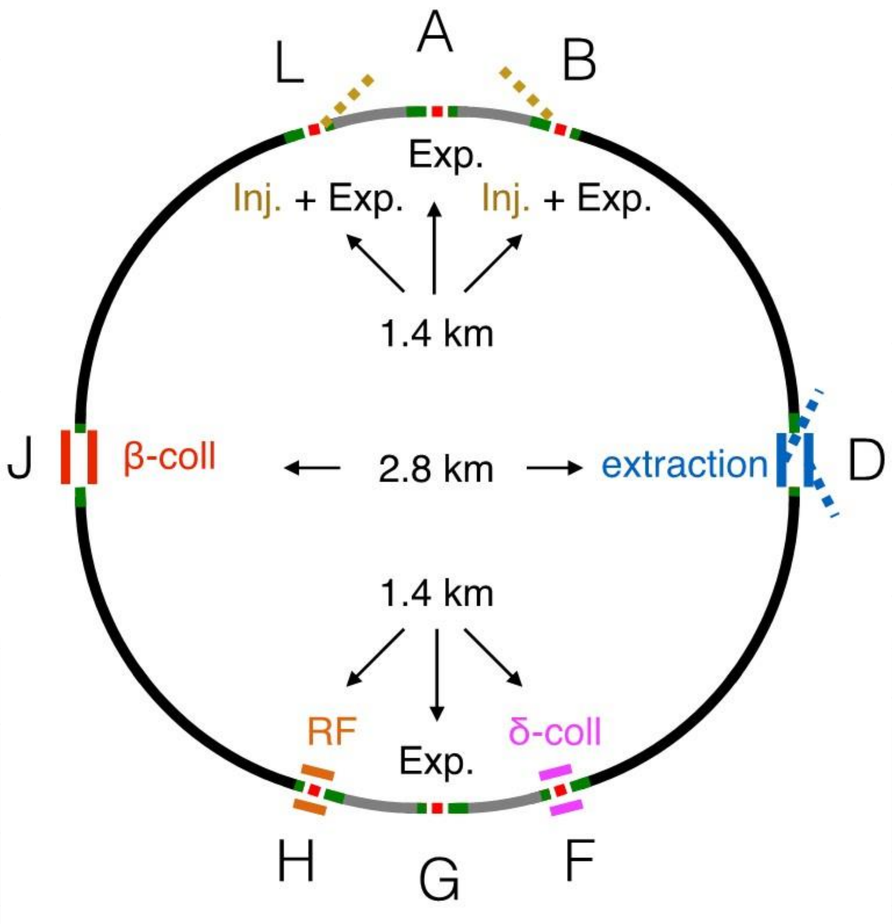
3.3 TeV beam injection into combined experimental and injection FCC machine insertions

M. Hofer, M.I. Besana, F. Burkart, F. Cerutti, R. Martin, D. Schulte, R. Tomas

The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.

Motivation

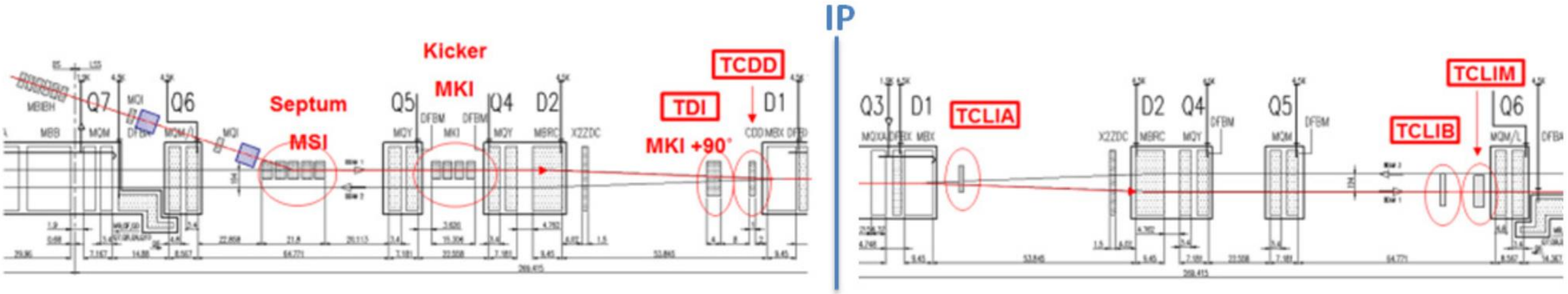
- Since the last FCC week in Rome 2016 the overall layout of the FCC-hh has changed
- The new layout has a reduced circumference of 97.75 km compared to 99.97 km for the previous baseline layout
- Low luminosity experiments moved from Points F & H to B & L and are now combined with the injection
- The length of these insertion remains at 1400 m



See Talk by Daniel Schulte

Combined injection and experimental insertion in (HL-)LHC

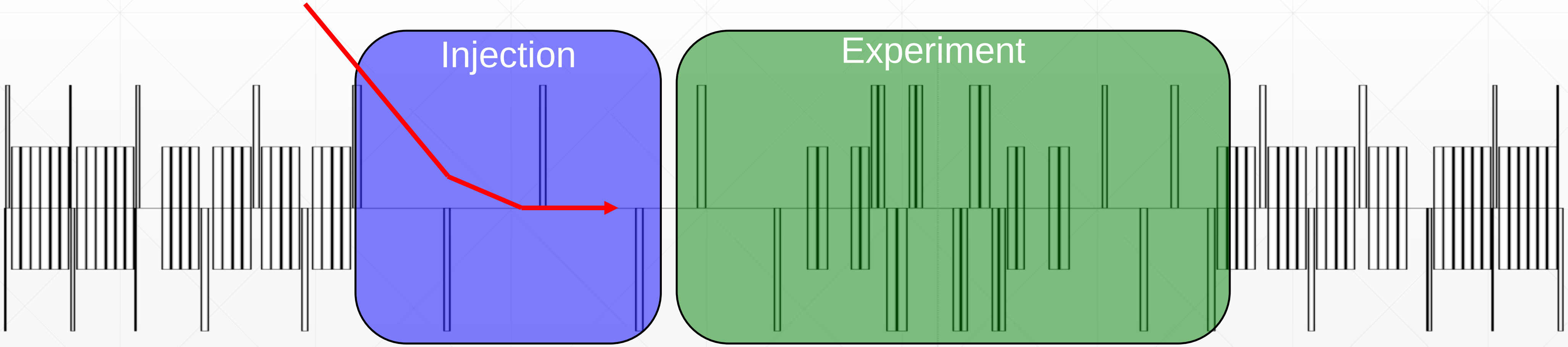
- Example for a combined insertion in the (HL-)LHC
- Insertion layout for ALICE
- Symmetric design and injection protection close to the experiments



High-Luminosity Large Hadron Collider (HL-LHC) Preliminary Design Report
https://cds.cern.ch/record/2116337/files/CERN-2015-005.pdf

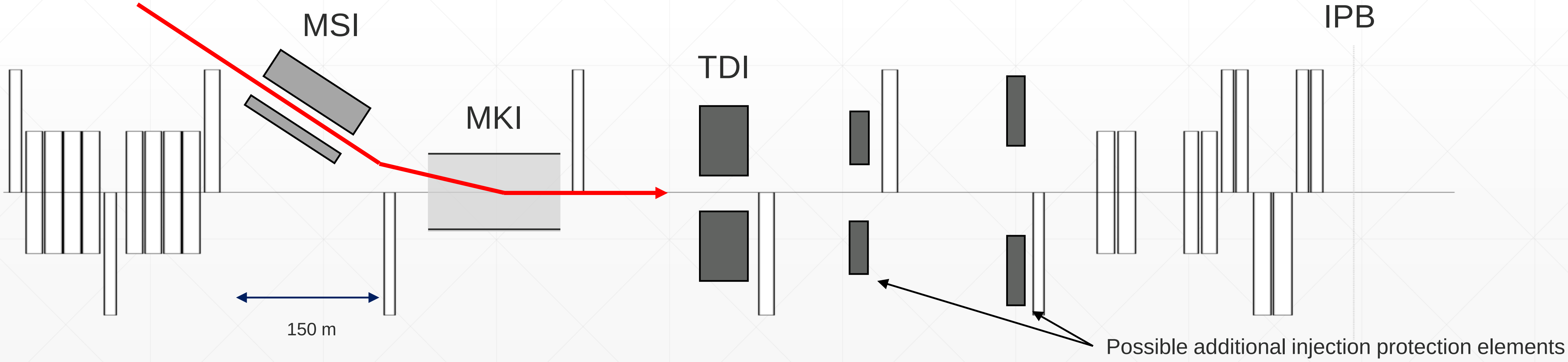
Strategy

- For these insertion a rather conservative approach was chosen separating Injection and Experiments as best possible
- Chosen as it seems preferable from a machine protection point of view
- Not as deeply interwoven as LHC
- Same layout is used for both IPB and IPL



Injection Layout

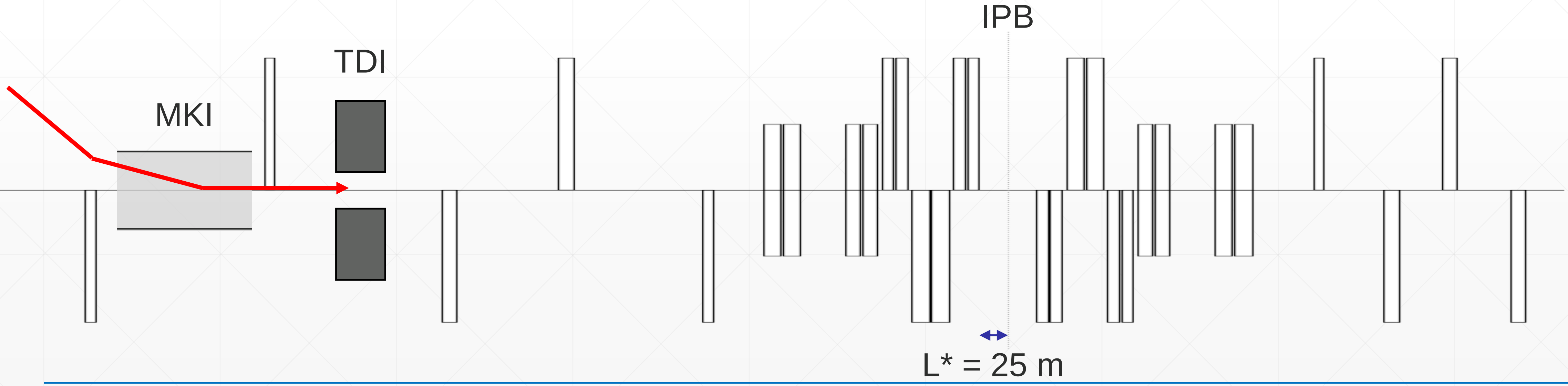
- Half cell length for injection devices is 150 m
- Septum is located right next to the Dispersion Suppressor
- Protection elements far away from the experiment



Possible additional injection protection elements

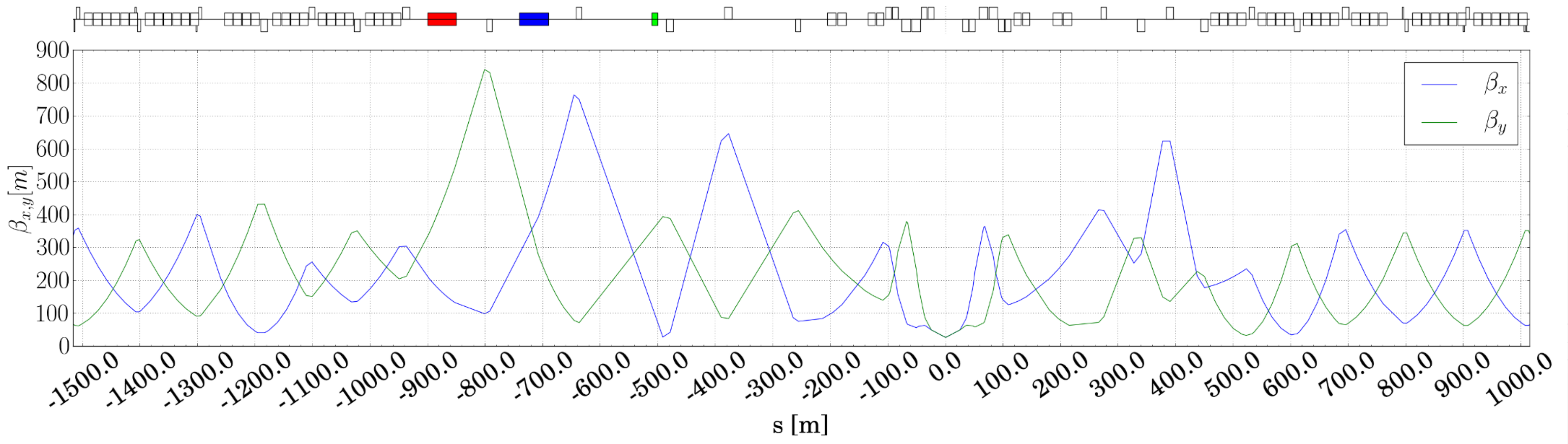
Experiment layout

- These Experiments were designed with no specific scenario in mind (e.g. Ions, FCC-he)
- For the low luminosity experiments an L^* of 25 m was suggested by the detector design group
- Keep separation section length as short as possible



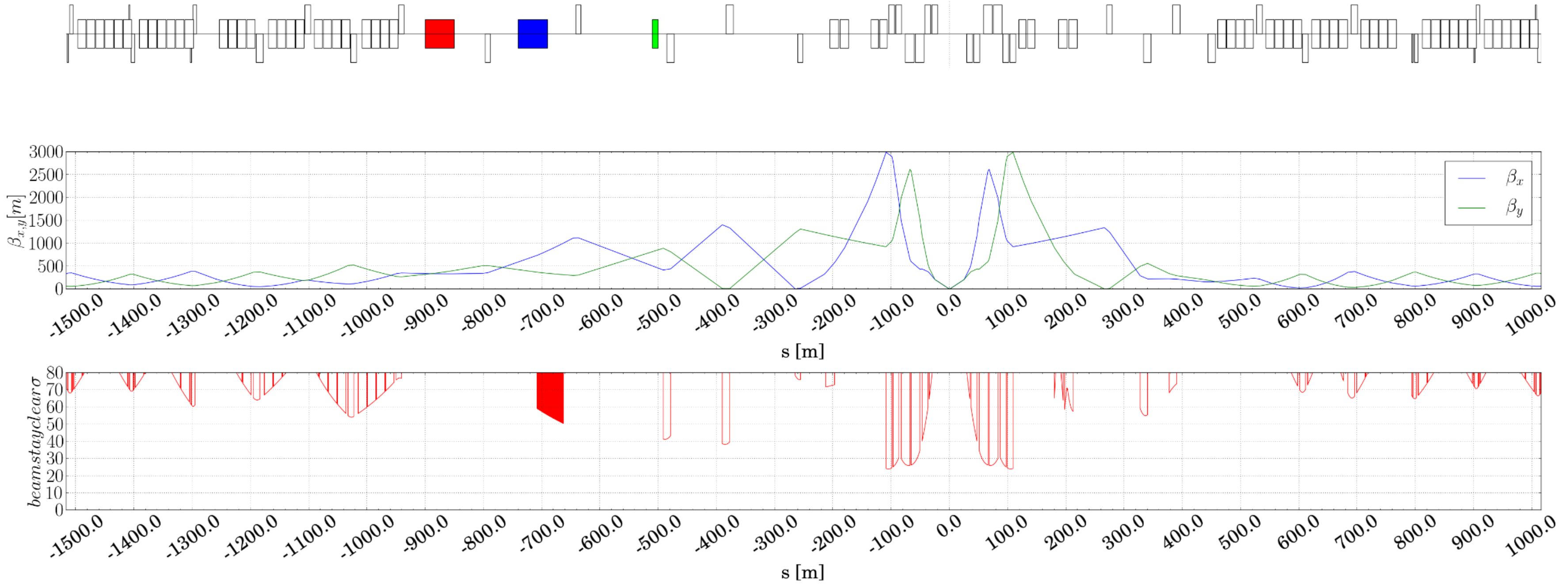
Injection Optics

- Predetermined injection cell length adds space constraints
- Injection optics requires special matching constraint to ensure optimum protection:
  - 90° phase advance constraint between the Kickers and the absorber TDI
  - vanishing dispersion to mitigate the effect of injection oscillation



Collision Optics

- During collision no special constraints need to be applied
- With this layout a minimum round β^* of 3 m has been matched
- Crossing angle has been scaled from Main Experiments with the reduced distance IP to D1 which yields $\theta = 39\ \mu rad$

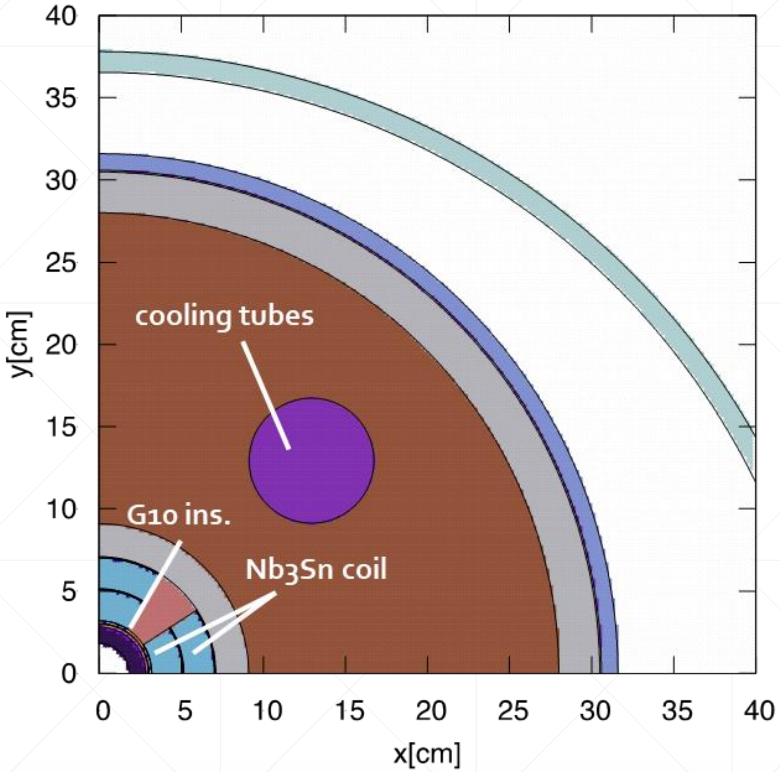


Energy depositions studies

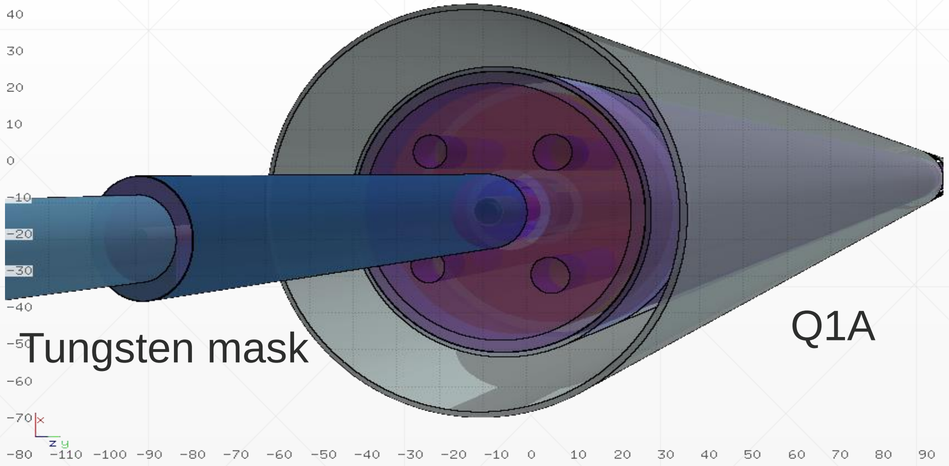
- Energy deposition in the magnets is one of the key factors that defines luminosity reach
- The maximum instantaneous luminosity is determined by the quench limit of the superconductivity magnets
- The cumulated dose sets the achievable integrated luminosity

Magnet Models

- Unlike in the main experiments, the triplet quadrupoles in these insertions are shorter and require a higher gradient and a significantly smaller aperture
- Same magnet model for all triplet quadrupoles and a constant 10 mm tungsten (INERMET180) shielding

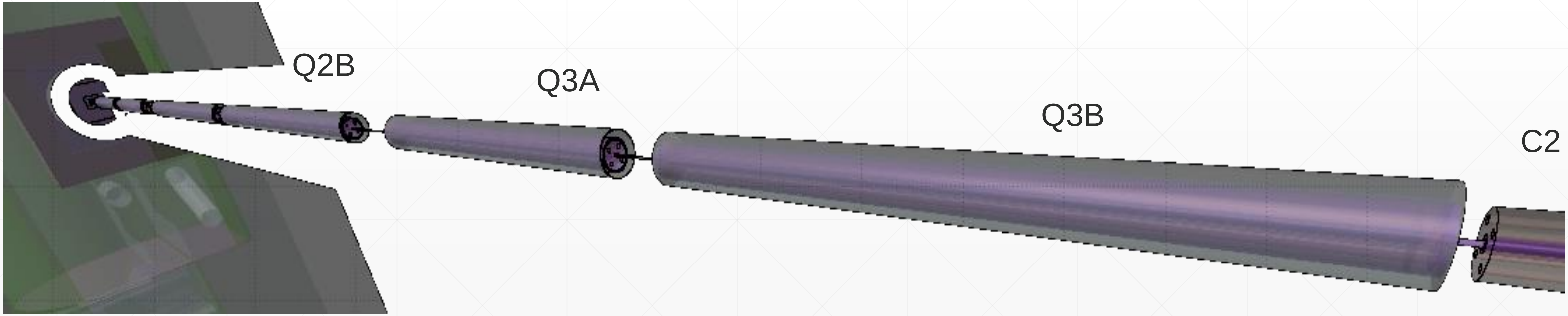


- An 80 cm long tungsten mask is placed in front of the quadrupole closest to the IP



Magnet Models

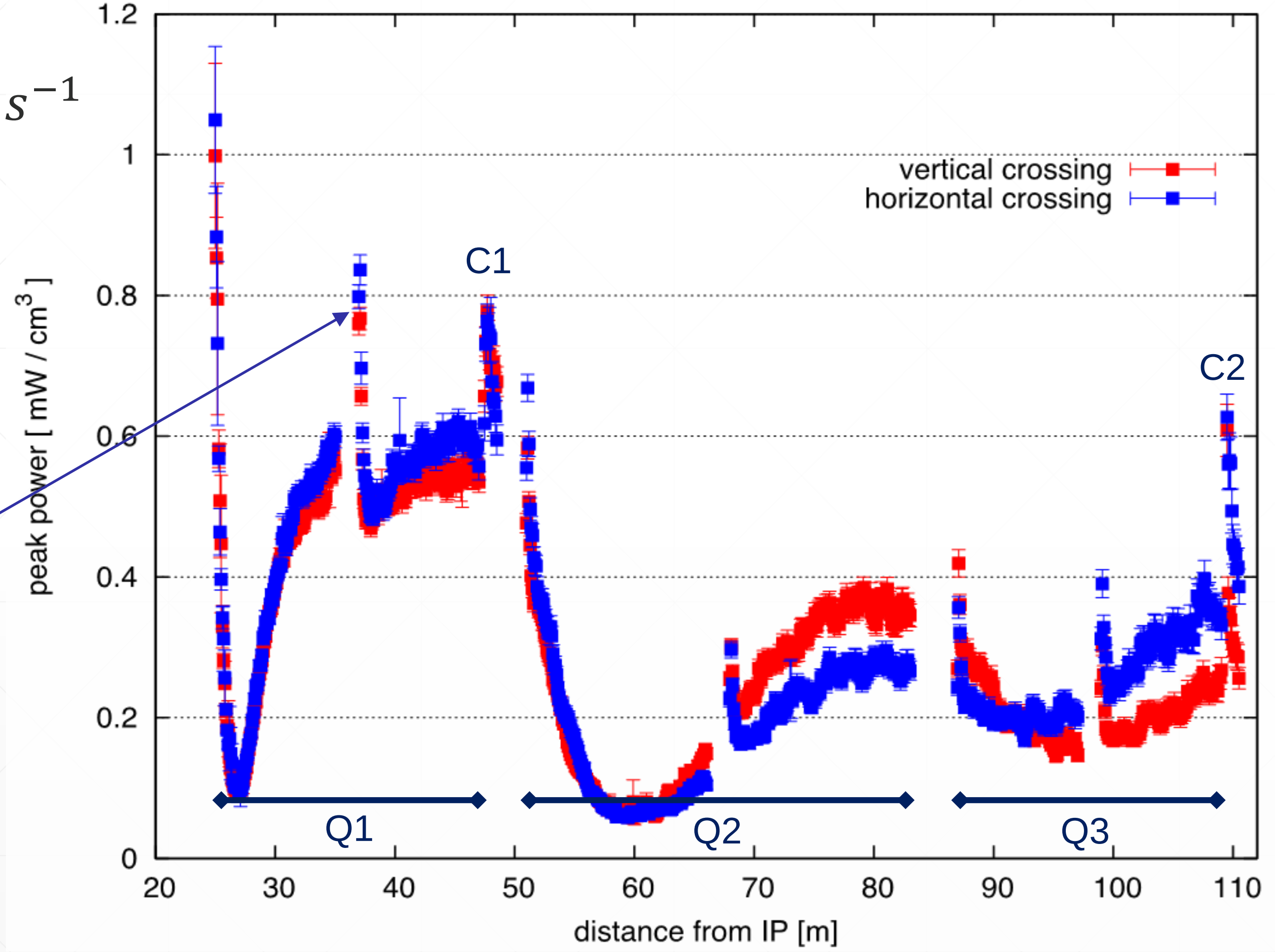
- Triplet quadrupoles also needed to be split and housed in separate cryostats
- 70 cm shielding gaps were assumed in the interconnects
- For the separation section after the triplet a design using superconducting dipoles was chosen to keep the section as short as possible which will also needed to be considered for energy deposition studies



Energy deposition

- For an instantaneous luminosity of $5 \cdot 10^{33}\ cm^{-2}s^{-1}$ the peak power density in the triplet is well below the current design limit of Nb_3Sn of $5\ mW\,cm^{-3}$

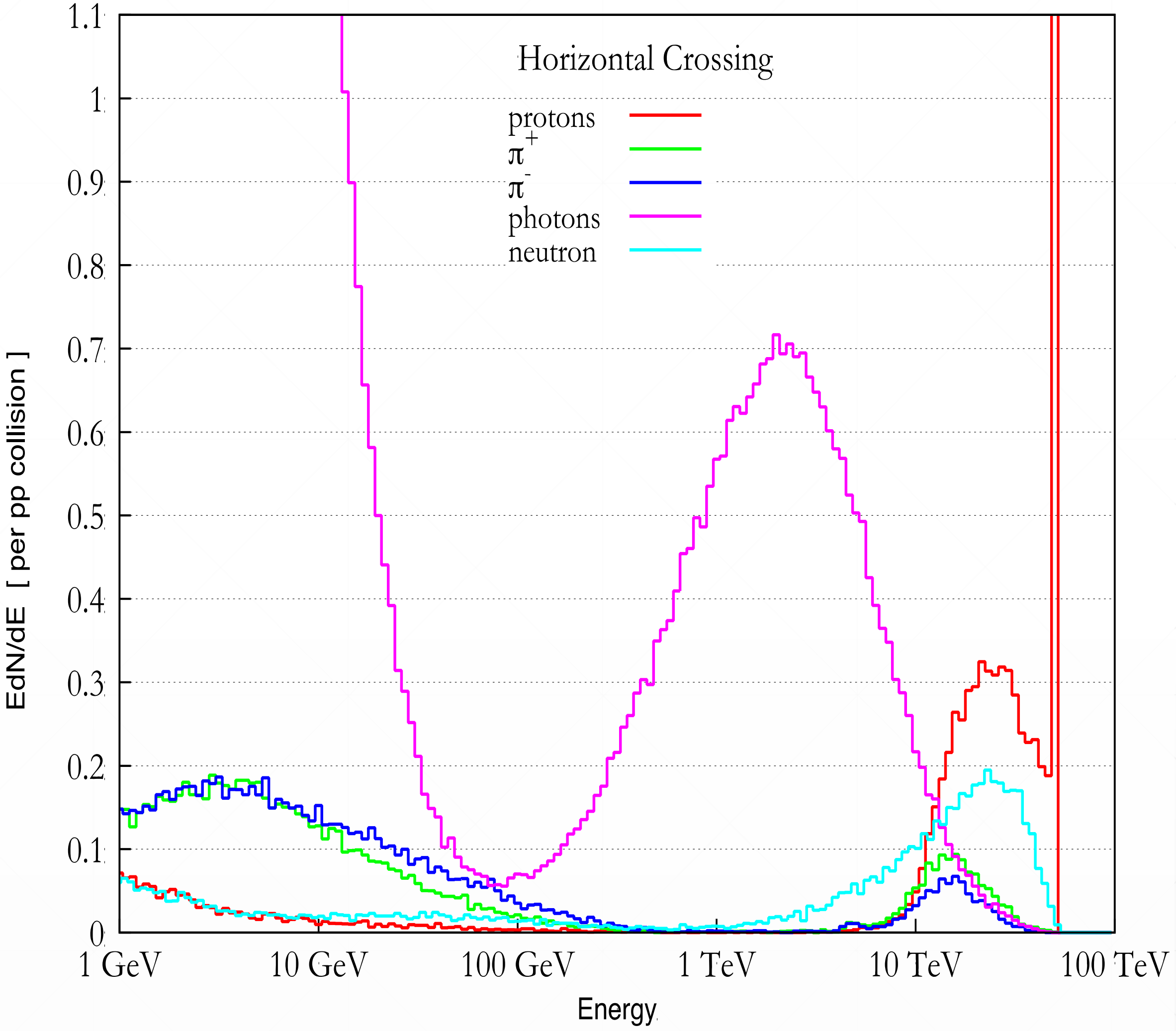
Effect of 70 cm shielding gaps in the interconnects from splitting the triplet quadrupoles clearly visible



Peak power density for $5 \cdot 10^{33}\ cm^{-2}s^{-1}$

Energy deposition

- Total Power for $5 \cdot 10^{33}\ cm^{-2}s^{-1}$: 4.3 kW per side
  - 1.7 kW deposited in the triplet
  - 2.6 kW going downstream
- maximum power per meter on Q1A for both crossing schemes: **~14.4 W/m**
- power on the **mask** in front of Q1A: **~280 W**
- Further simulations needed to understand where these particles will impact
  - Single diffractive protons (50 TeV) lost further downstream (DS, collimation section)
  - Lower energy protons (~25 TeV) and pions expected to be lost in D1, D2, TAN or MS
  - Neutral particles lost in TAN or further downstream



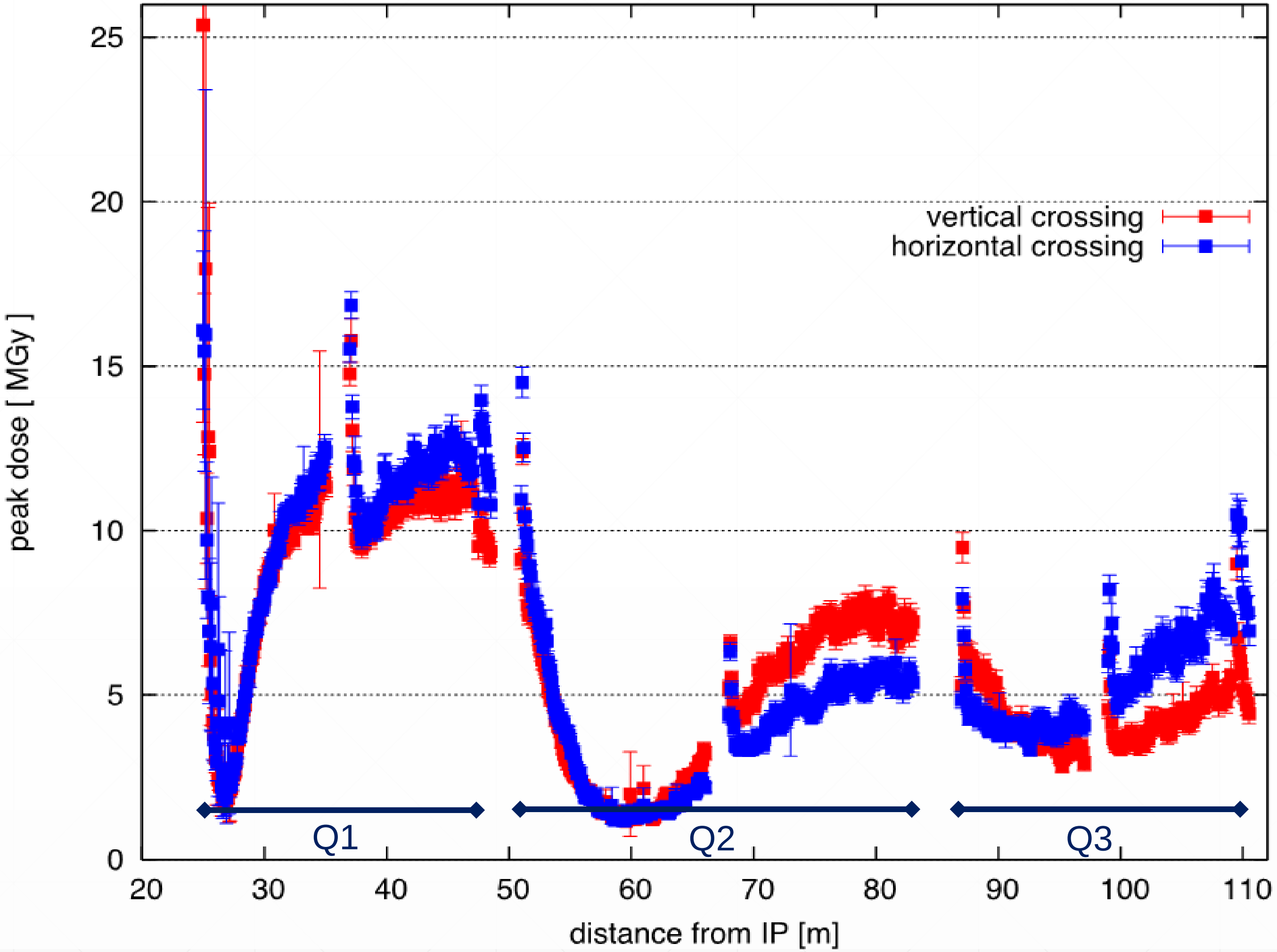
Particle Spectra at the exit of Q3B per collision

Energy deposition

- With the current baseline radiation limits $500\ fb^{-1}$ seems feasible

- In order to survive longer, options like thicker shielding with a higher β^*, switching the crossing plane or swapping the triplet quadrupoles in a LS could be explored

Current FCC-hh target radiation limits	
Baseline	30 MGy
Ultimate (R&D Goal)	250 MGy



Peak dose for $500\ fb^{-1}$

Conclusions and Outlook

- Since last FCC-week in Rome new, more compact FCC-hh layout with combined injection and experimental insertions as in the LHC
- A design for these insertion has been presented, which uses a L* of 25 m and achieves a β* = 3 m
- From energy deposition studies using the current baseline target radiation limits sets the attainable integrated luminosity to $500\ fb^{-1}$
- Many things to follow up:
  - Dynamic Aperture studies
  - Impact on particles escaping the triplet
  - Beam-Beam effects
  - Impact of injection failures on experiments and Studies for additional masks and injection protection elements

Thank you for your attention!

Reserve

Geology

“The favoured layouts avoid the Jura and Pre-Alps limestone whilst also avoiding exceptionally deep shafts in Points H, G and F, however it has proved difficult to simultaneously fulfil these criteria.”

See J. Stanyard, V. Mertens, J. Osborne, Y. Loo, C. Sturzaker, M. Sykes “Optimisation of the design of the future circular collider from a civil engineering perspective”,
in Proc.IPAC2017, Copenhagen, Denmark

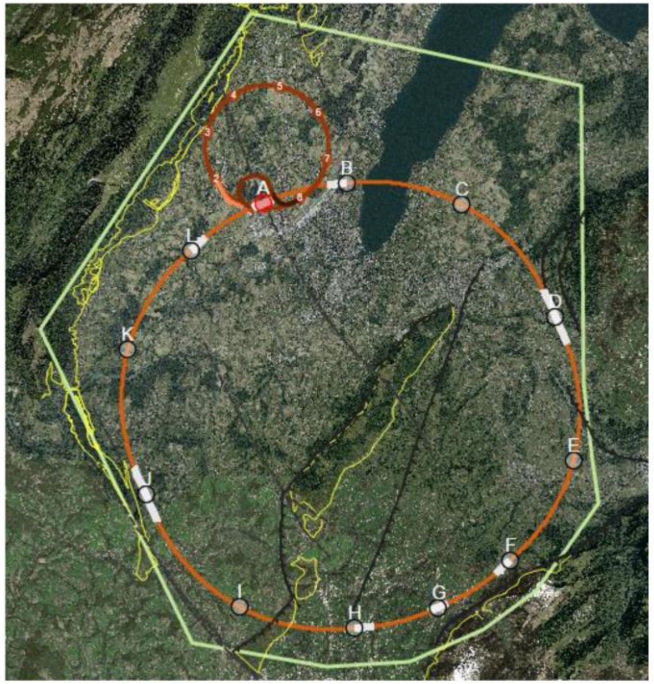


Figure 2: Example position of 97.75 km layout.

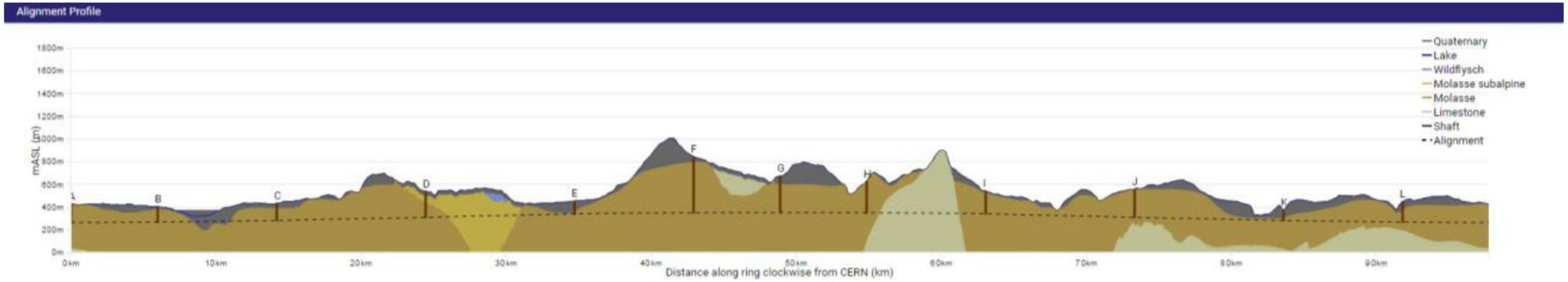


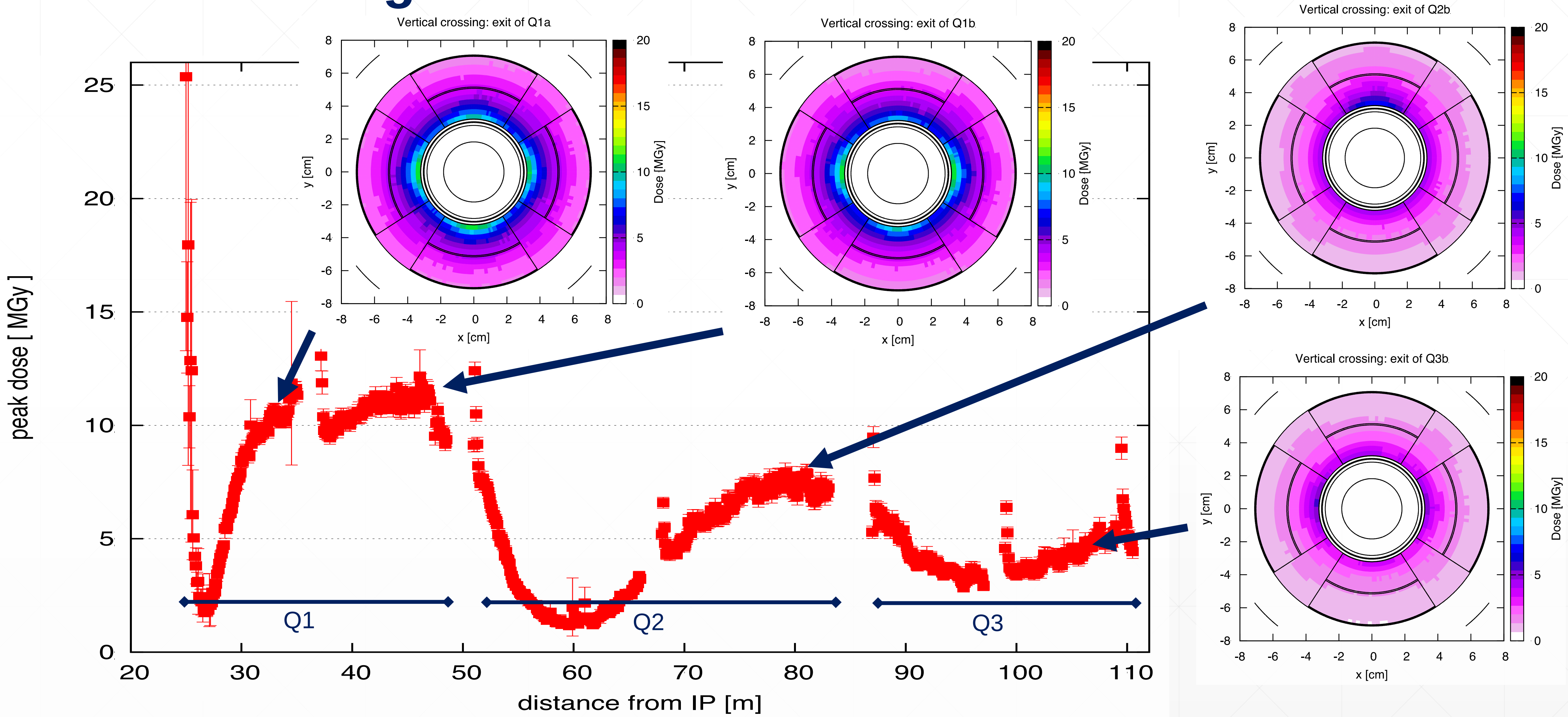
Figure 1: Example graphical output from TOT showing the geological profile.

Total Power deposited in triplet

Magnet	Power [W] vertical crossing			Power [W] horizontal crossing		
	Total	Shielding	Cold Mass	Total	Shielding	Cold Mass
Q1A	248.8	100.9	147.9	251.3	101.9	149.4
Q1B	267.9	182.7	85.2	269.0	183.7	85.3
C1	27.1	18.9	8.2	27.7	19.3	8.4
Q2A	118.1	82.3	35.8	119.3	83.3	36.0
Q2B	204.4	147.1	57.3	190.9	137.3	53.6
Q3A	111.1	76.7	34.4	112.9	80.3	32.6
Q3B	112.6	81.2	31.4	132.1	95.2	36.9
C2	14.7	10.7	4.0	17.5	12.8	4.7
Total on Magnets	**1104.6**	**700.6**	**404.1**	**1120.7**	**713.9**	**406.8**

- maximum power per meter on Q1A for both crossing schemes: **~14.4 W/m**
- power on the **mask** in front of Q1A: **~280 W**

Peak dose: Angular Position



Magnets

Type	Gradient [T/m]	Field [T]	Aperture [mm]	Length [m]	Units per IP
Triplet Q1	270	-	64	10	4
Triplet Q2	270	-	64	15	4
Triplet Q3	270	-	64	10	4
Separation Dipole D1	-	12	100	12.5	4
Recombination Dipole D2	-	10	60	15	4
Matching Quadrupole Short Type MQM	200	-	70	9.1	4
Matching Quadrupole Long Type MQML	300	-	50	12.8	6
Orbit Corrector	-	3	64	1	6

Parameters

β* during collision	3 m
β* during injection	27 m
Full crossing angle	39 µrad
Separation during injection	1.5 mm

Normalized emittance	$2.2\ \mu m$
Closed Orbit uncertainty	$4\ mm$
Momentum offset	$6 \cdot 10^{-4}$
β-beating coefficient	1.1
Relative parasitic dispersion	0.14