Machine Detector Interface including L* preferences

M. Boscolo for the FCC-ee MDI group

FCC-ee Review, CERN, October 13th 2016

MDI Group

- Our WG was formed officially last January 2016
- We have monthly Vidyo meetings since February 2016
- Indico: http://indico.cern.ch/category/5665/

- **MDI WG Mandate**
  - **Synchrotron Radiation and Masking**
  - **Other accelerator backgrounds**
  - **Magnetic integration**
  - **luminosity measurements**

Outline

- IR Optics
- IR magnet integration
- IR layout
- Luminosity monitor
- Background studies
  - Synchrotron radiation -> main issue
  - Beamstrahlung and pairs (first look)
- Infrastructures
- Conclusions

Optics: main requirements with an impact to MDI

- **Crab waist scheme**
  - ✓ large crossing angle
- **2 IPs**
- **β^*_x / β^*_y = 1m / 2mm (175 GeV)**
  - ✓ 0.5m/1mm (45.6 GeV)
- **Vertical emittance ~ pm**
  - ✓ very good solenoid compensation scheme needed
- **Horizontal emittance 1-2 nm**
- **Energy acceptance 2%**
  - ✓ for acceptable beamstrahlung lifetime
- **$E_{critical}$ < 100 KeV for incoming beam to IP from 100 m**
  - ✓ based on LEP experience
- **As close as possible to the FCC-hh beam line**

FCC-ee baseline parameters

	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

MDI design

Different studies performed by the MDI group to determine the best design:

- large crossing angle together with ε_y~ pm requires good **solenoid compensation scheme and influences L* choice**
- Position, size and optimal coverage of **the luminosity detector** influences on the request on L*
- **Synchrotron radiation** heavily influences the design: simulation with different approaches and check its detector sustainability
- Possible **HOM** in the IR being studied with proposed symmetric and asymmetric IR beam pipes.
- **Infrastructure** studies to fit with FCC-hh constraints.

IR symmetric and asymmetric Optics

all based on the crab waist scheme

SYMMETRIC

- A.Bogomyagkov (AB)
- K. Oide (KO)

ASYMMETRIC (KO)

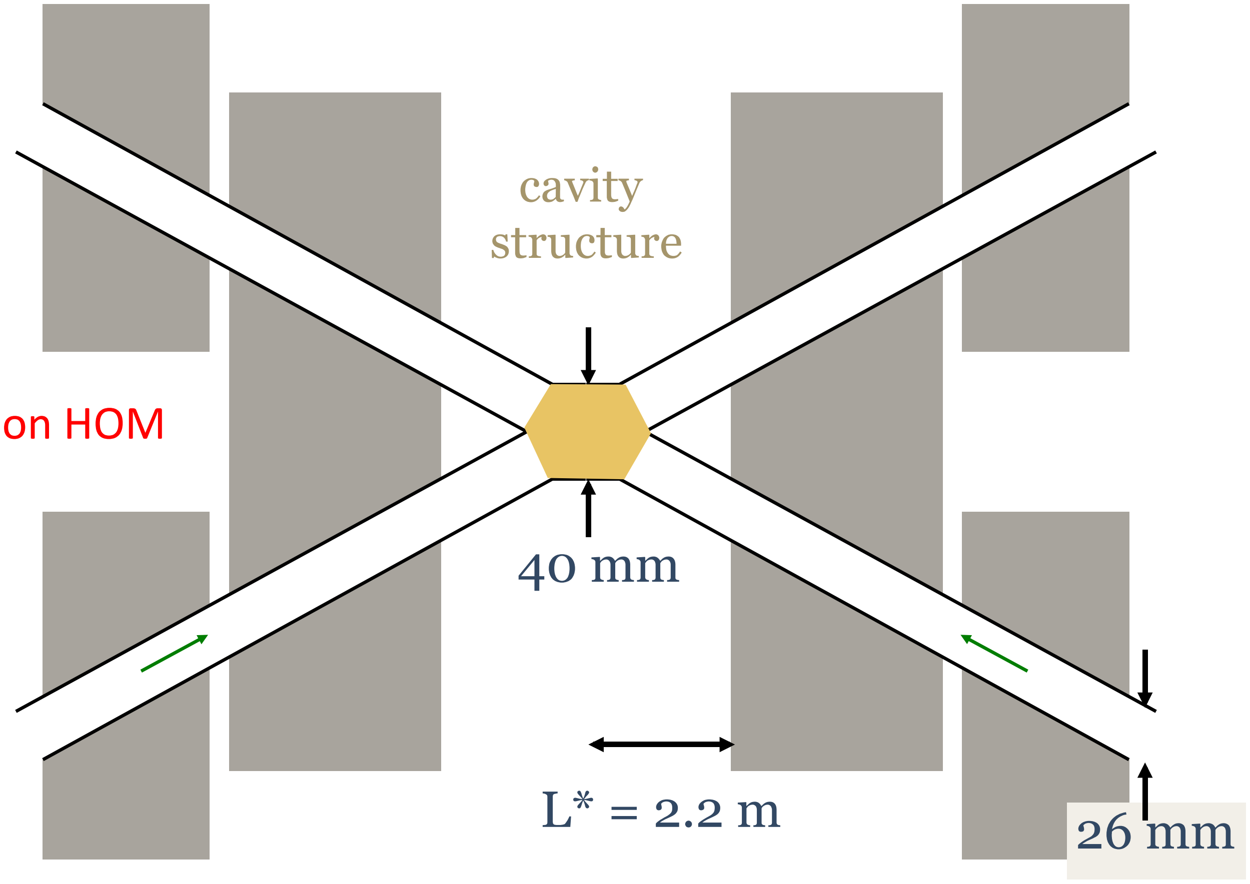
main impact for MDI:

- **last bend:** 100m upstream IP and 42m downstream the IP
- **great benefit for SR in the IR**
- **last bend & QC1 (length and strength)** (sad v.74_11)
  - asymmetric **L*** (no gain for luminometer)
  - asymmetric **beam pipe** option (main impact on HOM, will drive to this option)

Symmetric IR

HOM trapping by the cavity structure at IP

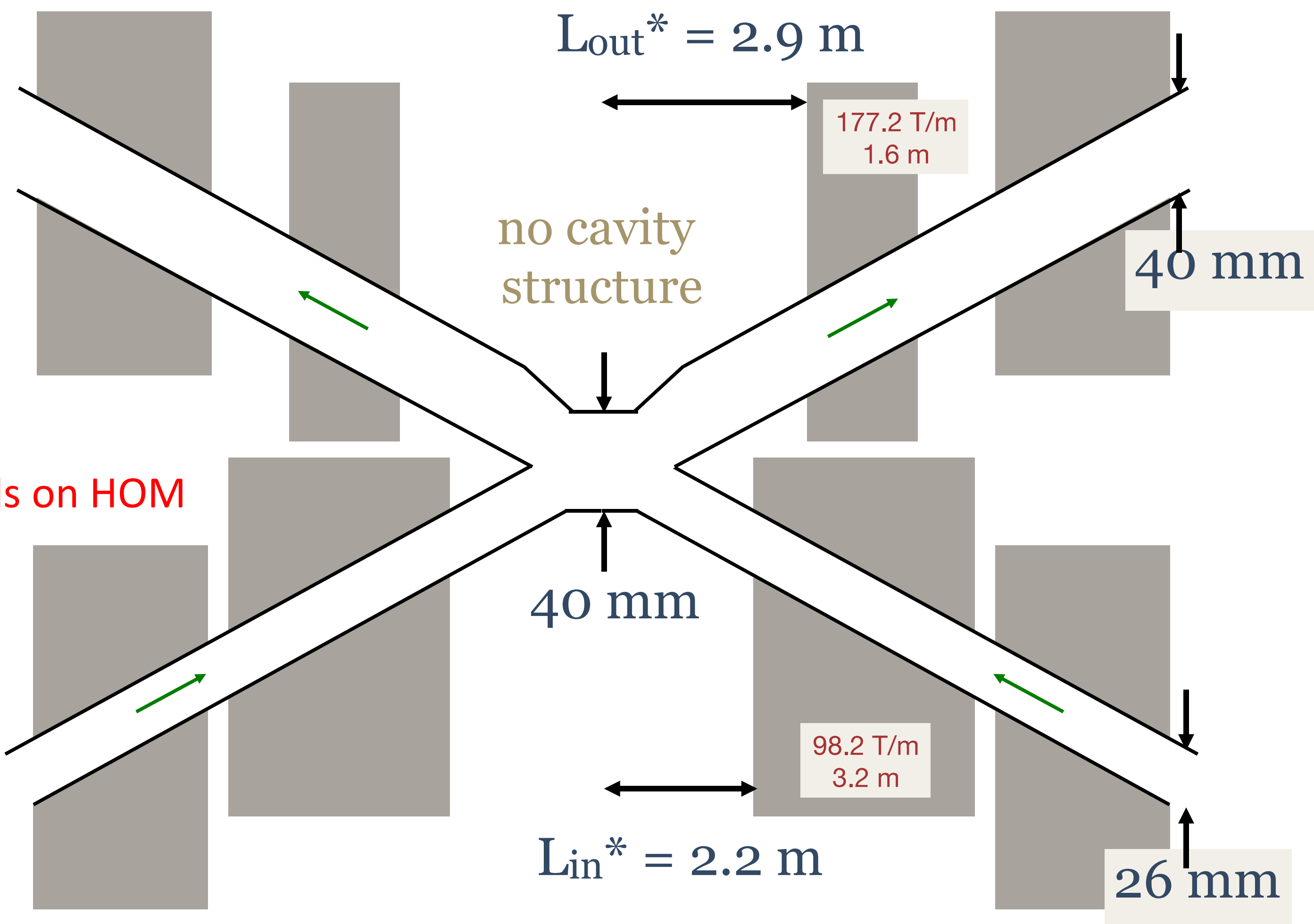
E. Belli talk
for more details on HOM



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.

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



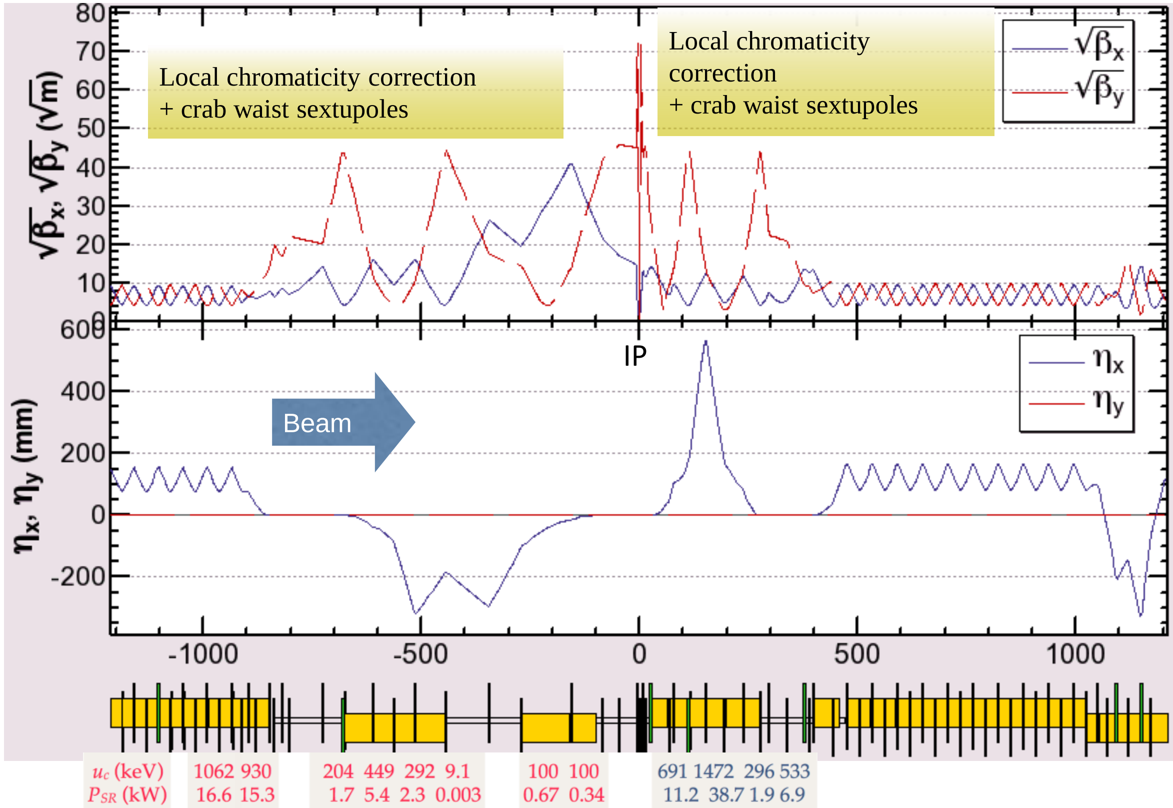
E. Belli talk
for more details on HOM

K. Oide

- 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).

Asymmetric IR optics

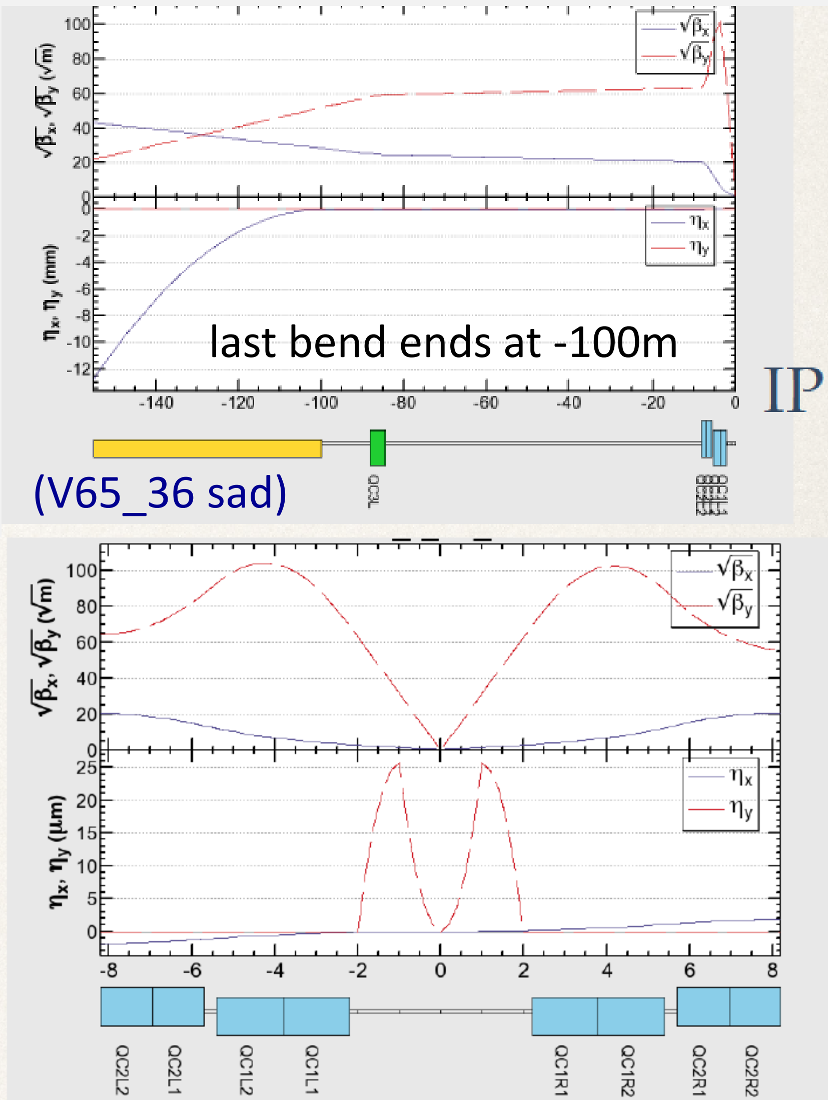
v74_11
K.Oide



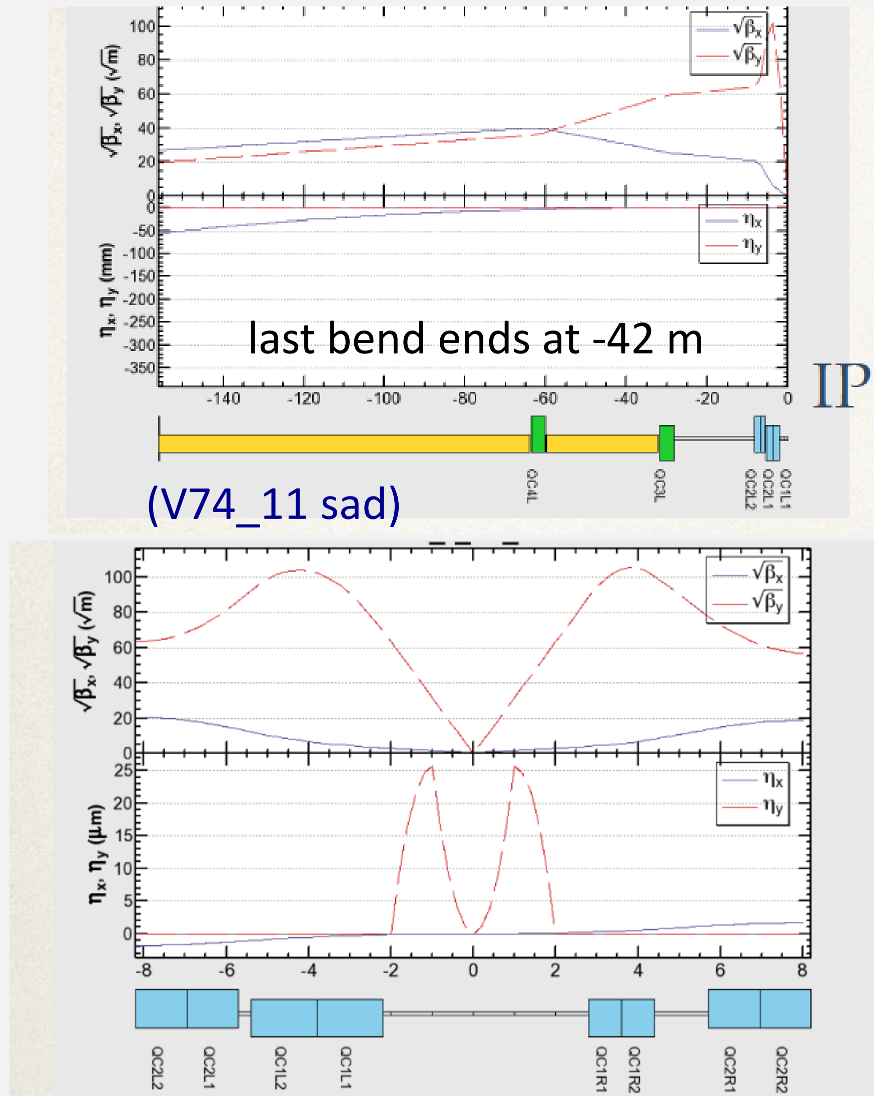
- Synchrotron radiation from the upstream last dipoles is suppressed to 100 keV up to 450 m from the IP.
- The large Crossing angle 30mrad and the vertical emittance as small as 1pm requires compensating solenoid
- Local chromaticity correction sections needed for the energy acceptance requirement of 2%

KO Asymmetric IR optics

Symmetric L*=2.2m



Asymmetric L* 2.2/2.9m



Circumference [km]	99983.76	
Number of IPs / ring	2	
Crossing angle at IP [mrad]	30	
Solenoid with compensation at IP	±2 T × 1 m	
ℓ* [m] (asymmetric version)	2.2 / 2.9	
Critical energy of photons to IP	< 100 keV @ 175 GeV, up to 510 m upstream	
IR Optics	asymmetric	
Local chromaticity correction	Y	
Crab sexts	integrated with LCCS	
Arc cell	FODO, 90°/90°	
Arc sextuple families	292 (paired)	
mom. comp. [10^{-5}]	0.70	
Tunes (x/y)	387.08 / 387.14	
Ebeam [GeV]	**45.6**	**175**
SR energy loss per turn [GeV]	0.0346	7.47
Current / beam [mA]	1450	6.6
$P_{SR,tot}$ [MW]	100.3	98.6
ε_x [nm]	0.86	1.26
β^*_x [m]	0.5 (1)	1 (0.5)
β^*_y [mm]	1 (2)	2 (1)
RF frequency [MHz]	400	
$\sigma_{\delta,SR}$ [%]	0.038	0.141
$\sigma_{z,SR}$ [mm]	2.8 @ V_c = 78 MV	2.4 @ V_c = 9.04 GV
Synchrotron tune	-0.0158 @ V_c = 78 MV	-0.0657 @ V_c = 9.04 GV

K. Oide

IR magnet design

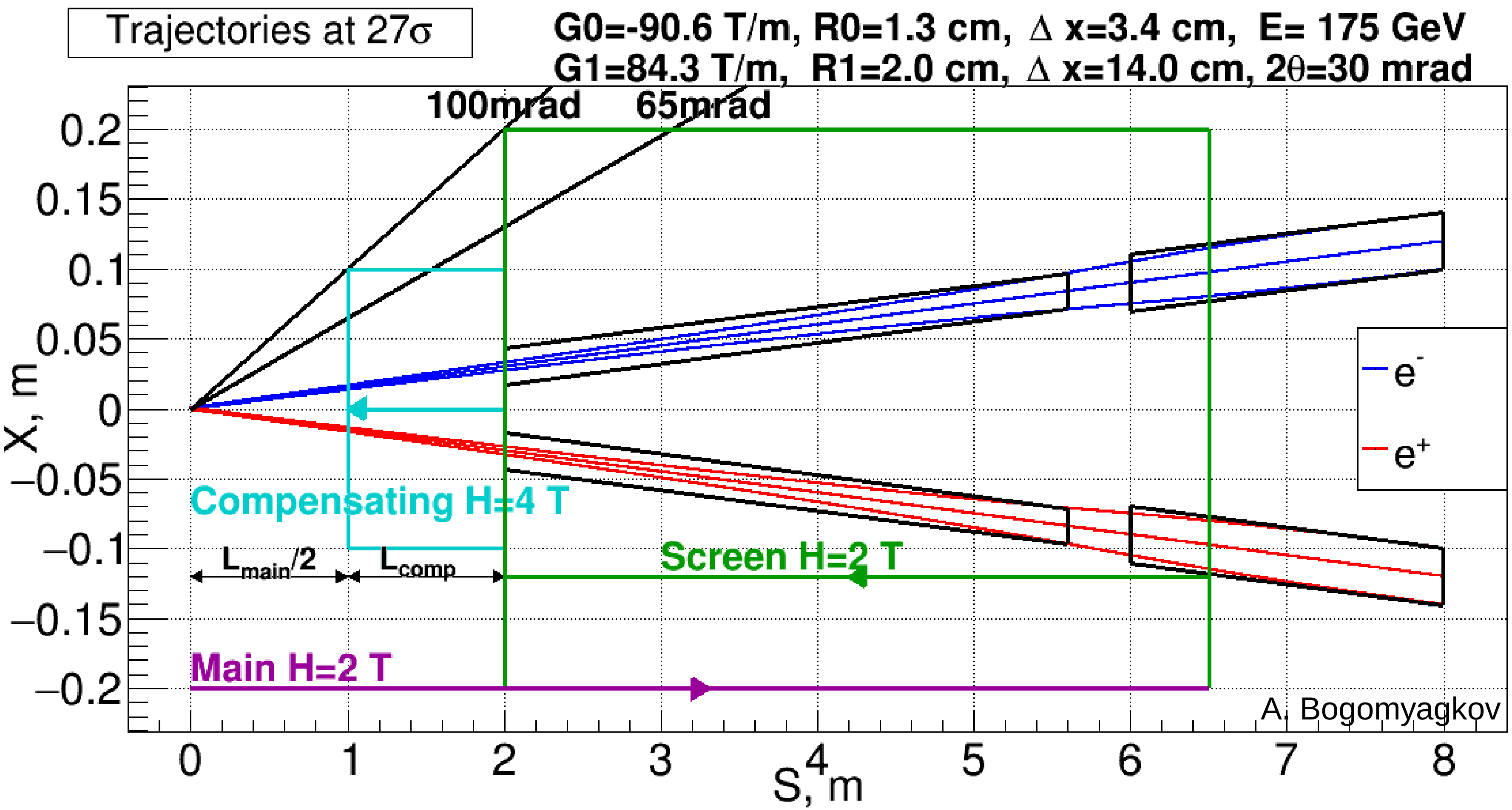
IR magnet design

Constraints:

- **2T** detector field
- L* ~2 m (scheme optimized for **L*=2.2m**)
- Free cone for physics ~**100 mrad**
- final focus quads inside the detector
  (low βy^* and large crossing angle)
- leave space for detectors at small angle (**luminosity detector**)

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 has been designed.

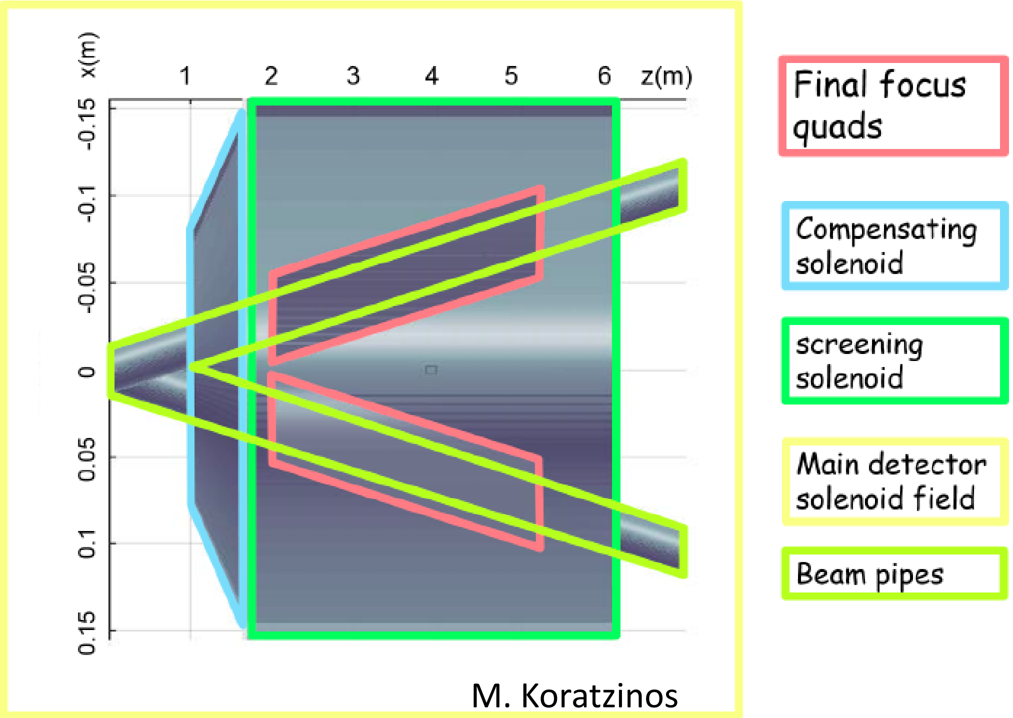
IR magnet compensating scheme



- **Compensating solenoid** starts at **z=1m** and **radius=10 cm**
- **Screening solenoid** starts at **Z=2m** and **radius=20 cm**

IR magnet design

L*=2.2 m



- 10% ε_y blow-up at Zpeak
- at 2m only 6 cm between QC1 (E. Levichev talk for details)

Two solenoids are introduced in the IR:

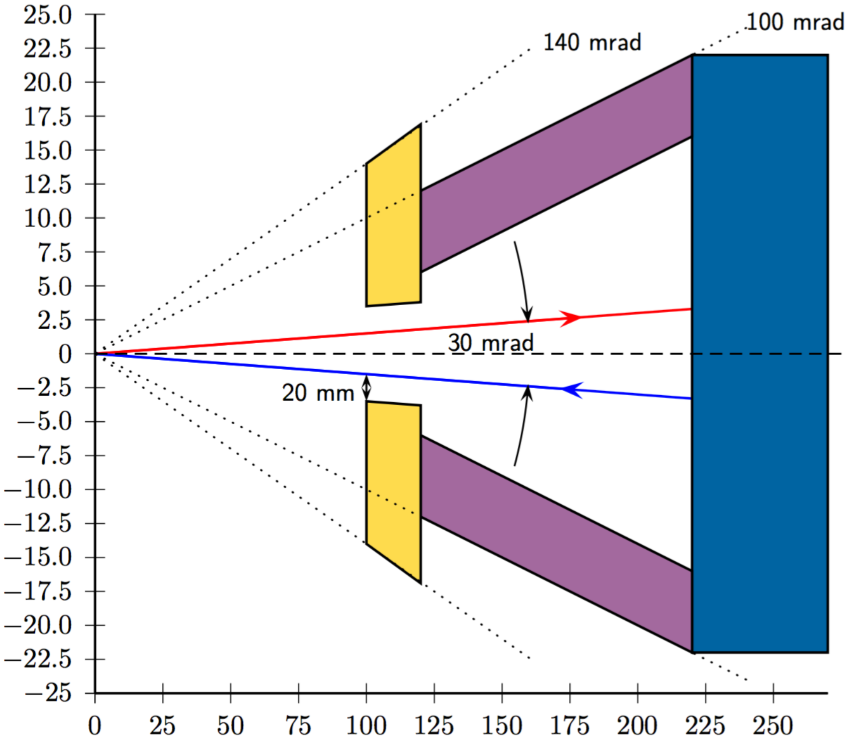
- **screening solenoid** that shields the detector field inside the quads (in the quad net solenoidal field=0)
- **compensating solenoid** in front of the first quad, as close as possible, to reduce the ε_y blow-up (integral BL~0)

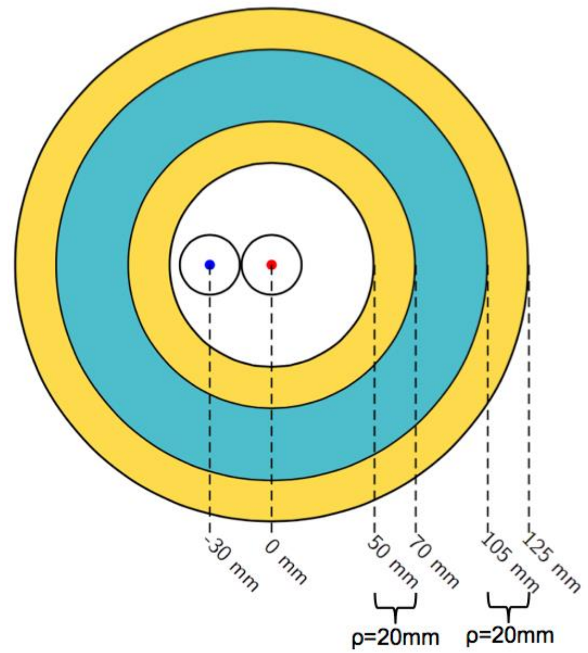
❖ **Feasibile system** (H. Ten Kate)

Luminosity monitor

Luminosity Detector

L*=2.2 m and 140 mrad



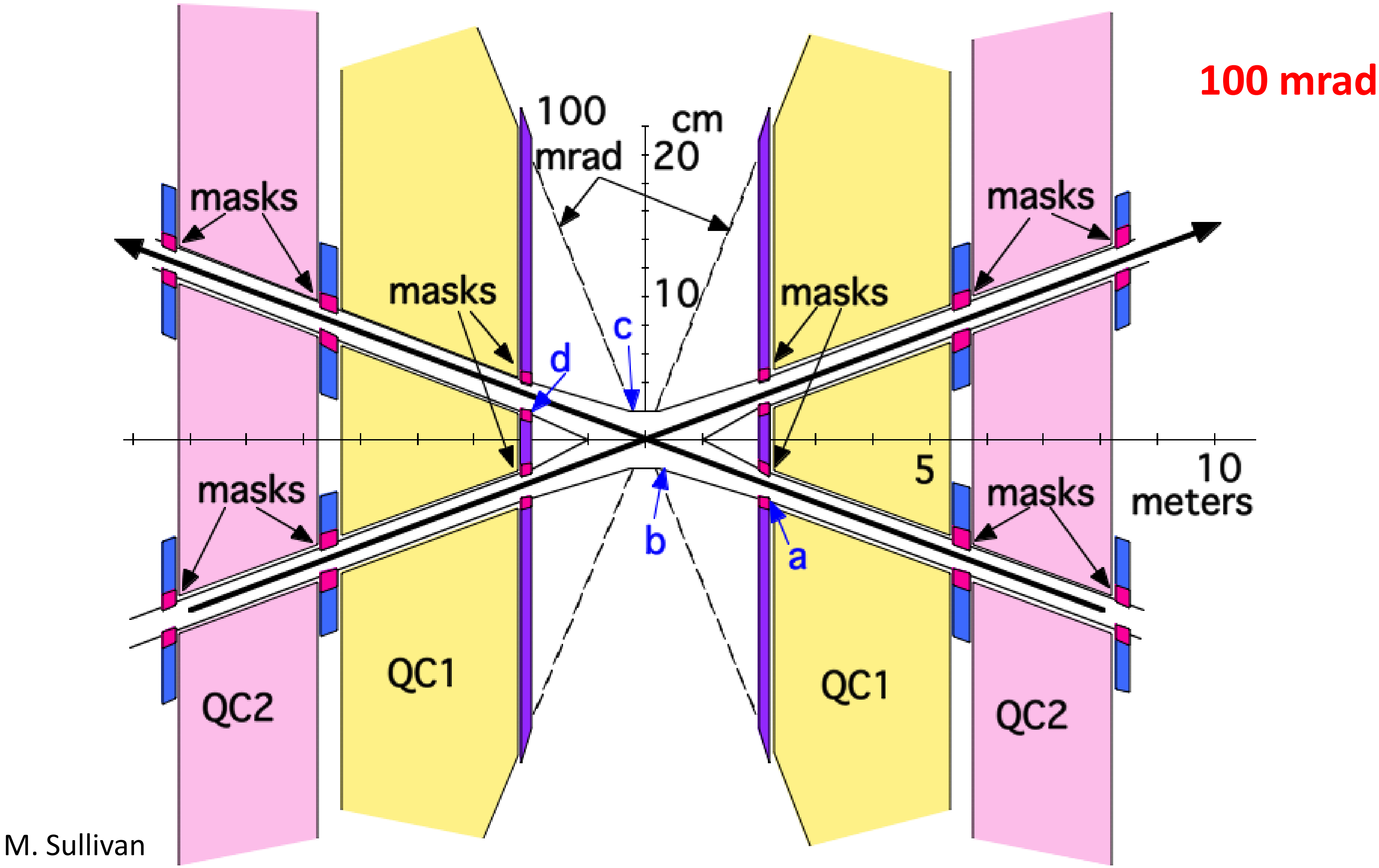


M. Dam

- **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 (L*=2.2 m)
- The closer is LCAL the harder is the design
- Be sure we do not push the LCAL closer to IP than necessary

IR Layout

IR Layout with L*=2.2 m



beam pipe circular aperture in quads =24 mm (diameter)
beam pipe circular aperture masks =20 mm (diameter)

IR Layout with L*=2.2 m

	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

(left=right)

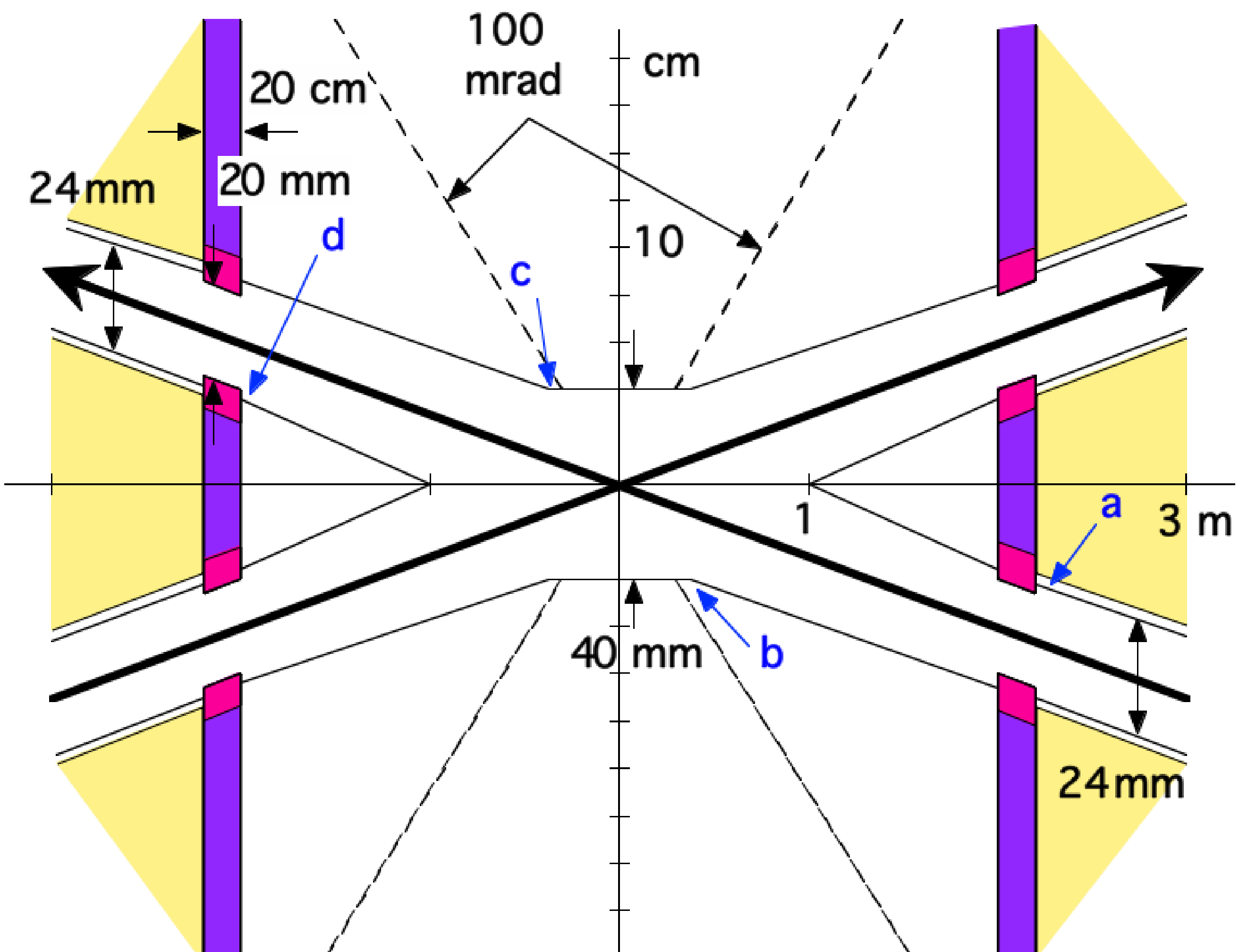
Beam energy	GeV	175
β_x^* / β_y^*	m /mm	1/2
$\varepsilon_x / \varepsilon_y$	nm/pm	1.3/2.5
σ_x / σ_y	μm/nm	36/71
L^*	m	2.2
full crossing angle	mrad	30
Beam current	mA	6.632
N_{part}/bunch	#	$1.7x10^{11}$
bunches	#	81

beam pipe aperture **in quads** =**24 mm (diameter)**
beam pipe aperture **masks** =**20 mm (diameter)**

- BSC used in FF (half aperture)
  - 20 σ_x (about 11 mm at back end of QC2)
  - 60 σ_y (about 5 mm in middle of QC1)
    - B factories had ½ ε_{tot} x β_y x 10 (>20 mm)

(M. Sullivan)

Zoom of IR Layout with L*=2.2 m



Synchrotron Radiation

Synchrotron Radiation is the main constraint for IR design and it drives the IR optics and layout.

General requirement for the optics based on LEP experience:

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

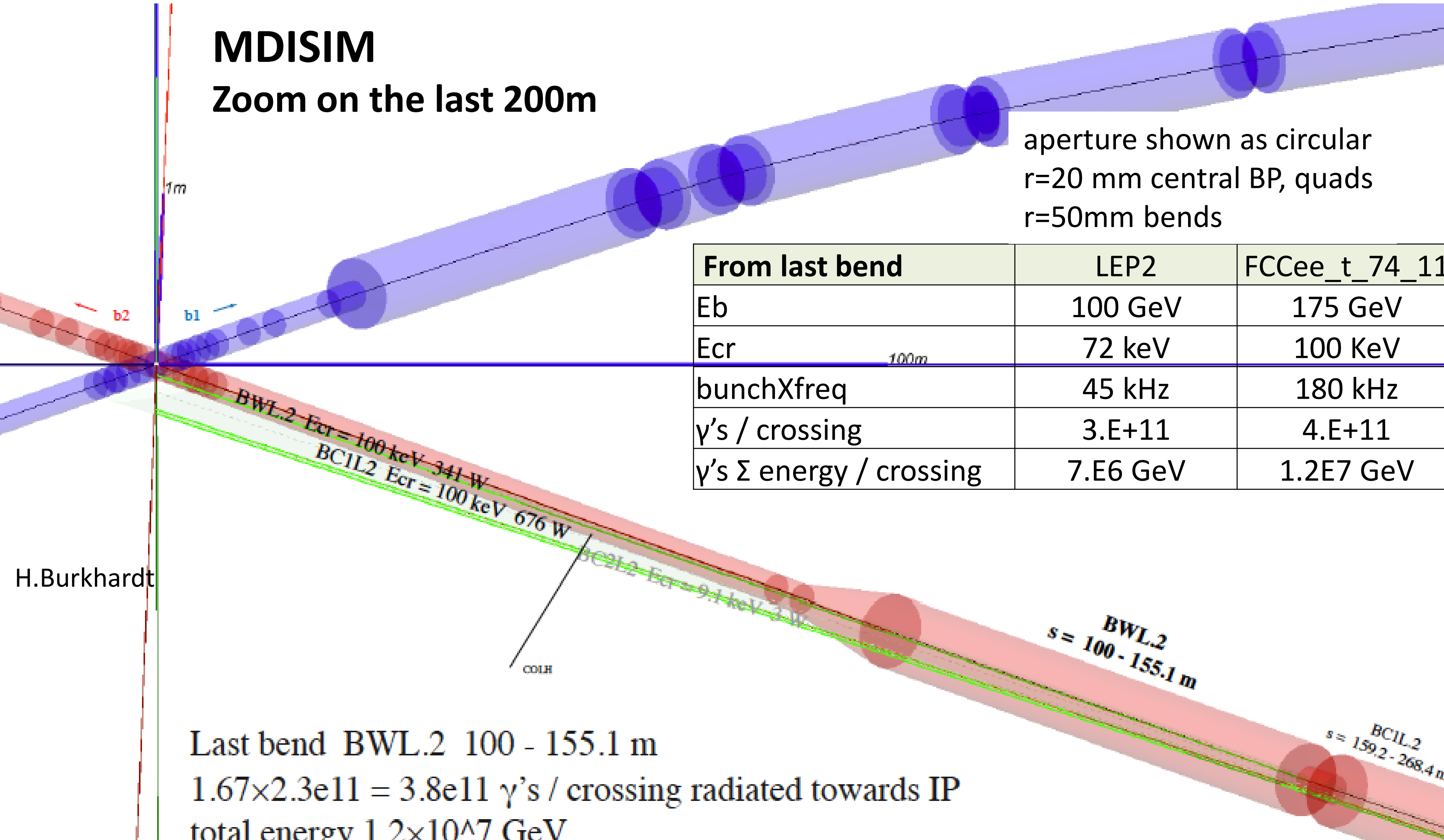
Various lattice options have been studied in detail with dedicated software:

- Flexible software toolkit developed H. Burkhardt (**MDISim**), recent good progress in technical details
  - ROOT based machine detector interface toolbox described by MAD-X sequence
  - particle interactions in the IR/detector regions using GEANT4
- M. Sullivan software for SR from FF quads and bends

Synchrotron Radiation: last bend

MDISIM

Zoom on the last 200m



aperture shown as circular
r=20 mm central BP, quads
r=50mm bends

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

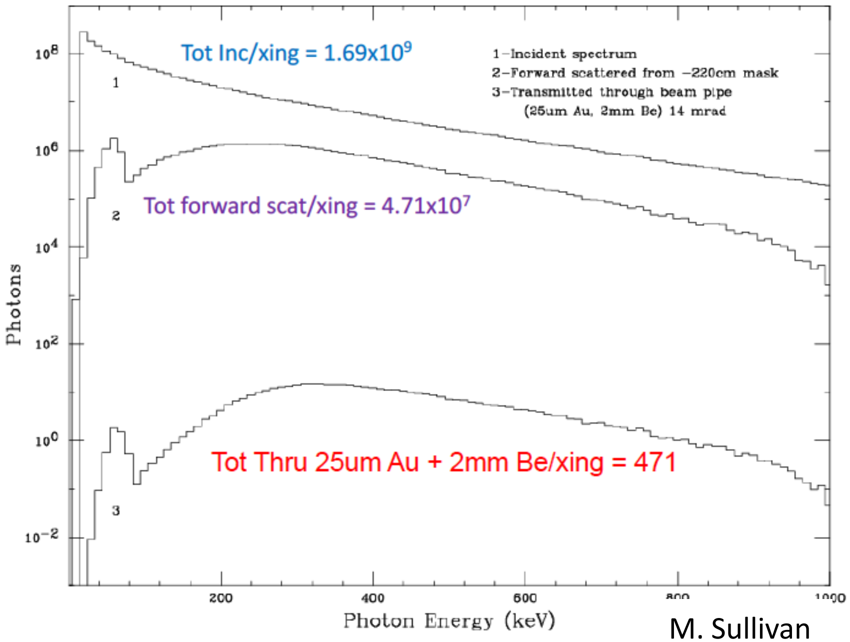
Last bend BWL.2 100 - 155.1 m
1.67×2.3e11 = 3.8e11 γ's / crossing radiated towards IP
total energy 1.2×10^7 GeV

- **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**

Last bend ending at 42m vs 100m from IP

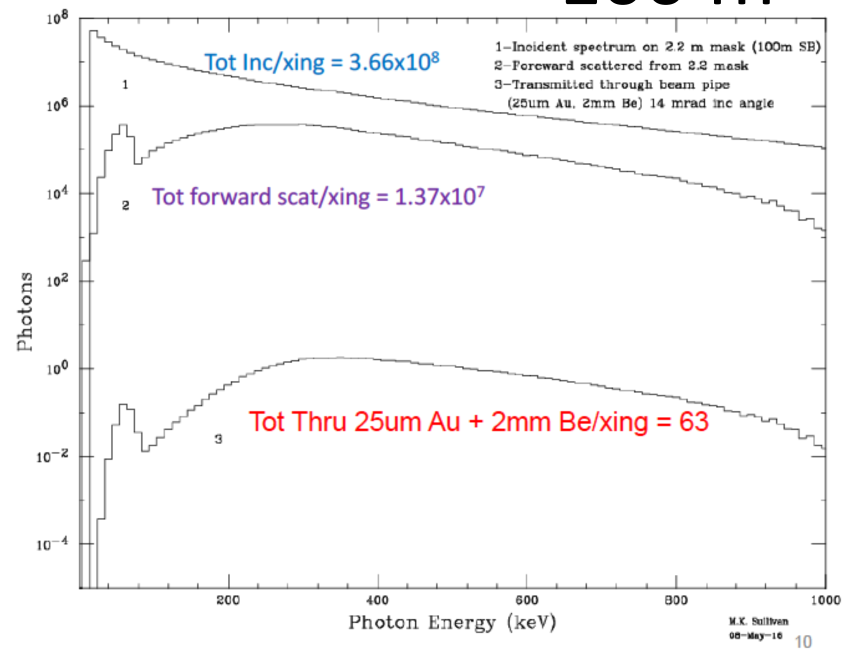
forward γ SR spectrum from last bend + FF quads

42 m



M. Sullivan

100 m



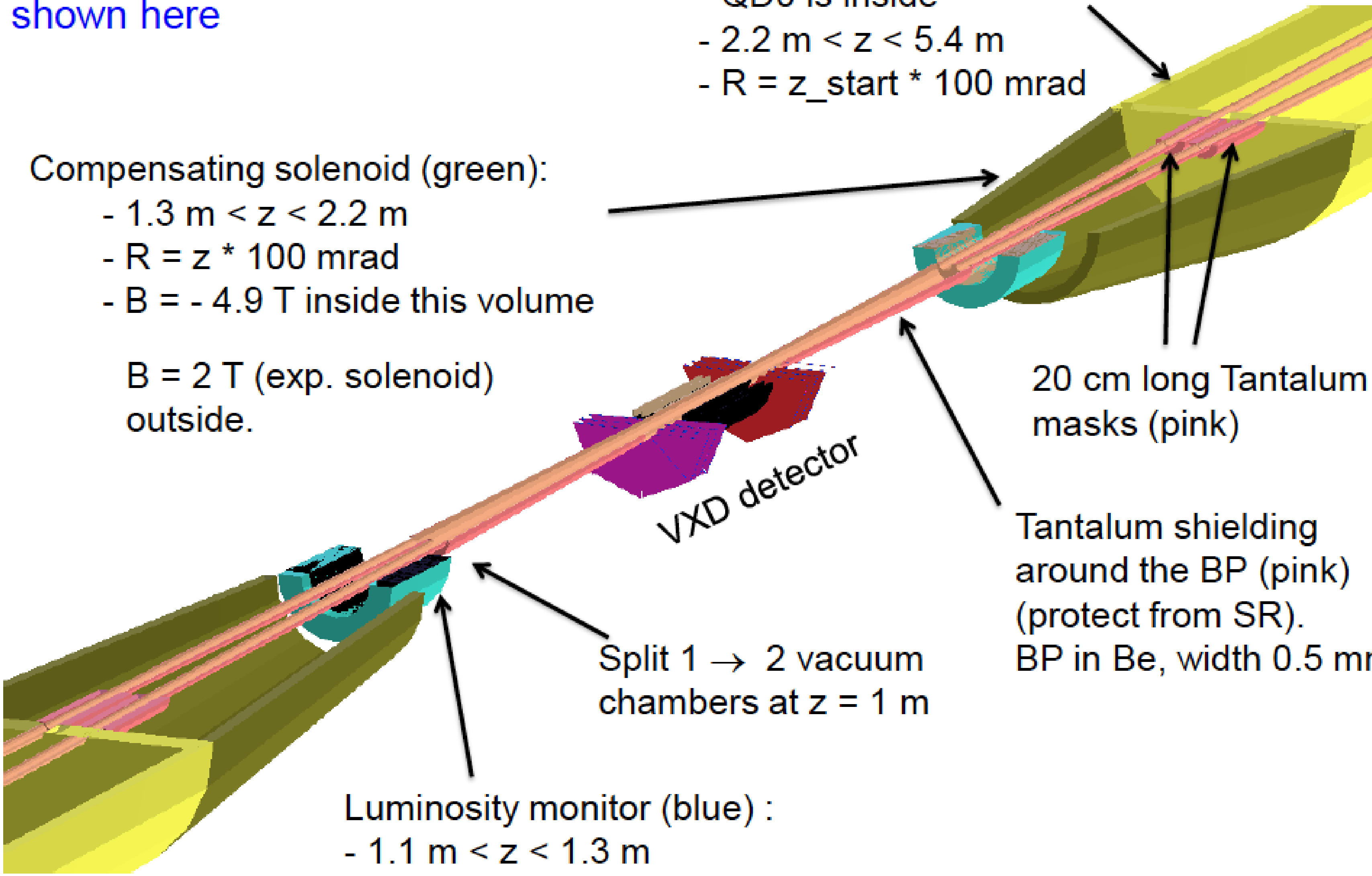
Geant implementation of the IR

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

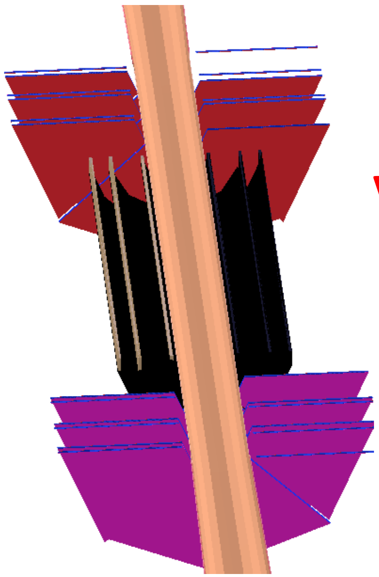
Split 1 → 2 vacuum chambers at z = 1 m

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

E. Perez

Geant implementation of the IR

Based on CLIC and adapted for the FCC-ee IR as a start



VXD

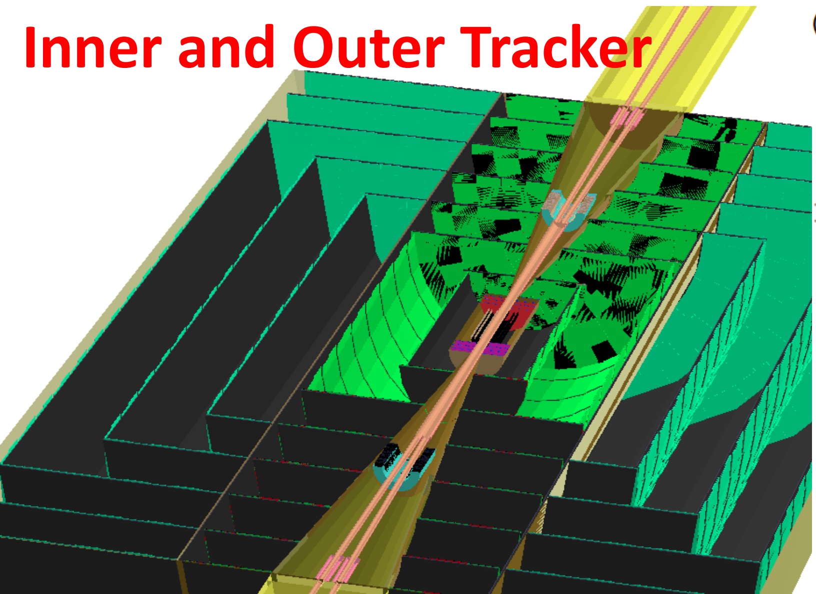
40mm diameter beampipe in central region

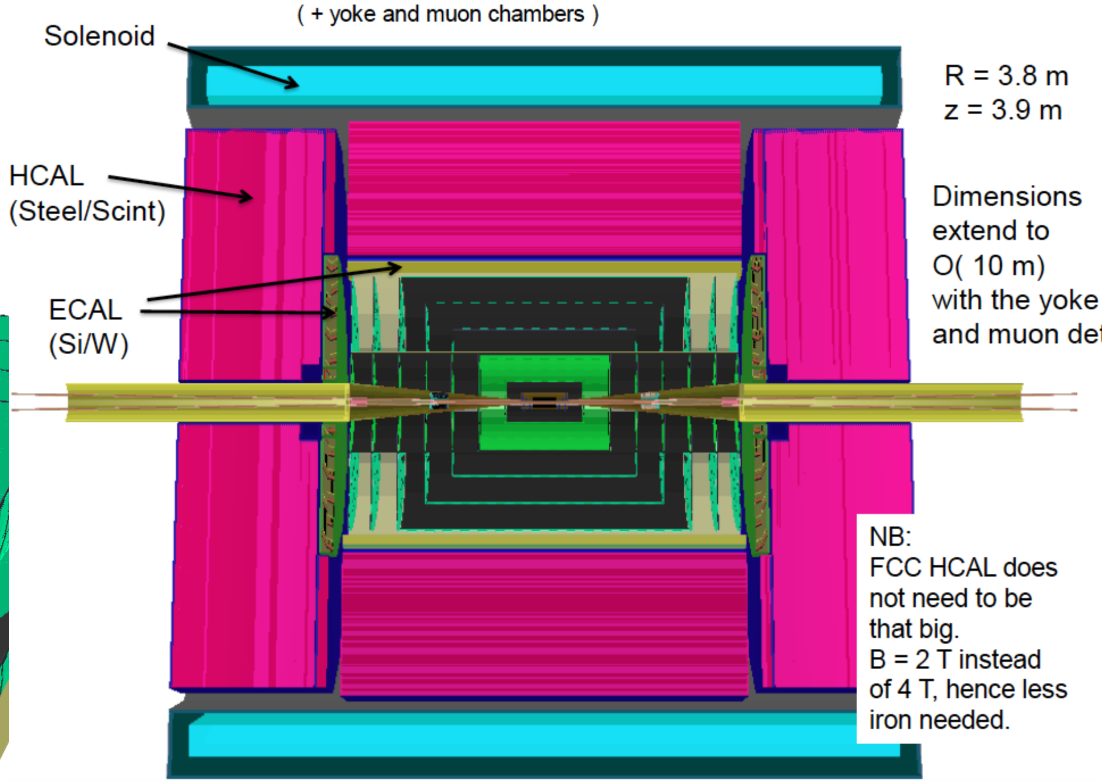
VXD **Barrel**: 3 double-layers R = 2.2 cm, 4.4 cm, 5.8 cm, $|z_{max}|$=13cm

VXD **Endcap** : 3 disks, “spiral” geometry, Rmax = 10.2 cm $|z_{max}|$=22.3cm

i.e. all endcap disks on the cylindrical BP

Inner and Outer Tracker





Synchrotron Radiation/ Detector (**last bend at 42 m)**

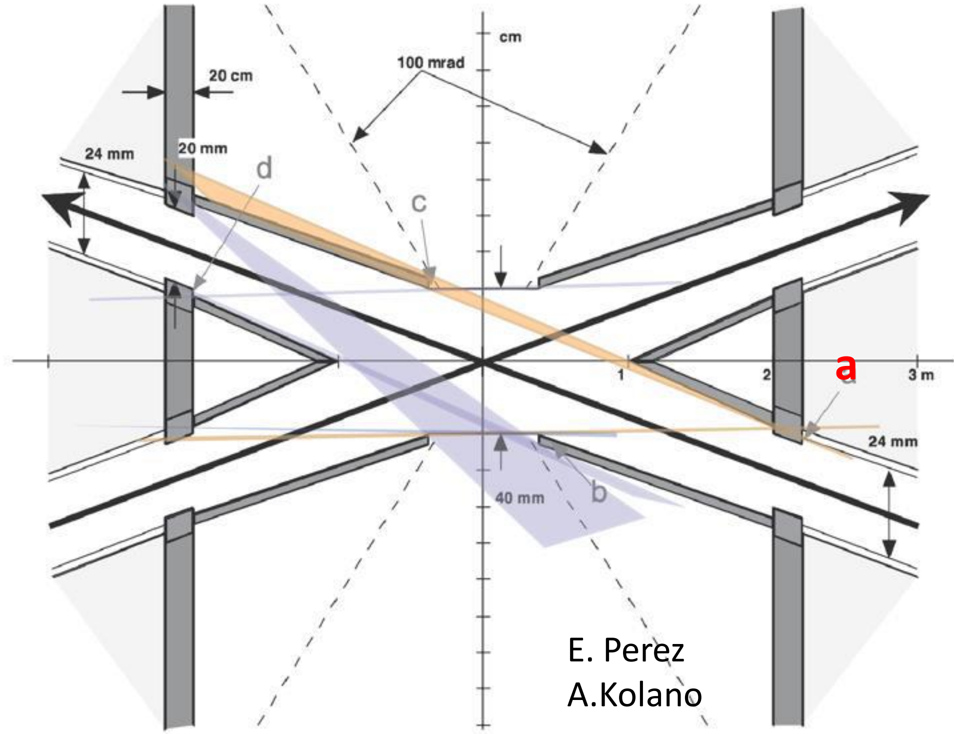
Starting point is forward-scattered on the mask (**a**) of 4.7×10^{7} photons/beam crossing x 2 for the two beams (from bend + final quad)

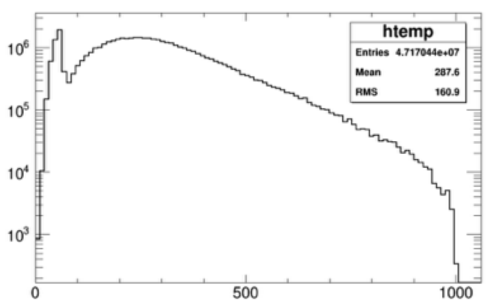
Forward Scatter

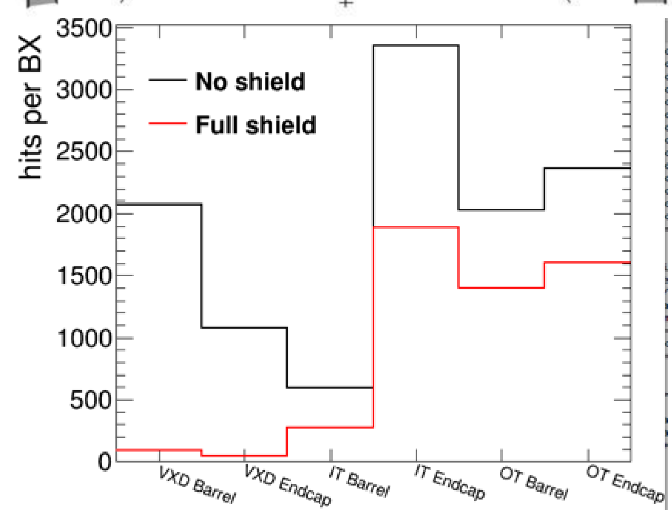
Send these photons through our full simulation.

Back Scatter

Fwd scattering expected to be the dominant source of background.





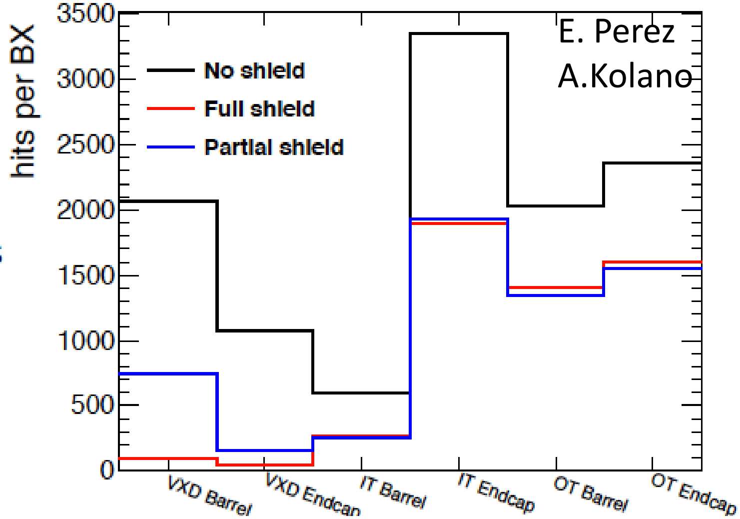


Number of hits in the VXD + tracker, per BX :
4500 x 2 beams = 9000 hits
mostly in the Tracker as the VXD acceptance is small for these γ.

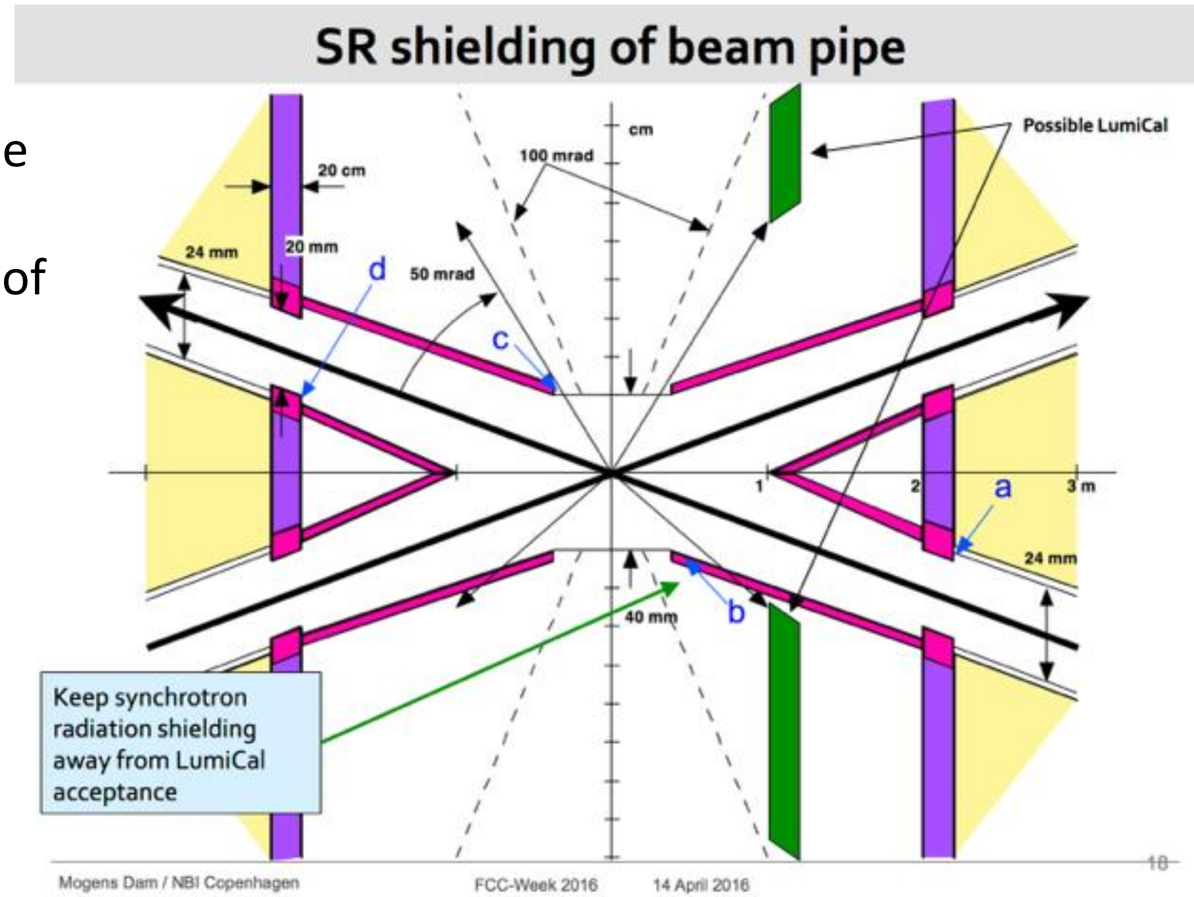
Synchrotron Radiation/ Detector (**last bend at 42 m**)

L*=2.2m

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



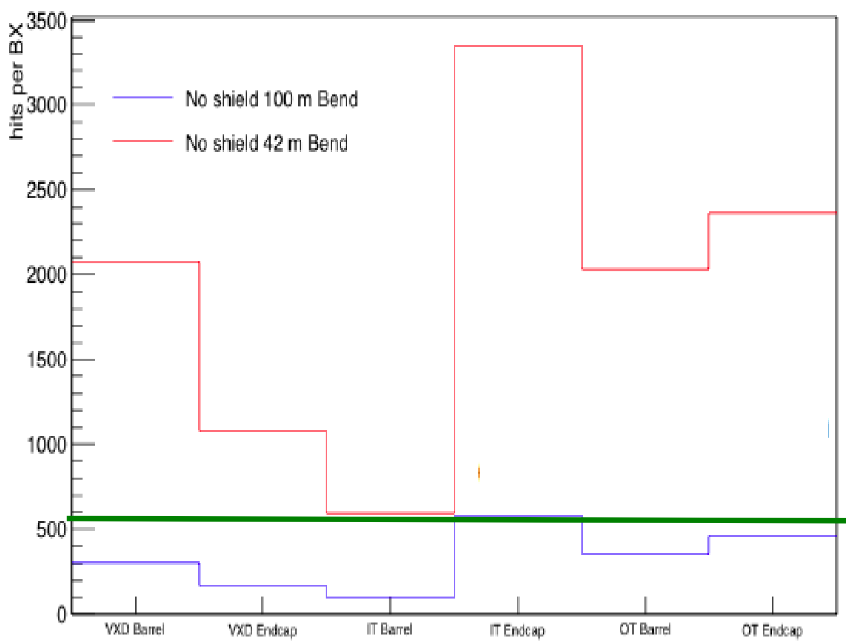
Partial shield is still effective in reducing hits on the VXD

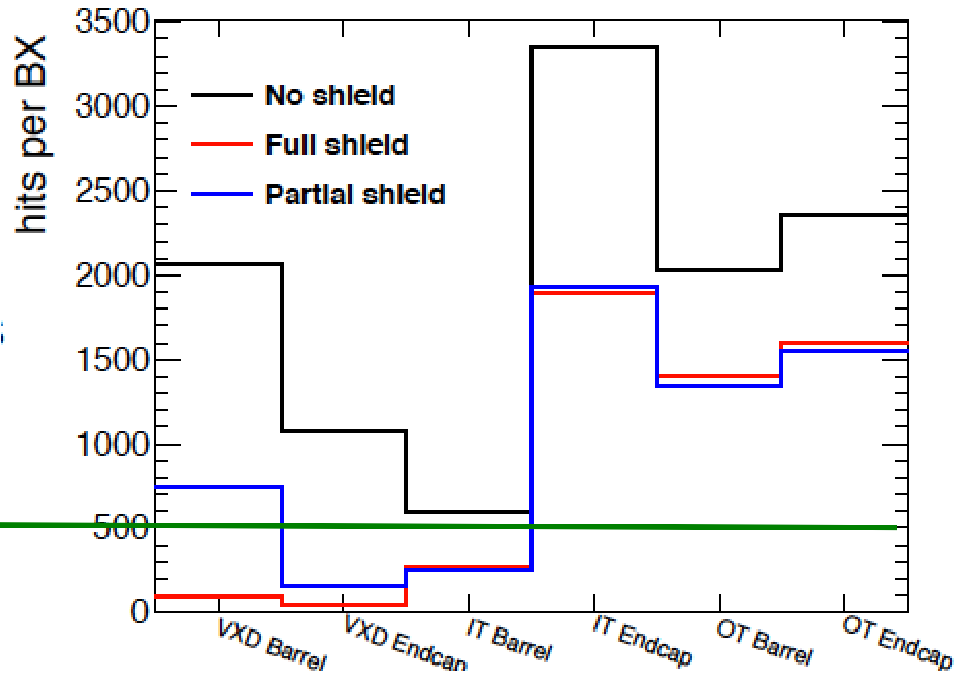


If **Lumi detector** placed in front of compensating solenoid (green bars in the right sketch), need to shorten the length of the shielding to keep it away from Lumi acceptance.

last bend at s=42 m vs 100 m

lower background with last bend ending at 100 m from IP and no shield wrt last bend ending at 42 m from IP and full shield





great benefit of placing last bend farther away

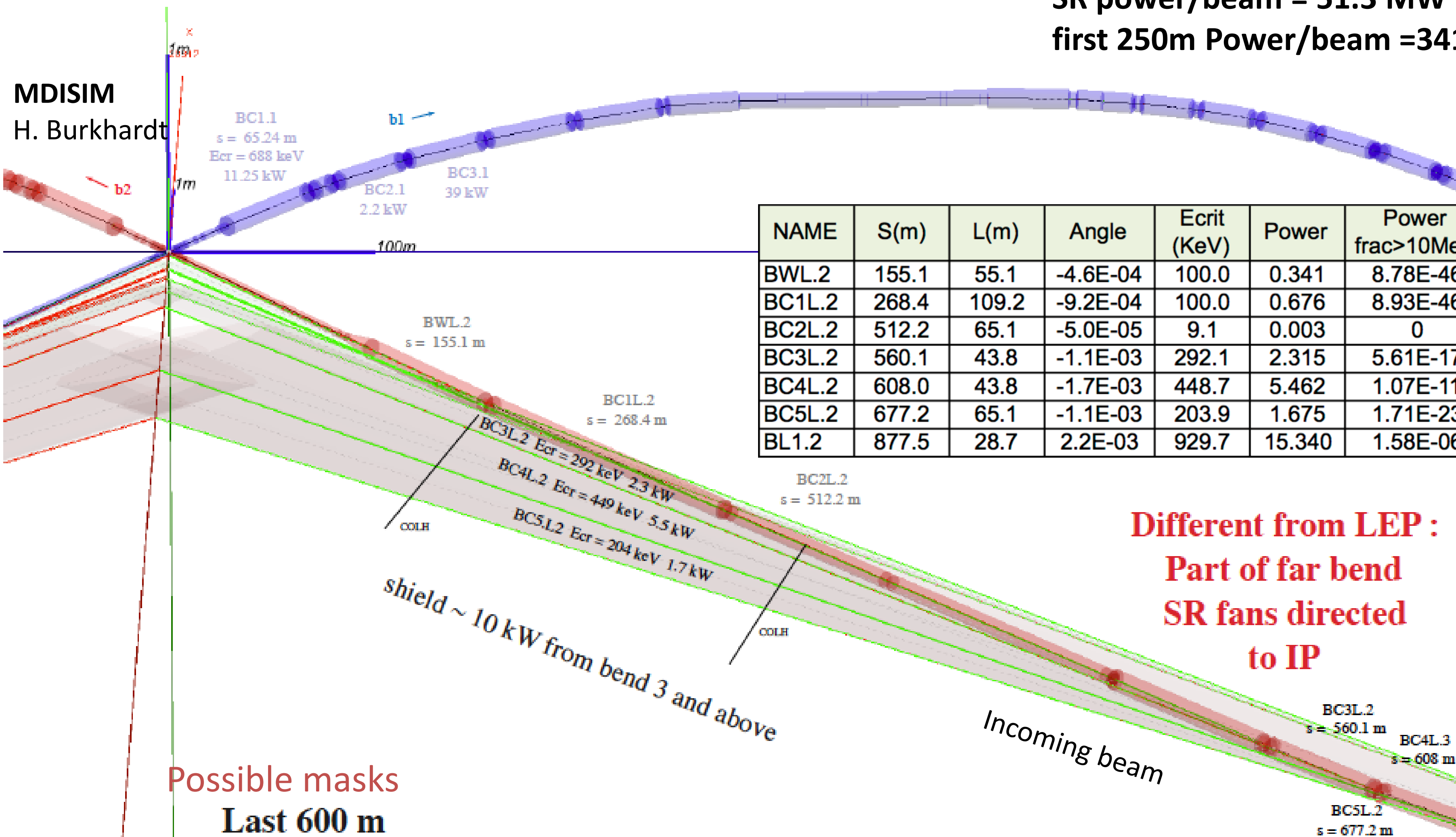
SR from far bends

Part of far bend SR fans directed to IP

to be checked in detail with dedicated studies

Beam Energy = 175 GeV
Ibunch = 0.11 mA
Ibeam = 6.6 A
SR power/beam = 51.3 MW
first 250m Power/beam =341 W

MDISIM
H. Burkhardt



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

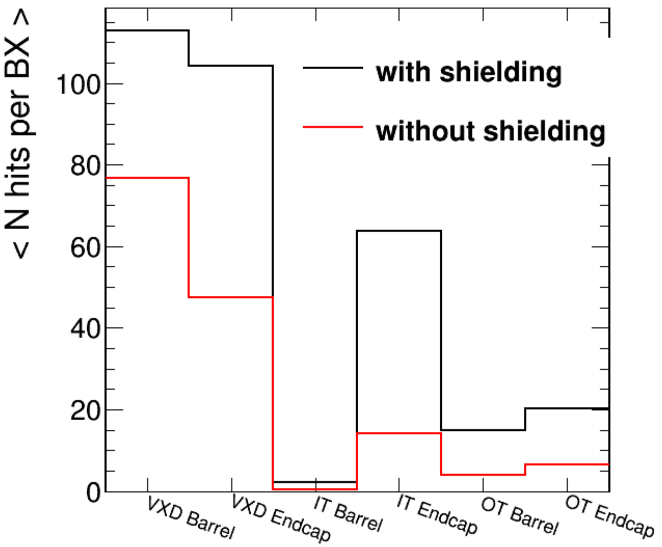
Different from LEP : Part of far bend SR fans directed to IP

Possible masks

Last 600 m

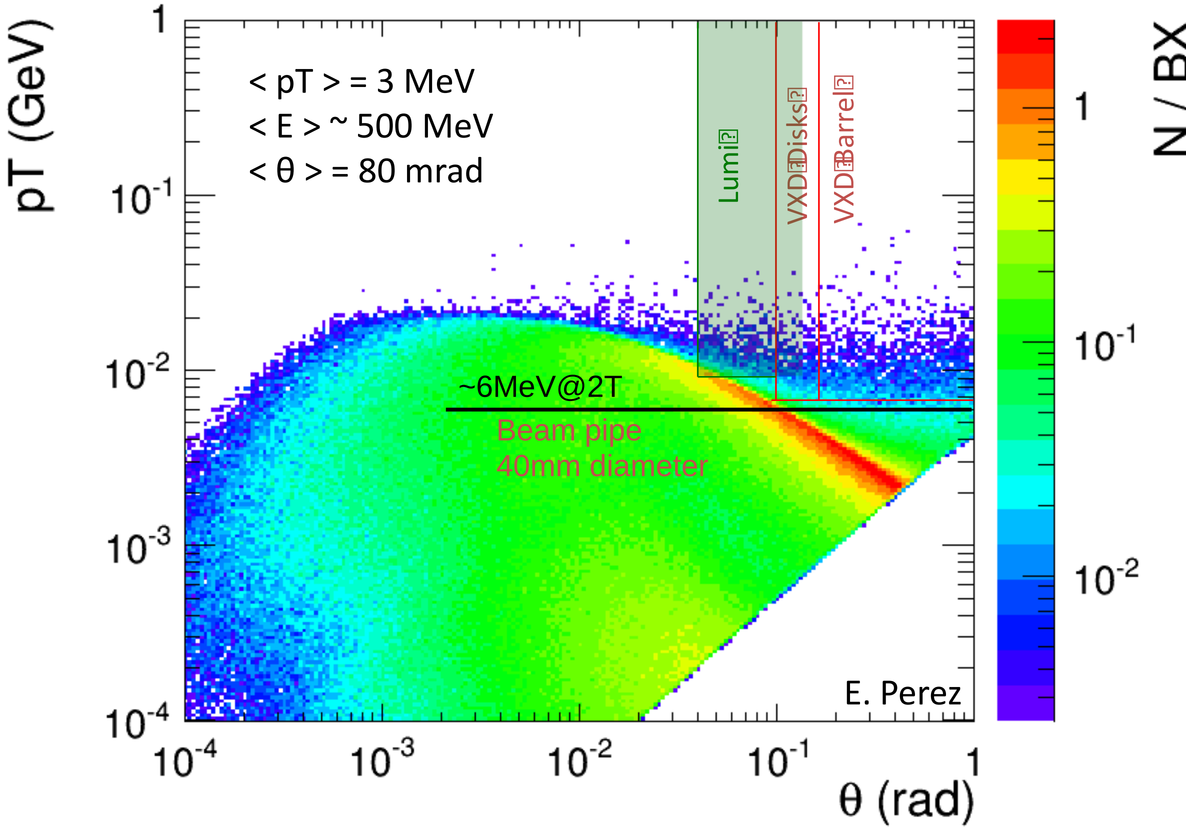
Beamstrahlung and pairs

Beamstrahlung and pair production



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

Guinea-Pig
@Zpeak

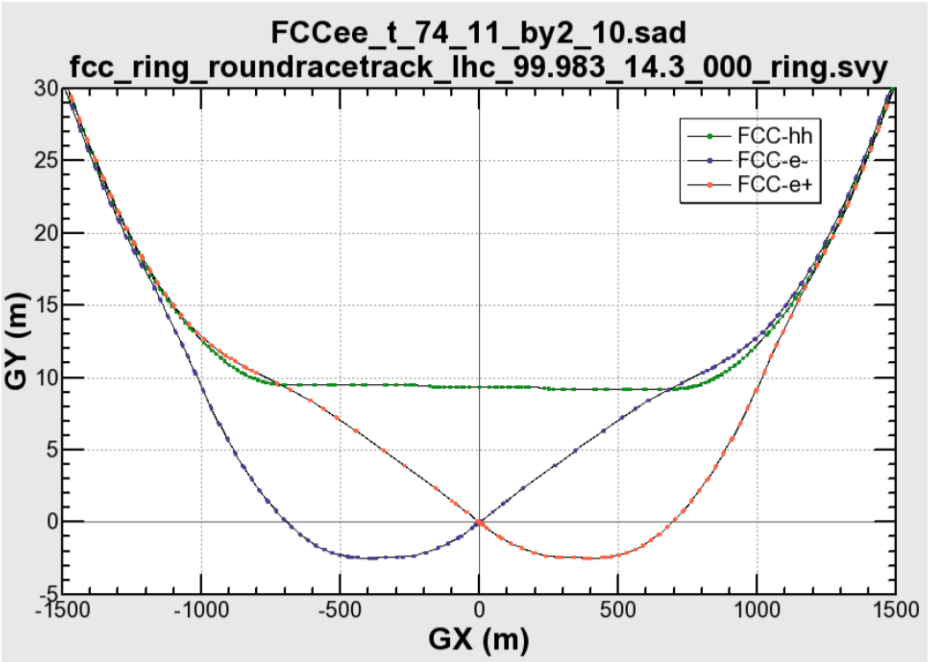


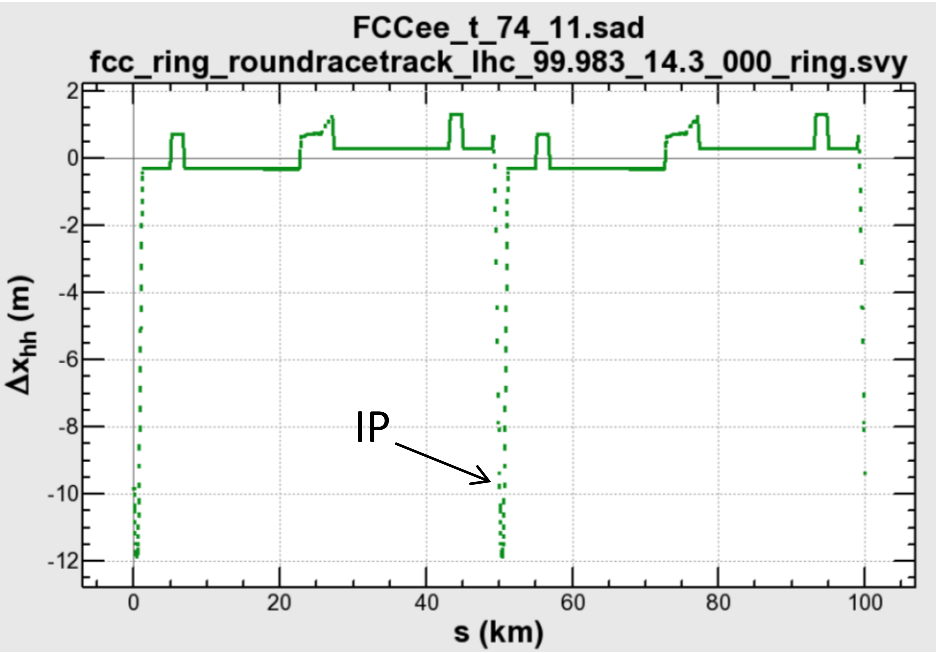
- On average : ~ 4000 pairs created per BX carry an energy of ~ 1 TeV (400 x less that at ILC500).
- On average : 320 hits / BX (70% on the VXD, 20% on Inner Tracker, 10% on Outer Tracker
- Beampipe shielding increases the number of hits (even **0.5mm Ta** is enough for electrons of < p > = 500 MeV to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

Infrastructures

FCC-ee lattice matches FCC-hh for the whole span of the ring except near the IPs

FCC-ee beam trajectories at IP

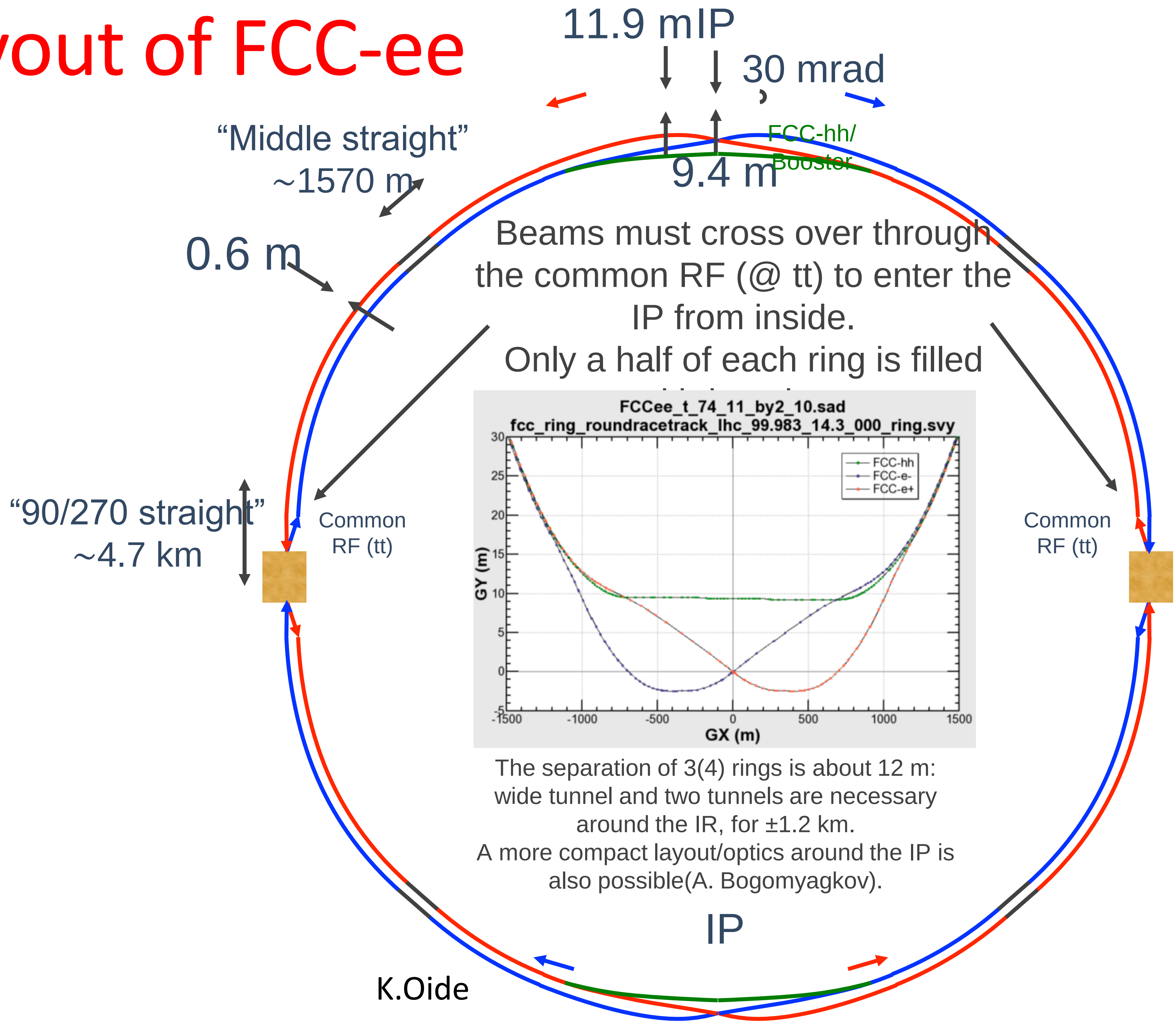




K.Oide

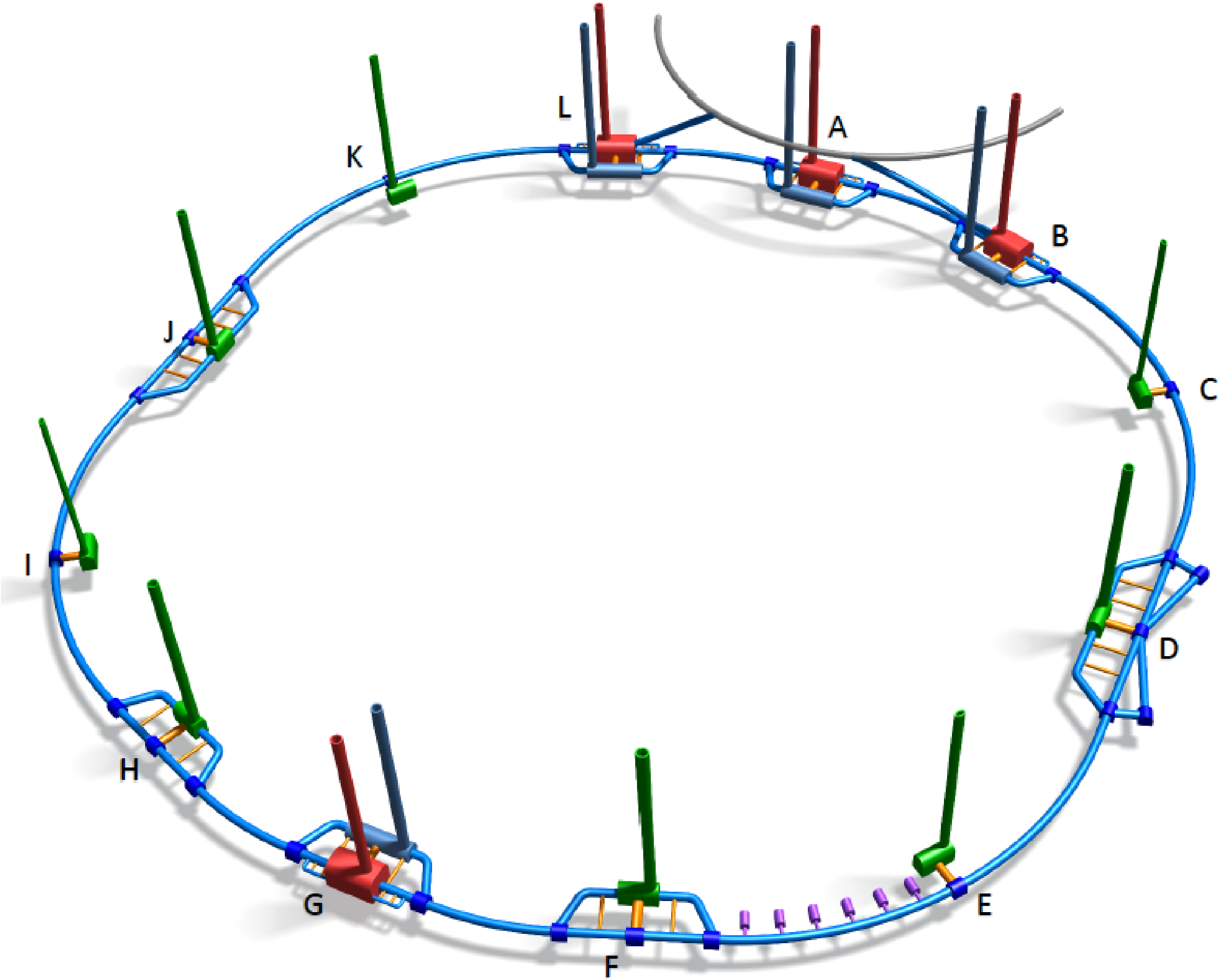
- FCC-ee IP displaced by about **9.4 m w.r.t. FCC-hh IP**, and up to **12m** between **200m-600m** from IP
- Wider tunnel needed for about 2.3 Km around each IP

Layout of FCC-ee



K.Oide

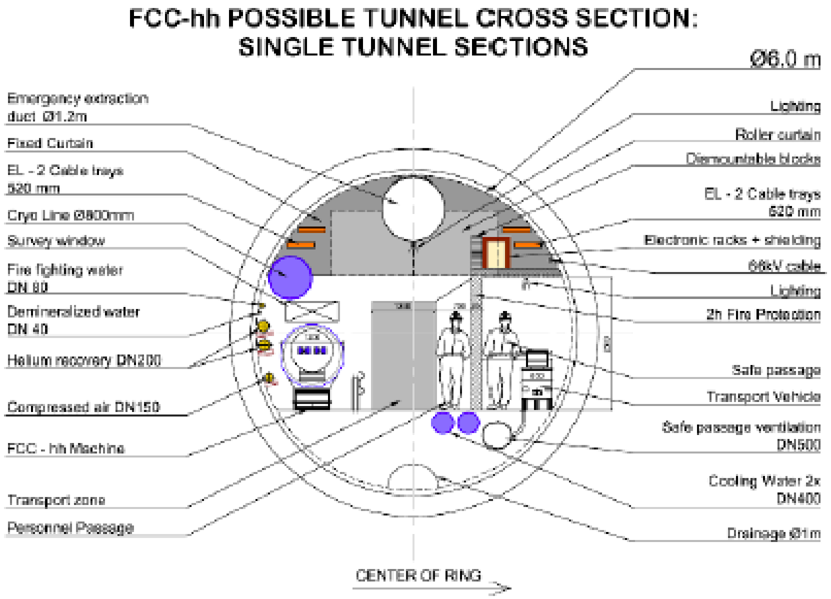
Infrastructure



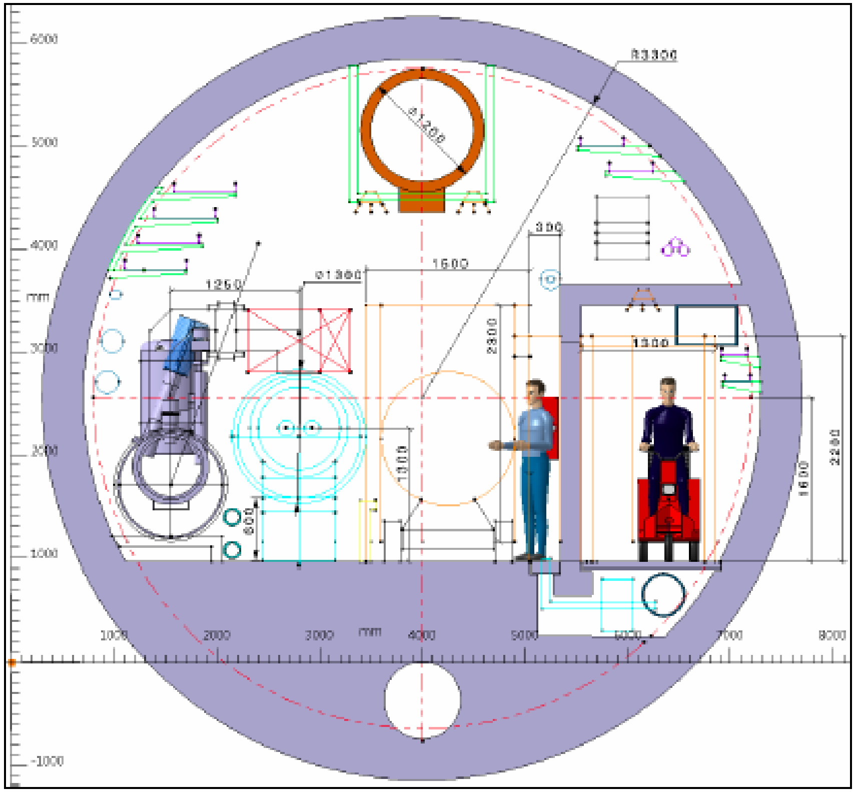
FCC-ee MDI meeting #7, J. Osborne, J. Stanyard

Infrastructures

6.0m tunnel



6.6m tunnel



03/08/2016

6.0m adopted for C&S Phase 1

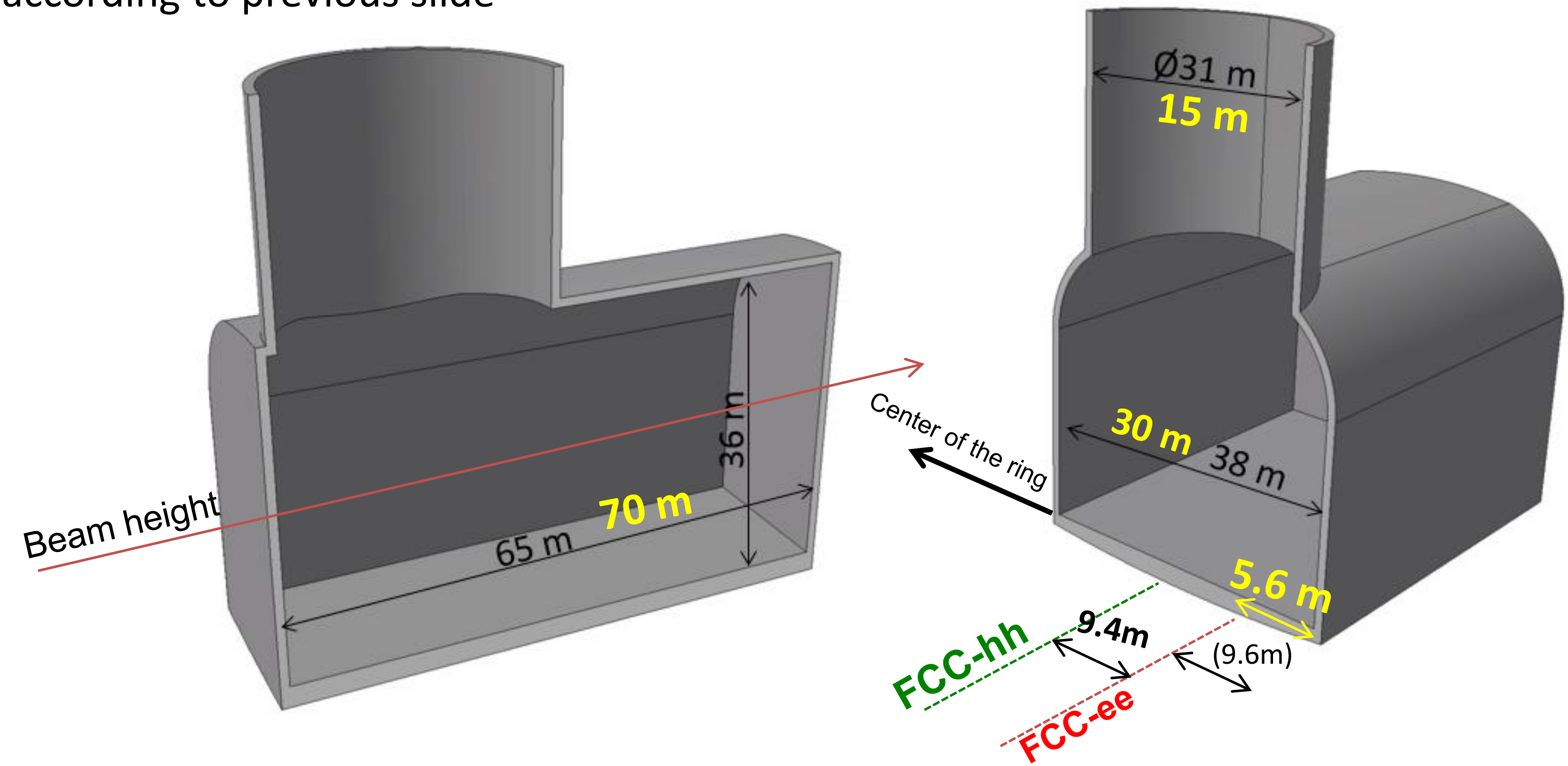
J. Osborne, J. Stanyard

Dimensions

Structure	Locations	Dimensions
Experimental shafts	L,A,B,G	ø 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	ø 12 m
Machine lowering service shafts	C,E,I,K	ø 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)

Example Cavern for FCC-hh

in yellow updated dimensions
according to previous slide



FCC-ee 10m diameter detector would fit in the FCC-hh experimental cavern

Comment on Asymmetric Optics and L* for MDI

- **Asymmetry of the last bend is very beneficial for SR**
- **Asymmetry in L***:
  - not influent for the lumical with current geometry
  - Asymmetry in L* can be beneficial for the HOM -> HOM simulations will drive to this option
- **Luminosity monitor requires L* as large as possible**
- **Great constraint for L* is the solenoid compensation scheme**
  - now optimal solution is for L*=2.2m

Conclusions

- **Lots of progress since last review (1 year) thanks to the combined effort of many people**
- **WG set up with regular meetings**
- **IR design**, ready to go in many details:
  - **L* at 2.2** m **good solution**
  - trade-off for **Luminosity monitor** integration ongoing
  - Optics design with **last bend at 100m** reduces the IR SR
  - detailed **collimation and shielding** studies ongoing
  - studies SR into IR from far bends started
  - Ideas of **beam-pipe geometry and material** on the table
- Infrastructures in synergy with FCC-hh
- **The group will be strengthened, three more people this year at CERN on MDI.**
  - planned studies for off-momentum beam particles
  - Beamstrahlung, $\gamma\gamma$ to hadrons, radiative Bhabha