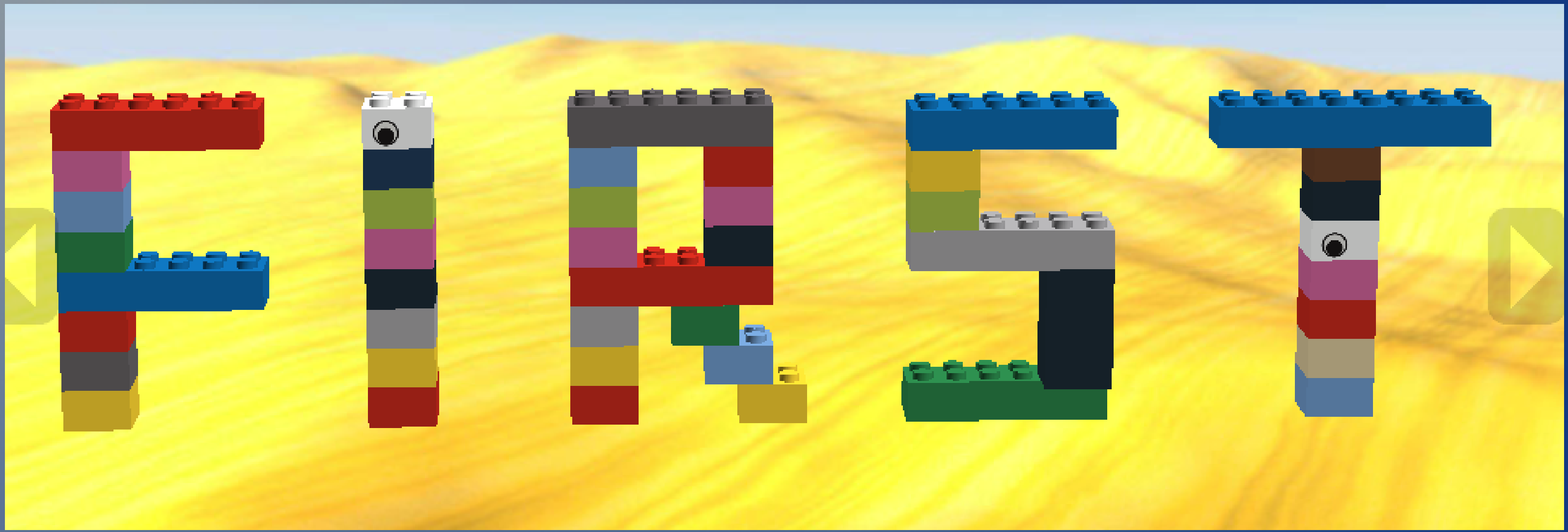
GSI biophysics seminar
15 Dec 2009



The FIRST experiment on fragmentation of high-energy heavy ions of biomedical interest at GSI

Vincenzo Patera
University of Rome and LNF-INFN (Italy)

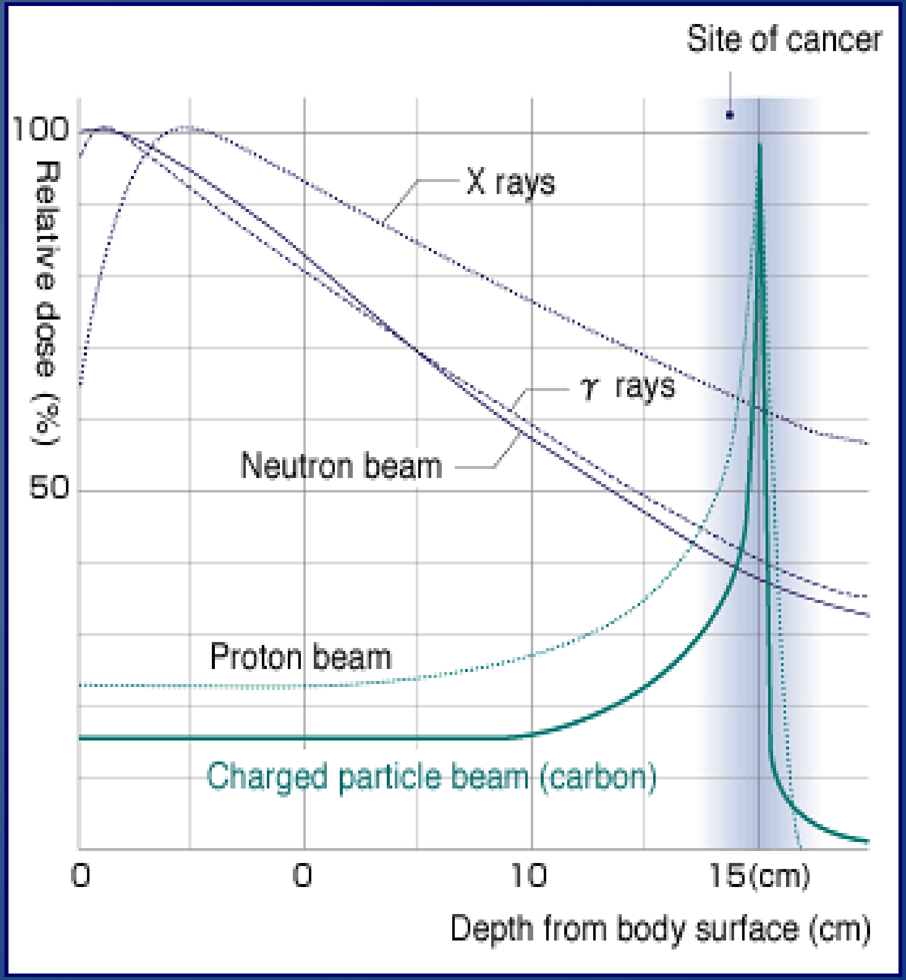
Outline

- ➔ Motivation
- ➔ The Collaboration
- ➔ Experimental setup
- ➔ Eventual future evolutions
- ➔ Summary & conclusion

Hadrontherapy and light ions

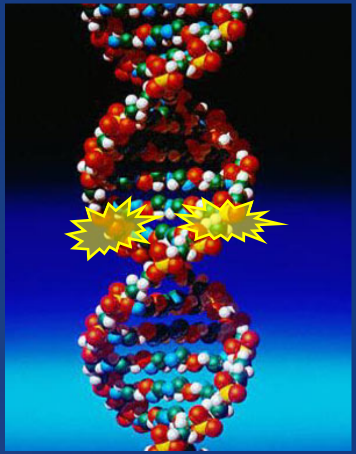
Light ions advantages in radiation treatments :

- Better Spatial selectivity in dose deposition: **Bragg Peak**
- Reduced lateral and longitudinal diffusion
- High Conformal dose deposition
- High Biological effectiveness



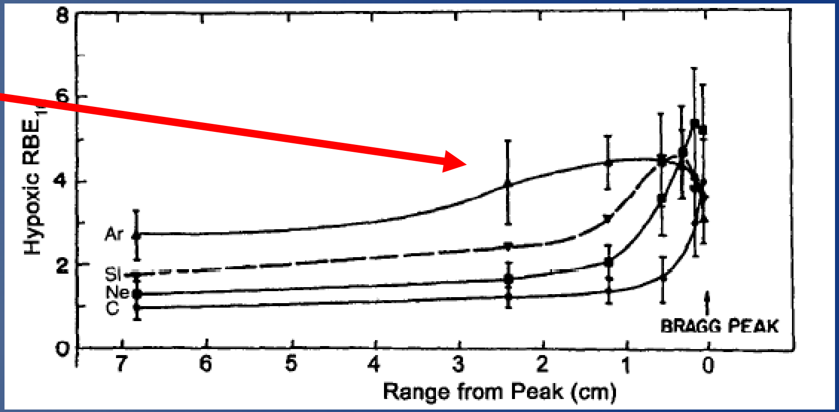
Treatment of highly radiation resistent tumours, sparing surrounding OAR

CARBON IONS ADVANTAGES



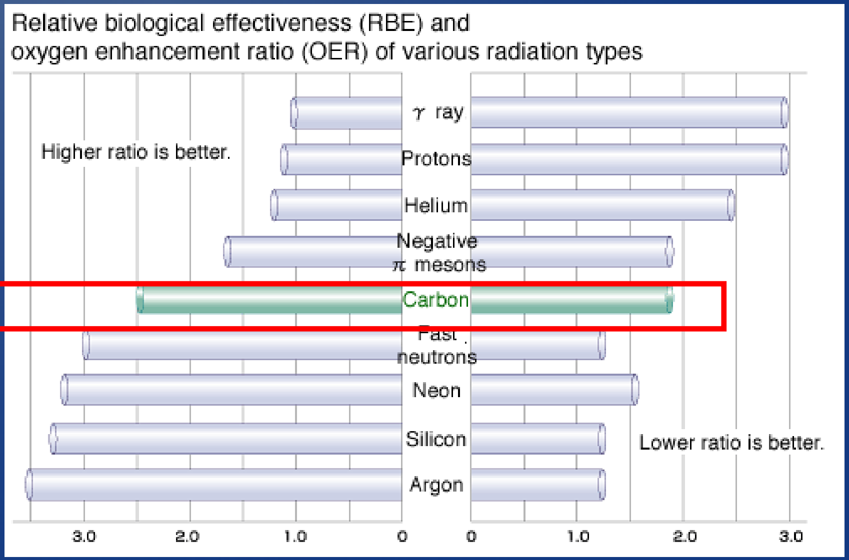
- Lower lateral and longitudinal diffusion vs. proton
  ⇨ More precise energy deposition

- Optimal RBE profile vs penetration depth position.



- Online PET for depth deposition monitoring

- Good Compromise between RBE and OER.



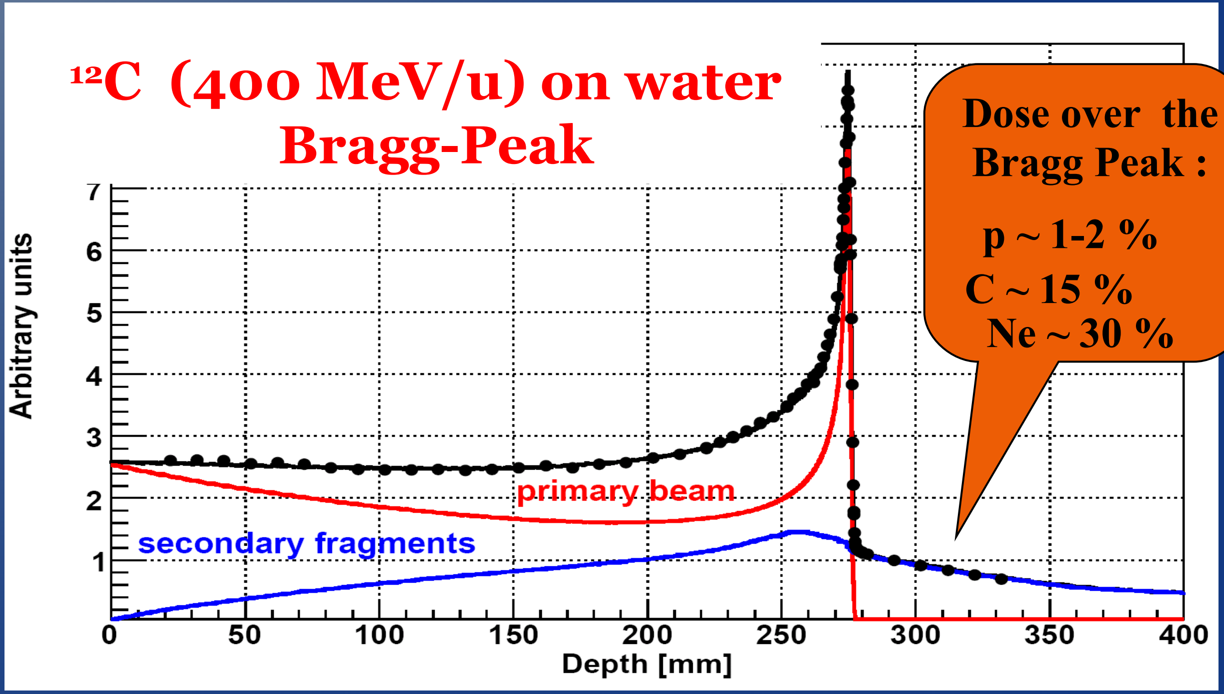
WATCH OUT!! RBE related problems & features will not be discussed in this talk!!!

DISADVANTAGE OF CARBON IONS

Nuclear Fragmentation of ^{12}C beam in the interaction with energy degraders and/or biological tissues

- Production of fragments with higher range vs primary ions
- Production of fragment with different direction vs primary ions

- Mitigation and attenuation of the primary beam
- Poblems due to different biological effectiveness of the fragments



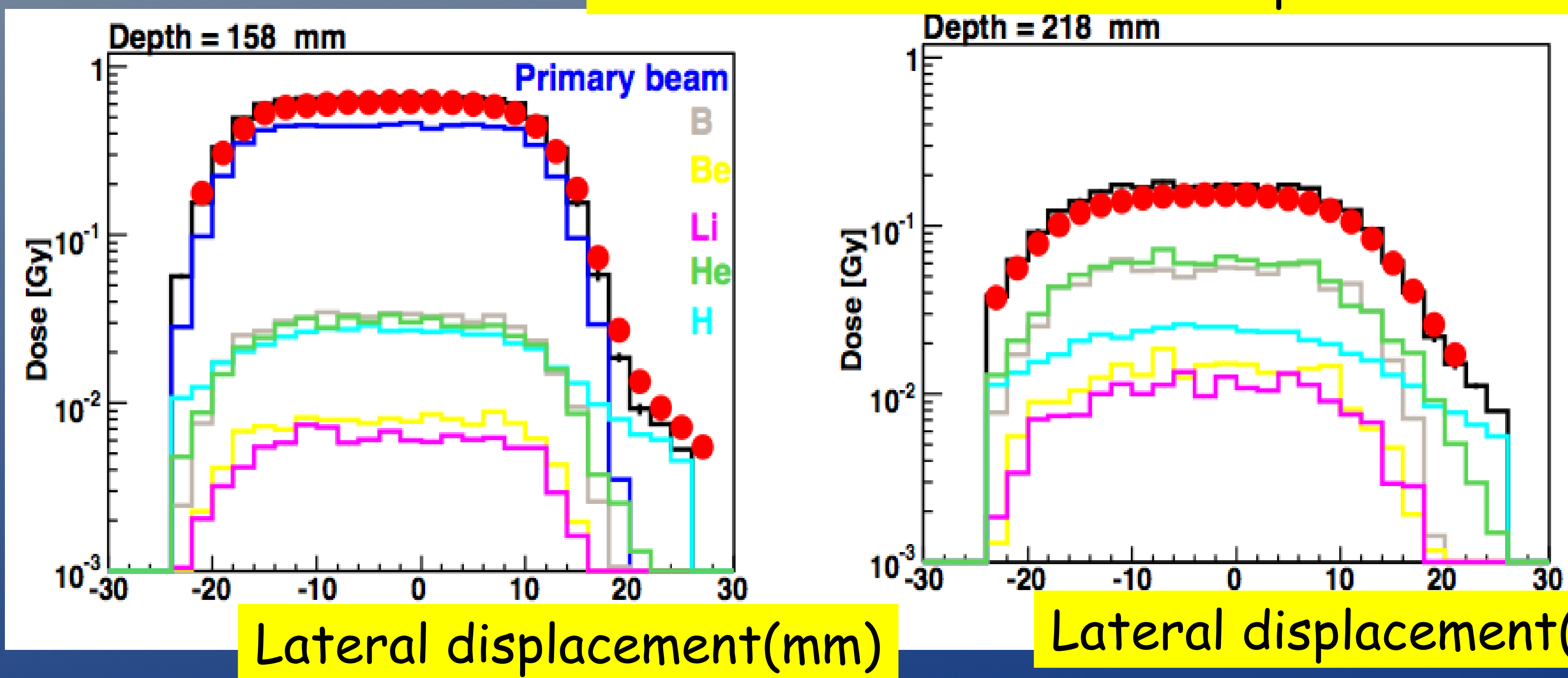
Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006
Simulation: A. Mairani PhD Thesis, 2007, Nuovo Cimento C, 31, 2008

Courtesy of Andrea Mairani

DISADVANTAGE OF CARBON IONS

The secondary fragments, especially the lighter ones such H and He, broad the lateral dose profile.
Effect gets more and more important approaching, and going beyond, the Bragg Peak i.e. the tumor region

SOBP centered al 20 cm depht in water

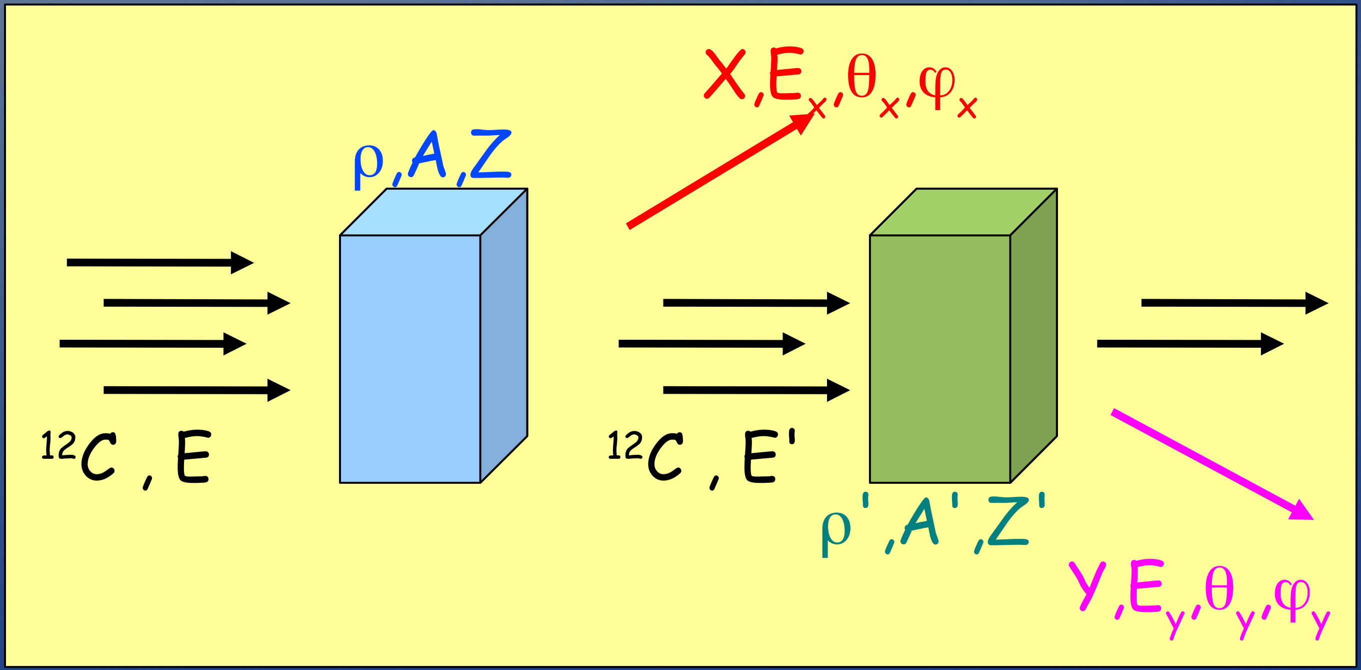


Data: S. Brons & K. Parodi (GSI)
MC-FLUKA: A. Mairani PhD Thesis 2007 Pavia

Courtesy of Andrea Mairani

What should we know to take care of fragmentation?

- Production yelds of Z=0,1,2,3,4,5 fragments
- $d^2\sigma/d\theta dE$ = double diff. cross sections wrt angle and energy
- For ^{12}C energy of interest for Hadrontherapy (100-200 MeV/nucl)
- On thin target of different materials on the ^{12}C path to the tumor



Not possible from measurement only

We need a nuclear interaction model !!

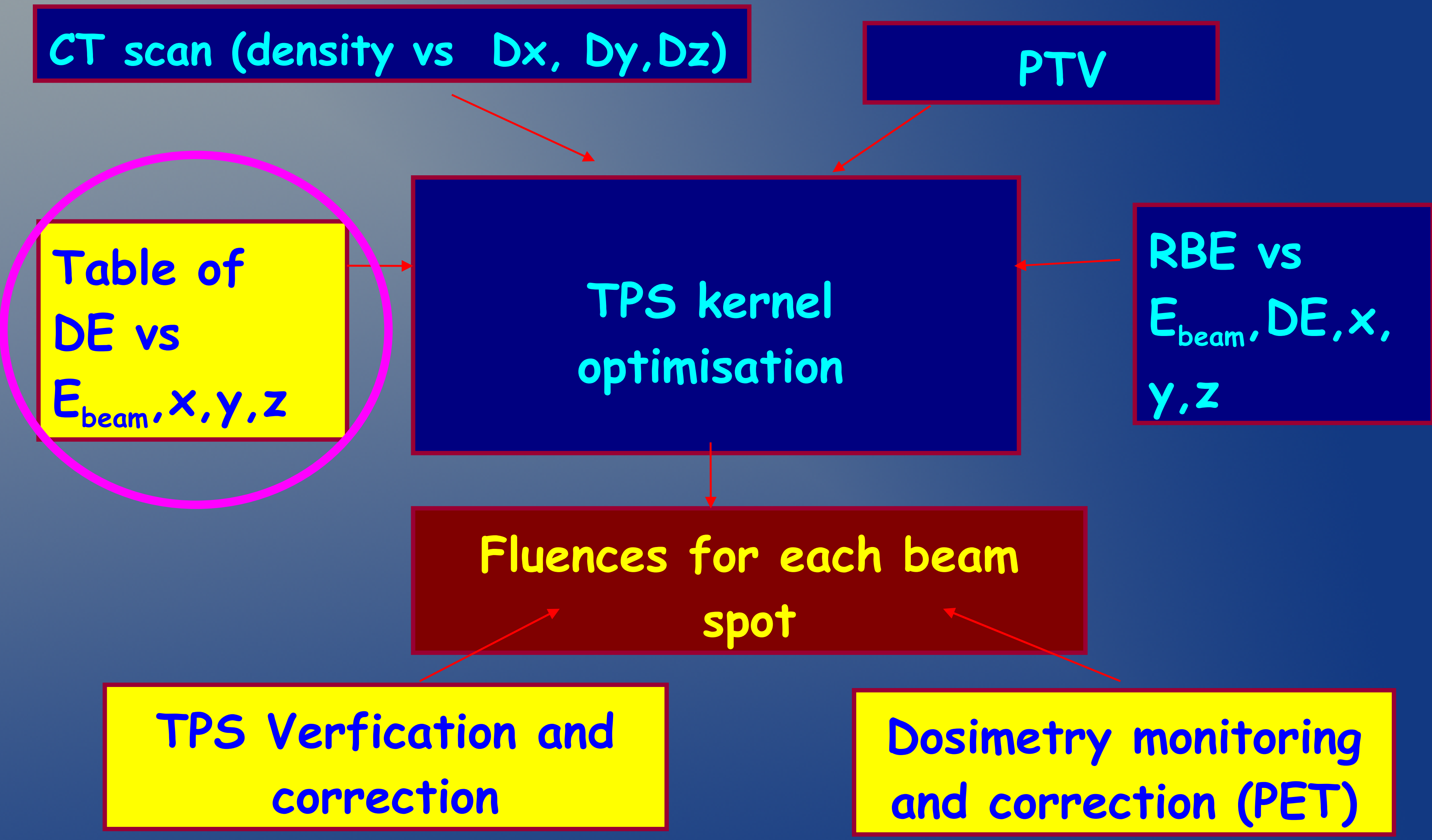
Fragmentation, TPS, MonteCarlo and all that..

The nuclear interaction description are embedded in the Treatment Planning System through a "physical" DB generated on the basis of a Interaction Model (by analytical computation or MC code) where the energy releases and the fragment produced by the beam are stored. Thus the benchmarking of the MC with the measurements are getting more and more important due to:

- ✓ Better representation of the nuclear interaction model wrt analytic calculation
- ✓ Natural and easy 3D treatment of physics processes
- ✓ More accurate patient representation wrt w.e. approach
- ✓ Possibility of exploiting PET online
- ✓ Easily taken into account the beam features

CPU time prevents the use of TPS entirely based on MC in hadrontherapy clinical routine

A (over) simplified scheme of a Treatment Planning System



Yellow = (can be) MC based

MC for TPS: what is on the market?

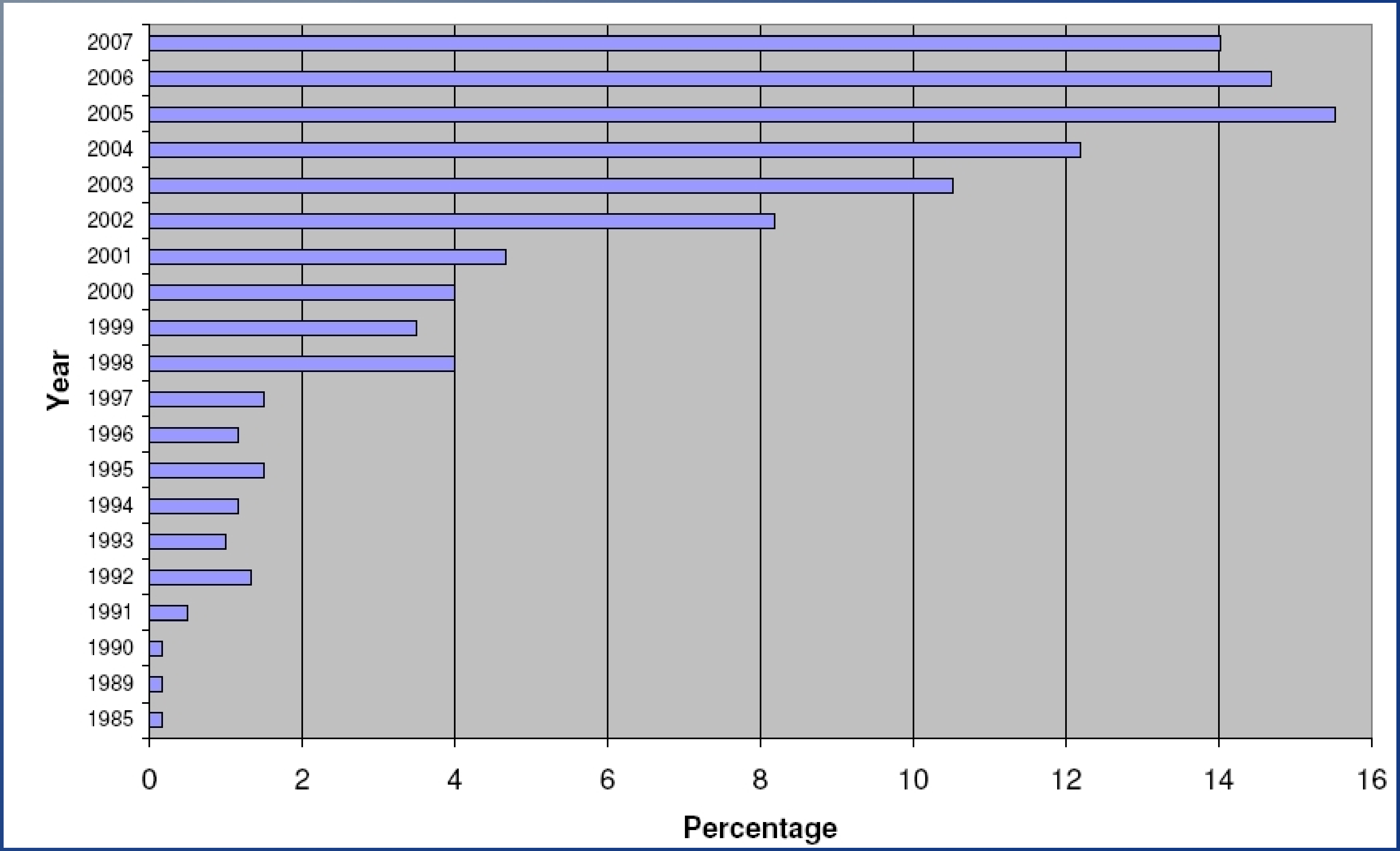
The list is absolutely not exaustive

- EGS4, EGSnrc, ETRAN, PENELOPE: electron and photon
- MCNP : only electron, photon and neutron
- VMCpro, ISTAR, MCNPX: only for proton. parametrised nuclear int
- Geant4 , PHITS, FLUKA : general purpose, transport any particle from photon to heavy ion → suitable for ^{12}C beam
- Geant4 : very large user community, optimised version for low energy, OO, flexible
- We will use FLUKA as reference code: very accurate physics description, old style coding (FORTRAN).

MC for physicist is like religion or favorite soccer team: you do not choose it , you are chosen by it, and once you are chosen, no way to change it !! (see the G4 vs FLUKA religion war...)

MC for TPS (MCTP): very popular (trendy?) ..!

In the period 2000-2007 there has been an exponential growth of the MCTP related papers (source: ISI Web Science)



Frag meas: thick target

A lot of integral measurements measurements are already around..

Projectile	Energy[MeV/N]	Target	
^{4}He	100, 180	C, Al, Cu, Pb	
^{12}C	100, 180,400	C, Al, Cu, Pb	
^{20}Ne	100, 180,400	C, Al, Cu, Pb	
^{28}Si	800	C, Al, Cu, Pb	HIMAC by Kurosawa et al.
^{40}Ar	400	C, Al, Cu, Pb	
^{56}Fe	400	C, Al, Cu, Pb	
^{126}Xe	400	C, Al, Cu, Pb	
^{20}Ne	337	C, A, Cu and U	BEVALAC by Schimmerling et al.
^{93}Nb	272	Al, Nb	BEVALAC by Heilbronn et al.
^{93}Nb	435	Nb	
^{4}He	155	Al	NSRL by Heilbronn et al.
^{12}C	155	Nb	
^{4}He	160	Pb	SREL by Cecil
^{4}He	180	C, H_2O, steel, Pb	
^{12}C	200	H_2O	GSI by Günzert-Marx et al.
^{12}C	400	H_2O	GSI by Haettner et al.

Tentative & incomplete list

Courtesy of M. Durante

Frag meas: thin target

A lot of measurements on thin target are already around.. but not wrt angle and energy

Projectile	Energy[MeV/N]	Target	
^{4}He	135	C, Poly, Al, Cu, Pb	
^{12}C	135	C, Poly, Al, Cu, Pb	RIKEN by Sato et al.
^{20}Ne	135	C, Poly, Al, Cu, Pb	
^{40}Ar	95	C, Poly, Al, Cu, Pb	
^{12}C	290, 400	C, Cu, Pb	
^{20}Ne	400, 600	C, Cu, Pb	HIMAC Iwata et al.
^{40}Ar	400, 560	C, Cu, Pb	
^{4}He	230	Li, C, CH_2, Al, Cu, Pb	
^{14}N	400	Li, C, CH_2, Al, Cu, Pb	
^{28}Si	600	Li, C, CH_2, Al, Cu, Pb	HIMAC Heilbronn et al.
^{56}Fe	500	Li, C, CH_2, Al, Cu, Pb	
^{86}Kr	400	Li, C, CH_2, Al, Cu, Pb	
^{126}Xe	400	Li, C, CH_2, Al, Cu, Pb	

Tentative & incomplete list

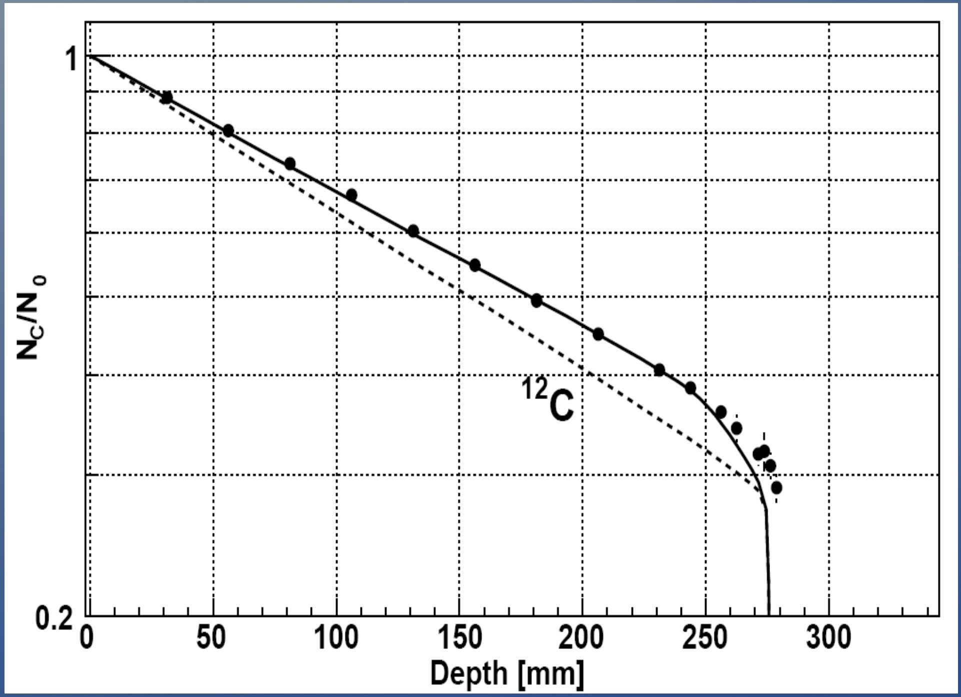
Courtesy of M. Durante

only with detectors at 0°!

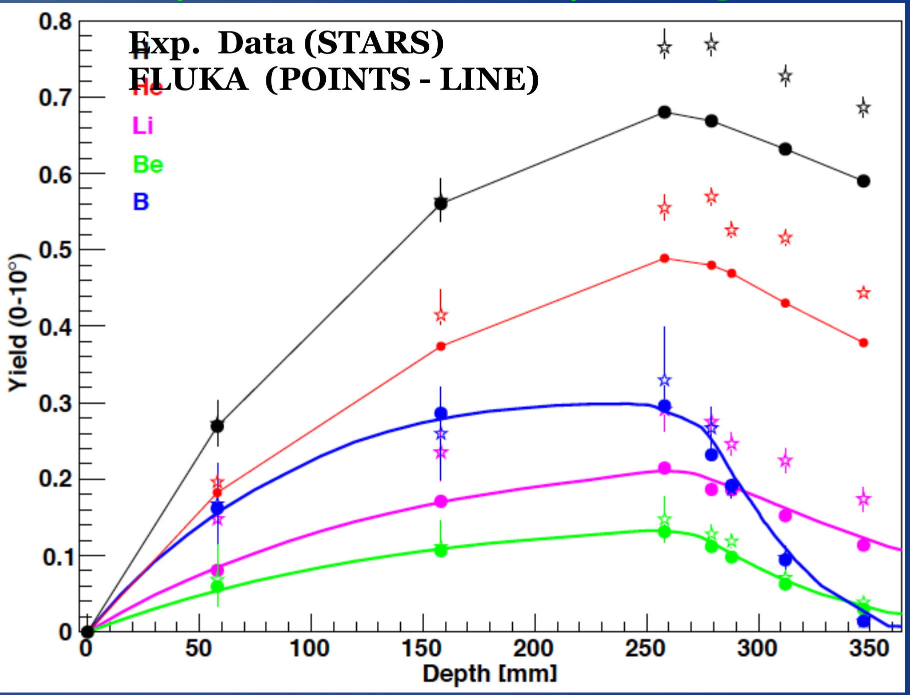
Mixed Radiation Field in Carbon Ion Therapy

FLUKA benchmark against thick target experimental data

Attenuation of primary beam



Build-up of secondary fragments



^{12}C (400 MeV/u) on water

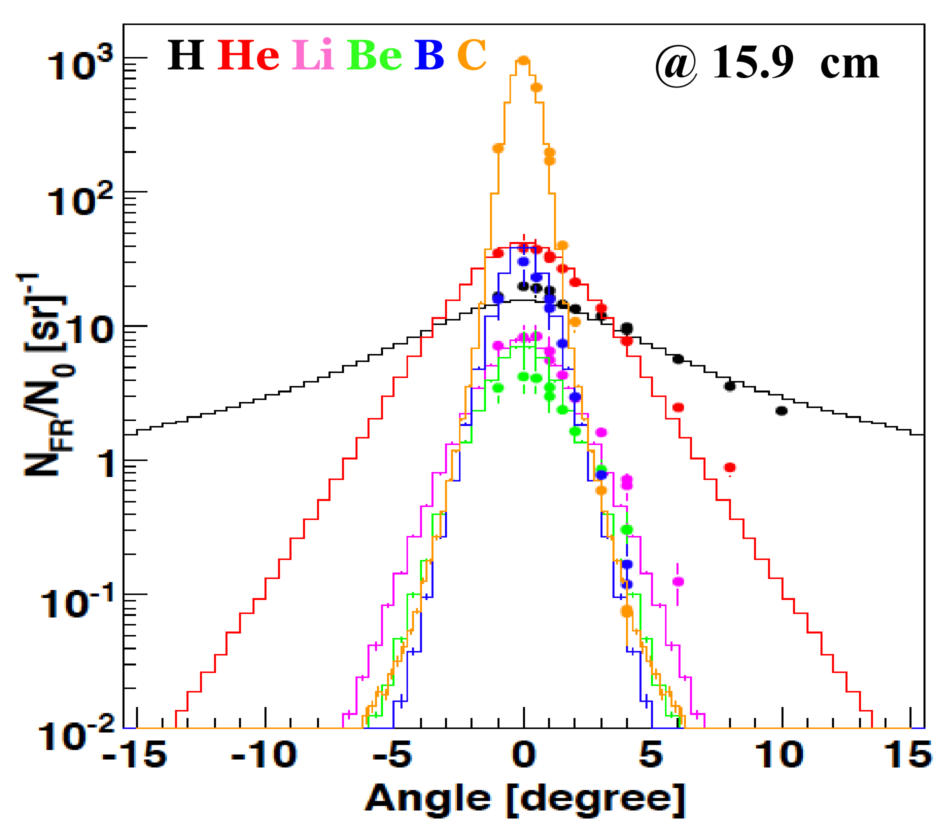
Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006
Simulation: A. Mairani PhD Thesis, 2007, PMB *to be published*

Courtesy of Andrea Mairani

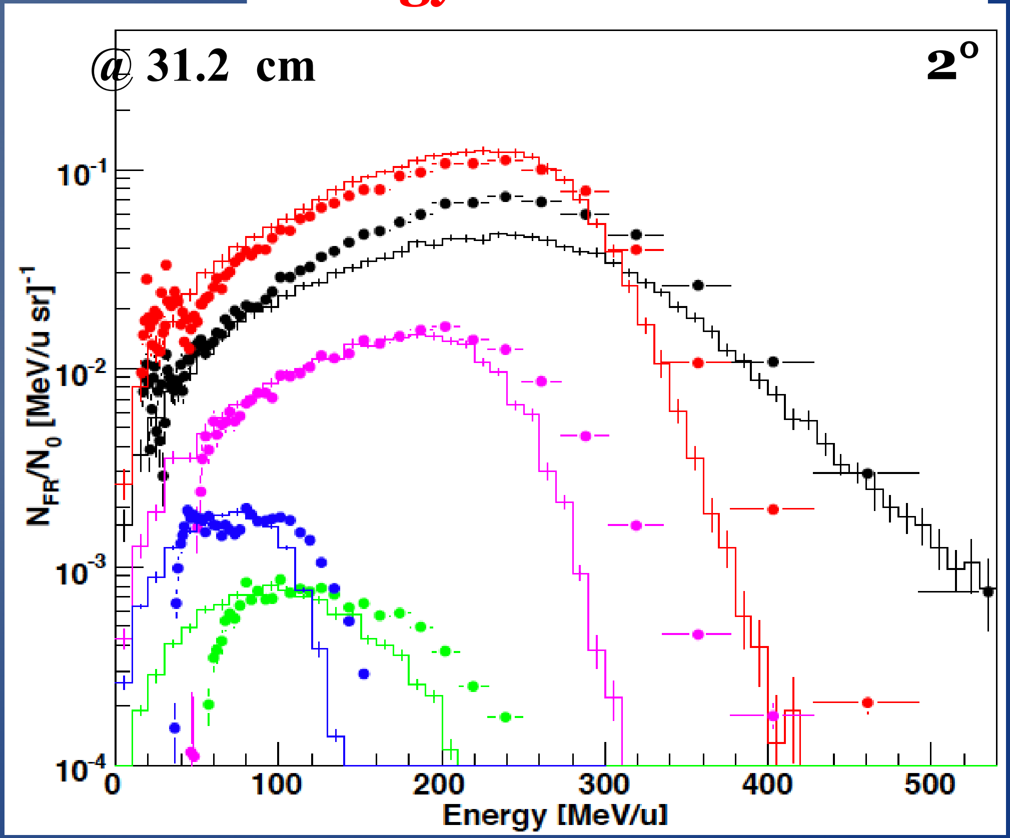
Mixed Radiation Field in Carbon Ion Therapy

FLUKA benchmark against thick target experimental data

Angular distribution



Energy distribution



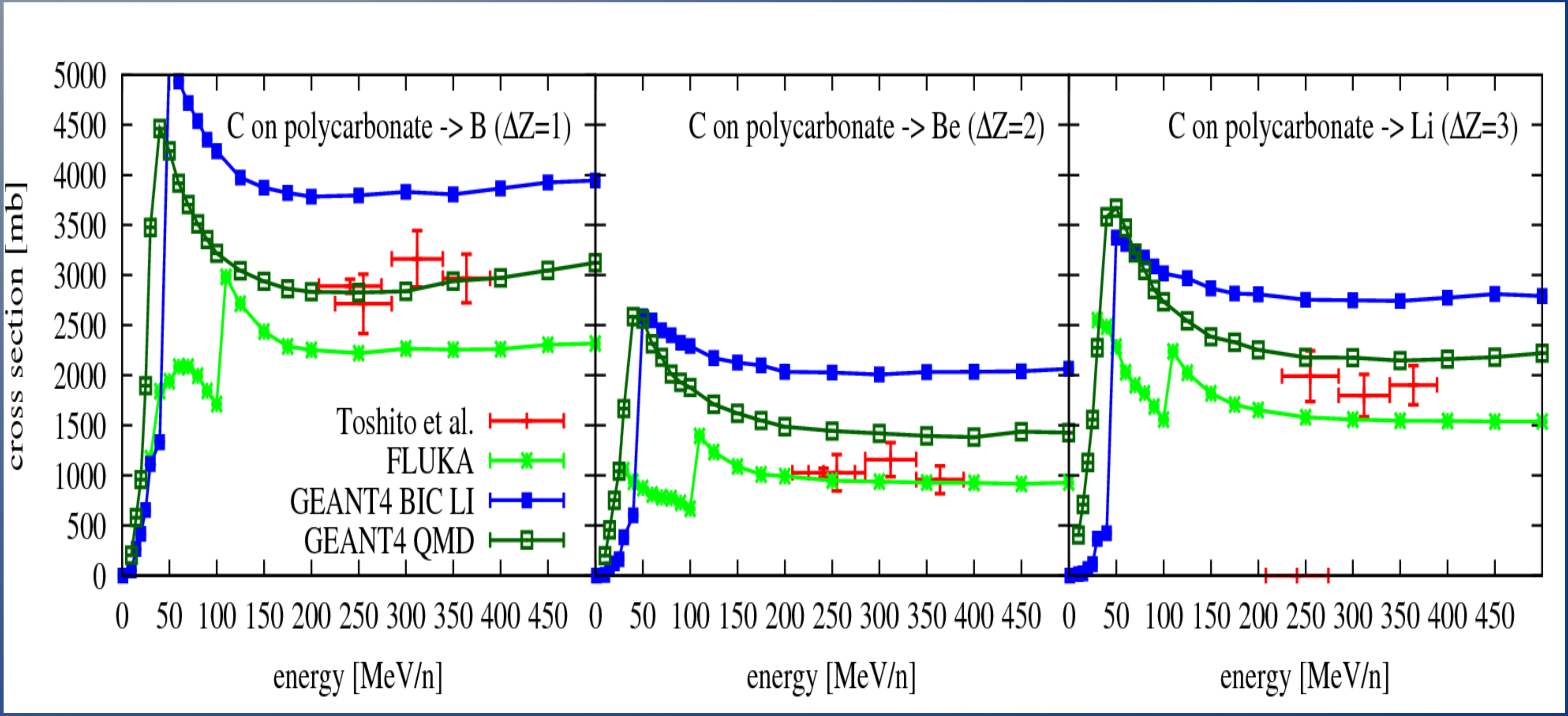
^{12}C (400 MeV/u) on water

Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006
Simulation: A. Mairani PhD Thesis, 2007, PMB *to be published*

Courtesy of Andrea Mairani

Benchmarking MC nuclear interaction model on thick target: FLUKA & G4

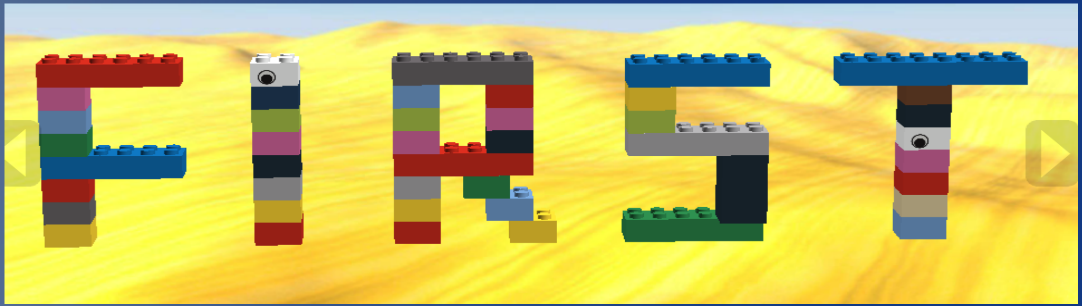
Charge-changing X-sections for C on polycarbonate



exp. data:
Toshito et al. 2006

Courtesy of T.Boehlen

The FIRST collaboration



INFN: Cagliari,LNF,LNS,Milano,Roma2,Torino: G.Cuttone, C.Agodi, G.Battistoni, M.Carpinelli, G.A.P.Cirrone, M.De Napoli, E.Iarocci, A.Mairani, V.Monaco, M.C.Morone, A.Paoloni, V.Patera, G.Raciti, E.Rapisarda, F.Romano, R.Sacchi, P.Sala, A.Sarti, A.Sciubba, C.Sfienti,

DSM/IRFU/SPhN CEA Saclay, IN2P3 Caen, Strasbourg, Lyon: S.Leray, M.D.Salsac, A.Boudard, J.E. Ducret, M. Labalme, F. Haas, C.Ray

GSI: M.Durante, D.Schardt, R.Pleskac, T.Aumann, C.Scheidenberger, A.Kelic,M.V.Ricciardi, K.Boretzky,M.Heil,H.Simon, M.Winkler

ESA: P.Nieminem, G.Santin

CERN: T.Bohlen

FIRST stands for: Fragmentation of Ions Relevants for Space and Therapy

S371 is the GSI label for us

The FIRST experiment: aim and genesis

Target: Double differential cross section (with respect to the emission θ and E) for each of the produced fragments in C-C, C-Au (Fe-C, Fe-Si, O-C) interaction, with 3% accuracy.

- ✓ 16 Dic. 2008 - Colloquium al GSI:

  Light Ion Fragmentation Measurements for Medical and Space Applications

- ✓ 29 Gen. 2009: Proposal to G-PAC:

  Extensive study of nuclear reactions of interest for medical and space applications

- ✓ 27 Feb. 2009: approval by G-PAC for C-C:

  beam in early 2011

Beam time: requested....

- Control of setup — 1 day per period of beam
- C+C @ 0.2, 0.4 and 1.0 AGeV — 6 days
- C+Au @ 0.2, 0.4 — 4 days
- O+C @ 0.2, 0.4 — 4 days
- Fe+Si @ 0.5 and 1.0 AGeV — 4 days
- Fe+C @ 1.0 AGeV — 2 days
- Calibration — 2 days

.. and obtained

Da: Paolo Giubellino <giubell@to.infn.it>
Date: 27 febbraio 2009 16.49
Oggetto: gpac
A: giacomo cuttone <cuttone@lns.infn.it>, agodi@lns.infn.it
Cc: m.durante@gsi.de

Cari amici,
sono lieto di confermarvi l'assegnazione di 33 shifts per fare le misure rilevanti per l'adroterapia.
Buon lavoro! A presto,
ciao, Paolo

Paolo Giubellino
ALICE deputy spokesperson
39-011-670 7356

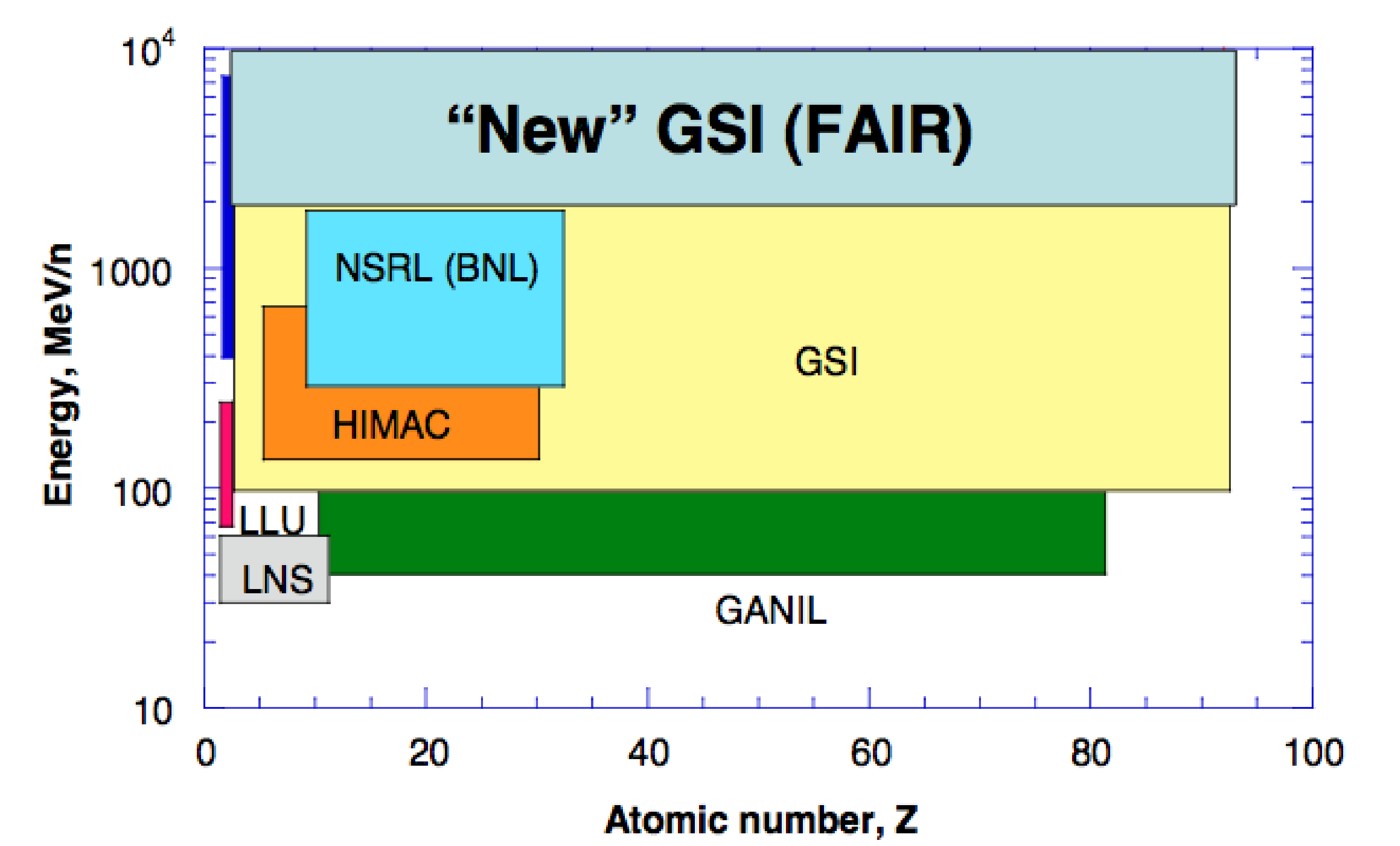
The IDEAL detector

On an event by event basis, the ideal detector should:

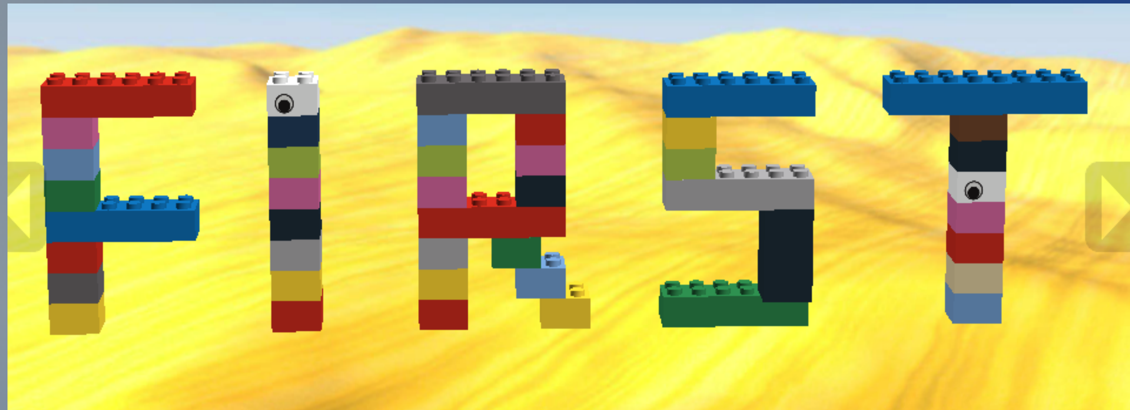
- Identify all the fragment produced, i.e. detect charge , with 0 < Z < 6 and detect mass, on all the solid angle
- Detect the energy of the fragments (from 0 to 700 MeV p)
- Measure the emission angle
- Detect all the correlations, with systematic below few %
- Be located on a suitable beam (^{12}C @200-400 MeV/nucl)

Starting from scratch, such a detector would be VERY, VERY expensive (several M€) , would take LONG, LONG time and a VERY LARGE group to design and build it.

FIRST: where and what...?

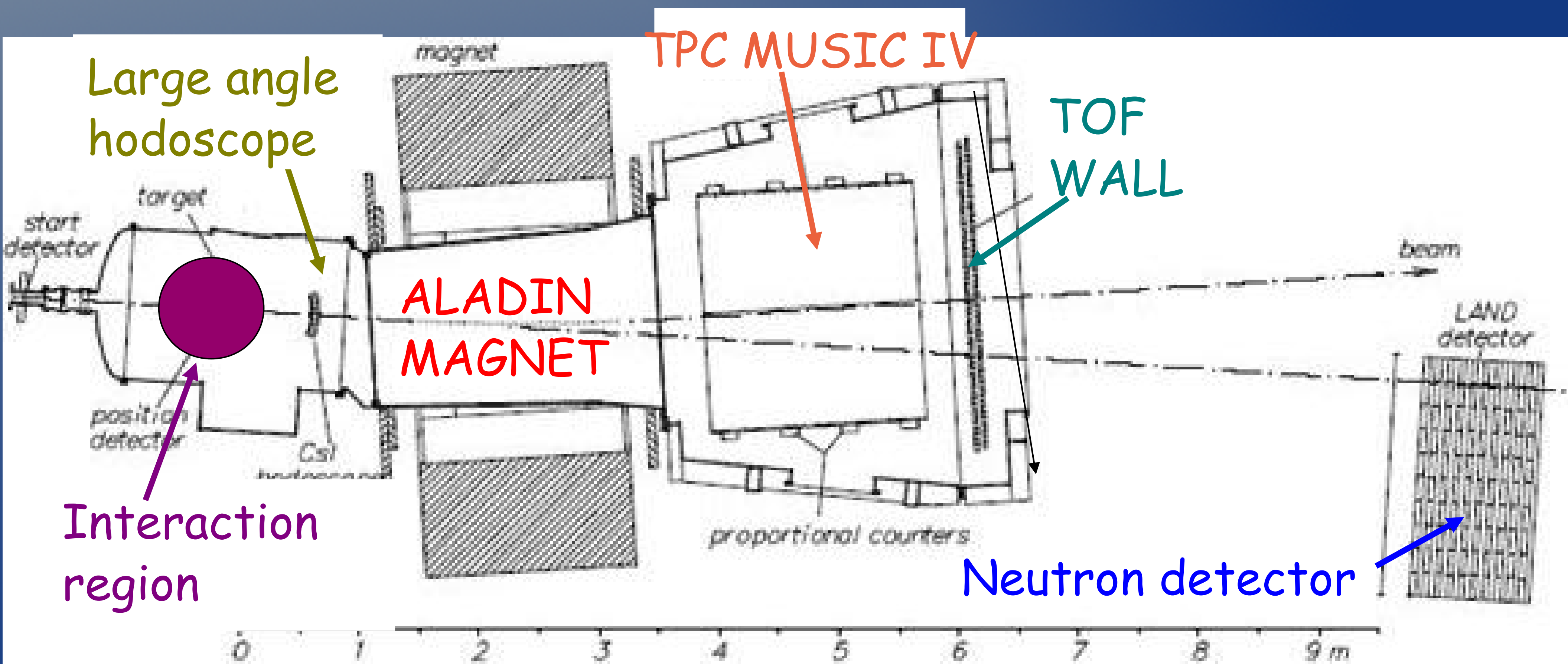


At GSI there are the proper beam and a previous setup that has been designed for a similar (but not the same) physics. We will improve, adapt and optimize the ALADIN experimental setup for our goal

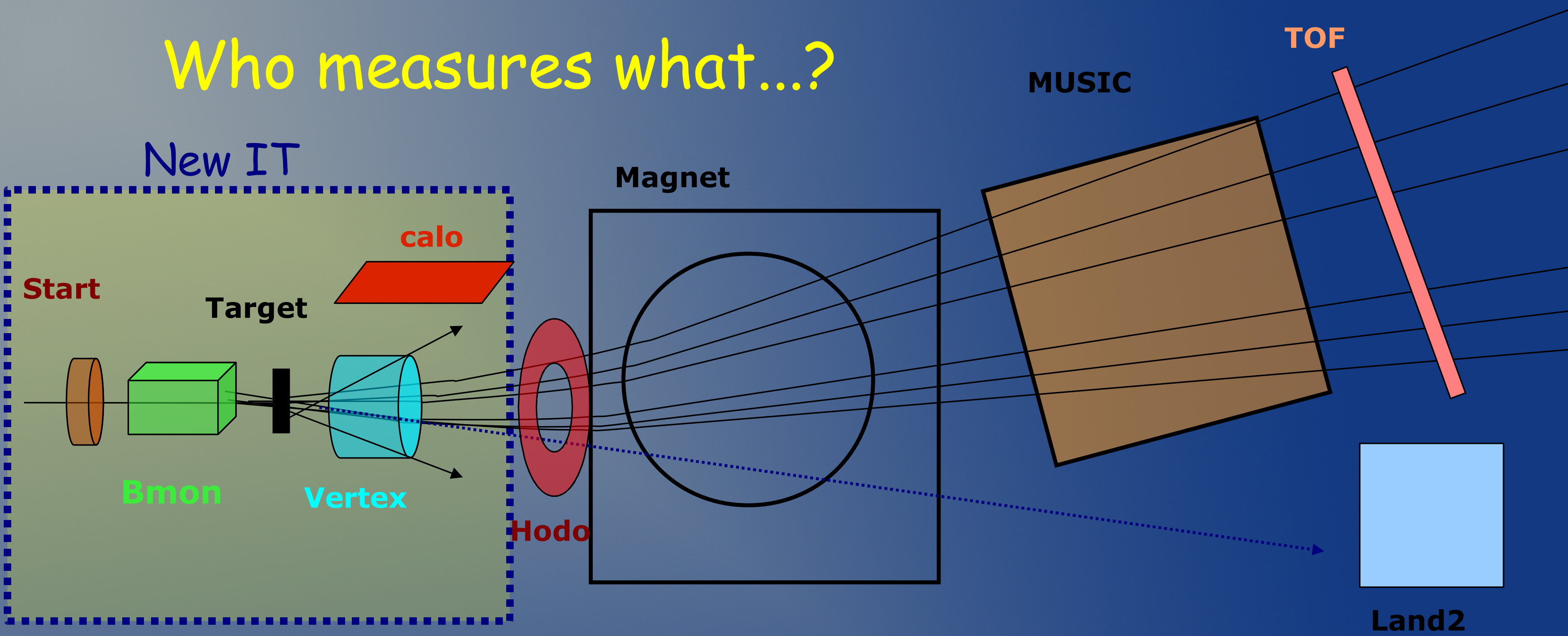


Have you ever played with LEGO?

Setup tailored for more energetic and higher Z fragments → added new sub-detectors mainly concentrated near the IR : Silicon hodoscope, Start Counter, Beam Monitor, Vertex Detector (& CALO?)



Who measures what...?



MUSIC → Z/p , θ,φ after bending

MUSIC → Energy loss ∝ $(Z/\beta)^2$

Hodo→ Large angle fragment energy, θ,φ

Vertex → Fragments emission θ,φ

Start and TOF wall →TOF= L(p,Z,θ,φ)/β

Bmon → Beam impact point

To extract Z, A, θ_{emiss}, p_{emiss} the reconstruction must exploit all the setup information

CALO →Large angle p

LAND2 →neutron flux

What we expect: MC studies

We use FLUKA as benchmark MC for our studies: the MC distribution can be used as "rule of thumb" indicator useful mostly to optimize the detector for critical items as:

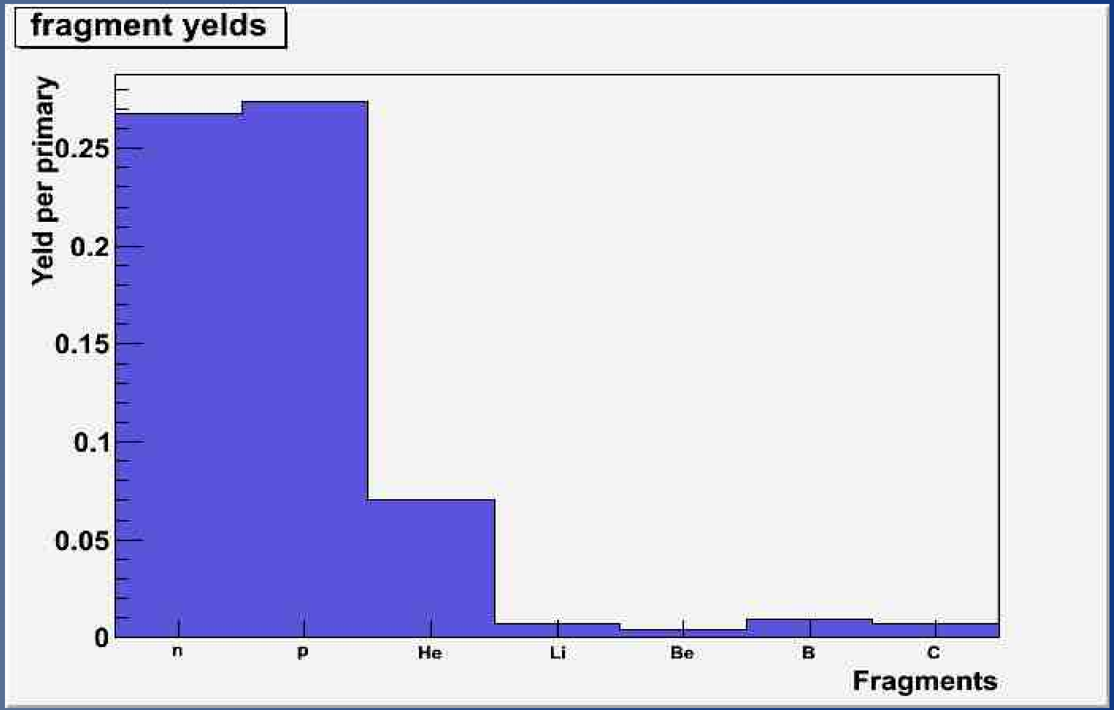
- ✓ Space and time resolution
- ✓ Detector occupancy
- ✓ Particle ID
- ✓ Trigger design
- ✓ Background and out of target interactions evaluation
- ✓ Reconstruction software development

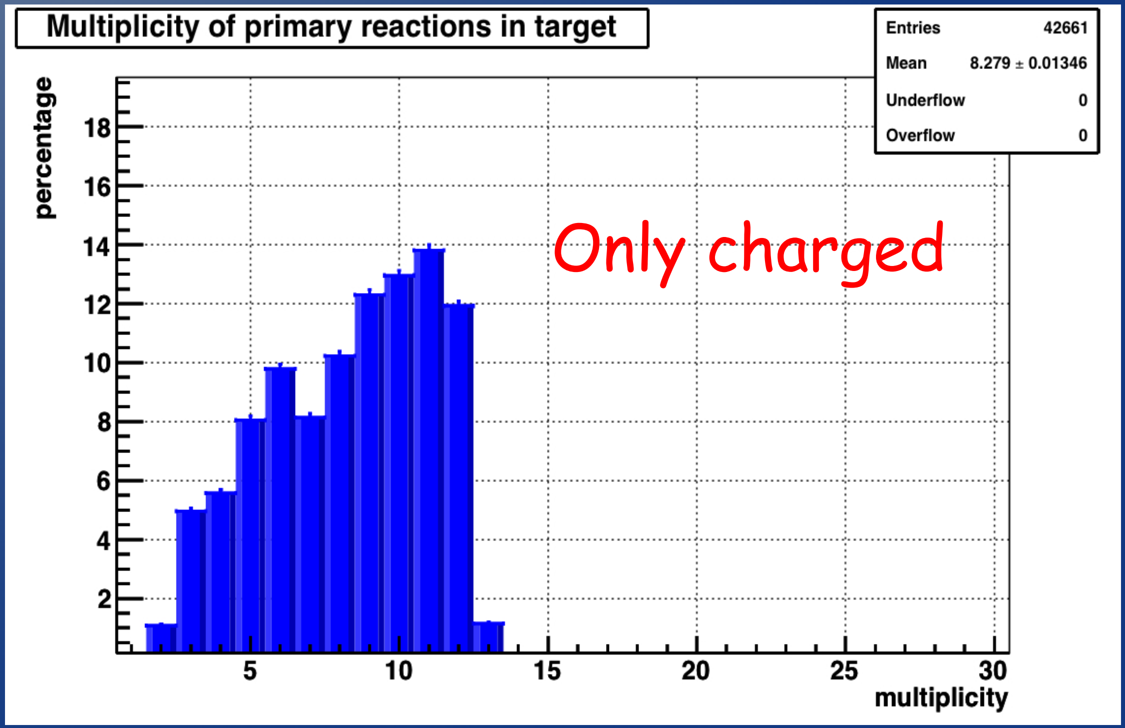
Expected fragment yield

As bench mark we considered the interaction of a 400 Mev/nucl Carbon ion on a 5mm thick Carbon target. 5% of the primary carbons interact in the target

The fragment production are dominated by Protons and Neutrons. They are 1 order of magnitude more than the other fragments!!

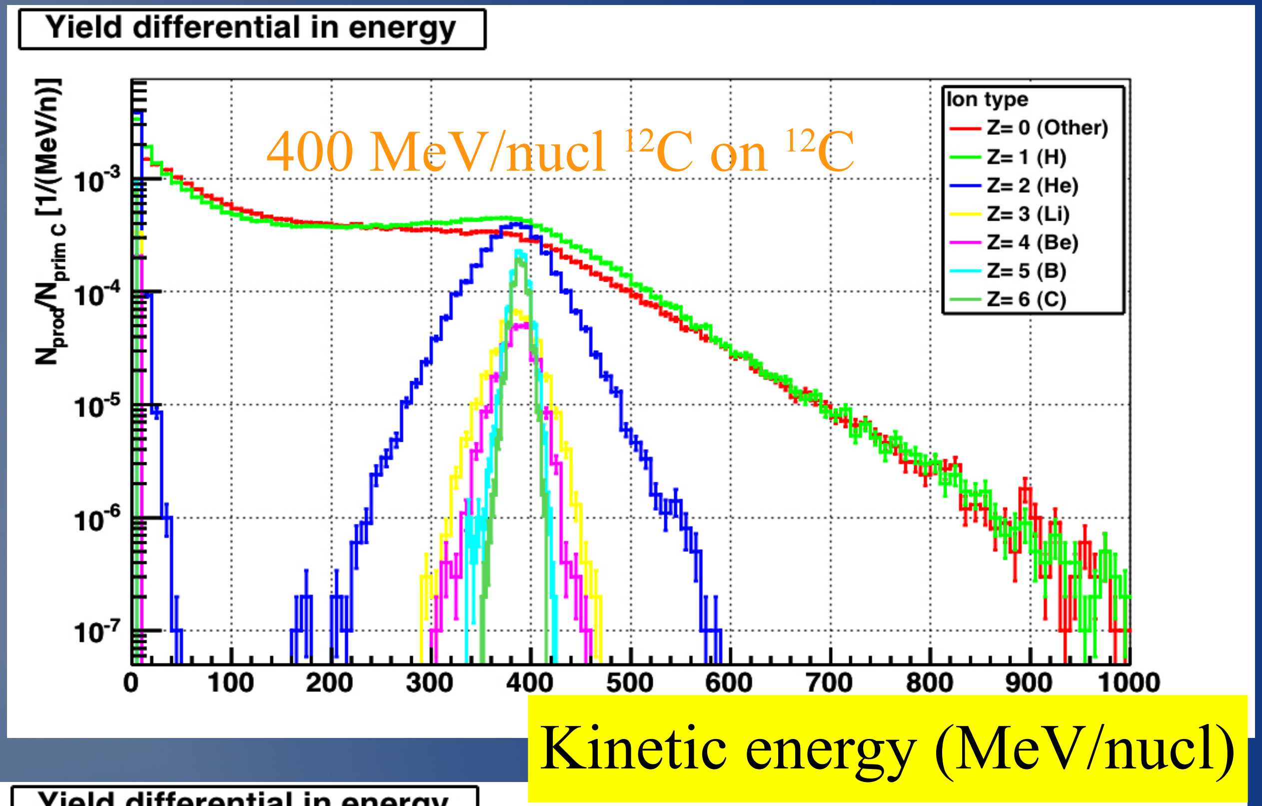
The events have small multiplicity (total ~ 13, charged ~ 8)

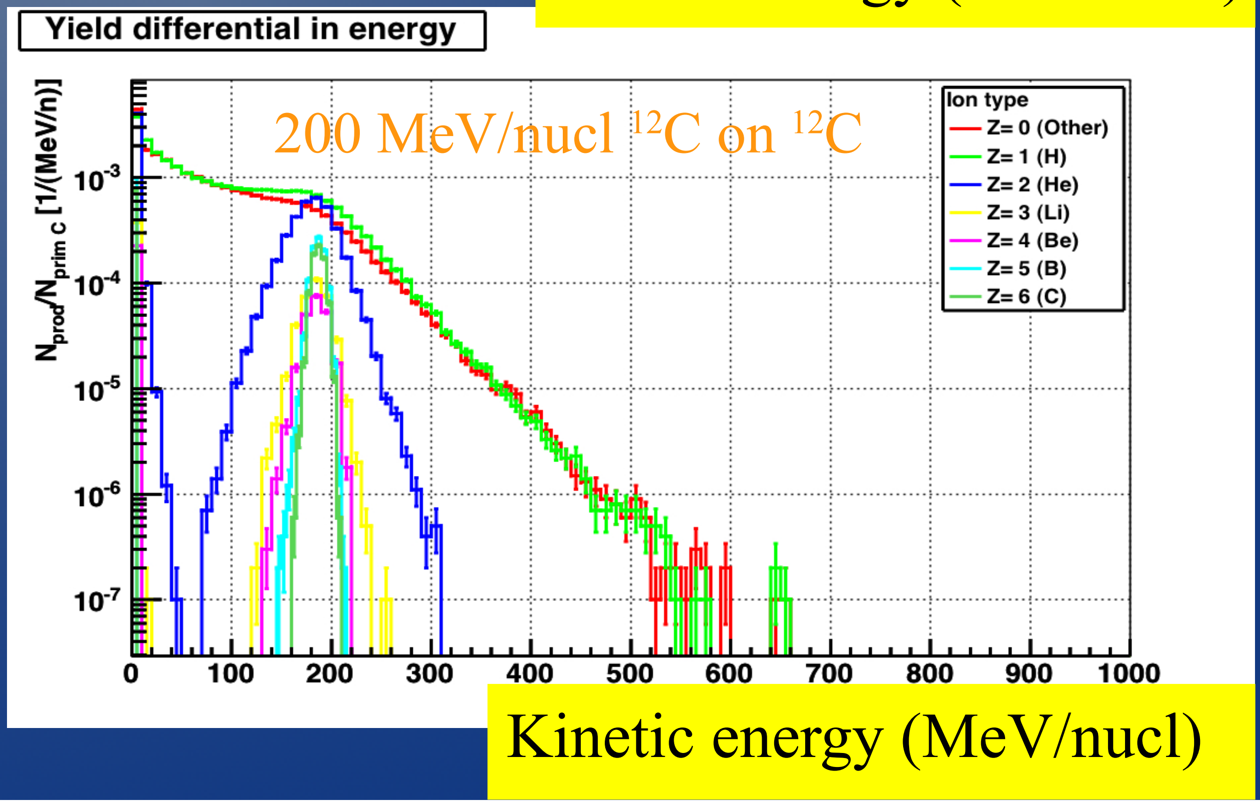




MC: fragment energy

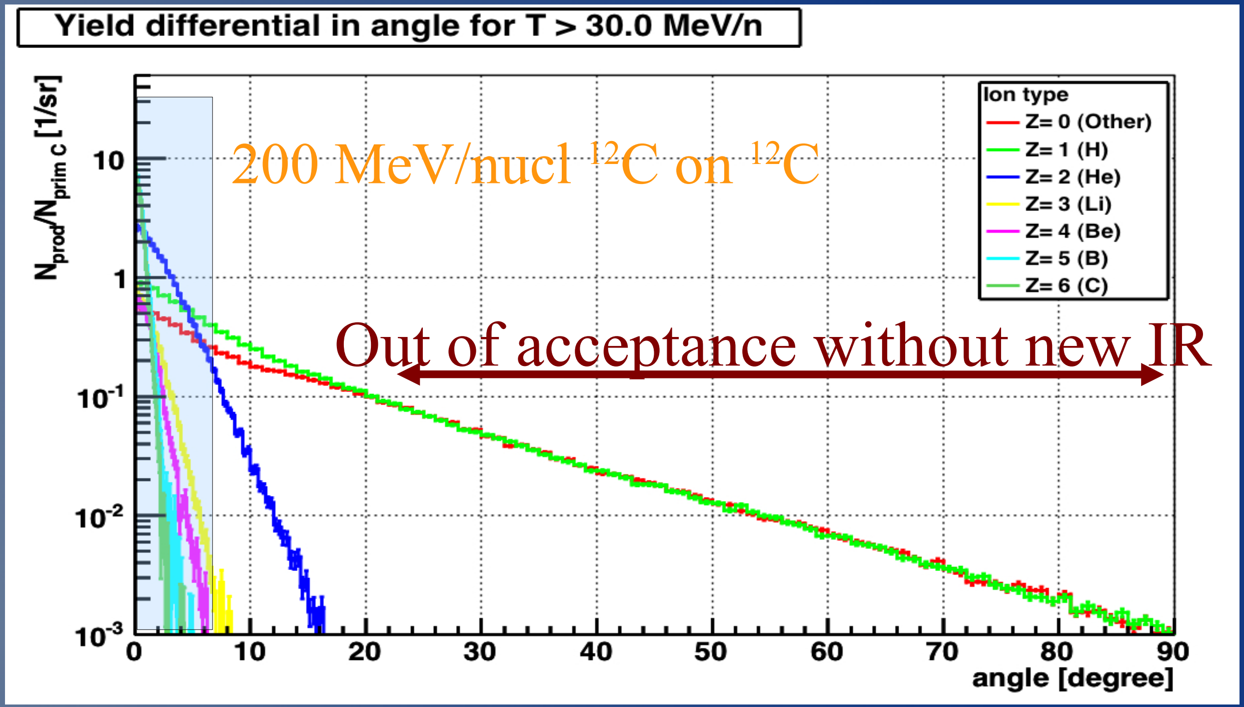
- The Z>2 produced fragments approximately have the same velocity of the C ion projectiles
- The proton have a very wide spectrum with $0<\beta<0.6$
- The DE/DX released by the fragment spans from ~2 to ~100 m.i.p.

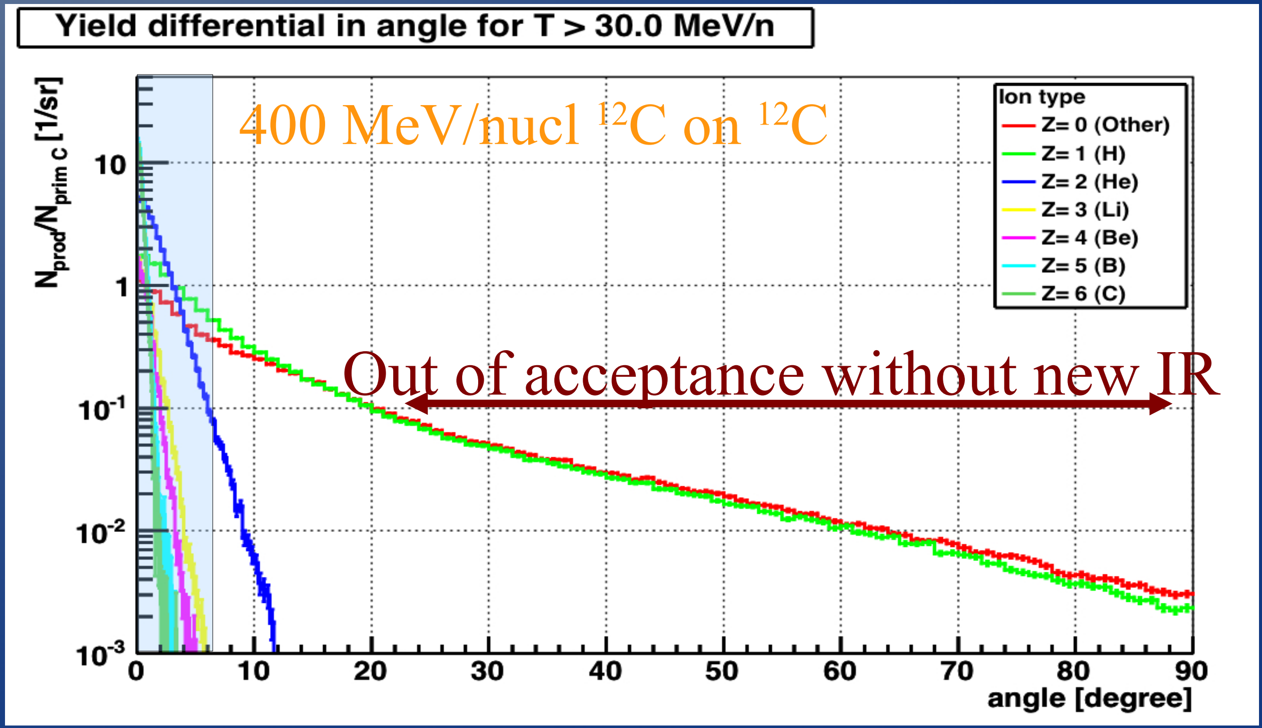




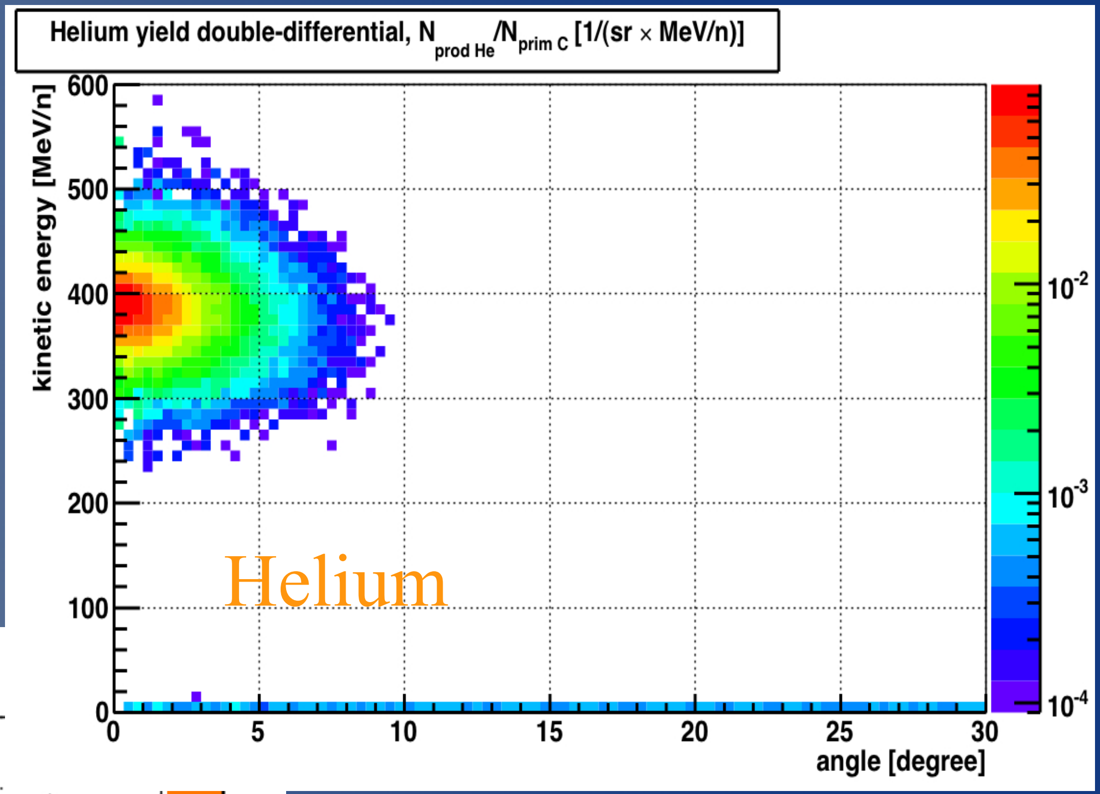
MC: Angular distributions

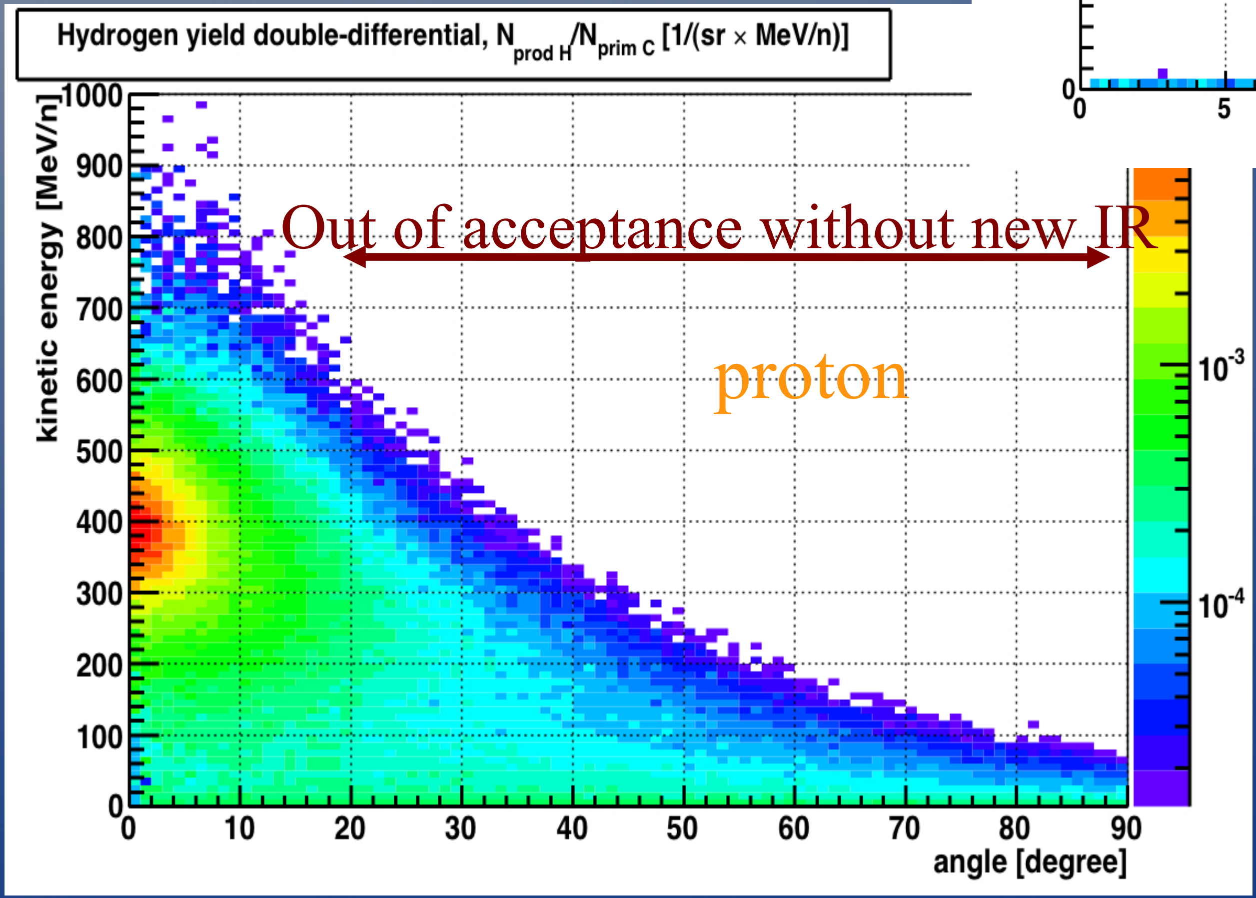
- The Z>2 fragment are well collimated in the angular acceptance of the ALADIN magnet
- The Z=2 fragment can be recovered by the Si Hodoscope
- The protons are emitted mostly at large angle, out of the acceptance of the existing setup →must be recovered by new IR





Produced p and He: angle vs energy

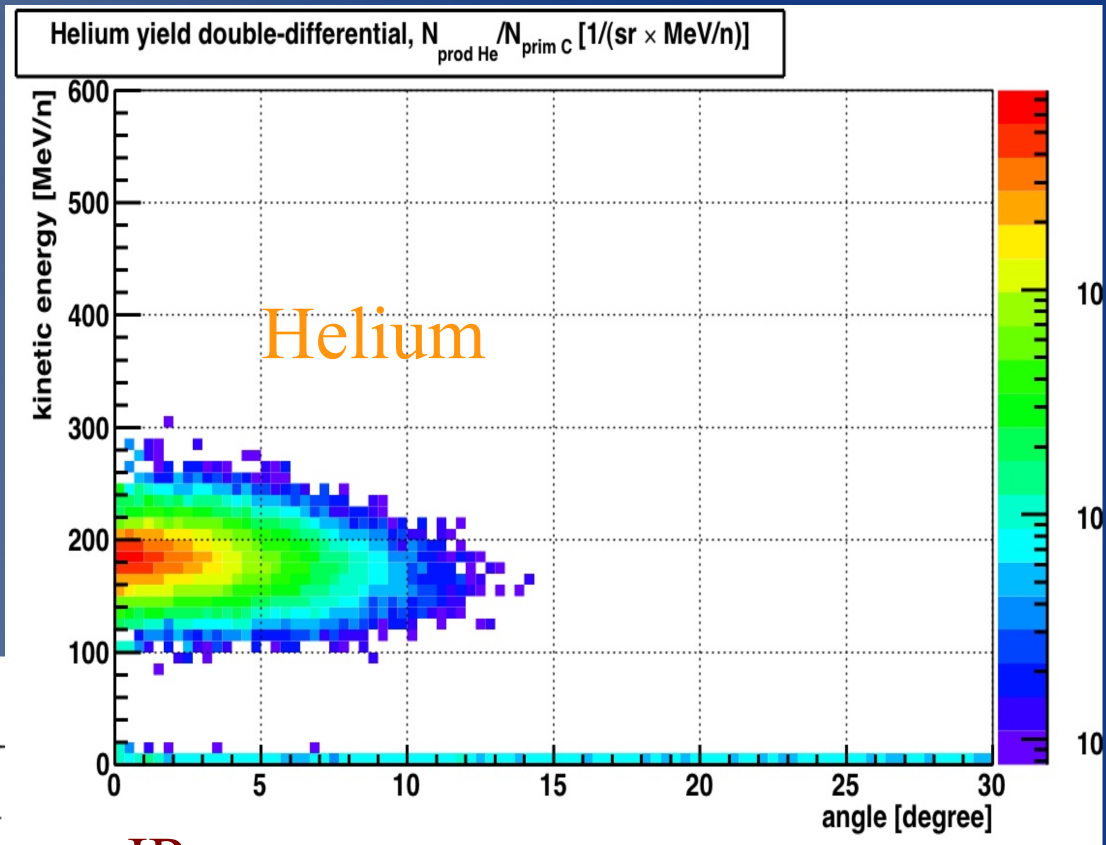


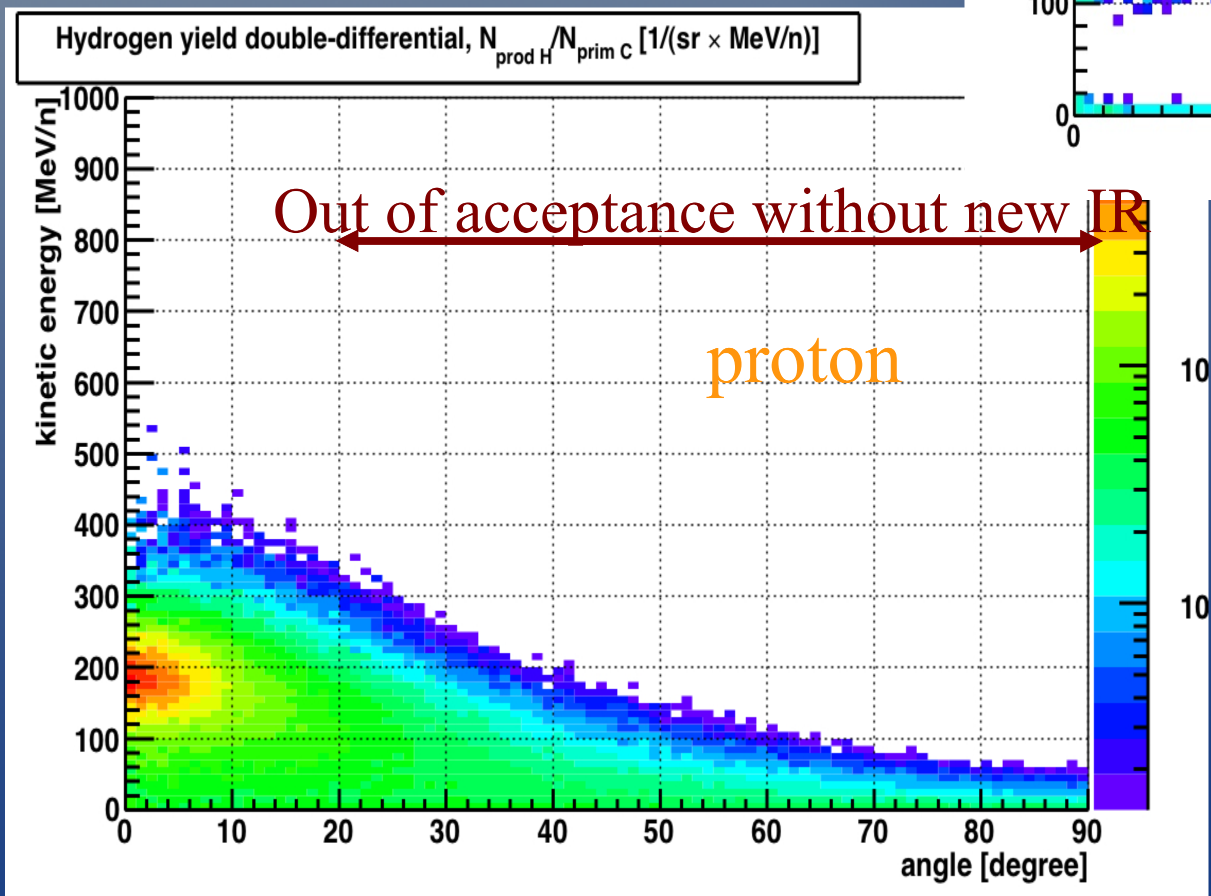


400 MeV/nucl ^{12}C on ^{12}C

WATCH OUT!! How much is FLUKA reliable?

Produced p and He: angle vs energy

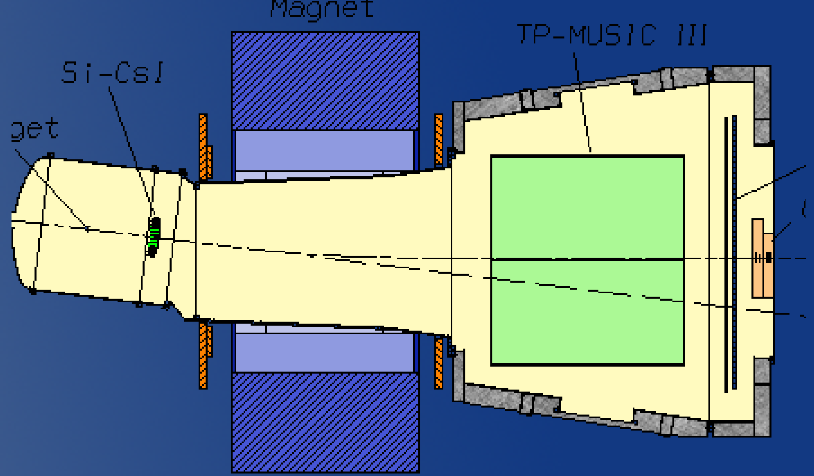




200 MeV/nucl ^{12}C on ^{12}C

WATCH OUT!! How much is FLUKA reliable?

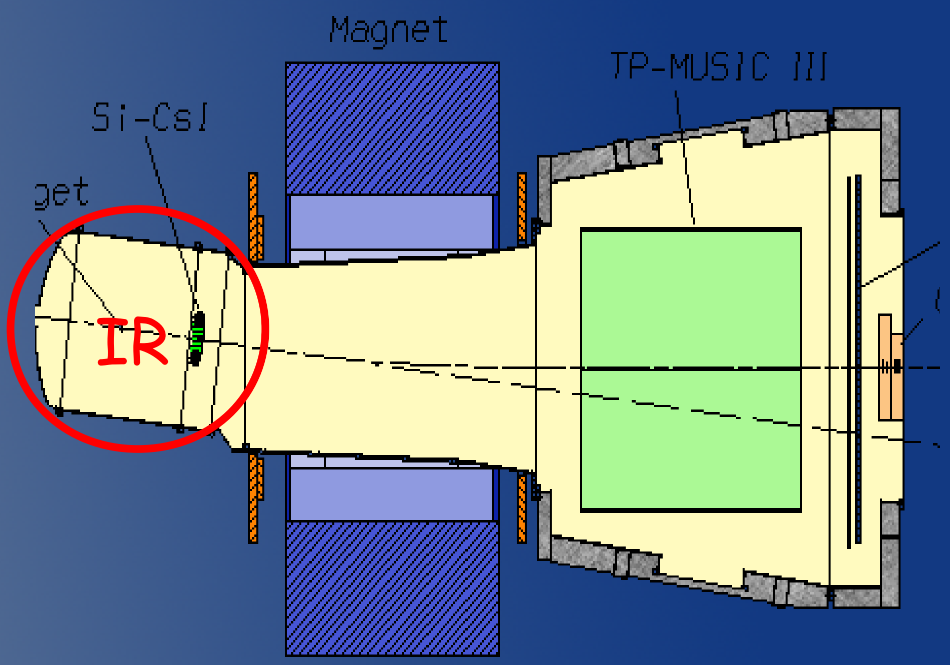
Some other boundary conditions



- Out of target interactions must be kept below ~ per cent level with respect to on target interactions.
- Trigger rate must be ≤ kHz due to pile-up in the MUSIC TPC (10% pile-up @4kHz)
- Considering a maximum target thickness of 10 mm, we expect at maximum ~10% of interaction probability.
- The beam spot for Carbon projectiles can be ~ 3mm FWHM
- The geometric acceptance of the ALADIN magnet for the produced fragments is ~4° in θ and ~9° in φ

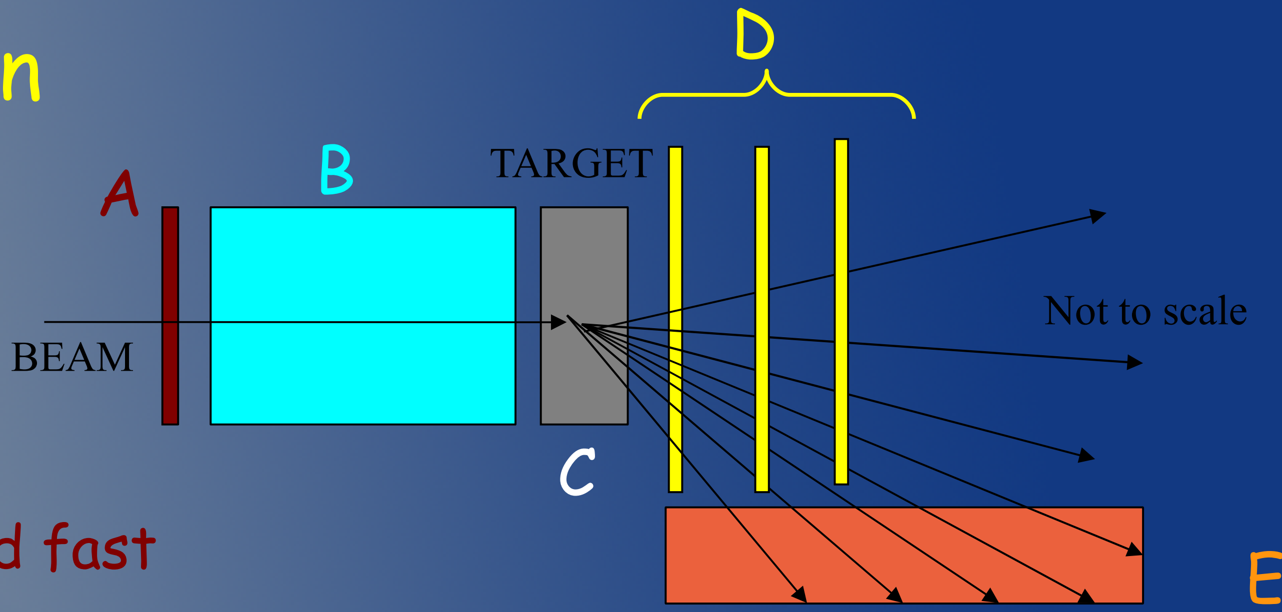
The Interaction Region

Brand new component. All components must operate in vacuum and must have very limited material budget to reduce as much as possible the out of target interactions



- Gives the start to Time Of Flight measurement. Should match the stop (TOF WALL) time resolution (~200ps)
- Measures the beam direction & impact point on target event by event.
- Host the target system. Remotely controlled system that embed different thin (~few mm) targets
- Tracks the fragments just downstream of the target.
- Detects the particle escaping from the magnet acceptance

New target region



A) Start counter. Thin and fast scintillation detector. Gives the start to TOF measurement.

B) Beam monitor. Drift chamber that measures the beam impact point on target.

C) Target system. Remotely controlled system that embed different thin (~few mm) targets

D) Vertex Si telescope: tracks the fragments just downstream of the target. Measures the emission angle with the requested precision and detects out of target interactions

E) One arm Lead-fiber calorimeter covering wide θ angular region in a narrow φ range (yet to be approved)

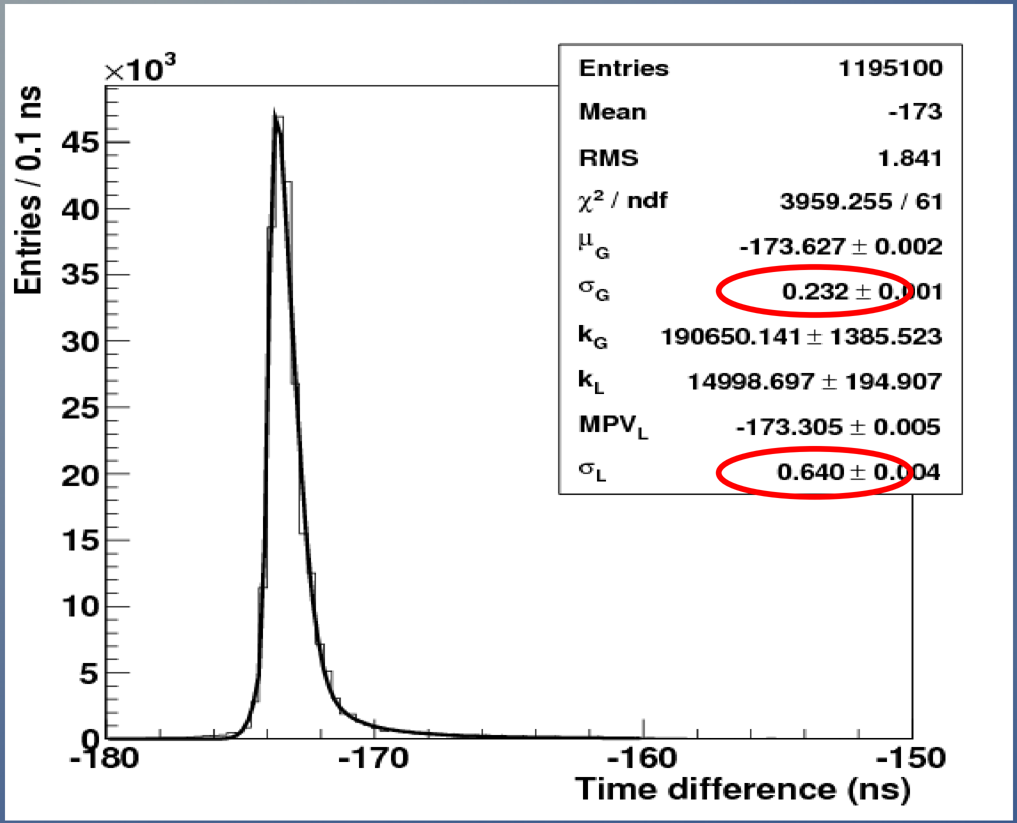
The start counter

Provides the START to the TOF measurement and to the TRIGGER. "Stardard" plastic scintillator but with peculiar features to fulfill the TOF requirements:

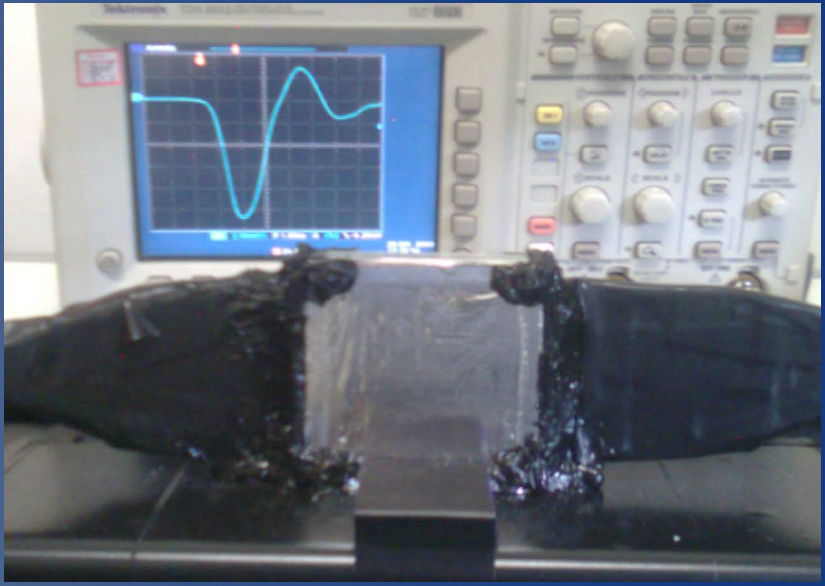
- At most 200 μm thickness to avoid interactions (2-3% of the target thickness)
- Must integrate enough light to have O(200-300ps) of time resolution. A ^{12}C @300 MeV releases in 200 μm as much as one mip in 5 mm, Birks saturation included.

Prototype with fiber built and tested @ 62MeV/nucl carbon beam in LNS. No cosmic, β sources or X sources can be used to test it in lab, only α particle

Timing performances



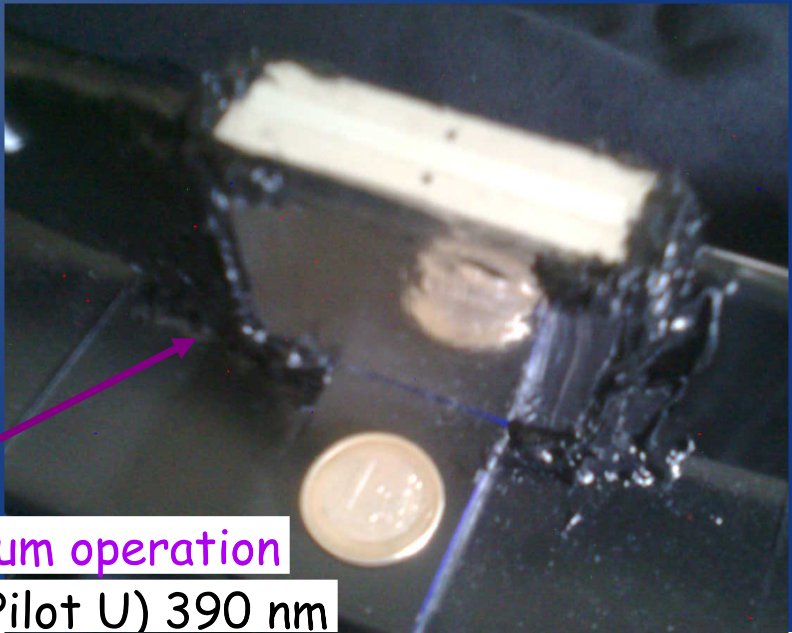
short signals: 5 mV vs 1 ns



~300 ps sigma with large tails → bad S/N (10 mV/5 mV r.m.s) due to grounding and small amplitude

Fast (~ 250ps/√(p.e.)) and high q.e. (~40%) brand new Hamamatsu photomultipliers H10721-210

Wrapped with thin aluminum-mylar envelope → 2 x 2,1μm aluminized mylar windows



Ready for vacuum operation

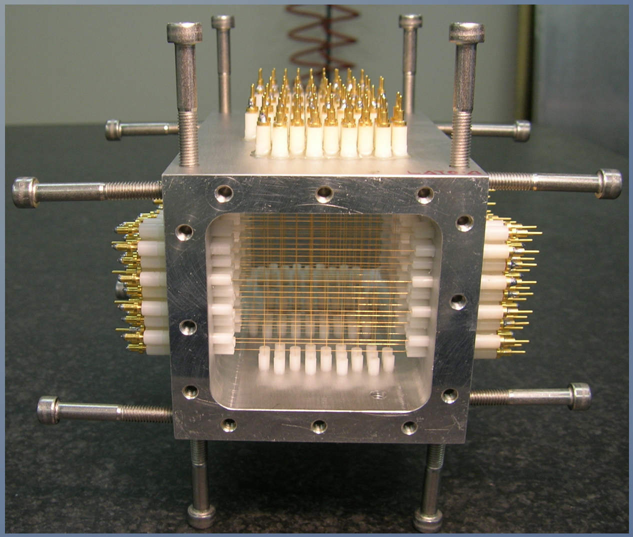
100 μm EJ228 (Pilot U) 390 nm

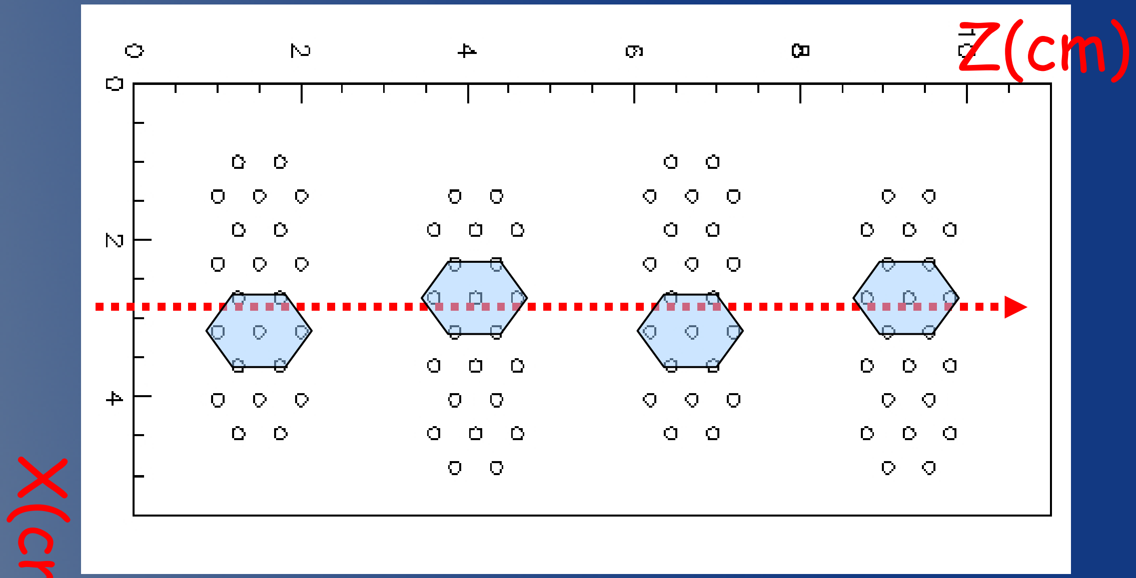
The Beam Monitor

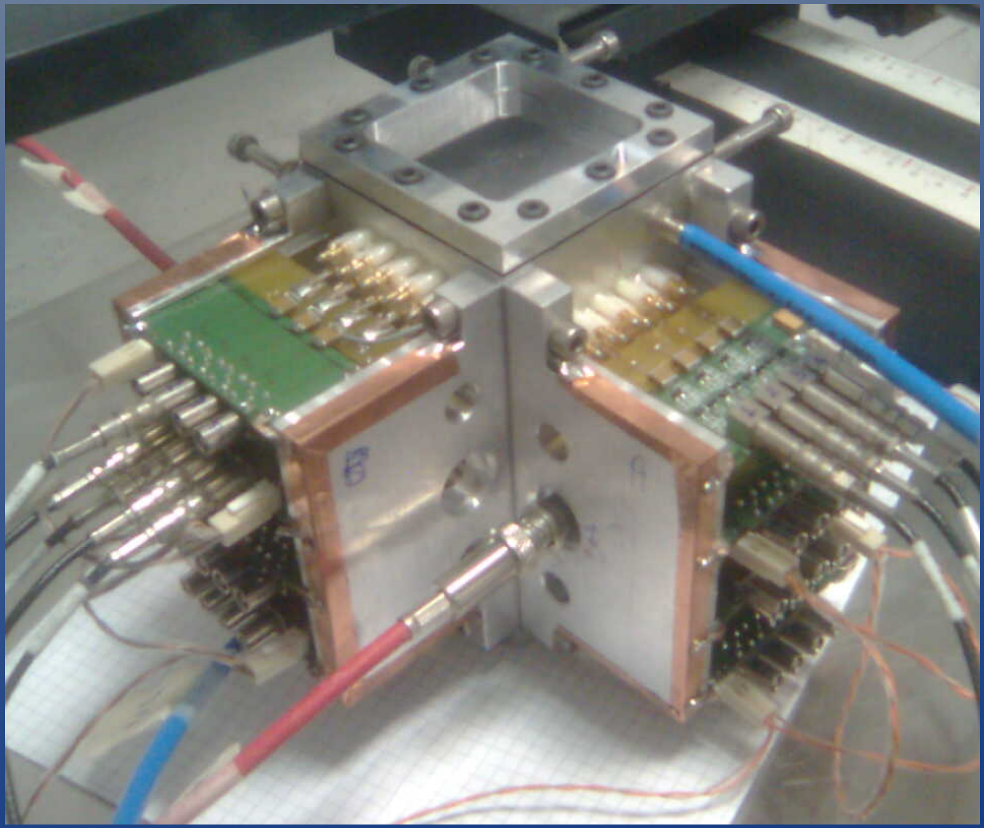
TRacks the carbon beam. Gives the impact point on target and the primary carbon direction: crucial to spot out of target interaction and to recover events with double primary carbons. Tested at LNS 62MeV/nucl ^{12}C beam

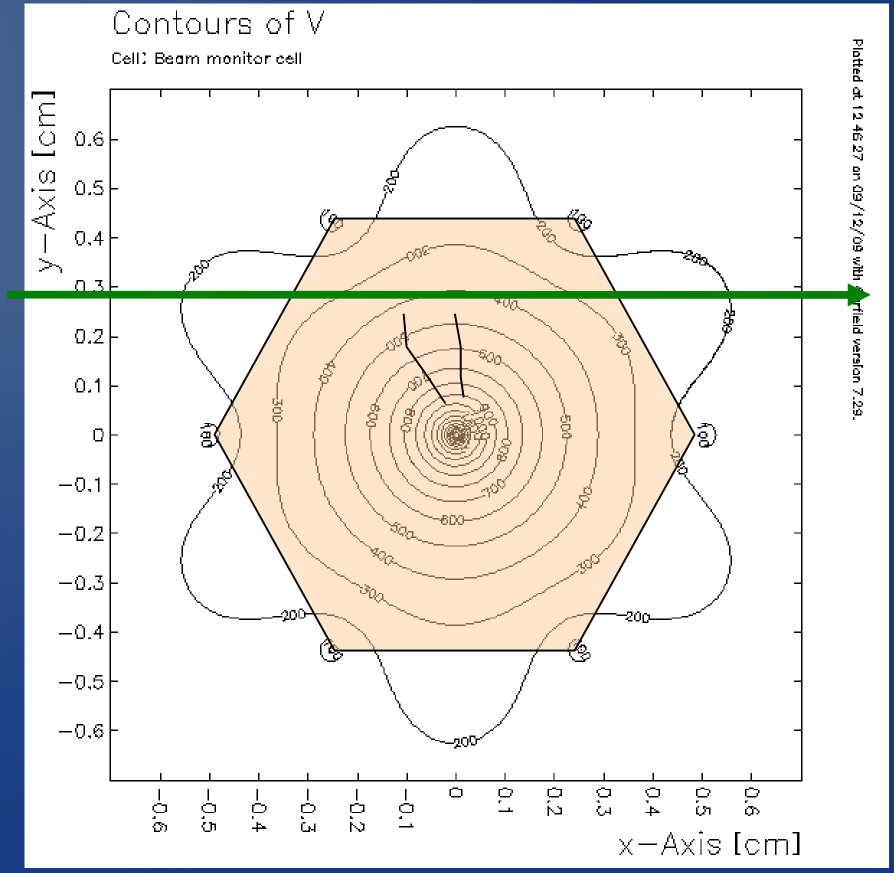
- Drift chamber with exgonal shape cells
- 4 planes in the y and x direction
- Wire thickeness: 90 μm field – 30 μm sense
- O(100 μm) single hit resolution with mip → O(100-50 μm) impact point resolution on target with ^{12}C
- Operation with carbon @ 300MeV/nucl ? Proportional vs quasi-proportional?
- Target mixture: P10 (AR-Ethane) but can operate both with Ar-CO2 (safety!)

The Beam monitor

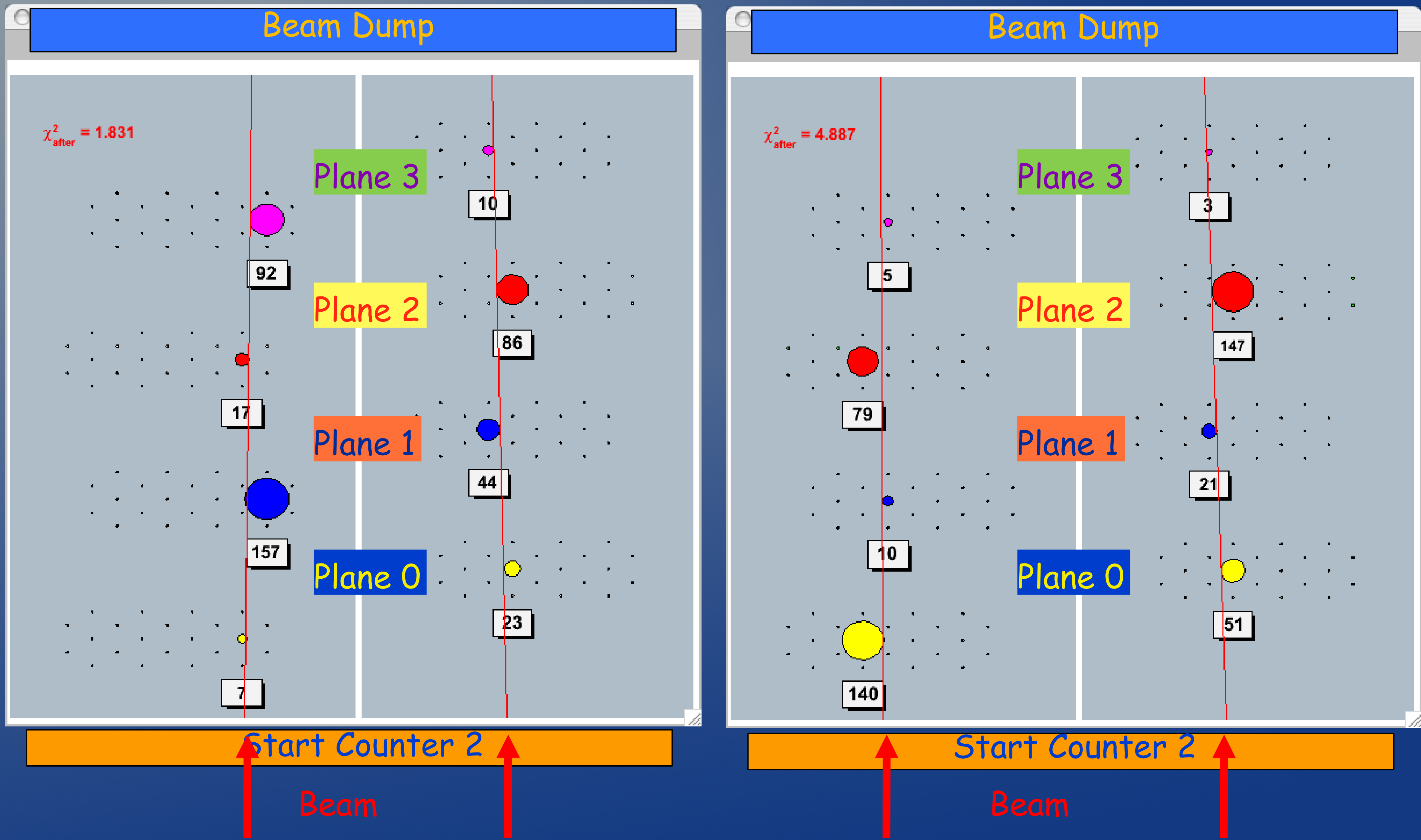






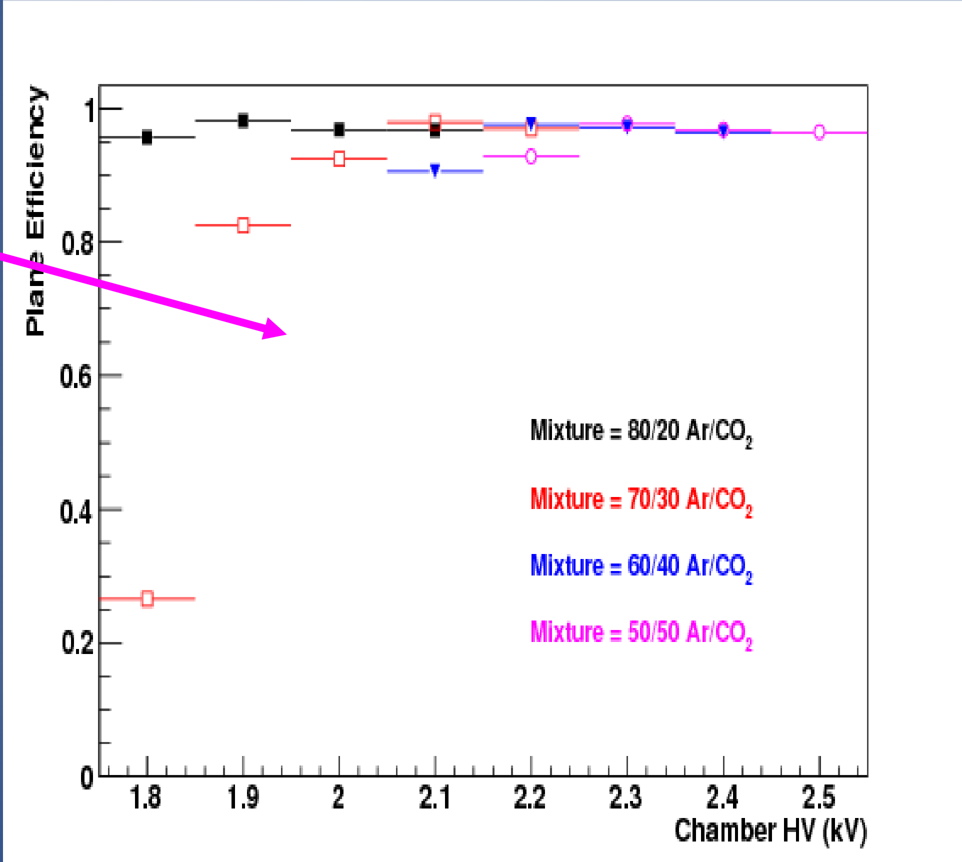


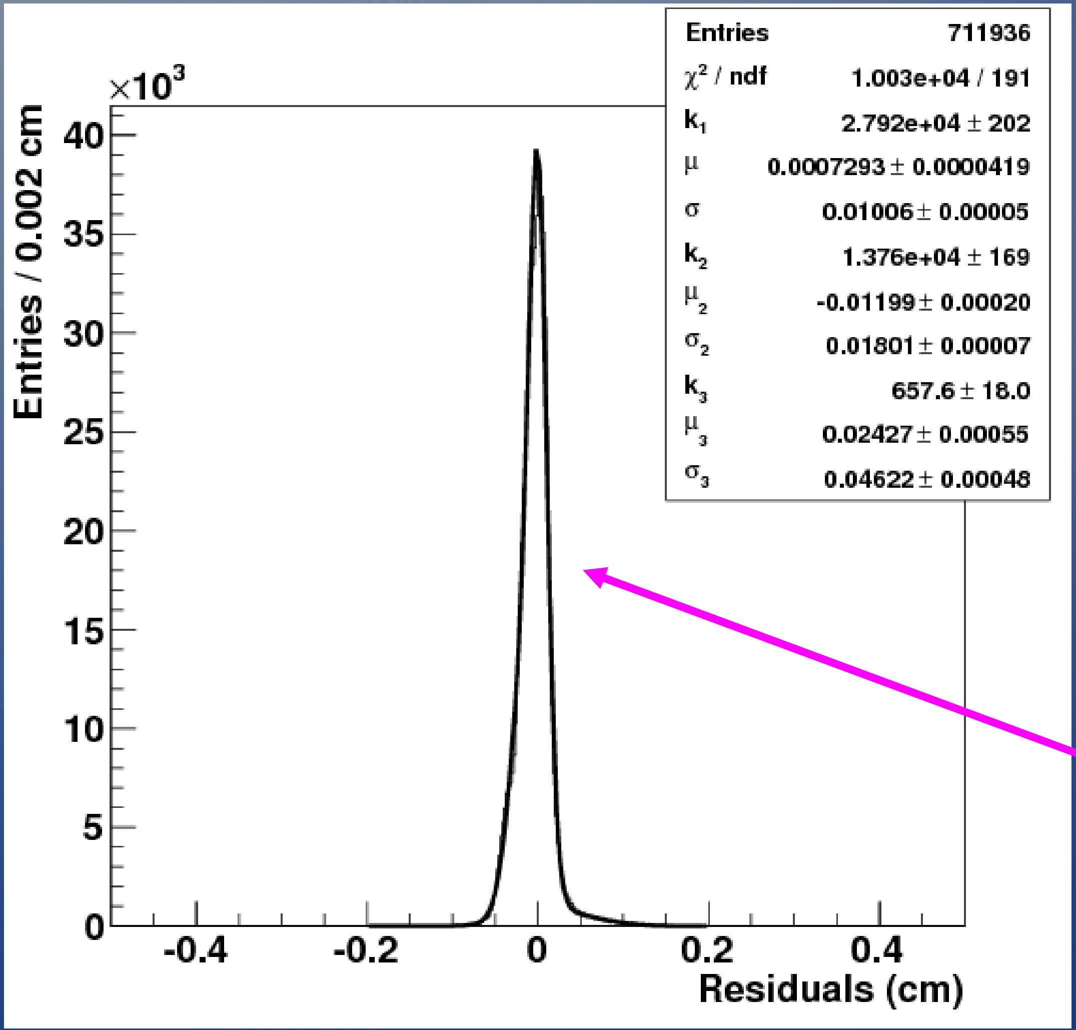
Beam Monitor @ 62Mev/nucl ^{12}C beam



B.M. Resolution & Efficiency preliminary

Fair efficiency (~ 95-96%) obtained with Ar-Co2 mixture . P10 mixture (default for exp.) should be even better





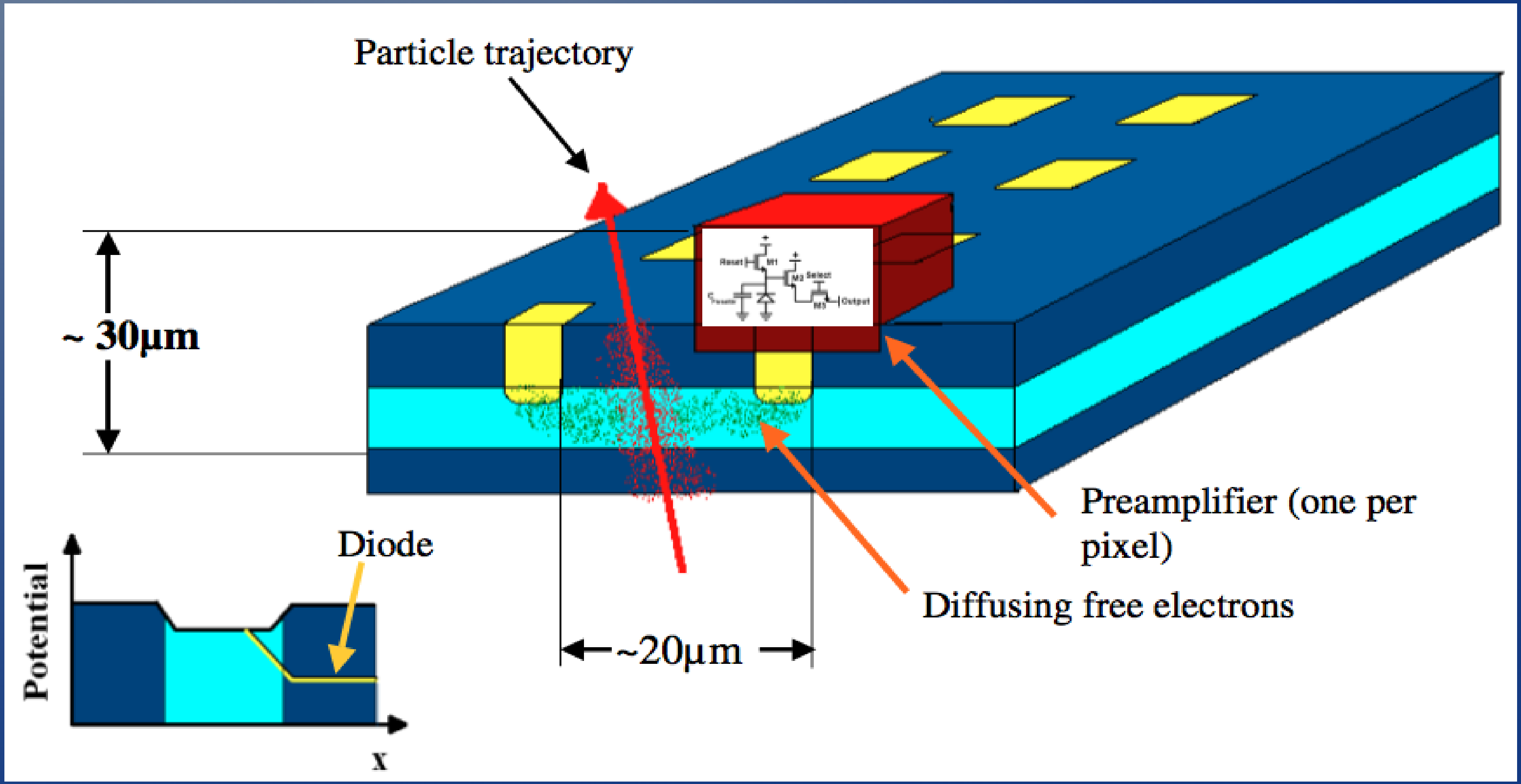
Spatial resolution of right order of magnitude O(100-200) μm is obtained (no R-T correction, no precise wire positioning, poor gas mixture knowledge)

Constraints on vertex detector

- ✓ The Carbon beam spot has a FWHM = 3mm → The active size must be at least in the range of cm^2
- ✓ The angular acceptance must be as large as possible to track the protons emitted at large angles (>40^0)
- ✓ The angular resolution on track must be ~ 0.3 deg to match the requirement for the therapy (1 CT voxel resolution after 15 cm of path) and to spot if the fragmentation vertex is outside the target
- ✓ Dinamic range should deal with signals ranging from 2 to 100 m.i.p. with good efficiency (>98-97%)
- ✓ If we consider 3 station then thickness must be less than 100 μm for each station, accounting for some % of the target thickness (N.B. Carbon interaction in vertex cannot be detected → directly contribute to systematic!!)

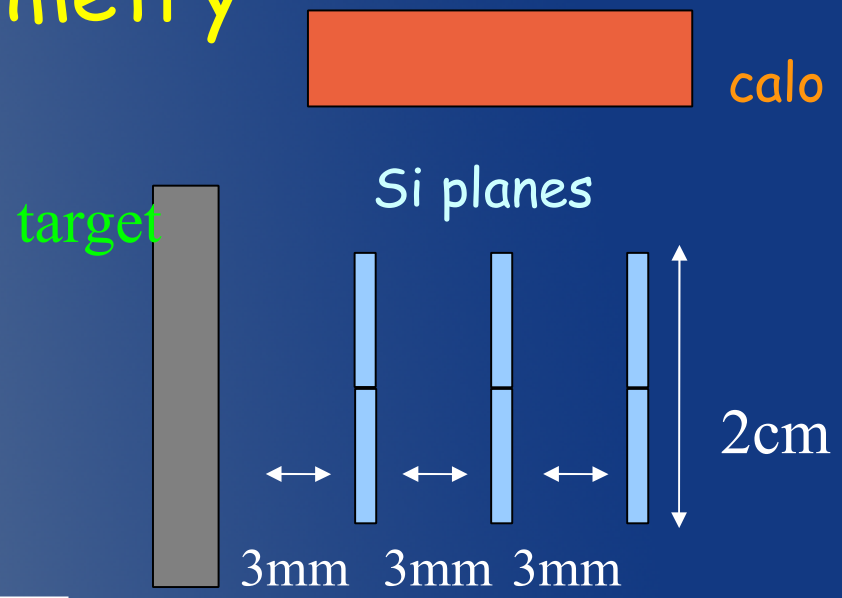
The MIMOSA26 detector

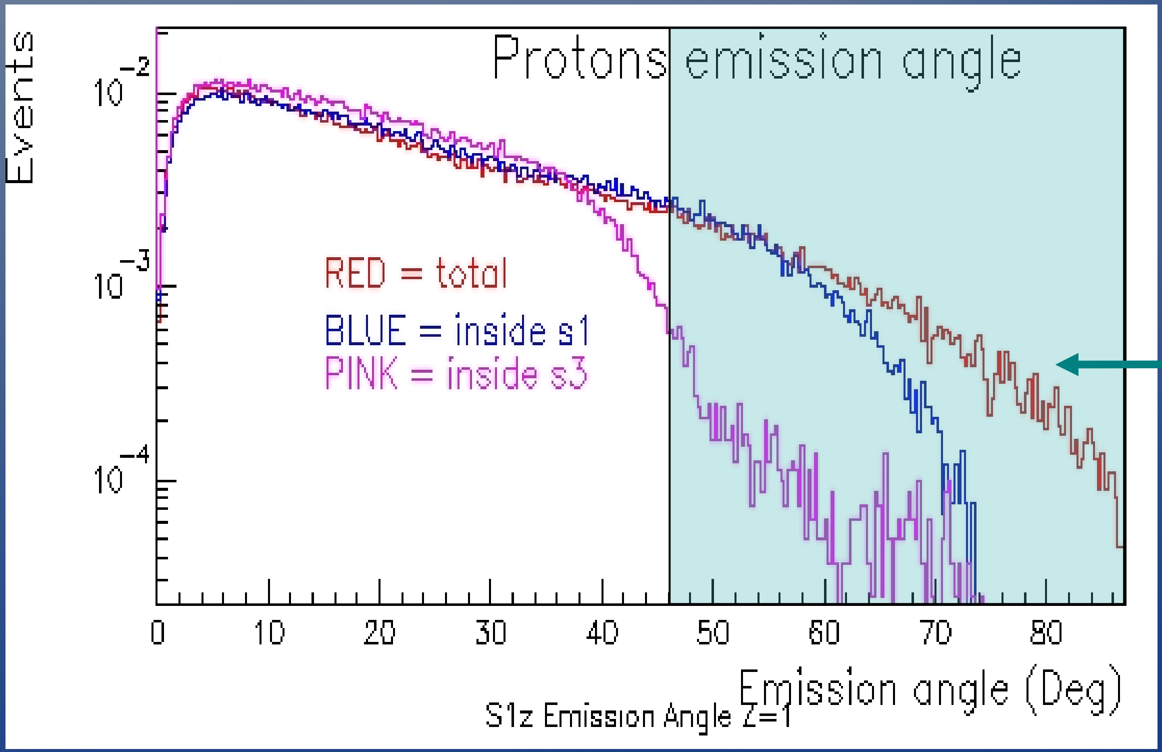
- Active surface :1152 columns of 576 pixels ($21.2 \times 10.6 mm^2$)
- Pitch: 18.4 μm → 0.7 Mpixel → σ_{sp} ~5μm
- Digital readout at 10 Khz rate
- On chip electronic to process the signal in few μm layer
- Zero suppression on board
- Can be thinned at 50-60 μm



Vertex detector : setup geometry

The shown setup, (6 MAPS in 3 planes) could give large angular acceptance and 0.4^0 angular resolution even with clusters of pixels detectd with 50 μm spatial resolution





Only ~15% of the proton angular distribution is out of acceptance of the Vertex (3 planes).
Only few % asking 1 plane + calorimeter
Proton energy coarsely measured by the lead-fiber calorimeter

MIMOSA26: response to light ions

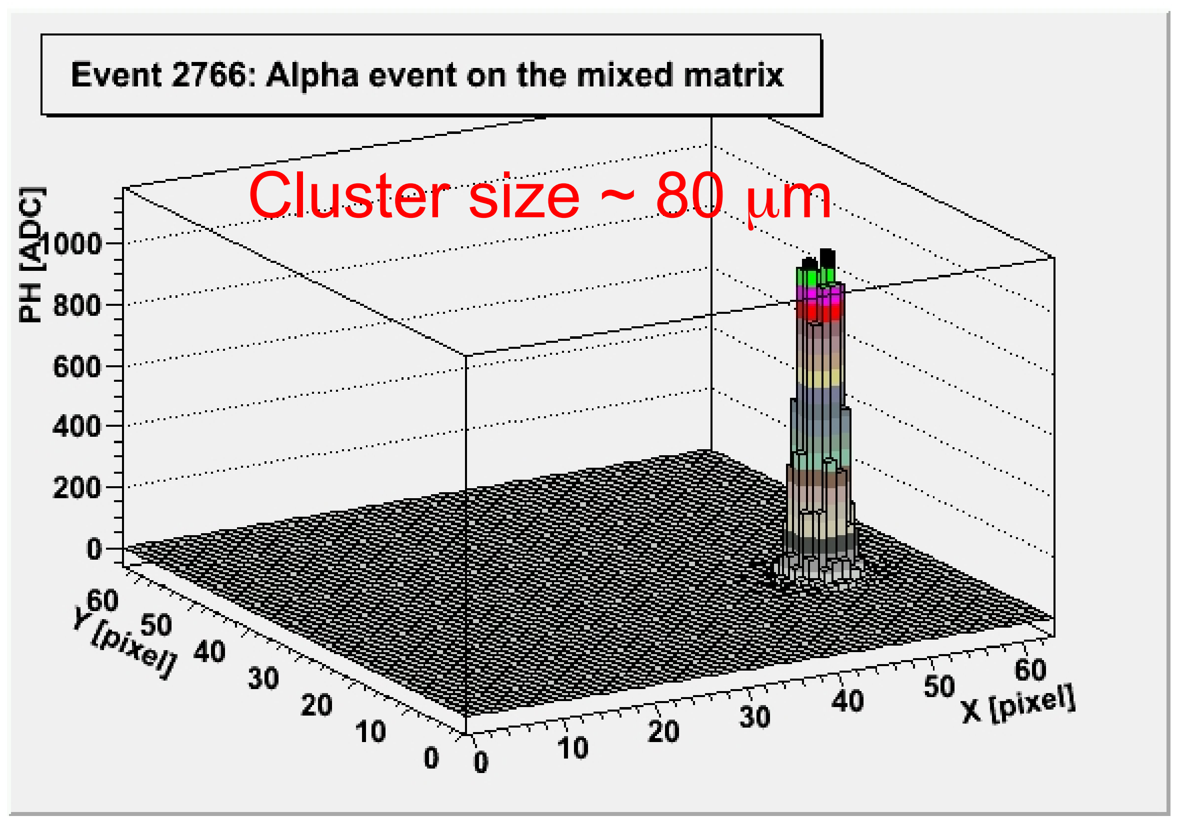
The MIMOSA chip shows a correlation between the energy deposit and the cluster size: can improve ion identification.

Am241 event in MIMOROMA, same MAPS technology of MIMOSA26

Response to light ions (cluster size, eff,..) foreseen to be studied at LNS ^{12}C beam

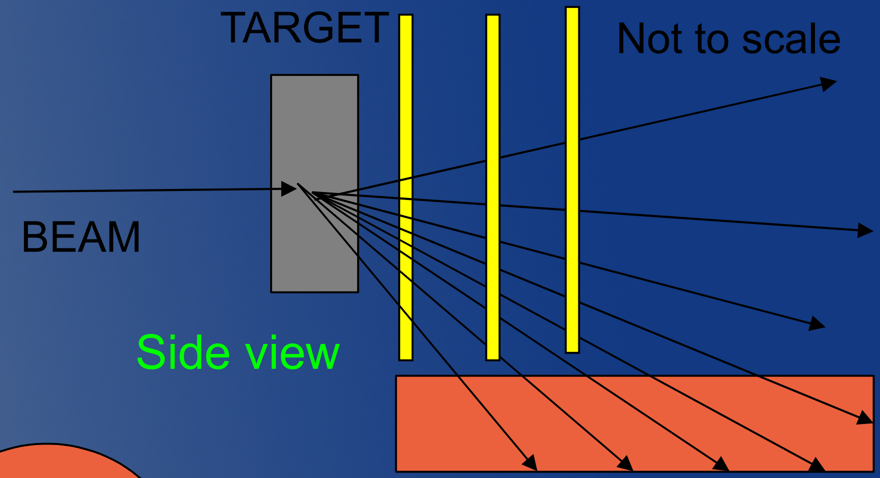
Can be tested also with α from Am241 source but…

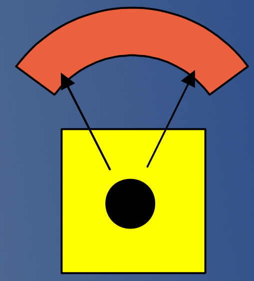
Energy release by Am241 is larger than by 200 MeV/nucl carbon → carbon has smaller cluster size



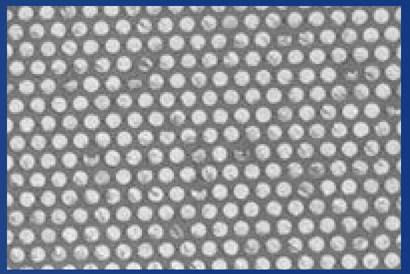
I.R. Calorimeter

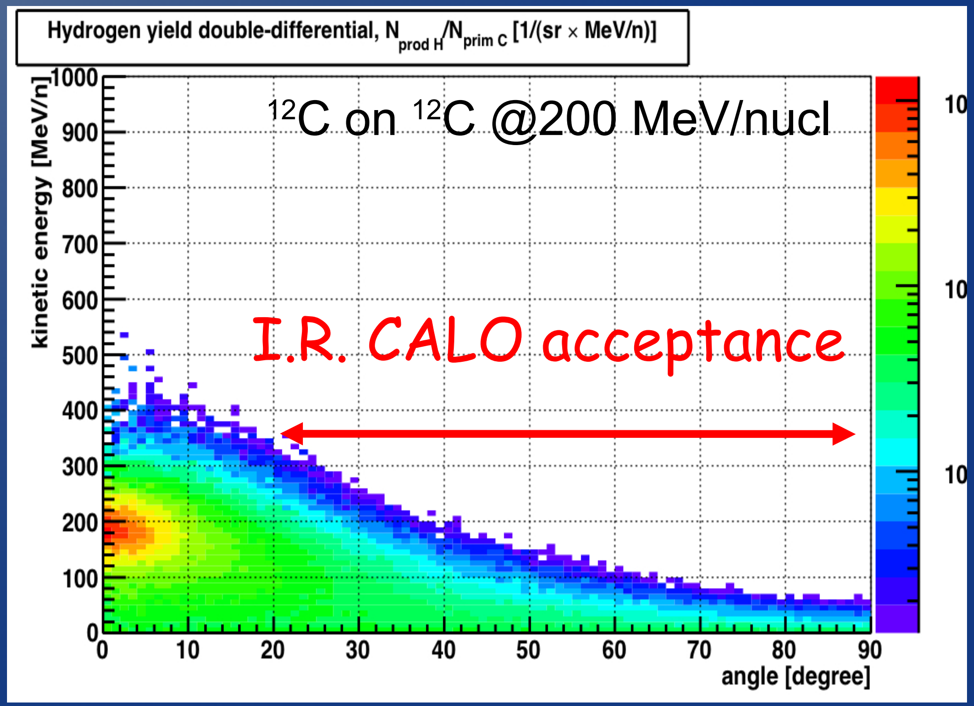
- Needed to detect the large angle fragment escaping from the HODO and ALADIN acceptance (mainly protons)
- Yet to be approved, but INFN institution already at work
- A possibility would be a lead-fiber calorimeter with reduced aperture in φ to save FEE (and MONEY!)
- Proton-deuteron-tritium ID possible by TOF
- Coarse tracking and sufficient Energy resolution for low energy proton





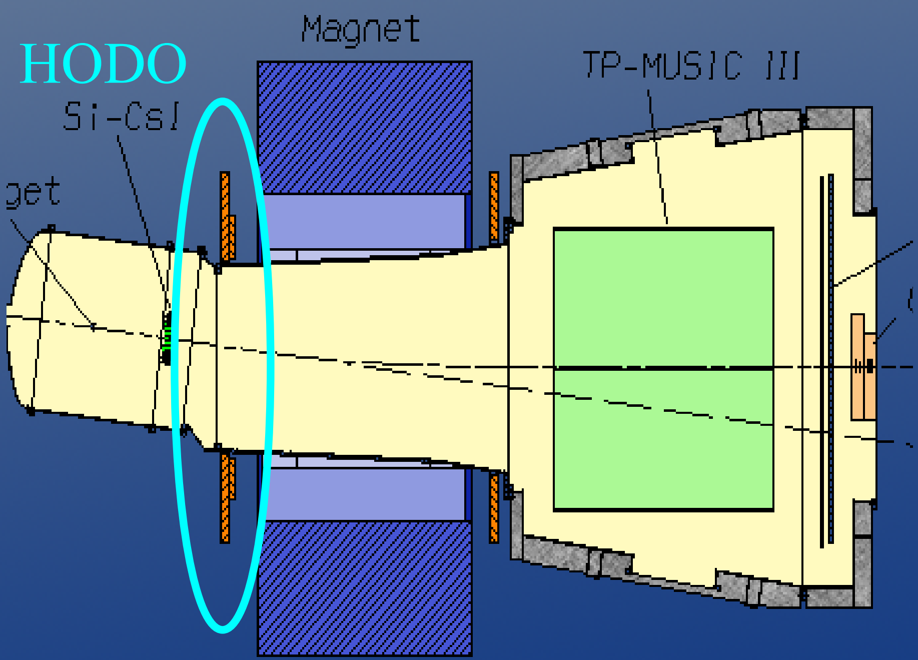
Front view

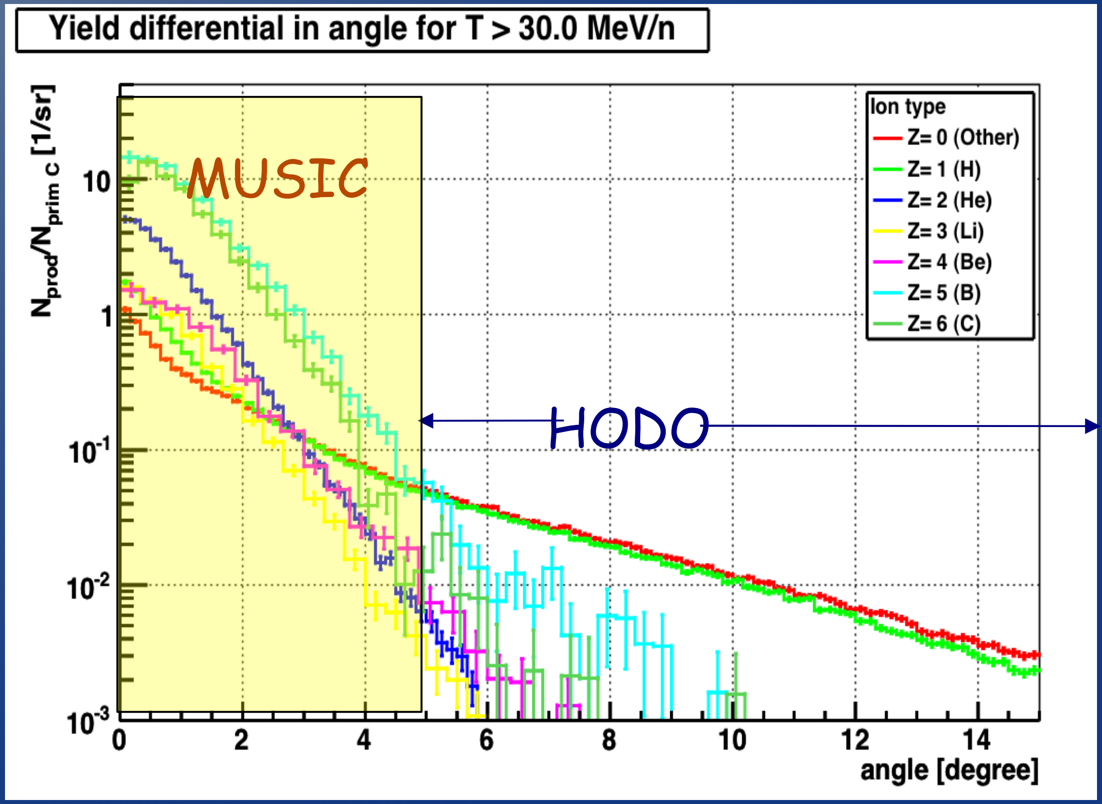




The Large angle Hodoscope

- 89 three-fold telescopes 50 μm + 300 μm Silicon detectors both having 3x3 cm² surface followed by a 6 cm long CsI(Tl)of the sa me surface.
- Acceptance θ_{lab} between ±4.5° and ±20°, tracks not entering in MUSIC, mainly p & He
- Measure dE/dx, E, θ, φ

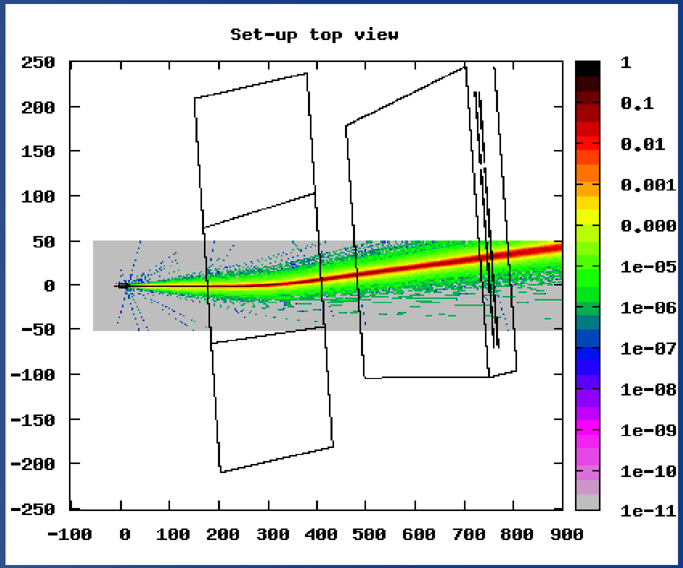


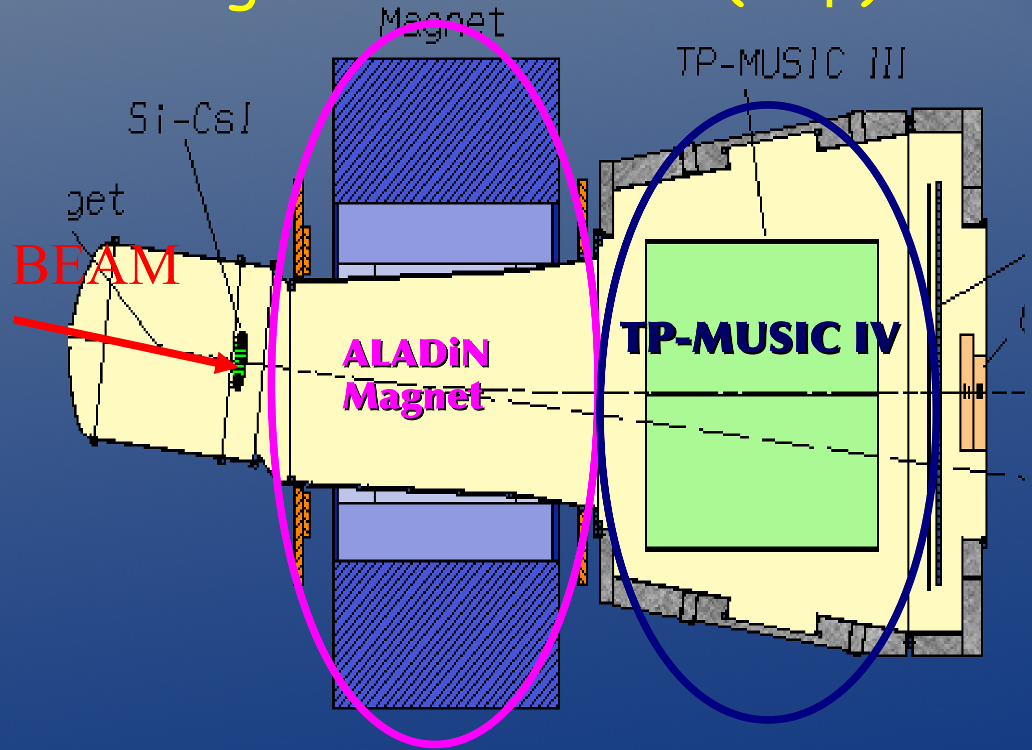


The Downstream Tracking: Aladin + Music

Downstream the IR we have Aladin, a large area dipole magnet, coupled with the large volume MUSIC IV TPC. The combination provides info on:

- Fragment tracks after bending → R=p/(ZeB)
- Fragment DE/Dx → $(Z/\beta)^2$





Large dinamic range needed (2-100 m.i.p signal)

Maximum track rate due to long drift time (~100 μs) of ionization electrons: O(1-2 KHz)

Full geometrical acceptance for frags Z>2, fair for He, poor for protons

The TP-MUSIC IV

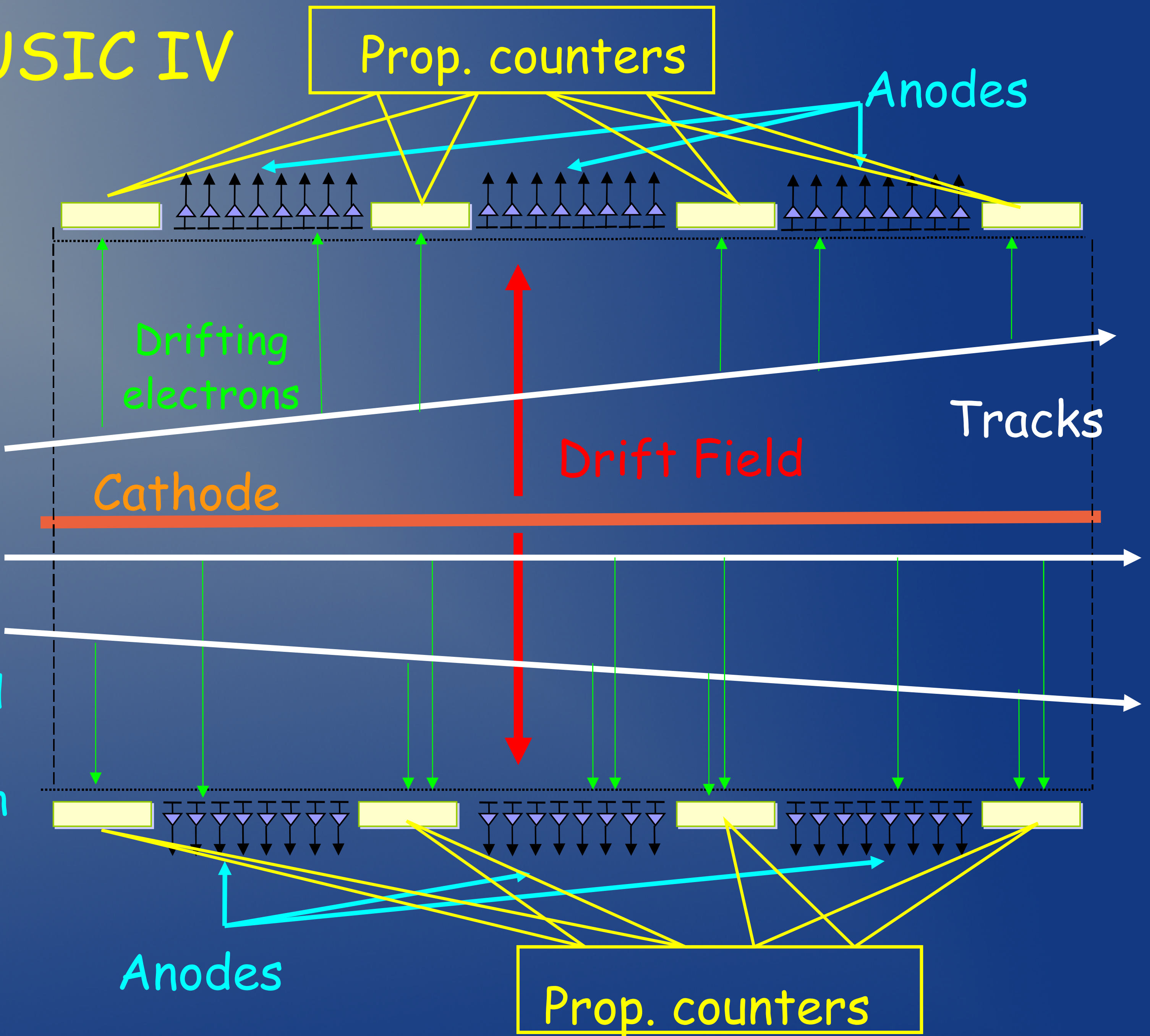
48 Ionization chamber layers

8 proportional chamber layers

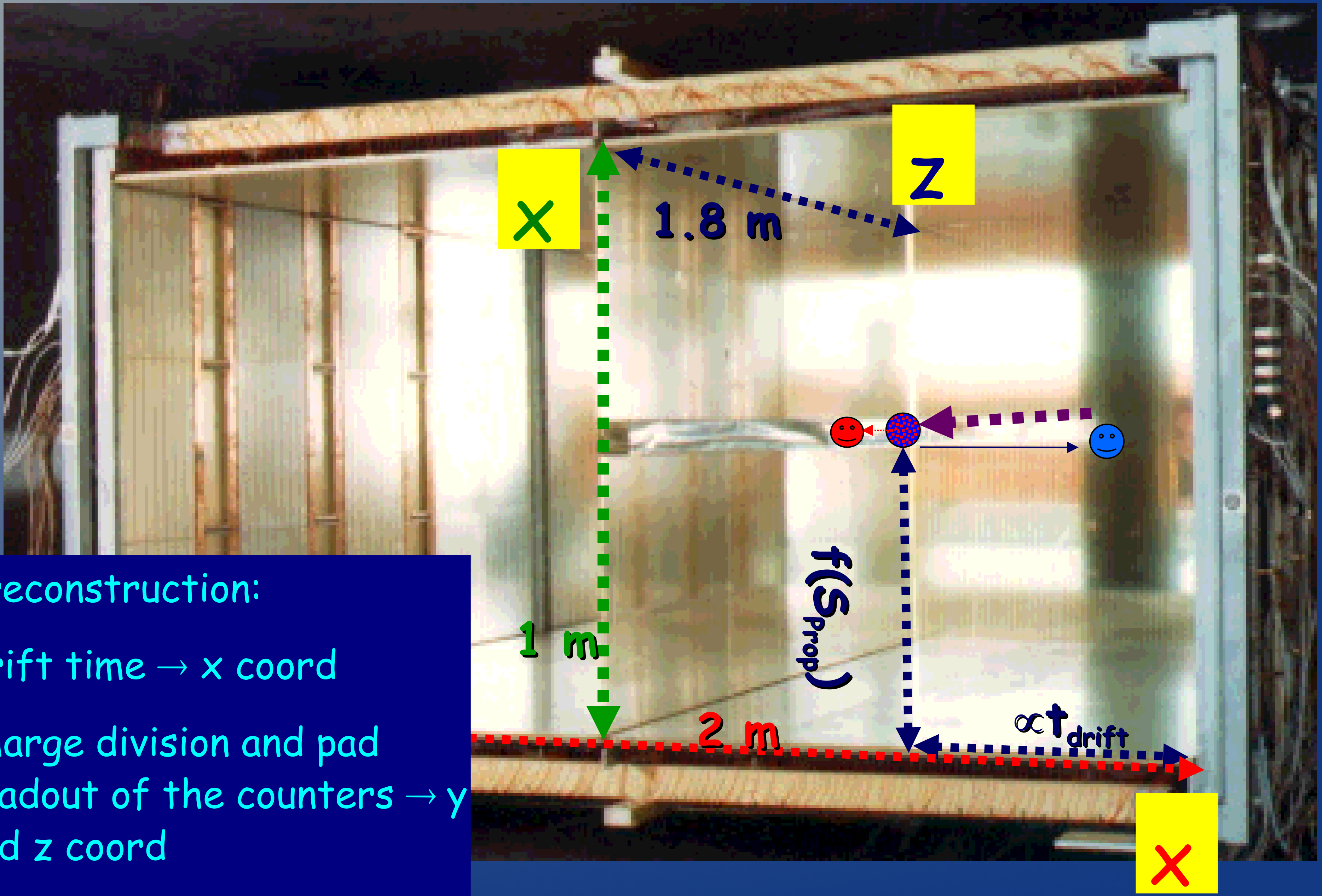
Time and charges of the counters registered

Prop counters read by pads to detect transverse position

Digital processing of the signal



The TPC-MUSIC IV



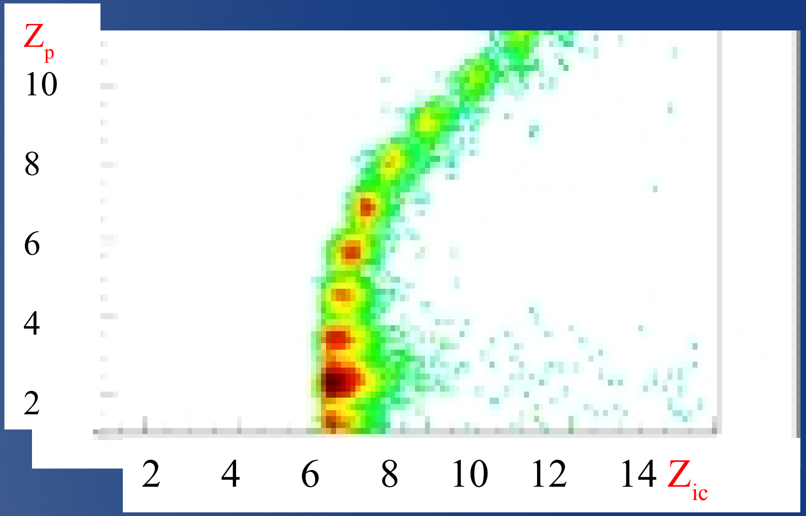
Space reconstruction:

- Drift time → x coord
- Charge division and pad readout of the counters → y and z coord

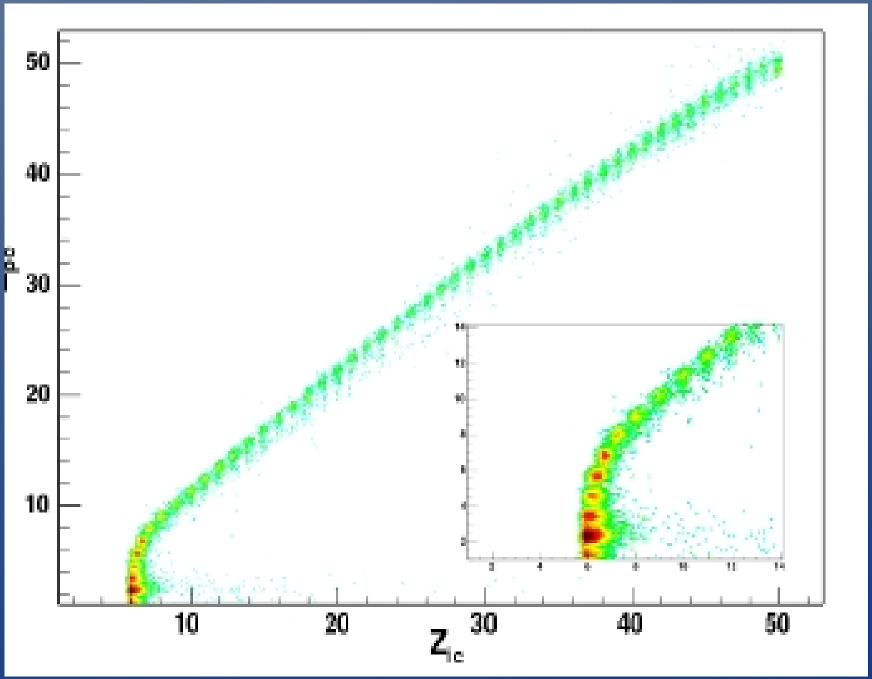
The beam is along the z coord

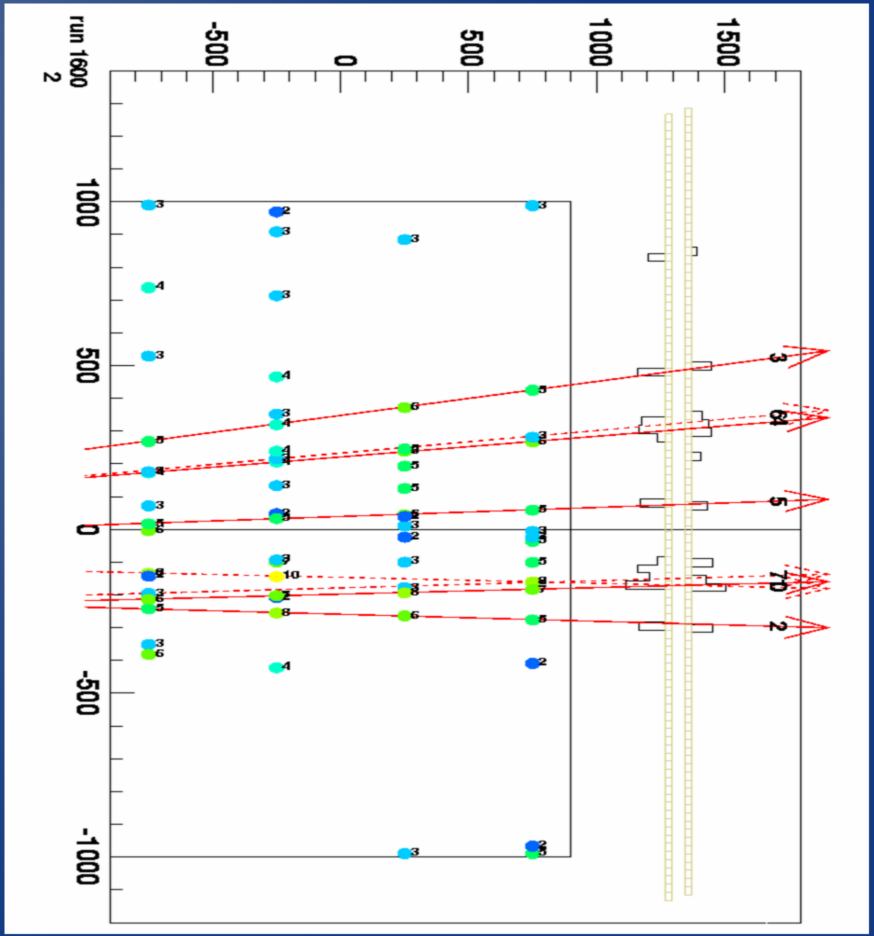
The MUSIC IV - TPC

- Must be tuned for low Z fragments →reduce the dinamic range



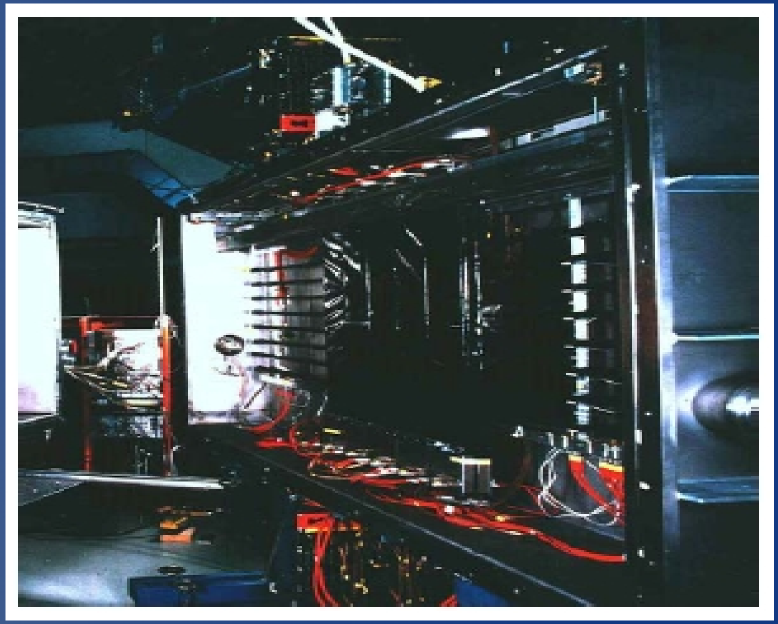
- Fragment directions measured must be bactraced along some meters to IP

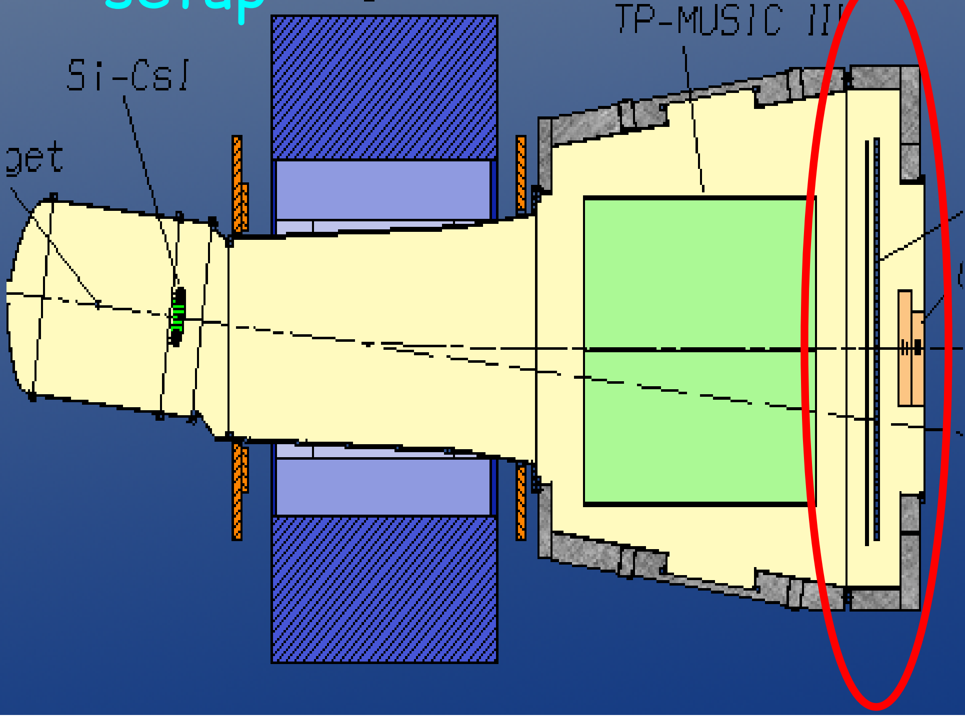


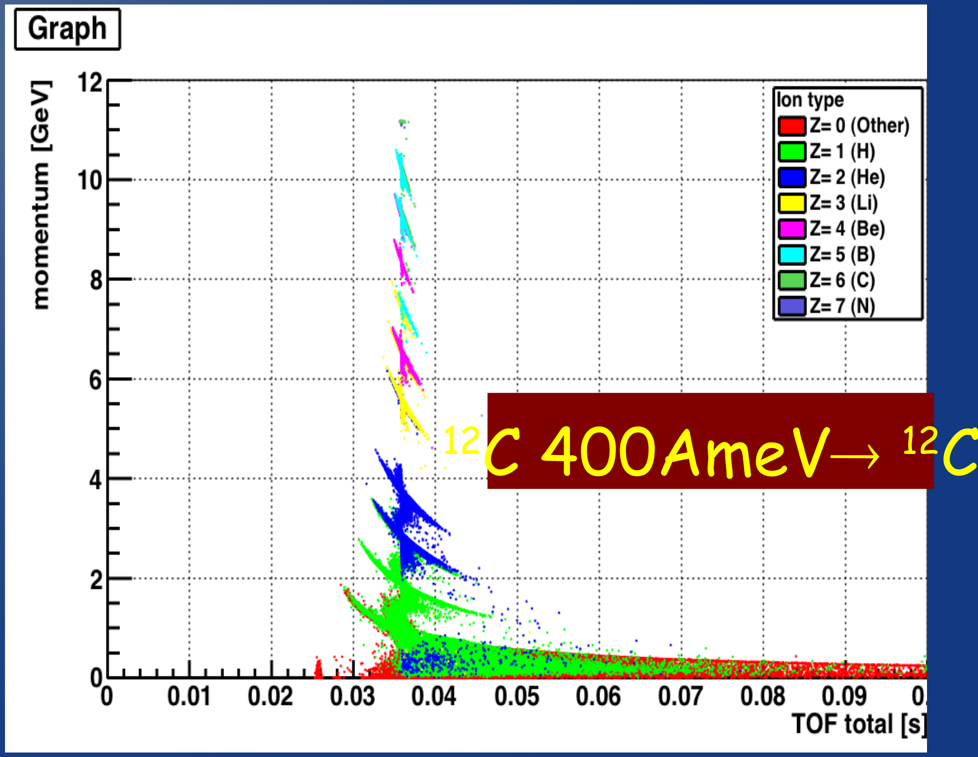


The TOF WALL

- Gives arrival time and impinging position of the fragments
- Time resolution be matched by resolution of start counter
- $\beta = L(p,Z,\theta,\varphi)/TOF$ The time performance must be matched by the tracking capabilities of the setup

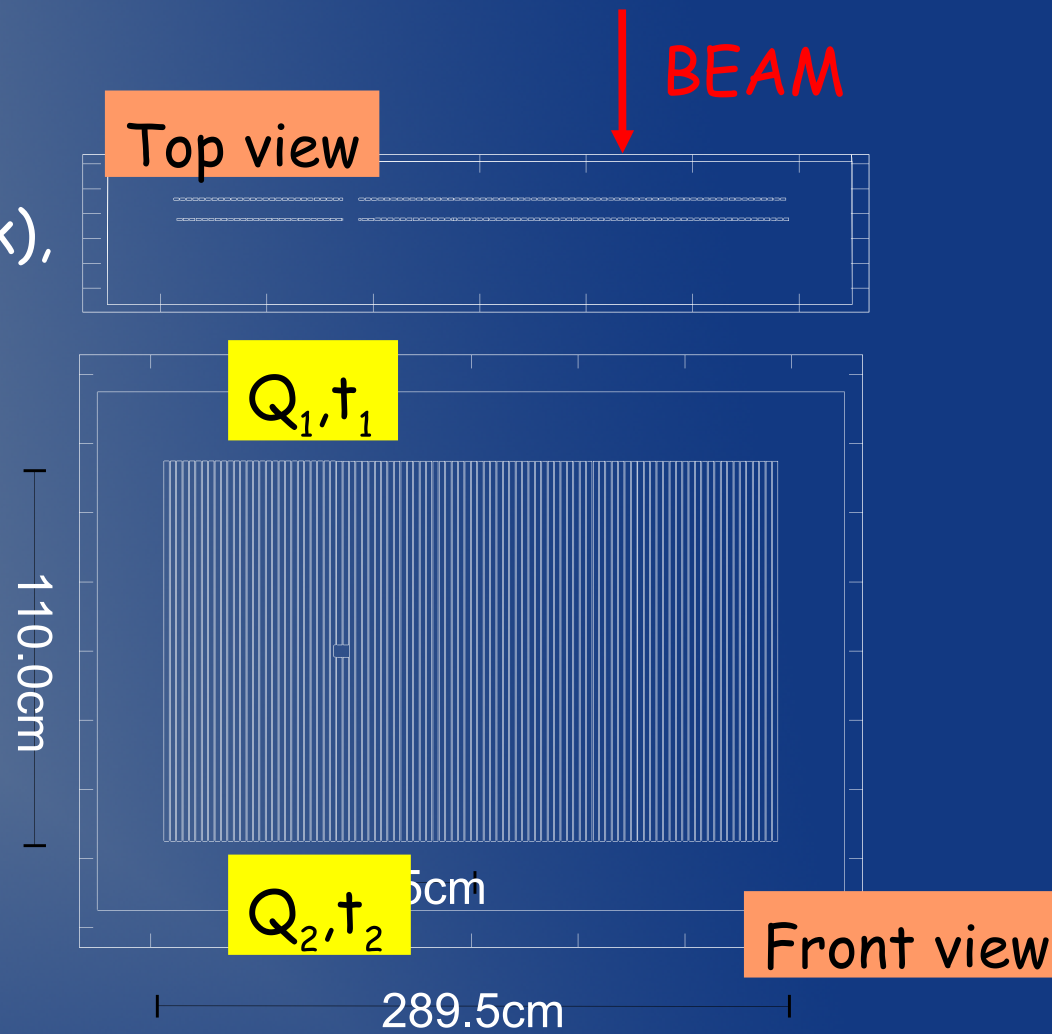


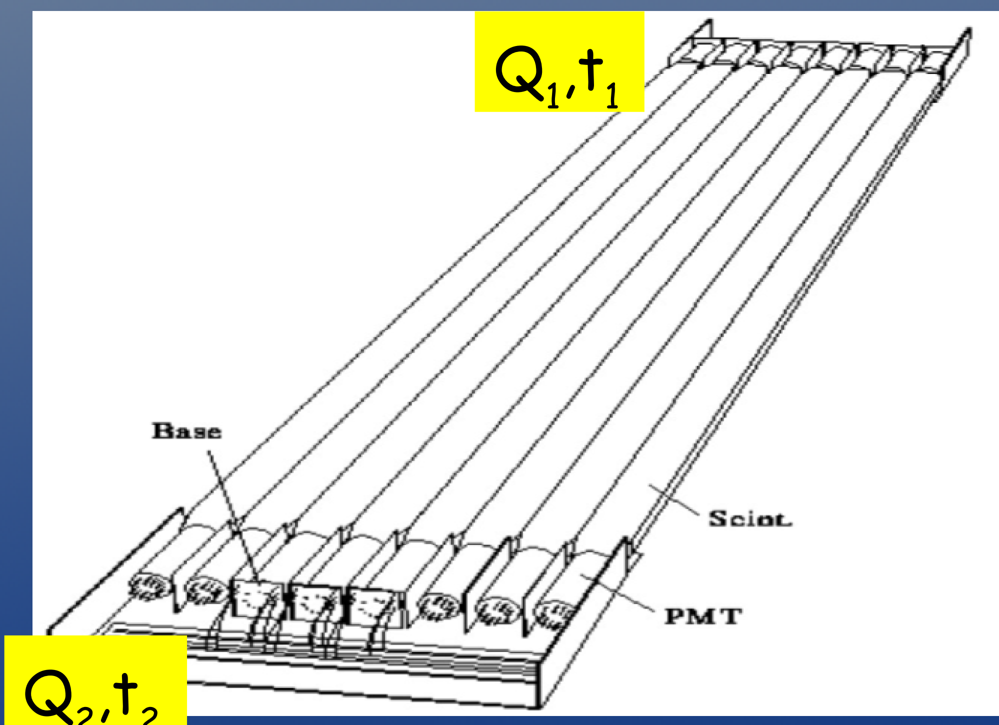




The TOF WALL

- Two detector layers (front and back), each made of 12 modules
- Each module made of 8 plastic scintillators (BC408), 1.10 m long, 2.5cm wide and 1 cm thick

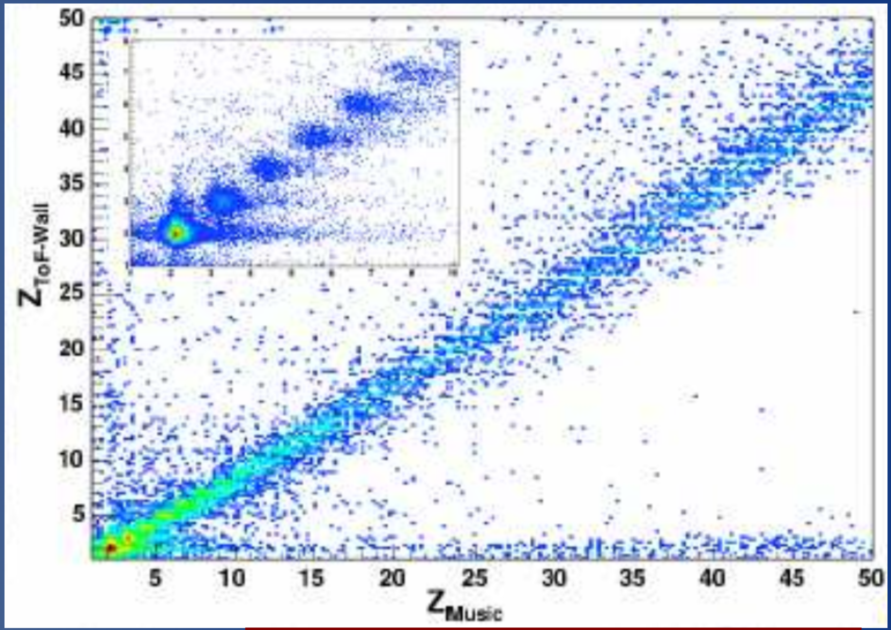




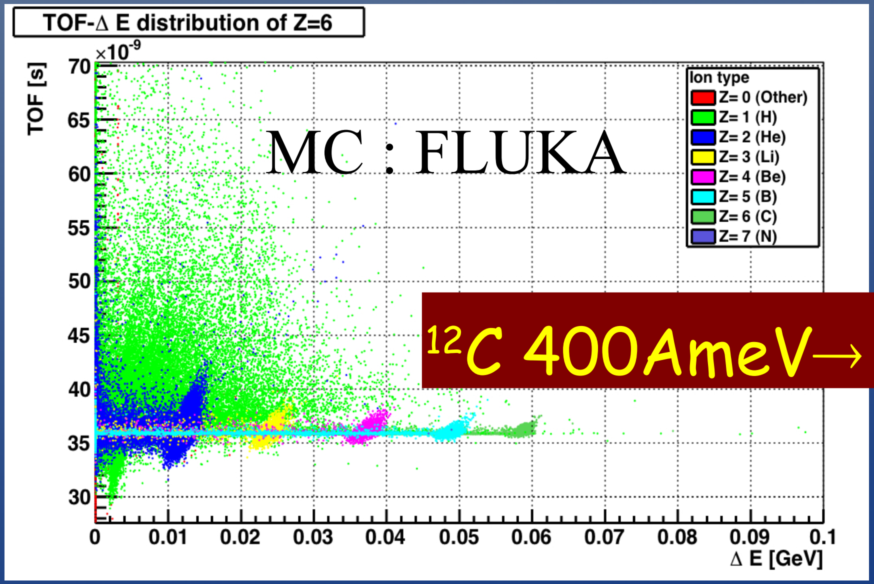
- Read Q & t at both sides of the slabs
- coord along slat from Q1/Q2
- Time resolution O(200) ps on carbon, worst on lighter frags

TOF-WALL performances

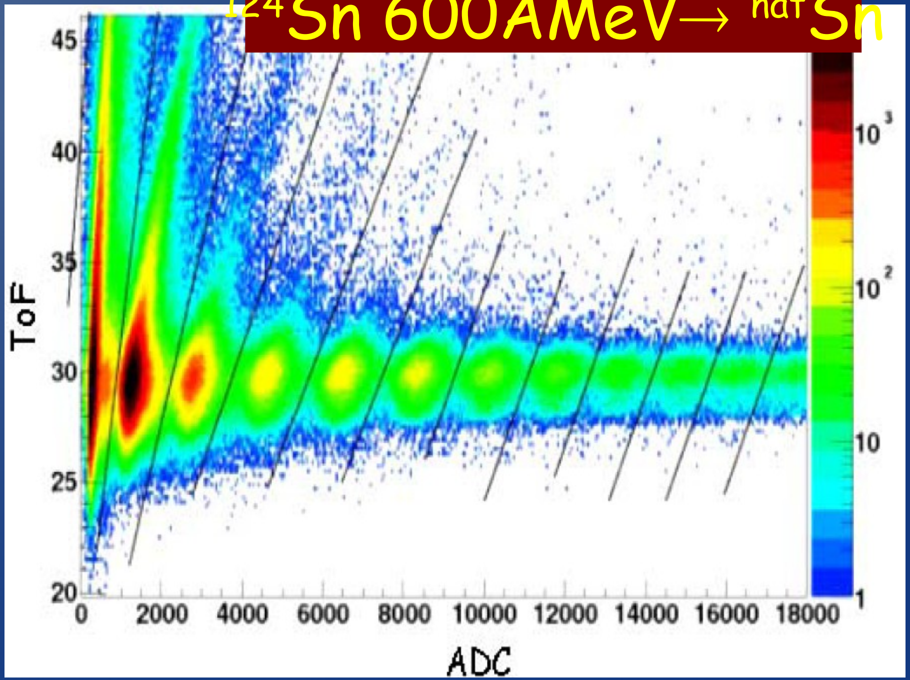
- TOF vs Q analysis provides standalone Z separation power
- Frag ID power fully exploited with MUSIC info
- Dinamic range to be optimized for low Z frags



^{124}Sn 600AMeV→ ^{nat}Sn



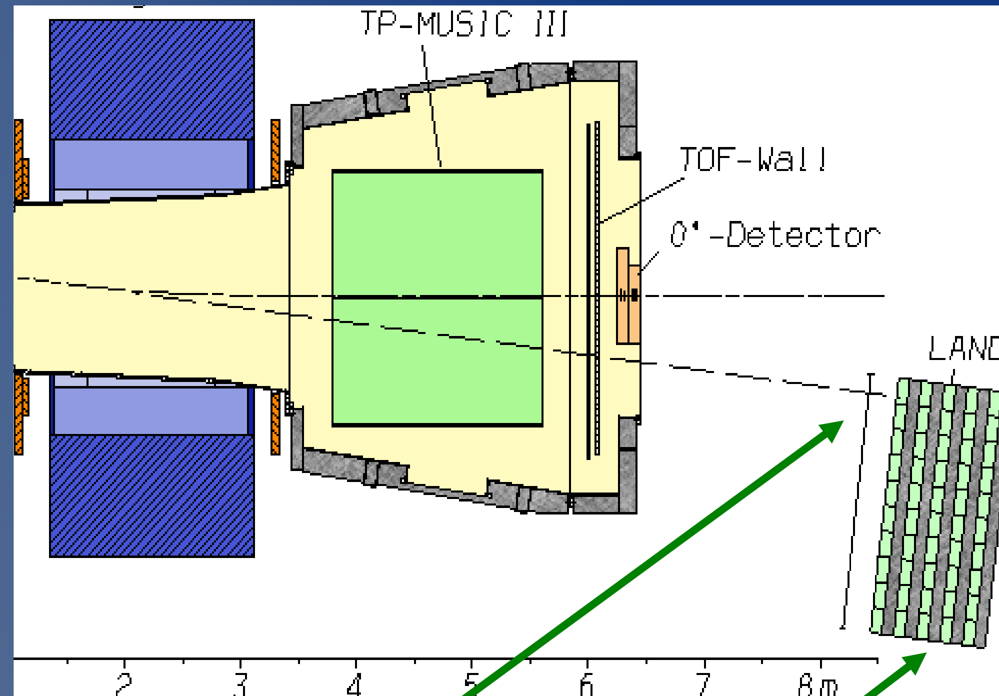
^{12}C 400AmeV→ ^{12}C

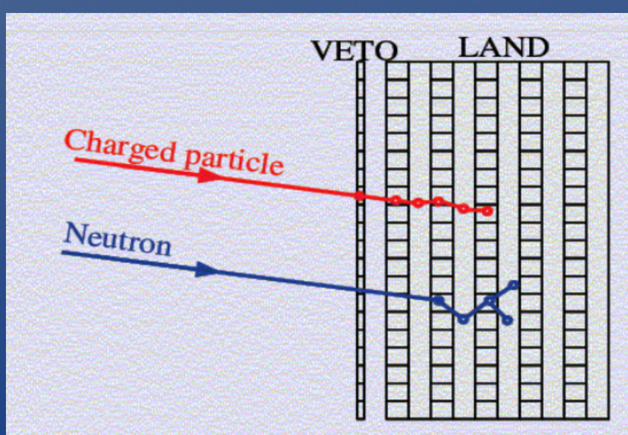


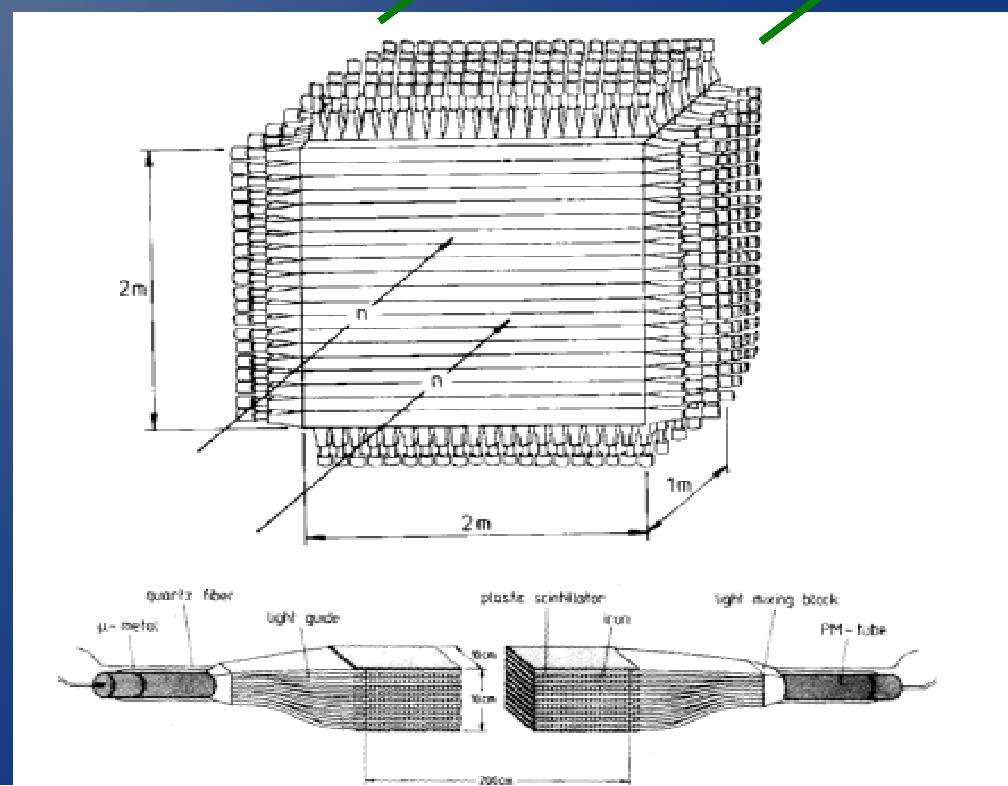
M.De Napoli: PhD Thesis 2005

LAND, the neutron detector

- Active volume: 2x2x1 m^3
- Divided in 200 paddles 200x10x10 cm3.
- Each paddle made of 11 sheet of iron ad 10 sheet of scintillator 5 mm thick
- Veto in front of the detector for charged particle





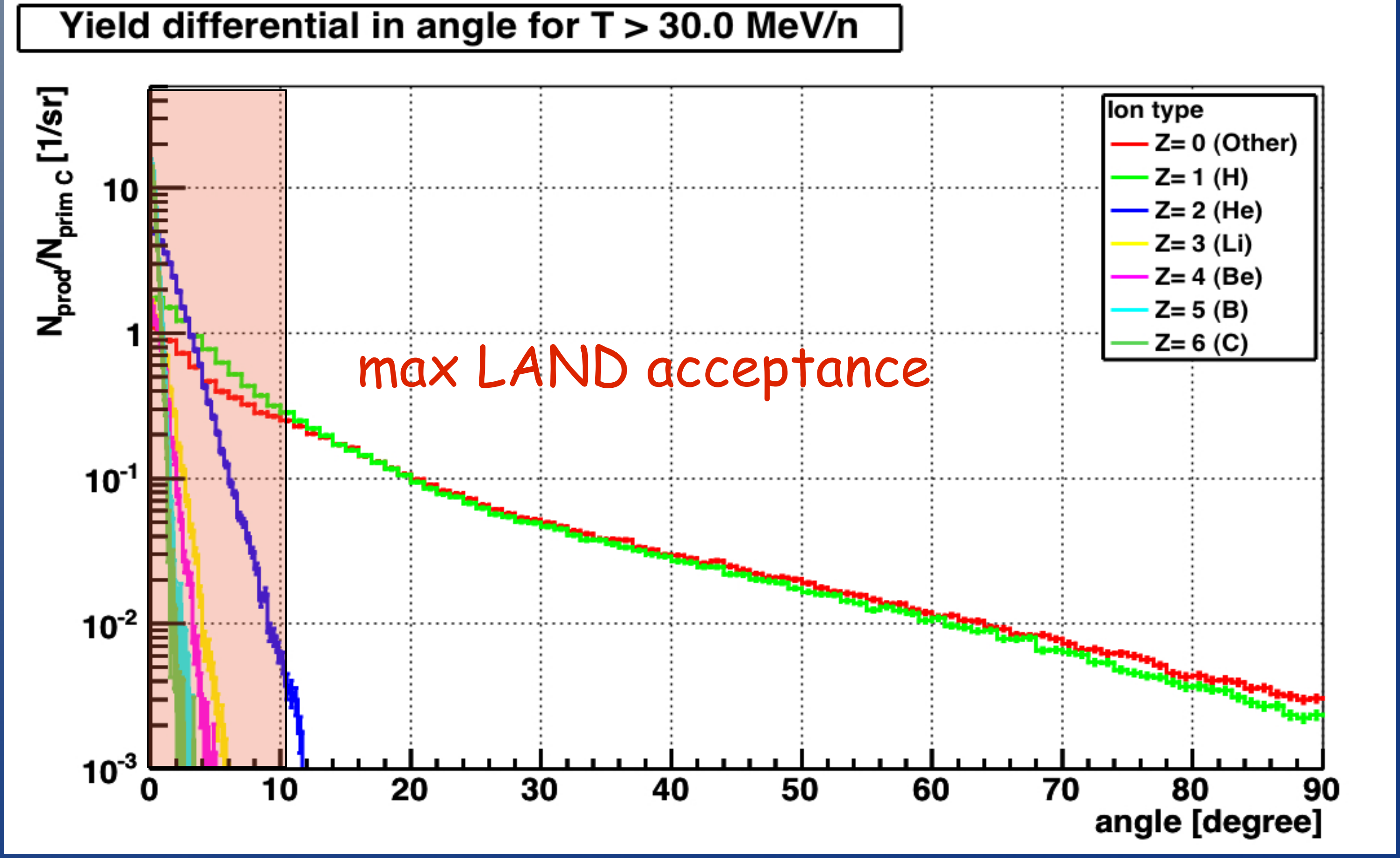


LAND, the neutron detector

Reduced angular acceptance: is it enough to test the model?

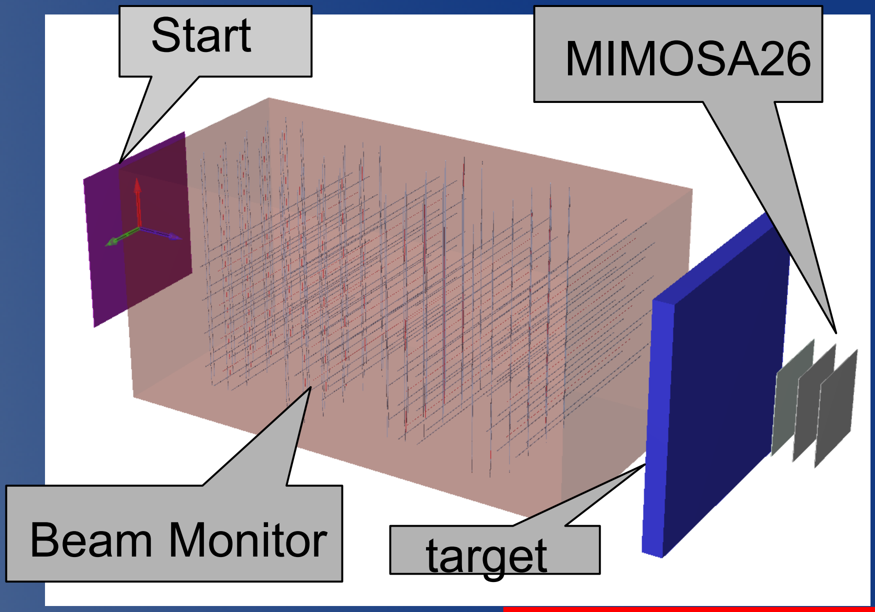
The IR calo could help the neutron flux measurement

- Eff ~ 90% for 300 MeV neutron
- Time res ~ 500 ps

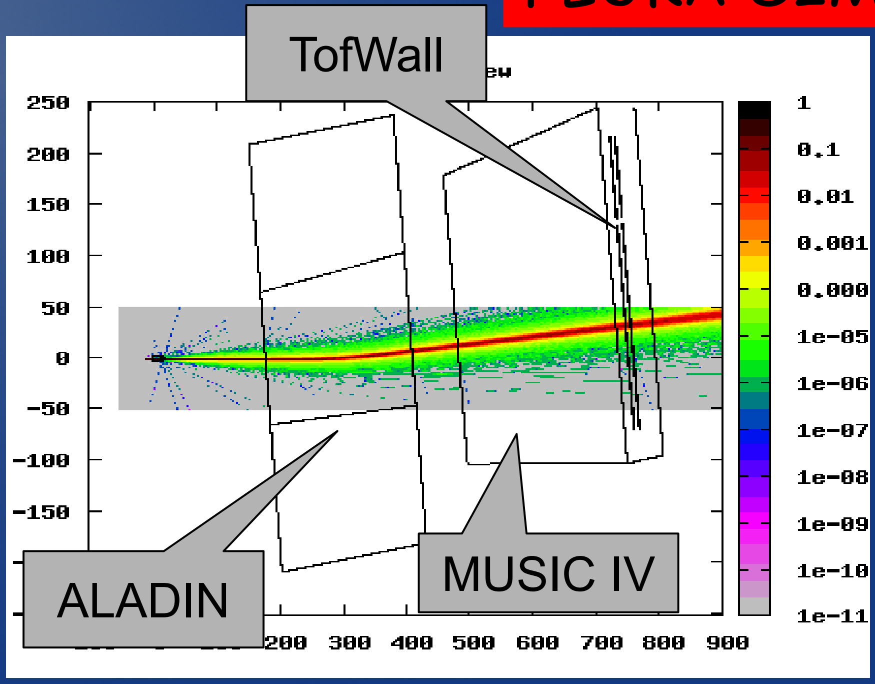


There is more than that...

- DAQ, FEE, TRIGGER, Calibrations.. anything can induce systematic errors on the measure (es: dead time, pile up, alignment, stability of det. response)
- Reconstruction software: a lot of hw data must be processed and combined
  - Tracking: MUSIC, Bmon, Vertex
  - Clustering: TofWall, vertex, Calo, Hodoscope
- Detector simulation is a central part of the analysis: detector efficiencies & geometrical acceptance (and correlations!!) can be taken into account only by MC

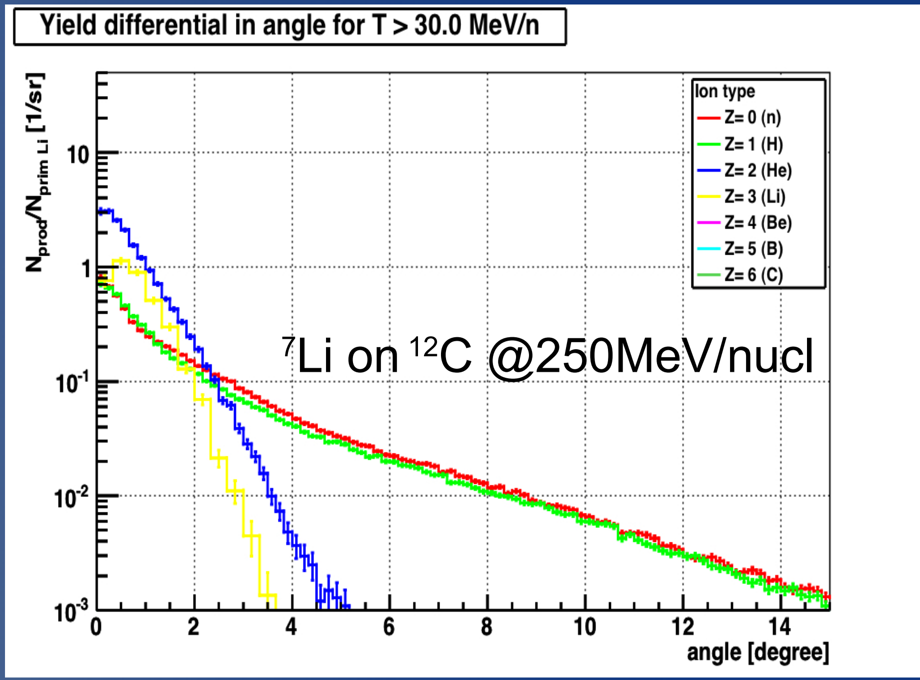


FLUKA SIM



Future... i.e. After 2011 !!!

There is a widespread interest in light ions fragmentation measurement, es: ^{7}Li (April 2010) and ^{16}O (second half of 2010) at GSI or ^{3}He + ^{12}C (thin target) @ 45 e 85 MeV/nucl at iThemba (proposal in prep.)

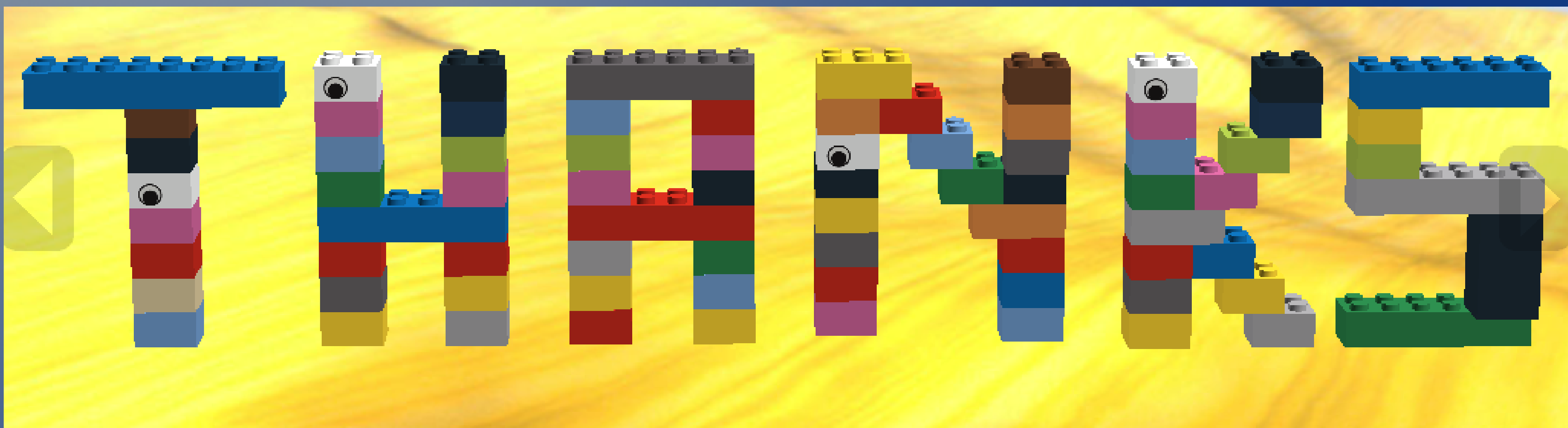


The FIRST detector is be able to measure the Fragmentation also with ions like Helium, Litium or Oxigen → GSI interest will be crucial for backing up these measures

The experimental setup is also designed to measure fragmentation cross section also with heavier ions like Fe @ 1Gev/nucl → would be interesting for radio protetion in space. ESA and NASA are also interested in this measures

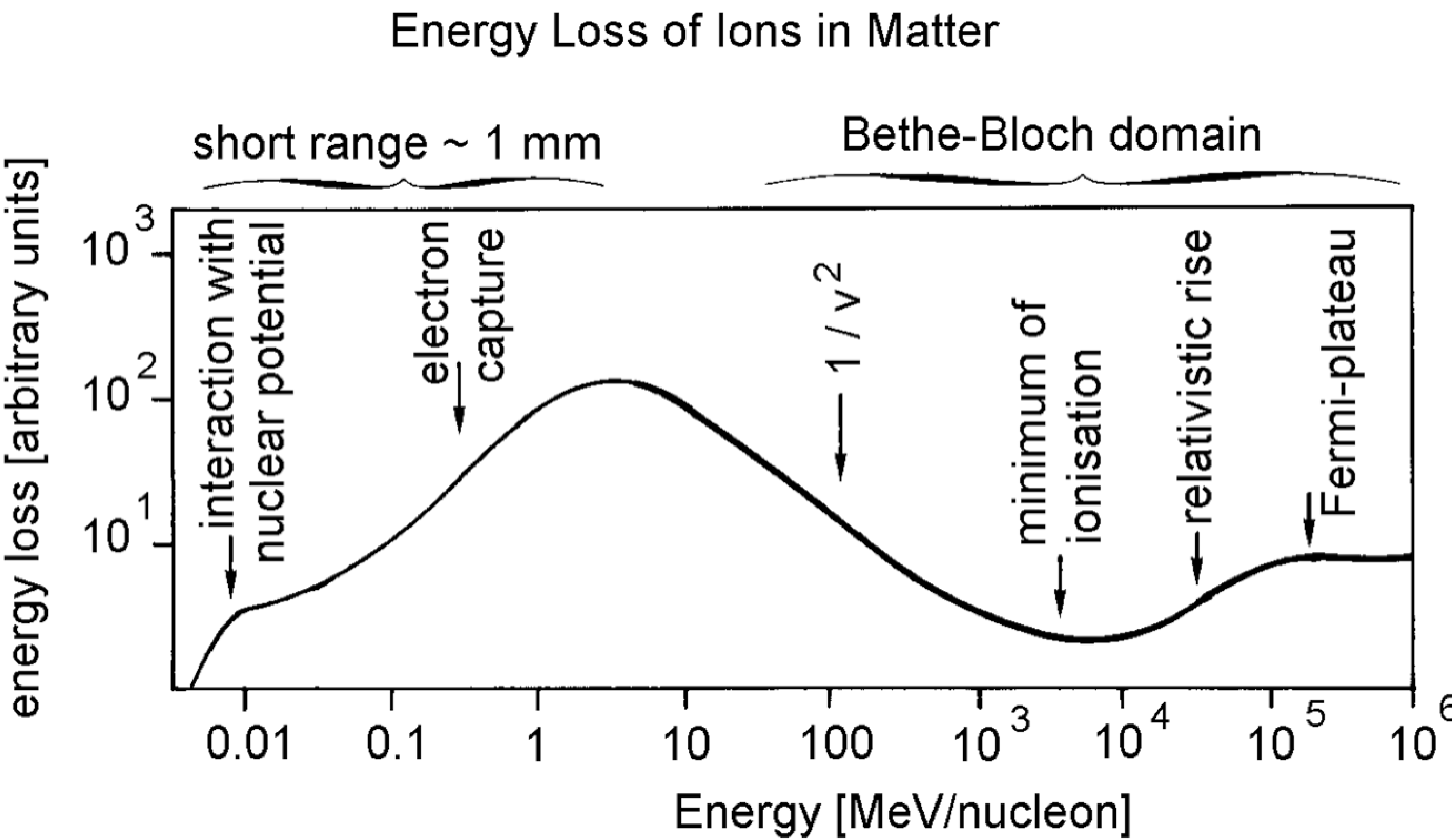
Summary & conclusions

- An international collaboration (France, Germany, Italy) has been created to measure the $d^2\sigma/d\theta dE$ fragmentation cross section for hadrontherapy at GSI
- The detector will be the evolution of a pre-existing setup, optimized for the detection of the Z<6 fragment with large angular acceptance and accuracy at the few % level
- Data taking is foreseen for spring (I would bet summer..) 2011
- The experimental setup can be seen as a facility to measure the fragmentation of light ions (He, Li, O projectiles on different target of interest) and for fragmentation measurement of interest for space radioprotection (mainly Fe projectiles)


THANKS

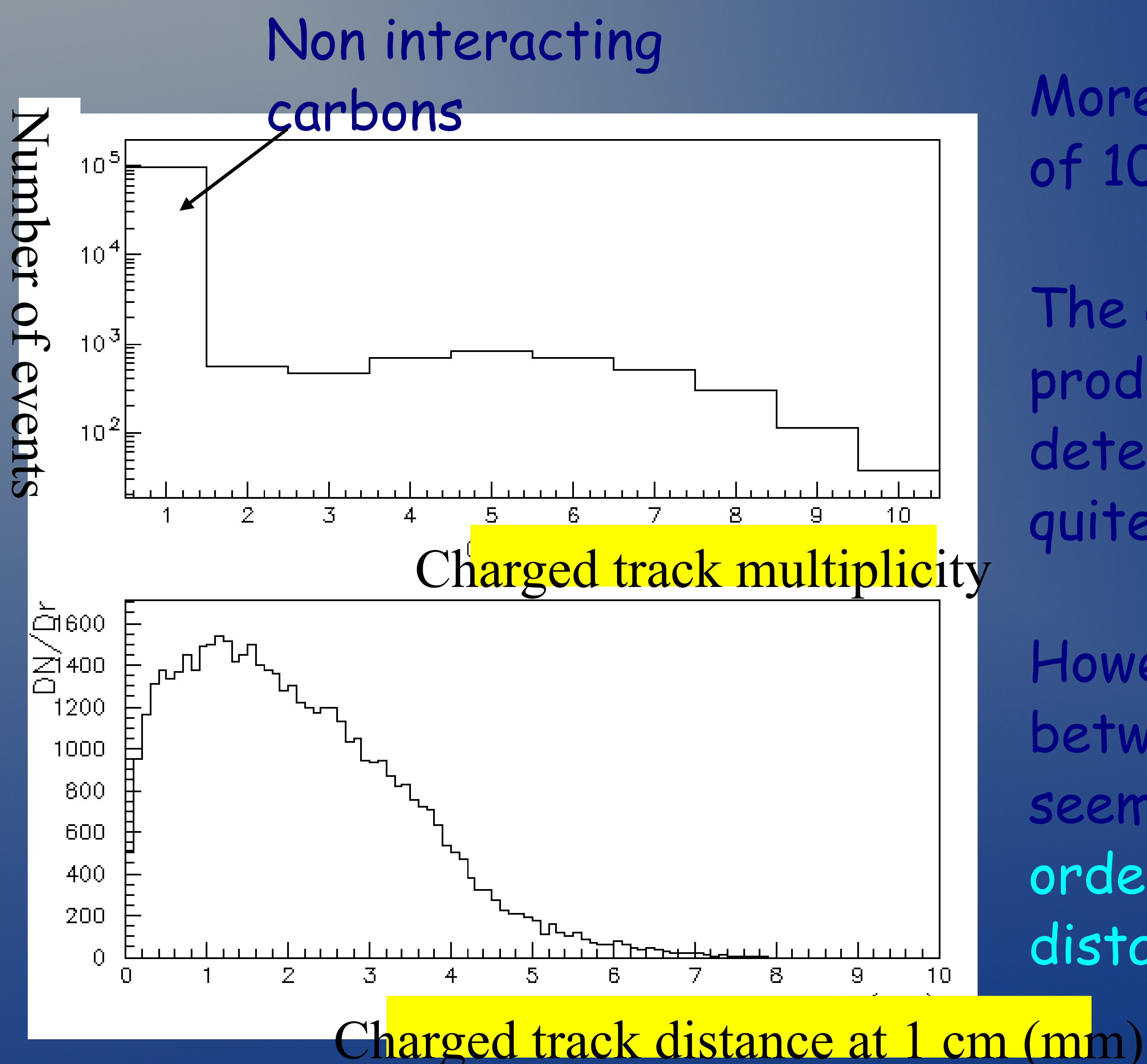
Spare slides

Energy loss of charged particles



Energy loss of ions in matter as a function of their energy

Events multiplicity in Vertex tracker

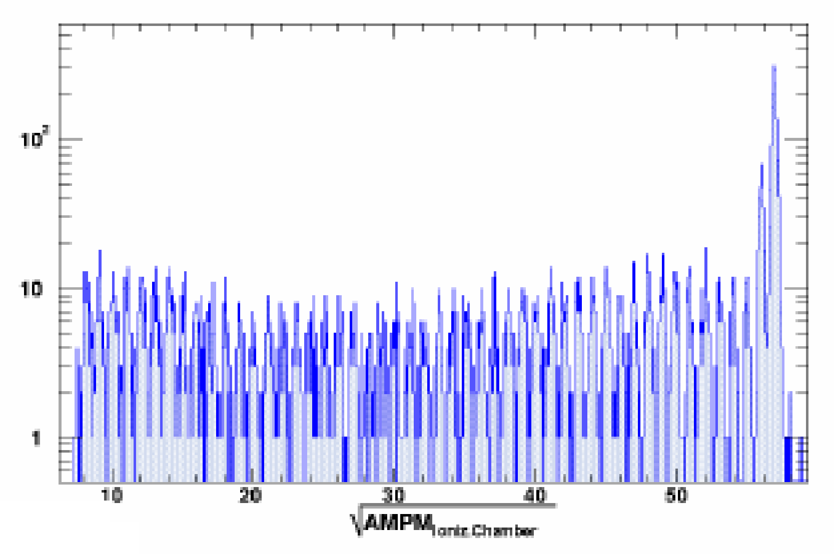


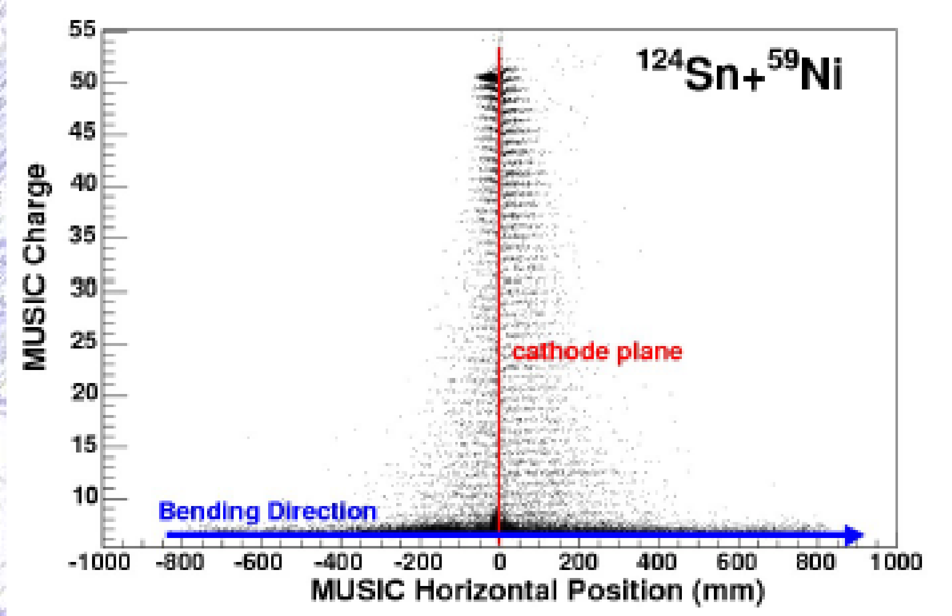
More than 9 events out of 10 are single C tracks

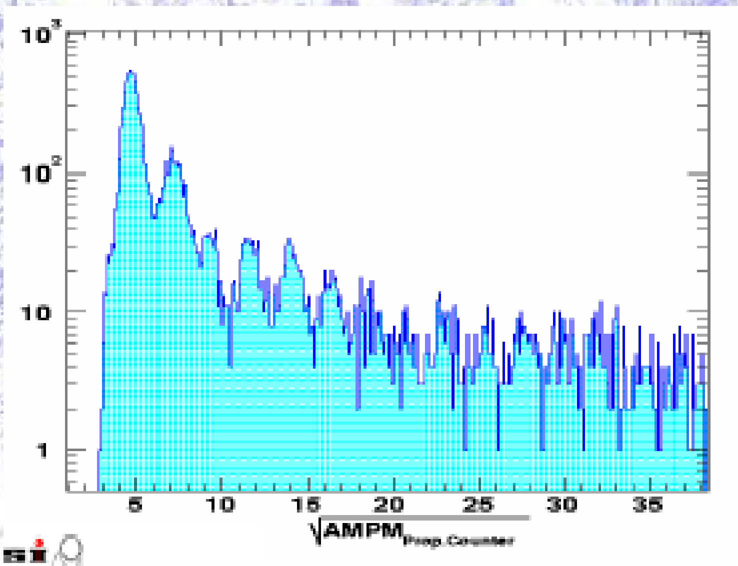
The event multiplicity produced in vertex detector seems to be quite flat up to Ntrack=7.

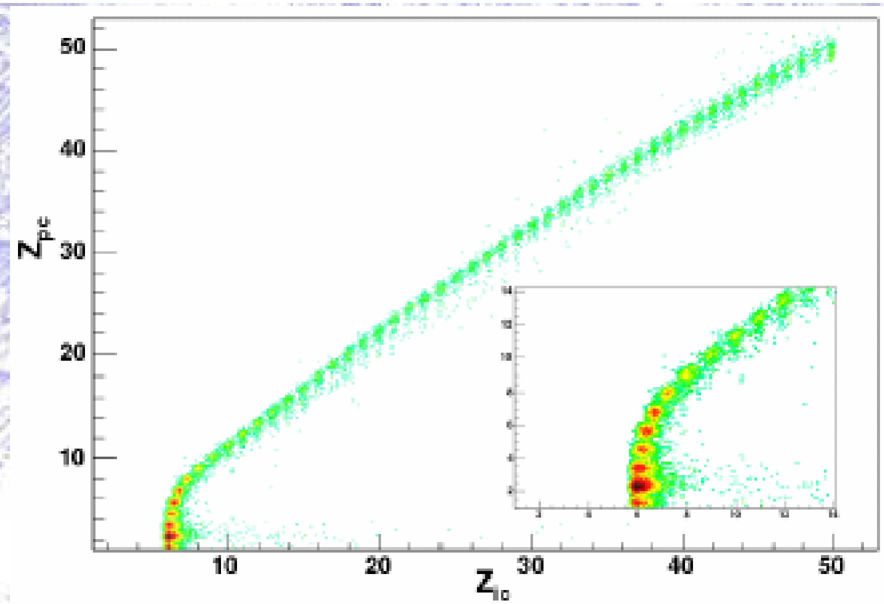
However the distance between these tracks seems to be quite large: order ~ mm at 1 cm distance from the target

The TP-MUSIC Performances









Treat Planning System: a complex object

- All the pro's and contra of the ^{12}C beams must be taken into account in the TPS
- All the knowledge of fragmentation must be inserted in TPS
- The use of MC can be a very effective way to implement the available info and knowledge into the TPS

- Patient modelling
- Transport and interactions of the ions
- Beam & beam line modeling
- RBE computation for the ions, the energies and cell lines of interest
- Optimization procedure (Kernel)
- Monitor & validation tools

Aspects contributing to the complexity of Treatment Planning in hadron therapy

- Management of interfaces/corrections
- Nuclear composition of materials

Relevant technical aspects

- Integration with local beam delivery systems
- Need for “fast” calculation; possibility of producing alternative plans in due time
- Production of general and flexible analysis tools for the inspection of isodose curves on CT scans and Dose-Volume histograms (DHV), etc

Exploitable benefits

- Production of active nuclides, particle emission
  → possibility of in-beam monitoring
  → possibility of feed-back correction to Planning

Radiation interaction in biological material

"standard" paradigm

1 Gy γ-rays in one nucleus:

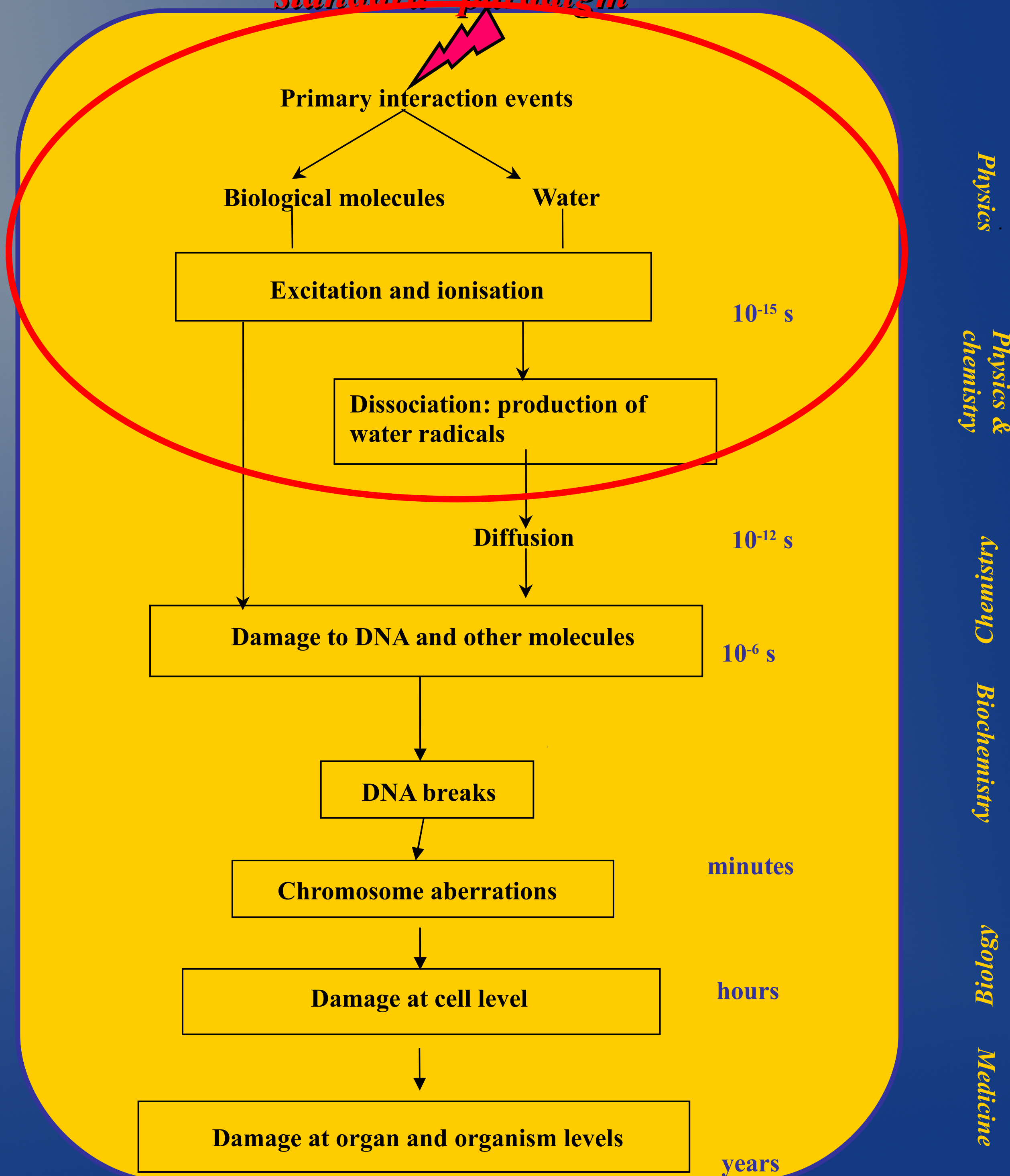
≈ 100,000 ionizations
(≈ 2,000 in the DNA)

≈ 40 DNA DSBs,
≈-1 "complex lesion"

≈ 0.5-1 chromosome aberrations

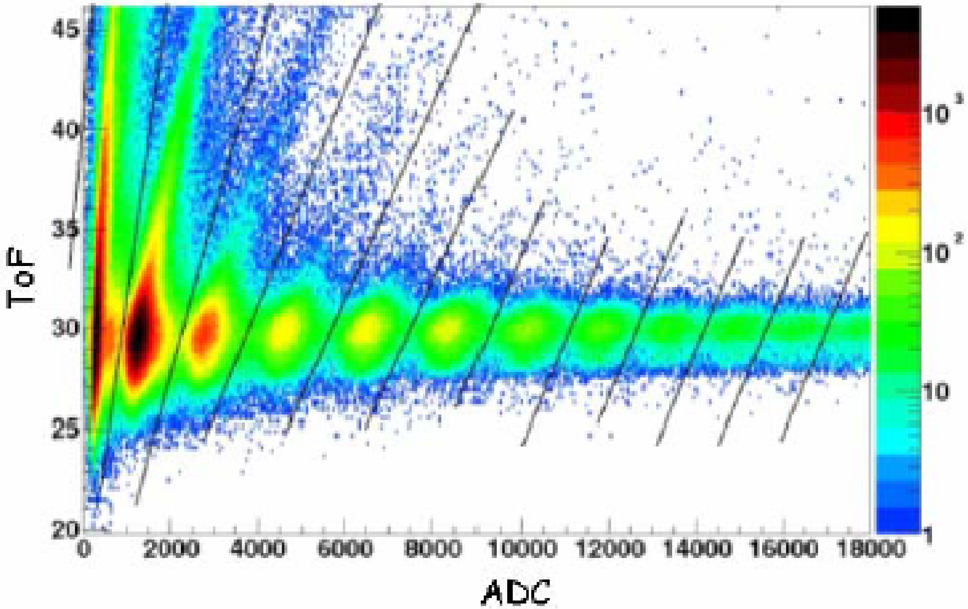
≈ 0.5-1 lethal lesions
≈ 10^{-5} HPRT mutations
≈ 10^{-5} neoplastic transformations

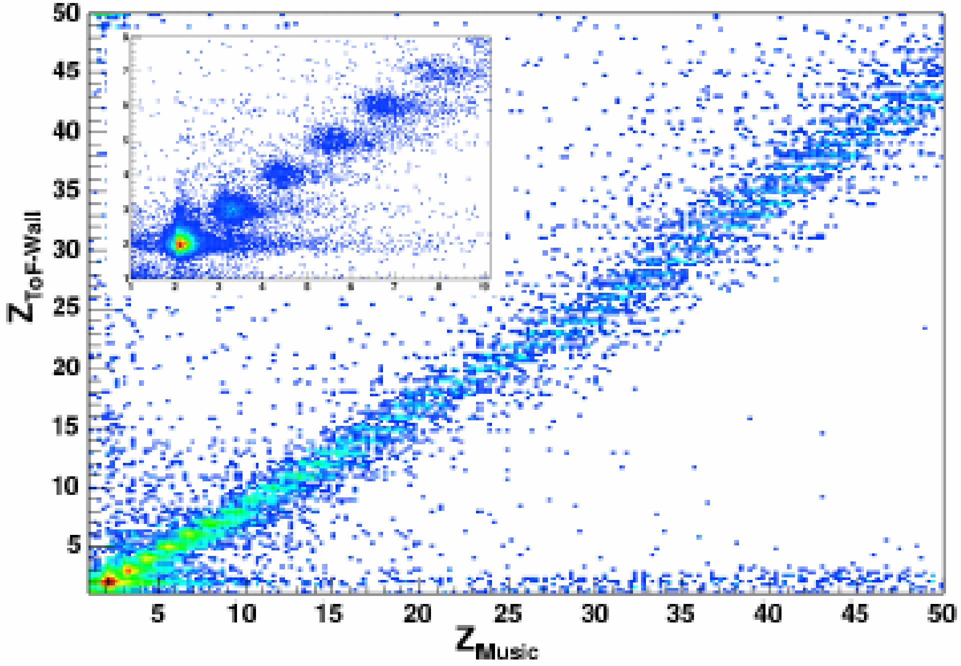
<< 10^{-5} cancers



With coutesey to F. Ballarini

The TP-MUSIC + TOF

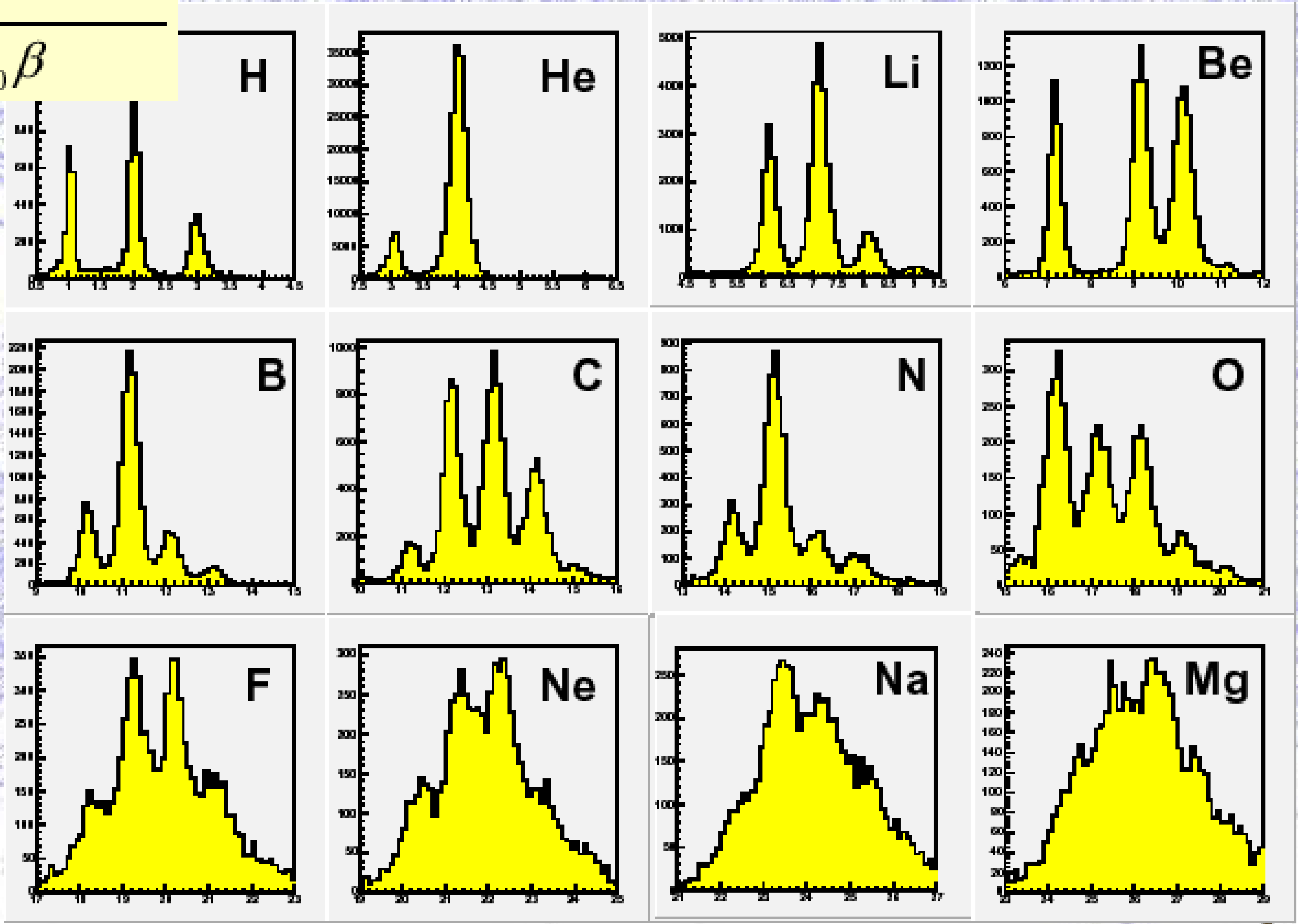




The TP-MUSIC Performances

$$A = \frac{0.3\left|\vec{R}\right| Z \sqrt{1-\beta^2}}{m_0 \beta}$$

The right performances for light ions fragmentations measurements!



Primary Particles - LNBL fragmentation / charge changing cross section data base

Targets: H, C, Al, Cu, Sn and Pb

Ion	Energy (MeV/nucleon)							
^{56}Fe	400	500	600	800	1,000	3,000	5,000	10,000
^{48}Ti					1,000			
^{40}Ar	290	400	650					
^{28}Si	290	400	600	800	1,200	3,000	5,000	10,000
^{20}Ne	290	400	600					
^{16}O	290	400	600		1,000			
^{14}N	290	400						
^{12}C	290	400				3,000	5,000	10,000
^{4}He	230							

Preliminary Data

Courtesy of M. Durante

INFN Istituto Nazionale di Fisica Nucleare

FLUKA vs TRip

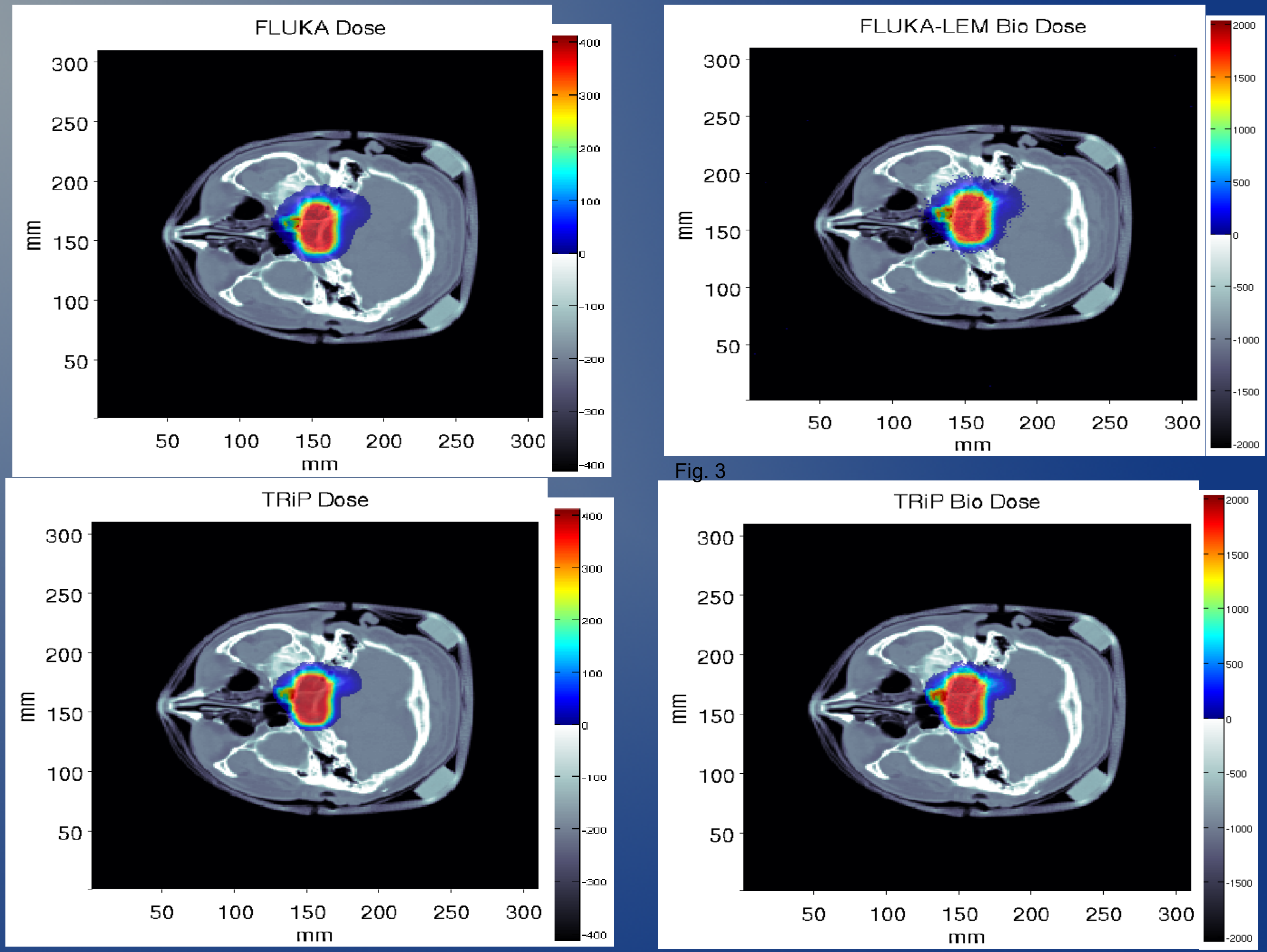
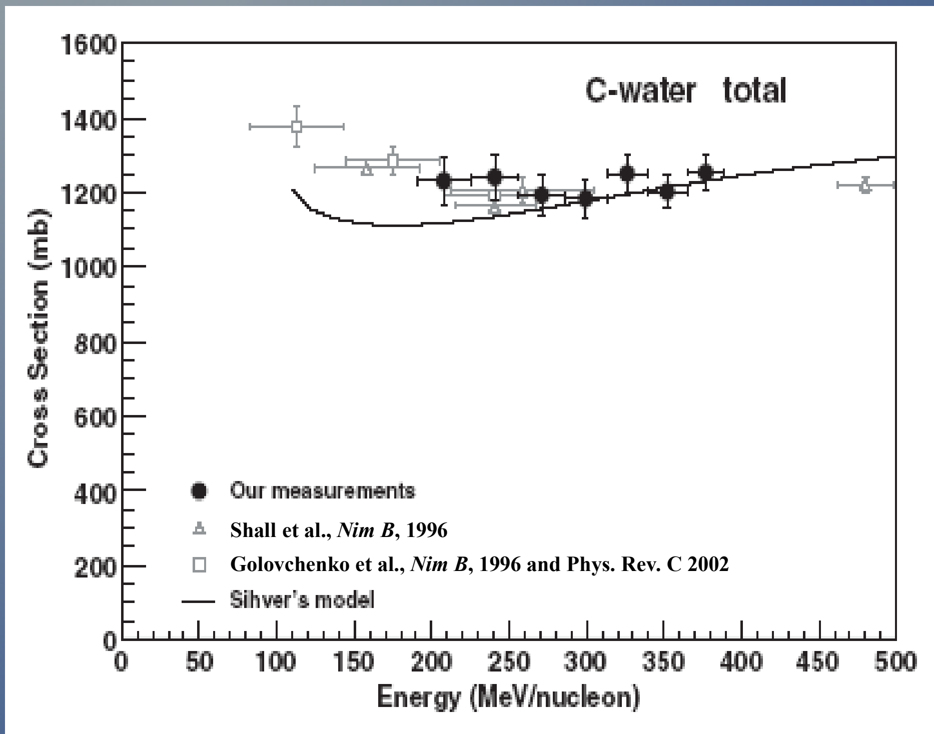
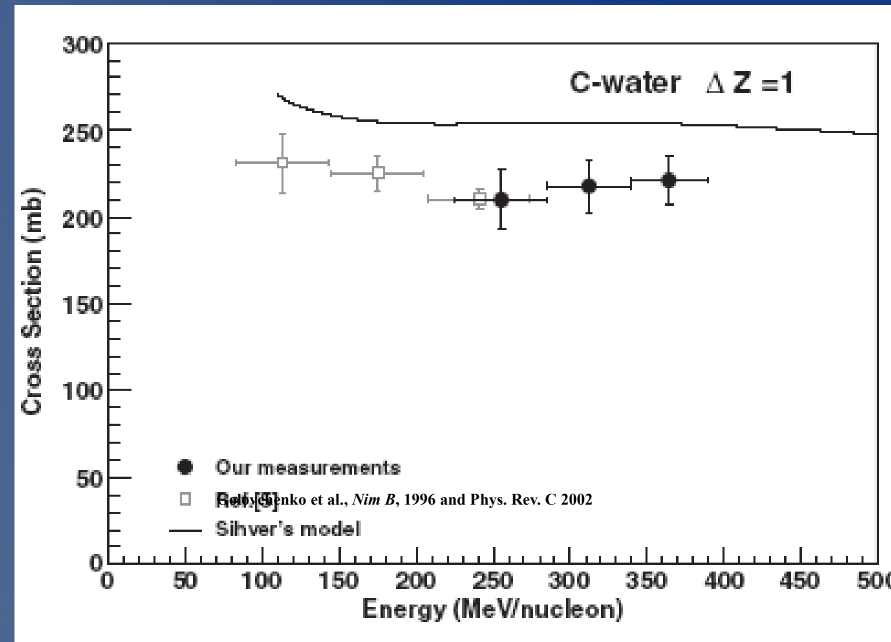


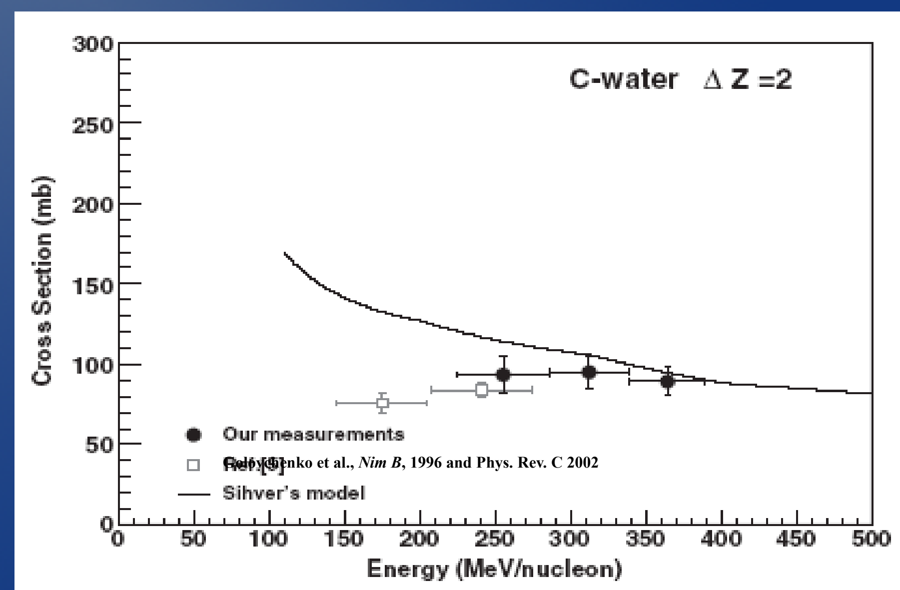
Fig. 3

Mairani et al 2008 Nuclear Science Symposium Conference Record 5612-5615

Benchmarking MC: total cross section





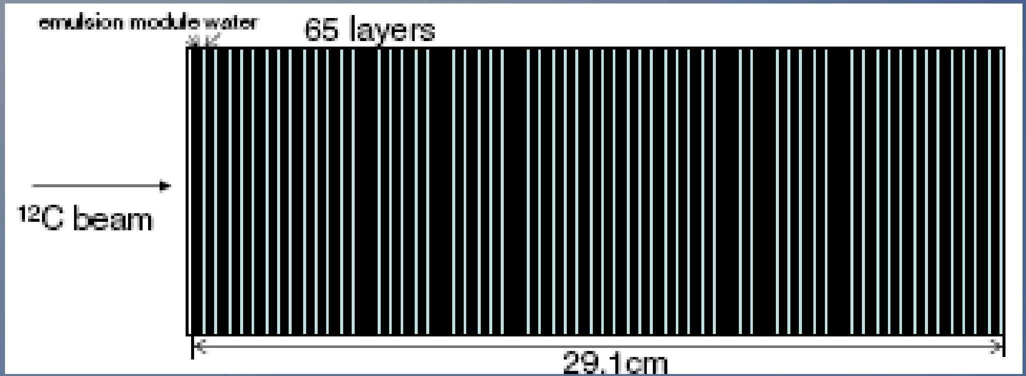


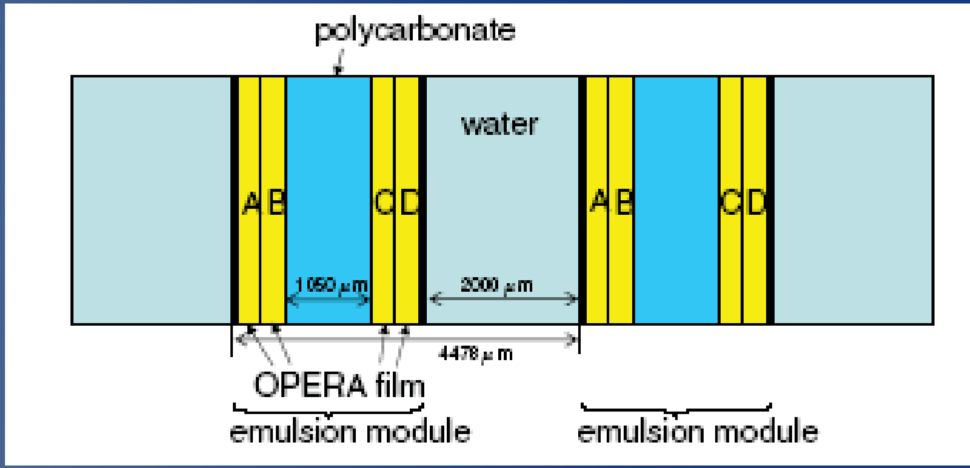
- ✓Good agreement with previous experimental data
- ✓Discrepancy of about 10% and 20% with model

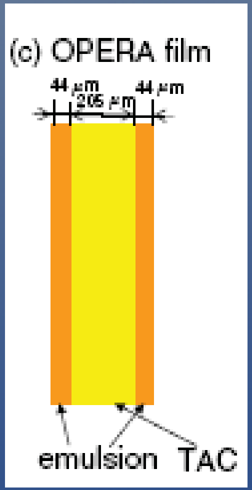
Toshito. et al., *Phys. Rev. C., 2008*

Benchmarking MC: Emulsion Cloud Chamber

Density grain is proportional to energy loss







- ✓High spatial resolution (~μm)
- ✓High angular resolution (~0.5 mrad)
- ✓Multiparticle separation
- ✓Refreshing method to extend dynamic range

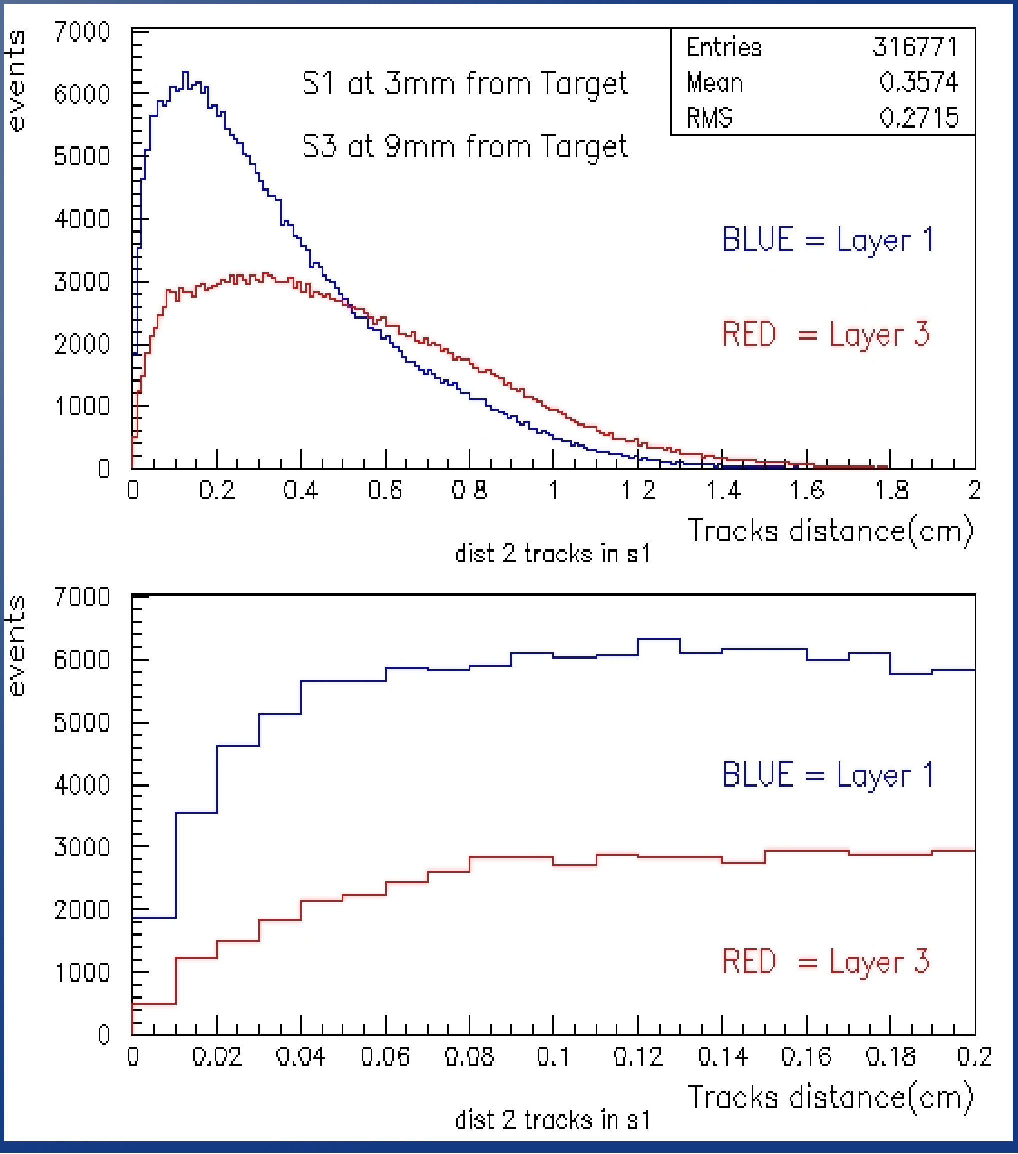
Toshito. et al., *Phys. Rev. C., 2008*

MIMOSA26: response to light ions

The MIMOSA chip shows a correlation between the energy deposit and the cluster size: can improve ion identification, but...

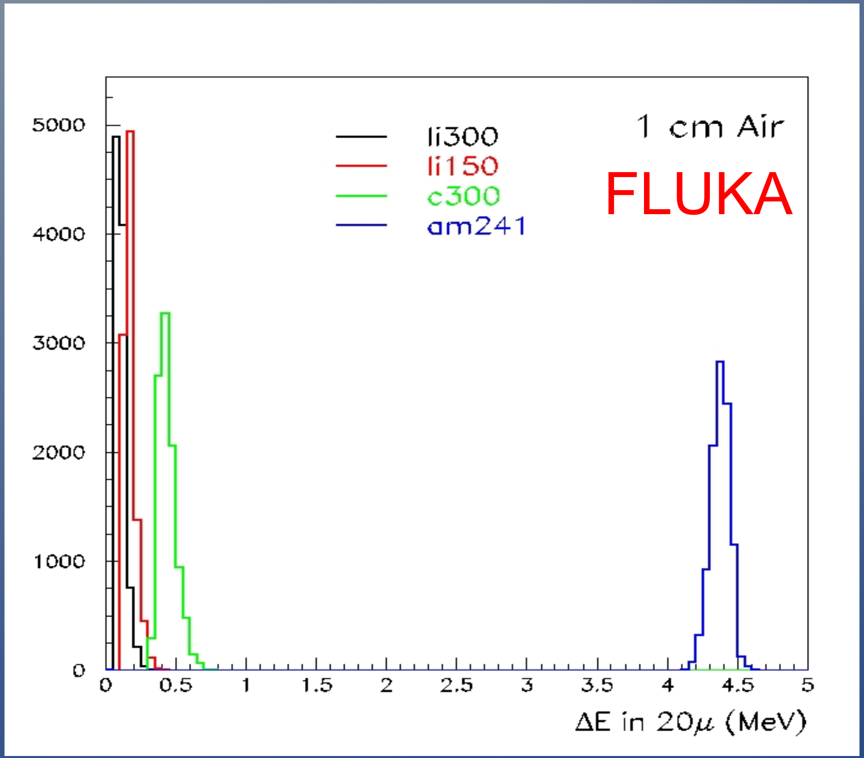
the increased cluster size could produce track overlaps due to the short lever arm between target and vertex layers

With the proposed setup only 0.3% of track pairs has separation < 100 μm in the first Si plane (the most critical)



MIMOSA26: response to light ions

Response to light ions foreseen to be studied at LNS ^{12}C beam but can be tested also with α from Am241 source (already done for mimoroma, same MAPS technology of MIMOSA26).



Energy release by Am241 is much larger than carbon → carbon has much smaller cluster size

Am241 event in MIMOROMA