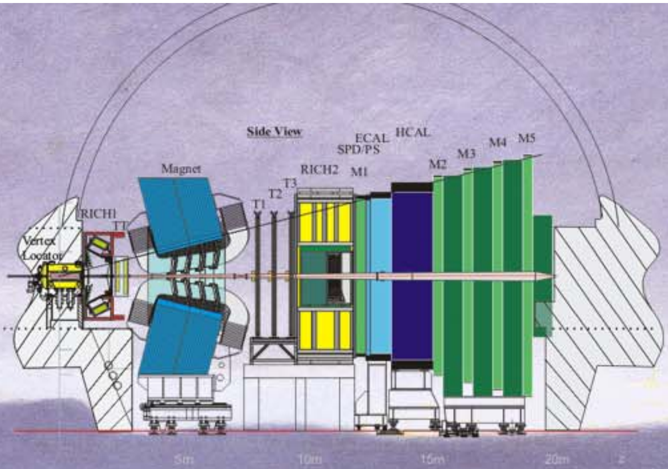


The LHCb Experiment.

Our Path to a Running Experiment and what comes after.

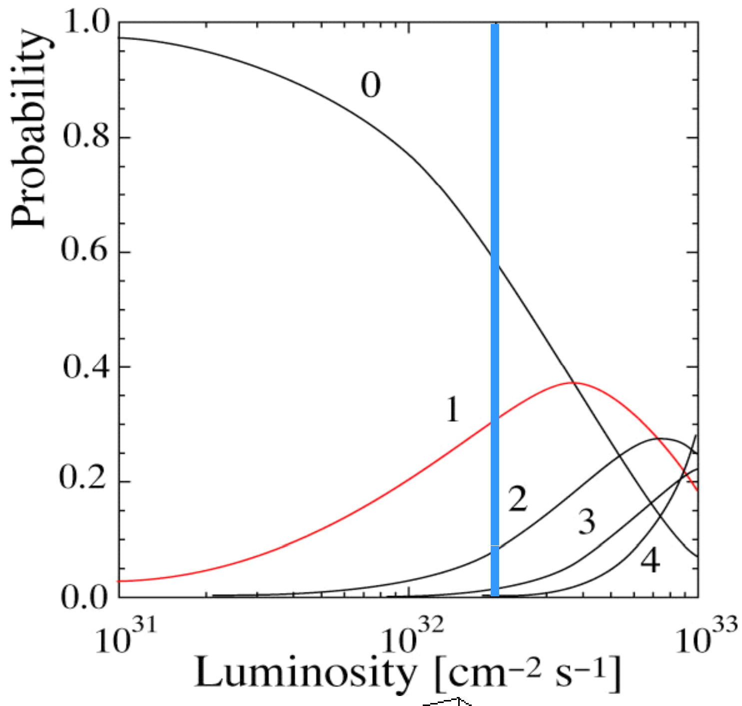
O. Ullaland
Ljubljana January 2008

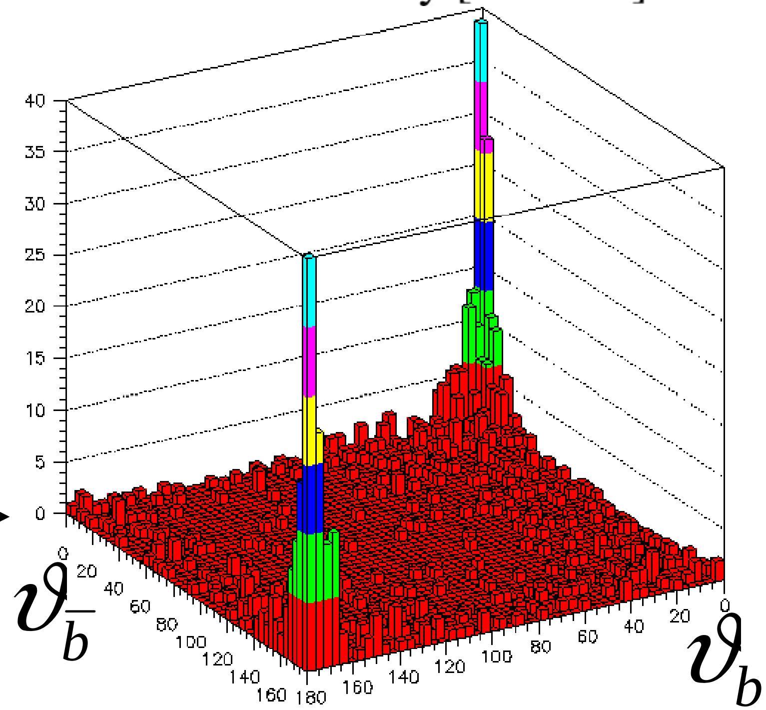
Theodor Kittelsen, Soria Moria (with modifications)

LHCb is dedicated to the Search for New Physics in CP violation and Rare B decays

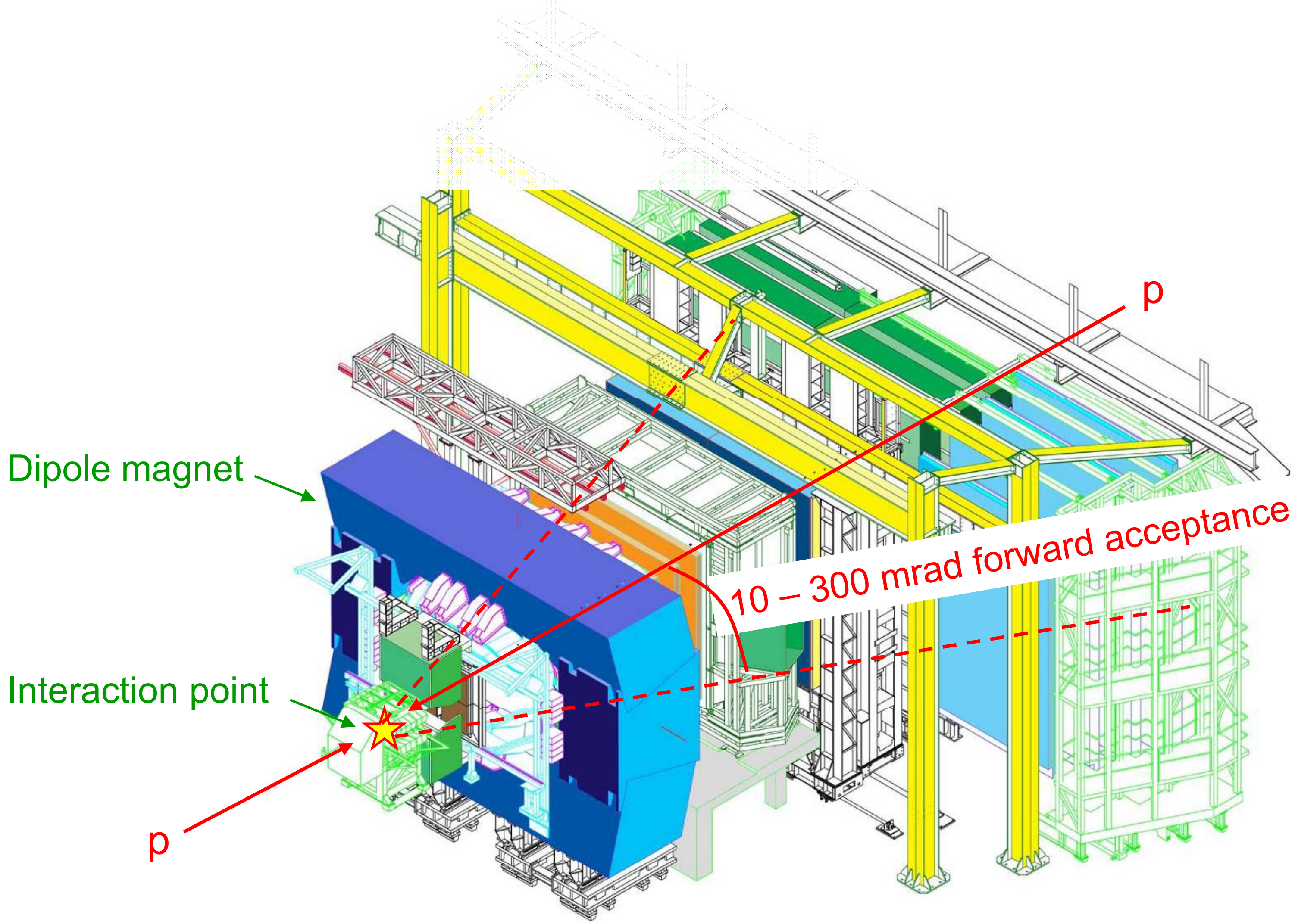
In the forward region ($4.9 > \eta > 1.9$):

- $b\bar{b}$ cross-section large (~230 μb)
- Luminosity $\mathcal{L}=2*10^{32}$ $cm^{-2}s^{-1}$
  ➡ 10^{12} B hadrons in 10^7 sec
- All species of B hadrons produced ($B^{\pm}$, B_d, B_s, B_c, b-baryons)
- B's have large momentum
  $\langle p_B \rangle_{acc} \sim 80$ GeV/c
  Mean flight path of B's ~7 mm.
- $b\bar{b}$ production correlated and sharply peaked forward-backward.

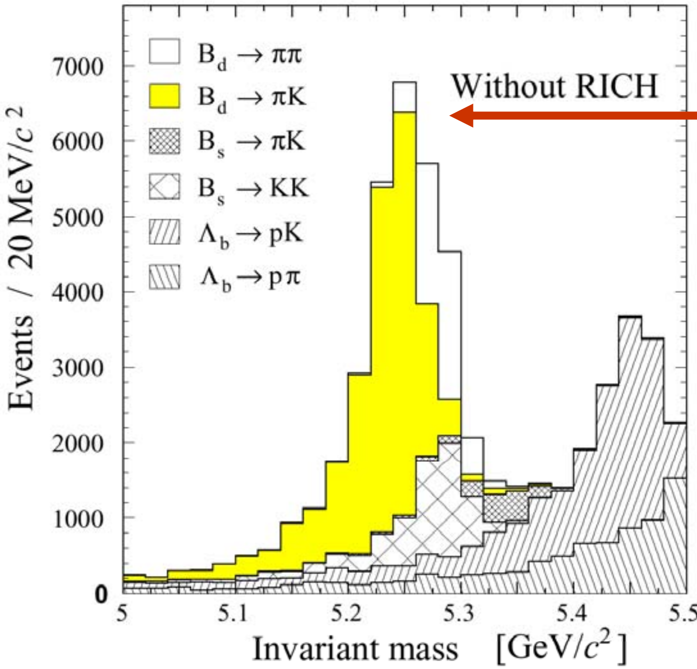


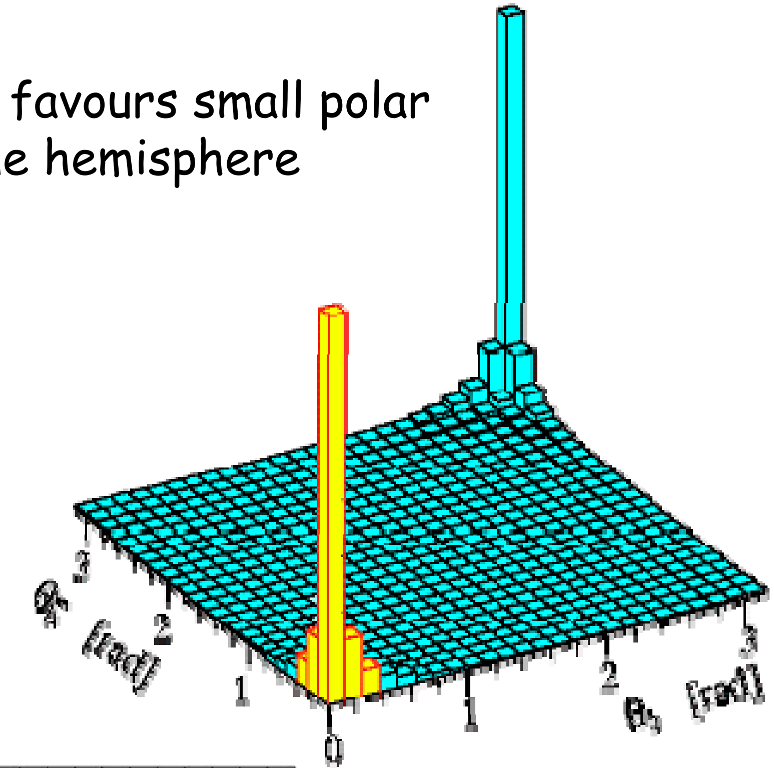


Collider-mode operation at same time as the general-purpose detectors,
with less-focused beams

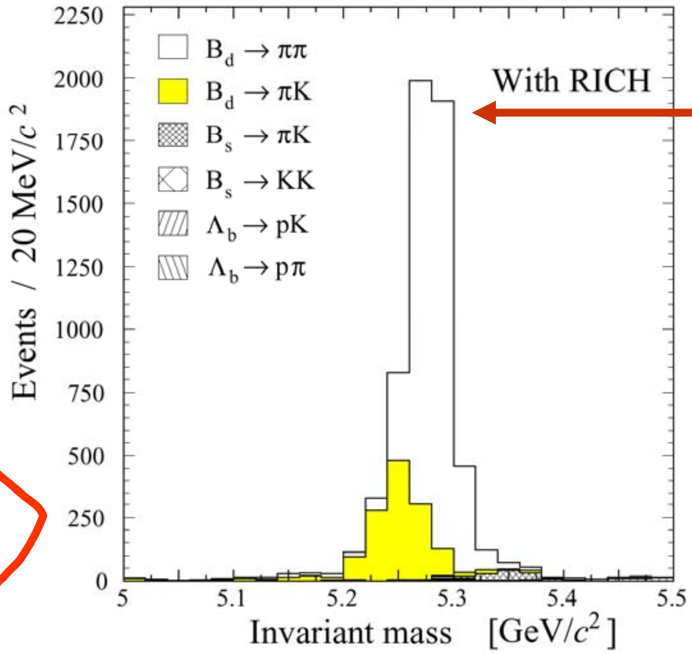


$b\bar{b}$ production favours small polar angles and same hemisphere





and physics favours particle identification



RICH 1:

Aerogel 2→10 GeV/*c*

n=1.03

(nominal at 540 nm)

C_4F_{10} up to 70 GeV/*c*

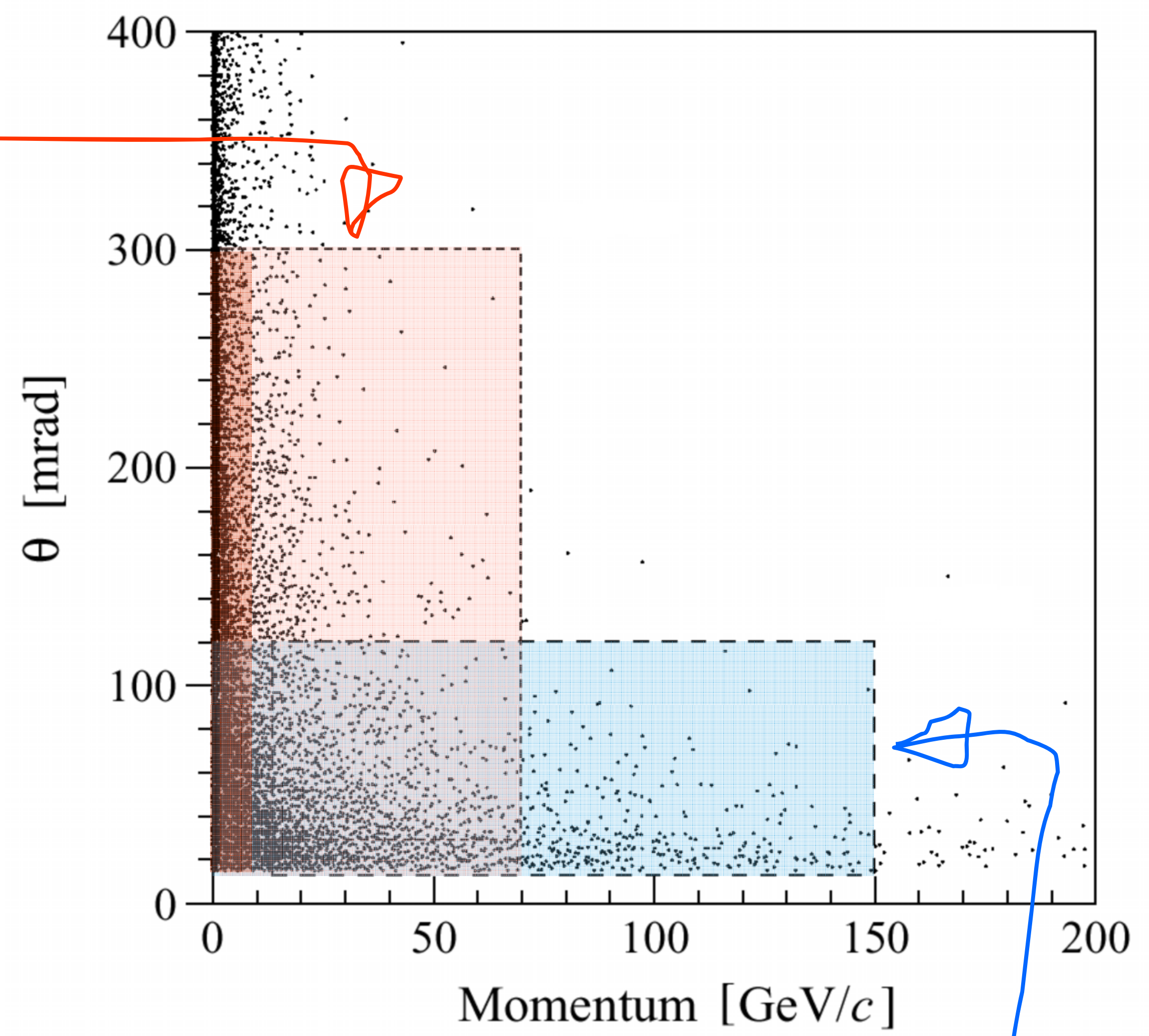
n=1.0014

(nominal at 400 nm)

Acceptance:

25→250 mrad (vertical)

300 mrad (horizontal)



RICH 2:

CF_4 up to 100 GeV/*c*

n =1.0005 (nominal at 400 nm)

Acceptance:

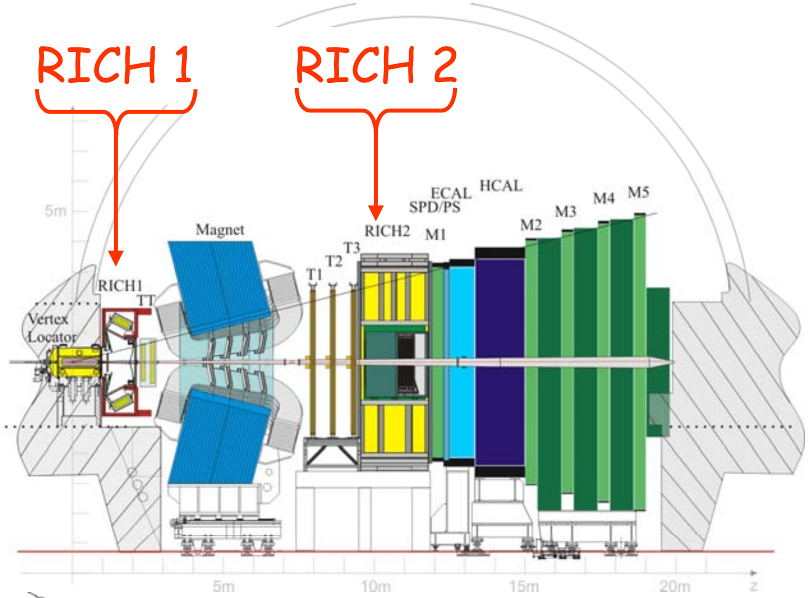
15→100 mrad (vertical)

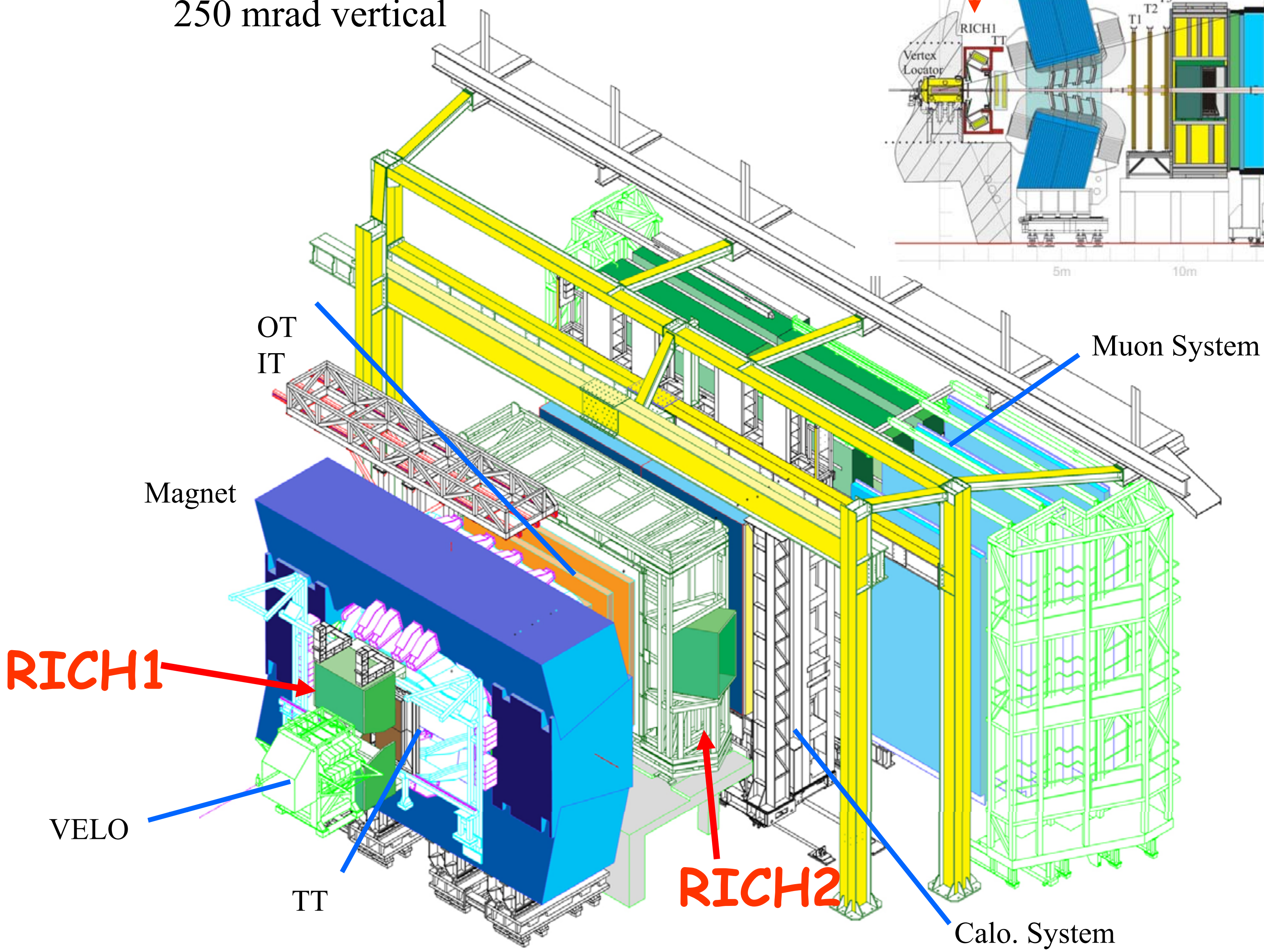
120 mrad (horizontal)

LHCb Spectrometer

Acceptance:

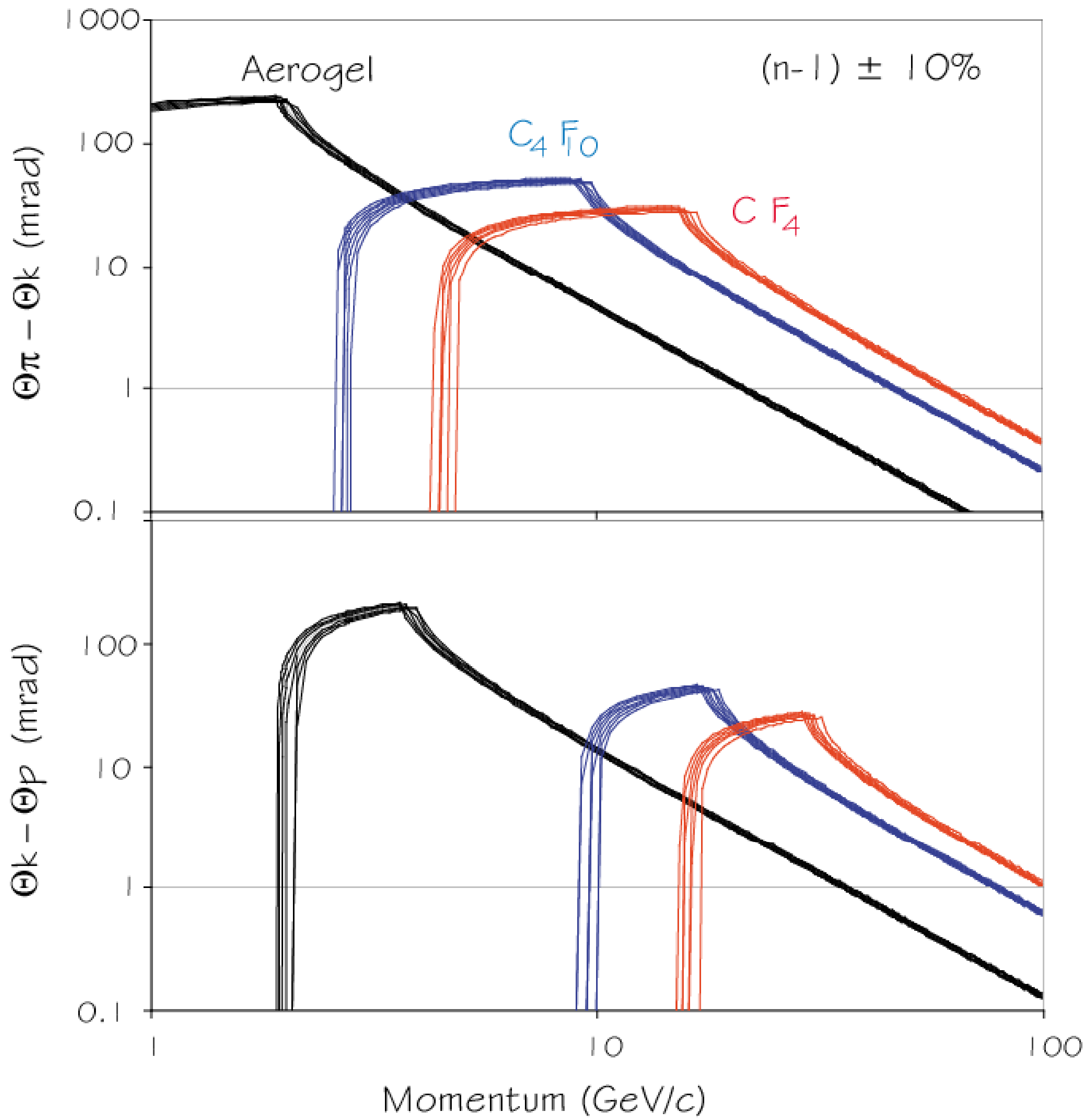
300 mrad horizontal
250 mrad vertical





Choice of
radiator media:

Positive
K-identification

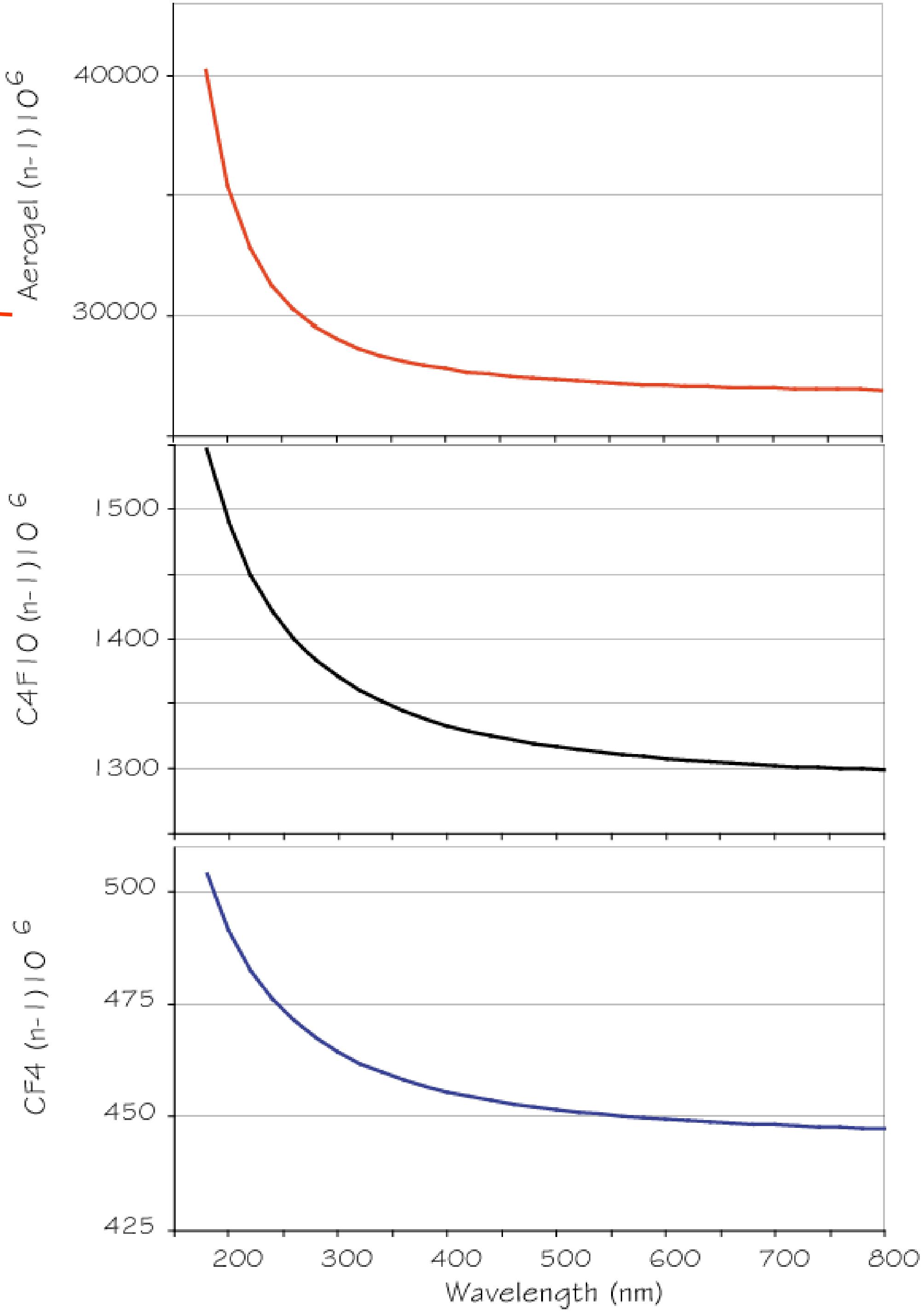


Choice of photon detector and detection resolution.

1\.
Quantum efficiency > 0
for λ>200 nm

2\.
Chromatic error (in C_4F_{10})
$\sigma_\Theta \cong 0.8$ mrad
$\Rightarrow$ pixel size:
$2.5 \times 2.5\ \mathrm{mm}^2$

3\.
The Pixel Hybrid Photon Detector

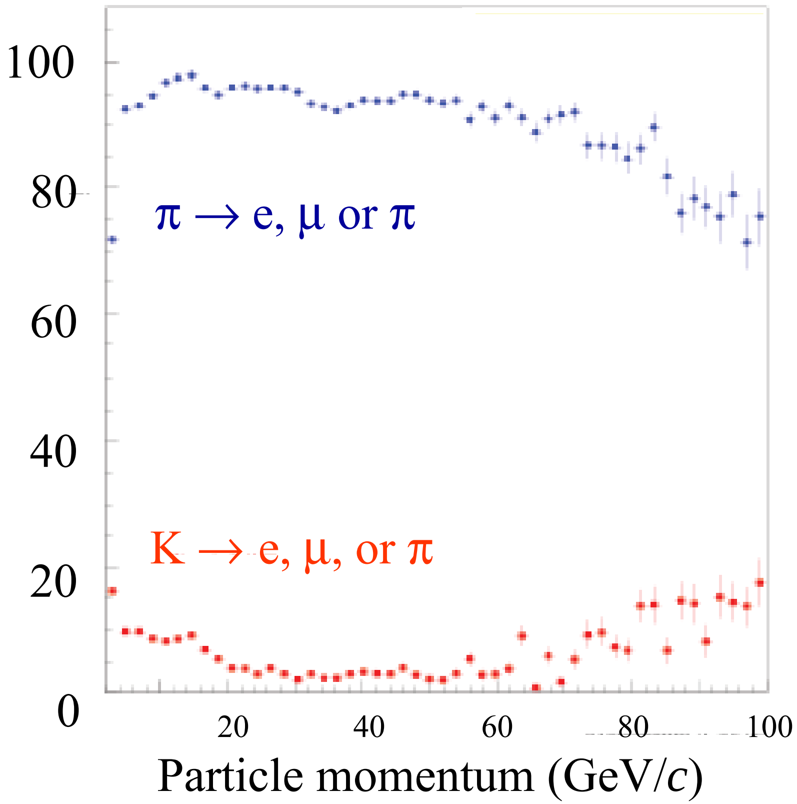


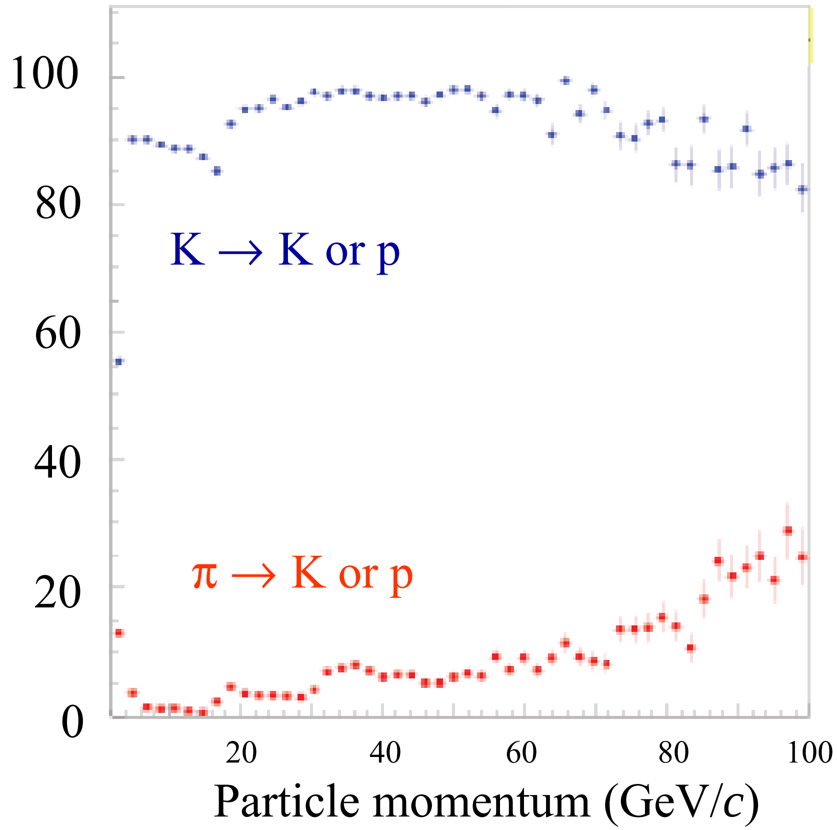
With these choices of parameters, we will expect the following

RICH performance

(full detector realistic simulation)

Efficiency (in %) of pion and kaon identification
and
Probability (in %) of misidentifying pion and kaon





The Radiators

Aerogel

Parameters

n=1.030 (± 0.001) at λ=400 nm

thickness 5 cm, transversal size 20x20 cm^2

Clarity < 0.0064 μm^4 cm^{-1}

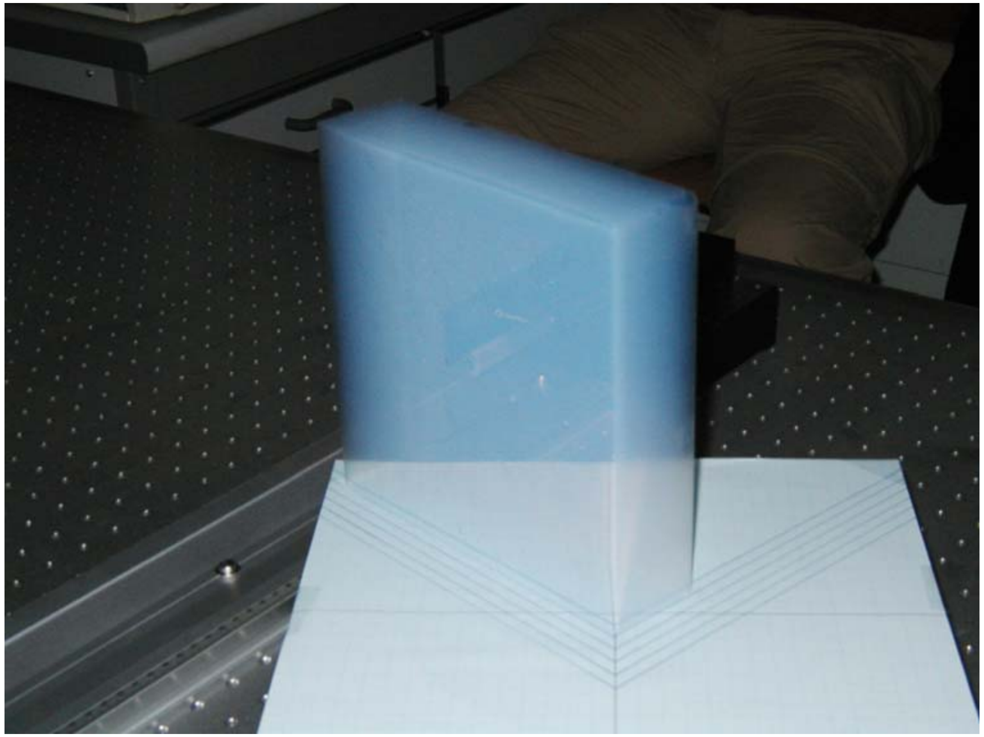
$$T = A \cdot e^{-C\frac{t}{\lambda^4}}$$

C: Clarity in units of $\frac{\mu m^4}{cm}$

Boreskov Institute of Catalysis (Novosibirsk) successfully produced in 2004

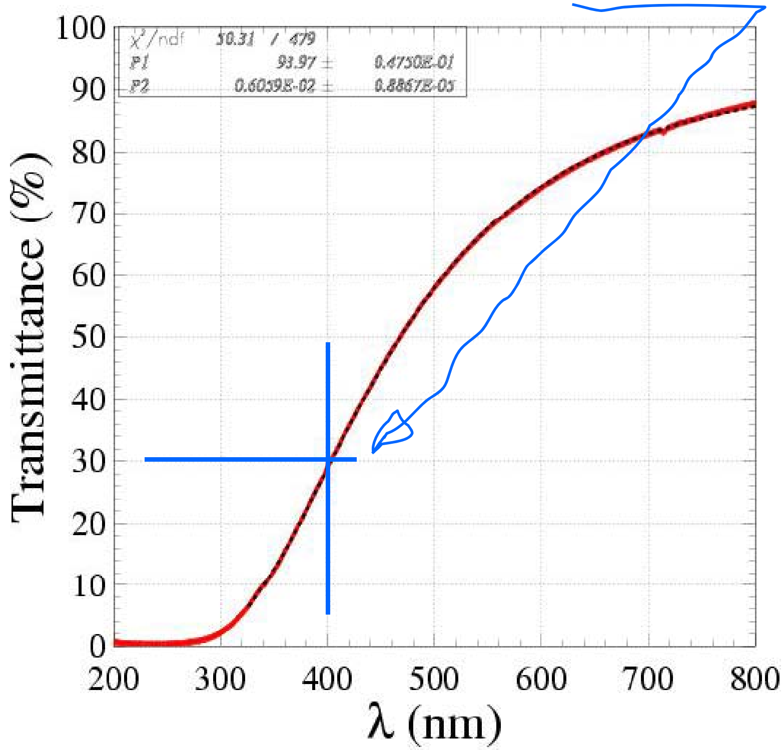
$20.0 \times 20.0 \times 5.1$ cm^3

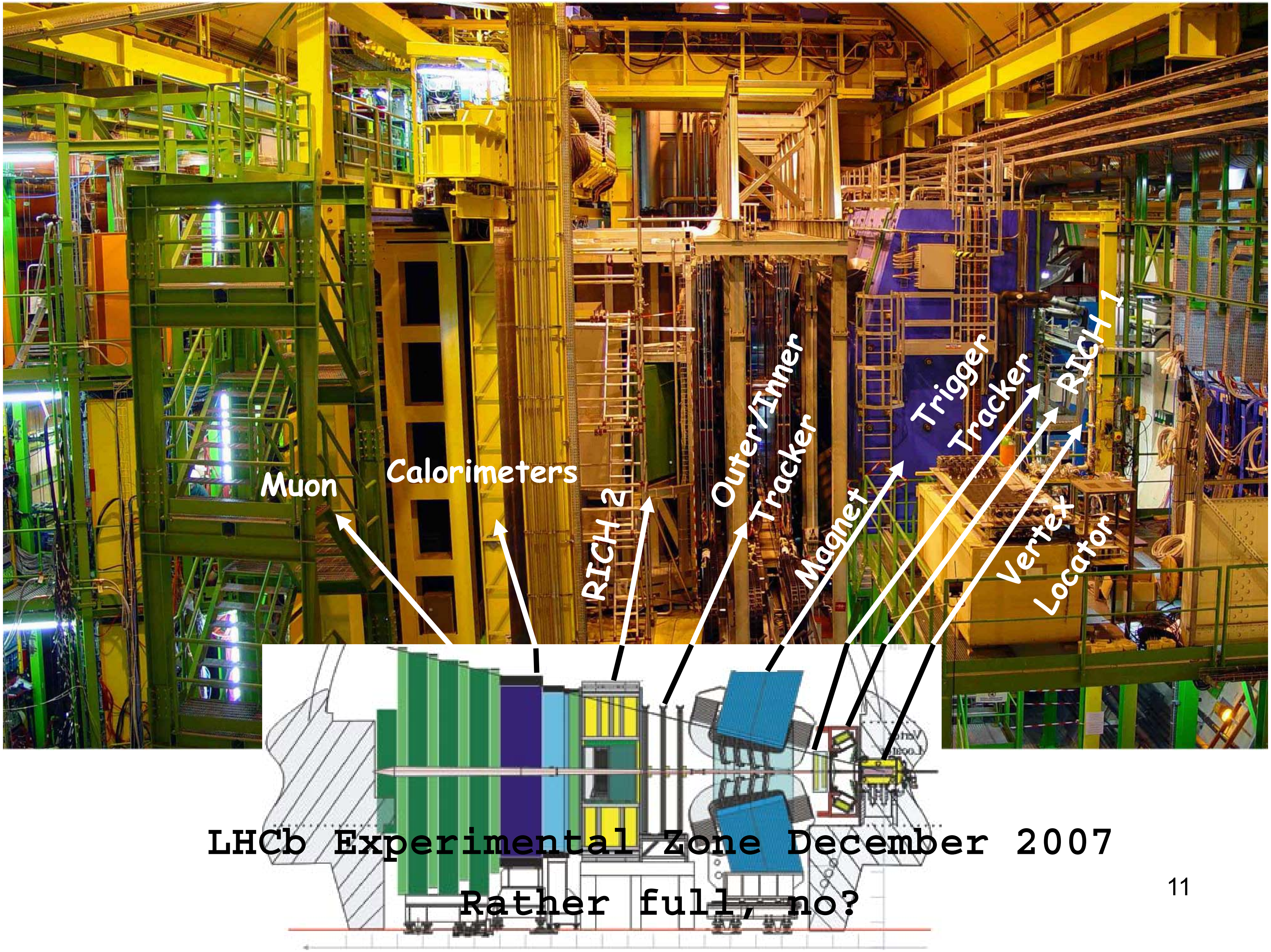
n=1.029–1.031 at λ=400 nm



C=0.0060

T≅30% at 400 nm



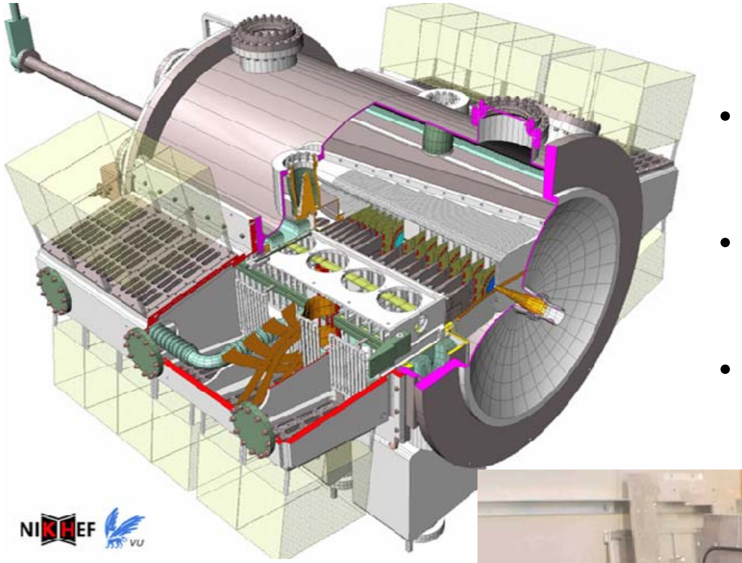


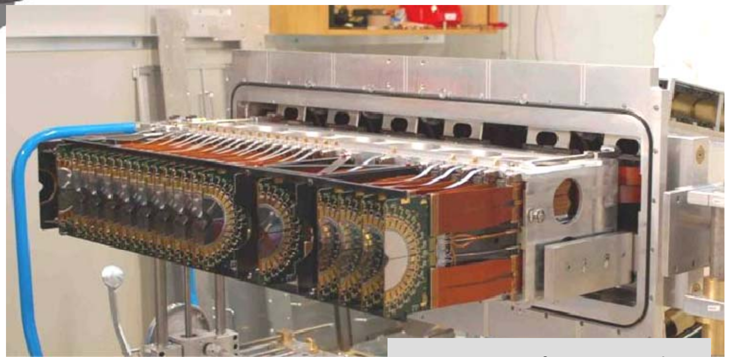
LHCb Experimental Zone December 2007

Rather full, no?

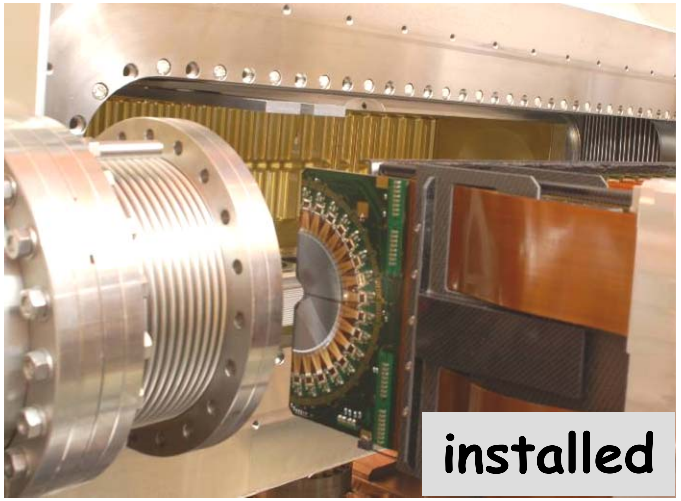
VErtex LOcator ≡ VELO

- 21 stations of Si wafer pairs with r and ϕ strip readout
- Split in two halves to allow retraction from beam line
- Both detector halves now completed and installed in the pit

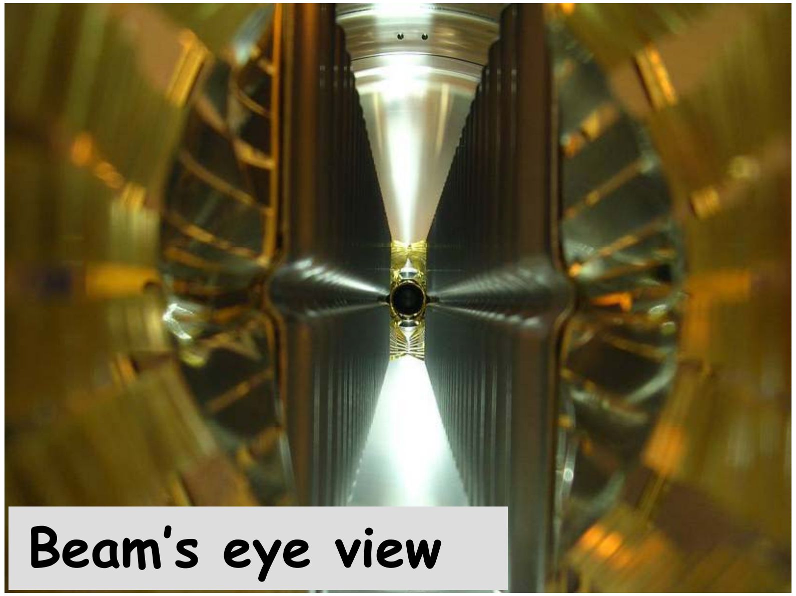




Completed,



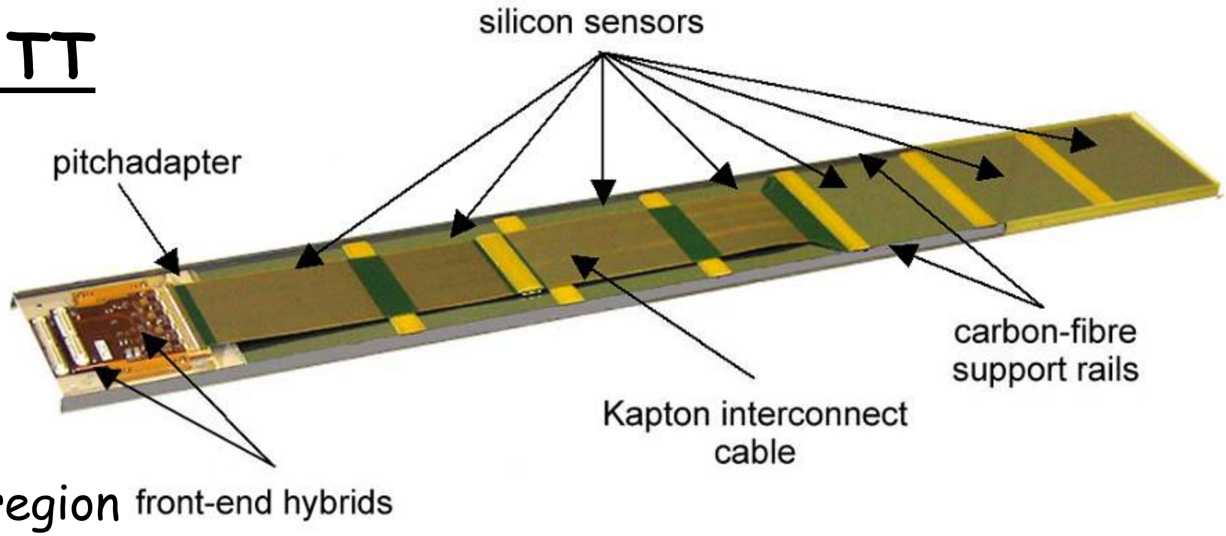
installed



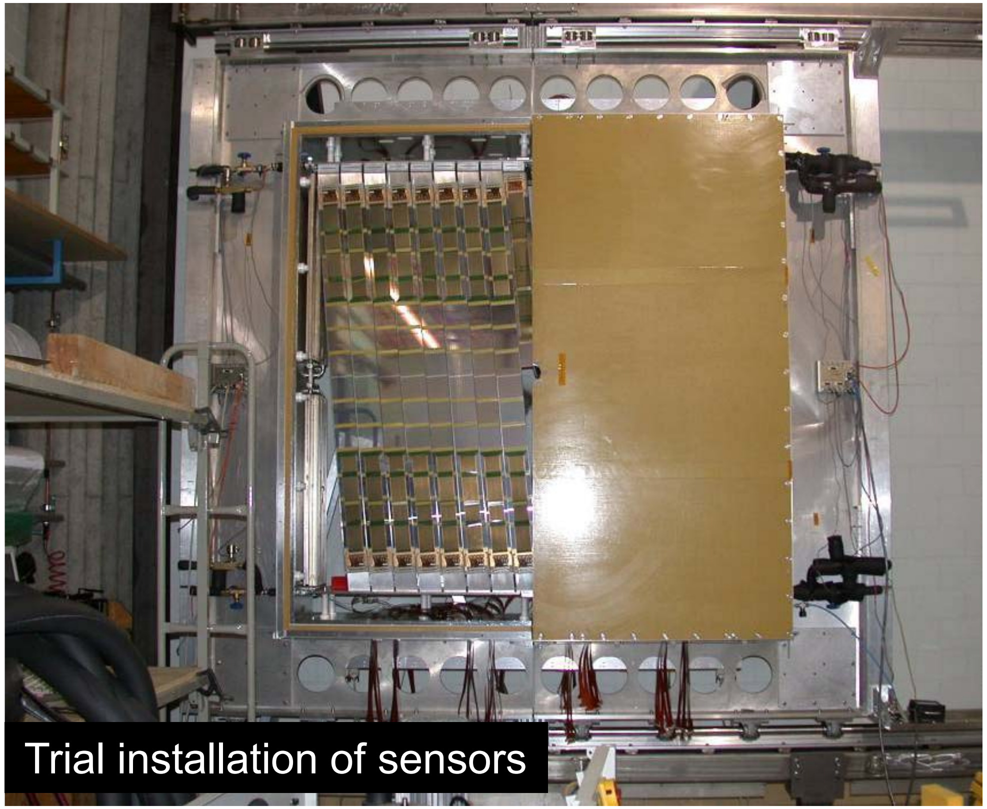
Beam's eye view

and data transferred to the counting room.

Trigger Tracker ≡ TT



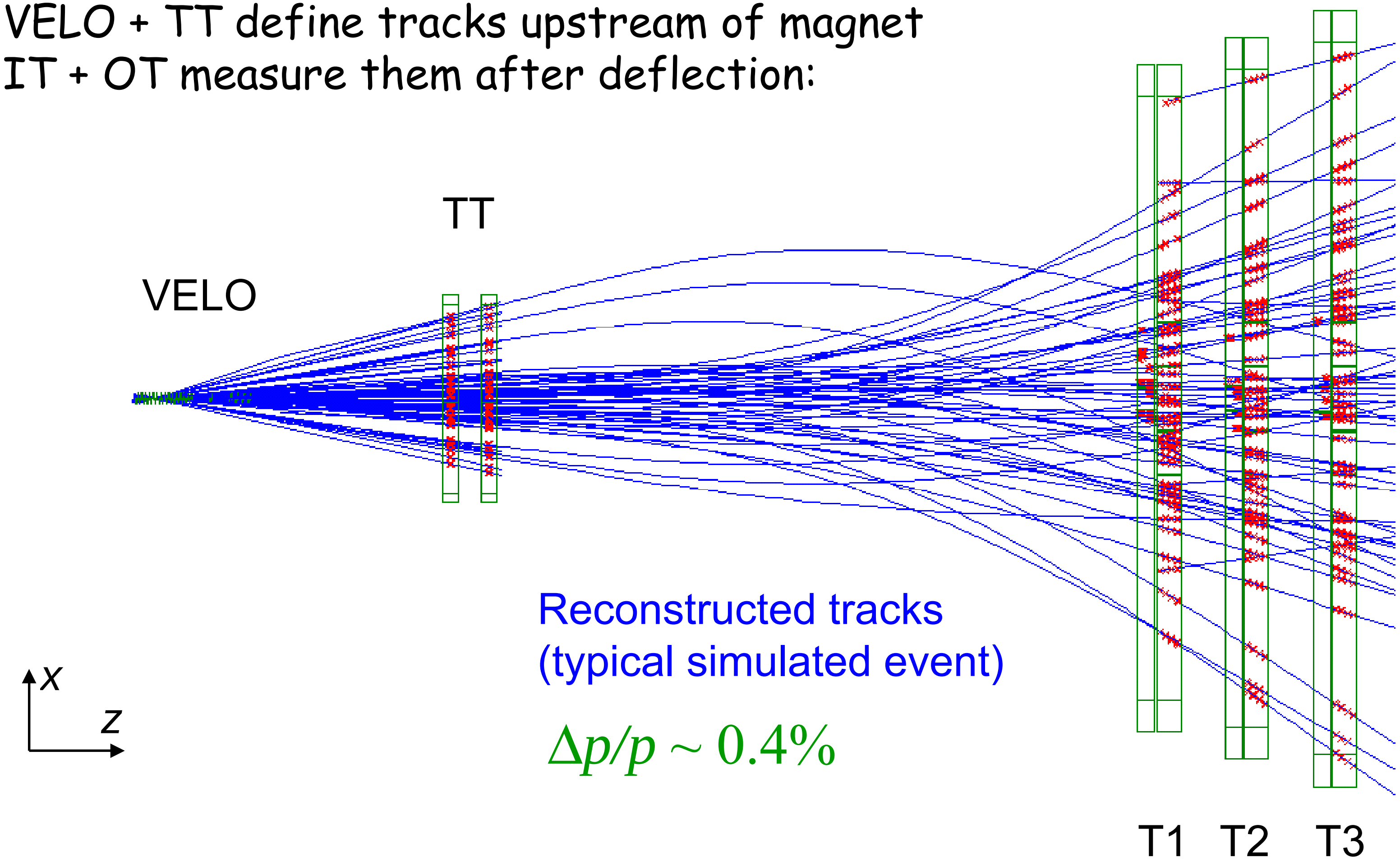
- VELO is in ~ field-free region → straight tracks
- TT is a silicon micro strip detector placed in fringe field of magnet to give first p_T measurement for the trigger
- Sensor ladders all completed
  Excellent quality < 0.1% bad strips
  Detector boxes + infrastructure installed in pit
- Installation of sensors into detector boxes underway, will be complete end-2007



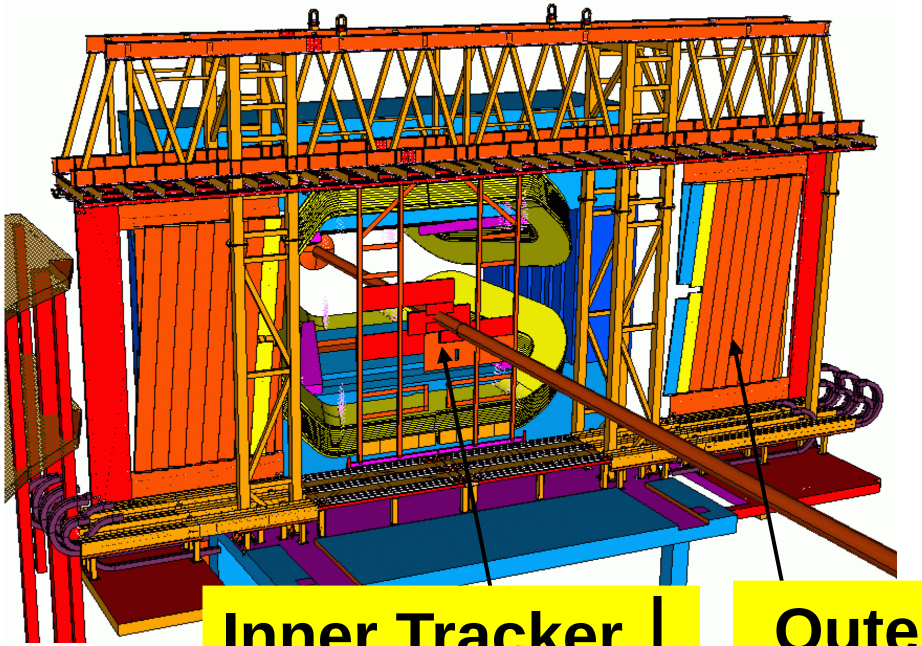
Trial installation of sensors

Tracking Stations

- VELO + TT define tracks upstream of magnet
  IT + OT measure them after deflection:



$\Delta p/p \sim 0.4\%$



Inner Tracker

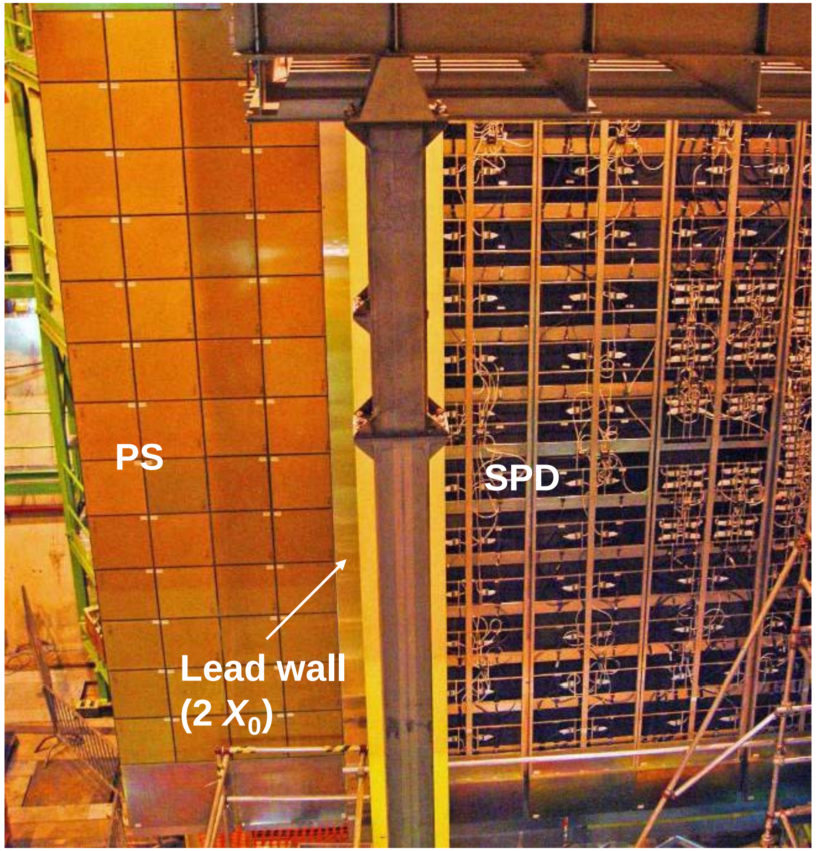
Outer Tracker

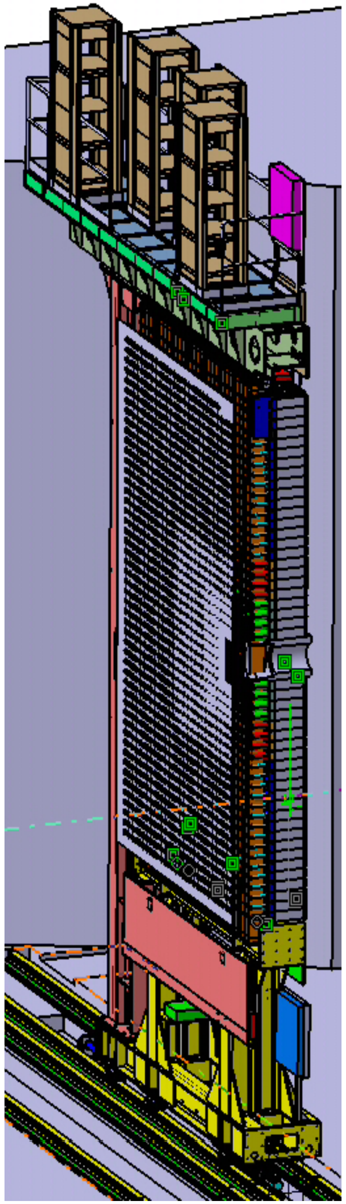
IT ladder production complete
Support system + infrastructure ready
Mounting of silicon detectors in their boxes in progress

Drift chambers: straw tubes
5 mm diameter, 5 m length
Detector installation complete
Electronics installation underway

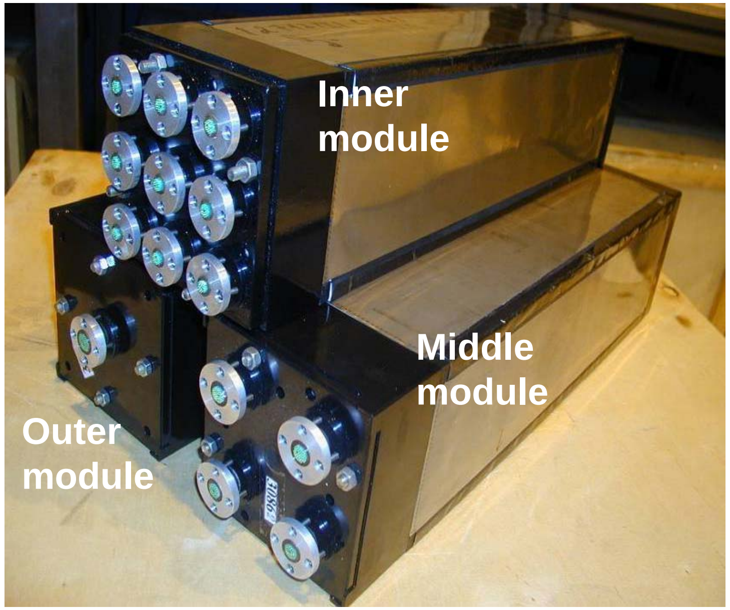
Calorimeter system

- Composed of Scintillating Pad Detector/PreShower + ECAL + HCAL
- First priority: Level-0 trigger

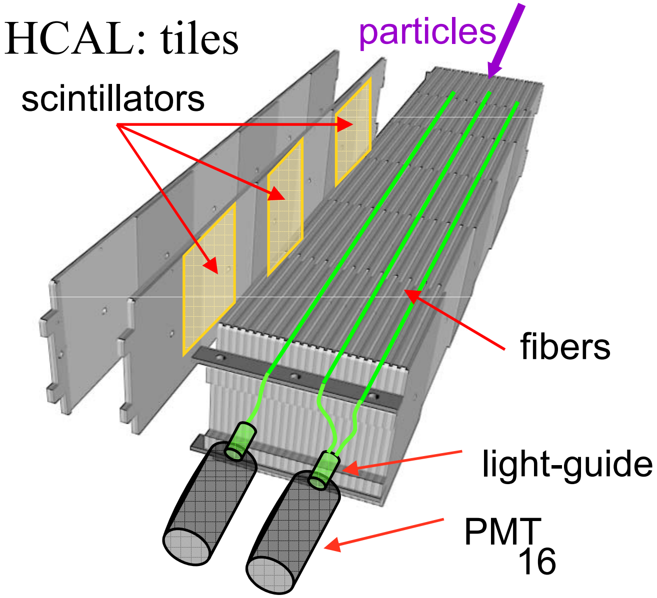




ECAL: Pb/sci.fi. Shashlik (25 X_0)



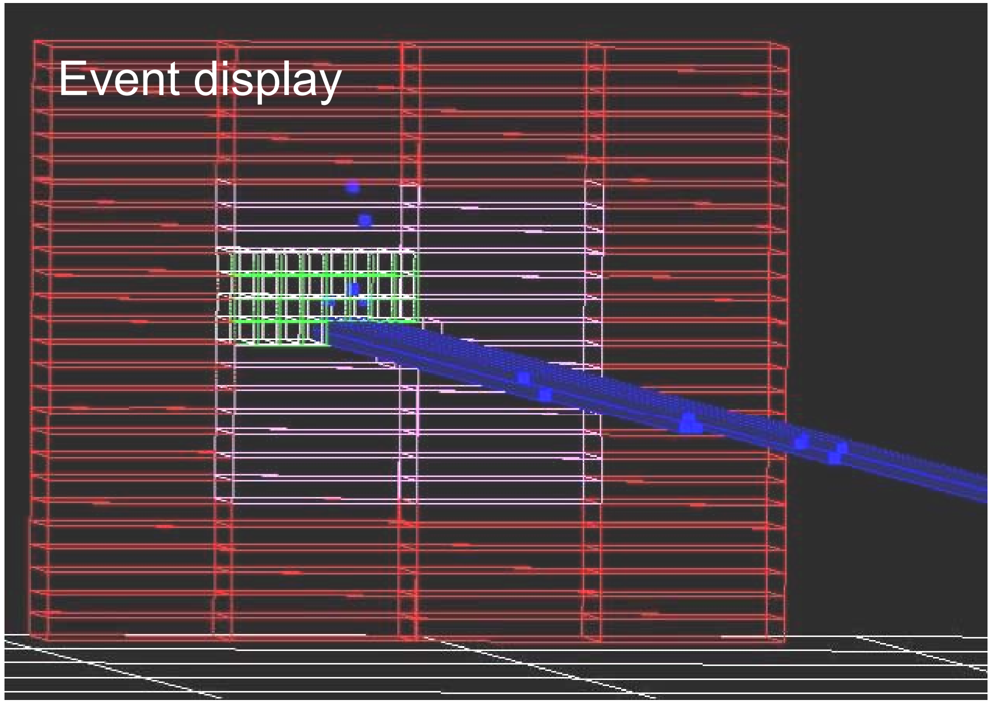
HCAL: tiles



Calorimeter system

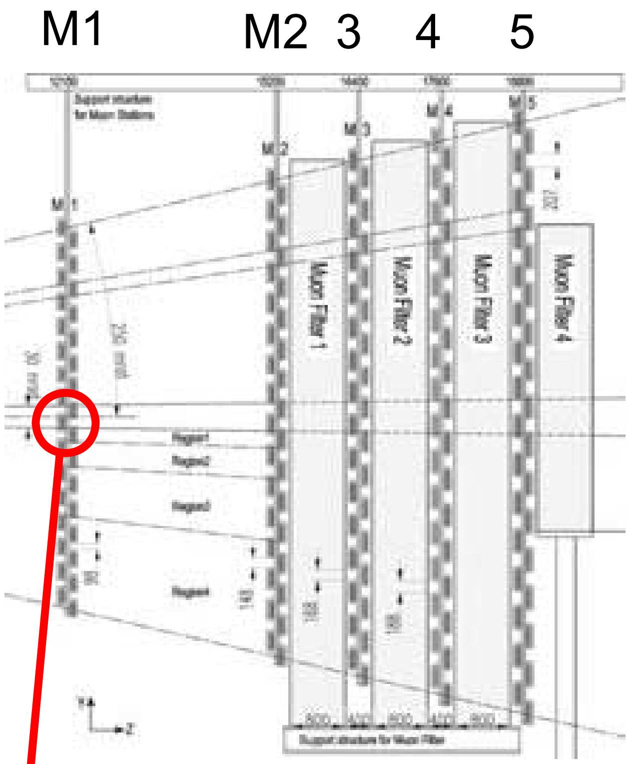
- Complete calorimeter system has been installed and cabled; Commissioning now in progress
- Cosmics not very well adapted for use in LHCb (few are horizontal 100 m underground) Nevertheless, cosmic triggers being set up for calorimeter commissioning
- In the mean time, system exercised using LED pulses: signal display in HCAL after reconstruction via full chain

HCAL

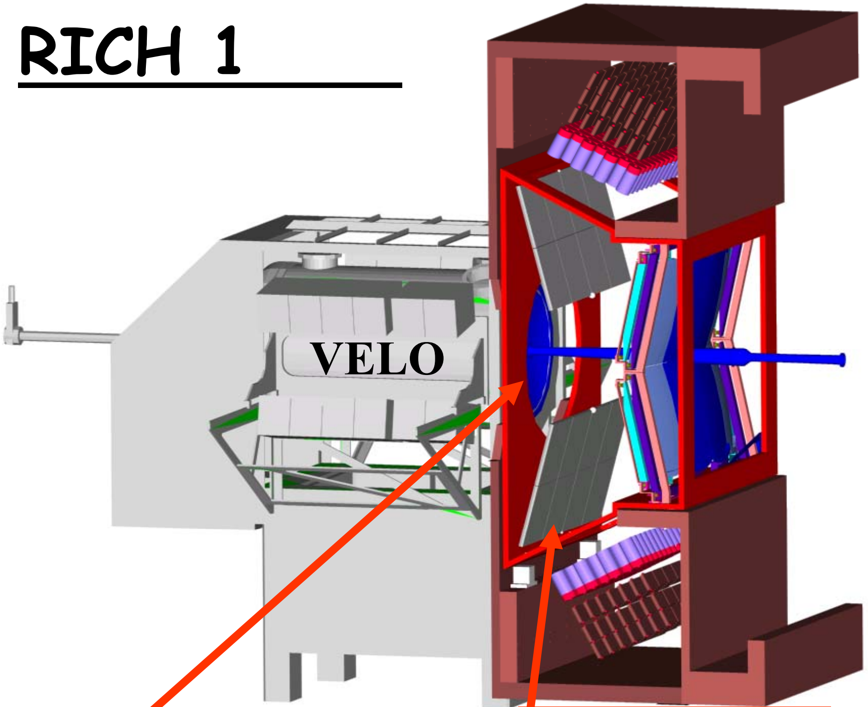


Muon detector

- All MWPCs for Muon detector stations M2–5 installed
  except for 20 (out of 1084, ~2%) that need to be replaced
- All MWPCs and 3-GEMs for M1 produced

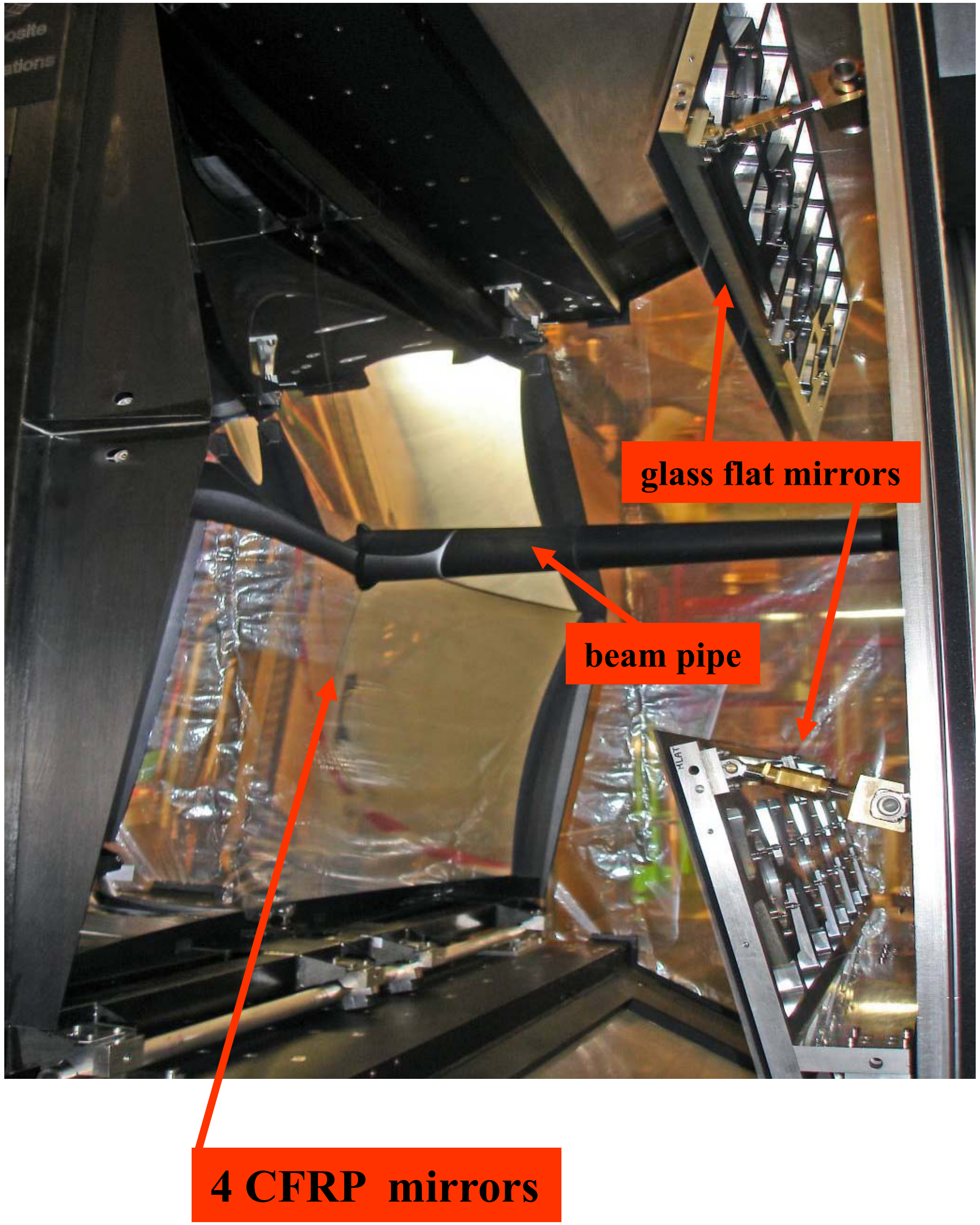


RICH 1

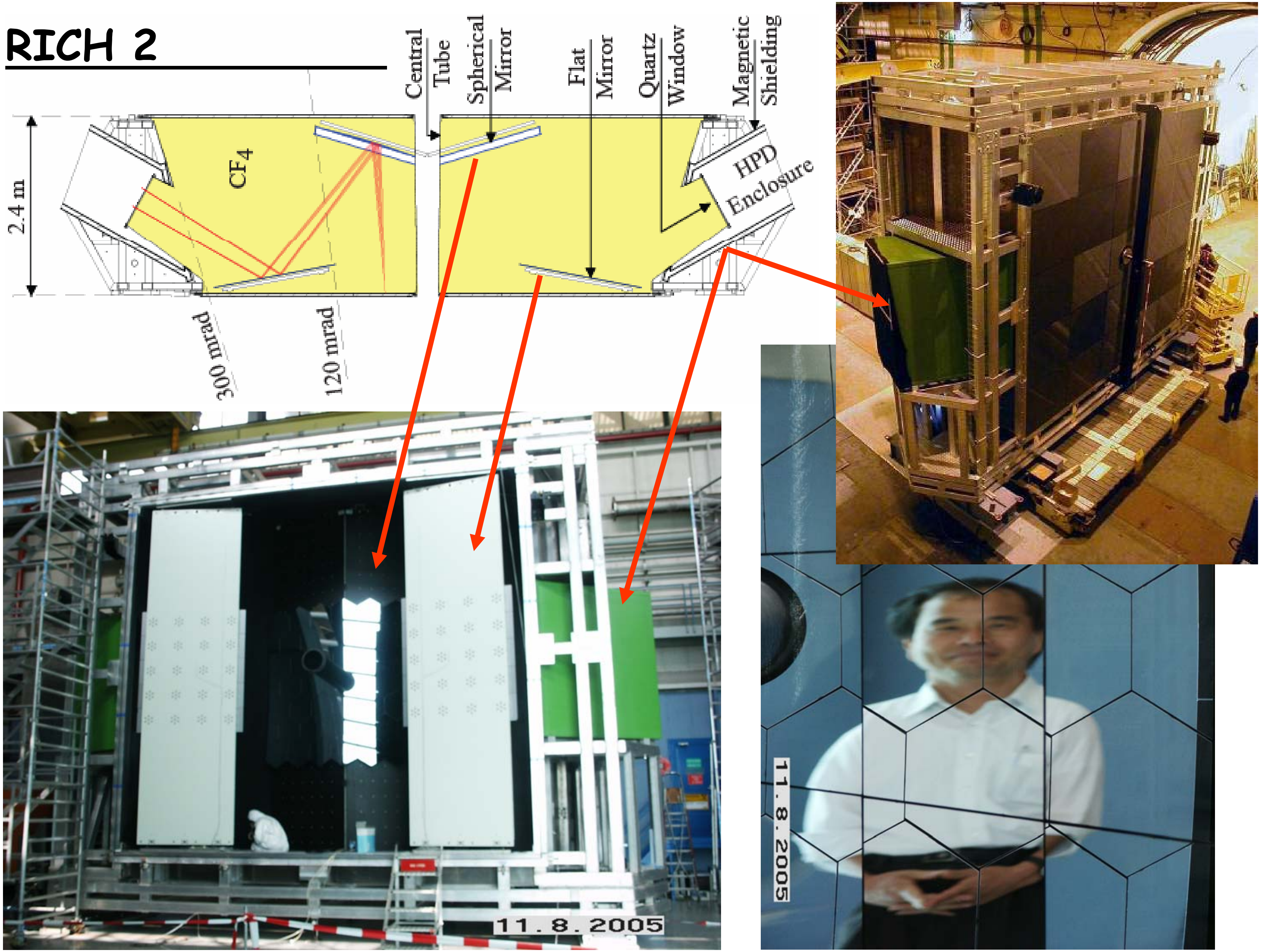

VELO


VELO exit window
Aerogel


glass flat mirrors


glass flat mirrors
beam pipe
4 CFRP mirrors

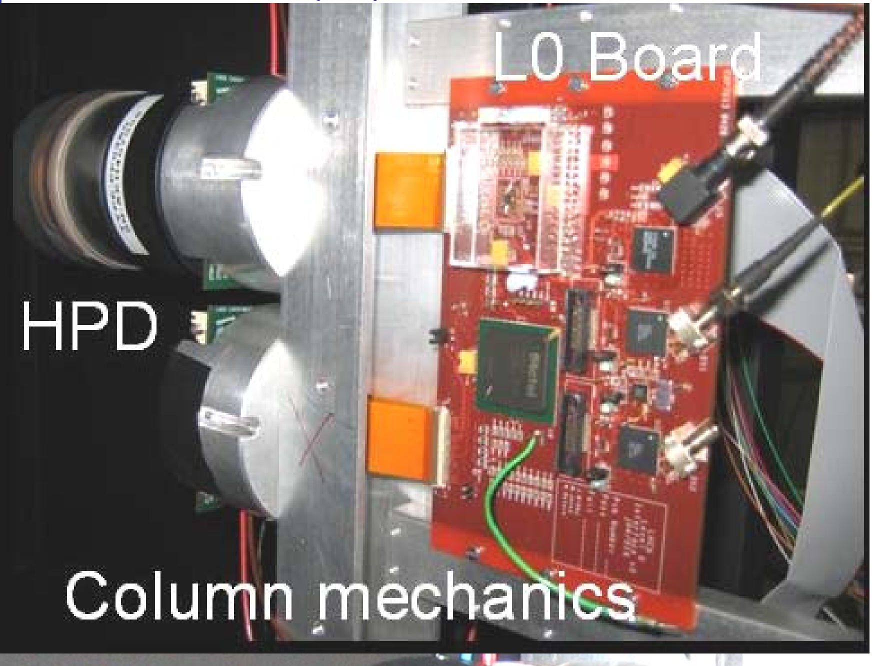
RICH 2

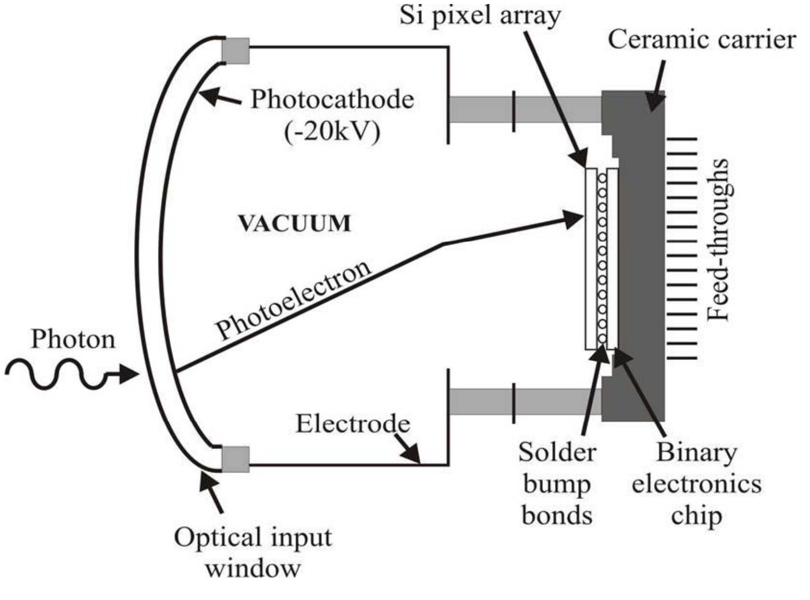


Central Tube
Spherical Mirror
Flat Mirror
Quartz Window
Magnetic Shielding
HPD Enclosure
CF_4
2.4 m
300 mrad
120 mrad
11.8.2005
11.8.2005

Pixel Hybrid Photon Detectors

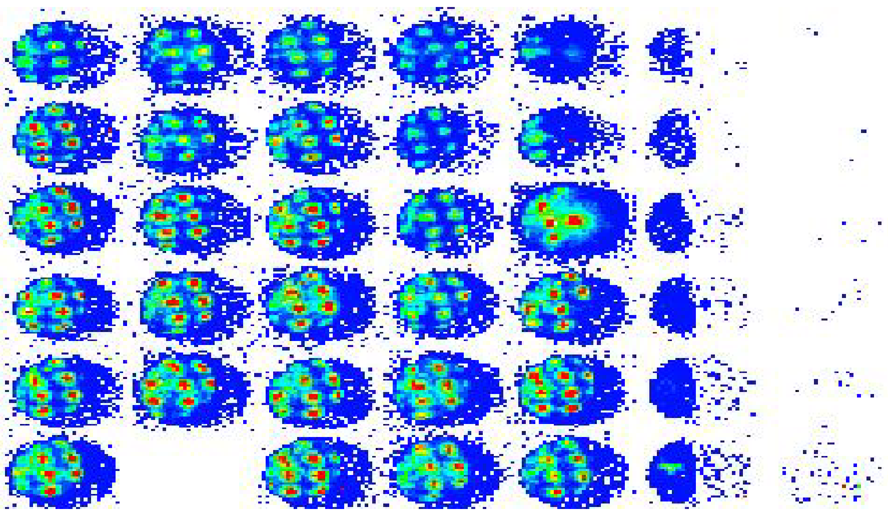
- Pixel HPDs developed in collaboration with industry.
- Combines vacuum technology with silicon pixel readout (Quartz window with S20 photocathode).
- 484 HPDs occupy a total area of 3.3m^2 with 2.5 x 2.5 mm granularity
- Factor 5 demagnification @ 20kV.
- Operates at the LHC bunch crossing frequency (40MHz)
- Encapsulated 32x32 pixel silicon sensor bump-bonded binary readout chip
- 200-600 nm wavelength coverage



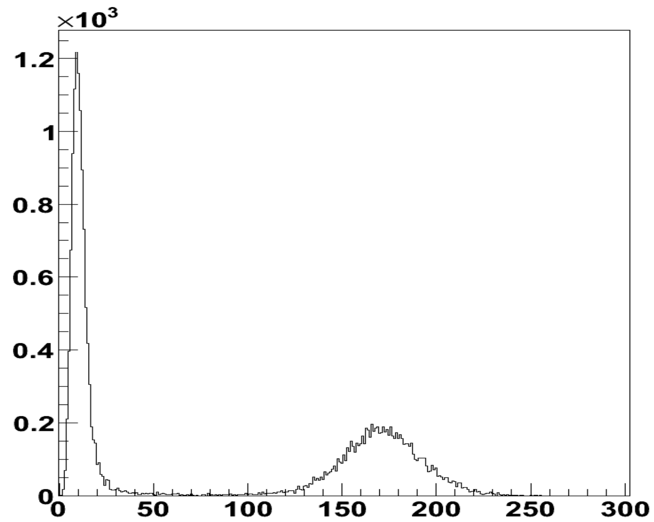


RICH-2 commissioning

- RICH-2 is now fully equipped with 288 HPDs
  - 10 cannot take 20 kV (~3%), to be replaced
- Commissioning is in progress
  Pattern of light spots projected onto the HPD plane
  (will be used for calibration of magnetic distortions)



Note: this layout is a feature of the display—
tubes are hexagonally close-packed in reality

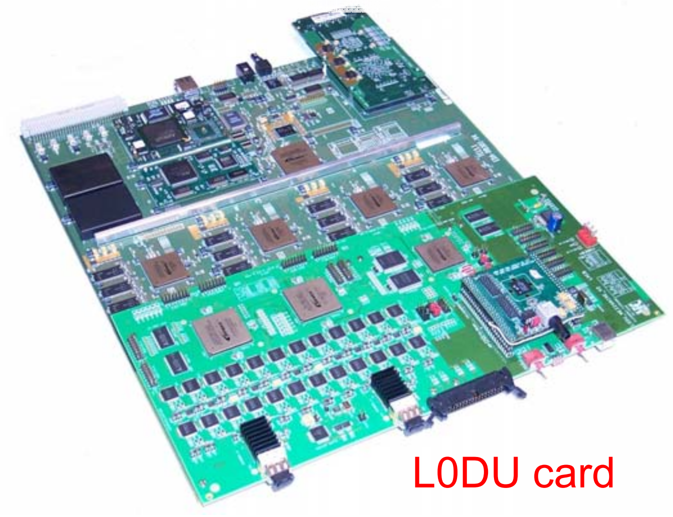


Number of photoelectrons

Trigger

- Trigger has two levels:
  1. Level-0 (hardware, 1 MHz output)
     Full detector then read out into farm of commercial CPUs
  2. HLT (software, 2 kHz output → storage)
- Level-0 uses information from:
  - *Pile-up system*
    Dedicated silicon sensors in VELO tank
    fast detection of multiple pp vertices
  - *Calorimeter trigger*
    high-p_T clusters from e, g, h
  - *Muon trigger*
    high-p_T (> ~1 GeV) μ candidates

L0 Decision Unit
→ overall decision

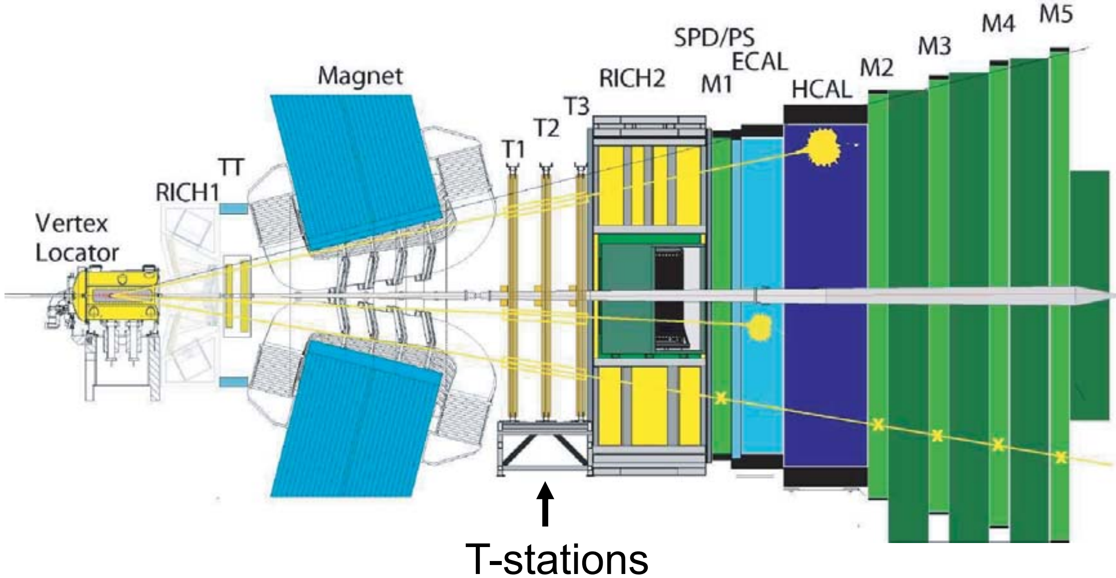


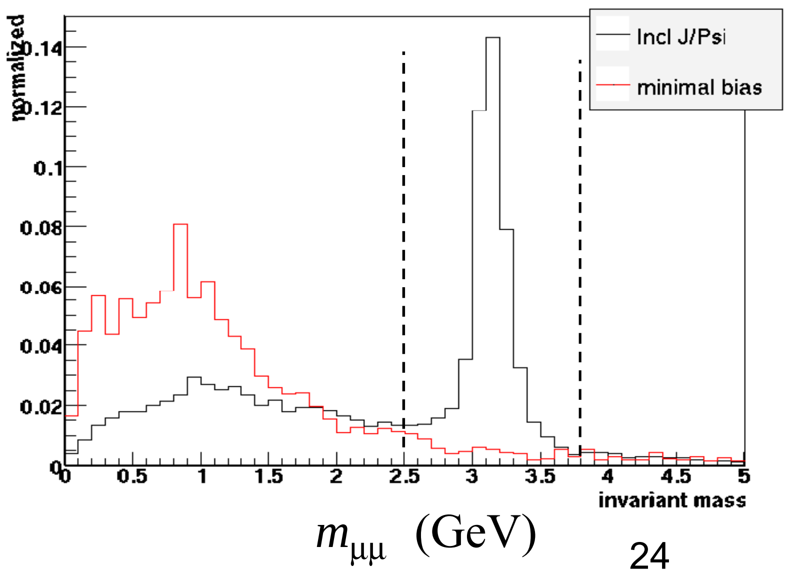
L0DU card

- Production of all Level-0 electronics boards now complete
  - Commissioning in progress

High Level Trigger

- First release of complete HLT framework last month
  Suitable for benchmarking CPUs to be purchased for the farm
- Implements strategy of "trigger confirmation"
  HLT focuses on confirming objects that triggered Level-0
  by matching them to tracks in VELO or T-stations
  - *e.g.* confirm L0 muons in T stations, extrapolate to origin, calculate mass $\rightarrow$ online J/ψ (takes ~ 1 ms)





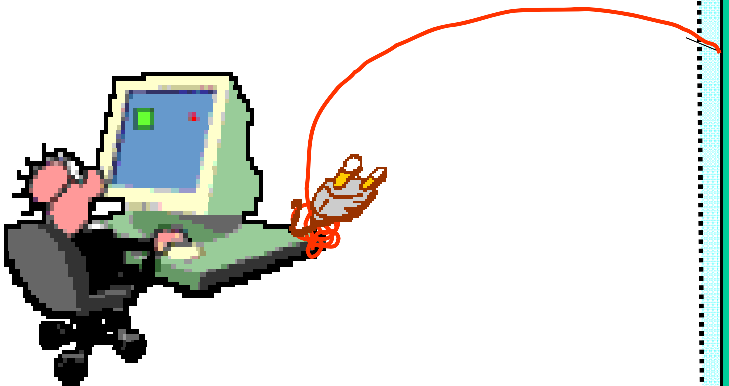
Online system

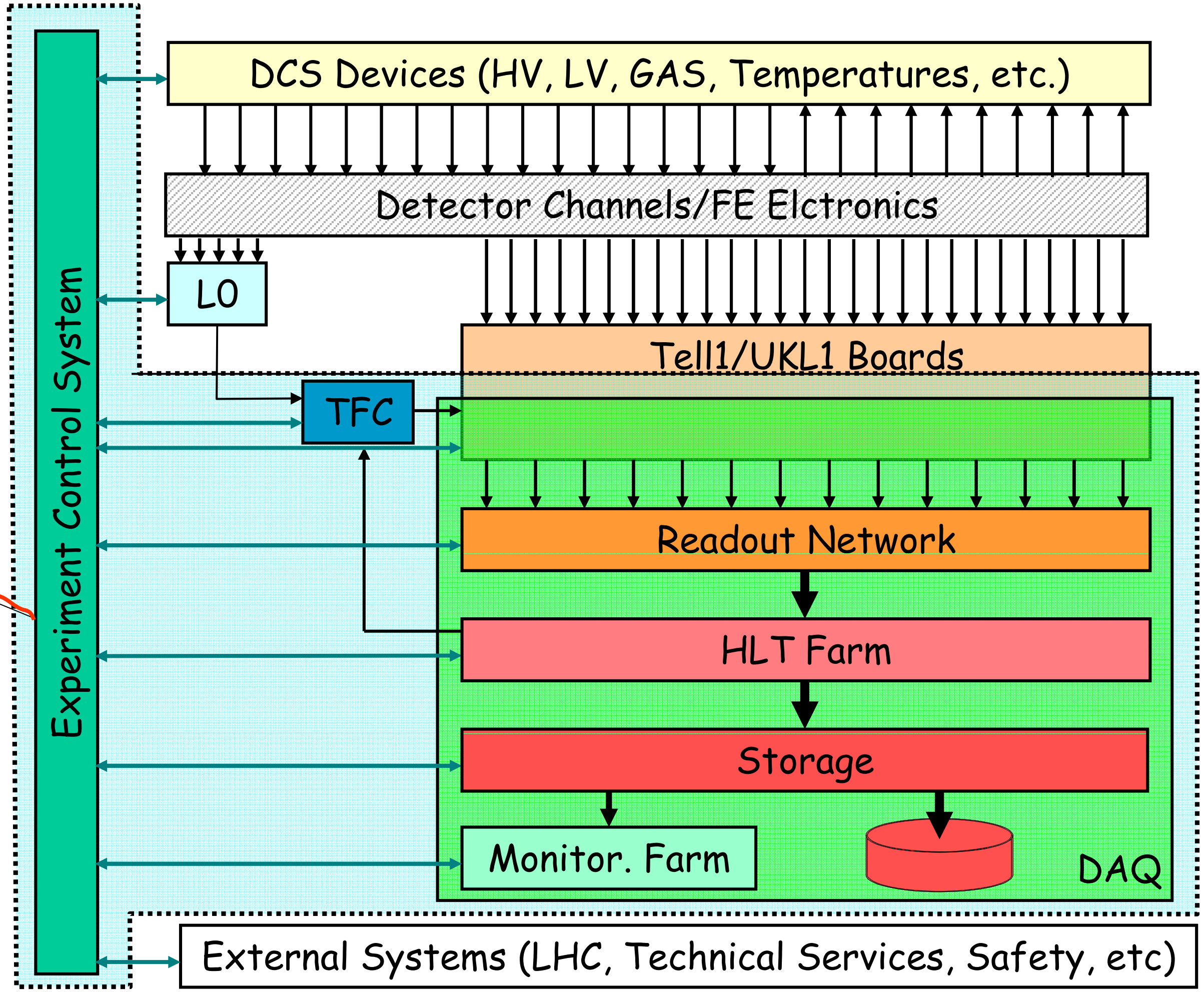
- Three major subsystems:

TFC: Timing and Fast Control

DAQ: Data Acquisition

ECS: Experiment Control System

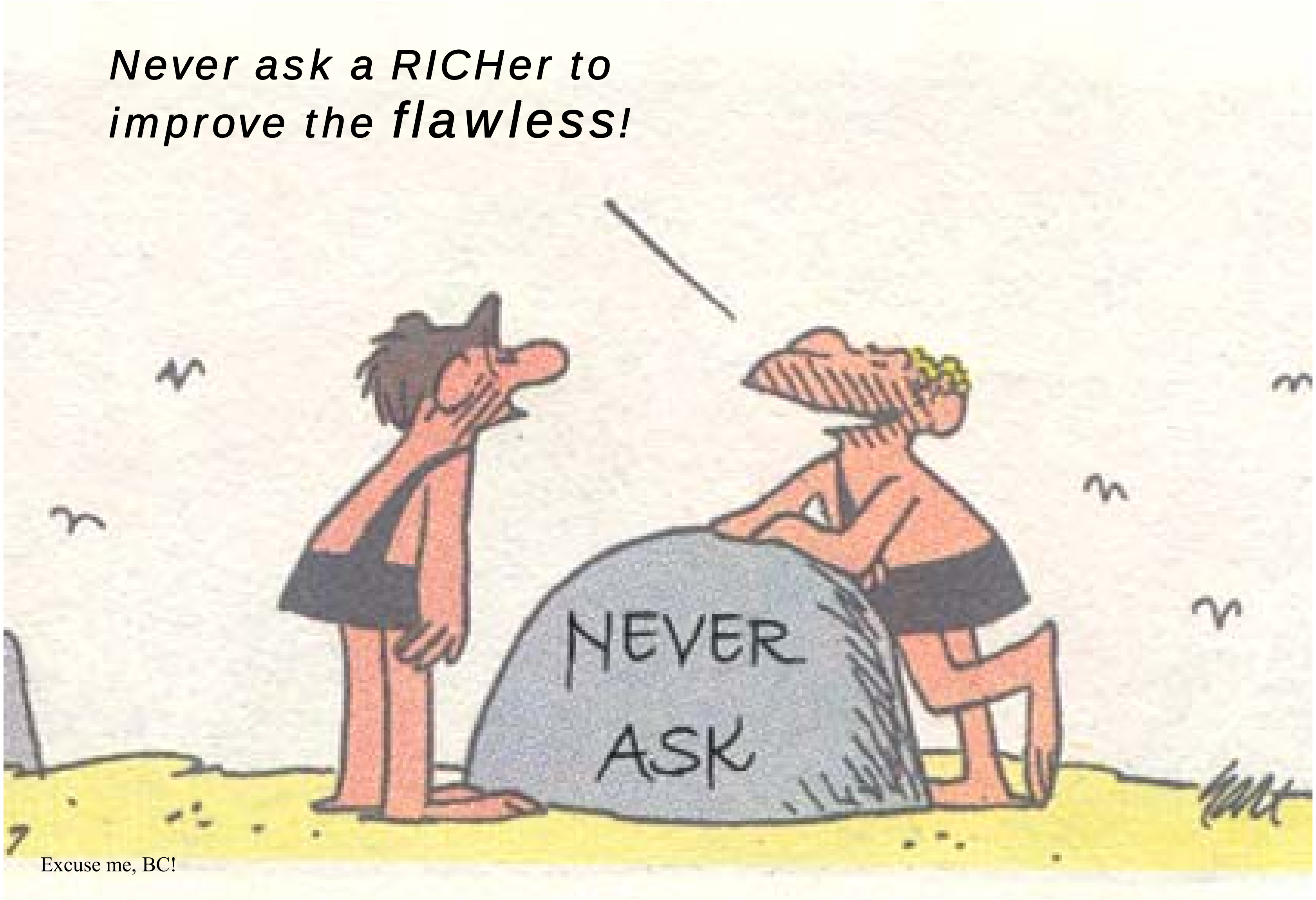




- In LHCb the ECS is used to control the DAQ, as well as for monitoring and control of the detectors
  - "One click" starting of a run recently achieved (reading RICH-2)

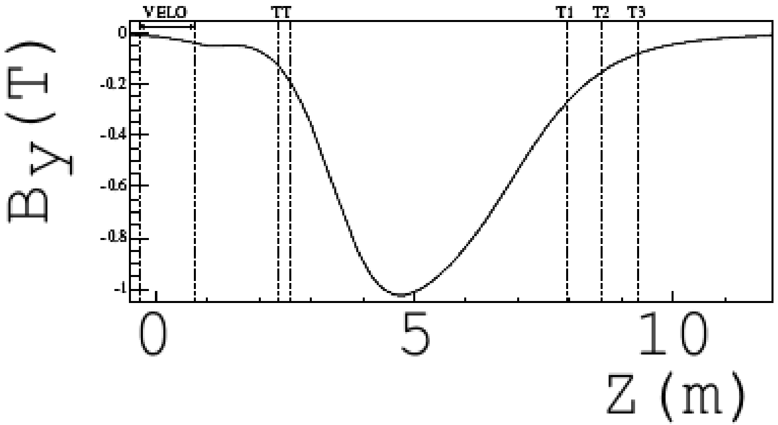
RICH Upgrade Plans.

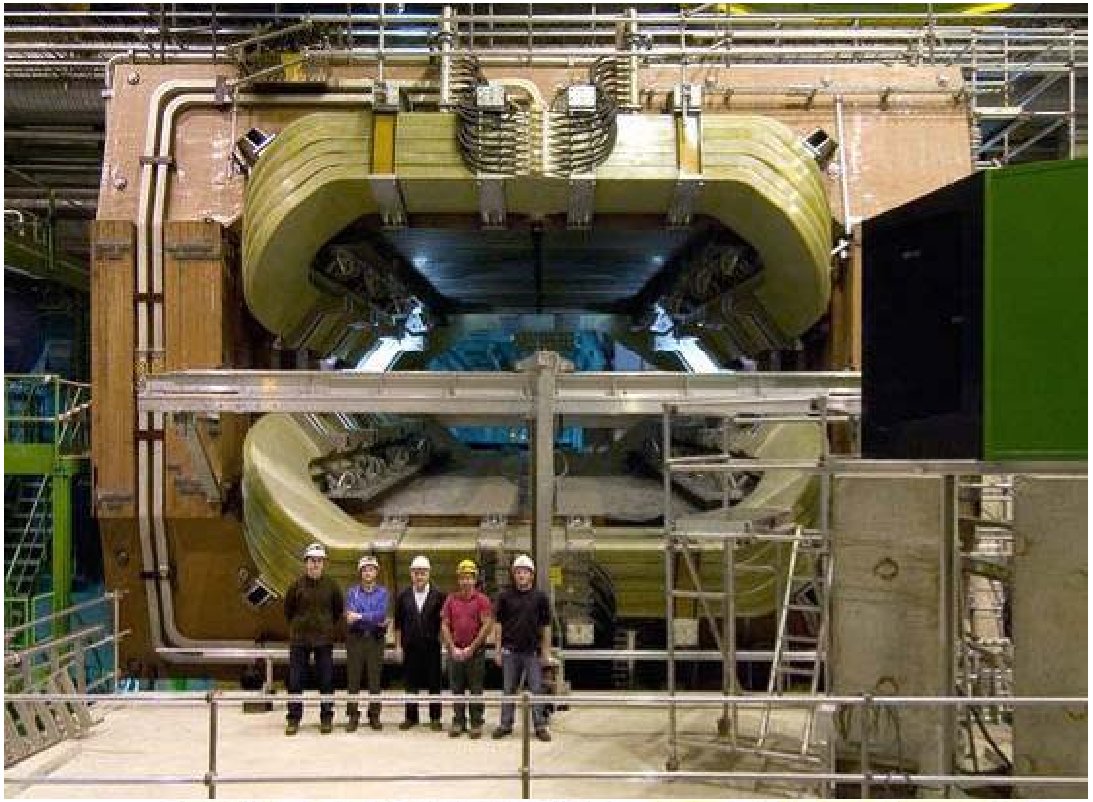
a personal view.



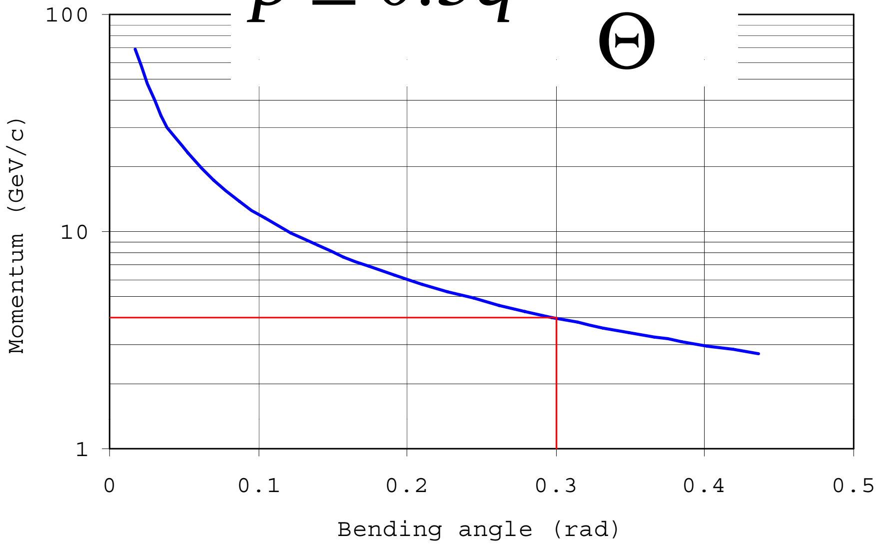
The Spectrometer Magnet

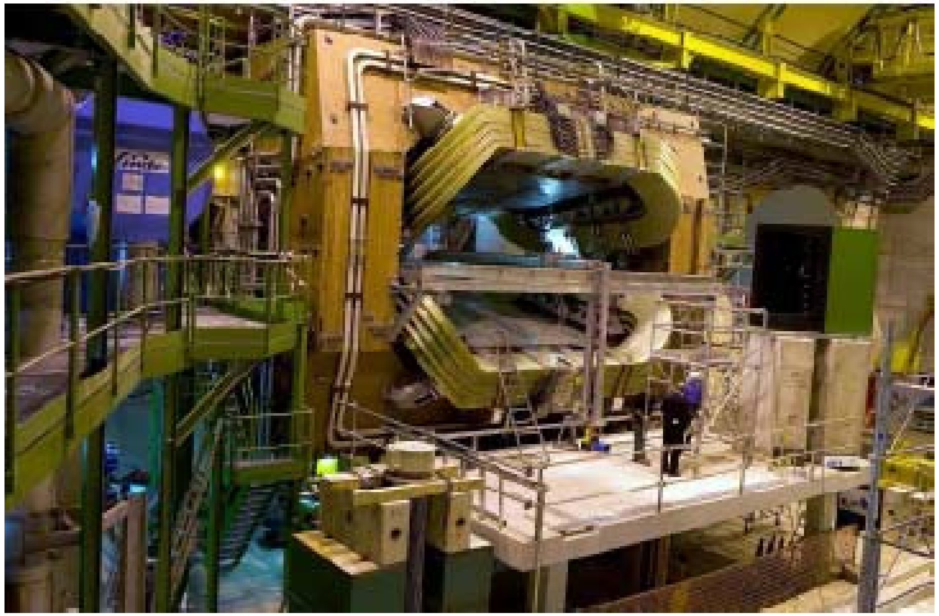
$\int B\,dl = 4$ Tm (10 m track length)





$$p \cong 0.3q \frac{\int B_{\perp} dl}{\Theta}$$





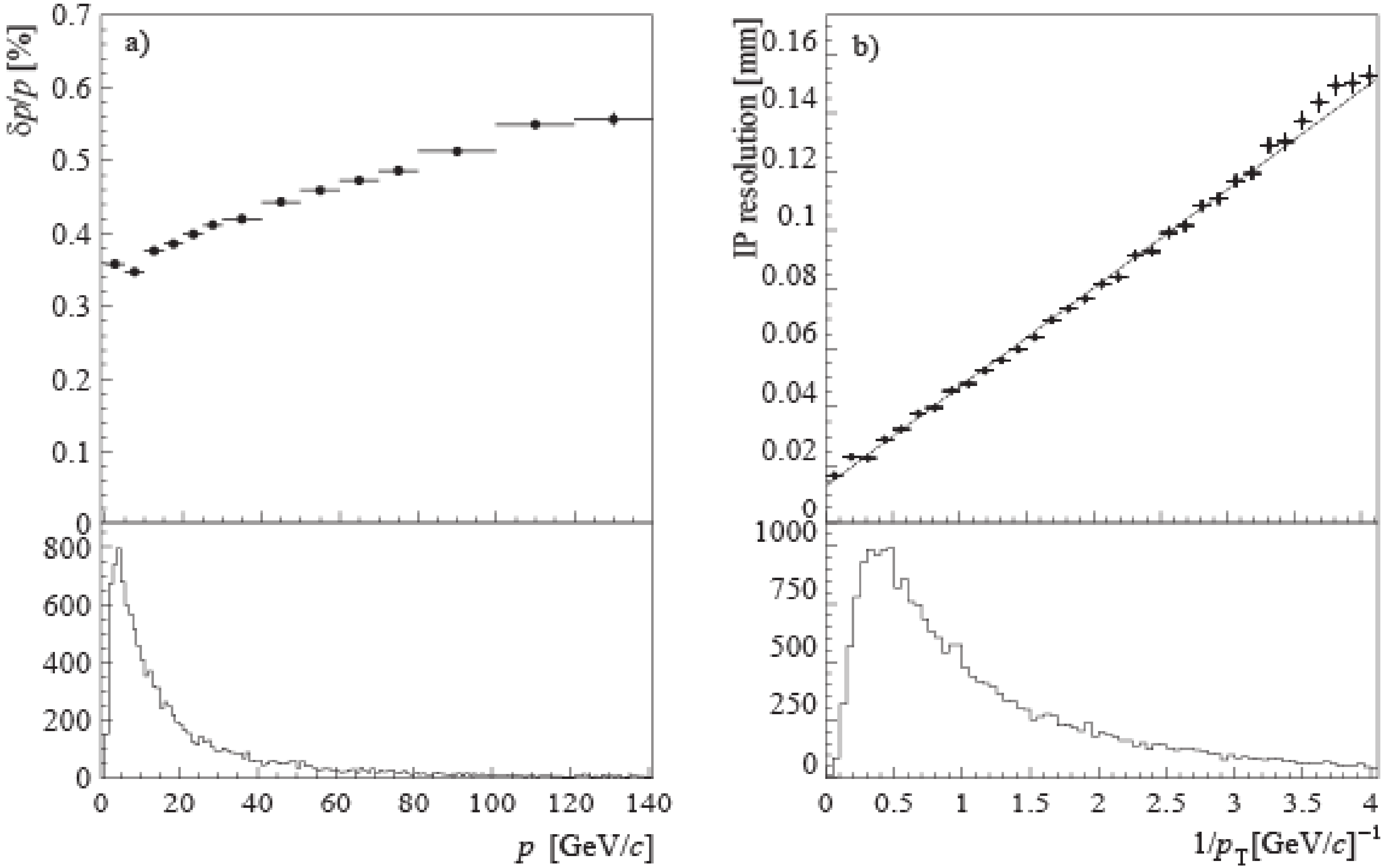
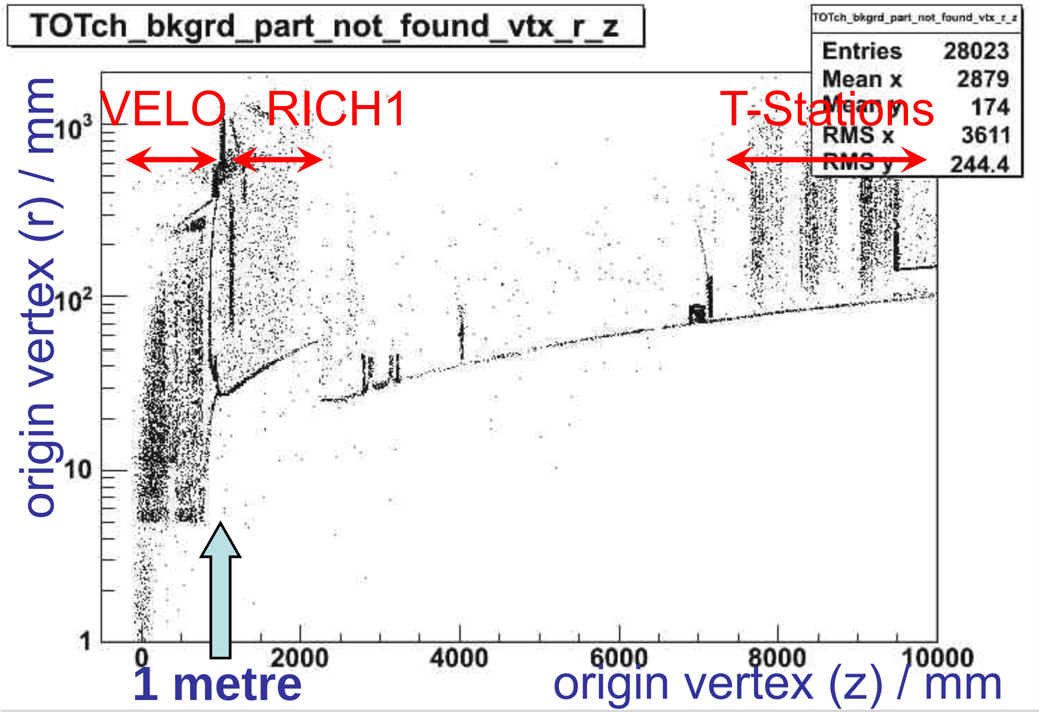
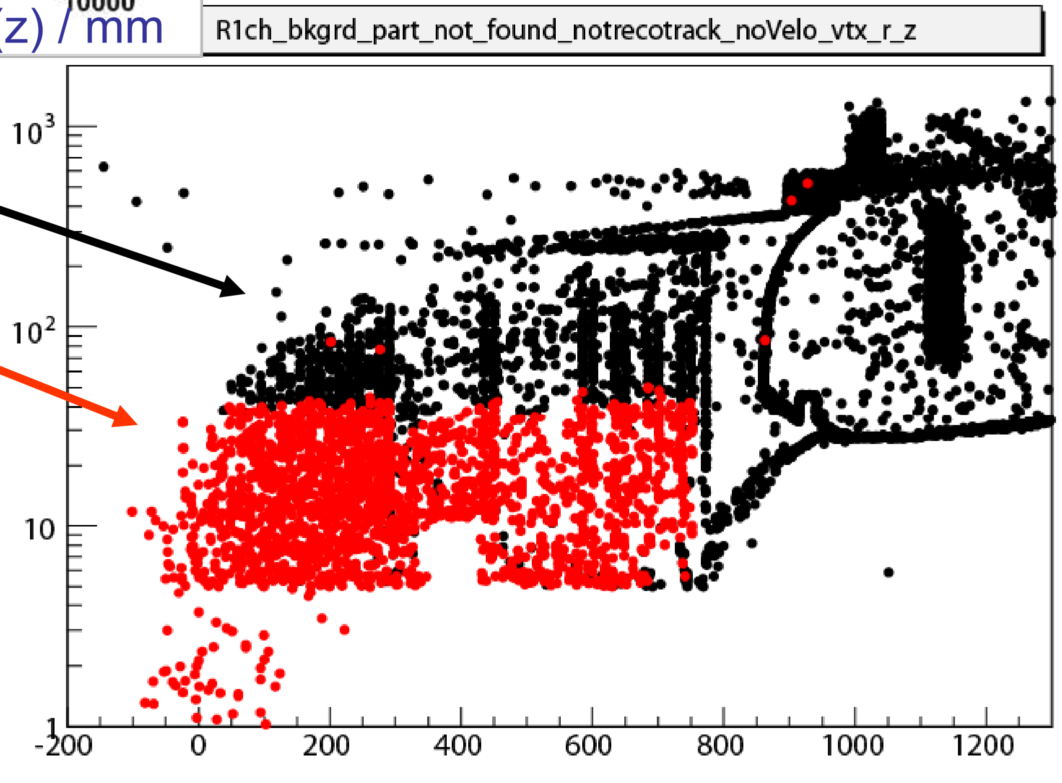


Figure 7.5: Resolution on the reconstructed track parameters at the production vertex of the track: (a) momentum resolution as a function of track momentum, (b) impact parameter resolution as a function of $1/p_T$. For comparison, the momentum and transverse-momentum spectra of B-decay particles are shown in the lower part of the plots.

RICH Group Meeting,
5th December 2007
Mitesh Patel (CERN)

Origin of bkgrd





Black – have 0 hits in VELO

Red – have >0 hits in VELO

→ majority missing particles conversions from VELO mechanics/downstream structures – are still giving Cherenkov radiation in RICH1

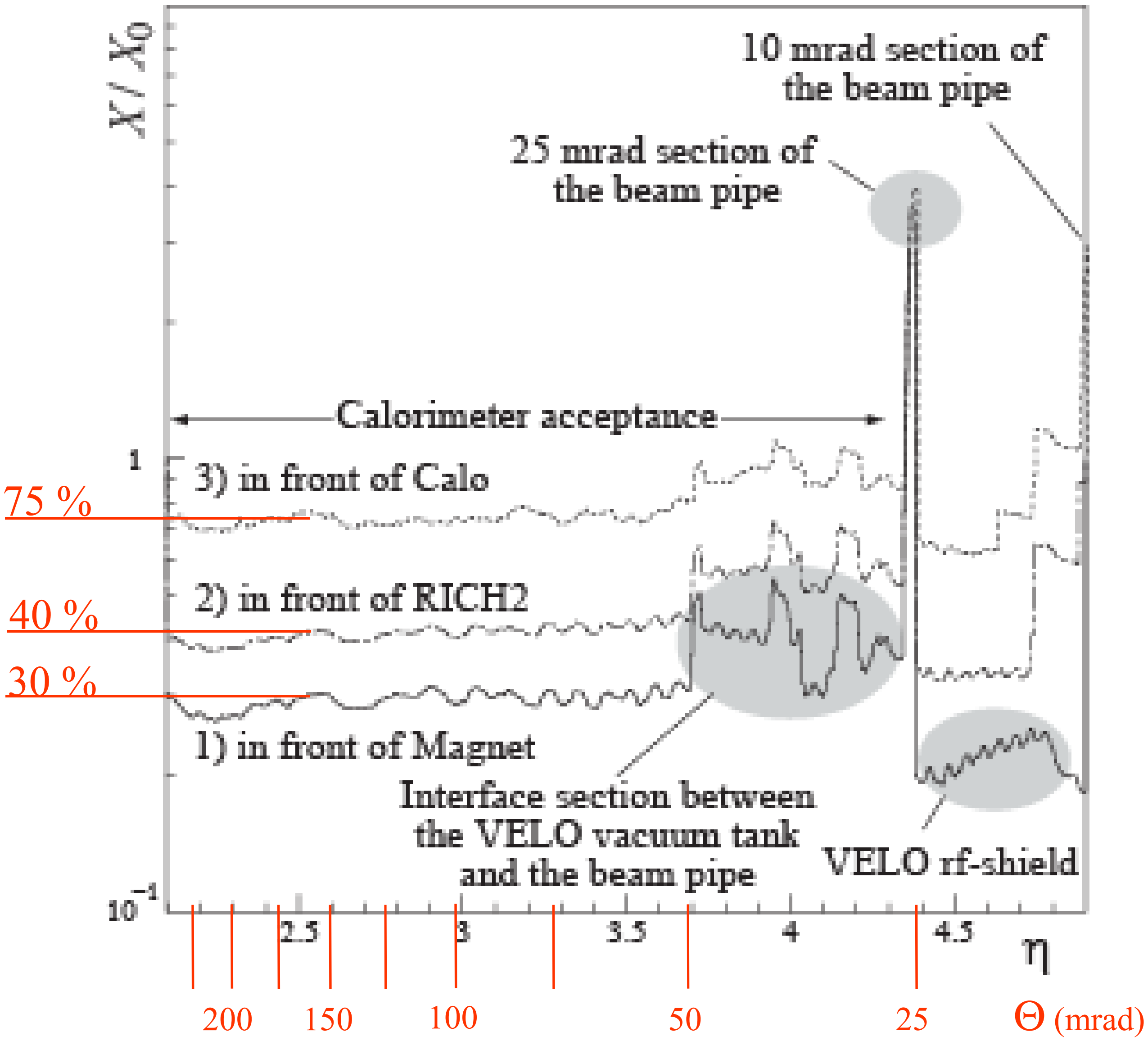


Figure 1.2: Material seen by a neutral particle from the nominal position of the primary vertex as a function of the pseudo-rapidity at three different *z* positions, averaged over the azimuthal angle.

From the LHCb Upgrade Working Group:

The main idea is to upgrade the LHCb experiment such that it can operate at 10 times the design luminosity, i.e. at **$\sim 2 \times 10^{33}$ cm^{-2}s^{-1}** and collect a data sample of **~ 100 fb^{-1}**

What is the impact of switching to a **40 MHz** read-out?

We also need to produce an R&D plan for the different subsystems, i.e what is happening already, and what is actually required for LHCb upgrade.

There is growing international consensus that future flavour physics experiments will be required in the second half of the next decade to either

- study the flavour structure of new particles discovered at the LHC

or

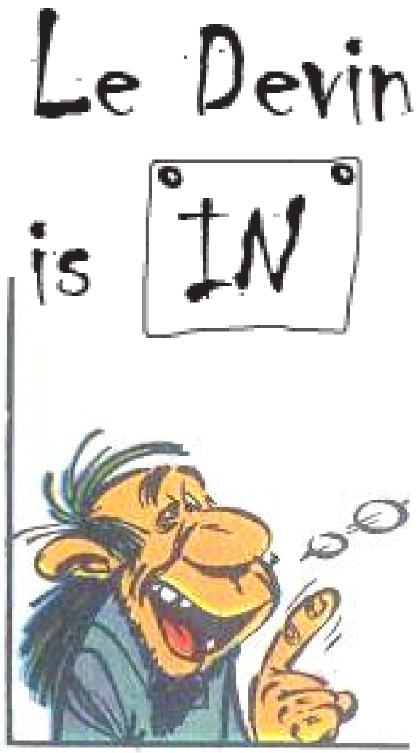
- to probe new physics at the multi-TeV scale.

I. Minimise/Reduce/Decrease
the amount of matter upstream of the magnet

II. Improve/ Extend (or at least) Maintain
the particle identification capability

III. Gear-up to 40 MHz read-out speed

IV. Simplify the experimental set-up



Can Time of Flight be useful?

Conclusions

- Our present best laser diode results:

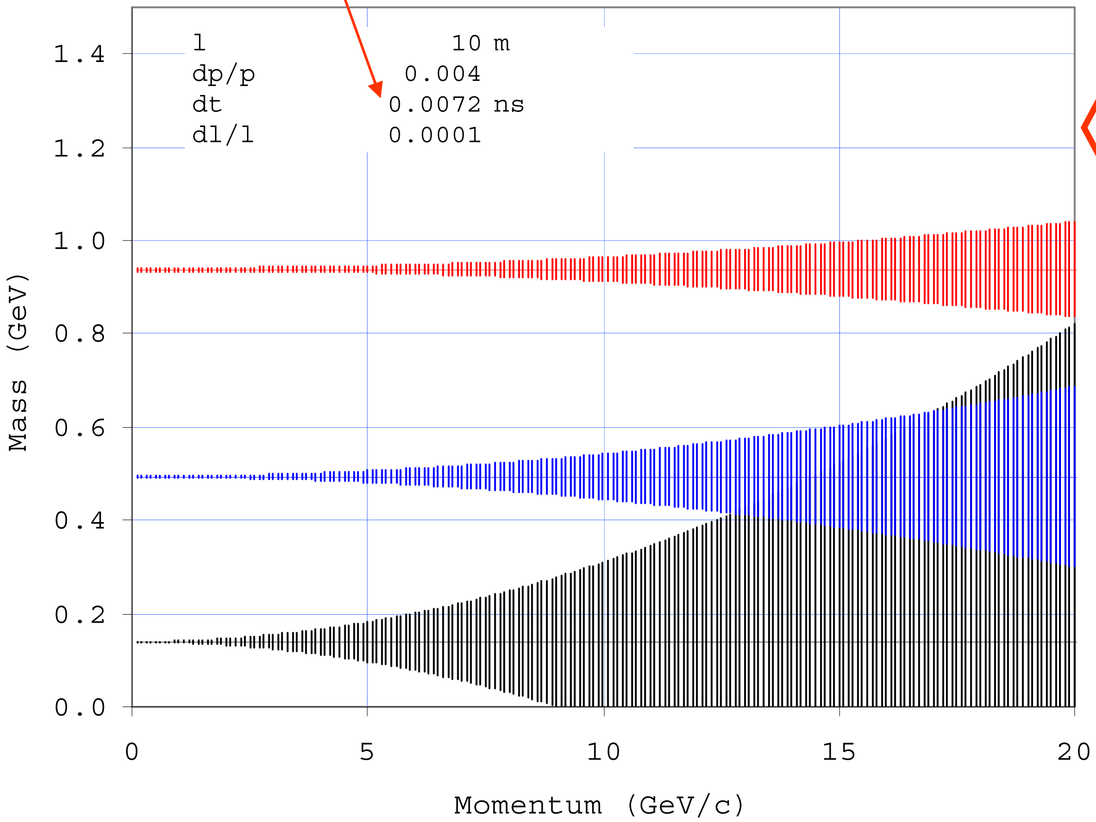
– **σ single MCP ~ 7.2 ps for Npe ~ 50**, expected from a 1cm thick radiator.

– σ TTS ~ 27 ps for Npe ~ 1.

– Electronics contribution (Amp, CFD, TAC, ADC): σ Total_electronics ~ 3.4 ps.

– Upper limit on the MCP-PMT resolution: σ MCP-PMT ~ 4.5 ps, obtained for a modified resistor chain and Npe ~120.

1σ bands for p, k and π

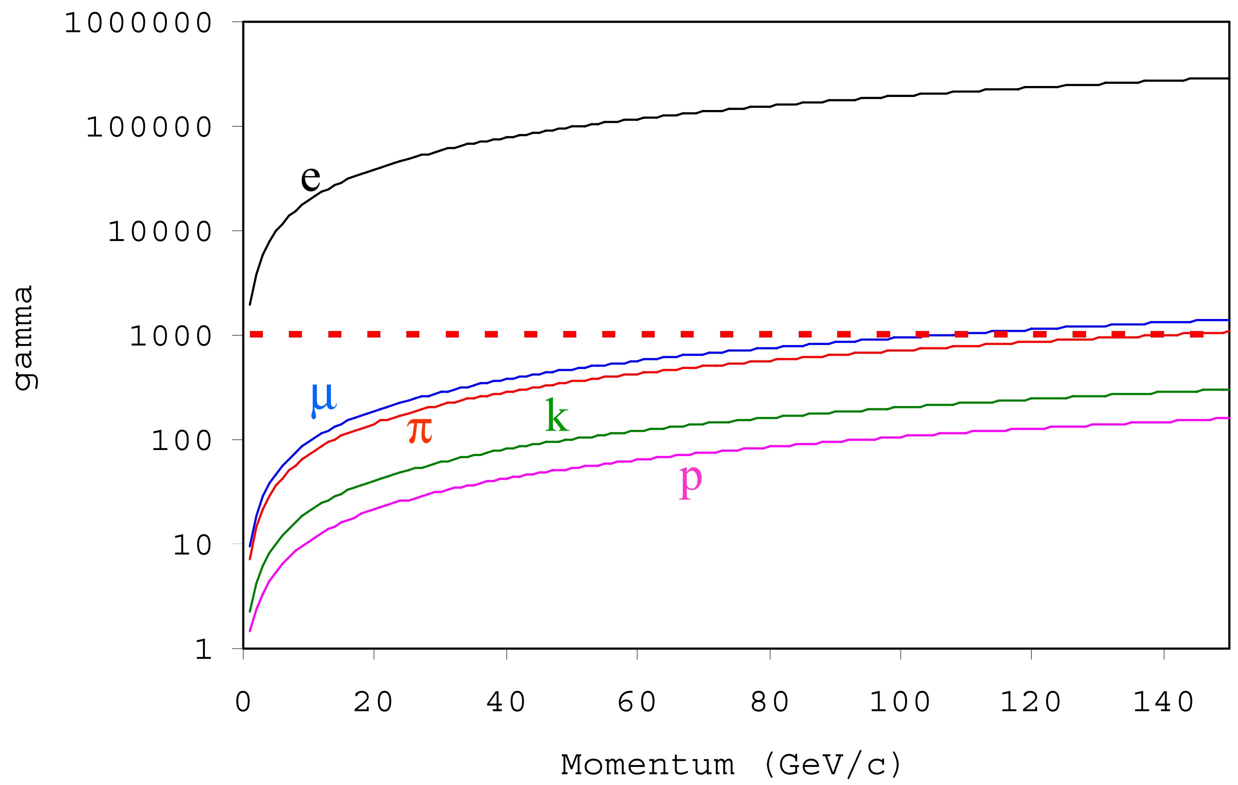


and - if I take him on his words

Possible (perhaps), but without trying, we will surely not get there.

What about the other end?

Can Transition Radiation be helpful?



Total radiated power

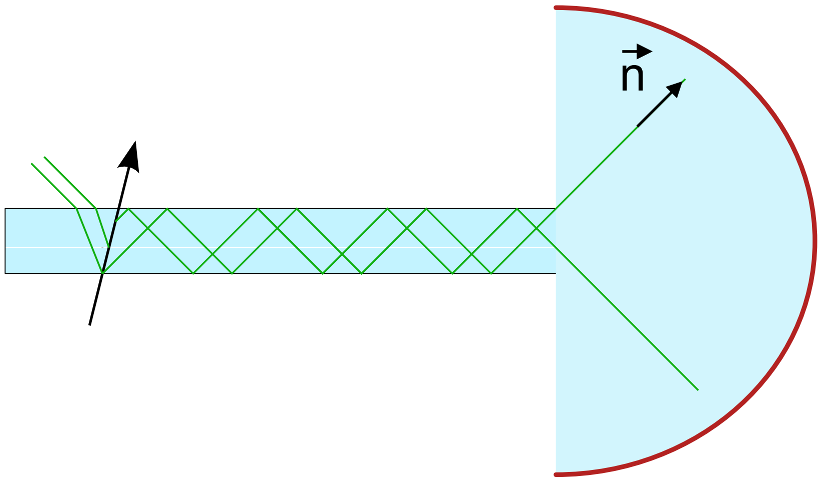
$S \approx 10^{-2}\, \gamma\, (eV)$

Rule of thumb:
(good) Signal if

$\gamma > 10^3$

What about a DIRC-like device

Detector of
Internally
Reflected
Cherenkov light



Remember:

X_0(Quartz) ≅ 11.7 cm

or

10 mm equivalent to 9 % X_0

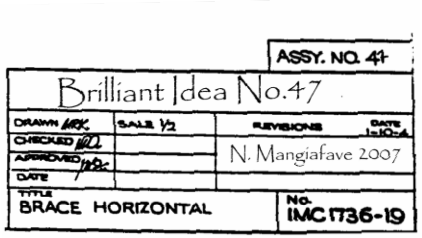
and

n=1.4 - 1.5

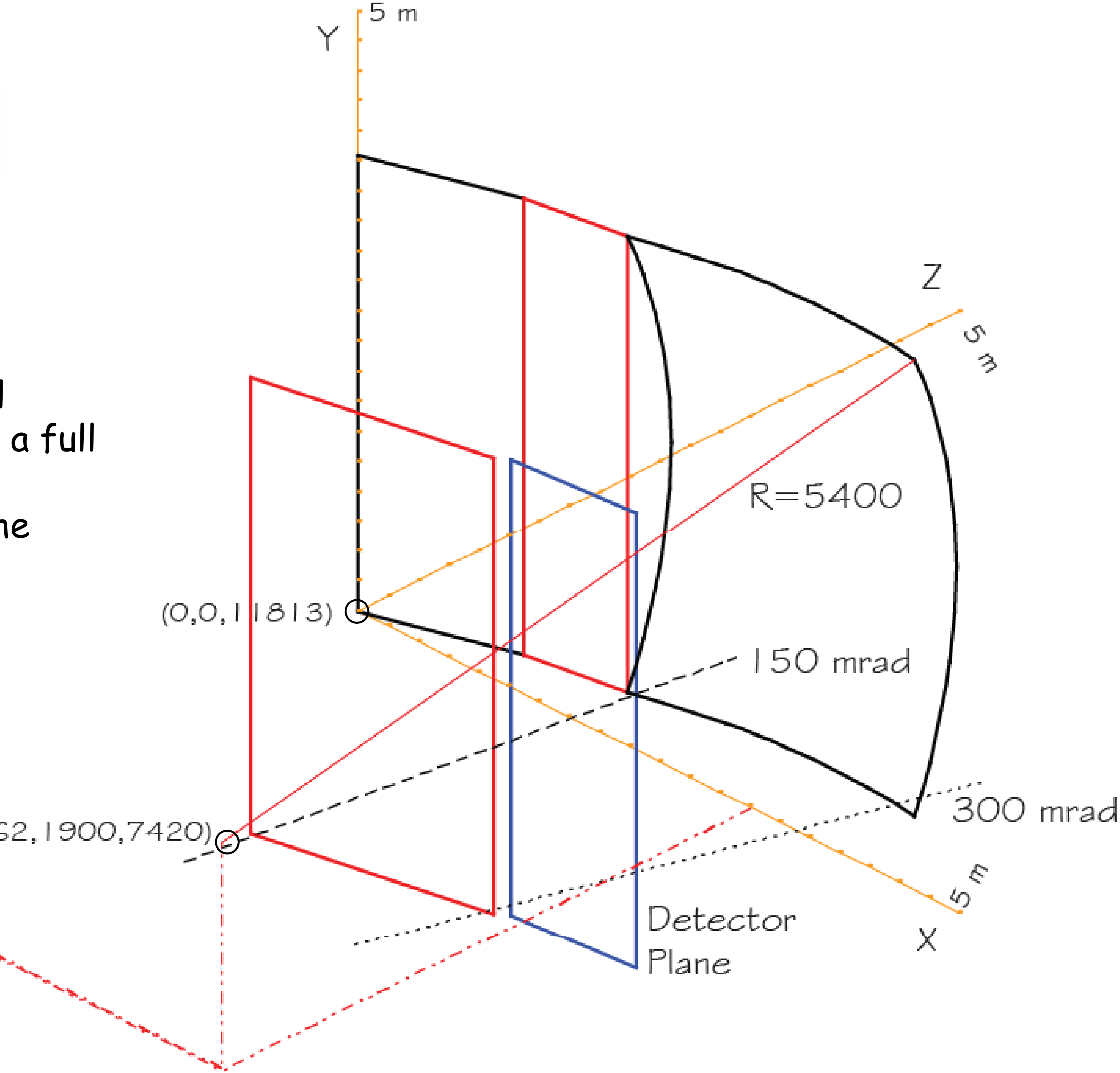
Have another look at a "mature" work horse in particle identification:

The RingImagingCHerenkov DETECTOR

But no liquid radiators, please! I have worked in DELPHI!!



A possible optical configuration for a full acceptance RICH downstream of the magnet.



N. Mangiafave 2007

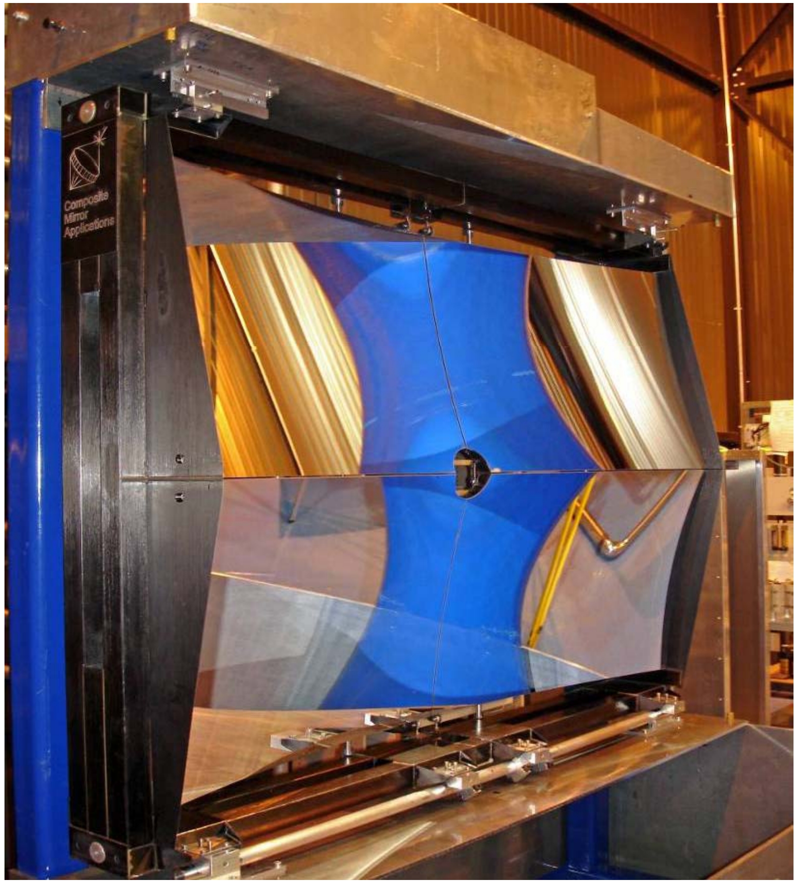
As the mirrors have to be placed inside the spectrometer acceptance

"Z_{ero}" X_0 optics

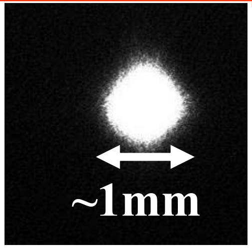
Spherical a la RICH 1

Carbon fiber reinforced polymer (CFRP)
Area density: ~ **5.5 kg/m²** **(~1.3%X_0)**

CFRP mirror assembly on testing rig

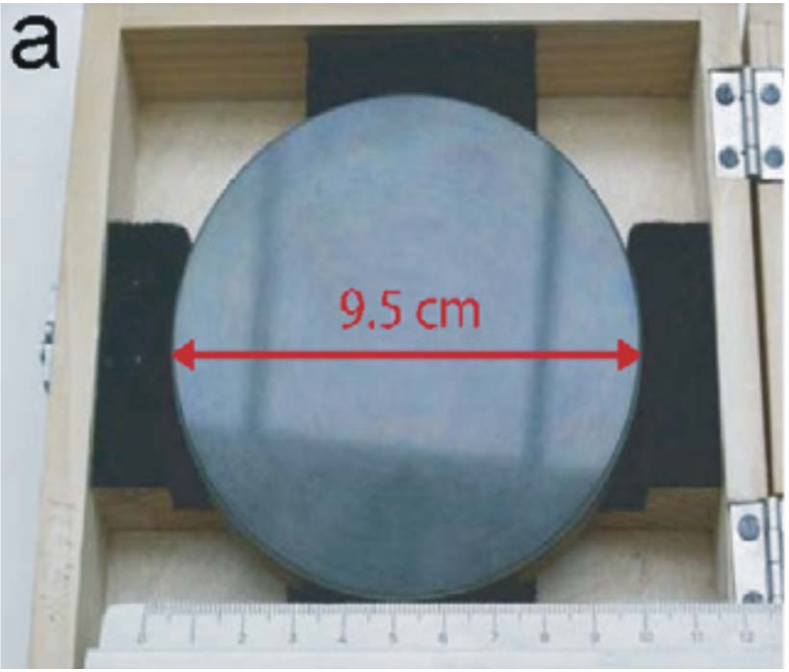


CoC Spot



Flat mass-less mirrors are difficult.
Probably beryllium is the best bet.

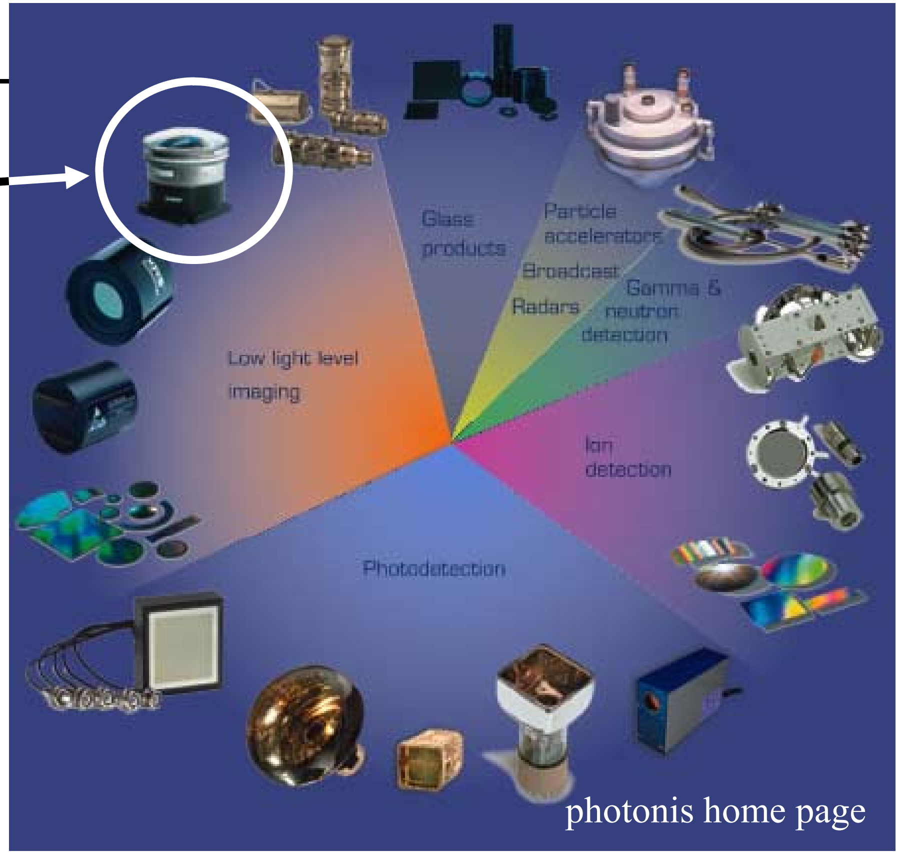
10 mm Be + 1 mm glass coating,
D_0<0.1 mm, 3.6 %·X_0

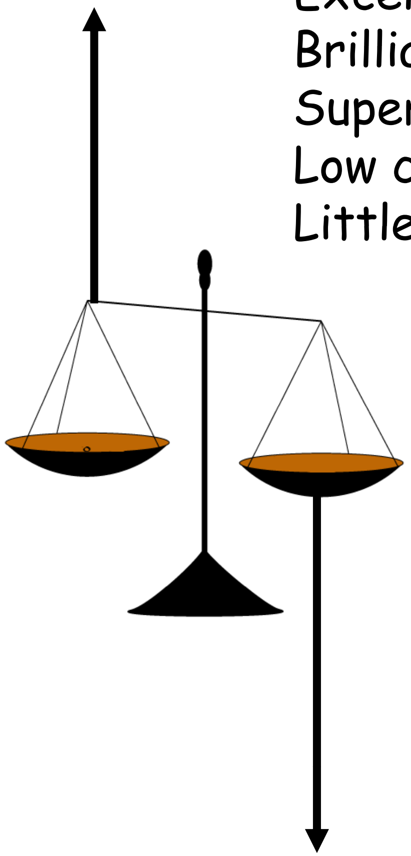


(can clearly be optimized in thickness)

Photon detectors

Why not continue with the HPD ?





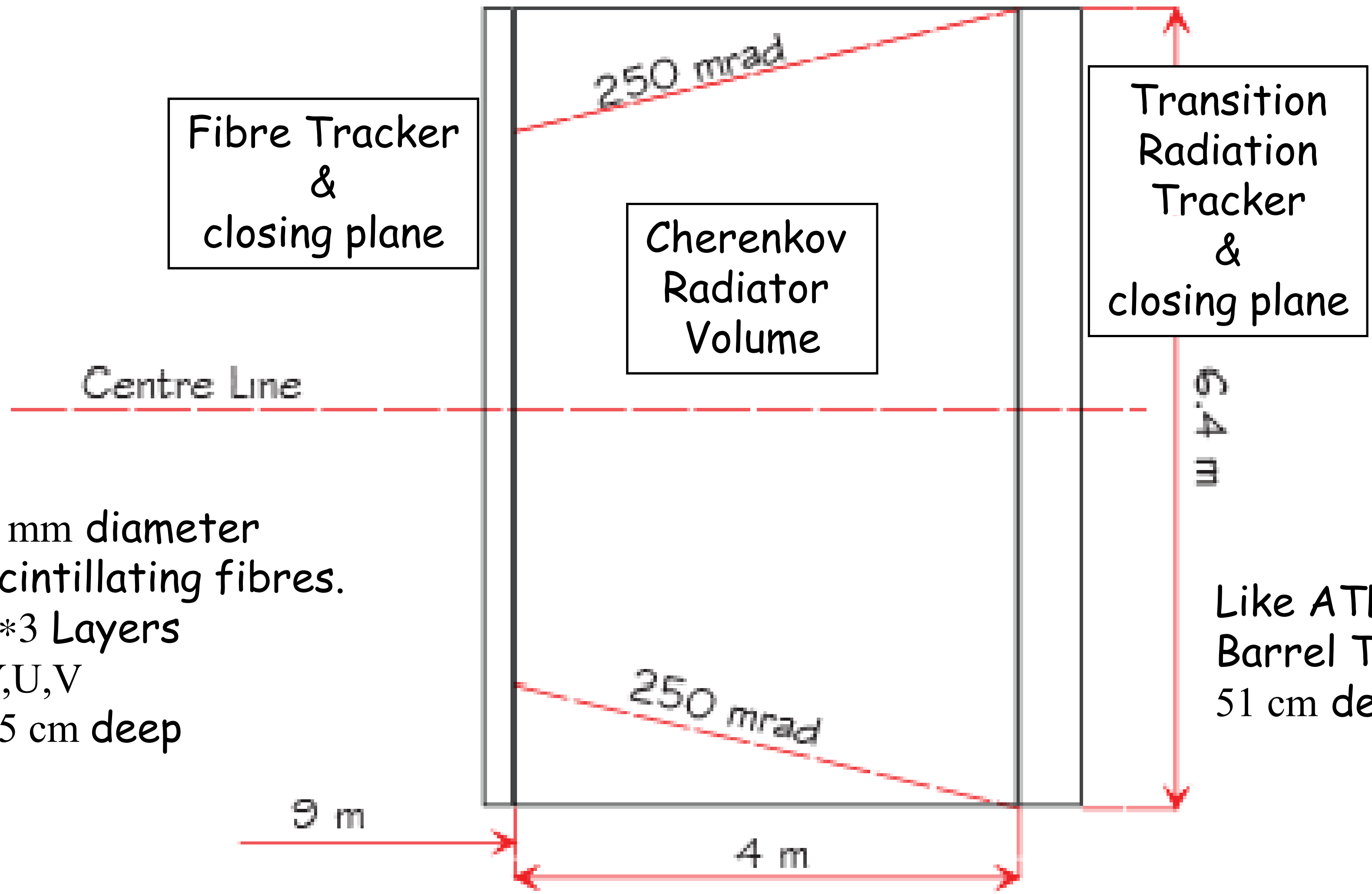
Excellent QE
Brilliant S/N
Superb (variable) pixel size
Low cross talk
Little signal variation

B field sensitive
Need new encapsulated electronics
Is a vacuum tube
If ps timing is required, perhaps not the obvious choice
Not cheap

Until otherwise proven, established and confirmed, I would still lean towards HPD-like photon detectors for a RICH detector.

(but Micro Channel Plates looks cute!)

How could such a device look like? Vertical view.



1 mm diameter scintillating fibres.
5*3 Layers
Y,U,V
25 cm deep

Like ATLAS Barrel TRT
51 cm deep.

MCP read-out?

How many radiators?

NON VALABLE POUR EXECUTION
NOT VALID FOR EXECUTION

Bundling together:

Time of Flight
&______RICH with 2 radiators
&______Transition Radiation Tracker

we will be able to cover the complete momentum range
from a few to well above 100 GeV/c
AND
we would have a very solid tracking system.

In addition, the material budget will go dramatically down. Up front.

and we
(really)
have to start soon

Simplified Microsoft Project Gantt Chart:

end 2008 - mid 2009:______Decide what we want
mid 2009 - end 2011:______Engineer what we want
2012 - mid 2014:_________Build what we want
2015:___________________Install what we wanted

Many thanks to

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Carmelo D'Ambrosio, RICH 2007

from whom I have borrowed, stolen or lifted a number of transparencies.

Spare Slide(s)