Direct searches for Higgs-like particles at LHCb

- How can LHCb contribute to the direct search for New Physics ? -

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- Introduction

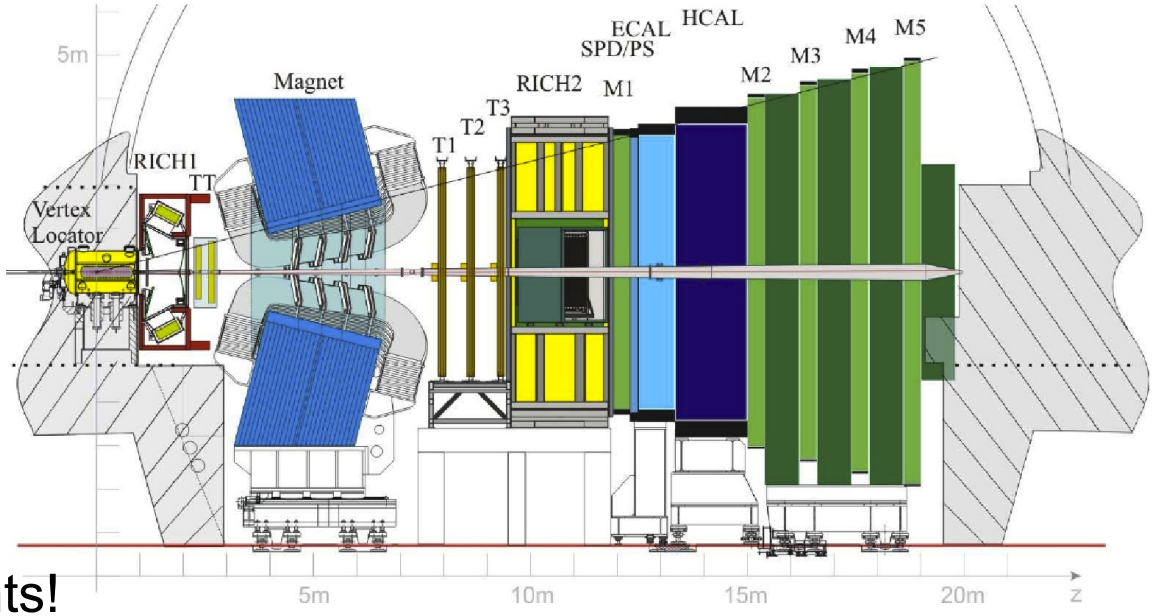
- Direct searches with taus: $H \rightarrow \tau\tau$
- Direct searches with B jets: Towards $H \rightarrow b\bar{b}$ and $H_2 \rightarrow H_1 H_1 \rightarrow 4b$
- Direct searches of new Long-Lived Particles

- Conclusion

2008 JINST 3 S08005

The LHCb detector

- Data collected:
  - 1 fb^{-1} @ √s=7 TeV
  - 2 fb^{-1} @ √s=8 TeV
- Luminosity leverage:
  - <Pile-up> ~ 2
  - Cleanest LHC events!



- Despite lower geom. acceptance and luminosity than ATLAS/CMS, LHCb offers a complementary strategy for *direct New Physics (NP) searches* :
  - Unique acceptance 2 <η< 5 : test central-forward asymmetries and models with enhanced forward production
  - Very large brandwith triggers for events with B jets or displaced vertices, and very efficient even at very low p_T
  - a "nightmare" scenario: if NP produces no high p_T lepton, no high missing energy, but only jets with p_T below ATLAS/CMS trigger thresholds...
    - If with b's and/or long lived (1-100 ps) particles, **LHCb could fill this gap!**

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Limits on Higgs → ττ

- Goal: set limits on Higgs production in the **forward** region
- Data sample used: 1 fb^{-1} @ √s = 7 TeV

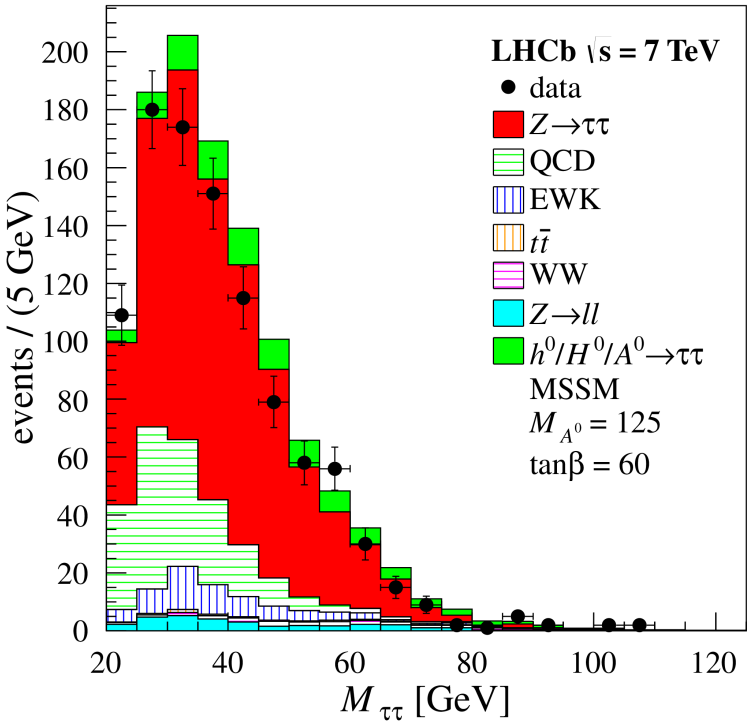
- Channels and selection:

$H \to \tau_\mu \tau_\mu, \tau_\mu \tau_e, \tau_e \tau_\mu$ (2l) and $H \to \tau_\mu \tau_h, \tau_e \tau_h$ (l + 1-prong)

$2 < \eta(e/\mu) < 4.5$; $2.25 < \eta(h) < 3.75$
$60 < M(\tau\tau) < 120$ GeV/c^2

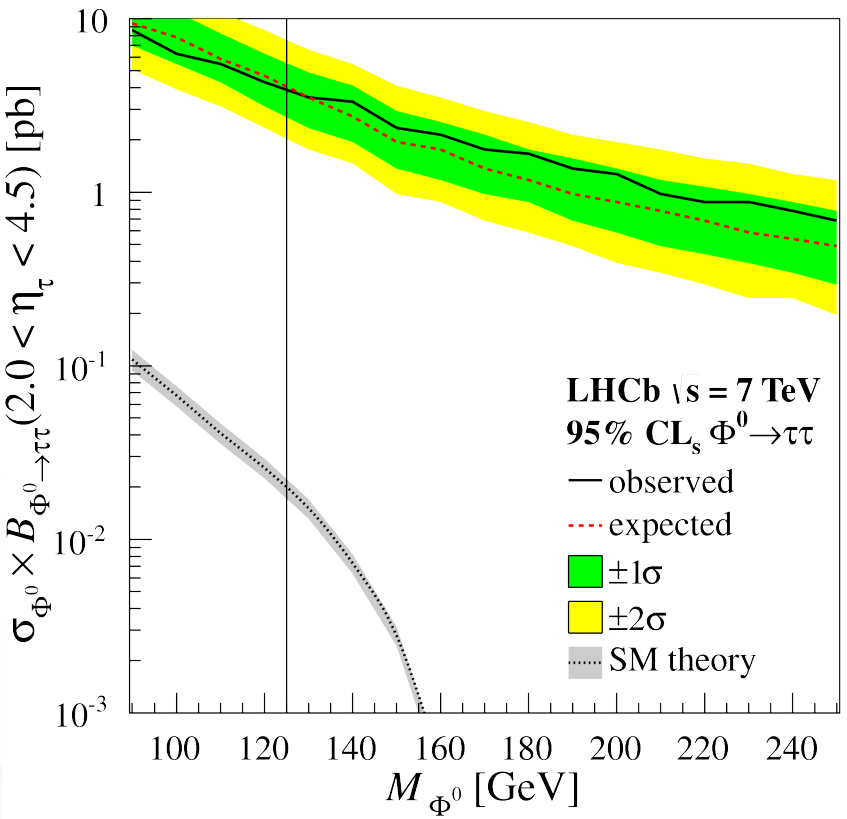
$p_T(e/\mu) > 20$ GeV/c $p_T(e/\mu/h) > 5$ GeV/c

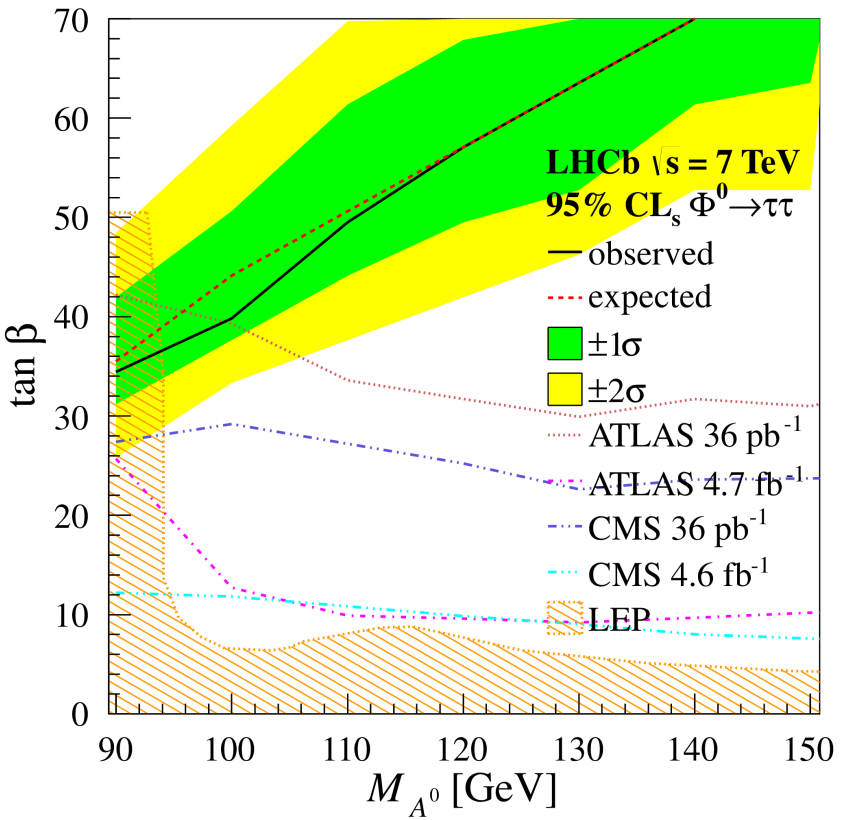
- The signal yield is obtained from a fit of the tau pair mass distribution using template shapes for signal and backgrounds
  - Signal: Higgs → ττ
  - Main backgrounds: Z→ ττ, QCD



Limits on Higgs → ττ

- Upper limits:
  - obtained from extended likelihood using mass shape and taking into account the systematics as nuisance parameters (method in arXiv: 1007.1727)
  - Given at CLs = 95%





LHCb can test models with enhanced BR(H→ ττ) and forward production

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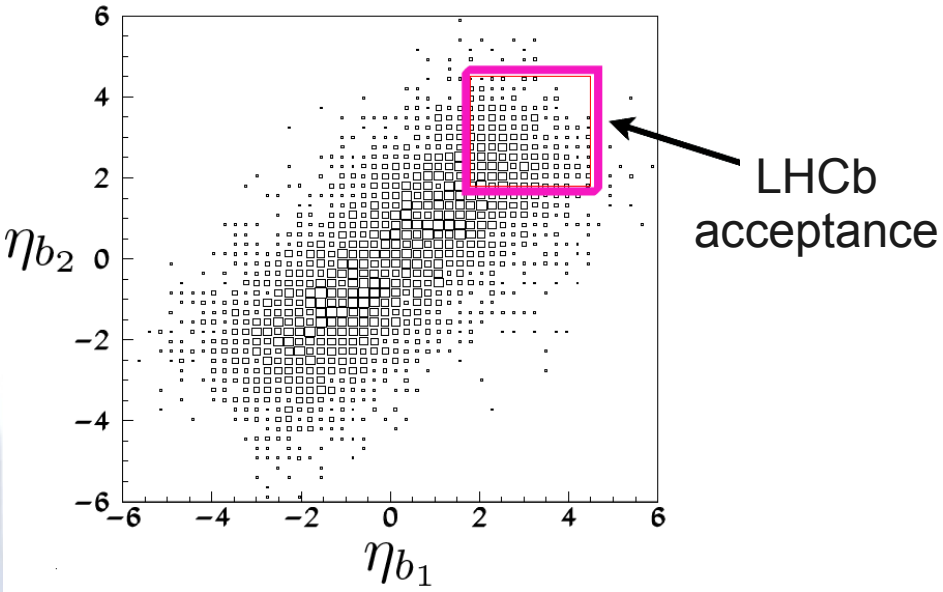
Towards W/Z+H → $b\bar{b}$ and $H_2 \to H_1 H_1 \to 4b$ at LHCb



- In WH and ZH the fraction of Higgs decaying into 2 b's in LHCb acceptance is:
  - 5% at √s = 7 TeV
  - 11% at √s = 14 TeV
- W/ZH and 4b analyses ongoing on the 2011/12 LHCb dataset

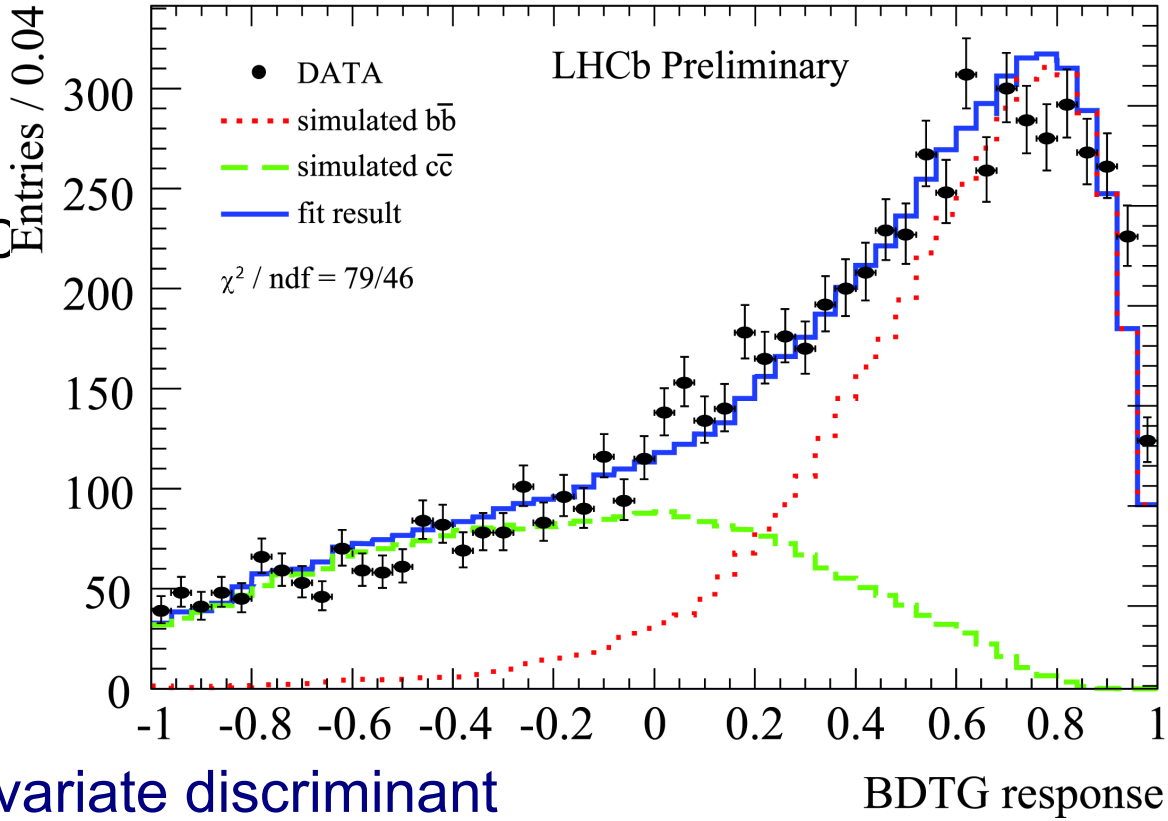
On this path:

- New tools developped: **jets** at LHCb and **B-jet tagging**
- Benchmark analyses already done:
  - Measurement of the central forward $b\bar{b}$ asymmetry (LHCb-CONF-2013-001)
  - Measurement of σ($b\bar{b}$) with inclusive final states (LHCb-CONF-2013-002)

Inclusive $b\bar{b}$ cross section measurement

Efficiencies:

- B seeding:
  - 81.7±0.7% from MC
  - 82.5±3.0% from data (other side $B \to D\pi$)
- Overall efficiency: 0.08 %



Measurement of $\sigma(b\bar{b})$:

- Fit of the shape of a multivariate discriminant built to isolate $b\bar{b}$ events
- $b\bar{b}$ and $c\bar{c}$ template shapes obtained from simulation checked with data
- Result for $2.5<\eta<4$ and $p_T>5$ GeV: $\sigma(b\bar{b}) = 7.7 \pm 0.12\ (stat) \pm 0.84\ (sys)\ \mu b$

(PowHeg-extrapolated to full space: 364 μb)

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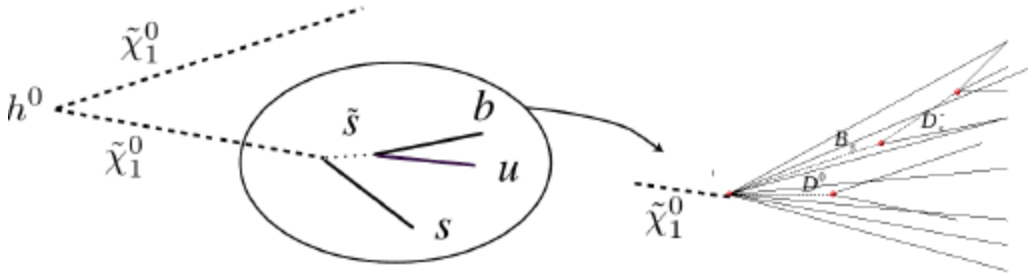
h^0 decaying to Long-Lived Particles

Many BSM theories predict Long Lived massive Particles (LLP) :

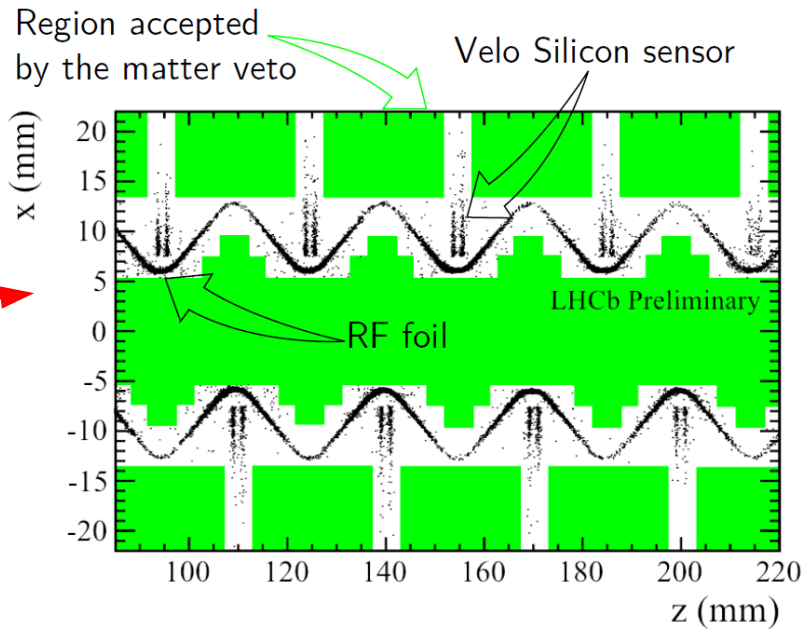
- SUSY with RPV through Baryon number Violation:
  - Carpenter, Kaplan and Rhee, Phys. Rev. Lett. 99 (2007) 211801
  - $h^0 \rightarrow X^0X^0$, with X^0 neutralino long-lived, $X^0 \rightarrow$ 3 quarks
  - For $m(h^0)$ = 114 GeV , $m(X^0)$= 48 GeV and $\tau(X^0)$ = 10 ps (BV48):
    - 25% of the events have a X^0 decay vertex inside LHCb.
  - X^0 mass and lifetime range tested at LHCb:
    - $20 < m(X^0) < 60$ GeV and $1 < \tau(X^0) < 25$ ps



- Some Hidden Valley (HV) models:
  - Strassler, Zurek, Phys. Lett. B651 (2007) 374
  - $h^0 \rightarrow \pi^0_v \pi^0_v \rightarrow$ **4 displaced b quarks** (π^0_v is the LLP (HV10))

h^0 decaying to Long-Lived Particles

- Strategy: Reconstruct the two X^0 decay vertices inside LHCb and combine to form the h^0 mother
- Dataset used: 36 pb^{-1} at $\sqrt{s}$ = 7 TeV
- Event selection:
  - X^0 reconstruction :
    - Matter veto
    - R > 0.4 mm, N(tracks) > 5
    - Mass (trks only) > 6 GeV
  - 2 X^0 reconstructed, back-to-back in φ
  - Efficiency obtained from simulation
    - Overall efficiency: 0.384 ± 0.017(stat) ± 0.085(sys)%



LHCb Trigger:

- 2 displaced vertices (R > 0.4 mm) with > 3 trks and mass (trks only) > 1.5 GeV
- Efficiency on selected "BV48" signal events: 65%
- LHCb is only LHC experiment testing $h^0 \rightarrow X^0X^0 \rightarrow 6q$ with vertex at very small distance from beam axis and low mass

h^0 decaying to Long-Lived Particles

Results:

- No candidate found in 36 pb^{-1}
- Upper limits on $\sigma(h^0) \times BR(h^0 \to X^0X^0)$ in these 2 tables (in pb)
  - For the BV48 point:

    $\sigma(h^0) \times BR(h^0 \to X^0X^0) < 32$ pb
    @ 95% CL
  - Results presently driven by the low statistics, will improve with more data
- In progress:
  - 80 times more data on pipe
  - include jet reconstruction
  - Extension to single LLP search.

LLP lifetime = 10 ps

m_{LLP}	30	35	40	48	55
m_{h^0}	(pb)				
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/c^2

m_{LLP}	30	35	40	48	55
τ_{LLP}	(pb)				
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

Outlook

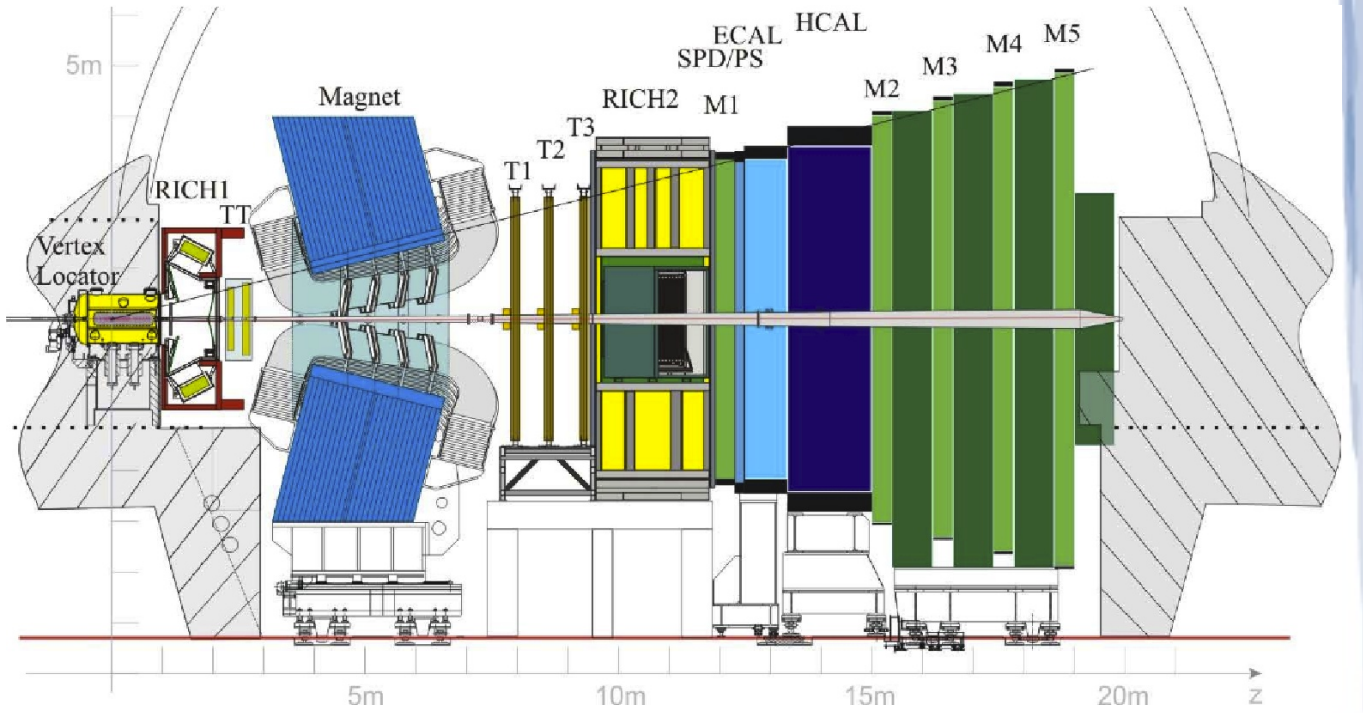
- Due to its unique forward acceptance and trigger system, ***LHCb complements the LHC program on direct searches for NP***
  - LHCb is only place to search for softer new physics signatures which don't pass ATLAS/CMS high p_T trigger cuts
  - Direct searches relevant at LHCb are “off the beaten track” and therefore often have ***lower experimental constraints***
- LHCb direct searches have not yet pointed to new physics but ...
- … direct Higgs-like and NP searches at LHCb will greatly benefit from:
  - Update with full 1 and 3 fb^{-1} datasets taken at 7 and 8 TeV resp. since present uncertainties are generally of statistical nature
  - 13 TeV collisions in 2015 (events more boosted forward + higher XS)
  - LHCb detector upgrade in 2019 that should enable to run with 5 times more instantaneous luminosity and an improved detector
- Common LHCb-theorists workshop 14-16 october:
  - Join the exotica session and help us extend the LHCb program on direct NP searches (http://indico.cern.ch/conferenceDisplay.py?confId=255380)

Backup

Theoretical references

- “Asymptotic formulae for likelihood-based tests of new physics”, Glen Cowan, Kyle Cranmer, Eilam Gross, Ofer Vitells, Eur.Phys.J.C71:1554,2011
- “Proposal for Higgs and Superpartner Searches at the LHCb Experiment”, David E. Kaplan, Keith Rehermann, JHEP 0710:056,2007
- “Reduced Fine-Tuning in Supersymmetry with R-parity violation”, Linda M. Carpenter, David E. Kaplan, Eun-Jung Rhee, Phys. Rev. Lett. 99 (2007) 211801
- “Echoes of a Hidden Valley at Hadron Colliders”, Matthew J. Strassler, Kathryn M. Zurek, JHEP 0710:056,2007

Typical resolutions at LHCb



- Detector resolution:
  - Tracking: σp/p = 0.4% at 5 GeV/c and 0.6% at 100 GeV/c
  - ECAL: σE/E = 10%/√E+1% , HCAL: σE/E = 70%/√E+10%
  - Vertex detector: 20 μm IP resolution at p_T=2 GeV/c

$Z \rightarrow \tau\tau$

- Trigger:

  $p_T(\mu) > 10$ GeV/c or $p_T(e) > 15$ GeV/c

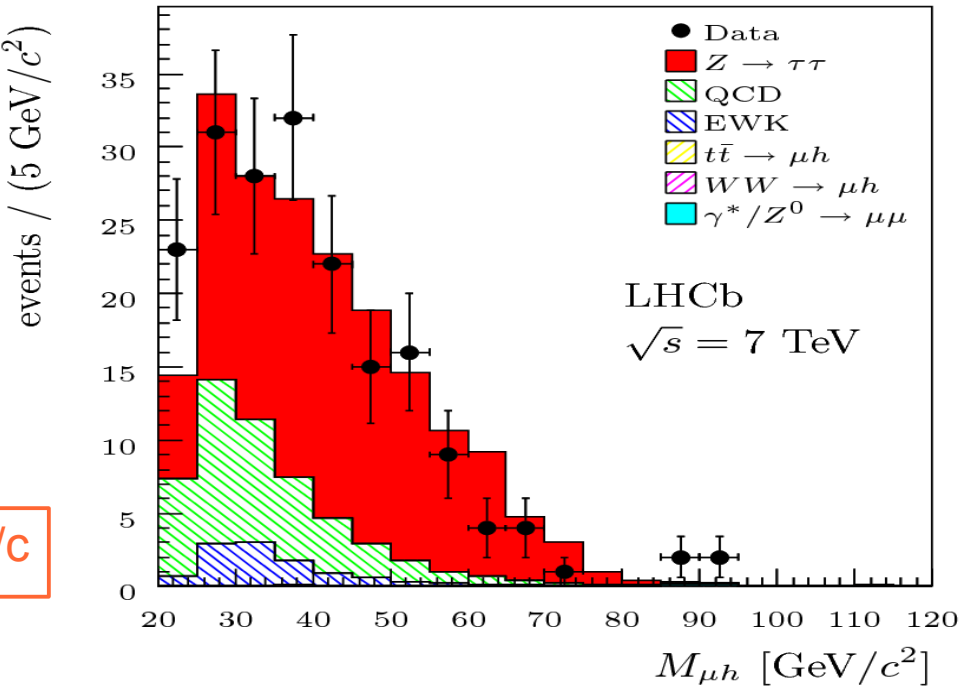
- Channels and selection:

  $Z \rightarrow \tau_\mu \tau_\mu, \tau_\mu \tau_e, \tau_e \tau_\mu$

  $Z \rightarrow \tau_\mu \tau_h, \tau_e \tau_h$ (1-prong)

  $p_T(e/\mu) > 20$ GeV/c $p_T(e/\mu/h) > 5$ GeV/c

  $2 < \eta(e/\mu) < 4.5$; $2.25 < \eta(h) < 3.75$



- Main backgrounds:
  - QCD and W+jet: from same sign ττ data
  - $Z/\gamma^* \rightarrow \mu\mu$: from $Z \rightarrow \mu\mu$ resonance and low impact parameter sidebands
- Purity: 65-70% in all channels
- Analysis extended to $H \rightarrow \tau\tau$ search

Selection of Higgs → ττ events

- Channels considered:

  $H \to \tau_\mu \tau_\mu, \tau_\mu \tau_e, \tau_e \tau_\mu$ (2l) and $H \to \tau_\mu \tau_h, \tau_e \tau_h$ (l + 1-prong)

- Selections applied to τ pairs:

$p_T(e/\mu) > 20$ GeV/c

$p_T(e/\mu/h) > 5$ GeV/c

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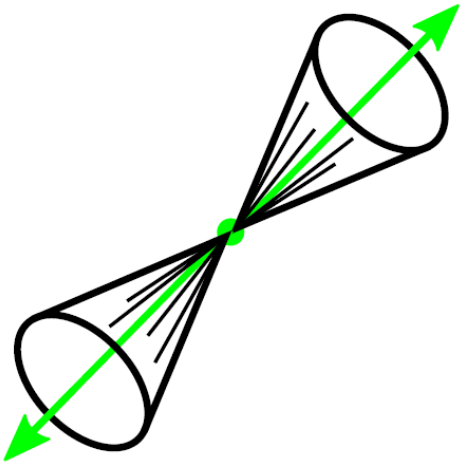
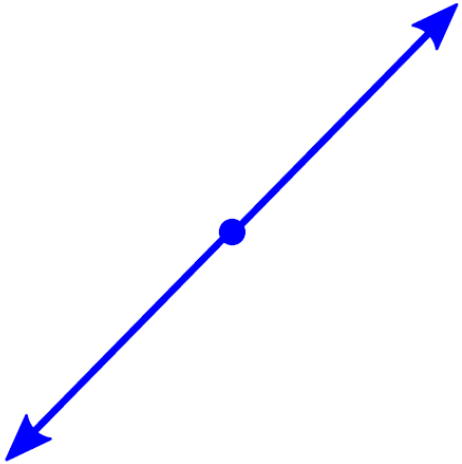
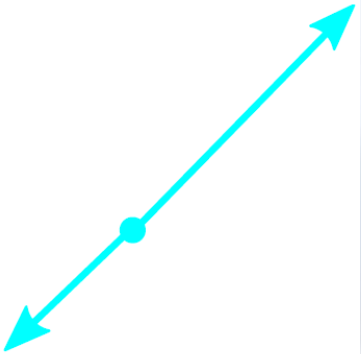






Isolated

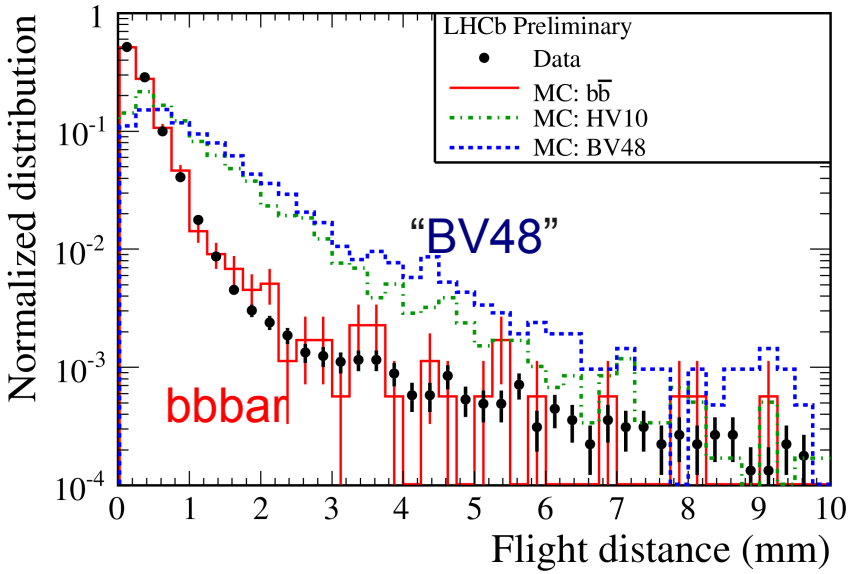
back-to-back in Φ

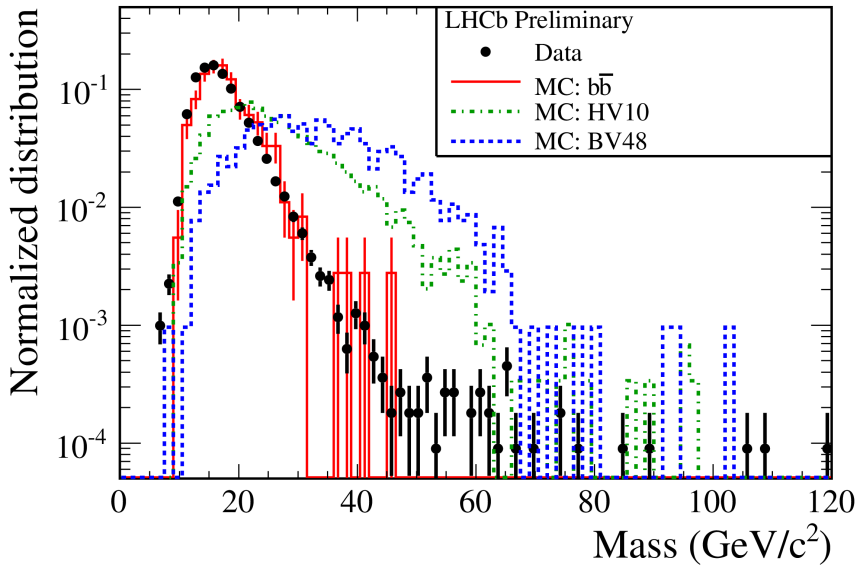
τ lifetime (for $\tau_\mu \tau_\mu, \tau_\mu \tau_h, \tau_e \tau_h$ only)

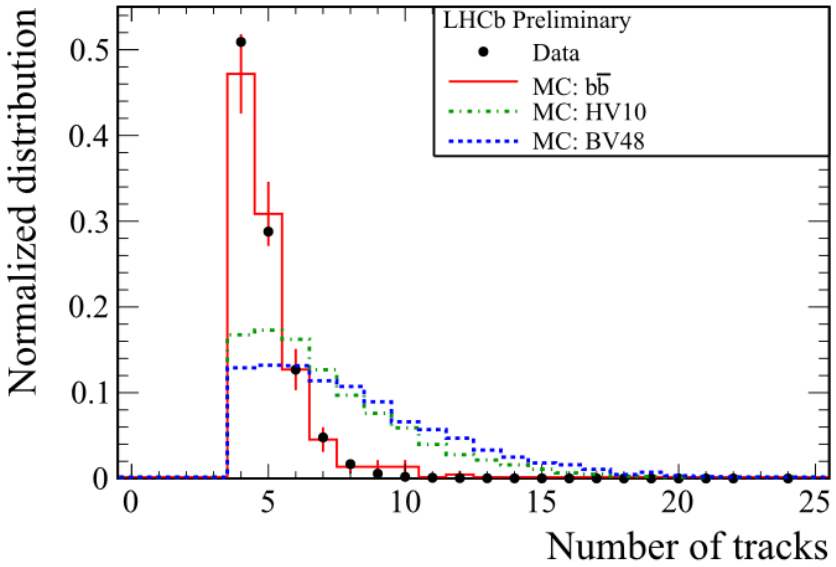
p_T asymmetry ($\tau_\mu \tau_\mu$ only)

h^0 decaying to Long-Lived Particles

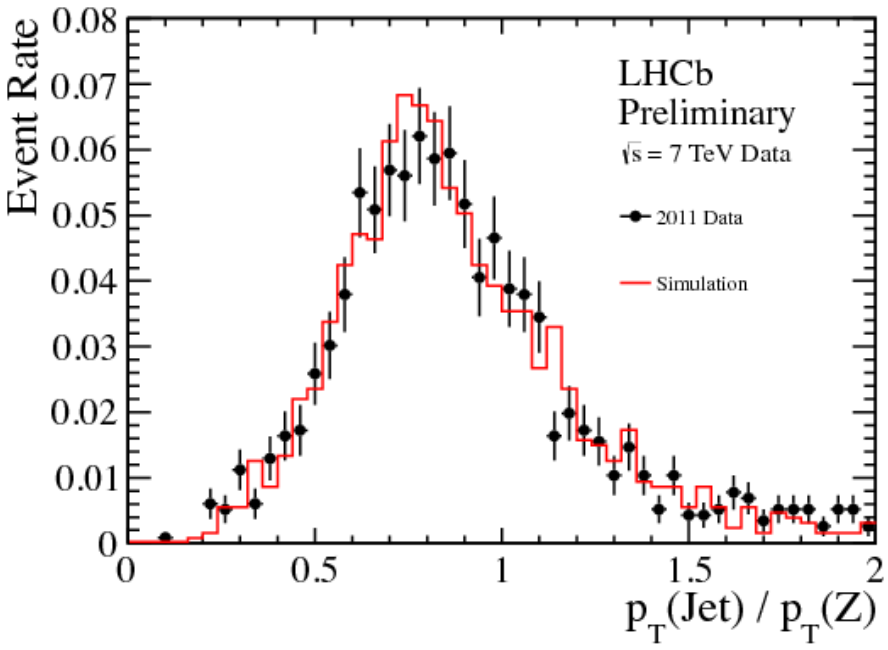
- Loosen selection for control region:
  - LLP vertex outside matter, m(trks) > 4 GeV , R > 0.4 mm, N(tracks) > 3
  - Shapes well compatible with pure bbbar (see 3 figs)
  - Yields also compatible with pure bbbar events







Jet energy resolution at LHCb



- Using jets back to back with Z bosons reconstructed in their dimuon decay, simulation of jet energy scale is found to represent data with a precision of 3%

- From simulation, jet energy resolution at LHCb is then found to be 17% at pT = 30 GeV

“LHCb implications” workshop 14-16 October 2013

- Mixed Theorists/LHCb workshop
- A “Forward exotica” session:
  - An occasion for theorists to propose new ideas to complement LHC direct searches using LHCb detector's unique viewpoint :
    - Test softer new physics signals (below ATLAS/CMS trigger p_T thresholds)
    - Detector optimized to see displaced vertices
    - High brandwith trigger
    - Low pile-up
    - Superior particle identification (eg. Pi^+/K^+ with Cherenkov)
    - Looking forward
- Contact us: http://indico.cern.ch/conferenceDisplay.py?confId=255380