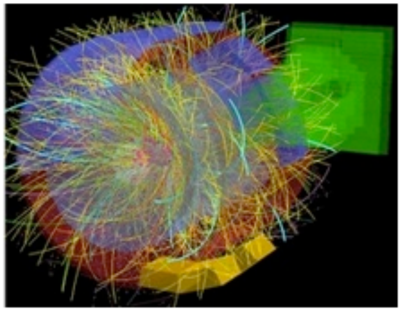
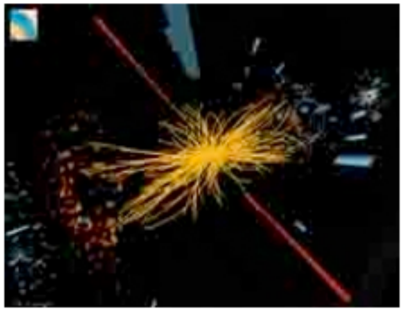


INTERNATIONAL WORKSHOP ON DISCOVERY PHYSICS AT THE LHC
KRUGER 2012
DECEMBER 3 - 7, 2012
PROTEA HOTEL, KRUGER GATE
SOUTH AFRICA



Testing the SM with Rare decays @ the LHCb

Eugeni Graugés

on behalf of the LHCb collaboration

LHCb

UNIVERSITAT DE BARCELONA

Institut de Ciències del Cosmos

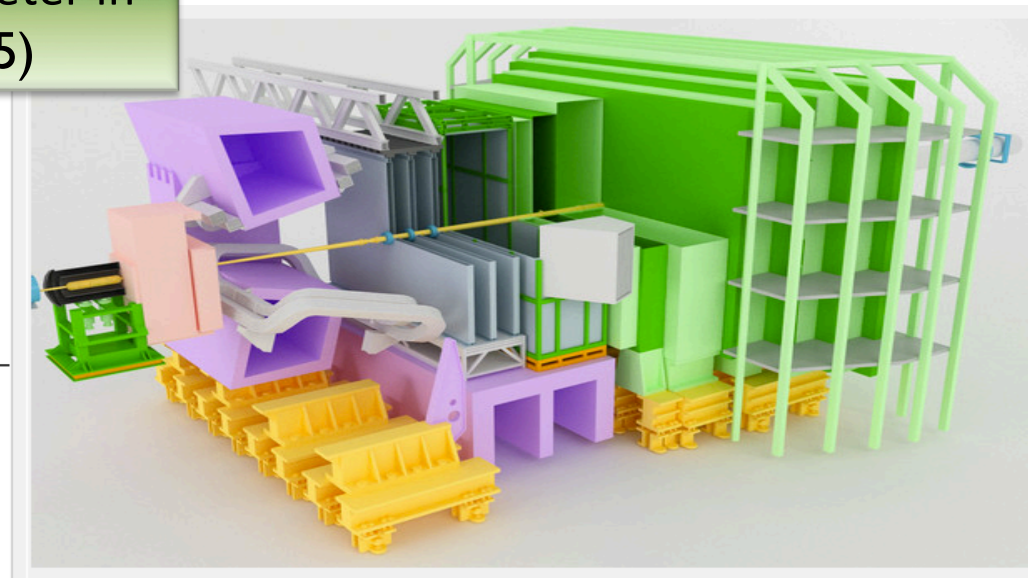
OUTLINE

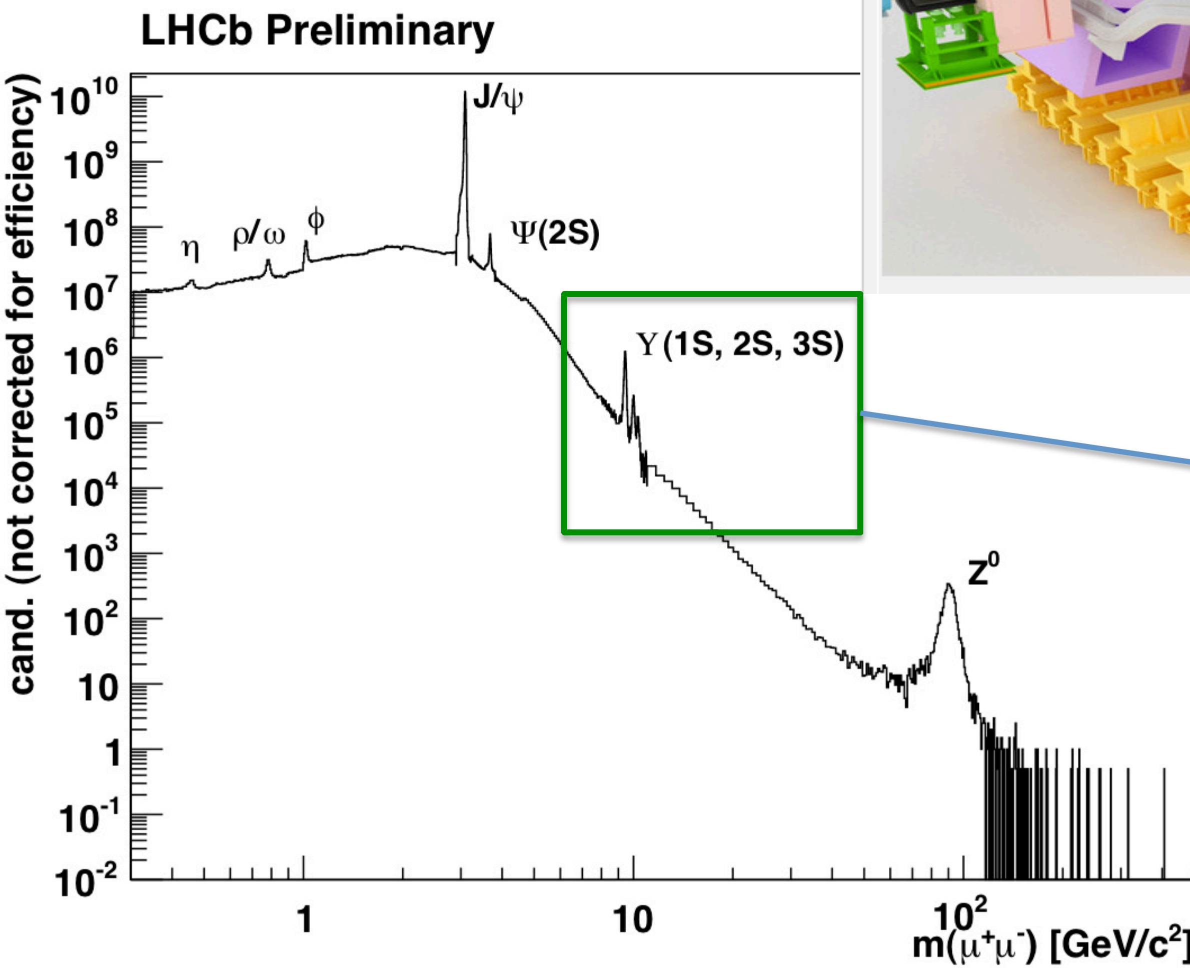
- Introduction
  - LHC & LHCb experiment
  - LHCb physics program, dataset & performance
- Rare Decays
  - Rare B decays
    - $B \to K^{*}\gamma$ / $B \to \Phi\gamma$ [PRD 85, 112013 (2012),;NPB 867 (2013) 1-18; LHCb-CONF-2012-004]
    - $B \to K^{(*)}\mu\mu$ [LHCb-CONF-2012-008; arXiv:1210.4492; arXiv:1209.4284; JHEP 07(2012)133]
    - $B_s \to \phi\,\mu\mu$ / $B_s \to \phi\, J/\Psi$ [LHCb-CONF-2012-003]
    - $B \to \pi\,\mu\mu$ [arXiv:1210.2645]
    - $B_s(B_d) \to \mu\mu$ (& $K_s \to \mu\mu$) [arXiv:1211.2674 ; arXiv:1209.4029]
  - Rare D decays
    - $D \to \mu\mu$ [LHCb-CONF-2012-005]
  - Search for LFV & LNV
    - $\tau \to \mu\mu\mu$ [LHCb-CONF-2012-015] ; $\tau \to p\,\mu\mu$ [LHCb-CONF-2012-027]
    - Search for Majorana neutrinos [Phys. Rev. D 85 (2012) 112004]

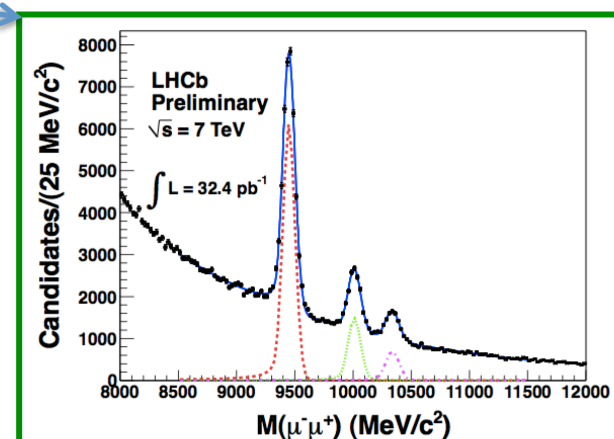
- Summary & Conclusions

→ for CP violation measurements @ LHCb, see Olaf Steinkamp talk (Thursday)

LHCb: a general purpose spectrometer in the forward direction ($2<\eta<4.5$)







LHC performance

- Great LHC running with $\mathscr{L}$ leveling,

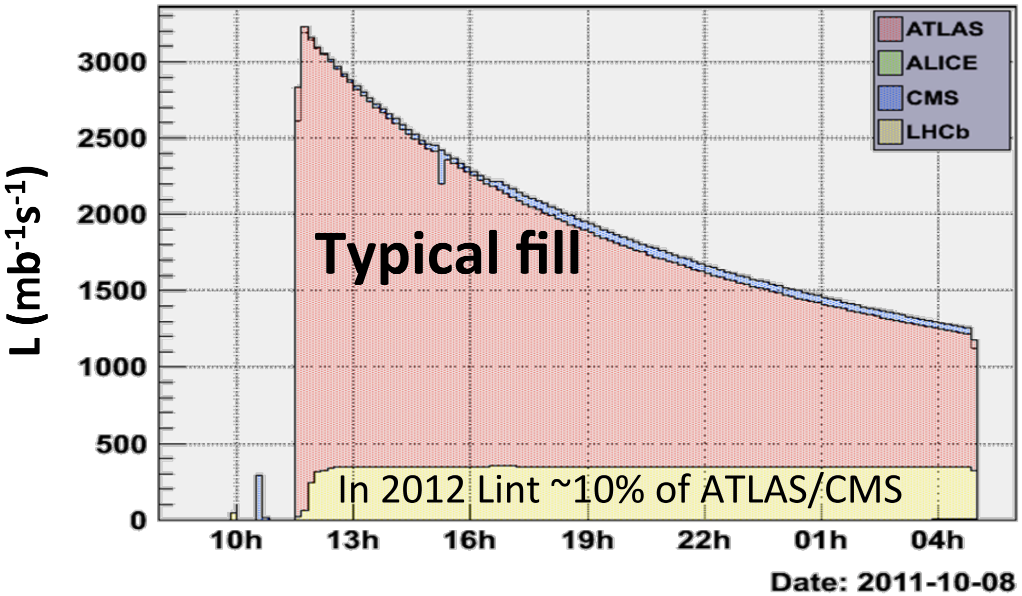
matched by …

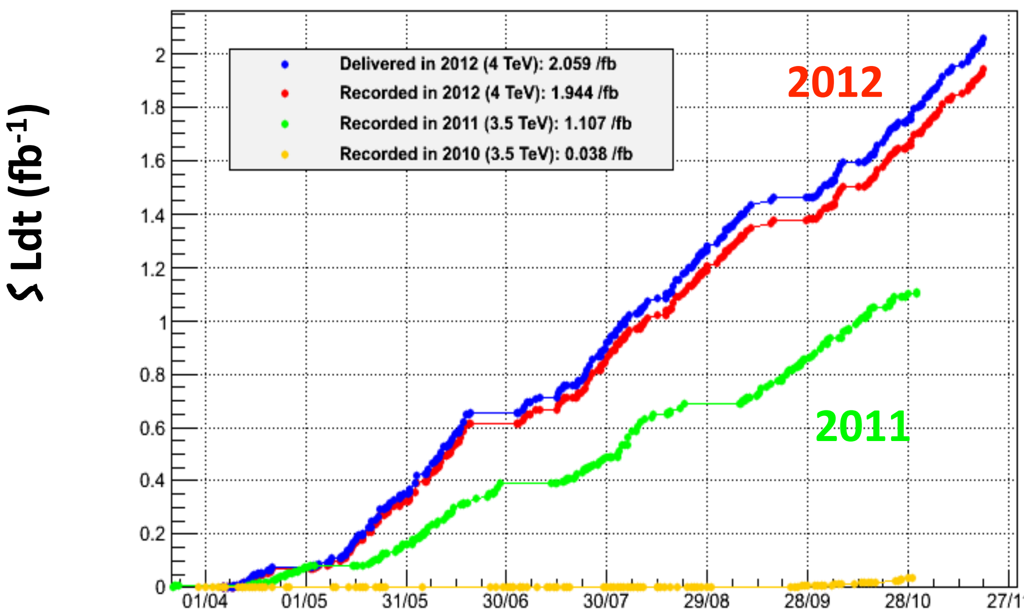
- excellent performance of LHCb detectors:
  - ~99% of operational RO channels,
  - ~95% data taking efficiency

- Dataset: 1/fb in 2011

  and already …

  ~2/fb in 2012





Beauty production at LHC

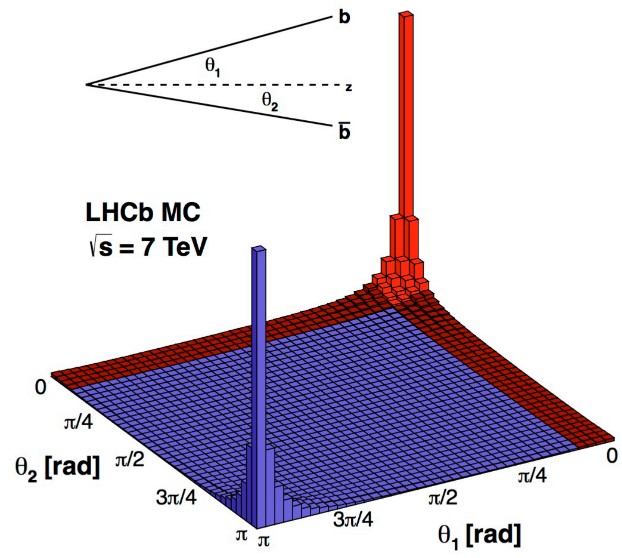
- σ_{bb} **= 284±53μb** (√s=7TeV),
In LHCb acceptance σ_{bb} **~ 75μb**

PLB 694 (2010) 209

  - All b-hadron species produced at LHC
  B^0, B^+, B_s, B_c, Λ_b, …
  (40% 40% 10% 10%)

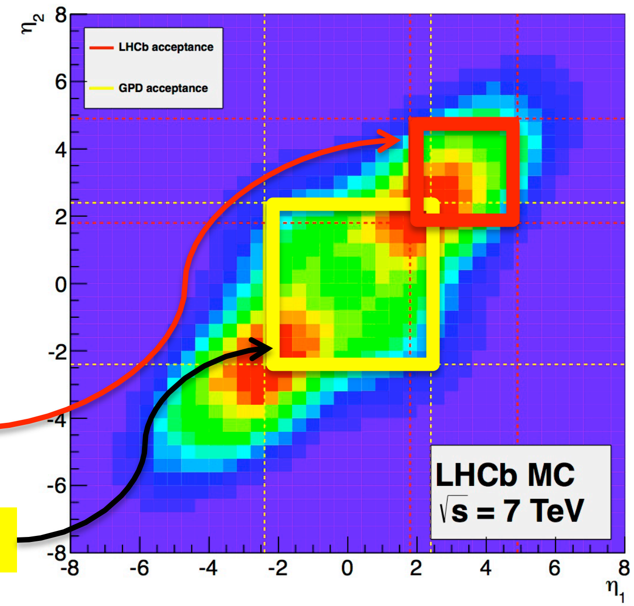
  - **Charm: ~ beauty x 20** CONF-2010-013

gluon-gluon fusion



- Operated since the end of 2011 at
$4 \cdot 10^{32}/cm^2\,s$ (2x design lumi)

~ 30KHz (@7TeV) of bb pairs
(10^4 x B factories)

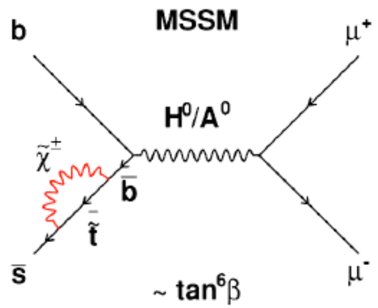


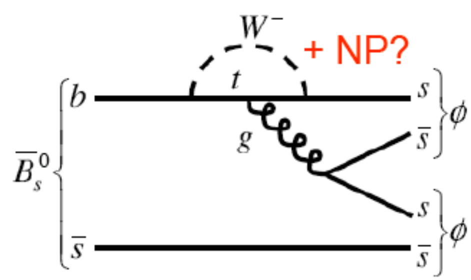
LHCb acceptance: 2<η<5

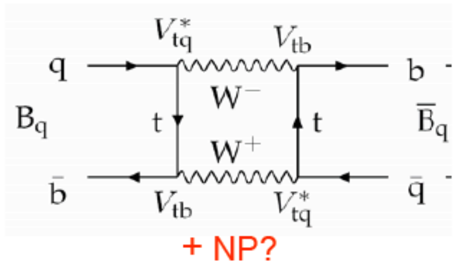
ATLAS/CMS acceptance: |η|<2.5

The LHCb physics program

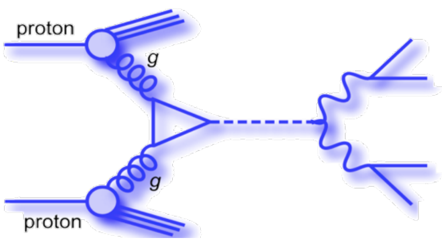
- **New Physics (NP)** evidence may appear both in measurements of CP violation and rare decays, mediated by new particles (via their contributions in loop diagrams); e.g.: Comparing CKM quantities determined in tree & loop process





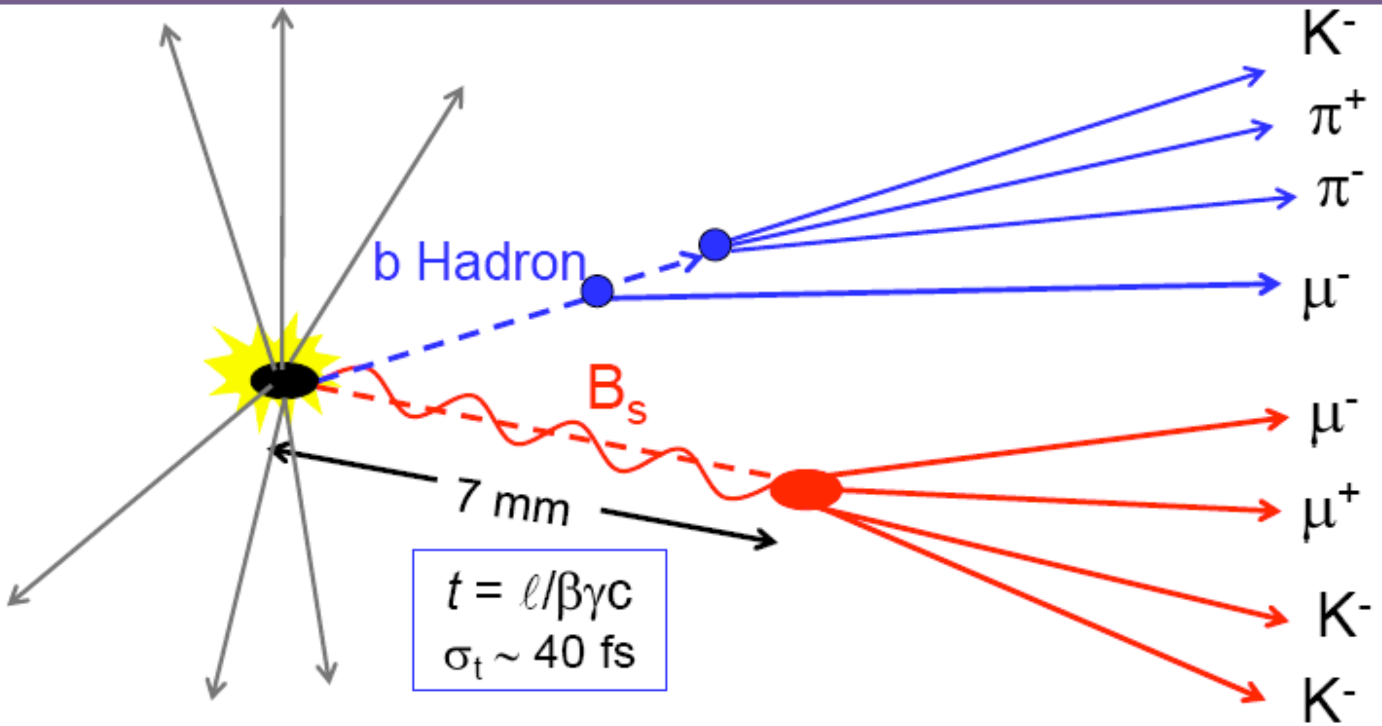


- Complementary to **ATLAS & CMS** direct searches
  - If NP is discovered, its structure must be determined



- **New particles would distort the SM (CKM) picture of B decays by modifying:**
  - **Phases** — CP violation
  - **Amplitudes** ⇔ Branching ratios
  - **Lorentz Structure** — Angular distributions

Beauty physics requirements @ LHC

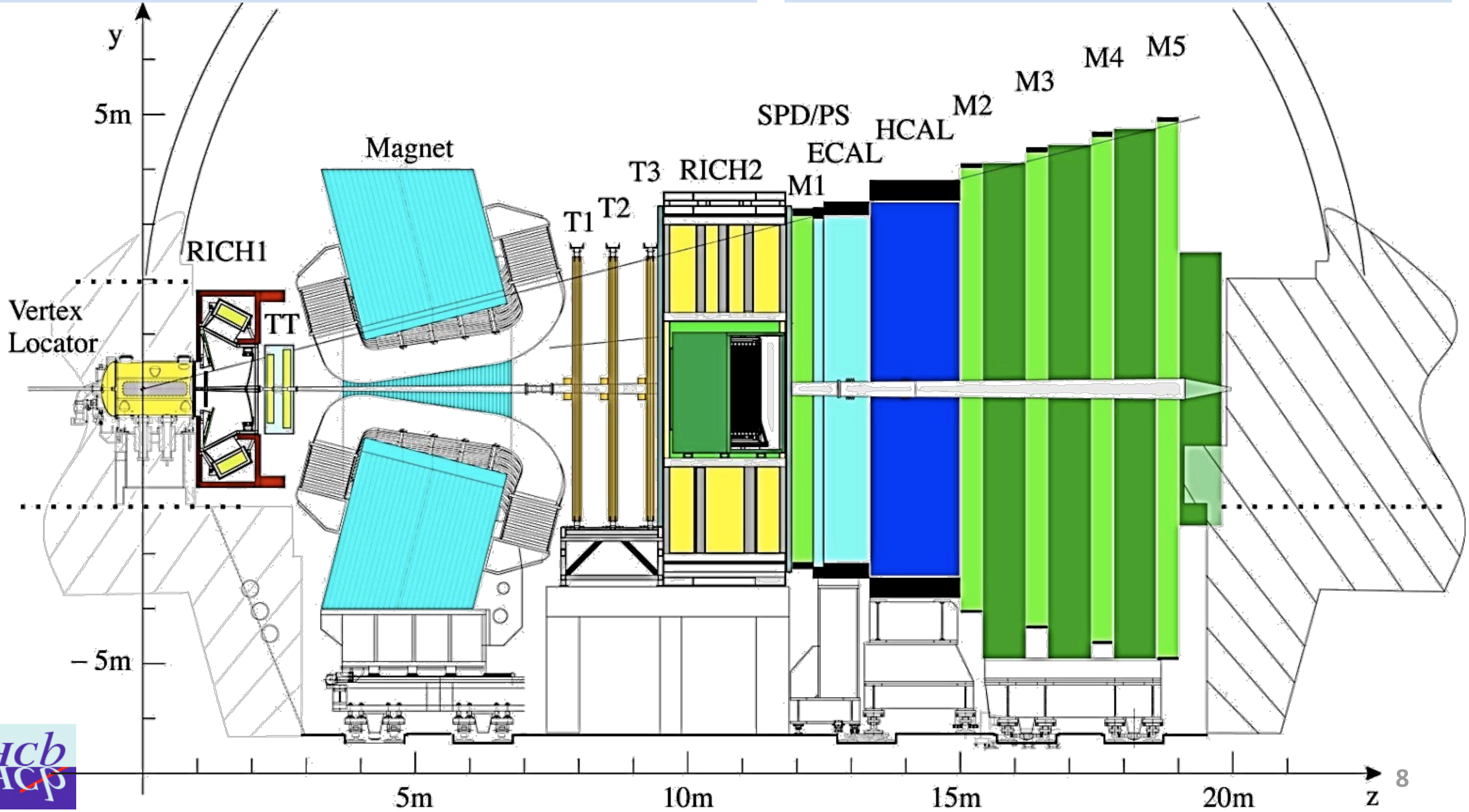


- High Statistics: Need an efficient trigger to select hadronic and leptonic B meson decays, specially taking into account $\sigma_{bb}/\sigma_{inel} \sim o(10^{-3})$
- Excellent vertex resolution, to resolve a displaced seconday vertex
- Background reduction:
  - Very good mass resolution
  - Very efficient particle identification (K/π)

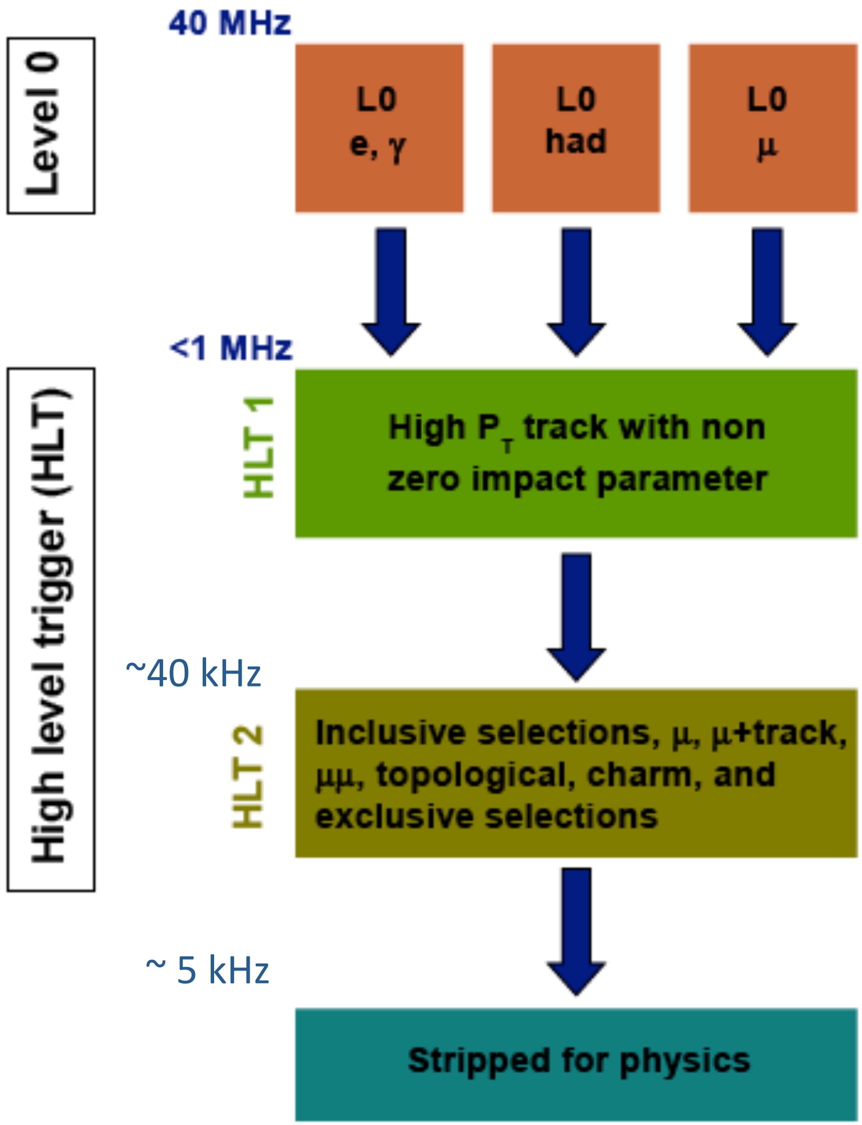
LHCb detector

- VELO: 21 (R+φ) Si station
- RICH 1& 2: C_4F_{10} + Aerogel / CF_4
  π/K separation 2<p<100 GeV
- TRACKING: Si+Straw tubes + 4 Tm
  δp/p = 0.4 – 0.6%

- CALO: SPD/PS, ECAL, HCAL
  (Lead,Iron,Lead-Scintillator)
- MUON: MWPC + GEM
  π/μ separation



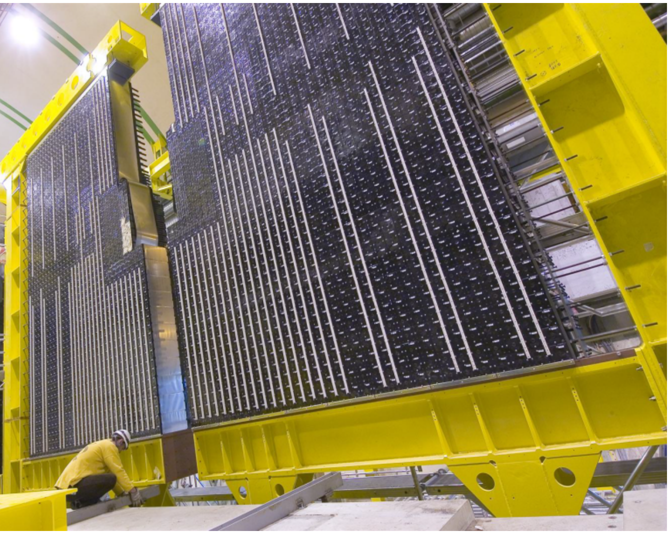
The LHCb trigger



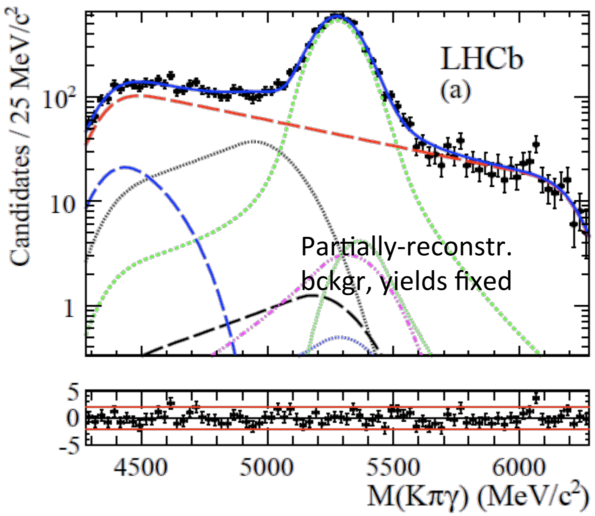
- **L0 hardware trigger**
  - Search for high p_T μ,γ ,e and hadron candidates:
    - CALO p_T>3.6 GeV
    - Muon p_T> 1.5 GeV
- **High Level Trigger software farm**
  - HLT1 adds impact parameter cuts
  - HLT2 does global event reconstruction

Rare B decays

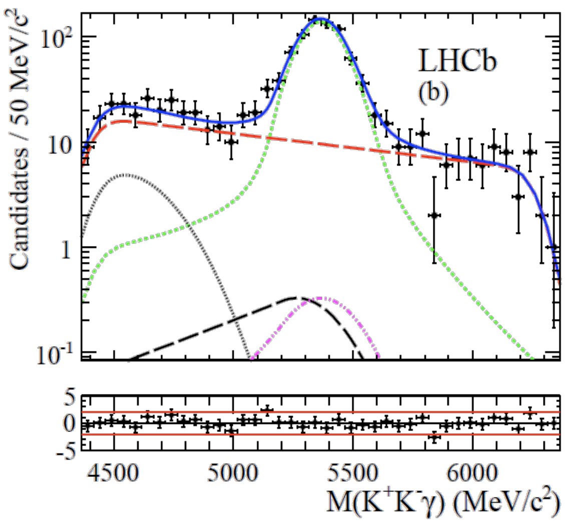
Radiative decays



$B^0 \to K^{*0}\gamma$



$B_s^0 \to \phi\gamma$



$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.23 \pm 0.06\,(\text{stat.}) \pm 0.04\,(\text{syst.}) \pm 0.10\,(f_s/f_d)$$

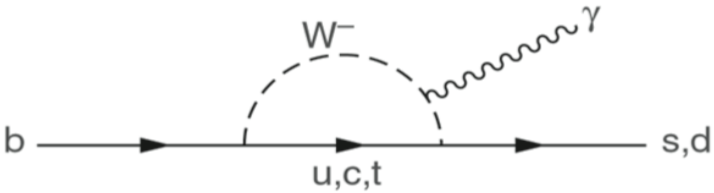
SM: 1.0±0.2

✔ **most precise measurement of BR($B_s \to \phi\gamma$ to date)**

-CP asymmetry measurement: Self tagging: $B^0 \to K^*\gamma$ with $K^* \to K^+\pi^-$

SM: (-0.61±0.43)%, some NP models down to -15%!

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = (0.8 \pm 1.7\,(\text{stat.}) \pm 0.9\,(\text{syst.}))\%$$



✔ **most precise measurement**

PRD 85, 112013 (2012)
NPB 867 (2013) 1-18

CP asymmetries in $B^0 \to K^* \mu^+ \mu^-$ (1/fb)

$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B}^0 \to \overline{K}^{*0}\mu^+\mu^-) - \Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{\Gamma(\overline{B}^0 \to \overline{K}^{*0}\mu^+\mu^-) + \Gamma(B^0 \to K^{*0}\mu^+\mu^-)}$$

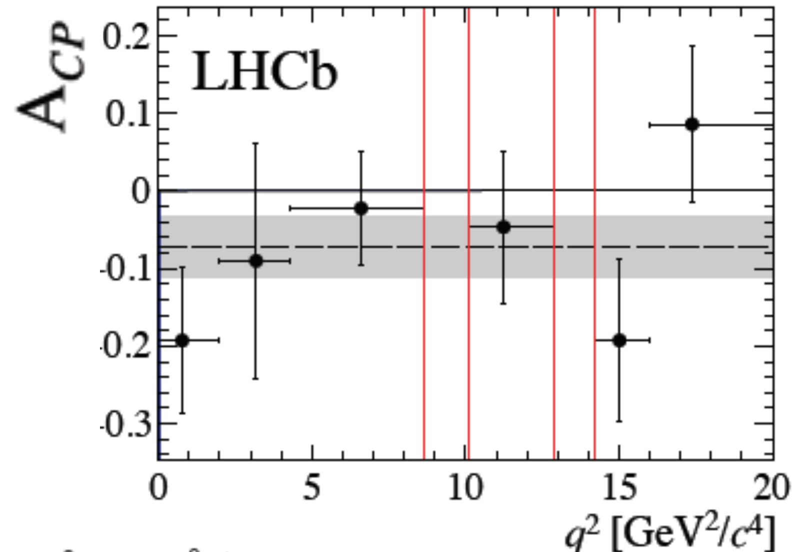
CP asymmetry in $B^0 \to K^* \mu^+ \mu^-$

- SM predicts $O(10^{-3})$

  [JHEP 01 (2009) 019] [JHEP 11 (2011) 122]

- NP could enhance it up to ±0.15

  [A, Alok, arXiv:1103.5344]



LHCb measurement:

- Self tagging: $B^0 \to K^* \mu^+ \mu^-$ with $K^* \to K^+ \pi^-$

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\mu^+\mu^-) = \mathcal{A}_{\rm RAW} - \mathcal{A}_{\rm D} - \kappa\mathcal{A}_{\rm P} \approx \mathcal{A}_{\rm RAW} - \mathcal{A}_{\rm RAW}^{K^{*0}J/\psi}$$

$$\mathcal{A}_{CP}\left(B^0 \to K^{*0}\mu^+\mu^-\right) = -0.072 \pm 0.040\ (\text{stat.}) \pm 0.005\ (\text{syst.}).$$

Consistent with SM at 1.8σ

it is assumed $A_{RAW}(B^0 \to K^* J/\psi)=0$

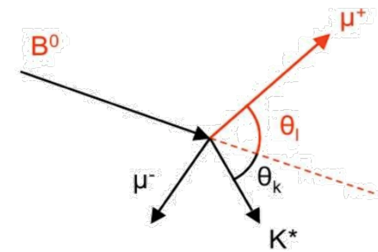
World's best measurement for A_{cp} in $B^0 \to K^* \mu^+ \mu^-$

arXiv:1210.4492

$B^0 \rightarrow K^*\mu^+\mu^-$ (1/fb)

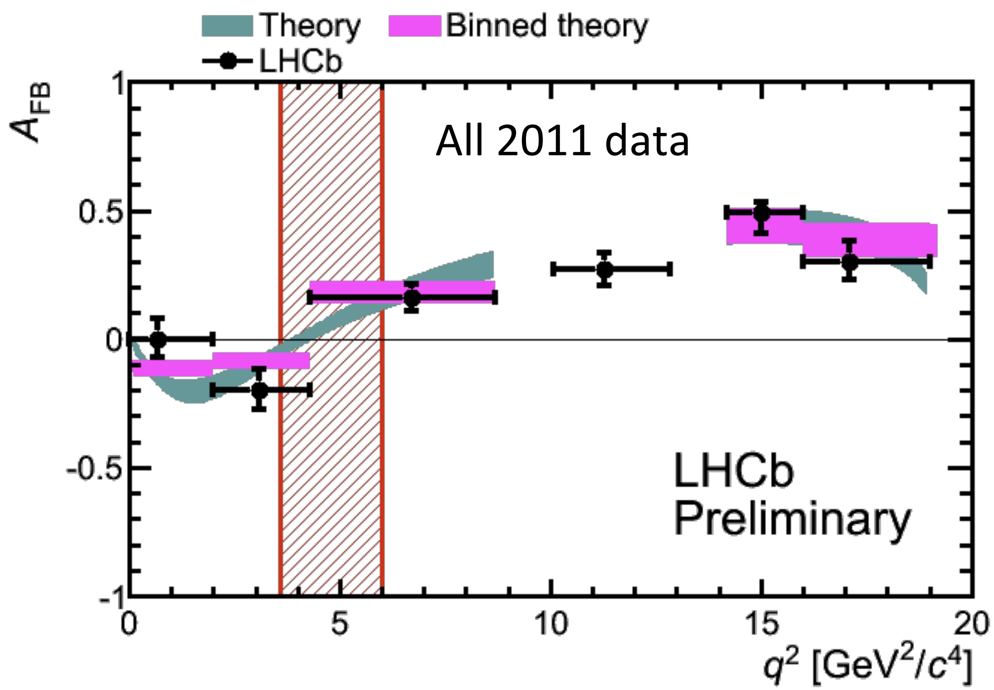
- BR < 10^{-6}, many observables sensitive to new operators from NP
- Example:

$$A_{FB}(q^2 = m^2_{\mu^+\mu^-}) = \frac{N_F - N_B}{N_F + N_B}$$



- In the SM, $A_{FB}(q^2)$ flips sign at a well predicted value of q^2, measured to be **$4.9^{+1.1}_{-1.3}$ GeV^2** at LHCb, consistent with SM prediction: 4-4.3 GeV^2

LHCb-CONF-2012-008



F_L and S_3 observables also measured to be consistent with SM

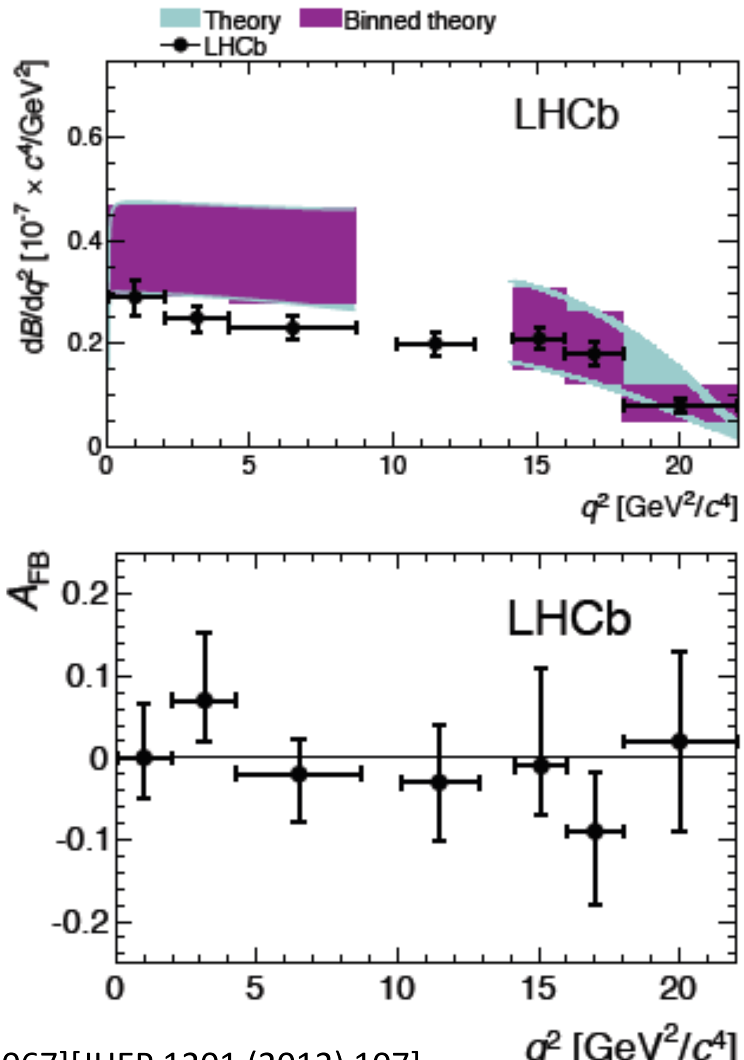
Angular analysis of $B^+ \to K^+\mu^+\mu^-$ (1/fb)

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma[B^+ \to K^+\mu^+\mu^-]}{\mathrm{d}\cos\theta_l} = \frac{3}{4}(1-F_{\mathrm{H}})(1-\cos^2\theta_l) + \frac{1}{2}F_{\mathrm{H}} + A_{\mathrm{FB}}\cos\theta_l$$

- The decay rate gives access to angular observables: A_{FB} and F_H predicted to be 0 in the SM
- LHCb analysis:
  - Differential BR, using $B^+ \to J/\psi K^+$ as normalization channel
  - BR at low q^2 measured below SM
  - A_{FB} and F_H measured in simultaneous fit to mass and $\cos\theta_l$

  → Results consistent with SM

arXiv:1210.4284



Theory from [JHEP 1107 (2011)067][JHEP 1201 (2012) 107]

Isospin asymmetry in $B^{(+)} \rightarrow K^{(*)(+)} \mu^+\mu^-$ (1/fb)

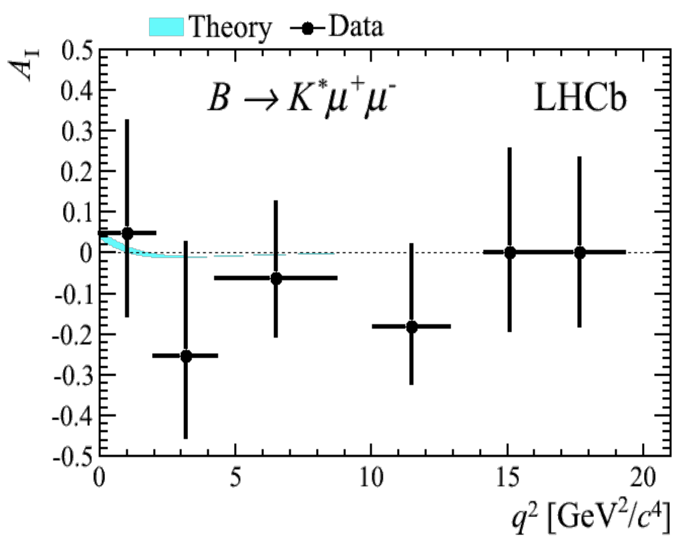
- Isospin asymmetry A_I, between $B^0 \rightarrow K^0(K^{*0})\mu^+\mu^-$ and $B^+ \rightarrow K^+(K^{*+})\mu^+\mu^-$, defined as

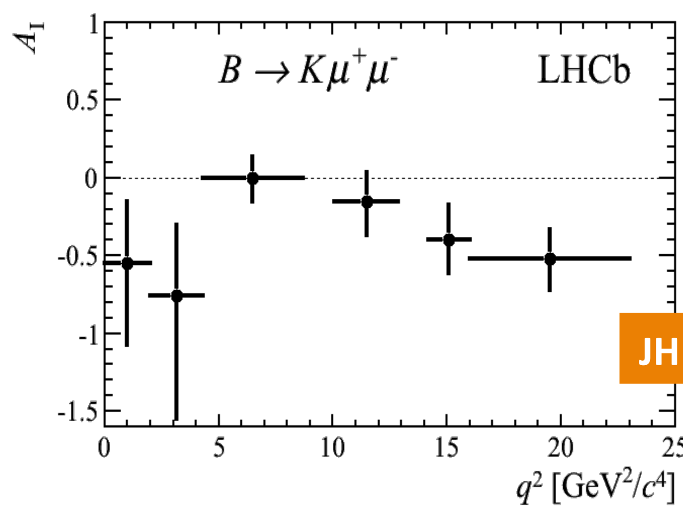
$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \frac{\tau_0}{\tau_+}\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \frac{\tau_0}{\tau_+}\mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

SM : $A_I \rightarrow -0.01$ for $K^*\mu^+\mu^-$

SM: $A_I \rightarrow 0$ for $K\mu^+\mu^-$

LHCb Measurements:



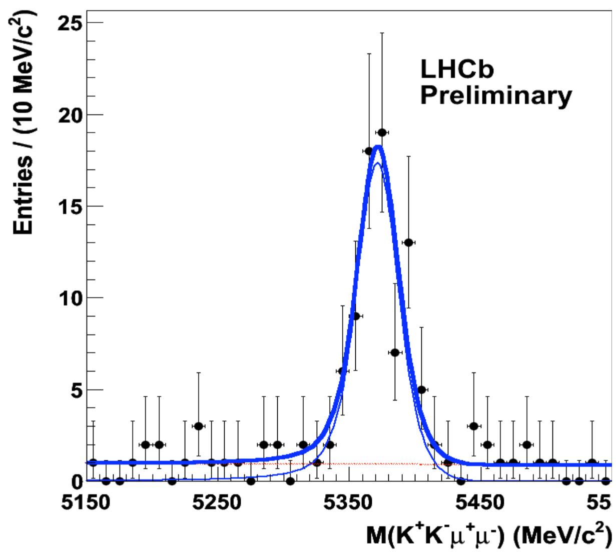


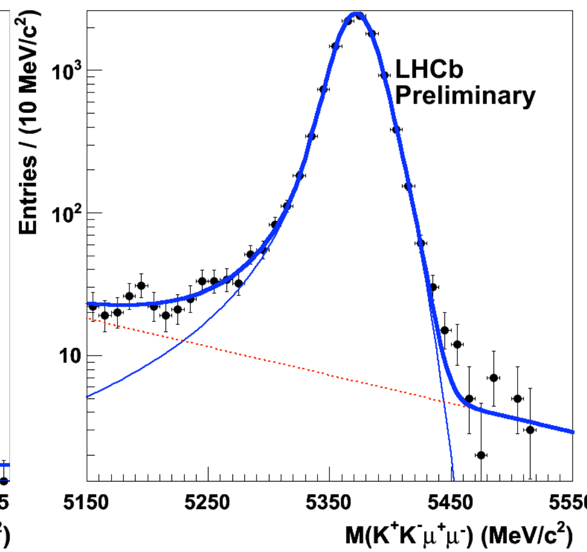
JHEP 07 (2012) 133

- Integrating over $\mathbf{q^2}$: 4.6σ from 0 seen for $B \rightarrow K\mu^+\mu^-$ decays, **not yet explained**
- Consistent with hints from CDF, BaBar, Belle

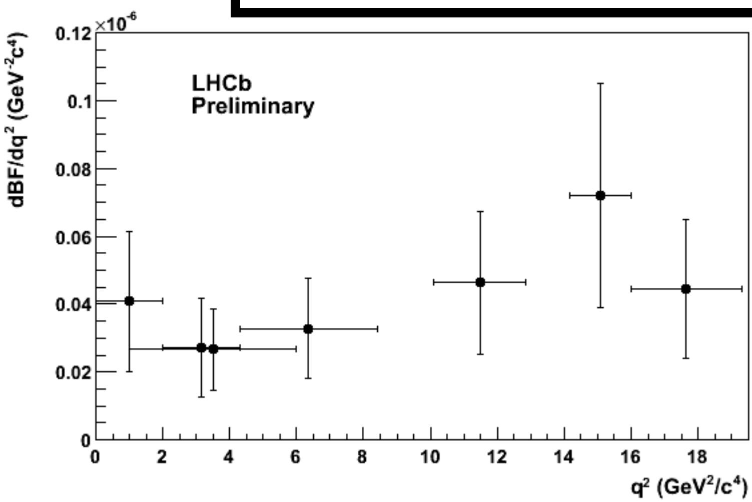
$B_s \to \phi\mu\mu$ / $B_s \to \phi$ J/Ψ [LHCb-CONF-2012-003]

- $B_s \to \phi\mu\mu$ is a FCNC
- SM: BR= ~1.6 x 10^{-6}
- Measurement of $BR(B_s \to \phi\mu\mu)/BR(B_s \to \phi\ J/\Psi)$ versus the $\mu\mu$ inv. mass
- The $BR(B_s \to \phi\mu\mu)$ defintion excludes the J/Ψ and Ψ' resonances (for $\mu\mu$)





$$\frac{\mathcal{B}(B_s^0 \to \phi\mu\mu)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = (0.558 \pm 0.070(\mathrm{stat}) \pm 0.043(\mathrm{syst}) \pm 0.006(\mathcal{B})) \times 10^{-3}$$



$$\mathcal{B}(B_s^0 \to \phi\mu\mu) = (0.78 \pm 0.10(\mathrm{stat}) \pm 0.06(\mathrm{syst}) \pm 0.28(\mathcal{B})) \times 10^{-6}$$

Data sample of 1/fb collected by the LHCb detector at 7TeV (2011 run)

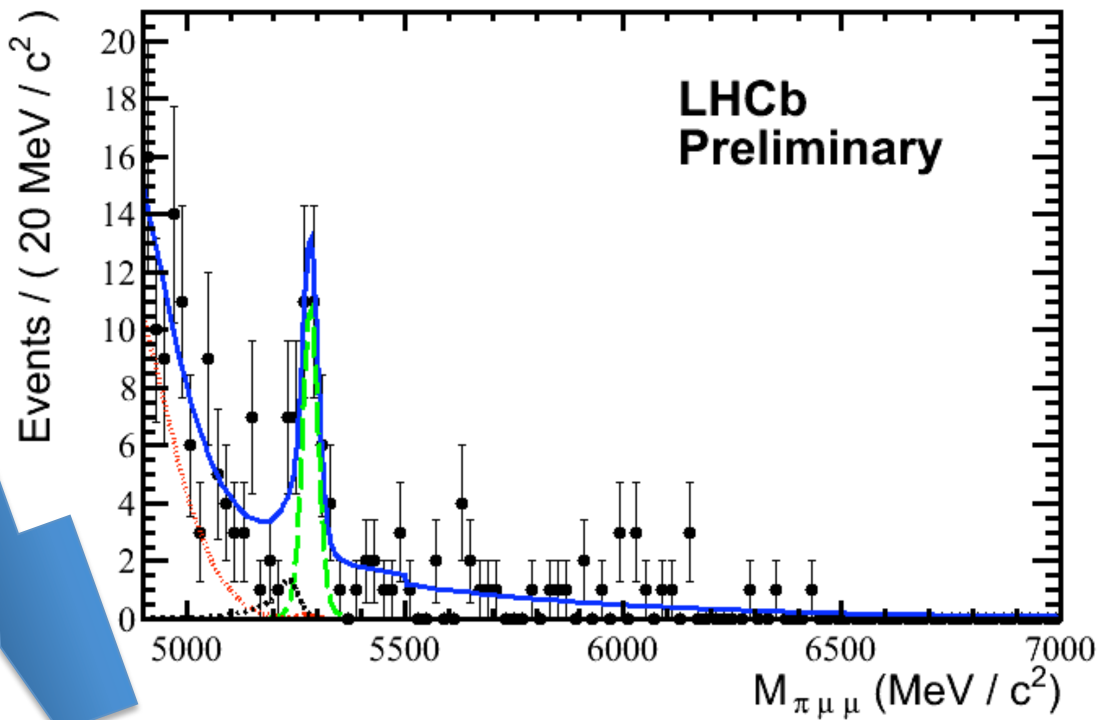
$B^+ \rightarrow \pi^+\mu^+\mu^-$ [arXiv:1210.2645]

- The rarest B decay ever observed (until 11/12).

SM prediction:

$BR(B^+ \rightarrow \pi^+\mu^+\mu^-) = (1.96 \pm 0.21)\cdot 10^{-8}$

- Gives access to V_{td}/V_{ts} when compared with $B^+ \rightarrow K^+\mu^+\mu^-$



  - $B^+ \rightarrow \pi^+\mu^+\mu^-$ signal (green)
  - Partially reco'ed decays (red dotted)
  - Misidentified $K^+\mu^+\mu^-$ (black dashed)
  - Total (blue solid line)

$B^+ \rightarrow \pi^+\mu^+\mu^-$ Signal yield
$25\pm7 \Leftrightarrow 5.2\sigma$
Normalizing it to the $B^+ \rightarrow K^+ J/\psi$

$BR(B^+ \rightarrow \pi^+\mu^+\mu^-) =$
$[2.4 \pm 0.6\ (stat) \pm 0.2\ (syst)] \cdot 10^{-8}$

- Candidates with $\mu^+\mu^-$ pair consistent with a J/ψ or $\psi(2S)$ decay are excluded

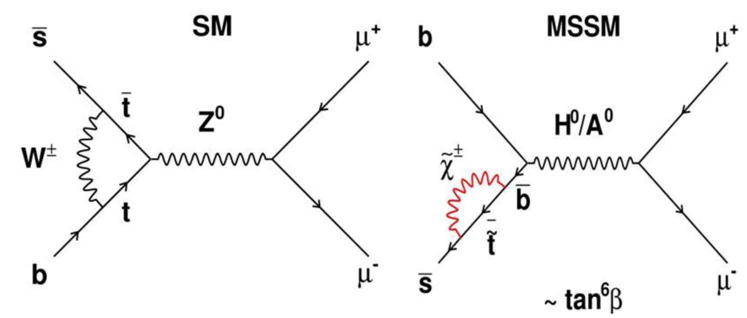
$B^0/B_s \to \mu^+\mu^-$, 2fb^{-1}

- Double suppression: FCNC & helicity
- Precise SM prediction:

  $BR(B_s \to \mu^+\mu^-)^{t=0} = (3.23 \pm 0.27) \times 10^{-9}$

  $BR(B^0 \to \mu^+\mu^-)^{t=0} = (0.107 \pm 0.01) \times 10^{-9}$

  Buras, Isidori: arXiv:1208.0934



- A time integrated BR is needed to compare with the experiment

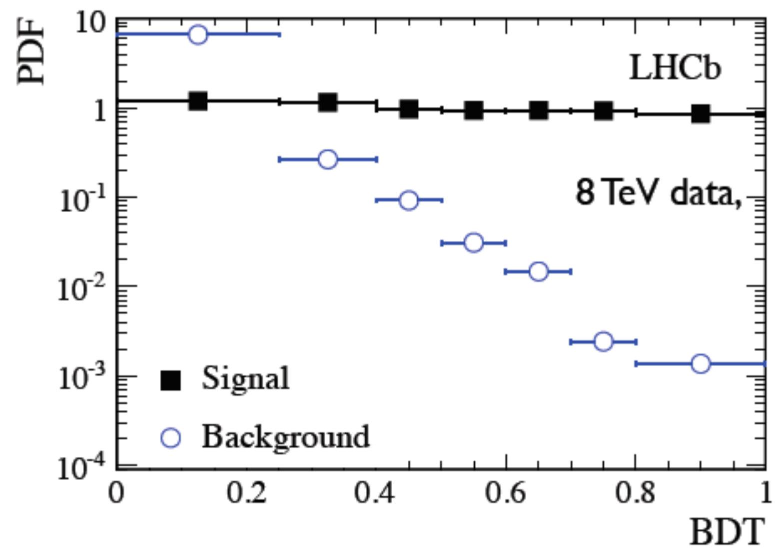
  $BR(B_s \to \mu^+\mu^-)^{\langle t \rangle} = (3.54 \pm 0.30) \times 10^{-9}$

  De Bruyn et al., PRL 109, 041801 (2012) using LHCb-CONF-2012-002

- Sensitive to NP in scalar/pseudo-scalar sector: MSSM, large tanβ approximation

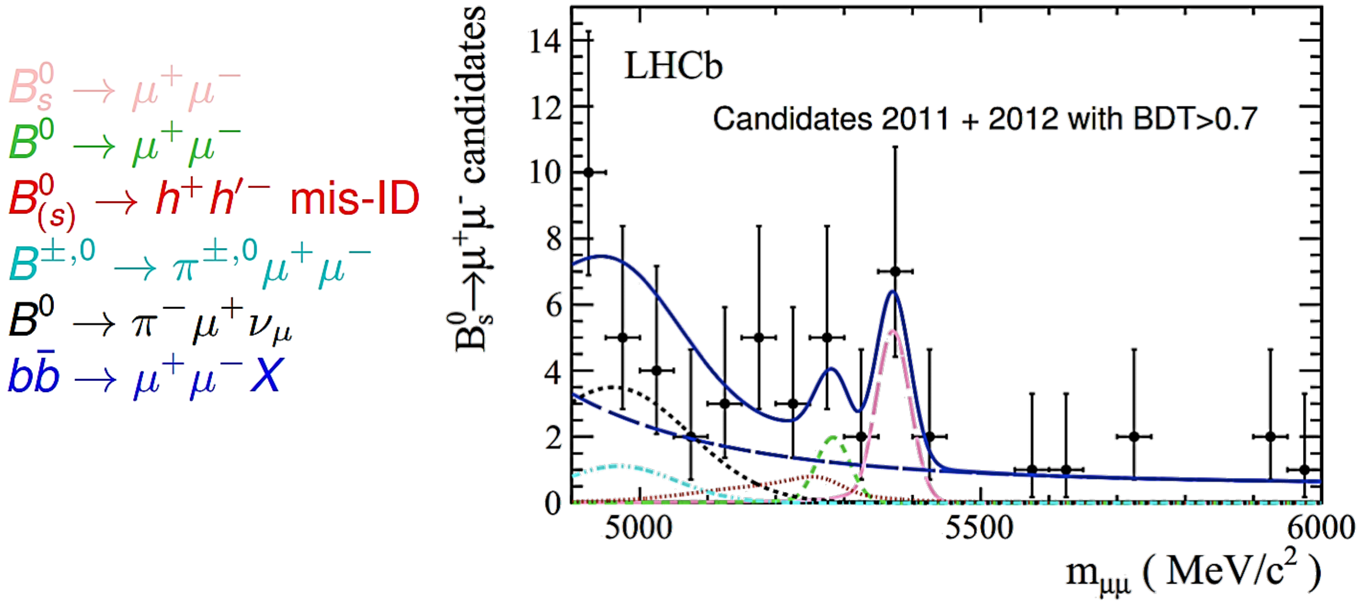
  $BR(B_{s,d} \to \mu^+\mu^-) \propto \tan^6\beta / M^4_A$

- **Analysis:** soft selection + Boosted Decision Tree combining geometrical and kinematic information
  - Use the copious $B_{(s)} \to h^+h^-$ as calibration



$B^0/B_s \rightarrow \mu^+\mu^-$, $2fb^{-1}$

- BR extracted from a simultaneous fit to different BDT bins
- For illustration, take those with high signal likelihood (BDT>0.7)::



- **BR($B_s \rightarrow \mu^+\mu^-$) = $(3.2^{+1.5}_{-1.2}) \cdot 10^{-9}$**

  Probability of background-only fluctuation: 5×10^{-4} → 3.5σ significance.

- BR($B^0 \rightarrow \mu^+\mu^-$) < 9.4×10^{-10} @ 95%C.L

  Probability of background-only fluctuation: 11%→ 1.2σ.

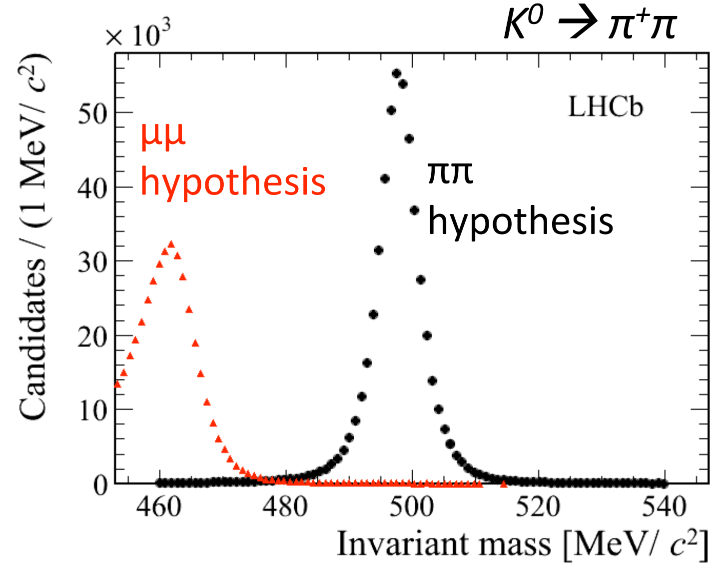
LHCb-PAPER-2012-043
arXiv:1211.2674, submitted to PRL

$K^0_S \rightarrow \mu^+\mu^-$

- In the 70's:

BR($K^0_L \rightarrow \mu^+\mu^-$) measured to be $(6.84\pm0.11)\cdot10^{-9}$, while it had been predicted to be ~ 10^{-4} → GIM mechanism, c quark proposed

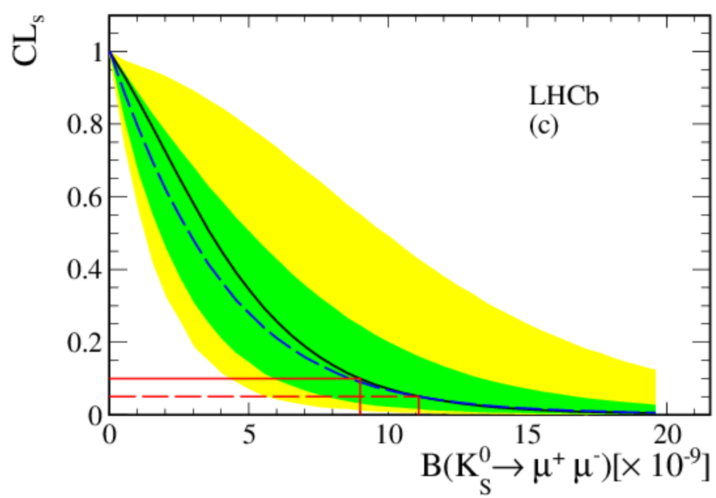
- SM prediction for BR($K^0_S \rightarrow \mu^+\mu^-$): $(5.0\pm1.5)\cdot10^{-12}$
- The peaking background from $K^0 \rightarrow \pi^+\pi^-$ shifted due to $m_\pi - m_\mu$

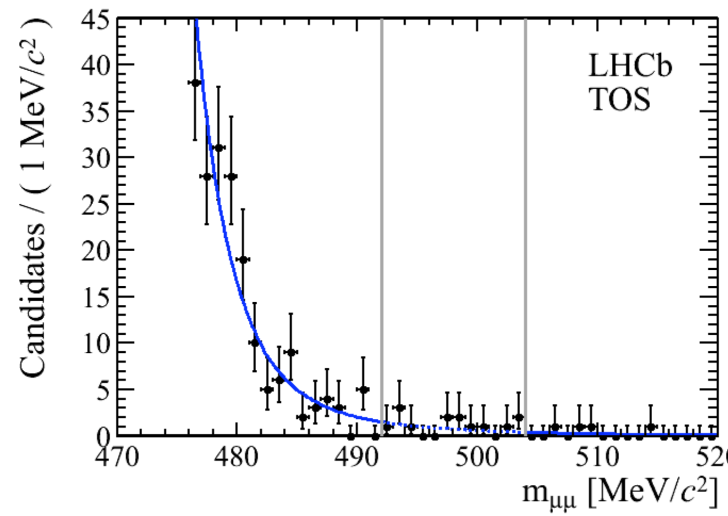


LHCb measurement:

BR($K^0_S \rightarrow \mu^+\mu^-$) < 11 (9) x$10^{-9}$ at 95% (90%) CL

- Approaching predictions of NP models
- Factor 30 improvement vs previous result (1973!)





arXiv:1209.4029, subm JHEP

Rare D decays

$D^0 \to \mu^+\mu^-$

- FCNC, GIM suppressed
- SM BR prediction dominated by long distance contributions
  $BR(D^0 \to \mu^+\mu^-) < \sim 6 \times 10^{-11}$
- LHCb measurement: No excess observed wrt predicted bkg
  → Consistent with the SM prediction → Upper limit set at

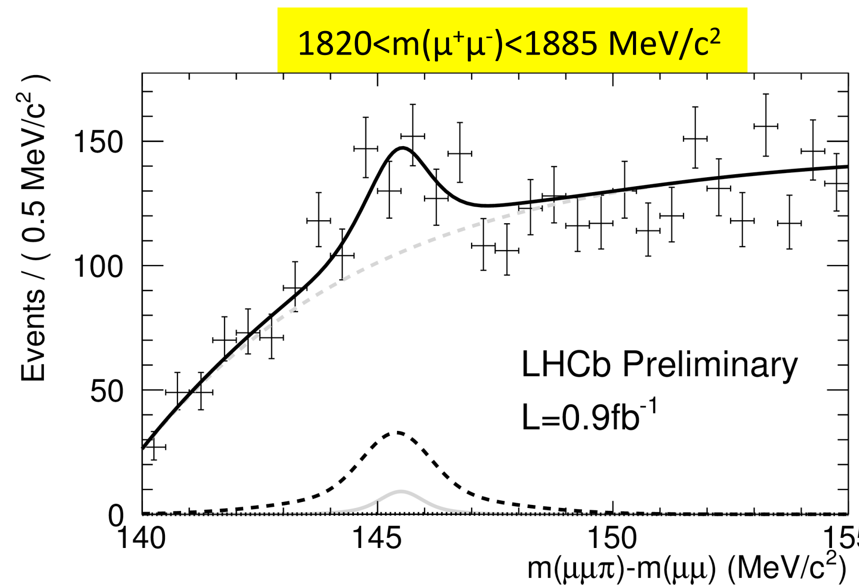
  $BR(D^0 \to \mu^+\mu^-) < 1.3 \times 10^{-8}$ at 95% C.L.

  – An order of magnitude improvement from previous best limit→
    $BR(D^0 \to \mu^+\mu^-) < 1.4 \times 10^{-7}$ by Belle [PRD 81 (2010) 091102]

→ The D^0 mesons are usually obtained from the decay $D^{*+} \to D^0\pi^+$

→ Invariant mass resolutions is gained plotting

$$\Delta m = m_{D^*} - m_D = m(\pi\pi\mu) - m(\mu\mu)$$



Full fit function (continuous black line),
$D^{*+} \to D^0(\pi\pi)\pi^+$ (dashed dark grey line),
combinatorial background (dashed light grey line),
$D^{*+} \to D^0(k\pi)\pi^+$ (dotted line)
Signal $D^{*+} \to D^0(\mu\mu)\pi^+$ (continuous light grey line).

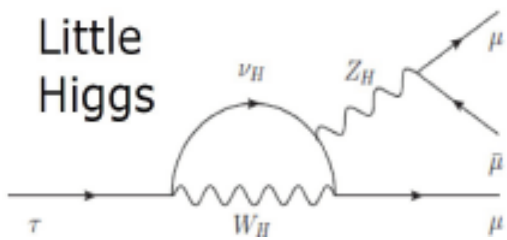
LHCb-CONF-2012-005

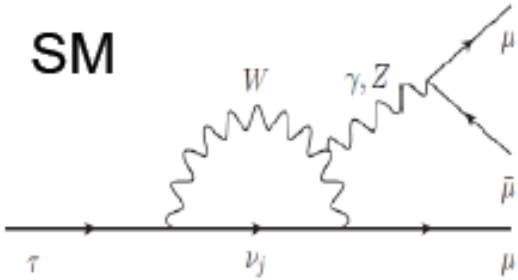
Search for Lepton Flavor Violation & Lepton/Baryon Number Violation

Search for $\tau^- \rightarrow \mu^-\mu^+\mu^-$

- LFV is allowed in the SM when accommodating the ν-oscillation observation
- The BR for the LFV decay $\tau^- \rightarrow \mu^-\mu^+\mu^-$: SM prediction is beyond the experimental scope ($\sim 10^{-54}$), but not for beyond the SM predictions:

  SUSY variant ($\sim 10^{-10}$), non universal Z' ($\sim 10^{-8}$)





- Current experimental UL on τ^- LFV:
  - BaBar, 468/fb: BR($\tau^- \rightarrow \mu^-\mu^+\mu^-$) < $3.3 \cdot 10^{-8}$ @90% CL
  - Belle, 782/fb: BR($\tau^- \rightarrow \mu^-\mu^+\mu^-$) < $2.1 \cdot 10^{-8}$ @90% CL
- Large τ^- production rate at LHC

  σ(τ) ~22μb within LHCb acceptance ➔ $\sim 10^{11}$ τ /fb @ 7 TeV (mostly from D^+_s decays)
- Observed limit (using 1/fb of data @ 7TeV) using CLs (Preliminary)

BR($\tau^- \rightarrow \mu^-\mu^+\mu^-$)<6.3 (7.8)$\cdot 10^{-8}$ @ 90(95)% CL

already close to the B-factories sensitivity, closer with the addition of 2012 dataset

LHCb-CONF-2012-015

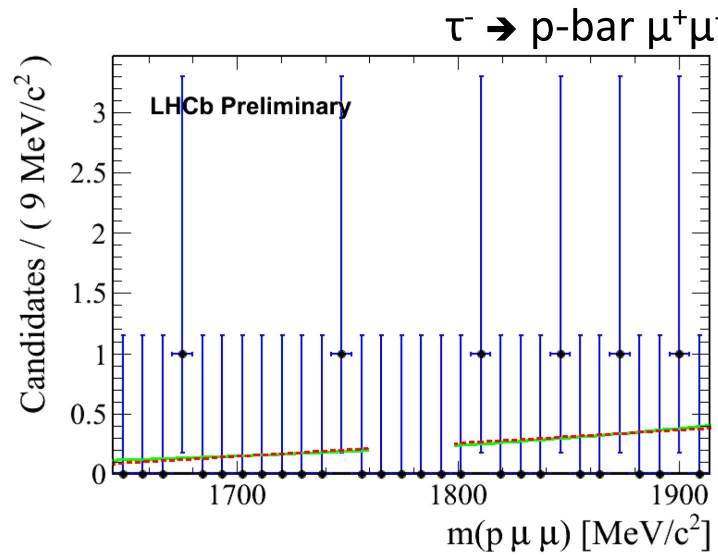
Search for $\tau^- \rightarrow p\mu^+\mu^-$ and $\tau^- \rightarrow \bar{p}\mu^+\mu^-$

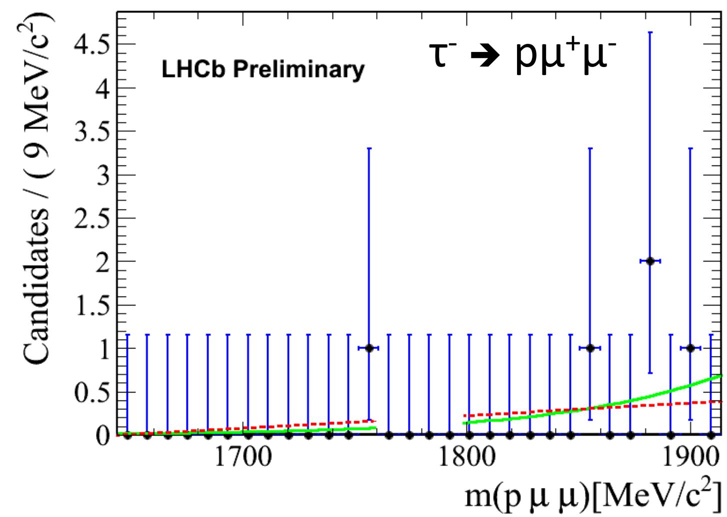
- An explanation for matter/anti-matter univers asymmetry would require:
  - CP violation
  - Baryon number violation
- ¿Are there any extra sources of CPV… or BNV?
- So far unsuccessful searches
- Existing BR limits (from B-fact.) on

  $\tau \rightarrow \Lambda h$ and $B \rightarrow \Lambda \ell$;

  in the 10^{-7}-10^{-8} range
- Searches in LHCb (using 1/fb of data @ 7TeV) for BNV in (adapting $\tau^- \rightarrow \mu^-\mu^+\mu^-$ analysis):
  - $\tau^- \rightarrow \bar{p}\mu^+\mu^-$
  - $\tau^- \rightarrow p\mu^+\mu^-$

- **LHCb puts first limits**
  - **$BR(\tau^- \rightarrow \bar{p}\,\mu^+\mu^-) < 4.5 \times 10^{-7}$**
  - **$BR(\tau^- \rightarrow p\,\mu^-\mu^-) < 6.0 \times 10^{-7}$**



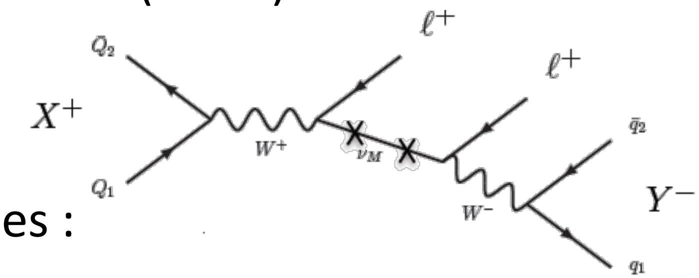


LHCb-CONF-2012-027

Search for Mayorana neutrinos in B^- decays

Phys. Rev. D 85 (2012) 112004

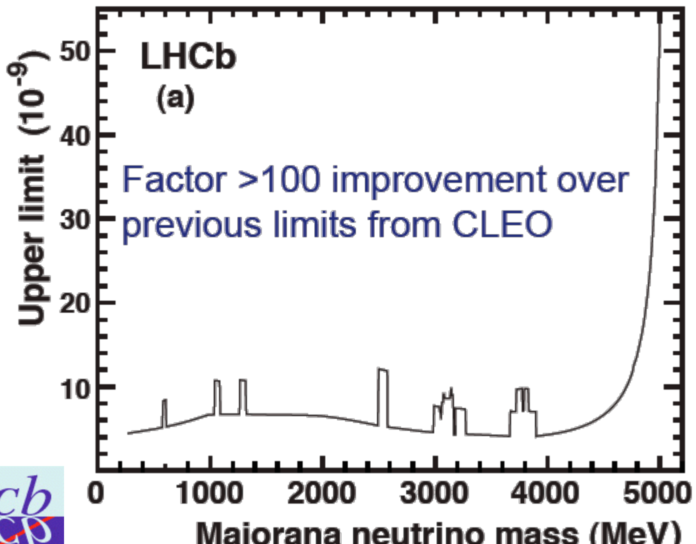
- Decays $B^+ \rightarrow h^- \mu^+ \mu^+$ are (DL=2) strictly forbidden in SM
- They can happen through sterile Majorana ν of mass O(1GeV)

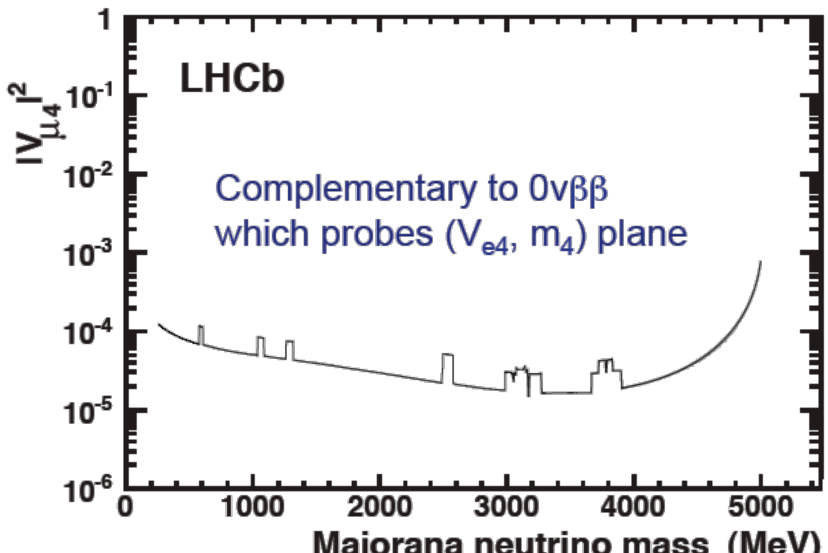


- LHCb search for a wide range of such decay modes :

$D^- \mu^+ \mu^+$, $D^{*-} \mu^+ \mu^+$, $\pi^- \mu^+ \mu^+$, $D_s^- \mu^+ \mu^+$, $D^0 \pi^- \mu^+ \mu^+$

- No signals found → UL are set on Majorana ν production on B decay BR





Summary & Conclusions

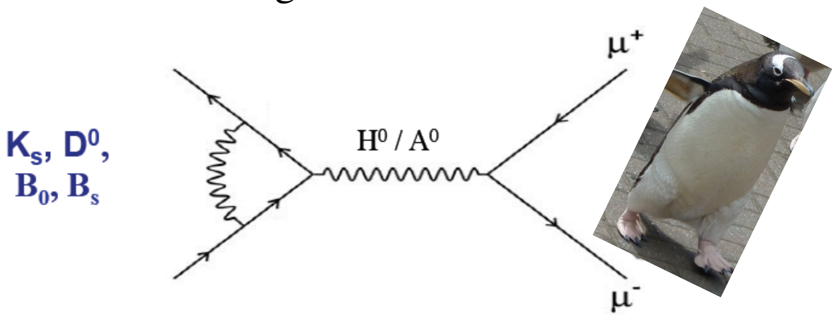
Summary

- Rare B, D and K decays
  - Radiative Decays:

    Most precise: CP asymmetry measurement on $B \to K^{*}\gamma$ and

    Branching Ratio of $B \to \phi\gamma$
  - A_{fb} in $B \to K^{*}\mu\mu$ decays consistent with SM
  - Isospin asymmetry in $B \to K\mu\mu$ decays >4σ away from zero
  - Measured $BR(B_s \to \phi\,\mu\mu)$ in agreement within 3σ with CDF and SM
  - First $b \to d\mu\mu$ transition observed in the $B \to \pi\,\mu\mu$ decay
  - Strong constrains on ΔF=1 Higgs penguins
    - $BR(B_s \to \mu\mu) = 3.2^{+1.5}_{-1.2} \times 10^{-9}$, evidence with 3.5σ significance
    - $BR(B_d \to \mu\mu) < 9.4 \times 10^{-10}$
    - $BR(K_s \to \mu\mu) < 1.1 \times 10^{-8}$
    - $BR(D \to \mu\mu) < 1.3 \times 10^{-8}$

    @95% CL



– No evidence for LFV & LNV in $\tau \to \mu\mu\mu$, $\tau \to p\,\mu\mu$ and $B^{+} \to h^{-}\mu^{+}\mu^{+}$ decays

Conclusions

- Excellent performance of LHC has allowed LHCb to gather 1/fb @ 7 TeV during 2011, and already 2/fb @ 8 TeV during 2012
- Plenty of results with 1/fb already public, in most cases very competitive measurement if not world's best. A large list of other analysis already under study, given the reach that the data gathered so far already provides.
- LHCb is revealing itself a fantastic experiment to look at rare B, D, K and lepton decays that are very sensitive to NP beyond the SM.
- So far, SM shows itself robust when put under stringent tests by rare decay measurements. No NP has been found (yet) in key channels, but still looking for NP remaining areas.
- After the LS1 (2013-2014), more data will be accumulated (@~13TeV) . It is foreseen an LHCb upgrade during LS2 (~2018), to improve the exploitation of the LHC data and increase the opportunities of NP discovery (see Olaf's talk on Thursday)

Back-up

$B^0 \rightarrow K^* \mu^+ \mu^-$

- Flavour changing neutral current → loop
- Allows to test Lorentz-structure:

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i [\ \underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed part}} + \underbrace{C_i'(\mu) O_i'(\mu)}_{\text{right-handed part suppressed in SM}}\ ]$$

$i = 1,2$	Tree
$i = 3-6,8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9,10$	Electroweak penguin
$i = S$	Higgs (scalar) penguin
$i = P$	Pseudoscalar penguin

- Angular analysis of $B^0 \rightarrow K^* \mu^+ \mu^-$
  - $K^* \rightarrow K\pi$ self tagging → allows to probe helicity structure
  - Highly sensitive to $C_7^{(')}$, $C_9^{(')}$, $C_{10}^{(')}$
- Can measure a variety of angular observables which have small hadronic uncertainties
  - A_{FB}, the forward-backward asymmetry and its zero crossing point
  - F_L, the fraction of K^{*0} longitudinal polarization
  - $S_3 \sim A^2_T (1-F_L)$, the asymmetry in K^{*0} transverse polarization

LHCb

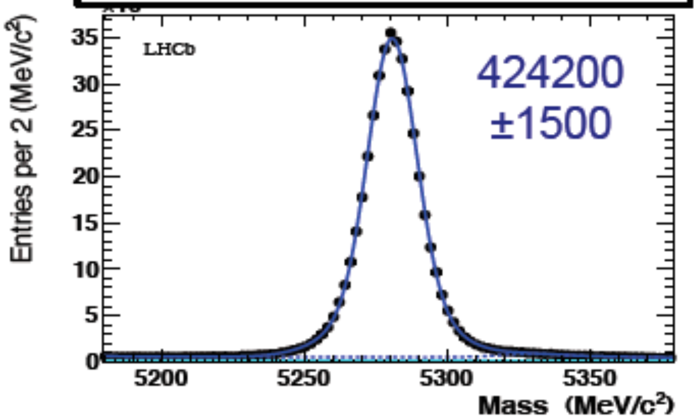
$B^0/B_s \to \mu^+\mu^-$

- **Selection**
  - Soft selection to reduce size of dataset, similar to control channels unchanged to previous analyses
- **Normalization**
  - Convert number of observed events in branching fraction by normalizing to $B^\pm \to J/\psi K^\pm$ and $B \to K^+\pi^-$

$$BR = BR_{cal} \cdot \frac{\varepsilon^{Rec}_{cal} \cdot \varepsilon^{Sel}_{cal}}{\varepsilon^{Rec}_{Bs} \cdot \varepsilon^{Sel}_{Bs}} \cdot \frac{\varepsilon^{Trig}_{cal}}{\varepsilon^{Trig}_{Bs}} \cdot \frac{f_{cal}}{f_{B_s}} \cdot \frac{N_{B\to\mu\mu}}{N_{cal}} = \alpha \cdot N_{B\to\mu\mu}$$

from MC data checked | from data | fraction $b \to B_s$ (updated, next slide)

$B^\pm \to J/\psi K^\pm$



Normalization factors

$$\alpha(B_s \to \mu^+\mu^-) = (2.52 \pm 0.23) \times 10^{-10}$$
$$\alpha(B^0 \to \mu^+\mu^-) = (6.45 \pm 0.30) \times 10^{-11}$$

Slightly lower than in 2011 measurement due to higher $\mathcal{L}$ and x-section

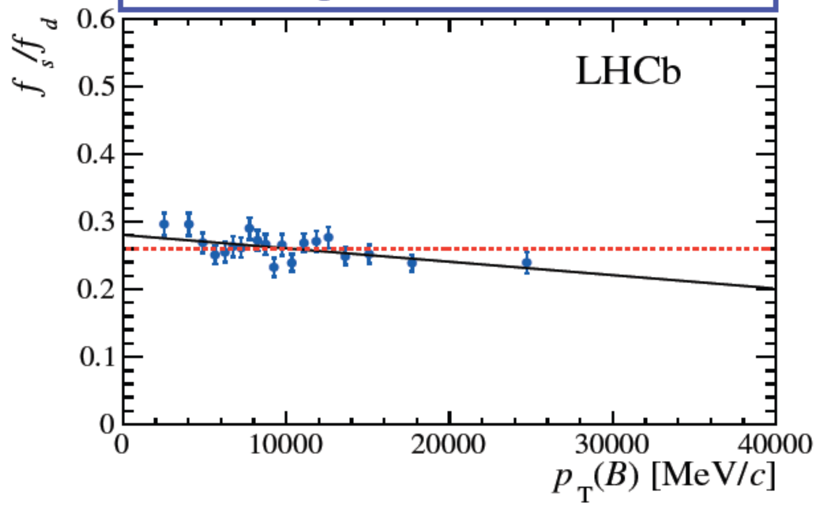
b fragmentation functions

- LHCb has measured the fraction of $b \rightarrow B_s$ in two ways:
  - Ratio of $B_s \rightarrow D_s \mu X$ to $B \rightarrow D^+ \mu X$ **[PRD85 (2012) 032008]**
  - Ratio of $B_s \rightarrow D_s \pi^+$ to $B \rightarrow D^+ K$ and $B^0 \rightarrow D^+ \pi^+$ (**newly updated: $1fb^{-1}$ @ 7 TeV**)
- Combined result $$\frac{f_s}{f_d} = 0.256 \pm 0.020$$

[LHCb-Paper-2012-037] to appear shortly

- Found to be dependent of p_T
  - For the p_T values involved: effect smaller than 0.02 → negligible
- Stability 7 vs 8 TeV checked
  - $B^+ \rightarrow J/\psi K^+ / B_s \rightarrow J/\psi \phi$ ratio stable

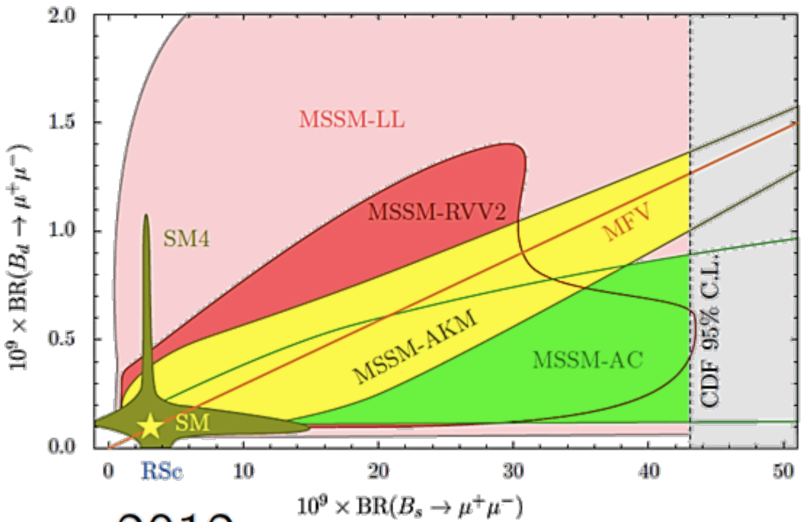
B fragmentation Vs PT

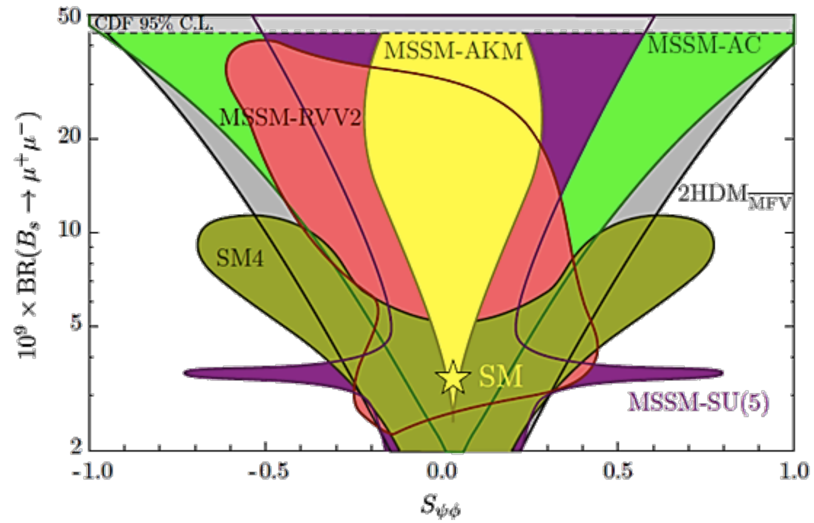


Constraints on SUSY

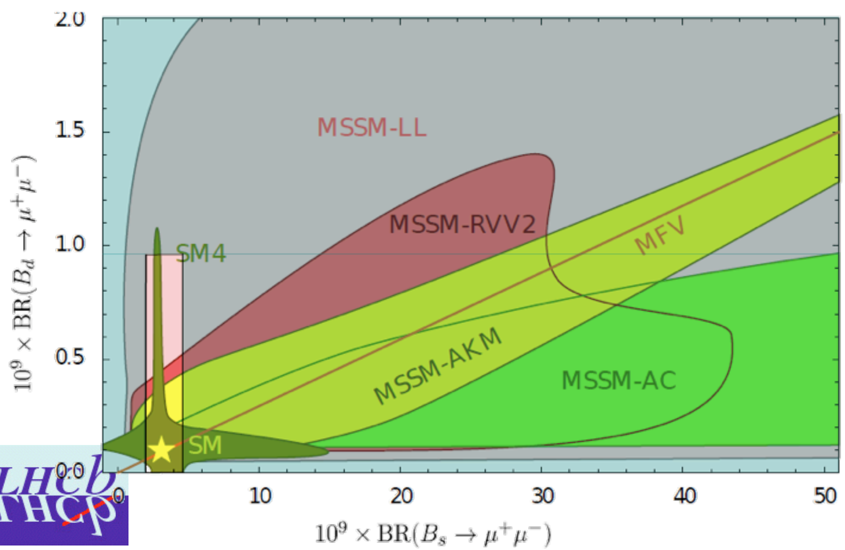
Based on Straub, DM, **arXiv:1107.0266**

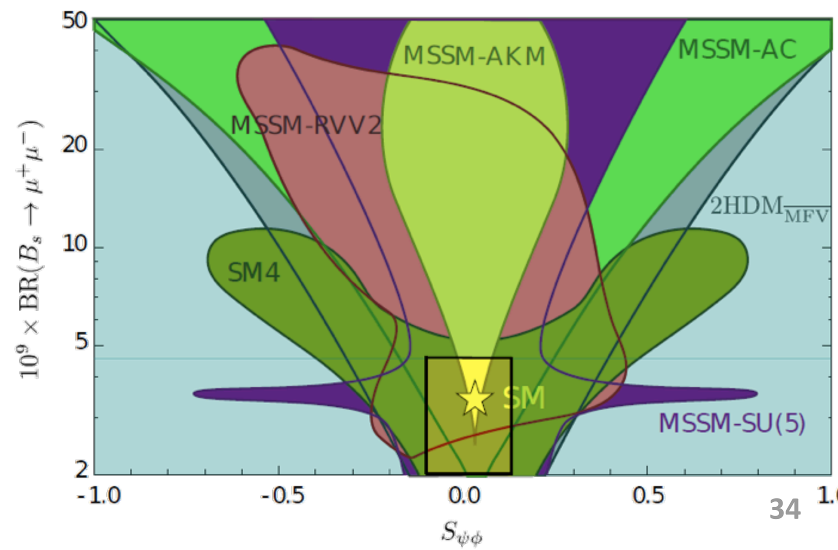
Summer 2010:





Autumn 2012:





Upgrade schedule

2012 **LHCb data taking (8 TeV)**

2013-14 Long Shutd. 1 / LHCb maintenance, first infrastructures for upgrade

2015-17 **LHCb data taking (13-14 TeV), double s_{bb}, s_{cc}**

2018-19 Long Shutd. 2 / LHCb upgrade installation [Atlas/Cms upgrades phase 1]

2019-21 **LHCb data taking (14 TeV) @ $2 \cdot 10^{33}$**

≥ 2022 HL-LHC [Atlas/Cms upgrades phase 2]

Preparation:

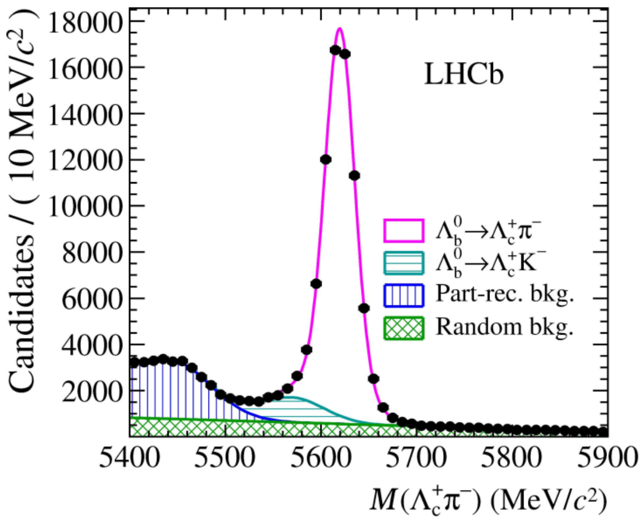
2012-13 R&D, technological choices, preparation of subsystems TDRs

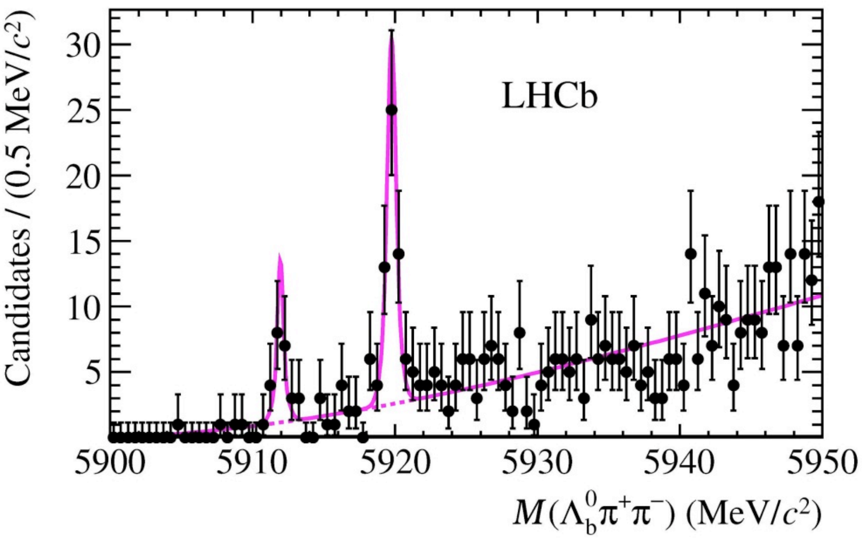
2014 Requests for approval/Funding/Procurements

2015-19 Construction & installation

Observation of excited Λ^0_b baryons

- First observation of excited baryons containing a b quark
- $\Lambda_b^{*0} \rightarrow \pi^+\pi^- \Lambda_b(\rightarrow\pi^-\Lambda_c^+(\rightarrow pK^-\pi^+))$.

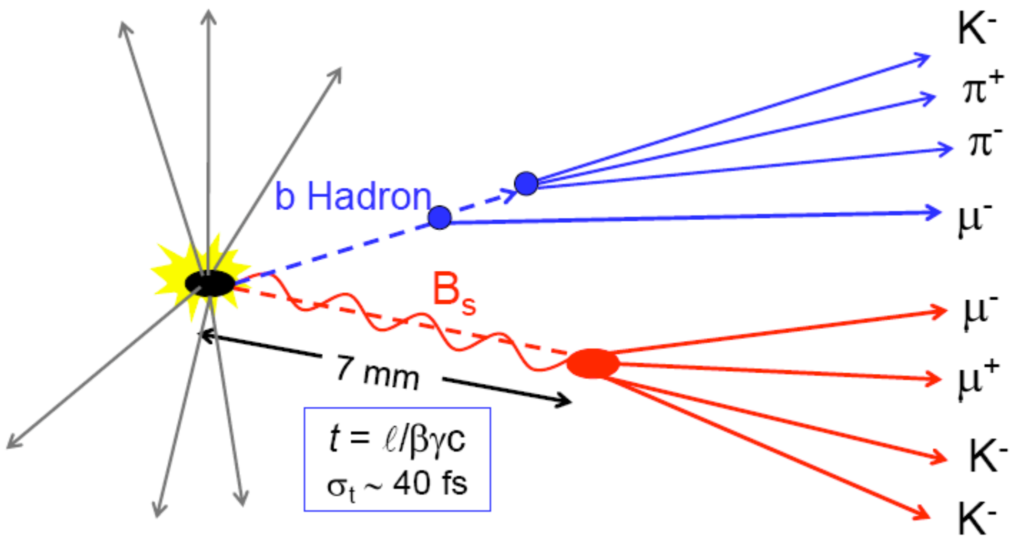




4.9σ , 10.1σ

Phys. Rev. Lett. 109 (2012) 172003

Beauty physics requirements @ LHC



At L0 trigger level (7 TeV)
min.bias : cc : bb
250 : 20 : 1

Excellent vertex resolution: to resolve fast B_s oscillation. → VELO

Background reduction: Very good mass resolution → Tracking
Good particle identification (K/π) → RICH, CALO, Muon

High statistics: Efficient trigger for hadronic and leptonic states → L0 x HLT

B decays with *μμ*	$\varepsilon_{\textbf{(L0 x HLT)}}$	~ 70-90 %
B decays with *hadrons*	$\varepsilon_{\textbf{(L0 x HLT)}}$	~ 20-50 %
Charm decays :	$\varepsilon_{\textbf{(L0 x HLT)}}$	~ 10-20 %

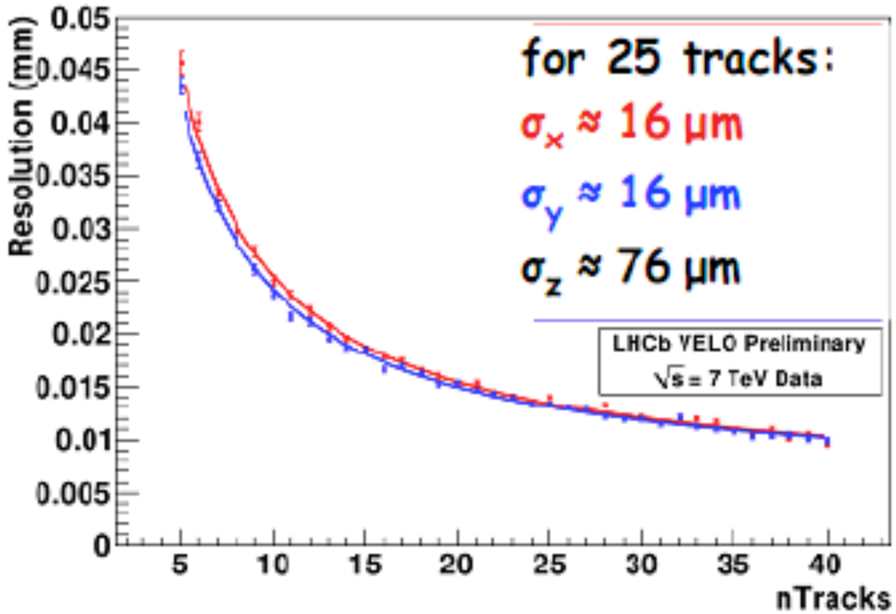
(trigger efficiencies for off-line selected events)

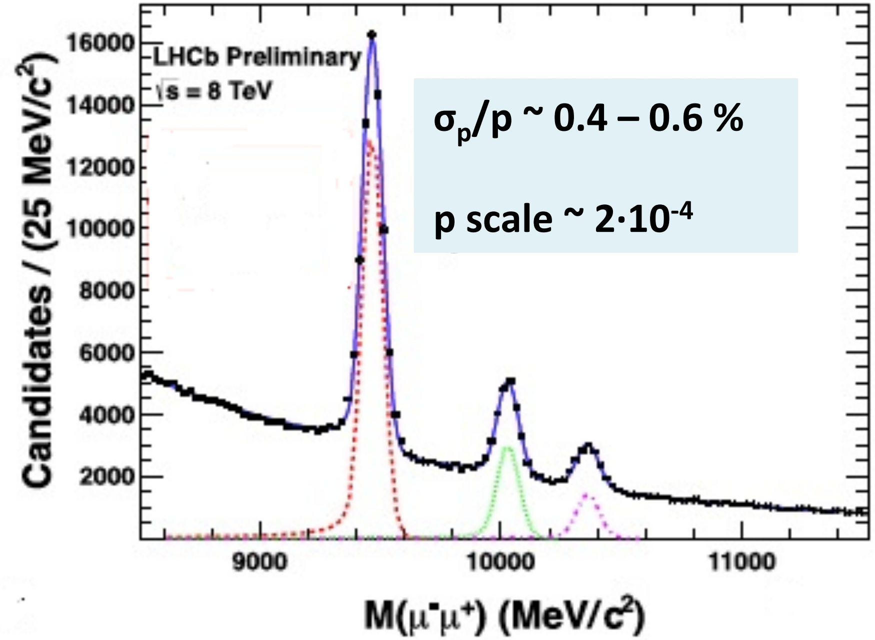
Flavor tagging plays a key role

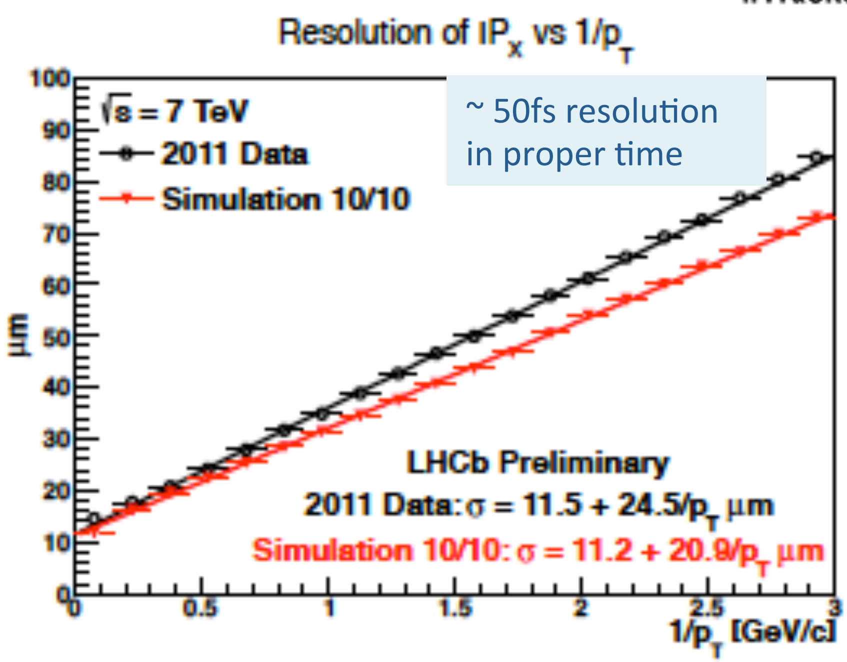
σ_{cc} ~ 6 mb (~1.7 mb in LHCb acceptance) :
LHC is a charm factory !

LHCb

Tracking: Primary Vertex (PV), impact parameter (IP) and invariant mass resolutions







Inv. Mass resolutions close to MC:

σ (J/Ψ →μμ) = 13 MeV

σ (B → κ π) = 25 MeV

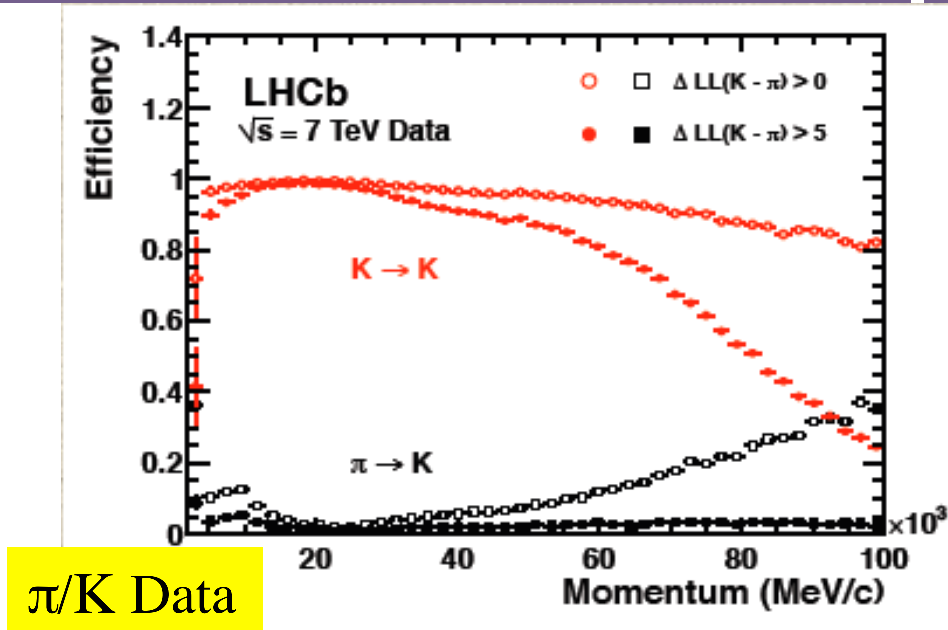
σ (B_s →J/Ψ ϕ) = 7 MeV

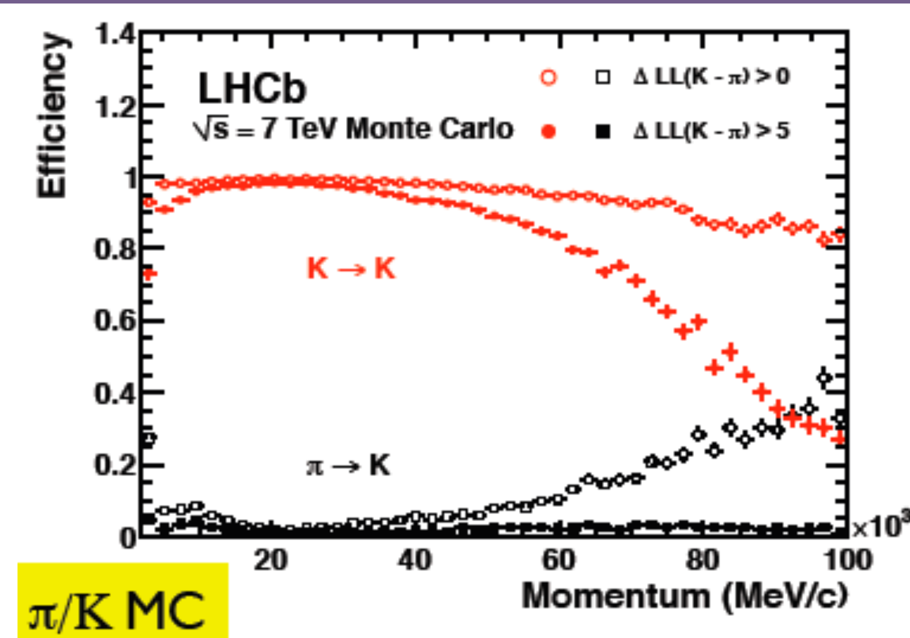
σ (ϒ(1s) →μμ) = 47 MeV

World best measurement of

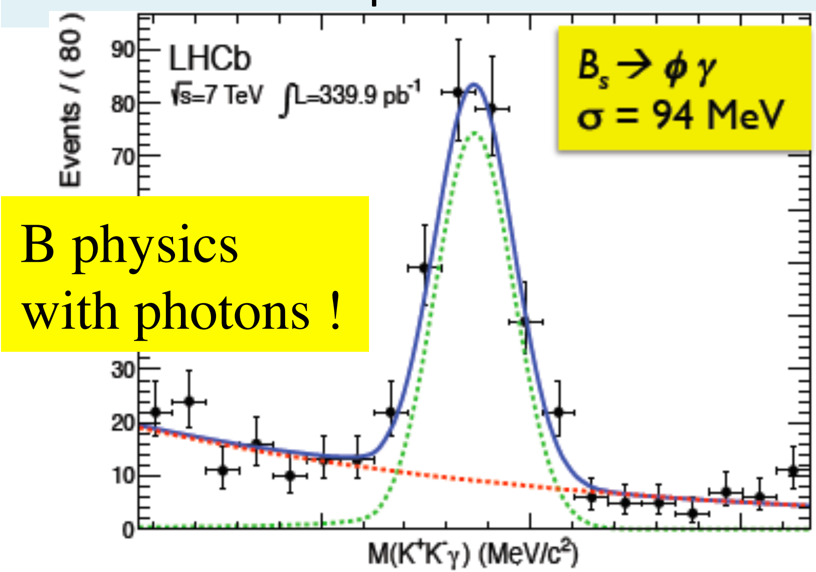
b-hadron masses [PLB 708(2012) 241]

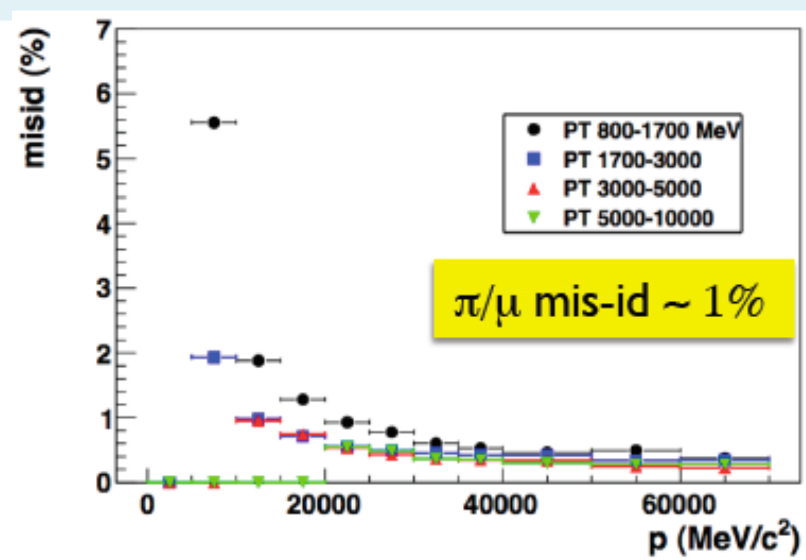
Particle ID performance





PID calibration, efficiency & purity determination based on data samples of clean final states: PID performance close to MC expectations





Beauty production at LHC

- X-section prediction (PYTHIA8)

$\sqrt{s}$ = 14, 10, 7 TeV

$\sigma_{inelastic}$ ~ 80 mb x (1, 0.95, 0.89)

σ_{bb} ~ 500 μb x (1, 0.67, 0.44)

~ 250μb

- **σ_{bb} = 284±53μb** ($\sqrt{s}$=7TeV),

In LHCb acceptance **σ_{bb} ~ 75μb** PLB 694 (2010) 209

  - All b-hadron species produced at LHC

    B^0, B^+, B_s, B_c, Λ_b, …

    (40% 40% 10% 10%)

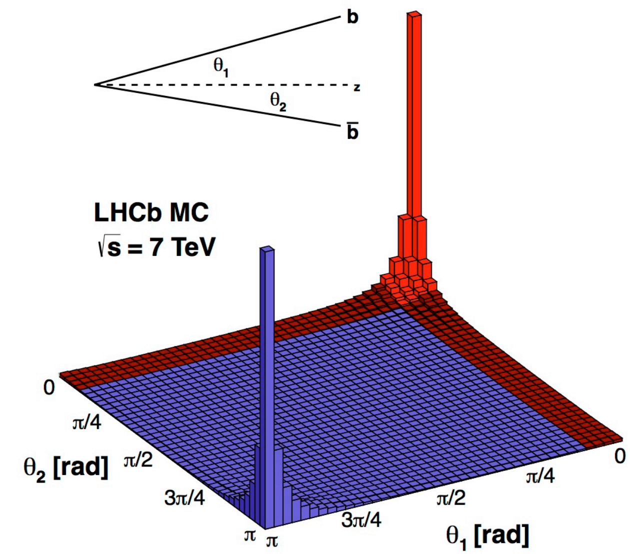
  - ~ 30KHz (@7TeV) of bb pairs (10^4 x B factories)
  - **Charm: ~ beauty x 20** CONF-2010-013

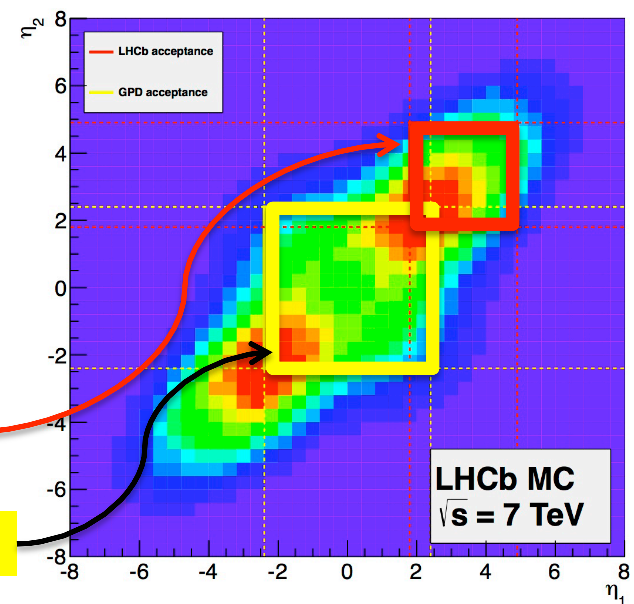
- Operated since the end of 2011 at

  $4 \cdot 10^{32}/cm^2$ s (2x design lumi)

- Pileup @ 50ns BX: <μ>=1.7

gluon-gluon fusion





LHCb acceptance: 2<η<5

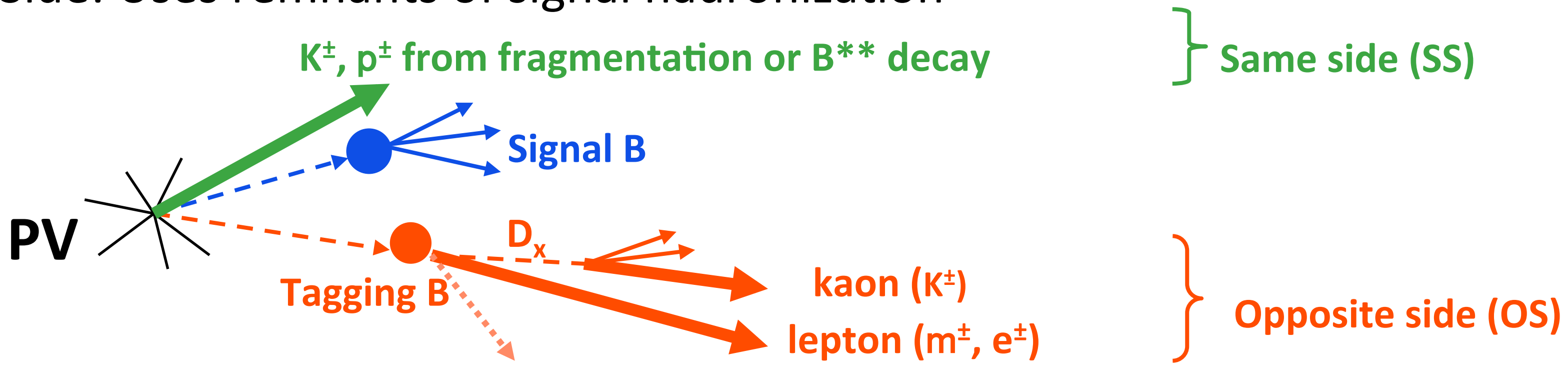
ATLAS/CMS acceptance: |η|<2.5

Flavour tagging

FLAVOR TAGGING: (EPJ C 72 (2012) 2022)

Algorithms implemented in NNs:

- Opposite side: Exploits of associated b-hadron
- Same Side: Uses remnants of signal hadronization



Effective tagging efficiency ~ 2-3%