FCC-ee IR magnetic element design – an update

M. Koratzinos

18/1/2017

The story

- Over the last three years we have completed a design of magnetic elements that fit all our requirements with a minimal system comprising a screening solenoid and a compensating solenoid.

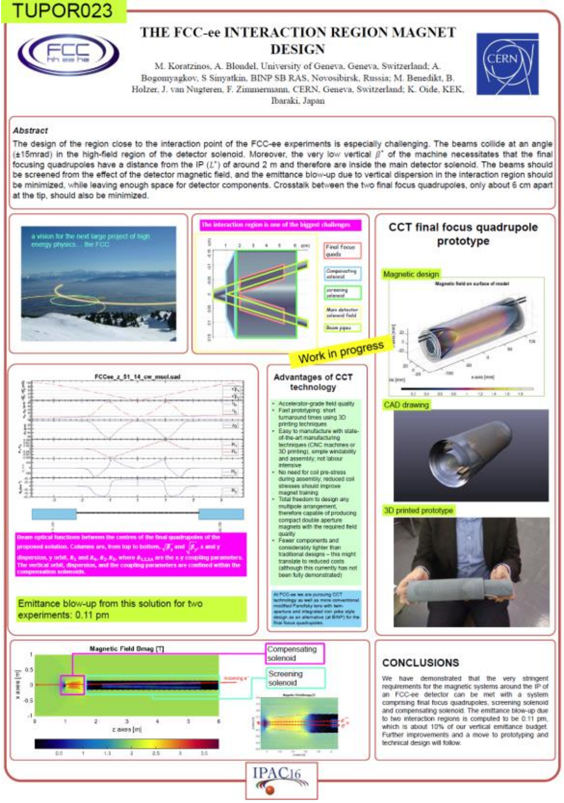
State of play

- Initially the baseline solution was the one where the first magnetic element (the compensating solenoid) was at an L* of 1.0m.
- This was deemed not sufficient as the space left for the luminometer was inadequate.
- That design however satisfied our emittance blow-up requirement (and all other requirements for the IR regarding field integral and value of solenoid field at the position of the quadrupole)
- We have redesigned things making sure that the luminometer fits – the final design is a bit more “fat” than the original design

IPAC 2016

- A paper was published for IPAC 2016. It contains our baseline design.

Poster. Presented by F. Zimmermann



THE FCC-ee INTERACTION REGION MAGNET DESIGN

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M. Benedikt, B. Holzer, J. van Nugteren, F. Zimmermann, CERN, Geneva, Switzerland
K. Oide, KEK, Tsukuba, Japan

Abstract

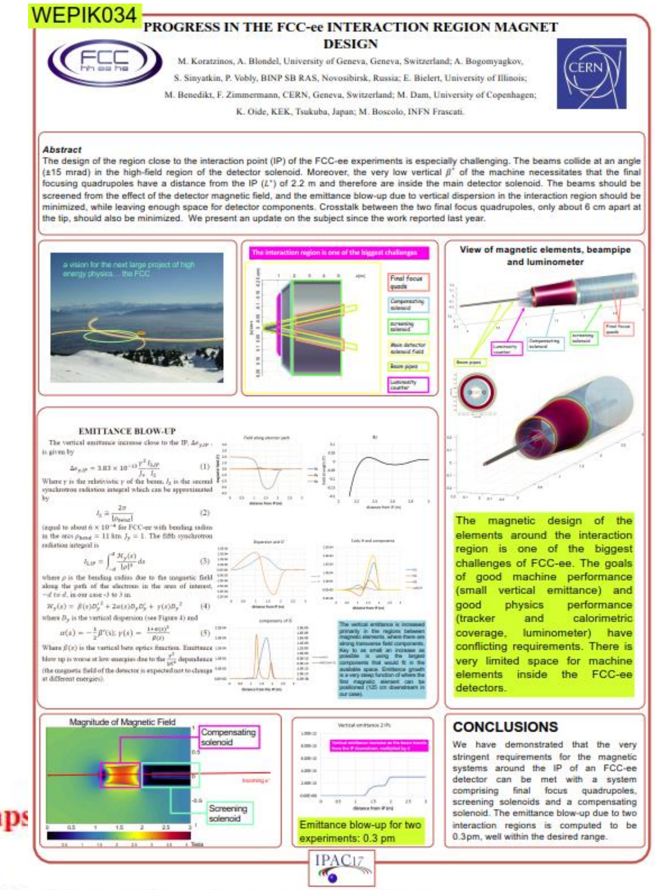
The design of the region close to the interaction point of the FCC-ee [1] [2] experiments is especially challenging. The beams collide at an angle (±15 mrad) in the high-field region of the detector solenoid. Moreover, the very low vertical β^* of the machine necessitates that the final focusing quadrupoles have a distance from the IP (L^*) of

solenoid field. It starts at around 2 m from the IP and extends all the way to the endcap region of the detector.

The *compensating solenoid* sits in front of the screening solenoid, has a field higher than that of the detector solenoid, so that the magnetic field integral seen by the beam is zero. In our design the length of this solenoid is around 0.7m, and its strength is approximately 5 T.

The *final focus quadrupoles* in our current design sit at a

IPAC 2017



PROGRESS IN THE FCC-ee INTERACTION REGION MAGNET DESIGN

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Abstract

The design of the region close to the interaction point (IP) of the FCC-ee [1] [2] experiments is especially challenging. The beams collide at an angle (±15 mrad) in the high-field region of the detector solenoid. Moreover, the very low vertical β^* of the machine necessitates that

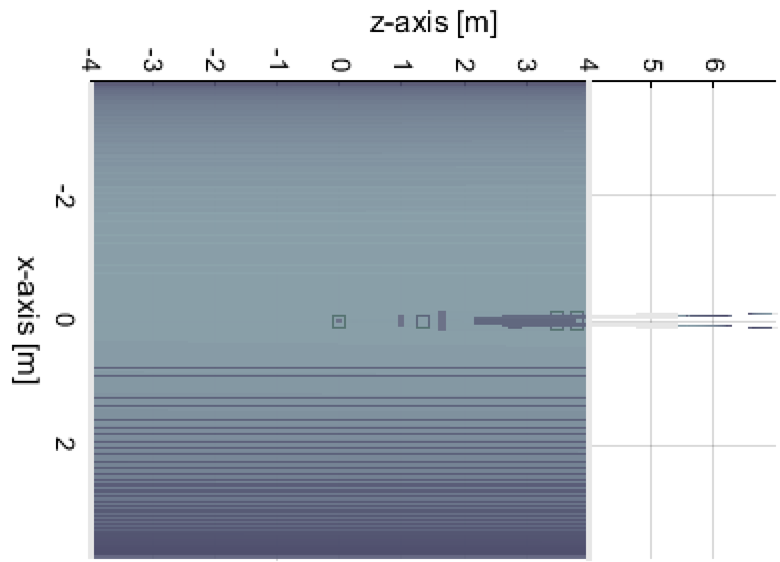
blow up is a very steep function of the position of the first magnet element, the whole design had to be readjusted.

Furthermore, the magnetic elements cannot occupy a space outside the acceptance of the luminosity counter (140 to 170mrad) as this would impact the physics performance.

Another requirement comes from the magnitude of the

Realistic detector solenoid

- I have now included a realistic detector solenoid according to the latest design. (up to now I had a constant and universal field of 2T)
  - solenoid dimensions 3.76m(inner radius) (outer radius 3.818m) × 4m (half-length)

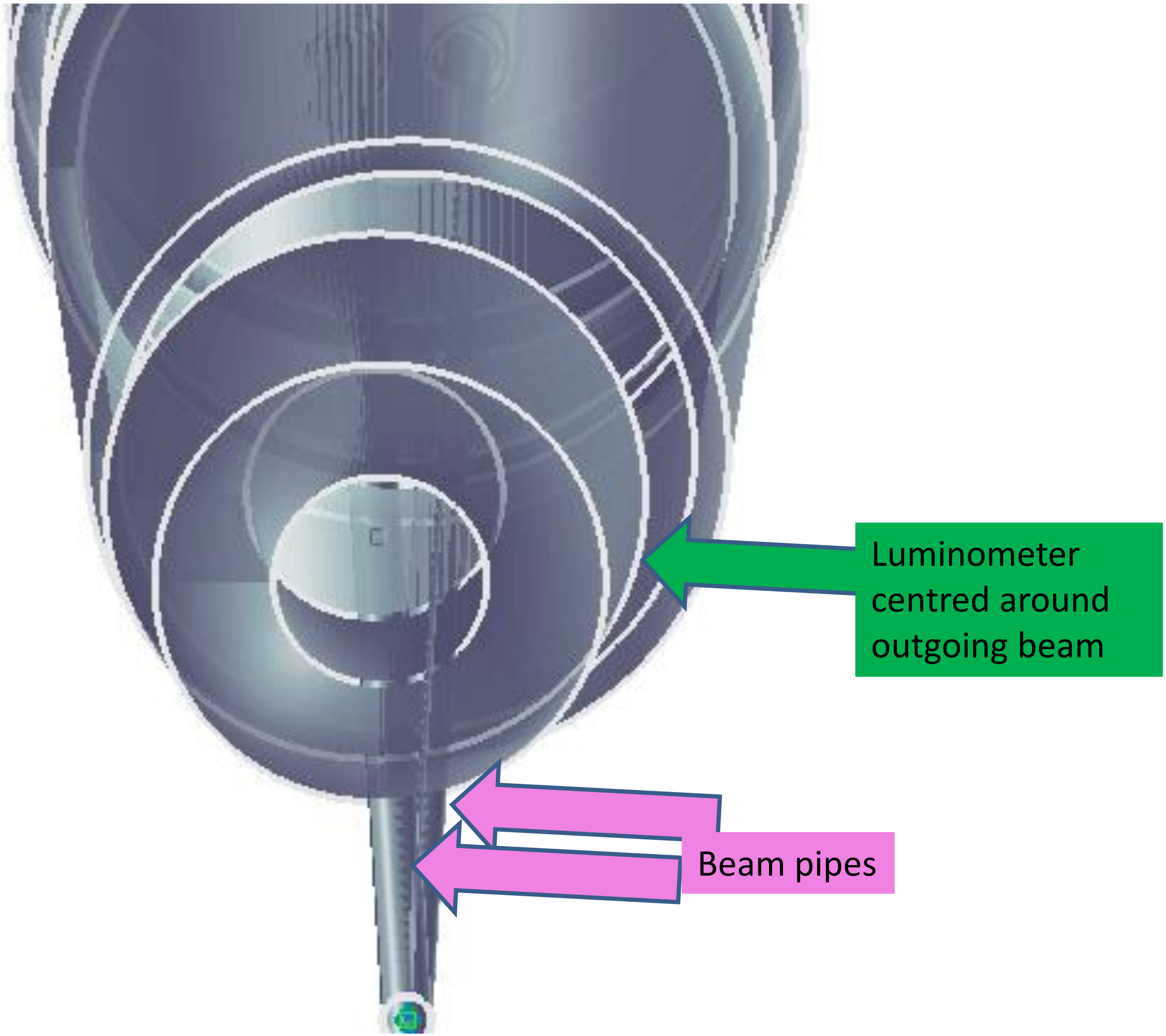


Positioning the luminometer

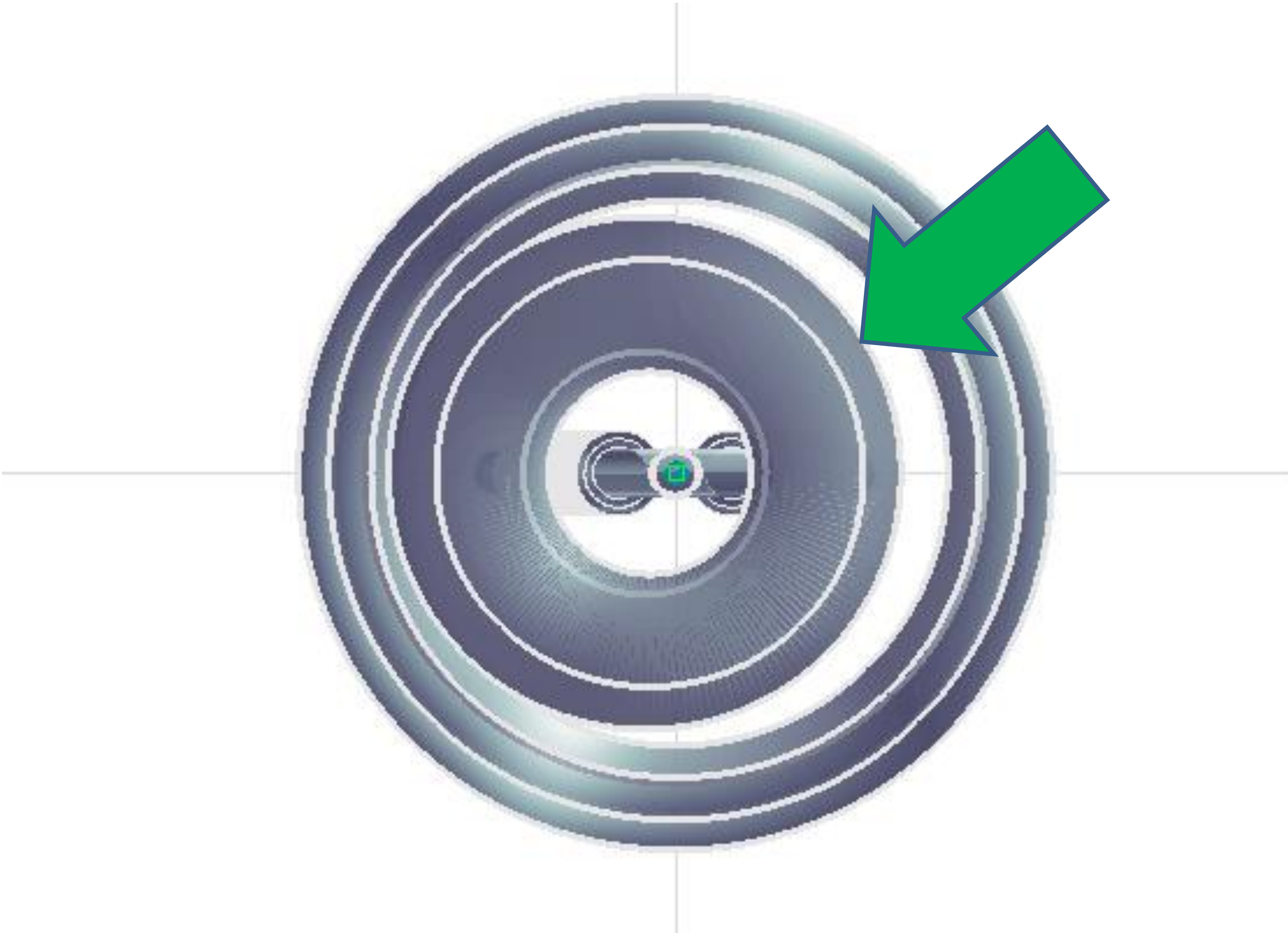
- I have positioned the luminometer between 100cm and 120cm in Z, tilted it by 15mrad and centered it around ougoing beam pipe.
- The edge of the luminometer is at 140mrad (the other side at 110mrad)

Lumi counter wrt the rest of the magnetic systems

Lumi counter wrt the rest of the magnetic systems

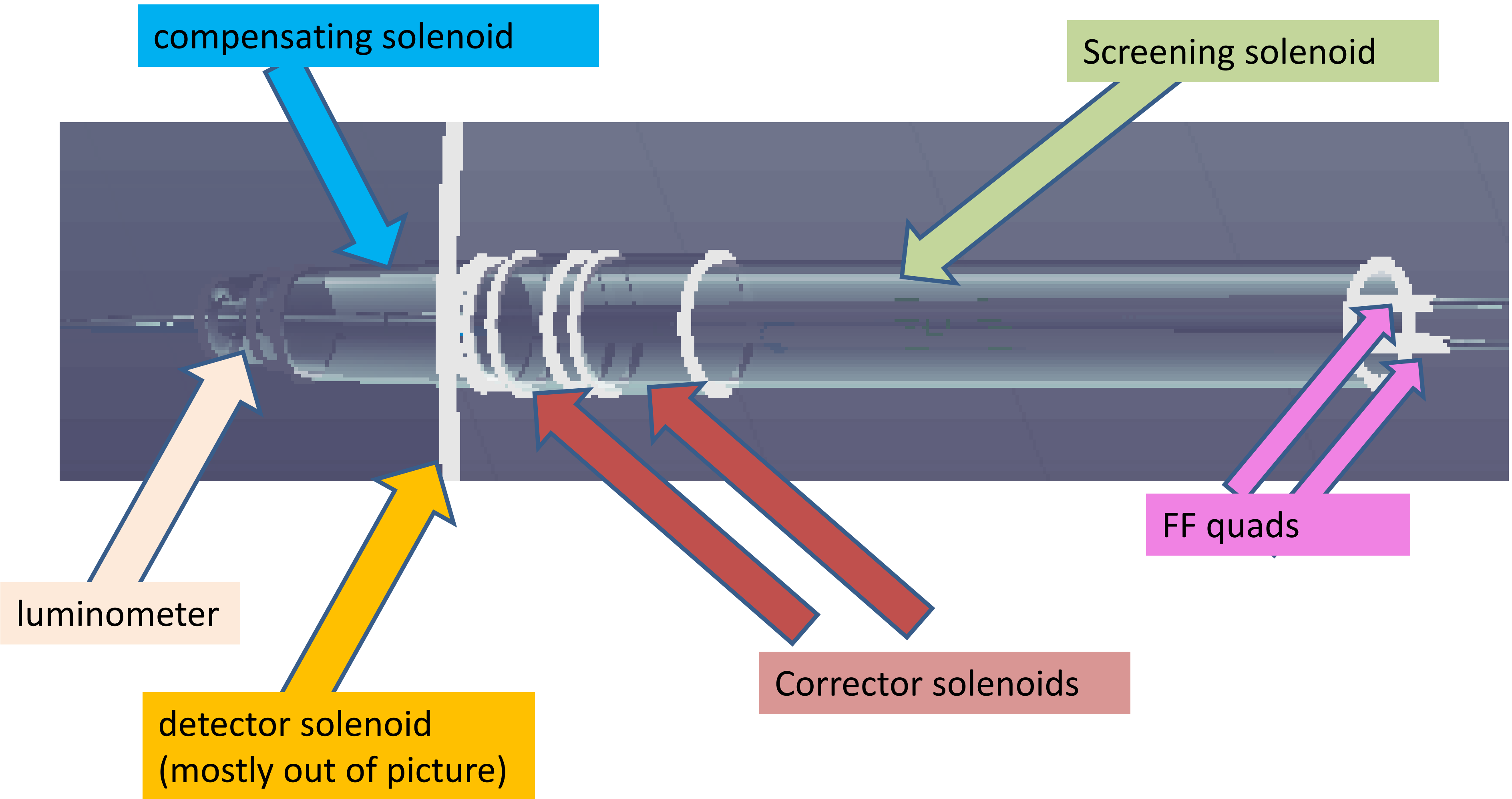


From the centre of the detector



More modifications

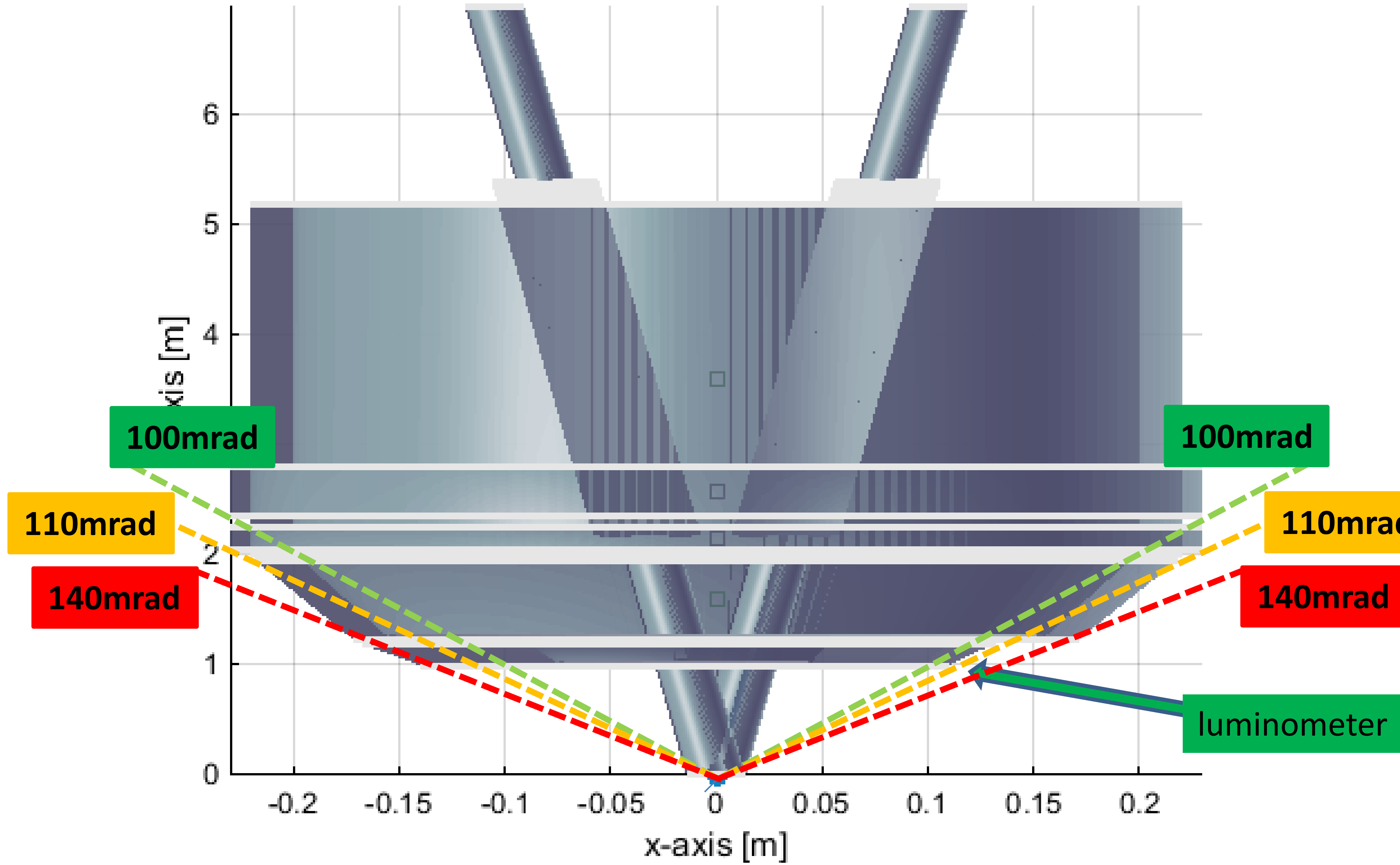
- Two extra solenoid corrector coils, to give more flexibility



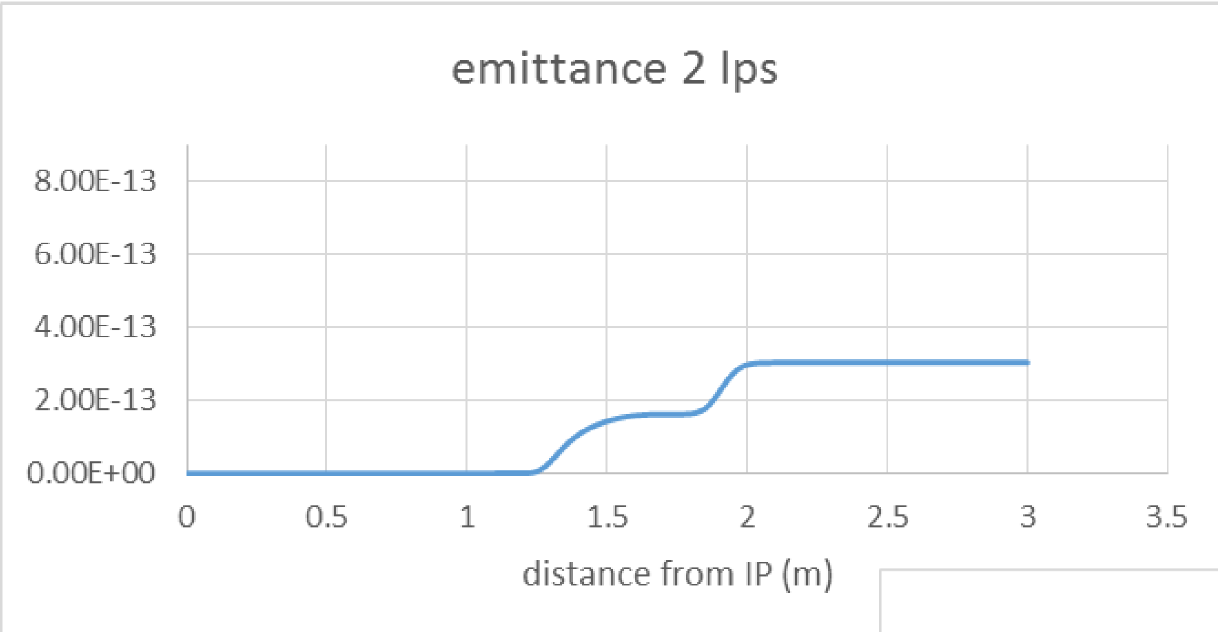
Further improvements

- I have moved things around to get better results
- Now the first element starts at 125cm and not 130cm from the IP – there are still 5cm between the luminometer and the compensating solenoid (just the length of a thin cryostat…)
- The screening solenoid has increased in diameter from 40cm to 44cm (i.e. does not fit in the envelope of the 100 mrad cone, but is fully in the shadow of the luminometer)
- End result is good: emittance blow-up down to **0.3pm** for 2IPs

Latest layout

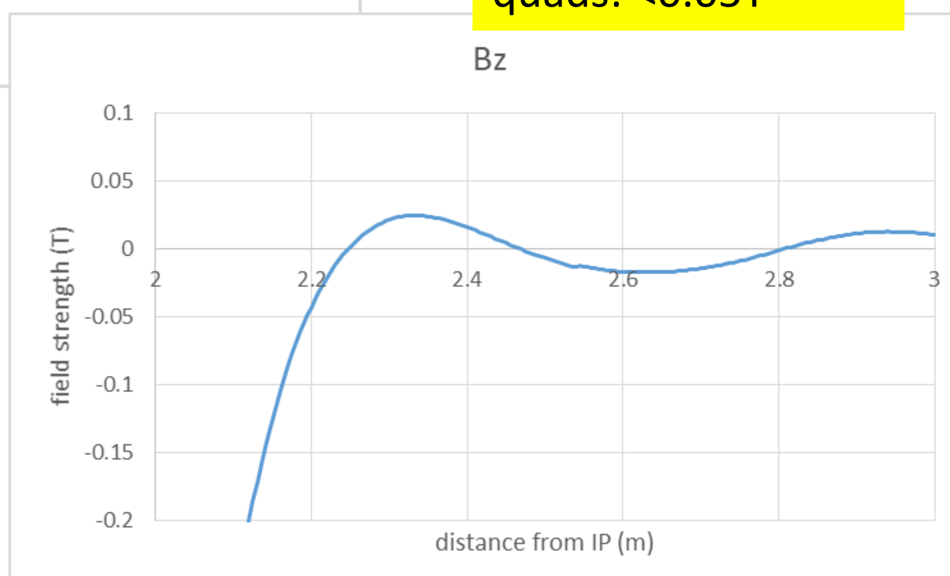


Results



Total emittance blow-up = 0.3pm

Remnant field at quads: <0.05T

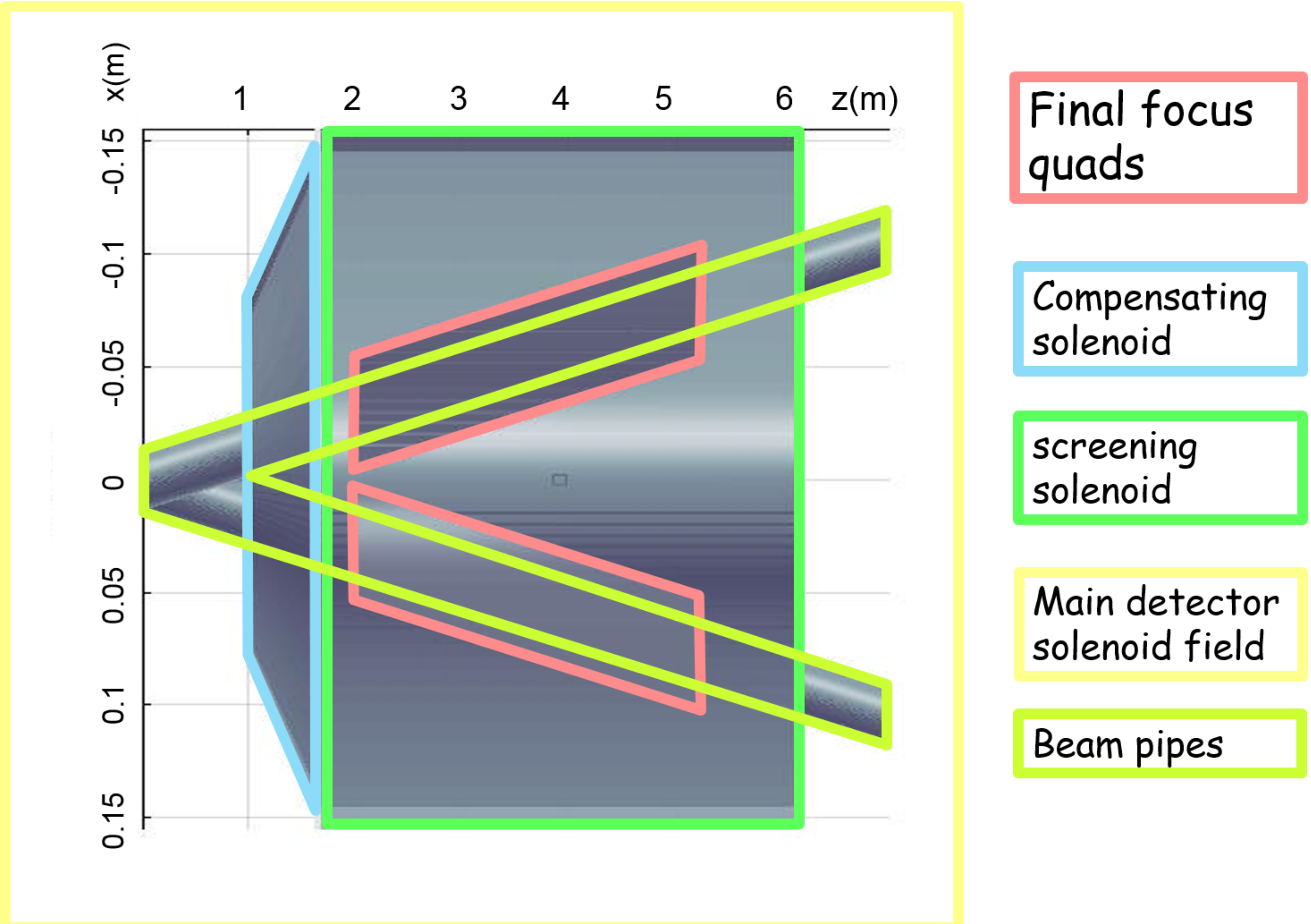


Backup slides

Related talks

- A talk in this group of meetings (the 9th) on 11/11/15 (https://indico.cern.ch/event/458740/)
- A talk on the 30th FCC-ee optics meeting (https://indico.cern.ch/event/533299/)
- A talk on the 10th FCC-ee physics workshop (https://indico.cern.ch/event/469576/timetable/)
- A talk on the 27th FCC-ee accelerator meeting 7/12/2015 (https://indico.cern.ch/event/464623/)
- A talk on the FCC-ee physics meeting 30/11/2015 (https://indico.cern.ch/event/446553/)

The IR region - baseline



Emittance blow up

More important at low energies!

Some formulas:

- Vertical emittance blow up at the IP:

$$\Delta\epsilon_y = 3.83 \times 10^{-13} \frac{\gamma^2}{J_y} \frac{I_{5,IP}}{I_2}$$

- $I_2 \cong \frac{2\pi}{|\rho_{bend}|}$ (for ρ=11km, $I_2 = 0.00057$)
- $I_{5,IP} = \int \frac{\mathcal{H}_y(s)}{|\rho|^3} ds$
- $\mathcal{H}_y(s) = \beta {D'_y}^2 + 2\alpha D_y D'_y + \gamma {D_y}^2$, D is the dispersion

where $\alpha(s) = -\frac{1}{2}\beta'(\mathrm{s})$; $\gamma(s) = \frac{1+\alpha(s)^2}{\beta(s)}$

Calculation of dispersion

- Vertical dispersion is simply the beam offset in y:

$$D(s) = -y(s)$$

- For the optimization I perform the computation numerically. The final version goes through the full SAD calculation
- The agreement between the two methods is very good.

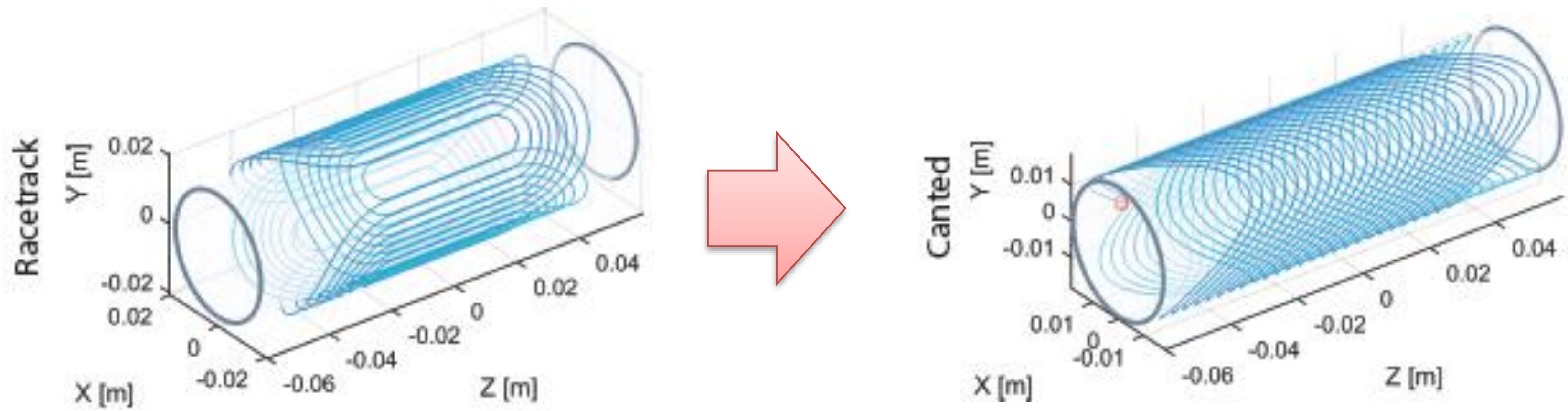
Second challenge: the FF quads

In the words of E. Paoloni:

Why I.R. Quadrupoles Are Not Easy Pieces

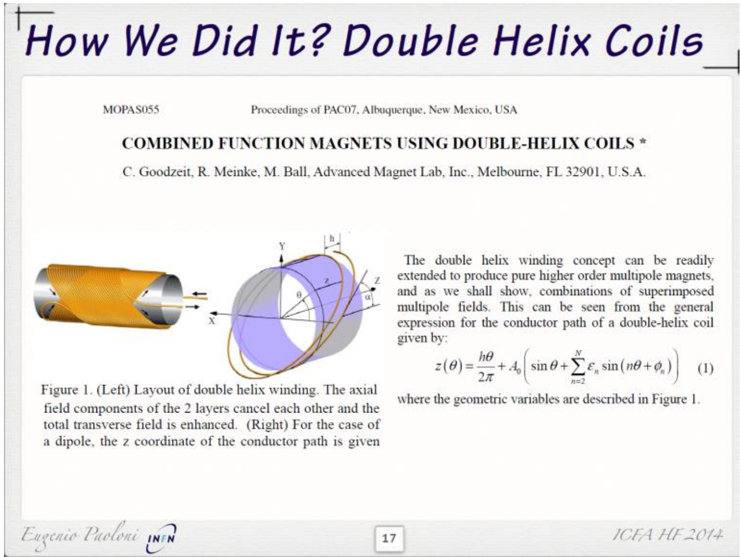
- Usually:
  - they are the strongest quadrupoles of the lattice
  - the β_y (β_x)function reaches her maxima at the QD0 (QF1): the mechanical aperture is large
  - their field quality must be excellent to preserve dynamic aperture
  - their thickness is limited by the detector acceptance (single ring), nearby beam line (two rings): they are thin

CCT magnets



…are very simple objects

- They comprise two coils on two concentric cylinders
- Each coil produces a solenoid field plus an arbitrary multipole field (dipole, quad, sextupole…)
- The two solenoid fields from the two coils exactly cancel
- Grooves are precisely defined for winding the cable on a substrate which could be metal (aluminium) or plastic (bluestone)



How We Did It? Double Helix Coils

MOPAS055 Proceedings of PAC07, Albuquerque, New Mexico, USA

COMBINED FUNCTION MAGNETS USING DOUBLE-HELIX COILS *

C. Goodzeit, R. Meinke, M. Ball, Advanced Magnet Lab, Inc., Melbourne, FL 32901, U.S.A.

Figure 1. (Left) Layout of double helix winding. The axial field components of the 2 layers cancel each other and the total transverse field is enhanced. (Right) For the case of a dipole, the z coordinate of the conductor path is given

The double helix winding concept can be readily extended to produce pure higher order multipole magnets, and as we shall show, combinations of superimposed multipole fields. This can be seen from the general expression for the conductor path of a double-helix coil given by:

$$z(\theta)=\frac{h\theta}{2\pi}+A_0\left(\sin\theta+\sum_{n=2}^{N}\varepsilon_n\sin(n\theta+\phi_n)\right) \quad (1)$$

where the geometric variables are described in Figure 1.

Eugenio Paoloni INFN 17 ICFA HF 2014

THANK YOU

Heat load and cooling needs

According to E. Belli:

- For the most difficult case, QC1L1
- e-cloud: for SEY=1.1 ~20W/m, for SEY=1.2 ~200W/m
- resistive wall: for copper, ~100W/m
- direct SR heating: zero (I assume that masks will take all direct SR)

From the above, the heat load appears to be O(100)W/m

Possible solution for cooling

- Warm beam pipe with water cooling
  - Black body radiation at 300K is ~500W/m2
  - The beam pipe close to QC1L1 is 0.13m2
  - Emissivity of polished copper 0.023 to 0.052
  - Assume emissivity of 0.05 (we can do a factor 2 better)
  - Heating power due to radiation: 500X0.13X0.05=3.2W
  - With one radiation shield, we can cut this by half to 1.6W
  - For comparison:
    - LHC magnet, arc: 0.2W/m
    - LHC triplet: 7-9W/m
- Water flow needed: for a 10 degree inlet-outlet difference, 1 lt of water per minute: 4/60*4*10=0.6kW
- Another calculation: for a rate of 1 lt/min and 100W load, water temperature rise is 1.5 degrees. – not challenging

addendum

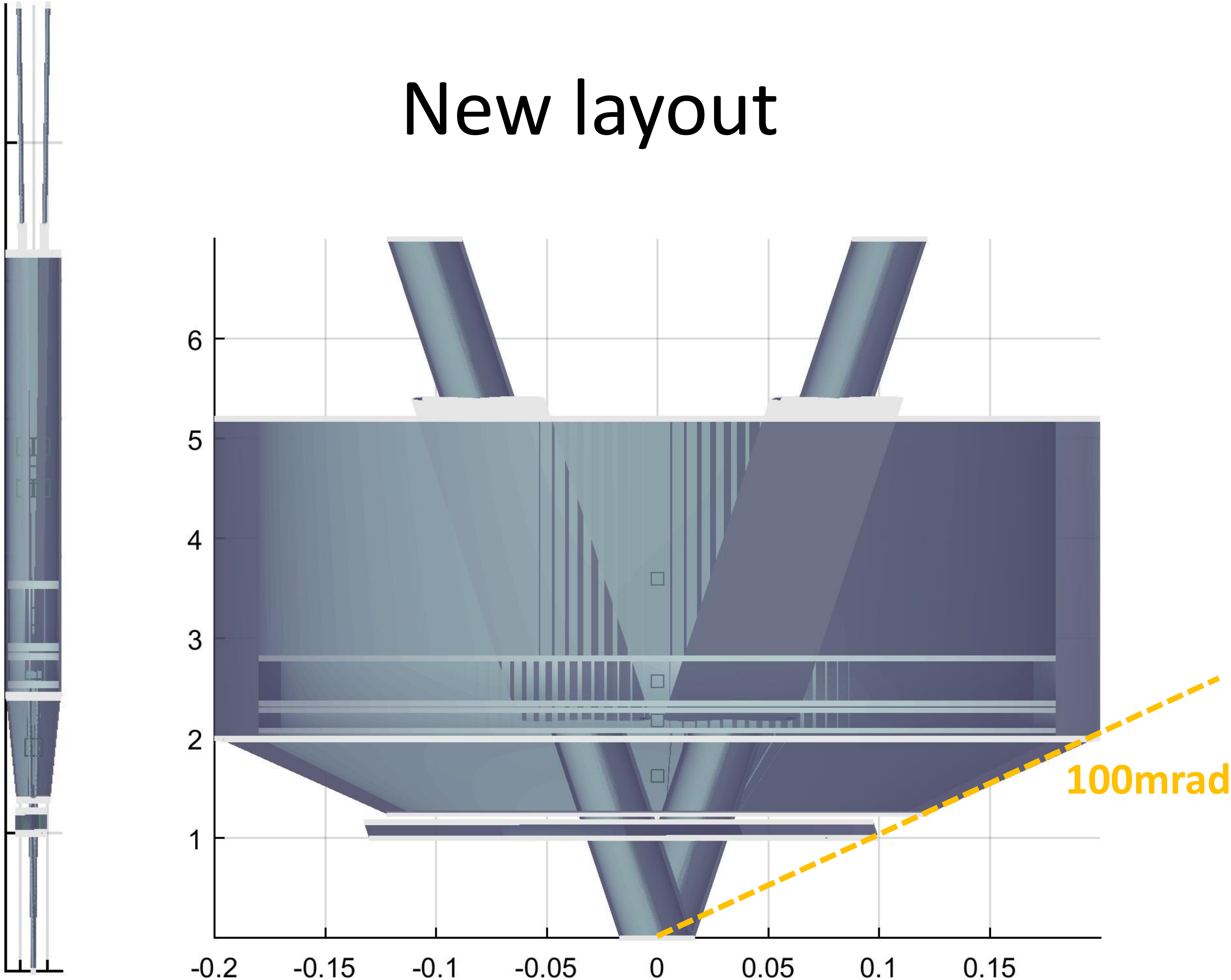
7/2/2018

M. Koratzinos

What's new

- I was asked to redesign the IR magnets sticking to the original 100mrad cone
- I have done so. Please note that only the coils are within the 100mrad cone. The cryostat will be outside the cone.
- Longitudinal dimensions have not changed. Compensating solenoid starts at 1.25m, screening solenoid at 2.0m
- I have reduced the distance between the compensating and screening solenoids to absolute minimum

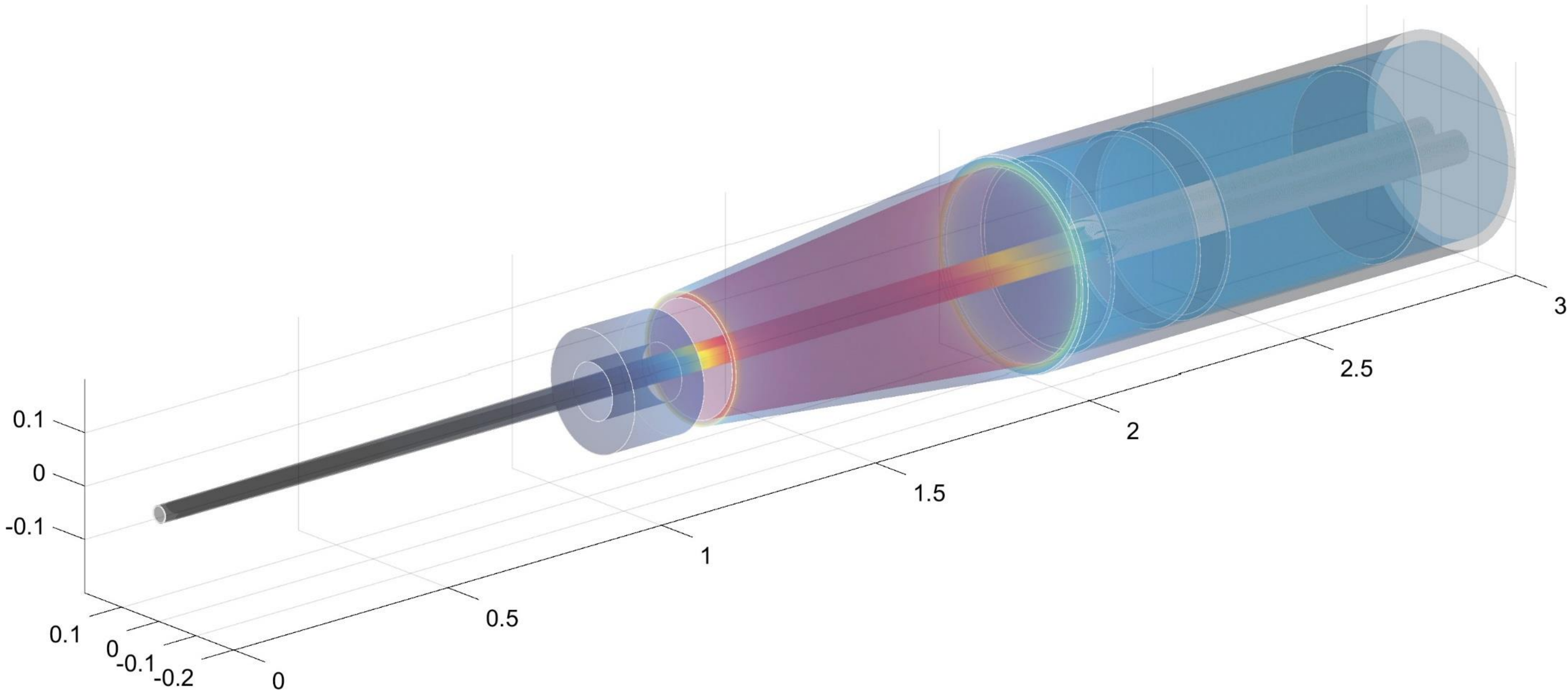
New layout



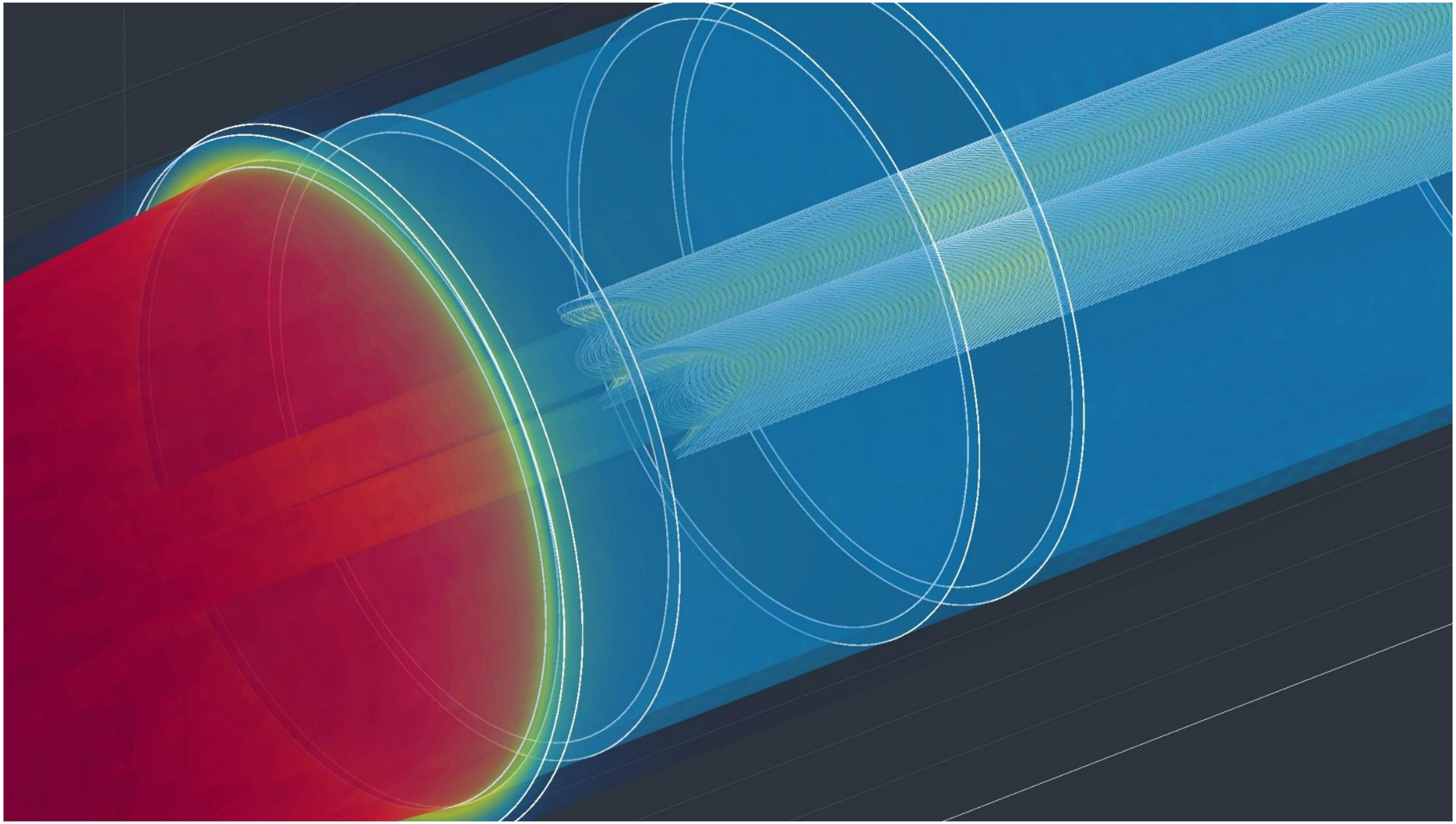
Results

- Emittance blow-up from 2 IPs (SAD calculation) is now 0.5pm
- this is probably at the limit of what we can accept
- Please note the following:
  - Reducing the solenoid magnetic field by 10% (to 1.8T) reduces the emittance blow up to 0.3pm
  - We are currently assuming a coupling of 0.2% which gives an additional 0.5pm of emittance in the rest of the ring. So still the total emittance is not larger than 1pm. We can probably do better than 0.2% of coupling
  - I am trying to do some further minimization, hoping to improve by 20% - this took longer than expected, but will be done

Pretty pictures



Pretty pictures



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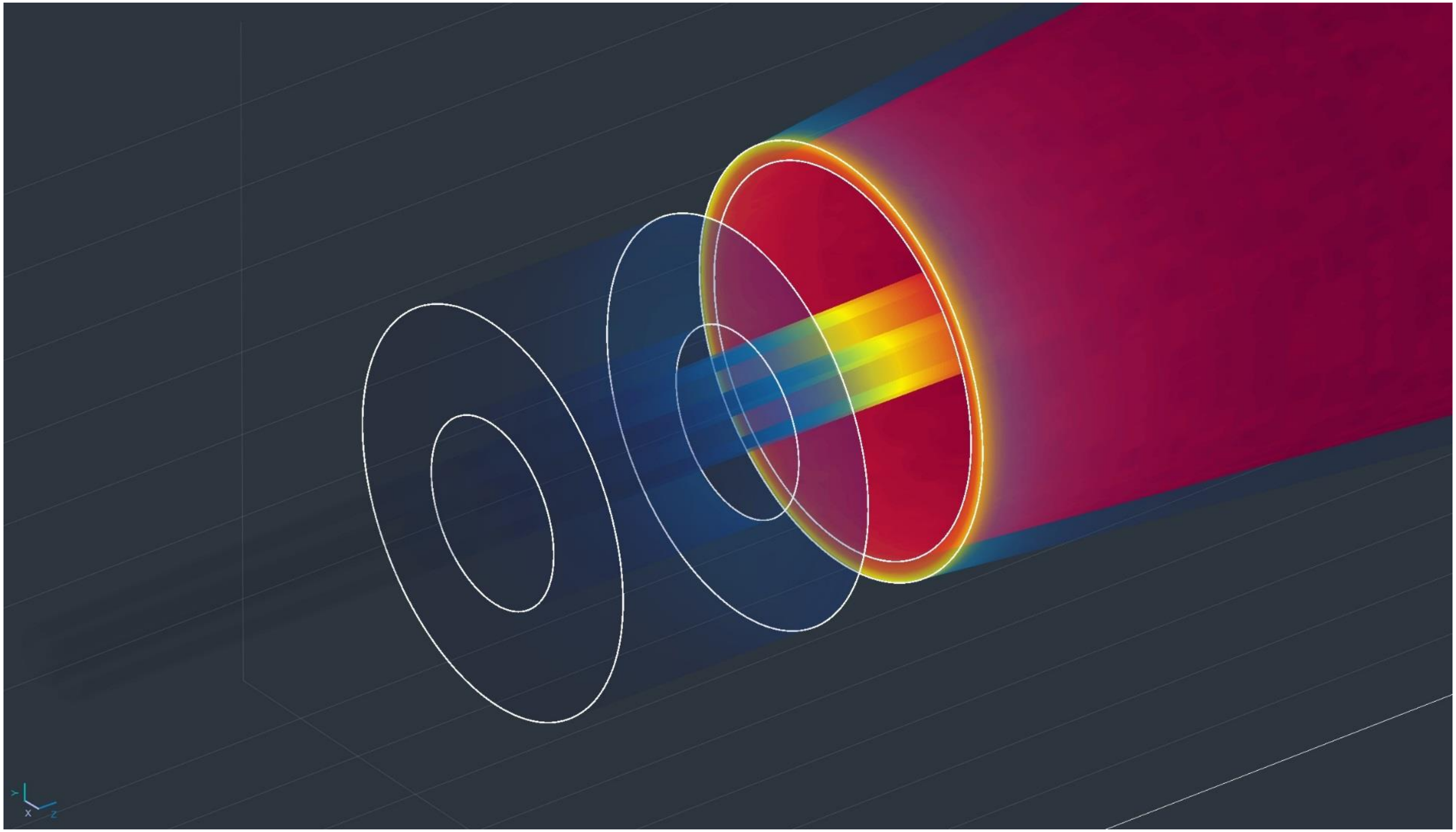
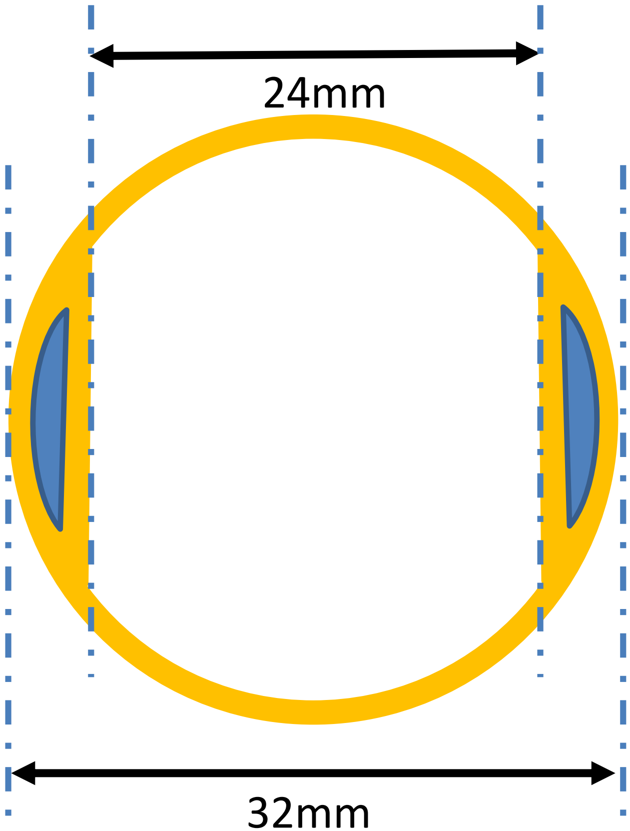


Conclusions/next steps

- We have a 100mrad design which is at the limit of acceptability regarding emittance blow up
- I hope to squeeze another 20% of performance by further optimization
- I can provide .stp files to the CAD programme directly if needed with all my elements.

Water cooling

- The beam pipe close to the IP is not round…
- There is space for adequate water cooling



Weights of individual components

- Very rough first estimate of weight of components.
- I have taken the coils to be made out of Aluminium (2/3rd), Copper (1/6th) NbTi (1/6th) – combined density 4200 Kg/m3
  - Weight of screening solenoid: ~300kg
  - Weight of compensating solenoid: ~60kg
  - Weight of QC1L1: ~12kg
  - Total weight of coils (one side): ~500kg