FCC-ee MDI: impact on detector design

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for the FCC-ee MDI Group

FCC-ee MDI: outline

- Optics
- Infrastructures
- IR design
- Synchrotron Radiation
- Detector studies:
  - Synchrotron Radiation
  - Beamstrahlung
- Conclusions

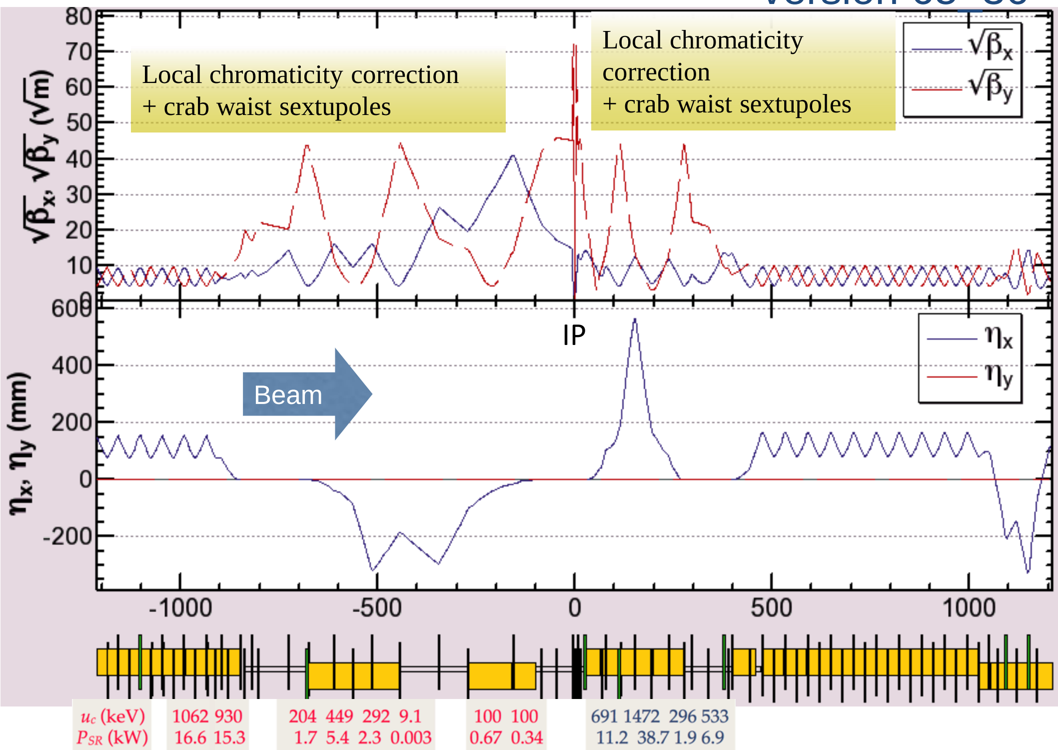
FCC-ee Parameter Table

	Z		WW	ZH	$t t_{bar}$
energy/beam [GeV]	45.6		80	120	175
bunches/beam	30180	91500	5260	780	81
bunch spacing [ns]	7.5	2.5	50	400	4000
bunch population [10^{11}]	1.0	0.33	0.6	0.8	1.7
beam current [mA]	1450	1450	152	30	6.6
Horizontal emittance [nm]	0.2	0.09	0.26	0.61	1.3
Vertical emittance [pm]	1	1	1	1.2	2.5
luminosity/IP x $10^{34} cm^{-2} s^{-1}$	210	90	19	5.1	1.3
βx^* [m] / βy^* [mm]	0.5/1	1/2	1/2	1/2	1/2
energy loss/turn [GeV]	0.03	0.03	0.33	1.67	7.55
SR power /beam [MW]	50	50	50	50	50
RF voltage [GV]	0.4	0.2	0.8	3.0	10
Energy acceptance RF [%]	7.2	4.7	5.5	7.0	6.7
Luminosity lifetime [min]	94	185	90	67	57

FCC-ee MDI: optics

K.Oide

version 65_36

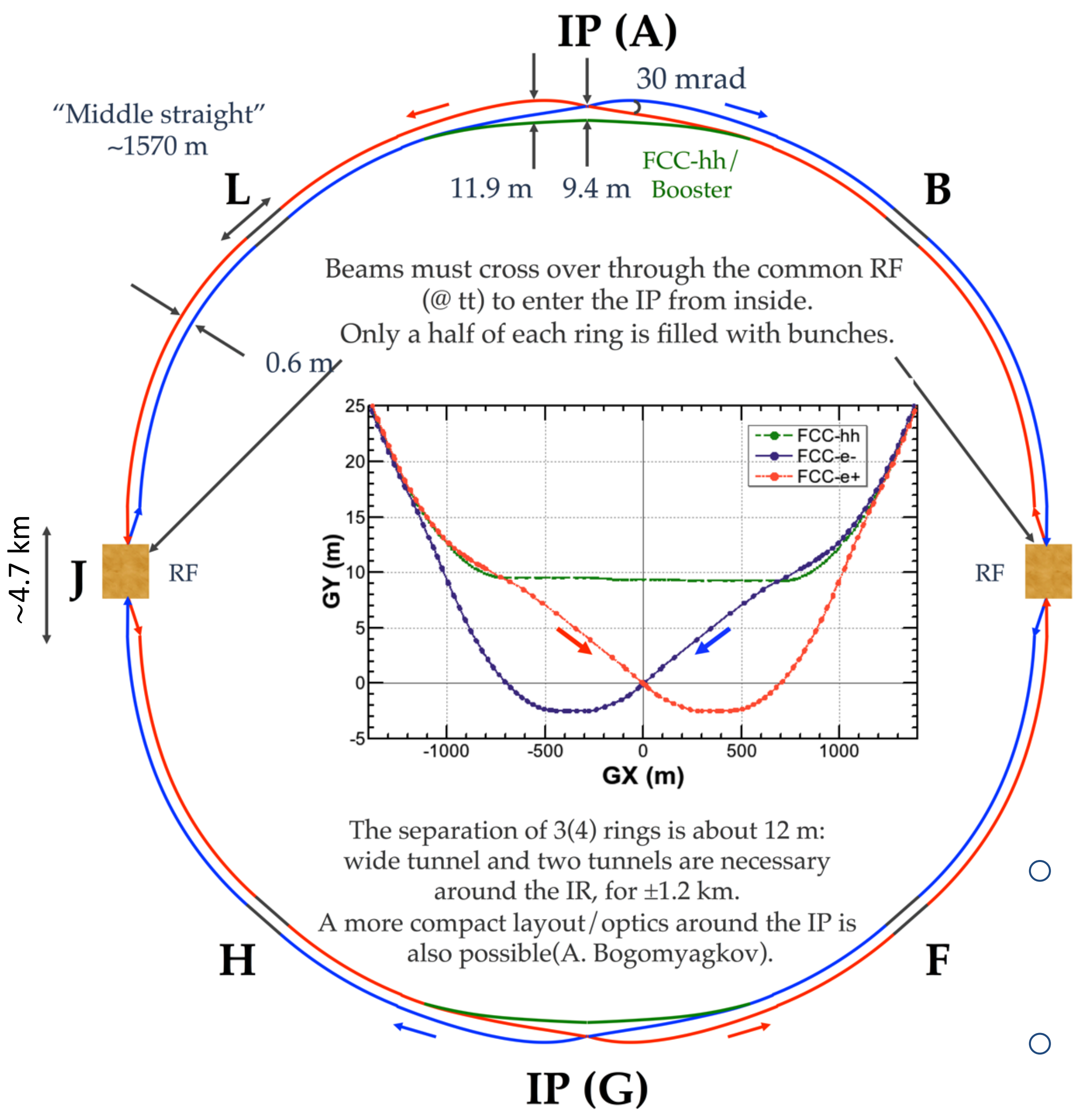


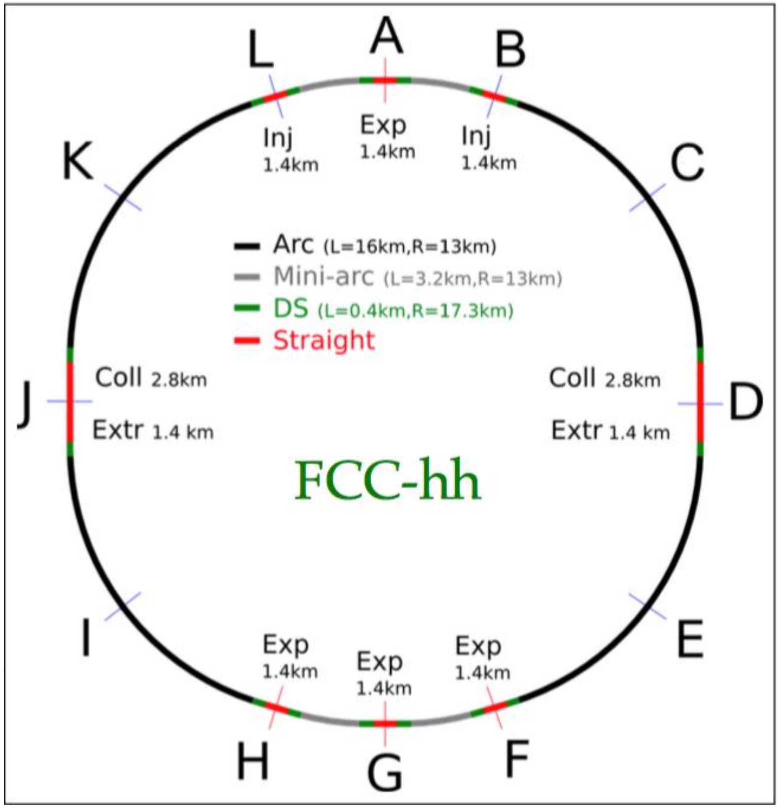
Main requirements

- Crab waist scheme
- 2 IPs
- β*x/y = 0.5m/1mm (1m/2mm)
- Vertical emittance 1 pm (@Z energy)
- Horizontal emittance ~1 nm (@t energy)
- Energy acceptance +/- 2%
- Eγ,c < 100 KeV within ±250m from IP
- As close as possible to the FCC-hh beam line

- Asymmetric optics solution (K.Oide), version 65_36
- The synchrotron radiation from the upstream dipoles are suppressed below 100 keV up to 510 m from the IP.
- Crossing angle 30mrad
- Small vertical emittance (< 1pm) requires compensating solenoid
- Local chromaticity correction sections needed for the energy acceptance

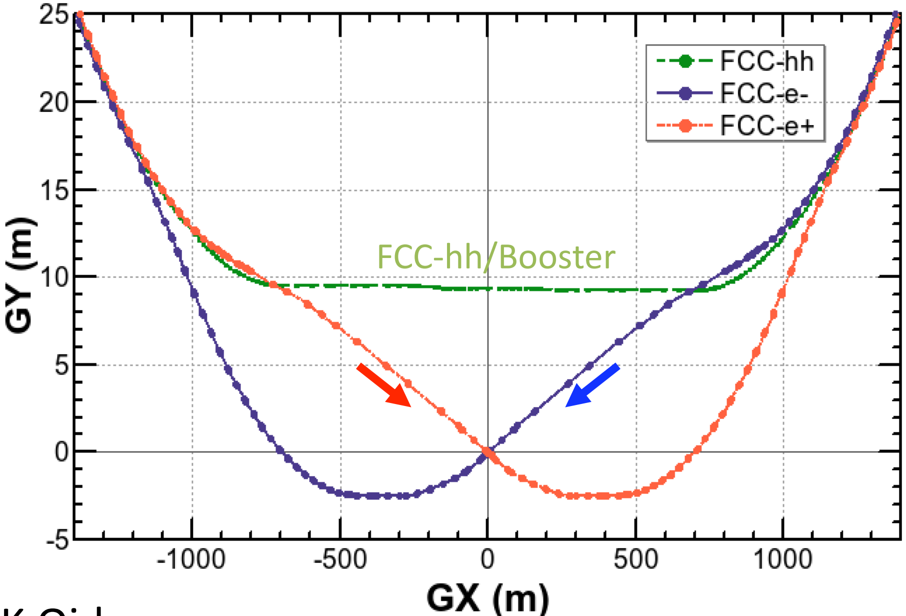
FCC-ee MDI: optics



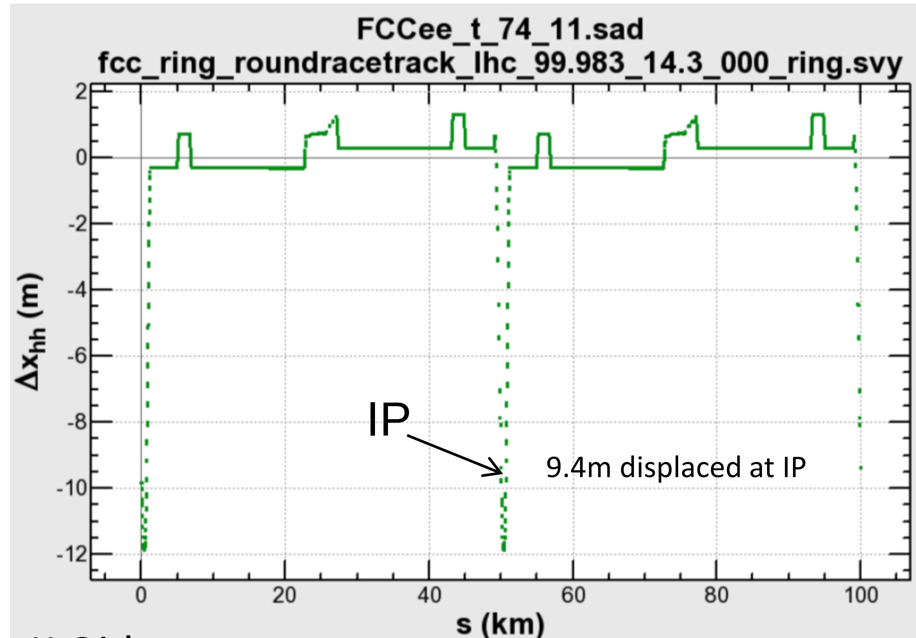


- The asymmetric IR forces a cross over of the beams.
- Beams cross over in J and D in order to collide always coming from the inside of the ring

FCC-ee MDI: optics



K.Oide



K.Oide

- FCC-ee IP displaced by about 9.4 m w.r.t. FCC-hh IP, and up to 12m in between 200m-600m from IP
- This forces to have a separate tunnel for about 1.2Km at each side of each IR
- Same experimental caver as FCC-hh constrains the overall dimension of the detector.

FCC-ee MDI: optics

The optics designed achieved can be a basic step toward the FCC-ee circular collider. There are a number of issues remaining to be addressed for a complete design such as:

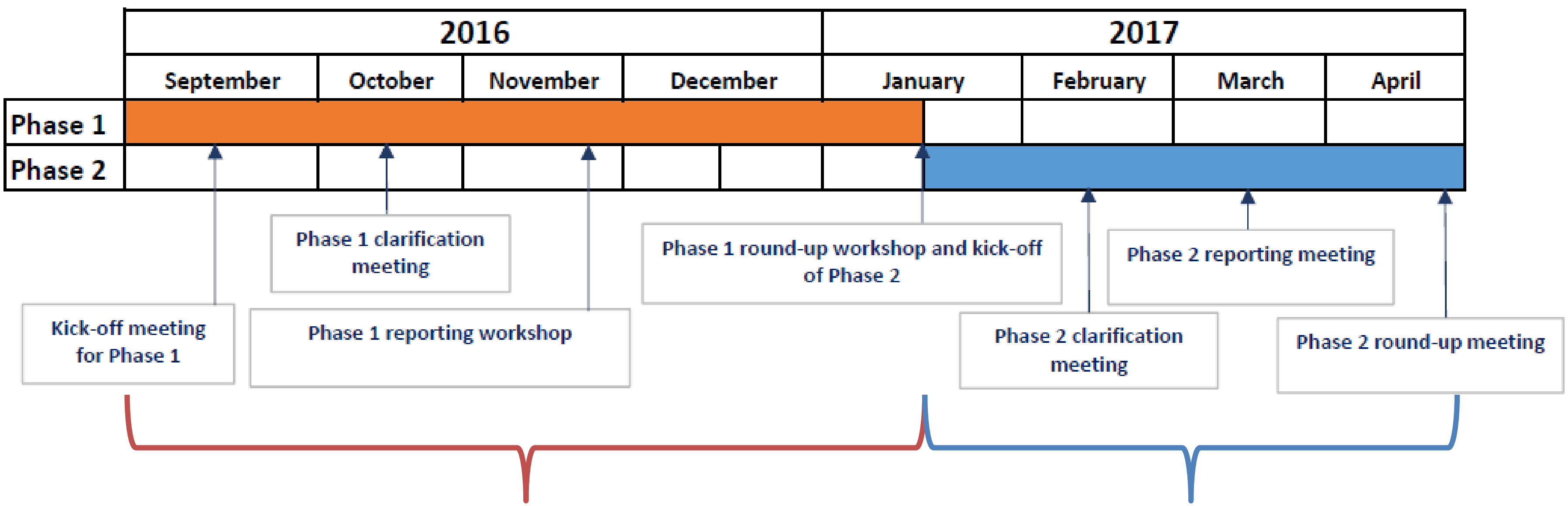
- Development of correction/tuning schemes on the emittance and the dynamic aperture to mitigate the possible higher-order fields, machine errors, and misalignments.
- Further study on the interplay with beam-beam effects.
- Refinement of the IR region considering the machine-detector interface.
- Iterations between hardware designs of the RF, beam pipes, and magnets, beam instruments., etc.
- Development of the injection scheme and necessary optics.

Other optics have been studied in some detail (mainly A. Bogomyagkov[1]), each with merits and demerits, but for the moment version 65_36 has been chosen as baseline

[1]http://indico.cern.ch/event/566684/contributions/2290725/attachments/1353756/2044919/Bogomyagkov.pdf

FCC-ee MDI: infrastructures

- Two companies have been awarded contract to undertake a cost & schedule study for the FCC infrastructures: ILF and Geoconsult/Synaxis.
- The study is split into 2 phases: the ee machine requirements to be considered in phase 2

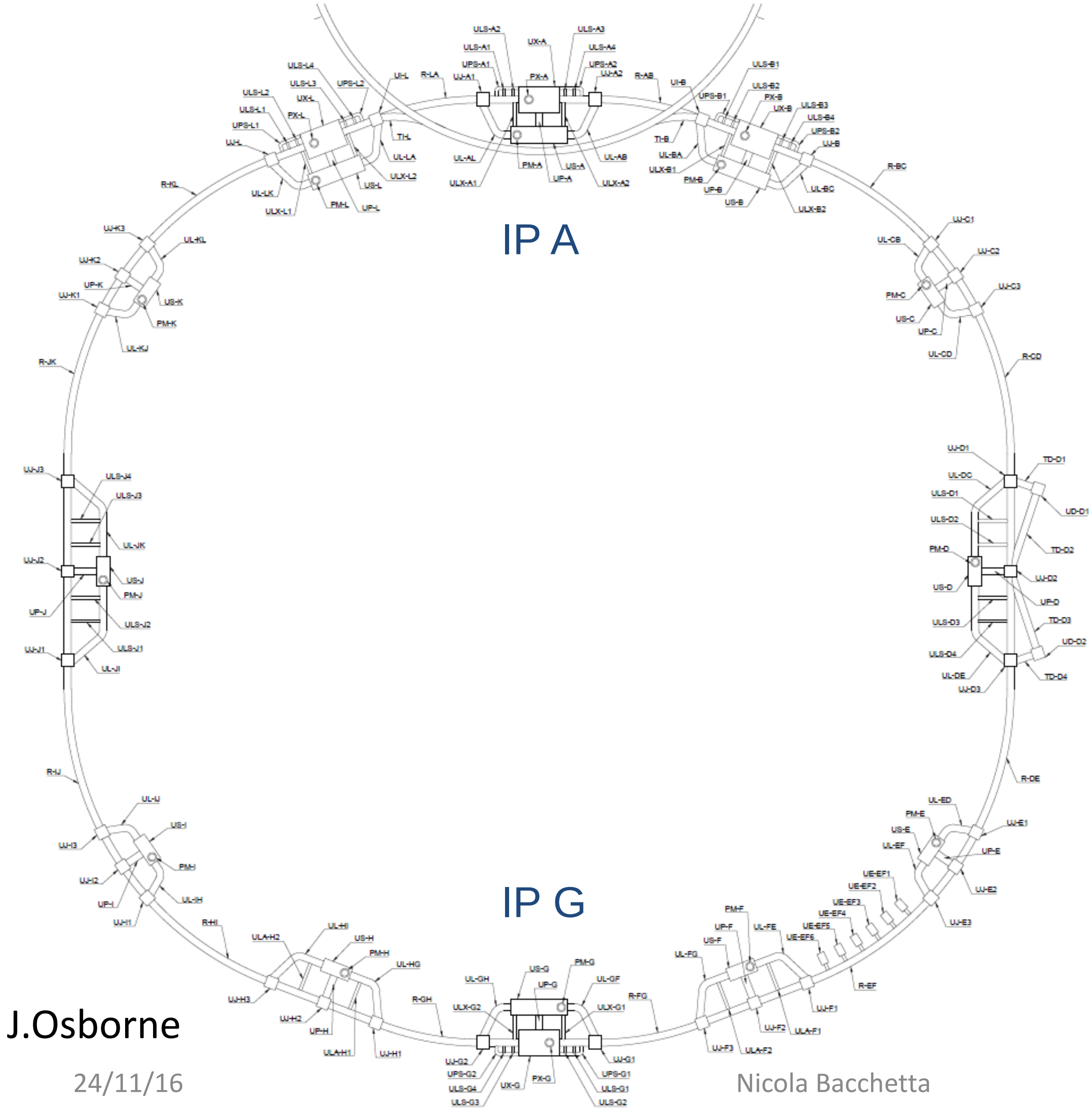


Estimate for baseline design

Estimate for variants
(including specificities of ee machine design requirements)

J.Osborne,

FCC-ee MDI: infrastructures



J.Osborne

Layout of Interaction Point “A”

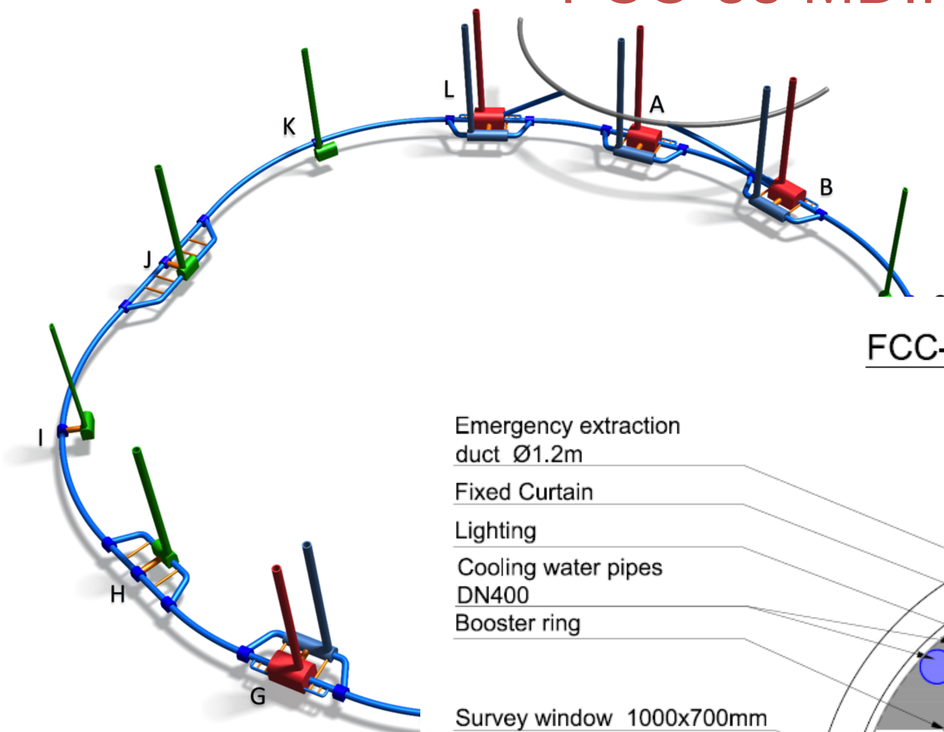
Collision hall “UX-A”

Service Cavern “US-A”

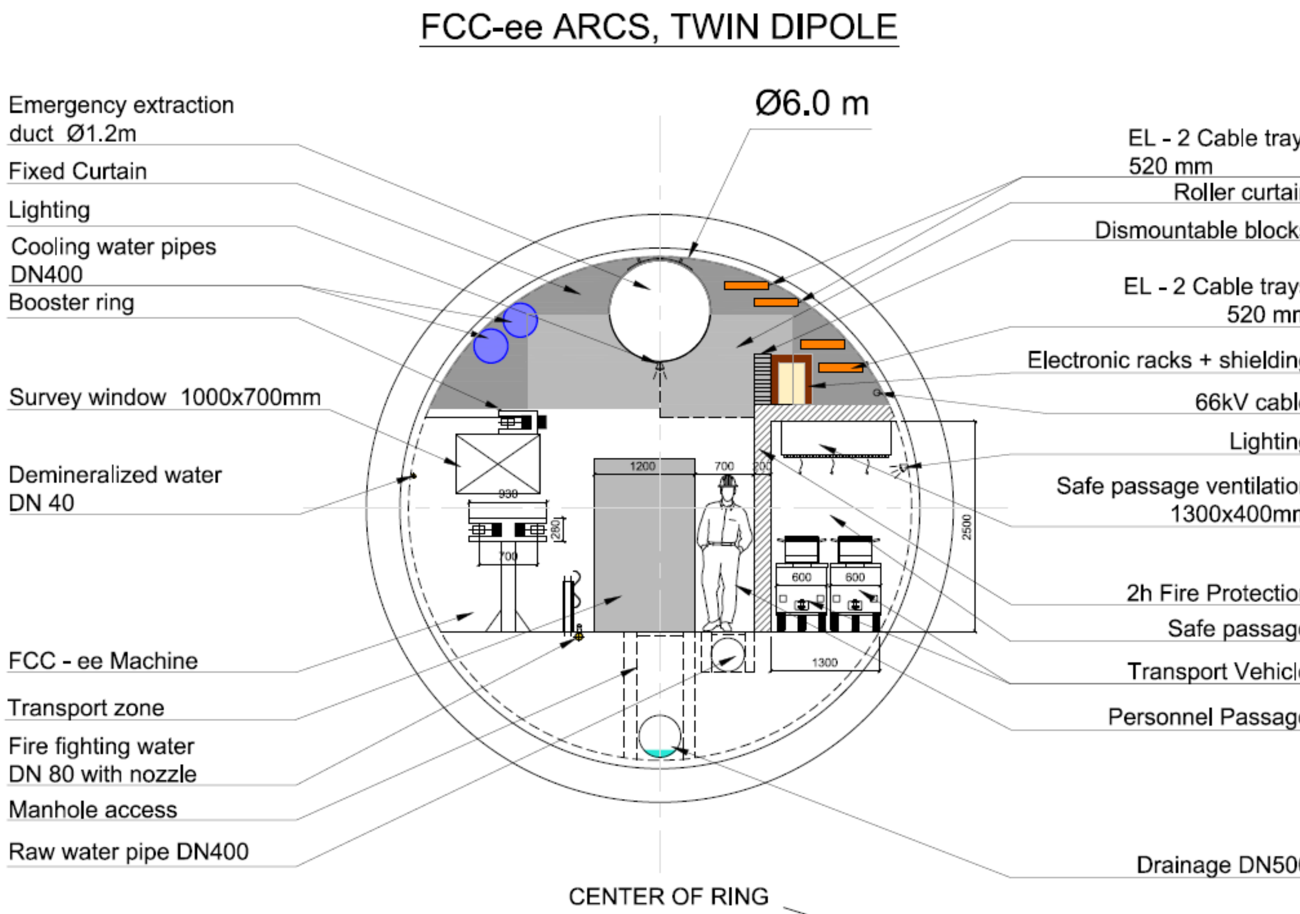
FCC-ee MDI: infrastructures

Structure	Locations	Dimensions
Experimental shafts	L,A,B,G	⌀ 15 m
Experimental caverns	L,A,B,G	30(w) x 35(h) x 70(l)
Service caverns at experimental points	L,A,B,G	20(w) x 15(h) x 120(l)
Regular service shafts	A,B,D,F,G,H,J,L	⌀ 12 m
Machine lowering service shafts	C,E,I,K	⌀ 18 m
Regular service caverns	D,F,H,J	15(w) x 15(h) x 100(l)
Machine lowering service caverns	C,E,I,K	22(w) x 15(h) x 100(l)
Alcoves	Every 1.5 km	6(w) x 6(h) x 25(l)

FCC-ee MDI: infrastructures



Single tunnel, Ø6.0m adopted for C&S Phase 1



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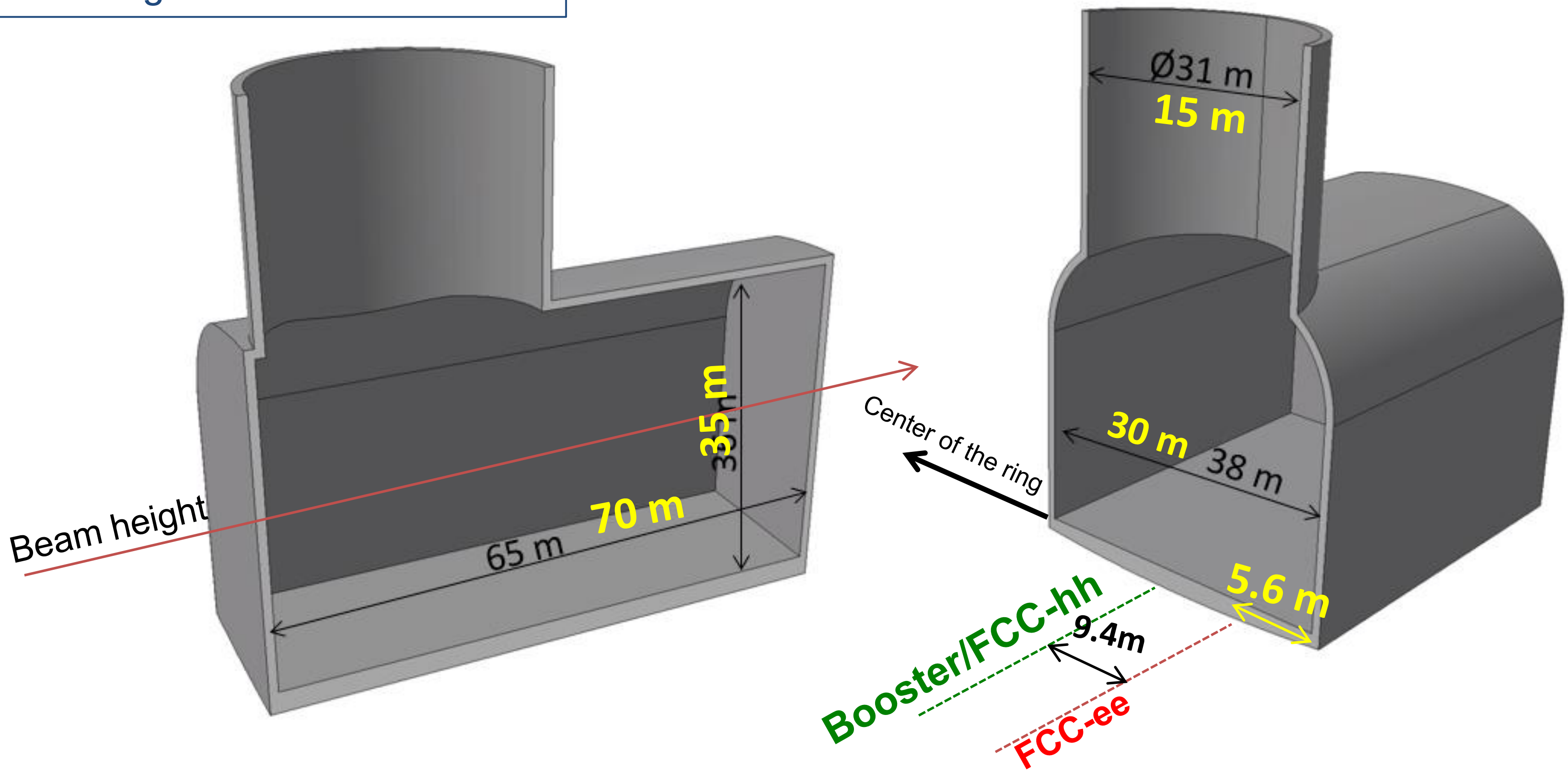
FCC-ee MDI: infrastructures

in yellow updated dimensions according to baseline C&S



- A Ø10m detector would ~fit in the baseline experimental cavern
- Same detector would need to be raised up by ~ 10m to reach beam height.
- Shaft dimensions not an issue

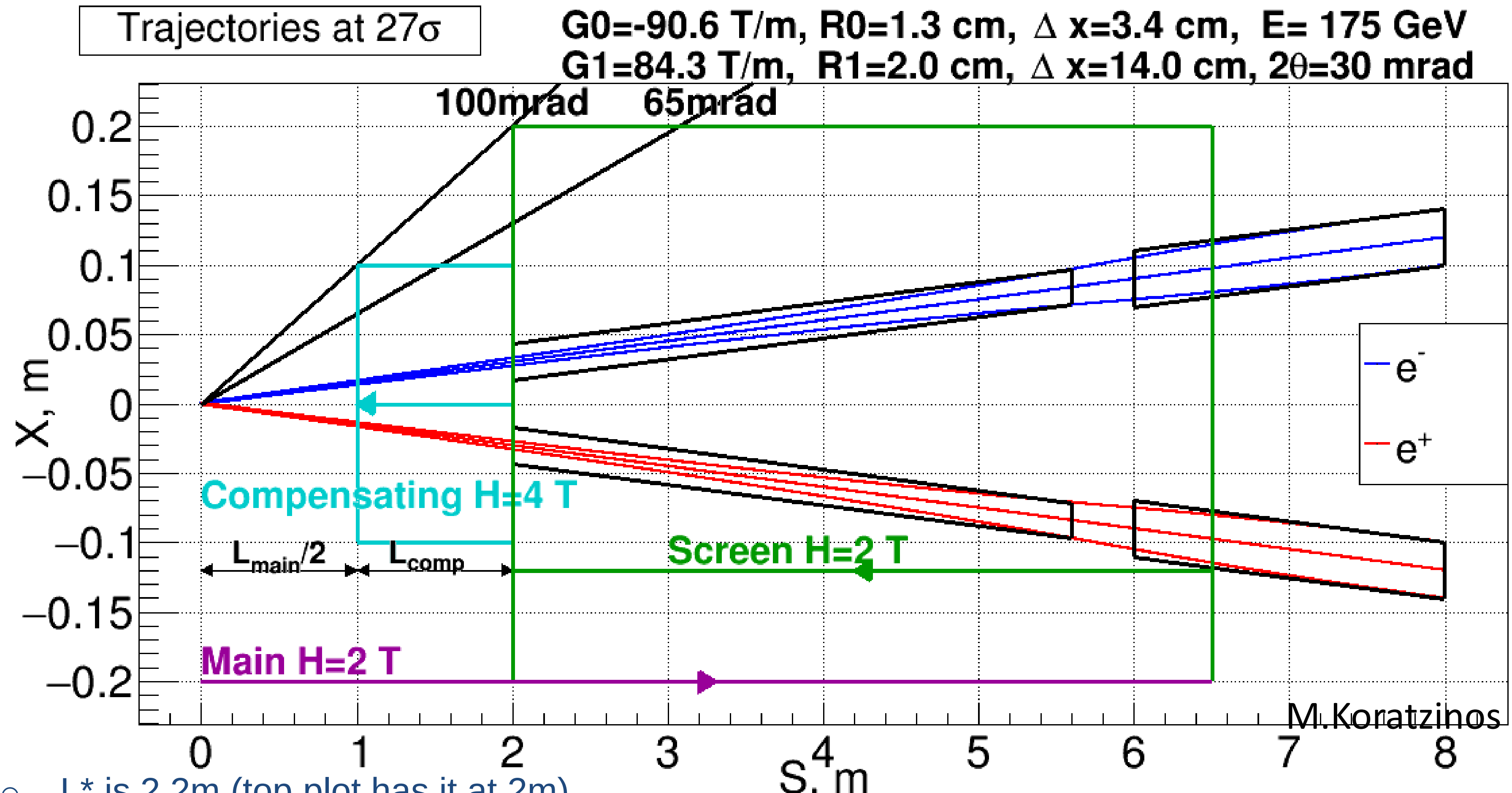
FCC-ee MDI: Interaction Region

- Based on the asymmetric optics 65_36
- L* is 2.2m
- Free cone for physics starting at ~100mrad
- final focus quads inside the detector (low βy* and large crossing angle)

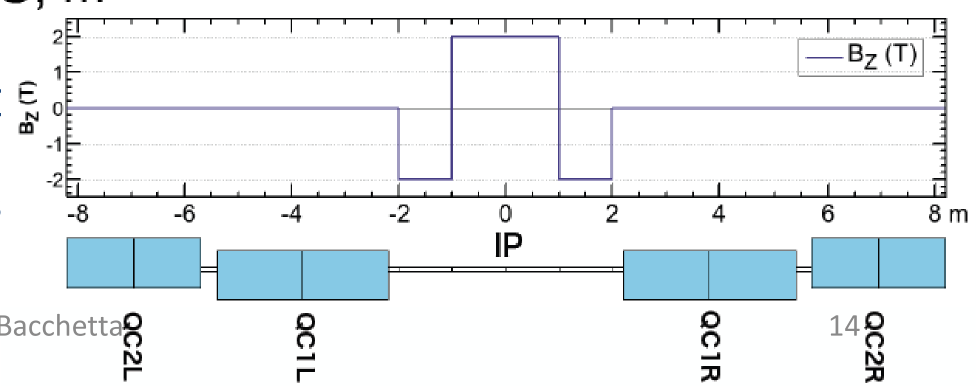
Particles on the beam axis are not on the detector axis, so they will experience vertical dispersion, that brings vertical emittance blow-up. Due to the low nominal ε_y~pm, this effect needs to be cured.

A compensating and screening solenoid scheme needs to be present.

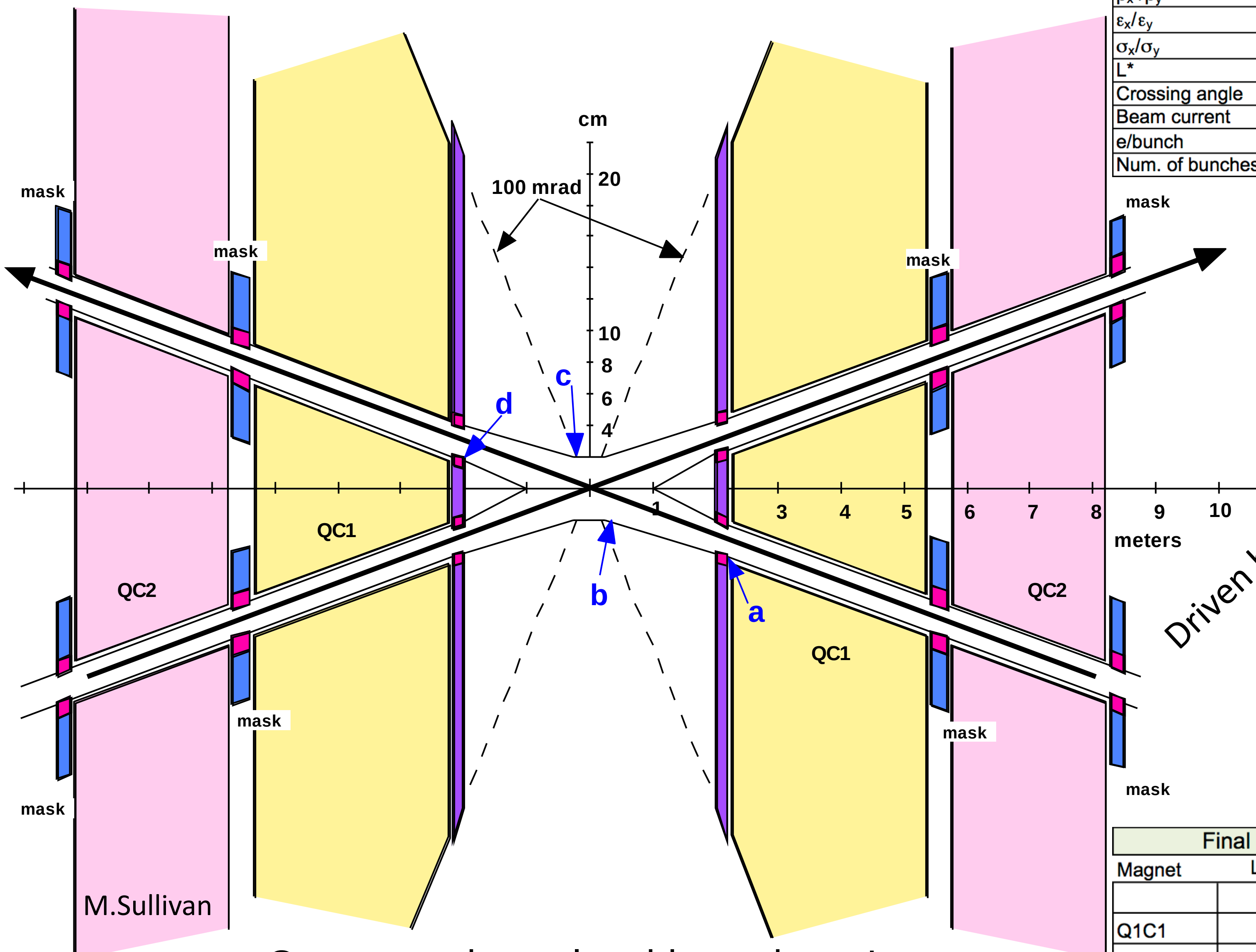
FCC-ee MDI: Interaction Region (Magnets)



- L* is 2.2m (top plot has it at 2m)
- Detector solenoid 2T
- Compensating solenoid starts at Z=1m, R=0.1
- Screening solenoid starts at Z=2m, R=0.2m
- Quads strength = 96 T/m (the above sketch s shows L*=2m)



FCC-ee MDI: IR Layout



Driven by SR considerations

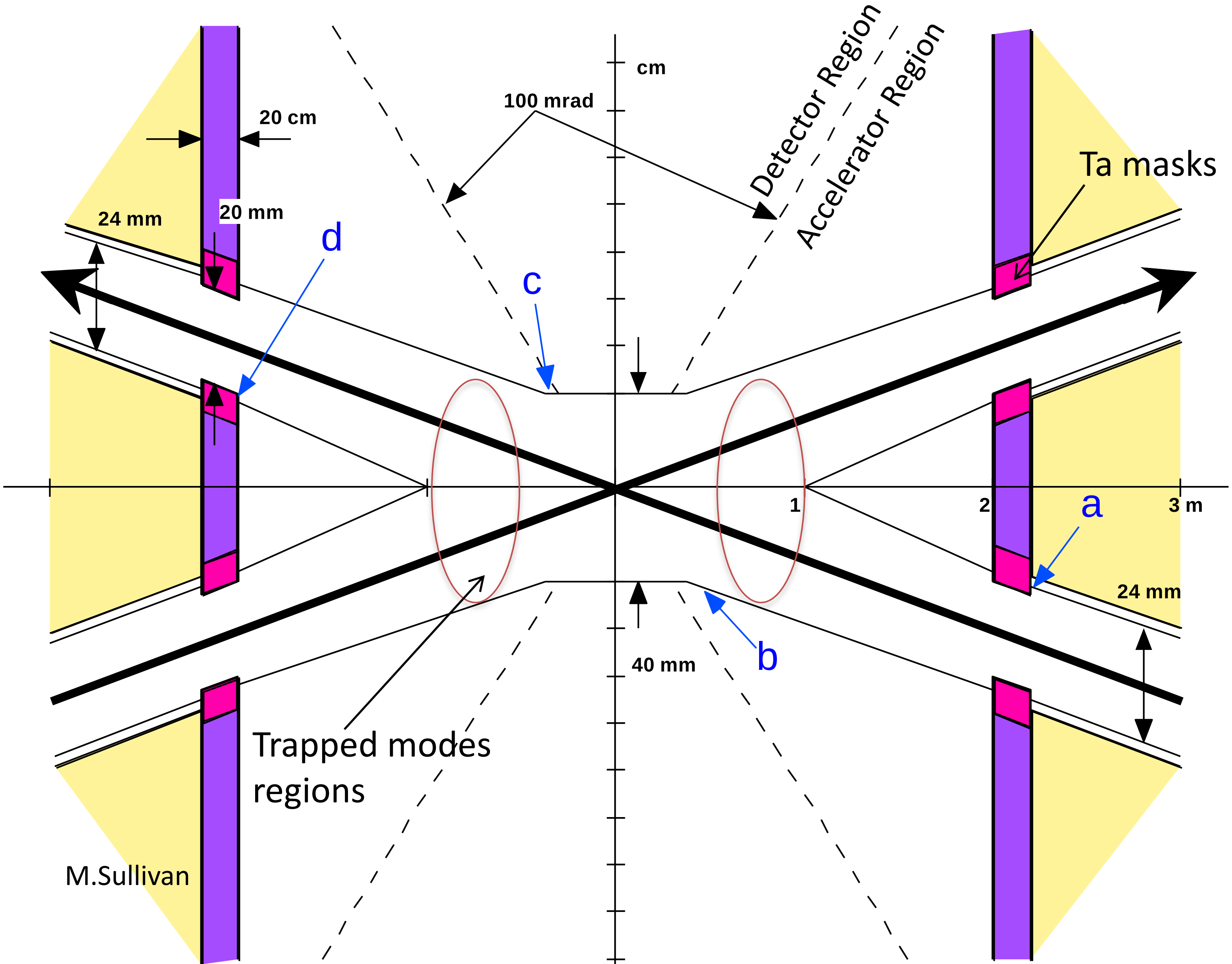
FCC-ee Parameters	
Beam Energy	175 GeV
β_x^*/β_y^*	1000/2 mm
$\varepsilon_x/\varepsilon_y$	$1.3*10^{-9}/2.5*10^{-12}$ m-rad
σ_x/σ_y	36 μm/71 nm
L*	2.2 m
Crossing angle	+/-15 mrad
Beam current	6.632 mA
e/bunch	$1.71*10^{11}$
Num. of bunches	81

Final Focus Parameters

Magnet	L(m)	Z face (m)	G (T/m)
Q1C1	1.6	2.2	97
Q1C2	1.6	3.8	97
Q2C1	1.25	5.7	61.5
Q2C2	1.25	6.95	61.5

Compensating solenoid not shown!

FCC-ee MDI: IR Layout



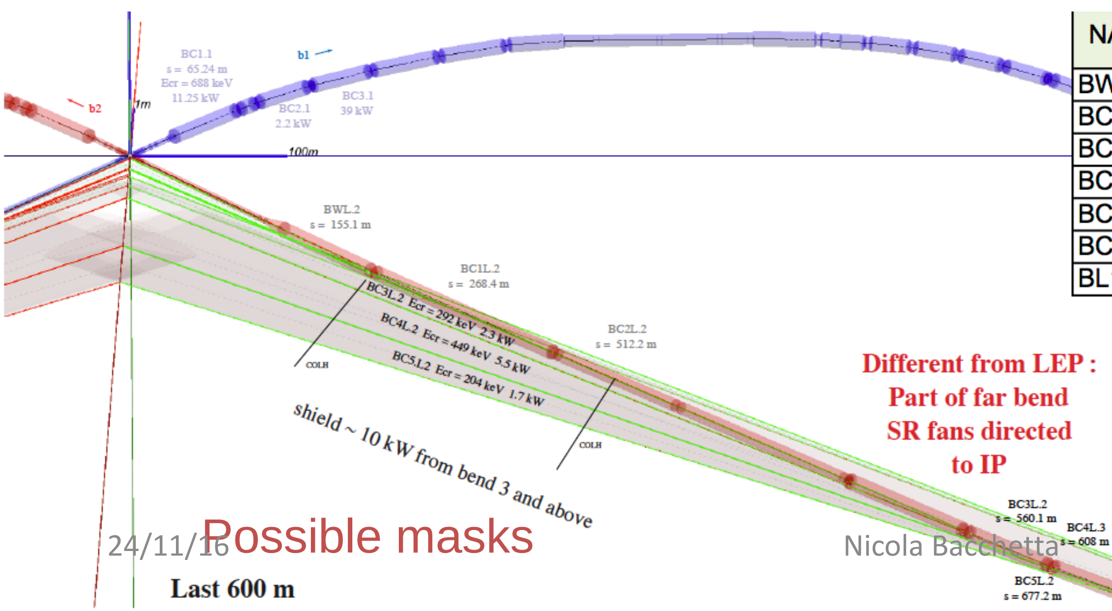
Central beam pipe ø40mm, quads beam pipe is ø24mm

FCC-ee MDI: Synchrotron Radiation

- SR criteria guided the optics design (based on LEP experience):

1. Weak bends Ecr < 100 keV (LEP2 72 keV)
2. Weak bends far from IP (LEP2 was 260 m from IP)
3. Keep Ecr ≲ 1 MeV in whole ring, to minimize n-production (LEP2 0.72 MeV)

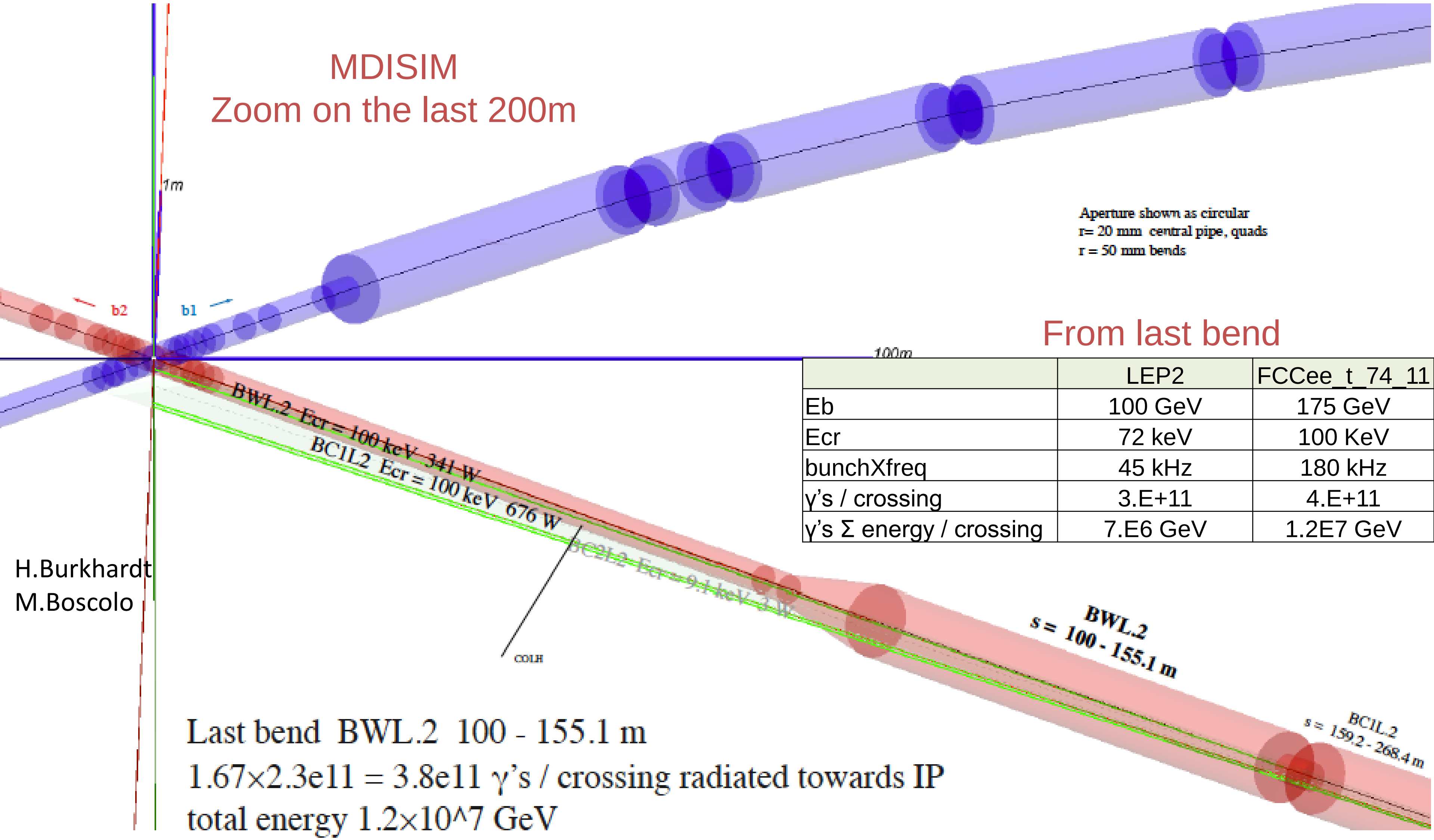
- Various lattice options have been studied in detail:
  - with MDISim by H.Burkhardt:
    1. MAD-X (adjust for SR 50MW/beam)
    2. Generate geometry
    3. Calculate SR, Plot Bend SR Cones
  - with dedicated software by M.Sullivan



NAME	S(m)	L(m)	Angle	Ecrit (KeV)	Power	Power frac>10MeV
BWL.2	155.1	55.1	-4.6E-04	100.0	0.341	8.78E-46
BC1L.2	268.4	109.2	-9.2E-04	100.0	0.676	8.93E-46
BC2L.2	512.2	65.1	-5.0E-05	9.1	0.003	0
BC3L.2	560.1	43.8	-1.1E-03	292.1	2.315	5.61E-17
BC4L.2	608.0	43.8	-1.7E-03	448.7	5.462	1.07E-11
BC5L.2	677.2	65.1	-1.1E-03	203.9	1.675	1.71E-23
BL1.2	877.5	28.7	2.2E-03	929.7	15.340	1.58E-06

Beam Energy = 175 GeV
Ibunch = 0.11 mA
Ibeam = 6.6 A
SR power/beam = 51.3 MW

FCC-ee MDI: Synchrotron Radiation



From last bend

	LEP2	FCCee_t_74_11
Eb	100 GeV	175 GeV
Ecr	72 keV	100 KeV
bunchXfreq	45 kHz	180 kHz
γ's / crossing	3.E+11	4.E+11
γ's Σ energy / crossing	7.E6 GeV	1.2E7 GeV

H.Burkhardt
M.Boscolo

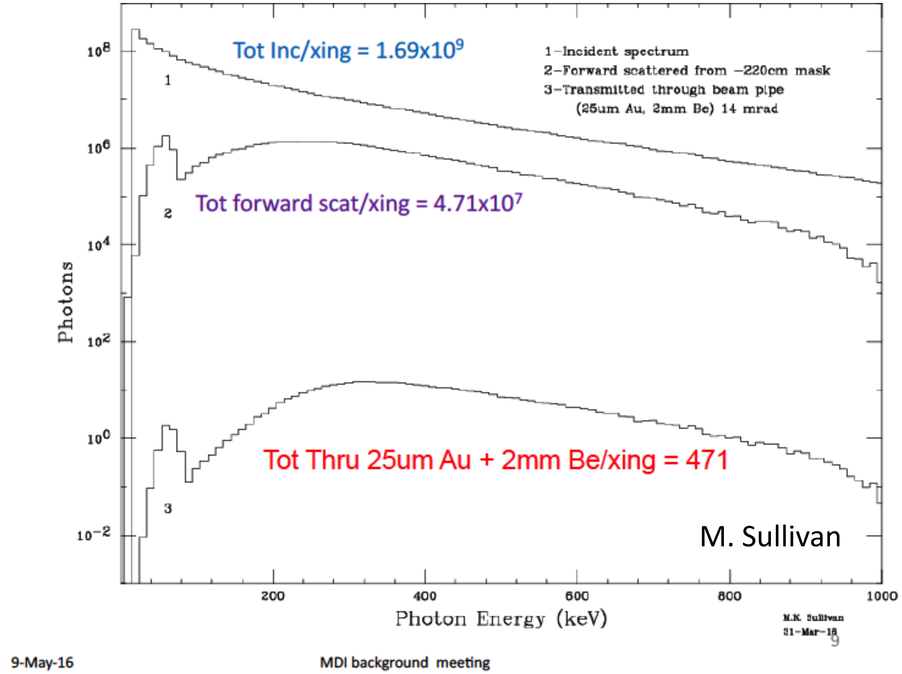
Last bend BWL.2 100 - 155.1 m
1.67×2.3e11 = 3.8e11 γ's / crossing radiated towards IP
total energy 1.2×10^7 GeV

- Last bend closer than in LEP2 (250 m / 100 m)^2 = 6.25 more solid angle
- less space for collimators, part for far bend - SR fans directed towards IP

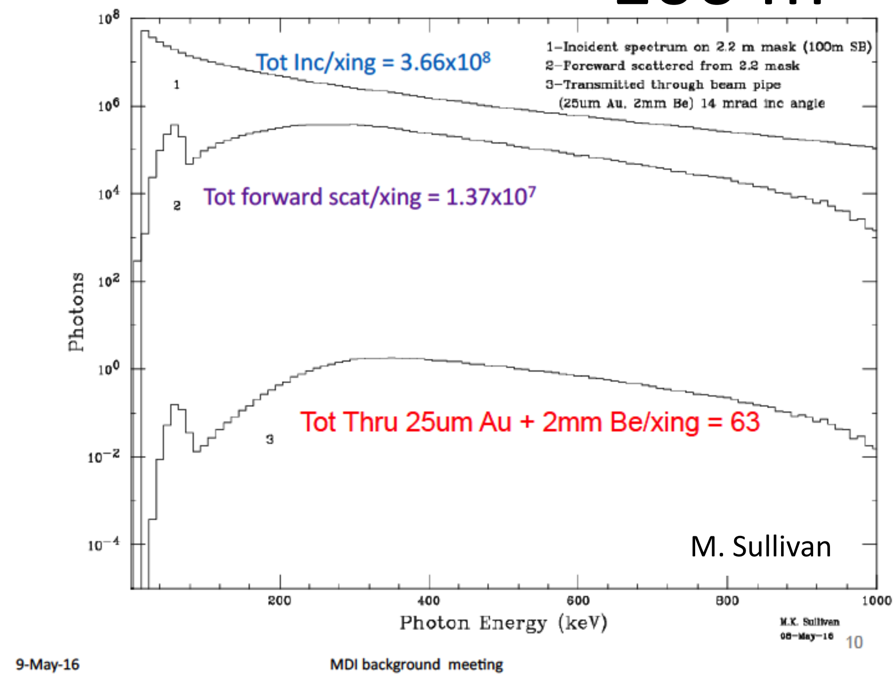
FCC-ee MDI: Synchrotron Radiation

- Comparison between 42m and 100m (baseline) last bend position

42 m



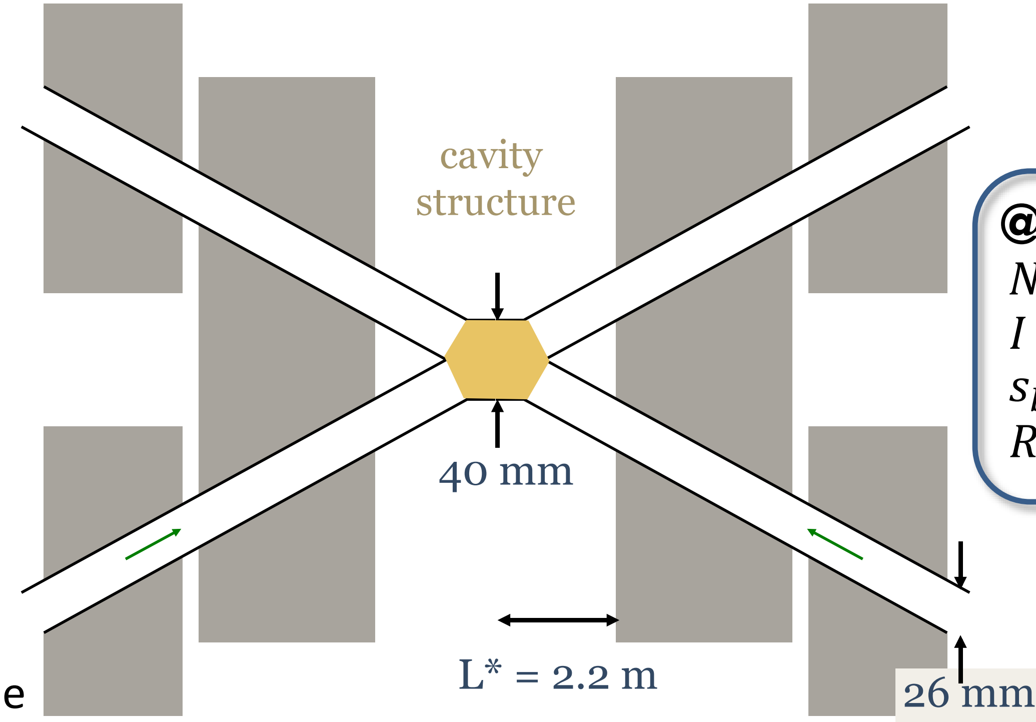
100 m



- As expected there is a scaling factor due to geometrical acceptance

FCC-ee MDI: HOM (Higher Order Modes)

HOM trapping by the cavity structure at IP



K. Oide

- HOM is trapped in the IP beam pipe, if all beam pipes are narrower than the IP, which needs to be larger that 40 mm (M. Sullivan).
- Heating, esp. at Z.
- Leak of HOM to the detector, through the thin Be beam pipe at the IP.

@45.6GeV

$N = 0.33e11$

$I = 1.45A$

$s_b = 2.5ns$

$R_s = 11.173\text{k}\Omega$

$\boldsymbol{P_{loss} \approx 68.5kW}$

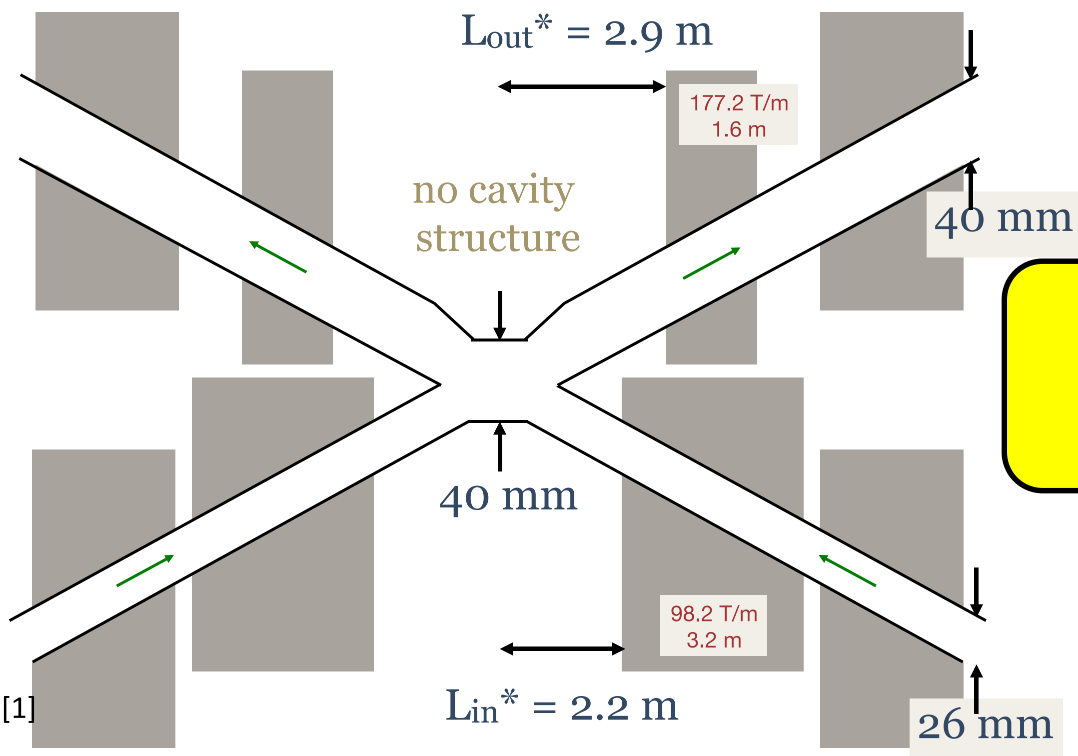
In the worst case

E.Belli

- Small variations in the beam pipe geometry can produce trapped modes
- These modes cannot propagate into the pipe and therefore they remain localized near the discontinuity, producing narrow resonance peaks of the impedance.
- Possible source of heating

FCC-ee MDI: HOM (Higher Order Modes)

Asymmetric L*: larger outgoing beam pipe & thinner final quads



K. Oide [1]

Asymmetric L* layout

It seems that the most dangerous modes are not trapped in the asymmetric layout case (**as expected**)

E.Belli [2]

- The HOM can escape to the outside through the outgoing beam pipe, which has a diameter not smaller than IP.
- The outgoing final quad becomes thinner and stronger (E. Levichev, S. Sinyatkin).

○ This seems to be an almost "transparent" choice in terms of optics, dynamic apertures, compensating solenoid etc., however it adds complexity.

[1]http://indico.cern.ch/event/566684/contributions/2290724/attachments/1353678/2045286/FCCee_Oide_161013.pptx
[2] http://indico.cern.ch/event/566684/contributions/2324659/attachments/1354376/2046037/FCCeeDesignReview_131016_CollectiveEffects.pptx

FCC-ee MDI: IR Layout

Several aspects have been considered (and struggled with) for this design:

- L*, position of QC1, strength of QC1-QC2, crossing angle, position of last bend, position of the compensating solenoid
- Position, size and optimal coverage of the luminosity detector
- Synchrotron radiation heavily influenced the design (as expected):
  a. Minimum pipe diameter at the IP is 40mm (perhaps still possible to have it 30mm)
  b. Masks and shielding (obviously still to be optimized)
  c. Last soft bent is now 100m away from IP, further limiting SR at IP

FCC-ee MDI: IR Layout

Work is ongoing on several fronts:

1. Consolidate the present design by expanding the background calculations to include[1]:
   a. Complete forward/backward SR calculation of the IR
   b. Check also with the Higgs machine parameters
2. How to optimize SR masks/absorbers (also to be effective for all sources of backgrounds)
3. Create more space at the IP for detector elements (luminosity monitor) by moving outwards compensating/screening solenoids[2], is this still a possibility ?
4. Study of trapped modes: Not clear that induced power might be handled (HOM absorbers to be studied) in the symmetric L* design.

Further steps:

1. Extend background studies with present IR
2. Move progressively toward a more realistic design for IR elements (quads, solenoids, beam pipe, supports, flanges etc.) whatever relevant for benchmarking detector performance.
3. Luminosity detector (?)

[1]http://indico.cern.ch/event/505741/contributions/2158992/attachments/1269223/1880026/FCC_IR_Update_09May16_MDI_meeting_sullivan.pdf
[2]http://indico.cern.ch/event/533299/contributions/2172423/attachments/1276083/1893611/IR_optics_meeting.pdf

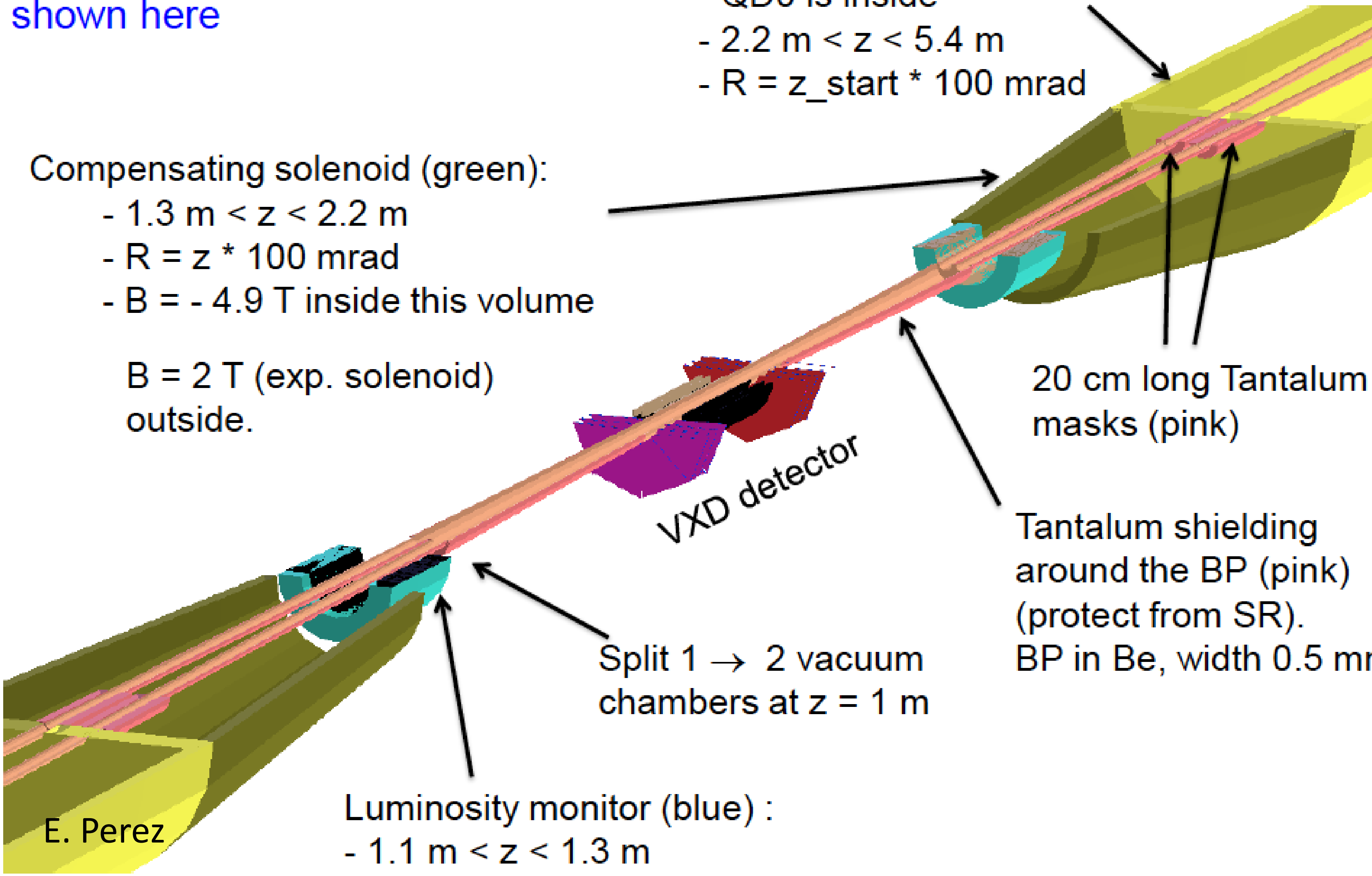
FCC-ee MDI: Geant implementation of the IR

Implemented for the simulations shown here

“envelope” for the shielding solenoid (yellow) :
- QD0 is inside
- 2.2 m < z < 5.4 m
- R = z_start * 100 mrad

Compensating solenoid (green):
- 1.3 m < z < 2.2 m
- R = z * 100 mrad
- B = - 4.9 T inside this volume

B = 2 T (exp. solenoid) outside.



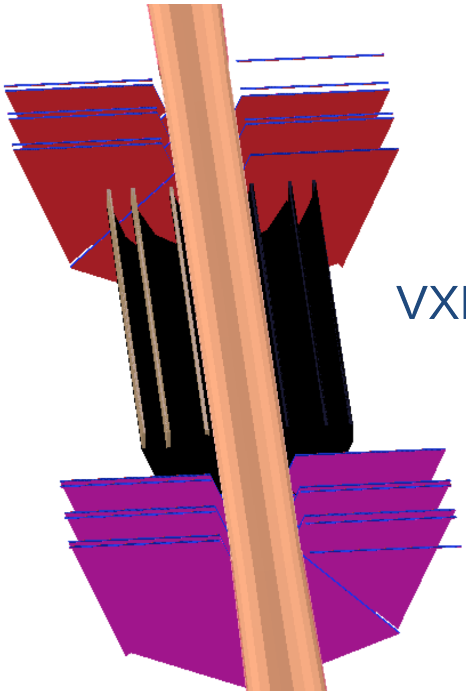
20 cm long Tantalum masks (pink)

Tantalum shielding around the BP (pink) (protect from SR).
BP in Be, width 0.5 mm

Split 1 → 2 vacuum chambers at z = 1 m

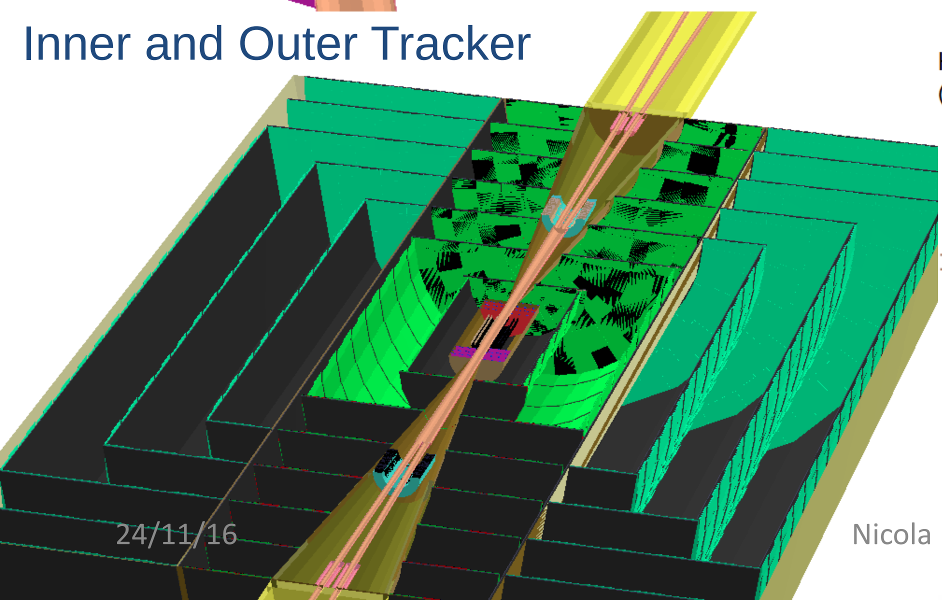
Luminosity monitor (blue) :
- 1.1 m < z < 1.3 m
- Si/W calorimeter, 5.6 < R < 9.3 cm
- centered around the outgoing beam

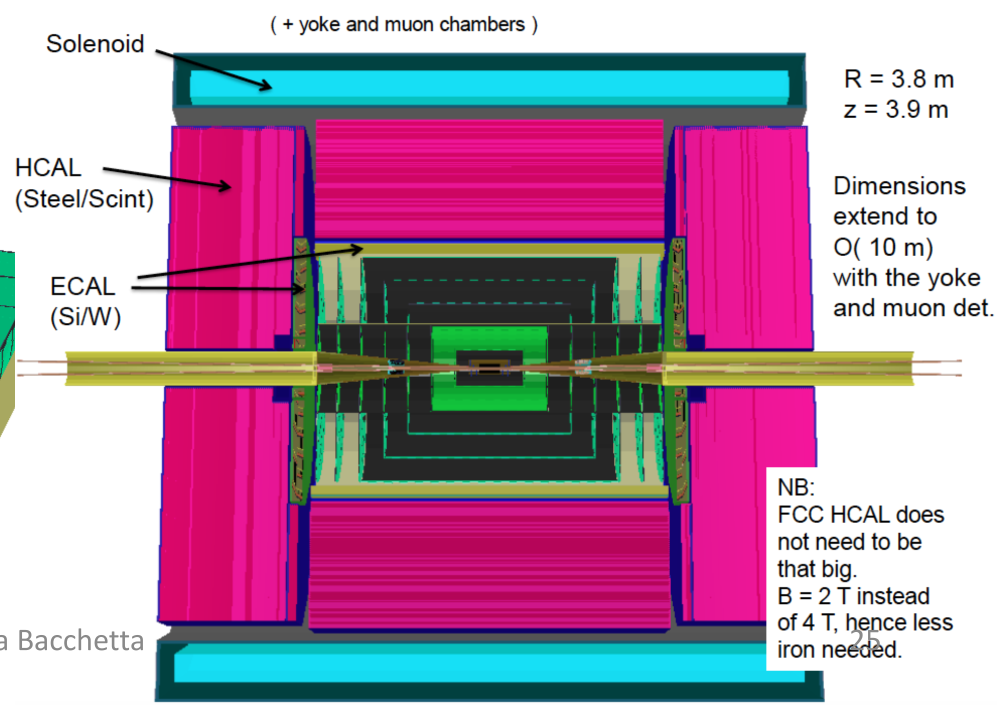
FCC-ee MDI: Geant implementation of the Detector



- Based on CLIC adapted for the FCC-ee IR as a start
  - 40mm diameter beampipe in central region
  - VXD Barrel: 3 double-layers R = 2.2 cm, 4.4 cm, 5.8 cm | z max | = 13 cm
  - VXD Endcap : 3 disks, “spiral” geometry, Rmax = 10.2 cm | z max | = 22.3 cm i.e. all endcap disks on the cylindrical BP

Inner and Outer Tracker



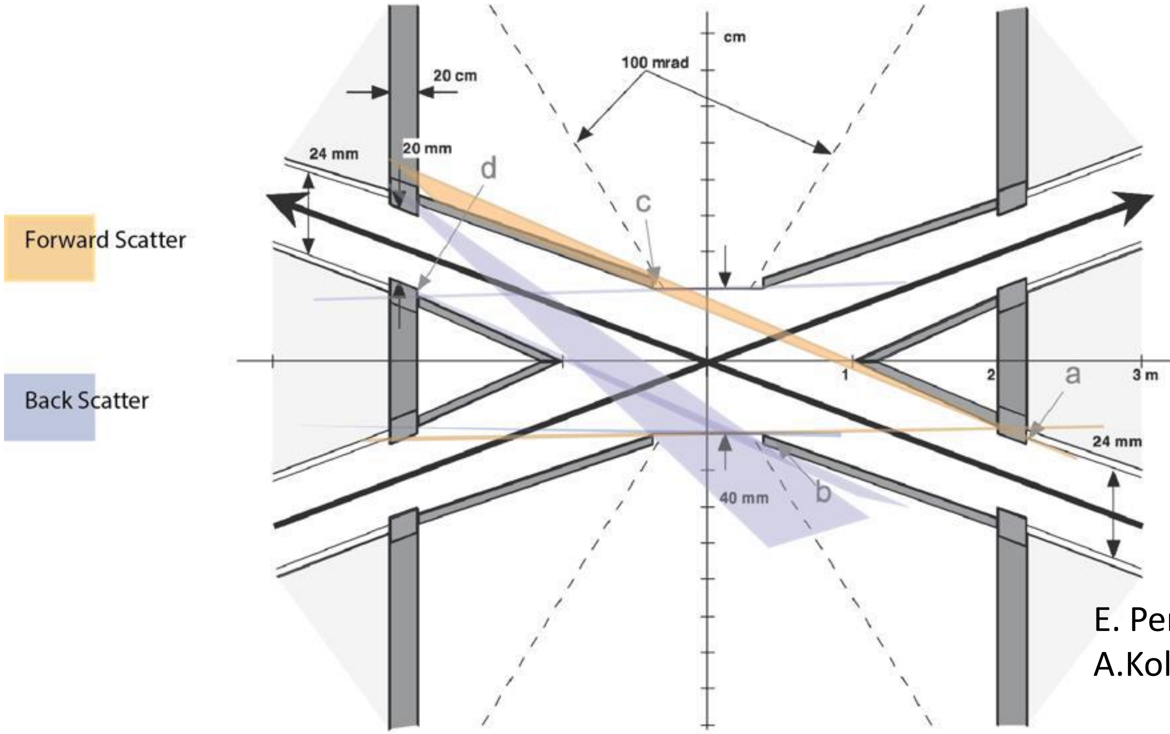


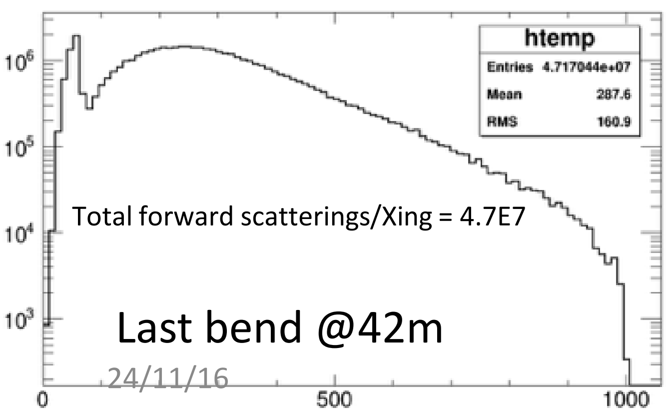
FCC-ee MDI: Sinchrotron Radiation/ Detector simulation

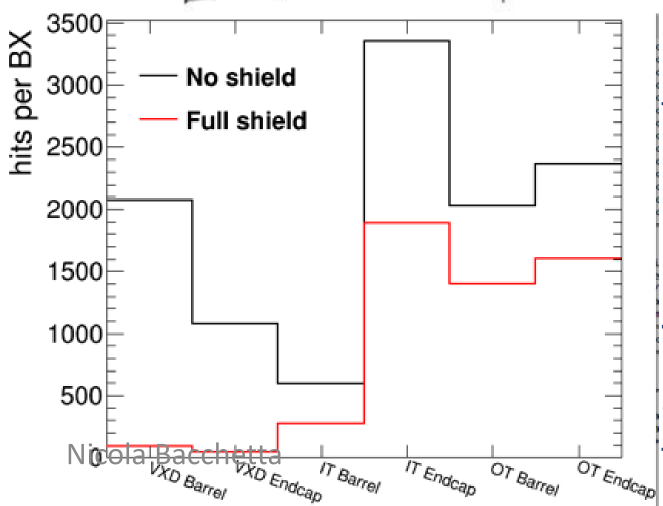
Starting point is forward-scattered on the mask (a) of 4.7E7 γ per BX (from bend + final quad) x 2 for the two beams(*).

Send these photons through our full simulation.

Fwd scattering expected to be the dominant source of background.



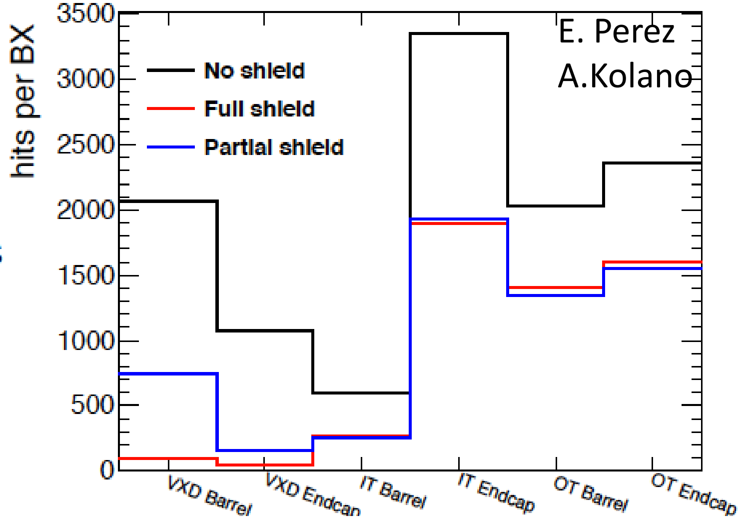




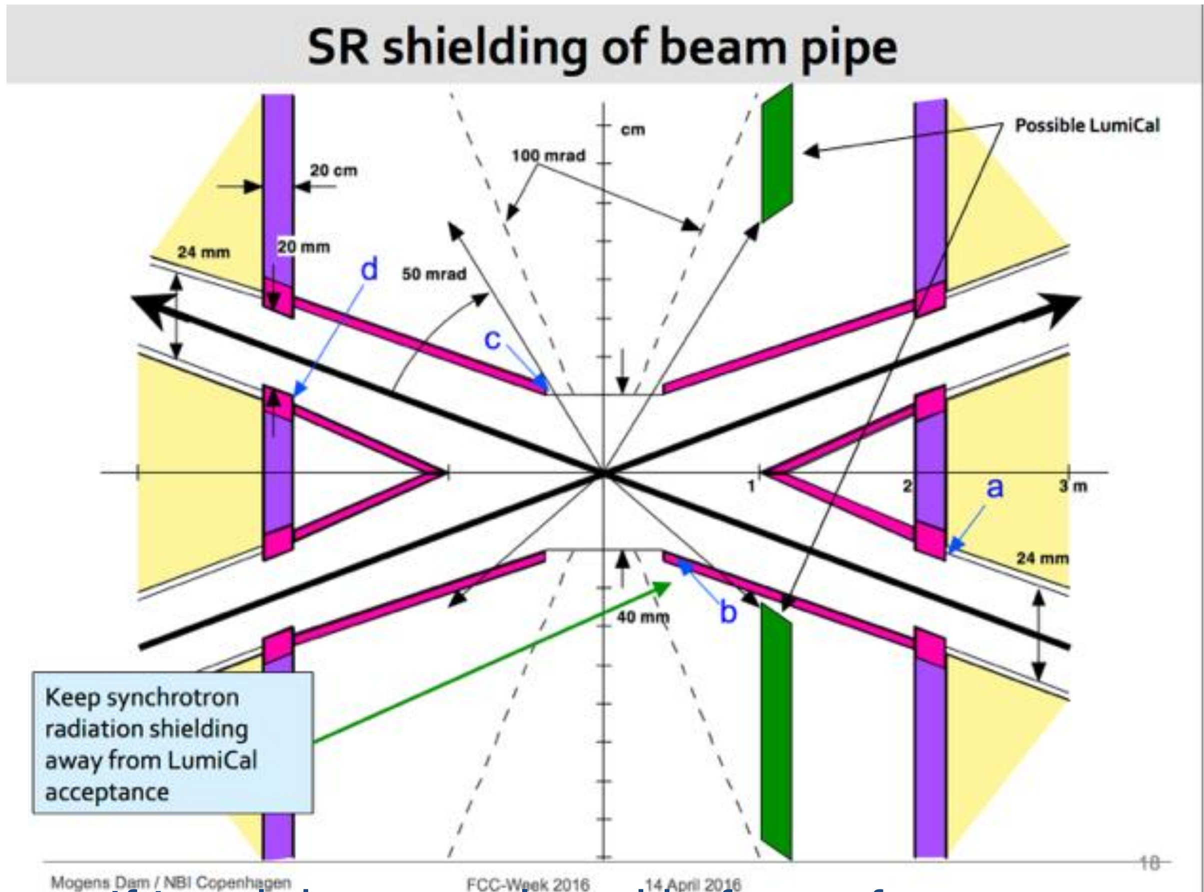
Number of hits in the VXD + tracker, per BX : 4500 x 2 beams = 9000 hits, mostly in the Tracker as the VXD acceptance is small for these γ.

FCC-ee MDI: Sinchrotron Radiation/ Detector simulation

- Full shielding of the beampipe with 2mm Ta (right sketch) dramatically reduces number of hits in the VXD

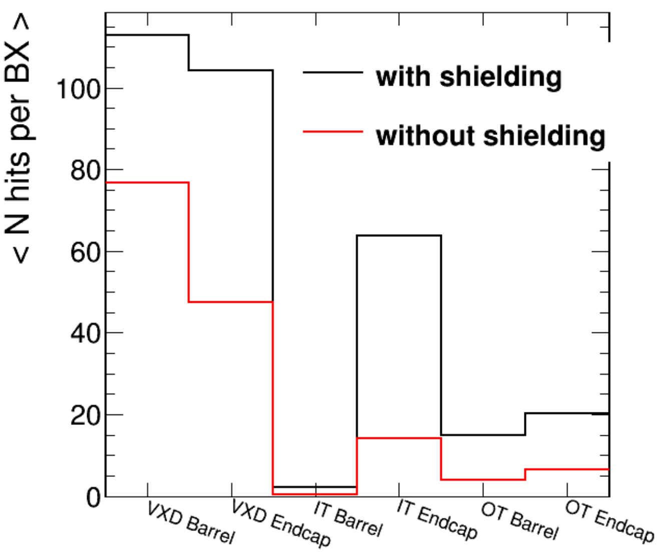


Partial shield is still effective in reducing hits on the VXD



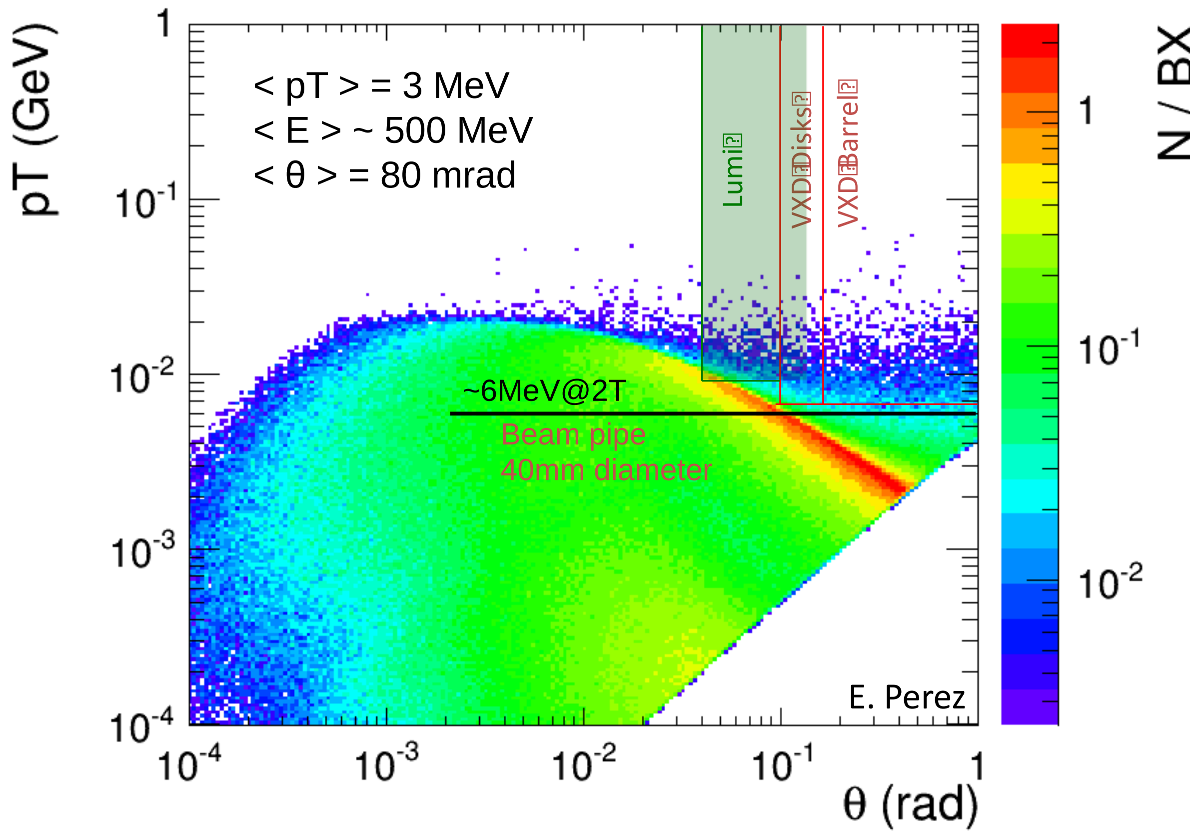
- If Lumi detector placed in front of compensating solenoid (green bars in the right sketch), need to shorten the length of the shielding to keep it away from Lumi acceptance.

FCC-ee MDI: beamstrhalung and pair production



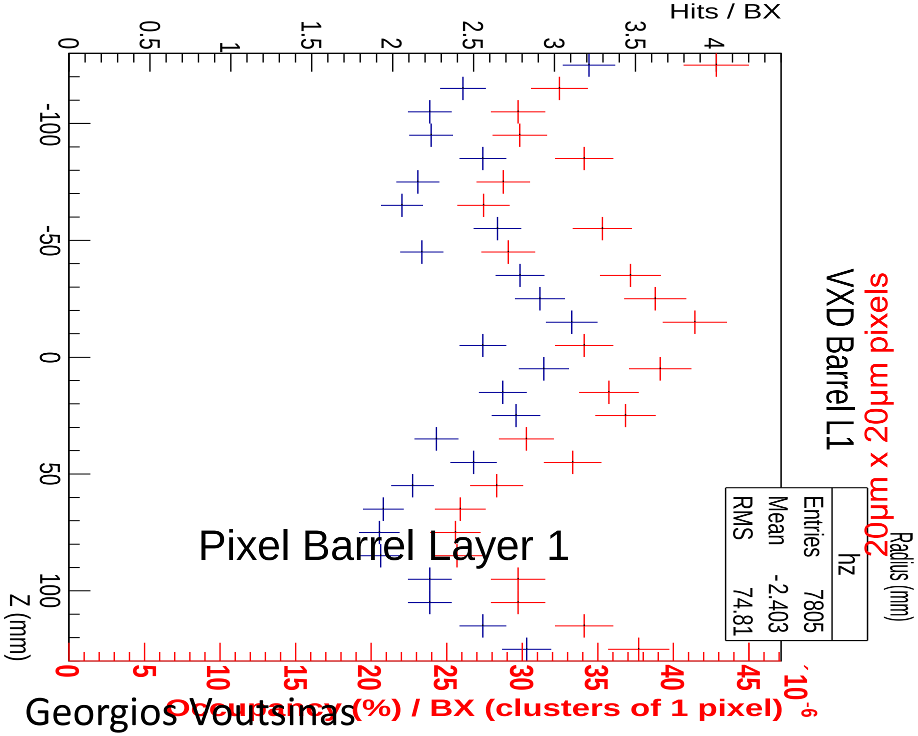
Shielding increases the number of hits by a factor of 2 in the VXD

Guinea-Pig @Zpeak

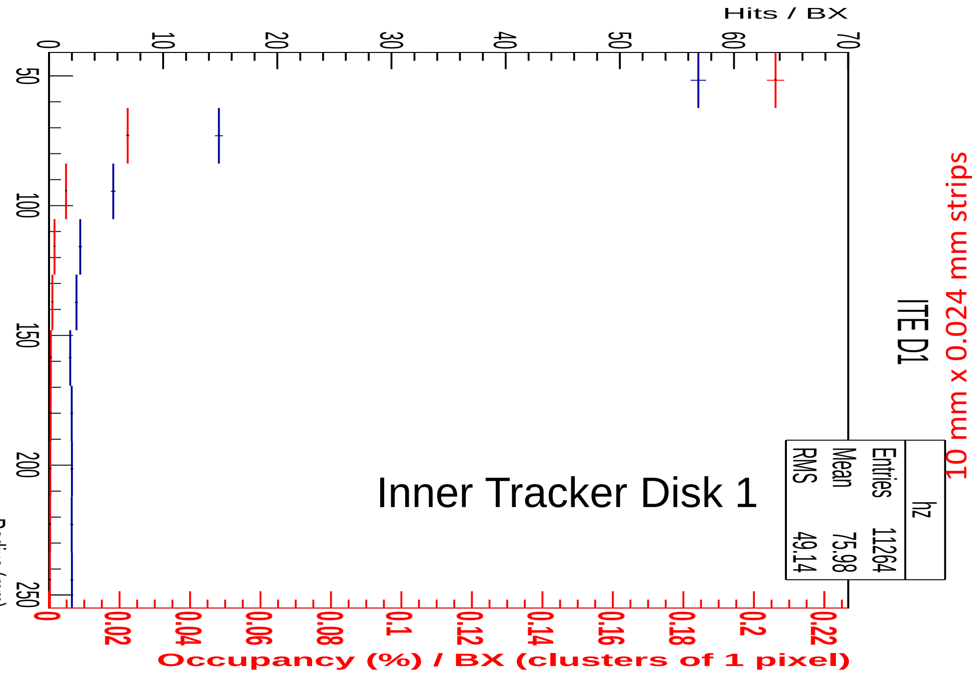


- On average : ~ 4000 pairs created per BX carry an energy of ~ 1 TeV (400 x less that at ILC500).
- On average : 320 hits / BX (70% on the VXD, 20% on Inner Tracker, 10% on Outer Tracker
- Beampipe shielding increase the number of hits (even 0.5mm Ta is enough for electrons of < p > = 500 MeV to make a shower)

FCC-ee MDI: beamstrhalung and pair production



Georgios Voutsinas



From GuineaPig @ Z peak: more detail studies ongoing

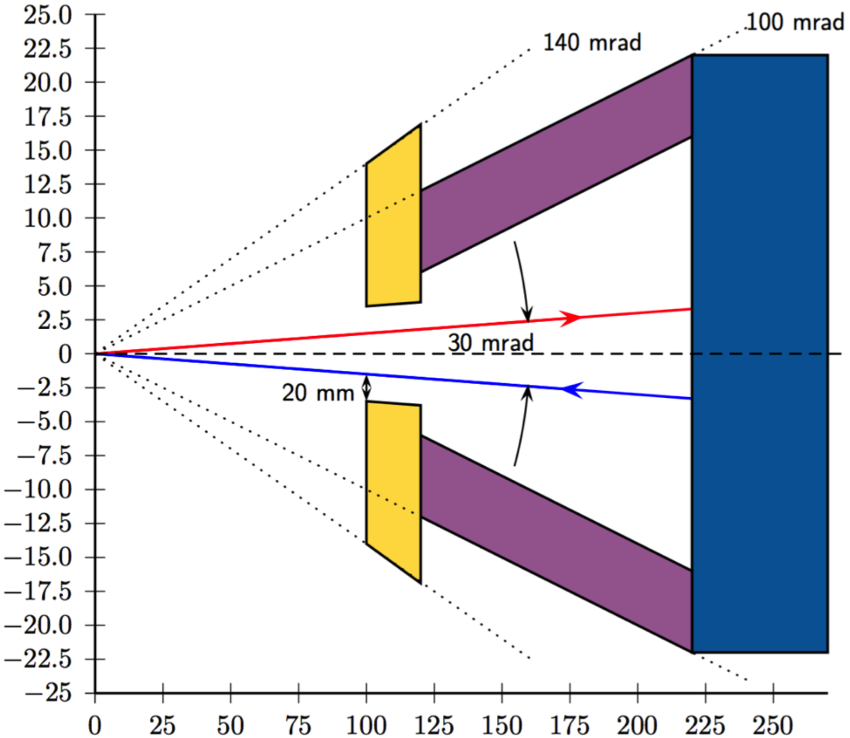
- Total occupancy on the innermost layer of the Pixel barrel as function of Z and at the Disk 1 of the Inner Tracker as a function of R .
- The central (straight) section of the beam pipe is considered to be 0.5mm Be

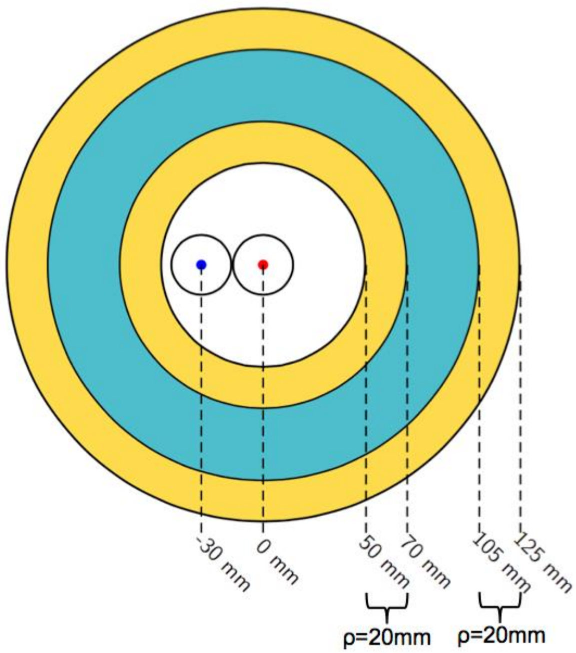
FCC-ee MDI: Conclusions

- Lots of progress thanks to the combined effort of many people (Thanks !)
- Optics design reduces now the SR from last bend to values similar to LEP2
- We have a baseline design for the optics and IR, but still struggling with the Luminoisty detector (see Mogens talk)
- Mechanisms are in place to study background effects into a proto-detector based on CLIC and contribution from the CLIC group is also coming (Thanks !). The group is strengthening and many interesting studies can now take place.
- Studying of shielding, masking, collimators, is ongoing
- More background studies are undergoing or soon to start (beamstrahlung, γγ to hadrons, radiative Bhabha)

BACK-UP

FCC-ee MDI: Luminosity Detector

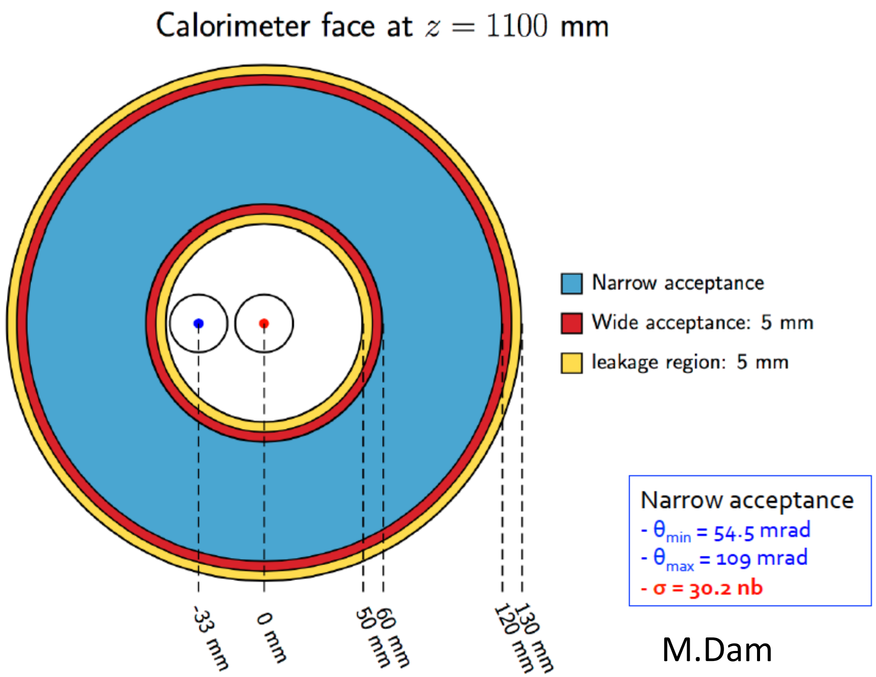




M.Dam

- Still quite challenging to squeeze in a lumi detector with sufficient cross-section for small angle elastic e^+e^- (Bhabha) scattering.
- Here it is assumed the compensating solenoid ends at 1.2m from IP leaving 20cm for the lumi detector to be placed in front of it.
- Effective lumi cross section depends critically on the difference ρ between loose and tight fiducial volumes (here ρ 20mm, OPAL had 15mm).
- Not clear yet whether this would be sufficient to achieve desired precision (here σ=14nb)

FCC-ee MDI: Luminosity Detector



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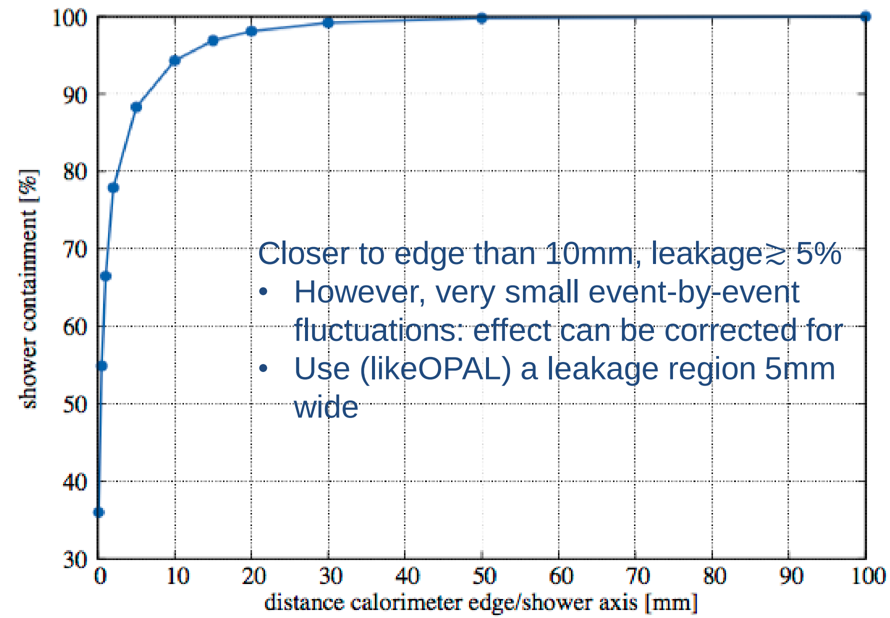
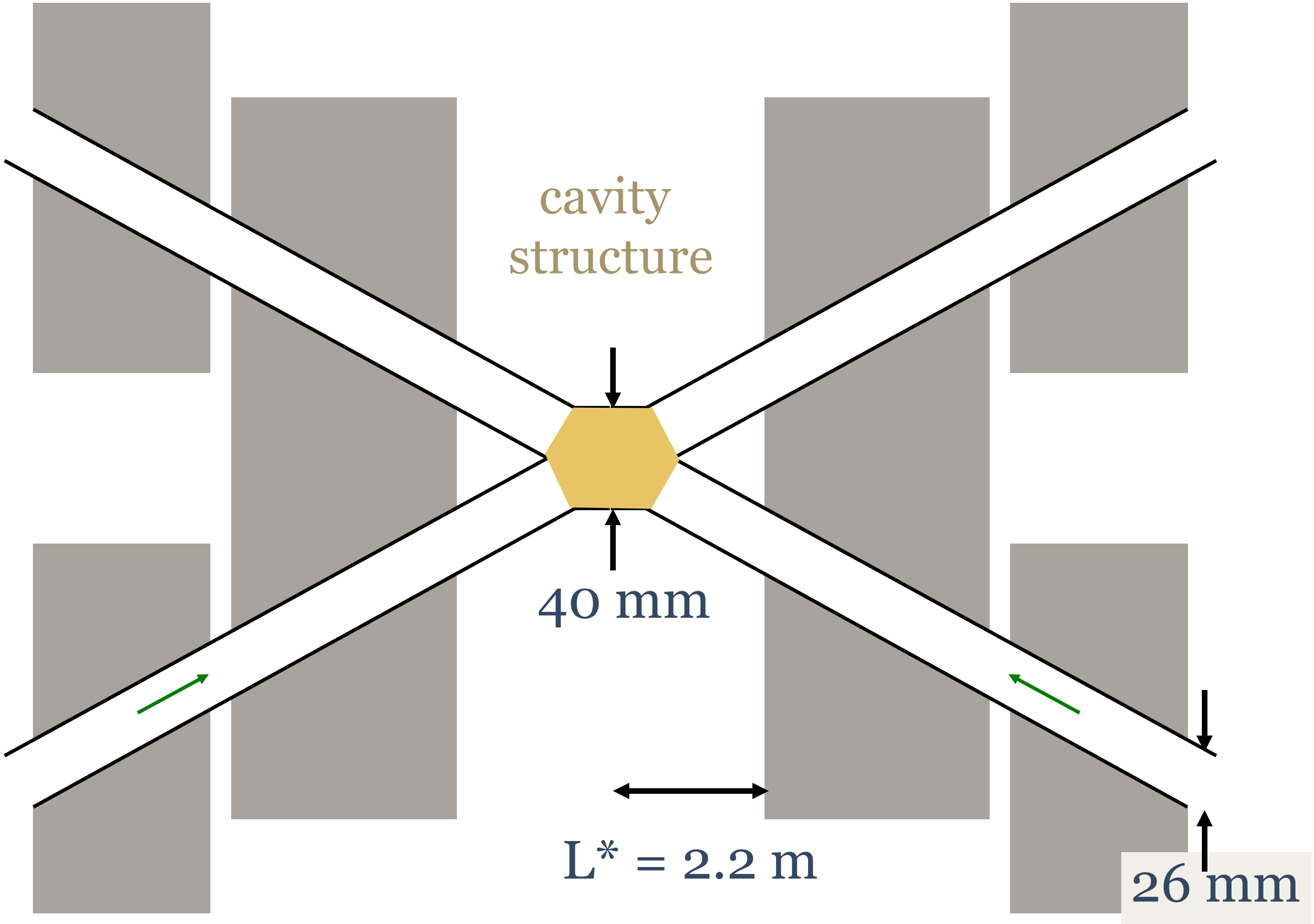


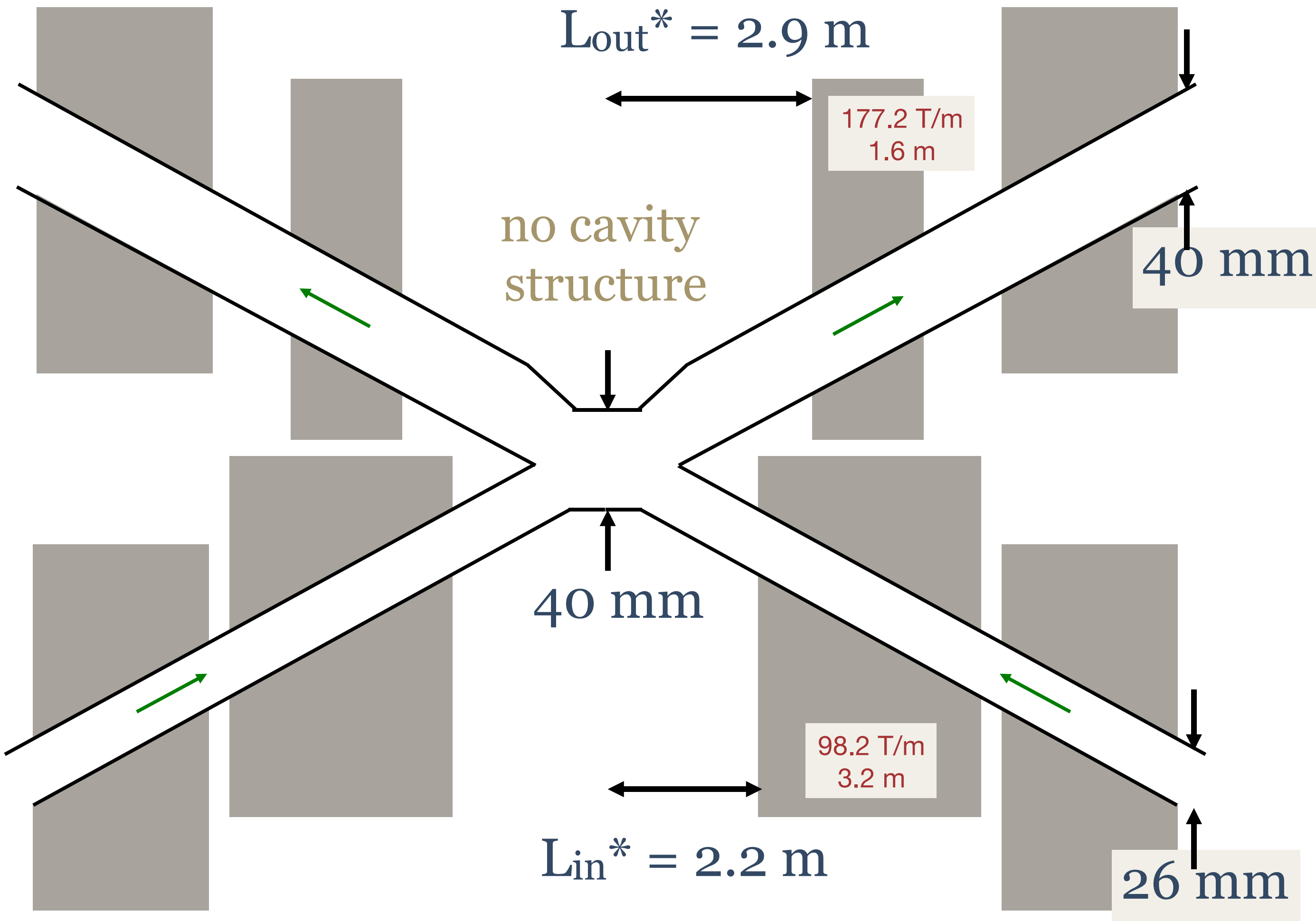
- New study from Mogens for Lumical at Z=1100, ρ of 10mm divided into 5mm for the effective difference between loose and tight cuts and 5mm for limiting the "leakage" (5mm at Z=1000 corresponds to the same angles present in OPAL).
- Cross-section would now be here σ=30.8nb
- With thickness of 20cm it means that the compensating solenoid should end at Z=1300 (instead of Z=1000 as now).

HOM trapping by the cavity structure at IP



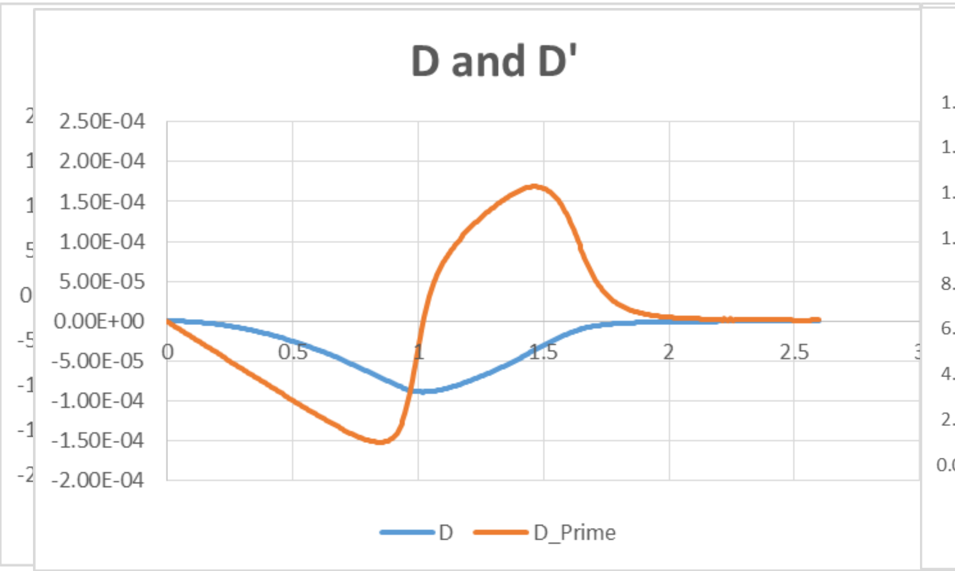
- HOM is trapped in the IP beam pipe, if all beam pipes are narrower than the IP, which needs to be larger that 40 mm (M. Sullivan).
- Heating, esp. at Z.
- Leak of HOM to the detector, through the thin Be beam pipe at the IP.

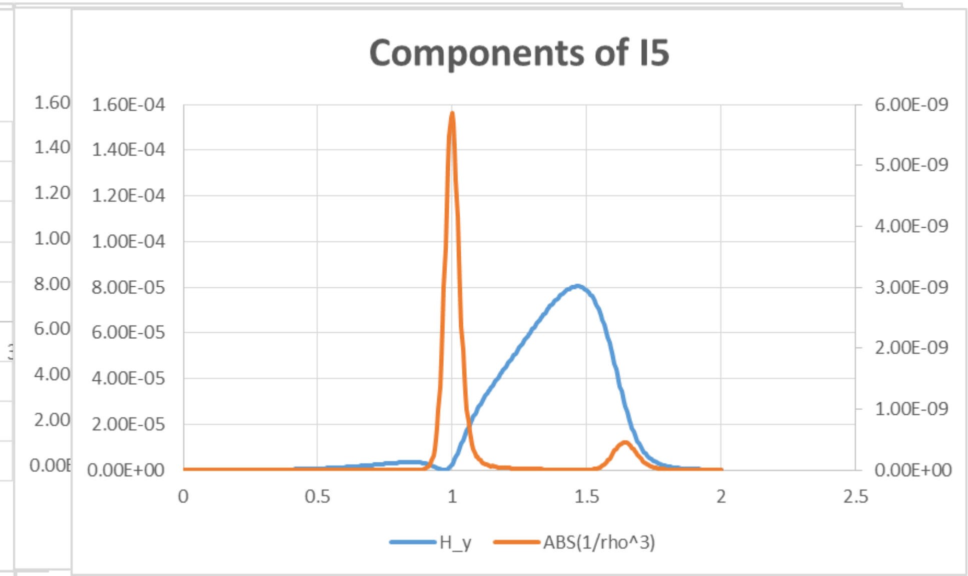
Asymmetric L*: larger outgoing beam pipe & thinner final quads



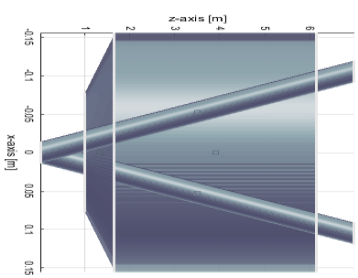
- The HOM can escape to the outside through the outgoing beam pipe, which has a diameter not smaller than IP.
- The outgoing final quad becomes thinner and stronger (E. Levichev, S. Sinyatkin).

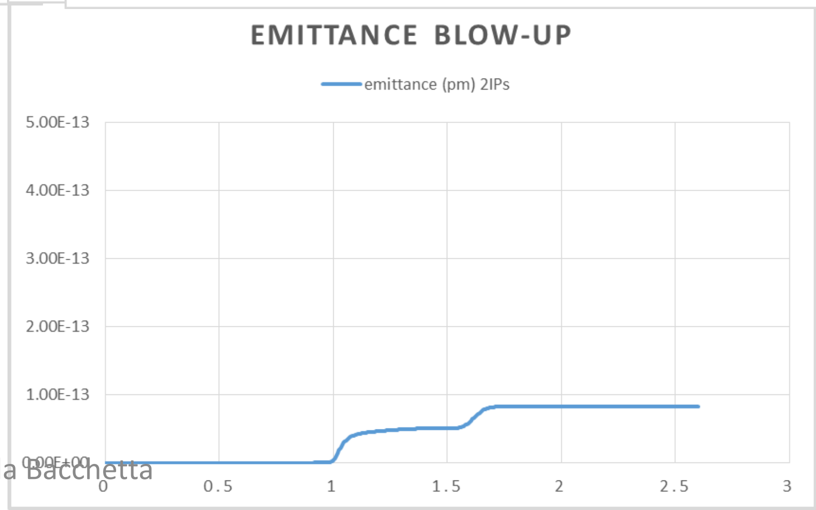
Presented baseline, 100mrad cone, solenoids start at 1.0m





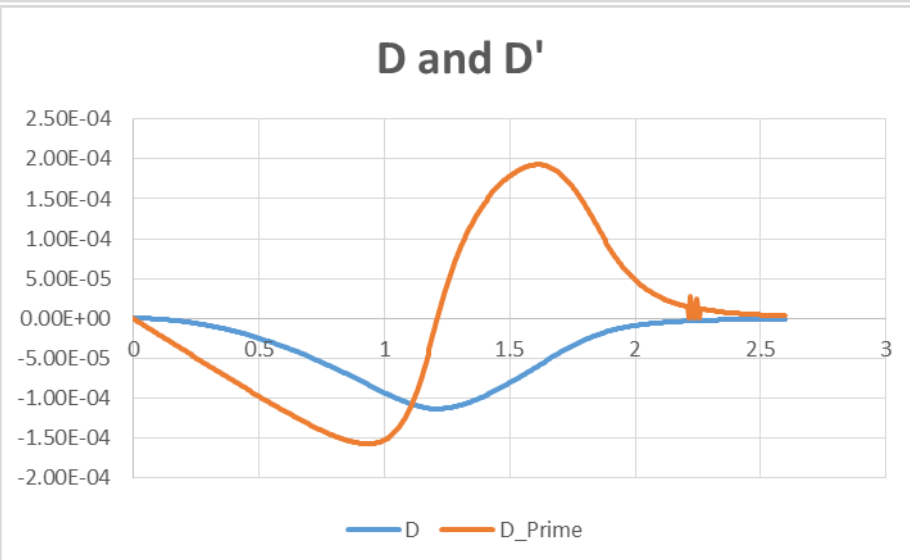
31cm

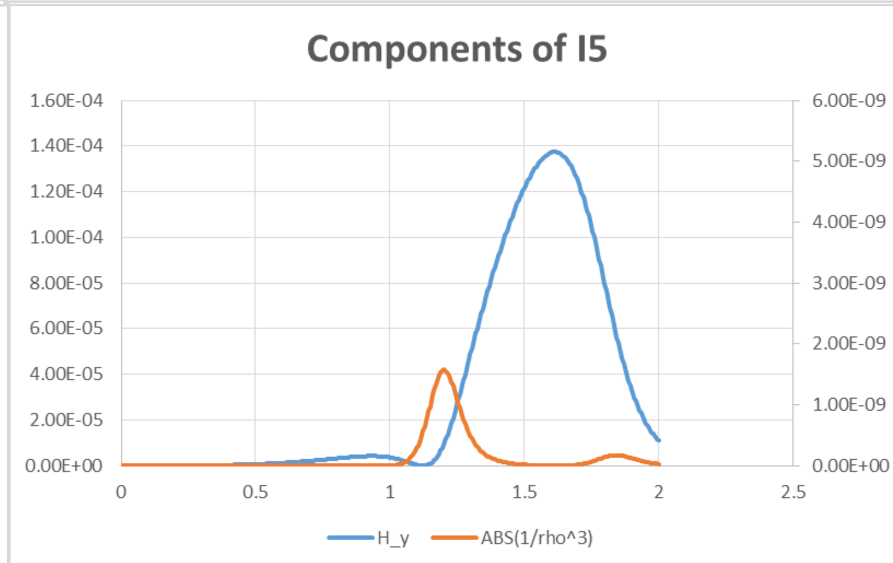




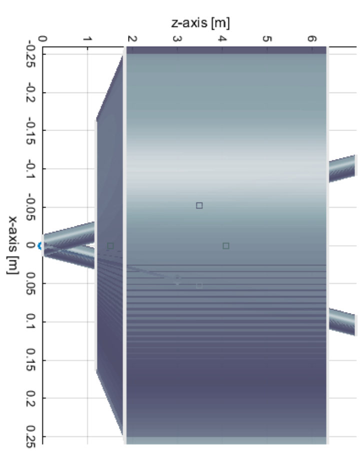
50%
of budget

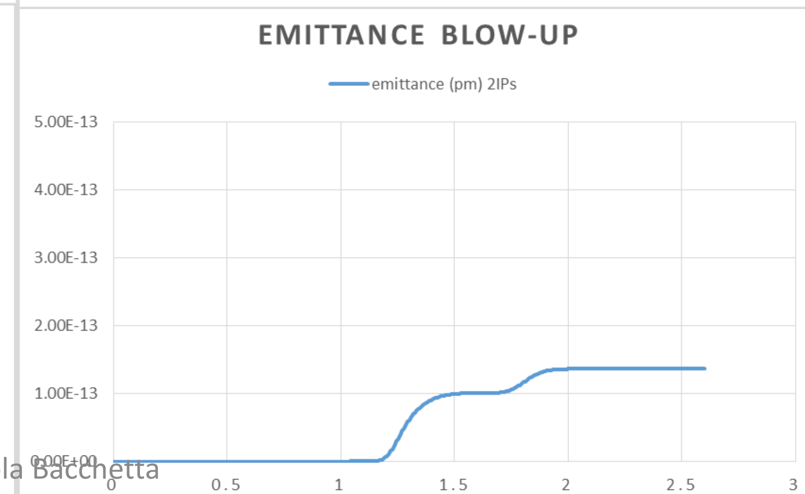
New proposal, 140mrad cone, solenoids start at 1.2m





52cm





50% of budget