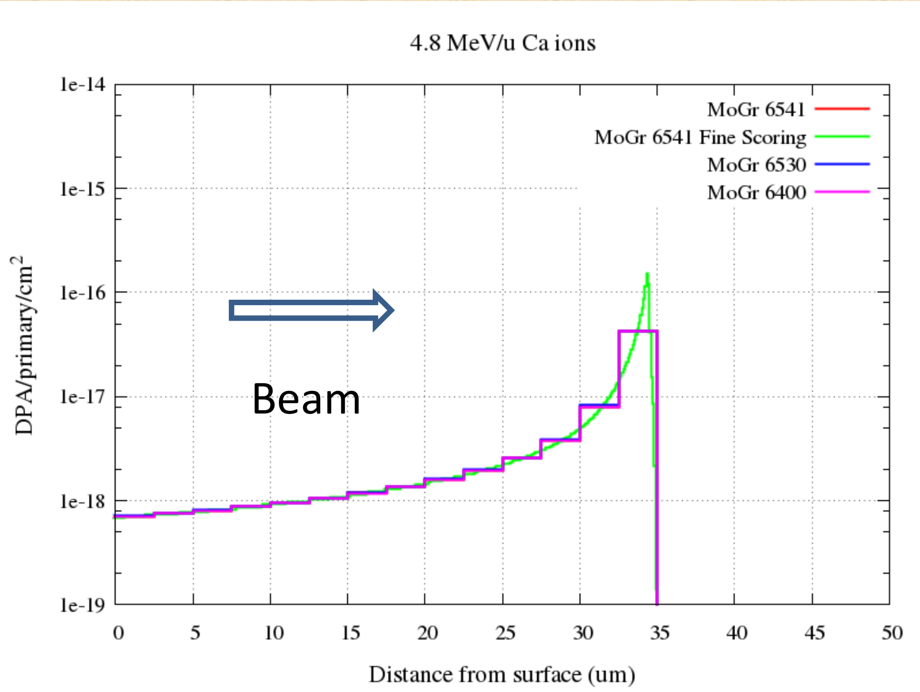
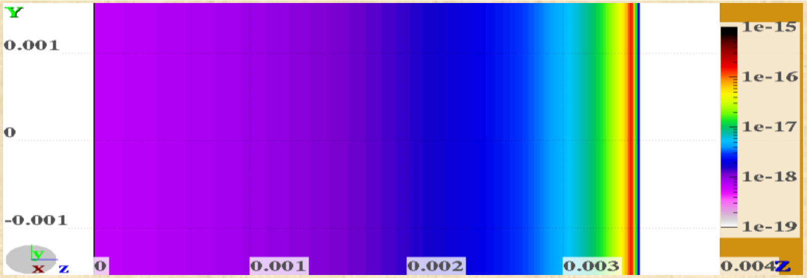
FLUKA estimation of DPA for ion irradiation and update on IR7 DPA calculations for LHC operations

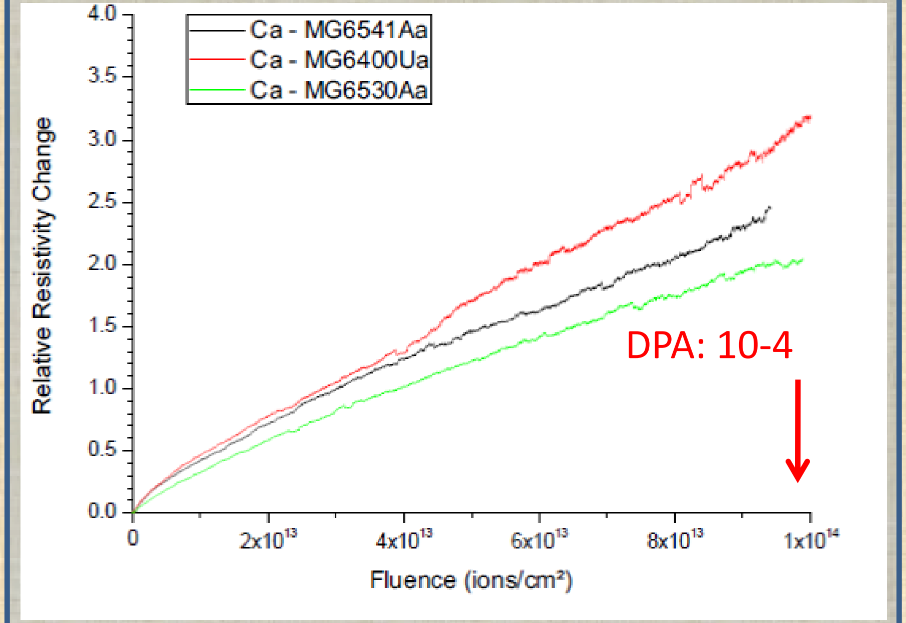
E. Skordis
On behalf of the FLUKA and Collimation teams

FLUKA for GSI

➢FLUKA: General purpose particle physics MonteCarlo code used for machine protection, design studies, R2E, activation, collimation -> simulates particle interaction with matter







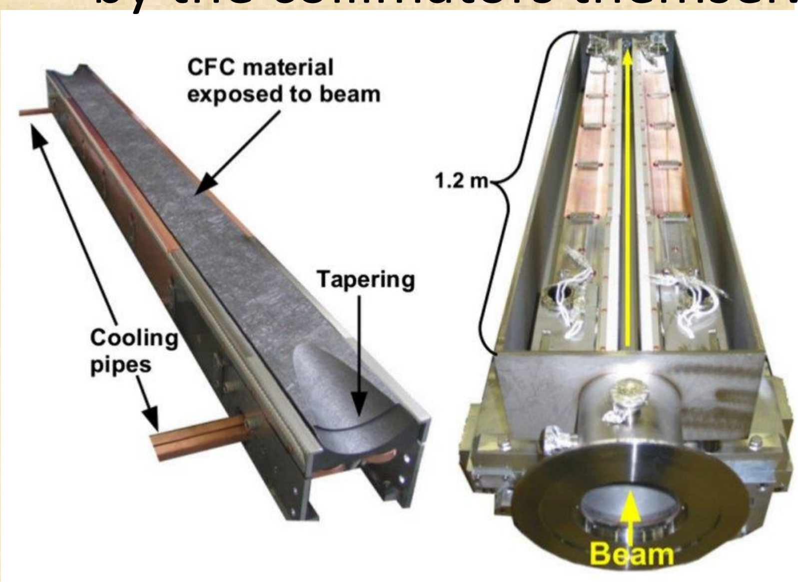
- relative change of average resistivity for the whole ion range ~ 35 μm)

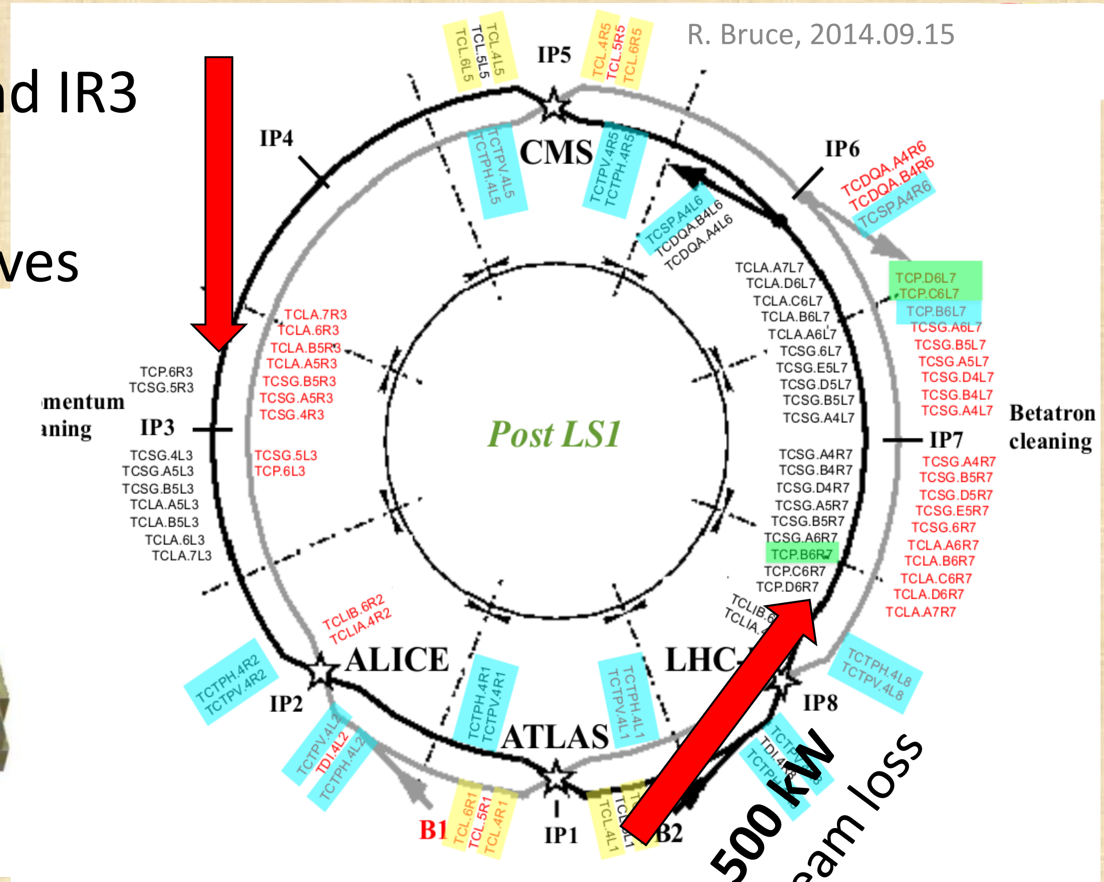
MG6530 (long fibers, no Ti)

Courtesy of Dr. Marilena Tomut (GSI)

LHC collimation system

- Capable of redirecting up to 500kW of proton loss rate in order to protect the Super Conducting Magnets from quenching (stop being SC due to energy deposition -> increase in temperature)
- 99% of that power is deposited in the whole IR7 and IR3
- **<u>Not</u>** all power is absorbed by the collimators themselves





Collimation losses simulation overview

- Simulation tools used:

Sixtrack and FLUKA are simulation tools regularly used at CERN to perform LHC studies.

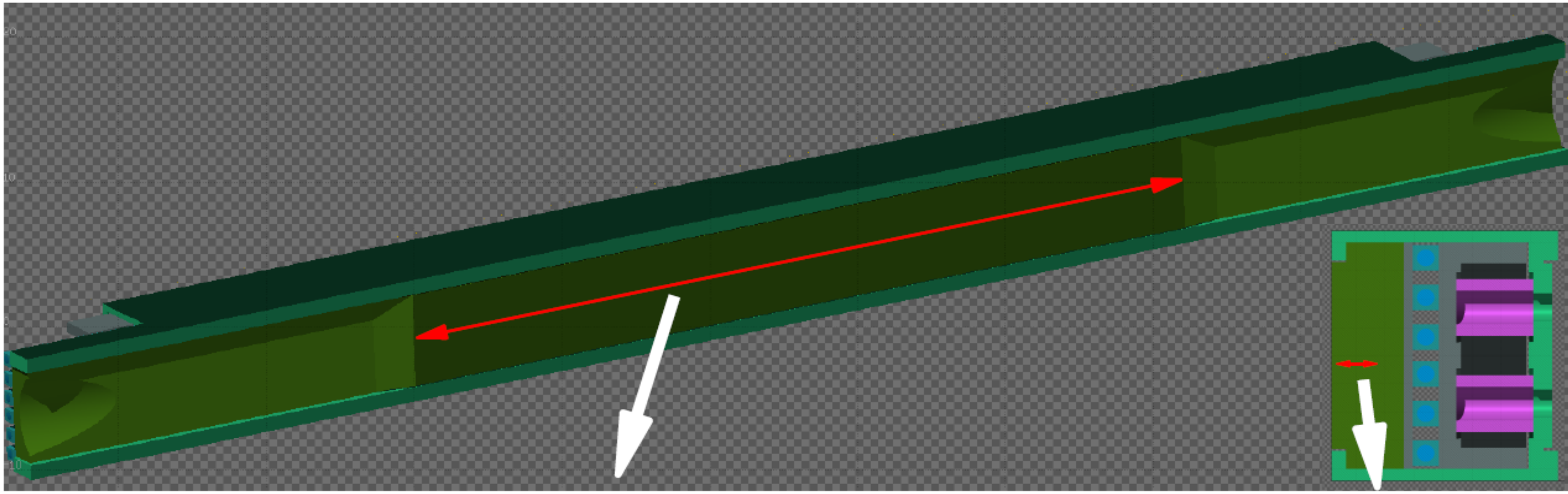
- ➢SIXTRACK : Single particle 6D tracking code for long term tracing in high energy rings -> complemented with dedicated interaction routines, predicts losses in collimators.
- ➢FLUKA: General purpose particle physics MonteCarlo code used for machine protection, design studies, R2E, activation, collimation -> simulates particle interaction with matter
- ➢SIXTRACK-FLUKA coupling: Sixtrack tracking capabilities utilising the FLUKA particle matter interaction models

Comparison of the two methods of loading collimation losses in FLUKA

- Creating input for further FLUKA simulations

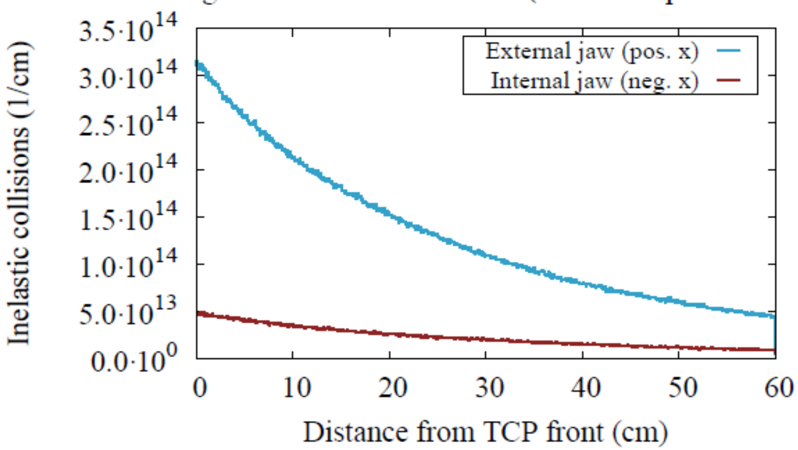
Old method: Lossmap of proton inelastic interactions inside the collimators. Primary non-inelastic interactions missing.

Spatial distribution of inelastic proton collisions in the horizontal TCP

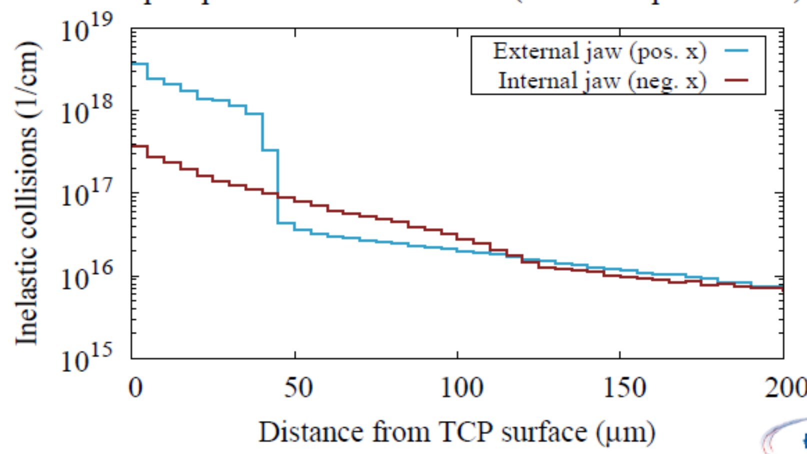


Tracking results from P. Garcia Ortega.

Long. loss distr. in TCP.C6L7 (1.15x10^{16} protons lost)



Impact parameters in TCP.C6L7 (1.15x10^{16} protons lost)



→ tracking simulations show unequal sharing of losses between TCP.C6L7 jaws (~6:1)

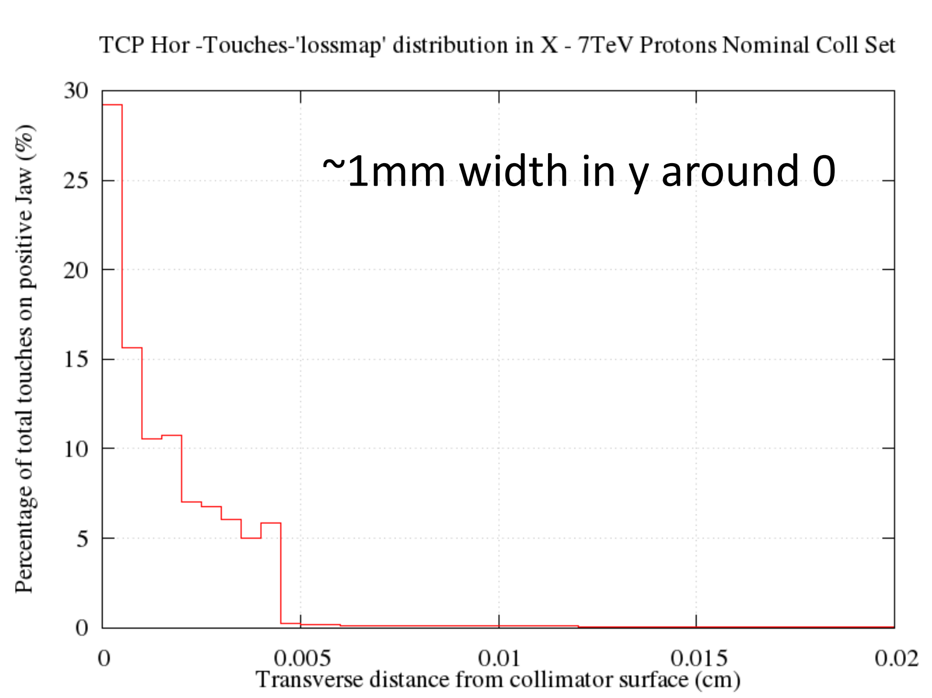
Comparison of the two methods of loading collimation losses in FLUKA

- Creating input for further FLUKA simulations

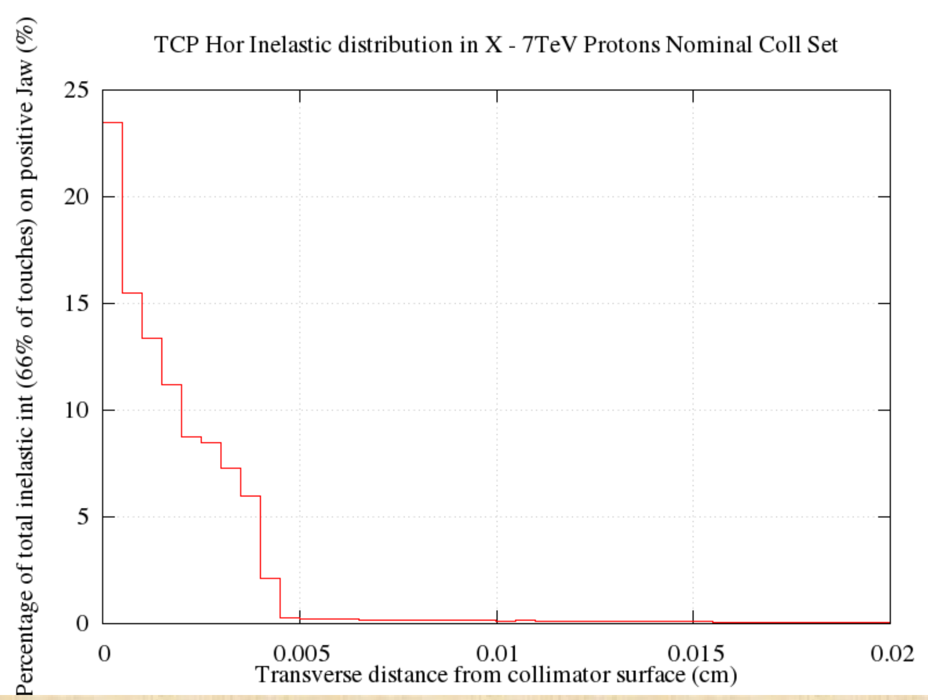
Old method: Lossmap of proton inelastic interactions inside the collimators. Primary non-inelastic interactions missing.

New method: Sixtrack-FLUKA Coupling provides “lossmap” of proton impacts on collimator surface (Touches)

- 7 TeV - Nominal collimator settings – TCP at 6 σ



All losses located at the front face of the col.



Losses distributed over the length of the col.

Energy deposition simulation requirements for collimation losses

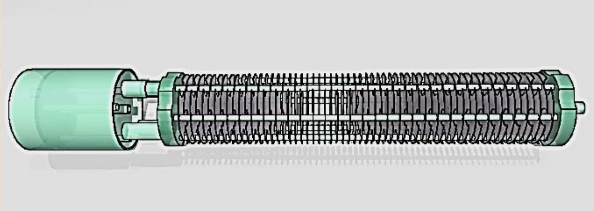
1. Creating input for further FLUKA simulations

Old method: Sixtrack simulations produce lossmap of proton inelastic interactions in the collimators

New method: Sixtrack-FLUKA Coupling provides input (lossmap of inelastic interactions or proton impacts on collimator surface)

2. FLUKA simulation set up
   - Model complex geometries of all key elements of the LHC
   - Set up the simulation parameters
     - Source routine
     - Magnetic fields routines
     - Physics settings
     - Scoring
     - Etc…

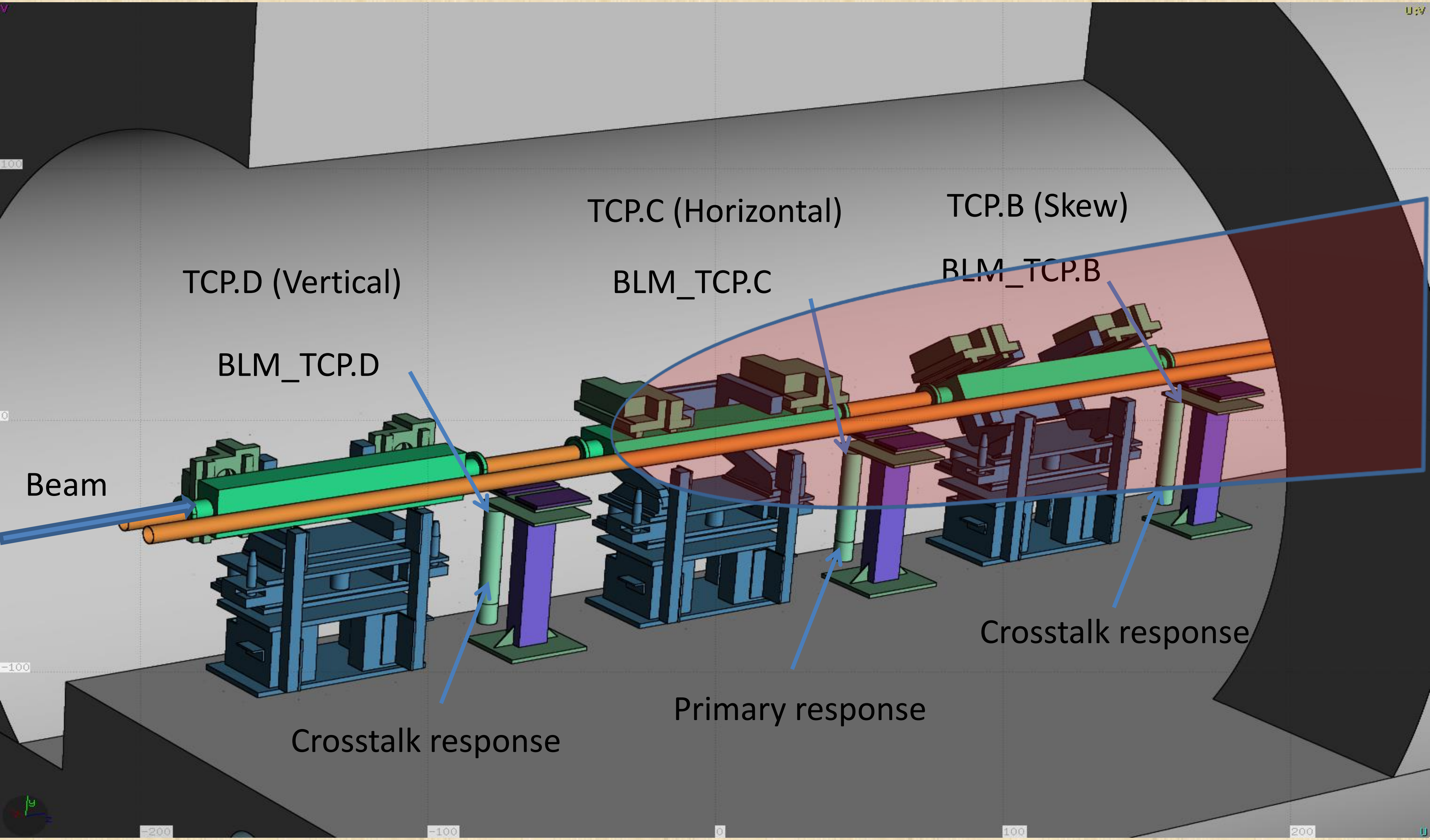
LHC BLM



FLUKA MODEL

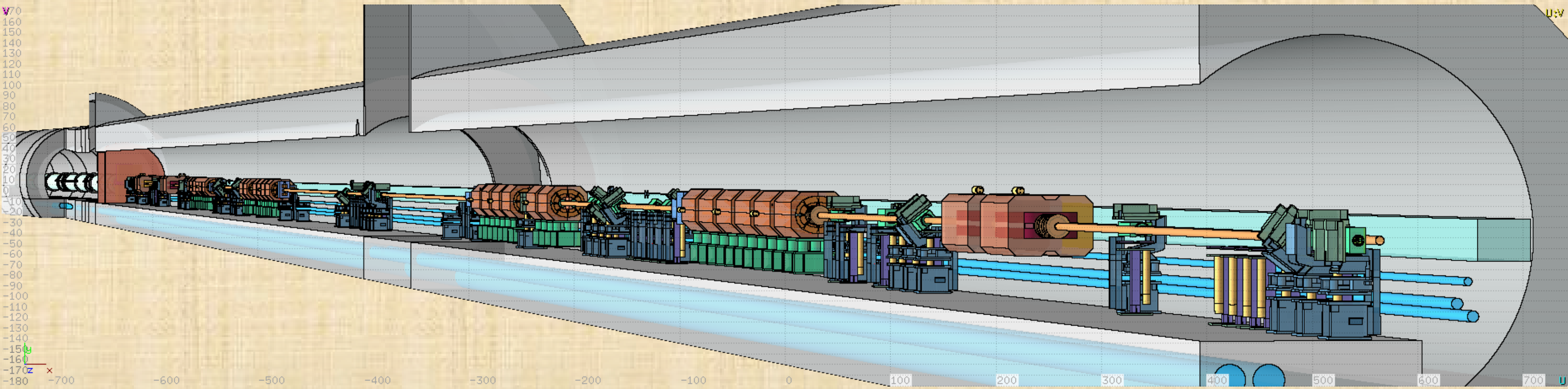
Picture

TCP simulated Geometry

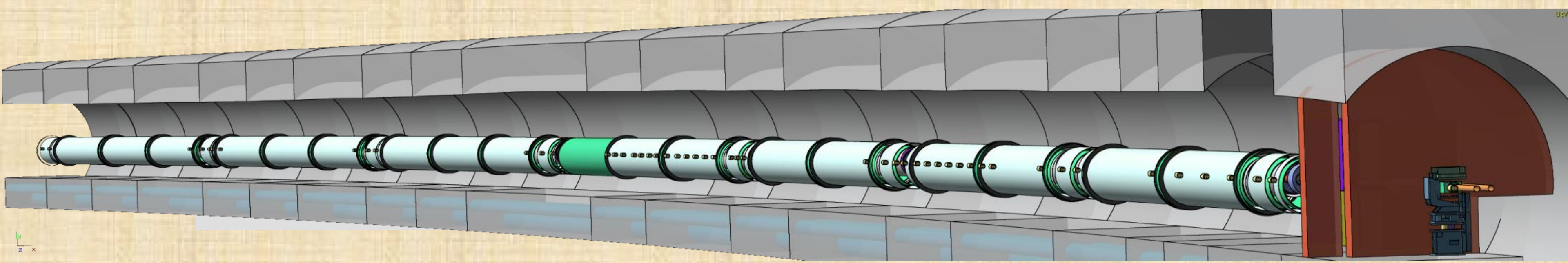


IR7 FLUKA geometry

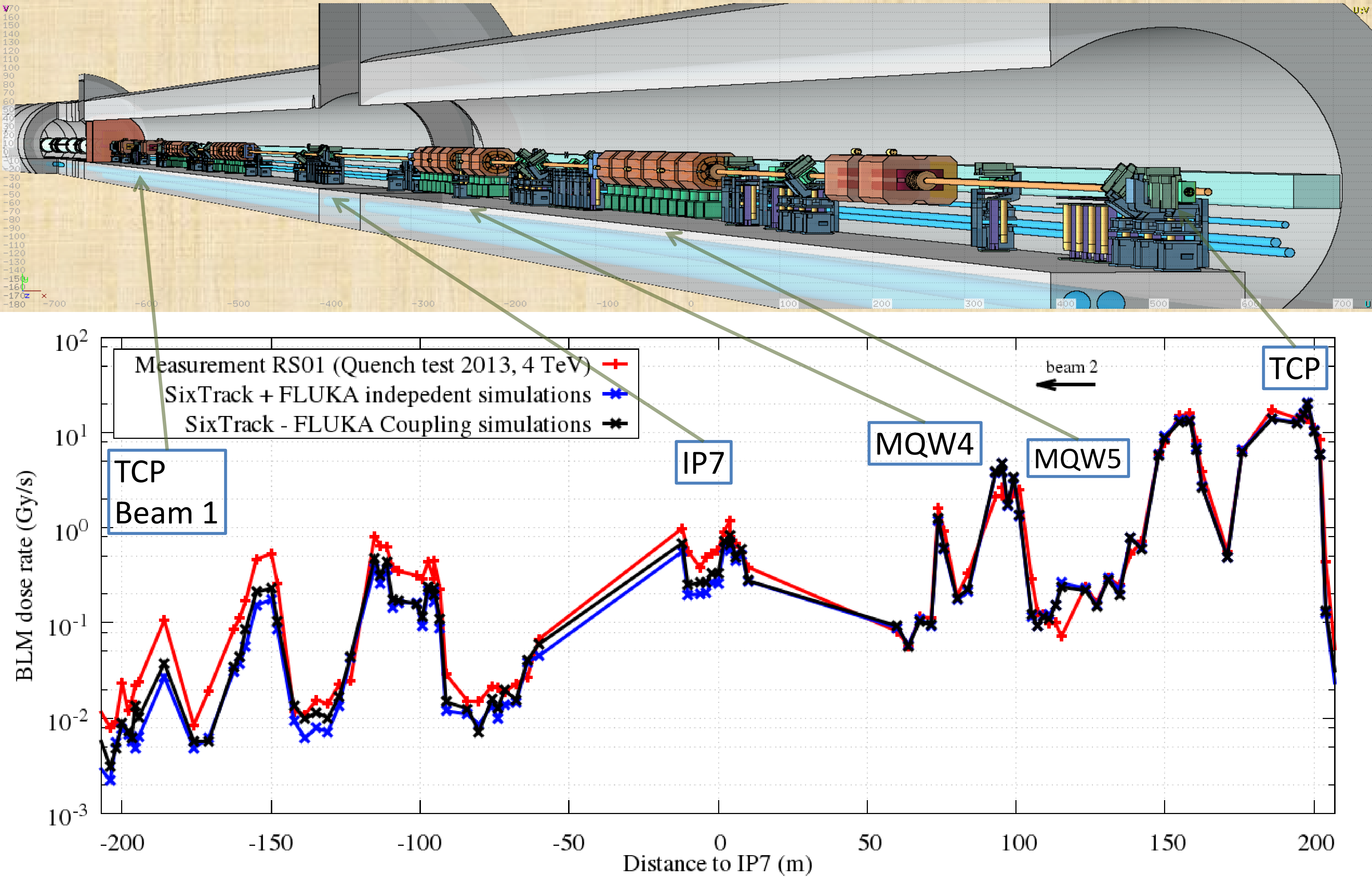
- Long Straight Section



- Left Dispersion Suppressor + Arch up to cell 14



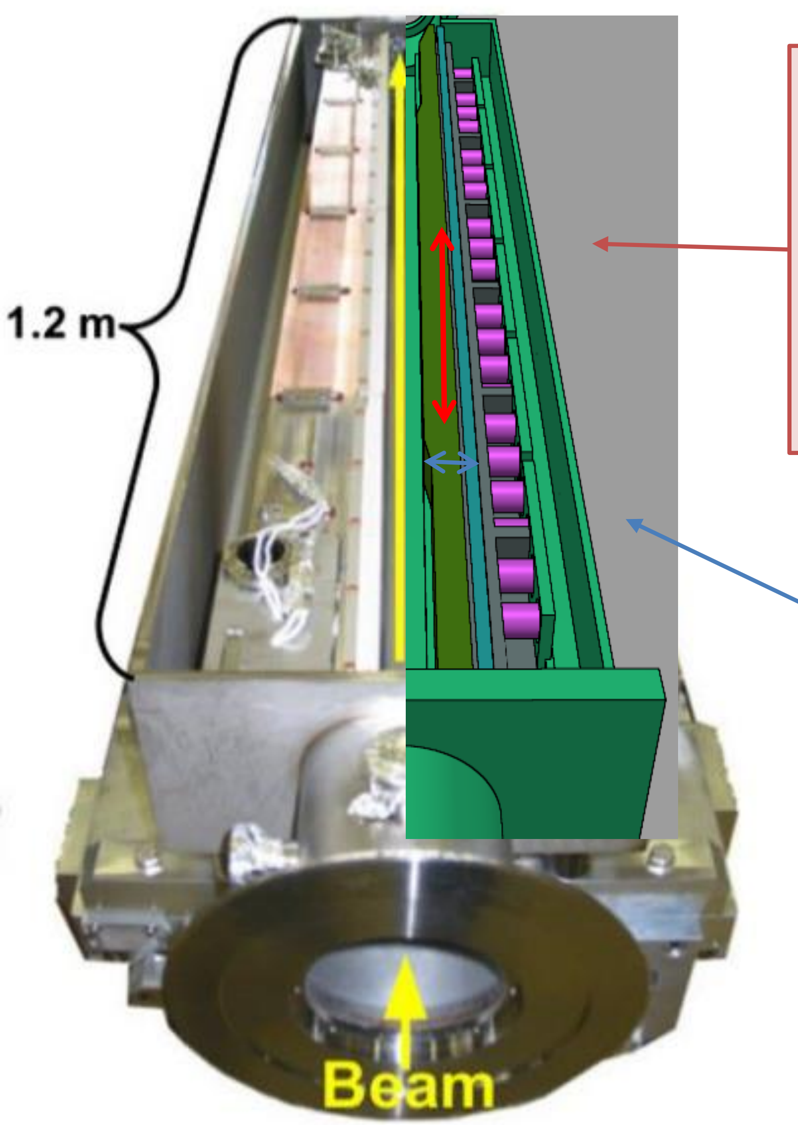
IR7 2013 Collimation Quench Test
FLUKA – Sixtrack Simulations



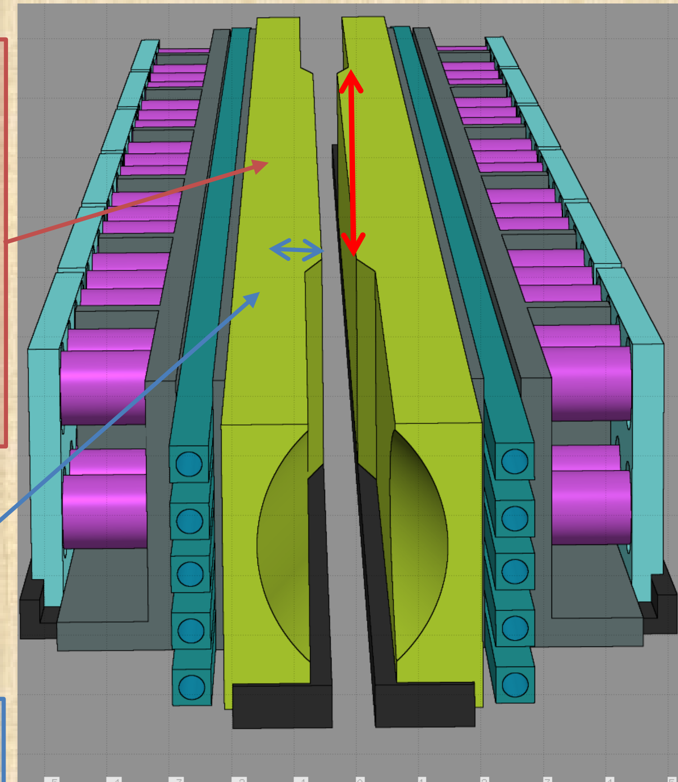
BLM integration Time : Running Sum 1 (40 μs)

Useful dimensions and coordinate system

TCP.C6L7



Longitudinal distance from collimator center (z)
-30<z<30 (cm)

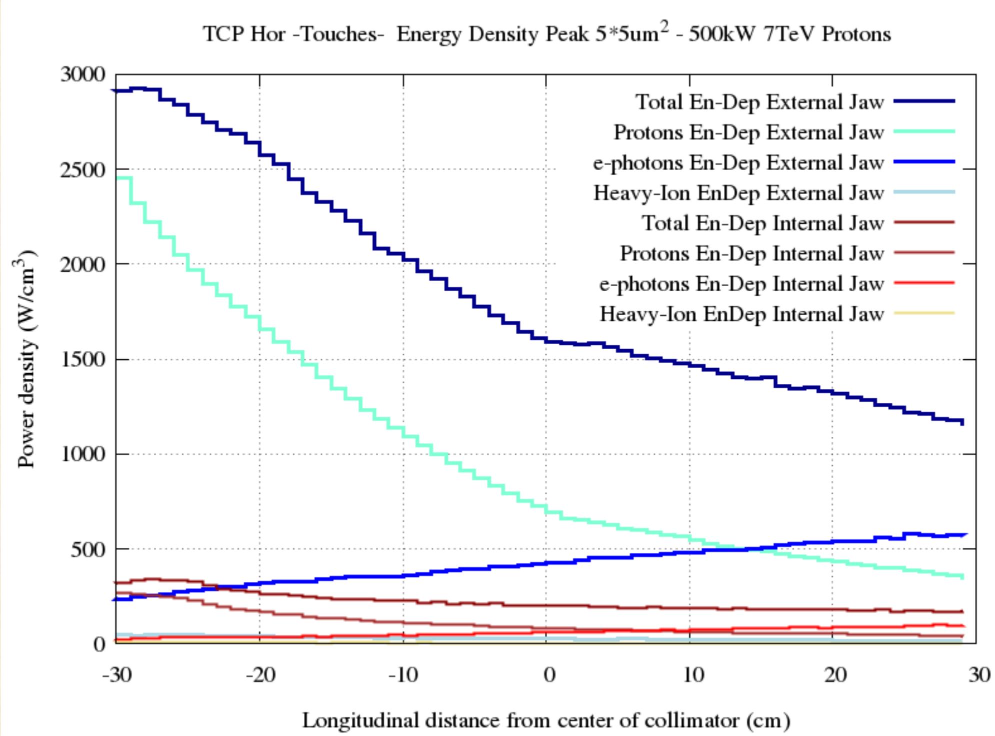


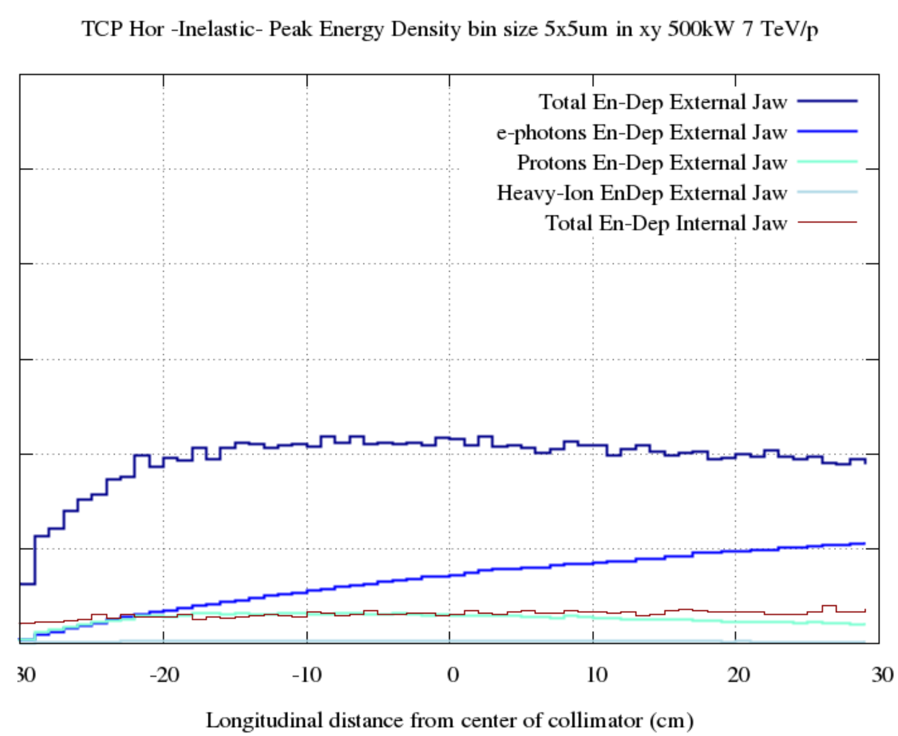
Transverse distance from collimator surface (x)
0<x<0.04 (cm)

External = Positive Jaw
Internal = Negative Jaw

Peak power density over z for 5x5μm^2 bin size

500kW of 7 TeV/p = 4.5e11p/s



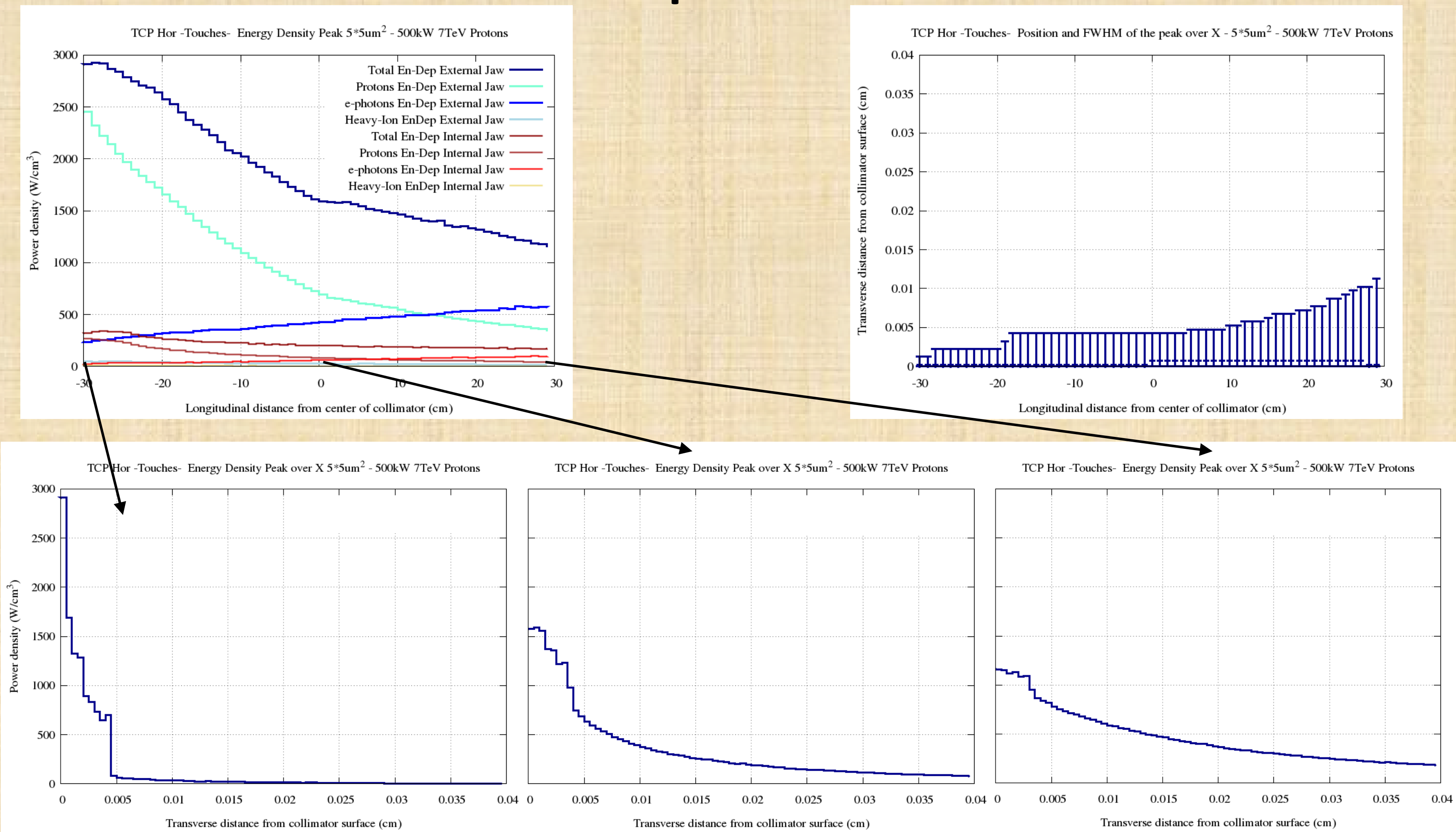


- The remaining energy deposition is attributed to other charged particles (i.e. Pions)

○ Difference of a factor of 2.5-3 attributed to ionising energy loss of the primary protons

Total Power <u>deposited</u> in both Jaws: 3kW

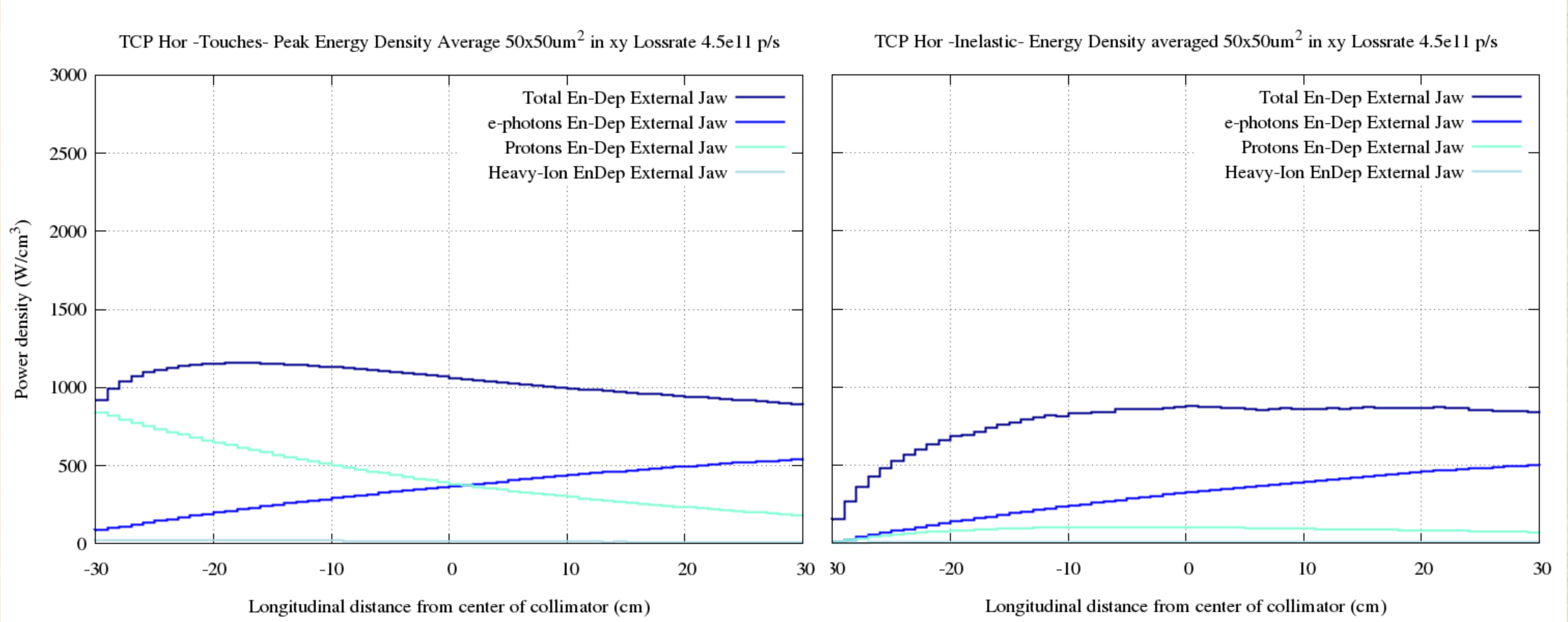
Peak power density over X for 5x5μm^2 bin size



- Strong surface effect especially on the first 5um in X

Peak power density over Z for 50x50μm^2 bin size

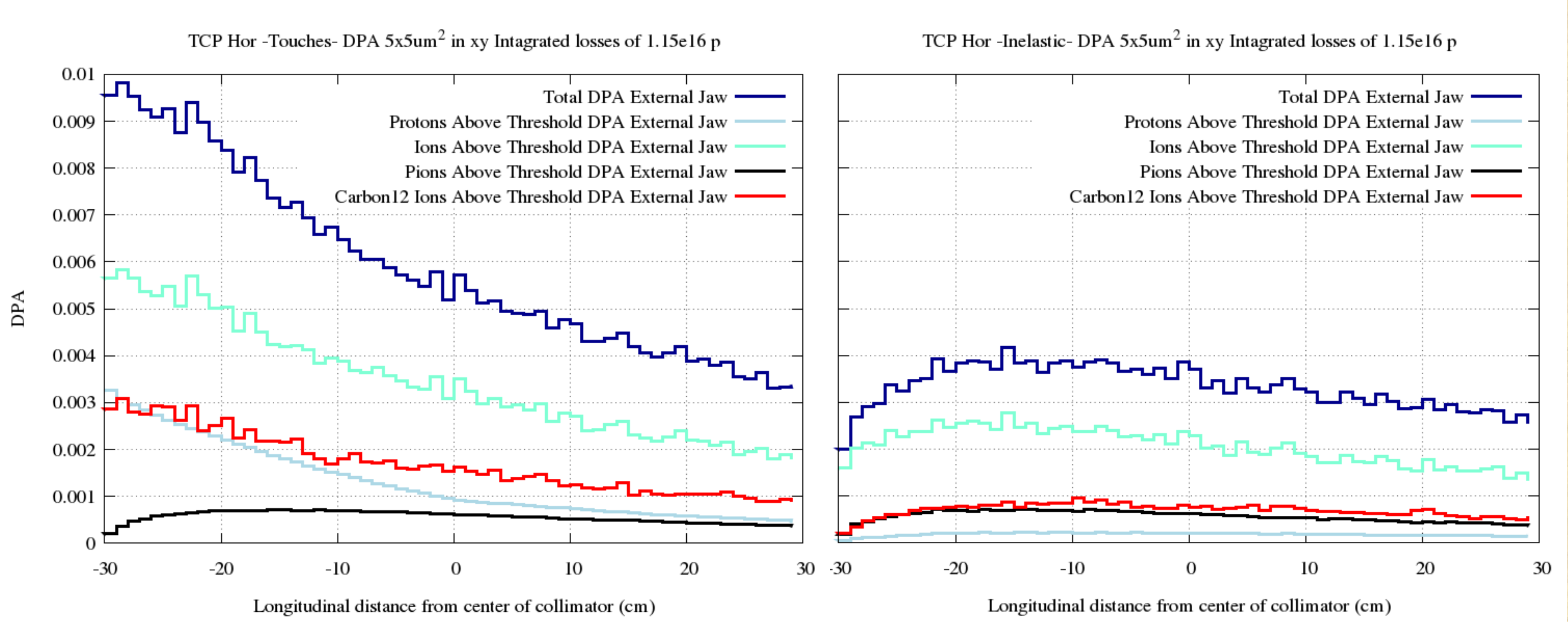
500kW of 7 TeV/p = 4.5e11p/s



- Less pronounced peak increase when averaging the energy deposition over 50um in x and y
- Increase of roughly a factor of 30%

Total Power <u>deposited</u> in both Jaws: 3kW

Peak DPA over Z for 5x5μm² bin size



- Carbon 12 contribution included in the Ions!

1.15e16p ≈ 30-40 fb^{-1}

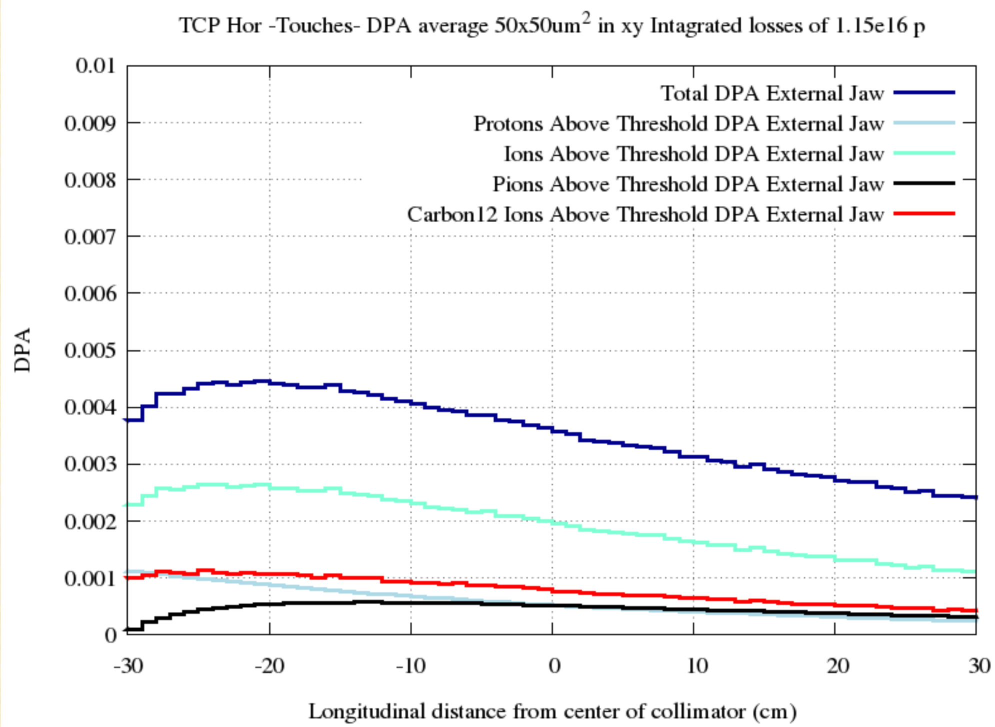
Area of impact 0.005*0.1=5e-4cm²

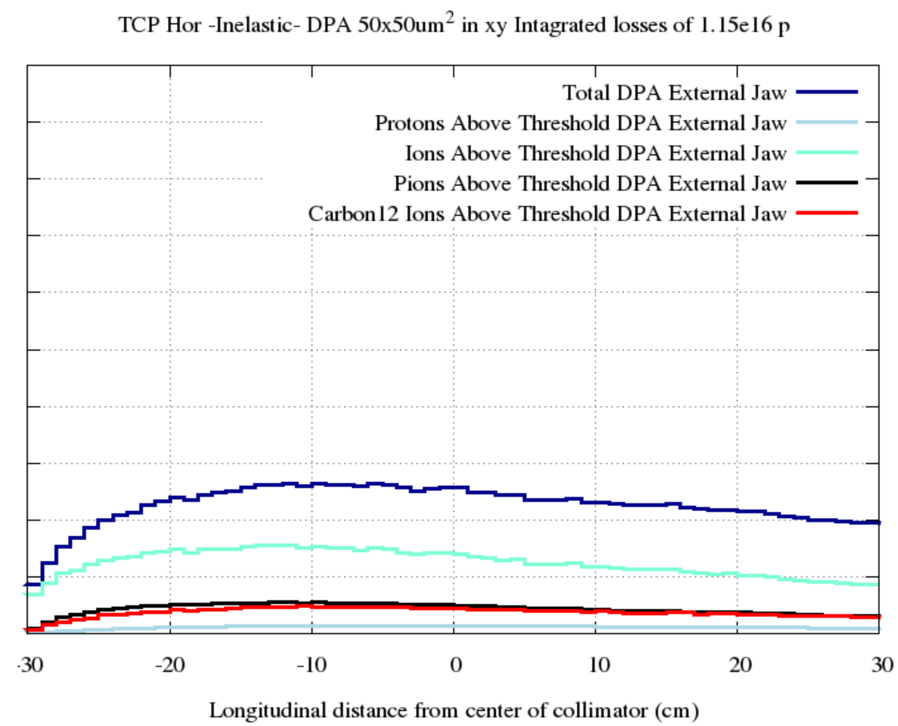
Multipass factor = 1.5 - Fluence = 3.45e19p/cm²

<u>a factor of ~100 more for HL-LHC</u>

- Difference attributed in the Coulomb scattering of primary protons and Carbon 12 Ions originating from nuclear elastic interactions of primary protons

Peak DPA over Z
for 50x50μm² bin size





- Carbon 12 contribution included in the Ions!

1.15e16p ≈ 30-40 fb^{-1}
a factor of ~100 more for HL-LHC

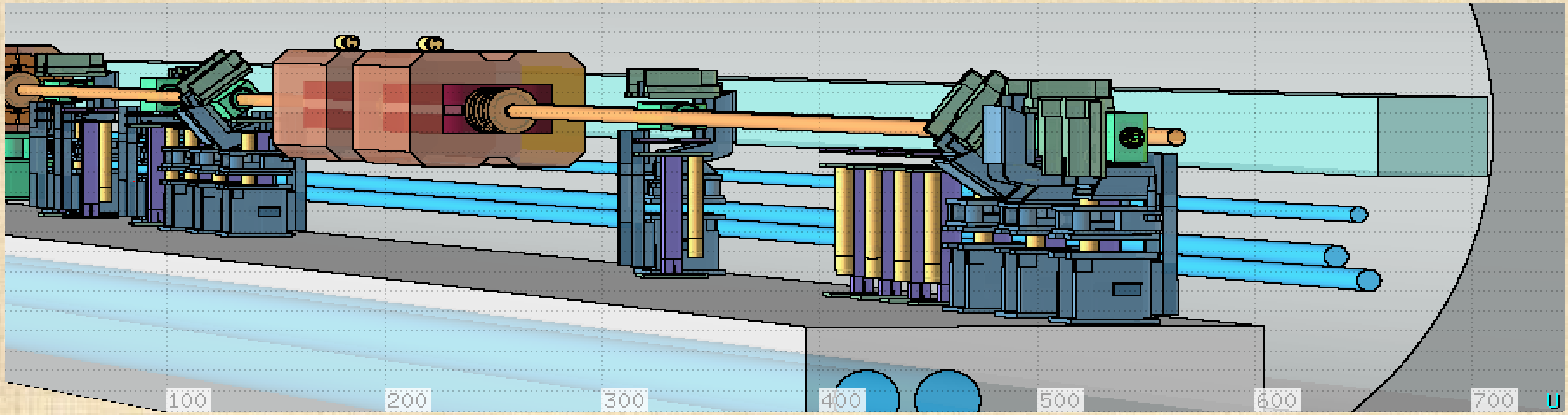
- Less pronounced peak increase when averaging the energy deposition over 50um in x and y
- Increase of roughly a factor of 60%

Simulation Settings for TCSG.A6R7

- Beam energy: 6.5 TeV – Beam 2
- Nominal collimator settings used in 2015 operation – TCP at 5.5 σ / TCSG at 8.0 σ
- Two materials considered:

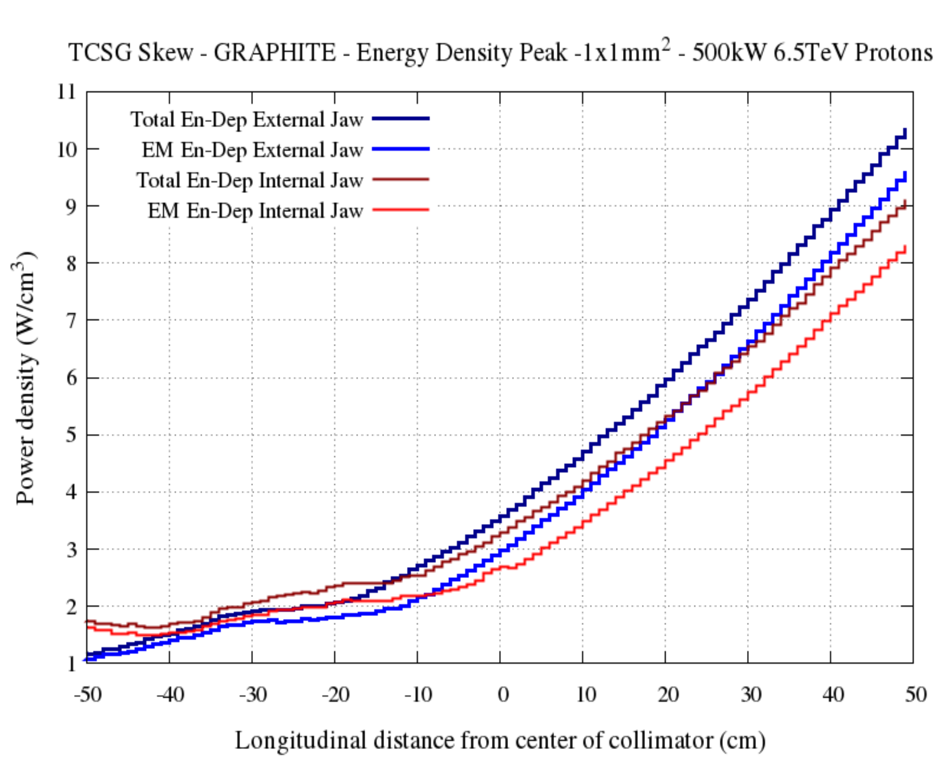
a. Graphite – density: 1.67 g/cm3

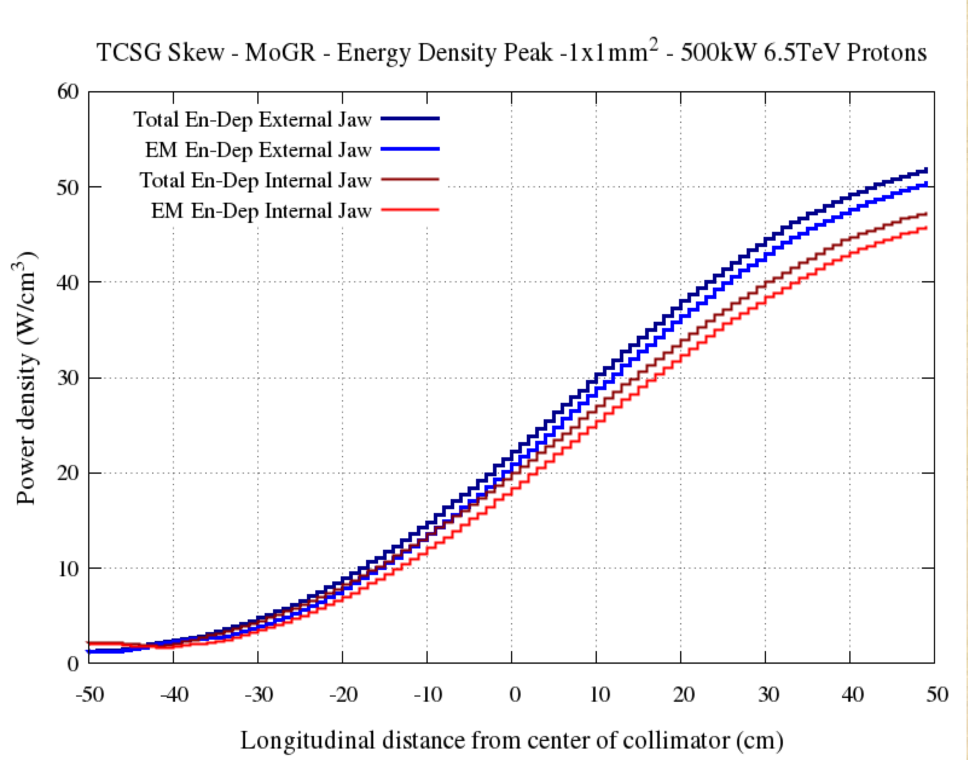
b. MoGR6400 – density: 2.48 g/cm3



Peak power density over z for 1x1mm^2 bin size

500kW of 6.5 TeV/p = 4.85e11p/s



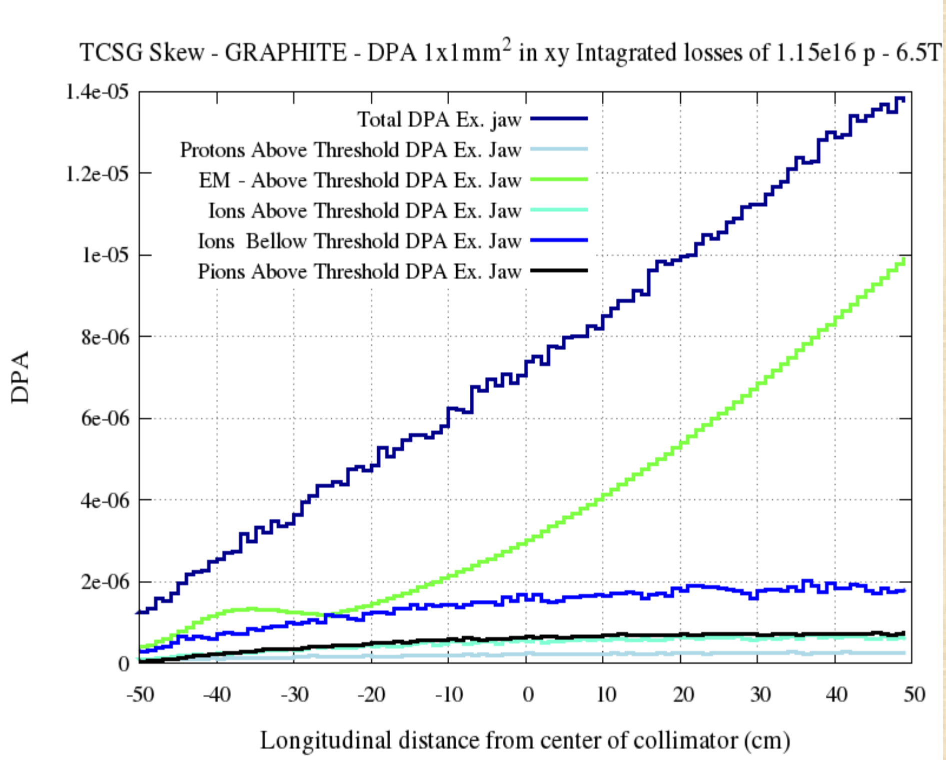


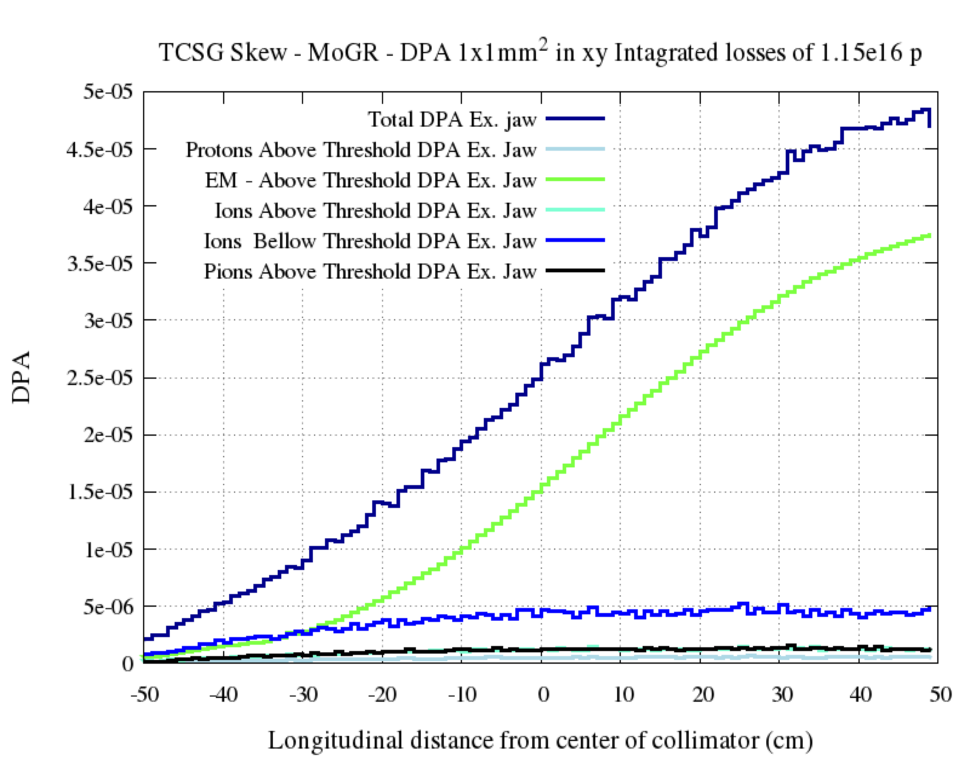
Total Power deposited in both Jaws for GRAPHITE: 15kW

Total Power deposited in both Jaws for MoGR: 37.5kW

- The remaining energy deposition is attributed to other charged particles (i.e. Pions,Kaons)

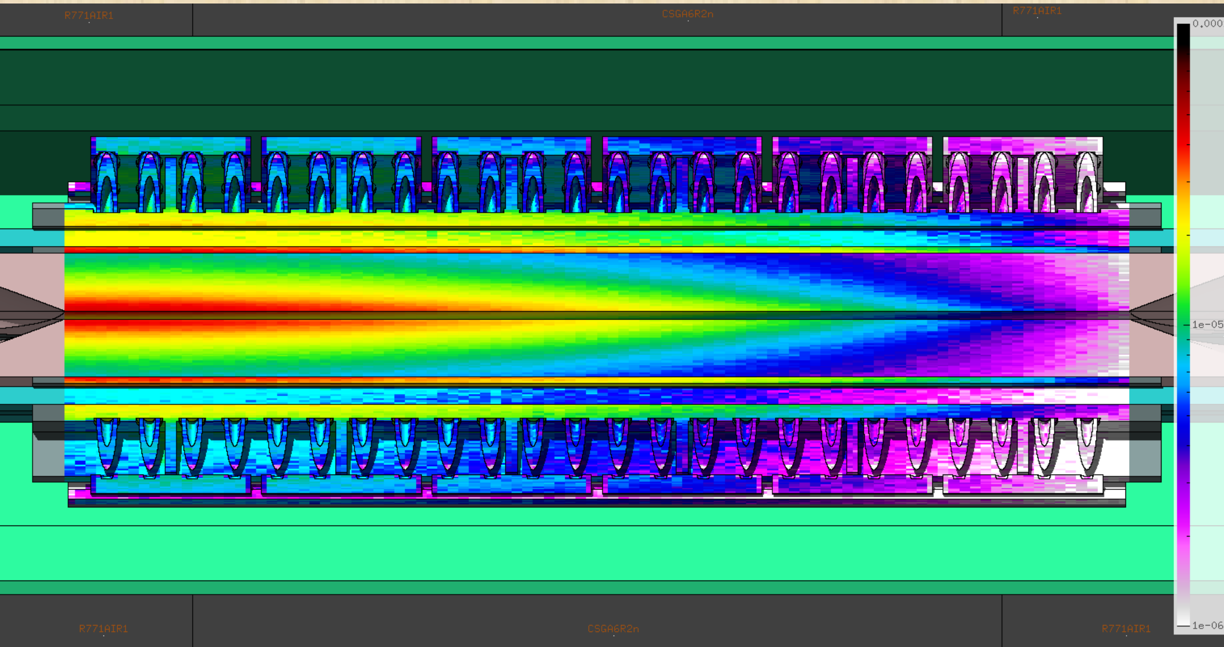
Peak DPA over z for 1x1mm^2 bin size

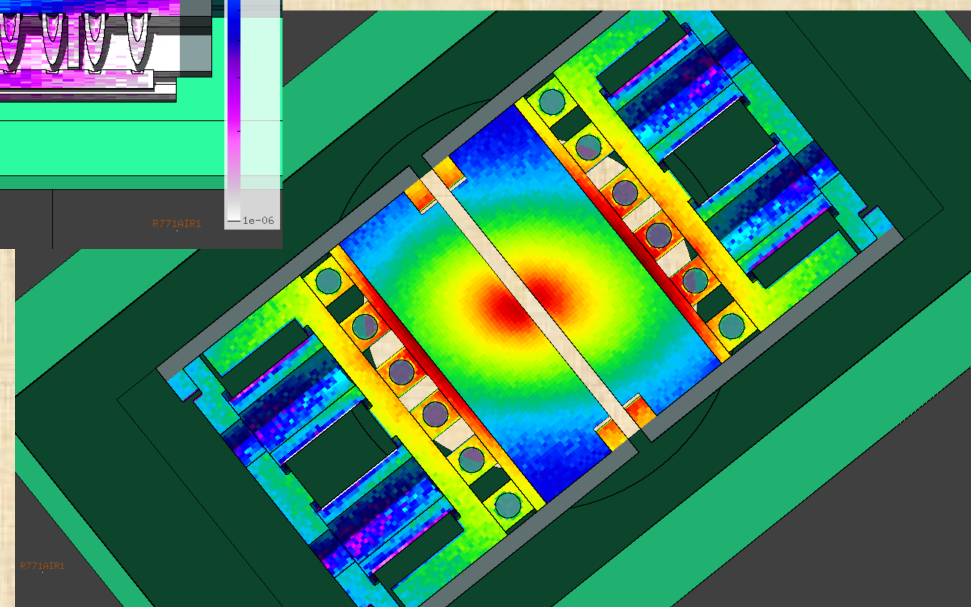




1.15e16p ≈ 30-40 fb^{-1}
a factor of ~100 more for HL-LHC

DPA x-sec for MoGR for 1x1mm^2 bin size





1.15e16p ≈ 30-40 fb^{-1}

a factor of ~100 more for HL-LHC

Conclusions

A. Effect of the nuclear elastic and EM interactions of primary proton assessed on the TCP

- Energy density and DPA peak increased by a factor of 2-3 in comparison to the old method
- ANCYS calculations may be needed for further evaluation of the importance of the strong surface effect

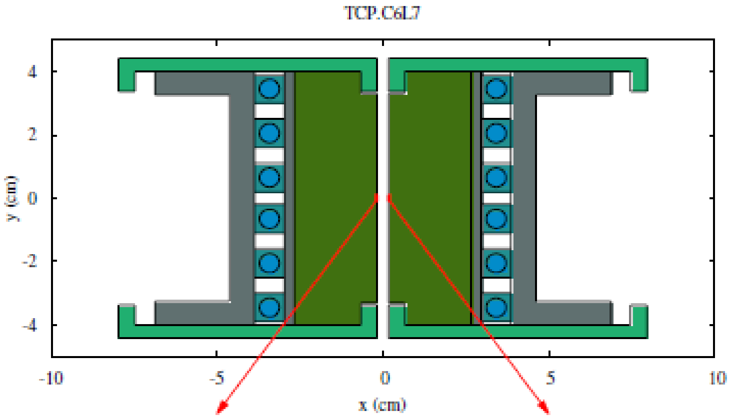
B. Considerations for HL-LHC for ~4000fb-1 requires a scale of the presented results by a factor of ~100

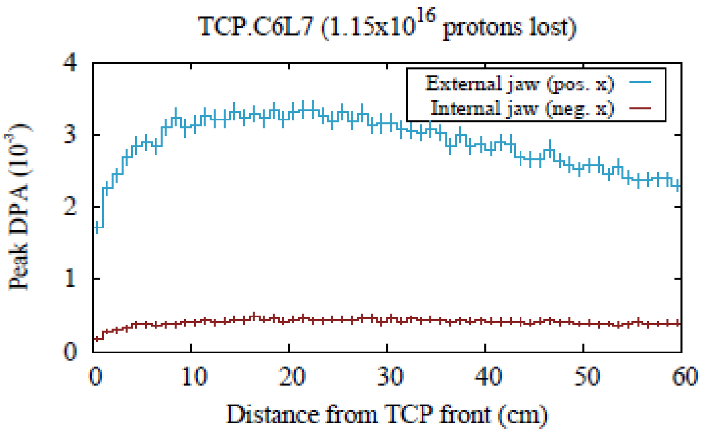
- Peak DPA on TCP.C approaches 1 on the 5-10 um layer in x with a width of 200 um in y
- For the most impacted secondary TCSG.A6R7 average values of DPA will range between 1e-3 for GRAPHITE to 3e-3 for MoGR.

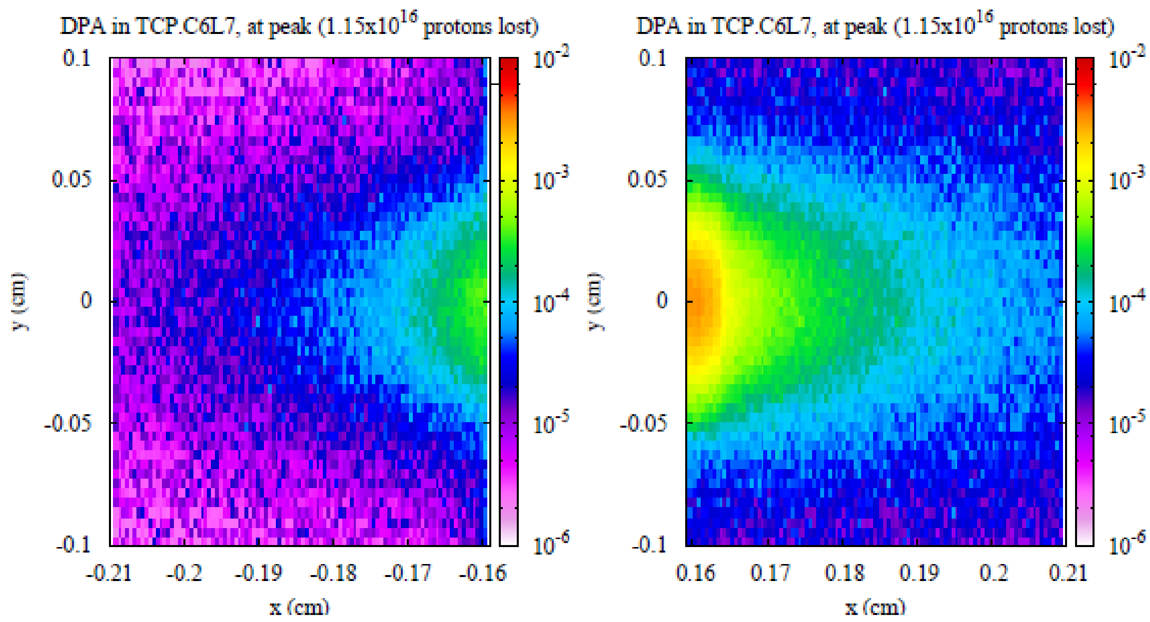
Thank you!

BACK UP SLIDES

DPA in TCP jaws (1.15×10^{16} protons lost) – preliminary results







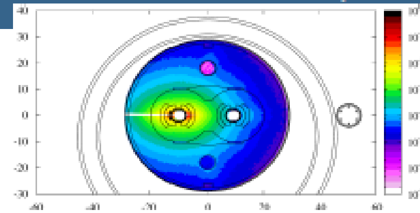
Assumed E_{thr} (AC150): 35 eV

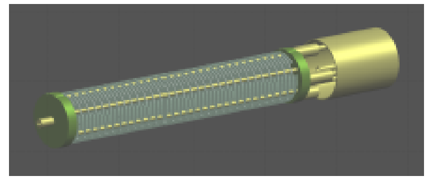
Max. DPA: $\sim3\times10^{-3}$

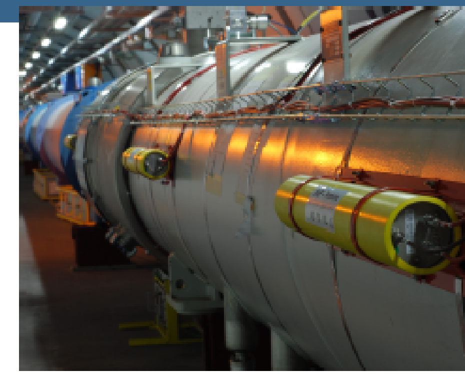
Transp. thre.	
photons	100 keV
e^-/e^+	500 keV
neutrons	10^{-5} eV
ions	0.25 keV/nucl
other	1 keV

Validation of dose calculations for TeV proton losses (controlled beam loss experiments)

- FLUKA is based, as far as possible, on well bench-marked microscopic models
- However, first years of LHC operation also allowed to validate FLUKA dose predictions against Beam Loss Monitors (BLMs) measurements
- BLMs measure dose from secondary showers in machine elements (magnets, collimators, etc.)
- Several thousand BLMs are installed around the ring (ICs, filled with N_2 gas, about 1500 cm^2 active vol.)

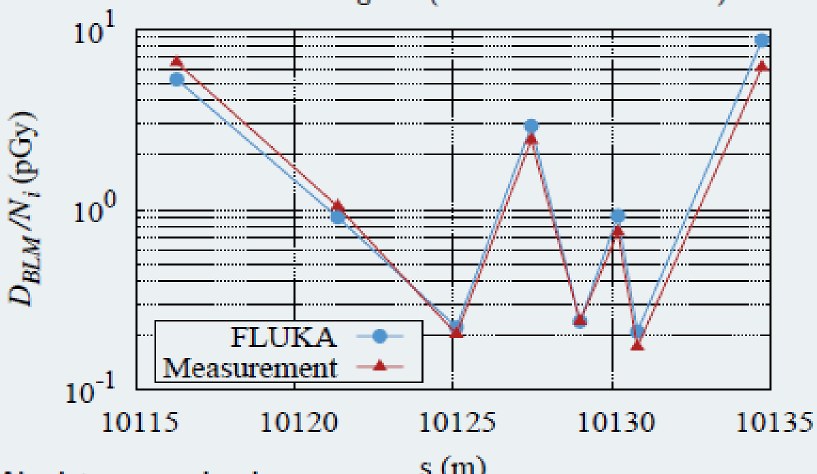






Losses induced by beam wire scanner (p@3.5 TeV)

- Quench test **2010** in LHC IR4 (M. Sapinski et al.)
- Wire scans: showers due to collision products registered in BLMs installed on downstream magnets (~35 from wire scanner)

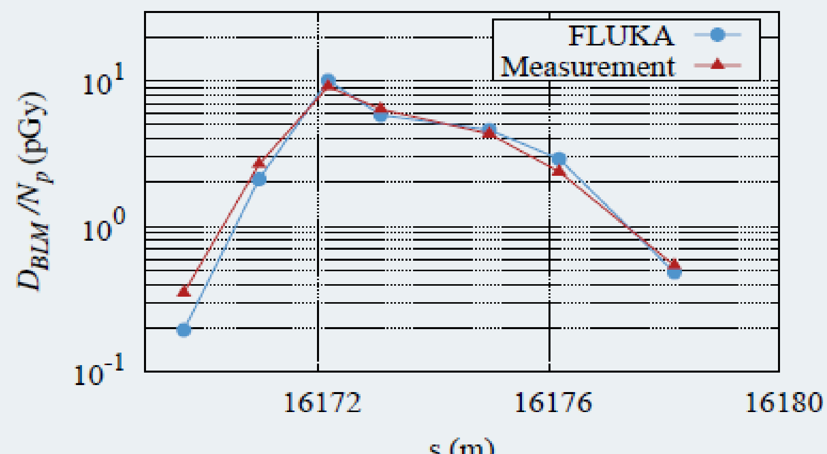


Absolute comparison!

N_i=number of inelastic proton-wire interactions (derived analytically)

Direct losses on MQ beam screen† (p@4 TeV)

- Quench test **2013** in arc sector 56 (A. Priebe et al.)
- Proton losses on beam screen (over ~1.5 m) by means of orbit bump/beam excitation, dose measured by BLMs outside of MQ cryostat



Absolute comparison! (N_p=number of lost protons (measured)

† FLUKA simulations based on MAD-X loss distribution from V. Chetvertkova et al.