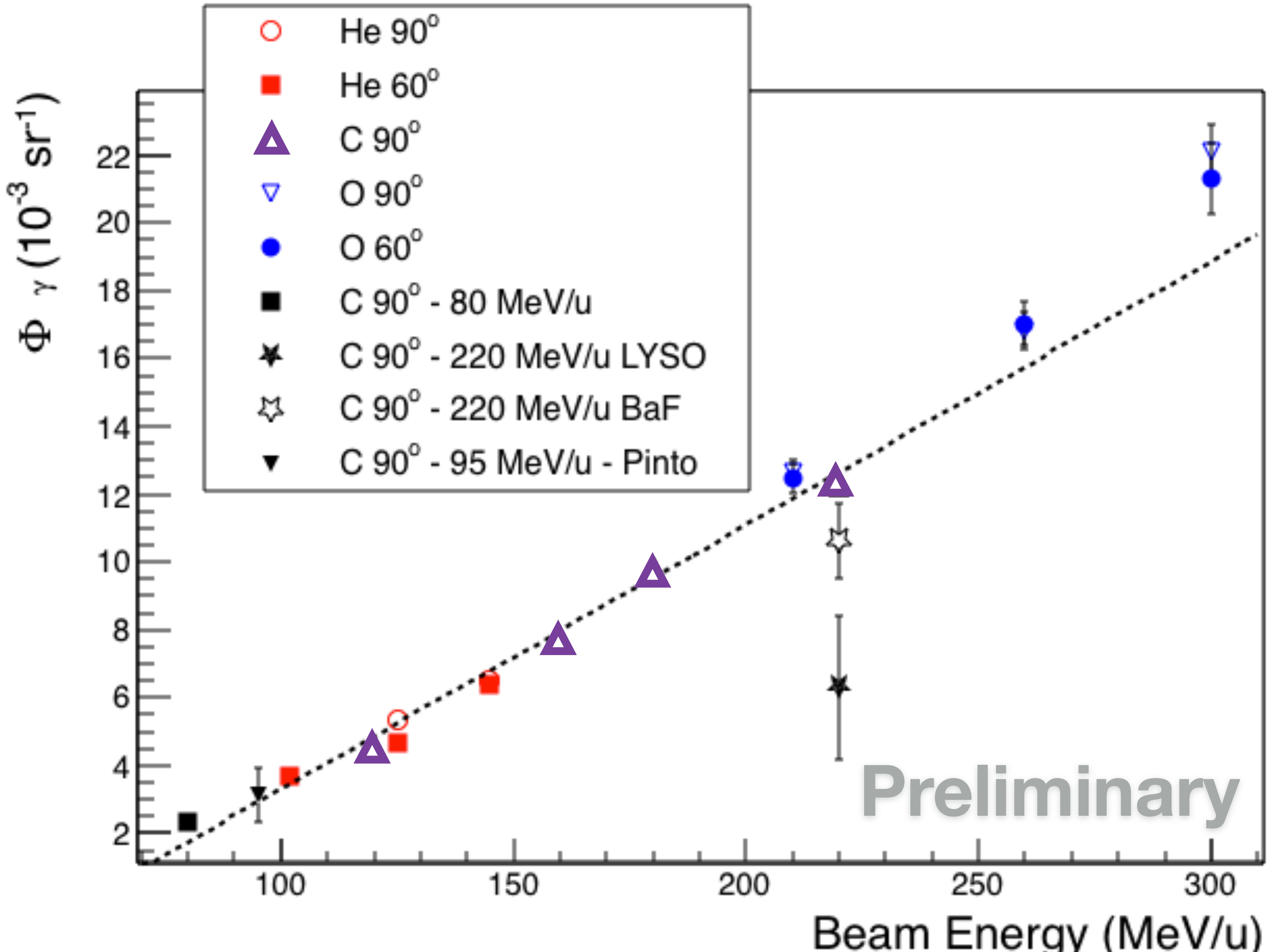
Some effort is ongoing for a further study on the systematic sources.

Prompt Photon

Paper in preparation:
prompt Yield at production
for He, C and O ion beams



Yield (at production) ϕ_γ Comparison:

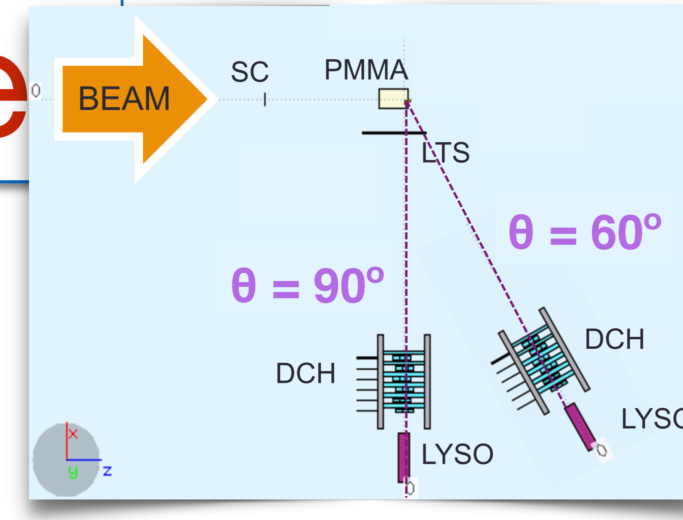


Evaluation:

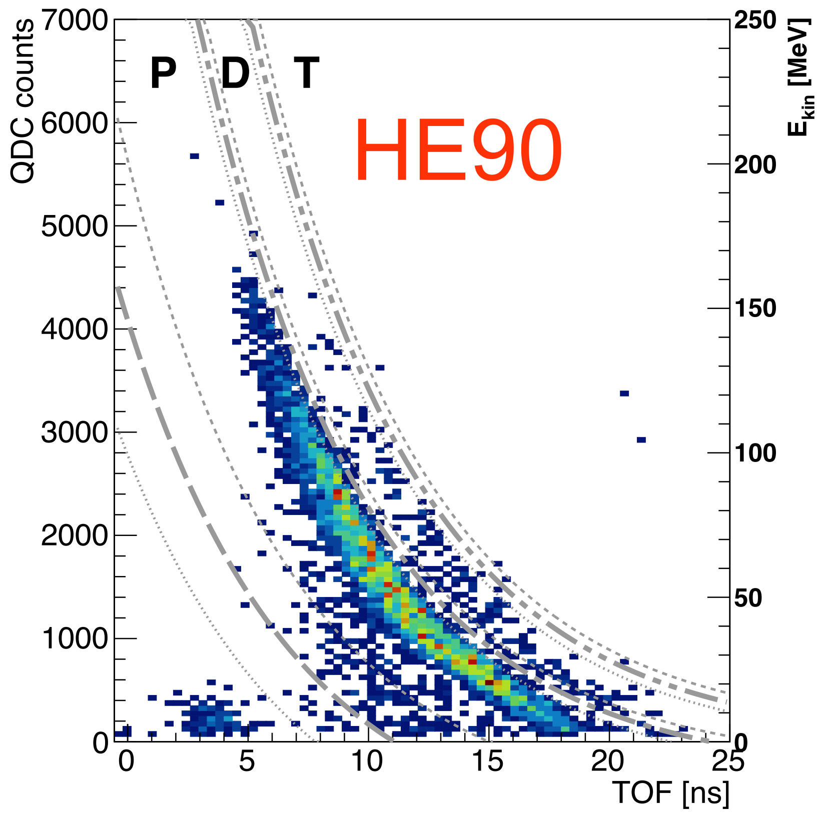
From the **measured prompt photon yields at production** we evaluated an achievable resolution on the BP estimation: ~ 2 mm for a treatment with He/Oxy beams in a real case scenario, using the IBA slit camera as photon detector [1] .

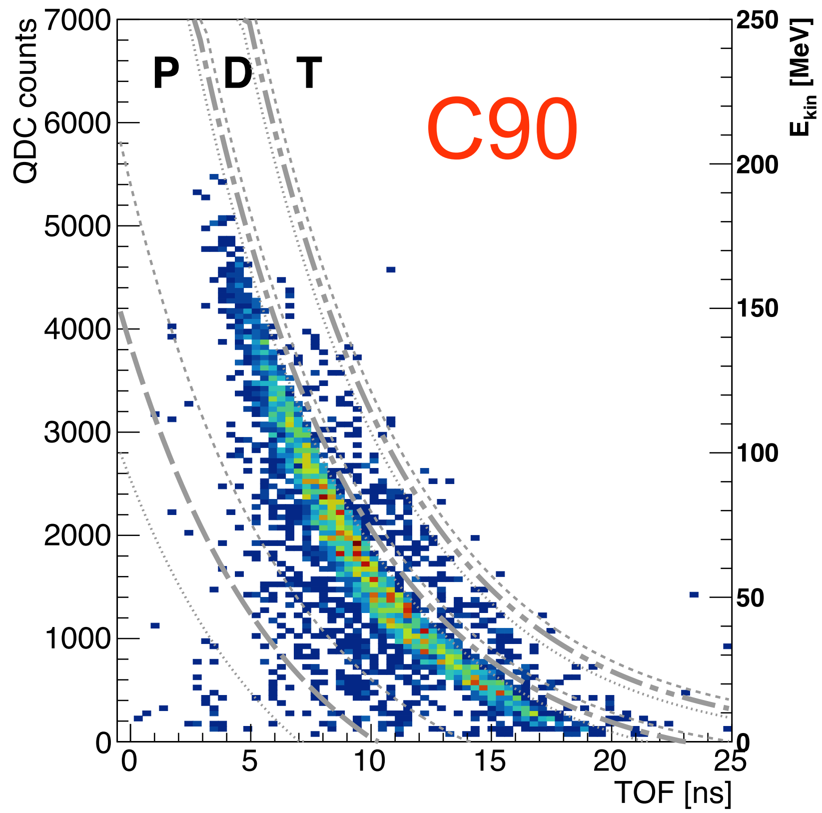
[1] Smeets et al., “Prompt gamma imaging with a slit camera for real-time range control in proton therapy”, Phys. Med. Biol. 57, 3371 (2012)

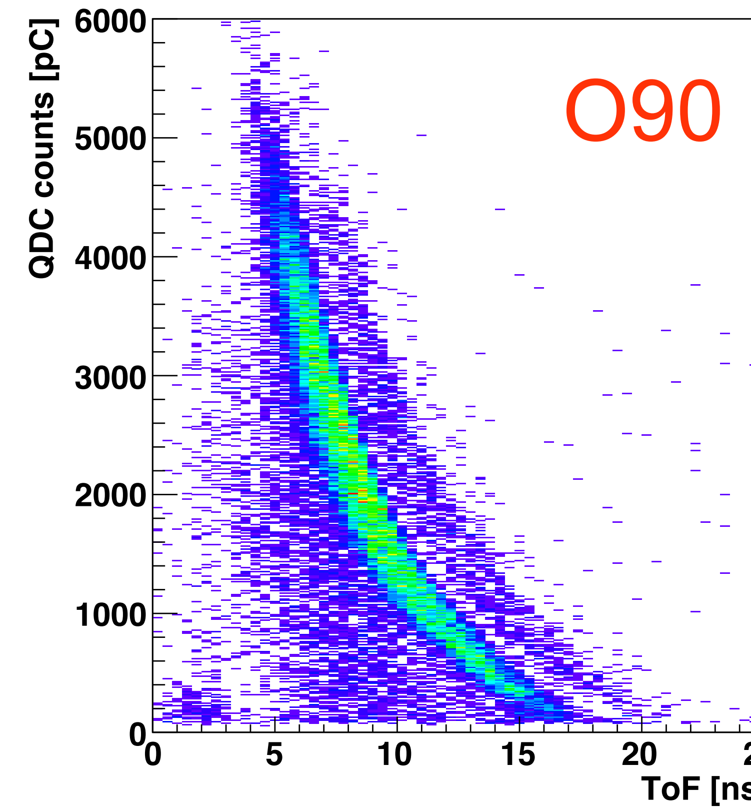
Secondary Charged Particle



Particle ID Distributions: QDC vs TOF

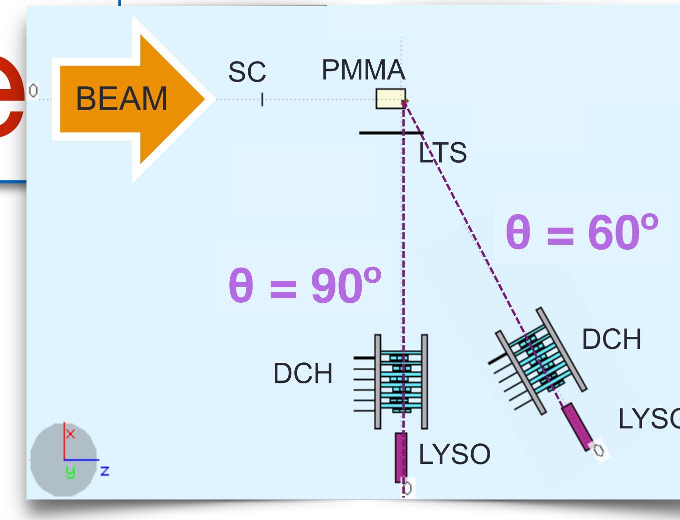






Paper in preparation: charged particle Yield, energy spectra and profile at production for He, C ion beams

Secondary Charged Particle



Yield (at production) $\phi_{p,d,t}$:

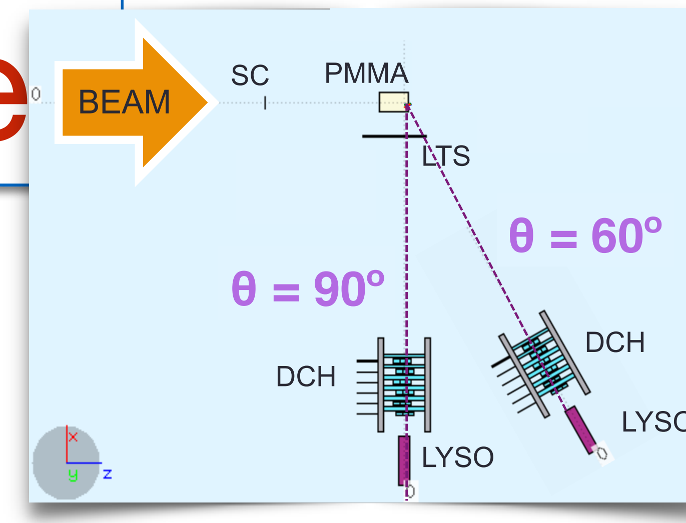
Some effort is ongoing for a further study on experimental efficiency calculation. Analysis on going..

Preliminary

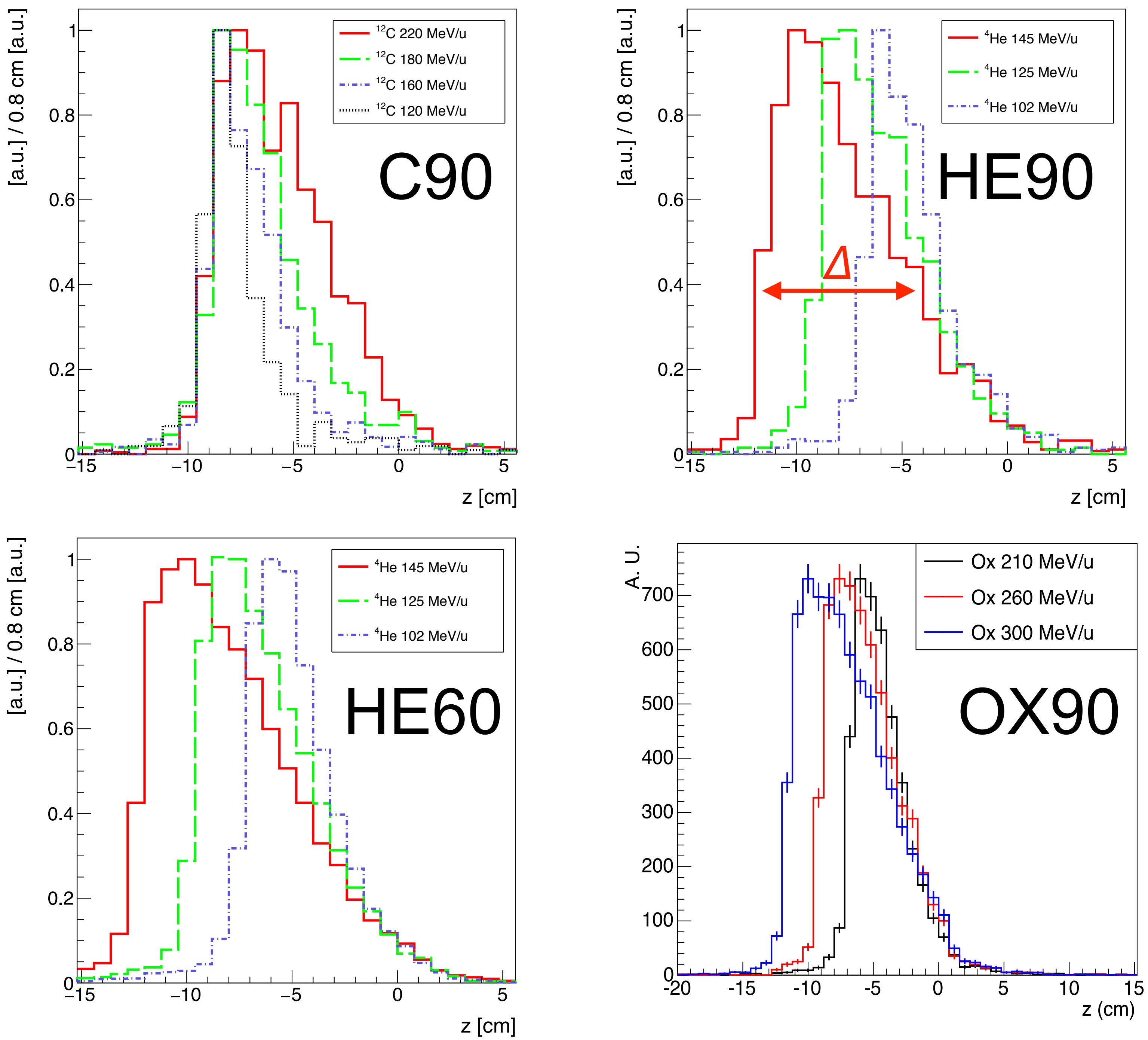
(very preliminary for Oxygen!)

θ	Ion	Energy (MeV/u)	$\Phi_p \pm \sigma_{stat} \pm \sigma_{sys}$ $(10^{-3}\ sr^{-1})$	$\Phi_d \pm \sigma_{stat} \pm \sigma_{sys}$ $(10^{-3}\ sr^{-1})$	$\Phi_t \pm \sigma_{stat} \pm \sigma_{sys}$ $(10^{-3}\ sr^{-1})$
90°	^{4}He	125	$0.789 \pm 0.027 \pm 0.073$	$0.066 \pm 0.005 \pm 0.024$	$0.001 \pm 0.001 \pm 0.000$
		145	$1.531 \pm 0.038 \pm 0.105$	$0.090 \pm 0.006 \pm 0.026$	$0.002 \pm 0.001 \pm 0.003$
	^{12}C	120	$0.447 \pm 0.027 \pm 0.029$	$0.011 \pm 0.003 \pm 0.003$	$0.001 \pm 0.001 \pm 0.000$
		160	$1.267 \pm 0.056 \pm 0.085$	$0.064 \pm 0.008 \pm 0.016$	$0.008 \pm 0.003 \pm 0.001$
		180	$1.950 \pm 0.087 \pm 0.113$	$0.102 \pm 0.013 \pm 0.022$	$0.012 \pm 0.004 \pm 0.002$
		220	$4.086 \pm 0.115 \pm 0.216$	$0.181 \pm 0.016 \pm 0.032$	$0.016 \pm 0.005 \pm 0.003$
	^{16}O	210	3.2 ± 0.1	analysis on going	analysis on going
		260	5.6 ± 0.1	”	”
		300	11.8 ± 0.1	”	”
60°	^{4}He	102	$4.788 \pm 0.070 \pm 0.402$	$0.315 \pm 0.010 \pm 0.063$	$0.031 \pm 0.003 \pm 0.011$
		125	$10.717 \pm 0.109 \pm 0.908$	$0.917 \pm 0.019 \pm 0.212$	$0.099 \pm 0.006 \pm 0.037$
		145	$17.658 \pm 0.155 \pm 1.787$	$1.948 \pm 0.030 \pm 0.542$	$0.168 \pm 0.008 \pm 0.095$
	^{16}O	210	17.7 ± 0.1	analysis on going	analysis on going
		260	32.2 ± 0.3	”	”
		300	58.2 ± 0.3	”	”

Secondary Charged Particle



Measurement of the beam range (BP position)



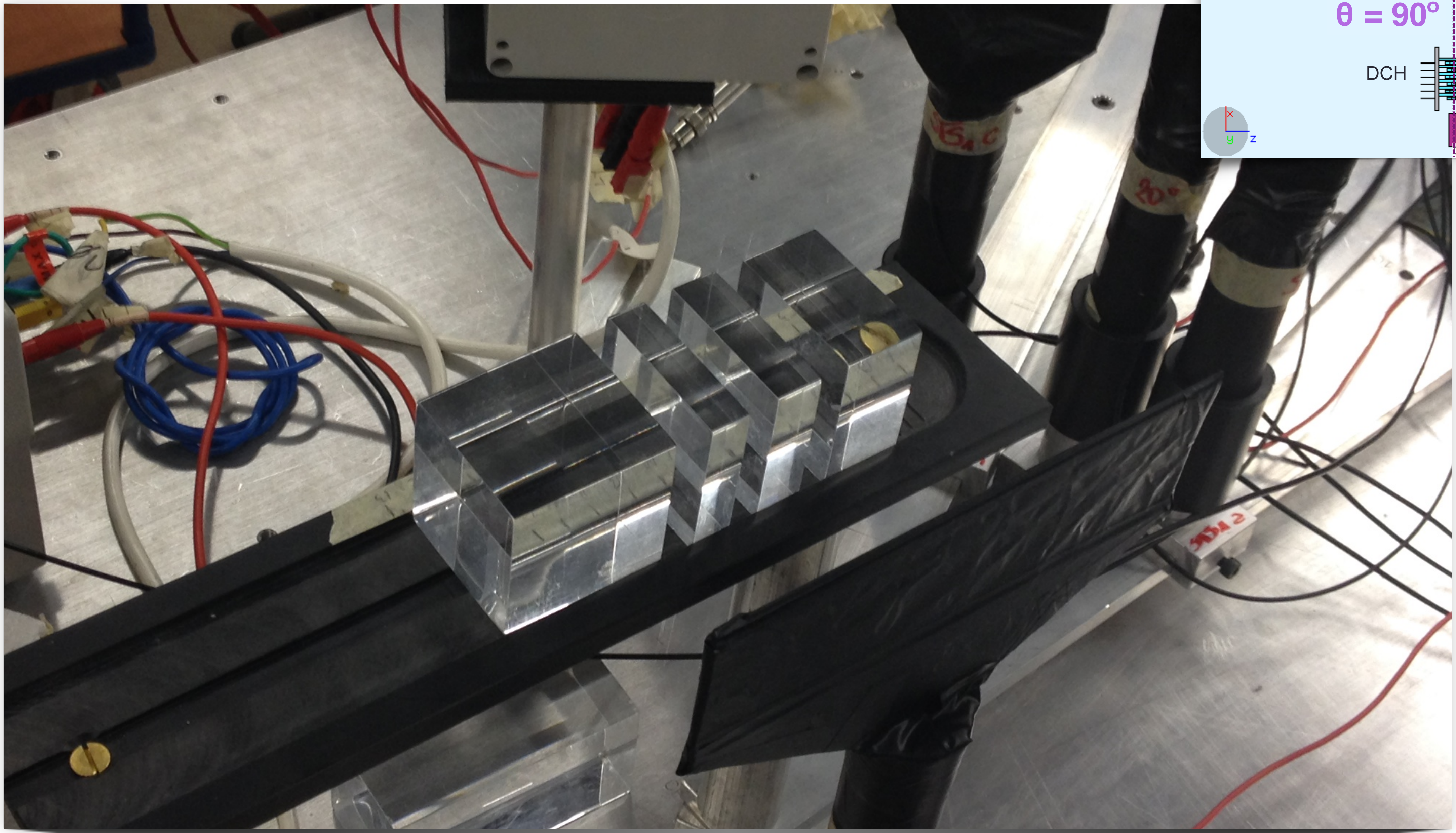
From previous experiments:

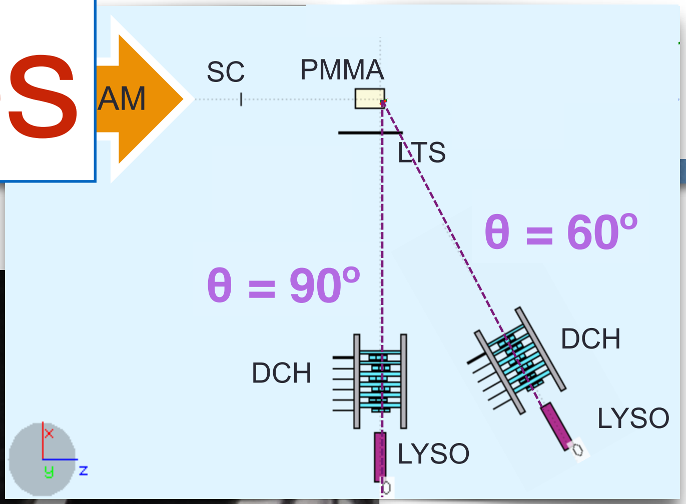
- the secondary charged z **emission distribution** is related to the beam **range**;
- with 10^3 secondary protons produced by 10^8 ions (220 MeV/u ^{12}C) the **parameter Δ** describing the width of the z distribution is known with a **resolution** of about **~ 3 mm**.

A calibration describing the **behavior of Δ as a function of the beam range** inside the target for the HIT experimental configurations is ongoing.

Paper in preparation: charged particle Yield, energy spectra and profile at production for He, C ion beams

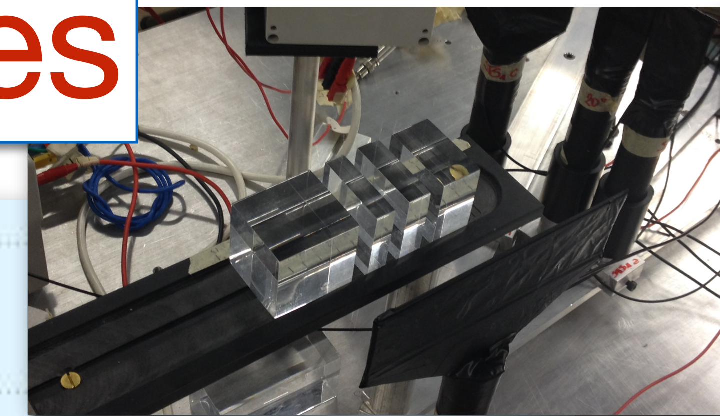
Secondary Charged Particles

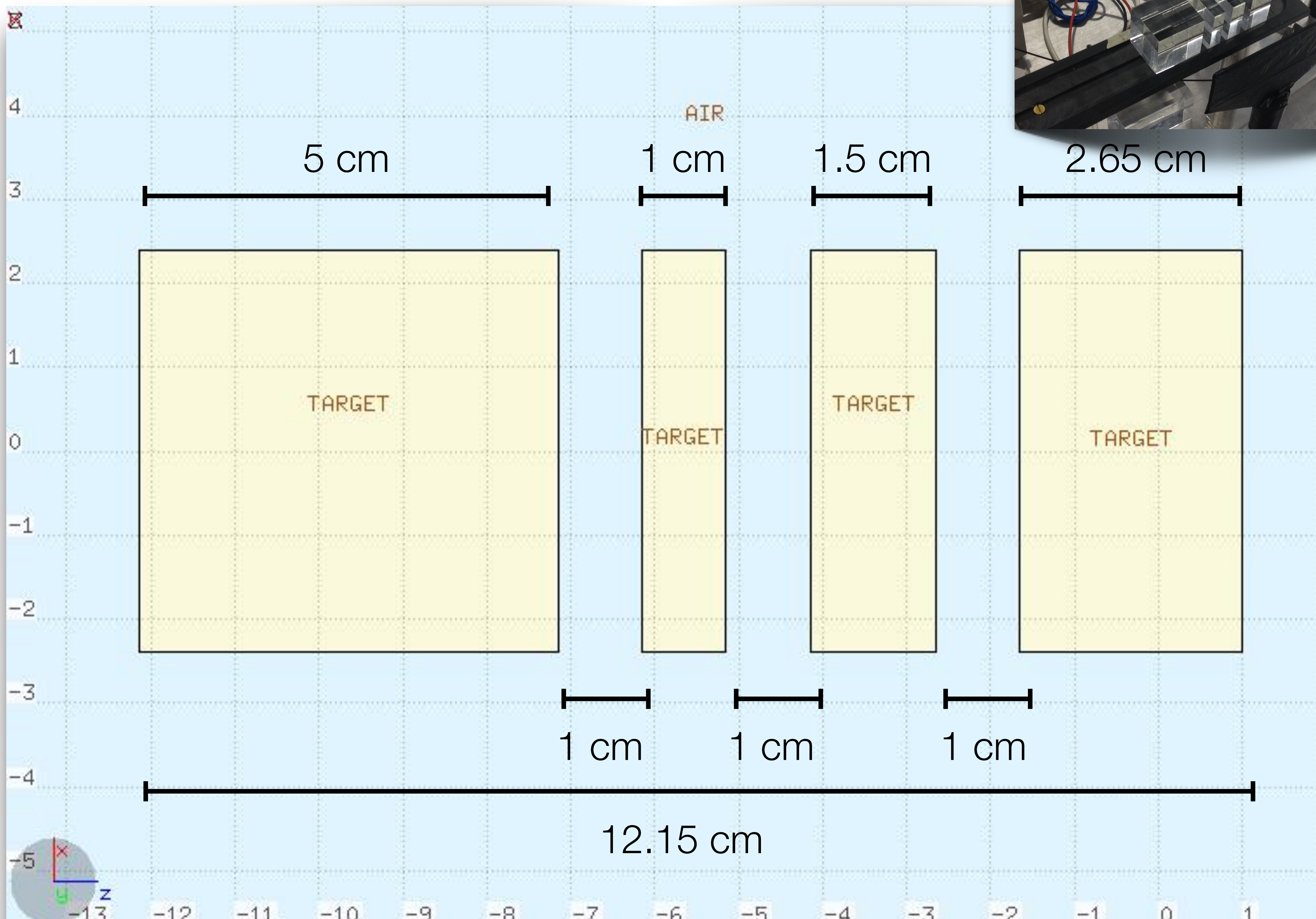




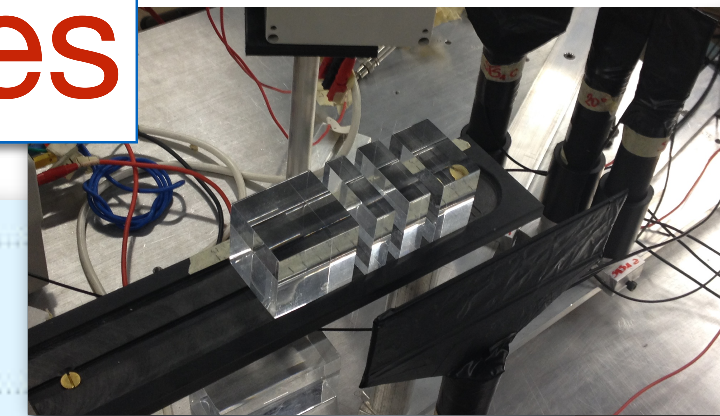
For ^{16}O ions at 260 MeV/u (LYSO at 90°) we performed a segmented target geometry measurement

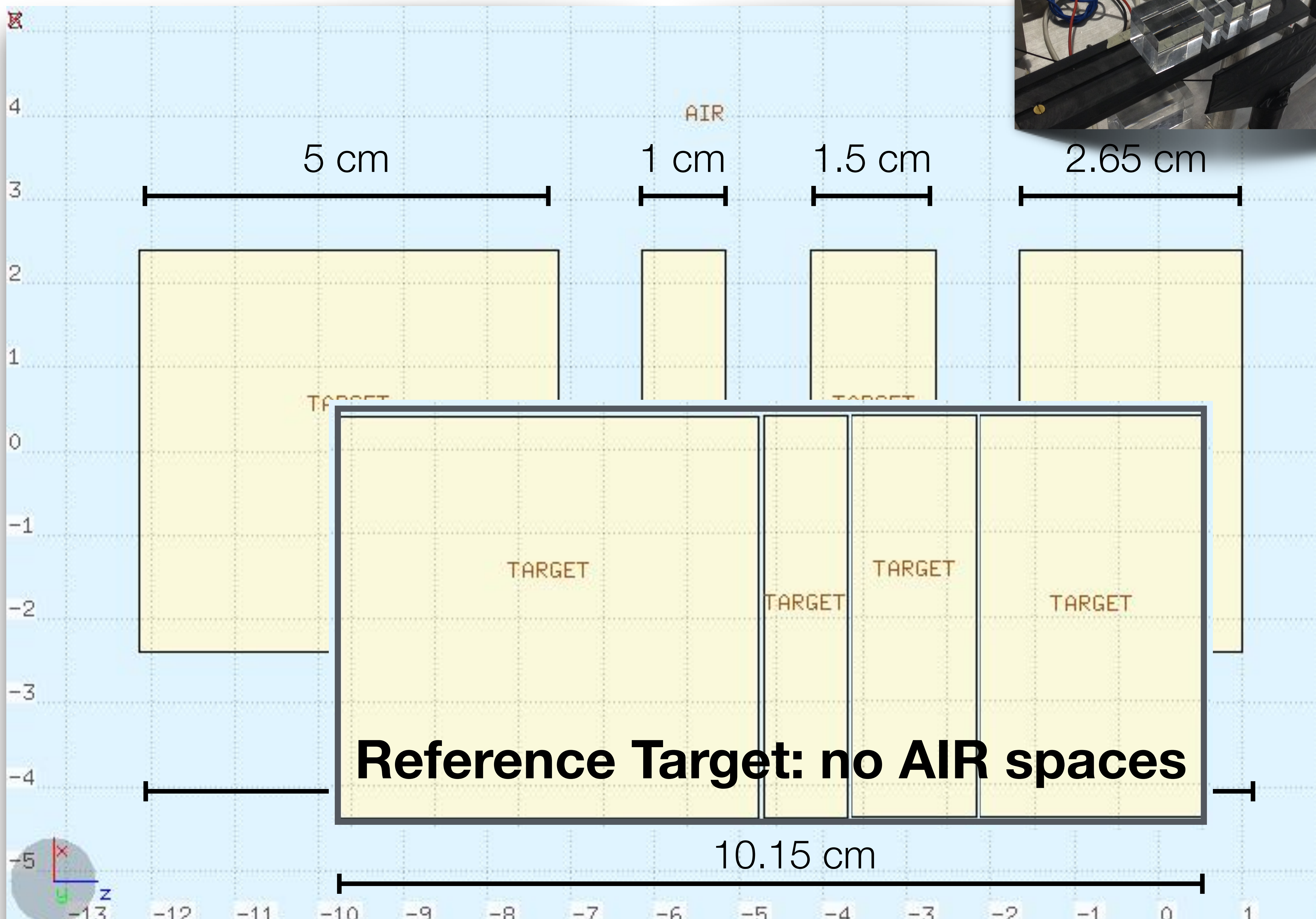
Secondary Charged Particles



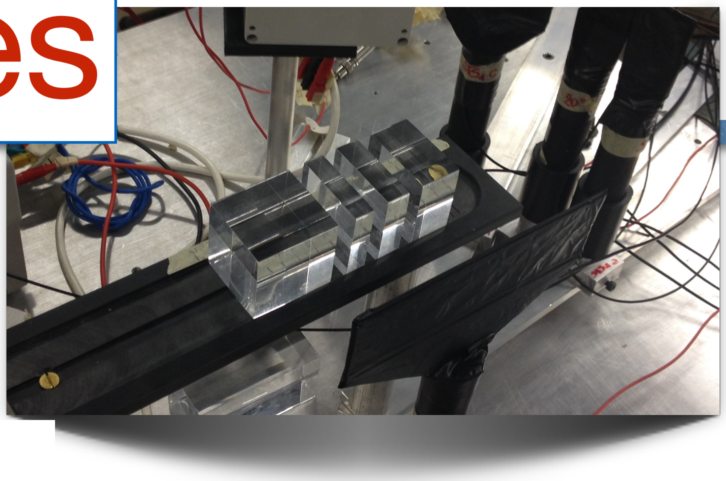


Secondary Charged Particles

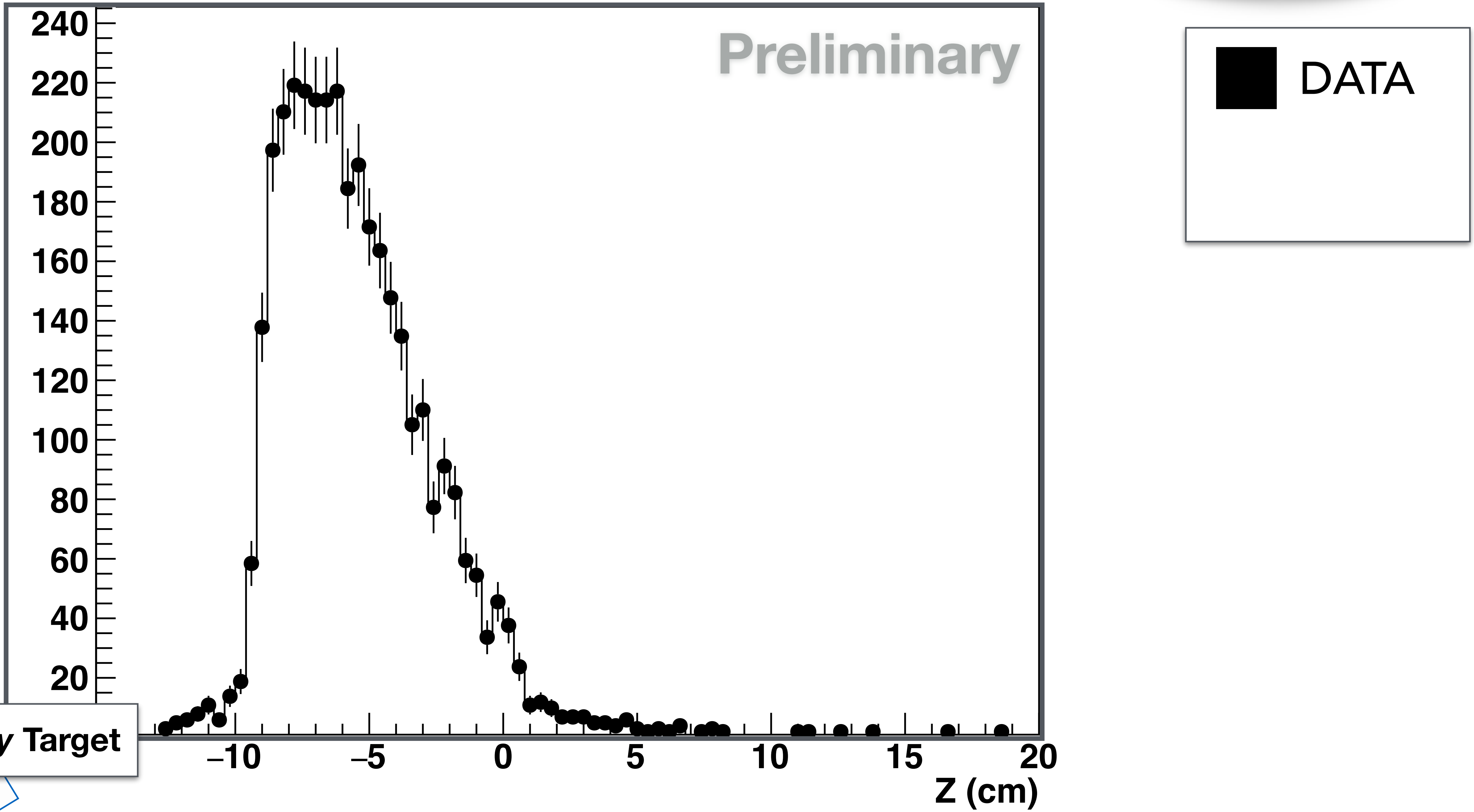




Secondary Charged Particles

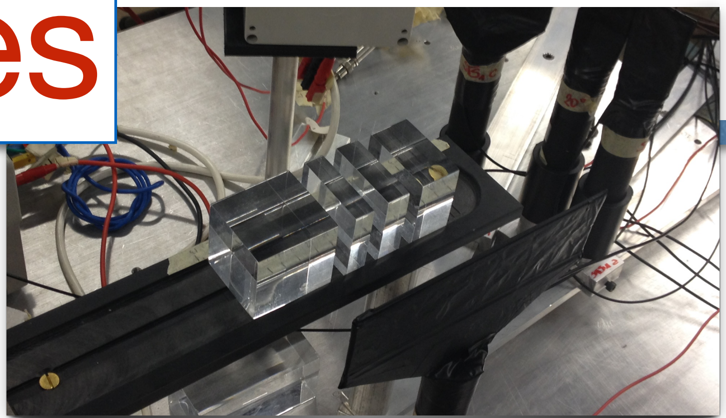


Reference 10 cm Target: no AIR spaces

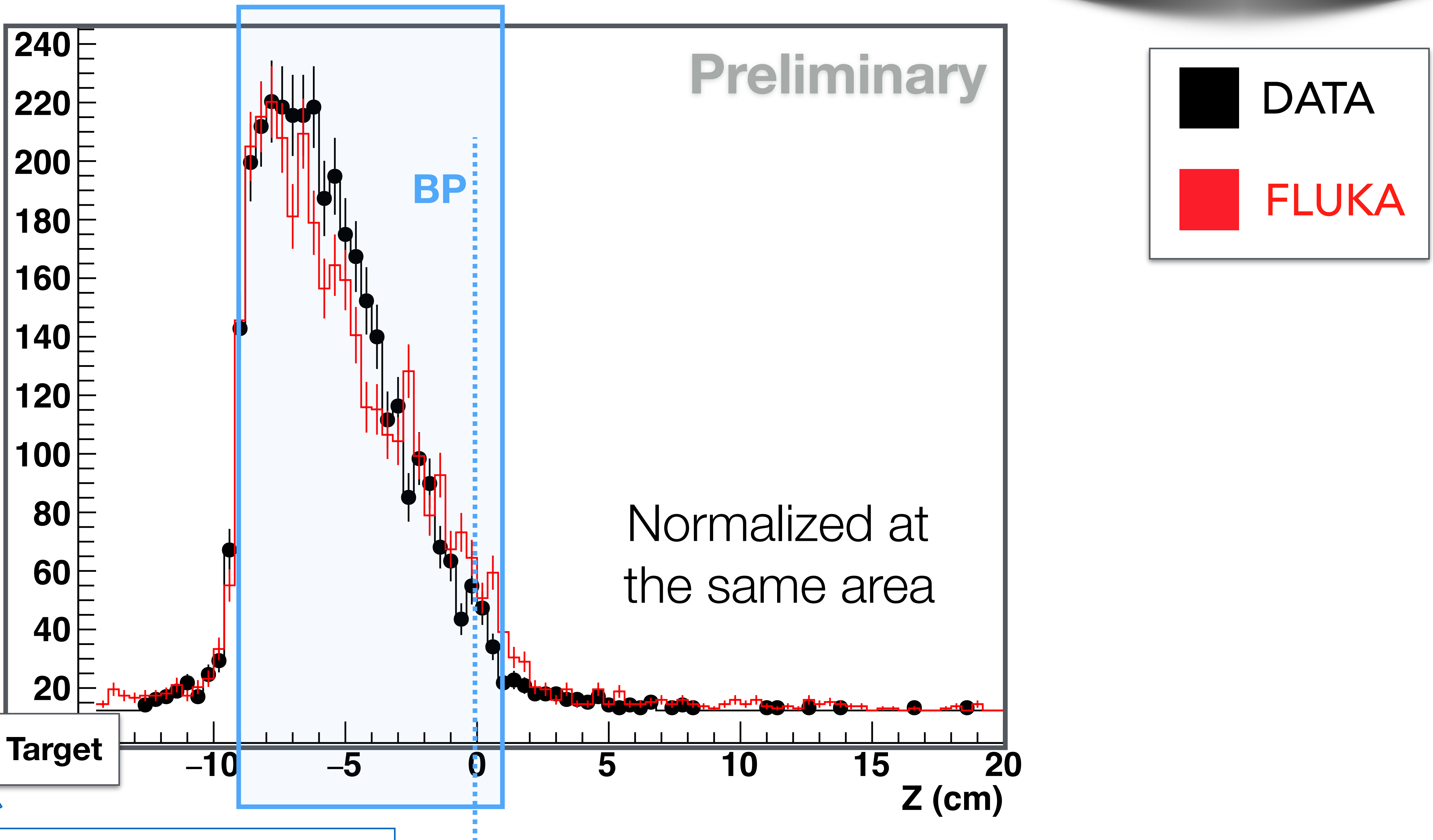


Crazy Target

Secondary Charged Particles

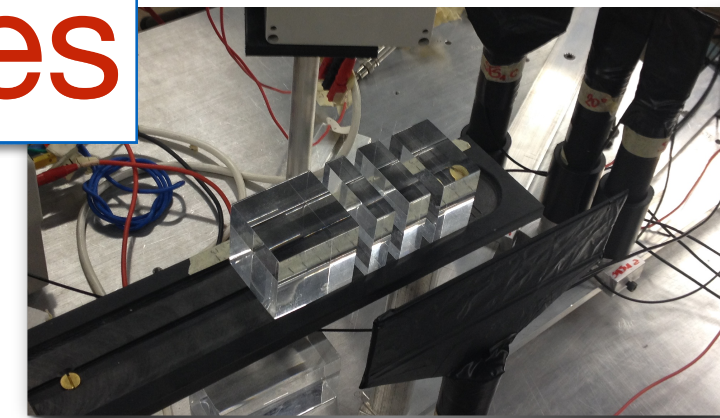


Reference 10 cm Target: no AIR spaces

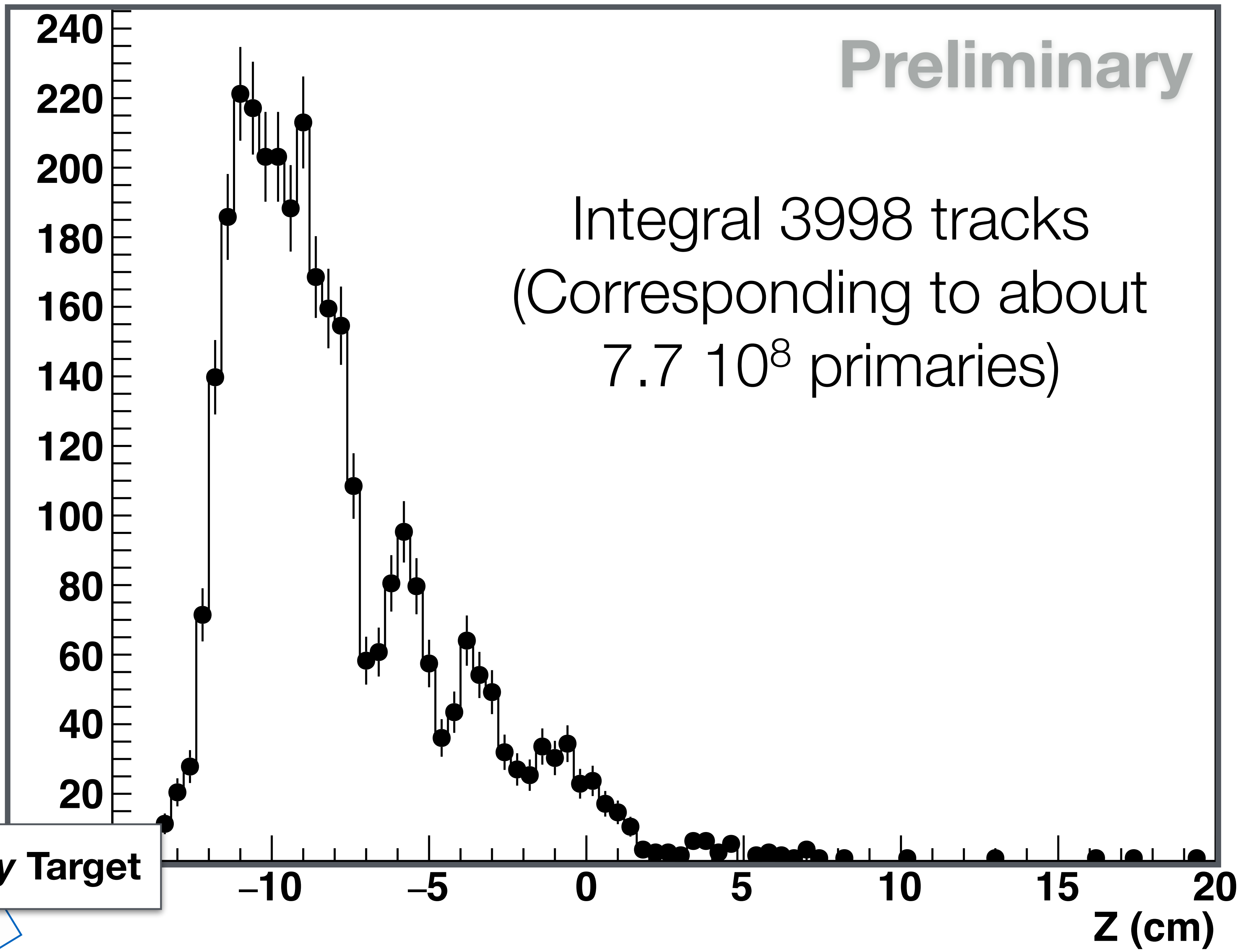


Crazy Target

Secondary Charged Particles



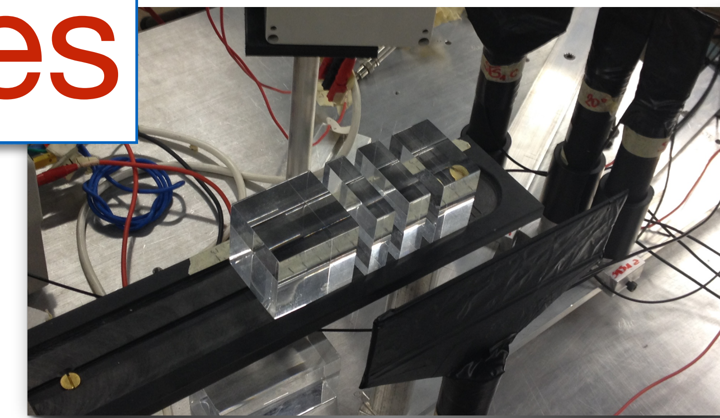
Segmented 12.65 cm Target: with AIR spaces



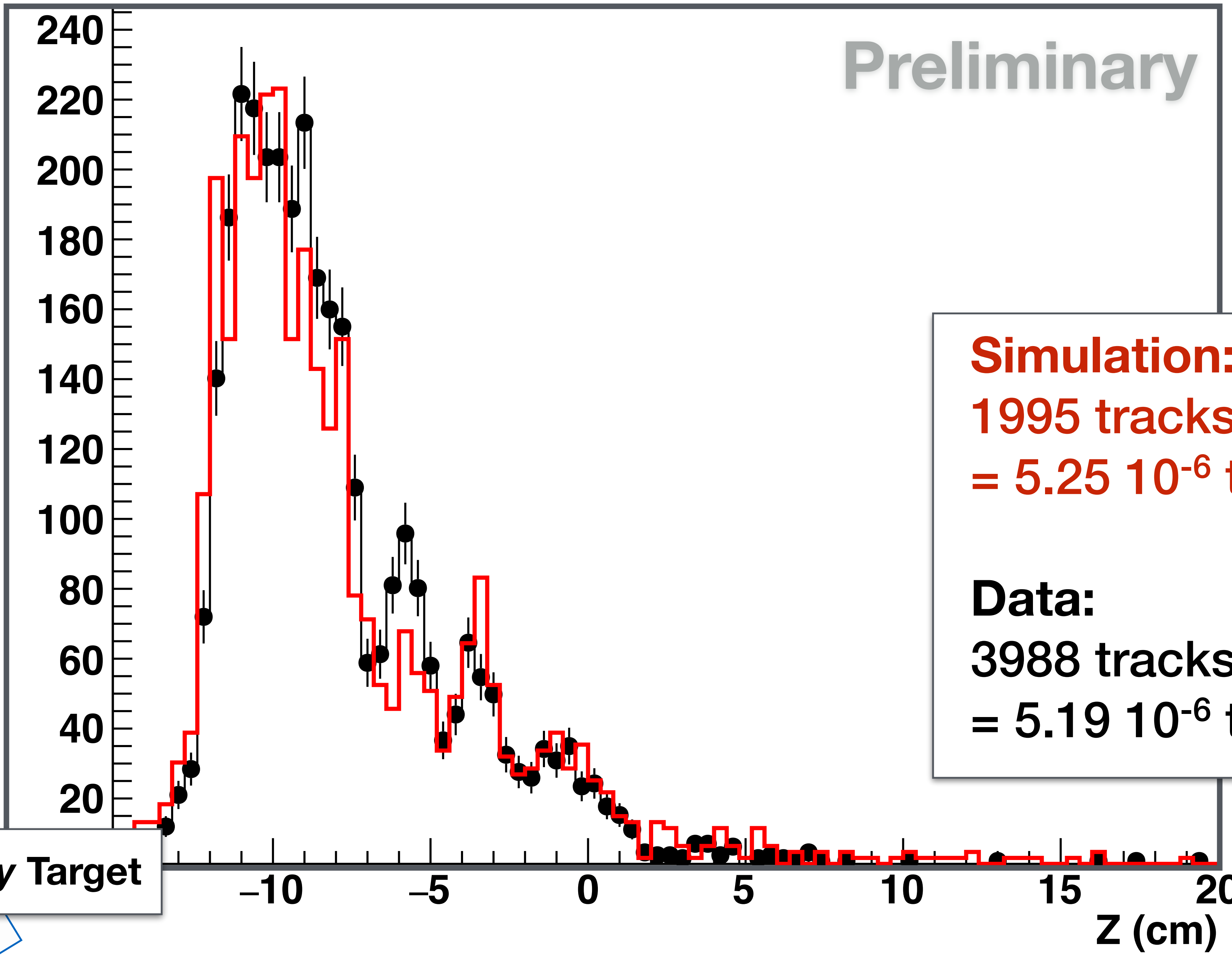
DATA

***Crazy* Target**

Secondary Charged Particles



Segmented 12.15 cm Target: with AIR spaces



DATA

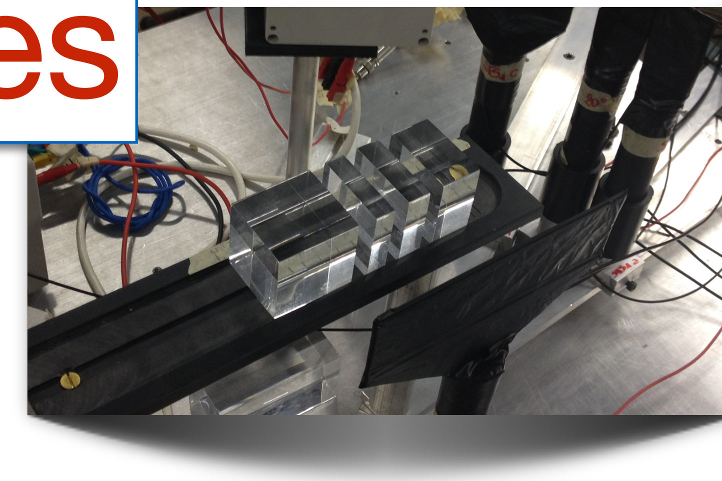
FLUKA

Simulation:
1995 tracks/3.8 10^8 primaries
= 5.25 10^{-6} tracks/primary

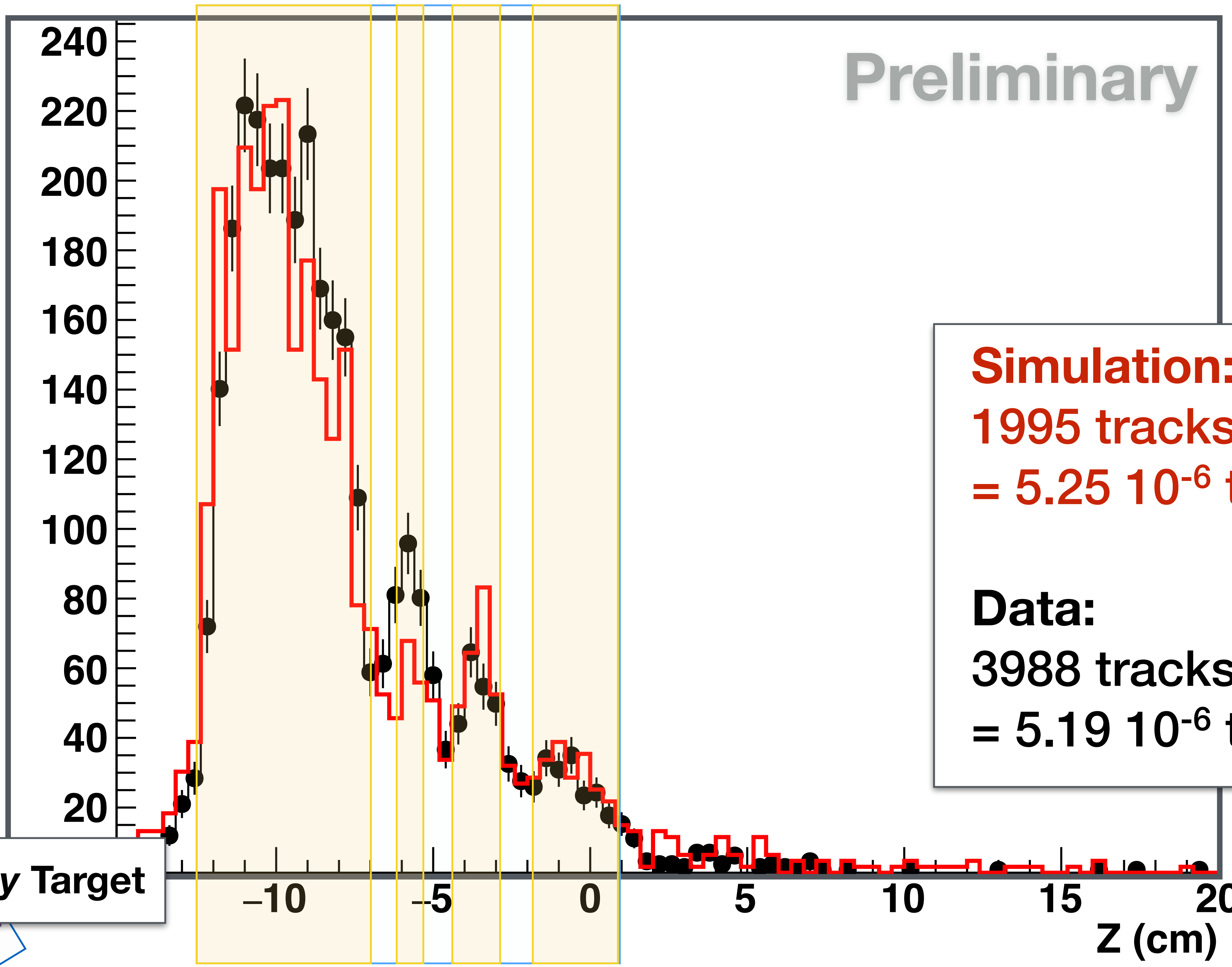
Data:
3988 tracks/7.7 10^8 primaries
= 5.19 10^{-6} tracks/primary

***Crazy* Target**

Secondary Charged Particles



Segmented 12.15 cm Target: with AIR spaces



DATA

FLUKA

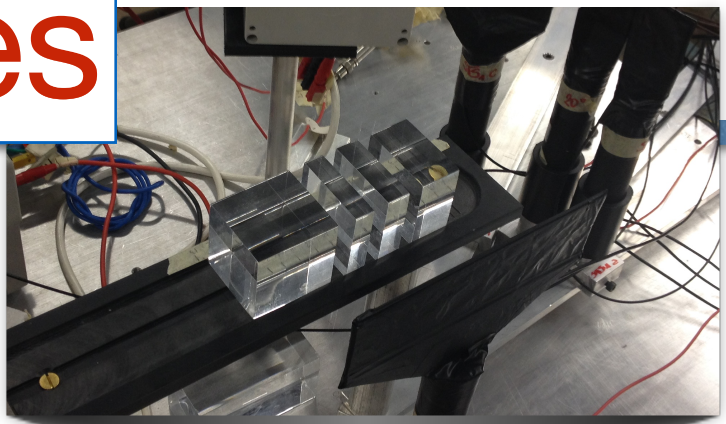
Simulation:
1995 tracks/3.8 10^{8} primaries
= 5.25 10^{-6} tracks/primary

Data:
3988 tracks/7.7 10^{8} primaries
= 5.19 10^{-6} tracks/primary

***Crazy* Target**

Secondary Charged Particles

DOSE PROFILER CONSIDERATIONS



The data plot shown here corresponds to a detector acceptance much smaller than that of DP.

We can approximately scale (at the same distance from target) to the acceptance of Dose Profiler considering a factor ~17 (conservative!!!): number of reconstructed tracks => **~4.5 10^7 primaries**.

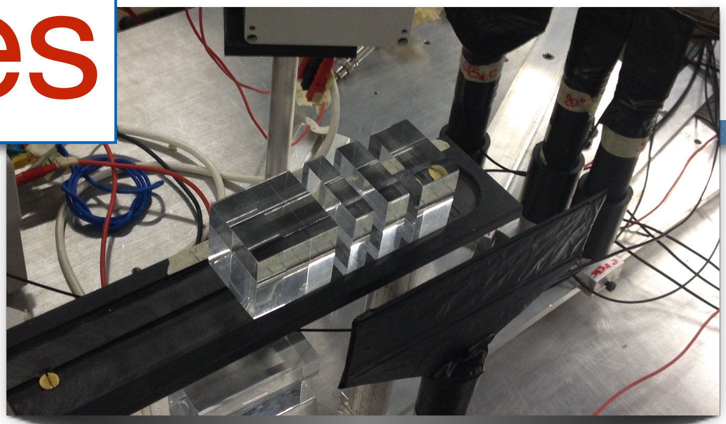
From MC we learn that for Oxigen at 260 MeV/u in order to deliver a 1 Gy on a 3 x 25 x 25 mm^3 slice around the Bragg Peak one needs **2.4 10^7 primaries:**
=> physical dose of **~1.9 Gy**.

We also know from MC how to scale for more reasonable thicknesses. That number of reconstructed tracks would correspond in the Dose Profiler to:

~2.71 10^8 prim: ~11 Gy @ 7 cm PMMA ~(8.4 cm H_20)
~6.66 10^8 prim: ~28 Gy @10 cm PMMA ~(12.0 cm H_20)

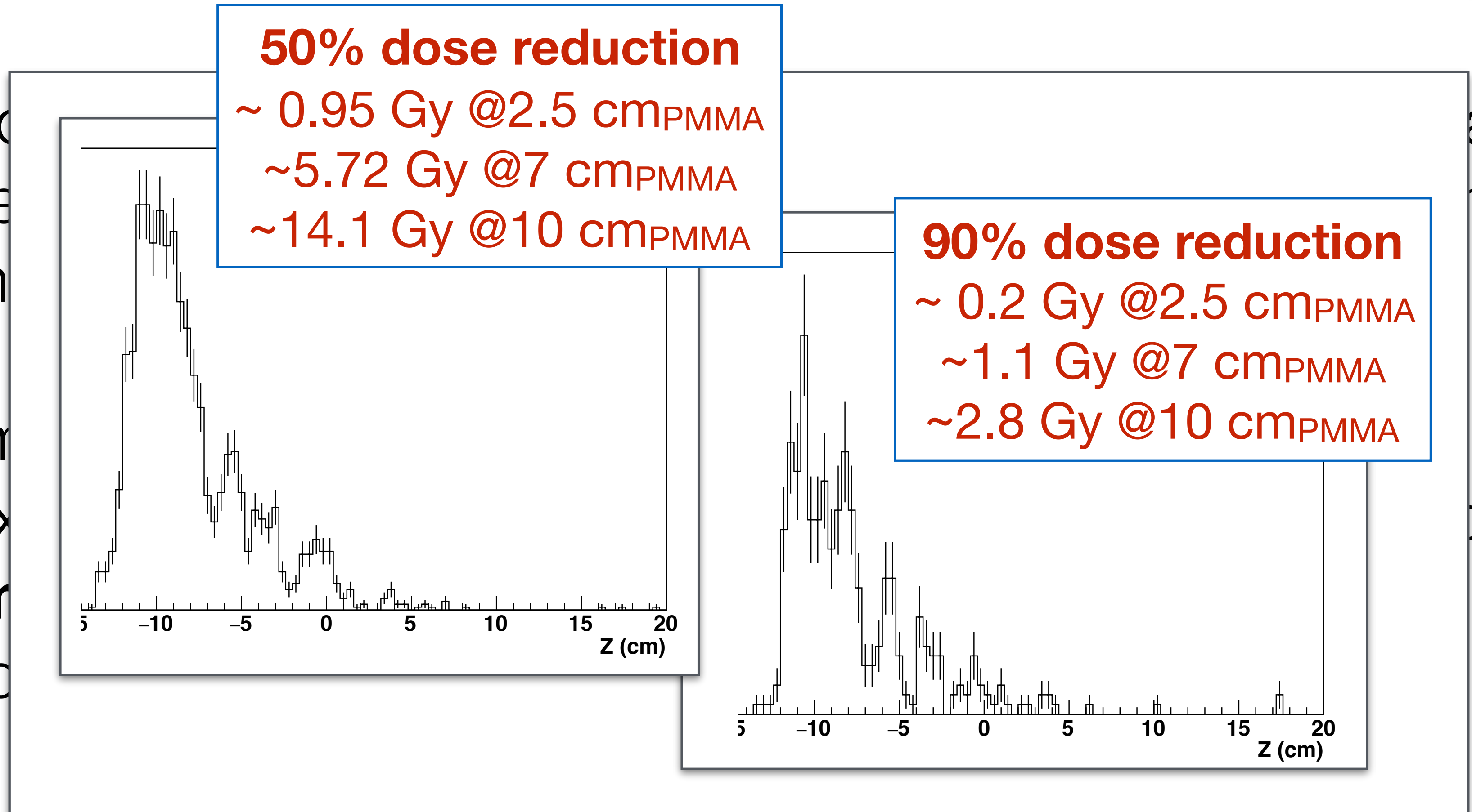
Secondary Charged Particles

DOSE PROFILER CONSIDERATIONS



The data plot shown here corresponds to a detector acceptance much smaller than that of DP.

We c … arget) to the
acce … nservative!!!):
num …



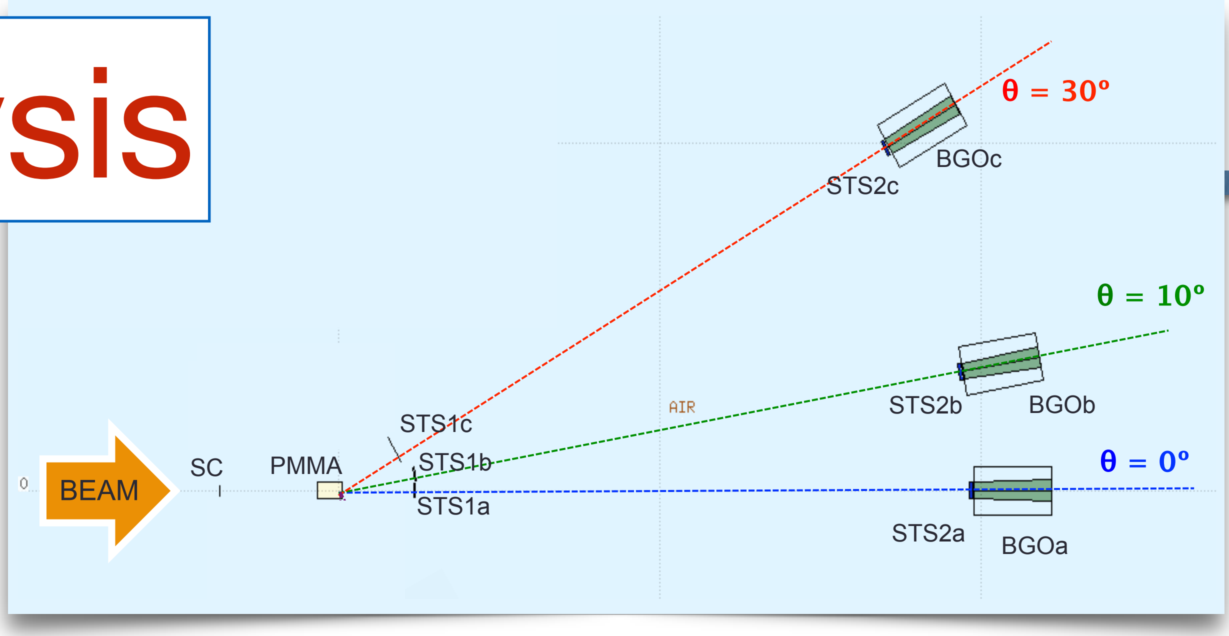
Fron … to deliver a 1 Gy on
a 3 … ds **2.4 10^{7}**
prim
=> p

We also know from MC how to scale for more reasonable thicknesses. That number of reconstructed tracks would correspond in the Dose Profiler to:

The presence of structures remains distinguishable also for lower doses

Very Preliminary!!

Fragmentation Analysis

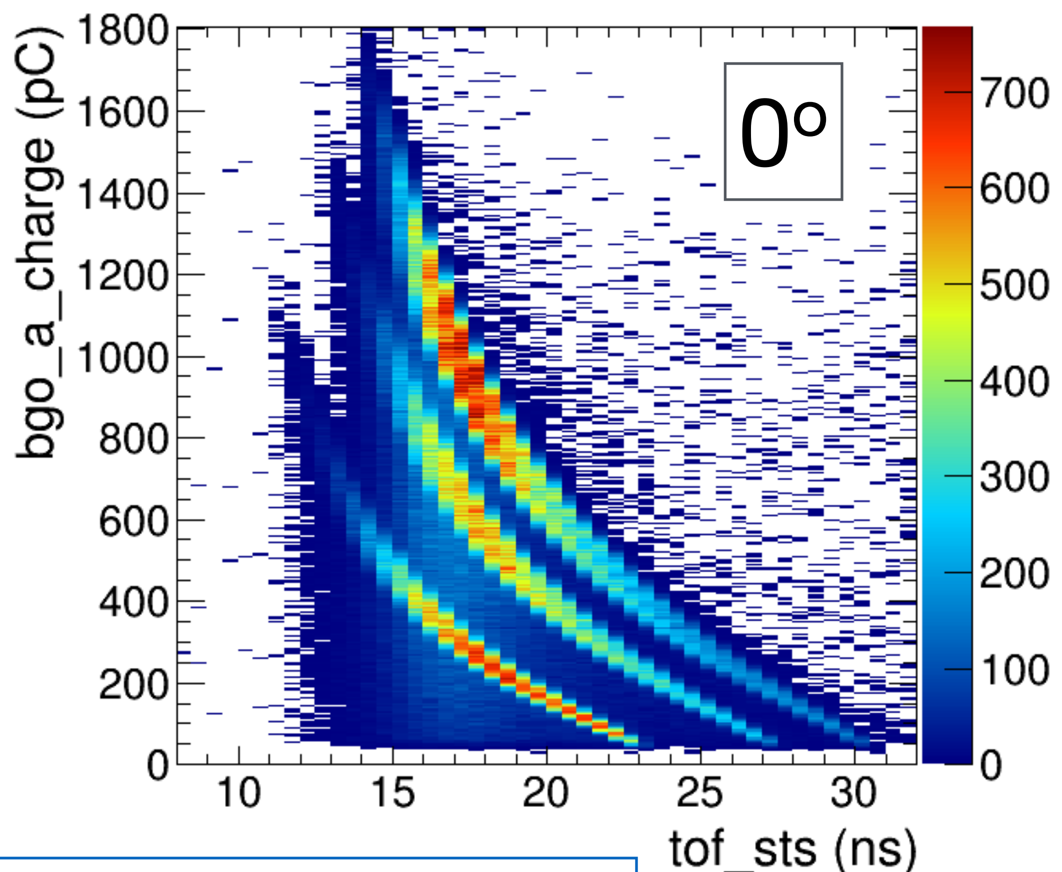


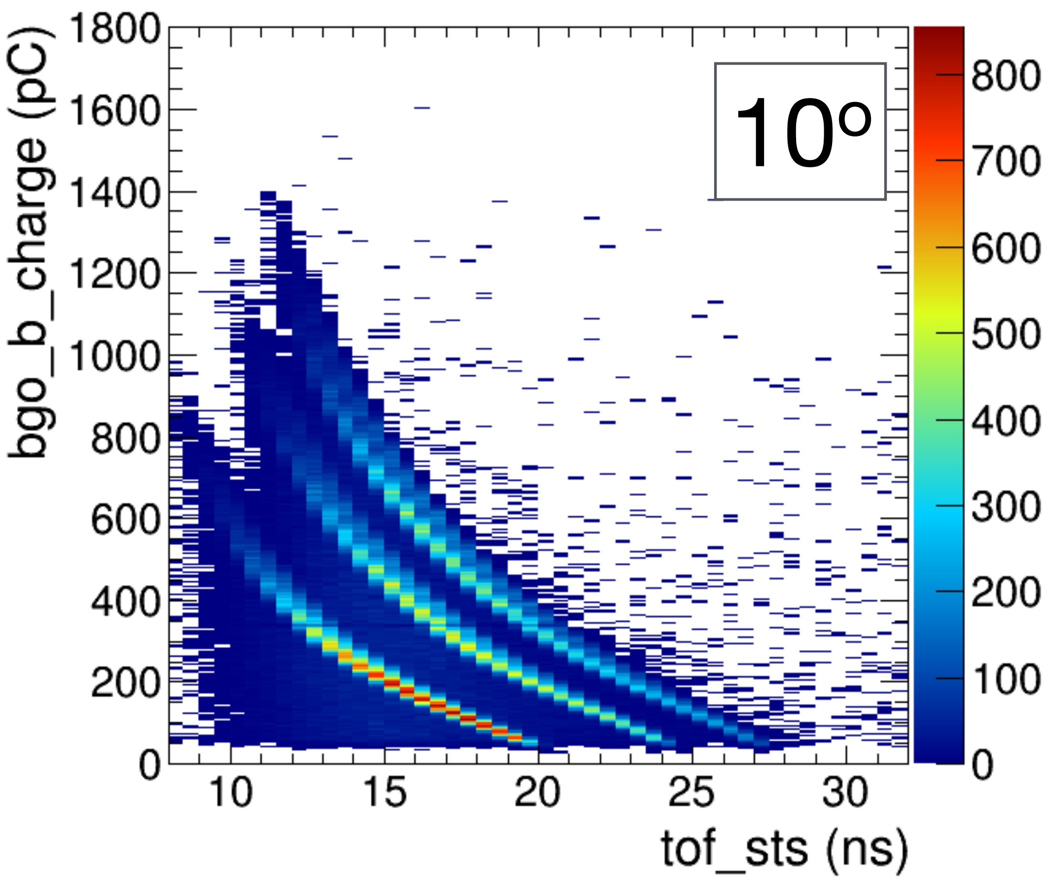
The ToF measurement combined with the deposit energy information allows for Particle Identification: p,d,t.

The analysis has been performed for 0,10,15 and 30 degrees..

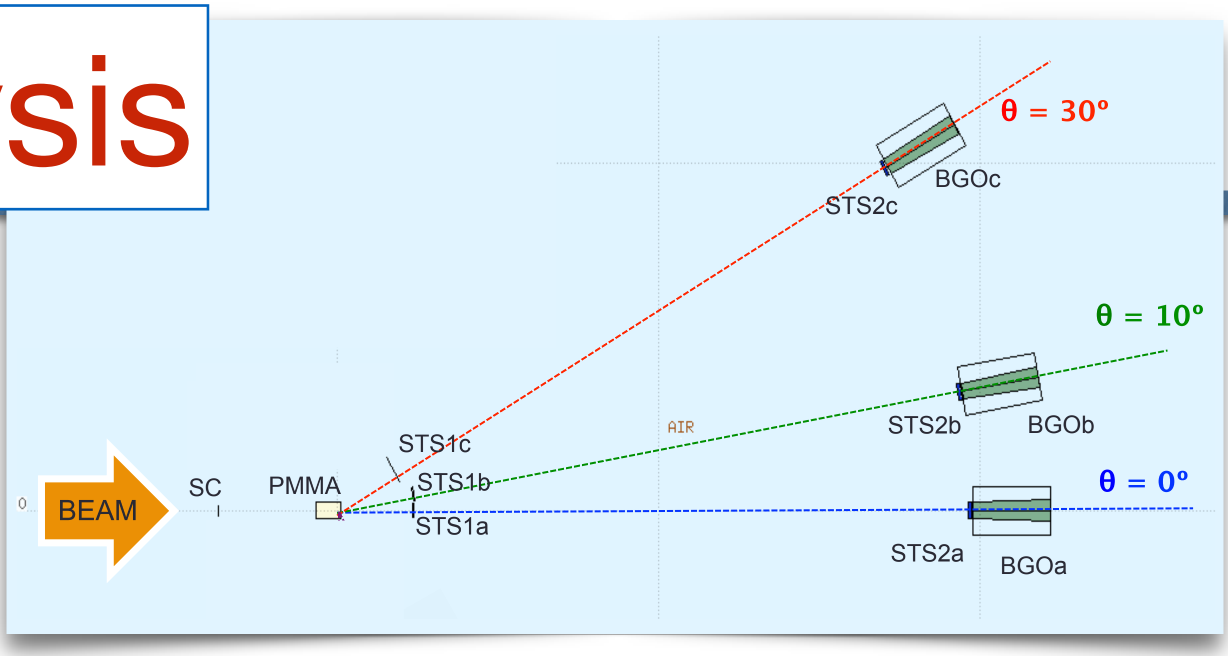
Paper in preparation: forward He ion beam fragmentation on PMMA target

Only Helium Beam analysis has been done.. Carbon and Oxygen ion beams will come in next months





Fragmentation Analysis



The relative Yield for p,d,t has been calculated for all angles and beam energies (102, 125, 145 MeV/u)

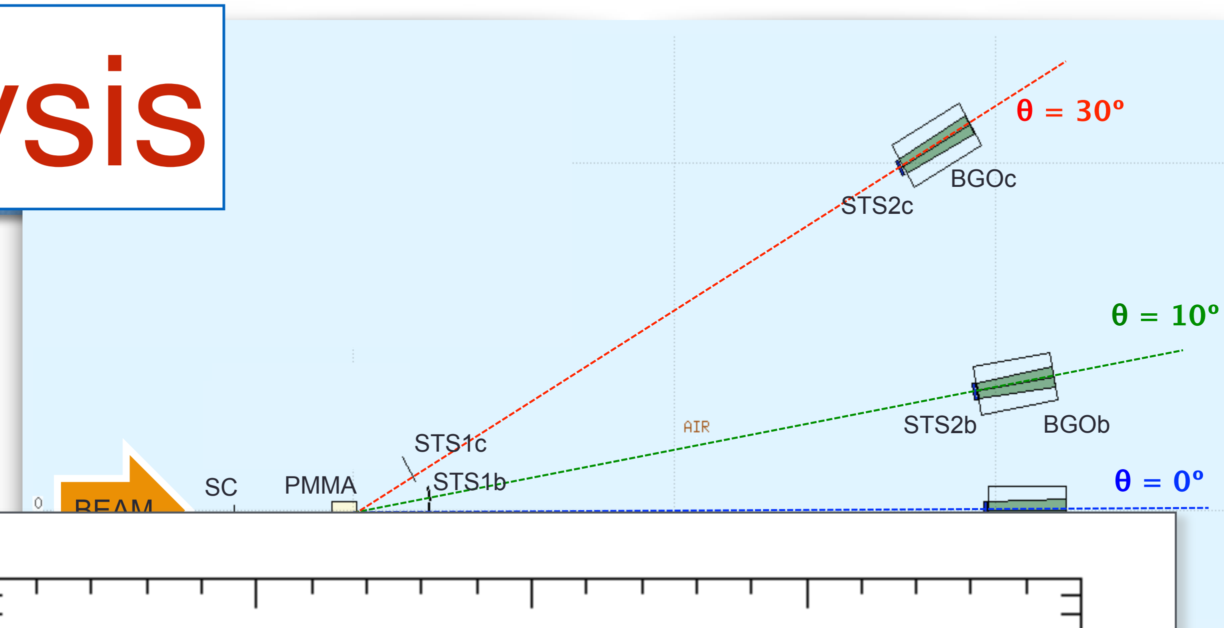
At 30° we have two separate set of measurements (in agreement!)

Preliminary

He102 (%)	0°	5°	10°	15°	30°	30°
proton	20.4 ± 2.8	25.8 ± 3.1	30.5 ± 4.0	35.5 ± 4.1	65.5 ± 8.4	65.4 ± 7.5
deuteron	31.2 ± 4.3	33.0 ± 3.9	32.6 ± 4.3	35.0 ± 4.1	26.8 ± 3.5	26.5 ± 3.1
triton	48.4 ± 6.3	41.2 ± 4.7	37.0 ± 4.8	29.5 ± 3.4	7.7 ± 1.1	8.0 ± 1.0
He125 (%)	0°	5°	10°	15°	30°	30°
proton	22.4 ± 3.1	27.4 ± 3.2	31.8 ± 3.8	37.2 ± 4.2	68.5 ± 7.6	69.2 ± 7.6
deuteron	32.7 ± 4.6	34.8 ± 4.0	34.7 ± 4.1	36.7 ± 4.1	25.6 ± 2.9	24.9 ± 2.7
triton	44.9 ± 6.0	37.8 ± 4.2	33.5 ± 3.8	26.1 ± 2.9	6.0 ± 0.7	5.8 ± 0.7
He145 (%)	0°	5°	10°	15°	30°	30°
proton	23.8 ± 3.4	29.1 ± 3.4	33.4 ± 4.0	39.2 ± 4.4	70.9 ± 8.0	70.6 ± 7.6
deuteron	34.0 ± 5.0	36.0 ± 4.2	36.0 ± 4.3	36.9 ± 4.1	24.3 ± 2.7	24.5 ± 2.7
triton	42.2 ± 5.8	35.0 ± 4.1	30.6 ± 3.5	24.0 ± 2.6	4.8 ± 0.6	4.8 ± 0.6

Paper in preparation: forward He ion beam fragmentation on PMMA target

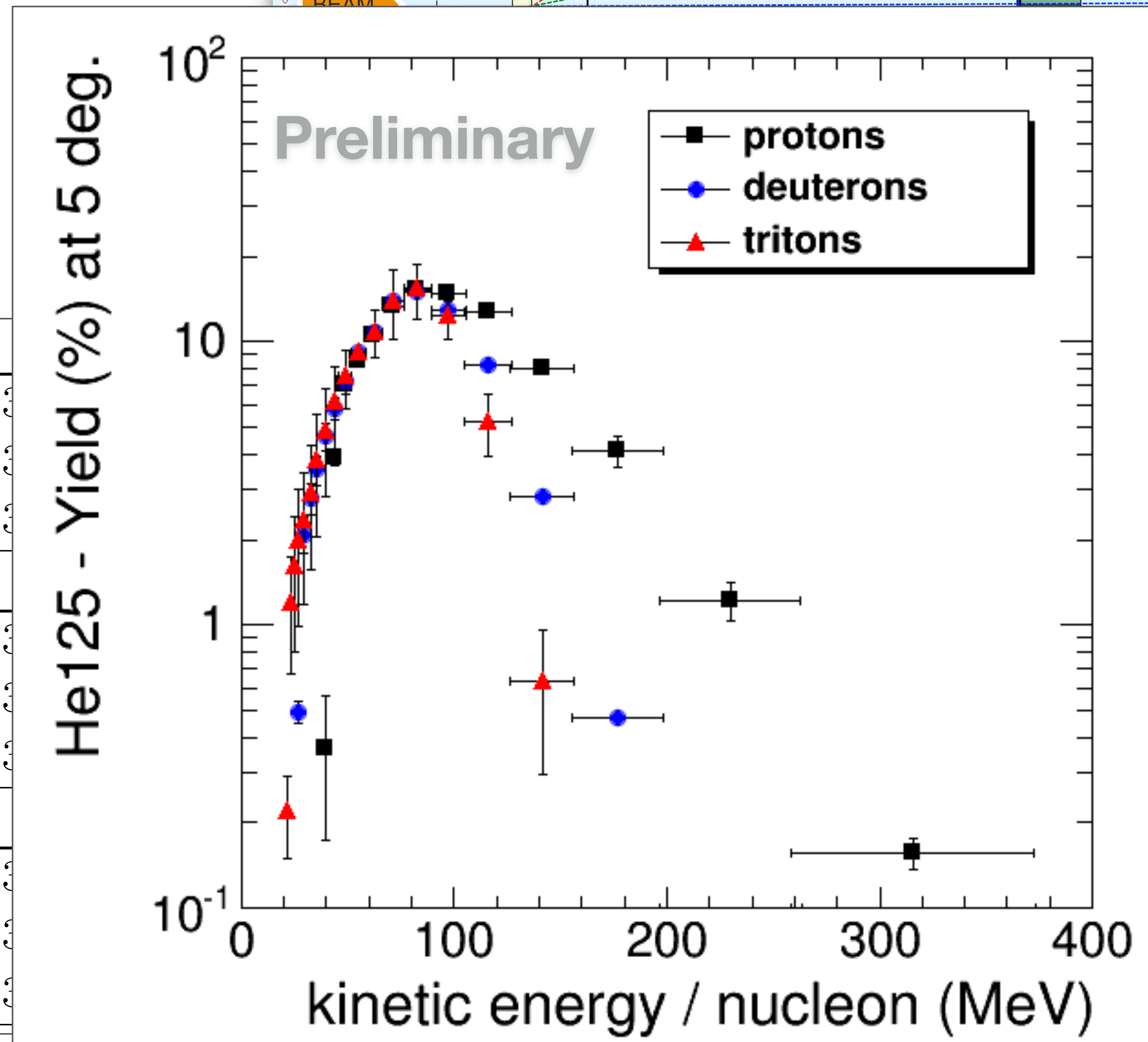
Fragmentation Analysis



The relative Yield for p,d,t has been calculated for all angles and beam energies (102, 125, 145 MeV/u)

The Kinetic Energy of the particles is obtained from the ToF measurements

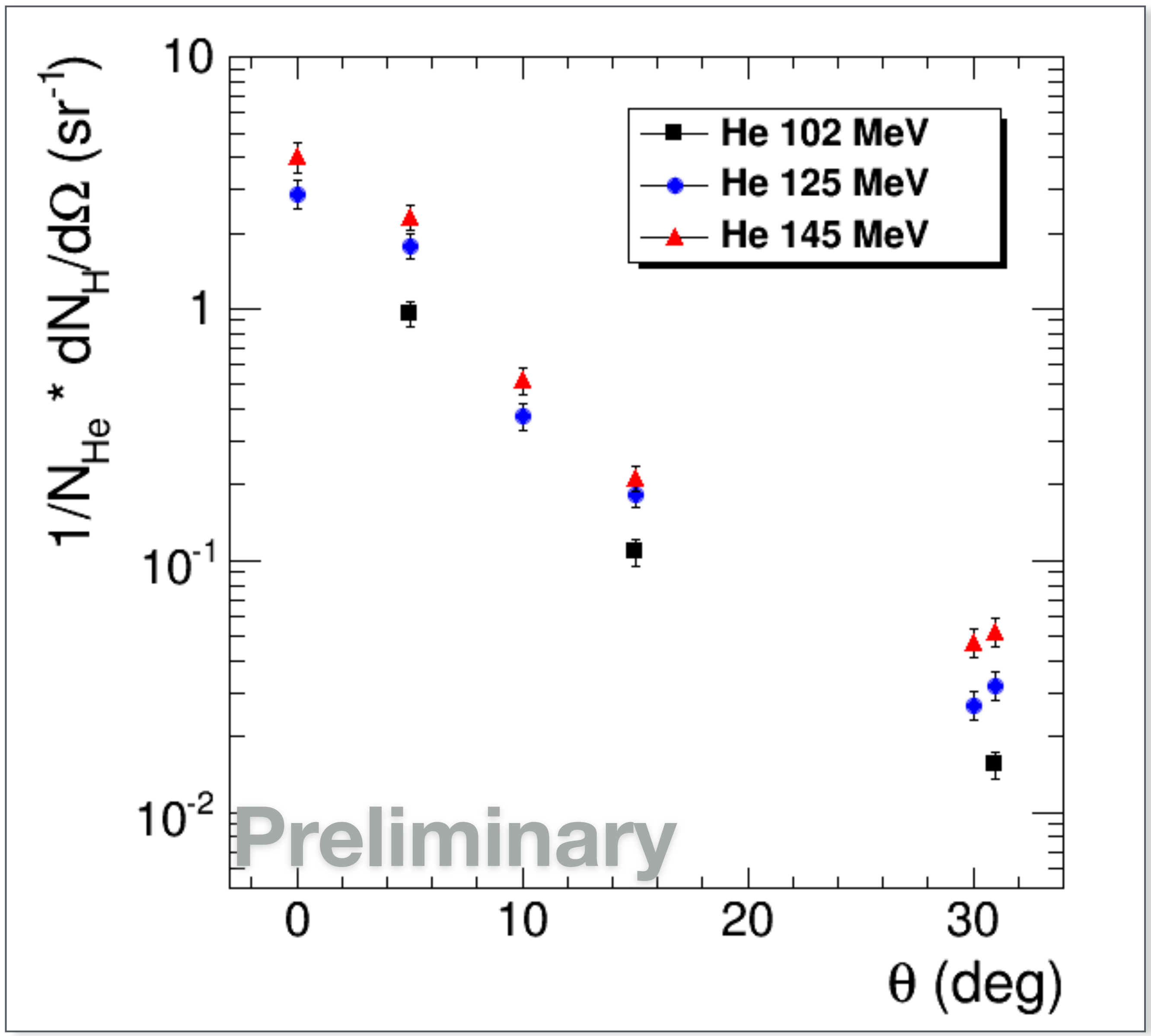
He102 (%)	0°	5°
proton	20.4 ± 2.8	25.8 ± 3.1
deuteron	31.2 ± 4.3	33.0 ± 3.9
triton	48.4 ± 6.3	41.2 ± 4.7
He125 (%)	0°	5°
proton	22.4 ± 3.1	27.4 ± 3.2
deuteron	32.7 ± 4.6	34.8 ± 4.0
triton	44.9 ± 6.0	37.8 ± 4.2
He145 (%)	0°	5°
proton	23.8 ± 3.4	29.1 ± 3.4
deuteron	34.0 ± 5.0	36.0 ± 4.2
triton	42.2 ± 5.8	35.0 ± 4.1

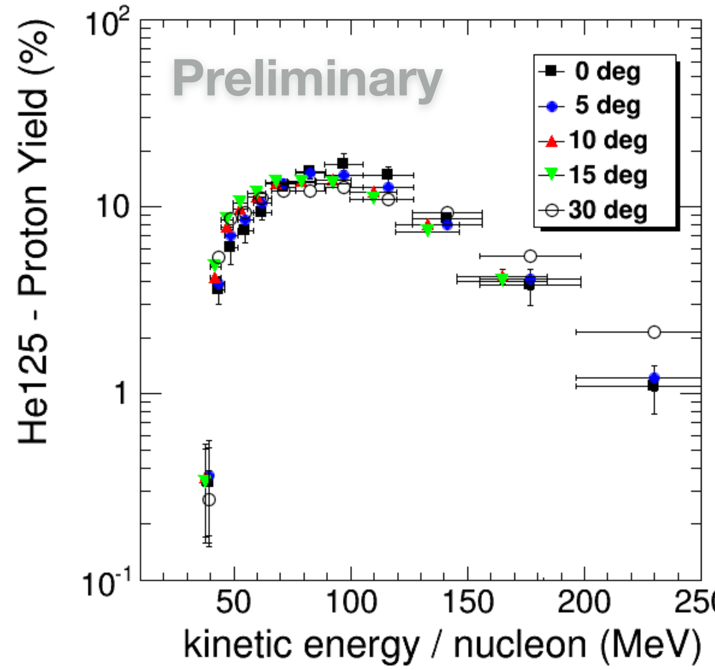


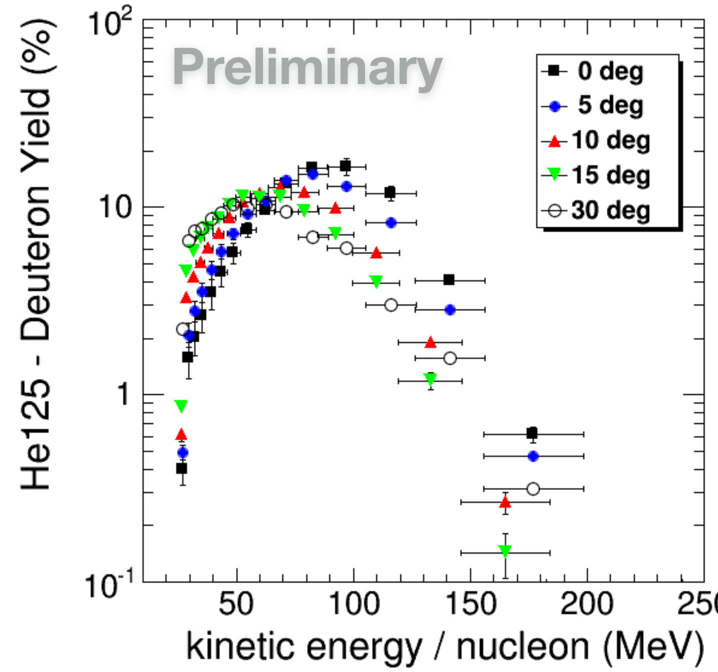
Paper in preparation: forward He ion beam fragmentation on PMMA target

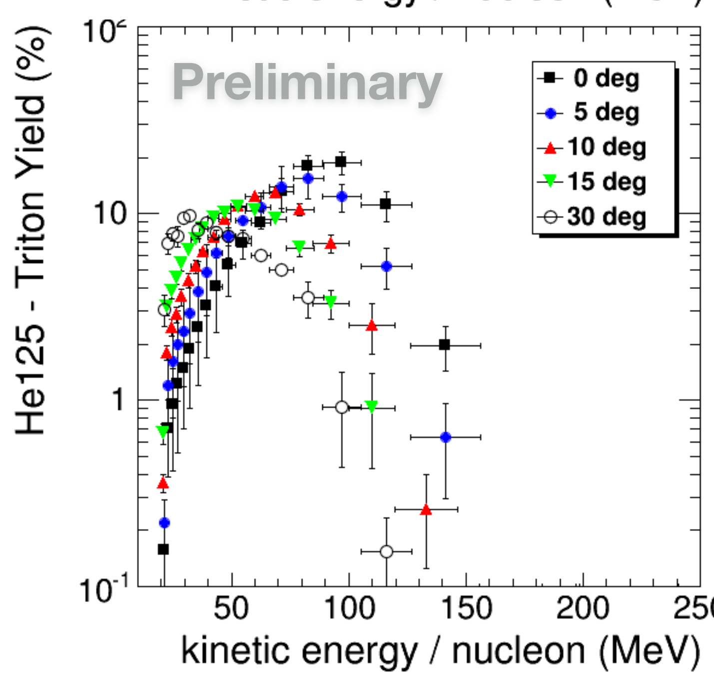
Fragmentation Analysis

The absolute Yield for p,d,t, and more in general for H, has been calculated for all angles and beam energies (102, 125, 145 MeV/u).









Paper in preparation: forward He ion beam fragmentation on PMMA target

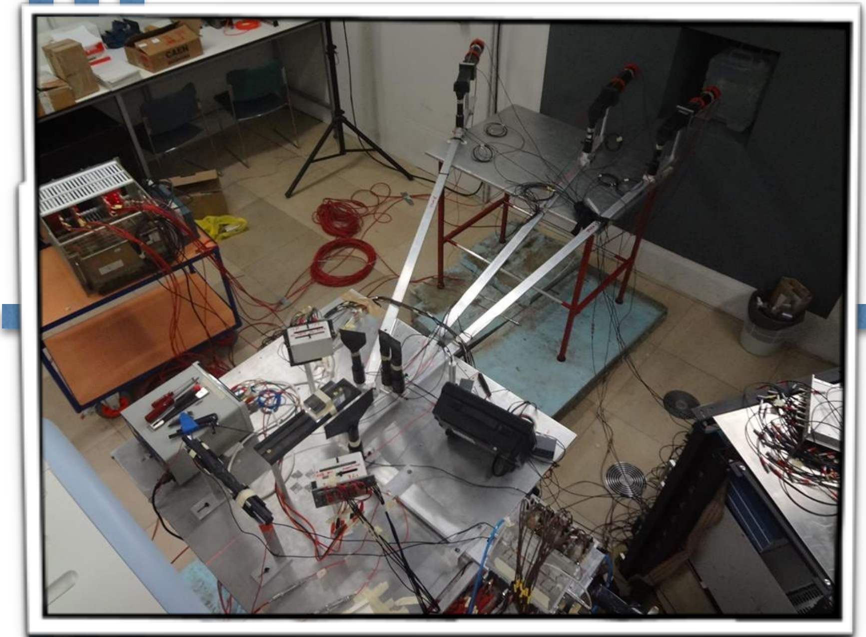
Report and Update on HIT Experiment Analysis

Resuming:

- the **prompt gamma** yield at production analysis is complete for **He**, **C** and **O** ion beams: it will be submit soon;
- the **charged secondary** analysis on yield, spectra and profile at production is done for **He** and **C** and it will be submit soon. The **O** analysis is still on going but we hope to finish it before summer;
- the **fragmentation** of the **He** ion beam at small angles is complete and it will the submit soon. For **C** and **O** analysis.. wait next few months..
- the **beta+ activity** analysis is still ongoing for **He** ion beams (unfortunately there are no available datas for **C** and **O**);

RDH Meeting

February, 1st 2016



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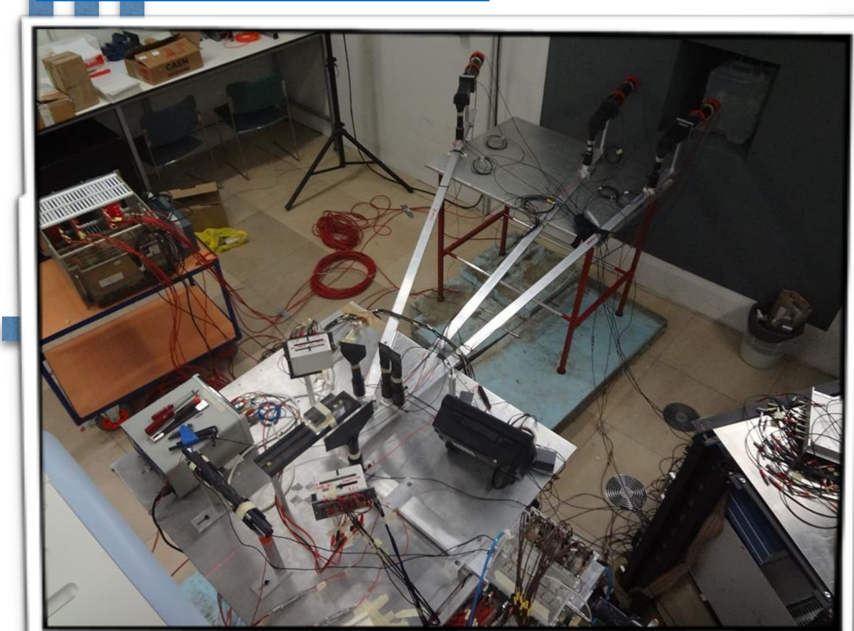
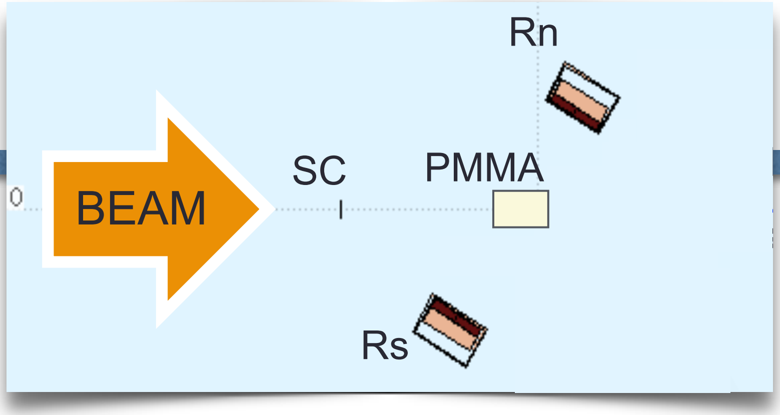


GRAZIE

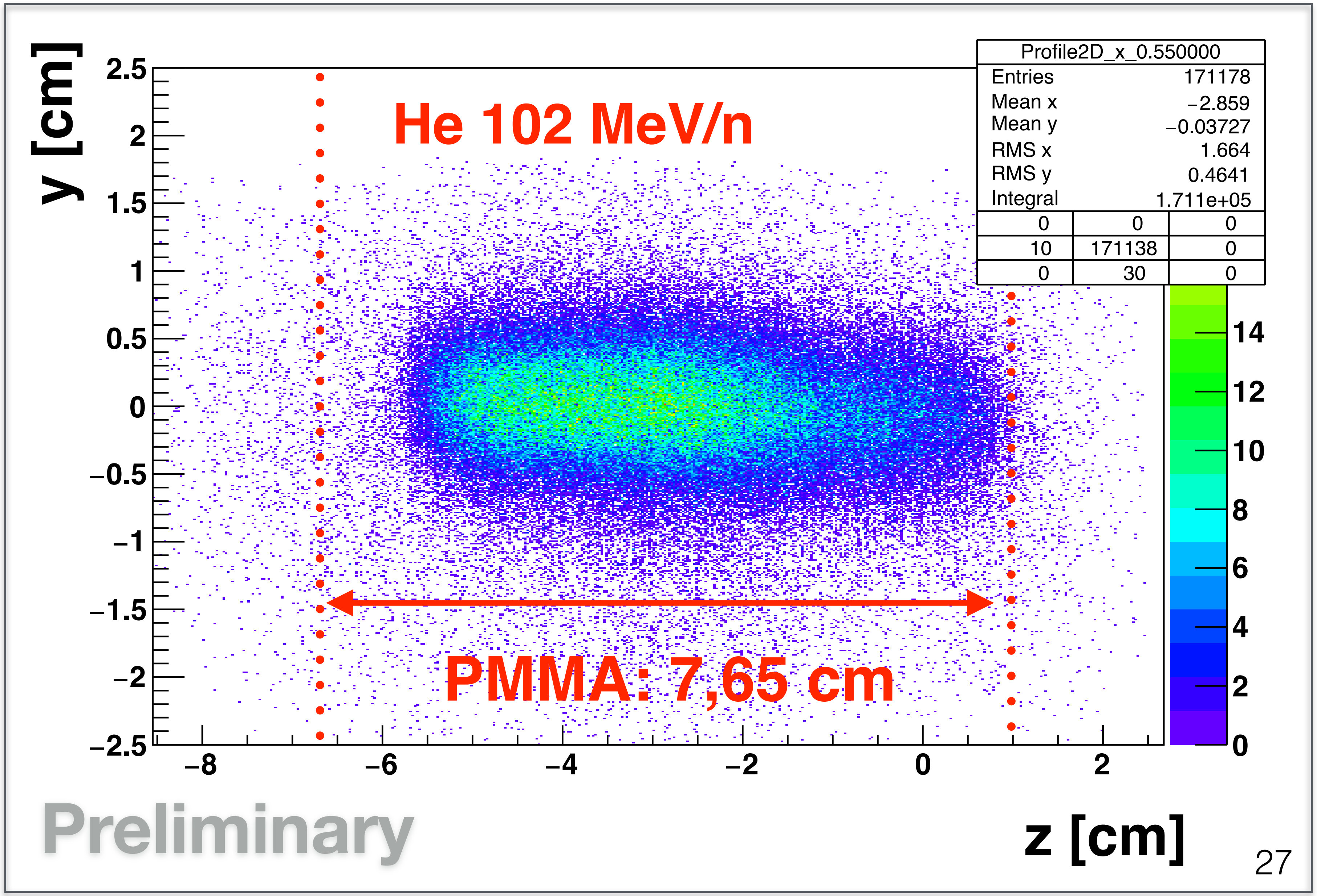
SPARES

Beta+ Analysis

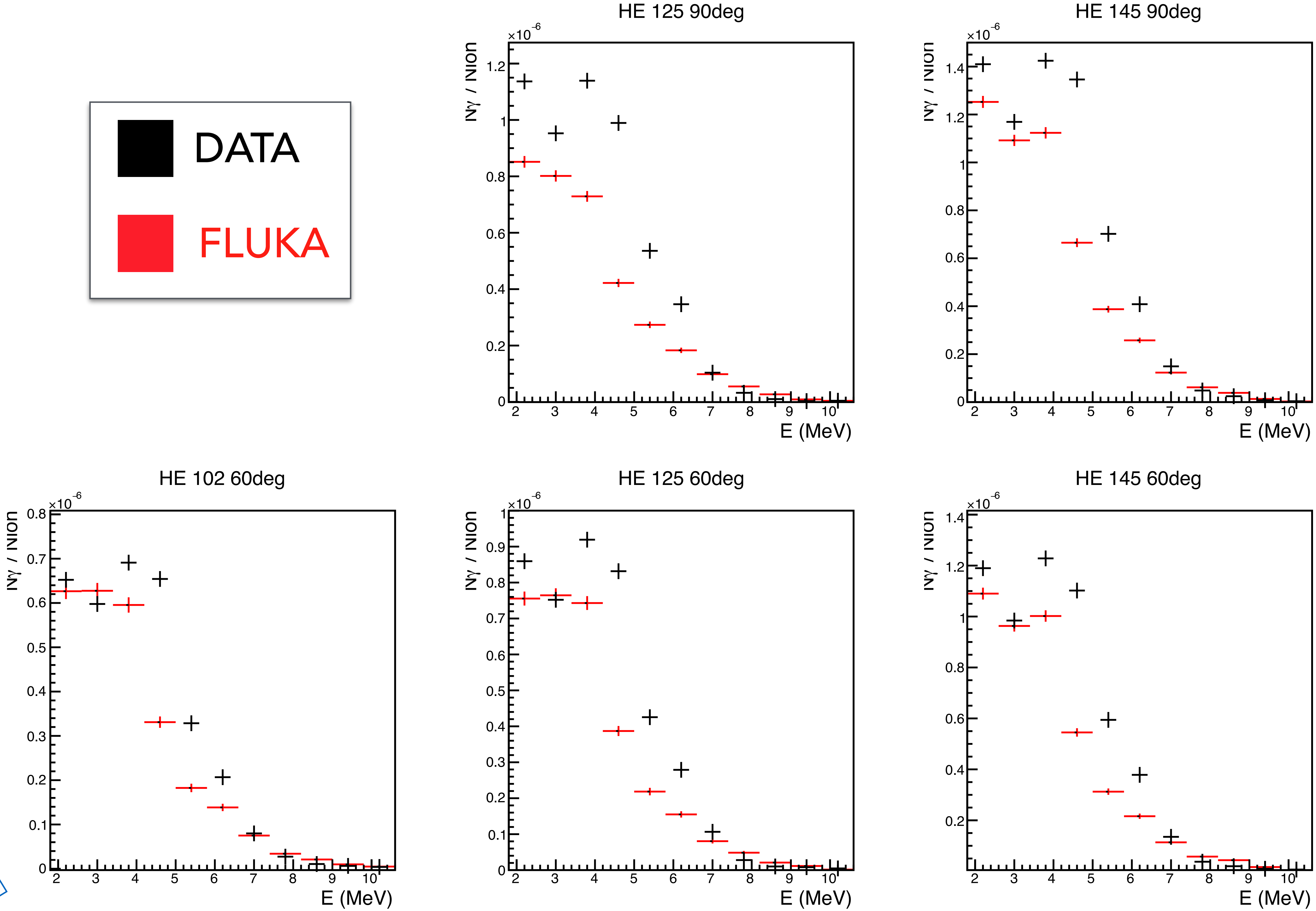
Some effort is ongoing for a further study on experimental efficiency calculation..



Off-Spill analysis



Prompt Raw Energy Spectra



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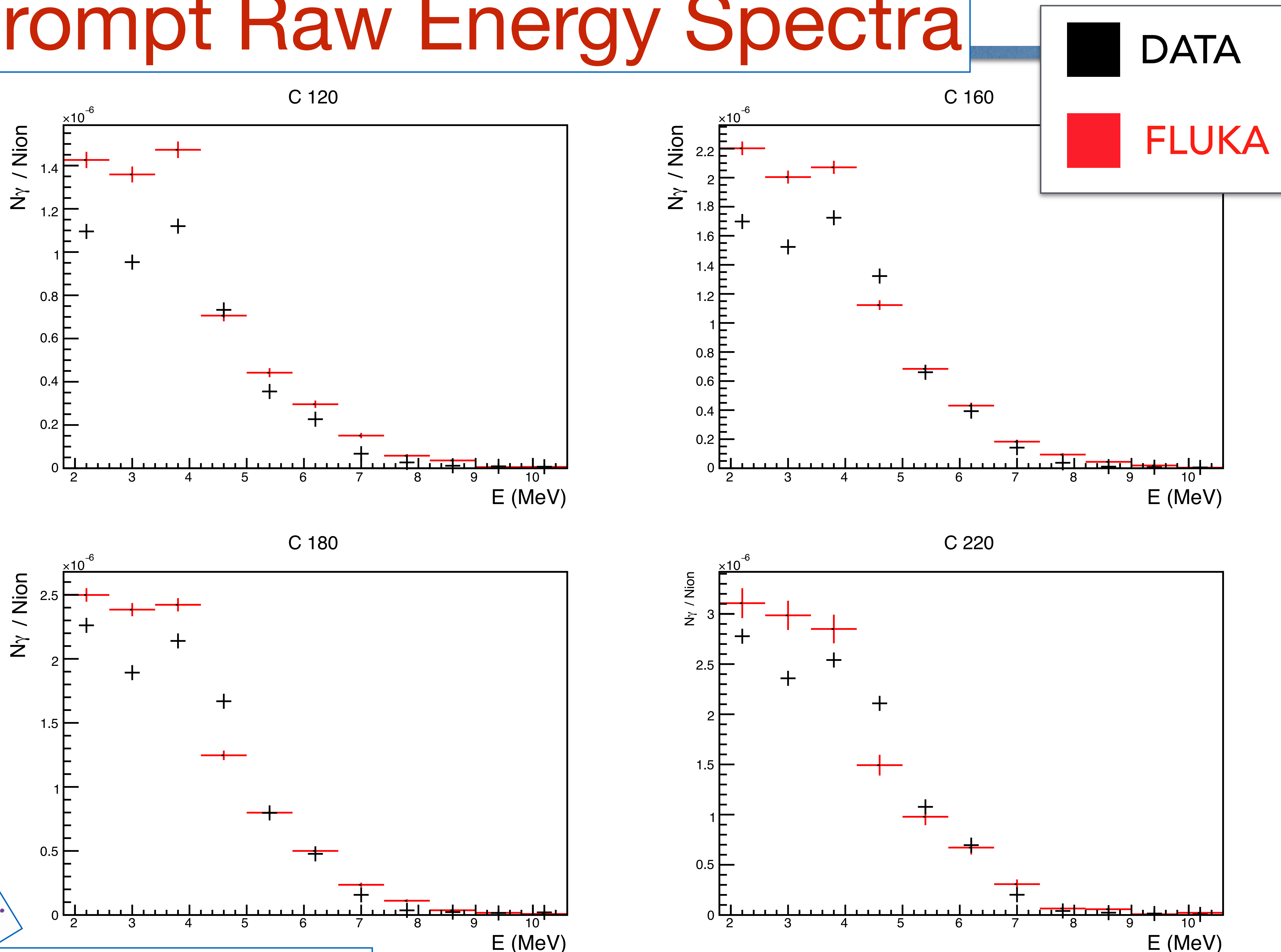

Prompt Raw Energy Spectra