Dose Profiler HIT test beam results

G.Battistoni, F Bellini, F Collamati, F. Collini,
E De Lucia, R Faccini, P. M. Frallicciardi, M Marafini,
I Mattei, P. Nocera, R Paramatti, V Patera, L Piersanti,
D. Pinci, **A Sarti**, A Sciubba, G Traini, C Voena

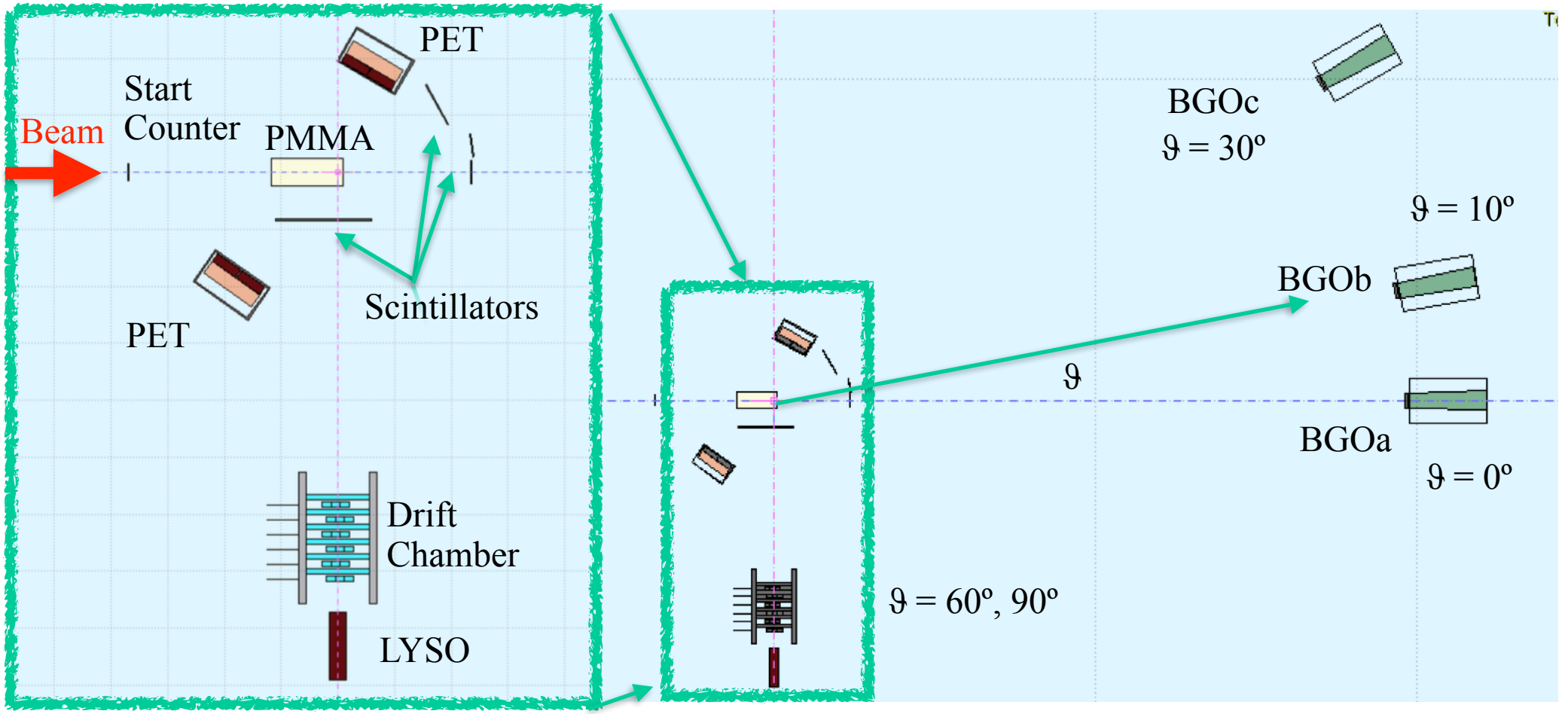
INFN Istituto Nazionale di Fisica Nucleare

Dipartimento di Scienze di Base e Applicate per l'Ingegneria
Sapienza Università di Roma

HIT experiment

- **Multipurpose experiment** aiming for secondary radiation measurements induced by the interaction of **Carbon, Oxygen and Helium beams** of therapeutical energies with a thick PMMA phantom
- The secondary components under study are:
  - **PET gammas**: induced by decays of β^+ emitters generated by the beam interaction with the PMMA. Detector: 2 PET heads equipped with pixelated LYSO crystals
  - **Charged fragments**: induced by the the beam interaction with the PMMA, produced at different angles [heavy fragments ~ along beam line while H fragments @ all angles]. Detector: BGOx [forward angles; only production yields] + Drift Chamber/LYSO [large angles: 60° and 90°; for full fragment tracking, used already for several publications]
  - **Prompt gammas**: "standard" LYSO setup [used already for several publications]

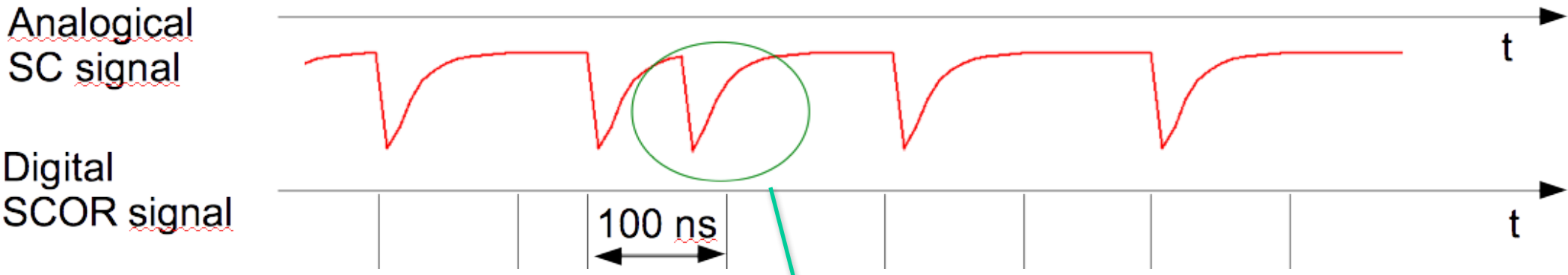
Quick reminder: exp. setup

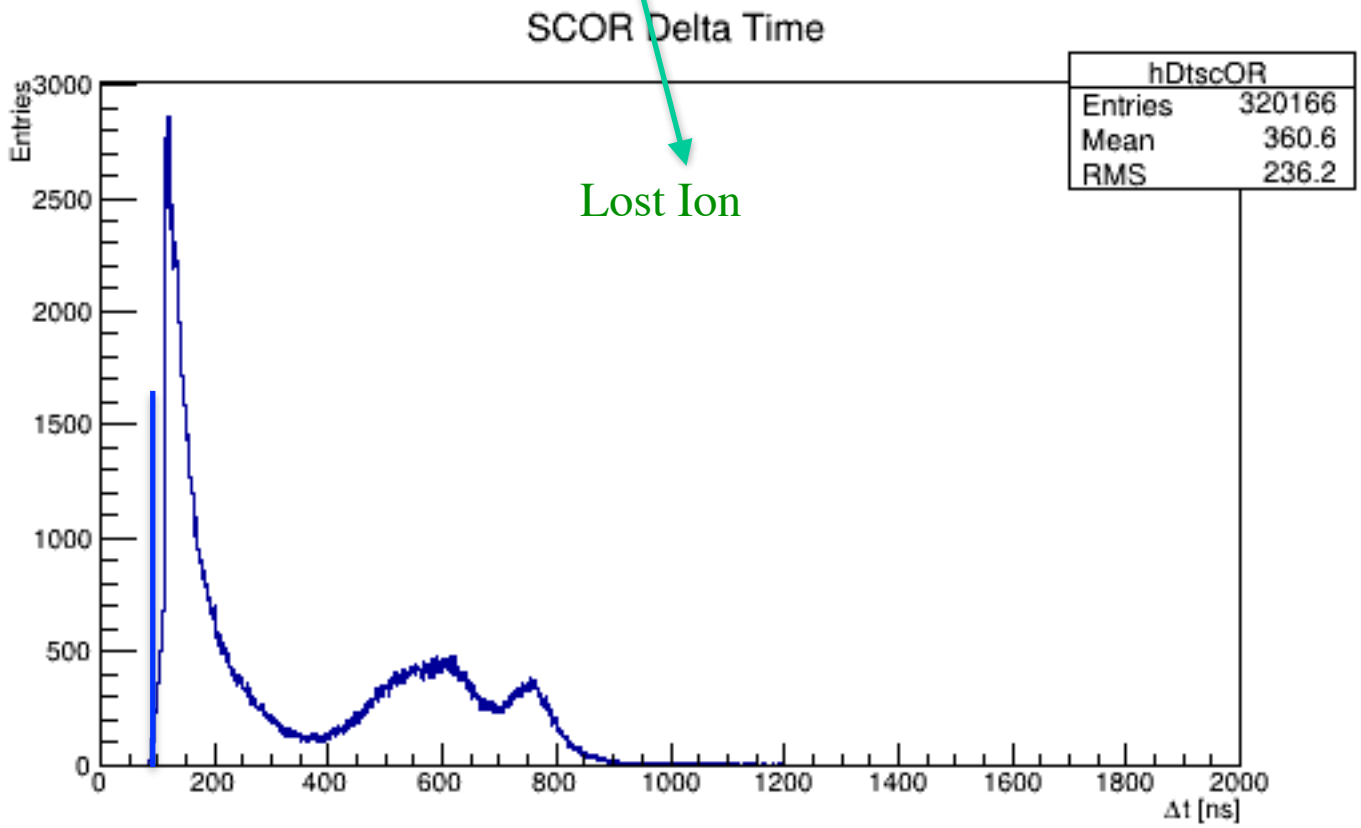


Beam studies

- Besides the "production position" measurements [that are interesting on their own, since they are related to the "per gamma/track resolution" achievable by dose monitors], a crucial input for the DoseMonitor project is the **flux** of the secondaries
  - To quote a flux, we need to know the absolute rate of incoming ions, impinging on the PMMA.
- The measurement is performed using the SC detector: a thin, fast, scintillator with high (~100%) efficiency. Problem: the SC signal is formed to have a 100 ns length: multiple ions are "seen" only if hitting the SC with $\Delta t > 100$ ns!
  - Started a **huge effort to have a proper simulation of the beam**, in order to evaluate the probability of "2 ions in less than 100 ns" occurrence.

In images…

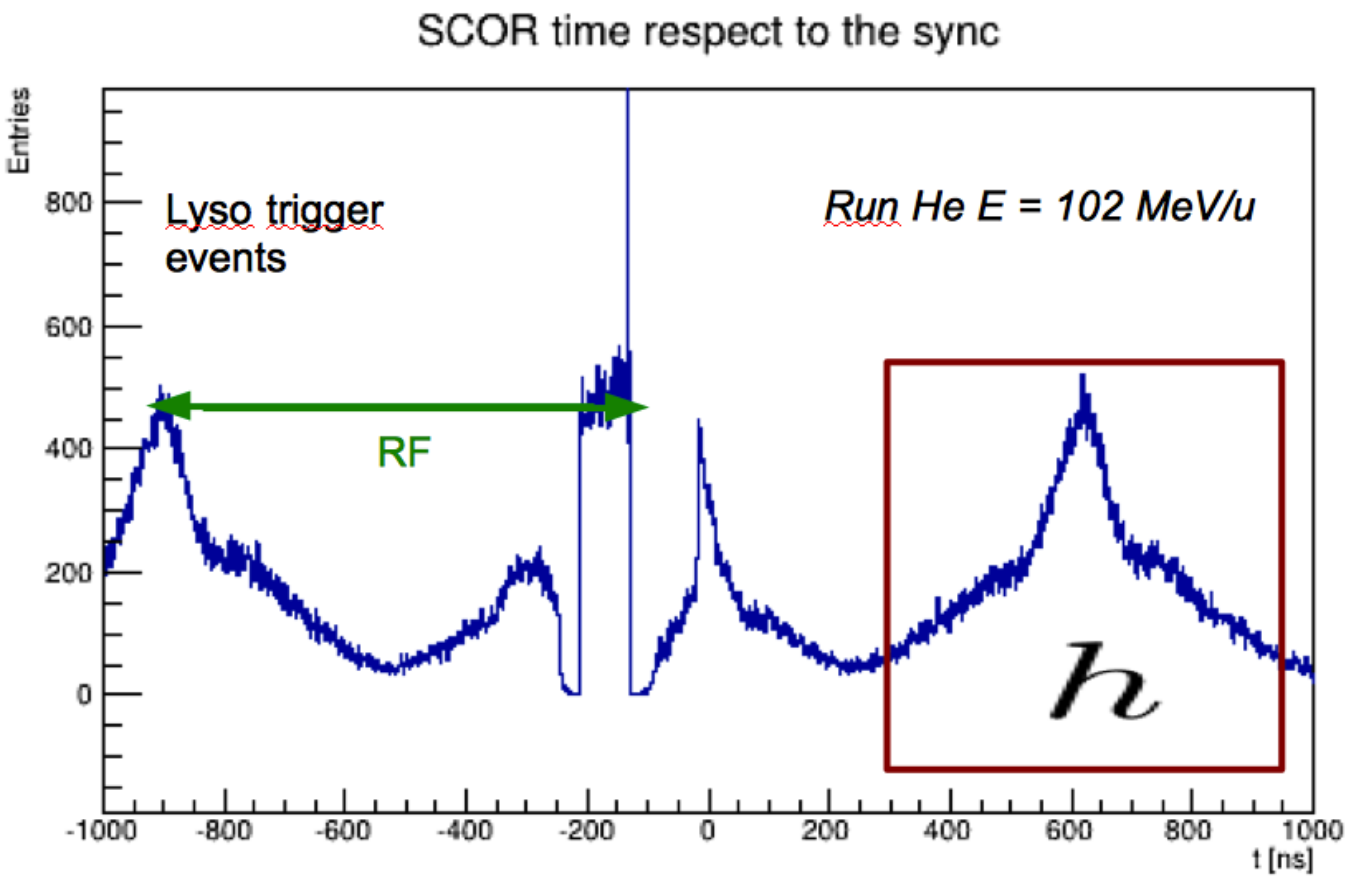




Lost Ion

No signals
with Δt<100 ns

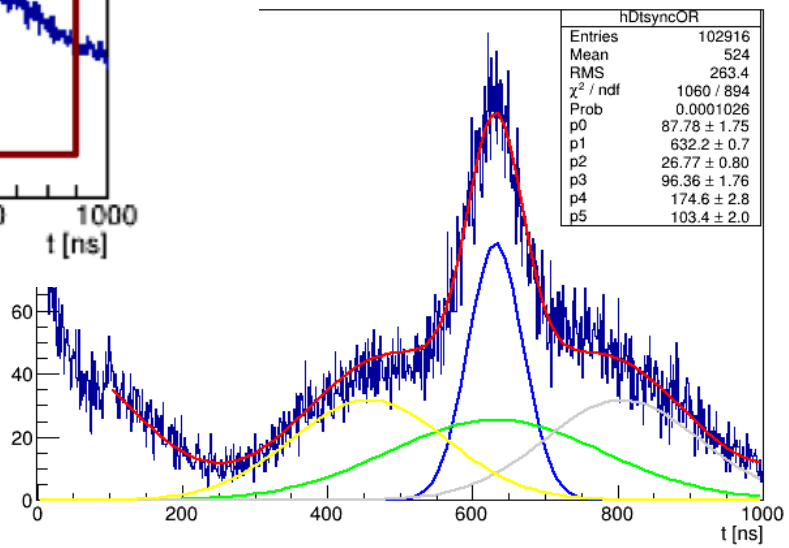
Beam Shape



$$h(\tau) \simeq \int f(t) f(t+\tau) dt$$

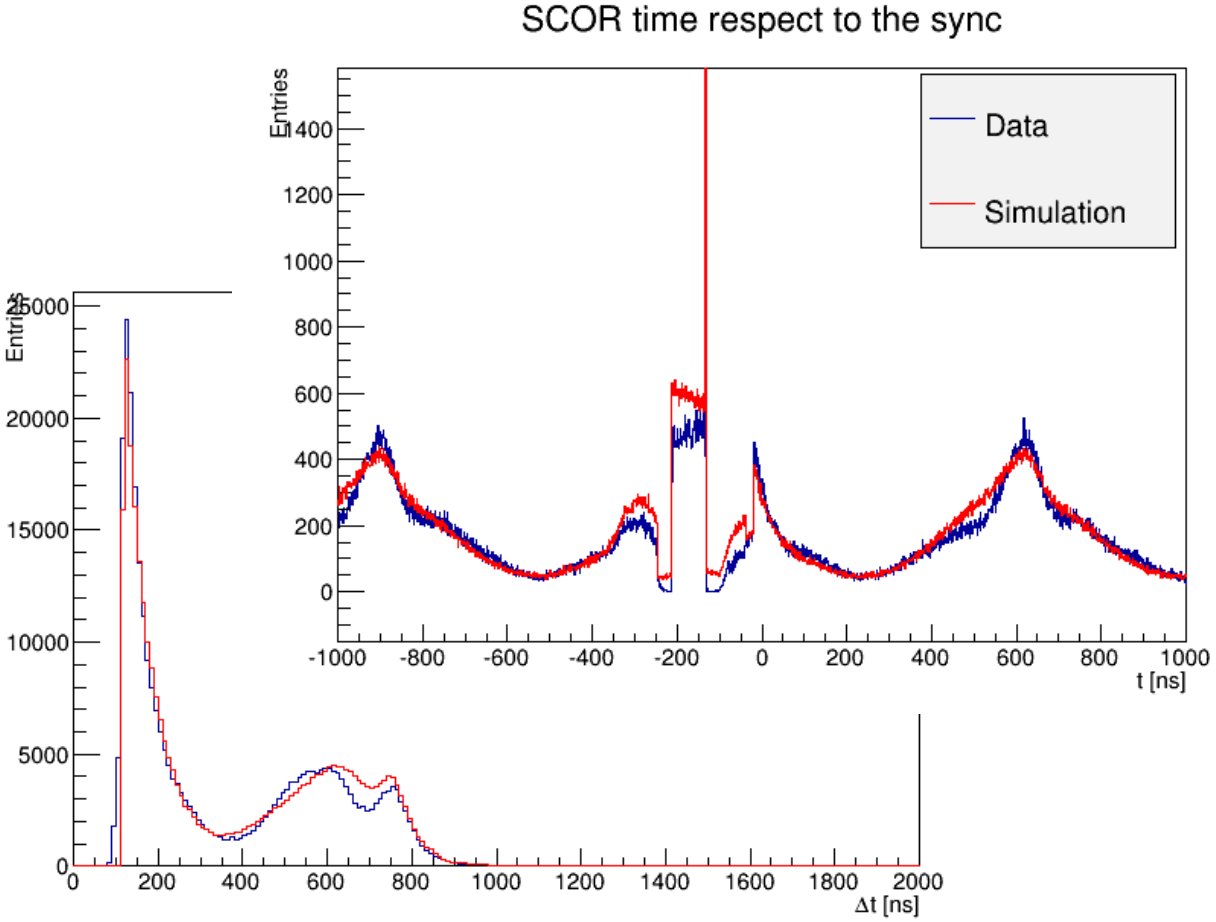
Beam shape

R time respect to the sync



Beam simulation

- Generate # ions in time window 20 μs, rate fixed
- Extract time of ions according f(t) distribution
- Reproduce time of secondary particles [needed for triggering purposes]
- Hide ions with Δt<100 ns
- For every triggered event get the time in SC in window of 2 μs



$$C = \frac{< N_{ion} >}{< N_{SC} >} \simeq 1.54\text{+/-}0.02$$

PET analysis: status

- Fully calibrated/characterized the PET heads

Time σ

	σ_{raw}	σ_{corr}
$N0S0$	9.1 ns	6.5 ns
$N0S1$	7.5 ns	5.8 ns
$N1S0$	4.3 ns	3.8 ns
$N1S1$	1.0 ns	1.0 ns

Energy σ

	$(\sigma/\mu)_{raw}$	$(\sigma/\mu)_a$	$(\sigma/\mu)_{ly}$
$N0$	13.6 %	10.4 %	9.7 %
$N1$	15.2 %	8.3 %	7.0 %
$S0$	14.4 %	13.5 %	13.6 %
$S1$	39.8 %	14.5 %	11.7 %

Spatial σ

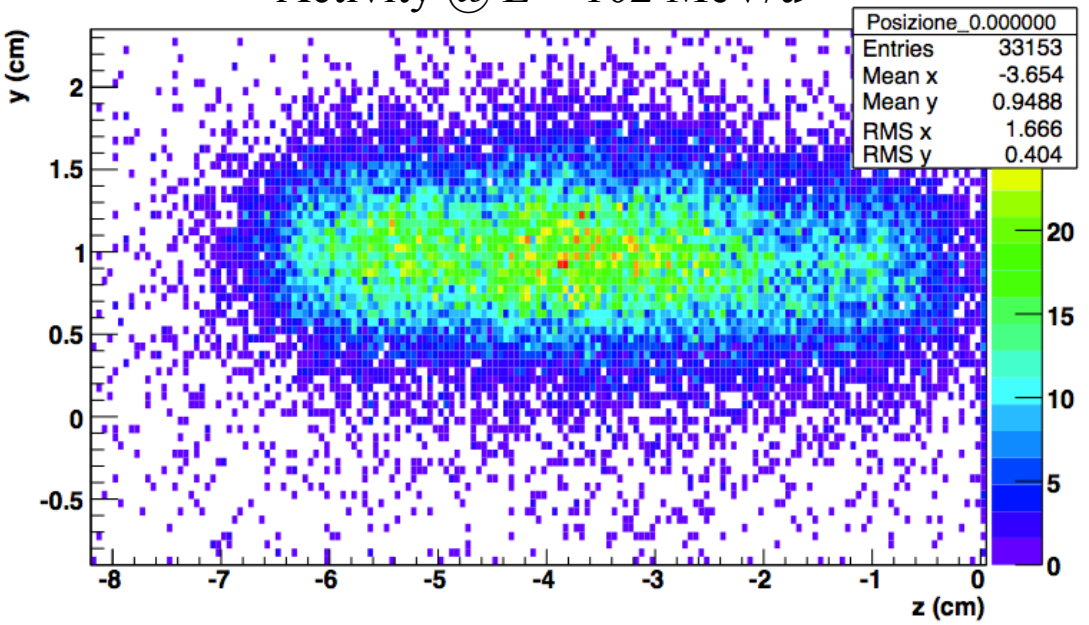
	σ_z (mm)	σ_y (mm)	x_{dec} (cm)	y_{dec} (cm)	z_{dec} (cm)
Run A	1.3 ± 0.1	1.2 ± 0.1	2.45 ± 0.08	0.48 ± 0.01	-6.52 ± 0.06
Run B	1.3 ± 0.1	1.1 ± 0.1	2.10 ± 0.07	0.52 ± 0.01	-1.31 ± 0.05
Run C	1.5 ± 0.1	1.3 ± 0.1	2.06 ± 0.02	0.45 ± 0.02	-3.82 ± 0.02

- Article in preparation (waiting from n(He) to quote final fluxes)
- Analysis of Oxygen and Carbon data is difficult: PET setup was only optimized/fixed with last beam time [He]. Still need to assess what we can measure with those beams…

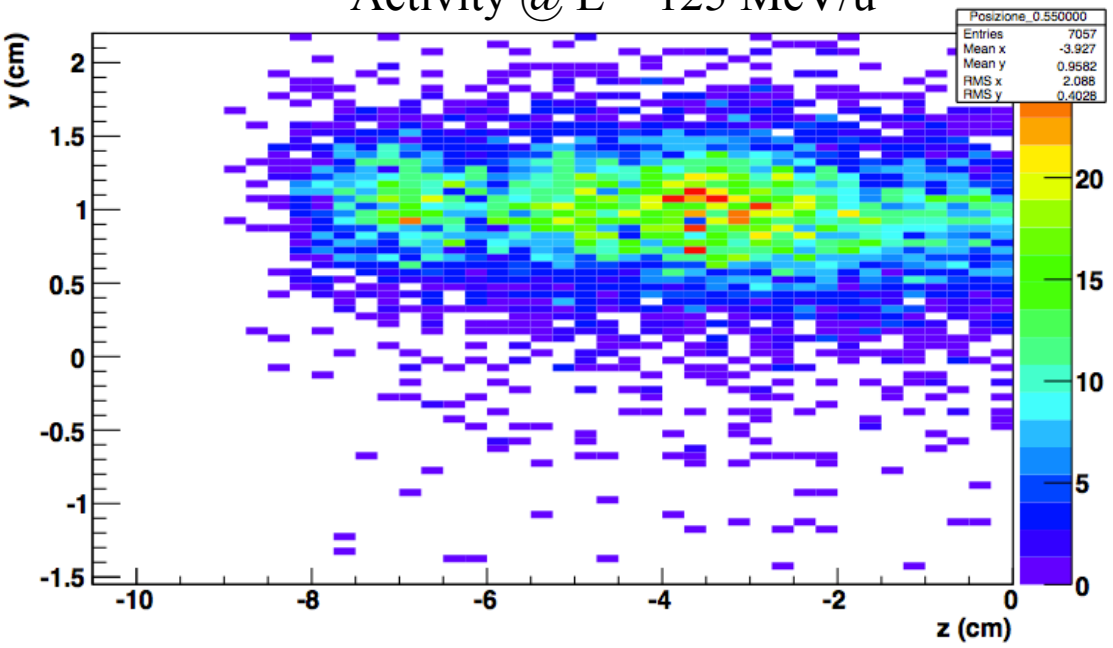
He beam PET analysis: profile

- Emission profile available for all energies: as expected no sharp emission peak around the BP [more H like than C like]

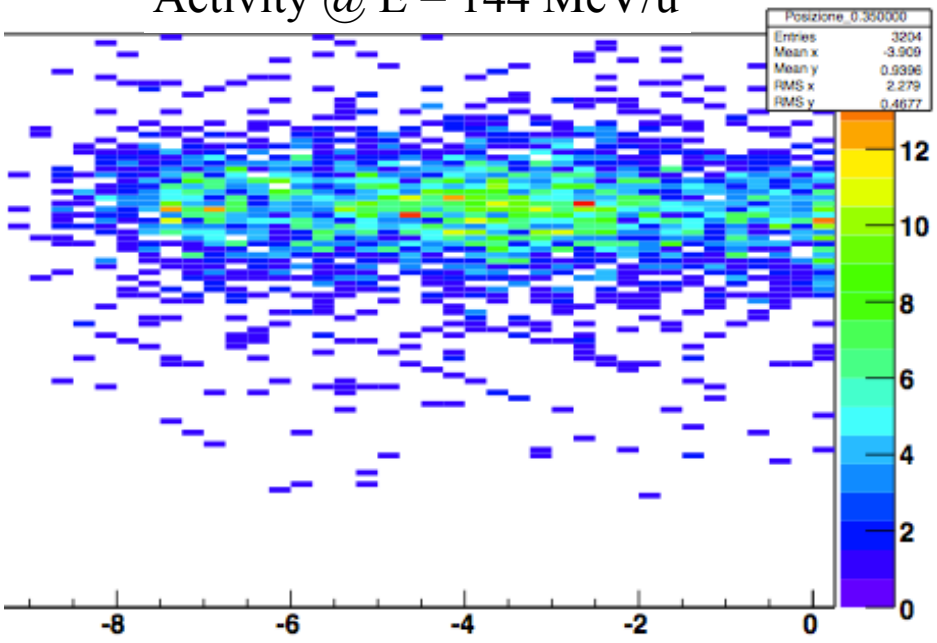
Activity @ E = 102 MeV/u



Activity @ E = 125 MeV/u

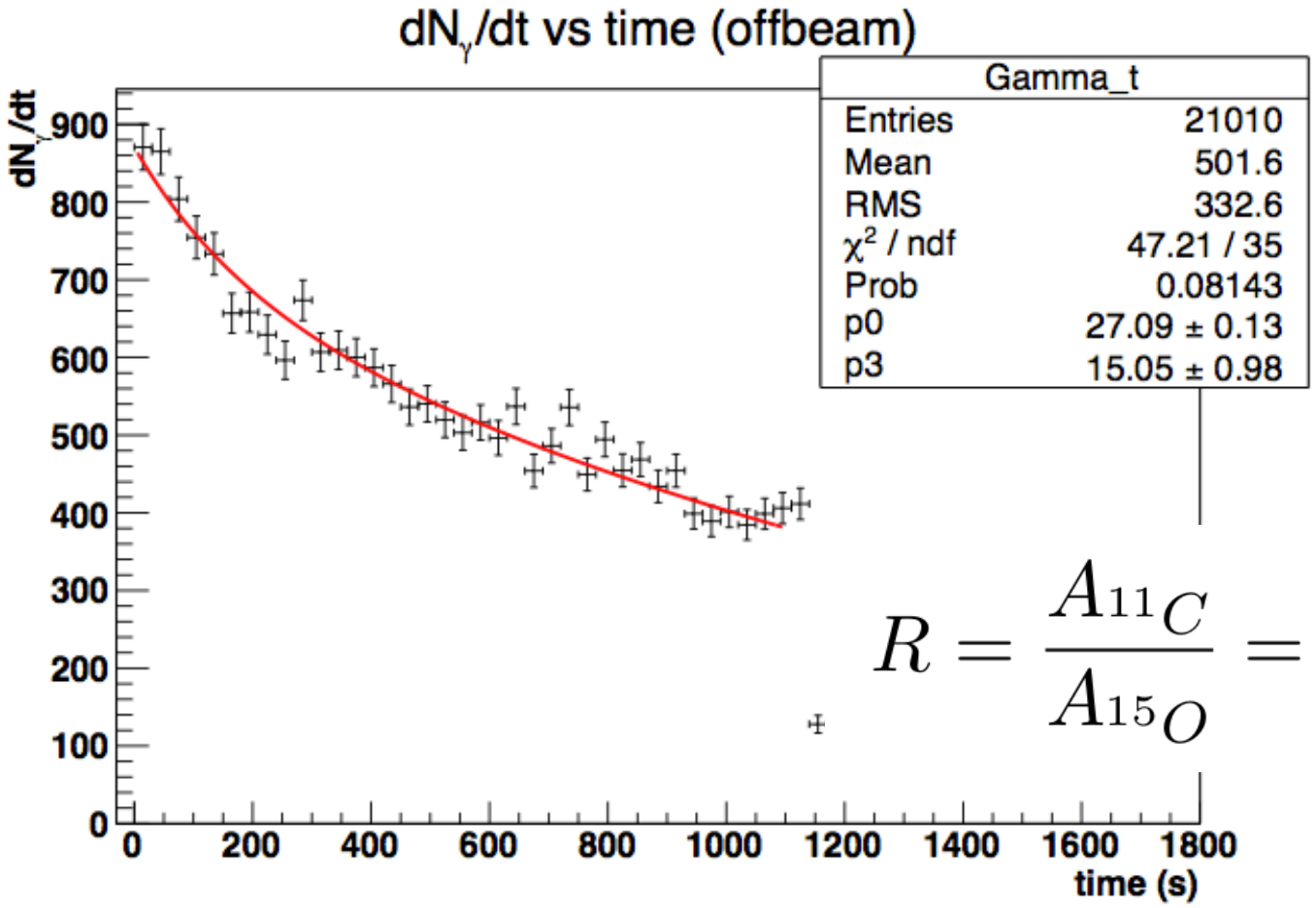


Activity @ E = 144 MeV/u



While waiting for n(He)…

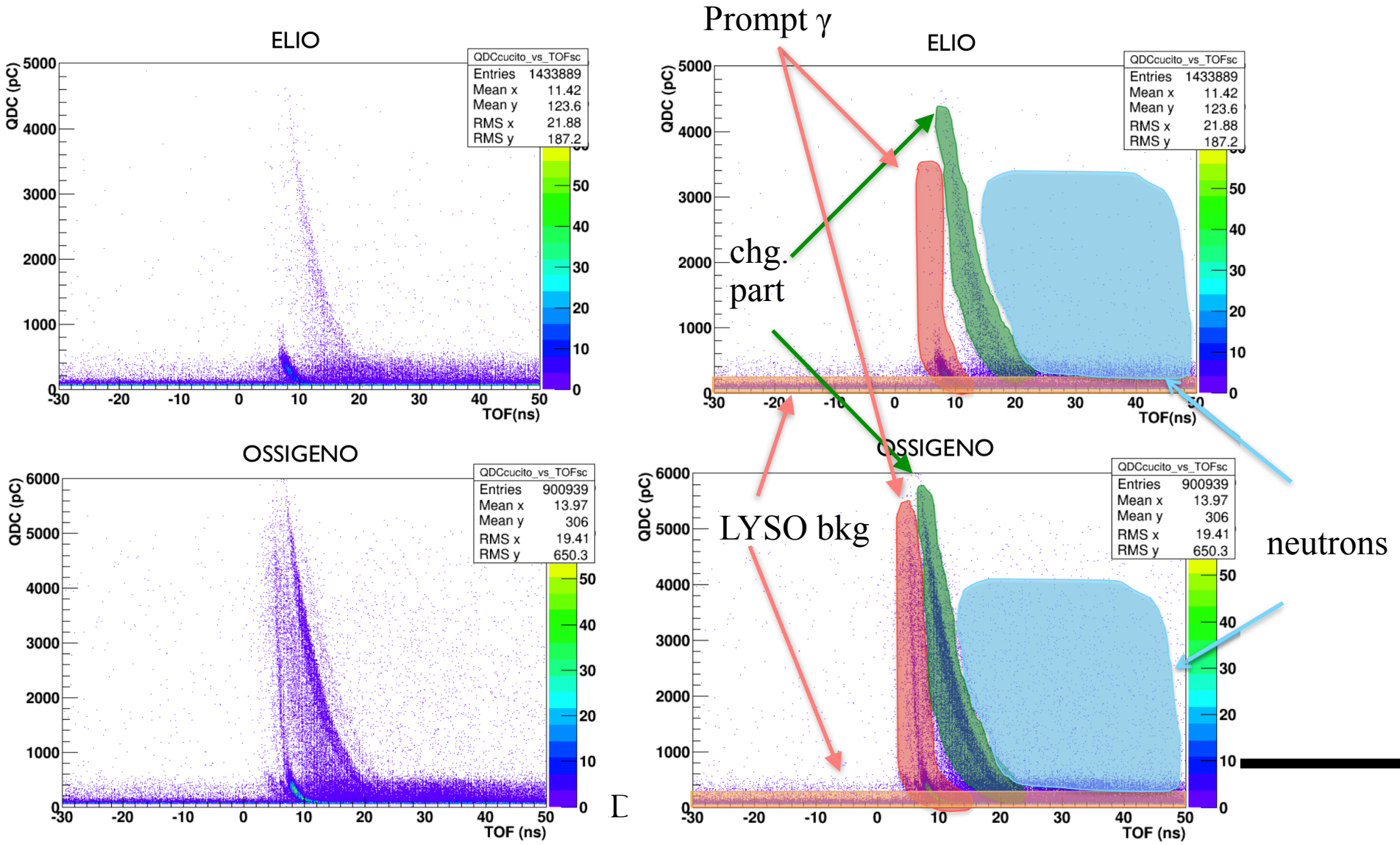
- .. practicing the rate measurements ;) … Focused on ratio!



$$R = \frac{A_{^{11}C}}{A_{^{15}O}} = 3.2 \pm 0.4$$

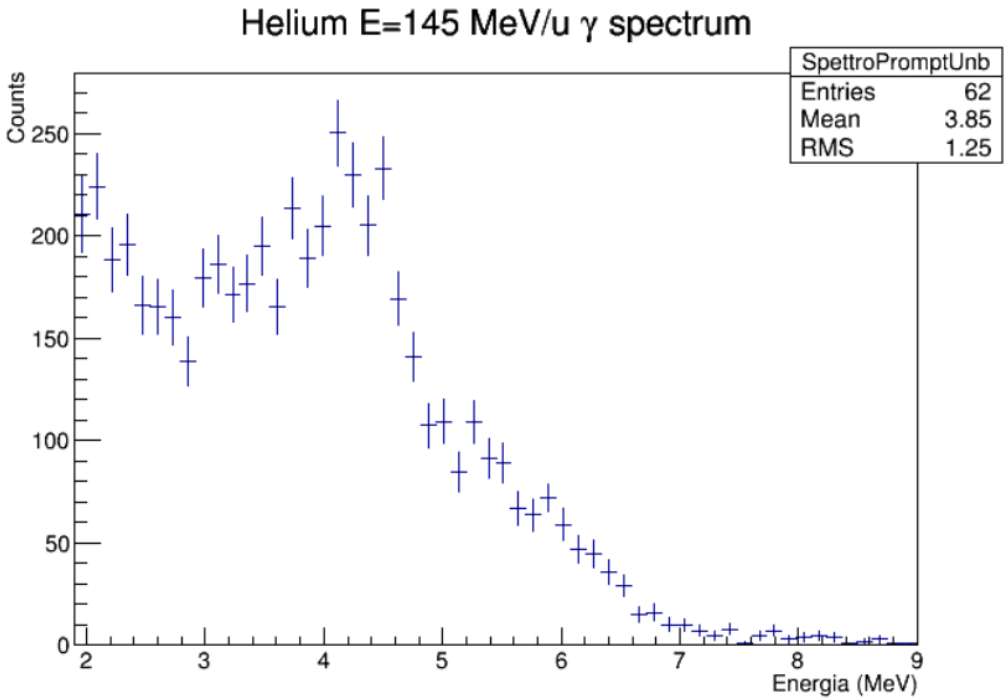
Prompt γ [at large ϑ]

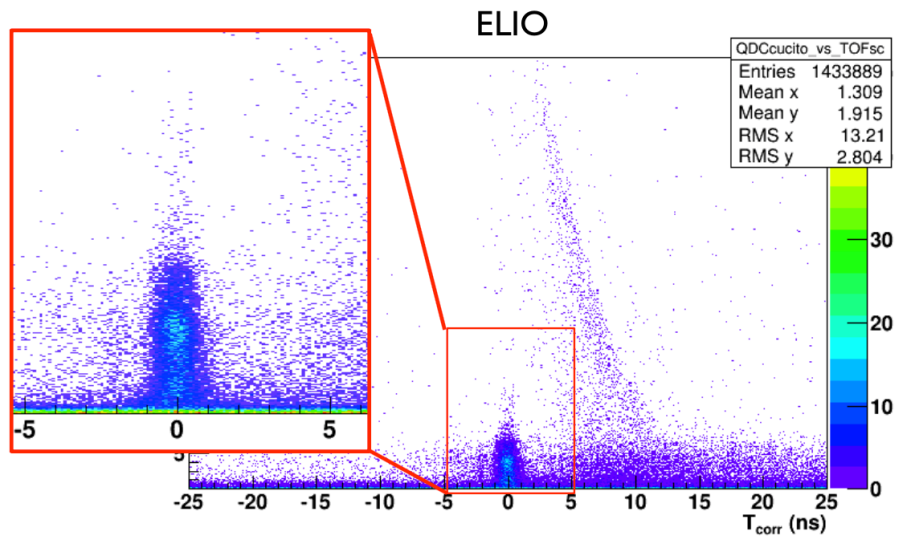
- "Standard" setup [published @ LNS , GSI]

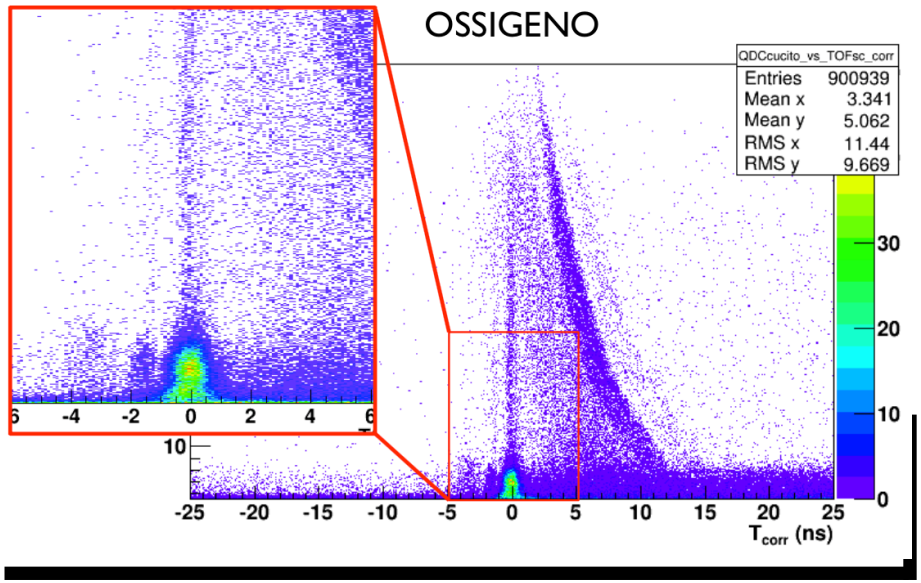


Prompt γ profile

- After calibration and time slewing correction..
  - Profile shape is available



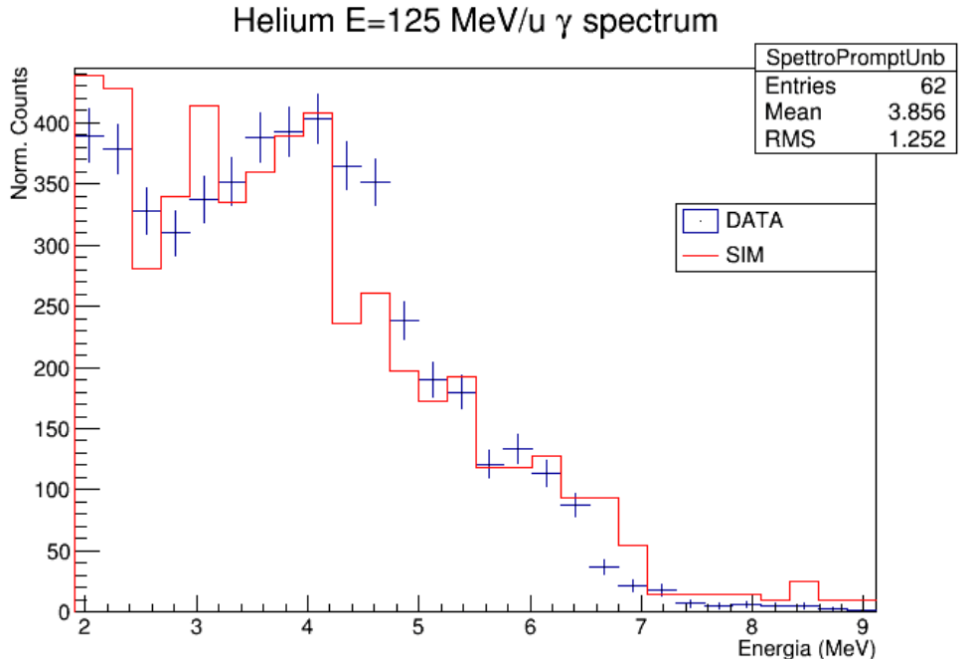


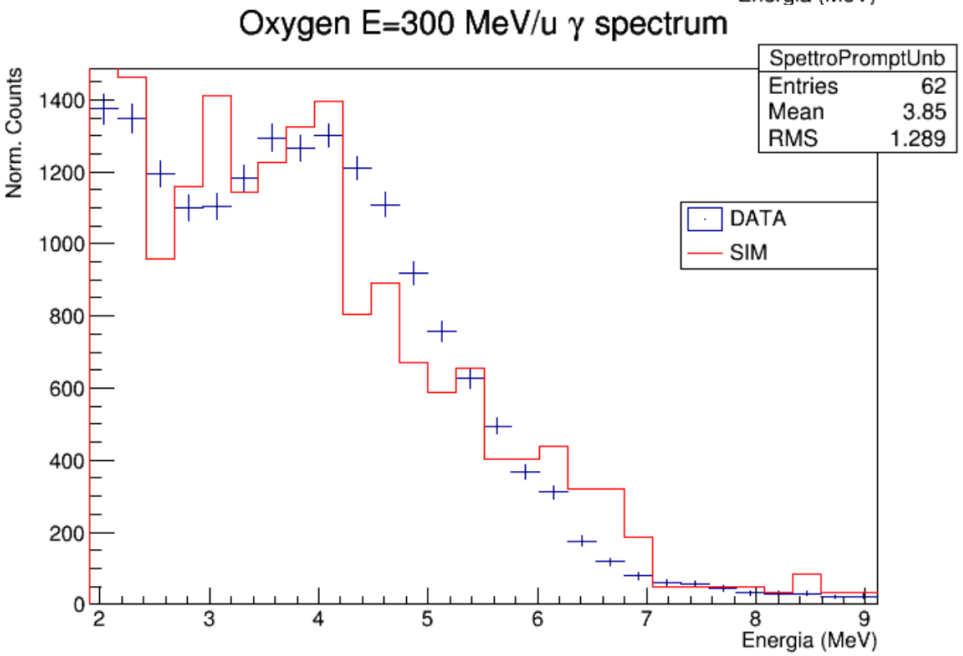


Data & MC results

- Fluka simulation of the HIT setup is available for different energies / beam types.
- Total yields available: still waiting for n(ions) to compute final fluxes

Ione/Energia (MeV/u)	Yield data ($\cdot 10^{-2} sr^{-1}$)	Yield sim. ($\cdot 10^{-2} sr^{-1}$)
He 102	0.25±0.03*	4.72 ± 0.2
He 125	2.6±0.3	5.47 ± 0.1
He 145	2.8±0.3	7.32 ± 0.2
O 210	6.8±0.7	22.2 ± 0.2
O 300	10.2±0.1	27.6 ± 0.1

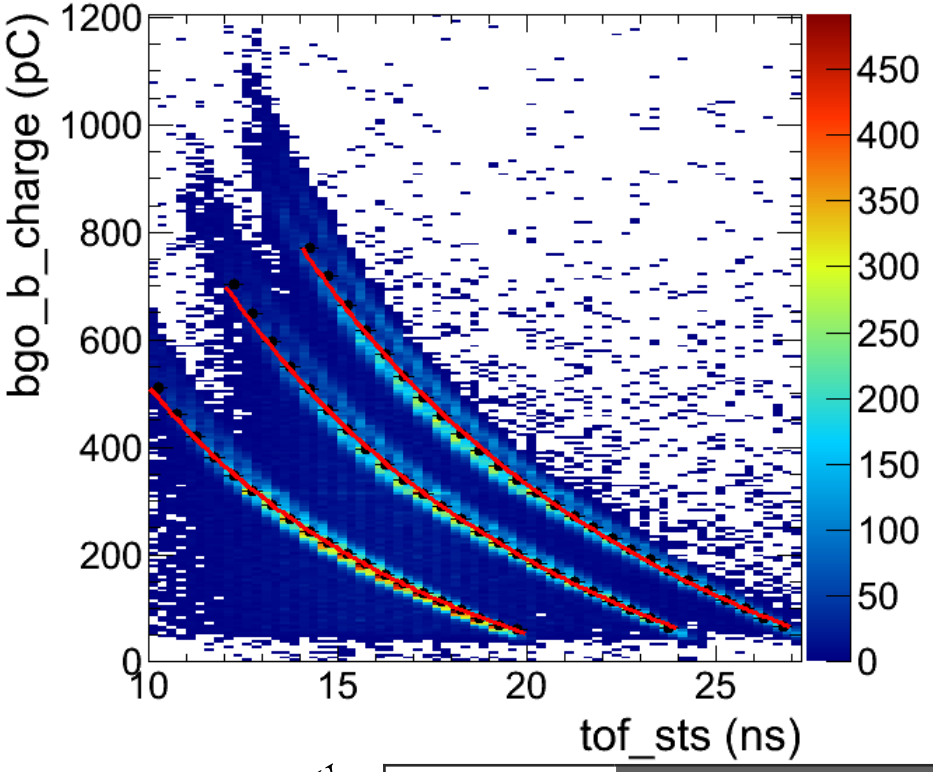




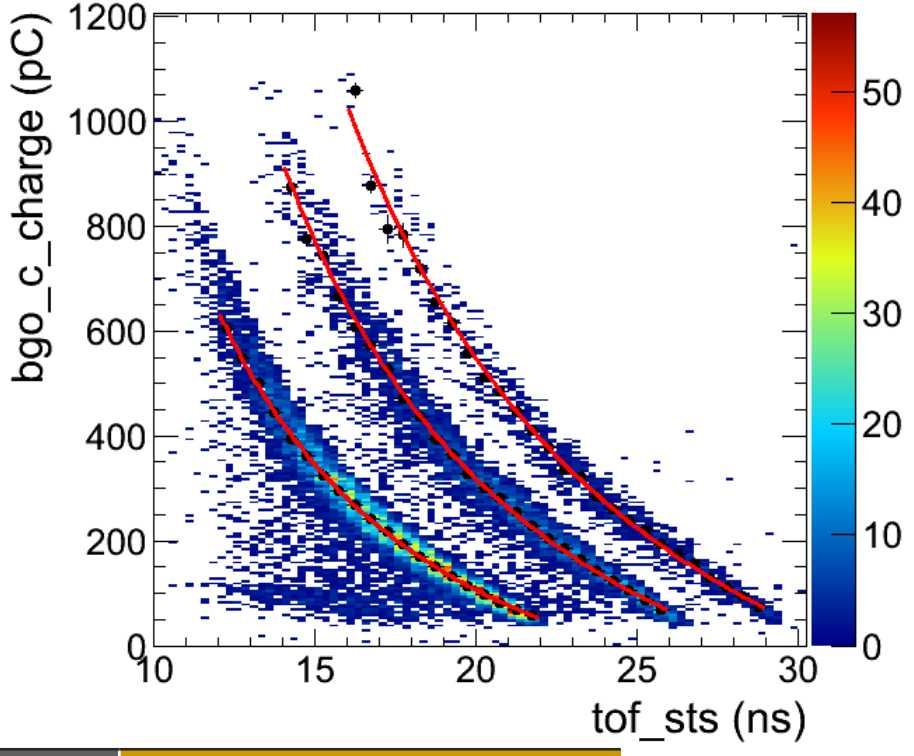
Fragmentation [small ϑ]

- Early stage analysis: for now looked at He 102 MeV/u beam
- Analysis of BGOb and BGOc data performed in the charge/tof plane

p/d/t @ 10°



p/d/t @ 30°

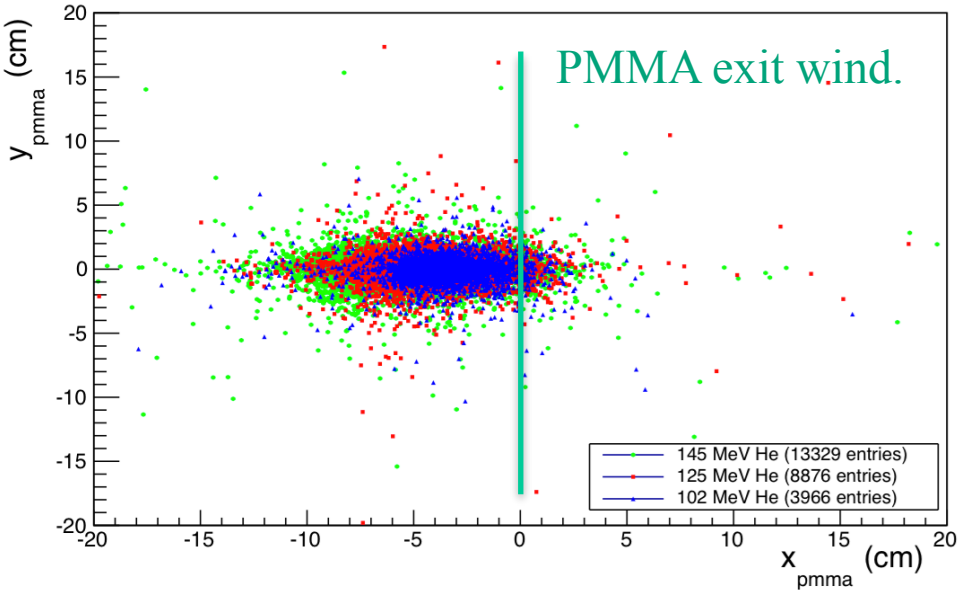


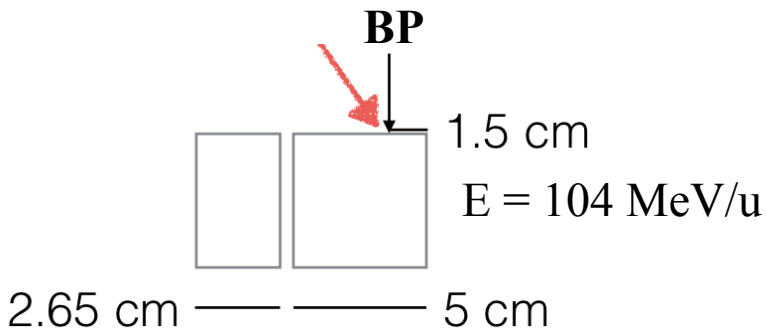
Preliminary

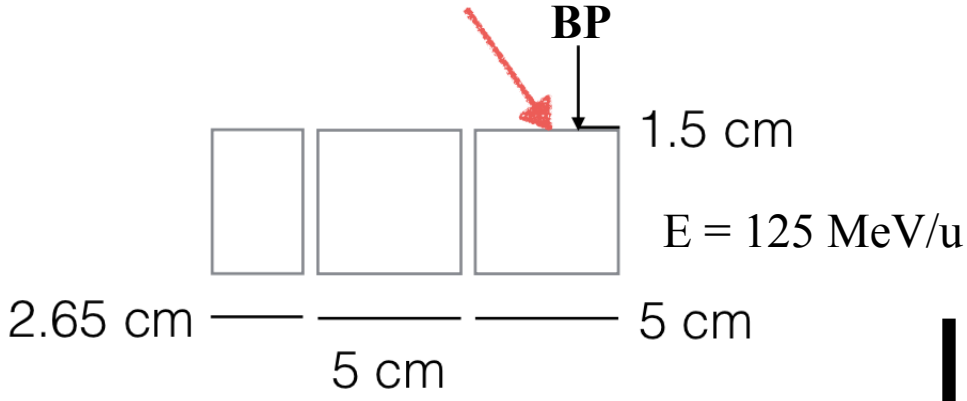
	10 deg	30 deg
#d/#p	0.976±0.039	0.385±0.013
#t/#p	1.066±0.124	0.109±0.014

Charged fragments!

- While waiting for the total number of impinging He ions [no fluxes!]… we still have access to the beam profiles… [crucial for monitoring]!
- Different PMMA configurations used to have the BP at a fixed position/distance [1.5 cm] from the PMMA exit window for the different beam energies (ranges)

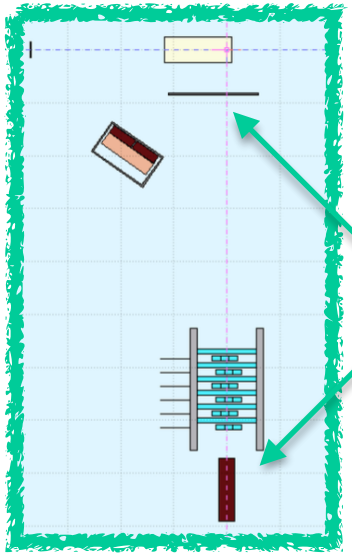




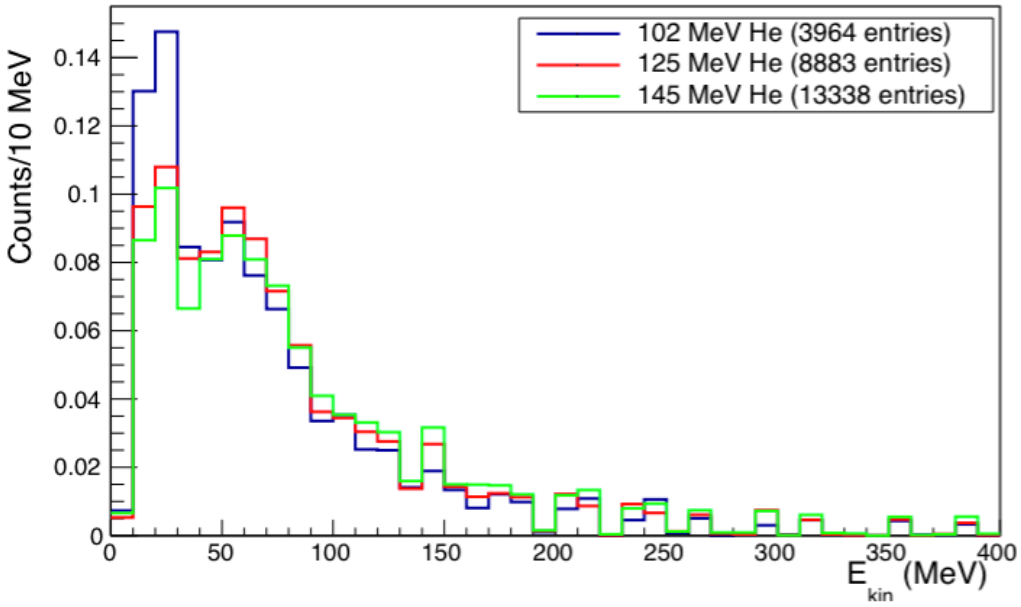


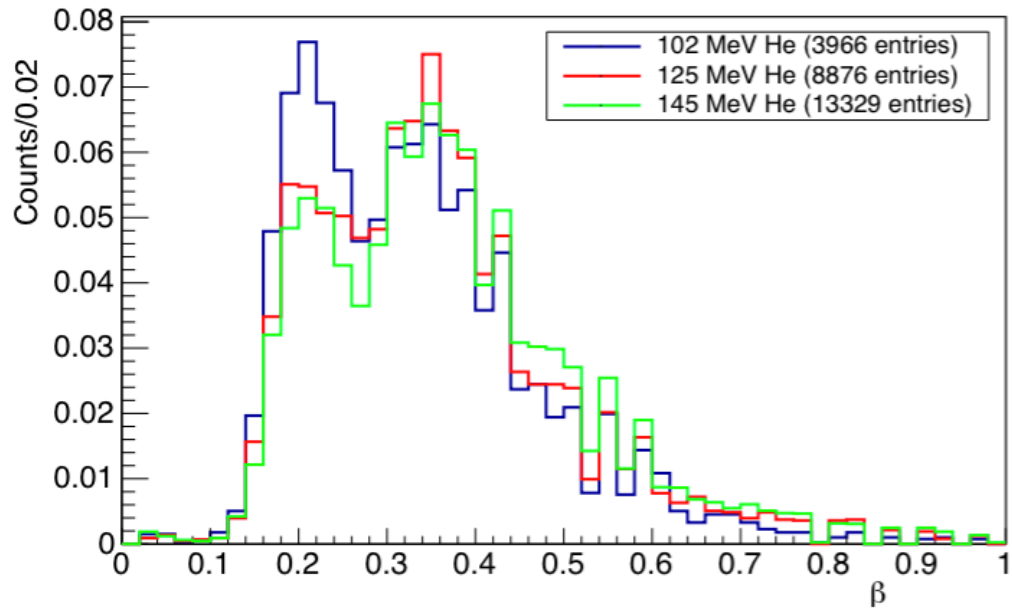
E_{kin} and β

- HIT exp. setup allows for a direct measurement of the β and the kinetic energy of the secondary charged particles using the ToF measurement!
  - QDC vs ToF plane can be used to separate p,d,t fragments



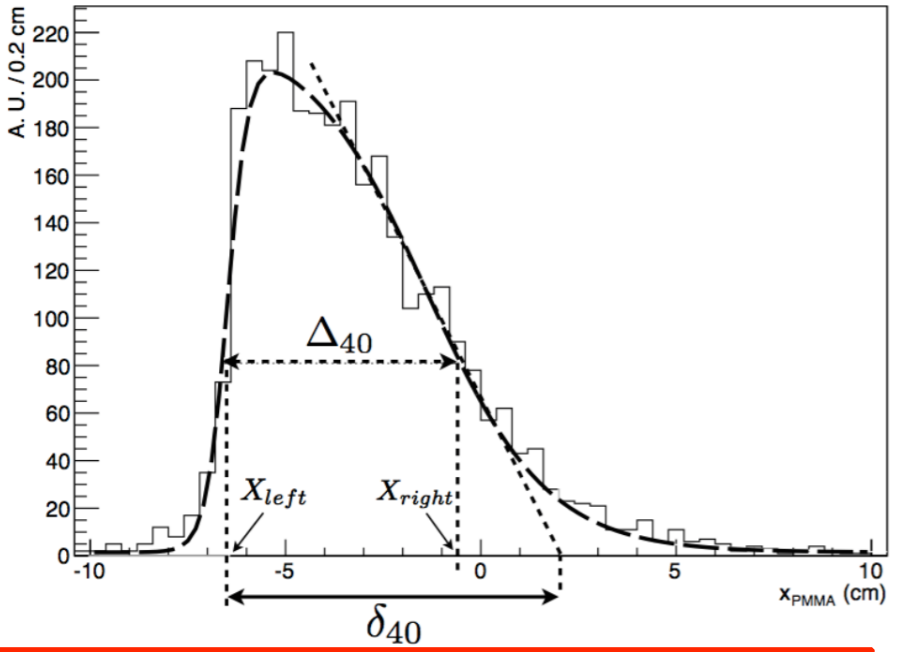
ToF btw LST [thin scintillator just outside PMMA] and LYSO



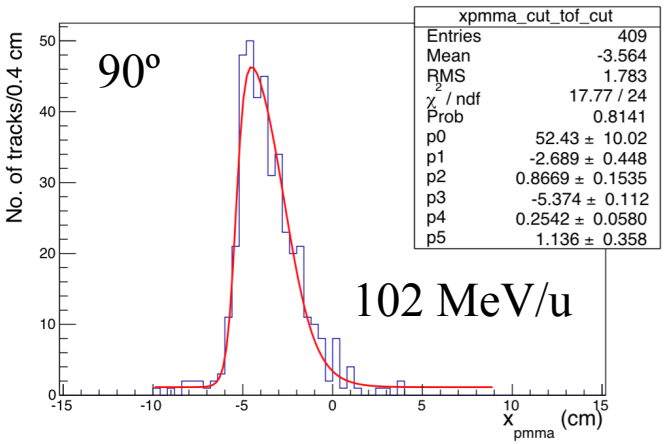


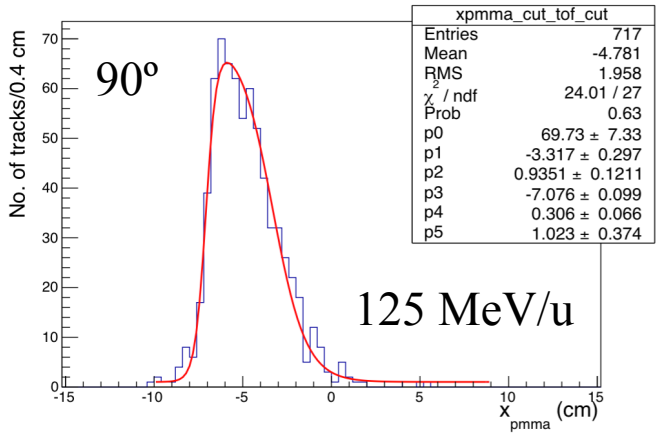
BP position monitoring

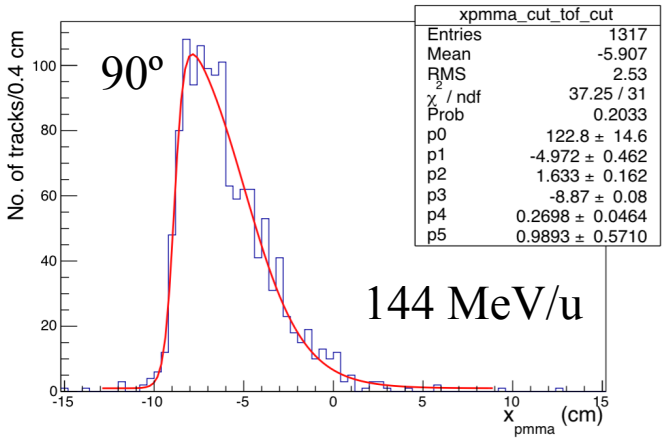
- Emission spectra described by product of 2 th. functions: several fit parameters can be correlated to the BP position [calibration needed]
- Profile broadens with increasing E as expected…
- **Confirmed H abundant production @ large angles!**



$$f(x) = p_0 \frac{1}{1 + exp(\frac{x-p_1}{p_2})} \frac{1}{1 + exp(-\frac{x-p_3}{p_4})} + p_5$$



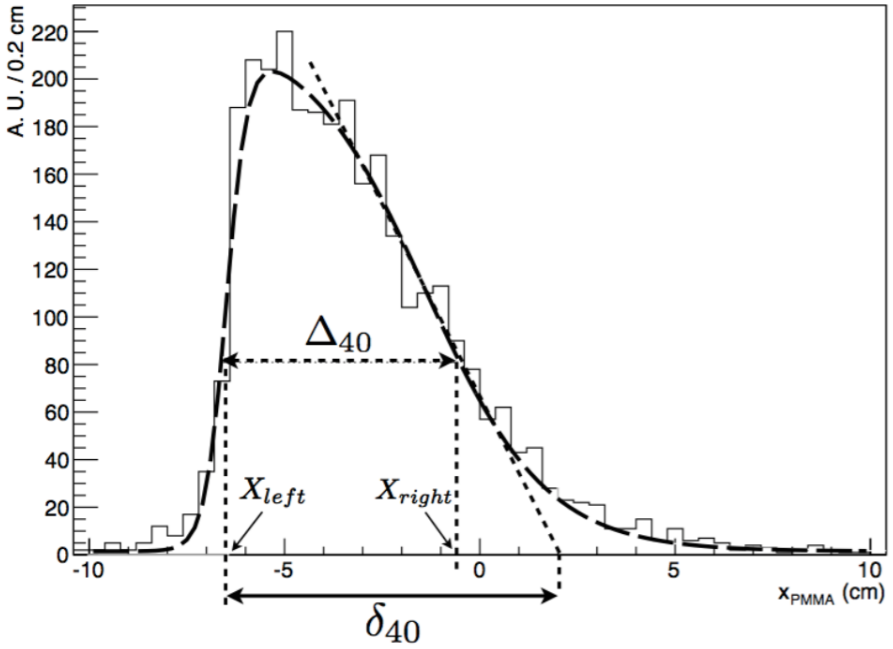




BP position monitoring

- From the preliminary analysis … monitoring capabilities are confirmed on He beams! So far studied:
  - x_0: from geom. setup
  - p_3: from fit
  - other [X_{left}, Δ_{40}, δ_{40}]: see pic on right

60°	102 MeV/u	125 MeV/u	145 MeV/u
x0 (cm)	-6.15 ± 0.05	-8.50 ± 0.05	-11.15 ± 0.05
p3 (cm)	-5.172 ± 0.088	-7.093 ± 0.032	-9.051 ± 0.028
xleft (cm)	-5.533 ± 0.092	-7.310 ± 0.035	-9.249 ± 0.030
δ_{40}	4.830 ± 0.263	6.620 ± 0.145	8.399 ± 0.138
Δ_{40}	3.361 ± 0.179	4.701 ± 0.108	5.955 ± 0.104



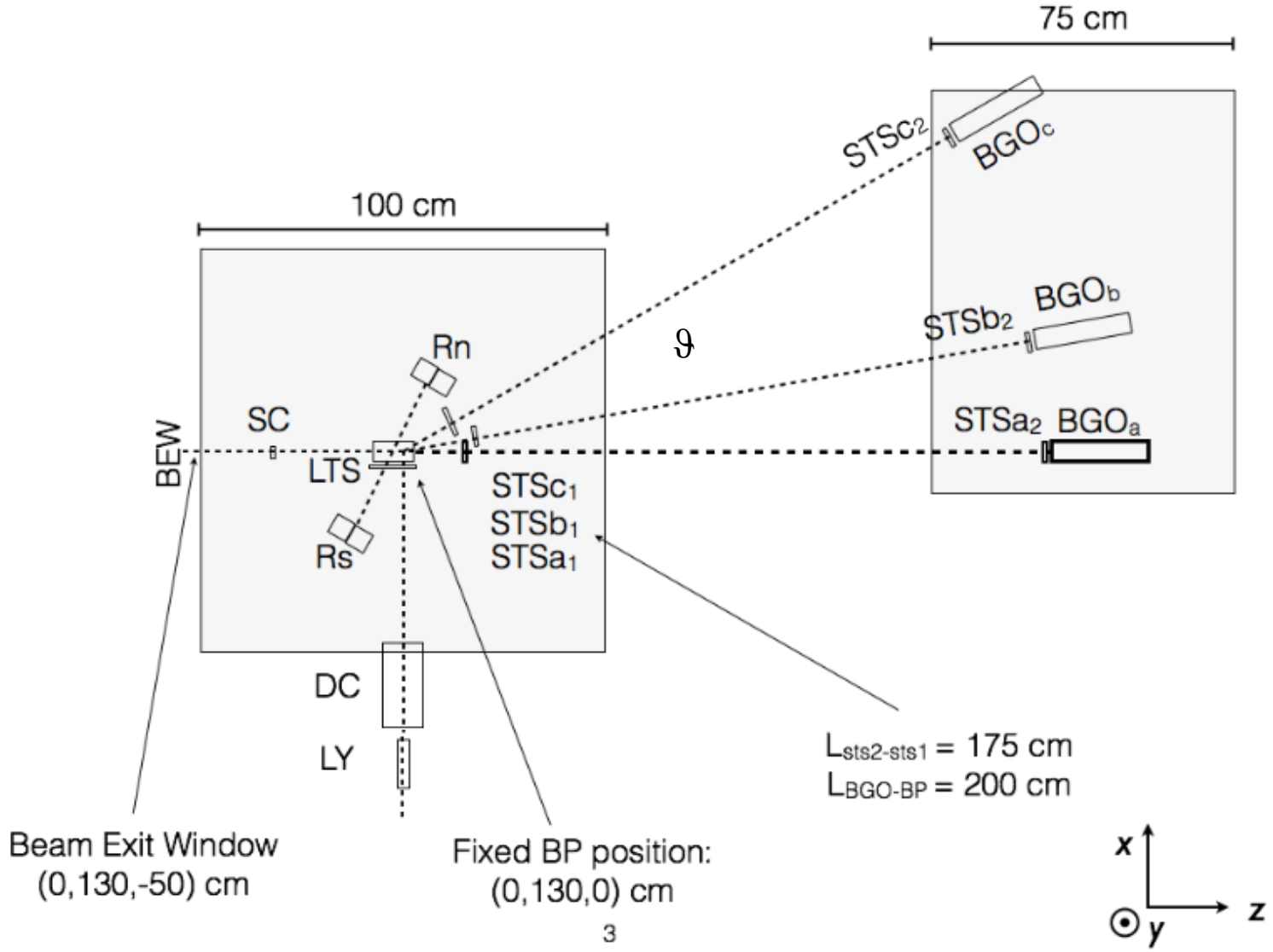
$$f(x) = p_0 \frac{1}{1 + exp(\frac{x-p_1}{p_2})} \frac{1}{1 + exp(-\frac{x-p_3}{p_4})} + p_5$$

Overview

- Beam characterization ~ finalized
- Analysis of all detectors is well advanced: once n(ions) becomes available **x-chk against other published data** and **systematic studies** will start/**proceed quickly towards publication**
- **Performances observed on other beams/energies are confirmed!** Result particularly interesting for
- For now we concentrated on He beam setup [only prompt gammas looked at Oxygen] a full review of all data will start once the beam characterization is performed for all beams.
  - will require some additional work to understand other beams setup [HW changed / fixed btw different beam types]

Conclusions

- We just started to play seriously…. but we're already having a lot of fun!!!!!!


75 cm
100 cm
STSc2
BGOc
STSb2
BGOb
STSa2
BGOa
ϑ
Rn
SC
BEW
LTS
Rs
STSc1
STSb1
STSa1
DC
LY
Lsts2-sts1 = 175 cm
LBGO-BP = 200 cm
Beam Exit Window
(0,130,-50) cm
Fixed BP position:
(0,130,0) cm
x
y
z