Searches for Higgs and Higgs-like particles at LHCb

Valdir Salustino Guimarães - on behalf of the LHCb Collaboration

WIN 2013 - September 16 - 23
Natal - Brazil

Introduction

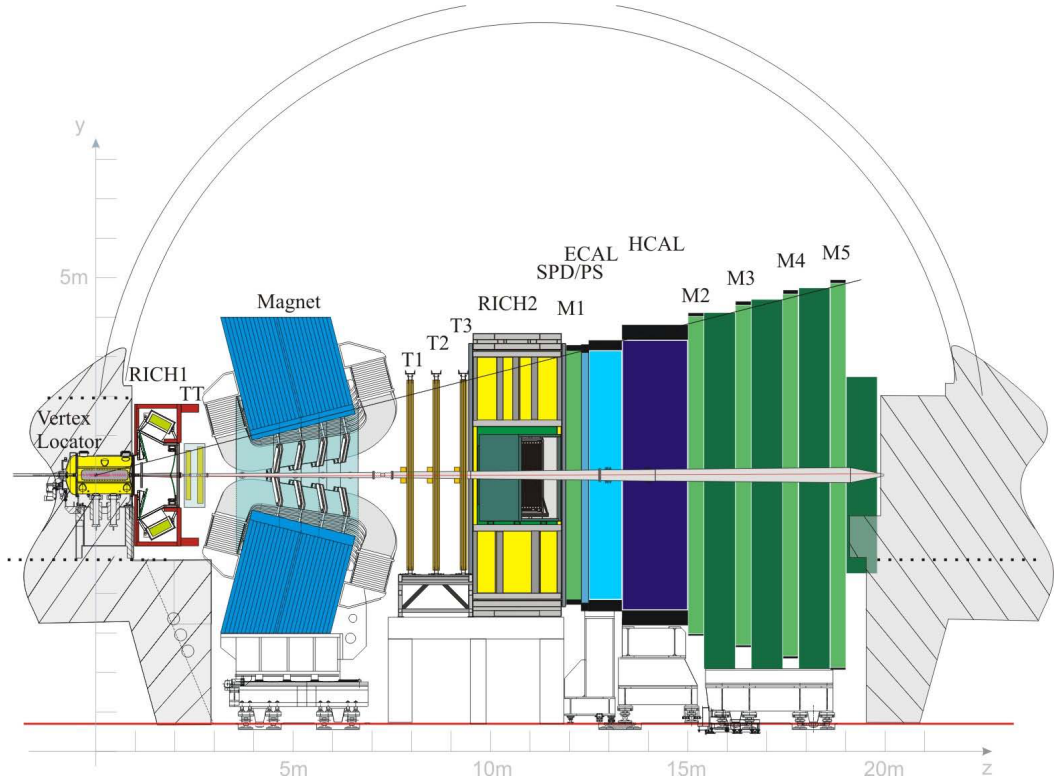
Presentation of the results from

J. High Energy Phys. 05 (2013) 132 and LHCb-CONF-2012-014

- Set limits on $\Phi_0 \rightarrow \tau^+\tau^-$ production in the **forward** region.
- Model dependent search for **L**ong **L**ived **P**article from higgs like boson decay.

The LHCb detector

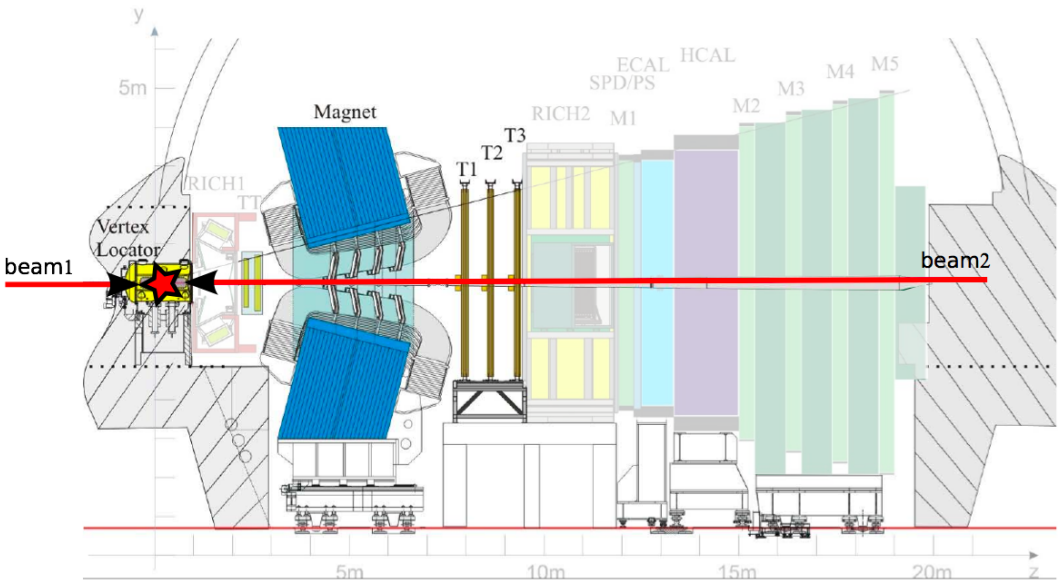
[2008 JINST 3 S08005]



- LHCb experiment is fully instrumented over a unique region of pseudorapidity at LHC.
- Designed for CP violation studies in B decay and rare decays.
- Single arm spectrometer covering the pseudorapidity range of $2 < \eta < 5$, where ~ 27 % of $b\bar{b}$ are in acceptance.

The LHCb detector

[2008 JINST 3 S08005]



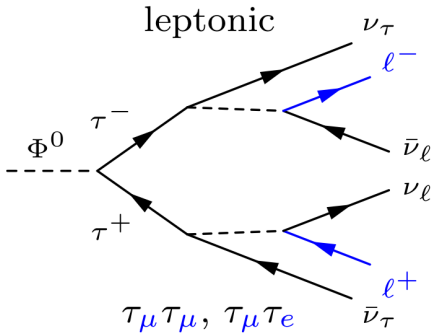
- Tracking efficiency > 95 %.
- $\delta p/p \sim 0.4\%$ at 5 GeV to 0.6% at 100 GeV/c^2.
- IP parameter resolution of 20 μm for high-pT tracks - important for b-tagging.
- 1.0 fb^{-1} at $\sqrt{s} = 7$ TeV and 2.0 fb^{-1} at $\sqrt{s} = 8$ TeV.
- Very stable data taking with average pile-up 2.

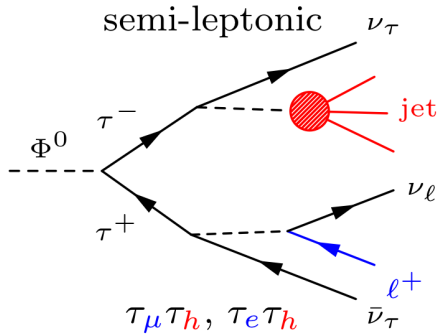
Limits on $\Phi_0 \to \tau^+\tau^-$ production [J. High Energy Phys. 05 (2013) 132]

Dataset

1.0 fb^{-1} at $\sqrt{s} = 7$ TeV (collected in 2011)

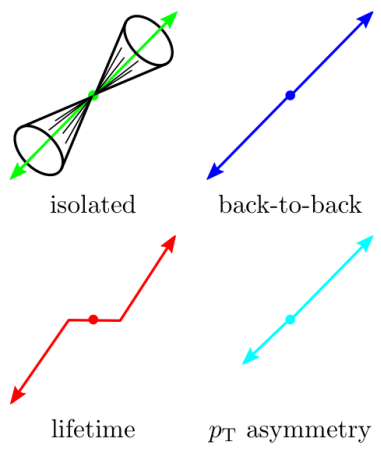
- Data sample used in $Z \to \tau\tau$ cross-section measurement [JHEP 01 (2013) 111]
- Selected 5 datasets: $\tau_\mu\tau_\mu$, $\tau_\mu\tau_e$, $\tau_e\tau_\mu$, $\tau_\mu\tau_h$ and $\tau_e\tau_h$.





Selection

- $p_{T1} > 20$ GeV $p_{T2} > 5$ GeV, $2.0 < \eta_{1,2} < 4.5$.
- Track displaced from PV, in $\tau_\mu\tau_\mu$, $\tau_\mu\tau_h$ and $\tau_e\tau_h$.
- $\Delta\phi > 2.7$ and $m_{1,2} > 20$ GeV.
- Lepton isolation.
- In $\tau_\mu\tau_\mu$, momentum asymmetry and exclusion of $80 < m_{\mu\mu} < 100$ GeV. ($Z \to \mu\mu$ background).



Signal and background estimation

- $\phi_0 \to \tau\tau$, $Z \to \tau\tau$, $t\bar{t}$ and WW.

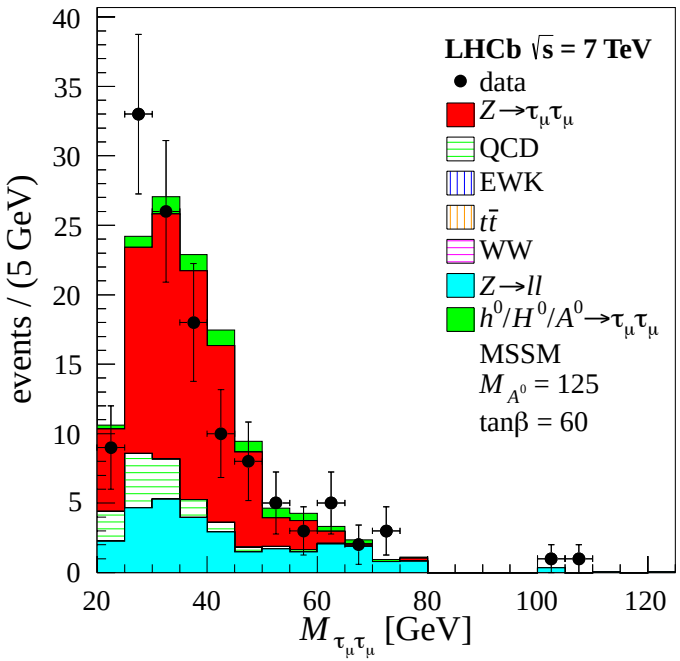
$$N = \mathcal{L} \cdot \sigma \cdot \mathcal{B} \cdot \mathcal{A} \cdot \epsilon$$

  - luminosity ($\mathcal{L}$) from Van der Meer scan and beam-gas imaging.
  - cross-sections (σ) and branching fractions ($\mathcal{B}$), from theory.
  - acceptances from simulation.
  - efficiencies (ϵ) from data using tag-and-probe methods.
  - simulated shape corrected for efficiencies and detector resolution.
- distribution and normalization of QCD events is found from data using same-sign events.
- Electroweak (EWK) is taken from simulation and normalised using data.
- $t\bar{t}$ and WW productions are taken from simulation.
- $Z \to \ell\ell$ shape and normalization are determined from data.

Observed $\tau_\mu\tau_\mu$

[J. High Energy Phys. 05 (2013) 132]

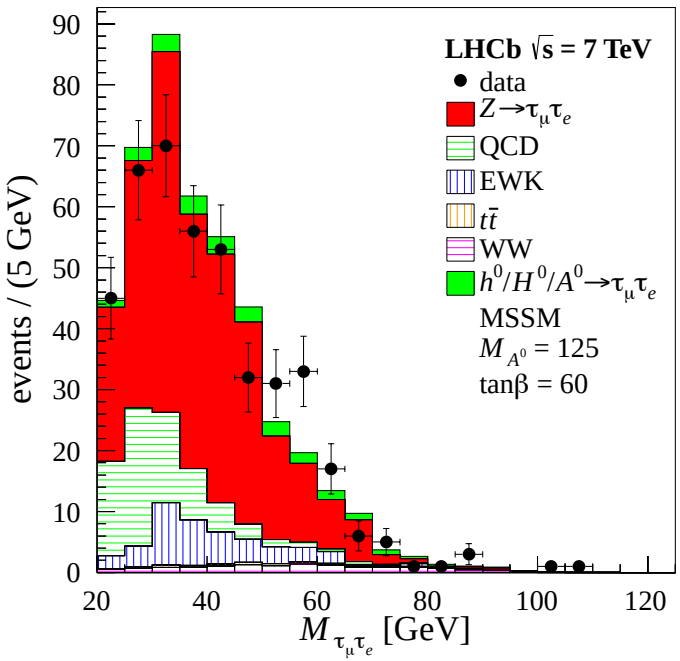
$Z \to \tau\tau$	79.8 ± 5.6
QCD	11.7 ± 3.4
EWK	0.0 ± 3.5
$t\bar{t}$	$< 0.1 \pm 0.1$
WW	$< 0.1 \pm 0.1$
$Z \to \ell\ell$	29.8 ± 7.0
Total expected	121.4 ± 10.2
Observed	124
SM Higgs $\times 100$	3.9 ± 0.5



Observed $\tau_\mu\tau_e$

[J. High Energy Phys. 05 (2013) 132]

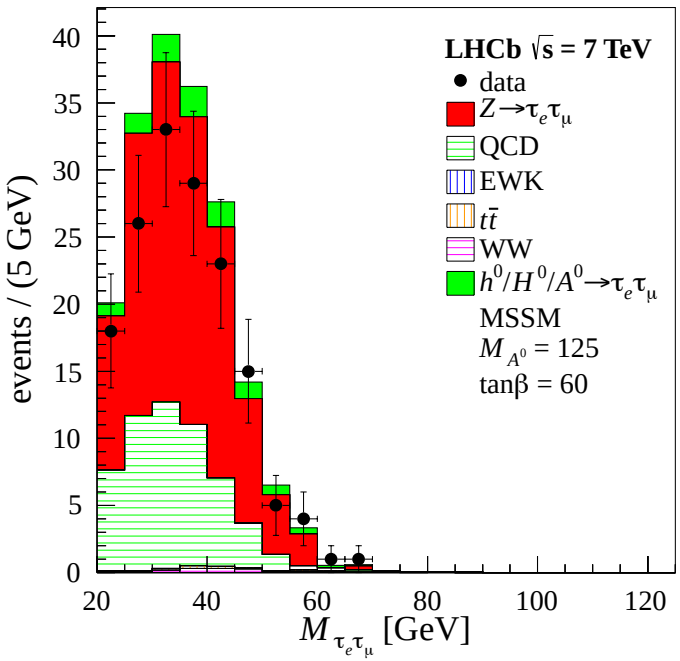
$Z \to \tau\tau$	288.2 ± 26.2
QCD	72.4 ± 2.2
EWK	40.3 ± 4.3
$t\bar{t}$	3.6 ± 0.4
WW	13.3 ± 1.2
$Z \to \ell\ell$	–
Total expected	417.9 ± 26.7
Observed	421
SM Higgs $\times 100$	11.9 ± 1.6



Observed $\tau_e\tau_\mu$

[J. High Energy Phys. 05 (2013) 132]

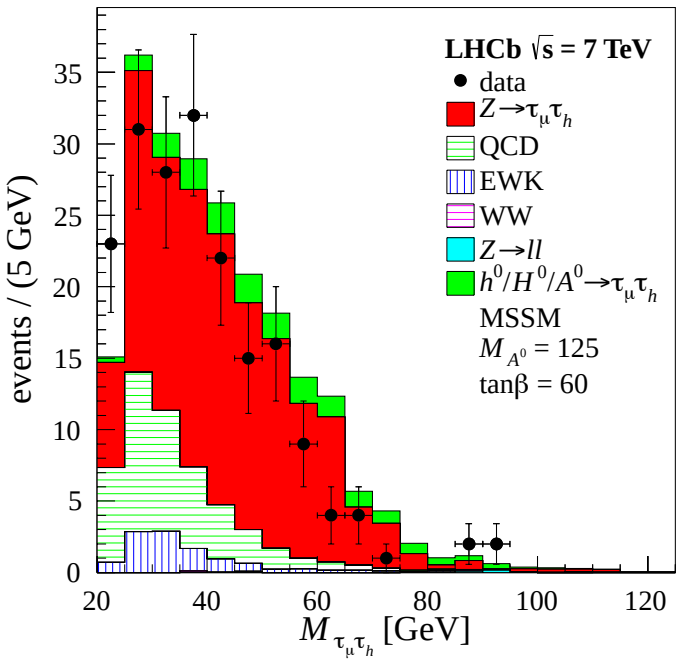
$Z \to \tau\tau$	115.8 ± 12.7
QCD	54.0 ± 3.0
EWK	0.0 ± 1.3
$t\bar{t}$	1.0 ± 0.1
WW	1.6 ± 0.2
$Z \to \ell\ell$	–
Total expected	172.4 ± 13.1
Observed	155
SM Higgs $\times 100$	3.8 ± 0.5



Observed $\tau_\mu \tau_h$

[J. High Energy Phys. 05 (2013) 132]

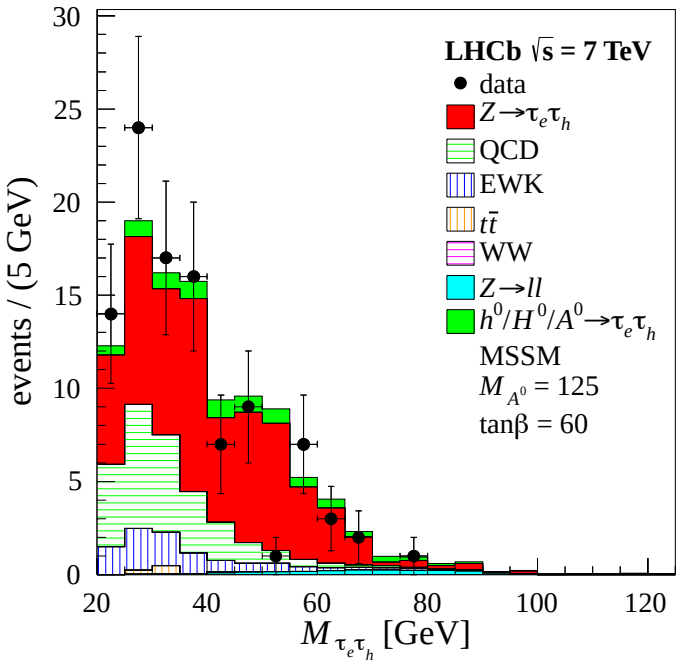
$Z \to \tau\tau$	146.1 ± 9.7
QCD	41.9 ± 0.5
EWK	10.8 ± 0.5
$t\bar{t}$	$< 0.1 \pm 0.1$
WW	0.2 ± 0.1
$Z \to \ell\ell$	0.4 ± 0.1
Total expected	199.3 ± 9.7
Observed	189
SM Higgs $\times 100$	9.7 ± 1.3



Observed $\tau_e\tau_h$

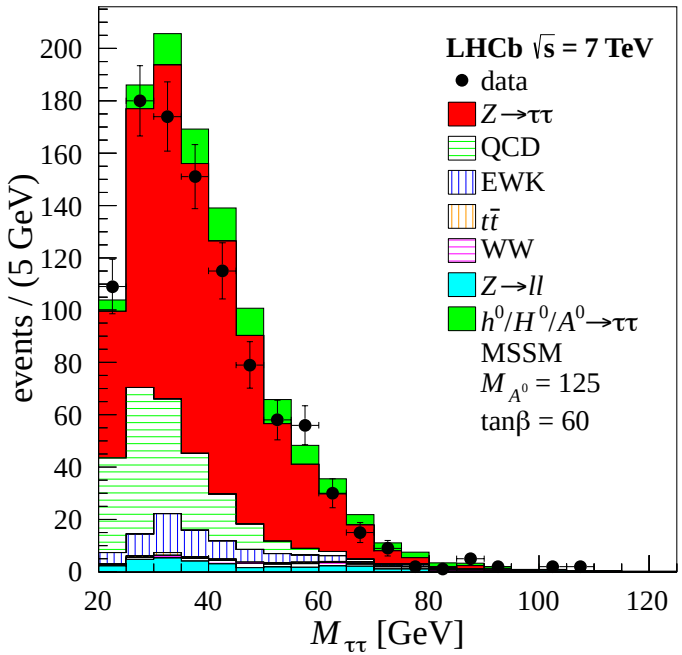
[J. High Energy Phys. 05 (2013) 132]

$Z \to \tau\tau$	62.1 ± 8.0
QCD	24.5 ± 0.6
EWK	9.3 ± 0.5
$t\bar{t}$	0.7 ± 0.4
WW	$< 0.1 \pm 0.1$
$Z \to \ell\ell$	2.0 ± 0.2
Total expected	98.7 ± 8.0
Observed	101
SM Higgs $\times 100$	4.2 ± 0.6



Observed combined result

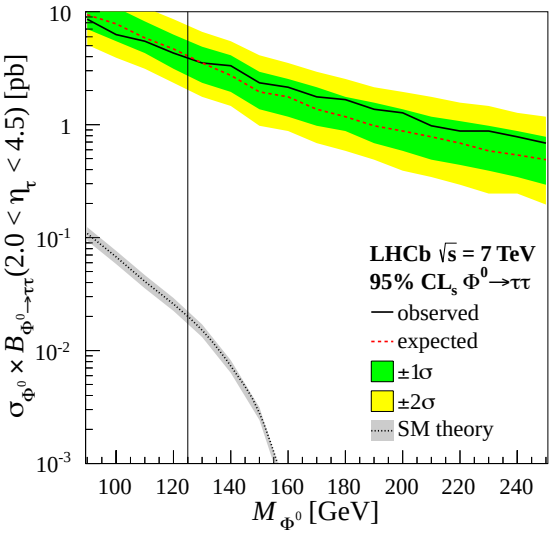
[J. High Energy Phys. 05 (2013) 132]

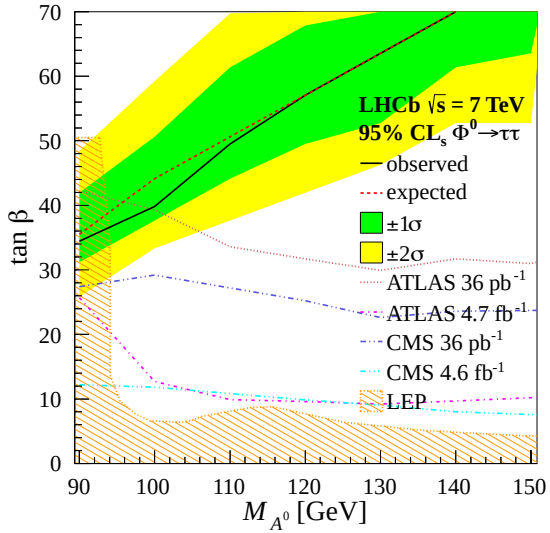


Results and Limits

[J. High Energy Phys. 05 (2013) 132]

Asymptotic limit from profile ratio of extended likelihood using mass shape, upper limit calculated at CLs = 95%





Which set the limits

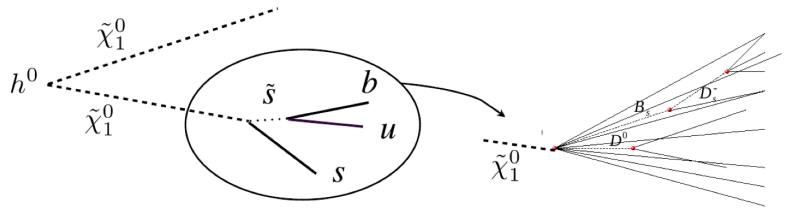
- $\sigma \times \mathcal{B}_{\phi_0 \to \tau\tau}$ exclusion in the forward region, $2.0 \leq \eta \leq 4.5$
  - 8.6 pb at $M_{\phi_0} = 90$ GeV
  - 0.7 pb at $M_{\phi_0} = 250$ GeV
- MSSM $m_{h_0^{\max}}$ exclusion
  - $\tan\beta = 34$ at $M_{A^0} = 90$ GeV
  - $\tan\beta = 70$ at $M_{A^0} = 140$ GeV

Motivation

Many beyond standard model predicts neutral LLP which is accessible with the early LHC data.

- **mSUGRA** model with R parity and baryon number violation [arXiv:hep-ph/9709356]:

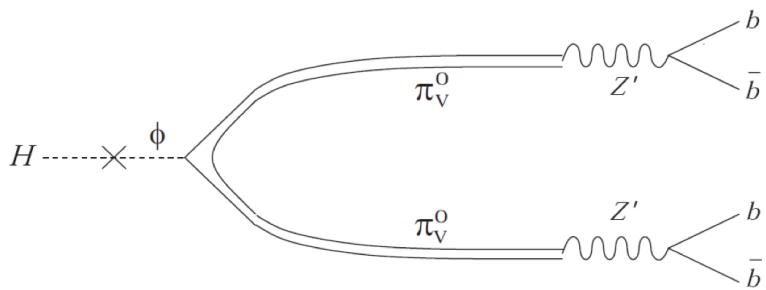
"Six-Quark Decays of the Higgs Boson in Supersymmetry with R-Parity Violation"



$h^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0 \to 3\text{jets} + 3\text{jets} \longrightarrow \sim 70\%$ **decays have a** b**-quark**.

- **Hidden-Valley model** [P.R.L 99 211801]

"SM Higgs may decay into 2 **HV** particles which decay to $b\bar{b}$"



$h_0 \to \pi_V^0\pi_V^0 \to b\bar{b}b\bar{b}$.

In both models selection

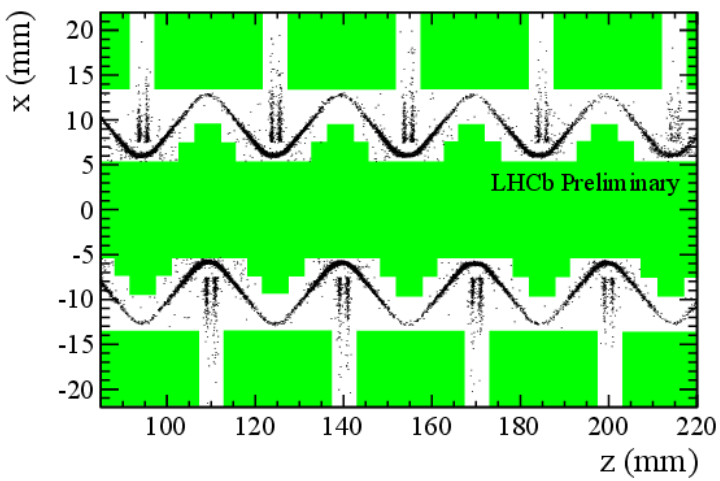
- Dataset: 36 pb^{-1} at $\sqrt{s} = 7$ TeV (2010 data).
- $m_{LLP} > 20$ GeV.
- LLP are obtained through inclusive vertex reconstruction in the trigger and offline
- $m_{\mathrm{vertex}} > 4$ GeV and $N_{tr} \geq 4$
- displaced from the PV, $R > 0.4$ mm
- Vertex outside matter region (to suppress hadronic interaction in the velo).

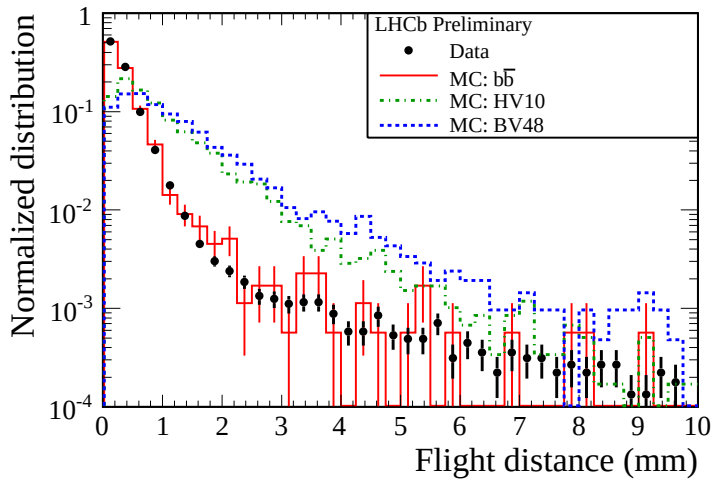
$h^0 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ candidates (BV48)

$m_{h_0} = 114$ GeV, $m_{\tilde{\chi}_1^0} = 48$ GeV and $\tau_{\tilde{\chi}_1^0} = 10$ ps

$h_0 \to \pi_V^0 \pi_V^0$ candidates (HV10)

$m_{h_0} = 120$ GeV, $m_{\pi_V^0} = 35$ GeV and $\tau_{\pi_V^0} = 10$ ps





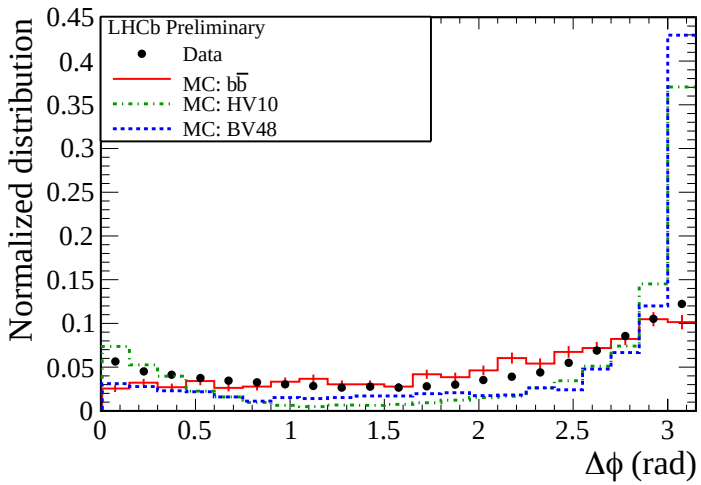
- Shape and yields compatible with $b\bar{b}$ backgrounds: (75 ± 13)k $b\bar{b}$ expected, 59k observed.

Final selection - for di-LLP candidates

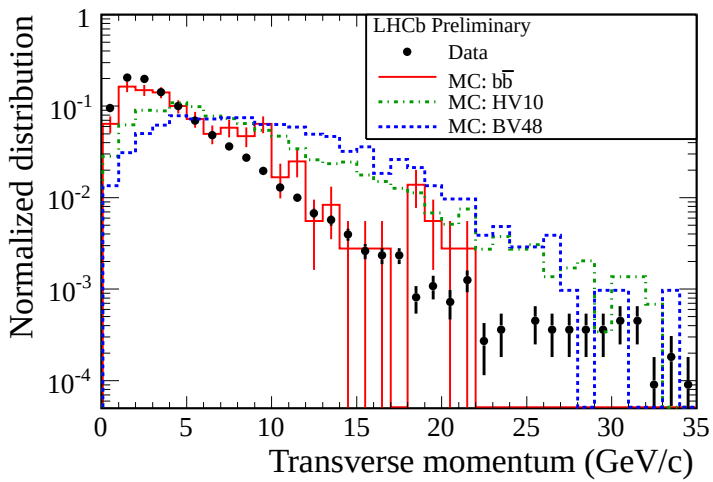
- Tighter cuts are applied to the single candidate
  - $m_{\mathrm{vertex}} \geq 6$ GeV, $N_{\mathrm{tr}} \geq 6$
  - Good quality vertex.
  - $\Delta\phi > 2.8$ rad.

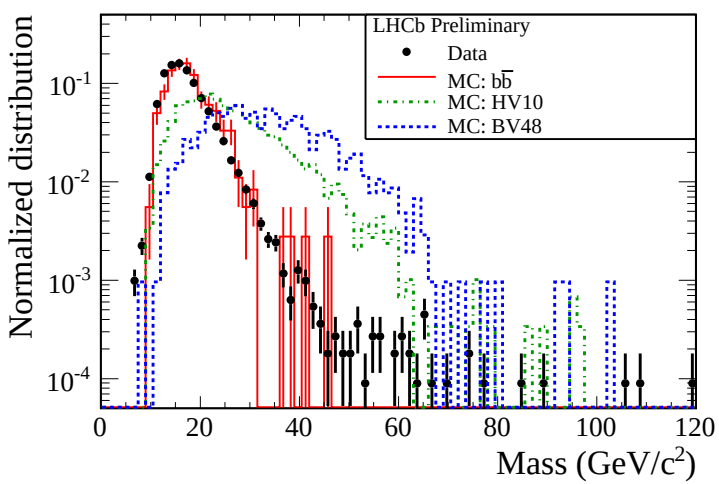
Results

No candidates observed in data.



Di-LLP candidate are formed out of 2 back-to-back single LLP





For BV48 Model

- Overall selection efficiency on BV48: 0.384 ± 0.017 (stat.) ± 0.086 (syst) %
- Main systematic uncertainties on the detection efficiency: trigger efficiency (15%) and vertex reconstruction (12%).
- $\sigma_{h_0} \times \mathcal{B}(h_0 \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0)$ 95%$C.L$ upper limit: 32 pb.
- A fast simulation of the analysis chain allow to extend the probed phase space.
- Update of the analysis including jet reconstruction and ~ 80 times more data on-going.

$\tau_{LLP} = 10$ ps

m_{LLP}[GeV/c^2]	30	35	40	48	55
m_{h_0}[GeV/c^2]					
100	101	58	44	58	
105	100	75	44	39	
110	132	75	56	34	
114	128	91	47	32	46
120	148	93	58	34	31
125	179	90	61	41	29

$\sigma_{h_0} \times \mathcal{B}(h_0 \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0)$ at 95%$C.L$ [pb]

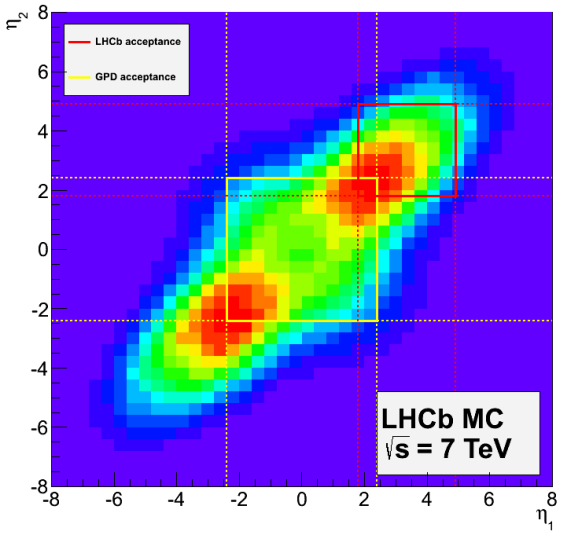
$m_{h_0} = 114$ GeV/c^2

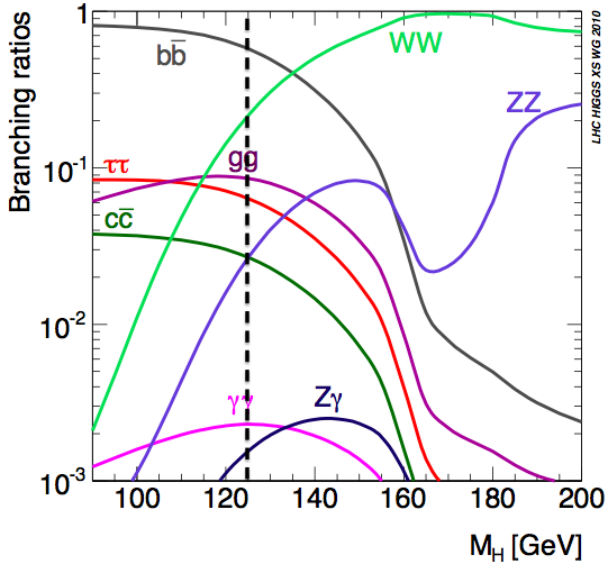
m_{LLP}[GeV/c^2]	30	35	40	48	55
τ_{LLP} [ps]					
3	210	156	136	168	410
5	145	101	68	58	137
10	129	91	47	32	46
15	155	90	49	31	33
20	131	93	63	32	31
25	142	100	61	34	25

$\sigma_{h_0} \times \mathcal{B}(h_0 \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0)$ at 95%$C.L$ [pb]

To see the Higgs at the LHCb is required development of new tools.

- Low luminosity, limited acceptance but excellent spatial resolution of the vertex locator: $H(Z, W) \to b\bar{b} + \ell$ is the best candidate.
- $\sim$ 5 (11) % of SM Higgs decays have 2 b-quarks in the LHCb acceptance at 7 TeV (14 TeV) .





- Sensitivity studies on-going at $\sqrt{s} = 7$ TeV and 8 TeV.
- Triggered development of new tools:
  - Jet reconstruction and calibration.
  - b-jet tagging.

Measurements in the $b\bar{b}$ sector have been performed

- Measurement of $\sigma_{b\bar{b}}$ with inclusive final states (LHCb-CONF-2013-002)
  - $\sigma_{b\bar{b}} = 7.7 \pm 0.12\ (\mathrm{stat.}) \pm 0.84\ (\mathrm{syst.})\ \mu\mathrm{b}$
  - $\sigma_{c\bar{c}} = 104.6 \pm 2.7\ (\mathrm{stat.}) \pm 11.4\ (\mathrm{syst.})\ \mu\mathrm{b}$
- Measurement of the central forward $b\bar{b}$ asymmetry $A_{FC}^{b\bar{b}}$ (LHCb-CONF-2013-001)

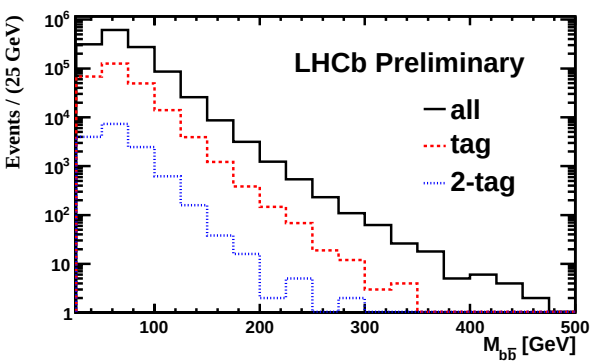
Motivation for $A^{b\bar{b}}{}_{FC}$

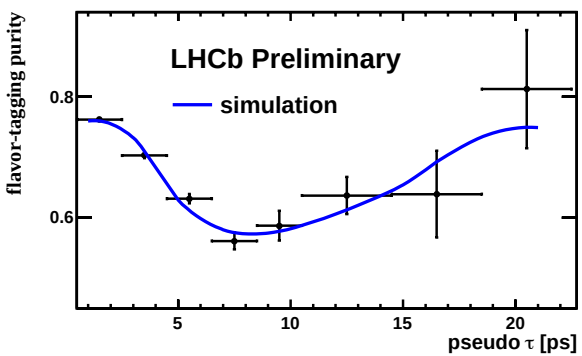
- CDF and D0 observe $A_{FB}^{t\bar{t}}$ 3 to 4 times larger than the SM prediction ($\sim 5\%$).
- $\sim 2.5\sigma$ discrepancy with SM
- $A_{FC}^{b\bar{b}} = \frac{N(\Delta y>0) - N(\Delta y<0)}{N(\Delta y>0) + N(\Delta y<0)}$, $\Delta y = |y_b| - |y_{\bar{b}}|$

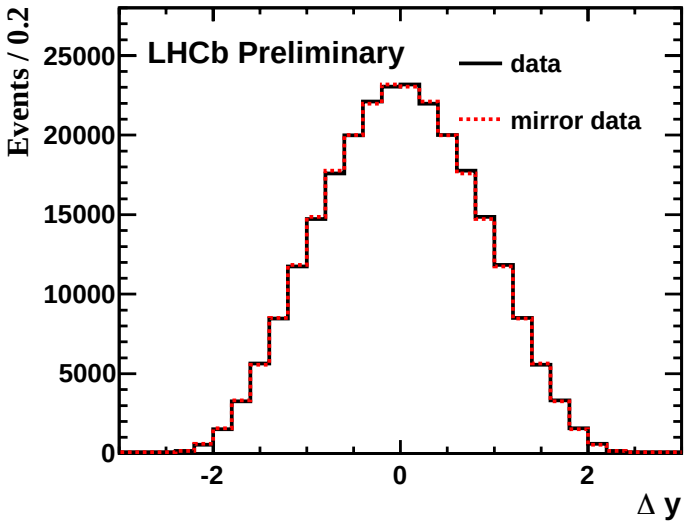
b and $b\bar{b}$ are tagged by the charge of a hard, displaced muon.
Time integrated total tagging purity (70.7 ± 0.4) %.

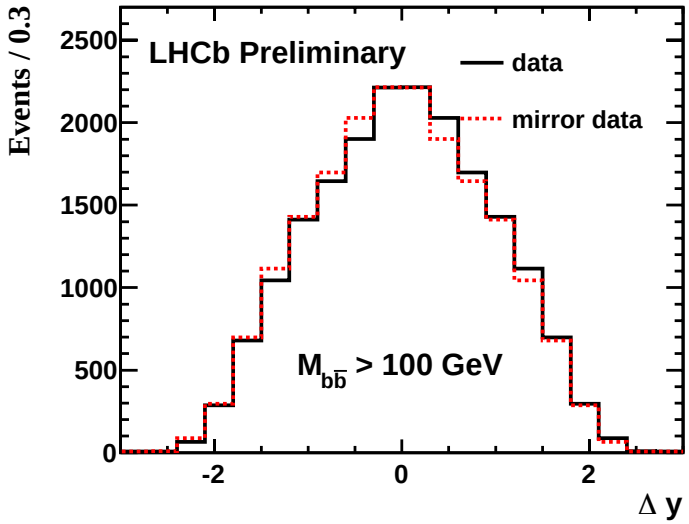
$A_{FC}^{b\bar{b}}$

Dataset $\sim 1\ \mathrm{fb}^{-1}$ at $\sqrt{s} = 7$ TeV
Di-jet events $p_{T\ 1,2} > 15$ GeV $2.0 < \eta < 4.5$
$\Delta\phi > 2.5$ rad jet reconstructed with anti-kT ($R = 0.5$) and corrected to quark level.









$A_{FC}^{b\bar{b}} = (0.5 \pm 0.5(\mathrm{stat.}) \pm 0.5(\mathrm{syst.}))\%$

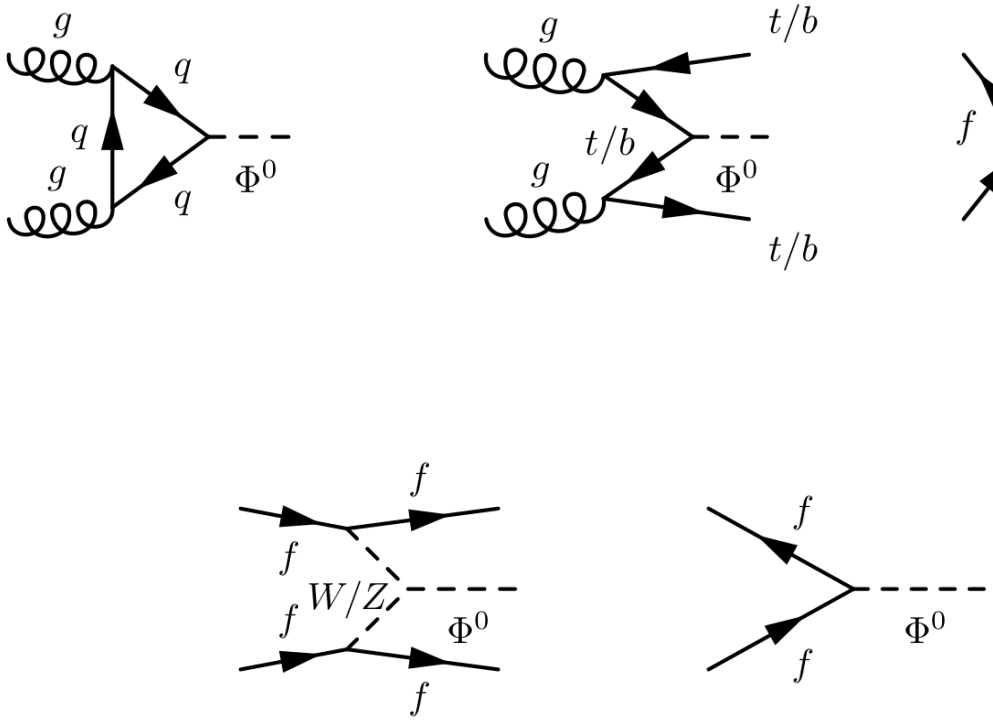
$A_{FC}^{b\bar{b}}(M_{b\bar{b}} > 100\mathrm{GeV}) = (4.3 \pm 1.7(\mathrm{stat.}) \pm 2.4(\mathrm{syst.}))\%$

- Systematic errors from the flavour-tagging purity and detector asymmetry.
- $\sigma_{b\bar{b}} \sim 15 \sim 20$ %, no unfolding $\to$ Migration to $m_{b\bar{b}} > 100$ GeV dilutes $A_{FC}^{b\bar{b}}$ by few percent.
- Work on-going on data driven method for mass unfolding and improved b-tagging efficiency.
- With addition of the 2012 data, a factor ~ 6 more events are expected for $m_{b\bar{b}} > 100$ GeV .
- Capability of reconstruction di-b jets and tagging them with high purity.

- Set limits on neutral Higgs production in the forward region.
- Preliminary searches of long lived exotic particles from Higgs-like boson decay.
- Preliminary measurements of $A^{b\bar{b}}$ compatible with SM.
- Tools have been developed for reconstruction of jets and b-tagging them with good efficiency and purity.
- Plans
  - update with full 3 fb^{-1}
  - Evaluate Higgs $\rightarrow b\bar{b}$ associated production potential.
- LHC energy upgrade
  - 13 TeV collisions in 2015 (events more boosted forward + higher σ's)

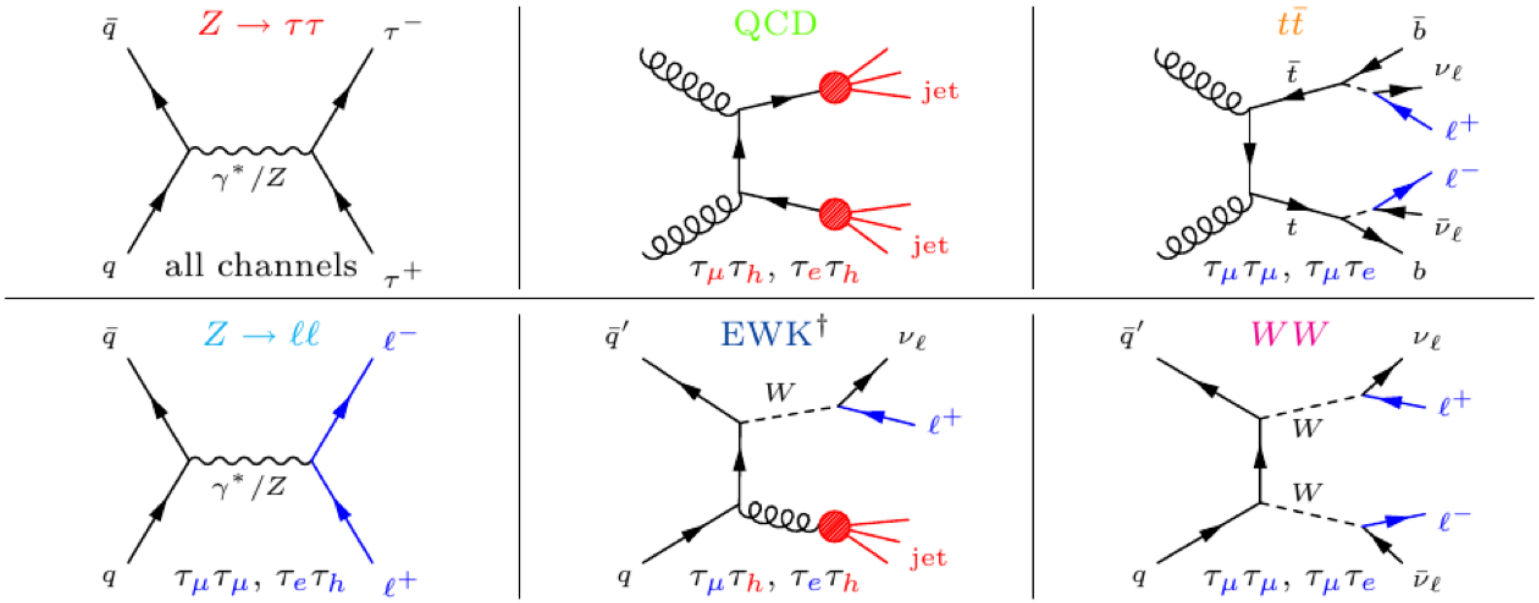
Higgs production

Primary production mechanisms of Higgs bosons at the LHC



$\phi_0 \to \tau^+\tau^-$

Backgrounds

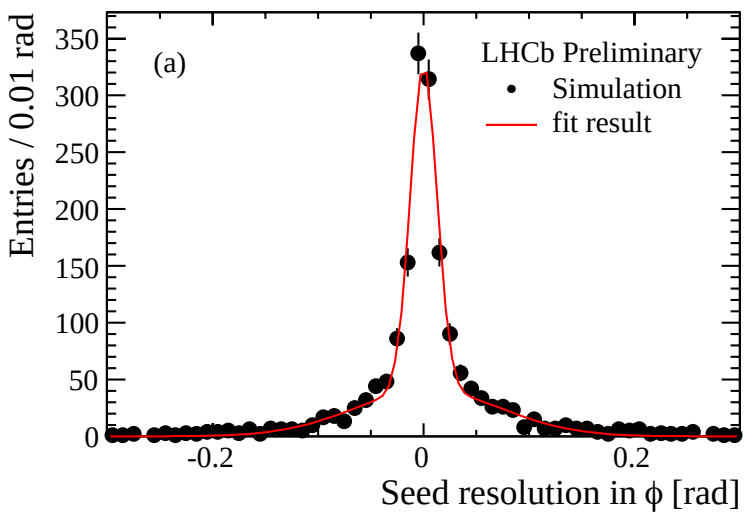


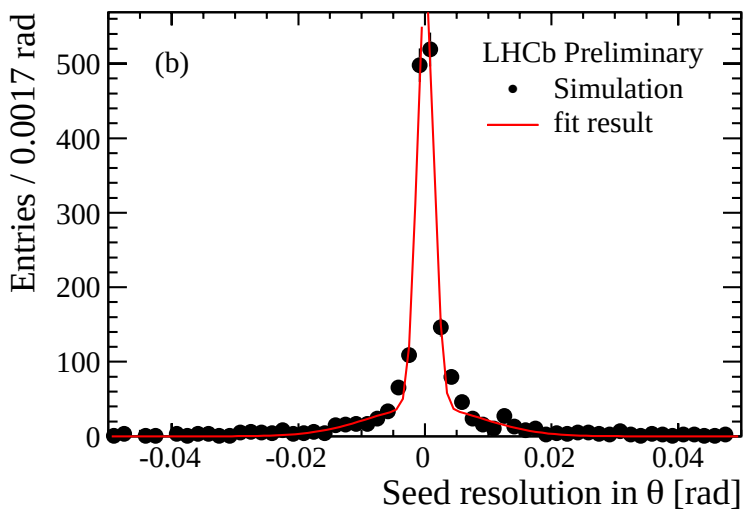
† EWK is a single hard lepton from an EWK boson and does not include $Z \to \tau\tau$, $Z \to \ell\ell$, $t\bar{t}$, WW

Measurement of $\sigma_{b\bar{b}}$ with inclusive final states

Selection

- 2.6 pb^{-1} at $\sqrt{s} = 7$ TeV , only events with one PV.
- Partial B hadron reconstruction using 2 or 3 track seed.
- Merging procedure.
- Good approximation of the B hadron direction
- Selection: events with exactly 2 seeds within $2.5 < \eta < 4$ and $p_T > 5$ GeV .





Measurement of $\sigma_{b\bar{b}}$ with inclusive final states

Results

- B seeds efficiency: MC: $(81.6 \pm 0.7)\%$ Data: $(82.5 \pm 3.0)\%$
- Global efficiency for b events 8×10^{-4}, for c events 1.8×10^{-5}.
- Fraction of $b\bar{b}$ and $c\bar{c}$ from template fit of a BDT variable.
- Shape of the BDT cross checked with other side $B \to D\pi$ and $D \to \kappa\pi\pi$.