Beam-beam Simulation

With Guinea Pig

Eugenio Paoloni
Università & I.N.F.N.
Pisa

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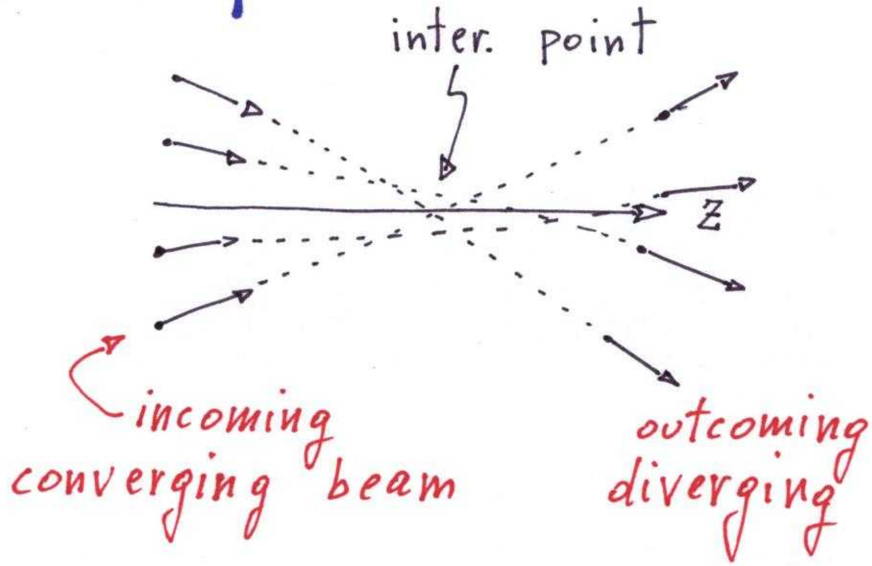
Talk outline

- Motivation
- Guinea pig internals
- Why guinea pig is so slow with the large crossing scheme
- How to "quick and dirty" speed up Guinea Pig
- How to use Guinea pig for back-grounds studies

Luminosity: PDG recipe

$$\mathcal{L} = \frac{1}{4\pi} \frac{n_1 n_2}{\sigma_x \sigma_y} f$$



σ are functions of z!

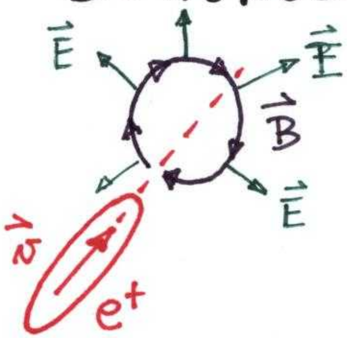
$$\sigma(z) = \sigma(0) \cdot \sqrt{1 + \left(\frac{z}{\beta}\right)^2}$$

for a non interacting gaussian bunch.

- PDG formula valid only in the $\beta \to \infty$ limit $\left(\frac{\beta}{\sigma_z} \ll 1\right)$

Beam-beam interaction

- Bunches are charged $\Rightarrow \vec{E}$ & $\vec{B}$ fields



- for particles in the same bunch

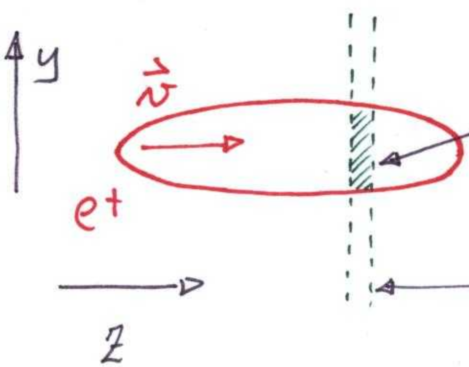
$q\vec{E}$ and $q\vec{v} \times \vec{B}$ cancls out to $o(1/\gamma^2)$

$\underline{\gamma \sim 10^4}$

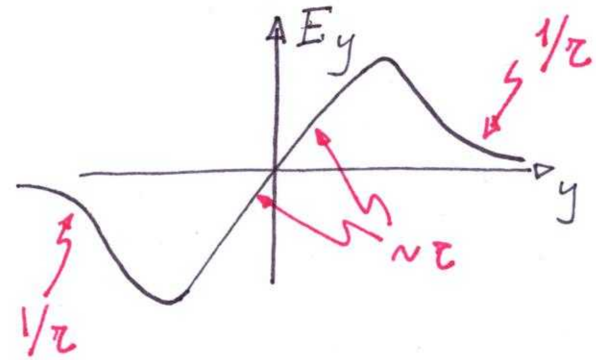
- for particles in opposite bunches $q\vec{E}$ and $q\vec{v} \times \vec{B}$ add to

$\vec{F} \simeq 2q\vec{E}$ (up to $o(1/\gamma^2)$)

- Extreme Lorentz contraction



only these particles contribute to the fields in this slice

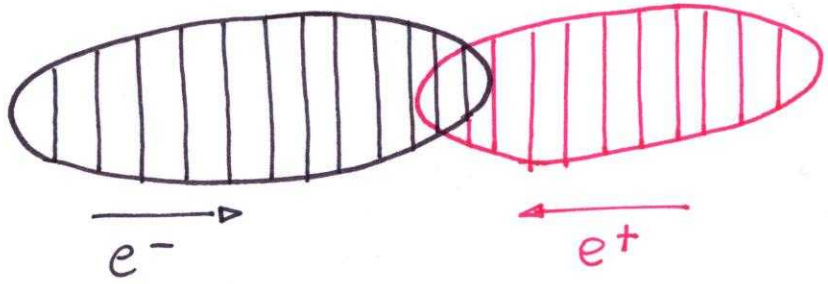


Gaussian beams no longer gaussian...

Motivation

- My first attempt to simulate the large crossing scheme with Guinea pig took 1 week CPU time (1 bunch crossing!)...
- Optimization of the bunch parameters requires hundreds runs → years of CPU time
- Backgrounds studies require thousands of bunch crossings ... multi turn simulations $10^5 - 10^6$....
- Faster (and worser) version of Guinea pig.

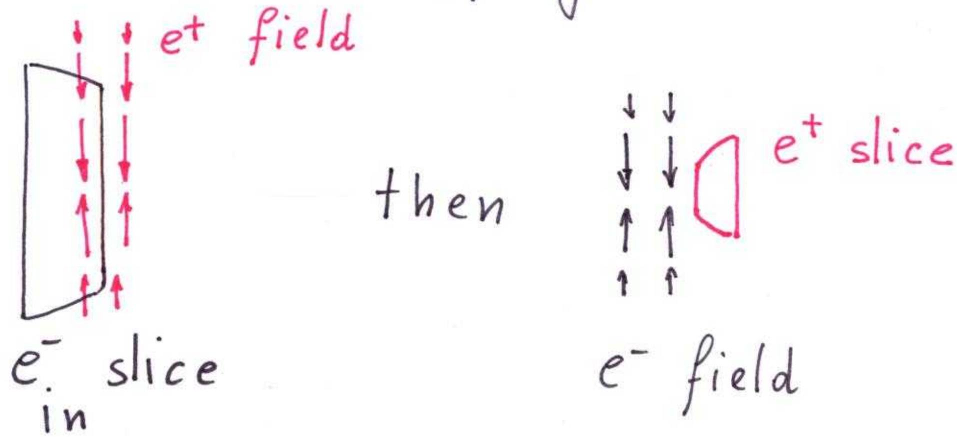
Guinea pig: a beam-beam sim.



- Divides the bunches in z slices

- Evaluates the $\vec{E}$ field generated by one slice

- Propagates the overlapping slice through this field



- Repeat for all the slices for all the steps

- Complexity : $N_{slice} \times N_{steps} \simeq N^2_{slices}$

Poisson equation Solvers

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) \varphi = - \rho$$

- Direct : $\varphi(\vec{x}') = \int d^2\vec{x} \; \rho(\vec{x}) \cdot G(\vec{x}' - \vec{x})$

  - complexity $\sim N_{macro\text{-}p} \times$ Mesh Size

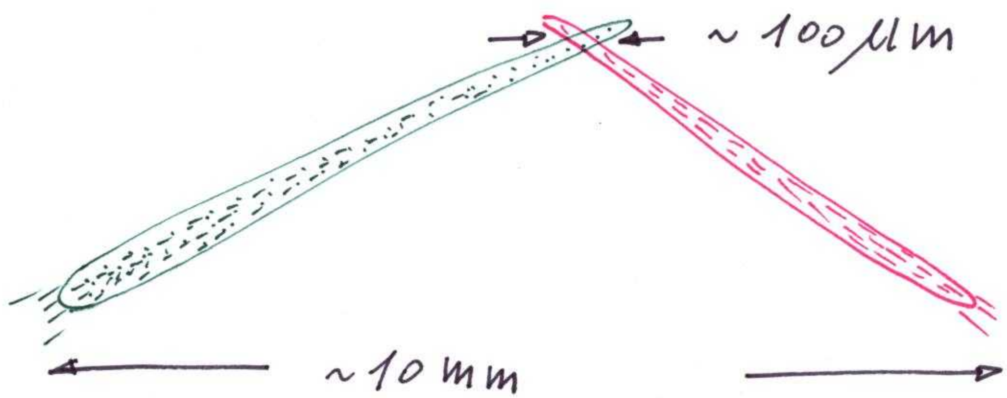
- Via Fast Fourier Transform

  $$\varphi = \text{Fourier}^{-1}\left[\tilde{\rho}(\vec{k}) \cdot \tilde{G}(\vec{k})\right]$$

  - complexity $\sim$ Mesh size $\times \ln$ Mesh_size

- Both available in Guinea Pig

Guinea Pig is not ideal for large Xing



(Sketched still picture of PANTALEO's movie)

- If you want to capture the interesting dynamic in the 100 μm region

⇓

slice ~ 10 μm

⇓

~ 10^3 slices

⇓

10^6 Poisson equation to solve!

⇓

hours to simulate

Bunch parameters

$\sigma_x = 2.67\ \mu m$

$\beta_x = 17.8\ mm$

$\sigma_y = 12.6\ nm$

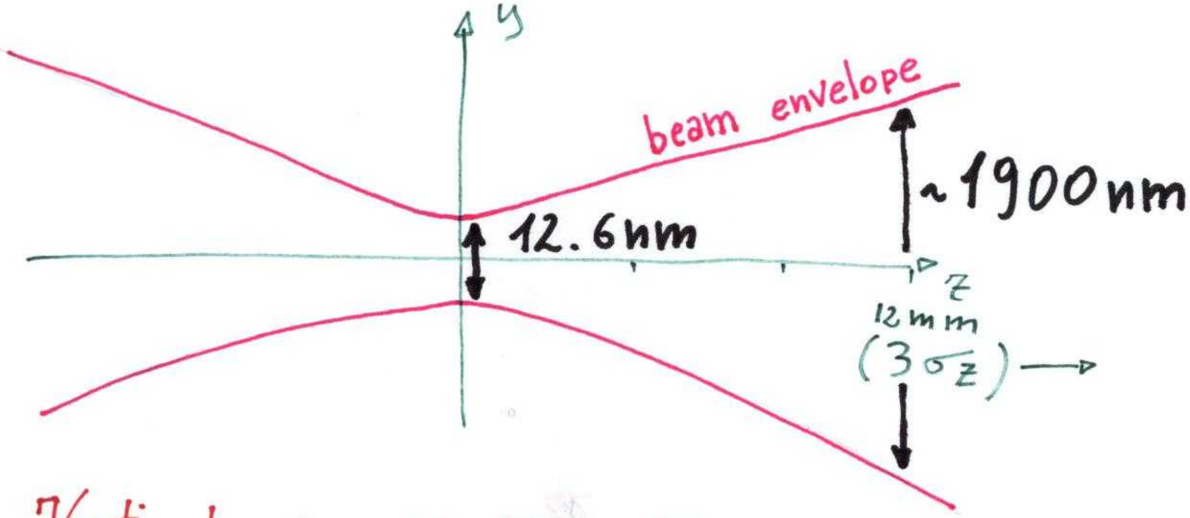
$\beta_y = \underline{80\ \mu m}$

$\sigma_z = 6\ mm$

$\Delta E/E = 1‰$

$\chi = \underline{2 \times 25\ mRad}$

$N_e = 2.5 \times 10^{10}$ part/bunch

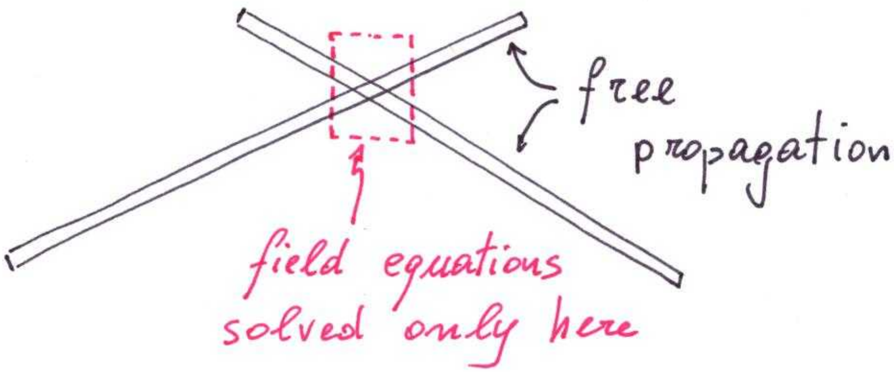


Vertical size x 100 @ $2\sigma_z$

$$\sigma_y(z) \simeq \sigma_y^{*} \cdot \frac{z}{\beta_y}$$

→ Guinea pig mesh fixed

I : VERY CRUDE APPROX.



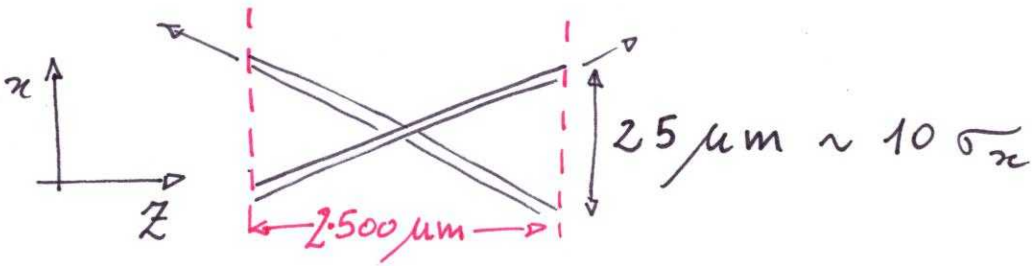
• Solve the Poisson equations only for the few colliding slices.

$N_{slice} \simeq 10^3$

$N_{colliding} \simeq 10$

• gain a factor 100 in CPU time

• simulating the field in $|Z| < 500\ \mu m$



• Not yet optimal : guinea pig evaluates $\vec{E}$ in the whole box...

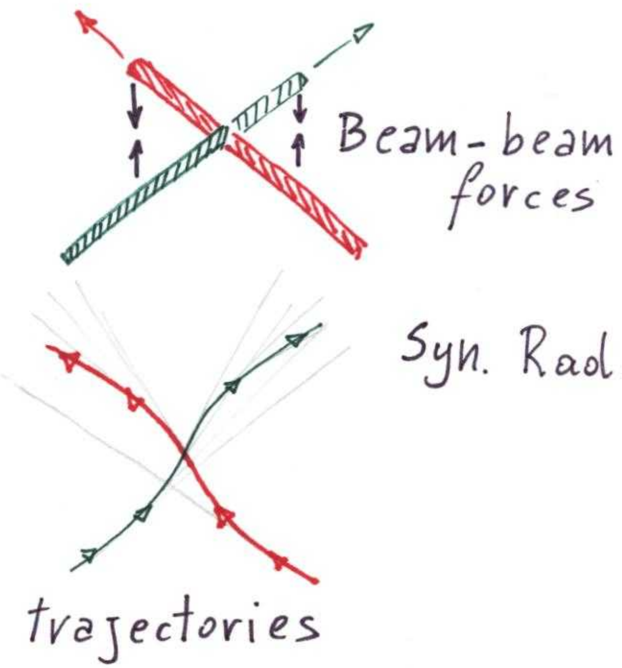
II : SMARTER APPROX.

wish list

- Multipole expansion of the field outside the colliding diamond
- Adaptive mesh size and finesse
- Adaptive slice width

→ Trade - off GPU time ↔ dev time

Beam- Strahlung



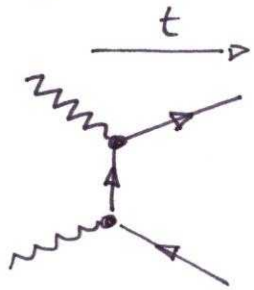
- Beam-beam forces deflect e^- and e^+ from the rectilinear motion
- Bending on the x-z plane

$\Downarrow$

- Syn. Rad. on the same plane
- More on next talk

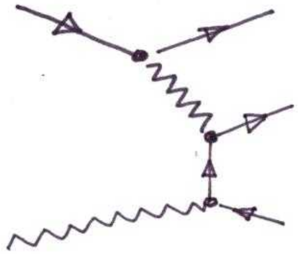
Pairs production.

Breit-Wheeler



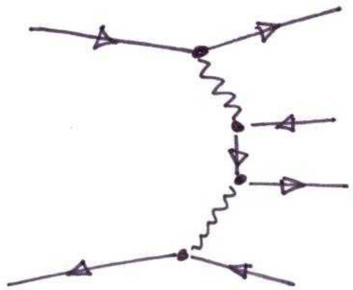
$\gamma\gamma \to e^+e^-$

Bethe-Heitler



$e\gamma \to e\, e^+e^-$

Landau-Lifshitz



$e^+e^- \to e^+e^-\, e^+e^-$

Guinea pig simulates these processes.

→ Vertices $\alpha_{e.m.}$ suppression

→ soft photons (propagators poles)

↓

huge cross section $O(10$ m barn$)$

Pairs production

- ~40 e^+e^- pairs produced / bunch crossing
- just a few wit p_t big enough to reach
  1 cm with 1.5 Tesla
- Remind $f_{crossing} = 600$ MHz
- Small beam pipe radius → longer p_t acceptance
  ↓
  High luminosity → High occupancy in inner tracker.
- See next talk

Conclusions

- Faster/coarser version of G.P. ready for next round of Mathematica campaign of parameters optimization
- Background studies (beam-strahlung, e^+e^-) possibles
- Wish list (even faster, more precise) in progres