Synchrotron radiation Backgrounds for the FCC-hh Experiments

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Outline

- FCC-hh IR layout
- Approach/tools
- Evaluation of synchrotron radiation in the IR
- Impact on experiments
- Conclusion

This work is part of the Experimental Insertion Region (WP3) EuroCirCol design study

Task 3.3 dedicated to the study of the impact of synchrotron radiation emitted by protons on detector and machine components in the interaction region.

Co-funded by the European Commission

EuroCirCol

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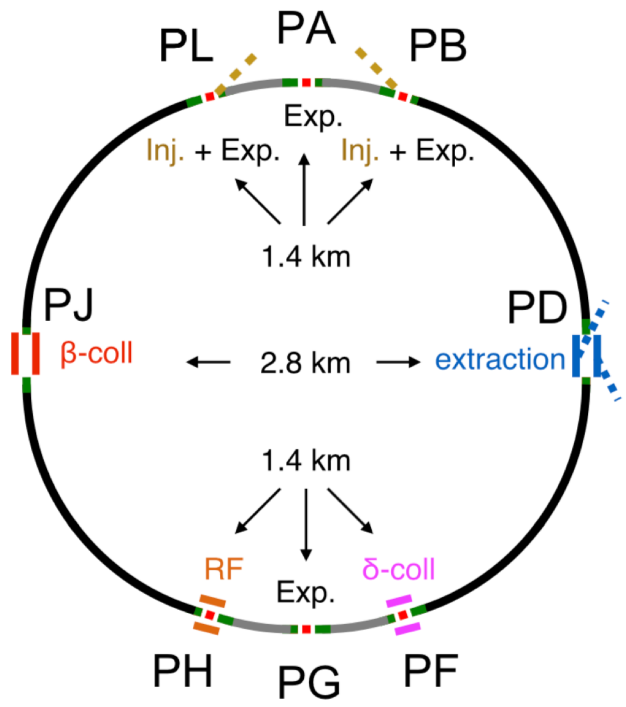
FCC-hh layout

- Experimental regions: PA, PB, PG, PL (high lumi. PA, PG)
- Injection region: PL, PB
- Extraction region: PD
- Collimation region: PF, PJ
- Radiofrequency: PH

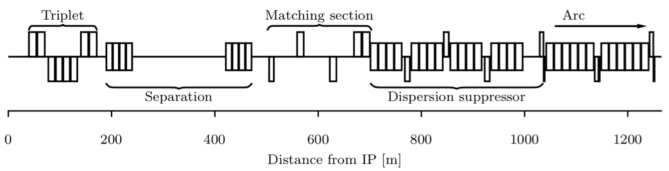


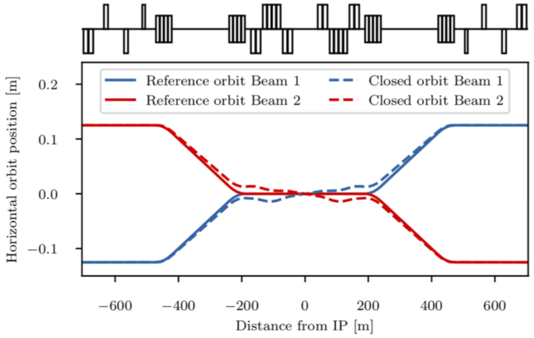
- c.o.m energy 100 TeV proton-proton collisions
- Circumference 97.75 km
- Arc cell: 213 m, 90° FODO, dipole filling factor ~0.8
- Dipole field 16 T, Nb_3Sn-based
- RF frequency 400 MHz
- 30 W/m/aperture due to synchrotron radiation at 50 K in the arcs

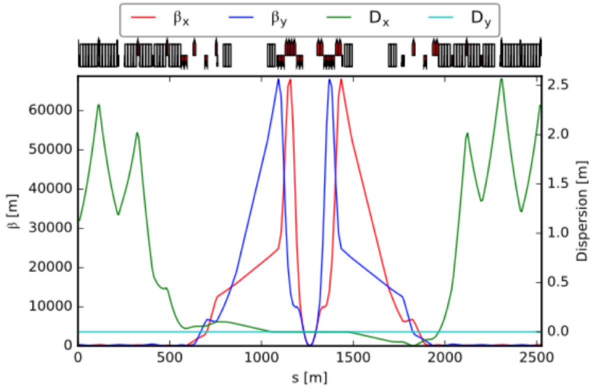
FCC-hh parameters

Lattice V9 (CDR)		Initial	Nominal
Beam **energy**	TeV	50	
Luminosity / IP	10^{34} **cm^{-2} s^{-1}**	5	< 30
Optimum average integrated luminosity/day	fb^{-1}	2.2	8
Beam current	A	0.5	
Bunches per beam	#	10400	
Average bunch spacing	ns	25	
Bunch population	10^{11}	1	
Transverse normalised emittance ε_x	μm	2.2	
IP beta function β^*	m	1.1	0.3
RMS IP spot size: σ^*	μm	6.8	3.5
Full crossing angle	μrad	104	200
Luminous region RMS length	cm	5.7	
Distance IP to first quadrupole L*	m	40	
SR power per ring	**MW**	**2.4**	
Arc SR heat load	**W/m/aperture**	**29**	
Energy loss per turn	MeV	4.67	
Critical photon energy	keV	4.3	
Longitudinal/transverse emittance damping time	hr	0.5 / 1	

IR optics







(a) Interaction region: LSS-PA-EXP & LSS-PG-EXP

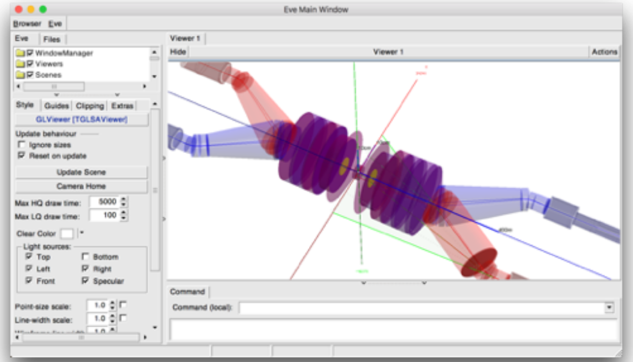
- Design follows the structure of the LHC IR
- small β^* at IP ($\propto 1/\sqrt{E}$): demanding IR optics design & large aperture in final focus triplet
- Challenge for magnet, protection design and collimation system (to intercept tail particles that could hit the triplet)
- 1.4 km required
- Final focus is a triplet (superconducting magnets) with a single aperture followed by normal conducting dipoles that separate the beams in individual aperture
- Design of the final focus system is driven by energy deposition from collision debris from the IP: short drift between IP and quad and large aperture in FF quads
- 20 m reserved for crab cavities

MDISim Toolkit

MDISim is a flexible software toolkit was developed specifically for this study, it is a set of C++/Root classes that allows to:

[Ref. MDISim]

- run MADX
- read MADX output
- calculate Synchrotron Radiation, i.e. critical energy, power, ...
- plot photon fans over the geometry using Root's TEve
- import the geometry and SR in Geant4 for the full simulation



SYNRAD+ used as benchmark MDISim (R. Kersevan)

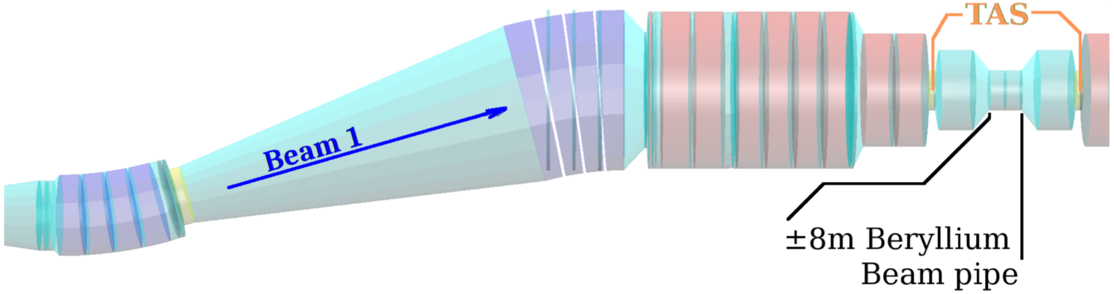
[Ref. Synrad+]

- It is able to **generate** and **trace photons** to calculate flux and power distribution on a surface caused by Synchrotron radiation
- Needs as input the geometry (in CAD-like format), the magnetic fields and the beam parameters

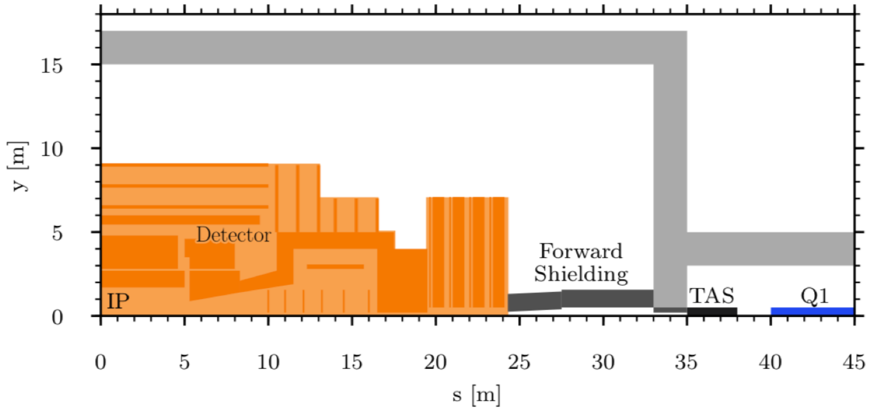
Beam pipe at IR

Beam pipe dimensions and material:

- **at IP** inner radius **20 mm**, 0.8 mm **Beryllium**
- for ± **8 m from IP** with **opening angle of 2.5 mrad**
- **from ± 16 m from the IP to the TAS**, the inner radius **40 mm**, **Aluminum**.
- **TAS aperture 20 mm**
- From the TAS to TAN radius **56 mm**
- TAN collimator **29 mm**

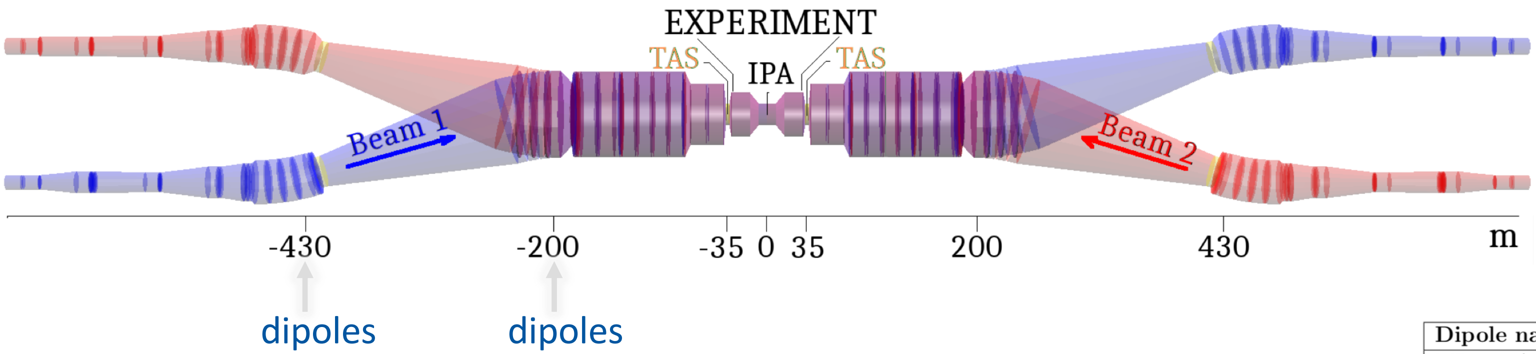


The goal of the study is to evaluate how much of the synchrotron radiation produced upstream the IR enters the TAS



- Detector ± 25 m
- forward shielding section from ±25m to ±35m
- At 35m from IP the TAS absorbs and protects the FF quads from collision debris (Target Absorber Secondaries, 3 m Copper absorber)

FCC-hh interaction region: top view with MDISim



(transverse dimensions scaled up 500 times for visualization)

Dipole name	Distance from IPA [m]
MBXW.A4LA.H	190.0
MBXW.B4LA.H	202.8
MBXW.C4LA.H	215.6
MBXW.D4LA.H	228.4
MBRW.A4LA.H1	421.3
MBRW.B4LA.H1	434.1
MBRW.C4LA.H1	446.9
MBRW.D4LA.H1	459.7

Upstream the experimental region low field dipoles:

2 T dipoles at 200m and 430m from the IP
with bending angle of 135 μrad

only a fraction will pass through the TAS and reach the central chamber: MDISim/G4 simulation performed

$E_{critical}$ = 0.54 keV
<E> = 0.165 keV
Power = 6.4 W per dipole
Power = 50 W (total dipoles)

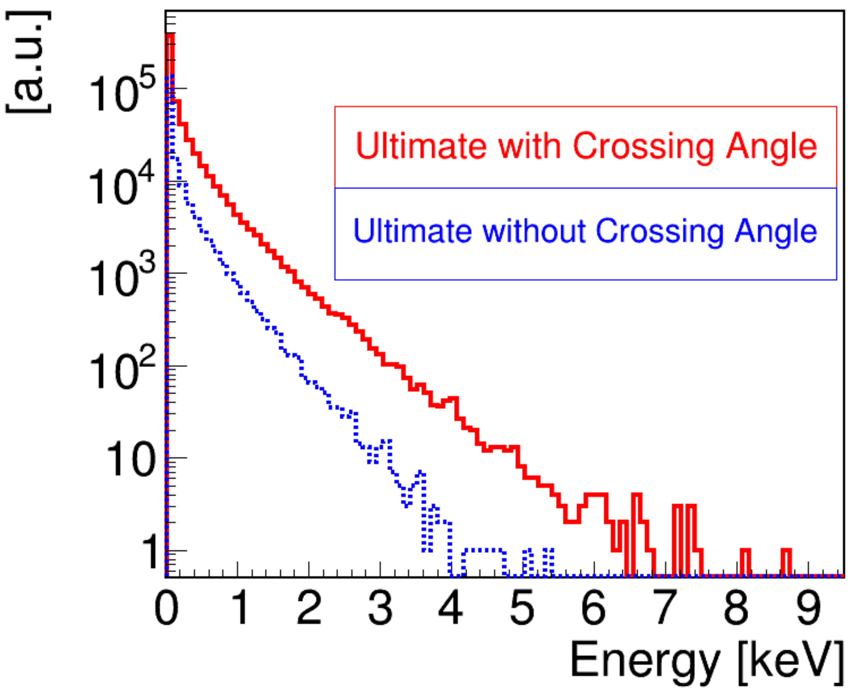
SR that reaches the experimental area

- MDISim used to produce geometry and magnetic field description
- SR simulation with GEANT4 from -700 m from IP, Gaussian proton beam

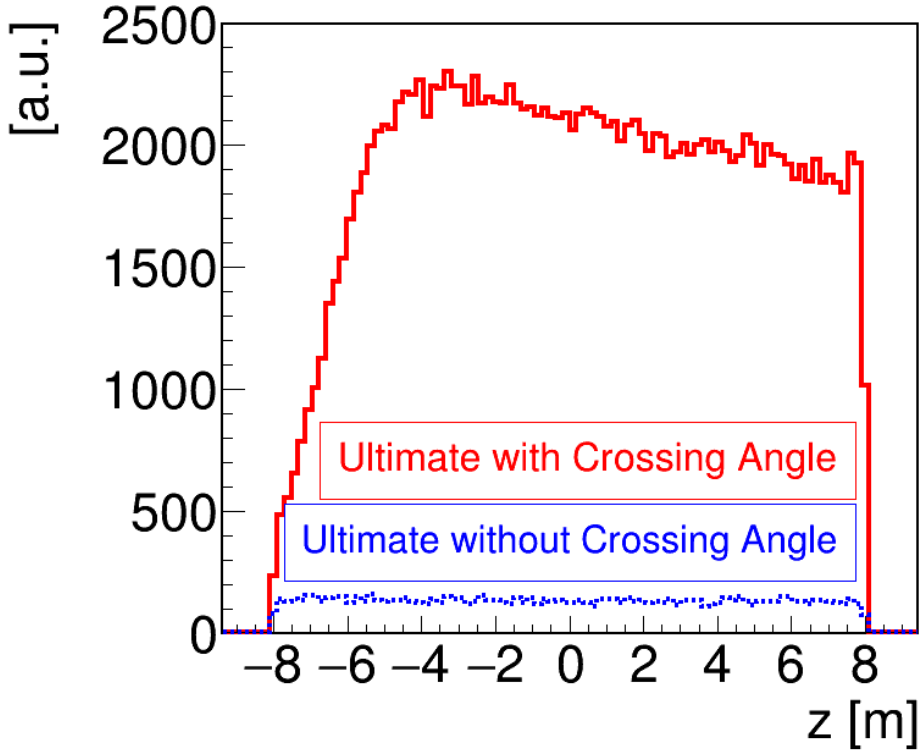
Lattice v9	half crossing angle	Power (TAS) [W]	Power(Be) [W]	Nγ(Be) [10^9]	Em(Be) [keV]
Initial	**No**	9	1	1	0.2
	yes, 52μrad	**27**	**1.2**	**2**	**0.2**
Nominal	**No**	9	1	1	0.2
	yes, 100μrad	**47**	**13**	**16**	**0.2**

- Slight increase of SR with the nominal crossing angle, due to the magnets that are switched on to produce it.

SR photons passing through the TAS

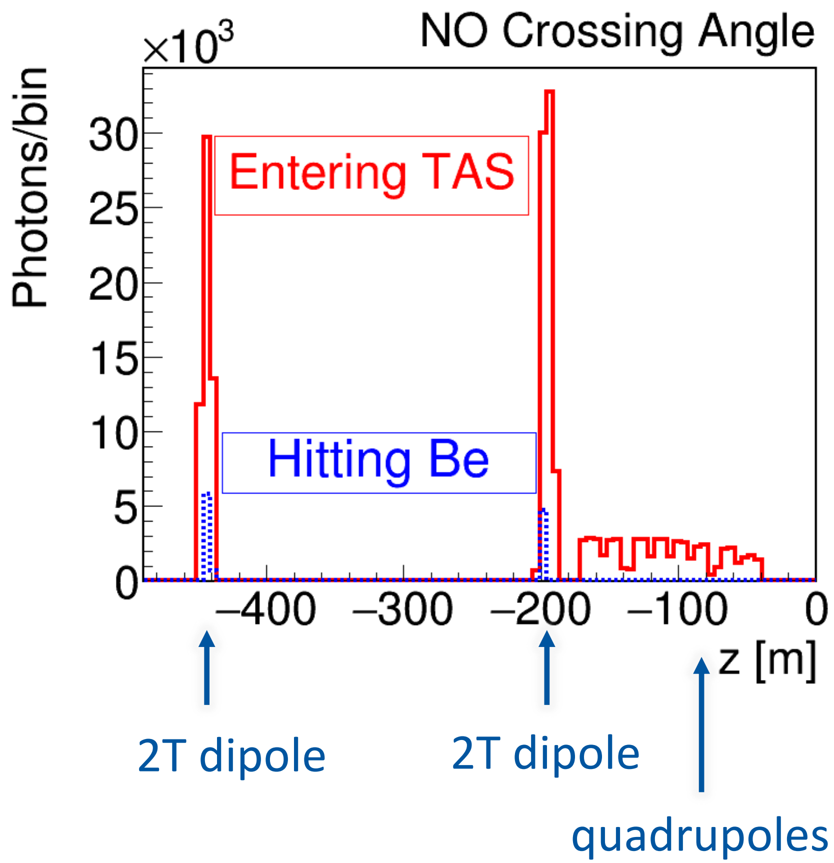


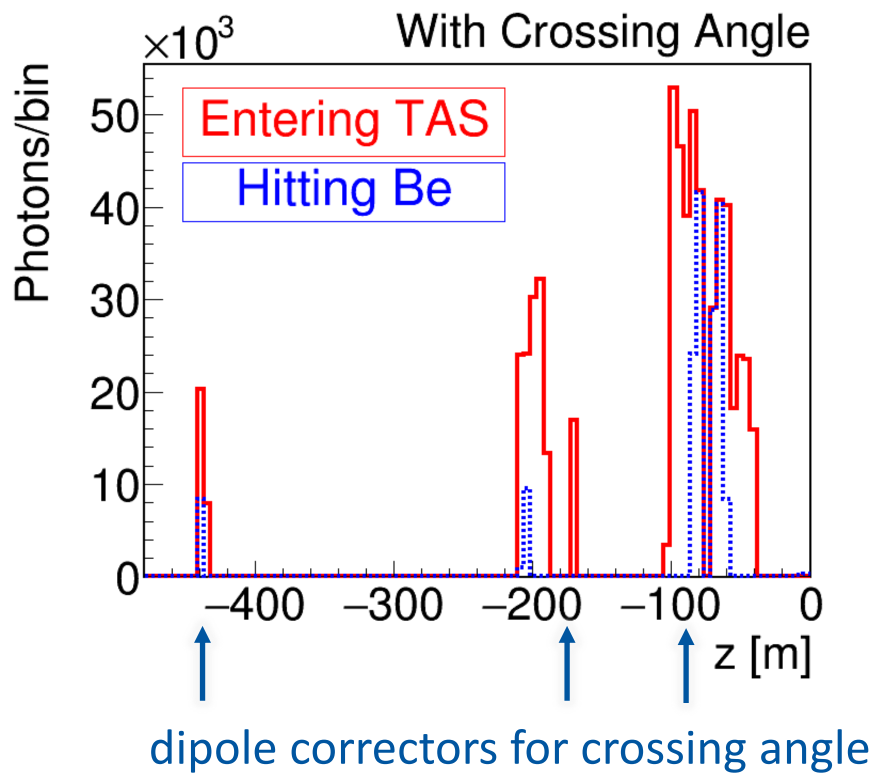
Photons entering the TAS:
photon energy distribution



Photons hitting poing for
-8 m < z < +8 m

Generation points of SR photon





Corrector name	Distance to IPA [m]	Length [m]	B field [T]	
			Baseline	Ultimate
MCBXDHV.A2LA.H	75.8	1.3	-0.168	-0.562
MCBXCHV.3LA.H	174.2	1.3	1.226	1.957
MCBRDH.4LA.H1	474.0	3.0	-0.821	-1.536

Comment on these results

- During these four years of the EuroCirCol design study we have evaluated the SR into the experiments for the different lattices, following up with the new versions.
- The expectations have always been found to be negligible, both in terms of power load and in number of photons.
- However it is worth mentioning that the outcome of the study is relevant in terms of the software toolkit **MDISim**, that was **started for this EuroCirCol study and then extended to other colliders designs, like now used for the FCC-ee MDI design.**

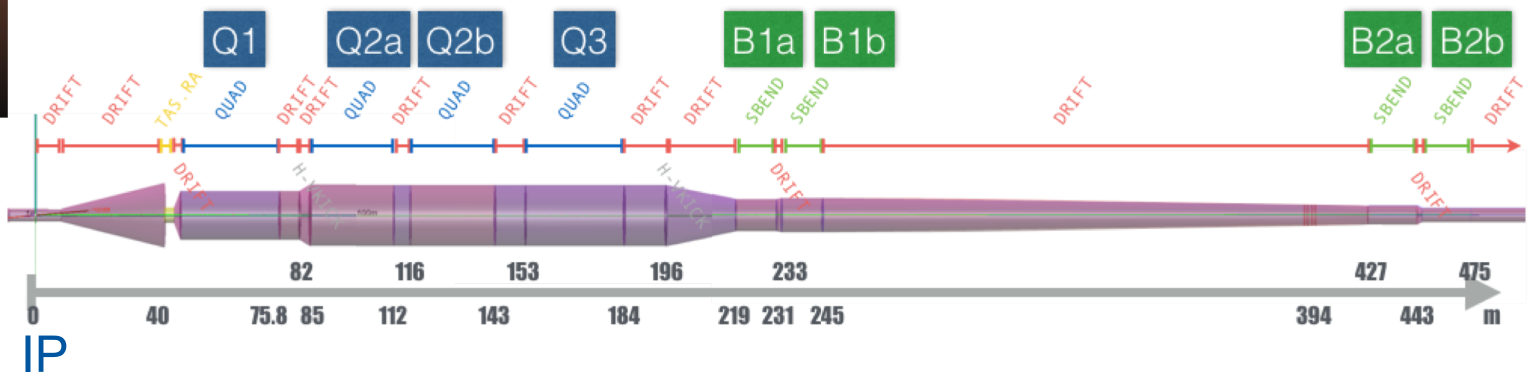
Benchmarking with SYNRAD+

optics used:
fcc_hh_v6_45

The differences can be attributed to differences in the vacuum chamber geometry implemented in the two codes.

Power (W)	No Crossing Angle		Crossing Angle	
	MDISim	SynRad	MDISim	SynRad
B2b	0	0	0	0
B2a	4,1	0,08	1,2	1E-03
B1b	0	0	0	4E-05
B1a	12,8	5,02	24,6	5,75
Q3	—	0	—	1,24
Q2b	—	0,139	—	2,19
Q2a	—	0	—	1E-04
Q1	—	0,0113	—	e-6
TOT	**16,9**	**5,3**	**25,8**	**9,2**

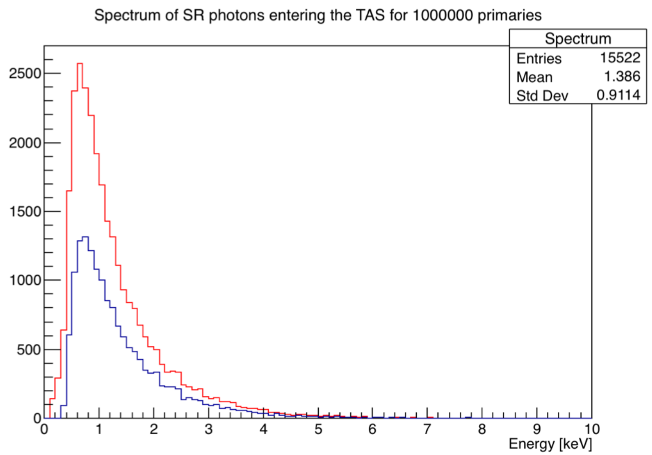
Beam pipe scheme from MADX



Comparison with previous lattices

Lattice_V8

β* = 0.3 m and L* = 45 m, 89 µrad crossing angle



CrAn.	$N_{\gamma TAS}$	$\bar{E}$ [keV]	P_{TAS} [W]	P_{Be}[W]
Yes	2.9×10^9	1.28	14.6	0.8
No	1.6×10^9	1.38	8.6	0.5

Spectrum of photons entering the TAS region with (in red) and without the Crossing Angle scheme (in blue).

F Collamati, M. Boscolo, H. Burkhardt and R. Kersevan, 'Synchrotron radiation backgrounds for the FCC-hh experiments' 2017 *J. Phys.: Conf. Ser.* **874** 012004

Conclusion

- The MDISim toolkit was developed on purpose to perform EuroCirCol-Task 3.3-WP3, then also very useful for other colliders design study, i.e. FCC-ee MDI design.
- During this four years of design study we have followed up with the lattice updates evaluating the SR for the new improved lattices.
- We have benchmarked our results with SYNRAD+ finding acceptable agreement.
- The contribution of SR in the experimental area is found to be negligible, including last bends and final focus quads

Conclusion

- The fraction entering the TAS is ~47 W and ~13 W reach the Be chamber.
- The emitted photons are ~10^{10} but have a critical energy ~1keV, safely stopped by the Be pipe
- No full simulation into experiments is needed
- Also the non-collisions scheme, with a beam separation at the IP was studied and found to be at a safe limit at 100 W

Lattice v9	half crossing angle	Power (TAS) [W]	Power(Be) [W]	Nγ(Be) [10^9]	Em(Be) [keV]
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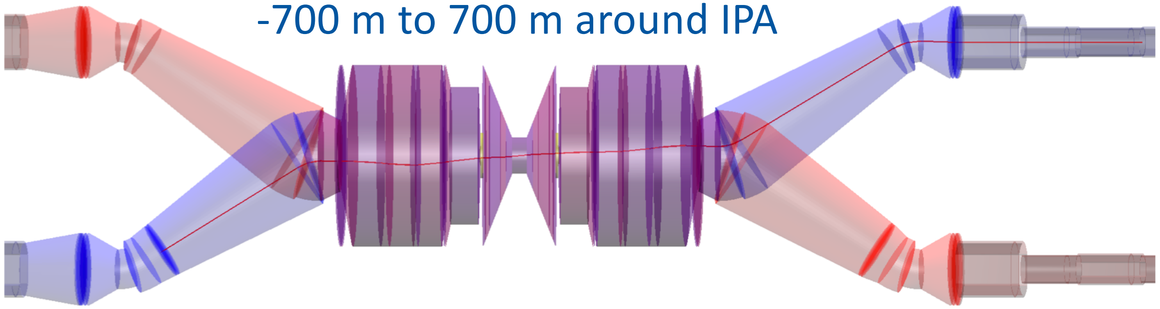
Back-up

Some References

- CERN-ACC-2019-0018 http://cds.cern.ch/record/2655283
- F Collamati *et al* 2017 *J. Phys.: Conf. Ser.* **874** 012004 (IPAC18)
- EuroCirCol meeting 9-10 Oct. 2017, CERN
- https://indico.cern.ch/event/669849/contributions/2740442/attachments/1537826/2410173/EuroCirColMeeting2017CERN_Collamati.pdf
- EuroCirCol meeting 7-9 Nov. 2016,Alba, Spain https://indico.cern.ch/event/586624/contributions/2363417/attachments/1367160/2071555/EuroCirColMeetingAlba_Collamati.pdf

2016 report

-700 m to 700 m around IPA



P @TAS (W)	N_{gamma} @Be	P @ Be (W)	PnoQauds	NNoQuads	PBeNo Quads
8,6	1,6E+09	0,5			
8,1	1,0E+09	0,62	7,79	9,9E+08	0,62
8,5	1,1E+09	0,74			

2018 update

-700 m to 700 m around IPA

Preliminar result of
Power on TAS w/o crossing angle from
Before 2016 in blue
2016 in red
2018/oct in green

Synchrotron Radiation

$$E_c = \frac{3}{2}\frac{\hbar c\,\gamma^3}{\rho} = 2.96\times 10^{-7}\mathrm{eV\,m}\;\frac{\gamma^3}{\rho}$$

$$\langle E_\gamma \rangle = \frac{8}{15\sqrt{3}}\,E_c \approx 0.308\;E_c$$

$$U_0 = \frac{e^2}{3\epsilon_0}\frac{\gamma^4}{\rho} \approx 6.0317\cdot 10^{-9}\;\mathrm{eV\;m}\;\;\frac{\gamma^4}{\rho}$$

$$P_b = \frac{U_0\,I_b}{e}$$

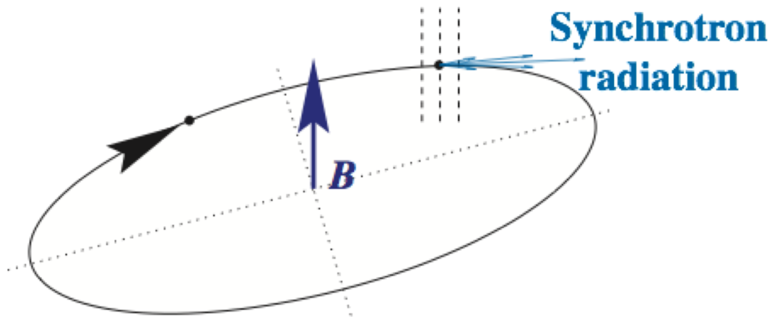
mean free path length λ between radiation

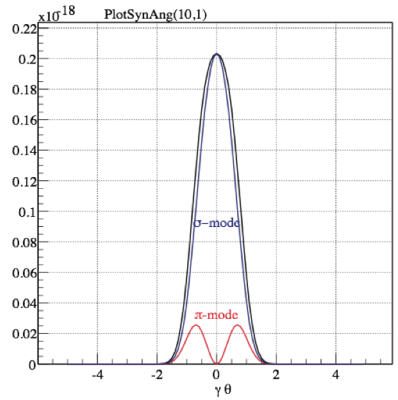
$$\lambda = \frac{\lambda_B}{B_\perp} \qquad \text{where} \quad \lambda_B = \frac{2\sqrt{3}}{5}\frac{m\,c}{\alpha\,e} = 0.16183\,\mathrm{Tm}$$

LEP2, TLEP, B ≃ O (0.1 T) O (1 m)

SynRad cone distribution mostly from bending angle O(mrad)

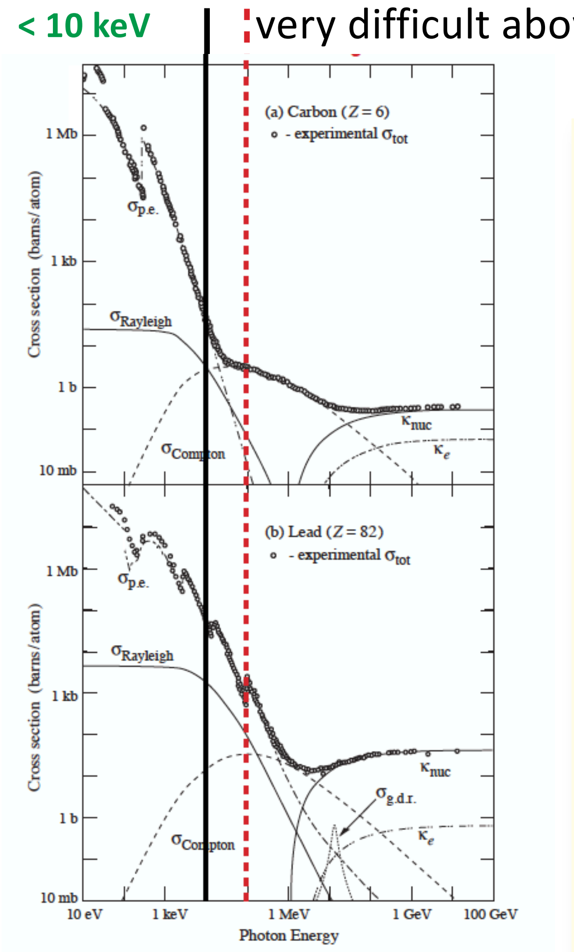
+ minor contribution from
beam divergence O(10 μrad)
and SynRad process





angular distribution (at E_c)
~ 1/γ = 3 μrad @ TLEP

Spectrum and absorption



Typical mean (0.3 E_c) photon energies

B-factories (and **FCC-hh**) mostly below 10 keV

LEP1 : 21 keV
LEP2 : 320 keV (arc, last bend 10× lower)

TLEP : ~ 350 keV (arc, 175 GeV)
-> very similar to LEP2
difficult to collimate

Enormous photon flux, MWs of power
can get kW locally, melt equipment, detectors..

Aim as for LEP2 :
do not generate hard synchrotron radiation
anywhere close to the IR

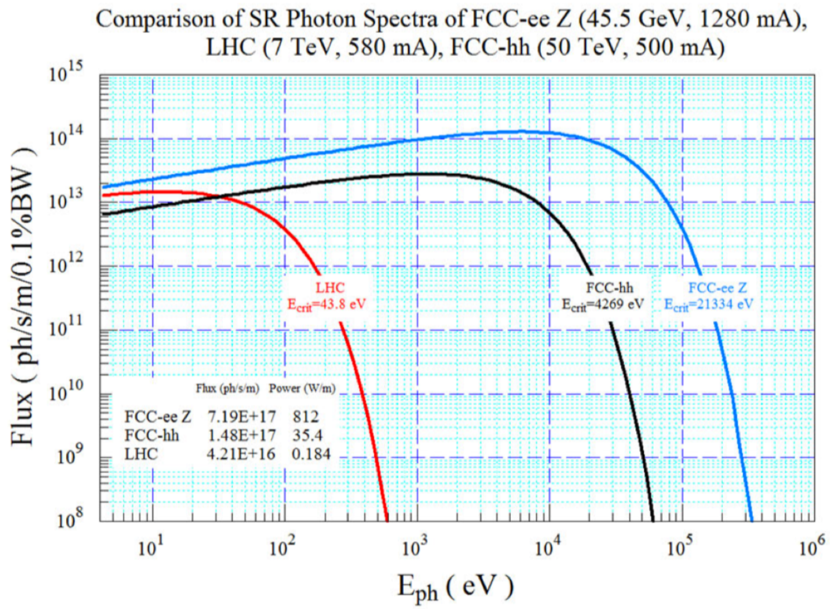
SR flux spectra in arcs

16 T dipoles

50 TeV protons $\gamma \sim 5.e{+}4$

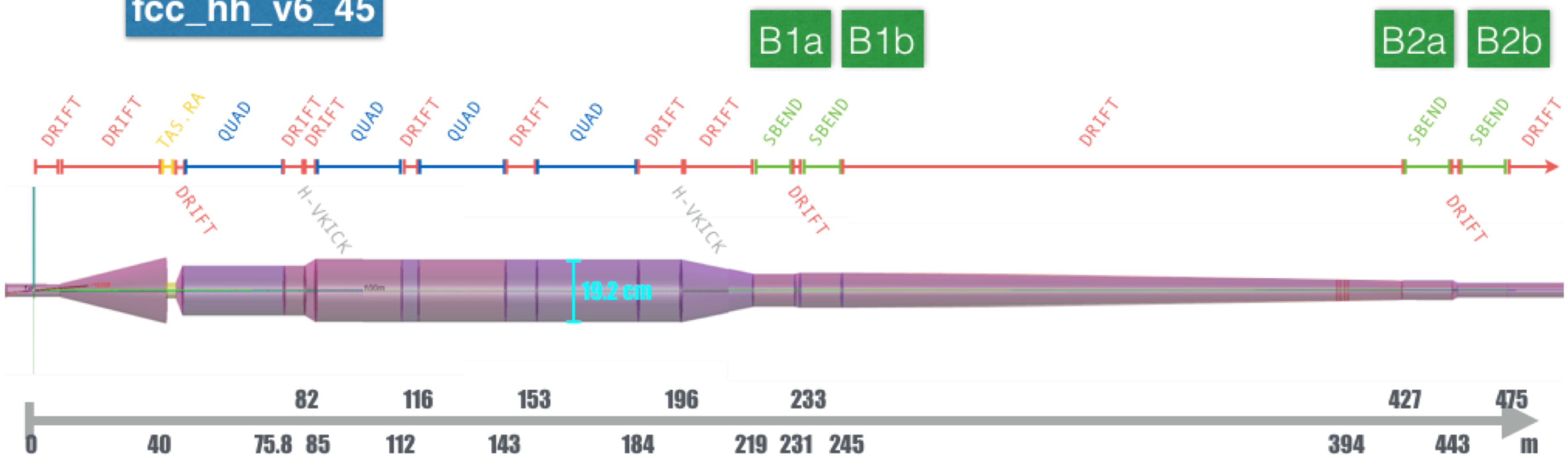
SR cone = $1/\gamma \sim 20\ \mu$rad (same as 25 GeV electrons)

Critical energy in the arcs $\propto \gamma^3/\rho$ = 4.3 keV



Beam pipe scheme from MADX

optics used:
fcc_hh_v6_45



- 5486 Bends in the lattice:
  - All but 4 “strong” (~16T)
  - 4 “soft” (~4T) near the IP

- B=4.27 T
- L=12.5 m
- Θ=-0.3 mrad
- E_C=1.146 keV
- N_γ/proton=0.1795
- P=32 W
- E_{TOT}=6.34 TeV

- B=3.56 T
- L=15 m
- Θ=0.3 mrad
- E_C=0.95 keV
- N_γ/proton=0.1795
- P=27 W
- E_{TOT}=5.28 TeV