Status of LHCb detector construction

Helge Voss

Max-Planck-Institut für Kernphysik

On behalf of the LHCb collaboration

- introduction to LHCb
- vertex detector and its performance
- other tracking detectors
- RICH and its performance
- calorimeters/muon detectors
- trigger/online
- inside the cavern
- summary

Introduction

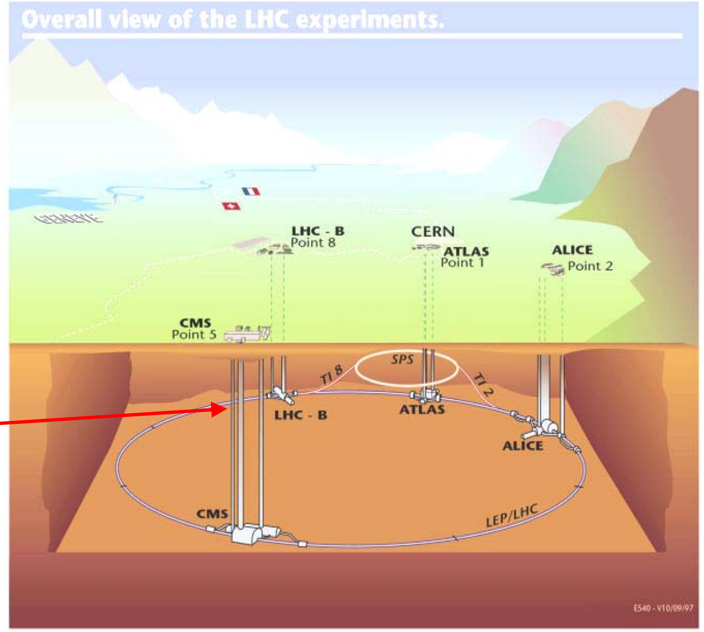
LHC:

- pp@14 TeV "b-factory"
- lumi=$2 \bullet 10^{32}$ $cm^{-2}s^{-1}$

  $\rightarrow 10^{12}$ $b\bar{b}$/year (10^8 at $\Psi(4S)$)
- full spectrum of B hadrons (incl. B_s)

LHCb:

- B-physics, CP-violation and tests of the CKM matrix



matter

↕

anti-matter

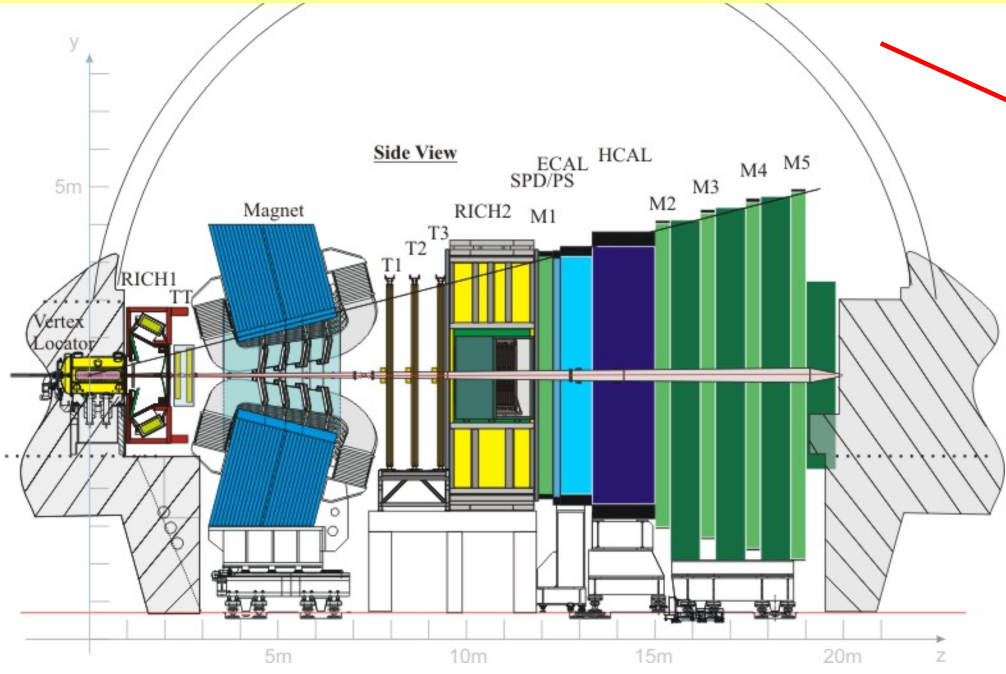
asymmetry in the universe

There must be something beyond the Standard Model in terms of CP violation… even if CDF just reported:
$\Delta m_s = 17.77 \pm 0.10 \pm 0.07 ps^{-1}$

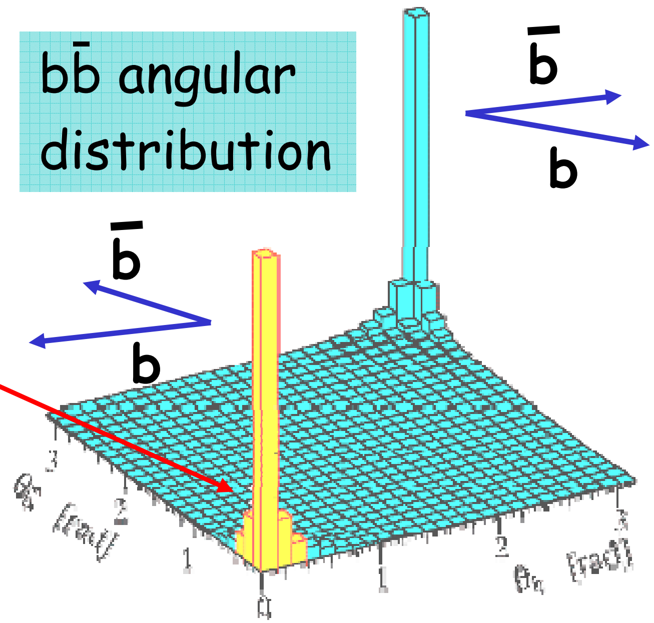
in agreement with Standard Model expectations

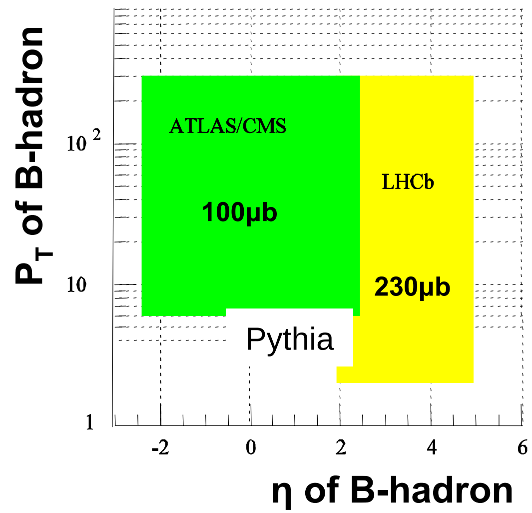
LHCb Introduction

LHCb: single-arm forward spectrometer
acceptance: 15-300(250)mrad:



$b\bar{b}$ angular distribution



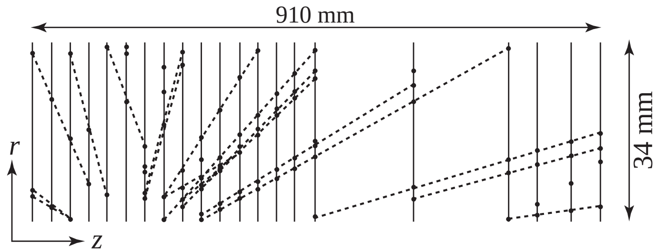


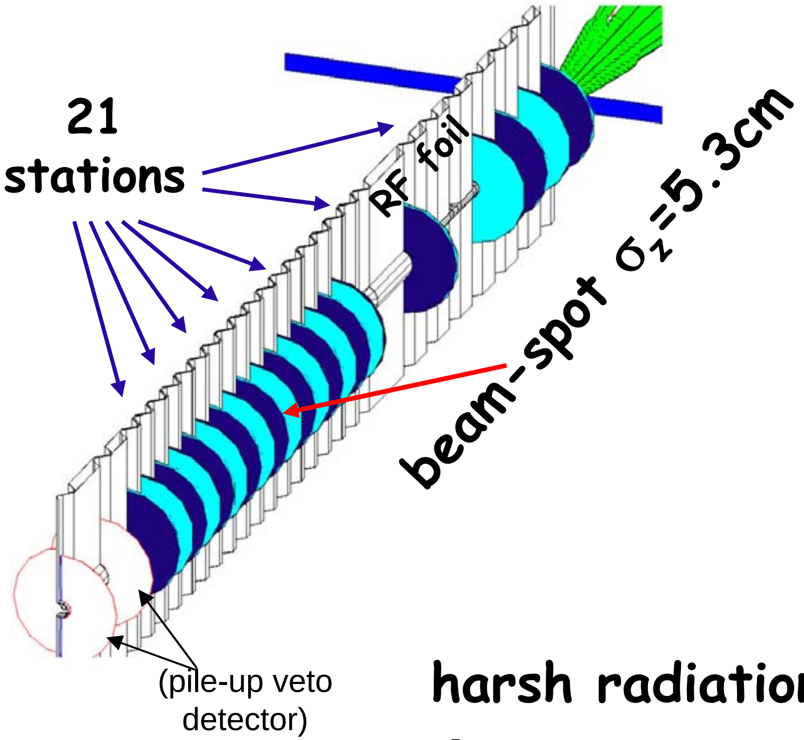
essential:

- good vertex resolution
- good tracking, momentum resolution
- good particle ID (π K separation)
- trigger for leptonic and hadronic B decays

VErtex LOcator "VELO"

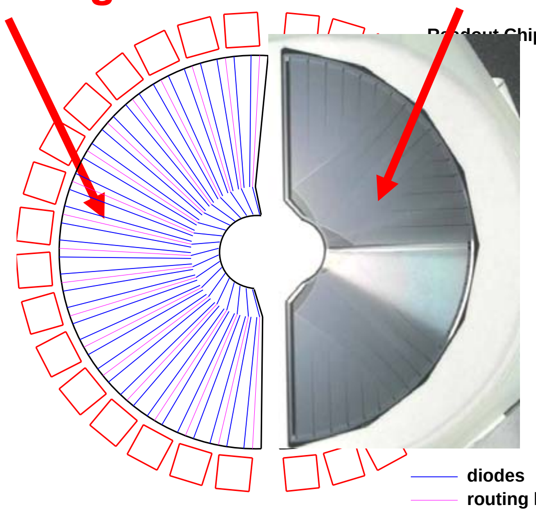
r- and φ measuring sensors rather than x,y
→ fast and easy impact parameters for use in the trigger





φ-measuring sensor

r-measuring sensor



φ-sensor:
- radial strips (inner and outer)
- 2048 strips
- stereo angle (-20°, +10°)
- 37–98 μm pitch

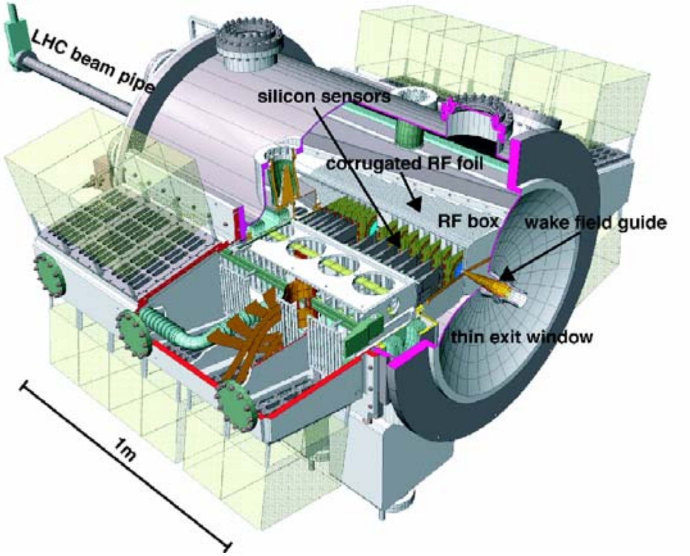
r-sensor:
- concentric strips
- 2048 strips
- 4 sectors (45°)
- 40-103 μm pitch

harsh radiation environment:
→ n-n sensors: keep good resolution if undepleted
→ sensor cooling to -5°C with CO_2 cooling system

Vertex Locator Mechanics

- good impact parameters
  → detectors as close as 8mm to LHC beam
  → sensors placed in secondary vacuum (10^{-9} mbar) separated from beam-vacuum just by an 300μm Al "RF-foil"
- move sensors out during filling (3cm)
- re-positioning accuracy: <10μm

RF-foils

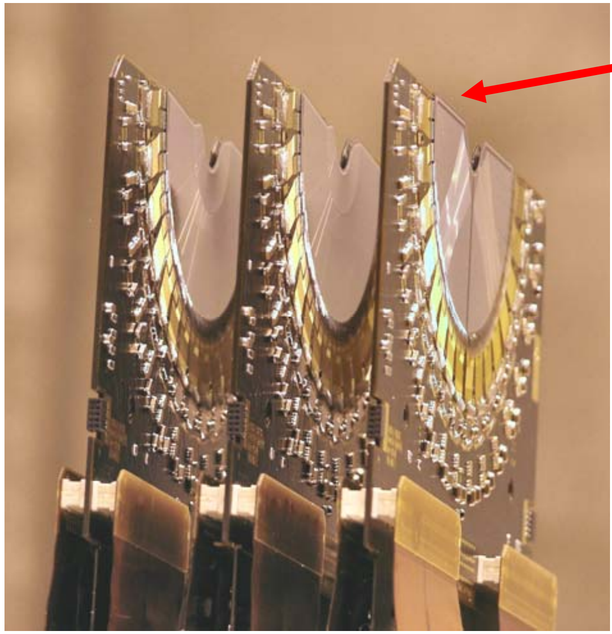


vacuum vessel installed and surveyed (0.2mm accuracy)

VELO Modules Production and Commissioning Test

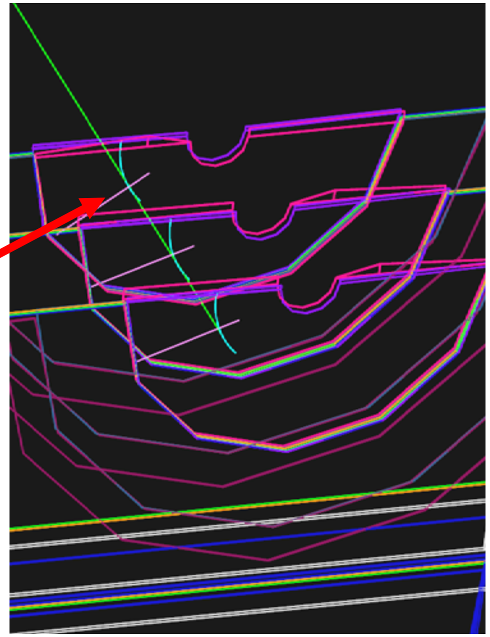
9 out of 42 final detector modules are ready → awaiting "burn-in"

Testbeam: Alignment and Commissioning challenge using (almost) final HARD and LHCb SOFTware



real life detector modules

real "LHCb visualisation tool"

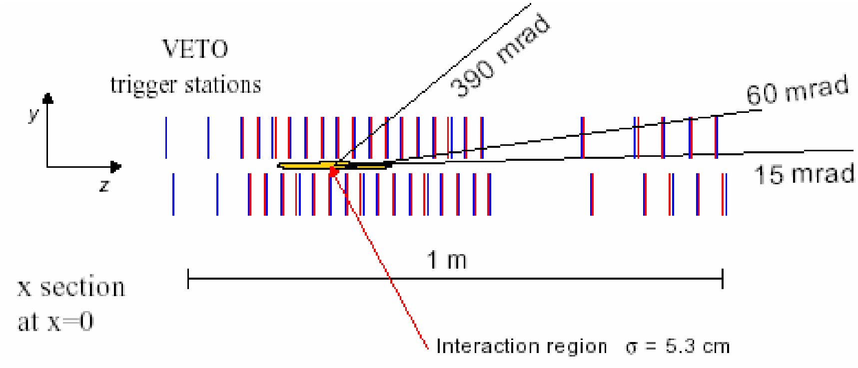


successfully operated:

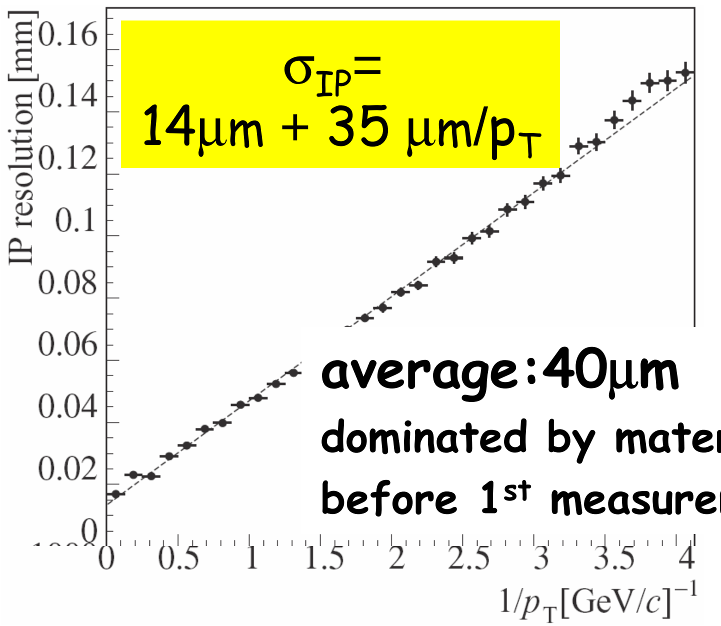
- important experience for commissioning online/offline software
- lots of test-beam data to be analysed now

Expected VELO Performance

use all tracks that include VELO:



impact parameter

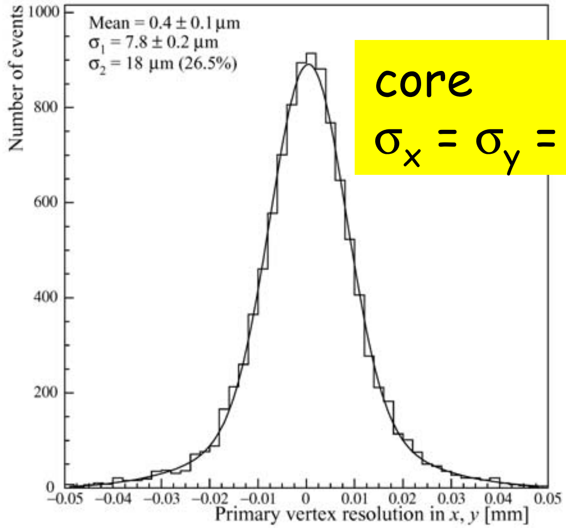


σ_{IP}= 14μm + 35 μm/p_T

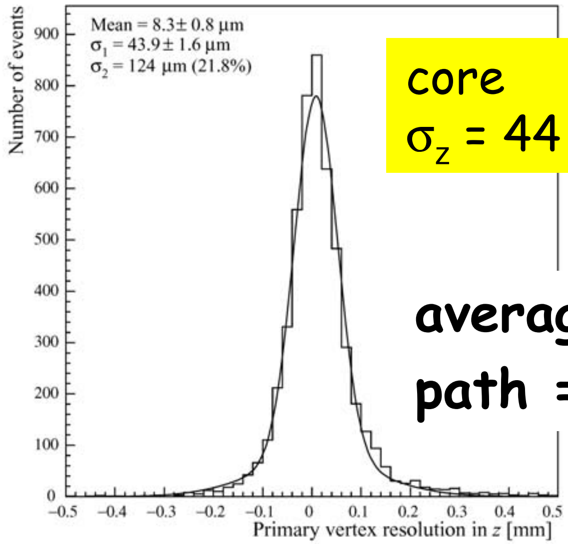
average:40μm

dominated by material before 1st measurement

$b\bar{b}$ vertex resolution:



core
$\sigma_x = \sigma_y$ = 8 μm

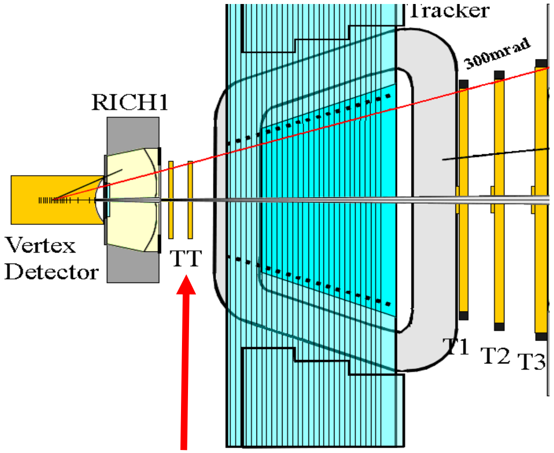


core
σ_z = 44 μm

average B flight path = ~1cm !!

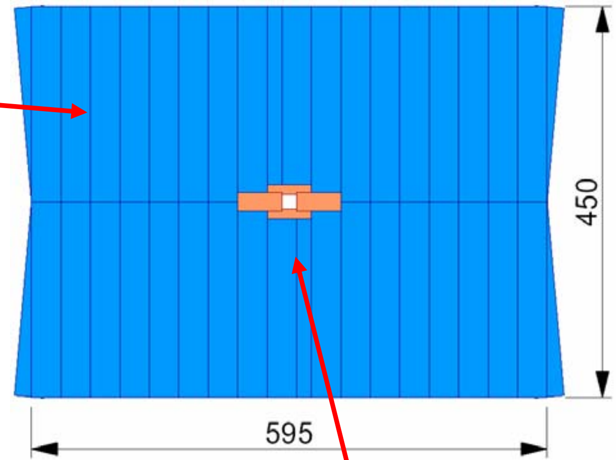
Other Tracking Detectors

magnet:



Outer Tracker:

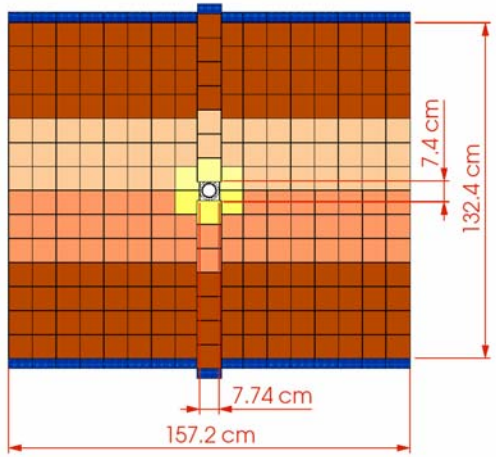
straw tubes

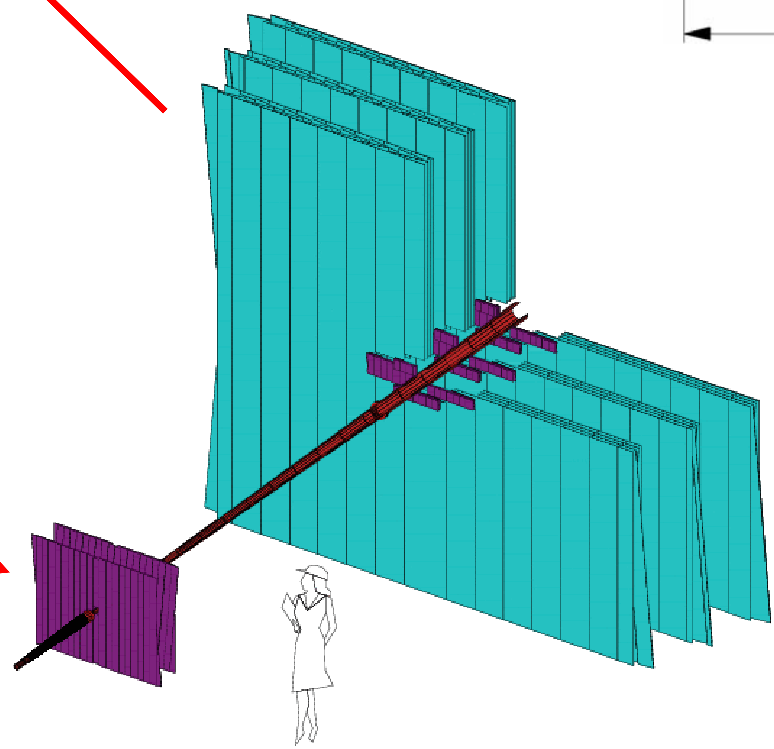


TT-station

silicon strips:

- P_T info for the trigger





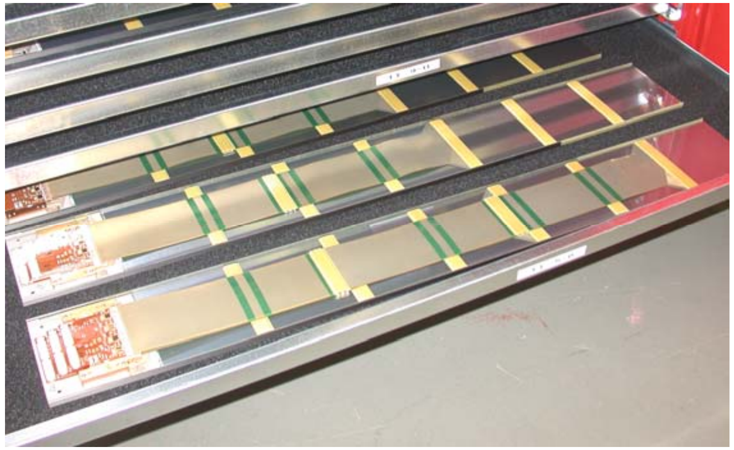
Inner Tracker:

silicon strips

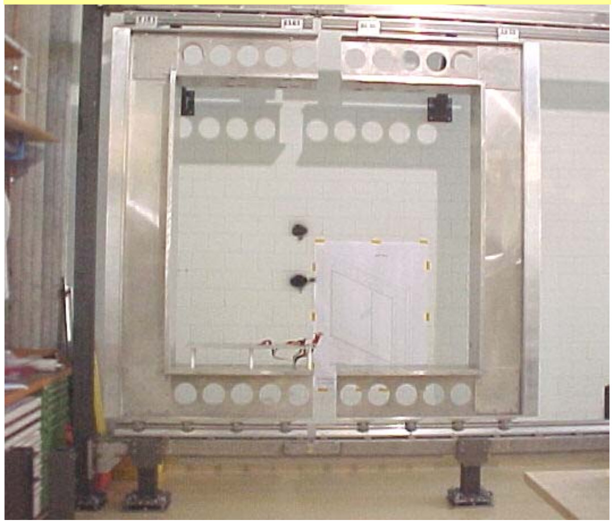
- 1.3% of the station surface
- 20% of accepted tracks

TT-Station

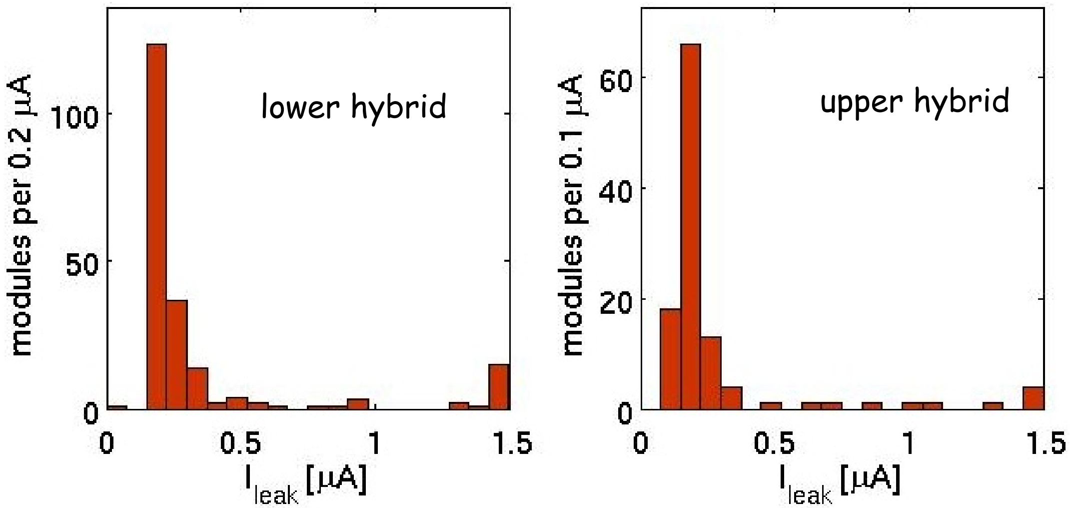
- 4 layers: (2 with ±5° stereo angle)
- silicon strips: 143k channels, 7.9m²
- up to 39cm readout strips
- inner sectors connected via Kapton interconnect cables
- operation at ~5°C, liquid C_6F_{14} cooling



Station assembly for testing in the lab



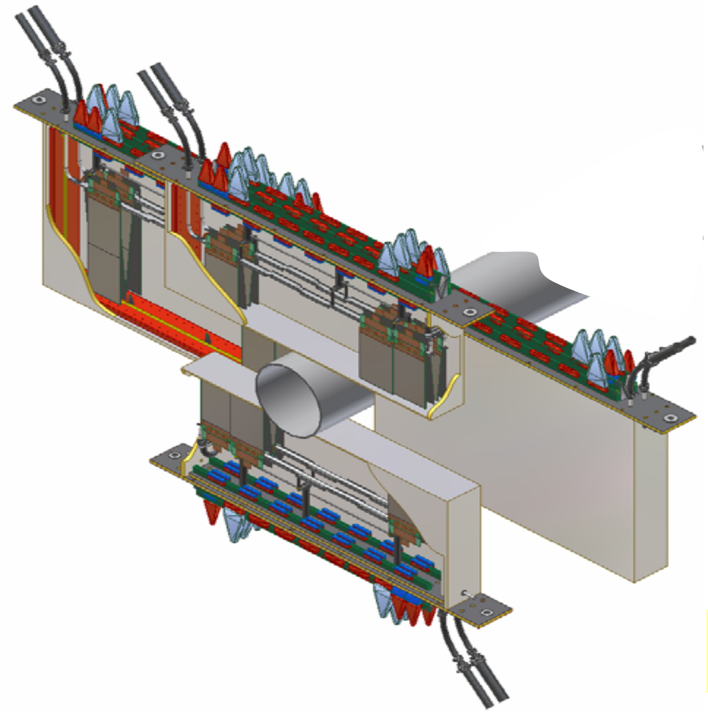
Good quality modules with low leakage currents

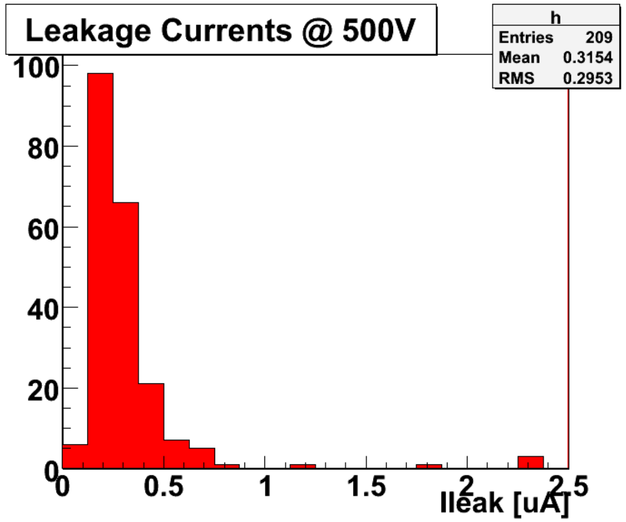


~ 60% of modules finished

Inner Tracker

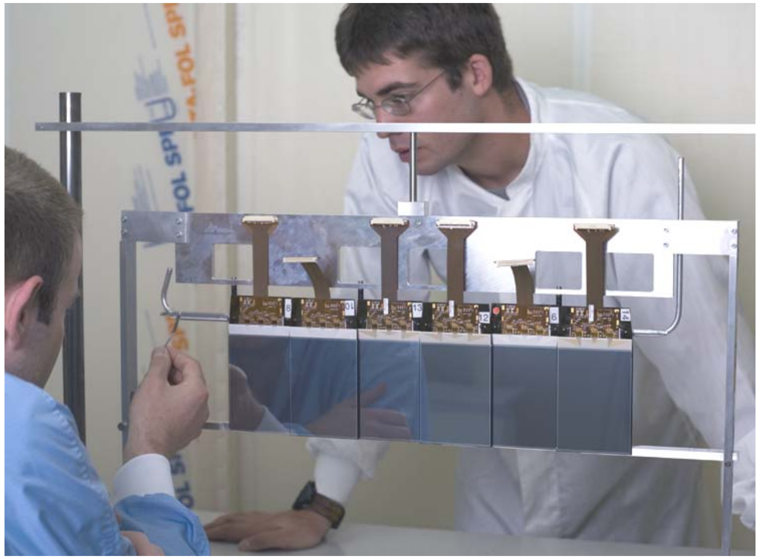
- silicon strips: 129k channels, 4.3m^2
- 336 modules
- 11 and 22cm long modules/strips
- 4 individual boxes per station
- 4 layers per station:(2 stereo layers)
- operation at ~5°C, liquid C_6F_{14} cooling



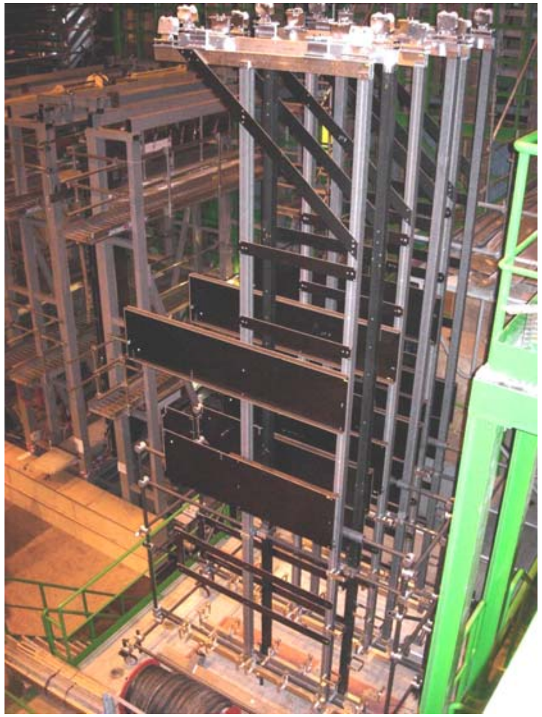


~ 60% of modules produced and tested

Inner Tracker Installation



First Inner Tracker box has been assembled and partially tested

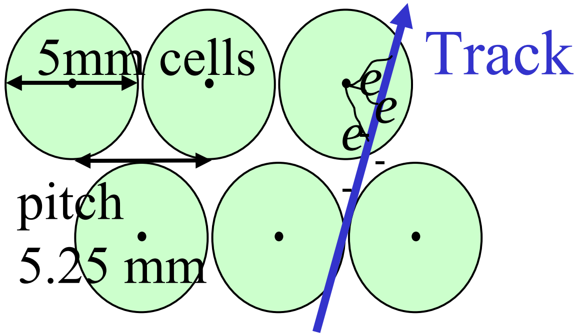


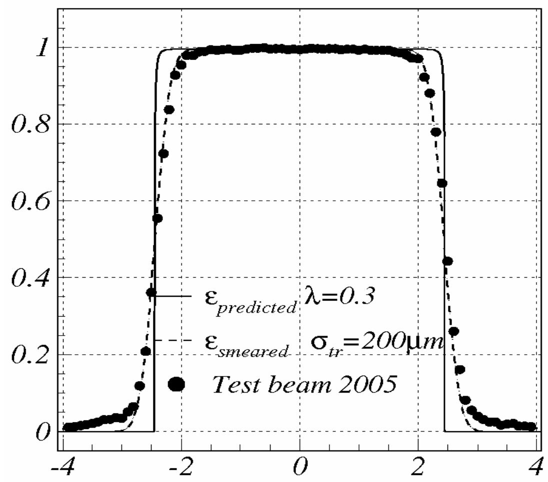
- support frames have been brought to the pit
- will be cabled soon

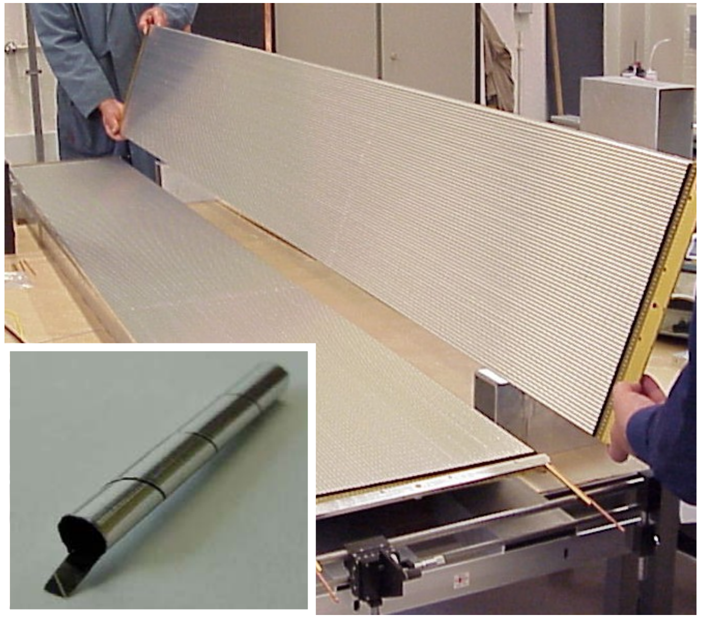
Outer Tracker

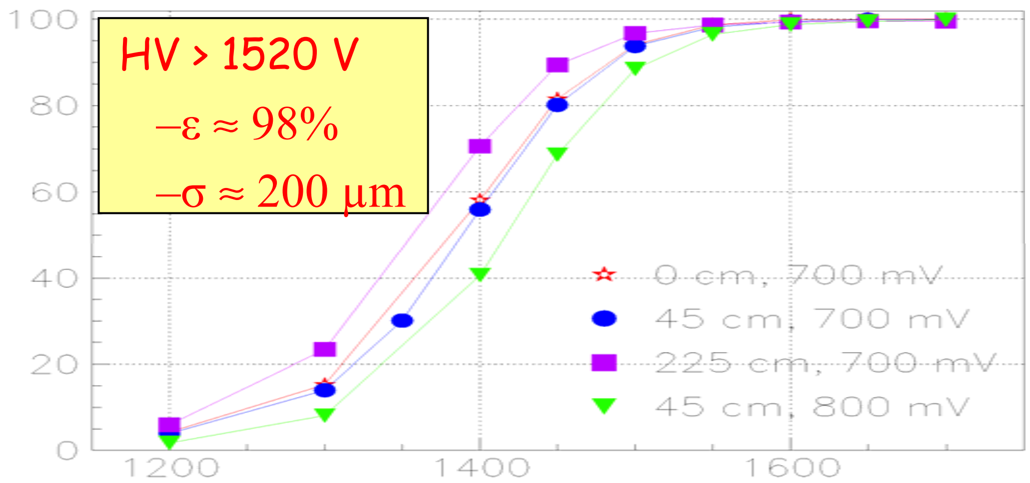
Straw tube tracker:

- $ArCO_2$ drift gas
- resolution: 200µm
- 4 layers / station
- 2 stereo layers ±5°





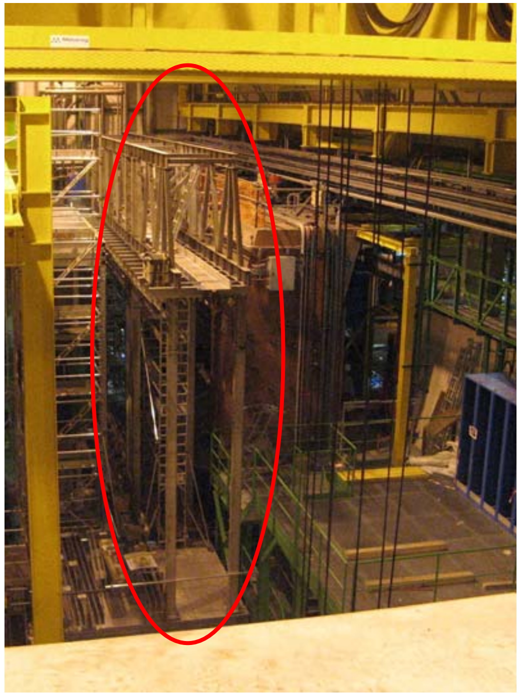




Module production finished December 2005 !

Outer Tracker Installation

Support bridge…   … installed   …with modules

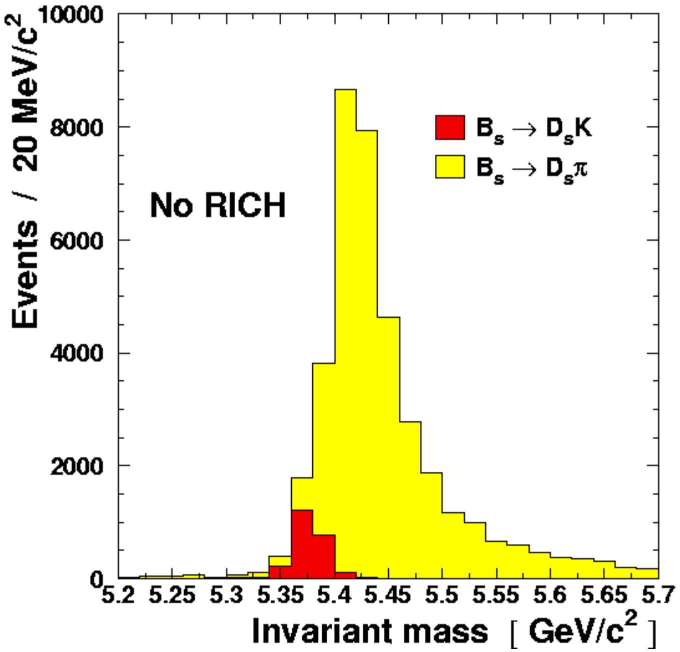


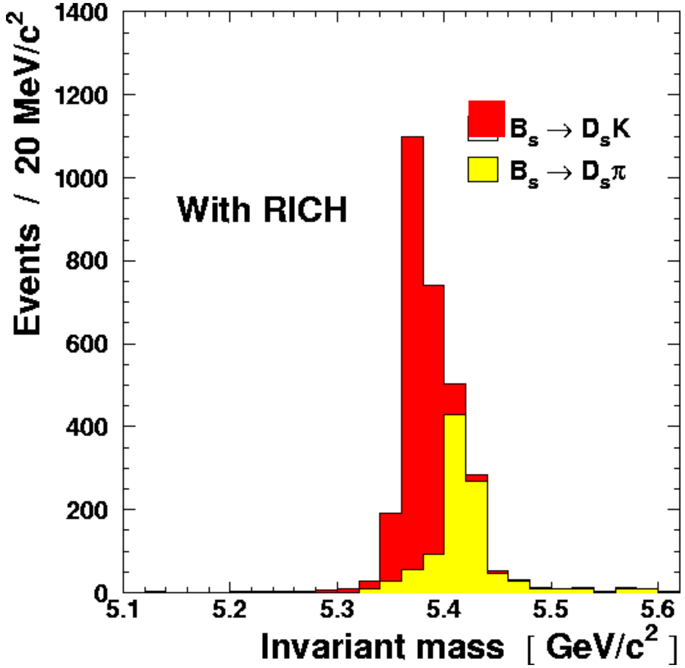
- 1/4 of the stations are already equipped with modules
- now: testing, cabling, survey

RICH – Particle ID

- selection of specific B-decay channels for CP measurements
- without particle ID, the bkg-dilutes/overwhelms the signal

$B_s \rightarrow D_s^{-+} K^{+-}$ $B_s \rightarrow D_s^{-}\pi^{+}$





2 RICH Detectors with 3 Cherenkov Radiators

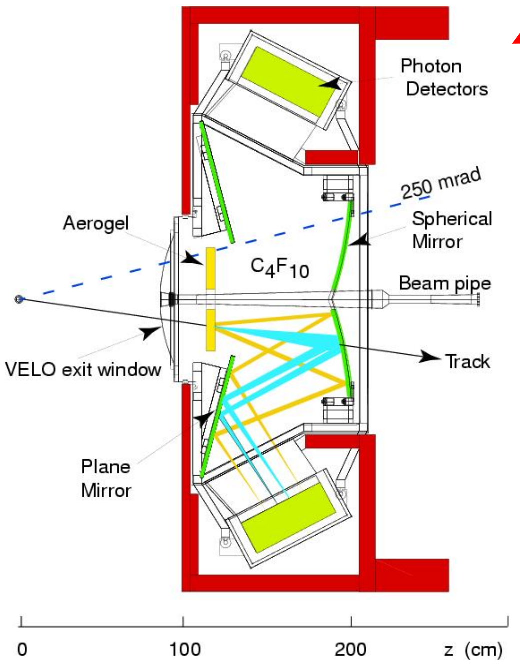
RICH1:

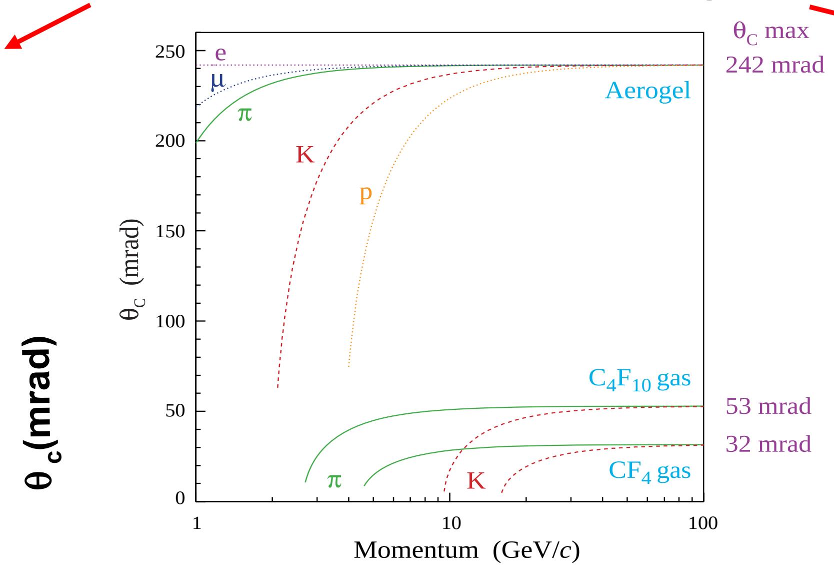
- 5cm silica aerogel (2-10GeV/c)
- 85cm C_4F_{10} gas (<50GeV/c)
- spherical (CF) and planar (glass) mirrors

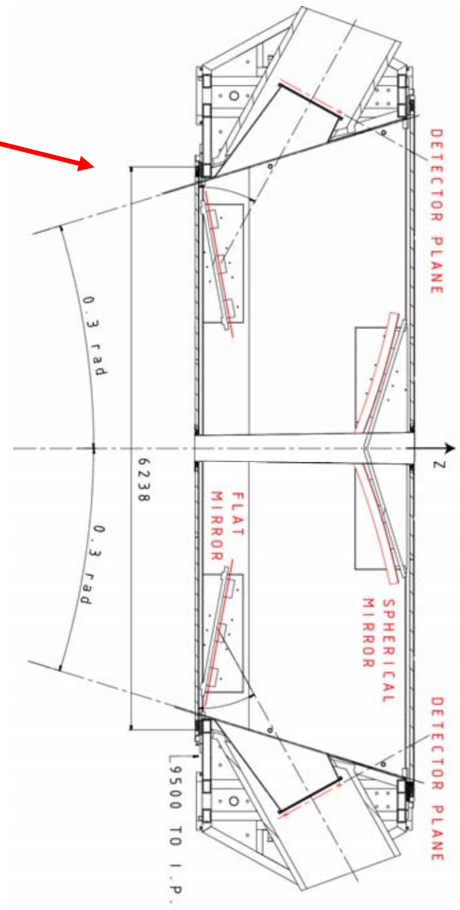
RICH2:

- 170cm CF_4 gas (<100GeV/c)
- spherical and planar glass mirrors

before and behind the magnet







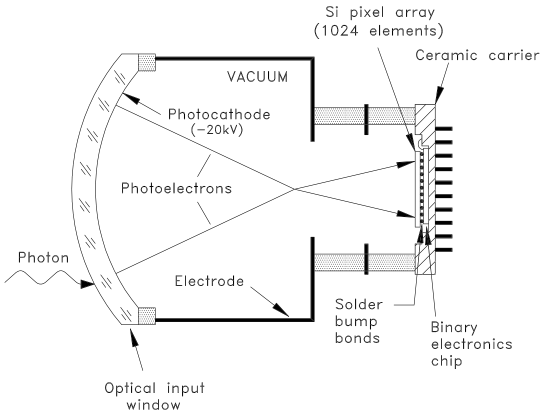
Expected photons detected

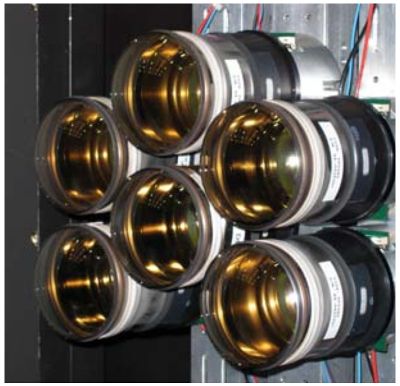
- Aerogel 7
- C_4F_{10} 30
- CF_4 23

RICH – Photon Detector

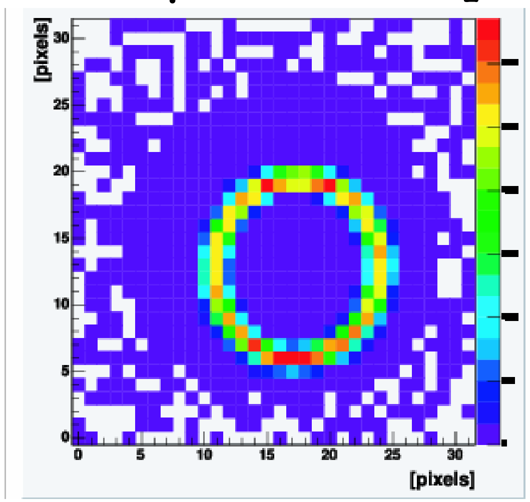
Hybrid Photon Detectors (HPDs):

- photo tubes with silicon pixel chip
- 2.5x2.5mm2 resolution for single photons
- low noise → excellent single photon detection efficiency (200nm–600nm)
- 85% detection efficiency (after photon conversion ~25%)

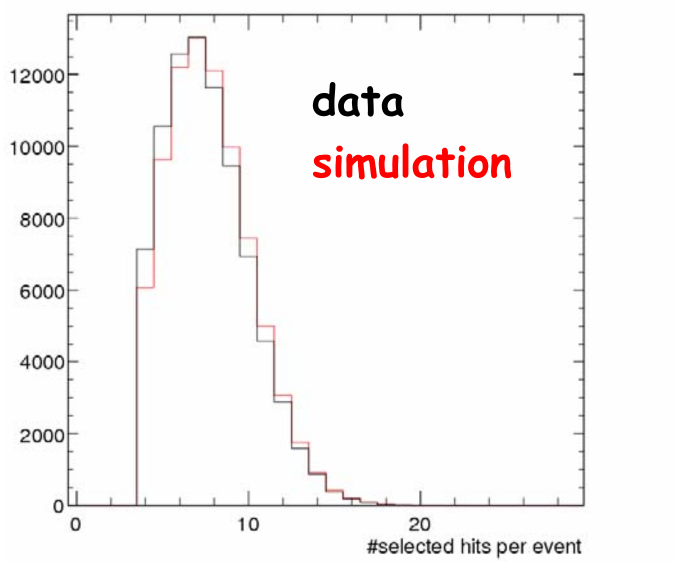




10GeV pions, 1.1m N_2



number of pixel hits/event



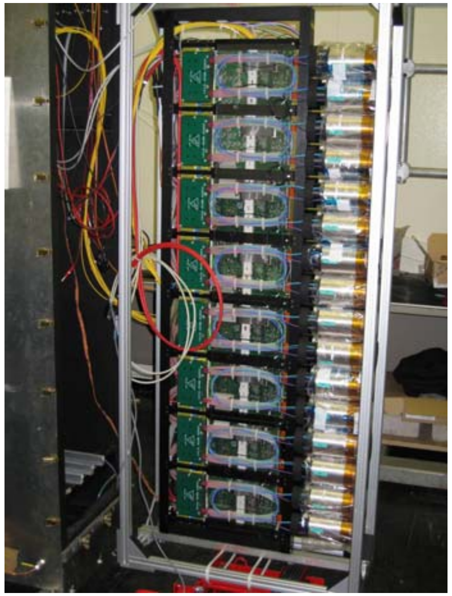
about 50% of HPDs are produced and tested
→ only 3% failures

RICH Installation

RICH1 magnetic shield, gas enclosure and seal to VELO

RICH2: installed end 2005
56 spherical mirrors aligned to σ_θ~ 50 μrad

RICH2 cabling ongoing

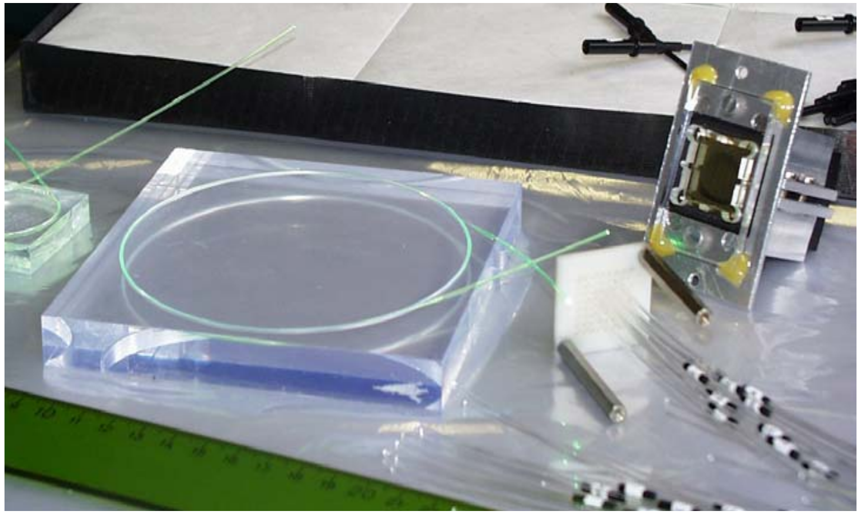


Calorimeter System SPD/PS/ECAL/HCAL

they all use similar cost efficient technology:

scintillating tiles in between lead/steel absorbers read out via wavelength shifting fibres

SPD-scintillating pad



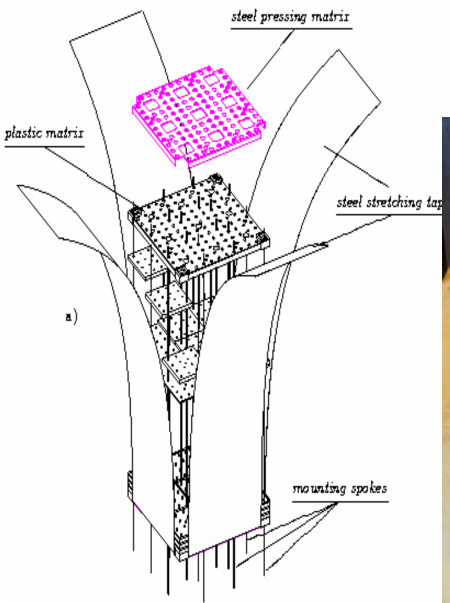
SPD: scintillating pads/tiles → distinguish $e^{\pm}$ and γ

PS: PreShower after 2.5cm of lead identifies electromagnetic particles

ECAL: shashlik type → measure energy of electromagnetic shower

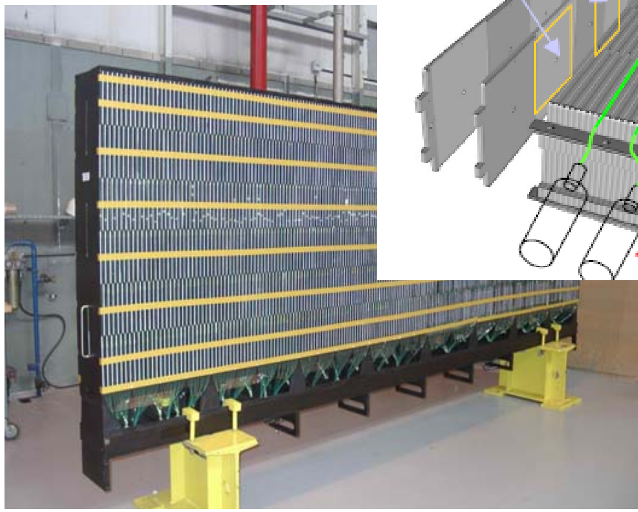
HCAL: iron interleaved with scintillating tiles → energy of hadrons

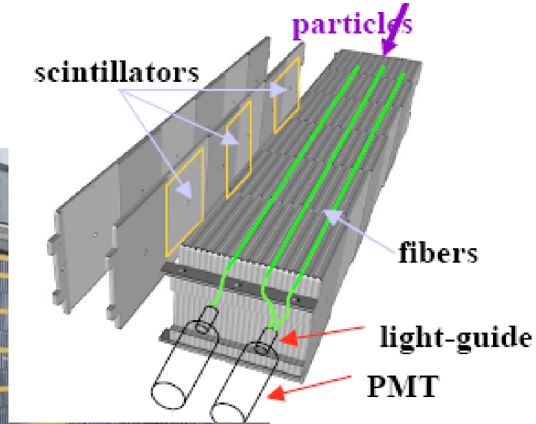
ECAL/HCAL Performance

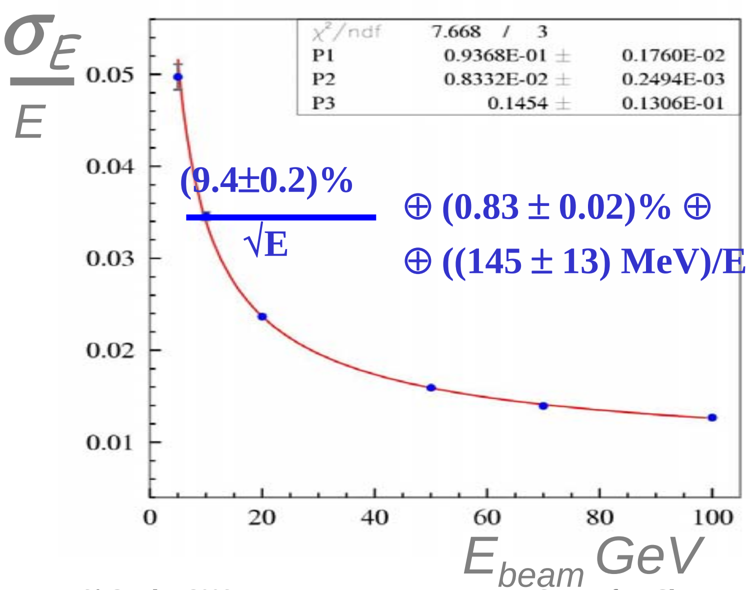


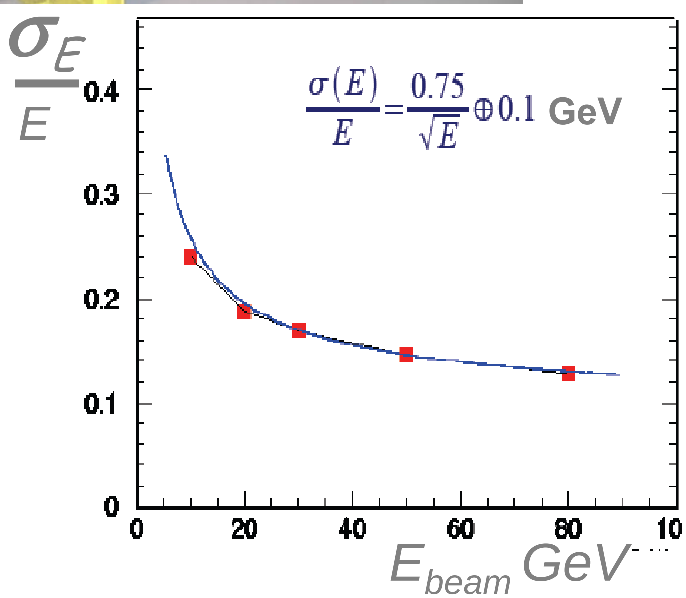
ECAL

HCAL







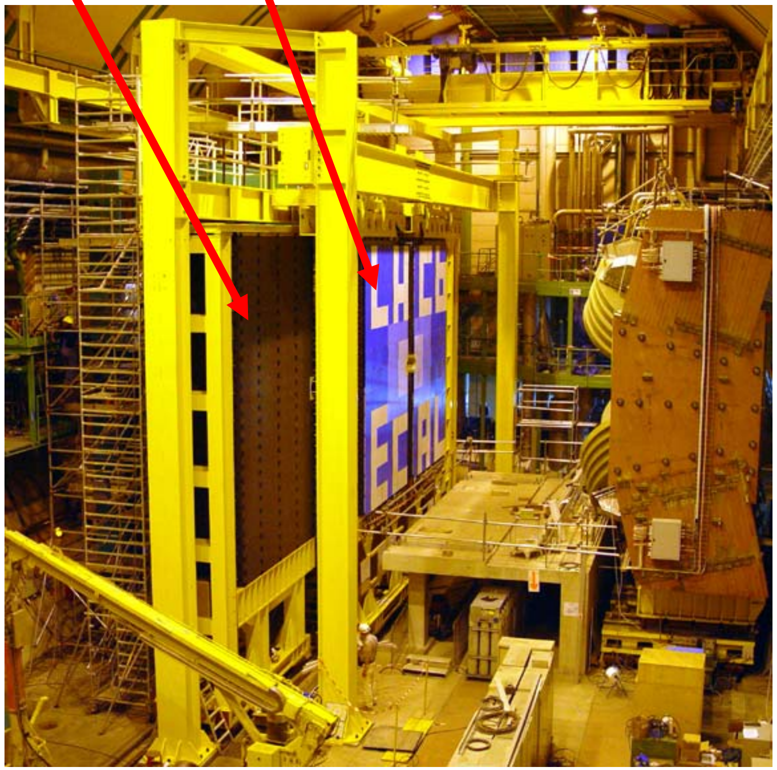


Calorimeter Installation

SPD/PS modules have been installed this summer

HCAL in place since Sept. 2005

ECAL in place since June 2005

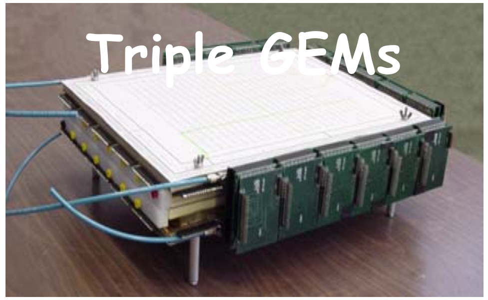


- **Activity now focuses on cabling / commissioning using calibration LEDs**

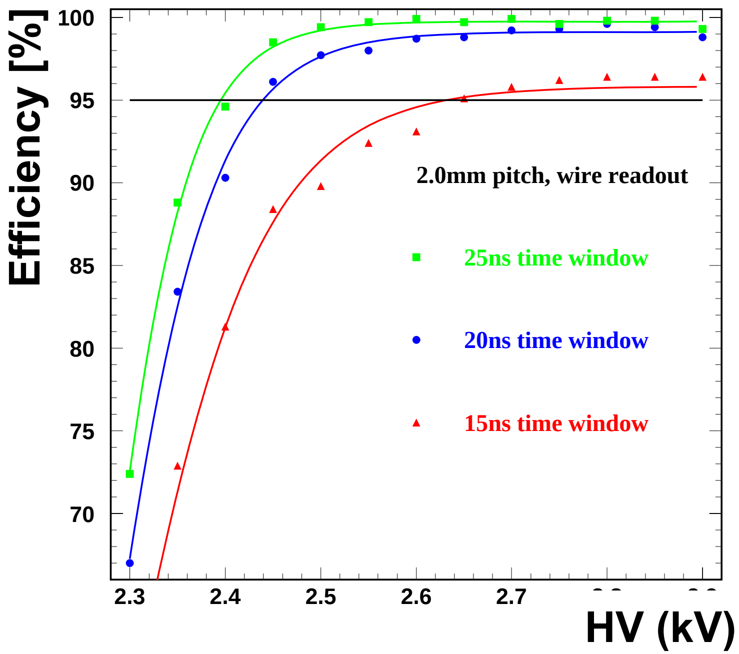
Muon

Multi-Wire-Proportional-Chambers (MWPC) & GEMs (at center at 1st station)

4ns time resolution → use in the trigger (20% P_T resolution)



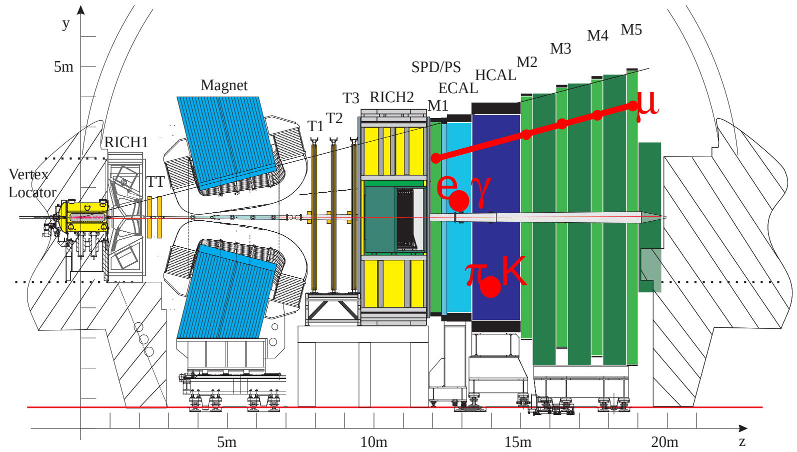
testbeam:anode efficiency



- muon filters are in place
- 1380 MWP-Chambers production completed
- 24 GEM production is ongoing

Two Trigger Levels:

- L0: hardware trigger
  10MHz (interaction rate) →1MHz
  - **calorimeter:** (SPD multiplicity, # E_T clusters)
  - **muon:** (two high p_T muons)
  - **pile-up system** (indentify multiple interactions)
  - L0 Decision Unit
  - Latency: 4μs



Many different custom electronics, all close to final production

Trigger commissioning will start 2007

- HLT: software trigger 1MHz→2kHz
  - all sub-detectors readings
  - L0 confirmation
  - dedicated physics channel triggers depending on type of L0 trigger
  - trigger on impact parameters

L0 efficiencies: for channels with

muons: ~90%

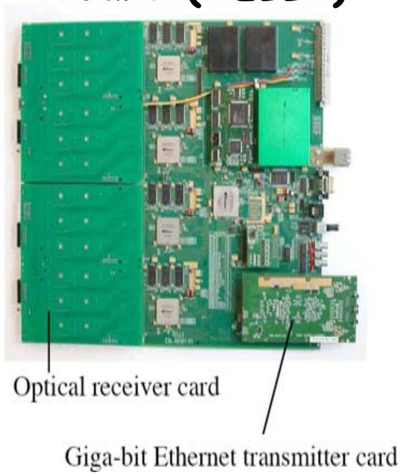
leptons: ~70%

hadrons: ~50%

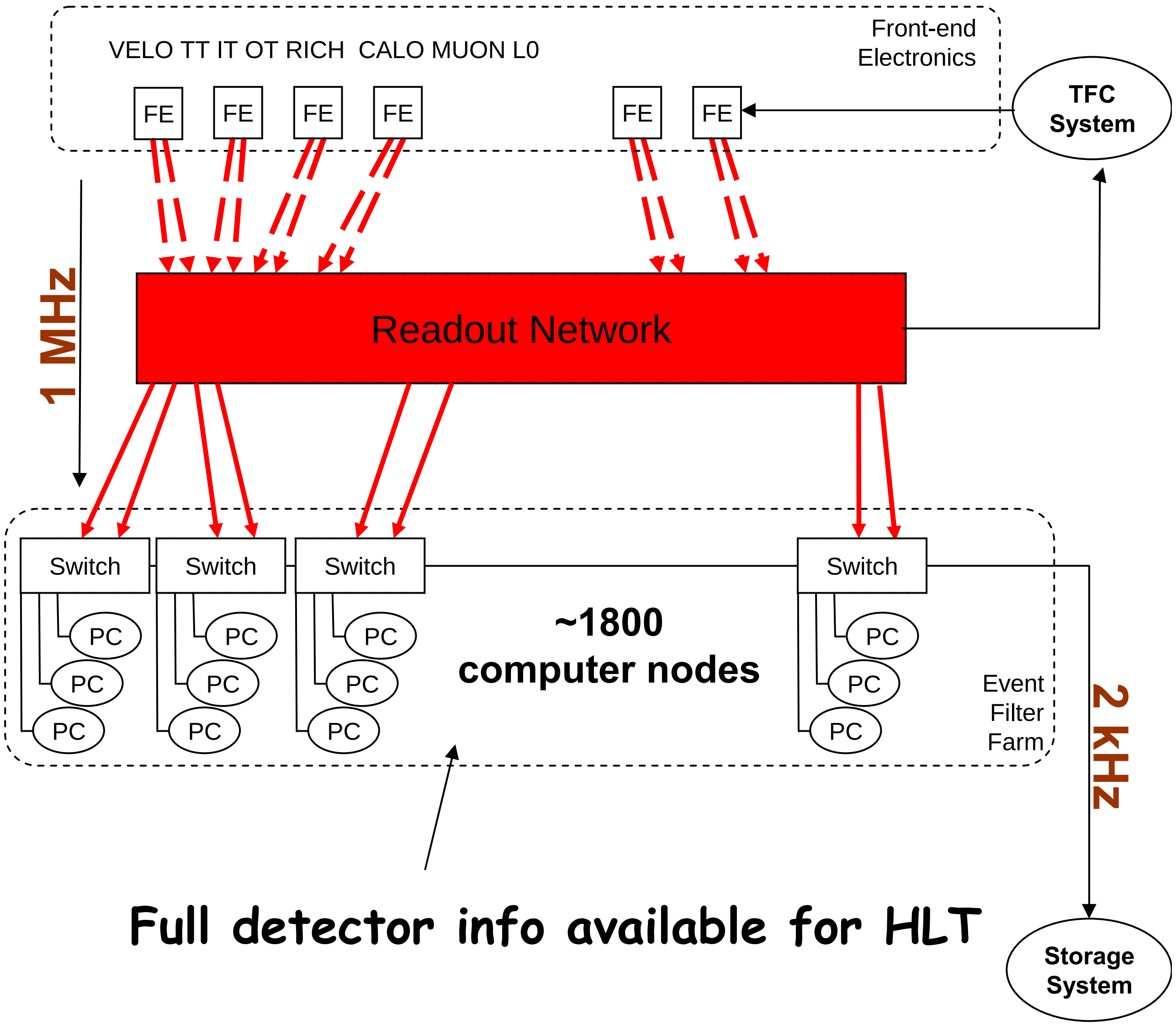
HLT efficiencies: .. no final numbers: still in transitions from former L1+HLT scheme (it was 50-80%)

Online

LHCb common readout board (TELL1)

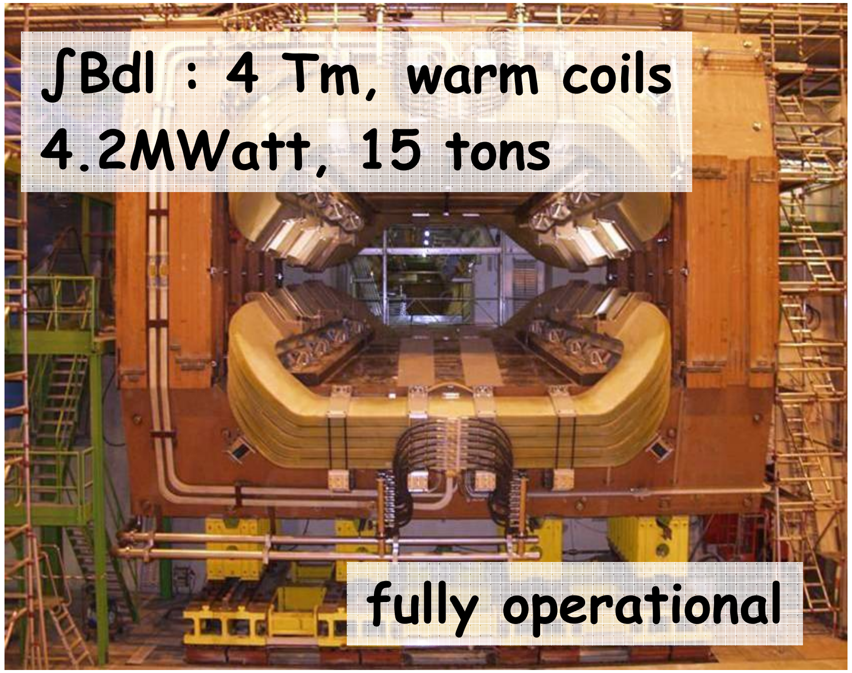


commercial network switch



Full detector info available for HLT

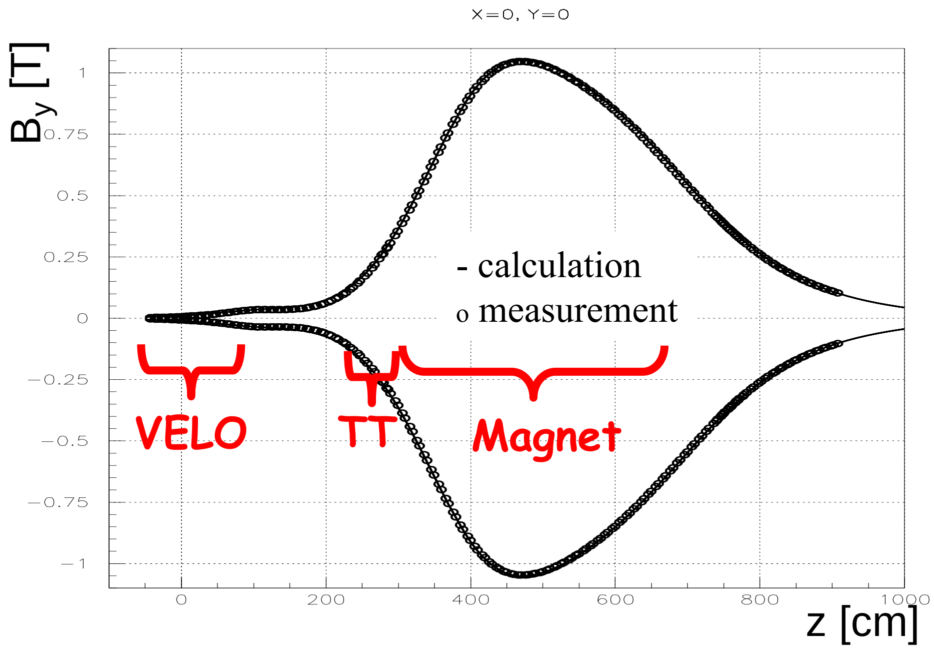
Magnet



- Magnet has long been installed

stray B stray field between VELO and TT

→ fast P_T info in Trigger

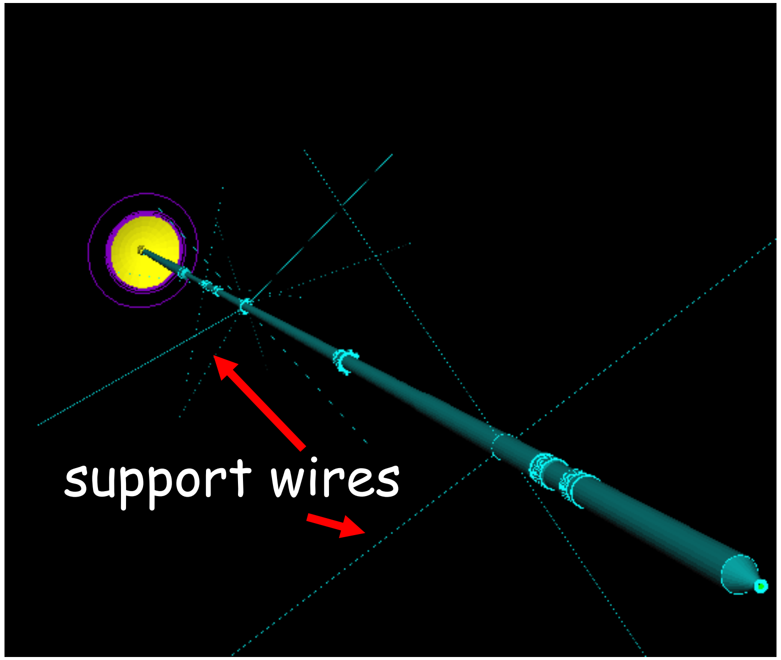


- magnetic field map to precision: 3×10^{-4} ,
- symmetry w.r.t. polarity:

  $\Delta B / \langle B \rangle \sim 3 \times 10^{-4}$

Beam Pipe

- 25mrad Be section + Velo exit window
- 1st and 2nd 10 mrad Be section
- stainless steel section

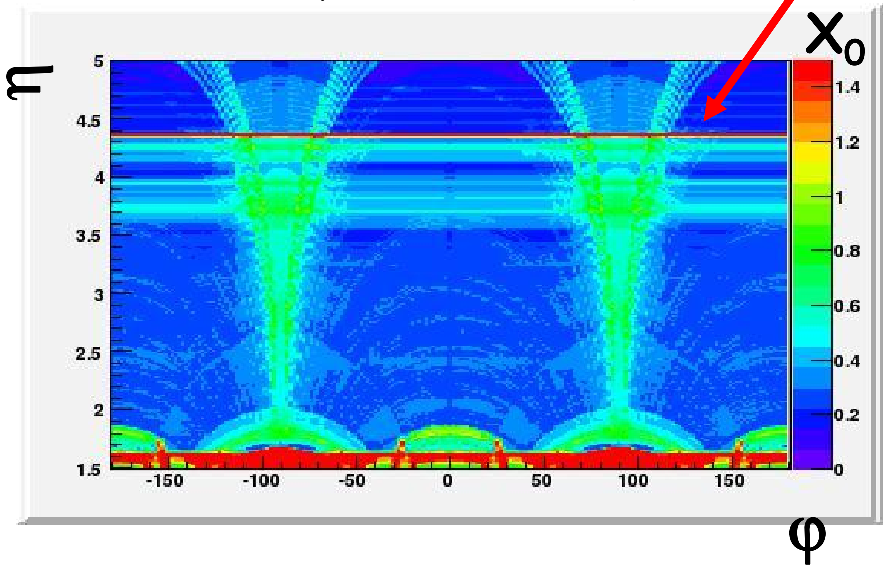


All beam-pipe pieces are at hand, 1st section installed and sealed to the VELO vessel

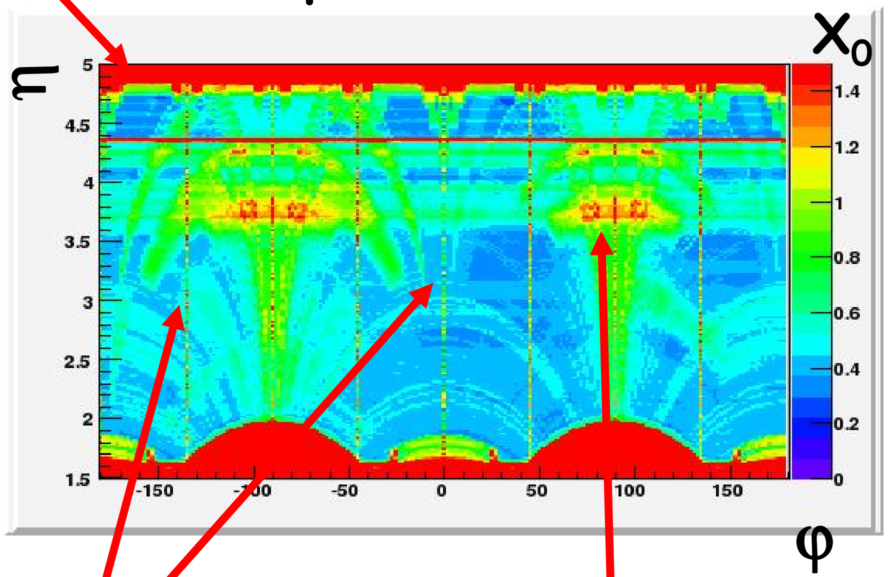
Material Scan

beam pipe

Material up to the magnet



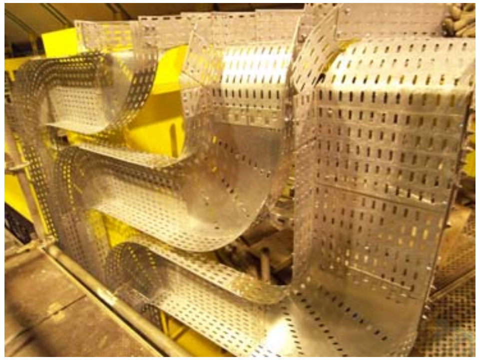
Material up to the RICH2



Inner Tracker

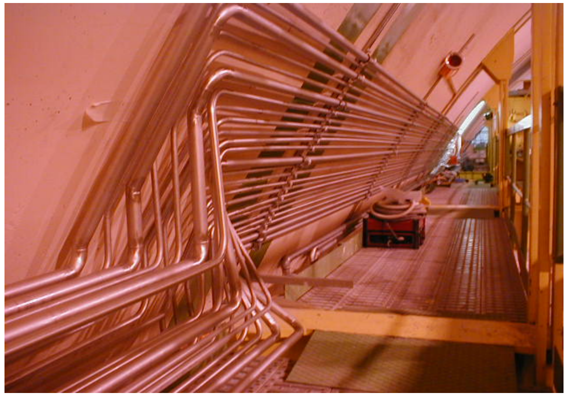
one can clearly see the beam-pipe support wires

Experimental Area/Services



- 90% of cable trays finished
- long distance cabling well advanced

- gas system in place
- piping well advanced
- SNIFFERs installed



- C_6F_{14} cooling installed and testing ongoing
- water cooling pipes installed in prox. to sub detectors

Summary

- LHCb is a dedicated B-physics experiment at the LHC which delivers physics from "day 1" (get design luminosity at LHC start-up)

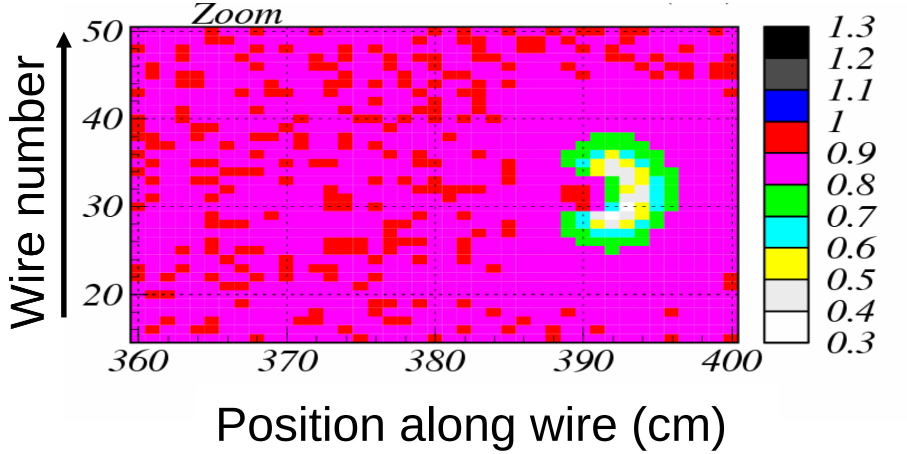
- detector construction is advancing well and global commissioning will start early 2007

- LHCb will be ready at LHC start-up end 2007

Outer Tracker

oops... ??

accidental irradiation with ^{90}Sr source (~20h):



→ gain loss (not observed in irradiation aging studies typicaly done with higher dose)

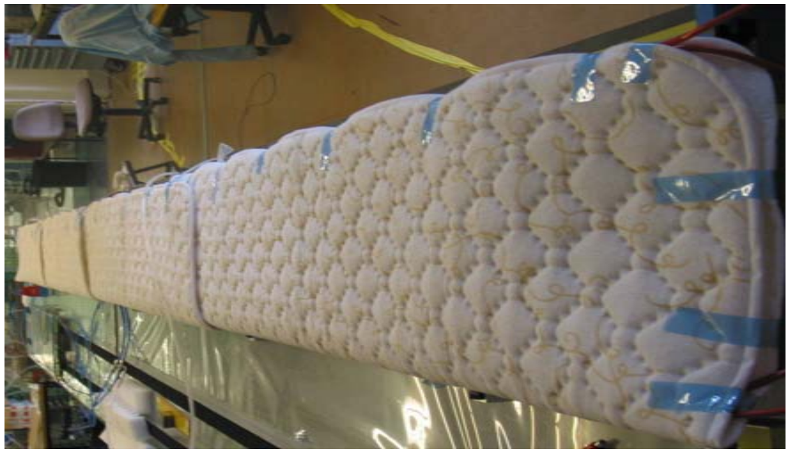
→ exact cause not yet identified:

<u>However:</u>

pre-conditioning the modules by:

- flushing with gas
- heating
- HV processing
- varying gas mixture
- etc. etc.

are found to be beneficial

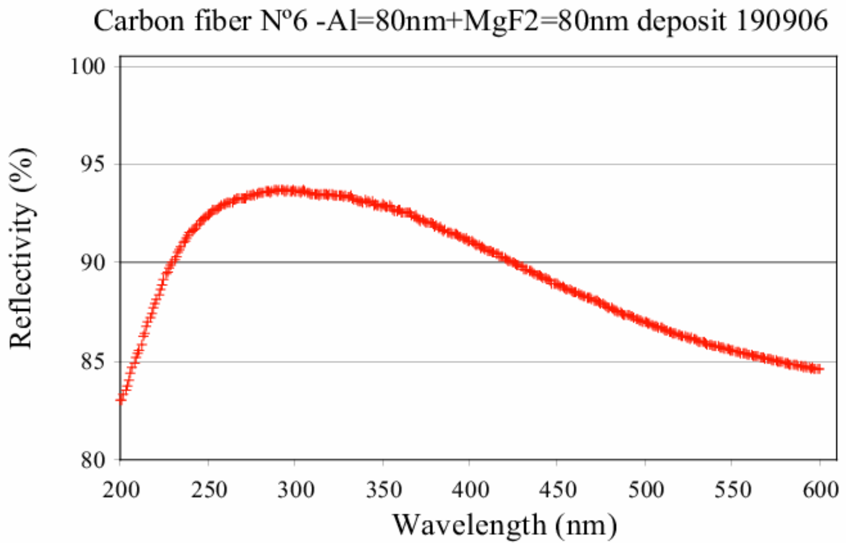


→ further studies are ongoing

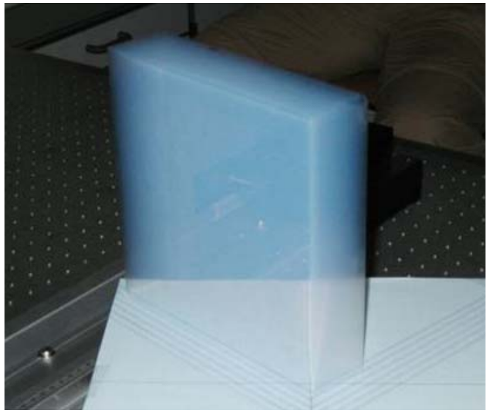
RICH Mirror/Radiator

new spherical mirrors for RICH1:

- Be → carbon fibre
- mirror production ongoing
- final optimization of reflective coating is ongoing



Silica-Aerogel production is completed



Trigger (L0 custom boards)

Many different boards, all close to final production

Calorimeters:

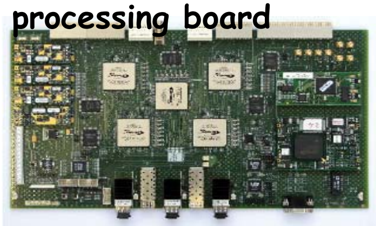
selection board

validation card

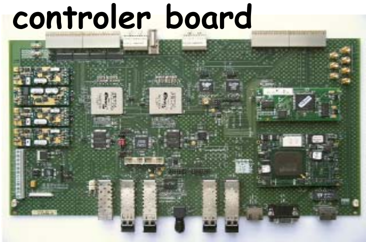
optical mezzanine

Muon:

processing board



controler board

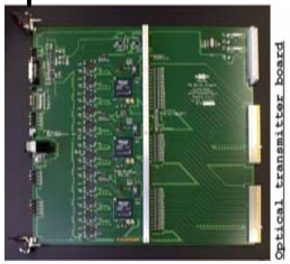


backplane

Pile-Up:

detector module

optical transmitter board

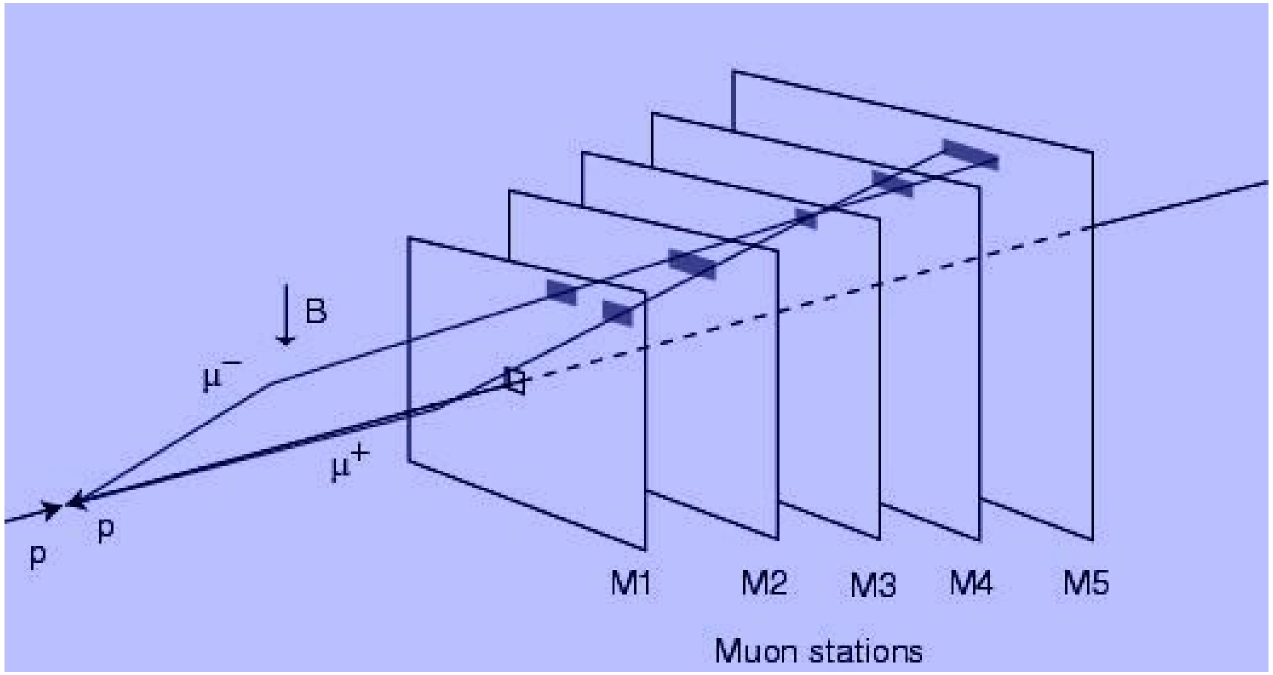


vertex finder board

L0 Decision Unit

L0 commissioning will start 2007 and will be ready August 2007

L0 Trigger μ reconstruction



TDR L0/L1 efficiencies

Table 7.4: L0 efficiencies at 1 MHz for several offline selected signal channels which have been used to determine the thresholds. The last three columns show the inclusive trigger efficiencies for the hadronic, electromagnetic (electron, photon, π^0's) and muon triggers.

Decay Channel	$\varepsilon_{L0}(\%)$	Inclusive efficiencies (%)		
		had. trig.	elec. trig.	muon trig.
$B_d^0 \to \pi^+\pi^-$	53.6 ± 0.4	47.6 ± 0.5	14.1 ± 0.3	6.8 ± 0.2
$B_s^0 \to D_s^-(K^+K^-\pi^-)\pi^+$	49.4 ± 0.6	42.2 ± 0.6	13.1 ± 0.4	8.3 ± 0.4
$B_s^0 \to D_s^-(K^+K^-\pi^-)K^+$	47.2 ± 0.3	39.4 ± 0.3	11.7 ± 0.2	8.2 ± 0.2
$B_d^0 \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$	89.3 ± 0.5	18.6 ± 0.7	8.3 ± 0.5	87.2 ± 0.6
$B_d^0 \to J/\psi(e^+e^-)K_S^0(\pi^+\pi^-)$	48.3 ± 1.0	21.5 ± 0.8	37.4 ± 0.9	7.0 ± 0.5
$B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$	89.7 ± 0.1	20.0 ± 0.2	8.4 ± 0.1	87.4 ± 0.1
$B_d^0 \to K^{*0}(K^+\pi^-)\gamma$	72.9 ± 1.0	32.7 ± 1.1	68.1 ± 1.1	7.8 ± 0.6

channel with:	$B \to$	ε_{L0}	$\varepsilon_{L0 \times L1}$
hadrons:	$D_s^-(K^+K^-\pi^-)K^+$	47.2%	29.5%
leptons:	$J/\psi(\mu^+\mu^-)\ \phi(KK)$	89.7%	64.0%
photon:	$K^{*0}(K^+\pi^-)\gamma$	72.9%	37.8%

efficiencies w.r.t. offline selected events,
L1 is now integrated in HLT, no new numbers yet

Table 7.7: L1 efficiencies at 40 kHz output rate for several signal channels. The efficiencies are normalized to L0-triggered events that are used for offline analysis.

Decay channel	$\varepsilon_{L1}(\%)$
$B_d^0 \to \pi^+\pi^-$	62.7 ± 0.5
$B_d^0 \to K^+\pi^-$	61.5 ± 1.0
$B_s^0 \to K^-\pi^+$	65.0 ± 1.4
$B_s^0 \to K^+K^-$	60.0 ± 0.4
$B_d^0 \to \pi^+\pi^-\pi^0$	46.6 ± 2.2
$B_d^0 \to D^{*-}(\overline{D^0}\pi^-)\pi^+$	56.0 ± 1.6
$B_d^0 \to \overline{D^0}(K^+\pi^-)K^{*0}(K^+\pi^-)$	66.7 ± 1.8
$B_d^0 \to \overline{D^0}(K^+K^-)K^{*0}(K^+\pi^-)$	61.6 ± 1.6
$B_s^0 \to D_s^-(K^+K^-\pi^-)\pi^+$	63.0 ± 0.9
$B_s^0 \to D_s^-(K^+K^-\pi^-)K^+$	62.6 ± 0.4
$B_d^0 \to J/\psi(\mu^+\mu^-)K_S^0(\pi^+\pi^-)$	67.7 ± 0.9
$B_d^0 \to J/\psi(e^+e^-)K_S^0(\pi^+\pi^-)$	54.9 ± 1.4
$B_d^0 \to J/\psi(\mu^+\mu^-)K^{*0}(K^+\pi^-)$	76.8 ± 0.3
$B_u^+ \to J/\psi(\mu^+\mu^-)K^+$	76.0 ± 0.5
$B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$	71.4 ± 0.2
$B_s^0 \to J/\psi(e^+e^-)\phi(K^+K^-)$	57.2 ± 0.8
$B_s^0 \to J/\psi(\mu^+\mu^-)\eta(\gamma\gamma)$	70.3 ± 1.5
$B_s^0 \to \eta_c(4\pi, 2K2\pi)\phi(K^+K^-)$	59.0 ± 4.0
$B_s^0 \to \phi(K^+K^-)\phi(K^+K^-)$	60.3 ± 1.5
$B_d^0 \to \mu^+\mu^-K^{*0}(K^+\pi^-)$	78.5 ± 1.1
$B_d^0 \to K^{*0}(K^+\pi^-)\gamma$	51.9 ± 1.4
$B_s^0 \to \phi(K^+K^-)\gamma$	49.3 ± 2.0
$B_c^+ \to J/\psi(\mu^+\mu^-)\pi^+$	65.6 ± 0.9