Recent results from LHCb

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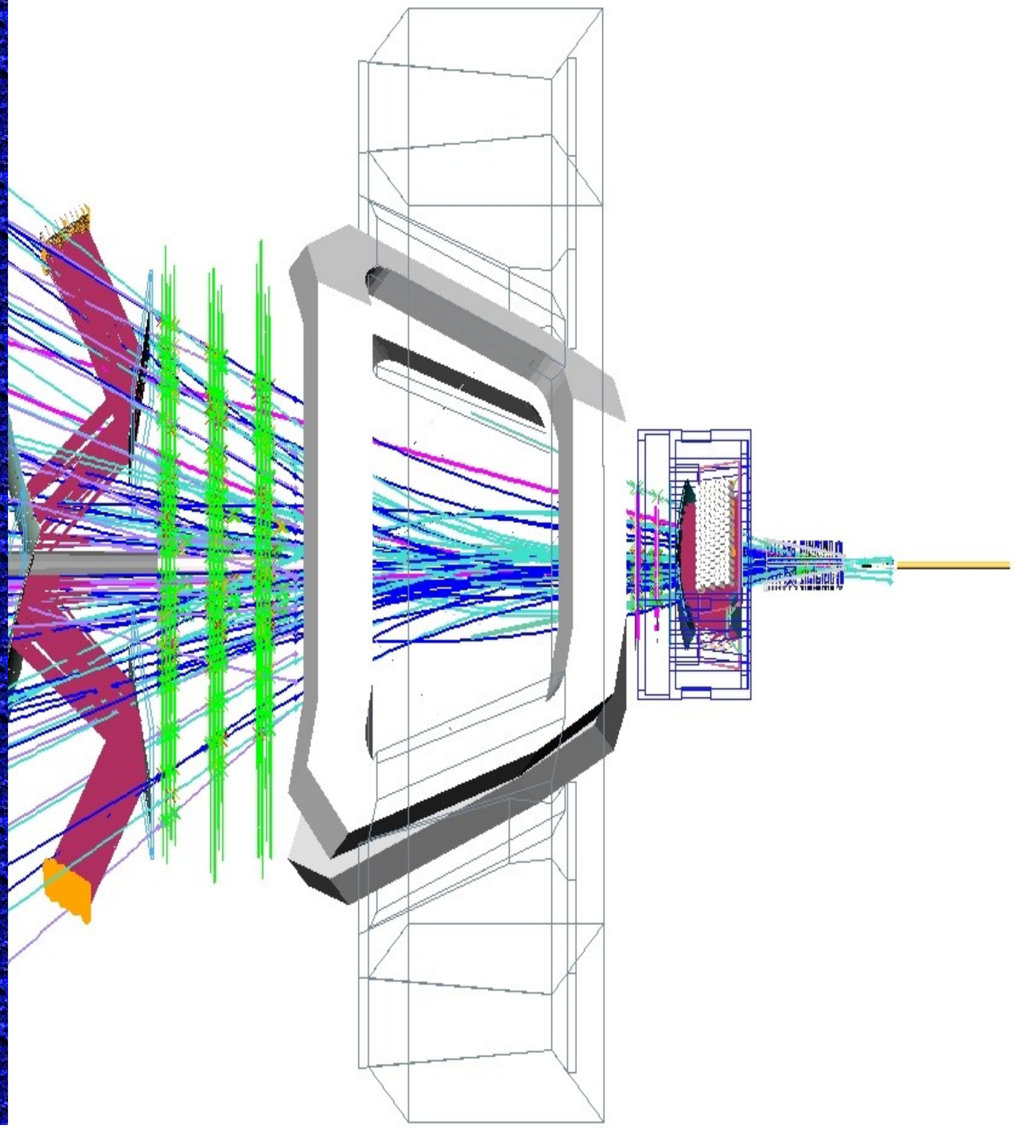
Invited seminar at the Karlsruhe Institute of Technology (Instituts-Seminar des IKP und IEKP) 29 May 2012, Germany

Outline

- LHCb experiment:
  - → physics program
  - → detector and its subcomponents
  - → data taking
- Recent physics results
- LHCb upgrade plans
- Summary



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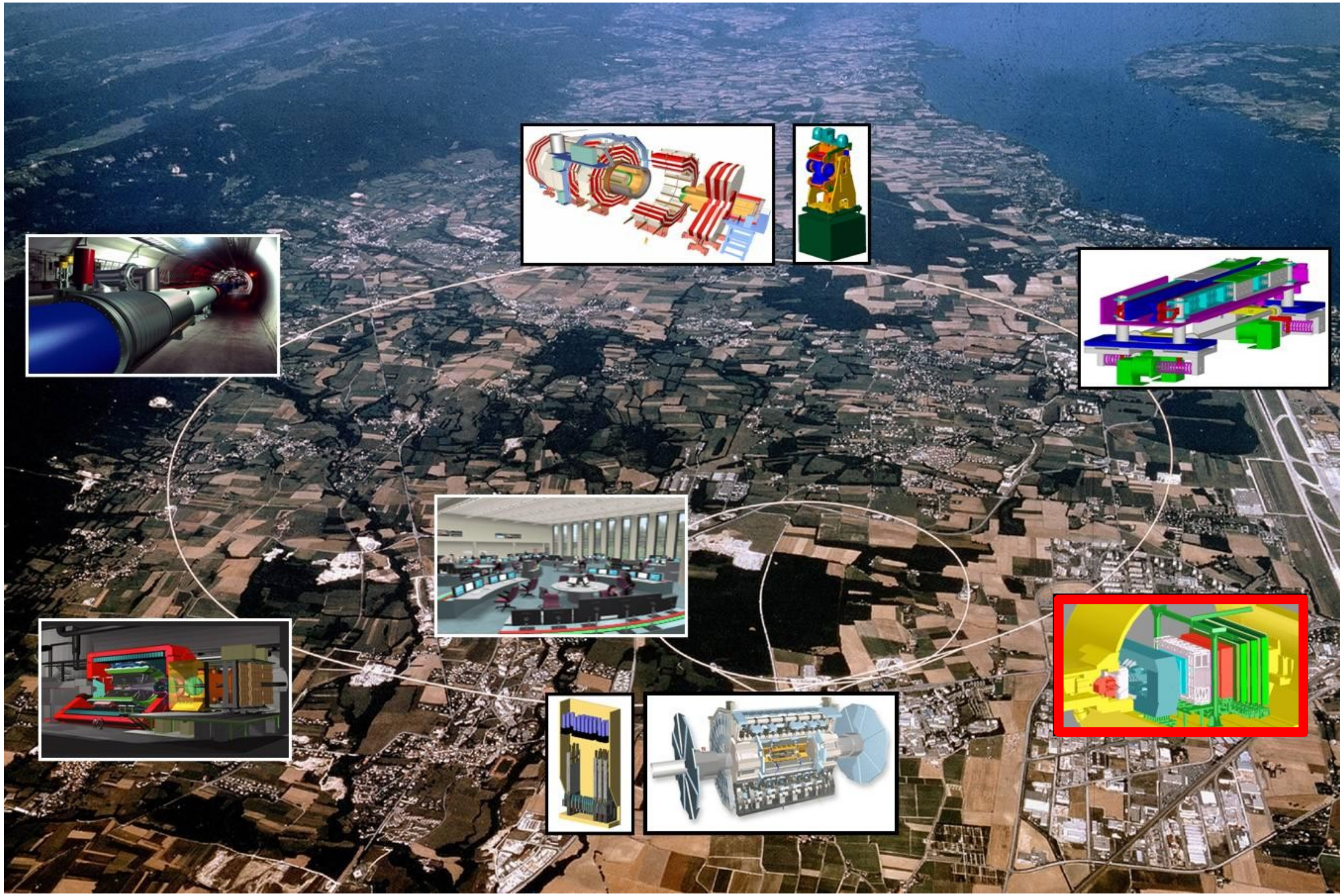
Part 1: LHCb experiment

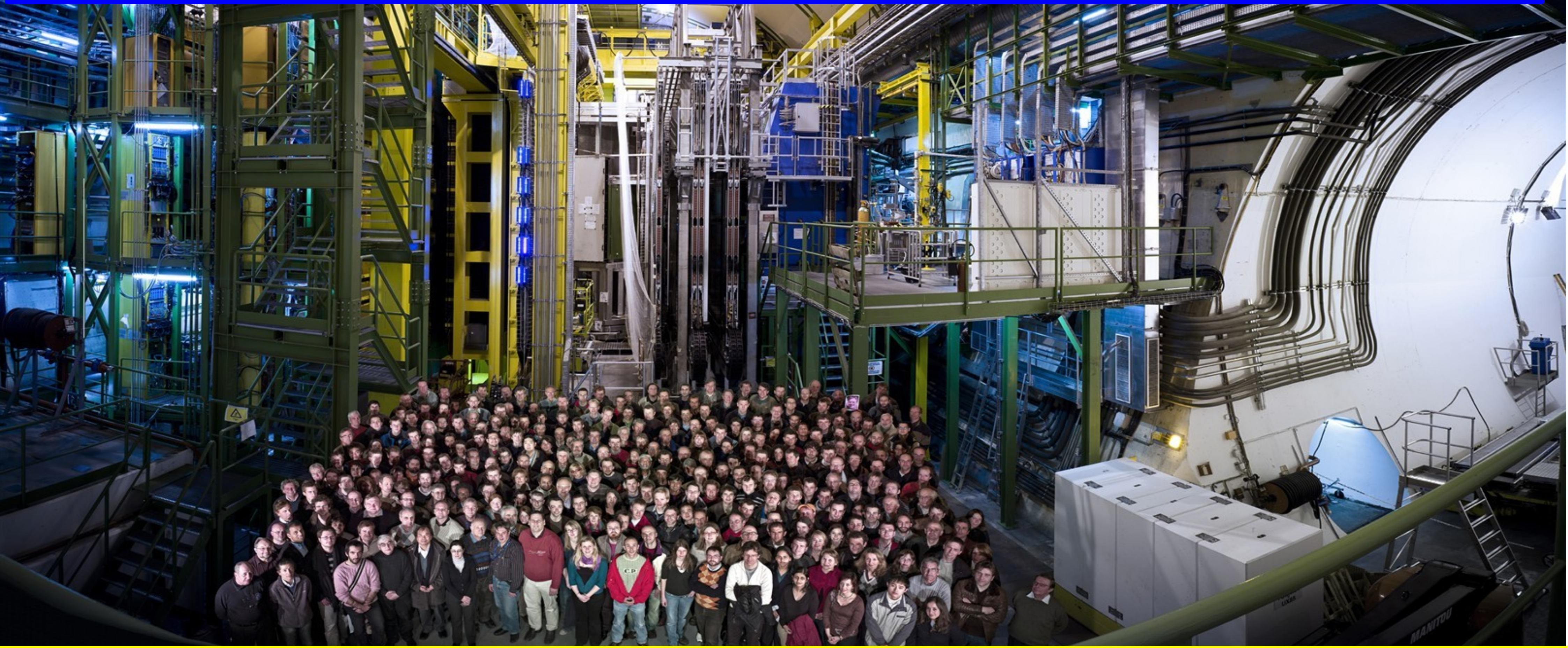
- *LHC: largest and most sophisticated scientific instrument ever built*
  → world's highest energy and beam intensity particle accelerator



- *Large Hadron Collider beauty experiment – one of the major projects at the LHC*

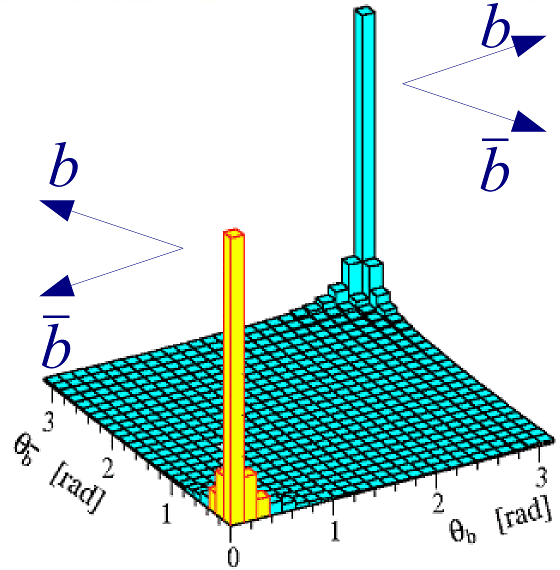
LHCb project history

- *Project conceived in 1994*
- *10 years of R&D: numerous test beam campaigns and MC simulations for every subcomponent*
- *2004-2008: detector production, installation and commissioning phase*
- *Collision data taking since 10/2009*
- *Manpower: 804 scientists from 55 institutes in 15 countries (as of 03/2012)*



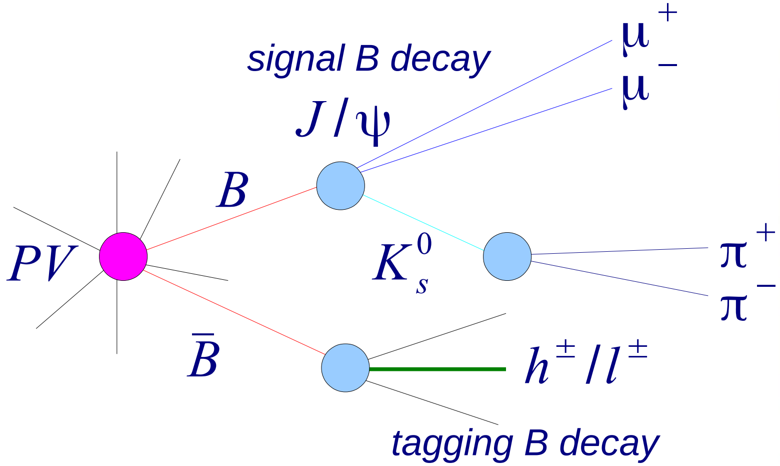
LHCb objectives

- *LHC delivers unprecedented amount of heavy flavor particles*
- *Great opportunity to perform high-precision measurements and study rare processes in the heavy flavor sector*
- *LHCb is mainly devoted to study the physics of the heaviest hadrons – beauty flavored ones*
- *CP violation in the B hadron sector: powerful test of the Standard Model (SM), which accommodates this phenomena but doesn't explain it*
- *New Physics may enter via contributions from virtual heavy particles in loop-mediated processes giving access to scales greater than the LHC centre-of-mass energy*
- *LHCb's major assignments:*
  - *→ measure processes strongly suppressed in SM and search for deviations from SM predictions – hints of the New Physics*
  - *→ improve measurements on CKM elements and overconstrain the unitarity triangles*
  - *→ study physics of FCNC via e.g.* $b \to s\gamma$ *transition*



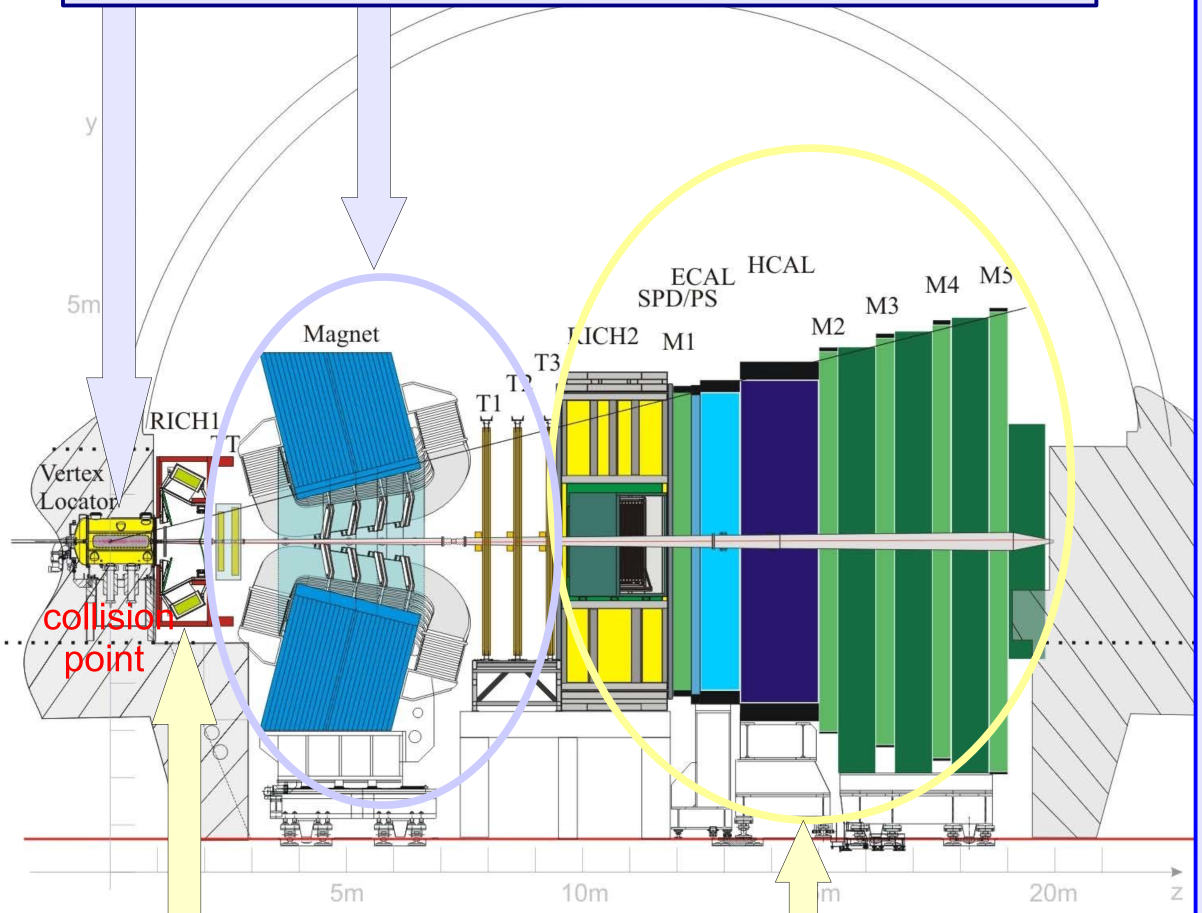
→ B hadrons at the LHC are mainly produced at low polar angles in the same forward cone

→ Typical topology:



=> *LHCb spectrometer: combination of tracking and PID detectors covering full acceptance*

Tracking detectors

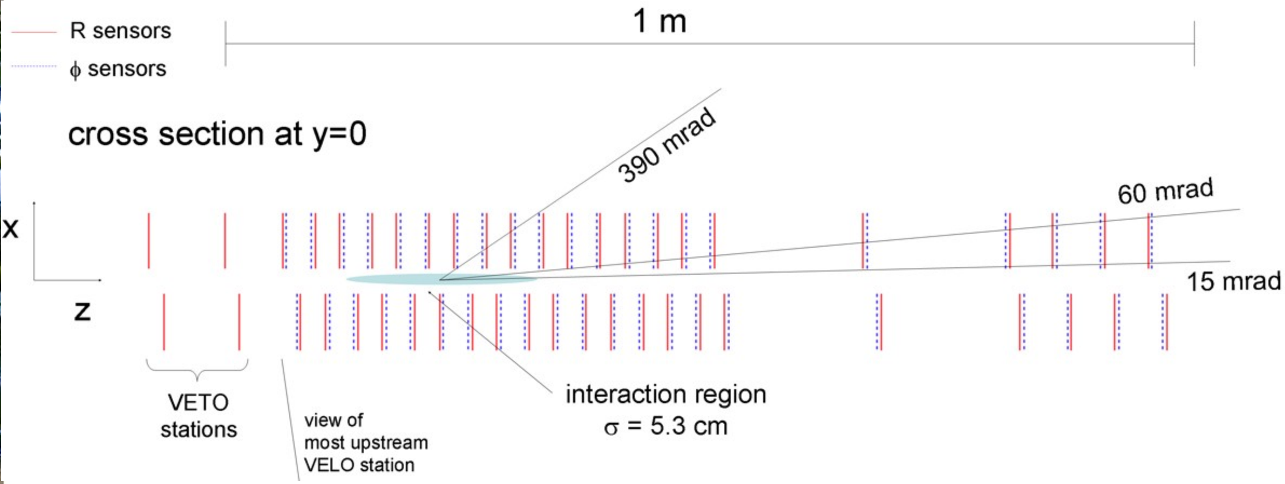


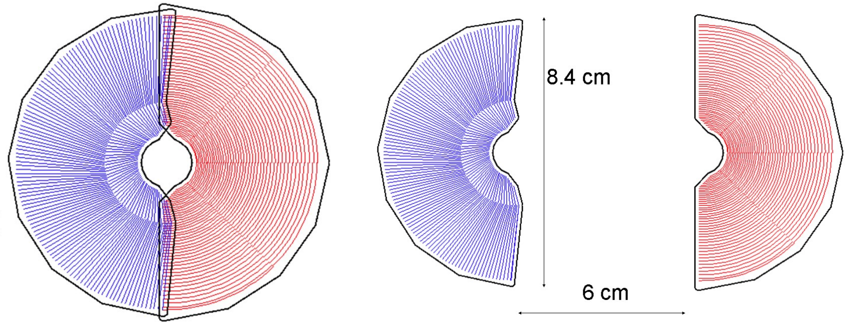
PID detectors

- *Forward spectrometer with planar detectors:* optimized for the forward peaked heavy quark production at the LHC
- *covers about 4% of the solid angle, but* captures around 40% of the heavy quark production cross-section
- *Detector acceptance:* $1.9<\eta<4.9$ fully covered by the tracking system → unique at the LHC
- *Size:* 10m high, 13m wide, 21m long
- *Weight:* ~5600 tons
- *Number of r/o channels:* ~10^6
- *Designed to run at a moderate luminosity:* large pile-up complicates identification of the B decay vertex and flavor tagging

Tracking system: VELO

- *reconstruction of the primary and decay vertices, track seeds + info for the trigger*
- *surrounds collision point being outside magnetic field, just 8 mm away from the beam line*
- *21 Si-strip stations measuring r and ϕ hit positions + 2 r-only stations*
- *largest angular coverage among LHCb subsystems*
- *detection coverage: $1.5<\eta<5.0$, $-4<\eta<-1.5$*
- *excellent performance during data taking*



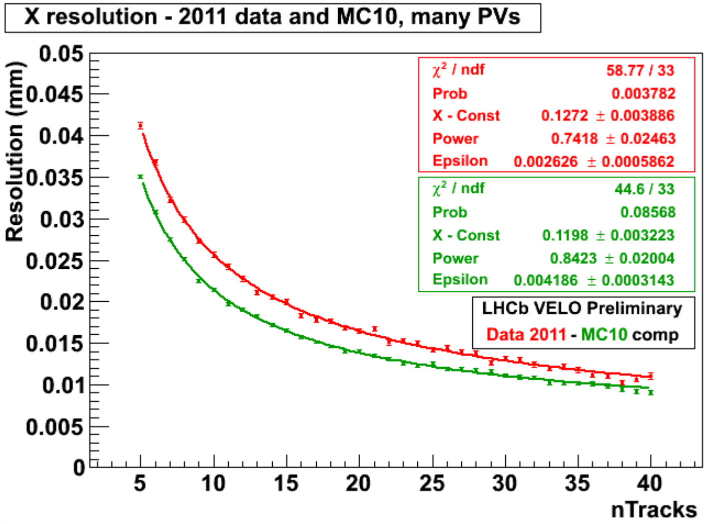


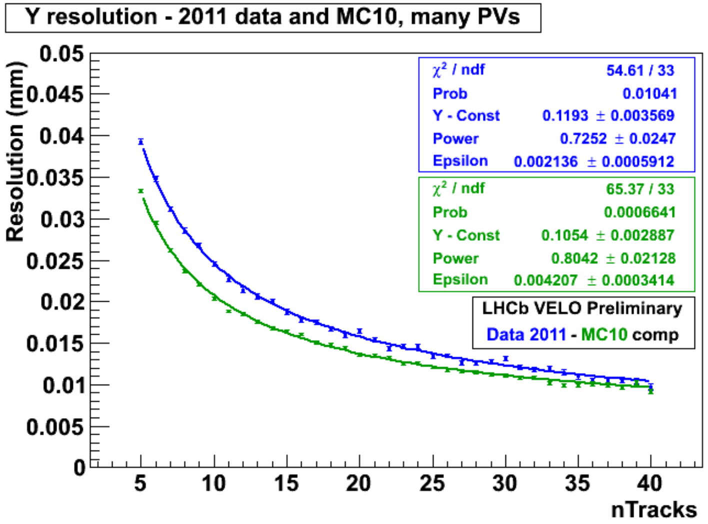
VELO fully closed (stable beam)

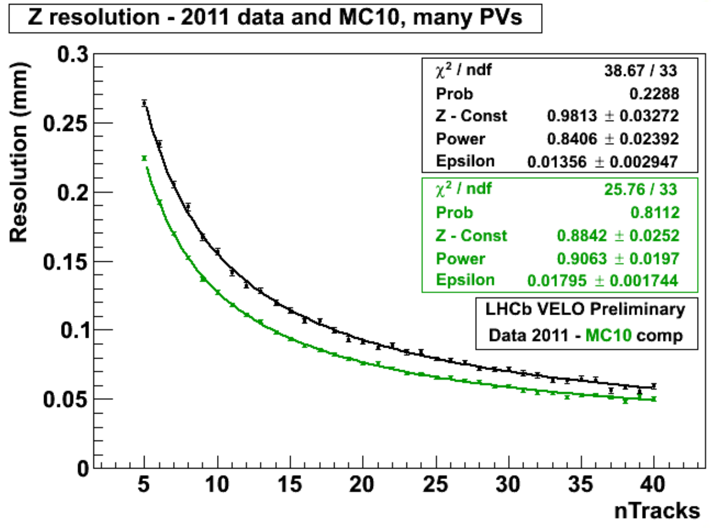
VELO fully open

VELO performance

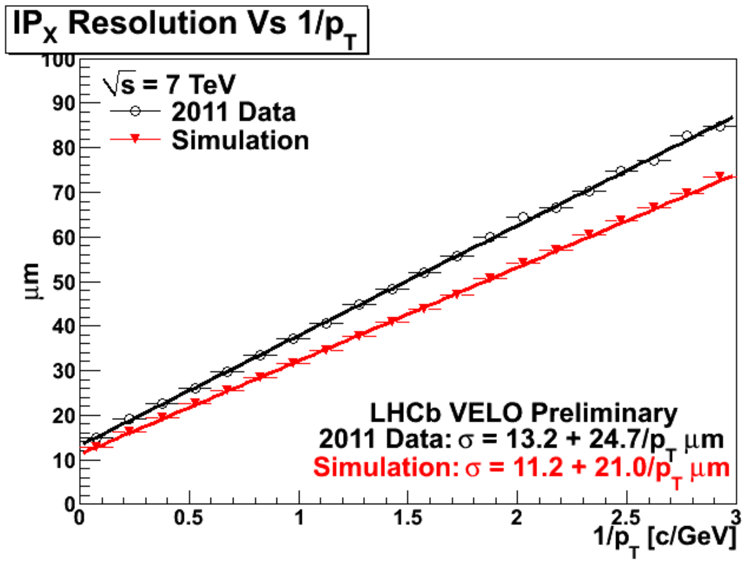
- *Primary Vertex resolution:*

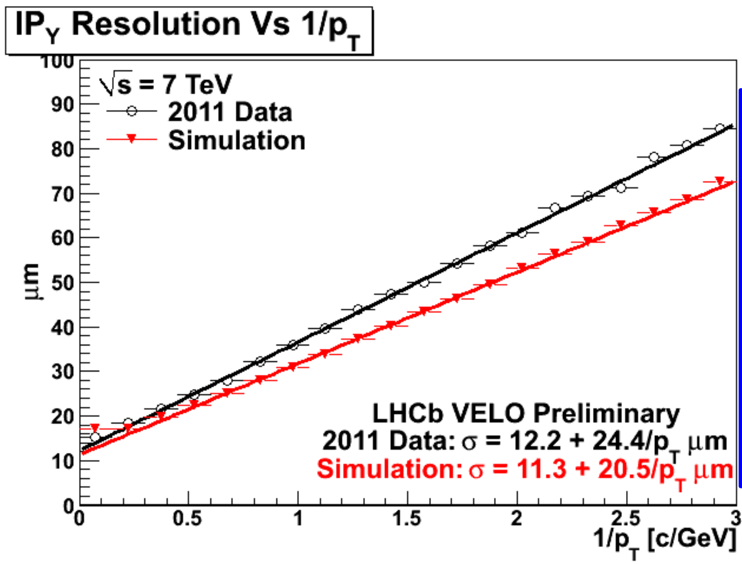






- *Impact-parameter resolution:*





- *single-hit resolution up to 4μm*
- *hit finding efficiency: >99.8%*
- *great IP resolution*
- *excellent primary+secondary vertex reconstruction: proper time resolution for B hadrons < 50 fs*

- *TT station:*

→ *4 layers of Si-Strip detectors in front of the magnet: ~150k r/o channels*

→ *adds momentum information and helps to reconstruct the decay products of long-lived particles*

→ *hit resolution ~ 62 μm*

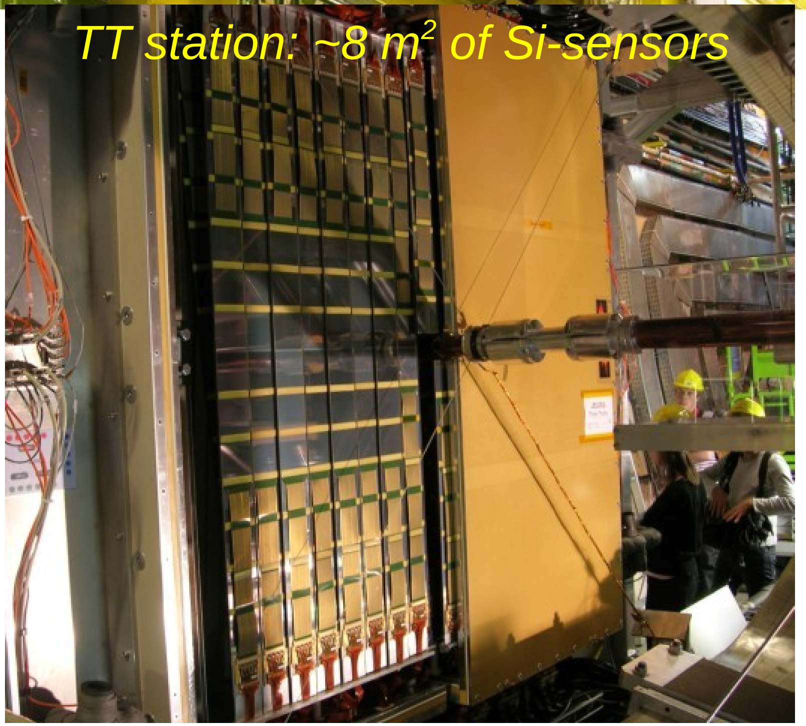
- *Magnet :*

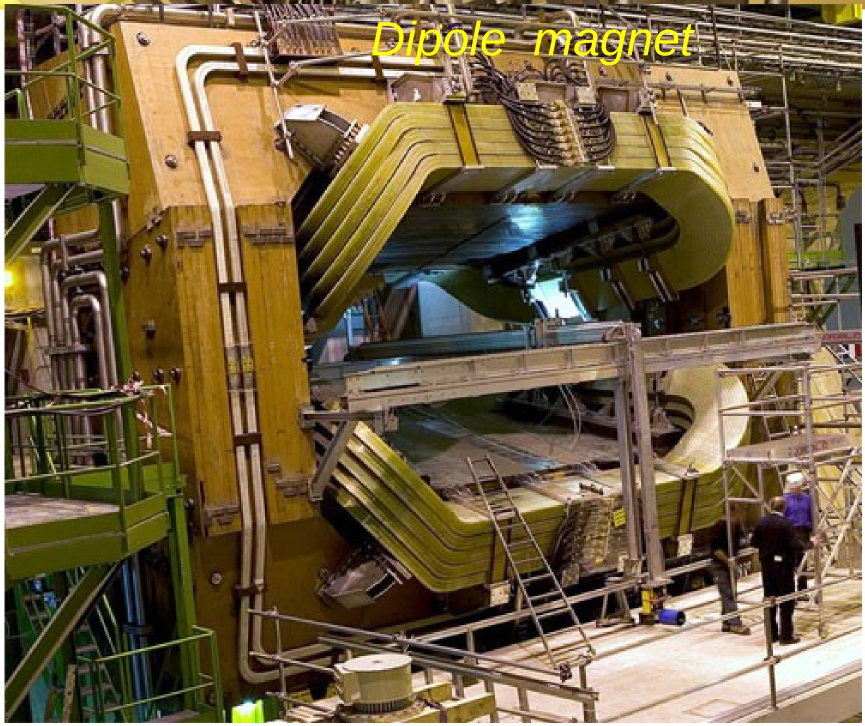
→ *essential component for track momentum measurements*

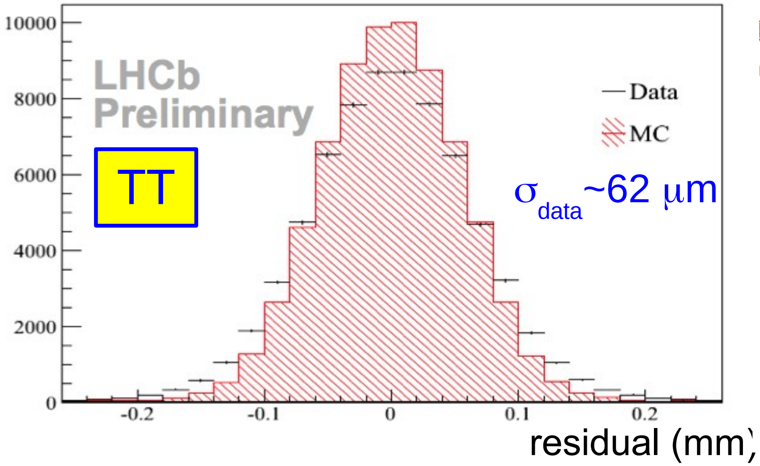
→ *its aperture defines the detector's acceptance*

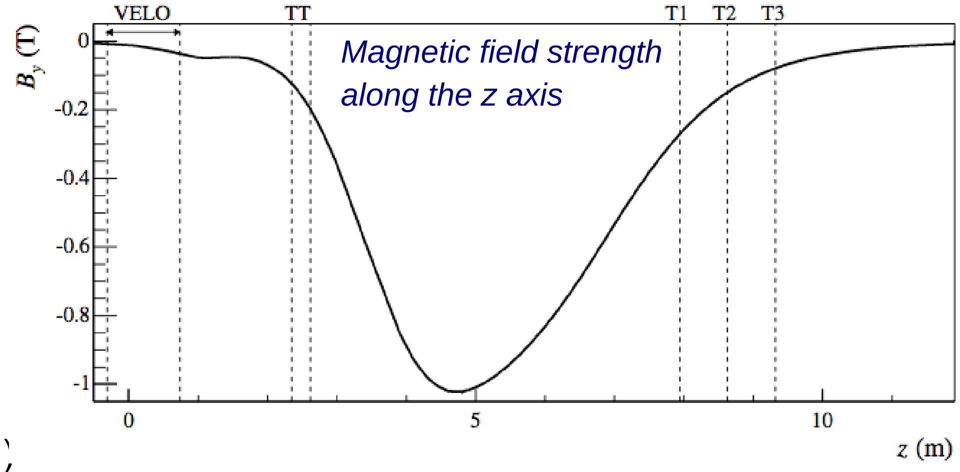
→ *bending power:*

$$\int Bdl = 4.2\, T \times m$$









Tracking system: T stations

- *T1 – T3 stations:*

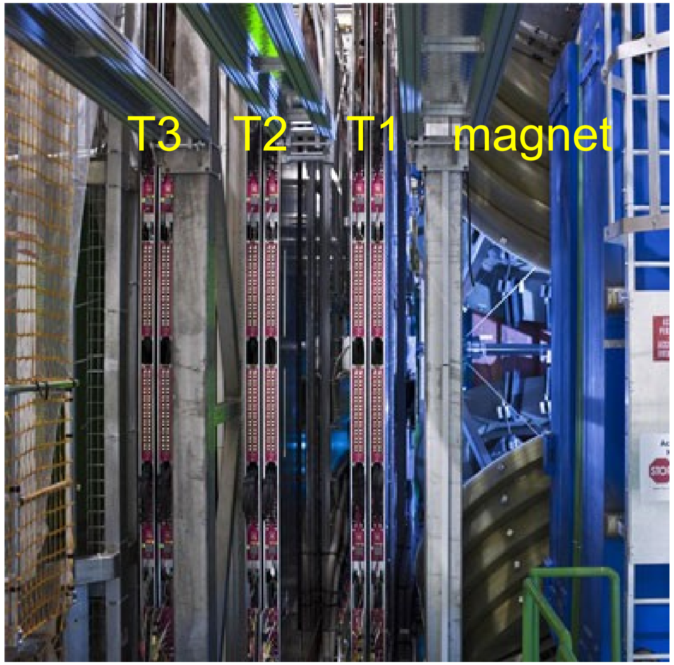
→ *each consists of 4 layers split into the Inner and Outer Trackers (IT/OT)*

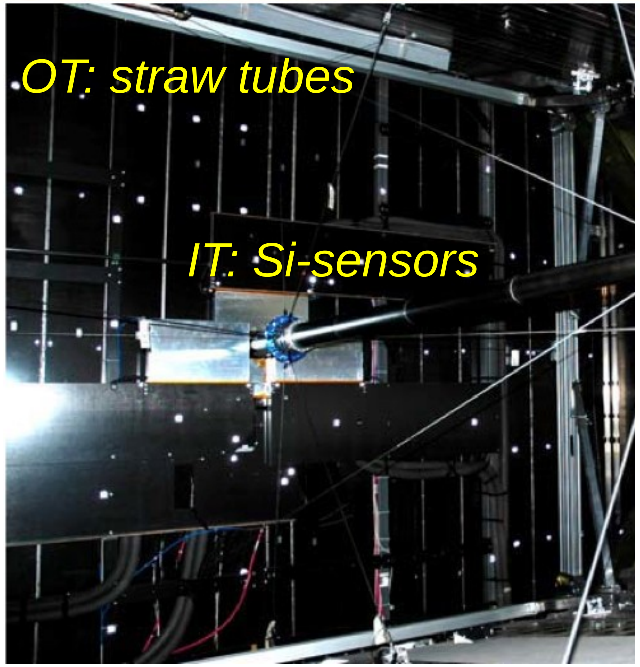
→ *IT: ~1.3% of the station sensitive area but 25% of all tracks pass through it*

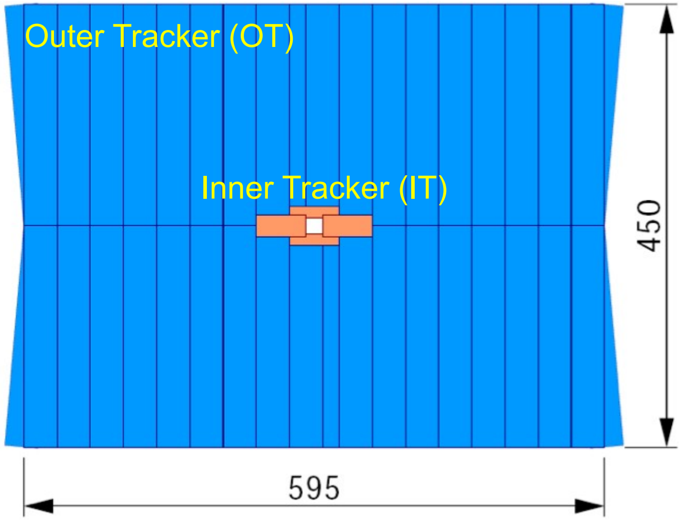
→ *deflection of the tracks at T1-T3 stations is used to measure their momenta*

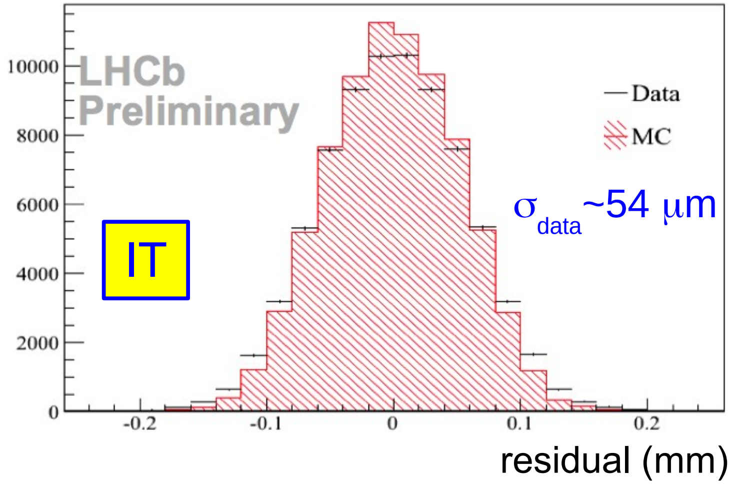
→ *IT hit resolution:* ~ 54 μm
OT hit resolution: ~ 270 μm

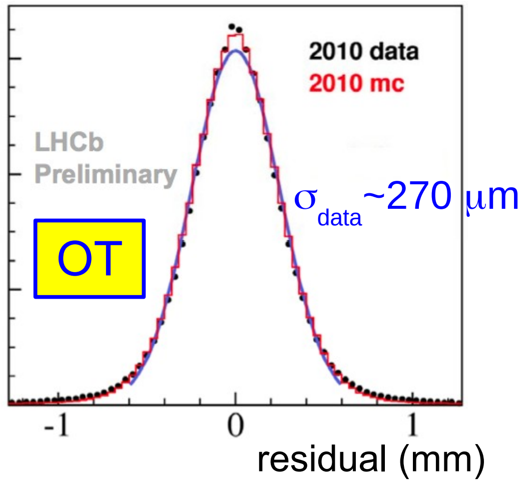
→ *good spatial hit resolution = accurate measurement of the track coordinates*



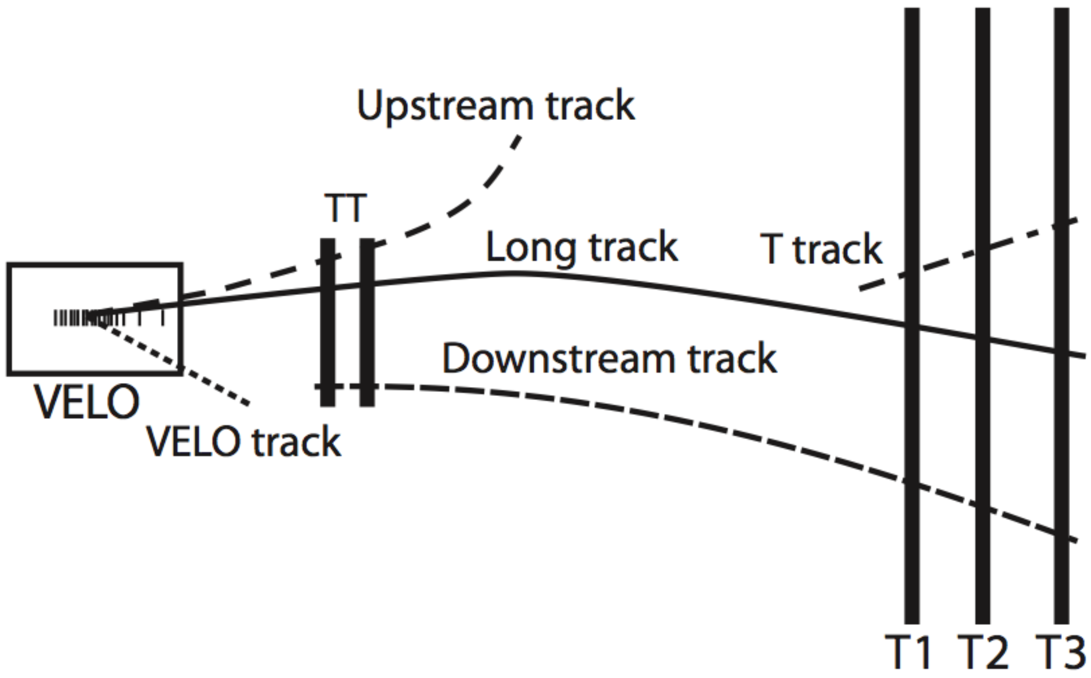








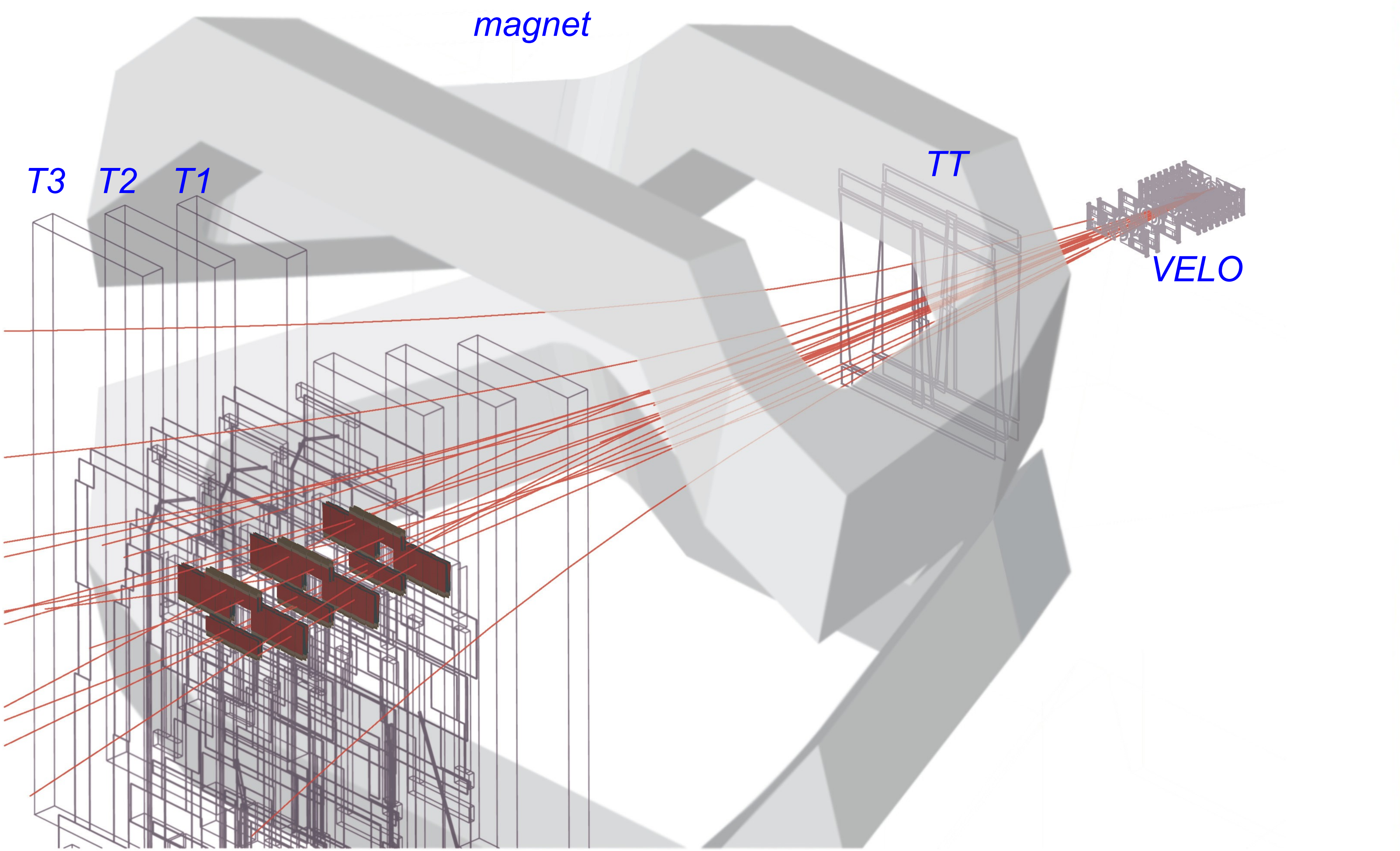
Track categories



- *Long tracks: high-momentum tracks traversing the full LHCb tracking setup*
  - *→ measured with the highest possible precision*
  - *→ most useful for physics analysis*
  - *→ most numerous in the main LHCb acceptance*
- *VELO tracks: large-angle or backward tracks, used for the primary vertex reconstruction*
- *Upstream tracks: low-momentum tracks which are swept away by the magnetic field*
- *Downstream tracks: typically the decay products of long-lived particles (e.g. K_s^0 and Λ) which decay outside the VELO acceptance*
- *T tracks: products of secondary interactions*

Long Tracks

=> *Long track reconstruction: combing VELO track seeds with the T track segments + adding TT hits*



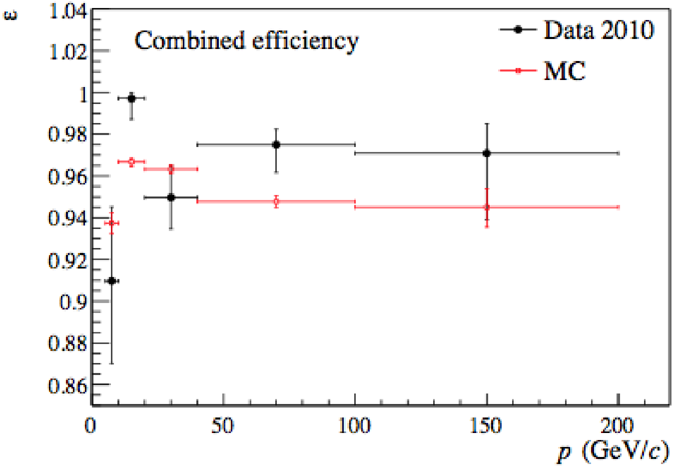
Tracking performance

Phys. Lett. B 708 (2012) 241-248

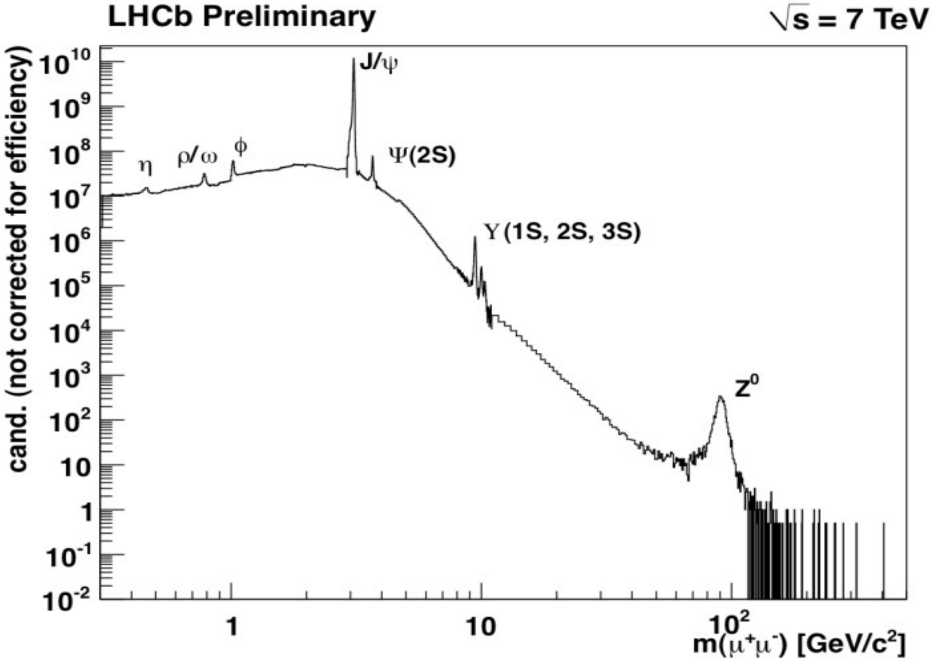
Quantity	LHCb measurement	Best previous measurement	PDG fit
$M(B^+)$	5279.38 ± 0.35	5279.10 ± 0.55	5279.17 ± 0.29
$M(B^0)$	5279.58 ± 0.32	5279.63 ± 0.62	5279.50 ± 0.30
$M(B_s^0)$	5366.90 ± 0.36	5366.01 ± 0.80	5366.3 ± 0.6
$M(\Lambda_b^0)$	5619.19 ± 0.76	5619.7 ± 1.7	–
$M(B^0) - M(B^+)$	0.20 ± 0.20	0.33 ± 0.06	0.33 ± 0.06
$M(B_s^0) - M(B^+)$	87.52 ± 0.32		
$M(\Lambda_b^0) - M(B^+)$	339.81 ± 0.72		

world's best measurements (done with just 2010 data!)

CERN-LHCb-PUB-2011-025

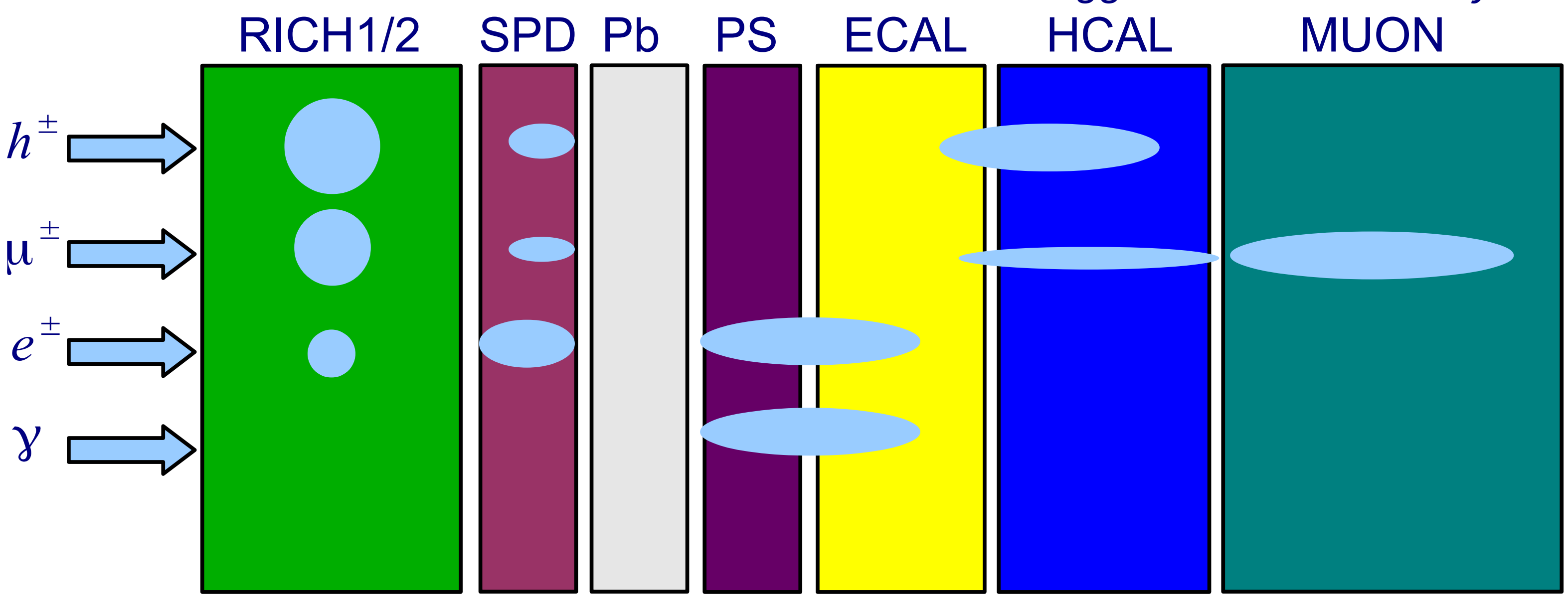


- *Excellent momentum resolution:*
  - → $\delta p/p$ ~ 0.35-0.55% depending on p
  - → *invariant mass resolution of B hadrons ~ 7-20 MeV depending on the decay mode*
  - → *rejection of combinatorial background*
- *Great track finding efficiency*
- *Rigorous suppression of multiply reconstructed (clones) and spurious long tracks (ghosts)*



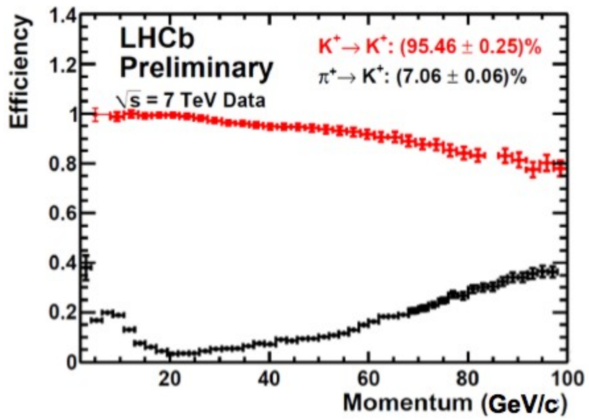
LHCb particle identification

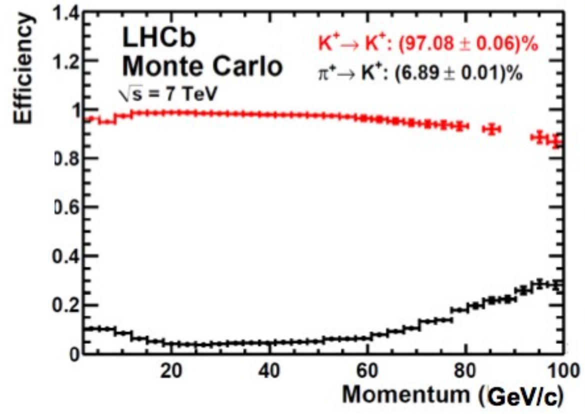
- *RICH system:*
  - → *efficient hadron ID over the wide momentum range*
  - → *unique at the LHC*
- *Scintillator Pad Detector (SPD) and Preshower (PS):*
  - → *robust e/γ and e/hadron separation*
  - → *single layer scintillator tiles separated by Pb sheet 2.5 X_0 in depth*
- *ECAL:*
  - → *e and γ energy measurement*
  - → *widely used in the offline analysis (e.g. $B^0 \to K^* \gamma$, $B_s^0 \to \phi\gamma$, $B^0 \to \pi^+\pi^-\pi^0$)*
  - → *trigger on electromagnetic decay channels*
- *HCAL:*
  - → *energy measurement for hadrons*
  - → *trigger on hadronic decay channels*
- *Muon stations: μ identification (multi-wire-proportional chambers) trigger on muonic decay channels*

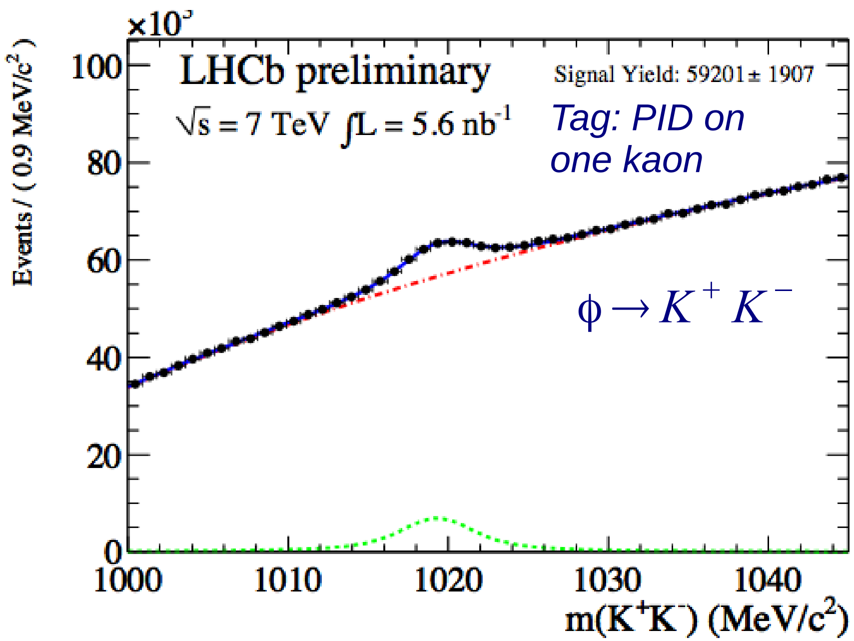


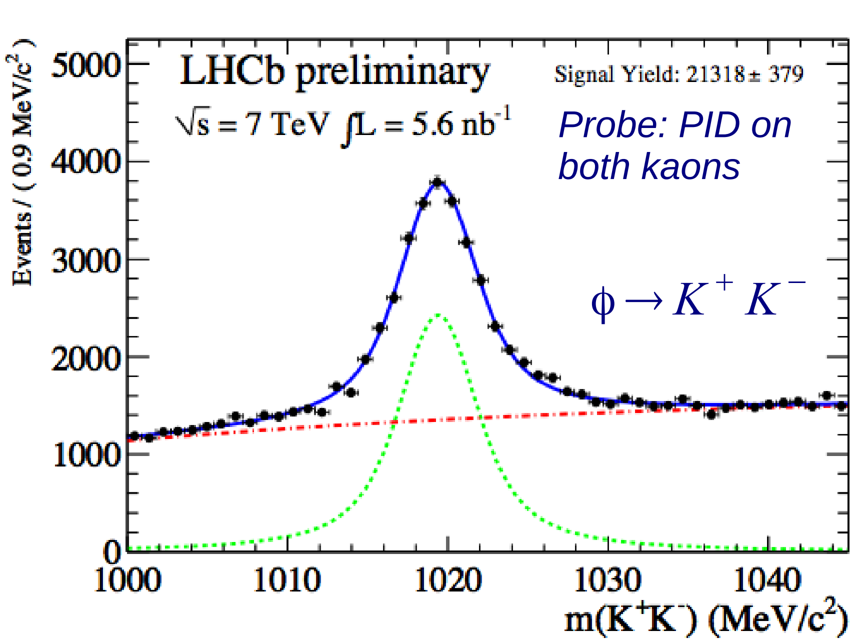
RICH system

- *Two RICH detectors with 3 radiators :*
  - → *efficient* K/π *separation for p=1–100 GeV/c range*
  - → *crucial for flavor tagging and separation of B decays with identical topology:* $B^0 \to K^{\pm}\pi^{\mp}$, $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$
  - → *efficiencies and mis-ID in data: tag-and-probe method*
  - → *performance is close to MC over the full momentum range*

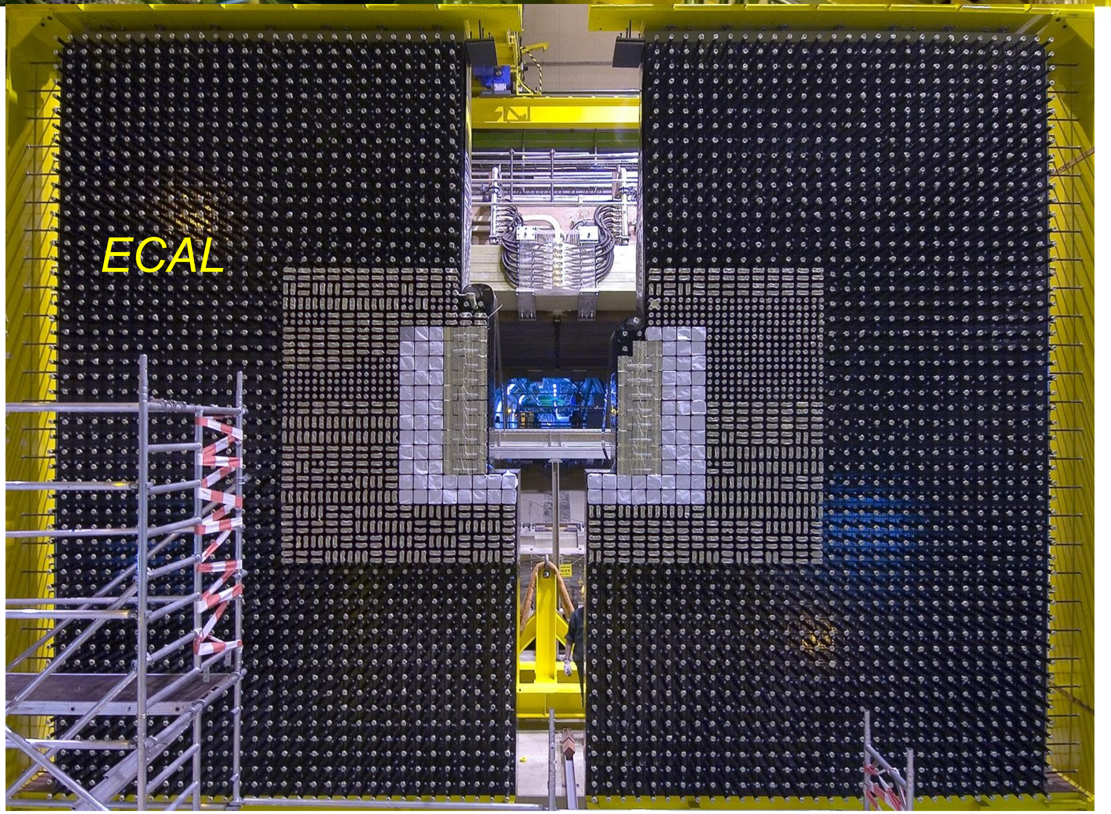








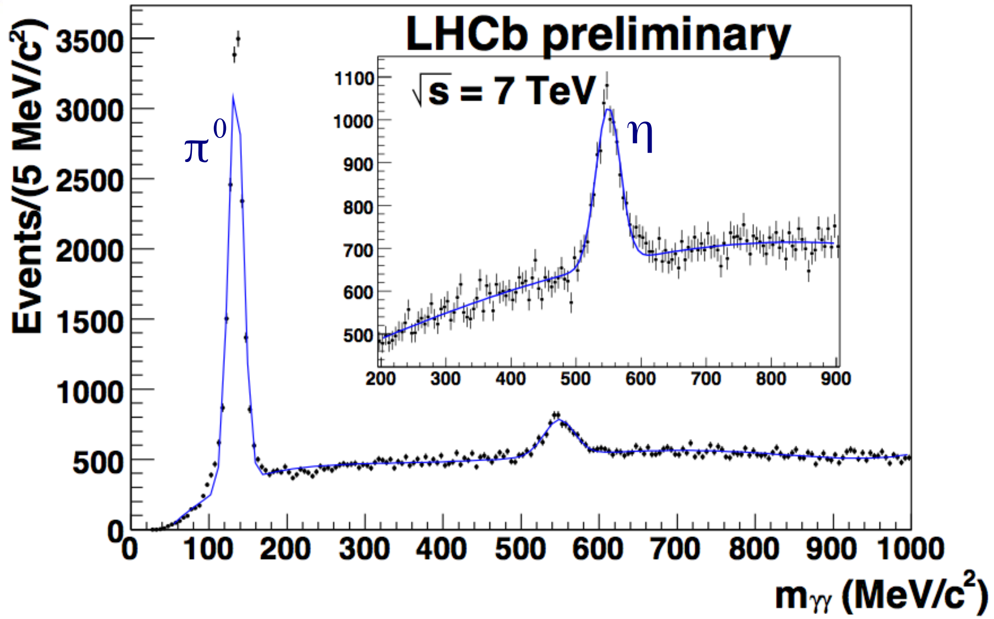
Calorimetry

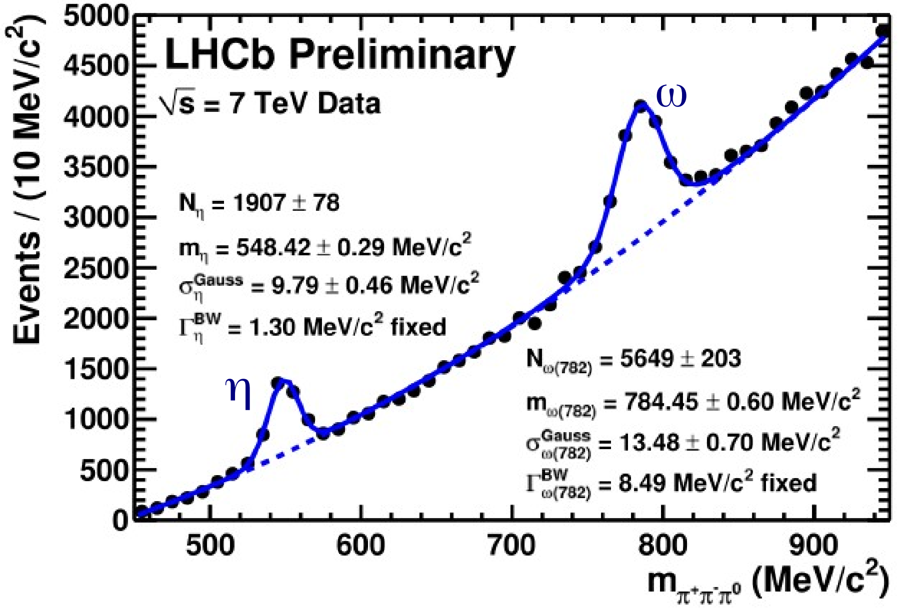


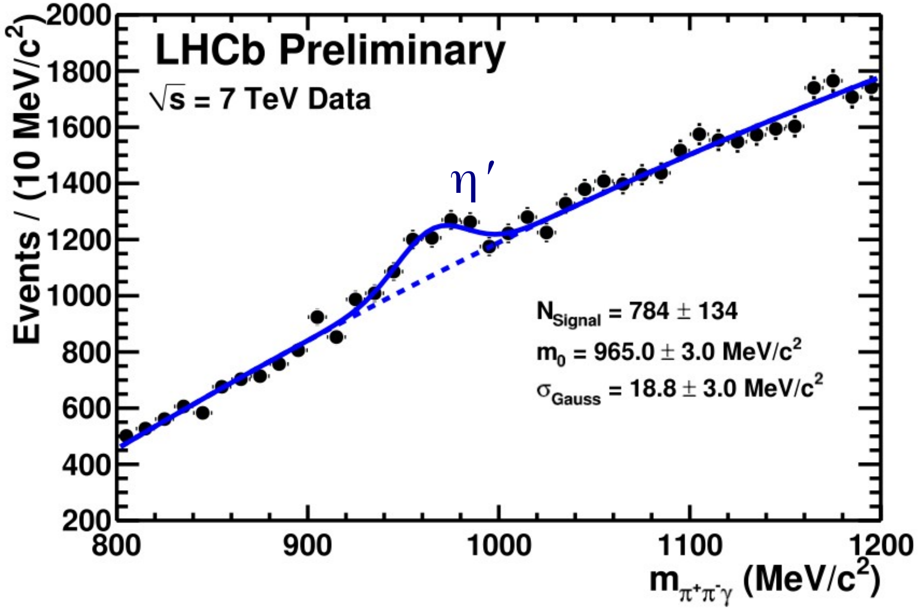
- ECAL: *Pb plates/scintillator tiles oriented perpendicularly to the beam axis*
  - → *central 30 mrad cut-out for the beam pipe*
  - → *3 different transverse segmentations*
  - → *depth: 25 X_0 and 1.1λ_I*
  - → $\sigma(E)/E = \frac{10\%}{\sqrt{E}} + 1\%$

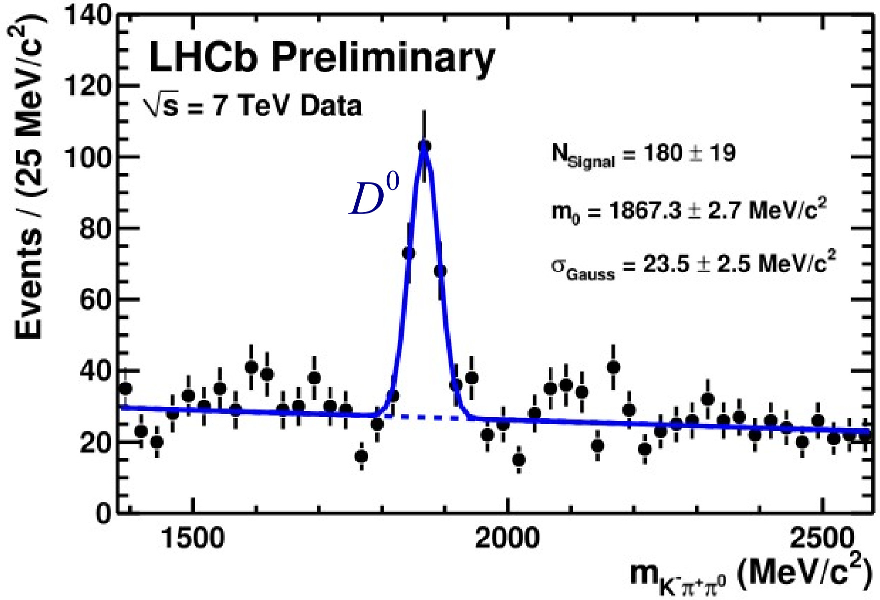
- HCAL: *Fe plates/scintillator tiles arranged parallel to the beam axis*
  - → *central 30 mrad cut-out for the beam pipe*
  - → *2 different transverse segmentations*
  - → *depth: and 5.6λ_I*
  - → $\sigma(E)/E = \frac{69\%}{\sqrt{E}} + 9\%$ *moderate but well enough for trigger purposes*

ECAL performance

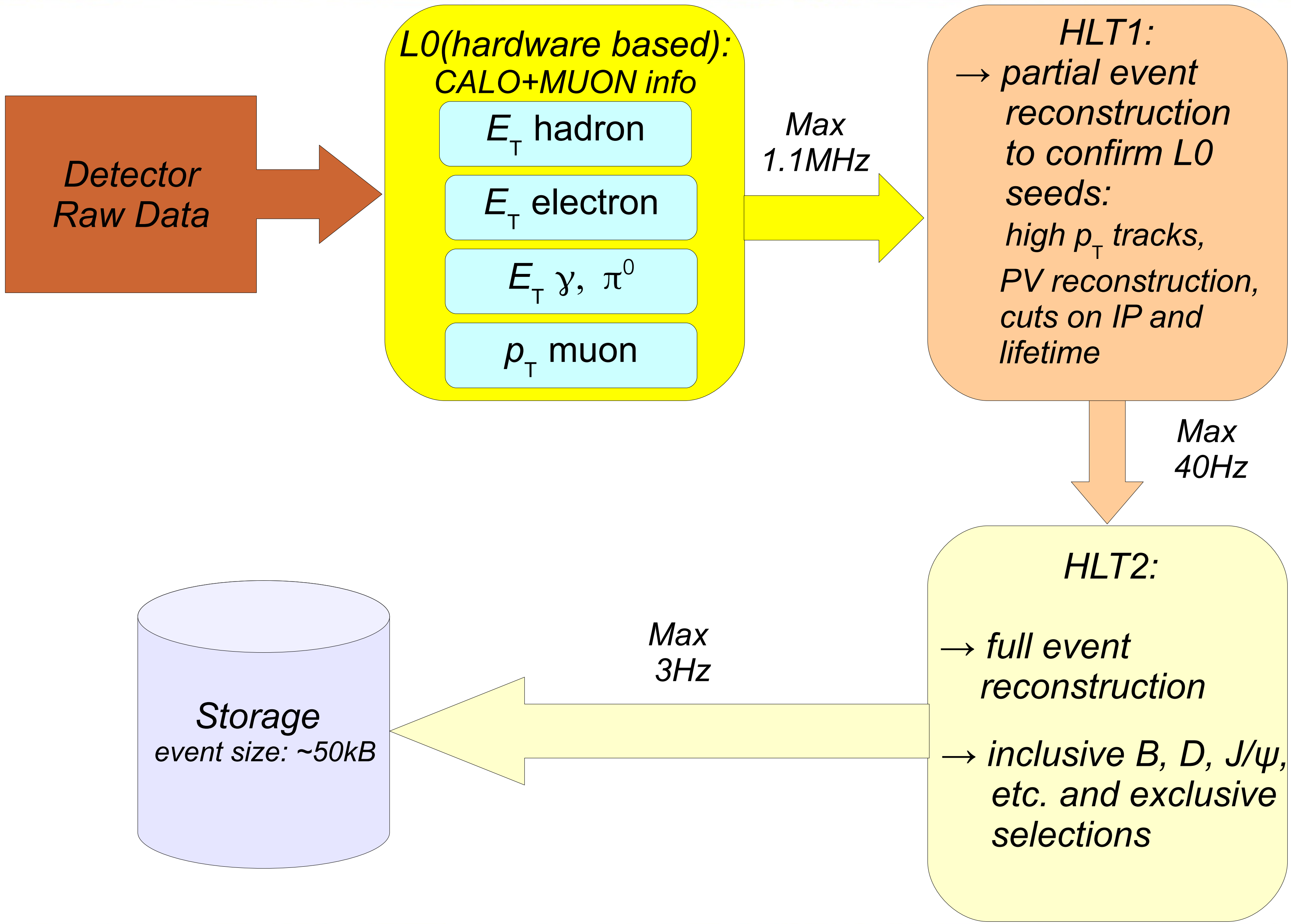




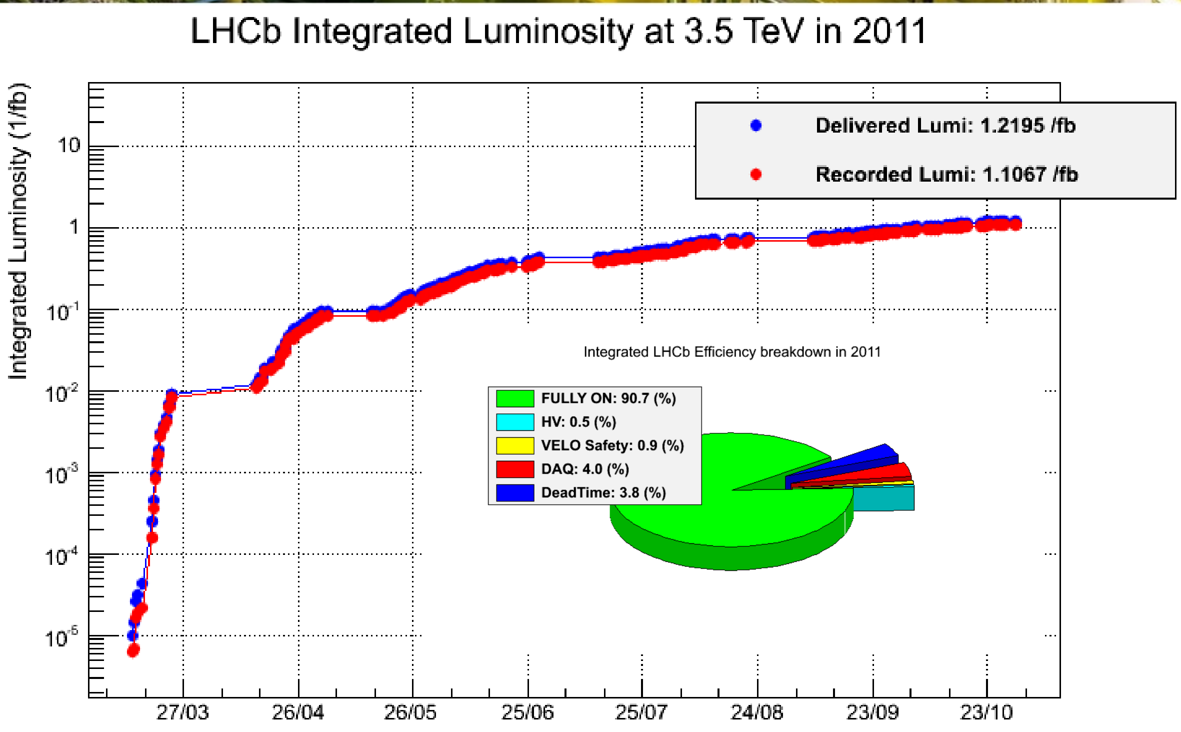




Trigger System

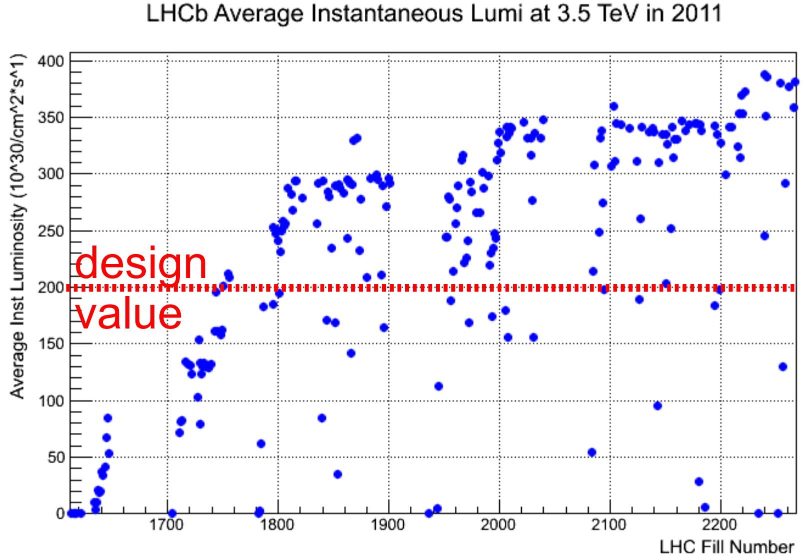


Data taking in 2009–2011



year	luminosity	energy (TeV)
2009	6.8 μb^{-1}	0.9
2010	0.3 nb^{-1}	0.9
2010	37 pb^{-1}	7
2011	0.1 pb^{-1}	2.76
2011	1.1 fb^{-1}	7

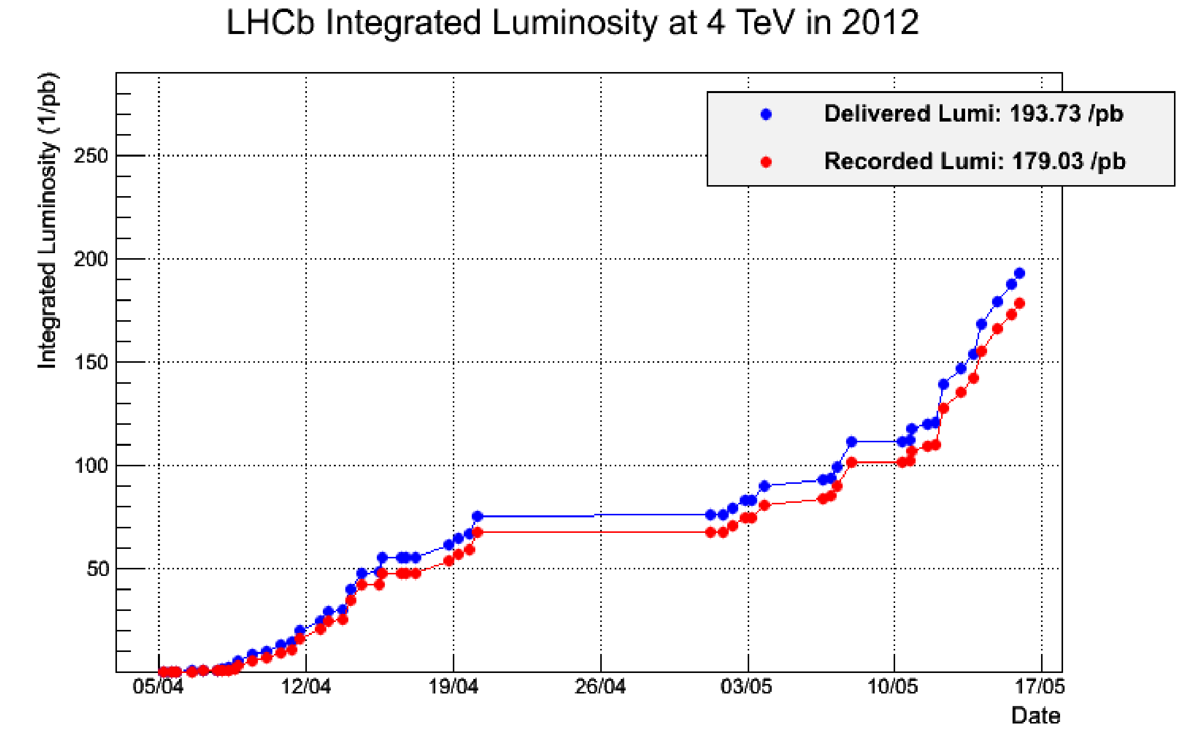
- *Good quality of recorded data:*
  - -> >95% of r/o channels are operational
- *Data taking efficiency in 2011: 91%*
  - -> *DAQ issues: major source of inefficiency*

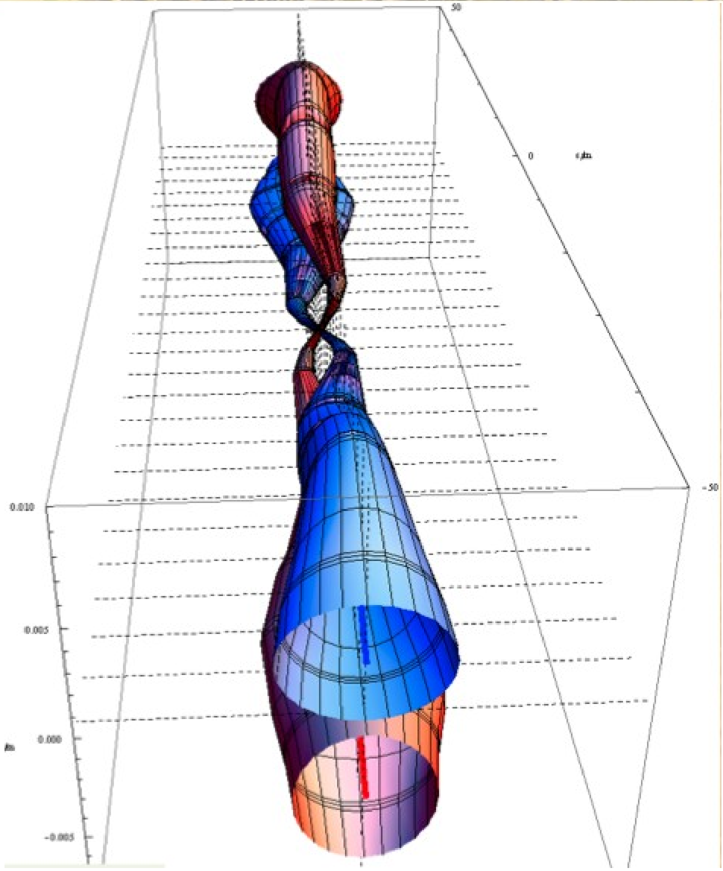


=> Running challenges:

- *Luminosities up to 3.9× 10^{32} cm^{-2} s^{-1} were achieved in 2011*
- *LHCb design luminosity: 2.0 × 10^{32} cm^{-2} s^{-1}*
- *Strong challenge for the trigger, offline reconstruction and data processing*
- *LHCb successfully copes with these extreme running conditions*

Data taking in 2012





=> 2012 running conditions:

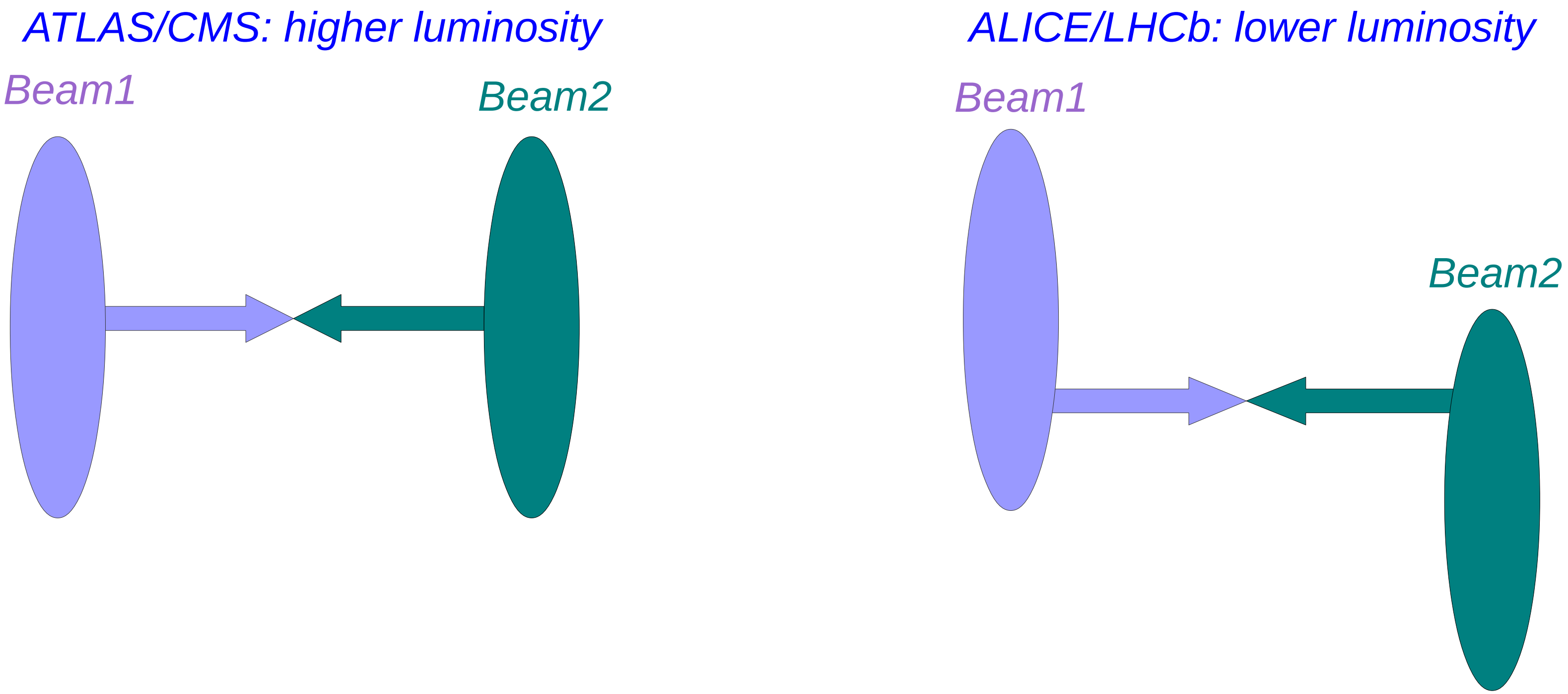
- *pp collisions at a centre-of-mass energy of 8 TeV*
  → *15% increase of the $b\bar{b}$ cross-section w.r.t. 7 TeV*
- *luminosities up to 4 × 10^{32} cm^{-2} s^{-1}*
- *average pile-up: ~2*
- *bunch spacing 50 ns*
- *1.5 fb^{-1} is expected to be collected by the end of 2012*

- *Instead of horizontal separation of the beams, in 2012 they are tilted vertically at the LHCb interaction point:*
  → *vertical separation+horizontal compensation=tilted crossing plane*

Luminosity leveling

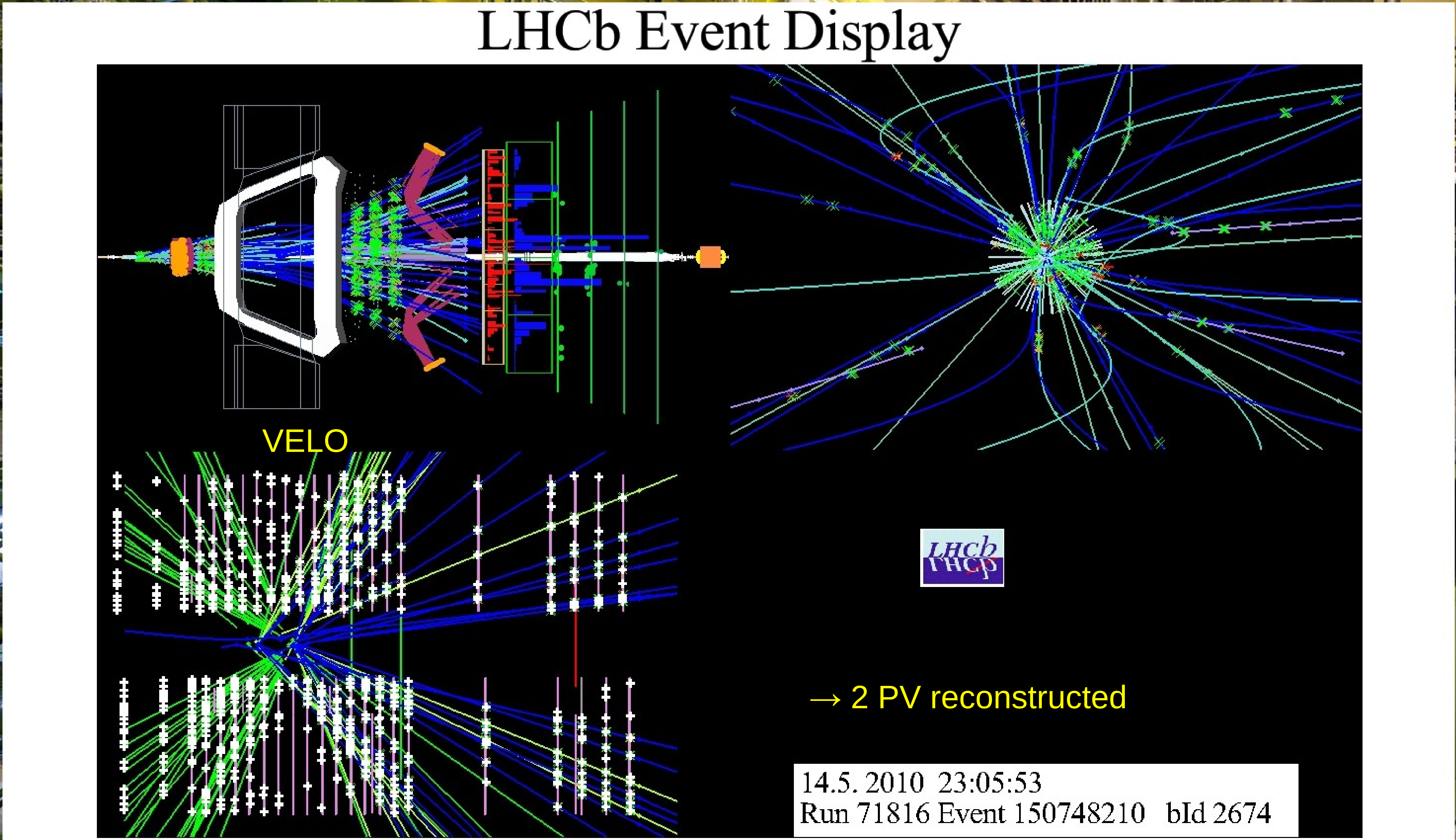
- As more proton bunches are injected, no way to moderate the instantaneous luminosity at LHCb and ALICE by limiting the number of colliding bunches

- Solution: luminosity leveling – reduces the area of interactions where the bunches pass through each other

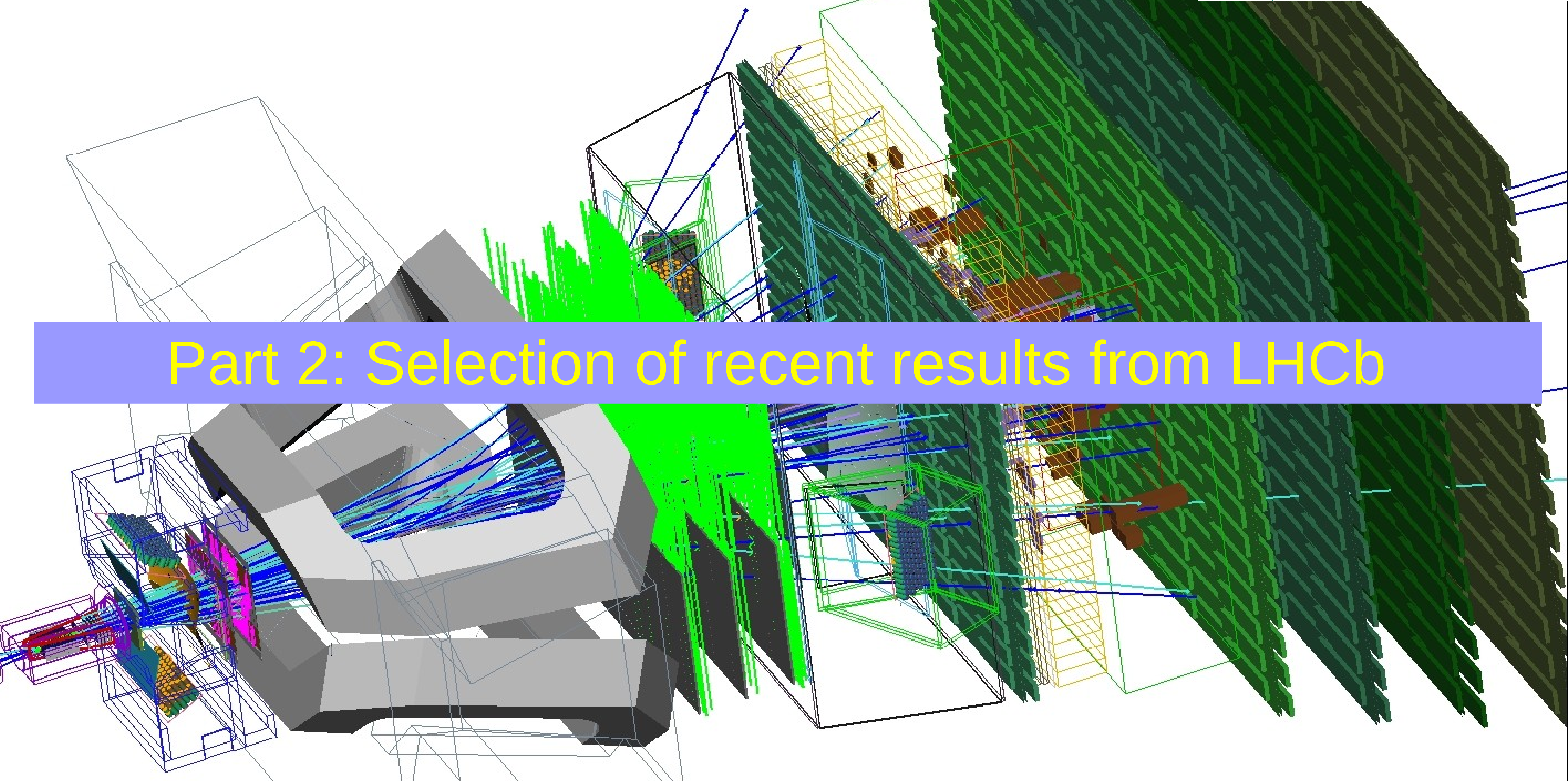


- Offset between the beams reduces the amount of interactions

- LHC continuously displaces both beams w.r.t. each other: instantaneous luminosity at a roughly constant value for the whole duration of a fill


LHCb Event Display
VELO
→ 2 PV reconstructed
14.5. 2010 23:05:53
Run 71816 Event 150748210 bId 2674

Part 2: Selection of recent results from LHCb



LHCb Physics Program

=> Rare B decays:
- Radiative, leptonic, electroweak, hadronic decays
- SM forbidden transitions

=> B decays to charmonium:
- B mixing parameters
- CP violation measurements

=> B decays to open charm:
- CKM γ angle from $B \to DK$
- B decays to double charm

=> Charmless B decays:
- $B \to hh$, $B \to VV$

=> Semileptonic B decays:
- Form factors and search for CP violation in mixing

=> Charm physics:
- production and spectroscopy
- CP violation and mixing
- Rare charm decays

=> B hadrons and quarkonia:
- Production and spectroscopy of B hadrons and quarkonia

=> QCD, electroweak and exotica:
- Soft and hard QCD processes
- Particle production (incl. Electroweak bosons)
- PDF
- exotic long-lived particles

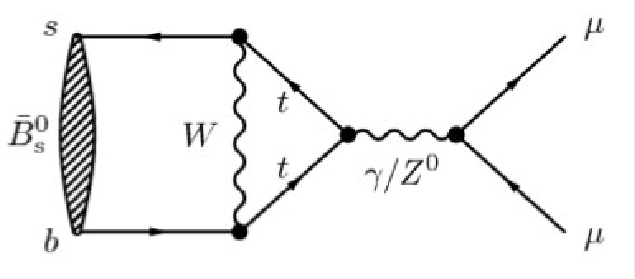
In this talk, recent results on:
- Rare decays: $B_s^0 \to \mu^+\mu^-$, $B^0 \to K^* \mu^+\mu^-$
- Bs mixing
- CP violation measurements
- Production W and Z bosons
- Energy Flow

are presented

$B^0_{d,s} \to \mu^+ \mu^-$ Analysis (1)

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

- *FCNC decays strongly suppressed in SM:*



$$SM : BR(B^0_s \to \mu^+ \mu^-) = (3.20 \pm 0.20) \times 10^{-9}$$
$$SM : BR(B^0_d \to \mu^+ \mu^-) = (0.10 \pm 0.01) \times 10^{-9}$$

→ can be significantly enhanced by New Physics
(SUSY models with non-universal Higgs masses and models with leptoquarks)

→ sensitive test of SM

→ previous upper limits:

$$BR(B^0_s \to \mu^+ \mu^-) < 1.4 \times 10^{-8} \quad BR(B^0_d \to \mu^+ \mu^-) < 3.2 \times 10^{-9}$$

- *Recent searches with $1 fb^{-1}$ @ 7 TeV*
- *Selection with MVA Boosted Decision Tree:*
  - *→ 6 variables: kinematic information*
  - *→ retains 92% of the signal, while removing 80% of the residual background*

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

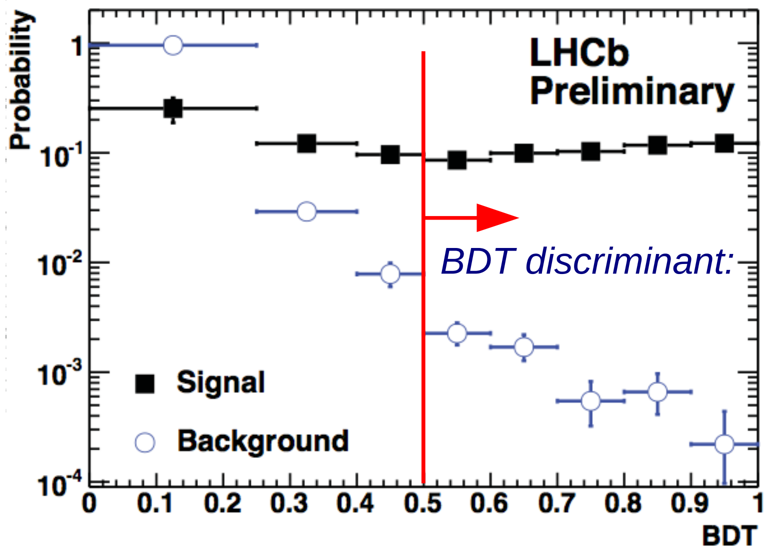
LHCb-PAPER-2012-007
CERN-PH-EP-2012-072
April 27, 2012

arXiv:1203.4493v2 [hep-ex] 26 Apr 2012

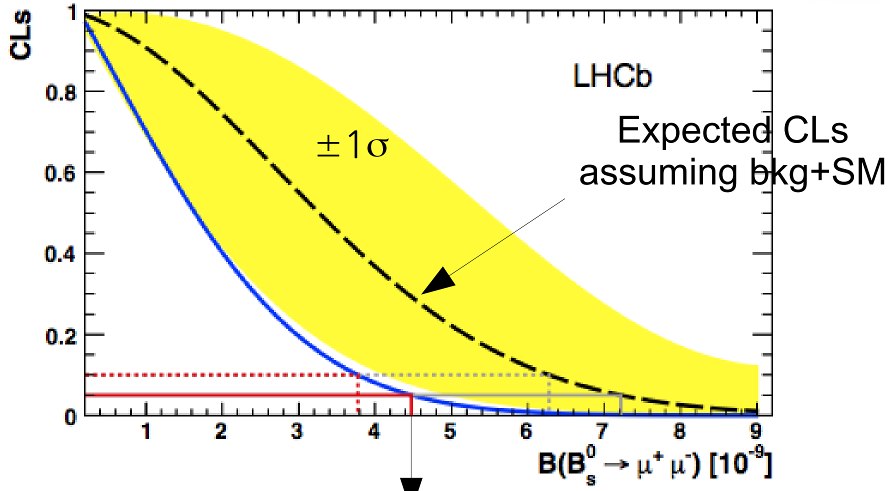
Strong constraints on the rare decays $B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$

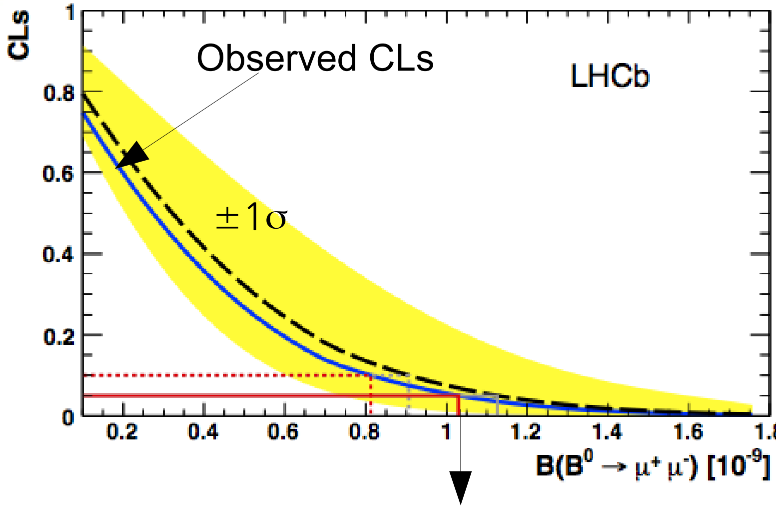
The LHCb collaboration

R. Aaij[38], C. Abellan Beteta[33,n], A. Adametz[11], B. Adeva[34], M. Adinolfi[43], C. Adrover[6], A. Affolder[49], Z. Ajaltouni[5], J. Albrecht[35], F. Alessio[35], M. Alexander[48], S. Ali[38], G. Alkhazov[27], P. Alvarez Cartelle[34], A.A. Alves Jr[22], S. Amato[2], Y. Amhis[36], J. Anderson[37], R.B. Appleby[51], O. Aquines Gutierrez[10], F. Archilli[18,35], A. Artamonov[32], M. Artuso[53,35], E. Aslanides[6], G. Auriemma[22,m], S. Bachmann[11], J.J. Back[45], V. Balagura[28,35], W. Baldini[16], R.J. Barlow[51], C. Barschel[35], S. Barsuk[7], W. Barter[44], A. Bates[48], C. Bauer[10], Th. Bauer[38], A. Bay[36], J. Beddow[48], I. Bediaga[1], S. Belogurov[28], K. Belous[32], I. Belyaev[28], E. Ben-Haim[8], M. Benayoun[8], G. Bencivenni[18], S. Benson[47], J. Benton[43], R. Bernet[37], M.-O. Bettler[17], M. van Beuzekom[38], A. Bien[11], S. Bifani[12], T. Bird[51], A. Bizzeti[17,h], P.M. Bjørnstad[51], T. Blake[35], F. Blanc[36], C. Blanks[50], J. Blouw[11], S. Blusk[53], A. Bobrov[31], V. Bocci[22], A. Bondar[31], N. Bondar[27], W. Bonivento[15], S. Borghi[48,51], A. Borgia[53], T.J.V. Bowcock[49], C. Bozzi[16], T. Brambach[9], J. van den Brand[39], J. Bressieux[36], D. Brett[51], M. Britsch[10], T. Britton[53], N.H. Brook[43], H. Brown[49], A. Büchler-Germann[37], I. Burducea[26], A. Bursche[37], J. Buytaert[35], S. Cadeddu[15], O. Callot[7], M. Calvi[20,j], M. Calvo Gomez[33,n], A. Camboni[33], P. Campana[18,35], A. Carbone[14], G. Carboni[21,k], R. Cardinale[19,i,35], A. Cardini[15], L. Carson[50], K. Carvalho Akiba[2], G. Casse[49], M. Cattaneo[35], Ch. Cauet[9], M. Charles[52], Ph. Charpentier[35], N. Chiapolini[37], M. Chrzaszcz[23], K. Ciba[35], X. Cid Vidal[34], G. Ciezarek[50], P.E.L. Clarke[47], M. Clemencic[35], H.V. Cliff[44], J. Closier[35], C. Coca[26], V. Coco[38], J. Cogan[6], E. Cogneras[5], P. Collins[35], A. Comerma-Montells[33], A. Contu[52], A. Cook[43], M. Coombes[43], G. Corti[35], B. Couturier[35], G.A. Cowan[36], R. Currie[47], C. D'Ambrosio[35], P. David[8], P.N.Y. David[38], I. De Bonis[4], K. De Bruyn[38], S. De Capua[21,k], M. De Cian[37], J.M. De Miranda[1], L. De Paula[2], P. De Simone[18], D. Decamp[4], M. Deckenhoff[9], H. Degaudenzi[36,35], L. Del Buono[8], ...



$B^0_{d,s} \to \mu^+\mu^-$ Analysis (2)





$BR < 4.5 \times 10^{-9}$ @ 95% CL → *getting closer to SM value* $BR < 1.0 \times 10^{-9}$ @ 95% CL

Status as of May 2012 at 95% CL:

experiment	*L_{int}*	$BR(B^0_s \to \mu^+\mu^-)$	$BR(B^0_d \to \mu^+\mu^-)$	*reference*
CMS	5 fb^{-1}	$<7.7\times10^{-9}$	$<1.8\times10^{-9}$	arXiv:1203.3976v1
LHCb	1 fb^{-1}	$<4.5\times10^{-9}$	$<1.0\times10^{-9}$	arXiv:1203.4493v2

- *LHCb with 5 times less data gets better results and sets world's best upper limits !*
- *LHCb results impose strong constraints on SUSY models*
- *With 2.5 fb^{-1} (end of 2012) we should see SM signal at 3 sigma (if it exists...)*

$B_d^0 \to K^* \mu^+ \mu^-$ Analysis (1)

- *b → s FCNC decay mediated by electroweak loop-diagrams*

→ high sensitivity to New Physics: new particles may enter in loop diagrams significantly affecting

- *Observables of interest:*

→ A_{FB}: lepton forward-backward asymmetry of a muon in the rest frame of B

→ F_L : fraction of the longitudinal polarization of the K meson*

→ Differential BF

→ all the variables are studied vs $q^2=M^2(\mu\mu)$

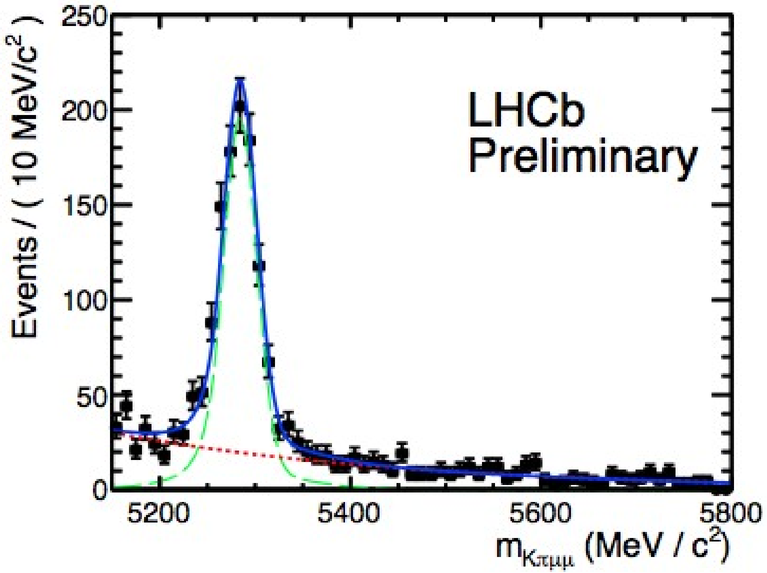
- *analysis performed with 1fb^{-1} @ 7 TeV*

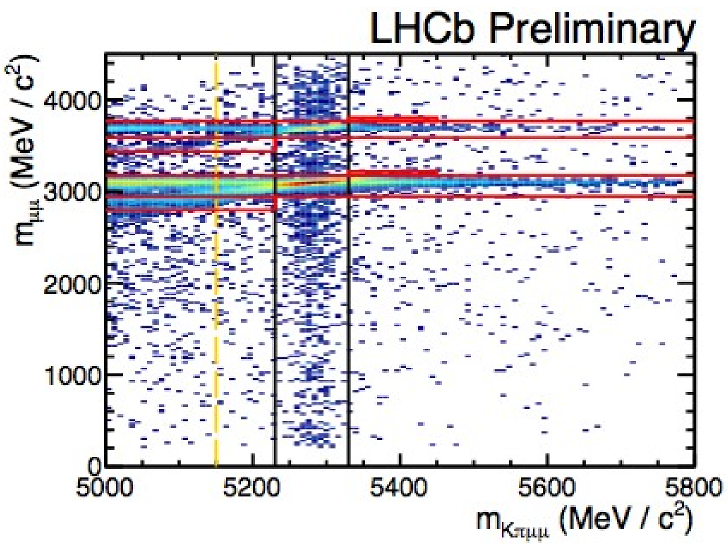
- *Selection with MVA Boosted Decision Tree*

→ rejection of J/ψ and $\psi(2S)$ resonances

→ kinematic + PID information

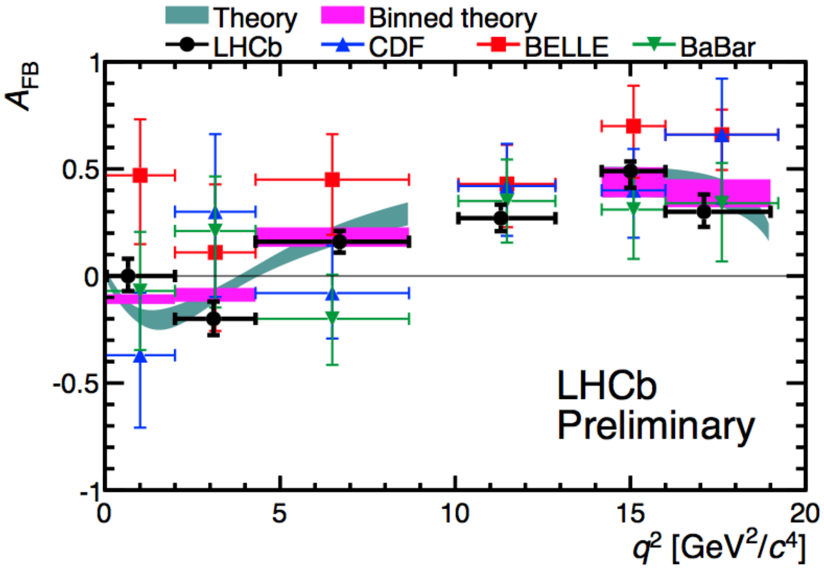
CERN-LHCb-CONF-2012-008

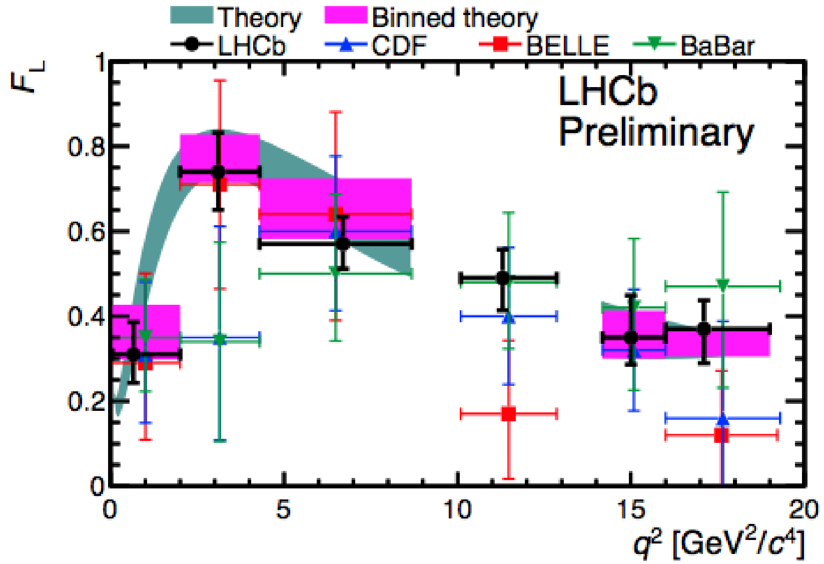




$B_d^0 \to K^* \mu^+ \mu^-$ Analysis (2)

- *Much more precise measurement of the observables than by the previous experiments*
- *Results are in good agreement with SM predictions*





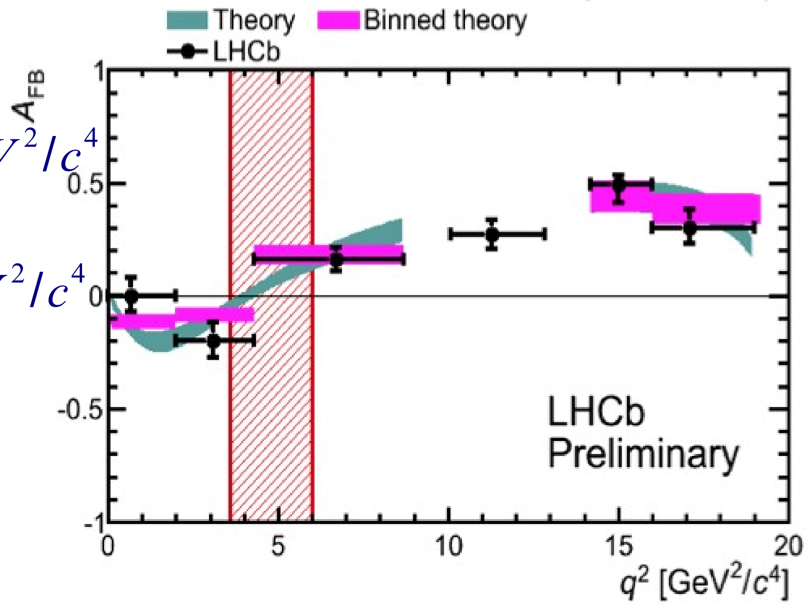
- *First measurement:*

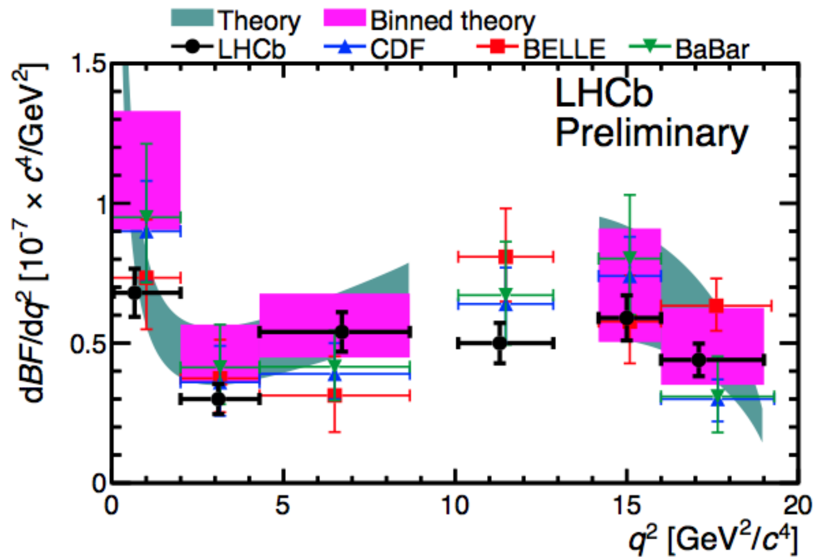
$$q^2(A_{FB}=0)=4.9^{+1.1}_{-1.3}\,GeV^2/c^4$$

SM prediction:

$$q^2(A_{FB}=0)=4-4.3\,GeV^2/c^4$$

- *more statistics is needed*





Prompt reaction

- *Immediate feedback from theoreticians on latest LHCb results for these rare decays:*

CERN-PH-TH/2012-120

arXiv:1205.1845v1 [hep-ph] 8 May 2012

Supersymmetric constraints from $B_s \to \mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ observables

F. Mahmoudi[1,2]*, S. Neshatpour[2]† and J. Orloff[2]‡

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CH-1211 Geneva 23, Switzerland

[2] *Clermont Université, Université Blaise Pascal, CNRS/IN2P3,*
LPC, BP 10448, 63000 Clermont-Ferrand, France

Abstract

We study the implications of the recent LHCb limit and results on $B_s \to \mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ observables in the constrained SUSY scenarios. After discussing the Standard Model predictions and carefully estimating the theoretical errors, we show the constraining power of these observables in CMSSM and NUHM. The latest limit on $\mathrm{BR}(B_s \to \mu^+\mu^-)$, being very close to the SM prediction, constrains strongly the large $\tan\beta$ regime and we show that the various angular observables from $B \to K^*\mu^+\mu^-$ decay can provide complementary information in particular for moderate $\tan\beta$ values.

- *SUSY with large $\tan\beta$ is practically excluded*

Some first observations of rare decays

- *Two excited Λ_b^0 baryons*

→ arXiv: 1205.3452v1 [hep-ex] 15 May 2012

$$M_{\Lambda_b^{*0}(5912)} = 5911.95 \pm 0.12 \pm 0.03 \pm 0.66\,\mathrm{MeV}/c^2,$$
$$M_{\Lambda_b^{*0}(5920)} = 5919.76 \pm 0.07 \pm 0.02 \pm 0.66\,\mathrm{MeV}/c^2,$$

- $B_c^+ \to J/\psi \pi^+ \pi^- \pi^+$ *decay*

→ arXiv: 1204.0079v1 [hep-ex] 31 Mar 2012

- *Cabibbo suppressed decays:*

$B_d^0 \to D^- K^+ \pi^+ \pi^-$ $\quad B^- \to D^0 K^- \pi^+ \pi^-$

→ arXiv: 1201.4402v1 [hep-ex] 20 Jan 2012

→ last one is sensitive to the CKM angle γ

- $B_s^0 \to K^* \bar{K}^*$ *decay:*

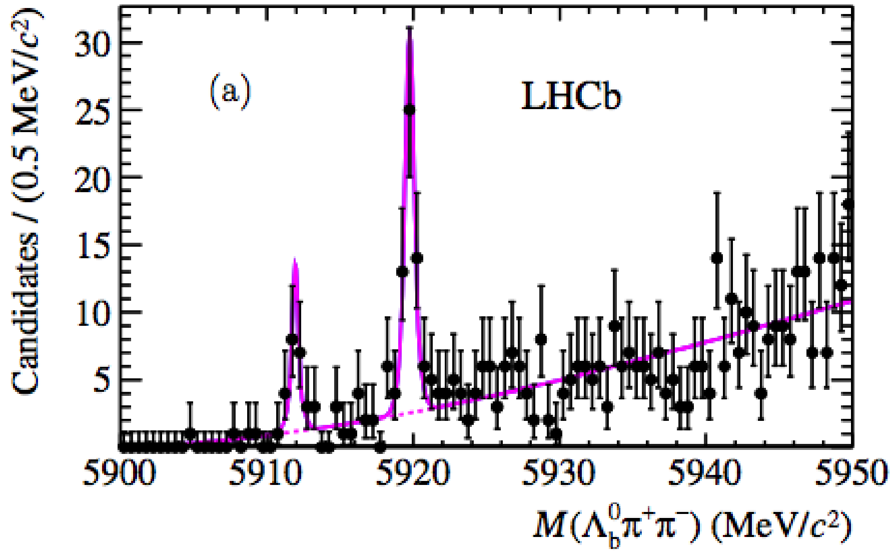
→ arXiv:1111.4183v3 [hep-ex] 9 Feb 2012

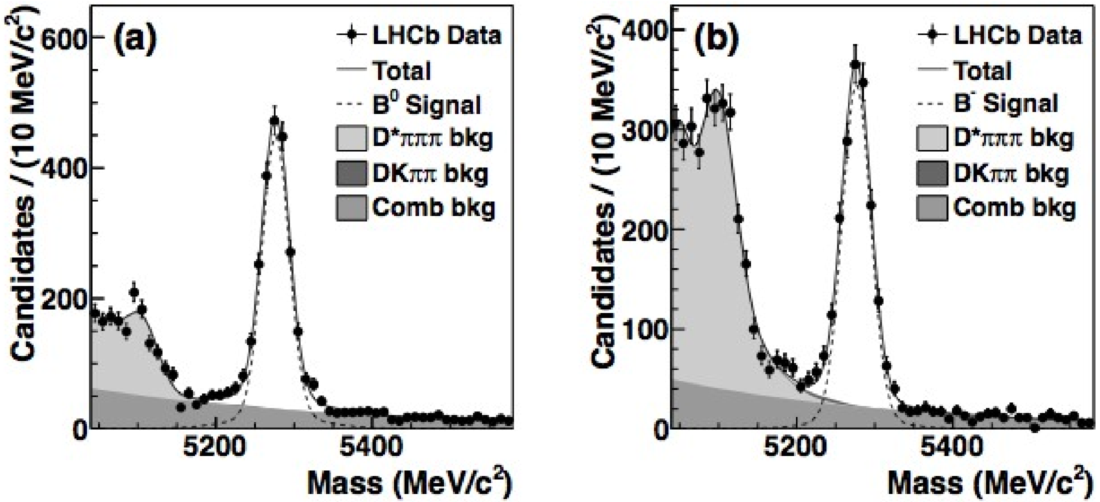
- $B_s^0 \to D^0 K^*$ *decay:*

→ arXiv: 1110.3676v3 [hep-ex] 15 Nov 2011

- $B_s^0 \to J/\psi f_0(980)$ *decay:*

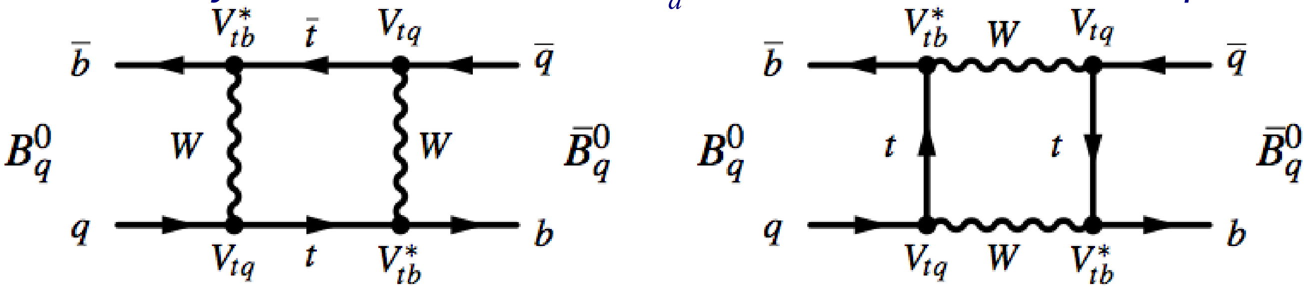
→ arXiv: 1102.0206v2 [hep-ex] 2 Mar 2011





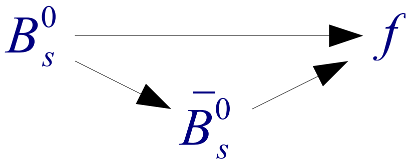
B_s^0 mixing (1)

- *One of the most interesting properties of neutral B mesons:*
  - → *discovered in the* B_d^0 *sector by ARGUS in 1987*
  - → B_s^0 *oscillations were firstly studied at Tevatron,* B_d^0 *sector was much better explored*



$q \in [d, s]$

- *Important parameters:*
  - → ΔM_q *and* $\Delta\Gamma_q$ *– mass and decay width differences between the heavy and light* B_q^0 *eigenstates*
  - → ΔM_q *defines frequency of oscillations* $\Delta M_q / \Gamma_q$ *average number of oscillations before the decay*
  - → ϕ_q *weak mixing phase of the* $B_q^0 - \bar{B}_q^0$ *oscillations* $\phi_q = 2\arg[V_{tq}^* V_{tb}]$
  - → ϕ_s *is tiny in SM, directly related to the CKM angle* χ *(* $\phi_s \approx -2\chi$ *) sensitivity to New Physics*
  - → ϕ_s *extraction via measurements of time-dependent CP-asymmetry in* $b \to c\bar{c}s$ *transition*



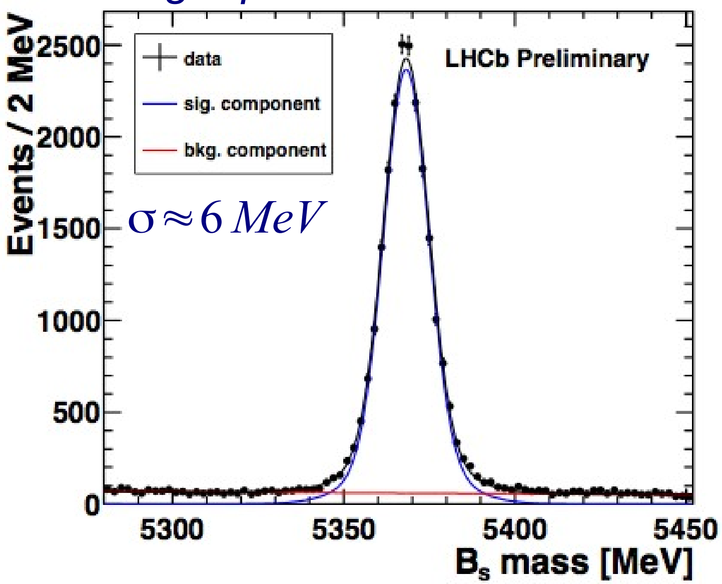
Interference gives rise to ϕ_s

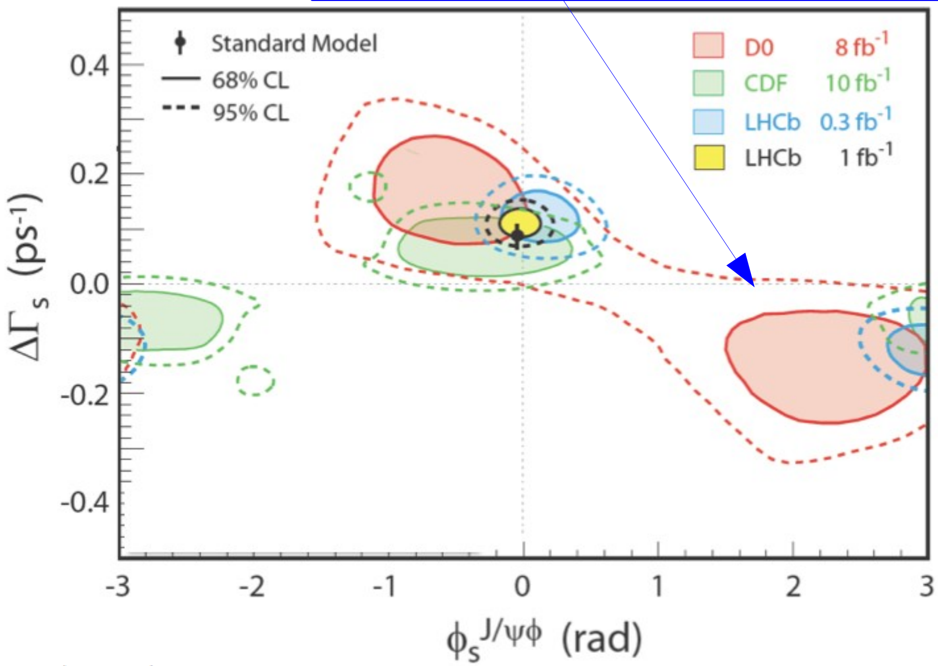
=> *Latest LHCb results on Bs mixing:*

- *arXiv:1204.5675v3* [hep-ex] *23 May 2012:* ϕ_s from $B_s^0 \to J/\psi\,\pi^+\pi^-$ with 1 fb^{-1}
- *LHCb-CONF-2012-002 5 March 2012:* $\phi_s, \Gamma_s, \Delta\Gamma_s$ from $B_s^0 \to J/\psi\,\phi$ with 1 fb^{-1}

- $B_s^0 \to J/\psi\phi$: *tagged time-dependent angular analysis*
  → *fitting 9 parameters*

rejected as $\Delta\Gamma_s > 0$ arXiv:1202.4617v2





$$\phi_s = -0.001 \pm 0.101 \;(\text{stat}) \pm 0.027 \;(\text{syst})\;\text{rad},$$
$$\Gamma_s = 0.6580 \pm 0.0054 \;(\text{stat}) \pm 0.0066 \;(\text{syst})\;\text{ps}^{-1},$$
$$\Delta\Gamma_s = 0.116 \pm 0.018 \;(\text{stat}) \pm 0.006 \;(\text{syst})\;\text{ps}^{-1}.$$

- *the world's most precise measurement of* ϕ_s
- *first observation for a non-zero value for* $\Delta\Gamma_s$
- *good agreement with SM...*

- $B_s^0 \to J/\psi\pi^+\pi^-$ *analysis:* $\phi_s = -0.019^{+0.173+0.004}_{-0.174-0.003}\,\text{rad}$

- *Latest results on* ΔM_s with 340 pb^{-1} $\Delta m_s = 17.725 \pm 0.041\;(\text{stat.}) \pm 0.026\;(\text{syst.})\;\text{ps}^{-1}$
  → *good consistency with the CDF result* LHCb-CONF-2011-050

Selected CP violation results

- *CP violation in charm sector is tiny in SM*
  - → *CP violation at the level of O(1%) – NP*
  - → *first evidence of CP violation in charm*

$$\Delta A_{CP} = (-0.82 \pm 0.21(\text{stat}) \pm 0.11(\text{syst}))\%$$

- *CP asymmetry was observed and measured in many different B decay channels e.g.:*

$B_d^0 \to \pi^+ \pi^-$

$$A_{\pi\pi}^{\text{dir}} = 0.11 \pm 0.21 \pm 0.03$$
$$A_{\pi\pi}^{\text{mix}} = -0.56 \pm 0.17 \pm 0.03$$

consistency with BaBar and Belle

$B_s^0 \to K^+ K^-$

$$A_{KK}^{\text{dir}} = 0.02 \pm 0.18 \pm 0.04$$
$$A_{KK}^{\text{mix}} = 0.17 \pm 0.18 \pm 0.05$$

measured for the first time

LHCb-CONF-2012-007

$$A_{CP}(t) = \frac{A_f^{\text{dir}} \cos(\Delta m t) + A_f^{\text{mix}} \sin(\Delta m t)}{\cosh\left(\frac{\Delta\Gamma}{2} t\right) - A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma}{2} t\right)}$$

$B_d^0 \to K^* \gamma$ $A_{CP} = 0.008 \pm 0.017(\text{stat}) \pm 0.009(\text{syst})$

LHCb-CONF-2012-004

good agreement with SM

Selected for a Viewpoint in *Physics*
PRL **108,** 111602 (2012) PHYSICAL REVIEW LETTERS week ending 16 MARCH 2012

Evidence for *CP* Violation in Time-Integrated $D^0 \to h^- h^+$ Decay Rates

R. Aaij *et al.**
(LHCb Collaboration)

(Received 6 December 2011; published 12 March 2012; publisher error corrected 12 March 2012)

A search for time-integrated *CP* violation in $D^0 \to h^- h^+$ ($h = K, \pi$) decays is presented using 0.62 fb^{-1} of data collected by LHCb in 2011. The flavor of the charm meson is determined by the charge of the slow pion in the $D^{*+} \to D^0\pi^+$ and $D^{*-} \to \bar{D}^0\pi^-$ decay chains. The difference in *CP* asymmetry between $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$, $\Delta A_{CP} \equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$, is measured to be $[-0.82 \pm 0.21(\text{stat}) \pm 0.11(\text{syst})]\%$. This differs from the hypothesis of *CP* conservation by 3.5 standard deviations.

DOI: 10.1103/PhysRevLett.108.111602 PACS numbers: 13.25.Ft, 11.30.Er, 13.85.Ni

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15 November 2011 Last updated at 12:18 GMT

LHC reveals hints of 'new physics' in particle decays

By Jason Palmer
Science and technology reporter, BBC News

LHC-beauty, or LHCb, is an enormous detector designed to examine CP violation

Large Hadron Collider researchers have shown off what may be the facility's first "new physics" outside our current understanding of the Universe.

Particles called D-mesons seem to decay slightly differently from their antiparticles, LHCb physicist Matthew Charles **told the HCP 2011 meeting** on Monday.

The result may help explain why we see so much more matter than antimatter.

Related Stories

Antimatter mystery gains ground
Science ups the 'anti' on matter
New clue to anti-matter mystery

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

- *Ability to investigate low-p_T region (<0.5 GeV/c) at large η(>4)*

  → *the only one LHC experiment that can investigate this region of the phase space*

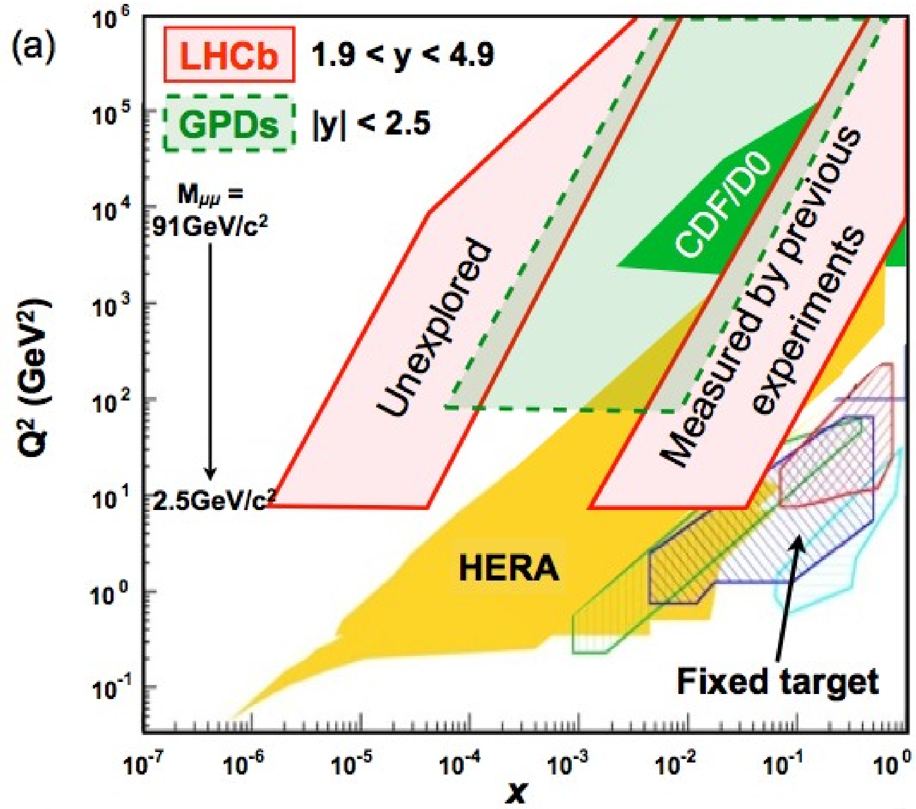
  → *great potential to study soft QCD physics*

- *LHCb, due to its rapidity coverage, explores particle production in an unique kinematic range:*

  → *probes of PDFs at very low and at high values of x and low-Q^2*

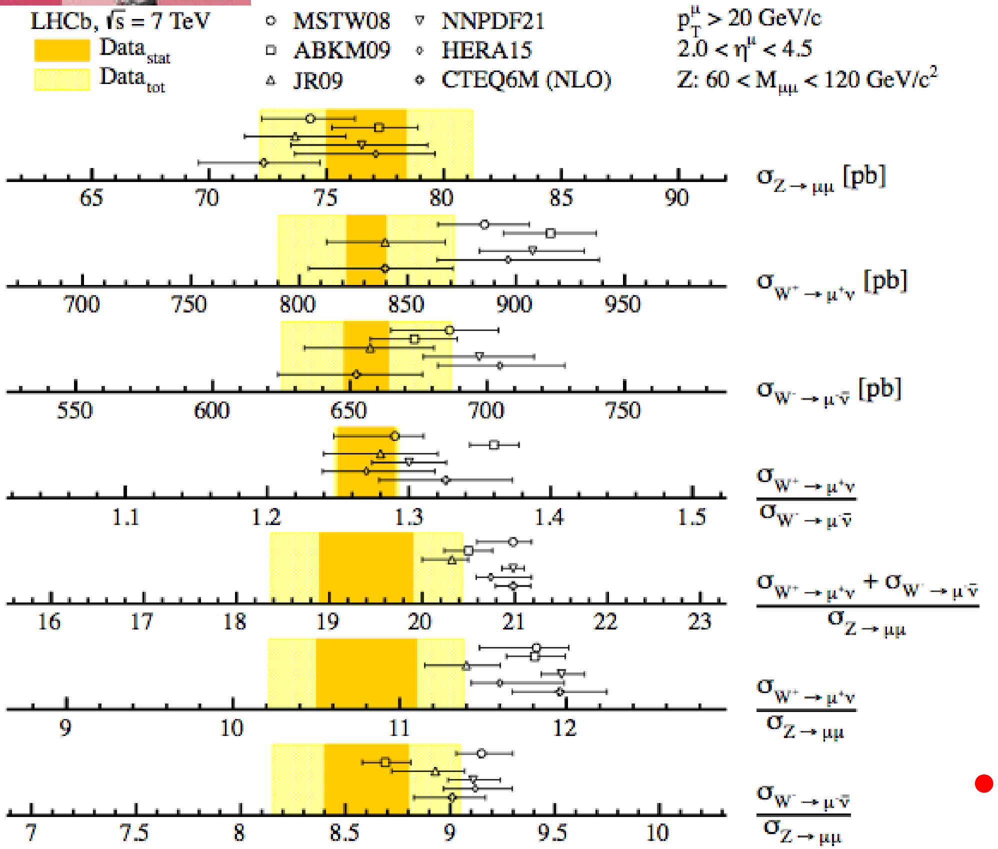
  → *measurements of the low-mass (up to 2.5 GeV) Drell-Yan cross-section are possible with LHCb – probe x values down to 1.5×10^{-6}*

arXiv:0808.1847v1 [hep-ph]
LHCb-CONF-2009-014



Electroweak results

- *analysis performed with 37pb^{-1}*
- $Z^0 \to \mu^+\mu^-$ and $W \to \mu\,\nu$ events
- *isolated muons from W decay*



arXiv:1204.1620v1 [hep-ex] 7 Apr 2012

CERN-PH-EP-2012-099
LHCb-PAPER-2012-008
April 5, 2012

Inclusive W and Z production in the forward region at $\sqrt{s} = 7$ TeV

The LHCb collaboration †

Abstract

Measurements of inclusive W and Z boson production cross-sections in pp collisions at $\sqrt{s} = 7$ TeV using final states containing muons are presented. The data sample corresponds to an integrated luminosity of 37 pb^{-1} collected with the LHCb detector. The W and Z bosons are reconstructed from muons with a transverse momentum above 20 GeV/c and pseudorapidity between 2.0 and 4.5, and, in the case of the Z cross-section, a dimuon invariant mass between 60 and 120 GeV/c^2. The cross-sections are measured to be $831 \pm 9 \pm 27 \pm 29$ pb for W^+, $656 \pm 8 \pm 19 \pm 23$ pb for W^- and $76.7 \pm 1.7 \pm 3.3 \pm 2.7$ pb for Z, where the first uncertainty is statistical, the second is systematic and the third is due to the luminosity. Differential cross-sections, W and Z cross-section ratios and the lepton charge asymmetry are also measured in the same kinematic region. The ratios are determined to be $\sigma_{W^+\to\mu^+\nu}/\sigma_{W^-\to\mu^-\bar{\nu}} = 1.27 \pm 0.02 \pm 0.01$ and $(\sigma_{W^+\to\mu^+\nu} + \sigma_{W^-\to\mu^-\bar{\nu}})/\sigma_{Z\to\mu\mu} = 19.4 \pm 0.5 \pm 0.9$. The results are in general agreement with theoretical predictions, performed at next-to-next-to-leading order in QCD using recently calculated parton distribution functions.

- *valuable input to the knowledge of the PDF of the proton*

EF Analysis: Physics Motivation

- *Energy Flow (EF)*

$$EF = \frac{1}{N_{inter}} \frac{dE_{TOTAL}}{d\eta}$$

LHCb-CONF-2012-012

directly sensitive to the amount of parton radiation and multi-parton interactions (MPI):

- -> *MPI – predominant source of the underlying event (UE) activity*
- -> *MPI phenomena is still not well known*
- -> *forward EF measurements should allow to discriminate between different MPI models*
- -> *additional input to the determination of the parameters of the existing MPI models*

- *EF measurements are strongly needed for MC tuning:*
  - -> *most of the current models were tuned to describe SPS and Tevatron data at central rapidities*
  - -> *accurate theoretical description of the UE structure still remains to be a challenge*

- *Forward EF has never been measured at a hadron collider in the pre-LHC era:*
  - -> *CMS has recently made first measurements for $3.15<\eta<4.9$*

EF Analysis: Physics Motivation

Cosmic Rays and Extensive Air Showers

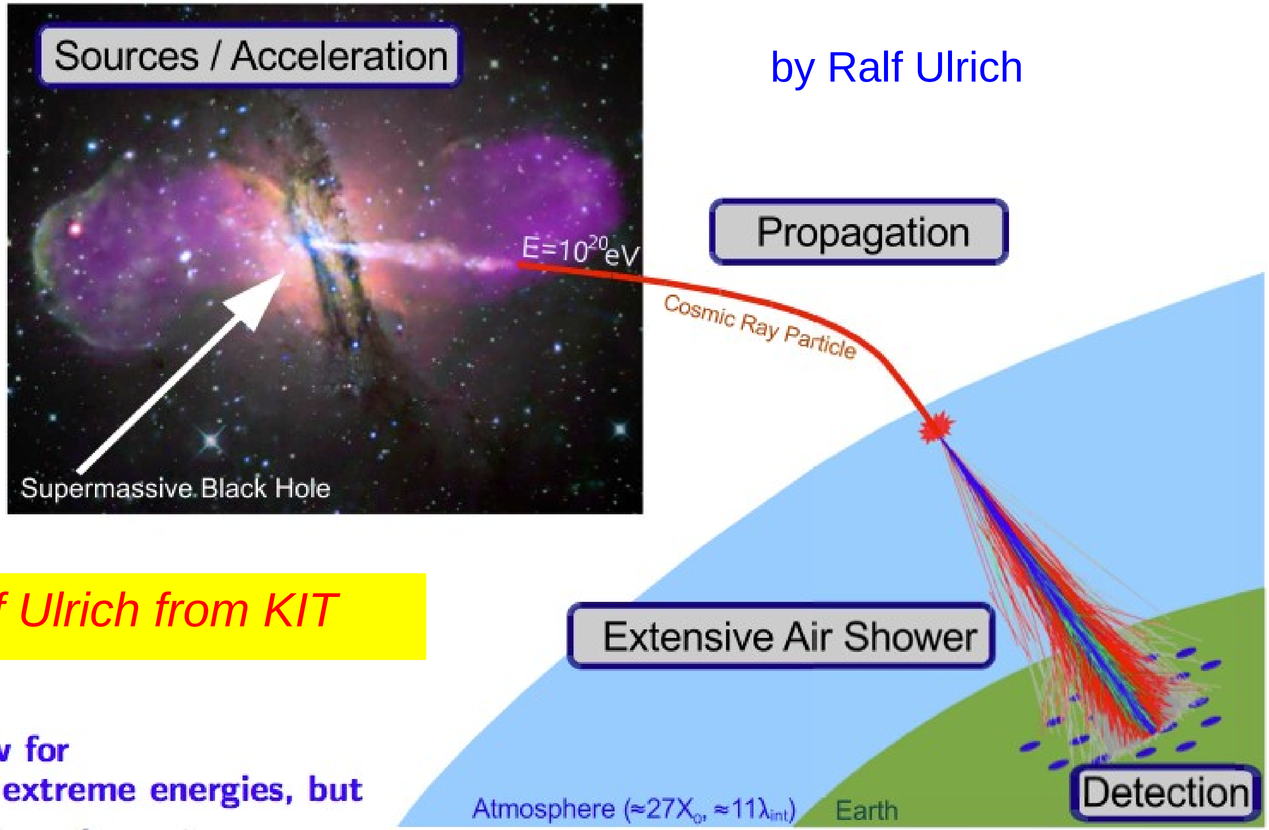
- *EF measurements supposed to improve the existing constraints on ultra-high energy cosmic-ray models:*

→ *LHC provides first possibility to compare cosmic-ray showering models at E_{lab} of up to ~10^{17} eV*

- *First analysis where LHCb data compared with the CR models:*

Many Thanks to Colin Baus and Ralf Ulrich from KIT

by Ralf Ulrich



Observational window for astrophysics at most extreme energies, but

- No direct detection of cosmic rays
- Extensive Air Showers (EAS)
- Need to understand ground based EAS observables
- **Very good EAS models required!**

⇒ Interactions up to $\sqrt{s}$ ~500 TeV

2

EF Analysis: Event Classes

- *Inclusive MB events:*
  - --> *detector level : at least 1 long track in $1.9<\eta<4.9$ with p>2 GeV/c + good quality additional cuts to suppress beam-related background and pile-up*
  - --> *generator level: at least 1 charged stable generated particle in $1.9<\eta<4.9$, no pile-up BXs no cut on E – correction of the measurements to the full energy flow*

- *Hard scattering events → selected among inclusive MB ones*
  - --> *detector level : at least 1 longtrack in $1.9<\eta<4.9$ with $p_T>3$ GeV/c*
  - --> *generator level: at least 1 charged stable particle in $1.9<\eta<4.9$ with $p_T>3$ GeV/c*

- *Diffractive enriched events → selected among inclusive MB ones*
  - --> *detector level : no backward tracks reconstructed in $-3.5<\eta<-1.5$*
  - --> *generator level: no charged stable particles in $-3.5<\eta<-1.5$*

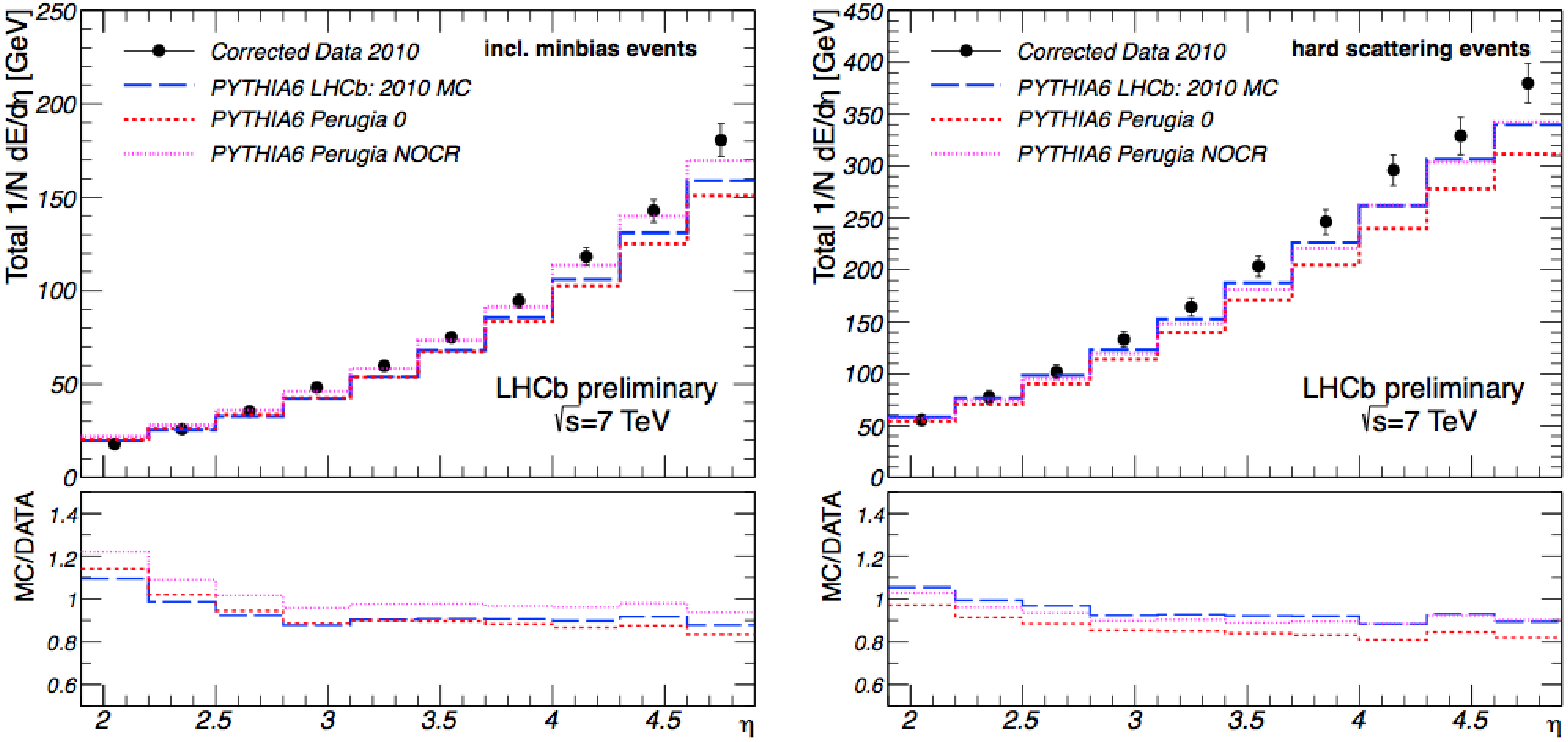
LRG over 2 units of η !

- *Non-diffractive enriched events → selected among inclusive MB ones*
  - --> *detector level : at least 1 backward track in $-3.5<\eta<-1.5$*
  - --> *generator level: at least 1 charged stable particle in $-3.5<\eta<-1.5$*

- *LHCb MC: ~70% of selected diffractive candidates at detector level are indeed the diffractive events ~90% of non-diffractive candidates are indeed non-diffractive events*
- *Purity gets much better at generator level*

EF Analysis: Results (1)

=> *total corrected EF vs PYTHIA-based generator level predictions:*

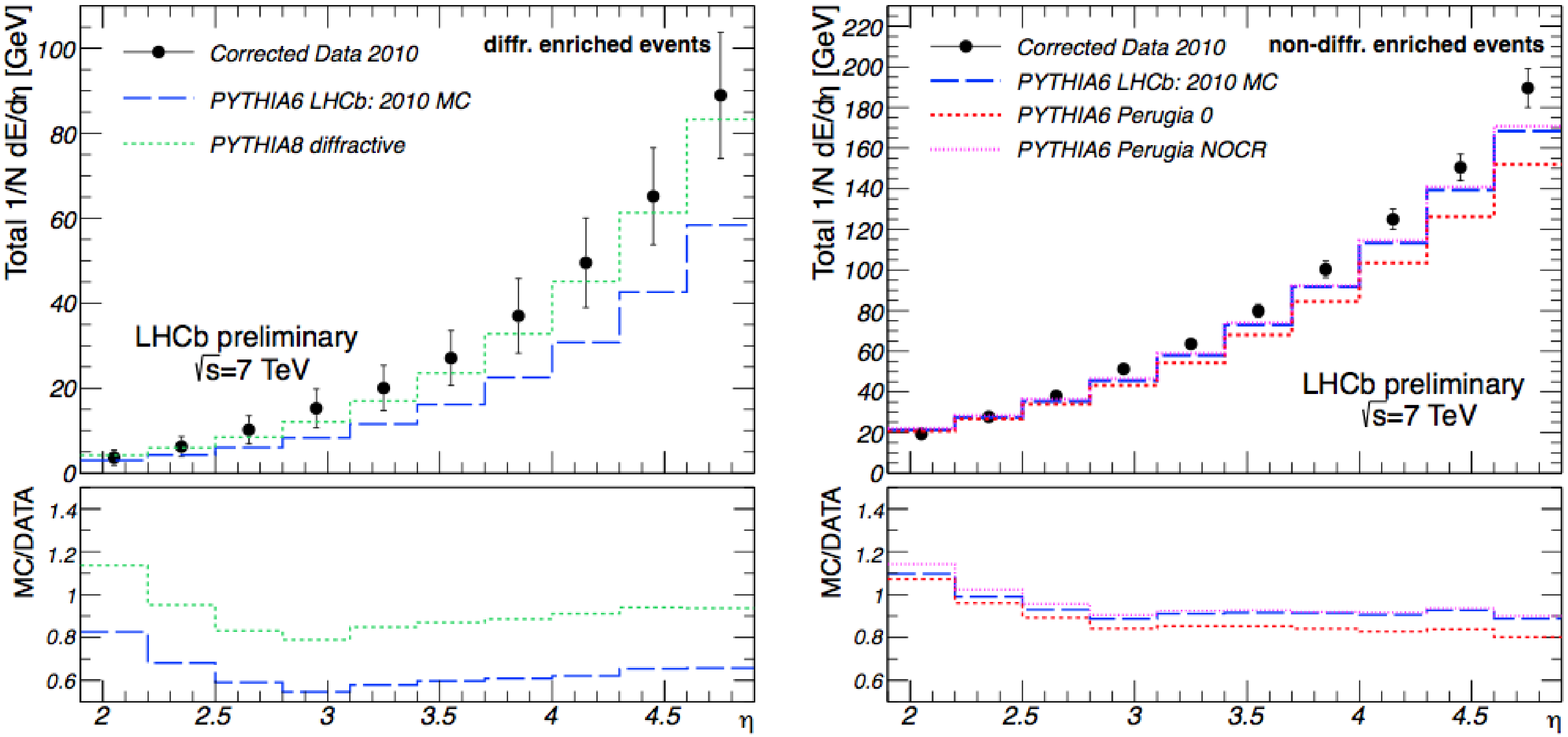


-> *PYTHIA-based models underestimate EF at large η*

-> *valuable input for MC tuning*

EF Analysis: Results (2)

=> *total corrected EF vs PYTHIA-based generator level predictions:*

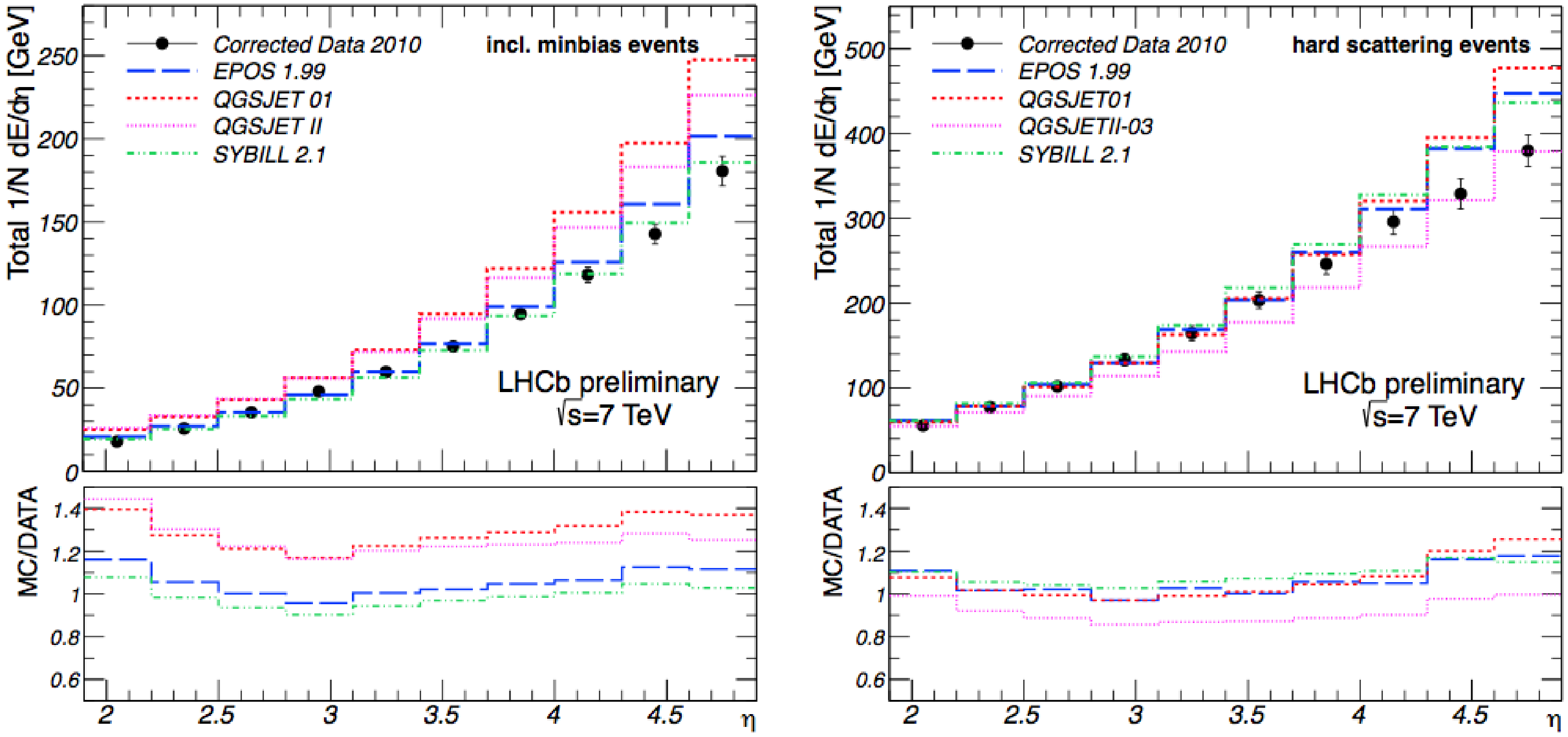


-> *PYTHIA8 describes the diffractive EF much better than all the other models do*

-> *non-diffractive and diffractive EF are underestimated by the PYTHIA-based models*

EF Analysis: Results (3)

=> *total corrected EF vs cosmic-ray model predictions:*

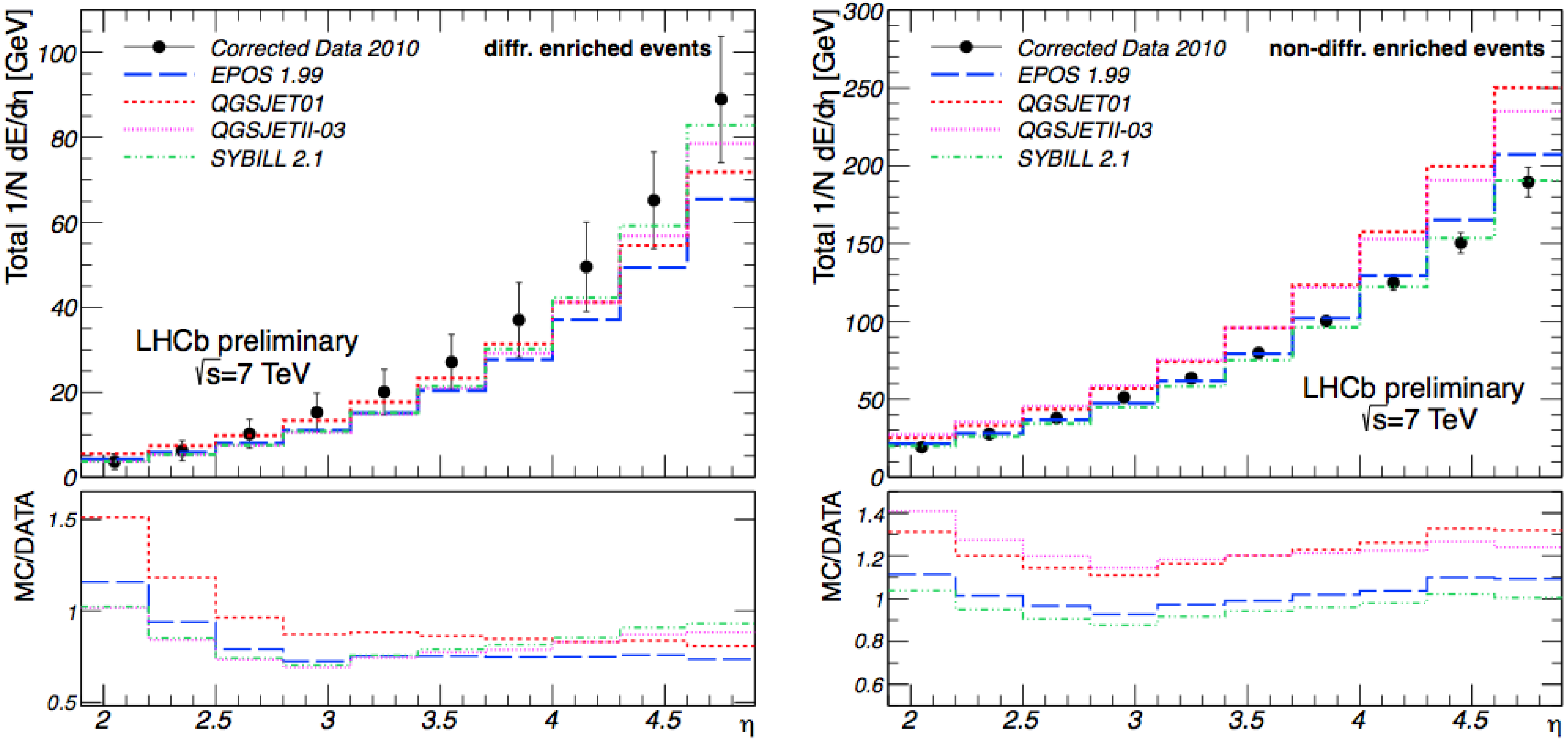


-> *SYBILL gives the best description of the total inclusive minbias EF among all the models !*

-> *QGSJETII-03 describes the hard scattering EF at large η better than all the other models*

EF Analysis: Results (4)

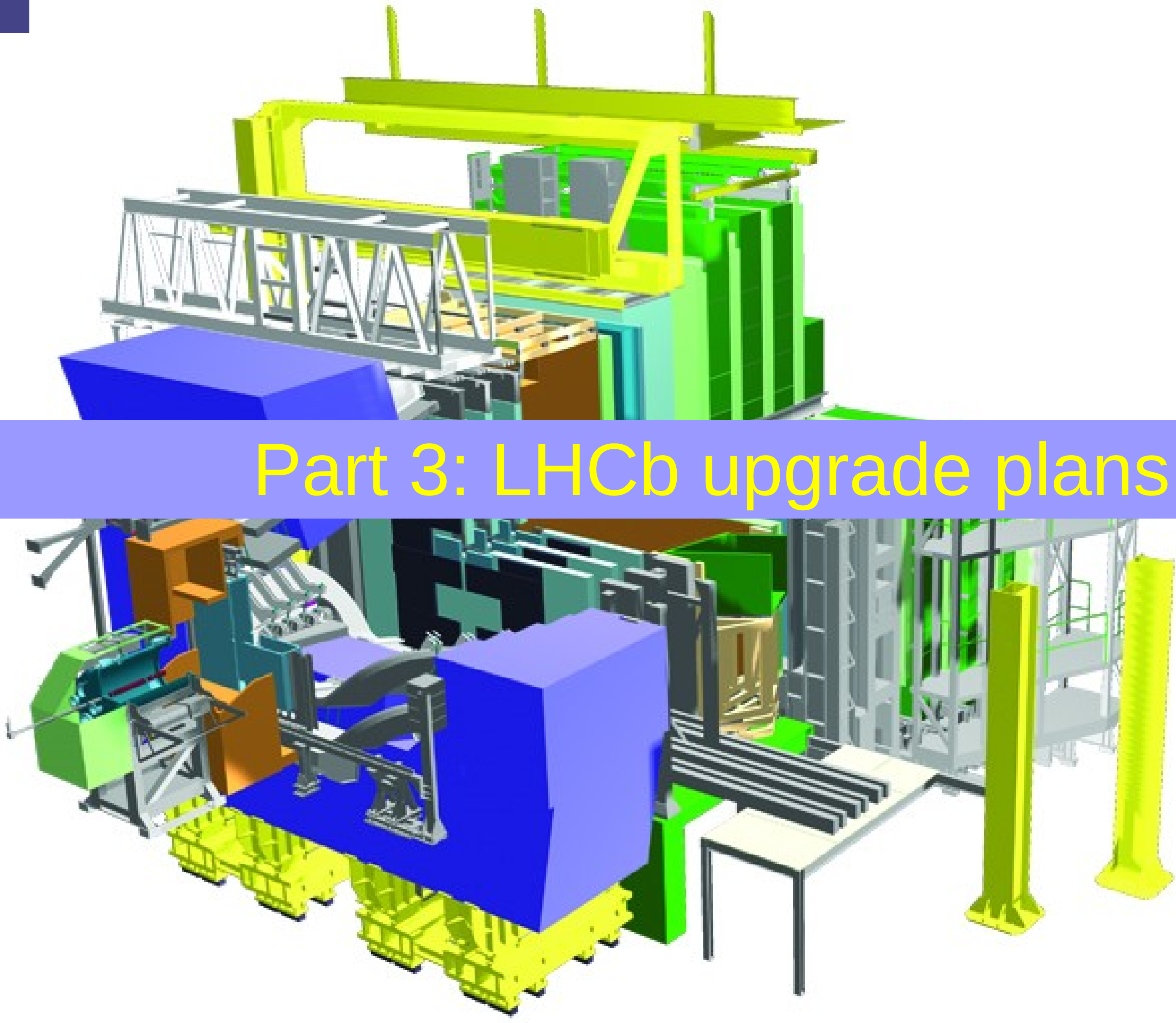
=> *total corrected EF vs cosmic-ray model predictions:*



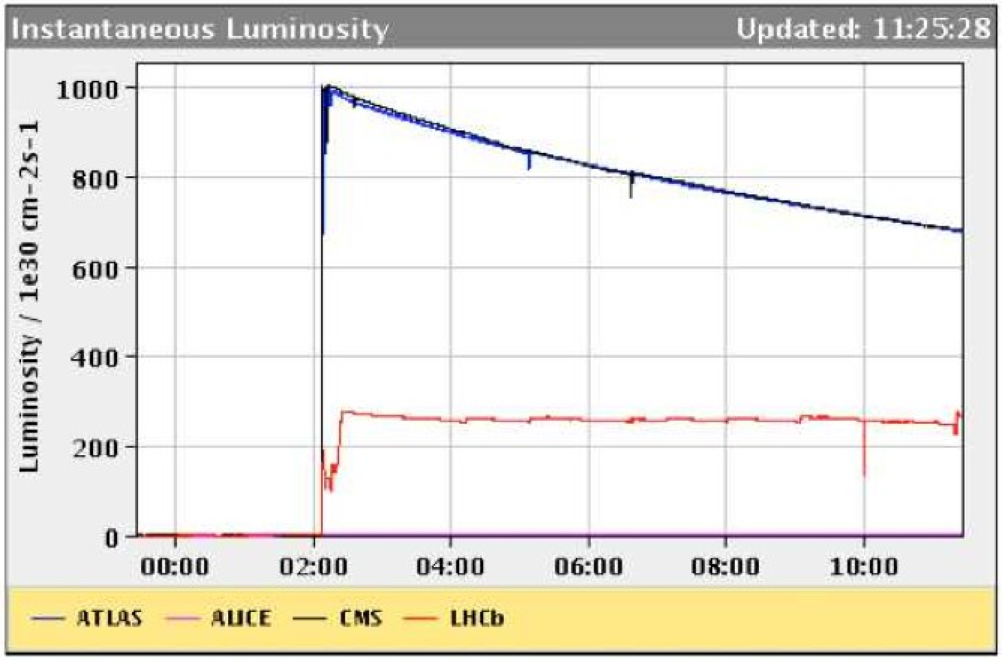
--> *SYBILL gives the best description of the total non-diffr. enriched EF among all the models !*

--> *SYBILL description of the diffractive EF is competitive with the one provided by PYTHIA8*

Part 3: LHCb upgrade plans



Motivation



- *LHCb can't now collect >1.5 fb $^{-1}$ per annum because of the maximum r/o rate of 1.1MHz*
- *Major Goals:*
  1) 40MHz r/o → 5 fb^{-1} per annum
  → hardware to be replaced
  2) increase trigger efficiencies
  → factor of 5 and >10 for muonic and hadronic channels, respectively
  → fully software based trigger system

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

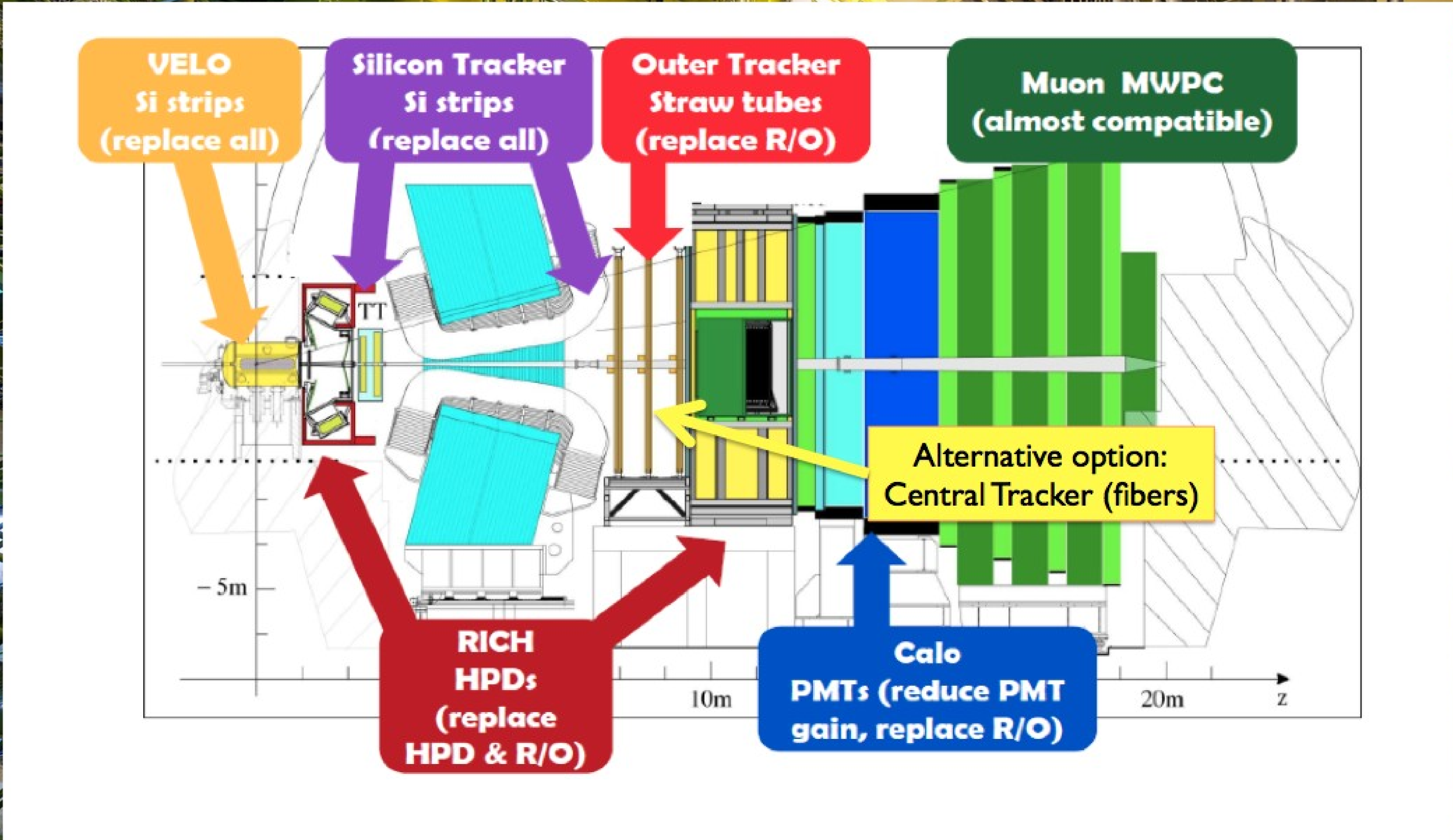
CERN-LHCC-2011-001
29 March 2011 (v2)

Letter of Intent for the LHCb Upgrade

The LHCb Collaboration[1]

Abstract

The primary goal of LHCb is to measure the effects of new particles or forces beyond the Standard Model. Results obtained from data collected in 2010 show that the detector is robust and functioning well. While LHCb will be able to measure a host of interesting channels in heavy flavour decays in the upcoming few years, a limit of about 1 fb^{-1} of data per year cannot be overcome without upgrading the detector. The LHC machine does not face such a limitation. With the upgraded detector, read out at 40 MHz, a much more flexible software-based triggering strategy will allow a large increase not only in data rate, as the detector would collect 5 fb^{-1} per year, but also the ability to increase trigger efficiencies especially in decays to hadronic final states. In addition, it will be possible to change triggers to explore different physics as LHC discoveries point us to the most interesting channels. Our physics scope extends beyond that of flavour. Possibilities for interesting discoveries exist over a whole variety of phenomena including searches for Majorana neutrinos, exotic Higgs decays and precision electroweak measurements. Here we describe the physics motivations and proposed detector changes for exploring new phenomena in proton-proton collisions near 14 TeV centre-of-mass energy.



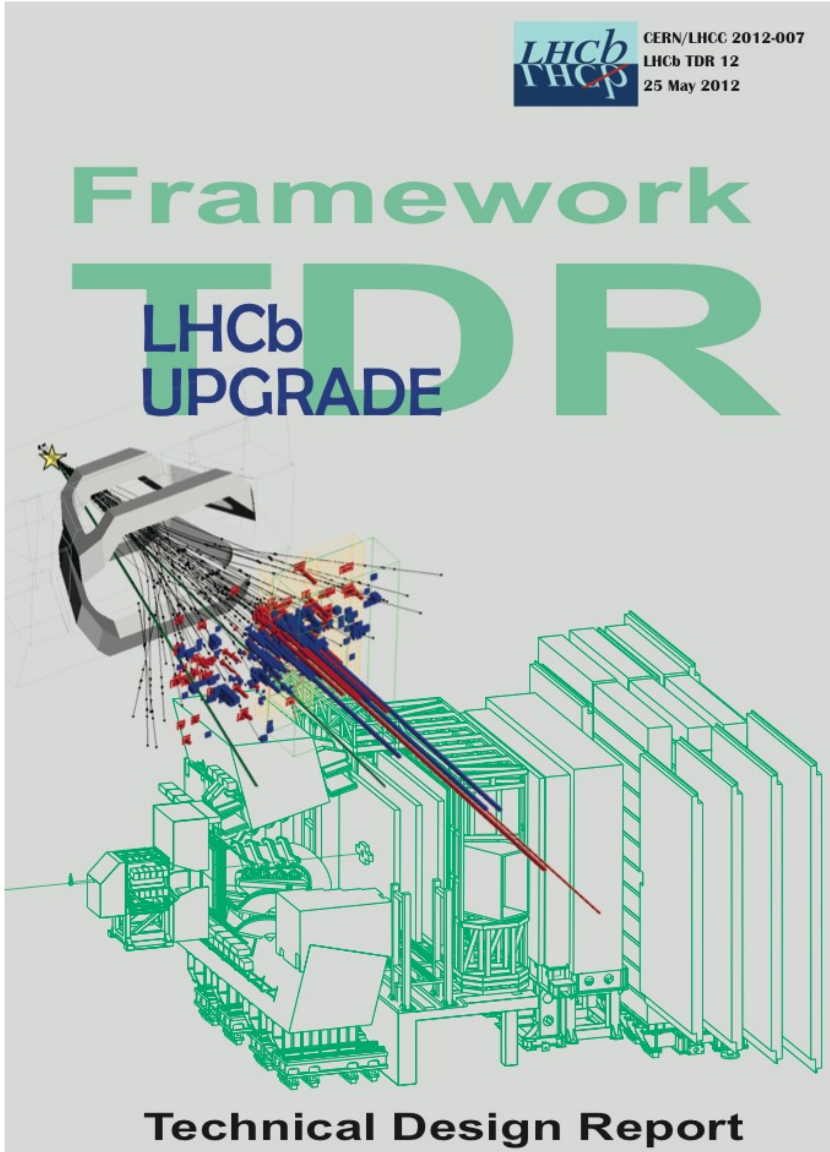
VELO
Si strips
(replace all)
Silicon Tracker
Si strips
(replace all)
Outer Tracker
Straw tubes
(replace R/O)
Muon MWPC
(almost compatible)
TT
Alternative option:
Central Tracker (fibers)
−5m
10m
20m
z
RICH
HPDs
(replace
HPD & R/O)
Calo
PMTs (reduce PMT
gain, replace R/O)

Schedule

- 2012: LHCb data taking @ 8 TeV / approval of "Framework TDR", start of R&D for the upgrade
- 2013-2014: 1st LHC long shutdown / LHCb maintenance/ submission of LHCb subsystems TDRs to LHCC
- 2015-2017: LHCb data taking @ 13-14 TeV / new hardware construction
- 2018: 2nd LHC long shutdown / installation and commissioning of the upgraded detector
- 2019-2021: LHCb data taking @ 14 TeV
- >2022: LHCb data taking @ High-Luminosity LHC (tbc)

Just released

Clock for LHCb upgrade has started to tick !



Summary

LHCb detector achievements:

- *Excellent vertex resolutions*
- *Great tracking performance*
- *Robust particle identification*
- *Selective and flexible trigger system*

→ *Great conditions to deliver high-quality physics results*

Just do it :-)

…and LHCb does it indeed :

- *56 papers submitted to journals so far, a lot more in the pipeline*
- *world's best measurements of many important physics parameters with rather moderate amount of data and manpower !!!*
- *Upgrade activities launched*
- *LHCb is much more than just a beauty experiment :-)*