GEANT4 Simulations of the DAΦNE Interaction Region and Study of the Touschek Effect

Stage de pré-thèse NPAC

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LAL, Orsay
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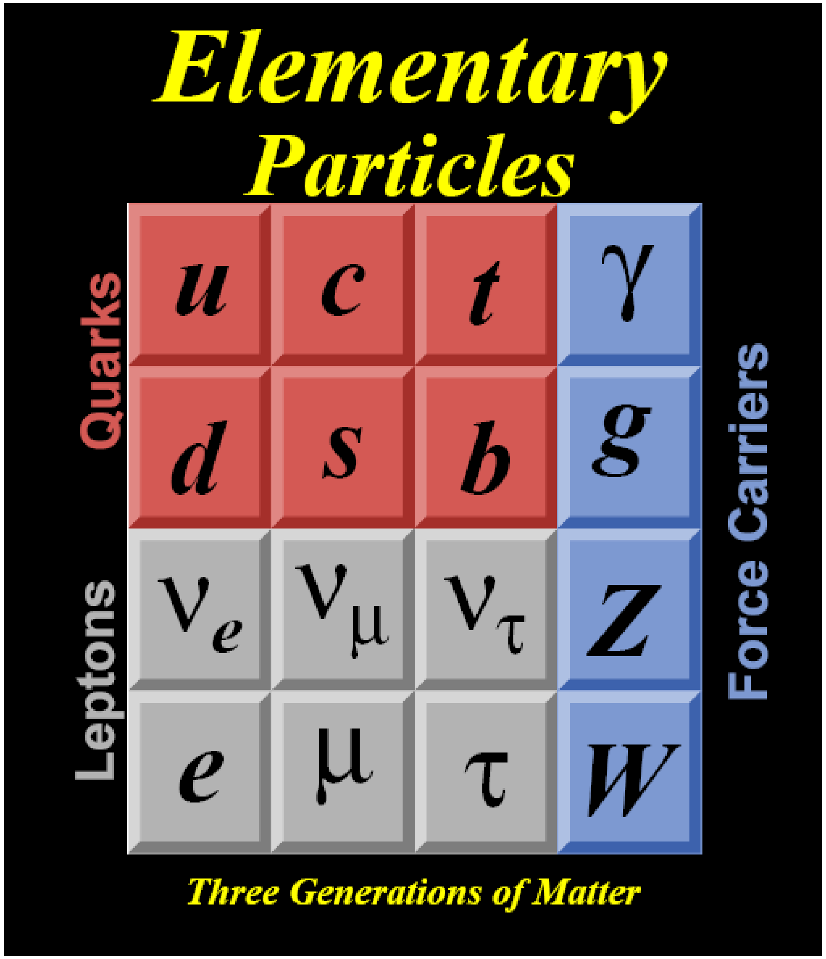
Standard Model and open questions

Standard Model (SM): accurately describes all the measurements performed until present moment.



BUT still there are open questions!!!

Why the number of generations is three?

Mass hierarchy problem:

Why are the quarks masses so different between the 3 generations ?

masses (MeV/c^2)

u	1.5 – 4.0	d	4 – 8
s	80 – 130	c	1150 – 1350
b	4100 – 4400	t	170900 ± 1800

Flavor and CP violation sector of the SM has open questions as well!

Flavour Physics : a way to look for New Physics (NP) beyond the Standard Model

Flavor and CP violation accounted for by SM **assuming** that the flavor eigenstates are not the same as the physical (mass) eigenstates

$|V_{ud}|e^{-i\beta}$ $\qquad$ $|V_{td}|e^{-i\gamma}$

Complex !
=> CP violation in SM

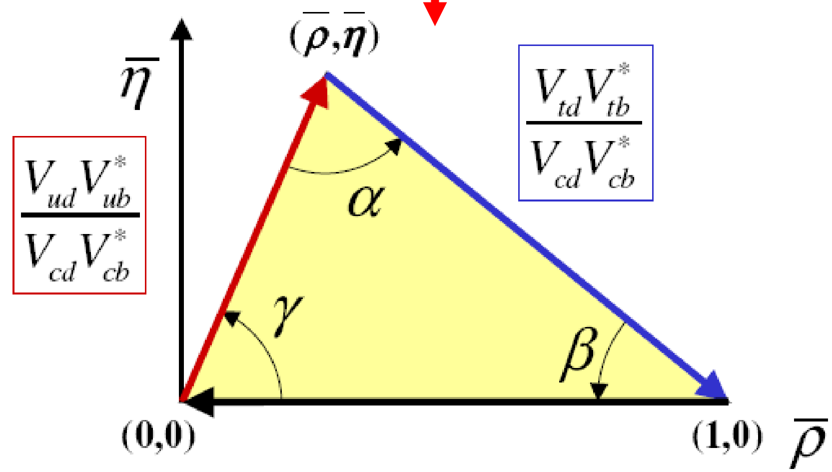
CKM matrix

$$\begin{pmatrix} d \\ s \\ b \end{pmatrix}_f = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_m$$

Unitarity of the CKM

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$$\frac{1}{V_{cd}V_{cb}^*} \quad \text{real}$$



Method to look for New Physics

Several independent measurements of the sides and angles of the UT

If they do not sum up to a triangle

→ **new physics !!!**

Flavour Physics : a way to look for New Physics (NP) beyond the Standard Model

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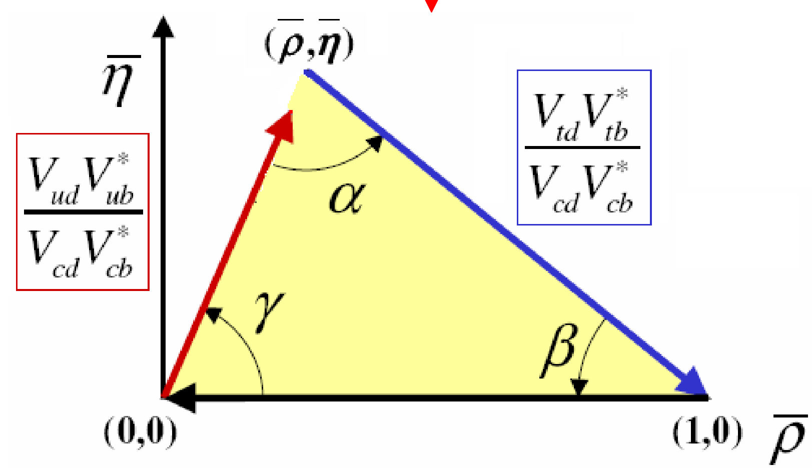

Method to look for New Physics

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If they do not sum up to a triangle

→ **new physics !!!**

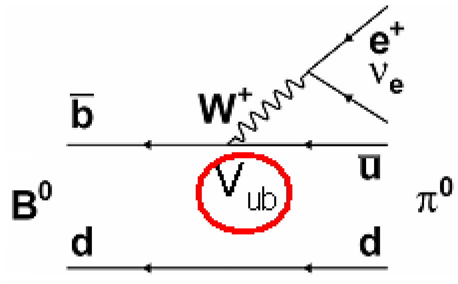
Possible decays for measure the parameters of the UT

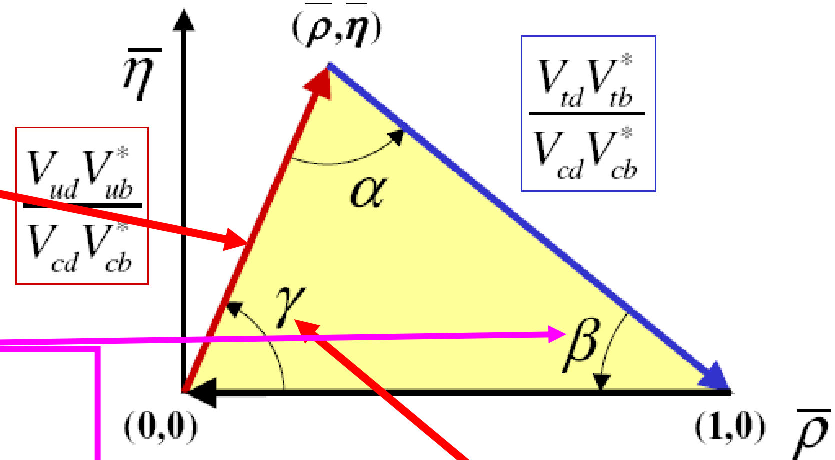
B-mesons decays are used to measure CKM parameters

$$|V_{td}| = 0.00814$$
$$|V_{ub}| = 0.00396$$

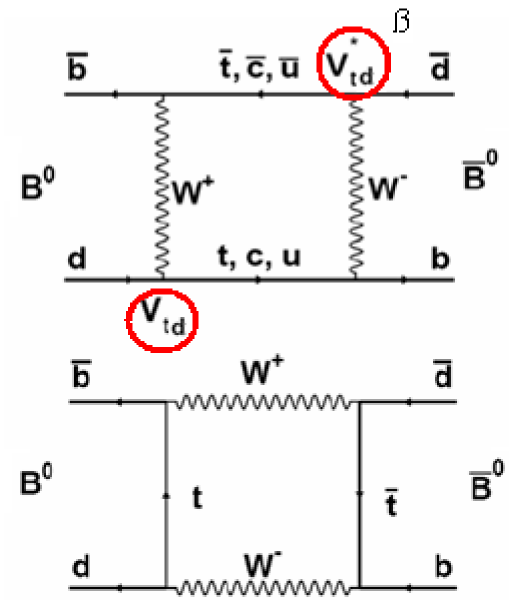
CP violation is a **subtle** effect

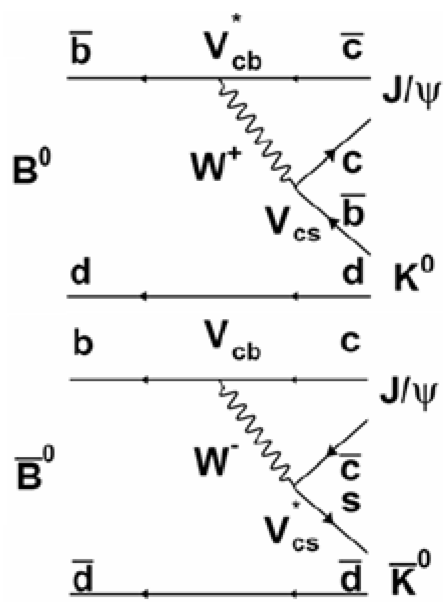
$$BR(B \to \pi^- l^+ \nu_l) \sim 10^{-4}$$



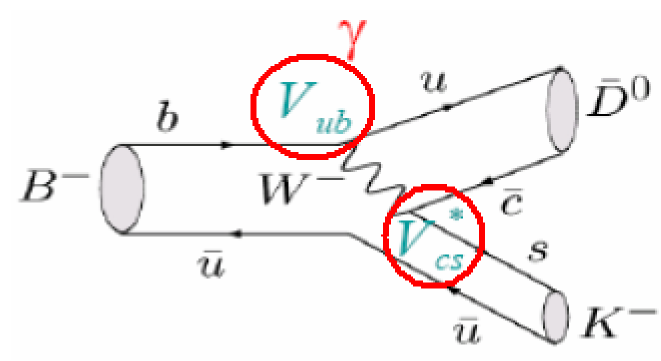


$$BR(B \to J/\psi K^0) \sim 10^{-4}$$





$$BR(B^- \to K^- \bar{D}^0) \sim 10^{-6}$$



Due to small *BR's* we need tons of $B\bar{B}$ pairs

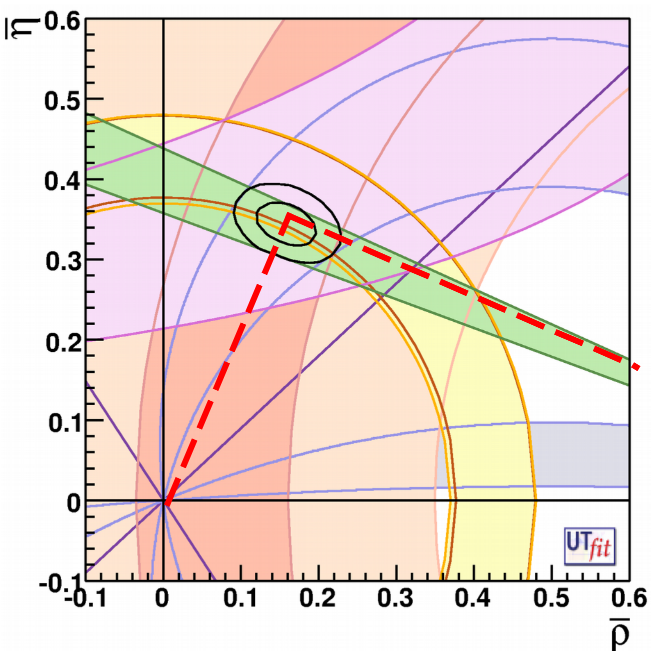
→ Super B - factory

Super B-factory

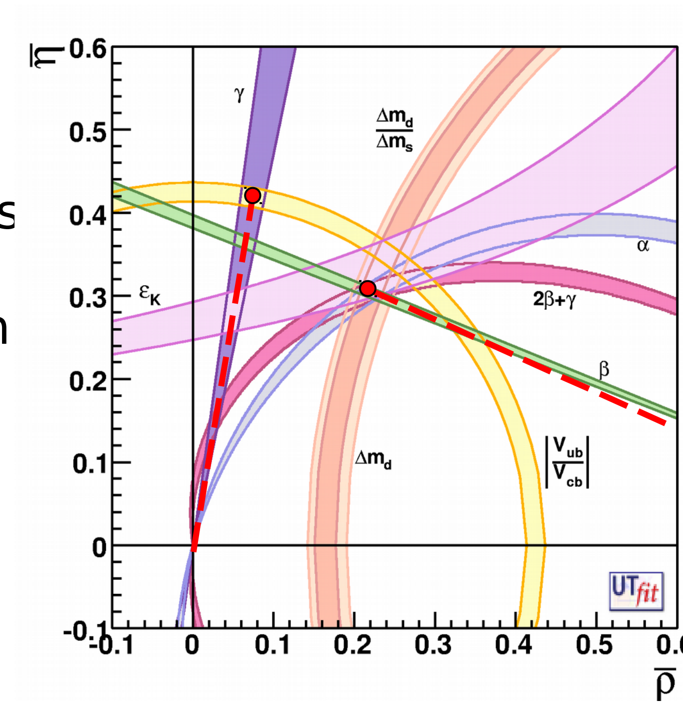
PEP-II and KEK-B B-factories accumulated nearly a billion $B\bar{B}$ pairs between 2000 and 2008: $e^+ e^-$ collisions with $L=10^{34}$ $cm^{-2}s^{-1}$.

No deviation from SM was observed within the present precision.

Super B-factory will improve a lot this picture :



We need 100 times more statistics to hopefully obtain th

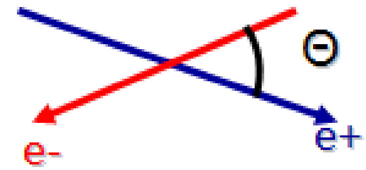


How to build a <u>Super</u> B factory with L=10^{36} cm^{-2}s^{-1}

How to increase luminosity

$$L = \frac{N_1 N_2 \cdot f_c}{4\pi\sigma_x\sigma_y\sqrt{1+\Phi^2}}$$

$$\Phi = \frac{\sigma_z}{\sigma_x} tg\left(\frac{\theta}{2}\right)$$



Overlapping angle

N_1 N_2 - are the number of particles in the e+ and e- bunches, respectively.

f_c - is the frequency at which an electron bunch crosses a positron bunch at the interaction point.

Inside a bunch, the particles are distributed according to 3 $\sigma_x, \sigma_y, \sigma_z$ dimensional Gaussian with

Φ - the Piwinski angle.

- **One possibility**: increase the e+/e- currents

Extremely expensive

Another Way: Reduce σ_x & σ_y !

BUT :

1 **D - disruption** $D \,?\, \frac{N\sigma_z}{(\sigma_x\sigma_y)}$

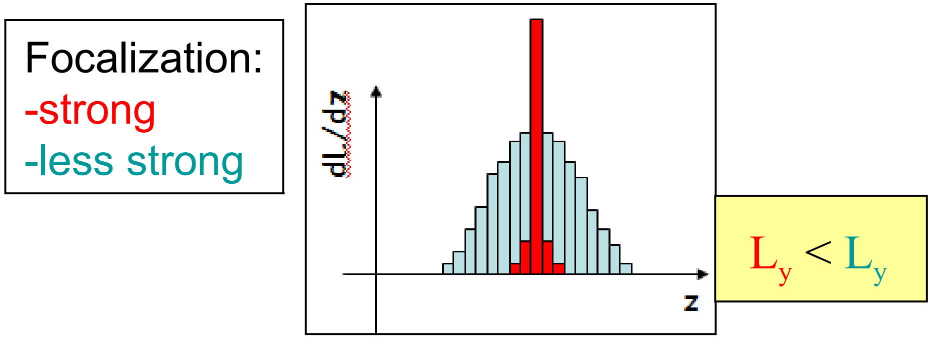
Distorts the bunch !
Must be kept small if we
want to re-use the bunch !

Impact of the E.M field from one bunch on the particles of the other bunch

2 **Larger "hourglass effect"** (see backup) **:**

- A very small σ_y at the IP needs a very quick focalization as function of z.
- If the focalization is too fast, we can produce luminosity only right at the IP

=> Luminosity killer



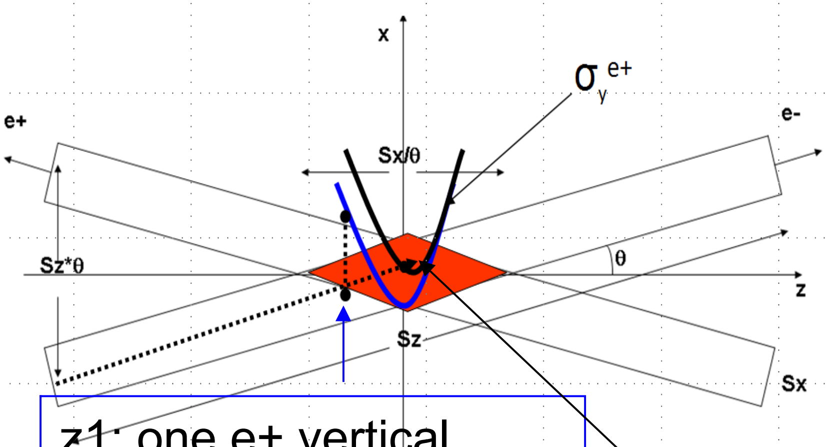
Both effects can be reduced by lowering σ_z

But this is very hard to do

Solution: Piwinski Angle and Crab Waists

Crossing angle between e^+ & e^- : bunch overlap length no longer σ_z, but $\sigma_x/\theta << \sigma_z$!

<u>*But*</u>*: Charge density, thus the forces, felt by e^+/e^- in the crossing region depends on x, y & z simultaneously !*



-Coupling between the x, y & z components of the e+/e- trajectories (**<u>oscillations around the collider</u>**)

-**Additional** betatron-betatron and synchro-betatron **resonances**, that make the accelerator **harder to control and tune.**

z1: one e+ vertical focalisation -> one density -> one Force

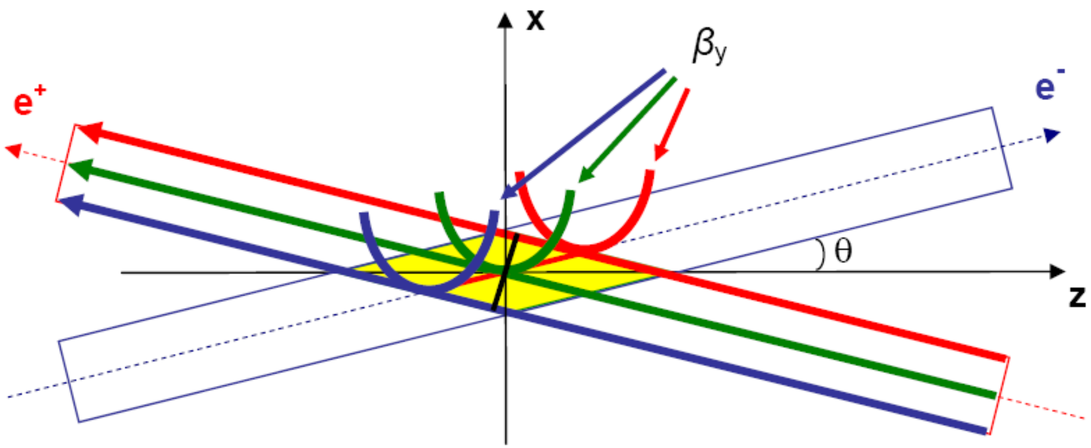
z2: another e+ vertical focalisation -> another density -> another Force

Force depends

on x**&z** or y**&z**

Solution: Piwinski Angle and Crab Waists

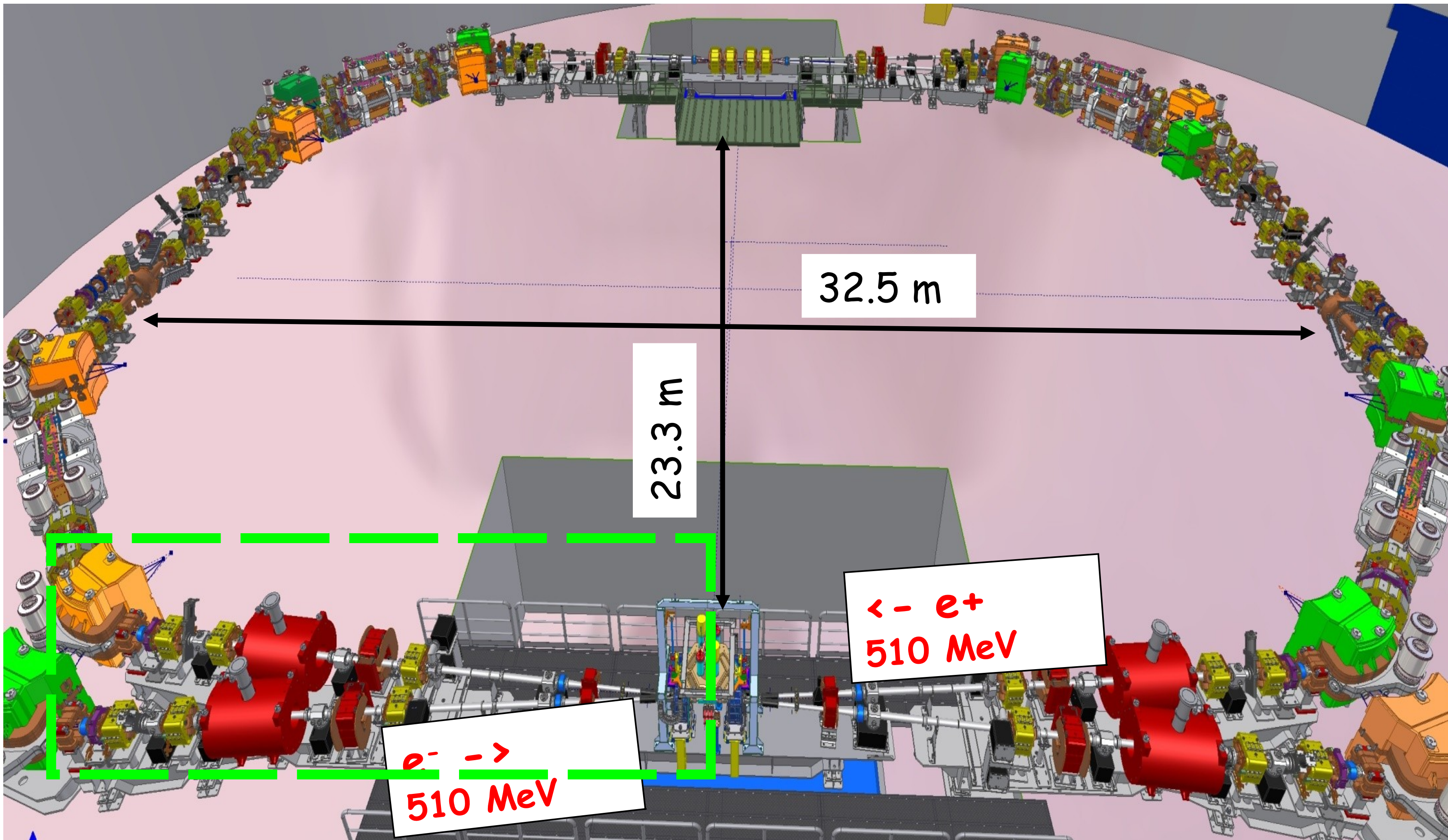
Solution is the crab waist scheme:



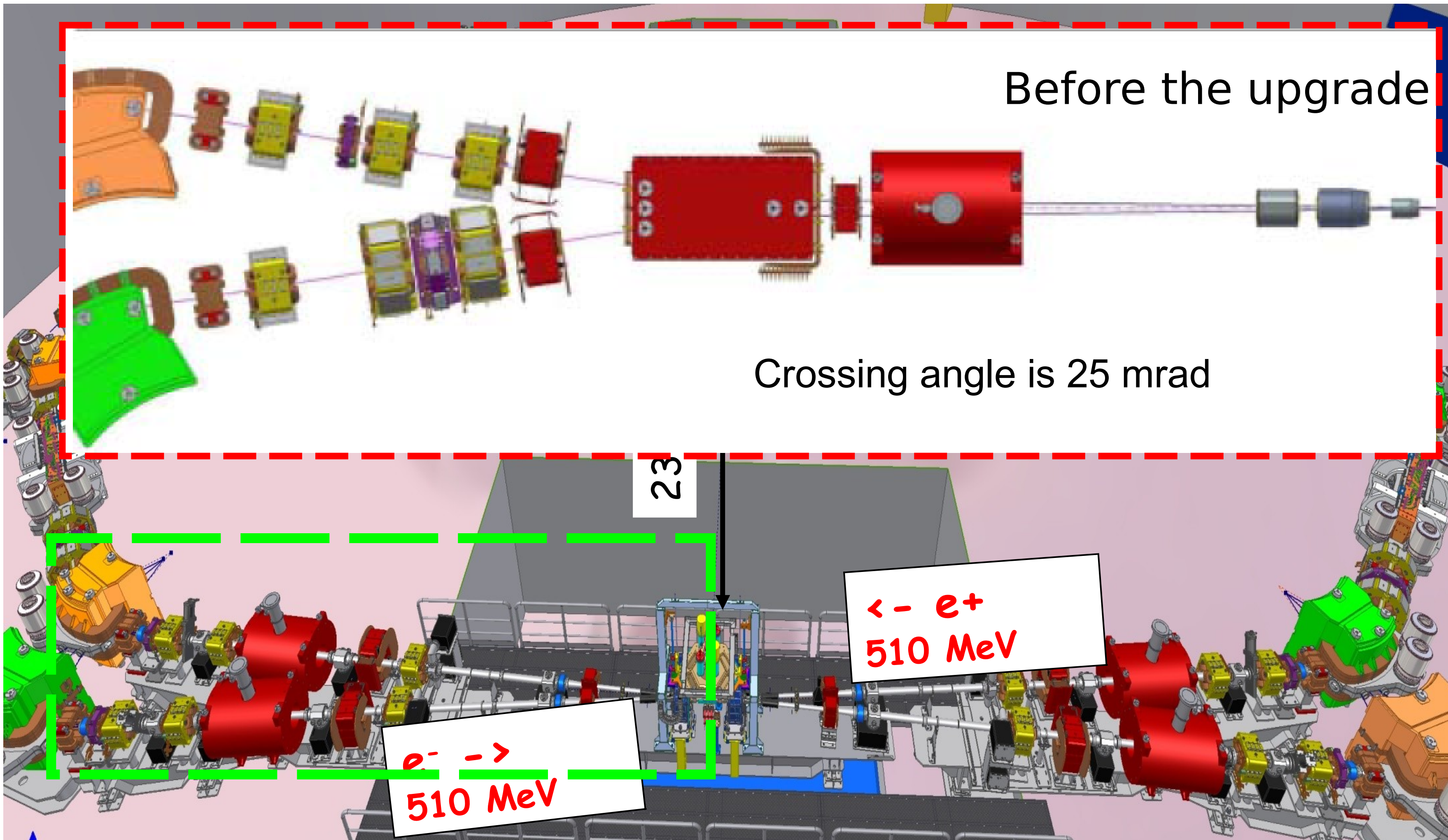
Implemented by 2 pairs of sextupoles on both sides of the IP

DAΦNE UPGRADE

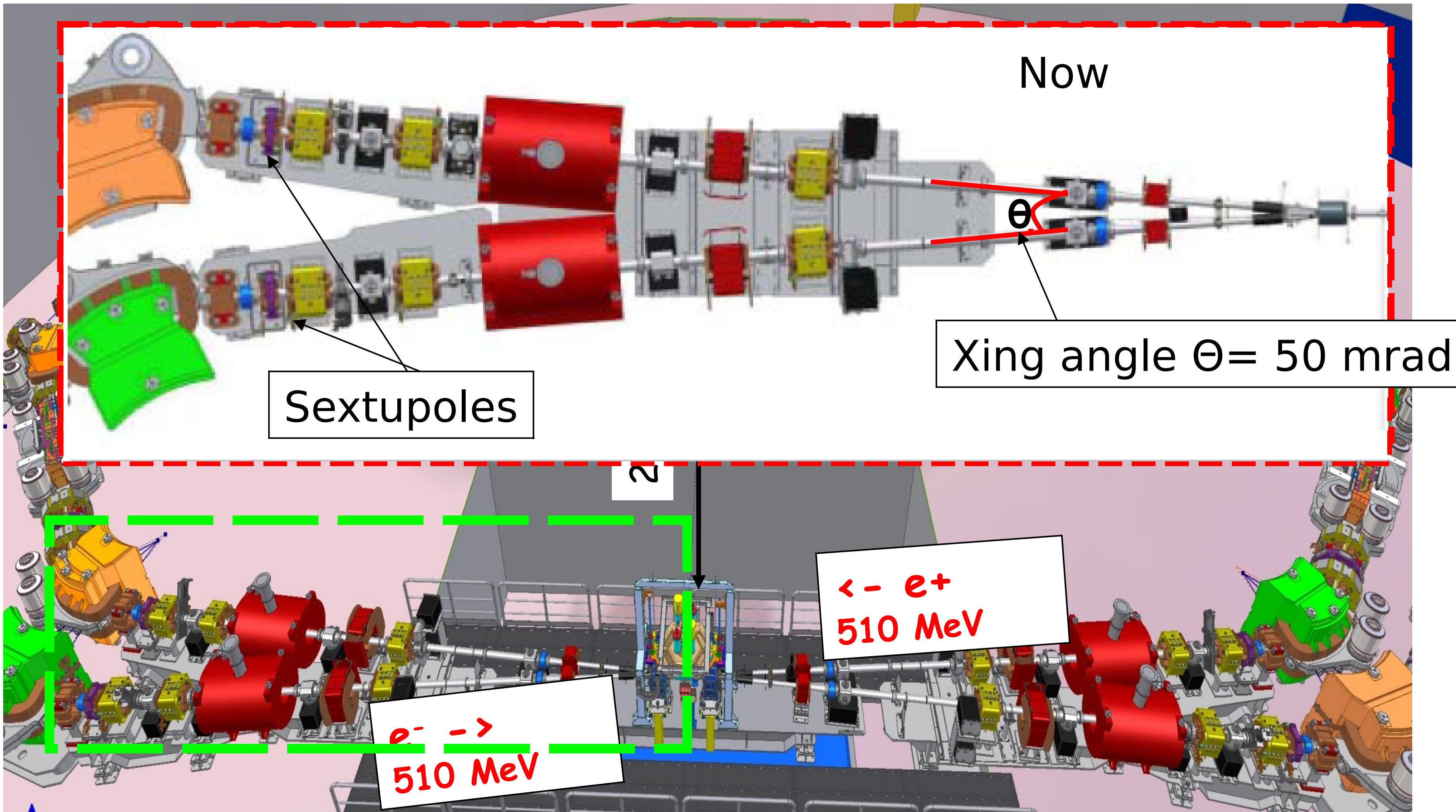
The DAΦNE Φ factory (LNF, Frascati, Italy) has been upgraded to test experimentally that the Crab Waist concept indeed works in reality.



DAΦNE UPGRADE

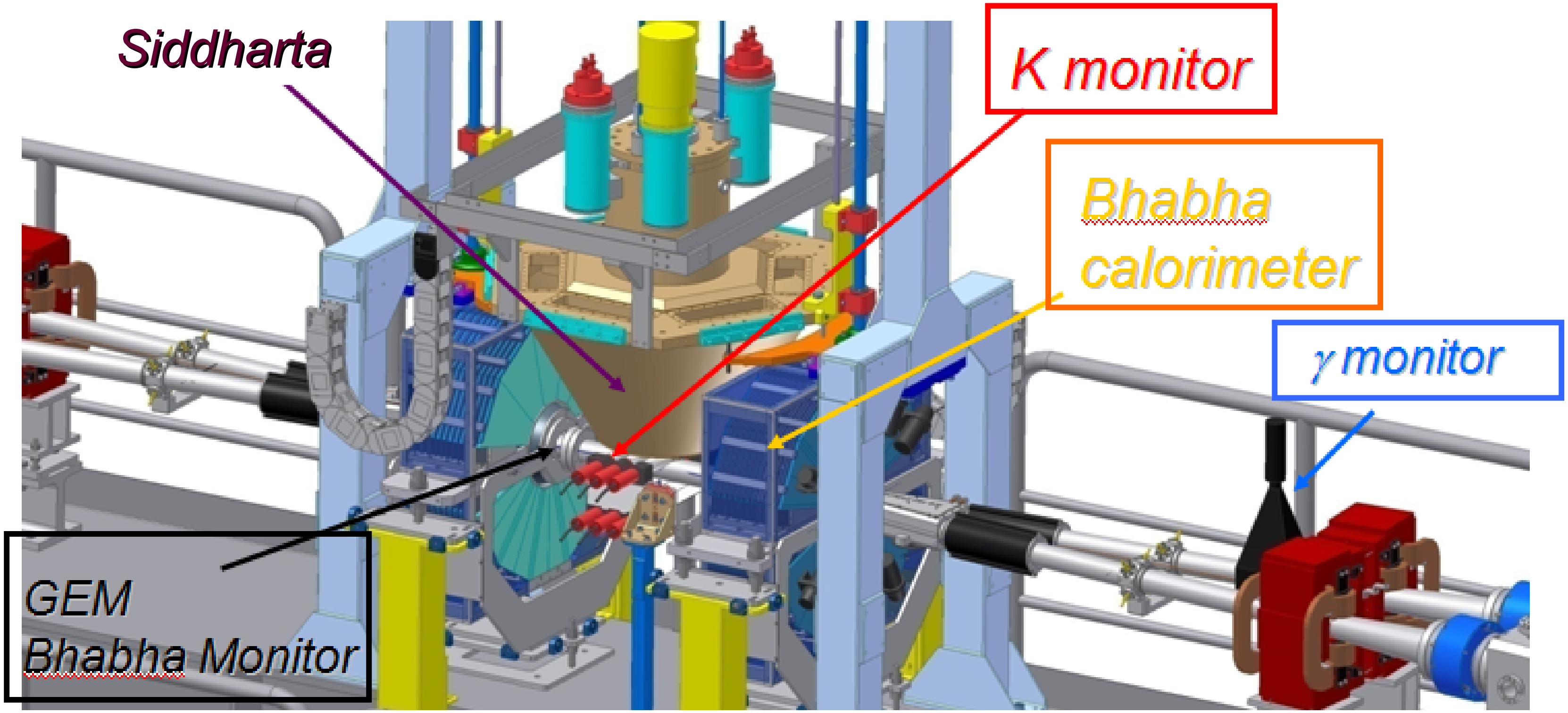


DAΦNE UPGRADE



Overview of the IP and Luminosity Monitors

Main idea ⟶ Luminosity ~ Bhabhas



- Use radiative Bhabhas $e^+e^- \rightarrow e^+e^-\gamma$
  - high angle e+/e- ($13^\circ < \Theta < 45^\circ$) : 1500 Hz
  - intermediate angle e+/e- ($18^\circ < \Theta < 27^\circ$) : 500 Hz
  - low angle γ ($\Theta \sim$ +/- 1.7 mrad) : some MHz

Online measurements !

Simulation of the Experimental Setup: Goals

- **Cross check and optimize the design and performance of the setup**
  - Is the energy resolution good enough ?
  - Is the acceptance good enough ?
  - How to modify the setup to improve those ?

Efficiency (detector acceptance + selection cuts). **From simulation**

- **Bhabha reconstruction efficiency**:

  Rate counted in the detector $R_{Bhabha\_reco} = L*\sigma*\varepsilon$ [Hz]

luminosity

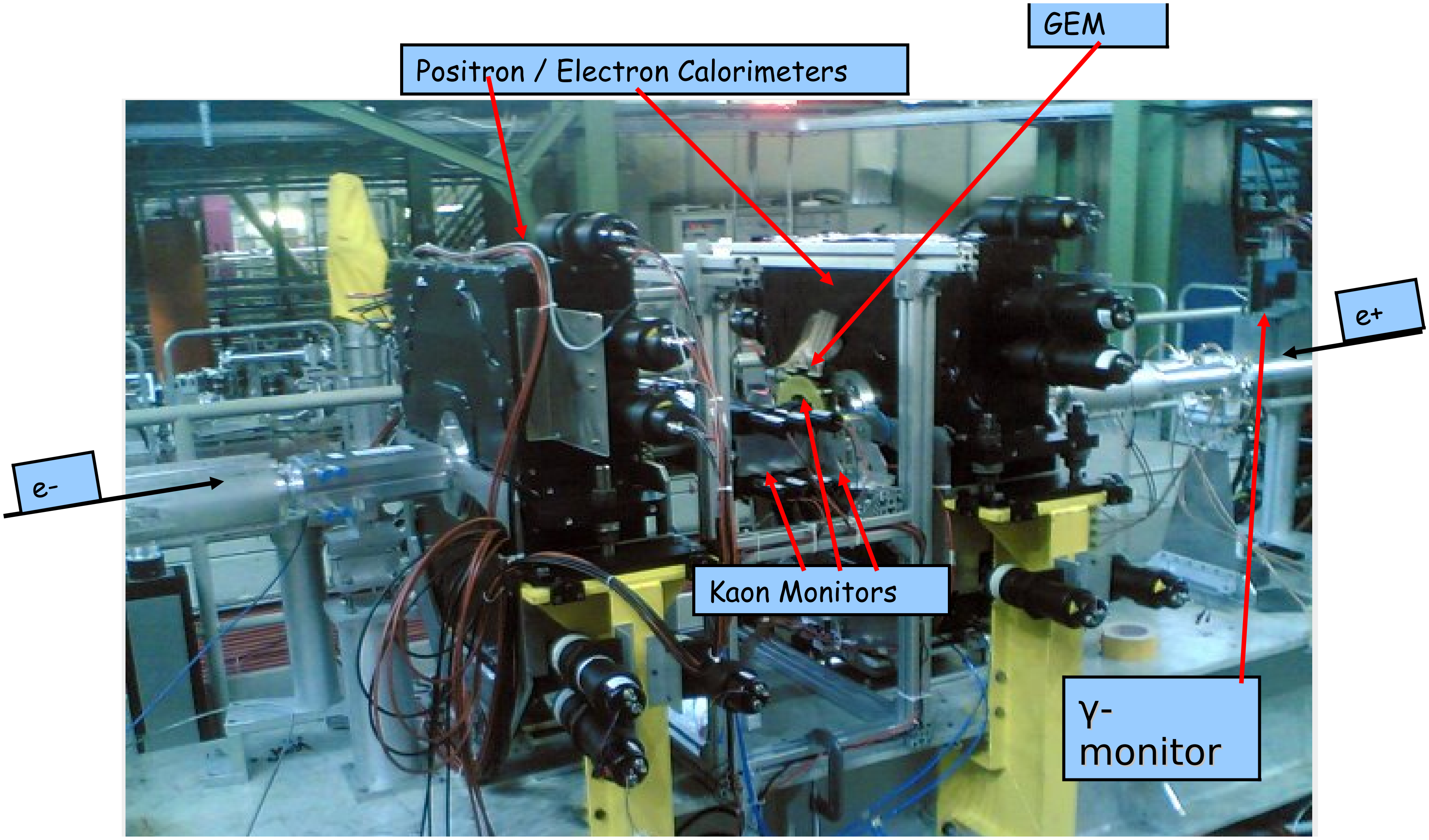
X-section well known from theory

<u>If</u> simulation predicts R = 450 Hz at L = 10^{32} cm^{-2}s^{-1}

and <u>if</u> in reality detectors see R= 600 Hz, <u>then</u> L= 1.33 10^{32} cm^{-2}s^{-}

- **Main steps of simulation**:
  - Implementation of the
    - geometry, material, magnetic fields
    - Interaction of particles with matter
  - Reconstruction:
    - Energy deposits $\xrightarrow{\text{convert } \boxed{1}}$ electronic signal $\xrightarrow{\boxed{2}}$ Reconstructed Energy, Time and Position of the hits $\xrightarrow{\boxed{3}}$ selection algorithm

In reality…



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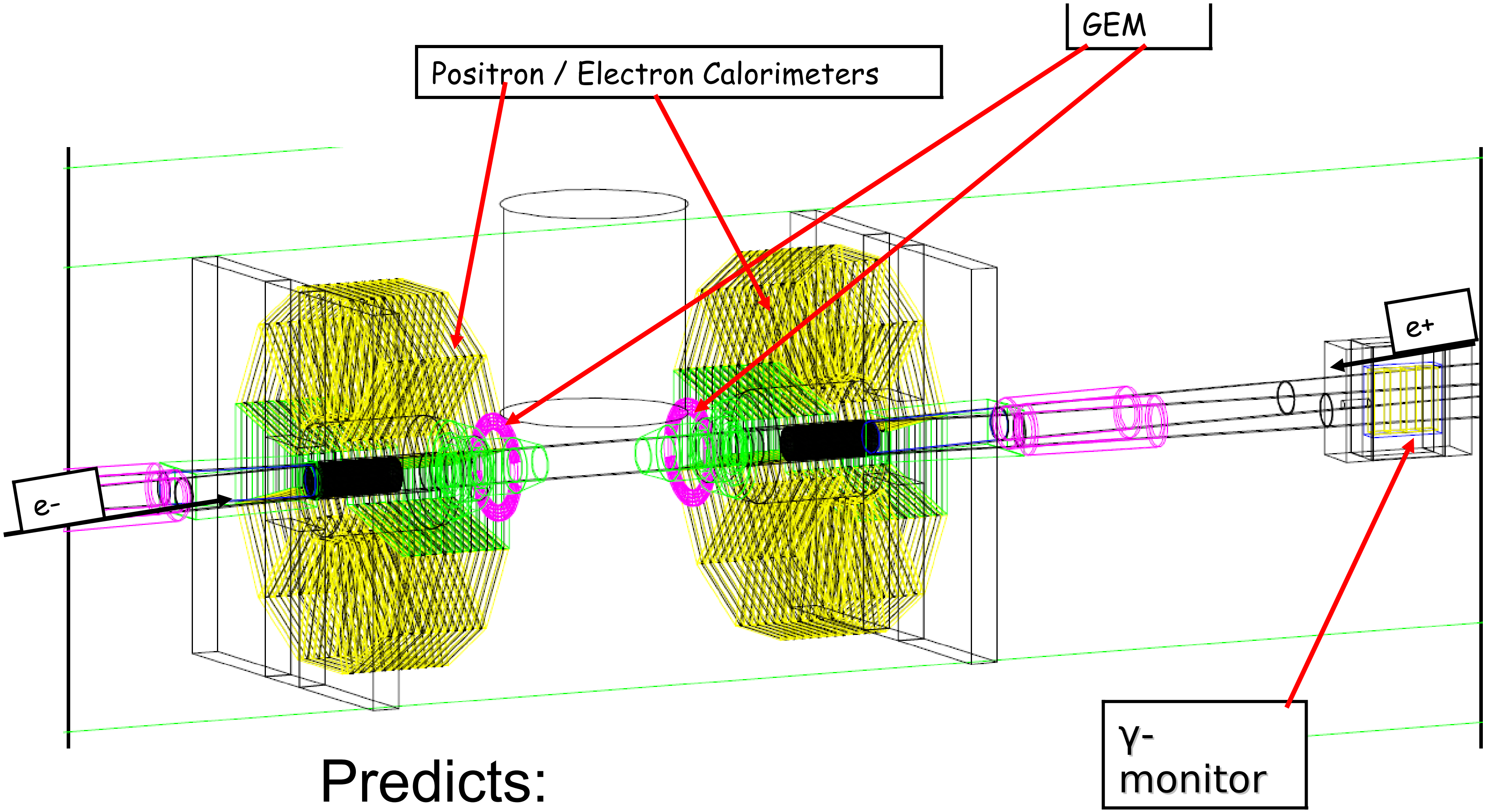
Already done with the GEANT3 package



Predicts:

$$R = 430 \pm 65 Hz \;@\; L = 10^{32} cm^{-2} s^{-1}$$

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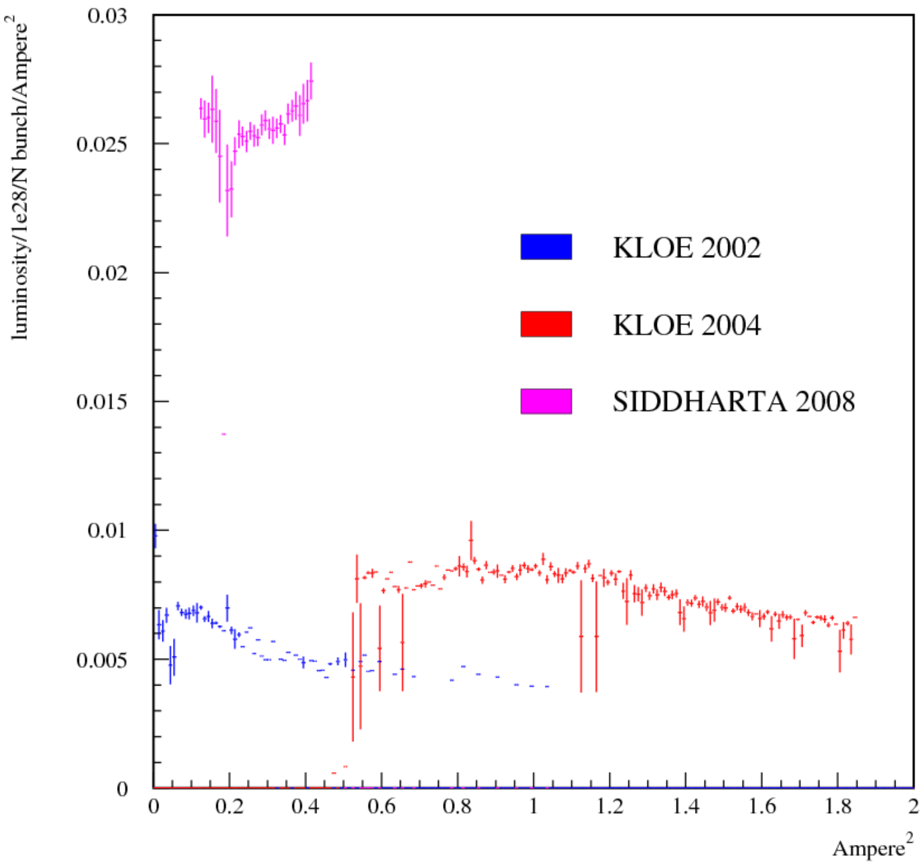
Experimental Results

$L_{Spec=.} L/10^{28}/N$ bunch [$cm^{-2}s^{-1}A^{-2}$]



Improvement of a factor ~2-3

	KLOE run	Upgrade
σ_y^* (μm)	7	4
σ_x^* (μm)	700	250

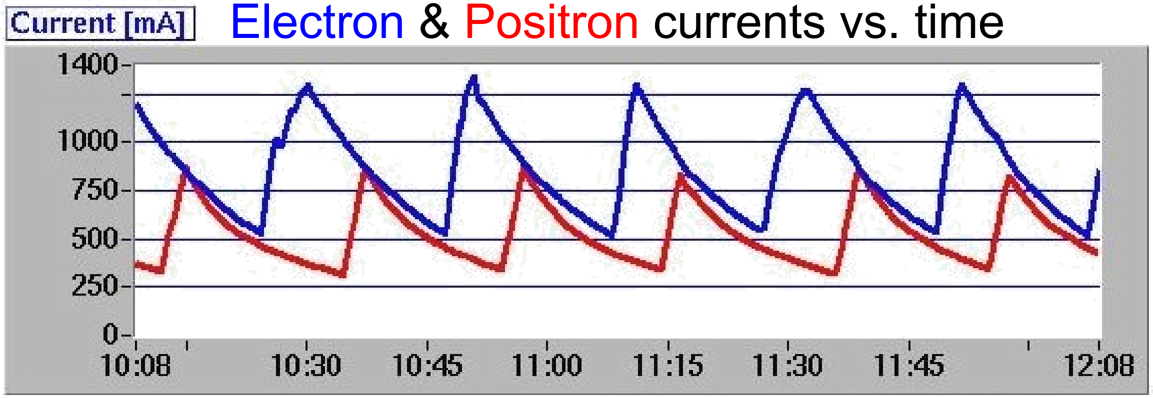
Sizes 3 times smaller and beams still under control !

Crabbed Waist scheme does work !

(at these currents)

My Work: Touschek Effect !!

Electron & Positron currents vs. time



~ 15 minutes lifetime !

Due to strong focalization, there is electromagnetic scattering between particles within one bunch. Some of the scattered particles can be lost by the beam:

Touschek effect

→This shortens the beam's **lifetime**

→Lost particles can be a **background** to the detectors (directly or via showers produced by their passage through matter)

Among the dominant sources of beam lifetime & background at a Super B-factory.

So must be well understood. **Study it with DAFNE !**

My work

The **physics simulation** gives us the **energy** of the Touschek particles, the **position** where they leave the beam pipe, and the **rate** at which this happens.

It does not take into account the interaction of these particles with matter (ex: when they cross the beam wall), nor the detector response.

This has to be done with GEANT. Already exist with GEANT3.

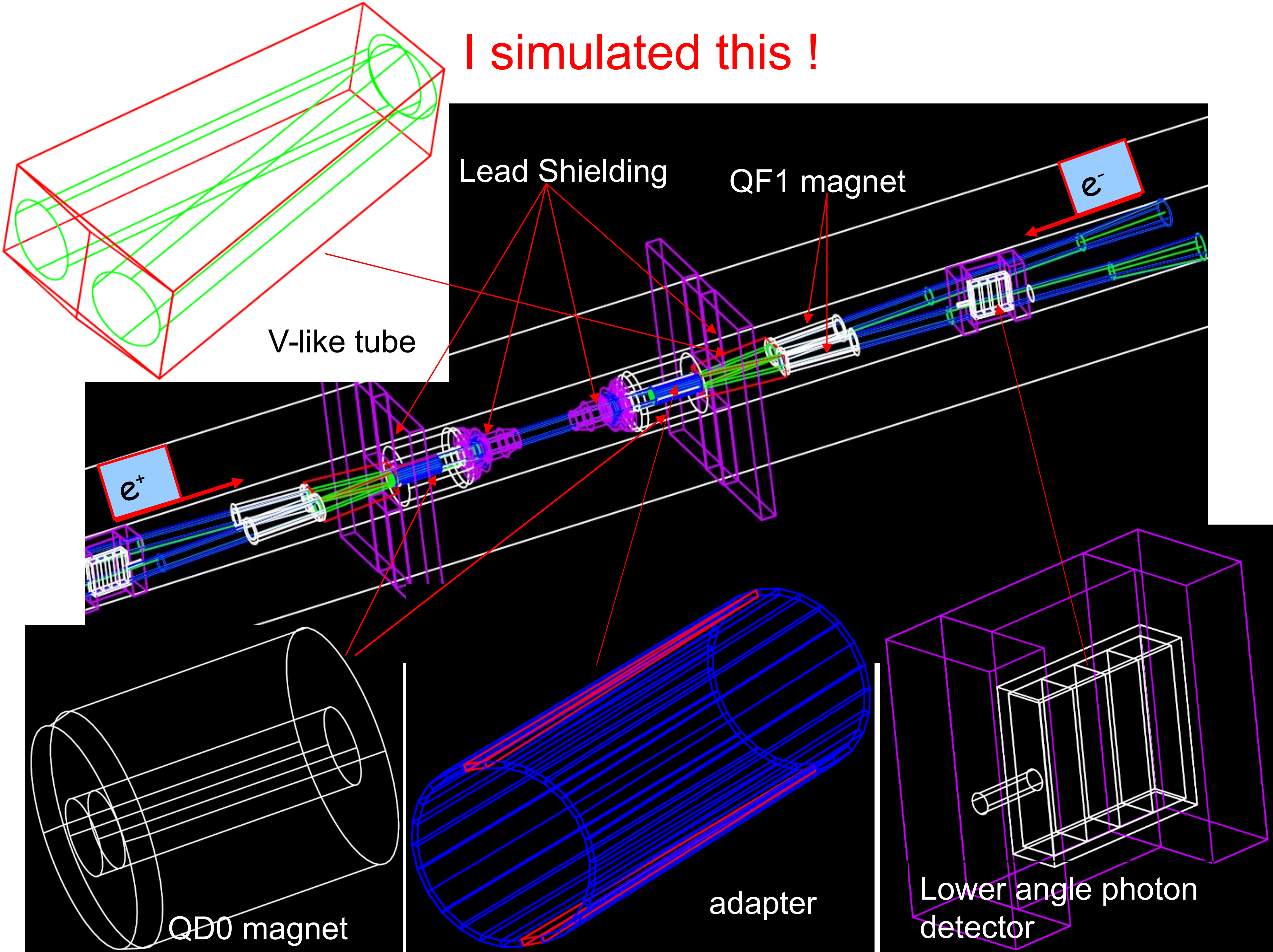
Has to be re-done with GEANT 4, since the results are very sensitive to what happens exactly when the particles interact with matter. Thus, it is a modern way to check:

- Correctness of implementation of the geometry
- Correctness of the material and mag. Fields implementation

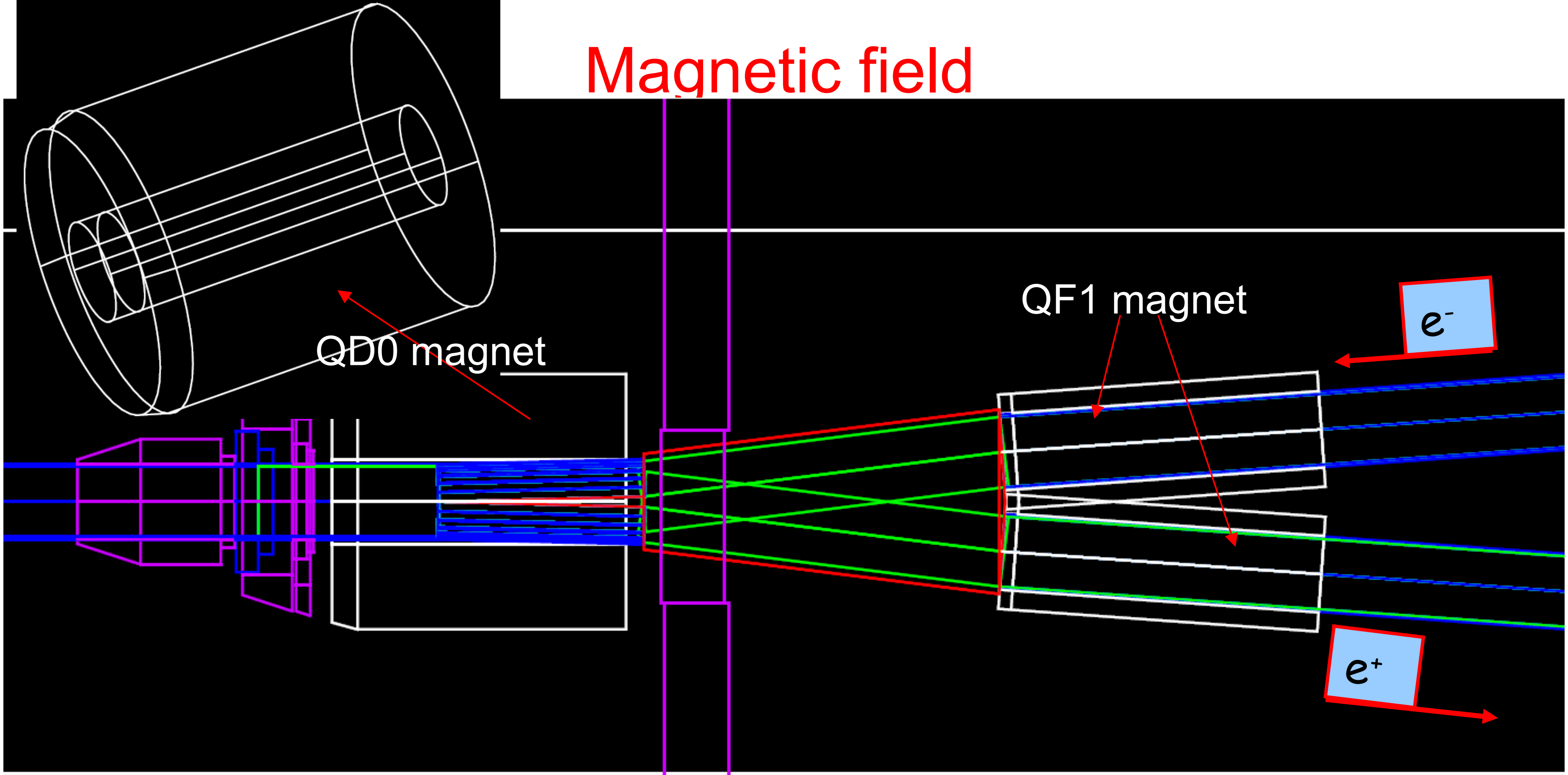
What I did during this stage !

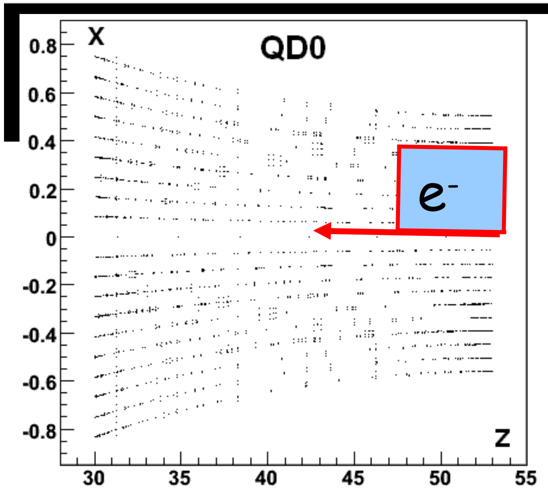
- To see on the difference between GEANT3 and GEANT4, in simulations of the interaction particles passing thru matter

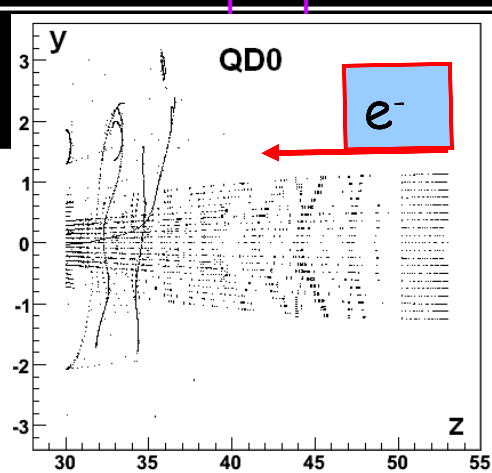
I simulated this !



Magnetic field







QD0 B_x [kG] = -2.938[kG/cm] y[cm]

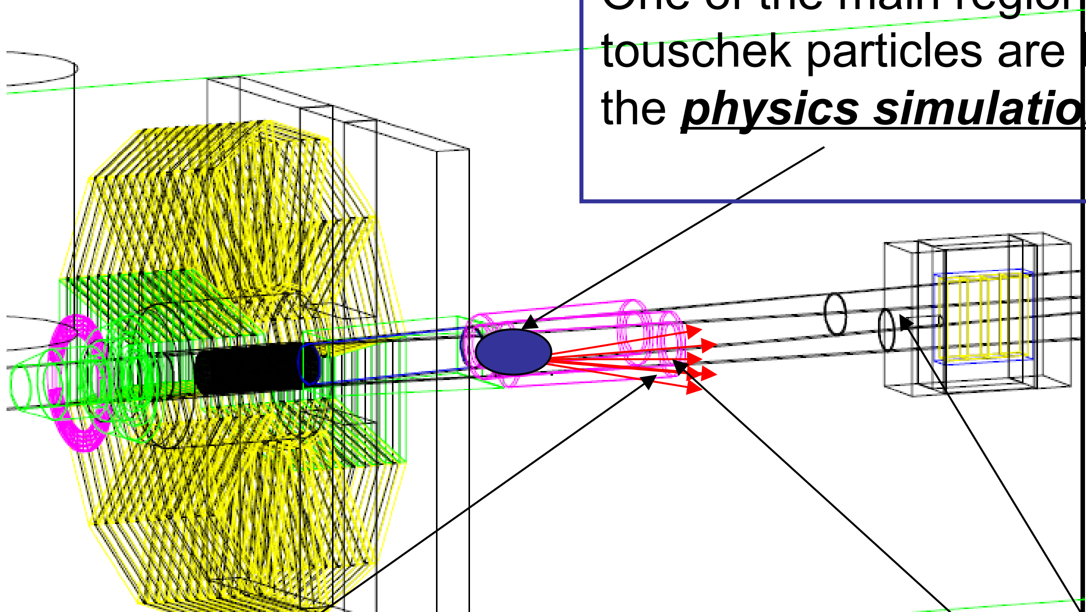
QD0 B_y [kG] = -2.938[kG/cm] x[cm]

Bz = 0

QF1 B_x [kG] = 1.25[kG/cm] y[cm]

QF1 B_y [kG] = 1.25[kG/cm] x[cm]

Next Step



One of the main regions where the touschek particles are lost, according to the ***physics simulation*** written at Frascati .

Shower created by the passage of Touschek particles through matter.

Flies right into the gamma monitor, that can thus be used to study this process !

What we want to do: check the accuracy of the physics simulation, i.e. of our understanding of the Touschek effect.
For that purpose: compare data with simulation.

Conclusion

- Important to study Touschek effect in the optic of the construction of a Super B factory, based on Large Piwinski Angle and Crab Waist.

- We use DAFNE for this study. Requires a full simulation of the DAFNE interaction region -> GEANT-4 simulation !

- I successfully completed the first part of this: material and fileds distribution.

- The rest of the study will be completed between now and early August:

  - Interface the Frascati Physics simulation my GEANT4 code
  - Simulate the response of the gamma monitor

    -> get the rate and energy distribution of the particles found in this detector and due to Touschek.
  - Compare this with real measurements at DAFNE

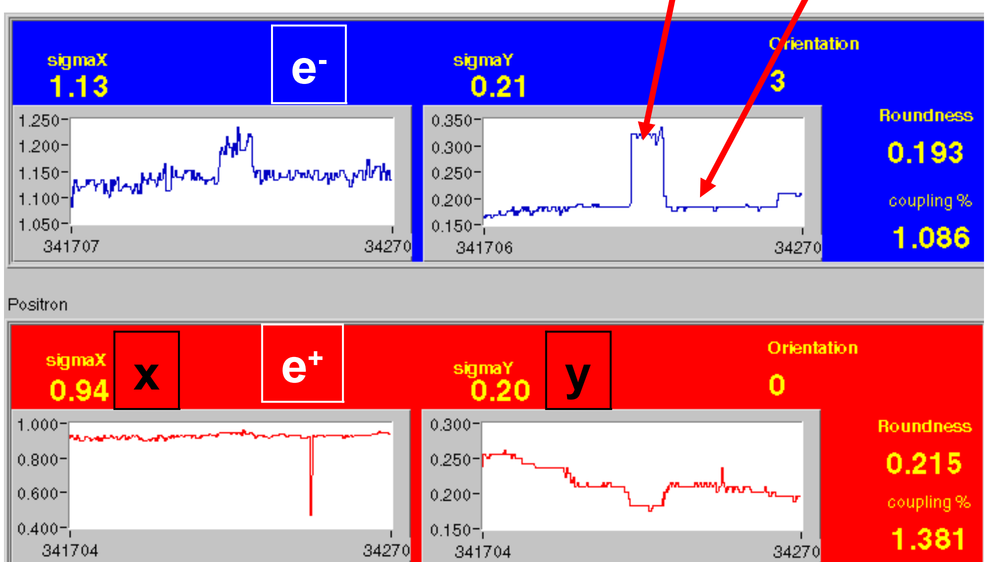
Backup

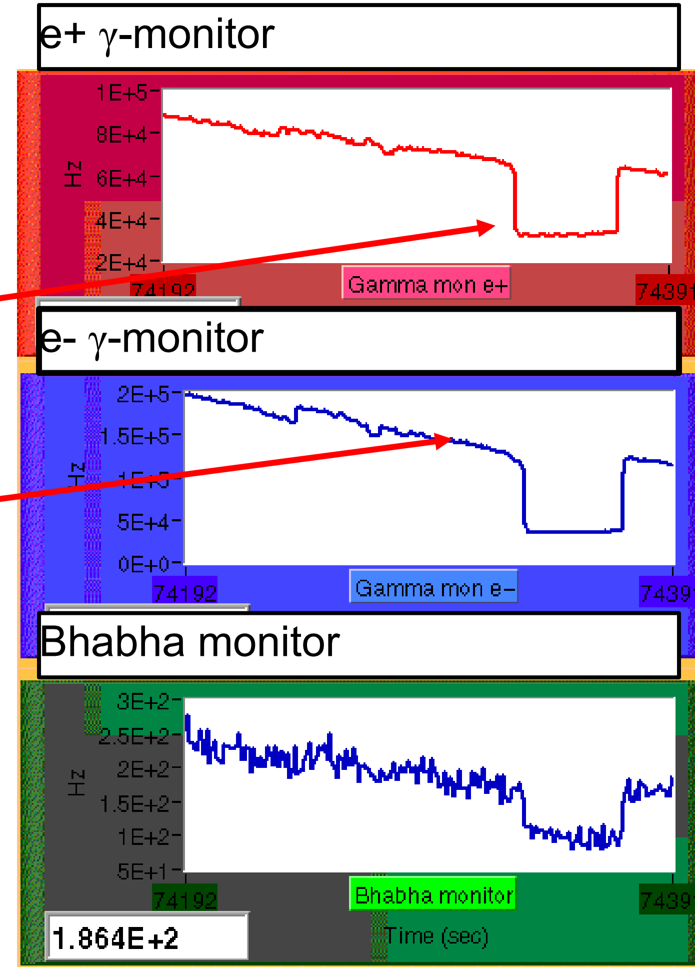
Evidence of working of the crabbed Waist scheme

- Switched off the electron beam crab sextupoles.
- Beam size immedialely blows up. (from synchr. light monitor)

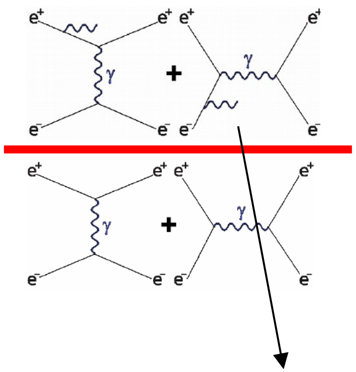
Crab OFF

Crab ON





Next Steps



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Additional crossed check and online monitor of Bhabha raid

To see this small effect the threshold have to be done to remove low energy noise.

Picture or formula of energy distribution of the energy of the gammas

Problem of this measurements is the is Height energy background comes from showers made by Touchek particle

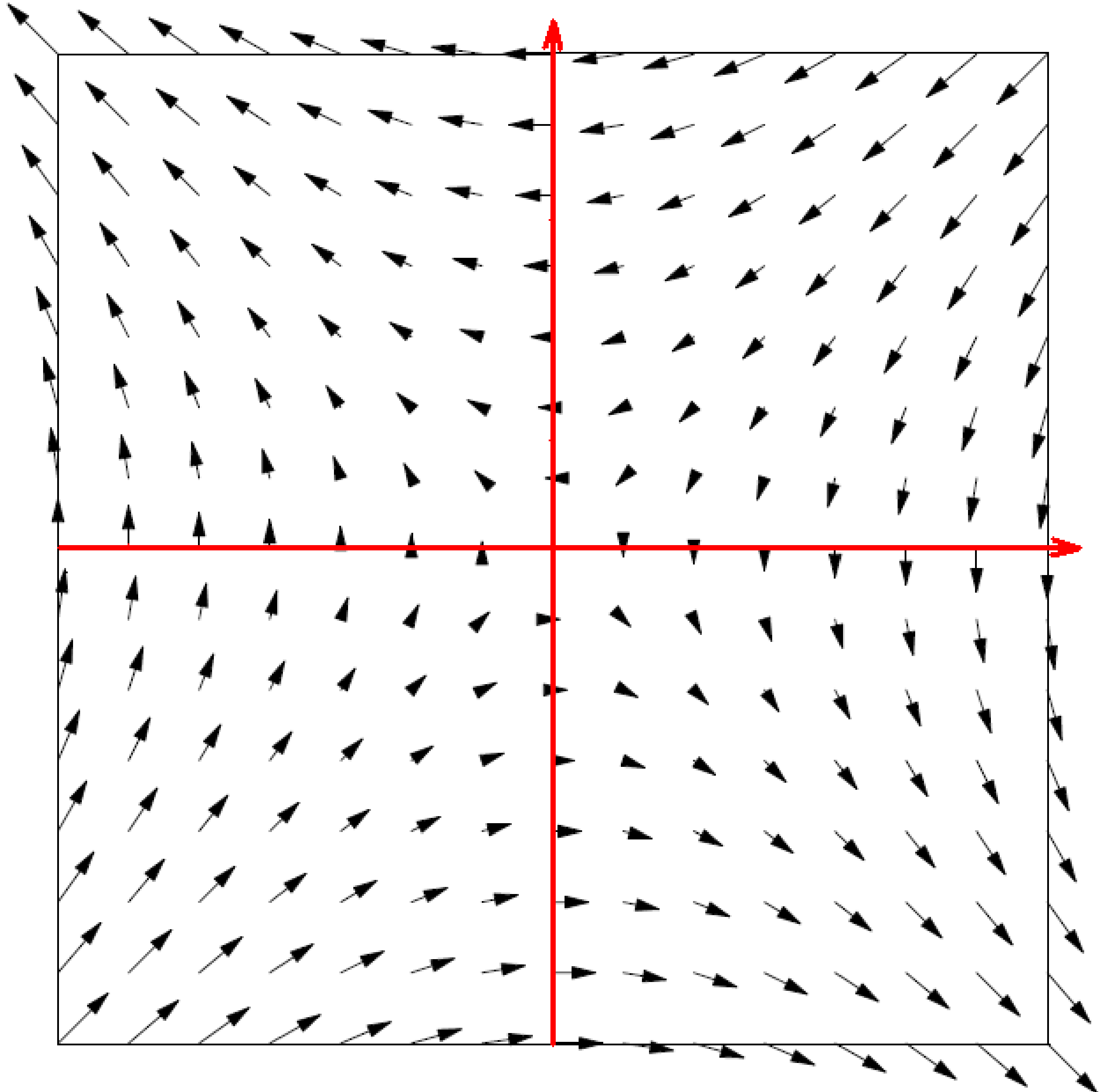
Planning proposed to the lumi coll :

-
-
-
-
-

Some pre. Results…

Use of photons detectors for

QD0



How to increase luminosity

Another possibility: decrease σ_x, σ_y

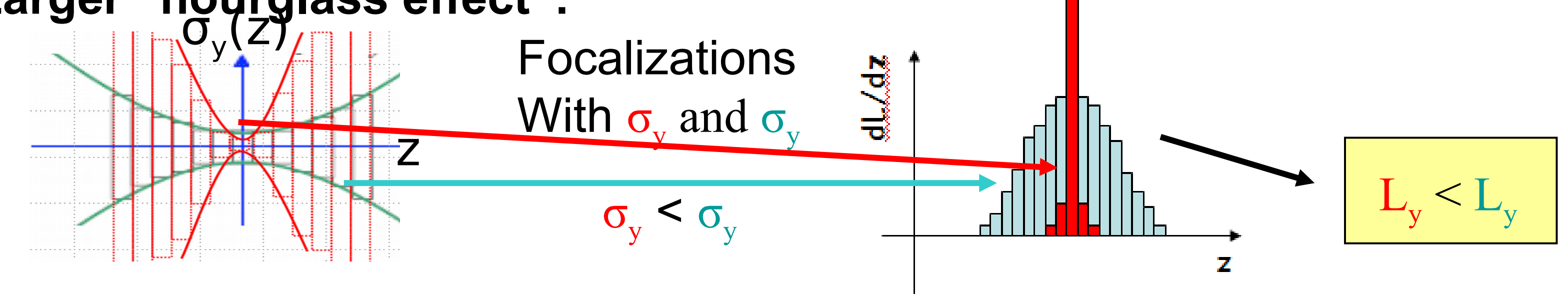
BUT :

1 **D - disruption** $D \propto \frac{N\sigma_z}{(\sigma_x \sigma_y)}$

Distorts the bunch !
Must be kept small if we want to re-use the bunch !

Disruption is due to the impact of the E.M field created by one punch into the particles from another bunch

2 **Larger "hourglass effect":**



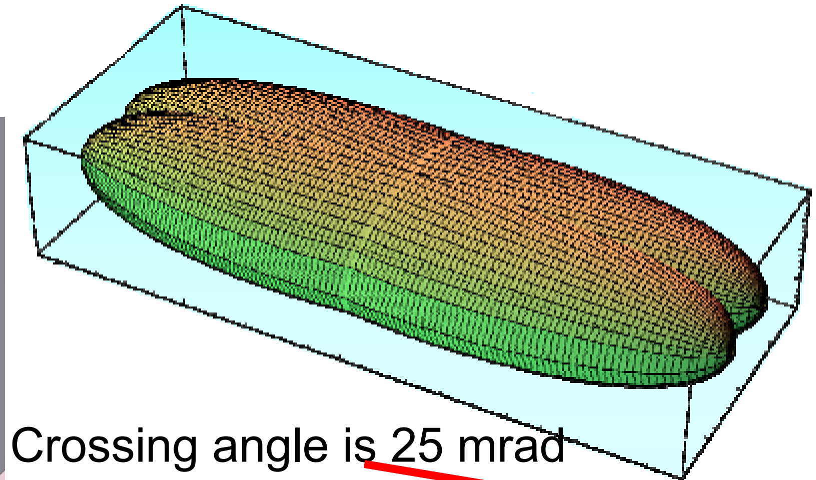
Focalization of the beam at the IP to increase the Lumi.
<u>But</u>: the stronger the focalization, the quicker the de-focalzation !

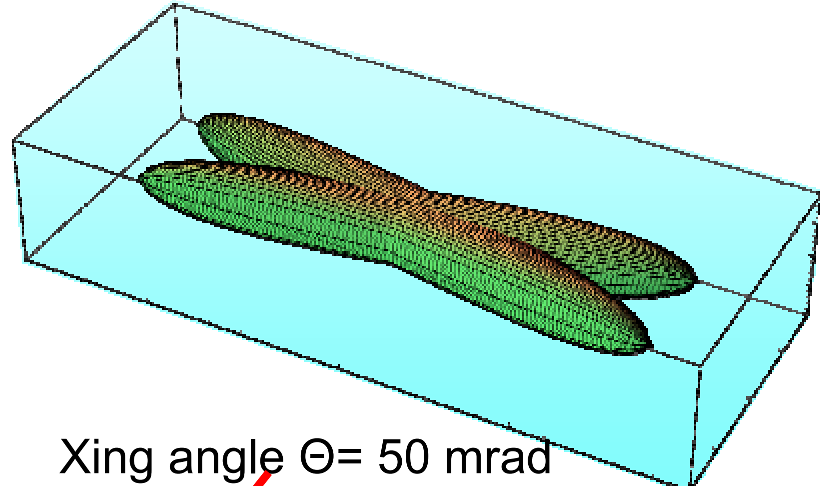
If σ_y too small w.r.t σ_z : particle density drops so fast, away from the IP, that in the end the Luminosity is in fact reduced.

Both effects can be reduced by lowering σ_z

This is very hard to do

DAΦNE UPGRADE





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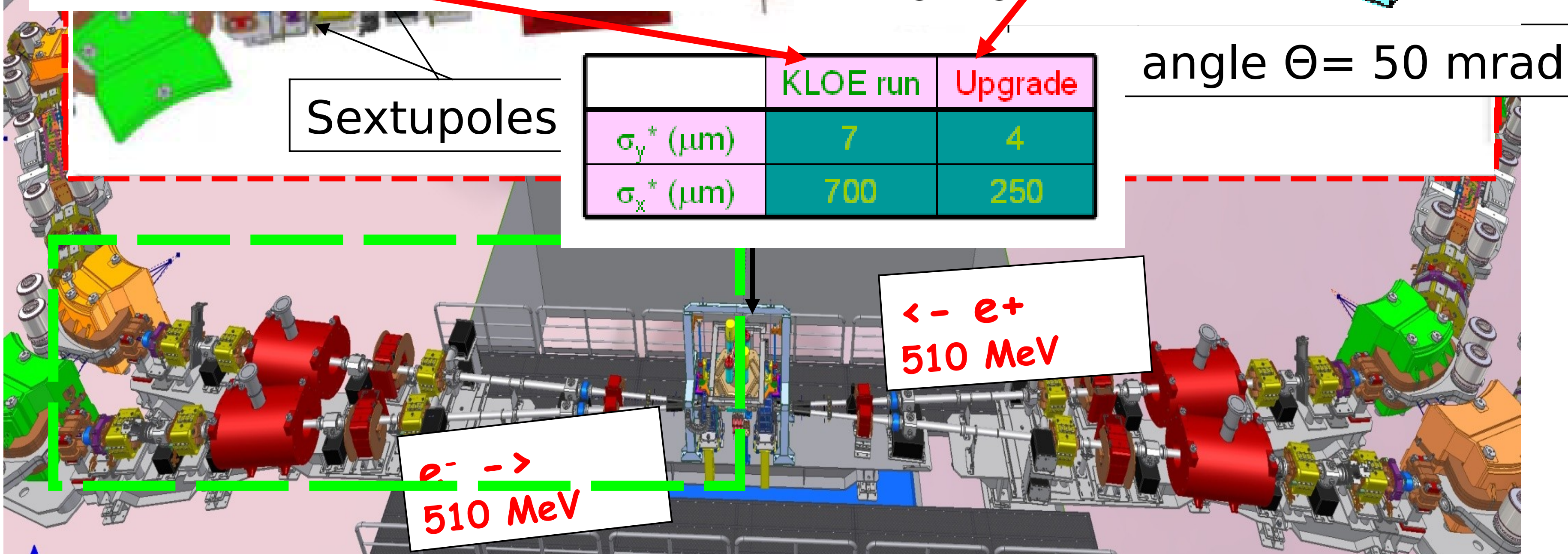


Another Way: Reduce σ_x & σ_y !

BUT :

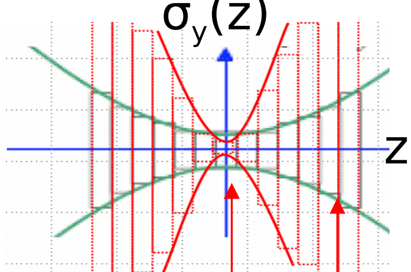
1 **D - disruption** $D \propto \frac{N\sigma_z}{(\sigma_x\sigma_y)}$

Distorts the bunch !
Must be kept small if we want to re-use the bunch !

Impact of the E.M field from one bunch on the particles of the other bunch

2 **Larger "hourglass effect":**
A very small σ_y at the IP needs a very quick focalization as function of z.

bunch longitudinal profile

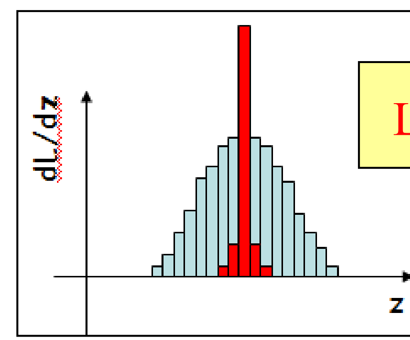


Very high Luminosity here

BUT

Lumi=0 here: charge density is too small.

Focalization:
-strong
-less strong



$L_y < L_y$

Both effects can be reduced by lowering σ_z

But this is very hard to do

(Θ,Φ) with σ~(3°,6°)
Helps finding back-to-back tracks

Triple-GEM trackers

Image Simu...

pads

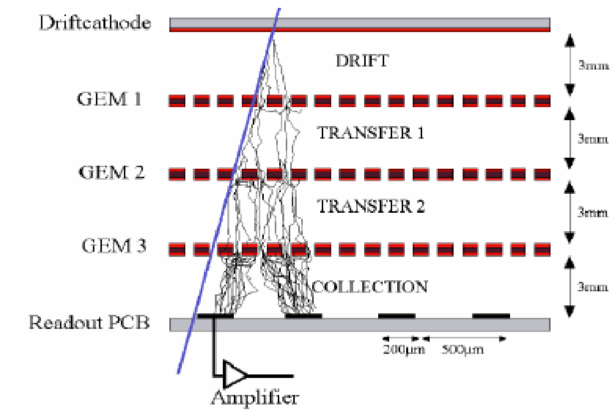
induction gap

GEM 3

GEM 2

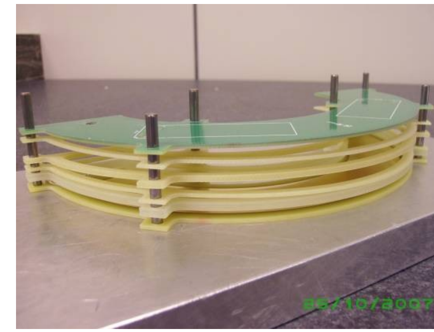
GEM 1

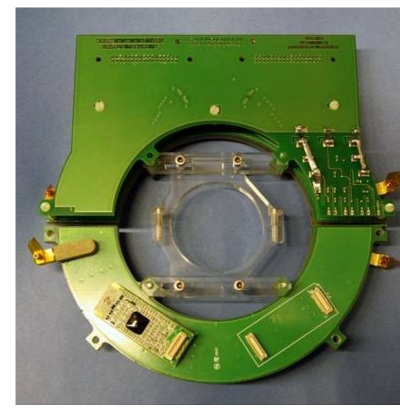
Cathode



→ Amplification ~ $20^3 = 8{,}000$
→ Sandwich {kapton, Cu, kapton}
→ ΔV between the copper layers

-> Eff(e+/-) > 99 %
-> Eff(γ) ~ 1%





Defines the acceptance of the Bhabha luminometer !

Still in commissioning...

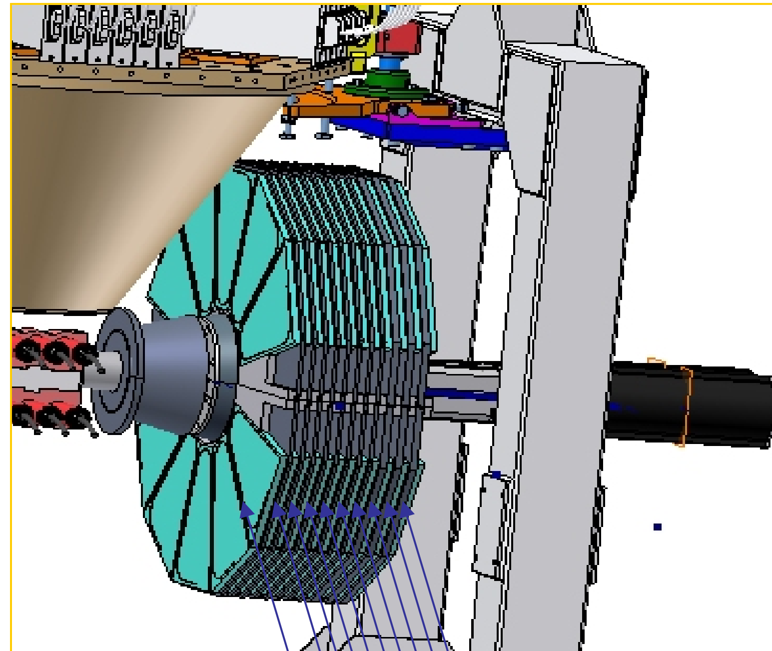
Bhabha Calorimeters

- 12 scintillator layers (Δz= 1 cm)
- 11 lead layers (8: Δz=0.5 cm + 3: Δz=1 cm)

⇒ ~$12X_0$: good shower containement

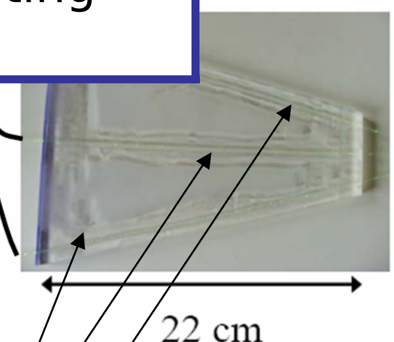
⇒ 2:1 active passive ratio : $\sigma E/E \sim 15\%/\sqrt{E}$

⇒ no longer than 20 cm to fit in available space (Siddharta -> Y-tubes)



Scintillating tiles

- 12 azimuthal sectors
  - horizontal ones not equipped (bkg+supports)
  - 12 = trade off between
    - the number of channels,
    - S vs. Bkg discrimination
    - Acceptance definition flexibility



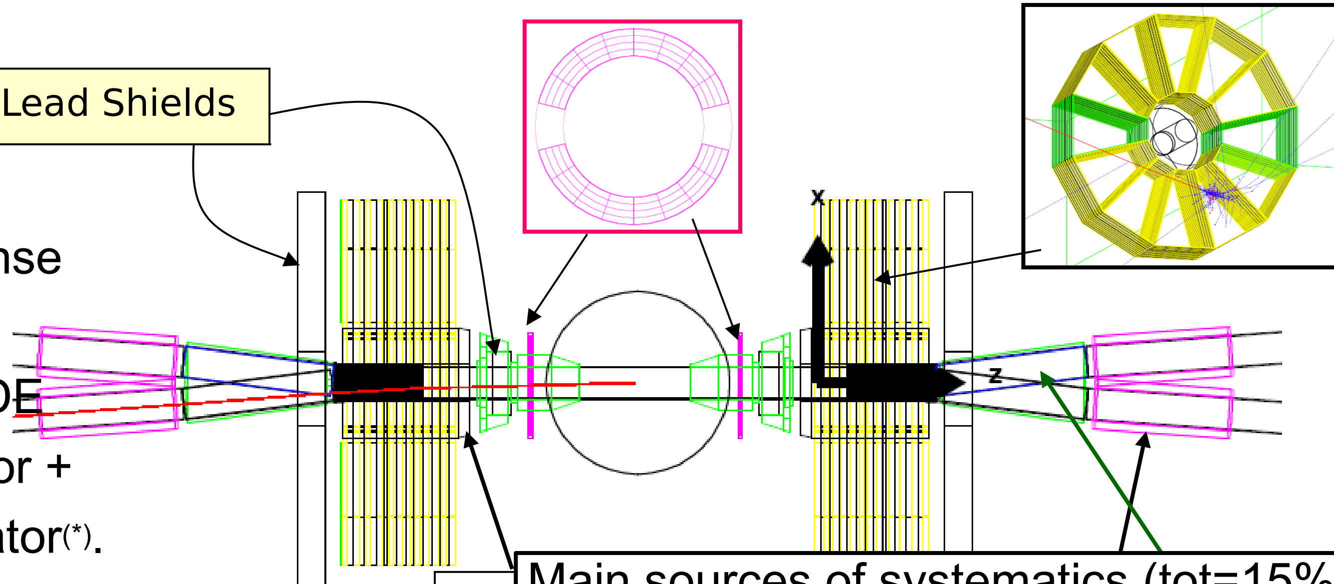
- 3 WLS fibers per tile
  (Bicron BCF-92, shift: blue to green)
- 12*3 per sector, fed into 1 PMT

Bhabha Calorimeters

Assembly carried out in December 07 and January 08.

Calorimeter Acceptance: GEANT-3 Simulation

- Full Simulation
  - Geometry
  - Material
  - Detectors response
  - Physics : BHWIDE ee->eeγ generator + Touschek generator(*).
  - Beamspot Size
  - Signal & Bkg acceptance

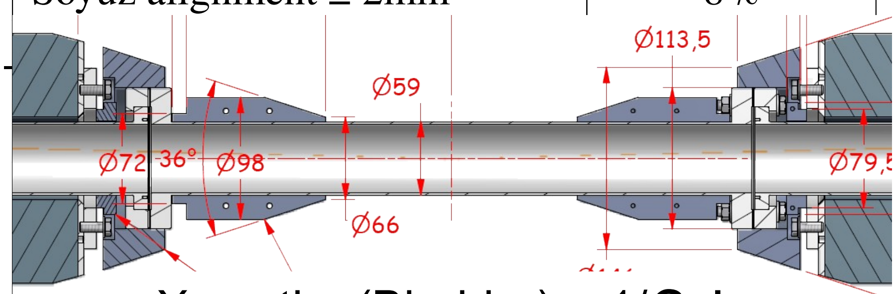


Main sources of systematics (tot=15%)

Sources	σ_{syst}
Calo alignment ± 2mm	4%
Soyuz alignment ± 2mm	8%

=> Predicted Bhabha rate @ L=10^{32} cm-

R = 430 +/- 65 Hz



X-section(Bhabha) ~ $1/\Theta^3$!

Another solution is to reduce the transverse size of the beams. One first problem in this case is that the disruption, which is due to the electromagnetic interaction between the electron and positron bunches becomes big, and the bunches can be distorted too much to be re-used. So we loose all the luminosity.

A second problem is due to the hourglass effect: to obtain very small sigma_y at the IP, we need a focalization which is very fast as a function of z, as you can see on this picture of the bunch longitudinal profile. In that case, the only region where the particle density is high enough to produce luminosity is right at the IP. All the other regions produce no luminosity, thus in total, we loose luminosity.

You can see this on this picture: when a electron crosses the positron bunch, it sees a particle density which smaller at this z than at this z, because of the shape of the vertical focalization of the positron bunch, which is small here, but maximum here. In other words…

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