



Luminosity measurements experience at DAFNE

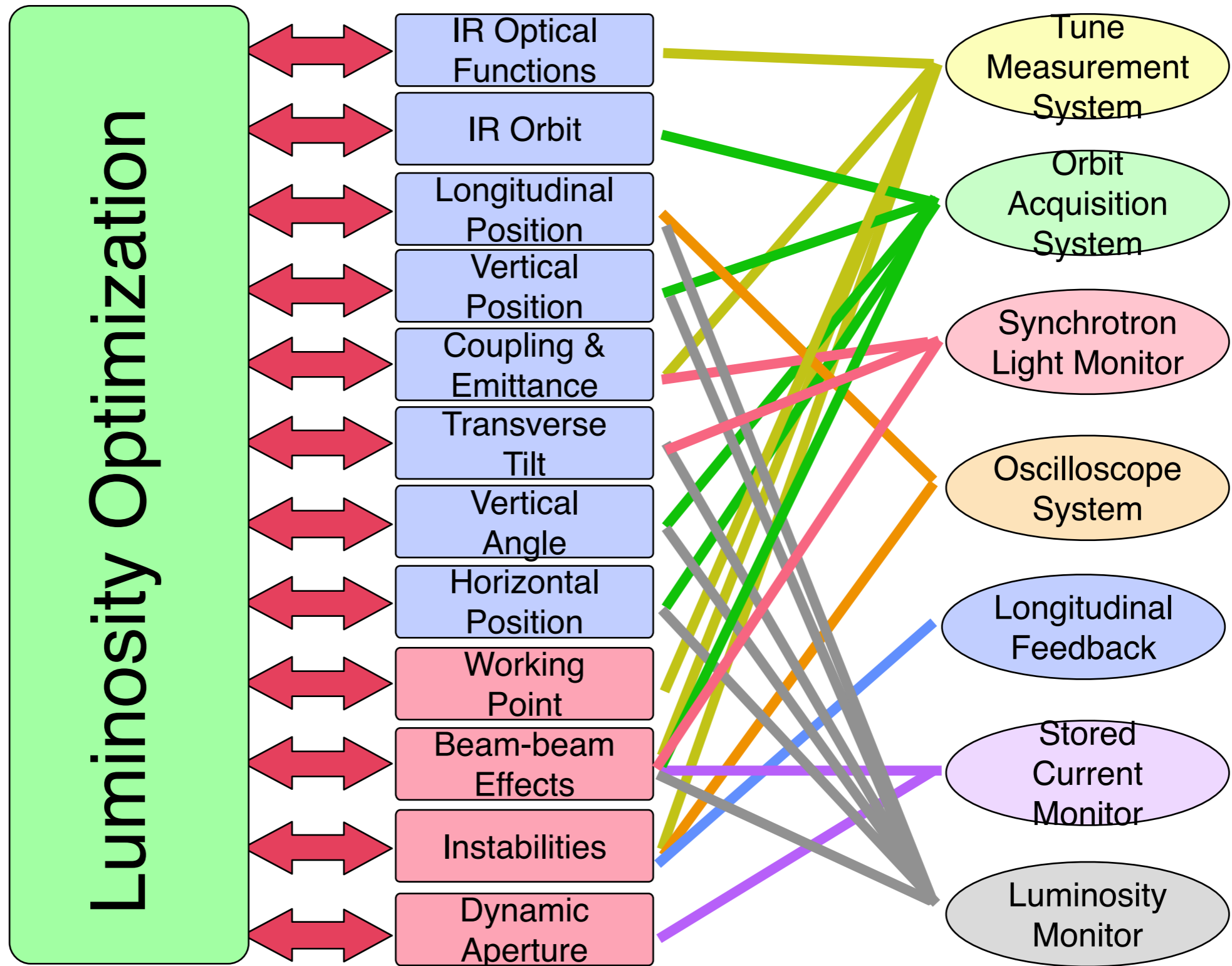
G. Mazzitelli

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



way a machine lumi monitor?



The Physics at DAFNE

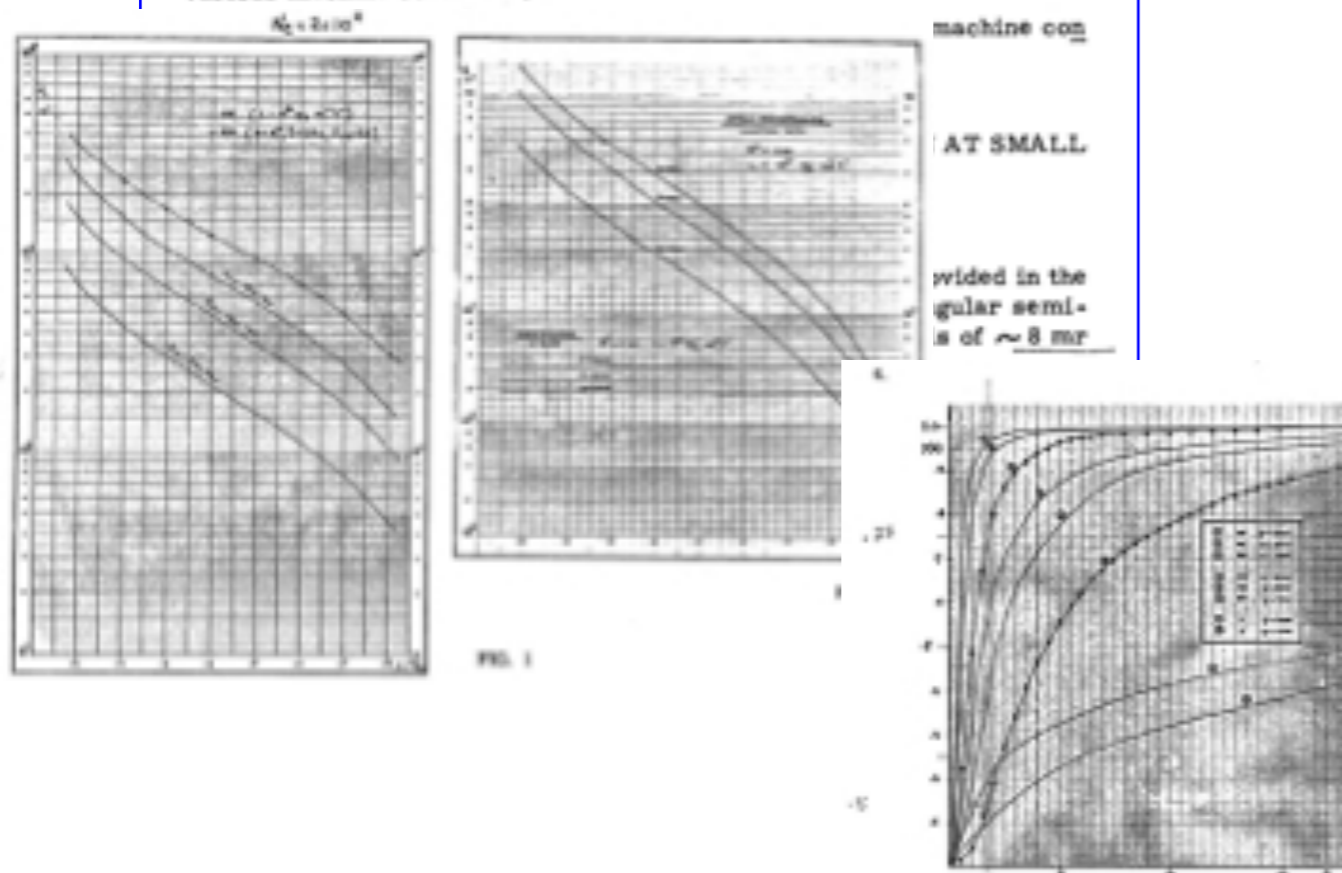
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LNF-67/23

Nota interna: n. 358
24 Marzo 1967

S. Tazzari: CONSIDERATIONS ON A LUMINOSITY MONITOR AT ADF-NE.

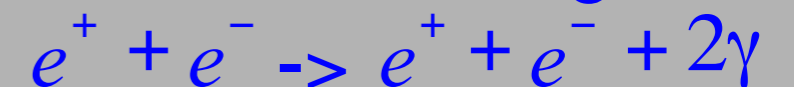
1) - The reactions that can be used for luminosity monitoring at our machine are reviewed, trying to establish the attainable accuracy under various machine conditions.



Single Bremsstrahlung:



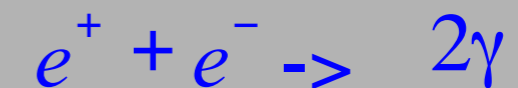
Double Bremsstrahlung:



Gas Bremsstrahlung:



Annihilations



~ 30Hz@10³²
on KLOE barrel

Bhabha



and more for higher energy machine...

Coincidence with γ @ small angle

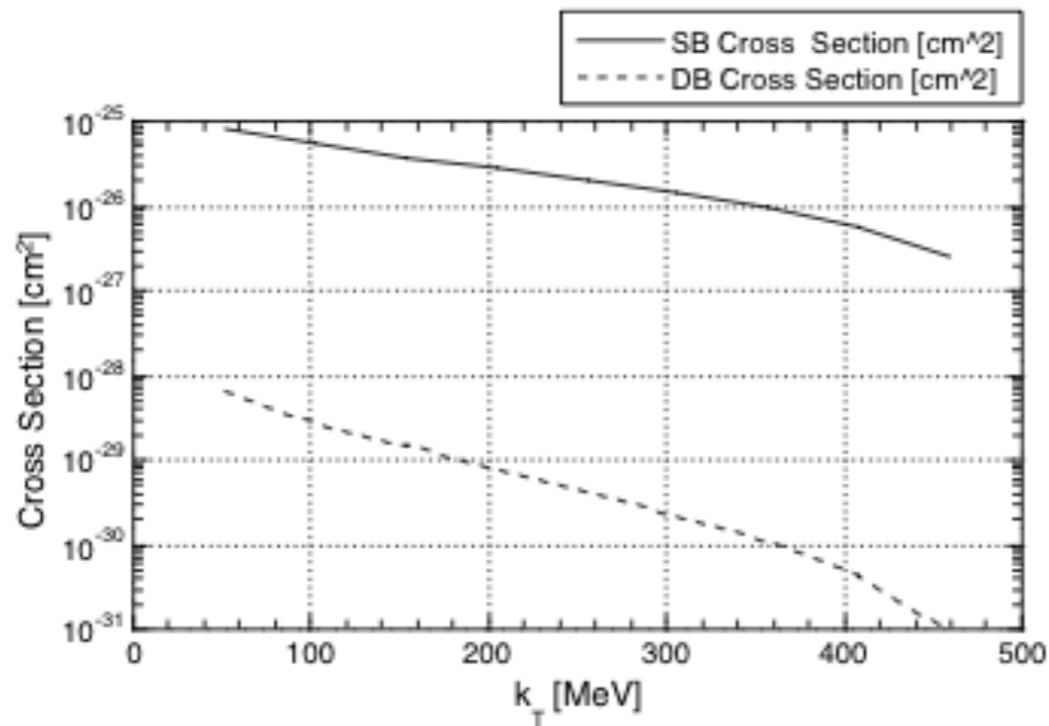
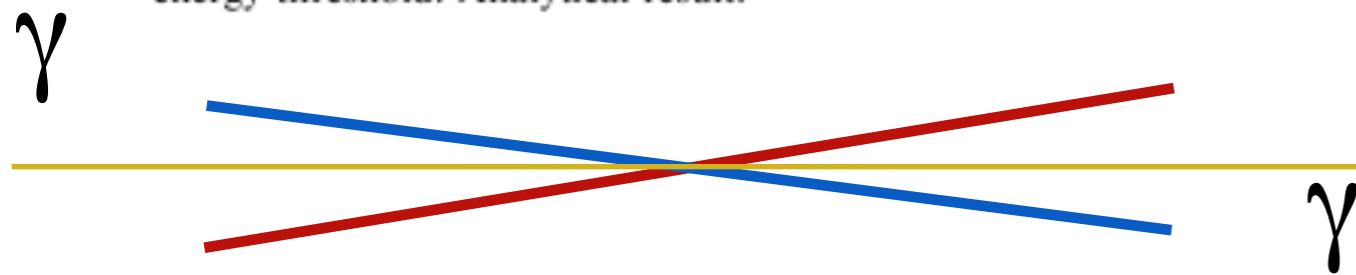


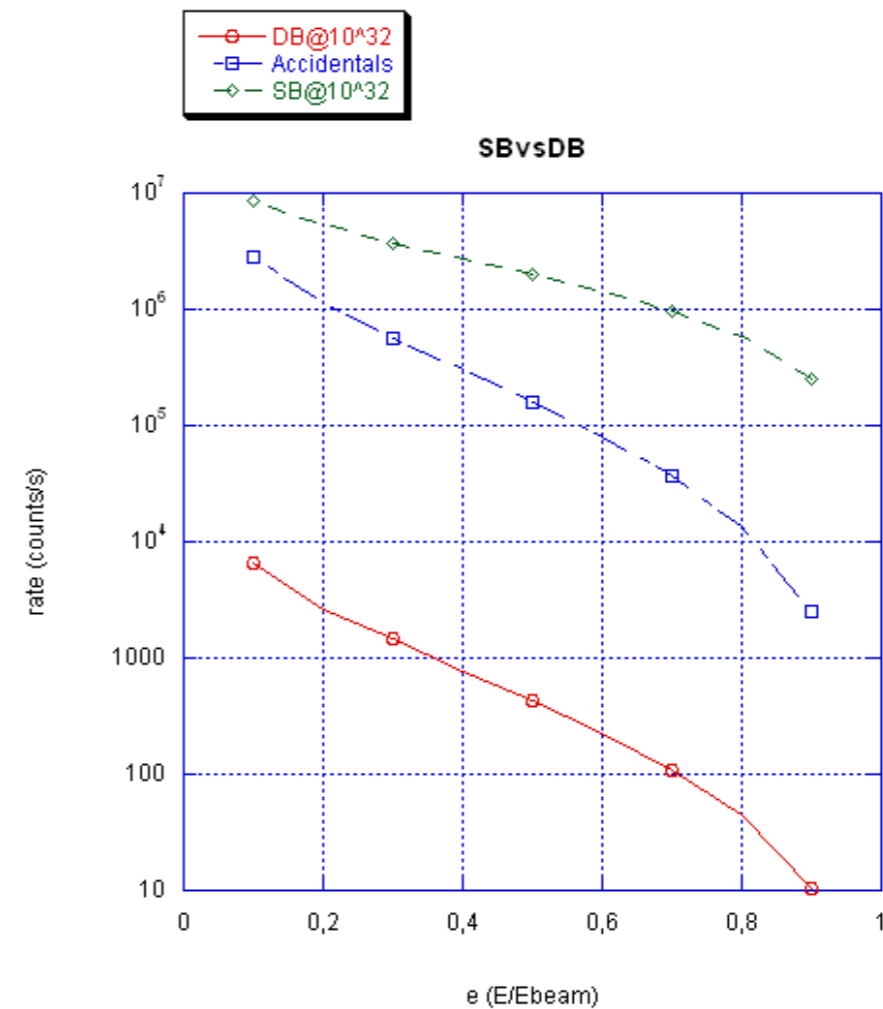
Fig. 11. Single and double Bremsstrahlung cross sections vs. energy threshold. Analytical result.



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

$$N(\text{accidental}) = 2 f_1 f_2 / Dt$$

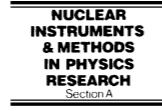
$$Dt = 2.0 \text{ E-}8 \text{ s}$$



DAFNE RUN1 γ monitor



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



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. © 2002 Elsevier Science B.V. All rights reserved.

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

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

1. Introduction

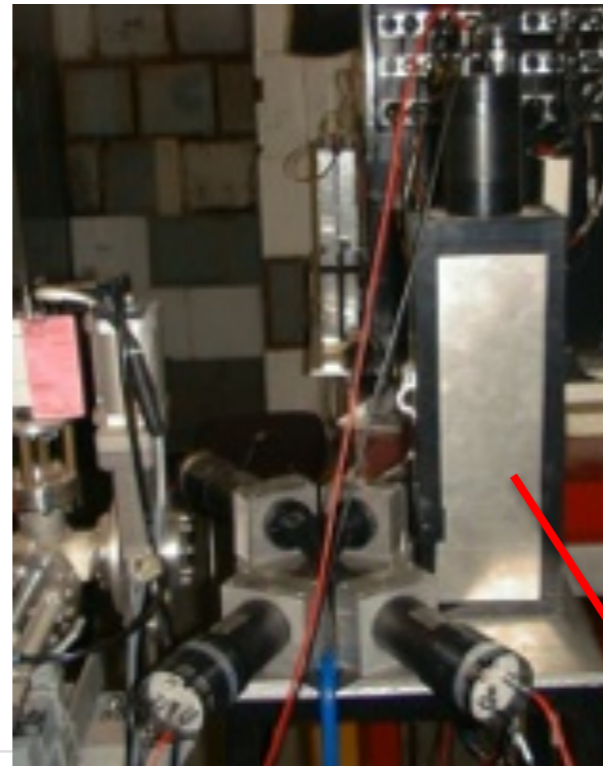
DAFNE, the Frascati phi-factory [1], is a 510+ 510 MeV electron-positron collider, tuned on the F meson resonance and mainly devoted to the study of CP violation in Kaon decay. In order to optimize the luminosity performance, the related machine parameters must be accurately set relying on a tuning process [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.

**KLOE
IP**

splitter magnet charge
particle cleaning effect



Lead/scintillating fibers calorimeters
(KLOE-type) resolution $4.7\%/\sqrt{E(\text{GeV})}$

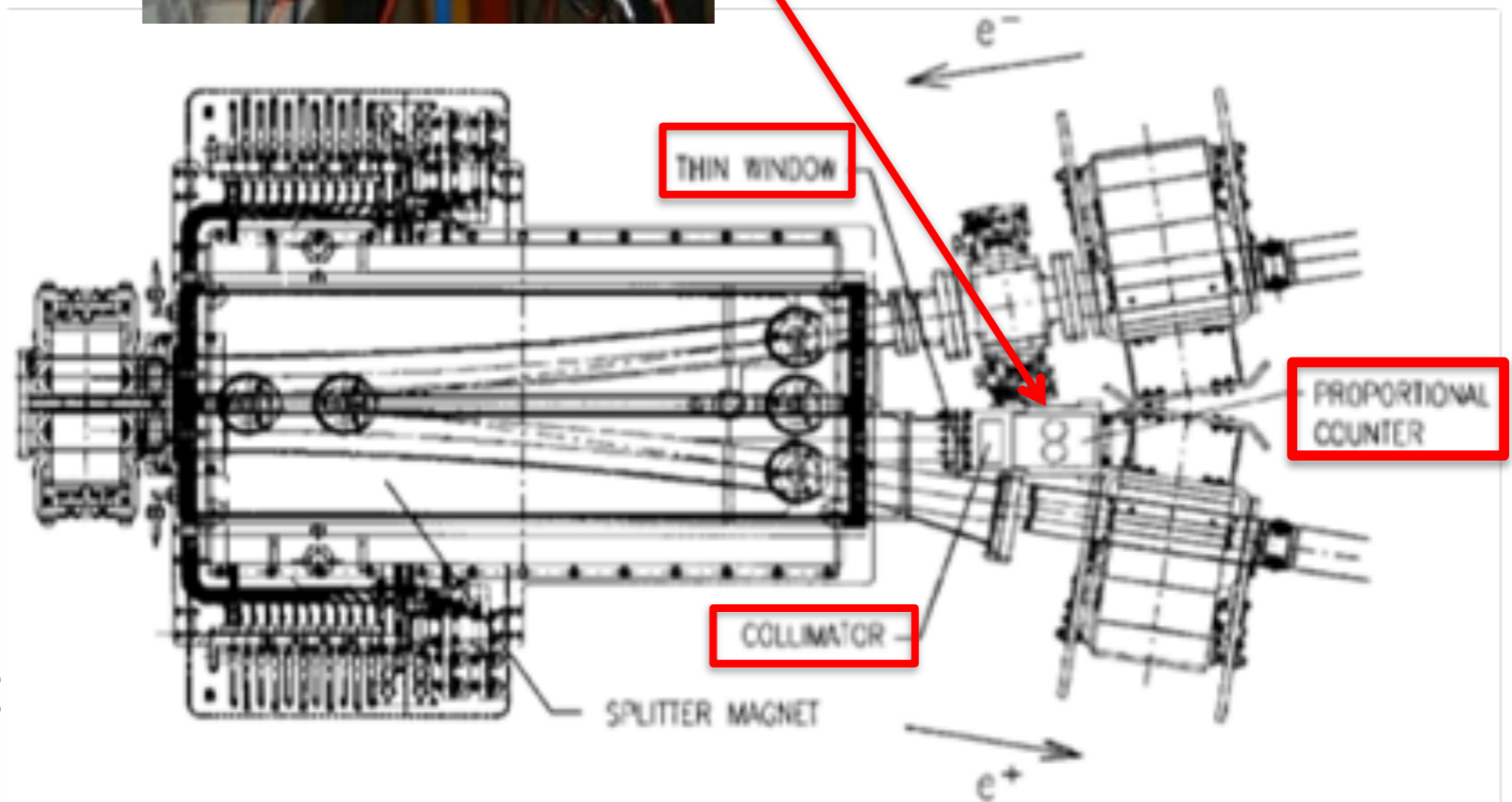
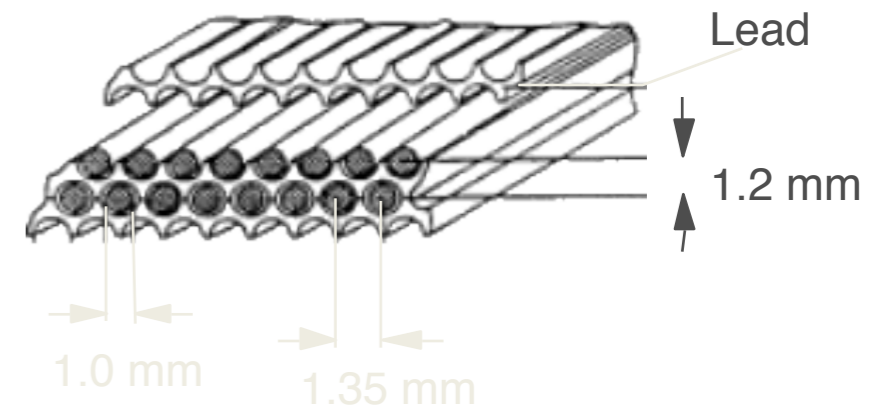
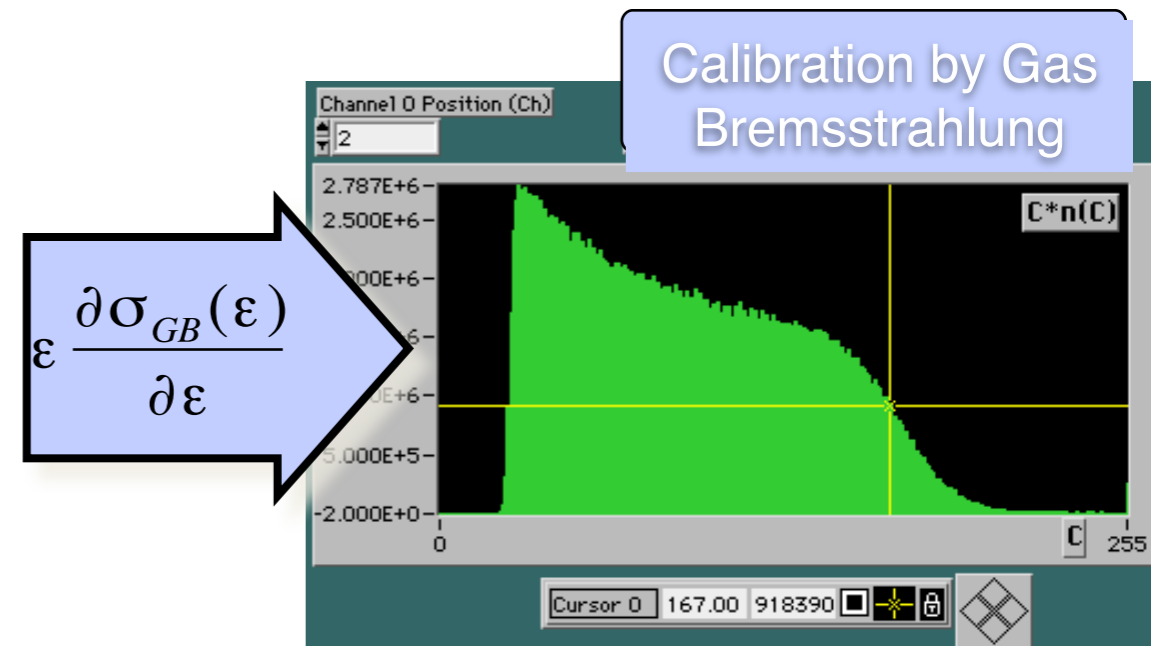
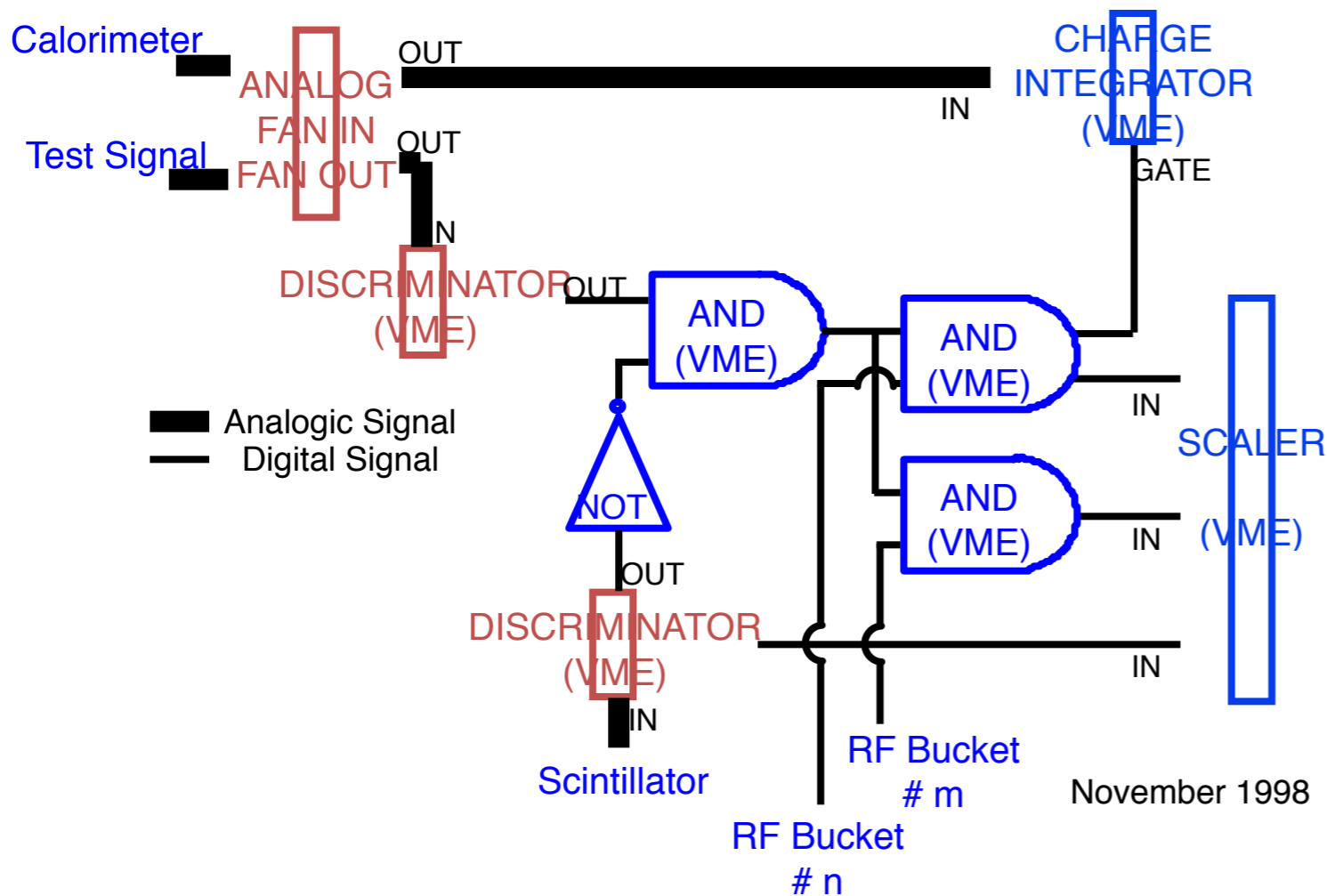


Fig. 2. Single Bremsstrahlung luminosity monitor layout at splitter magnet area.

DAFNE γ monitor (con't)

Single Bremsstrahlung:
 $e^+ + e^- \rightarrow e^+ + e^- + \gamma$

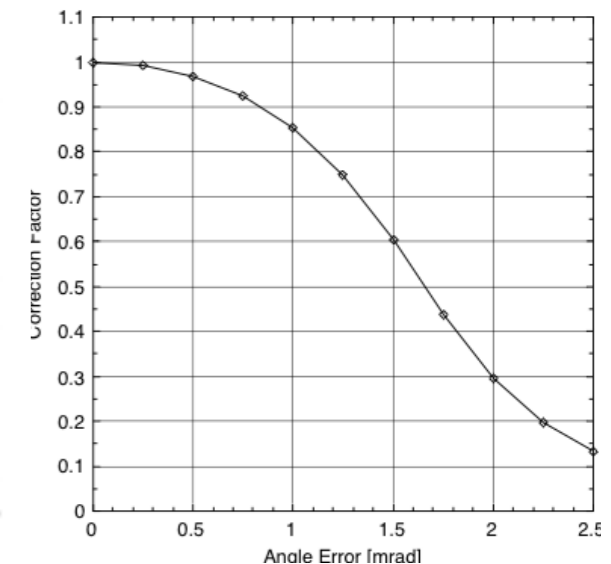
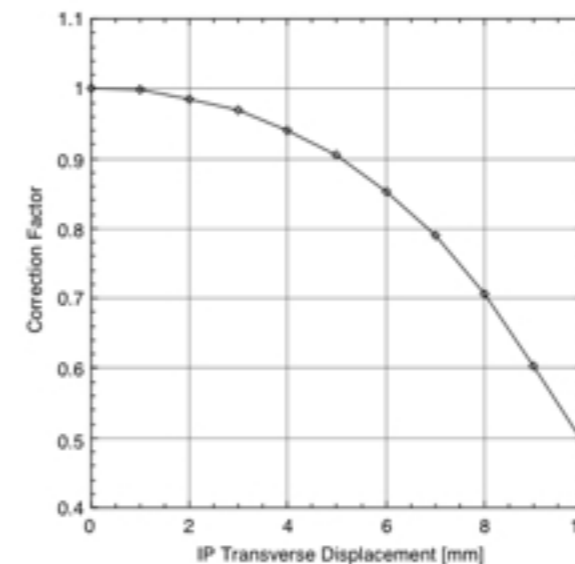
$$L = \frac{\dot{N}_{SB}}{\int_{E_T}^{E_{\max}} dE \int_{\Omega_D} d\Omega \frac{\partial^2 \sigma_{SB}}{\partial E \partial \Omega}}$$



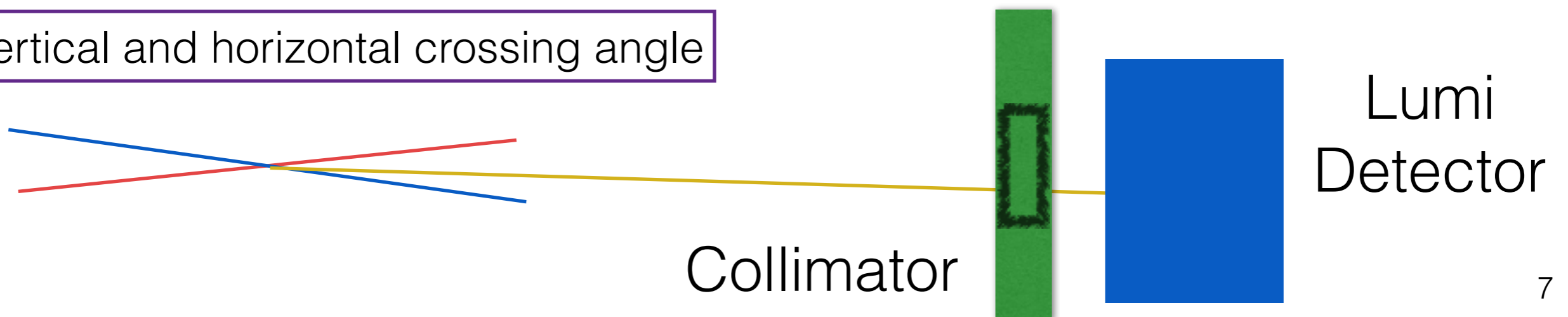
Requirements for an accelerator lumi monitor

- fast (< 1 s) at very low luminosity (2/3 order of dynamic range)
- absolute
 - day one
 - MD
 - Detector maintenance
- accurate ($\sim 10\%$)
- 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 beam **transverse displacement and vertical crossing angle**



vertical and horizontal crossing angle



DAFNE Day 1 (flat machine)

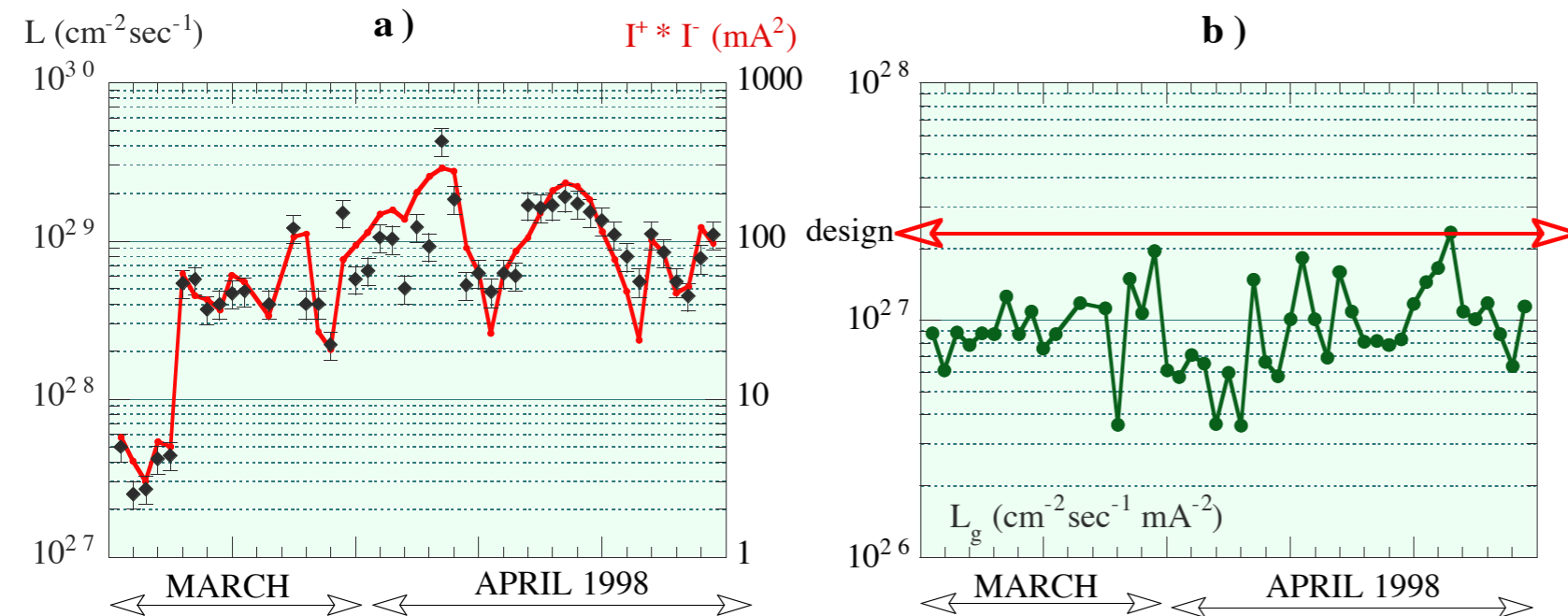


Figure 8: a) Luminosity (circles with error bars) and product of bunch currents (solid line); b) Geometrical luminosity

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.

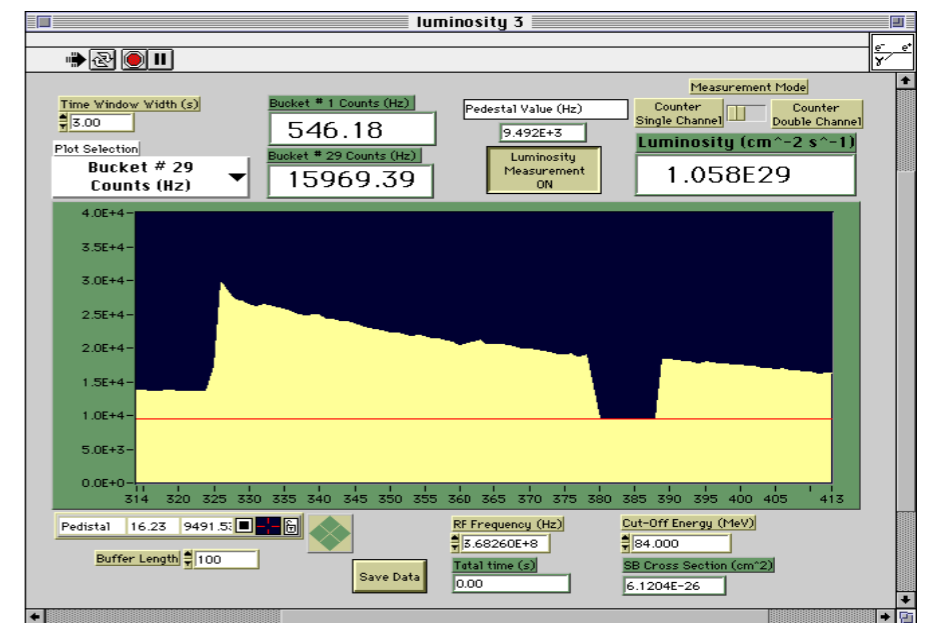
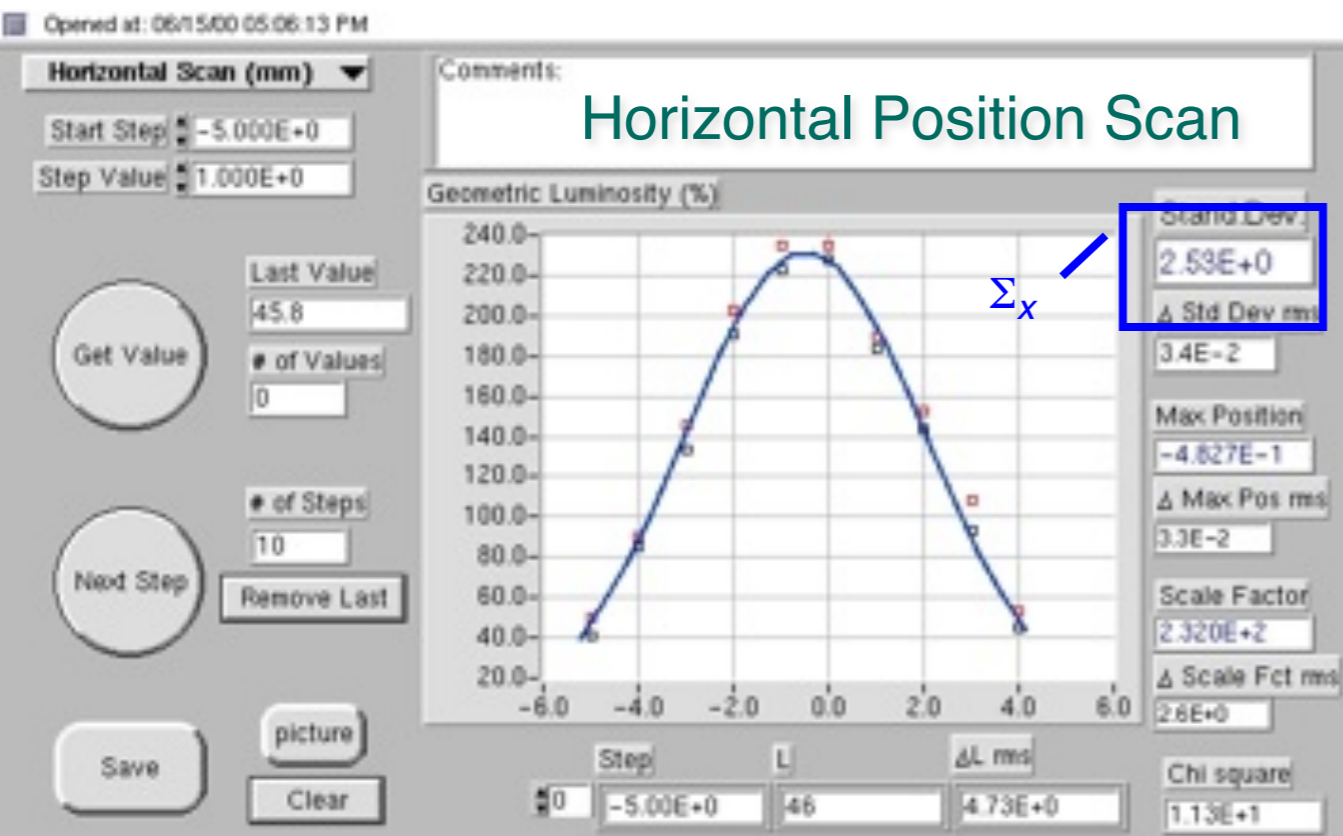
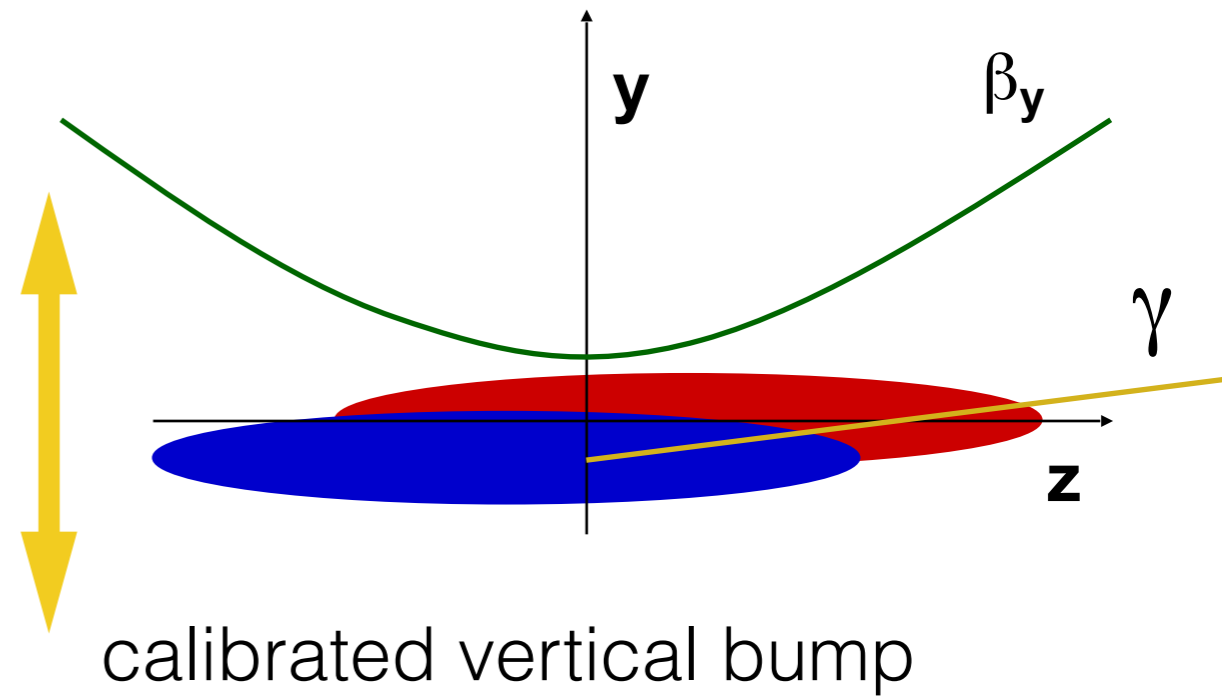
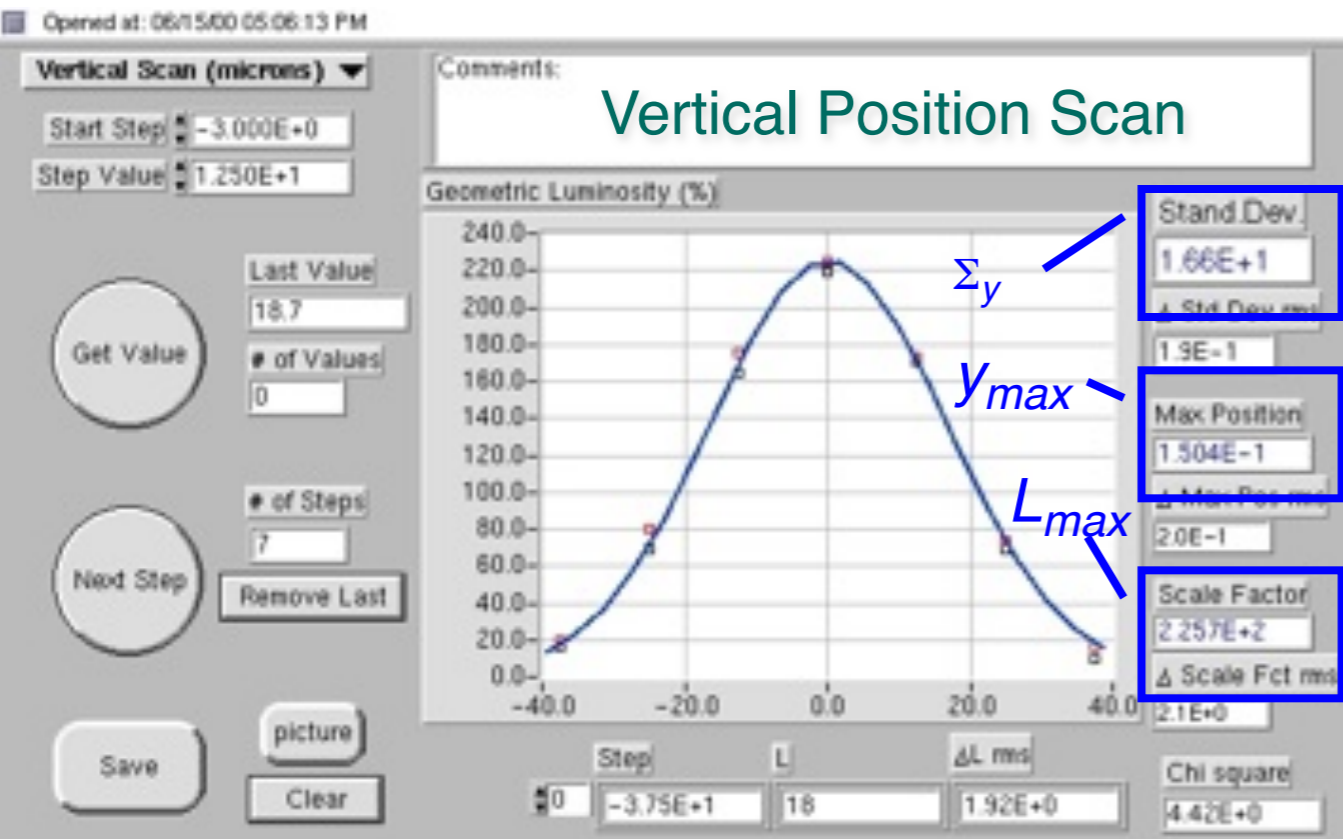


Figure 6: Luminosity monitor output.

Luminosity Position Scans



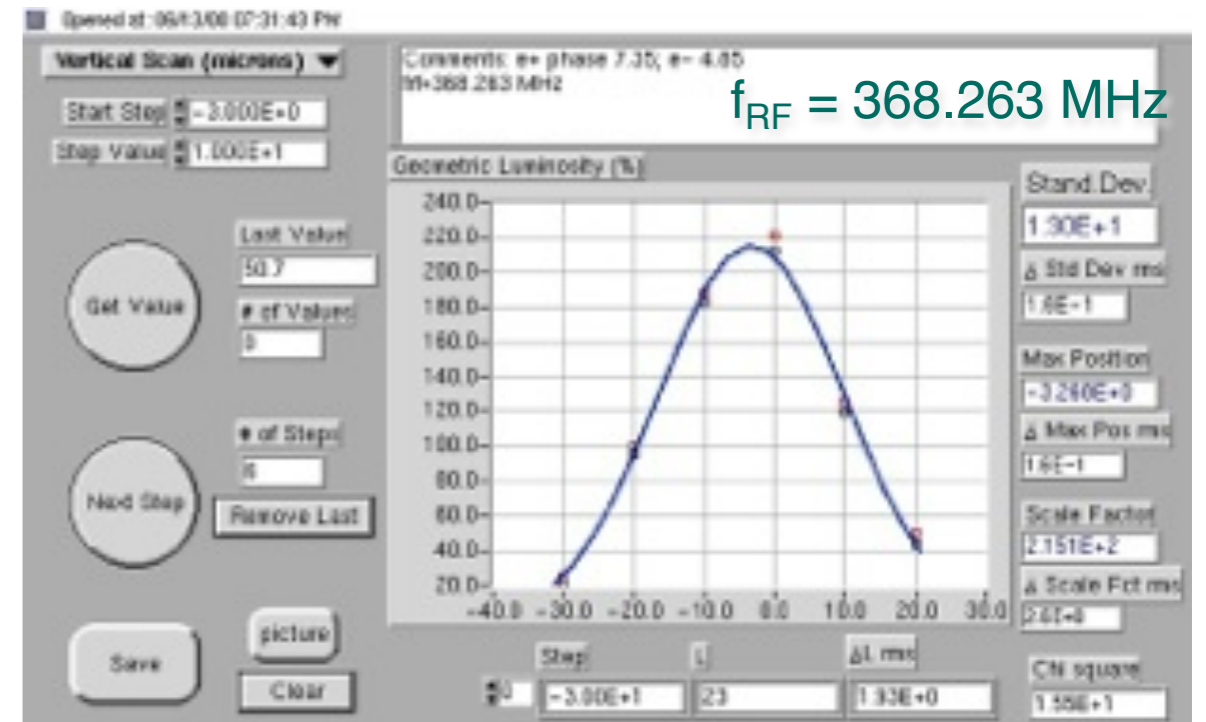
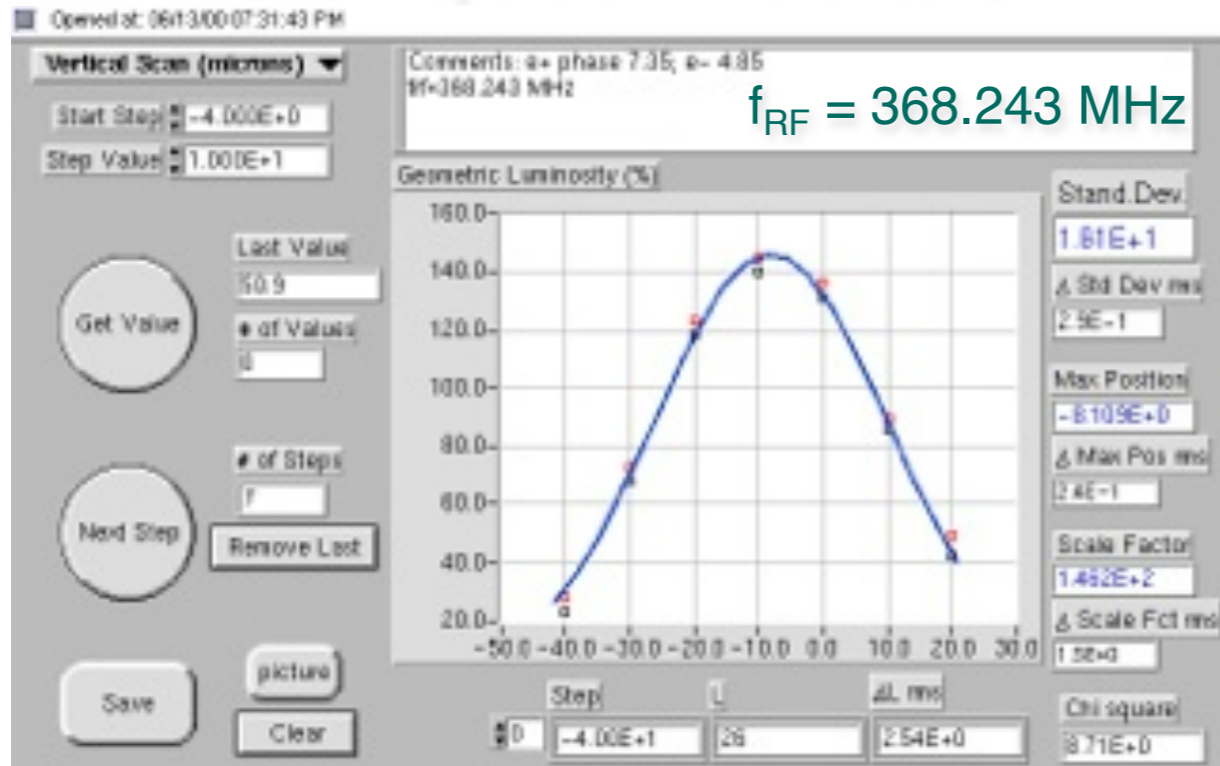
$$L = f_R \frac{N_+ N_-}{2\pi \Sigma_x \Sigma_y}$$

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

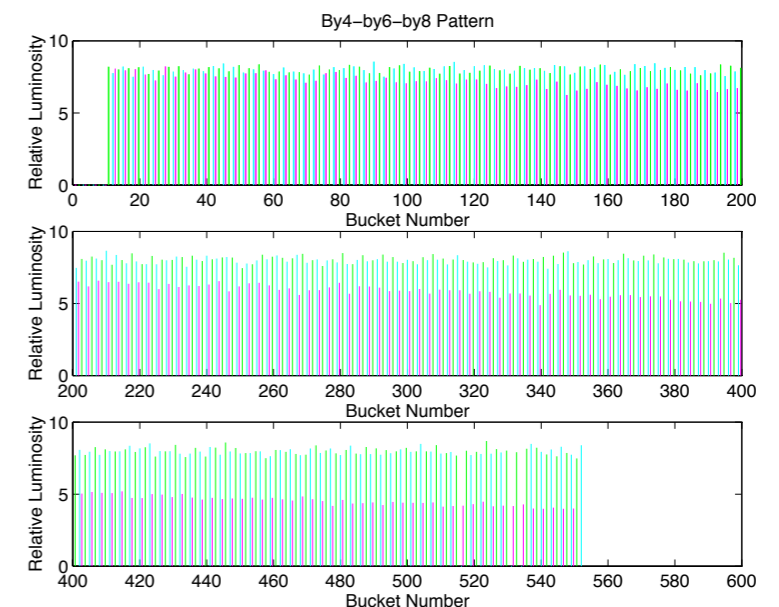
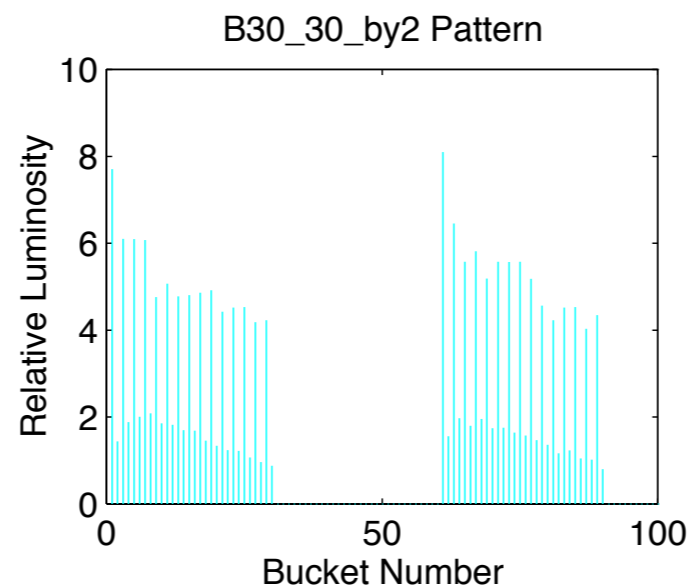
Diagnostics (dispersion, electron cloud)

Vertical Dispersion Difference @ IP

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



PEP-II 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 (maintain 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

collimator
front view

needle

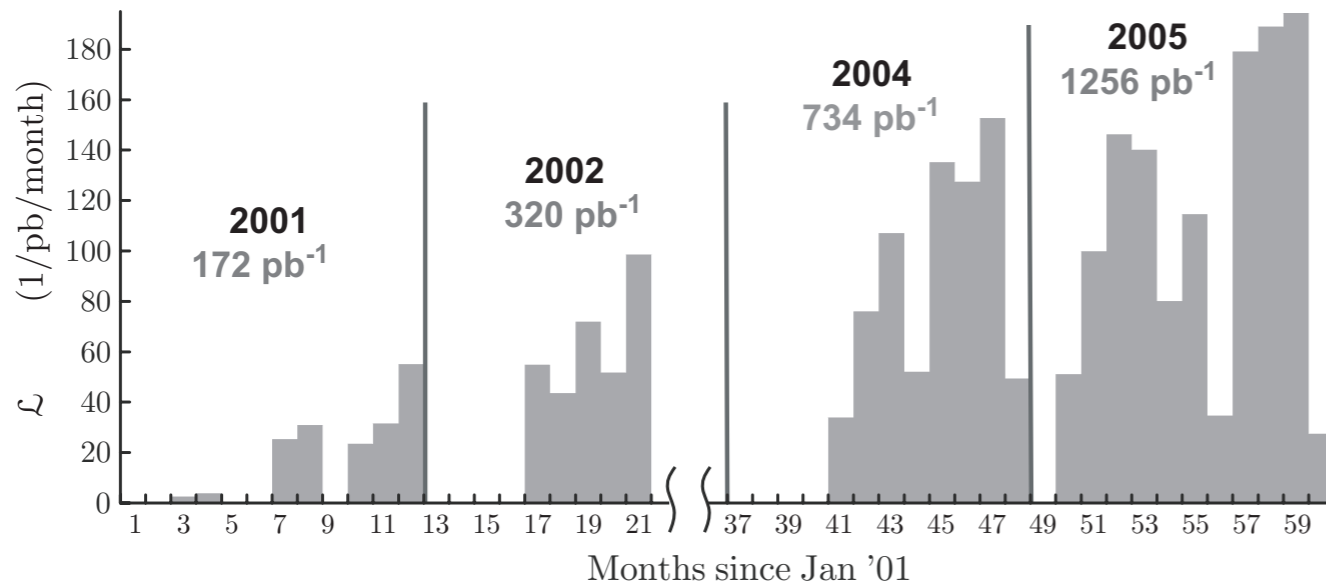
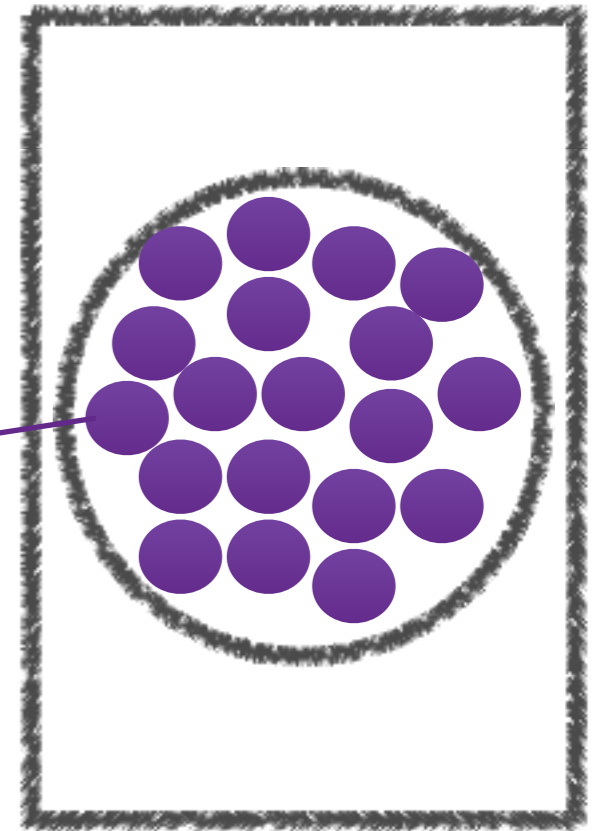
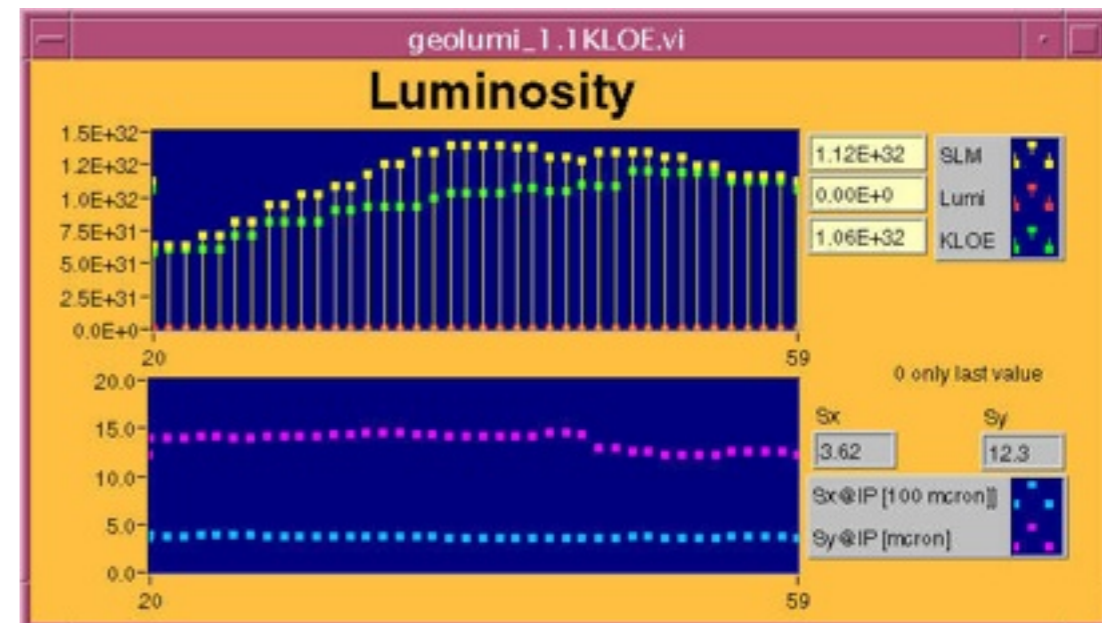
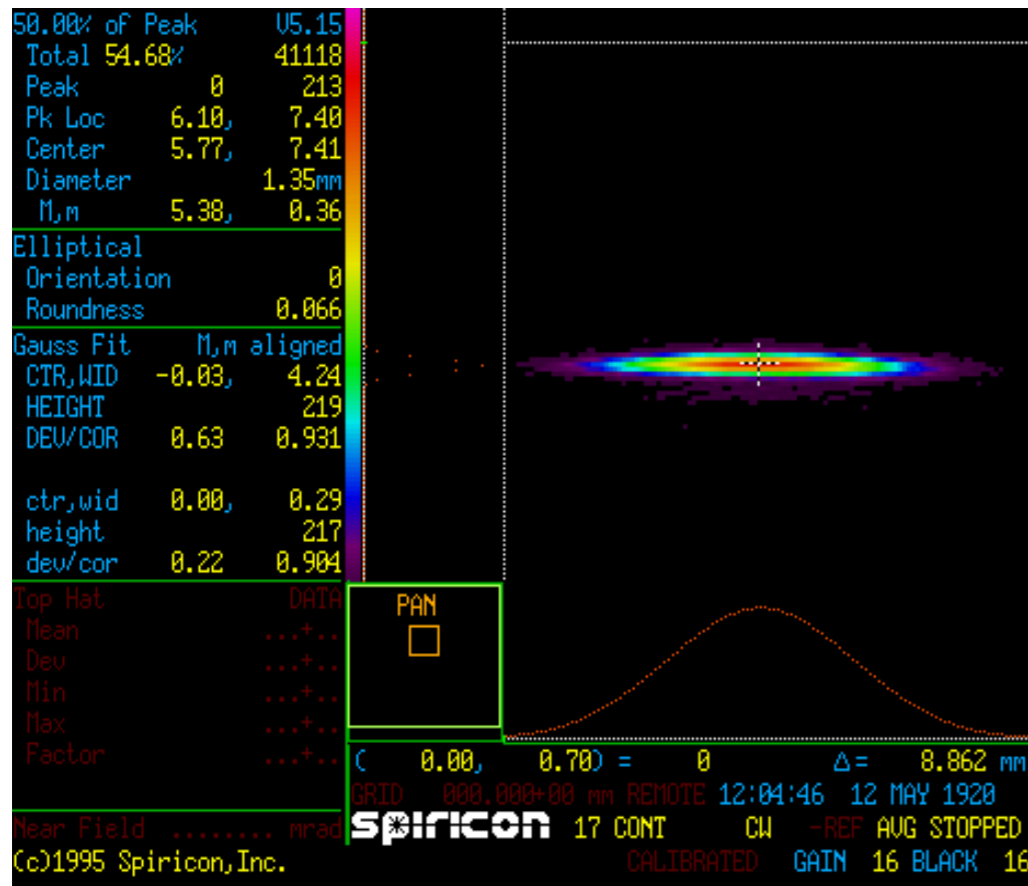


Fig. 2. Luminosity integrated by KLOE from 2001 to 2005.



Geometric Luminosity estimator

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

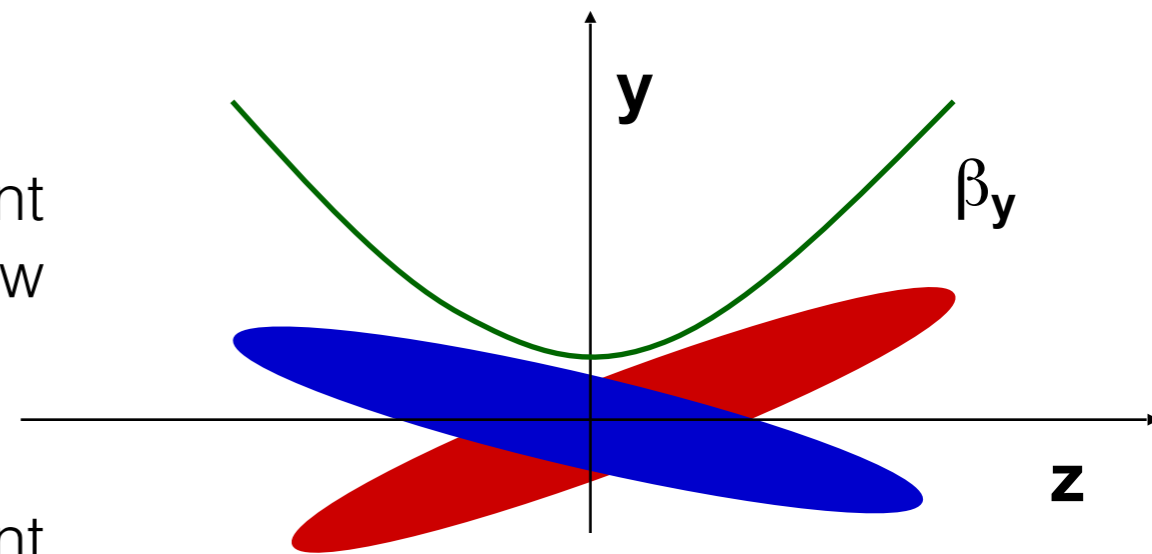
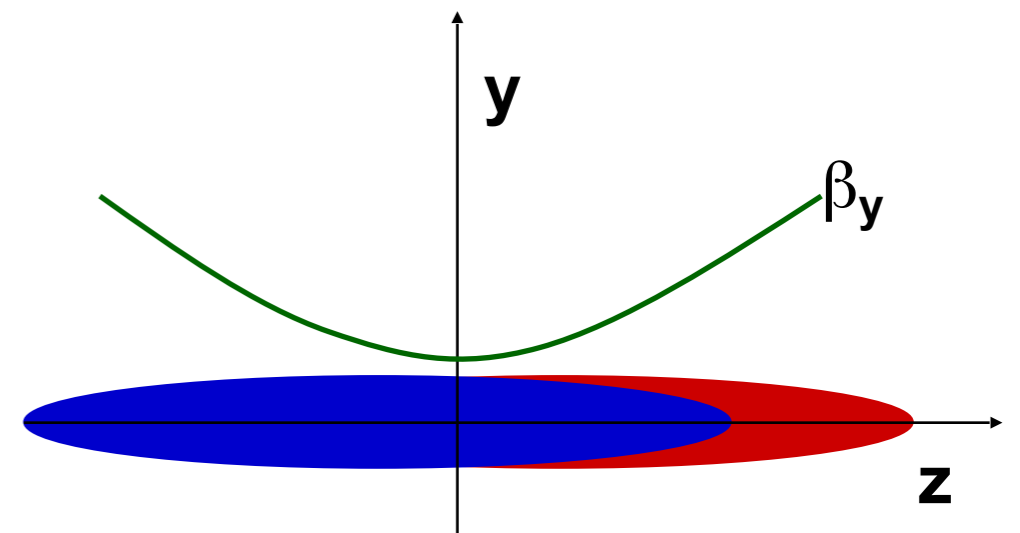


- Beam overlap
- $\sigma_x = 2 \text{ mm}$ $\sigma_y = \text{wid}/2$
- $\beta_y/\beta_y@SLM = 0.03/7.60$ @ KLOE,
- $\beta_y/\beta_y@SLM = 0.04/7.53$ @ DEAR
- SLM monitor resolution

SLM beam characteristics (vertical and horizontal dimension)

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



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

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M. Schioppa^b, F. Iacovageli^c, P. Valente^c, N. Arnaud^{d,e}, D. Berton^d, L. Burnistrov^d,
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ABSTRACT

The crab waist collision scheme has been successfully tested at the e^+e^- Frascati collider during the 2008–2009 runs: the gain in luminosity is consistent with the predictions while the background remains sustainable. Among the various inputs used by the DAΦNE accelerator team to steer the new machine and improve its performances, key online information, absolute luminosity and background level measurements, has been provided by the GEM detectors: a Shubba calorimeter and two gamma beamcounting proportional counters. This paper focuses on the results achieved with this experimental setup, described in details in another article.

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1. Introduction

Proposals of future flavor factories [1–4] emphasize the need of very high luminosity. For instance, the new generation of B-factories [1,2] requires improvements up to two orders of magnitude above the performances of the PEP-B [4] and KEK-B [5] e^+e^- colliders. Among the ideas currently being developed to achieve this ambitious physics-driven goal, the crab waist compression scheme associated with large θ -waist angle and low vertical beta function [6] is very promising. Luminosities as high as $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ could be reached with beam currents similar to those operated routinely in today's accelerators, which would also help keeping the background under control. In addition to being based on existing technologies, this scheme would significantly limit the power (and hence the cost) needed to run such a new machine.

The DAΦNE accelerator, located in the National Laboratory of Frascati (INFN), is optimized for the production of ϕ mesons ($\sqrt{s} = 1020 \text{ MeV}$) at a high rate. Since 2000 it has been delivering e^+e^- collisions to three experiments: KLOE [7], FINUDA [8] and

DEAR [9], steadily improving performances in terms of luminosity, beam lifetimes and background. The best peak luminosity was $\sim 1.5 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$ with typical daily integrated luminosities of $\sim 8 \text{ pb}^{-1}$ during the KLOE run.

In 2000, the DAΦNE interaction point 1 (IP) has been modified to test the crab waist septupole compensation scheme [10]. According to calculations, this upgrade should increase the luminosity by a factor between 3 and 5. To test this prediction and to measure the associated background, various detectors have been built around the IP by the lumi collaboration: a Shubba calorimeter, a GEM [10] tracker and two gamma monitors. By providing accurate information to the DAΦNE operators in real time, they aim at allowing them to steer the collider, to monitor its performances and to get direct feedback when performing optimization studies. There is some redundancy between these measurements which helps fighting transient backgrounds which could impact strongly a particular detector. It should be noted that the SIDDHARTA experiment [11], installed at the same location, can in principle provide a luminosity measurement by counting kaon pairs produced by the well-known decay $\phi \rightarrow K^+K^-$. However, this method suffers from a few practical limitations. The main ones are: a low rate for the K^+K^- production; a difficult event rate to luminosity conversion due to the dependence of the ϕ -mesonance linehape on the exact

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

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ABSTRACT

Testing the new crab waist collision scheme at the e^+e^- Frascati DAΦNE accelerator complex requires a fast and accurate measurement of the absolute luminosity, as well as a full characterization of the background conditions. To fulfil these requirements, dedicated detectors have been built by the lumi Collaboration and operated during the 2008 and 2009 DAΦNE runs, providing valuable inputs to the accelerator team. This article motivates their design, describes their installation in the modified interaction region and presents their performances. Another article in the same issue focuses on the results achieved using these detectors.

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1. Introduction

The DAΦNE accelerator, located in the National Laboratory of Frascati (INFN) and optimized for the production of ϕ mesons ($\sqrt{s} = 1020 \text{ MeV}$) at a high rate, has been modified in 2007. The new design of the interaction point 1 (IP) is based on the crab waist septupole compensation scheme [1], a promising idea to increase the collider luminosity while keeping the background under control—in this scheme, the beam currents are similar to those operated by the current generation of B-factories [2,3]. This test is motivated by the fact that future flavor factories [4–6] will clearly have to integrate much more luminosity than the current experiments in order to achieve their ambitious physics goals. After completion of the IP upgrade, operations resumed at DAΦNE during winter 2007–2008 for about two years.

The expected luminosity increase, a factor 3–5 [2], is significant. Quantifying the improvement requires a measurement precise at the $\sim 10\%$ level. In addition, real time and accurate information about luminosity and backgrounds is mandatory to tune the new collider and improve its performances. Some redundancy between measurements is also suitable in order to maintain an accurate monitoring of

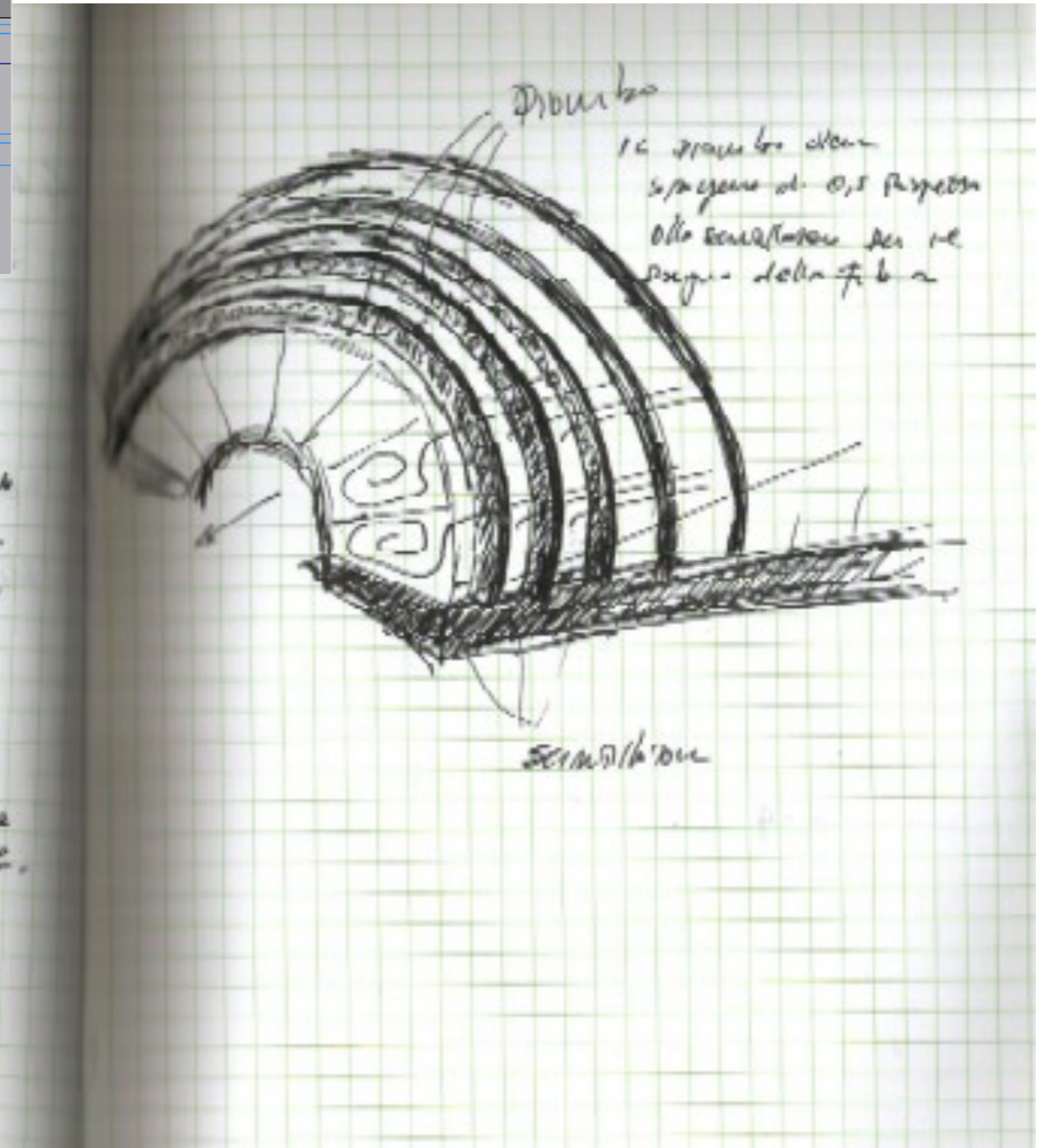
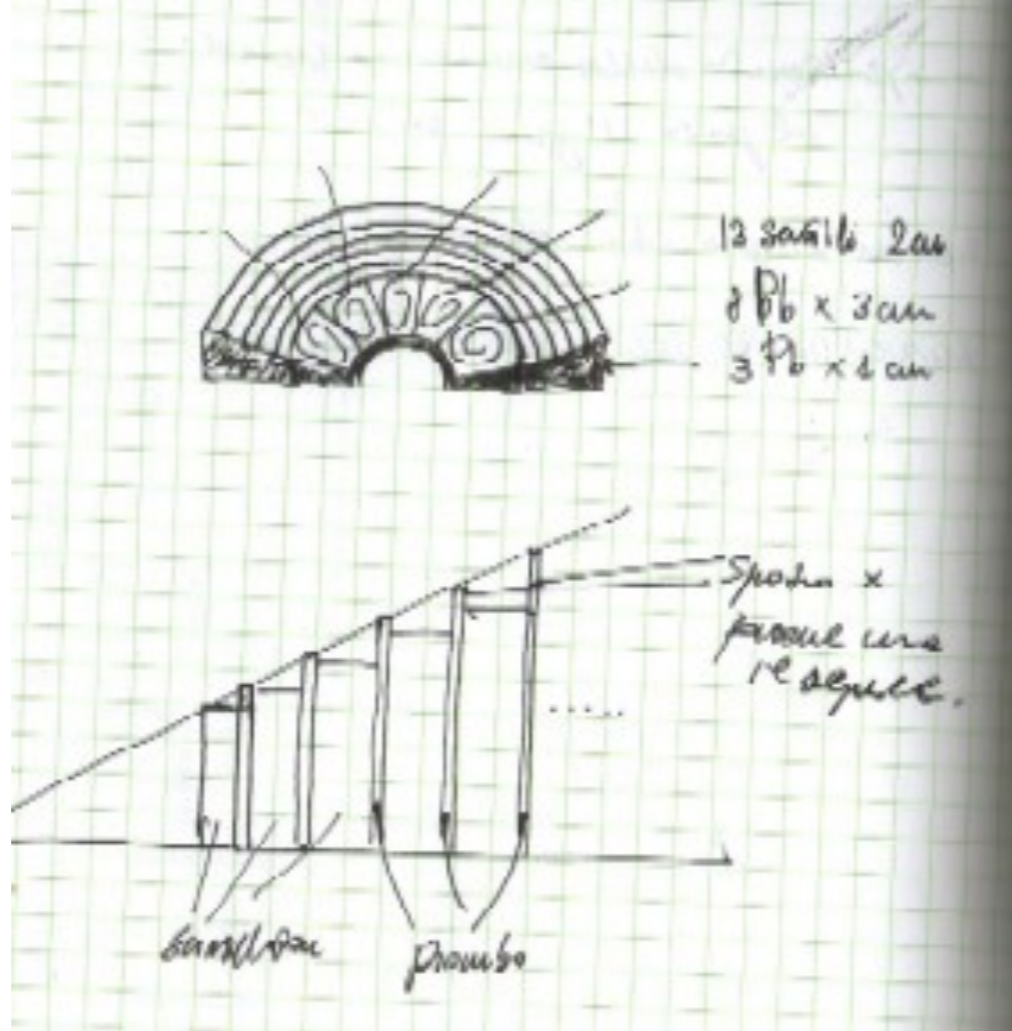
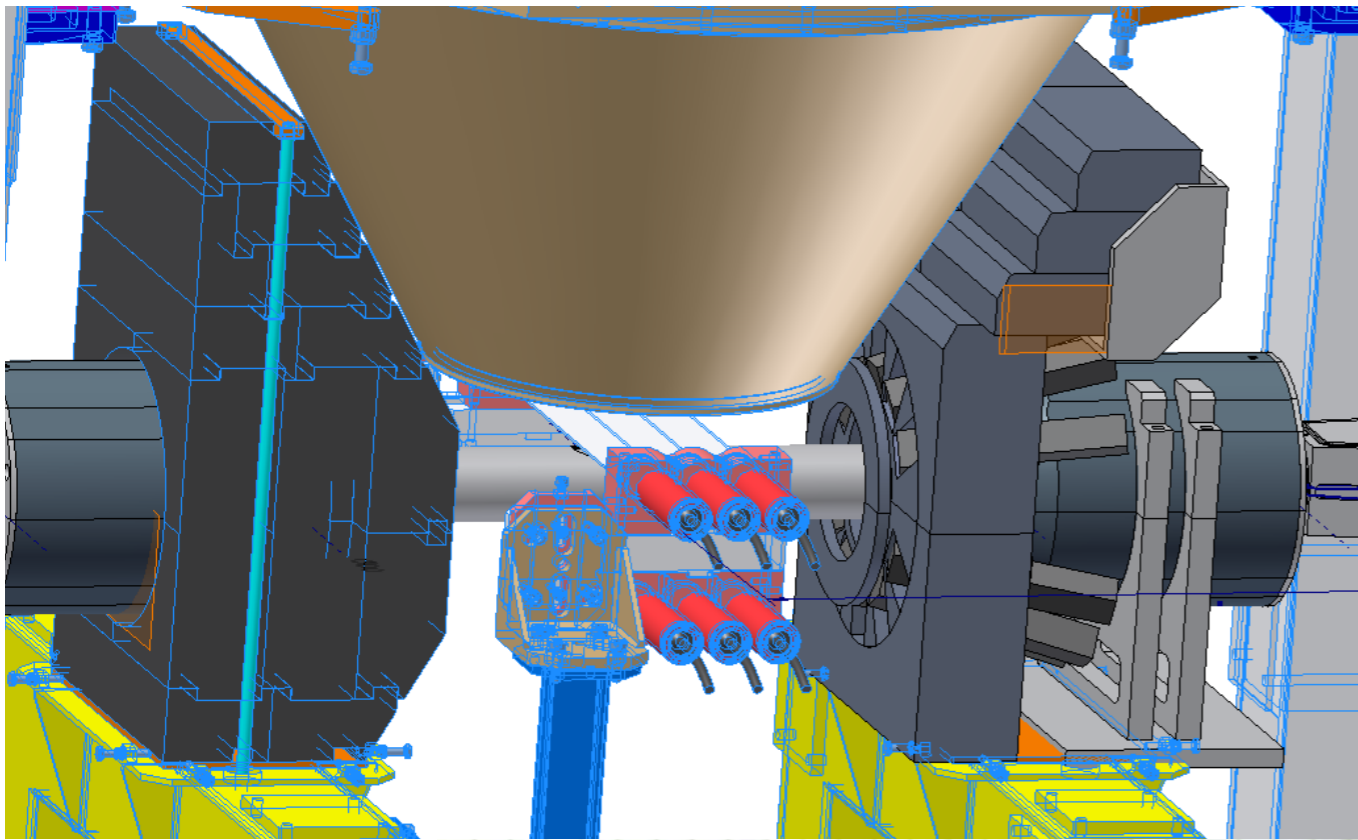
the machine conditions regardless of transient effects such as localized background bursts impacting severely a particular probe. Therefore, various independent and luminosity-oriented detectors have been built by the lumi Collaboration around the DAΦNE IP and put in operation beginning of February 2008 with a threefold goal: to guarantee an accurate measurement of the absolute luminosity; to monitor the background levels and to provide powerful and fast diagnostics to help steering the new machine.

Facilitated by the upgrade of the DAΦNE interaction point 1 (IP), the SIDDHARTA experiment (SILICON DRIFT DETECTOR for Hadronic Atom Research by Timing Application) [7] aiming at studying kaonic hydrogen and kaonic deuterium has been installed at the same location. The presence of this additional detector, whose operation requires a very good shielding against machine background, has consequences on the design and on the performances of the main luminometers. These are discussed in the following sections of this article. In principle, SIDDHARTA can also provide a luminosity measurement based on the counting of charged kaon pairs produced by the well-known decay $\phi \rightarrow K^+K^-$. However, this method suffers from a few limitations [8].

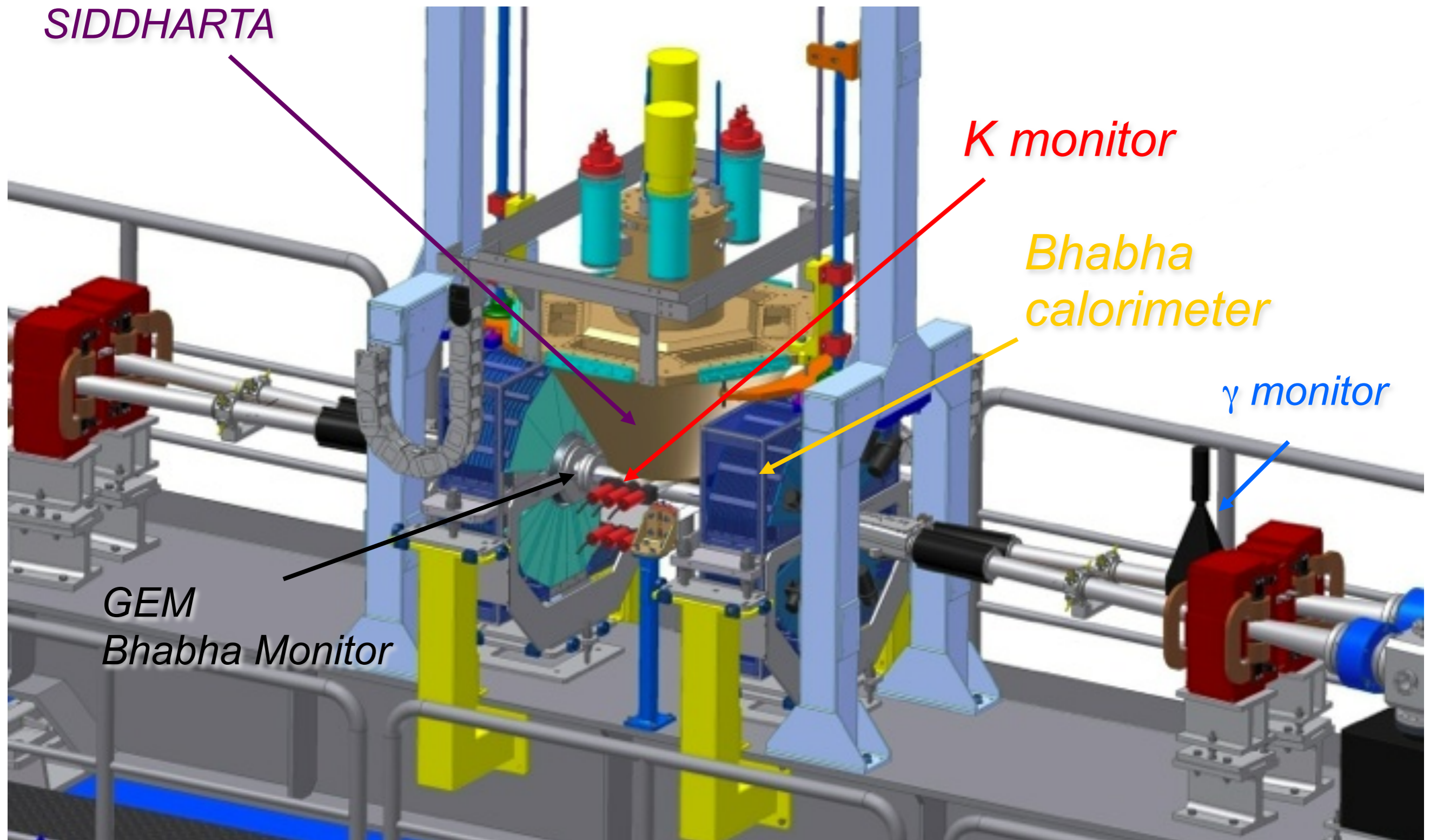
This paper focuses on the design, the construction and the operation of the GEM detectors: a Shubba calorimeter, a GEM tracker [9] (which could not really be used due to space conflicts with the SIDDHARTA shielding) and two gamma beamcounting proportional counters, referred to as two gamma monitors in the

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February 2007

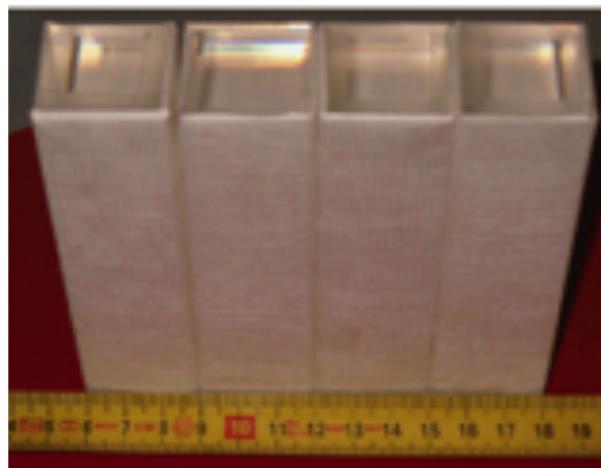


Layout and Luminosity Monitors



Gamma monitor

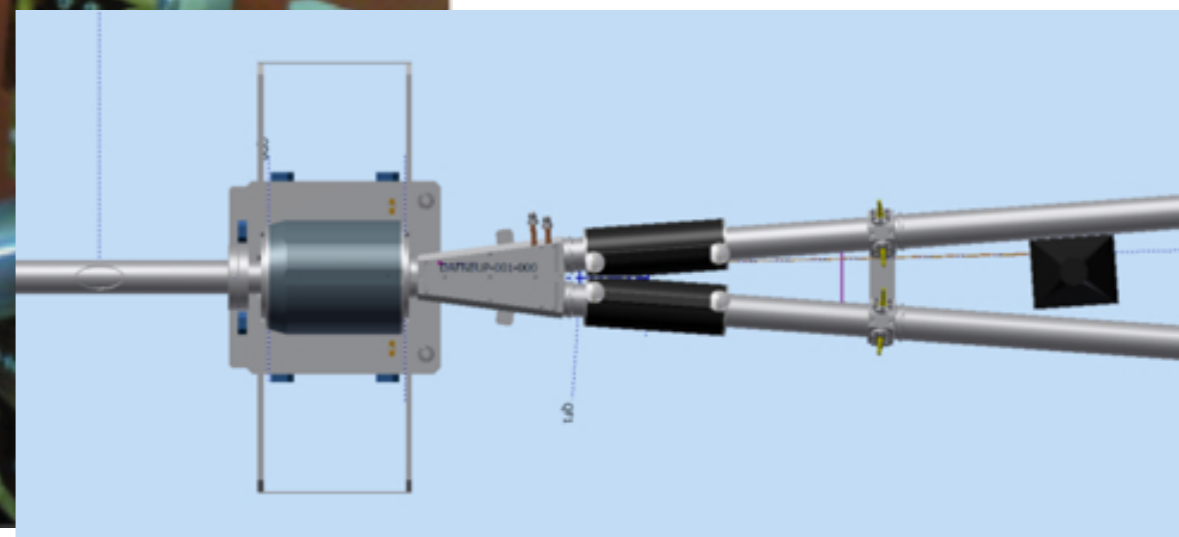
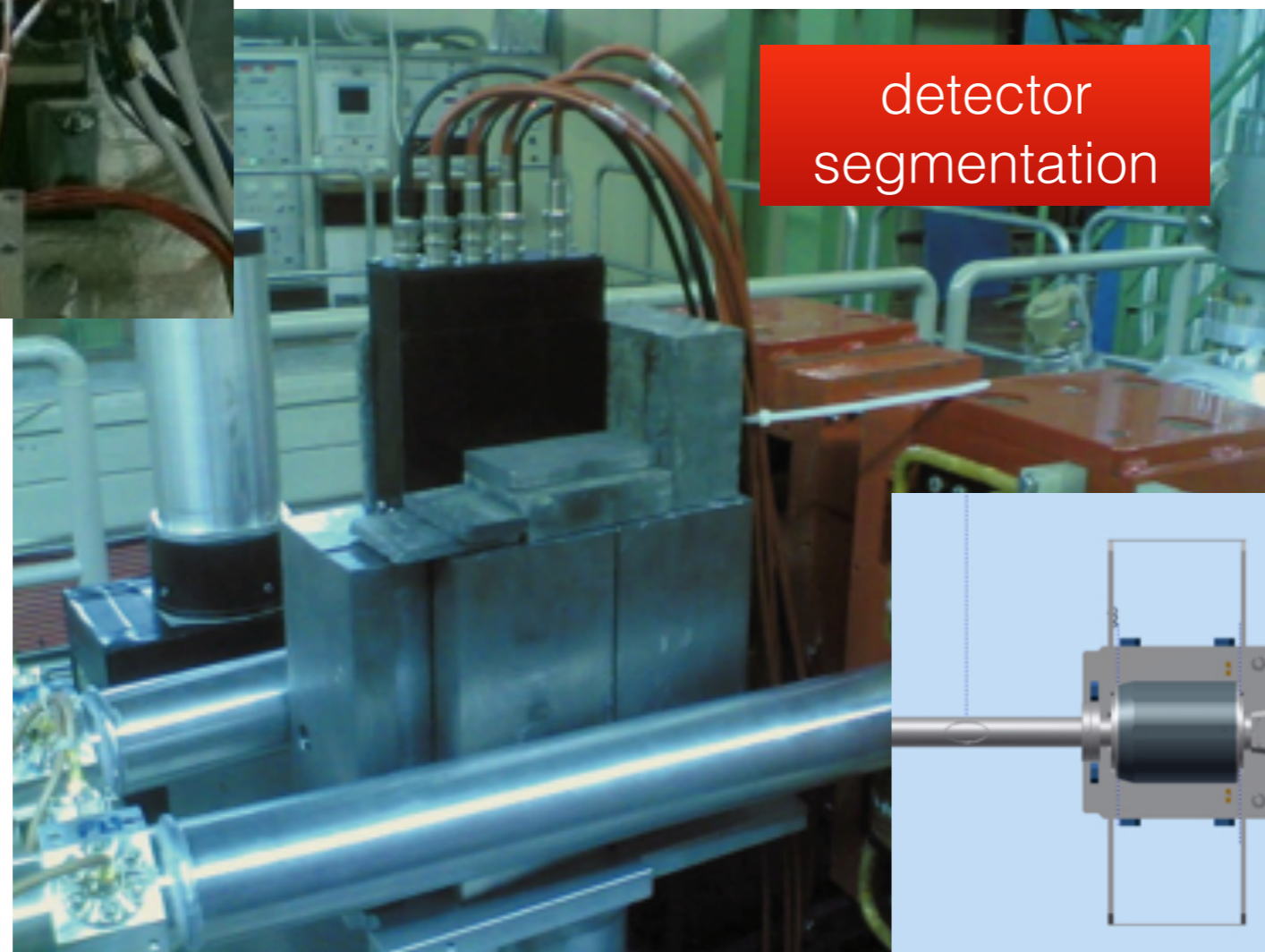
PbWO₄ crystals



- 2 calorimeters PbWO₄ crystals, 13 X₀ total depth
- Readout by Hamamatsu R7600
- High-statistics, very fast counter, main tool for luminosity optimization...
- ...but affected by background [not absolute luminosity measurement]



collimator



Kaon Monitor (SIDDHARTA)

PM: Hamamatsu R4998

Scintillators: BC420

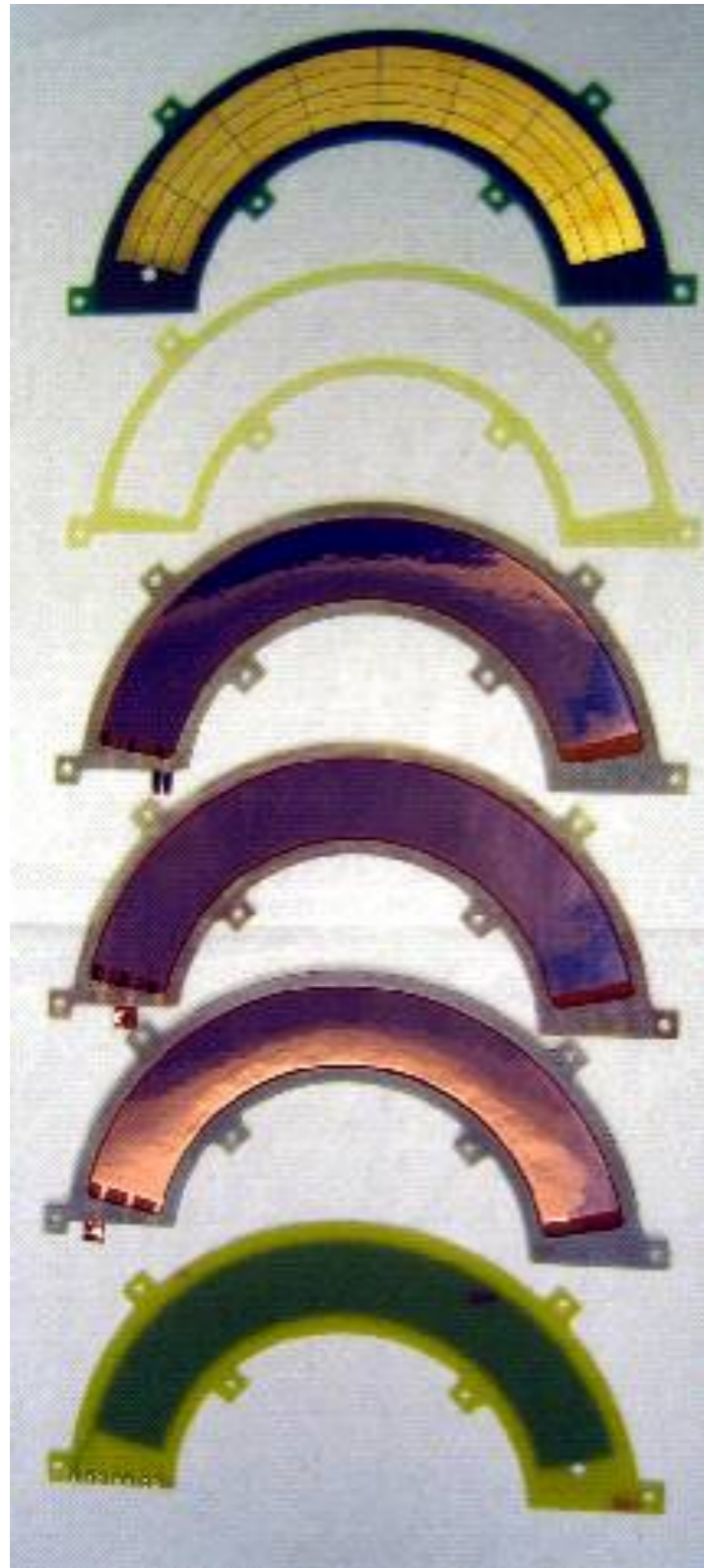
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***Triple-GEM
tracker***

***Triple-GEM
tracker***

Triple-GEM trackers



pads

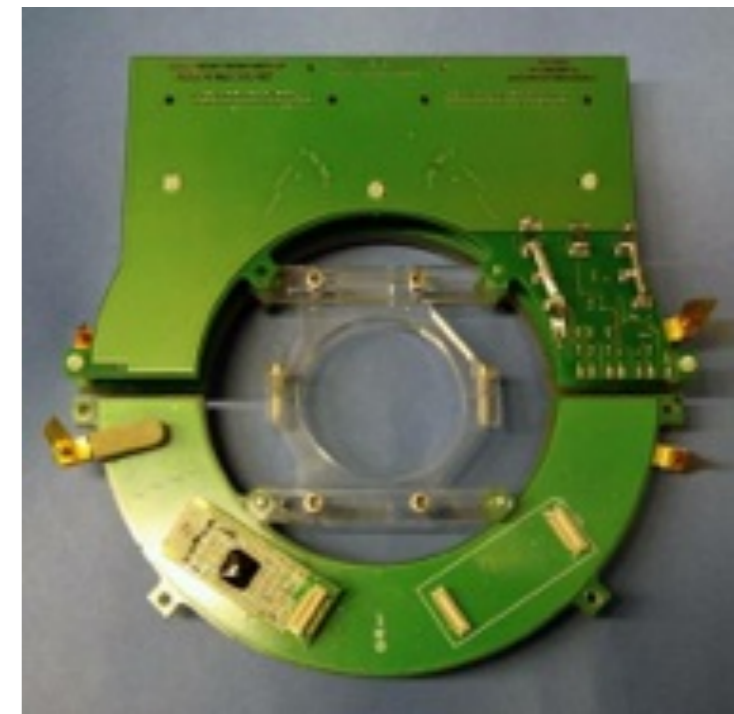
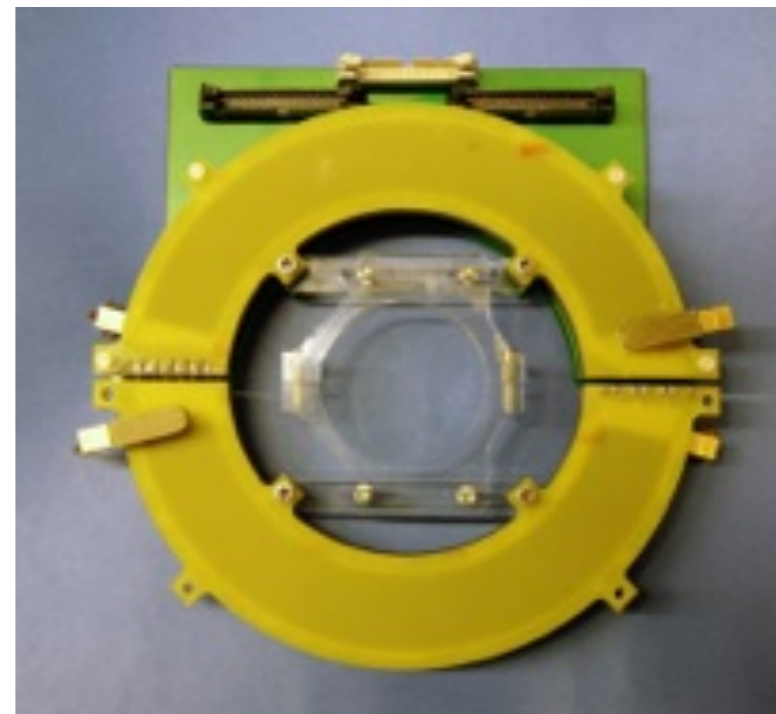
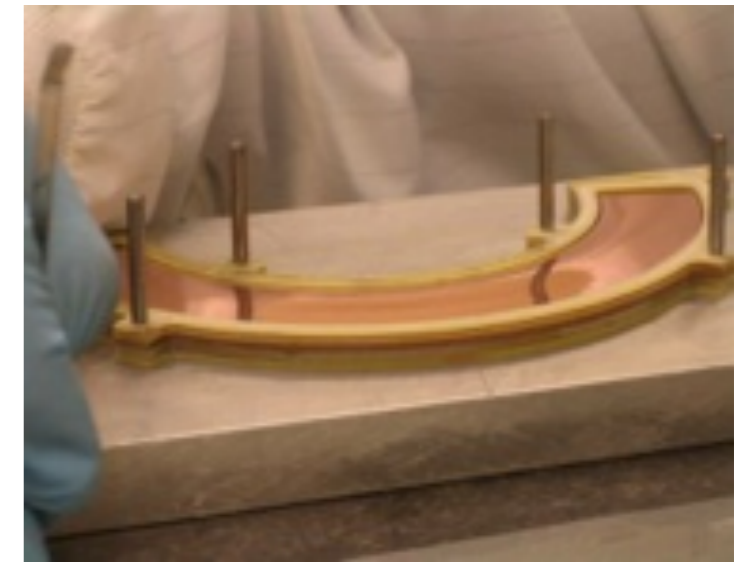
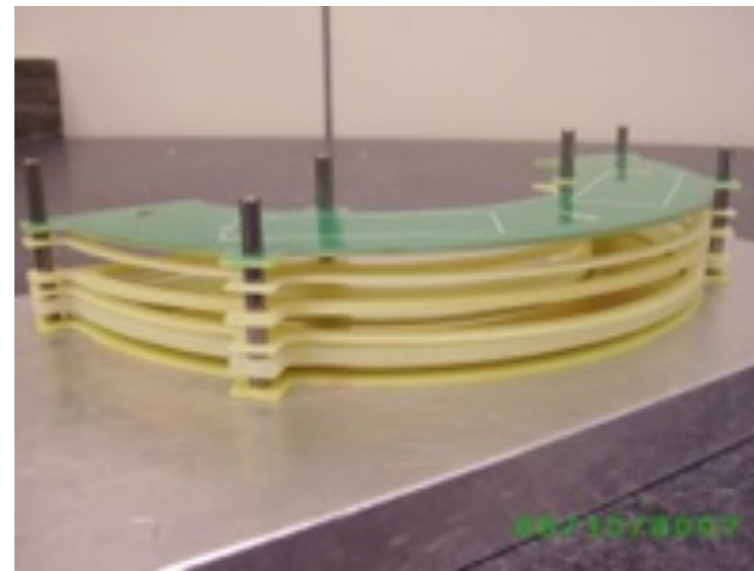
induction gap

GEM 3

GEM 2

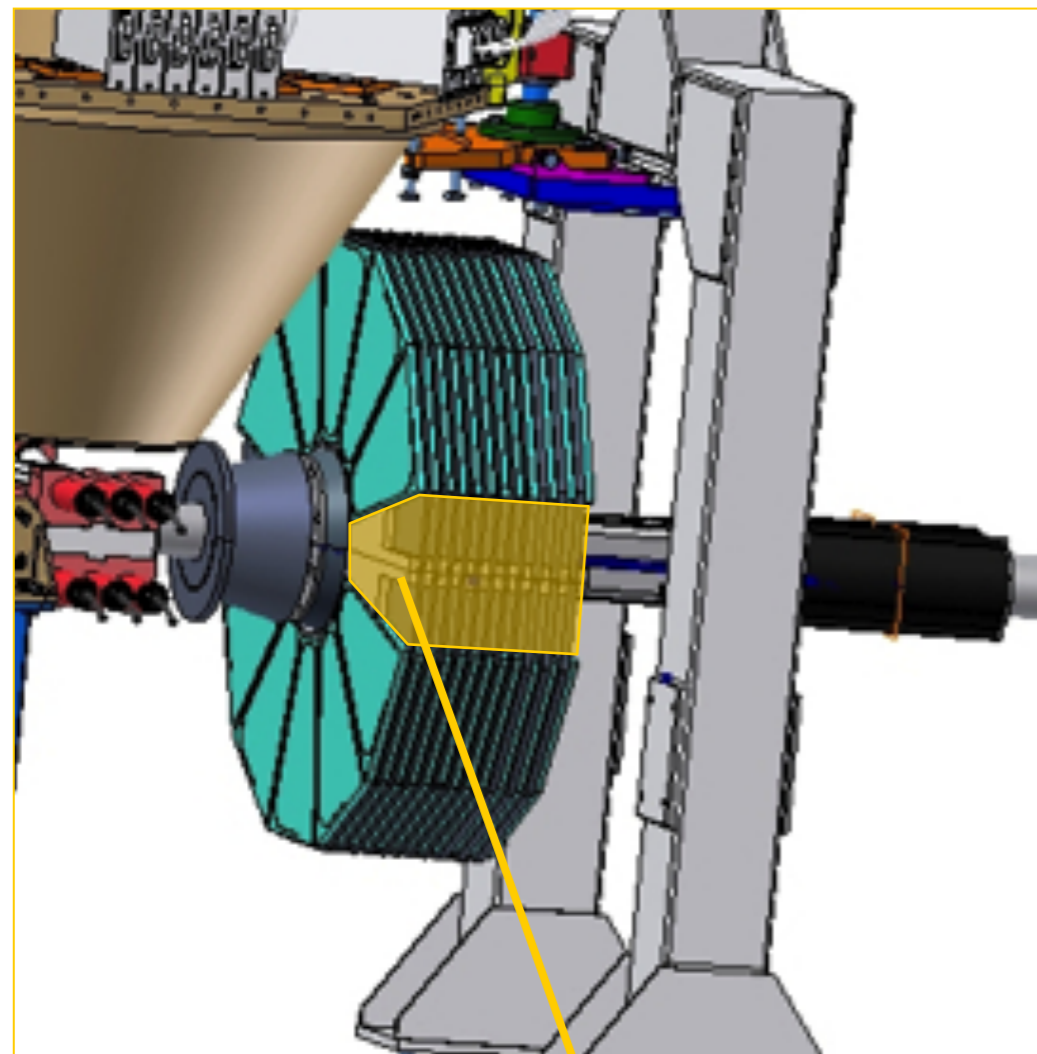
GEM 1

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 $\approx 12.5 X_0$ should ensure sufficient shower containment
 - 12×1 cm scintillator
 - 2:1 active:passive ratio should ensure $\approx 15\%/\sqrt{E(\text{GeV})}$ 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

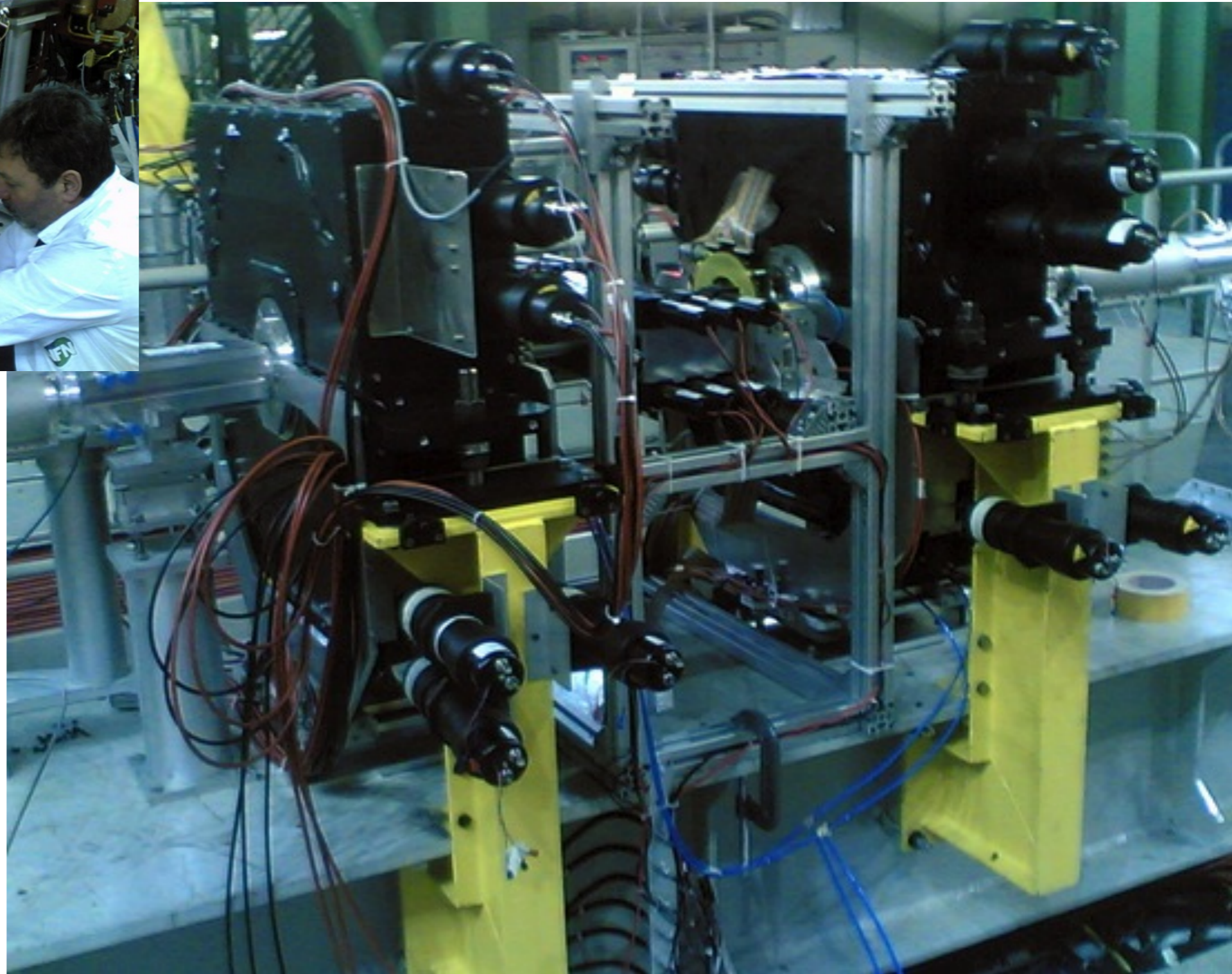
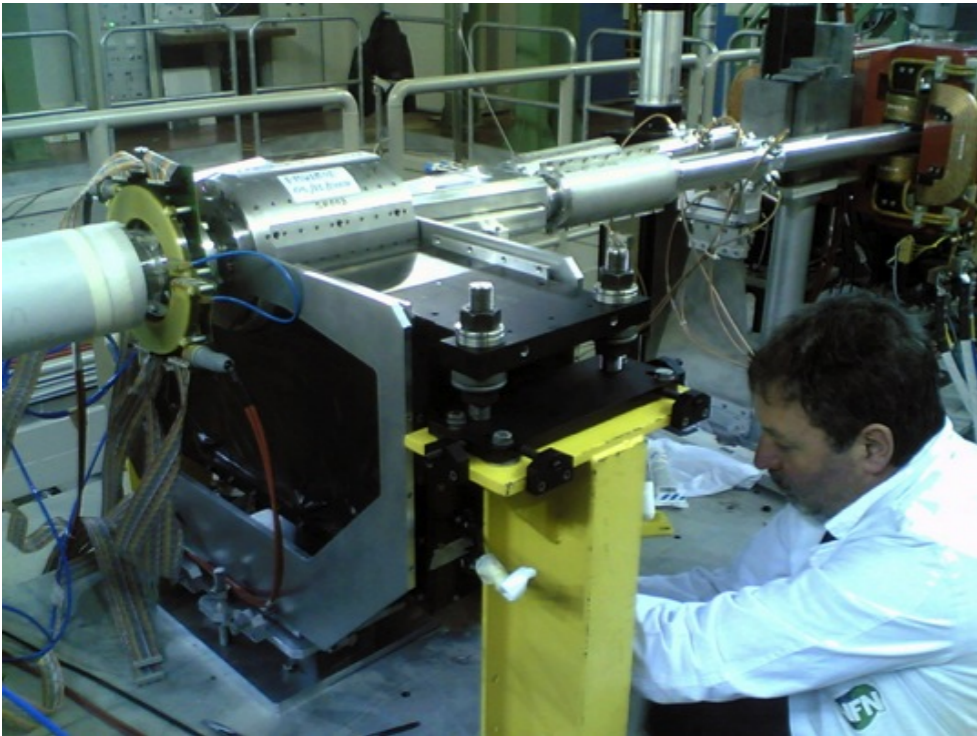
We decided to equip only 10 out of 12 sectors, keeping out the $\phi=0^\circ-180^\circ$ plane, since we expect larger backgrounds from there

CaloLumi construction



December '07 – January '08

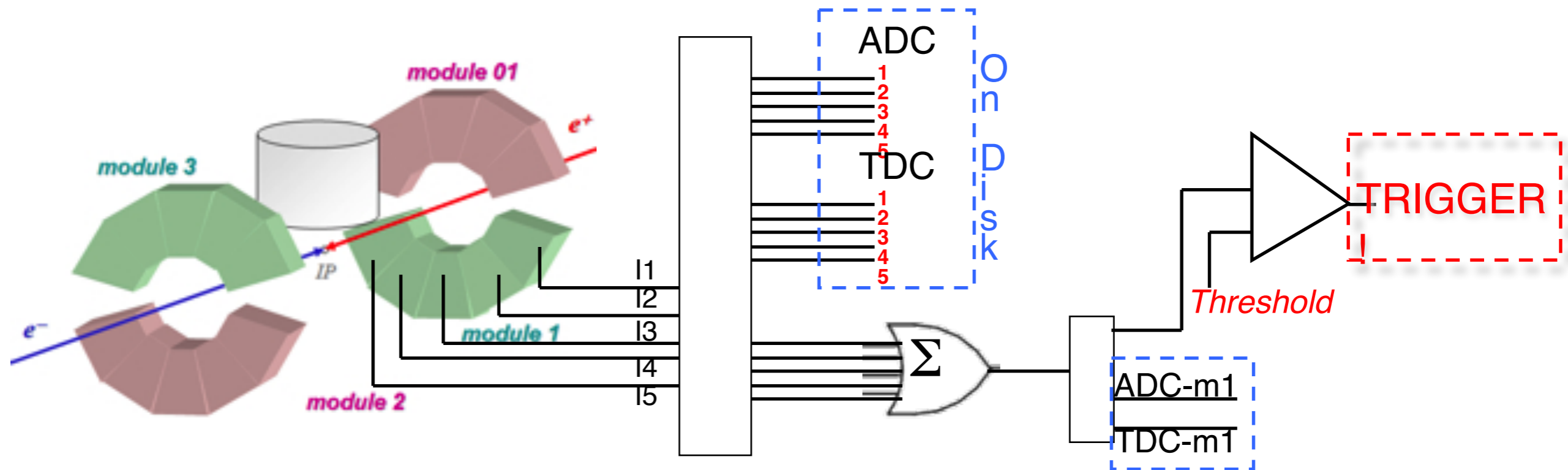
CaloLumi installation



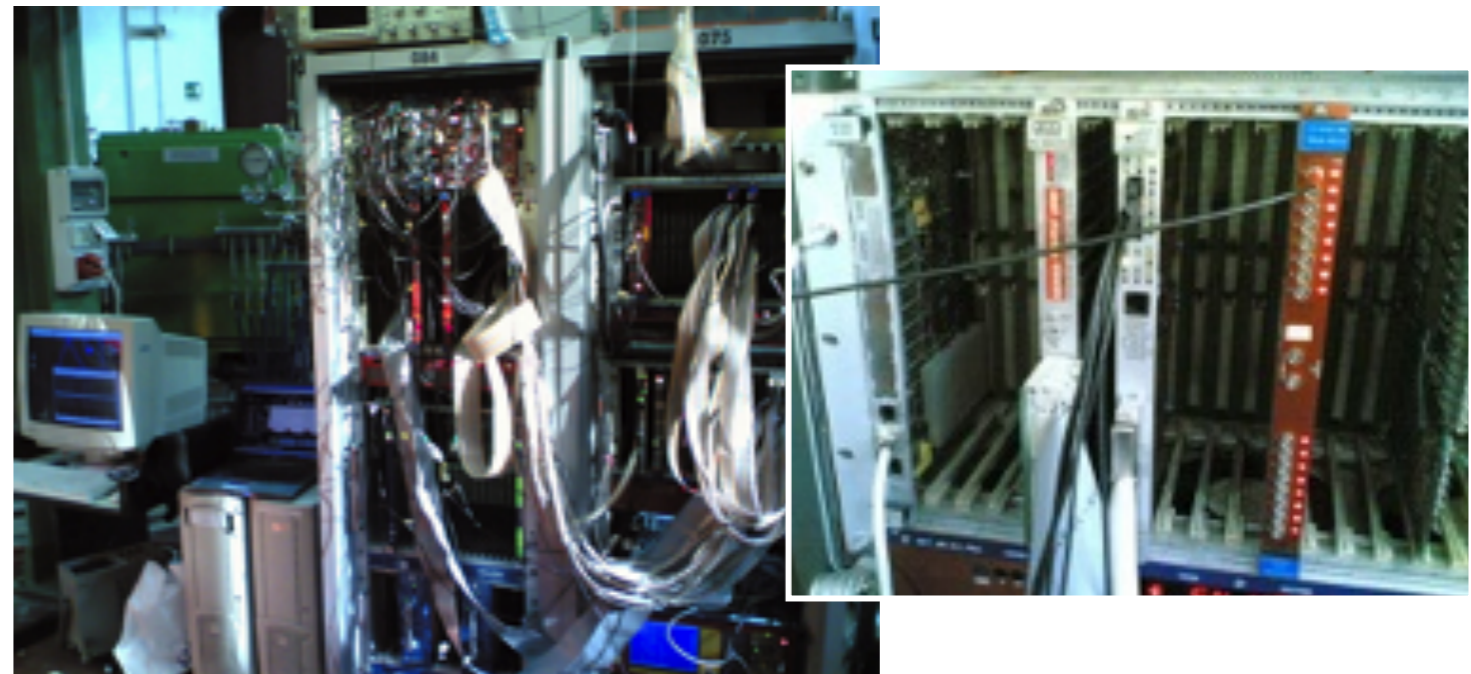
7 February 2008

DAQ and Trigger

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

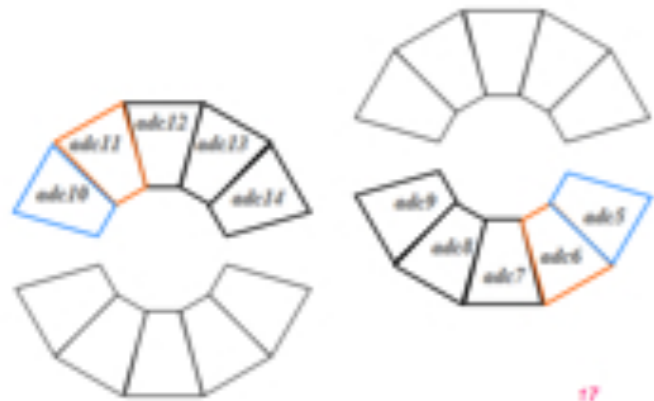
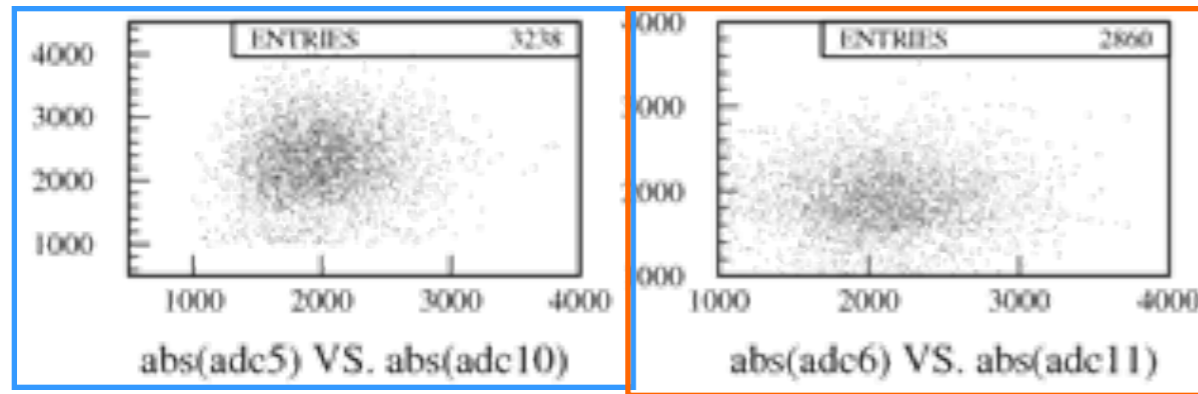


- Re-use KLOE's DAQ
 - KLOE's SDS boards to split, discriminate and sum the signal to assert a trigger ;
 - DAQ software also KLOE-based running on Motorola CPU MVM-E6100

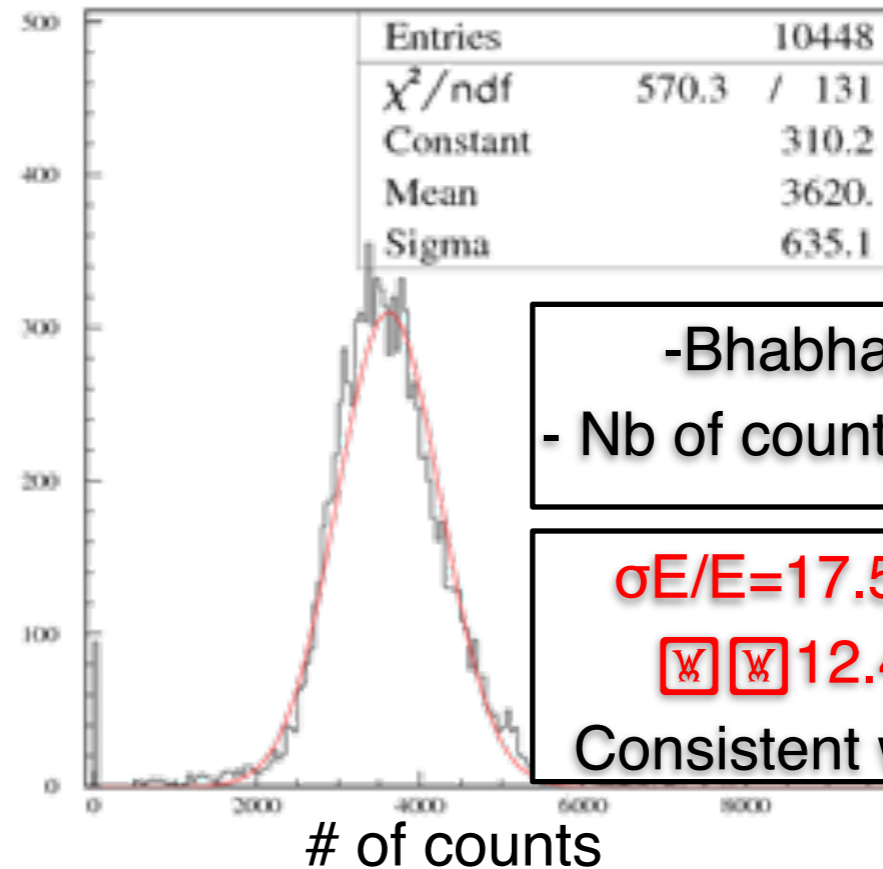


Performance

- Clear Bhabha Peaks !



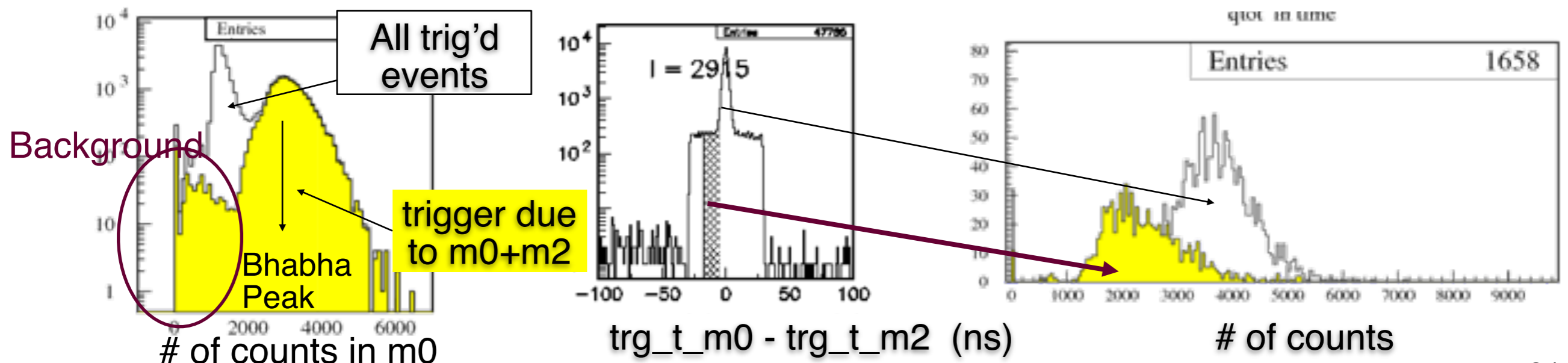
- Energy resolution



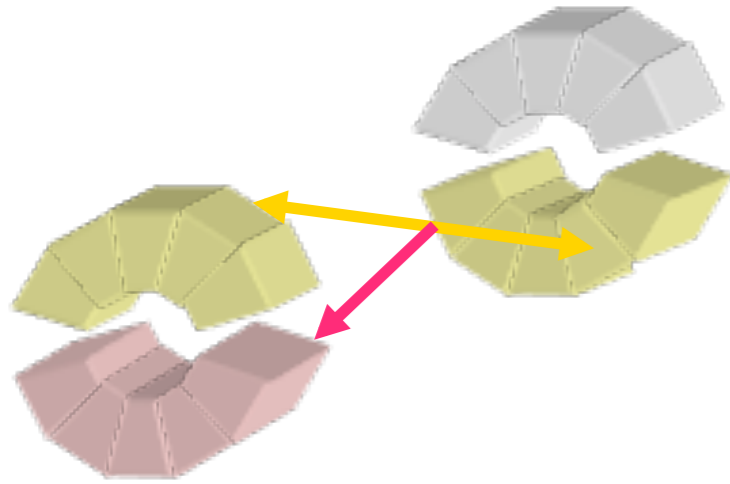
-Bhabha events in data
- Nb of counts in one module (?)

$\sigma E/E = 17.5\%$ @ 510 MeV
 $\approx 12.4\%/\sqrt{E}$ (GeV)
 Consistent with test beams.

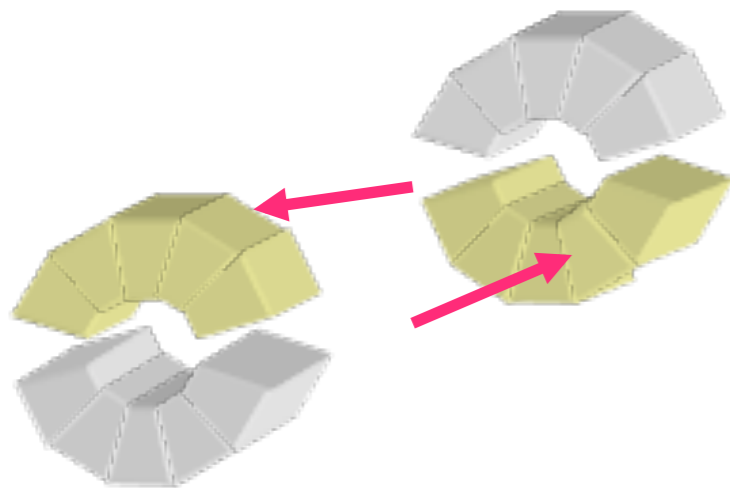
- Time resolution good enough to subtract backgrounds from Trigger Rate



Background



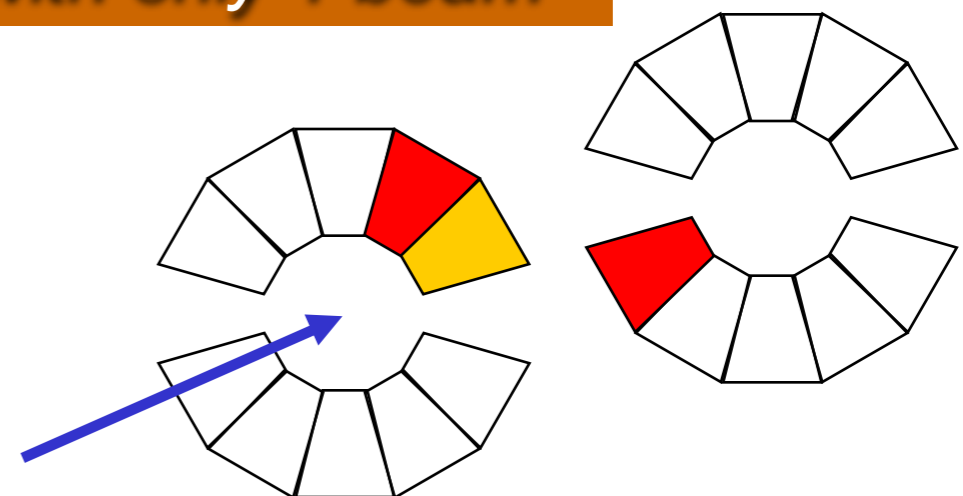
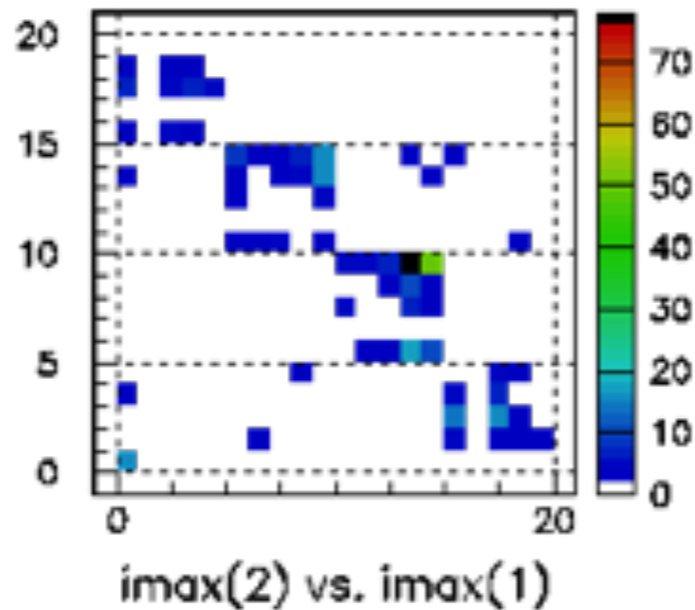
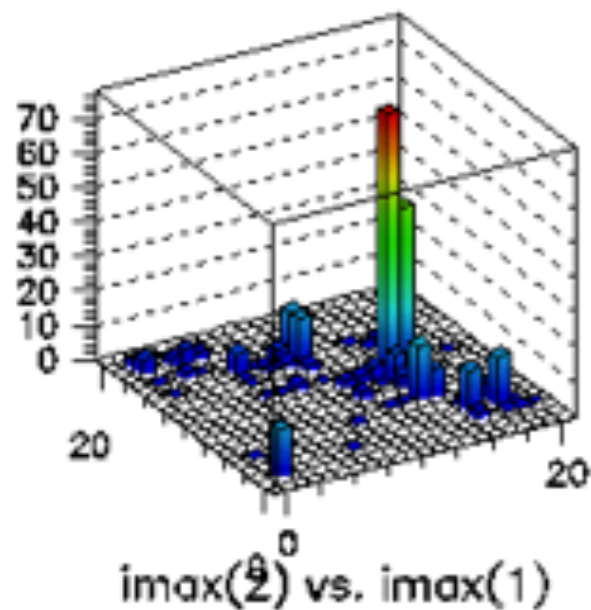
*We can have energy deposits over threshold in **another module**, in addition to the **couple of triggering modules**: this gives us the “triples”*



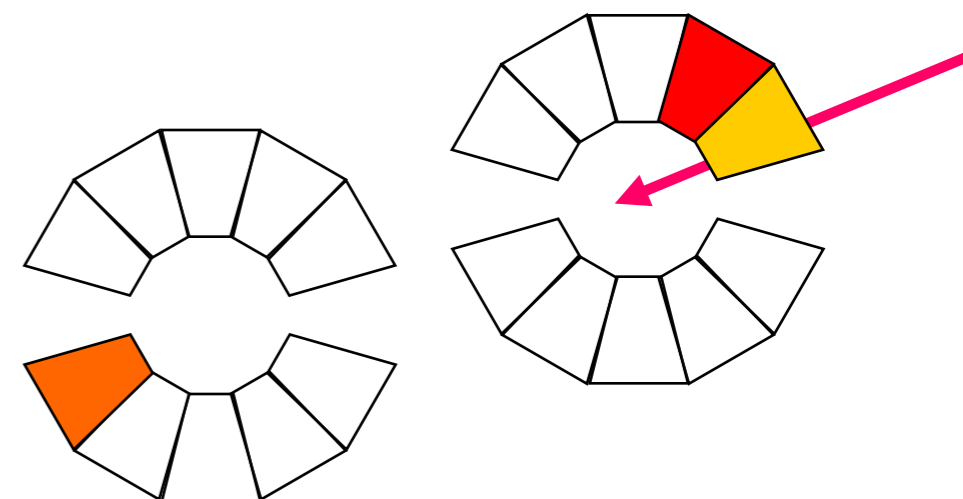
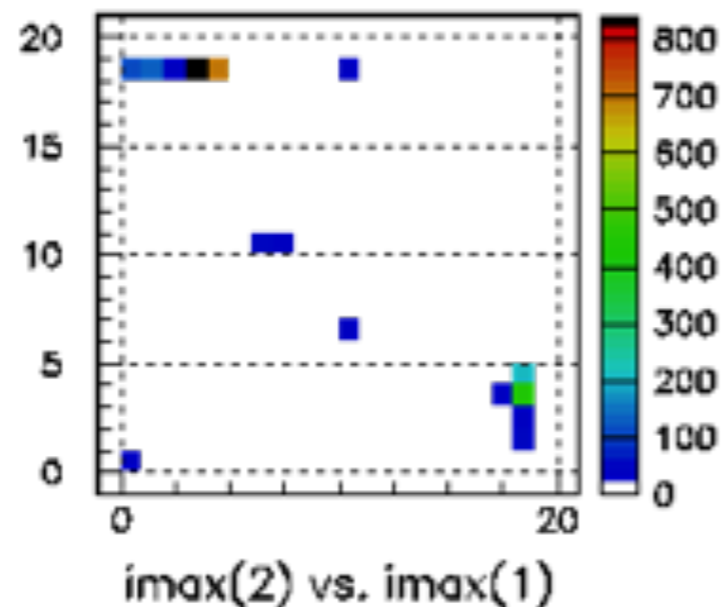
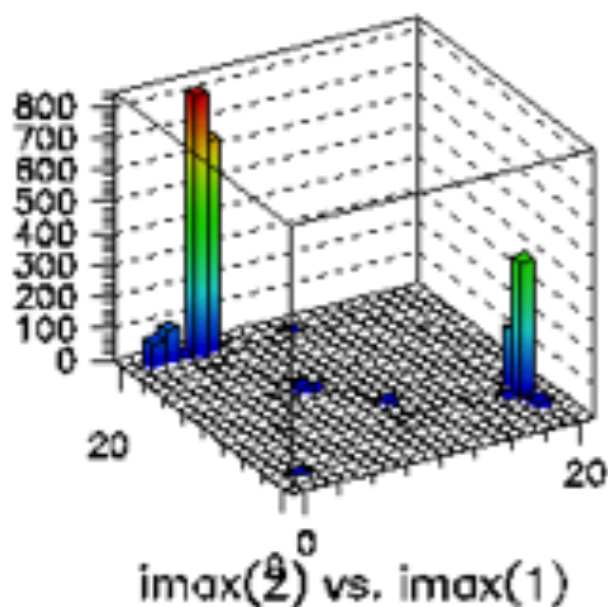
*We expect a similar level of events with no Bhabha, but with **two** “spurious” deposits, giving a **fake coincidence***

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)

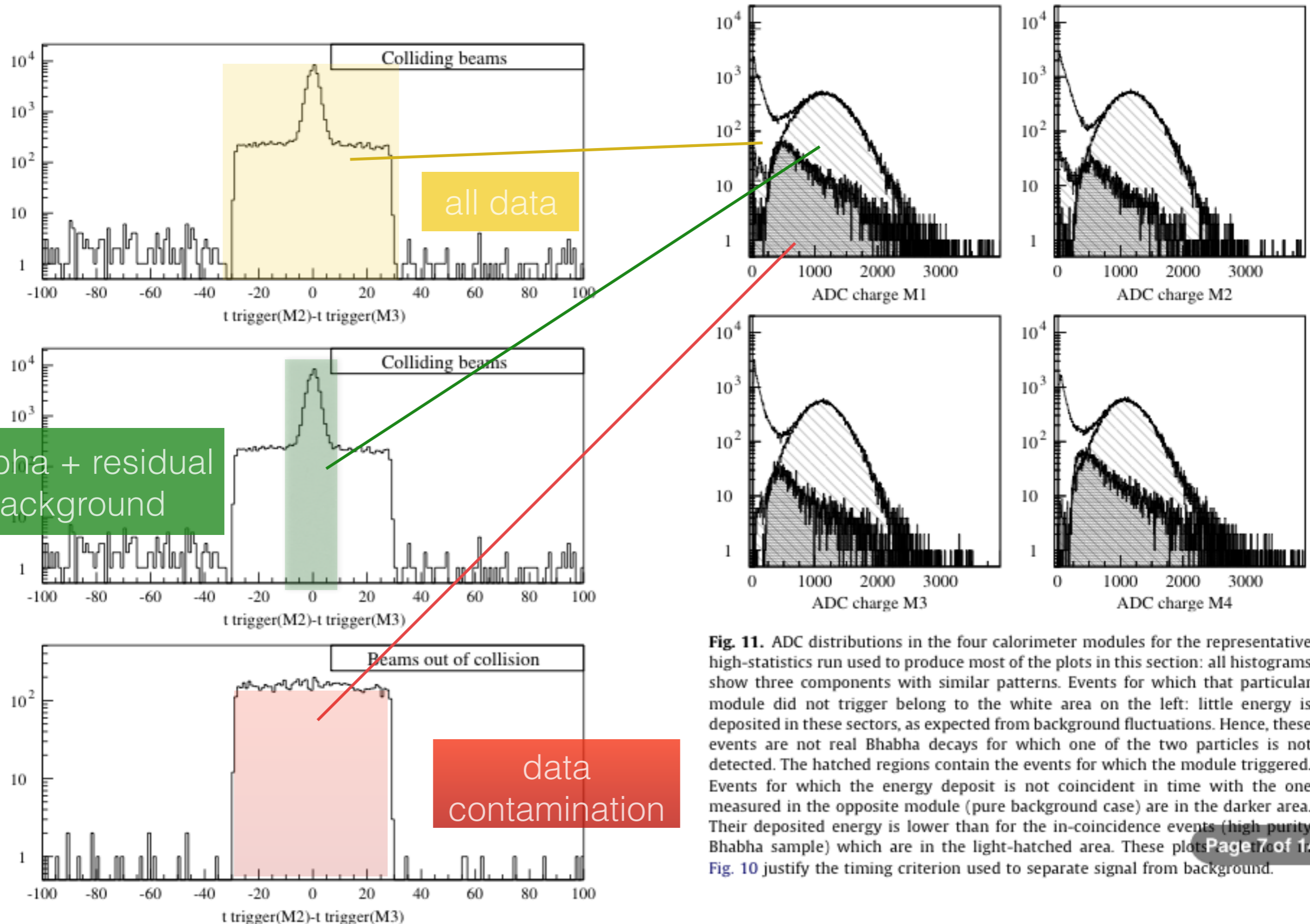
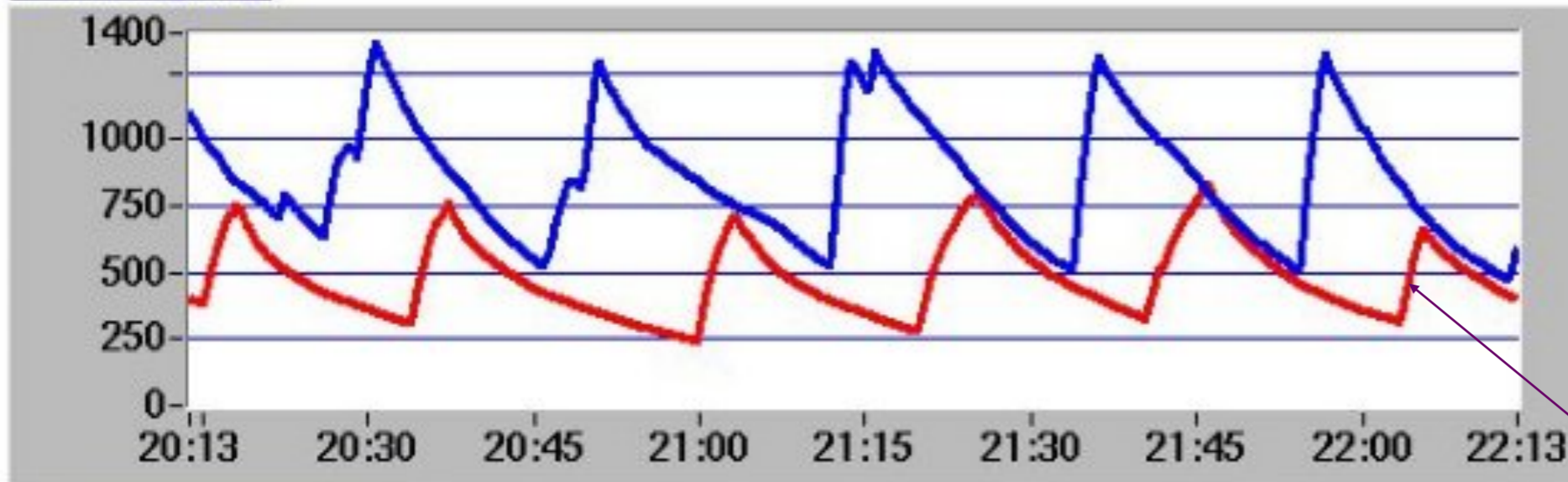


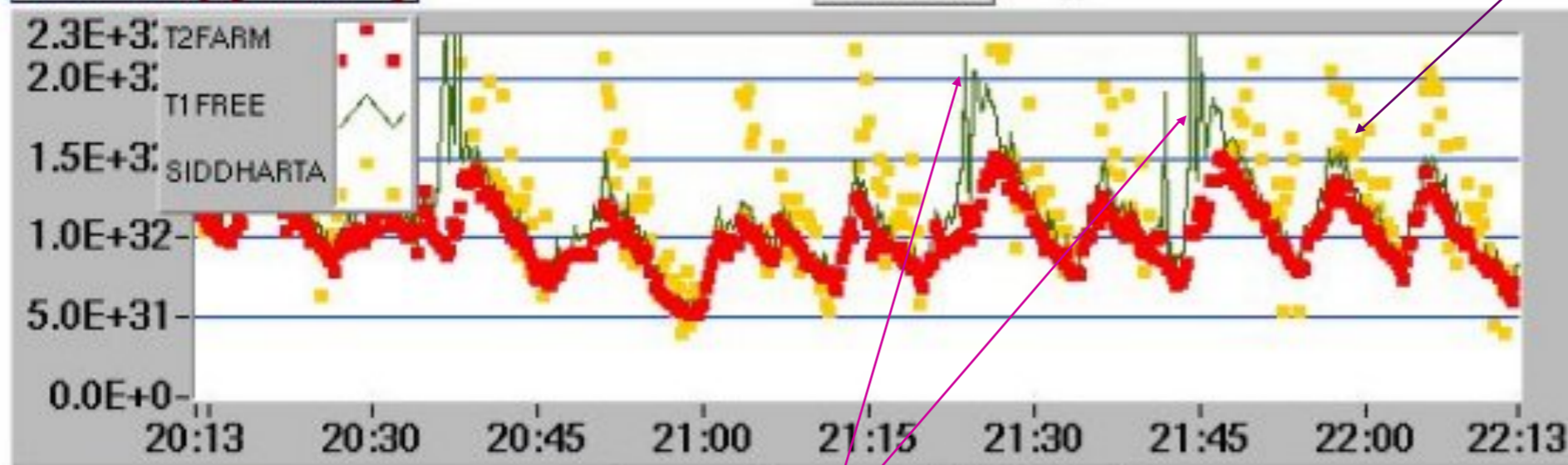
Fig. 11. ADC distributions in the four calorimeter modules for the representative high-statistics run used to produce most of the plots in this section: all histograms show three components with similar patterns. Events for which that particular module did not trigger belong to the white area on the 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 [Page 7 of 14 Fig. 10](#) justify the timing criterion used to separate signal from background.

Online timing filter effect

Current [mA]



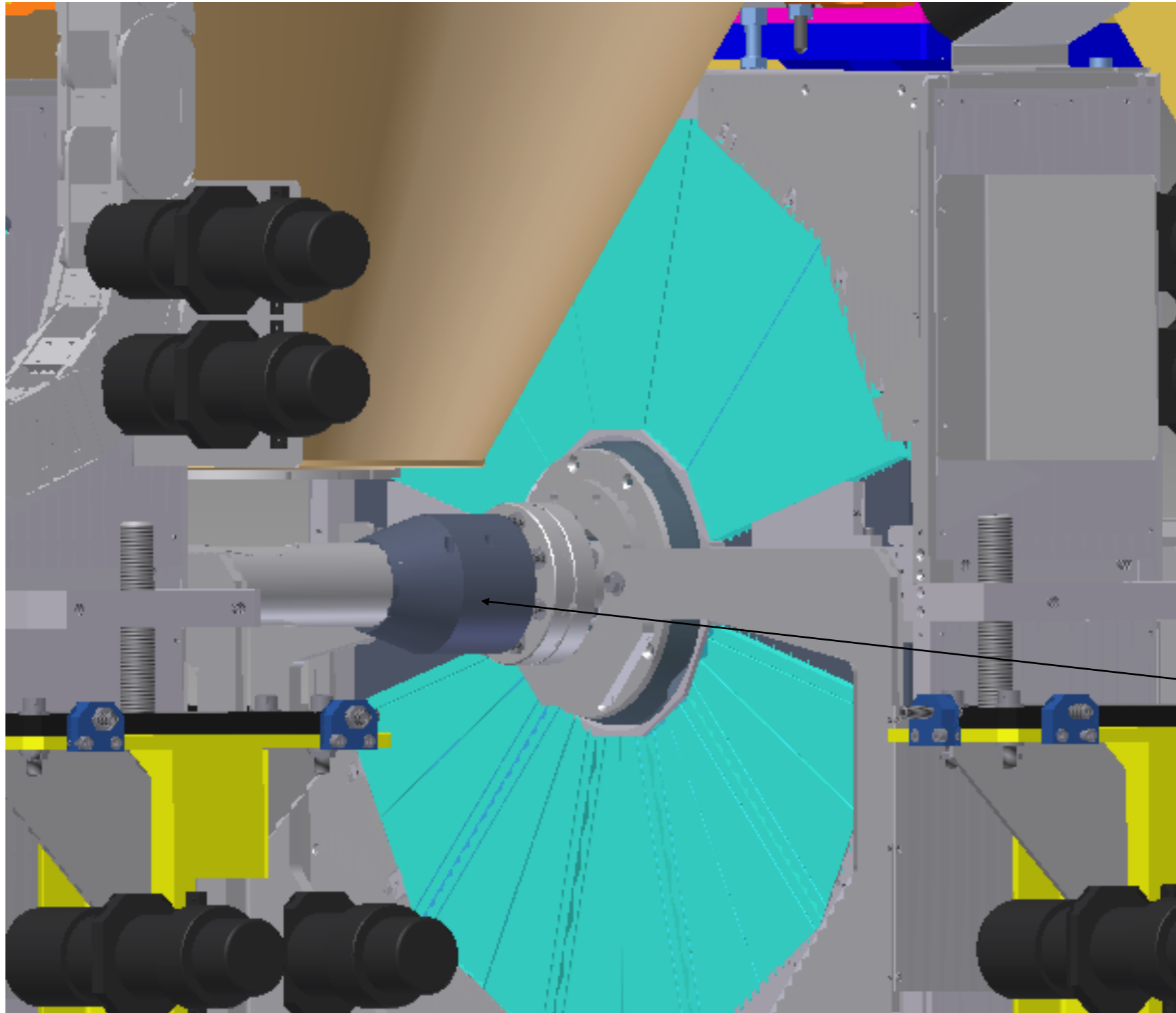
Luminosity [cm⁻² s⁻¹]



good e⁺ injection

bad, dirty, e⁺ injections

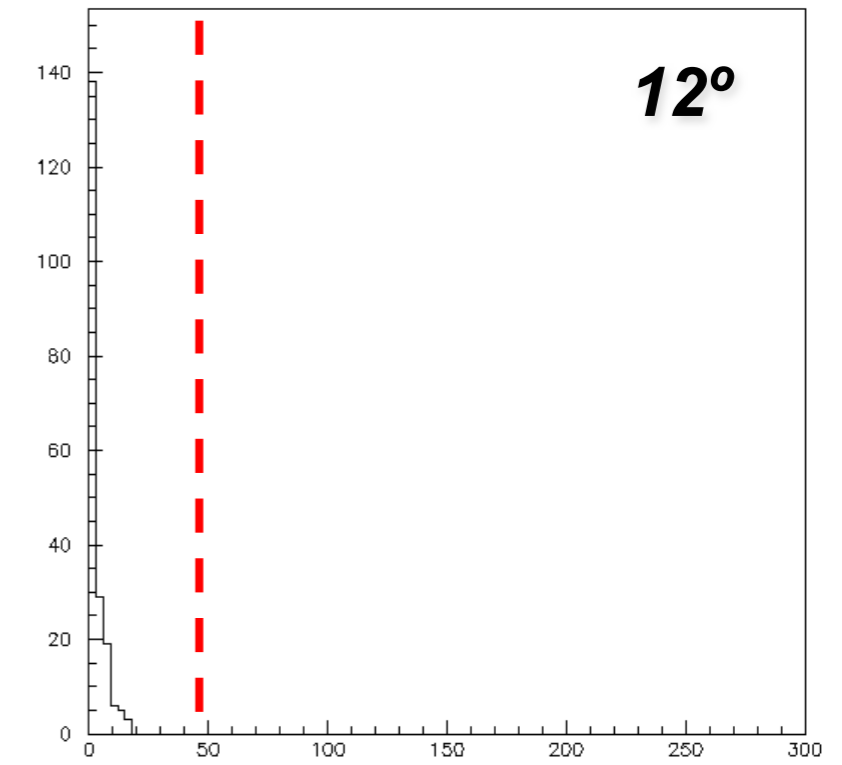
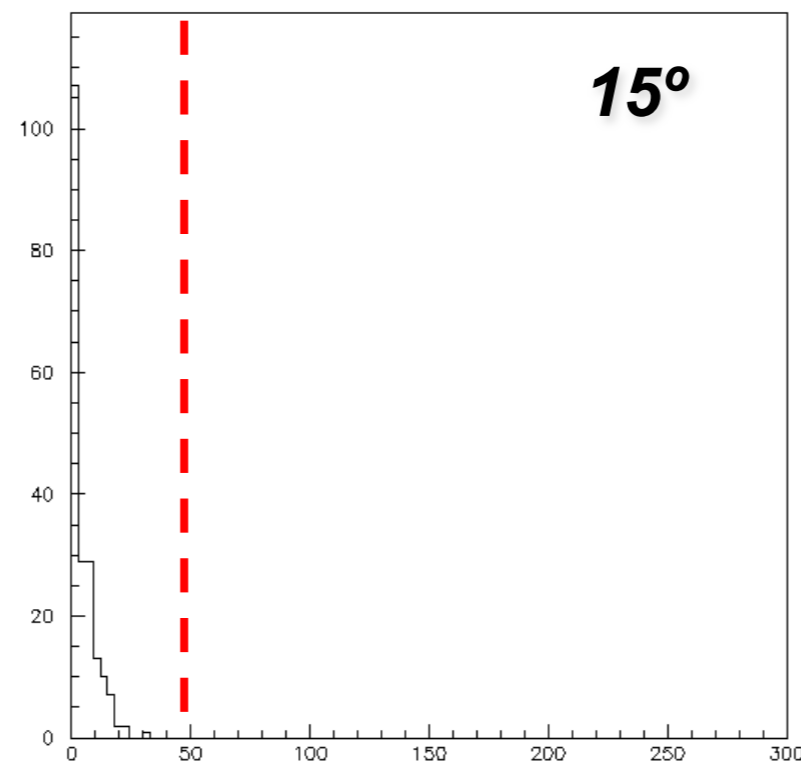
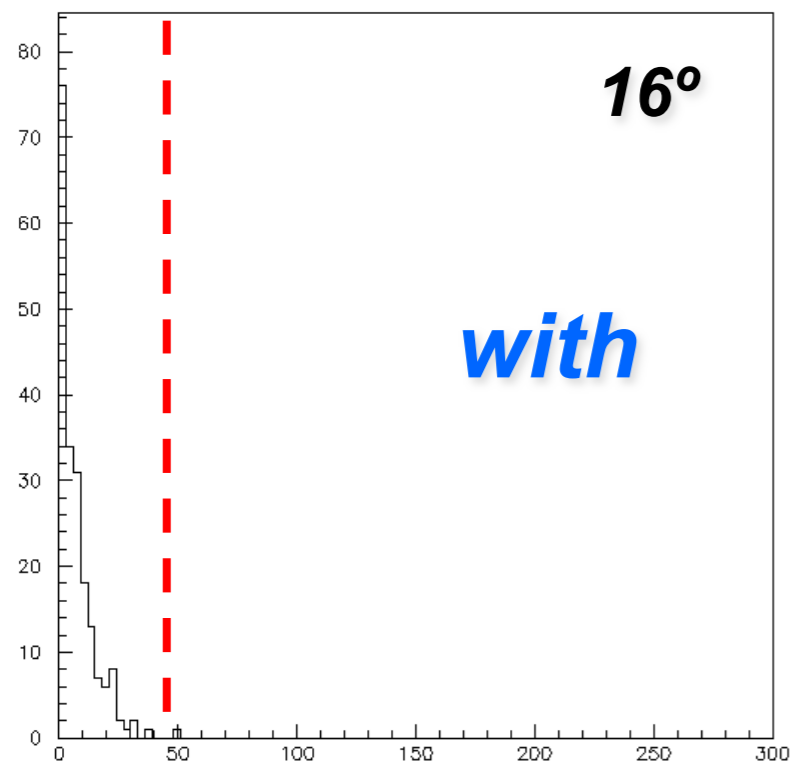
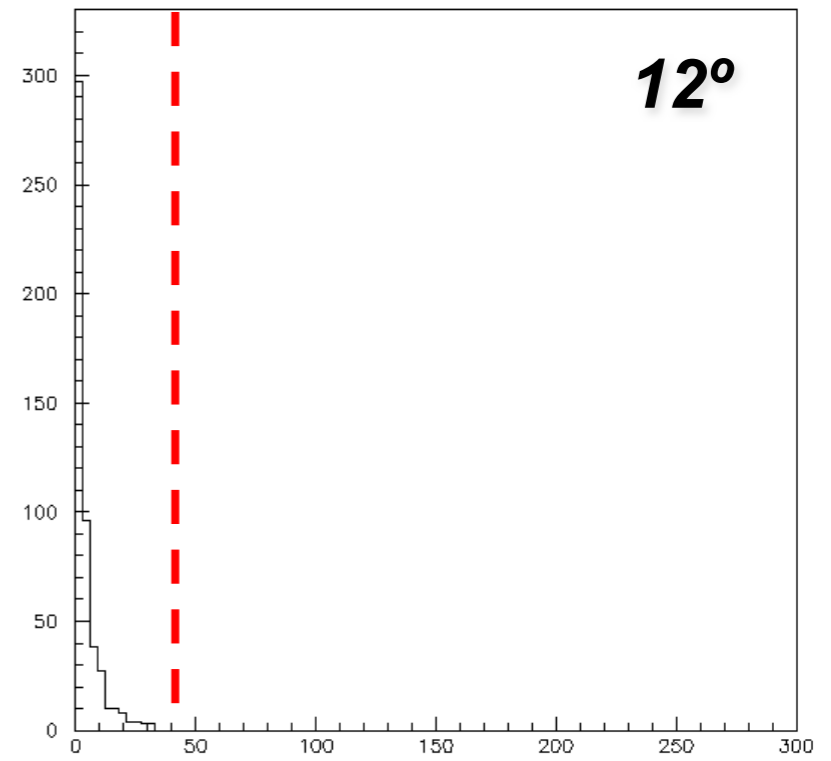
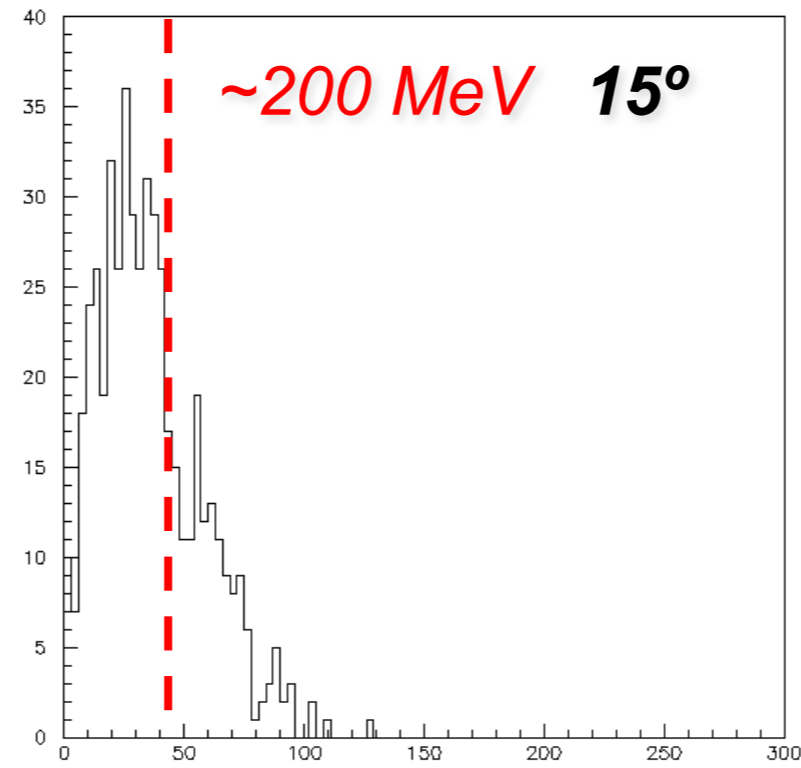
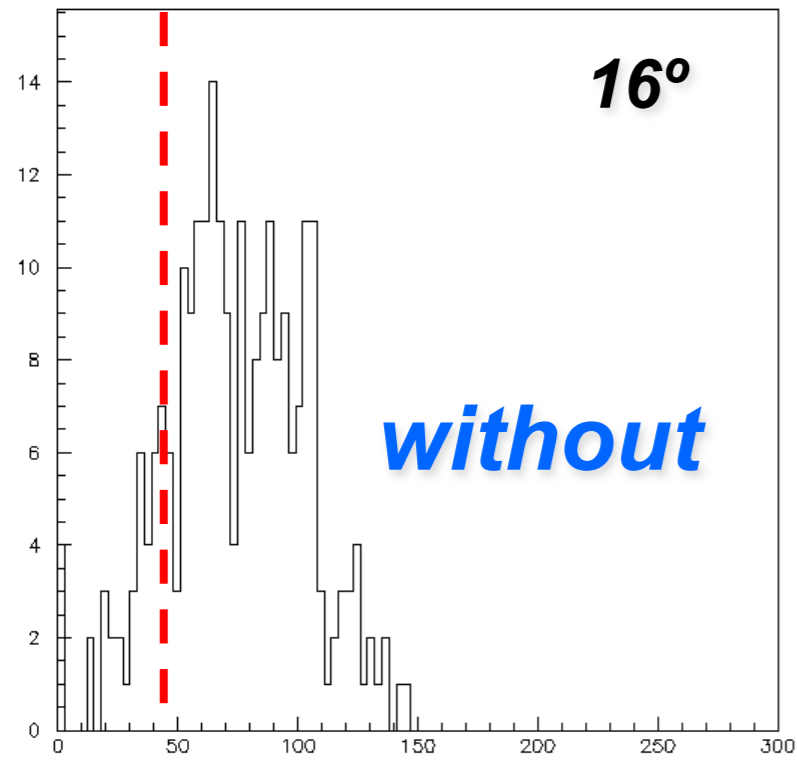
Soyuz



$\theta > 18^\circ$

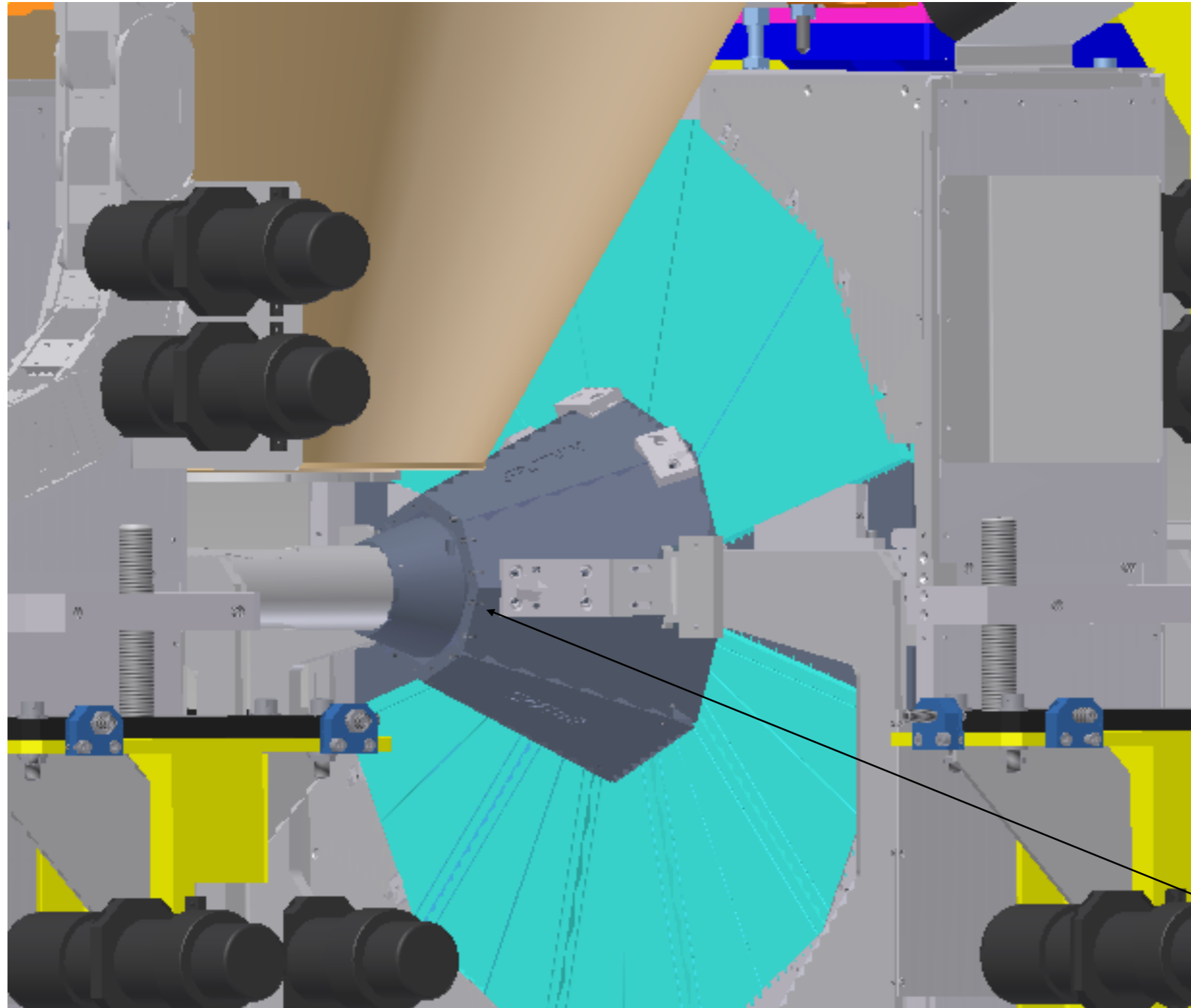
Soyuz

Soyuz simulation results effect



Sputnik

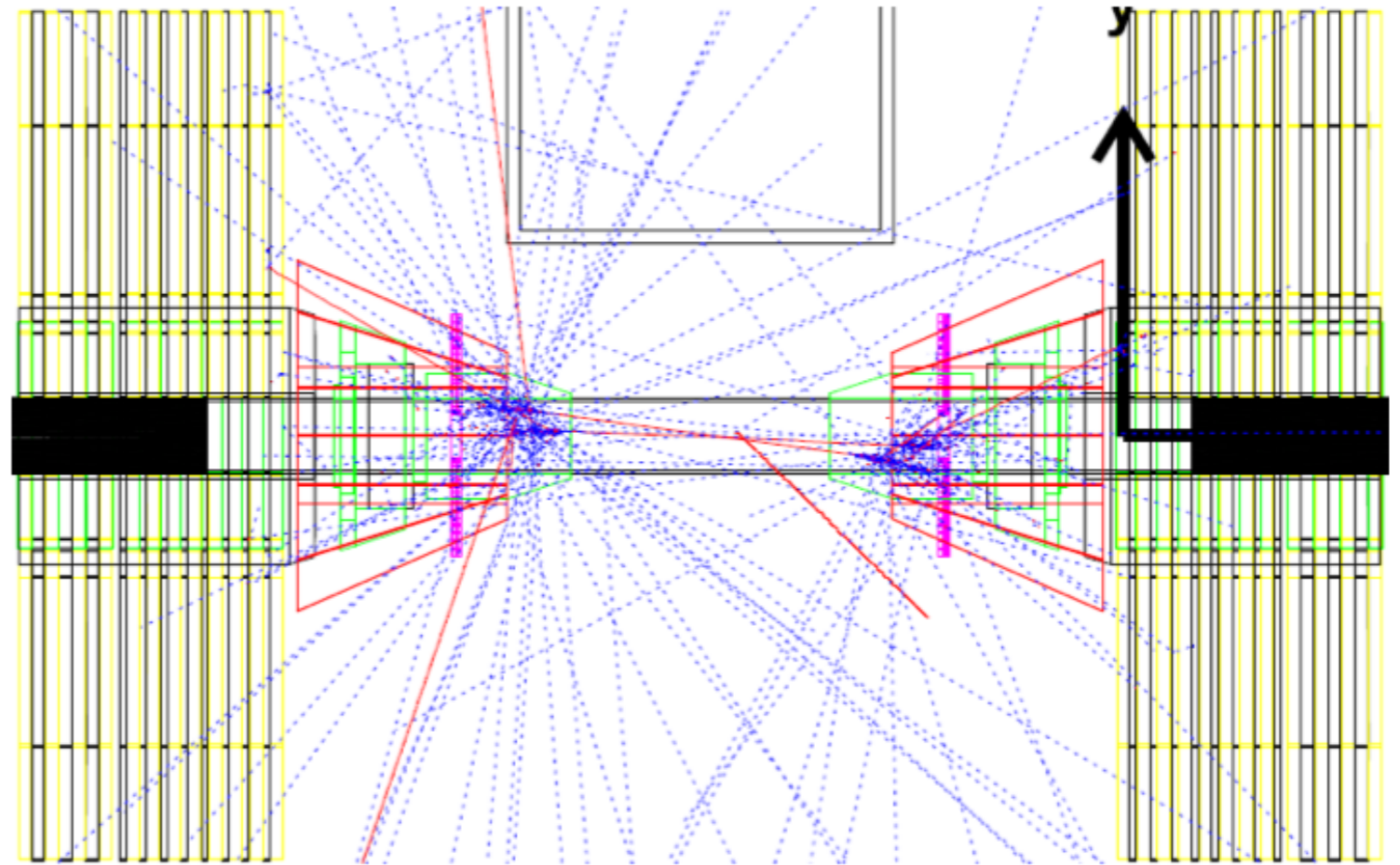
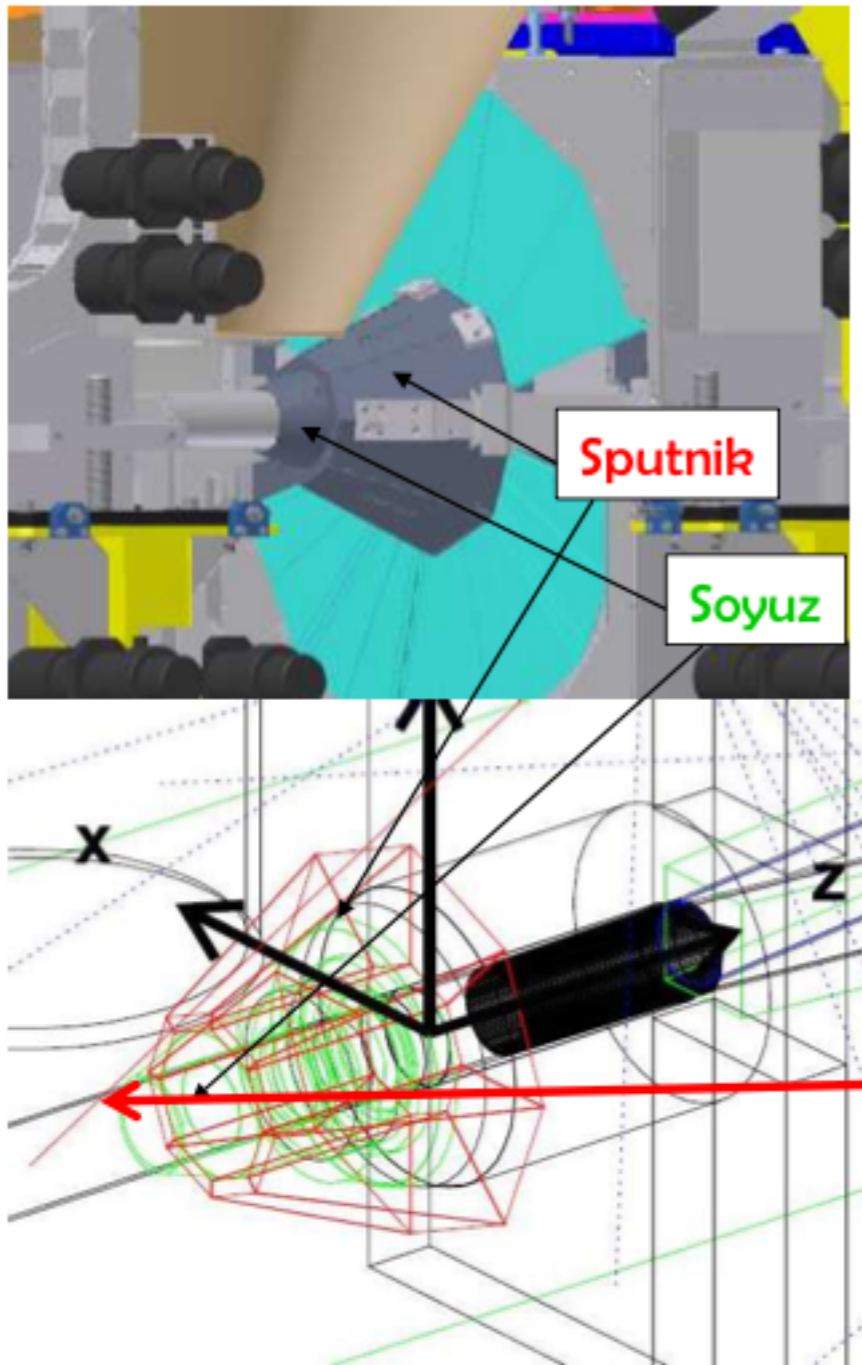
Since May 29th, 2008



$\theta > 22^\circ$

Sputnik

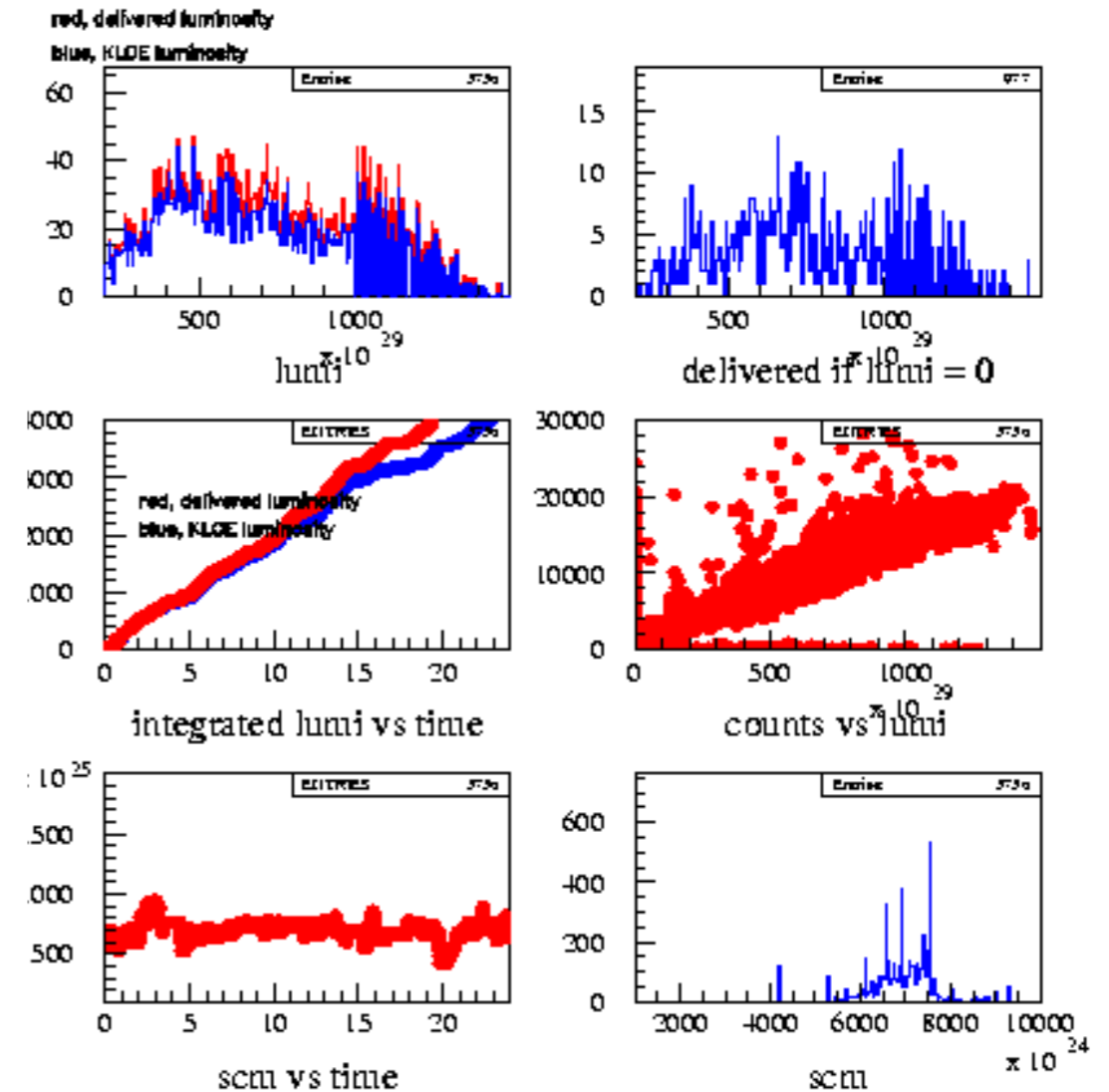
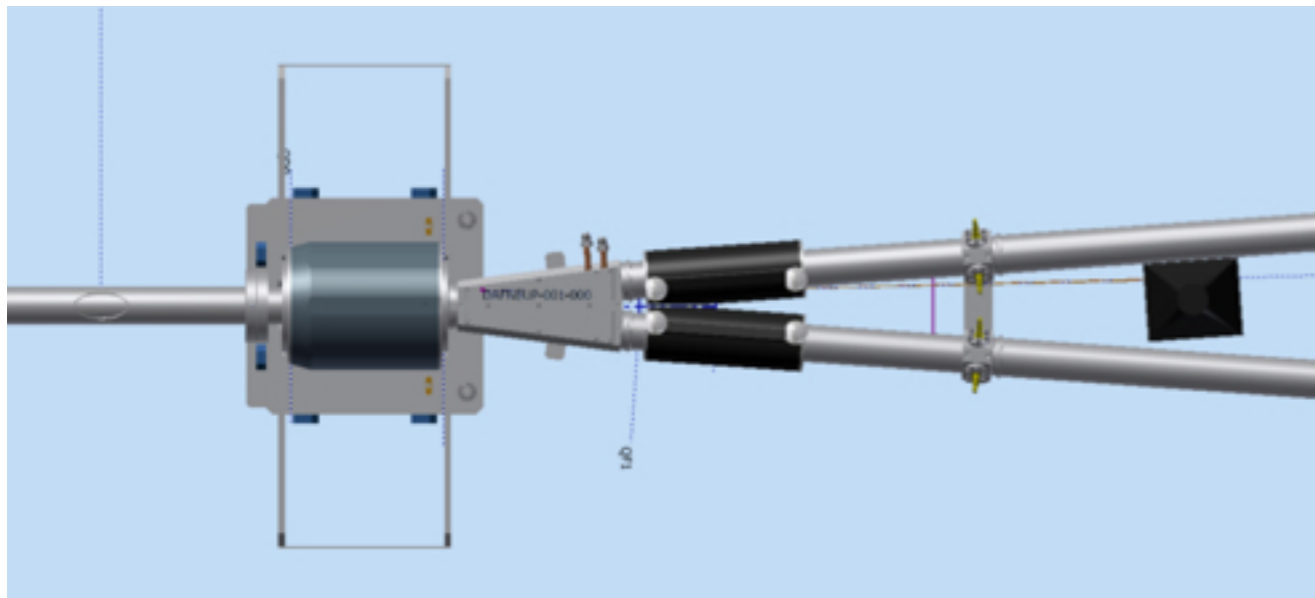
Simulation



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 to 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

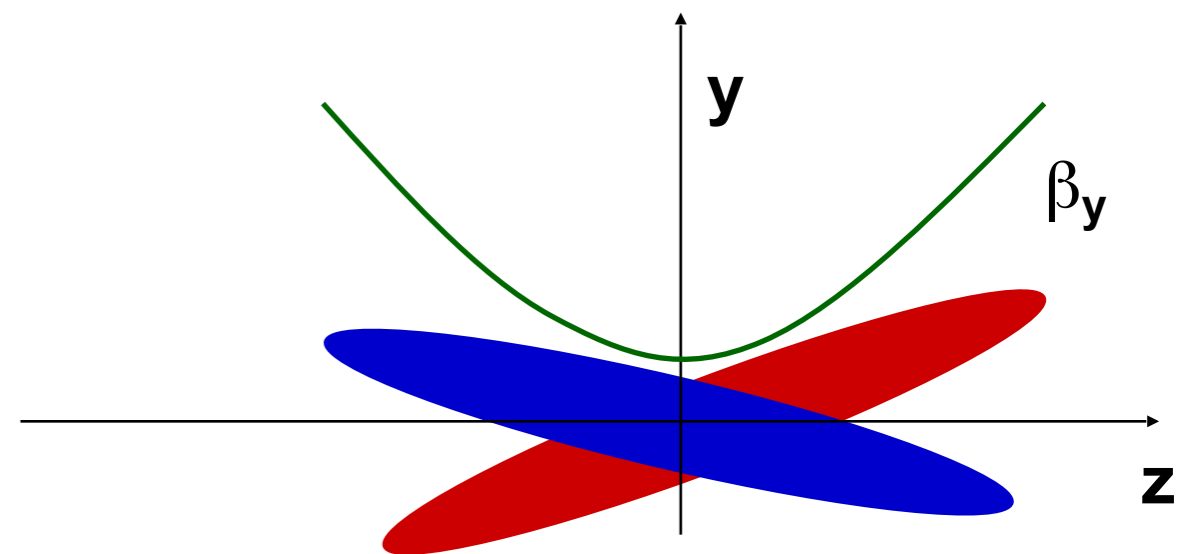
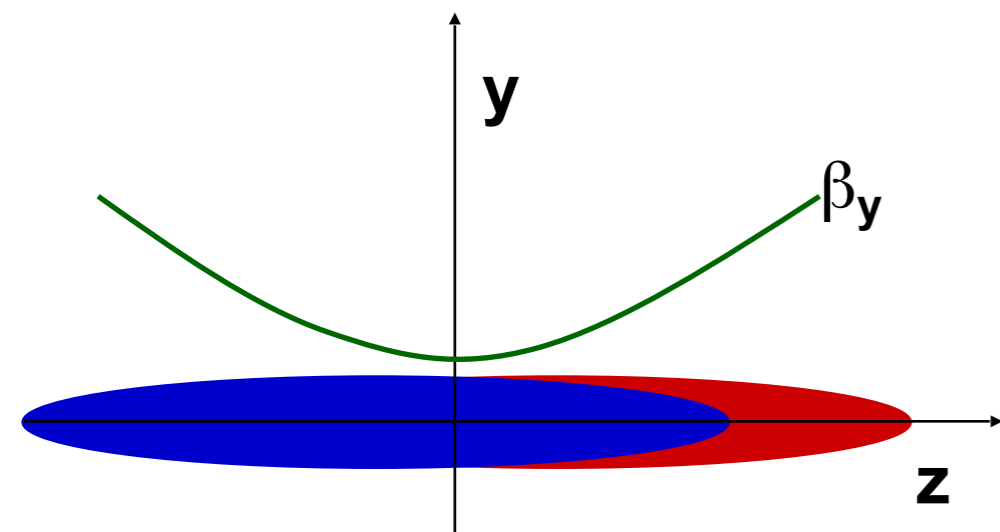
Luminosity and crossing angle

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

**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

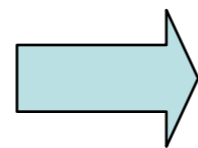
but allows to play with transversal dimension σ_x and β_y optical function, keeping limited the vertical tune-shift and strongly depressing horizontal tune-shift

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

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

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

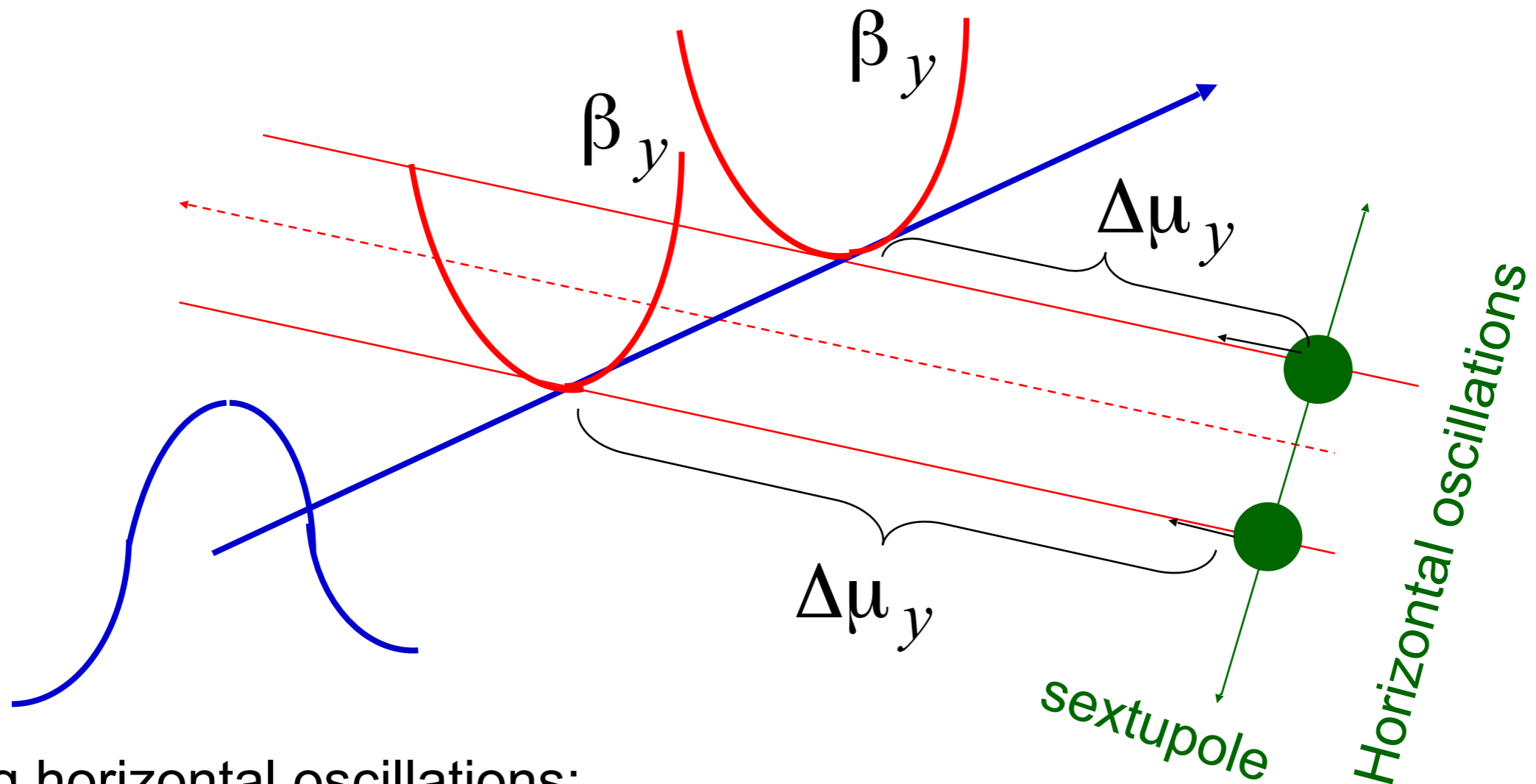
• σ_z large
 σ_x small



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

but 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 ($\pi/2$)

