Status of LHCb

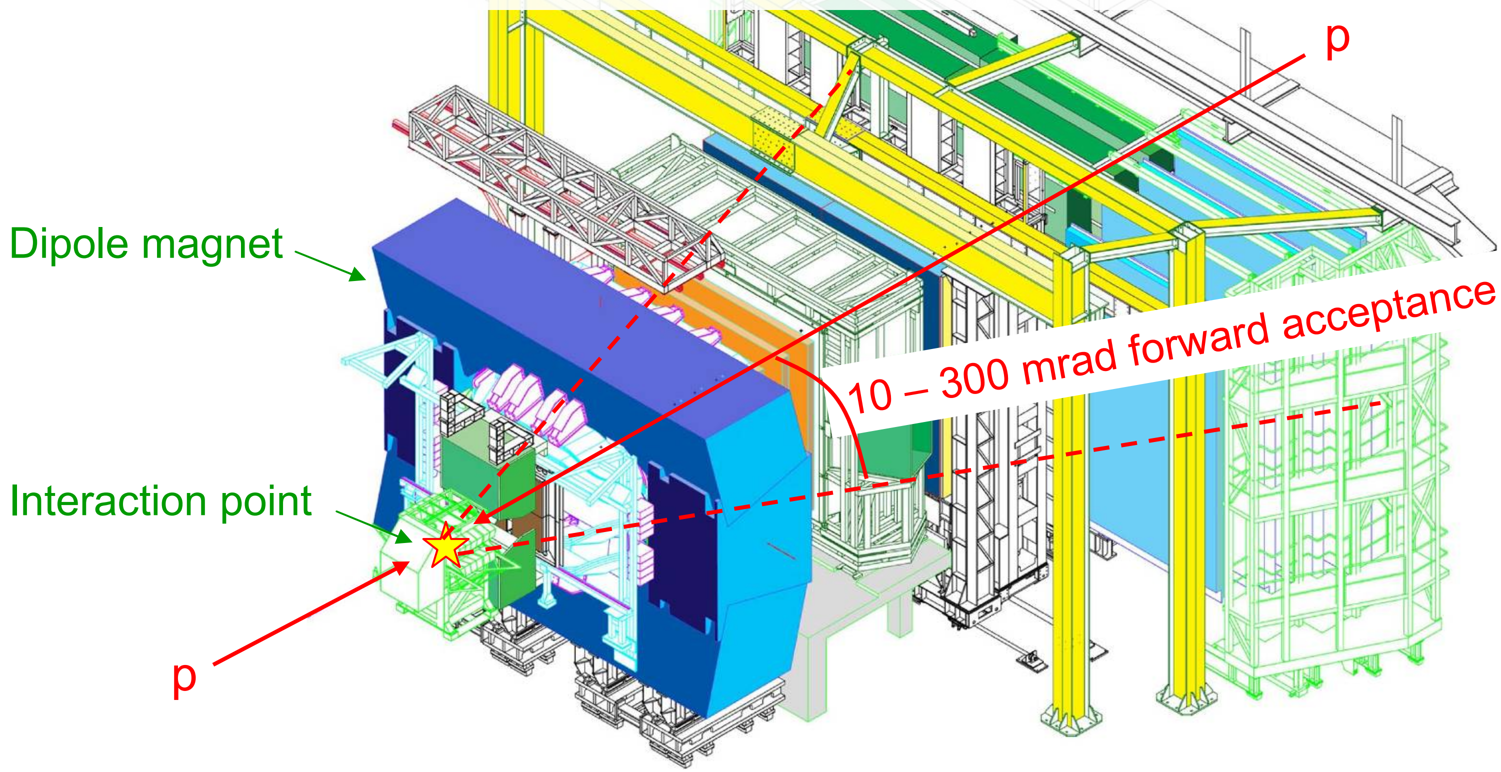
Roger Forty (CERN)

On behalf of the LHCb Collaboration

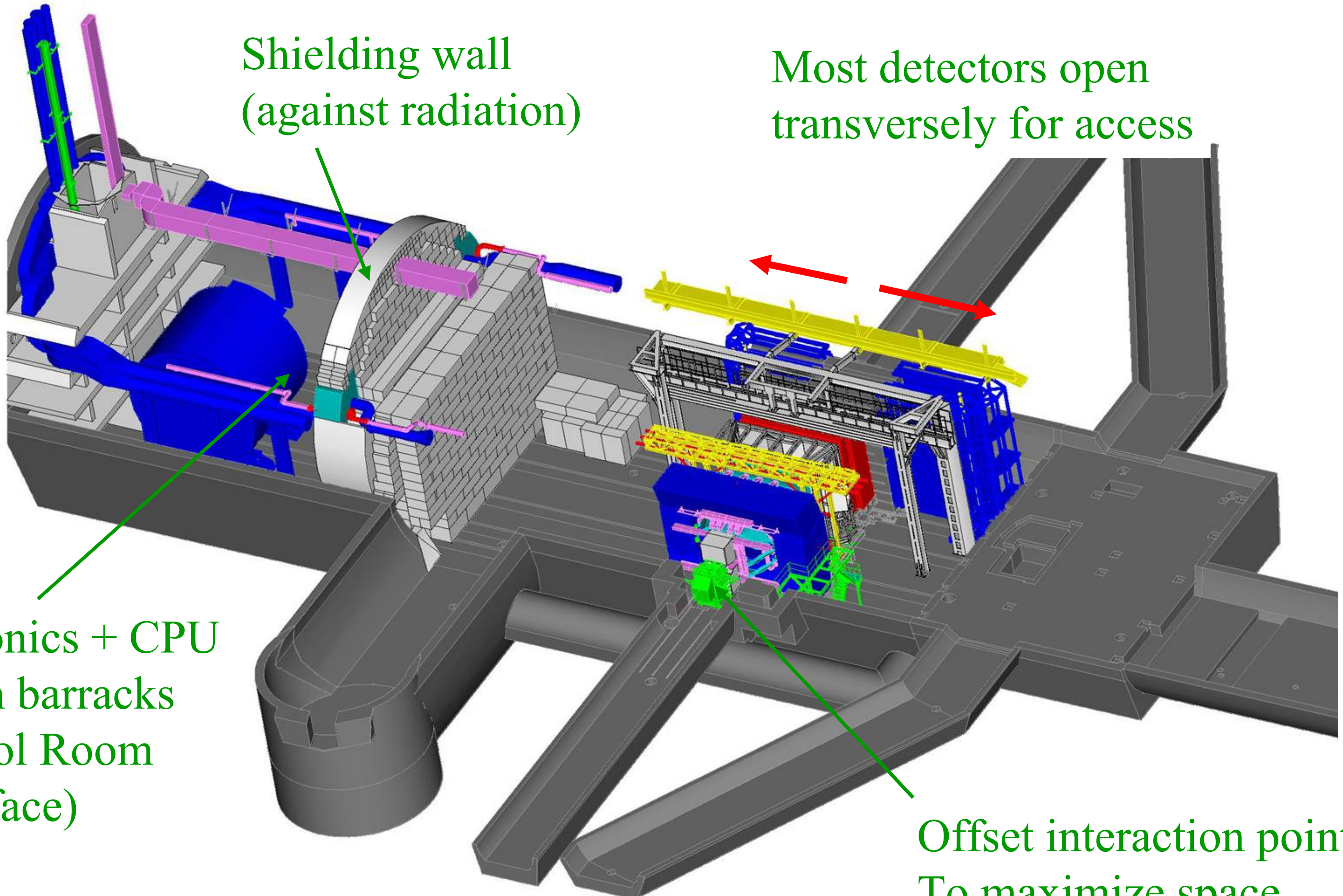
1. Experimental infrastructure
2. Detector installation
3. Preparation for physics
4. Collaboration matters

The LHCb Experiment

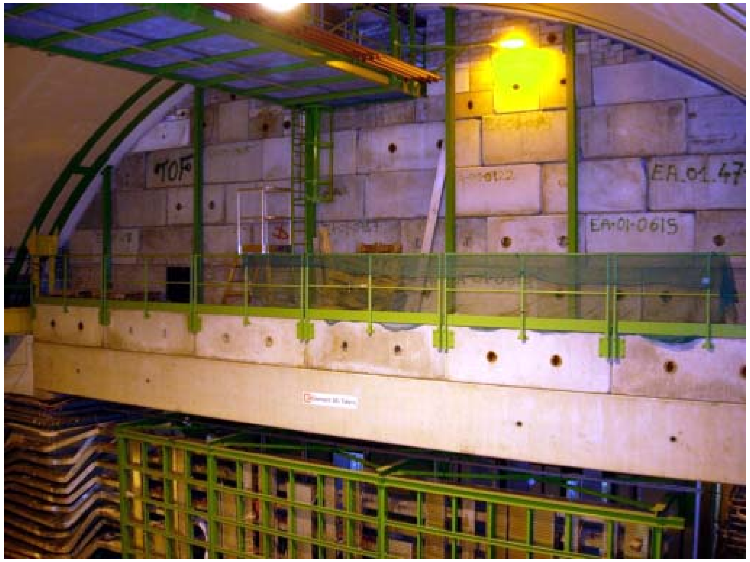
- Dedicated experiment for precision measurement of CP violation and rare decays of b-hadrons (and charm) at the LHC
- Collider-mode operation at same time as the general-purpose detectors, with less-focussed beams → most events have a single pp interaction



1. Experimental infrastructure



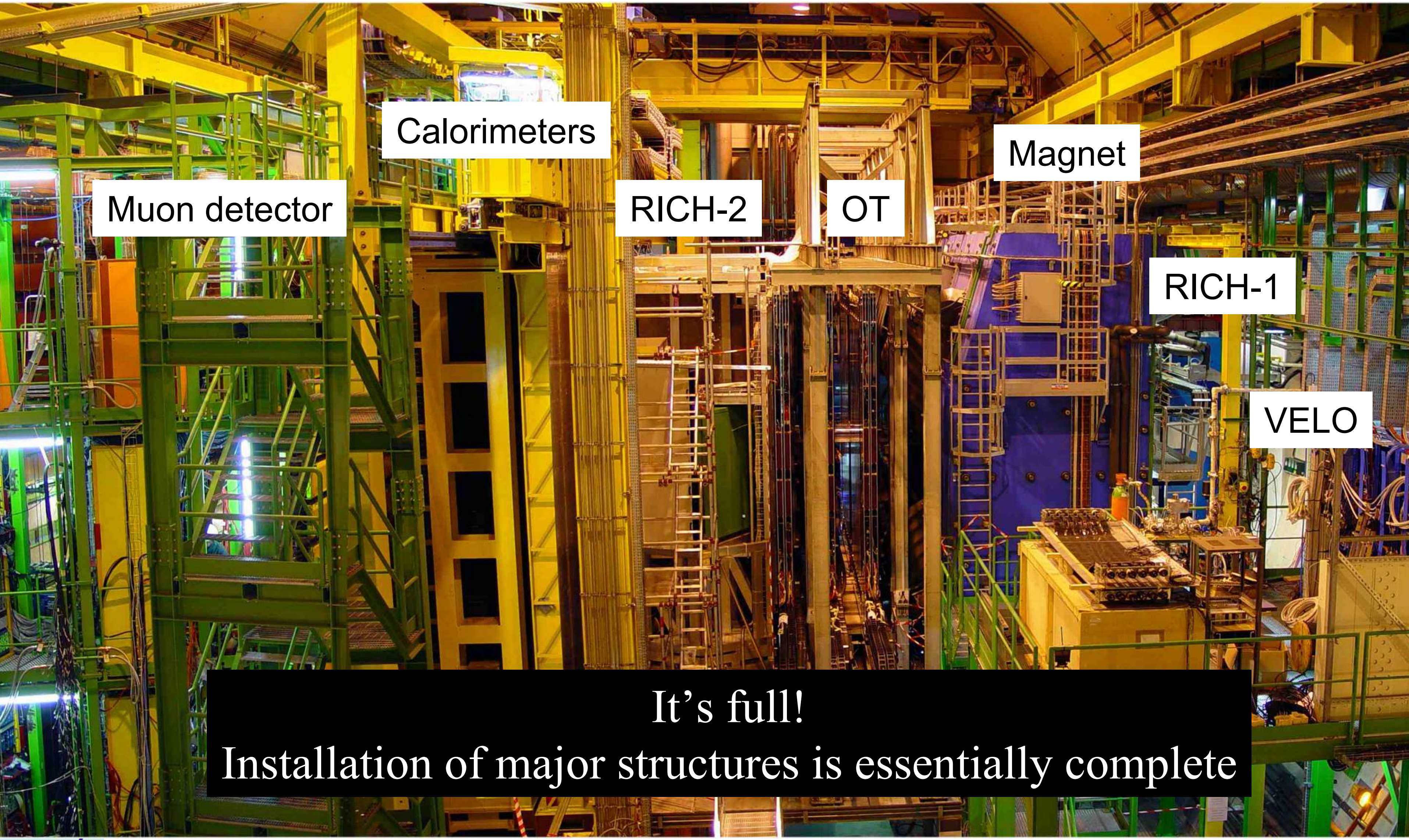
Shielding wall



- Upper part completed
  Labour intensive "Egyptian work" as inaccessible by crane…

- Assembly of lower part is progressing well
  Paused while a problem with leaking cooling-water pipes is investigated

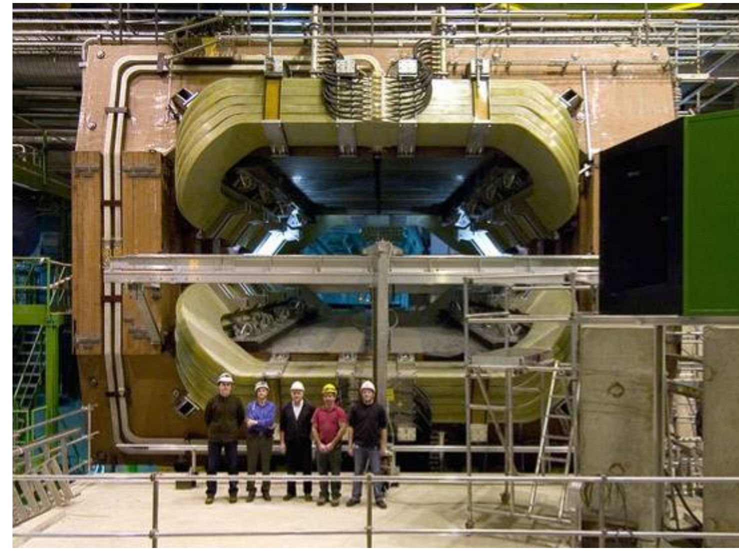
View of the cavern



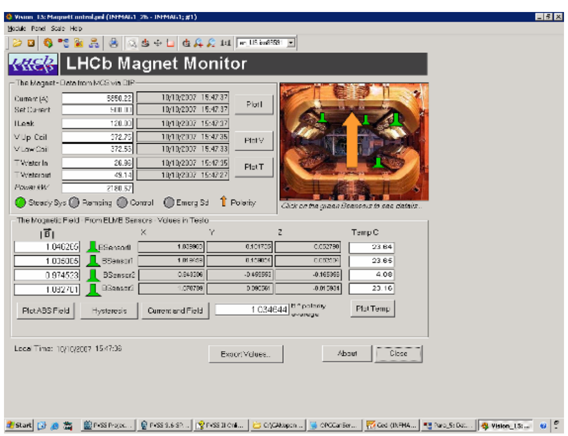
It's full!
Installation of major structures is essentially complete

Spectrometer magnet

- Warm dipole magnet completed and mapped two years ago
- Switched on again last month
- Operated from CERN Control Centre, together with the three compensating magnets

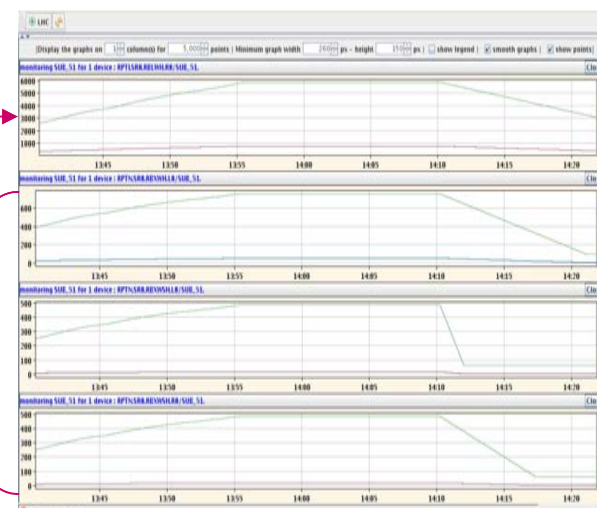


- Monitored by ECS:



LHCb dipole

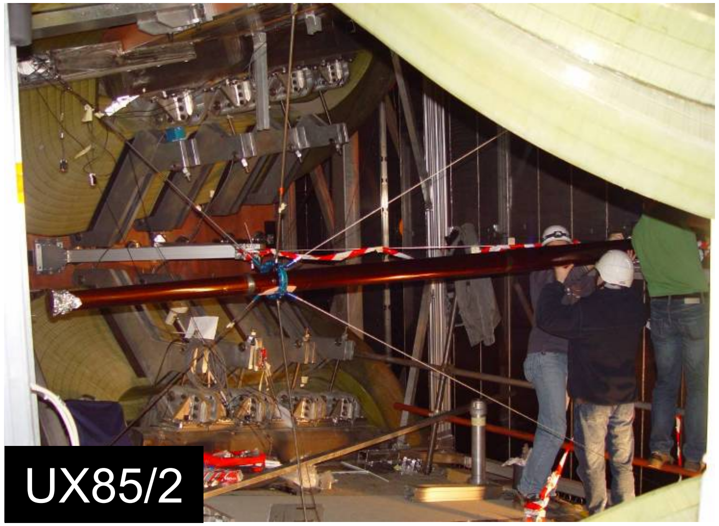
Compensators



Successful test

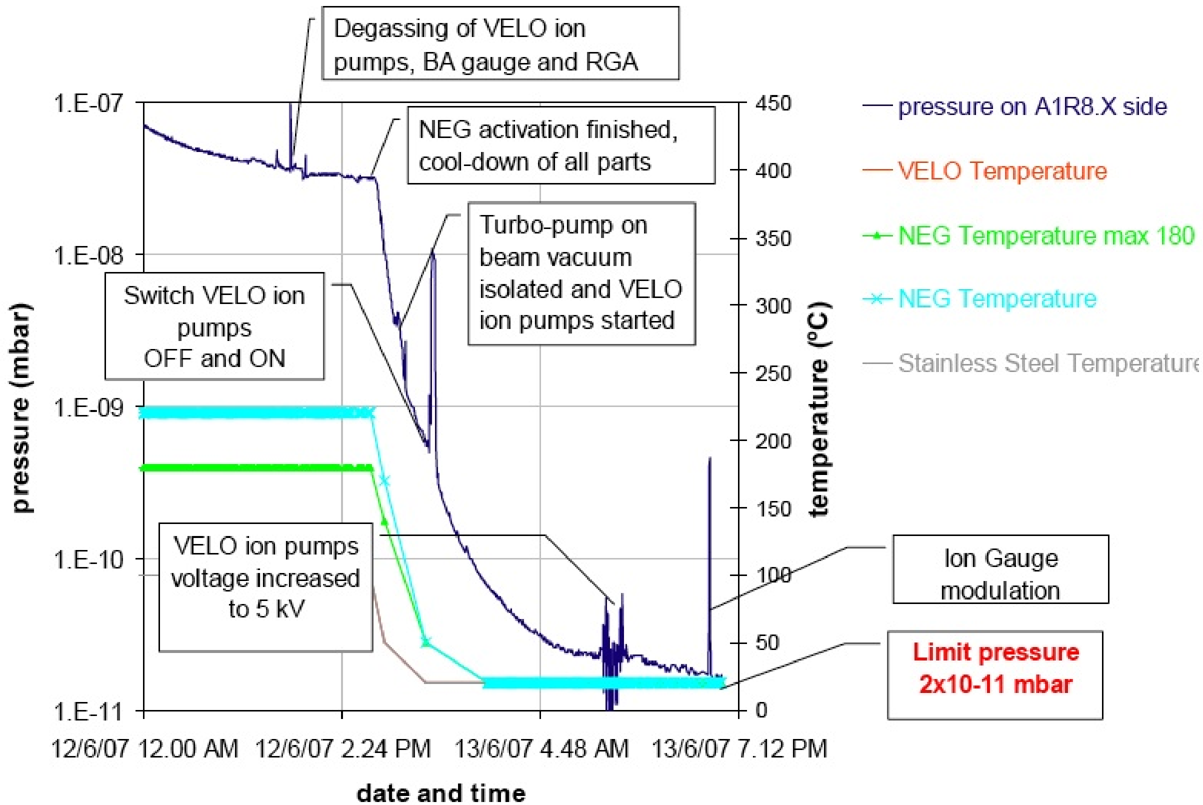
Beam pipe

- Conical, three beryllium sections
- Installation now complete
- Aluminium spares being made (in case of accident)



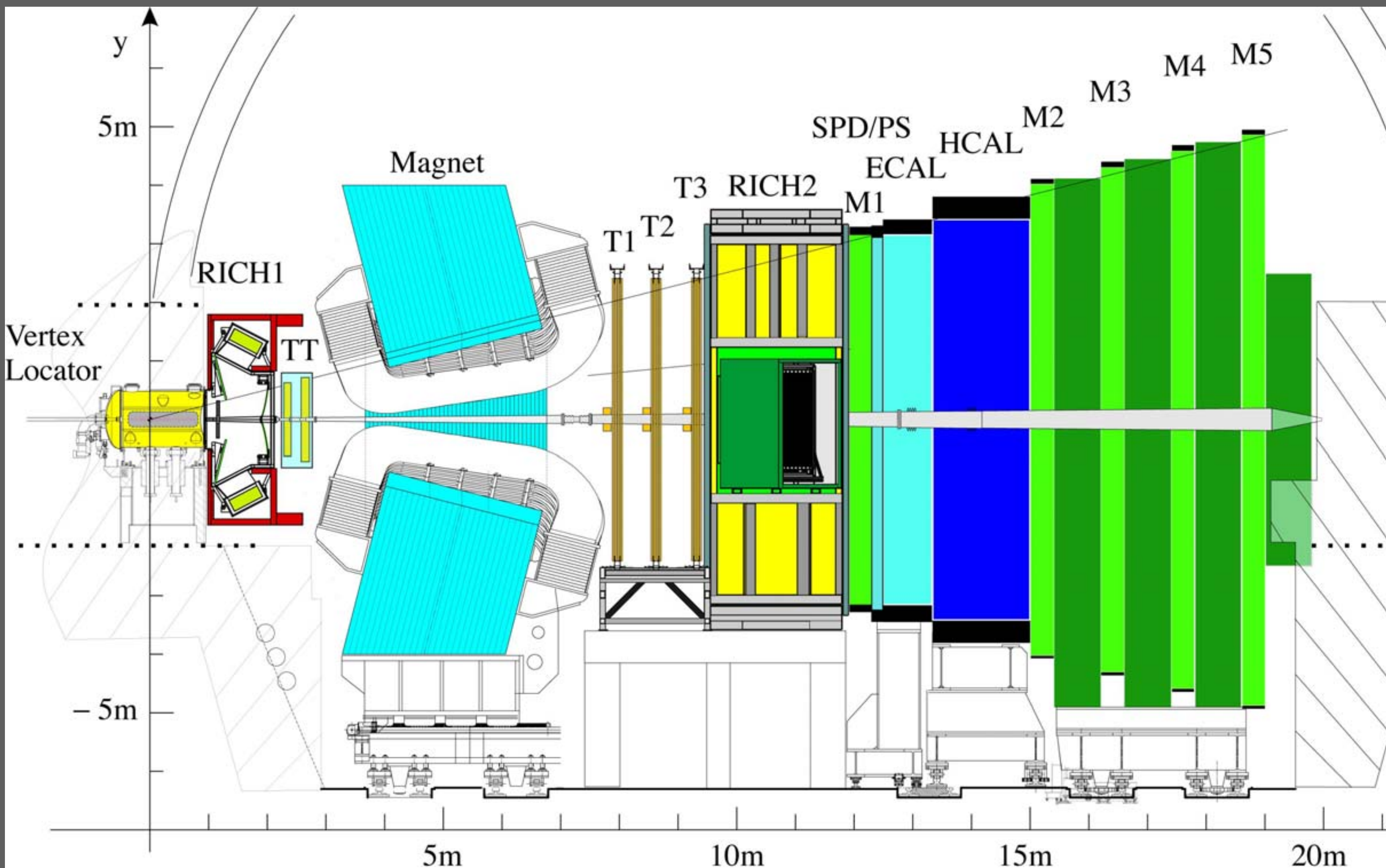
Bake-out

- Leaks developed in the third Be section during acceptance tests
  Sealed by LHC vacuum group (AT/VAC) using silicon varnish
- Bake-out completed successfully in June: ready for operation

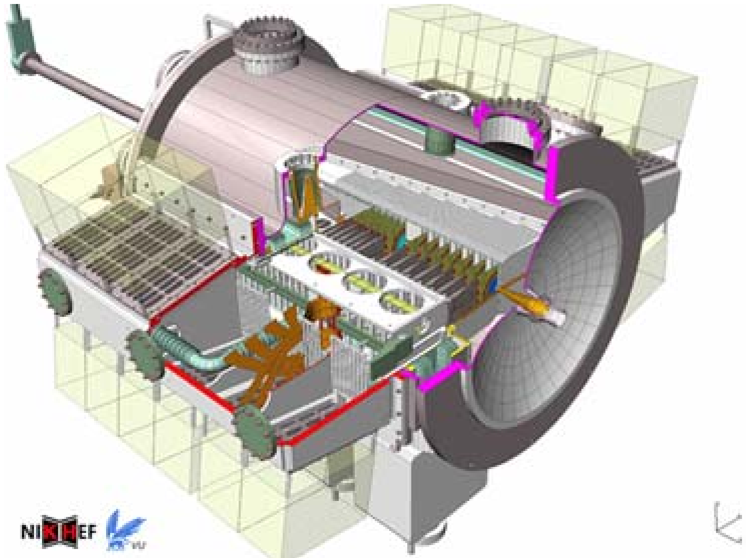


2. Detector installation

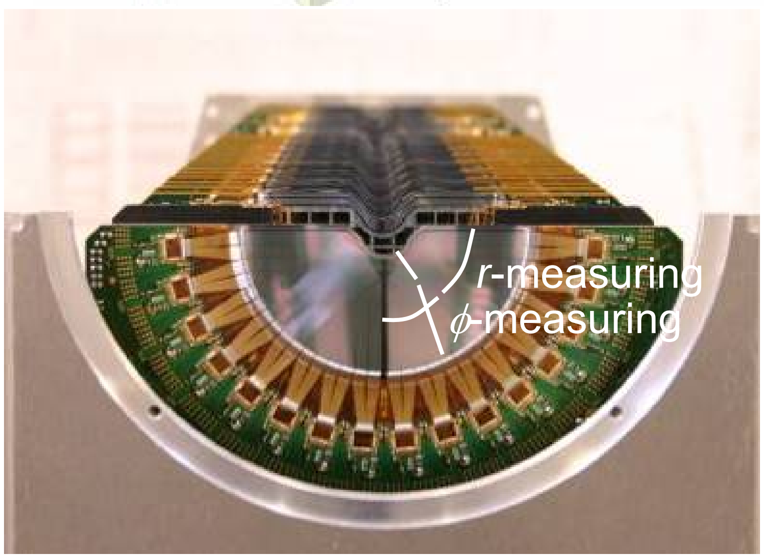
Muon detector



VELO

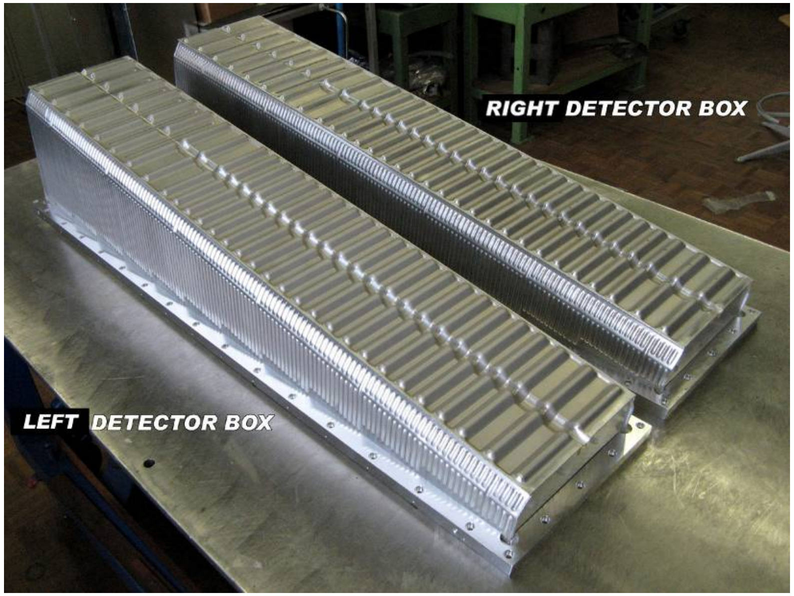


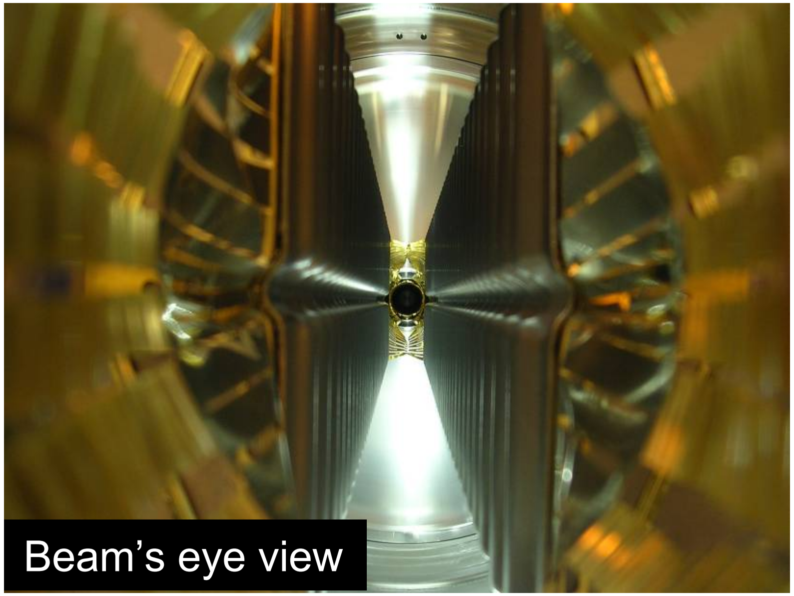
- 21 stations of Si wafer pairs with *r* and ϕ strip readout
- Split in two halves to allow retraction from beam line
- Both detector halves now completed, installed in the pit



RF-boxes

- Modules sit in secondary vacuum, separated from machine vacuum by 300 μm AlMg3 foil RF-boxes
  - Intricately formed to allow for overlap of the two halves
- Leaks developed (~10^{-5} mbar l/s) but only between primary and secondary vacua: no immediate concern for operation
  - R&D has started for replacement RF-boxes

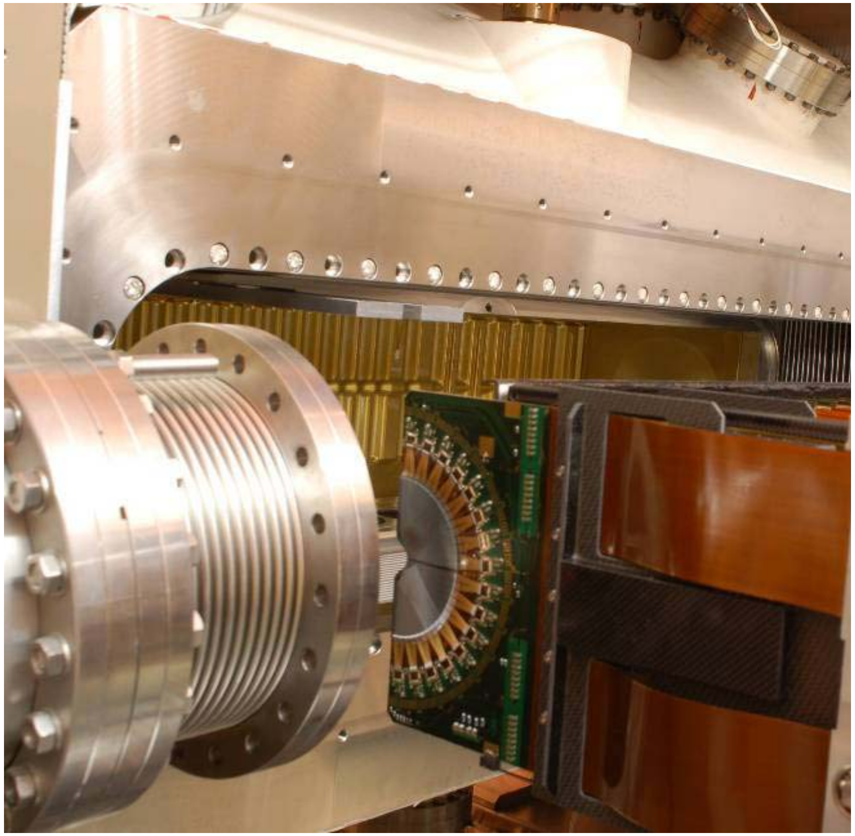


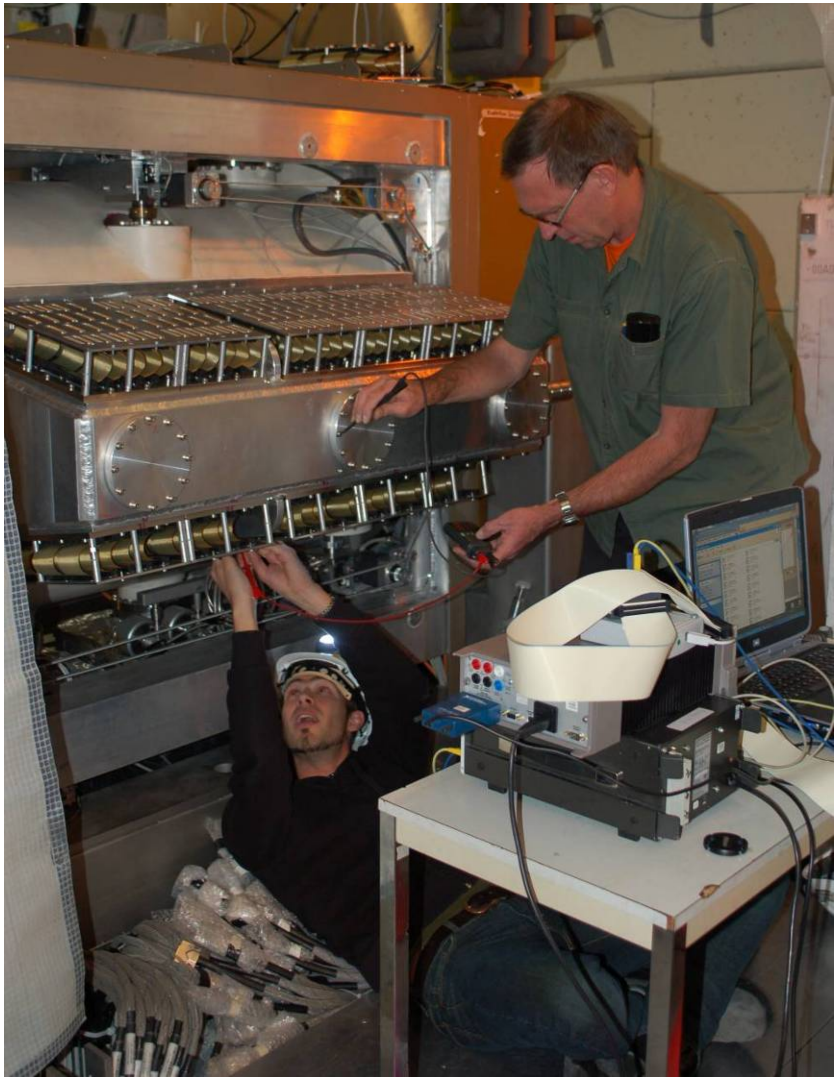


Installation of detector halves

C-side installation, 30 October (video extracts…)

Installation of detector halves

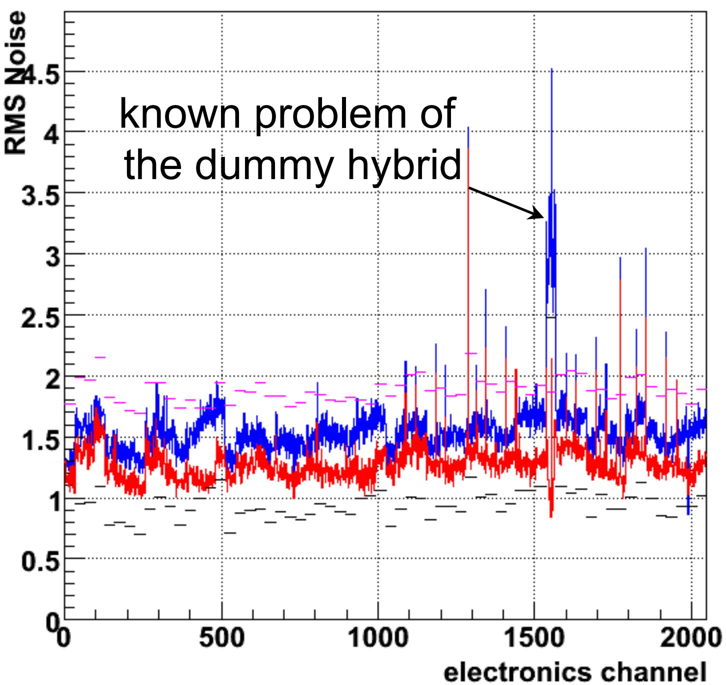


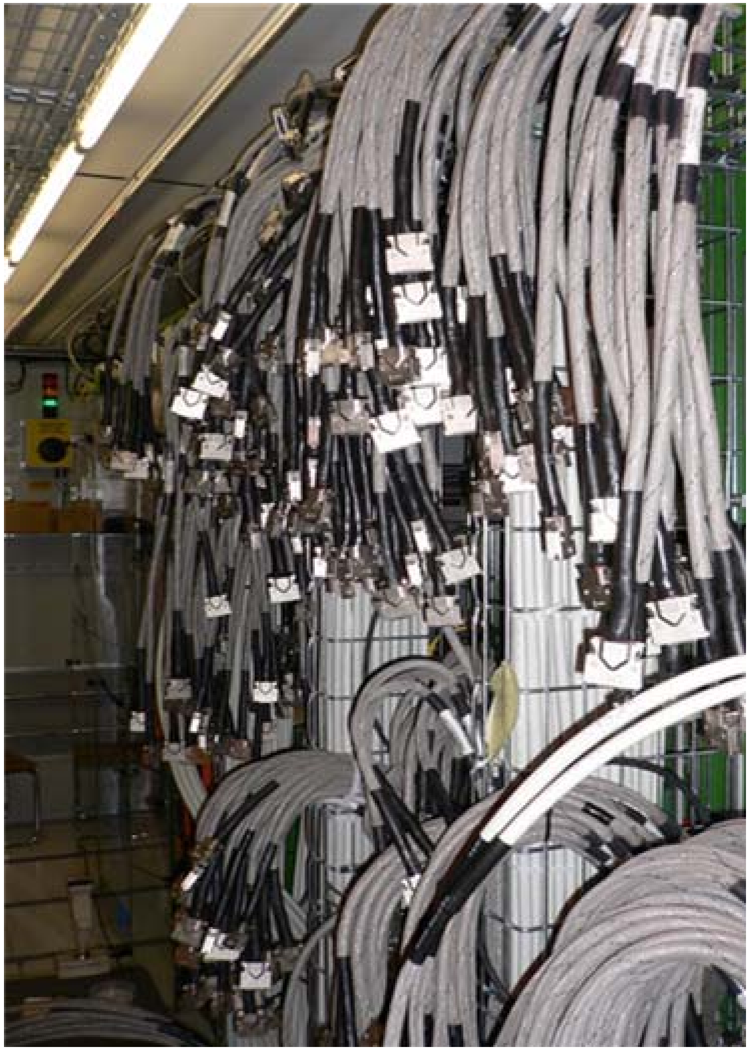


- After completion: testing I/V characteristics of modules → all OK

VELO readout

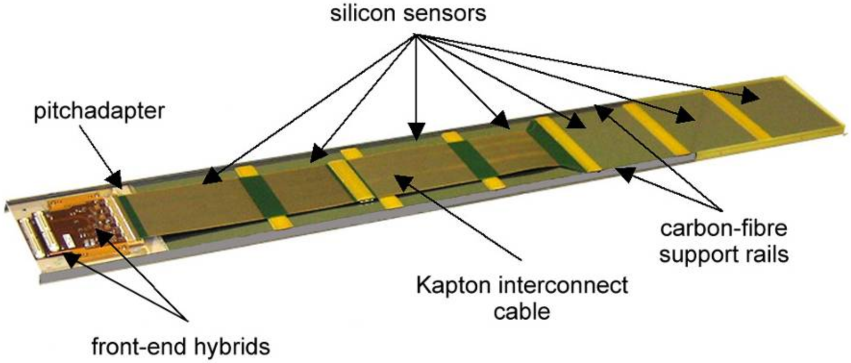
- Analogue readout → plenty of copper cables, all now installed
- First read-out of data (noise) using the full electronics chain

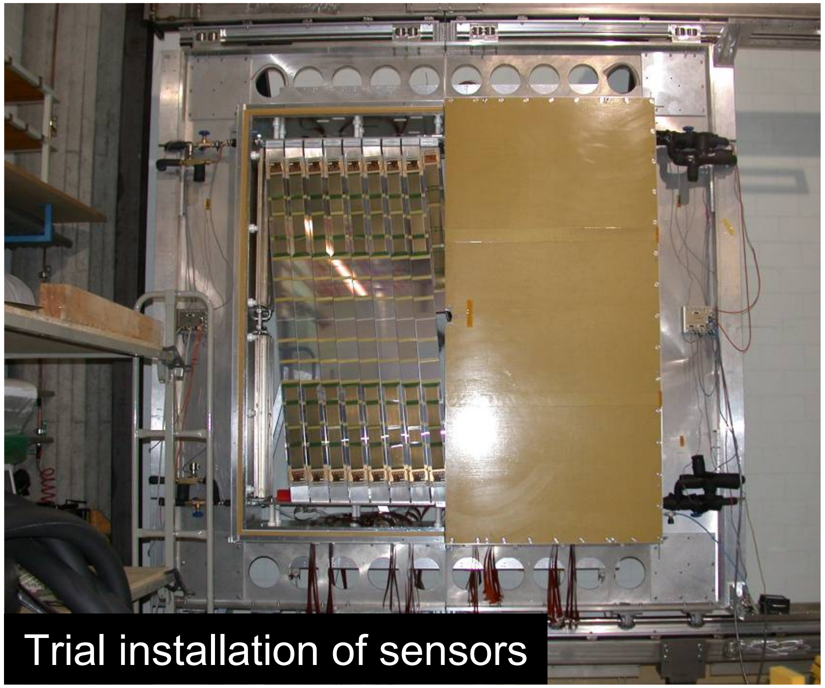




Trigger Tracker

- VELO is in ~ field-free region
  → straight tracks
- TT is a silicon microstrip 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

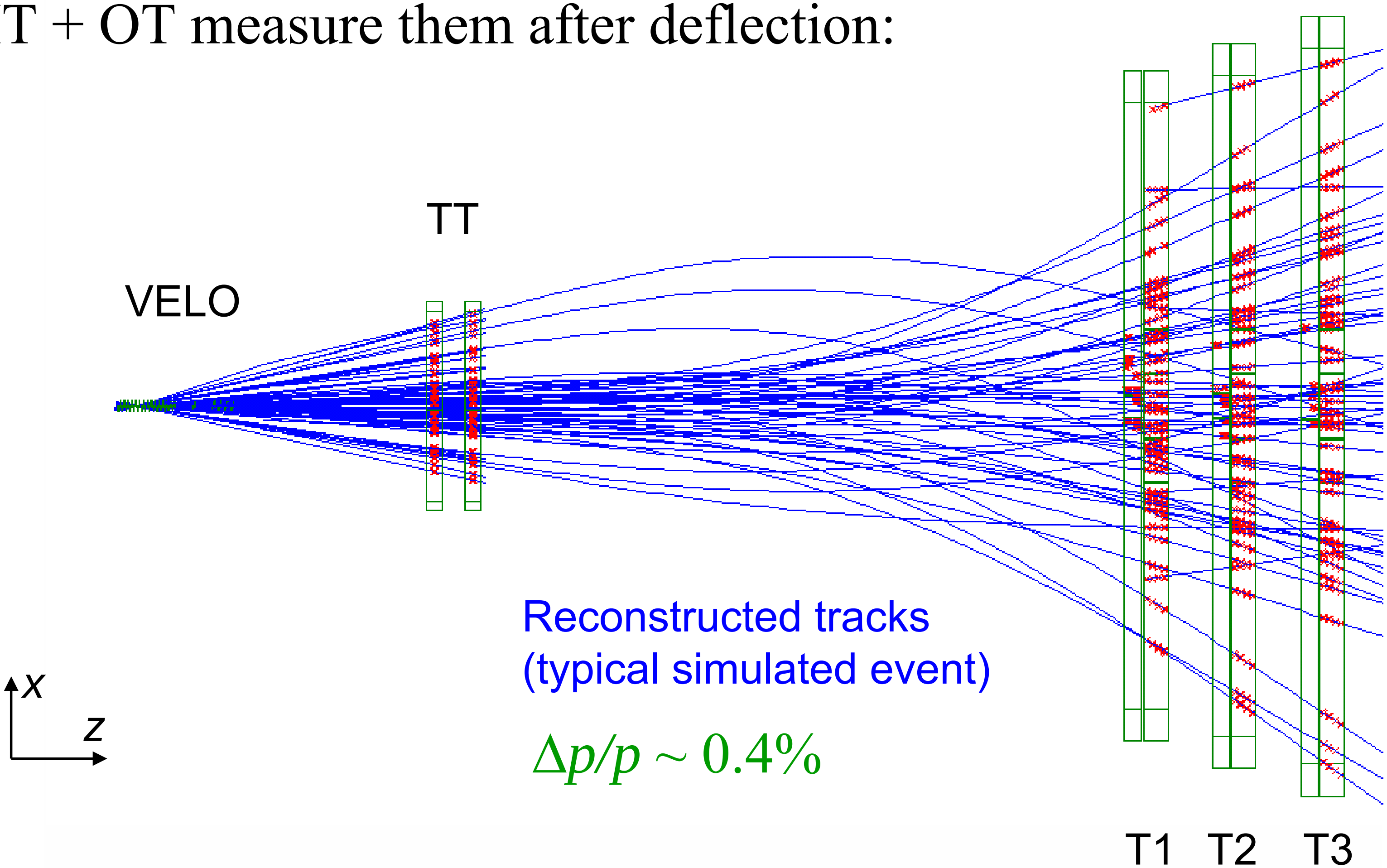




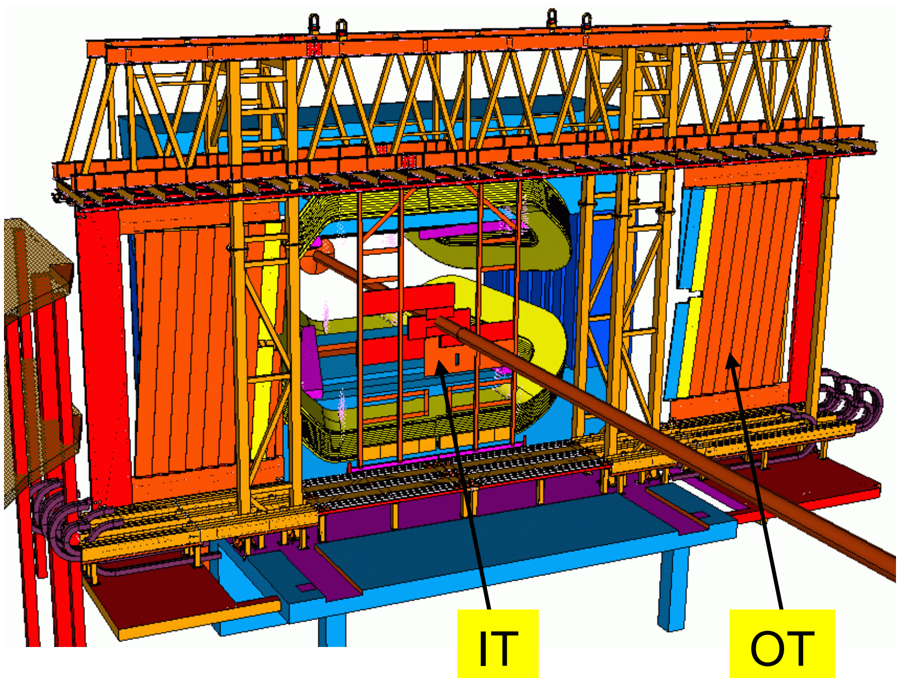
Trial installation of sensors

Tracking Stations

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



Inner Tracker

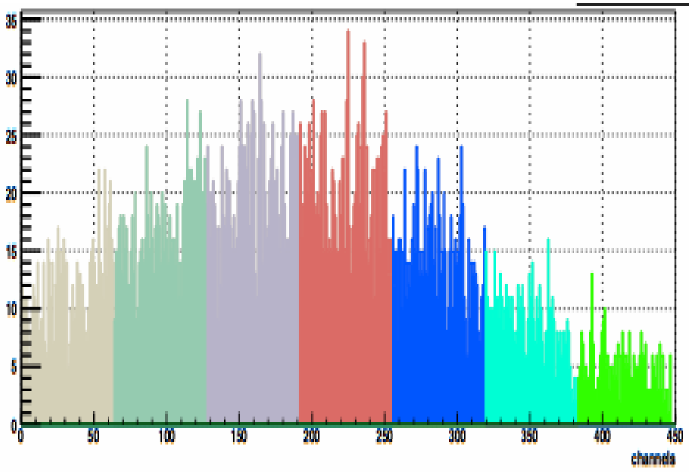


- IT ladder production complete
  Support system + infrastructure ready
- Mounting of silicon detectors in their boxes in progress
- First two boxes installed in pit
  Remaining 10 installation ~ one/week

Outer Tracker

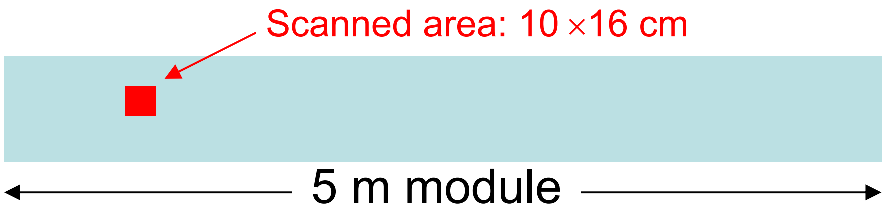
- Drift chambers: straw tubes
  5 mm diameter, 5 m length
- Detector installation complete
  Electronics installation underway
- Cosmic trigger counters
  set up for commissioning

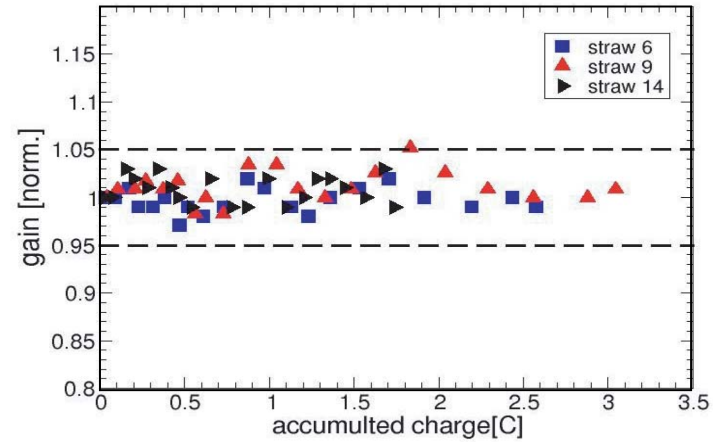
Raw hit map of cosmics over 7 modules

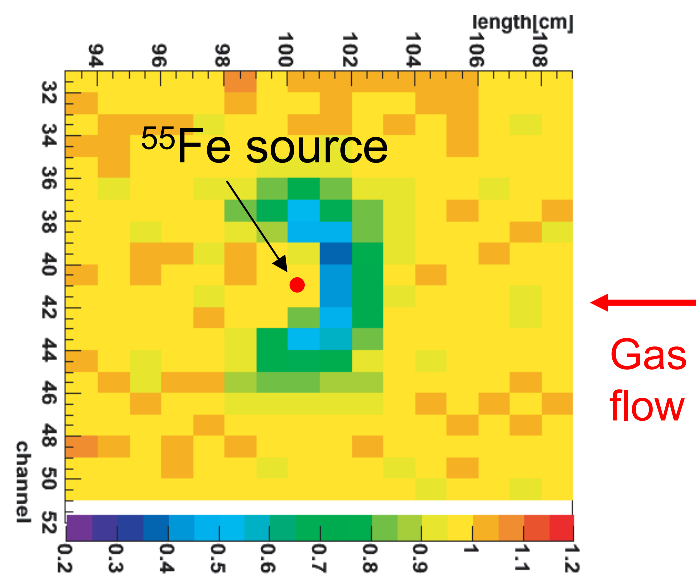


OT gain-loss issue (recap)

- Extensive ageing studies made during R&D phase
  - Expect 1 C/cm integrated charge at hottest region after 10 years
  - High rate, high dose tests → no ageing detected
- However, irradiation with weak lab source for a short period (left over a weekend)
  - Significant gain loss observed Similar results with ^{90}Sr (β-emitter)
  - Largest effect for 2–5 nA/cm

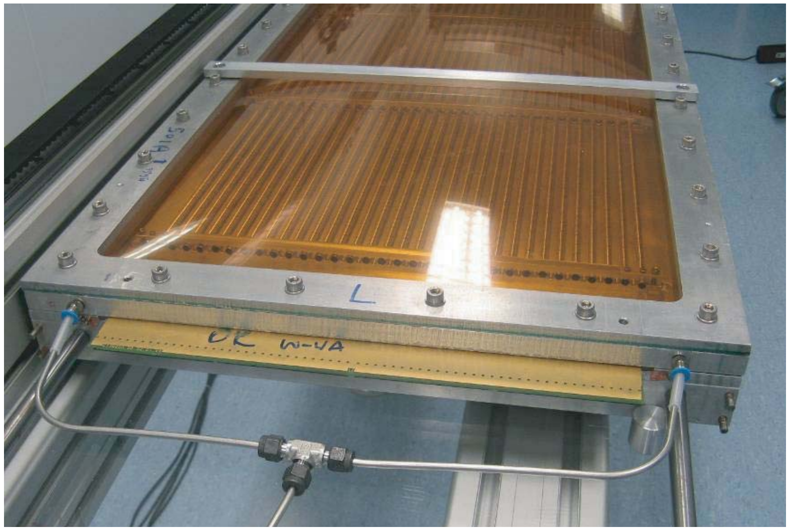




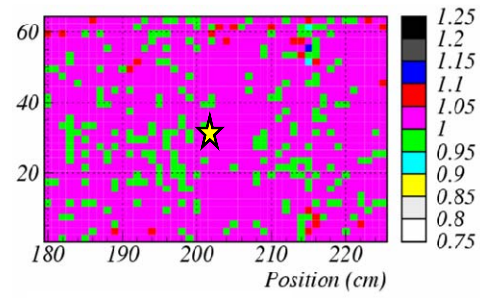


Ratio of signals after/before irradiation

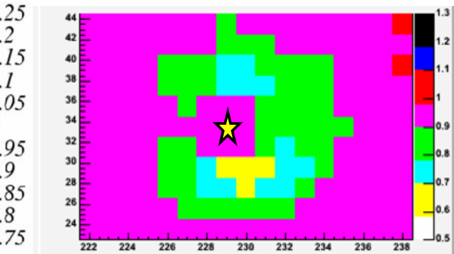
Culprit identified



- Test chamber built without glue

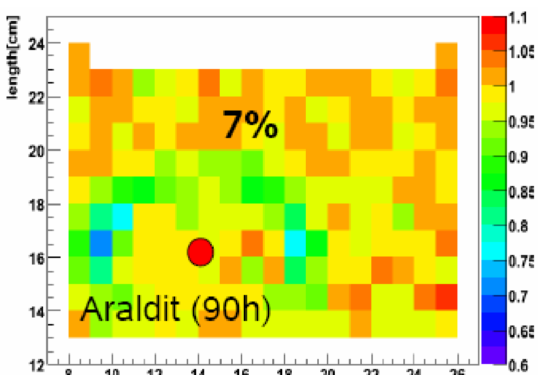


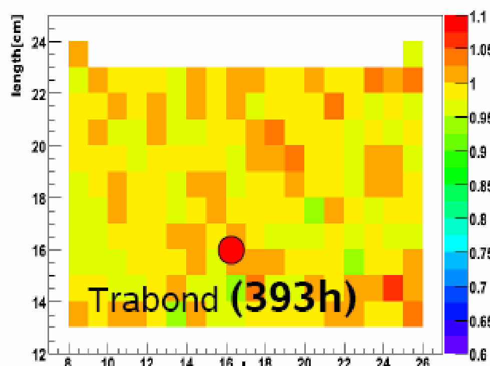
20 mCu
480 hours



Araldite (AY103)
added at entrance

- 1 m-long chambers constructed with different glue:



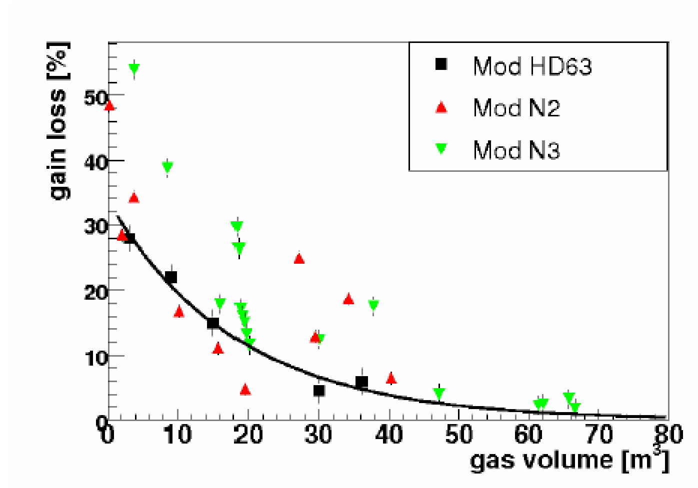


– Trabond (2115) gives no apparent gain loss

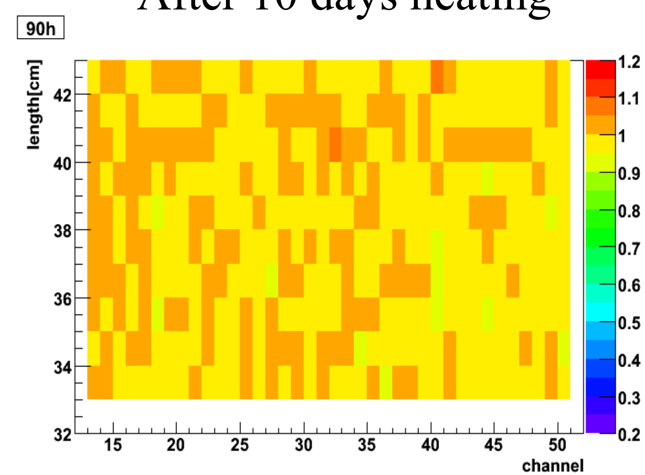
→ Problem is from out-gassing of Araldite

Minimising the effect

- The gain-loss effect is clearly reduced by flushing chambers
  - All modules are continuously flushed, including next ~ year to first data
- Warming modules to 40ºC during flushing also helps
  - Heating jackets prepared for use in situ

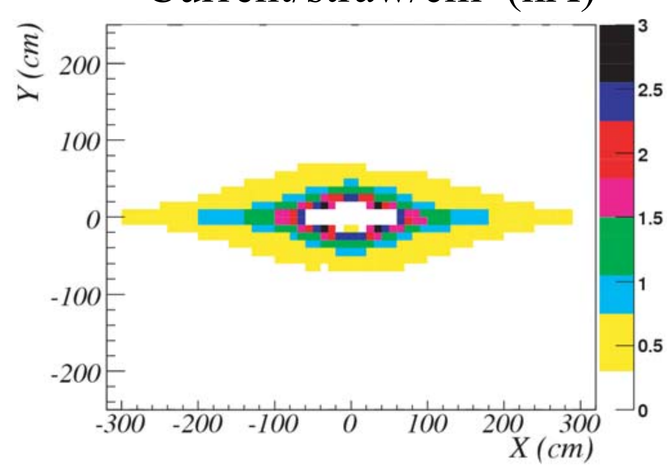


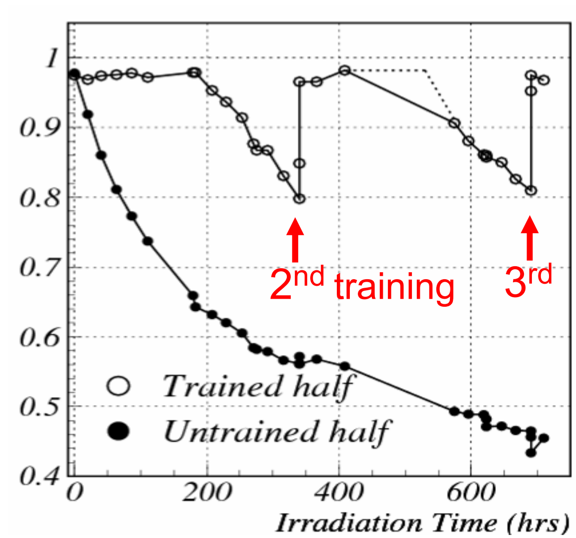
After 10 days heating



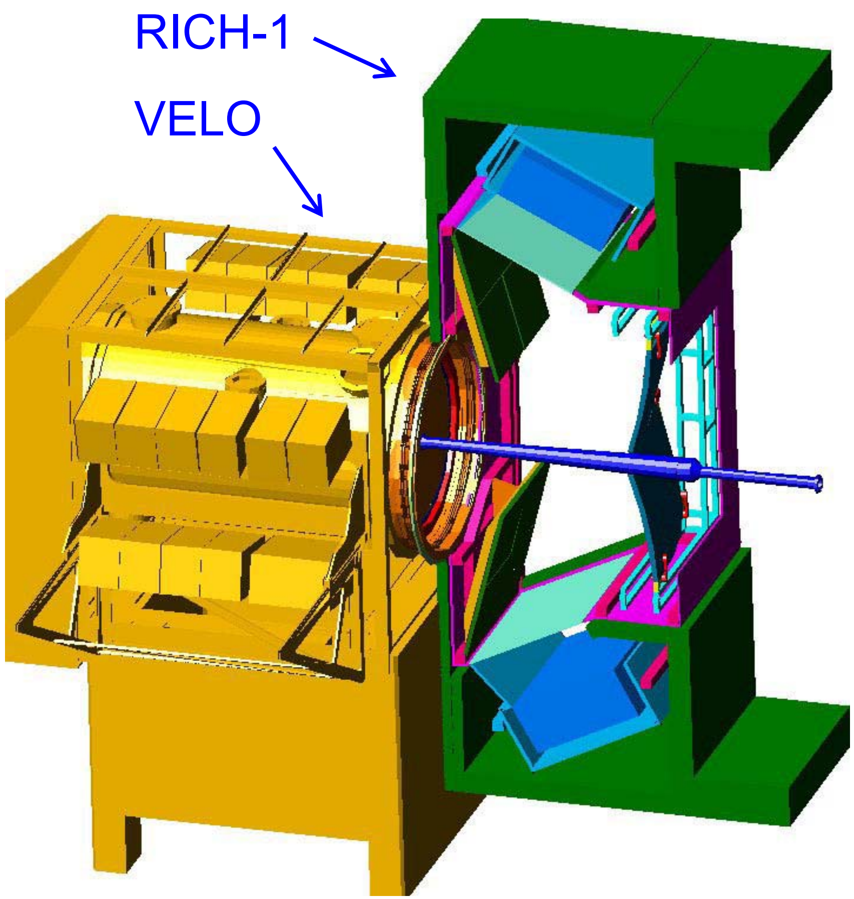
Effect on experiment

- Strongly varying occupancy over OT → variation of current expected
  - Region likely to be affected is close to beam pipe
- If flushing + heating does not remove gain-loss effect, would start to see lower efficiency in those modules
- Effect can be repaired (temporarily) by HV training
  - 20 hours at 1.9 kV
- Module production capability will be maintained, and we will investigate resources required for production of replacement modules in case of need

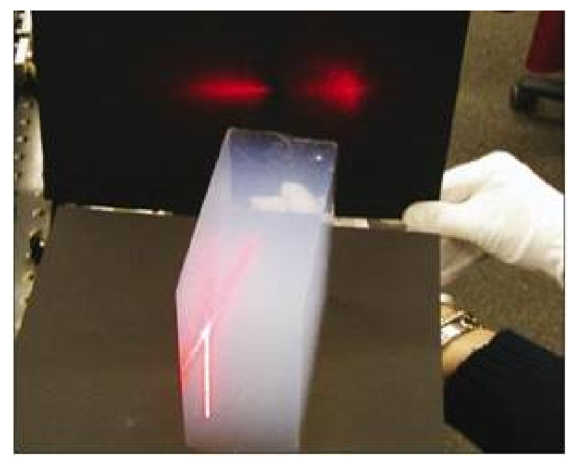




RICH system

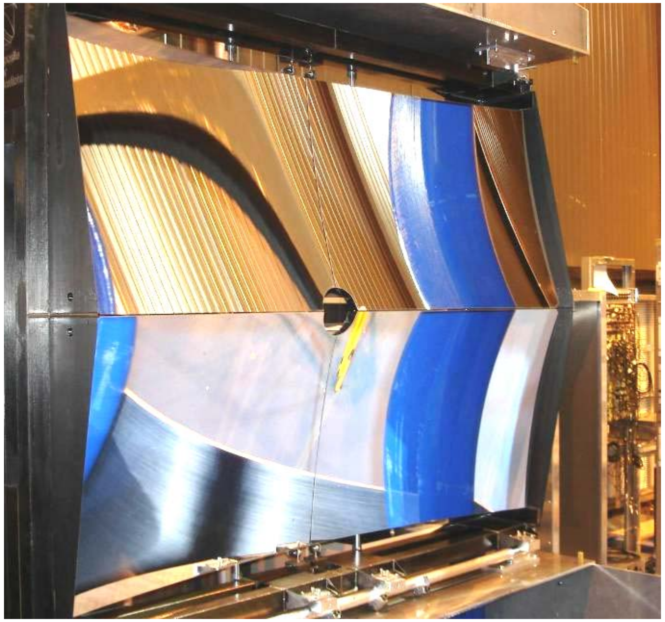


- Two RICH detectors to cover momentum range 2–100 GeV
- RICH-2 already completed last year, was only waiting for its photon detectors
- RICH-1 now nearly complete
  Aerogel radiator delivered

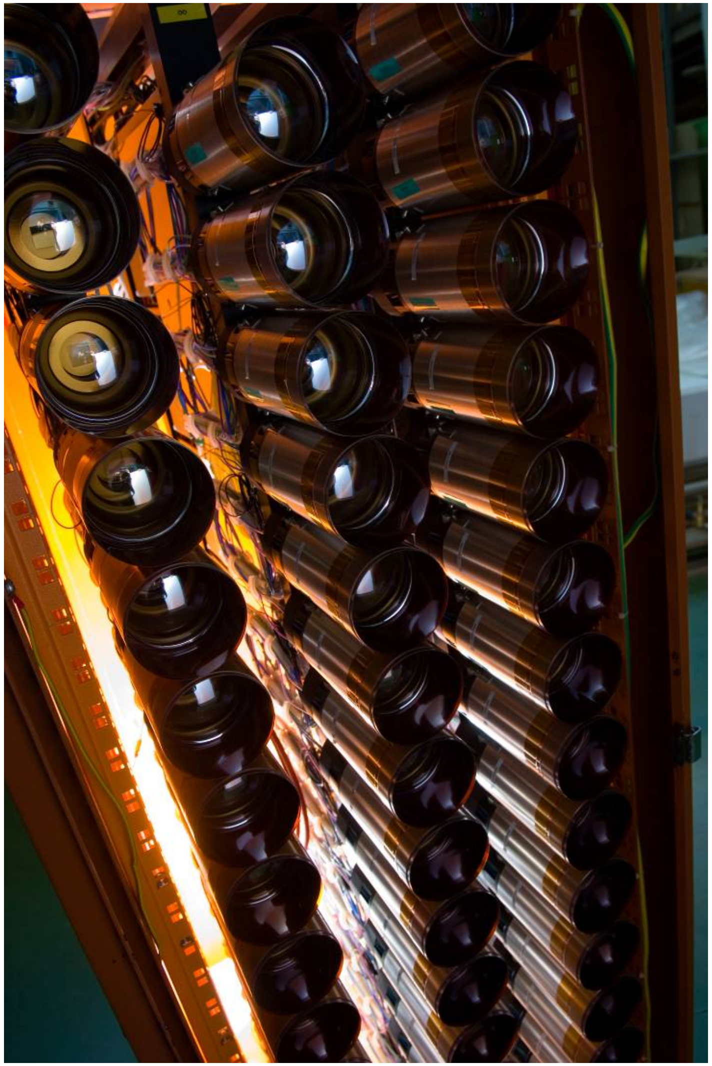


RICH-1 mirrors

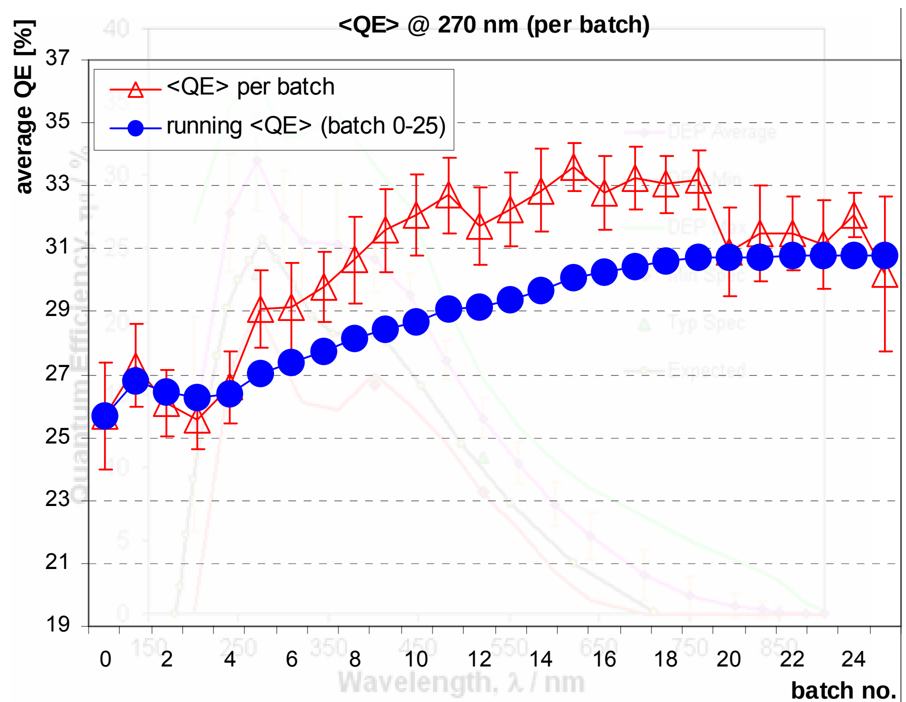
- Material budget critical for spherical mirrors as inside tracking volume
- Carbon fibre construction: 1.5% X_0
  produced by CMA (US) and
  coated by SESO (France)



Photon detectors

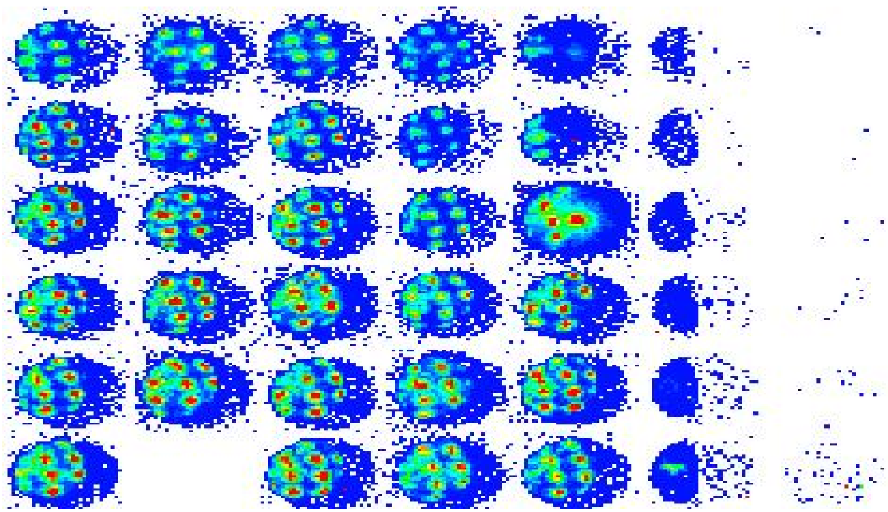


- After the long history of HPD development, production of all 550 required tubes is now complete!
  (Principal industrial partner: DEP, Holland)
- Excellent performance measured

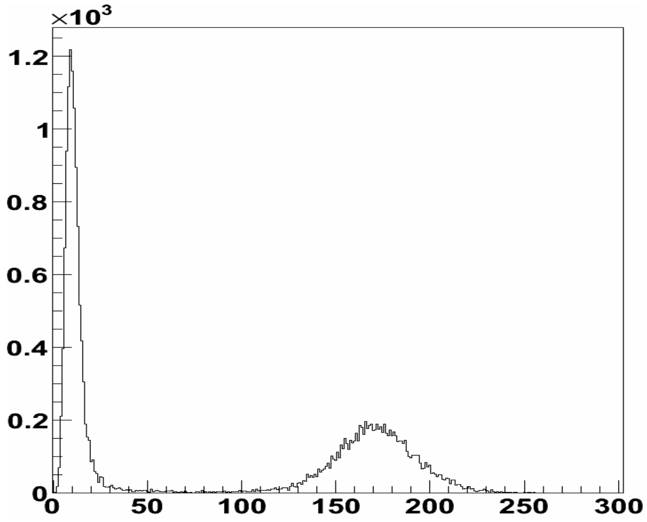


RICH-2 commissioning

- 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)



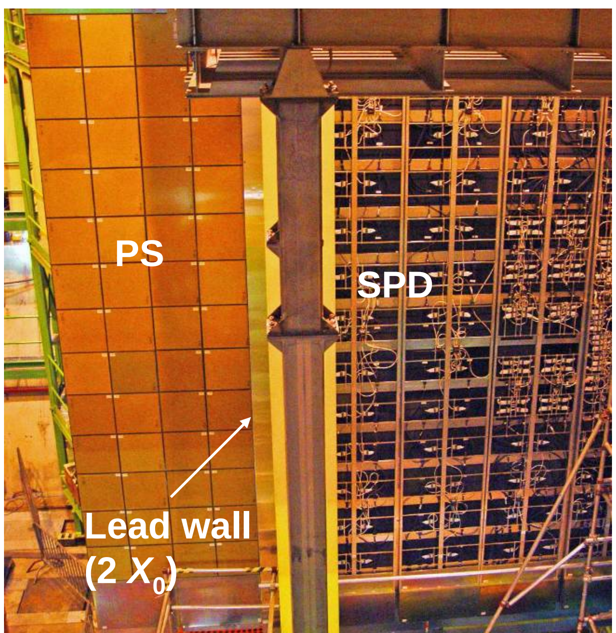
Note: this layout is a feature of the display—tubes are hexagonally close-packed in reality

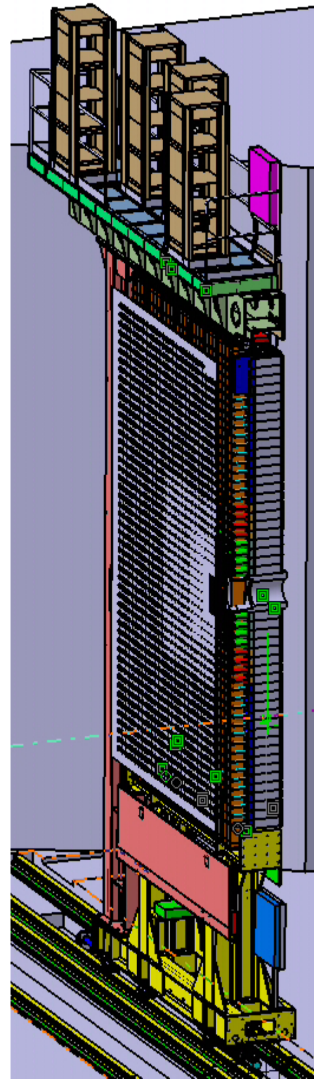


Number of photoelectrons

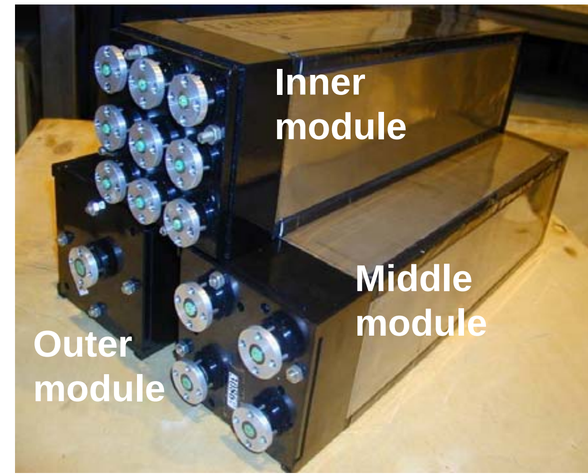
Calorimeter system

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

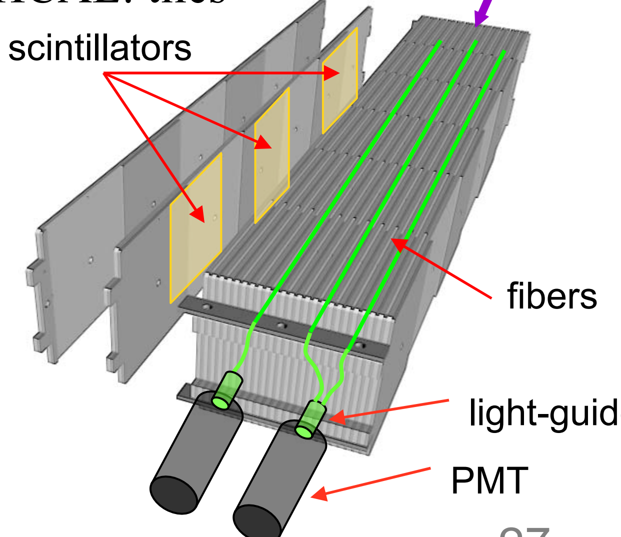




ECAL: Pb/sci.fi. Shashlik (25 X_0)



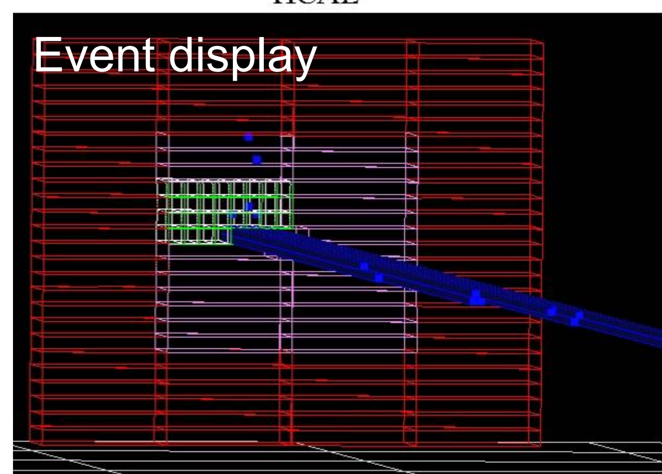
HCAL: tiles



Calorimeter system

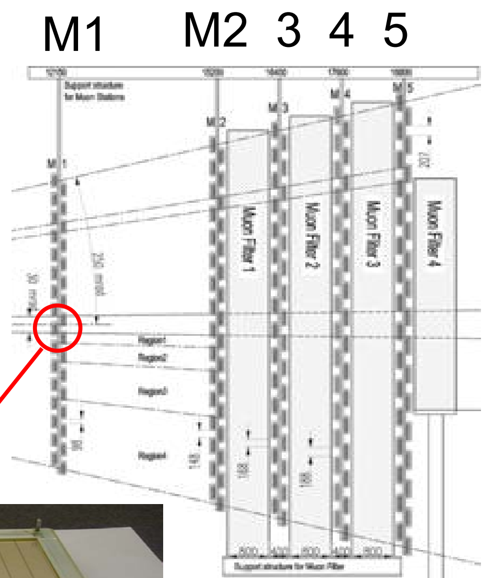
- Complete calorimeter system has been installed and cabled; Commissioning now in progress
- Cosmics not very well adapted for use in LHCb (few are horizontal 100 m underground)
  Nevertheless, cosmic triggers being set up for calorimeter commissioning
- In the mean time, system exercised using LED pulses: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

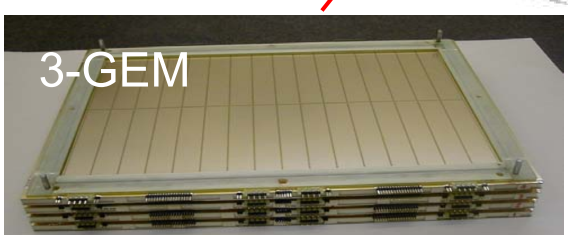
HCAL



Muon detector

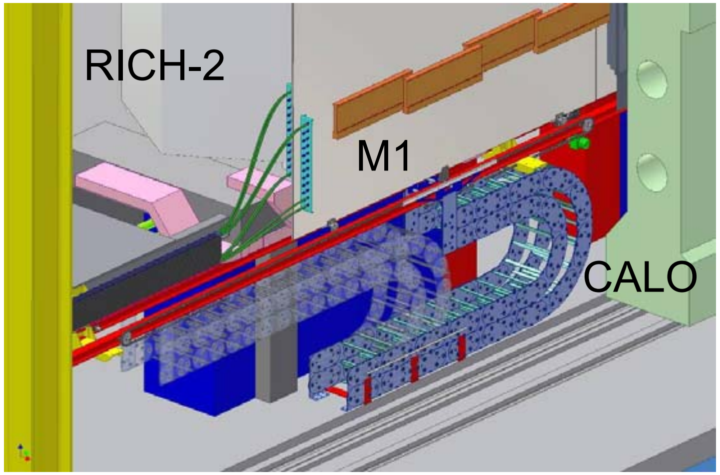
- All MWPCs for Muon detector stations M2–5 installed
  except for 20 (out of 1084, ~2%) that need to be replaced
- All MWPCs and 3-GEMs for M1 produced





M1 installation

- Completion of the M1 infrastructure expected early 2008
  - Delayed: priority given to completing M2–5
  - Has to fit in the crowded region between RICH-2 and Calorimeters:

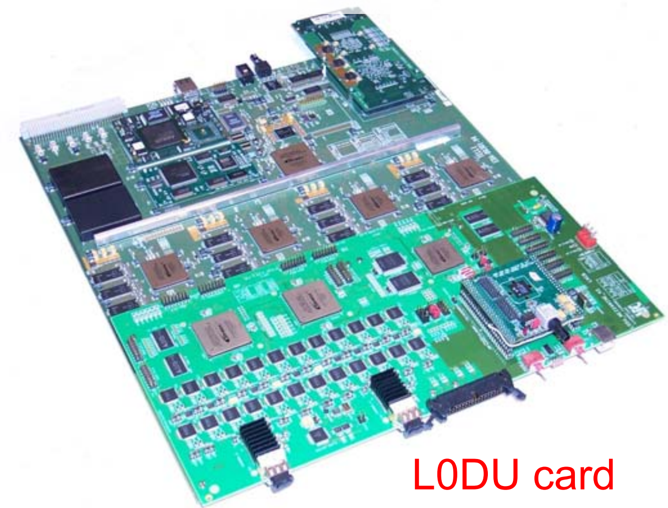


- Installation of chambers will follow, but may not be complete for the 2008 run
  - Use of M1 is to improve p_T determination in the Level-0 trigger
  - Not crucial for the low-rate conditions expected in 2008

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, γ, *h*
  - *Muon trigger*
    high-p_T (> ~1 GeV) μ candidates

  → *L0 Decision Unit*
  → overall decision

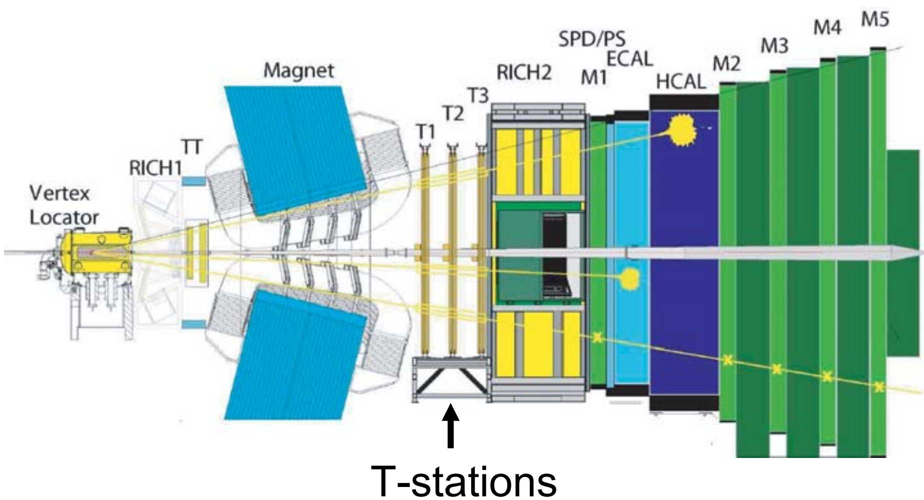


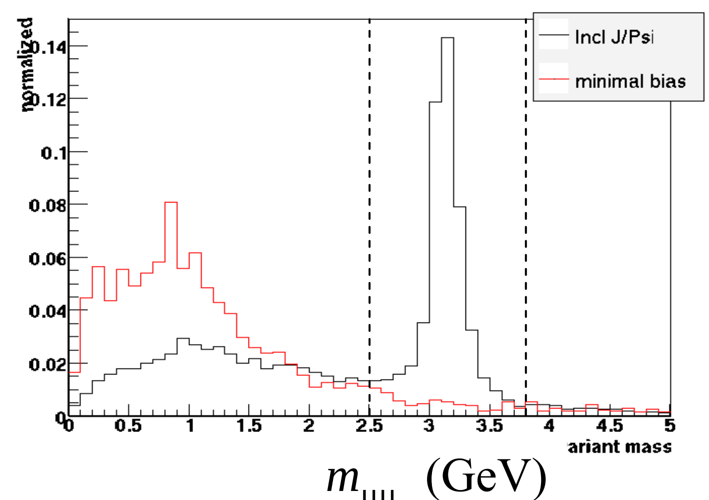
L0DU card

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

High Level Trigger

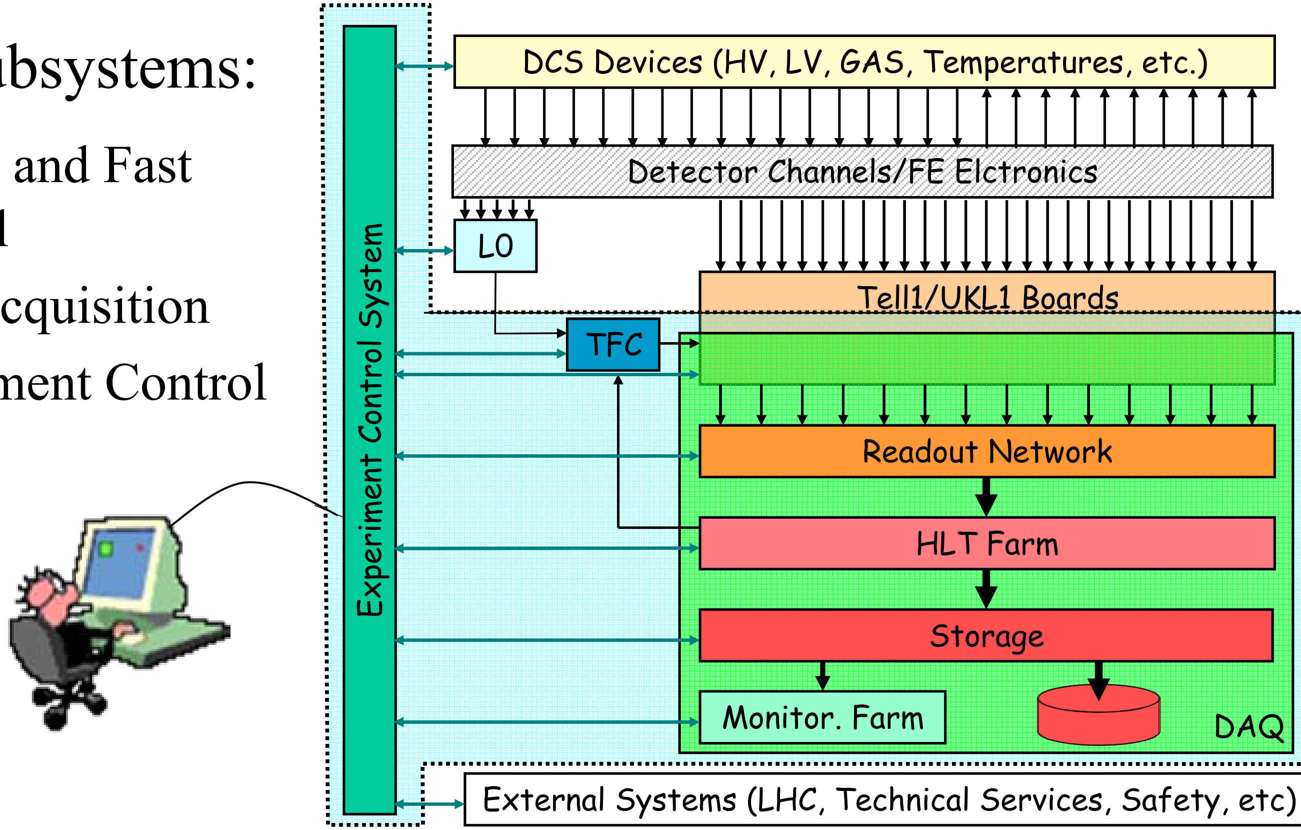
- First release of complete HLT framework last month
  Suitable for benchmarking CPUs to be purchased for the farm
- Implements strategy of "trigger confirmation"
  HLT focuses on confirming objects that triggered Level-0
  by matching them to tracks in VELO or T-stations
  - *eg* confirm L0 muons in 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)

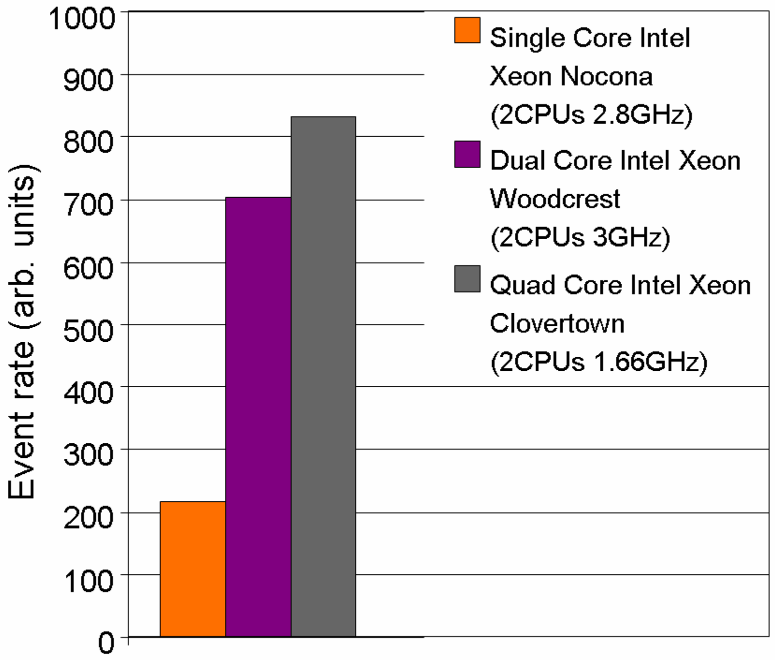
Data Acquisition

- Common read-out board used by most detectors (TELL1)
  all now installed
- Read-out network is based on Force10 switch
  (E1200, as used by CERN/IT)
- Control room is now equipped — and is being used!

CPU farm

- CPU farm for HLT (and monitoring) will eventually be 1000–2000 boxes
  - Depends on price/performance of CPU selected (and processing time required for HLT)
  - Market survey completed, tendering underway for first slice
- Due to lower rates expected at start-up, plan to install ~20% of CPU farm and switch capacity by May 2008, remainder early 2009

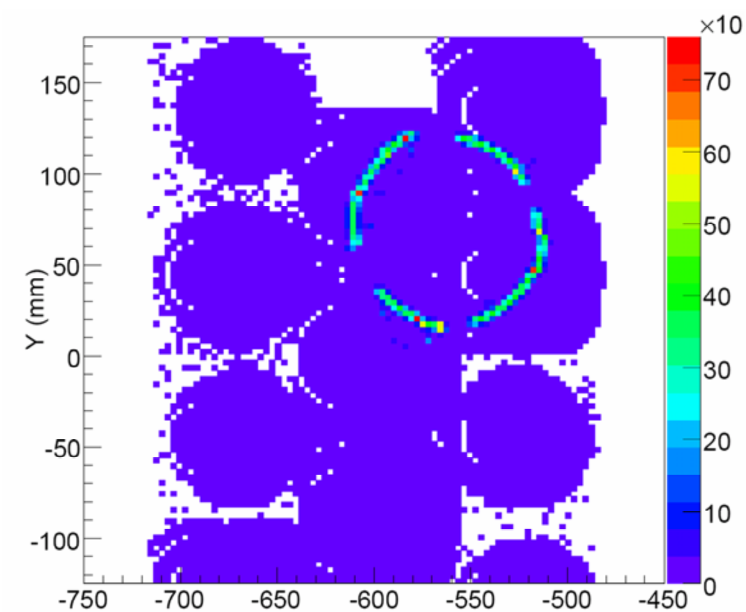
Recent test of CPU performance



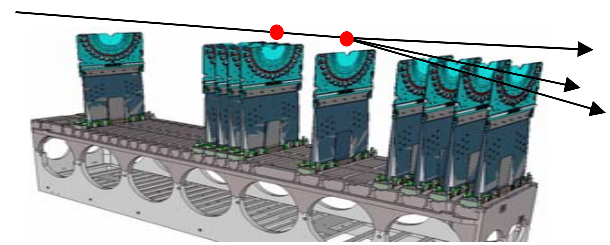
3. Preparation for physics

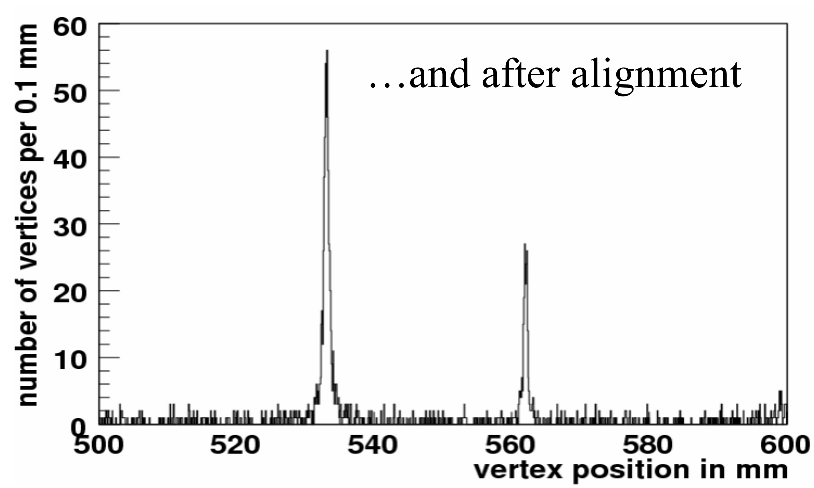
- Alignment of detectors under study using simulation
  - Matrix inversion (Millepede) and iterative residual minimisation
- Exercising alignment techniques using test-beam data

RICH (C_4F_{10} radiator gas)



VELO





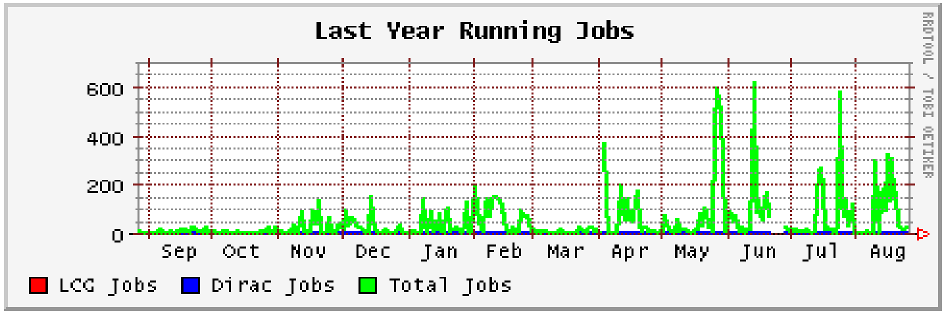
Computing

- Successful use of Grid made for large scale simulation + reco.

  > 10^8 fully-simulated events recently generated ("DC06" data) including $b\bar{b}$ background at 2 and 5 $\times 10^{32}$ cm^{-2}s^{-1} luminosity

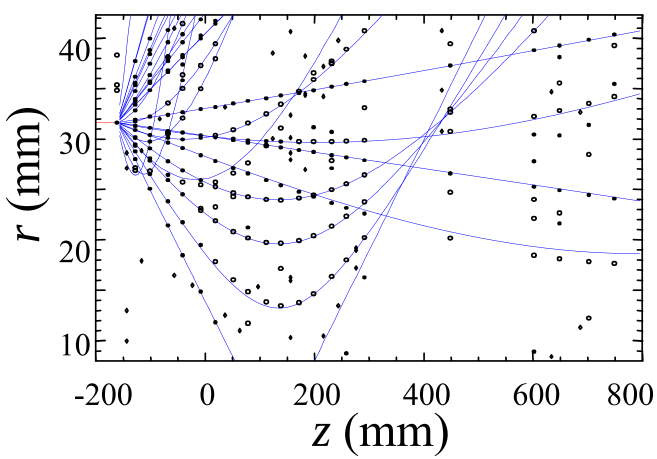
- However, difficulties encountered with "stripping" the data
  - After reconstruction, first step for physics analyses is to centrally run pre-selections (with loose cuts) for the channels of interest
  - Jobs need to read in rDST's and write DST's (+ETC) at Tier-1 sites (CERN, CNAF, GridKa, IN2P3, NIKHEF, PIC, RAL)
    Problems encountered with storage management at the sites
    $\rightarrow$ stripping of DC06 data now restarted + reprocess at same time

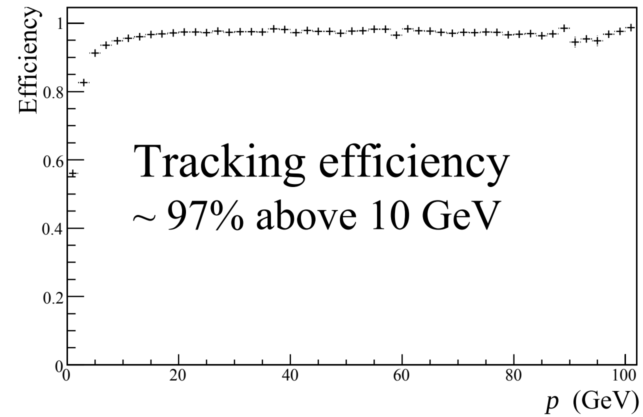
- Use of the Grid for analysis jobs is increasing steadily

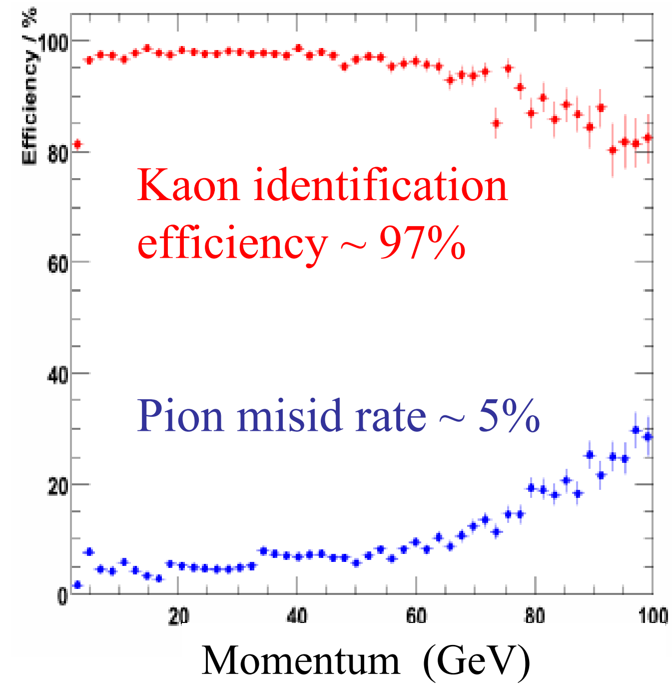


Reconstruction

- Continuous effort made to maintain excellent performance of tracking and particle ID software
  - Keep up with added realism in simulation (tilted detectors, updated material budget)
  - Prepare for adaptation to real data
- Tracking developed for open VELO
  (will be important at start of run)



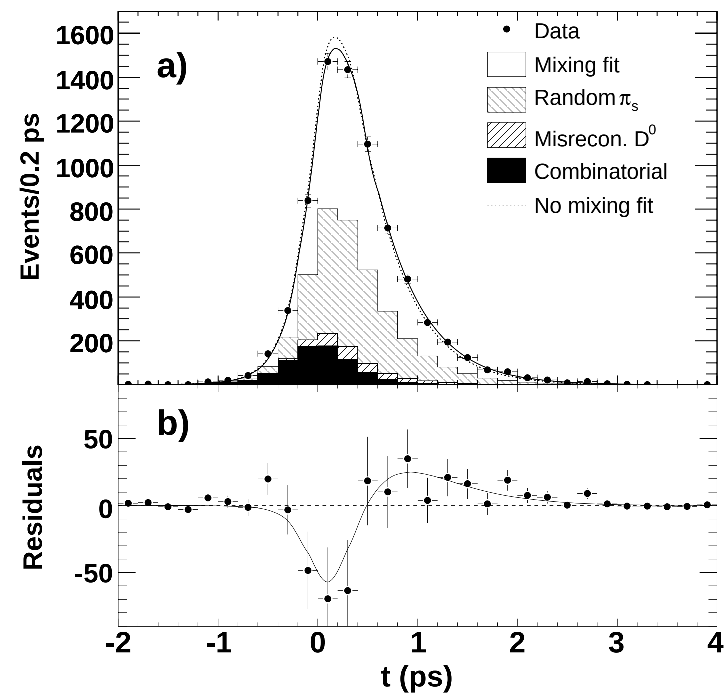




Physics studies

- References to recent analyses collected together on a web page
  http://lhcb-phys.web.cern.ch/lhcb-phys/DC04_physics_performance
- Keeping an eye on the impressive progress of the B factories:
- Observation of D^0–$\overline{D}^0$ mixing:
  - Time dependence of ~ 4000 wrong-sign $D^0 \to K^+\pi^-$ decays
  - LHCb has ~ 300 Hz of trigger output rate dedicated to charm…
    $\to$ 47,000 tagged wrong-sign decays/year (2fb^{-1})
  - Will probe CP violation in the D^0 system at the 10^{-3} level
- First constraints on CKM angle γ using $B^\pm \to D(K_S\pi^+\pi^-) K^\pm$

BaBar hep-ex/0703020



Summary of DC04 physics performance

Home | Physics | E-mail | Notes | Meetings | Search

Quick access to sections of this page: Expected yields and sensitivities | Flavour tagging and proper time | Reconstruction | DC04 MC samples |

This page summarizes the LHCb physics performance obtained at the end of 2007 using Monte Carlo studies based on the so-called DC04 samples. These results, documented in public LHCb notes, update and supersede the ones reported in the physics chapter of the LHCb re-optimization TDR.

Expected yields and sensitivities

Decay mode	Total eff. (%)	2 fb^{-1} signal yield	B_{bb}/S	$B_{specific}/S$	Physics observable	2 fb^{-1} statistical precision	10 fb^{-1} statistical precision	Assumptions, comments	More info
B_u control channels									
$B_u \to D^0 \bullet^+ \nu$	0.125	2.4M	0.75±0.03						CERN-LHCb-2006-058
$B_u \to D^0(K\pi)\pi^+$	0.64	1.0M	0.13±0.03						CERN-LHCb-2006-058
B_s mixing effects (including CPV) in tree decays									
$B_s \to D_s^- \bullet^+ \nu$	0.123	1.06M	0.36±0.13						CERN-LHCb-2007-029
$B_s \to D_s^- \pi^+$	0.39	140k	[0.014,0.05] 90% CL	[0.08,0.4] (all) 0.044±0.014 ($D\pi$)	Δm_s	0.007 ps^{-1}		B/S=0.2	CERN-LHCb-2007-017 CERN-LHCb-2007-041
$B_s \to D_s K^\pm$	0.32	6.2k	< 0.18 90% CL	[0.08,3] (all) 0.15±0.05 ($D_s\pi$)	$\gamma+\phi_s$ (tagged) $\gamma+\phi_s$ Δ(T1/T2) $\lvert\lambda\rvert$	12.7 deg 10.3 deg 10.3 deg 0.061	5.7 deg 4.6 deg 4.6 deg 0.027	B/S=0.7	CERN-LHCb-2007-017 CERN-LHCb-2007-041
$B_s \to J/\psi(\bullet\bullet)\phi$	2.05	131k	0.12±0.03		R_T $\Delta\Gamma_s/\Gamma_s$ ϕ_s	0.0004 0.0092 0.023			CERN-LHCb-2006-047 CERN-THESIS-2006-042
$B_s \to J/\psi(\bullet\bullet)\eta(\gamma\gamma)$	—	~8.5k	2.0 (tot)		ϕ_s	0.109			

$B^\pm \rightarrow D(K_S\pi^+\pi^-)\,K^\pm$

- Mode used by B factories to give best existing constraint on CKM angle γ:

$53^\circ\ {}^{+15^\circ}_{-18}\ \pm 3^\circ\ \pm 9^\circ$ [Belle]

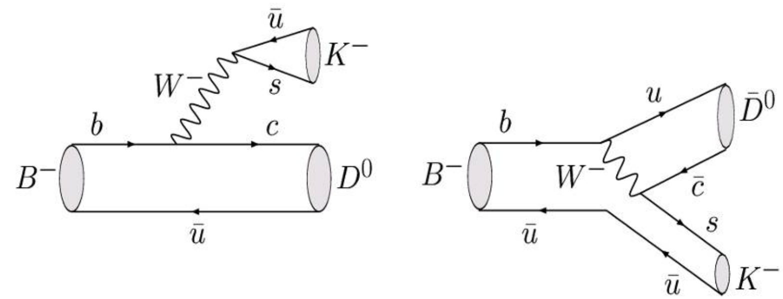
$92^\circ \pm 41^\circ \pm 11^\circ \pm 12^\circ$ [BaBar]

(stat, syst, model)

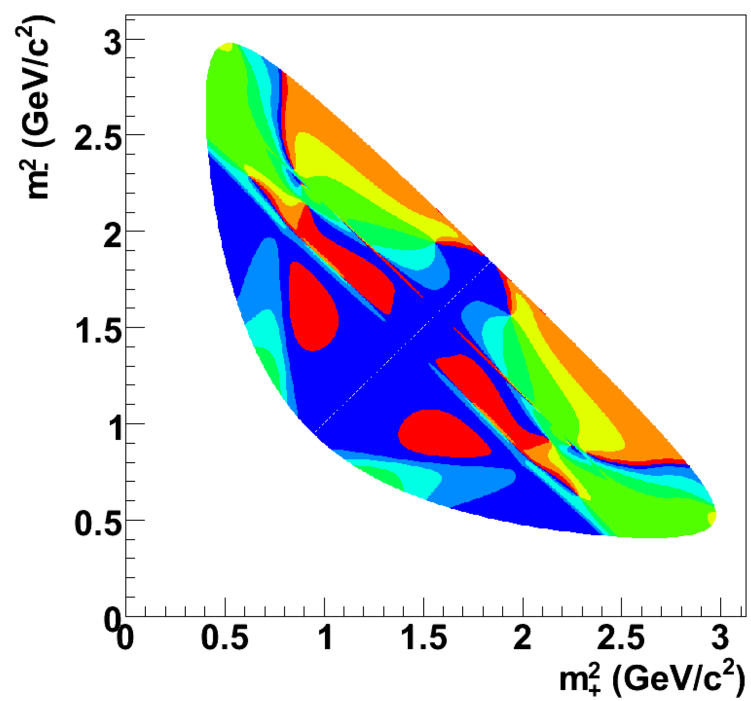
~ 400 events each

- LHCb yield ~ 5000 events/2 fb^{-1}
- Spot the difference between the Dalitz plots for B^+ and B^- → effect of CP violation
- Binning can reduce model dependence

Precision on γ ~ 12° (in one year)

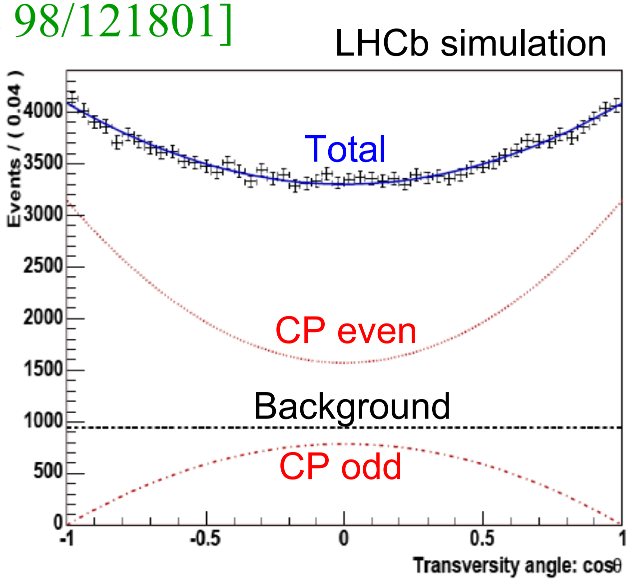


hep/ph 0703267



Physics Studies (continued)

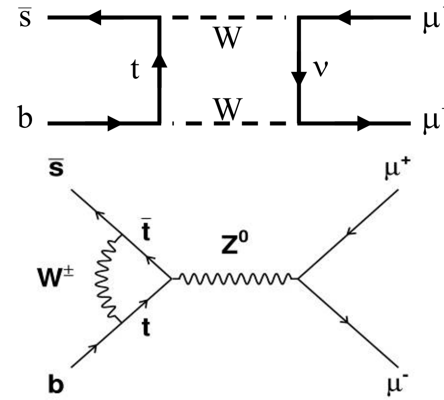
- Preparing to open up the ~ unexplored B_s sector
- Current competition is from the Tevatron experiments *eg* measurement of the B_s–$\bar{B}_s$ mixing phase ϕ_s
  - Counterpart for B_s system of the B^0–$\bar{B}^0$ mixing phase $\phi_d = 2\beta$ Very small in the Standard Model: $-2\lambda^2\eta \approx -0.04$ rad
  - First experimental constraint from D0: $\phi_s = -0.79 \pm 0.56$ rad using ~1000 $B_s \to J/\psi\,\phi$ events [PRL 98/121801]
  - LHCb expects ~ 130,000 events/year (2 fb^{-1}) $\to \sigma(\phi_s) = 0.02$ rad

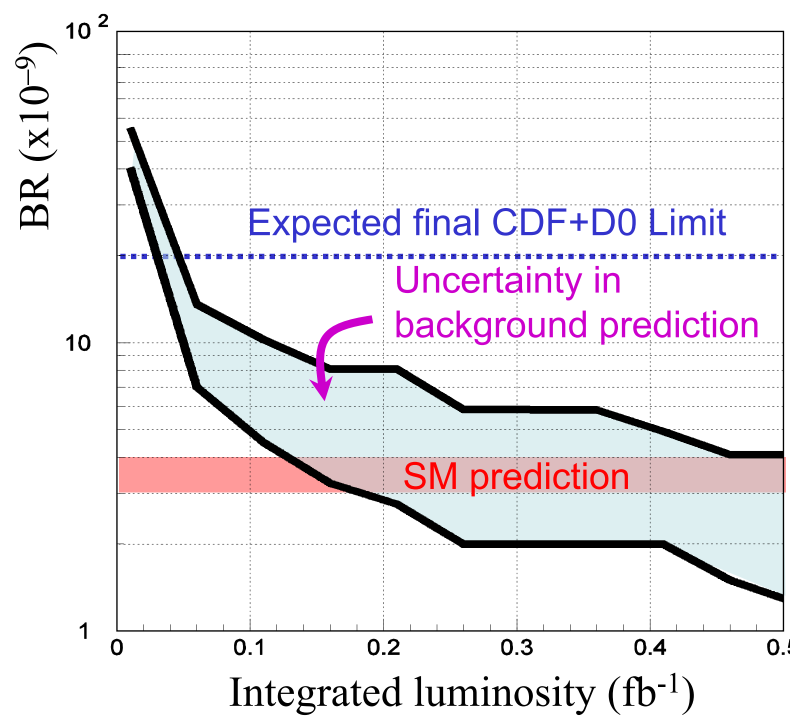


- Preparing analyses where we can make an early impact
  - *eg* $B_s \to \mu^+\mu^-$

$B_s \to \mu^+\mu^-$

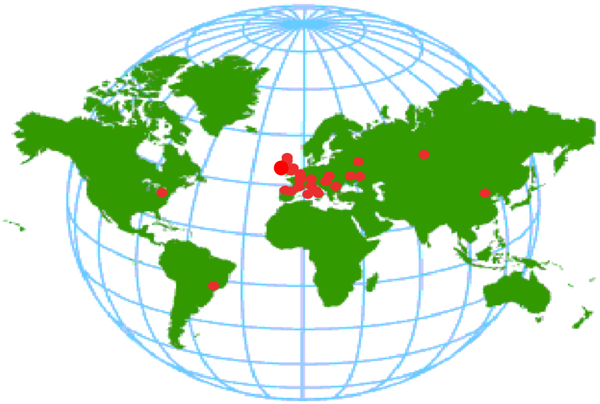
- BR = $(3.4 \pm 0.5) \times 10^{-9}$ in Standard Model
  Can be significantly enhanced in SUSY
- Current limit < 47×10^{-9} at 90% CL [CDF]
- Using loose selection, LHCb expects
  - ~ 40 signal events/2 fb^{-1} (SM BR)
  - ~ 1500 bkg evs (mostly $b \to \mu$, $\bar{b} \to \mu$)
  - Statistical method then applied to separate signal from background using particle ID, vertexing and mass variables
  - $\sigma(m_{\mu\mu}) = 18$ MeV
- Limit set at 90% CL (if no signal):
  Already interesting for 0.1 fb^{-1}





4. Collaboration matters

- LHCb is a collaboration of ~ 650 members from 48 institutes
  - in Brazil, China, France, Germany, Ireland, Italy, Poland, Romania, Russia, Spain, Switzerland, Ukraine, UK, and the US



- At our last collaboration week (11-14 September):
  - University College Dublin was admitted as a full member (previously Technical Associate)
  - Olav Ullaland (CERN) took over from Alasdair Smith as Resource Coordinator
  - Andrey Golutvin (ITEP) was elected as new Spokesperson He will take over from our first spokesperson, Tatsuya Nakada on 1 May 2008 for 3 years

Cost and Funding

- The cost of the experiment is 75.3 MCHF, unchanged from MoU and last LHCC status report (15 November 2006)
- At that time 1.3 MCHF was missing from the funding
  Since then extra contributions have been pledged:
  kCHF 55 (Brazil), 300 (France), 20 (Spain), 400 (UK), 500 (US)
  → Experiment is now fully funded
- Further expenditure is however foreseen:
  1. *Replacement of the third beryllium beam pipe section*
     Installed section UX85/3 had minor leaks, closed with varnish
     OK for initial operation, but concern for long-term reliability
  2. *Replacement set of VELO modules*
     The installed silicon sensors will receive a substantial radiation dose
     Expected to survive for $\int L \sim 6\ \text{fb}^{-1}$ (i.e. 3 "nominal" years)
     Profit from existing production setup to produce a replacement set

Organization (simplified)

New bodies introduced to adapt to next phase:

Construction → Exploitation

Preparation for the future

Collaboration Board
Chairperson: E. Aslanides

LHCb management
Spokesperson T.Nakada
Deputy spokesperson R. Forty
Technical coordinator W. Witzeling
Resource coordinator O. Ullaland

Operations Planning Group
Spokesperson (chair)
LHCb management
Physics Coordinator O. Schneider
LHC contact person A. Schopper
Commissioning Coordinator
Project leaders for Computing,
Physics Software, Trigger and Online

Technical Board
Technical Coordinator (chair)
LHCb management
Subsystem Project Leaders
Commissioning Coordinator
Electronics Coordinator
Upgrade Convener
Integration Manager, GLIMOS

Physics Planning Group
Physics Coordinator (chair)
Spokesperson + deputy
Physics working group conveners:
Production & decay models,
Tagging, Proper-time & mixing,
CP measurements,
Rare decays, and Jets

Commissioning Task Force
Commissioning Coordinator O. Callot

Subsystem Projects
Exptl. Area, Magnet, VELO,
RICH, ST, OT, Calorimeter,
Muon, Level-0, Trigger, Online,
Physics Software, Computing

Upgrade Working Group
Upgrade Convener: F. Muheim

Upgrade Working Group

- LHCb is designed to run at an average luminosity of 2×10^{32} and be able to handle 5×10^{32} cm^{-2}s^{-1} for short periods
  - For a "nominal" year of 10^7 seconds this corresponds to 2 fb^{-1} Most physics goals are expressed in terms of the reach for 10 fb^{-1} (i.e. 5 nominal years)
- Sensitivities would then only slowly increase → investigating upgrade of detector to handle higher luminosity: few $\times10^{33}$ cm^{-2}s^{-1}
  - Not directly coupled to SLHC machine upgrade, since already available, but may well overlap in time with upgrades of ATLAS+CMS
- Working Group set up to identify the R&D required to make an upgrade of LHCb feasible, and to make the physics case
  - Issues of triggering, fast vertex detection, electronics, radiation dose, handling the pile-up and higher occupancy, etc…

→ Expression of Interest for R&D towards an upgrade is in preparation

Conclusion

- Installation of LHCb is almost complete
  - All major structures are in place (except for M1, in progress)
  - Sensitive elements are now produced and mostly in place: RICH-1, the Silicon Trackers, and M1 remain to be instrumented, schedule continues to be tight for those detectors
  - Progress made to understand and minimise the OT gain-loss
- Commissioning is now underway
  - Using cosmics where possible, otherwise test pulses, light spots, etc.
  - The first beam-gas events will be very instructive
- Preparation for physics continues
  - The experiment, including software, will be ready for first beam
  - Important measurements can made even with 0.1 fb^{-1} of data
    We are eager to see the first collisions!