LHCb status and results in 2010-2012

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XVII. International Symposium on Very High Energy Cosmic Ray Interactions

ISVHECRI 2012

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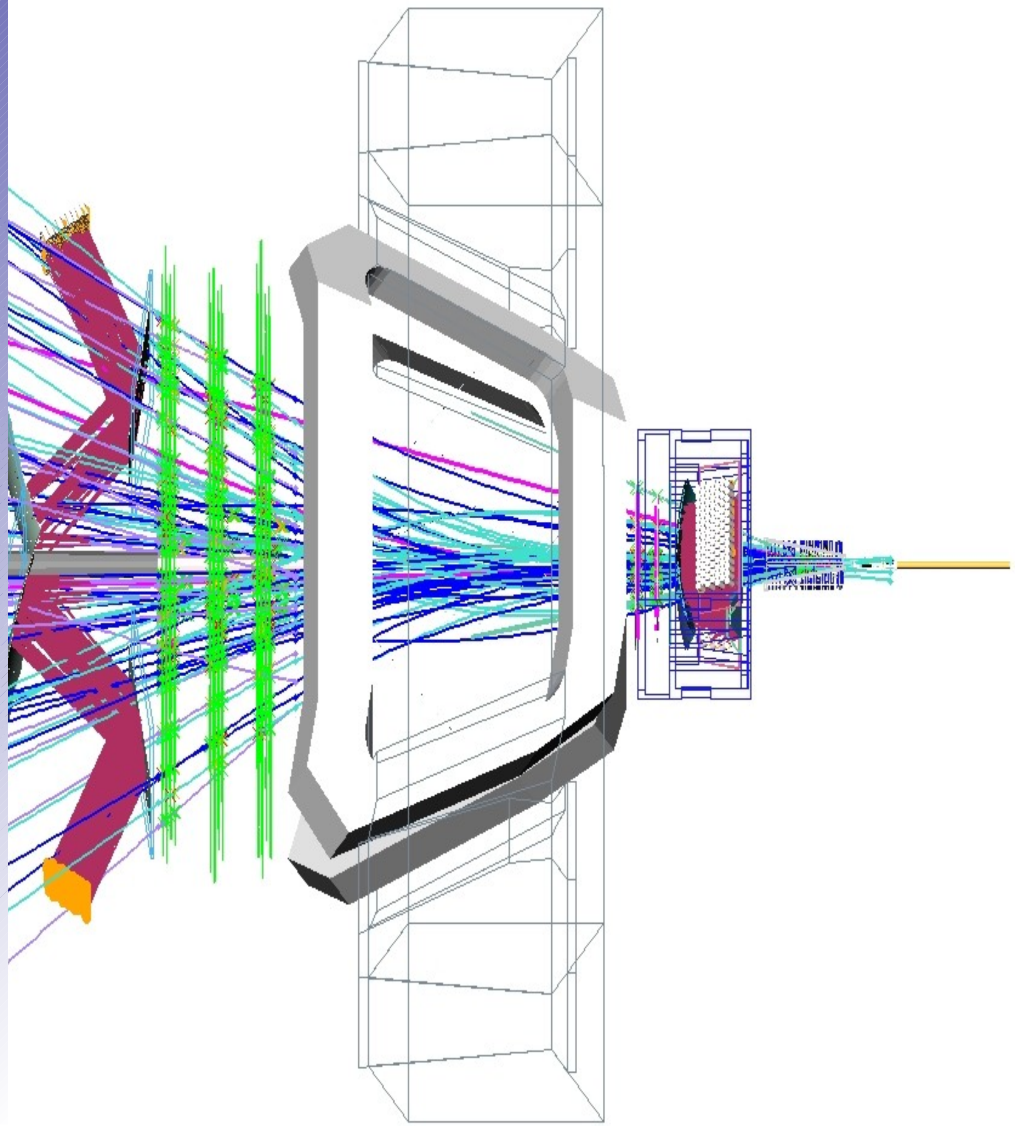
- LHCb experiment:
  - → physics objectives
  - → detector and its subcomponents
  - → data taking
- Physics program and some results
- Particle multiplicities and forward energy flow
- Summary



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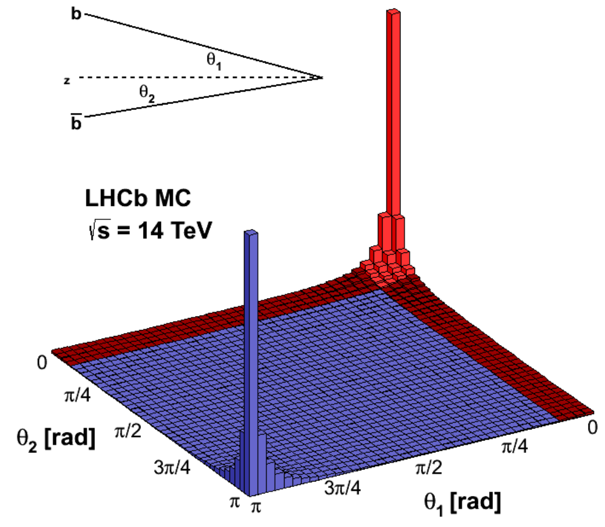
Part 1: LHCb experiment

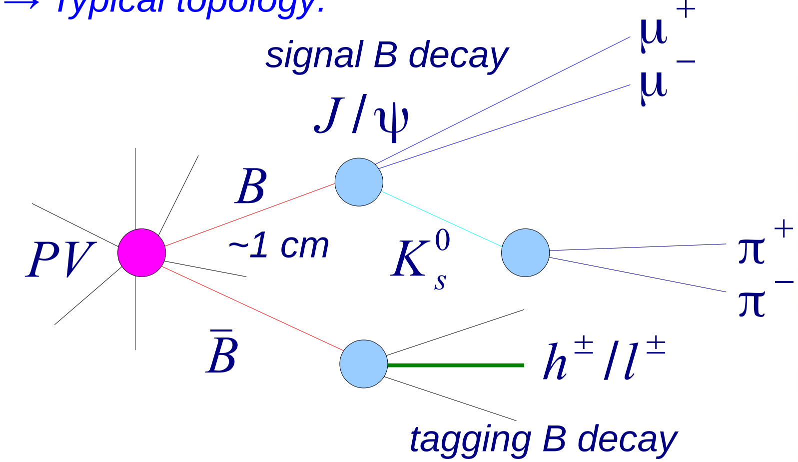
LHCb objectives

- 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
  → study physics of FCNC via e.g. $b \to s\,\gamma$ transition
  → improve measurements on CKM elements and overconstrain the unitarity triangles

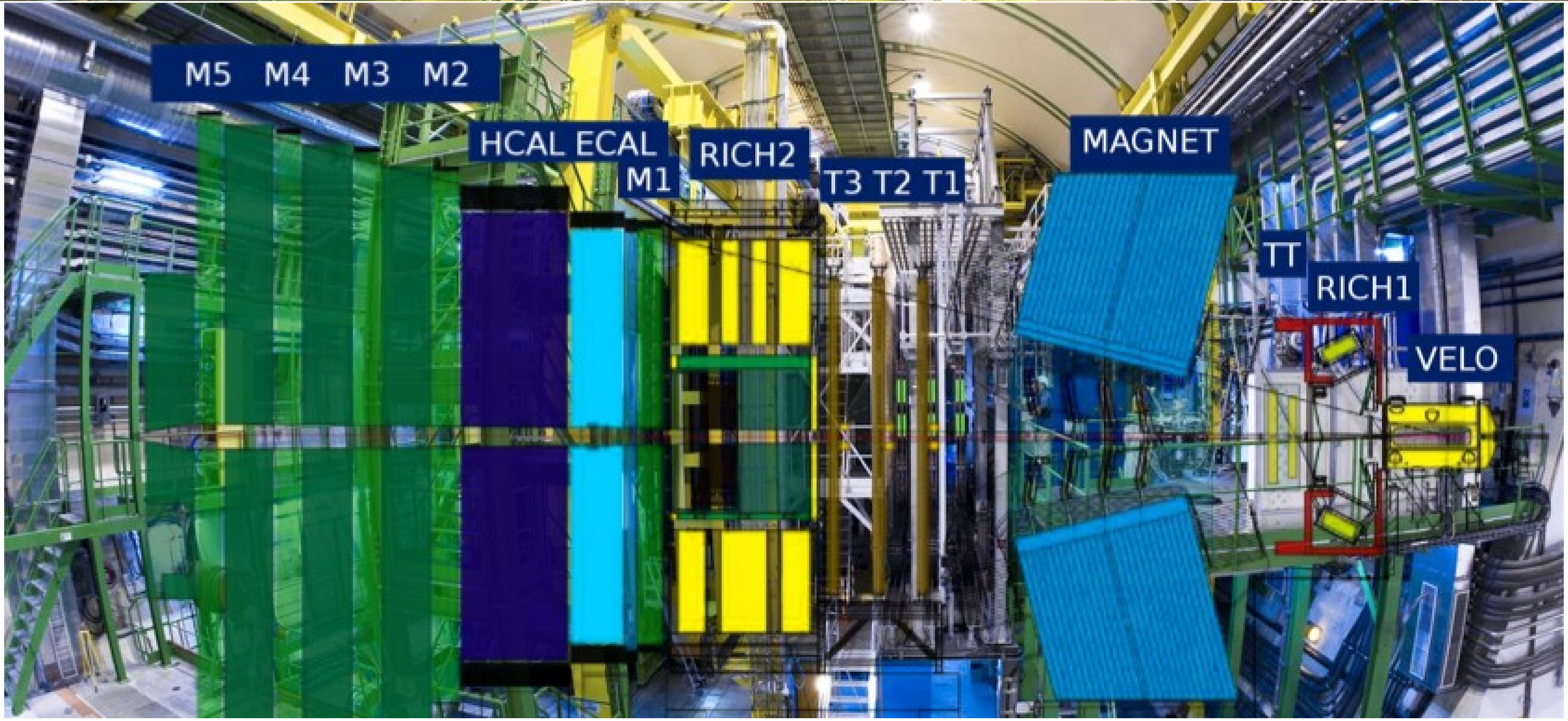


→ B hadrons at the LHC are mainly produced at low polar angles in the same forward cone

→ Typical topology:



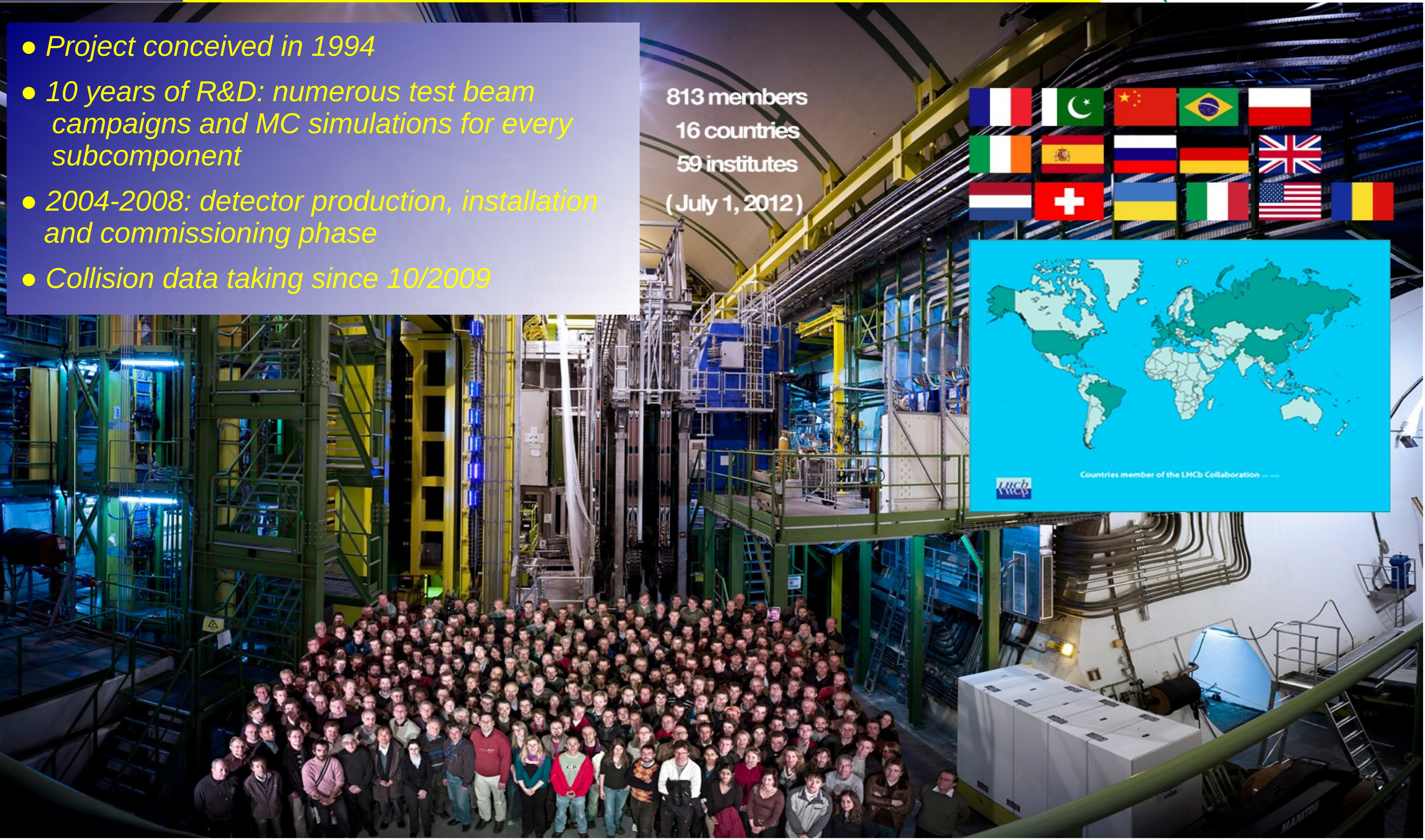
LHCb spectrometer



- *Forward spectrometer with planar detectors: optimized for the forward peaked heavy quark production*
  → *covers ~4% of the solid angle, but captures ~40% of the heavy quark production cross-section*
  → *combination of tracking and PID detectors covering full acceptance*
- *Detector acceptance: 2<η<5 fully covered by the tracking system – unique @ LHC*
  → *ability to study low-p_T region (<0.5 GeV/c) at large η(>4) – unique @ LHC*
  → *10m high, 13m wide, 21m long, ~5600 tons , ~1M r/o channels*
- *Designed to run at a moderate luminosity: large pile-up complicates B decay vertexing and flavor tagging*

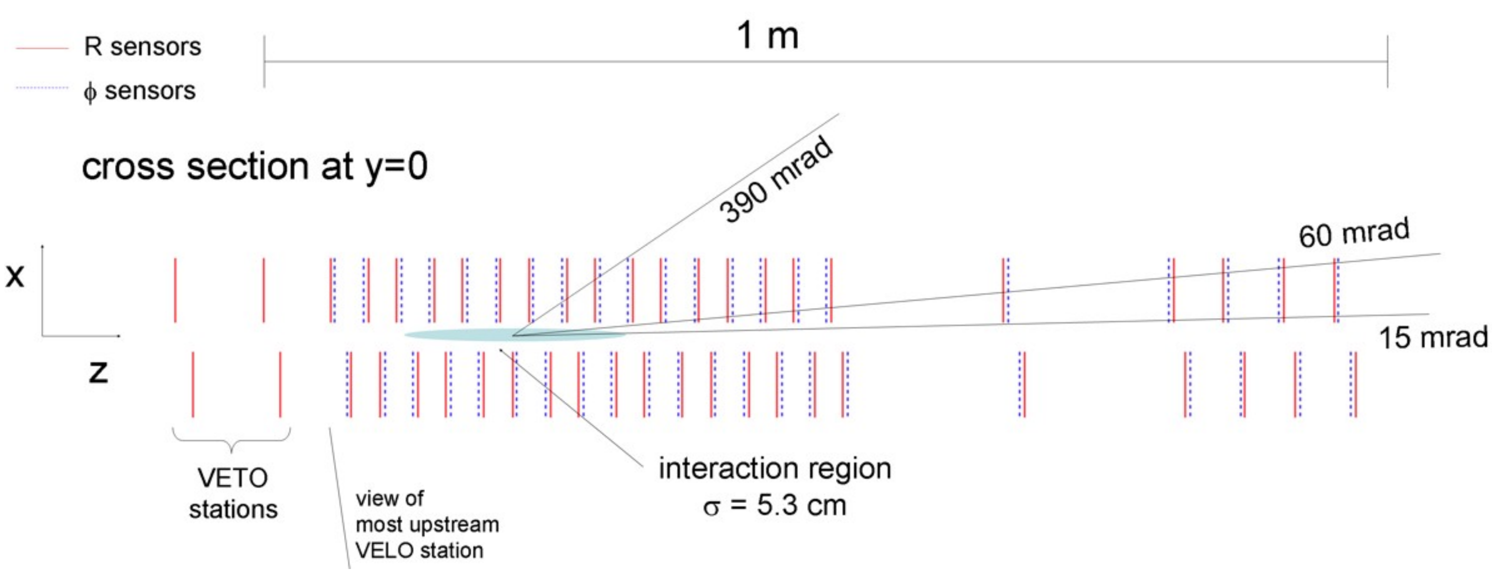
LHCb project history

- *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*

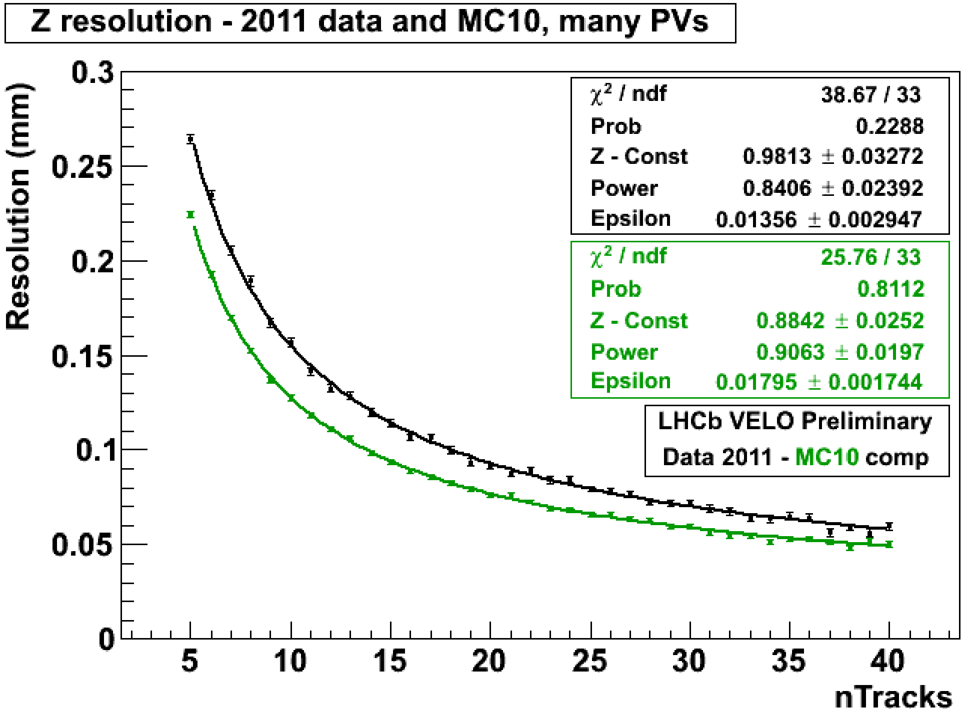


Tracking system: VELO

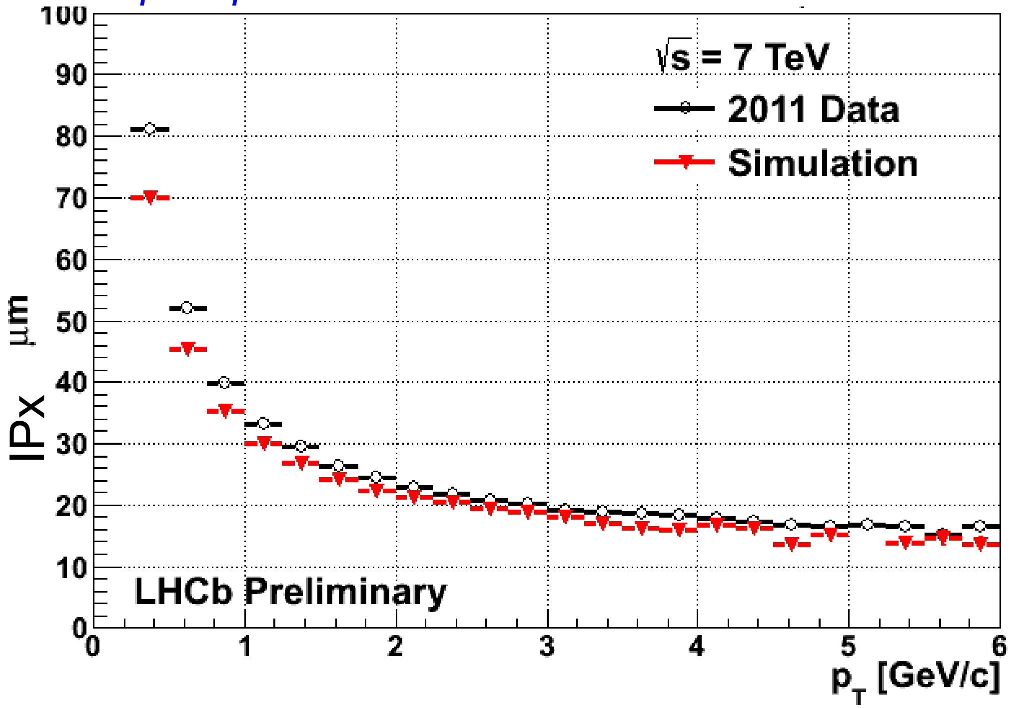
- *reconstruction of the primary and decay vertices, track seeds + info for the trigger*
- *surrounds collision point being outside magnetic field, just 8 mm away from the beam line*
- *21 Si-strip stations measuring r and ϕ hit positions + 2 r-only stations*
- *largest angular coverage among LHCb subsystems*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



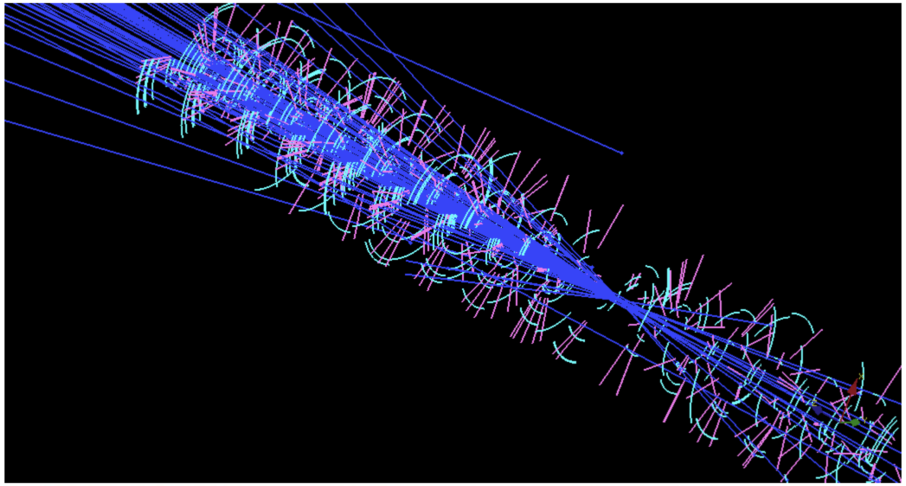
- *Primary Vertex resolution:*



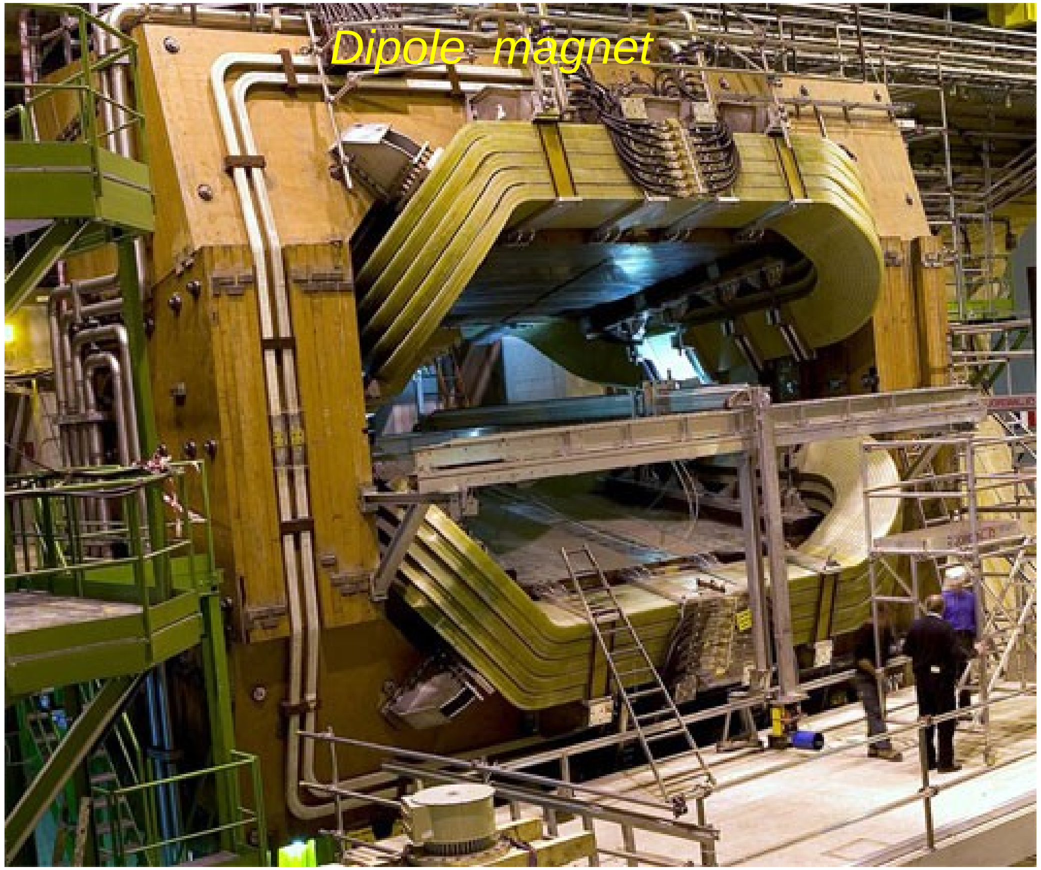
- *Impact parameter resolution:*



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



Tracking system: TT and Magnet



- *TT station:*

→ 4 layers of Si-Strip detectors in front of the magnet

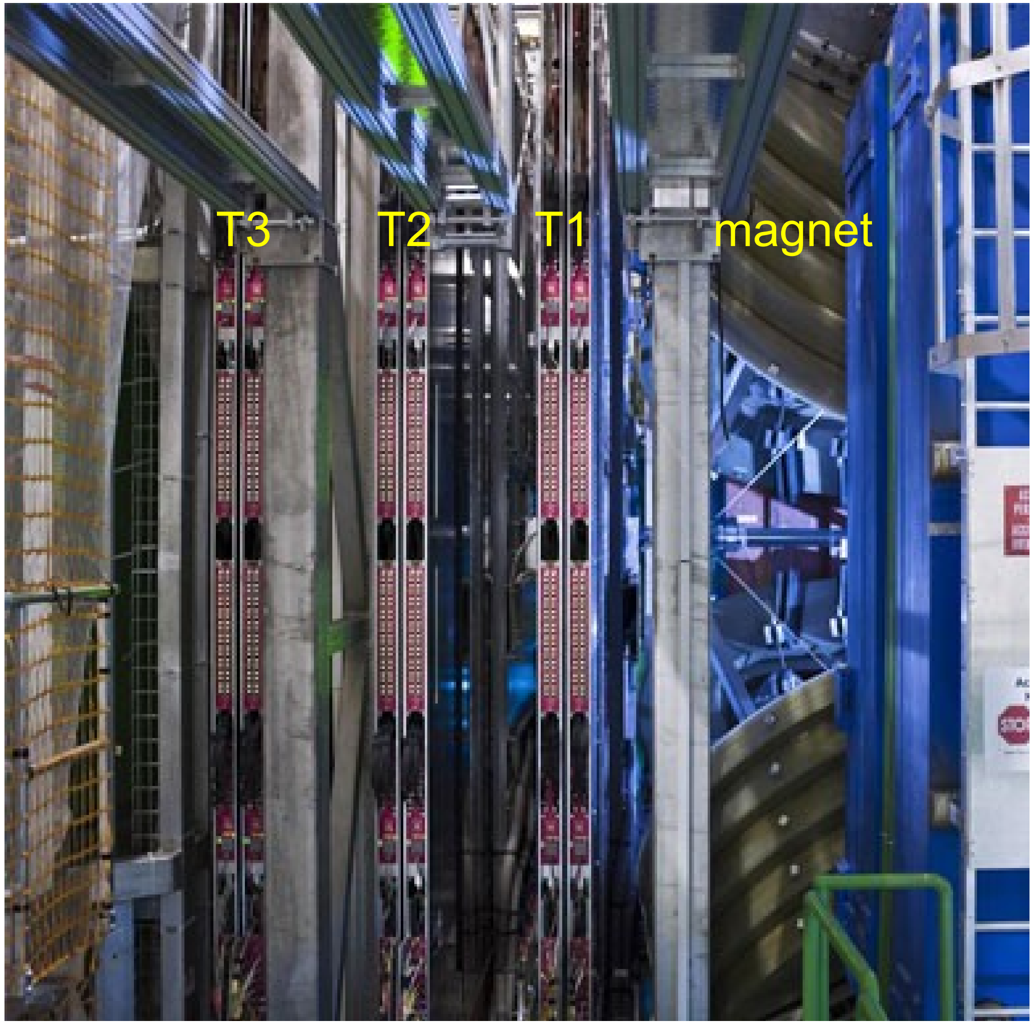
→ adds momentum information and helps to reconstruct the decay products of long-lived particles

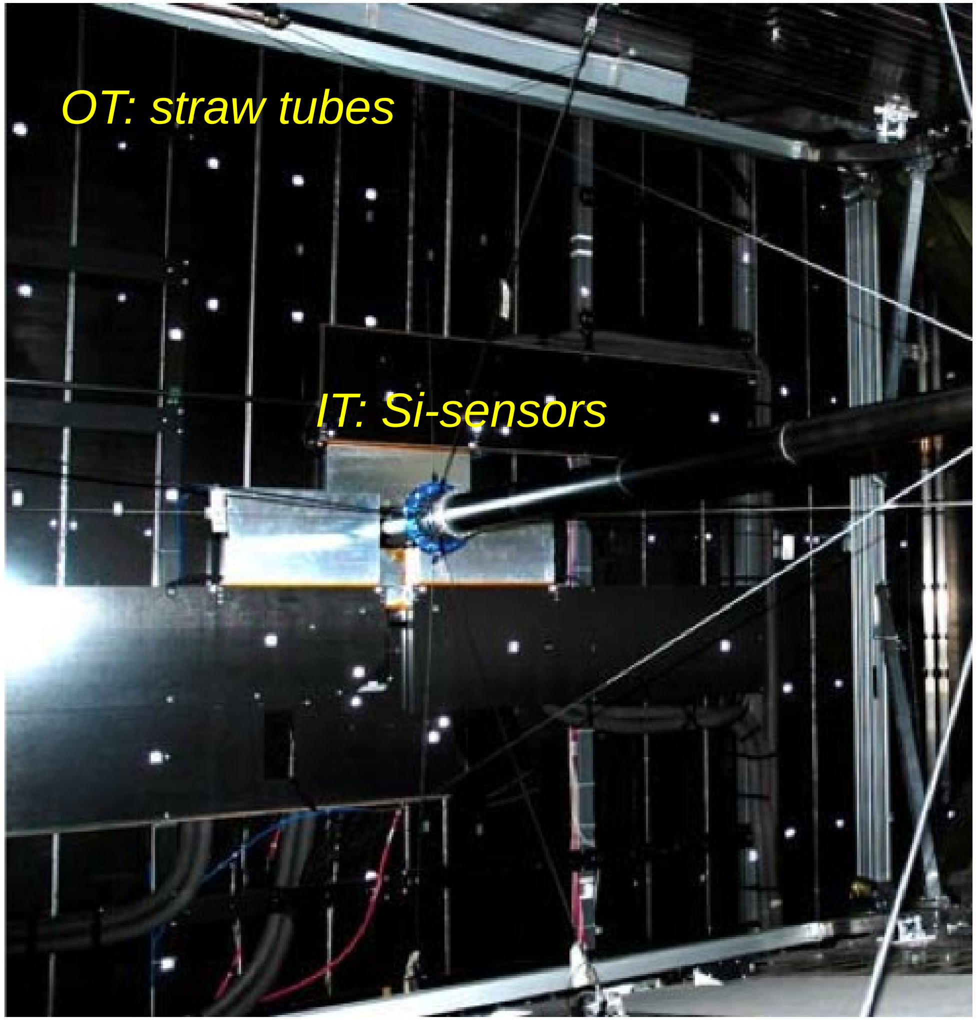
- *Magnet :*

→ essential component for track momentum measurements

→ its aperture defines the detector acceptance

→ bending power: $\int B dl \approx 4\, T \times m$





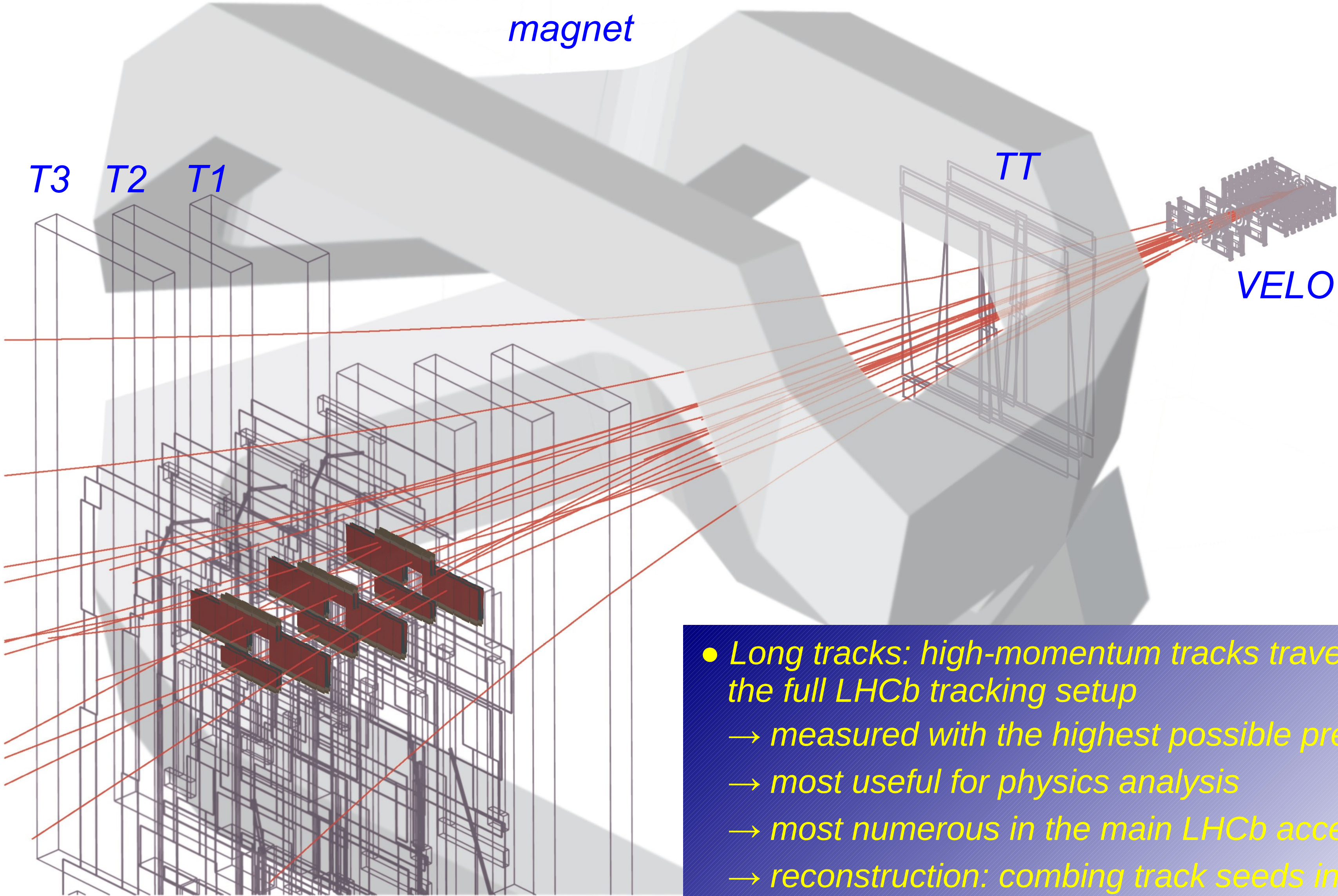
- *T1 – T3 stations:*

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

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

→ good spatial hit resolution achieved

Long Tracks



- 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
  - → reconstruction: combing track seeds in the VELO and T stations + adding TT hits

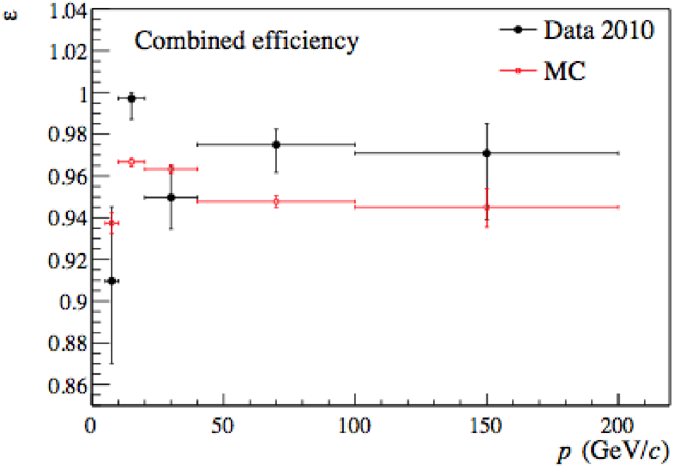
Tracking performance

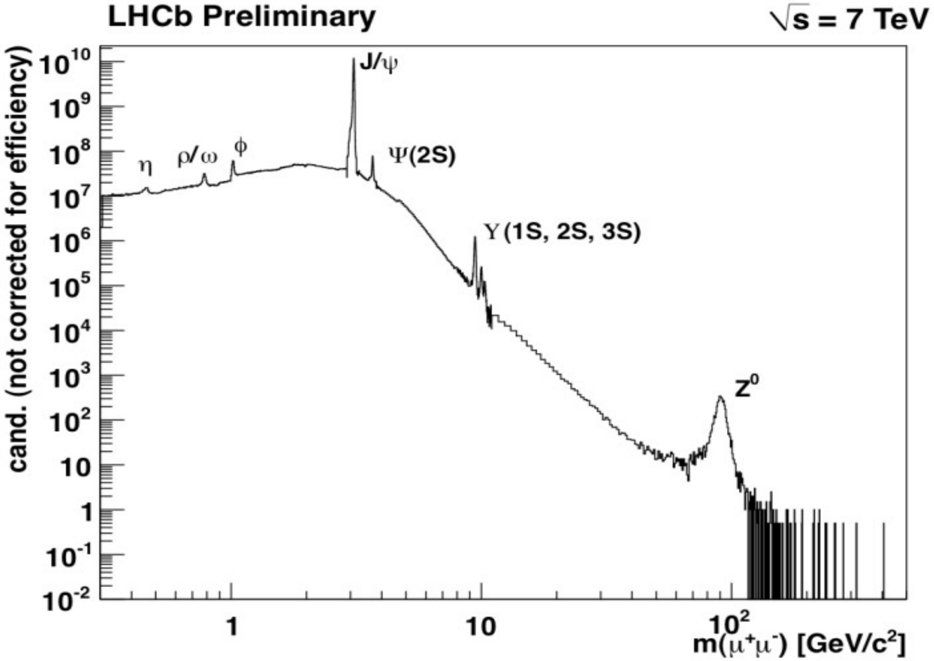
Phys. Lett. B 708 (2012) 241-248

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



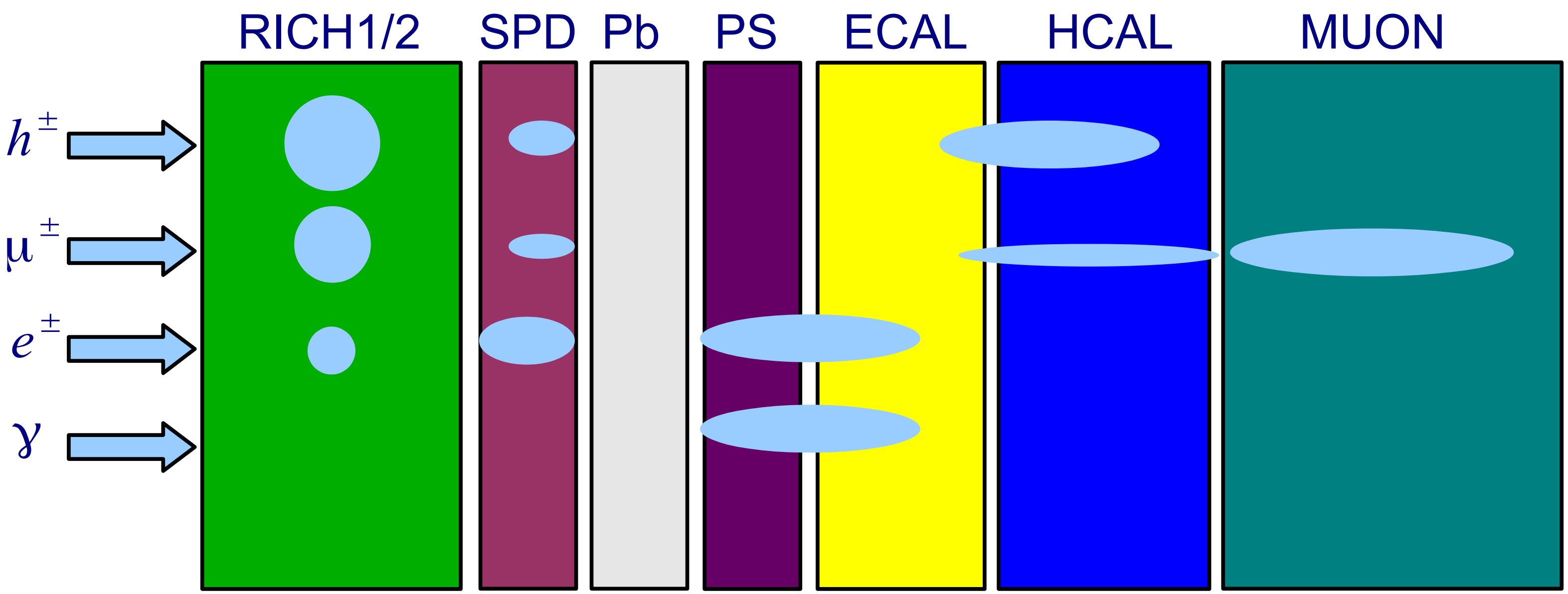


- *Excellent momentum resolution:*
  - → *$\delta p/p$ ~ 0.4-0.6% depending on p*
  - → *great invariant mass resolution*
  - → *rigorous rejection of combinatorial background*
- *Great track finding efficiency*
- *Rigorous suppression of multiply reconstructed (clones) and spurious long tracks (ghosts)*

LHCb particle identification

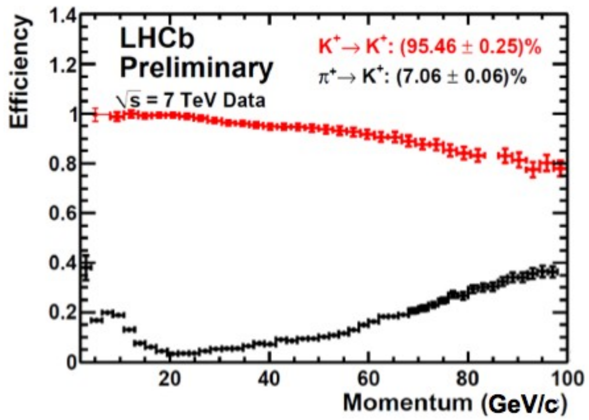
- *RICH system:*
  → *efficient hadron ID over the wide momentum range – unique @ LHC*
- *Scintillator Pad Detector (SPD) and Preshower (PS):*
  → *robust e/γ and e/hadron separation*
- *Muon stations:*
  → μ *identification & trigger on muonic channels*

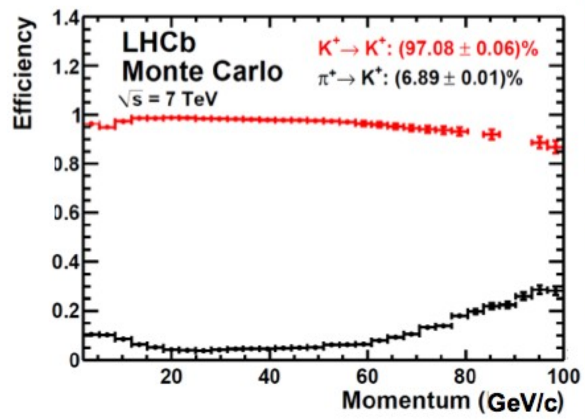
- *ECAL:*
  → *e and γ energy measurement*
  → *widely used in the offline analysis (e.g. $B^0 \to K^* \gamma$, $B_s^0 \to \phi \gamma$, $B^0 \to \pi^+ \pi^- \pi^0$)*
  → *trigger on electromagnetic decay channels*
- *HCAL:*
  → *energy measurement for hadrons*
  → *trigger on hadronic decay channels*

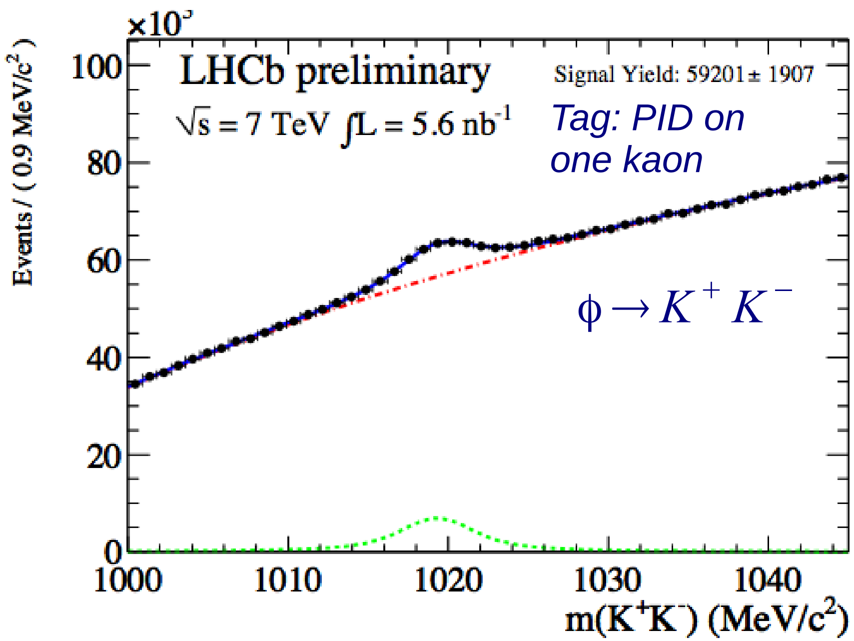


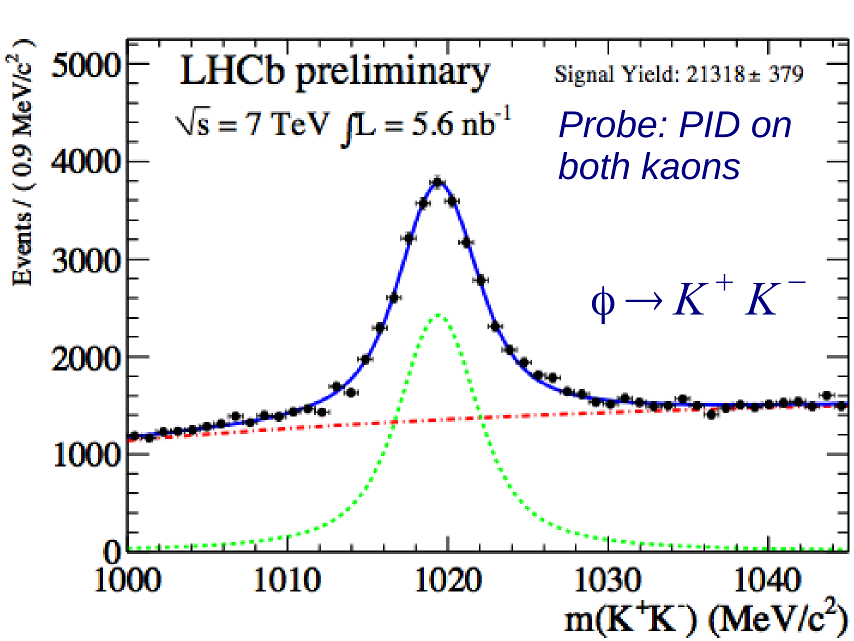
RICH performance

- *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*

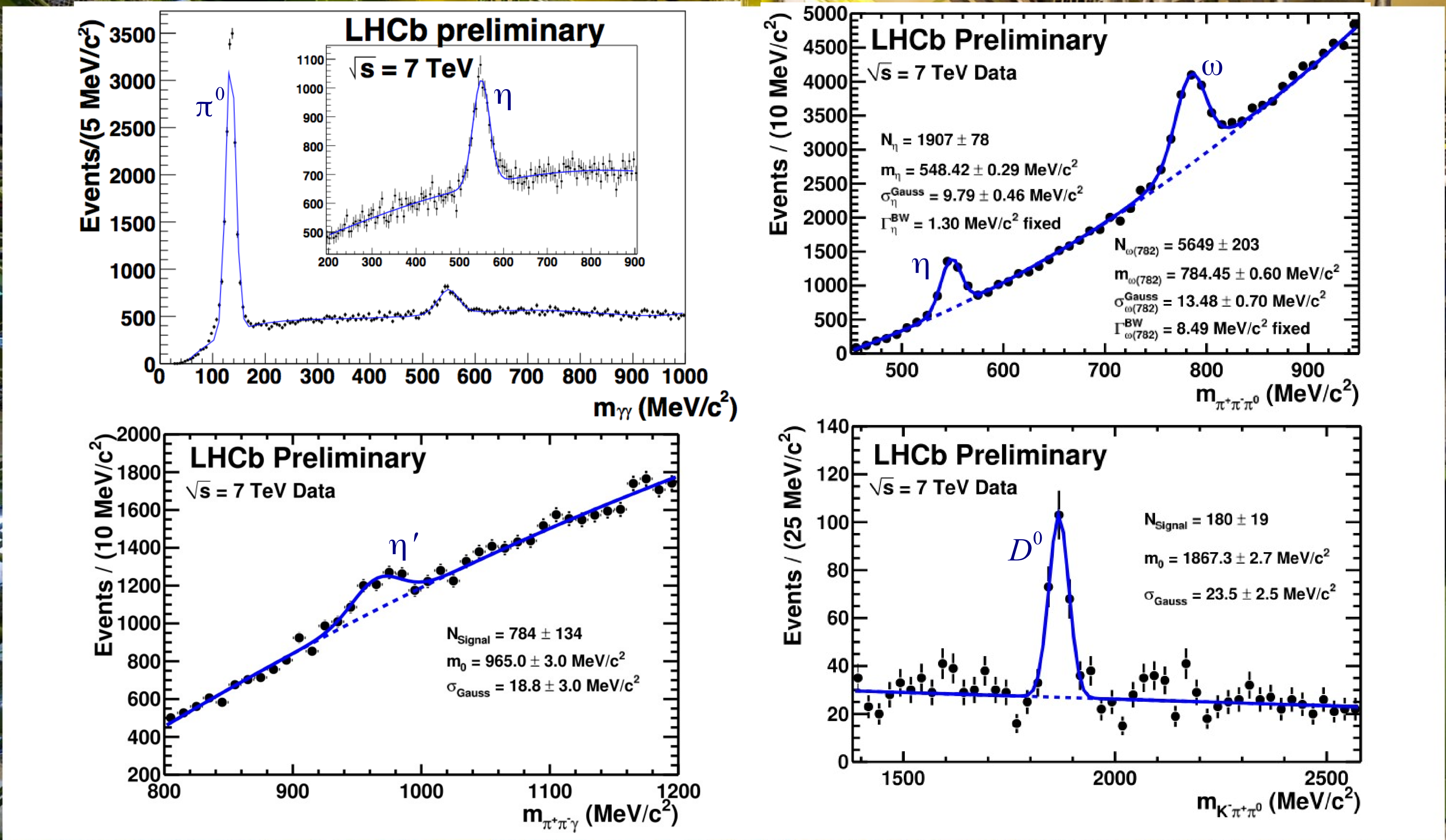




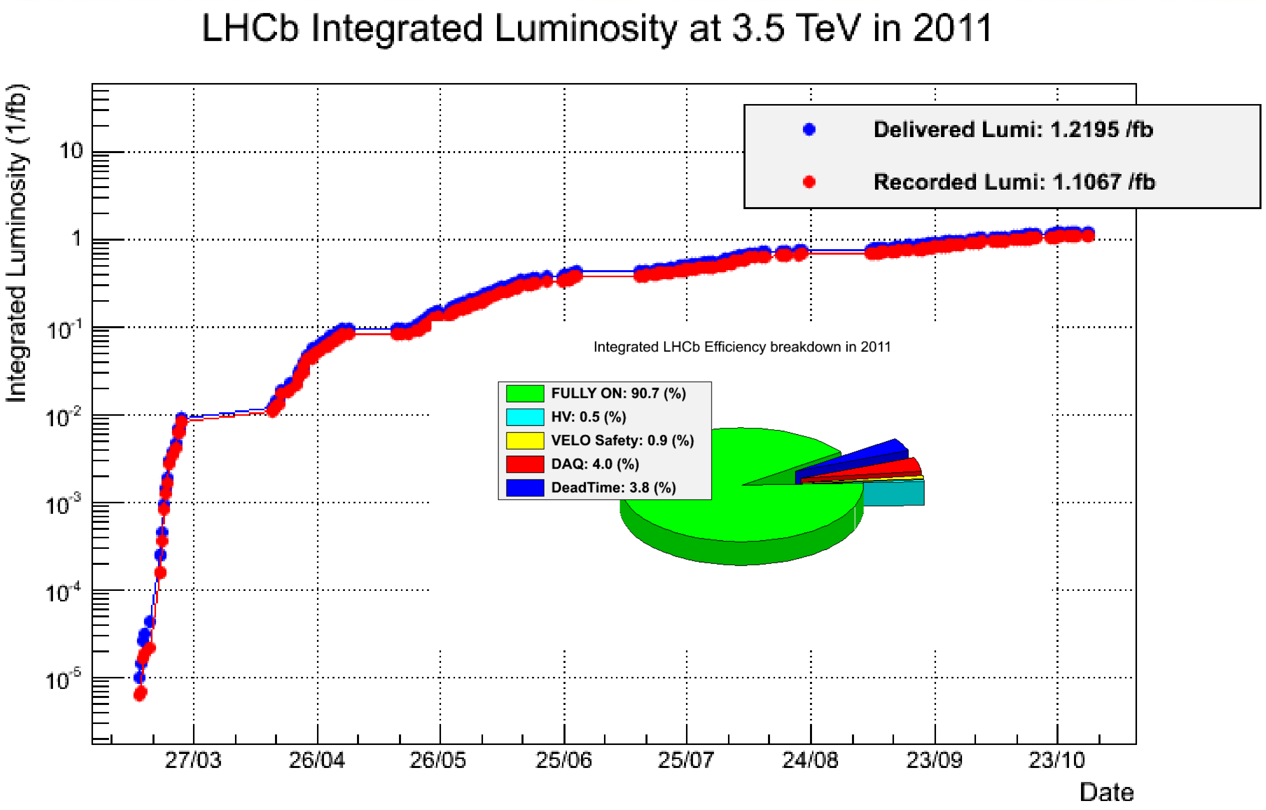




ECAL performance



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	1.0 fb^{-1}	7

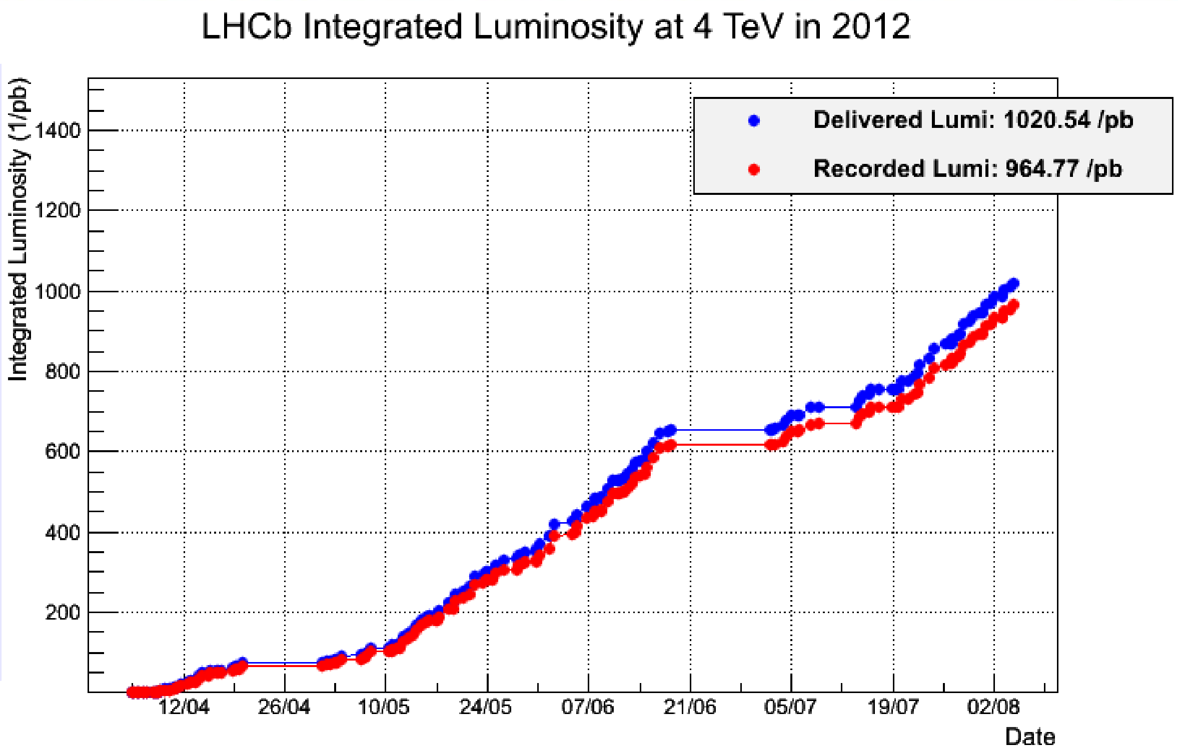
- *> 90 % data taking efficiency*
- *~99% r/o channels operational*
- *~99% of accumulated data is useful for physics analysis*

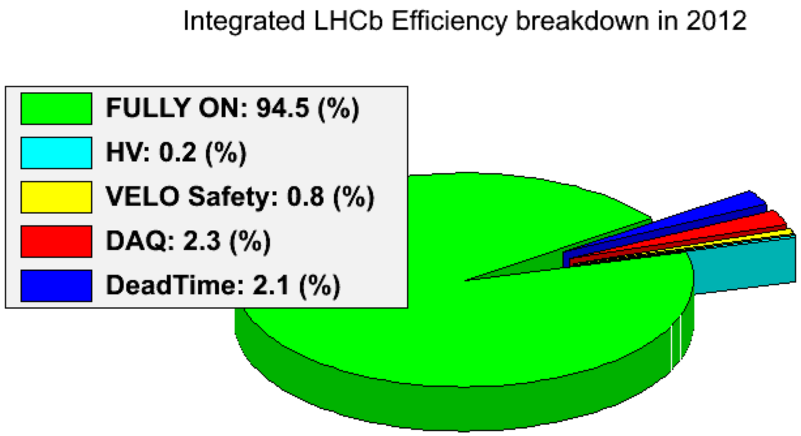
Running challenges:

- *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*

Current running conditions:

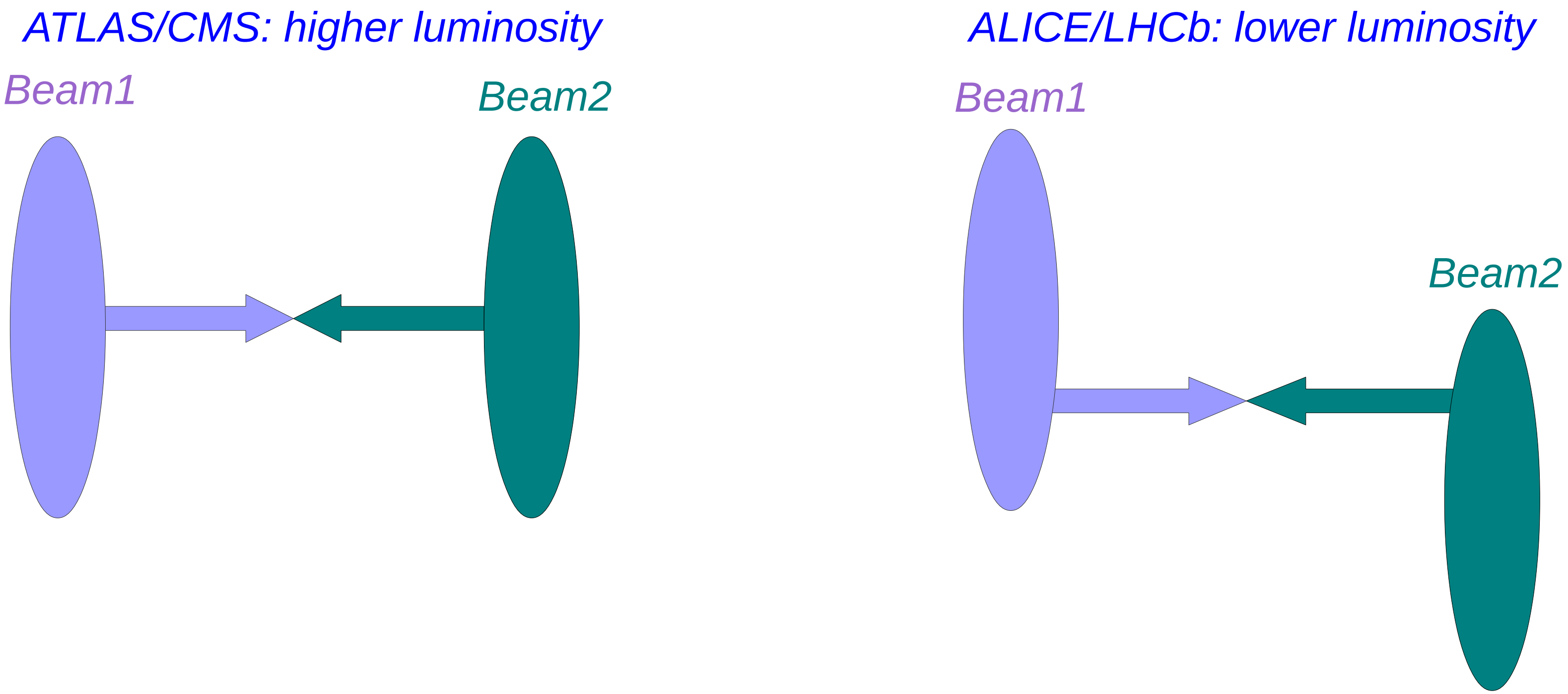
- *pp collisions at 8 TeV*
  → *15% increase of the $b\bar{b}$ cross-section w.r.t. 7 TeV*
- *luminosities up to 4×10^{32} cm^{-2} s^{-1}*
- *luminosity leveling (see next slide)*
- *>2 fb^{-1} is expected to be collected by the end of 2012*





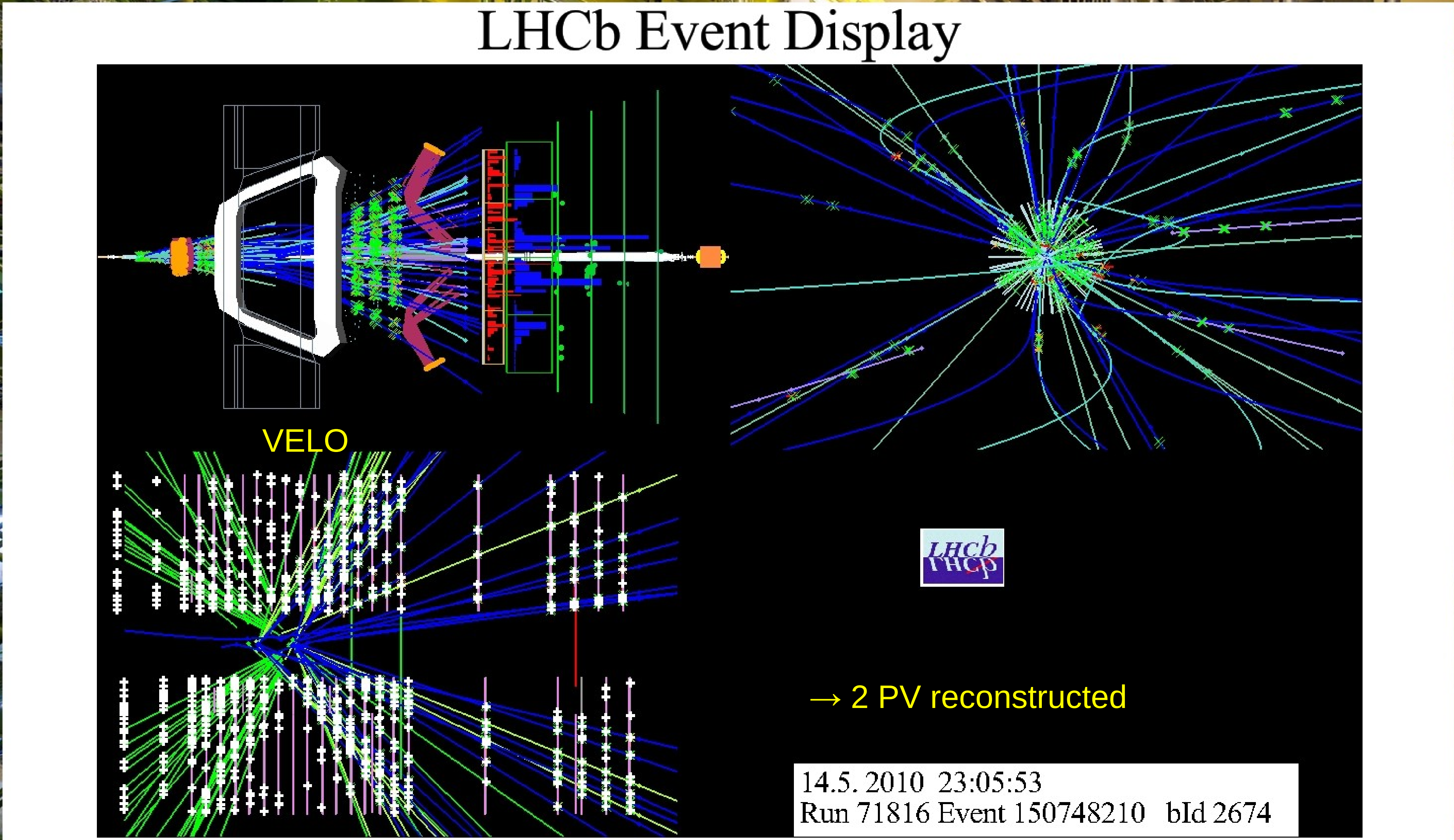
Luminosity leveling

- *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*

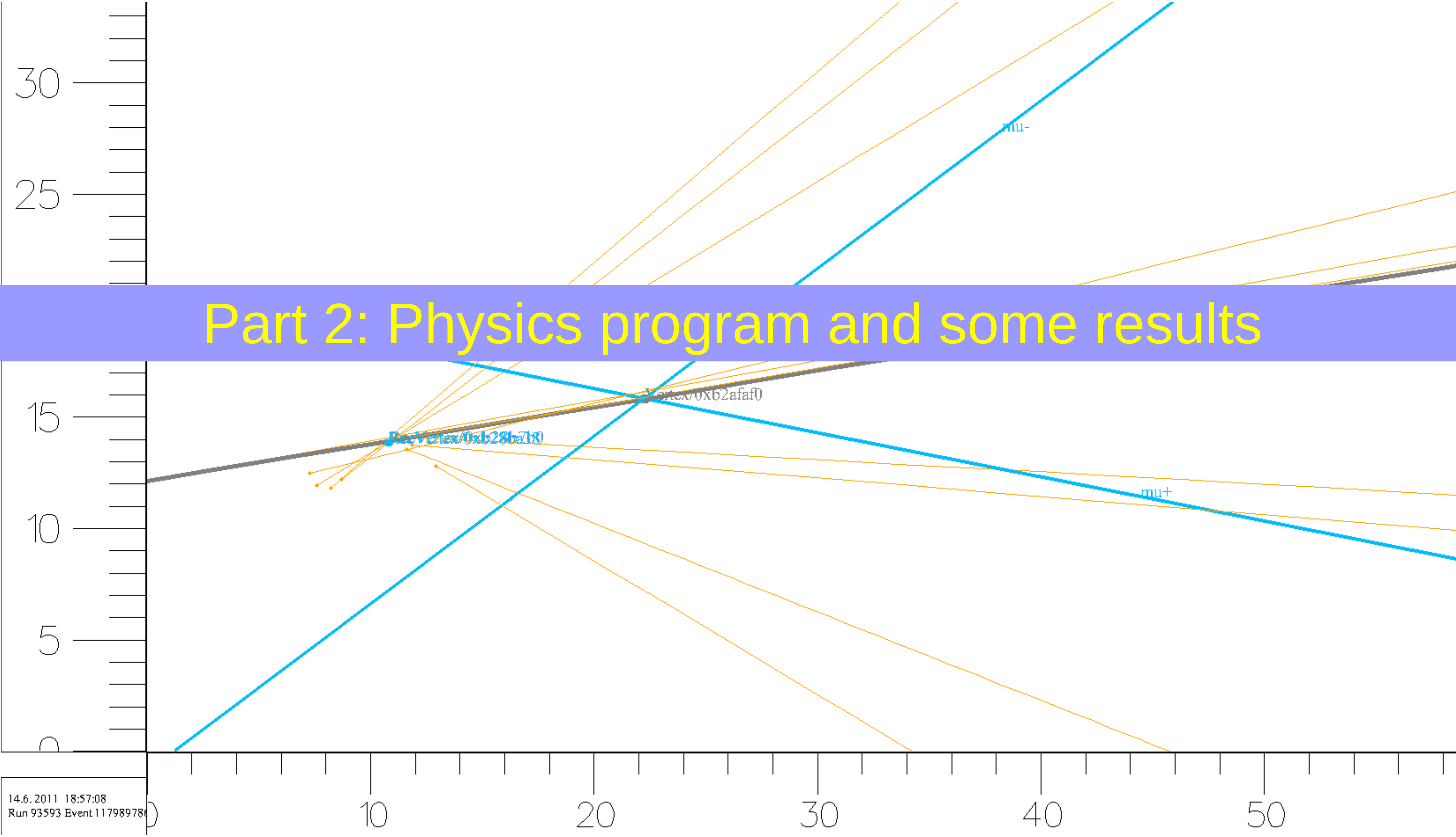


- *Offset between the beams reduces the amount of interactions*
- *LHC continuously displaces both beams w.r.t. each other: instantaneous luminosity at a roughly constant value for the whole duration of a fill*

Typical event



Part 2: Physics program and some results



=> 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 $B \rightarrow DK$
- B decays to double charm

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

=> 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

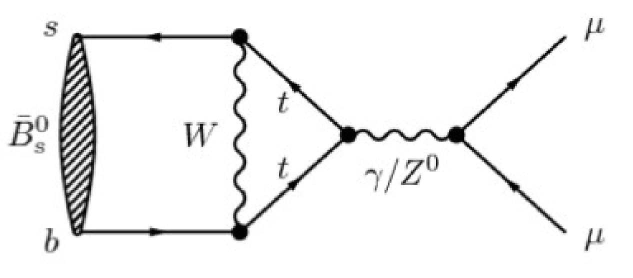
=> QCD, electroweak and exotica:
- Soft and hard QCD processes
- Particle production (incl. Electroweak bosons)
- PDF
- exotic long-lived particles

In this talk, recent results on:
- Rare decays: $B^0_{s,d} \rightarrow \mu^+ \mu^-$, $B^0 \rightarrow K^* \mu^+ \mu^-$
- Bs mixing
- CP violation measurements
- Energy Flow and Particle Multiplicities

are presented

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

- *FCNC decays strongly suppressed in SM:*



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

J. High Energy Phys. 10 (2010) 009
Acta Phys. Pol. B 41, 2487 (2010)

→ *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 @95% CL:*

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

Phys. Lett. B 708, 55 (2012)

- *Recent searches with 1fb^{-1} @ 7 TeV*

  → *control channels B→h+h-*

- *Selection with MVA Boosted Decision Tree*

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

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

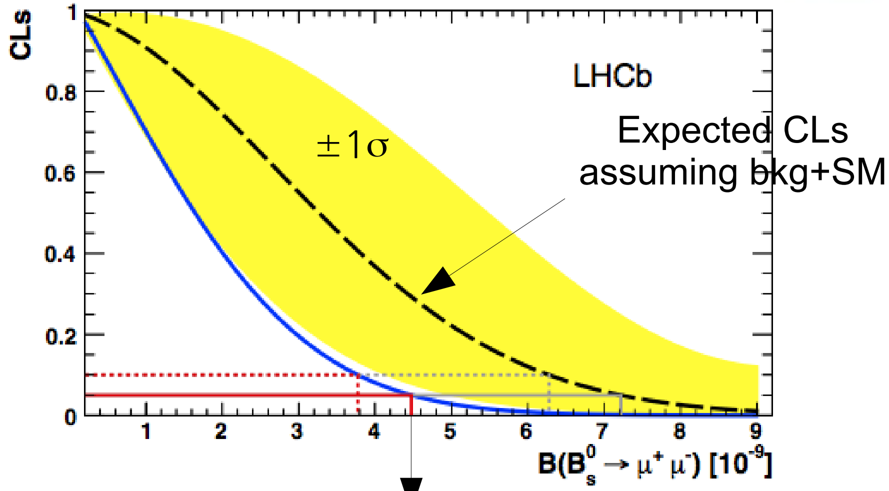
arXiv:1203.4493v2 [hep-ex] 26 Apr 2012

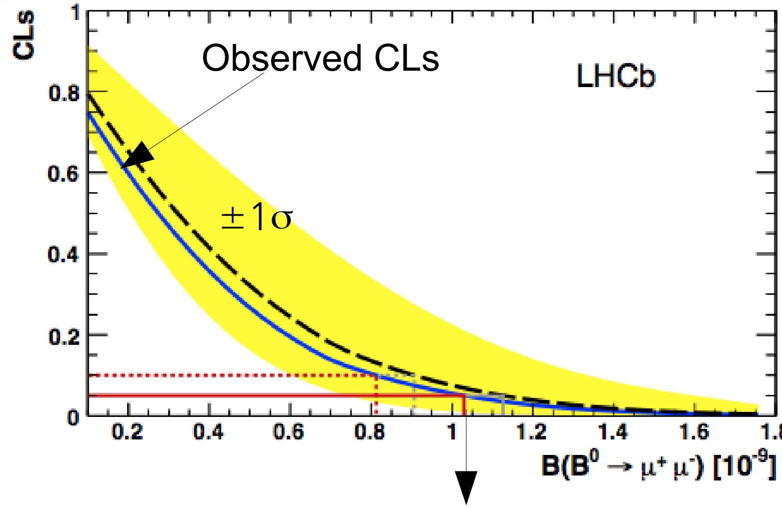
Strong constraints on the rare decays $B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$

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], C. Deplano[15], D. Derkach[14,35], O. Deschamps[5], F. Dettori[39], J. Dickens[44], H. Dijkstra[35], P. Diniz Batista[1], F. Domingo Bonal[33,n], S. Donleavy[49], F. Dordei[11], P. Dornan[50], A. Dosil Suárez[34], D. Dossett[45], A. Dovbnya[40], F. Dupertuis[36], R. Dzhelyadin[32], A. Dziurda[23], A. Dzyuba[27], S. Easo[46], U. Egede[50], V. Egorychev[28], S. Eidelman[31], D. van Eijk[38], F. Eisele[11], S. Eisenhardt[47], R. Ekelhof[9], L. Eklund[48], Ch. Elsasser[37], D. Elsby[42], D. Esperante Pereira[34], A. Falabella[16,e,14], C. Färber[11], G. Fardell[47], C. Farinelli[38], S. Farry[12], V. Fave[36], V. Fernandez Albor[34], M. Ferro-Luzzi[35], S. Filippov[30], C. Fitzpatrick[47], M. Fontana[10], F. Fontanelli[19,i], R. Forty[35], O. Francisco[2], M. Frank[35], C. Frei[35], M. Frosini[17,f], S. Furcas[20], A. Gallas Torreira[34], D. Galli[14,c], M. Gandelman[2], P. Gandini[52], Y. Gao[3], J-C. Garnier[35], J. Garofoli[53], J. Garra Tico[44], L. Garrido[33], D. Gascon[33], C. Gaspar[35], R. Gauld[52], N. Gauvin[36], M. Gersabeck[35], T. Gershon[45,35], Ph. Ghez[4], V. Gibson[44], V.V. Gligorov[35], C. Göbel[54], D. Golubkov[28], A. Golutvin[50,28,35], A. Gomes[2], H. Gordon[52], M. Grabalosa Gándara[33], R. Graciani Diaz[33], L.A. Granado Cardoso[35], E. Graugés[33], G. Graziani[17], A. Grecu[26], E. Greening[52], S. Gregson[44], O. Grünberg[55], B. Gui[53], E. Gushchin[30], Yu. Guz[32], T. Gys[35], C. Hadjivasiliou[53], G. Haefeli[36], C. Haen[35], S.C. Haines[44], T. Hampson[43], S. Hansmann-Menzemer[11], N. Harnew[52], J. Harrison[51], P.F. Harrison[45], T. Hartmann[55], J. He[7], V. Heijne[38], K. Hennessy[49], P. Henrard[5], J.A. Hernando Morata[34], E. van Herwijnen[35], E. Hicks[49], K. Holubyev[11], P. Hopchev[4], W. Hulsbergen[38], P. Hunt[52], T. Huse[49], R.S. Huston[12], D. Hutchcroft[49], D. Hynds[48], V. Iakovenko[41], P. Ilten[12], J. Imong[43], R. Jacobsson[35], A. Jaeger[11], M. Jahjah Hussein[5], E. Jans[38], F. Jansen[38], P. Jaton[36], B. Jean-Marie[7], F. Jing[3], M. John[52], D. Johnson[52], C.R. Jones[44], B. Jost[35], M. Kaballo[9], S. Kandybei[40], M. Karacson[35], T.M. Karbach[9], J. Keaveney[12], I.R. Kenyon[42], U. Kerzel[35], T. Ketel[39], A. Keune[36], B. Khanji[6], Y.M. Kim[47], M. Knecht[36], I. Komarov[29], R.F. Koopman[39], P. Koppenburg[38], M. Korolev[29], A. Kozlinskiy[38], L. Kravchuk[30], K. Kreplin[11], M. Kreps[45], G. Krocker[11], P. Krokovny[31], F. Kruse[9], K. Kruzelecki[35], M. Kucharczyk[20,23,35,j], V. Kudryavtsev[31], T. Kvaratskheliya[28,35], V.N. La Thi[36], D. Lacarrere[35], G. Lafferty[51], A. Lai[15], D. Lambert[47],

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





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

$BR < 1.0 \times 10^{-9}$ @ 95% CL

Status as of June 2012 at 95% CL:

experiment	*Lint*	$BR(B^0_s \to \mu^+\mu^-)$	$BR(B^0_d \to \mu^+\mu^-)$	*reference*
ATLAS	2.4 fb^{-1}	$<2.2\times10^{-8}$	no result	arXiv:1204.0735v3
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 much less data gets better results and sets world's best upper limits !*
- *Results impose strong constraints on SUSY models*
- *By the end of 2012 LHCb should observe the SM signal at ~3 sigma (if it does exist...)*

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

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

→ high sensitivity to New Physics: new particles may enter in loop diagrams causing large deviations from the SM

- *Some 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 $1 fb^{-1}$ @ 7 TeV*

- *Selection with MVA Boosted Decision Tree*

- *Rejection of J/ψ and ψ(2S) resonances*

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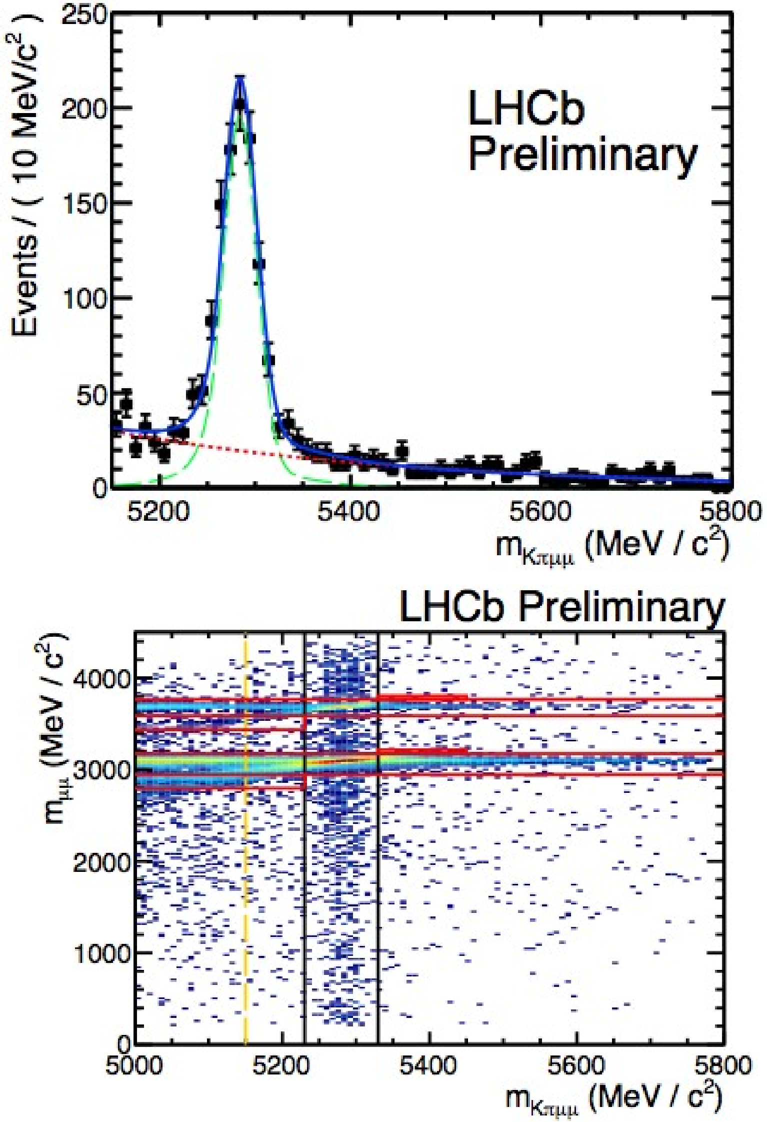


$B_d^0 \to K^* \mu^+ \mu^-$ Analysis (2)

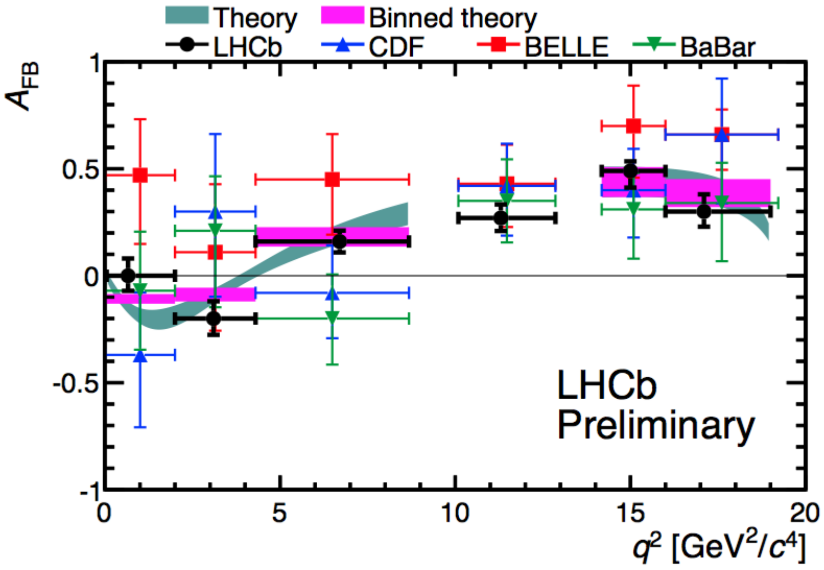
- *Much more precise measurement of the observables than by the previous experiments*
- *Results are in good agreement with SM*
- *First measurement:*

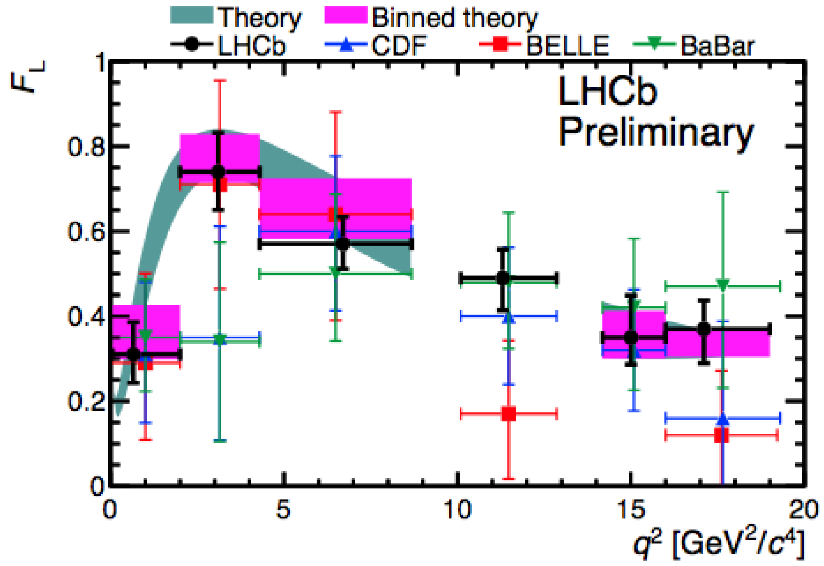
$$q^2(A_{FB}=0)=4.9^{+1.1}_{-1.3}\,GeV^2/c^4$$

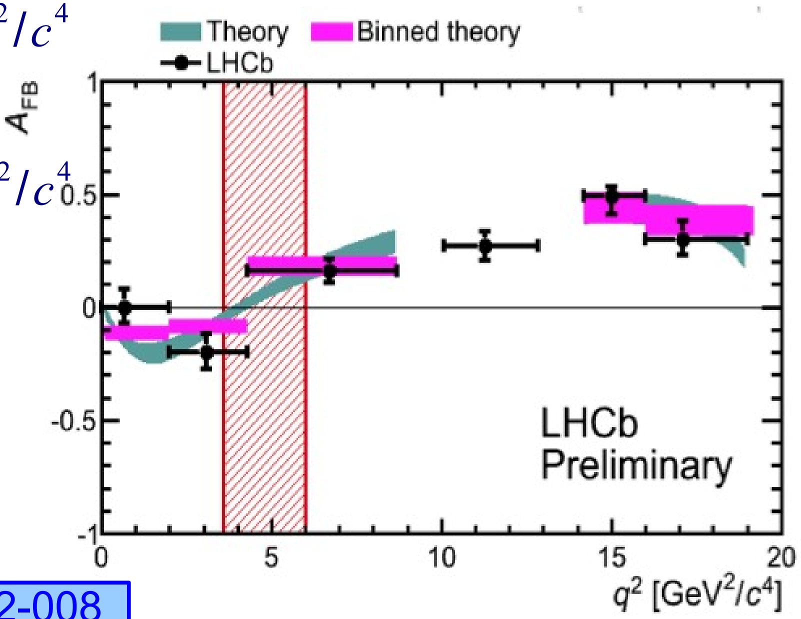
SM prediction:

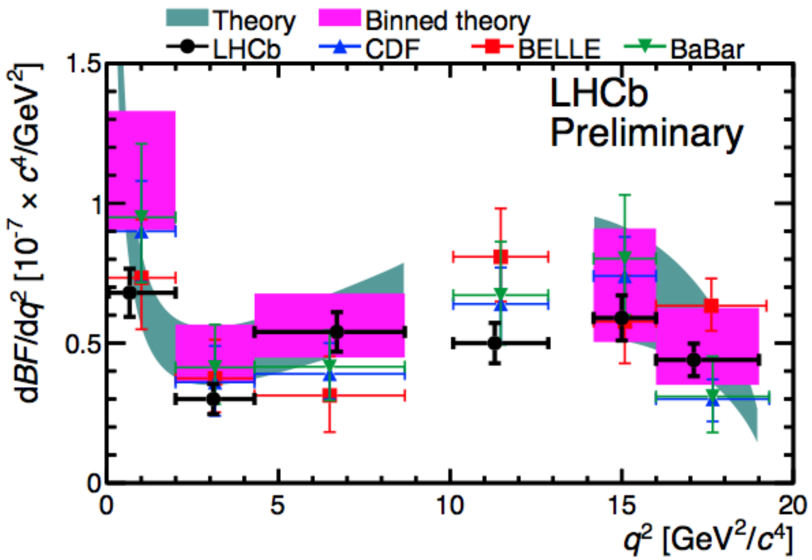
$$q^2(A_{FB}=0)=4-4.3\,GeV^2/c^4$$

- *better precision with more data + additional observables*









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Prompt reaction

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

CERN-PH-TH/2012-120

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

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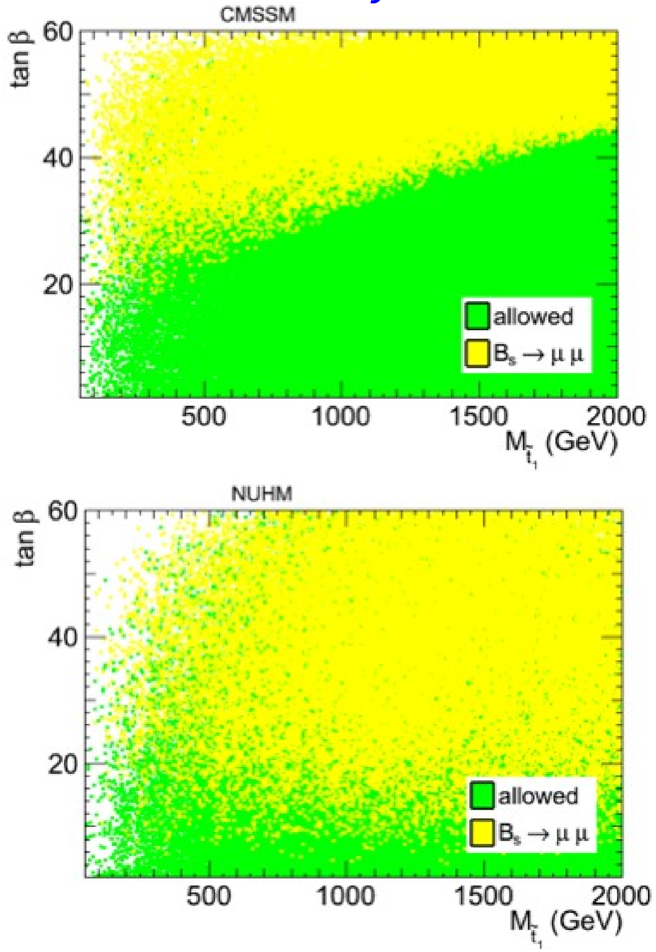
LPC, BP 10448, 63000 Clermont-Ferrand, France

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

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.



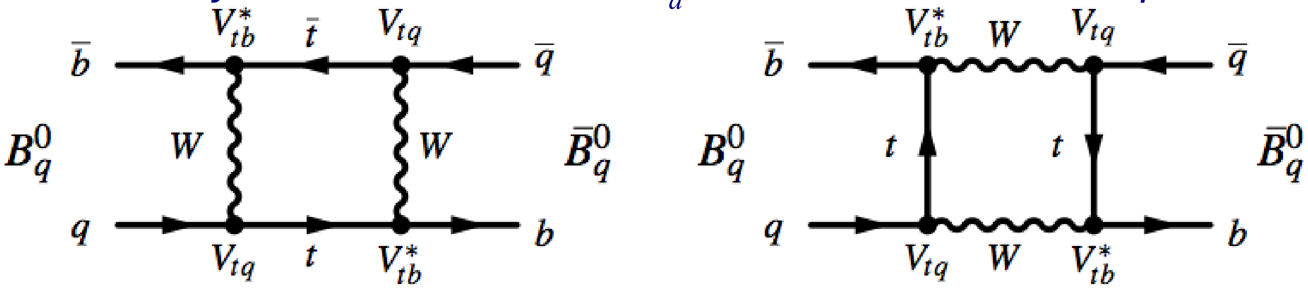
- *SUSY with large $\tan\beta$ is practically excluded*

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 is much better explored*

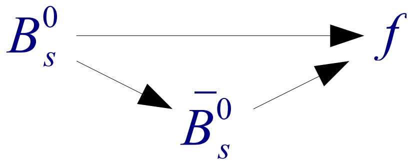


$q \in [d, s]$

- *Some observables of interest:*

  → $\Delta\Gamma_s$ *decay width differences between the heavy and light* B_s^0 *eigenstates*

  → ϕ_s *weak mixing phase of the* $B_s^0 - \bar{B}_s^0$ *oscillations, directly related to the CKM angle* χ, *tiny in SM* *(high sensitivity to New Physics)* *extraction via measurements of time-dependent CP-asymmetry in* $b \to c\bar{c}s$ *transition*



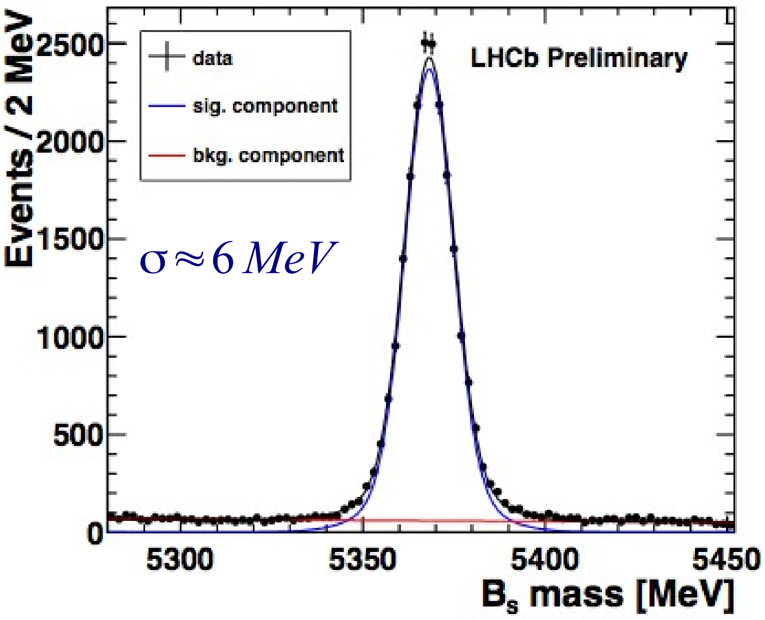
Interference gives rise to ϕ_s

=> *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 $1\,\mathrm{fb}^{-1}$
- *LHCb-CONF-2012-002 5 March 2012:* $\phi_s, \Gamma_s, \Delta\Gamma_s$ from $B_s^0 \to J/\psi\,\phi$ with $1\,\mathrm{fb}^{-1}$

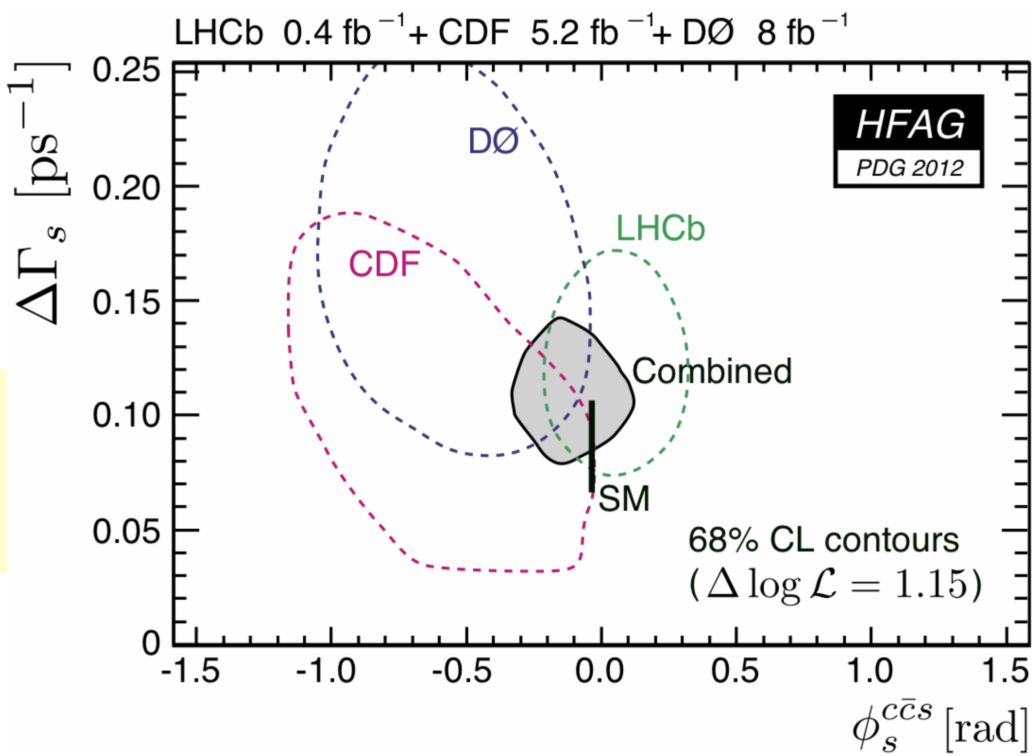
B_s^0 mixing (2)

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



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

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



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

Selected CP violation results

- *CP violation in charm sector is tiny in SM*
  → 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

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

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

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

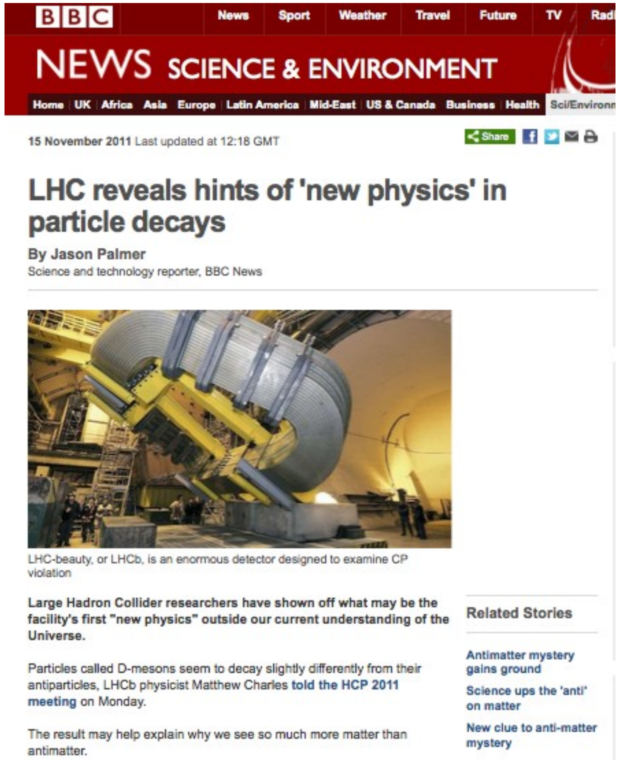
Evidence for *CP* Violation in Time-Integrated $D^0 \to h^- h^+$ Decay Rates

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

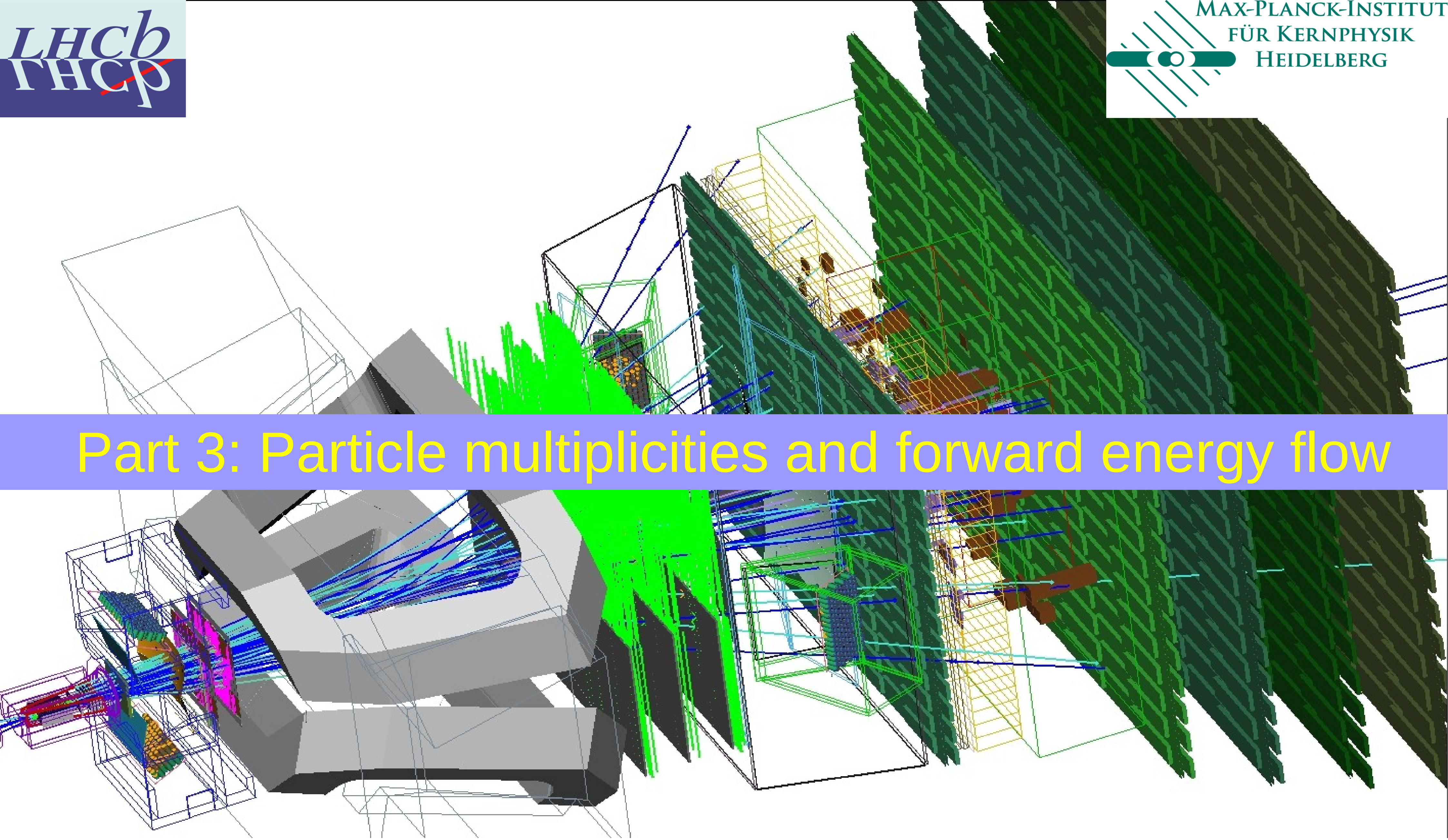
LHC-beauty, or LHCb, is an enormous detector designed to examine CP violation

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.

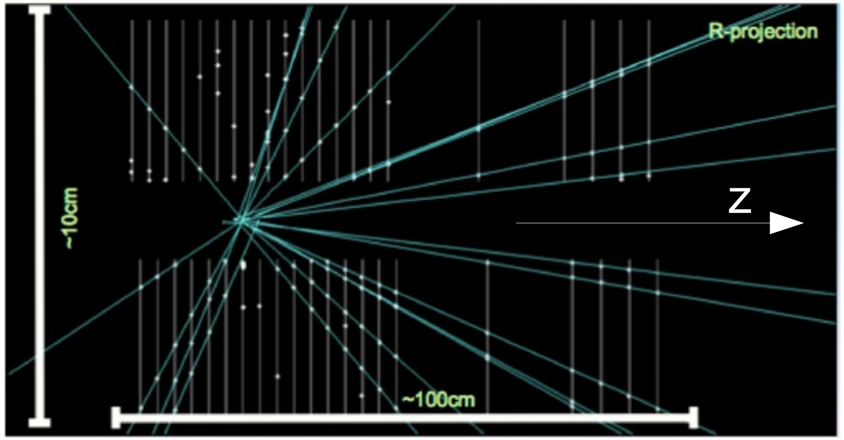
Related Stories
Antimatter mystery gains ground
Science ups the 'anti' on matter
New clue to anti-matter mystery



Part 3: Particle multiplicities and forward energy flow

Charged Particle Multiplicities (1)

- *Measurement of the charged particle multiplicities :*
  - → *sensitivity to the underlying QCD dynamics*
  - → *charged particles counted using reconstructed tracks in the LHCb VELO:*
    - – *high detection efficiency for 2.0<η<4.5 and –2.5<η<–2.0*
    - – *tracks are straight lines in the VELO as no magnetic field there – no momentum measurements*
  - → *measurements with minimum bias and hard interaction (at least 1 long track with p_T>1 GeV/c) events*



- *Charged particle density per event vs η for the data and models:*
  - → *normalized to events with at least 1 charged particle in the forward acceptance*

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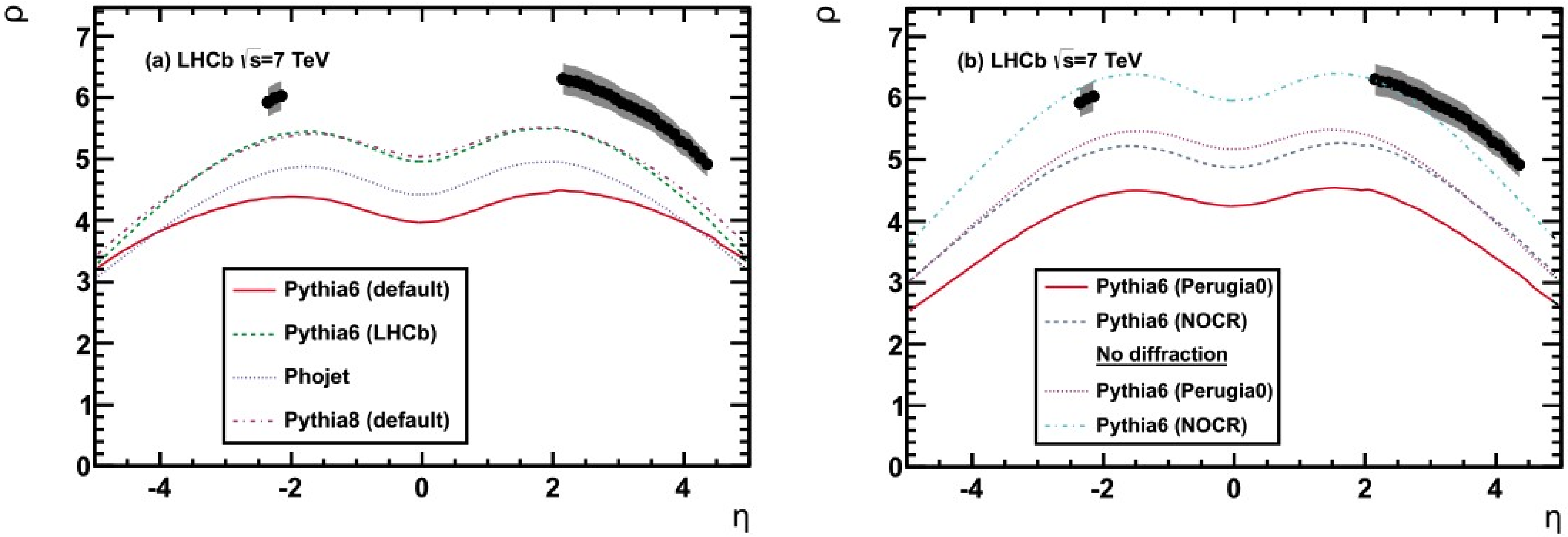
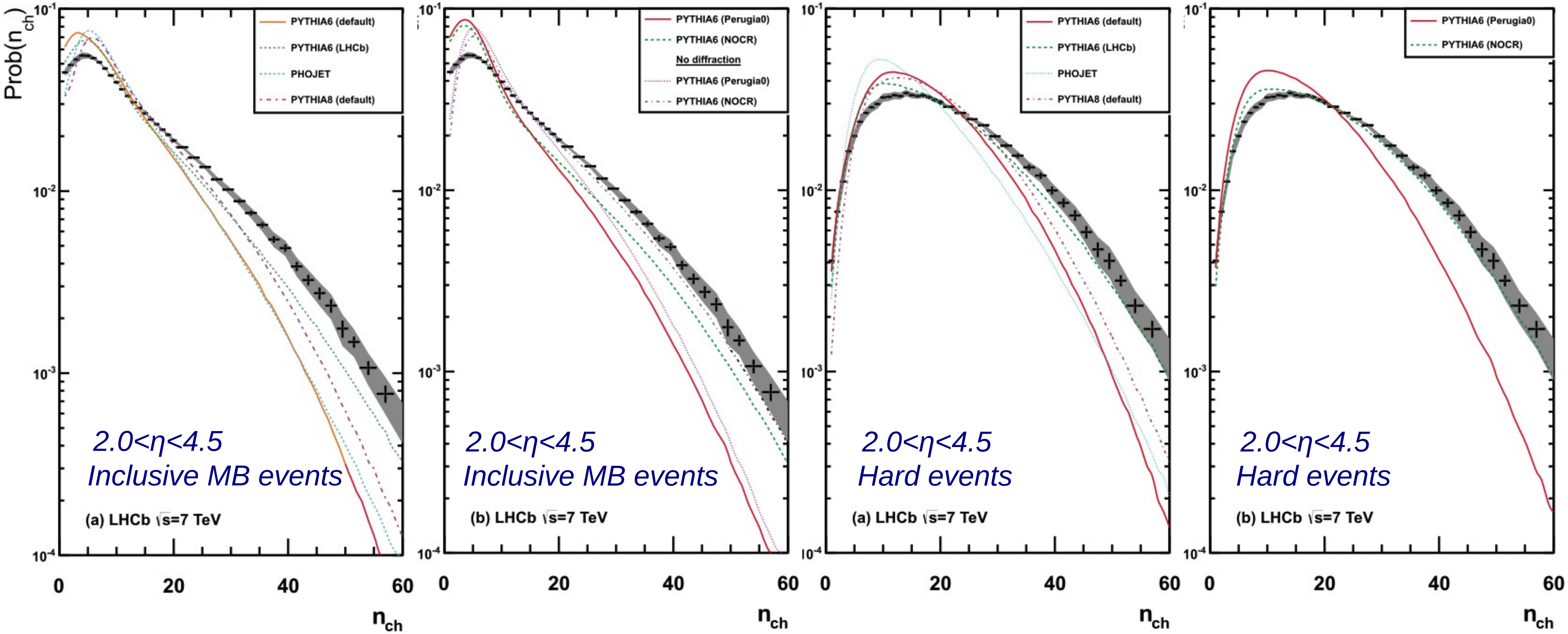


→ *large discrepancy between the data and model predictions: Perugia NOCR without diffraction gives the best description of the measurements*

Charged Particle Multiplicities (2)

- *multiplicity distributions for inclusive MB and hard events vs generator level predictions:*



Eur. Phys. J. C 72 (2012) 1947

- *none of the generators are fully able to describe the multiplicity distributions or the charged density distribution as a function of η in the LHCb acceptance*

- *models underestimate the charged particle production in the forward region*
  → valuable input for MC tuning and UE models + powerful test for the cosmic-ray interaction models

Forward Energy Flow: outline

- Energy Flow (EF) :

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$$\frac{1}{N_{\rm int}}\frac{dE_{tot}}{d\eta} = \frac{1}{\Delta\eta}\left(\frac{1}{N_{\rm int}}\sum_{i=1}^{N_{part,\eta}} E_{i,\eta}\right)$$

average energy created in a particular η interval per inelastic pp interaction and normalized to the η bin size

- EF directly sensitive to the amount of parton radiation and multi-parton interactions (MPI) at large pseudorapidity

→ MPI features are still not well known: strongly needed for a precise description of the UE

→ possibility to discriminate between MPI models and determine important parameters

→ great input for MC tuning

- it has never been measured at a hadron collider in the pre-LHC era

→ CMS has recently made first measurements at 7 TeV for 3.15<|η|<4.9

- EF is measured in 1.9<η<4.9 with low pile-up pp MB data at 7 TeV for the following event classes:

→ inclusive MB: at least 1 long track in 1.9<η<4.9 with p > 2 GeV/c

→ hard scattering: at least 1 long track in 1.9<η<4.9 with p_T > 3 GeV/c

→ diffractive enriched: inclusive MB with no backward tracks in −3.5<η<−1.5

→ non-diffractive enriched: inclusive MB with at least 1 backward track in −3.5<η<−1.5

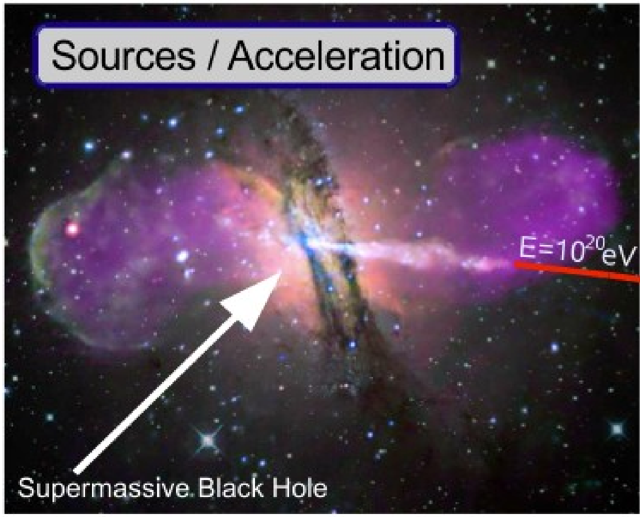
- Data corrected for detector effects & compared to the generator level predictions (PYTHIA-based and cosmic-ray models)
- Systematic effects: tracking related factors, model dependency, pile-up contamination

Forward Energy Flow and CR physics

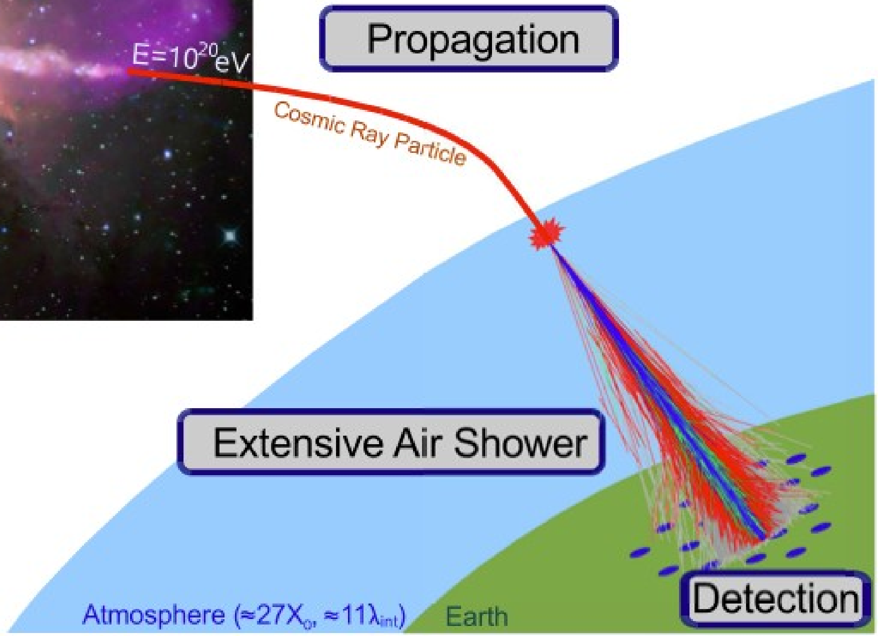
Cosmic Rays and Extensive Air Showers

- *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*



by Ralf Ulrich



- *First analysis where LHCb data are compared with the cosmic ray interaction models:*

  many thanks to Colin Baus and Ralf Ulrich from KIT

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

Charged EF vs PYTHIA tunes

- Charged EF increases with the momentum transfer in an underlying pp process: $EF_{hard} > EF_{non\text{-}diffr} > EF_{incl} > EF_{diffr}$
- PYTHIA-based models underestimate EF at large η in case of all event classes
- Perugia NOCR gives the best description of the inclusive charged EF among the tunes
- None of the models provide a reasonable description of the hard scattering charged EF at large η
- PYTHIA8 describes the diffractive enriched charged EF much better than PYTHIA6

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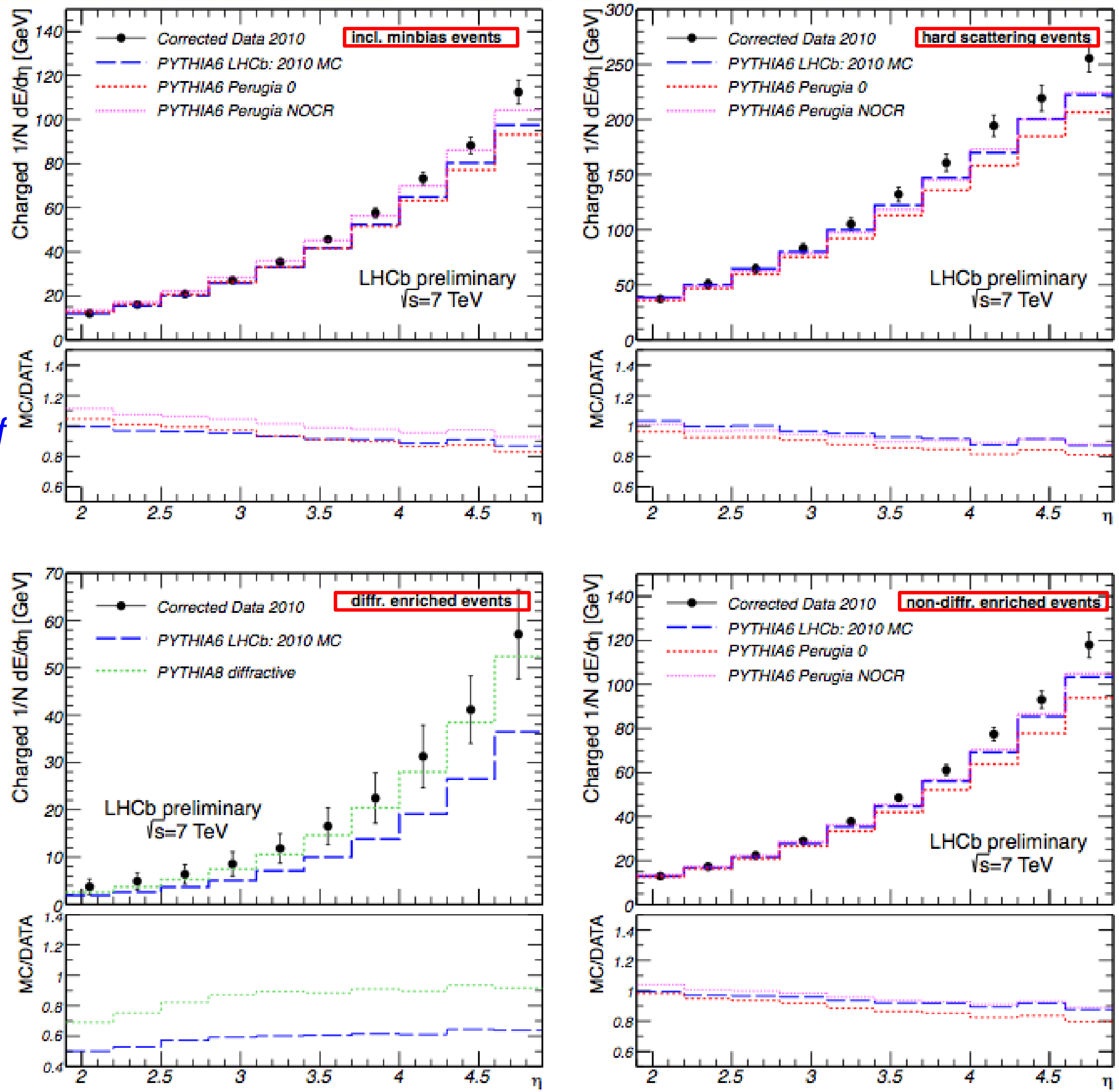

Charged EF vs cosmic-ray models

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- *EPOS 1.99, SYBILL 2.1, QGSJET01, QGSJETII cosmic-ray interaction models*
  - *→ soft processes via Pomeron exchanges (Gribov's Reggeon Field Theory)*
  - *→ hard processes: pQCD or exchanges of semi-hard Pomerons*
  - *→ models are not tuned to LHC data*
- *Good agreement between the data and SIBYLL 2.1 & EPOS 1.99 predictions for the inclusive and non-diffractive enriched charged EF*
- *QGSJETII-03 gives good description of the data at large pseudorapidity in case of hard scattering interactions*
- *All cosmic-ray interaction models underestimate the diffractive enriched charged EF*

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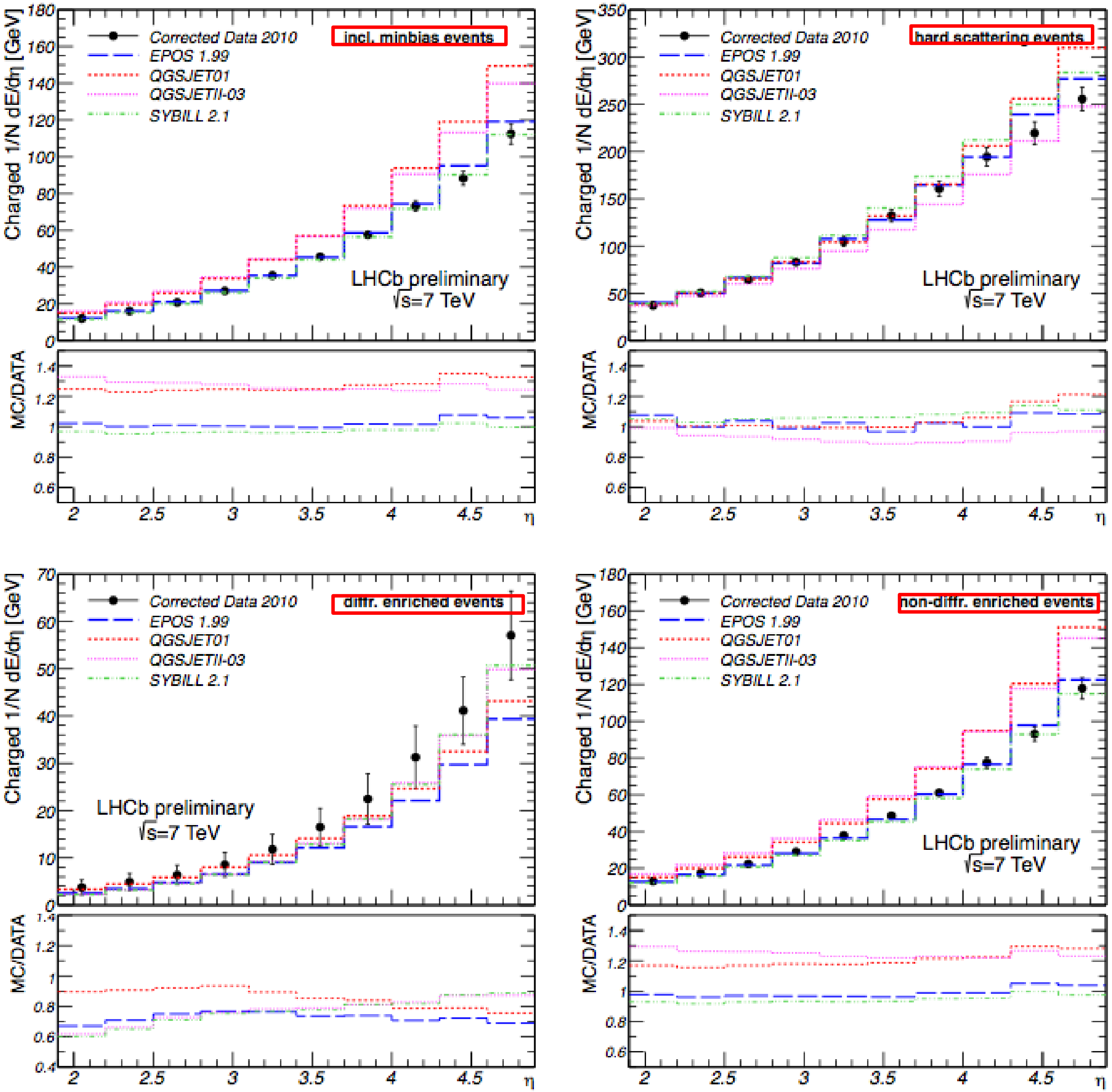

Total EF vs PYTHIA tunes

- *EF increases with the momentum transfer in an underlying pp process:*
  $EF_{hard} > EF_{non\text{-}diffr} > EF_{incl} > EF_{diffr}$
- *PYTHIA tunes reproduce the EF evolution as a function of η*
- *PYTHIA-based models underestimate EF at large η and overestimate it at low η in case of all event classes*
- *PYTHIA LHCb tune and Perugia NOCR predictions for the selected inclusive and non-diffractive enriched events are similar*
- *Perugia 0 significantly underestimates EF at large η in case of all event classes*
- *PYTHIA8 describes the diffractive enriched EF much better than PYTHIA6*

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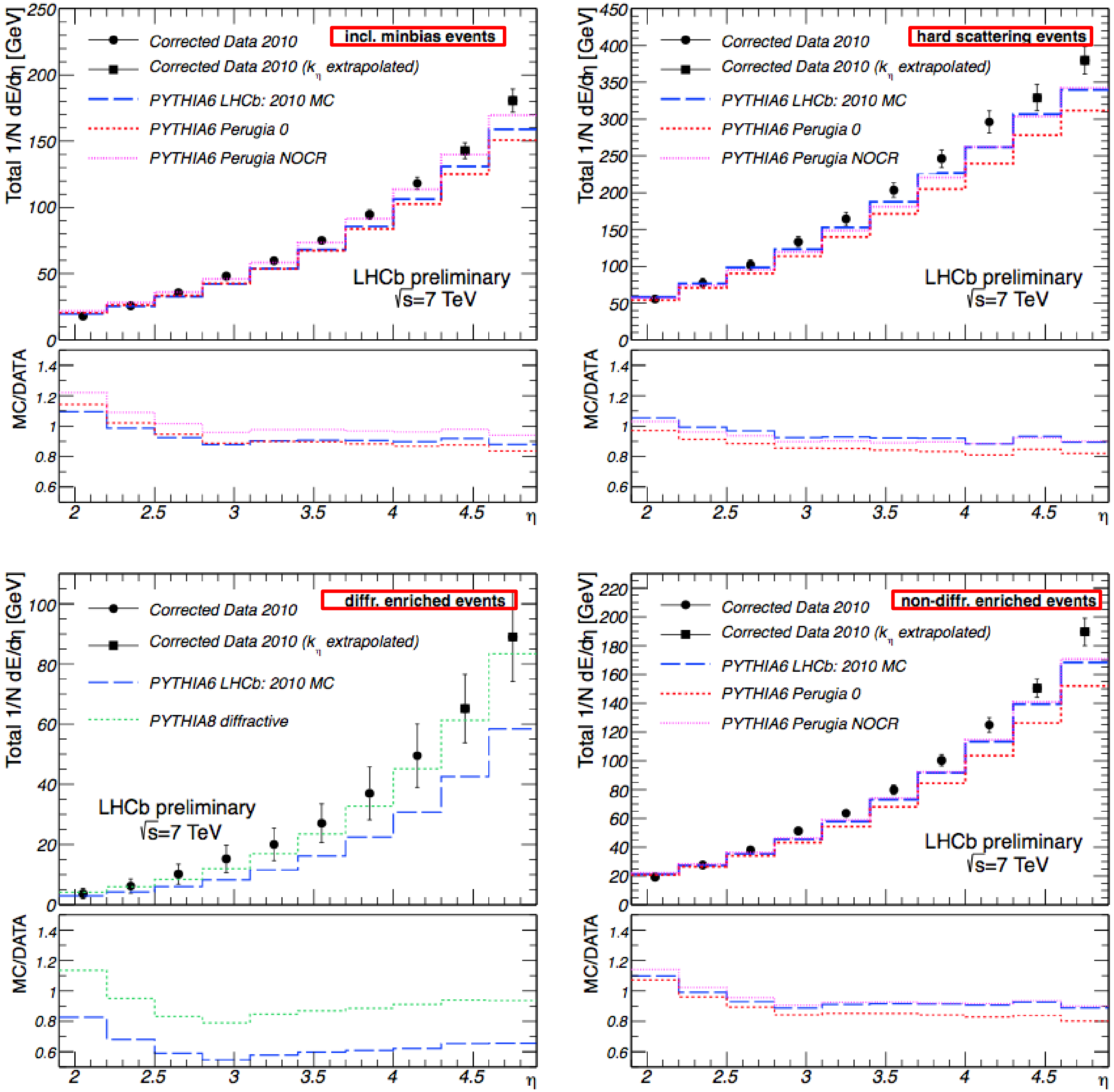

Total EF vs cosmic-ray models

- *SYBILL 2.1 gives the best description of the inclusive and non-diffractive EF*
- *EPOS 1.99 describes the inclusive and non-diffractive EF reasonably well*
- *Good agreement between the data and QGSJETII prediction for the hard scattering EF at large η*
- *Diffractive enriched EF is underestimated by all cosmic-ray interaction models:*
  → SIBYLL 2.1 description is competitive with the one given by PYTHIA8
- *None of the models are able to describe the EF measurements for all event classes:*
  → valuable input for MC tuning and MPI/UE models

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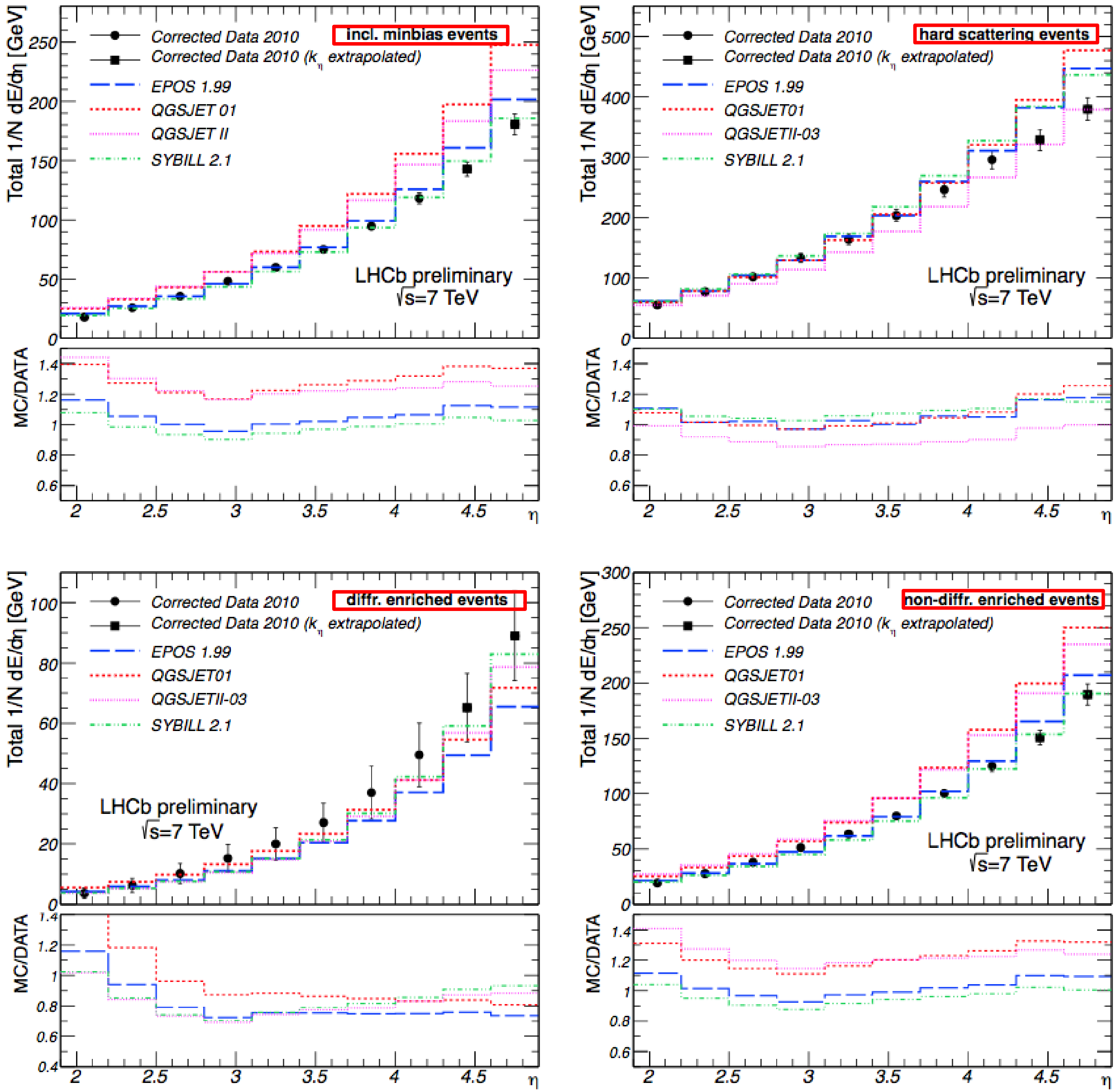

Summary

- *LHCb detector achievements:*
  - *→ excellent vertex resolutions, great tracking performance, robust particle ID*
  - *→ great conditions to deliver high-quality physics results*
- *63 papers are already submitted to journals, a lot more in the pipeline*
- *world's best measurements of many important physics parameters:*
  - *→ so far no evidence of New Physics beyond the Standard Model is observed*
- *SIBYLL 2.1 and EPOS 1.99 cosmic-ray generators give good description of the inclusive and non-diffractive enriched energy flow:*
  - *→ further studies of LHCb data vs cosmic ray models are on the way – stay tuned*
- *LHCb is much more than just a beauty experiment :-)*

Backup: Trigger System