Istituto Nazionale
di Fisica Nucleare

FOOT
FragmentatiOn Of Target

An experiment for the measurement of the nuclear fragmentation for Particle Therapy & Radioprotection in space

V. Patera

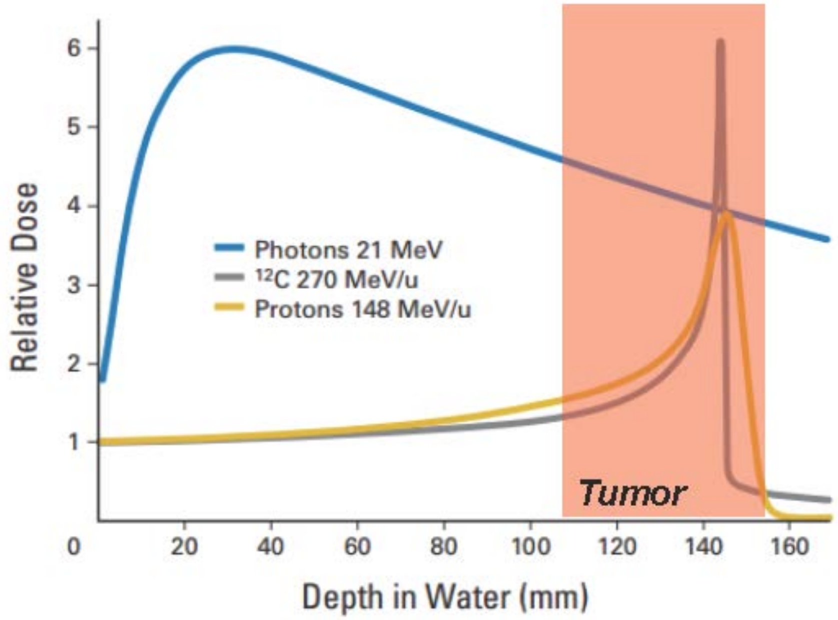
Meeting implementazione meccanica

Pisa 04/05/2018

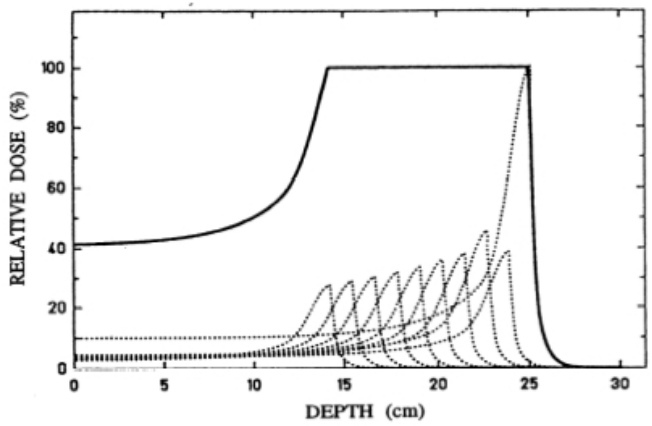
Charged Particle Therapy

Charged Particle Therapy vs “Conventional” radiotherapy (photons)

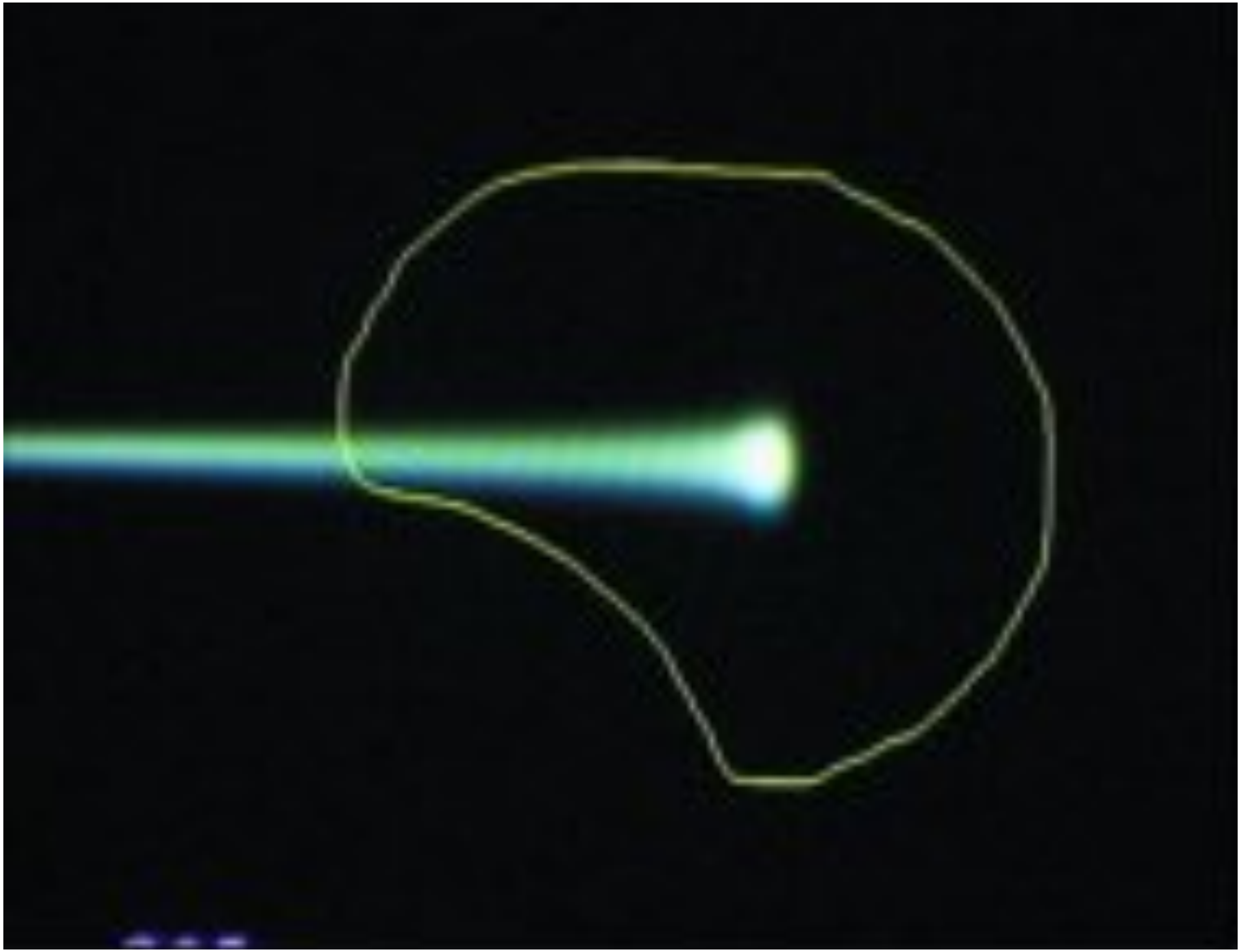
- ✓ Peak of dose released at the end of the track, **better sparing the normal tissue**
- ✓ Beam penetration in tissue is function of the beam energy
- ✓ Accurate conformal dose to tumor with Spread Out Bragg Peak



Schulz-Ertner et al. *J. Clin. Oncol.* (2007)



Painting the tumor…



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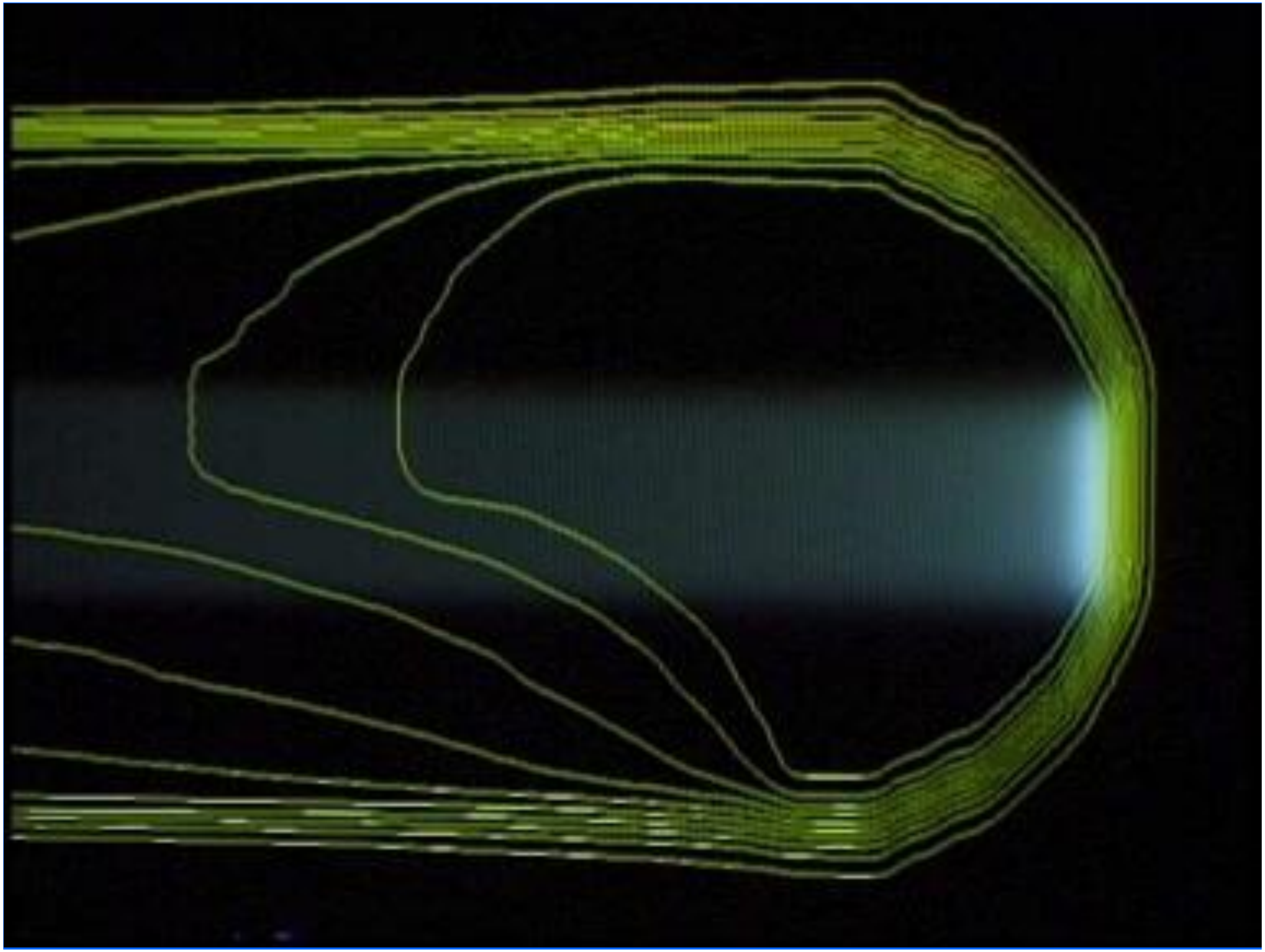

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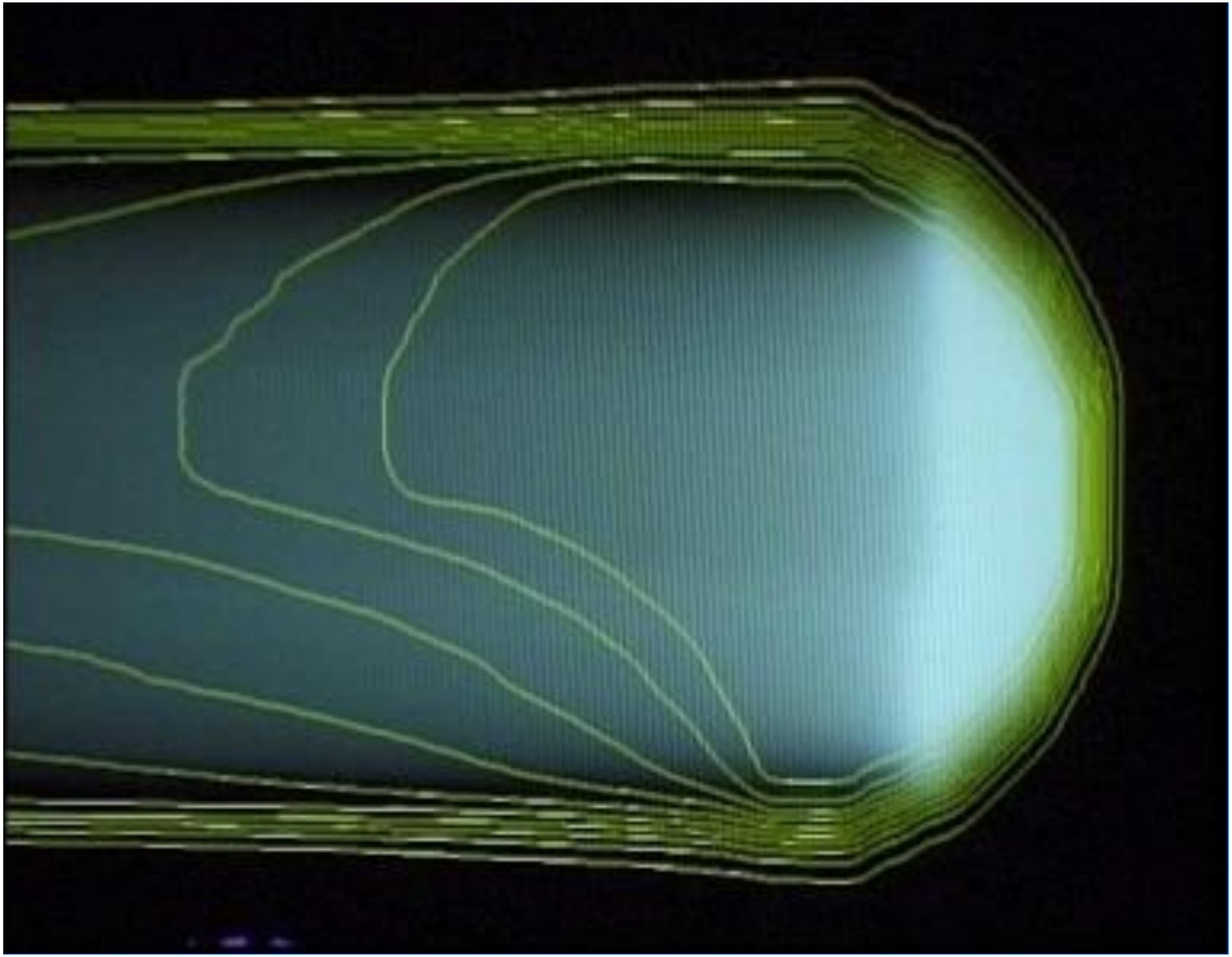

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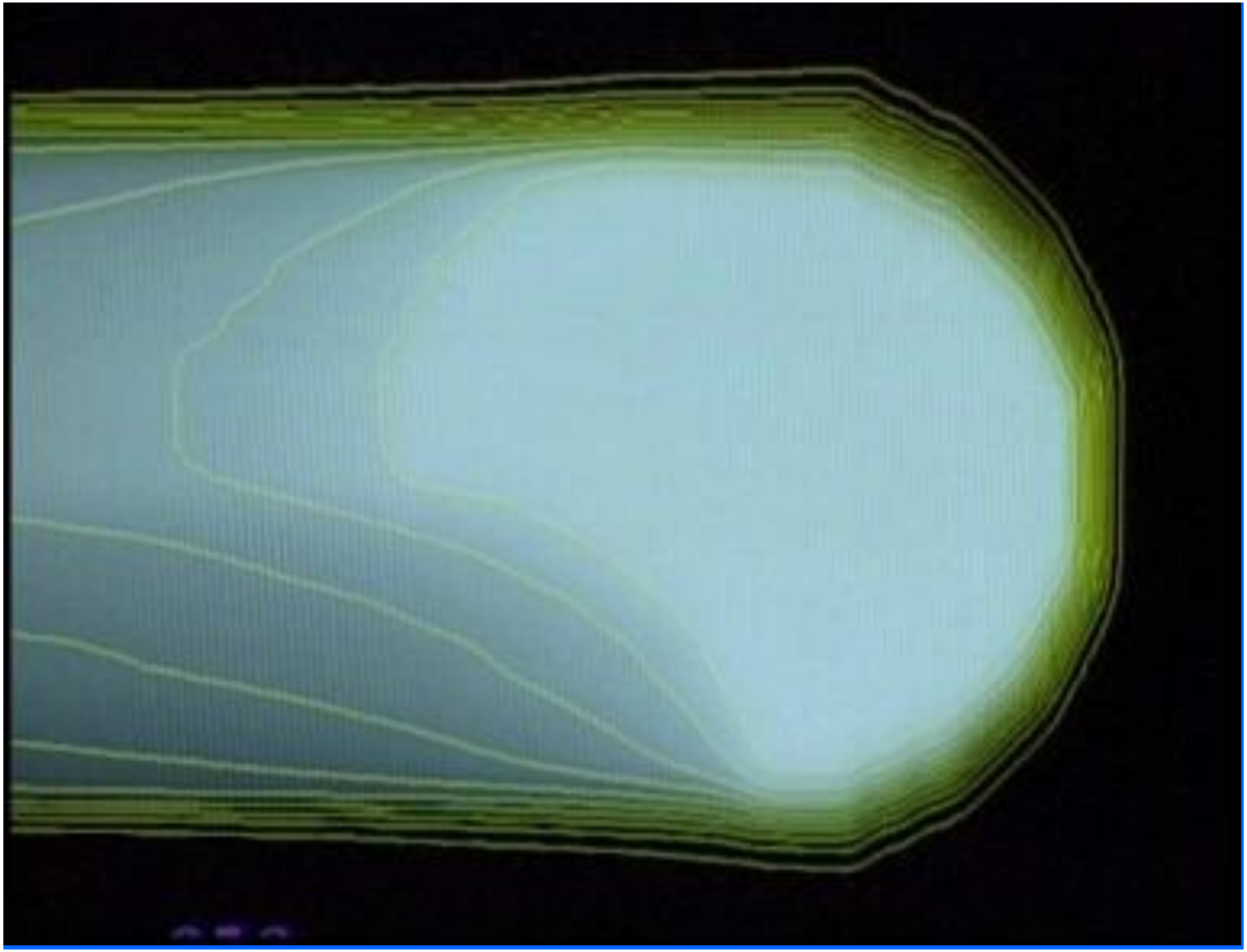
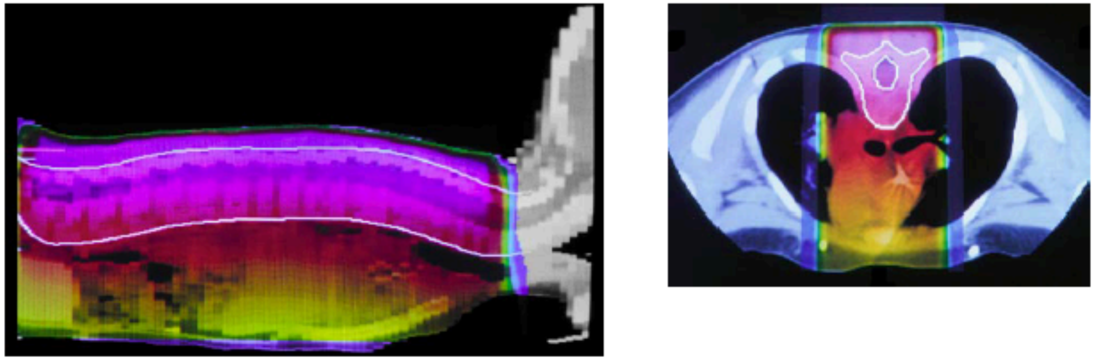
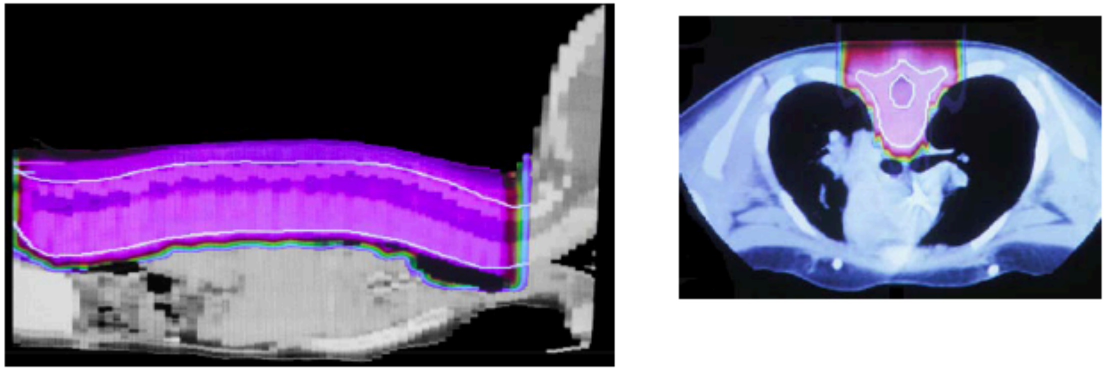


Typical example of advantages of Charged Particle Therapy

Image guided, conformal (IMRT), photon therapy

- 35% local recurrence
- Preventable distant metastases
- Large volumes irradiated
- Early, late and very late normal tissue damage

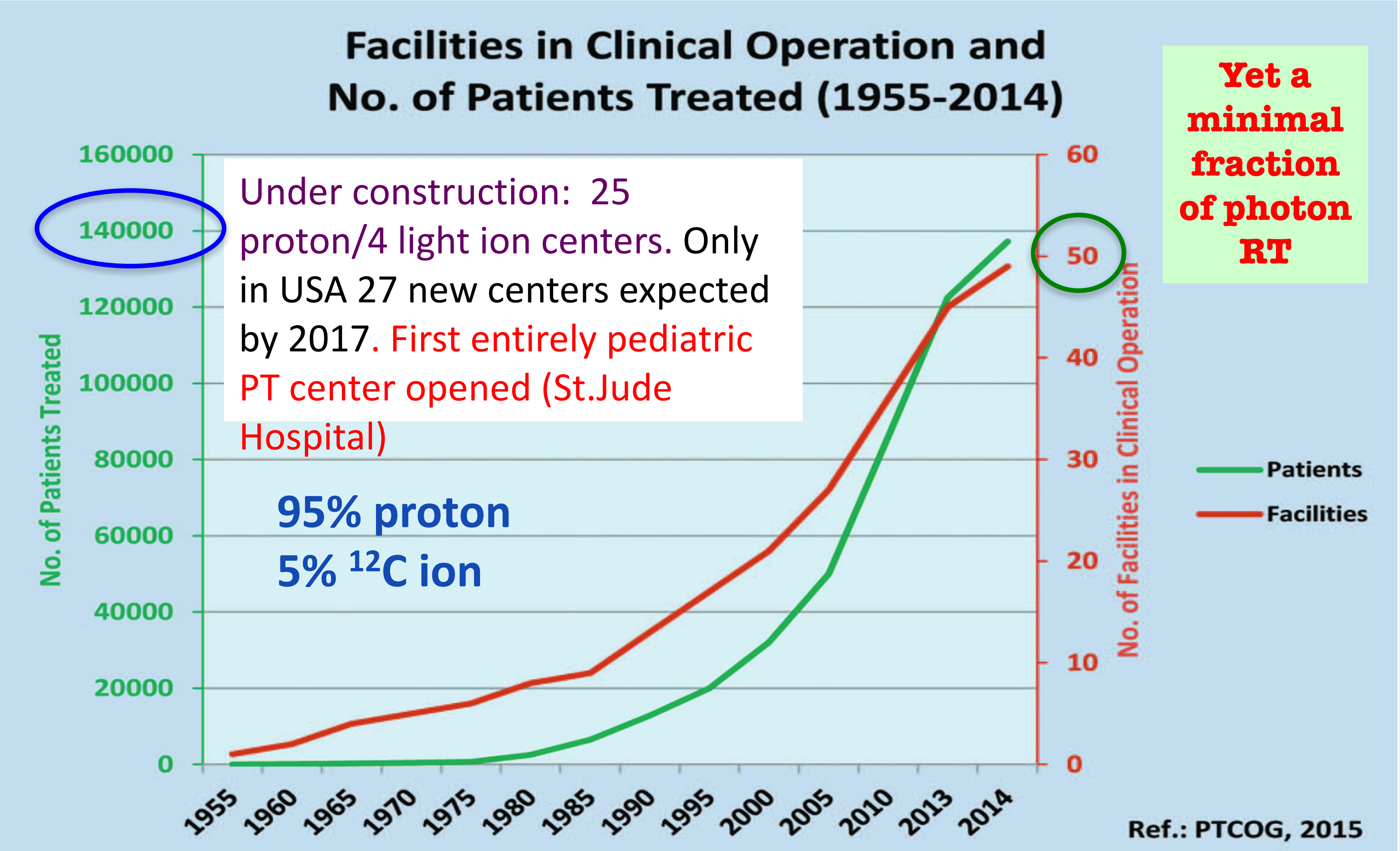




Conformal Proton therapy: higher selectivity!

The future development of Charged Particle Therapy is strongly related to the possibility of demonstrating the effective reduction of complication probability in normal tissues for the same (or sometimes better) control of the tumoral region

Charged Particle Therapy in the world



Under construction: 25 proton/4 light ion centers. Only in USA 27 new centers expected by 2017. First entirely pediatric PT center opened (St.Jude Hospital)

95% proton
5% ^{12}C ion

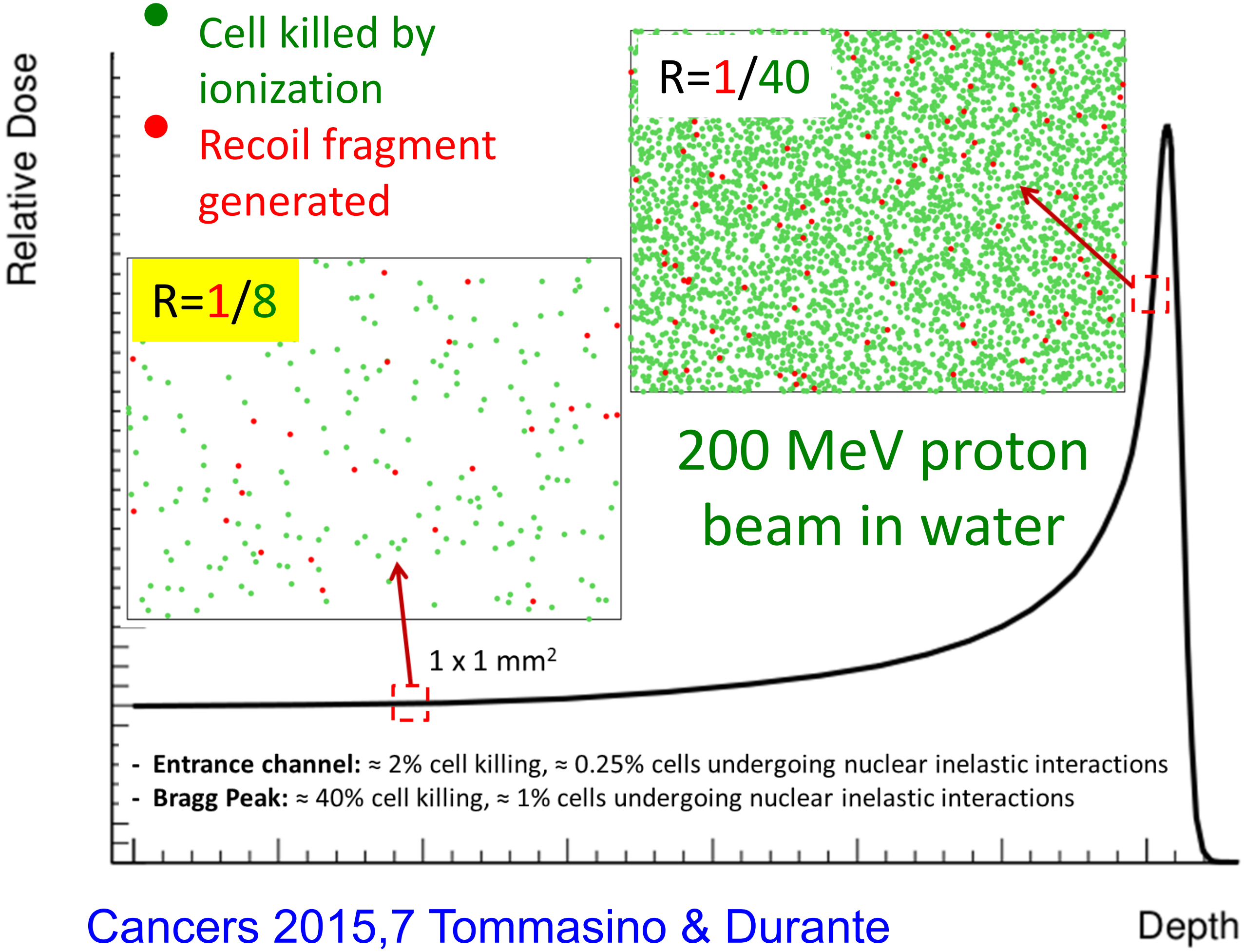
Yet a minimal fraction of photon RT

Ref.: PTCOG, 2015

Community looking at ^{4}He – ^{16}O beams: begin to be tested at clinical center

Target (patient) fragmentation & PT

Target fragmentation in proton therapy: gives contribution also outside the tumor region!



- **Entrance channel:** ≈ 2% cell killing, ≈ 0.25% cells undergoing nuclear inelastic interactions
- **Bragg Peak:** ≈ 40% cell killing, ≈ 1% cells undergoing nuclear inelastic interactions

Cancers 2015,7 Tommasino & Durante

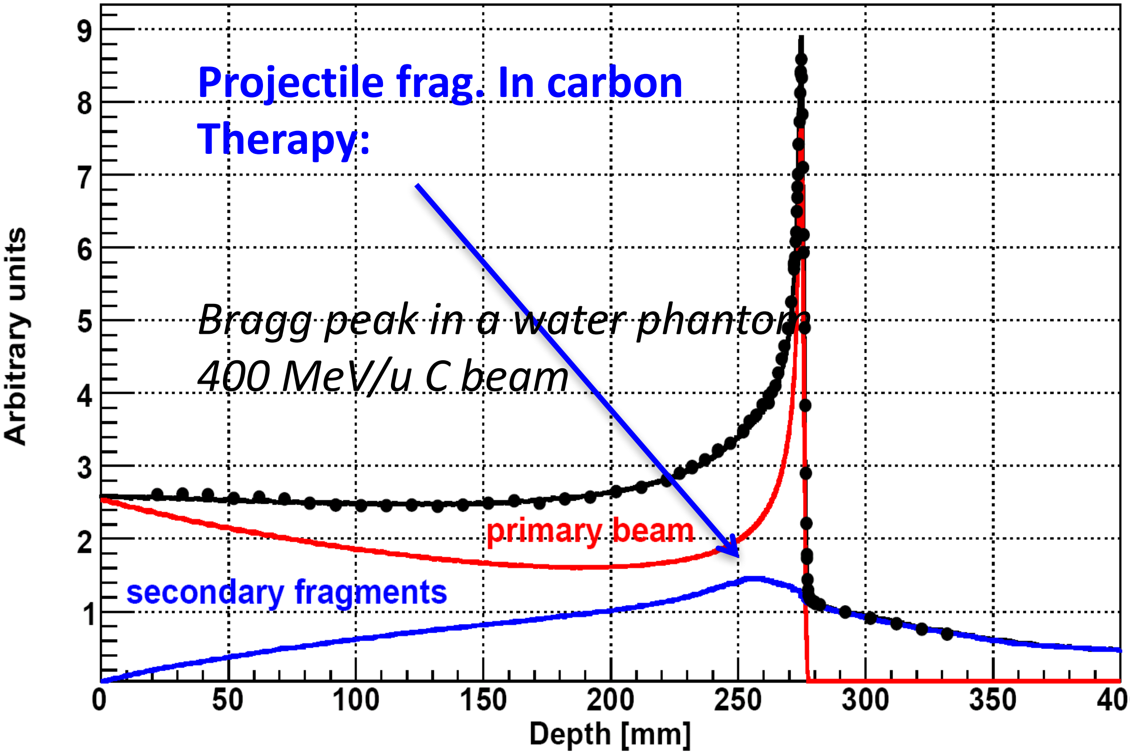
About 10% of biological effect in the entrance channel due to secondary fragments (Grun 2013)

Largest contributions of recoil fragments expected from
He, C, Be, O, N
In particular on Normal Tissue Complication Probability

MoVe IT

Beam fragmentation in light ion Therapy

Effect of beam Fragmentation already known to produce mixed particle field of different RBE/LET. Considered in ^{12}C treatment, but still scarce validation data!



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

Effect to be taken under control also with the new beams in use: ^{4}He, ^{16}O

Data badly needed for TPS

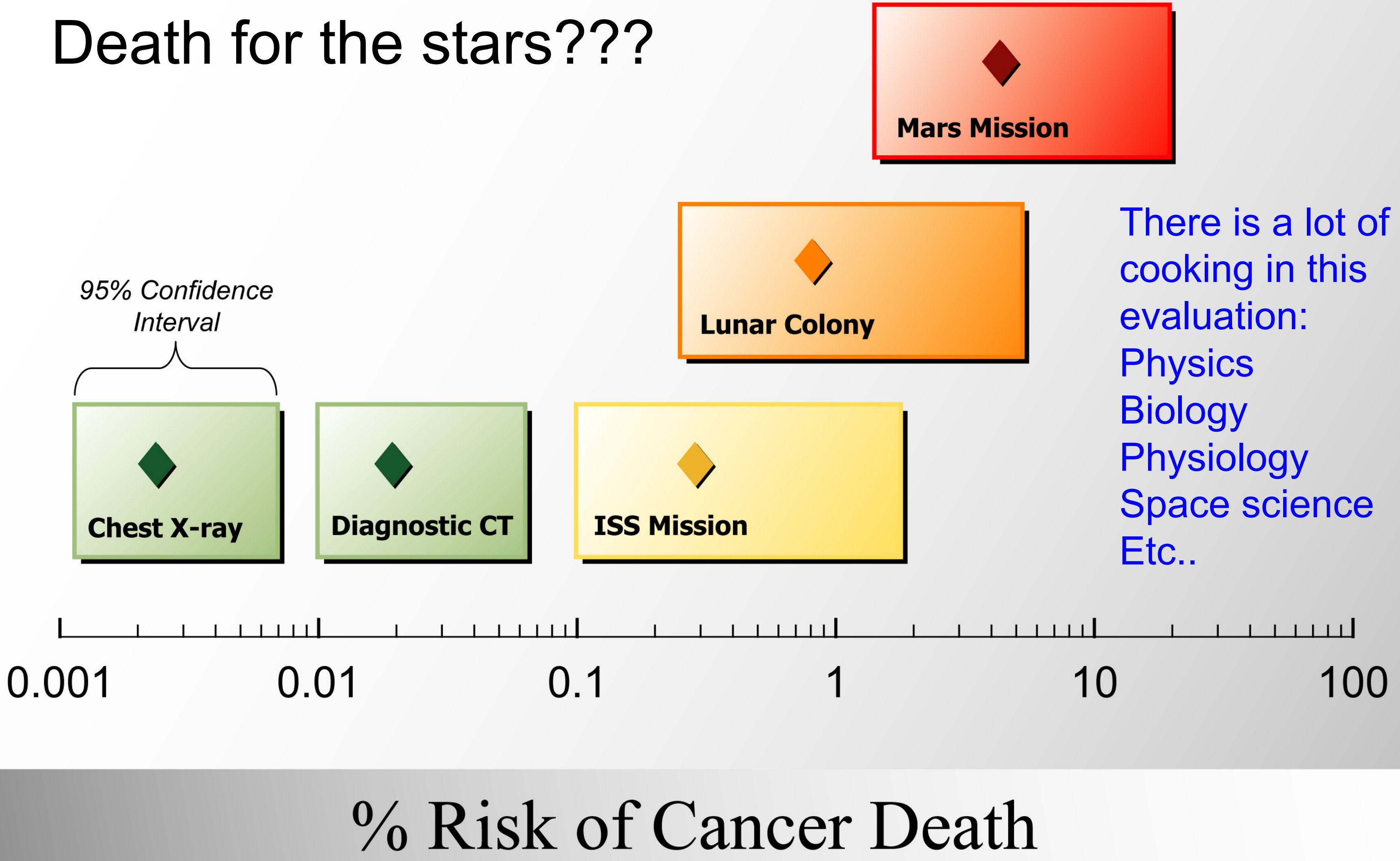
^{12}C → ^{12}C, ^{16}O, H @ 350 MeV/u

^{16}O → ^{12}C, ^{16}O, H @ 400 MeV/u

^{4}He → ^{12}C, ^{16}O, H @ 250 MeV/u

Phys 3) radio protection in space

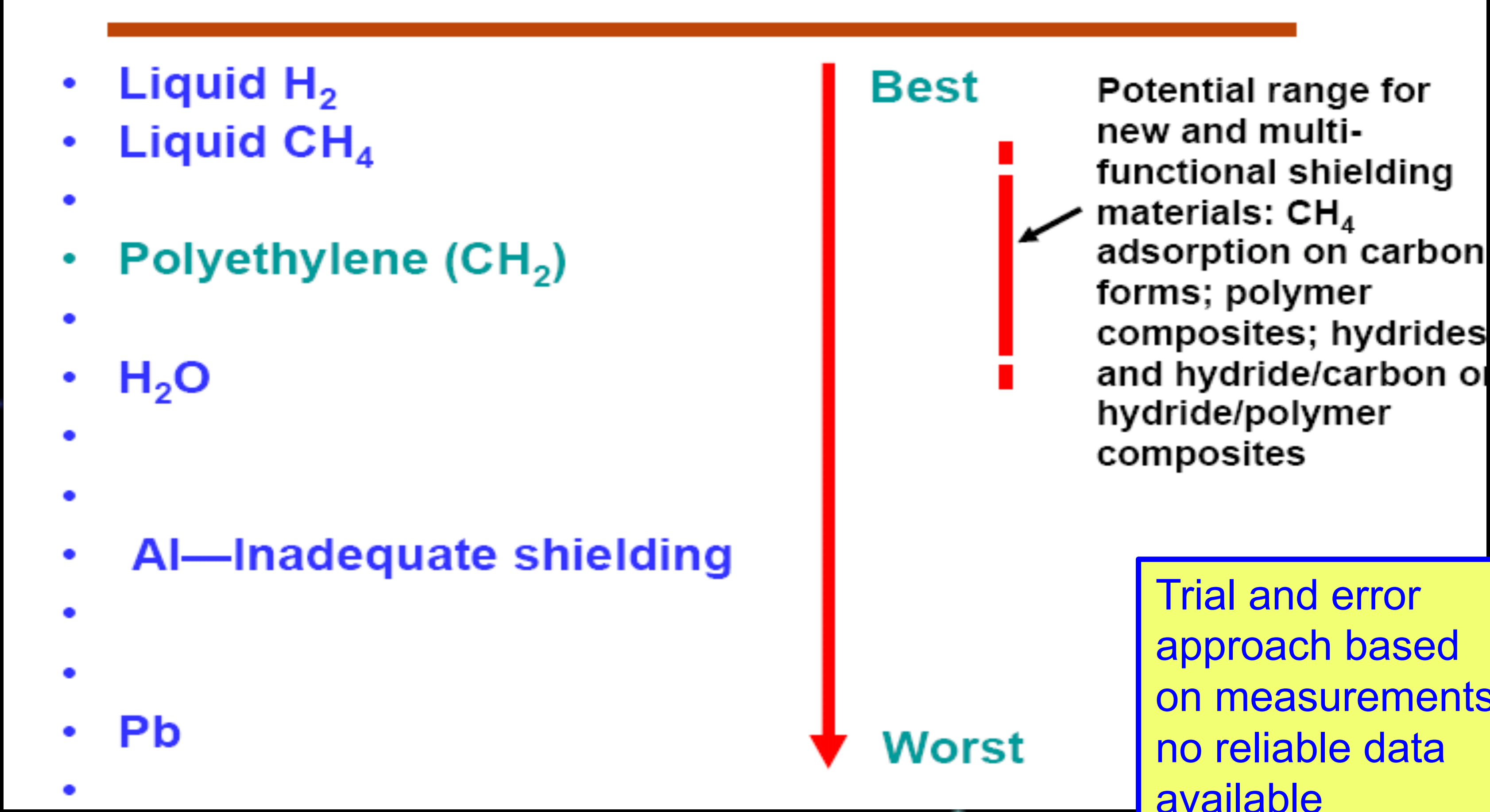
Death for the stars???



There is a lot of cooking in this evaluation:
Physics
Biology
Physiology
Space science
Etc..

Durante & Cucinotta, *Nature Rev. Cancer* (2008)

“Best” shielding materials ?



- Liquid H_2
- Liquid CH_4
- Polyethylene (CH_2)
- H_2O
- Al—Inadequate shielding
- Pb

Potential range for new and multi-functional shielding materials: CH_4 adsorption on carbon forms; polymer composites; hydrides and hydride/carbon o hydride/polymer composites

Trial and error approach based on measurements: no reliable data available

Fragmentation on shield is main source of dose to astr.
FOOT can provide ^{4}He, ^{12}C, ^{16}O ➔ C, C_2H_4 @ 700MeV/u

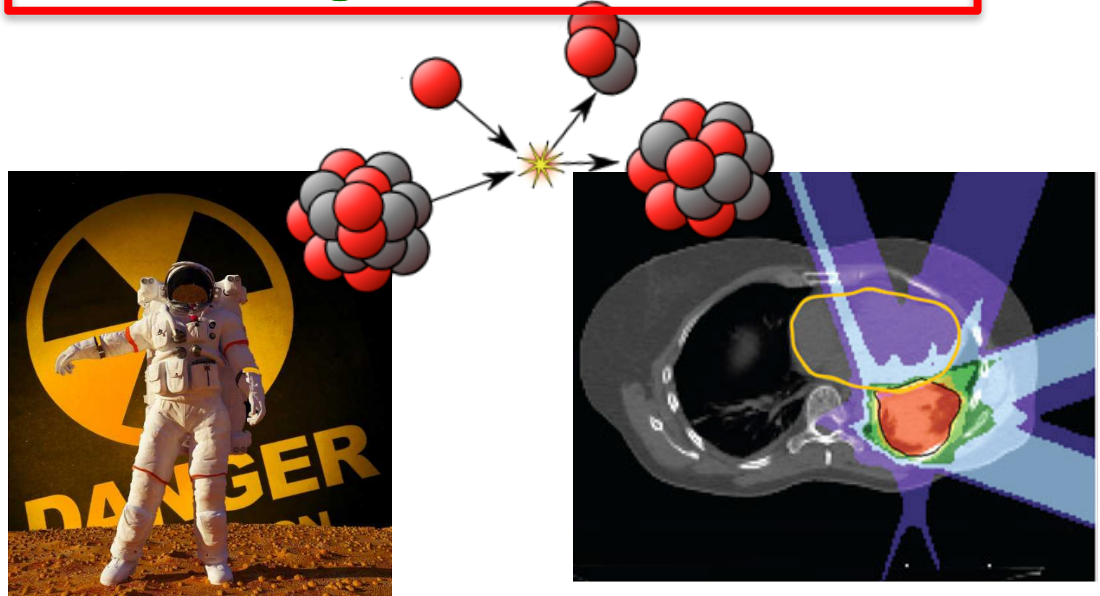
FOOT in pills

Bologna, Frascati, Milano, Napoli, Perugia, (Pavia), Pisa, Roma1, Roma2, Torino, Trento

Strasbourg, GSI, Aachen, Nagoya

People: ~70 researcher, ~27 FTE

Data taking 2018-2021@ GSI, Heidelberg, CNAO

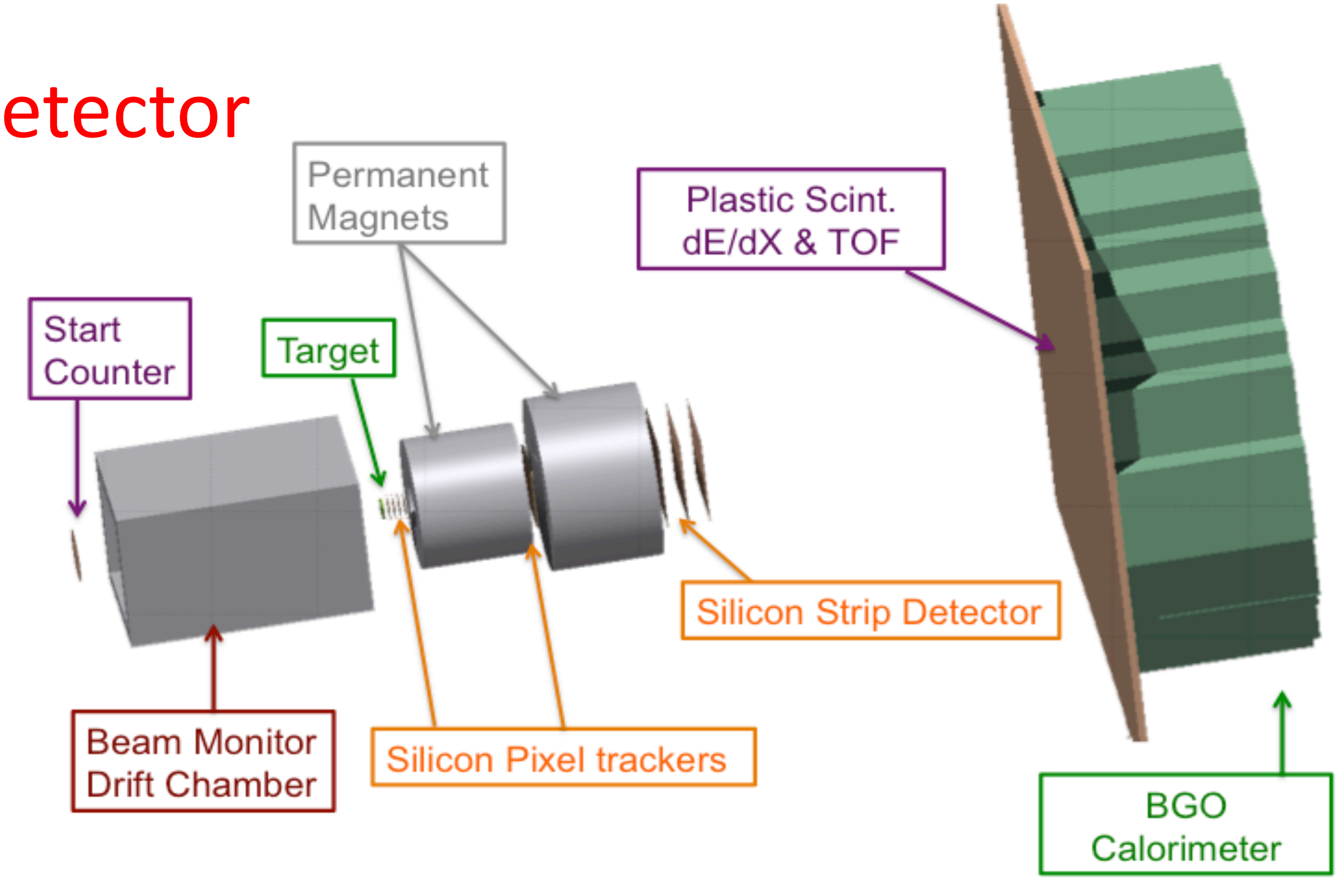


Experiment with translational approach: focus on nuclear physics, physics applied to medicine and radioprotection in space

FOOT Detector

For the fragment with Z>2 measurements of TOF, P, Ekin, DE

Maximum 2 meters length



- ✓ Start Counter = thin plastic scintillator
- ✓ Beam Monitor = drift chamber
- ✓ Vertex detector & Intermediate Tracker = monolithic silicon pixel detector
- ✓ Large tracker = silicon strip detector
- ✓ DE/TOF Detector = plastic scontillator
- ✓ Calorimeter = BGO crystal calorimeter

Expected target fragmentation performances:

σ_p/p ~4-5%

σ_{TOF} ~ 100 ps

$\sigma_{Ekin}/Ekin$ ~ 1-2%

$\sigma_{\Delta E}$ ~ 2%

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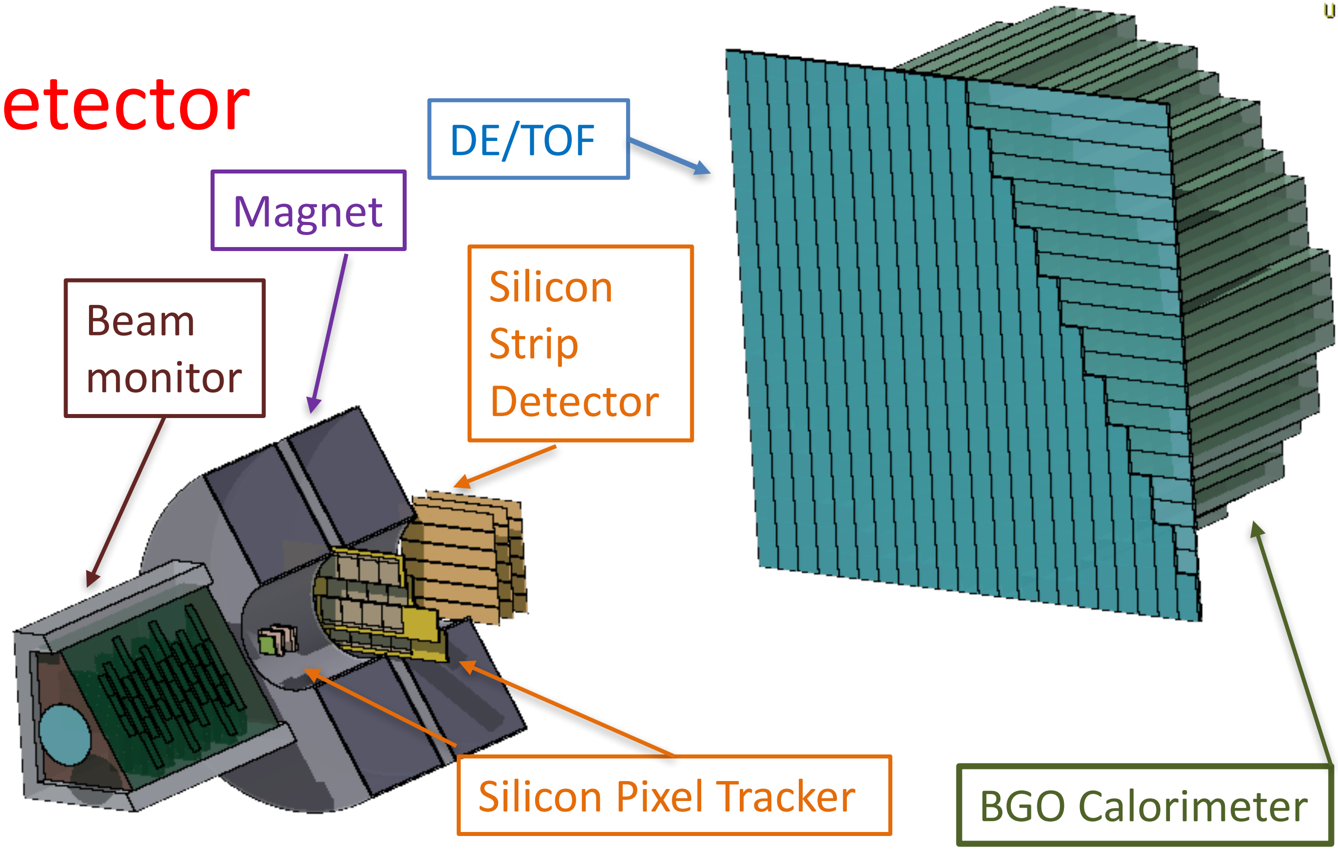

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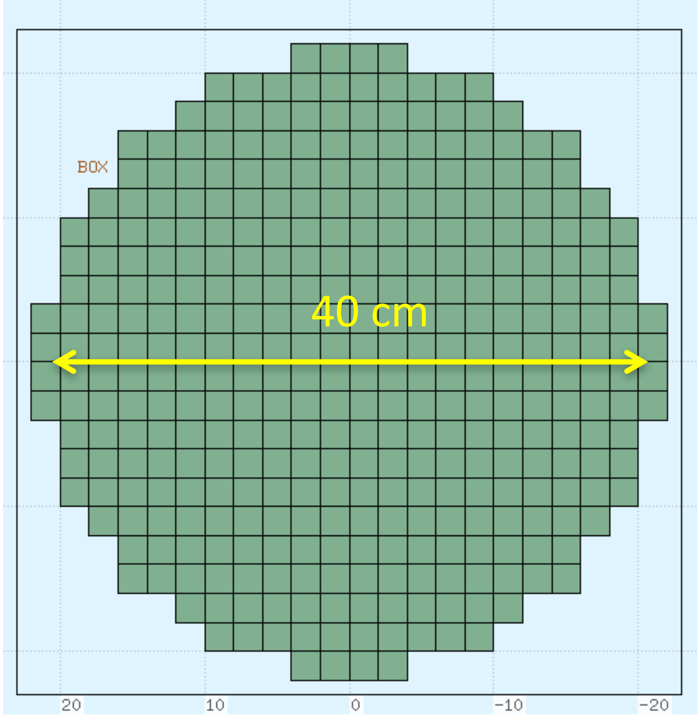
BGO Calorimeter

The BGO calorimeter is 0.5 m in diameter

The BGO density (7 g/cm^3) make it quite heavy even with its limited size.

The crystal depth : 14-22 cm (to be yet decided)

Crystal cross section: 2x2 cm^2

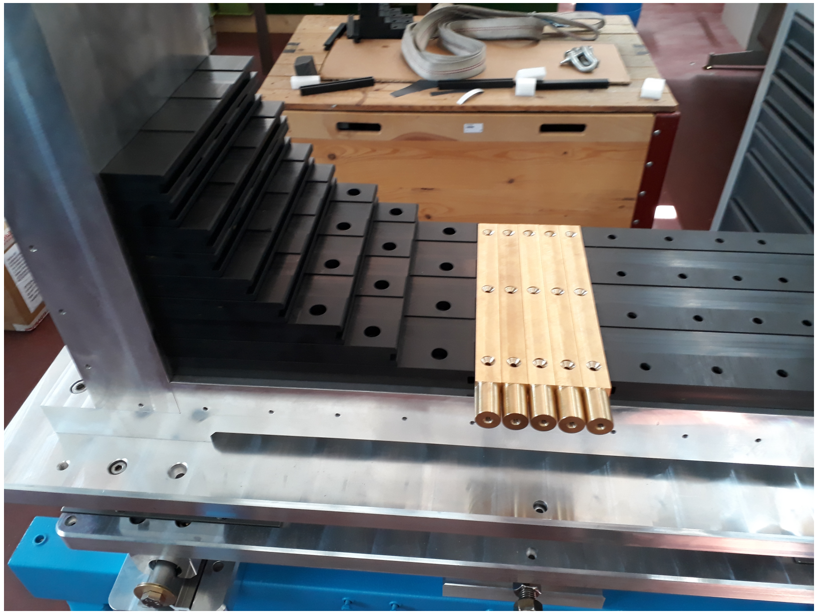


Calorimeter XY view: 360 2x2cm^2 crystals

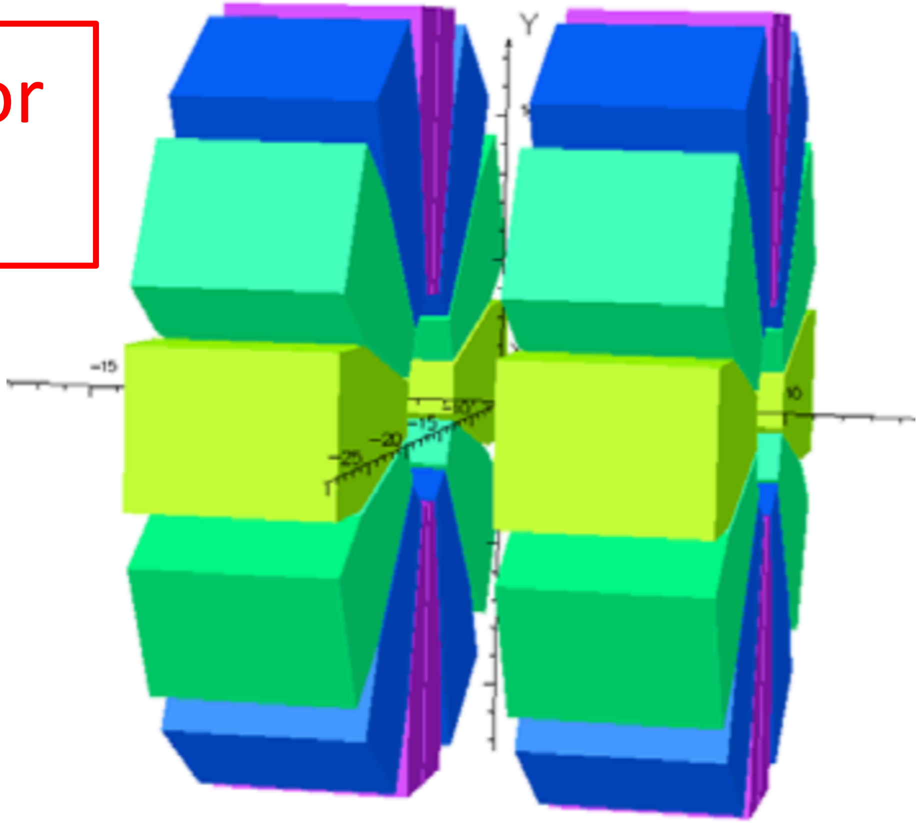
BGO crystal of the PADME experiment (LNF): same origin of FOOT (L3)

PADME BGO Calorimeter

The PADME solution (~600 crystals –> 600 kg, fixed experimental site -> BTF @ LNF)



Halbach geometry for Magnet



Halbach geometry provides uniform transverse magnetic field in a cylindrical geometry: B field ~ 0.8 T proportional to $\ln(R_{out}/R_{in})$

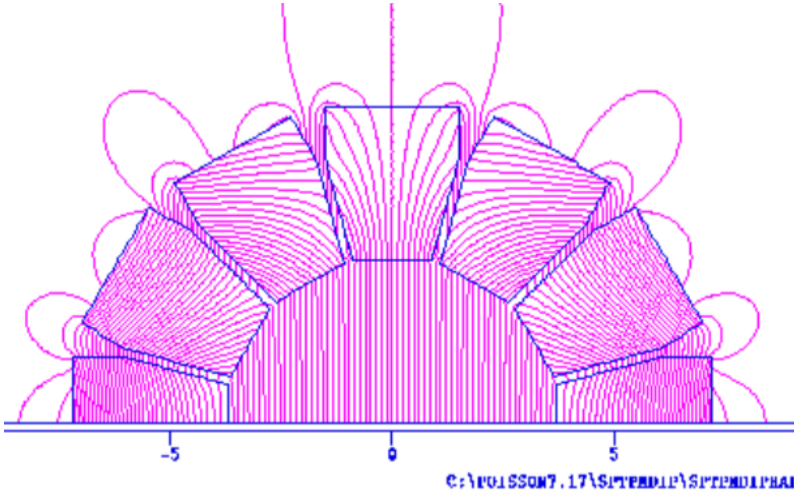
R_{in} = 3.5 cm

R_{out} ~ 12 cm

Distance ~ 5 cm

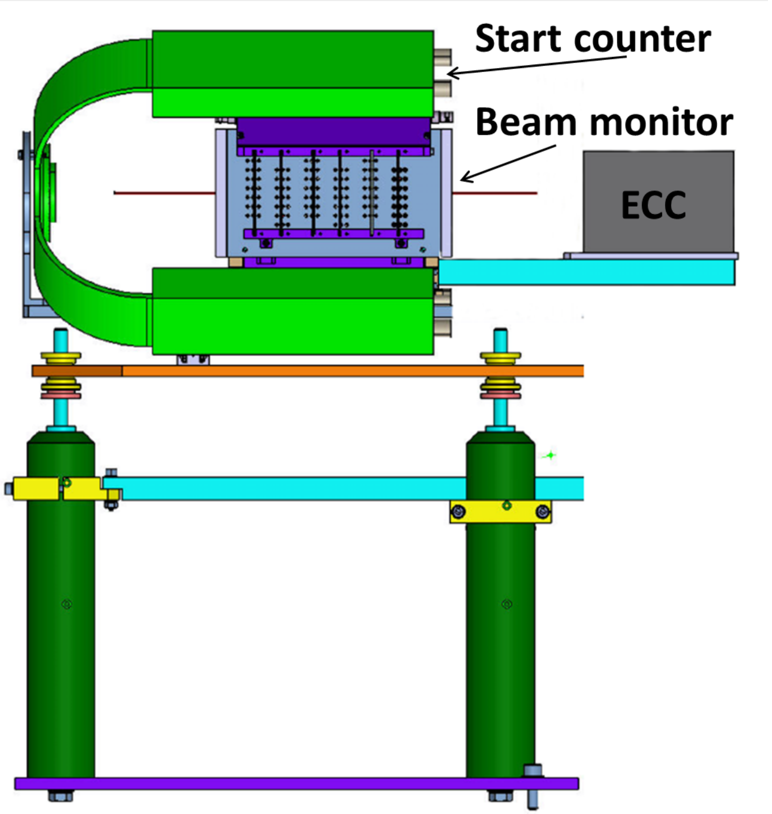
Thickness 7-10 cm

Weight ~ 30 kg each



Emulsion chamber for light fragments measurement

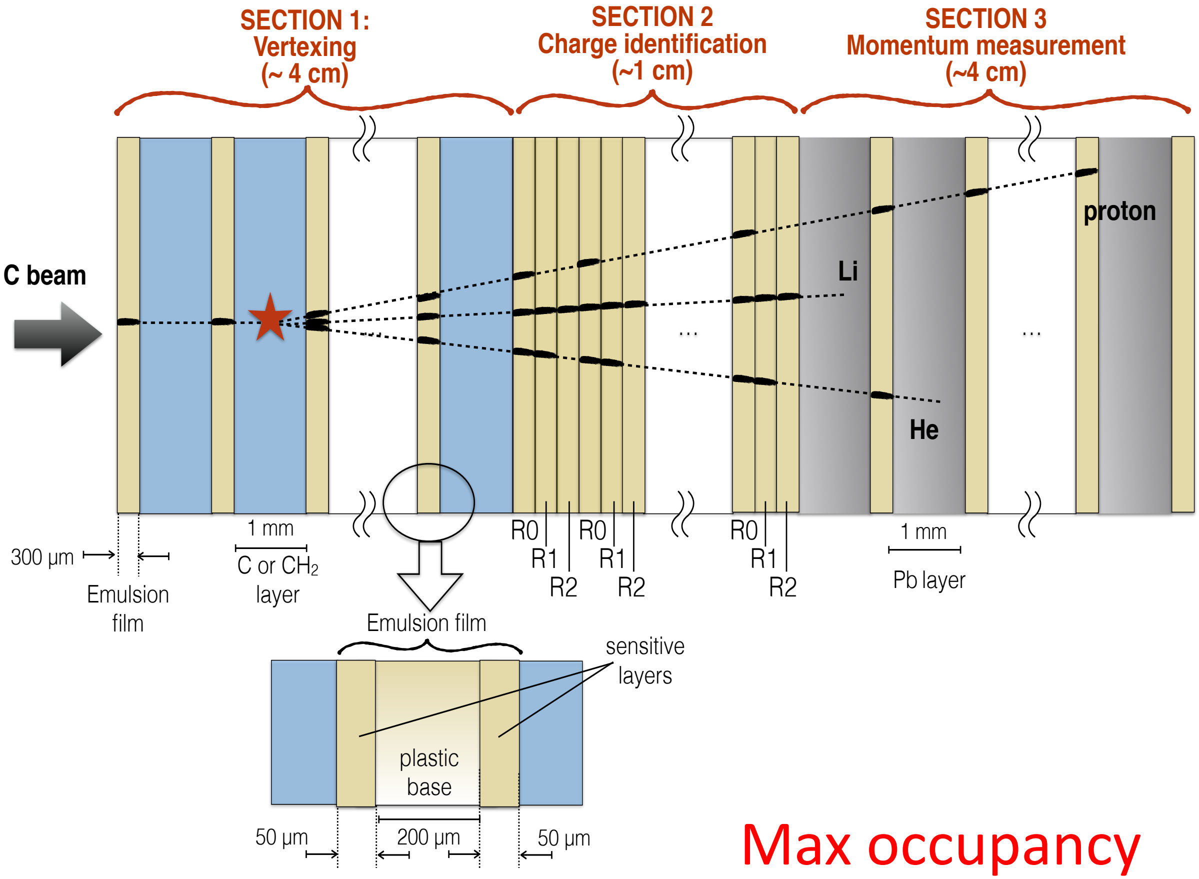
- P and He fragments are emitted with a broader angular distributio with respect to heavier fragments
- P and He fragment can have long range, can easily punch through the calorimeter
- Difficult to cover all Z,A with a single detector design



Special Emulsion Chambers, built by Nagoya University, will be coupled with the Start counter and the beam monitor as active medium to detect the Z <=3 fragments.

Emulsion and light fragments

- The emulsion chamber must be exposed with a remotely controlled movement to avoid local pile-up
- Must be run with Start counter and Beam monitor for absolute flux normalization



Max occupancy $10^3 – 10^4$ tracks/cm^2

Emulsion run could be the first data taking of FOOT in 2018

Mechanics related issues (I)

- ✓ The FOOT detector is not going to have its own “home”: possible experimental data taking at GSI, HIT, CNAO. The detector will be moved several times
- ✓ The magnetic spectrometer must fulfill severe constraints on the mechanics: relative precision of the order of 10 μm between the silicon tracker are needed
- ✓ The calorimeter is “heavy” (order of 500 kg) and must travel to different experimental sites (modular approach? 1/4 - 1/8?)
- ✓ The magnets are permanent: the mechanical structure must foreseen the calibration procedure ☞ rotating the magnet?

Mechanics related issues (II)

- ✓ The emulsion setup need a XY movement control of the emulsion to avoid pile-up
- ✓ The emulsion movement must have a feedback with the beam parameters (impact point, rate) detected on line by the start counter and the beam monitor
- ✓ All the mechanical structure must fit in the HIT experimental room (order of 2.5 m of length)

Conclusions

- ✓ The impact of the mechanics on FOOT performances will be non negligible even if the detector will be “light and small”
- ✓ The mechanical issues must be taken into consideration asap due to the consequences on detector construction
- ✓ Mechanical issues for emulsion run must be considered NOW -> data taking is foreseen in November 2018
- ✓ A coordination of the different mechanical aspects of the construction/run of the detector is badly needed

Thanks……