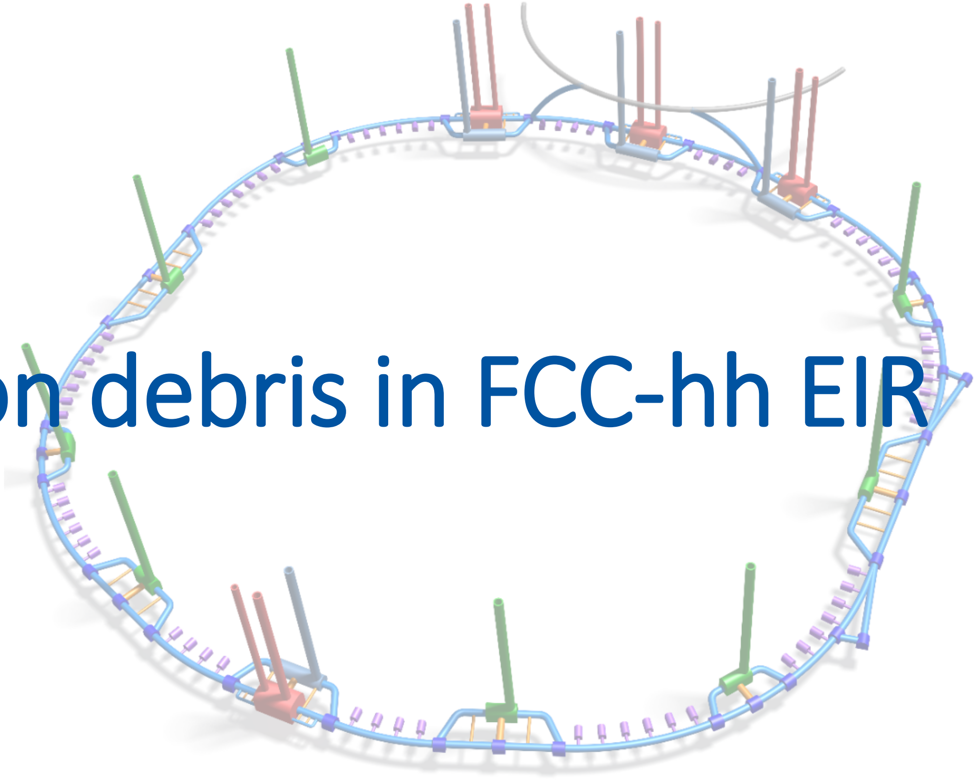
CERN

# Energy deposition from collision debris in FCC-hh EIR



**Angelo Infantino, Barbara Larissa Humann, Francesco Cerutti**

CERN EN-STI-BMI

FLUKA Team

*<u>With additional inputs from:</u> Roman Martin (BE-ABP-LAT)*

# Outline

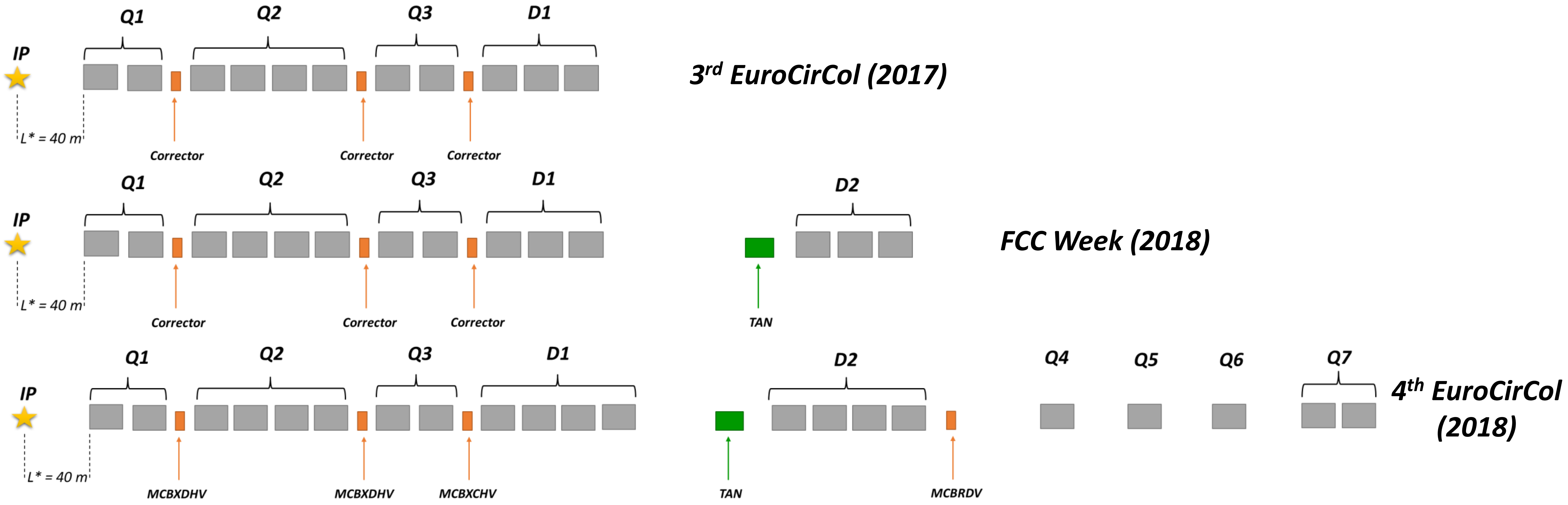
Introduction

FLUKA model

Energy Deposition

Summary

# From EuroCirCol 2017 to EuroCirCol 2018




## What's new

- Matching section (Q4 to Q7)
- Larger crossing angles (half-crossing angle from 89 -> 100 μrad)
- D1: 4 modules – (slightly) different position
- D2: 4 modules - different aperture & position
- TAXN: Different aperture & position
- Beam separation distance: 250 mm

# Apertures

## TAS

- Length: ***3.0 m***
- Aperture: ***34 mm*** diameter

## Q1A and Q1B (MQXC)

- Magnetic Length/Field: ***14.3 m*** - 126 T/m gradient
- Aperture: ***164 mm*** coil diameter - ***35 mm*** tungsten (INERMET180) shielding

## Q2A to Q2D (MQXD)

- Magnetic Length/Field: ***12.5 m*** - 101 T/m gradient
- Aperture: ***210 mm*** coil diameter - ***35 mm*** tungsten (INERMET180) shielding

## Q3A and Q3B (MQXE)

- Magnetic Length/Field: ***14.3 m*** - 100 T/m gradient
- Aperture: ***210 mm*** coil diameter - ***35 mm*** tungsten (INERMET180) shielding

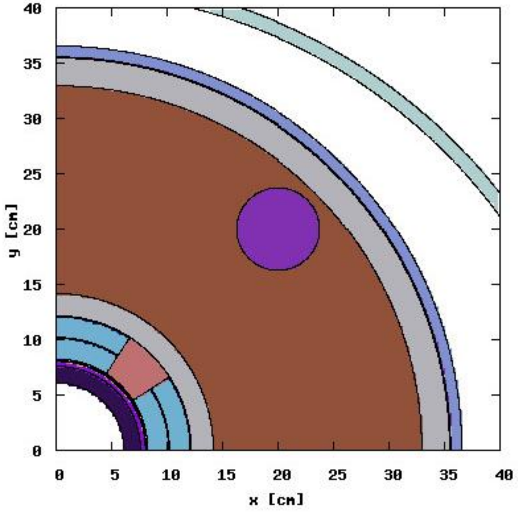
## Orbit Corrector(s) (MCBXDHV/CHV)

- Magnetic Length/Field: ***1.3 m***
- Aperture: ***210 mm*** coil diameter - ***35 mm*** tungsten (INERMET180) shielding

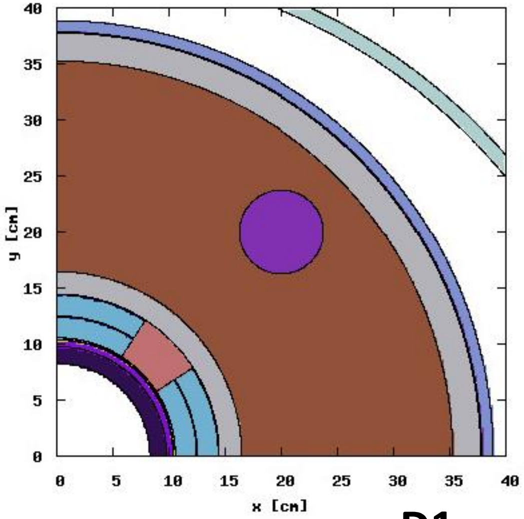
## D1A to D1D (MBXW)

- Magnetic Length/Field: ***11.3 m*** – 2.0 T field
- Aperture: ***170 mm*** pole tip aperture - ***5 mm*** thick vacuum chamber

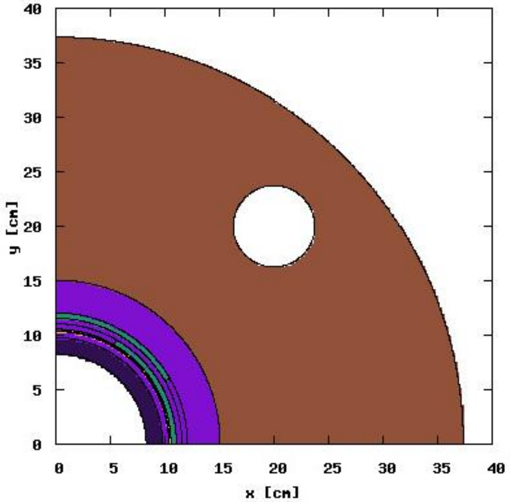
**Q1**



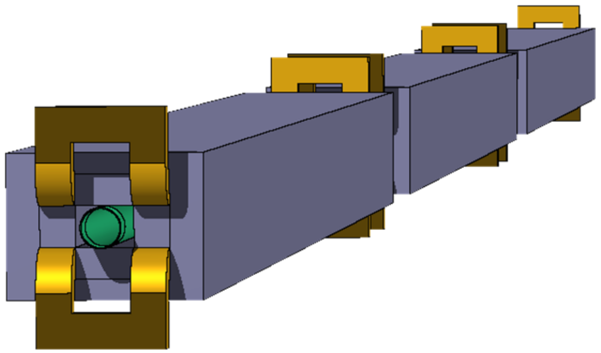

**Q2/Q3**




**Corrector**




**D1**



# Apertures

## TAN

- Length ***5.0 m – 4.0 m*** absorber
- Twin Apertures: ***52 mm*** diameter
- Diverging beam pipes: 104.2 mm (s=407.8 m) and 106.9 mm (s=412.8 m)

## D2A to D2D (MBRW)

- Magnetic Length/Field: ***11.3 m*** – 2.0 T field
- Aperture: ***85 mm*** pole tip aperture
- Parallel beam pipes with different beam separation distance in the modules

## MCBRDV

- Magnetic Length/Field: ***3 m*** – 1.5 T field
- Aperture: ***70 mm*** coil diameter

## Q4 (MQY)

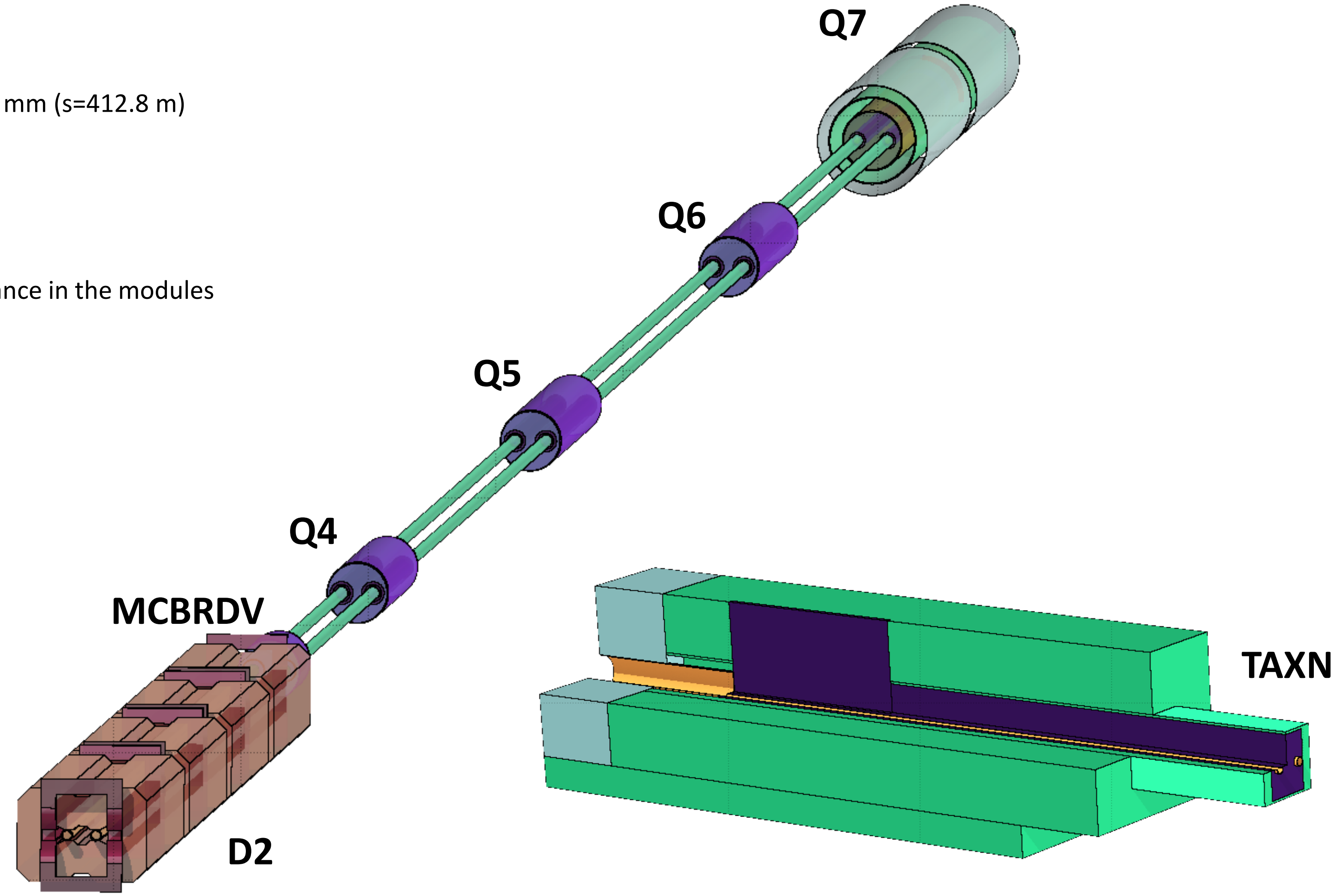
- Magnetic Length/Field: ***9.1 m*** – 144 T/m gradient
- Aperture: ***70 mm*** coil diameter

## Q5/Q6 (MQYL)

- Magnetic Length/Field: ***12.8 m*** – 168/127 T/m gradient
- Aperture: ***60 mm*** coil diameter

## Q7 (MQM)

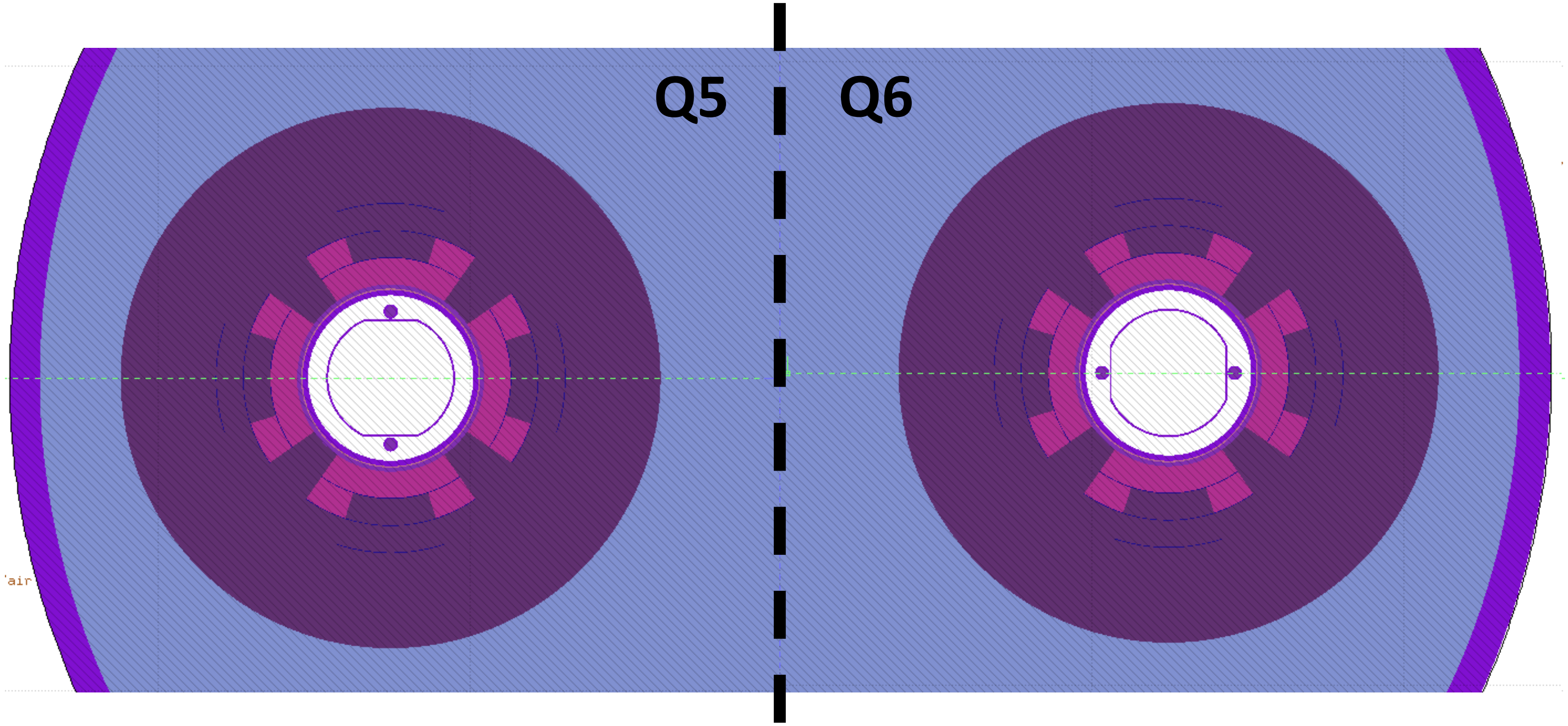
- Magnetic Length/Field: ***14.3 m*** – 320 T/m gradient
- Aperture: ***50 mm*** coil diameter



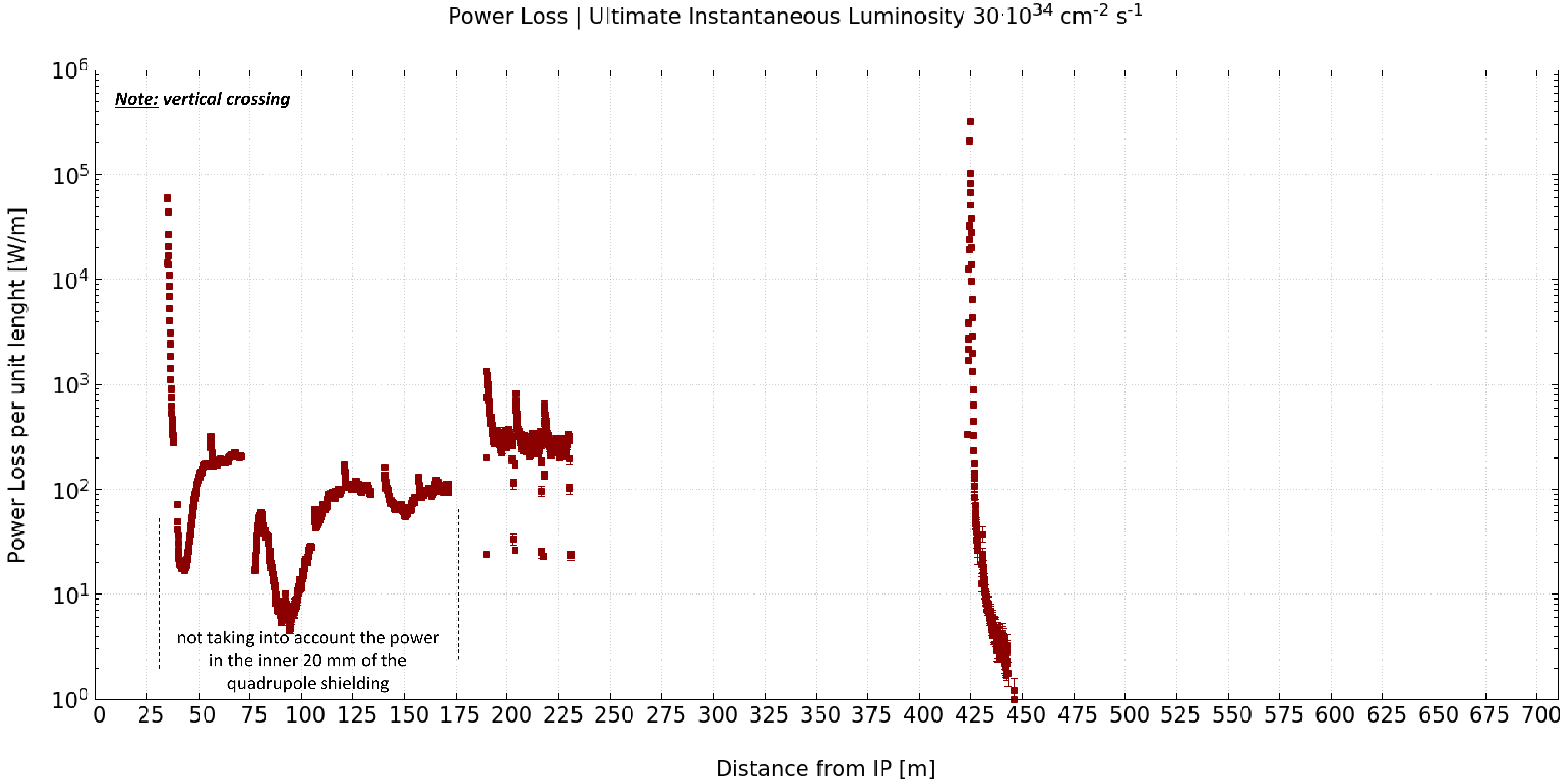
# Rectellipse beam screen

MQY.4RA.H1, APERTYPE=RECTELLIPSE, APERTURE={ 0.028900, 0.024000, 0.028900, 0.028900 };
MQYL.5RA.H1, APERTYPE=RECTELLIPSE, APERTURE={ 0.020000, 0.018200, 0.020000, 0.020000 };
MQYL.6RA.H1, APERTYPE=RECTELLIPSE, APERTURE={ 0.018200, 0.020000, 0.020000, 0.020000 };
MQM.A7RA.H1, APERTYPE=RECTELLIPSE, APERTURE={ 0.015000, 0.013200, 0.015000, 0.015000 };

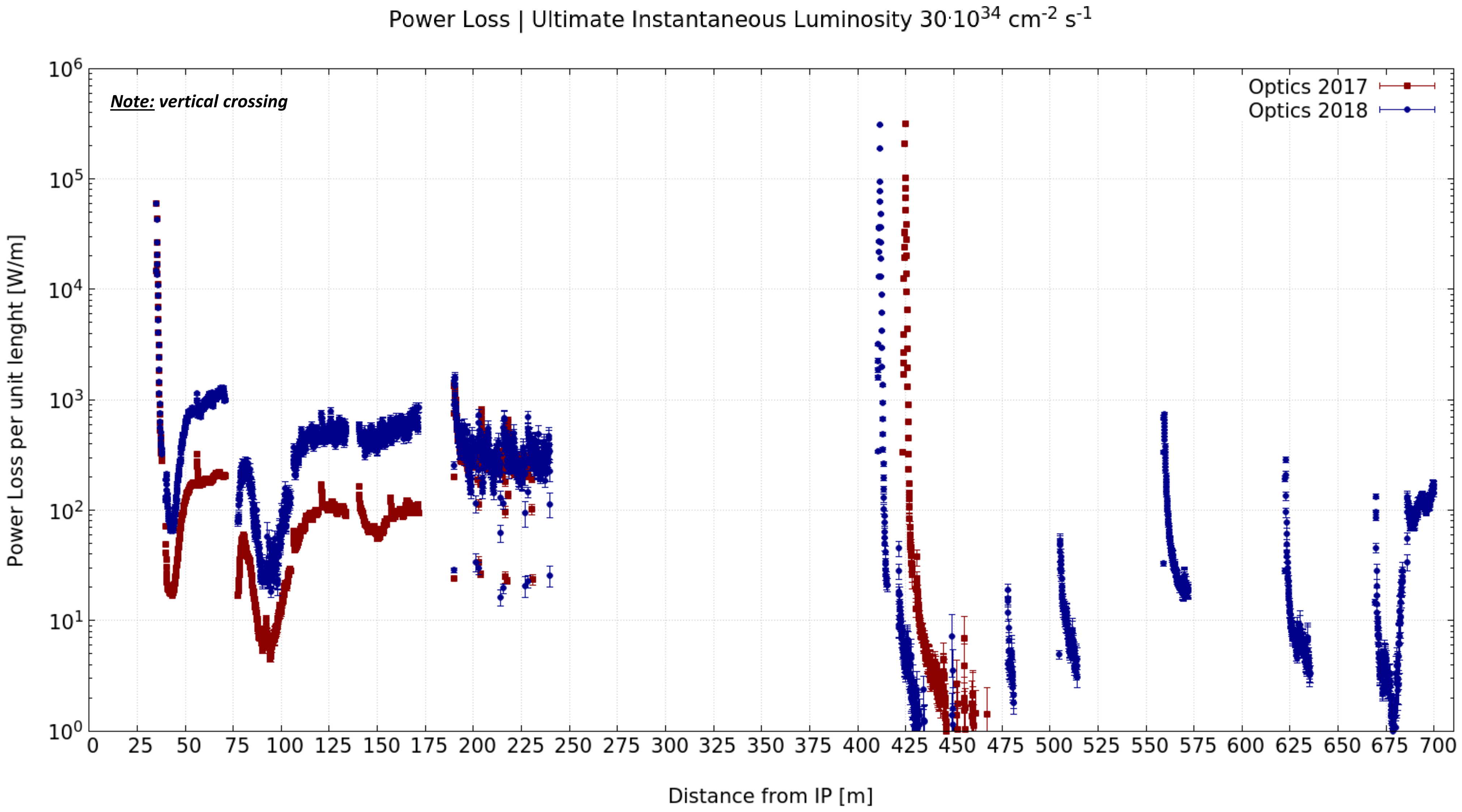
*{half width of rectangle, half height of rectangle, horizontal semi-axes of ellipse, vertical semi-axes of ellipse}*



# Collision Debris Power (FCC Week 2018)



# Collision Debris Power



# Collision Debris Power

| All values in kW | 2018 | | | 2017 | | |
|---|---|---|---|---|---|---|
| Element | Cold Shielding | Cold Mass | Warm Mass | Cold Shielding | Cold Mass | Warm Mass |
| TAS | | | 26.5 | | | 26.5 |
| Q1A | 4.6 | 0.78 | | 4.7 | 0.78 | |
| Q1B | 13 | 1.92 | | 12.6 | 1.89 | |
| C1 | 0.06 | 0.06 | | 0.06 | 0.06 | |
| Q2A | 1.53 | 0.32 | | 1.47 | 0.22 | |
| Q2B | 0.7 | 0.09 | | 0.77 | 0.11 | |
| Q2C | 4.6 | 0.63 | | 4.54 | 0.61 | |
| Q2D | 5.93 | 0.81 | | 6.4 | 0.89 | |
| C2 | 0.51 | 0.05 | | 0.71 | 0.08 | |
| Q3A | 6.02 | 0.77 | | 5.38 | 0.71 | |
| Q3B | 7.8 | 0.95 | | 7.57 | 0.93 | |
| C3 | 0.94 | 0.17 | | 0.87 | 0.15 | |

# Collision Debris Power

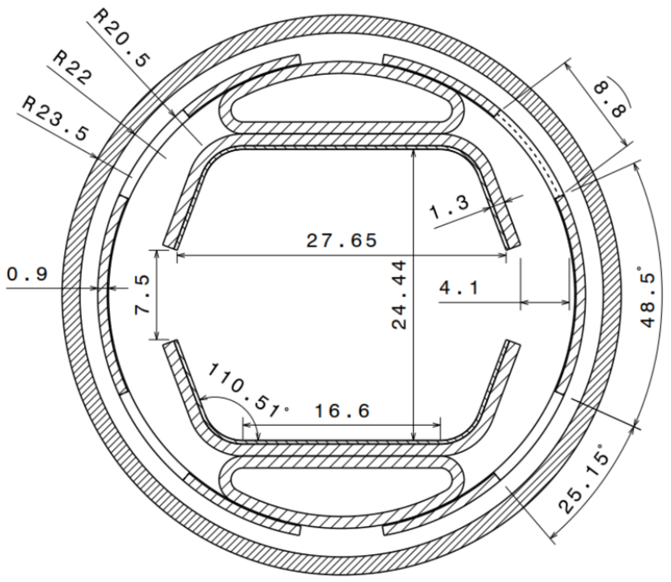
| All values in kW | 2018 | | | 2017 | | |
|---|---|---|---|---|---|---|
| Element | Cold Shielding | Cold Mass | Warm Mass | Cold Shielding | Cold Mass | Warm Mass |
| D1A | | | 4.99 | | | 5.06 |
| D1B | | | 3.57 | | | 3.74 |
| D1C | | | 3.57 | | | 3.59 |
| D1D | | | 3.96 | | | |
| TAXN | | | **107** | | | **112** |
| D2A | | | 0.07 | | | 0.08 |
| D2B | | | 0.01 | | | 0.012 |
| D2C | | | 0.003 | | | 0.006 |
| D2D | | | 0.002 | | | |

# Collision Debris Power

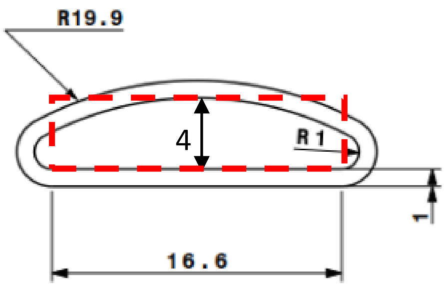
| All values in kW | | 2018 | | | 2017 | |
|---|---|---|---|---|---|---|
| **Element** | **Cold Shielding** | **Cold Mass** | **Warm Mass** | **Cold Shielding** | **Cold Mass** | **Warm Mass** |
| **C4** | | | 0.017 | | | |
| **Q4** | | 0.12 | | | | |
| **Q5** | | **1.01** | | | | |
| **Q6** | | 0.22 | | | | |
| **Q7A** | | 0.12 | | | | |
| **Q7B** | | **1.59** | | | | |

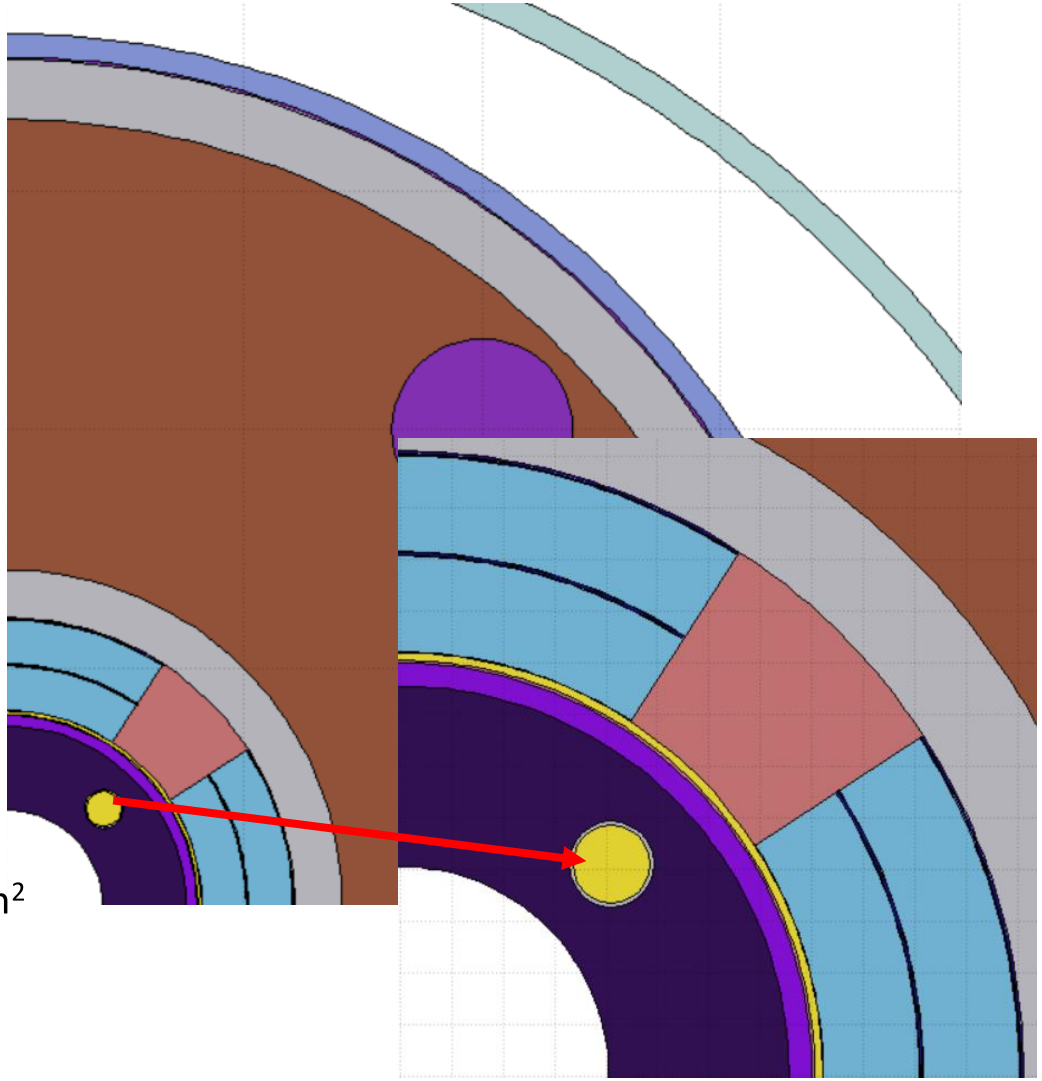
*Statistical uncertainty for the matching quadrupoles: 1-3%*

# Collision Debris Power



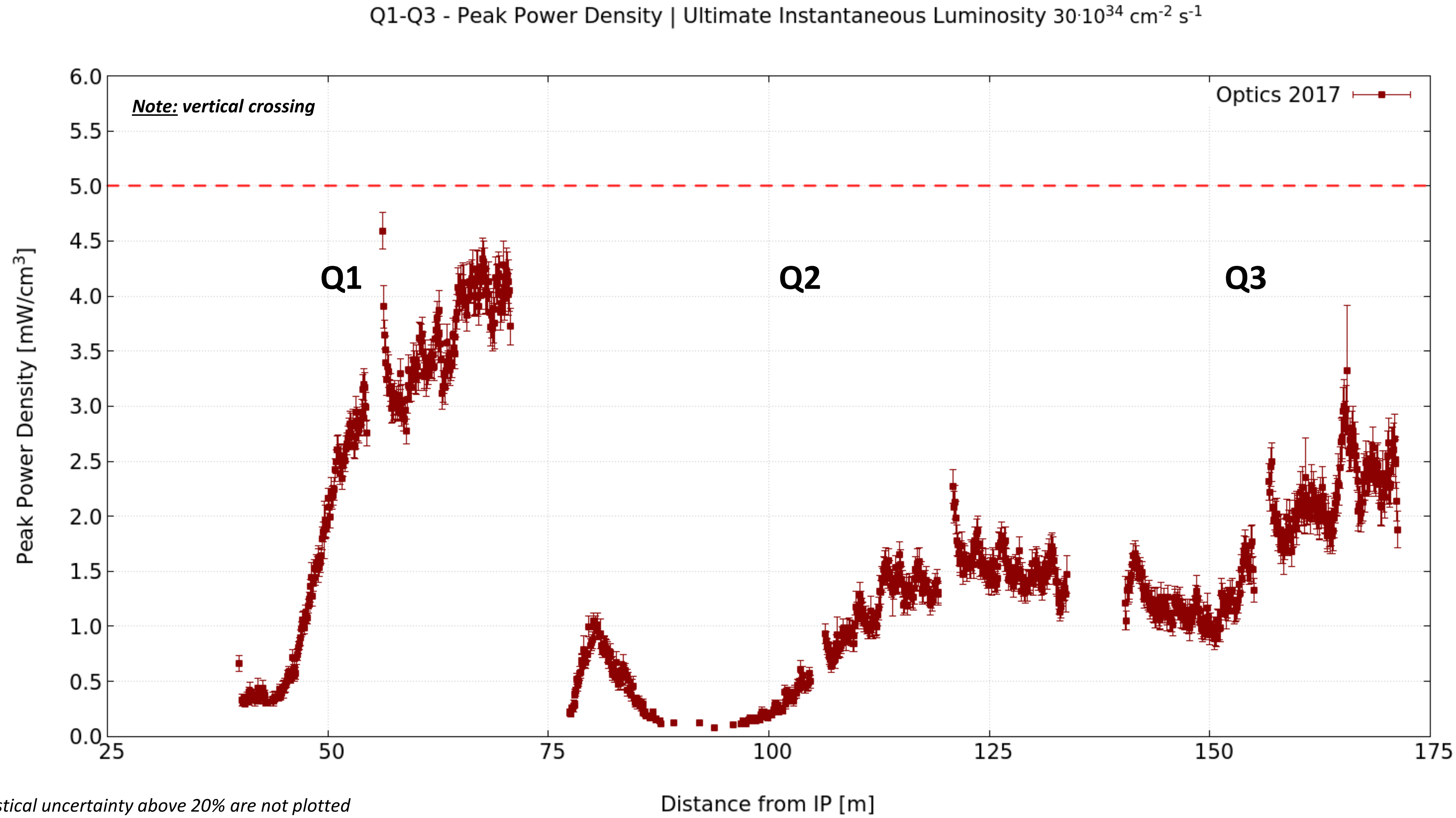

**FCC Week 2018**
**(Last Day Summary)**



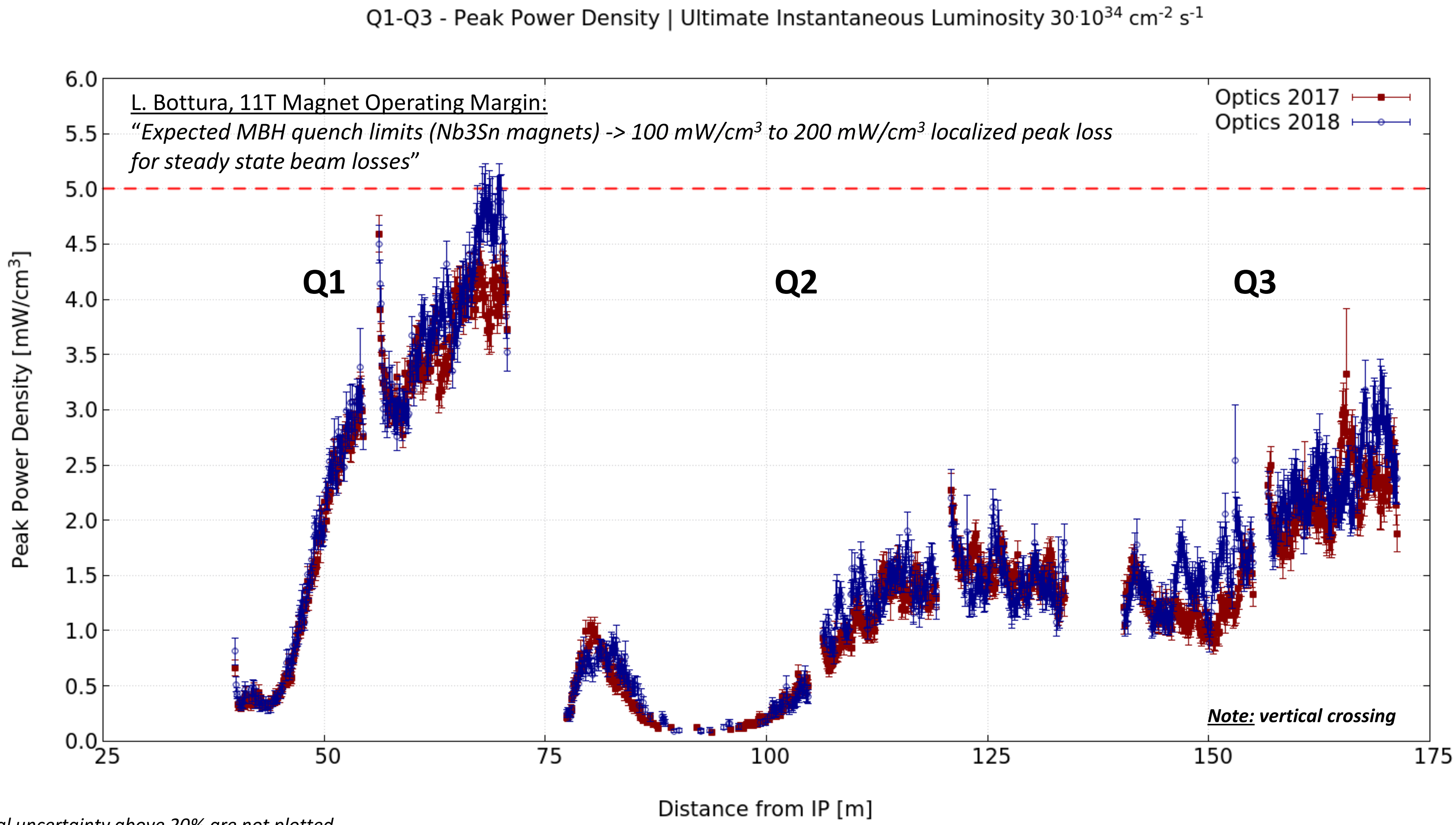
- Dipole cooling: 0.5 kW x 6 dipoles = 3kW
- Need of ~4x dipole cooling for the cooling of Q1 shielding -> 13kW
- Active cross section (beam screen cooling channels) => 2 x 4 x 16.6=132.8 mm$^2$
  - ✓ Cylindrical capillary equivalent diameter => 15mm
  - ✓ 0.8mm pipe wall thickness

# Margin to Quench: Triplet (FCC Week 2018)



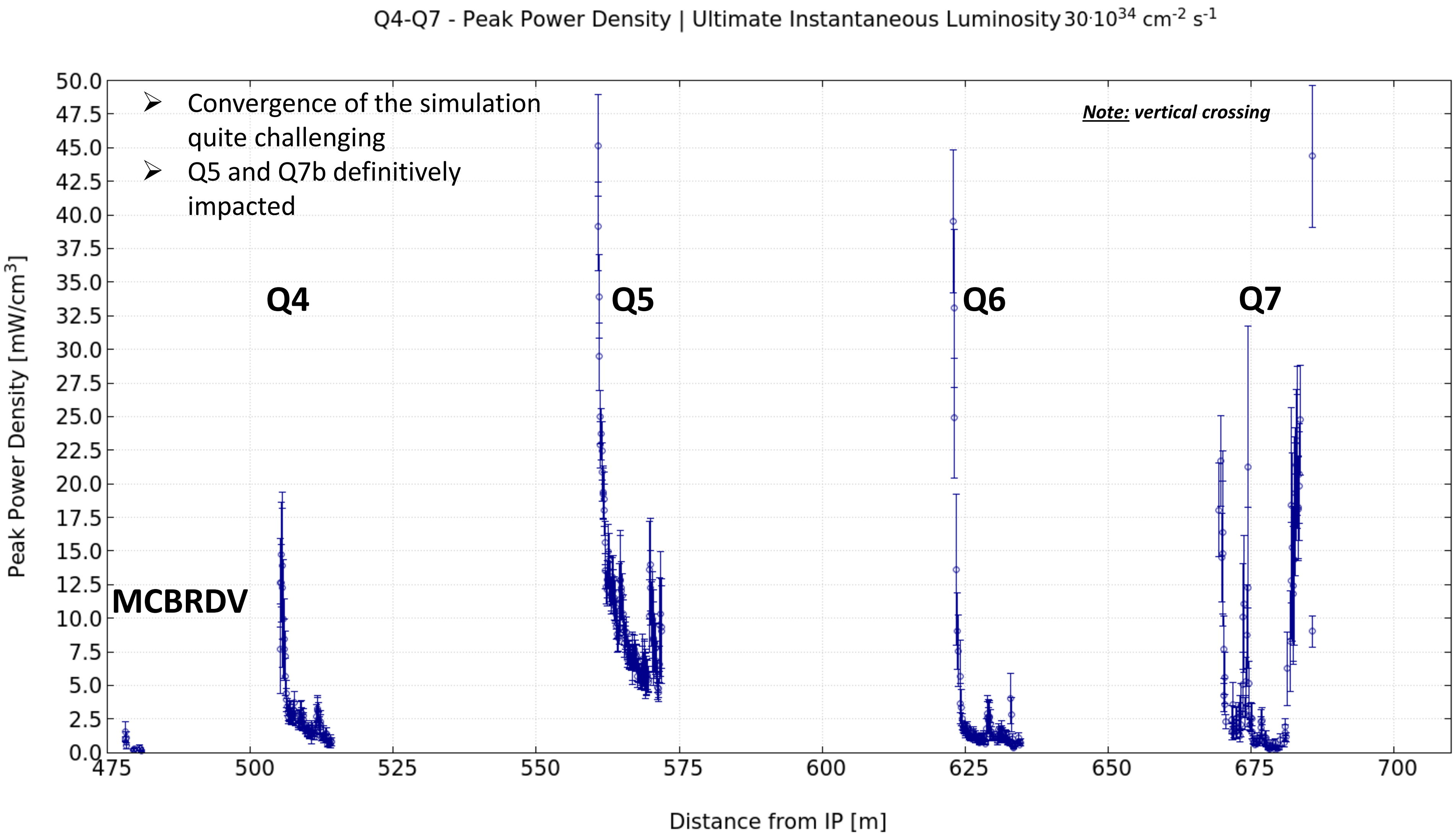

*Note:* data with statistical uncertainty above 20% are not plotted

# Margin to Quench: Triplet



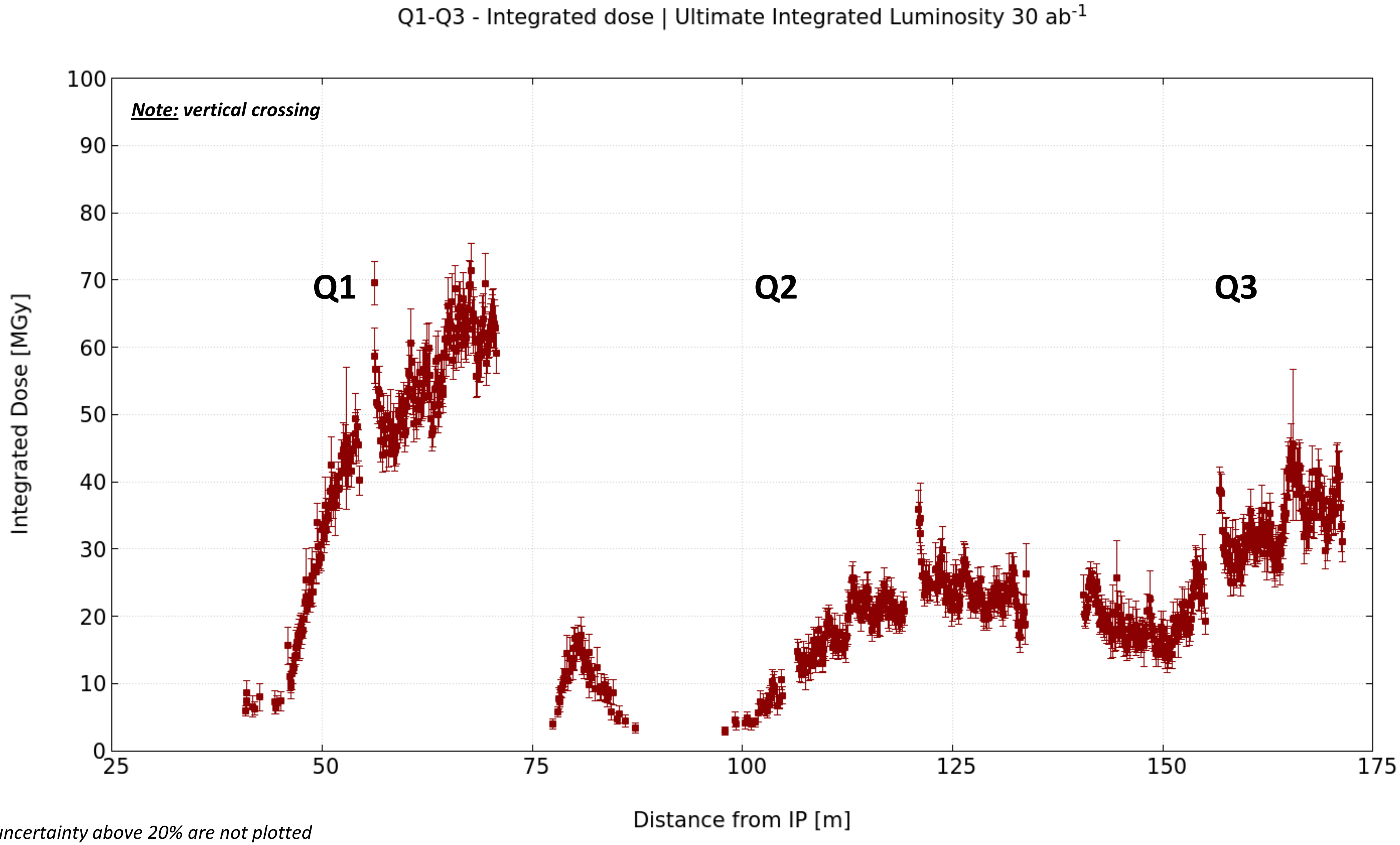

*Note: data with statistical uncertainty above 20% are not plotted*

# Margin to Quench: Q4-Q7



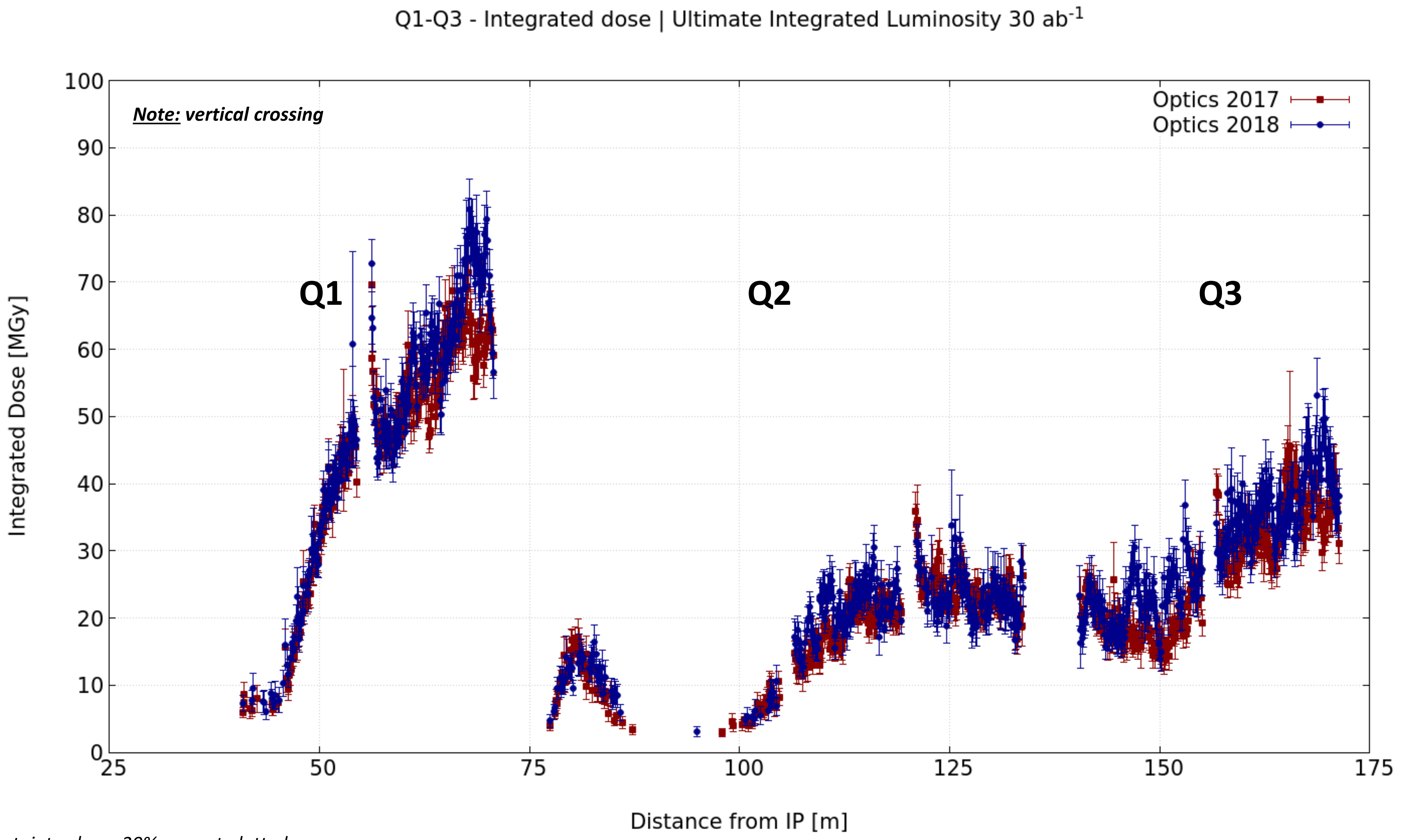

- Convergence of the simulation quite challenging
- Q5 and Q7b definitively impacted

# Triplet Coil Insulator Lifetime (FCC Week 2018)




*Note: data with statistical uncertainty above 20% are not plotted*

# Triplet Coil Insulator Lifetime

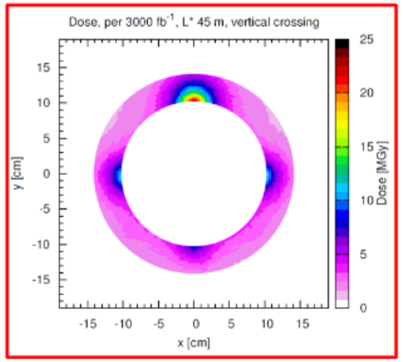



*Note: data with statistical uncertainty above 20% are not plotted*

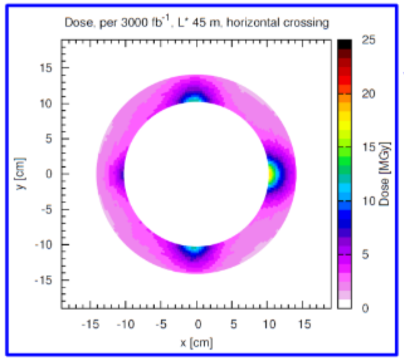
# Triplet Coil Insulator Lifetime

## CROSSING POLARITY & PLANE ALTERNATION

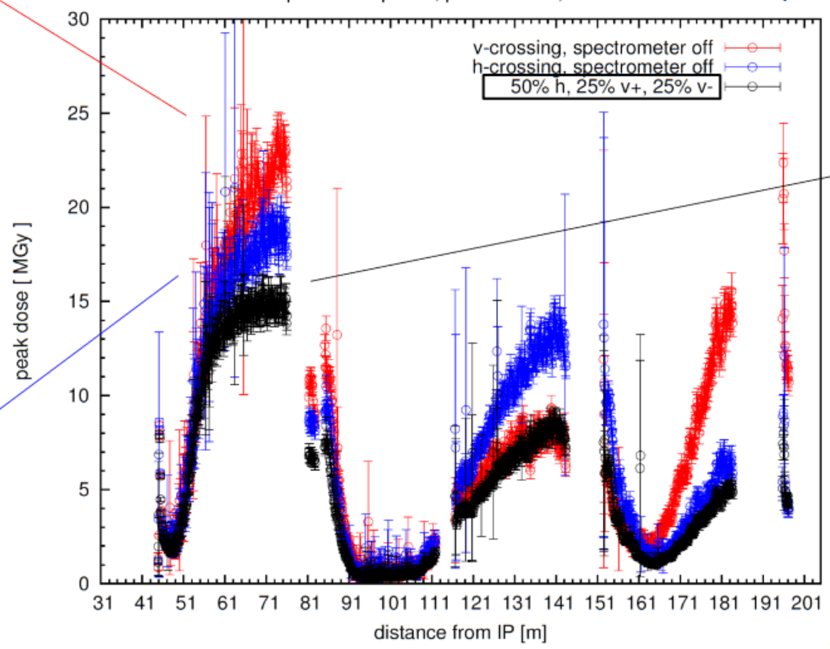
idea by S. Farthouk (CERN BE-ABP)

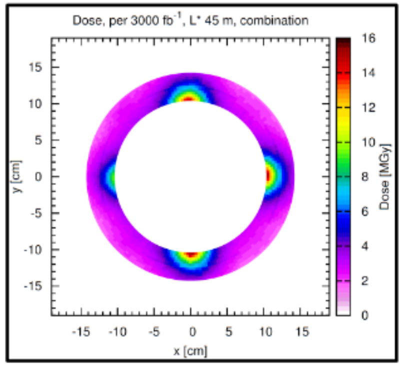



well localized hot spots, reflecting the interplay of crossing plane and magnetic configuration




ancient layout example




equalizing the dose in three spots, a reduction of more than 35% can be achieved on the maximum dose, i.e. a **60% lifetime increase**

*From FCC Week 2018*

2018 April 10th F. Cerutti FCC-hh accelerator: Design II FCC week, Amsterdam 8

# Triplet Coil Insulator Lifetime

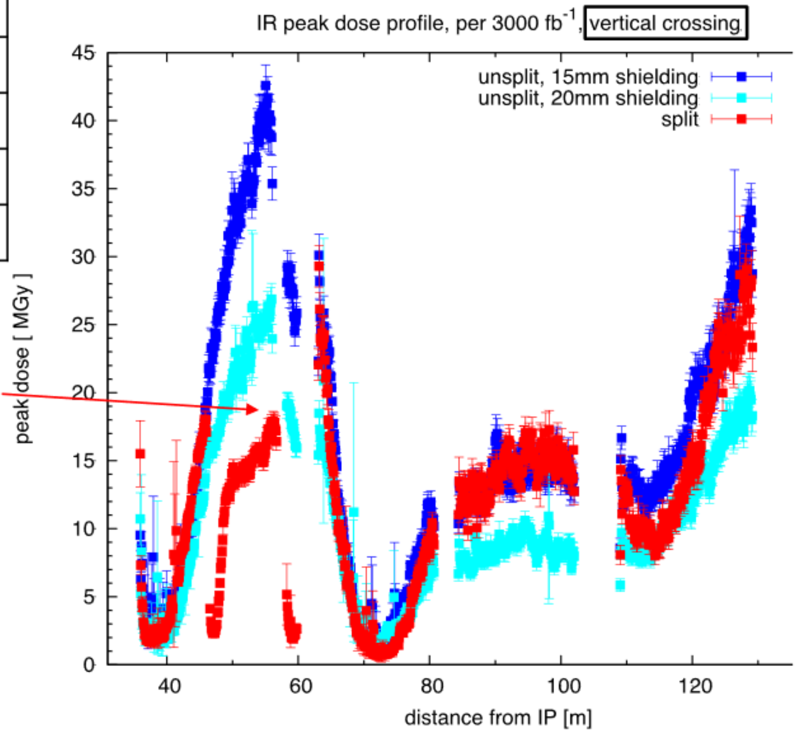
## OPTIMIZED Q1 SPLITTING

ancient layout example

idea by R. Martin (CERN BE-ABP)

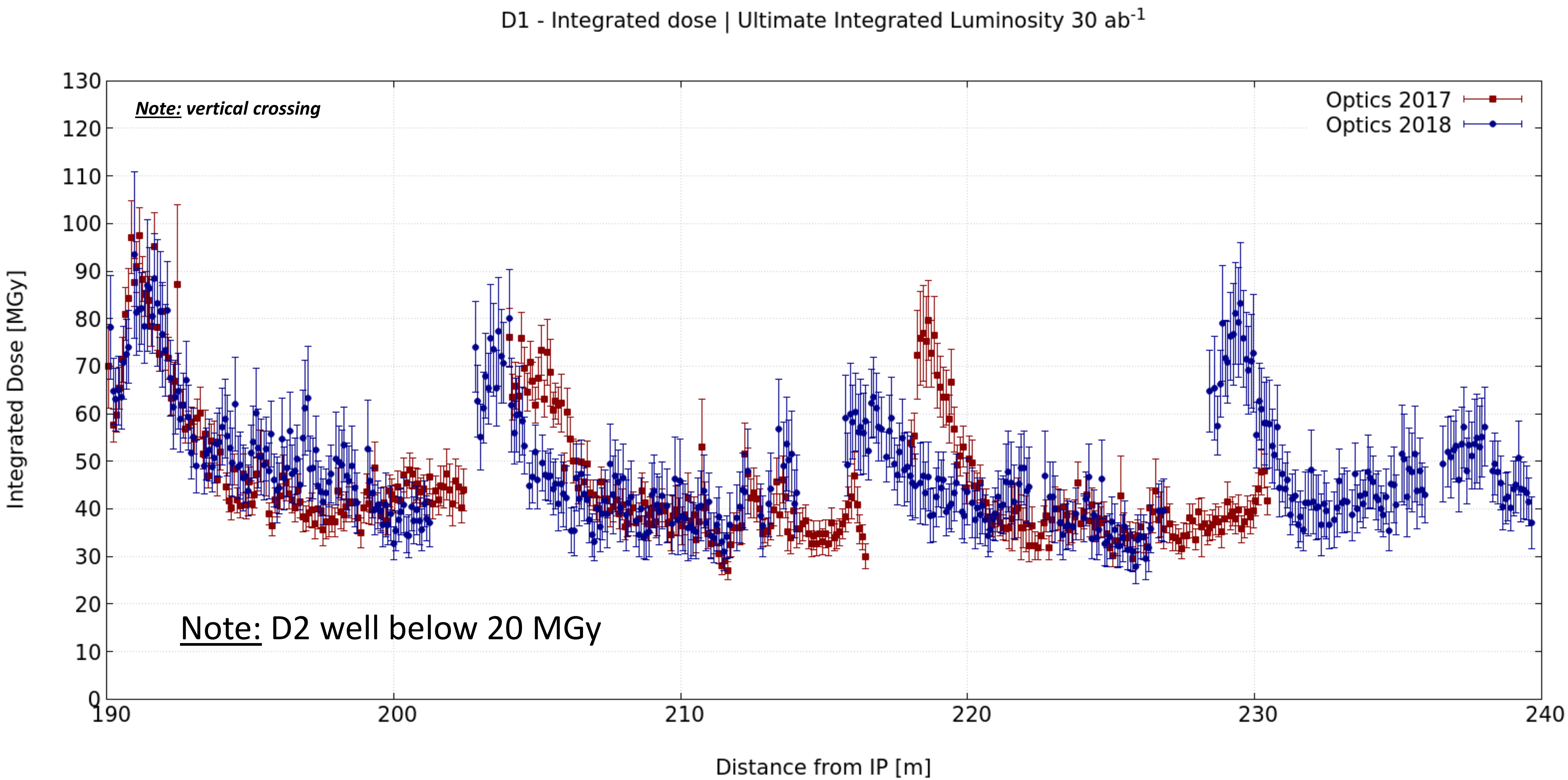
| $L^*$=36m | length [m] | gradient [T/m] | coil ID [mm] | W thick. [mm] |
|---|---|---|---|---|
| Q1A | 10 | 239 | 92 | 21 |
| Q1B | 10 | 200 | 110 | 24 |
| Q2A&B | 17.5 | 189 | 115 | 15 |
| Q3 | 20 | 191 | 115 | 15 |

*the maximum dose at the Q1 (non-IP) end* is counteracted by increasing in Q1b the coil aperture and the absorber thickness, thanks to relaxed beam aperture requirements in Q1. Q1a provides strength compensation.



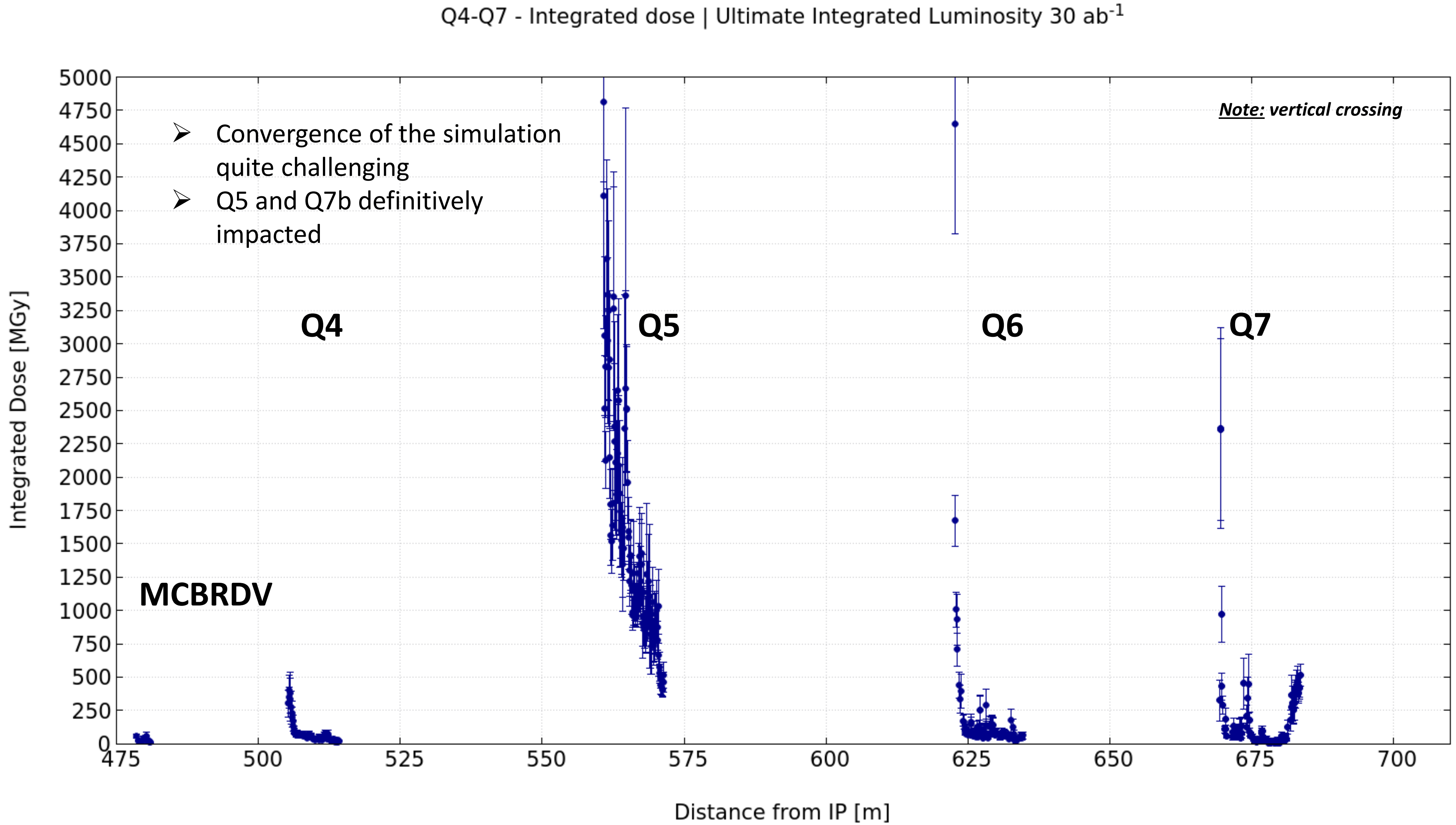

From FCC Week 2018

# D1-D2 Coil insulator lifetime

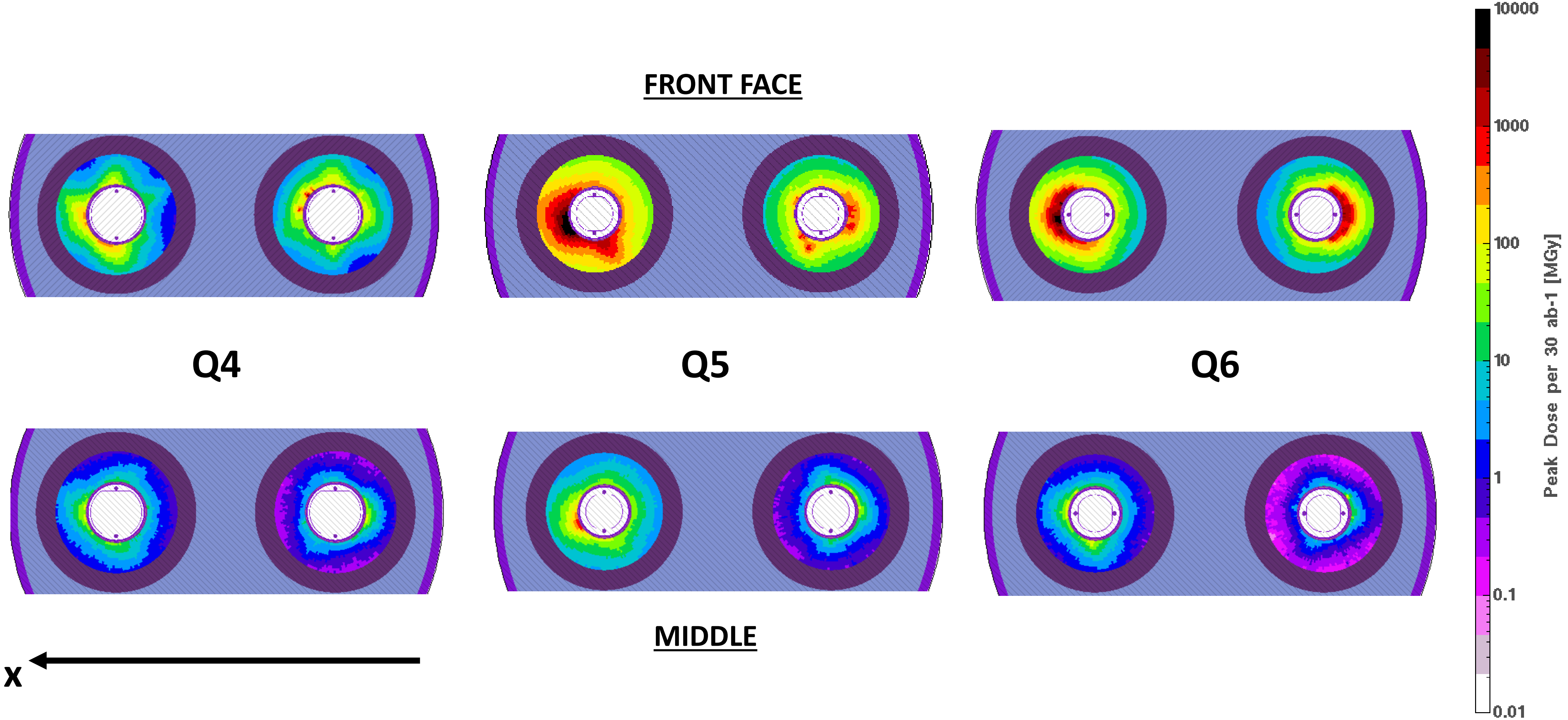



*Note: data with statistical uncertainty above 20% are not plotted*

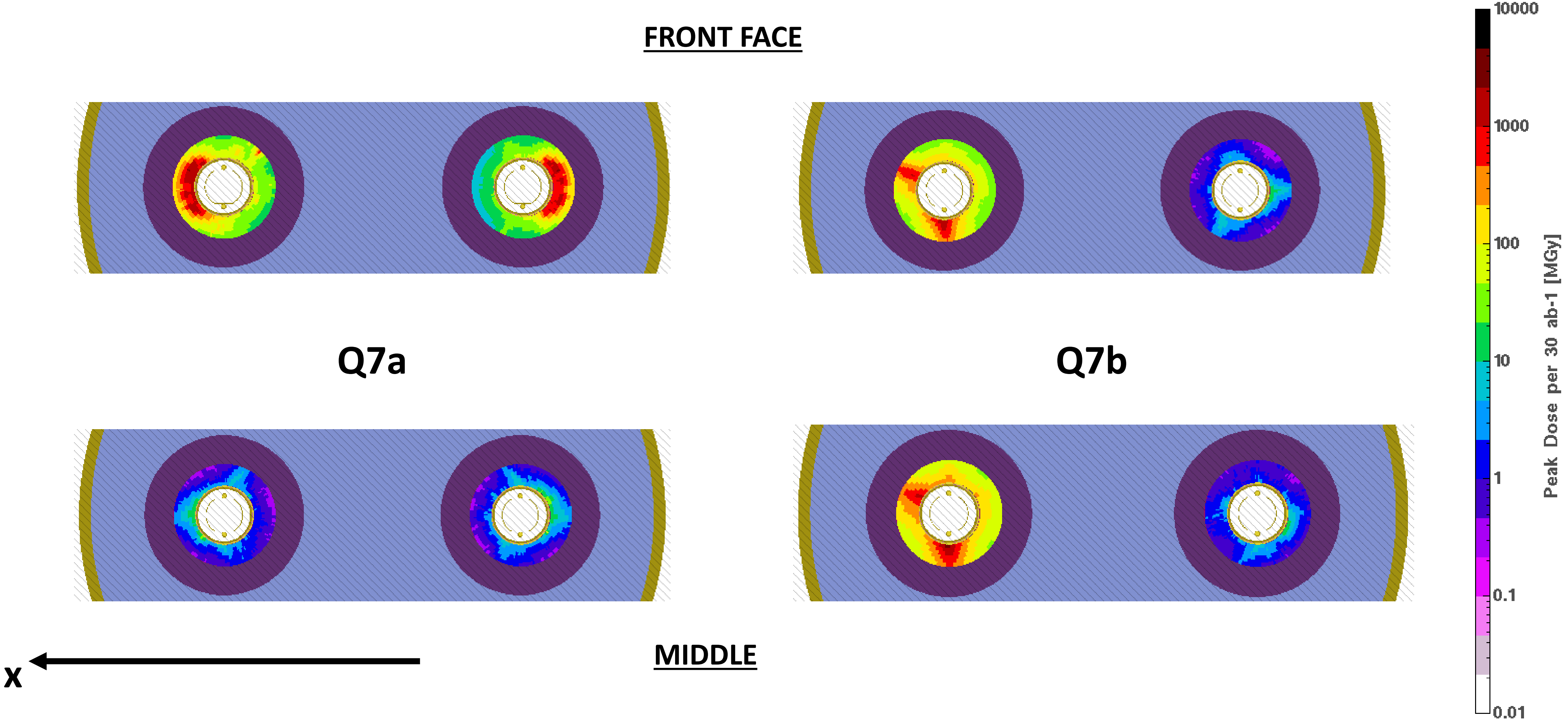
# Q4-Q7 Coil insulator lifetime



# Q4-Q7 Coil insulator lifetime



# Q4-Q7 Coil insulator lifetime



# Summary

***Take-Home Message:***

**TRIPLET**

- ✓ No significant changes in the Triplet-D2 region from FCC Week 2018: the increase in the peak dose and power density is compatible with the increase of the crossing angle.

**MATCHING SECTION**

- ✓ Q5 and Q7b:
  - Severely impacted from collision debris;
  - ~1kW total power to be dissipated.
- ✓ Overall, all the matching quadrupoles will face a severe radiation environment: peak dose results, from a first evaluation, significantly above the design limits.
- ✓ The current study does not include any collimator (TCLs) or mask for this region: a careful design of a dedicated protection is therefore necessary.

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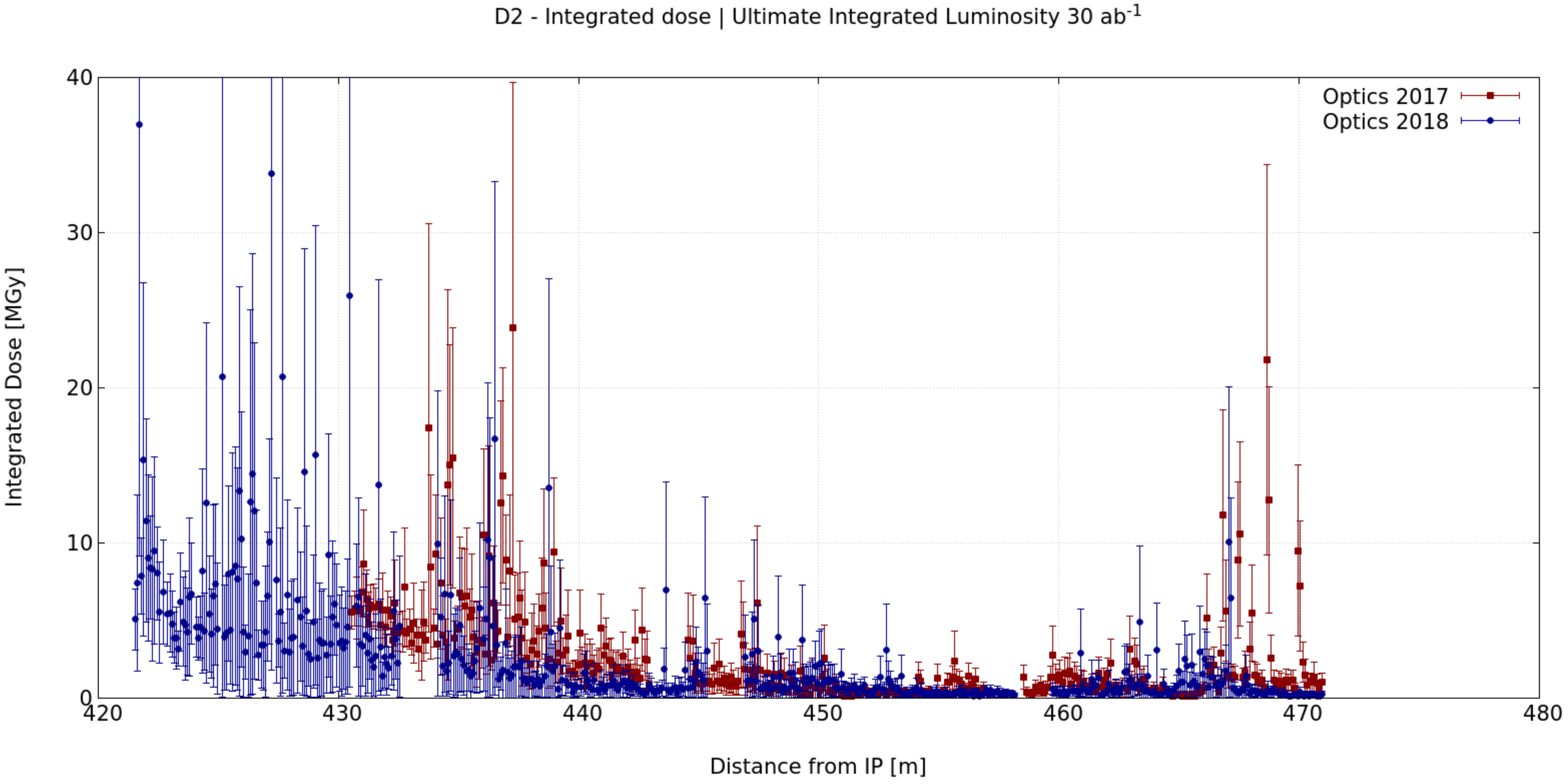
# BACKUP SLIDES

www.cern.ch

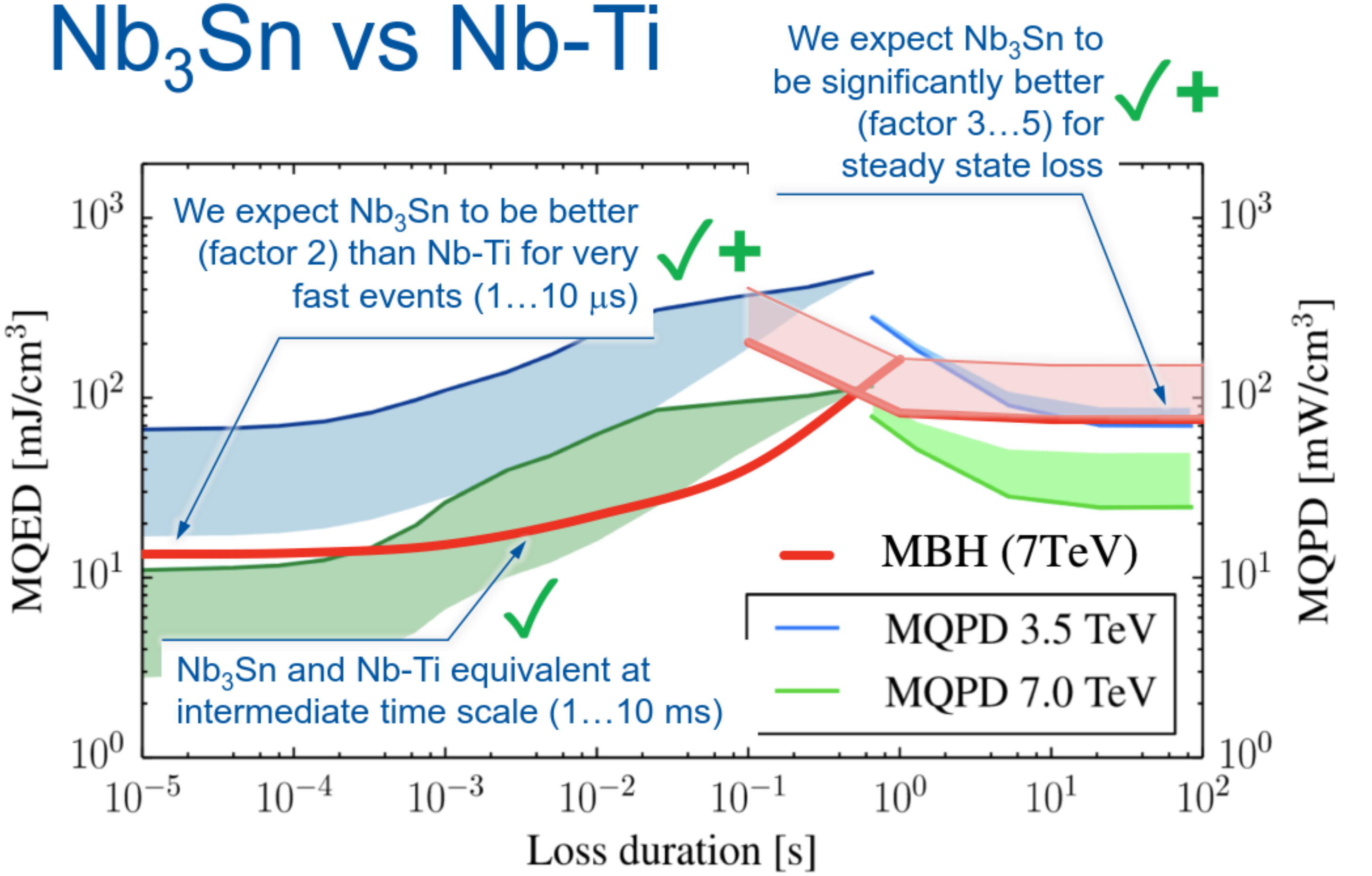
# D2 Coil insulator lifetime



# Margin to Quench

NOTE: energy and power are intended as averaged over the cable

## $Nb_3Sn$ vs Nb-Ti



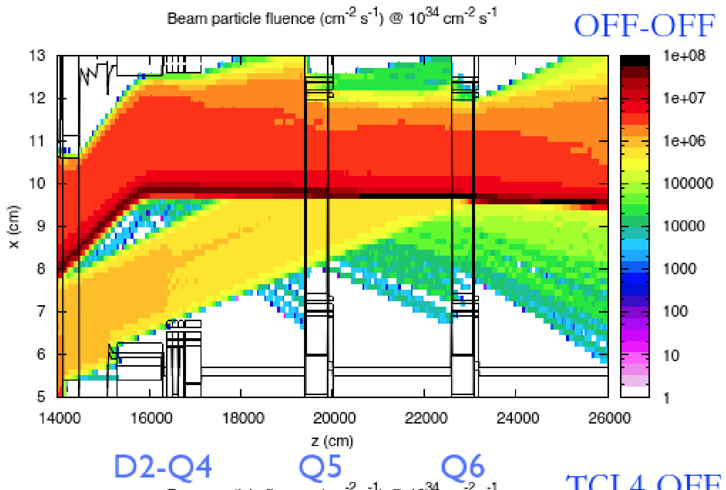

Nb-Ti from B. Auchmann et al., Phys. Rev. ST Accel. Beams, 18, 061002 (2015)
$Nb_3Sn$ from E. Felcini, unpublished data, 2018

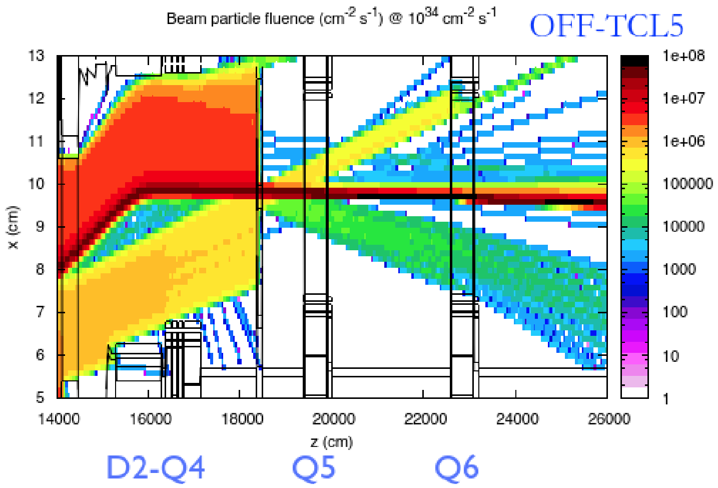
<u>L. Bottura, 11T Magnet Operating Margin:</u>

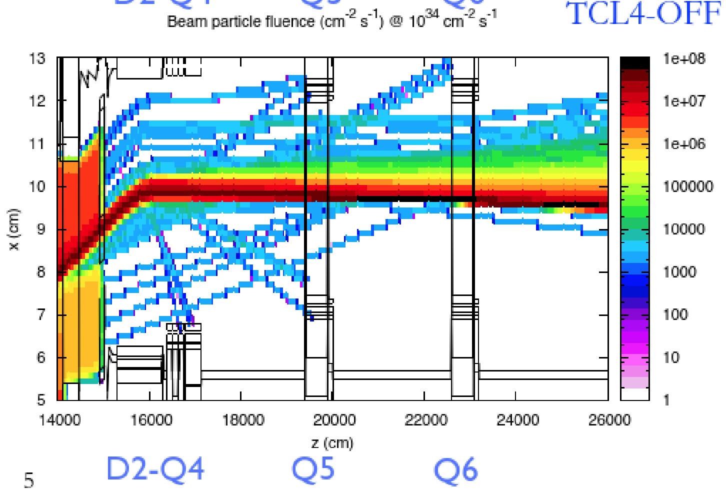
*“Expected MBH quench limits (Nb3Sn magnets) -> 100 mW/cm$^3$ to 200 mW/cm$^3$ localized peak loss for steady state beam losses”*

# Margin to Quench

## IR5: primary collision product fluence




vertical average over 6 cm at beam height

better cleaning of collision product by TCL4

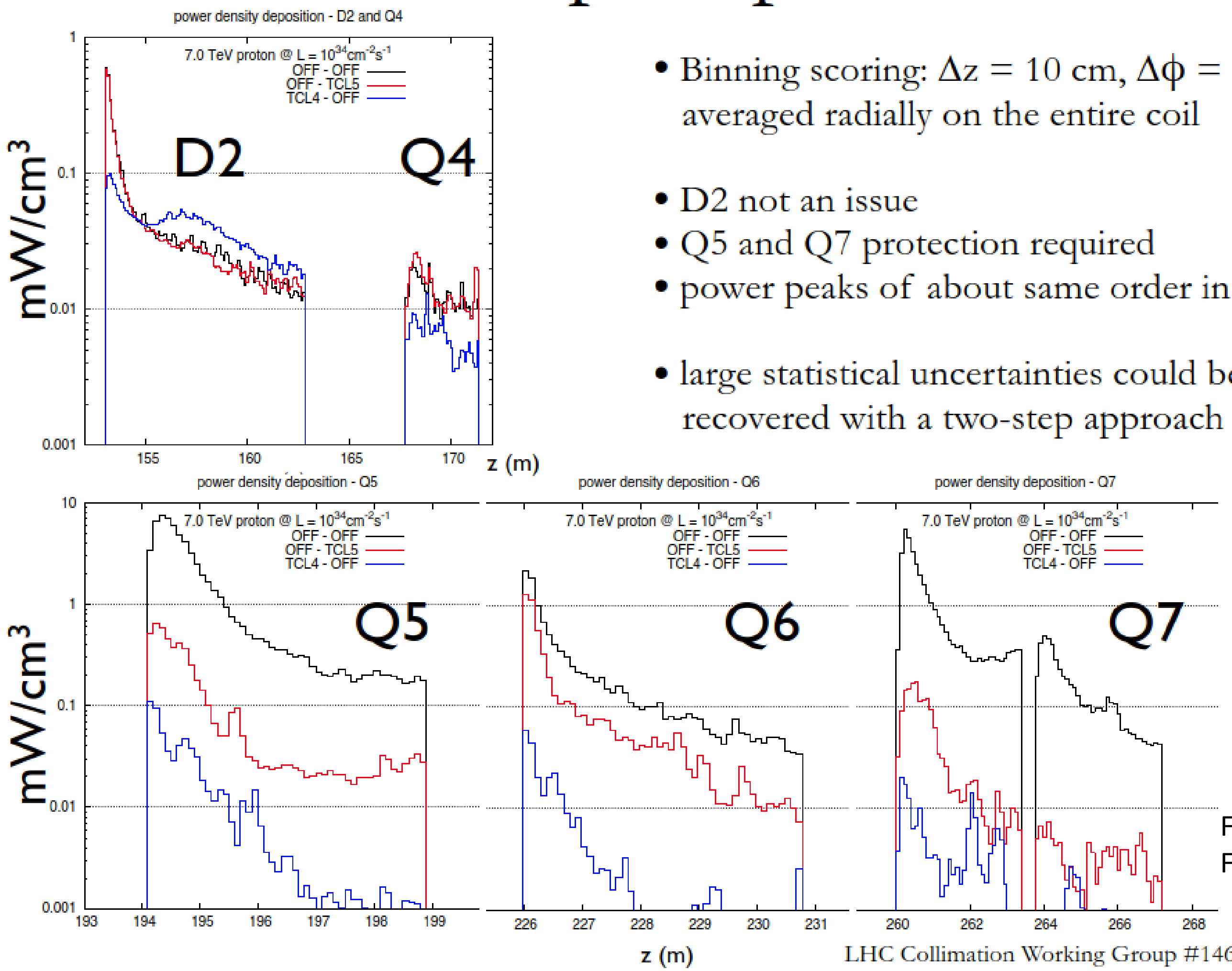
F. Cerutti, L.S. Esposito, A. Lechner, A. Mereghetti
FLUKA studies on TCLs in experimental IRs

5

LHC Collimation Working Group #146, 30 July 2012

# Margin to Quench

## IR5: peak power




- Binning scoring: $\Delta z$ = 10 cm, $\Delta\phi$ = 2 deg averaged radially on the entire coil
- D2 not an issue
- Q5 and Q7 protection required
- power peaks of about same order in IR1
- large statistical uncertainties could be recovered with a two-step approach

F. Cerutti, L.S. Esposito, A. Lechner, A. Mereghetti
FLUKA studies on TCLs in experimental IRs

9 LHC Collimation Working Group #146, 30 July 2012