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Beam-beam effects on luminosity measurement

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Introduction

Required precision in luminosity measurement ($\sqrt{s}$ 91.2 GeV): $\Delta L/L = 10^{-4}$

- It is expected to match theoretical precision by the time FCCee will be running

Small angle Bhabha scattering is the standard option for luminosity measurement

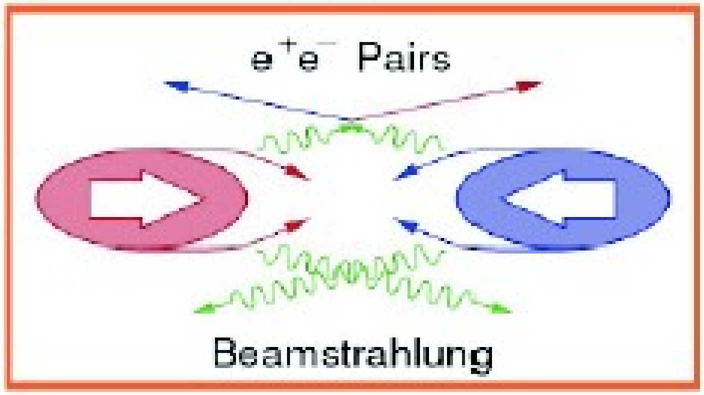
- Alternatively, large angle γ pair production is considered: → to be futher studied

Very challenging task!

- Various sources of systematics
- Focus on beam – beam effects, that are expected to introduce a bias 15-20 times larger than the required precision

Beam – beam effects

We will discuss the beam – beam interactions that affecting the luminosity measurement



By beam-beam effects we mean the forces applied to the particles of one bunch by the approaching 2^{nd} bunch

- The trajectories of the particles will be deflected

For the purposes of this talk, we divide them in 2 categories

Prior to interaction

- All events are receiving a transverse boost along x - 'Px kick'

After the interaction

- The bhabhas are focussed from the field of the opposing bunch

We will propose corrections for the induced bias

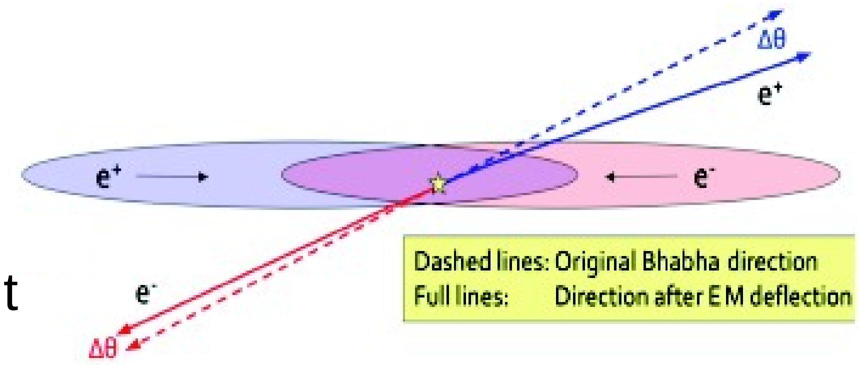
Finally, we will test the robustness of the corrections versus misalignment

Tools used

- BHWIDE for generation of Bhabha events
- Then fed to Guinea Pig (GP) which applies the beam-beam effects

After the interaction – EMD of Bhabhas

The particles will be focussed by the field of the opposite bunch



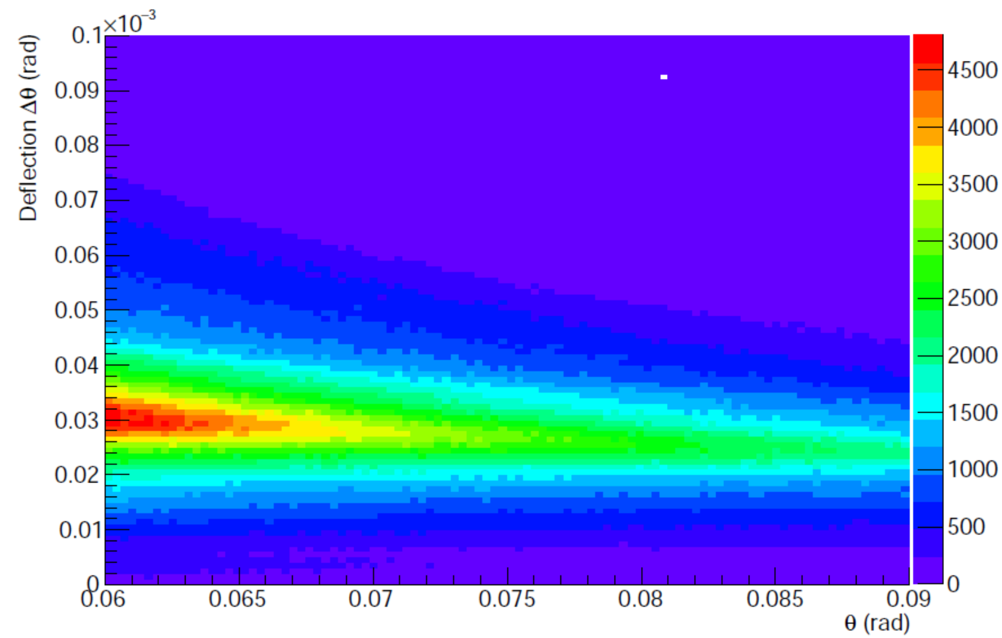
Simplified sketch for head-on collisions

Change in their θ angle →bias in L measurement

First studied for the ILC*

Mean deflection angle ~ 30μrad

- Bias: ~15 larger than the precision
- Need to be corrected
  - 7% precision in the correction is required



* C. Rimbault et al, 'Impact of beam-beam effects on precision luminosity measurements at the ILC' JINST 2 P09001, September 2007

Prior to interaction – Px "kick"

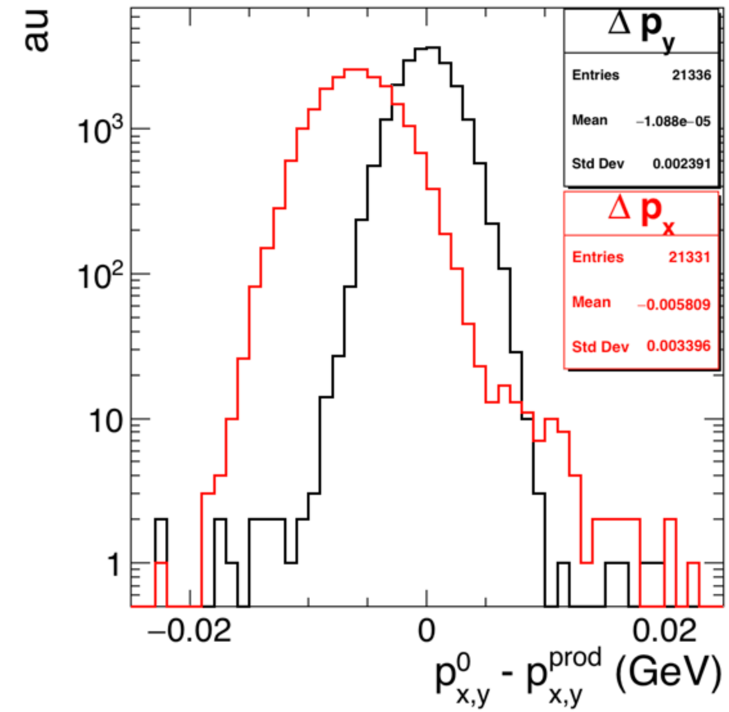
All particles will receive an avg kick ~ 3MeV along X

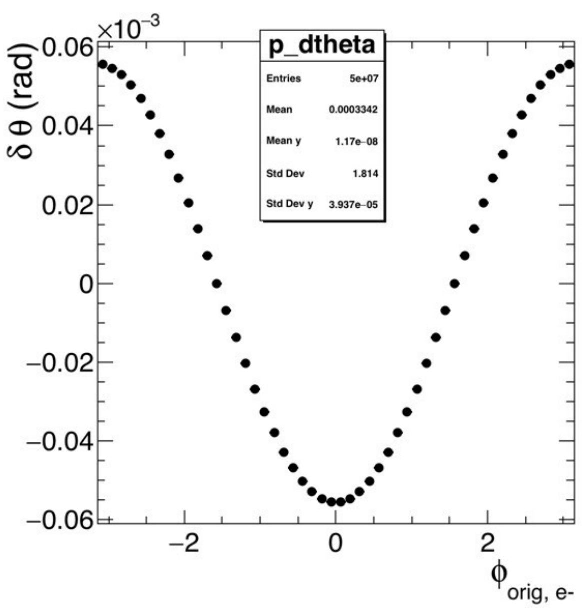
- Affects all final states – not only Bhabhas!

Plot on the right: shows the difference

$p_{x,y}^{tot} = p_{x,y}(e-) + p_{x,y}(e+)$

It will modify the θ,φ angles of the particles

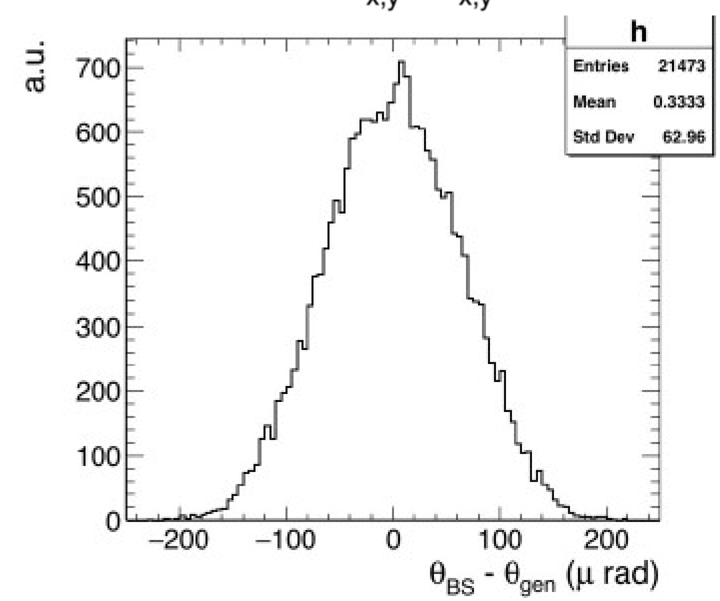




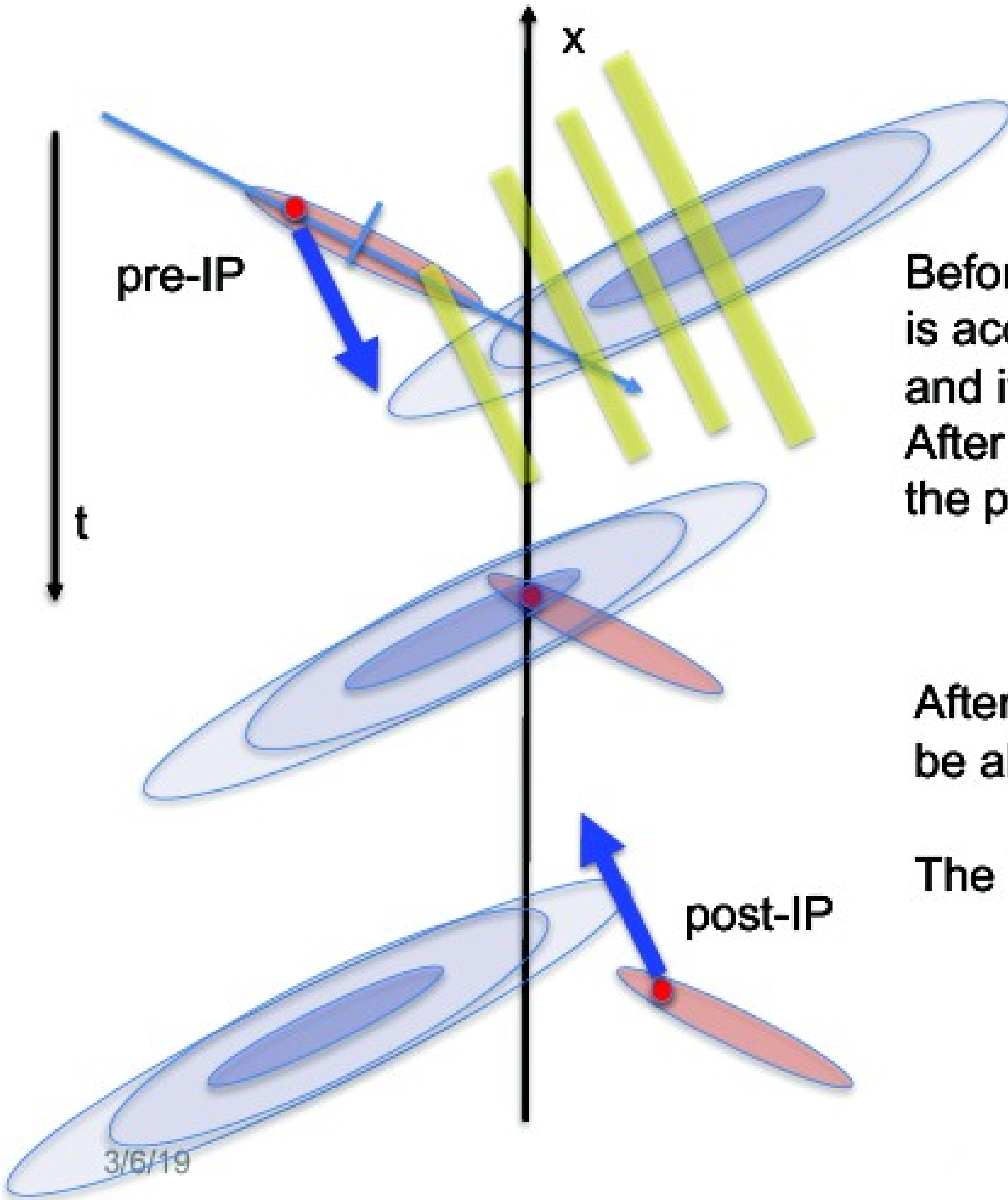
Modulation observed analytically

The prior to interaction beam-beam effects do not introduce any bias in the luminosity measurement

- They create a φ modulation, but the average effect is negligible (<Δθ>~0.3 ± 0.4μrad)



Px kick explained



Before it reaches the IP : the particle is accelerated by the force along -x, and it gains energy.
After the IP, the force is in the other direction, the particle is decelerated and loose energy.

After it has crossed the IP, the particle won't be able to collide anymore.

The "kick" is built by the pre-IP forces.

(Effect of the kick on beam energy)

The kick is an already known effect

- e.g. presentation from D. Shatilov

https://indico.cern.ch/event/687643/contributions/2821791/attachments/1575955/2488613/de_by_bs.pdf

It is expected to alter the beam E by 60 KeV

- Large compare to the precision goals for $\sqrt{s}$
  - Need to be corrected for

Patrick proposed a solution for the measurement of the correction

https://indico.cern.ch/event/803859/contributions/3345265/subcontributions/276593/attachments/1807306/2950165/EnergyKick.pdf

The Px kick can be measured with an expected precision at the per cent level

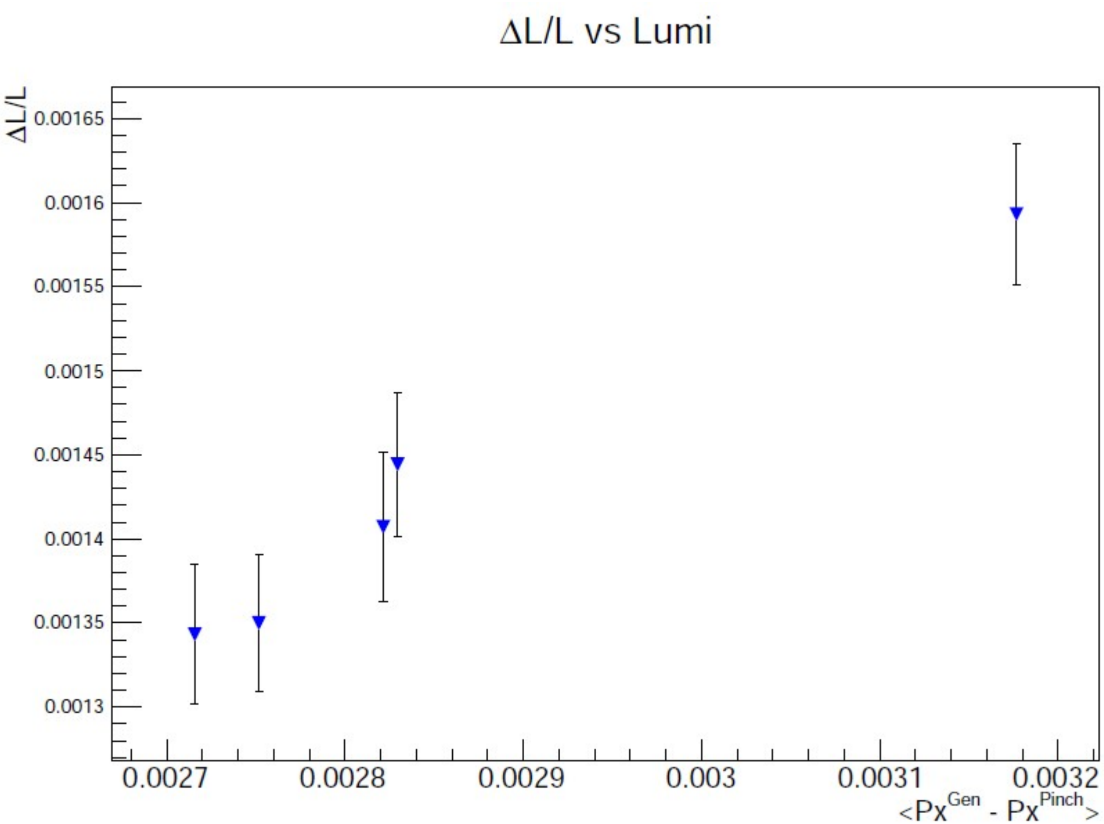
- Using dimuon events in the tracker

Proposed correction to $\Delta L/L^{\text{beam-beam}}$

The bias is due to the EM deflection (EMD) of final state Bhabhas

- The kick is very much the same effect, but applied to the initial state instead of to the final one. Hence the strong correlation !

- So one can correct for a bias introduced after the interaction by using an effect prior to it



Generated 5 beam parameters scenarios

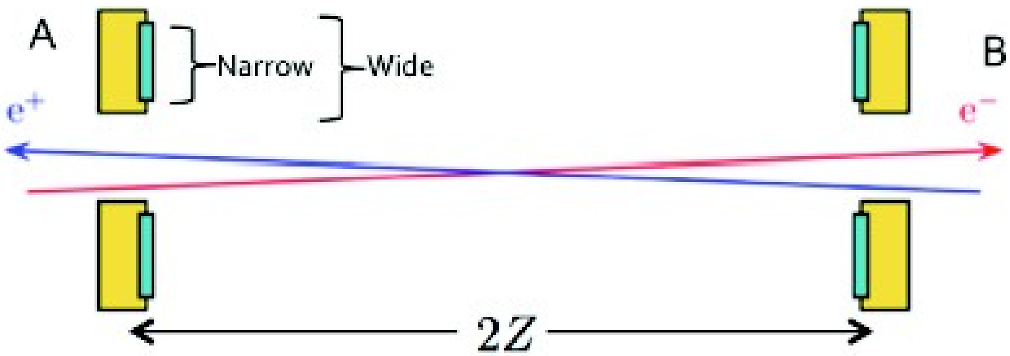
- Run GP
- Calculated the kick & the ΔL/L due to EMD
- Plot ΔL/L vs Kick

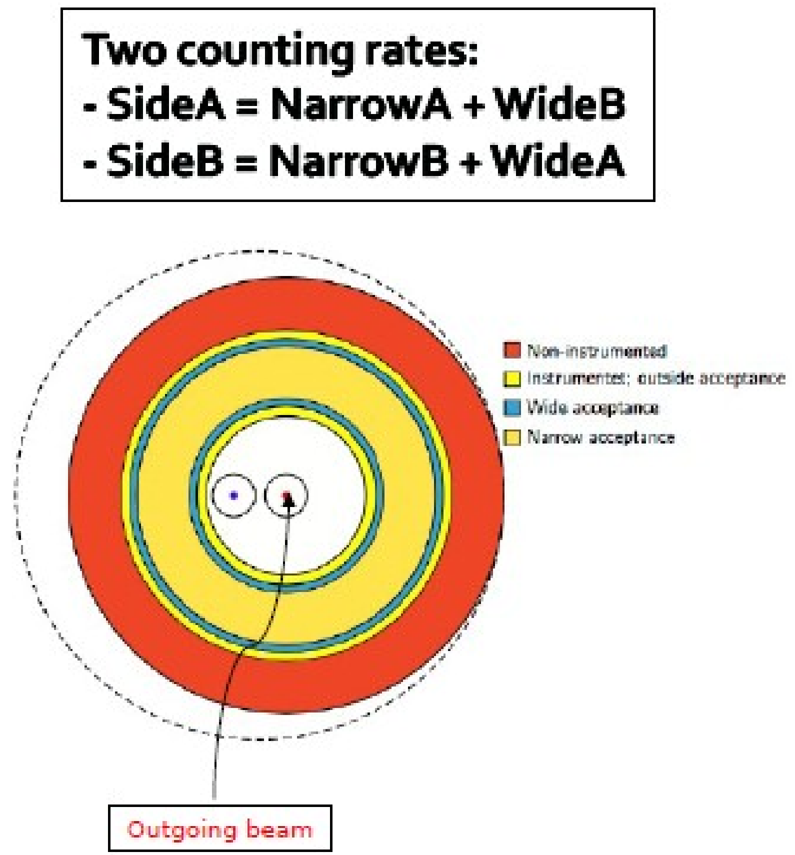
(How we measure L in FCCee)

Luminosity is measured with a pair of SiW calorimeters placed on both sides of IP

Require coincidences between narrow left & wide right (& vice versa)

- Averaging the 2 rates



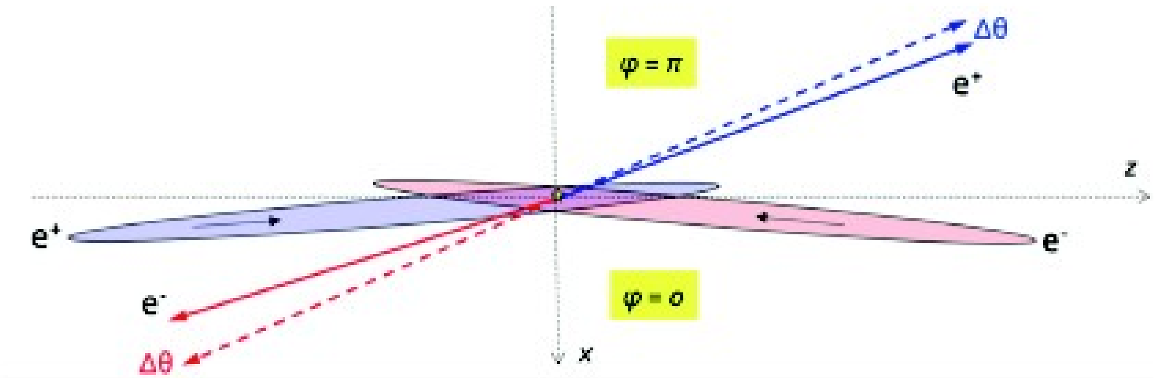


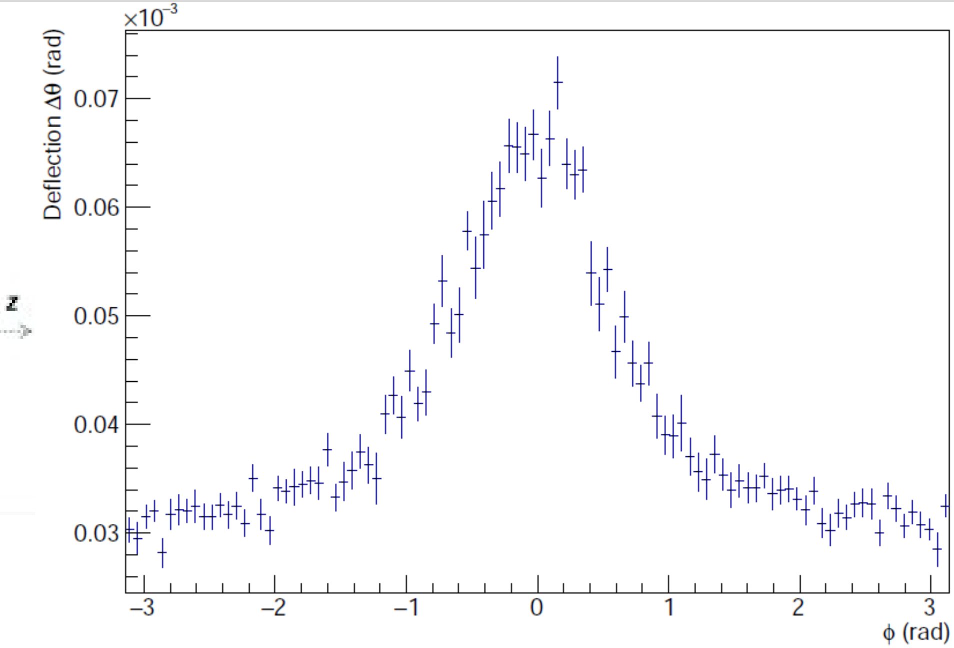
Located around 1m from the IP along Z

- 54mm < Radius < 145mm
- Fiducial volume: 65 < θ < 85mrad

Centered around the outgoing beam pipe

EMD & crossing angle





60 mrad < θ < 90 mrad
Typical LumiCal FV acceptance

The focussing is more pronounced for tracks going along positive X axis

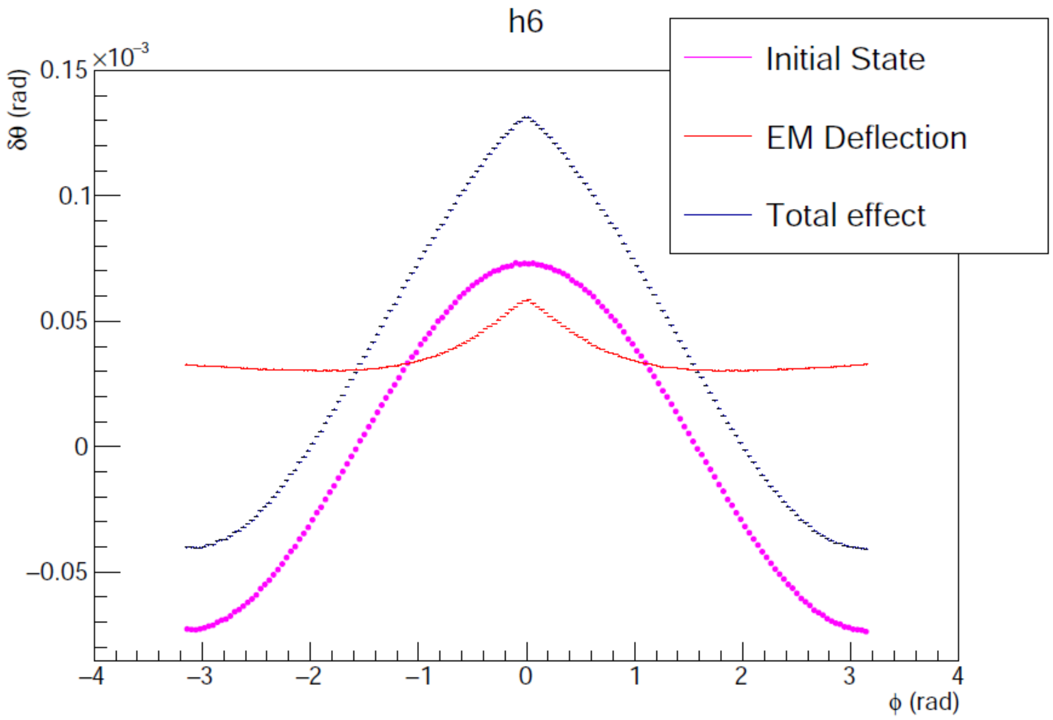
- Electrons (positrons) emitted along positive x-axis are closer to the opposite positron (electron) bunch → the focussing is stronger

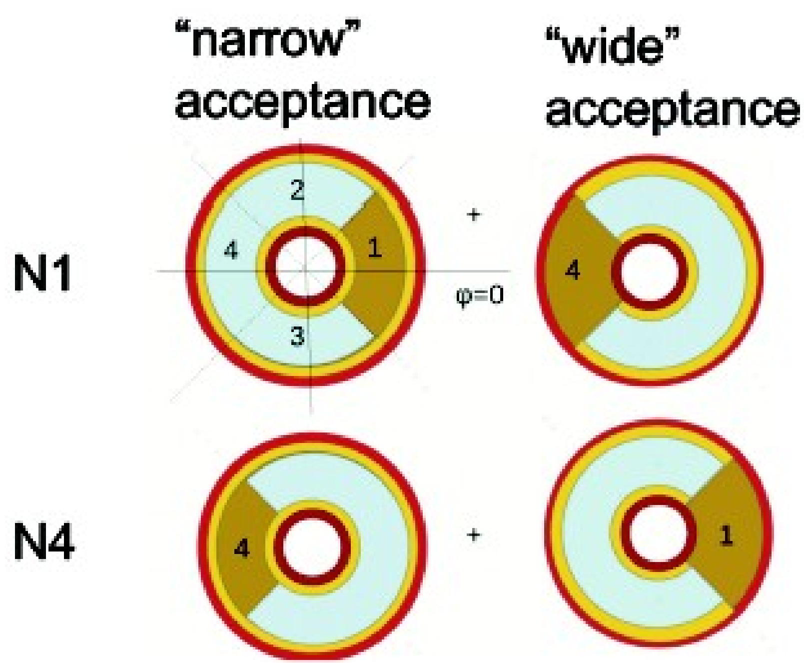
The expected φ asymmetry in LumiCal's counting rate can be exploited to provide a correction

Asymmetry in LumiCal's counting rate

The asymmetry in counting rate along φ is not solely due to EMD

- Initial state effects have the dominant contribution!
- We expect a higher counting rate for $\varphi > 3\pi/4$ OR $\varphi < -3\pi/4$
- And a lower one for $-\pi/4 < \varphi < \pi/4$





$$A = \frac{N_{41} - N_{14}}{N_{32} + N_{23}}$$

Proposed correction (on going work)

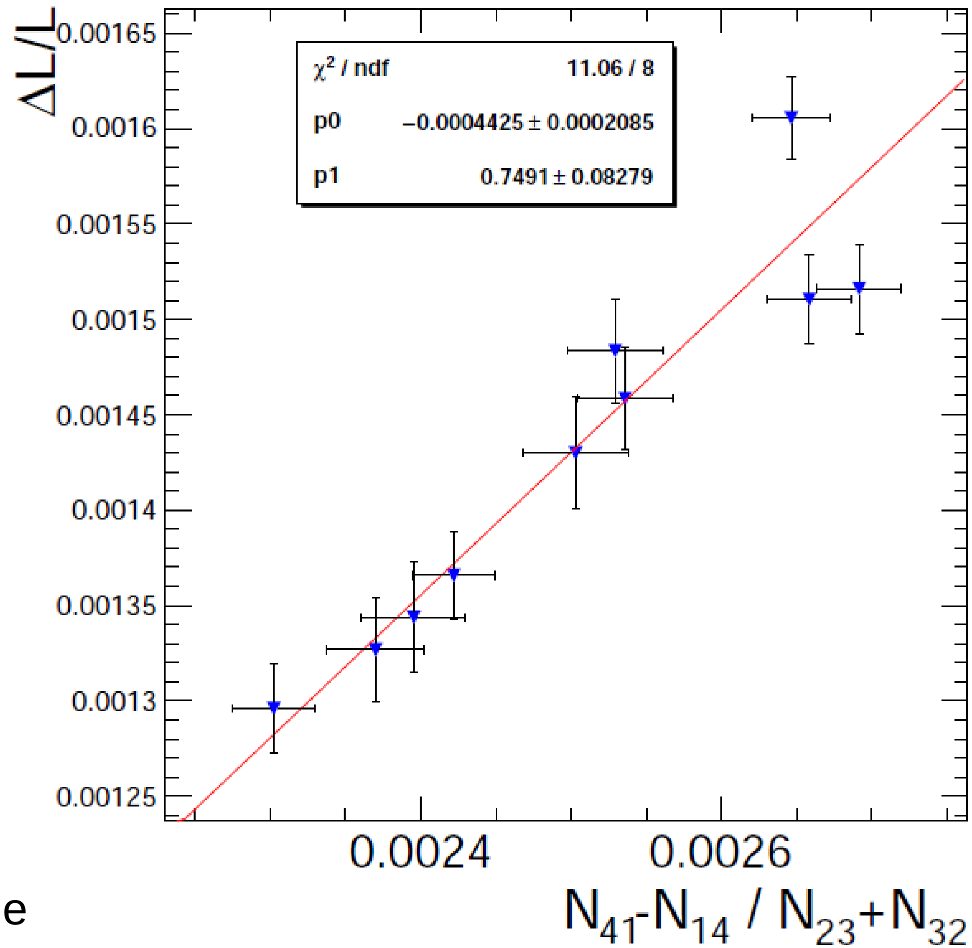
The deflection angle cannot be measured

But we can map it versus the asymmetry A measured in LumiCal

- ΔL/L seems to be a linear function of A
- As a first step, to see the dependence on the various beam parameters, we run scans where 1 parameter was changed each time, and plot ΔL/L = f(A)
- The obtained linear fits were consistent

Then created 10 beam par. Sets

- All parameters were varied randomly inside expected limits around their nominal values
- The L bias seems to be indeed proportional to the measured asymmetry
- Data needed in order to correct with the required correction uncertainty can be collected in few min



Shortcuts - more realism is needed

Summarising the correction idea

- Use GP simulations to calculate the asymmetry expected for various values of the bias $\Delta L/L^{EMD}$
- Measure the asymmetry in LumiCal from the data and then map it to the corresponding $\Delta L/L^{EMD}$

Shortcuts of the approach

- We put all our trust to GP simulations
- We consider that the only source of azimuthal asymmetry measured in LumiCal comes from beam-beam effects

The latter is not true!

- Misalignment will cause a similar modulation
- Can we disentangle the 2 effects?

Asymmetry and misalignment

A misalignment along X -axis will produce the same modulation as the Px kick

Asymmetry in φ in LumiCal counting rates has 3 sources

1) Initial state beam-beam effects (Kick)
2) Final state beam-beam effects (EMD)
3) Misalignment

So:

$A^{meas} = A^{kick} + A^{EMD} + A^{misalignment}$

The first 2 depend on beam parameters (e.g. number of particles / bunch, σ_z)

- Scale linearly with # particles per bunch

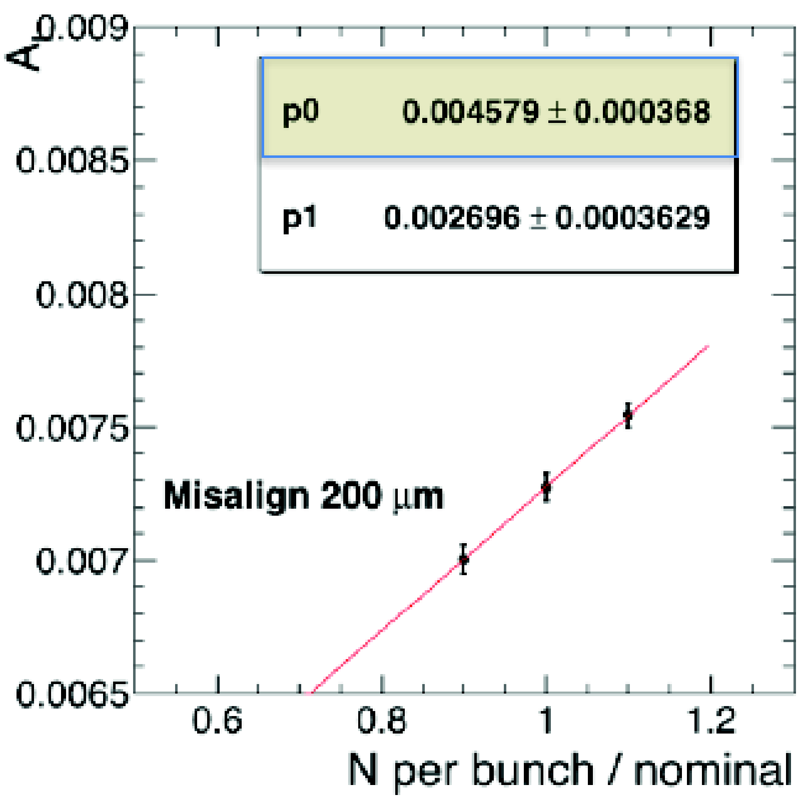
We will present a way to disentangle between misalignment and beam-beam effects

Just an example: assuming 3 types of bunch trains

For example, to illustrate the rationale of the method, we can consider having 3 types of trains, one with the nominal npart/bunch, one with 10% higher and one10% lower

Here we examine 2 sources of A

- Kick of ~ 5MeV → A^{kick} = 0.0027
- A misalignment δx ~ 200μm → A^{mis} = 0.0046



Measured A for the 3 types of trains

Data collection time ~ 10min

Perform a linear fit

- The y-intercept gives the A^{mis}
- More generally it gives the non beam-beam part of A
- Determined with a relative uncertainty of ~13% of the A^{kick}
- A precision of ~7% can be achieved with 40min of data collection

Data collection time depends of course on the size of the misalignment

- 15min enough for δx ~ 10μm

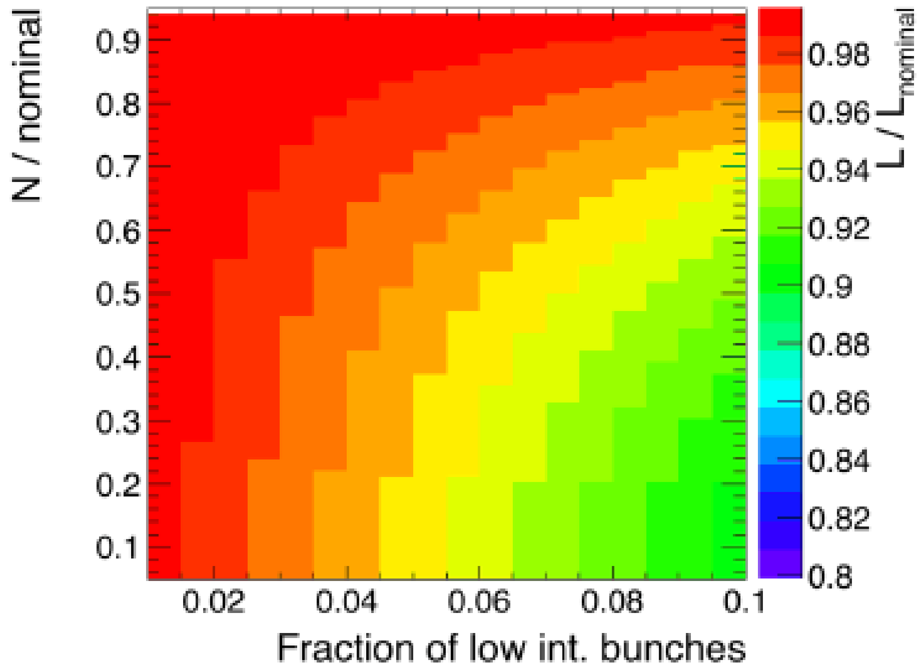
1. Using pilot bunches

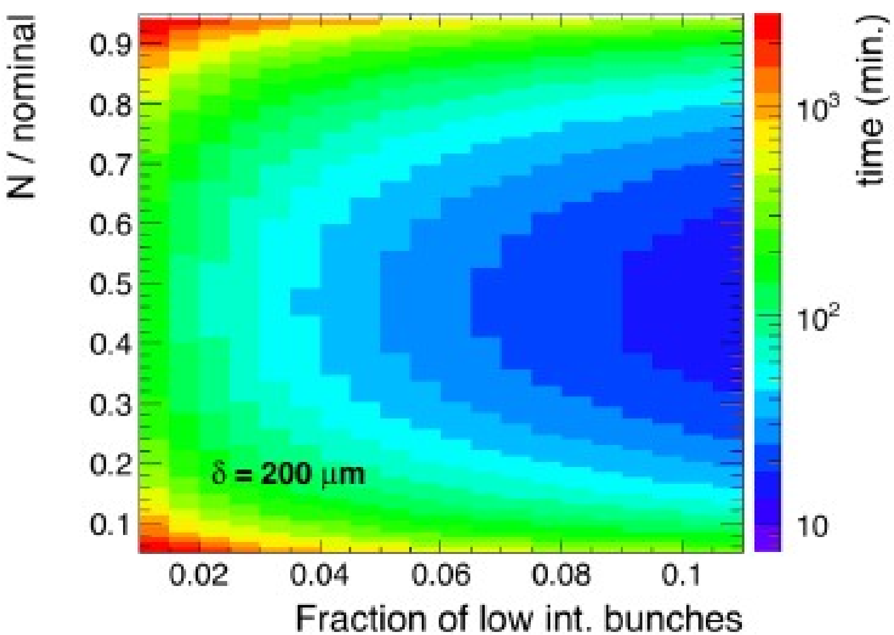
Assuming that a fraction of bunches features lower intensity

Want to minimize the luminosity loss, still allowing a measurement of $A_{misalign}$ on a time-scale << fill duration

Low intensity : larger lever-arm… but low

statistics !





Assuming that 3% of the bunches have 60% of the nominal number of particles

- 2% loss in L
- 120 min needed to get the required precision for a misalignment ~200μm
  - 30min for a misalignment ~10μm

2. Using the fill

We are exploiting Patrick's idea to use the filling of the machine in order to measure the shift on √s due to the kick

The Nparts/ bunch is gradually increasing during the fill

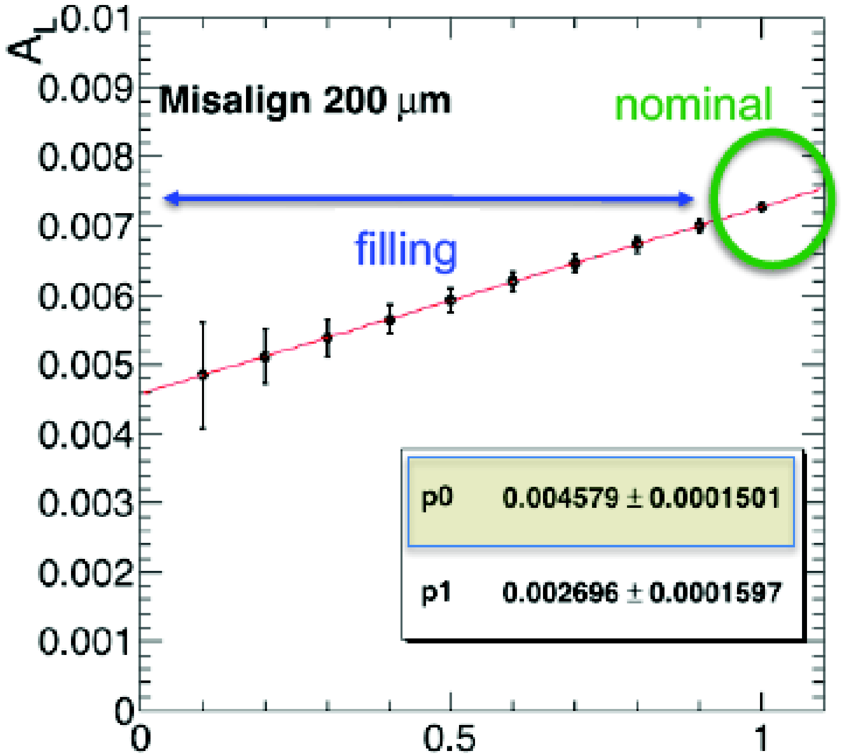
- Assuming here an increase of 10% / min
- And 1 measurement for each minute of the fill (+1 for nominal # of particles)

The method can be used since β function is nominal during the fill (we will have collisions)

No luminosity loss!

During filling time + 10min

- Asymmetry due to 200µm of misalignment can be determined with precision < 6% A^{kick}
- Asymmetry due to 10µm of misalignment can be determined with precision < 2.7% A^{kick}



N per bunch / nominal

Summary / outlook

The EMD of bhabhas due to the field of the opposite bunch will cause a bias of ~15×10^{-4}

We propose 2 correction approaches

Both take advantage of the strong correlation between initial & final state effects

1) Exploit the correlation of the initial state effects (kick – not the cause of the bias) with EMD (the actual cause of the bias)
   - The kick can be measured precisely in the tracker
2) Exploit the expected φ asymmetry in LumiCal's counting rate
   - The dominant contribution to the asymmetry comes from the kick, not the EMD
   - However is strongly correlated to the bias

To do

- We rely heavily on GP
  - E. Perez had produced a code that analytically calculates the beam-beam effects using the std field formulas
    - Good agreement with GP!
  - Numerical stability of GP is current under scrutiny – no major surprises expected
  - Bottom line: we are confident about our simulation results
  - But also: we need to examine many more beam par. scenarios, and increase the statistics of our simulated samples