Luminosity measurements experience at DAFNE

G. Mazzitelli

on behalf of various people that during 13 years have worked on an high background/ luminosity accelerator...

G. Mazzitelli, F. Sannibale, F. Cervelli, T. Lomtadze, M. Serio, G. Vignola

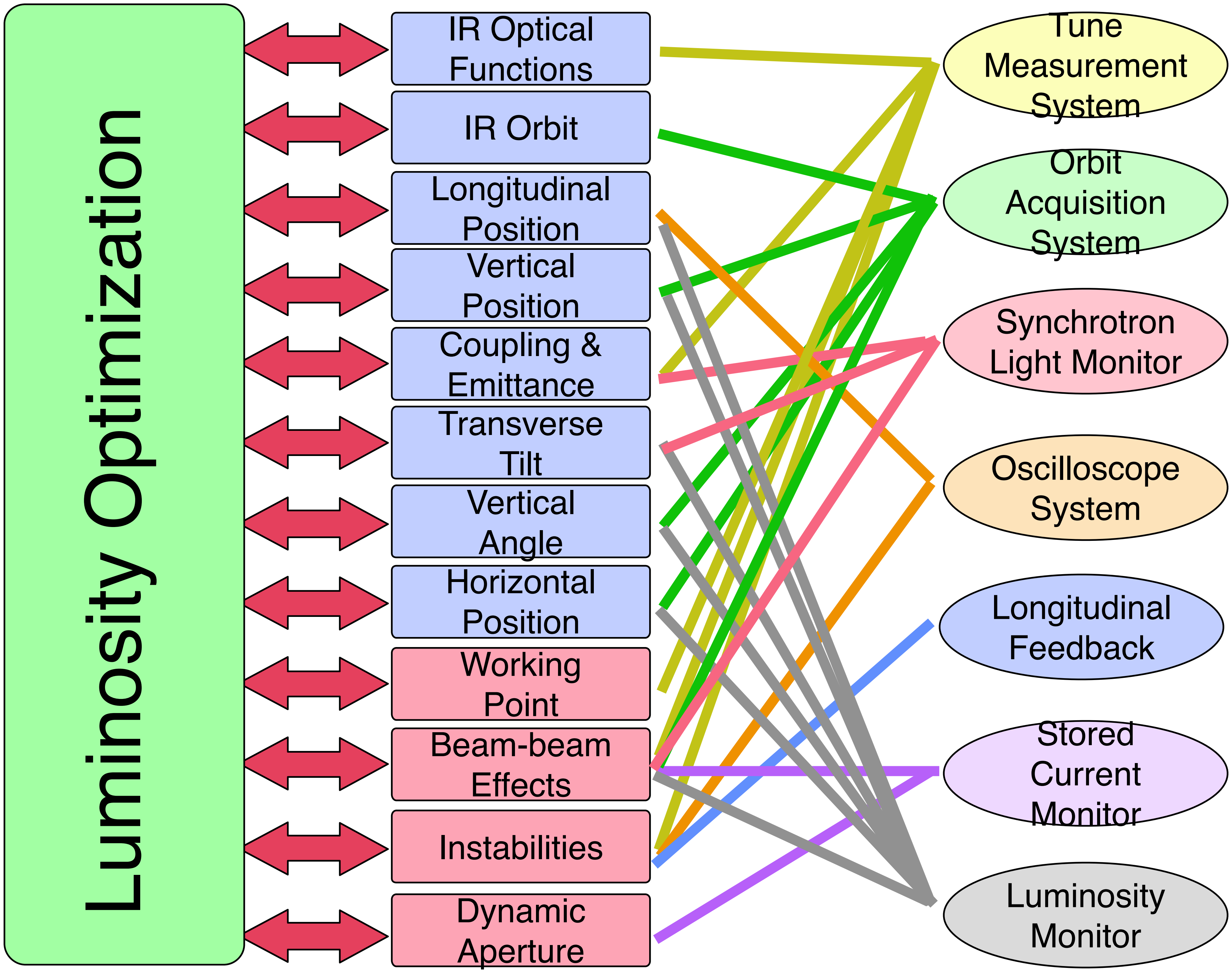
M. Boscolo, F. Bossi, B. Buonomo, **G. Mazzitelli**, F. Murtas, P. Raimondi, G. Sensolini, M. Schioppa, F. Iacoangeli, P. Valente, N. Arnaud, D. Breton, L. Burmistrov, A. Stocchi, A. Variola, B. Viaud, P. Branchini

CABIBBO LAB
Laboratorio Nicola Cabibbo

INFN
Istituto Nazionale di Fisica Nucleare

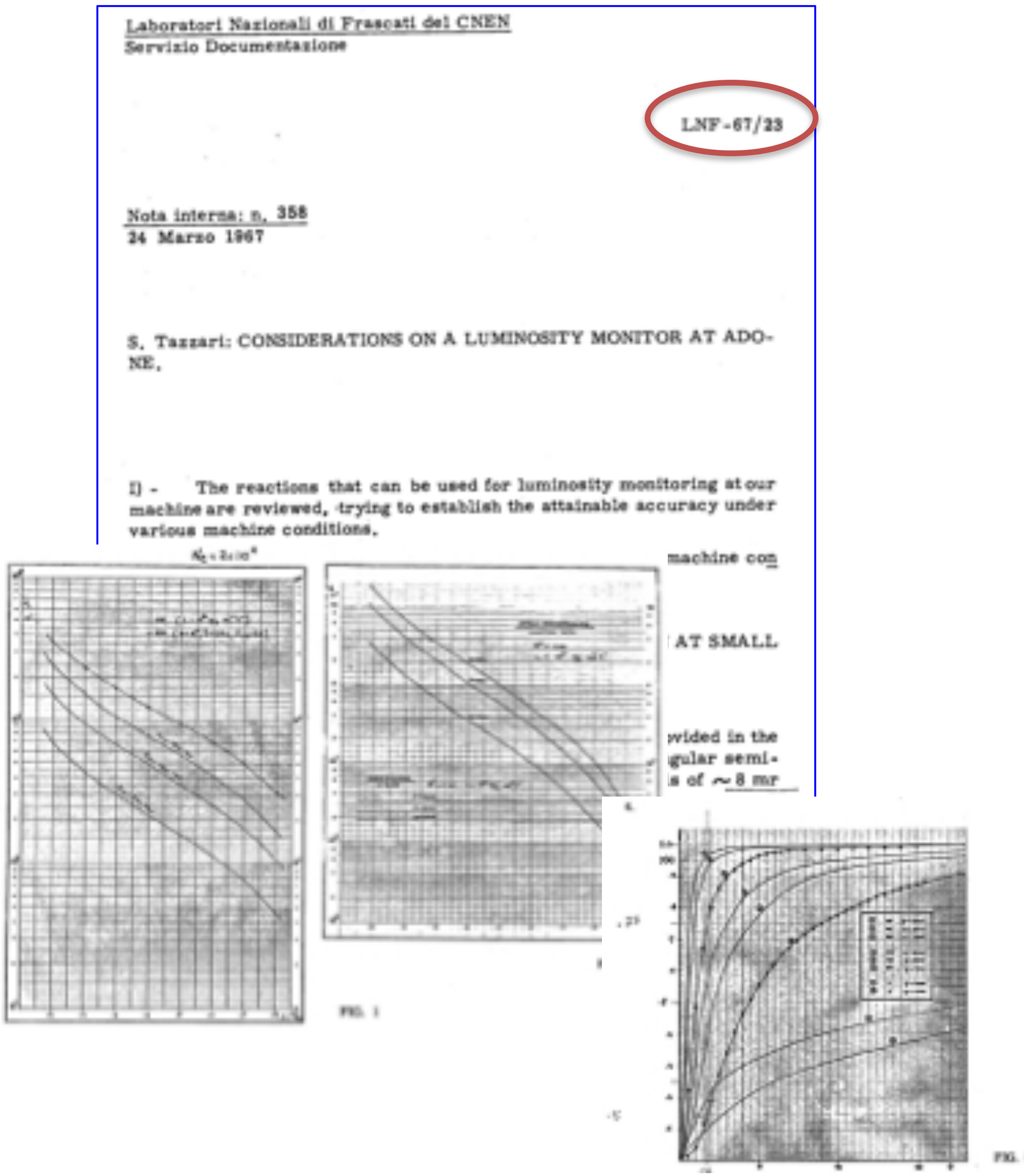
SuperB

way a machine lumi monitor?



F. Sannibale DIPAC09

The Physics at DAFNE



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Nota interna: n. 358
24 Marzo 1967

S. Tazzari: CONSIDERATIONS ON A LUMINOSITY MONITOR AT ADONE.

I) - The reactions that can be used for luminosity monitoring at our machine are reviewed, trying to establish the attainable accuracy under various machine conditions.

FIG. 1

FIG. 3

Single Bremsstrahlung:

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

Double Bremsstrahlung:

$$e^+ + e^- \to e^+ + e^- + 2\gamma$$

Gas Bremsstrahlung:

$$e^{+/-} + Z \to e^{+/-} + Z + \gamma$$

Annihilations

$$e^+ + e^- \to 2\gamma$$

Bhabha

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

~ 30Hz@10^32 on KLOE barrel

and more for higher energy machine...

Coincidence with γ @ small angle

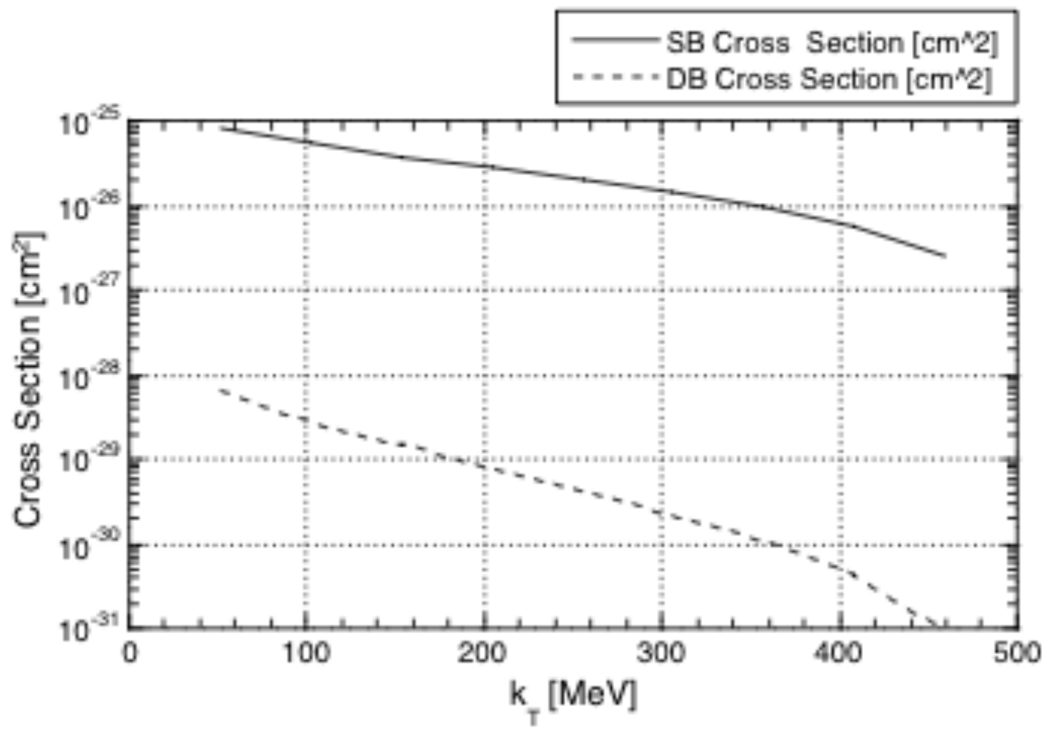
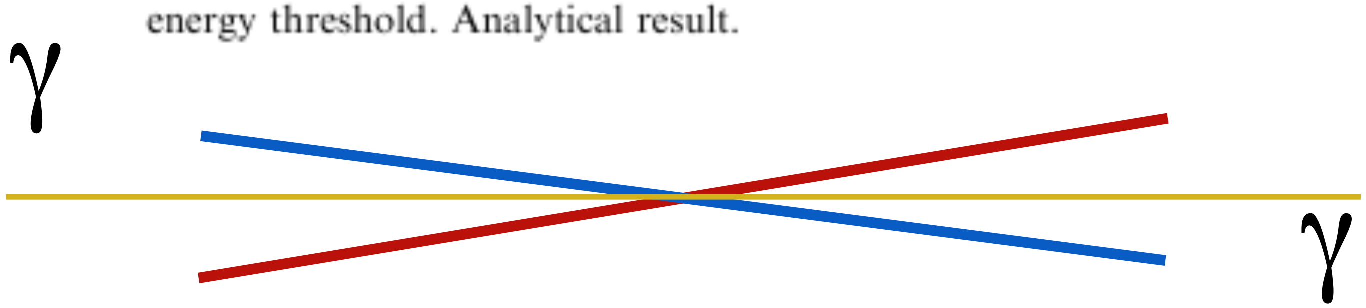
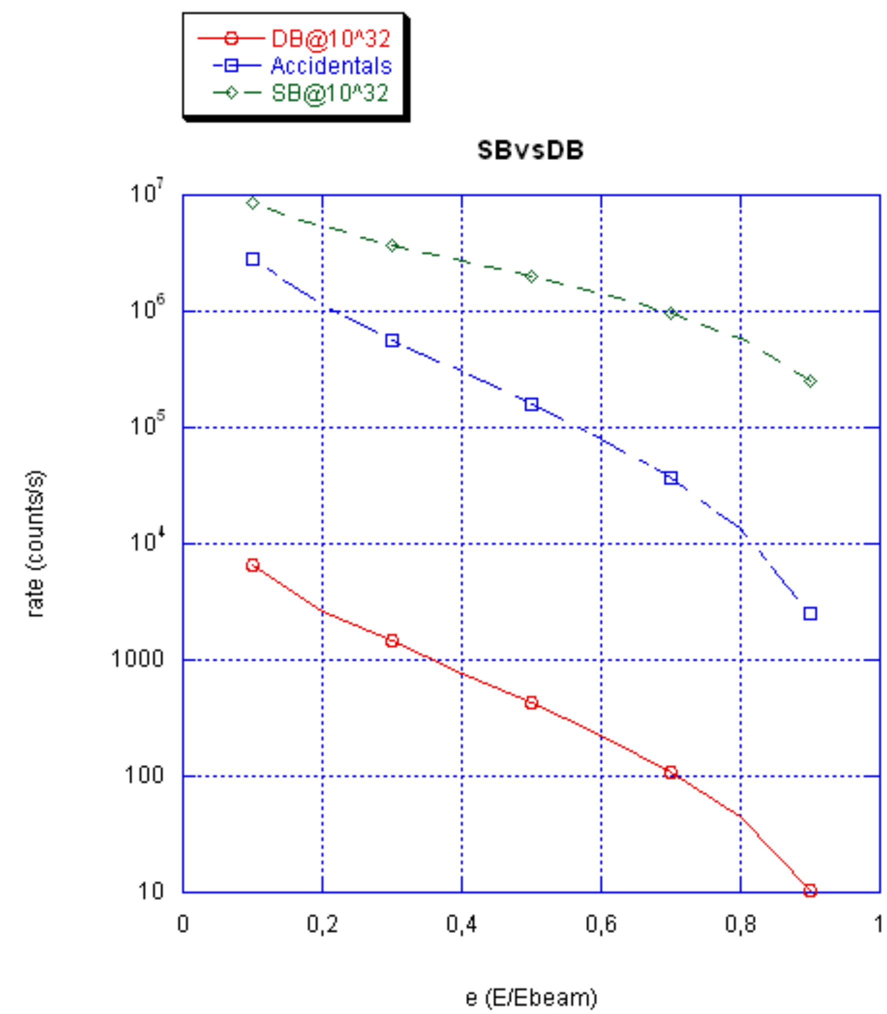


Fig. 11. Single and double Bremsstrahlung cross sections vs. energy threshold. Analytical result.

N (accidental) = 2 f1*f2/Dt

Dt = 2.0 E-8 s





--> no possible to make coincidence with gamma physic at small angle

DAFNE RUN1 γ monitor

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Nuclear Instruments and Methods in Physics Research A 486 (2002) 568–589

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Single Bremsstrahlung luminosity measurements at DAFNE

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Abstract

At DAFNE luminosity measurements are performed by detecting the photons from single Bremsstrahlung at the two interaction points. Set up and measurement method are presented with special emphasis on background subtraction schemes, error evaluation and machine related issues.

PACS: 41.85.Qg; 02.50.Ng; 29.40.Vj; 07.50.−e

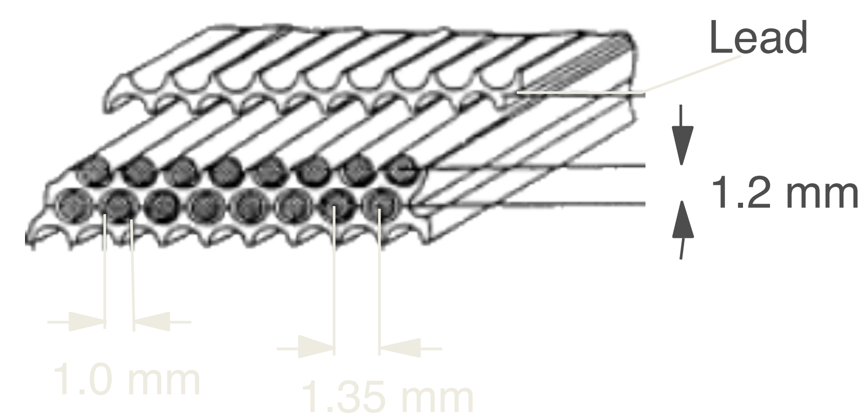
Keywords: Luminosity measurement; Single Bremsstrahlung; Radiative Bhabha; DAFNE; DAFNE

1. Introduction

DAFNE, the Frascati phi-factory [1], is a 510+ 510 MeV electron-positron collider, tuned on the F meson resonance and mainly devoted to the study of CP violation in Kaon decay. In order to optimize the luminosity performance, the related machine parameters must be accurately set relying on a tuning process [2,3] based on the readout of a luminosity monitor. In designing such a monitor the following major requirements were pursued: (i) capability of performing very fast measurements to allow tuning machine parameters in real time, (ii) measurement stability with respect to variations of the beam position and angle at the interaction point (IP), (iii) no interference with the experiments, to ensure independent luminosity measurements during the data taking and during the initial phase of the machine commissioning with no experiment installed in the two interaction regions (IR).

A direct way to measure luminosity consists in measuring the counting rate of a known electromagnetic process while the beams are colliding. Good candidates are small angle Bhabha scattering (BB), single Bremsstrahlung (SB) and double Bremsstrahlung (DB). Differential and integrated cross-sections for BB, DB and SB are reported in Refs. [5–7]; an interesting comparison among measurements with the three different processes can be found in Ref. [8]. At DAFNE SB was chosen because it better fulfills requirements (i) and (ii) [4] and ensures measurements at a few percent level when an efficient background subtraction method is used.

Lead/scintillating fibers calorimeters (KLOE-type) resolution 4.7%/√E(GeV)



KLOE IP

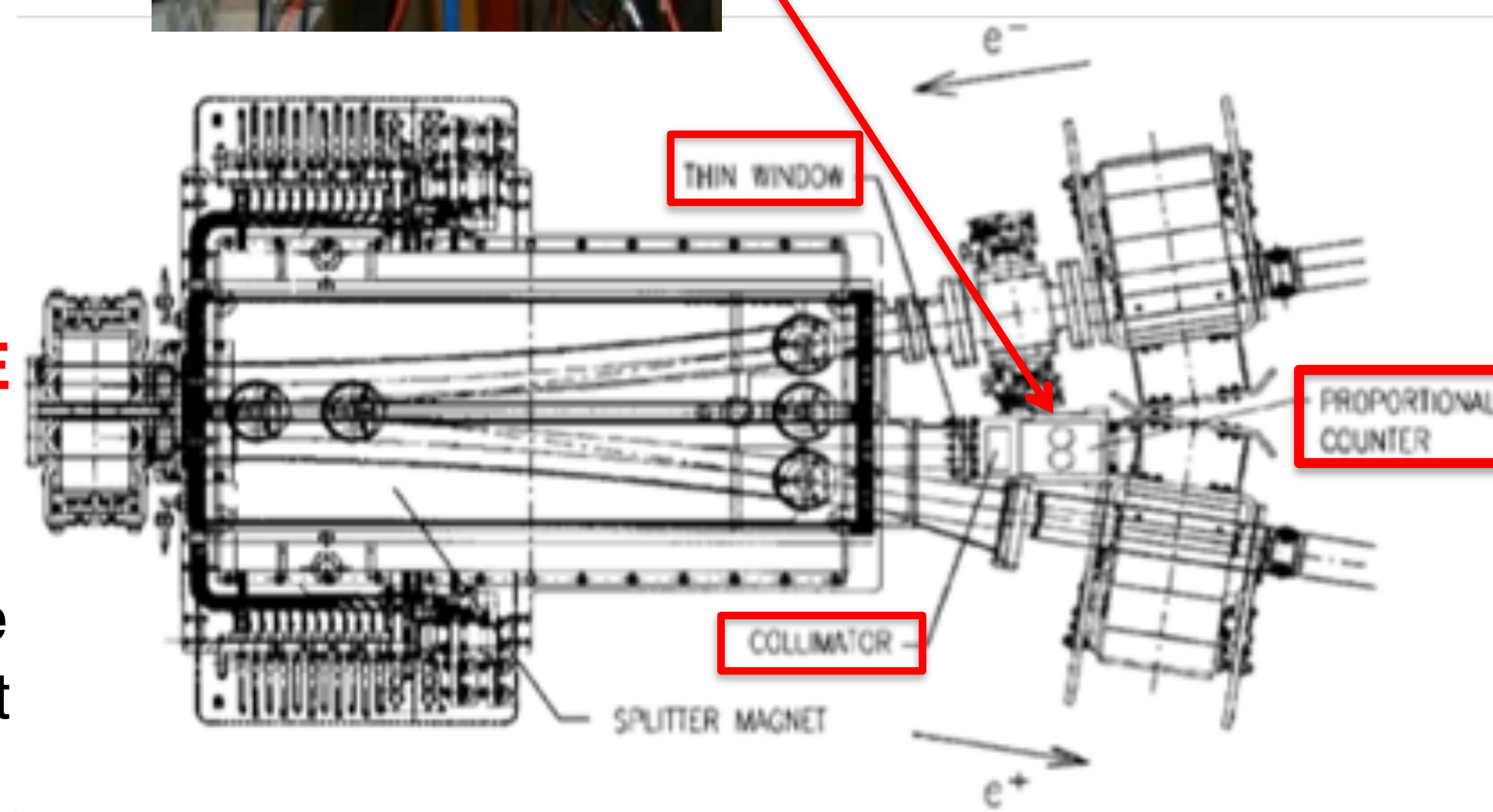


Fig. 2. Single Bremsstrahlung luminosity monitor layout at splitter magnet area.

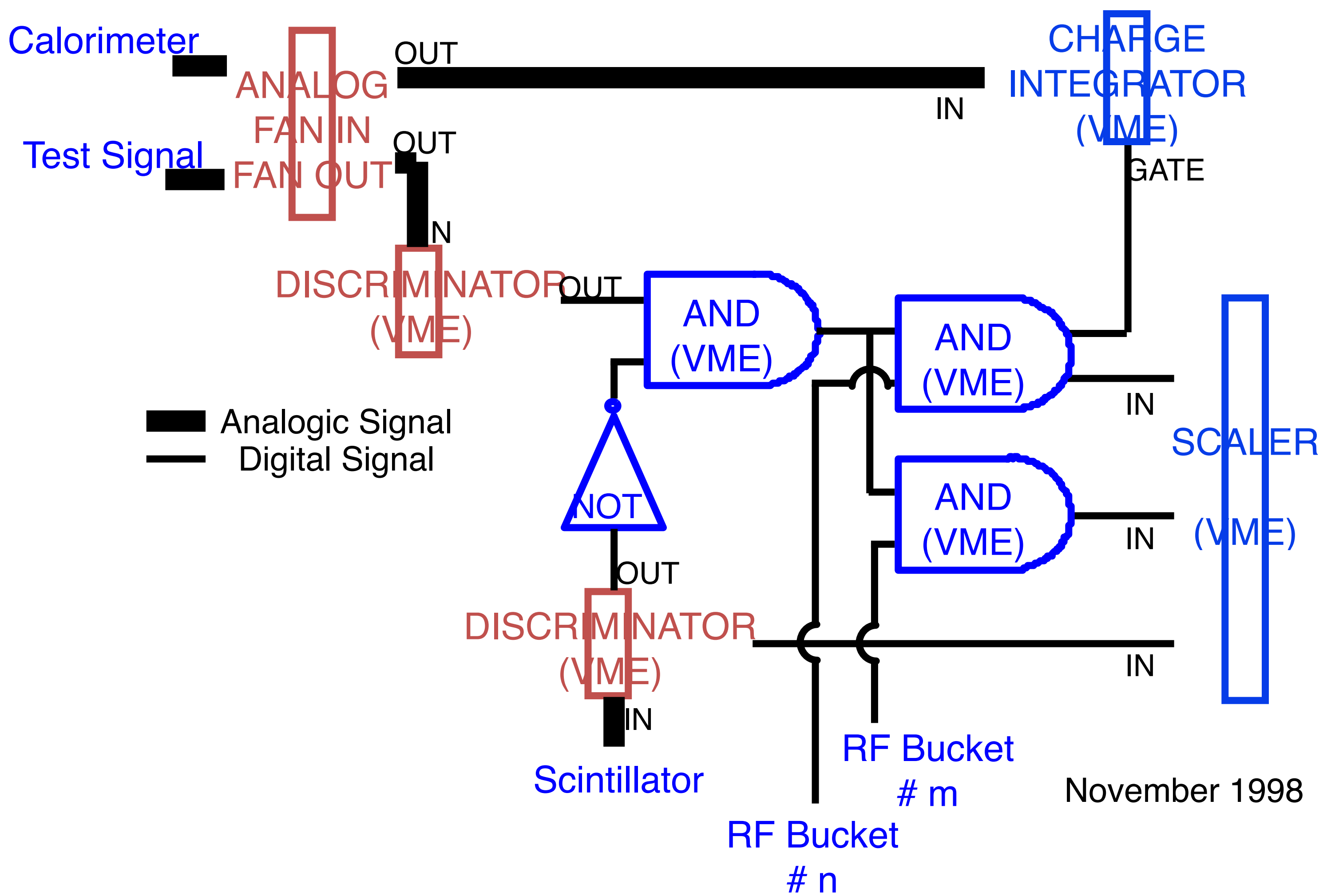
splitter magnet charge particle cleaning effect

DAFNE γ monitor (con't)

Single Bremsstrahlung:

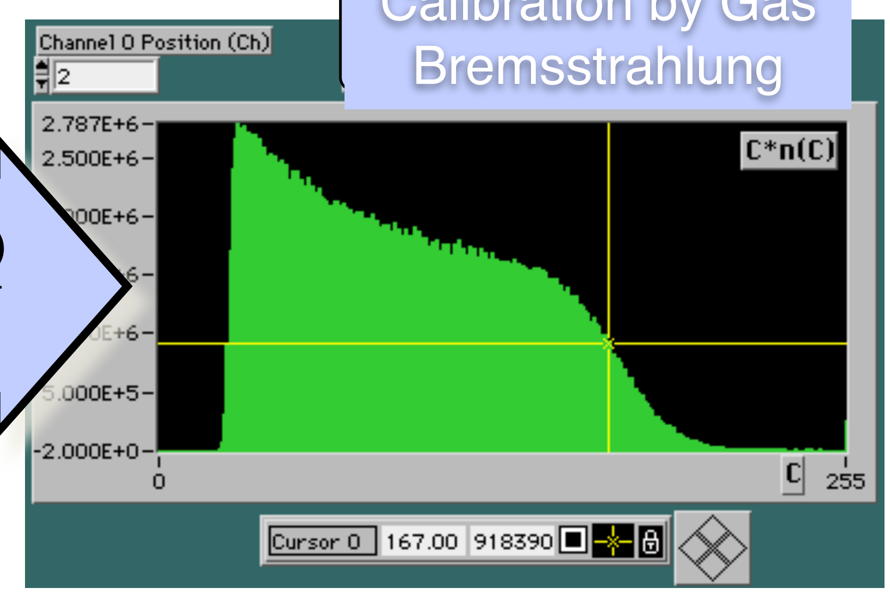
$$e^+ + e^- \to e^+ + e^- + \gamma$$

$$L = \dot{N}_{SB} \Big/ \int_{E_T}^{E_{max}} dE \int_{\Omega_D} d\Omega \frac{\partial^2 \sigma_{SB}}{\partial E \, \partial \Omega}$$



$$\varepsilon \frac{\partial \sigma_{GB}(\varepsilon)}{\partial \varepsilon}$$

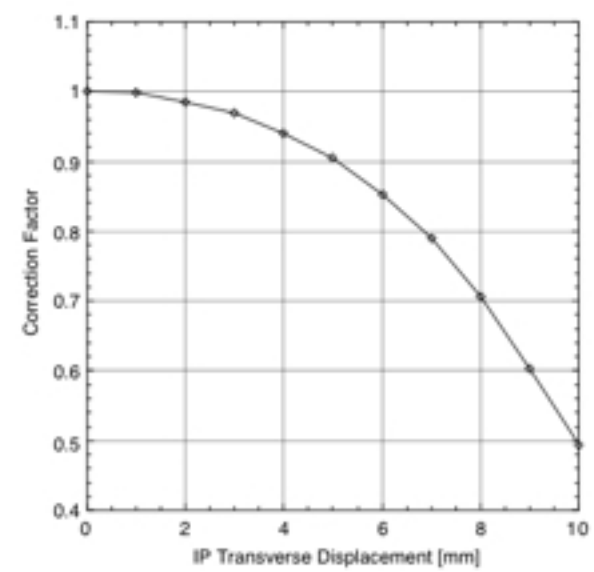
Calibration by Gas Bremsstrahlung

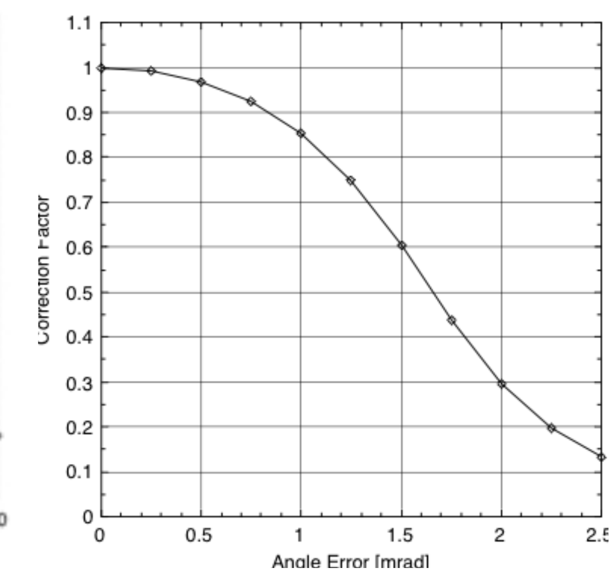


Requirements for an accelerator lumi monitor

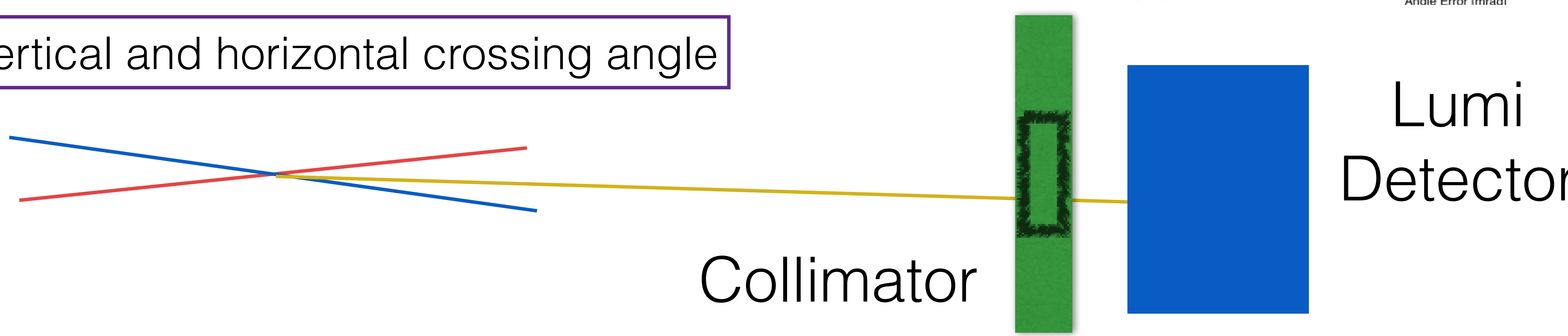
- fast (< 1 s) at very low luminosity (2/3 order of dynamic range)
- absolute
  - day one
  - MD
  - Detector maintenance
- accurate (~ 10 %)
- wide range beam acceptance
  - Ip displacement
  - vertical and horizontal angle

expected percentage of rate lost in the lumi monitor due to collimator beam acceptance and bem **transverse displacement and vertical crossing angle**





vertical and horizontal crossing angle



DAFNE Day 1 (flat machine)

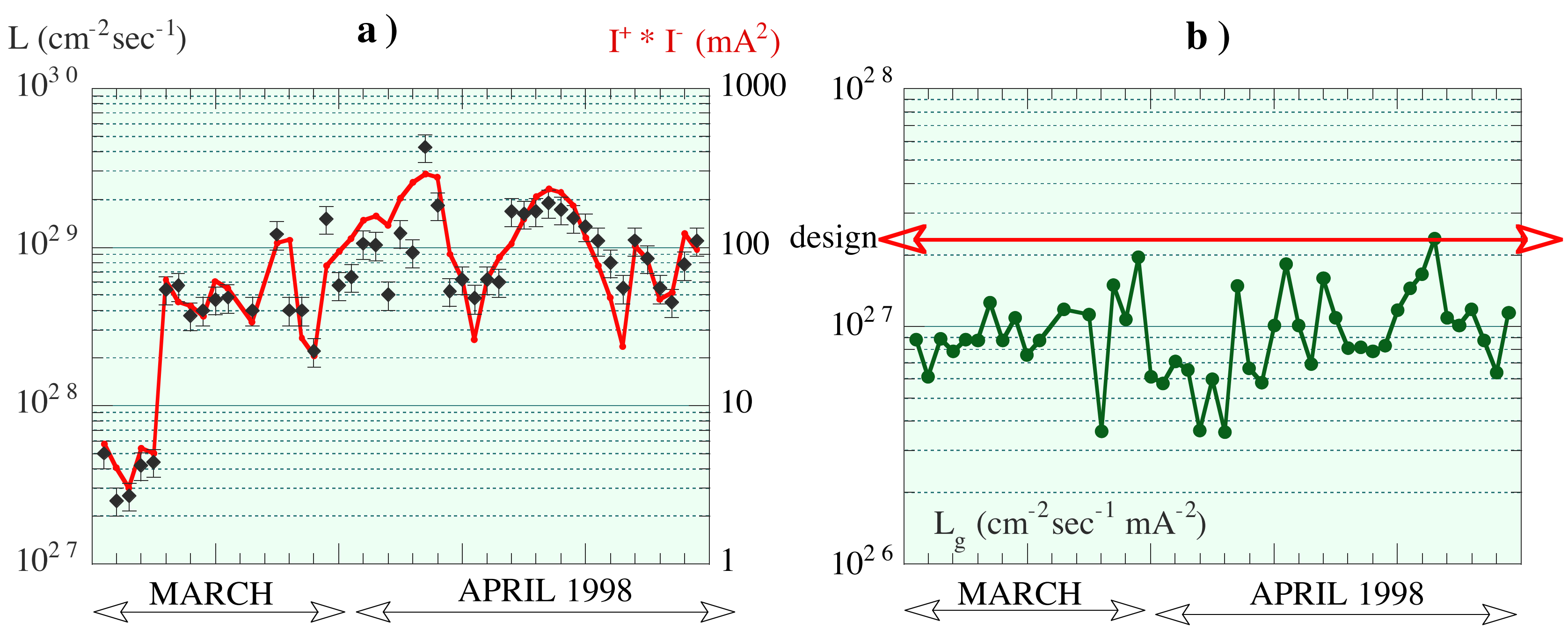


Figure 8: a) Luminosity (circles with error bars) and product of bunch currents (solid line); b) Geometrical luminosity

A luminosity monitor based on the measurement of the photons from the single bremsstrahlung (SB) reaction is used. The SB high counting rate allows fast monitoring, which is very useful during machine tune-up. The contribution of the gas bremsstrahlung reaction is subtracted by measuring the counting rate with two non interacting bunches. **The estimated error on the measurements is of the order of 20%.**

When running at **low current** the effect of the incoming **beam trajectory** on the background is negligible as well as beam beam effect, etc.
As as been shown by KLOE 1 run experience, the luminosity monitor is able to perform absolute and correct measurement only in low current condition where **background** and **instrumental effect** where negligible.

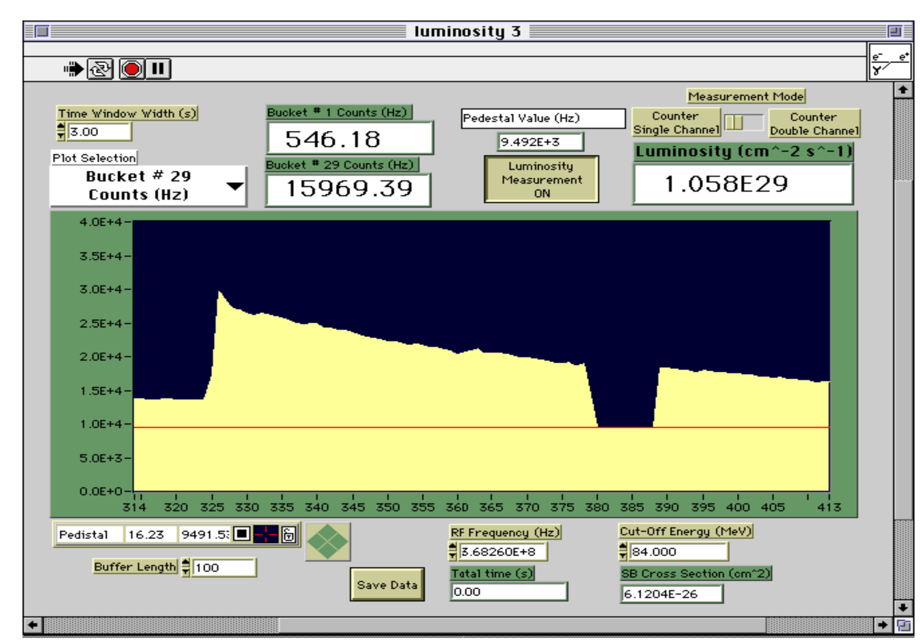
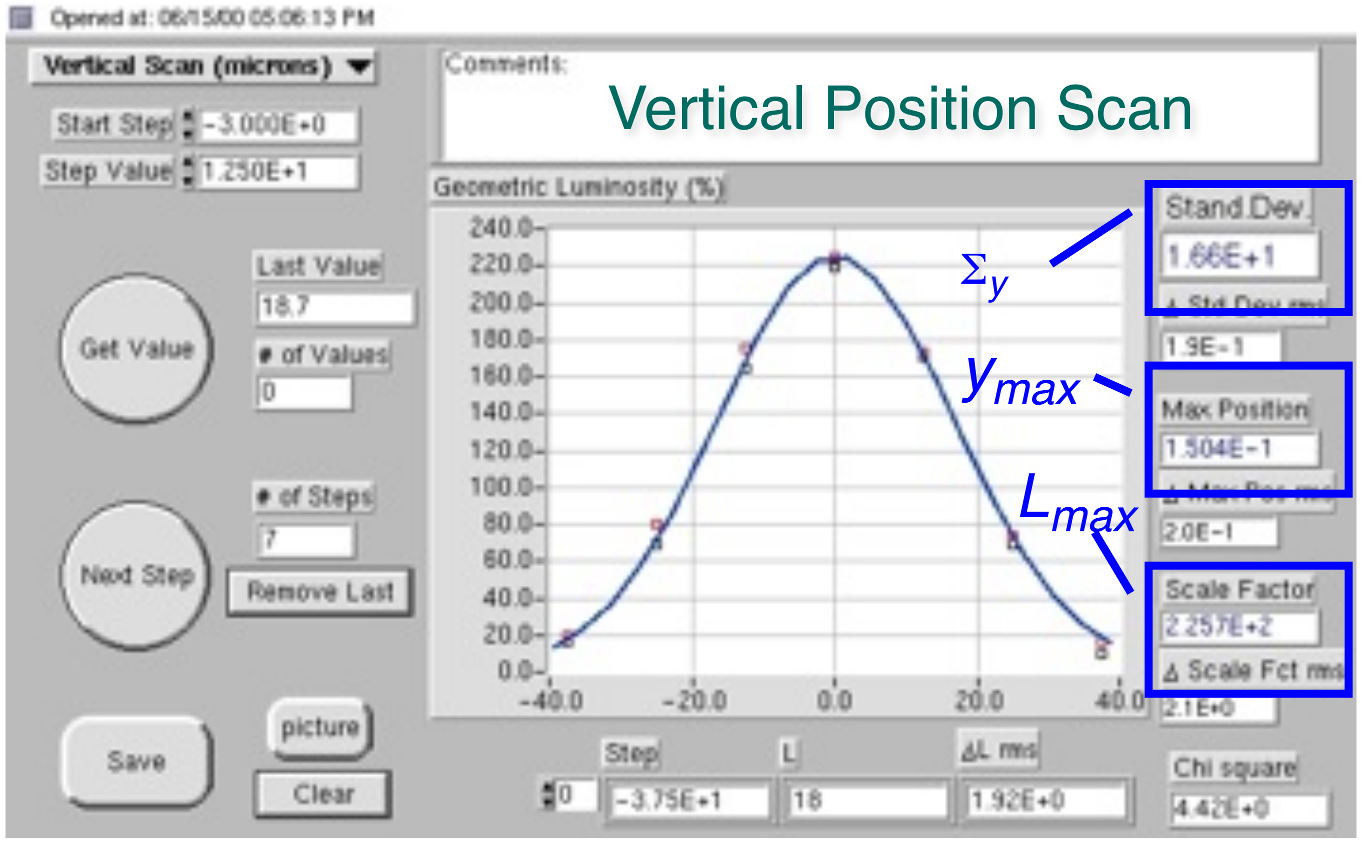
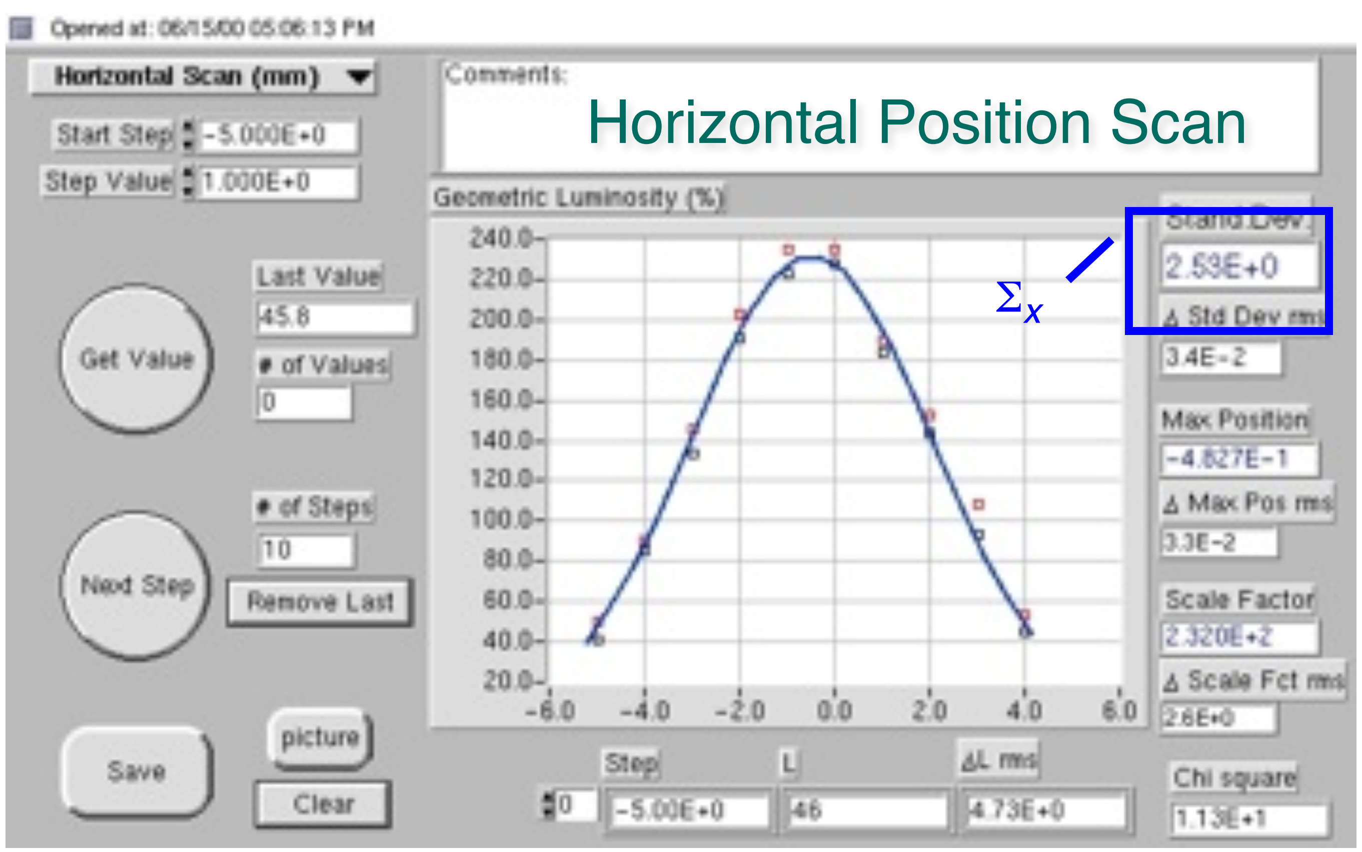
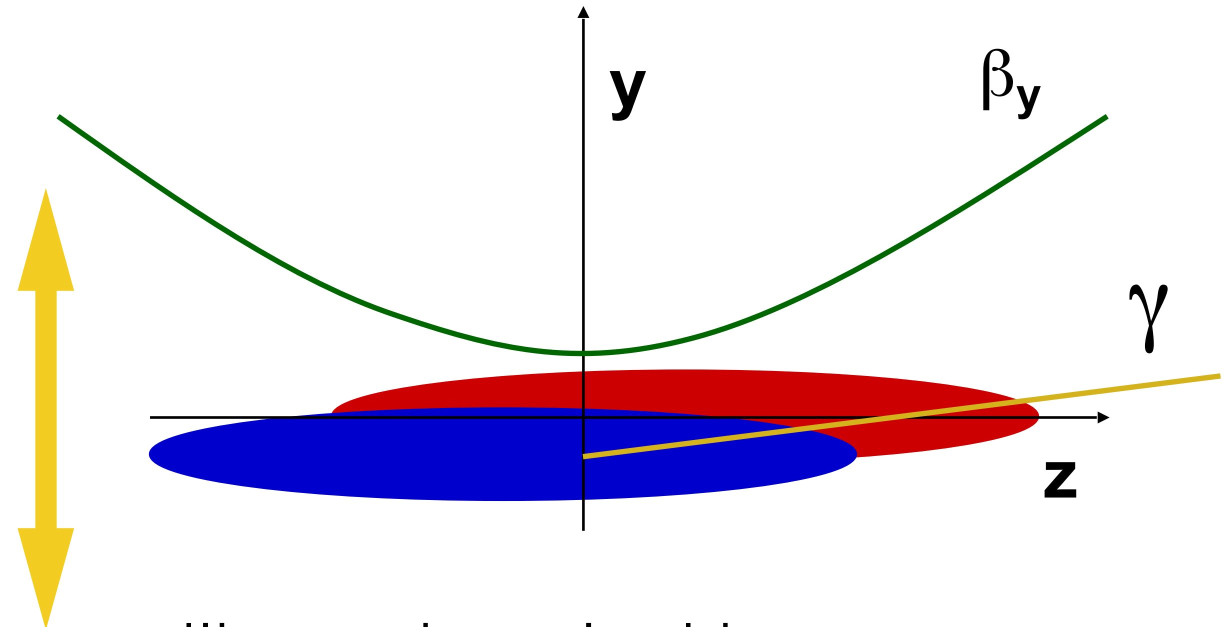


Figure 6: Luminosity monitor output.

Luminosity Position Scans







calibrated vertical bump

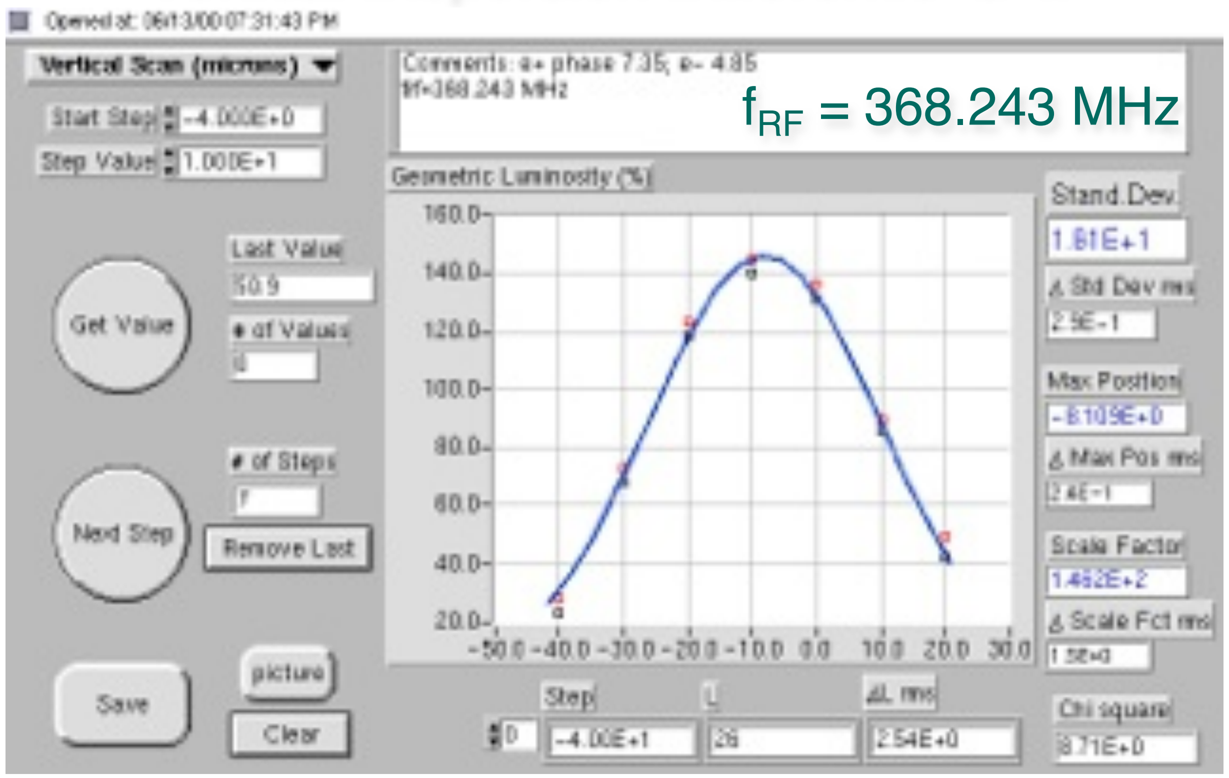
$$L = f_R \frac{N_+ N_-}{2\pi \ \Sigma_x \Sigma_y}$$

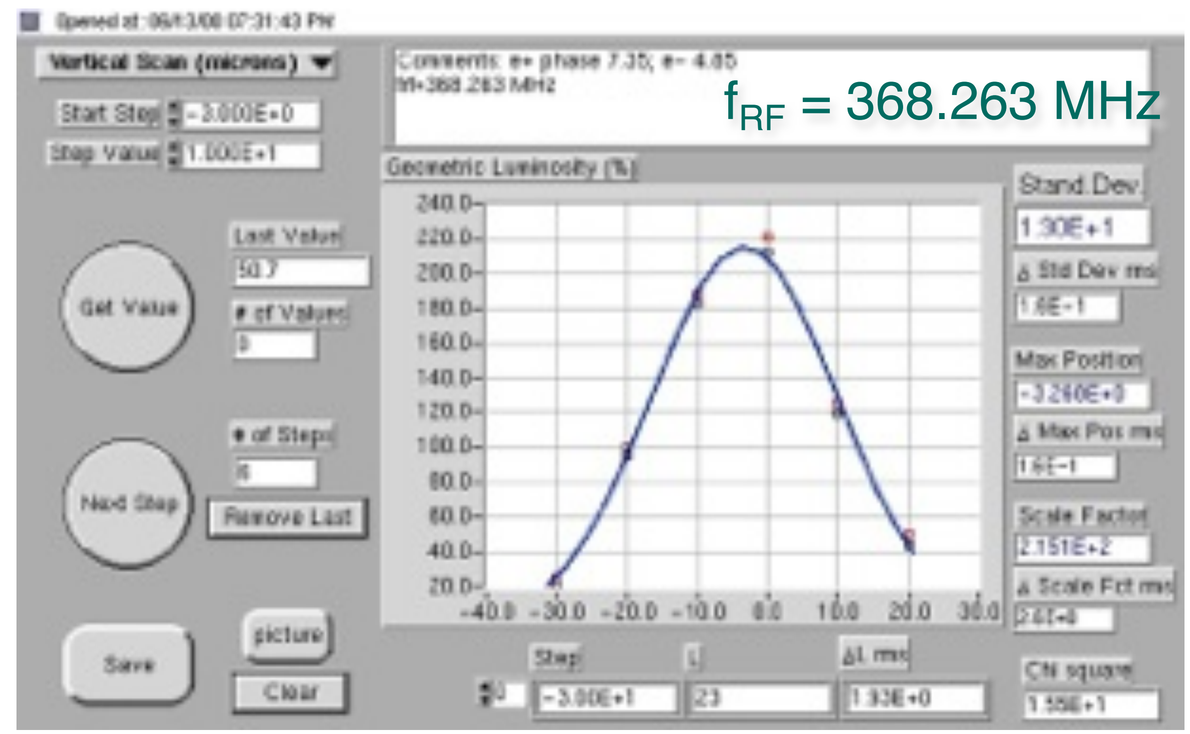
$$\Sigma_w = \sqrt{\sigma_{w+}^2 + \sigma_{w-}^2} \qquad w = x, y$$

Diagnostics (dispersion, electron cloud)

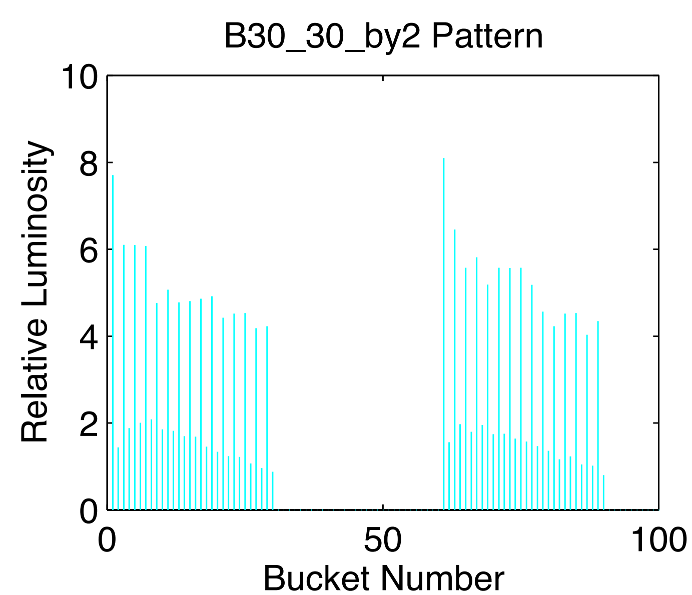
Vertical Dispersion Difference @ IP

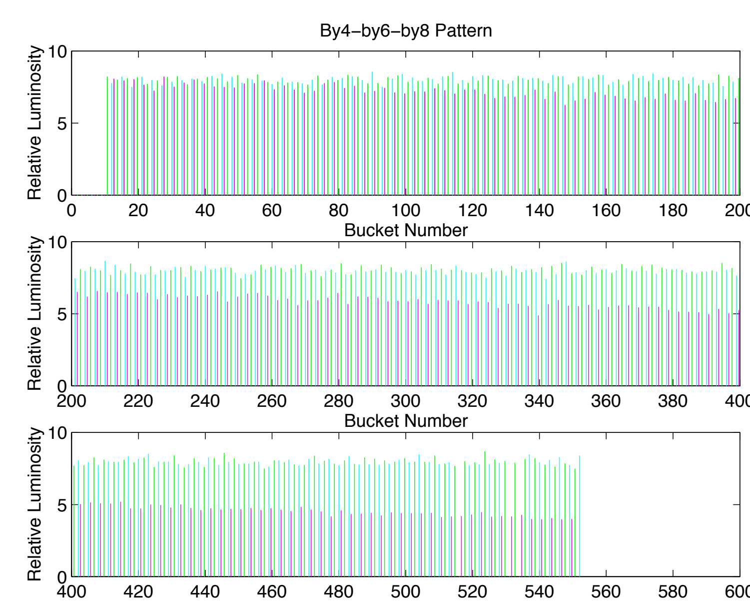
$$\Delta y_{\max} = (4.8 \pm 0.4)\ \mu m \Rightarrow \Delta\eta_y^{IP} = (2.3 \pm 0.4)\ mm$$





PEPII photo electron cloud blowup effect on the bunch by bunch luminosity measurements



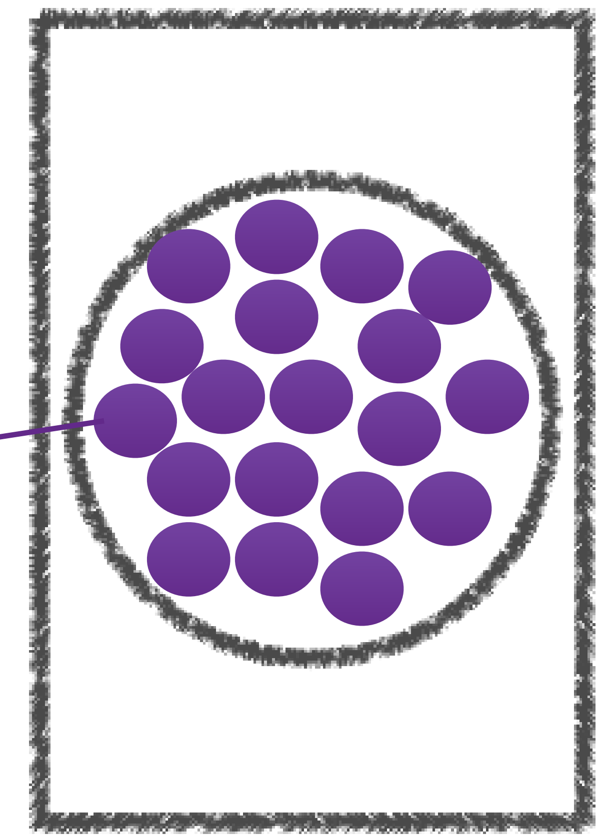


but… (KLOE run1)

- High current --> high background:
  - PM saturation;
  - Discriminator over rate;

-->

  - upgrade of readout system;
  - limitate rates with the same acceptance (mantain angular and beam position acceptance) filling of needle the collimator hole;
  - use independent lumi estimator to validate data: slm lumi based, cross calibration with KLOE



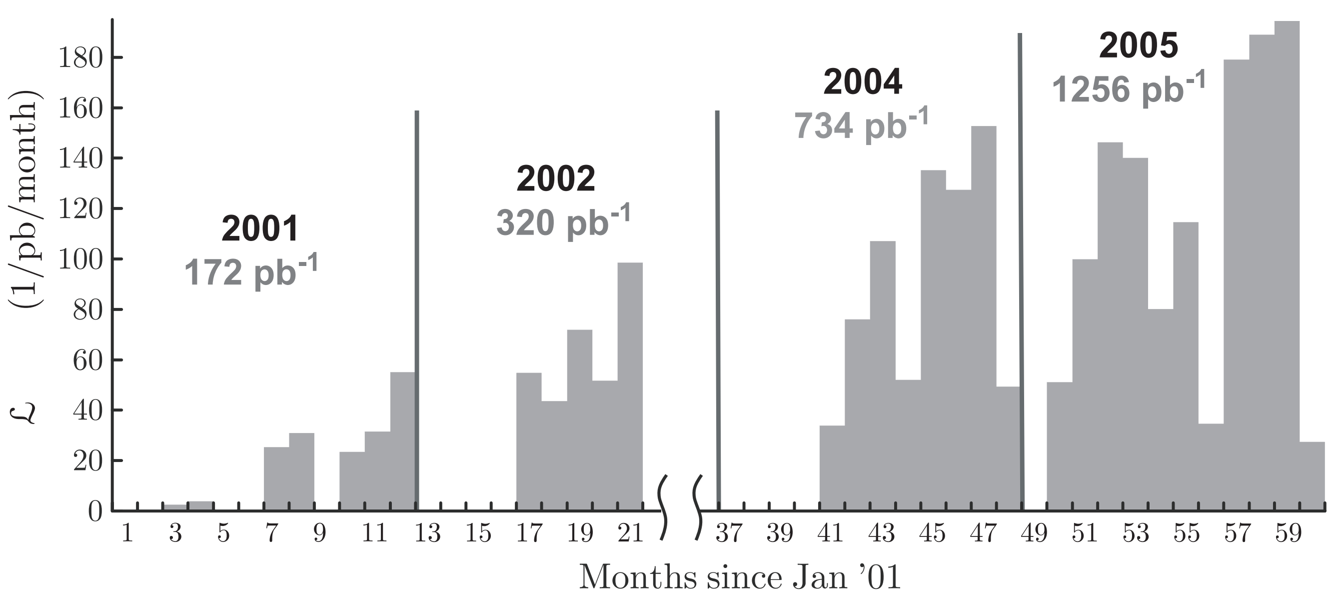
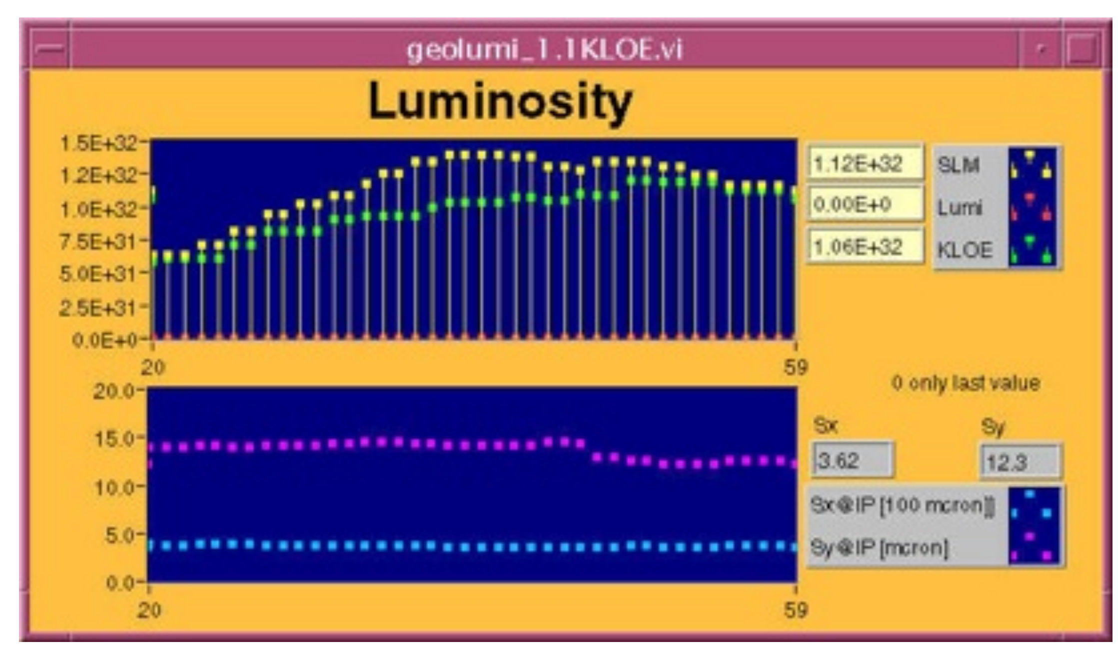
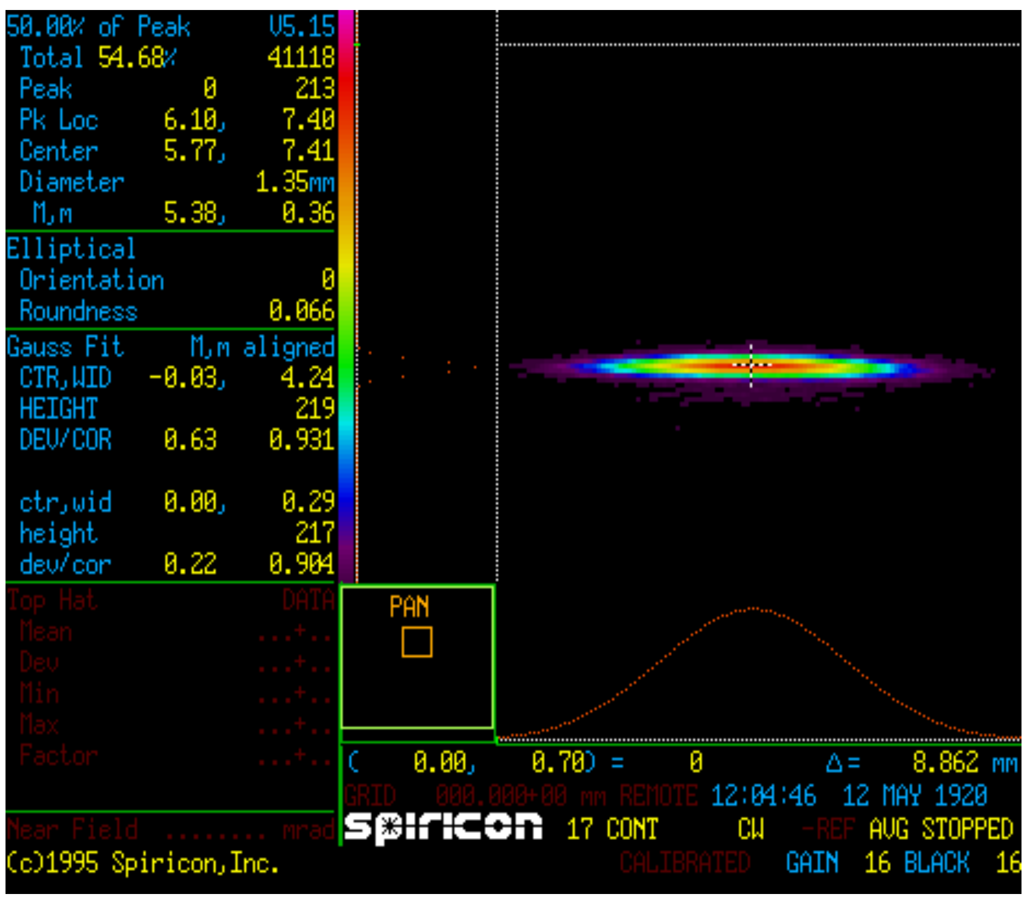


Fig. 2. Luminosity integrated by KLOE from 2001 to 2005.



Geometric Luminosity estimator

$$L_{geo} = \frac{I^{+}I^{-}}{4\pi N_b e^2}\,\frac{120}{f_{rf}}\,\frac{1}{\sigma_x\sqrt{(\sigma^2_{ey@SLM}+\sigma^2_{py@SLM})\dfrac{\beta_y^{IP}}{2\beta_y^{SLM}}}}$$

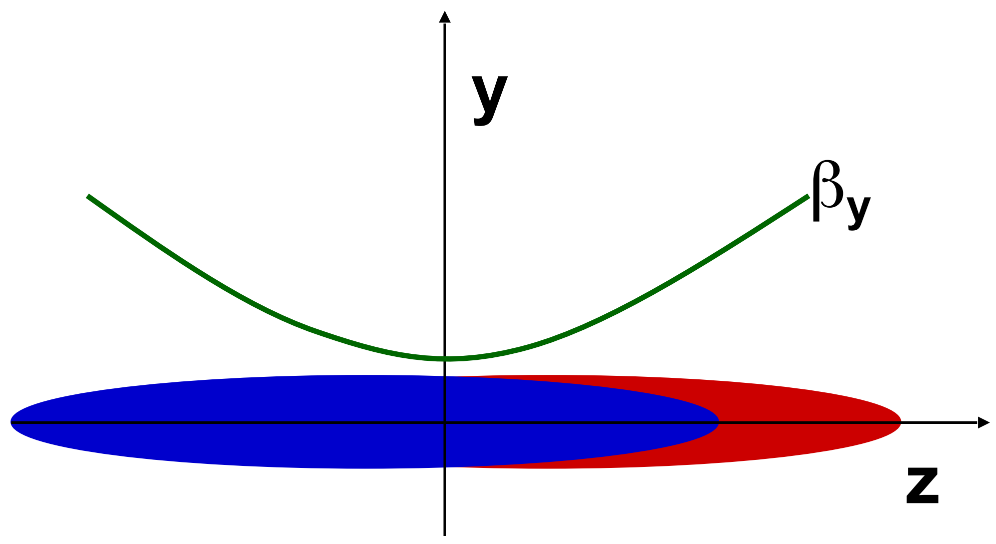


SLM beam characteristics (vertical and horizontal dimension)

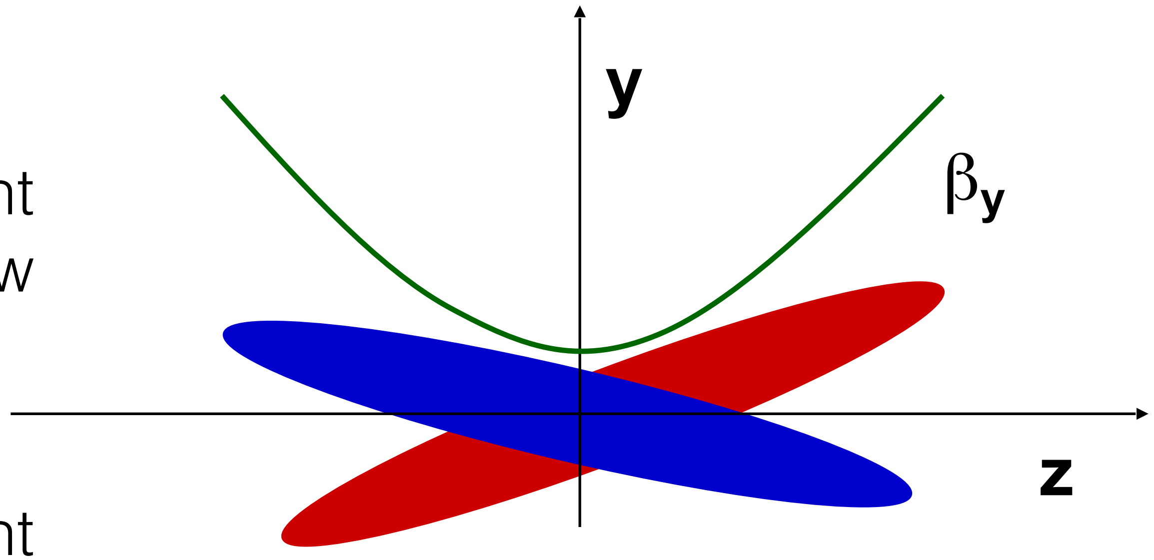
- Beam overlap
- σ_x = 2 mm σ_y = wid/2
- β_y/β_y@SLM= 0.03/7.60 @ KLOE,
- β_y/β_y@SLM = 0.04/7.53 @ DEAR
- SLM monitor resolution

SIDDHARTA run (the crab waist test)

- The crab waist, moreover the background, have introduced very important difficulties in the measures:
  - A) shorter beta minimum respect to beam dimension
  - B) vertical and horizontal rate maximization could not be equivalents to luminosity optimization



- These required:
  - a fast and absolute luminosity measurement not affected by background issue and new beam condition
  - maintaining all the γ monitor measurement characteristic, optimization futures, and integration in DAFNE control system



The lumi Collaboration

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

INFN Istituto Nazionale di Fisica Nucleare

IN2P3 Institut National de Physique Nucléaire et de Physique des Particules

UNIVERSITÉ PARIS-SUD 11

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Luminosity and background measurements at the e^+e^- DAΦNE collider upgraded with the crab waist scheme

M. Boscolo [a], F. Bossi [a], B. Buonomo [a], G. Mazzitelli [a], F. Murtas [a], P. Raimondi [a], G. Sensolini [a], M. Schioppa [b], F. Iacoangeli [c], P. Valente [c], N. Arnaud [d,*], D. Breton [d], L. Burmistrov [d], A. Stocchi [d], A. Variola [d], B. Viaud [d], P. Branchini [e]

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Description and performances of luminosity and background detectors at the upgraded e^+e^- DAΦNE collider

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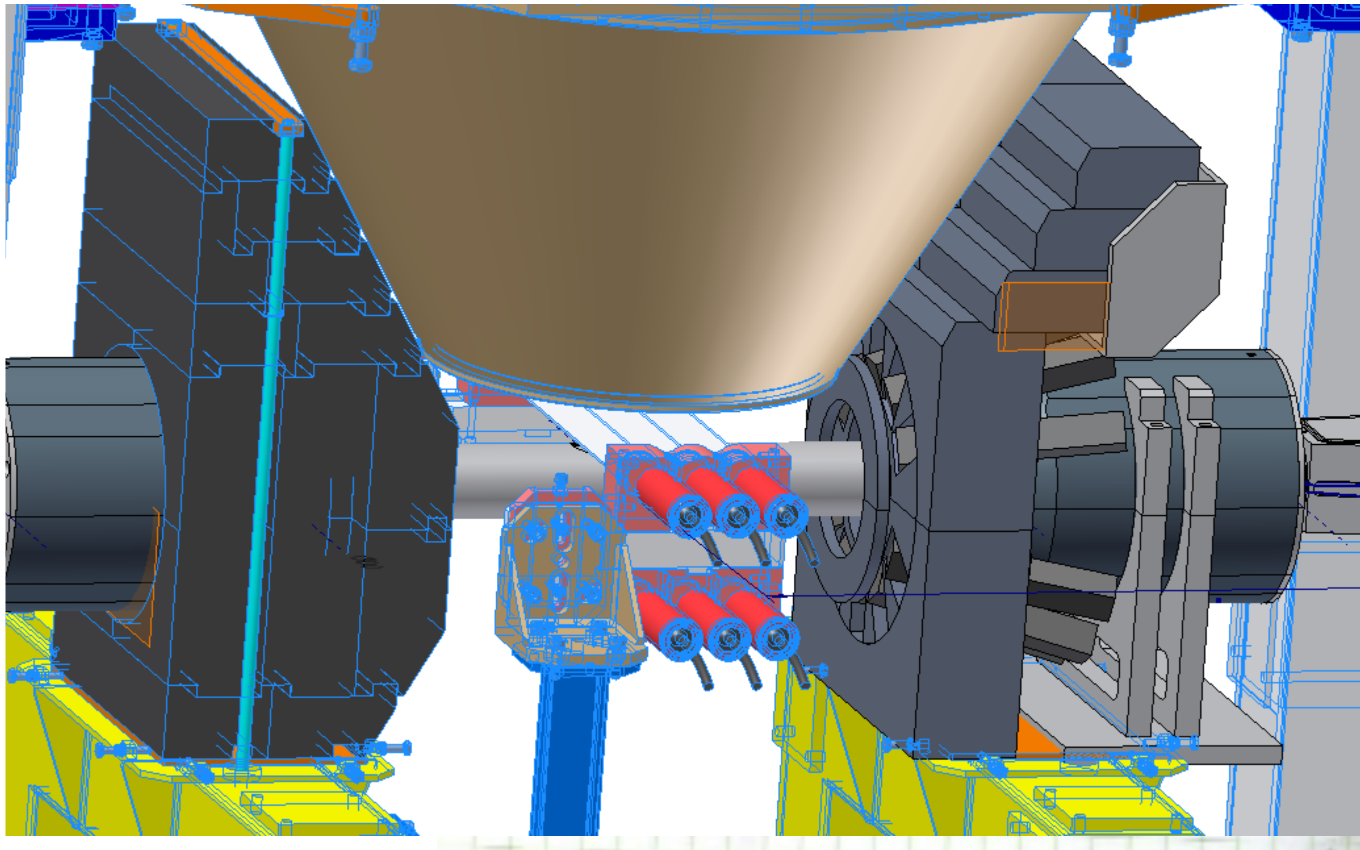
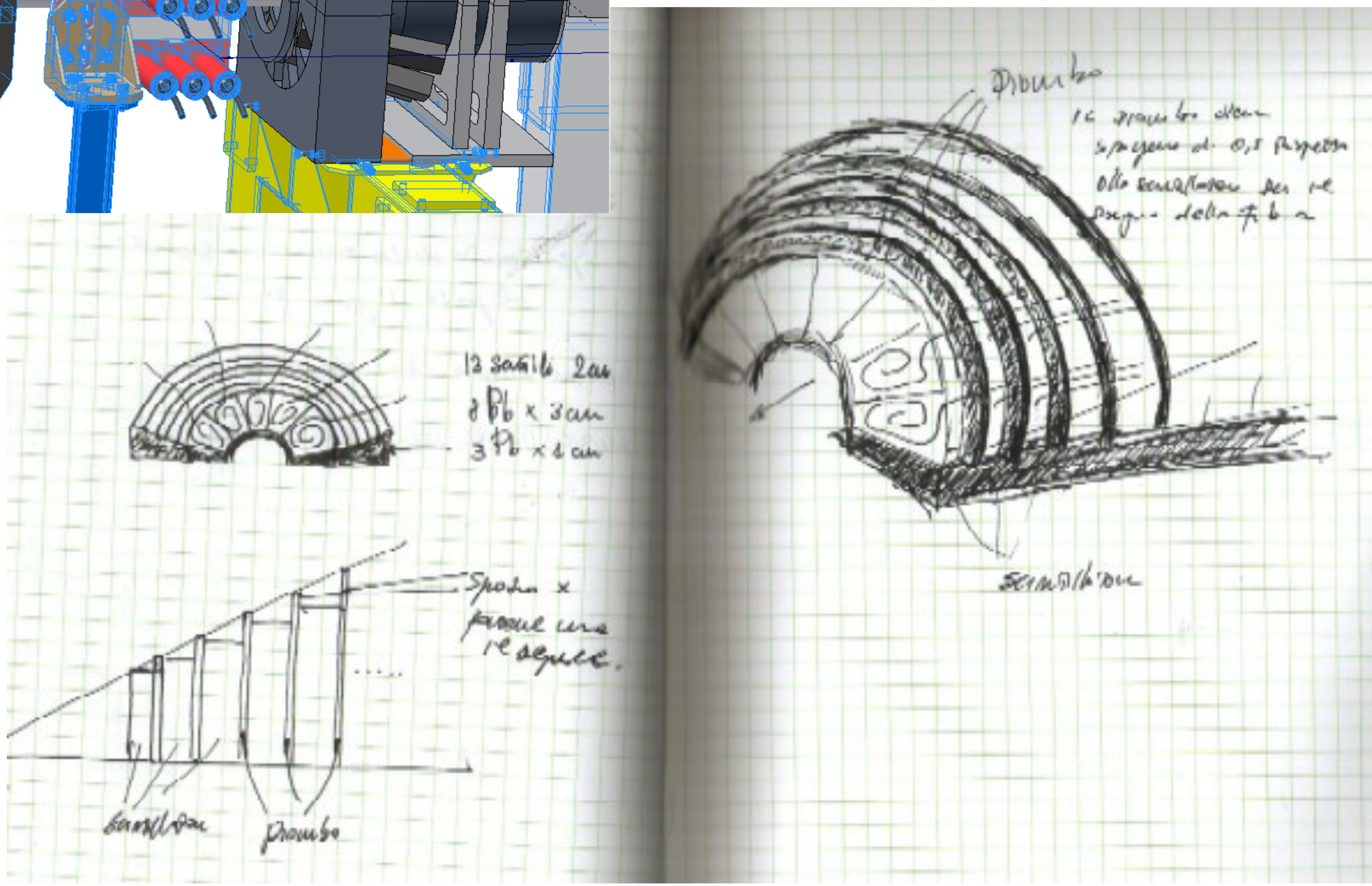
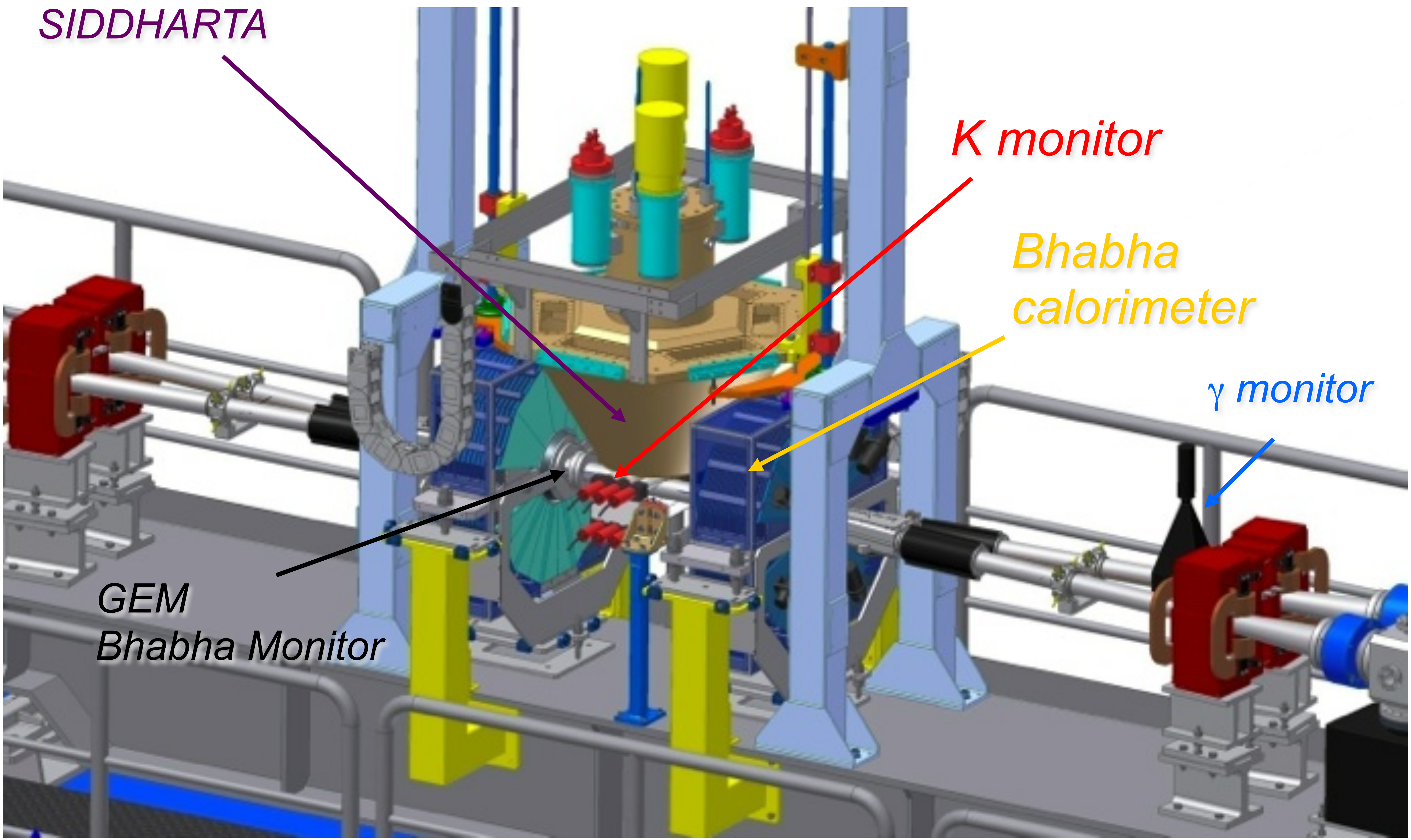
February 2007





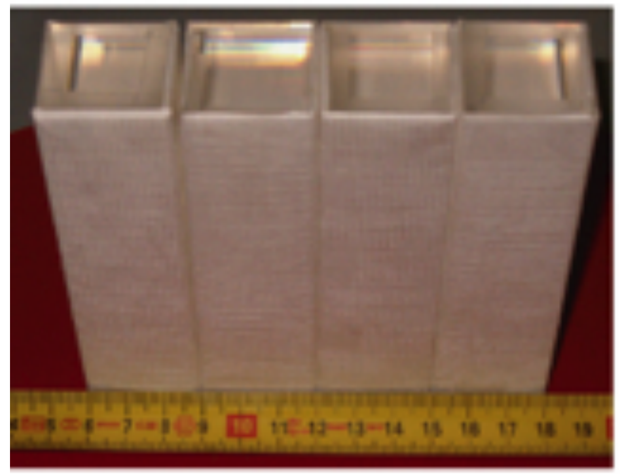
Layout and Luminosity Monitors

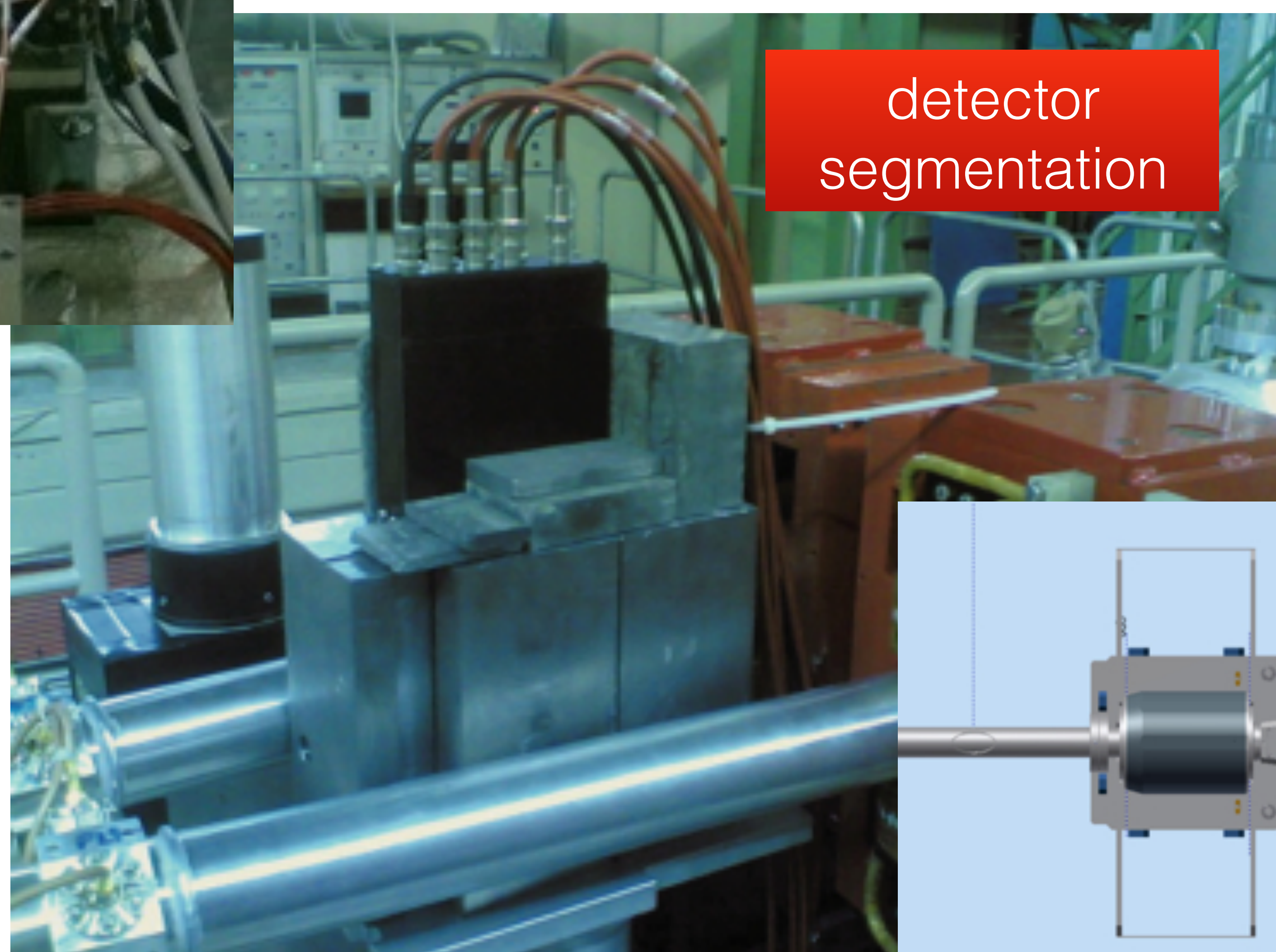


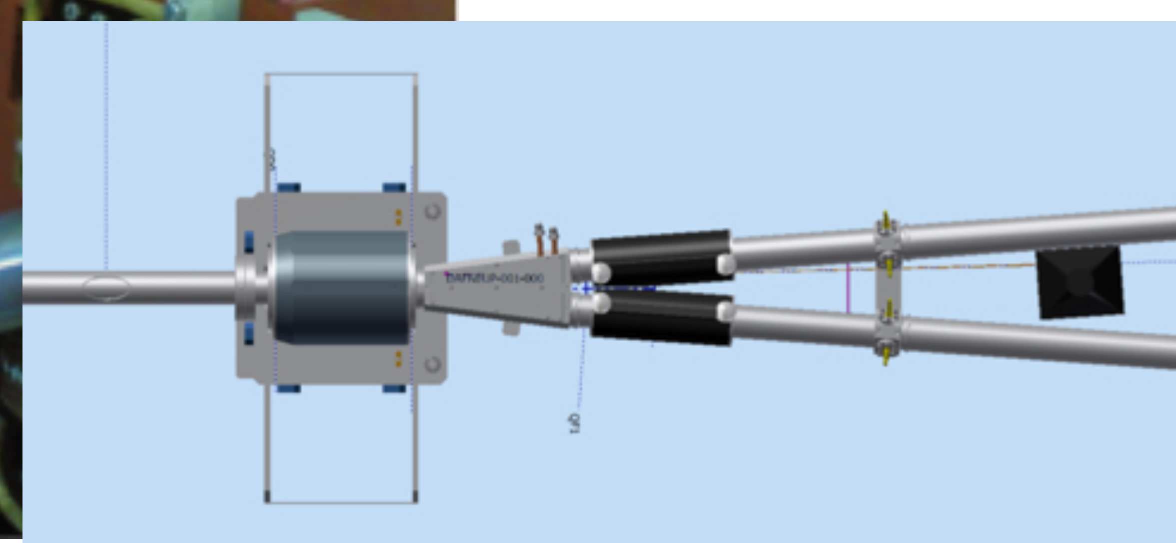
Gamma monitor

collimator

PbWO$_4$ crystals







- 2 calorimeters PbWO$_4$ crystals, 13 X_0 total depth
- Readout by Hamamatsu R7600
- High-statistics, very fast counter, main tool for luminosity optimization…
- …but affected by background [not absolute luminosity measurement]

Kaon Monitor (SIDDHARTA)

PM: Hamamatsu R4998

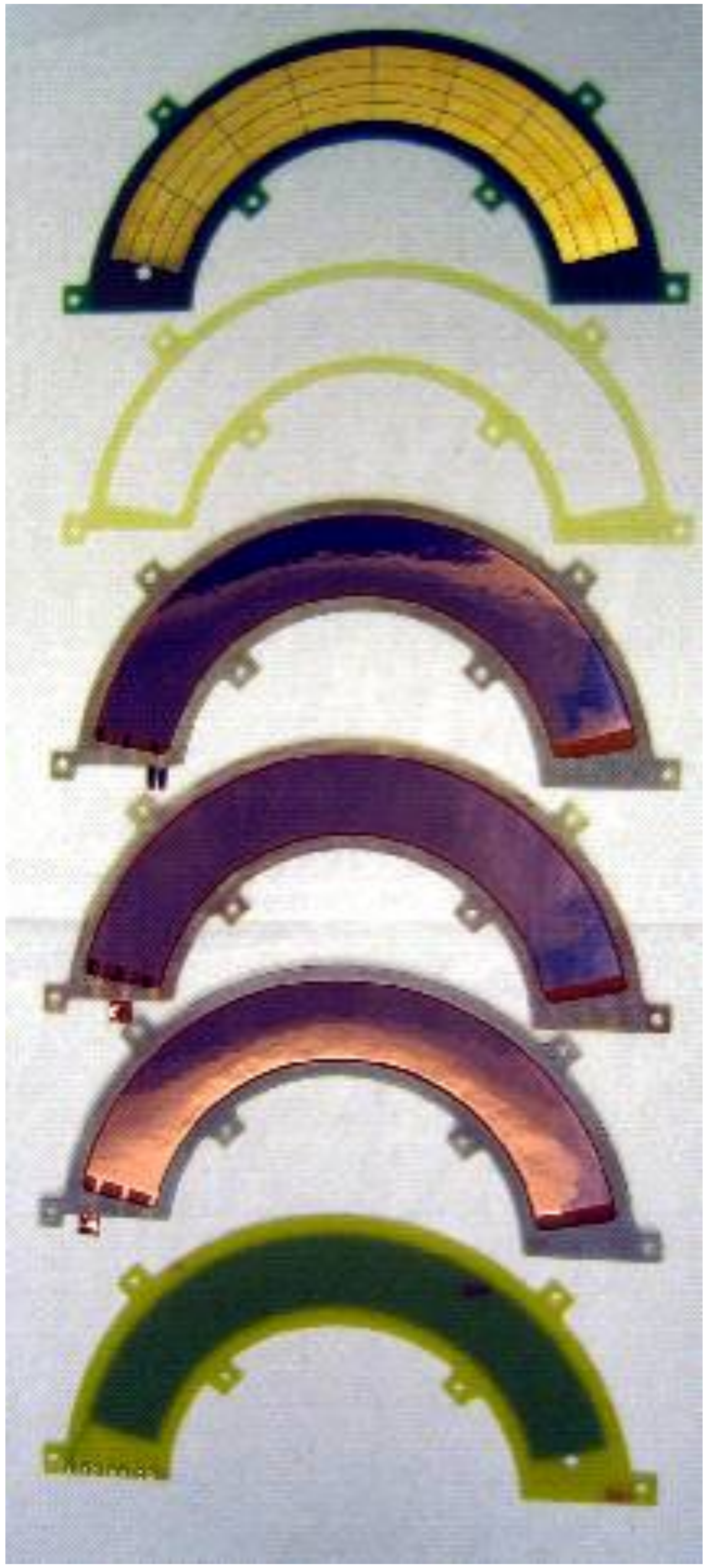
Scintillators: BC420

Dimensions: 200 x 50 x 2.0 mm

Triple-GEM tracker

Triple-GEM tracker

Triple-GEM trackers



pads

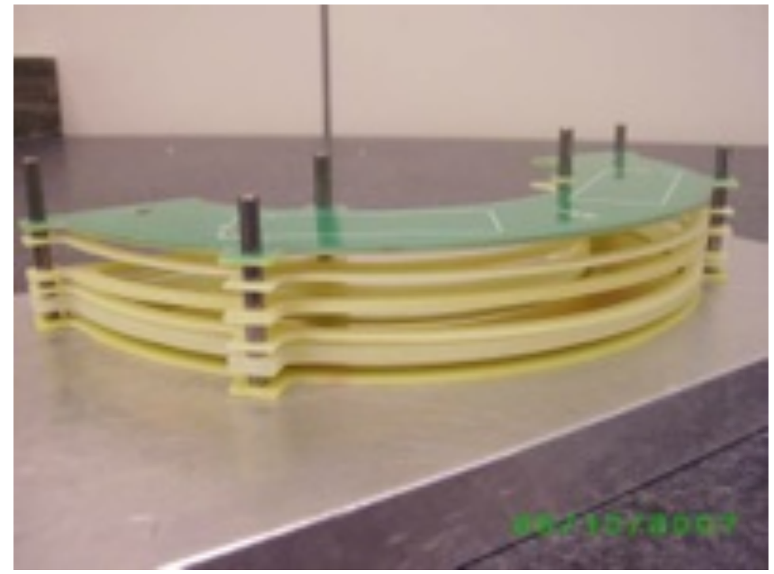
induction gap

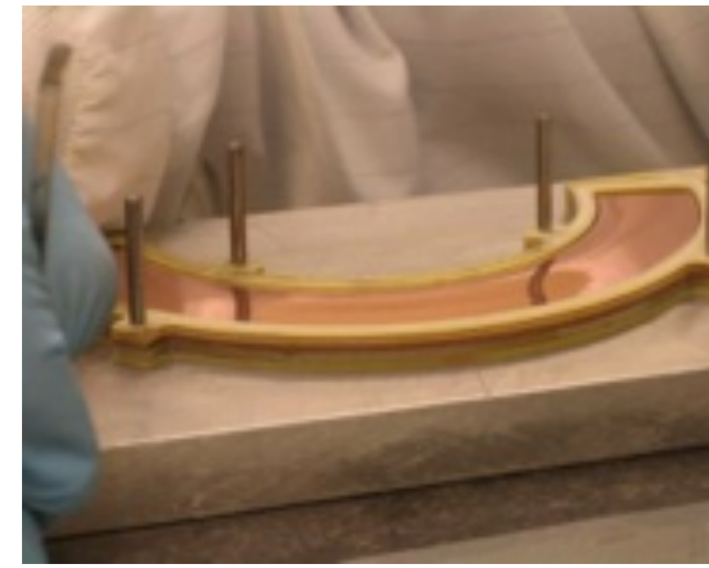
GEM 3

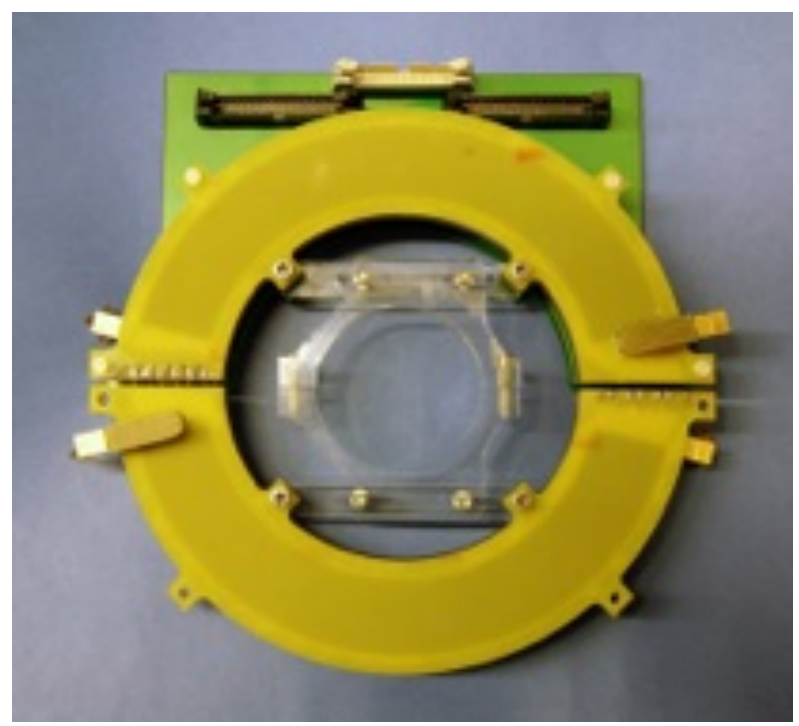
GEM 2

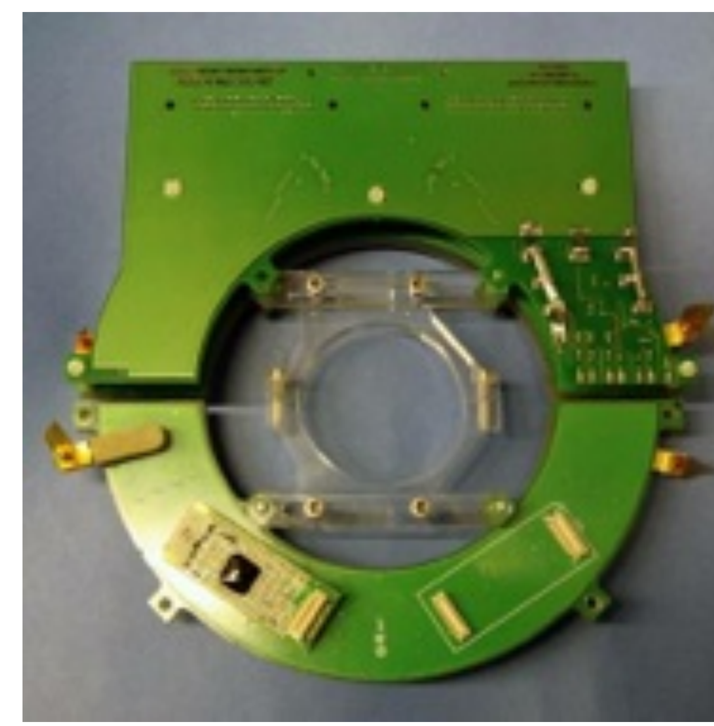
GEM 1

Cathode



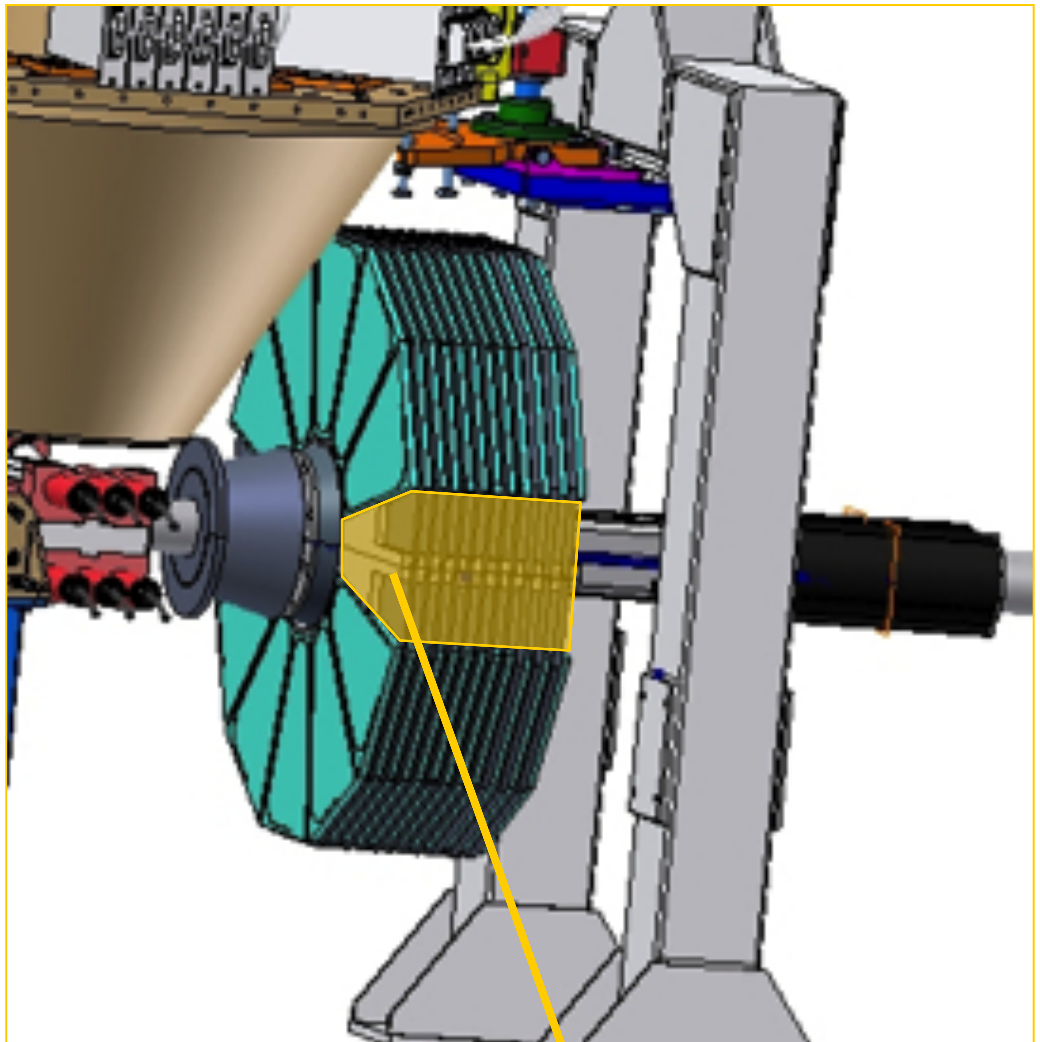






Final luminometers with Carioca FEE

Bhabha calorimeter design



- **Longitudinal segmentation has been optimized keeping in mind that the total available depth is only the length of the quadrupole ≈ 20 cm**

- 11 absorber plates + 12 samplings:
  - 8×0.5 cm + 3×1 cm lead ≈ **12.5 X_0** should ensure sufficient shower containment
  - 12×1 cm scintillator
  - 2:1 active:passive ratio should ensure **≈15%/√E(GeV)** resolution

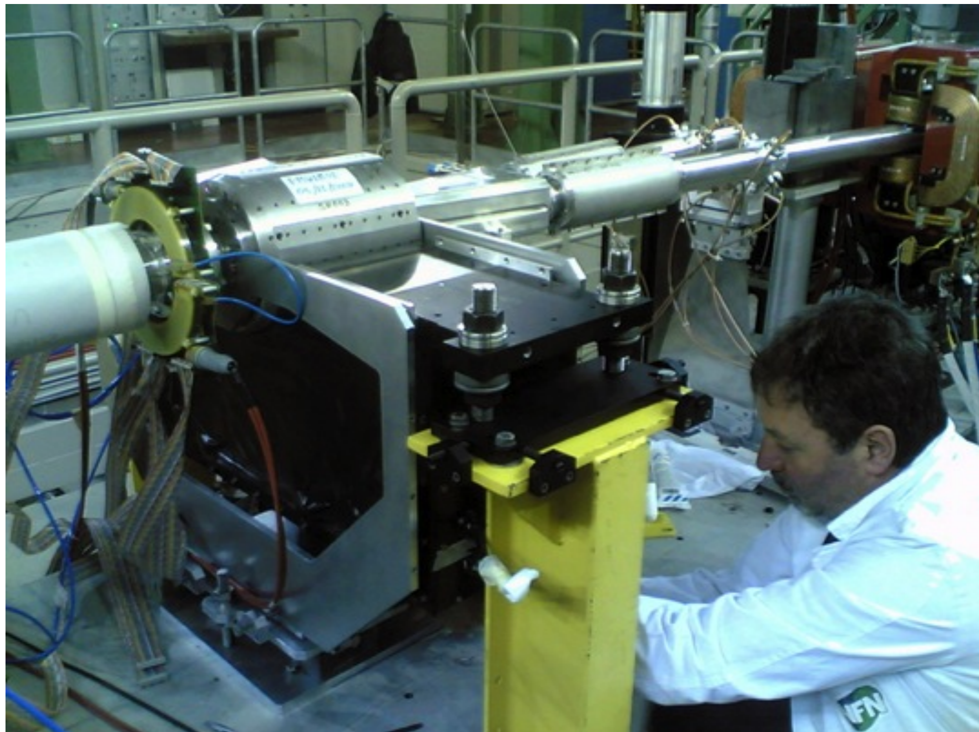
- **Lateral segmentation dictated by the need of keeping a reasonable number of channels and to have some degree of freedom in defining the acceptance**

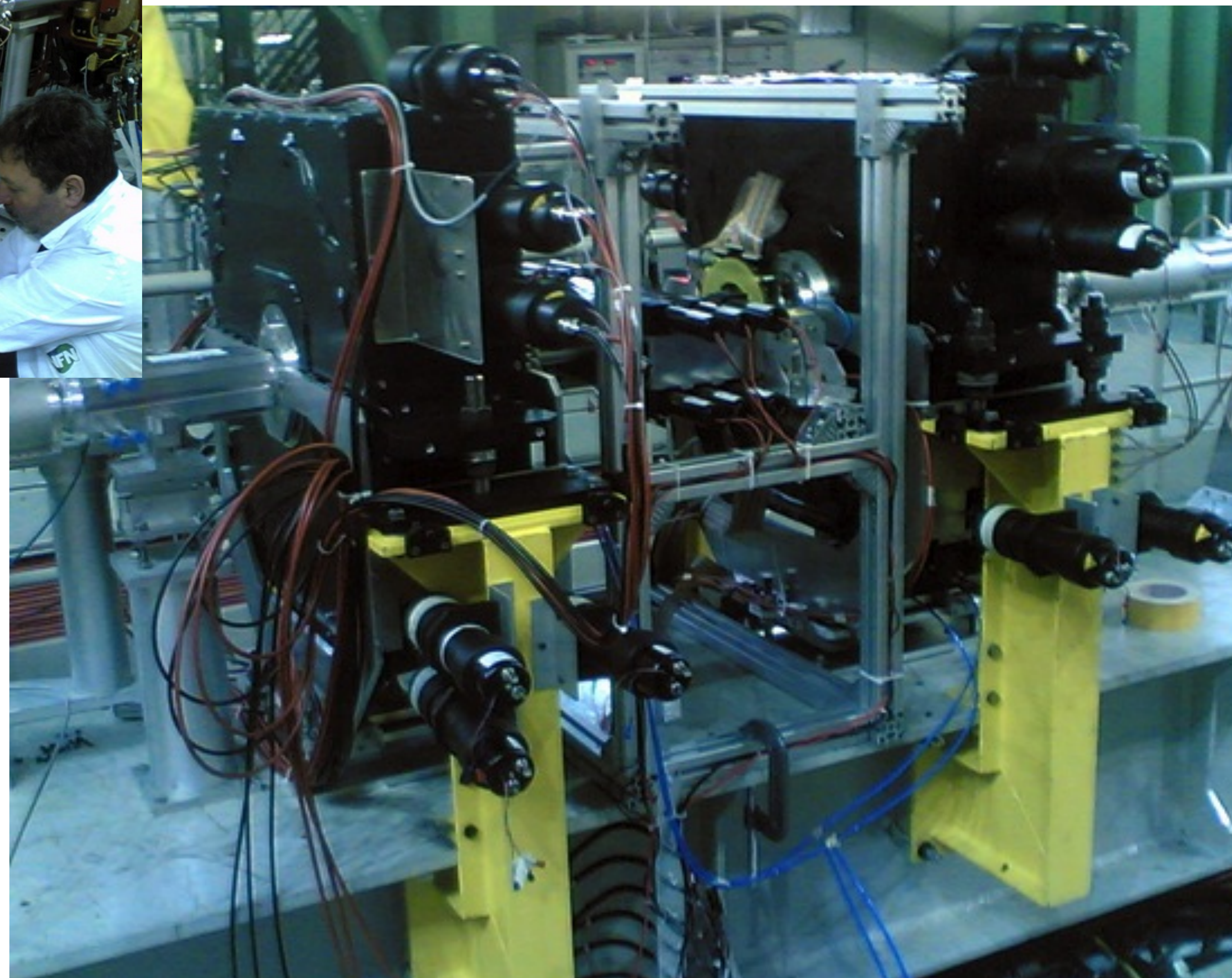
We decided to equip only 10 out of 12 sectors, keeping out the ϕ=0º-180º plane, since we expect larger backgrounds from there

CaloLumi construction

December ‘07 – January ‘08

CaloLumi installation

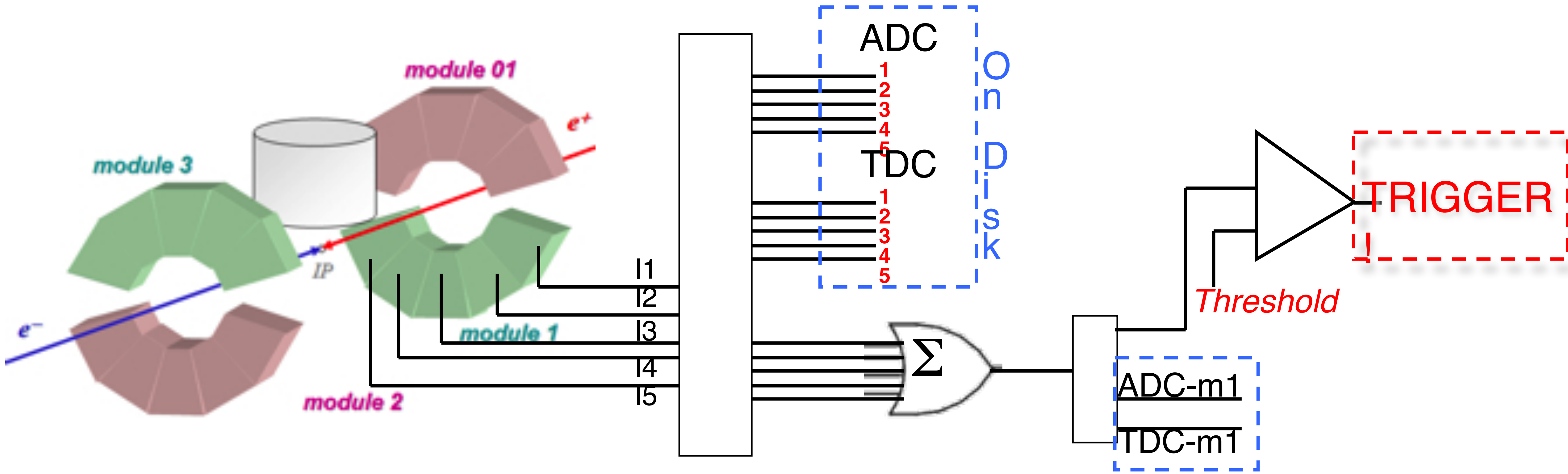




7 February 2008

DAQ and Trigger

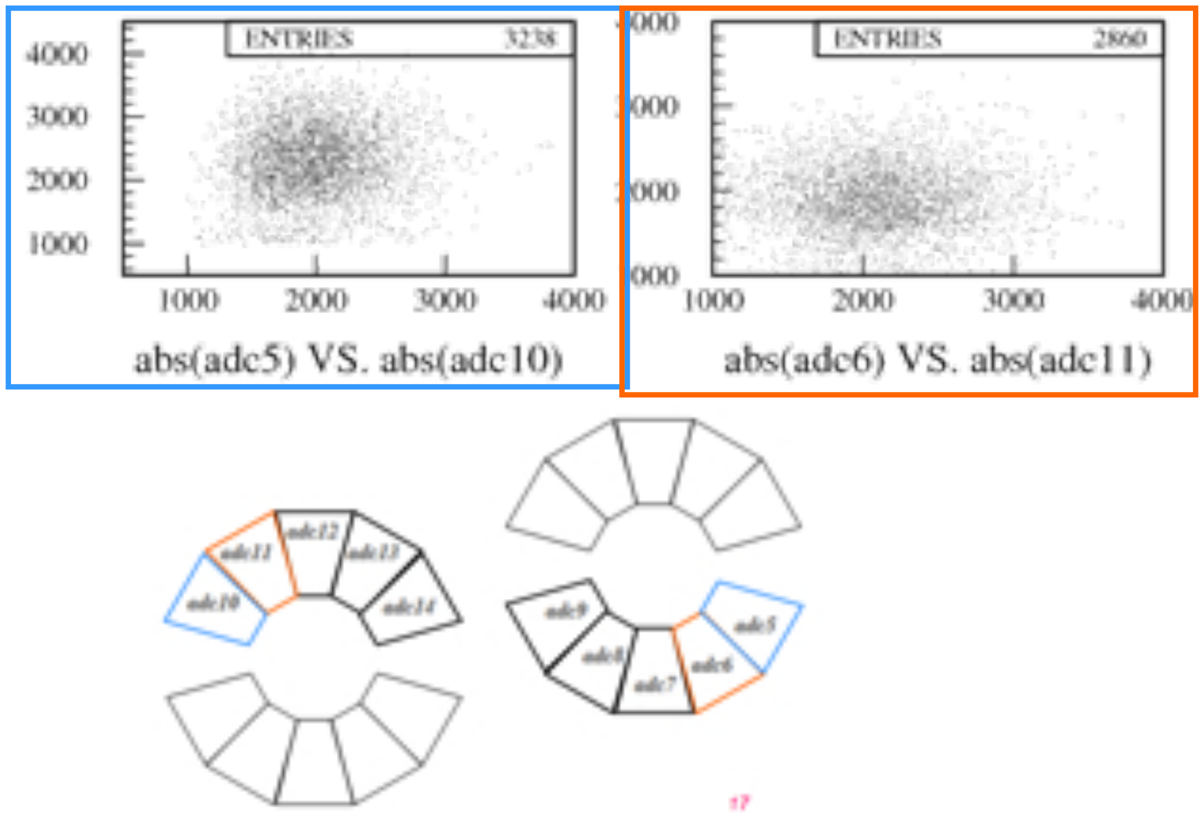
- Offline and Online measurements (i.e. trigger rate)



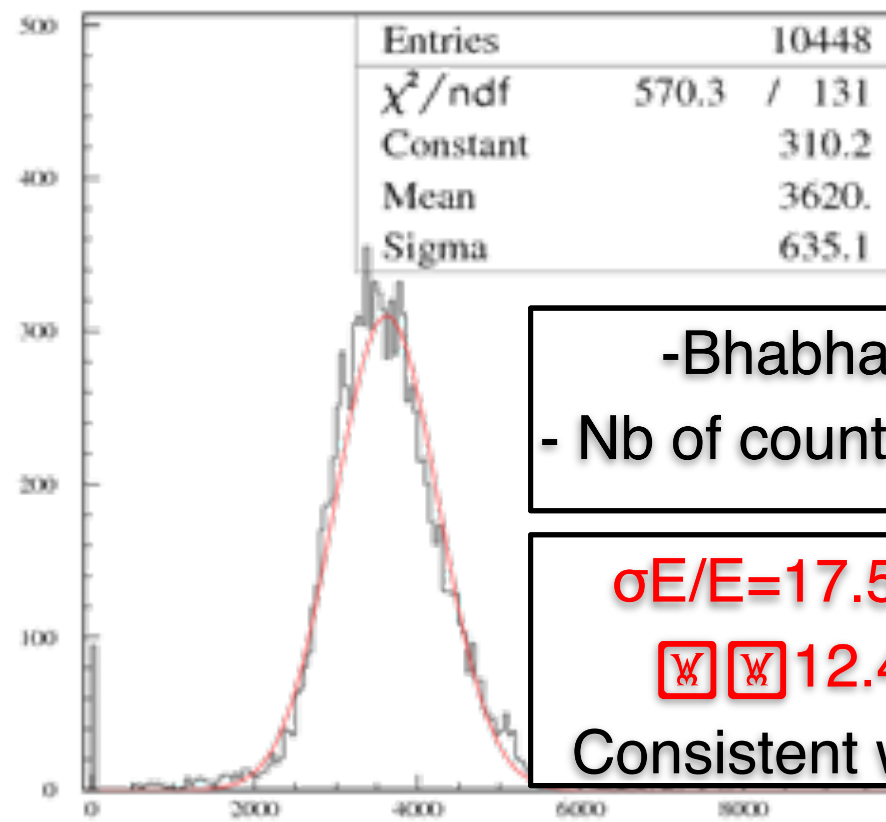
- Re-use KLOE's DAQ
  - KLOE's SDS boards to split, discriminate and sum the signal to assert a trigger ;
  - DAQ software also KLOE-based running on Motorola CPU MVM-E6100

Performance

- Clear Bhabha Peaks !



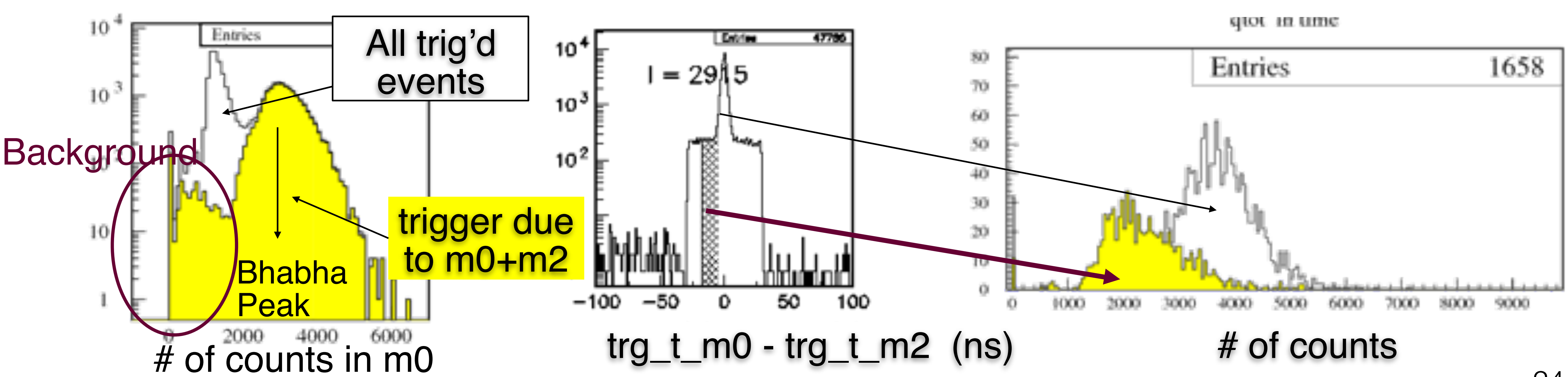
- Energy resolution



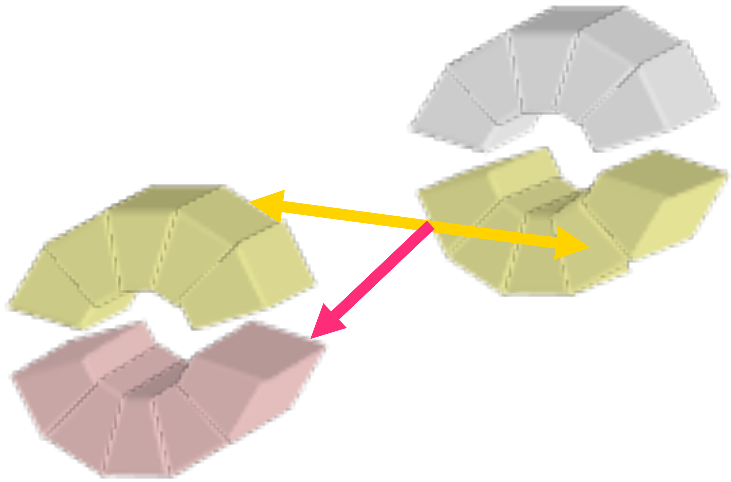
-Bhabha events in data
- Nb of counts in one module (?)

$\sigma E/E$=17.5% @510 MeV
[illegible] 12.4%/√E (GeV)
Consistent with test beams.

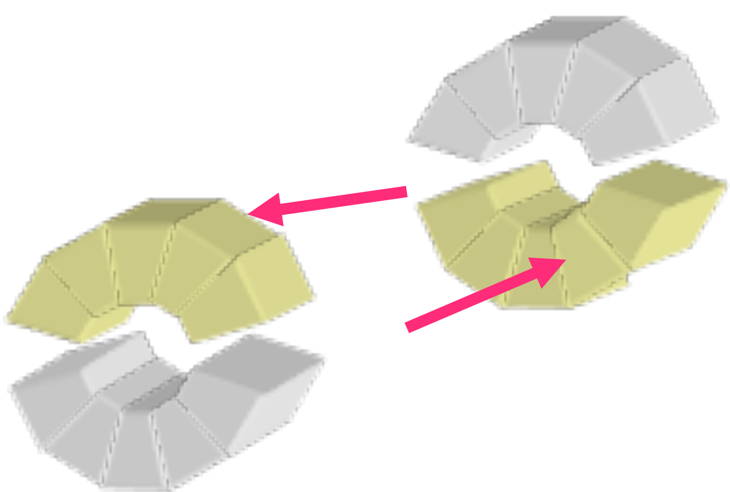
- Time resolution good enough to subtract backgrounds from Trigger Rate



Background



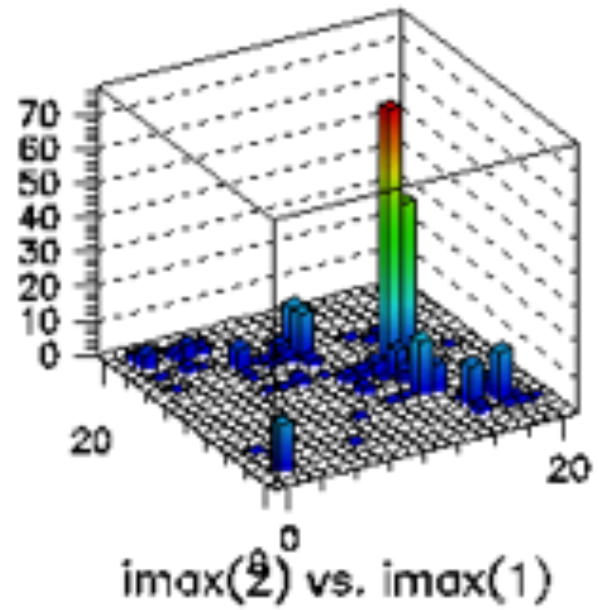
We can have energy deposits over threshold in another module, in addition to the couple of triggering modules: this gives us the "triples"

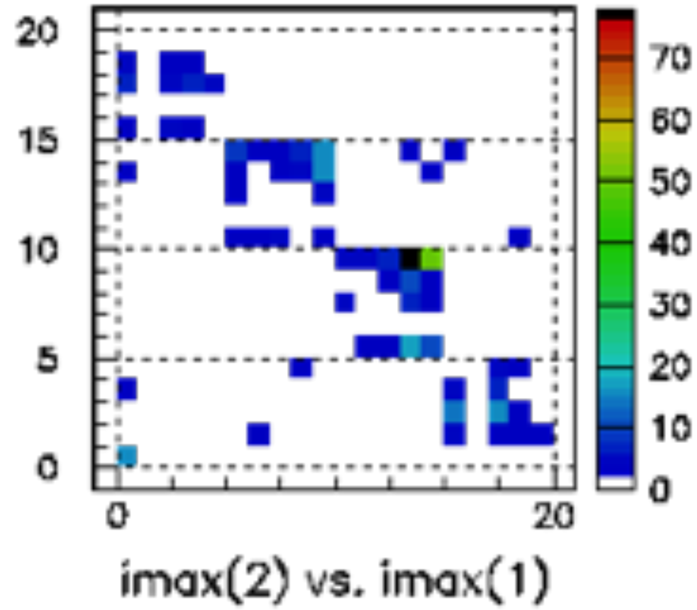


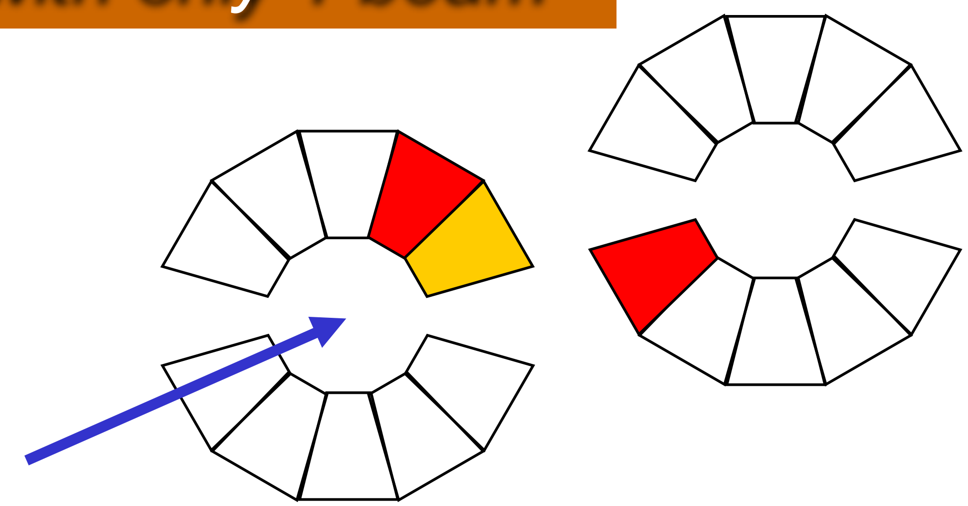
*We expect a similar level of events with no Bhabha, but with **two** "spurious" deposits, giving a fake coincidence*

Background topology

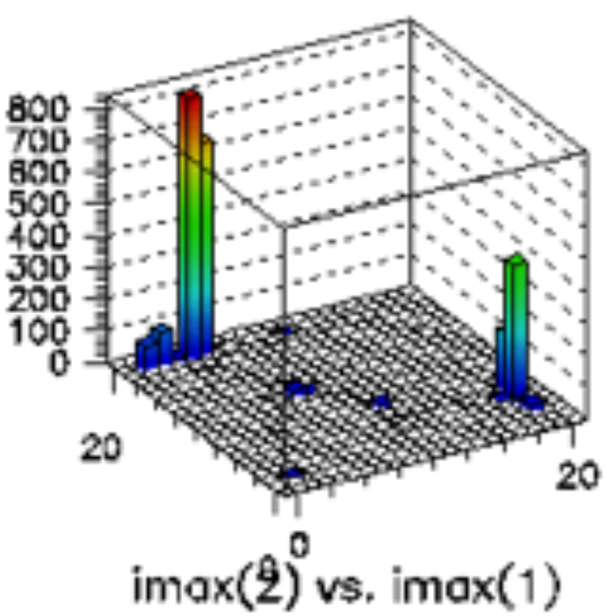
Cross check looking at runs with only 1 beam

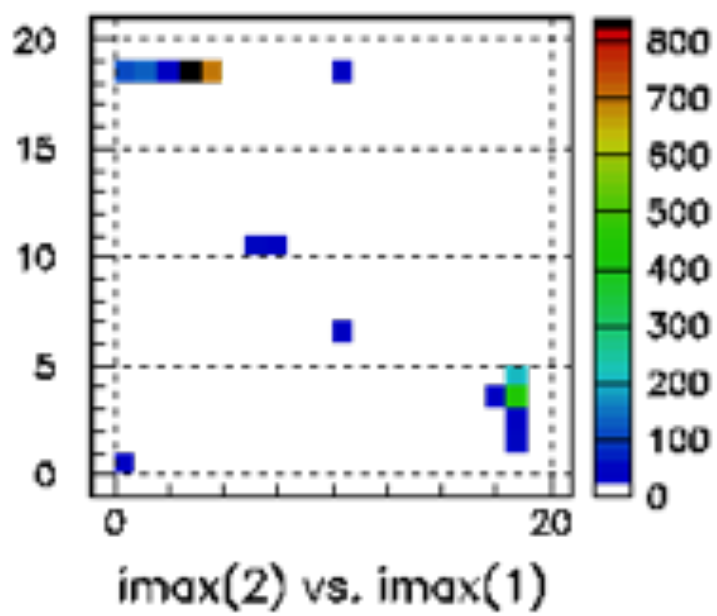


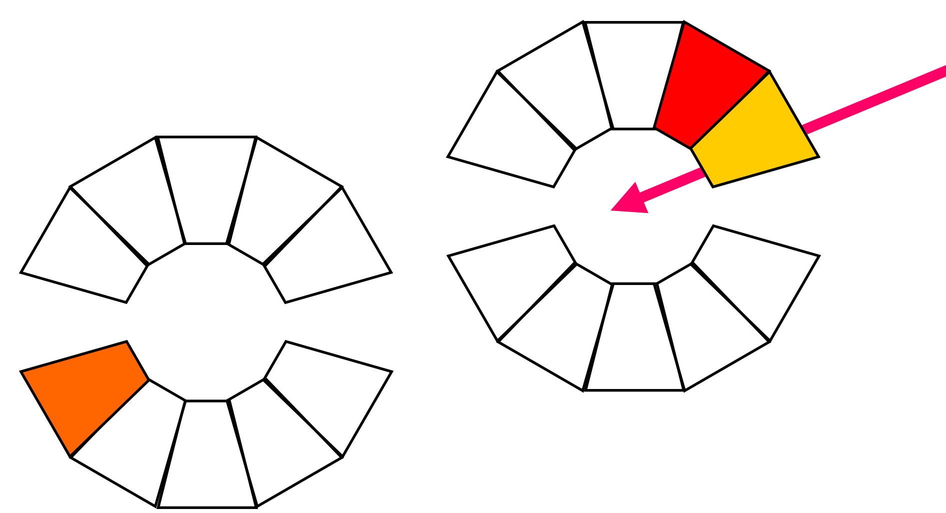




run 1392, e- 350 mA, 100 bunch

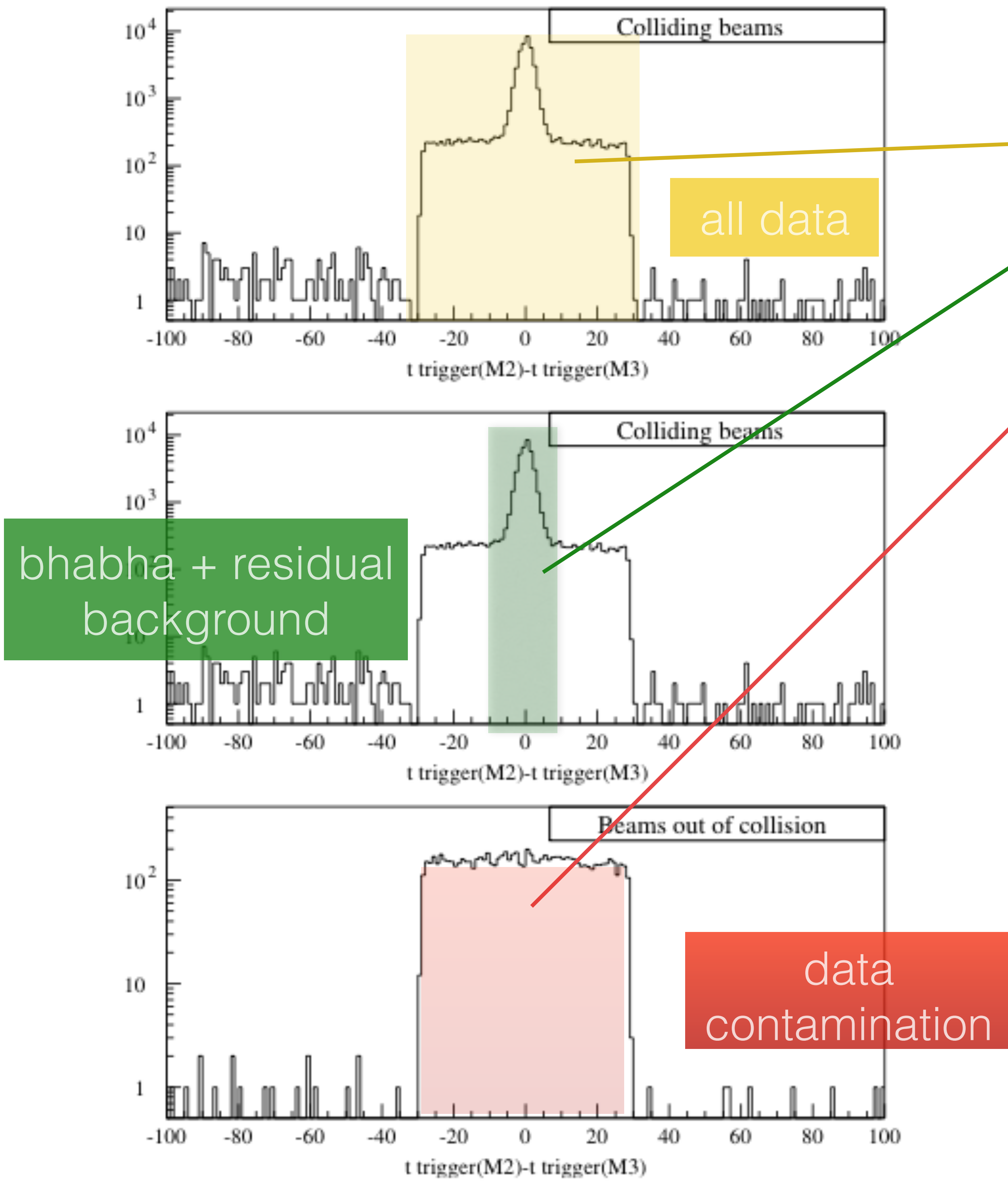






run 1394, e+ 290 mA, 100 bunch

Background subtraction (timing rejection procedure)



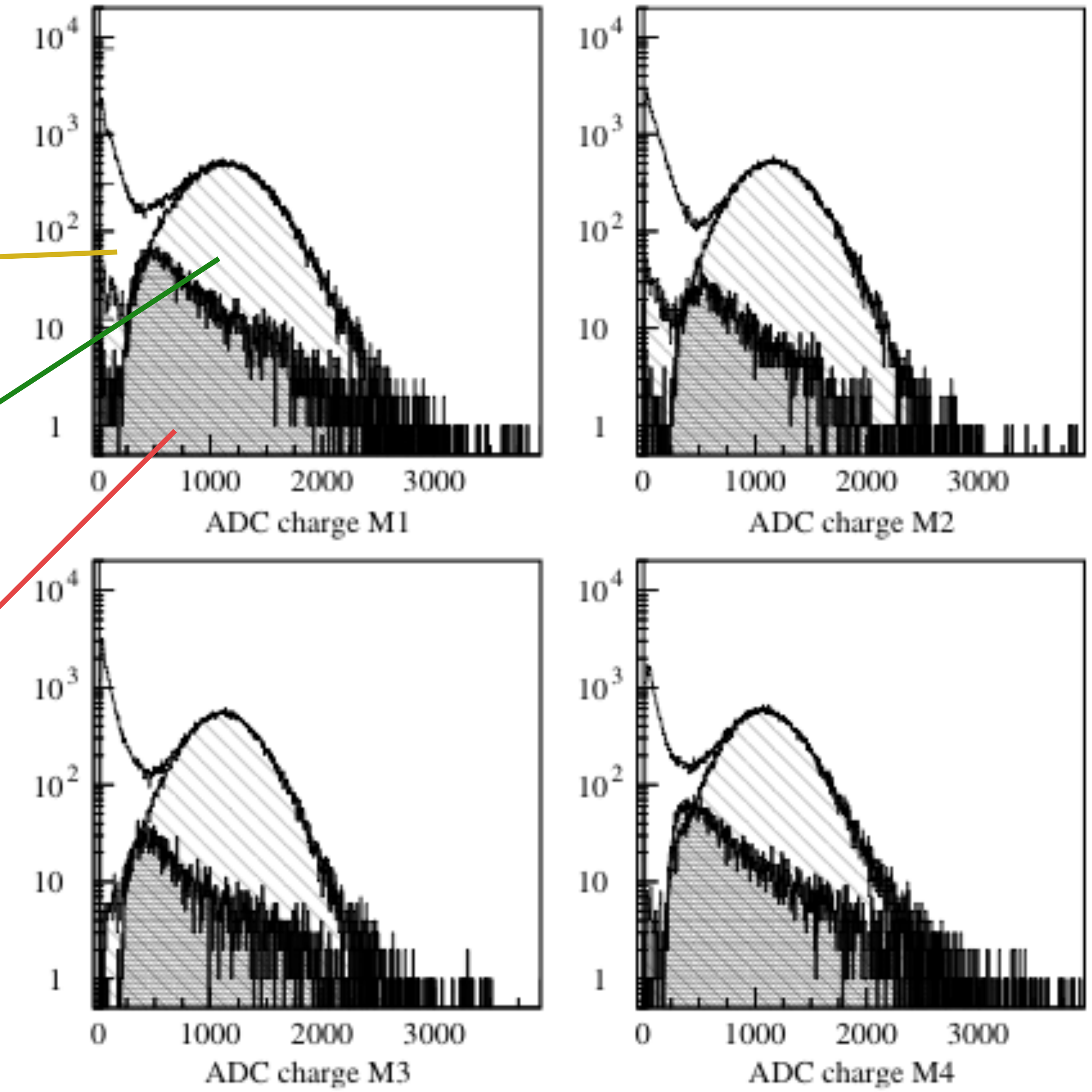
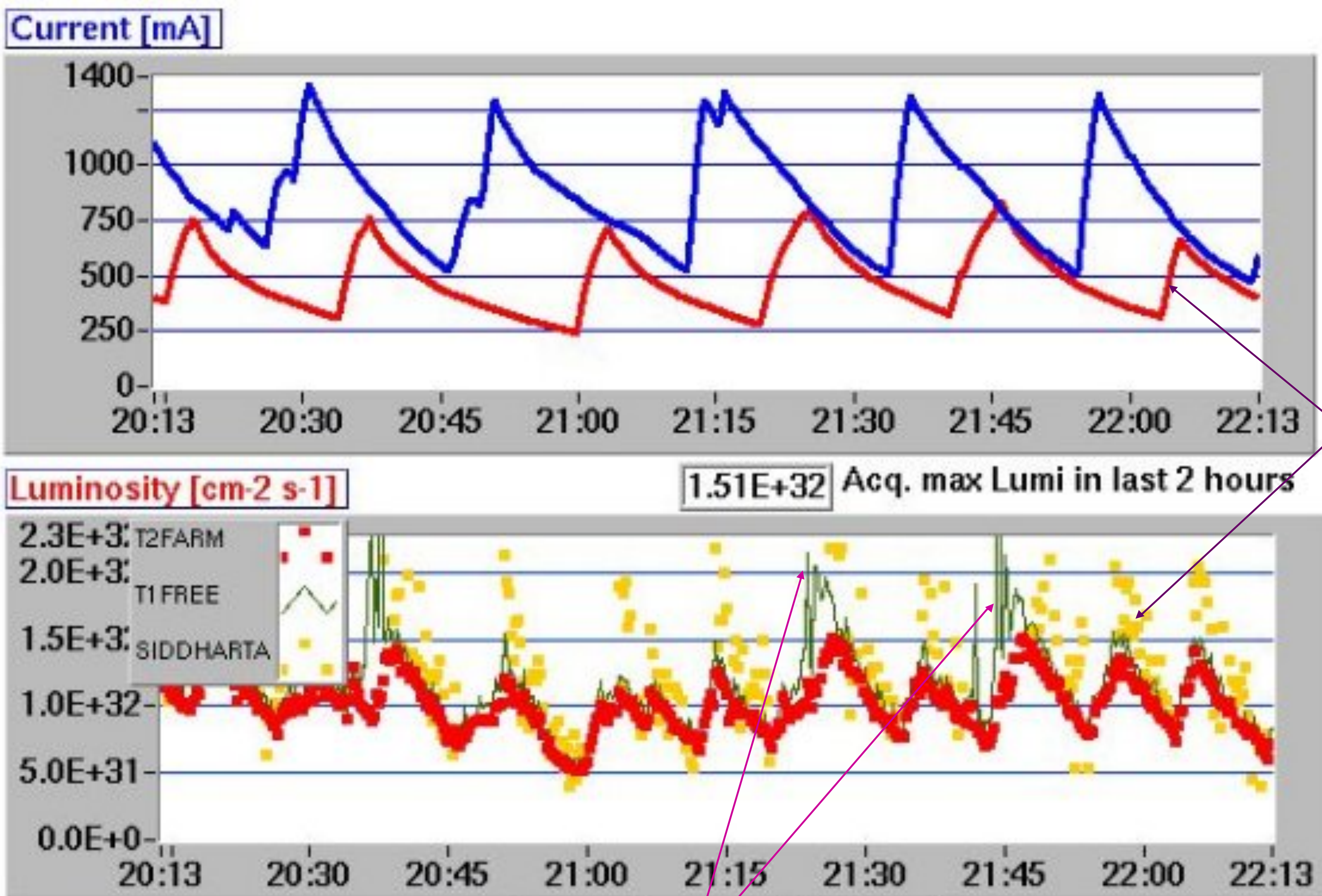


Fig. 11. ADC distributions in the four calorimeter modules for the representative high-statistics run used to produce most of the plots in this section: all histograms show three components with similar patterns. Events for which that particular module did not trigger belong to the white area on the left: little energy is deposited in these sectors, as expected from background fluctuations. Hence, these events are not real Bhabha decays for which one of the two particles is not detected. The hatched regions contain the events for which the module triggered. Events for which the energy deposit is not coincident in time with the one measured in the opposite module (pure background case) are in the darker area. Their deposited energy is lower than for the in-coincidence events (high purity Bhabha sample) which are in the light-hatched area. These plots and those of Fig. 10 justify the timing criterion used to separate signal from background.

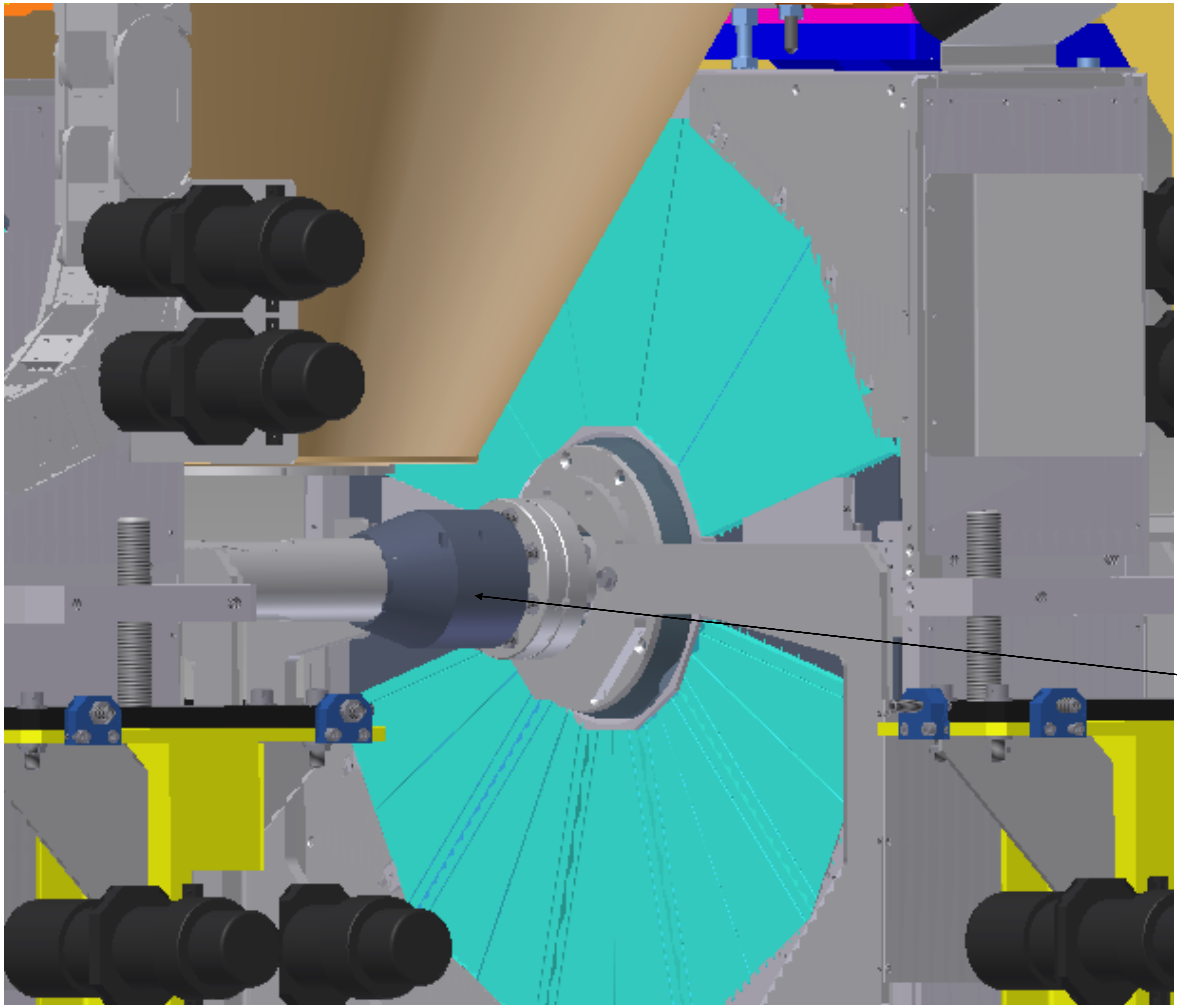
Online timing filter effect



good e+ injection

bad, dirty, e+ injections

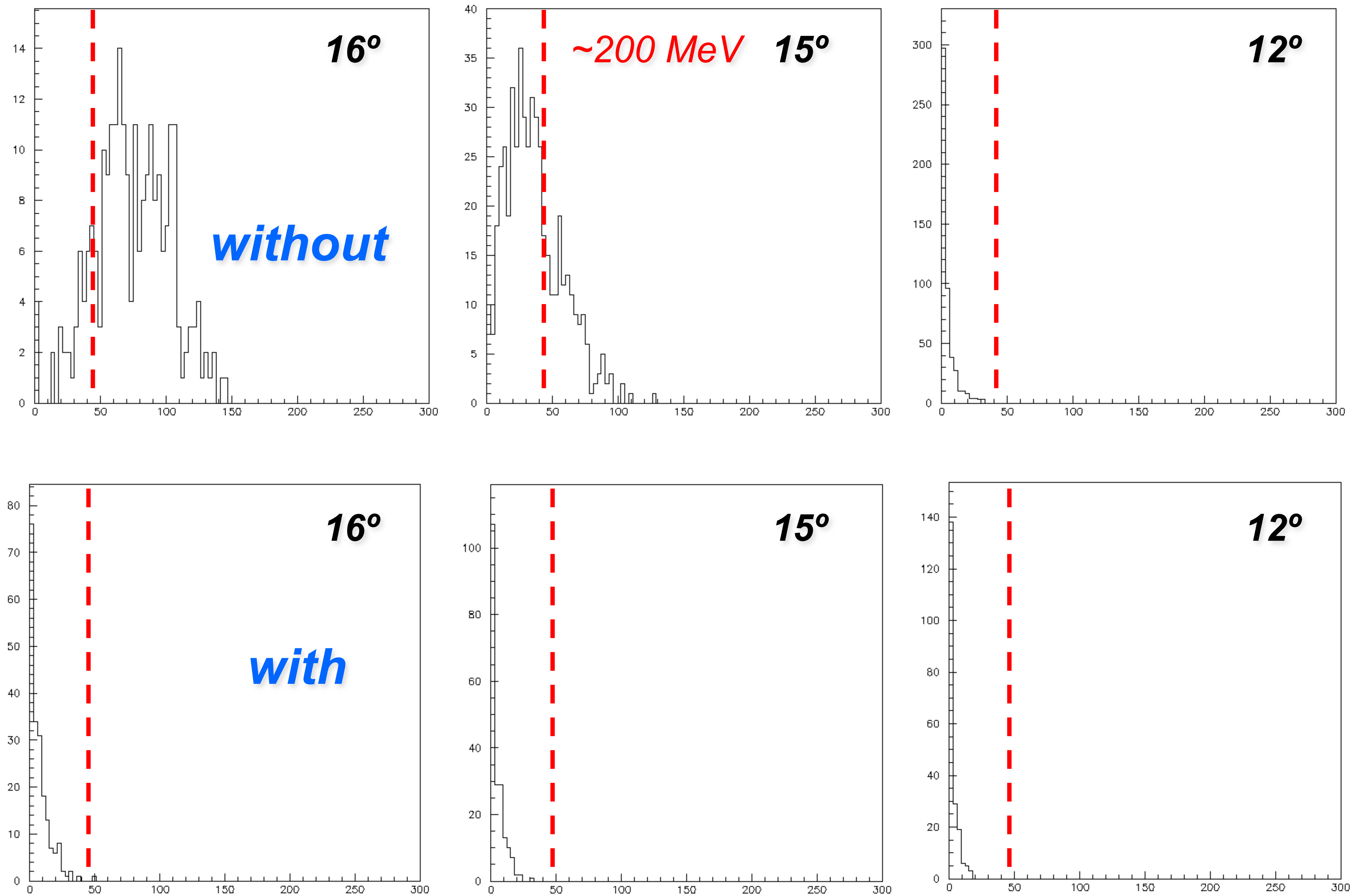
Soyuz



$\theta > 18^{\circ}$

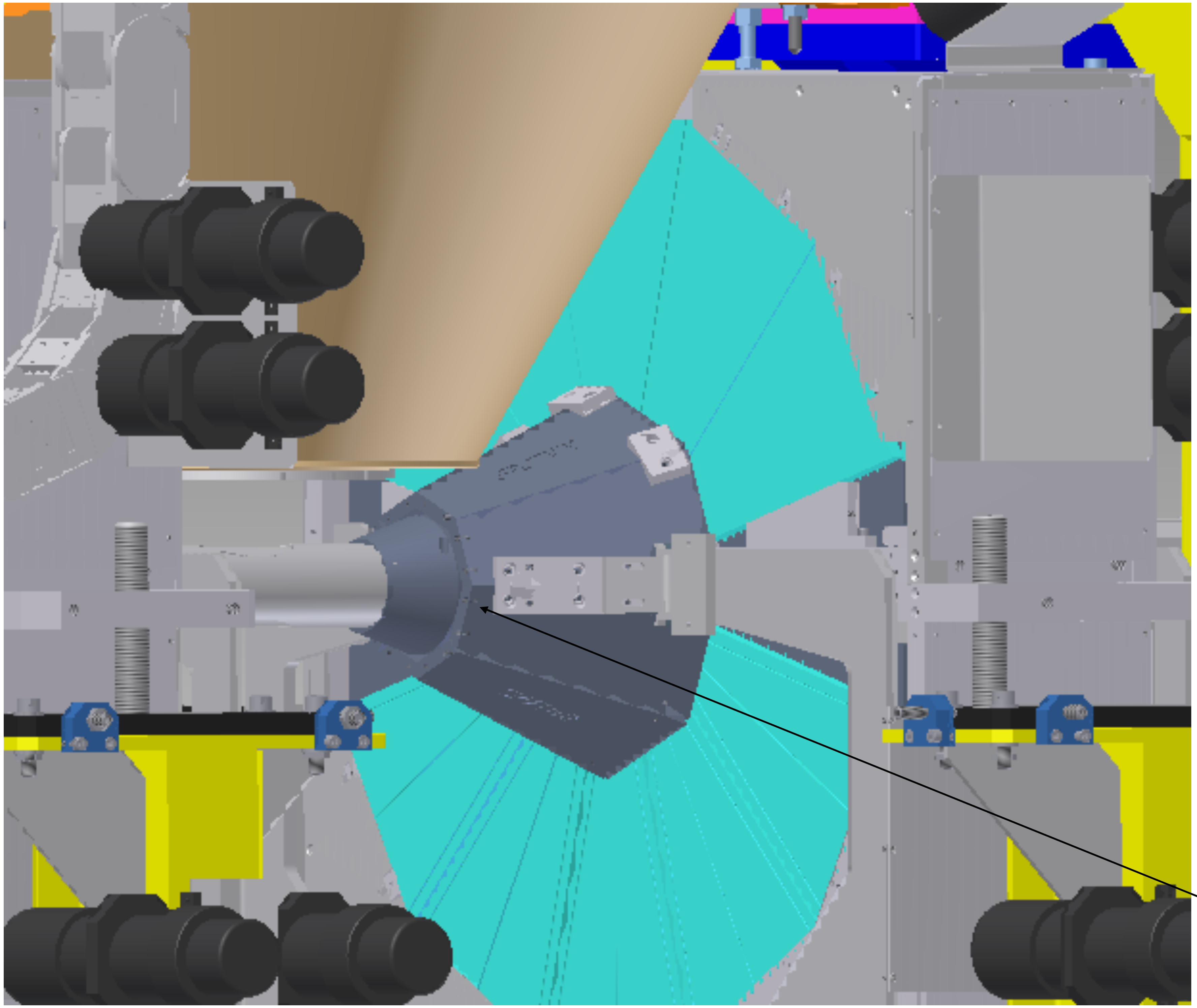
Soyuz

Soyuz simulation results effect



Sputnik

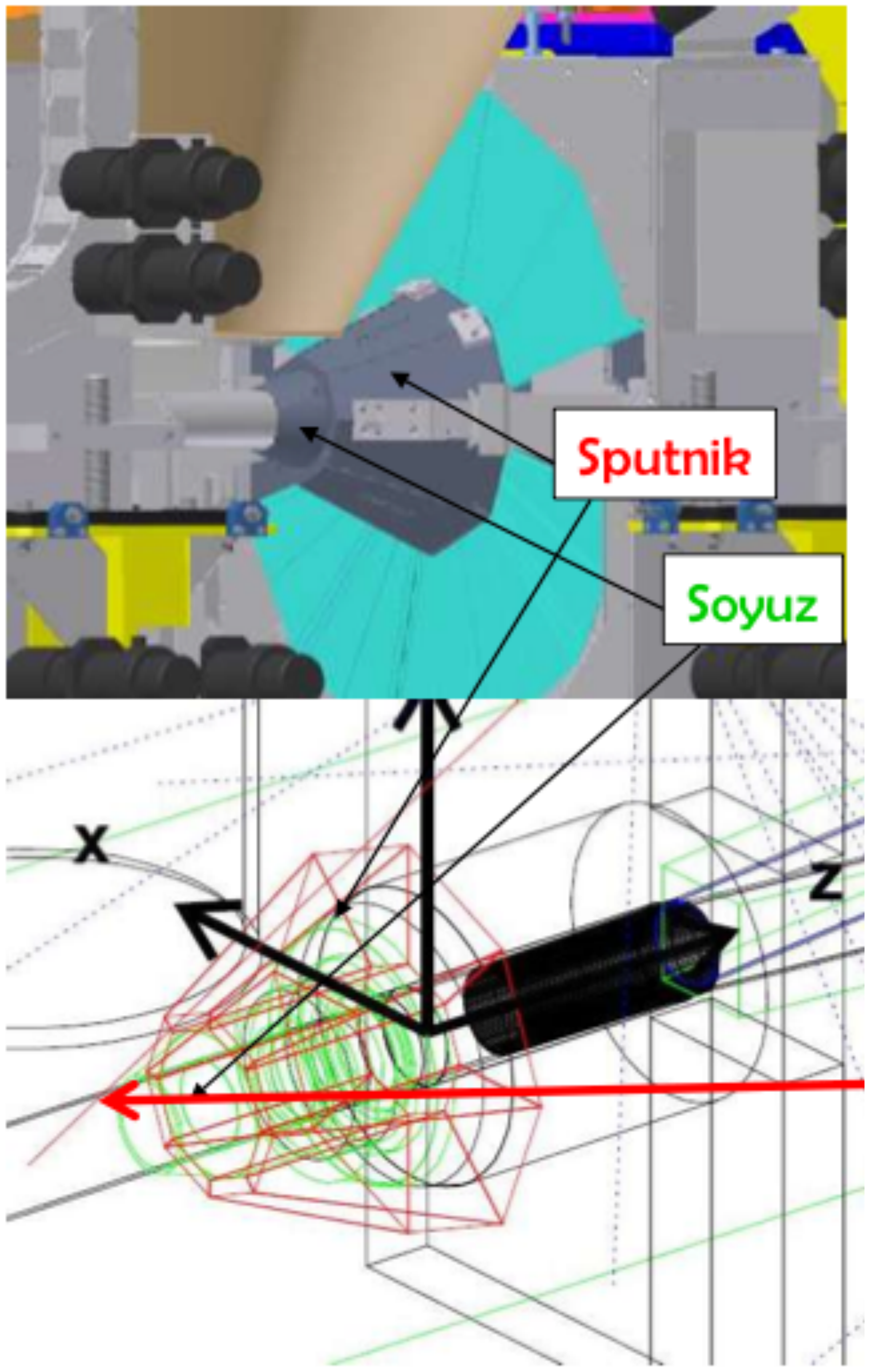
Since May 29th, 2008

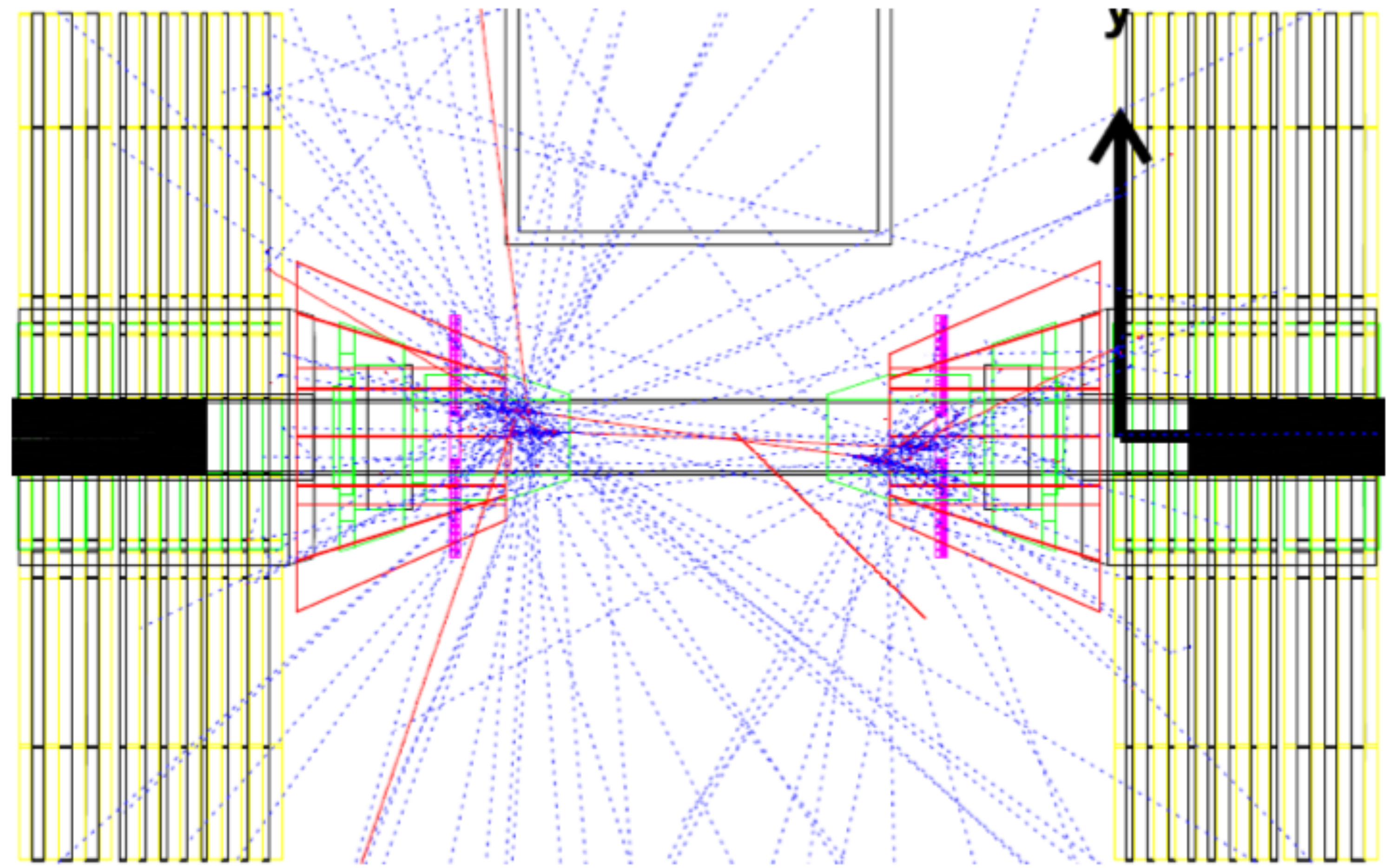


$\theta > 22^o$

Sputnik

Simulation

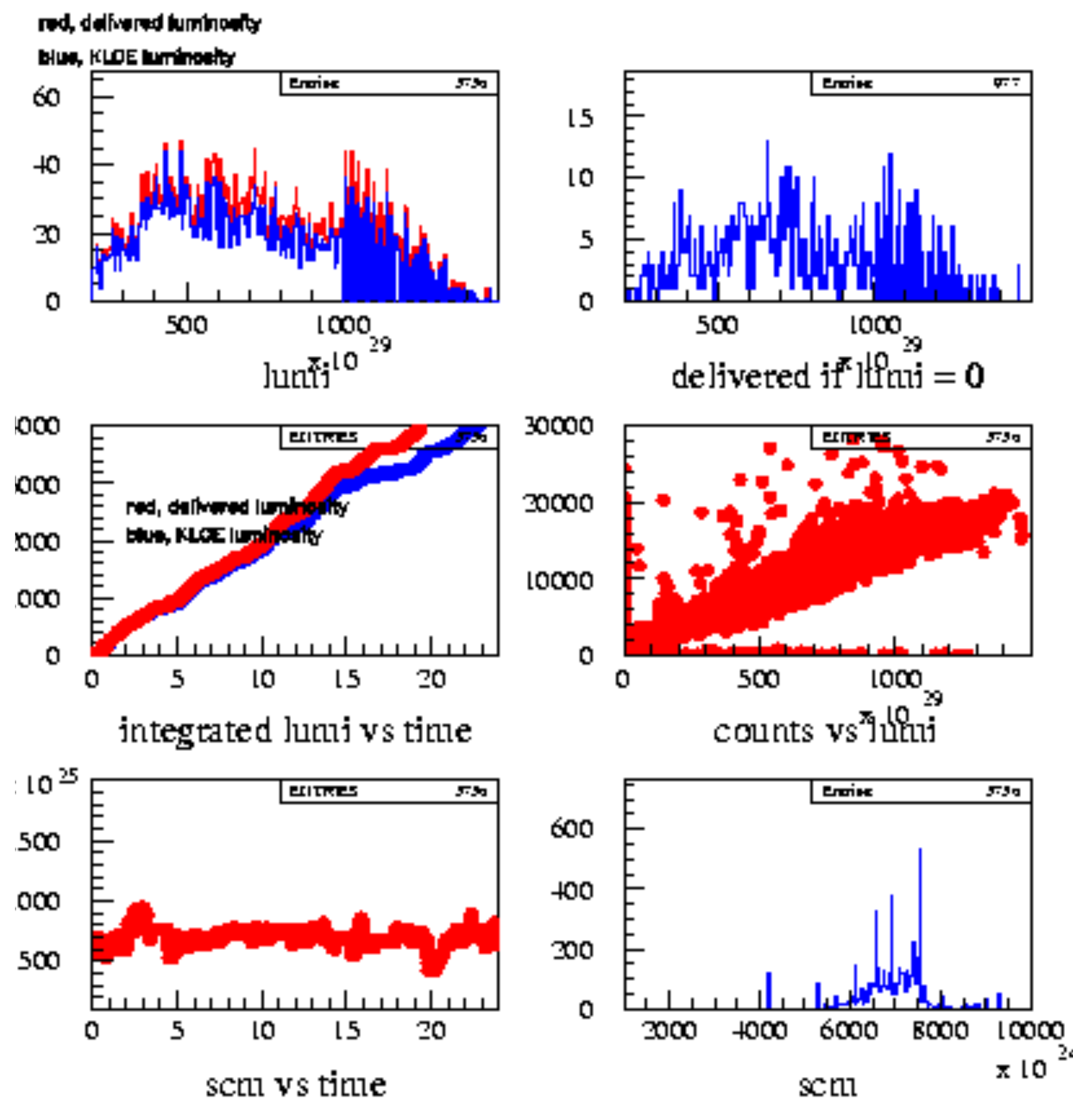


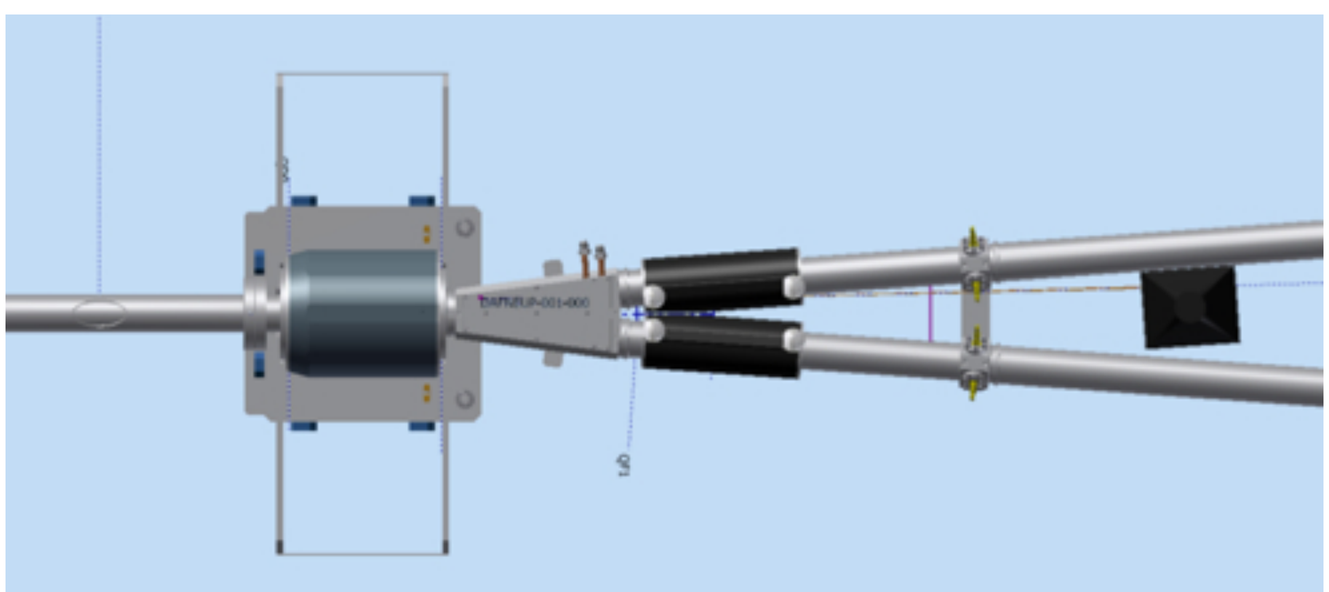


A full simulation has been essential tool for understanding not only the real acceptance and normalization but also how to optimize detector performance

Today (very bad condition)

- no space available
- final focusing quadrupoles are covering the gamma exit line, and the quantity of material intercepted is depending by orbit path
- very high background condition
- trajectory effect, and overlap complicated by experiment magnetic field
- It's not possible calibrate the lumi monitor





auto-calibration procedure based on running average online luminosity KLOE data

Conclusion

- Have a fast, absolute, background free luminosity monitor on **DAFNE** has been always a **not easy task**.
- The **crab waist** scheme introduced many issue due to:
  - physic (significance) **measurements**;
  - **background**.
- In the very simple layout, like SIDDHARTA one, a **tracker** system (GEM) was not usable alone or a gamma monitor at zero angle, and a large angle calorimeter needed an accurate data analysis.
- To be completely background free we have to use also **timing** information and strongly increase the **shielding** detector protection.

The combinatin of **energy, position and timing** information looks to be fundamental to avoid background of an accelerators running with the crab waist scheme, as well as accurate selection of the lumi detector **acceptance** (shielding)

In the same time, the introducion of crab waist, and the consequent complication in the understanding the beam interaction behavior make fundamental have a **machine accelerator luminosity detector with the above characteristics.**

Conclusion (cont)

- the luminosity monitor is a fundamental instrument for accelerator measurement parameters and operation optimization

- the physic, in terms of signal, background and beam-beam behavior in the detector(s) must be very well known and understood (full simulation)

- the detector characteristic and design must be based on the accelerator quantity to be measured and background condition of operation

Spare

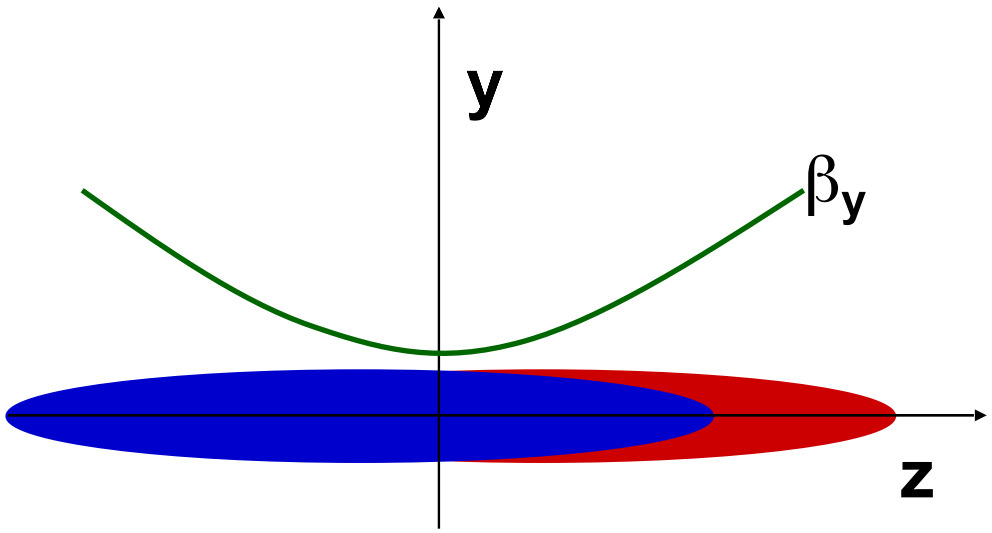
Luminosity and crossing angle

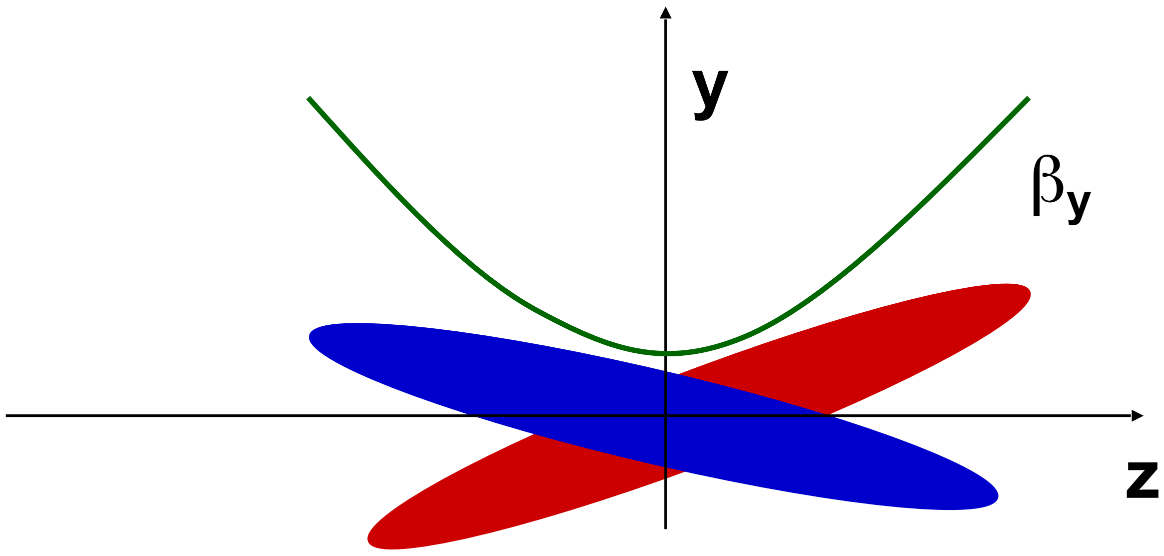
$$L \propto \frac{N^2}{\sigma_x \sigma_y} \quad + \quad \Phi \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2} \quad \Rightarrow \quad L \propto \frac{N^2}{\sigma_x \sqrt{\beta_y (1+\Phi^2)}}$$

luminosity is limited by hourglass and tune-shift effects

crossing angle θ (Piwinski angle Φ)

high density N
low β_y
low σ_x





The introduction of a crossing angle do NOT improve luminosity

luminosity and tune-shift

bat allows to play with transversal dimension σ_x and β_y optical function, kipping limited the vertical tune-shift and strongly depressing horizontal tune-shift

$$\xi_y \propto \frac{N\sqrt{\beta_y}}{\sigma_x\sqrt{1+\Phi^2}} \qquad \xi_x \propto \frac{N}{\sigma_x^2(1+\Phi^2)}$$

$$\Phi \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2}$$

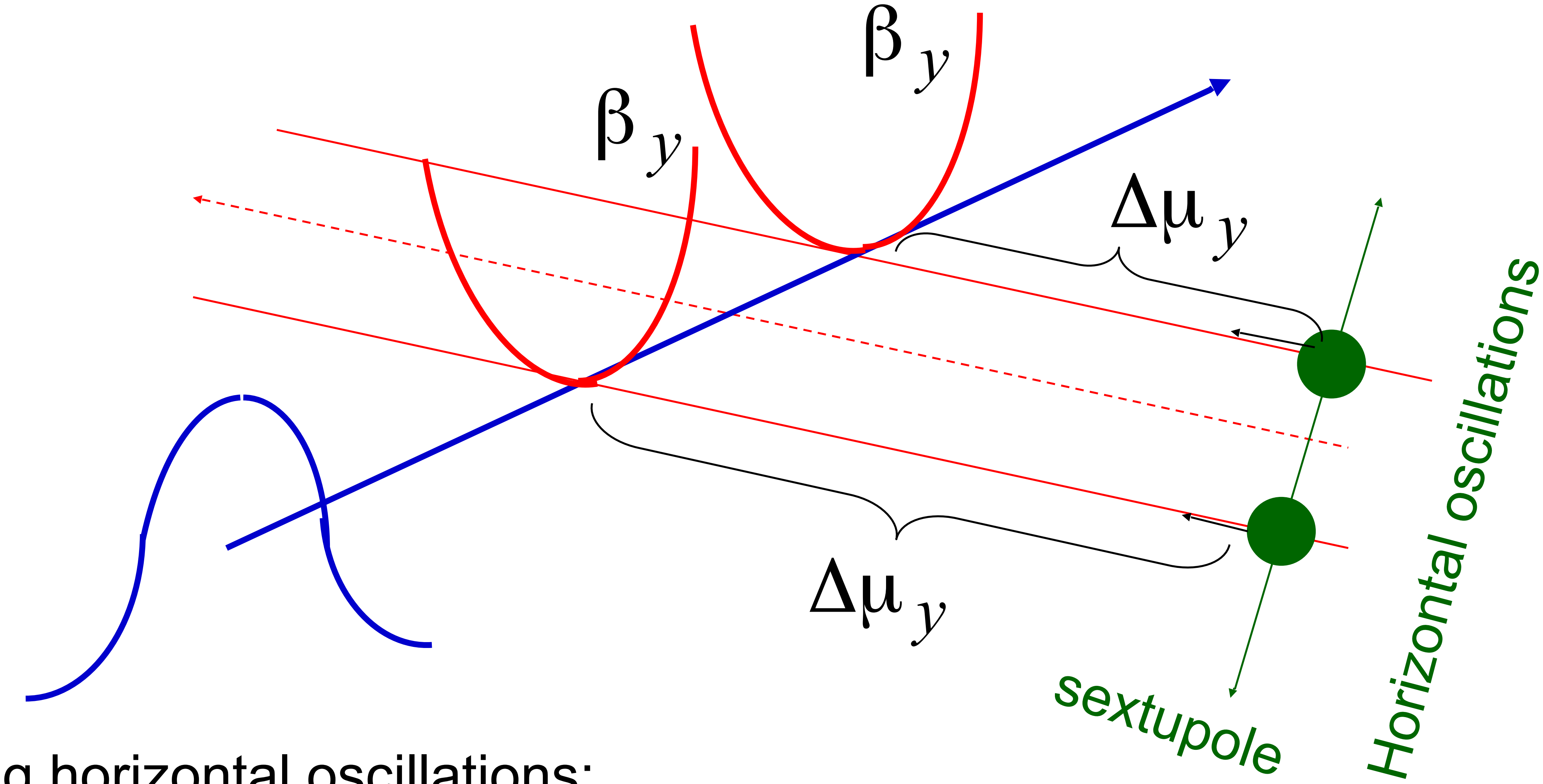
- **σ_z large**
  σ_x small

⇨

$$\beta_y \approx \frac{\sigma_x}{\theta} << \sigma_z$$

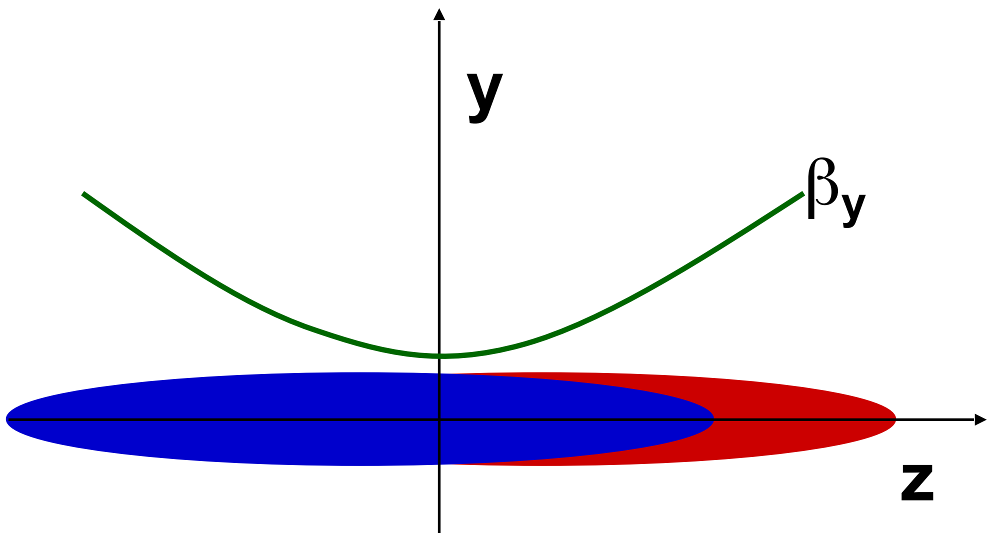
bat a large Piwinski angle can generate strong sincro-bethatron oscillation

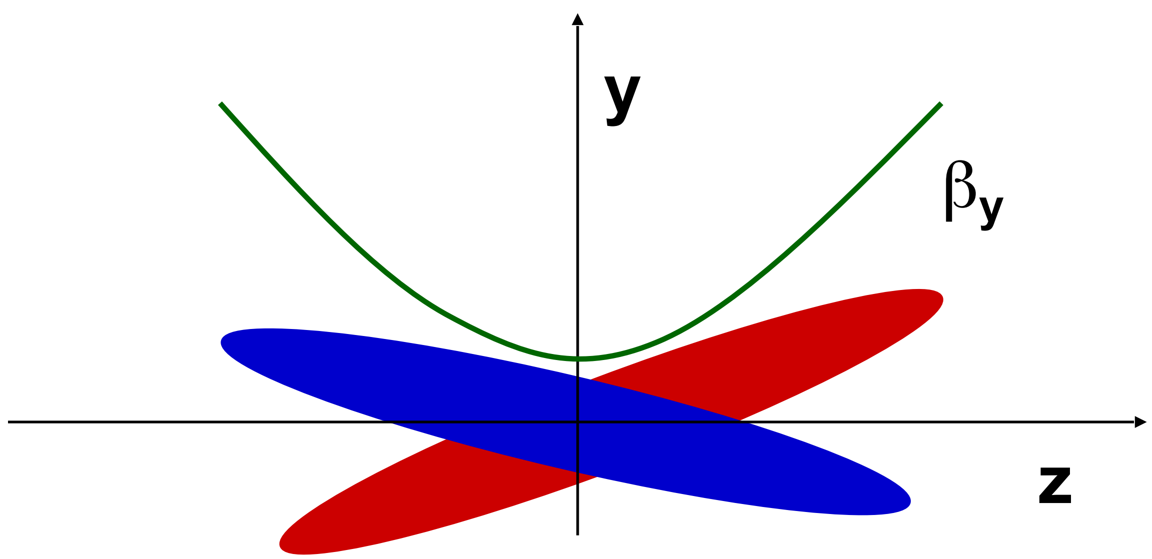
Suppression of X-Y Resonances



Performing horizontal oscillations:

1. Particles see the same density and the same (minimum) vertical beta function
2. The vertical phase advance between the sextupole and the collision point remains the same ($\pi/2$)


y
β_y
z


y
β_y
z