CERN LHC Experiments and B Physics Programme

B-factory and New Measurements 2006-II

Nara, Japan, December 18-19, 2006

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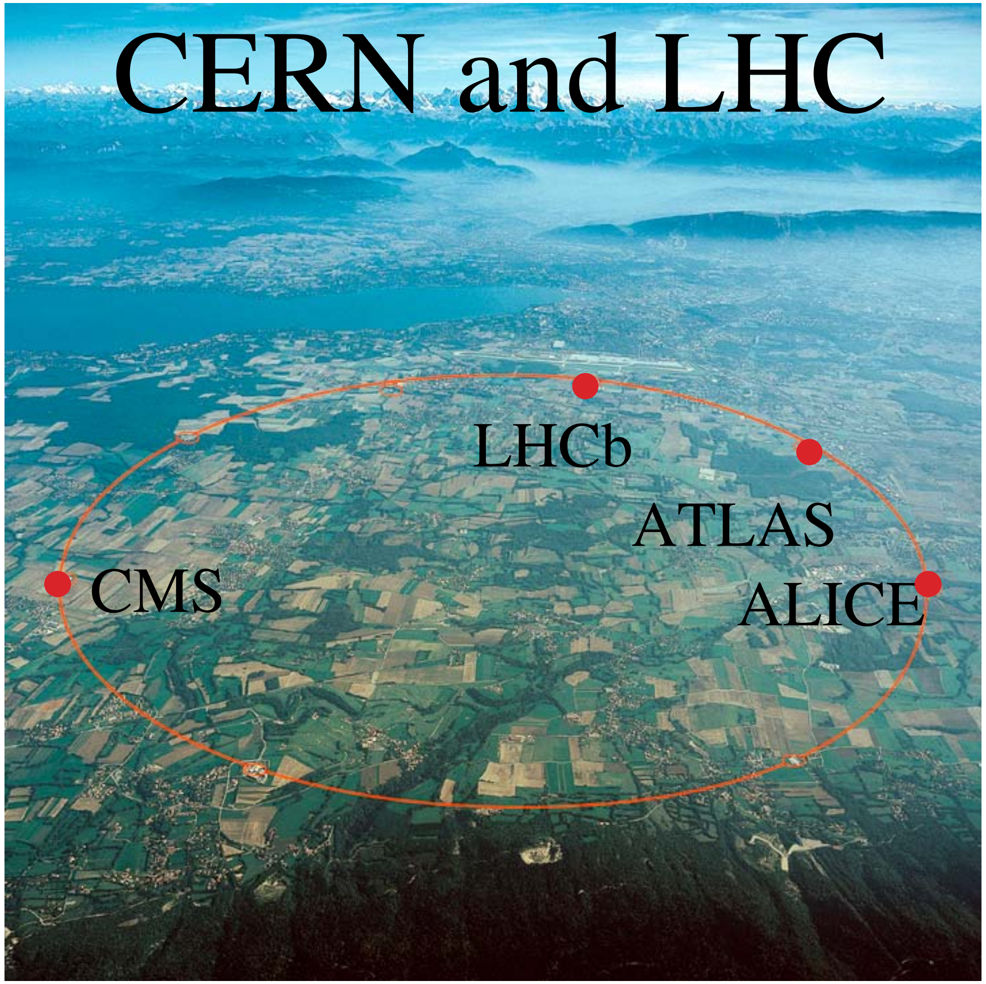
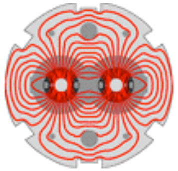
CERN and EPFL

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

LHC and Detectors at CERN

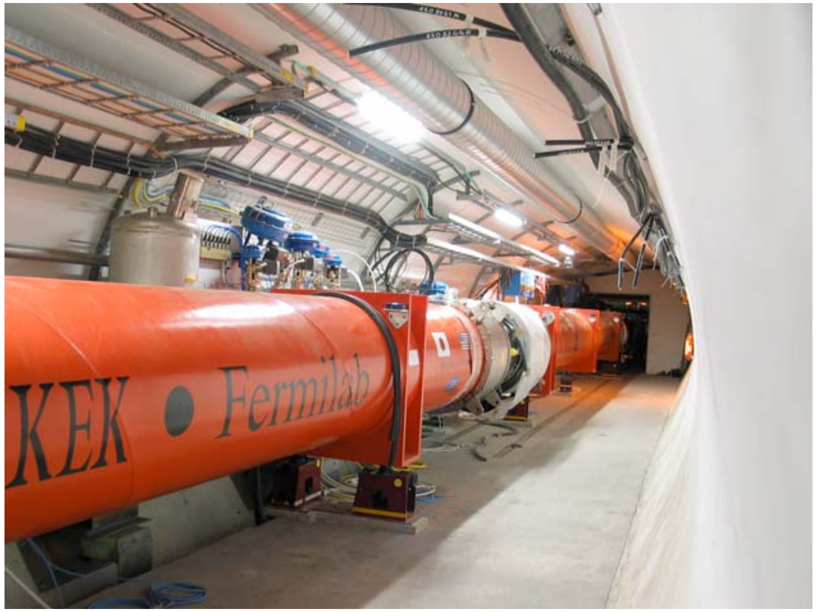
CERN and LHC

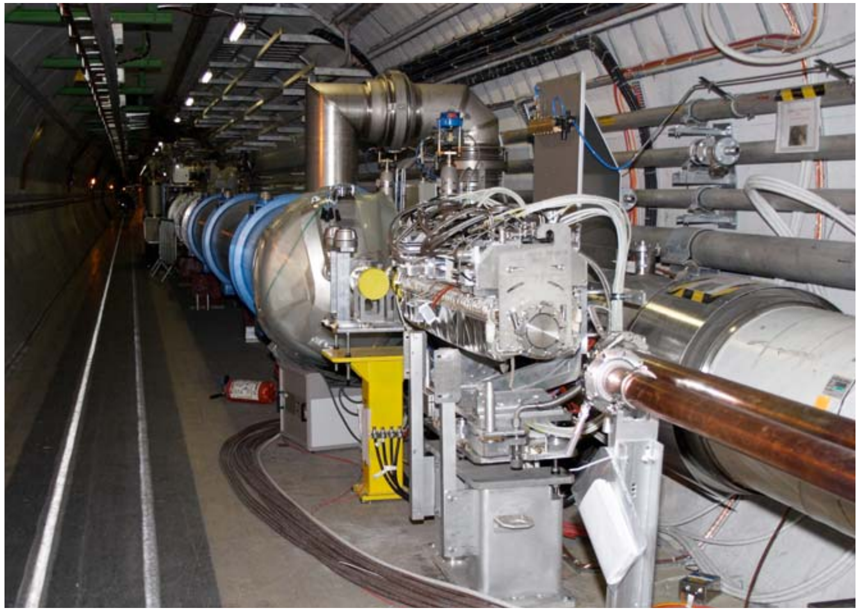




- Pilot run in Dec 2007 at $\sqrt{s}$ = 900 GeV (injection energy)
  L=10^{27} to 10^{28} cm^{-2}s^{-1} (40 to 400 Hz inelastic interactions)
  $\Rightarrow$ detector alignment and calibration
- Collisions at 14 TeV by the middle of 2008
  L=10^{32} to 10^{33} cm^{-2}s^{-1} $\Rightarrow$ physics can start

LHC construction advancing, and major milestones





Last magnet delivered	November 2006 ✔
Last magnet tested	January 2007
Last magnet installed	March 2007
Machine closed	August 2007
First collisions	November 2007

Relevant LHC experiments

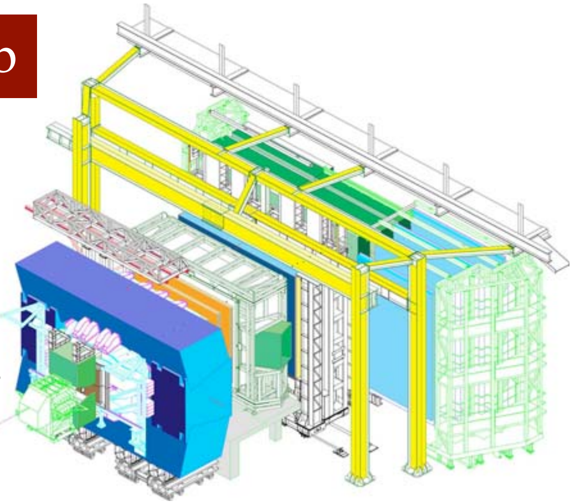
LHCb: (Not LHCB nor LHC-B)

dedicated B physics experiment, locally adjusted luminosity of 2×10^{32} c.f. LHC design luminosity 10^{34}

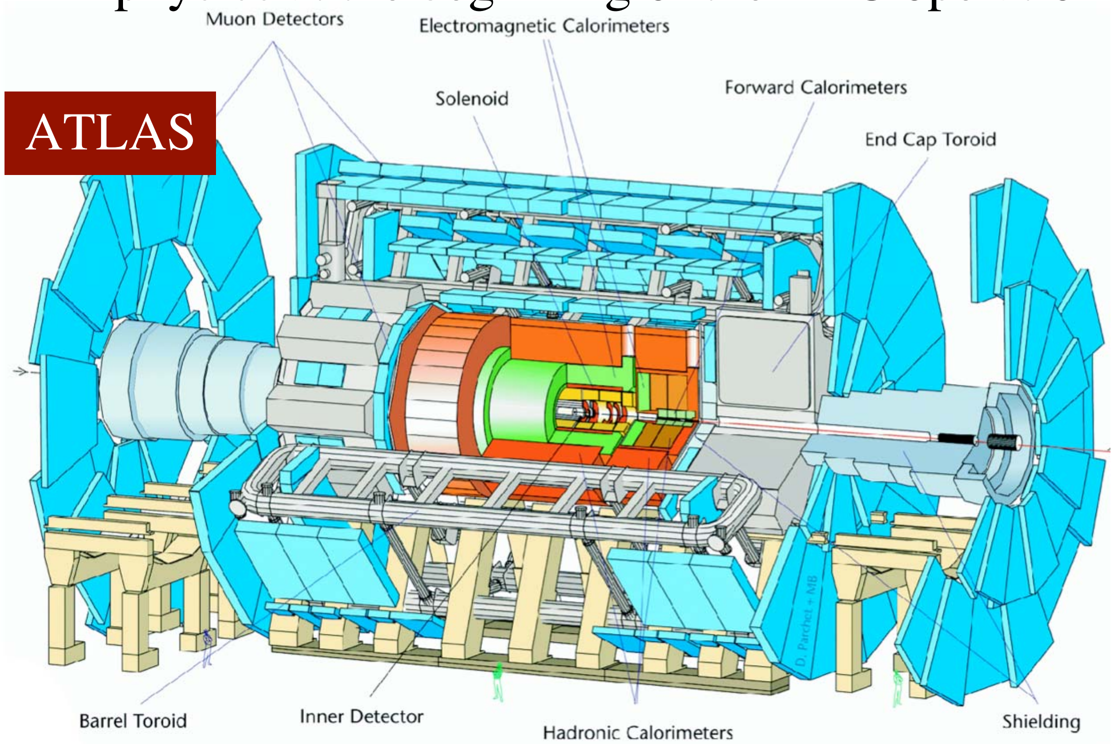
ATLAS/CMS:

general purpose experiments,
optimized for high-p_T discovery physics at 10^{34} cm^{-2}s^{-1}
B physics at the beginning of the LHC operation with 10^{33}

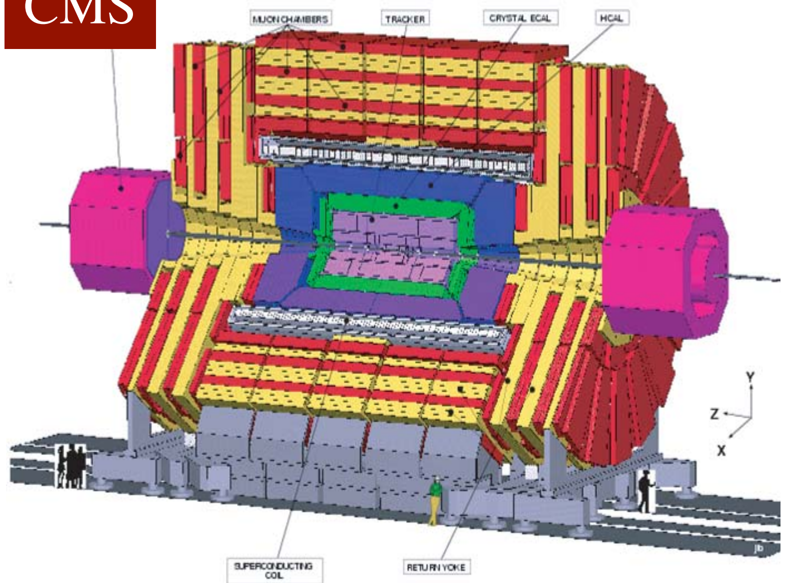
LHCb



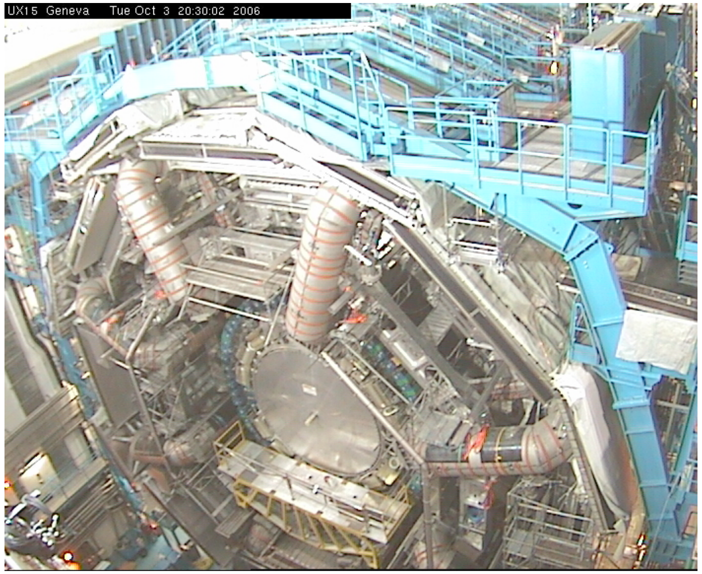
ATLAS

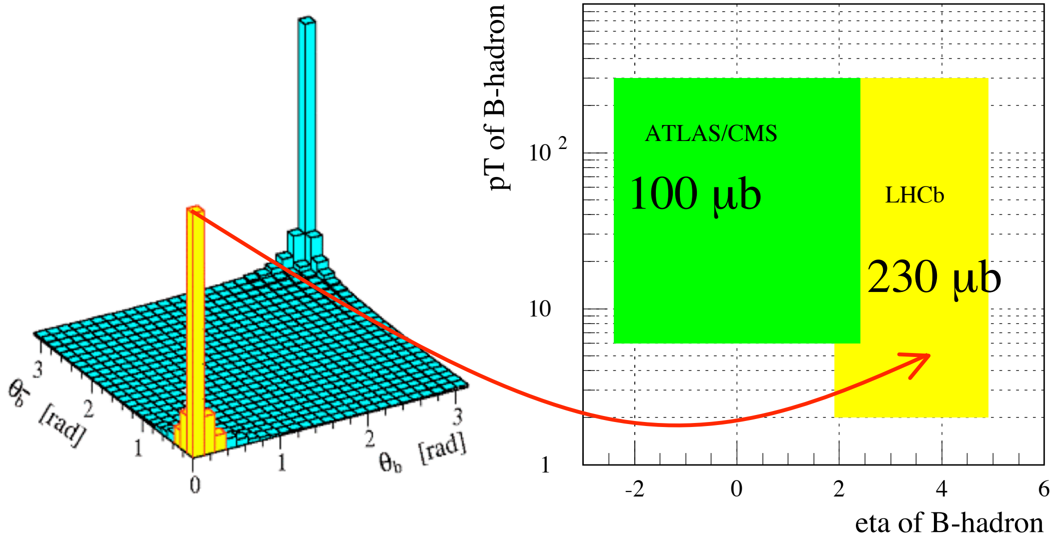


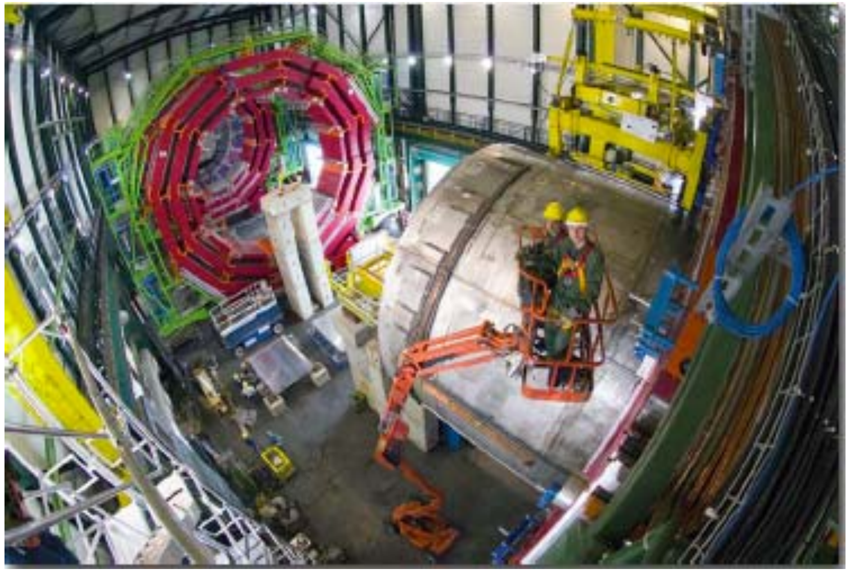
CMS



Detector construction advancing







LHCb: efficient trigger for photon, lepton and hadron

- important for the final states with only hadrons

particle identification for all the particles

- $\gamma/e/\mu/\pi/K/p$

+ excellent decay time and mass resolution

ATLAS/CMS

efficient trigger for lepton

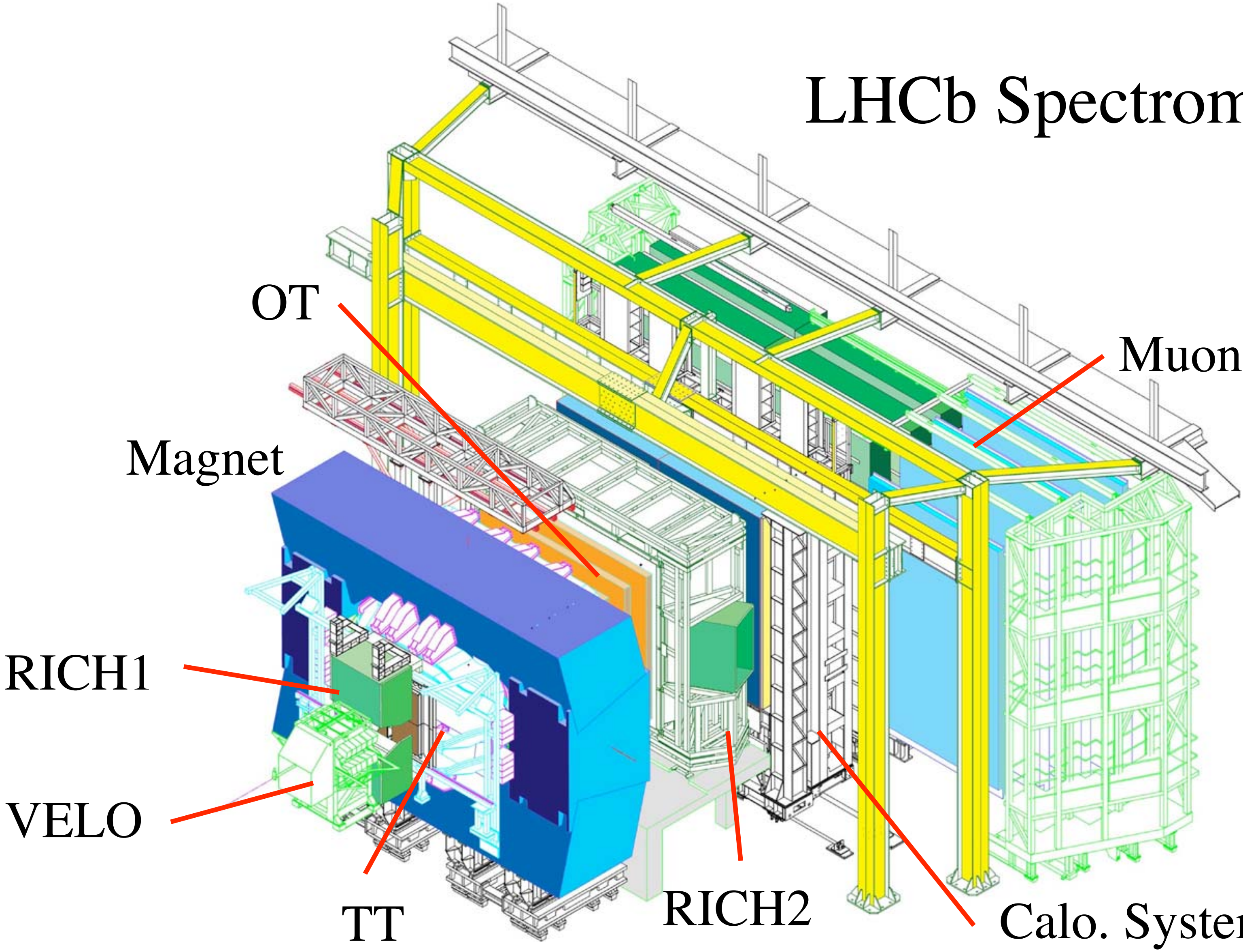
- only leptonic or semi-leptonic final states

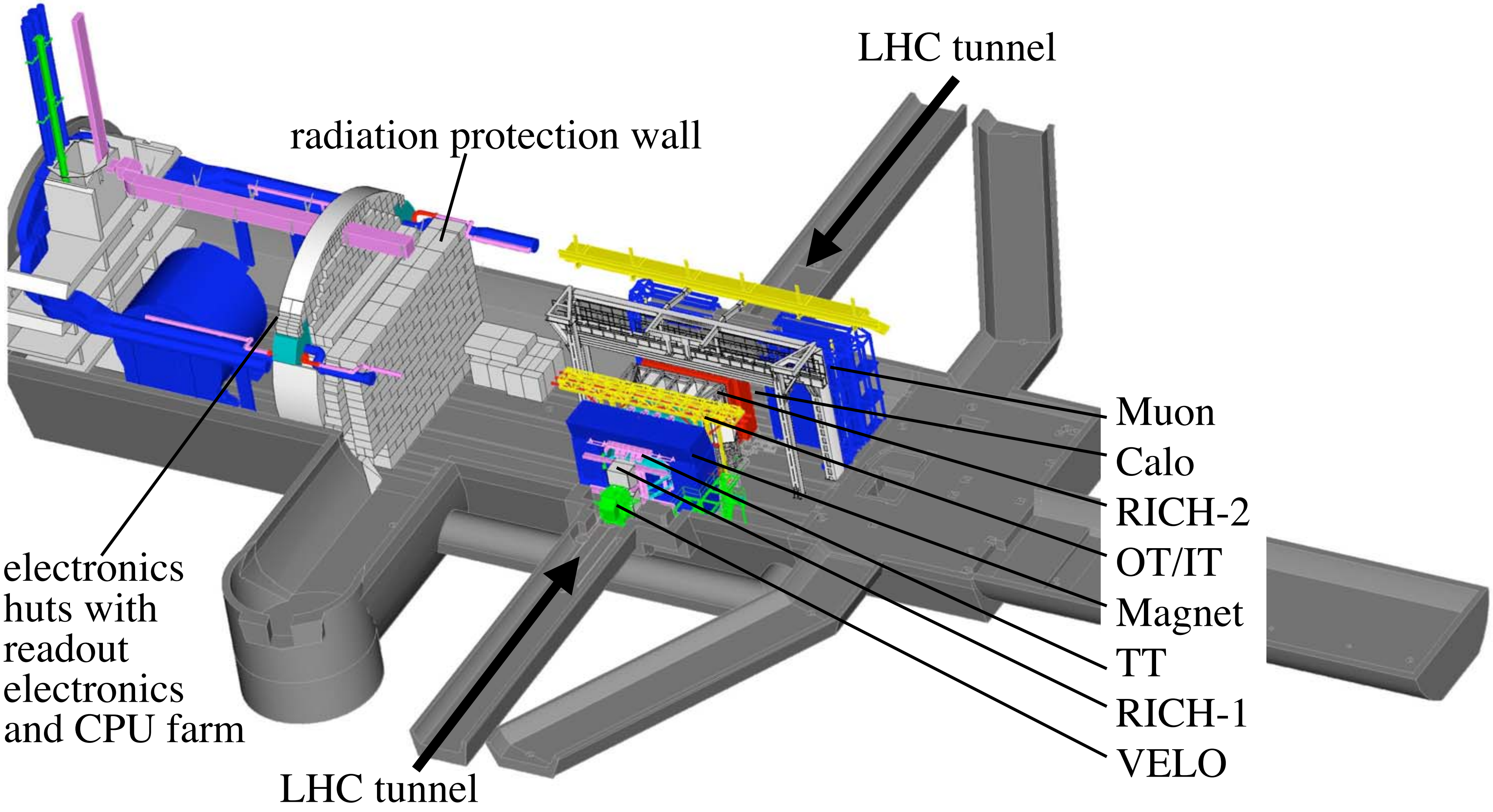
particle identification only for $\gamma/e/\mu$/hadrons

i.e. no hadron ID

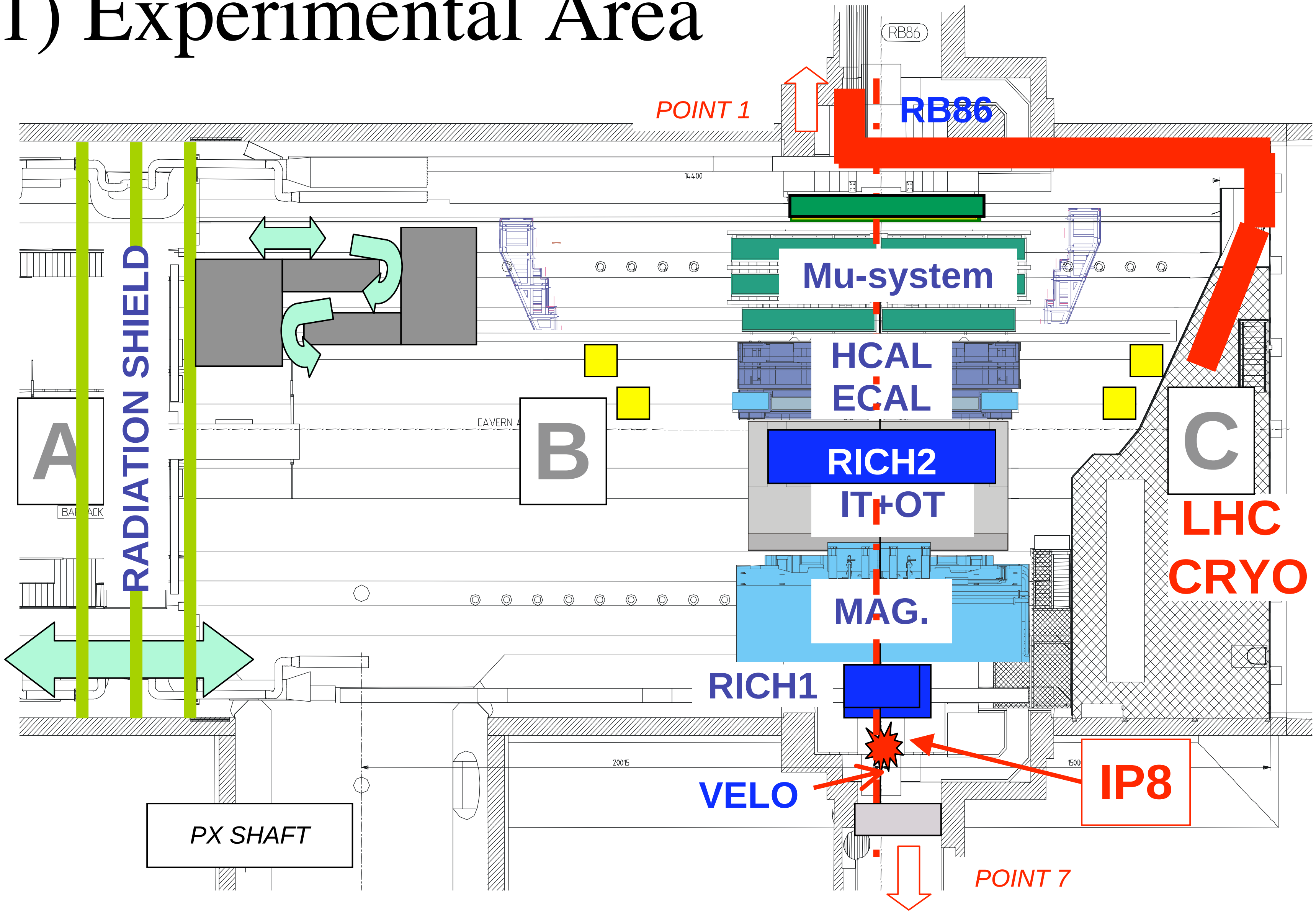
LHCb Experiment Status

LHCb Spectrometer




LHC tunnel
radiation protection wall
Muon
Calo
RICH-2
OT/IT
Magnet
TT
RICH-1
VELO
electronics huts with readout electronics and CPU farm
LHC tunnel

1) Experimental Area



Installation of the major metallic structures completed

Gas and cooling pipes installed in the detector area

Most of the cable trays installed

Installation of long HV, LV, ECS and signal cables and mounting of connectors in progress

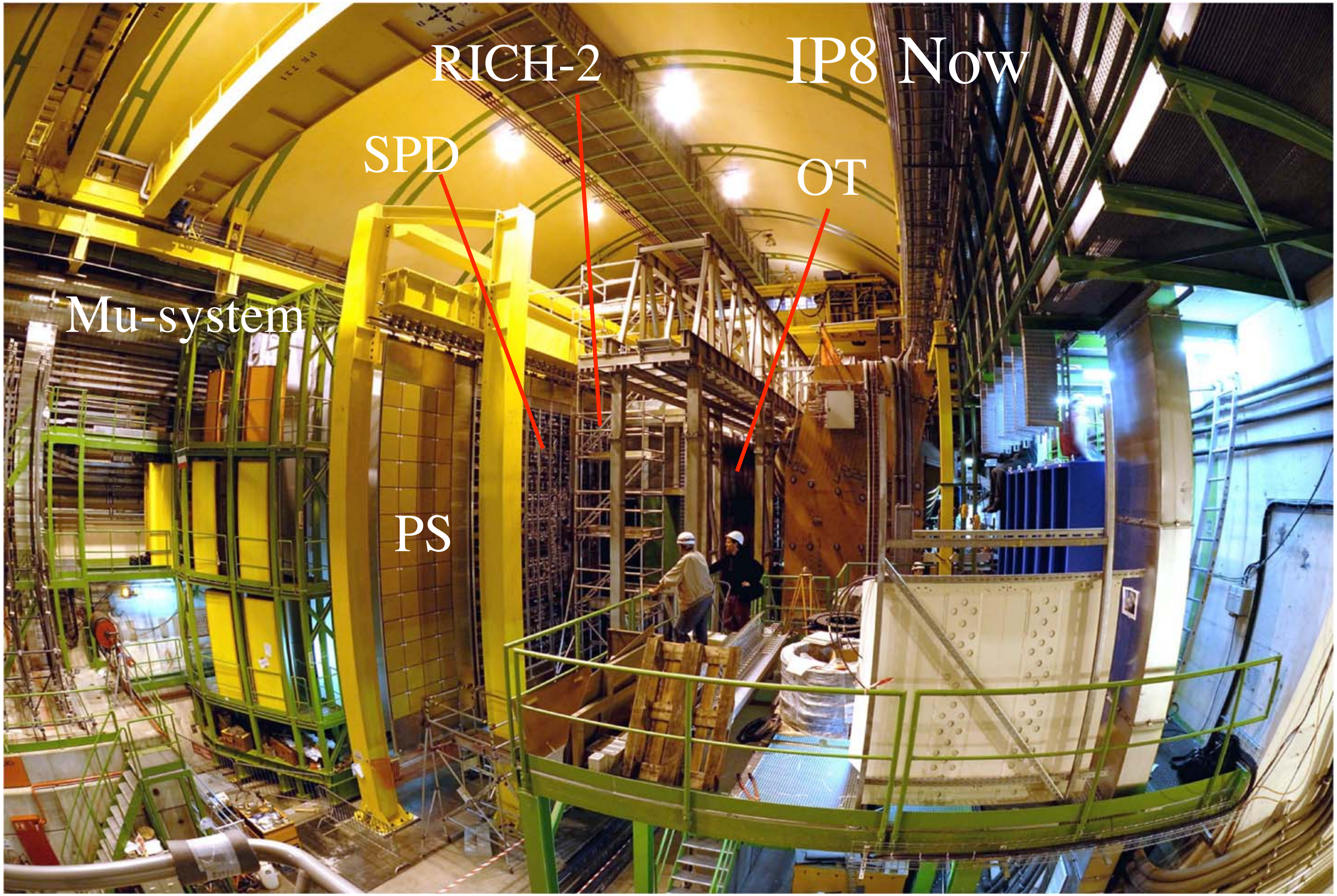
Installation of safety system in progress

gas system

Calo access tower

cabling and connector mounting

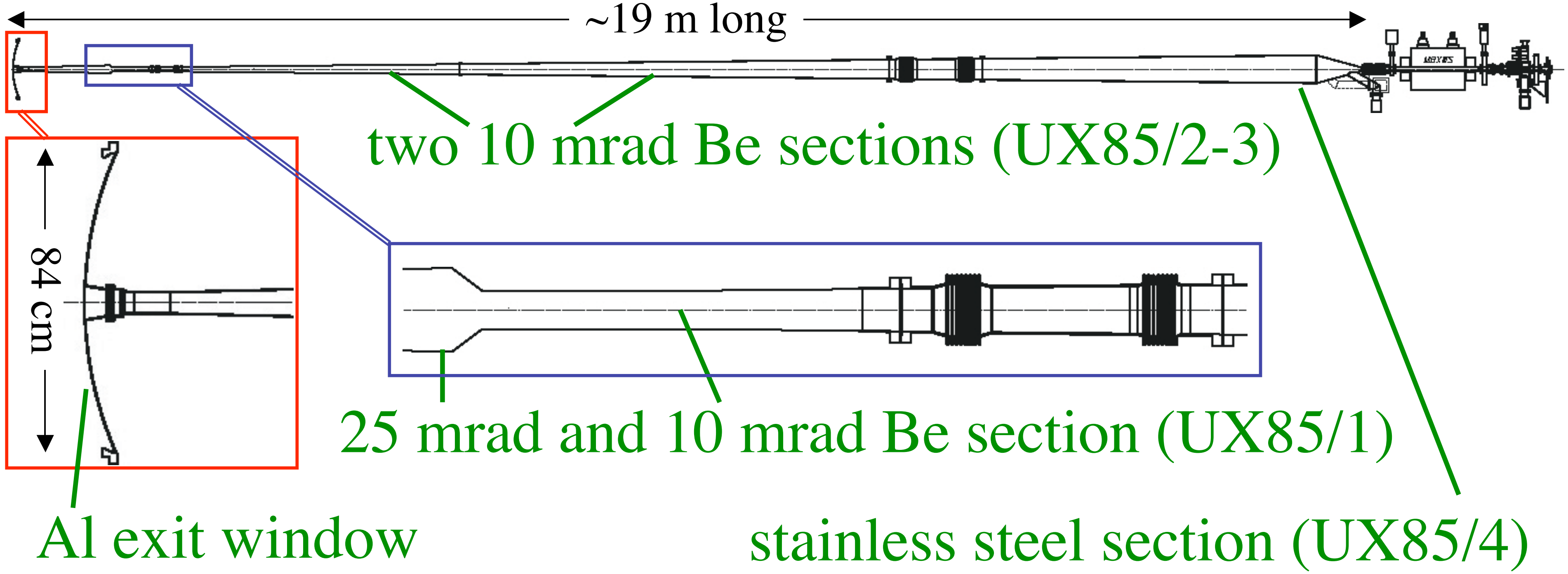
new access gate


IP8 Now
RICH-2
SPD
OT
Mu-system
PS

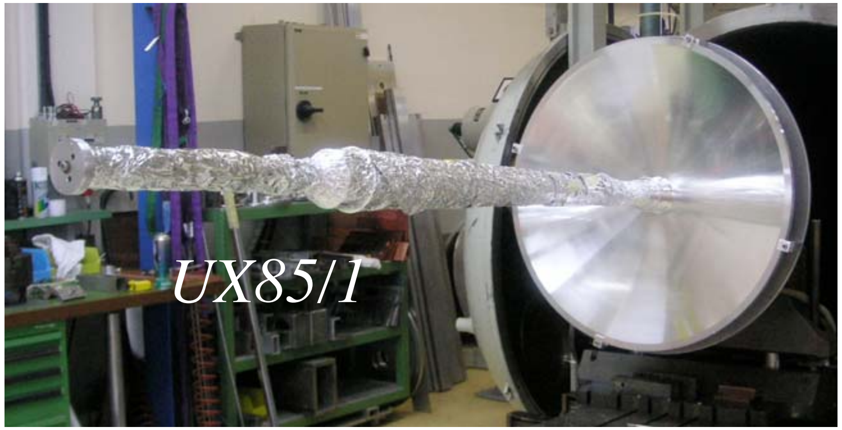
2) Beam Pipe

Under the responsibility of the LHC vacuum group with a close contact with the experiment

Built from four sections (3 Be and 1 stainless steel) joined by bellows and flanges (Al) (+ Al backups for the Be sections)

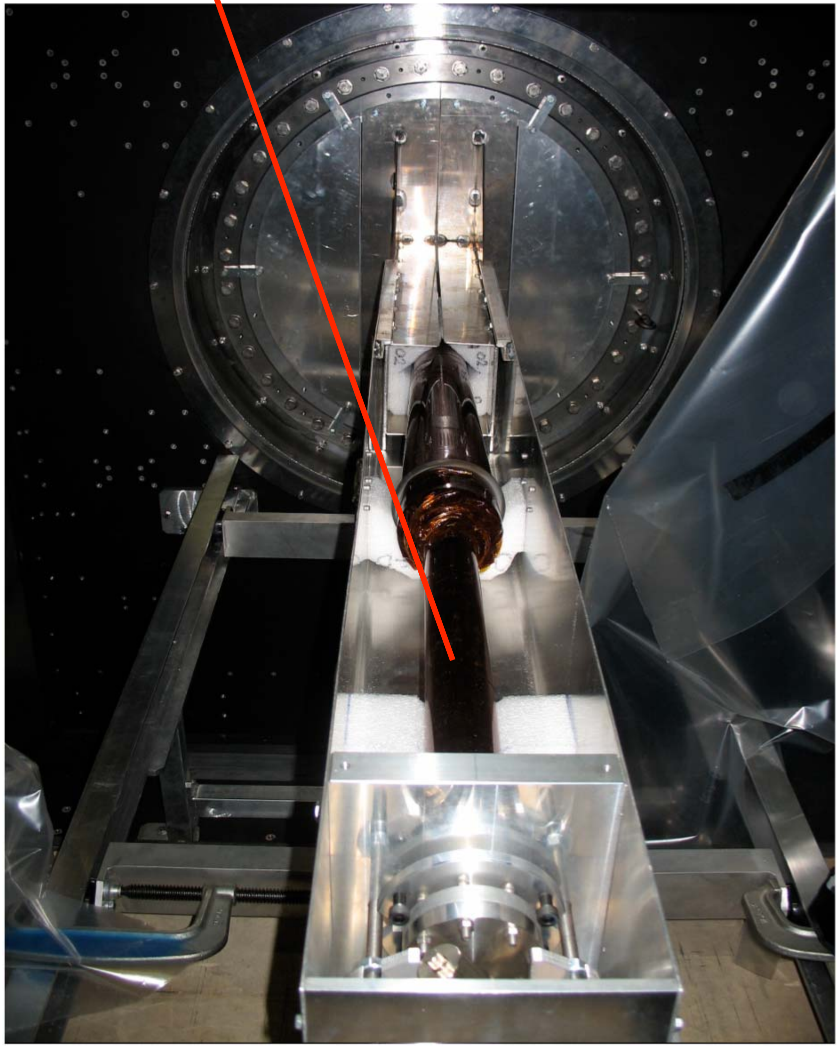


All the beam pipe sections delivered to CERN.
UX85/1, 2 and 4 ready for installation
UX85/3 just arrived with several months of delay,
undergoing acceptance test (showing small leak, fixed for the moment but long term solution may be needed)



UX85/1 installed

Al exit window (protected)
+ UX85/1 Be beam pipe section

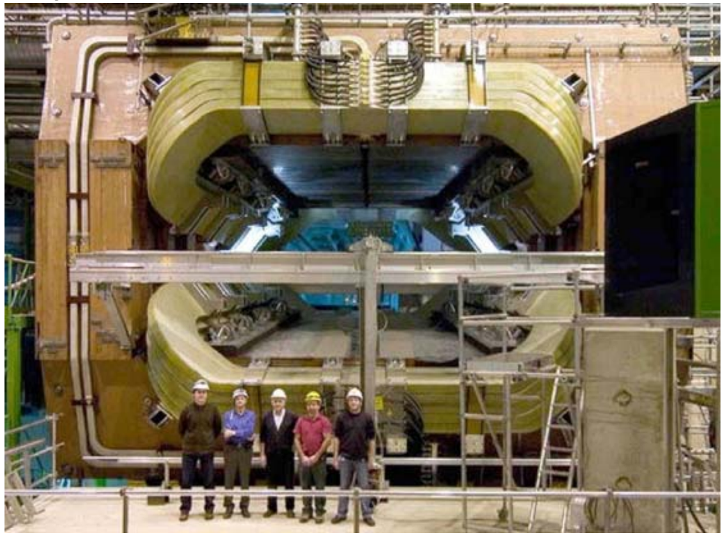


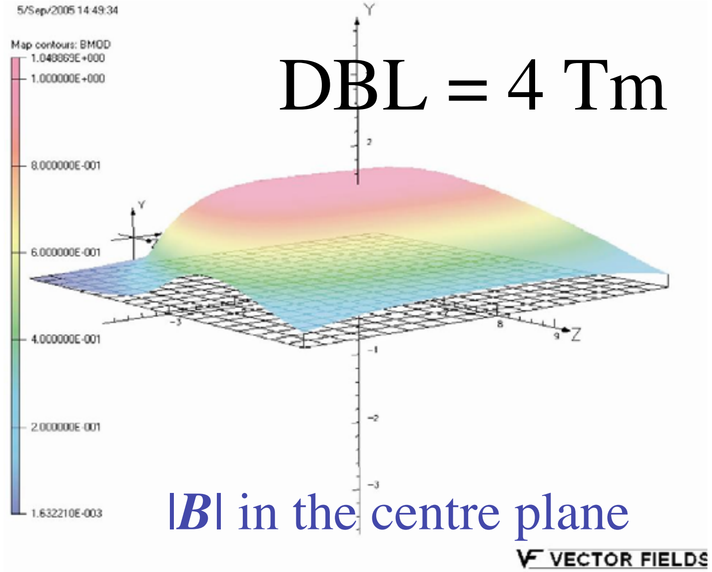
Production of the beam pipe supports in progress

Support-ring

3) Magnet

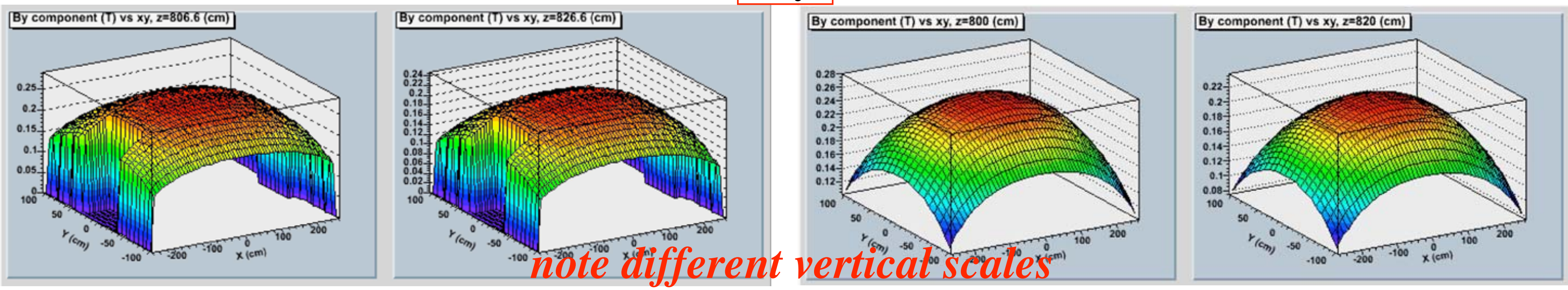
Fully commissioned and B field measured for both polarities





Analysis is in progress for incorporating the measurements into the software

measurements B_y calculation

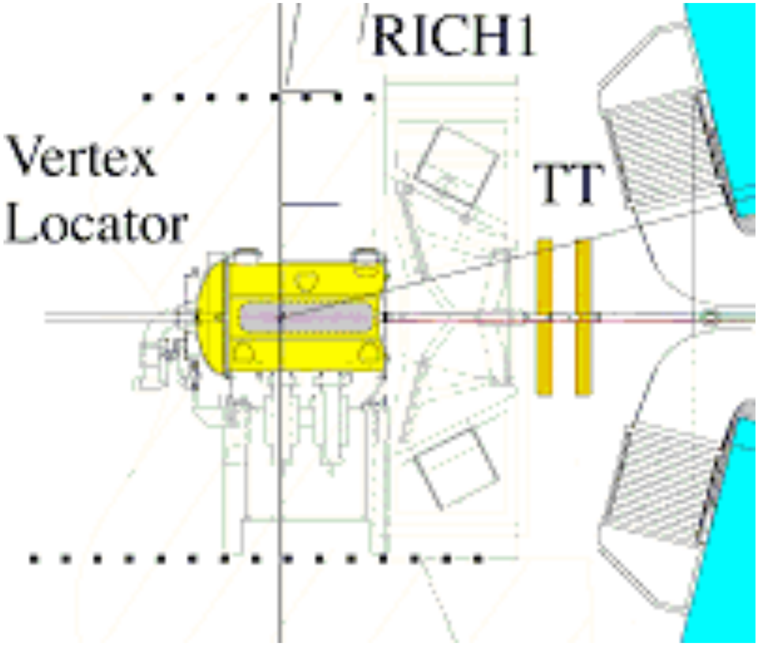


4) VErtex LOcator

VELO tank and its vacuum system from NIKHEF installed at IP8; vacuum leak tested

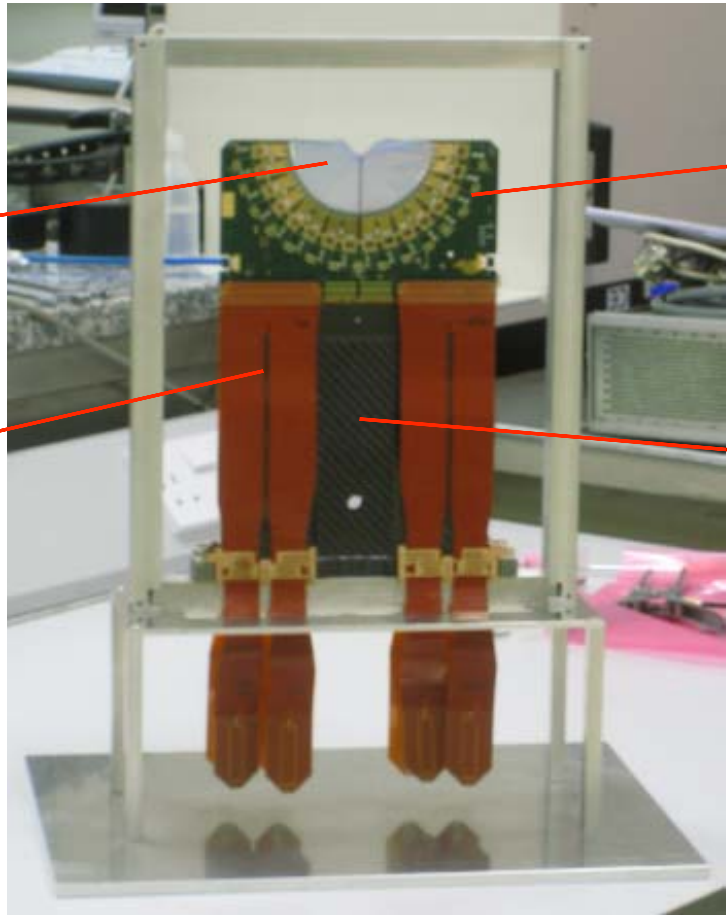
Al exit window (downstream) together with the first section of the beam pipe connected

Al window and wake field suppressor



Upstream side of the vacuum tank at IP8

Production of the sensor modules (42 + spares) started in Liverpool

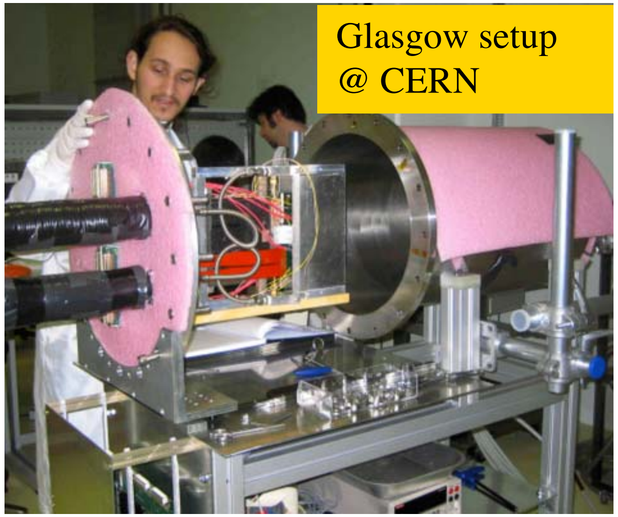


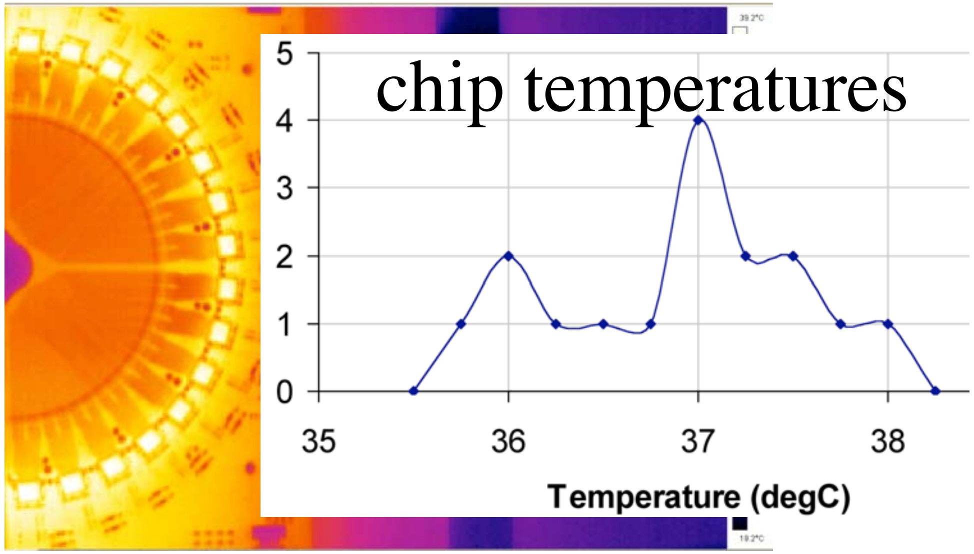
17 modules completed

Now reached the steady production stage, 2 modules/week

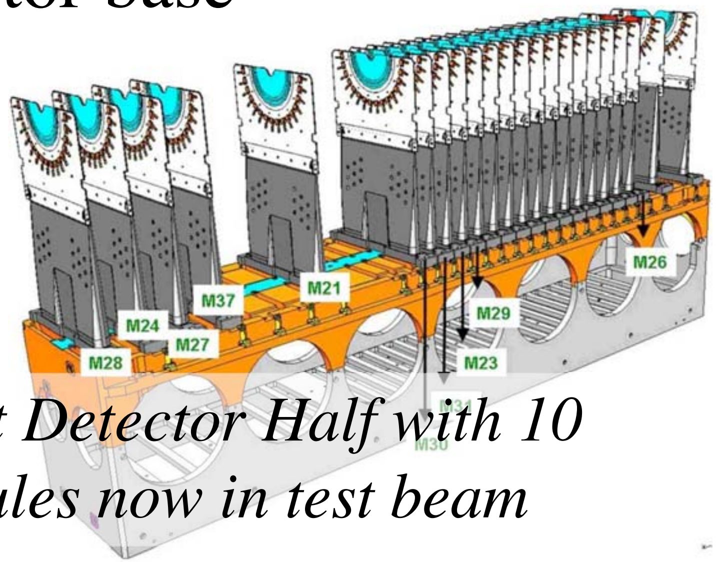
Expect to finish production by March 2007.

On arrival at CERN, visual inspection and burn-in test





Followed by assembly onto the detector base

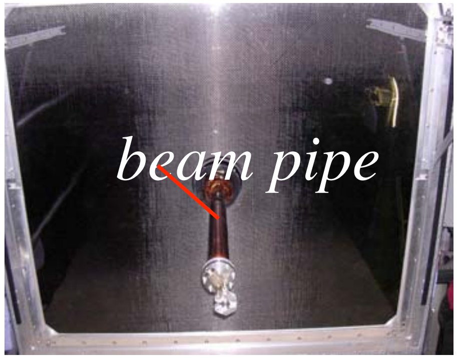


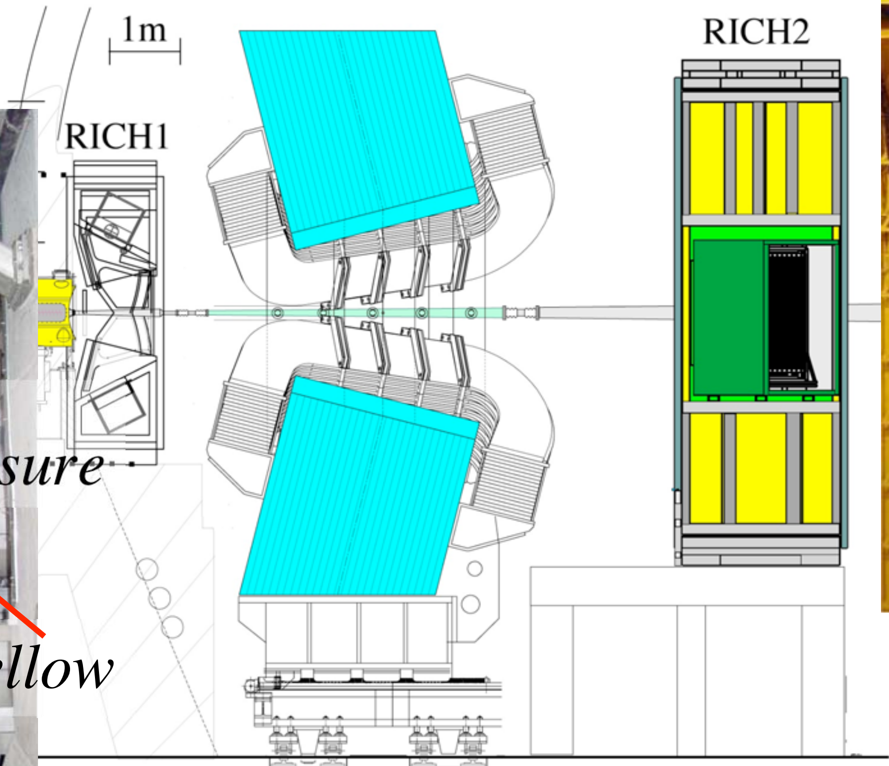
Right Detector Half with 10 modules now in test beam

5) RICH

RICH-2: In place and waiting for the Photon Detectors

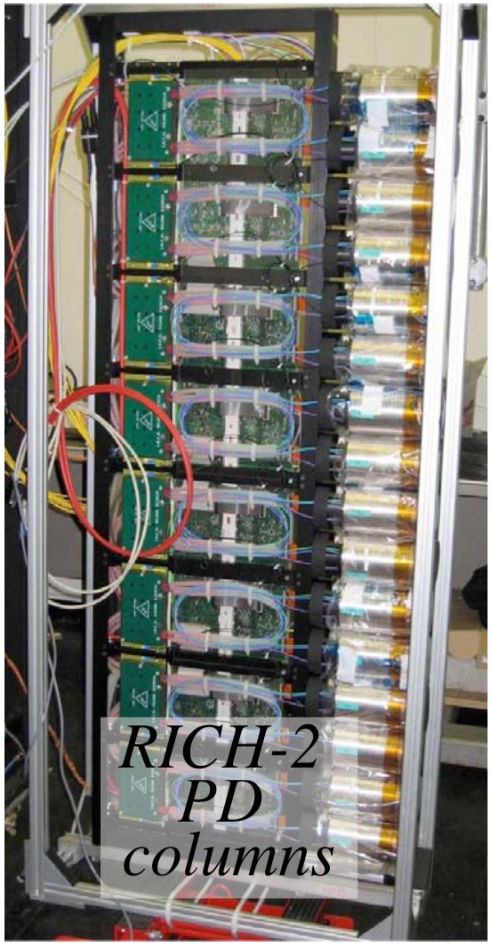
RICH-1: Mag. shielding box, gas enclosure in place, gas shielding bellow connected to the VELO tank, exit window installed





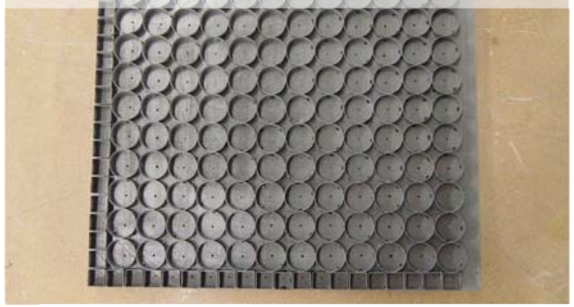
RICH-2: Photon Detector column assembly in progress
→installation for C-side starts in December

RICH-1: C-fibre spherical mirror prototype test successful, production in progress→ end of this year

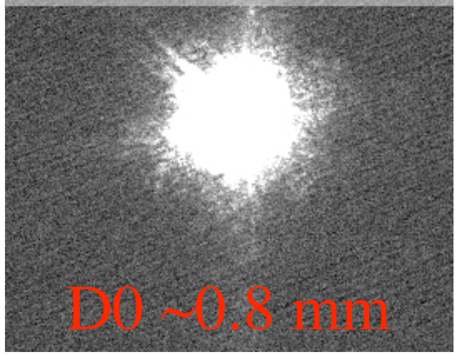


RICH-2 PD columns

backside of the RICH-1 prototype mirror



Good optical quality



No deterioration in C_4F_{10} nor radiation

Improvement needed for the Al + MgF_2 mirror coating to decrease the reflectivity loss in the UV region

mandrel for the final mirror

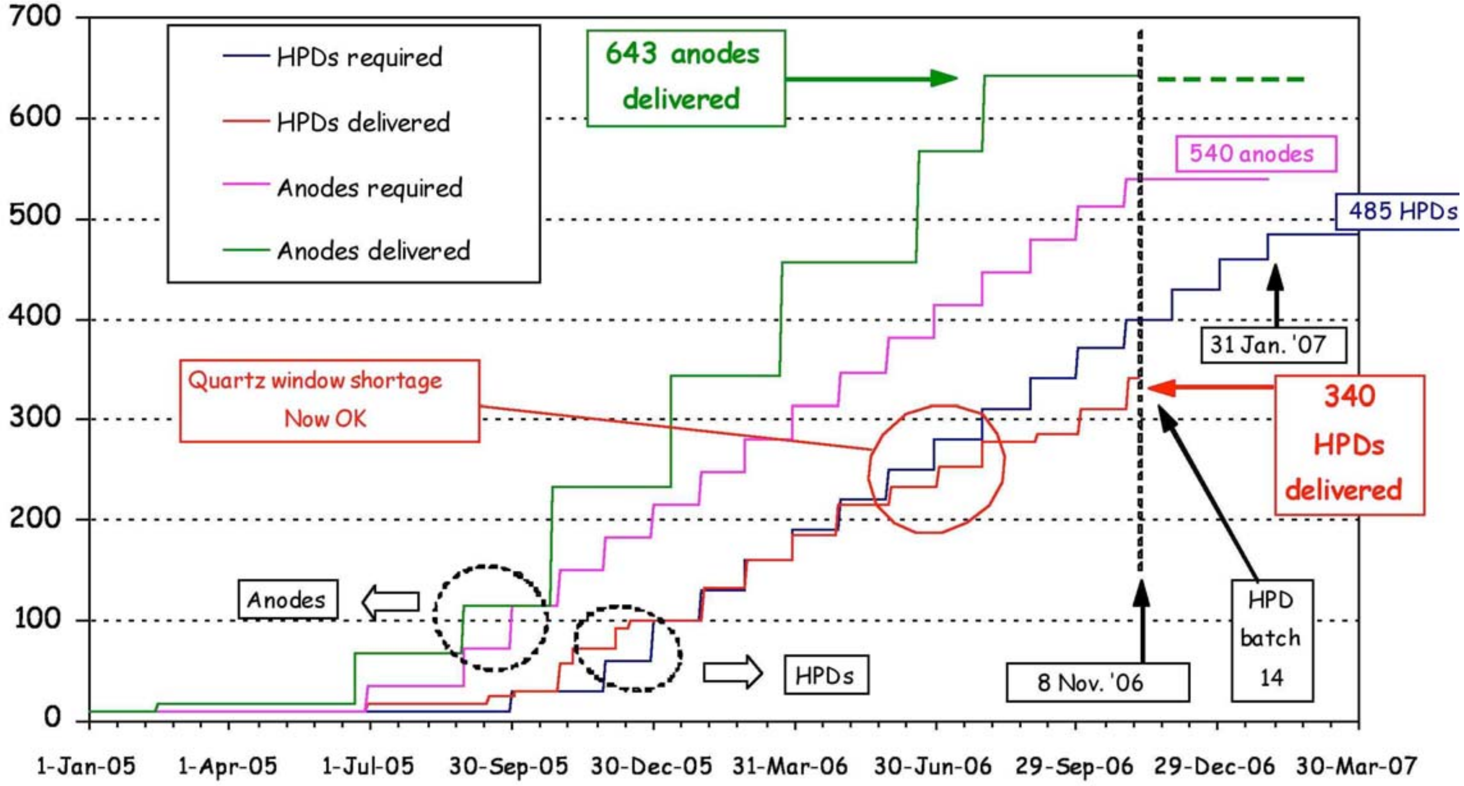
340 HPD's delivered out of 485 ordered (+ option for 65),

-2 months delay ⇒ recovery plan agreed with DEP additional production line

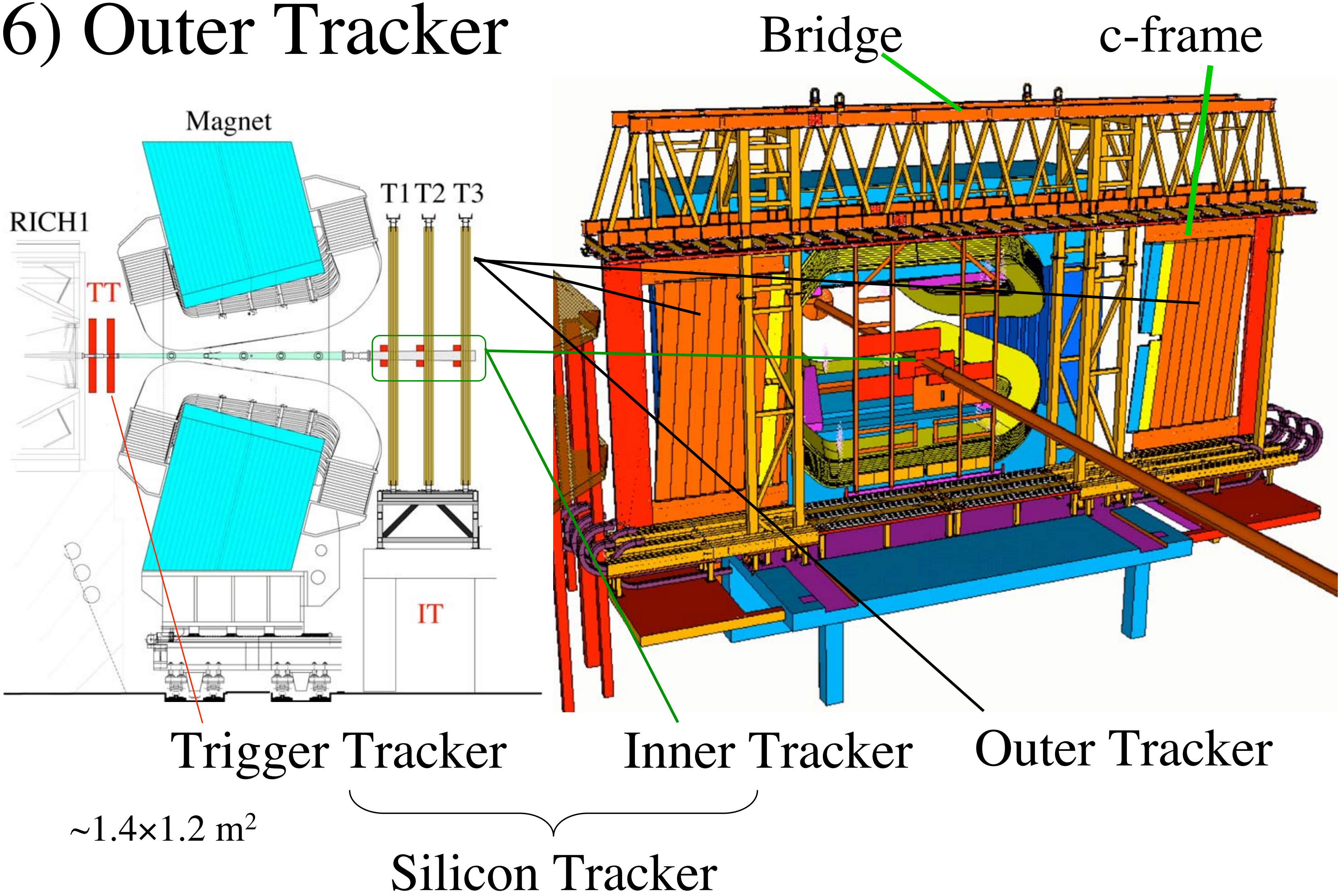
-only 3% failed the acceptance test, very good quality

Test beam with the full readout chain successfully completed

HPD production plot



6) Outer Tracker

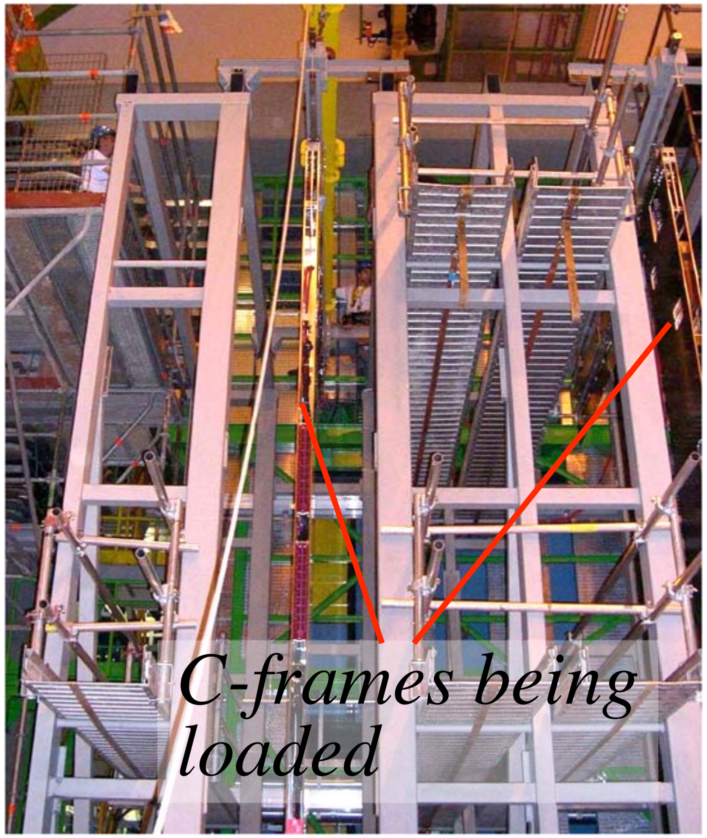


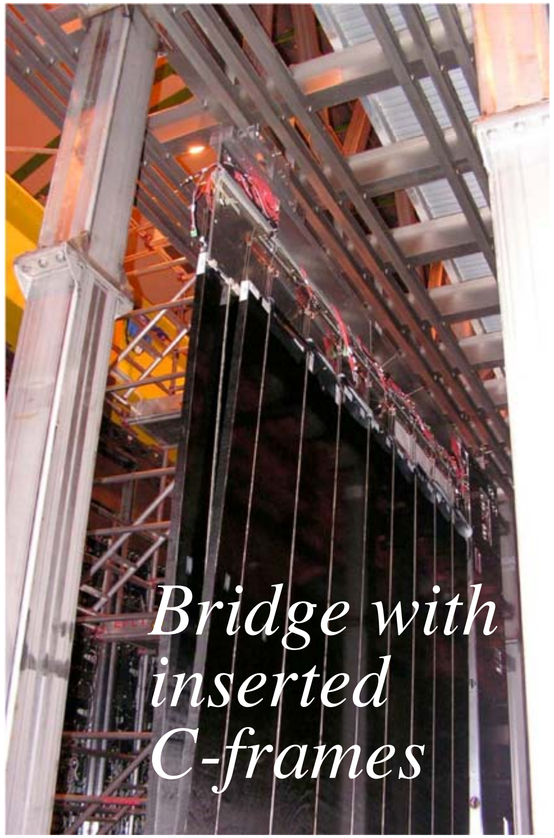
~1.4×1.2 m²

Loading of the C-frame with modules in progress with specially built metal cage at IP8

OT/IT support bridge assembled

After testing, loaded C-frames are inserted to the bridge

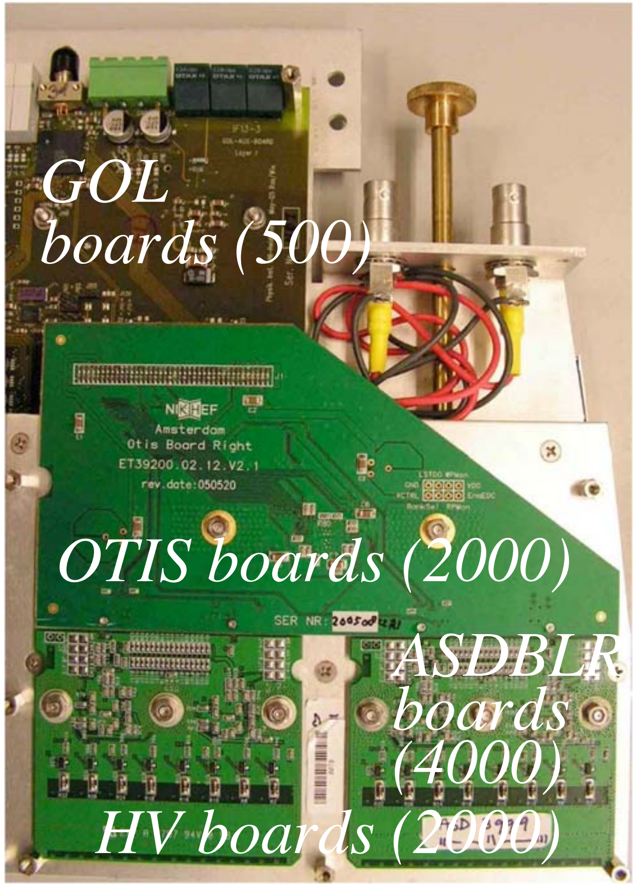




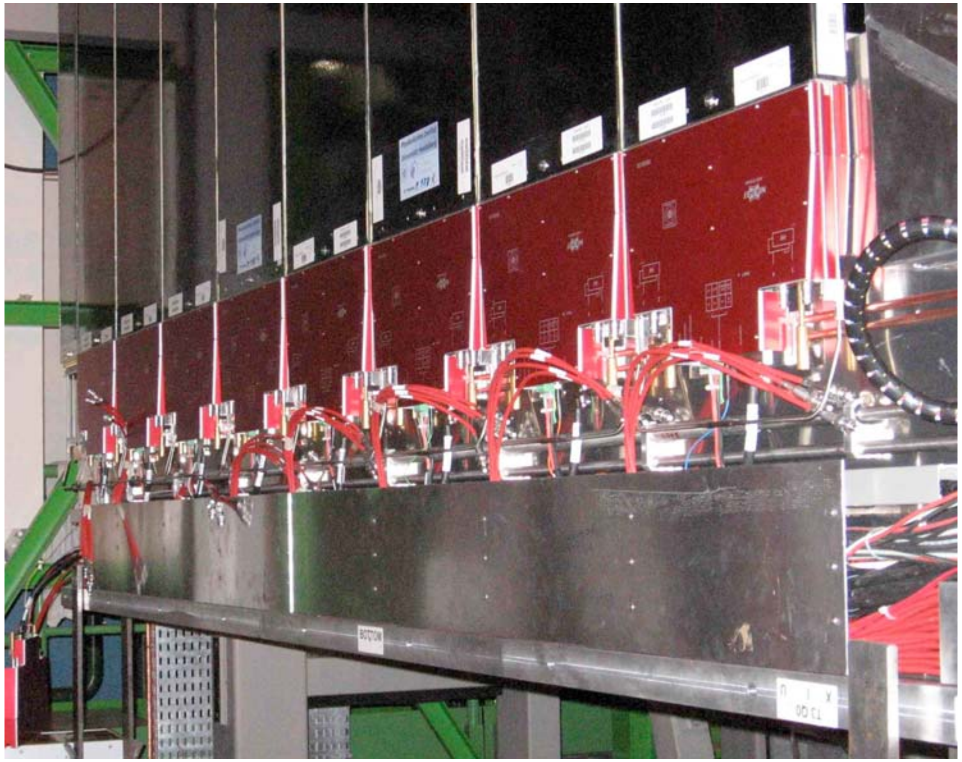
4/12 of C-frames inserted

Front-end electronics production in progress

All the ASIC chips produced and tested



Full scale test of the production front-end electronics with module loaded C-frame



7) Silicon Tracker

Trigger Tracker

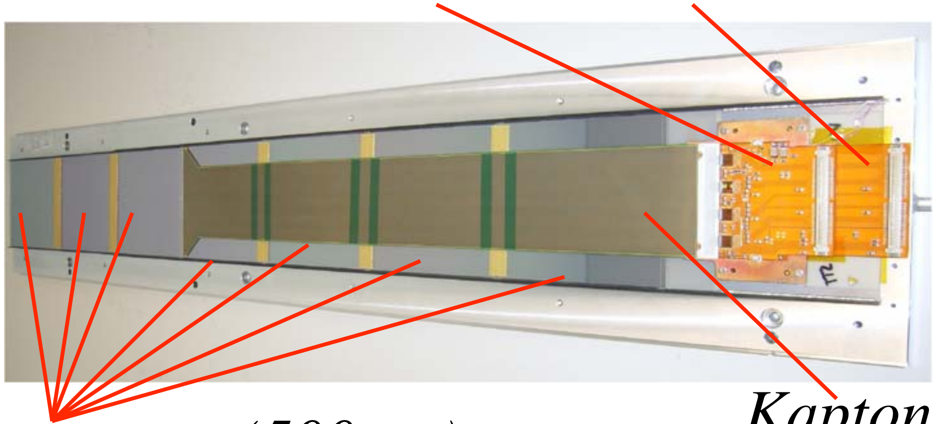
Ladder production completed

Inner Tracker

almost completed

tests are still on going

hybrid for the top and bottom

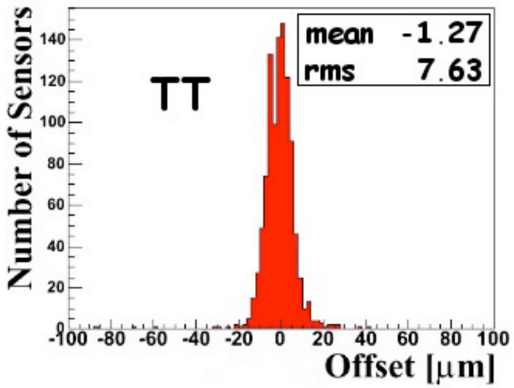


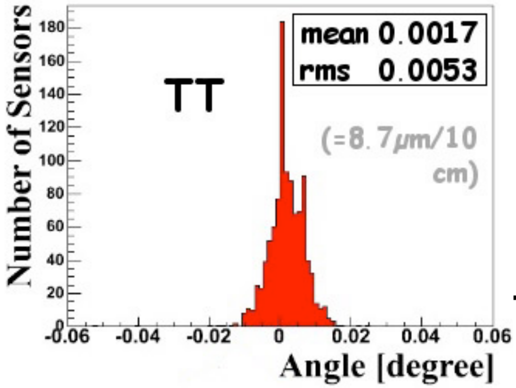
sensors (500μm)

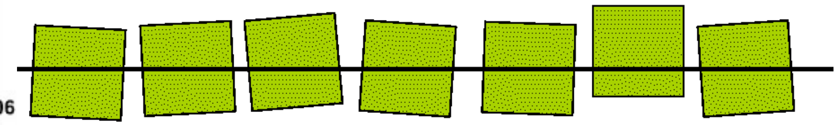
Kapton cable

two sensor (410 μm) ladder

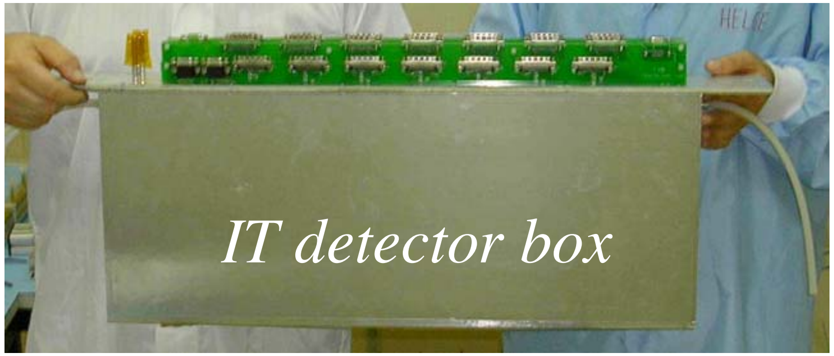
one sensor (320 μm) ladder







First IT box assembled

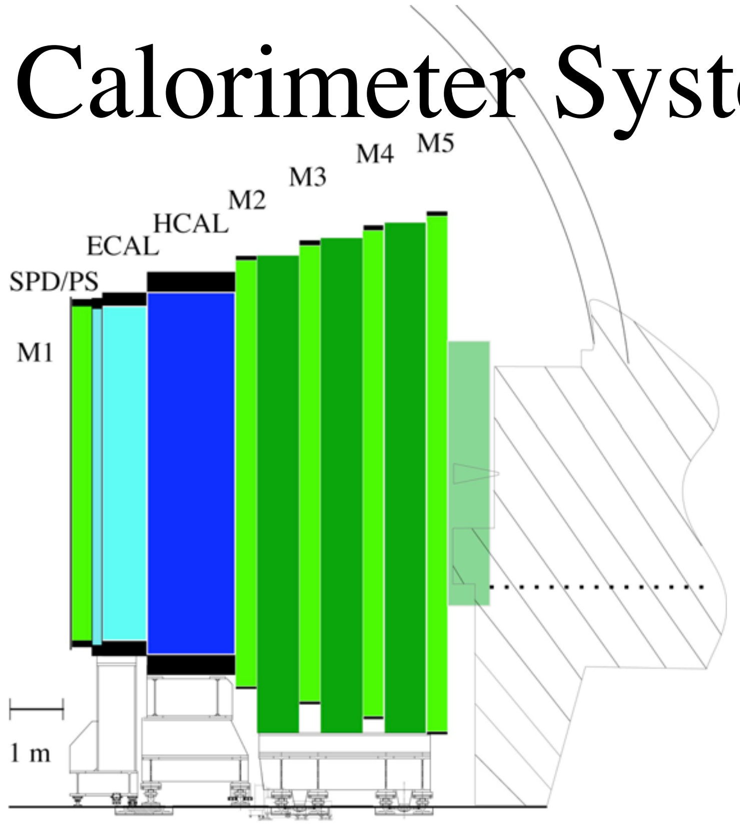


Some improvements for the tools and the next assembly starts soon

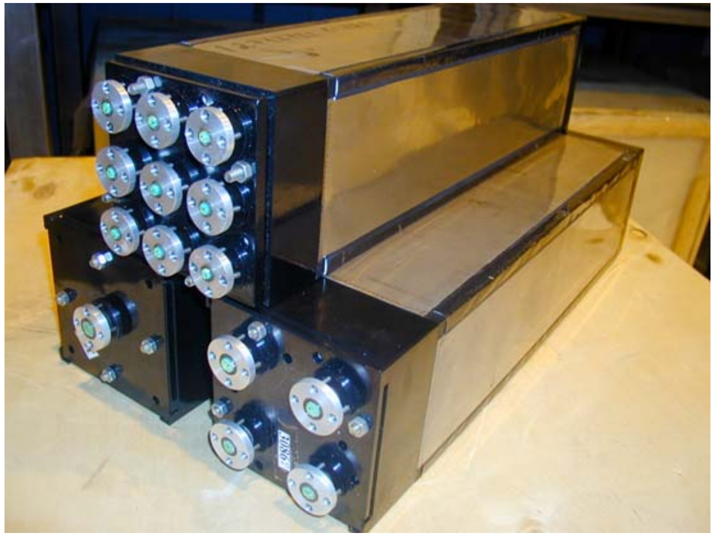
6 IT support frames constructed
3 cabled and inserted to the Bridge

TT Support frame
installed

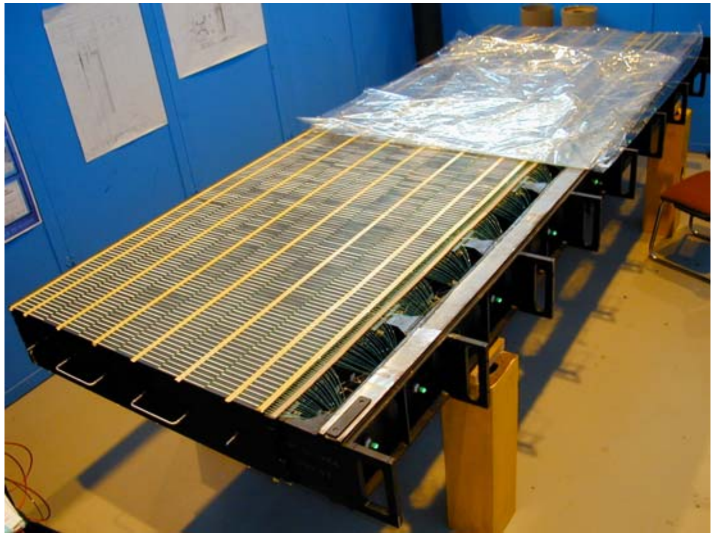
8) Calorimeter System



Ecal
Shashlik



Hcal
Fe-Scintillator tile



SPD/PS
Scintillator-Pb-Scintillator

Production and installation completed

Scintillator Pad Detector/Preshower (recently), E-cal and H-cal all installed

E-cal

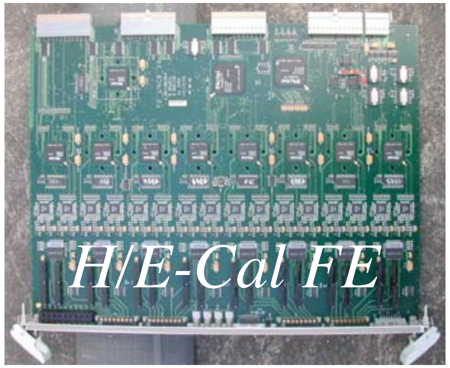
H-cal

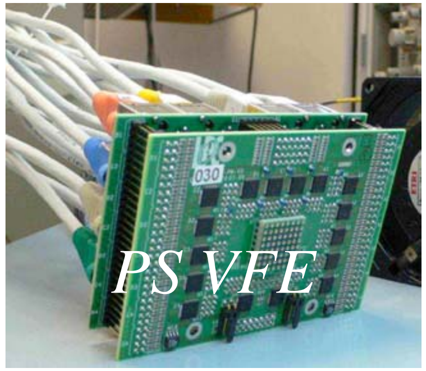
SPD/PS

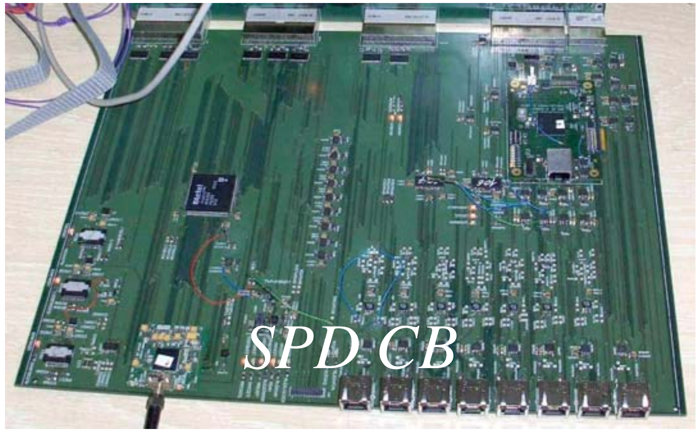
Electronics

E/H-Cal Front-End cards >90% produced
PS and SPD Very Front-End cards completed
PS FE cards production started (100 needed)
Calorimeter Read-Out Cards 2/26 produced
SPD Control boards PRR soon (16 needed)

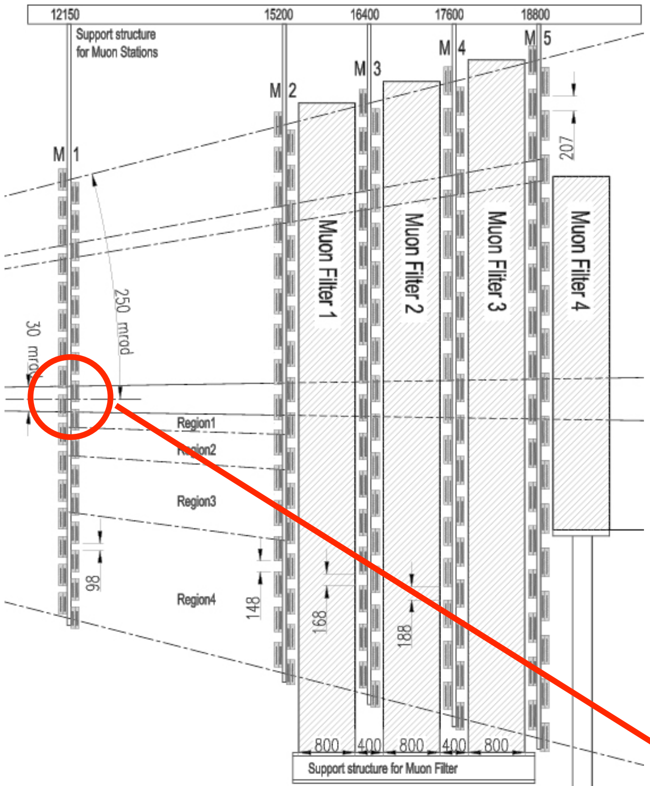
Racks with E/H-Cal FE cards on the platform (top of the E-cal)







9) Muon System



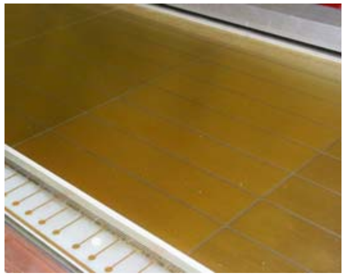
100 % of MWPC produced

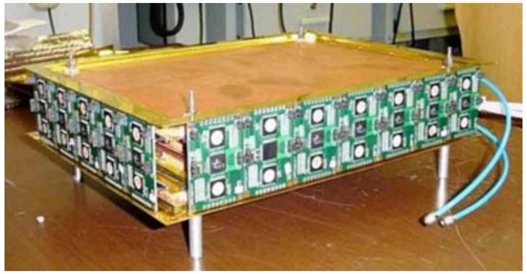
Fe shield

Electronics tower

MWPC support wall

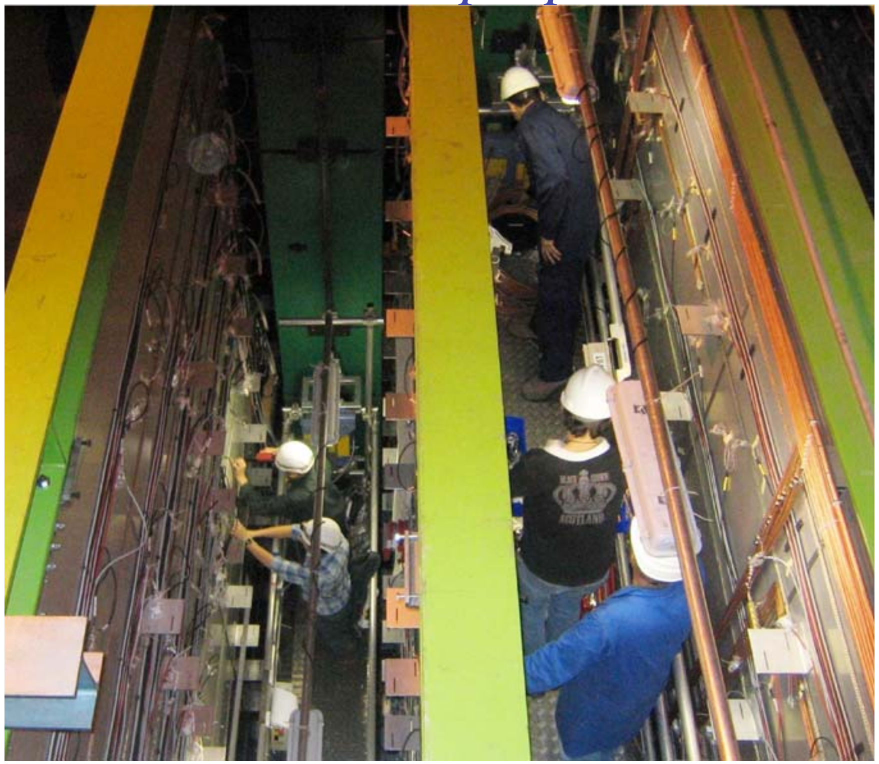
Projective readout based on MWPC's except 3-GEM at M1R1(high occupancy)





- Chamber support wall for M2-M5 assembled and necessary infrastructure (gas, cable, etc.) being installed
- Chamber installation for M5 started with delays
  - gas and cable connection and noise level tested
  - currently ~6 (2 to 4) chambers/day for installation (testing)
  - need to go up to 10 → Parallel installation required.

Muon wall preparation

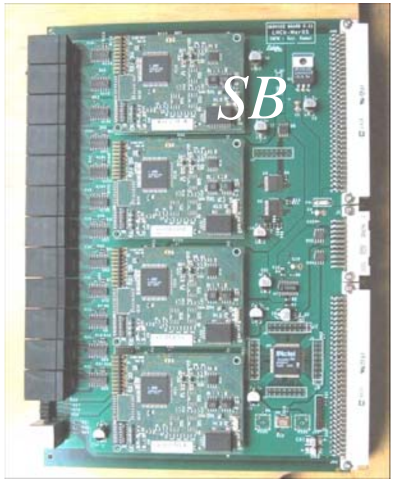


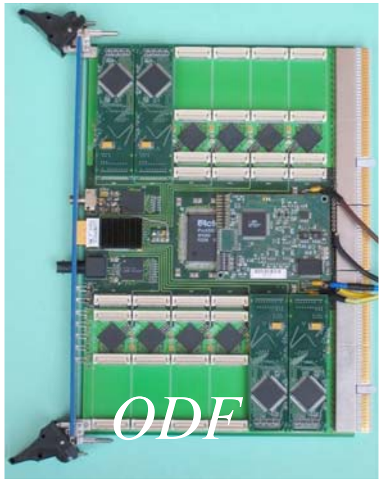
MWPC installation for M5

Electronics

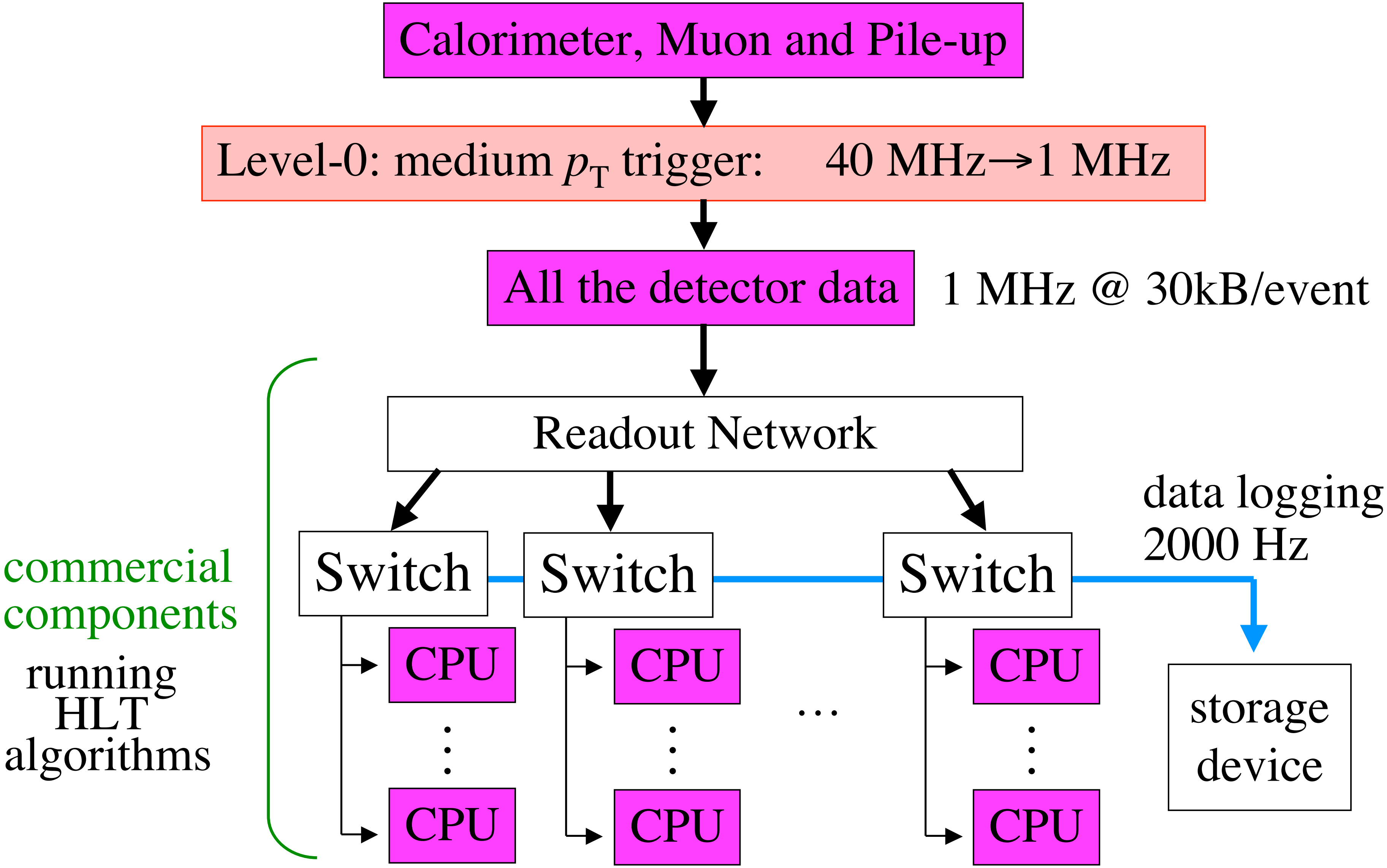
All the ASIC's have been produced
Spark Protection Boards: 8000 needed, 80% completed
Cardiac Boards: 8000 needed, 70% completed
Intermediate Boards: 100% completed
Service Boards: 100%
Off-Detector Electronics boards: in production, 160 needed
3-GEM Cardiac Boards: in production, 300 needed

Full readout chain used in the test beam with MWPC and 3-GEM





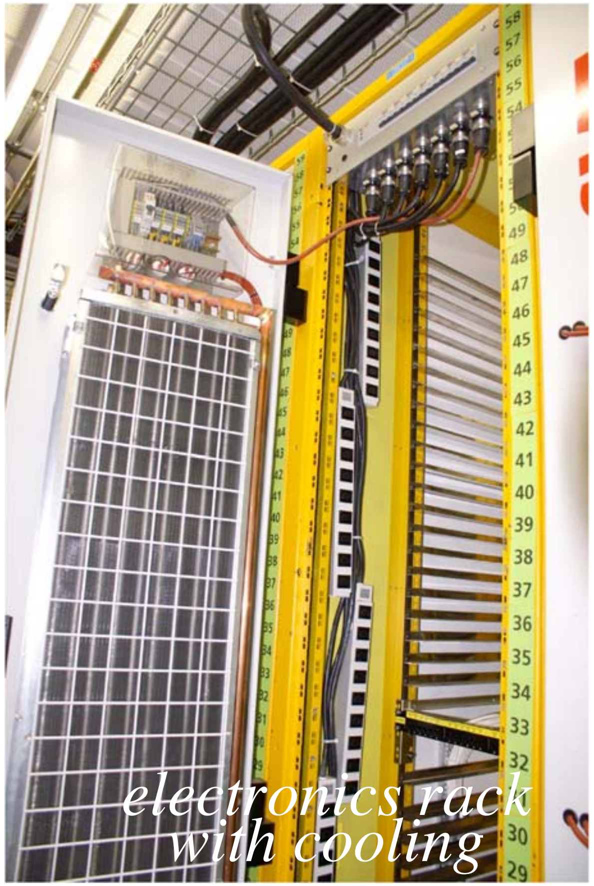
10) Trigger and Online



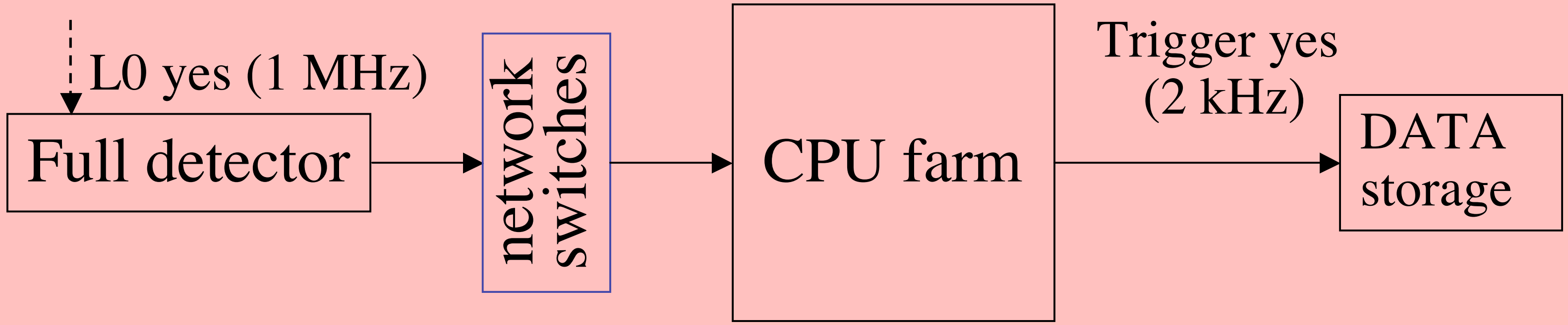
Level-0 electronics being produced

Infrastructure of the electronics huts at IP8 ready and cabling is being done

CPU's and servers necessary for the commissioning arrived



1 MHz DAQ/HLT



Hardware implementation defined using Force10 network switch

Software development: event building farm control etc. in progress.

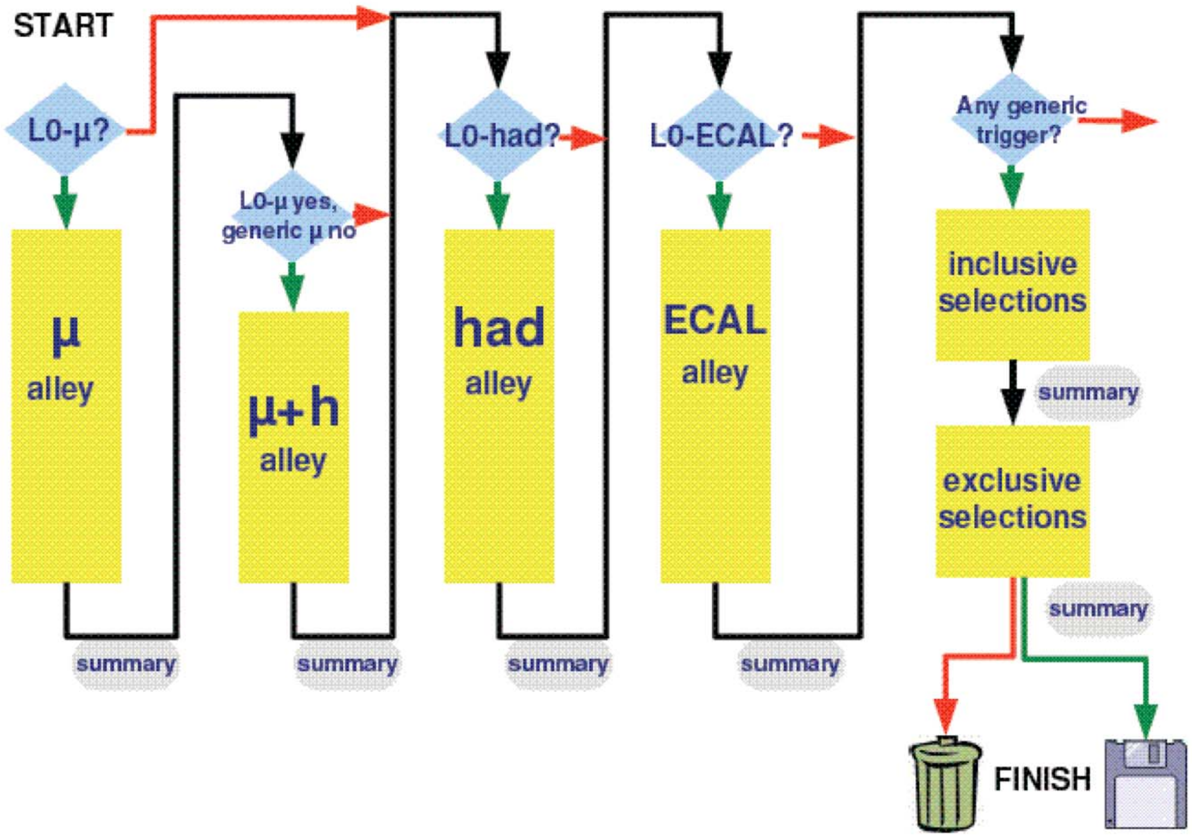
Part of software being used in the test beam DAQ

ECS is now being implemented by the subsystems and partly used in the test beam.

New HLT selection framework (optimized for the 1MHz RO) is being developed: so called "HLT alleys"

Starting with the validation of the L0 objects

ends with exclusive final state reconstruction



11) Computing

Continuous improvement of software

Track reconstruction now adapted to the new event model
and detector geometry description
-material budget update
-subdetectors after the magnet tilted (3.6 mrad)
with respect to the beam direction

Tuning of the tracking and particle identification
performance in progress

Alignment strategy established and implementation started
global alignment challenge in early 2007

Event generator to accommodate new physics channels

Data Challenge 06 ongoing

Validation of the Computing model: i.e.

Event reconstruction, stripping and analysis by
CERN and Tier-1 centres

Monte Carlo production by Tier-2 centres

Phase I: events generated and stored at Tier-0 (CERN)
Phase II: events distributed to Tier-1's and reconstructed
Phase II′: events stripped at Tier-1's

Phase I worked well. (Well established procedure by now)
Phase II is now working in most of the Tier-1's
→Problems in data access had to be solved
Due to the incompatibility between the different systems at Tier-1's and LCG software
Phase II′ is now to be established

Triggering automatically reconstruction and stripping job after the completion of the previous task is functional

LHCb physics programme

Reconstructable final states

Reconstruction of B **decay vertex with a good resolution**
is essential to **reduce combinatorial background**:

decay vertex: >1 well reconstructed tracks

well reconstructed track =

- charged particle seen by vertex detector
- reconstructed particle from tracks measured by vertex detector
  $D^0(\to K^-\pi^+)$, $D_s(K^+K^-\pi^+)$, etc., also K_S

examples are

$B_{(s)}{}^0 \to l^+l^-$, h^+h^-, ..., $B_s{}^0 \to \overline{D}_s(\to K^+K^-\pi^-)\,\pi^+$, $B^+ \to D(\to K_S\pi^+\pi^-)\,K^+$

π^0 and γ can be **associated** to a reconstructed vertex (if not too many)

$B^0 \to K^{*0}(K^+\pi^-)\gamma$, $\rho^0(\to \pi^+\pi^-)\pi^0$, etc. are possible

but not

$B^0 \to K_S\pi^0$, $\rho^+(\to \pi^+\pi^0)\pi^0$, $\pi^0\nu\nu$, etc.

$B^+ \to \mu^+\nu$, $K^+\nu\nu$, $\tau^+\nu$

Semileptonic decays may be possible, **under investigation**

A possible scenario for 2008

Let us assume 0.5 fb^{-1} of physics data with LHCb

1/4 of the "nominal" year with $\langle L \rangle = 2\times10^{32}$cm^{-2}s^{-1}

= less than 10% of a calendar year

With this data, first check some established results, e.g.

$\sigma_{\Delta m_s} = 0.014$ ps^{-1} cf. 0.10 ps^{-1} by CDF now

$\sigma_{\sin 2\beta} = 0.04$ cf. 0.03 current world average

lifetimes

$\Rightarrow$ understanding of trigger, momentum scale, σ_τ, tagging performance, detector acceptance etc.

Then proceed to exclude (or discover!) not yet excluded (relatively) large New Physics effects

e.g.

CP violation in B_s, $\overline{B}_s \to J/\psi\phi$ measuring $\phi_s = -2 \arg V_{ts}$

ϕ_s: B_s-$\overline{B}_s$ oscillation phase (respect to that of V_{cb})

$\sigma_{\phi s} = 0.04$ rad, SM prediction $\phi_s \approx -0.04$ rad

cf. current D0 result: $\sigma_{\phi_s} = -0.56^{+0.44}_{-0.41}$ rad @1 fb^{-1}

Search for very rare $B_s \to \mu^+\mu^-$ decays

$Br(B_s \to \mu^+\mu^-) \lesssim$ SM-Br (90% CL) SM-Br$\sim 3\times10^{-9}$

cf current CDF result $<0.8\times10^{-7}$ (90% CL) @780 pb^{-1}

cf current D0 results $<1.9\times10^{-7}$ (90% CL) @700 pb^{-1}

i.e. With 2008 LHCb data, we should be able to reach the Standard Model level of sensitivities

With nominal one year data

LHCb = 2 fb^{-1} and ATLAS/CMS = 10 fb^{-1}

require 10^7s data taking → only ~50% possible in early years

with $L = 2\times10^{32}$ (LHCb) or 10^{33} (ATLAS/CMS) → feasible

For LHCb $\int L\mathrm{d}t$ = 2 fb^{-1} by ~2010

LHCb: 2σ measurement of ϕ_s if SM value

$\sigma(\Delta\Gamma/\Gamma) = 0.0092$ (σ_τ = 36 fs for J/ψϕ)

ATLAS: 90k $B_s \to J/\psi\phi$ untagged events, σ_m = 16.5 MeV/c^2, σ_τ = 83 fs,
$\sigma_{stat}(\Delta\Gamma_s/\Gamma_s) \sim 0.023$, $\sigma(\sin\phi_s) = 0.08$ (fit incl. strong phases in helicity amplitude)

CMS: 109k $B_s \to J/\psi\phi$ untagged events, σ_m = 13 MeV/c^2, σ_τ = 77 fs,
$\sigma_{stat}(\Delta\Gamma_s/\Gamma_s) \sim 0.011$ stat. with untagged sample, $\sigma(\sin\phi_s)$ in progress

LHCb: 3σ observation of $B_s \to \mu^+\mu^-$ if SM branching fraction

CMS: $Br(B_s \to \mu^+\mu^-) < 1.4\times10^{-8}$

A similar work for ATLAS

$B_d \to \mu^+\mu^-$ has an irreducible background $B_d \to \pi^+\pi^-$

Start of precision measurements

CKM angle measurements, σ for LHCb (2 fb^{-1})

γ:

interfere $b \rightarrow u$ and $b \rightarrow c$ tree (see talk by Mitesh Patel)

with B-$\overline{B}$ oscillations:	$B_s \rightarrow D_s K$	13°	(AD)
with DCSD:	$B \rightarrow DK$	5-15°	(ADS)
with D-$\overline{D}$ mixing:	$B \rightarrow DK^*$	7-10°	(DGW)
with K-$\overline{K}$ mixing:	$B \rightarrow D_{(Dalitz)}K$	8°	(BG)

combine $b \rightarrow u$ tree and penguin with P/T from...

U-spin $B_d + B_s \rightarrow hh$ 4° or 7-10°

depending on the U-spin assumption

Quite significant measurements!

CKM angle measurement, σ for LHCb (2 fb^{-1}) cont.

α ($\beta+\gamma$): interfering box + tree + penguin

$B \rightarrow \rho\pi$ (time dep. 3π Dalitz plot) 10° (SQ)

(14 k events with B/S = 1)

$B \rightarrow \rho\rho$ only $\rho^0\rho^0$ reconstructable

no independent a determination

β: with box + tree

$B \rightarrow J/\psi\, K_S$ 0.6°

CP asymmetry in $B_s \rightarrow \phi\phi$: B_s equivalent for $B_d \rightarrow J/\psi\phi$

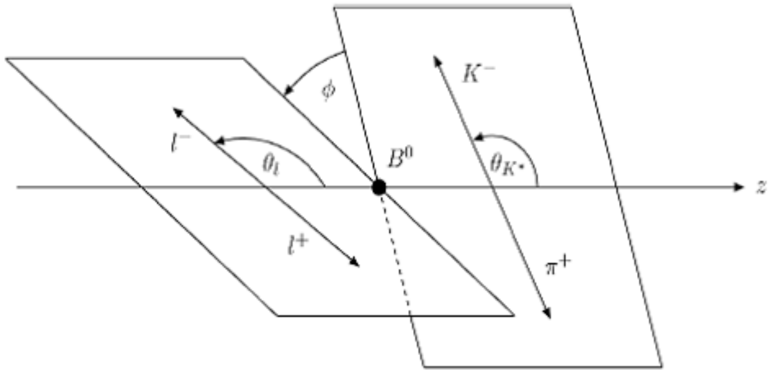
measurement of $\phi_s - 2\arg A_{B_s \rightarrow \phi\phi}$ 5.7°

0 in SM to a very good approximation

Search for non SM current in $B \rightarrow K^{*0}\, \mu^+\mu^-$ decays

e.g $\mu^+\mu^-$ F-B asymmetry, K^{*0} polarization etc.

$$d^4\Gamma = \frac{9}{32\pi} I(s, \theta_l, \theta_{K^*}, \phi) ds\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi$$



s = $\mu\mu$ mass squared

θ_l = FBA angle (between m and B in $\mu\mu$ rest-frame)

θ_{K^*} = equivalent K^* angle (between K and B in K^* rest-frame)

ϕ = angle between K^* and $\mu\mu$ decay planes

LHCb 2 fb^{-1}

expected number of events = 7.7k

Standard Model zero crossing point 4.1 GeV^2

with $\sigma = 0.6\ GeV^2$

(ATLAS 800 $B^0 \rightarrow K^{*0}\mu^+\mu^-$ events/10fb^{-1})

Effect of $K\pi$ non-resonant background?

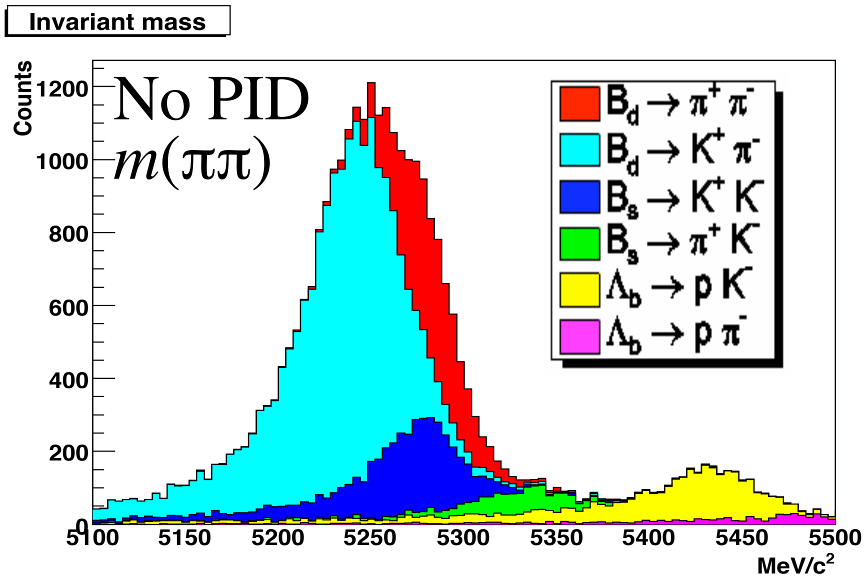
$B_s \rightarrow \phi\mu^+\mu^-$ is an interesting alternative

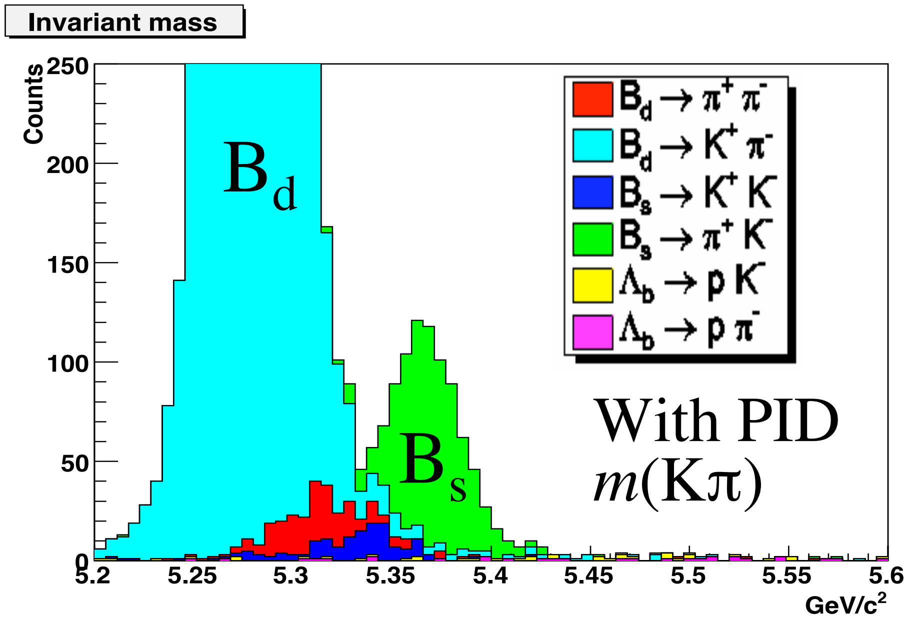
Also high statistics with real γ, with LHCb (2fb^{-1})

Decay	2 fb^{-1} yield	B/S
$B_d \to K^*\gamma$	35000	< 0.7
$B_s \to \phi\gamma$	9000	< 2.4
$B_d \to \omega\gamma$	40	< 3.5

~~CP~~ in decay amplitudes for $B \to hh$: LHCb (2fb^{-1})

PID and σ_m are essential to separate all the decay modes





After fitting the time dependent CP asymmetries...

	$B_d \to \pi^+\pi^-$	$B_s \to K^+K^-$
$\sigma(C)$	0.043	0.042
$\sigma(S)$	0.037	0.044
	$B_s \to K^+\pi^-$	$B_s \to \pi^+K^-$
$\sigma(A_{CP})$	0.003	0.02

Good precisions, but....

how should we interpret?

And charm physics at LHCb

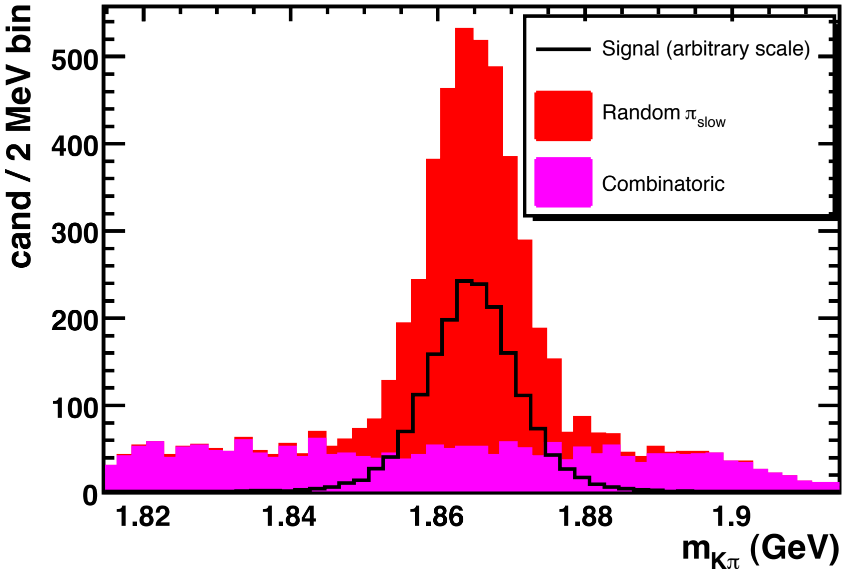
NB Studies are on going:

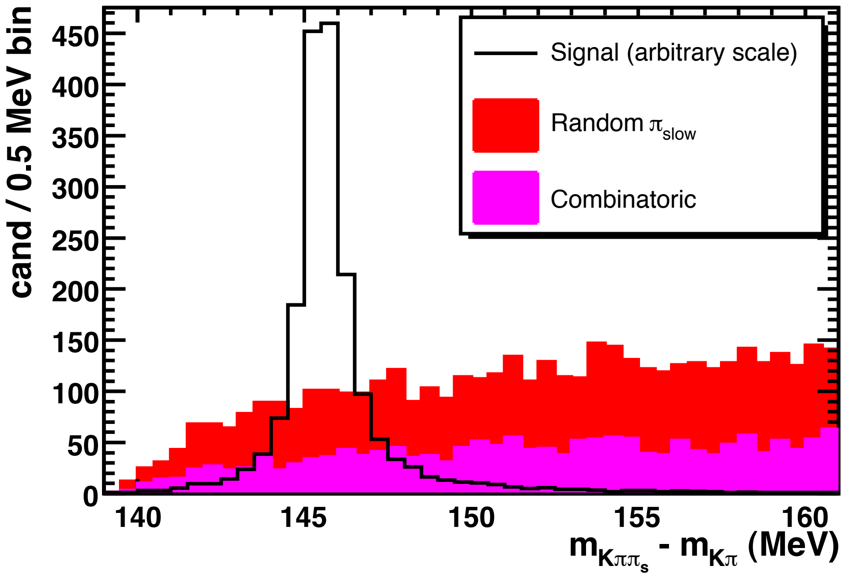
Initial flavour tagged D^0 and $\overline{D}^0$ from D^{*+} and D^{*-} decays

charge sign of "slow" pion

Standard L0 high-pT (h, l, γ) trigger + HLT

$\rightarrow$ higher efficiency for D^* from B decays





$50\times10^6\ D^0(K^-\pi^+)$ + c.c. per 2 fb^{-1}
$0.2\times10^6\ D^0(K^+\pi^-)$ + c.c. per 2 fb^{-1}

D-$\overline{\text{D}}$ oscillations

sensitivity study on x and y in progress

$$x = \frac{\Delta m}{\overline{\Gamma}} \quad y = \frac{\Delta\Gamma}{\overline{\Gamma}}$$

CP violation in $D\rightarrow K^+K^-$ decays

$$A_{CP} = \frac{(D^0\rightarrow KK - \overline{D}^0\rightarrow KK)}{(D^0\rightarrow KK + \overline{D}^0\rightarrow KK)}$$ Standard Model $\sim10^{-3}$

LHCb expects 5×10^6 KK, 2×10^6 $\pi\pi$ initial flavour tagged events

Estimated statistical precision $\sim10^{-3}$ in one year

Systematics must be controlled by the Kπ mode

Detailed study, in particular background, starts now...

With more statistics...

Tau Physics

ATLAS study on Lepton number violation in $\tau \to \mu\gamma$
for integrated luminosity 30 fb^{-1} (3×10^7s of $L = 10^{33}$)
90% CL UL < 0.6×10^{-6}
using τ from $W \to \tau\nu$ events.

CMS study on Lepton number violation in $\tau \to 3\mu$
for integrated luminosity 10 fb^{-1} (10^7s of L=10^{33})
$\tau \to 3\mu$: 90% CL UL < 3.8×10^{-7}
$\tau \to \mu\gamma$: 90% CL UL < 10^{-6}

LHCb under study
$\tau \to 3\mu$, $e\mu$, ...

Or more speculative decays such as
$B \to \mu e$ or $\tau\mu$

Around 2011, ATLAS/CMS will boost luminosities ↗ 10^{34}

no longer B physics (except possibly $B_s \to \mu^+\mu^-$)

LHCb may try to run at a little higher luminosities, ↗ 5×10^{32}

LHC can deliver this with no problem

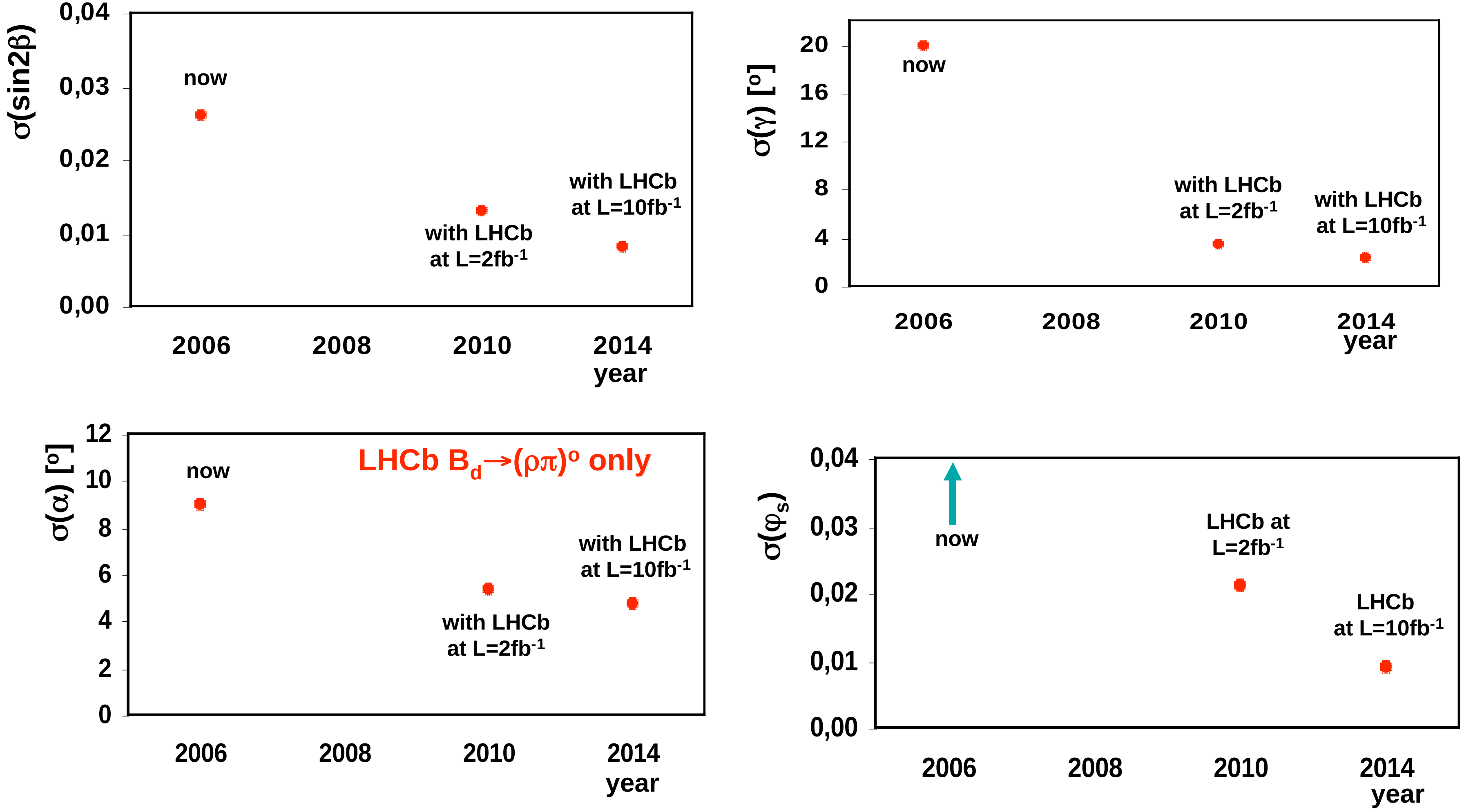
Can we handle multiple primary vertex events?

Most probably the detector works OK

L0 trigger may need tuning not to loose hadronic channels

LHCb eventually correct 10fb^{-1} by ~2014

Progression of the CKM angle errors with LHCb($10fb^{-1}$)



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4) ....

For sure, the next five years will be really exciting!

Conclusions

- LHCb expects to take B physics a significant step forward from the B factories:
  - access to other b hadron species + high statistics
  - excellent vertexing and particle ID
  - flexible and efficient trigger, dedicated to B physics

  Many channels with different sensitivities to new physics
- Construction of the LHCb detector is advancing well
- Low luminosity ($\sim 10^{32}$) required for the LHCb experiment will allow to exploit full physics potential from the beginning of the LHC operation, and we will be ready for the pilot run in 2007 and the start of physics exploitation in Spring 2008