Search for New Physics with rare decays of B and B_s mesons at LHCb

Physics @ LHC
9. June 2011

Johannes Albrecht (CERN)
on behalf of the LHCb collaboration

Introduction

- Why study rare decays of B and B_s mesons
  - Flavour Changing (b→s,d transitions) Neutral Currents in the Standard Model induced only through loops
  - Sensitive to much larger masses than directly accessible
    - Higgs and top quark mass in SM and new particles in NP models
    - **Discovery potential for NP at scales much above $\sqrt{s}$=7TeV**
    - If no NP found: Provide strong constraints to parameter space

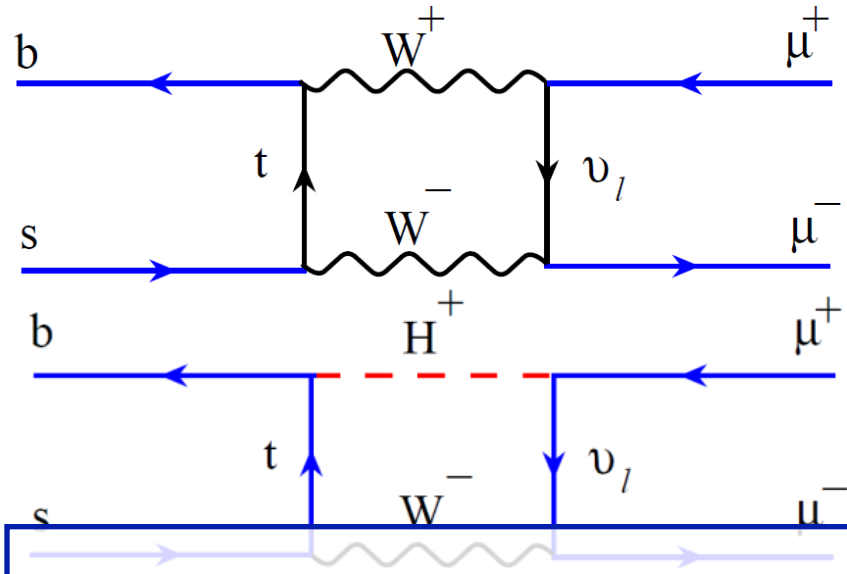
- Why at LHCb
  - They're rare and the LHC produces a lot of $b\bar{b}$ pairs
  - LHCb has large acceptance for B decays and is constructed to trigger and measure them efficiently → see plenary talk of A. Schopper

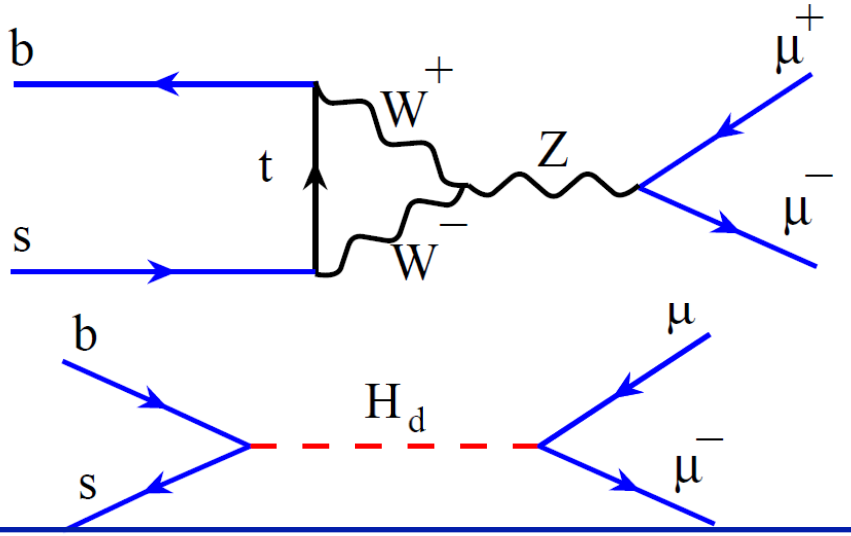
Outline of this talk

- Probe new scalar / pseudoscalar interactions
  - Search for the decays $B_s \rightarrow \mu^+\mu^-$ and $B_d \rightarrow \mu^+\mu^-$
    → present 2010 measurement and extrapolate using 2011 data
- Probe Lorentz structure
  - Angular analysis of the decay $B^0 \rightarrow K^*\mu^+\mu^-$
    → present validation steps towards a measurement this summer
- Other rare decays
  - Direct CP asymmetry and photon polarization with radiative decays: $B_s \rightarrow \phi\gamma$ and $B^0 \rightarrow K^*\gamma$
    → validate performance for 2011 measurement
  - Search for heavy Majorana neutrinos with $B^+ \rightarrow K^-\mu^+\mu^+$
    → present measurement with 2010 data

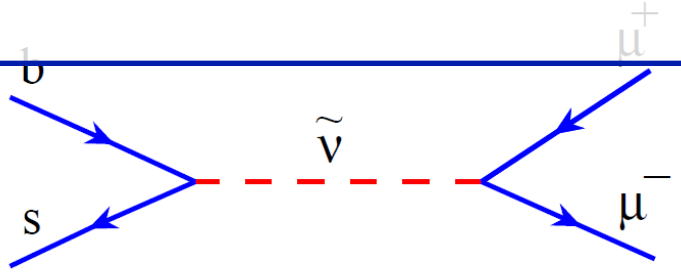
Dataset used:

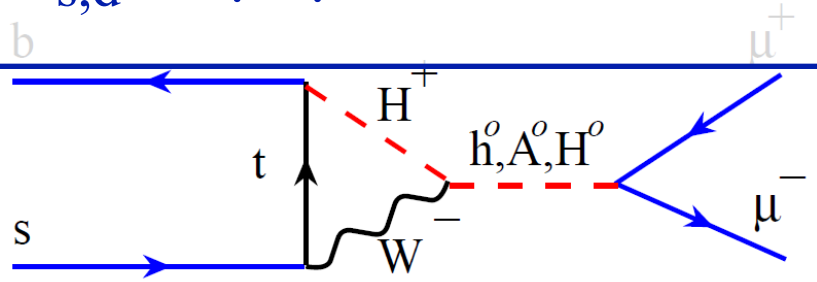
2010: 36.5 pb^{-1} passing all data quality → dataset for 2010 analyses
2011: up to now >*230pb^{-1}* on tape → expect for EPS ~300 pb^{-1}, to end 2011 ~1fb^{-1}

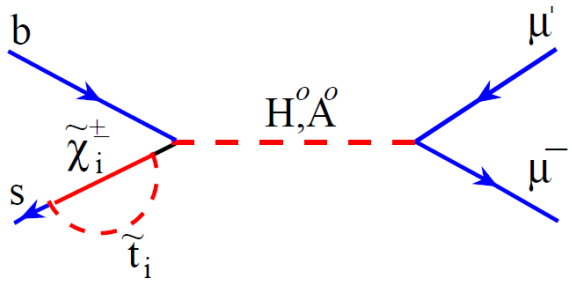


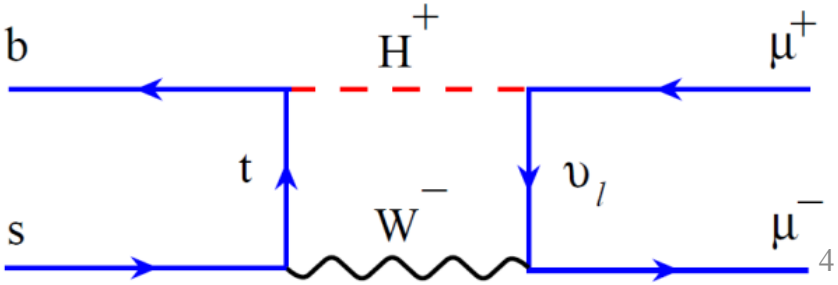


New (pseudo-) scalar interactions: Search for $B_{s,d} \rightarrow \mu^+\mu^-$





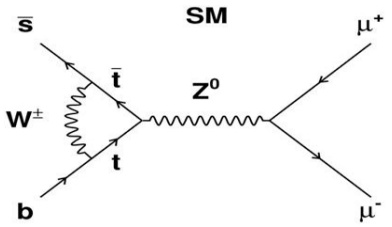




$B_{s,d} \rightarrow \mu^+\mu^-$ in Theory and Experiment

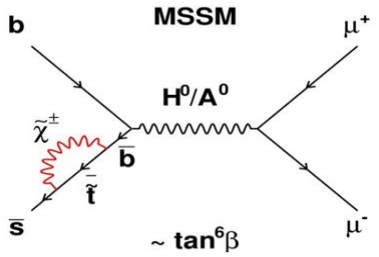
Double suppressed decay: **FCNC process** and **helicity suppressed**:

Mode	SM (*)
$B_s \rightarrow \mu^+\mu^-$	$3.2 \pm 0.2\ 10^{-9}$
$B^0 \rightarrow \mu^+\mu^-$	$0.10 \pm 0.01\ 10^{-9}$



* A.J.Buras: arXiv:1012.1447
E. Gamiz et al: PRD 80 014503

→ sensitive to contributions in the **scalar/pseudo-scalar sector**
→ highly interesting to probe **extended Higgs** models



Example: MSSM

$$BR(B_S \rightarrow \mu^+\mu^-) \propto \frac{\tan^6 \beta}{m_A^4}$$

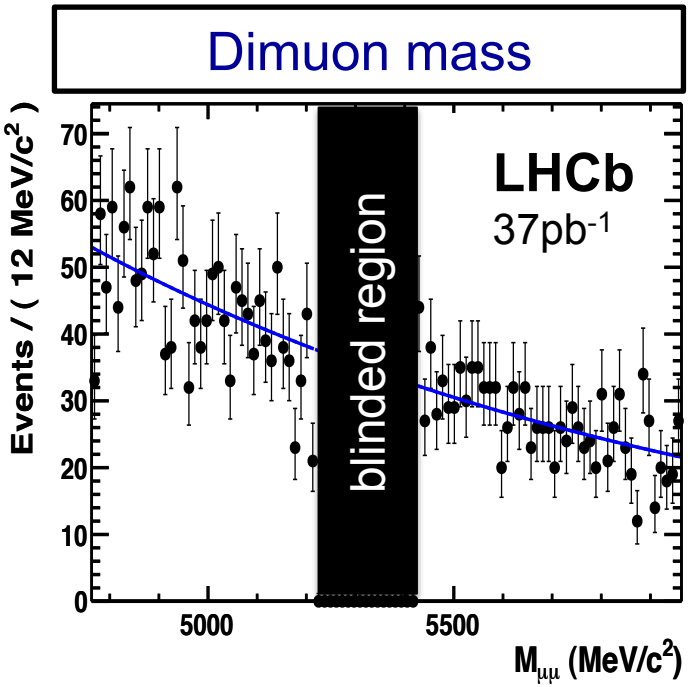
➔ limit or measurement will constrain tanβ vs M_A plane

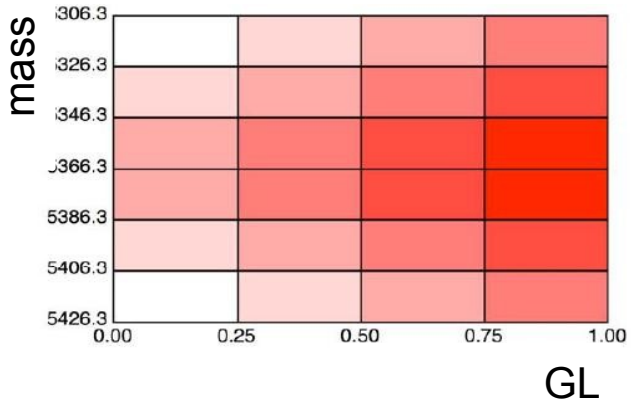
Experimental status of $B_s \rightarrow \mu^+\mu^-$

	Luminosity	Limit @ 90% CL	
CDF	3.7fb^{-1}	36x10^{-9}	CDF public note 9892 (2009)
D0	6.1 fb^{-1}	42x10^{-9}	PLB 693 (2010) 539
LHCb	0.037fb^{-1}	43x10^{-9}	PLB 699 (2011) 330-340

Analysis strategy

- **Selection**
  - Soft selection to reduce size of dataset
- **Signal and background likelihoods**
  - Geometrical Likelihood (GL)
    Multivariate classifier combining topological and kinematic information
  - Invariant mass
- **Normalization**
  - Convert number of observed events in branching fraction by normalizing with channels of known BR
- **Extraction of the limit**
  - Extract observation / exclusion measurement using the modified frequentist (CL_S) method in bins of mass and GL





Signal and background discrimination

- Soft signal selection: expect for 37pb^{-1} (dataset of 2010):
  - **Signal: $B_S(B^0)\rightarrow\mu\mu$: 0.3 (0.04) events**
  - **Background ~ 300 events** in m($B_{d,s}$) ±60 MeV/c^2

Background composition after selection:

bb→μμX	fake + muon	peaking background
90%	10%	negligible in 37pb^{-1}
Double semileptonics and cascade decays	~0.3% from double fake	• Double misID from B→hh': < 0.1 events in signal region

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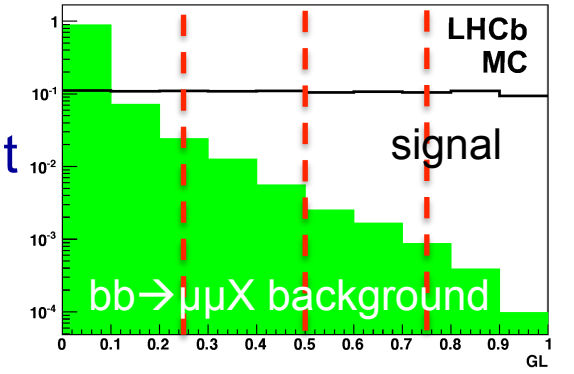
Further discrimination by Geometrical Likelihood (GL):

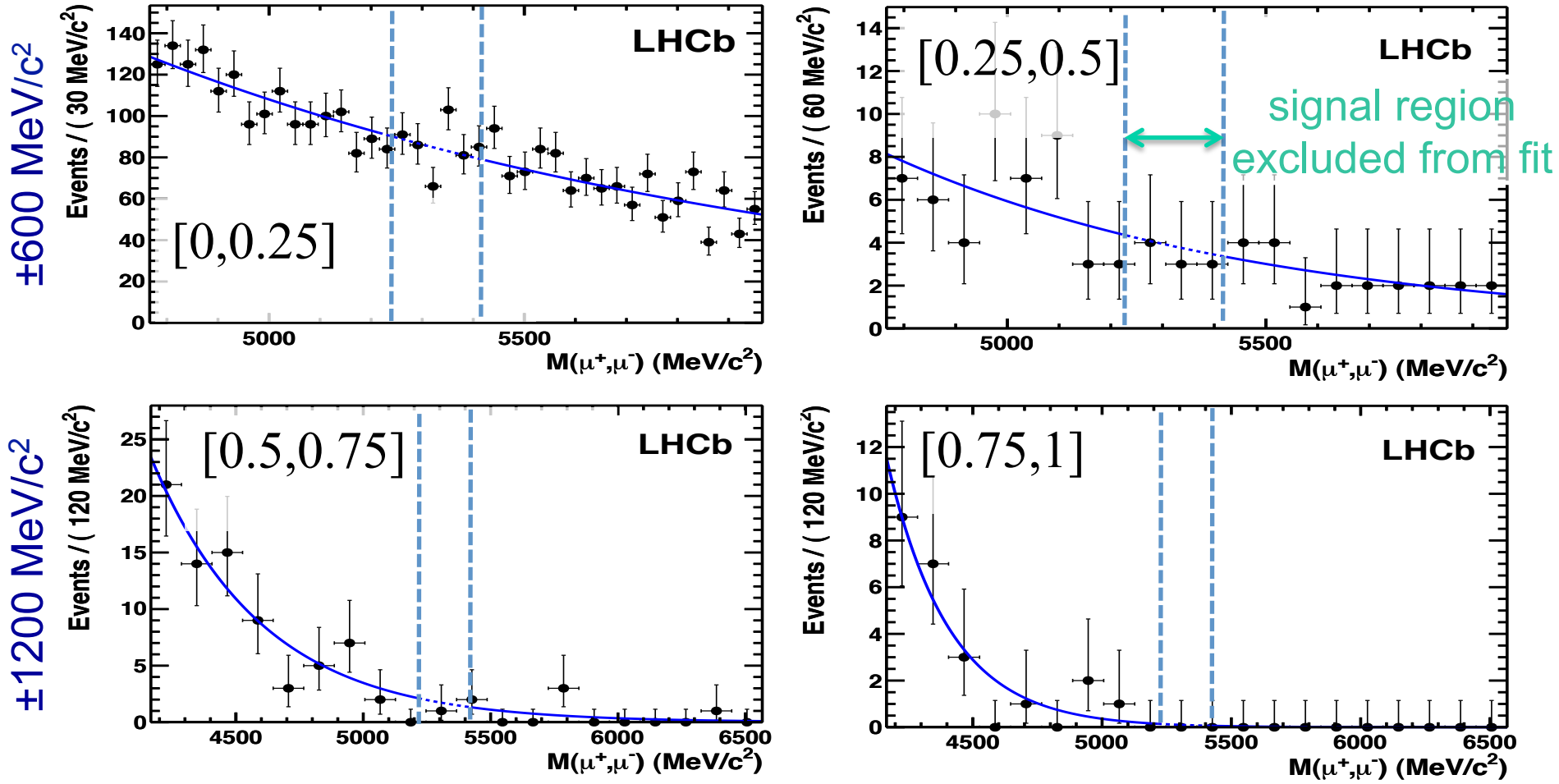
- Combination of kinematic & topological variables
  - μ-DOCA, μ-IPS, μ-isolation, B IP, B p_T, B lifetime
  - **GL is defined on MC and calibrated on data**
- Variables are decorrelated and a discriminant is built
  - Flat for signal
  - Strongly peaked at zero for background
- Analysis is performed in 4 bin of GL

GL shape of signal and bkg



Background likelihood calibration

Expected background in signal region is extracted from a fit to mass sidebands divided in GL bins



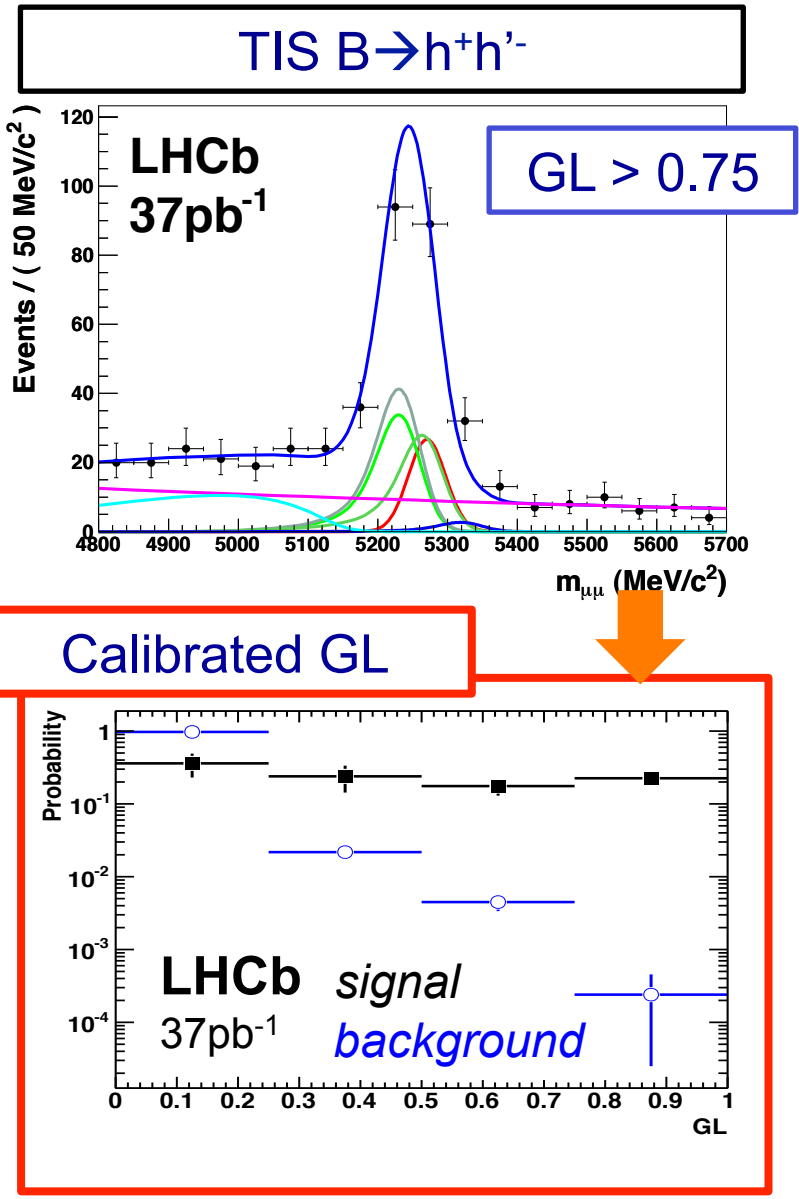
Very low background in regions of high sensitivity

Signal likelihood calibration

- GL calibration:
  - $B \to h^+h'^-$ ideal sample: identical decay topology
  - Use events triggered independent of signal (TIS) to avoid trigger bias
- **Signal distribution in GL flat as expected from simulation**
- Signal invariant mass modelled with a crystal ball
  - Resolution obtained from data:
    - Interpolation between dilepton resonances (J/ψ, ψ(2S) and Υ)
    - Inclusive $B \to h^+h'^-$

  → weighted average:

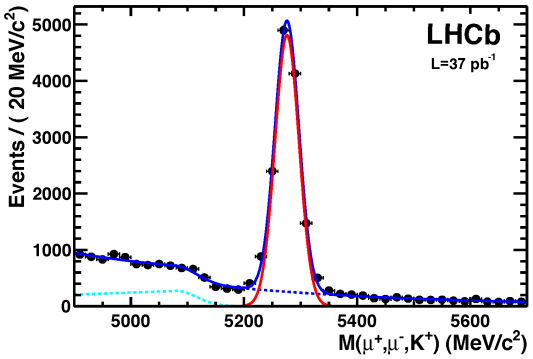
  $\sigma(B_{S,d}) = 26.7 \pm 0.9^{stat+syst}$ MeV/c²



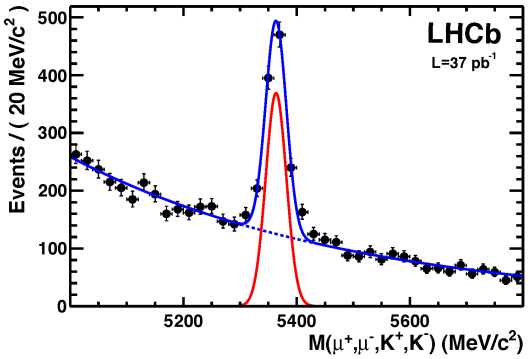
Normalization to channels with known BR

Three independent normalization channels used:

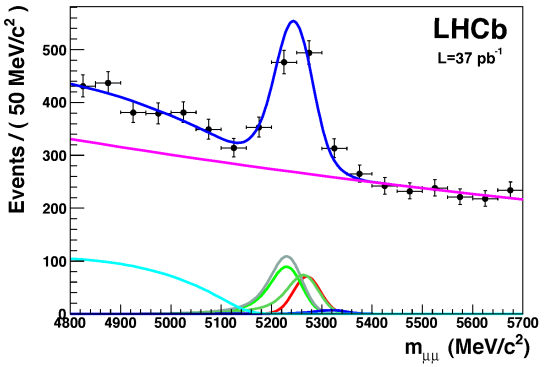
$B^{\pm} \rightarrow J/\psi K^{\pm}$



$B_S \rightarrow J/\psi\phi$



Trigger unbiased $B \rightarrow h^+h'^-$



	$B^{\pm} \rightarrow J/\psi(\mu\mu)\, K^{\pm}$	$B_S \rightarrow J/\psi(\mu\mu)\, \phi(KK)$	$B^0 \rightarrow K^+\pi^-$
BR	5.98×10^{-5} (±3.7%)	3.35×10^{-5} (±26%)	1.94×10^{-5} (±3.1%)
nSignal	$12{,}366 \pm 403^{\text{stat+syst}}$	$760\pm71^{\text{stat+syst}}$	$578\pm74^{\text{stat+syst}}$

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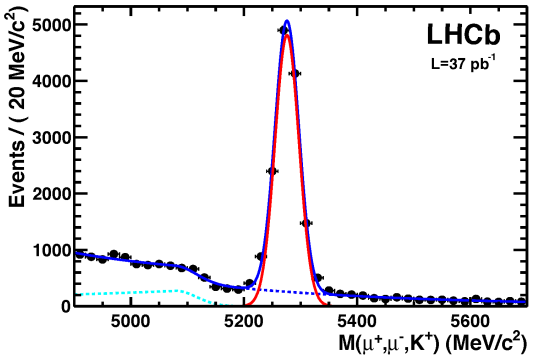

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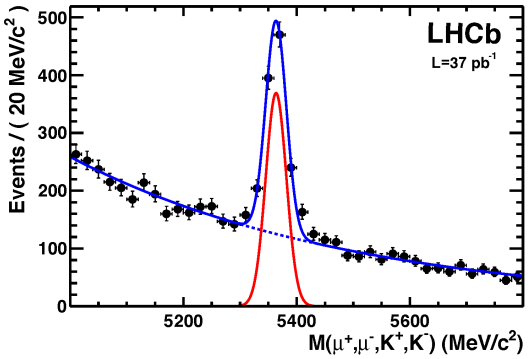

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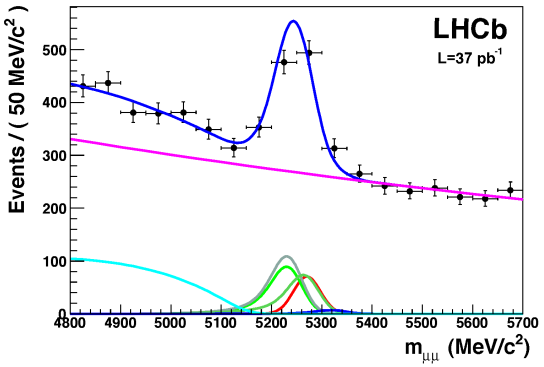

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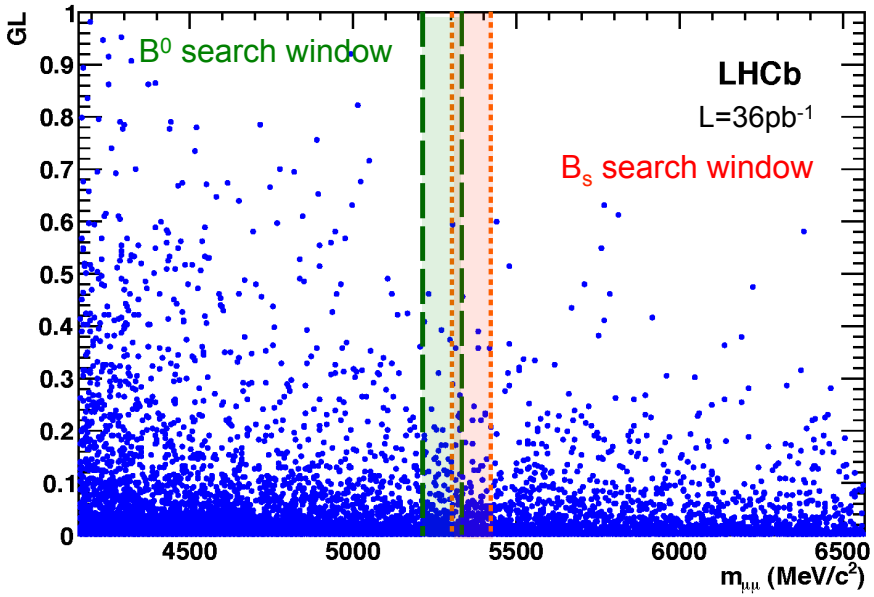
nSignal	12,366 ±403 stat+syst	760±71 stat+syst	578±74 stat+syst
$\alpha(B_S \rightarrow \mu\mu)$	**$8.4\pm1.3\times10^{-9}$**	$10.5\pm2.9\times10^{-9}$	$7.3\pm1.8\times10^{-9}$
$\alpha(B^0 \rightarrow \mu\mu)$	**$2.27\pm0.18\times10^{-9}$**	$2.83\pm0.86\times10^{-9}$	$1.99\pm0.40\times10^{-9}$

weighted average

$$\alpha_{B_S \rightarrow \mu\mu} = 8.6 \pm 1.1 \times 10^{-9}$$
$$\alpha_{B^0 \rightarrow \mu\mu} = 2.24 \pm 0.16 \times 10^{-9}$$

Extraction of the limit

Events are classified in 2D plane: mass and GL



- Evaluate compatibility of measurement with
  - B only hypothesis [CL_B] → quote observation
  - S+B hypothesis [$CL_S=CL_{S+B}/CL_B$] → quote exclusion limit

« Search for the rare decays $B_s \to \mu\mu$ and $B^0 \to \mu\mu$ »
Physics Letter B 699 (2011) 330-340, The LHCb collaboration

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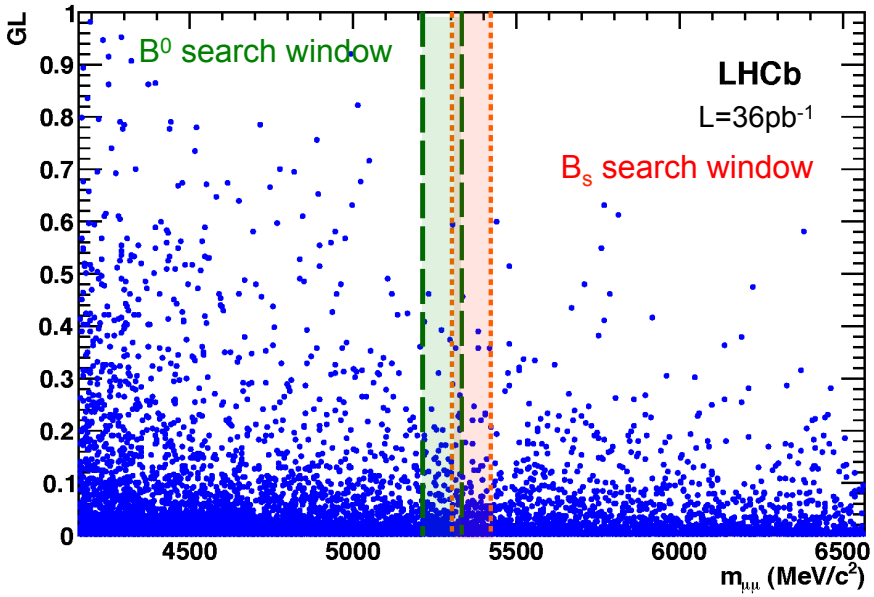

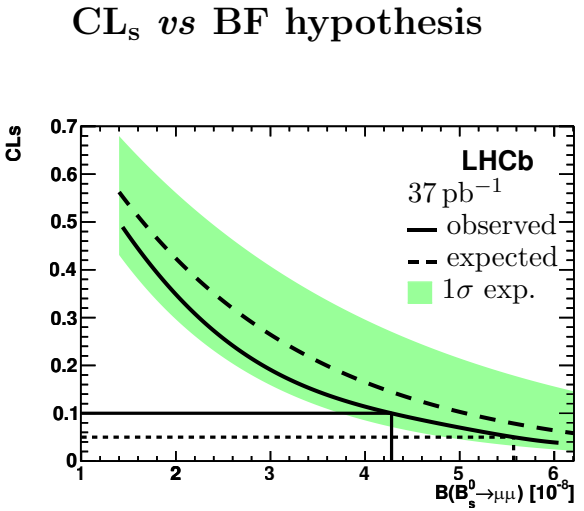

- Evaluate compatibility of measurement with
  - B only hypothesis [CL_B] → quote observation
  - S+B hypothesis [$CL_S=CL_{S+B}/CL_B$] → quote exclusion limit
- With 37pb^{-1} of data at $\sqrt{s}$ = 7TeV, LHCb measures:

$BR(B_s \to \mu^+\mu^-) < 4.3\ (5.6)\ \ 10^{-8}$ @ 90 (95% CL) Expected are: 5.1 (6.5)

$BR(B^0 \to \mu^+\mu^-) < 1.2\ (1.5)\ \ 10^{-8}$ @ 90 (95% CL) 1.4 (1.8)

« Search for the rare decays $B_s \to \mu\mu$ and $B^0 \to \mu\mu$ »
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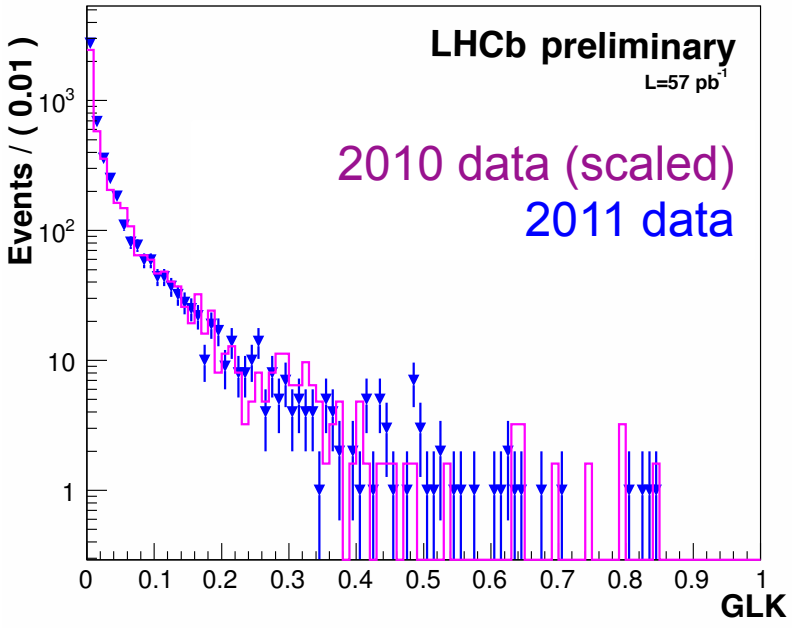
Validation of 2011 data

NEW!

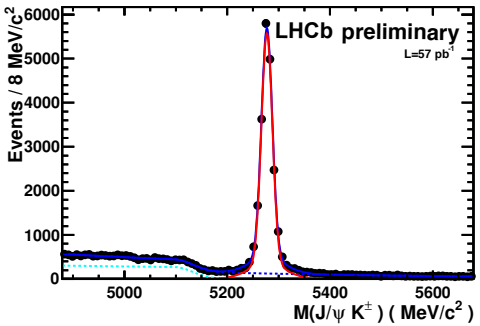
- Data quality of 2011 data with ~60pb^{-1}
  - Yields per pb^{-1} comparable to 2010
  - Resolution, S/B ~unchanged

→ we are confident that we can extrapolate 2010 result

Mass sidebands vs GL



$B^{\pm} \rightarrow J/\psi K^{\pm}$



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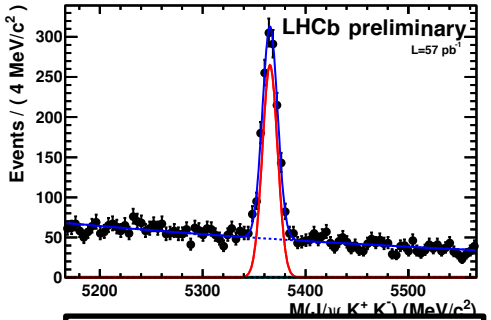

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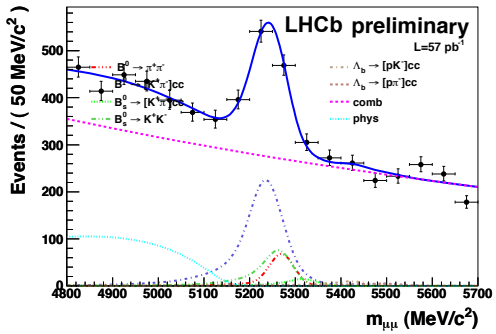

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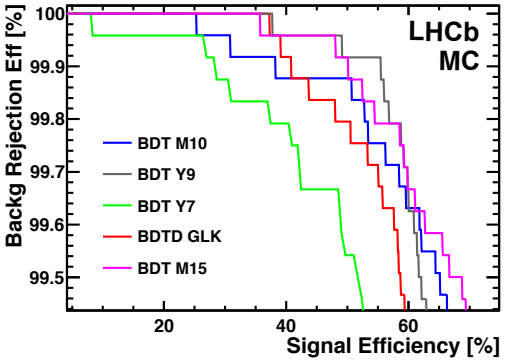
- Data quality of 2011 data with ~60pb^{-1}
  - Yields per pb^{-1} comparable to 2010
  - Resolution, S/B ~unchanged

  → we are confident that we can extrapolate 2010 result
- Improvements of analysis on-going
  - Use of full PID system planned
  - Improve multivariate qualifier

  → we are confident that we can **at least** extrapolate 2010 result

GL optimization



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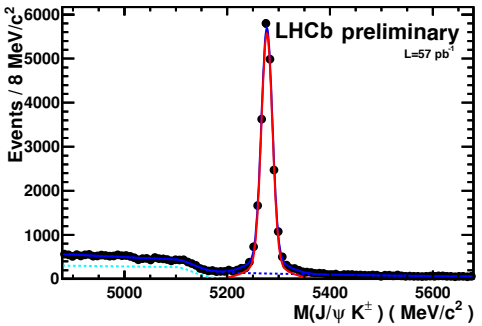

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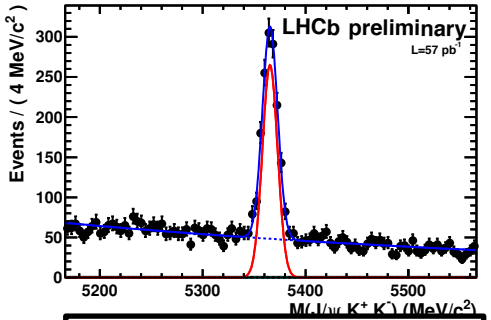

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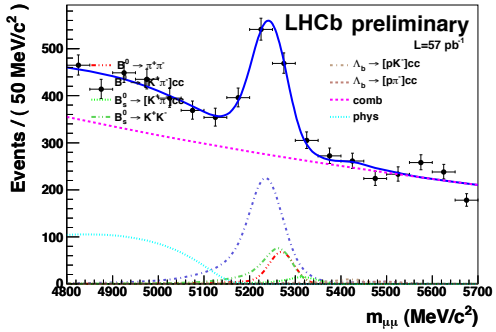
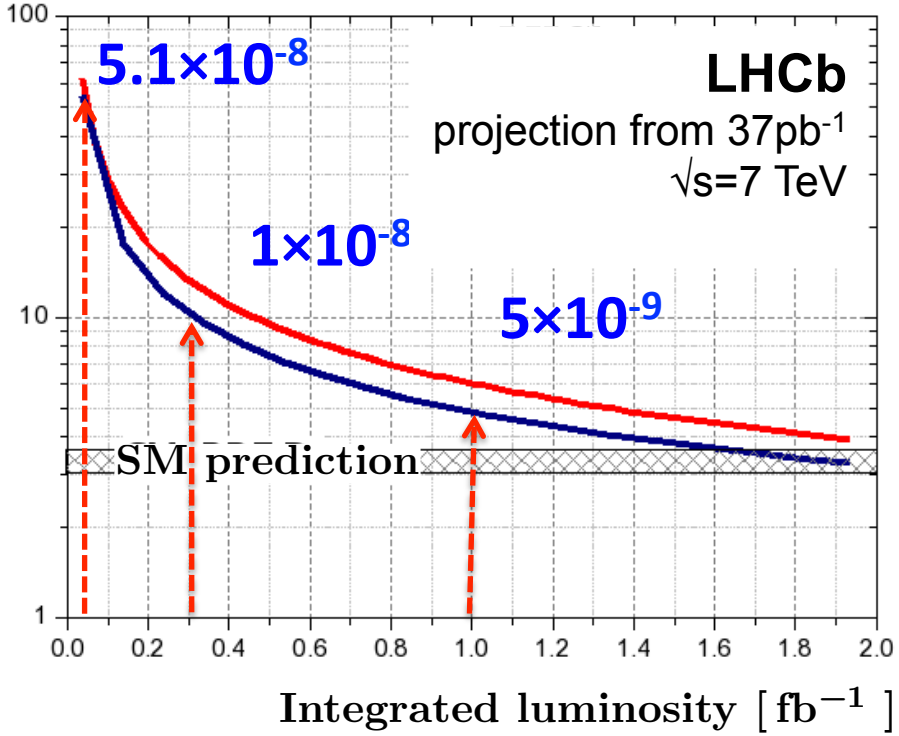


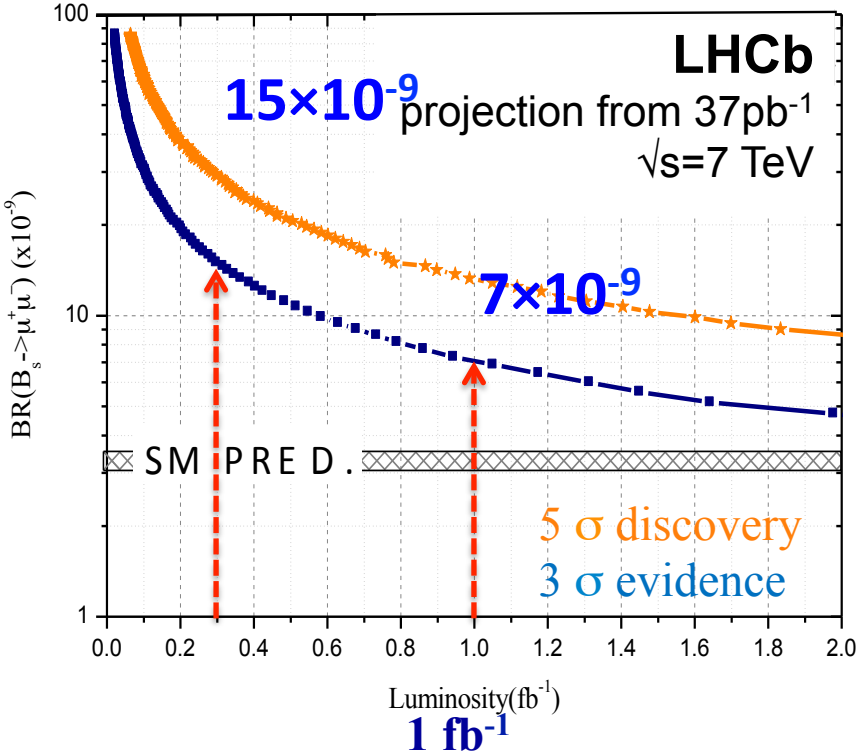
Prospects: $B_s \rightarrow \mu^+\mu^-$

$B_S \rightarrow \mu^+\mu^-$ exclusion @ 90% CL



37 pb^{-1} 300 pb^{-1} 1 fb^{-1}

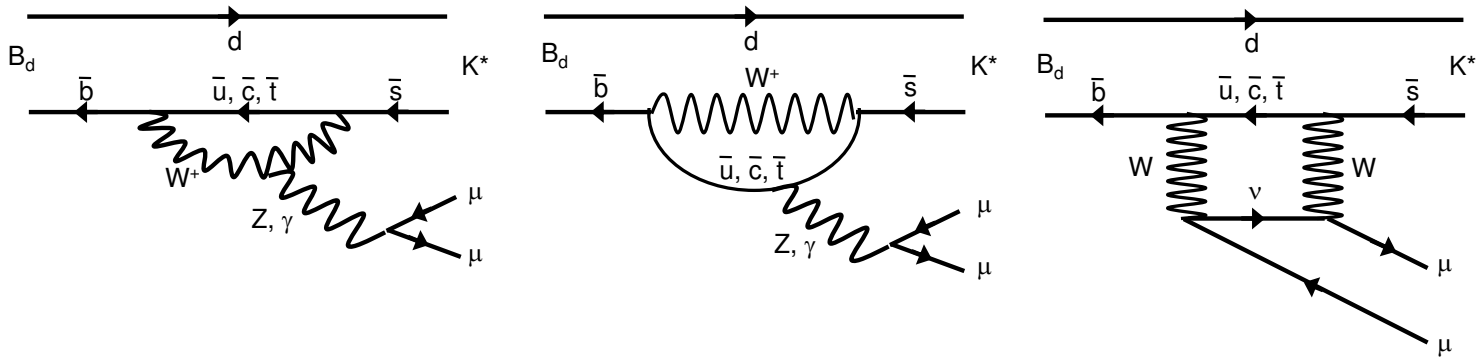
$B_S \rightarrow \mu^+\mu^-$ observation



1 fb^{-1}

With the data collected in 2011 we will be able to explore the region BR~ 5-10×10^{-9}

New Lorentz structure:
Angular analysis of $B^0 \rightarrow K^* \mu^+\mu^-$



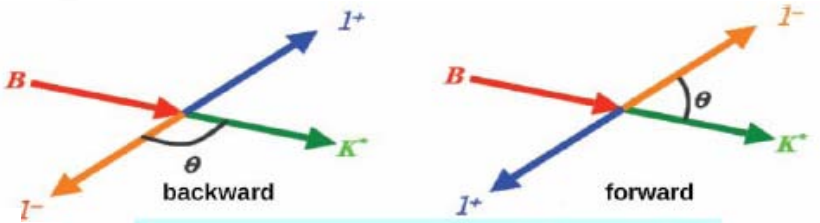
New Lorentz structure: $B^0 \to K^* \mu^+\mu^-$

- Angular distribution mostly sensitive to magnetic (O_7) and (axial-) vector (O_9, O_{10}) operators
- Measurement of angular distributions as function of $q^2=m_{\mu\mu}^2$

$$\frac{1}{\Gamma}\frac{\partial\Gamma}{\partial\cos\theta\ \partial q^2} = \frac{3}{4}F_L\sin^2\theta + \frac{3}{8}(1-F_L)(1+\cos^2\theta) + A_{FB}\cos\theta$$

forward-backward asymmetry A_{FB}, Longitudinal polarization F_L

Forward-backward asymmetry A_{FB}:



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

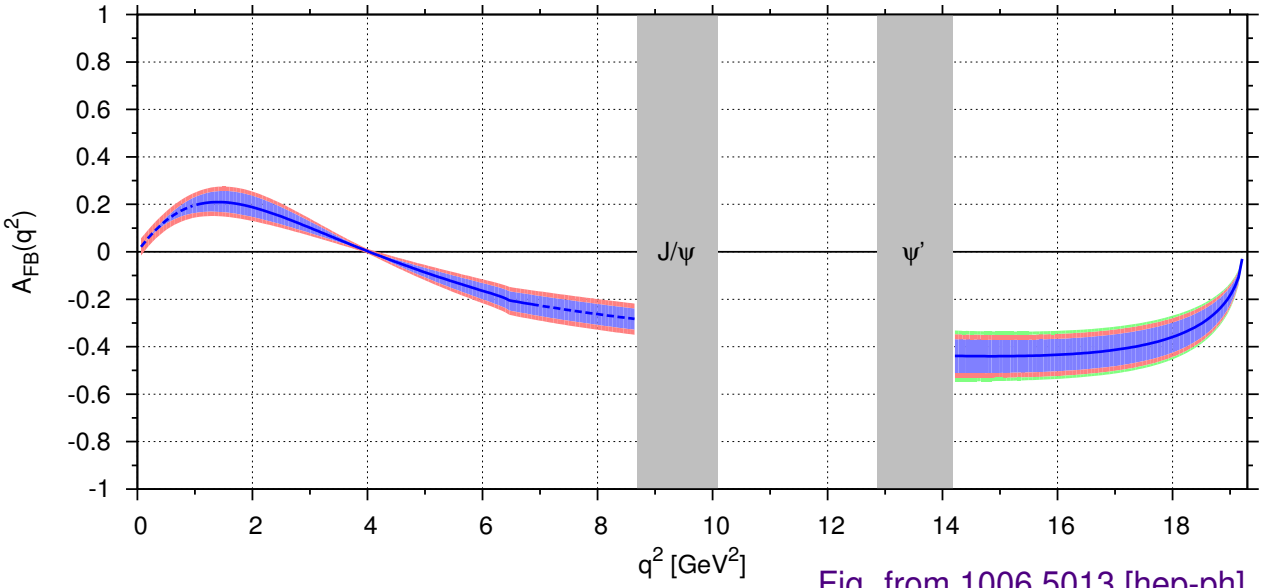


Fig. from 1006.5013 [hep-ph]

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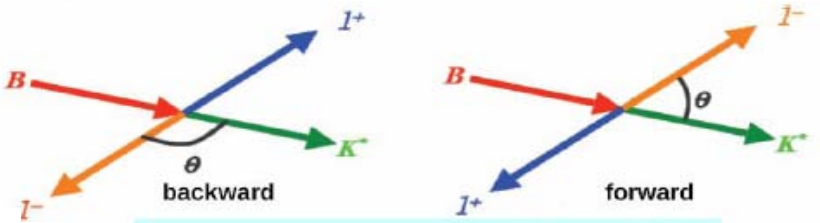
forward-backward asymmetry A_{FB}, Longitudinal polarization F_L

- Data at B-factories and CDF might hint a non-SM contribution

Forward-backward asymmetry A_{FB}:



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

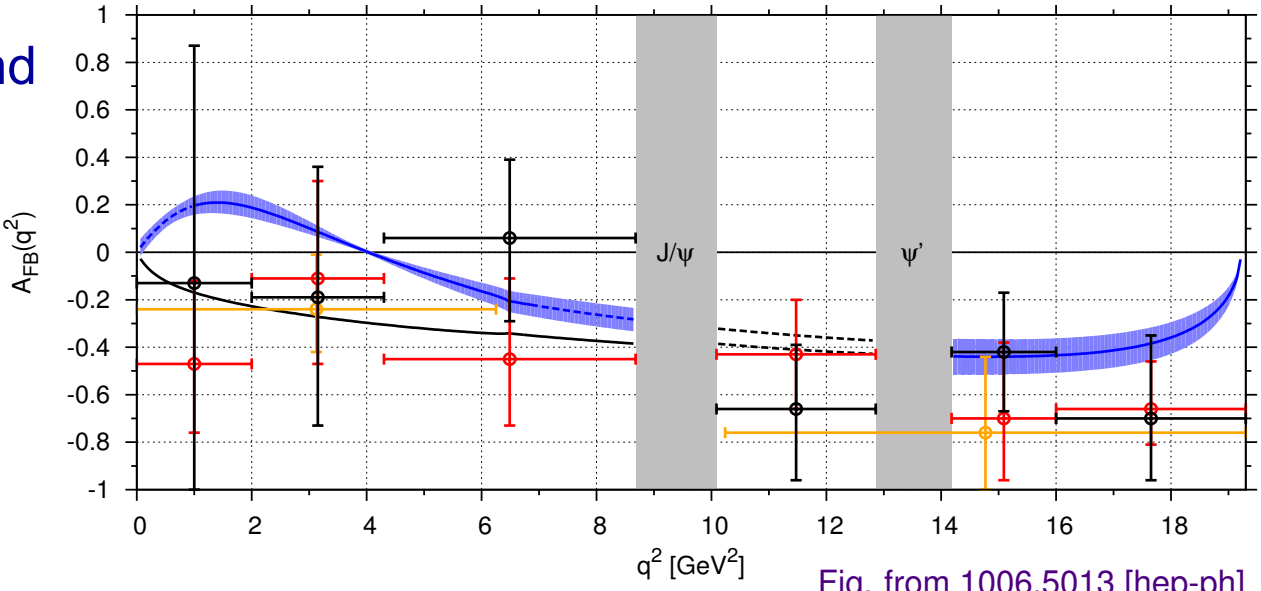


Fig. from 1006.5013 [hep-ph]

230 events, B/S = 0.3

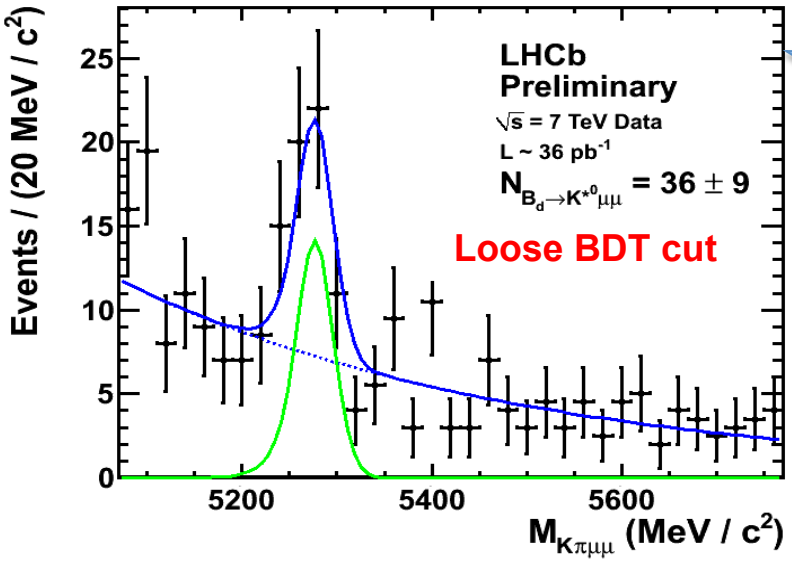
70 events, B/S = 0.25

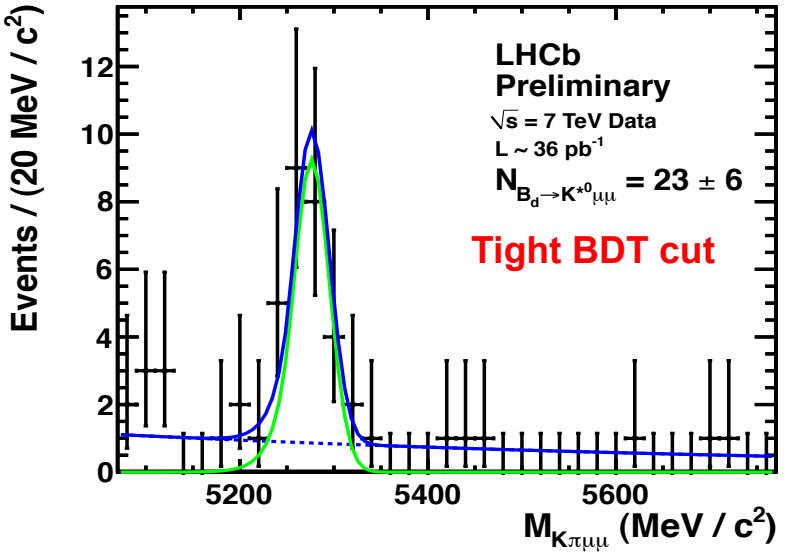
100 events, B/S = 0.4

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

- Two selection approaches pursued:
  - Simple cut based
  - Boosted Decision Tree (BDT) based, gains 30% signal for same bkg
- Extrapolate to $1fb^{-1}$:
  - 1000 signal candidates with B/S~1
  - 600 signal candidates with B/S=0.2
- Correct acceptance distortion using MC, xcheck with $B^0 \rightarrow J/\psi K^*$ data
- First results expected this summer
  - Measurement of F_L and A_{FB}
    → **with $200pb^{-1}$, LHCb gets competitive to CDF and to the B-factories**
- Assuming central value of Belle, ~4 sigma SM deviation could be established this year

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





More channels:

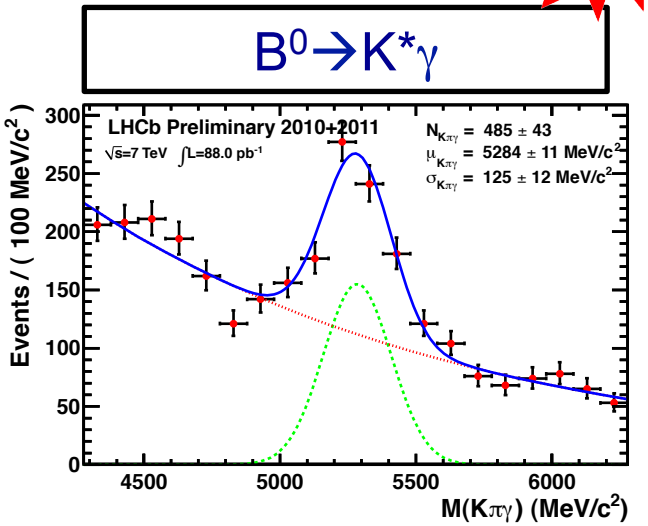
- Radiative decays
- Lepton Flavour Violation

Photon polarization in b→sγ

NEW!

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

- Good proxy to test radiative decay performance (calorimeter energy, photon trigger)
- $BR(B^0 \to K^*\gamma) = (43.3 \pm 1.5) \times 10^{-6}$ (HFAG2010)
- End 2011: Measurement of direct CP asymmetry
  - **A_{CP} predicted less than 1% in SM**
  - **Measured by BaBar: A_{CP}=(-1.6±2.3)%**

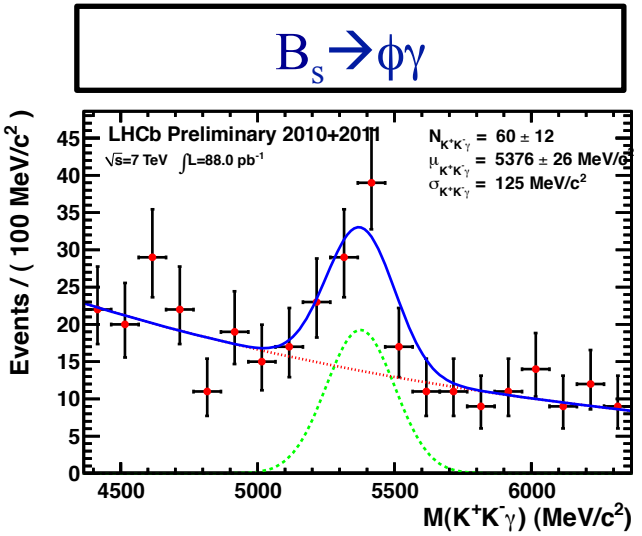


$B_s \to \phi\gamma$

- First seen by BELLE 2008 with 35% BR uncertainty

$$BR(B_s \to \phi\gamma) = 57^{+21}_{-18} \times 10^{-6}$$

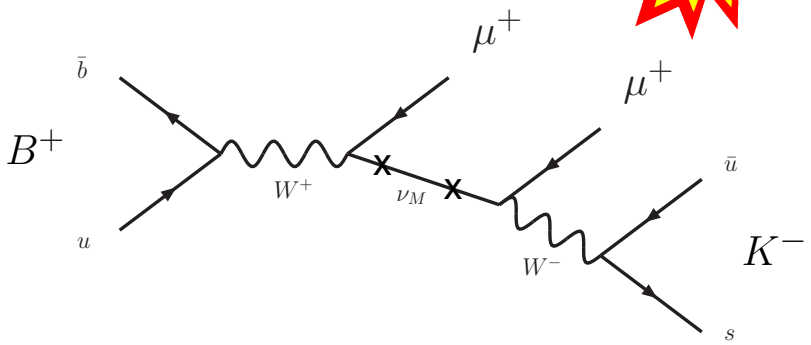
- This summer: measurement of the BR ratio $B(B_s \to \phi\gamma)/B(B^0 \to K^*\gamma)$ with <20% precision
- Later: measure photon polarization in time dependent CP asymmetry
  → probe Lorentz structure of the interaction (O_7)



LFV: Search for $B^+ \to h^- \mu^+ \mu^+$

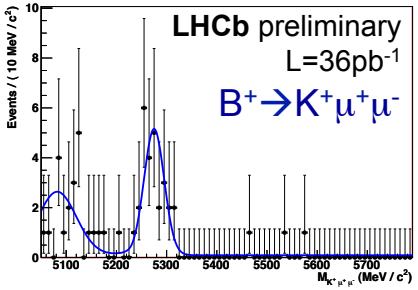
NEW!

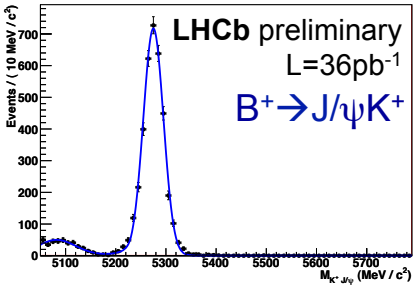
- Search for $B^+ \to K^- \mu^+ \mu^+$ and $B^+ \to \pi^- \mu^+ \mu^+$
  - $\Delta L=2$ transition, strictly forbidden in SM
  - Sterile Majorana neutrinos of mass $O(1\text{GeV}/c^2)$ enhance BR significantly



- Analysis strategy:
  - Tight selection, use opposite sign $B^+ \to K^+ \mu^+ \mu^-$ as proxy
  - Normalize to $B^+ \to J/\psi K^+$
  - Estimate peaking bkg from control channels (J/ψ, D^{*+})

Normalization channels





- Observed signal / background
  - < 0.3 (0.1) bkg events expected in $\pi\mu\mu$ ($K\mu\mu$) mode
  - **Zero events observed in both signal regions & sidebands**

- Observed limit @ 90% CL:
  - $BR(B^+ \to K^- \mu^+ \mu^+) < 4.3 \times 10^{-8}$
  - $BR(B^+ \to \pi^- \mu^+ \mu^+) < 4.5 \times 10^{-8}$

Factor 40 (30) improvement of previous best limit (CLEO)!

Summary

- The B-physics program contributes significantly to the overall LHC effort to find and study Physics beyond the SM
- Highly-sensitive b→s observables accessible in 2011:
  - **$B_{s,d} \to \mu^+\mu^-$ competitive measurement with 2010 data, 2011 update will explore 10^{-8} range**
  - **$B^0 \to K^*\mu^+\mu^-$ competitive measurement expected soon**
  - First radiative measurements expected soon
  - Improvement on limit for Lepton Flavour Violation
- Wide range of other rare decay measurements at LHCb will become interesting with 2011 data

$B_s \to \phi\mu\mu$ $D \to e\mu$ $\tau \to \mu\mu\mu$ $B \to \tau\mu$

$B_d \to K^*ee$ $B^+ \to K^+ ee / \mu\mu$ $\tau \to \phi\mu$

… and many more …

$D \to \mu\mu$ $B \to \mu\mu\mu\mu$ $B_s \to \mu\mu\gamma$

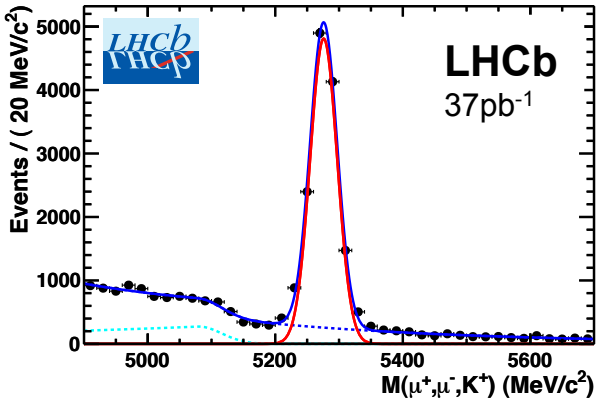

STOP

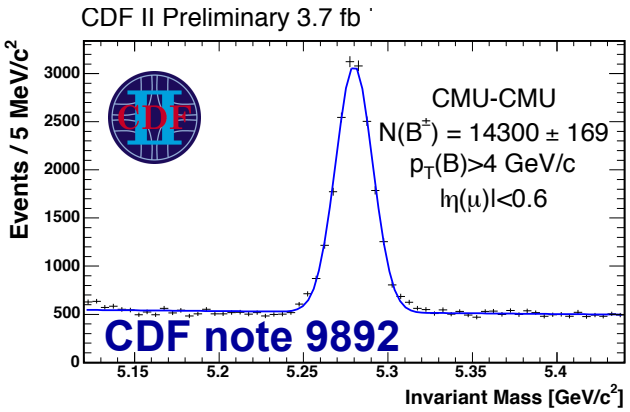
LHCb acceptance

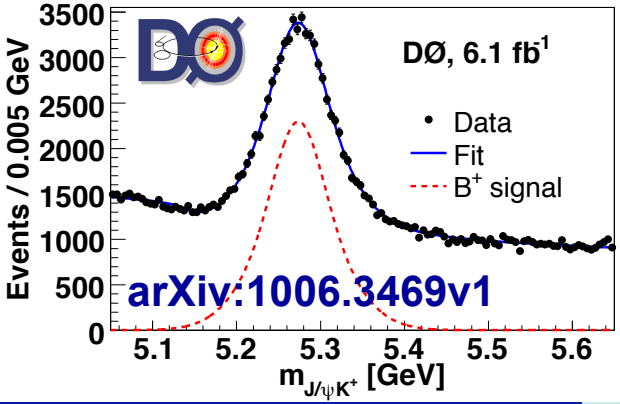
- LHCb: maximize B acceptance @ LHC
  → forward spectrometer, $1.9<\eta<4.9$
  - B hadrons produced at low angle
  - B pairs are produced in same forward or backward cone → single arm ok

- Rough estimate for B acceptance: compare $B^{\pm}\rightarrow J/\psi K^{\pm}$ yield with CDF / D0
  - **LHCb**
    N^{signal}: $12{,}366\pm403^{stat+syst}$ $(0.037fb^{-1})$
  - **CDF**$_{(CMU\text{-}CM(U+X))}$
    N^{signal}: $19{,}762\pm203^{stat+syst}$ $(3.7fb^{-1})$
    D0$_{(RunIIa+b)}$
    N^{signal}: $46{,}803\pm1099^{stat+syst}$ $(6.1fb^{-1})$

(CDF: $|\eta|<1$; D0: $|\eta|<2$; CMS/ATLAS: $|\eta|<2.4$)





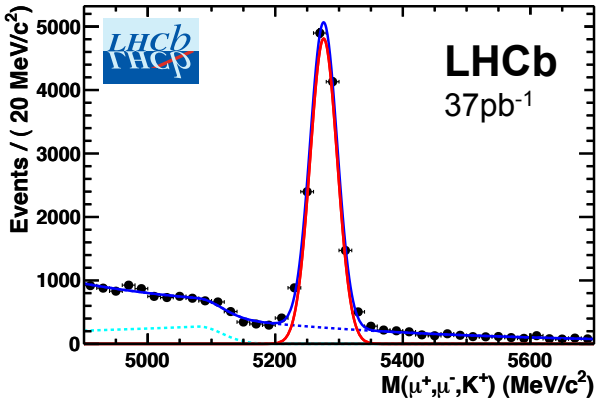


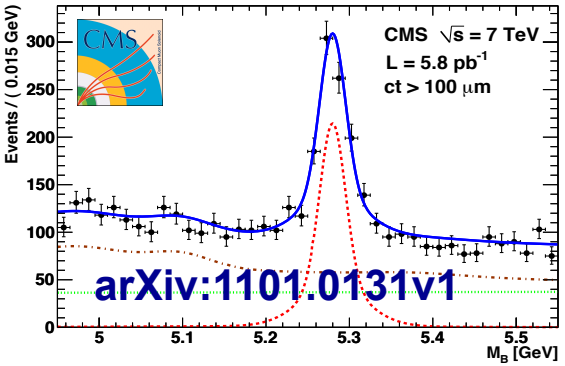
LHCb acceptance

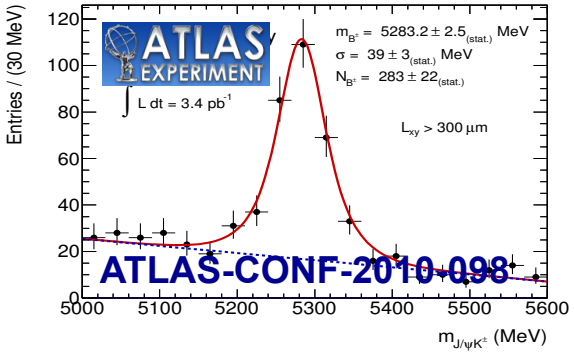
- LHCb: maximize B acceptance @ LHC
  → forward spectrometer, $1.9<\eta<4.9$
  - B hadrons produced at low angle
  - B pairs are produced in same forward or backward cone → single arm ok

- Rough estimate for B acceptance: compare $B^{\pm} \rightarrow J/\psi K^{\pm}$ yield with CDF / D0
  - **LHCb**
    N^{signal}: $12{,}366 \pm 403^{stat+syst}$ $(0.037 fb^{-1})$
  - **CMS (from 5.8pb-1)**
    N^{signal}: 5,818 scaled
  - **ATLAS (from 3.4pb-1)**
    N^{signal}: 3,080 scaled

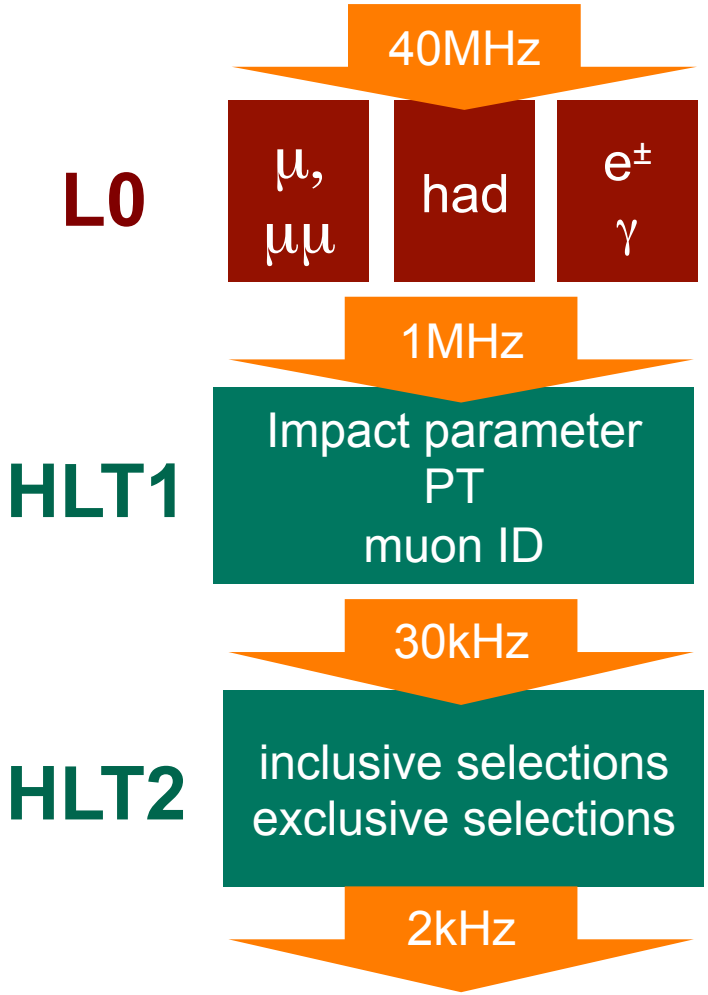
(CDF: $|\eta|<1$; D0: $|\eta|<2$; CMS/ATLAS: $|\eta|<2.4$)







Keys for b-physics I: Trigger



Small event size (60kB)
→ large bandwidth
→ allows low trigger thresholds

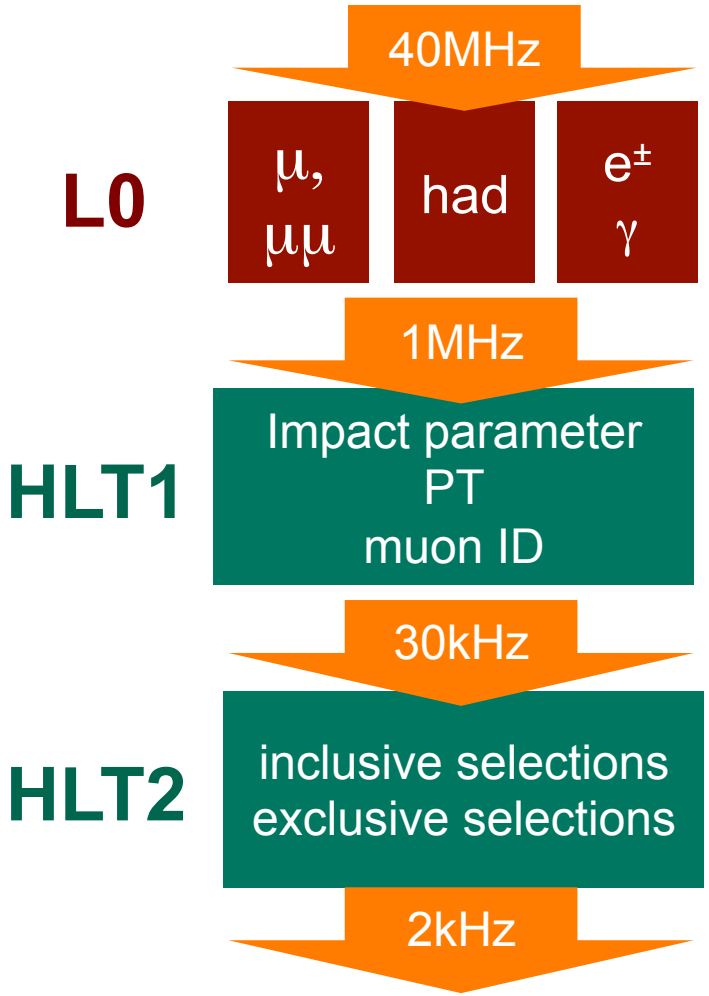
L0 hardware	"high p_T" signals in calorimeter and muon systems
HLT1 software	Partial reconstruction selection based on one or two tracks (dimuon) displaced in the VELO, muon ID (offline like)
HLT2 software	Global reconstruction (very close to offline) dominantly inclusive signatures

+ Global event cuts rejecting busy events

	Charm	Hadr. B	Lept. B
Global efficiency	~10%	~40%	75-90%

Keys for b-physics I: Muon trigger

Half of the bandwidth (~1 kHz) given to the muon lines
p_T cuts on muon lines kept very low → trigger efficiency very high
Trigger rather stable during the whole period (despite L increased by ~10^5)

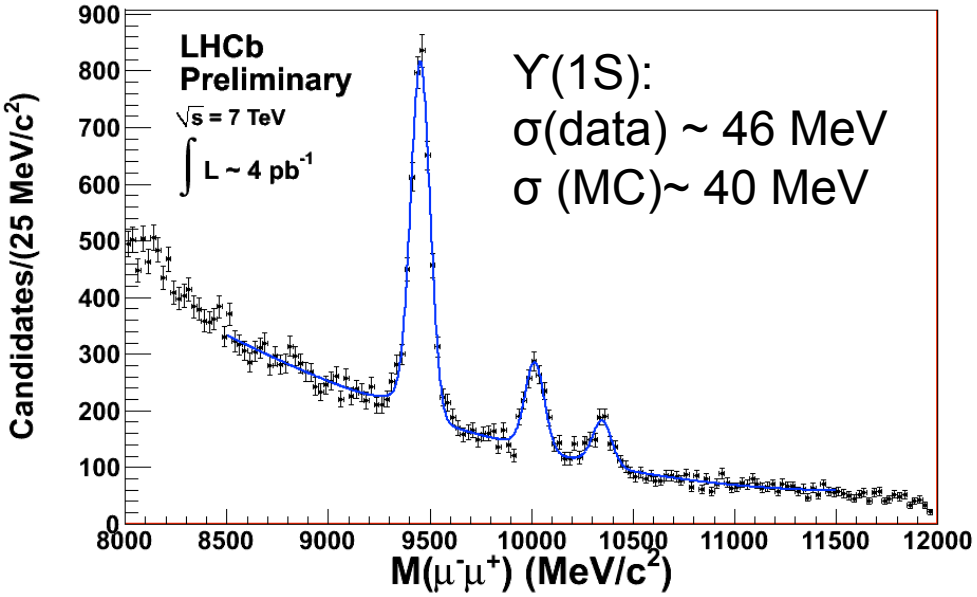


Muon lines:

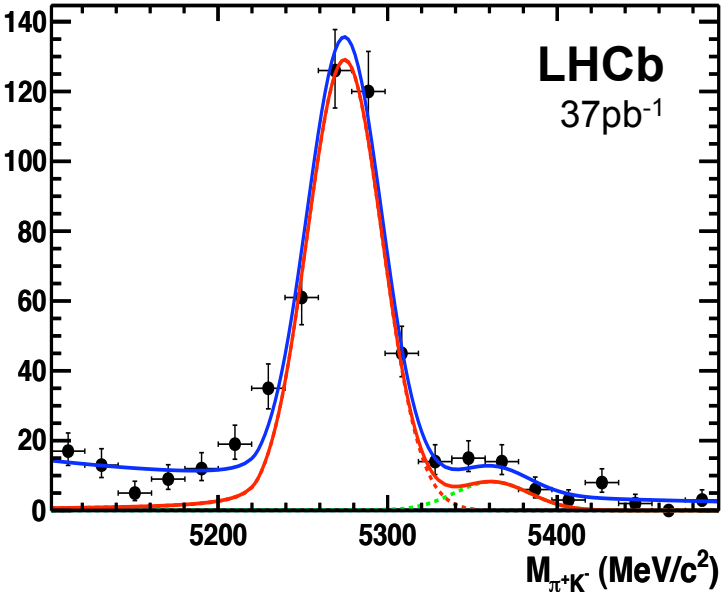
L0 hardware	**Single-μ: p_T>1.4GeV/c** **Di – μ : 2 clean muons** **p_{T1}>0.56GeV/c** **p_{T2}>0.48GeV/c**
HLT1 software	Single-μ: p_T>0.8GeV/c IP > 0.11mm, IPS > 5 Single-μ: p_T>1.8GeV/c (no IP)
HLT2 software	Dimuon: $M_{\mu\mu}$ > 4.7GeV/c^2 $\Delta m(J/\psi)$ < 120 MeV/c^2 Several lines with p_T and vertex displacement cuts

Keys for b-physics II: mass resolution

Υ(1S), Υ(2S), Υ(3S)



$B^0 \rightarrow K^{\pm}\pi^{\pm}$



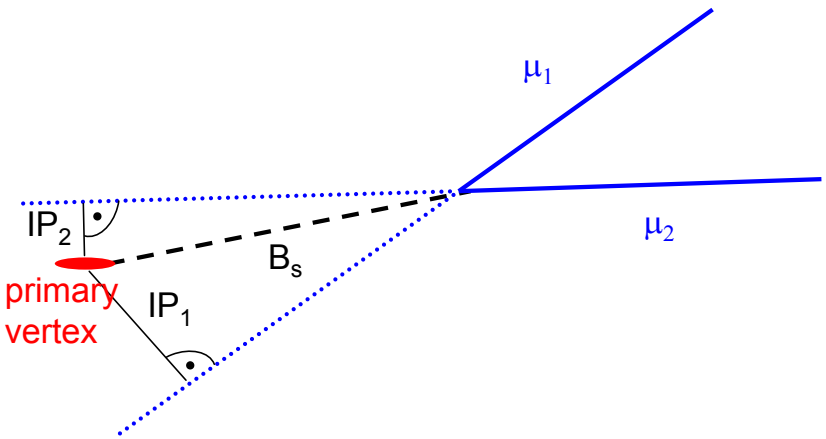
	momentum resolution	mass resolution J/ψ→μμ
LHCb	δp/p = 0.4-0.6 %	13 MeV
CMS	δpt/pt = 1-3 %	40 MeV
ATLAS	δpt/pt = 5-6 %	71 MeV

Keys for b-physics III: IP and vertex resolution

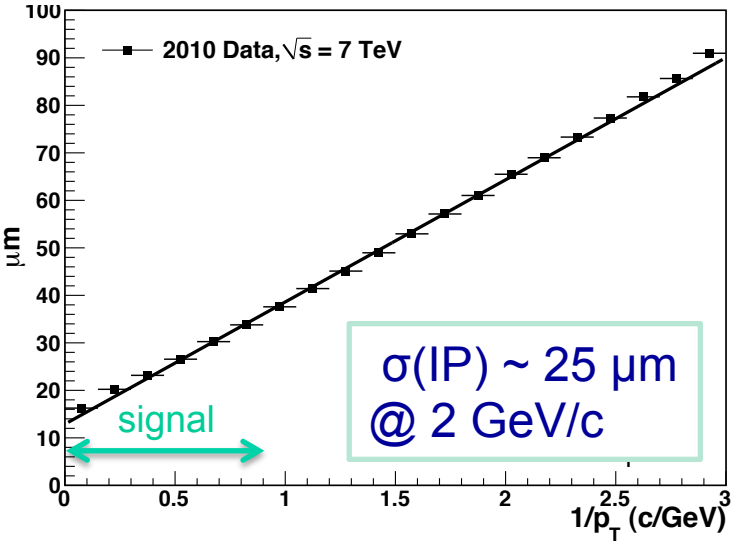
Primary vertex resolutions (25 tracks):

	LHCb [μm]	ATLAS [μm]	CMS [μm]
σ(x)	15.8	60	20-40
σ(y)	15.2	60	20-40
σ(z)	76	100	40-60

Impact parameter (IP):



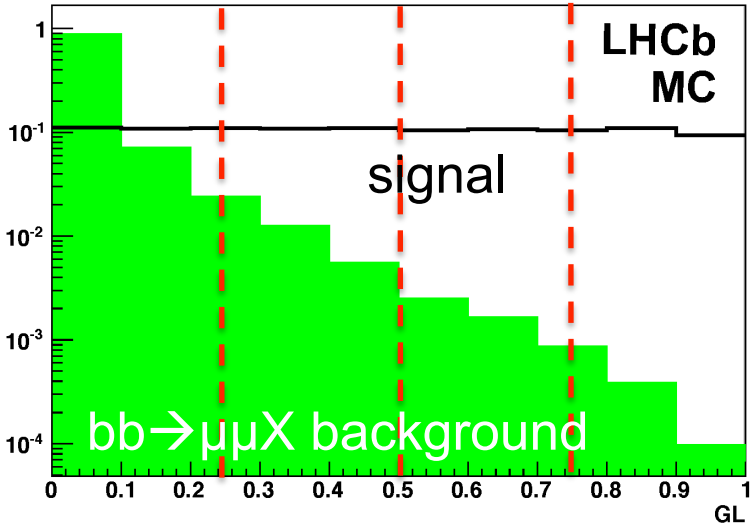
IP resolution vs 1/pT



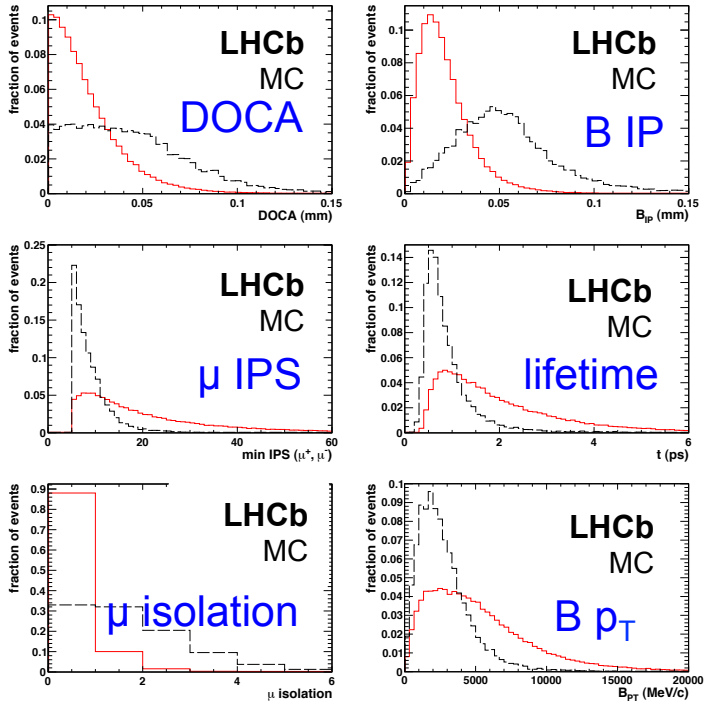
Geometrical likelihood definition

- Combination of kinematic and topological variables
- Variables are decorrelated and a discriminant variable is built
- Optimization and training using MC
  - Signal $B_s \rightarrow \mu\mu$
  - Background $bb \rightarrow \mu\mu X$

GL shape of signal and bkg



GL input variables



→ flat for signal

→ peaked at zero for background

Analysis is done in 4 bins of GL

Normalization

Normalize measured events to a channel with known BR

→ many uncertainties cancel

→ no knowledge of luminosity or cross section needed

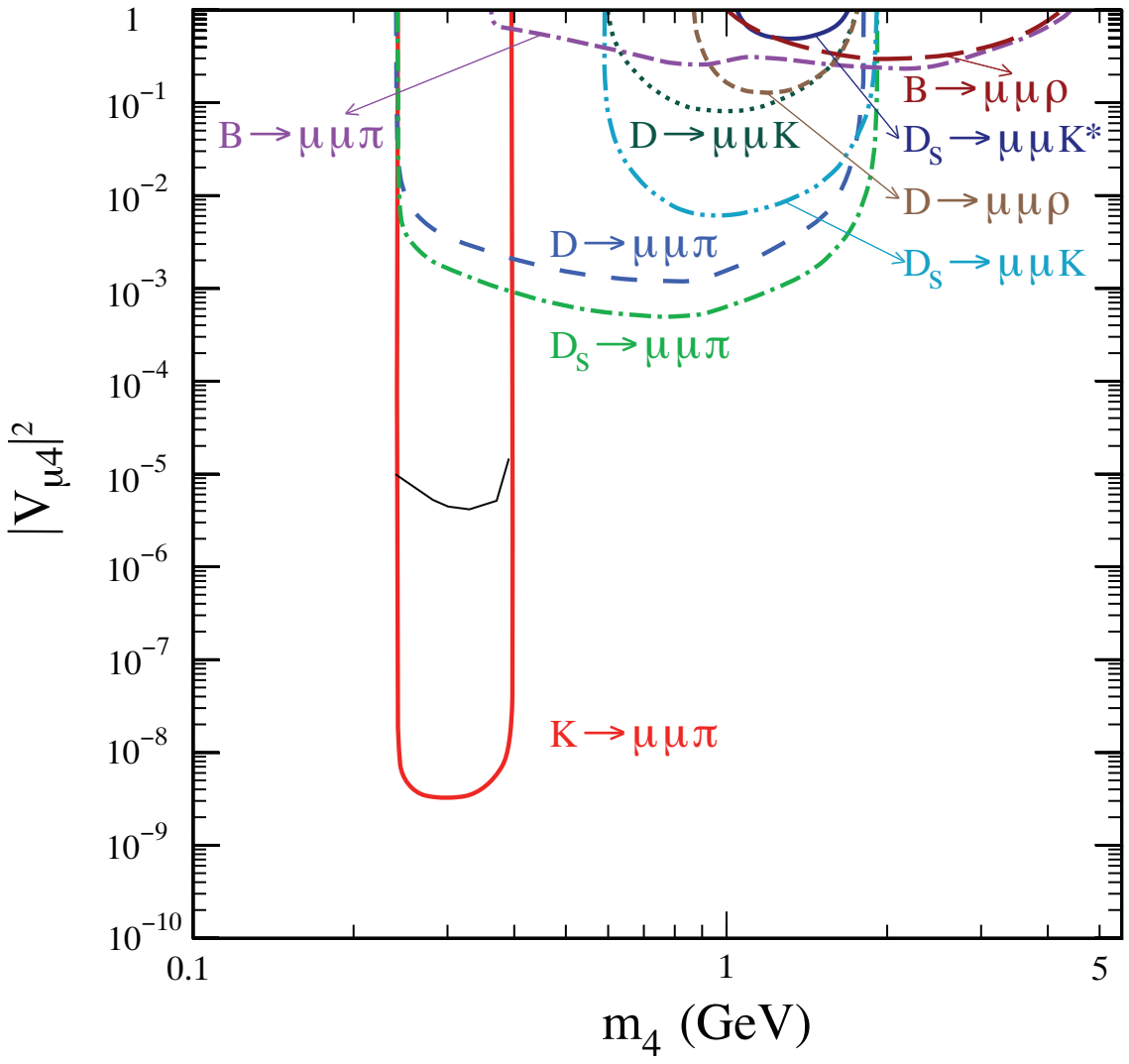
$$BR = BR_{cal} \cdot \frac{f_{cal}}{f_{B_s}} \cdot \frac{\varepsilon_{cal}^{Rec} \cdot \varepsilon_{cal}^{Sel} \cdot \varepsilon_{cal}^{Trig}}{\varepsilon_{Bs}^{Rec} \cdot \varepsilon_{Bs}^{Sel} \cdot \varepsilon_{Bs}^{Trig}} \cdot \frac{N_{B\to\mu\mu}}{N_{cal}} = \alpha \cdot N_{B\to\mu\mu}$$

Three independent normalization channels used:

$B^{\pm}\to J/\psi(\mu\mu)\, K^{\pm}$	$B_S\to J/\psi(\mu\mu)\, \phi(KK)$	$B^0\to K^+\pi^-$
BR = 5.98×10^{-5} (±3.7%)	BR = 3.35×10^{-5} (±26%)	BR = 1.94×10^{-5} (±3.1%)
• Similar trigger and PID • f_d/f_s dominates overall uncertainty	• Similar trigger and PID • BR dominates overall uncertainty	• Identical topology • Different trigger → use events triggered independent of signal • Uncertainty from f_d/f_s, trigger, mass fit

Experimental status of $|V_4|$

Status from B, D, K decays



arXiv:0901.3589v2