The LHCb Outer Tracker: Production & Ageing studies

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MPI-K

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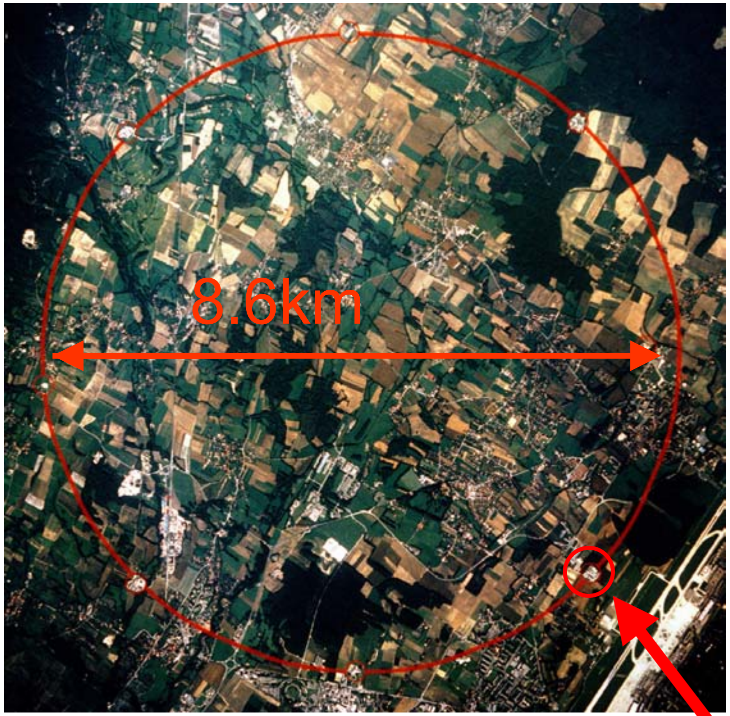


p-p collisions
beam energy 7 TeV

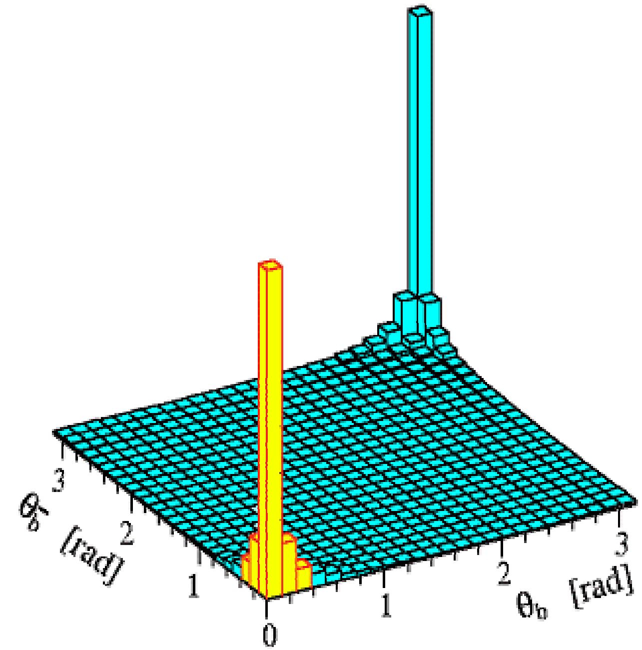
Four experiments:
Atlas, CMS, Alice and LHCb

First collisions:
2007

LHCb

LHCb: Designed to exploit CP violation and rare decays of B-mesons at LHC

$\sigma_{tot} = 80$ mb
$\sigma_{bb} = 500$ µb
→ 10^{12} $b(\bar{b})$ per year



Production mechanism:
Gluon-gluon fusion

LHCb:

•Single arm forward spectrometer

12 mrad < θ < 300 mrad(1.8<η<4.9)

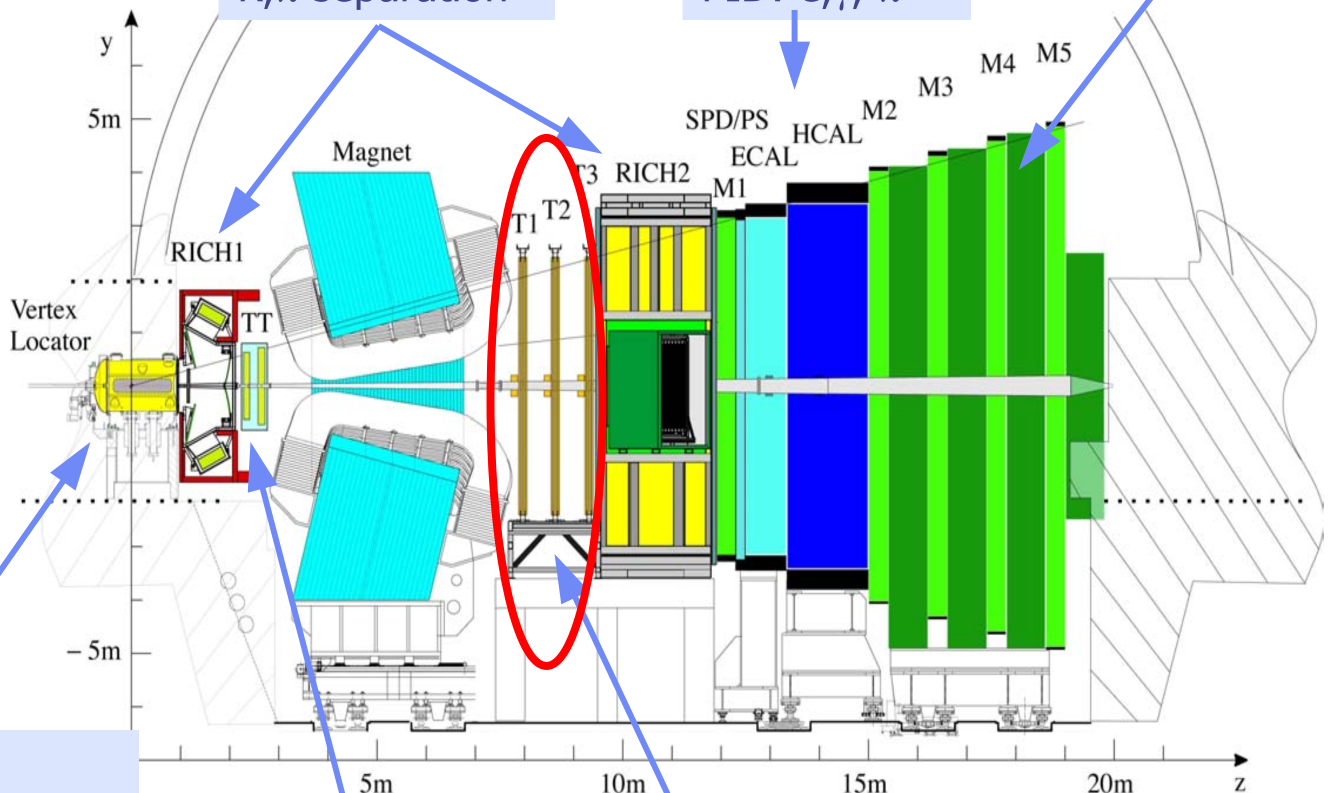
The LHCb experiment

Particle ID:

RICHES: PID
K,π separation

Calorimeters:
PID: e,γ, π^0

Muon System



Tracking system:

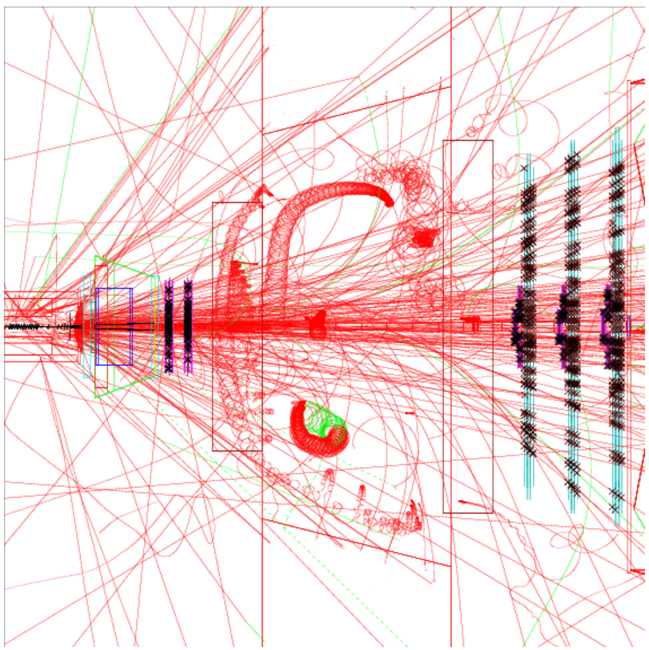
VELO:
- primary +displaced vertex
- impact parameter

Trigger Tracker:
p for trigger

Tracking Stations:
p of charged particles

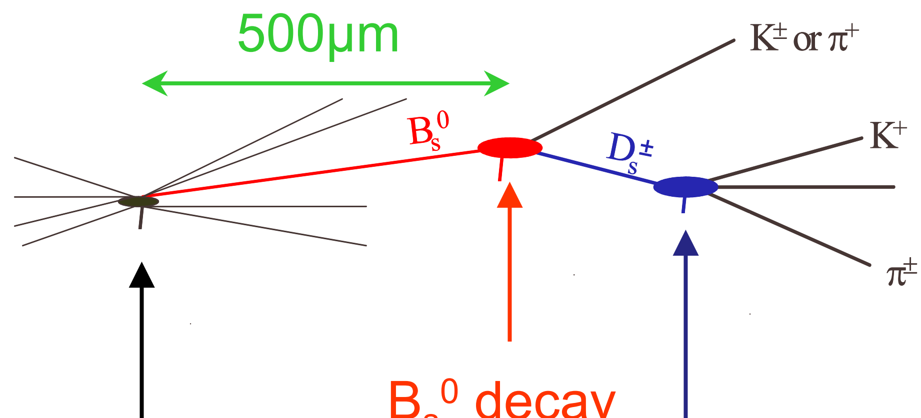
Physics

typical event at LHCb:
(simulation)



10m

Challenge:
Reconstruct decay vertex of B-meson,
e.g. $B_s^0 \longrightarrow D_sK$



Primary vertex

B_s^0 decay vertex

D_s^{+-} decay vertex

Contributions of the PI to LHCb

1. Construction of ~1/4 of Outer Tracker detector modules.
2. Development and test of TDC chip (OTIS) for drift time measurement.
3. Development and test of optical data transmission.

Outer tracker: demands

1. Measurement of momentum

   ($\delta p/p$ = 0.4% @ 20GeV)

   ➔ $\sigma_x < 200\mu m$

2. LHC bunch structure (40 MHz interaction rate)

   ➔ fast charge collection

3. LHC environment

   ➔ rate capability (~400kHz/cm²)
   ageing resistant

4. Pattern recognition

   ➔ Occupancy < 7%

5. Low radiation length

➔ Usage of Straw tubes

Outer tracker: parameters

3 stations (6m x 5m)

4 planes per station (X/U/V/X)

2 layers of straw tubes per plane

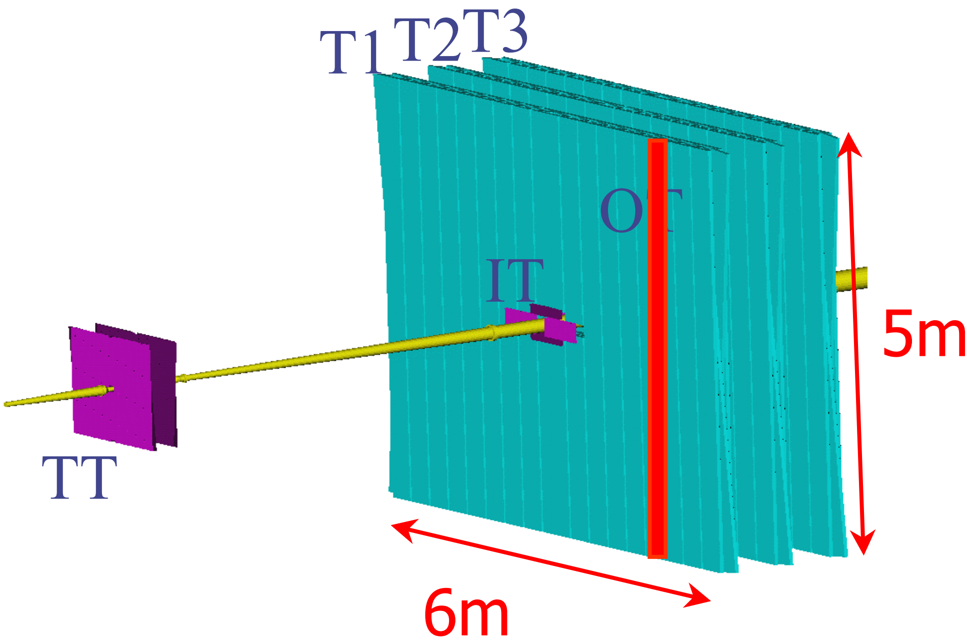
➔ 55.000 straw tubes

137.5 km of straw tubes

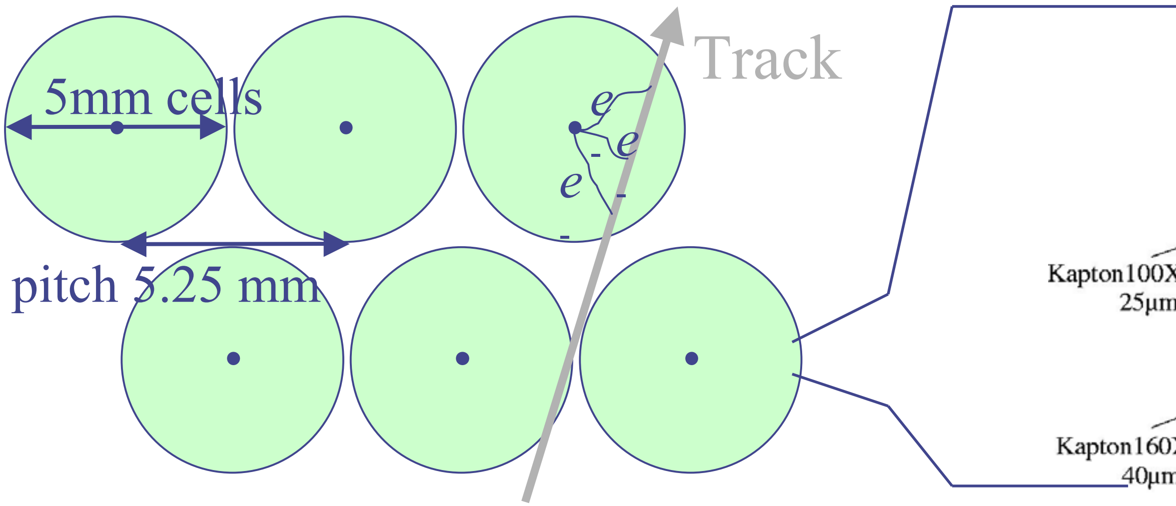
➔ modular design

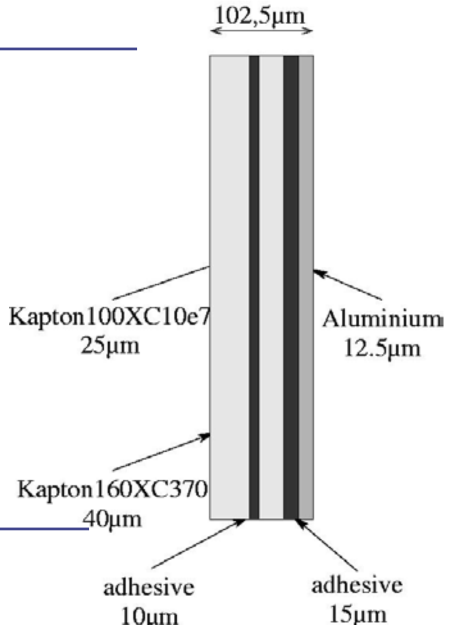
264 modules of 5 m x 0.34 m

256 straws of 2.5 m



Detector technology: straw tubes



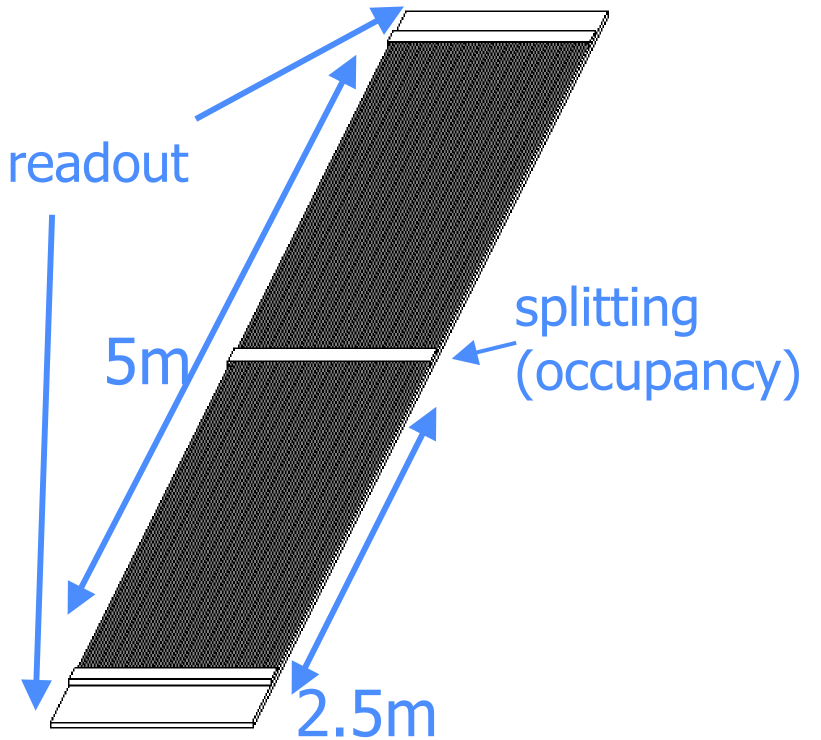


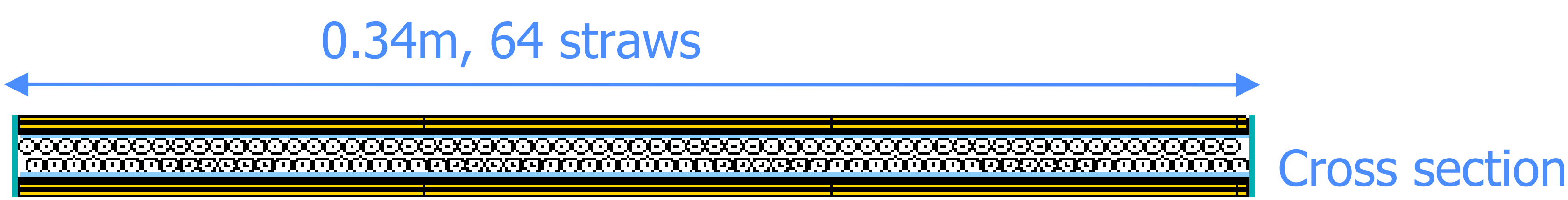
- Inner foil (cathode):
  Kapton XC
- Outer foil:
  Kapton/Aluminium-laminate
- Anode:
  25 µm wire (gold coated tungsten)

Design of detector modules

length : 5m
width: 0.34m
length of straws: 2.5m

2*64 straws per half module
→ 256 straws per module

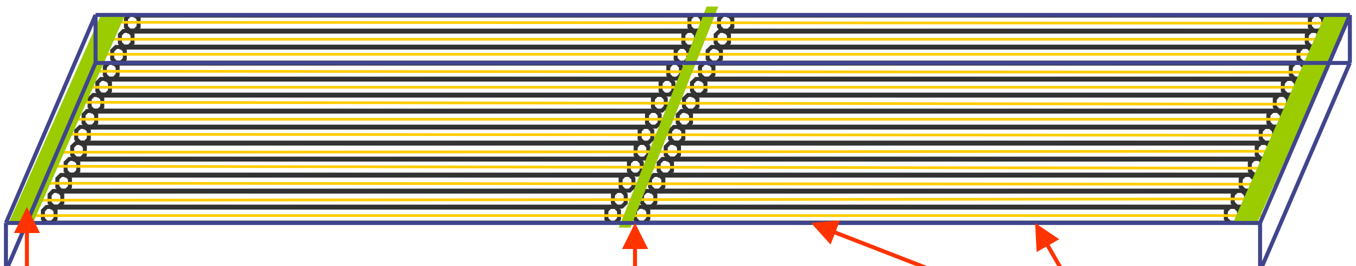


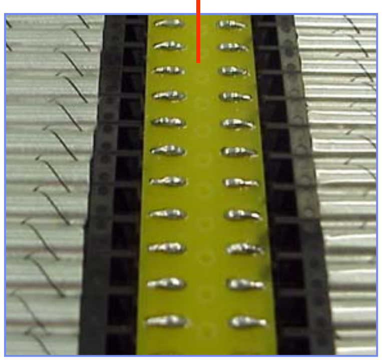


Detector modules I

A. Half modules (one straw layer):

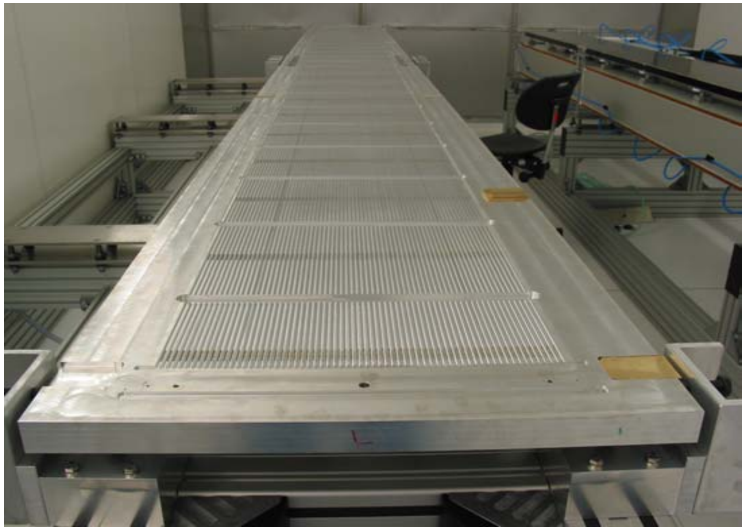
1. Rohacel panels with CF skins, covered with Kapton/Al-laminat
2. PCB's
3. Straws + wire locator and endpieces
4. Wires

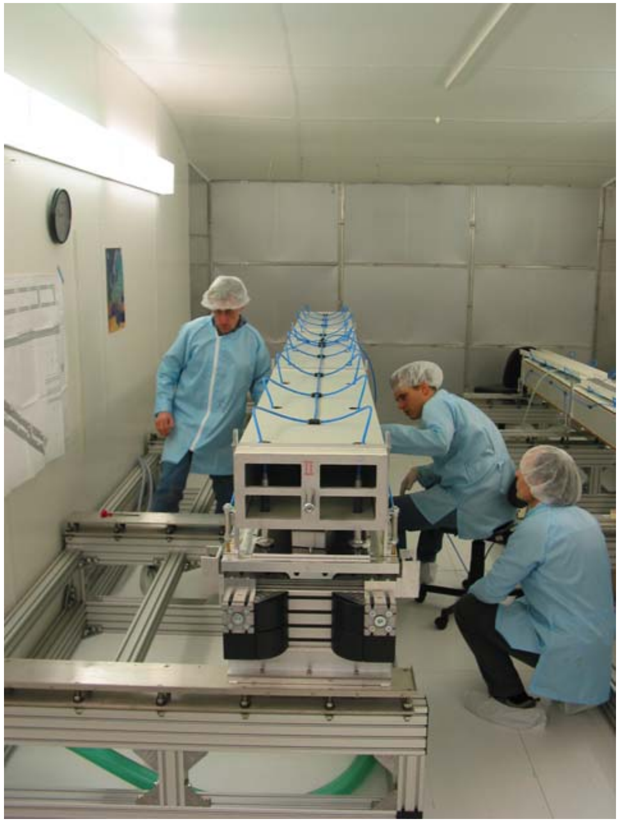




Wire locator (2x per straw) and endpieces

Module production



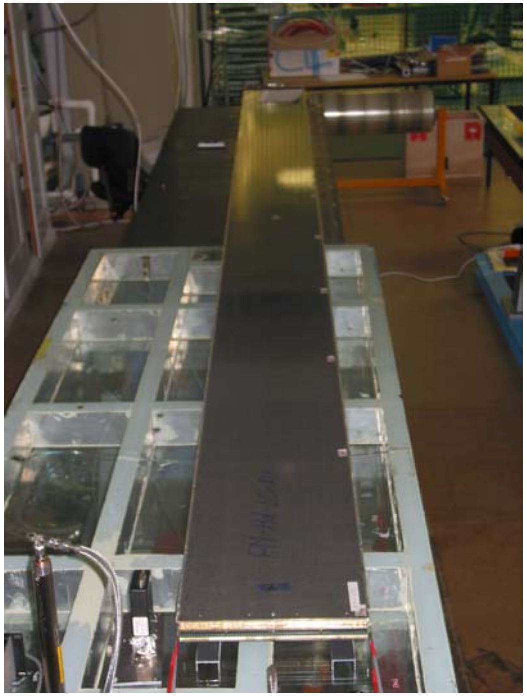


Module production II

Two half modules
+ side walls

gluing

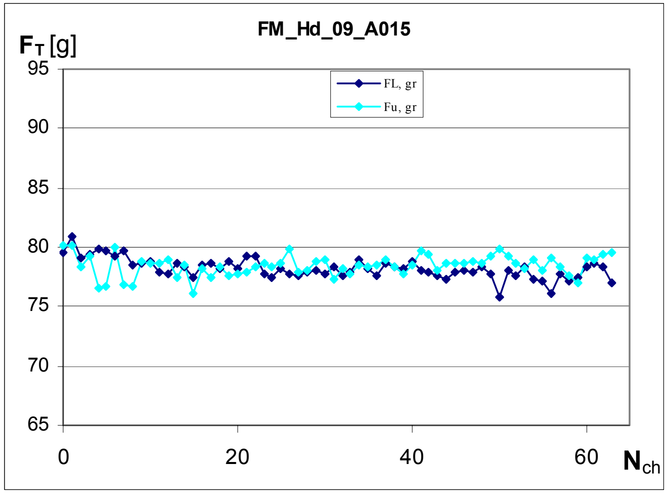
Full module



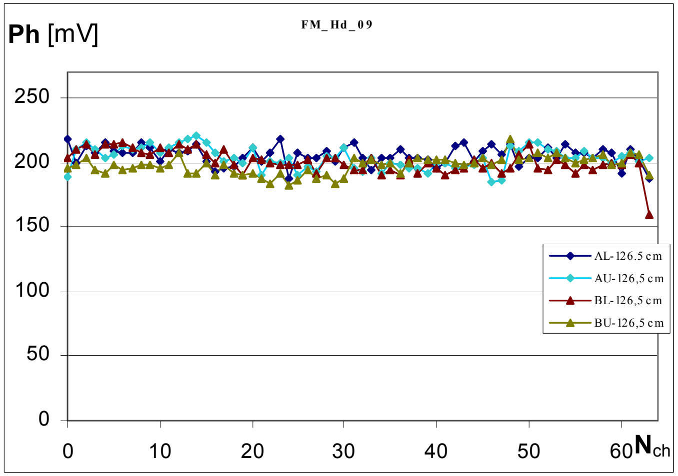
Quality control

Half modules:
- HV tests
- dark current measurements
- wire tension measurements

Final modules:
- gas tightness
- dark current
- uniformity of response
  - (pulse height from ^{55}Fe)



wire tension



pulse height

Choice of the counting gas

Requirements to the counting gas

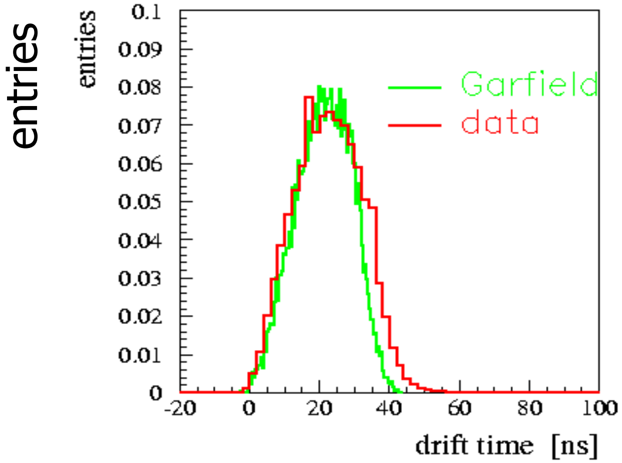
1) fast
2) good position resolution
3) no aging

⇒ $Ar + CO_2 + CF_4$? ? ? ?

Usage of CF_4:

Pro: fast

Compare the gases



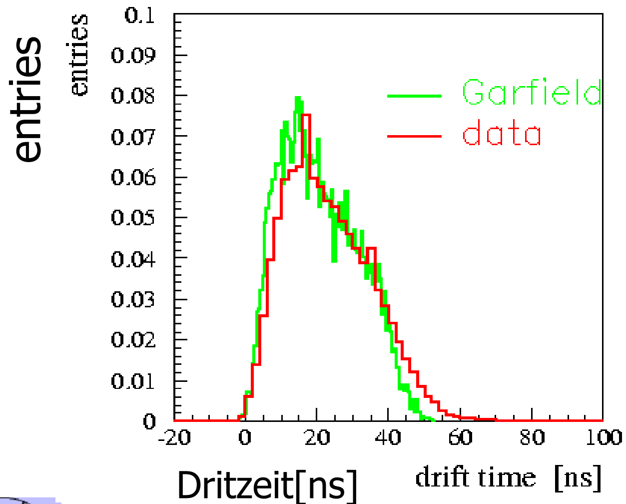
37+/-1 ns
for 95%
of the data

Interaction every 25 ns

→ Bunch crossing rate

BX rate = 40MHz

$ArCO_2CF_4$ (75:10:15):
fast gas
readout within 2 BX



44+/-1 ns
for 95%
of the data

$ArCO_2$ (70:30)
readout within 3 BX

Choice of the counting gas

Requirements to the counting gas

1) fast
2) good position resolution
3) no aging

→ Ar + CO_2 + CF_4 ? ? ? ?

Usage of CF_4:

Pro: fast

Contra: electronegative

→ degradation of spatial resolution

??? Impact on aging ???

Ageing of gas detectors

Long term operation of gas detectors:

Possible degradation of detector performance, induced by radiation

Symptons:

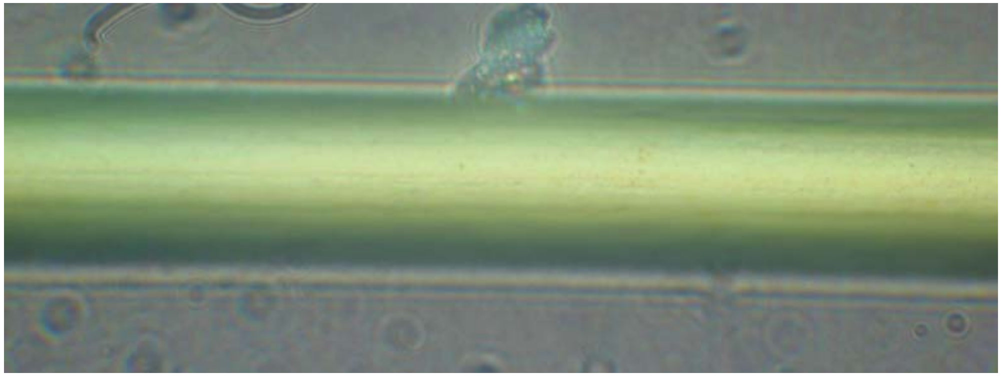
- gain loss → reduced efficiency
- degradation of energy and spatial resolution
- dark currents

caused by:

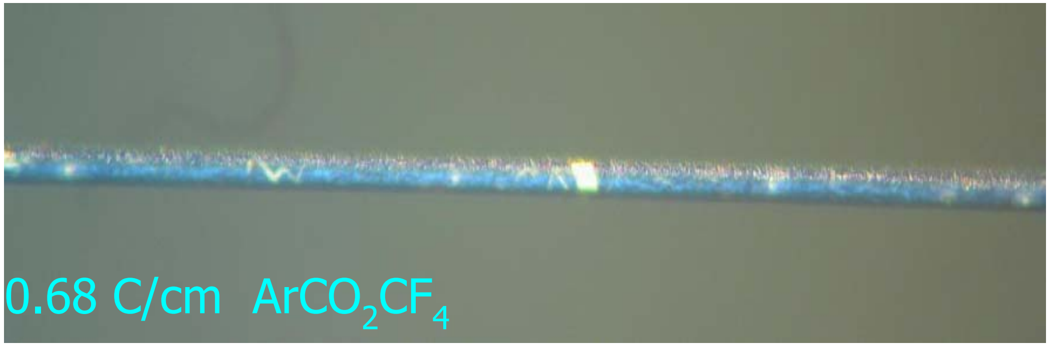
- deposits on anode and cathode
- etching of wire (wire rupture!)

Examples for aged detectors

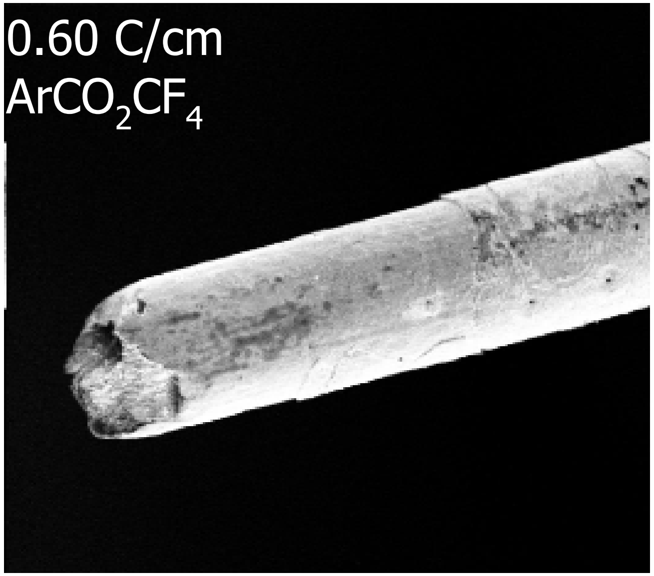
New wire



Deposits on wire



Wire etching and rupture



Parameters affecting ageing

1. Accumulated charge per wire length
   (2 C/cm for 10 years operation at LHCb)
2. Intensity
3. Primary ionisation
4. Irradiated area
5. Counting gas
6. Impurities (e.g. Si) !

Precautions:

Careful choice of operating parameters

Purity of complete system

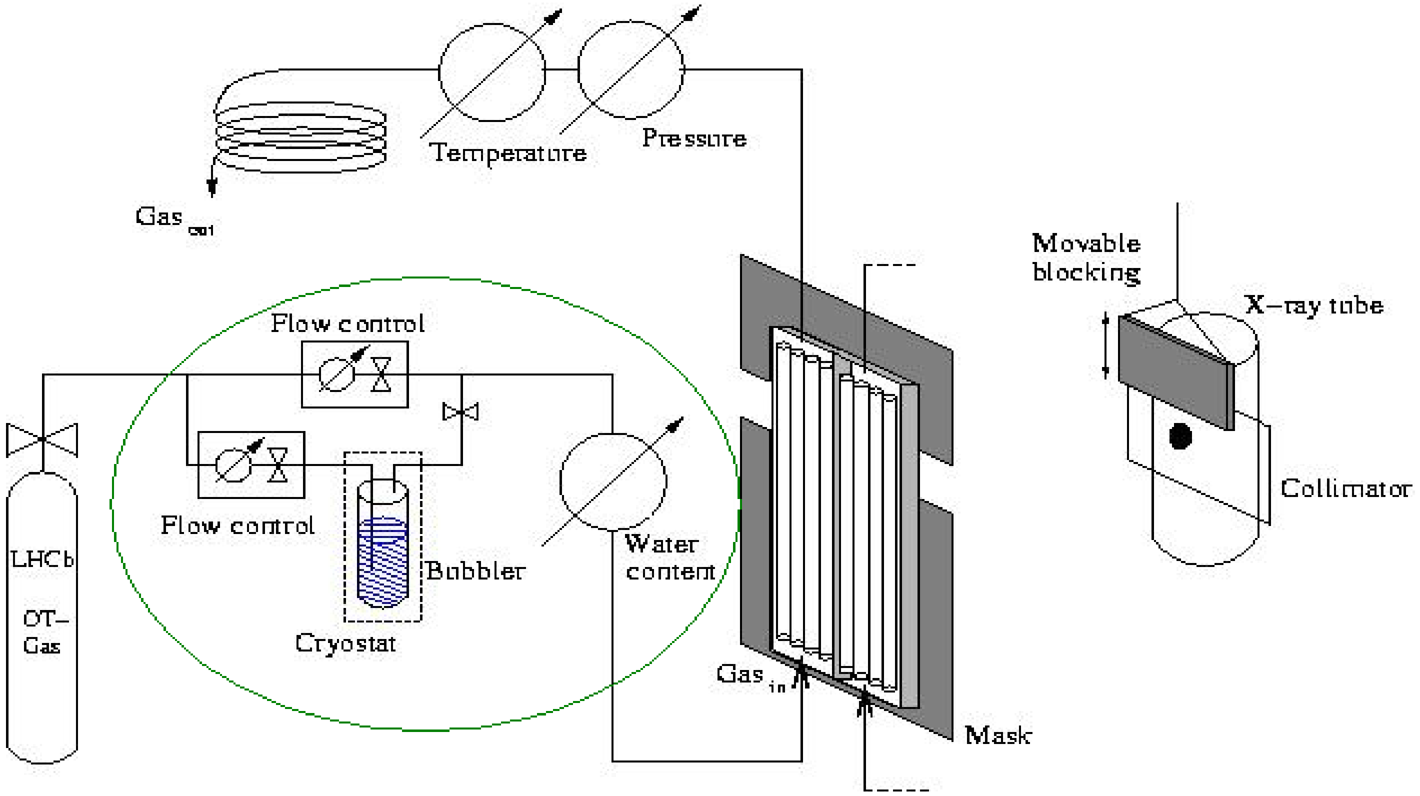
Comparision of ionising particles

	minimal ionising particles	^{55}Fe (5.9keV)	γ (9keV) X-ray	protons @ Bragg- Peak
number of primary ionisations	ca. 35	ca.220	ca. 330	ca. 3500

⤷ Motivation for tests at the MPIK

X-ray tests

Set-up:



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Procedure for ageing tests

Before irradiation:

measure gain along wire

During irradiation:

monitor gain and current of irradiated wire

monitor gain and current of reference wire

After irradiation:

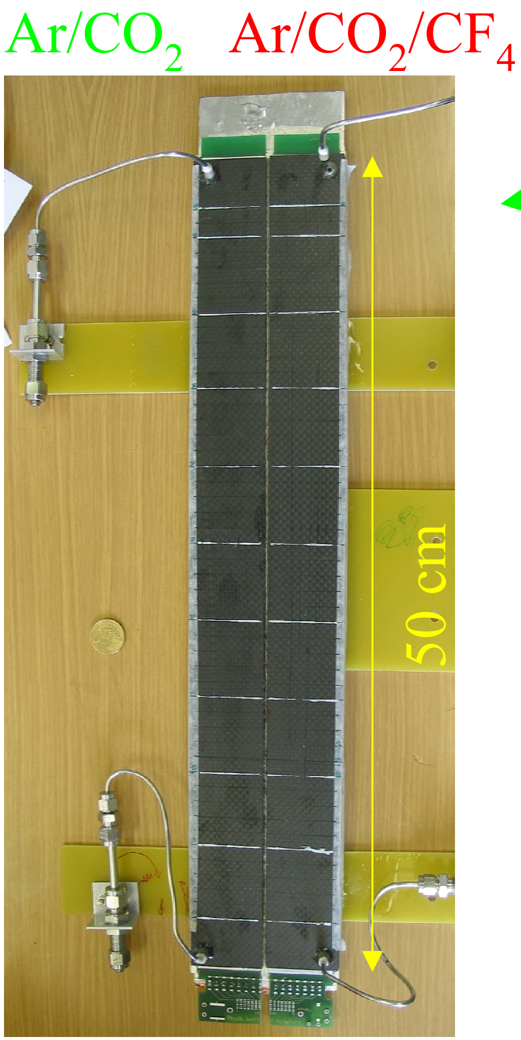
remeasure gain along wire

inspection of wire by means of

optical and electron microscope and

energy dispersive X-ray analysis (EDX)

Operating conditions



Double chamber:

- test both gases at same time
- final materials

<u>Parameters:</u>

HV: Ar/CO2 (70/30): 1520V

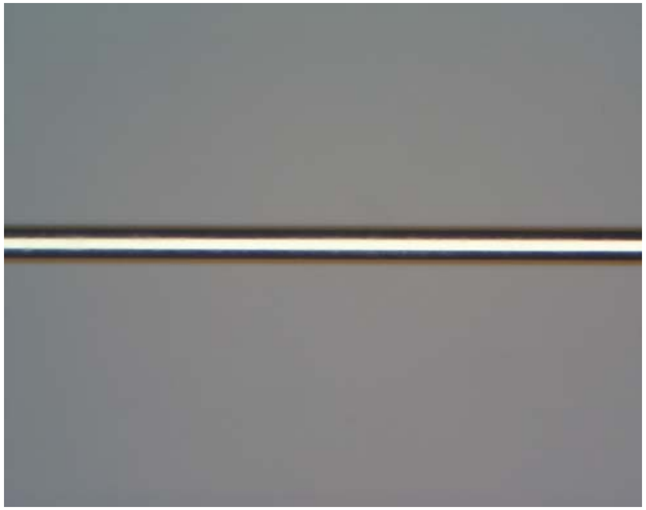
Ar/CO2/CF4 (75/10/15): 1550V

gas gain: 28000 (550 kHz)

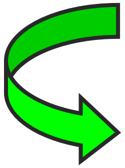
40000 (low rate)

Results for Ar/CO_2

Optical inspection of wires after 1C/cm



- no gain loss
- no degradation of resolution
- no polymerisation (EDX)

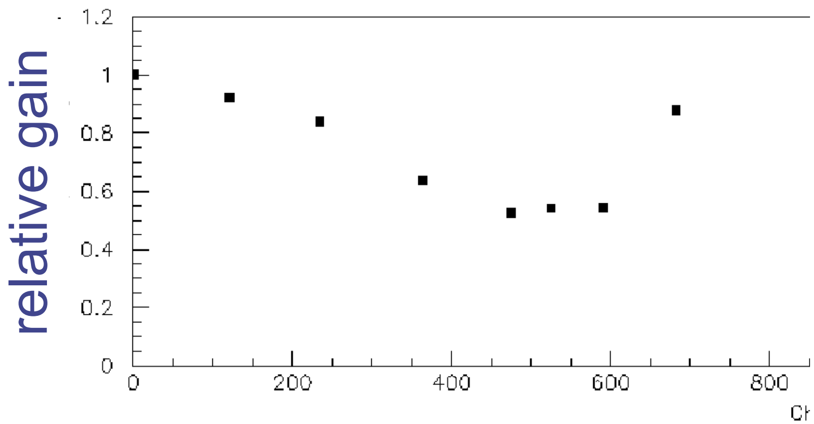


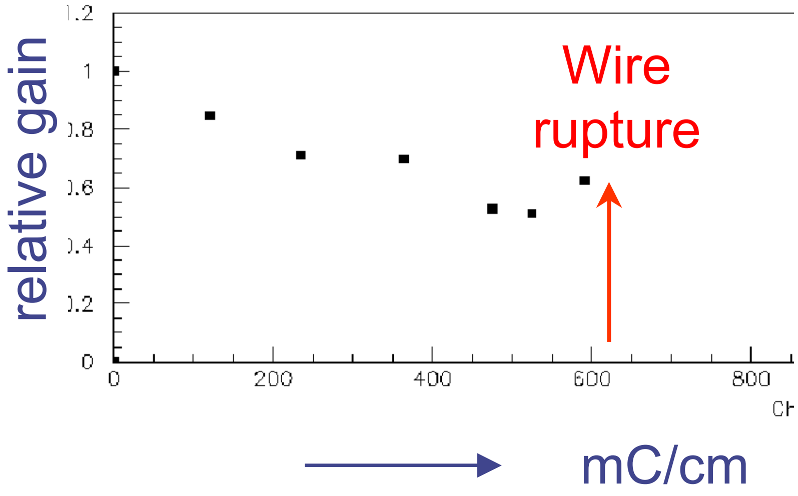
Validation of system

Results for Ar/CO_2/CF_4

Same test conditions as for Ar/CO_2 mixture:

- wire rupture after 0.6 C/cm !
- gain loss, not restricted to irradiated area
- degradation of resolution
- strong carbon and oxygen deposits
- no Si-pollutions observed





Final choice of counting gas

$Ar/CO_2/CF_4$ (75/10/15):

Long term operation in a large system risky

→ abandoned

Ar/CO_2 (70/30):

Slower charge collection, but no major impact on physics performance

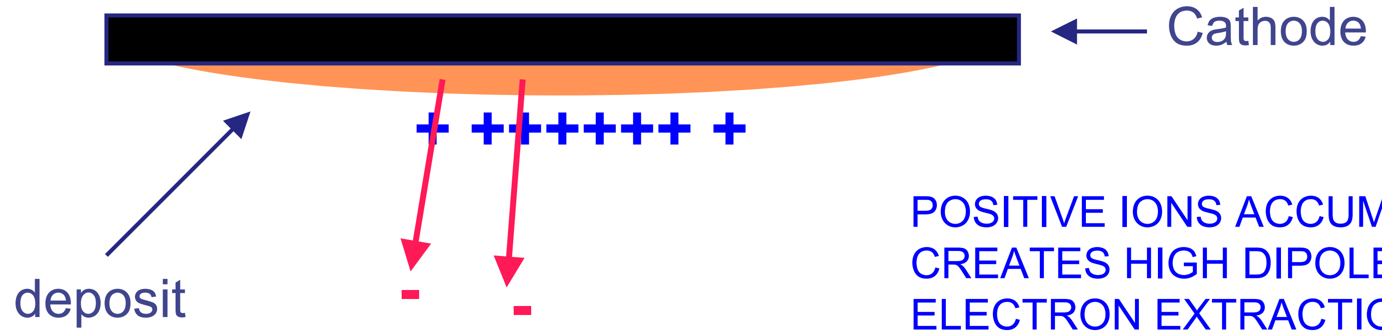
→ baseline gas mixture

Tests with low energetic protons

Aim: Validate cathode, i.e. straw tube materials
Search for unwanted effects

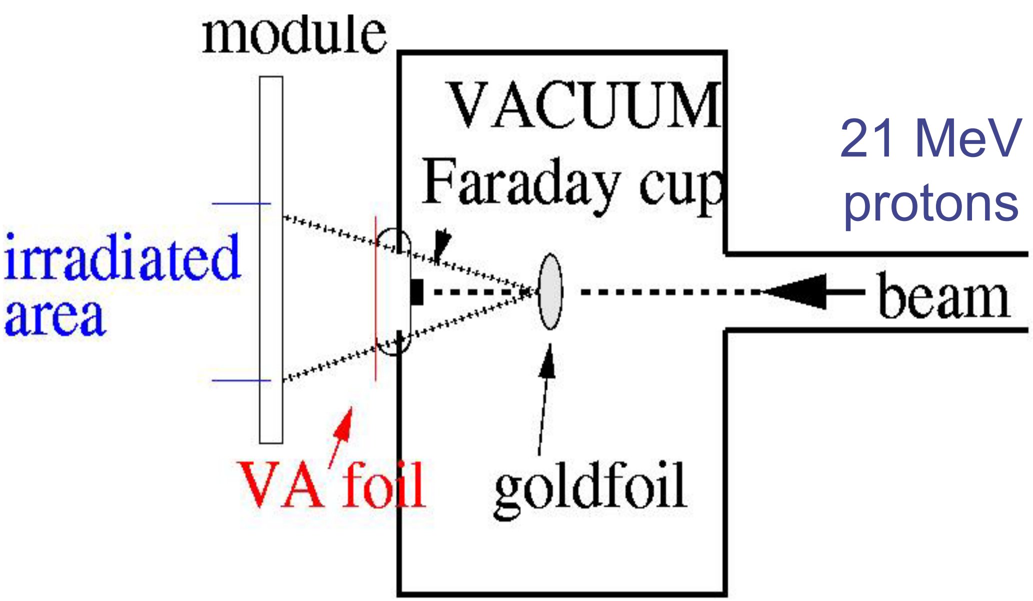
e.g. Malter effect:

CATHODE DEPOSITS INDUCE DISCHARGES:



POSITIVE IONS ACCUMULATION CREATES HIGH DIPOLE FIELD, INDUCING ELECTRON EXTRACTION (MALTER EFFECT)

Setup

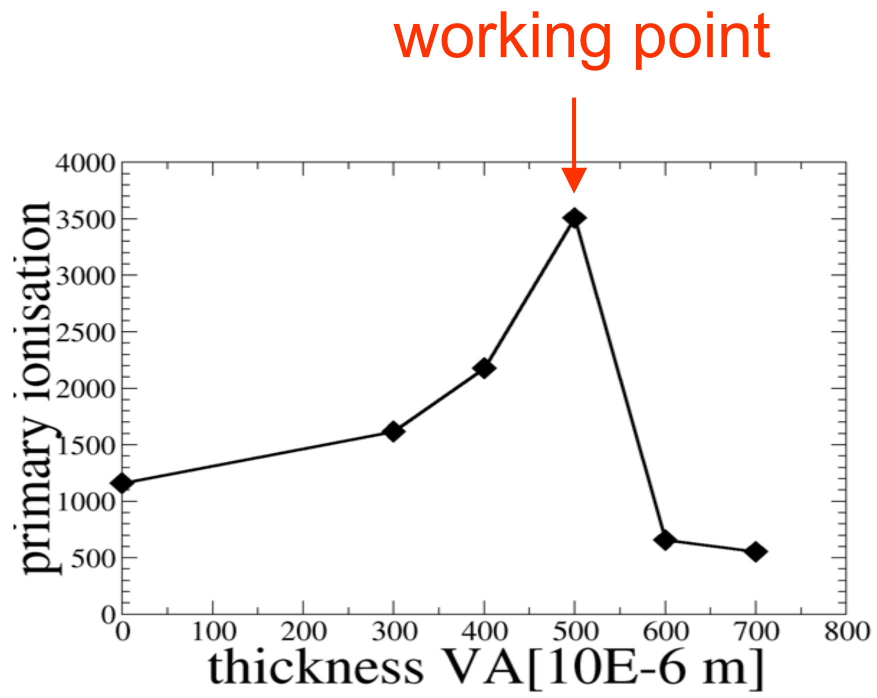


- Rutherford scattering at Au target to reduce current and increase irradiated area
- Faraday cup to absorb the unscattered beam
- Stainless steel (VA) foil to reduce proton energy Bragg peak for highest ionization

Primary ionisation of protons

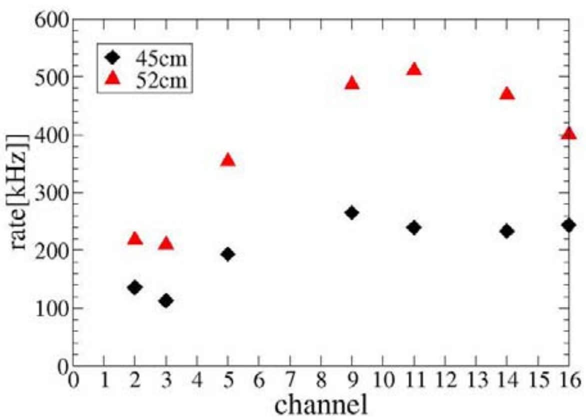
Thickness of VA foil adjusted to Bragg peak

→ maximum primary ionisation

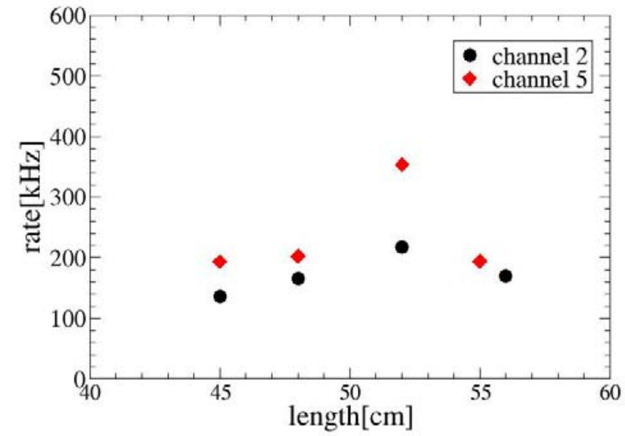


Primary ionisation: up to 1600 MIP‘s,
average 100 MIP‘s

Result I



Vertical beam profile

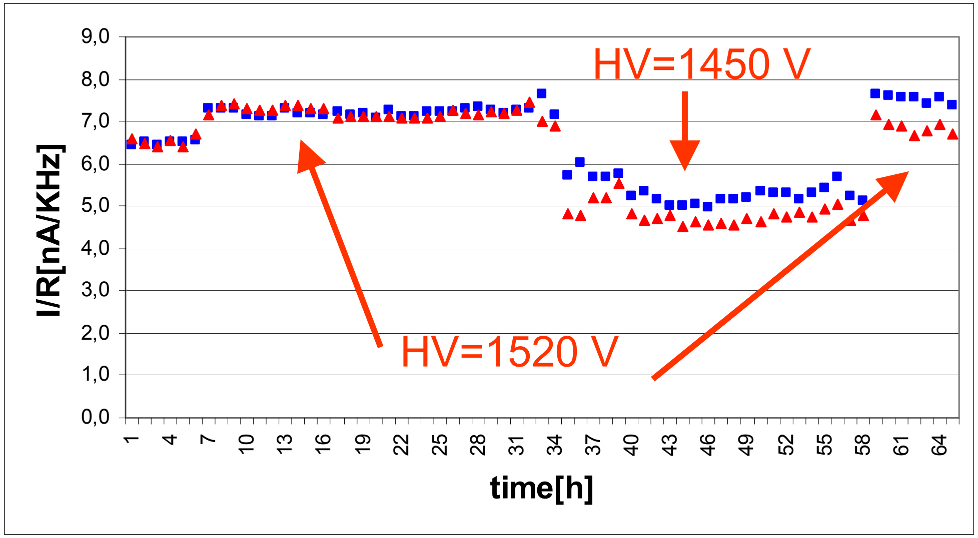


Horizontal beam profile

- 60 hours irradiated
- 9 straws under high voltage
- 1 reference straw
- intensity: 50 – 90 x LHCb intensity
- accumulated charge correspond to 1 – 2 LHCb years

Results II

Stability of gain:



$I = n\, q_e\, R\, G$

I: current

n: primary ionisation

R: rate

G: gain

→ $I/R \sim G$

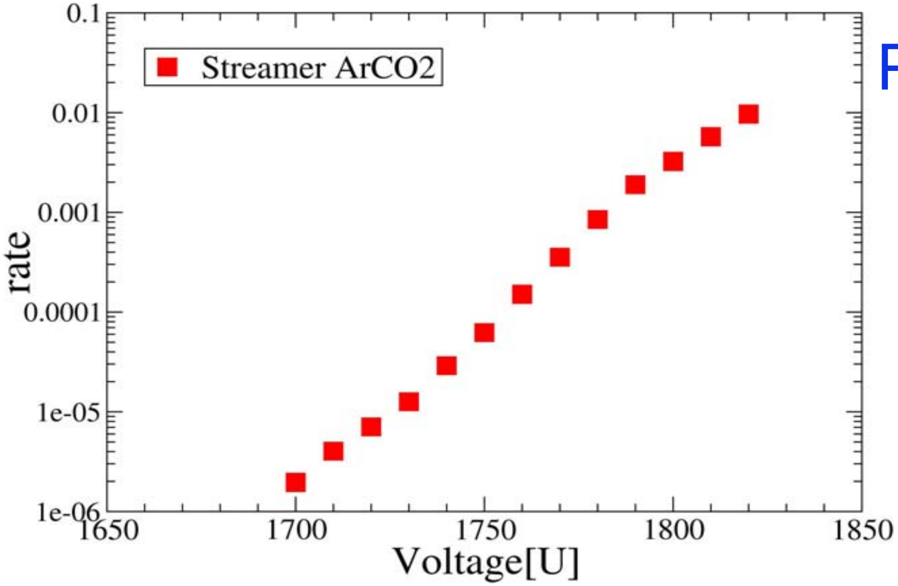
- channel 9
- channel 13 (reference)

- no gain loss (first analysis)
- no Malter effect observed

⇒ Scan with ^{55}Fe will follow

streamer

local gas discharge at high voltage



Problems: - dead time
- huge charge
→ ageing!
- possible damage of electronics

first Streamer @ 1700 V

- operating point @ 1520 V

gain x 16

$$\text{rate} = \frac{\text{rate[streamer]}}{\text{rate[signal @plateau]}}$$

- charge deposition @ 1700 V ≈ 1600 MIPs

Summary/Outlook

- mass production started in May
- Detector design has been validated in many aging tests with X-rays and low energetic protons.
- Ar/CO_2 (70/30) chosen as counting gas
- Final tests with detectors build from materials taken out of the production are on the way with
    - lower acceleration factor (~10)
    - larger irradiated area (~50cm)
    - complete LHCb gas system