MCMA 2017

Beam characterization for the TULIP accelerator for protontherapy through Full Monte Carlo simulations

C. Cuccagna

TERA Foundation (CERN) and University of Geneva

Naples, 17/10/2017

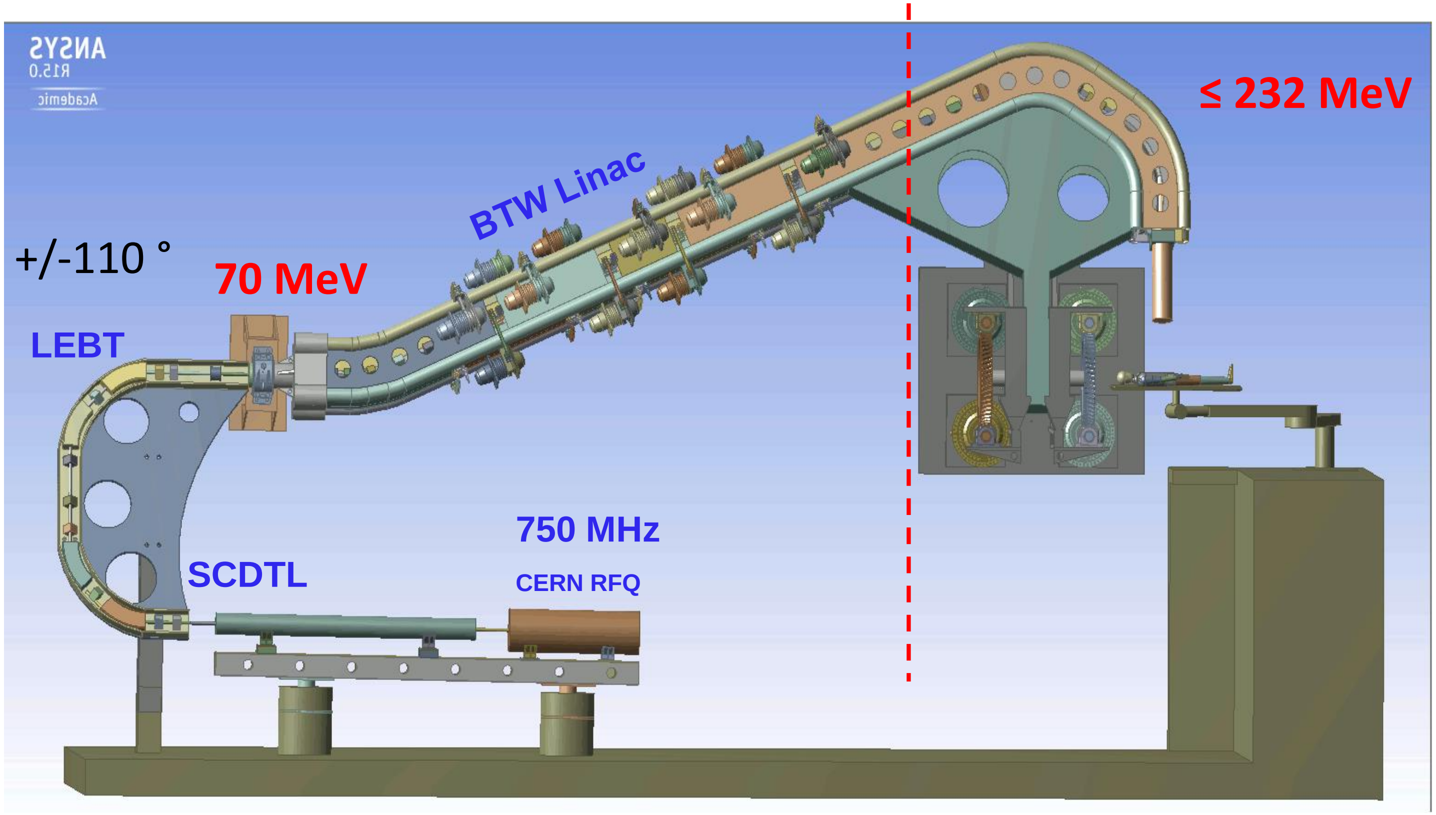
TERA: Vittorio Bencini , Daniele Bergesio , Pedro Carrio Perez , Enrico Felcini , Mohammad Varasteh Anvar , Adriano Garonna , Ugo Amaldi

CERN: Stefano Benedetti , Wioletta Kozlowska , Vasilis Vlachoudis ,

TULIP-Turning Linac for Protontherapy

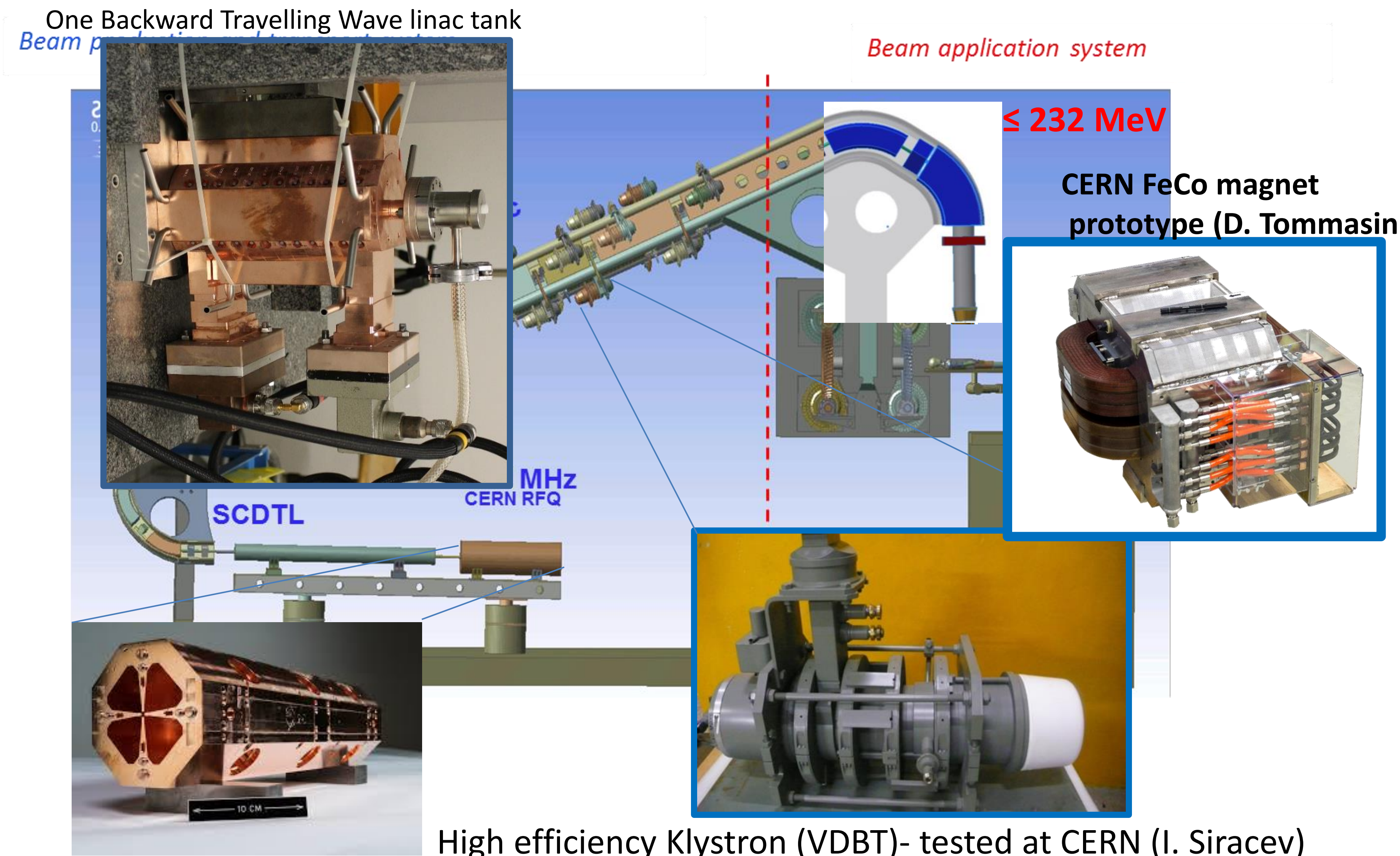
Beam production and transport system

Beam application system

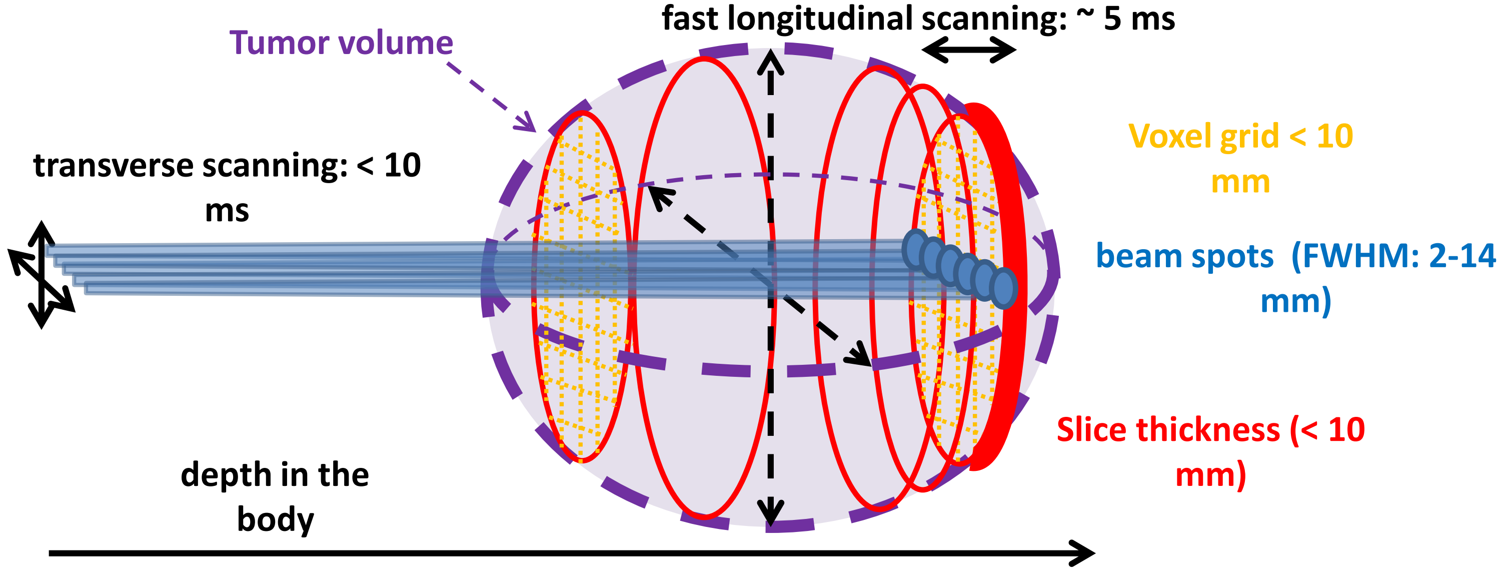


S. Benedetti, A. Grudiev, A.Latina, High Gradient LINACS for Protontherapy
[PhysRevAccelBeams 20 040101 2017]

TULIP-Turning Linac for Protontherapy



Proton LINAC



- ✓ 4D active fast spot scanning (ACTIVE and FAST energy variation)
- ✓ suitable for volumetric rescanning
- ✓ Small beam emittance (small spots)

- ✓ Lower shielding requirement wrt cyclotrons

Courtesy of
A. Degiovanni

Why Full MC simulations for TULIP?

Primary Proton Beam

Generally, for Full Photon Linac MC Modeling

2 Approaches

Source model approach

Calculates particle distribution differential in Energy, position or angle

- lost of information on individual particles
- approximated

Phase-space approach

Follows each particle with all the phase-space parameters

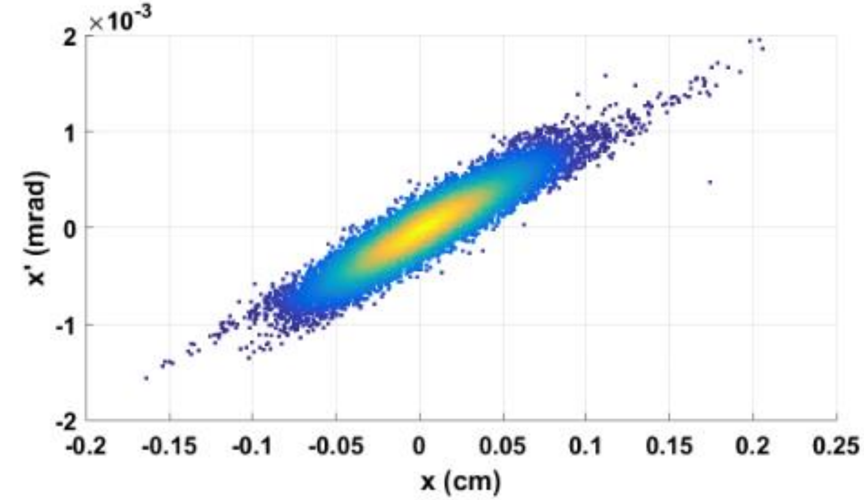
+ information in individual particles
+ correlation between angle, energy, position preserved
- large amount of information to be stored
- Computing time

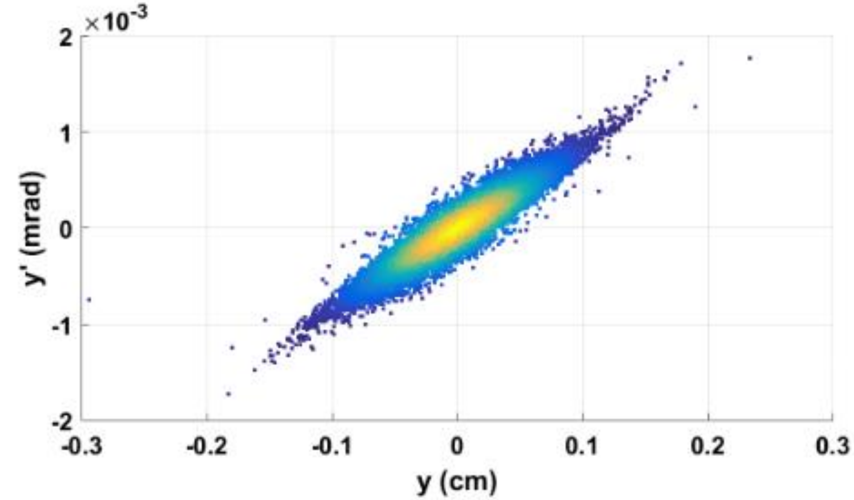
MC techniques in Rad. therapy, Joao Seco, Frank Verhaegen, 2013

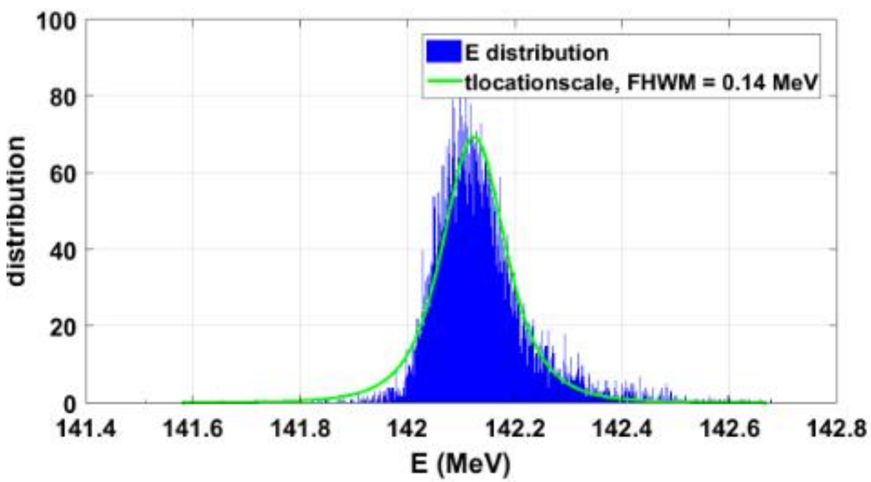
Why Full MC simulations for TULIP?

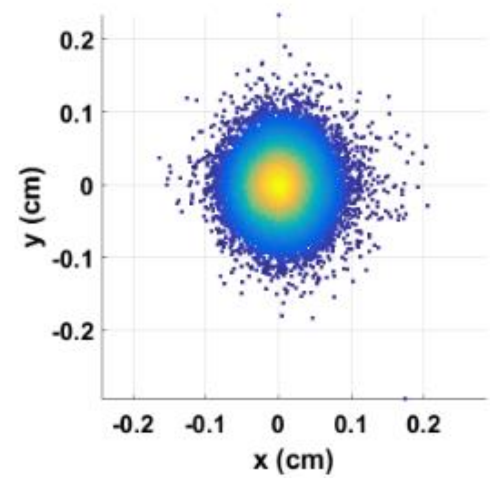
En =142.1 MeV

INFORMATION ON INDIVIDUAL PARTICLE for each beam



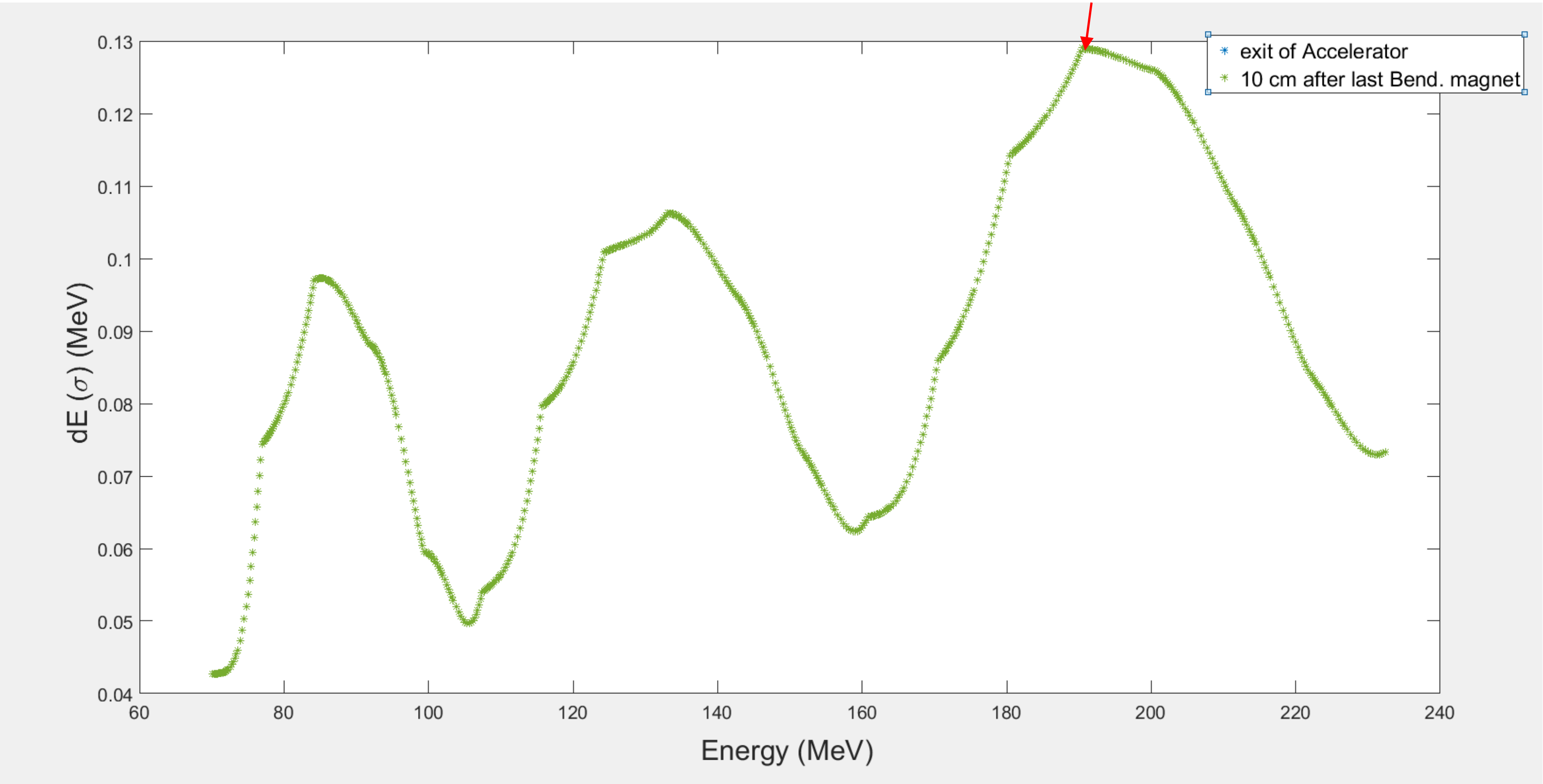






Why Full MC simulations for TULIP?

0.13 MeV (≤ 0.1 % dE/E)



660 multi particle files corresponding to different Energy values

Energy step ~0.5 MeV

Methods : Full MC simulations for TULIP

Beam production | *Beam transport line* | *Beam application*

FLUKA &FLAIR §

RF TRACK* ***Code***

Linac simulations

Phase-space files
.dat
.dst

MADX-PTC + ***Code***

Beam transport lines simulations

Phase-space files
.dat

Beam interaction with:
Last magnets
Dose delivery systems
WATER Phantom/AIR

FLUKA

MATLAB ***Code for the integration***

python

TULIP Beam model files

RFA300-ASCII BDS format

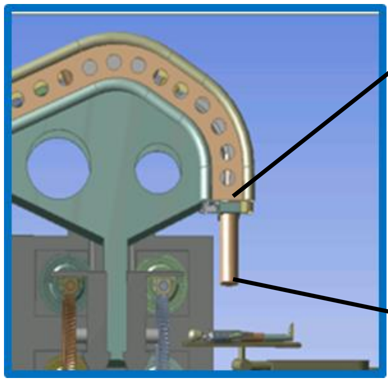
Commercial TPS (Physics module)

*CERN A. Latina, S.Benedetti

+CERN http://madx.web.cern.ch/madx/

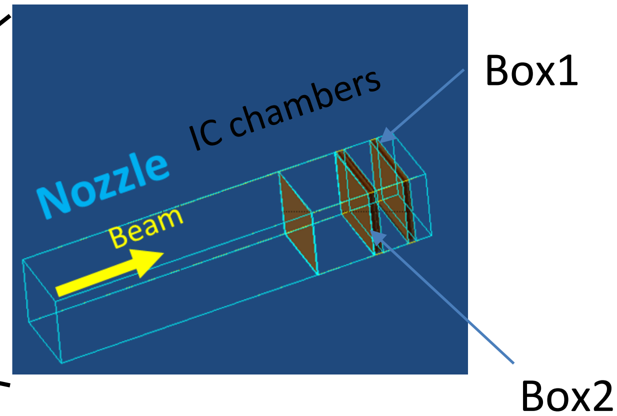
§ Ferrari A, Sala PR, Fasso A, Ranft J. FLUKA: A multi-particle transport code, CERN-2005-10; 2005. INFN/TC05/11, SLAC-R-773

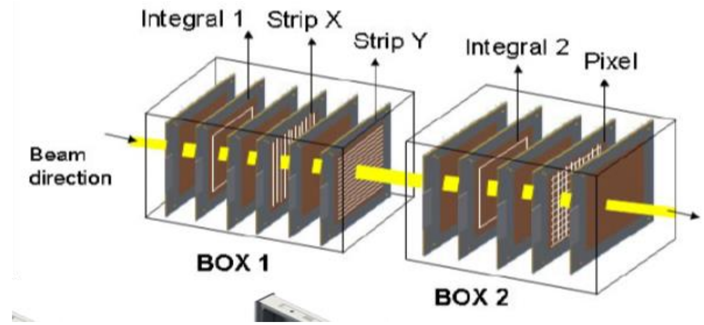
MODEL OF THE NOZZLE

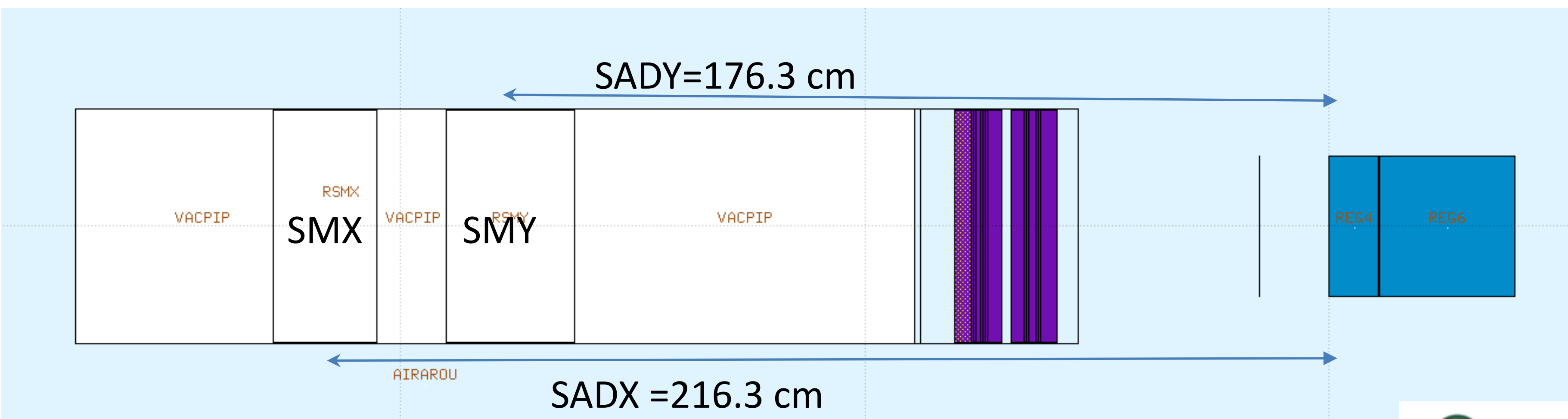


re-adapted from CNAO nozzle specifications

fondazione CNAO
Centro Nazionale di Adroterapia Oncologica per il trattamento dei tumori

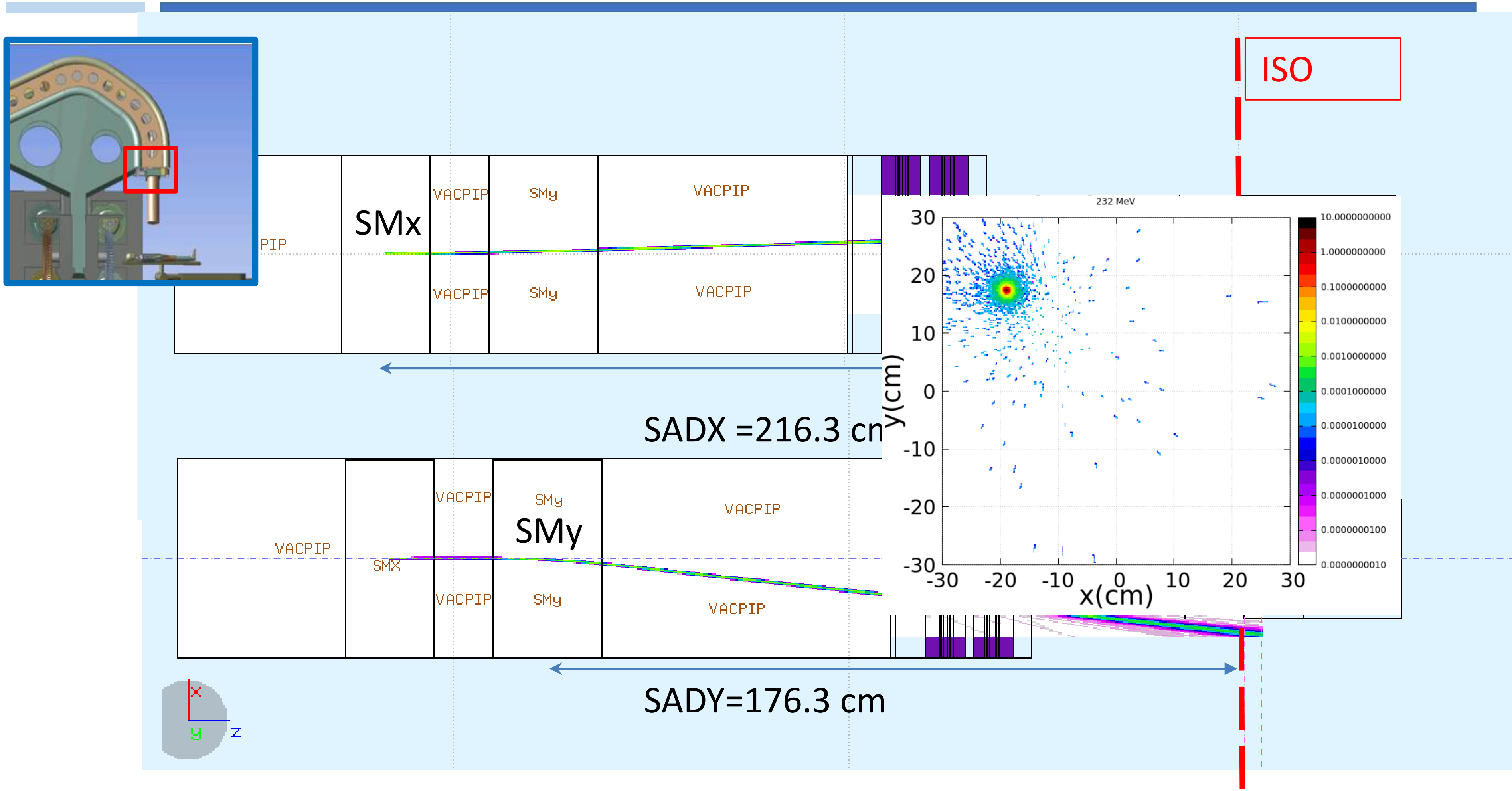






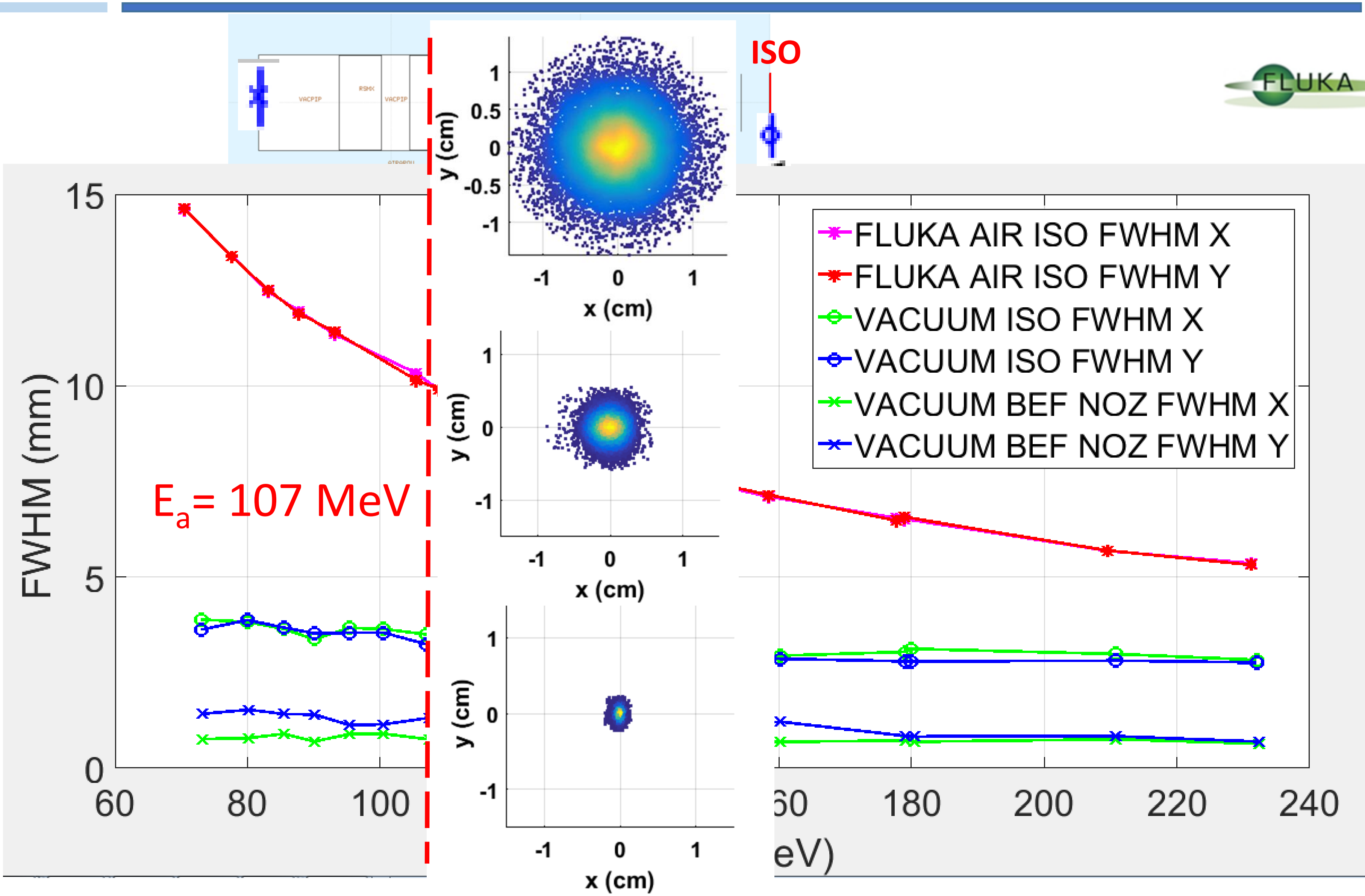
Modelled to have an Irradiation field :35x38 cm2

Scanning magnet xy: Magnetic Field in Fluka



En =232 MeV

Results : Nozzle effect on the beam size



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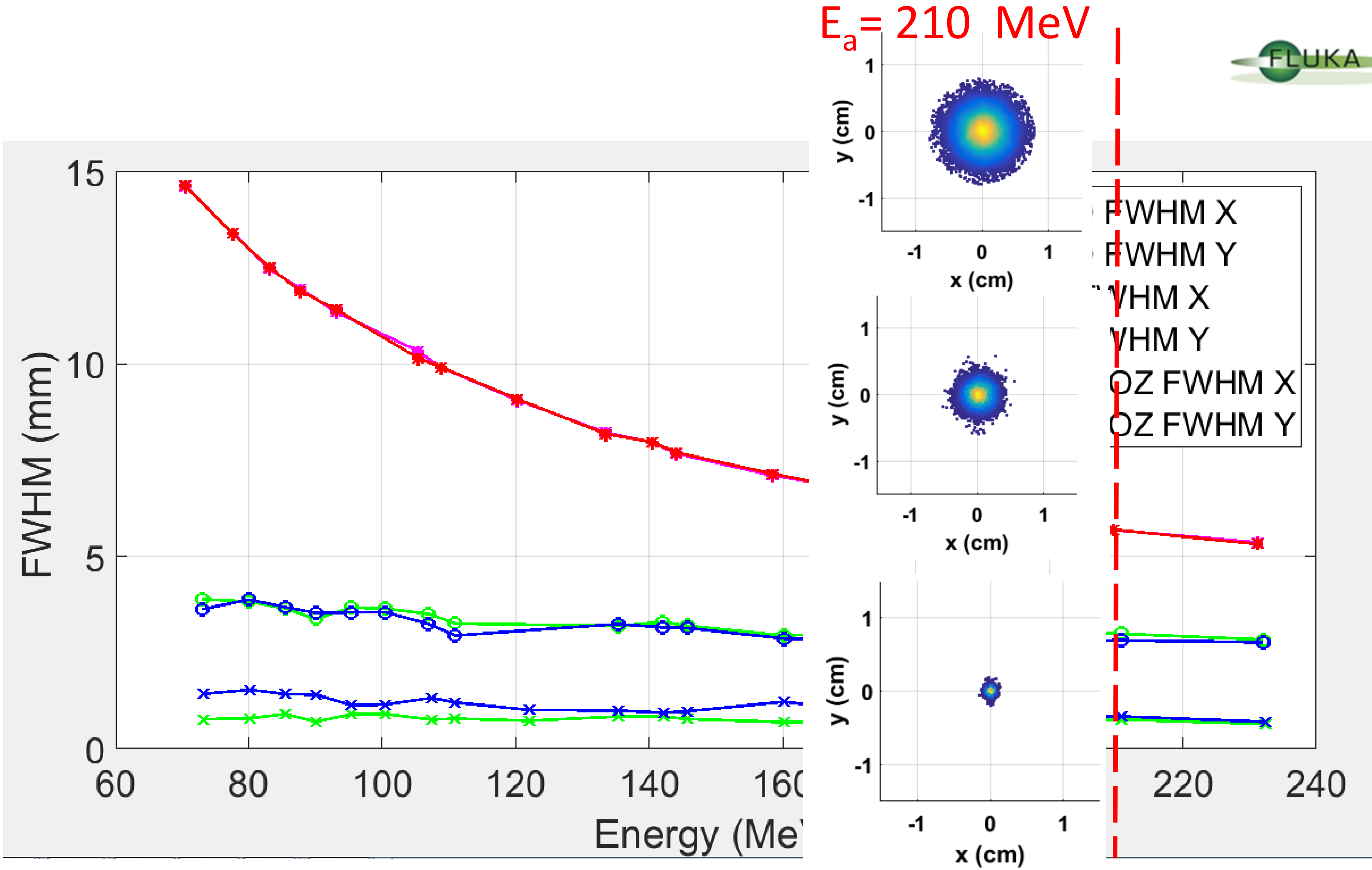
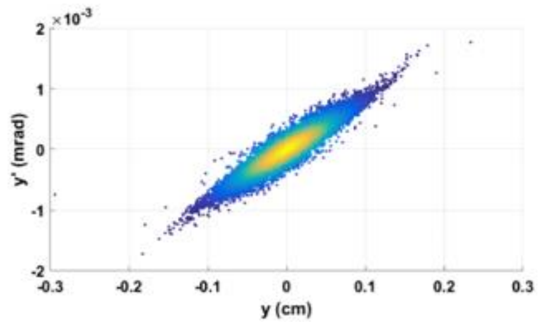
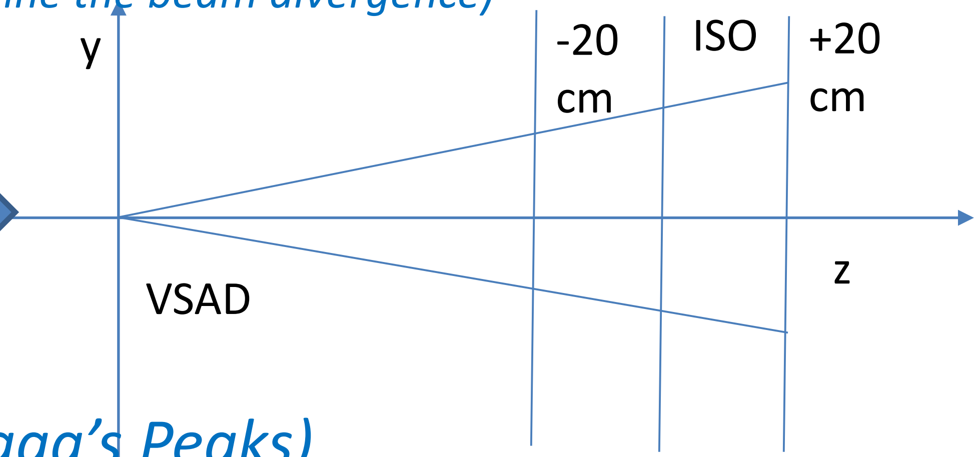


Results: TULIP –Beam Characterization for TPS

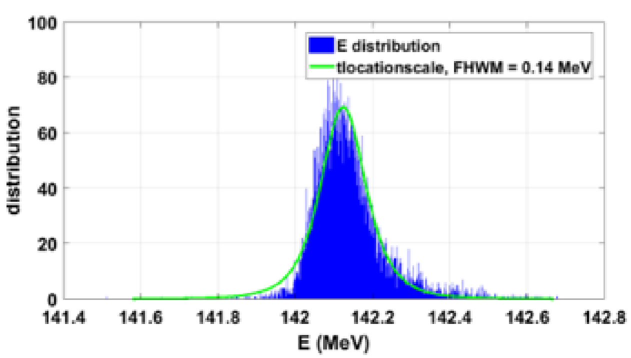
1. In-air fluences :

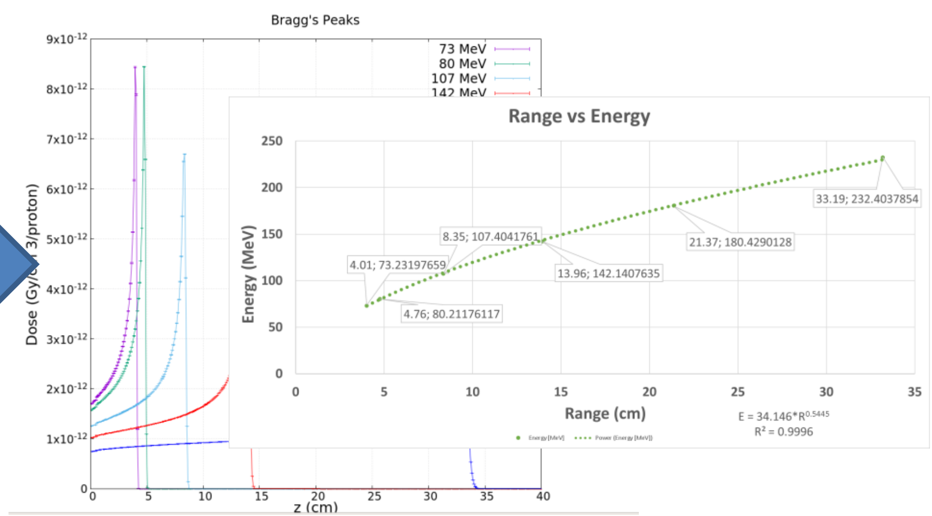
Distributions in air at isocenter and at other predefined points before and after isocenter (in order to define the beam divergence)





2. IDD Integral Depth Dose (Bragg's Peaks)





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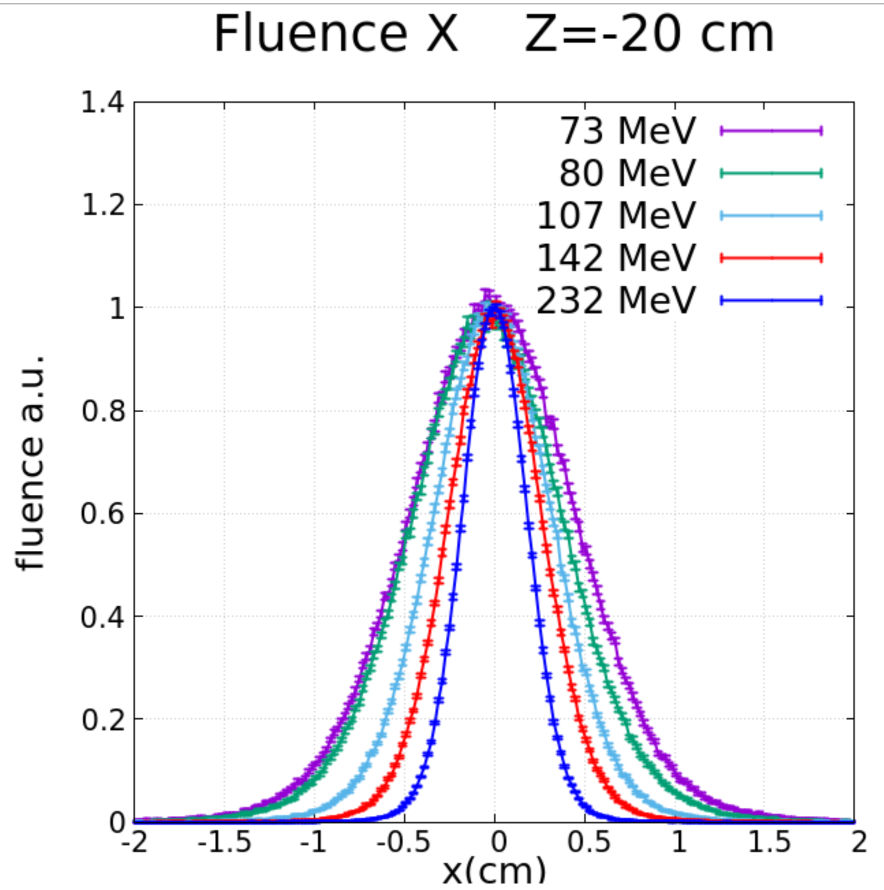
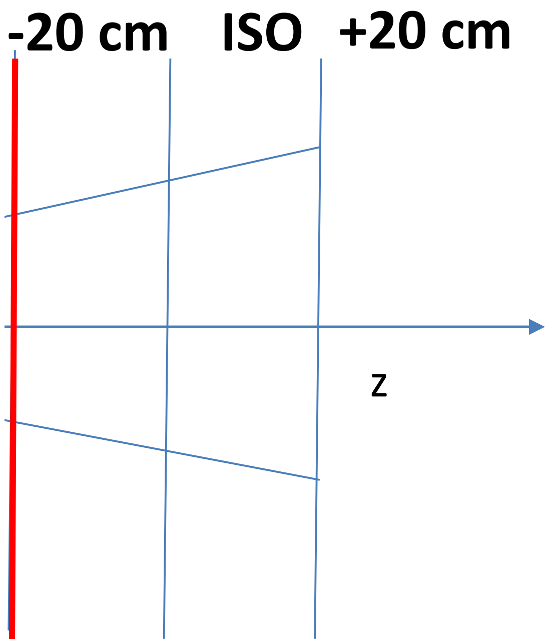
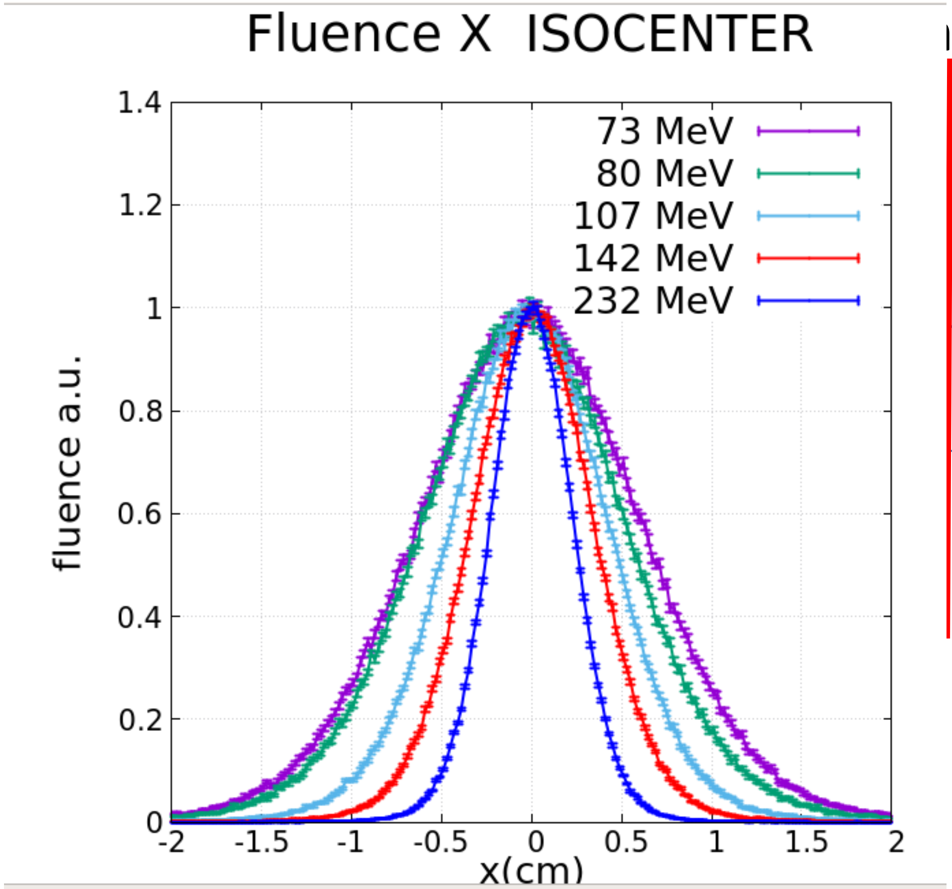
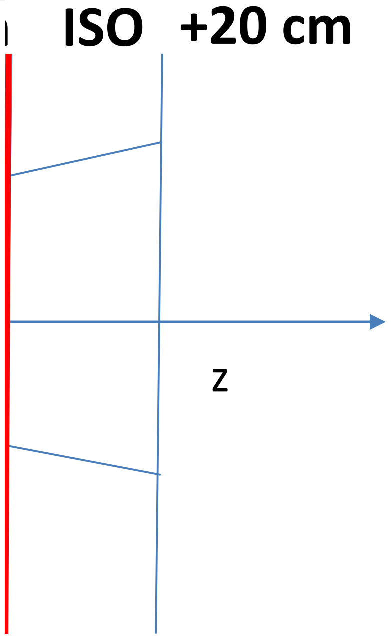




1. *In-air fluences :*





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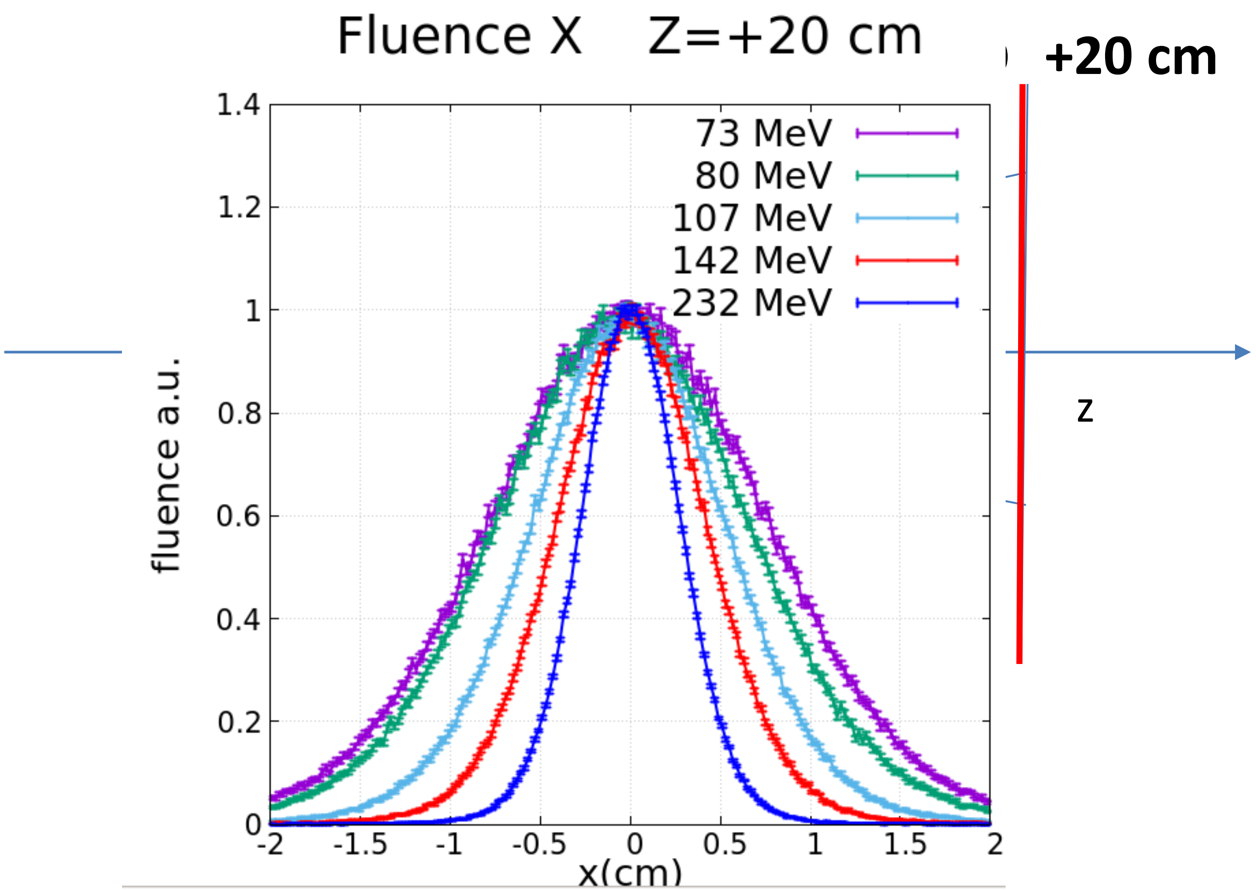
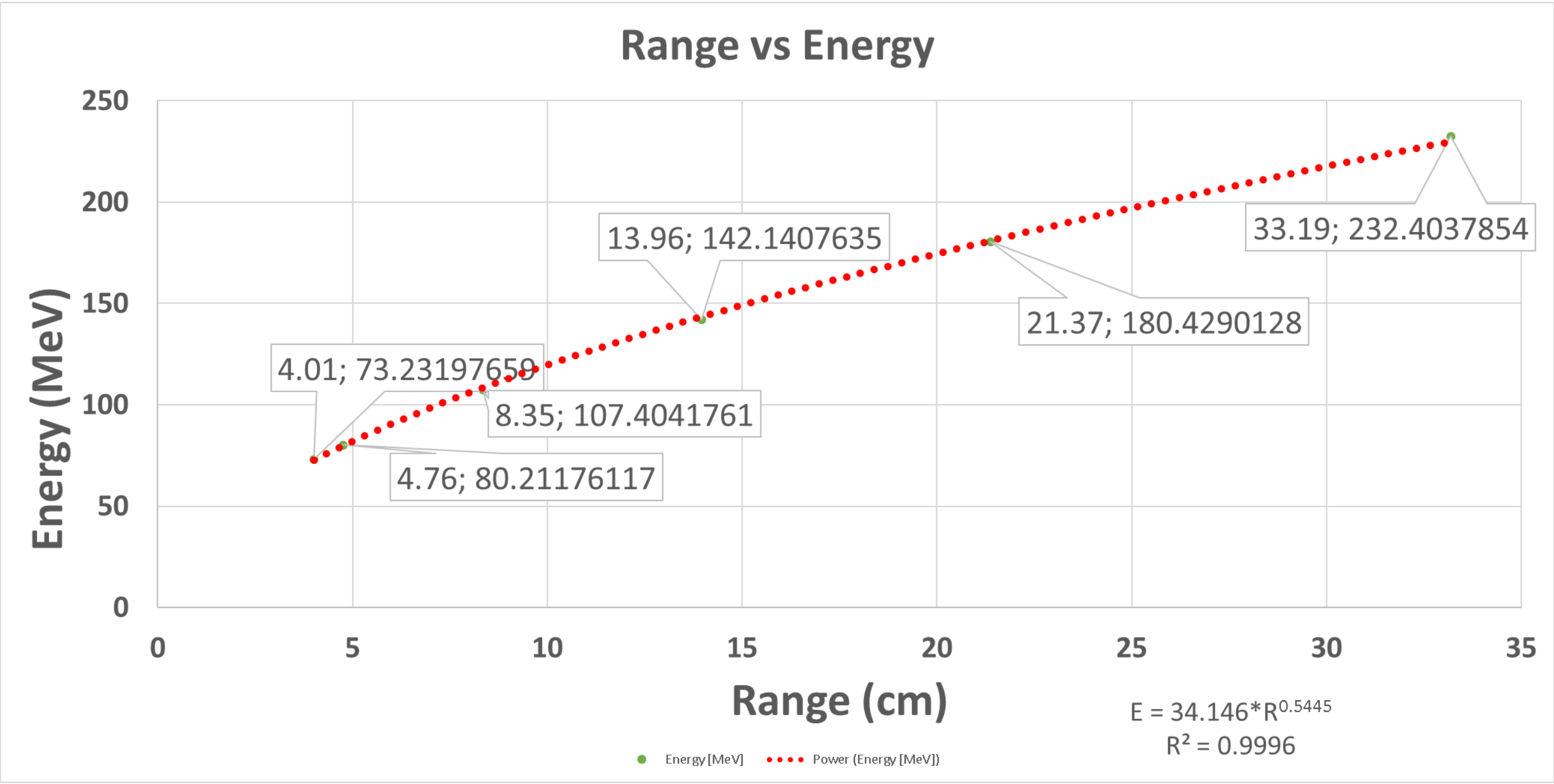


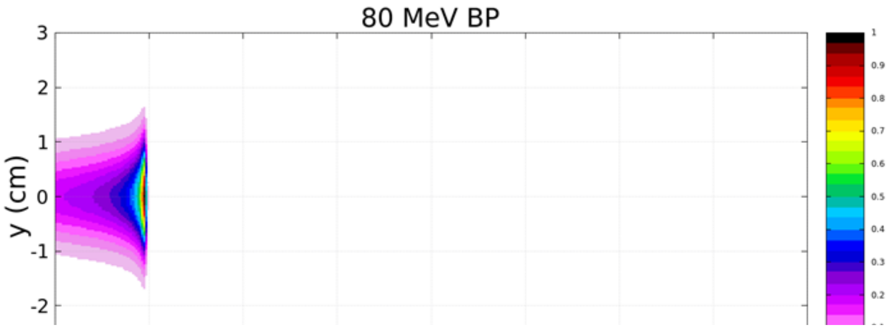
Results: TULIP –Beam Characterization for TPS

2. IDD Integral Depth Dose curves (Bragg's Peaks)

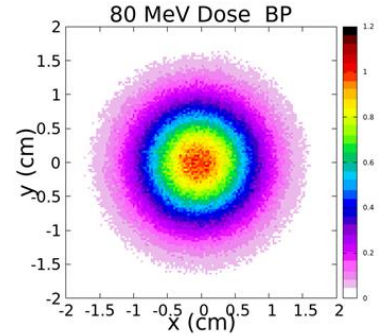


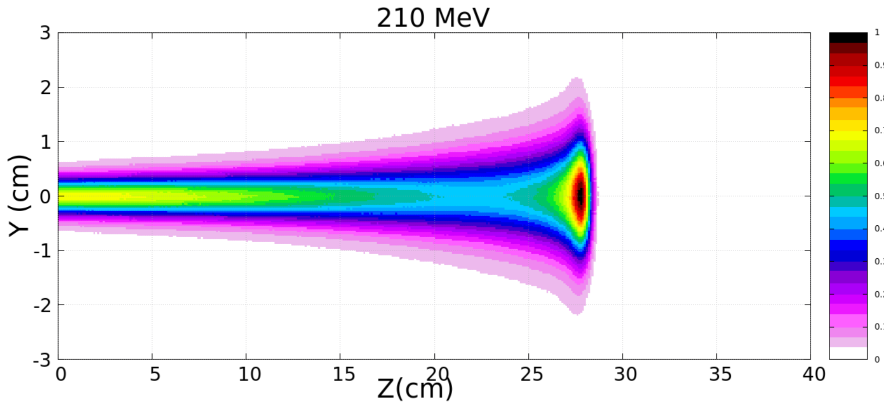
Results: TULIP –Beam Characterization for TPS

2. IDD Integral Depth Dose curves (Bragg's Peaks)

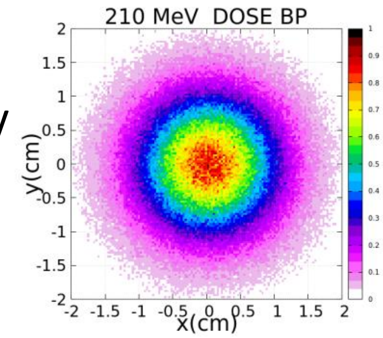


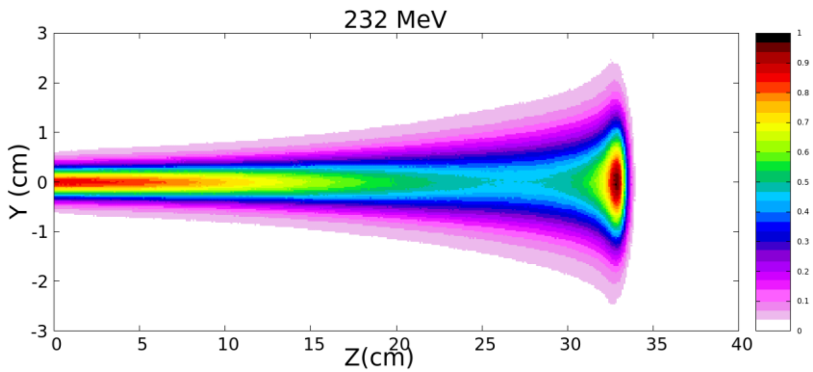
80 MeV



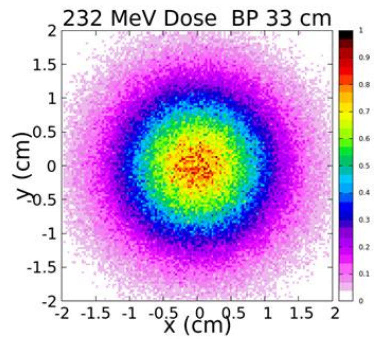


210 MeV





232 MeV



Conclusions and future works

Beam production
RF TRACK *Code*

Linac simulations

Beam transport line
MADX-PTC *Code*

Beam transport lines simulations

Beam application

FLUKA &FLAIR

Beam interaction with:
Last magnets
Dose delivery systems
WATERPhantom/AIR/PATIENT

FLUKA

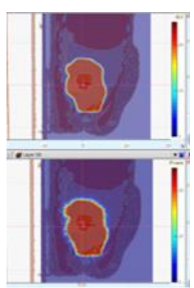
Dose recalculations
With FLUKA QA MC TPS*
And phase-space files

DICOM RT files

python

TULIP Beam model files
RFA300·ASCII format

Dose Comparisons



Dose recalculations
With clinical TPS

Clinical TPS
(Physics module)

* Front. Oncol., 11 May 2016
https://doi.org/10.3389/fonc.2016.00116

TERA

CERN

Thank you!!

Coming together is a beginning
keeping together is progress
working together is success Henry Ford

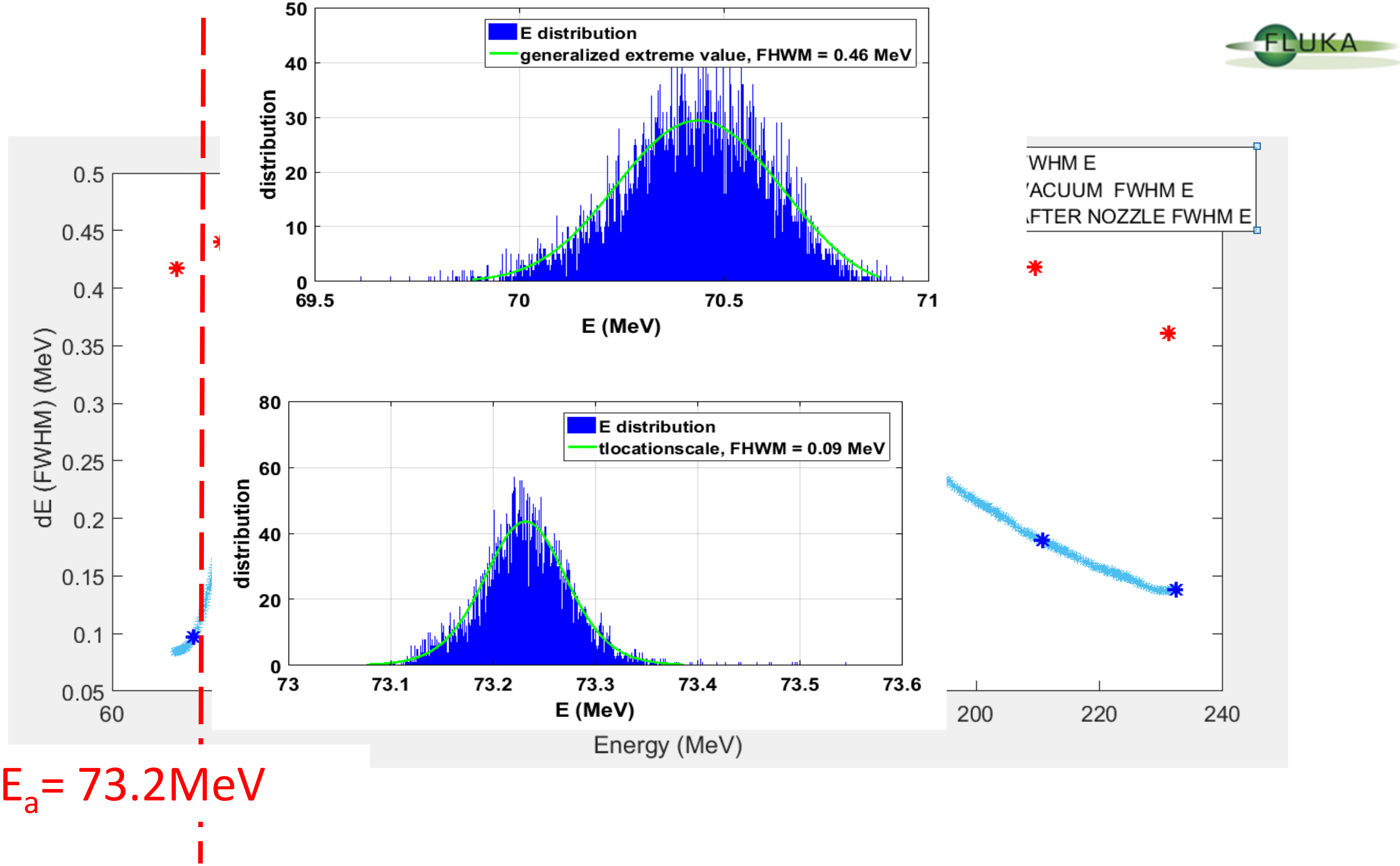
FLUKA

fondazione CNAO
National Center of Oncological Hadrontherapy for the treatment of tumours

GENOLIER
Clinique

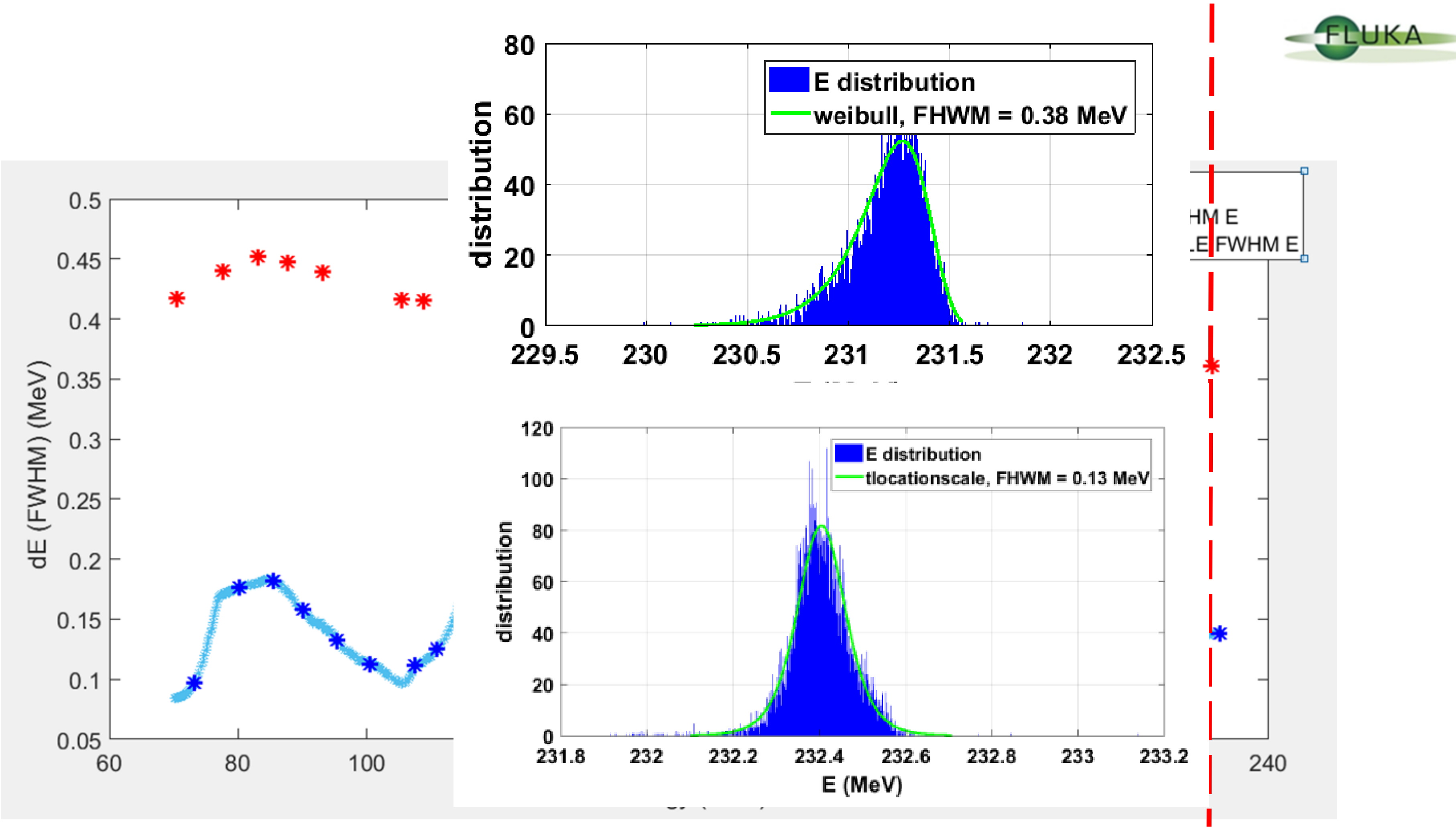
ATreP
Agenzia Provinciale
per la Protonterapia

Results : Nozzle effect on the energy spread



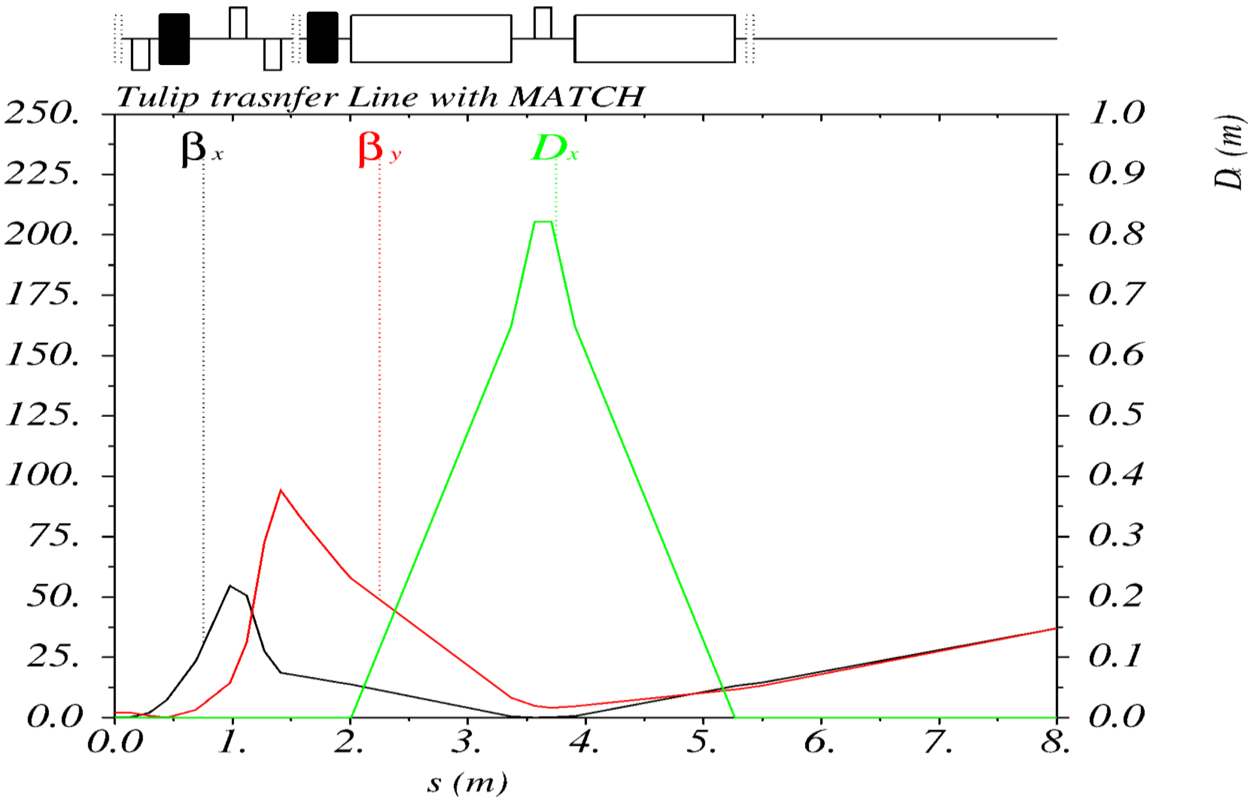
E_a= 73.2MeV

Results : Nozzle effect on the energy spread



E_a= 232.2MeV

TULIP Optics in MADX

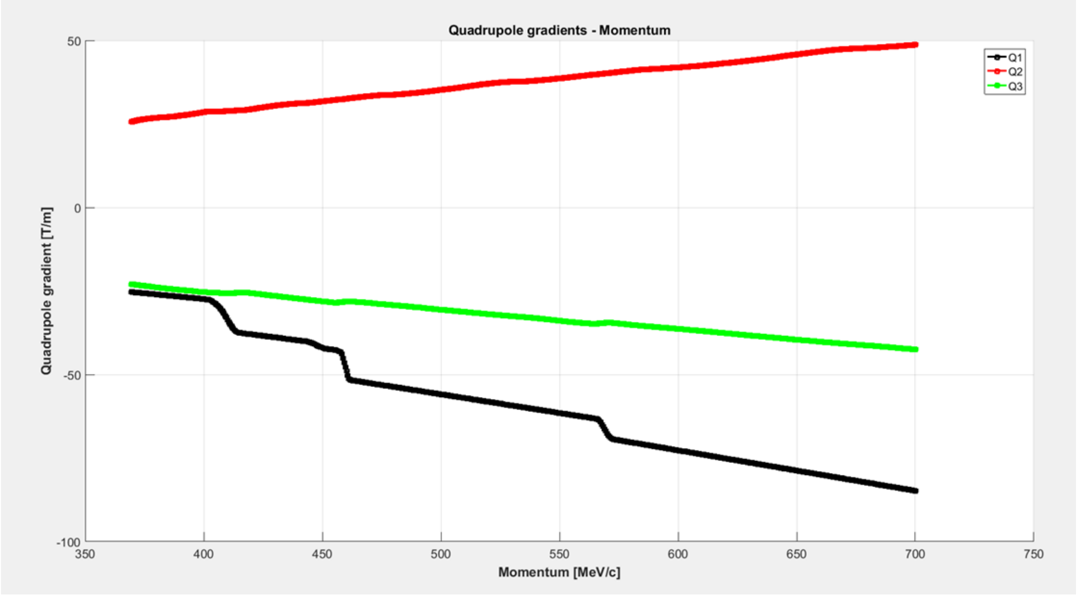


Matching for the complete spectrum of energy:70-232 MeV

Fixed value of Beta at the isocenter in vacuum
(beam size ~2.5mm for all energies)

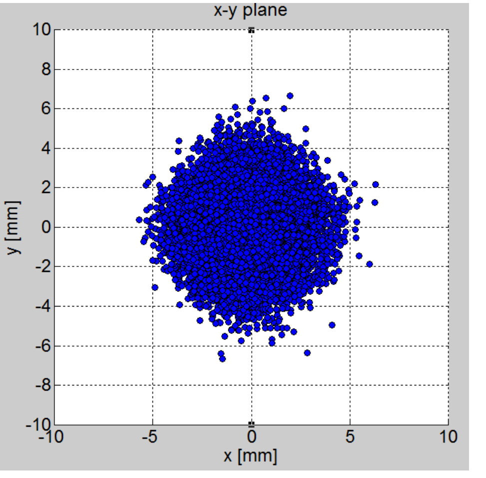
TULIP Optics in MADX-PTC

- Optimization and linearization of the quadrupole gradients

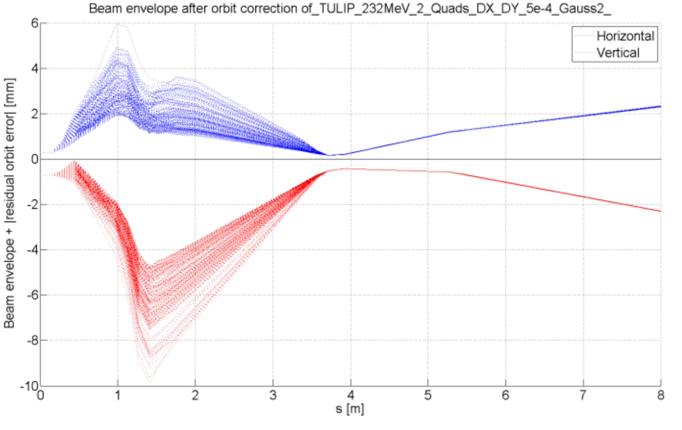


- Field error analysis on the harmonic components on dipoles and quadrupoles

- Multi Particle analysis (PTC)



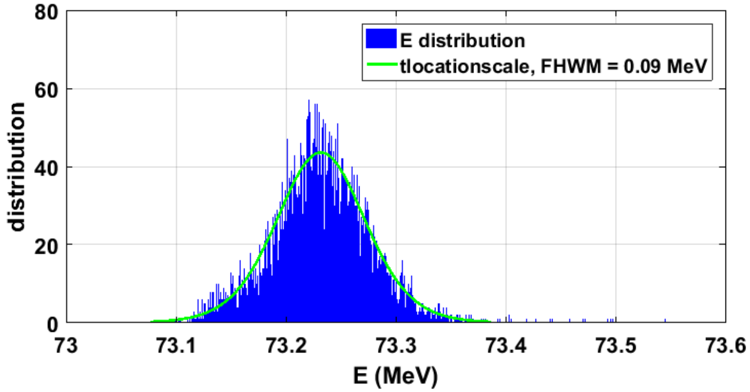
- Orbit deviation (misalignment) correction

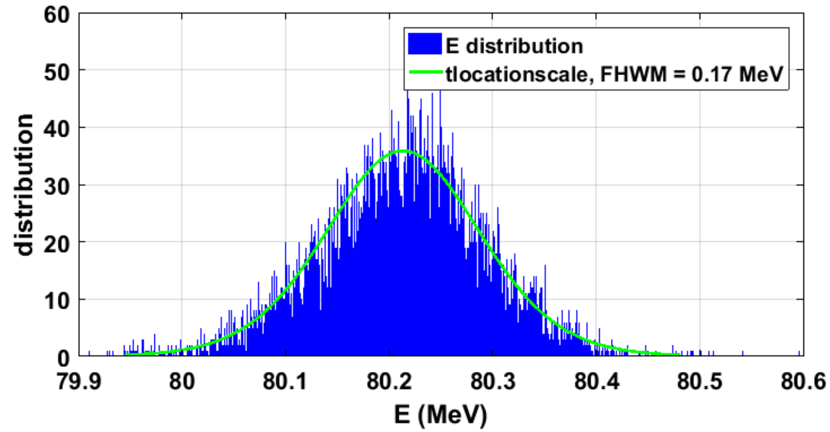


BEFORE NOZZLE

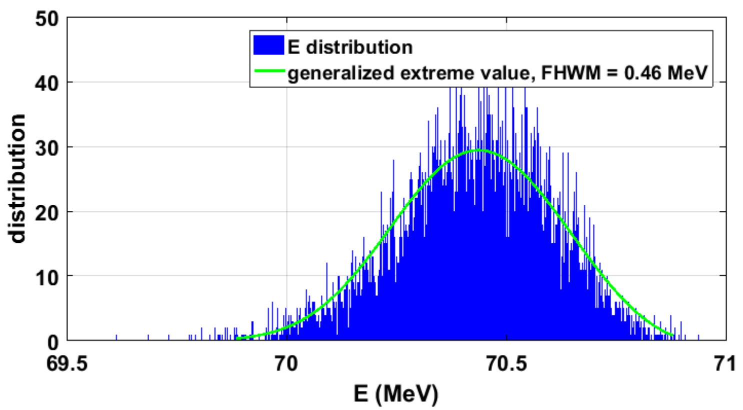
En=73 MeV

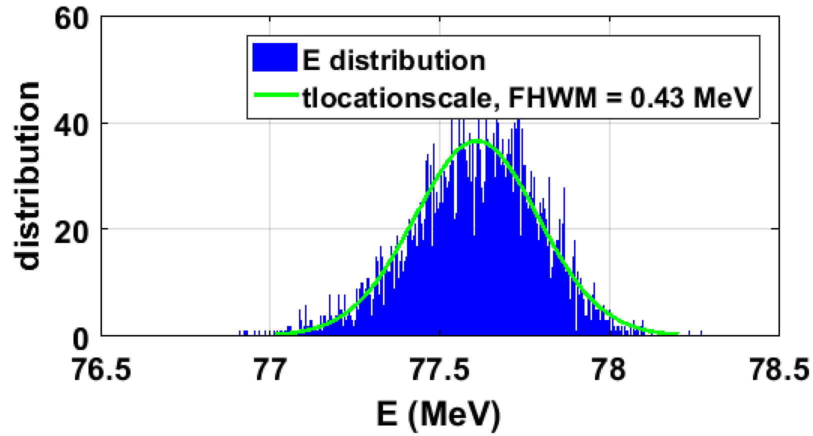
En= 80 MeV





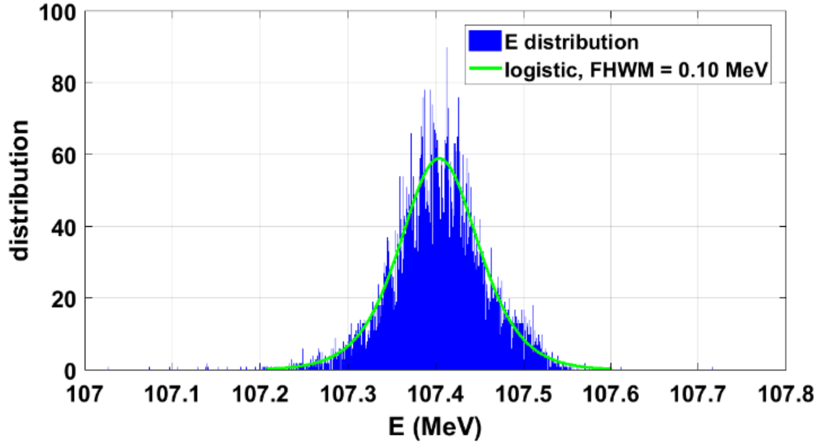
AFTER NOZZLE



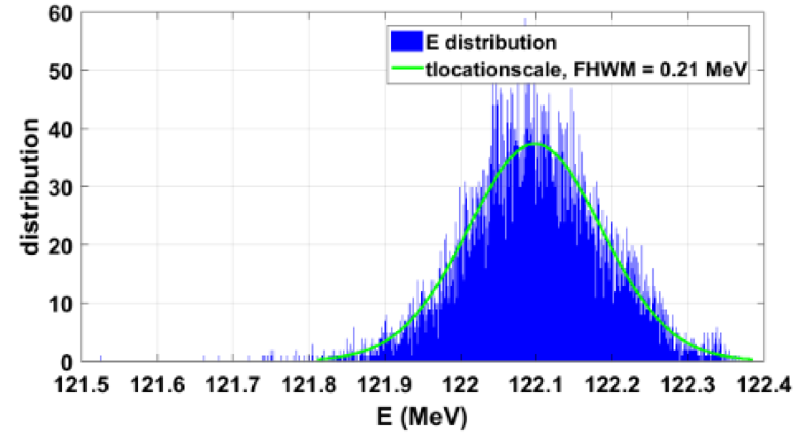


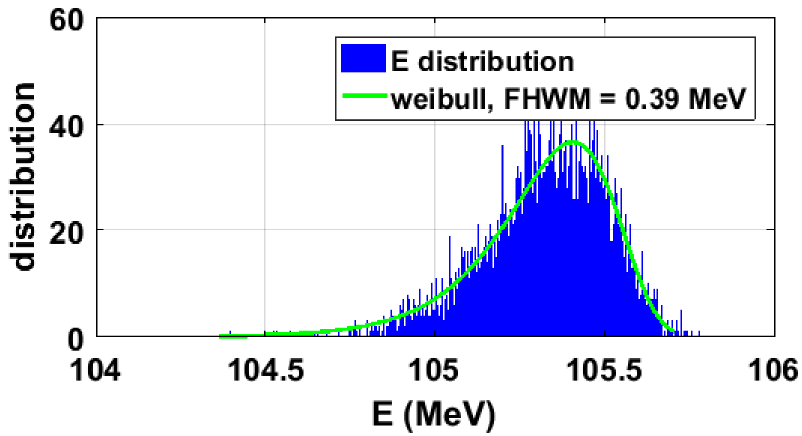
BEFORE
NOZZLE

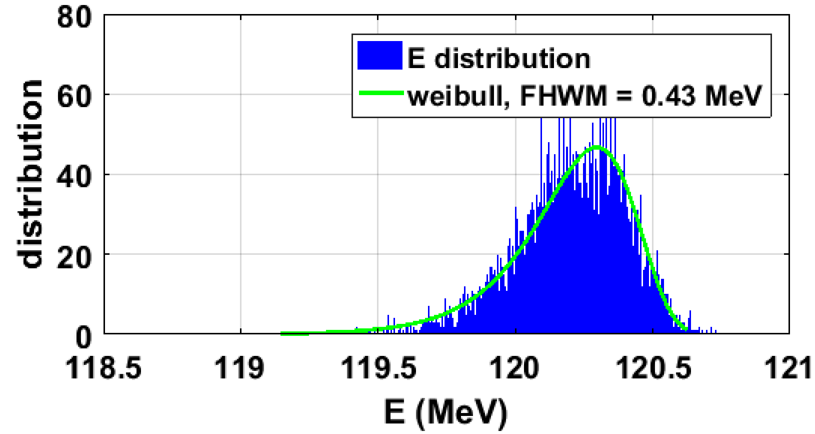
En=107.4 MeV



En= 122.1 MeV





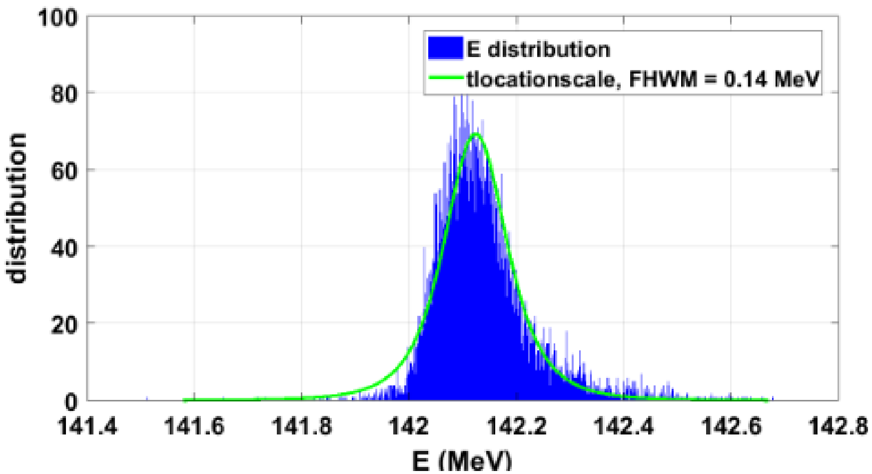


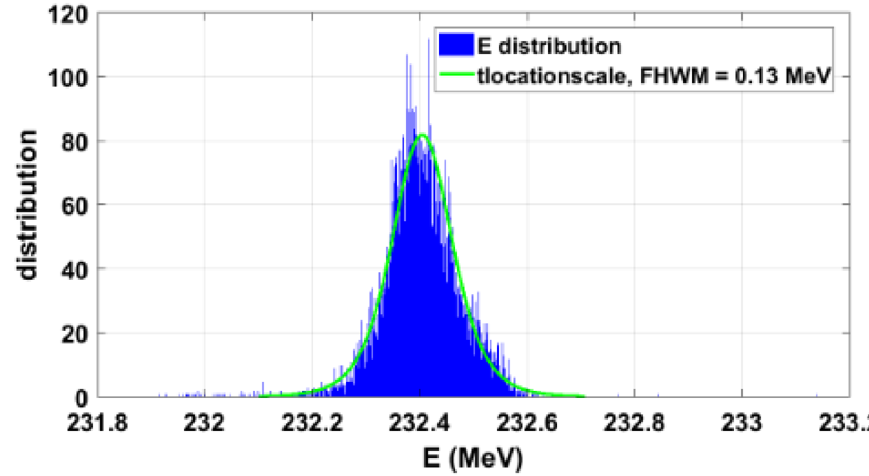
AFTER
NOZZLE

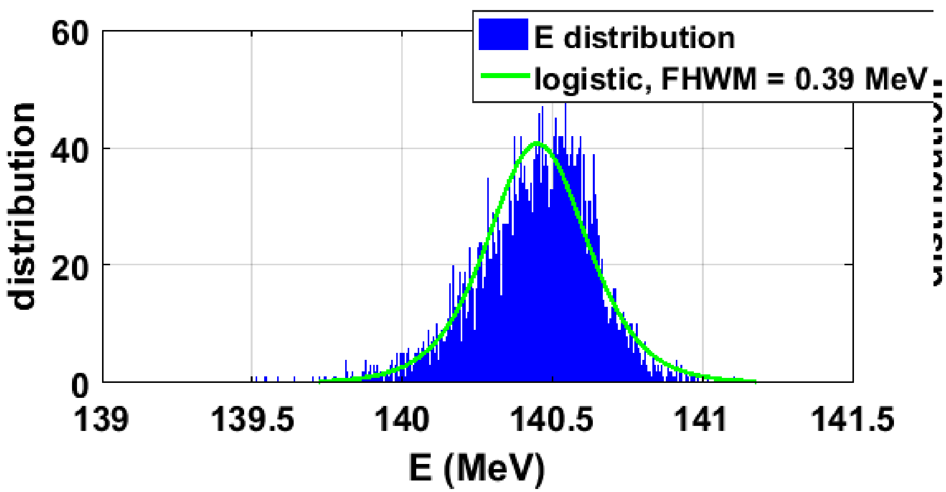
BEFORE NOZZLE

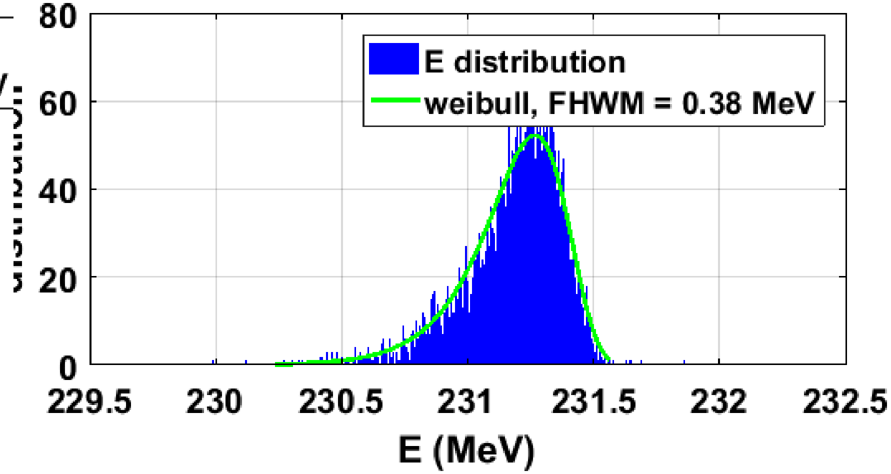
En=142.1 MeV

En=232.4 MeV





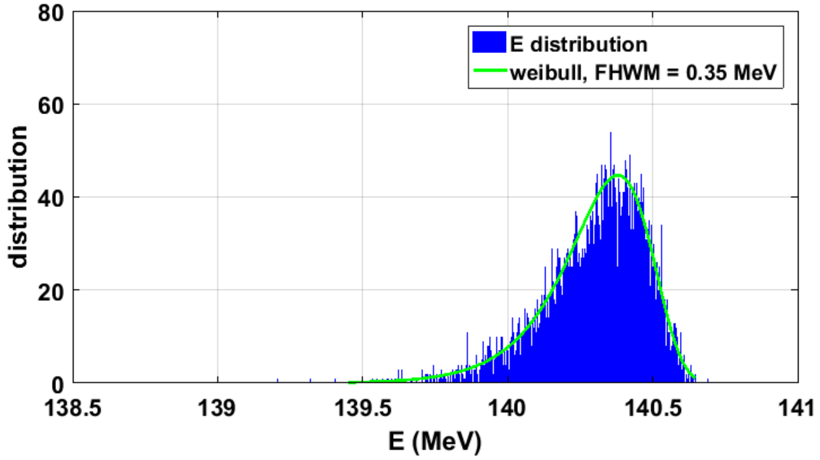


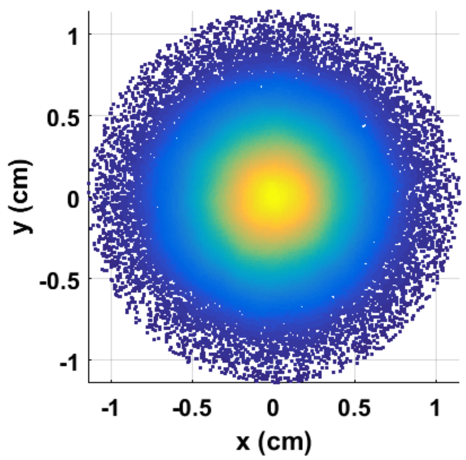


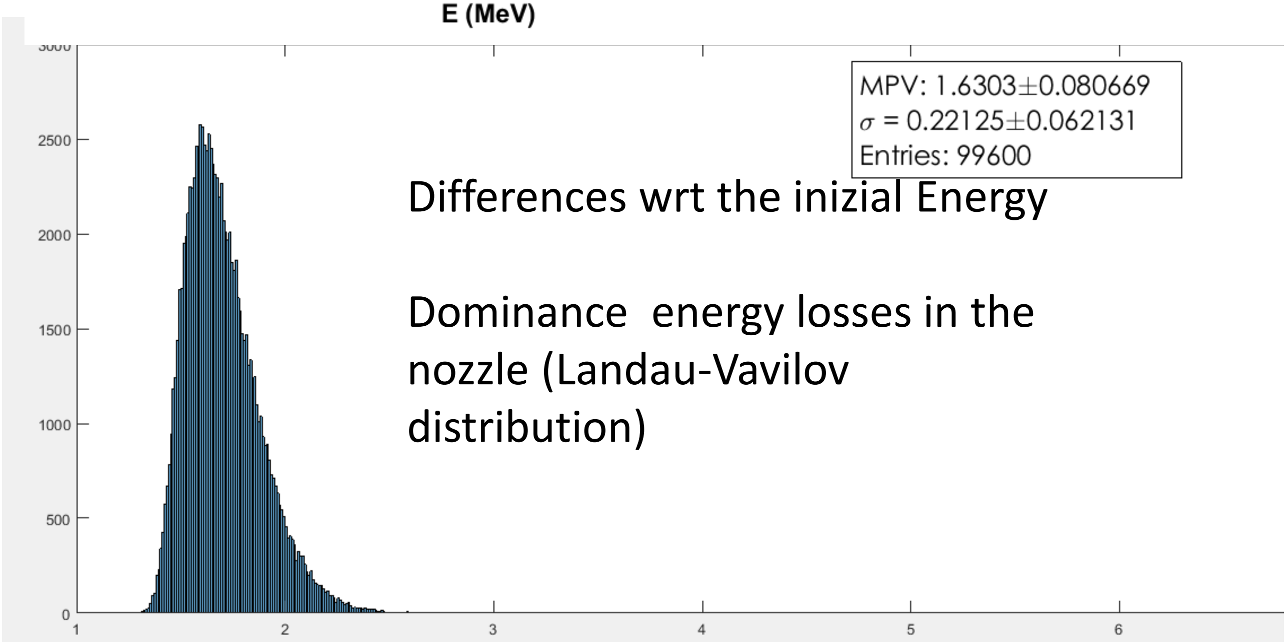
A NOZZLE

Results

Pencil beam without energy spread





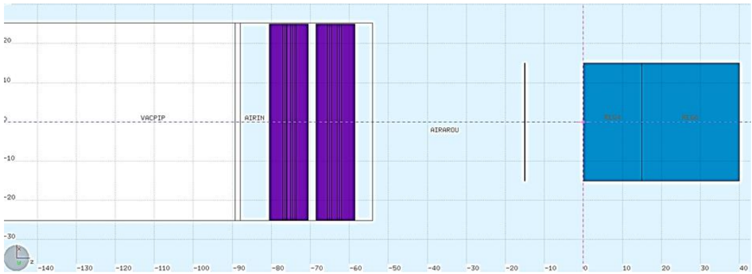


Differences wrt the inizial Energy

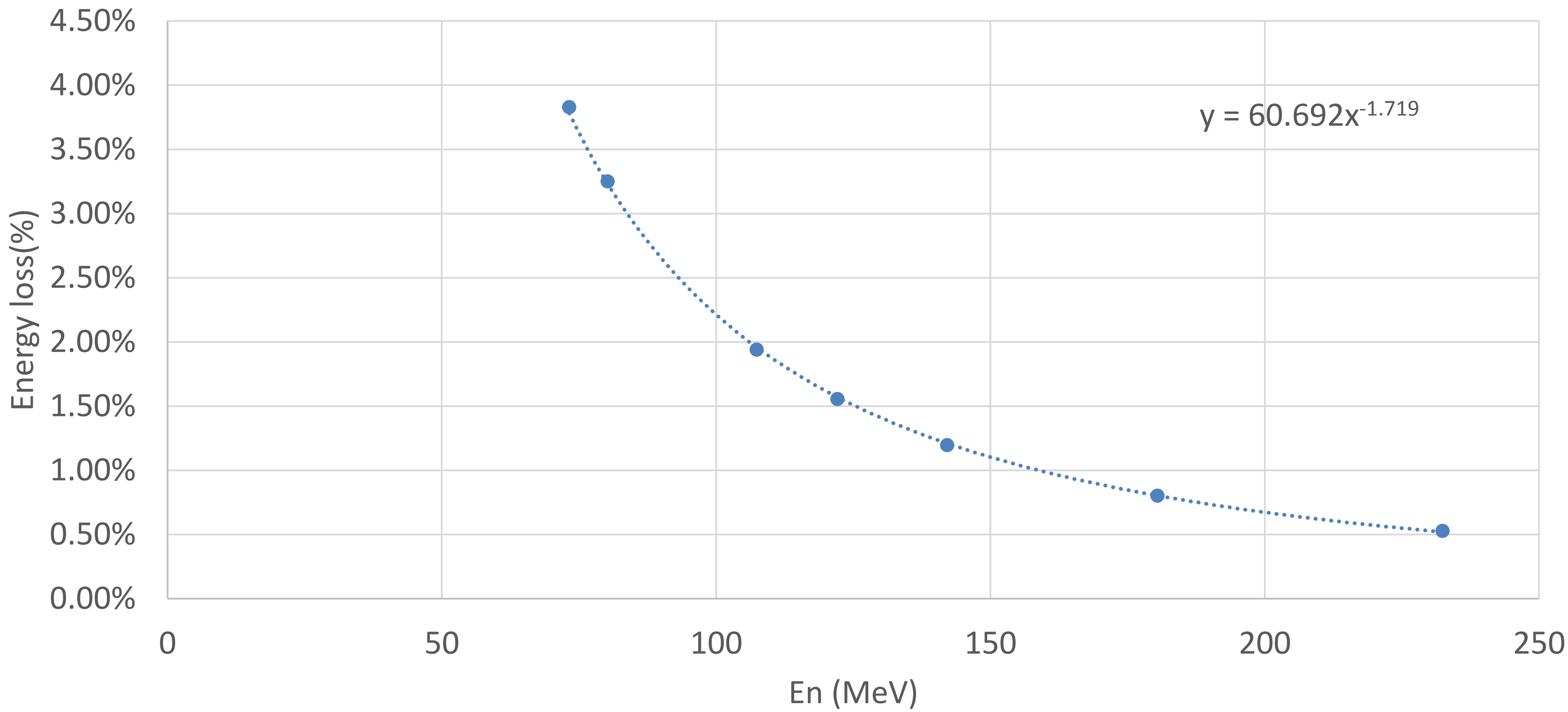
Dominance energy losses in the nozzle (Landau-Vavilov distribution)

Delta E

TULIP –Beam Characterization in air

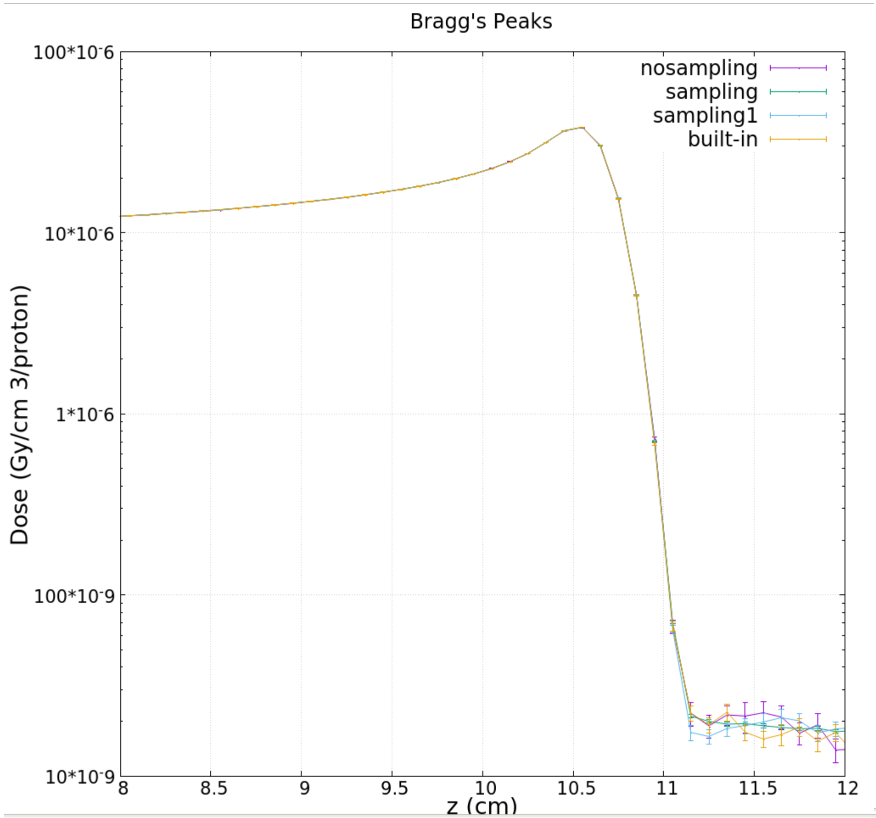


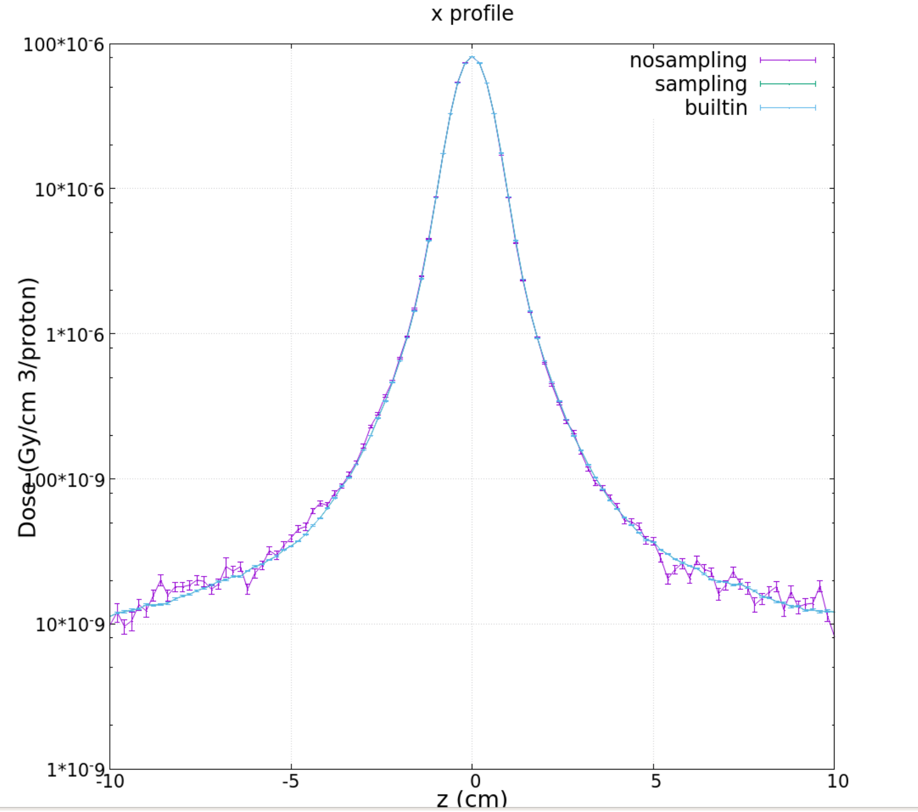
Energy loss in the nozzle and air



Multi particle-Fluka Bragg’s Peak

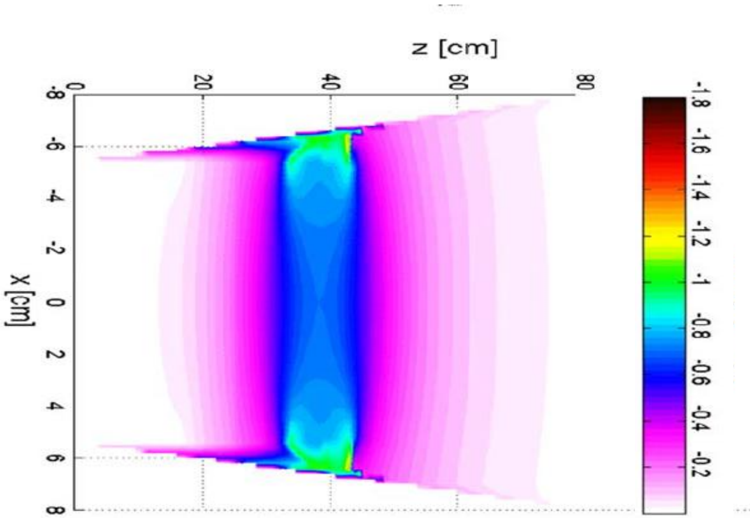
Comparison with built-in

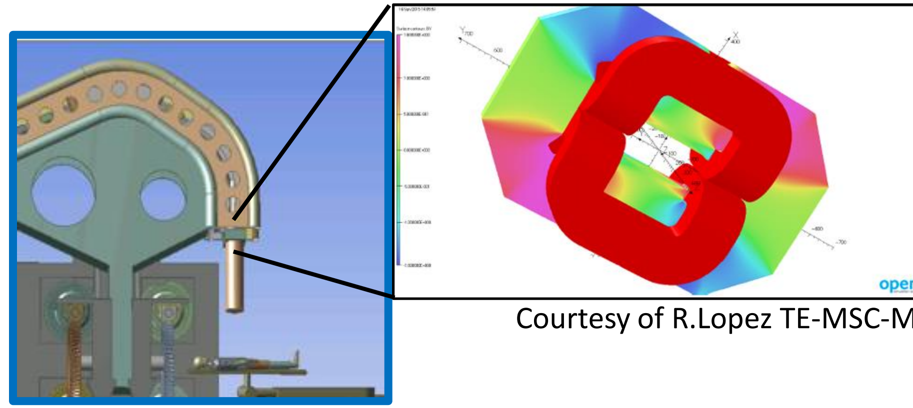




Scanning magnet : Complex Map Field Field

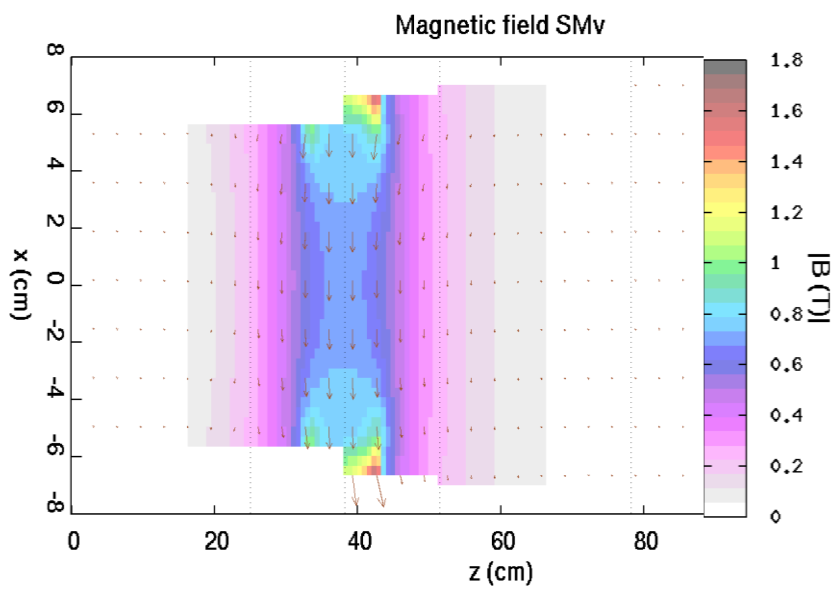
Opera code



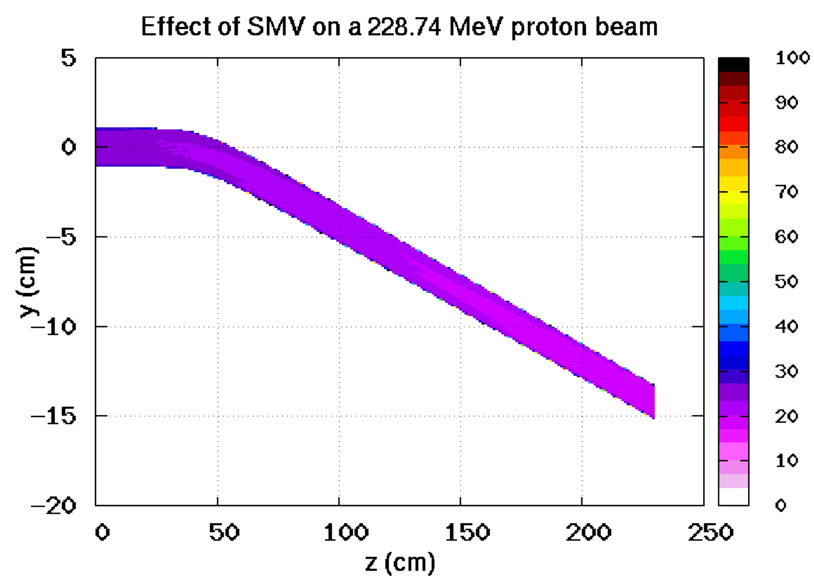


Courtesy of R.Lopez TE-MSC-MNC

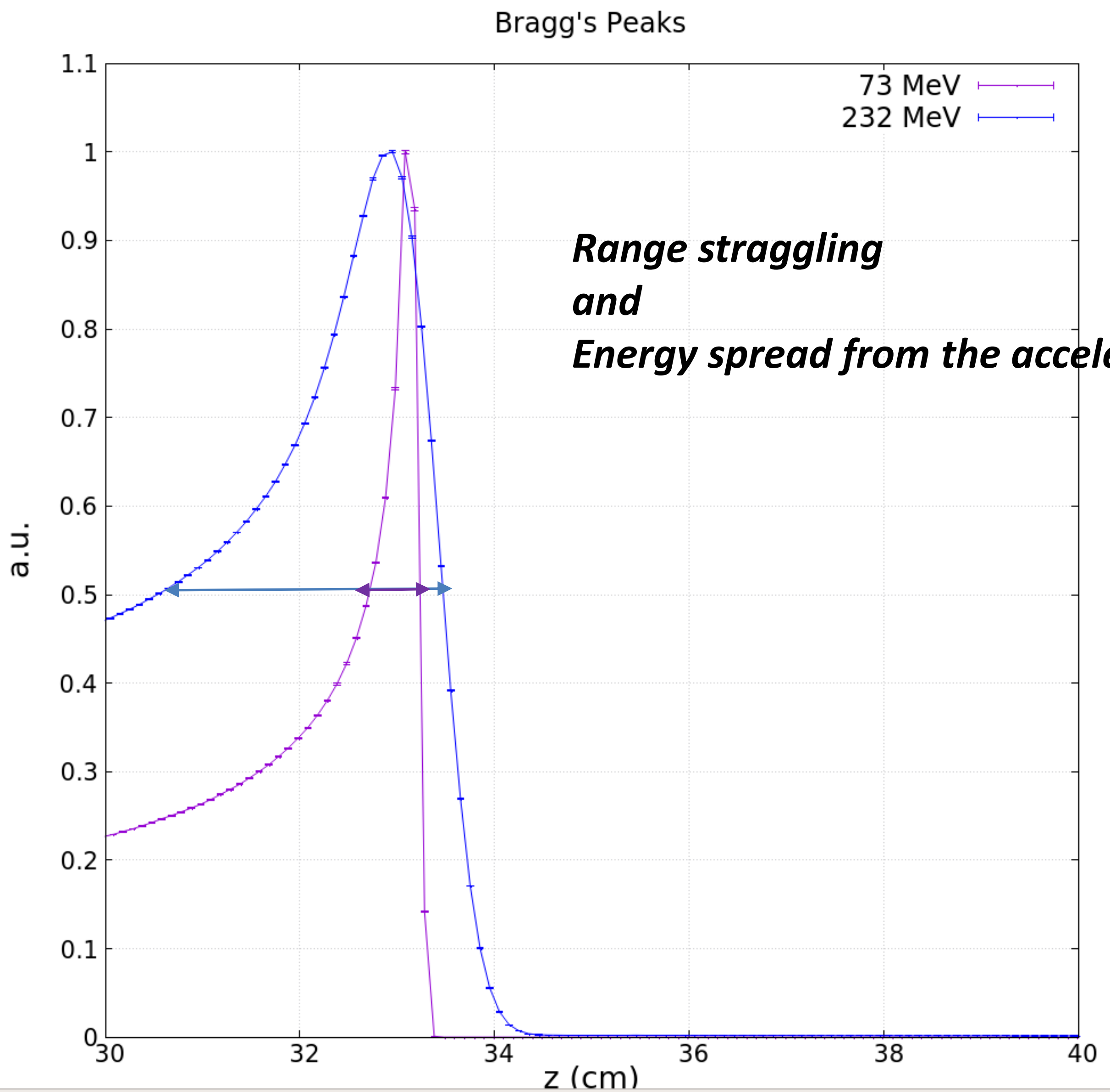
FLuka



Bending effect on the beam in Fluka



Multi particle-Fluka-Energy straggling



Range straggling
and
Energy spread from the accelerator

No profit Foundation created in 1992

by prof. U.Amaldi

http://enlight.web.cern.ch/sites/enlight.web.cern.ch/files/media/downloads/enlight_highlights_2017-web.pdf

✓ Two programmes in accelerators :

Synchrotron for carbon ions (and protons)

- ✓ **CNAO in Pavia from PIMMS TERA/CERN DESIGN**

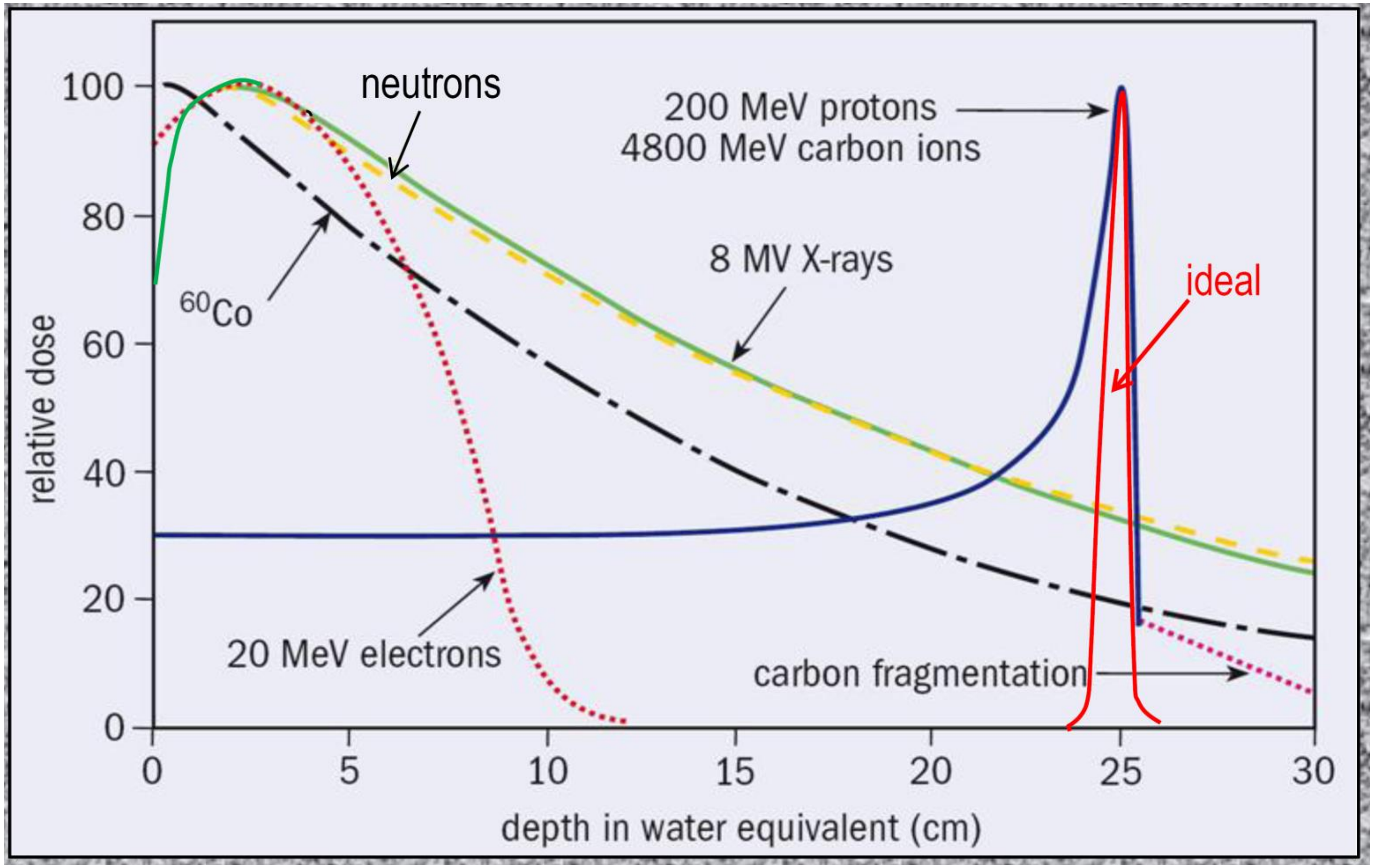
Linacs for protons and carbon ions :

- ✓ **proton linacs: ADAM's LIGHT and TULIP**
- ❖ **Cyclinac & ion linacs for C-12 an He-4– under development**

✓ AQUA* program in monitoring *lead by prof. F.Sauli*

**Advanced QUality Assurance*

Physical advantage: the Bragg's Peak



Radiation beam in matter

Proton Single Room facility: TULIP

TULIP- TUrning Linac for Protontherapy

PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 040101 (2017)

High gradient linac for proton therapy

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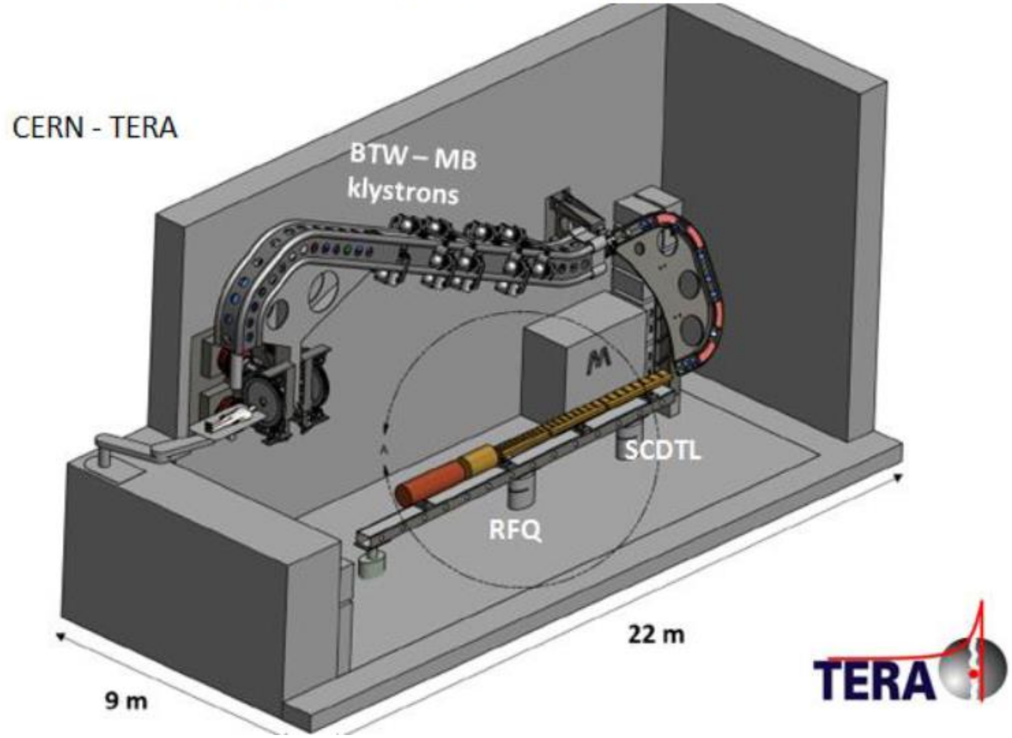

http://medicalphysicsweb.org/cws/article/research/69024

AVO-ADAM's LIGHT proton system

Radio Frequency Quadrupole (CERN-RFQ)

Side Coupled Drift Tube Linac (SCDTL)

Coupled Cavity Linac (CCL)

http://www.advancedoncotherapy.com/