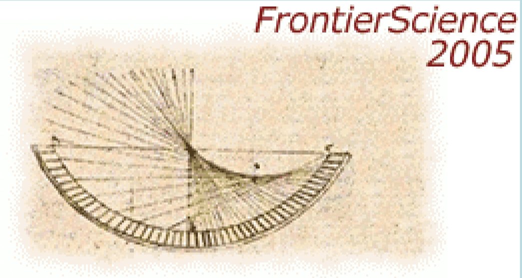
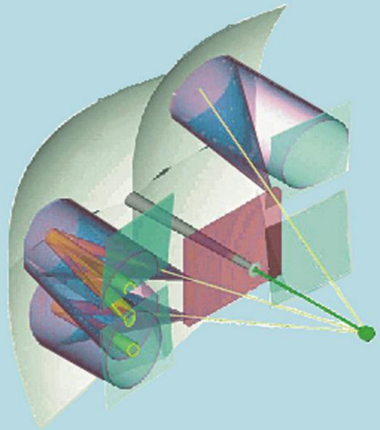
The Ring Imaging CHerenkov Detectors.

Applications in LHCb

LHCb
RICH





for the

LHCb

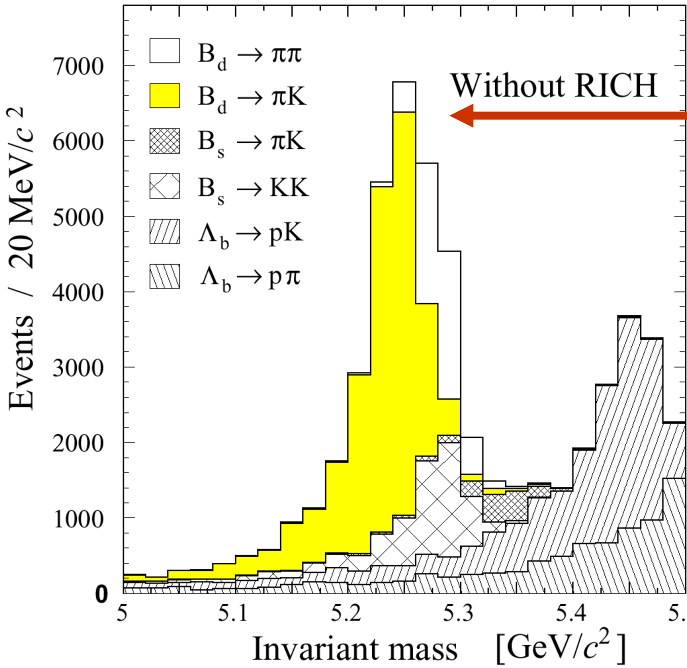
RICH Collaboration

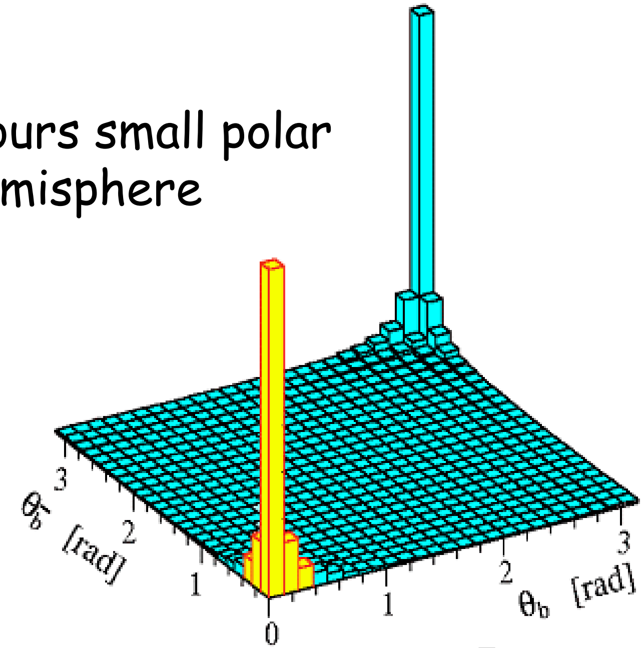
Olav Ullaland

PH Department, CERN

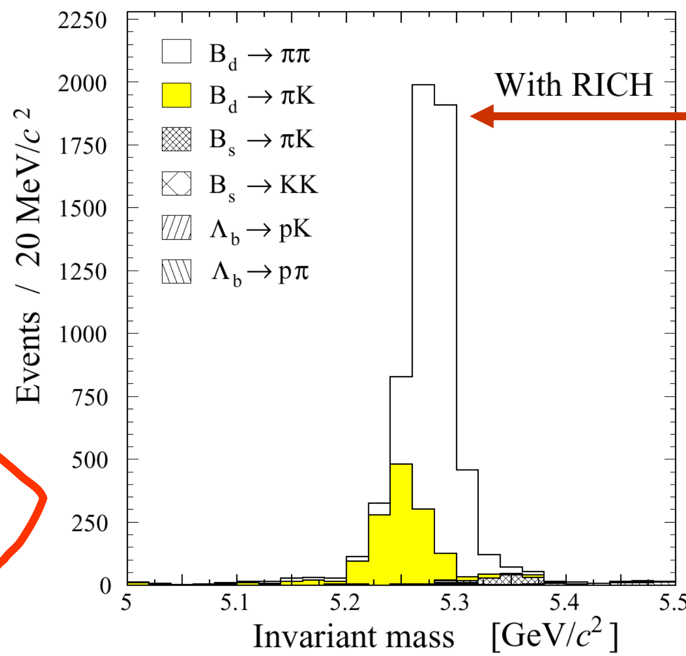
The aim of the LHCb experiment.

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





Polar angles of the b- and the $\bar{b}$-hadrons.
14 TeV. PYTHIA event generator.



and physics favours particle identification

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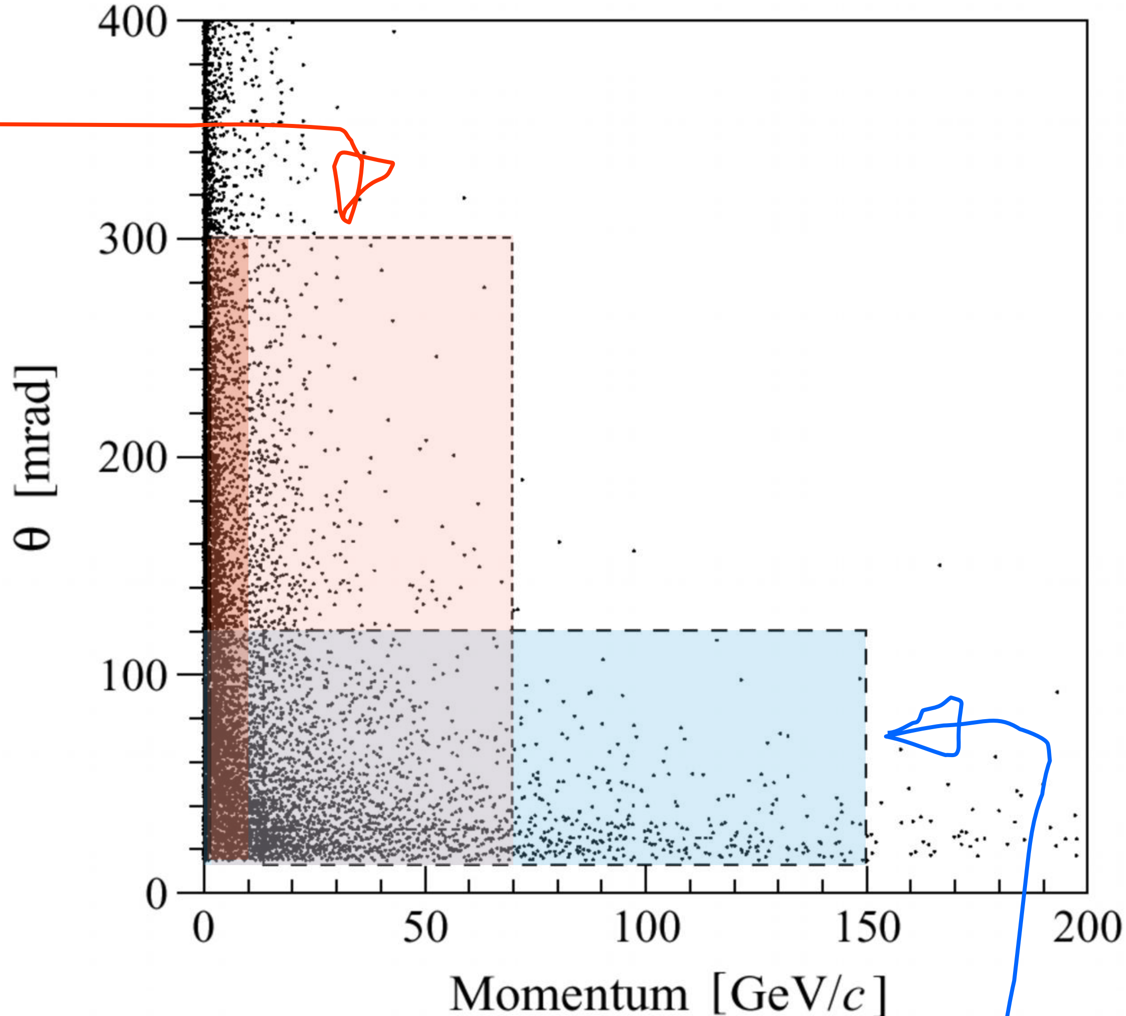


RICH 1:

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:

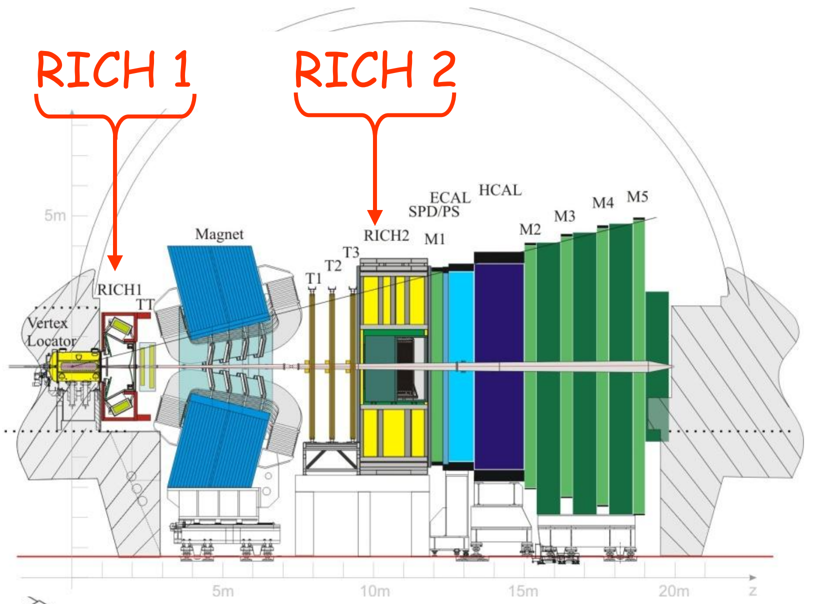
CF_4 up to 100 GeV/c
n =1.0005 (nominal at 400 nm)

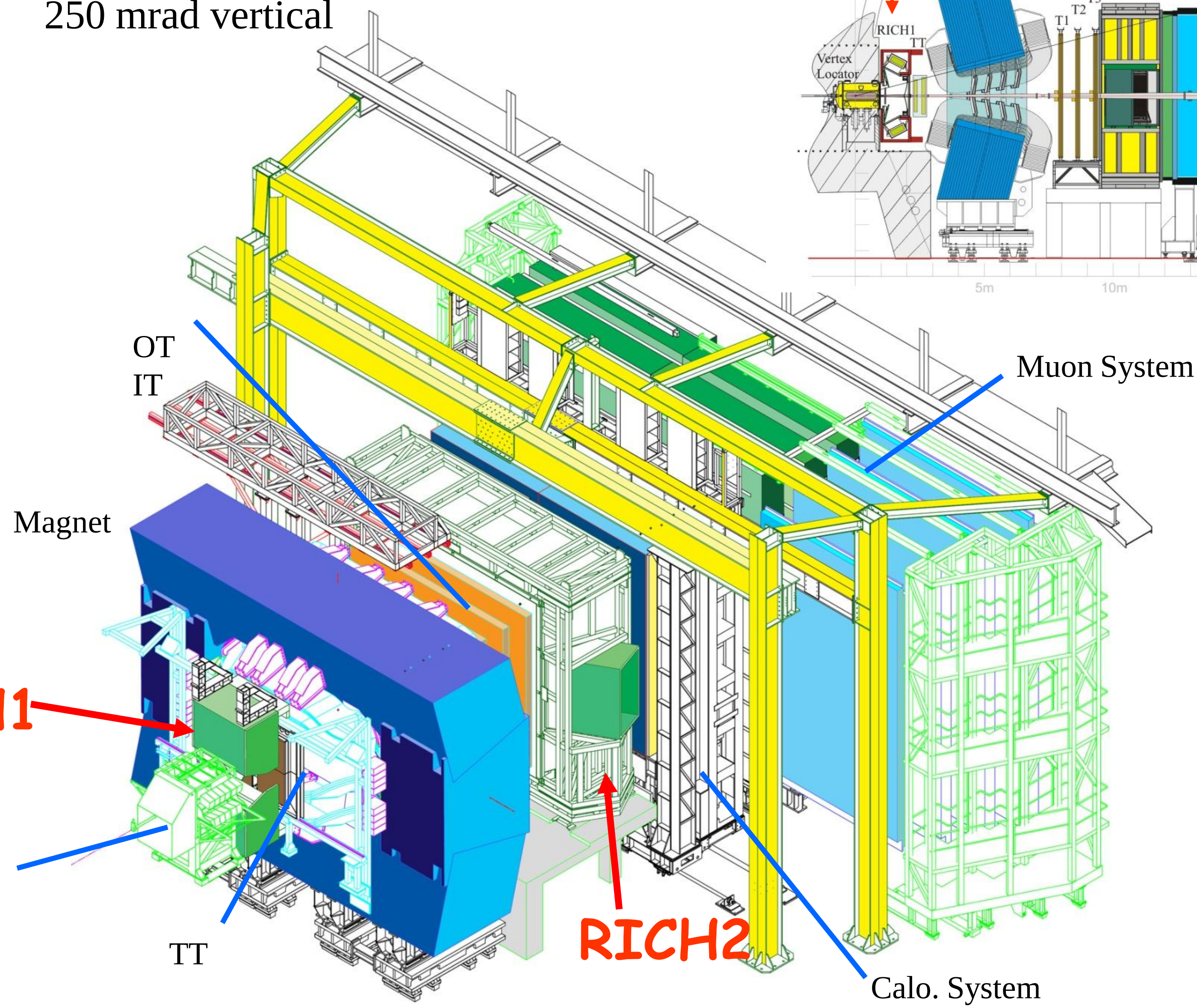
Acceptance:
15→100 mrad (vertical)
120 mrad (horizontal)

LHCb Spectrometer

Acceptance:

300 mrad horizontal
250 mrad vertical





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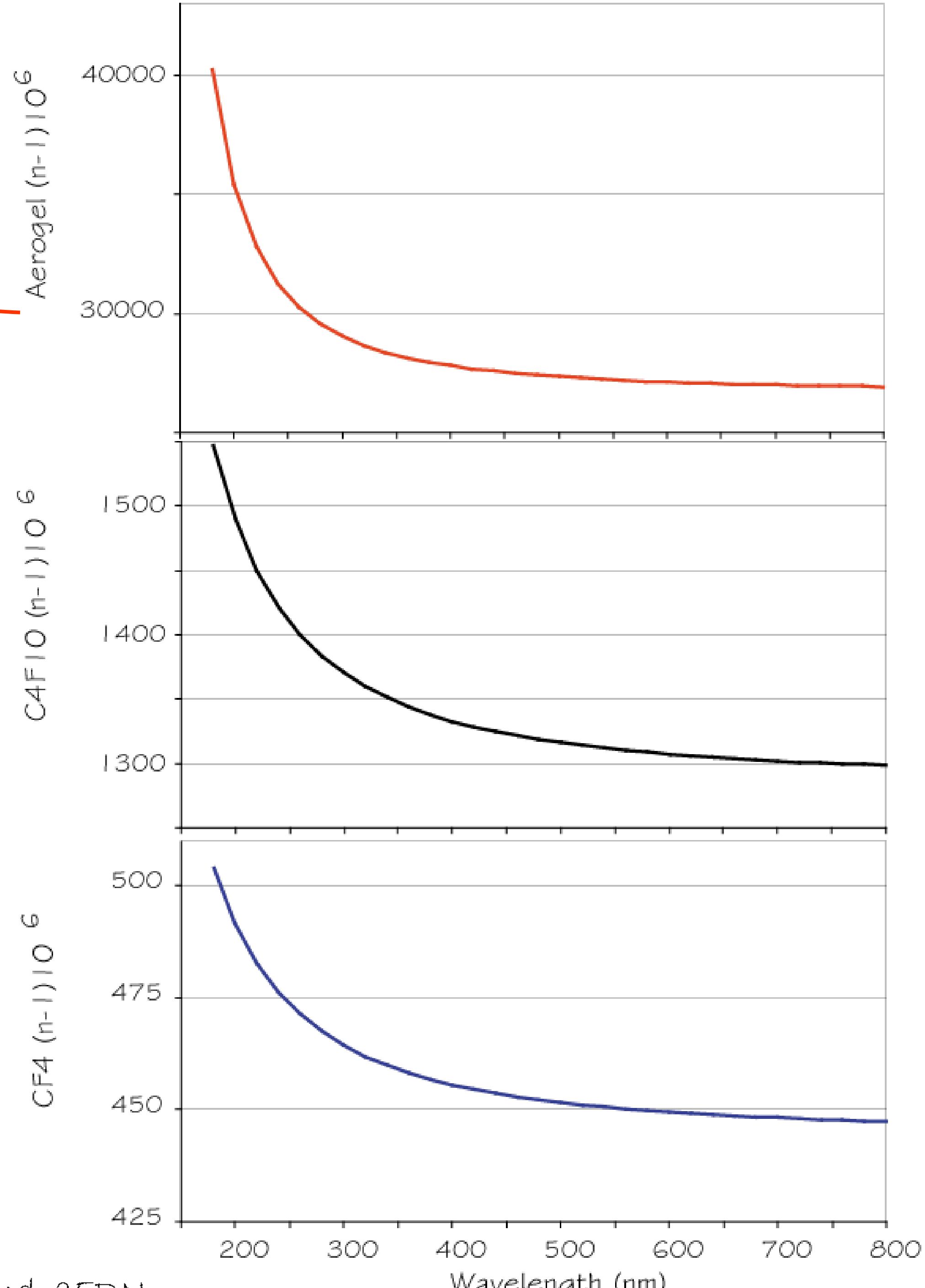
Choice of photon detector and detection resolution.

1.
Quantum efficiency > 0
for λ>200 nm

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

3.
The Pixel Hybrid Photon Detector



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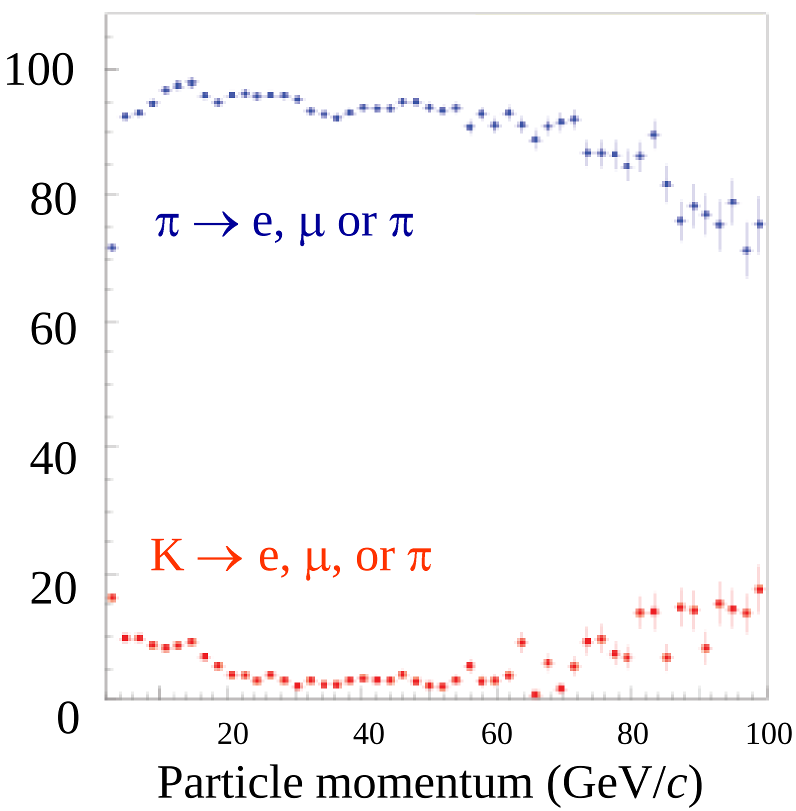
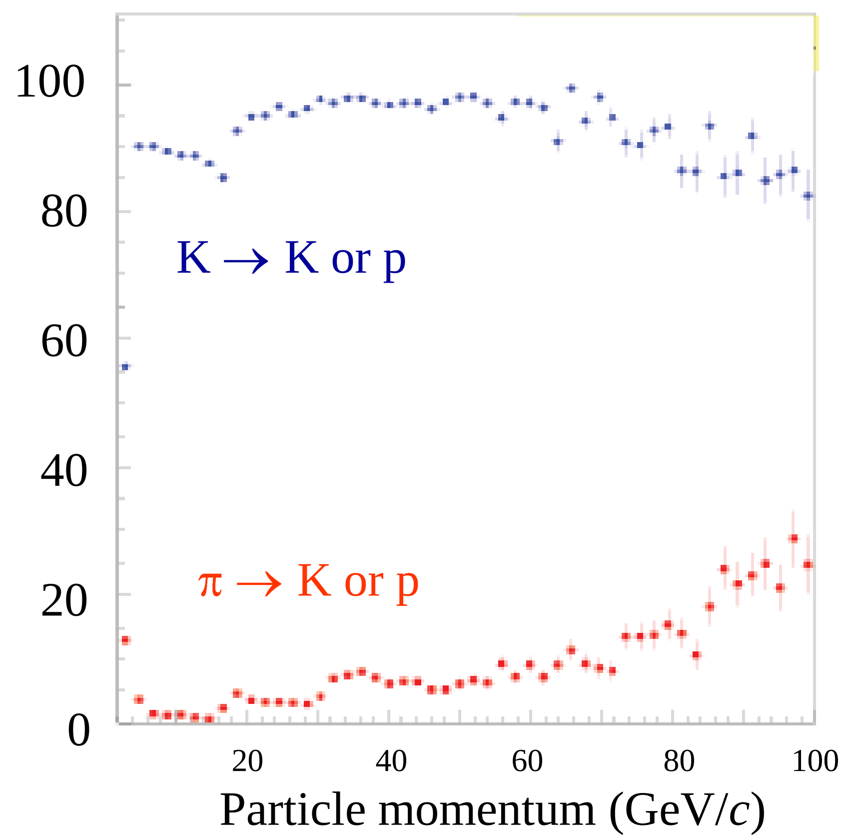
With these choices of parameters, we will expect the following

RICH performance

(full detector realistic simulation)

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





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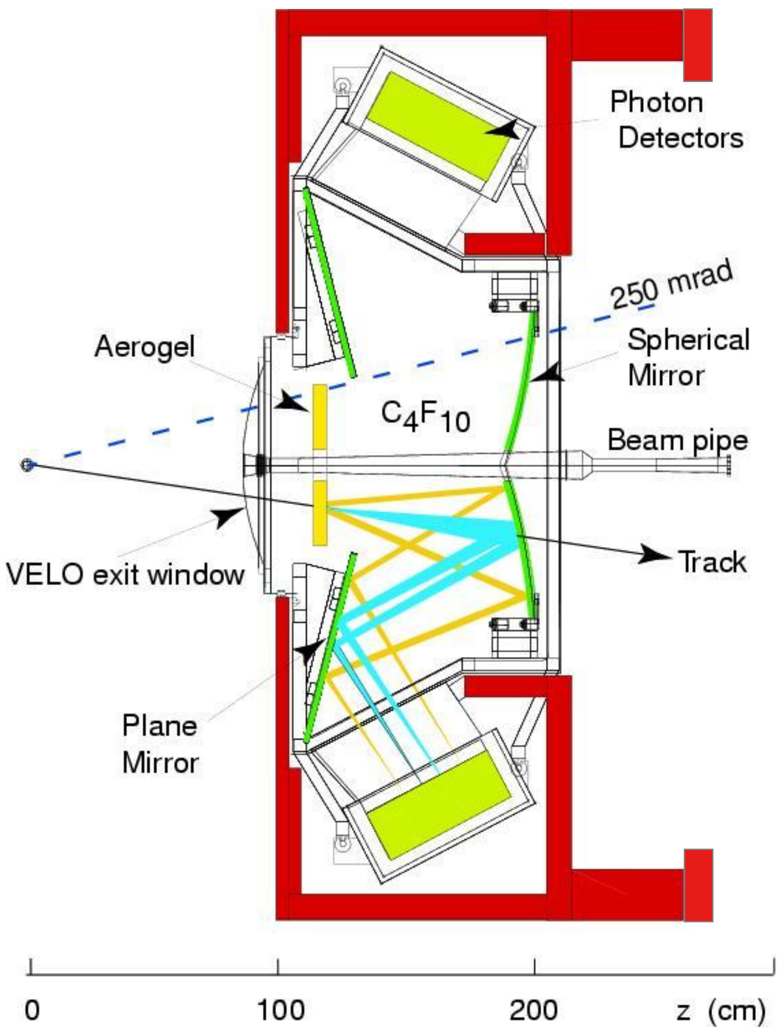
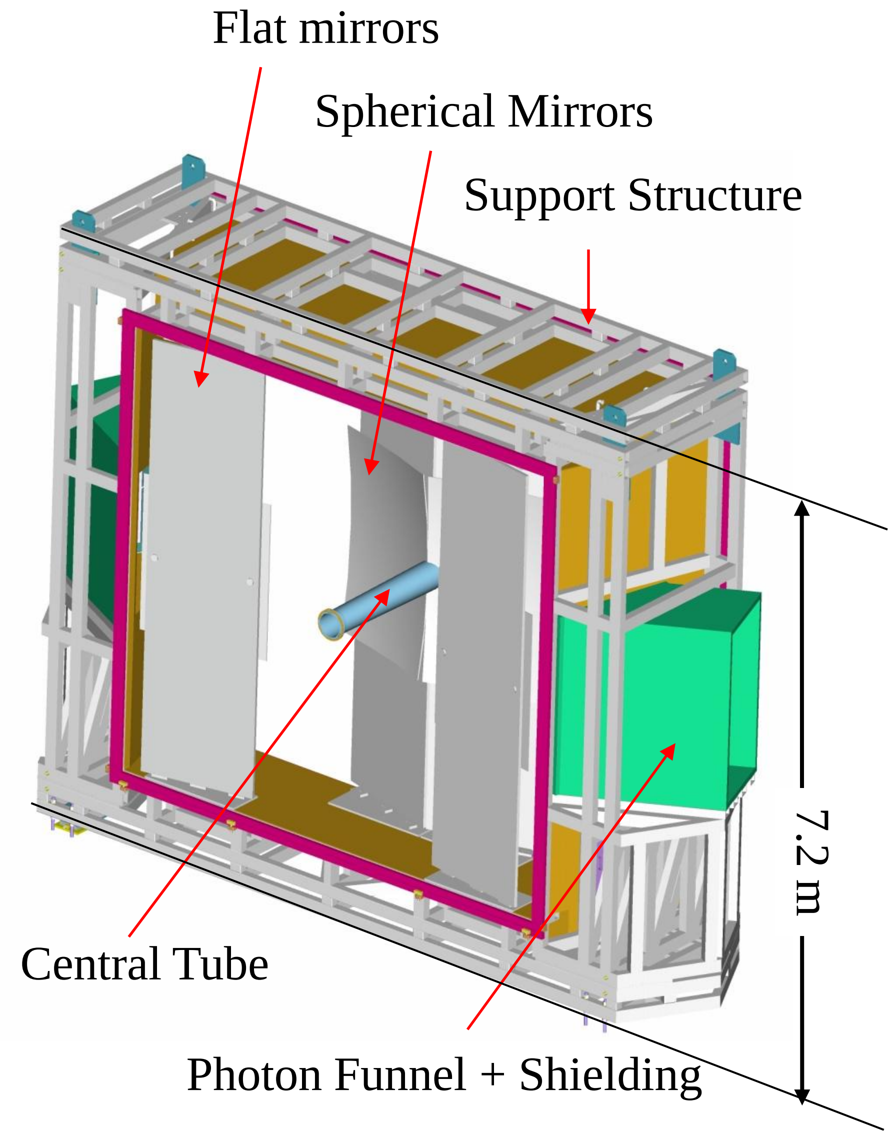
RICH 1 and RICH 2





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The Radiators

Aerogel

Parameters

n=1.030 (± 0.001) at λ=400 nm

thickness 5 cm, transversal size 20×20 cm^2

Clarity < 0.0064 $\mu m^4\ cm^{-1}$

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

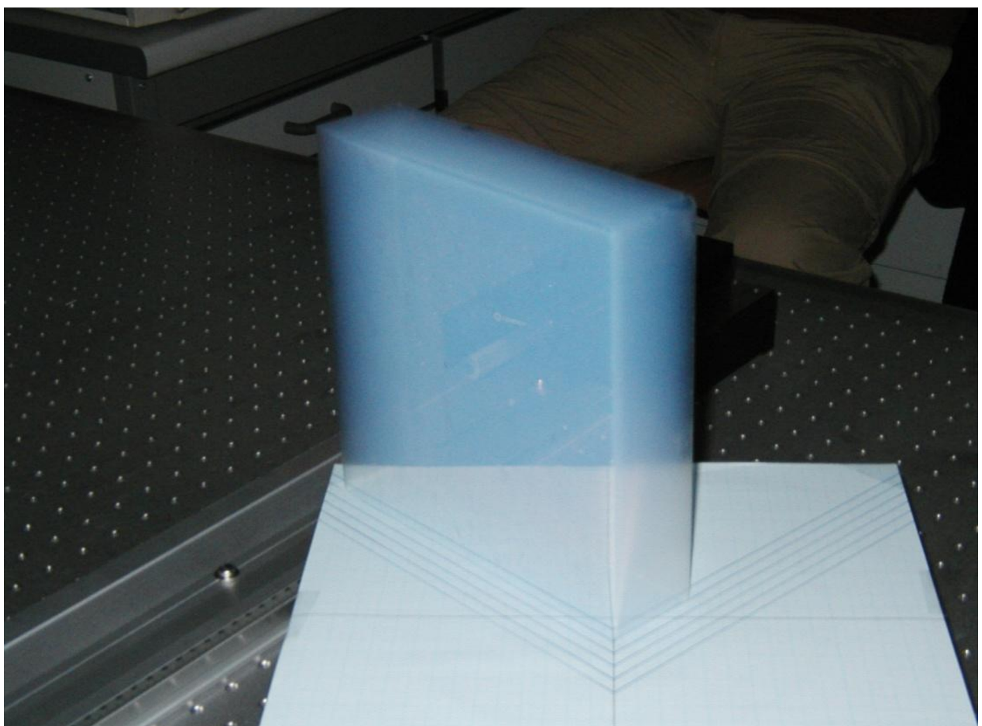
C: Clarity in units of $\frac{\mu m^4}{cm}$

t: radiator thickness (cm)

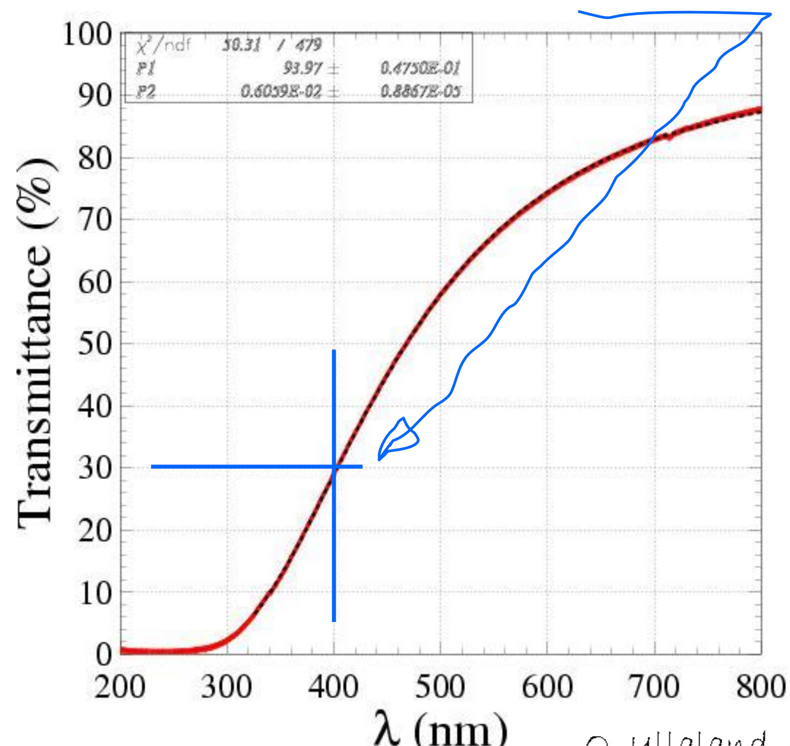
Boreskov Institute of Catalysis (Novosibirsk) successfully produced in 2004

20.0 × 20.0 × 5.1 cm^3

n=1.029–1.031 at λ=400 nm



C=0.0060 T≅30% at 400 nm



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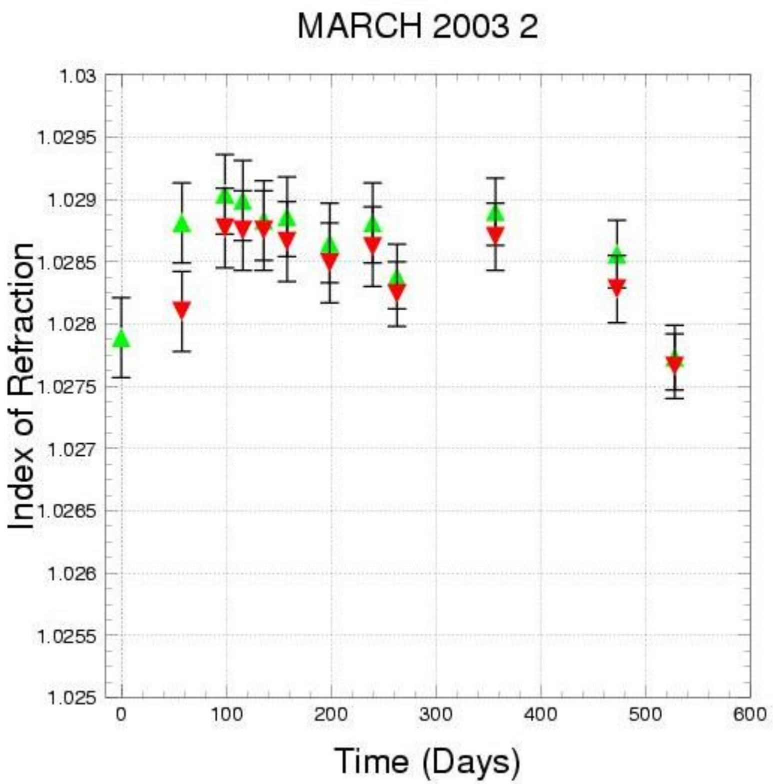
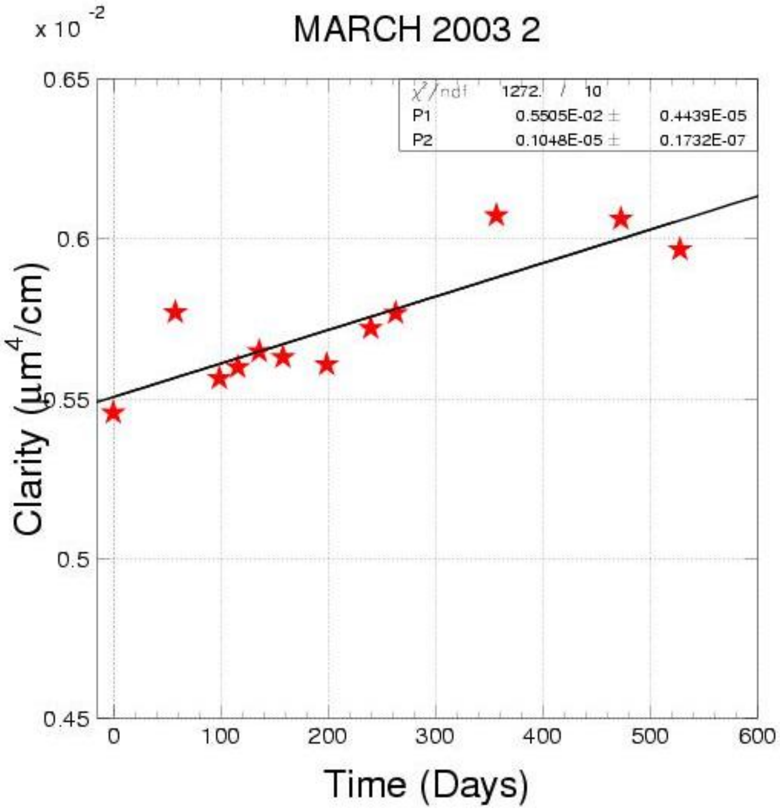
Is Aerogel stable?

Ageing tests I

'natural' ageing tests





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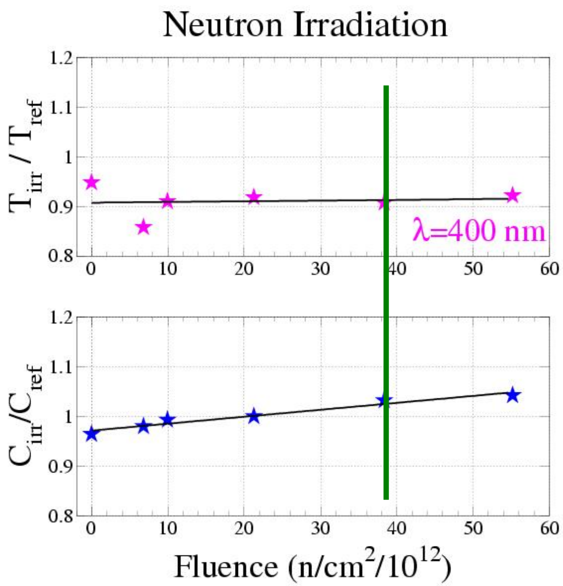
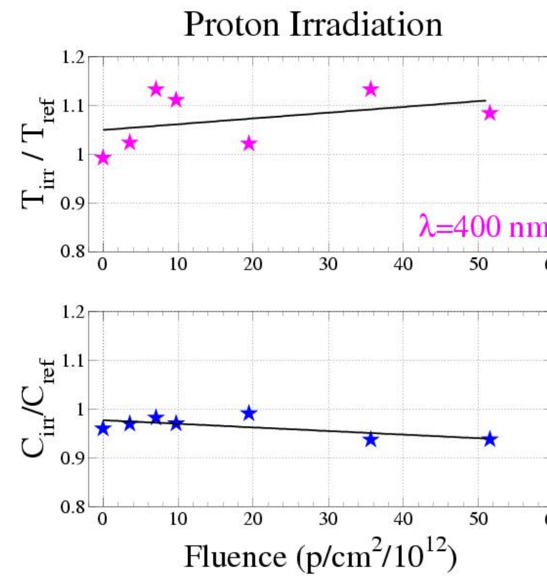
Is Aerogel stable?

Ageing tests II

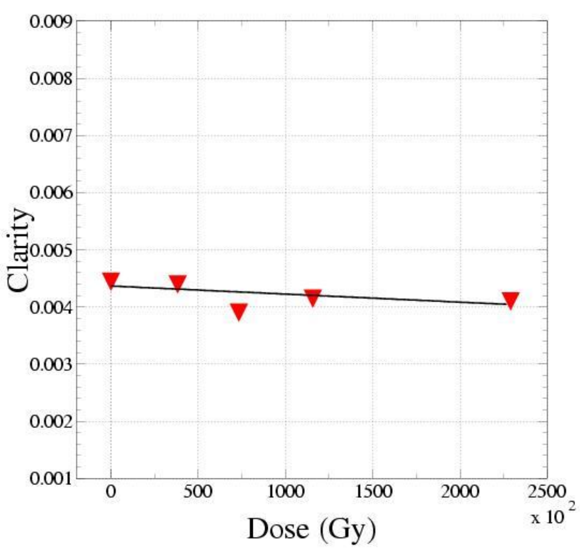
C and T measurements



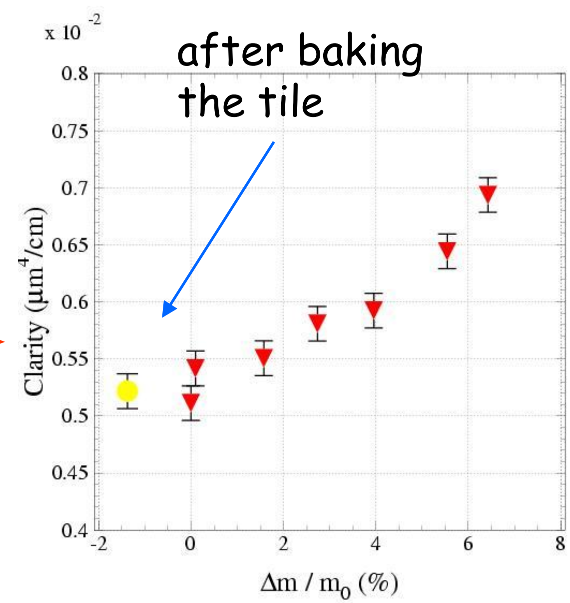
neutrons
from IRRAD-2
(CERN-PS)



protons
from IRRAD-1
(CERN-PS)



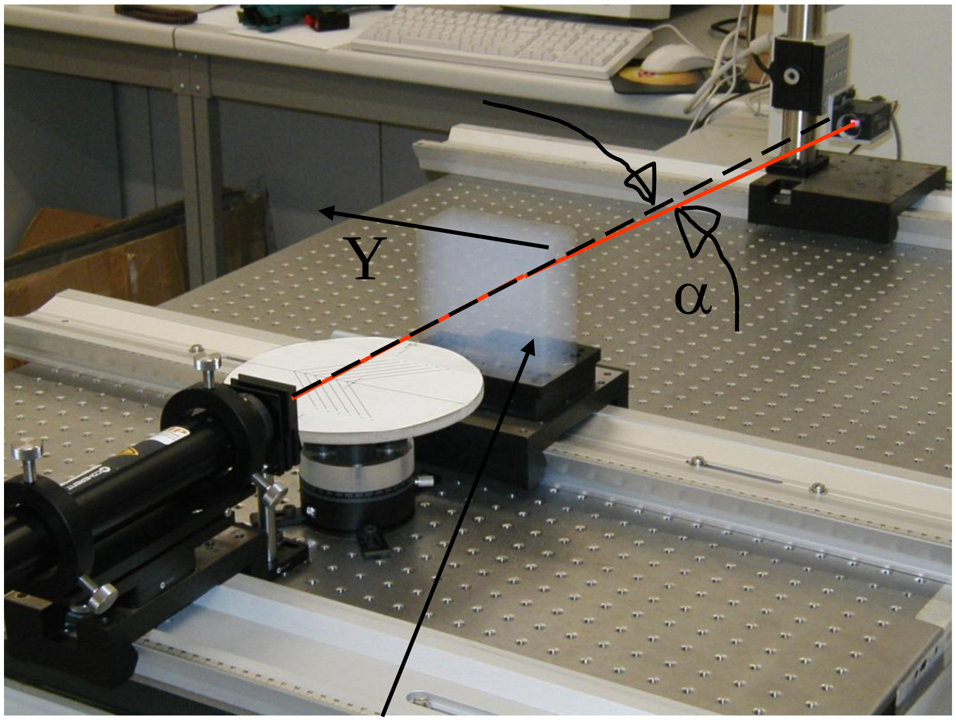
γ's
from ^{60}Co (ISS)

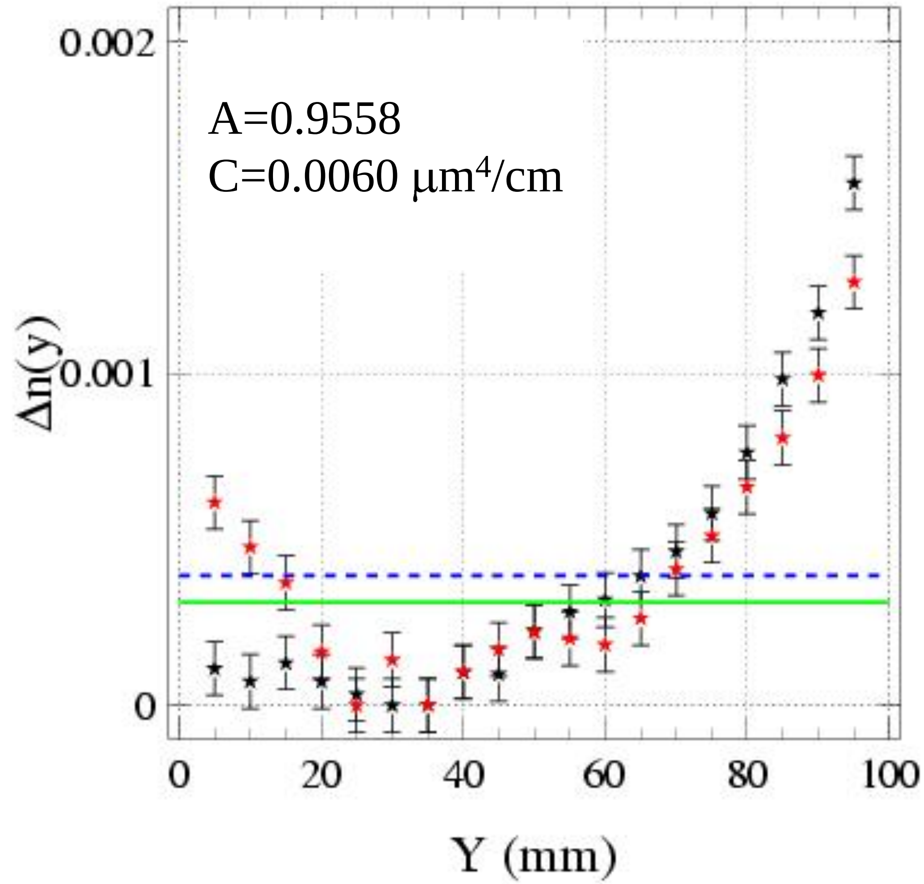


humidity
absorption

Is the refractive index of Aerogel constant across a tile ?

Measure Δn with laser beam





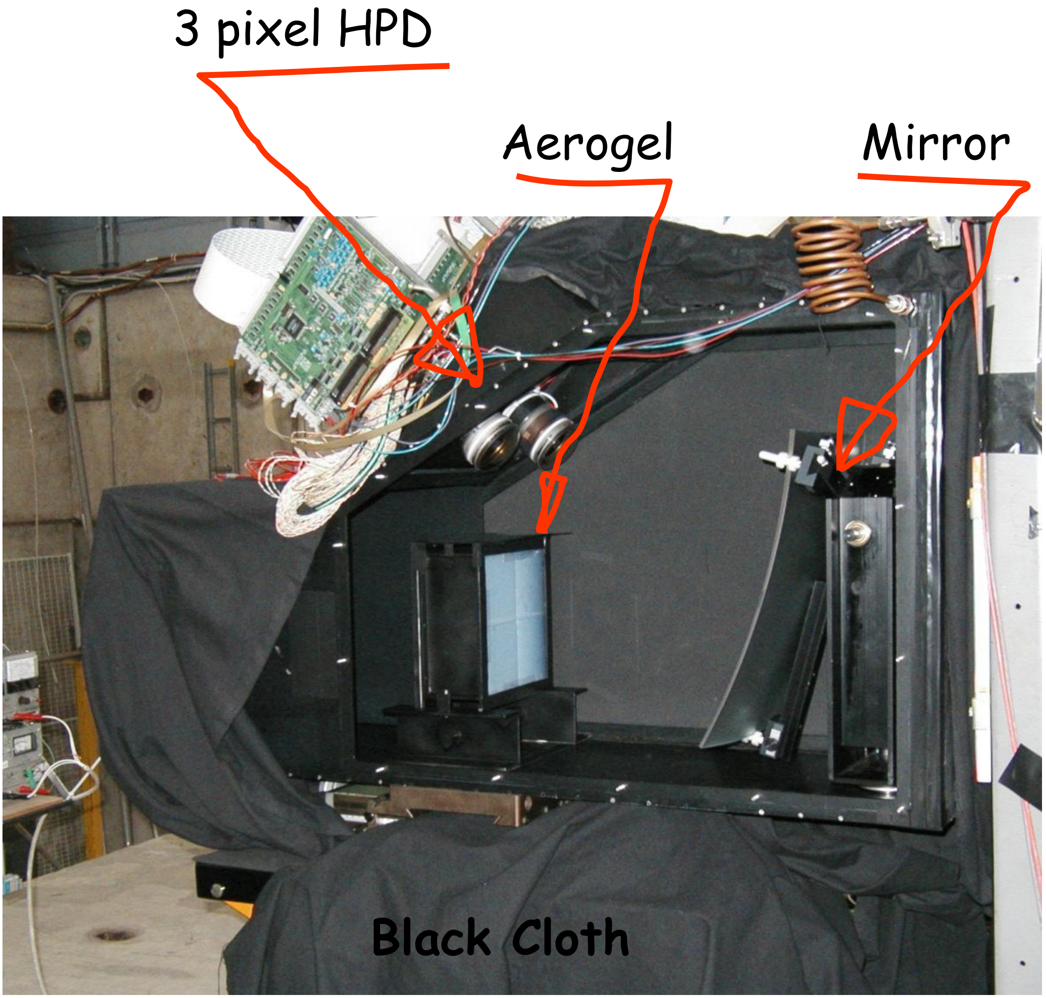
$10{\times}10{\times}4.2\ cm^3$ tile
with
n=1.031
or
Θ_C=246 mrad for β~1

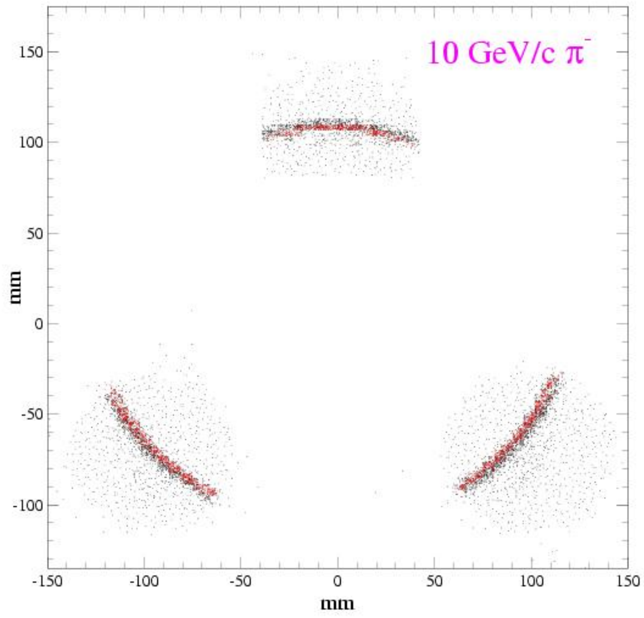
$\sigma_n \approx 4.6\cdot10^{-4} \Rightarrow \sigma_\theta \approx 1.8$ mrad

$\sigma(n-1)/(n-1)$~1.3%

Is Aerogel a Cherenkov Radiator ?

AEROGEL test beam
(October 2003)





Aerogel thickness	with filter θ_C	σ_θ	no filter θ_C	σ_θ	
4 cm	238.2	3.2	239.3	4.1	*
	239.3	2.4	240.3	3.0	**
$N_{p.e.}$	9.3 ± 0.2		13.2 ± 0.3		*
	10.2 ± 1.1		13.7 ± 1.6		**

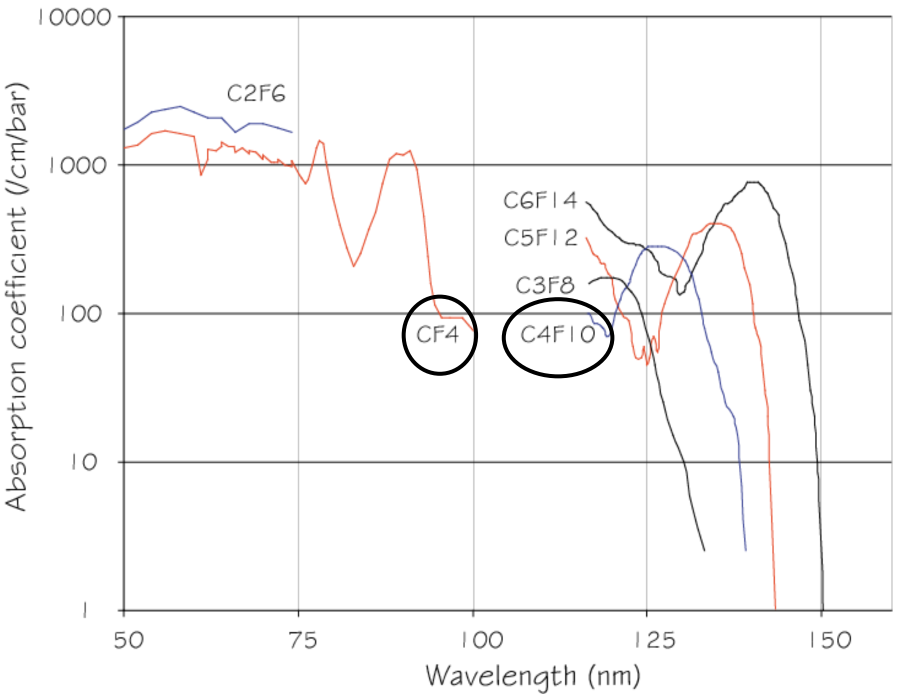
Analysis being finalized

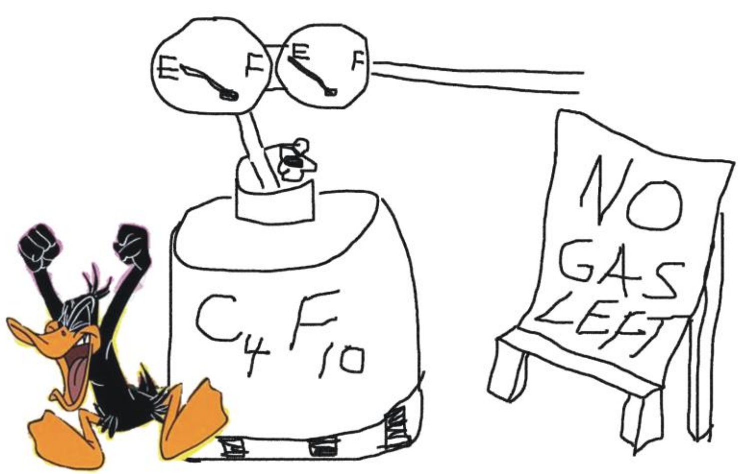
Data *
Simulation **

The Radiators

CF_4 and C_4F_{10}

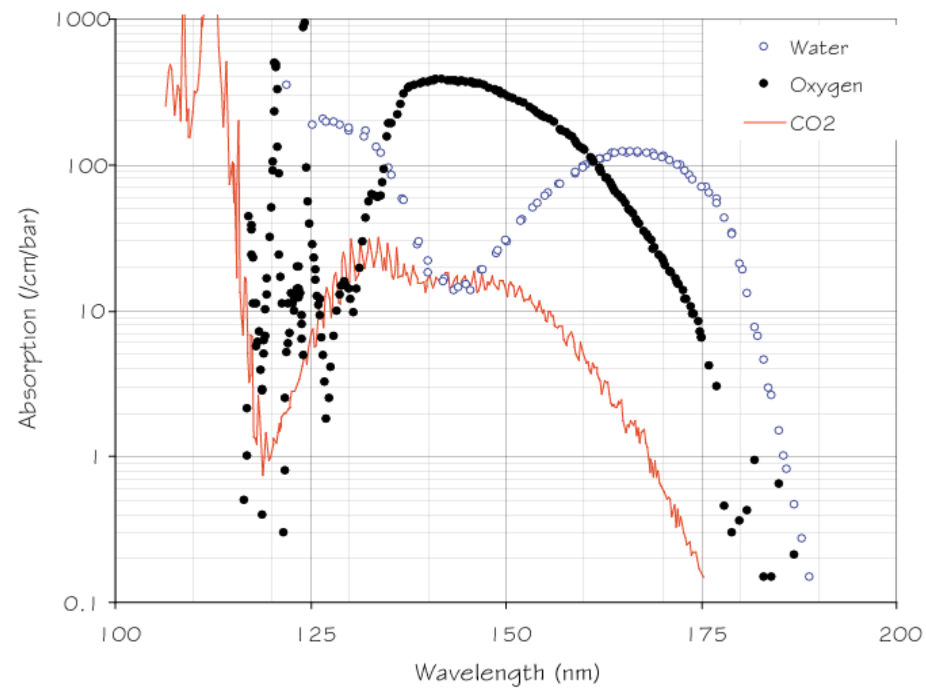
The gas radiators needs less attention.





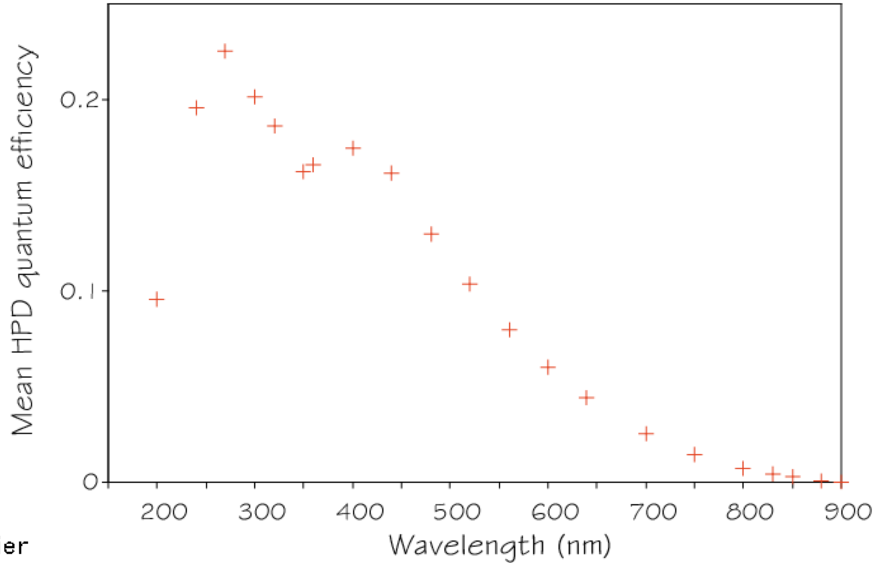
(and the leak rate even smaller).

Just make sure that the air admixture is very small,



No photon absorption for $\lambda > 190$ nm.

The Hybrid Photon Detector



Requirements:

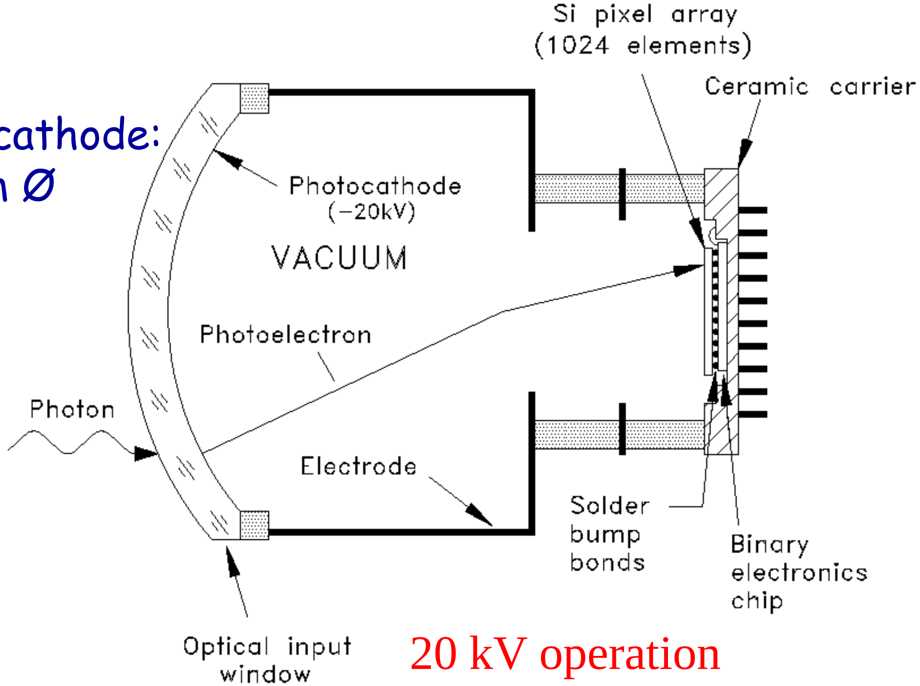
2.6 m^2 coverage with ~65% active area

2.5 x 2.5 mm^2 granularity

Single photon efficiency

40 MHz readout

S20 photocathode: 75 mm Ø active



20 kV operation

Cross-focused, 83 mm diameter,

encapsulated binary electronics 32 x 32 pixels (500 µm x 500 µm).

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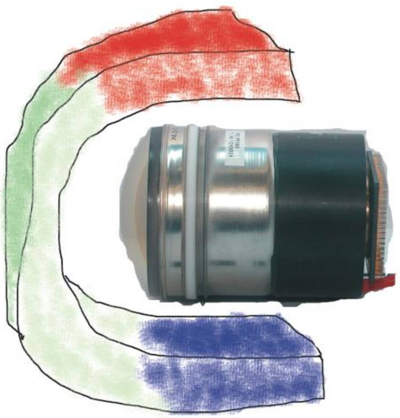
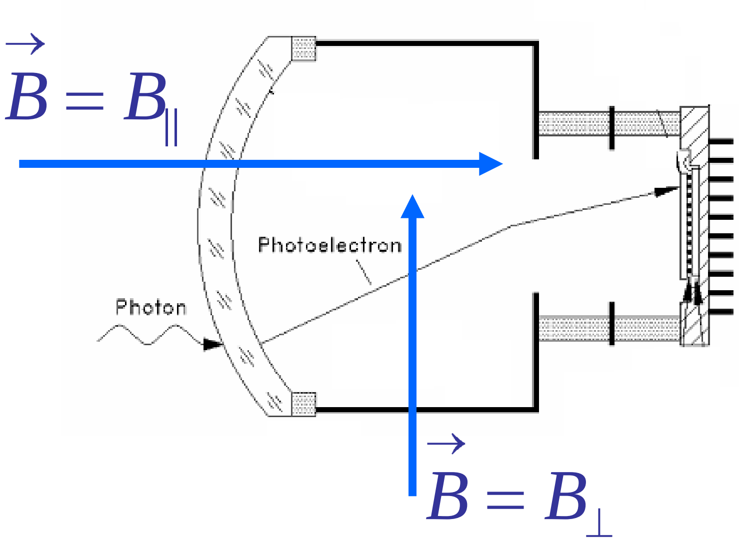
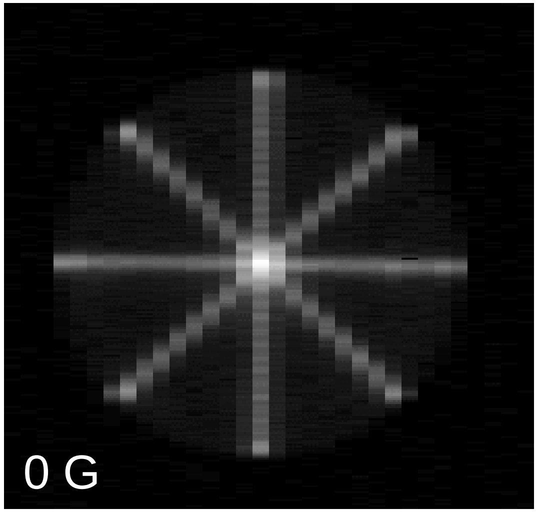
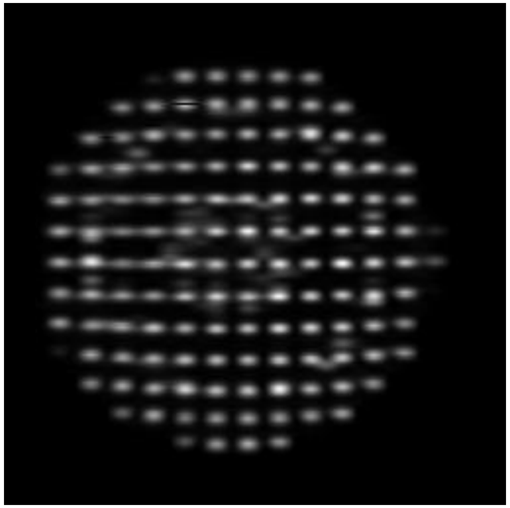
HPD and Magnetic Fields



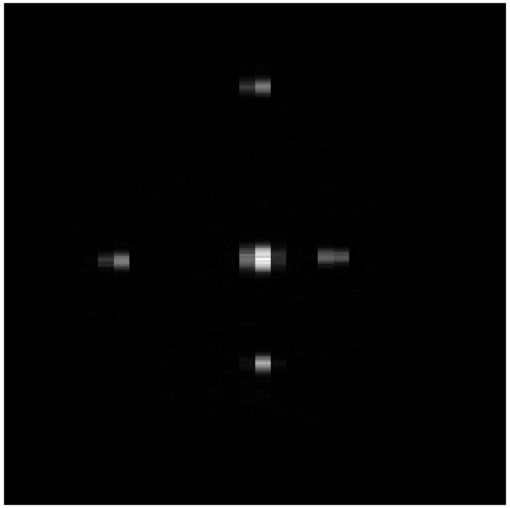




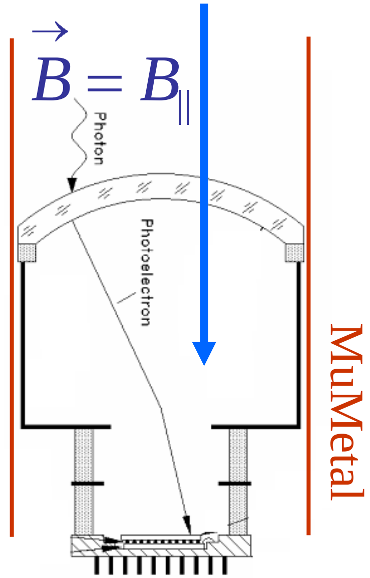
Pattern I

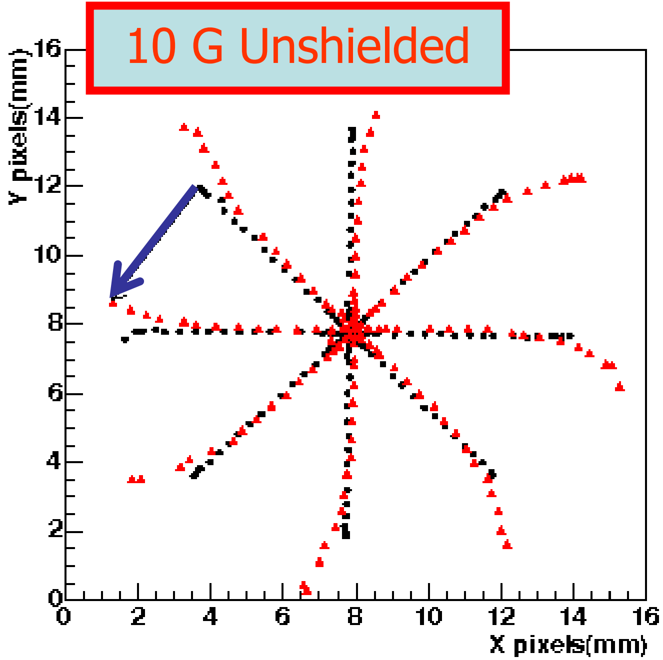


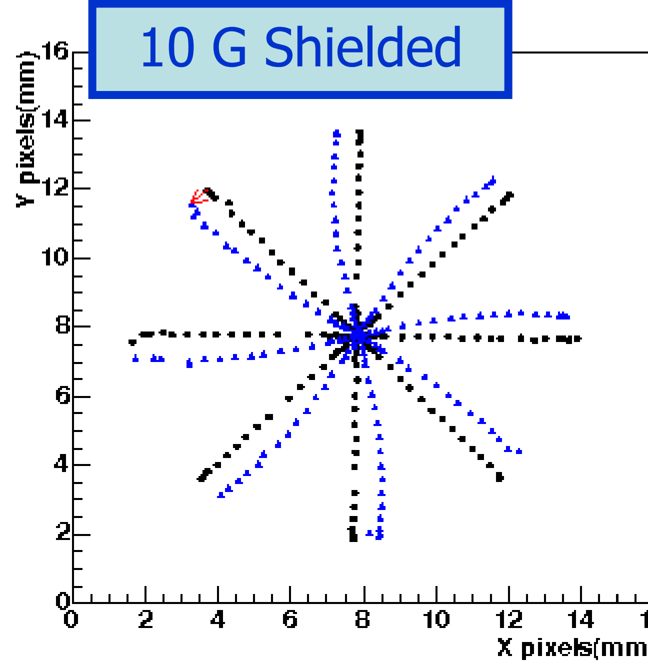
Pattern II

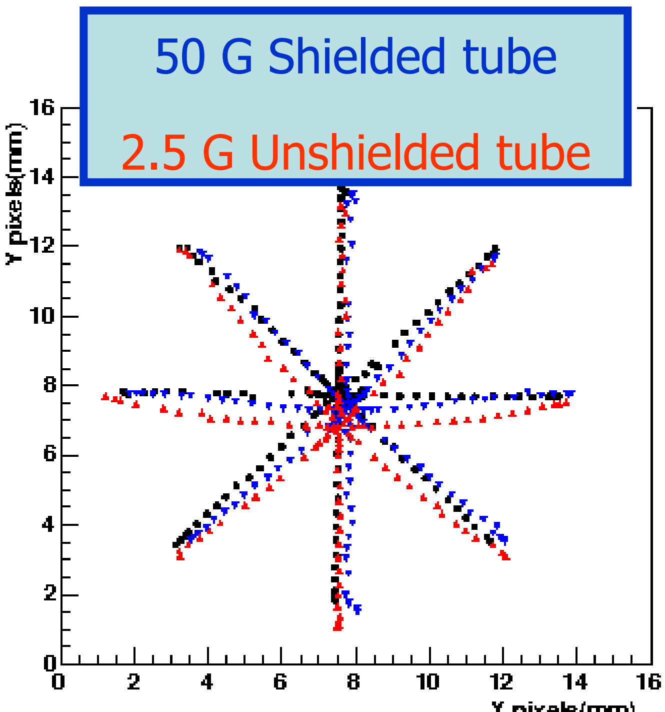


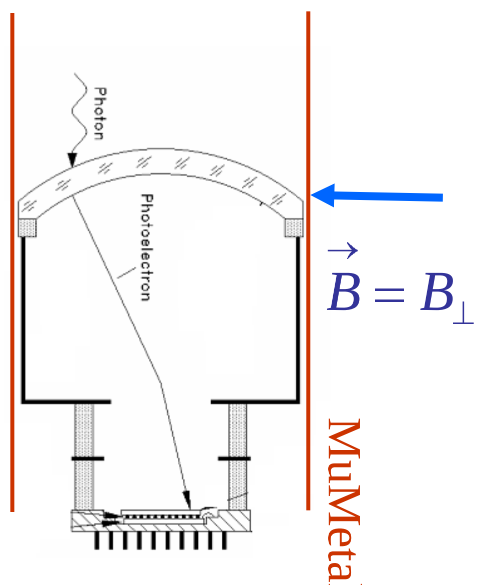
Pattern III







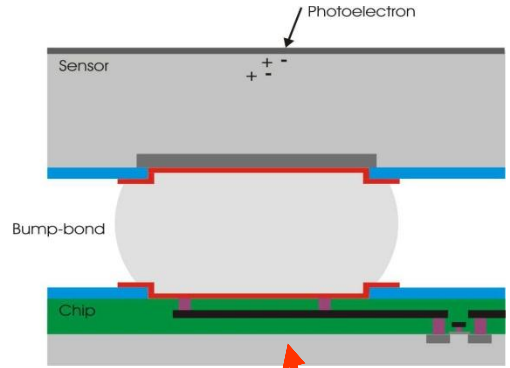


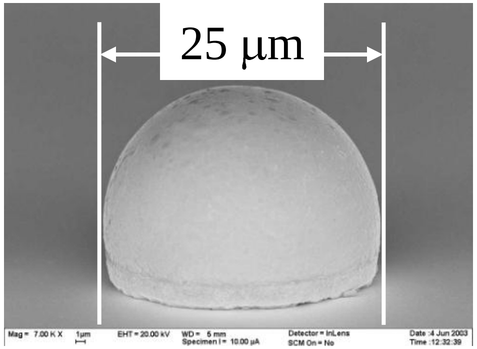


<u>Calibration and distortion monitoring system</u>
in both RICHes to allow corrections.

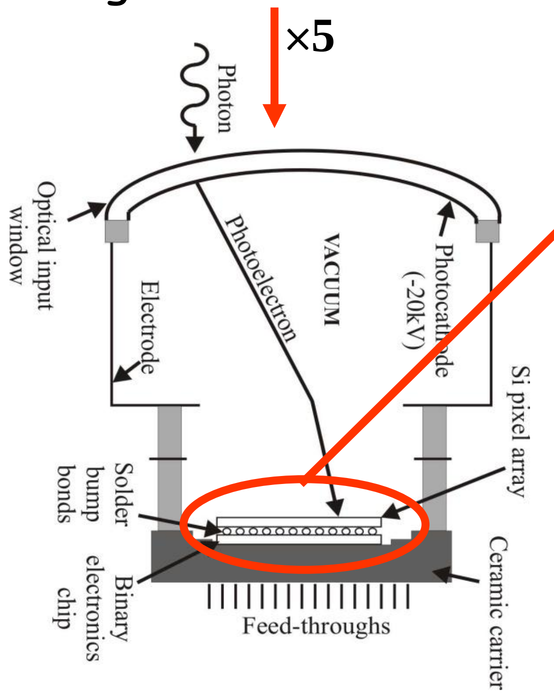
<u>Parameterisation</u>
under control for both axial and transverse field distortions.

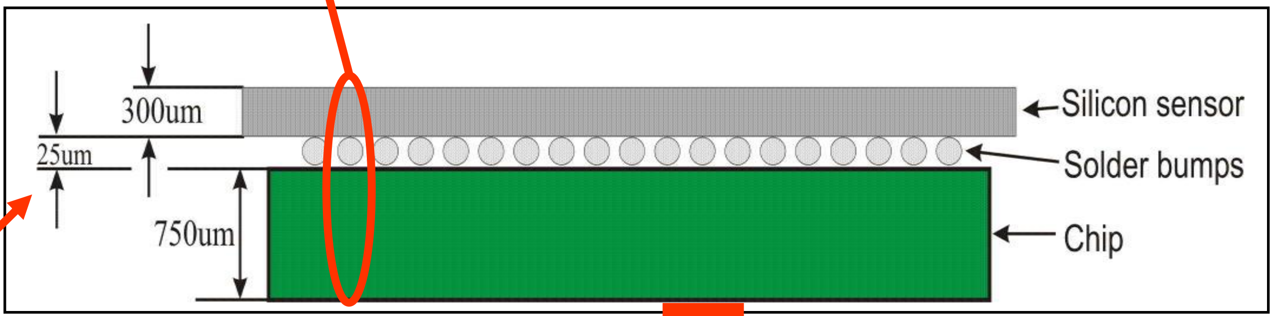
Front__ End__________ Electronics___________

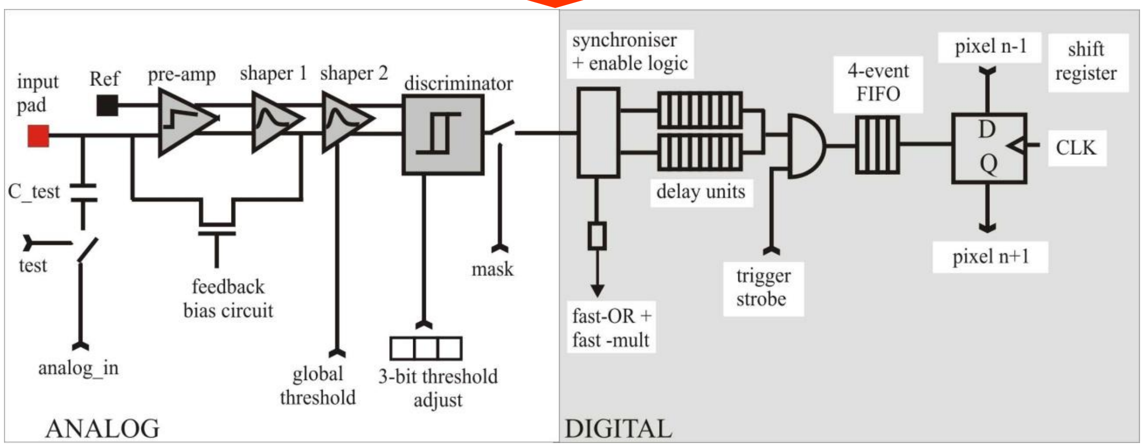




Demagnification:







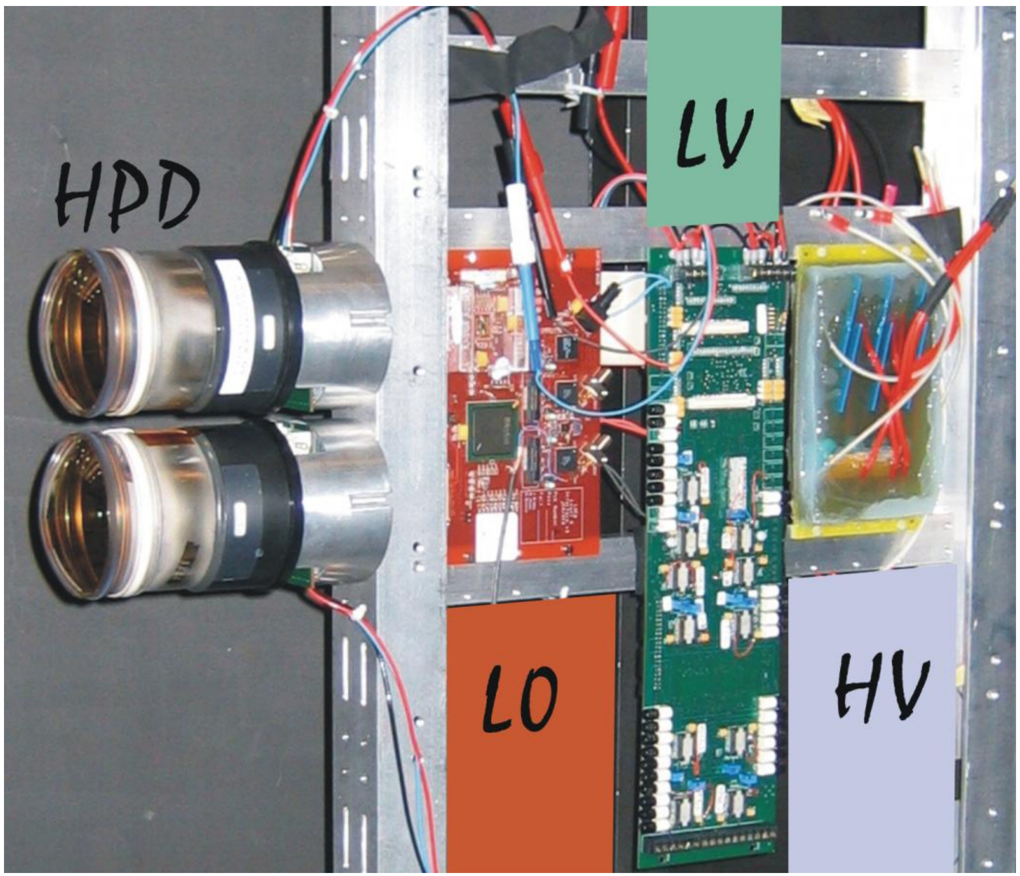
Advantages of this hybrid, pixel structure:

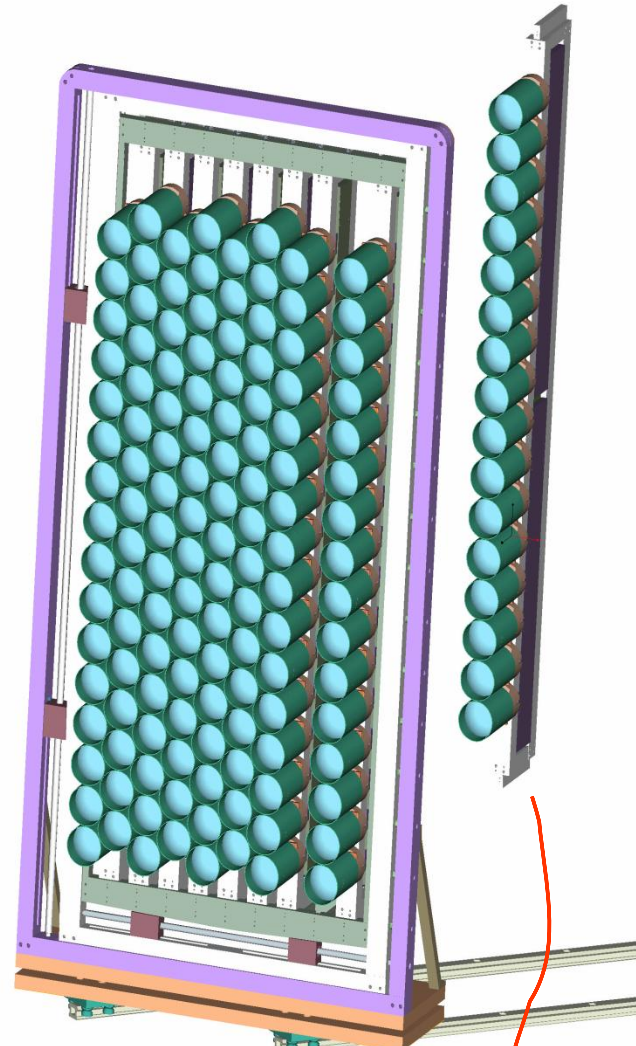
- **low noise ⇒ excellent resolution of single photoelectrons**
- **high channel number/density**

Four matrices of photon-detectors
to measure Cherenkov light over $2.6\ m^2$

500 pixel hybrid photon detectors (HPDs)
500,000 channels of data

HPDs mounted on columns together with readout
electronics, power distribution & active cooling
Each column = one independent module





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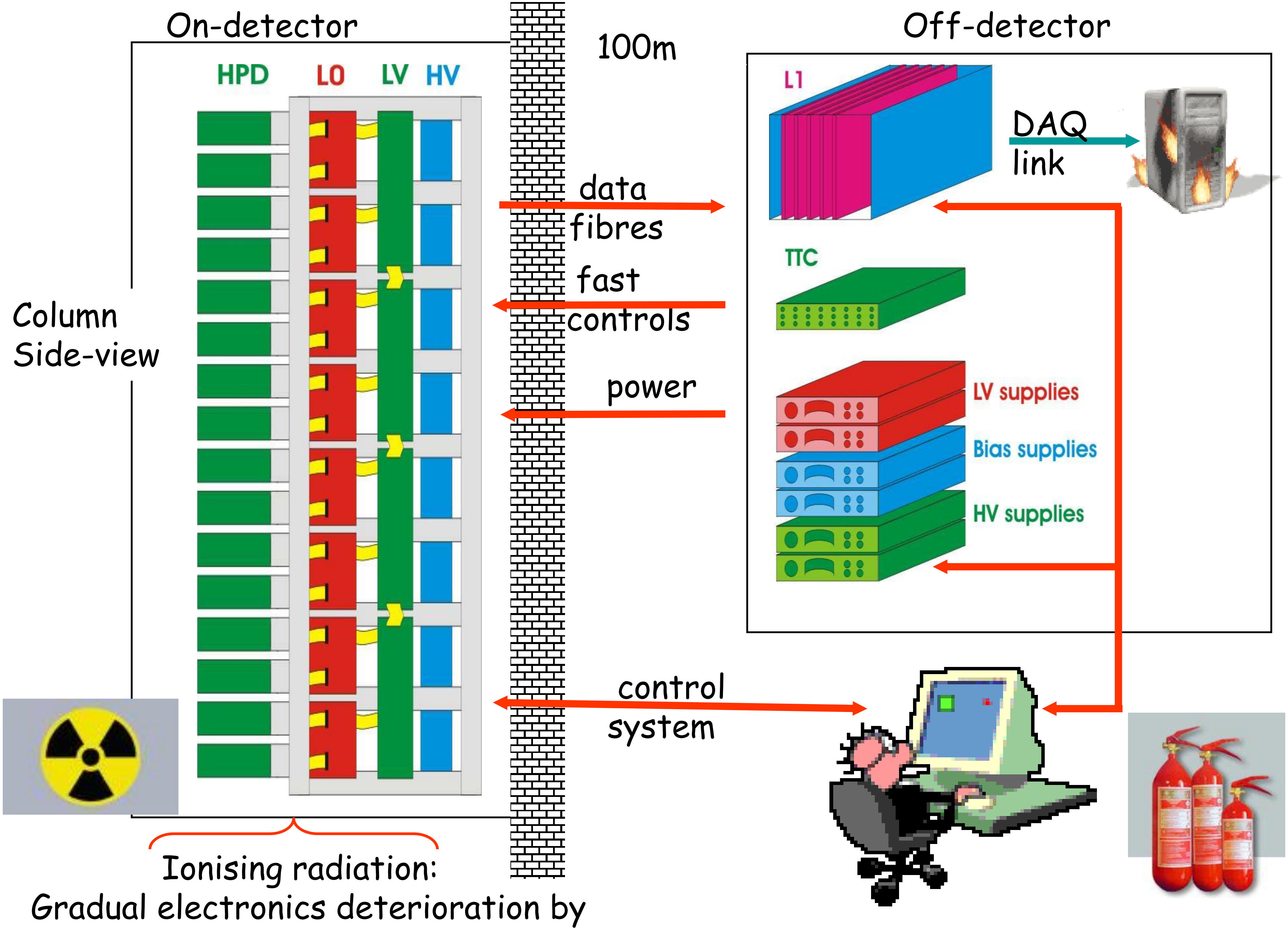
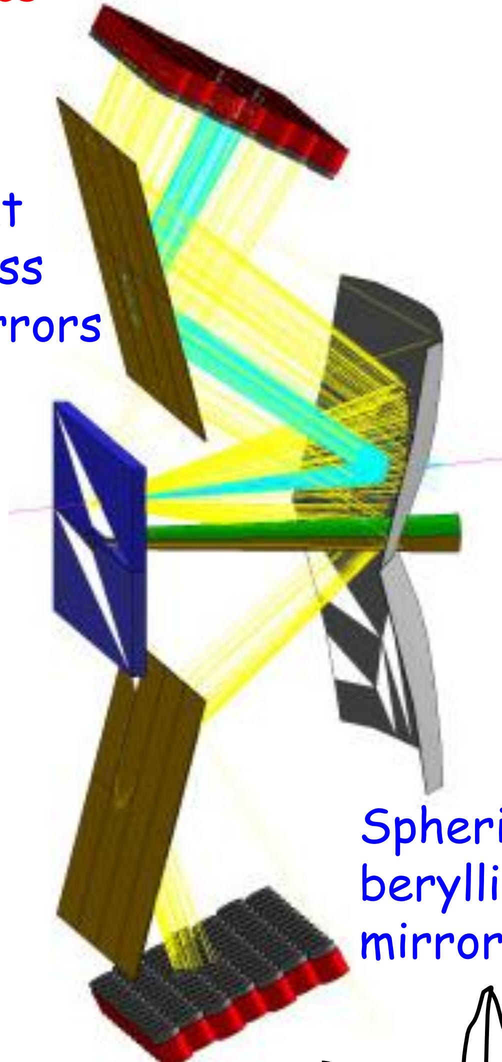

On-detector
100m
Off-detector
HPD
L0
LV
HV
Column
Side-view
L1
DAQ
link
data
fibres
fast
controls
power
TTC
LV supplies
Bias supplies
HV supplies
control
system
Ionising radiation:
Gradual electronics deterioration by
Heavy particles, Single-event effects, Bit flips, latch-up and Restricted access

RICH 1

Optics

Flat glass mirrors

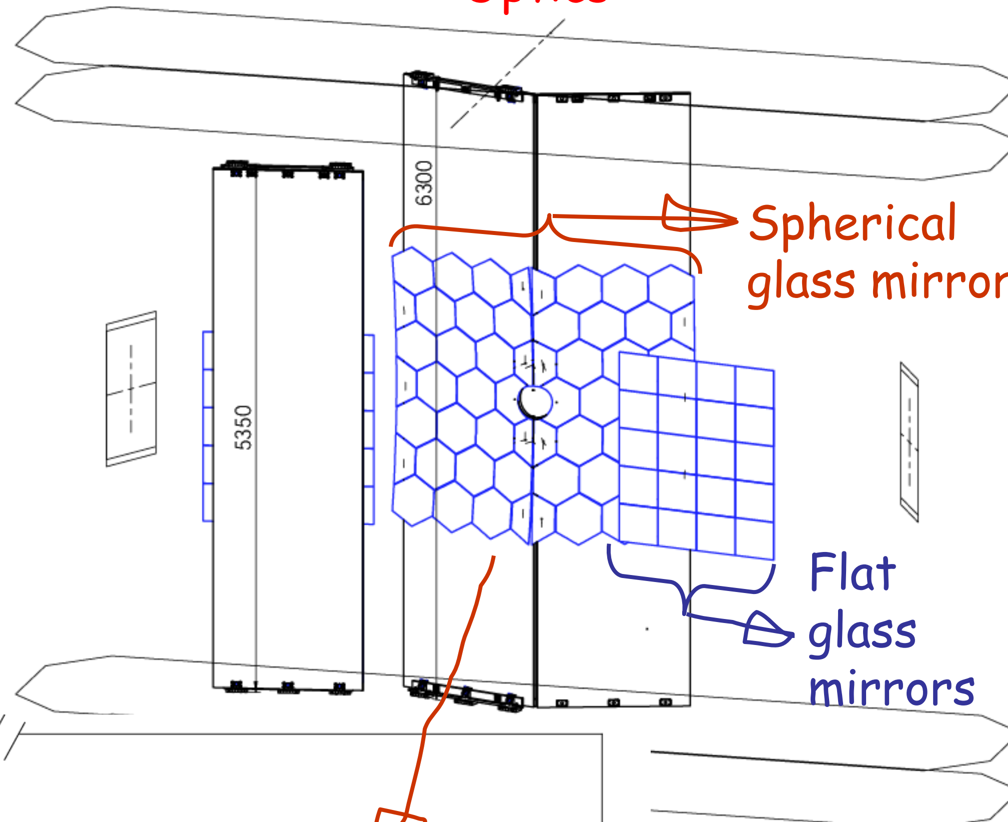


Spherical beryllium mirrors

Long X_0 and λ_0
High mechanical stability
C_4F_{10} compatible

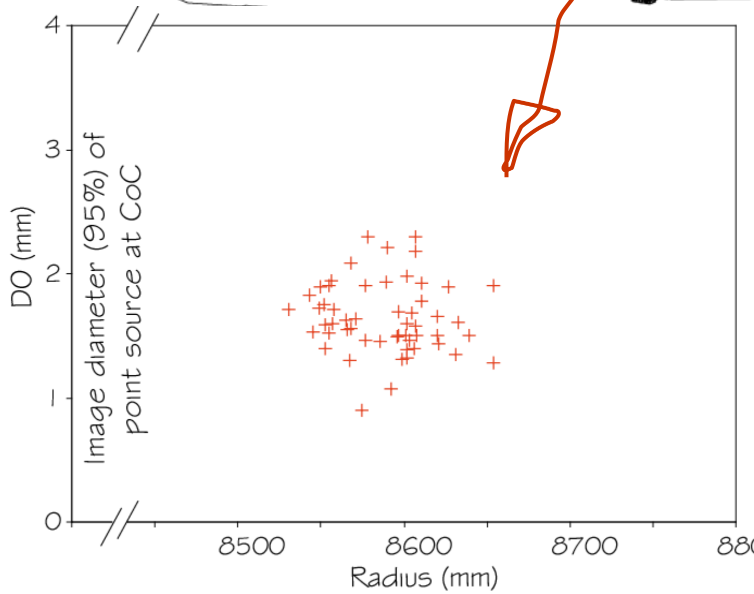
RICH 2

Optics



Spherical glass mirrors

Flat glass mirrors



6 mm Simax glass substrate

Coating:
Cr+Al+MgF_2+HfO_2

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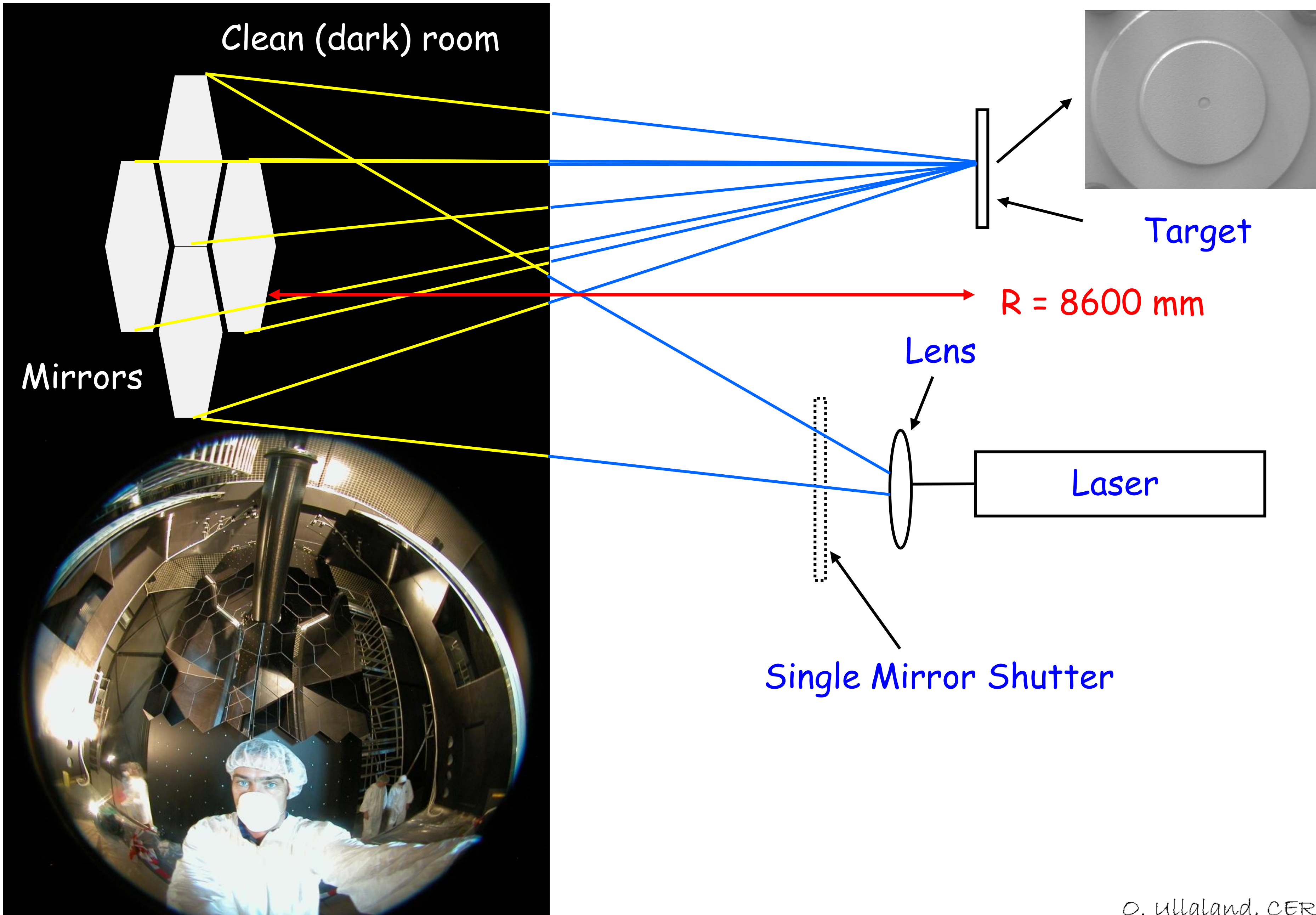
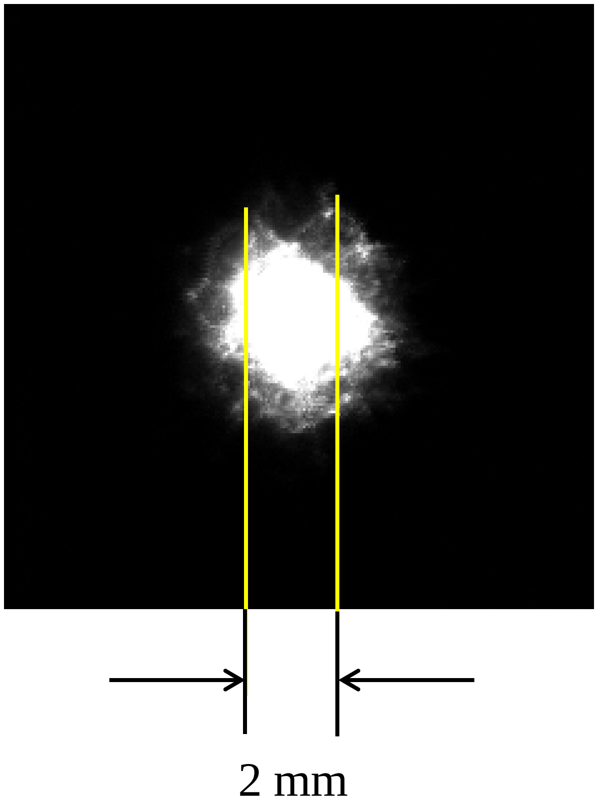
RICH 2 Alignment



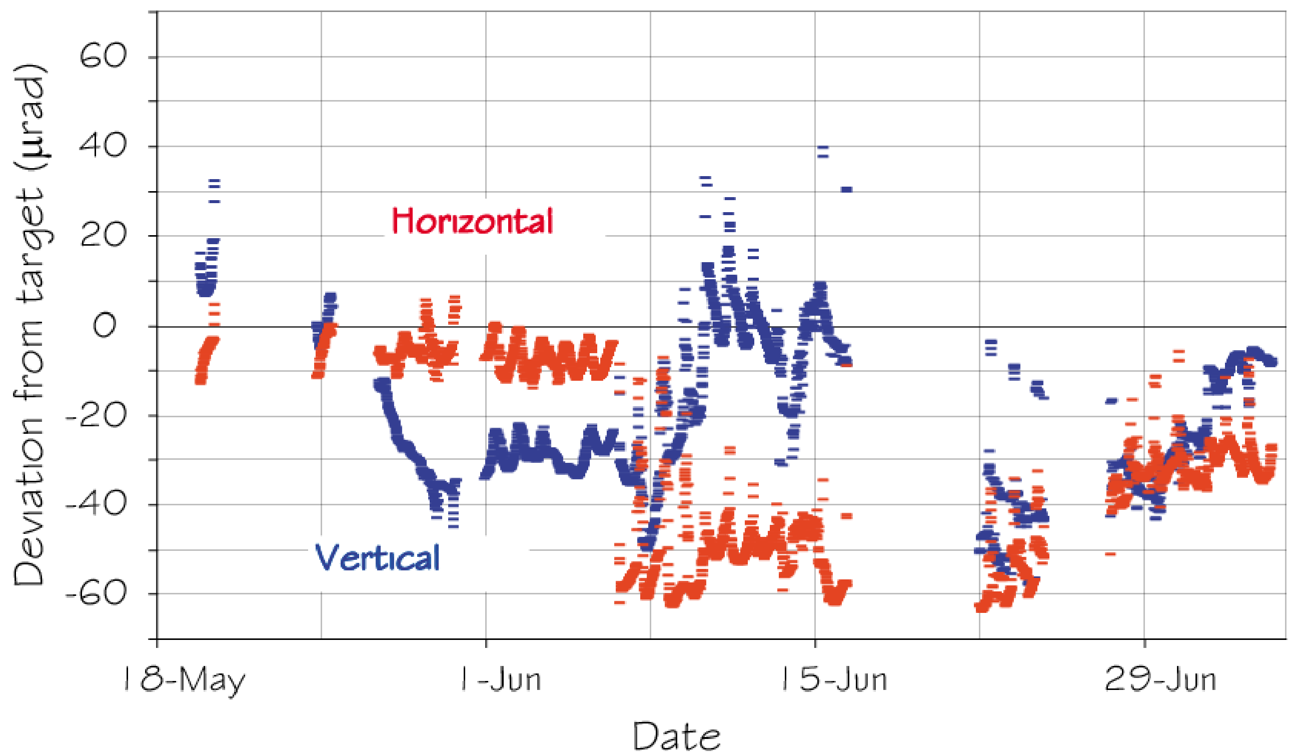
RICH 2

Spherical Mirrors Alignment

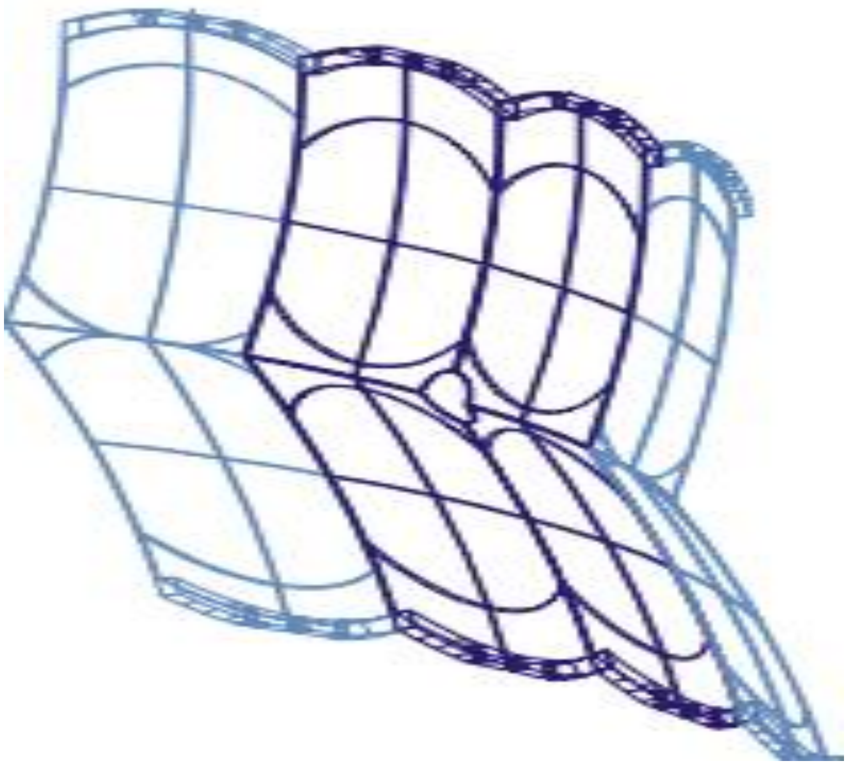
All mirrors from one side

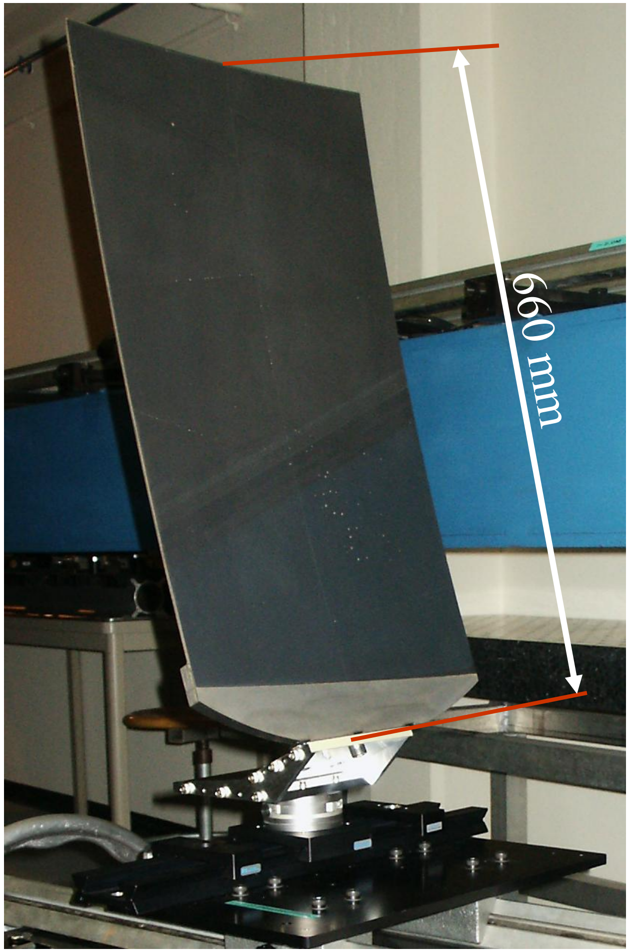


Alignment and stability set a 50 μrad contribution to the overall uncertainty in the single photon Cherenkov angle reconstruction



The RICH 1 spherical glass/beryllium mirrors
about 7 years of R&D





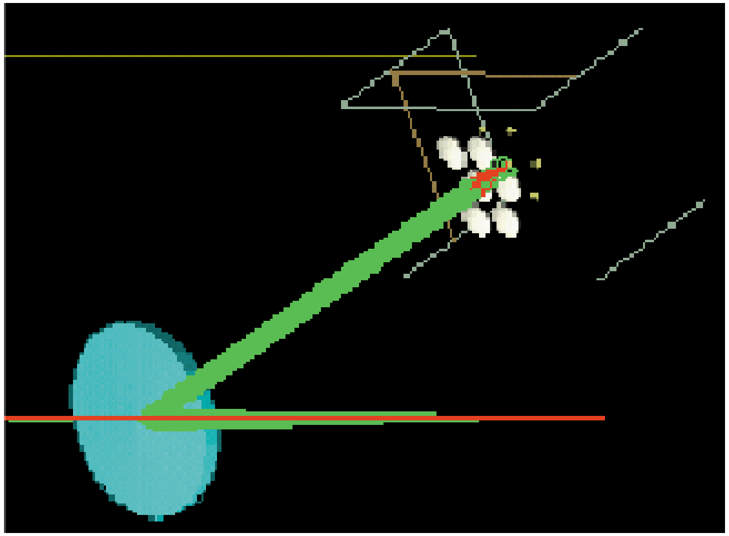
R: 2690 mm
D_0: 3.3 mm

Be-mirror substrate machined at Kompozit in Moscow-Russia.
Final thickness: ~4 mm.

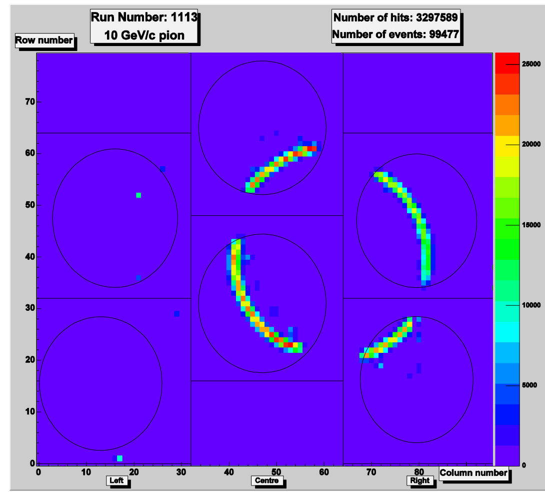
Glass Dressing at Vavilov State Optical Institute St. Petersburg-Russia
Final thickness: ~0.5 mm.

What did we learn From The Test Beam ?

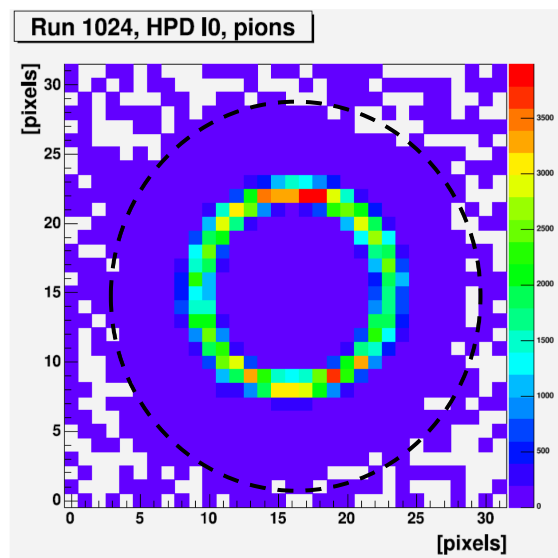
That the truth is in the details (but that we knew already).



Full simulation.



Accumulated rings in C_4F_{10}



3500

0

N_2 run, one HPD accumulated rings

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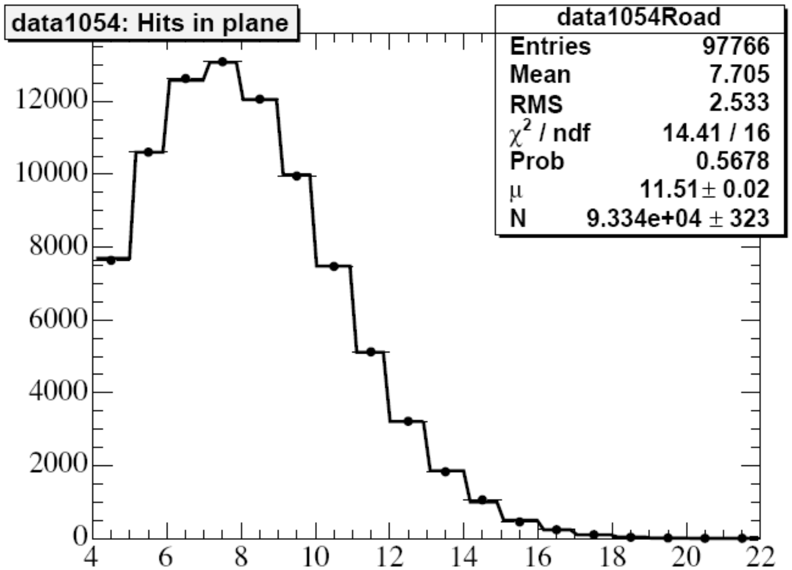
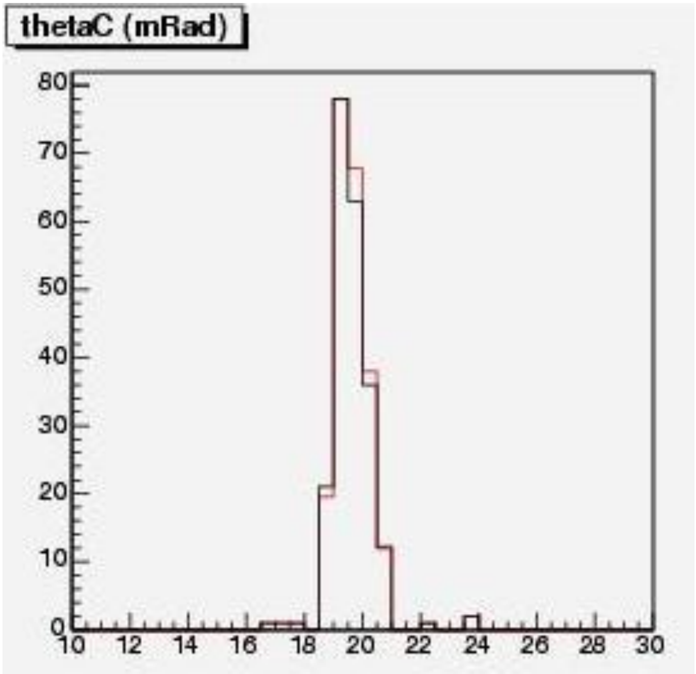
Photon yield and photon impact point: N_2



Typical Poisson fit

Comparison between data and simulation

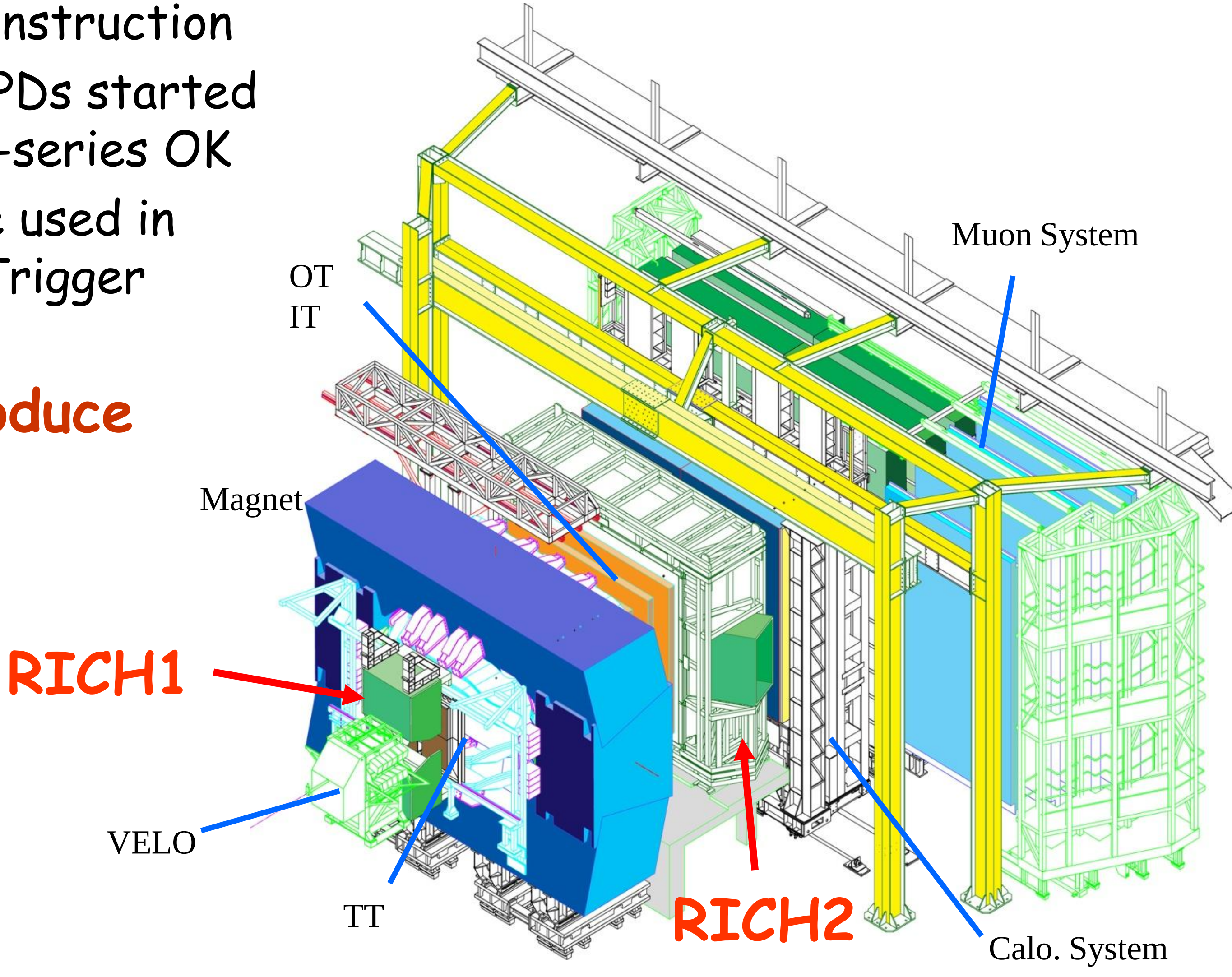
HPD	μ (fit)	μ (theory)	Ratio
L1	**10.1**	**10.0**	1.01
C1	**11.5**	**11.2**	1.03



- Take θ_C directly from MC info (beam & photon directions) **(red)**
- Reconstruct θ_C **(black)**
    - MC & reconstruction have the same mirror centre-of-curvature
- Detection point is the photon impact on the HPD quartz

Conclusion

- Particle identification and thereby the RICHes are an essential part of LHCb
- RICH 2 ready for installation
  RICH 1 under construction
- Production of HPDs started
  Pre-series OK
- RICH data to be used in the High Level Trigger
- **LHCb will produce physics from DAY ONE of LHC running**



Spare slides

"Just a second, I've got your interesting plots right here"

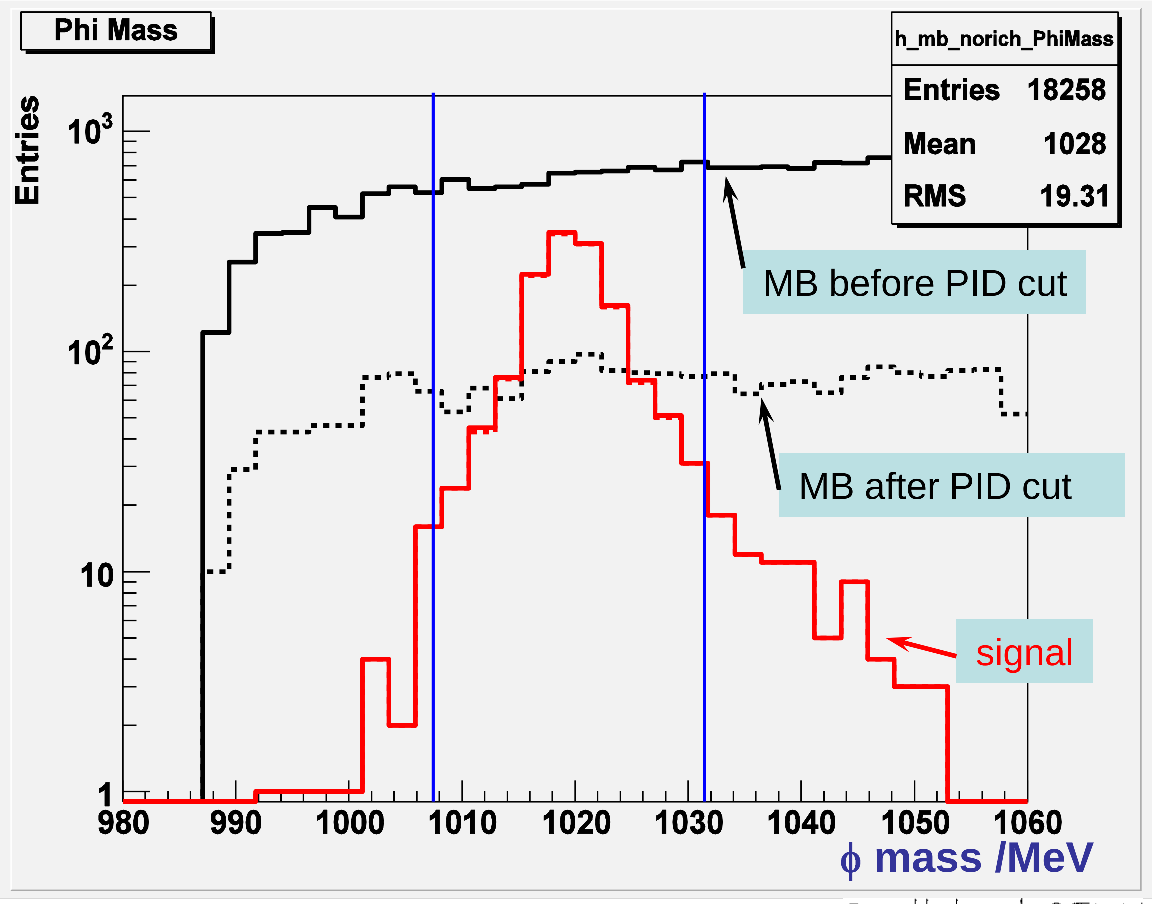
Towards Physics, Trigger and all that
An Inclusive Phi Stream

- LHCb uses a number of **inclusive** triggers to select events in the High Level Trigger (HLT) : single μ (900Hz), di-μ (600Hz)and D^* (300Hz) variants
- Will be extremely important in the 1^{st} year where tracking may not yet be perfect (→ substantial inefficiency in the HLT Exclusive Streams)

•Advent of online RICH allows minimum bias to be controlled to extent that can propose a new inclusive trigger:

- Select $\phi \to KK$ events
- Reject substantial background use tight online PID – order magnitude reduction in the background
- Add IP, ϕ mass and p_T cuts

→ ~40 Hz rate



•Why is this useful … ?

- Present inclusive triggers are focused on μ

  – what about <u>channels without μ ?</u>

- An inclusive ϕ stream would select :
  - $\phi\phi$ 97% of events with 3 track selection (made possible by online RICH)
  - $\phi\gamma$ 89% of the events we would have taken with the standard HLT exclusive trigger – no requirement at all on the g
  - $D_s(\phi\pi)h$ 80% of events with standard HLT exclusive trigger
  - $\phi\eta_c$ … ? [6 tracks to find ! Will be a very inefficient online!]
  - ϕl^+l^- … ? [w/o inv. mass requirement on the l^+l^-]
  - …
- Are a no. of channels that are difficult to select in the HLT: eg. $B_d \rightarrow \phi K_s$

  Don't have the time to do full tracking online :

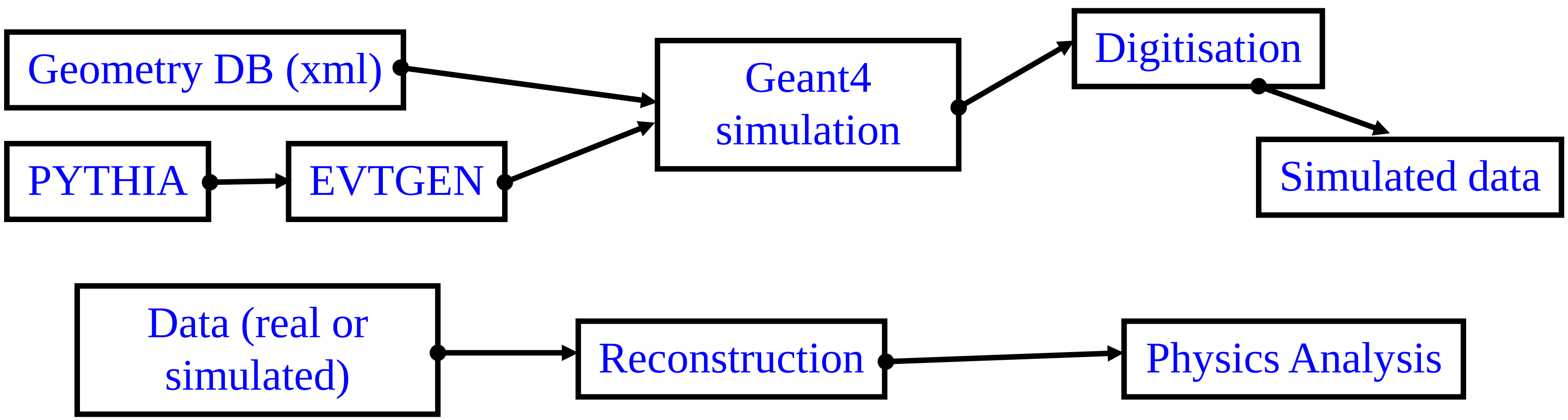
  only find those K_s that decay in the VELO. $\rightarrow$ ~30%
- Can more than double trigger efficiency from ~30% $\rightarrow$ ~70% with incl. ϕ

- While the price is ~40Hz, we have a number of channels with ϕ's, some of which are high multiplicity and we will struggle to select

- Such inclusive triggers will make us flexible and robust at start-up

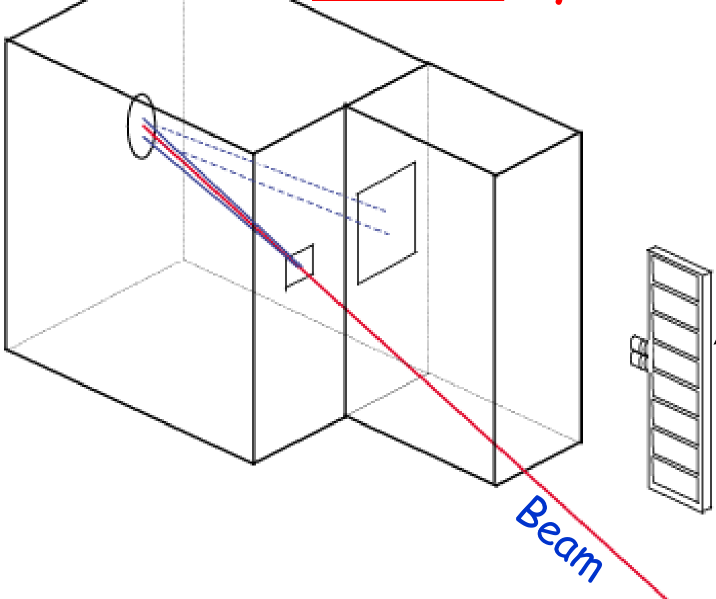
Leading up to physics

- Custom simulation of Cherenkov light production allowed the study and optimisation of the various system parameters.
- LHCb now use a C++ OO framework (Gaudi) and have incorporated Geant 4 in the framework

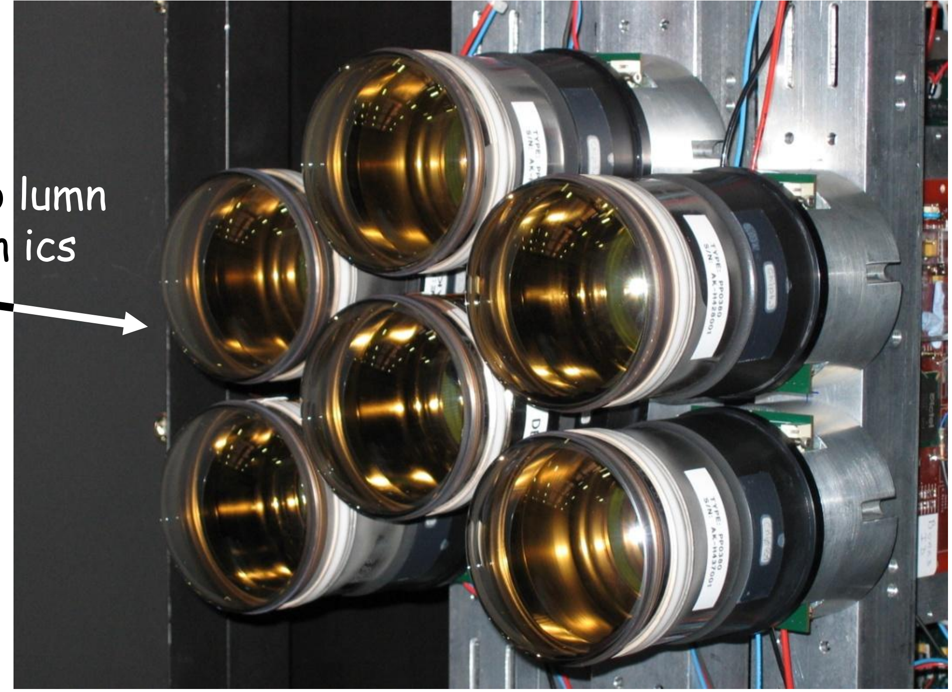


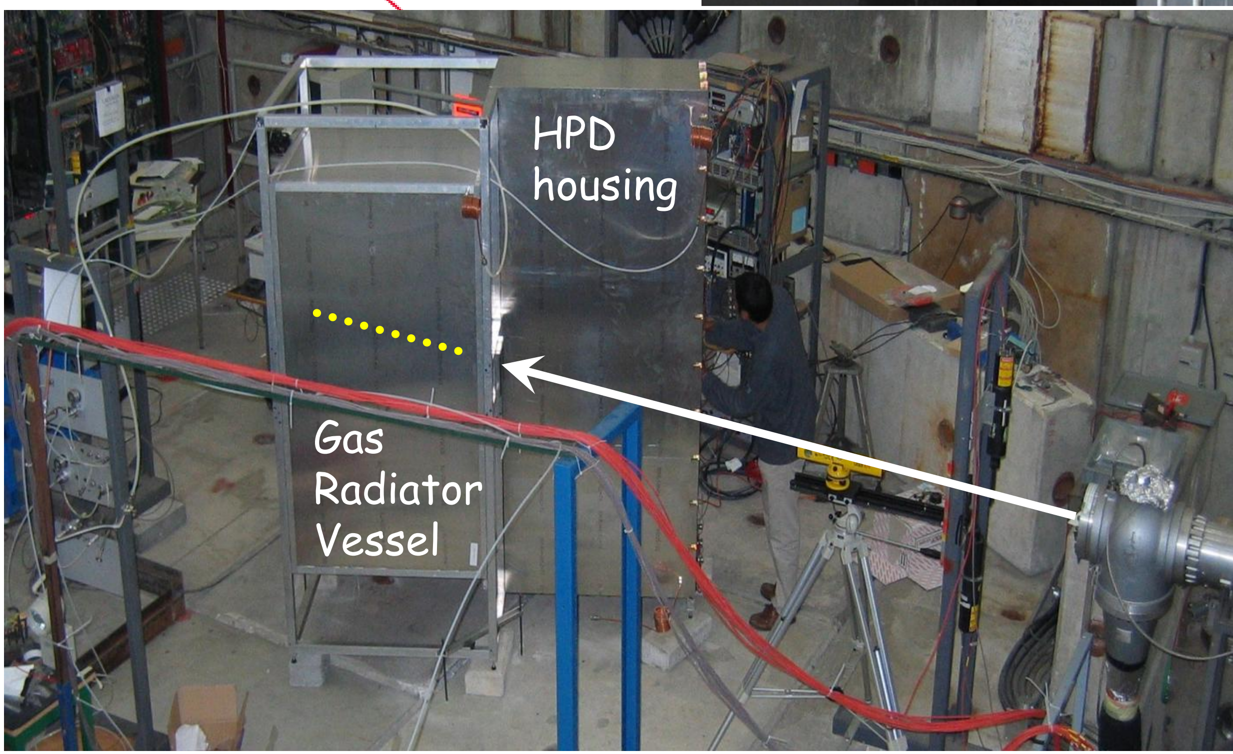
Gaudi is a very flexible framework that simplifies the introduction and testing of new pattern recognition algorithms.
Currently testing the use of RICH information in High Level Trigger

System Test



HPD column mechanics





PS beam:
10 Gev/c π^- / e

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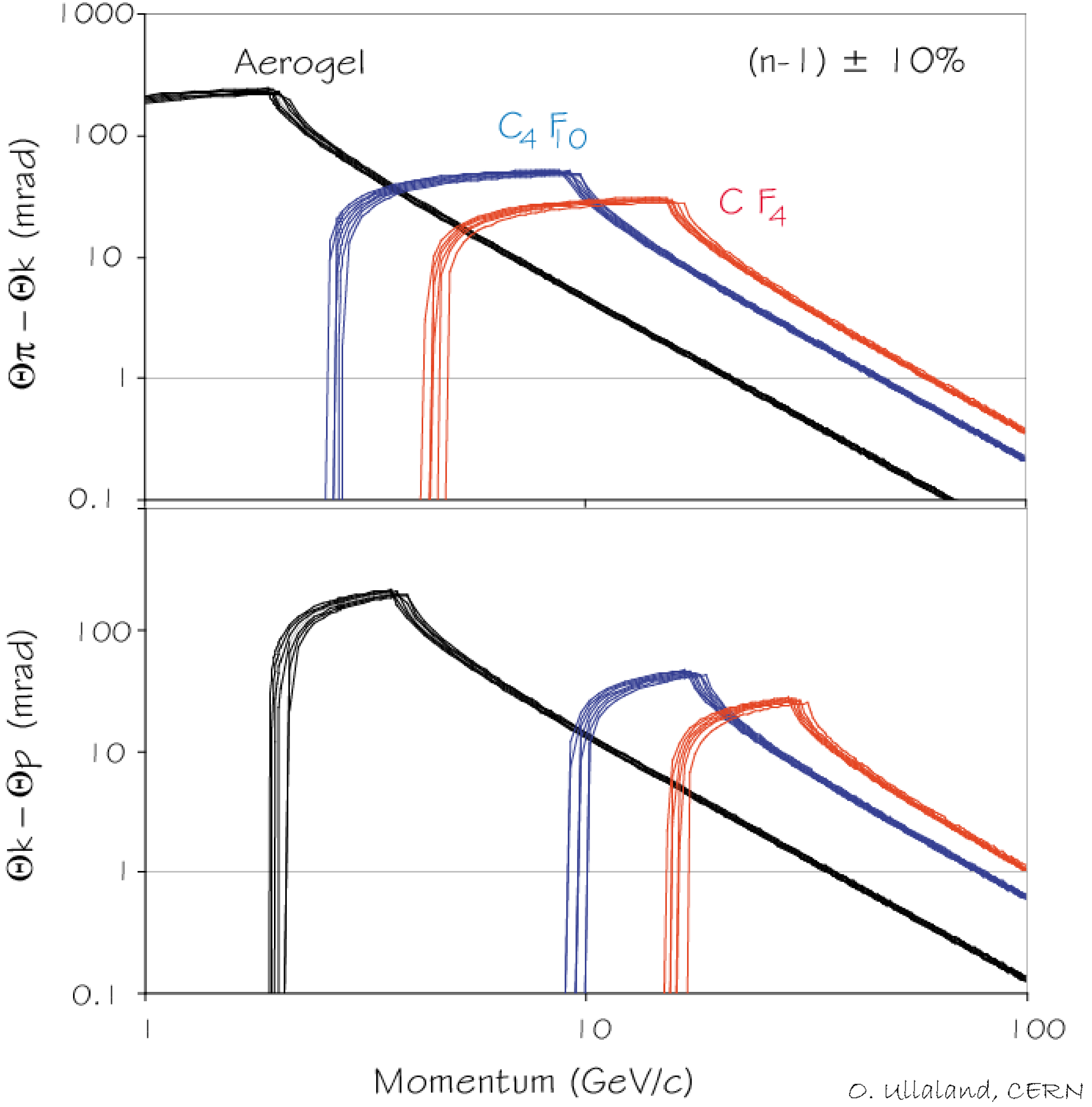
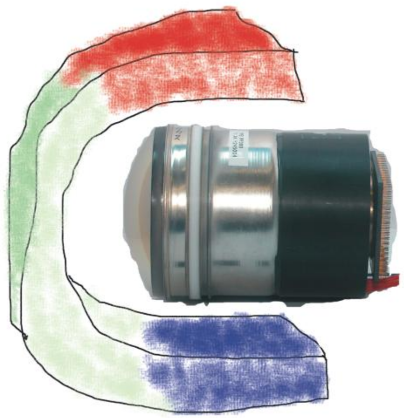
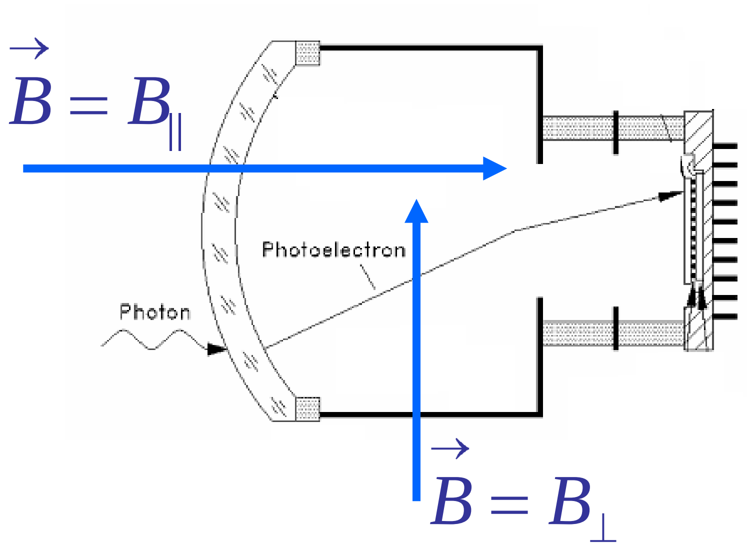
Choice of radiator media:

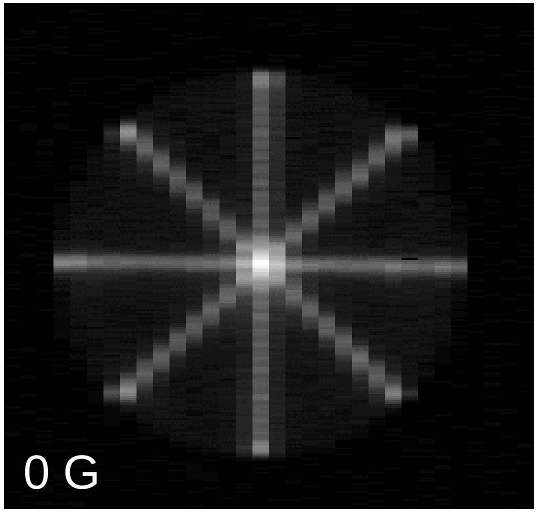
Positive K-identification

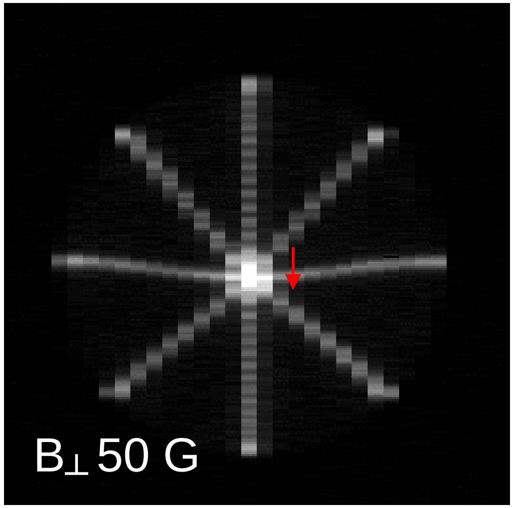


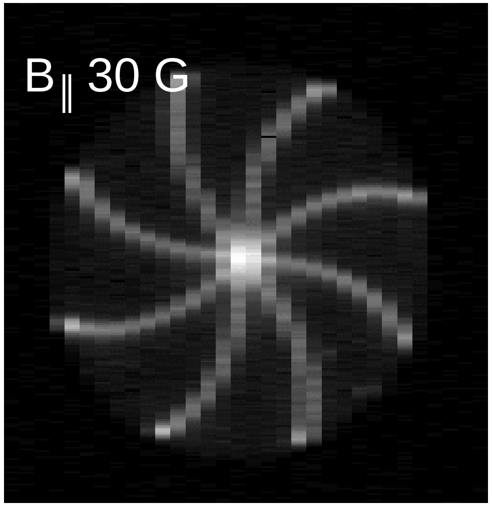
HPD and Magnetic Fields

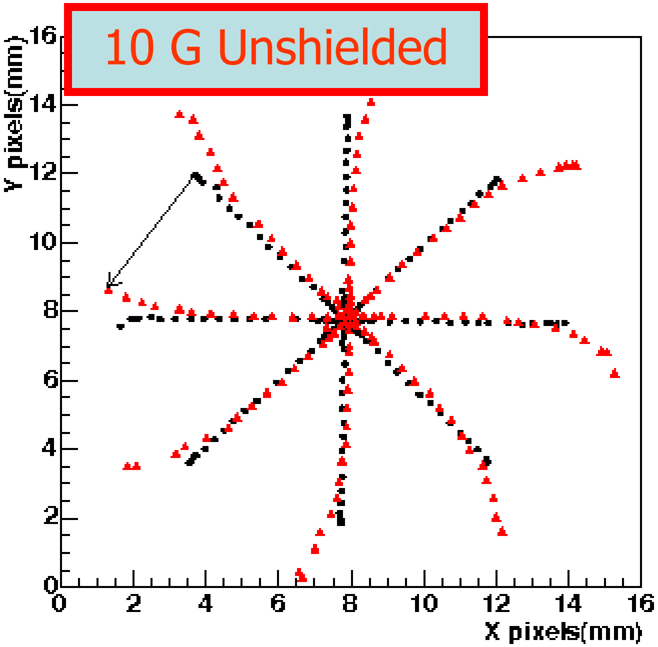


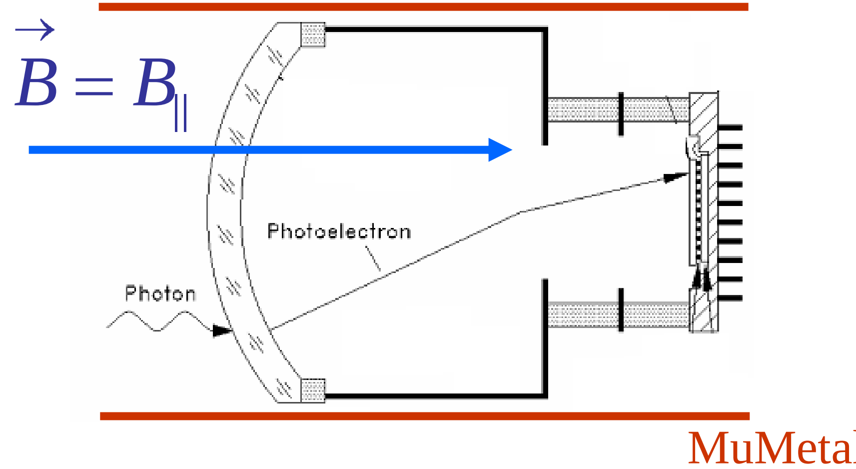


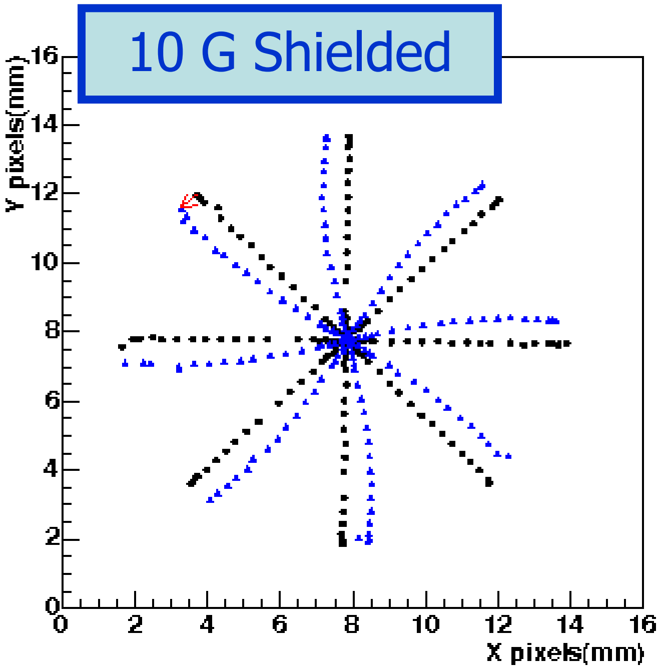


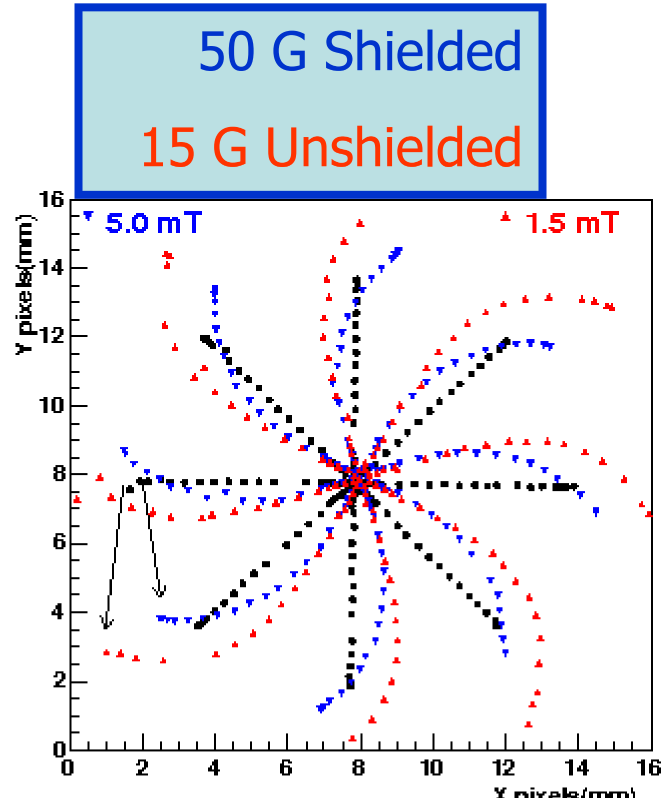












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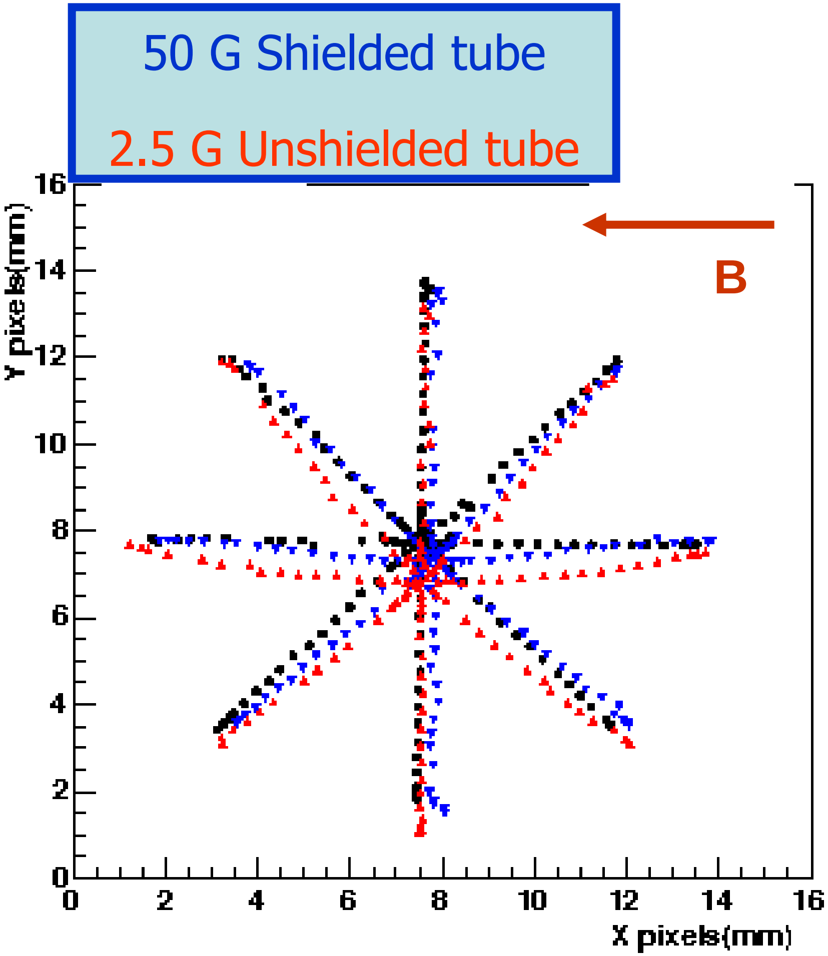

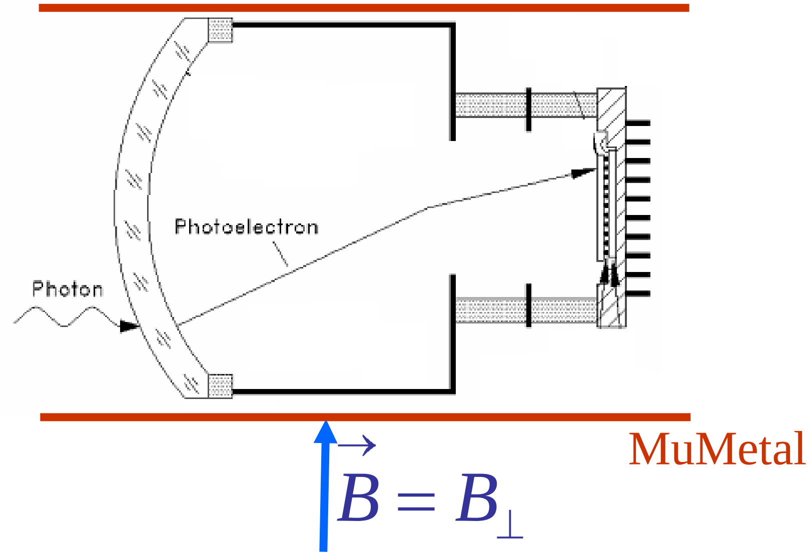

Unshielded Tube	
B(G)	Δd_{max} (mm)
2.5	**0.99**
5.0	1.64
7.5	2.23
10	2.76
15	3.62

Shielded Tube	
B(G)	Δd_{max} (mm)
30	0.45
50	**0.73**

Calibration and distortion monitoring system

in both RICHes to allow corrections.

Parameterisation

under control for both axial and transverse field distortions.

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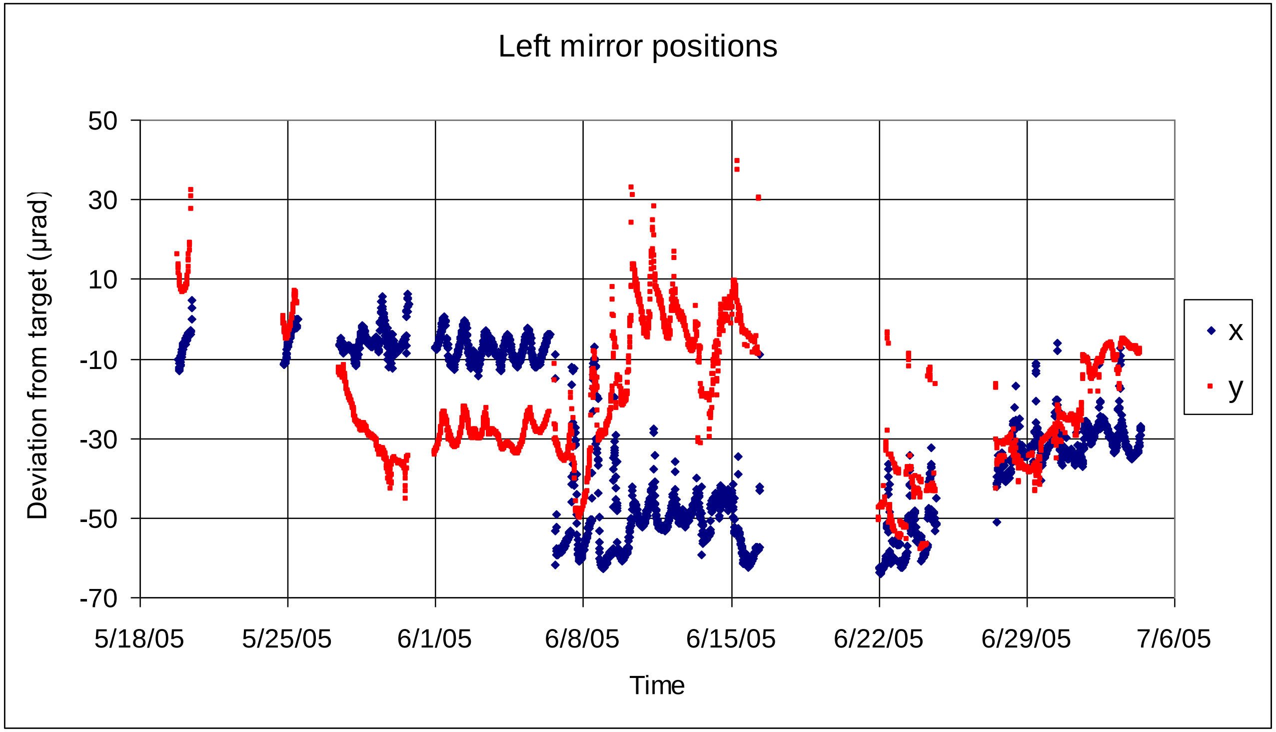

Left mirror positions
50
30
10
-10
-30
-50
-70
Deviation from target (µrad)
5/18/05
5/25/05
6/1/05
6/8/05
6/15/05
6/22/05
6/29/05
7/6/05
Time
x
y