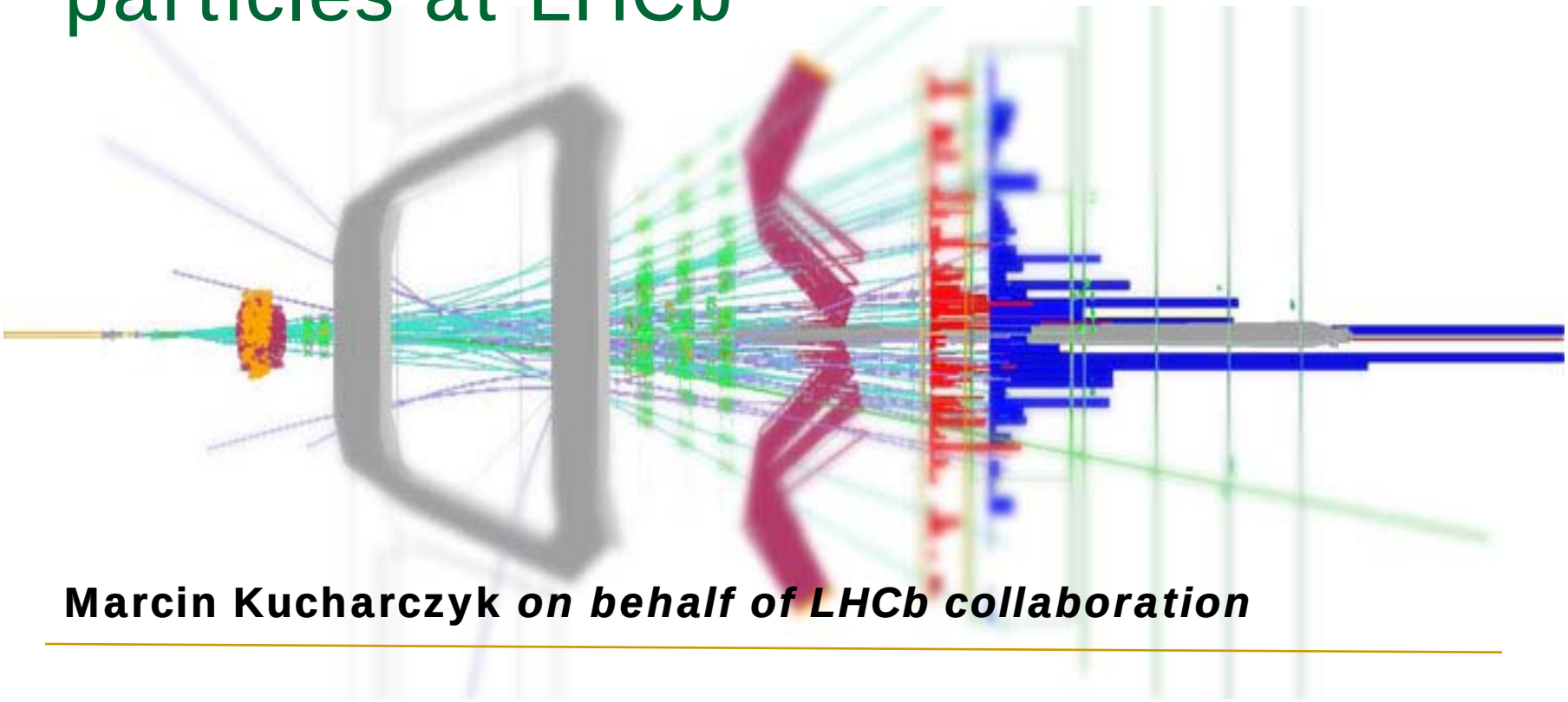
Searches for Higgs and Higgs-like particles at LHCb



Marcin Kucharczyk ***on behalf of LHCb collaboration***

EPS-HEP 2013, Stockholm

18.07.2013

Contents

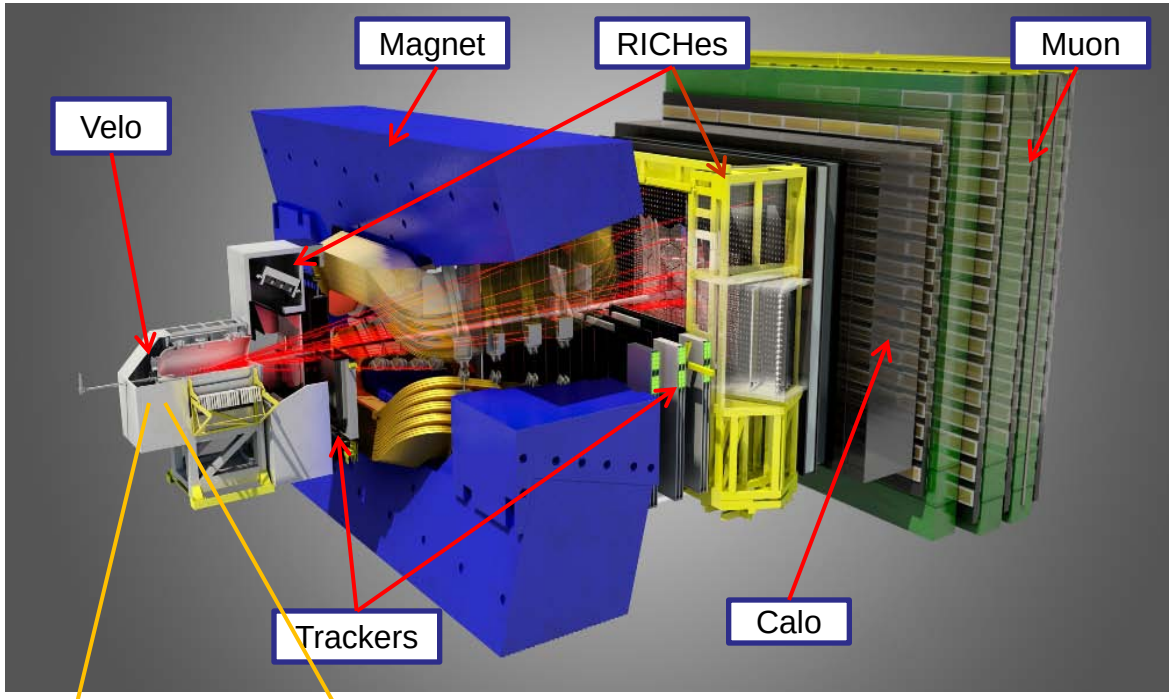
- LHCb overview
- $H \rightarrow \tau^+ \tau^-$
- Higgs boson decays into long-lived exotic particles
- Towards $H \rightarrow bb(bar)$ in associated production with W/Z

  $\rightarrow$ *bb(bar)* inclusive cross section

  $\rightarrow$ forward-central *bb(bar)* production asymmetry

LHCb experiment

Designed for CP violation & rare decays of heavy mesons

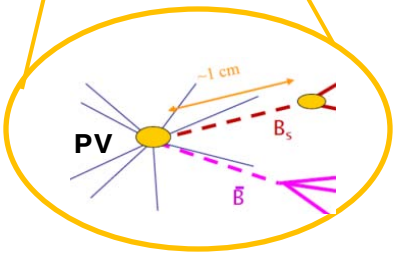


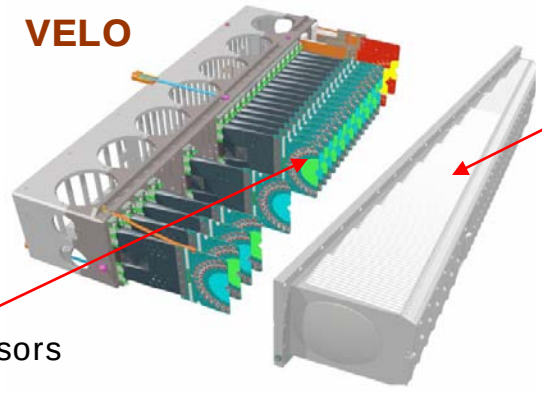
Unique acceptance
(10-300) mrad

able to access low p_T

test models with enhanced forward production

precise tracking / vertexing in $\eta \in$ (2-5)





$\int L$: ~**37** pb^{-1} *(2010)*
~**1** fb^{-1} *(2011)*
~**2** fb^{-1} *(2012)*

$H \to \tau^+ \tau^-$

Goal: set limits on neutral Higgs production in the **forward** region

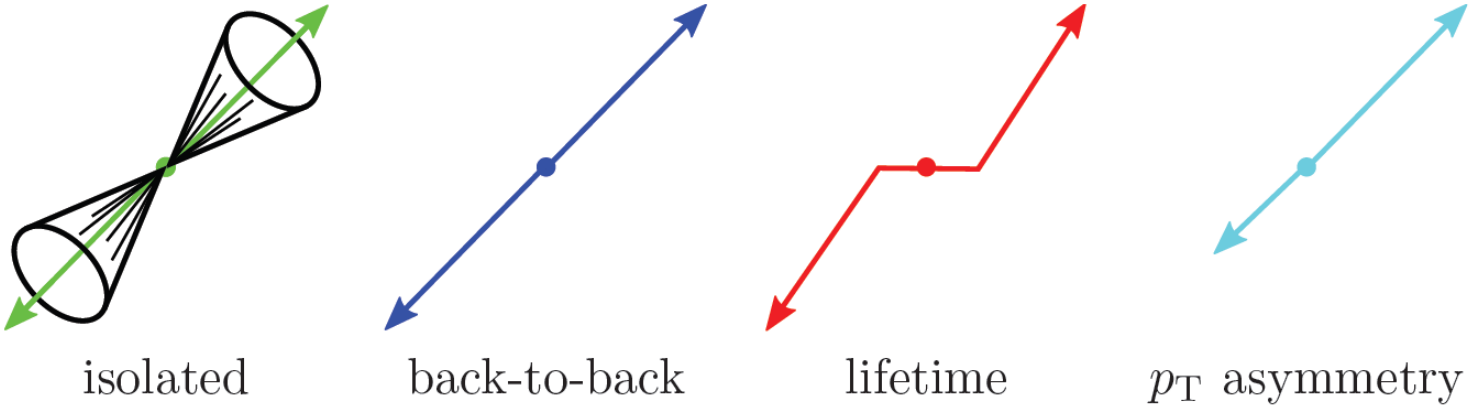
Data sample used: 1 fb^{-1} @ $\sqrt{s}$ = 7 TeV

5 channels: *(2 l's):* $H \to \tau_\mu \tau_\mu$ $H \to \tau_\mu \tau_e$ $H \to \tau_e \tau_\mu$

(l + 1-prong): $H \to \tau_\mu \tau_h$ $H \to \tau_e \tau_h$

Selection

- cuts on lepton/hadron p_T
- leptons must be isolated + impact parameter wrt primary vertex
- leptons in $2 < \eta < 4.5$, hadrons in $2.25 < \eta < 3.75$
- pair must be ~back-to-back ($\Delta\varphi > 2.7$ rad)
- for di-muon stream: p_T asymmetry > 0.3, $60 < m_{\tau\tau} < 120$ GeV/c^2



$H \to \tau^+ \tau^-$

Signal: SM and MSSM Higgs considered

Standard Model: model independent
cross sections from DFG *(Phys. Lett. B 674 (2009) 291)*

MSSM: $m(h^0)_{max}$ scenario (*only $m(A^0)$ and tanβ free*)
x-sections and efficiencies functions of $m(A^0)$ and *tanβ* from *gg* fusion and *bb(bar)* associated production (*HIGLU, GGH@NNLO, BBH@NNLO*)
contributions from h^0, A^0 and H^0 summed

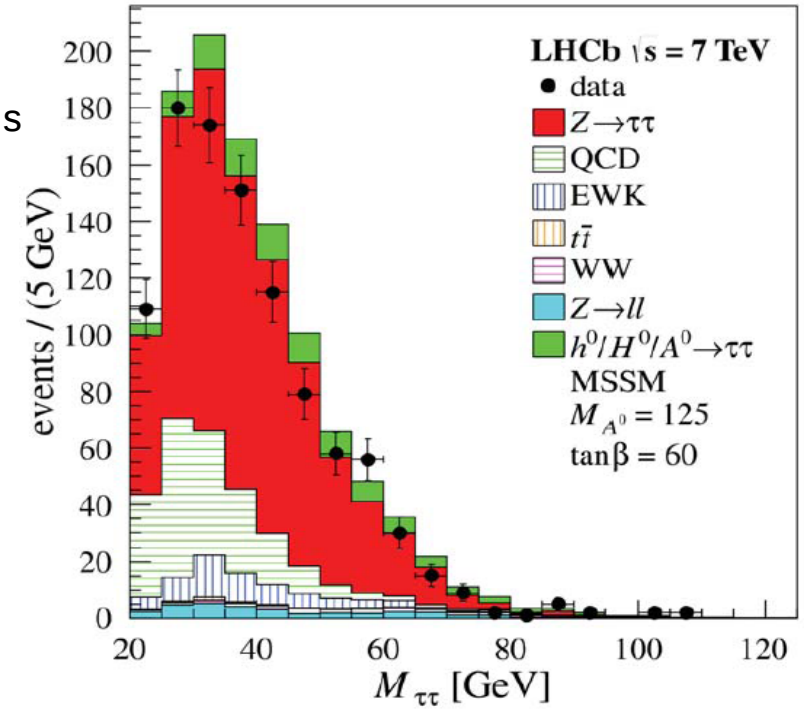
Branching fractions with ***FeynHiggs 2.7.4***
All efficiencies determined from data-based methods

Main background

- **Z → ττ**
- **QCD:** *leptonic b- or c-hadron decay or mis-ID hadron*

Signal yield from fit to the $m_{\tau\tau}$ using template shapes of signal and background contributions

All channels combined

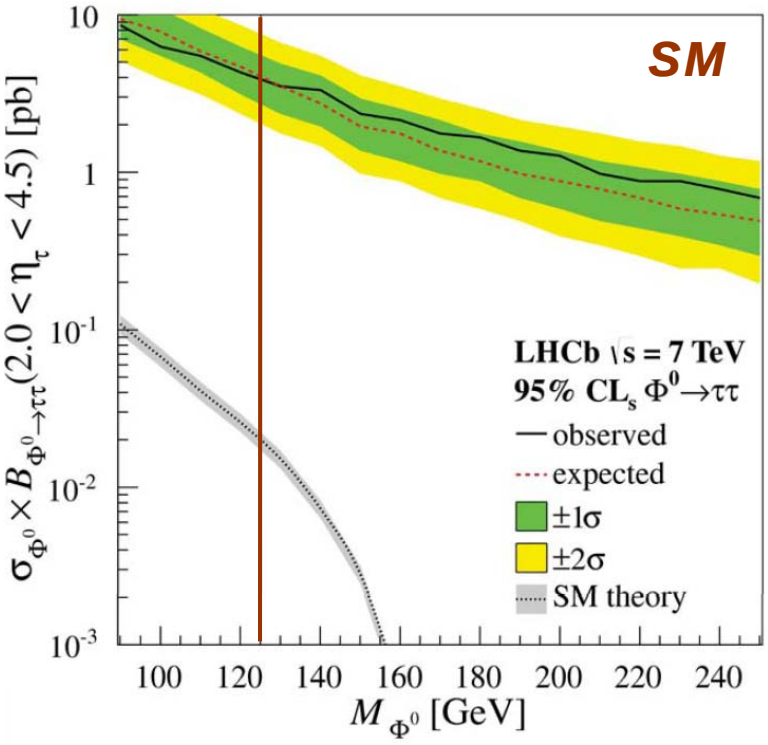


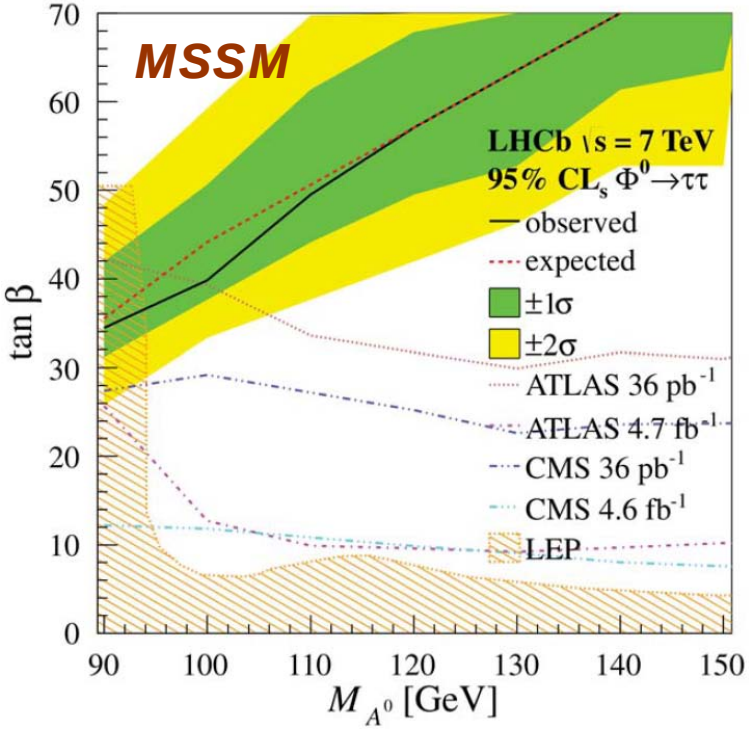
$H \to \tau^+ \tau^-$

Upper limits calculated at CLs = 95%

Eur. Phys. J. C71 (2011) 1554, arXiv:1007.1727

MSSM limits compared to ATLAS, CMS and LEP results





LHCb is able to test models with enhanced BR($H \to \tau\tau$) + forward production

SM: *$H \to \tau\tau$ $\sigma \times$ BF upper bound ~3 pb for Higgs mass of 125 GeV/c^2*

MSSM: *values above tanβ $\in$ (32 – 70) excluded for A^0 mass 90-150 GeV/c^2*

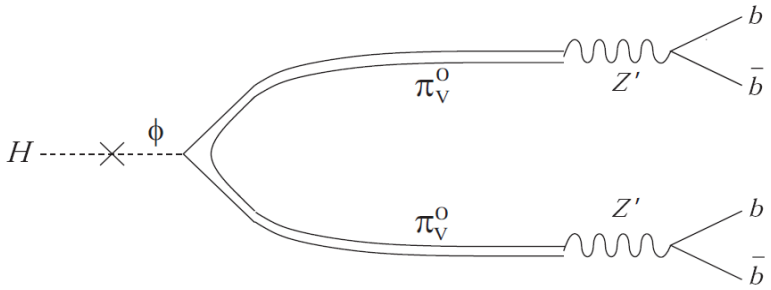
$h^0 \rightarrow$ Long-Lived Particles *(LLP's)*

Many BSM models predict Long-Lived massive Particles *(LLP's)*

Hidden Valley models (*Strassler & Zurek* *Phys. Lett. B651 (2007) 374*)

- SM Higgs may decay into 2 HV particles which decay to *bb(bar)*

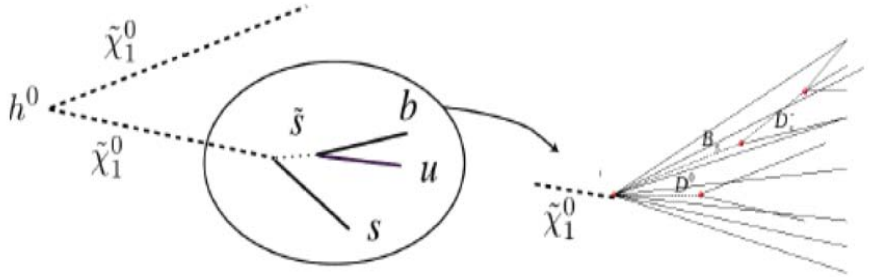
$$h^0 \rightarrow \pi_V^0 \pi_V^0 \rightarrow b\bar{b}b\bar{b}$$



mSUGRA with baryon number violation (*Kaplan et al.* *Phys. Rev. Lett. 99 (2007) 211801*)

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

$$h^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \qquad \tilde{\chi}_1^0 \rightarrow 3\,\text{jets}$$



In both cases

- $m_{LLP} > 20$ GeV/c^2, $\tau_{LLP} > 1$ps
- far from PV and beam axis

$h^0 \rightarrow$ LLP's

Data *(~36 pb^{-1})* compared to **MC**: bb, HV10, BV48

Models shown on the plots

HV10 *(Hidden Valley)*

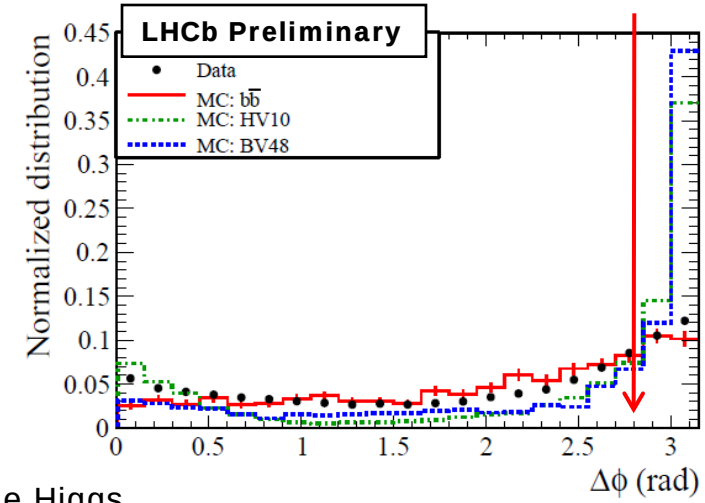
m_H = 120 GeV, m_{LLP} = 35 GeV, τ_{LLP} = 10 ps

BV48 *(Kaplan et al.)*

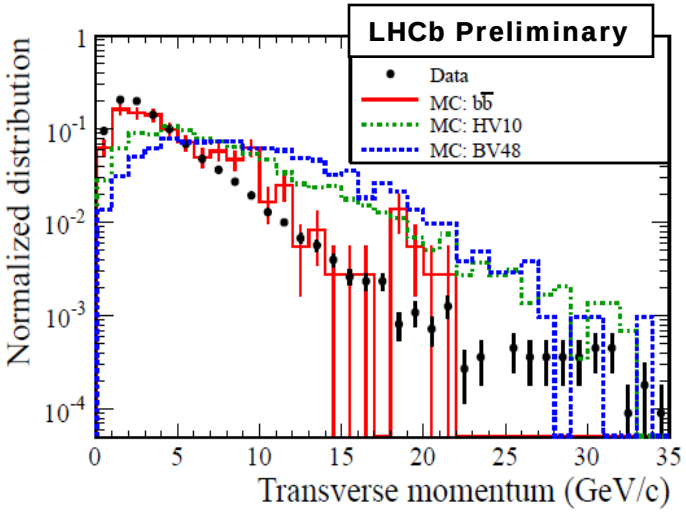
m_H = 114 GeV, m_{LLP} = 48 GeV, τ_{LLP} = 10 ps

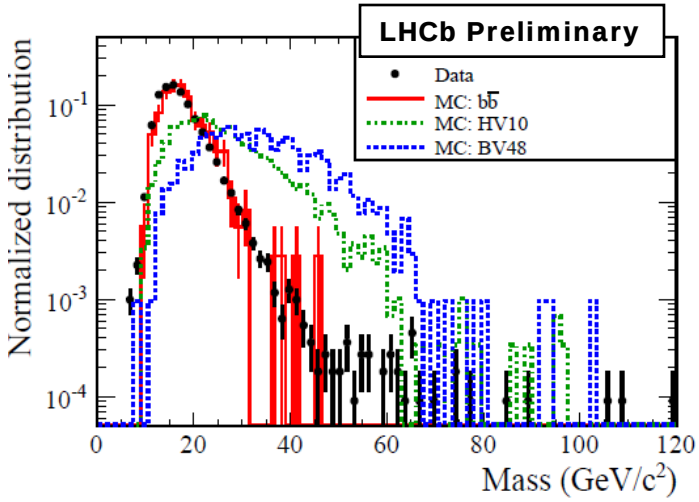
- Shapes well compatible with inclusive *bb(bar)*
- Yields also compatible with *bb(bar)*

MC predicts LLP candidates are back-to-back $\rightarrow$ *cut:* $\Delta\varphi > 2.8$



Distributions of combinations of two LLPs to form the Higgs





$h^0 \rightarrow$ LLP's

Zero candidates found in DATA ***(~36 pb^{-1})***

Upper limits *(in pb)*

$\sigma(h^0) \times BR(h^0 \rightarrow 2\ LLP's) < 90$ pb

HV10

$\sigma(h^0) \times BR(h^0 \rightarrow 2\ LLP's) < 93$ pb

BV48

$\sigma(h^0) \times BR(h^0 \rightarrow 2\ LLP's) < 32$ pb

Ongoing

→ use 2011 + 2012 data

should increase sensitivity by a factor of ~10

→ extend to single LLP search

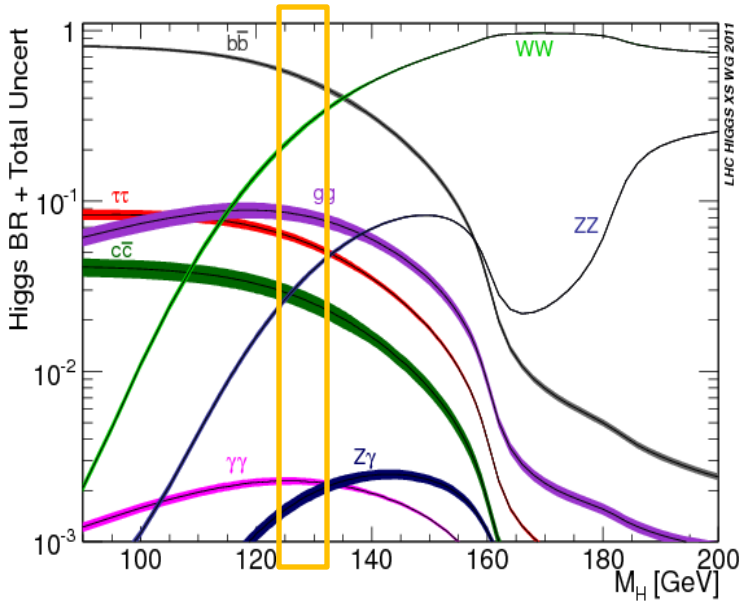
LLP lifetime = 10 ps @ 95% CL

m_{h^0} \ m_{LLP}	30	35	40	48	55
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

Higgs mass = 114 GeV/c² @ 95% CL

τ_{LLP} \ m_{LLP}	30	35	40	48	55
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

SM Higgs into *bb(bar)*



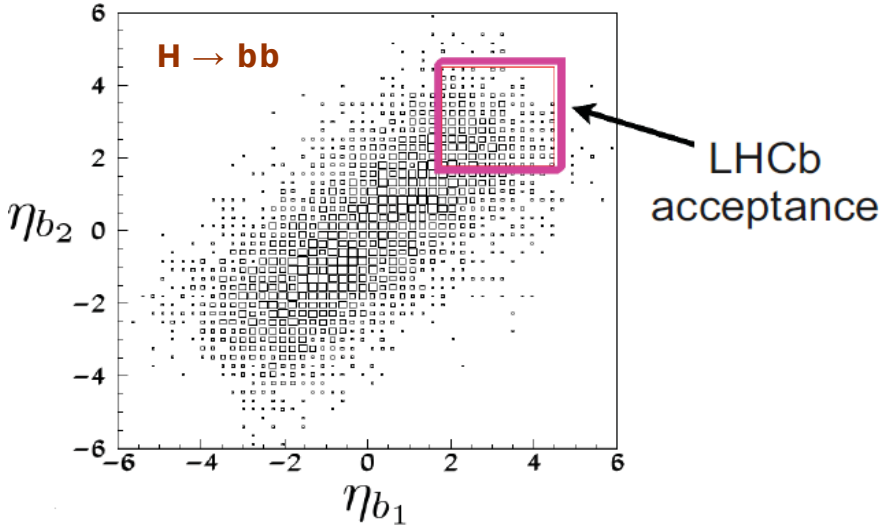
HW / Z (*H→bb(bar)*)

- σ(7 TeV) = 0.89 pb, σ(8 TeV) = 1.09 pb
- fraction of events with 2 *b*-quarks from Higgs in LHCb acceptance: ~5% @ 7 TeV
- similar acceptance for lepton from *Z/W*

Analysis of *HW / Z* ongoing

New tools developed:

- *jet reconstruction*
- *b-jet tagging, calibration, etc.*



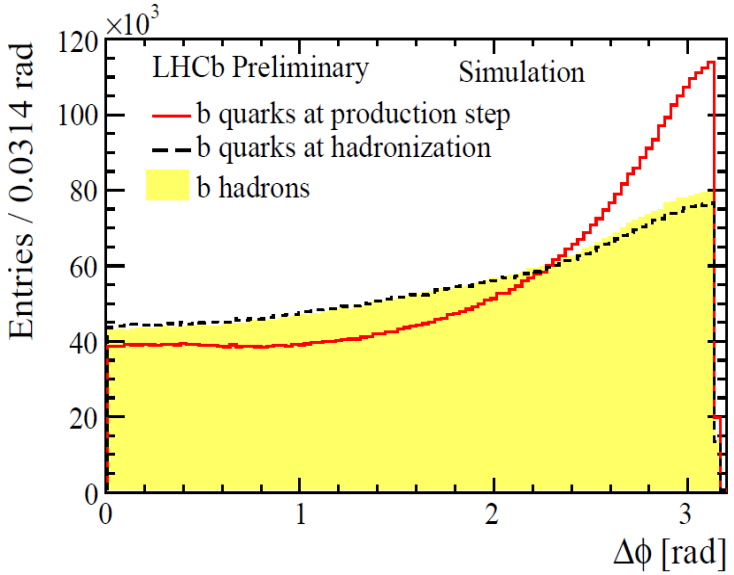
Studies towards *H → bb(bar)*

- *σ(bb(bar)) with inclusive final states* (LHCb-CONF-2013-002)
- *forward-central bb(bar) production asymmetry* (LHCb-CONF-2013-001)

Inclusive $\sigma(bb)$ & $\sigma(cc)$

***b*-quark carries heavy mass**

- *b*-hadron keeps characteristics of hadronizing quark
- inclusive measurement: *study angular correlations in a wide kinematical range*
- less dependence on BR's and fragmentation



Main steps of analysis

- reconstruct *b*-seeds

  2- or 3-track secondary vertices

- seeds close in $\Delta\varphi$ merged according to invariant mass of the pair
- seeds calibrated wrt the true *b*-hadron
- sample decomposition with BDT

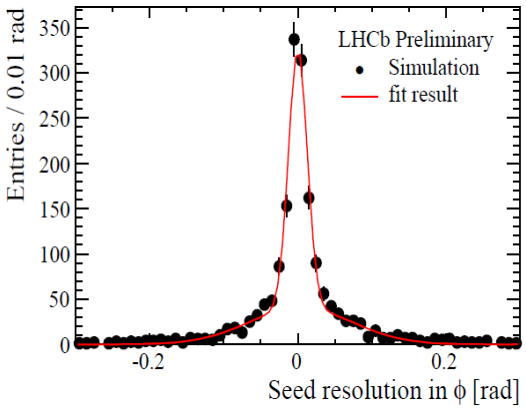
b-seed tagging based on excellent spatial resolution of the vertex locator

Inclusive $\sigma(bb)$ & $\sigma(cc)$

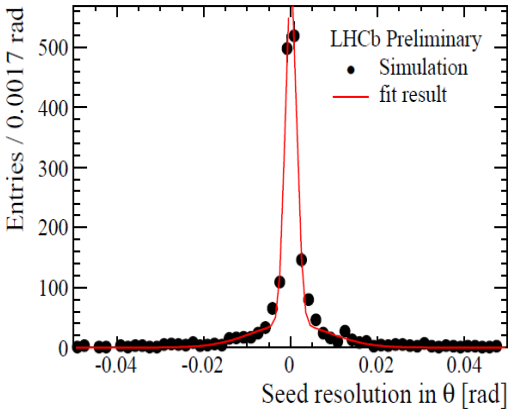
DATA sample

- only events with 1 rec. PV
- effective lumi = 2.6 pb^{-1}

Seeds approximate well the initial *b*-hadron direction



$\sigma(\varphi)$ = (12.7 ± 0.8) mrad



$\sigma(\theta)$ = (1.33 ± 0.05) mrad

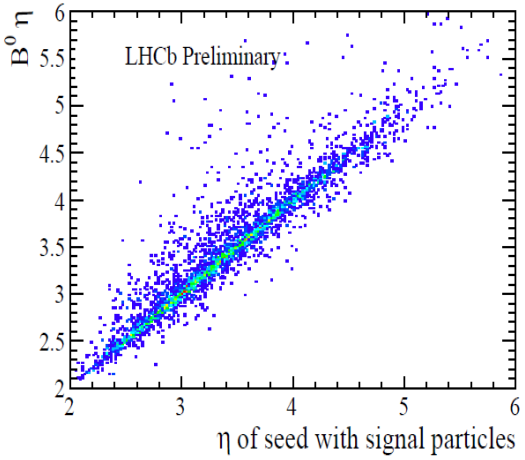
Inclusive *b* seeding efficiency

- MC: *(81.6 ± 0.7)%*
- x-check with DATA: *(82.5 ± 3.0)%*
  (tag with other side B→Dπ)

GLOBAL EFFICIENCY

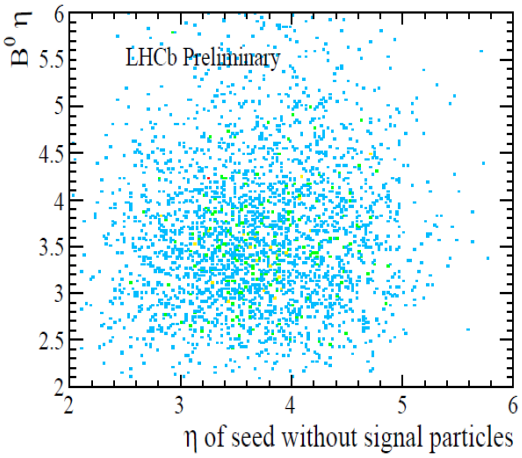
$$\epsilon^{bb} = (8.0 \pm 1.1) \cdot 10^{-4}$$
$$\epsilon^{cc} = (1.8 \pm 0.2) \cdot 10^{-5}$$

DATA



Seeds built with signal particles

DATA

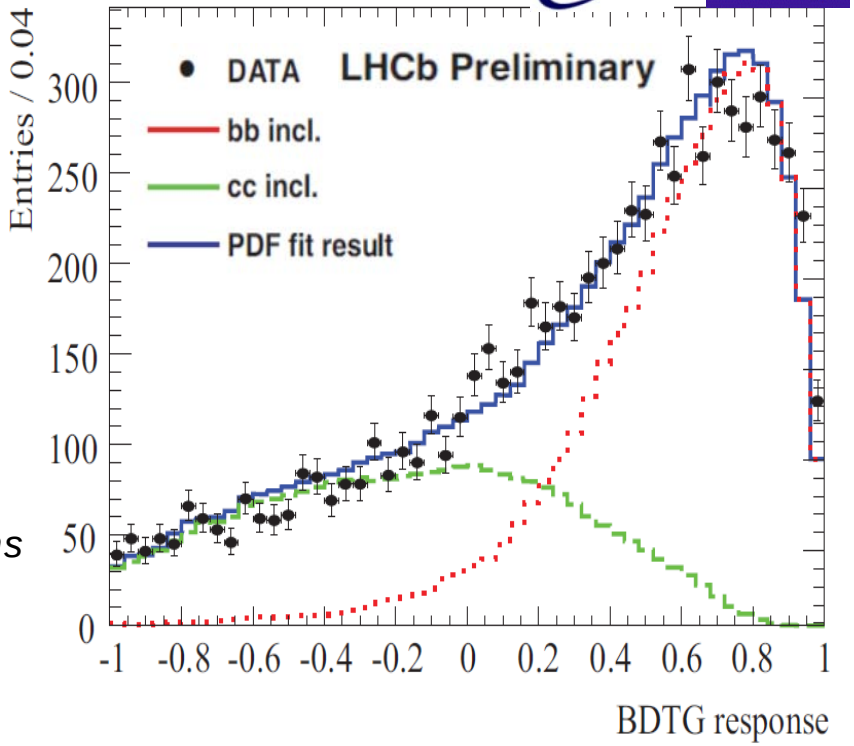


Seeds built excluding signal particles

Inclusive $\sigma(bb)$ & $\sigma(cc)$

Contributions from *bb* and *cc* determined from PDF fit to BDT response

- x-check of the shapes with DATA *(other side)* $B \to D\pi$ and $D \to K\pi\pi$



Preliminary measurement of total $\sigma(bb)$ and $\sigma(cc)$

Ongoing: *conclude studies of angular correlations*
use larger statistics (2011 & 2012)

Total x-section	$\sigma(bb)$ [μb]	$\sigma(cc)$ [μb]
FV: $\eta \in (2.5\text{-}4.0)$, $p_{Tjet} > 5$ GeV	7.7 ± 0.12 *(stat)* ± 0.84 *(syst)*	104.6 ± 2.7 *(stat)* ± 11.4 *(syst)*
LHCb acceptance	79.7 ± 1.2 *(stat)* ± 8.7 *(syst)*	-
Extrapolated to 4π angle	217.7 ± 24.1	3352.6 ± 450

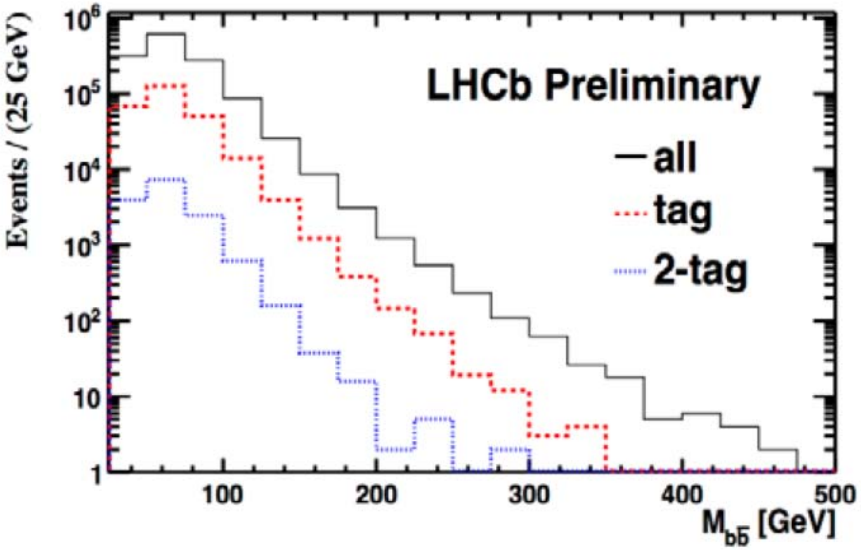
A_{FC} in *bb(bar)*

$$A_{FC}^{b\bar{b}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} \qquad \Delta y = |y_b| - |y_{\bar{b}}|$$

b-tagging based on 2-, 3- or 4-track vertices significantly displaced from PV

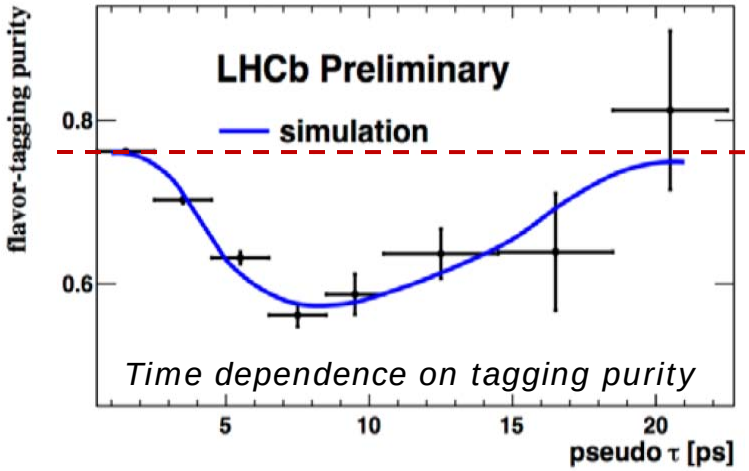
DATA: ~*1 fb*$^{-1}$ @ 7 TeV

- 2 jets from anti-k_T *(R = 0.5)*, p_T > 15 GeV/c
- $\Delta\varphi(j_1,j_2) > 2.5$ rad, $2 < \eta < 5$
- jet energy corrected to quark level



Flavour tagging

- hardest displaced track must be a muon
- masses of *B's* from $B \to D\pi$ and $B \to J/\psi K$



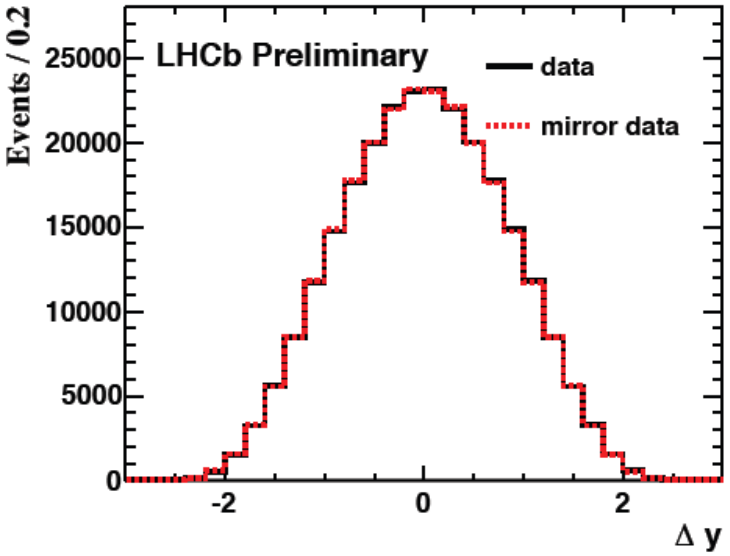
***~20 %**, mainly from b → cX, c → μνX*

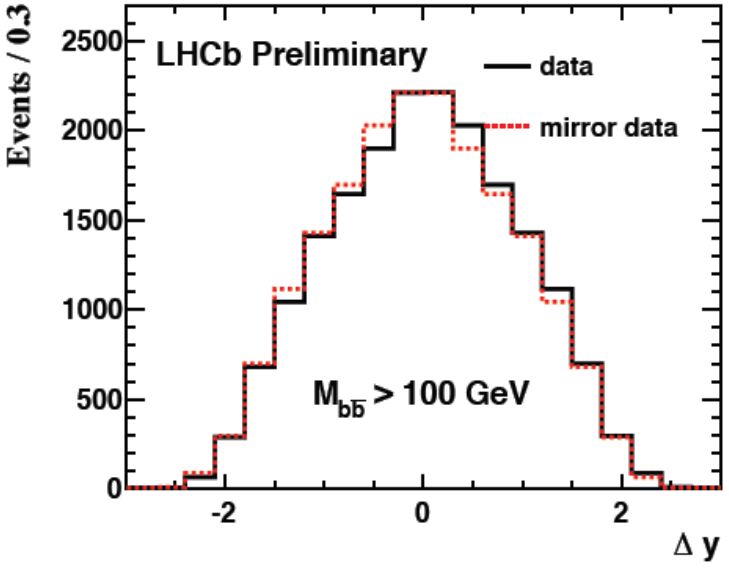
***~10 %** (time integrated), from B^0 oscillations*

Time integrated total tagging purity

(70.7 ± 0.4) %

A_{FC} in *bb(bar)*





Reflected plots along Δy = 0 in red

Final result *(after correction on mistag)*

$$A_{\rm FC}^{b\bar{b}} = (0.5 \pm 0.5\ ({\rm stat}) \pm 0.5\ ({\rm syst}))\%$$
$$A_{\rm FC}^{b\bar{b}}(M_{b\bar{b}} > 100\ {\rm GeV}) = (4.3 \pm 1.7\ ({\rm stat}) \pm 2.4\ ({\rm syst}))\%$$

Systematics: *mainly from flavor tagging purity and detector asymmetry*

Ongoing: *more efficient b-tagging, m_{bb} resolution unfolding, adding 2012, …*

Conclusions

- LHCb has a potential to complement LHC program of NP searches
  - unique forward acceptance $\eta \in (2 - 5)$ + trigger system
  - search for soft NP signatures that cannot pass ATLAS/CMS high p_T cuts
- Set limits on neutral Higgs production in the forward direction
- Measurements towards $H \rightarrow bb$
  - *bb(bar)* and *cc(bar)* inclusive cross sections
  - A_{FC} for *bb(bar)* production
- Plans
  - update with full 3 fb^{-1}
  - conclude with Higgs $\rightarrow$ *bb(bar)* associated production
- LHC upgrade
  - 13 TeV collisions in 2015 *(events more boosted forward + higher σ's)*