Constraints from accelerators to future e^+e^--factory experiments

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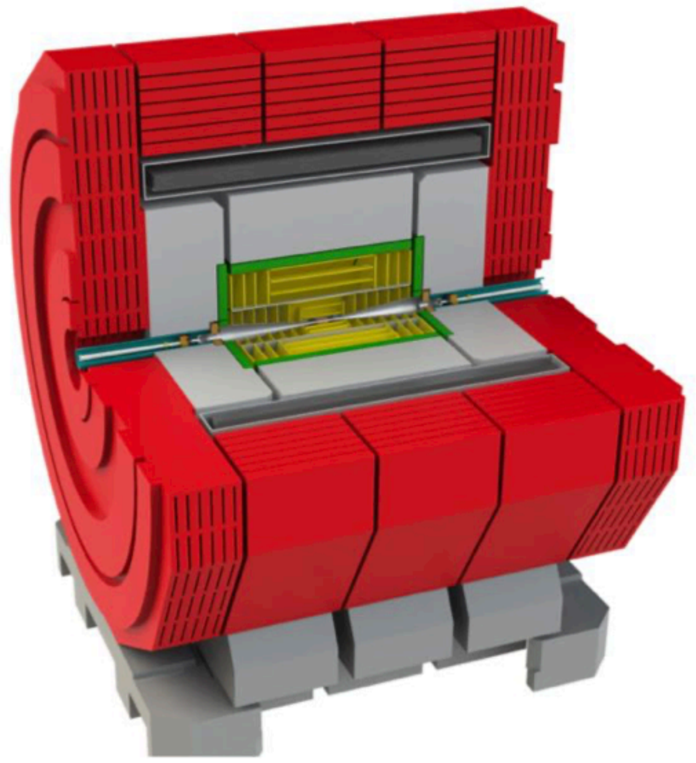
ECFA PED study WG3 workshop on calorimetry and photodetectors/PID (03 May 2023)
ECFA PED study WG3 workshop on vertexing and tracking (30 May 2023)

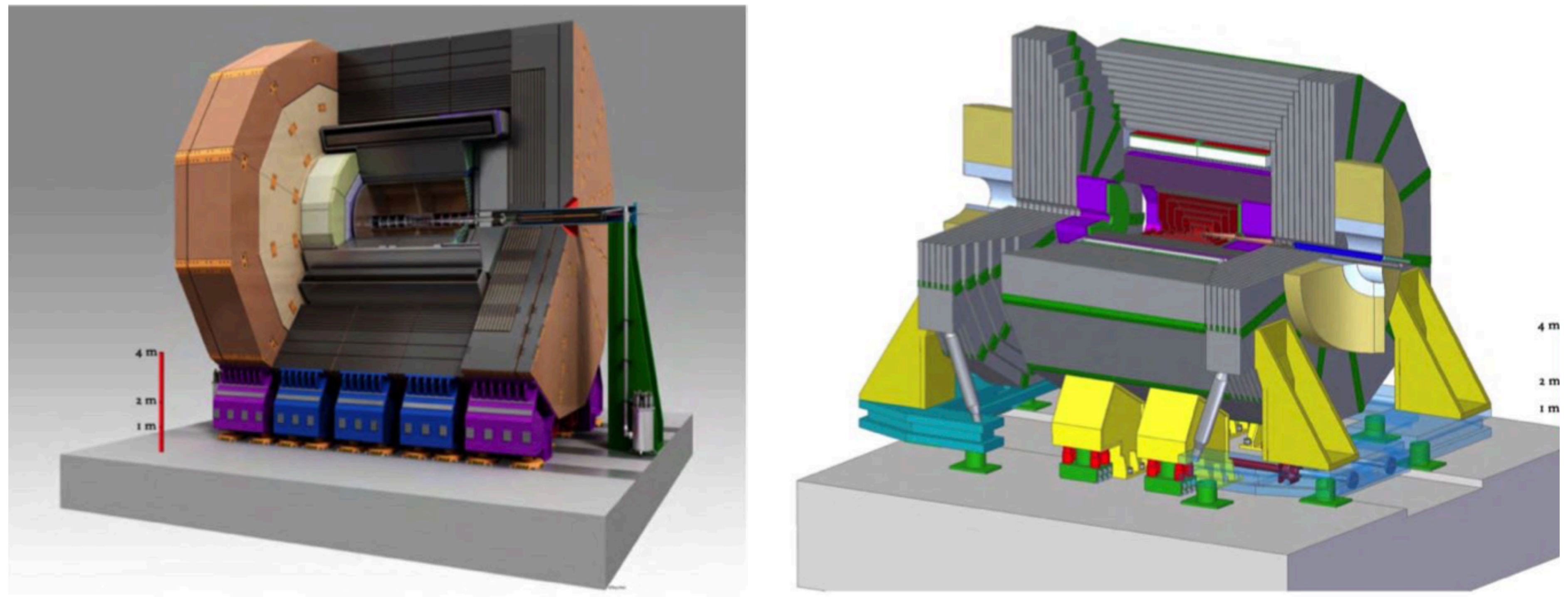
Many thanks to M. Boscolo, A. Ciarma, M.-C. Fouz, A. Robson, F. Sefkow

Consolidated e^+e^-factory proposals (and experiments)

Linear

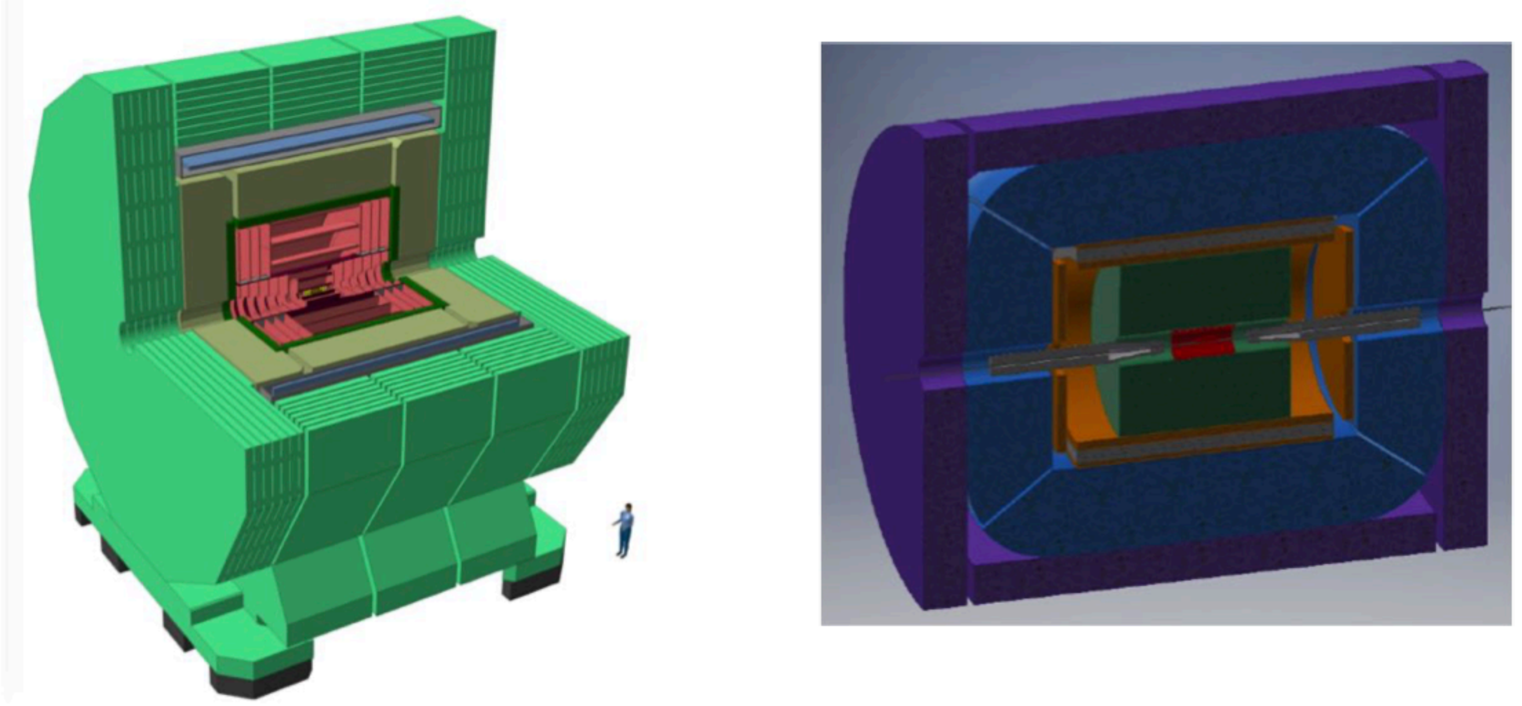


CLIC => **CLICdet**,
√s: 380 GeV, 1.5 TeV, 3 TeV

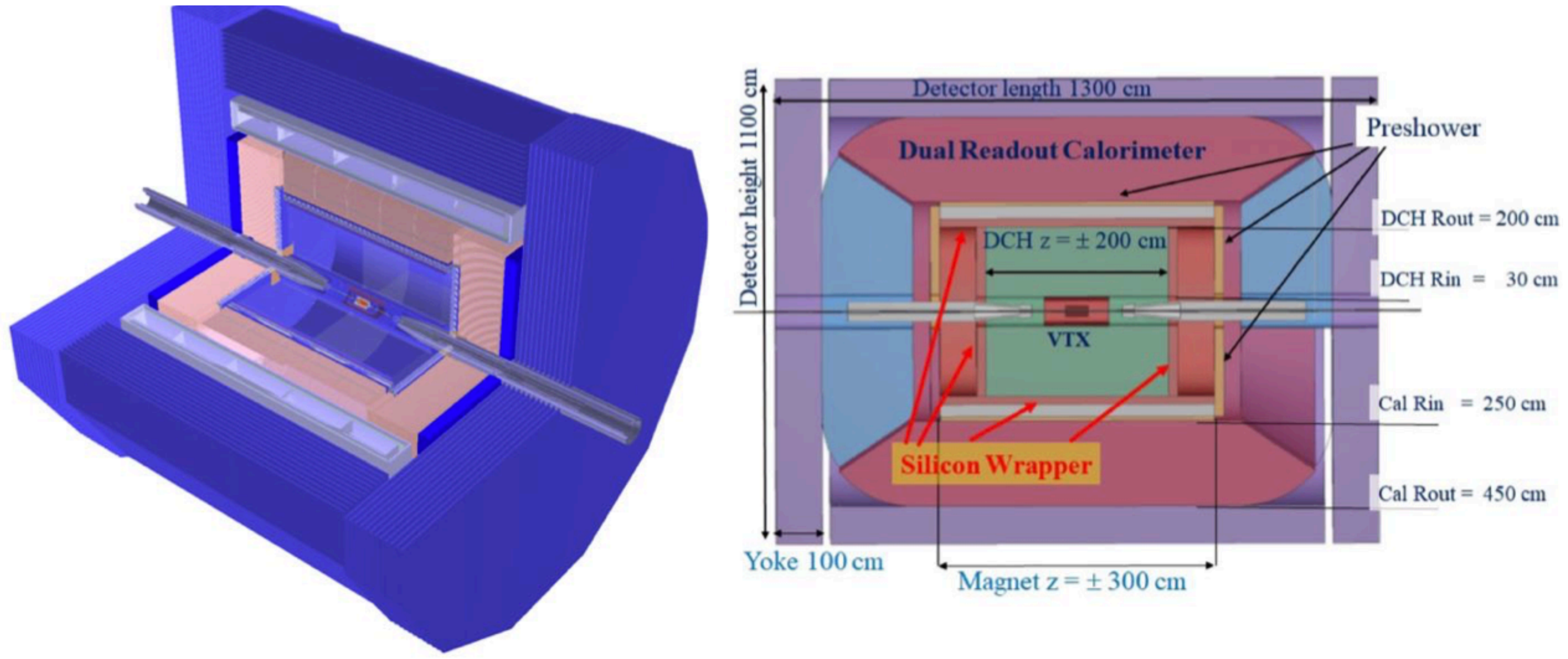


ILC => **ILD** and **SiD**:
√s: 250 – 500 GeV (1 TeV)

Circular



FCC-ee => **CLD** and **IDEA**
√s: 90 - 365 GeV



CEPC => **baseline** and **low-B**
√s: 90-240 GeV

References

- Numbers in the following taken from e+e- factories **CDRs** + **recent updates** such as
  - **FCC**: MDI presentations in FCC-US workshop (agenda, 04/2023)
  - **CEPC**: beam parameters from 50 MW upgrade in TDR (slides at eeFact2022, 09/2022)
  - **ILC**: MDI sessions at ILCX 2021 (agenda, 10/2021) and talk on TPC@tera-Z @ ILD s/w meeting (slides, 12/2022)
  - **CLIC**: post-CDR CLICdp studies (link1, link2)

- **Caveat**:
  - For circular colliders, some studies are still preliminary and some smaller bkg are not computed yet
    - Latest updates = big step forward in realism of IR design wrt CDS but numbers can still evolve as design itself evolves

Beam parameters: *linear* colliders (ILC/CLIC)

	ILC		CLIC		
	ILC250	ILC500	CLIC380	CLIC1500	CLIC3000
√s [GeV]	250	500	380	1500	3000
Luminosity/IP ($10^{34}/cm^2s$)	1.35	1.8	1.5	3.7	5.9
Train collision frequency (Hz)	5	5	50	50	50
Bunches/train	1312	1312	352	312	312
Bunch separation (ns)	554	554	0.5	0.5	0.5
Train length (μs)	730	730	0.176	0.156	0.156
Beam size at IP σ_x/σ_y (nm)	515/7.7	474/5.9	150/2.9	~60/1.5	~40/1
Crossing angle	14 mrad	14mrad	16.5 mrad	20 mrad	20 mrad

- 1 IP / collider
- Multiple detectors possible, alternating with push-pull scheme (abandoned in latest baseline CLICdp working scenario)
- **Large x-ing angle** needed to avoid parasitic interactions away from IP
- **Very low duty cycle** (train separation ~20 ms @ CLIC, ~200 ms @ ILC) allows for power-pulsing (beneficial for cooling)

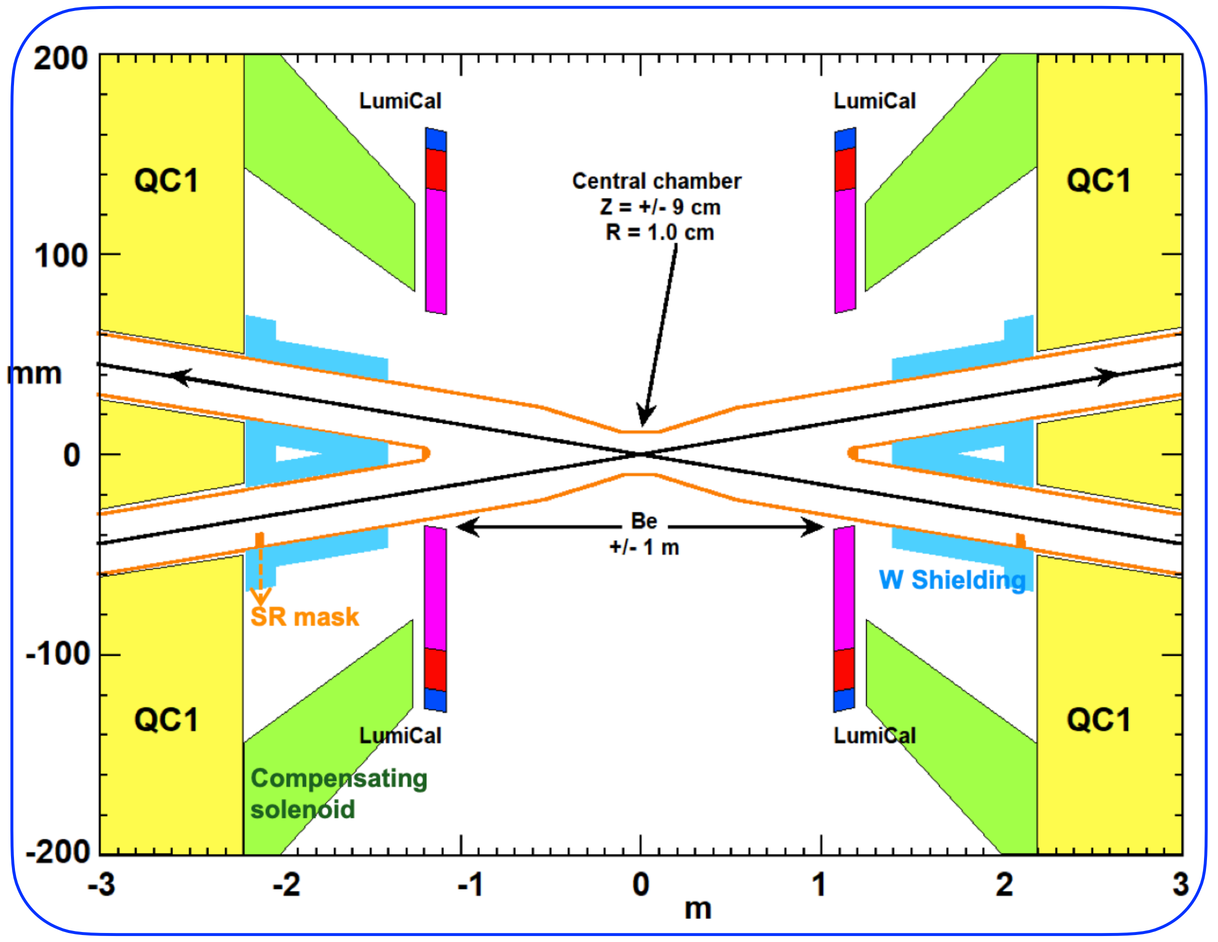
Beam parameters: *circular* colliders (FCC-ee and CEPC)

	FCC-ee			CEPC		
	Z	H	Top	Z	Higgs	Top
$\sqrt{s}$ [GeV]	91.2	240	365	91.0	240	360
Luminosity/IP ($10^{34}/\text{cm}^2\text{s}$)	182	7.3	1.33	192	8.3	0.8
Bunches/beam	10000	248	36	19918	415	58
Bunch separation (ns)	30	1200	8400	15	385	2640
Beam size at IP σ_x/σ_y (μm/nm)	8 / 34	14 / 36	39 / 69	6/35	15/36	39 / 113
Crossing angle	30 mrad	30 mrad	30 mrad	33 mrad	33 mrad	33 mrad

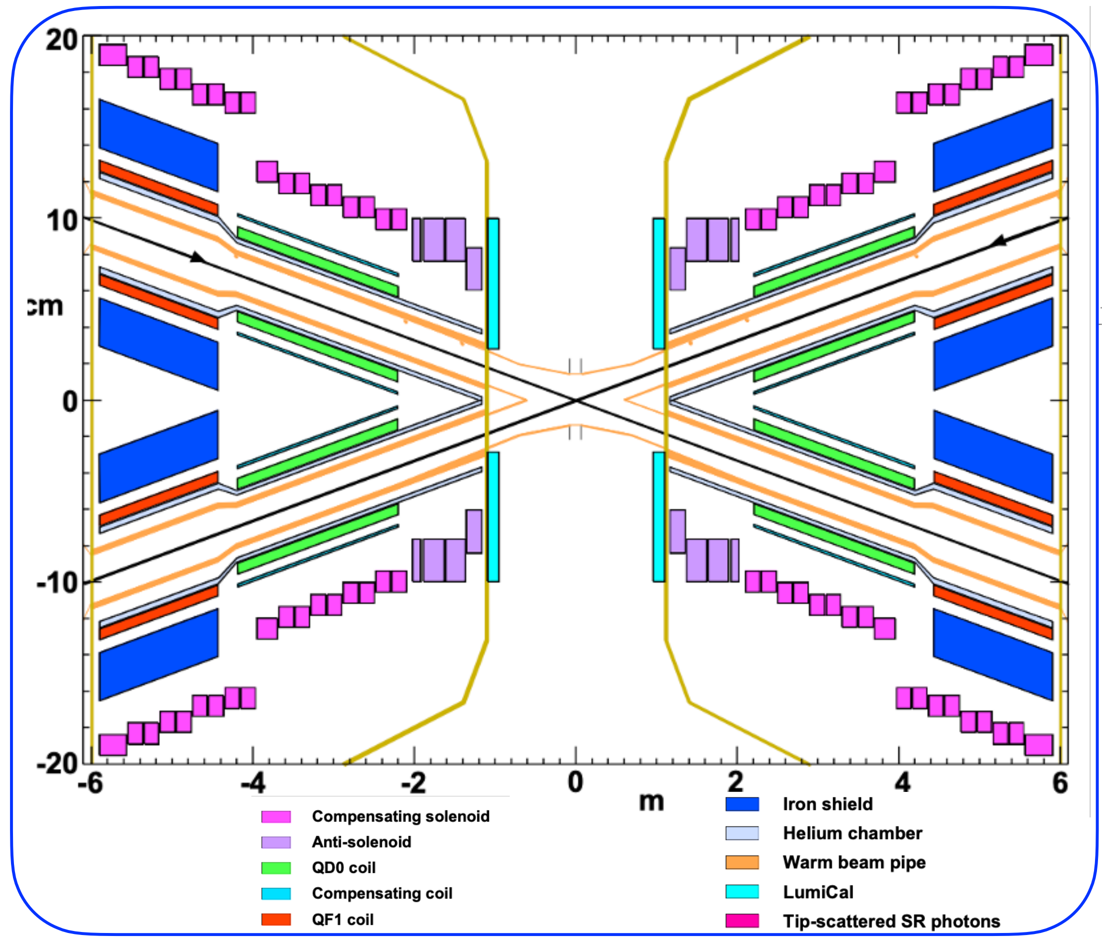
- 2-4 IP / collider (CEPC - FCC-ee)
- **Even larger x-ing angle** needed
- **“Continuous” beams** with high collision frequency (up to ~33 MHz at Z peak at FCC-ee) ⇒ no power pulsing possible (cooling)

Interaction regions

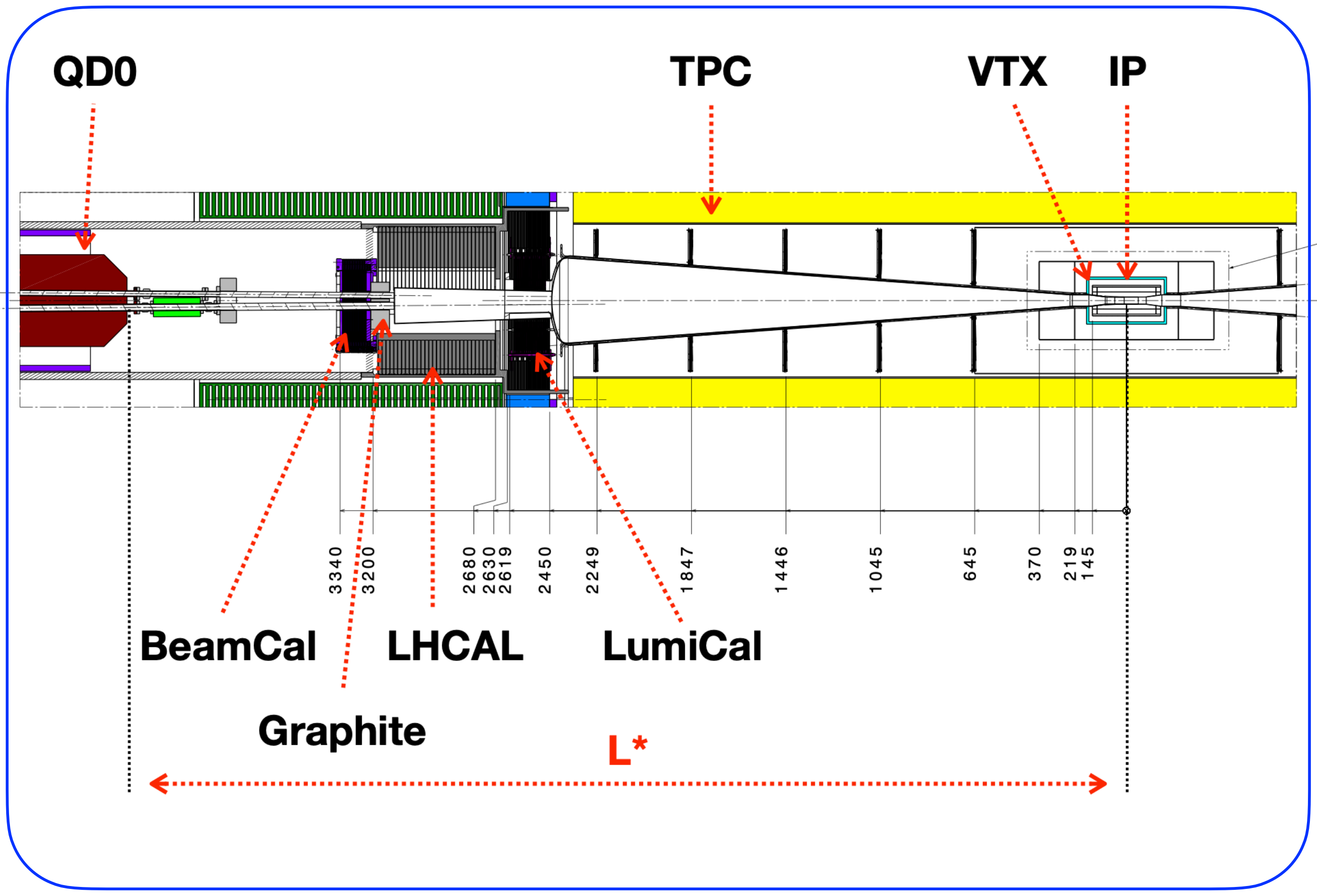
FCC-ee



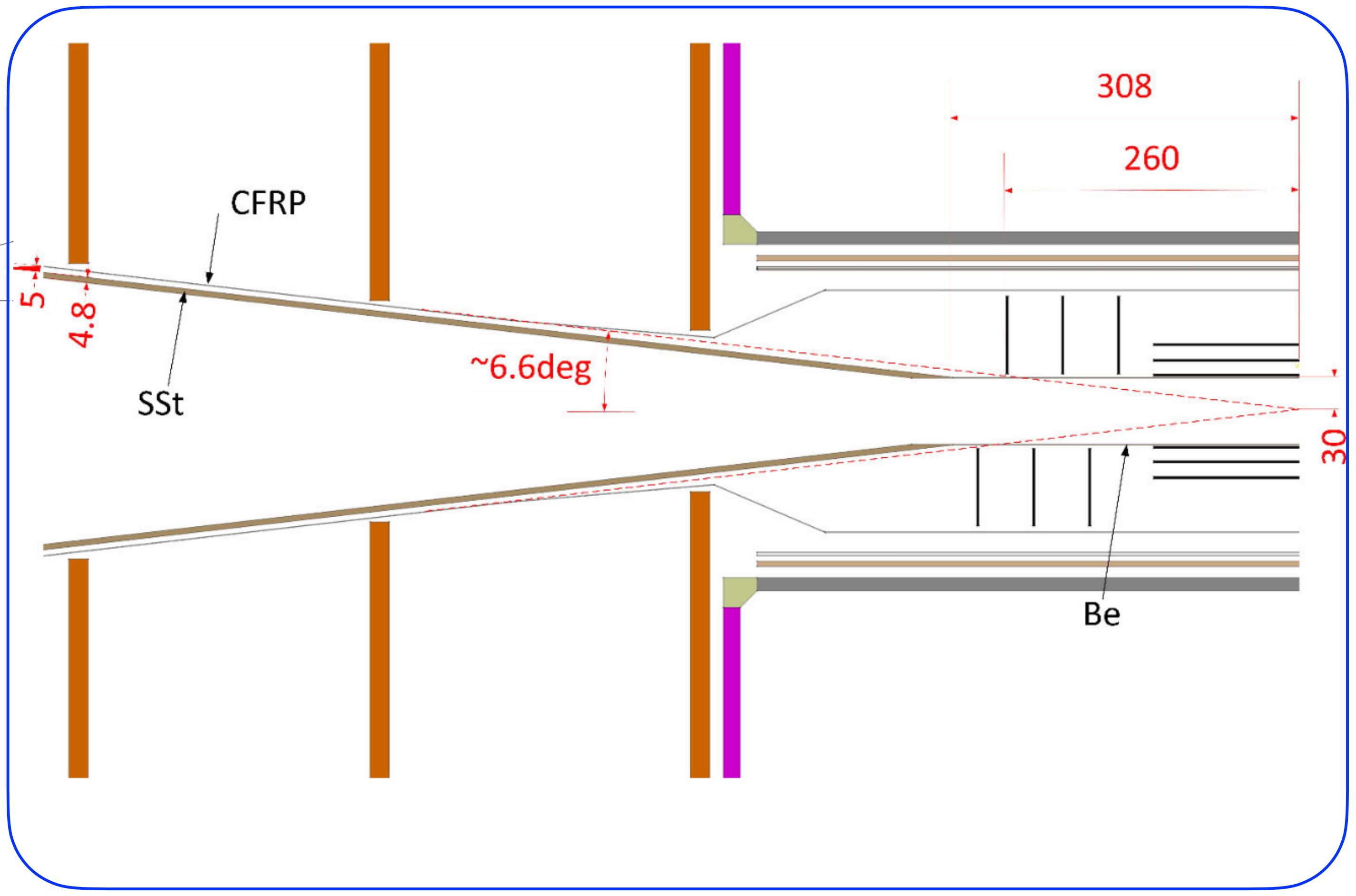
CEPC



ILC

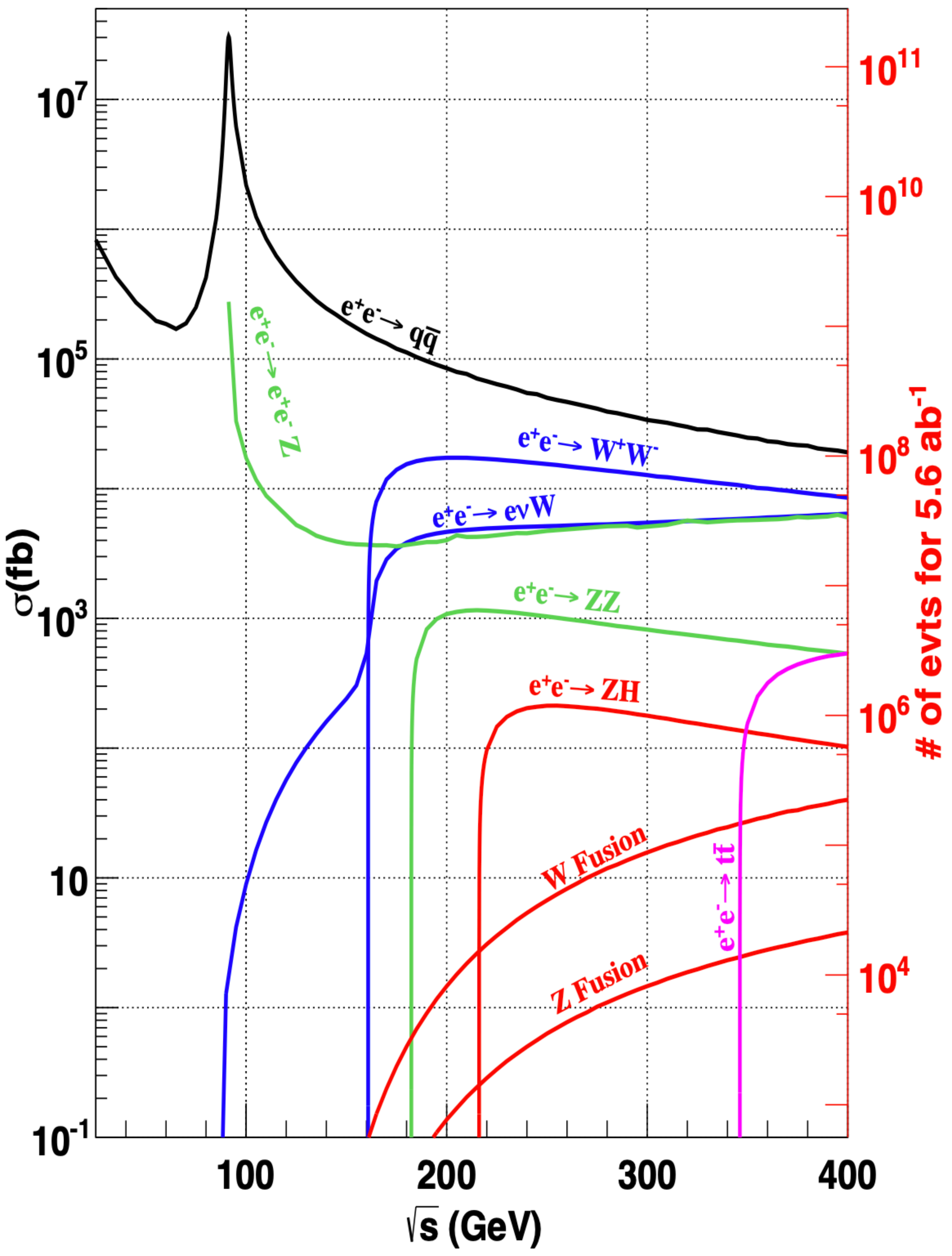


CLIC



	FCC-ee	CEPC	ILC	CLIC
L* (Δz between IP and first	2.2 m	2.2 m	4.1 m	6 m
Position of final quadrupole	Inside detector	Inside detector	Outside detector	Outside detector
LumiCal position	z=1m, ~50-100 mrad (Constrained by compensating solenoid)	z~0.95~1.11m 26-105 mrad (fiducial volume 53-79 mrad)	z=2.5m, 33-80 mrad	z=2.5m, 39-134 mrad
Tracker acceptance	Down to ~9 degrees (defined by luminometer)	Down to ~8 degrees	Down to ~6° (defined by conical beam pipe)	Down to ~7° (defined by conical beam pipe)
Inner beam pipe radius	10 mm	10 mm	16 mm	29.4 mm
Crossing angle	30 mrad	33 mrad	14 mrad	20 mrad
Main solenoid B field	2T	3T (2T at Z pole)	3.5-5T	4T

Physics rates

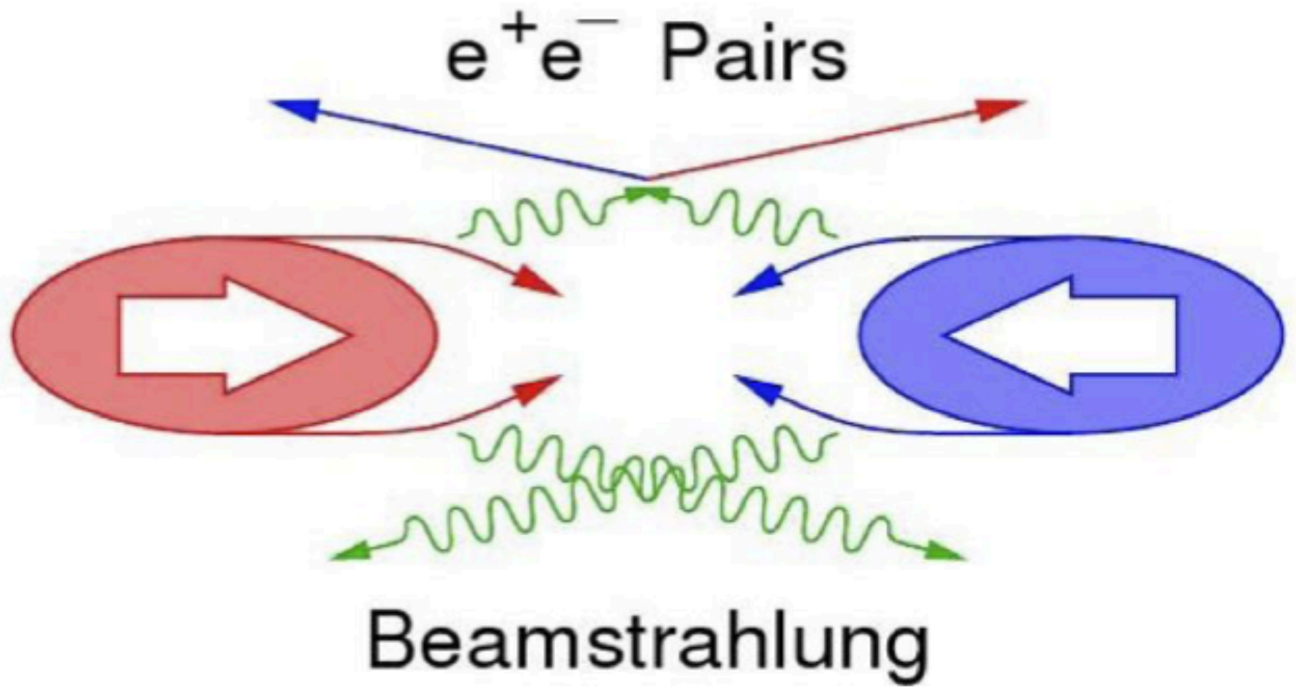


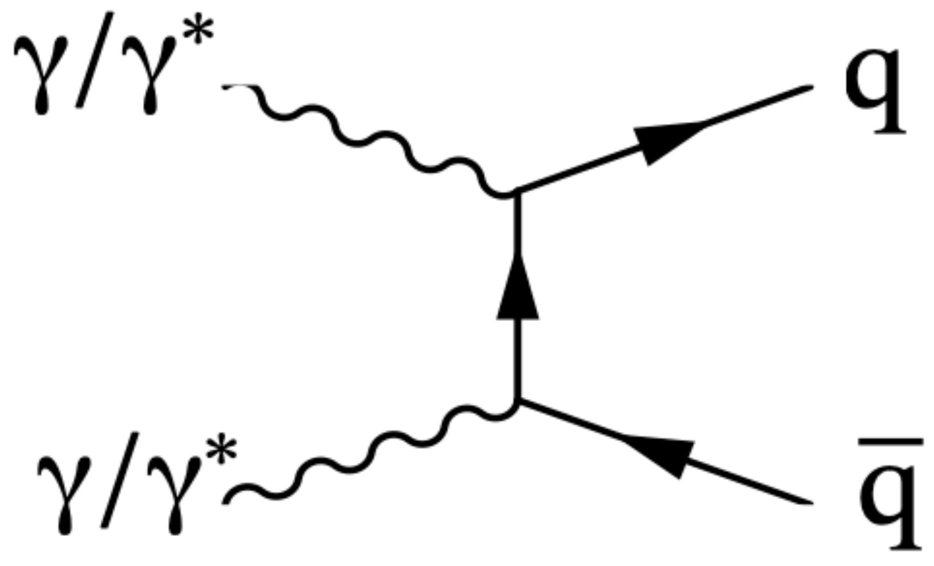
- In central detector
  - At Z resonance:
    - ~80 kHz for L = $180*10^{34}$/cm^{2}s (FCC-ee, CEPC)
      - includes O(10) kHz from ee→ee and O(100 Hz) from ee→γγ in detector acceptance (θ ~9–171°)
      - ➡ fast **detector response** to minimise dead time
      - ➡ **zero-suppression** to reduce data transfer/output rate
      - ➡ **trigger-less design** (preferable to avoid trigger efficiency systematic uncertainties) **could be challenging**
  - At $\sqrt{s}$ >= 160 MeV: L<10^{35}/cm^{2}s, σ≲1 nb ⇒ rate ≲ 100 Hz

- In forward luminosity calorimeters
  - sustained rate due to large Bhabha xsections at small angles: ~80 kHz for L = $180*10^{34}$/cm^{2}s (FCC-ee, CEPC)
  - ➡ **radiation hardness** in very forward region

Backgrounds at e^+e^--factories

- **All projects**: very small beams ⇒ high EM fields ⇒ bend the trajectories of the opposite bunch particles
  - **beamstrahlung** ⇒ photons
  - **incoherent pair creation** (IPC) ⇒ $e^\pm$
  - **γγ→qqbar** ⇒ hadrons (jets)





- **Circular colliders**: bending of charged beam particles in dipole magnetic field
  - **Synchrotron radiation** ⇒ photons
- **Increase with energy**: most significant at 365 GeV (FCC-ee) / 500 GeV (ILC) / 3 TeV (CLIC)
- **Mitigated** through machine-detector-interface (**MDI**) design, but pose **constraints** on **detector** design too

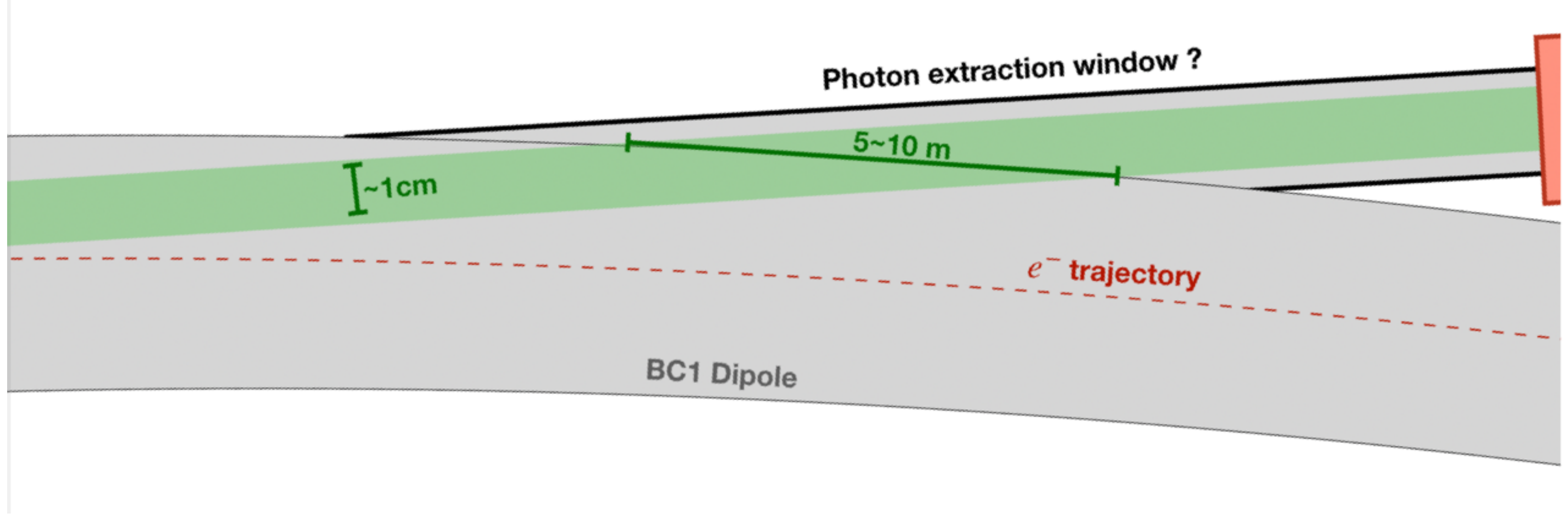
Backgrounds at e^+e^--factories

- **All projects**: very small beams ⇒ high EM fields ⇒ bend the trajectories of the opposite bunch particles
  - **beamstrahlung** ⇒ photons
    - ⇒ increase of IP size / center-of-mass energy spread. Impact on physics but not on detector (but requires measurement in situ of luminosity profile vs $\sqrt{s}$)
  - **Incoherent pair creation** (IPC) ⇒ $e^\pm$
  - **γγ→qqbar** ⇒ hadrons (jets)
    - ⇒ can lead to large occupancy and energy deposited in detector
    - ⇒ space granularity / time resolution for use of timing in offline reconstruction
    - ⇒ very large $e^\pm$ rate at low p_T => impact on design of inner region and on forward region (envelope around IR limits beam pipe and inner detector radii)
- **Circular colliders**: bending of charged beam particles in dipole magnetic field
  - **Synchrotron radiation** ⇒ photons
    - ⇒ can lead to energy deposited in the detector if unshielded
    - ⇒ SR in solenoid due to x-ing angle limits B field to minimise impact on luminosity
- **Increase with energy**: most significant at 365 GeV (FCC-ee) / 500 GeV (ILC) / 3 TeV (CLIC)
- **Mitigated** through machine-detector-interface (**MDI**) design, but pose **constraints** on **detector** design too

Additional backgrounds

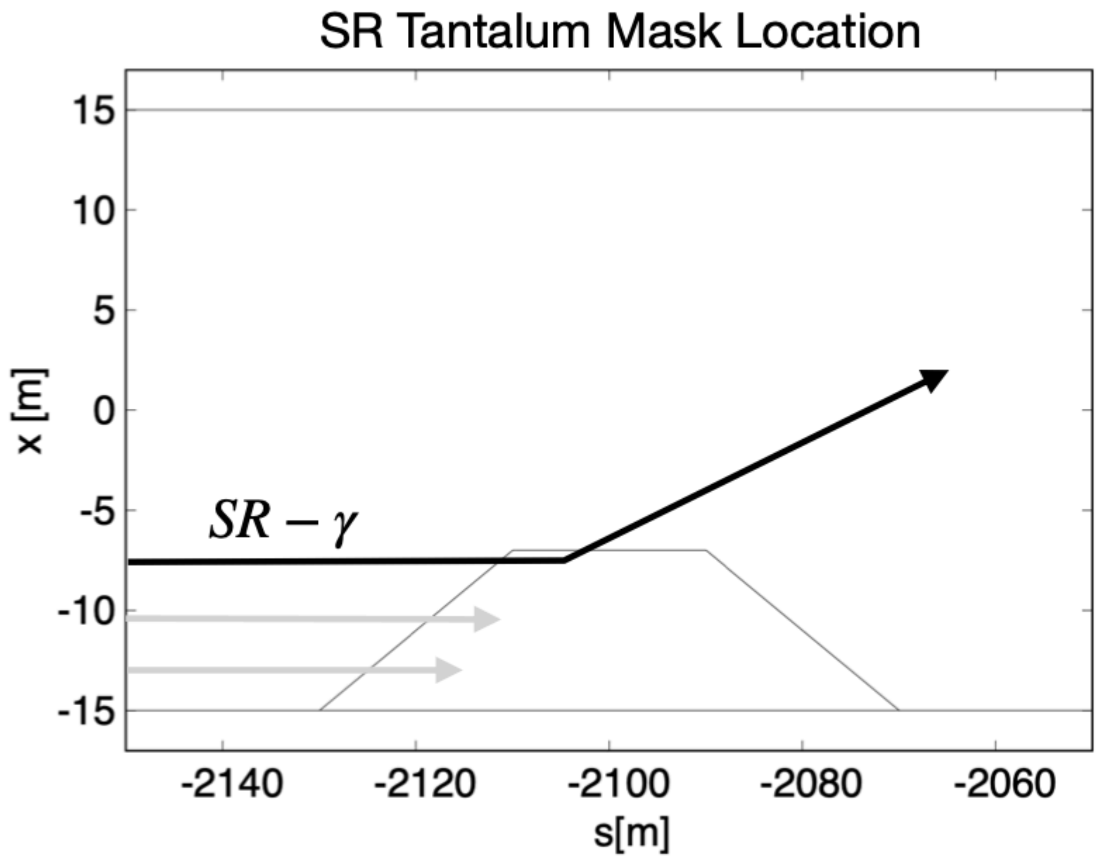
- Additional sources of backgrounds that **have been studied and found to be negligible in CLIC:**
  - **Beam halo muons** from inelastic collisions of beam halo (inelastic beam collisions with gas in beampipe) with collimators
    - can be suppressed with proper design of collimators and spoilers in BDS: 1 muon/BX with x20 safety factor, small occupancy => should be easy to identify and reject by reconstruction algorithms)
  - **Backscattering** from downstream beam elements / beam dump: ~20γ (E<0.5 MeV) + 4n (E<1 MeV)/cm^2, absorbed by detector yoke => **negligible**

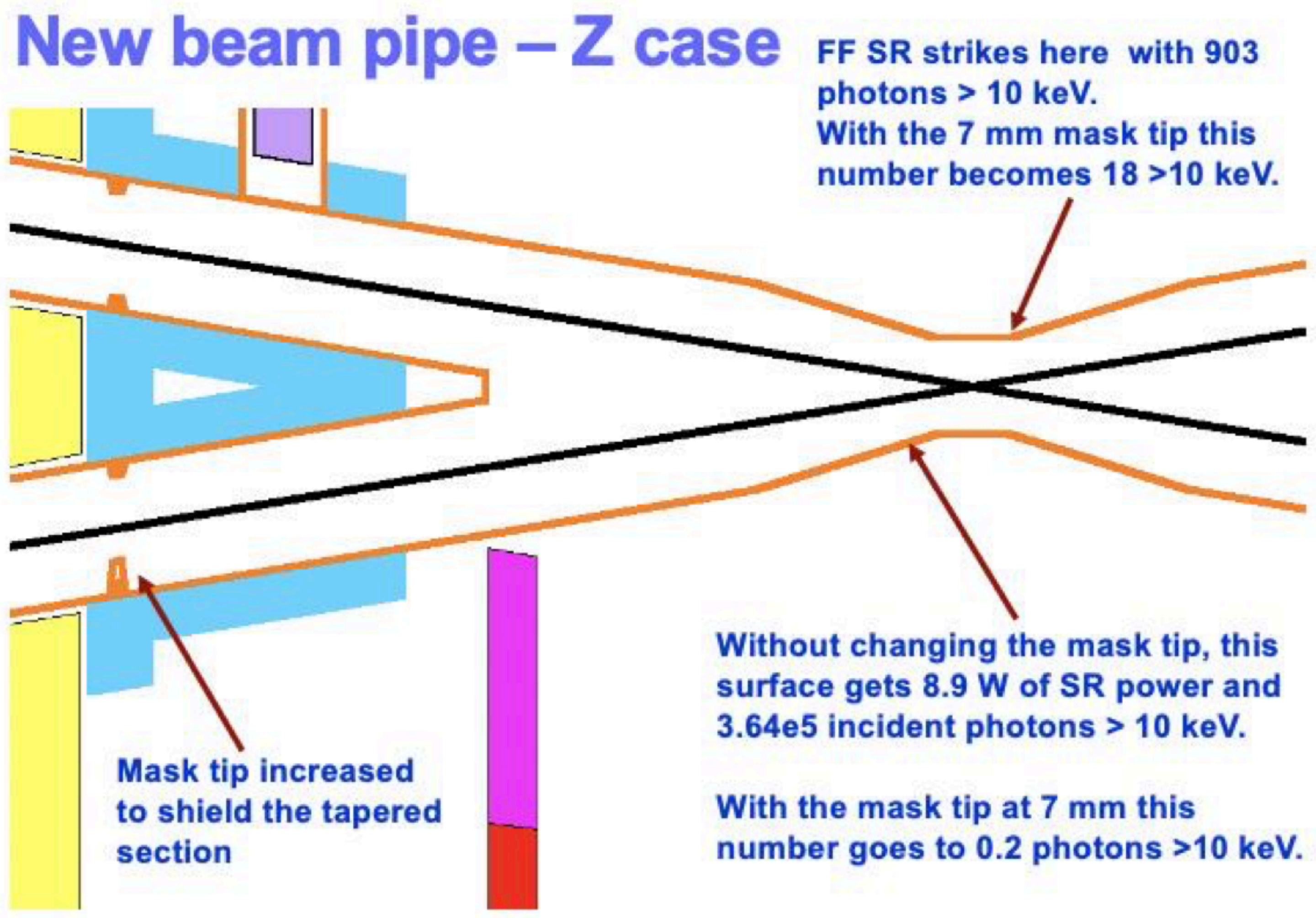
- Additional sources of background **under study at FCC-ee**:
  - **Beam-halo** diffused by collimators: some preliminary results available, shown later (muons from inel. collisions: to be studied)
  - **Backscattering**: included as consequence of bkg produced by mechanisms described before, from detector support. Not studied yet: backscattering from beamstrahlung photon dump (design not finalised), but very far from IP (500m) -> expect negligible impact
  - **Beam-gas scattering**: preliminary studies exist, but need to be replicated for new beam parameters
  - From **top-up injection**: study ongoing, no results yet



Synchrotron radiation at FCC-ee

- **Beam optics** around IP ⇒ critical energy of γ <100 keV from upstream dipoles up to ~480 m (most power emitted @$E<E_c$)
- Synchrotron-radiation **mask tips** @ z=2.1m intercept most SR scattered particles
- 5 um gold **coating** of beam pipe partially absorbs scattered photons from the mask tips
- Cu beam **pipe** (outside central region) + high-Z **shields** (W) absorb most of remaining photons.
- With shielding proposed **in CDR**:
  - **CLD**: < 1 hit/BX @$\sqrt{s}$ up to Higgs, few hundred hits / BX @ top, mainly in first 2 layers of tracker (R ~2.5 cm, 25 um pitch) ⇒ negligible occupancy ~10^{-4}
  - **IDEA**: average occupancy O(%) in drift chamber (R=35–200cm, z=±200 cm, ~1.4cm cells) with 400 ns integration time (maximum drift time) ⇒ need to exploit timing (γ: localised depositions) to reduce to O(.1%)


SR Tantalum Mask Location


New beam pipe – Z case

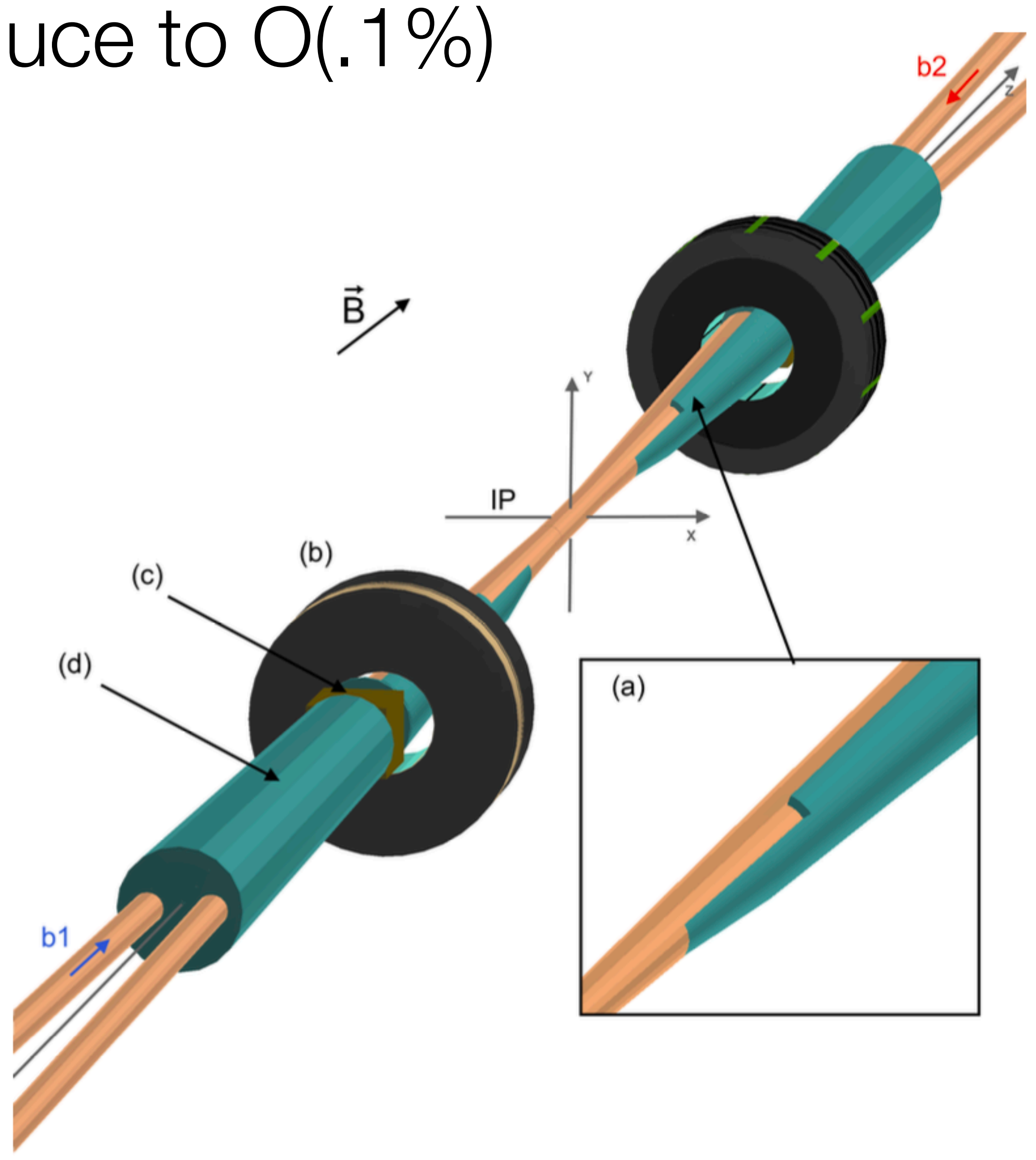
FF SR strikes here with 903 photons > 10 keV. With the 7 mm mask tip this number becomes 18 >10 keV.

Without changing the mask tip, this surface gets 8.9 W of SR power and 3.64e5 incident photons > 10 keV.

With the mask tip at 7 mm this number goes to 0.2 photons >10 keV.

Mask tip increased to shield the tapered section

mask tips prevent FF quad radiation from striking nearby beam pipe elements

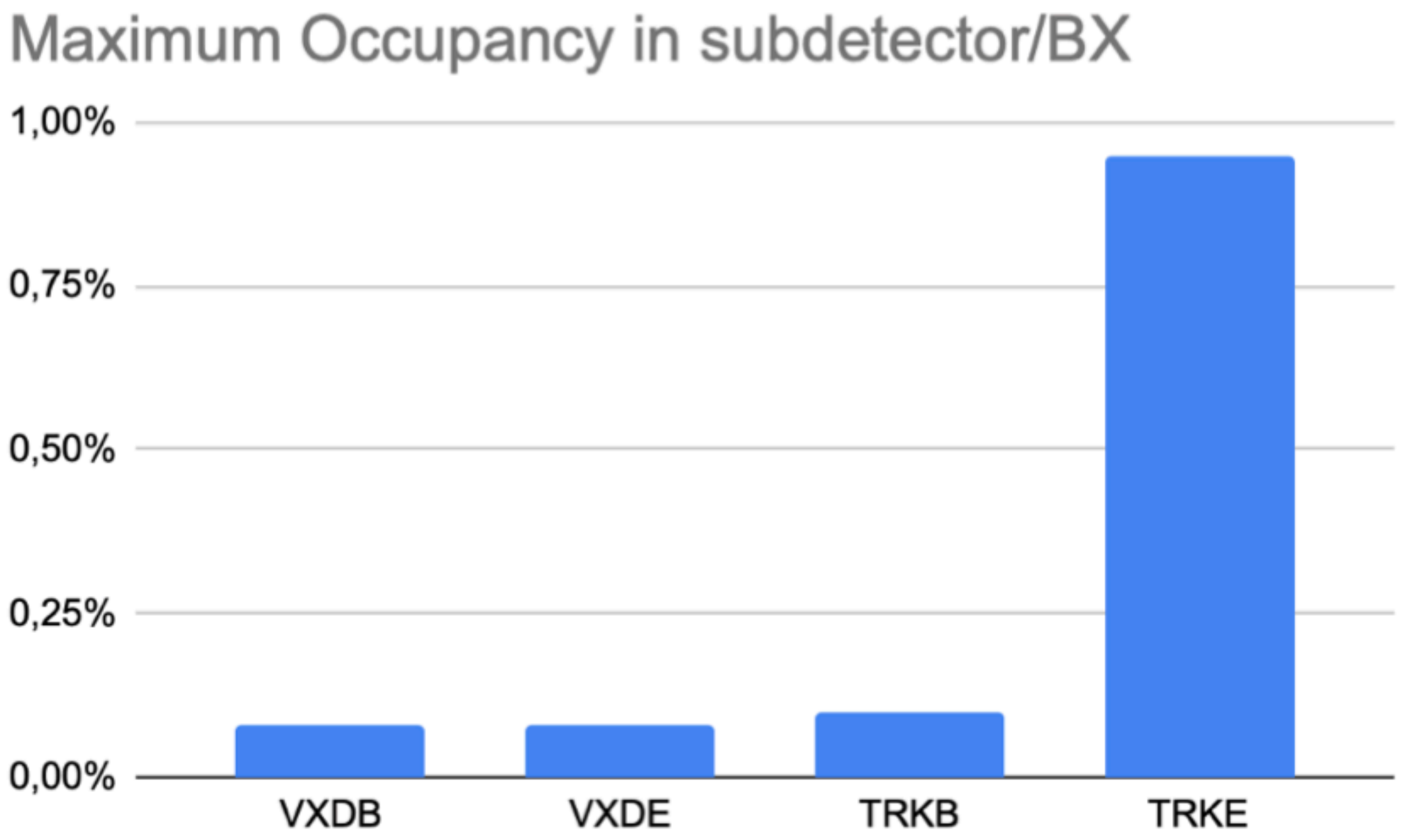


Synchrotron radiation at FCC-ee

- **Updated** studies of SR with new lattice and detector layout and latest software **in progress**
- Preliminary study to replicate CDR results using tracking in Key4HEP, for the CLD detector ⇒ **overall good agreement**
  - **CLD tracker**: without shielding, SR photons scattered by mask tip lead to occupancy<0.1%, except tracker endcaps (1%)
  - For trackers with limited z segmentation (eg **drift chambers**) effect could be significantly higher (⇒ use timing)

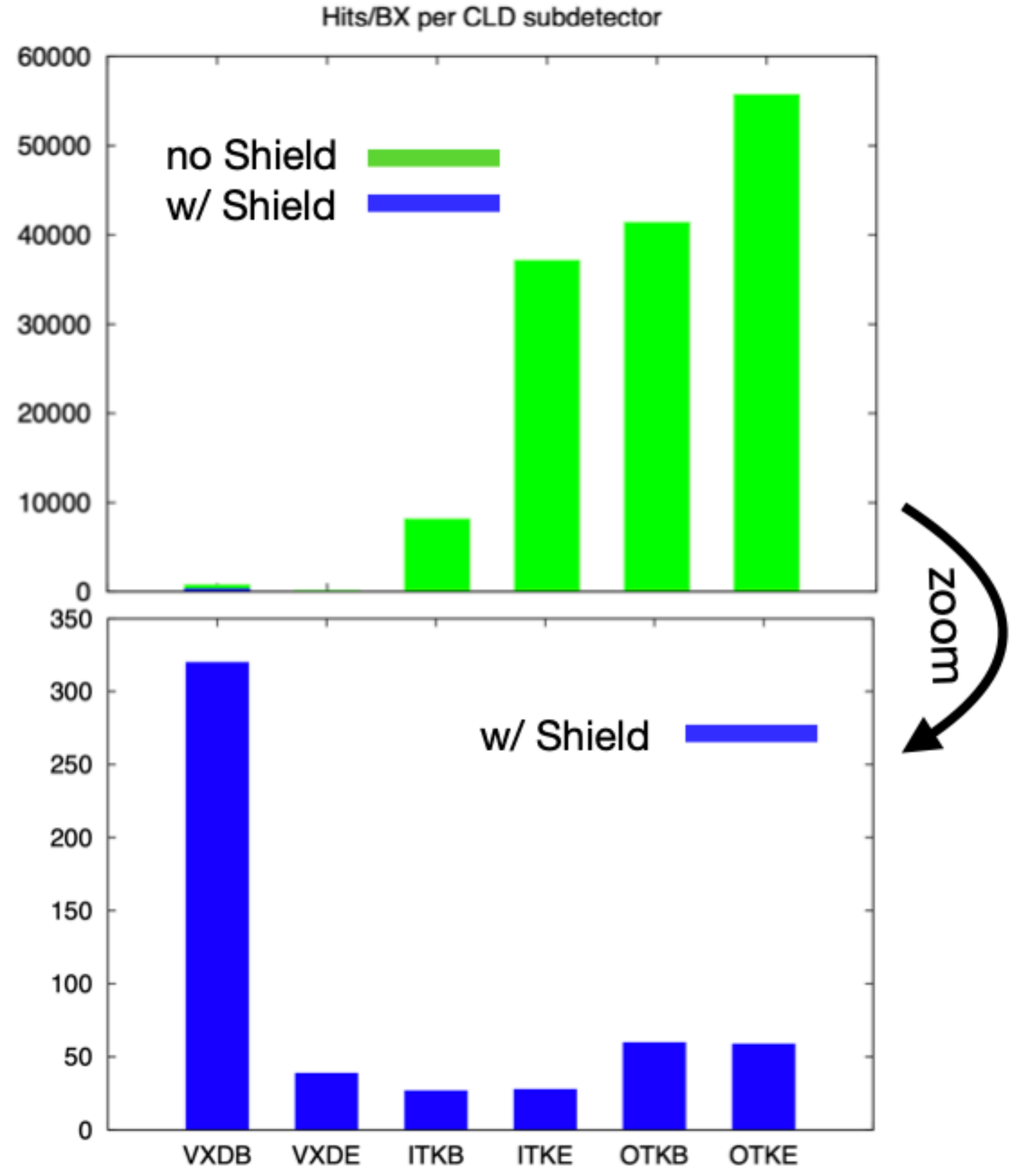
$$occupancy = hits/mm^2/BX \cdot size_{sensor} \cdot size_{cluster} \cdot safety$$

$$size_{sensor} = \begin{matrix} 25\mu m \times 25\mu m\ (pixel) \\ 1mm \times 0.05mm\ (strip) \end{matrix} \qquad size_{cluster} = \begin{matrix} 5\ (pixel) \\ 2.5\ (strip) \end{matrix} \qquad safety = 3$$



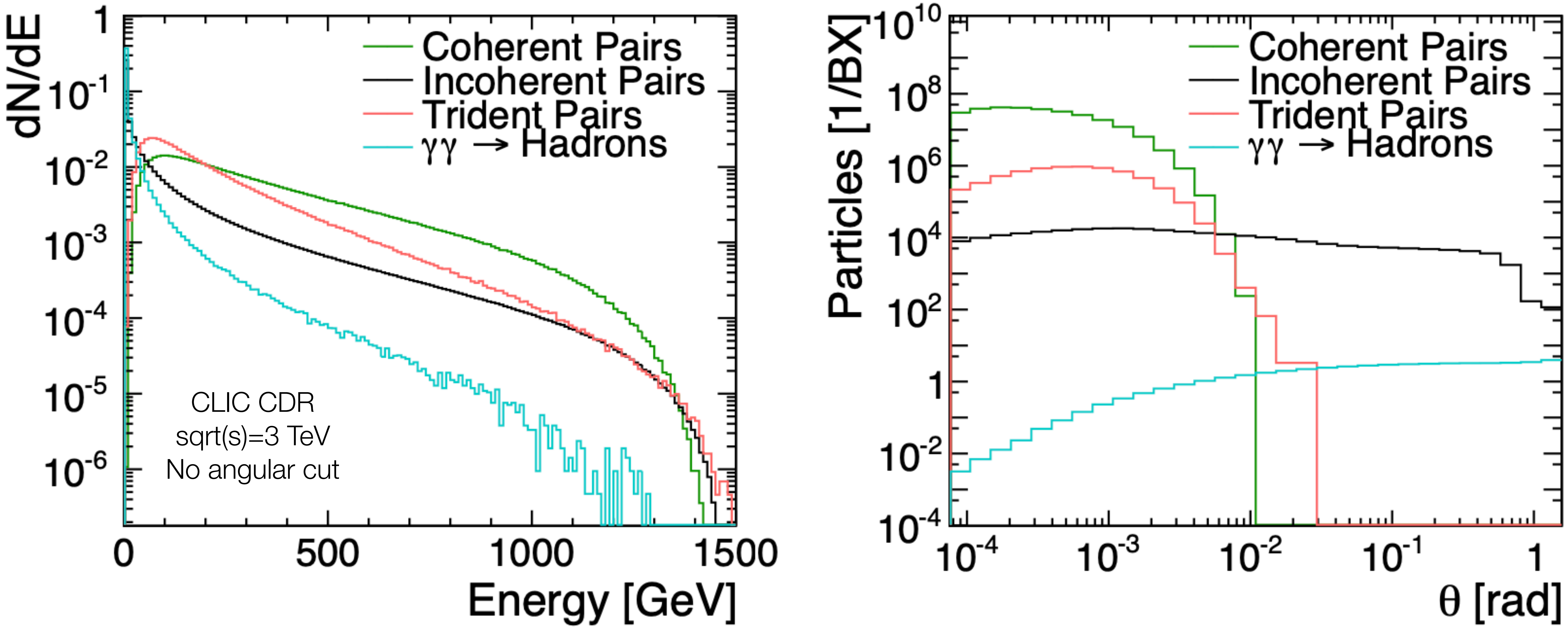
($t\bar{t}$ threshold - CDR beam parameters
CLD detector - NO shieldings)

Adding the **Tungsten shieldings** of course reduces by a lot the background in particular in the trackers, and with a smaller effect on the vertex detector.



Electron-positron pair production and hadron production

- **e^+e^-** production: emitted photons interact coherently/incoherently with opposing bunch particles and convert to ee
  - most pairs from **coherent** production are produced along outgoing beam direction and **remain in beampipe**
  - pairs from **incoherent** production have flatter θ spectrum ⇒ **can reach detector**, though typical **energy small**
- **Hadron** production: mainly in **central region** and at **low p_T**. High p_T tail can produce **jets** in calorimeters

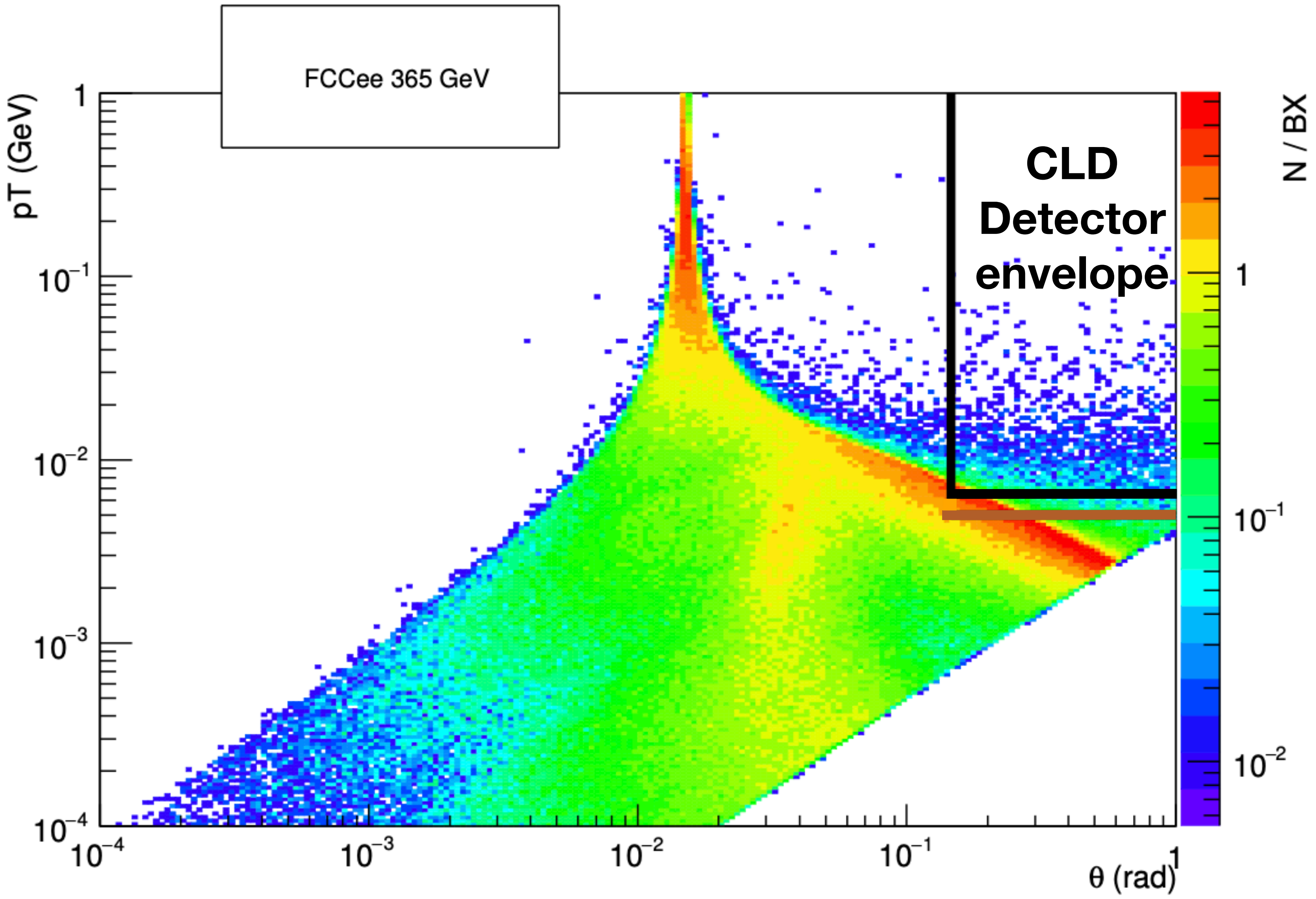


CLIC CDR
sqrt(s)=3 TeV
No angular cut

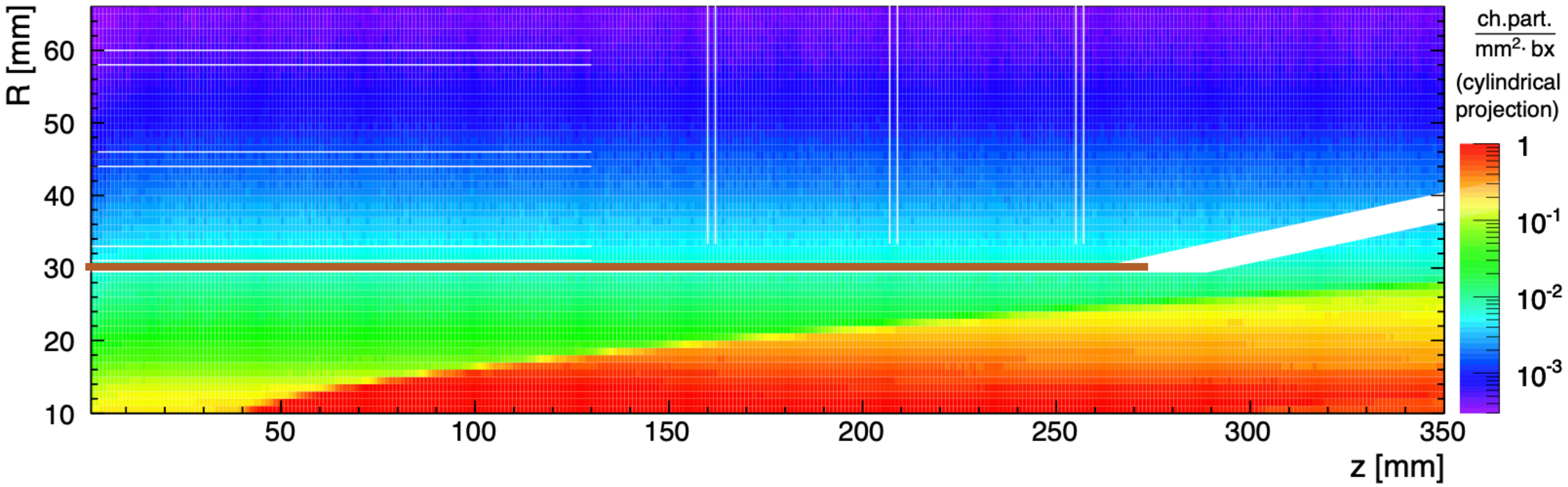
Electron-positron pair production and beam pipe radius

- Large flux of scattered ee pairs spiralling in main solenoid's field **determines radius of beam pipe** (envelope of high-p_T component)
  - **CLIC** (B=4T, $\sqrt{s}$ = 3 TeV) : 30 mm
  - **ILC** (B=3.5-5T, $\sqrt{s}$ = 500 GeV) : 16 mm
  - **FCC-ee** (B=2T, $\sqrt{s}$ = 365 GeV) : 10 mm

FCC-ee 365 GeV



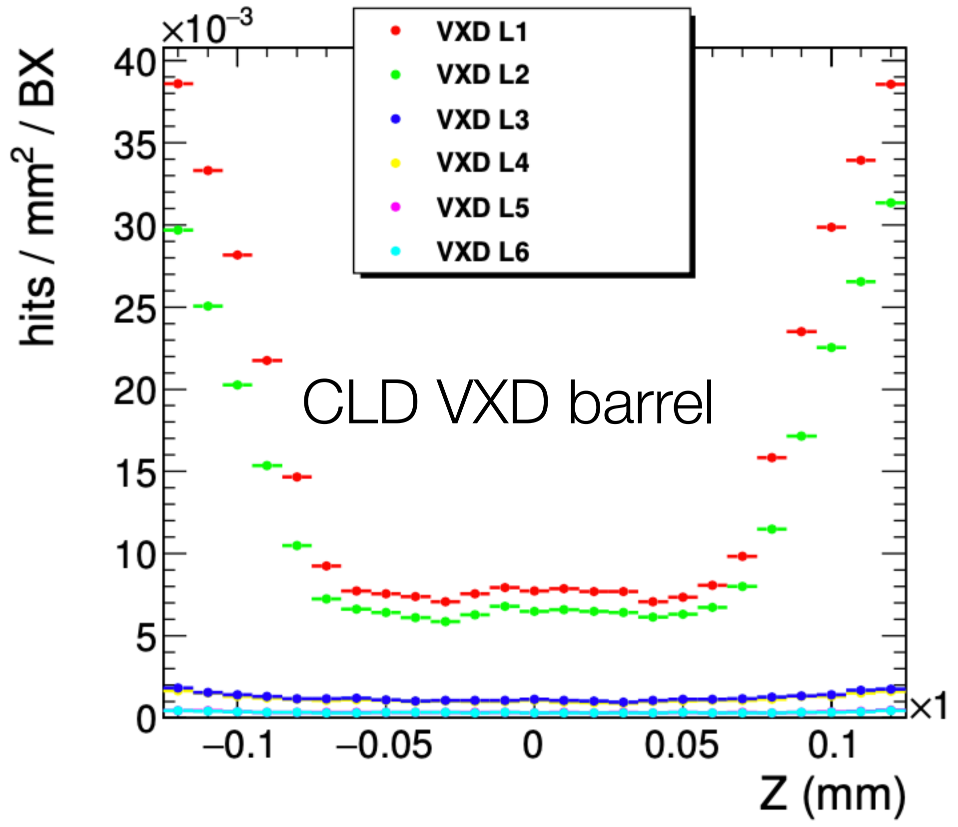
CLIC 3 TeV

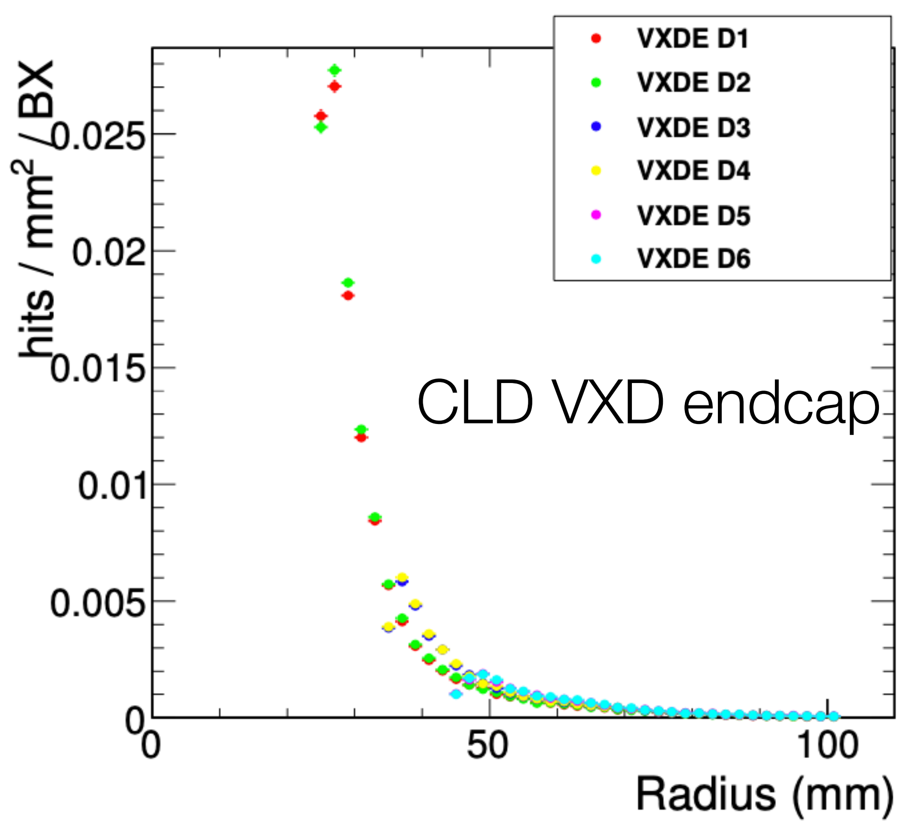


Electron-positron pair production and hadron production @ FCC-ee

- Studies for **CDR** indicate that incoherent pair production and hadron production lead to **negligible** backgrounds **in central det**:
  - **Incoherent e^+e^- pair production**:

$\sqrt{s}$ [GeV]	91.2	365
Total particles	800	6200
Total E (GeV)	500	9250
Particles with $p_T \geq 5\,\text{MeV}$ and $\theta \geq 8^\circ$	6	290





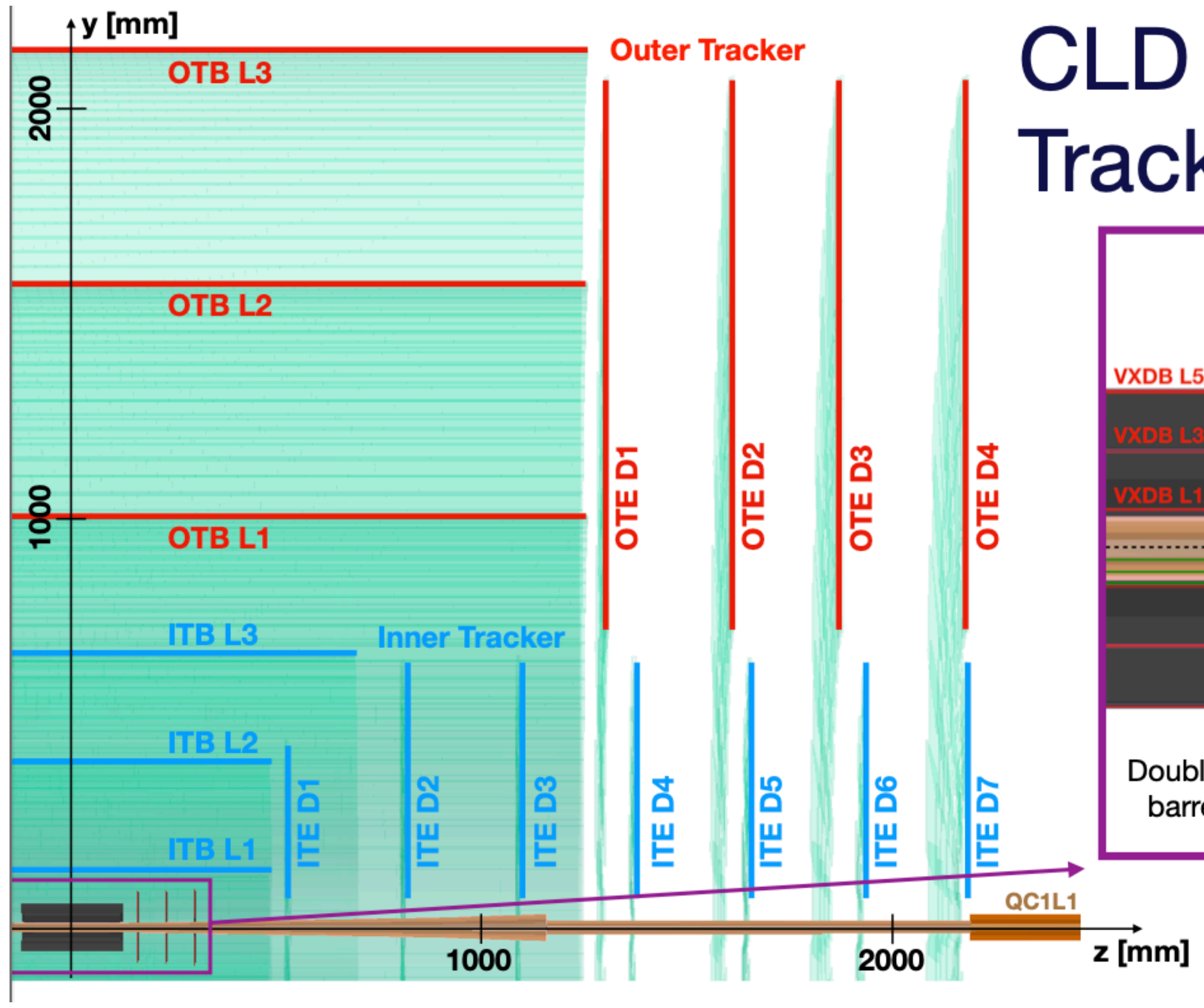
    - ➡ Peak occupancy in CLD tracker 10^{-4}/BX (inner radii of first disk: R~70 cm, pixelated, pitch = 25um)
    - ➡ Average occupancy in IDEA drift chamber 2.9%
  - **γγ→hadrons**: < 0.01 events/BX @top with $m_{\gamma\gamma}$ > 2 GeV
    - Negligible occupancy both for CLD and IDEA trackers

Background	Average occupancy	
	$\sqrt{s} = 91.2$ GeV	$\sqrt{s} = 365$ GeV
e^+e^- pair background	1.1%	2.9%
$\gamma\gamma \rightarrow$ hadrons	0.001%	0.035%
Synchrotron radiation	-	0.2%

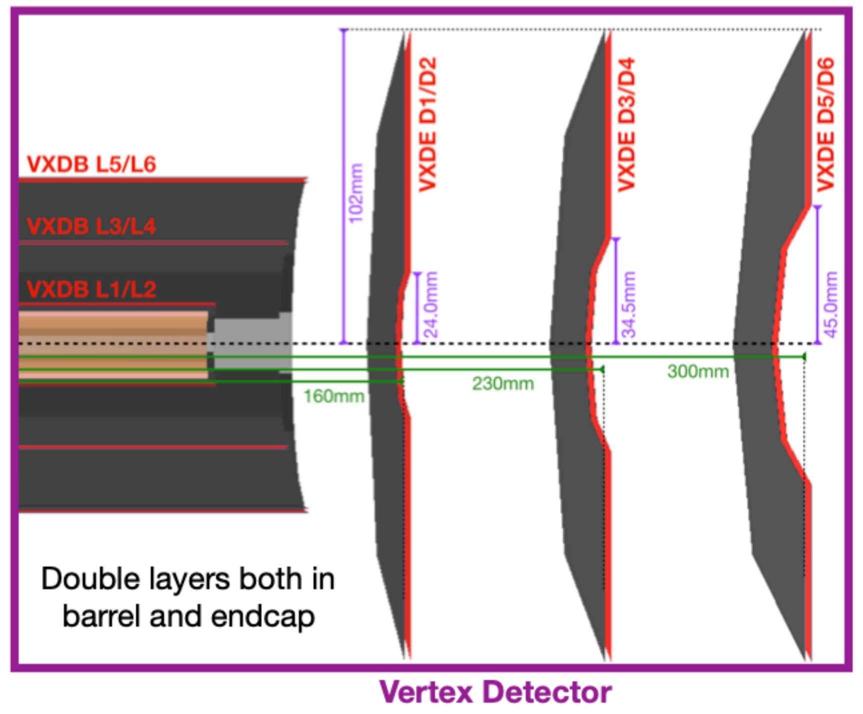
IDEA, timing information used for photon signal suppression (ee bkg mostly due to secondary photons from scattering off upstream material)

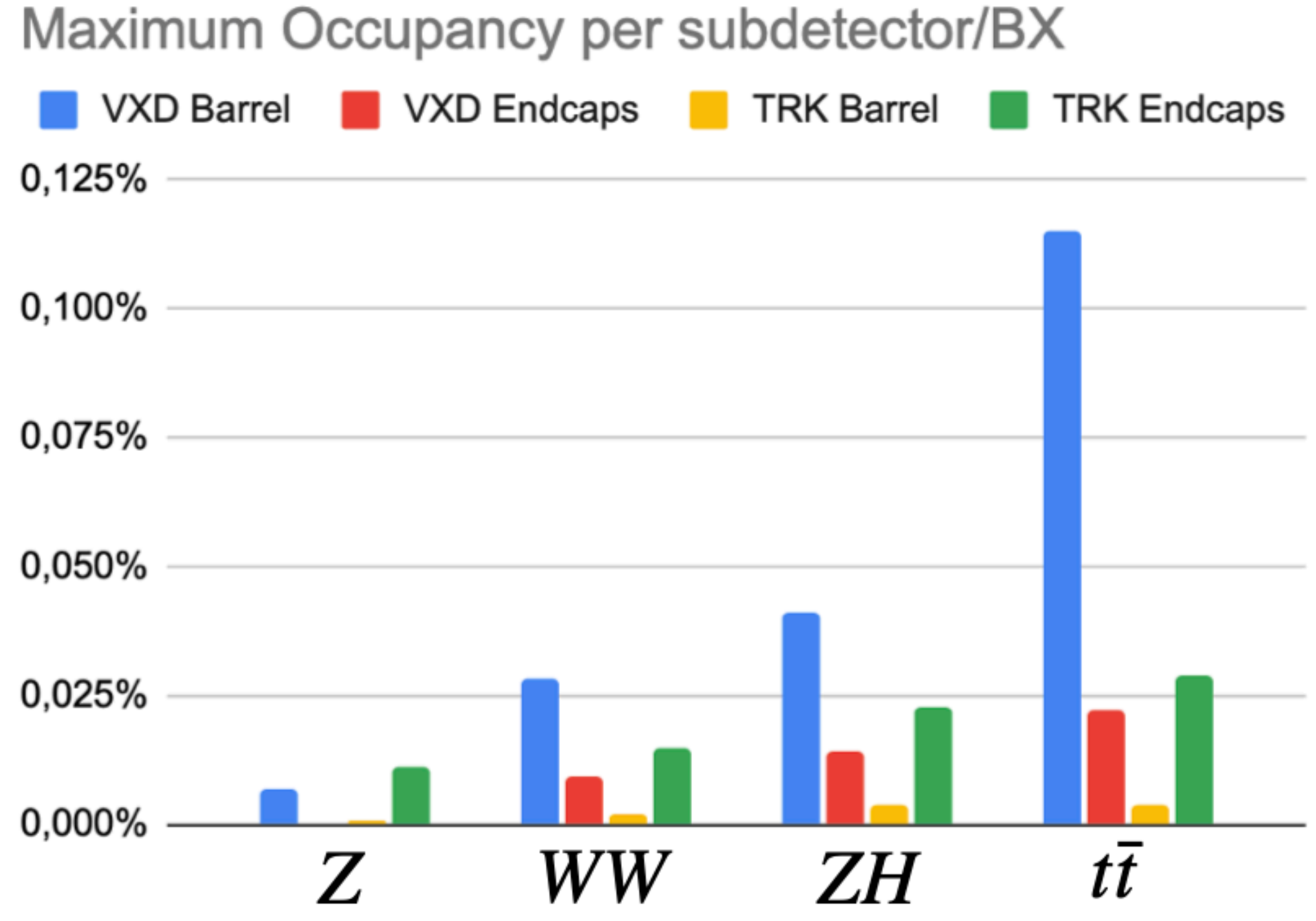
Electron-positron pair production @ FCC-ee - latest updates

- Updated studies of IPC with **new layout** (smaller-R beam pipe and vertex, 4 IP lattice, realistic field map including screening and compensating solenoids), **updated CLD detector** design (new VXD radii: L1 = 13 mm, L2=35 mm (L3=57mm)



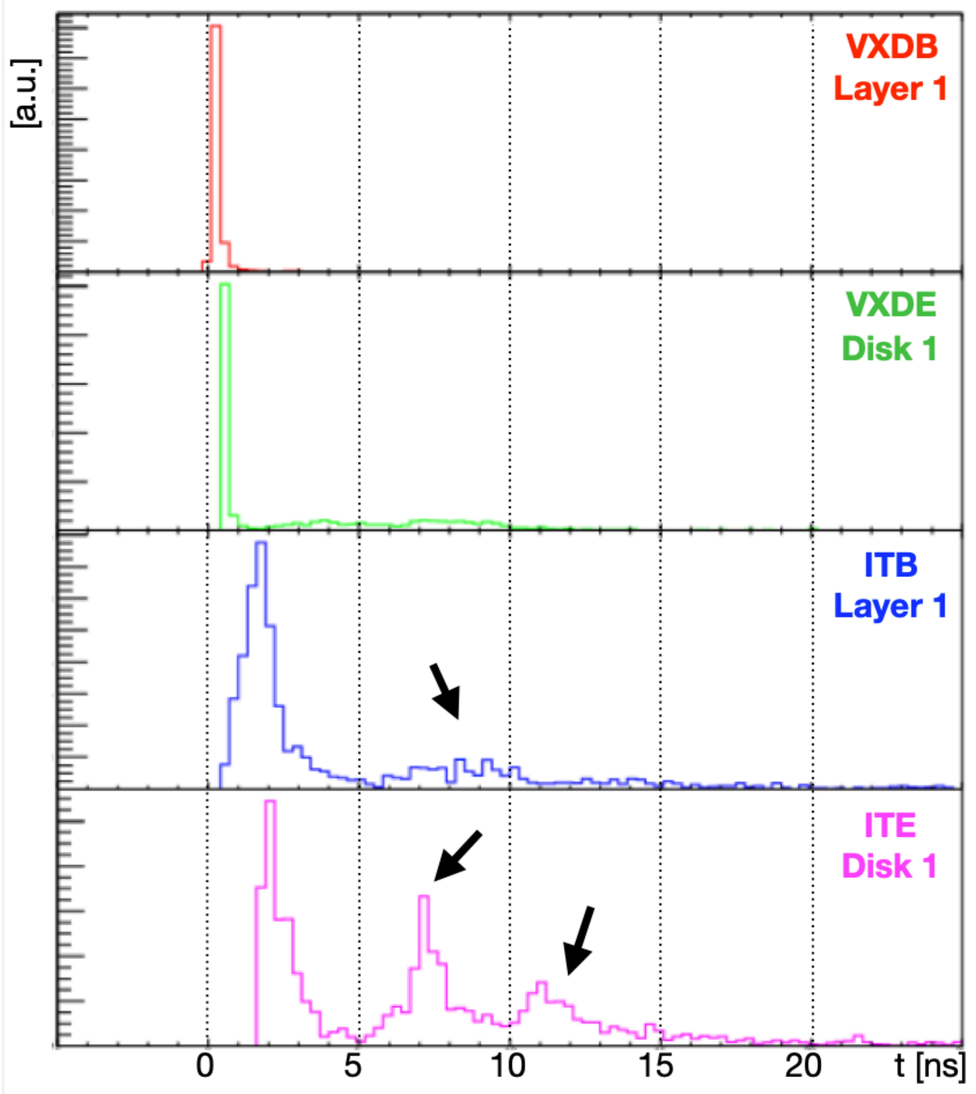
CLD Subdetectors: Trackers and Vertex





per BX

- No big impact from new lattice+anti-solenoids
- Occupancy <% everywhere, even with long 10us readout window, except VXDB @Z
- Non negligible fraction from backscattering, out of time - could be exploited offline for further bkg suppression



	Z	WW	ZH	Top
Bunch spacing [ns]	30	345	1225	7598
Max VXD occ. 1us	2.33e-3	0.81e-3	0.047e-3	0.18e-3
Max VXD occ.10us	23.3e-3	8.12e-3	3.34e-3	1.51e-3
Max TRK occ. 1us	3.66e-3	0.43e-3	0.12e-3	0.13e-3
Max TRK occ.10us	36.6e-3	4.35e-3	1.88e-3	0.38e-6

In readout window

Bkg @ FCC-ee: impact on calorimeters and luminometers

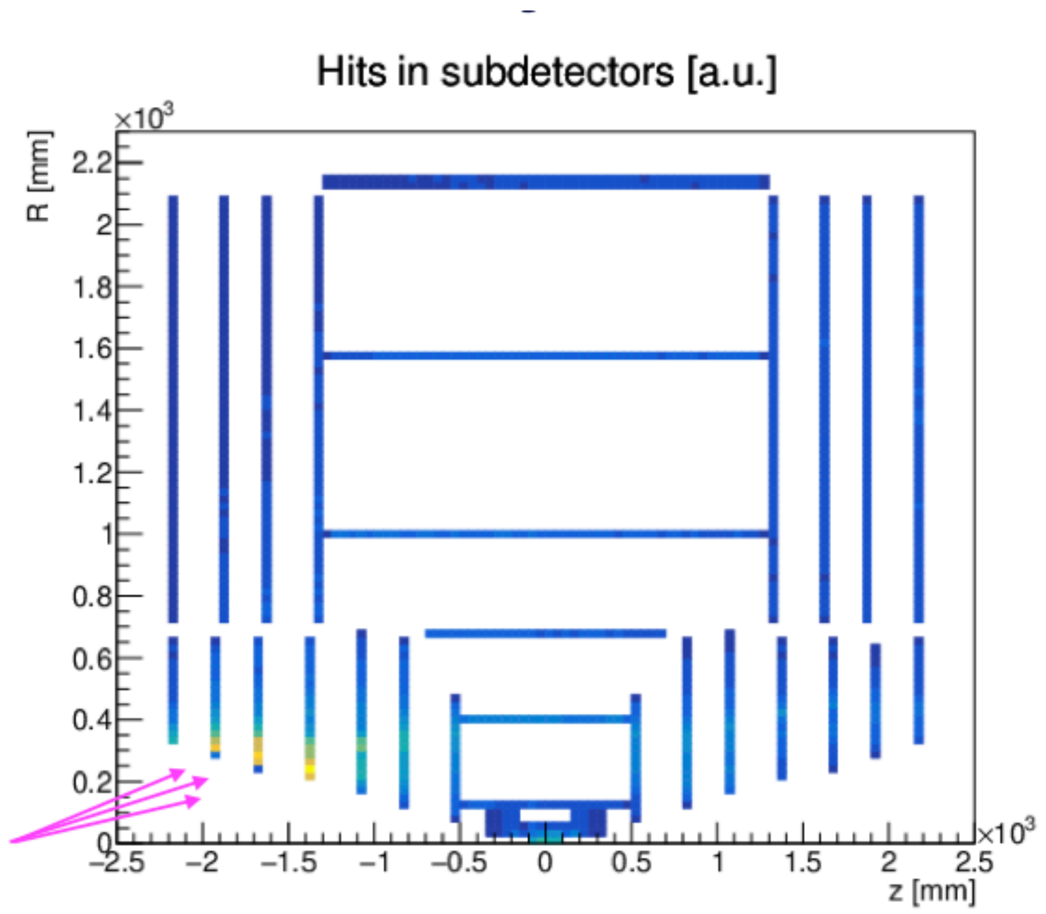
- **Central calorimeters**: not studied yet, as supposedly not impacted as significantly as vertex detector or very forward regions

- **Luminometers** in forward region:
    - **Synchrotron radiation**: @top (where highest) proposed beam-pipe shielding leads to 7 MeV/BX
    - **Incoherent pair production**: @Z 350 MeV/BX in each calo, mostly outside fiducial volume
        - Could be eliminated with thin layer of W **shielding** at inner radius of luminometers
    - Potential additional background from off-momentum particles from **beam-gas scattering** deflected by the quadrupoles
        - vacuum + shielding + coincidence => negligible rate compared to Bhabha

FCC-ee - other beam backgrounds

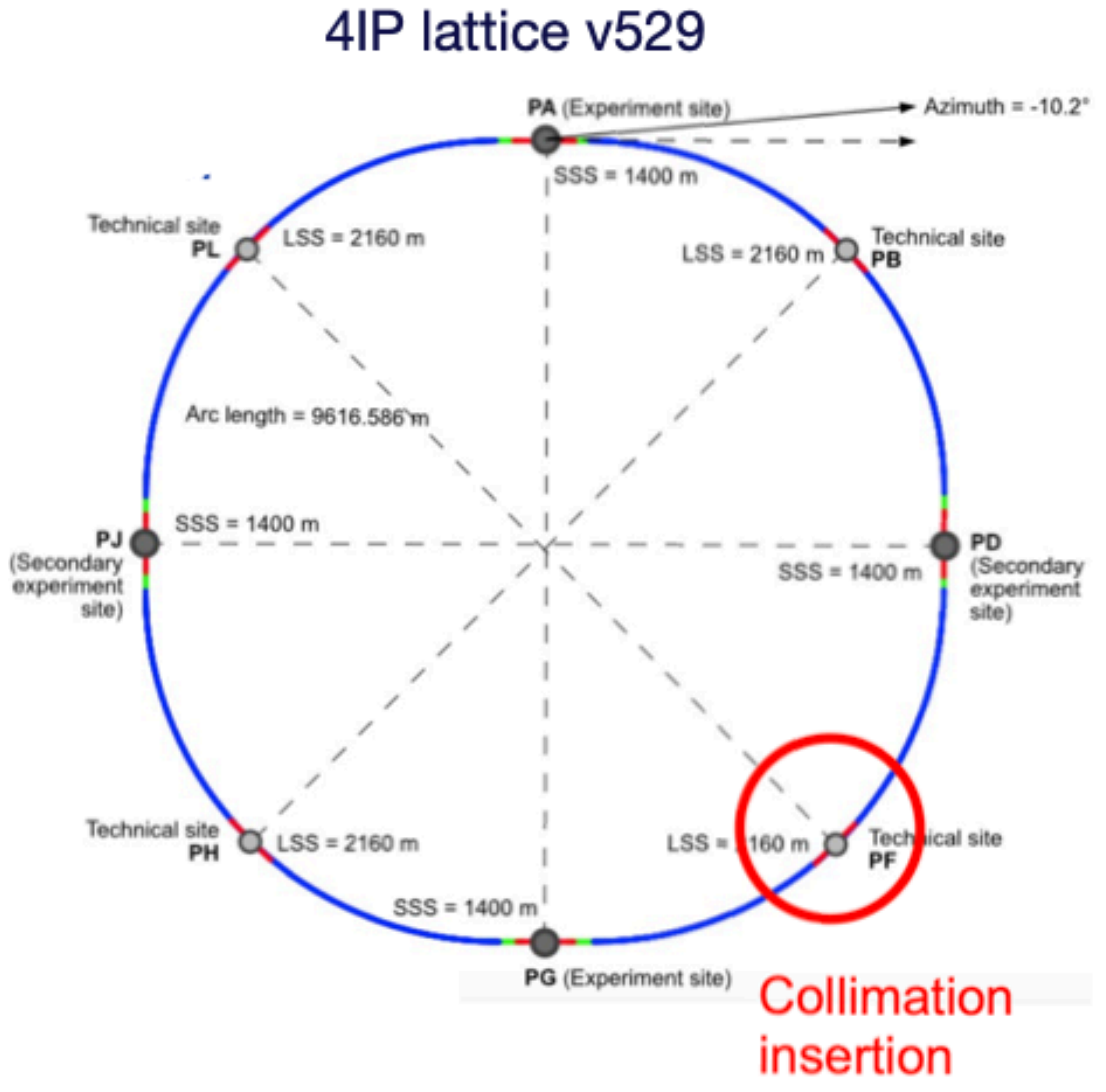
Very preliminary!

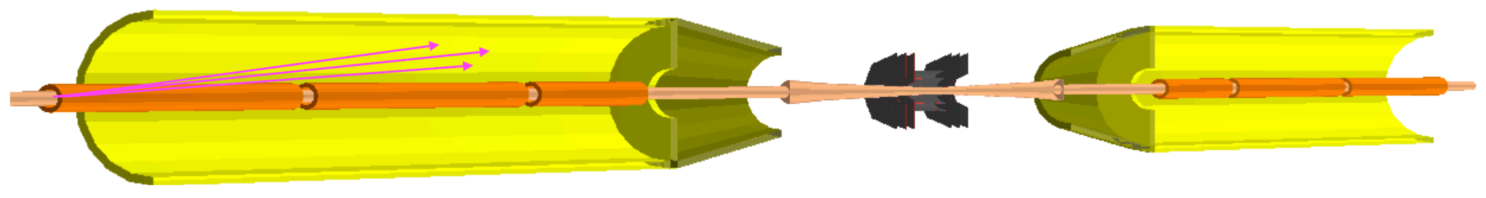
- **Beam losses on the horizontal primary collimator and the off-momentum collimators**
  - Dedicated halo collimation system in PF (two-stage betatron and off-momentum collimation in one insertion)
  - Bkg from halo losses at horizontal primary collimator mostly affects tracker endcaps



	Highest occupancy @Z	Highest occupancy @tt
IPA	0.02% (ITE)	5.73% (ITE)
IPD	< 0.01% (ITE)	3.99% (ITE)
IPG	< 0.01% (ITE)	3.16% (ITE)
IPJ	0.11% (ITE)	8.88% (ITE)

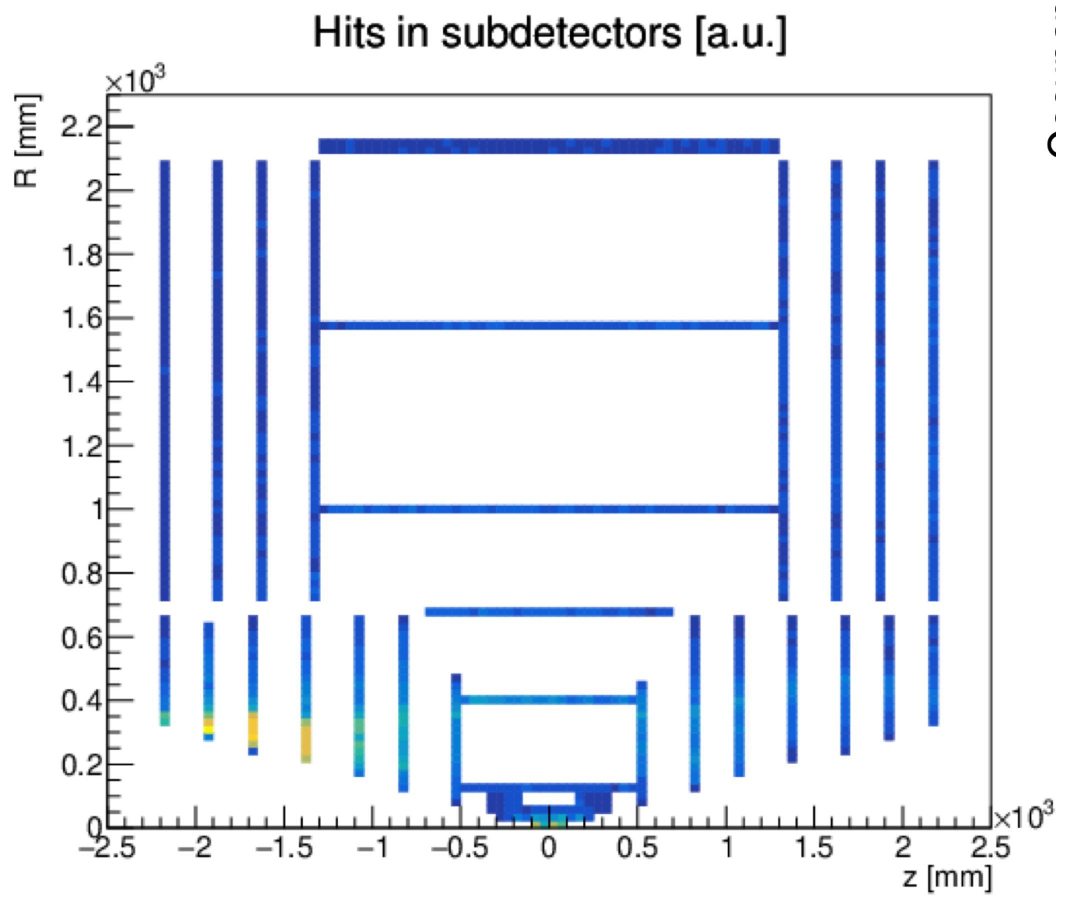
CLD Inner tracker endcap

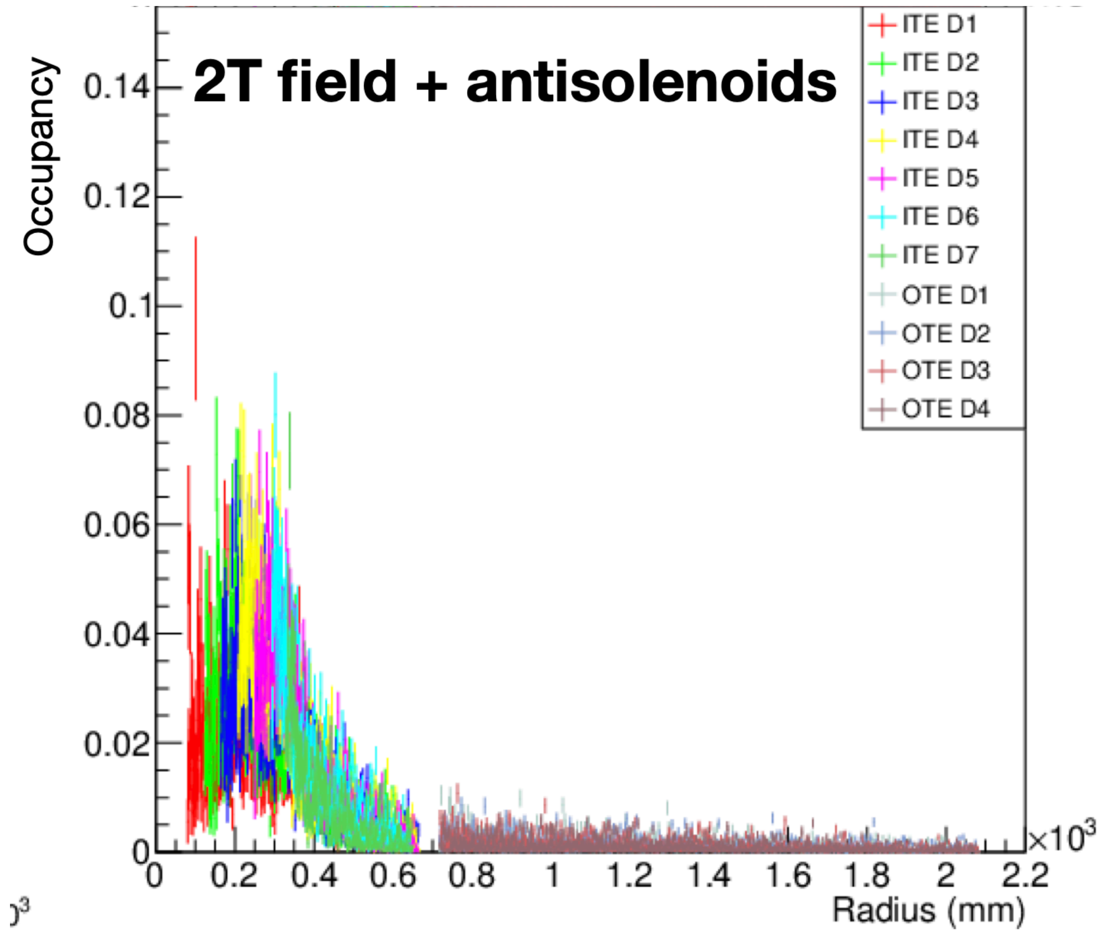




- Background @Z from losses at off-momentum collimator

	Losses per second (10^9)	Highest occupancy
IPA	0.15	< 0.01% (ITE)
IPD	0.24	0.01% (ITE)
IPG	182.10	14.54% (ITE)
IPJ	37.24	2.86% (ITE)

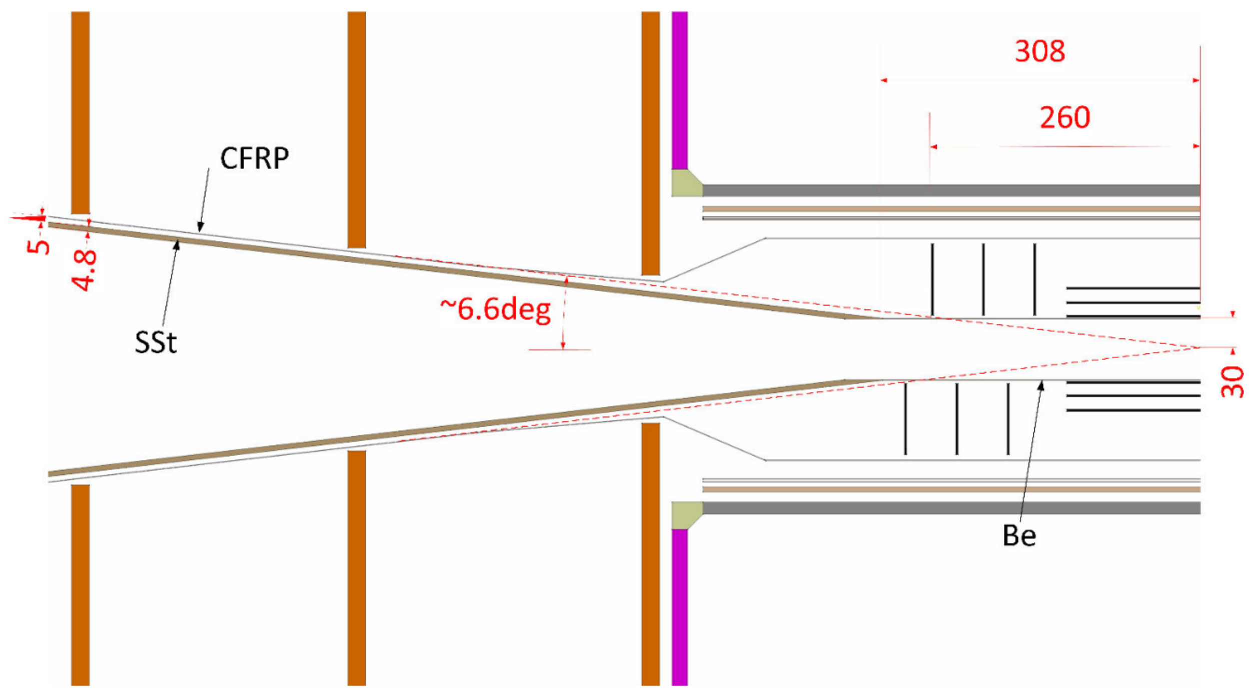


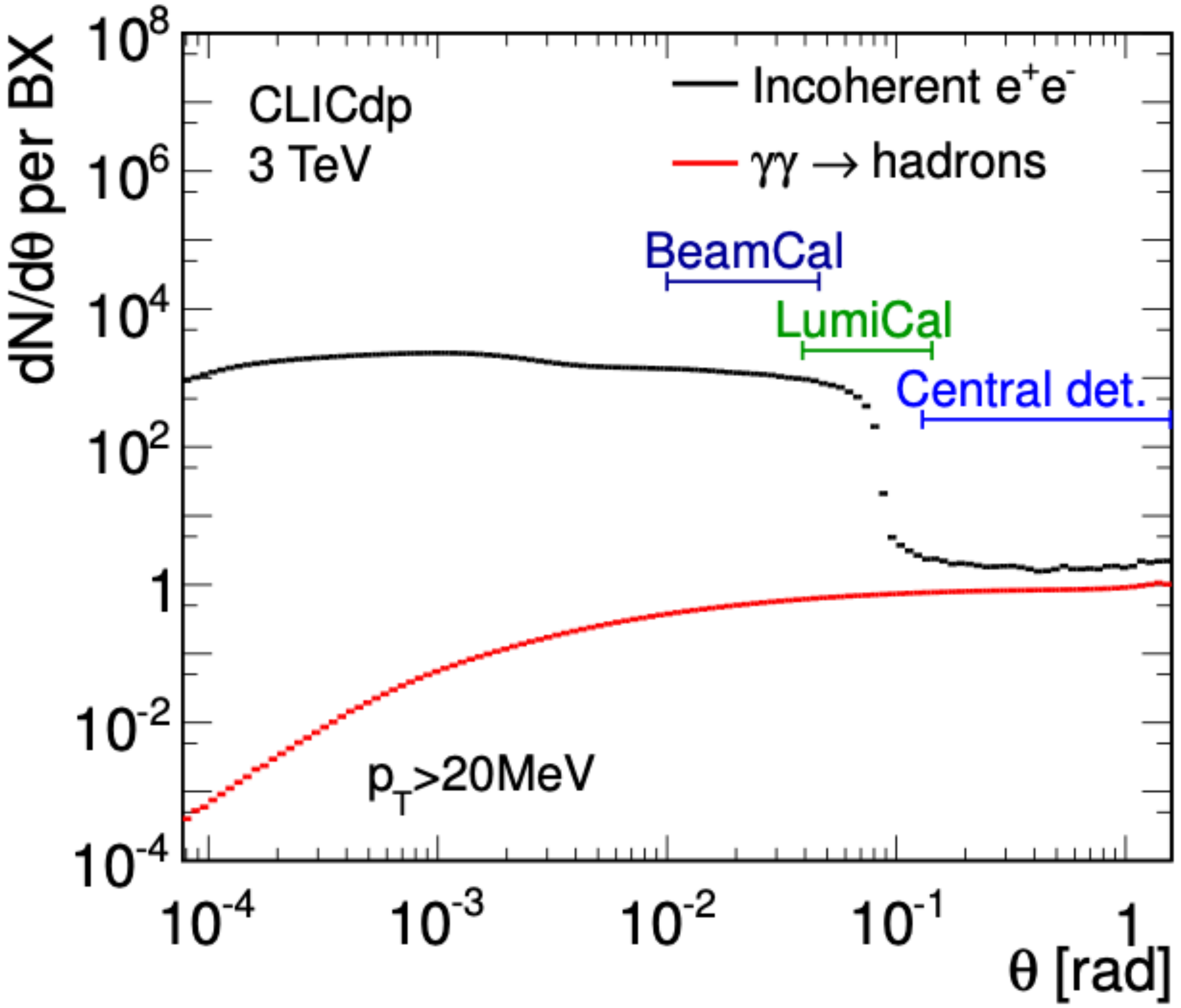


- Studies on bkg from top-up injections are starting

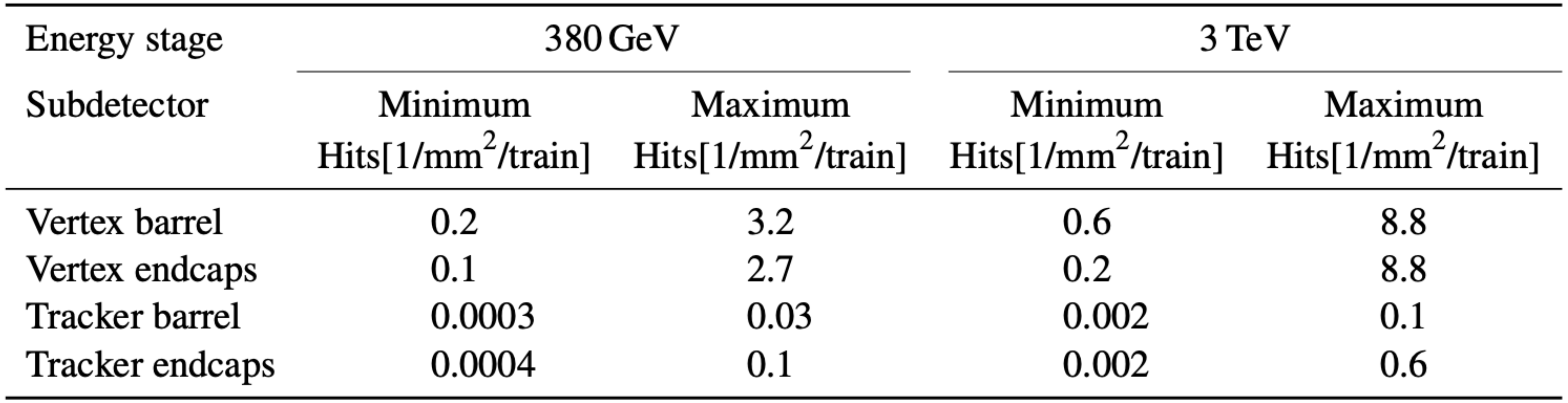
CLIC beam-related background (e^+e^-, $\gamma\gamma \rightarrow$ hadrons): impact on tracker

- Inner detectors are **shielded** from back-scattered particles originating in forward region by 4.8 mm thick steel walls of conical beam pipe sections. The walls point to the IP at an angle ~7°, which defines the forward acceptance of the tracking system.





Flux in trackers, with safety factors 5*e^+e^-, 2*$\gamma\gamma \rightarrow$had:



Energy stage	380 GeV		3 TeV	
Subdetector	Minimum Hits[1/mm^2/train]	Maximum Hits[1/mm^2/train]	Minimum Hits[1/mm^2/train]	Maximum Hits[1/mm^2/train]
Vertex barrel	0.2	3.2	0.6	8.8
Vertex endcaps	0.1	2.7	0.2	8.8
Tracker barrel	0.0003	0.03	0.002	0.1
Tracker endcaps	0.0004	0.1	0.002	0.6

=> **occupancy** for vertex (25x25 um^2 pixels) : < 2.8%/pixel/train
tracker (30x300 um^2 pixels) : < 0.6%/pixel/train

Radiation damage @ 3TeV:

- NIEL damage: 1MeV n_{eq} fluence at most 6e10 n/cm^{2}yr (inner layers)
- TID: up to 9 Gy/yr in inner layers
  - In general, fluences and doses much smaller than at LHC

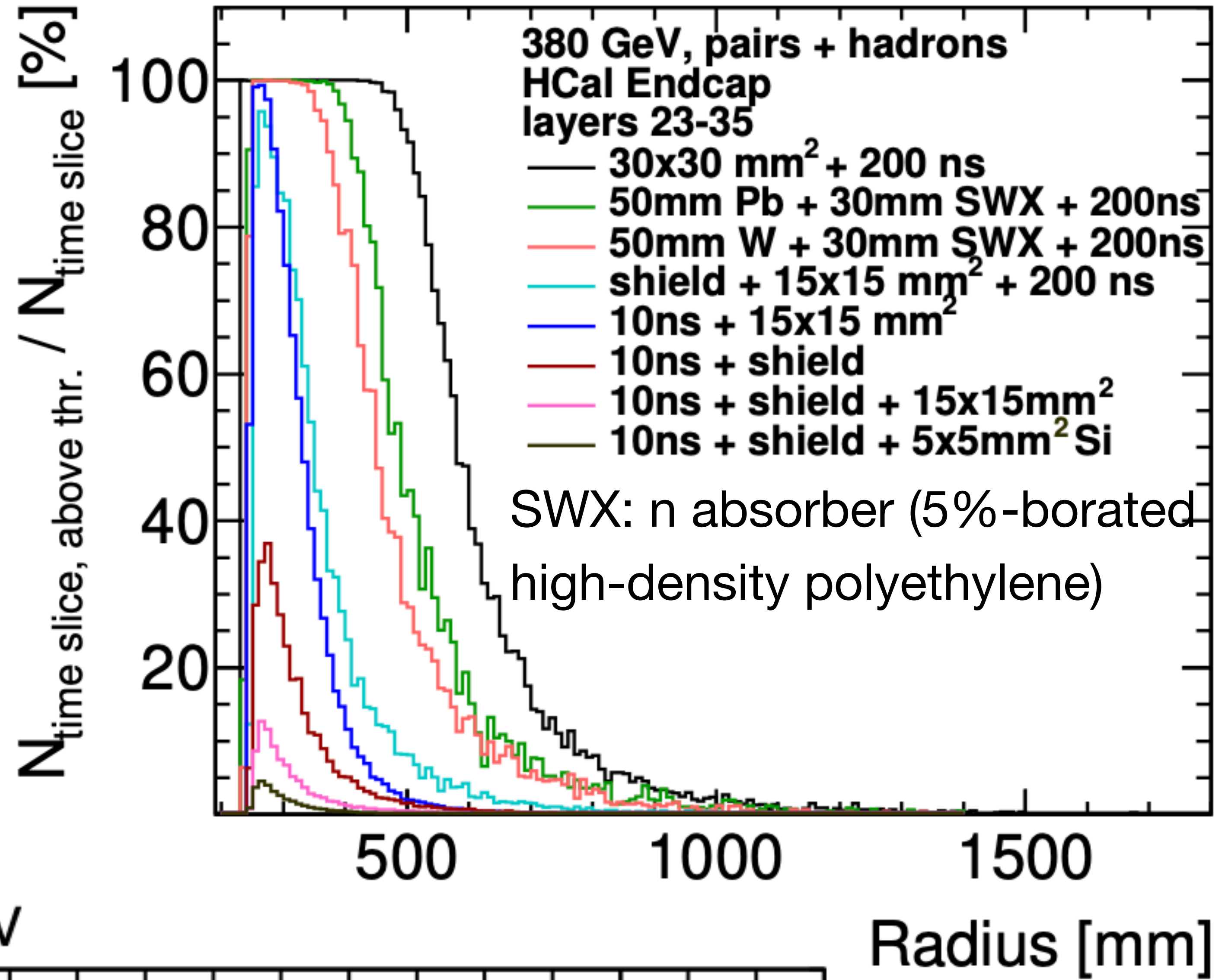
CLIC: impacts of e+e- and γγ→hadrons bkg on calorimeters

- **γγ→had** dominates bkg energy in **ECAL**, **IPC** (backscattered n from e± on BeamCal) in **HCAL**
- **Occupancy/train** (post-CDR, w/safety factors):
  - **Barrel** (no time slicing): ECAL < 1.8% (5x5 mm² cells), HCAL < 0.8% (3x3 cm² cells)
  - **Endcap** (assuming 25ns slicing):

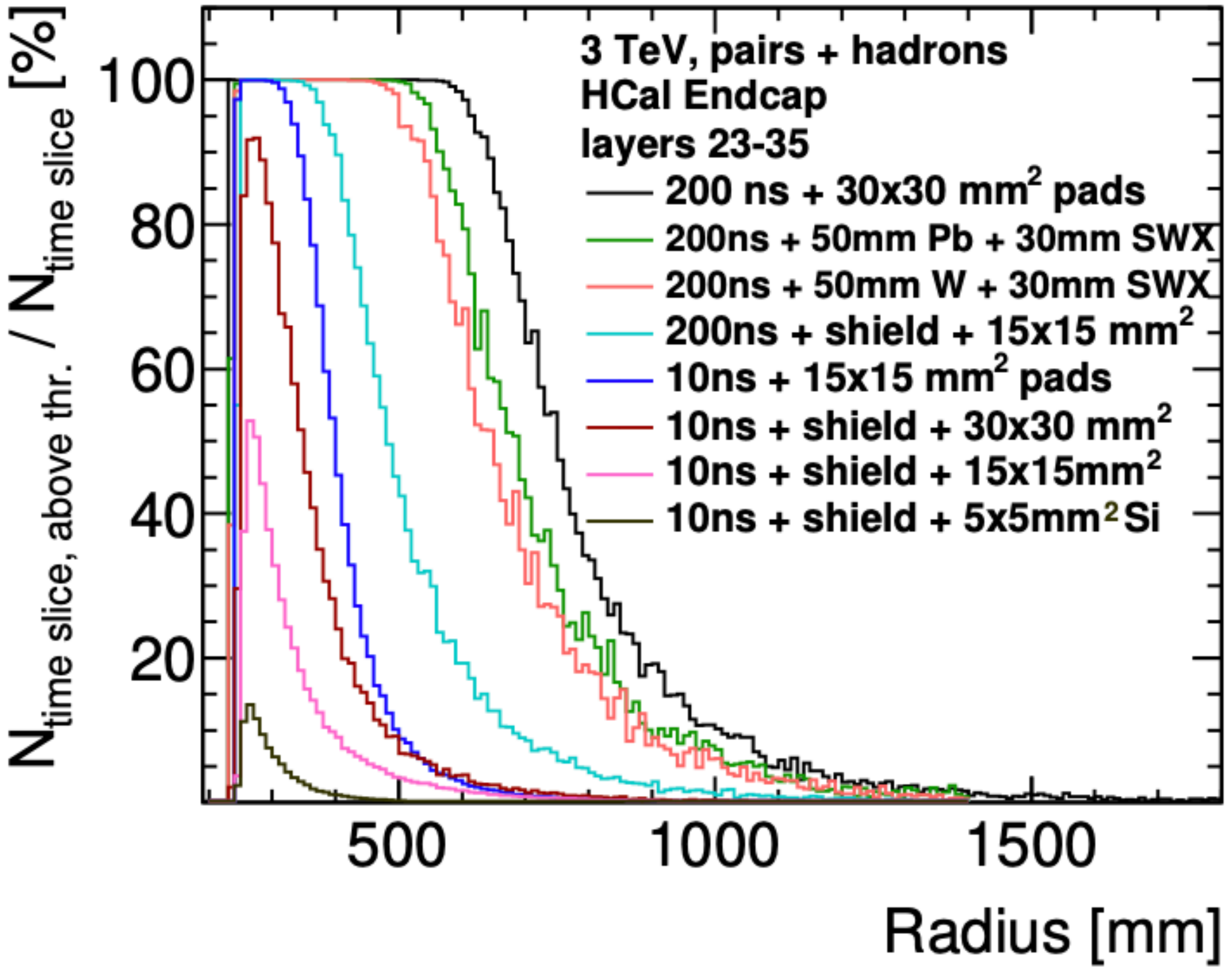
	380 GeV		3 TeV	
	max [%]	average [%]	max [%]	average [%]
ECal	1.7	0.1	7.1	0.3
HCal	100	1.6	100	2.7

    - ECAL barrel max occupancy ~30% at lowest R with 200 ns readout ⇒ timestamping
    - HCAL: reduction of occupancy from back-scattered neutrons possible from redesign of fwd region (shielding) / detector (more granularity in space / timestamping)
- **Energy/train** (post-CDR, no safety factors)

	380 GeV		3 TeV	
	pairs [TeV]	γγ → hadrons [TeV]	pairs [TeV]	γγ → hadrons [TeV]
ECal barrel	0.1	0.1	0.4	1.9
ECal endcap	0.2	0.2	0.7	5.0
HCal barrel	1.6×10^{-3}	6.8×10^{-3}	7.5×10^{-3}	0.2
HCal endcap	75.3	0.1	310.4	7.7
Total calorimeter	75.6	0.4	311.5	14.8


CLIC 380 GeV

SWX: n absorber (5%-borated high-density polyethylene)


CLIC 3 TeV

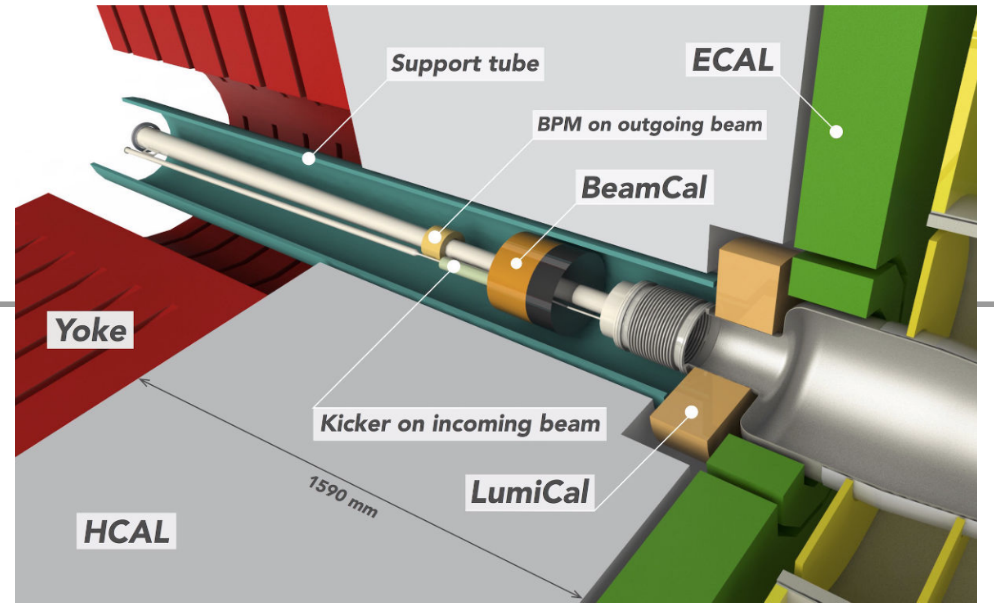
CLIC: impacts of bkg on very forward calorimeters

- Direct hits from **coherent pair production** (CPC) avoided by adopting conical vacuum pipe with half opening angle of 10 mrad for outgoing beam pipe (coherent pair production very focused around beam direction)

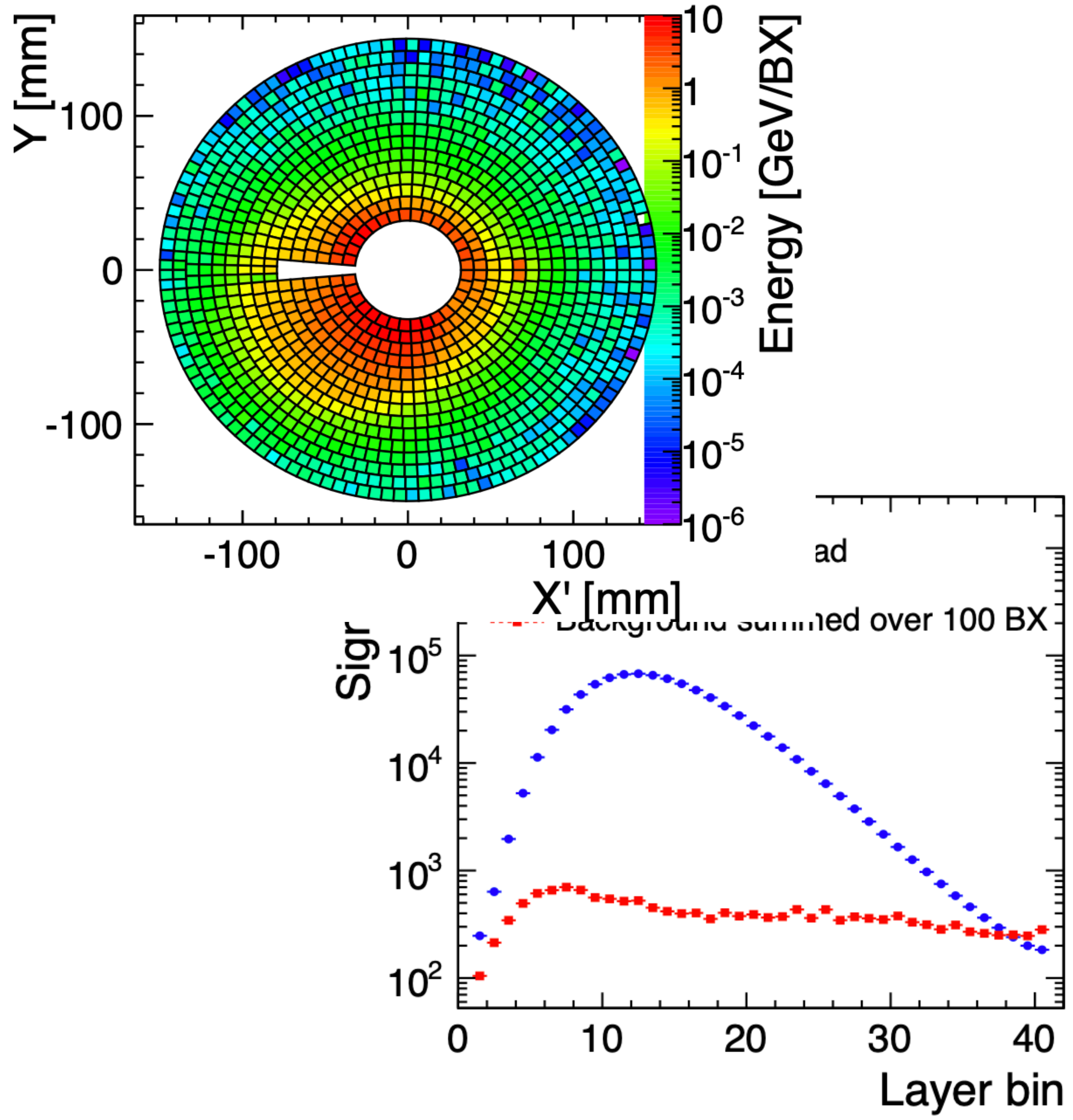
- Very high rates from **incoherent pair production** (IPC) that are less focused

Energy stage	380 GeV		3 TeV	
Subdetector	Incoherent pairs [GeV/train]	$\gamma\gamma \to$ hadrons [GeV/train]	Incoherent pairs [GeV/train]	$\gamma\gamma \to$ hadrons [GeV/train]
LumiCal	68.5	4.5	283	193
BeamCal	54 730	5.6	270 600	540

- **Occupancy:** very large in both LumiCal (~90%/pad/train with pads of 3.75 mm x 13-44 mm) and BeamCal (100%/pad/train with pads of 8x8 mm^2) ⇒ granularity (pixels?), timing (fast readout)
- **Dose**: max in BeamCal: TID 7 MGy/yr, NIEL up to 1.4e14 n_{eq}/cm^{2}yr ⇒ rad hardness
- Side-effect: IPC impact on BeamCal produce **backscattering into inner detectors** e.g. vertex ⇒ **optimise geometry** to reduce amount of backscattered particles to **negligible** compared to bkg from IP:
    - low-Z absorber coating on IP side of BeamCal
    - Increase diameter of vacuum pipe wherever possible
    - Increase mask of conical part of vacuum pipe on IP side of LumiCal



LumiCal	Acceptance [mrad]	39—134
	Z (start) [m]	2.5
	Number of layers (W + Si)	40
BeamCal	Acceptance [mrad]	10—46
	Z (start) [m]	3.2
	Number of layers (W + Si)	40
	Graphite layer thickness [mm]	100



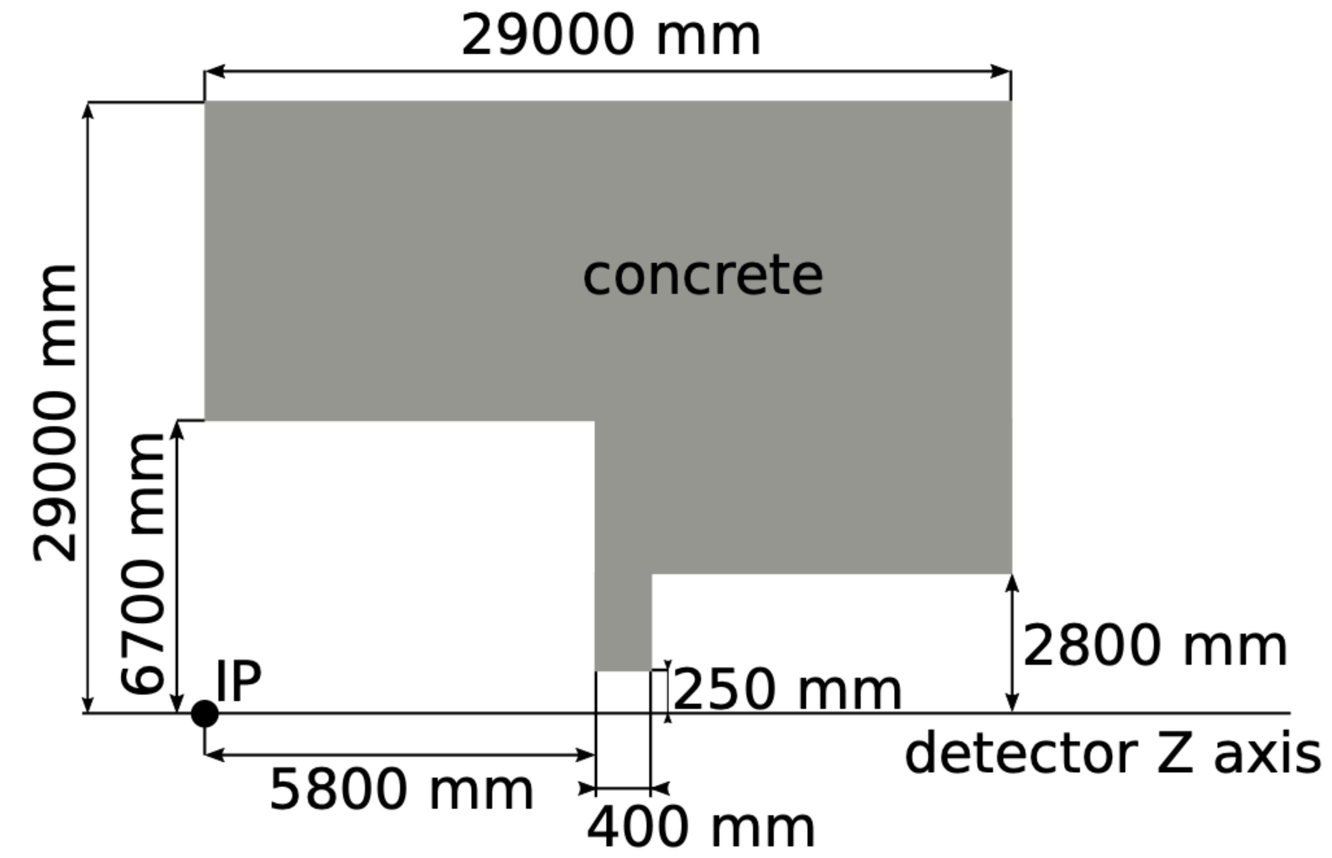
CLIC: impacts of bkg on muon system

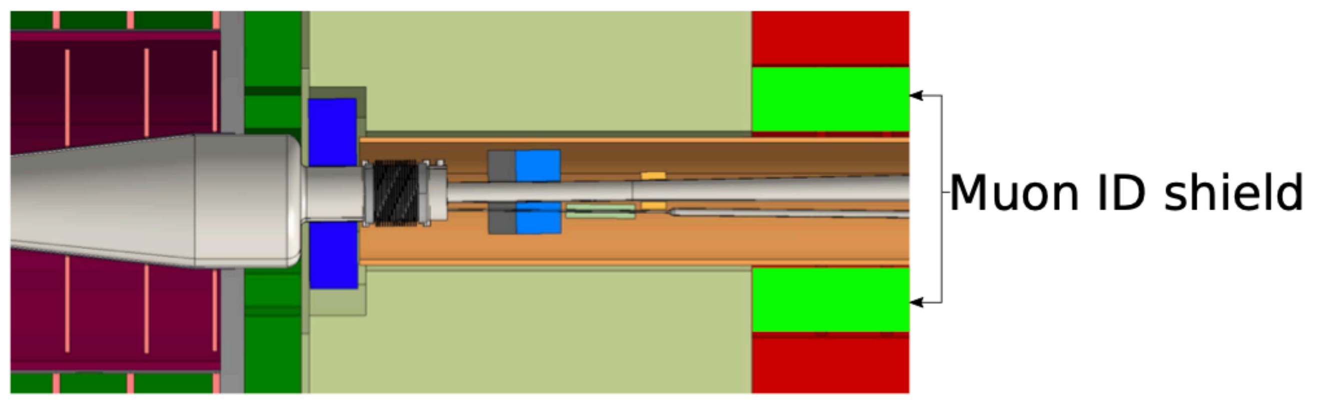
- Muons from inelastic collisions of beam halo with collimators also included in calculations/simulations

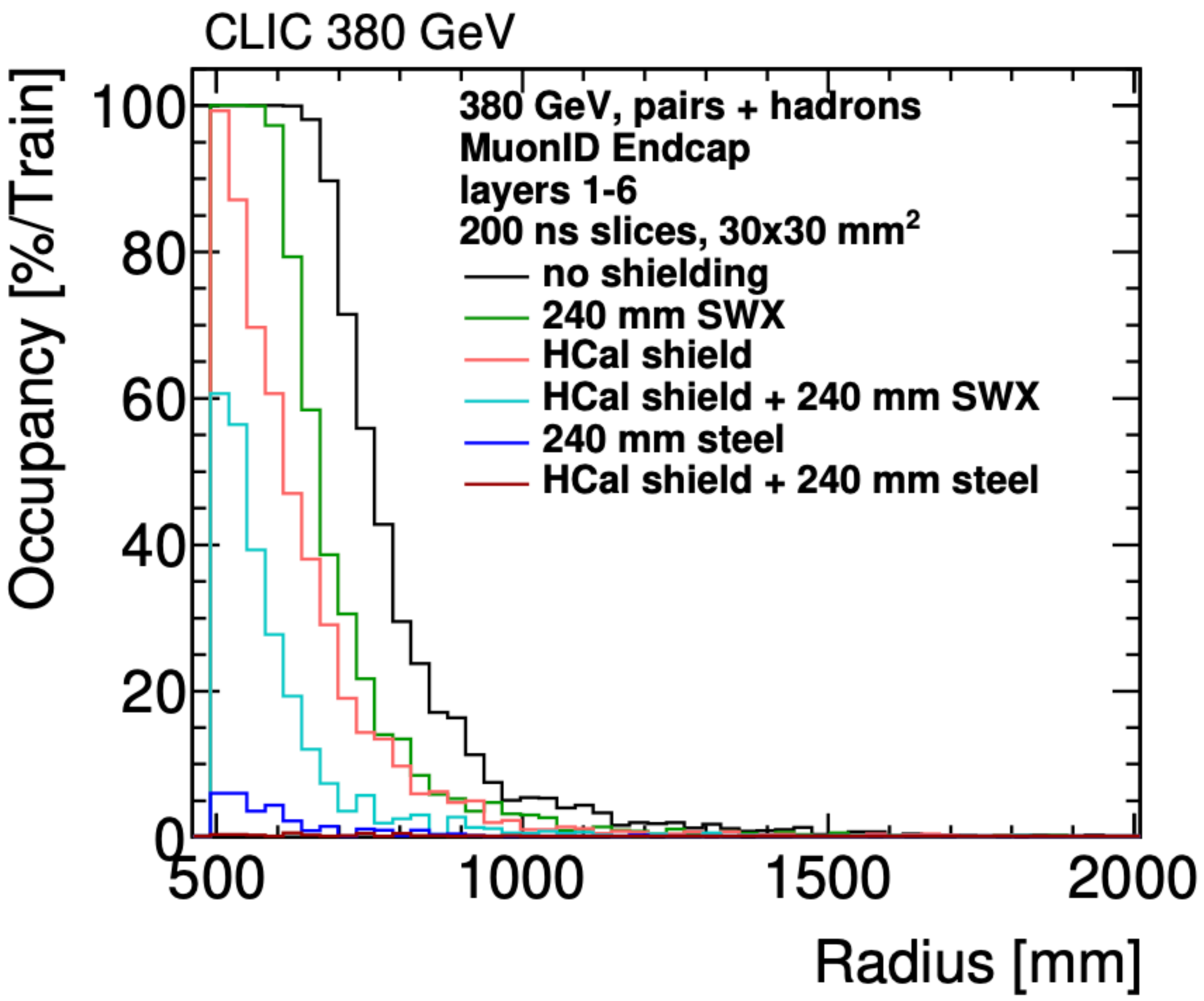
- With pad readout of (RPCs) of 30x30 mm^2, no time slicing:
  - **Occupancy/train in barrel** < 1%
  - **Occupancy/train in endcap** as high as 100% in inner radius of endcap yoke

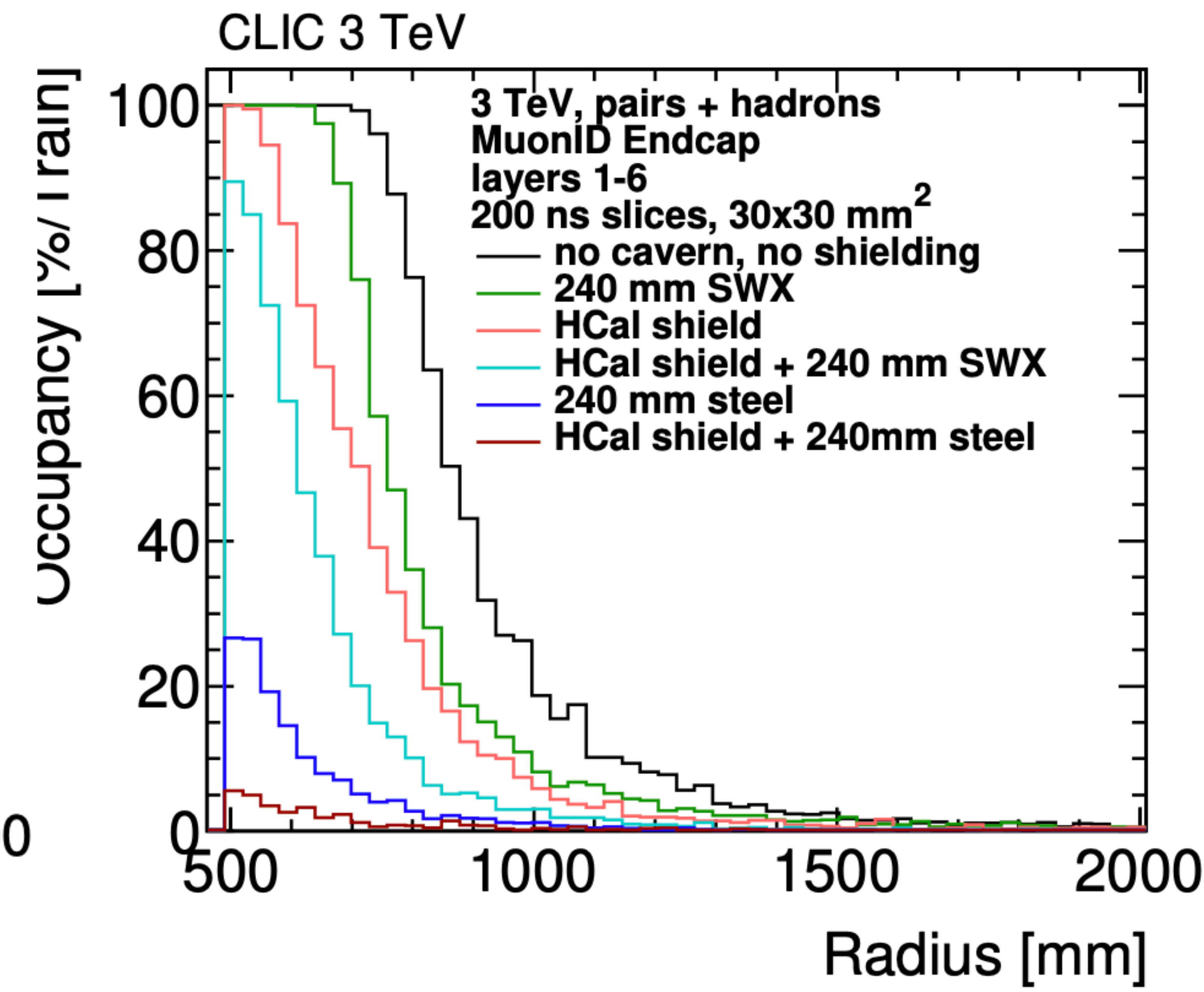
	380 GeV		3 TeV	
	max [%]	average [%]	max [%]	average [%]
Layer 1	100	1.05	100	1.65
Layer 2	100	1.06	100	1.67
Layer 3	100	1.00	100	1.63
Layer 4	100	0.93	100	1.51
Layer 5	100	0.93	100	1.52
Layer 6	100	1.14	100	2.06

➡ Can be mitigated with shielding (and further with more granularity)









Backgrounds in ILD-like TPC @ Z-pole

- ILC sits in a "sweet spot" (250-500 GeV) where bkg are not as demanding as @ Z-pole or at 3 TeV
    - Si tracking / muon detector / sandwich calorimeter technologies for CLIC also well adapted to ILC
- "Relaxed" constraints of ILC environment also favourable for use of a TPC for tracking
- However, ILC detector concepts are being evaluated for use @FCC-ee => severe constraints on TPC due to **I**on-**B**ack**F**low:
    - Ions produced copiously in amplification device, a fraction flows back to drift space and drifts very slowly, leading to positive charge that accumulates and gives rise to space charge that distorts E field
- Recent study uses **e+e- beamstrahlung pairs from FCC-ee simulations** (100 BX @Z) to assess **impact on TPC** with Geant4

- ILD_l5_v02 with 2T field
- FCCee_o1_v04 with silicon tracking replaced by TPC
- ILD TPC only in 2T field

	primary ions / "event"	event rate	primary ions / 0.44 s "TPC frame*"
Z_had ILD_l5_v02 @ 2T	1.27M	54 kHz	30 x10^9
pairs ILD_l5_v02 @ 2T	75 k	33 MHz	1100 x10^9
pairs ILD TPC only @ 2T	15 k	33 MHz	220 x10^9
pairs FCCee w/ TPC	0.43 M	33 MHz	6200 x10^9

* maximum ion drift time in TPC = 0.44s

→ distortions in r-phi due to ions from hadronic Z decays can be up to O(100) μm, but are stable to O(1) μm [studied for IBF=1]

beamstrahlung gives ~200x more TPC primary ions than hadronic Z decays

forward region plays a very important role
room for optimisation ?

Conclusions

- Careful accelerator design reduces the constraints on detectors
- Remaining constraints exist in terms of granularity / time stamping / read-out … but no showstopper so far
- Radiation hardness should not be an (or a big) issue, at least for the sensors
    - Detailed radiation maps are / will be available => feasibility of using COTS electronic equipment can also be assessed
- Numbers evolve in parallel with updates of accelerator (& detector) designs as well as with improvements in reconstruction software
    - Particularly for less mature projects such as the circular e+e- machines