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Uncertainties in luminosity measurement, focus on beam – beam effects

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Outline

We use bhabha pairs to precisely measure the luminosity

- Goal: $\Delta L/L < 10^{-4}$ (for the Z peak)

First look on the impact of beam-beam effect on $\Delta L/L$

- Use BHWIDE to generate bhabha pairs
- Input the generated files to Guinea Pig (GP)
- Evaluation of the induced systematic uncertainty
- Discussion of possible correction methods

Re-evaluation of pair / hadron bkg taking into account the crab waist

Guinea Pig treatment of Bhabha pairs

Feeding BHWIDE-generated sample to GP, which applies the beam-beam effect in 2 steps (exactly as does with e^+e^- pairs)

1) Modification of the initial state
   - Beamstrahlung rescaling
   - Boost from the 2 interacting particles frame (which is rotated due to pinch effect) to the beam Ecm frame
2) Modification of the final state
   - Deflection of the bhabhas due to the field of the bunch

Here we focus only on the deflection effect

- Therefore we consider as our starting point the BHWIDE data after GP applies the initial state modification

EM deflection of Bhabhas in FCCee

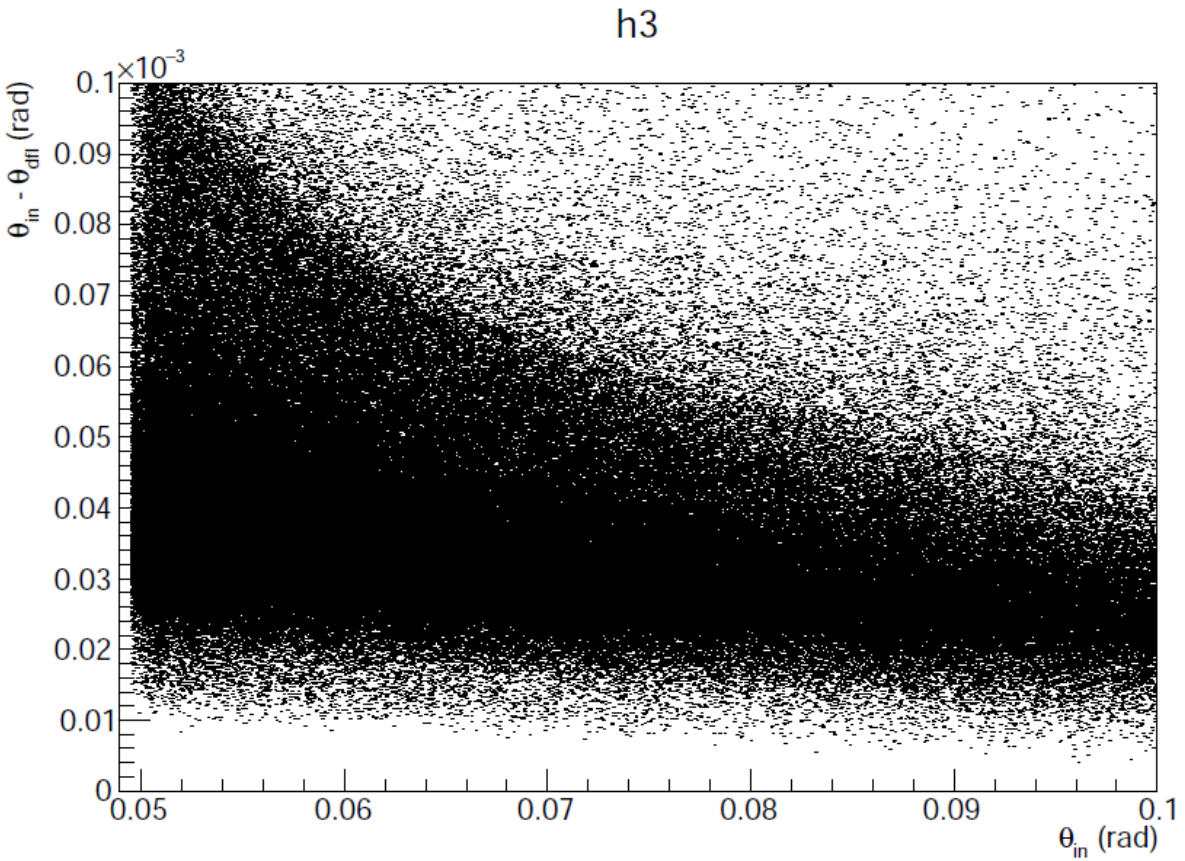
We observe a reduction in the polar angle wrt the initial one, due to the EM deflection

- A number of bhabhas will jump out the LumiCal
- That will introduce a bias on the luminosity measurement, and an additional uncertainty

The mean Δθ for θ = 65mrad (inside LumiCal's fiducial volume) is Δθ ~39μrad

A first estimation for the impact on ΔL/L can be obtained by the approximation

- $\Delta L/L \sim 2\Delta\theta / \theta_{min}$



Estimating the effect on luminosity precision measurement

Use of generated info - ~1M generated events with BHWIDE

Seeing how many bhabha pairs are inside the acceptance

- Before deflection (but after BS rescaling & pinch effect) = Nin
- After deflection Nfin

Using asymmetrical cuts (narrow-wide acceptance)

$\Delta L/L = (1.7 \pm 0.3) \times 10^{-3}$

Introduces a bias in luminosity measurement 17 times larger than the desired precision

- Needs to be corrected
- A correction factor can be derived from Guinea Pig
  - Needs to be known with a precision of few %, in order to achieve our goal ($\Delta L/L < 10^{-4}$)

Understanding the effect

On going studies to understand the dependence of Δθ on the time and the position inside the bunch where the bhabha pair was created

Here we focus on the correlation between the Δθ and variation of the beam parameters

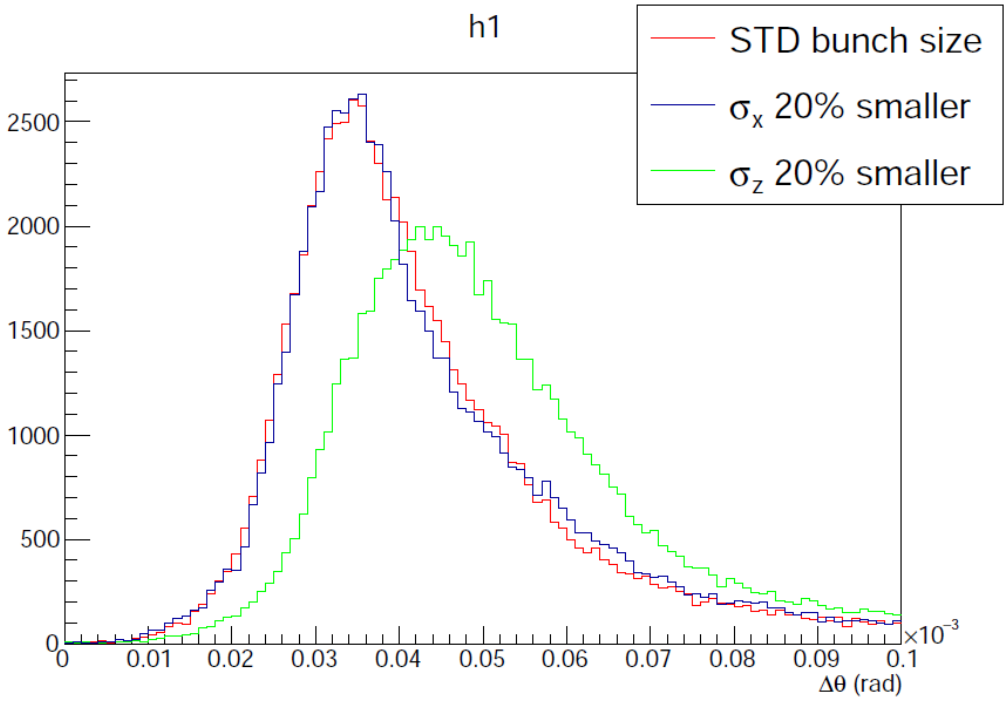
- Sensitivity of deflection angle on beam parameters
- Trying to probe the precision required in the knowledge of the beam parameters to effectively correct for the effect
- Method: vary σ_x, σ_y, σ_z and number of particles / bunch, and see how Δθ is changing

Dimensions of the bunch

Deflection angle seems to depend strongly on bunch length

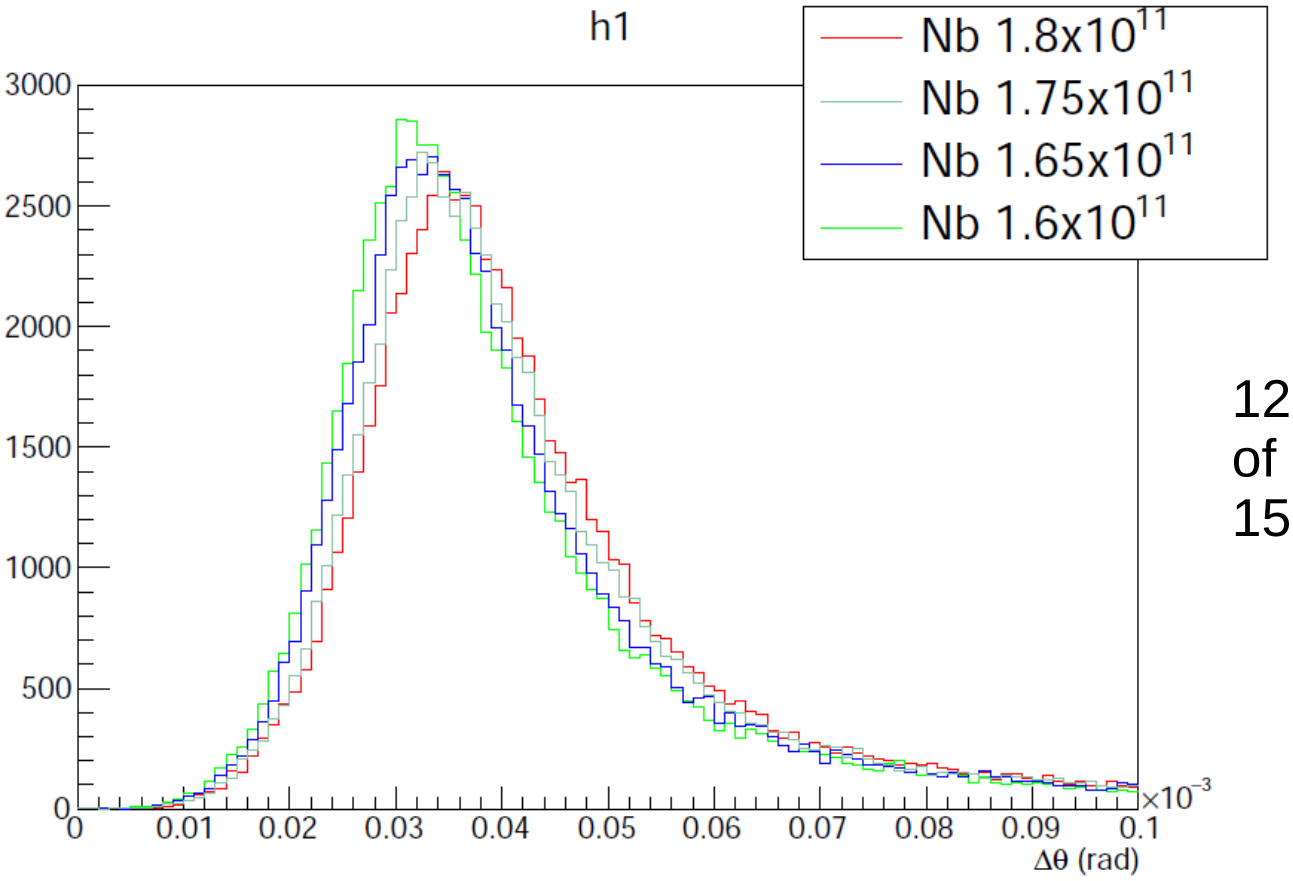
Varying σ_x, σ_y seems to have a very small effect

A variation of σ_z by 20% leads to a variation of ~25% of the deflection angle



Range of θ: 30mrad < θ < 100mrad

Number of particles per bunch



12.5 % variation of the number of particles per bunch -> 15% change in deflection angle

Range of θ: 30mrad < θ < 100mrad

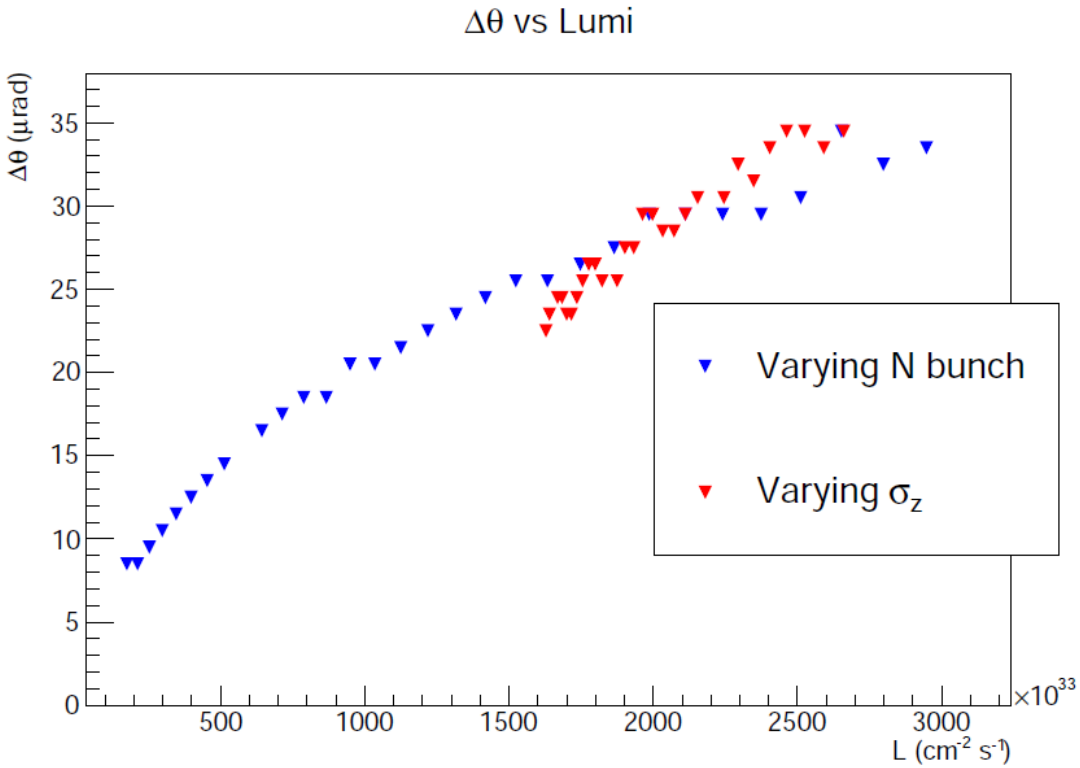
EM deflection & luminosity

Testing whether the deflection angle can be expressed as f(L)

We could then use the uncorrected luminosity measurement (as measured using Bhabhas) as a correction factor

- Seems not to be the case
- Δθ depends differently on N bunch and σz

Nevertheless if we know one of this parameters (N bunch) with high precision we could still map the correction factor to the uncorrected luminosity



- Nbunch: starting from $5x10^{10}$ and increasing by $0.5x10^{10}$ for each data point
- Bunch length: starting from 10.1mm and increasing by 0.2mm for each data point

Correction (preliminary)

Expressing ΔL/L (due to EM deflection) as a function of luminosity, we can deduce a correction factor

Due to lack of statistics (~10k particles/ data point) for now we use the approximate relationship:

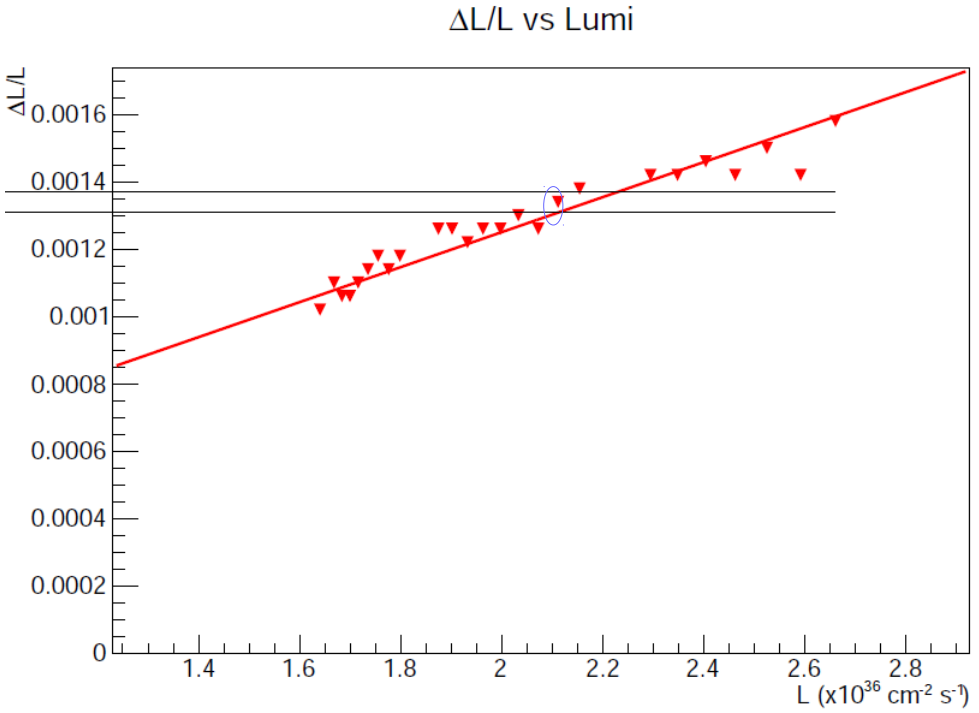
1) $\Delta L/L \sim 2\Delta\theta / \theta_{min}$

Where Δθ is the deflection angle and θ_{min} is defined by the minimum radius of the LumiCal

For $\Delta L/L \sim 2\times10^{-3}$, i.o. to achieve a precision $<10^{-4}$, we need to know the correction with a relative uncertainty of: ~2% (-> $\Delta L/L \sim 5\times10^{-5}$)

So (assuming we know very precisely N bunch) we can map L to σ_z and deduce a requirement in the precision of bunch length

- Very preliminary, $\delta\sigma_z$ ~< 0.2mm



The 2 black lines correspond to the 2% uncertainty

Incide the circle is the area corresponding to the design luminosity

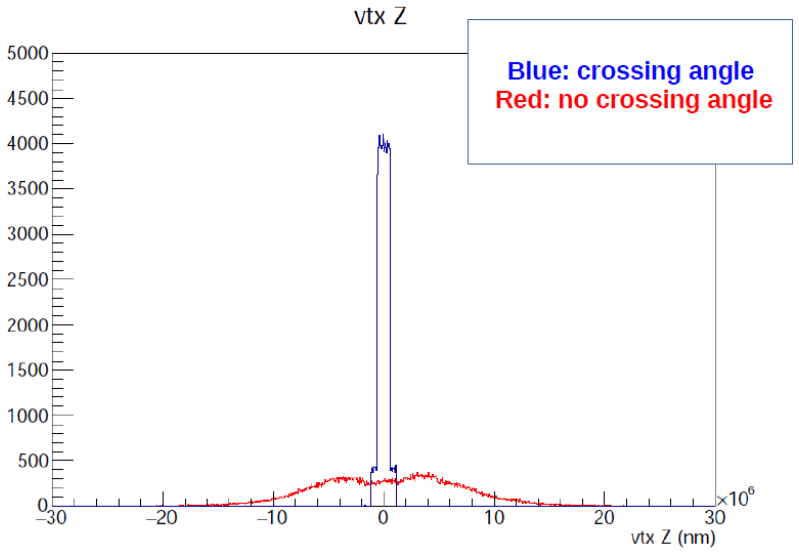
Pair bkg with crab waist

Till now, in GP framework, we consider head on collisions

- The crossing angle being compensated by crab crossing cavities, as done at ILC/CLIC
- Then apply the boost on the produced particles

However, there are no crab crossing cavities in FCCee, but crab-waist cavities -> the assumption of head-on collisions is not valid

- Running GP while applying the crossing angle describes accurately our configuration



Plot showing the Z coordinate of the vertex of beam particles that interact to produce an e^+e^- pair for E_{cm} = 91.2 GeV. The 2 histos are not in scale

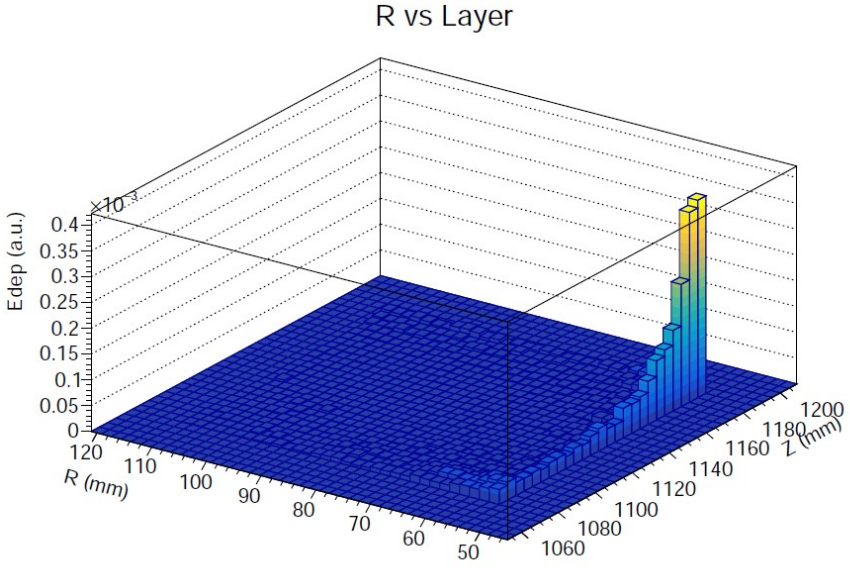
Pair bkg with crab waist (II)

It affects strongly the Z working point due to the very elongated bunches

- Considering head-on collisions we were overestimating the effect of pair bkg by a factor more than 10

  The energy deposited at LumiCal is ~300 MeV / arm / BX

On the other hand, for Top working point the effect of pair bkg remains at the same level



Conclusion

EM deflection of bhabhas due to the bunch charge induce a bias on the luminosity measurement – $\Delta L/L \sim 1.7 \times 10^{-3}$

- On going studies on other sources of uncertainty not presented today (energy/polar angle resolution, polar angle bias, energy scale) show that they can be controlled

We are studying the dependence of $\Delta\theta$ on the position/time the pair was created

As well as the sensitivity of $\Delta\theta$ on variations of beam parameters

We envisage a correction based on the uncorrected measurment of the luminosity

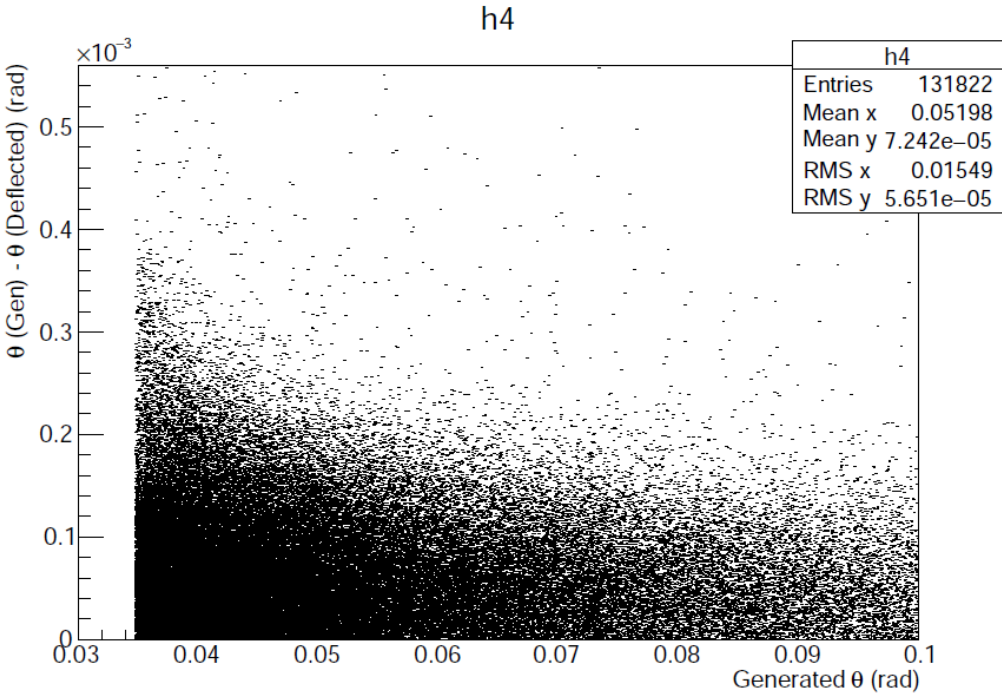
- $\Delta\theta$ seems not to have a unique correlation to the luminosity
- However, in case we know very precisely a parameter (e.g. Nbunch) we can still apply this method

The studies of pair/hadron bkg on VXD/Tracker/LumiCal were repeated accounting properly for the crab waist

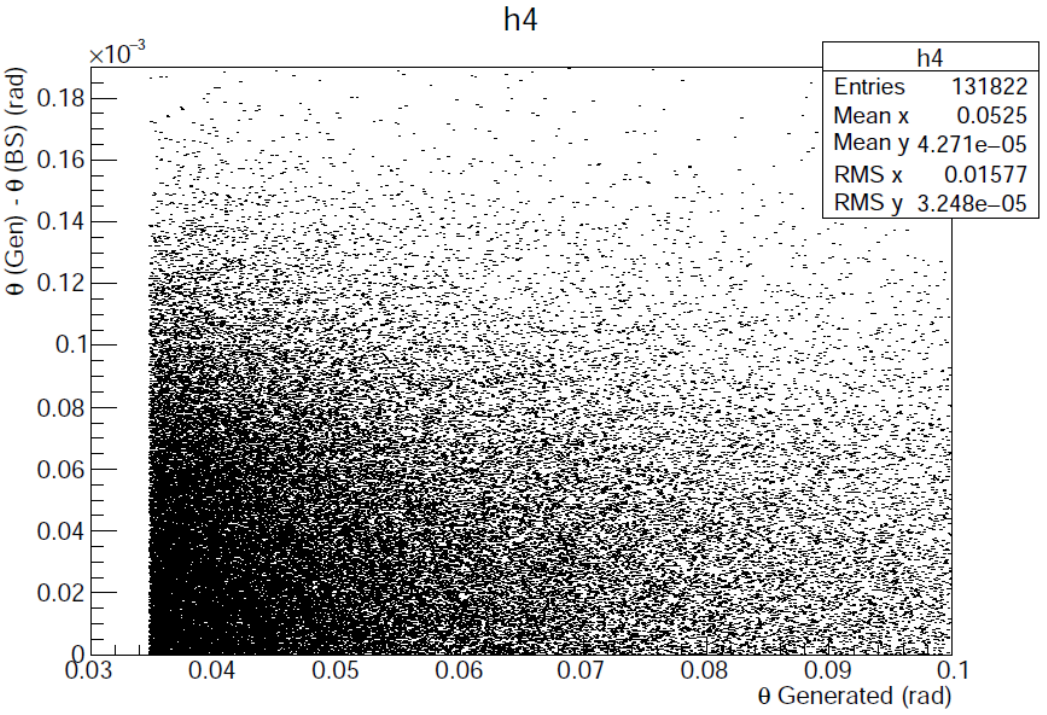
- The bkg impact for Z point was estimated ~10 times smaller compared with head-on collisions

BACKUP

Δθ wrt to BHWIDE output



Θ after BS rescaling, pinch effect && deflection – θ as given from generator



Θ after BS rescaling, pinch effect – θ as given from generator

IR elements in simulation

LumiCal: please see Mogens talk from:

https://indico.cern.ch/event/693602/contributions/2877018/attachments/1591766/2519358/LumiCal180130.pdf

Using magnetic field map, provided by Mike Koratzinos (instead of constant B field)

HOM absorbers implemented according to

https://indico.cern.ch/event/694811/contributions/2877708/attachments/1593262/2523890/Novokhatski_IR_HOMs_02_1_18_v2.pdf

- However not used cause of a G4 overlap with SR Ta shield

Non-smooth beam pipe splitting