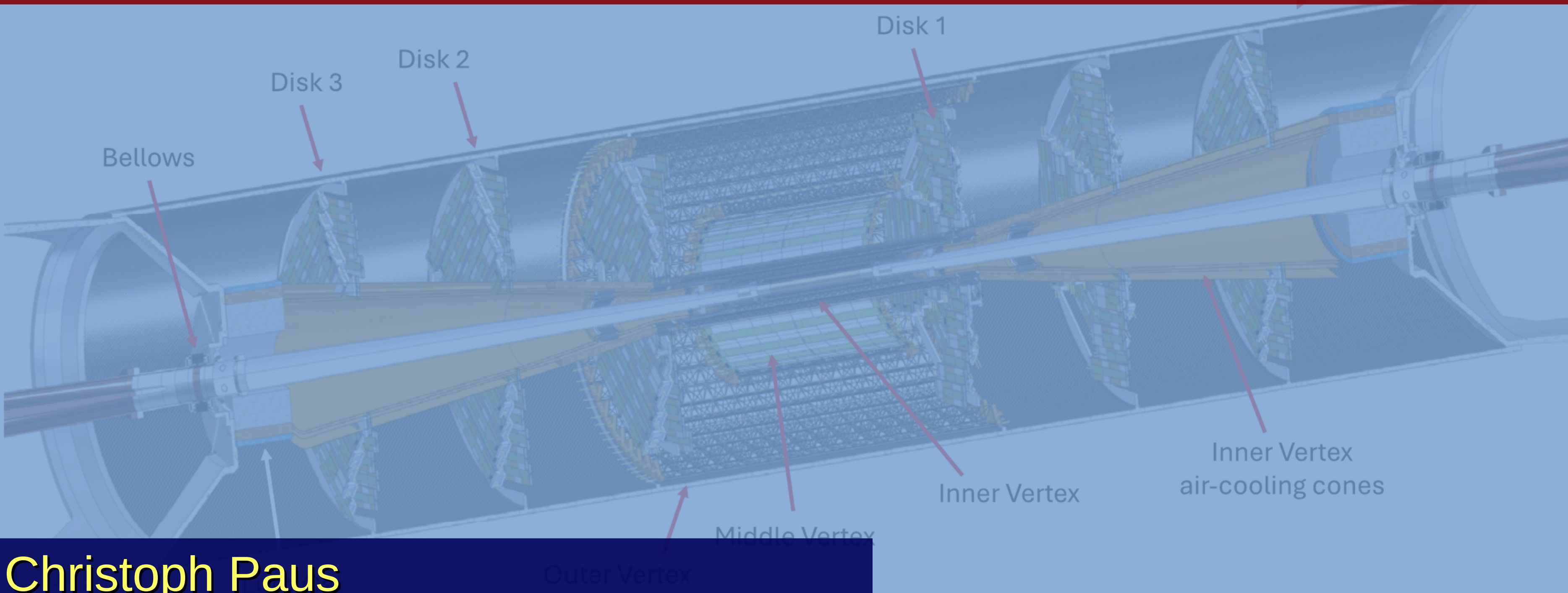
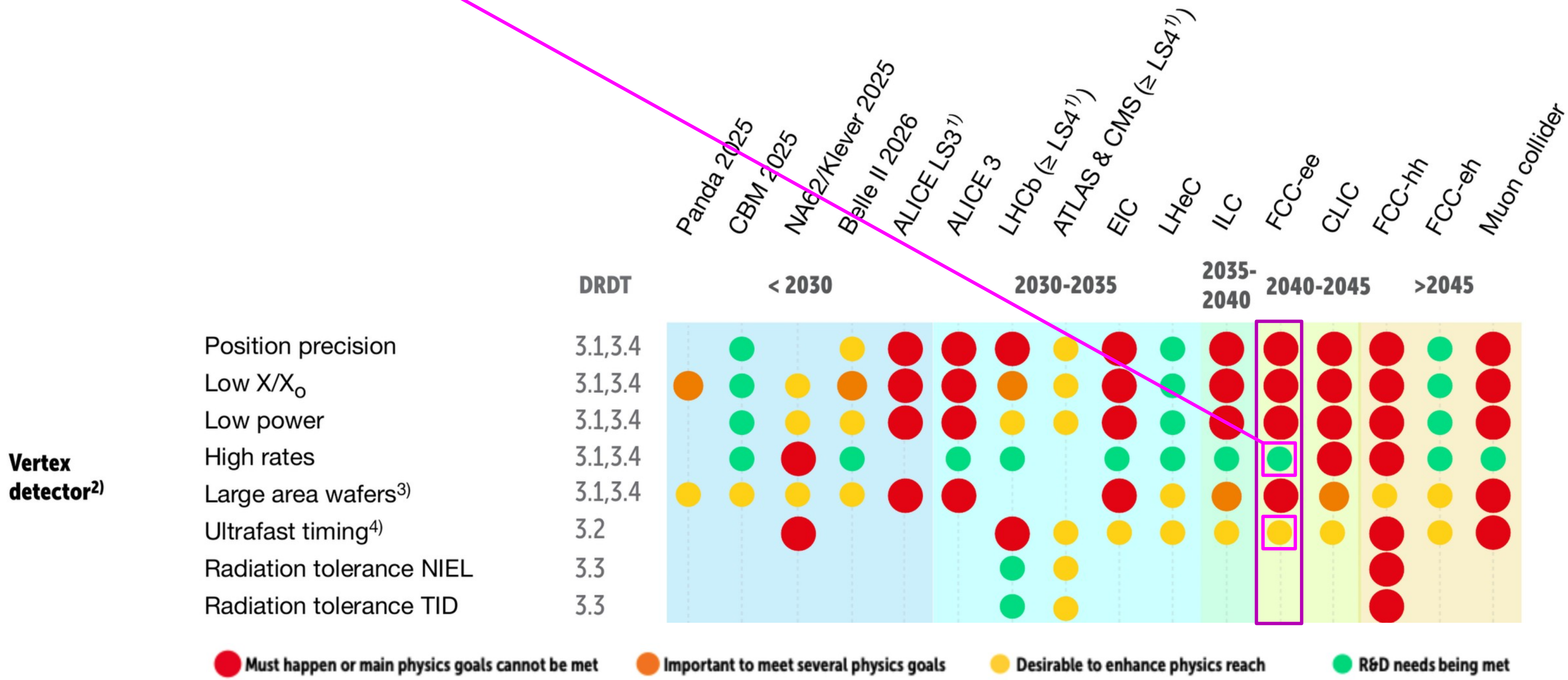
Trigger/Triggerless Impact



Christoph Paus
October 30-31, 2025, Pisa, Italy
FCC-ee vertex detector R&D workshop

Do we need a trigger?

Requirements on data density
are not extreme



ECFA Detector R&D Roadmap Process Group. The 2021 ECFA Detector Research and Development Roadmap. Technical report, Geneva, 2020.

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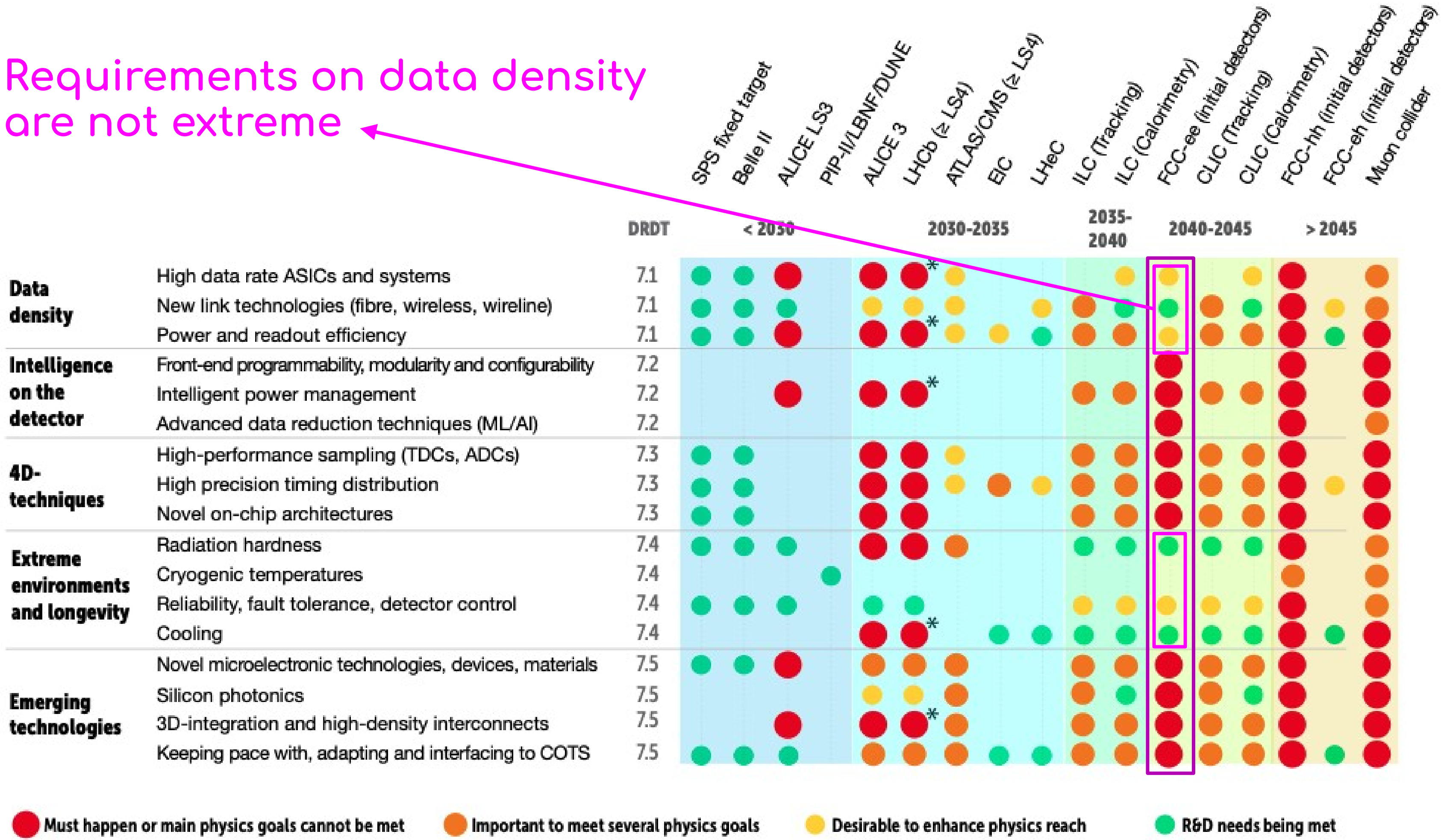

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Do we need a trigger?

Physicists do not like triggers! → want to look at everything

- Computing people love triggers … less data to deal with
- LEP: multi-level, yet minimal trigger system → ‘should’ be good for FCC-ee
- LHC: there is no life without a sophisticated trigger system
- FCC-ee: higher precision / better control needed, can we maybe stream?

Top down approach

Let’s work with some assumptions

G.Ganis talk Jan 2025

- BX rate is about ~40 MHz at the Z pole (lower anywhere else)
- Physics events about 100 kHz and assume Z→ hadrons: ~1.1 MB; Z→ll: ~0.1 MB
- Remember: Z→hadron (20 charged, 10 neutral), Z→ll 2 charged
- This means on average one event in 400 BX, and about 2 pileup events in 1000 events
- Total event rate is about 100 GB/sec (CMS writes a third of that in HL-LHC)
- Also assume MC is about same size as data and we should have $n_{MC} \sim 10 \times n_{data}$

What is the problem?

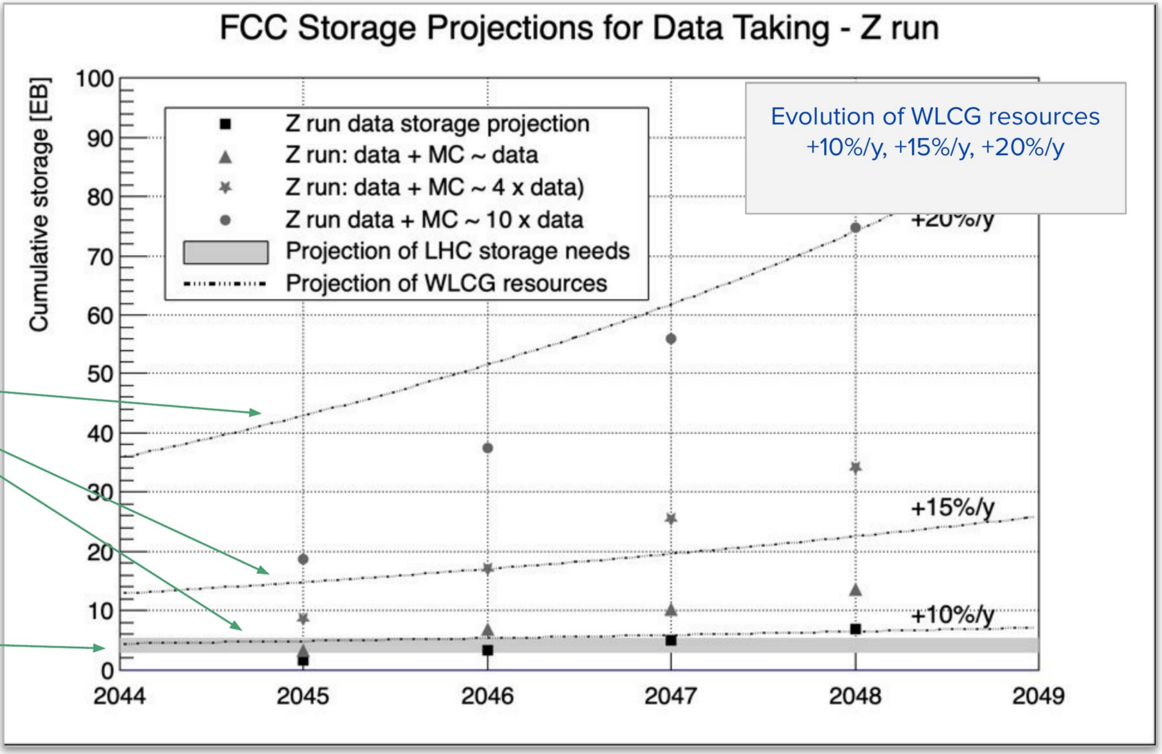
FCC-ee parameters		Z	W^+W^-	ZH	ttbar
√s	GeV	91.2	160	240	350-365
Luminosity / IP	10^{34} cm^{-2} s^{-1}	**140**	20	7.5	1.5
Bunch spacing	ns	25	160	680	5000
"Physics" cross section	pb	35,000	10	0.2	0.5
Total cross section	pb	70,000	30	10	8
Event rate	Hz	**100,000**	6	0.5	0.1
"Pile up" parameter [μ]	**10^{-6}**	2,500	1	1	1

J. Bracinik @ FCC week May ‘25

Projecting to 4 year Z runs

Illustrative Storage Projection for Z Run

4 experiments
4 equal runs {2045, 2046, 2047, 2048}



Evolution of WLCG resources
+10%/y, +15%/y, +20%/y

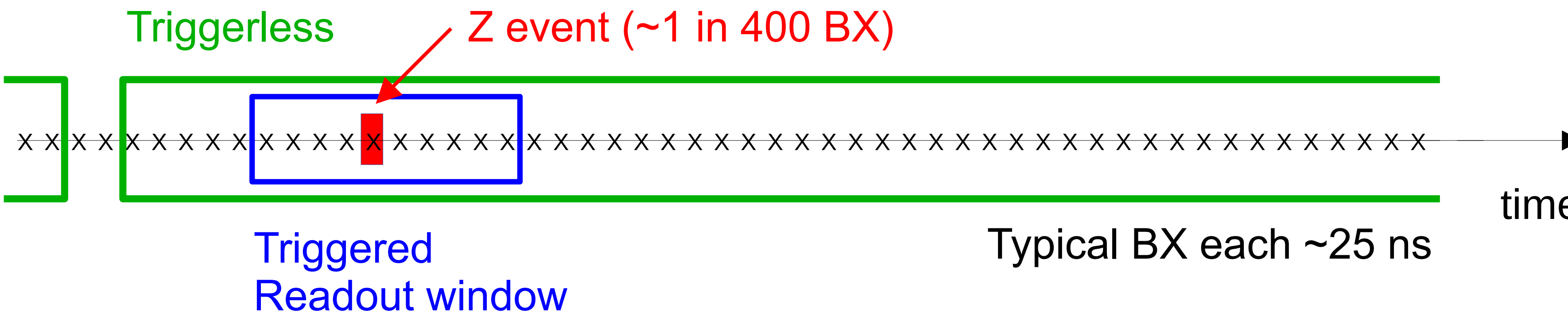
(starting point: 500 PB in 2020 ≈ ATLAS+CMS + 10%)

LHC at the end of HL (≈ 5 EB)

G.Ganis talk Jan 2025

Bottom up approach?
Estimate size of BX

Triggerless versus Trigger



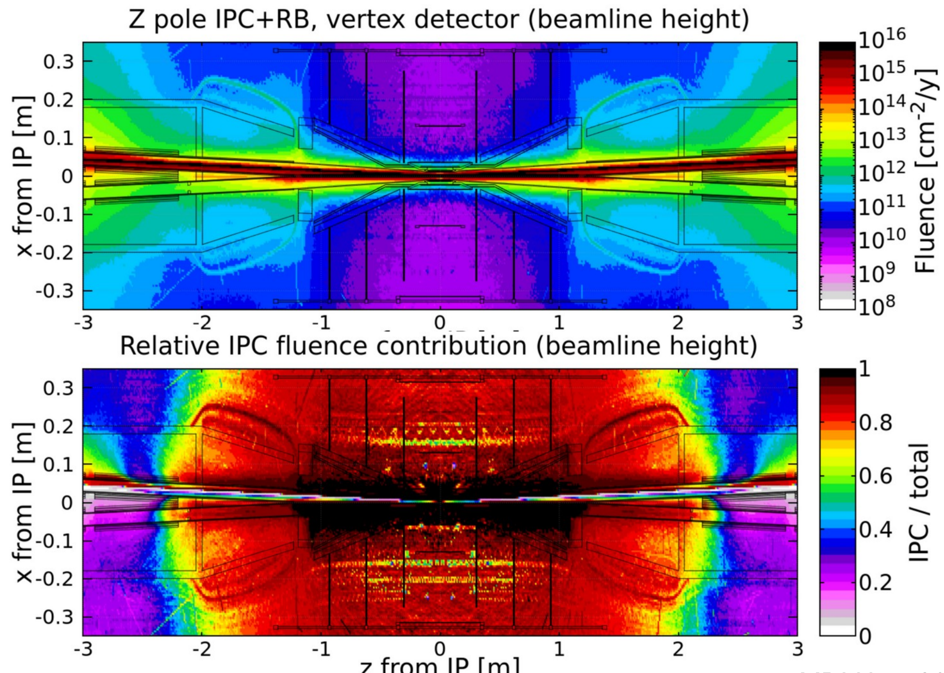
Questions to figure out

- How large is a Z collision event (hadrons versus, electrons, muons)?
- How large is an ‘empty’ beam crossing (BX) event?
  - Core unit to calculate triggerless overhead
- How large is the integration window?
  - Determines overhead: tracker ex. 200 ns ~ 8 BX versus 400 BX
- How much dead time is there after readout?

Beam Induced Background (BIB)

Various sources contribute

- Single beam induced
  - Synchrotron radiation, Beam gas, Beam halo loss, Injection backgrounds, instabilities, ...
- Beam beam interactions (luminosity backgrounds)
  - **Incoherent Pair Creation (IPC), Radiative Bhabhas (RB),** Beam Strahlung, Two photons (hadron, muon, electrons)



Overall impression

- Occupancy drops sharp outside the vertex tracker
- 3-6 orders of magnitude

BIB: what dominates?

- Barrel by far IPC
- Endcaps: RB makes a dent

Study IPC in detail

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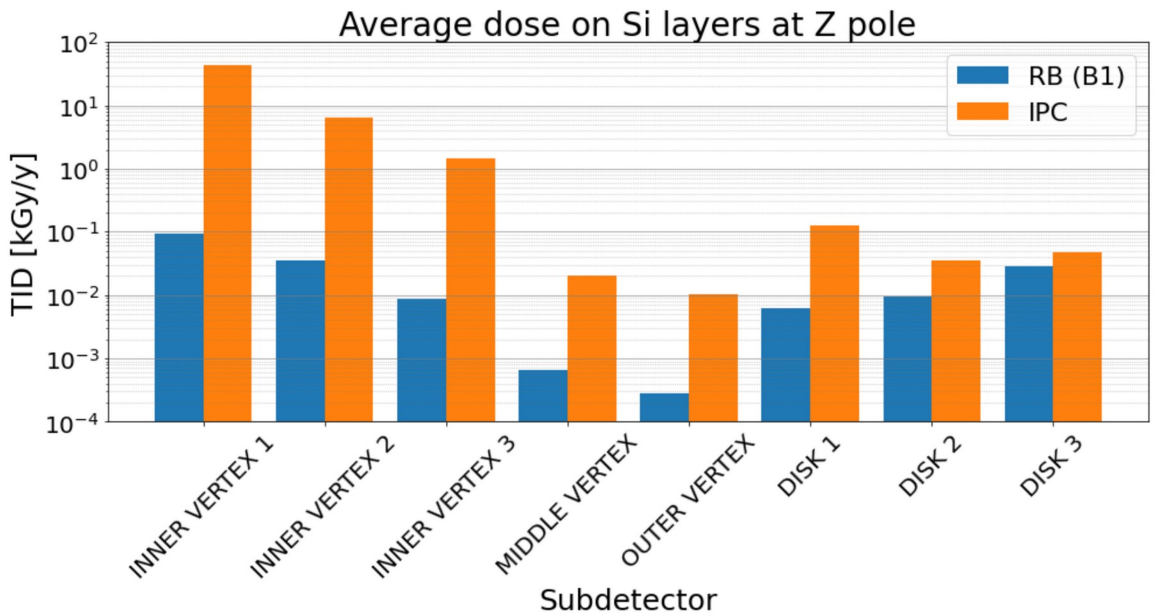

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Study IPC in detail

Other BIB can become important for other subdetectors.

Example:

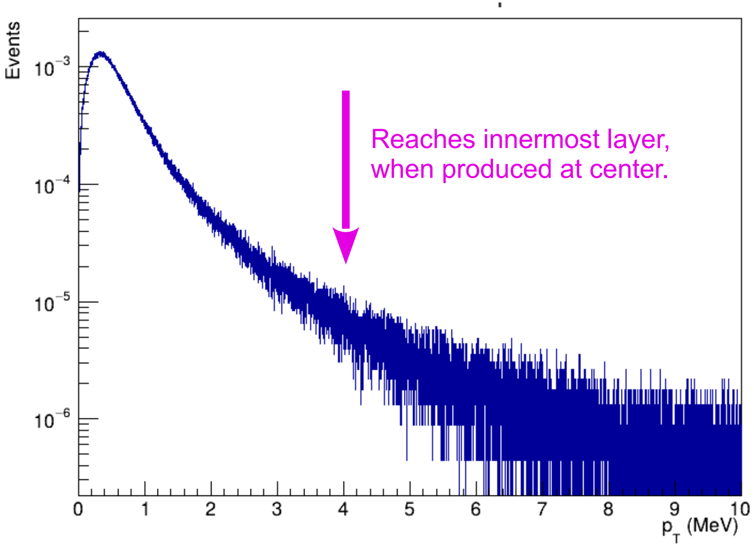
Synchrotron Radiation is likely an issue for the calorimeters.

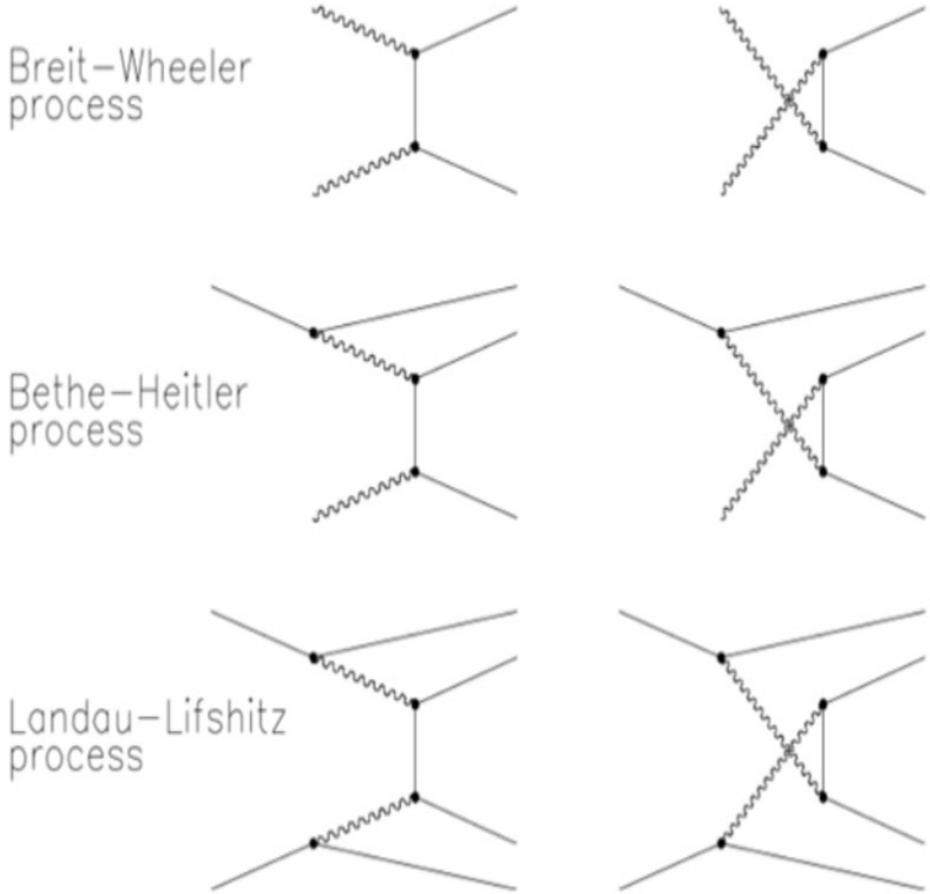
What does the BIB look like?

Parameter	Units	Z	WW	ZH	$t\bar{t}$
beam energy	GeV	45.6	80.0	120.0	182.5
IPC per Bunch Crossing		1300	1800	2700	3300
Bunch Spacing	ns	30	345	1225	7598

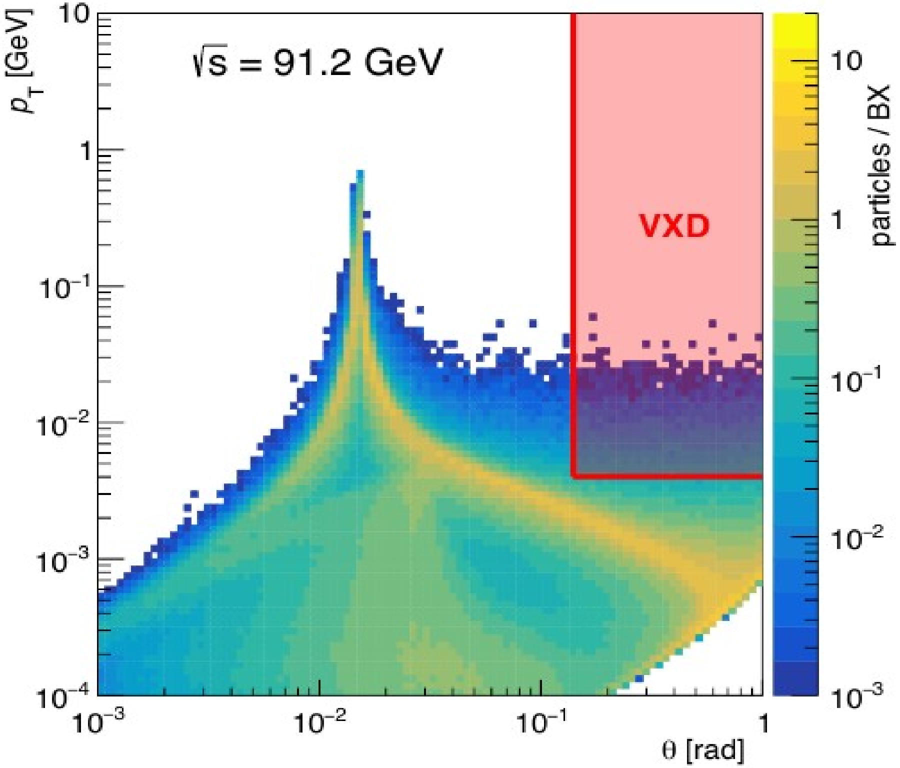
How many hits?

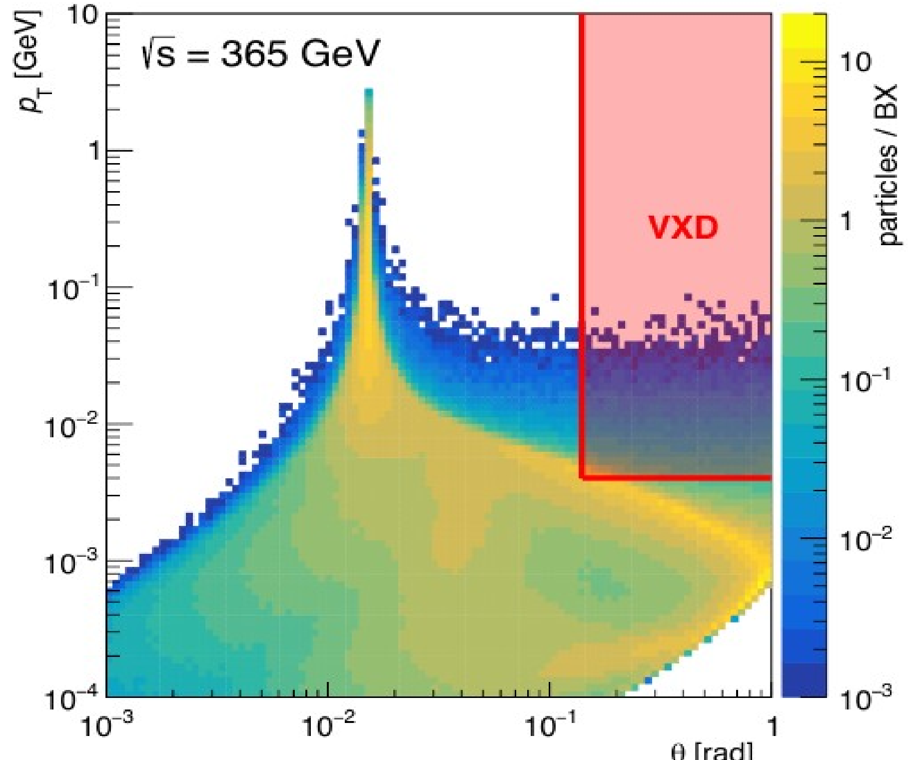
- At Z pole: ~1300 IPCs per BX
- Sounds like a lot, but how does it materialize in the inner detector?
- 1300 IPCs means 1300 x 2 particles





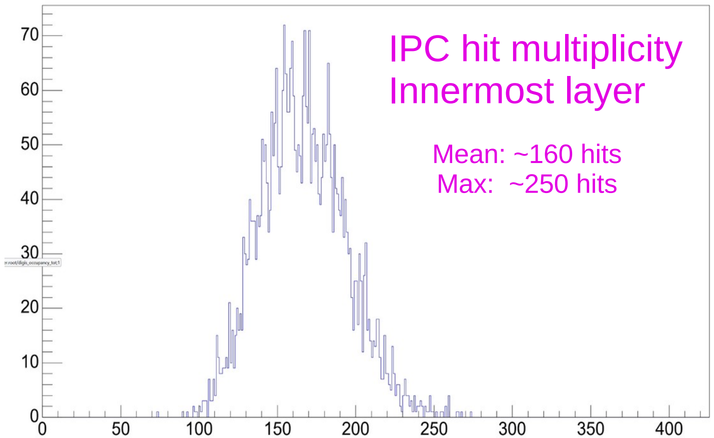
What does the BIB look like?





Majority of particles do not hit the detector

How much data just from BIB?



Hit rate calculated as h = total # hits / total area

$O = h * A_{pix} * CLS * SF = \#hits * CLS * SF / N_{tot}$

Area of inner layer = 19176.28156 mm^2

Average hit density = 8.34×10^{-3} hits/mm^2

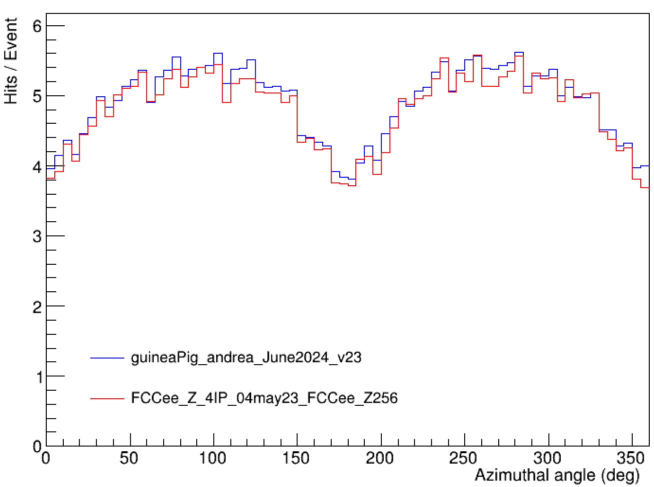
Max hit density = 1.30×10^{-2} hits/mm^2

Cl. Size * Safety F. = 2.5 x 3; A_{pix} = 25x25um^2

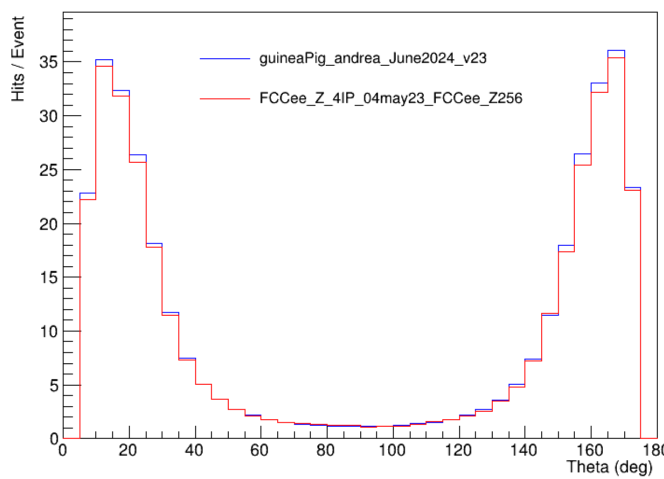
Average occupancy = 39.1×10^{-6}

Max. occupancy = 61.1×10^{-6}

Azimuthal Angle Distribution (normalized)



Theta Distribution (normalized)



Size per BX

160 * 64 bits

Corresponding Rate

40M/s * 160 * 64/8 B =
51200 MB/s =

51.2 GB/s

Beam Induced Background (BIB)

Does BIB impact the event size?

MDI Note 2025

- According to MDI report: BIB completely dominates the occupancy in inner detector
- Top down approach does not include any BIB but numbers seem conservative

Is triggerless data taking plausible?

- Streaming means all BX are recorded … additional data could be in the same order of magnitude as physics event estimate only → so maybe?
- Other detectors could have much more serious issues, silicon is fast, what about calorimeters and drift chamber?

Other impacts of BIB

- It seems that BIB need to be overlaid over the Z events ….
- Monte Carlo will become expensive to generate and potentially quite large (remember: MC of ten times the available data is desirable)

Triggering has major implications

Positive implications

- Substantial reduction in output size
- Substantial reduction in processing and re-processing times

Problems that come with a trigger

- Some physics might not be possible (exotic things especially, you loose)
- Trigger hardware has to be able to identify the BX number per detector involved in the trigger to match information correctly: 1/(25 ns)
- Slew of implications of higher power budget with complex triggers running
- Trigger effects have to be very carefully modelled and implemented in the MC
- Early planning in the design is very important because trigger cannot be easily added after the fact

Preliminary conclusions

- Plan for a lightweight trigger to reduce rate but minimally affects physics

Summary

Running without a trigger is a physicists dream

- We do not have to think about the data while taking it
- Anything can be searched for

Running without a trigger is Computing people's nightmare

- Data size is substantial (although maybe doable)

Data sizes

- Conservative assumption for physics, more work needed
- BIB seems similar in size much more study needed

Serious planning is needed because trigger cannot be added late: November 6 FCC-ee TDAQ workshop at CERN

Additional material