Experimental Insertions

R. Martin

FCC Week 2018
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On behalf of the EuroCirCol WP3 team

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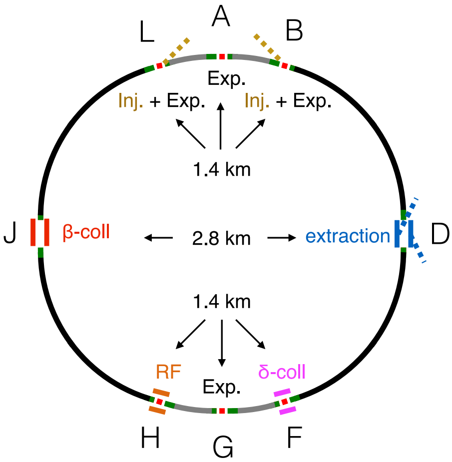
FCC-hh Layout



- LHC-like 2+2 interaction points
- 1.4 km straight section length
- Main experiments in Point A and G with $\beta^* = 0.3\,\mathrm{m}$
- "Low luminosity" experiments in Points L and B with $\beta^* = 3\,\mathrm{m}$
- 1400 m straight section in Points L and B to be shared with injection

FCC-hh parameter overview

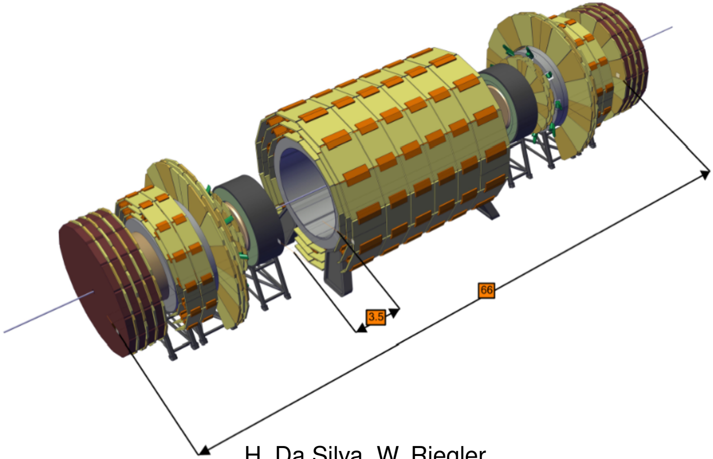
	FCC-hh Baseline	FCC-hh Ultimate
Peak luminosity/IP [$10^{34} cm^{-2} s^{-1}$]	5	30
Events/crossing	170 (34)	1020 (204)
Bunch spacing [ns]	25 (5)	
Bunch population $N_b [10^{11}]$	1.0 (0.2)	
Beam current [A]	0.5	
Norm. emittance [µm]	2.2 (0.45)	
IP beta function β^* [m]	1.1	0.3
Transv. emittance damping time [h]	1.1	
Beam beam parameter ξ_{bb}	0.01-0.02	0.03-0.05

Numbers in parentheses refer to 5 ns option

- Two parameter set with same beam current but different luminosity
- **Focus on Ultimate parameters**
- Integrated luminosity target: 17.5 ab^{-1}

Machine detector interface

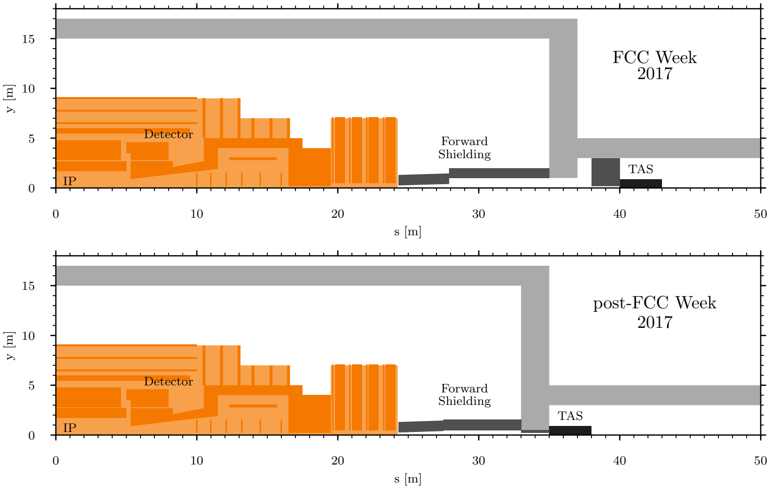
- Changes to **opening scenario**



H. Da Silva, W. Riegler

Machine detector interface

- Changes to **opening scenario** and **forward shielding**



Machine detector interface

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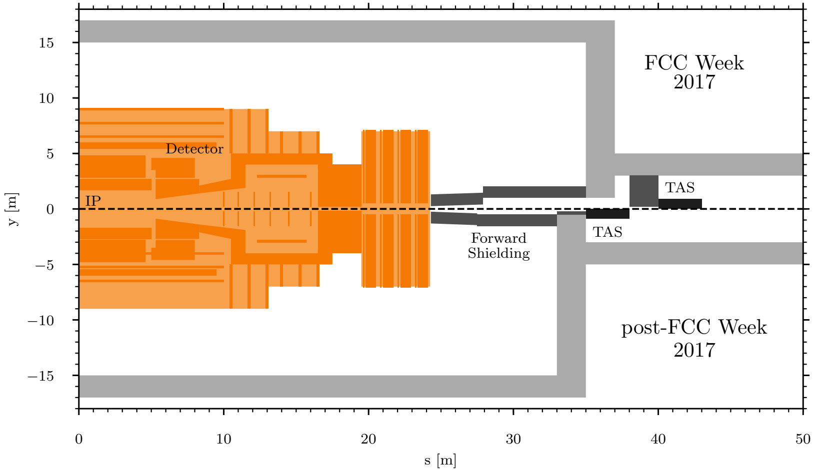
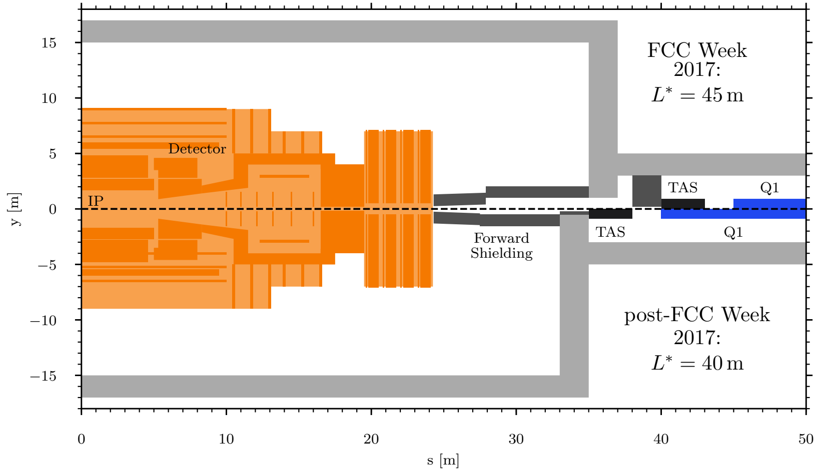
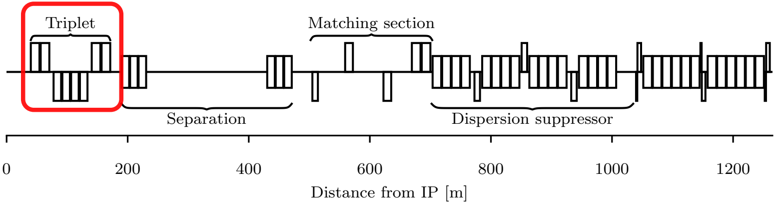


- Changes to **opening scenario** and **forward shielding**



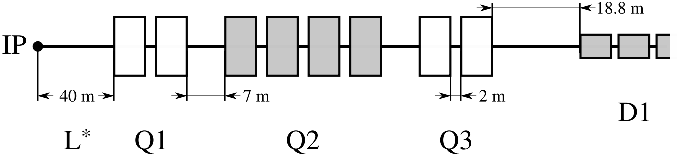
⇒ possible to **shorten L^* to 40 m**

Main IR optics: Triplet

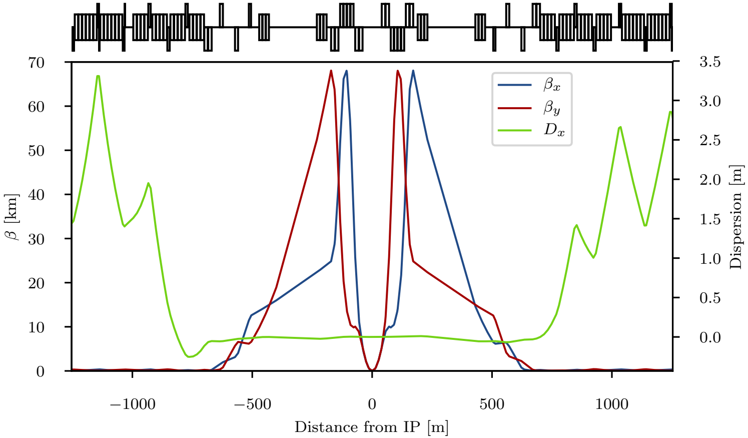


- With new L^* triplet gradients and apertures had to be adapted
- Magnet lengths reduced to fit into 15 m cryostats

	Q1	Q2	Q3
Coil Ø [mm]	164	210	210
Gradient [T/m]	130	105	105
Length [m]	14.3	12.5	14.3



Main IR Optics



Main IR optics for $\beta^* = 0.3\,\text{m}$.

- Peak β function decreased from 80 km to $\approx$ 70 km

Main IR Optics: Triplet

Thin shielding option:

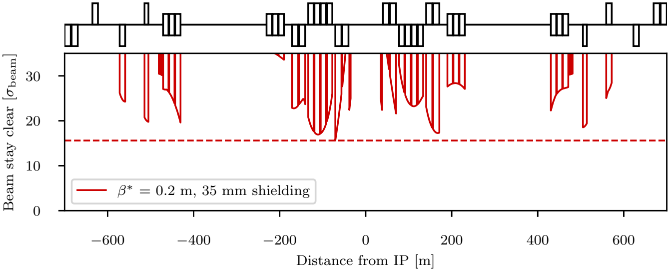
- Shielding thickness of 15 mm
- Aperture large enough to accomodate <u>$\beta^* = 0.1$ m</u>

Thick shielding option:

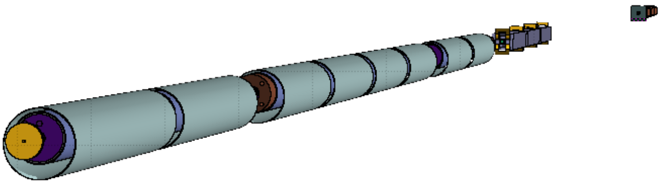
- Shielding thickness of 35 mm
- Aperture large enought to accomodate <u>$\beta^* = 0.2$ m</u>
- Higher survivable integrated Luminosity

Both options can reach β^* beyond Ultimate / have comfortable margins

Currently thick shielding option is preferred



Energy deposition from collision debris



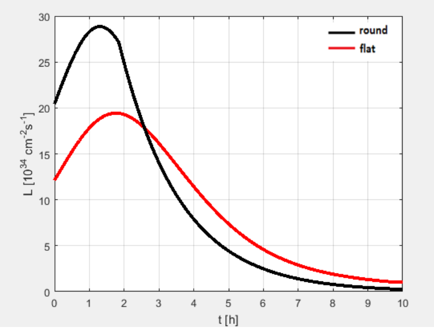
F. Cerutti, A. Infantino, J. Keintzel

- FLUKA studies now include IR up to D2
- Reduced aperture in new triplet **increased** radiation load
- **Peak power density** still **below** expected quench limit

More details in talk by F. Cerutti

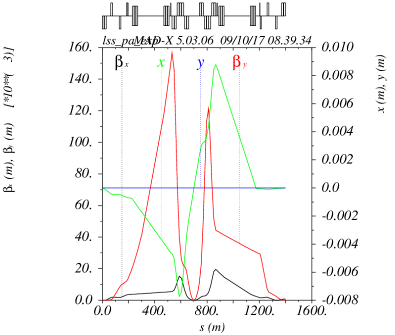
- Triplet coil insulator lifetime:
  - Peak dose 70 MGy at Ultimate goal of 30 ab^{-1}
  - Operational limit: 30 MGy
  - Crossing plane alternation and optimized triplet expected to reduce load below 40 MGy per 30 ab^{-1}
- Separation dipole needs shielding or mask for improved protection
- Significant power on shieding and absorbers

Alternative triplet: Flat optics



- Flat optics reached: $\beta^* = 0.15 \times 1.2\,\mathrm{m}$
- Round optics reached: $\beta^* = 0.2\,\mathrm{m}$
- Beam-beam effects for flat optics are being studied

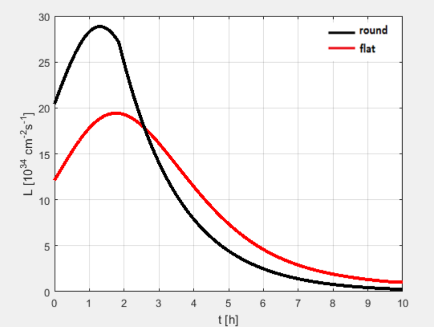
- Can operate **without crab cavities**
- Lower pile-up



J. L. Abelleira. L van Riesen-Haupt

More details in talk by J. L. Abelleira

Alternative triplet: Flat optics



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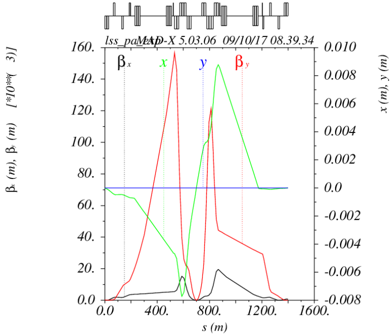

J. L. Abelleira. L van Riesen-Haupt

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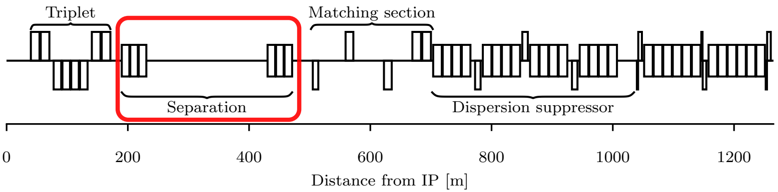
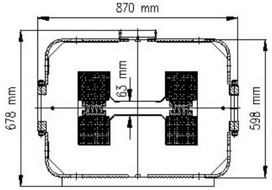
Beam-beam studies in talk by T. Pieloni

More details in talk by J. L. Abelleira

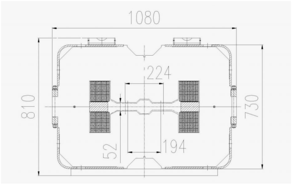
Main IR optics: Separation



- Dipole strengths were close to 2 T
- Redesigned to use normal conducting magnets
- Assuming LHC-like magnet designs
- Advantages:
  - Robustness in the highly radiative environment
  - Better field quality

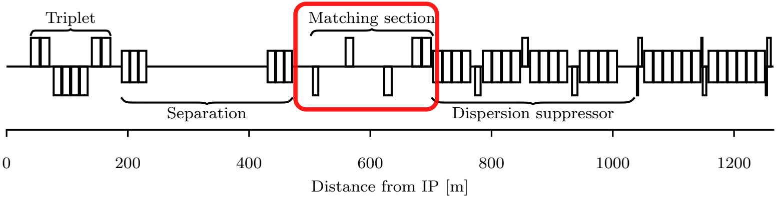


D1 (MBXW design)



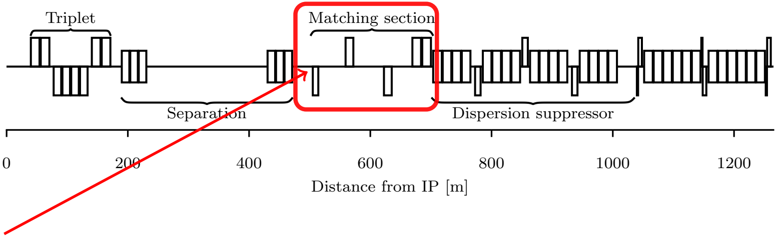
D2 (MBW design)

Main IR optics: Matching section



- **Crab cavities** between recombination dipole and first matching quadrupole
- First studies with varying degrees of orbit leakage:
  - Full crabbing at Ultimate parameters: $V_{\text{crab}} = 12.0\,\text{MV}$
  - Full crabbing at $\beta^* = 0.15\,\text{m}$: $V_{\text{crab}} = 18.5\,\text{MV}$
  - $\approx 20\,\text{m}$ of space reserved $\Rightarrow$ expected to be compatible with **full crabbing beyond Ultimate**
- Total IR length now complies with design goal of 1.4 km
- Matched optics found for $\beta^* \geq 0.15\,\text{m}$

Main IR optics: Matching section



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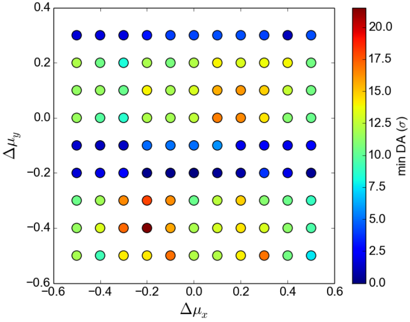
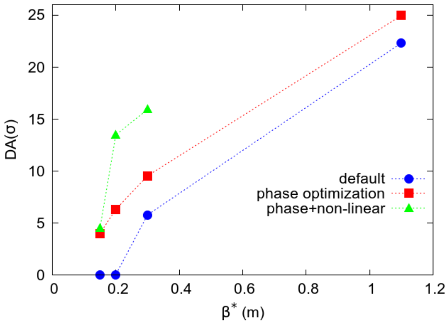
Dynamic aperture studies with collision optics



DA-phase scan

- Phase optimization significantly increased DA
- Non-linear correctors increase DA further $\Rightarrow$ necessary for $\beta^* < 0.3\,\mathrm{m}$

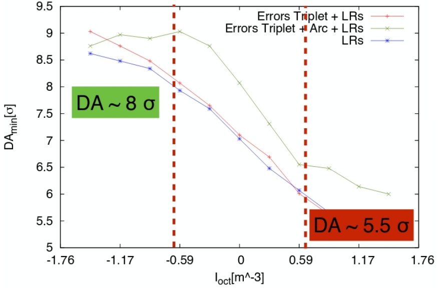
- DA of new lattice originally very low
- Tracking studies revealed **phase advance between main IPs** as crucial factor for DA

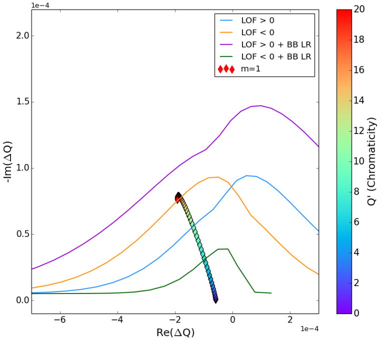


DA for round optics, $L^* = 40\,\mathrm{m}$

E. Cruz-Alaniz

More details in talk by E. Cruz-Alaniz





- Negative octupole polarity provides **better dynamic aperture** in presence of beam-beam effects

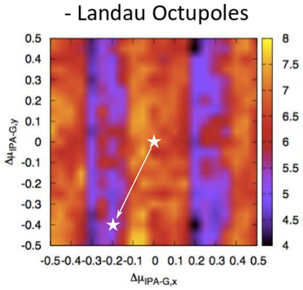
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE J. Barranco, X. Buffat, T. Pieloni, C. Tambasco

- Octupole strength with negative polarity **not sufficient** with high chromaticity operational scenarios ⇒ need for more octupoles...
- ... or e-lens / larger β functions in arcs / feedback

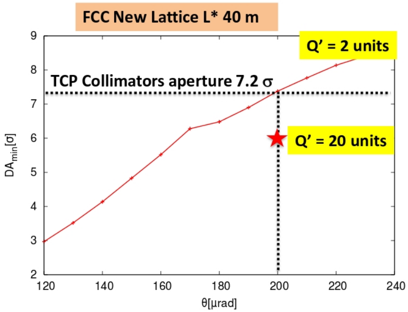
Talk by C. Tambasco on Thursday afternoon

Beam-beam effects

- Increase of crossing angle **from 180 µrad to 200 µrad** in the main IP is suggested:
  - Achieve **dynamic aperture of 6.0 σ**
  - Keeps **margins** for non-linear effect, e.g. magnet errors



Talk by T. Pieloni on Thursday afternoon



- Optimized phase advance reduces DA when Landau octupoles compensate beam-beam effects $\Rightarrow$ Different Phase advances at different stages of the operational cycle

J. Barranco, X. Buffat, T. Pieloni, C. Tambasco

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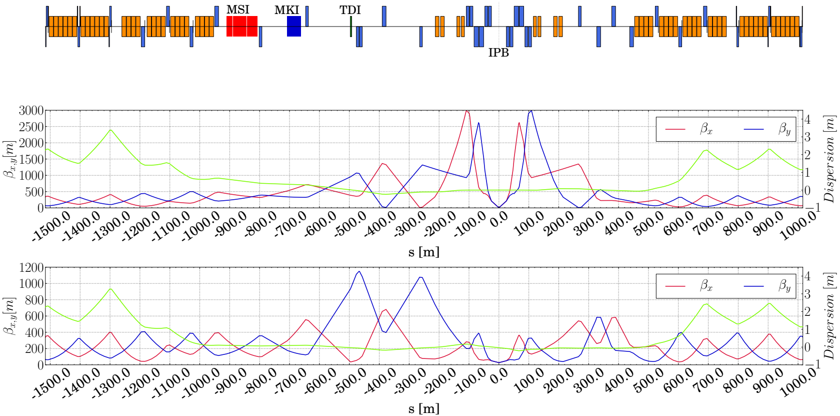
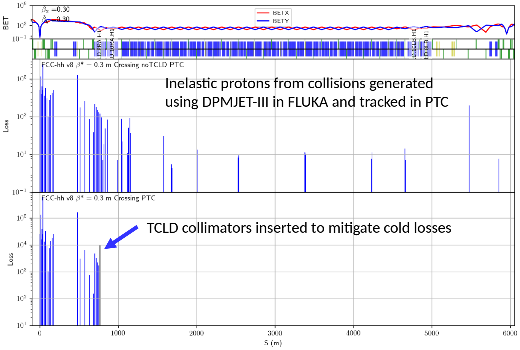
Low luminosity IRs

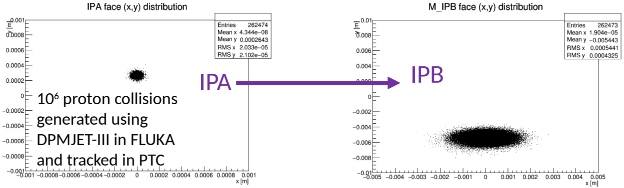


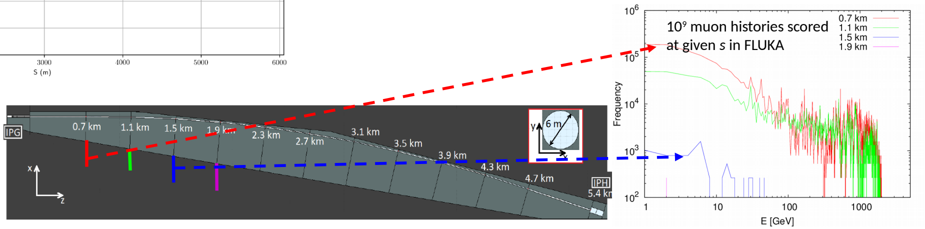
M. Hofer, F. Burkhard, E. Renner

- Combined with injection section
- No requirements from physics provided yet
- Low luminosity IRs provide $\beta^*_{\text{min}} = 3.0\,\text{m}$ with $L^* = 25\,\text{m}$
- Luminosity $\mathcal{O}(2 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1})$
- Triplet lifetime $\mathcal{O}(0.5\,\text{ab}^{-1})$

Detector cross-talk







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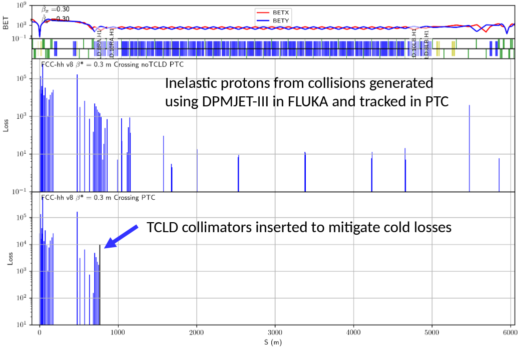

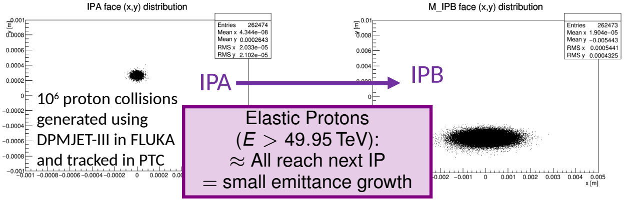

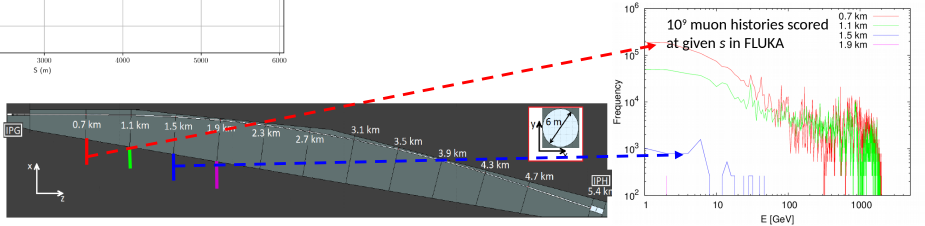

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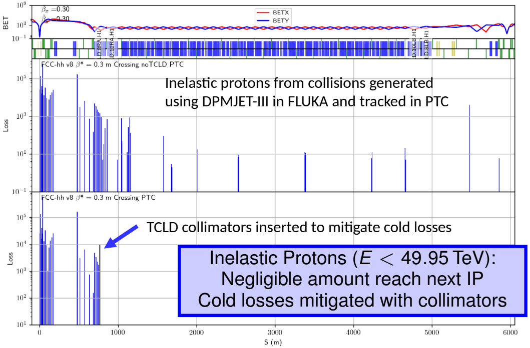
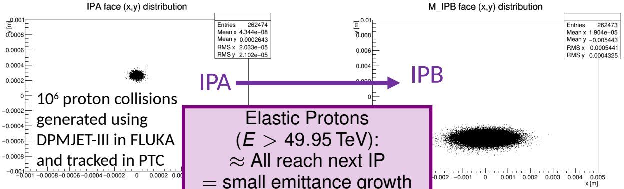
Detector cross-talk



Inelastic protons from collisions generated using DPMJET-III in FLUKA and tracked in PTC

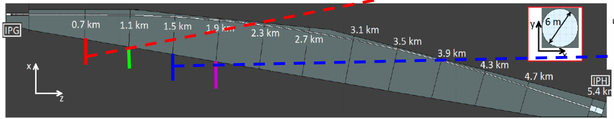
TCLD collimators inserted to mitigate cold losses

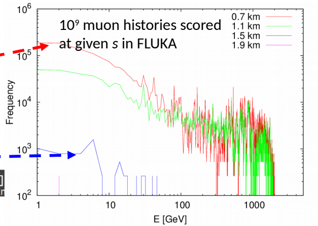
Inelastic Protons ($E < 49.95$ TeV):
Negligible amount reach next IP
Cold losses mitigated with collimators



10^6 proton collisions generated using DPMJET-III in FLUKA and tracked in PTC

Elastic Protons
($E > 49.95$ TeV):
$\approx$ All reach next IP
= small emittance growth





10^9 muon histories scored at given s in FLUKA

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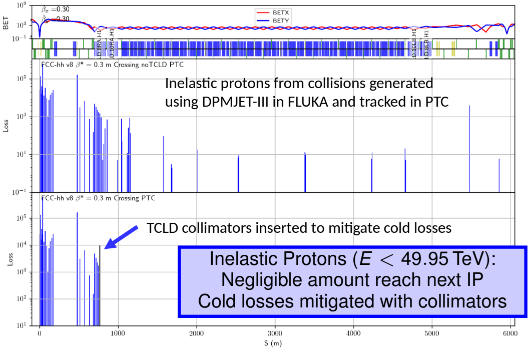

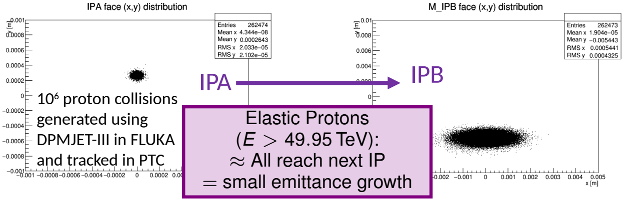

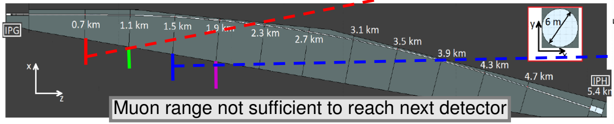

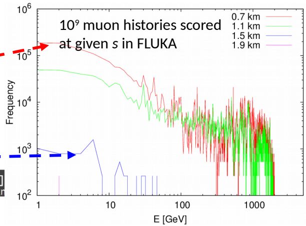

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Conclusions

- The main IR design **complies with the allocated length** and the manufacturing and transport **constrains for the cryostats**
- IR design leaves **comfortable margins** for Ultimate parameters
- Energy deposition shows **no show stoppers**
  - Main IR: $\approx$ 13 ab^{-1} triplet lifetime but $>$ 20 ab^{-1} expected with mitigation measures
  - Low luminosity IR: $\approx$ 0.5 ab^{-1} triplet lifetime
- Alternative IR design that **does not require crab cavities** is being studied with promising results so far
- Optimized dynamic aperture at collision optics significantly **above 12 σ** with non-linear correctors
  - study includes non-linear triplet errors...
  - ... but no beam-beam effects
- Dynamic aperture **with beam-beam effects**, octupoles and increased crossing angle above 6 σ
  - triple errors not included
- Low luminosity IP design can reach $\beta^* = 3.0\,\mathrm{m}$ with $L^* = 25\,\mathrm{m}$
- **Detector cross talk** was determined to be **negligible**

Outlook

- Implementation and simulation of **radiation mitigation strategies** in new IR lattice
- Beam-beam studies indicate need for **larger crossing angle**
- Impact of beam-beam effect on **collimation** to be studied
- **Optimum phase advance** between IPs to be found for Beam-Beam + octupoles + field errors
- Damping of instabilities non-trivial: **higher number of octupoles, e-lens, larger arc β functions and wideband feedback system** are being discussed