Beam Delivery System performance simulated with Placet 1 & 2 and Guinea-Pig C & C++

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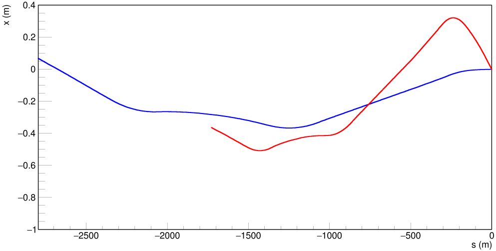
Overview

Motivation

- Beam-beam interactions in TeV-scale electron-positron collider can lead to high amount of detector's backgrounds and thus needs to be properly analyzed and taken into account
- Strong magnets in Final Focus System yield a need to analyze the possible impact of produced synchrotron radiation on the IP region
- Detailed cross-check between widely used tracking and beam-beam interaction software can point to possible errors present in the code

Beam delivery system design



- How much of the beamline would be needed for a reliable study of synchrotron radiation impact on the detector or the IP? An idea: simulate the straight part from the last sbend on.
- 380 GeV, $L^* = 4.3$ m design: 15.65 m, containing: QD0, OCTD0, SD0, DEC0, QF1, OCT1 and SF1
- 3 TeV, $L^* = 3.5$ m design: 14.21 m, containing: QD0, DD0, SD0, QF1, OCTF1 and SF1

Used software and assumptions

- Newest available versions of Placet1, Placet2, Guinea-Pig and guineapig++ have been used in this study
- Beams have been transported through ideal machines - no misalignment, energy spread or any other imperfection has been included, unless explicitely specified
- Luminosities have been calculated using one-beam approach with zero additional offset, unless specified
- Grid sizes in Guinea-Pig: $3\sigma_x$, $12\sigma_y$, $3\sigma_z$, with number of cells: 32x128x24
- 6-dimensional tracking was used whenever possible in Placet1 while in Placet2 the 6D tracking was default

Placet 1 & 2 beam parameters 380 GeV

design	σ_x (nm)	σ_y (nm)	σ_z (μ m)	ε_x (nm)	ε_y (nm)
nominal	149	2.90	70	950	30
Placet1 w/o SR	147.3	2.90	69	969	30.9
Placet1 w/ SR	149.8	2.91	69	985	31.0
Placet1 realistic	148.2	2.91	69	1216	31.2
Placet2 w/o SR	147.4	2.89	69	969	30.8
Placet2 w/ SR	149.8	2.90	69	985	30.9
Placet2 realistic	148.5	2.90	69	1218	31.1

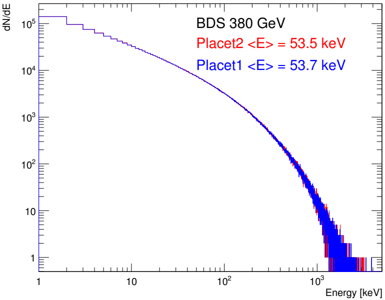
- Both models provide the spatial beam parameters close to the nominal values in all scenarios
- Synchrotron radiation does not have a major impact at this energy, but it increases the horizontal emittance nevertheless

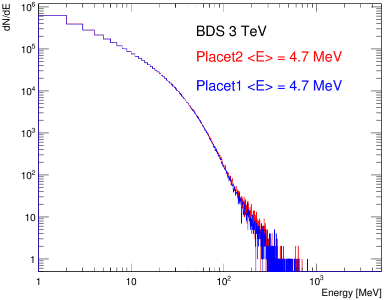
Placet 1 & 2 beam parameters 3 TeV

design	σ_x (nm)	σ_y (nm)	σ_z (μ m)	ε_x (nm)	ε_y (nm)
nominal	40	1	44	660	20
Placet1 w/o SR	39.9	0.96	43	668	27.9
Placet1 w/SR	46.7	1.96	43	852	54.1
Placet1 realistic	46.5	2.16	43	874	59.7
Placet2 w/o SR	39.9	0.91	43	668	26.6
Placet2 w/ SR	46.5	1.93	43	851	55.9
Placet2 realistic	46.6	1.99	43	874	59.7

- Both models' predictions reproduce the nominal parameters when no synchrotron radiation is included
- Synchrotron radiation and energy spread lead to significant deviation of most parameters from the nominal values
- Placet2 usually predicts slightly smaller values of vertical beam size

Synchrotron radiation energy spectra at 380 GeV and 3 TeV





- The energy spectra produced by Placet1 and Placet2 are in good agreement for both 380 GeV and 3 TeV designs
- At 380 GeV there are 23.5 SR photons per macroparticle, with 22.6 from sbends and 0.8 from quadrupoles
- At 3 TeV there are 59.1 photons, with 57.1 from sbends and 2.0 from quadrupoles

Luminosity simulation at 380 GeV

scenario / $\mathcal{L}$ $(x10^{34}\frac{1}{\mathrm{s\ cm^2}})$	w/o SR	w/SR	realistic
Placet1 + Guinea-Pig	1.55	1.53	1.53
Placet1 + guineapig++	1.55	1.53	1.53
Placet2 + Guinea-Pig	1.56	1.52	1.52
Placet2 + guineapig++	1.55	1.52	1.51
nominal at 380 GeV	1.50		

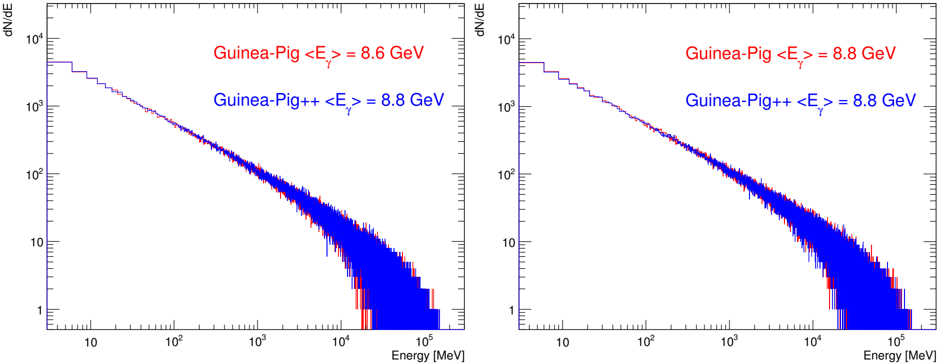
- All results are above the design luminosity
- The luminosity is minimally higher when using Placet1 beam
- Adding the energy spread of 0.36% (realistic scenario) does not impact the results significantly

Luminosity simulation at 3 TeV

scenario / $\mathcal{L}$ $(x10^{34}\frac{1}{\mathrm{s\ cm^2}})$	w/o SR	w/SR	realistic
Placet1 + Guinea-Pig	9.51	6.98	7.68
Placet1 + guineapig++	9.51	6.98	7.69
Placet2 + Guinea-Pig	9.51	5.98	7.16
Placet2 + guineapig++	9.51	5.98	7.16
nominal at 3 TeV	5.9		

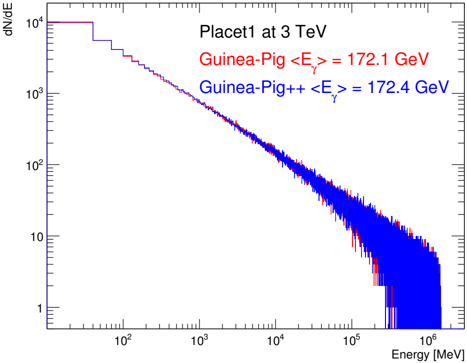
- Both C and C++ versions provide comparable results
- At 3 TeV luminosity is very sensitive to any imperfections in the beam - ISR leads to large luminosity loss
- The realistic scenario has luminosity above the design value and higher than when only ISR is included

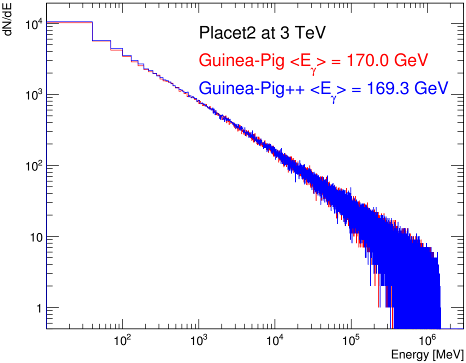
Beamstrahlung photons' energy spectra - 380 GeV



- Energy spectrum is comparable for both Placet1 (left) and Placet2 (right) beams as well as between Guinea-Pig and guineapig++
- At 380 GeV there are 1.46 beamstrahlung photons per tracked macroparticle

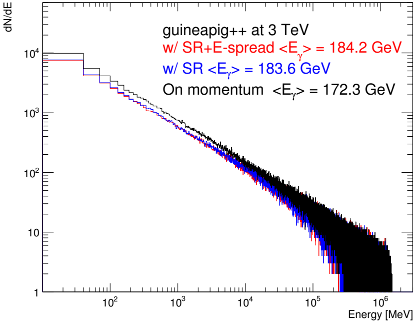
Beamstrahlung photons' energy spectra - 3 TeV





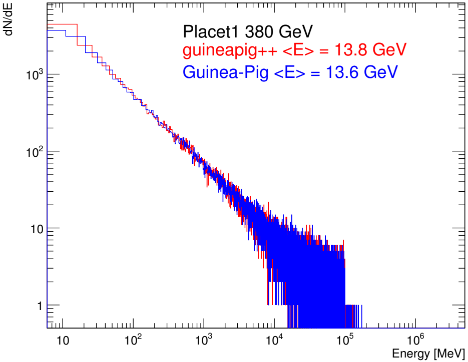
- Energy spectrum in very good agreement in all scenarios
- Clearly visible cut-off energy at 3 TeV suppressing the beamstrahlung
- At 3 TeV there are 2.39 beamstrahlung photons per tracked macroparticle

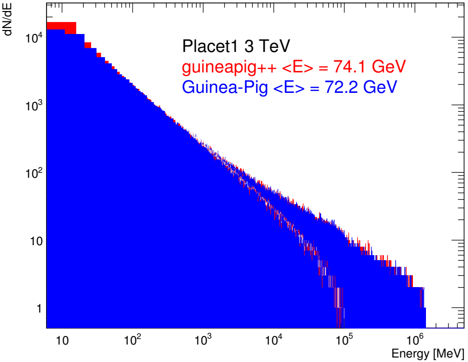
SR and energy spreads impact on beamstrahlung at 3 TeV



- On momentum beam creates more photons in medium- and low-energy region, leading to an average energy lower by 6%
- Synchrotron radiation's presence has the biggest impact on beamstrahlung photons' average energy
- The addition of the energy spread leads to no significant change in beamstrahlung's spectra

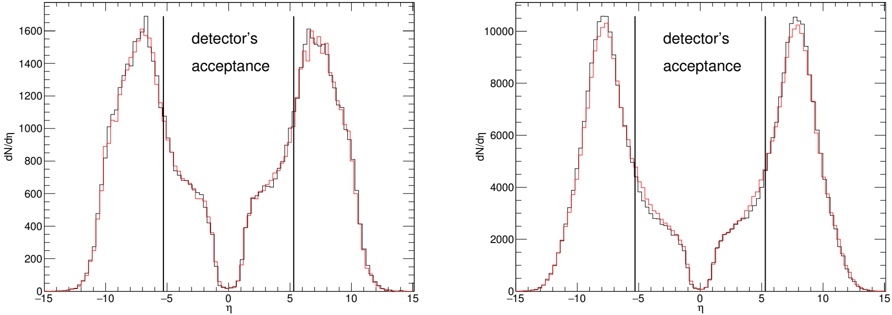
Incoherent pairs' energy spectra at 380 GeV and 3 TeV





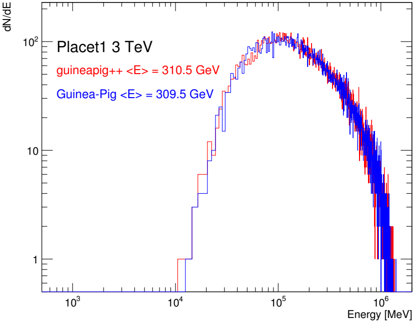
- Pairs coming from realistic beam distributions
- Energy spectra in good agreement in all scenarios
- $5.8 \cdot 10^4$ incoherent pairs per bunch crossing at 380 GeV, and $3.81 \cdot 10^5$ at 3 TeV

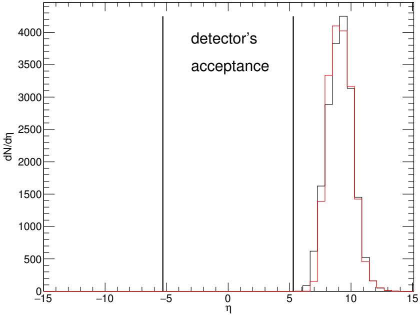
Incoherent pairs' pseudorapidity distributions at 380 GeV and 3 TeV



- Distributions from Guinea-Pig (black) and guineapig++ (black) - are in agreement
- 29% of the incoherent pairs pointing into detector's acceptance at 380 GeV (left), and 22% at 3 TeV (right) - possible source of direct background in the detector

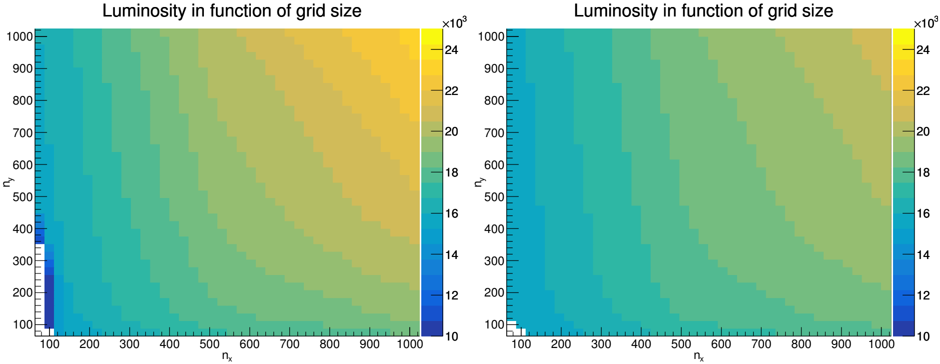
Coherent pairs' energy and pseudorapidity distributions at 3 TeV





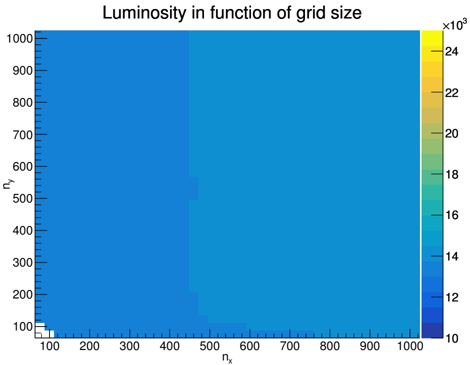
- Energy spectra in good agreement in Guinea-Pig and guineapig++
- $3.5 \cdot 10^8$ coherent pairs per bunch crossing at 3 TeV, no coherent pairs at 380 GeV, as expected according to Chen and Telnov (*Phys.Rev.Lett. 63 (1989) 1796*, eq. 5)
- Coherent pairs do not constitute direct background

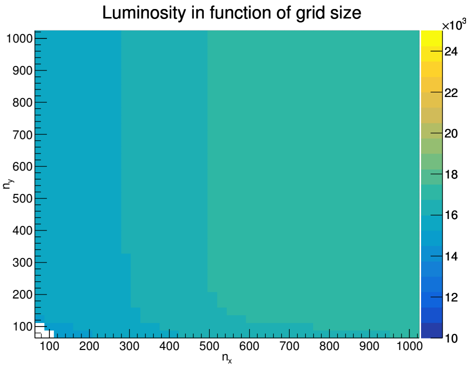
Guinea Pig sensitivity to grid size - one beam at 380 GeV



- Checking for possible initial parameters mismatch shows a strong correlation between grid granularity and calculated luminosity
- No plateau observable when using 100k macroparticles (left) nor 200k (right) - challenges the validity of one-beam approach

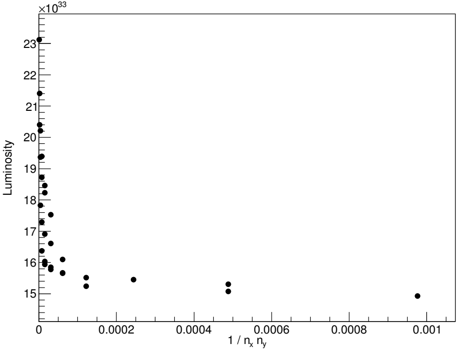
Guinea Pig sensitivity to grid size with offset or two beams

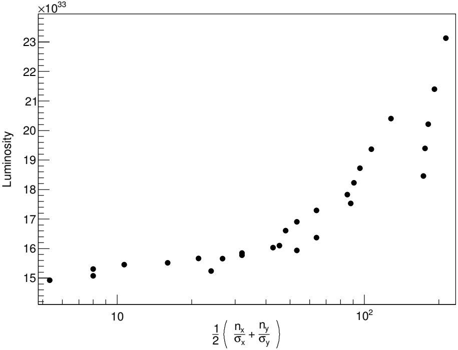




- Introducing offset (left) removes most of the correlation between grid granularity and luminosity - choice of grid size has little impact on luminosity-offset dependence
- Using two-beams (right) with no offset instead of one reduces the luminosity dependence on simulation settings

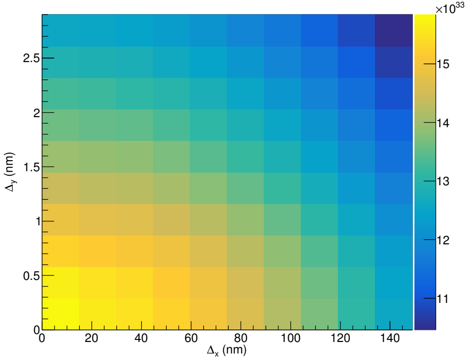
Luminosity sensitivity to cell size, one beam at 380 GeV

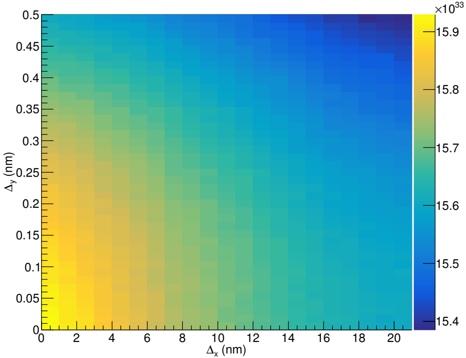




- Different sensitivity in each axis results in varying results at the same cell area
- Reducing cell sizes leads to exponential growth of luminosity
- Luminosity saturates for more coarse grids - at around 10 cells per sigma

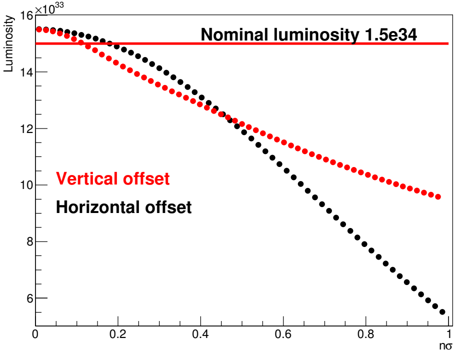
Luminosity offset dependence scan at 380 GeV





- Both coarse (left) with offset $\pm\sigma_{x,y}$ and fine (right) binned with offset $(20\ \mathrm{nm}, 0.5\ \mathrm{nm})$ scenarios have been studied at 380 GeV
- No hint of maxima different than at (x, y) = (0, 0) found
- At small offsets horizontal deviation leads to faster luminosity descent although in general it is more sensitive to vertical offset

Luminosity offset dependence scan - projections at 380 GeV



- Vertical luminosity over nominal values up to 0.1 σ_y offset, horizontal luminosity up to 0.2 σ_x at 380 GeV
- Luminosity more sensitive in vertical axis, especially at small offsets
- Horizontal offset dominates luminosity loss at deviations over 0.5 σ

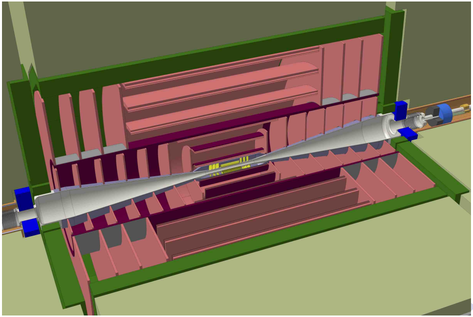
Summary

- Benchmark results of widely used software have been presented for both 380 GeV and 3 TeV designs
- All results are in good agreement, the checked models can be interchanged
- One-beam collisions' results without any offset are strongly dependent on grid granularity and number of macroparticles
- Two beam approach is more realistic, especially when no offset is applied but one-beam can be used when offset is introduced
- Special attention needs to be paid to minimise vertical offset in order to preserve luminosity at nominal values
- The main source of direct background are incoherent pairs, with coherent pairs and beamstrahlung outside of detector's acceptance
- The code developed for this analysis is available as a branch of Placet2: Placet2-SR_photons

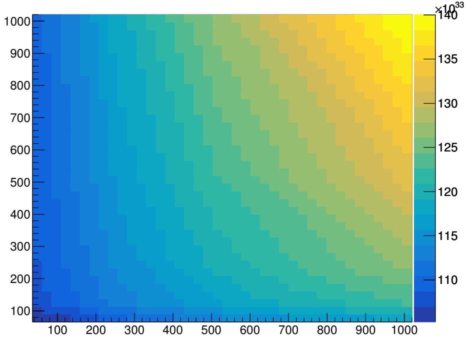
Outlook

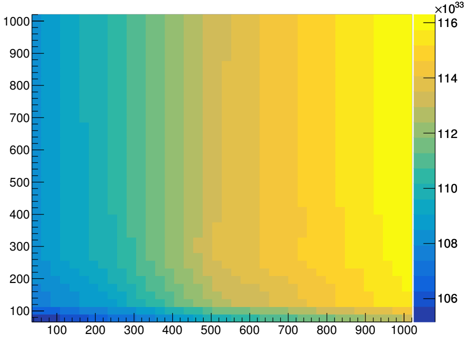
Next tasks:

- Implementation of Final Focus System to the detector model
- Studying Final Focus' synchrotron radiation's and beam-beam interaction's - beamstrahlung and pairs - impact on the detector performance and backgrounds
- Detailed analysis of properties of produced backgrounds: angular, transverse momentum distributions



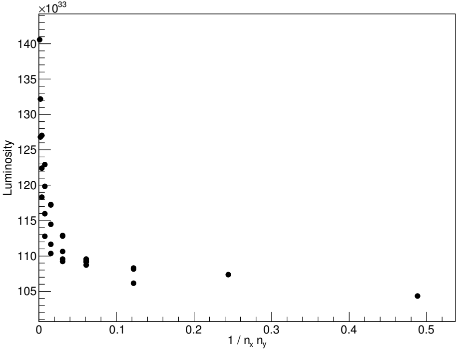
Guinea Pig sensitivity to grid size, one- & two beams at 3 TeV

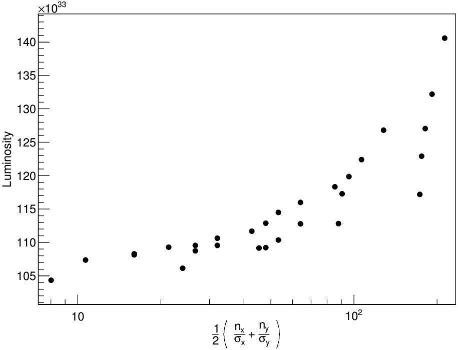




- The dependency is similar to 380 GeV, though the correlation is stronger with two beams
- Using two beams more reliable and less prone to self-correlation

Luminosity sensitivity to cell size, one beam at 3 TeV





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