FCC-ee IR magnetic element design – status

M. Koratzinos

MDI meeting

6/3/2018

The story

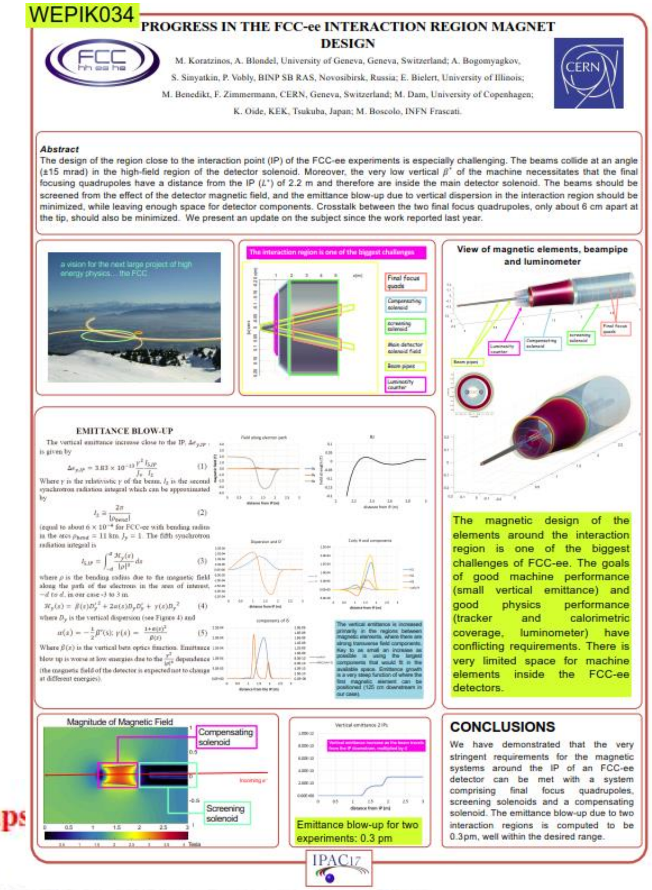
- Over the last three years we have completed a design of magnetic elements that fit all our requirements with a minimal system comprising a screening solenoid and a compensating solenoid.
- All magnetic elements rest inside a 100 mrad cone, (but small parts of the cryostat will be outside this cone – few millimetres of stainless steel)
- Emittance blow-up has been computed by SAD to be 0.34pm for two IPs. This is considered acceptable.

Some history

- 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 redesigned things making sure that the luminometer fits – now the first magnetic element started at an L* of 1.25m – but to avoid emittance blow-up the cone of the shadow of the element was increased to 140mrad.
- This was deemed not acceptable due to the deterioration of the physics performance
- I have re-designed the system to stay within the 100mrad cone eating up 2 cm (now the system starts at 1.23cm from the IP. The emittance blow up is at the limit of what can be considered acceptable (0.34pm for 2IPs)

IPAC 2017

- A paper was published for IPAC 2016. It contained our baseline design at the time (140mrad cone).



WEPIK034

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 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 2.2 m and therefore are inside the main detector solenoid. The beams should be screened from the effect of the detector magnetic field, and the emittance blow-up due to vertical dispersion in the interaction region should be minimized, while leaving enough space for detector components. Crosstalk between the two final focus quadrupoles, only about 6 cm apart at the tip, should also be minimized. We present an update on the subject since the work reported last year.

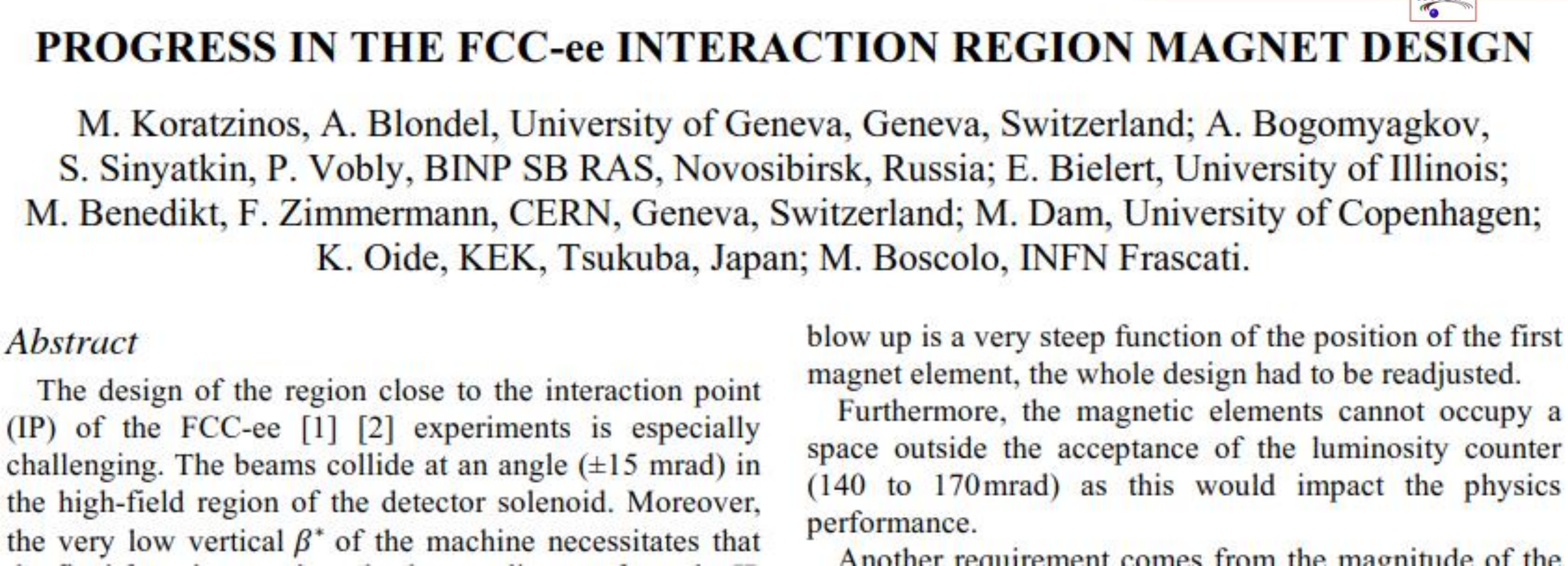
The magnetic design of the elements around the interaction region is one of the biggest challenges of FCC-ee. The goals of good machine performance (small vertical emittance) and good physics performance (tracker and calorimetric coverage, luminometer) have conflicting requirements. There is very limited space for machine elements inside the FCC-ee detectors.

Emittance blow-up for two experiments: 0.3 pm

CONCLUSIONS

We have demonstrated that the very stringent requirements for the magnetic systems around the IP of an FCC-ee detector can be met with a system comprising final focus quadrupoles, screening solenoids and a compensating solenoid. The emittance blow-up due to two interaction regions is computed to be 0.3pm, well within the desired range.

WEPIK034 Proceedings of IPAC2017, Copenhagen, Denmark - Pre-Release Snaps



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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

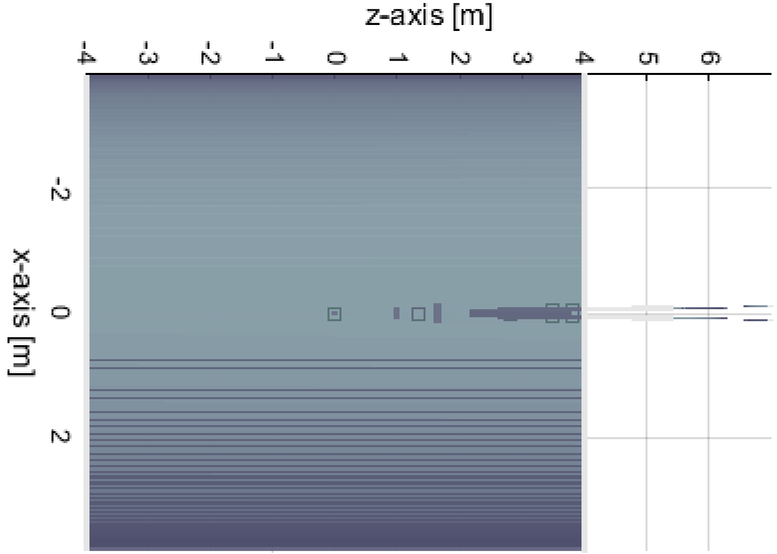
blow up is a very steep function of the position of the first magnet element, the whole design had to be readjusted.

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

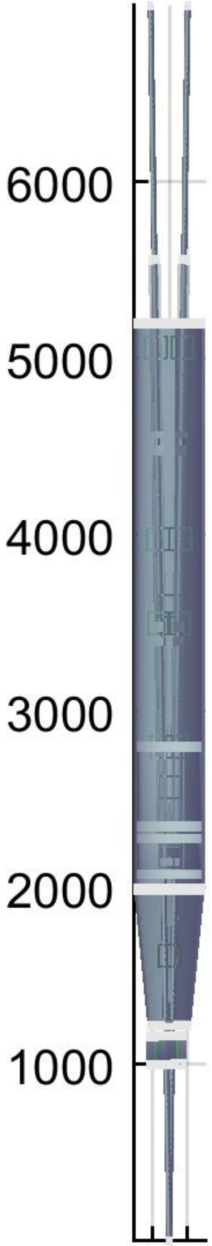
- I have now included a realistic detector solenoid according to the latest design. (up to now I had a constant and universal field of 2T)
  - solenoid dimensions 3.76m(inner radius) (outer radius 3.818m) × 4m (half-length)

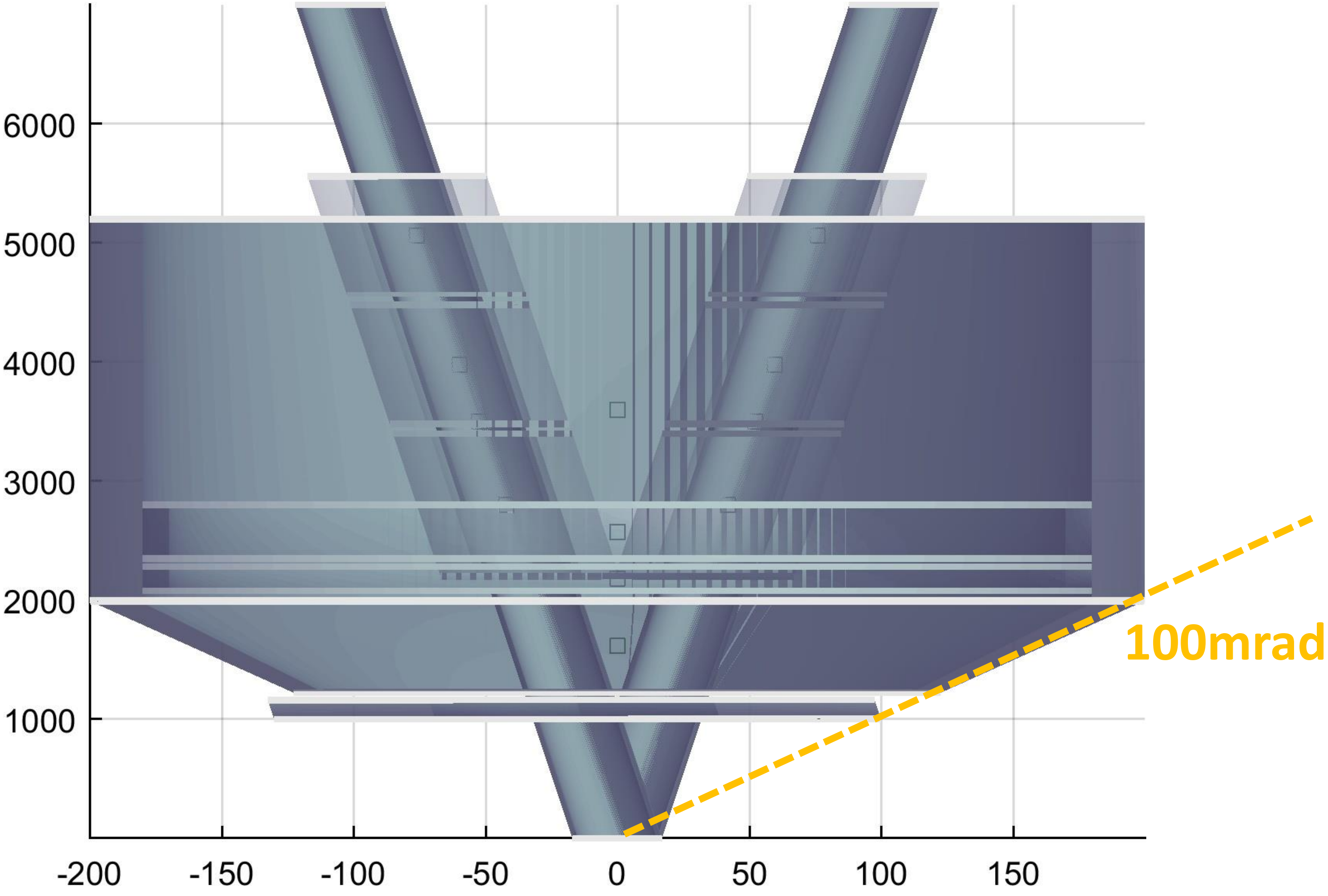


Position of the luminometer

- The luminometer sits between 1.074 and 1.190 m from the IP. It is a cylinder with an outer radius of 115mm (active calorimeter) and 145mm (including services.
- It sits at a 15mrad tilt, following the outgoing beam pipe
- Geometry:
  - outer active edge between 92 mrad and 112 mrad
  - Outer passive edge between 120 mrad and 150 mrad

New layout (for the CDR)

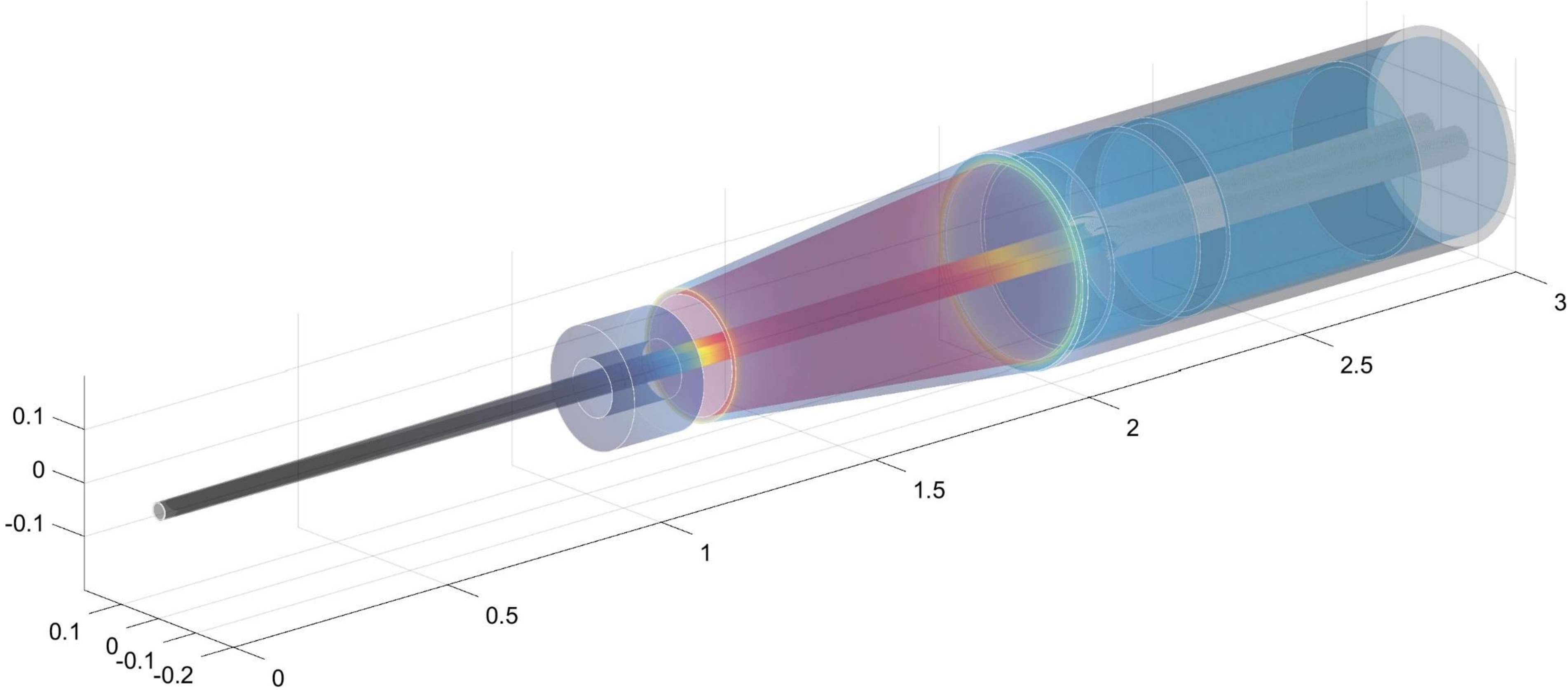




Results

- Emittance blow-up from 2 IPs (SAD calculation) is now 0.34pm
- 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 by 40%
  - 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

Pretty pictures



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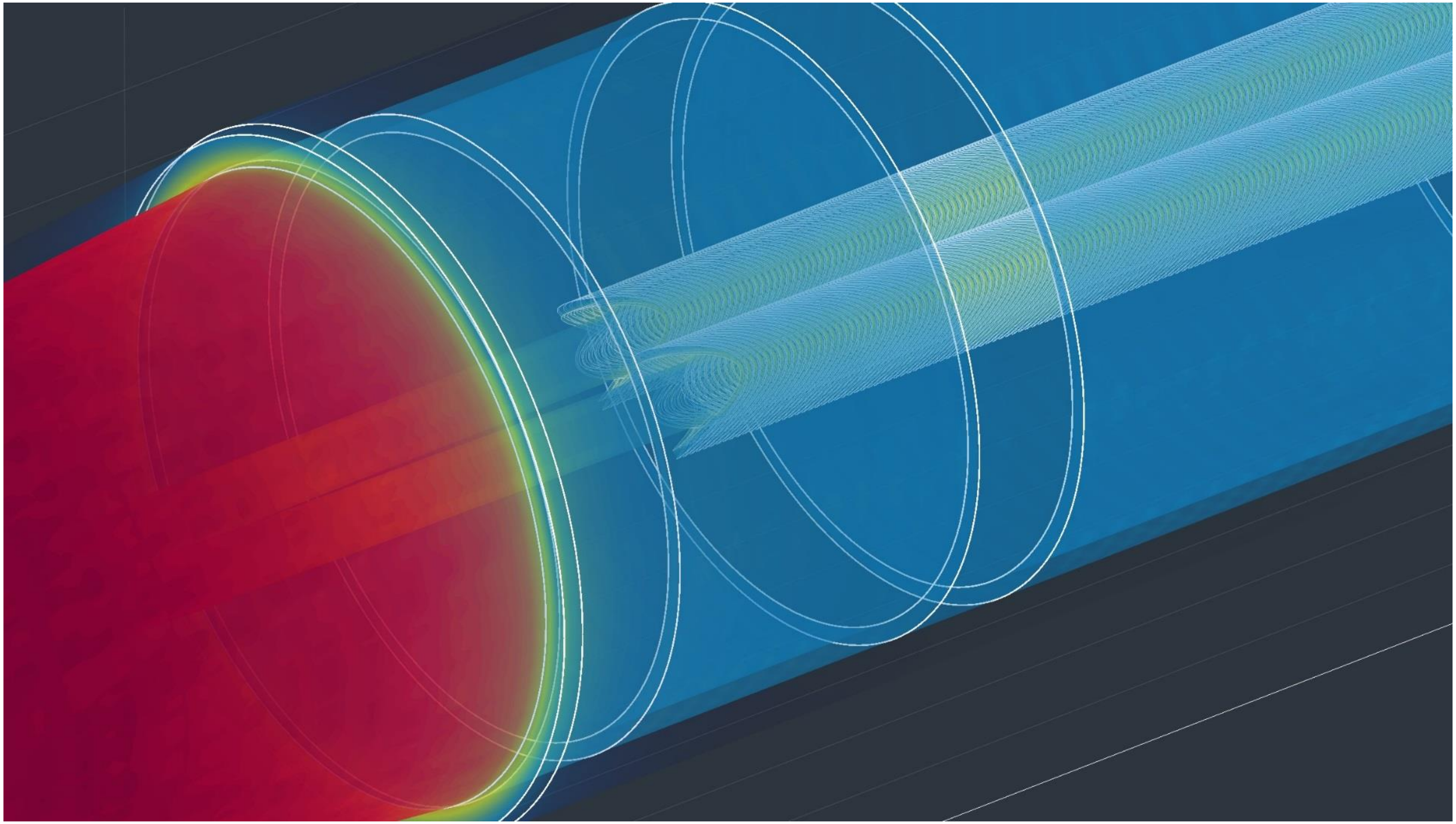

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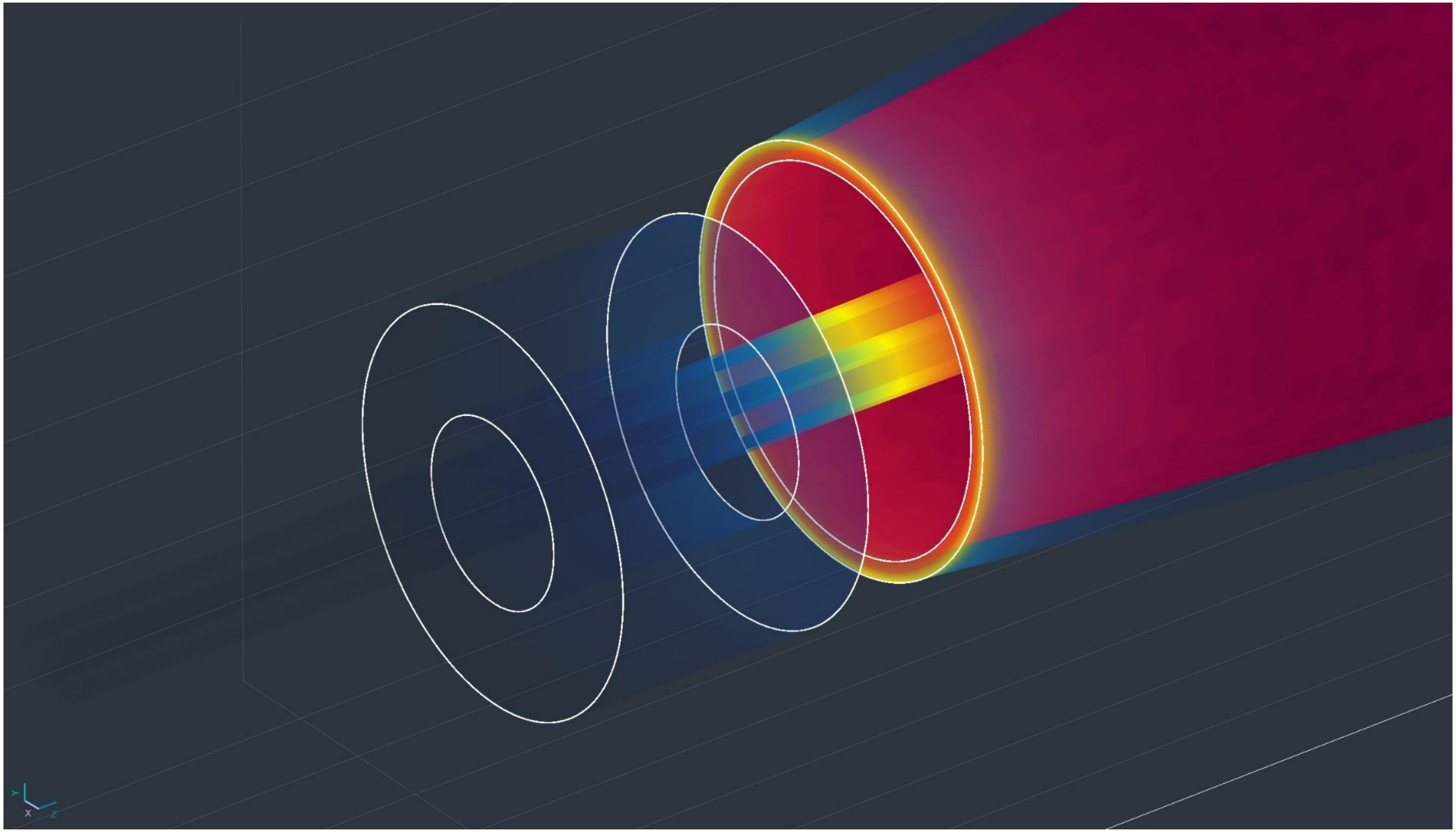

Conclusions

- We have a 100mrad design which is satisfies our requirements

Extra 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/)

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, $I_2 = 0.00057$); J_y=1
- $I_{5,IP} = \int \frac{\mathcal{H}_y(s)}{|\rho|^3}ds$
- $\mathcal{H}_y(s) = \beta {D_y'}^2 + 2\alpha D_y D_y' + \gamma {D_y}^2$, D is the dispersion

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

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

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