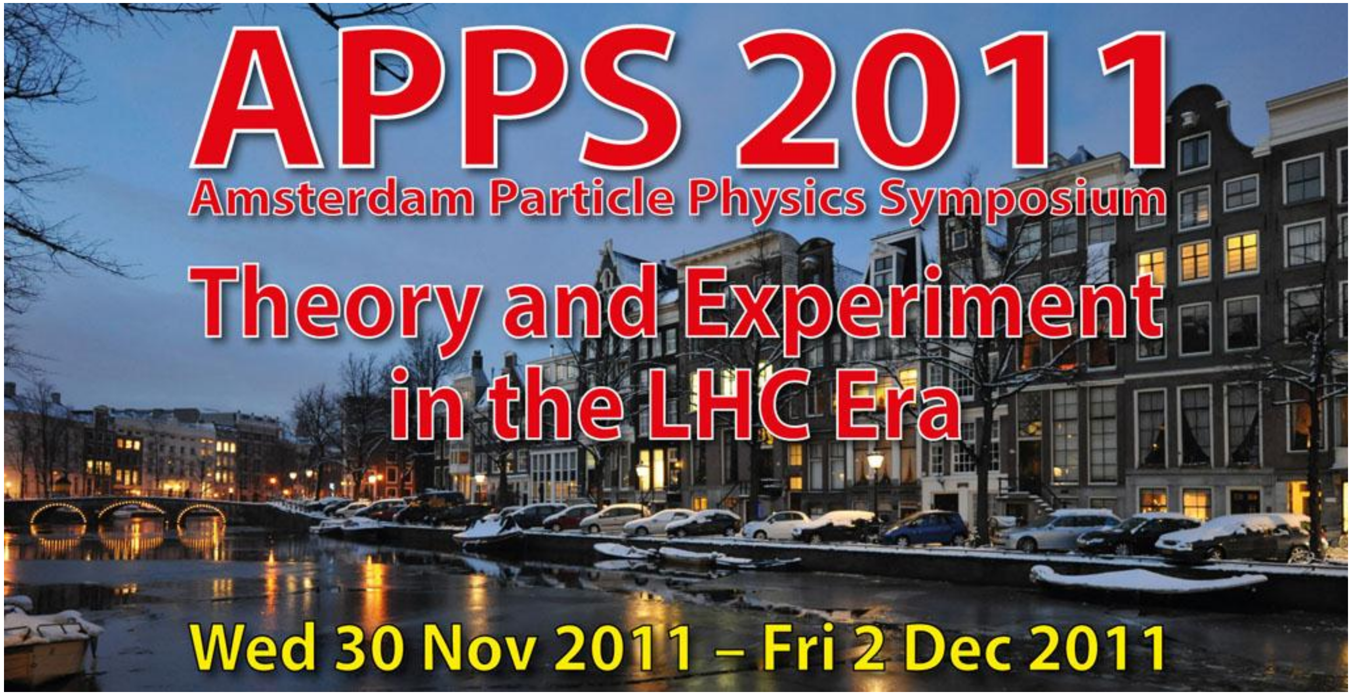
View on Recent Results from LHCb

Niels Tuning
on behalf of the LHCb collaboration



Disclaimer

- In the rest of the talk I will assume the speed of light to be constant and that particles cannot travel faster than c.

Search for New Physics with B-physics

<u>Search for new particles</u> or forces via their virtual loop contributions in *B* decays

1) <u>CP Violation:</u>

Search for CP asymmetries incompatible with SM fits.

Study of couplings of New Physics

Examples:

1. $B_s^0 \rightarrow J/\psi\varphi$

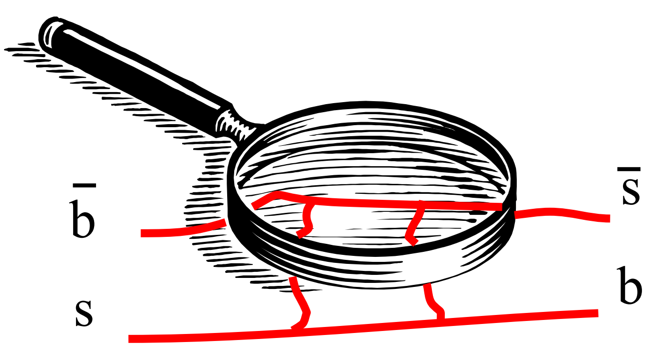
2) <u>Rare Decays:</u>

Search for enhanced BR's or decay distributions that deviate from SM

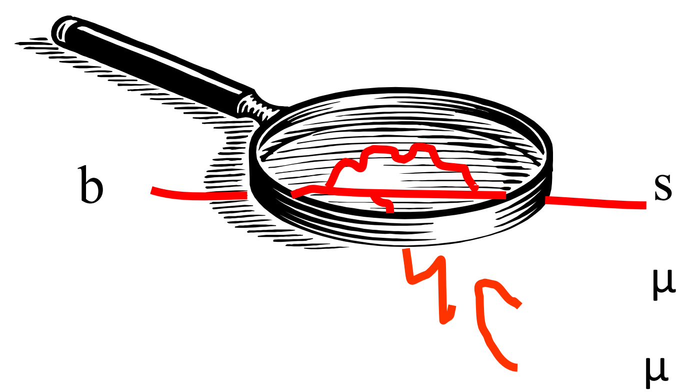
Examples:

2. $B^0 \rightarrow K^*\mu\mu$
3. $B^0_s \rightarrow \mu\mu$

"Box" diagram: ΔB=2



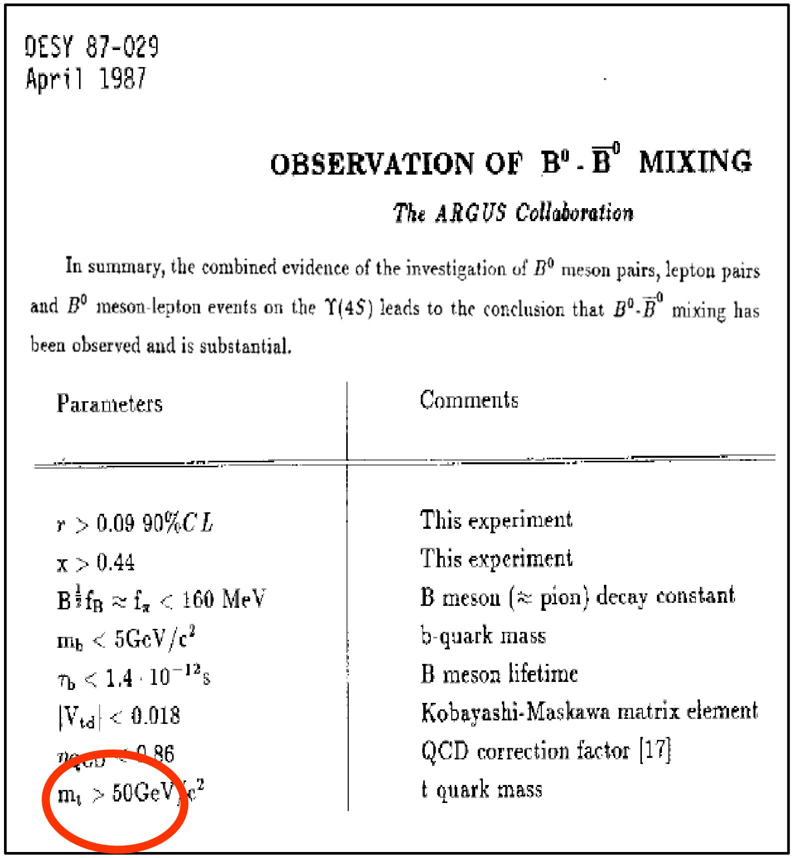
"Penguin" diagram: ΔB=1



Reminder: Mixing and Rare Decays for discoveries

B^0 mixing pointed to the **top** quark:

ARGUS Coll, Phys.Lett.B192:245,1987

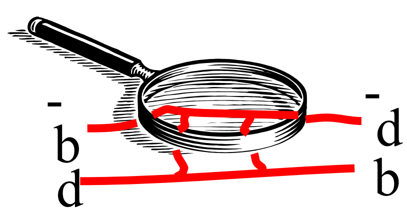

DESY 87-029
April 1987

OBSERVATION OF B^0 - $\overline{B}^0$ MIXING

The ARGUS Collaboration

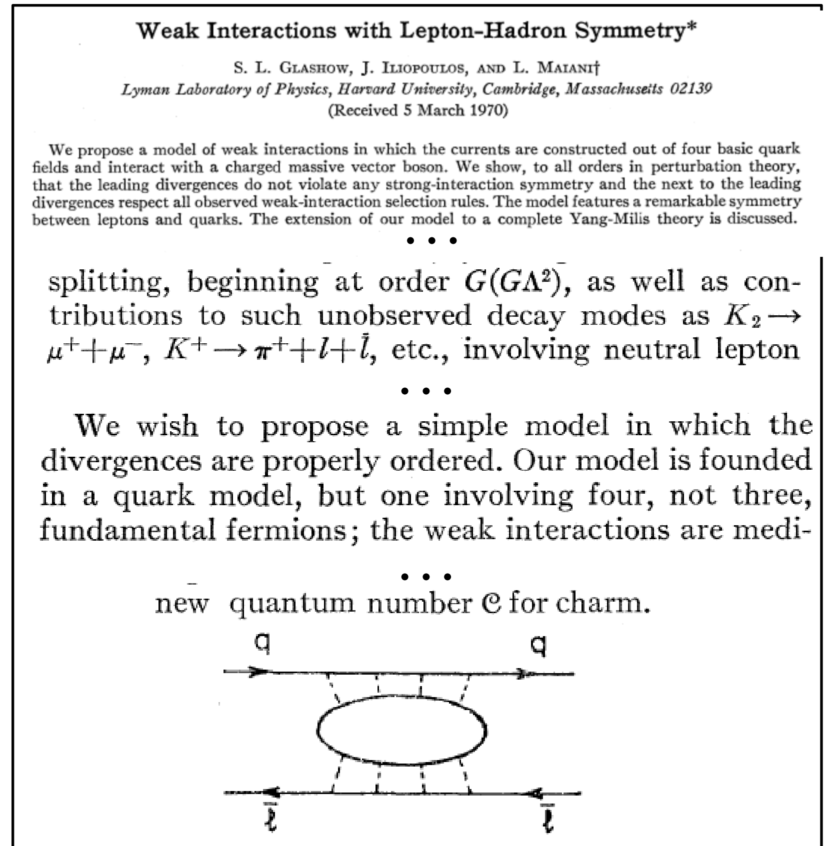
In summary, the combined evidence of the investigation of B^0 meson pairs, lepton pairs and B^0 meson-lepton events on the $\Upsilon(4S)$ leads to the conclusion that B^0-$\overline{B}^0$ mixing has been observed and is substantial.

Parameters	Comments
$r > 0.09$ 90%CL	This experiment
$x > 0.44$	This experiment
$B^{\frac{1}{2}} f_B \approx f_\pi < 160$ MeV	B meson (≈ pion) decay constant
$m_b < 5\mathrm{GeV}/c^2$	b-quark mass
$\tau_b < 1.4 \cdot 10^{-12}$s	B meson lifetime
$\lvert V_{td} \rvert < 0.018$	Kobayashi-Maskawa matrix element
$\eta_{QCD} < 0.86$	QCD correction factor [17]
$m_t > 50\mathrm{GeV}/c^2$	t quark mass



$K^0 \rightarrow \mu\mu$ pointed to the **charm** quark:

GIM, Phys.Rev.D2,1285,1970


Weak Interactions with Lepton-Hadron Symmetry*

S. L. Glashow, J. Iliopoulos, and L. Maiani†
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139
(Received 5 March 1970)

We propose a model of weak interactions in which the currents are constructed out of four basic quark fields and interact with a charged massive vector boson. We show, to all orders in perturbation theory, that the leading divergences do not violate any strong-interaction symmetry and the next to the leading divergences respect all observed weak-interaction selection rules. The model features a remarkable symmetry between leptons and quarks. The extension of our model to a complete Yang-Mills theory is discussed.

• • •

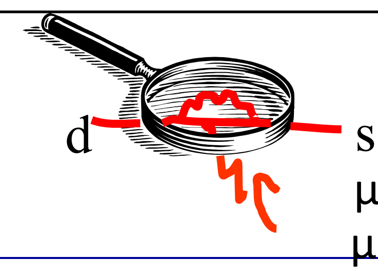
splitting, beginning at order $G(G\Lambda^2)$, as well as contributions to such unobserved decay modes as $K_2 \rightarrow \mu^+ + \mu^-$, $K^+ \rightarrow \pi^+ + l + \bar{l}$, etc., involving neutral lepton

• • •

We wish to propose a simple model in which the divergences are properly ordered. Our model is founded in a quark model, but one involving four, not three, fundamental fermions; the weak interactions are medi-

• • •

new quantum number $\mathfrak{C}$ for charm.



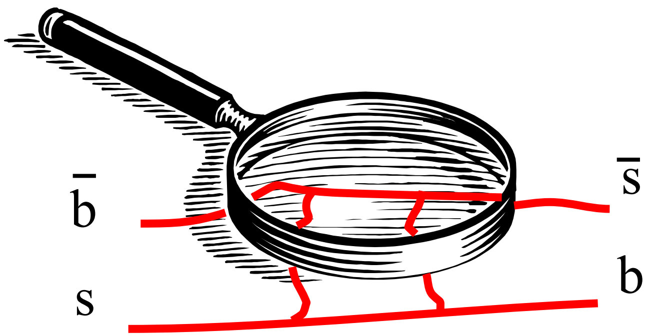
Menu: LHCb "Superstars"

1) $B^0_s \to J/\psi\varphi$

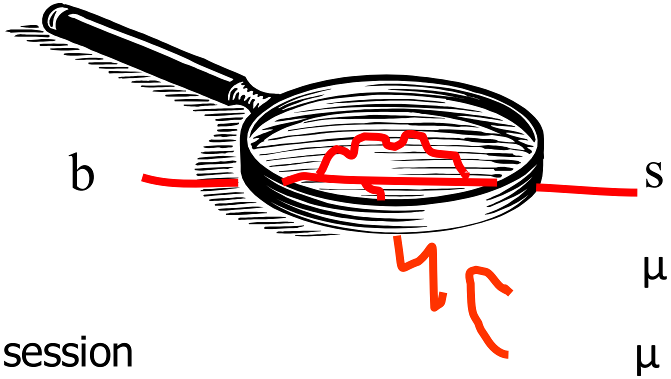
2) $B^0 \to K^*\mu\mu$

3) $B^0_s \to \mu\mu$

"Box" diagram: $\Delta B=2$



"Penguin" diagram: $\Delta B=1$



Other LHCb talks:

- today: W. Hulsbergen in *BSM* session
- tomorrow N. Serra in *discrete symmetries* session

Menu: LHCb "Superstars"

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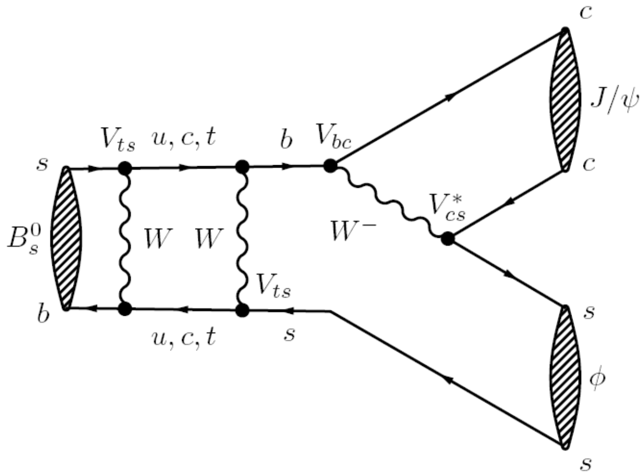
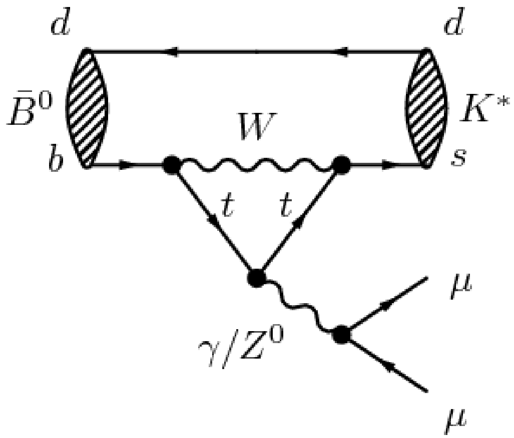
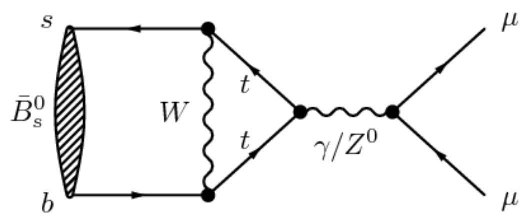
$B^0_s \rightarrow J/\psi\varphi$



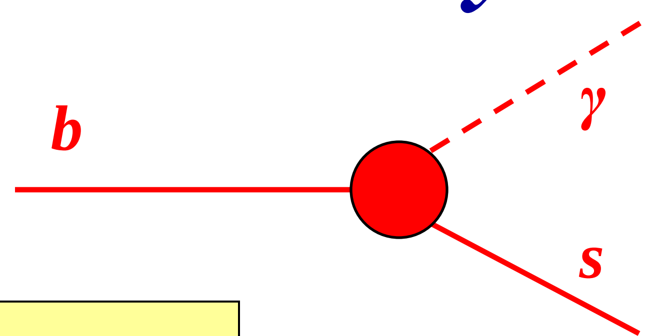
$B^0 \rightarrow K^*\mu\mu$



$B^0_s \rightarrow \mu\mu$



Commonality: "FCNC"



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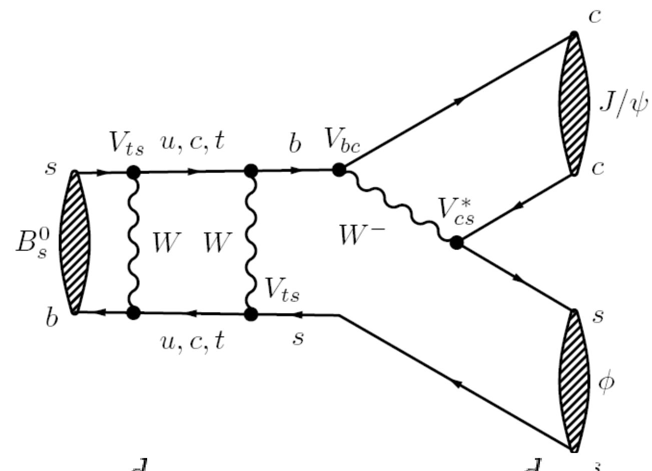

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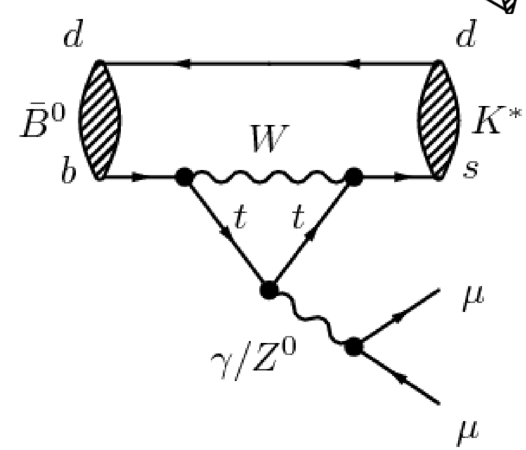

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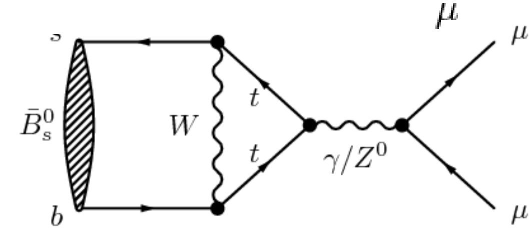

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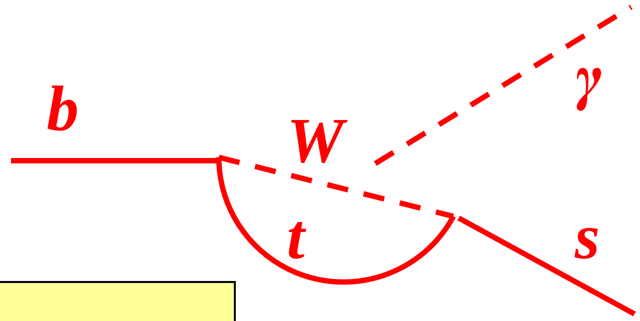

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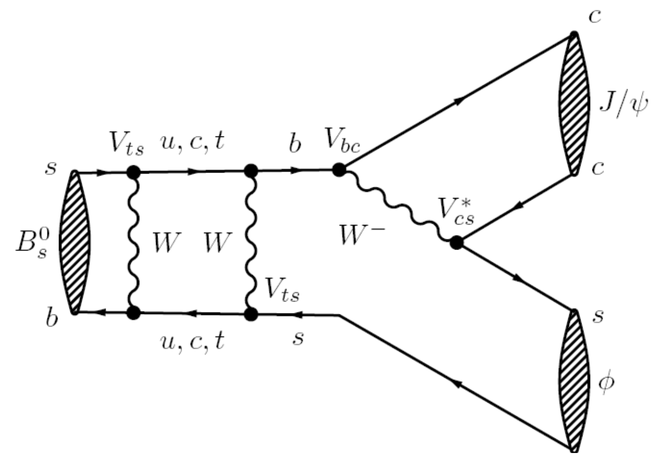
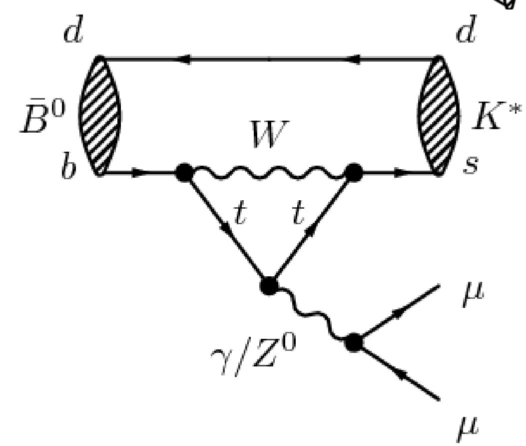
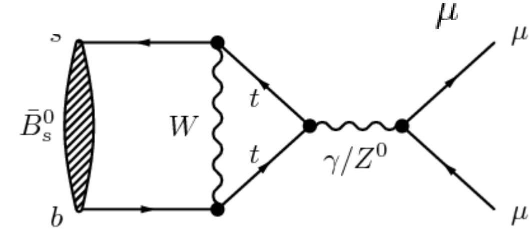
$B^0_s \rightarrow J/\psi\varphi$



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



$B^0_s \rightarrow \mu\mu$



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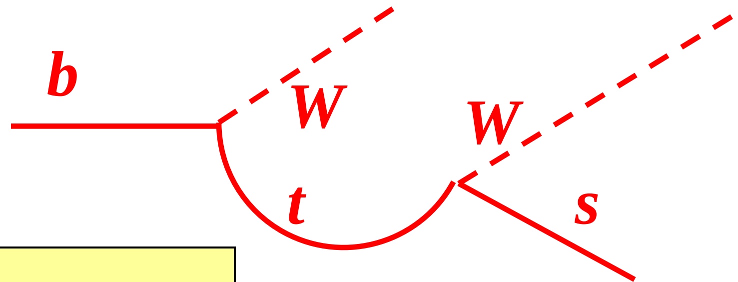

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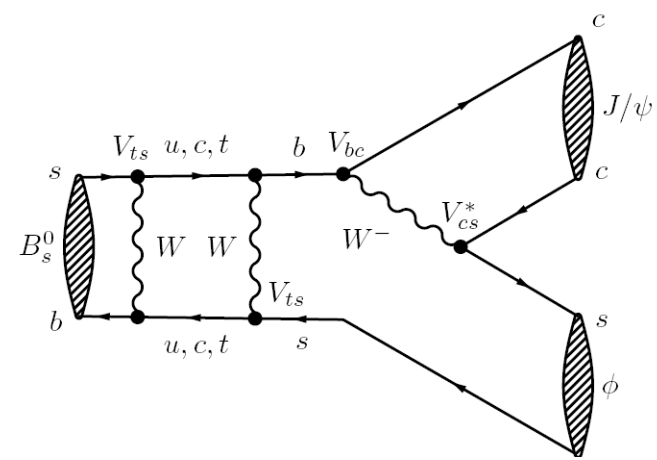
$B^0_s \rightarrow J/\psi\varphi$



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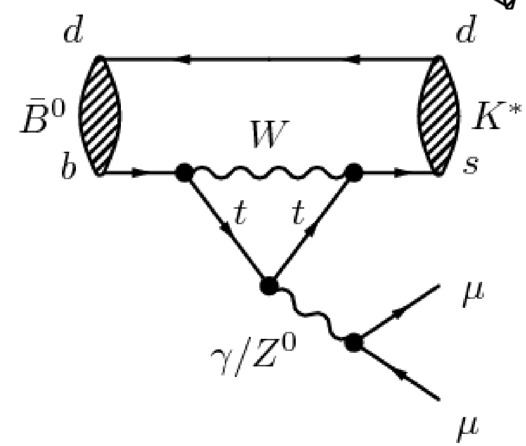

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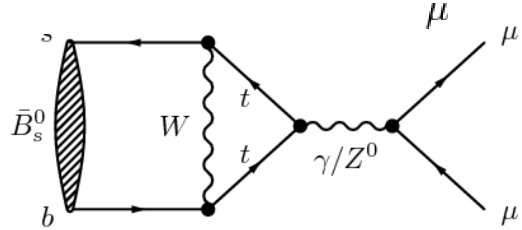
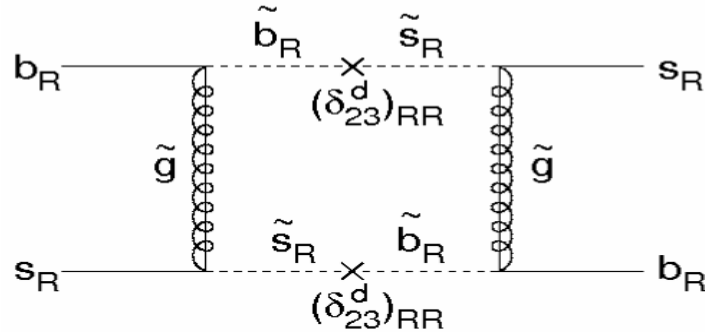


Sensitive to NP: appetizer

$B^0_s \rightarrow J/\psi\varphi$



1) $B^0_s \rightarrow J/\psi\varphi$

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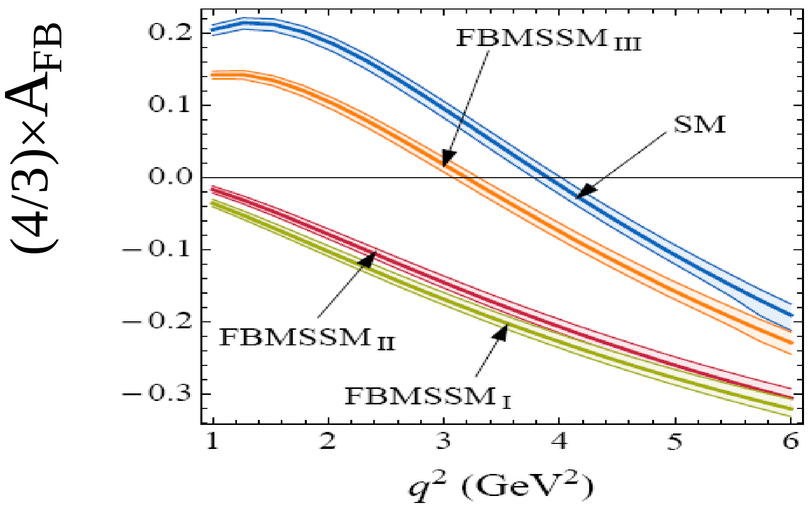
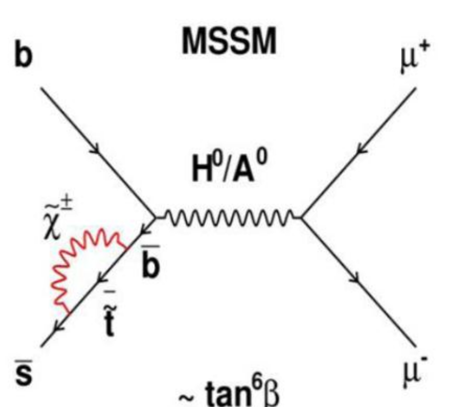
$B^0 \rightarrow K^*\mu\mu$



$B^0_s \rightarrow \mu\mu$



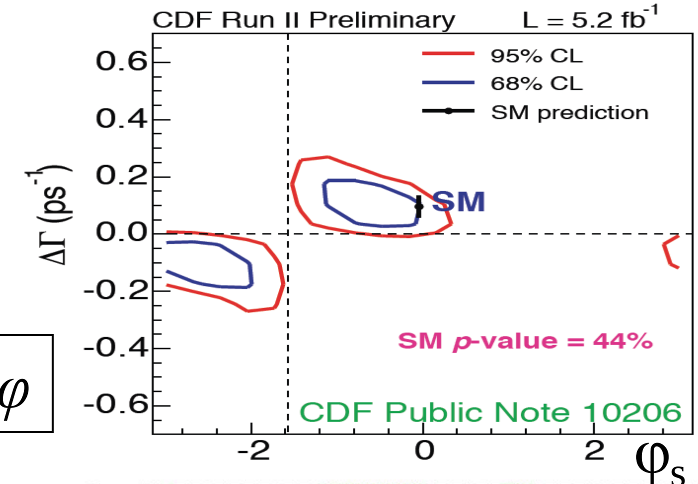
Status before Summer

1) $B^0_s \rightarrow J/\psi\varphi$
   - *Decreased 3σ→ 1σ*

2) $B^0 \rightarrow K^*\mu\mu$
   - *Hint for deviaton*

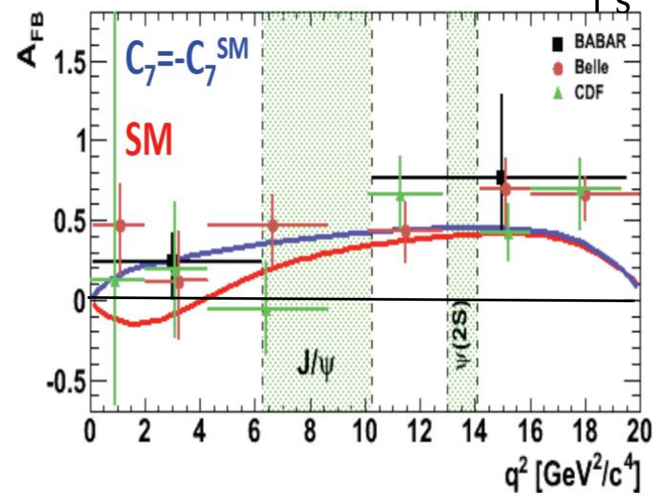
3) $B^0_s \rightarrow \mu\mu$
   - *SM p-value 1.9%*

$B^0_s \rightarrow J/\psi\varphi$



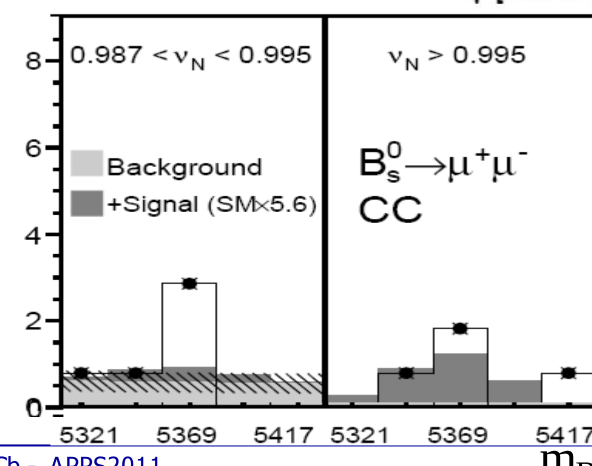
CDF, Conf Note 10206

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



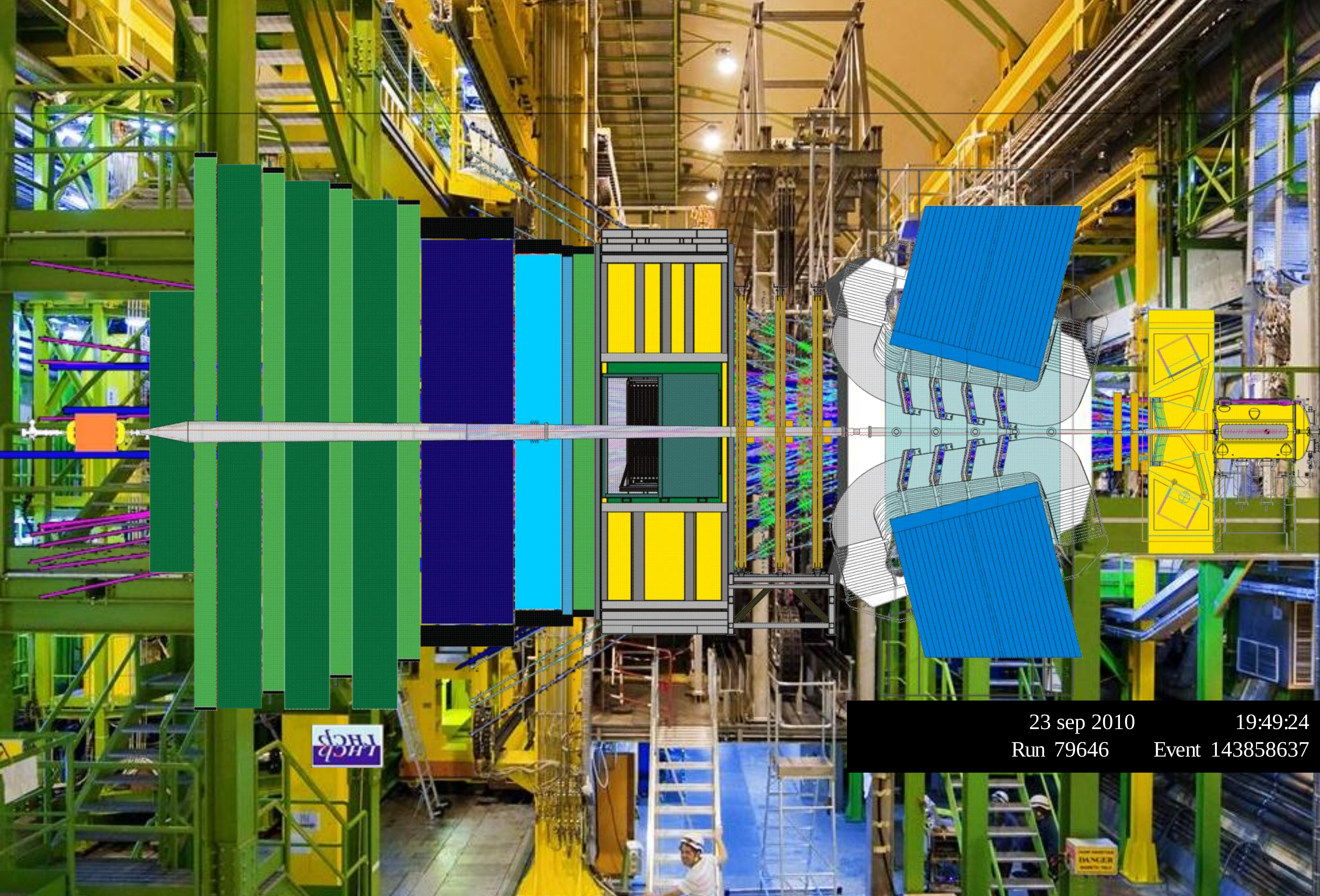
BABAR: PRL 102, 091803 (2009)
CDF: Note 10047 (2010)
Belle: PRL 103, 171801 (2009)

$B^0_s \rightarrow \mu\mu$



CDF, arXiv:1107.2304

The LHCb Detector

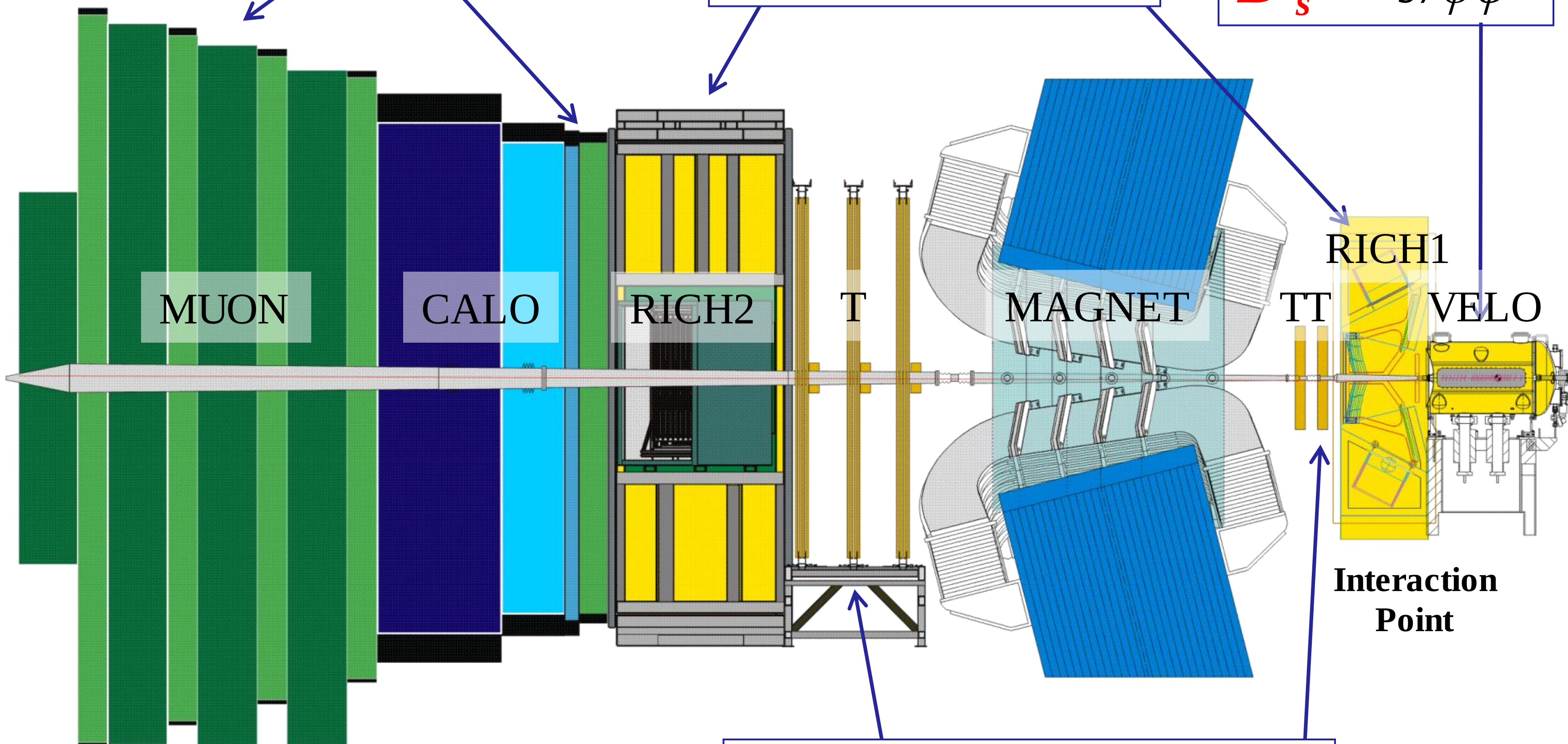


The LHCb Detector

$B^0 \to K^*\mu\mu$
$B^0_s \to \mu\mu$

PID
$B^0 \to K^*(K\pi)\mu\mu$

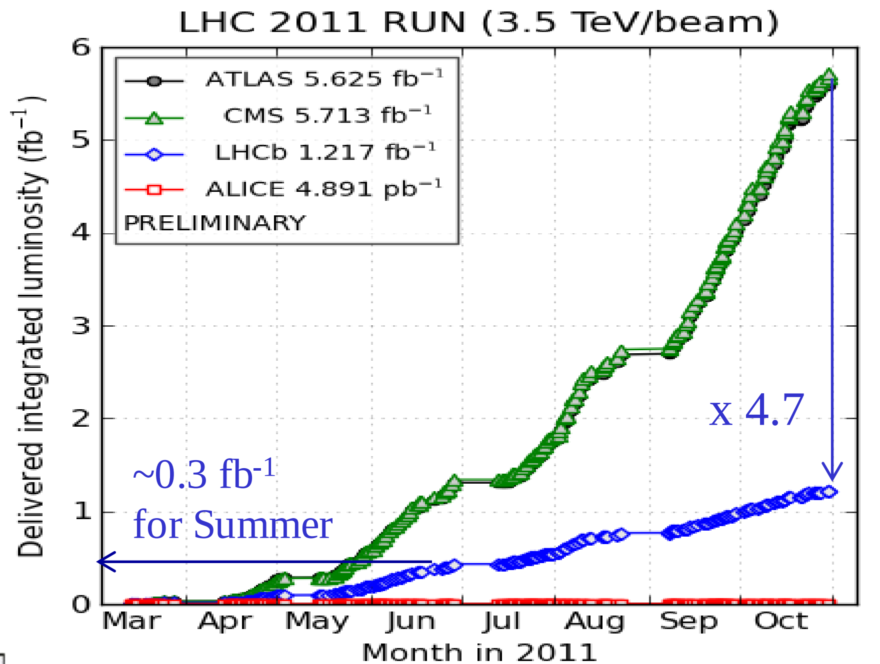
Lifetime,
$B^0_s \to J/\psi\varphi$

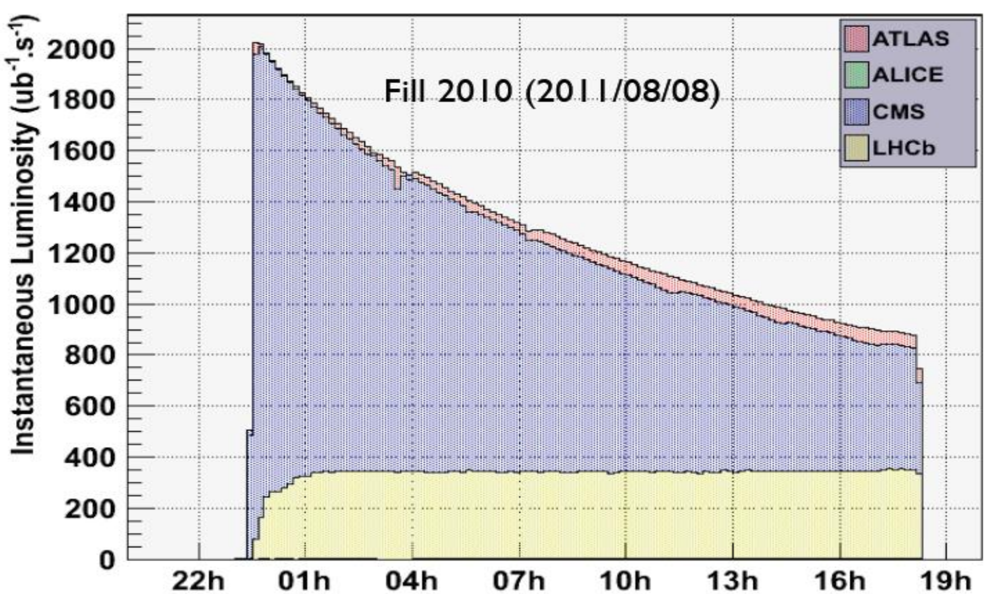


Suppress background, $\sigma(M_B)$
$B^0 \to K^*\mu\mu$
$B^0_s \to \mu\mu$

LHC and LHCb performance

- LHC and LHCb show excellent performance
- Analyzed 330 pb^{-1} for Summer conferences
- 10^{11} bb-pairs produced!





- Optimal use of LHC beam:
  - "Lumi levelling" at 3.5 10^{32}
    (Design was 2.0 10^{32} !)
  - Max. luminosity for entire fill
    With maximum detector occupancy

Menu: LHCb "Superstars"

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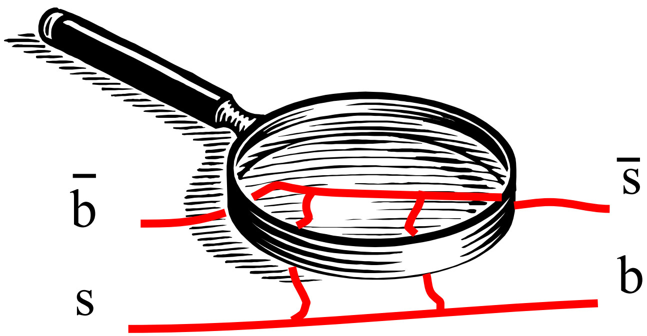
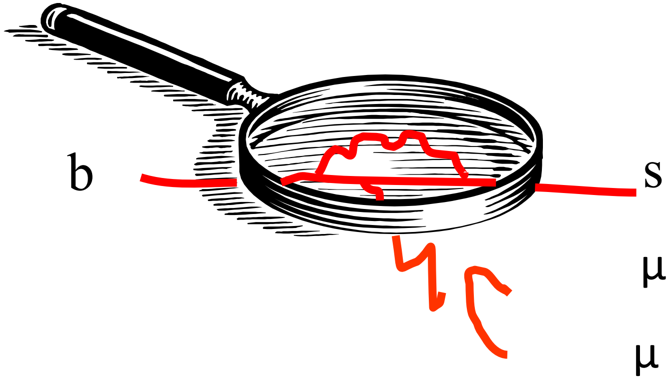
"Box" diagram: ΔB=2



"Penguin" diagram: ΔB=1



$B^0_s \rightarrow J/\psi\varphi$

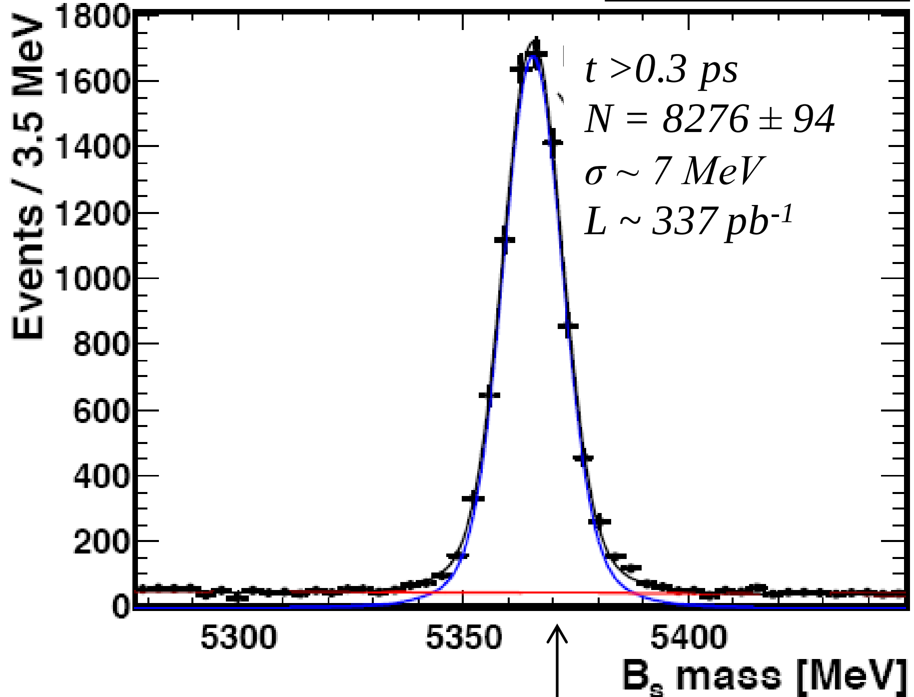
$B^0_s \to J/\psi\varphi$: Introduction

$B^0_s \to J/\psi\varphi$

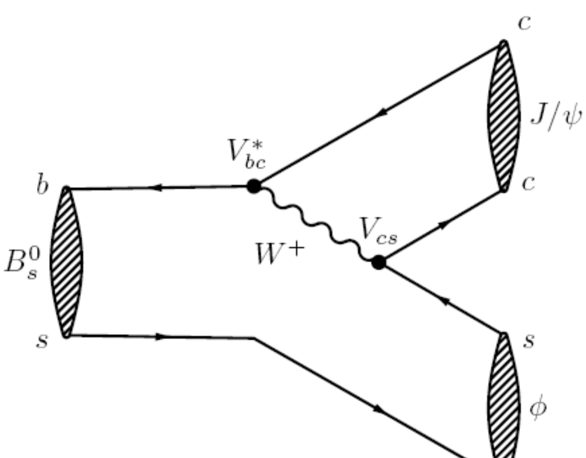
- Interfering decay amplitudes:

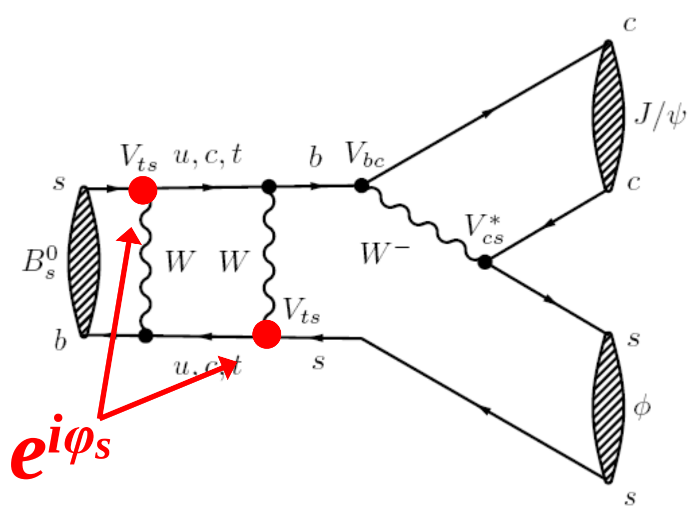
  1) $B^0_s \to J/\psi\varphi$
  2) $B^0_s \to \bar{B}^0_s \to J/\psi\varphi$

$$V_{CKM} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix}$$



NB: Despite hadronic environment very clean signals!



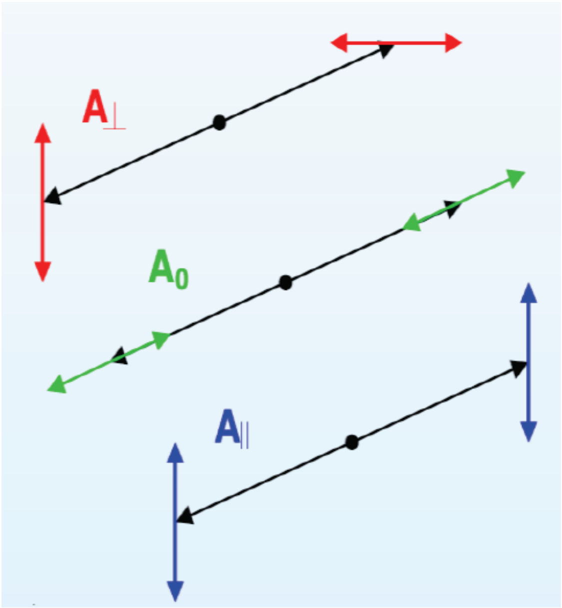


A.S.Dighe, I.Dunietz, R.Fleischer
Eur.Phys.J.C6:647-662,1999

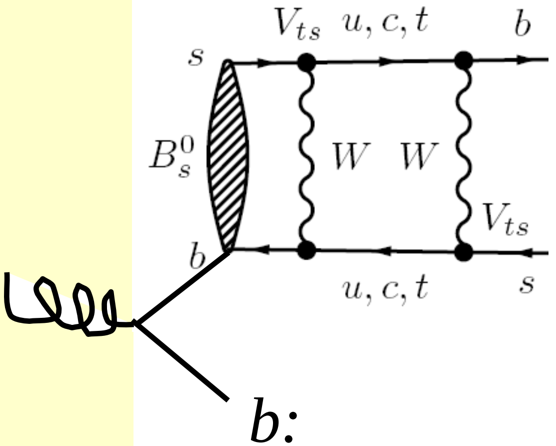
$B^0_s \to J/\psi\varphi$: Analysis

- Angular analysis
  - $B^0_s \to J/\psi\varphi$:
    - *Pseudo-scalar →2 vectors*
    - *CP ~ $(-1)^L$*

L=1	$A_\perp$	CP= -
L=0,2	A_0,$A_\parallel$	CP=+



- Flavour tagging



use this b to check if other b oscillated

$B^0_s \to J/\psi\varphi$: Analysis

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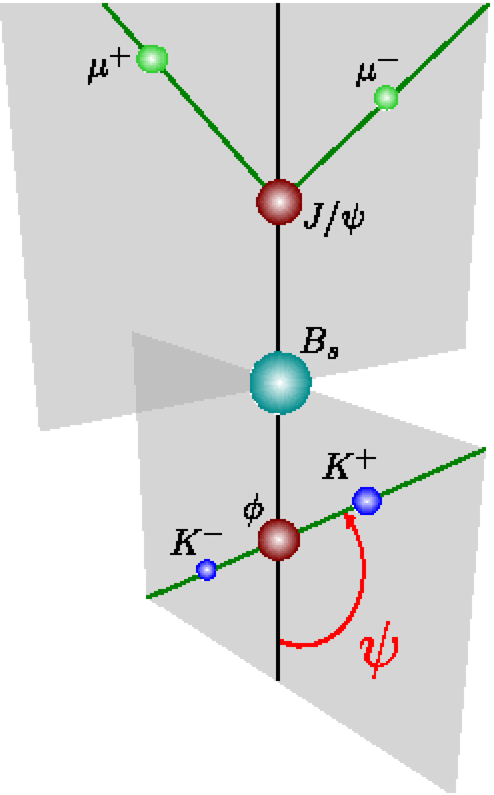

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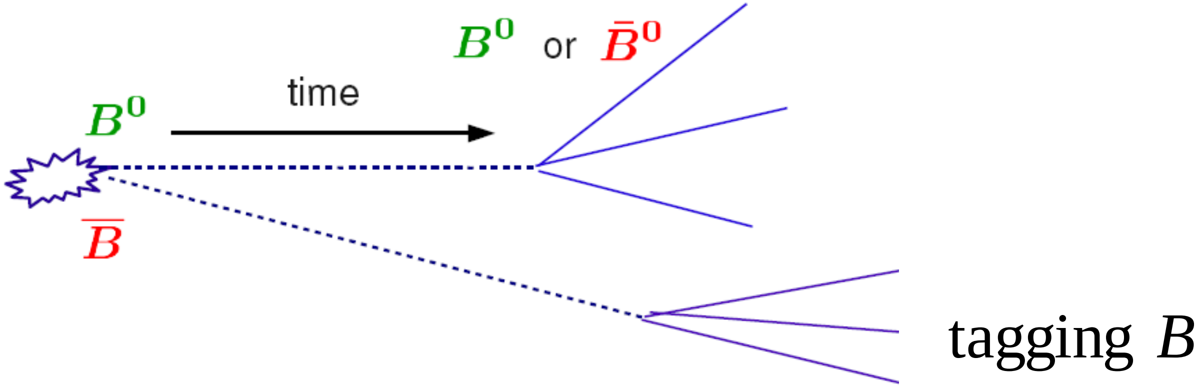
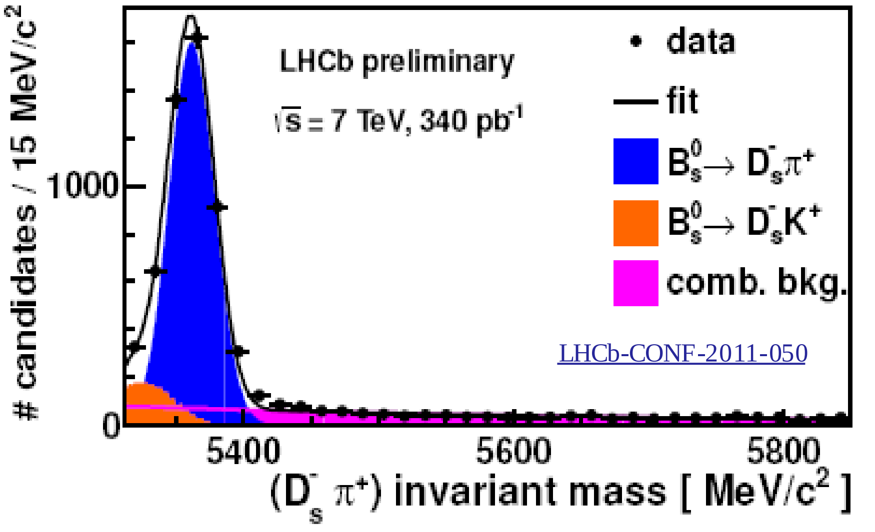


Intermezzo: Tagging with $B_s^0 \rightarrow D_s^- \pi^+$

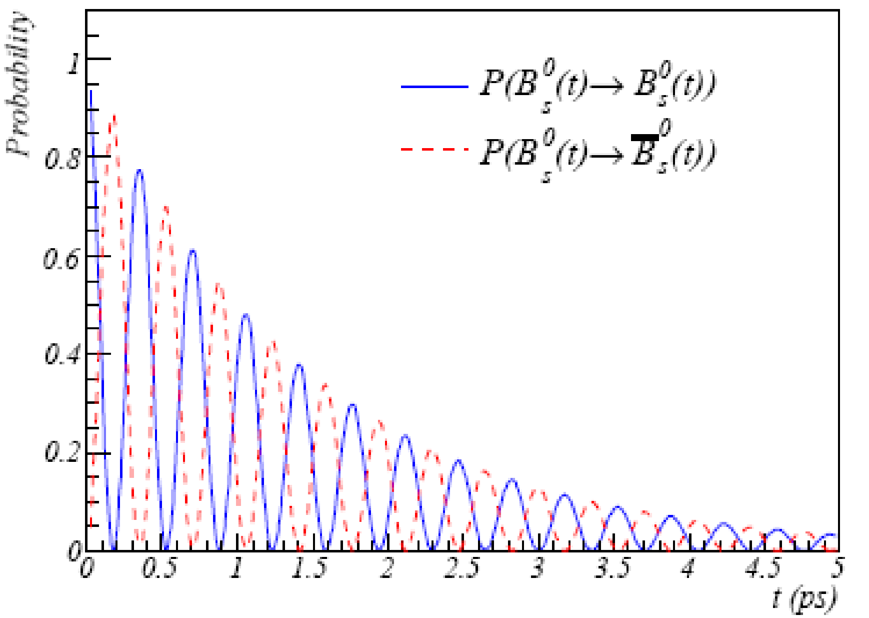
1) Need "flavour specific decay"
   - $N(B_s^0 \rightarrow D_s^- \pi^+) = 9189 \pm 147$

2) B_s oscillates fast
   - $B_s^0 \rightarrow D_s^- \pi^+$ or $B_s^0 \rightarrow \bar{B}_s^0 \rightarrow D_s^+ \pi^-$

3) Need good proper time resolution



- ε: tagging efficiency
- ω : wrong tag fraction
- $\varepsilon(1-2\omega)^2$: tagging power



$$A_{mix} = \left(N(B \rightarrow B) - N(B \rightarrow \bar{B})\right) / \left(N(B \rightarrow B) + N(B \rightarrow \bar{B})\right)$$

$$A_{mix} = (1-2\omega) \cos \Delta m_s t$$

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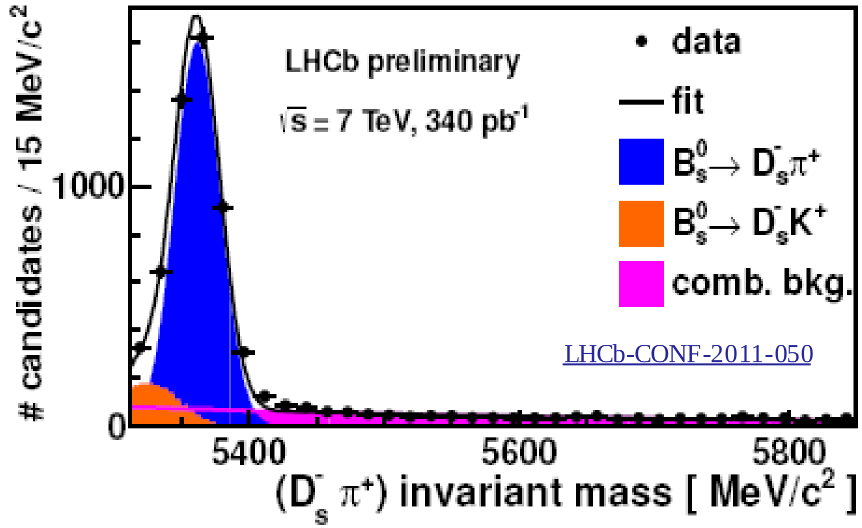

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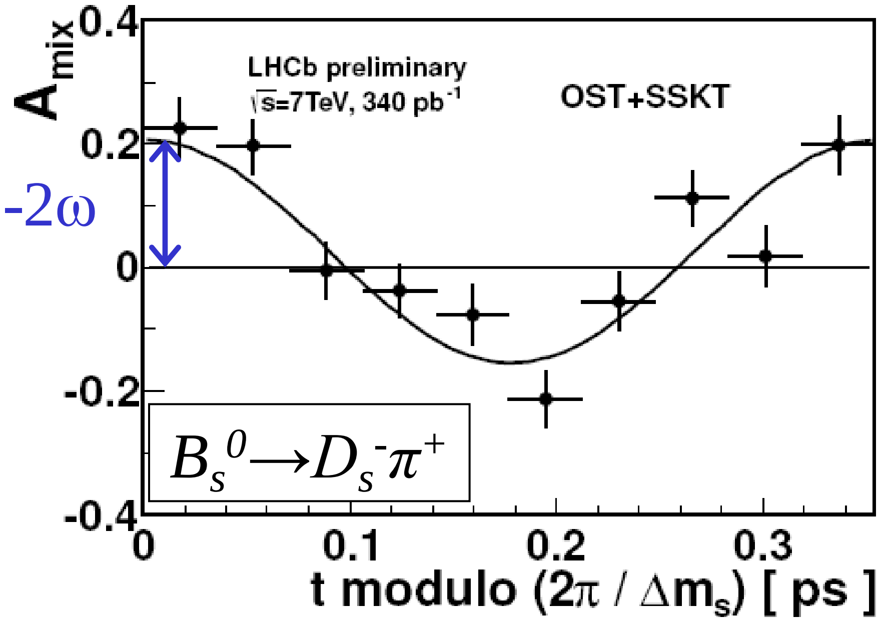

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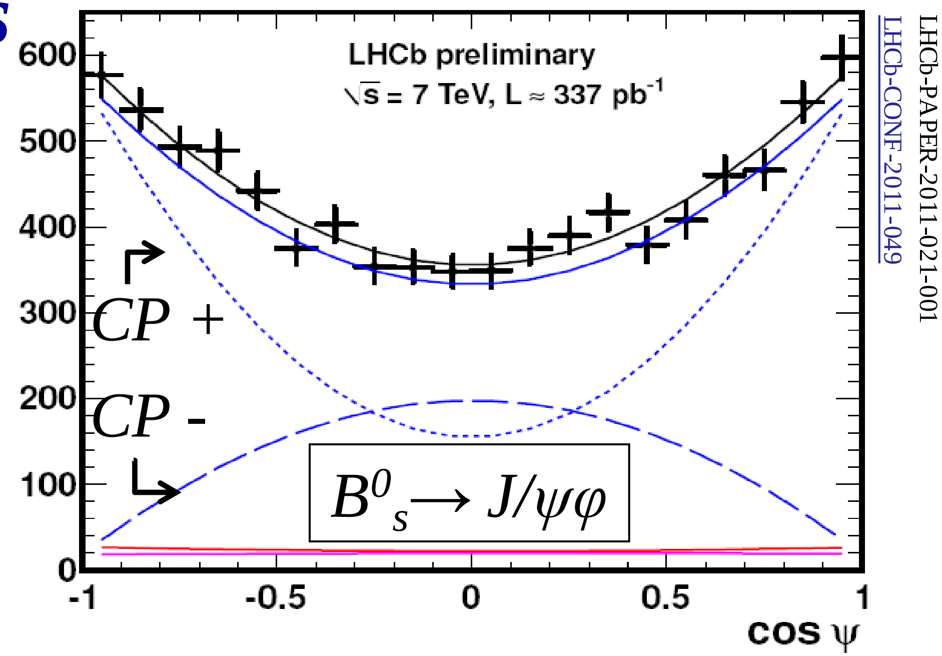
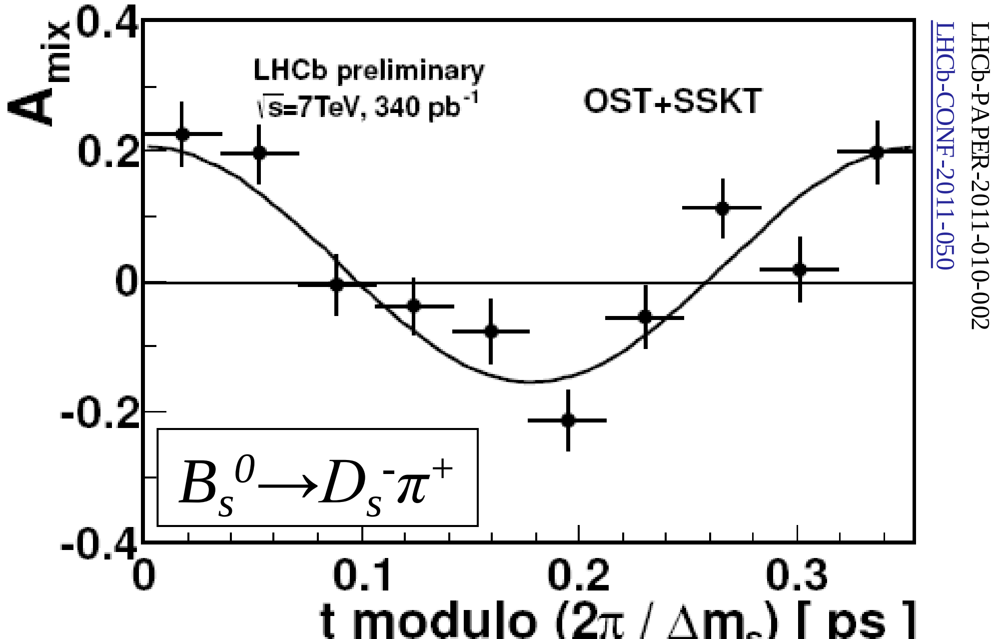
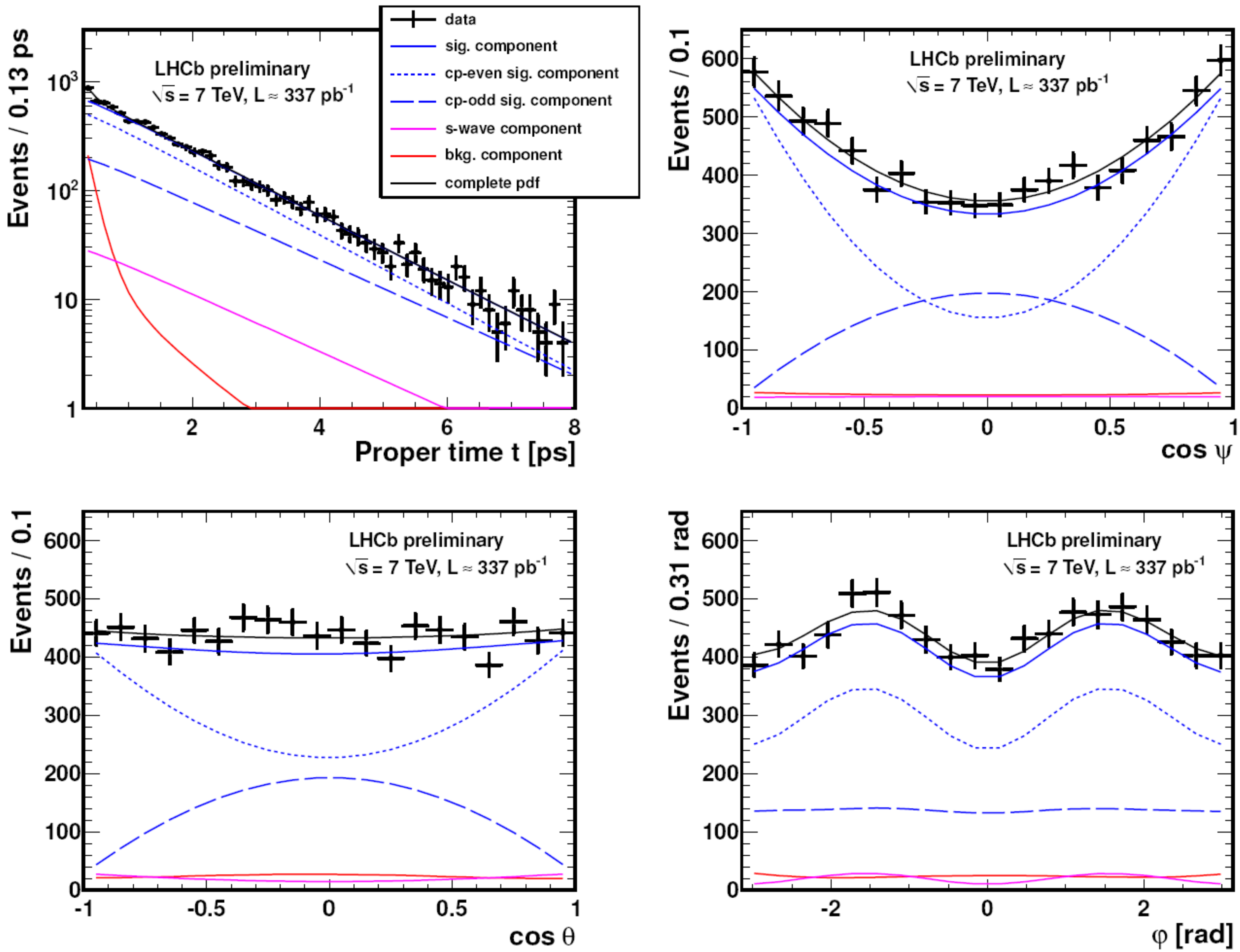


- Flavour tagging
  - $\omega = 36\%$
  - $\varepsilon D^2 = 3.1 \pm 0.8\%$
- PDG: $\Delta m_s = 17.77 \pm 0.120$ ps^{-1}
- **LHCb: $\Delta m_s = 17.725 \pm 0.041 \pm 0.025$ ps^{-1}** (preliminary)

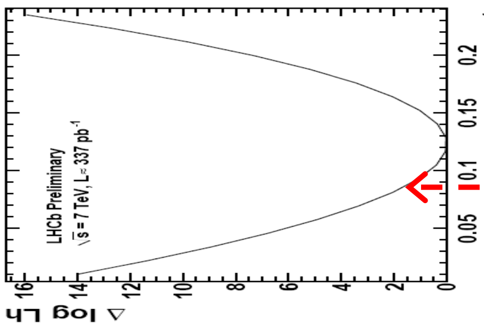


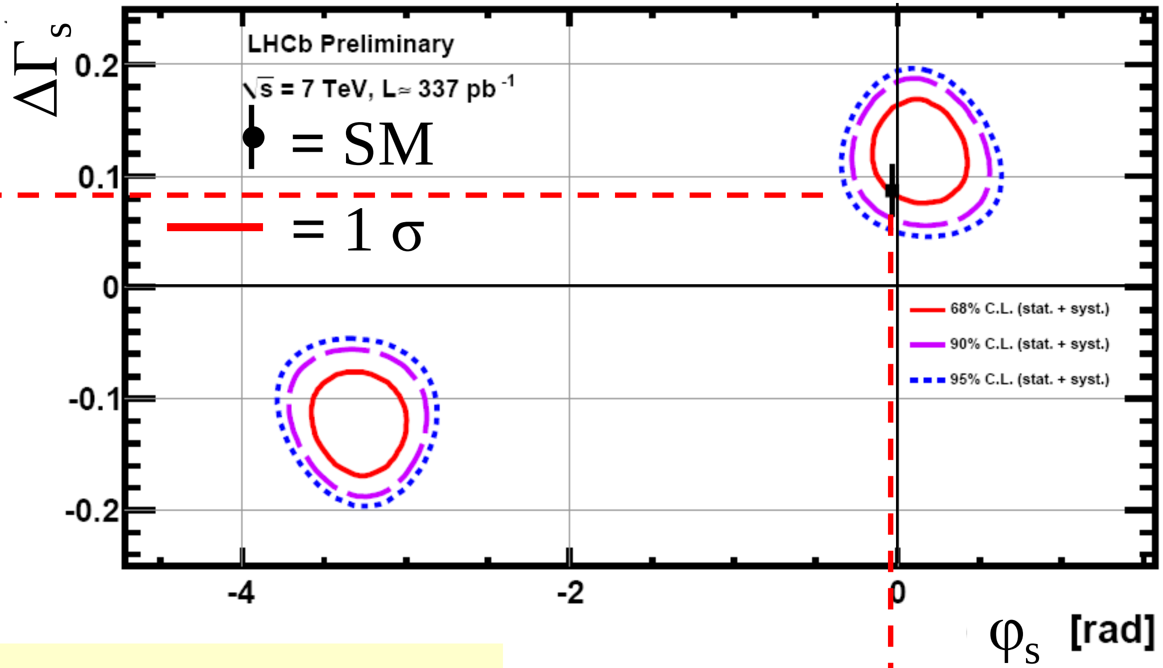
$B^0_s \to J/\psi\varphi$: Angular Analysis



$B^0_s \to J/\psi\varphi$: Results

LHCb-CONF-2011-049



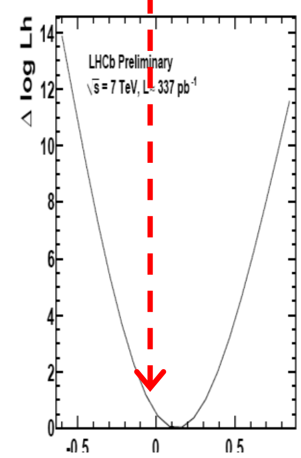


- Most precise value of φ_s!

$\varphi_s = 0.13 \pm 0.18(\text{stat}) \pm 0.07(\text{sys})$ rad (preliminary)

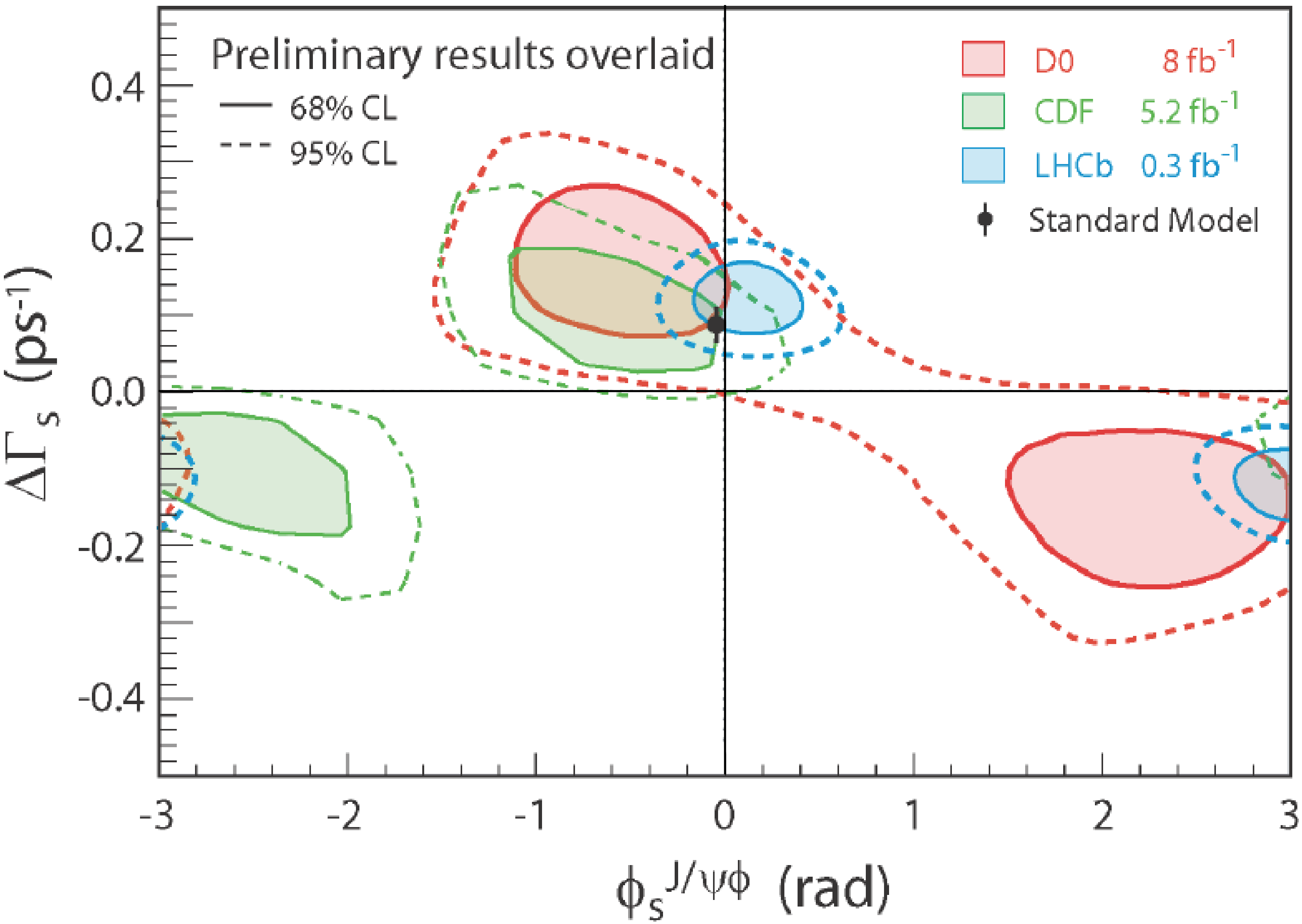
- Consistent with SM: $\varphi_s = -0.03$

$\Delta\Gamma_s = 0.123 \pm 0.029(\text{stat}) \pm 0.008(\text{sys})\ \text{ps}^{-1}$



CDF: $\Gamma_s = 0.076 \pm 0.059(\text{stat}) \pm 0.006(\text{sys})\ \text{ps}^{-1}$
D0: $\Gamma_s = 0.19 \pm 0.07\ (\text{stat}) \pm 0.015(\text{sys})\ \text{ps}^{-1}$

$B^0_s \to J/\psi\varphi$: Comparison



Sub-Summary

1) $B^0_s \rightarrow J/\psi\varphi$

2) $B^0 \rightarrow K^*\mu\mu$

3) $B^0_s \rightarrow \mu\mu$

- Most precise measurement of φ_s
- **φ_s=0.13 ± 0.18(stat) ± 0.07(sys) rad**
- Combine with $B^0_s \rightarrow J/\psi f_0$
  - *See talk from W. Hulsbergen today*

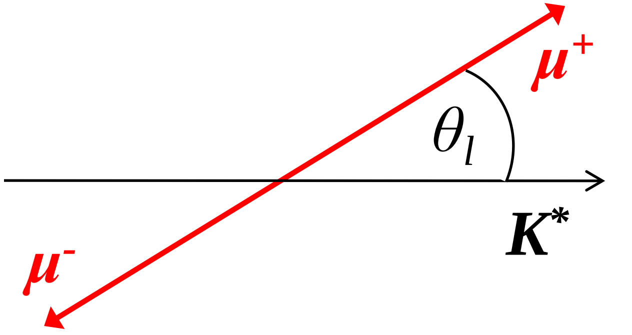
(preliminary)

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

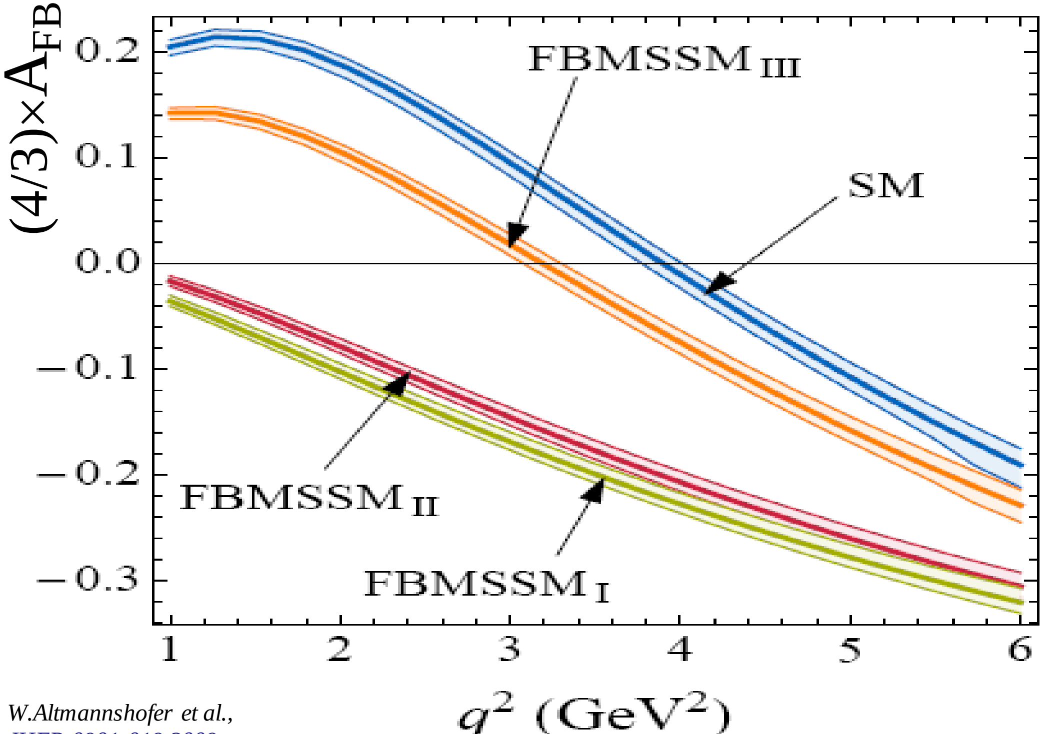
A.Ali, Th.Mannel, T.Morozumi
Phys.Lett. B273 (1991) 505-512

$B^0 \rightarrow K^*\mu\mu$: Motivation

- Hadronic uncertainties largely cancel in angular asymmetries
  - Forward-backward asymmetry A_{FB} easiest



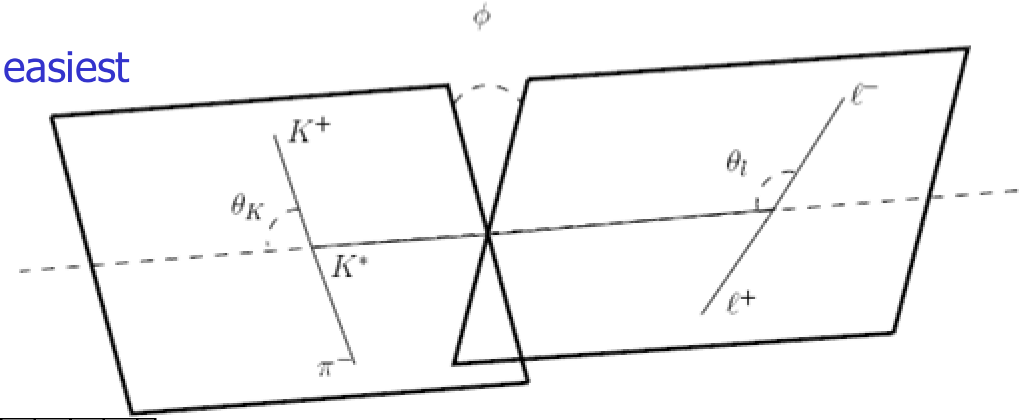
Example:



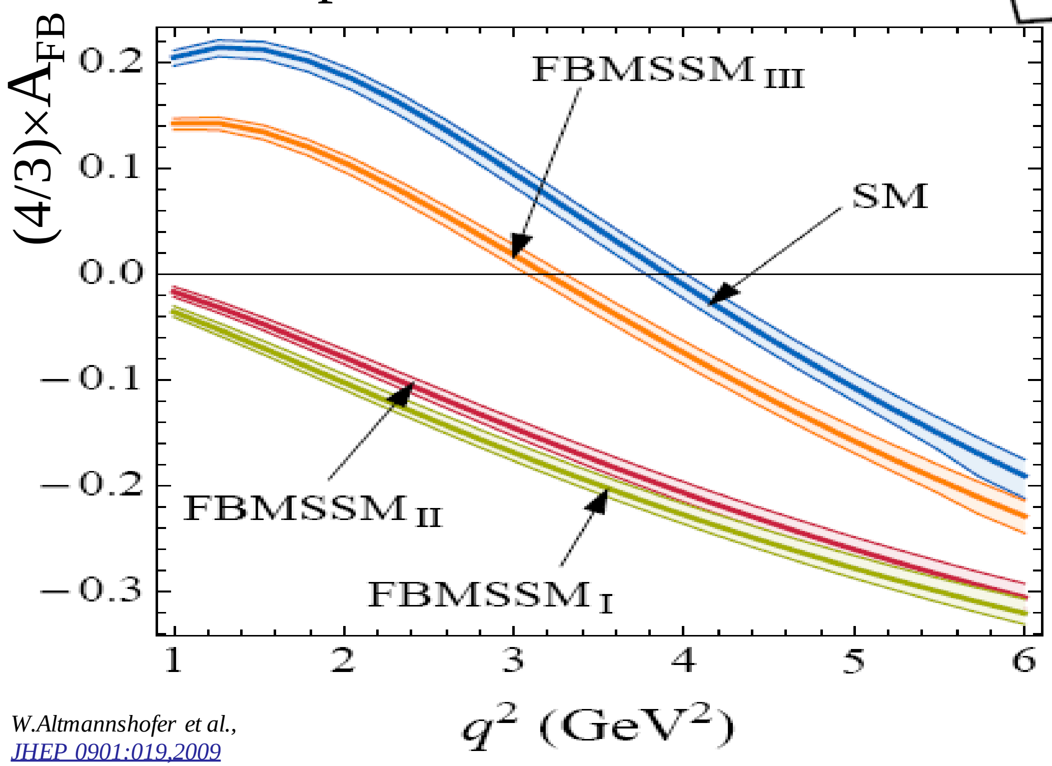
W.Altmannshofer et al.,
JHEP 0901:019,2009

$B^0 \rightarrow K^*\mu\mu$: Motivation

- Hadronic uncertainties largely cancel in angular asymmetries
  - Forward-backward asymmetry A_{FB} easiest



Example:

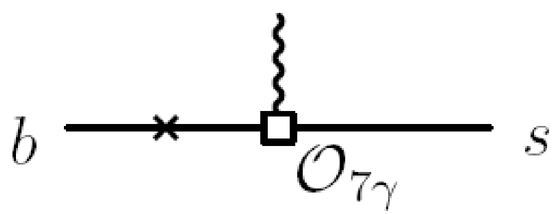


W.Altmannshofer et al.,
JHEP 0901:019,2009

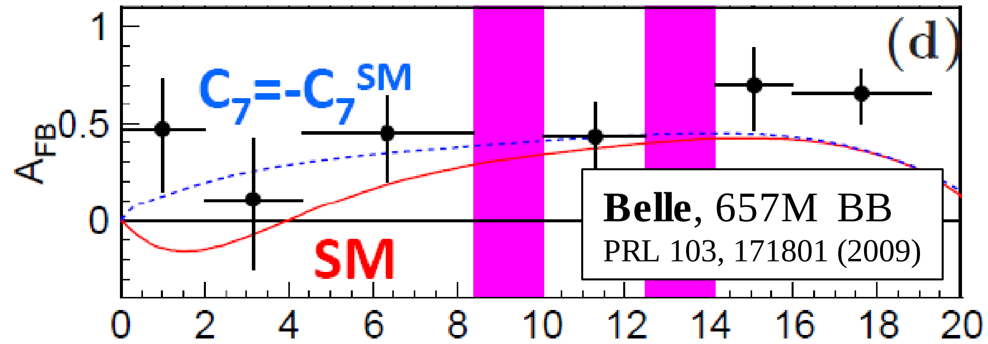
$B^0 \to K^* \mu\mu$: Status

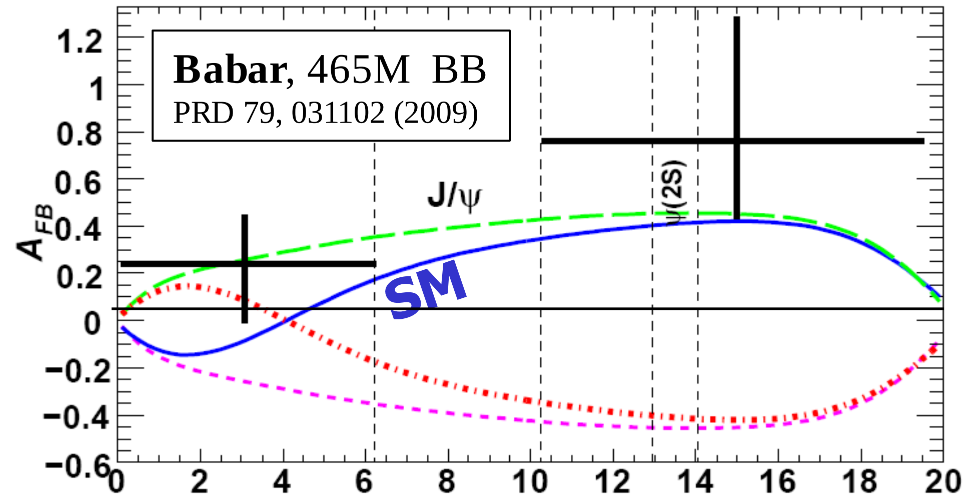
- A_{FB} measured at B-factories and CDF
- All opposite sign for A_{FB}?

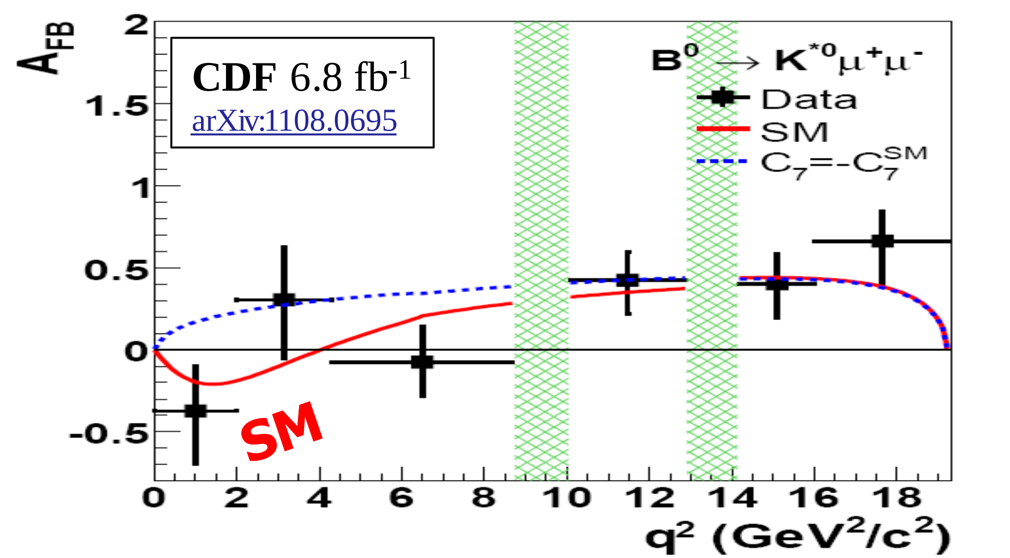
➢ Hint of deviation?



NB: *Size* of C_7 constrained by BR($B^0 \to K^* \gamma$) but not the *sign*.

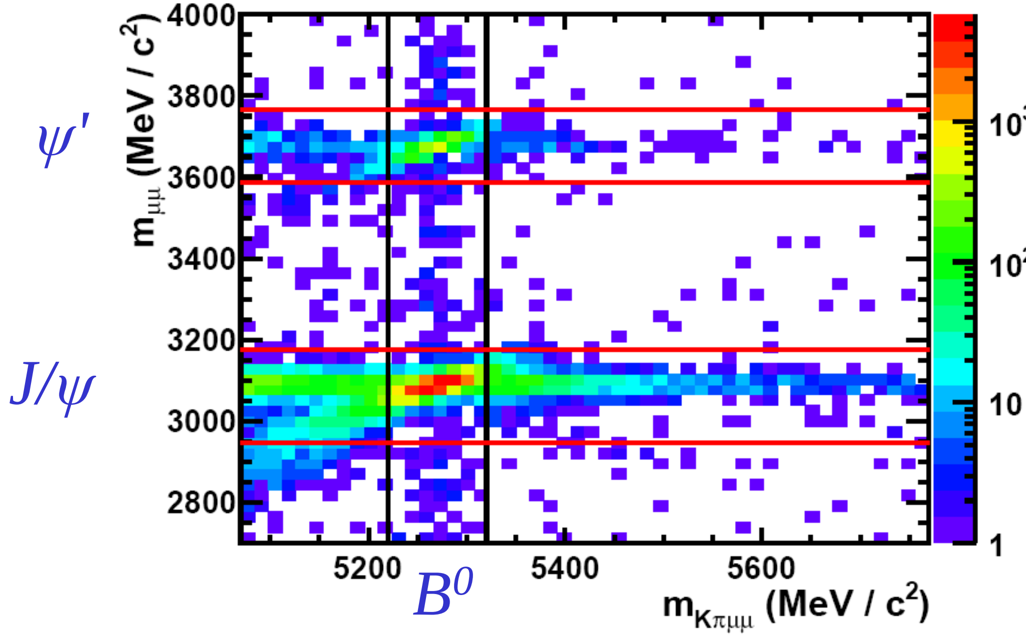


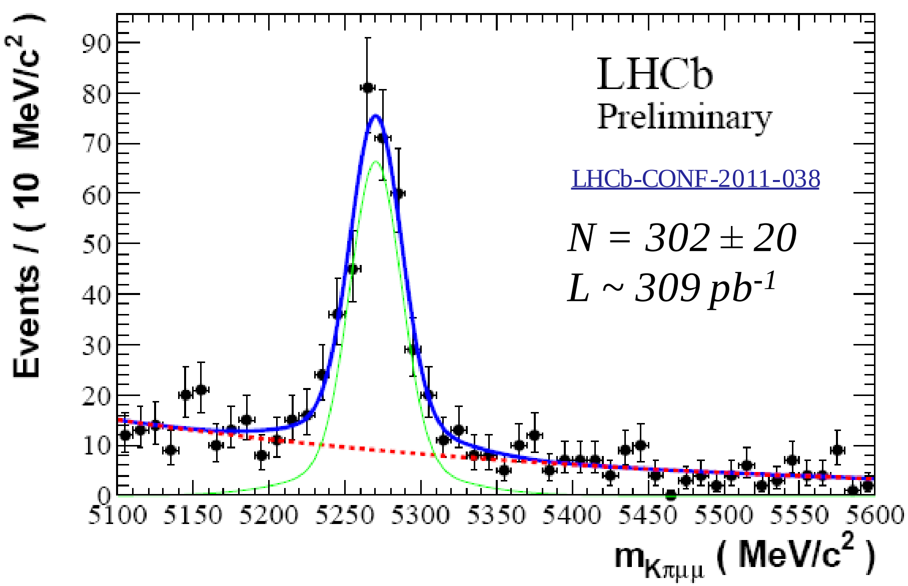




$B^0 \to K^* \mu\mu$: at LHCb

- Reject J/ψ and ψ' resonances
- Veto peaking backgrounds
- Select with boosted decision tree
  - *E.g.* B, J/ψ, K^* vtx, FD, IP, …
- ➢ N($B^0 \to K^* \mu\mu$) = 302 ± 20
  - Babar: 60
  - Belle: 247
  - CDF: 164

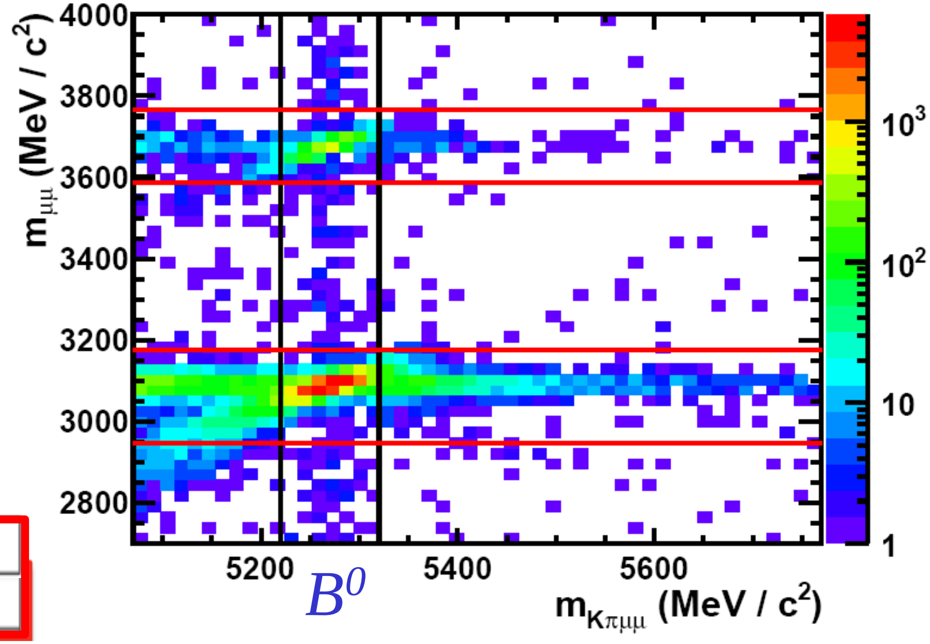


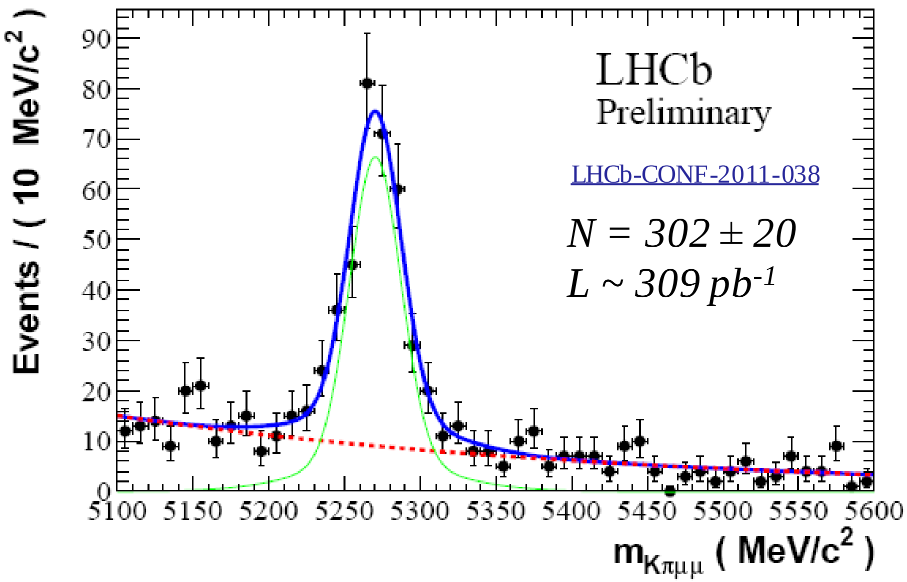


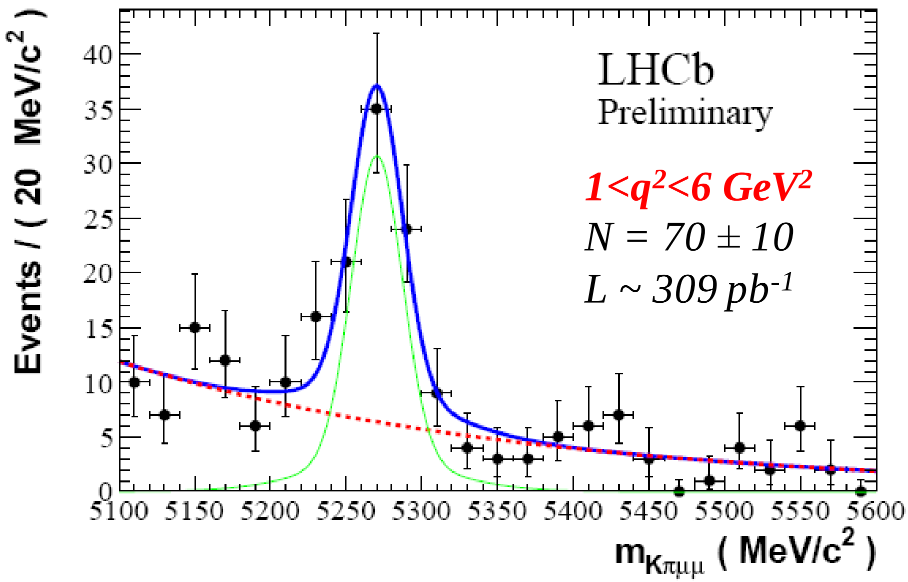
$B^0 \to K^* \mu\mu$: at LHCb

- Reject J/ψ and ψ' resonances
- Veto peaking backgrounds
- Select with boosted decision tree
  - *E.g.* B, J/ψ, K^* vtx, FD, IP, …
- ➢ N($B^0 \to K^* \mu\mu$) = 302 ± 20
  - Babar: 60
  - Belle: 247
  - CDF: 164

q^2 (GeV^2)	n_{sig}	n_{bkg}	significance (σ)	Belle
$1 < q^2 < 6\,\mathrm{GeV}^2$	70.0 ± 10.2	$32. \pm 3.2$	9.4	29.4







$B^0 \to K^* J/\psi$: Asymmetry

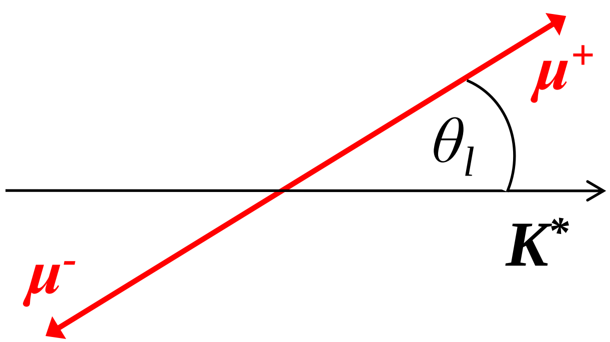
(preliminary)

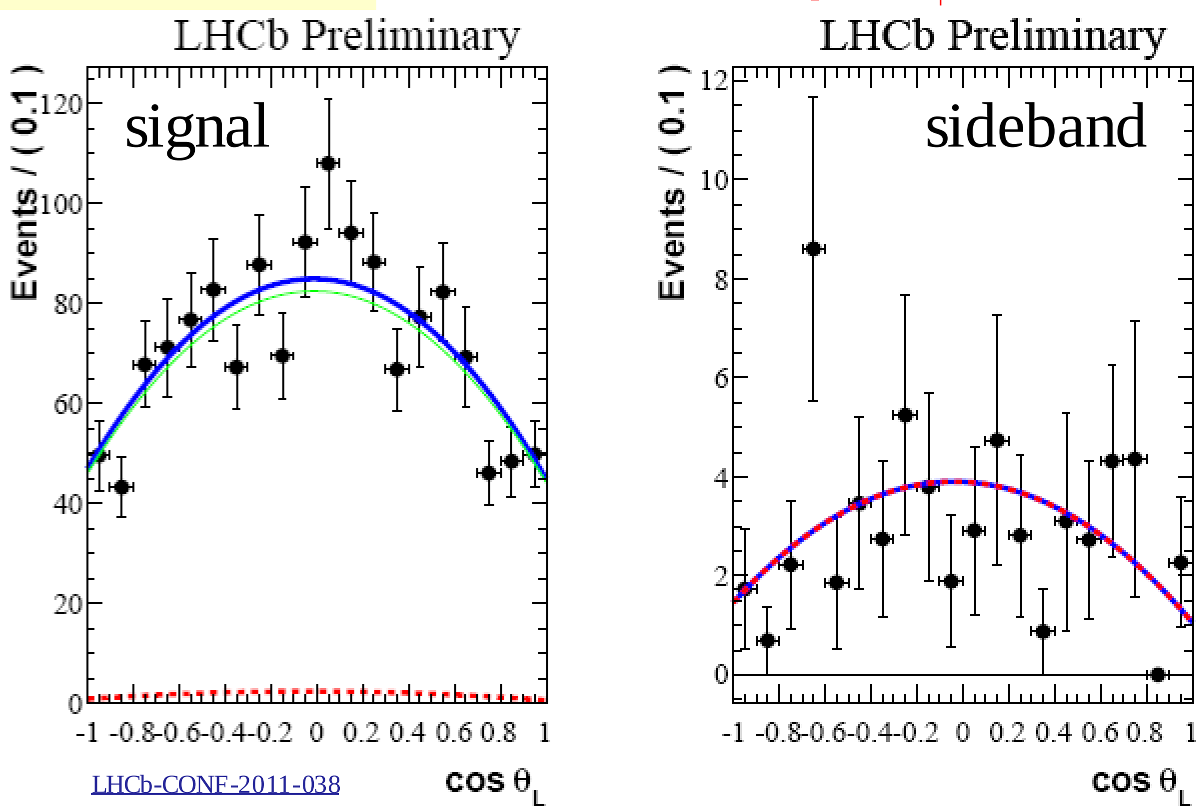
- Validate analysis on $B^0 \to K^* J/\psi$:
  - $F_L = 0.556 \pm 0.015$ (Babar: $0.556 \pm 0.009 \pm 0.010$)
  - $A_{FB} = -0.006 \pm 0.008$

BaBar, PRD 79, 031102 (2009)

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_\ell\, dq^2} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

NB: $q^2 = m_{J/\psi}^2 = 9.6\ \text{GeV}^2$





LHCb-CONF-2011-038

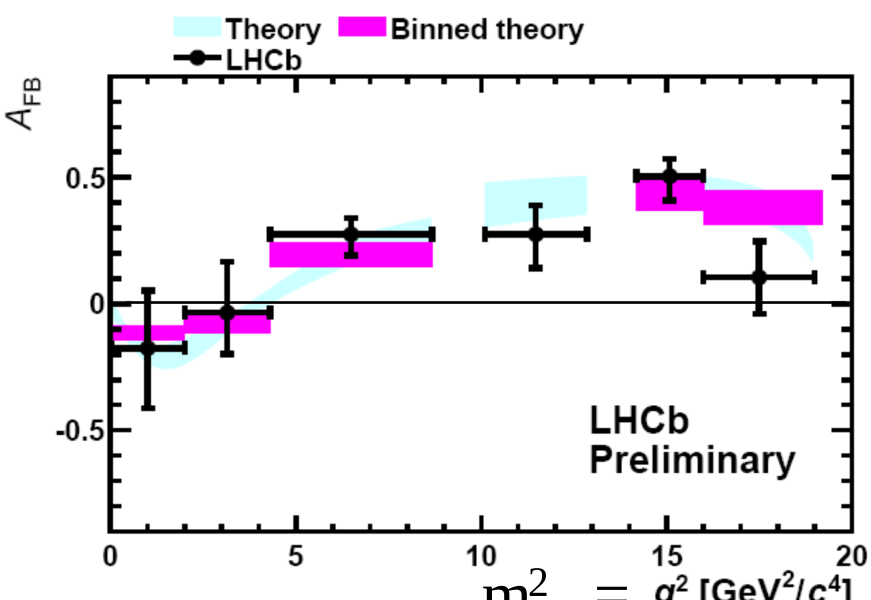
$B^0 \to K^* \mu\mu$: Asymmetry

Ch.Bobeth,G.Hiller,D.van Dyk
JHEP 1107:067,2011

- Validate analysis on $B^0 \to K^* J/\psi$:
  - F_L = 0.556±0.015 (Babar: 0.556±0.009±0.010)
  - A_{FB} = -0.006±0.008

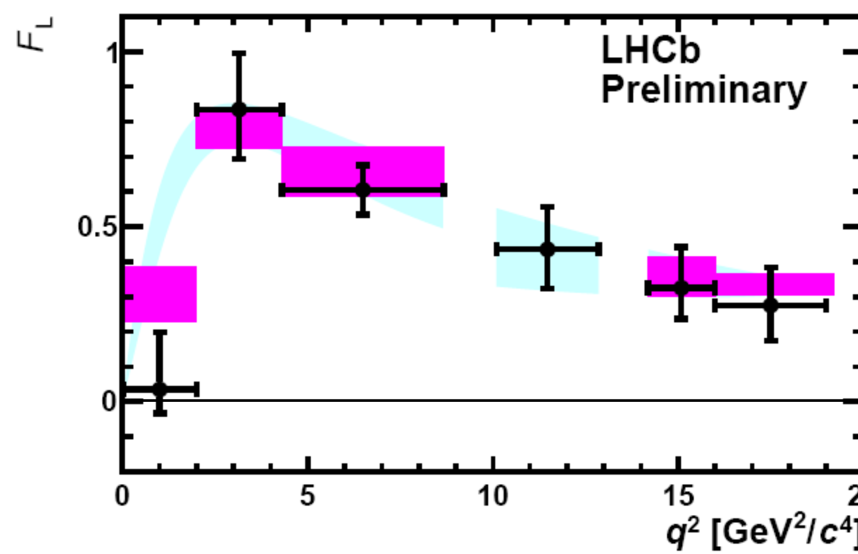
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_\ell\, dq^2} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

- Measure A_{FB} and F_L in bins of q^2
- Event-by-event acceptance correction

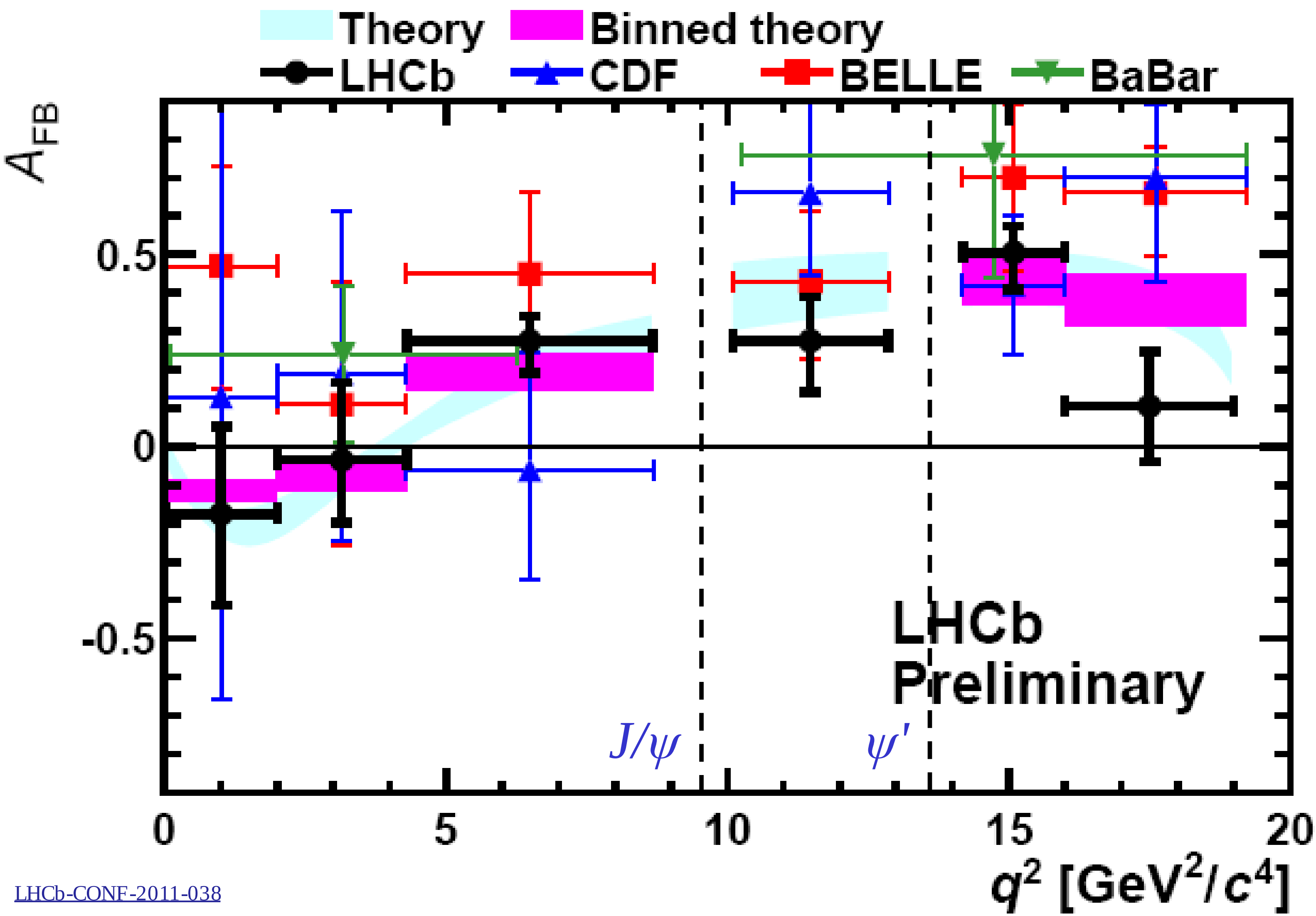


$m^2_{\mu\mu} = q^2$

LHCb-CONF-2011-038



$B^0 \to K^*\mu\mu$: Comparison



LHCb LHCb-CONF-2011-038

Belle, PRL 103, 171801 (2009)

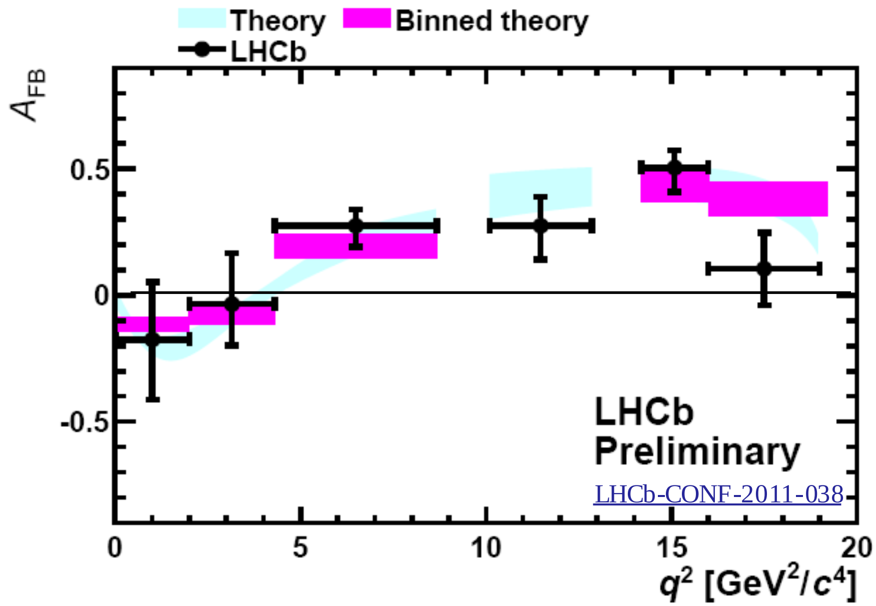
Babar, PRD 79, 031102 (2009)

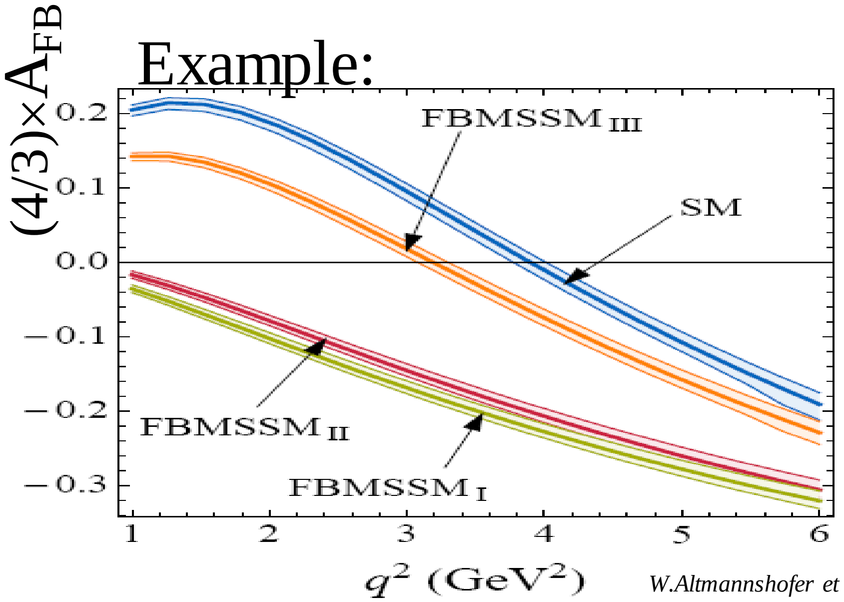
CDF, PRL 106, (2011)

Ch.Bobeth,G.Hiller,D.van Dyk
JHEP 1107:067,2011

$B^0 \to K^* \mu\mu$: Asymmetry

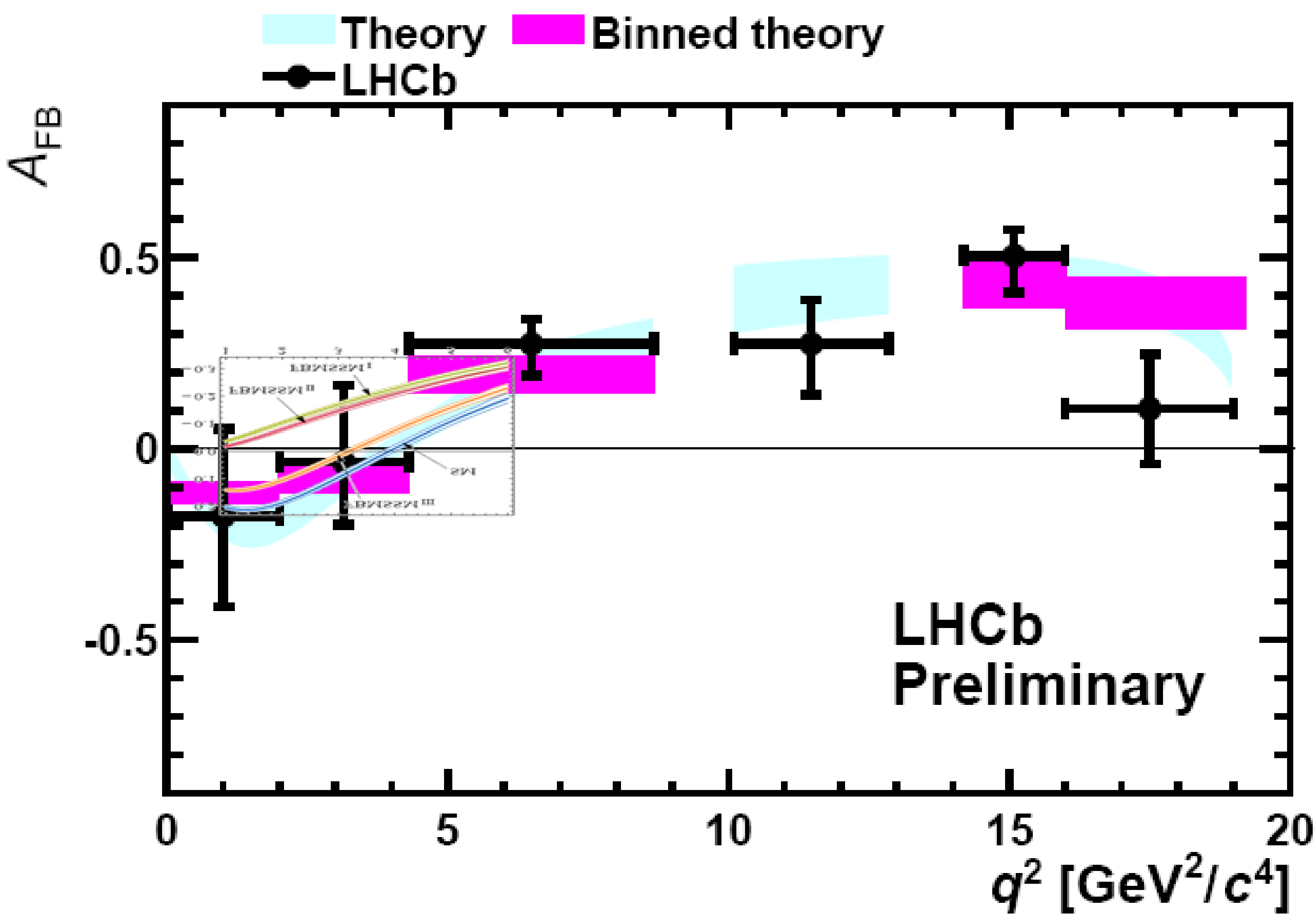
- Still limited statistics
- Good agreement with SM





W.Altmannshofer et al.,
JHEP 0901:019,2009

$B^0 \to K^*\mu\mu$: Comparison



Sub-Summary

1) $B^0_s \rightarrow J/\psi\varphi$

2) $B^0 \rightarrow K^*\mu\mu$

3) $B^0_s \rightarrow \mu\mu$

- Most precise measurement of A_{FB}
  - *Zero-crossing point is next*
- Still limited statistical precision
  - *3x more data on tape*
- More angular observables available

$$A_T^{(1)} = \frac{\Gamma_- - \Gamma_+}{\text{[illegible]}} = \frac{-2\mathrm{Re}(A_\parallel A_\perp^*)}{\text{[illegible]} + |A_\parallel|^2}$$

$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_\parallel|^2}{\text{[illegible]}}$$

$$A_T^{(3)} = \frac{|A_{0L}A_{\parallel L}^* + A_{0R}^* A_{\parallel R}|}{\text{[illegible]}}$$

$$A_T^{(4)} = \frac{|A_{0L}A_{\perp L}^* - A_{0R}^* A_{\perp R}|}{|A_{0L}^* A_{\parallel L} + A_{0R}A_{\parallel R}^*|}$$

U.Egede at al
JHEP 0811:032,2008

$B^0_s \rightarrow \mu\mu$

$B^0_s \to \mu\mu$: Motivation

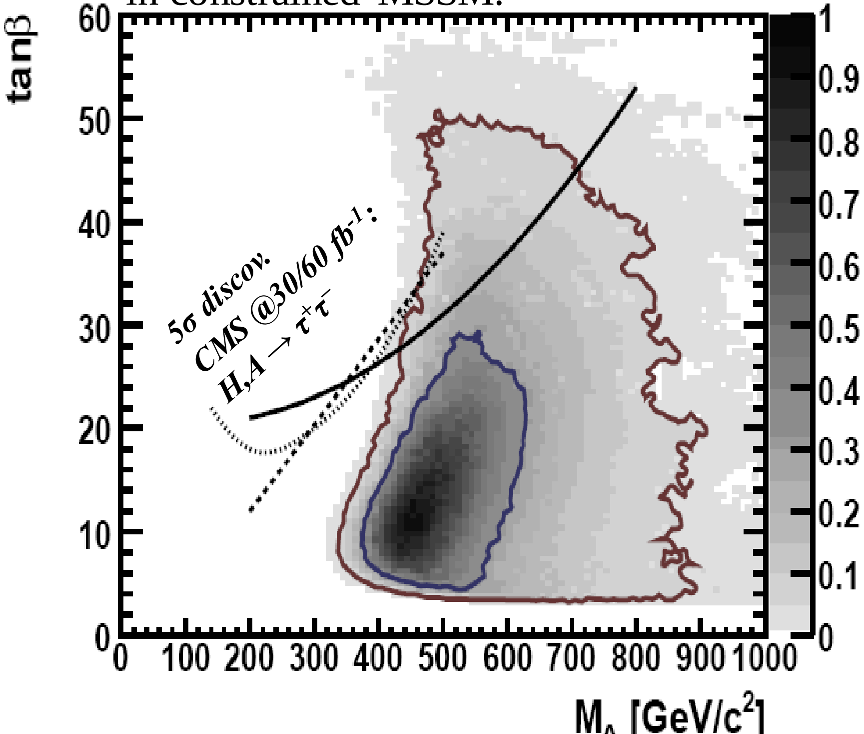
- Branching Ratio very sensitive to NP models

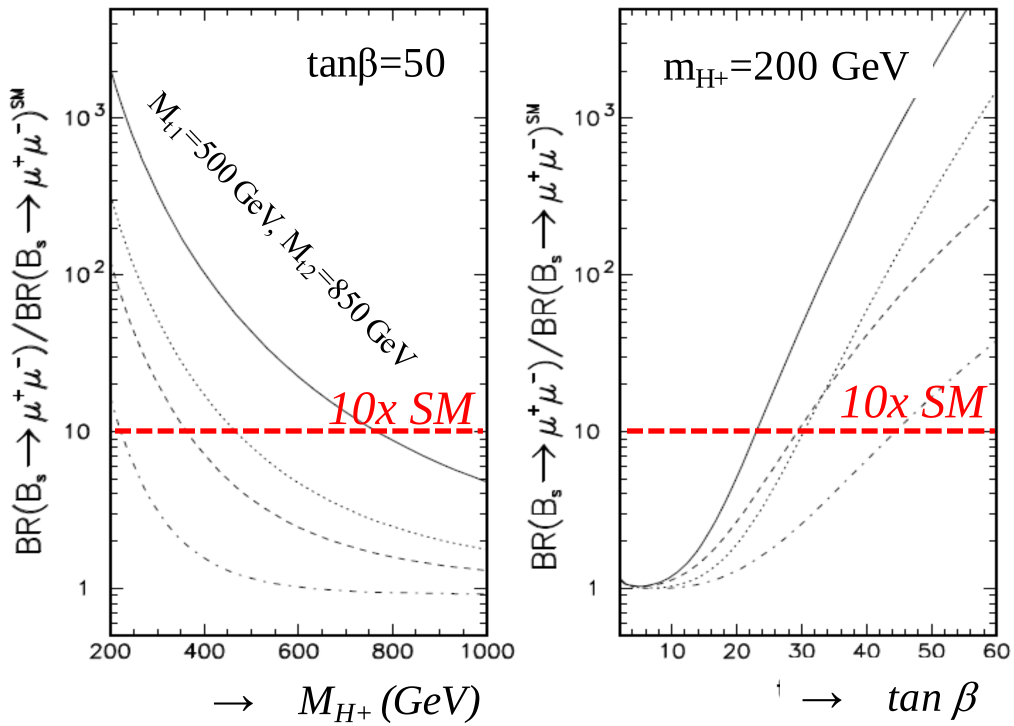
$$\mathrm{Br}(B_s \to \mu^+\mu^-)_{\mathrm{SM}} = (3.2 \pm 0.2) \times 10^{-9}$$

A.Buras, G.Isidori, P.Paradisi
Phys.Lett.B694:402-409,2011

- BR strongly enhanced in MSSM at large tanβ: $\propto \tan^6\beta / m_A^4$
  - Example: 10x higher BR for tanβ=50(20), m_{H+}=800(200) GeV

Allowed parameter space from fit in constrained MSSM:





O.Buchmueller et al. Eur.Phys.J.C64:391-415,2009

(Direct limits at CMS: Gennai et al. Eur.Phys.J.C52:383-395,2007)

A.Buras et al., Nucl.Phys.B659:3,2003

$B^0_s \to \mu\mu$: Motivation

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A.Buras, G.Isidori, P.Paradisi
Phys.Lett.B694:402-409,2011

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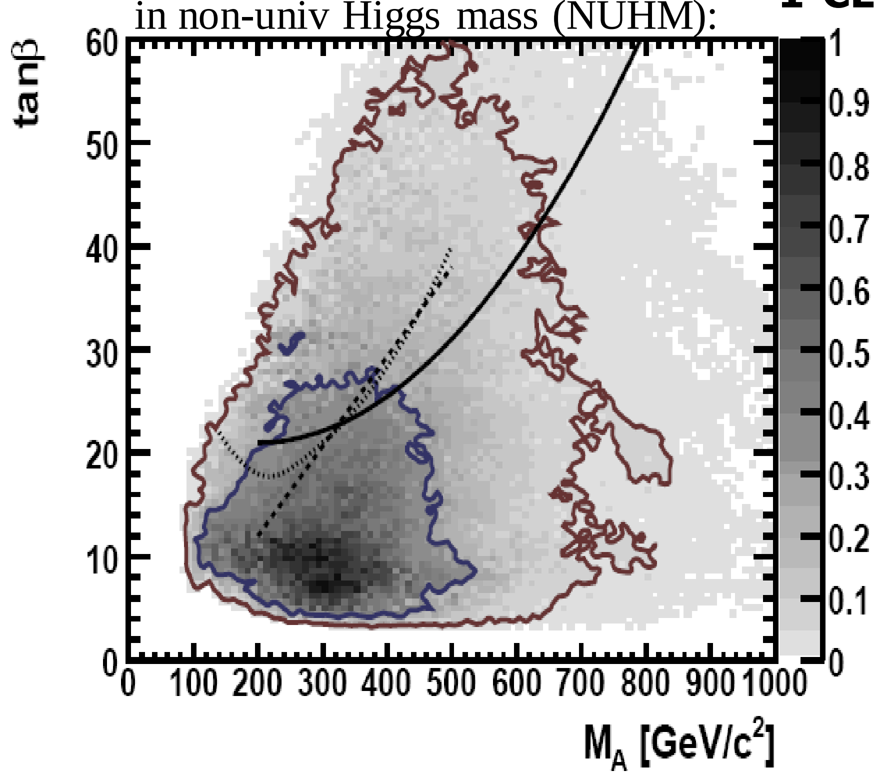
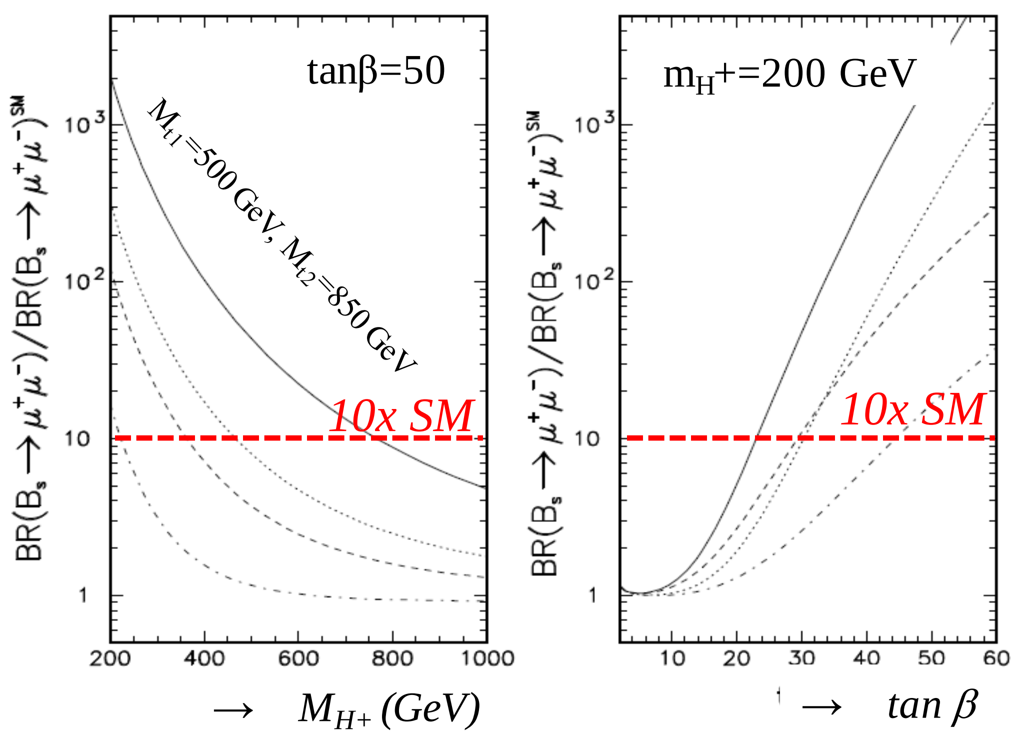
  - Example: 10x higher BR for $\tan\beta$=50(20), m_{H+}=800(200) GeV

Allowed parameter space from fit in non-univ Higgs mass (NUHM):





O.Buchmueller et al. Eur.Phys.J.C64:391-415,2009

A.Buras et al., Nucl.Phys.B659:3,2003

$B^0_s \to \mu\mu$: *Motivation*

- Branching Ratio very sensitive to NP models

$$\mathrm{Br}(B_s \to \mu^+\mu^-)_{\mathrm{SM}} = (3.2 \pm 0.2) \times 10^{-9}$$

A.Buras, G.Isidori, P.Paradisi
Phys.Lett.B694:402-409,2011

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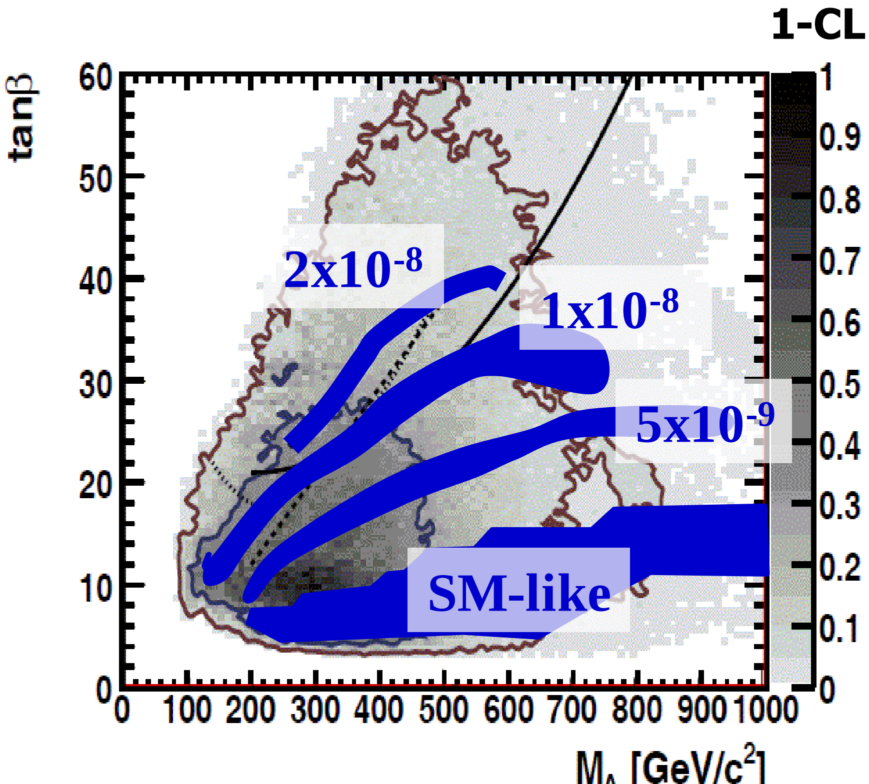
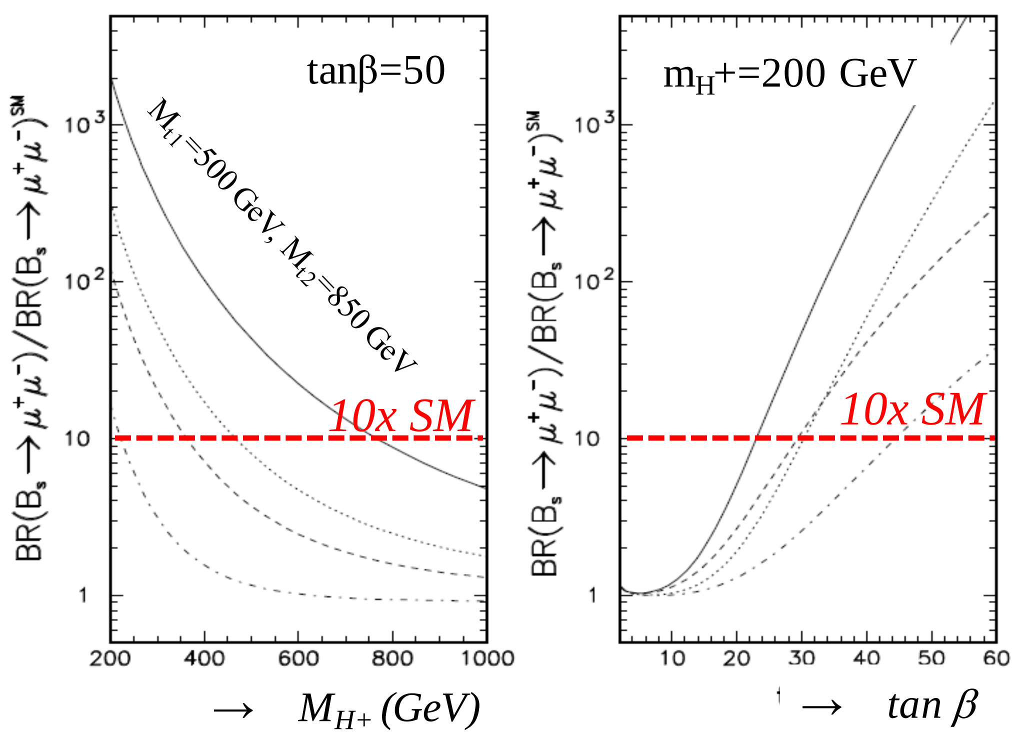
  - Example: 10x higher BR for tanβ=50(20), m_{H+}=800(200) GeV

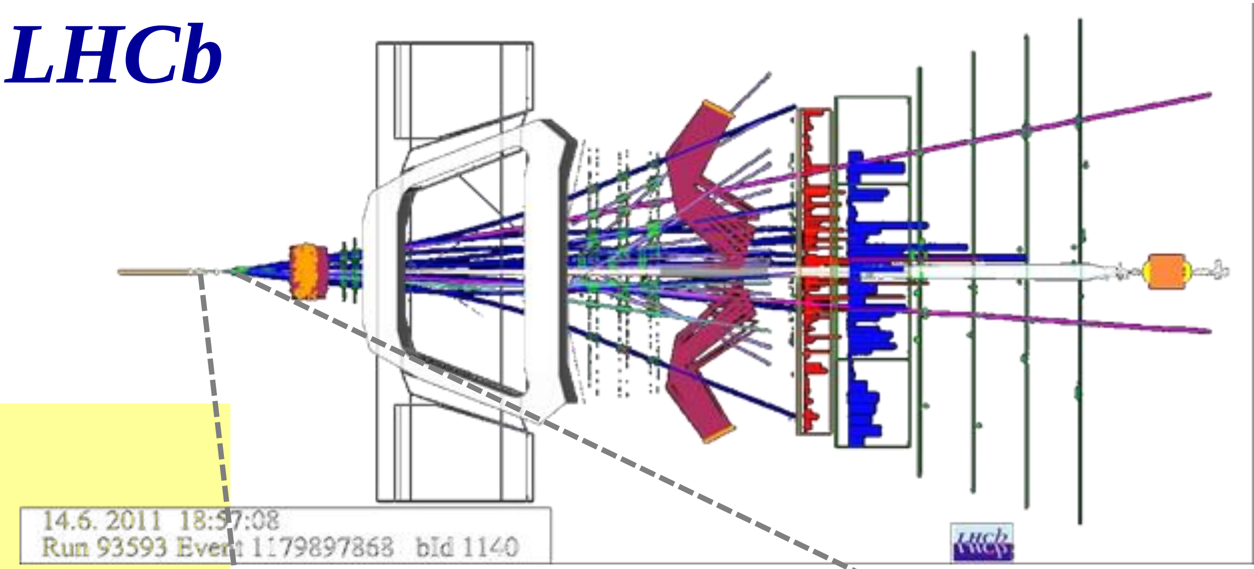




Curves obtained through SuperIso, (eg. F.Mahmoudi, arXiv:0906.0369)

A.Buras et al., Nucl.Phys.B659:3,2003

$B^0_s \to \mu\mu$: at LHCb

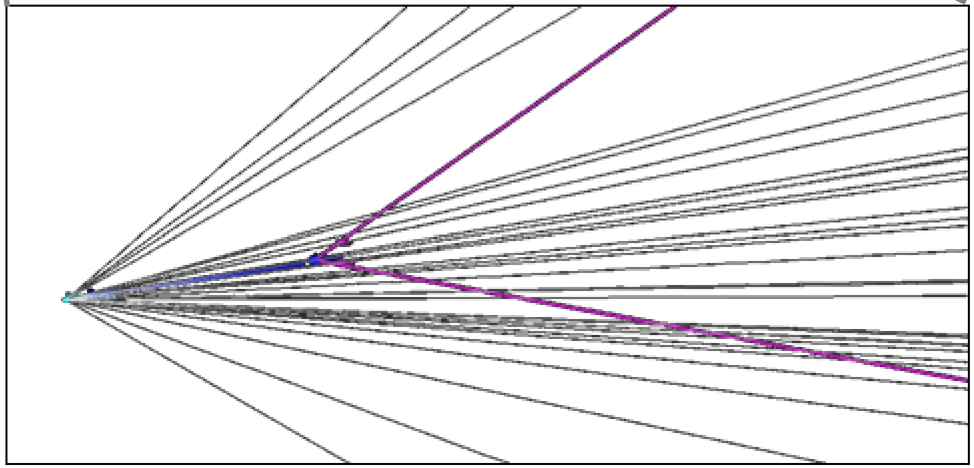


Analysis based on

1) Mass

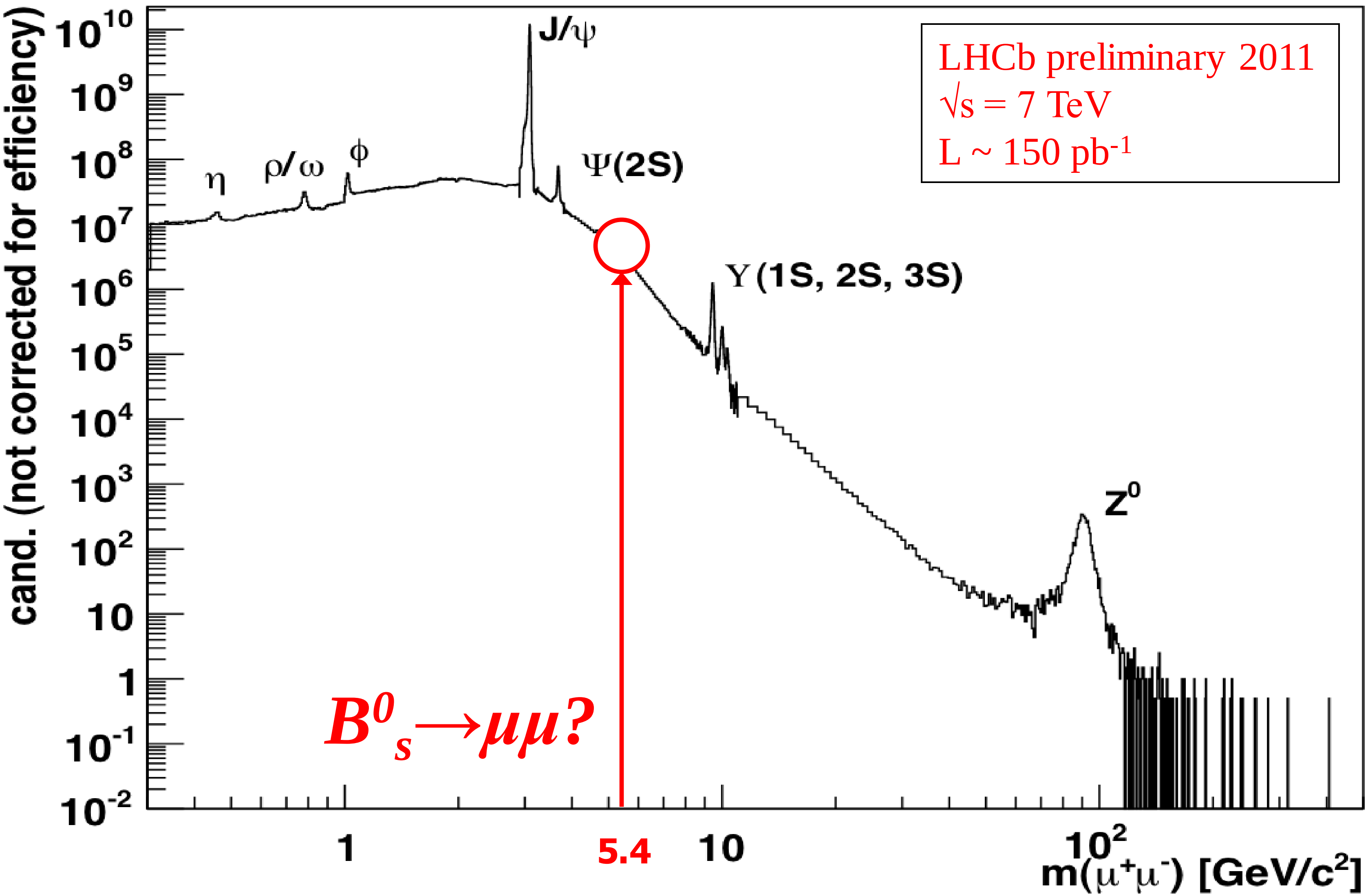
2) Kinematic / geometrical
(eg. τ_B, IP_B, IPS_μ, DOCA, isolation, …)

➢ Compare observed to expectation

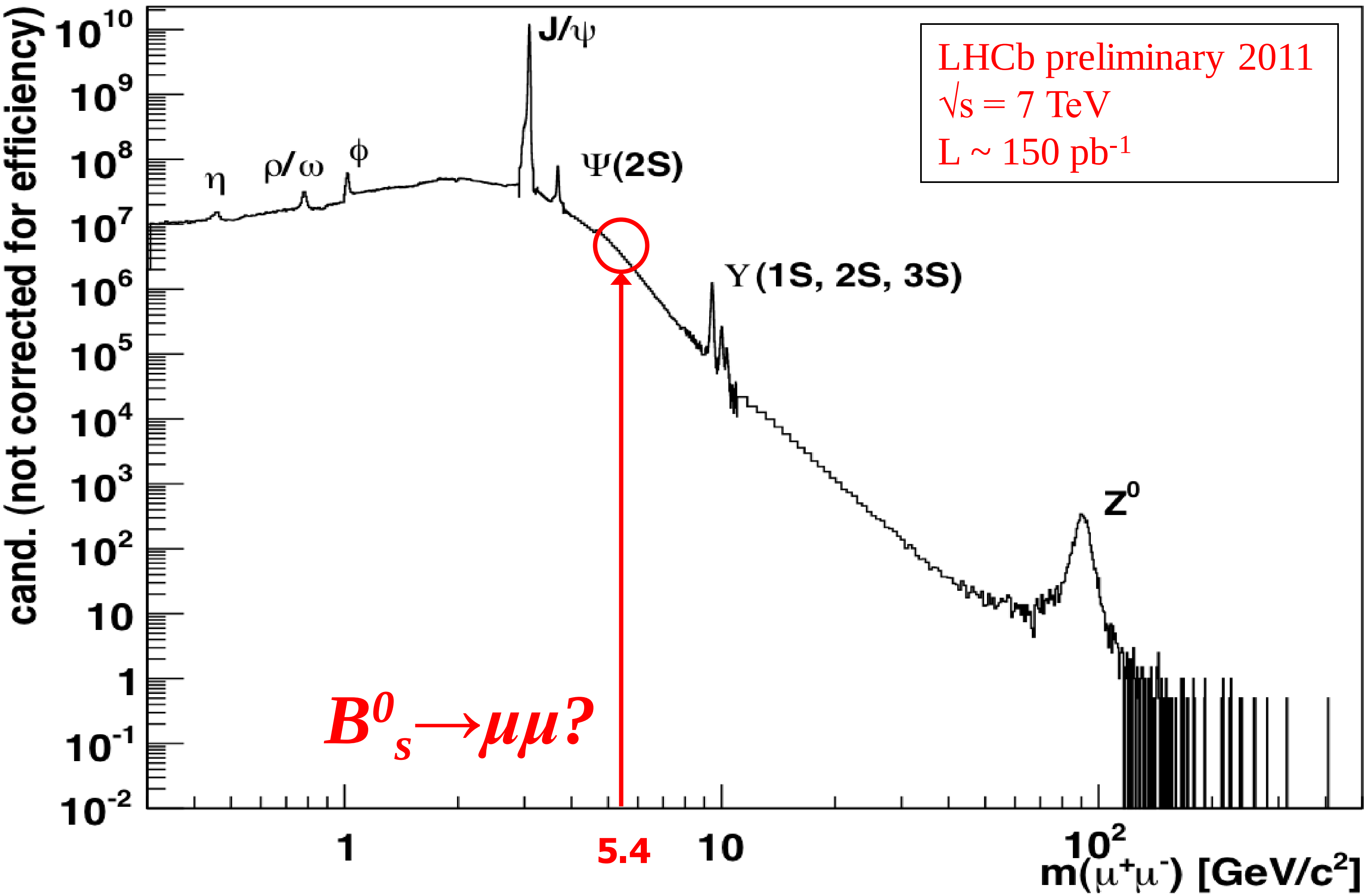


Candidate $B^0_s \to \mu\mu$ event, 14 June 2011

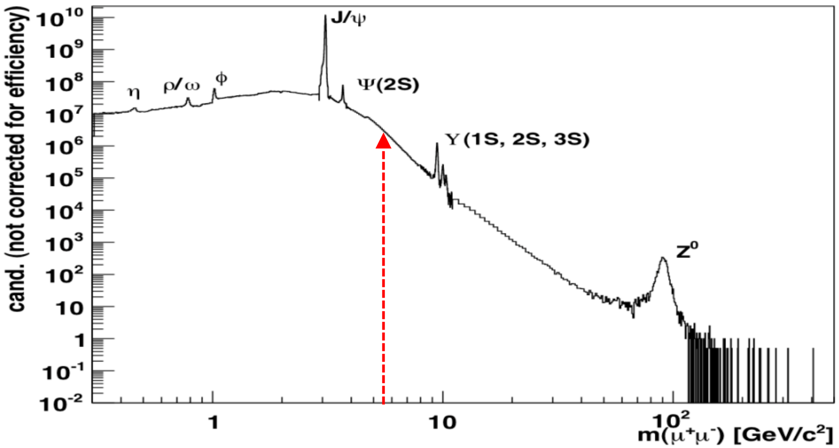
$B^0_s \to \mu\mu$: mass



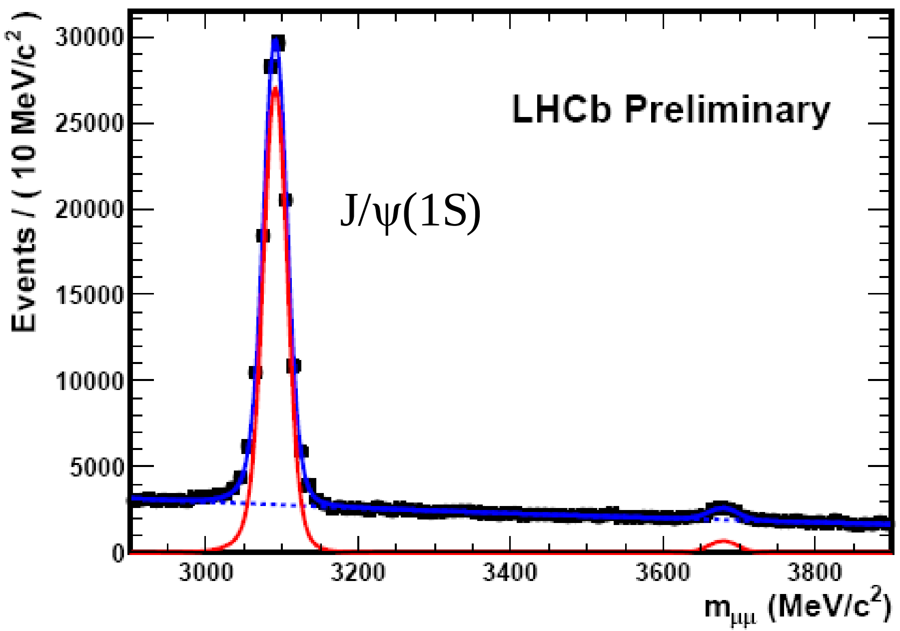
$B^0_s \to \mu\mu$: mass

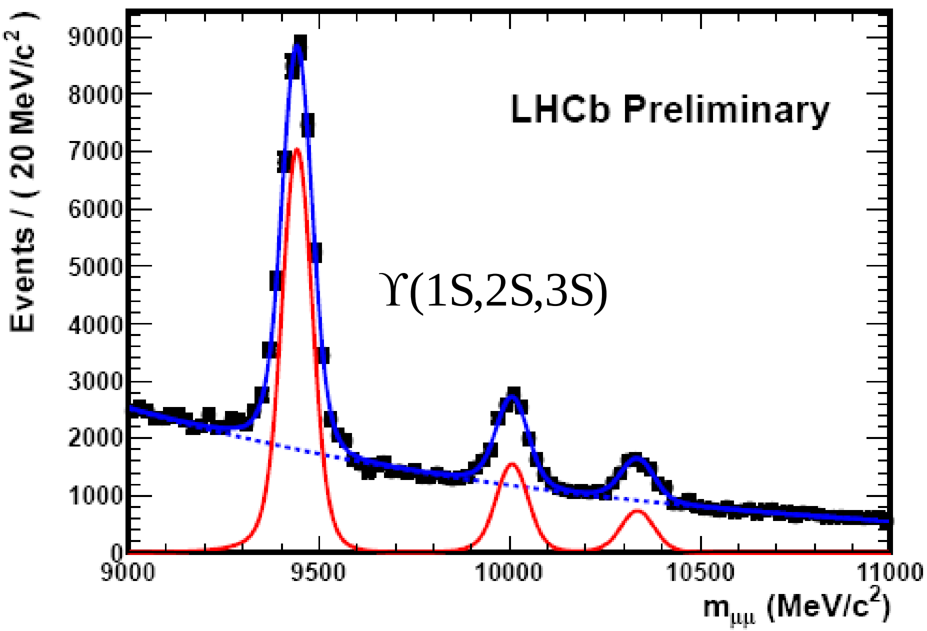


$B^0_s \to \mu\mu$: mass

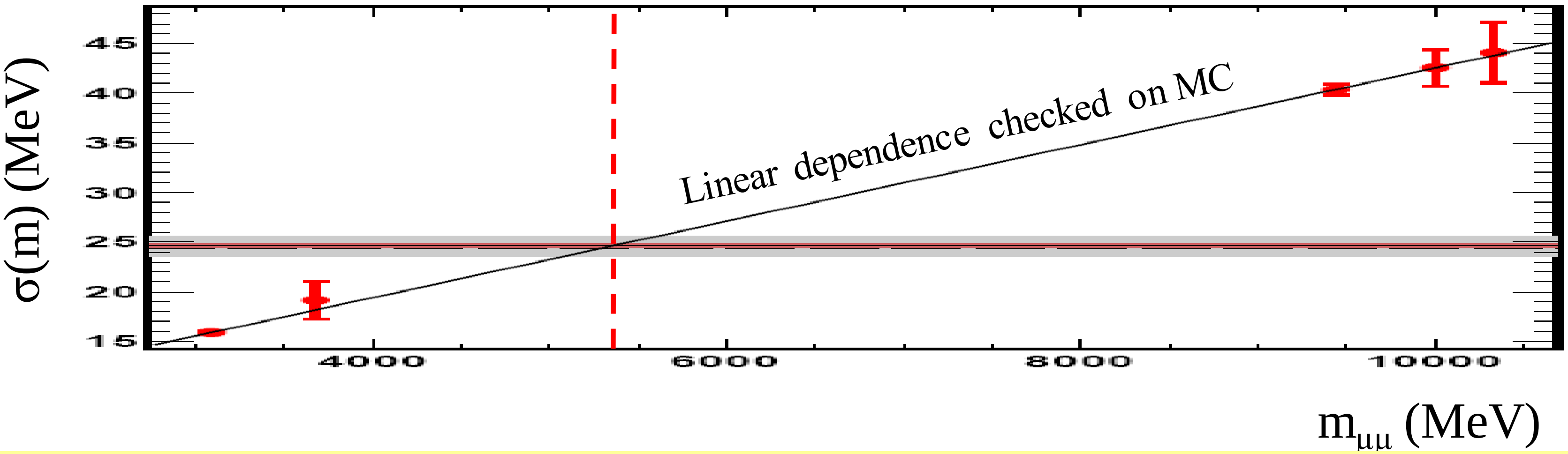


σ(M) = 16 MeV ⟶ σ(M) = 40 MeV

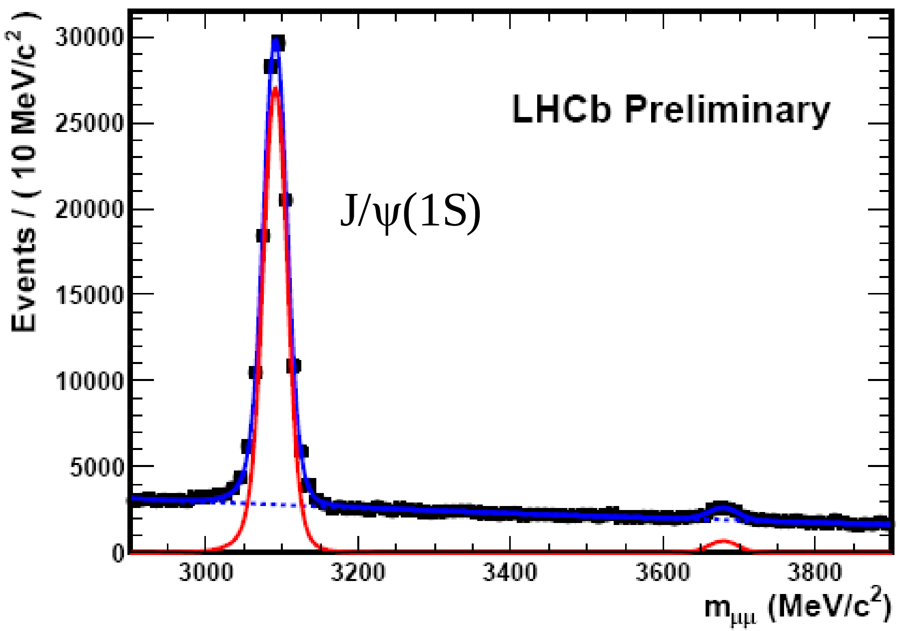


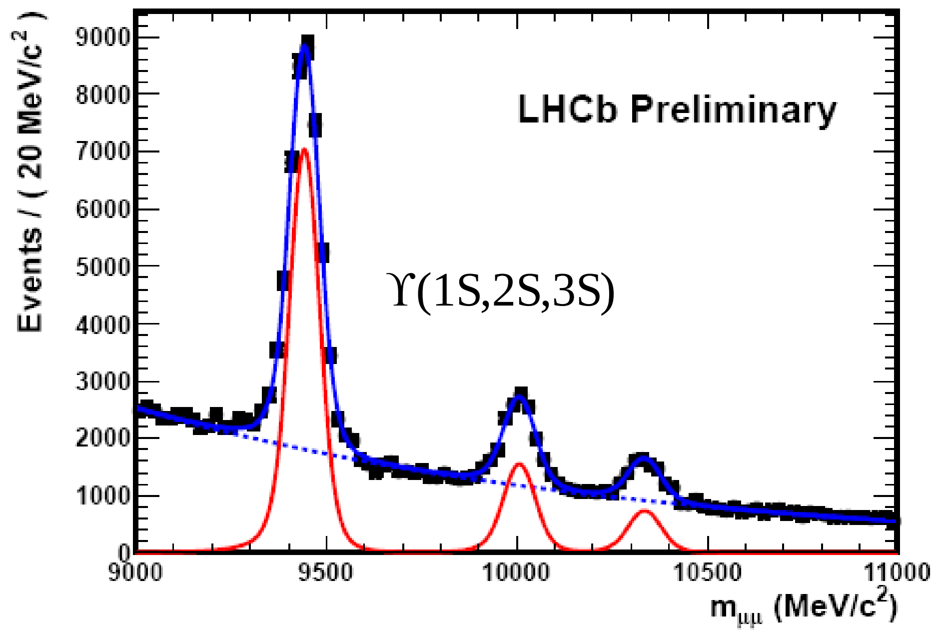


$B^0_s \to \mu\mu$: mass



$\sigma(M)_{mB}$ = 24 MeV (confirmed with $B \to \pi\pi$ decays)



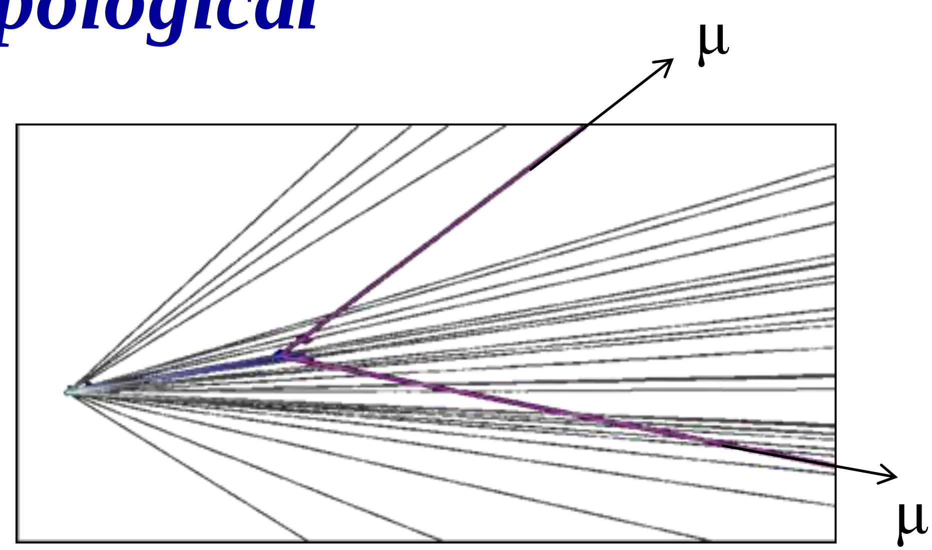


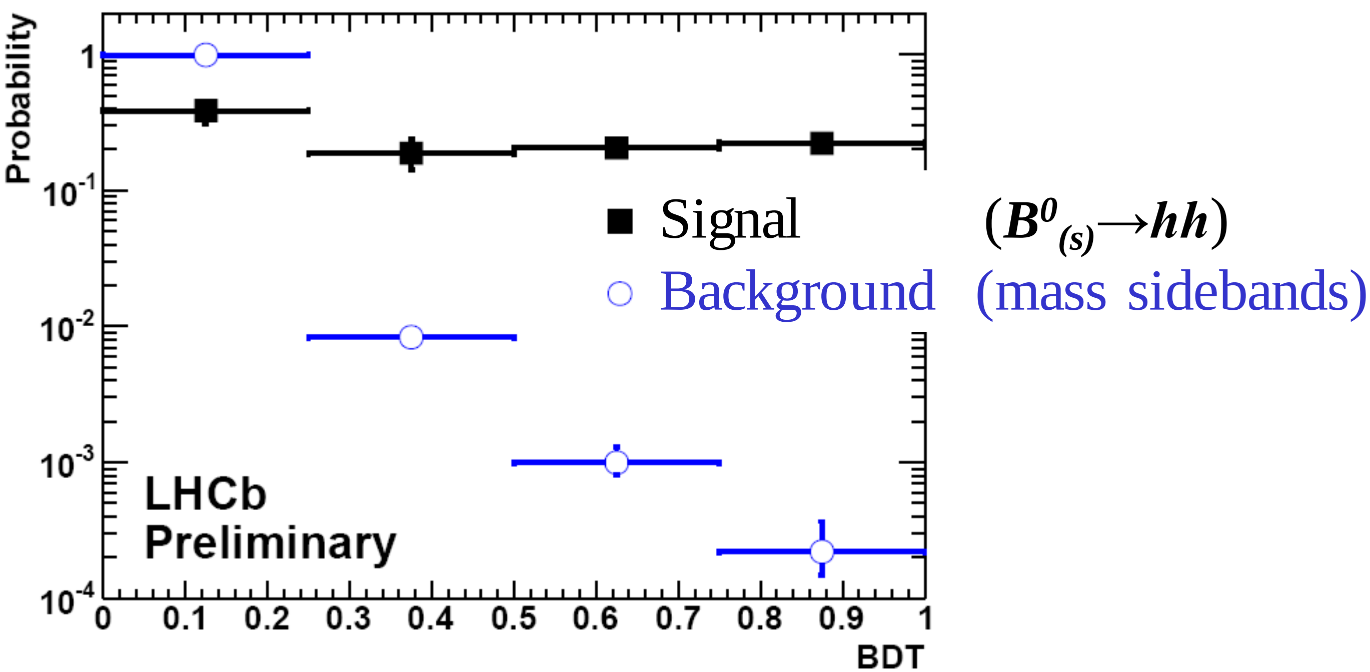
$B^0_s \to \mu\mu$: topological

Kinematic / geometrical:

1) B lifetime
2) IP_{μ} , IPS_{μ} , $p_{T,\mu}$, $\min(p_{T,\mu})$
3) DOCA 2 muons
4) μ and B isolation

➢ Combine the info ("BDT")

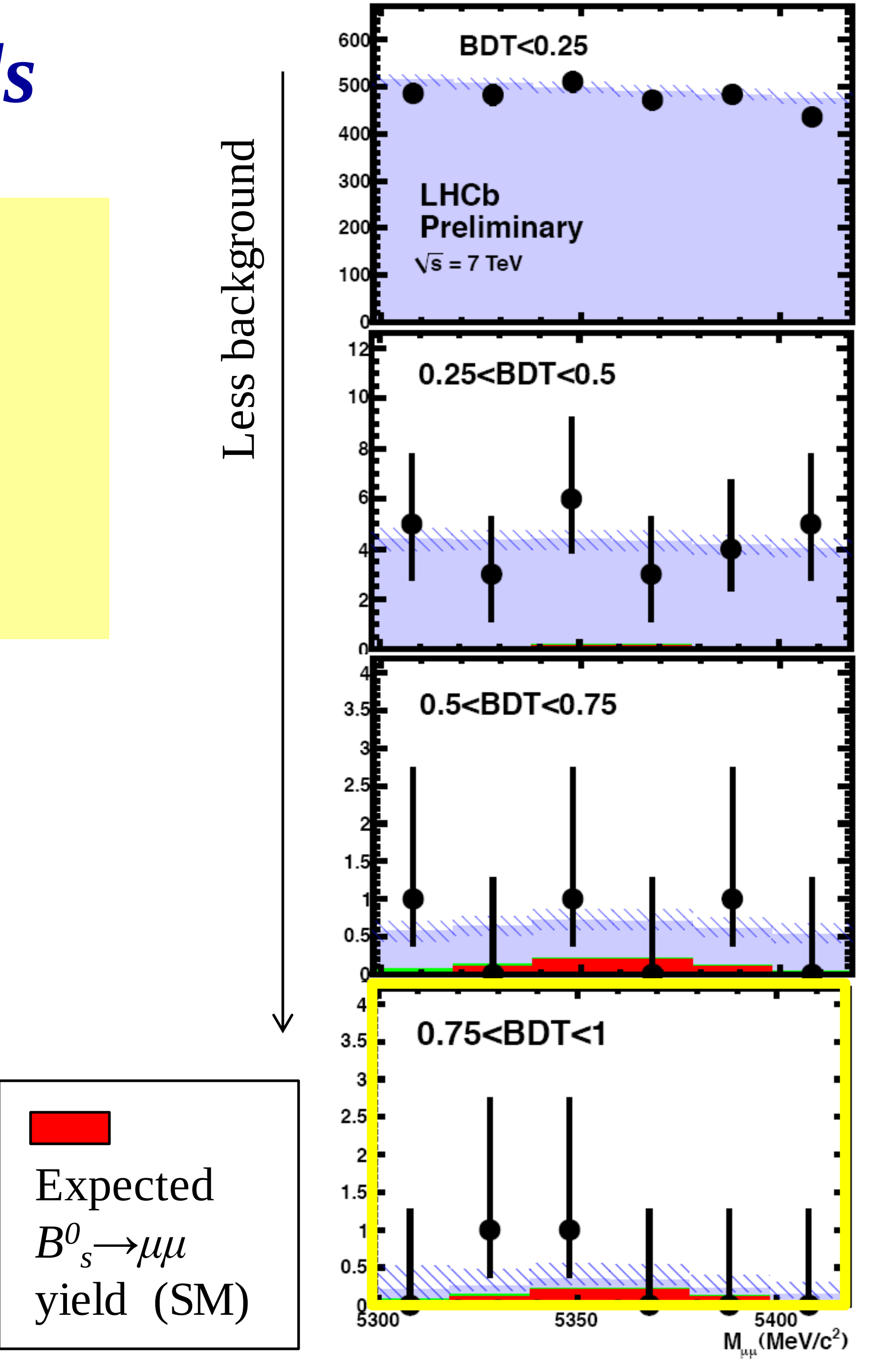




$B^0_s \to \mu\mu$: event yields

(preliminary)

- Analysis based on 300 pb^{-1}
- Highest BDT-bin similar to CMS:
- Observe 2 events, expect:
  - *~0.7 background*
  - *~0.8 SM*

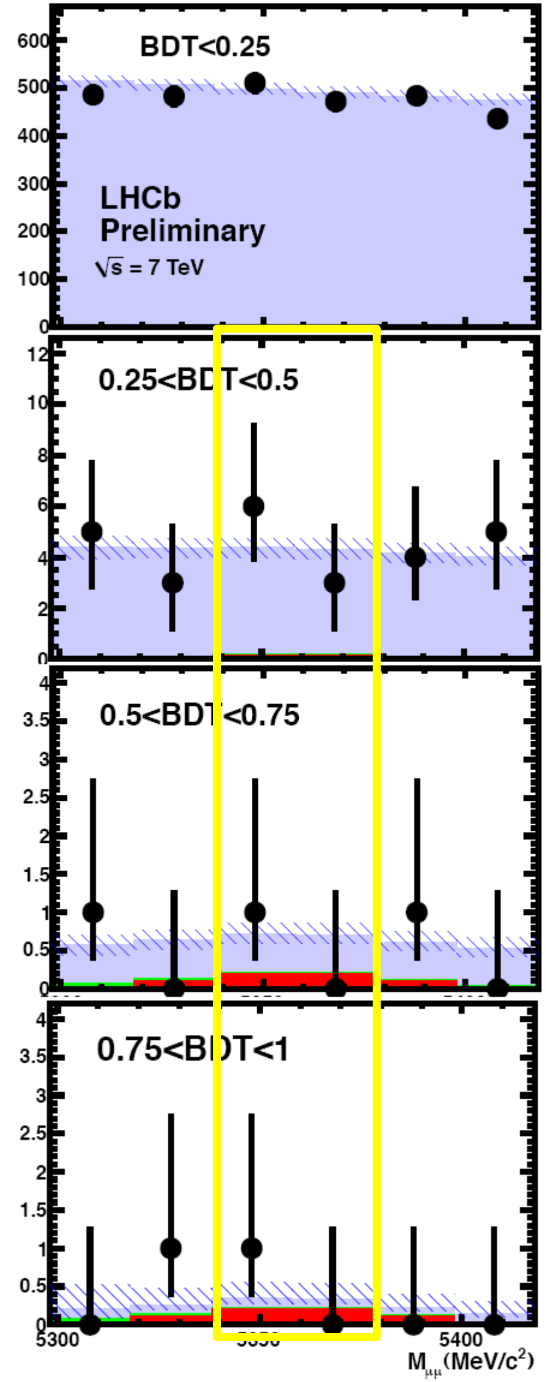


$B^0_s \to \mu\mu$: event yields

- Analysis based on 300 pb^{-1}
- Around B_s mass ±20 MeV:
- Observe 11 events, expect:
  - *~9.5 background*
  - *~1.2 SM*

(preliminary)

Less background



Expected $B^0_s \to \mu\mu$ yield (SM)

$B^0_s \to \mu\mu$: Branching Ratio

$$\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = \mathrm{BR}(B_q \to X) \frac{f_q}{f_s} \frac{\epsilon_X}{\epsilon_{\mu\mu}} \frac{N_{\mu\mu}}{N_X}$$

- Main normalization channels:
  - $B^+ \to J/\psi K^+$
  - $B^0 \to K^+\pi^-$
  - $B_s^0 \to J/\psi\varphi$

CDF: $f_s/(f_d+f_u)=0.142\pm 12\%$
(ignoring SU(3) breaking effects and environment dependent)
PDG, a.o.: CDF, Phys.Rev.D77:072003,2008

Belle: $\mathrm{BR}(B_s \to J/\psi\phi) = 1.15\times 10^{-3} \pm 25\%$
(23.6 fb^{-1}, 20% of available dataset)
R. Louvot, arXiv:0905.4345v2

$B^0_s \to \mu\mu$: Normalization: f_d/f_s

$$\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = \mathrm{BR}(B_q \to X)\frac{f_q}{f_s}\frac{\epsilon_X}{\epsilon_{\mu\mu}}\frac{N_{\mu\mu}}{N_X}$$

f_d/f_s: Largest uncertainty in BR determination

- Main normalization channels:
  - $B^+ \to J/\psi K^+$
  - $B^0 \to K^+\pi^-$
  - $B_s^0 \to J/\psi\varphi$

CDF: $f_s/(f_d+f_u) = 0.142 \pm 12\%$
(ignoring SU(3) breaking effects and environment dependent)
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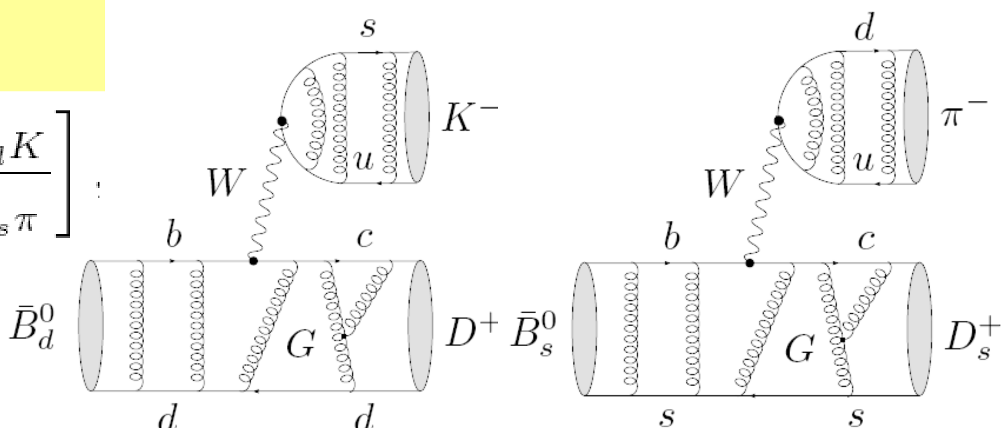
(23.6 fb^{-1}, 20% of available dataset)
R. Louvot, arXiv:0905.4345v2

Novel method:

- Use $B_s \to D_s^-\pi^+$ and $B^0 \to D^-K^+$

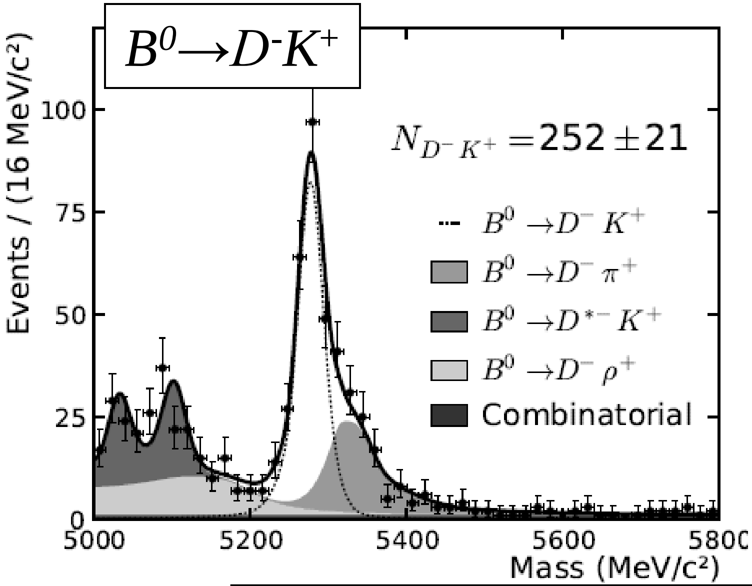
$$\frac{f_d}{f_s} = 12.88 \times \frac{\tau_{B_s}}{\tau_{B_d}} \times \left[\mathcal{N}_a\mathcal{N}_F\frac{\epsilon_{D_s\pi}}{\epsilon_{D_dK}}\frac{N_{D_dK}}{N_{D_s\pi}}\right]$$

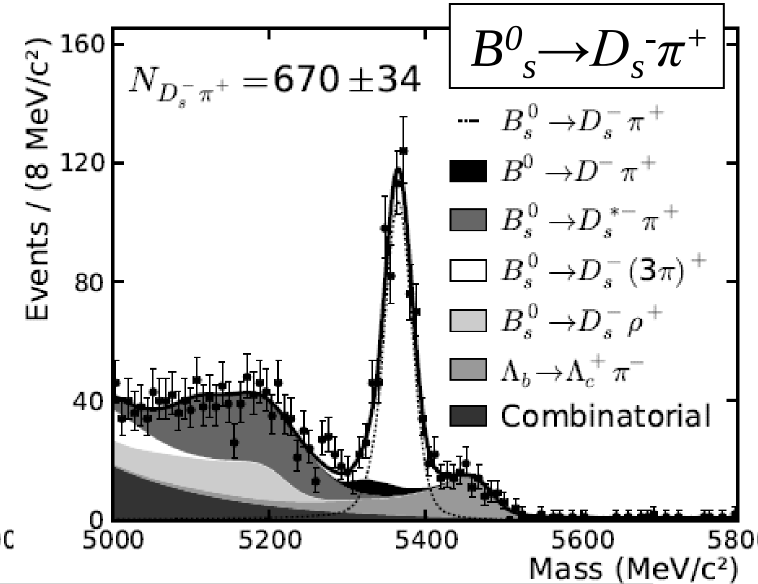
$$\mathcal{N}_a \equiv \left|\frac{a_1(D_s\pi)}{a_1(D_dK)}\right|^2, \quad \mathcal{N}_F \equiv \left[\frac{F_0^{(s)}(m_\pi^2)}{F_0^{(d)}(m_K^2)}\right]^2$$



R. Fleischer, N. Serra, N.T, Phys.Rev.D82:034038,2010

$B^0_s \to \mu\mu$: Normalization: f_d/f_s





$$f_s/f_d = 0.253 \pm 0.017^{\text{stat}} \pm 0.017^{\text{syst}} \pm 0.020^{\text{theor}}$$

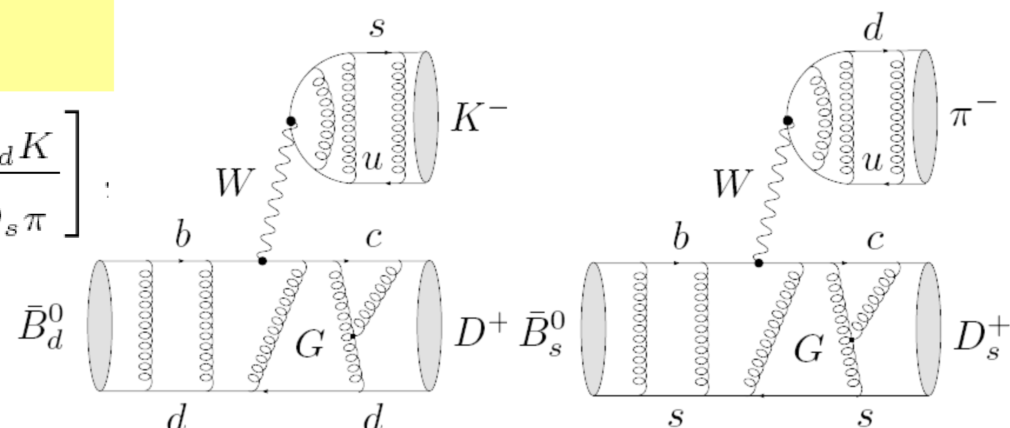
LHCb, arXiv:1106.4435
Accepted by PRL

Novel method:

- Use $B_s \to D_s^- \pi^+$ and $B^0 \to D^- K^+$

$$\frac{f_d}{f_s} = 12.88 \times \frac{\tau_{B_s}}{\tau_{B_d}} \times \left[\mathcal{N}_a \mathcal{N}_F \frac{\epsilon_{D_s\pi}}{\epsilon_{D_d K}} \frac{N_{D_d K}}{N_{D_s \pi}} \right]$$

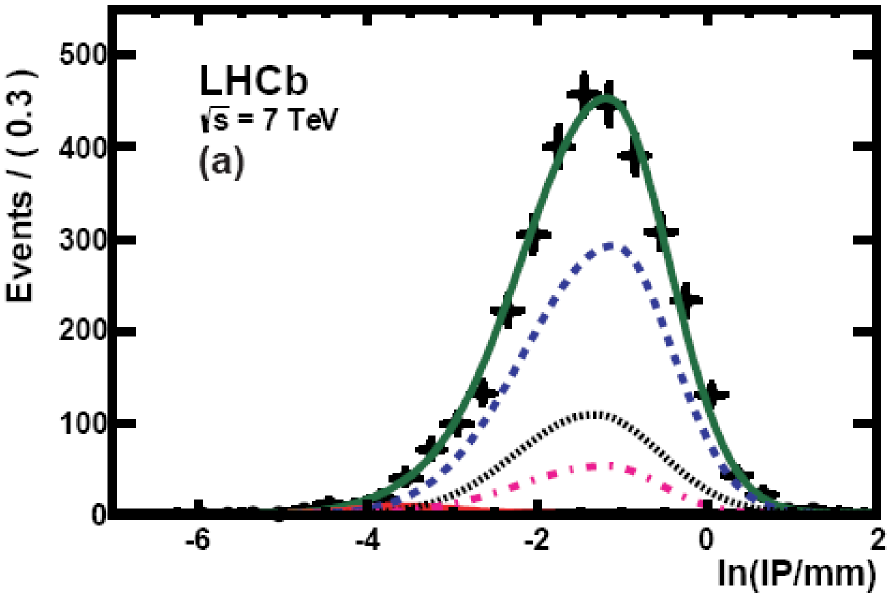
$$\mathcal{N}_a \equiv \left| \frac{a_1(D_s\pi)}{a_1(D_d K)} \right|^2, \quad \mathcal{N}_F \equiv \left[\frac{F_0^{(s)}(m_\pi^2)}{F_0^{(d)}(m_K^2)} \right]^2$$



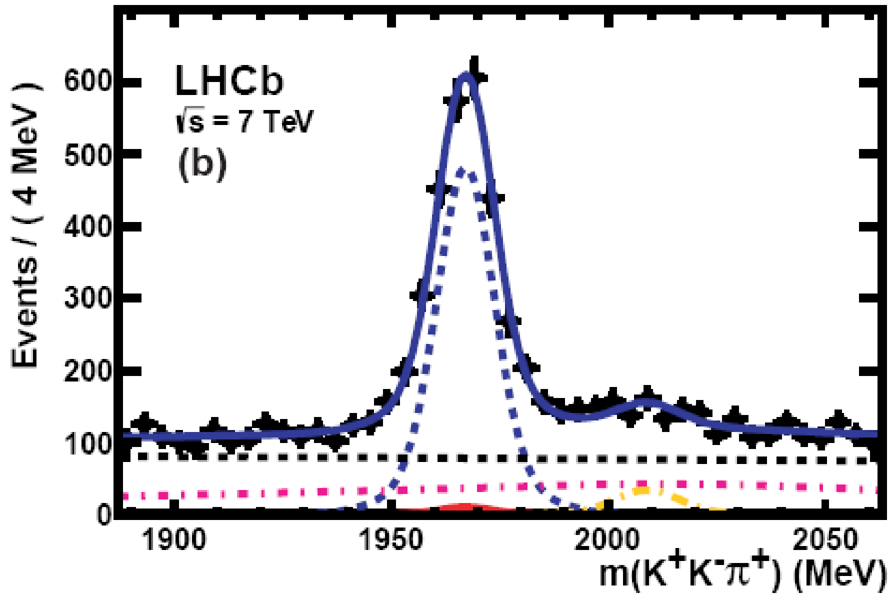
R. Fleischer, N. Serra, N.T, Phys.Rev.D82:034038,2010

$B^0_s \to \mu\mu$: Normalization: f_d/f_s

IP of $(D_s^+\mu^-)$-pairs:



D_s mass of $(D_s^+\mu^-)$-pairs:



LHCb, arXiv:1111.2357
Submitted

Average with semi-leptonic analysis:

- Use $B_s \to D_s^- \mu^+ X$ and $B^0 \to D^- \mu^+ X$

Combined value for f_s/f_d:

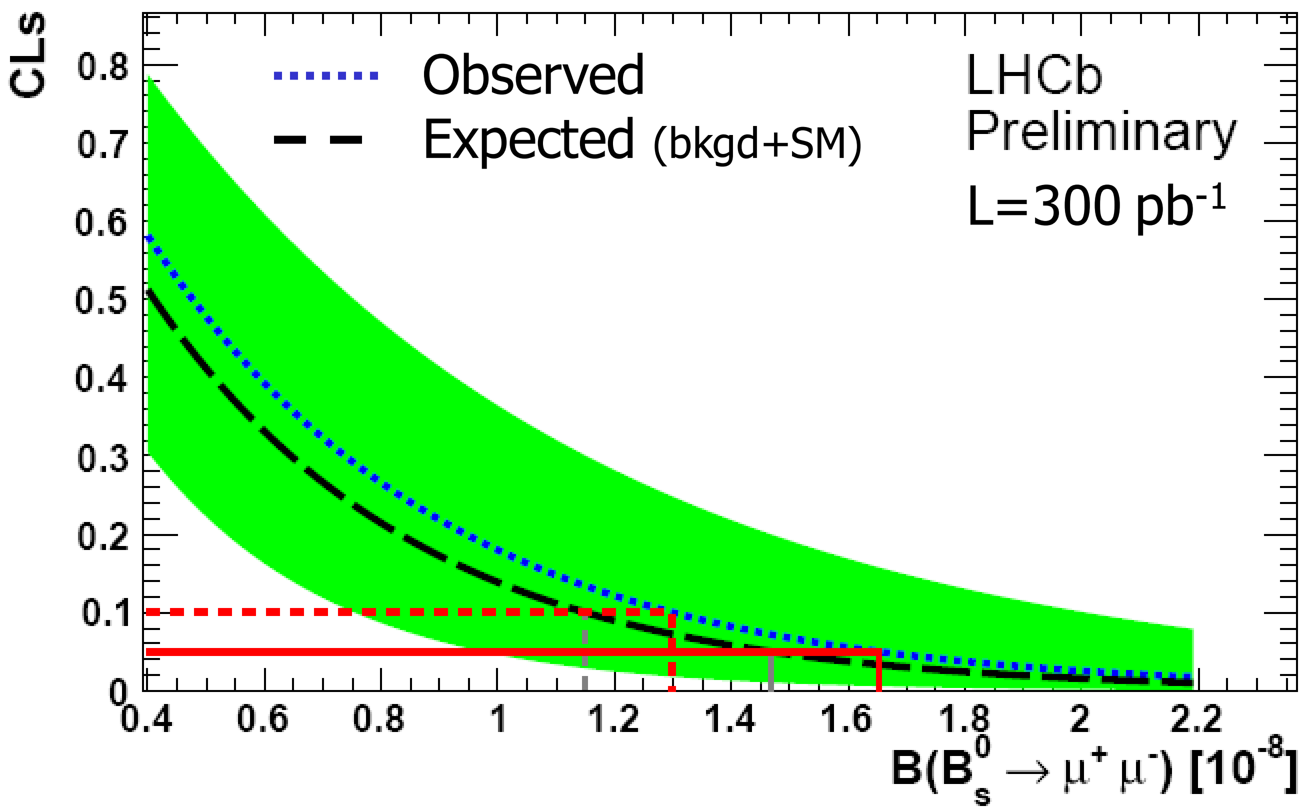
$$\langle f_s / f_d \rangle = 0.267^{+0.021}_{-0.020}$$

LEP+Tevatron: $f_s/f_d = 0.271 \pm 0.027$

$B^0_s \to \mu\mu$: Branching Ratio

$$BR(B^0_s \to \mu\mu)_{SM} = (0.32 \pm 0.02) \times 10^{-8}$$

- Expected limit: BR($B^0_s \to \mu\mu$)<1.5 x 10^{-8} @ 95% CL (bkgd+SM)
- Observed limit: BR($B^0_s \to \mu\mu$)<1.6 x 10^{-8} @ 95% CL (preliminary)
- p-value background only: 14%



LHCb-CONF-2011-037

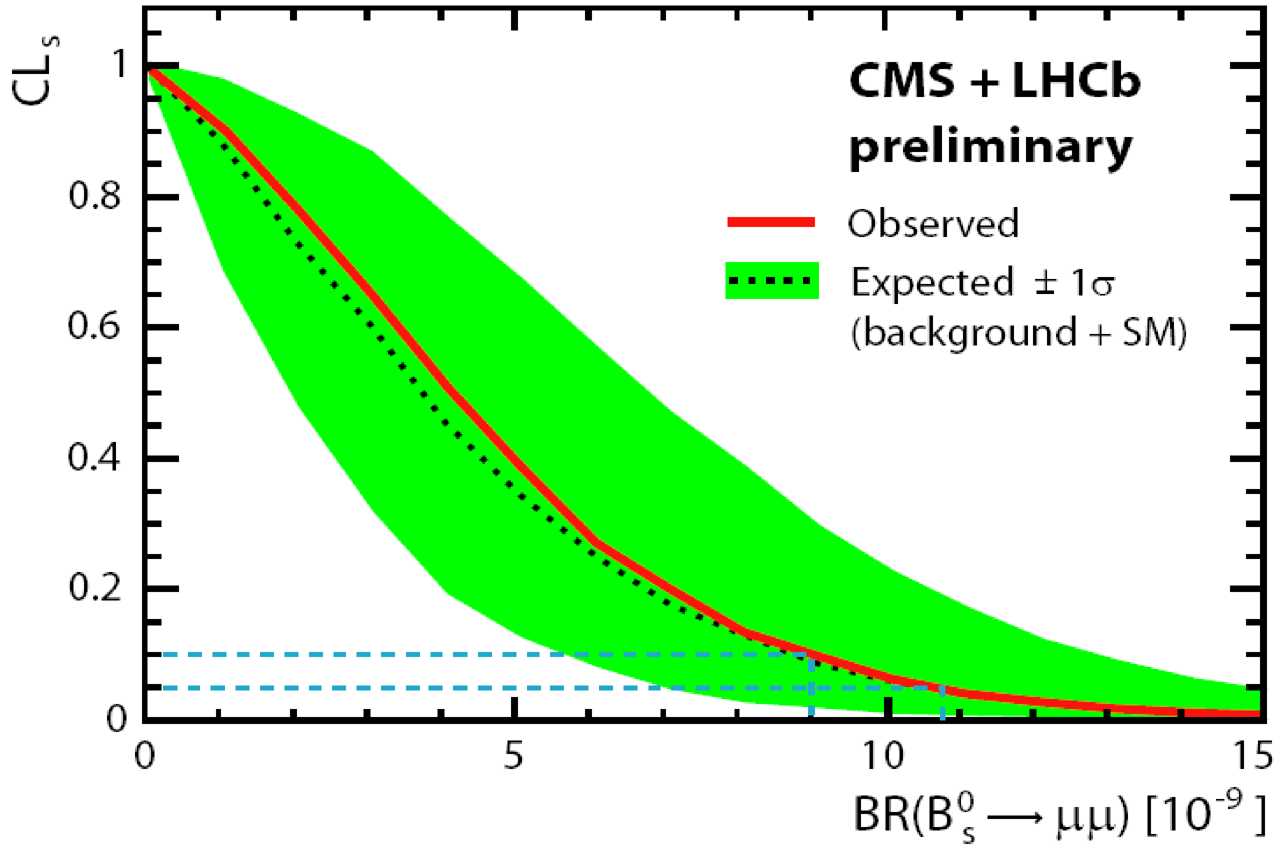
$B^0_s \to \mu\mu$: LHCb + CMS combination

CMS:

Invariant Mass (MeV/c^2)		Barrel region	Endcap region
5300 – 5450	Exp. bkg.	0.60 ± 0.35	0.80 ± 0.40
	Exp. misid.	0.07 ± 0.02	0.04 ± 0.01
	Exp. signal	0.76 ± 0.11	0.34 ± 0.06
	Observed	2	1

- Observed limit: **BR($B^0_s \to \mu\mu$)<1.08** x **10^{-8}** @95%CL
- p-value background only: 8%

(CMS only: BR<1.9 10^{-8})



CMS-PAS-BPH-11-019 ; LHCb-CONF-2011-047

Sub-Summary

1) $B^0_s \to J/\psi\varphi$

2) $B^0 \to K^*\mu\mu$

3) $B^0_s \to \mu\mu$

- Best limit on BR !
- BR < 3.4 x BR_{SM}
- Plenty of room for NP
- The smaller BR, the more critical is knowledge on f_d/f_s

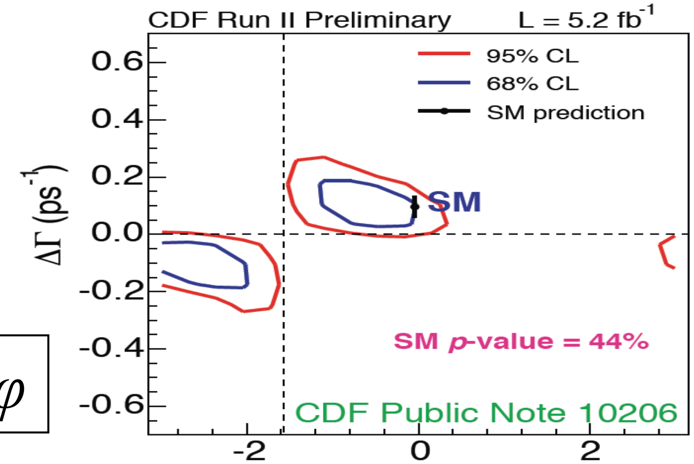
Status before Summer

1) $B^0_s \to J/\psi\varphi$
   - ➢ SM p-value 44%

2) $B^0 \to K^*\mu\mu$
   - ➢ Hint for deviaton

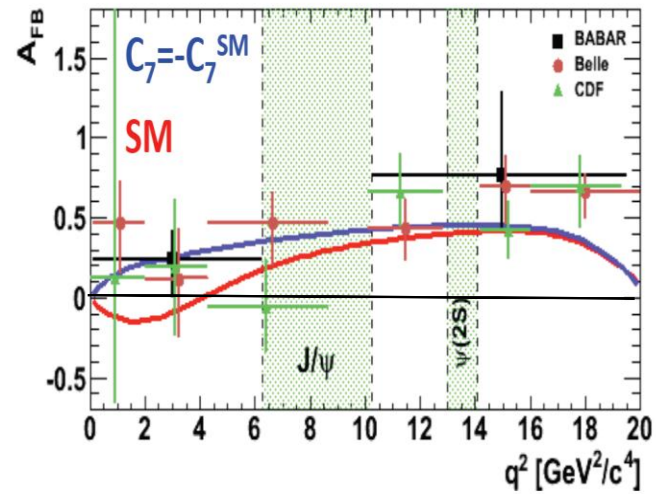
3) $B^0_s \to \mu\mu$
   - ➢ BR($B^0_s \to \mu\mu$)=
   - ➢ SM p-value 1.9%

$B^0_s \to J/\psi\varphi$



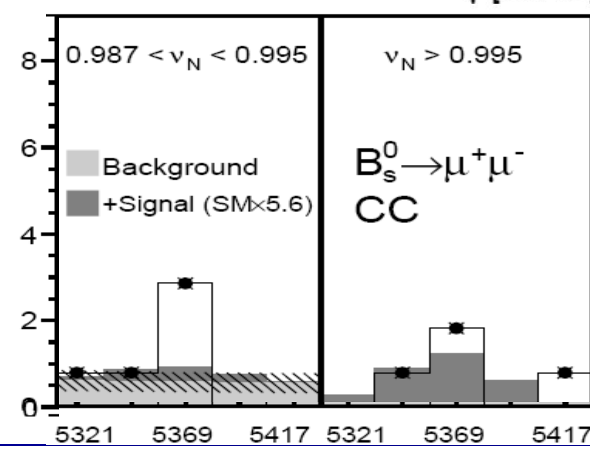
CDF, Conf Note 10206

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



BABAR: PRL 102, 091803 (2009)
CDF: Note 10047 (2010)
Belle: PRL 103, 171801 (2009)

$B^0_s \to \mu\mu$



CDF, arXiv:1107.2304

LHCb after Summer

1) $B^0_s \rightarrow J/\psi\varphi$

- φ_s=0.03 ± 0.16(stat) ± 0.07(sys) rad

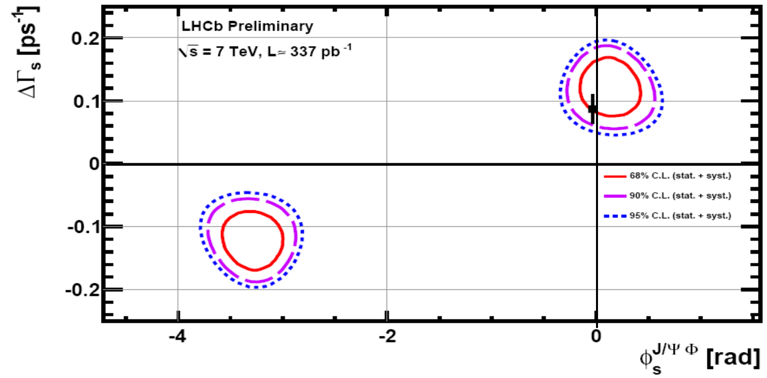
2) $B^0 \rightarrow K^*\mu\mu$

- $A_{FB}<0$

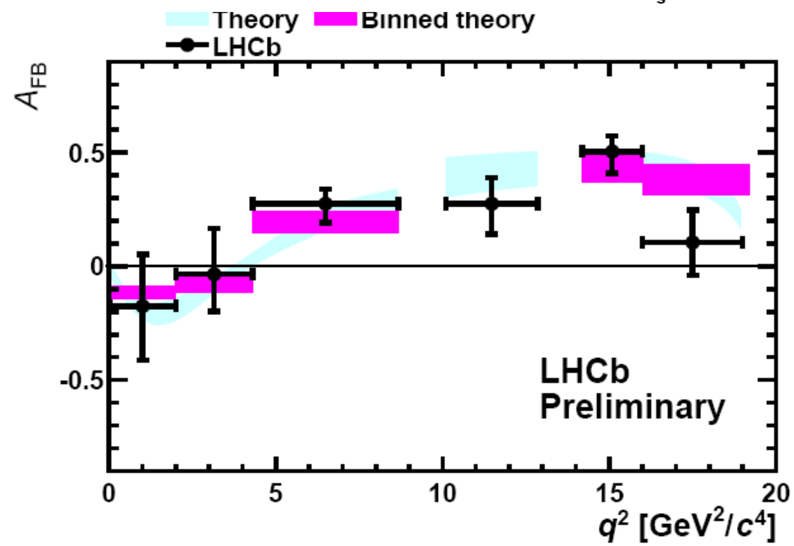
3) $B^0_s \rightarrow \mu\mu$

- BR($B^0_s \rightarrow \mu\mu$)<1.5 10^{-8}

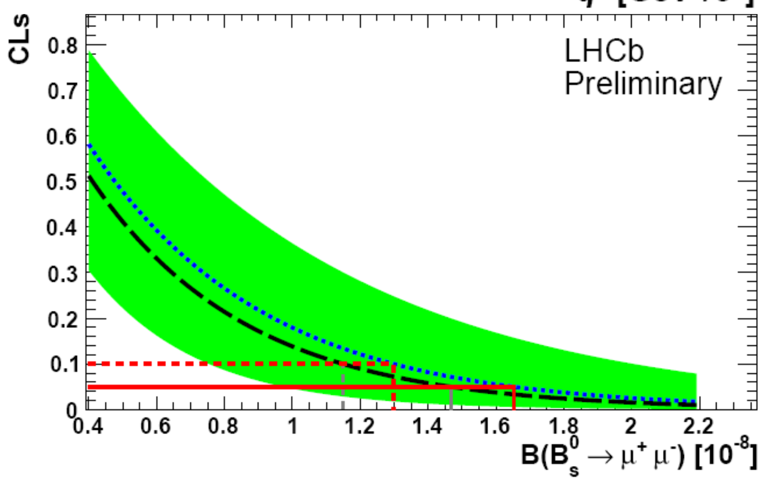
$B^0_s \rightarrow J/\psi\varphi$



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



$B^0_s \rightarrow \mu\mu$

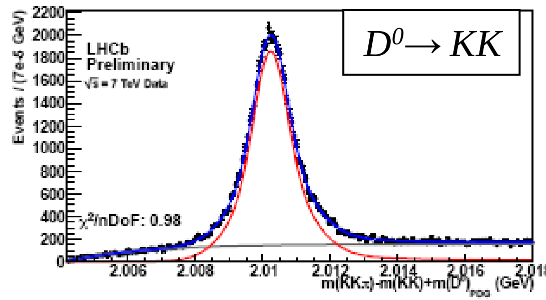


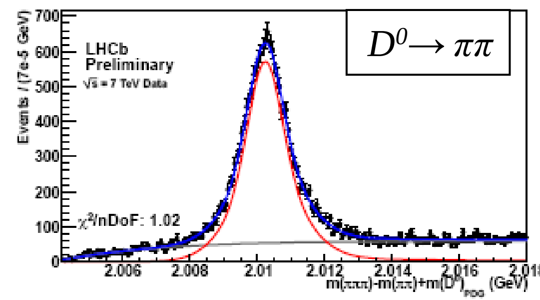
Thank you

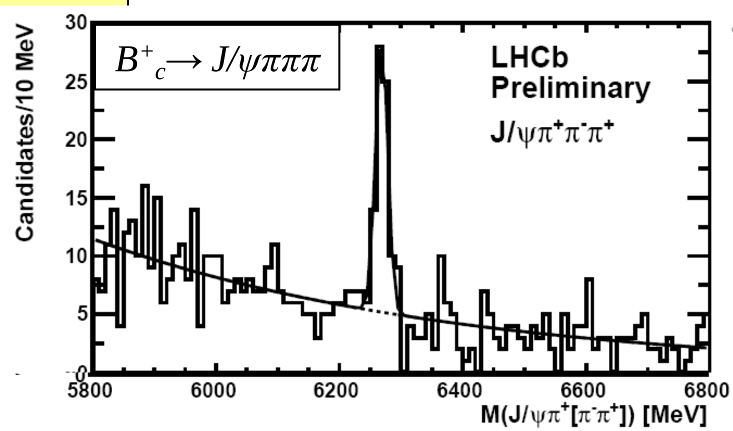
Things I did not show…

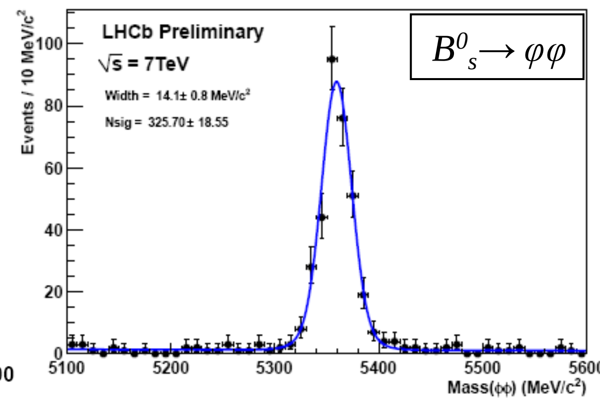
1) Charm (and ΔA_{CP})
2) $B^0 \to K\pi$
3) $B^0 \to DK^*$, $B^+ \to DK^+$
4) $B^0 \to K^*\gamma$
5) $B^0_s \to \varphi\varphi$
6) $B^{*(*)}$ spectroscopy
7) Λ_b
8) $B_c^+ \to J/\psi\pi\pi\pi$
9) Semi-leptonic
10) W/Z

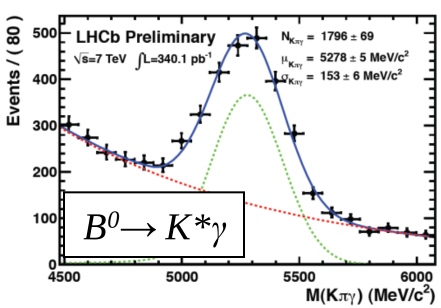
→ see talk by N.Serra

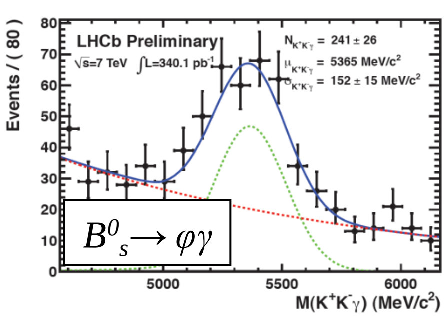


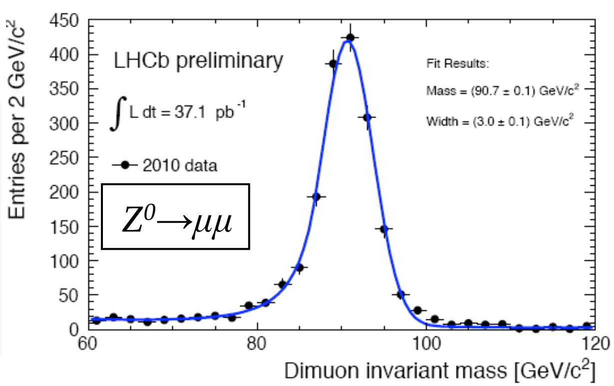


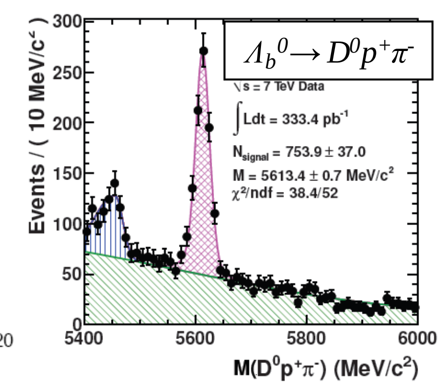


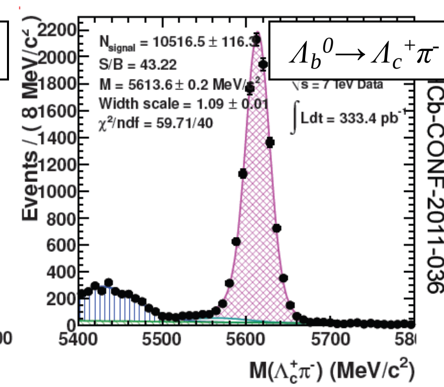












$BR(B^0_s \to \mu\mu)$ vs $\tan^6\beta$

- Branching Ratio very sensitive to NP models

$$\mathrm{Br}(B_s \to \mu^+\mu^-)_{\mathrm{SM}} = (3.2 \pm 0.2) \times 10^{-9}$$

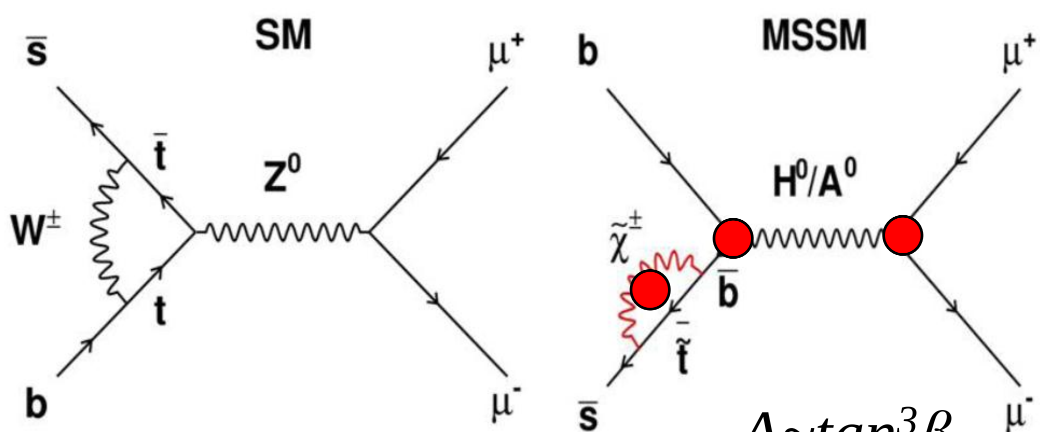
A.Buras, G.Isidori, P.Paradisi Phys.Lett.B694:402-409,2011

- BR strongly enhanced in MSSM at large tanβ: $\propto \tan^6\beta / m_A^4$

$$R_{B\ell\ell} = \frac{\mathcal{B}^{\mathrm{SUSY}}(B_q \to \ell^+\ell^-)}{\mathcal{B}^{\mathrm{SM}}(B_q \to \ell^+\ell^-)} = (1+\delta_S)^2 + \left(1 - \frac{4m_\ell^2}{M_{B_q}^2}\right)\delta_S^2 ,$$

$$\delta_S = \frac{\pi \sin^2\theta_w M_{B_q}^2}{\alpha_{\mathrm{em}} M_A^2 C_{10A}(m_t^2/M_W^2)} \frac{\epsilon_Y \lambda_t^2 \tan^3\beta}{[1+(\epsilon_0+\epsilon_Y\lambda_t^2)\tan\beta][1+\epsilon_0\tan\beta]}$$

G.Isidori & P.Paradisi , Phys.Lett.B639:499-507.2006.

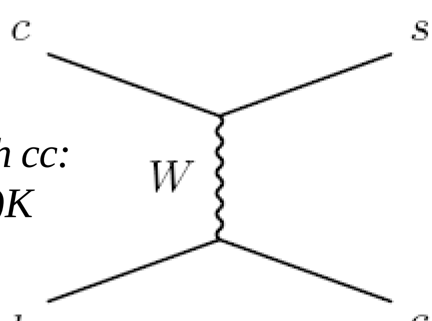


$A \sim \tan^3\beta$

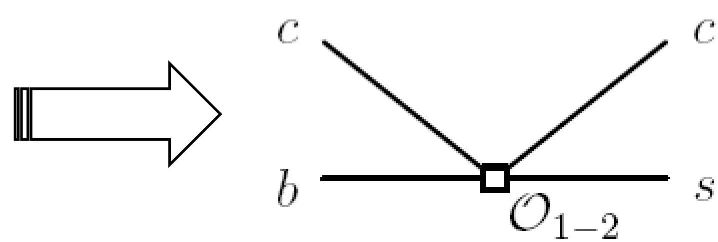
Intermezzo: OPE

- *Example: B→μμK*
- *Think of Fermi…: remove W from theory:*

e.g. through cc:
B→J/ψ(μμ)K



(a) Current–current operator $\mathcal{O}_1$

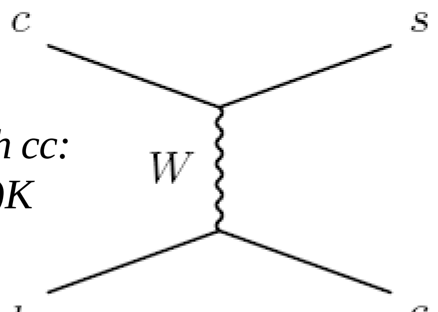


Intermezzo: OPE

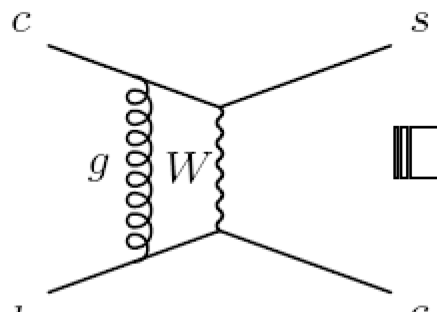
- *Example: B→μμK*

- *Think of Fermi…: remove W from theory*
- *Add QCD corrections:*

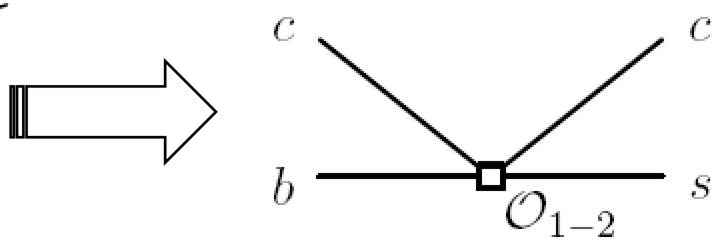
e.g. through cc:
B→J/ψ(μμ)K



(a) Current–current operator $\mathcal{O}_1$



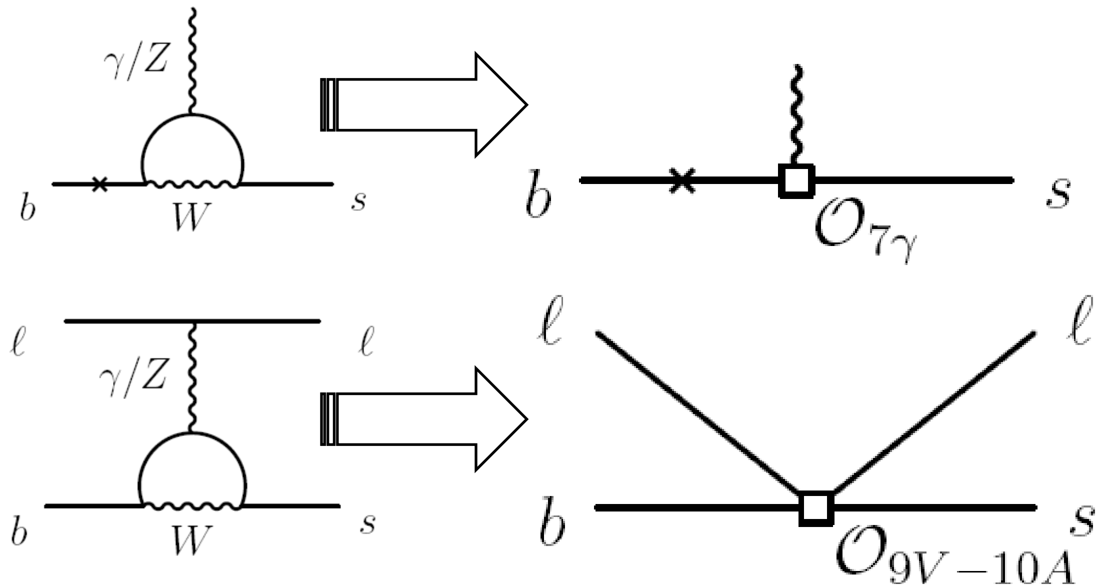
(b) Current–current operator $\mathcal{O}_2$



Intermezzo: OPE

- *Example: B→μμK*

- *Think of Fermi…: remove W from theory:*
- *Add penguin operators:*



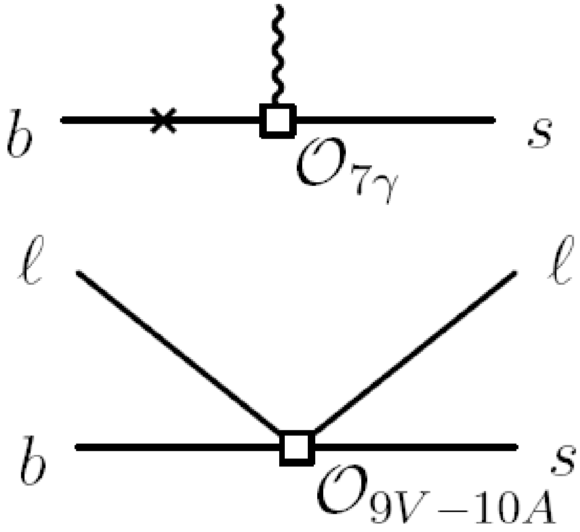
$$H_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu, M_{heavy}) \mathcal{O}_i(\mu)$$

$$A(B\to\mu\mu K) = \langle \mu\mu K | H_{eff} | B \rangle \sim G_F V_{tb} V^*_{ts} \sum C_i \langle \mu\mu K | O_i | B \rangle$$

Intermezzo: OPE

- *Example: B→μμK*

- *Think of Fermi…: remove W from theory:*
- *Add penguin operators:*



- *C_i: Wilson coefficients*
  - *Calculable*
- *O_i: operators*
  - *Long distance hadr. eff.*

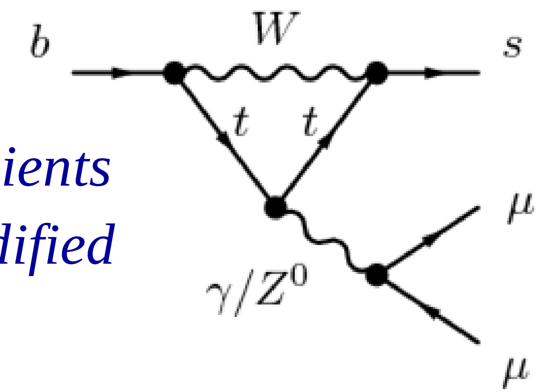
$$H_{\rm eff} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu, M_{heavy}) \mathcal{O}_i(\mu)$$

➢ *"Master formula for weak decays":*

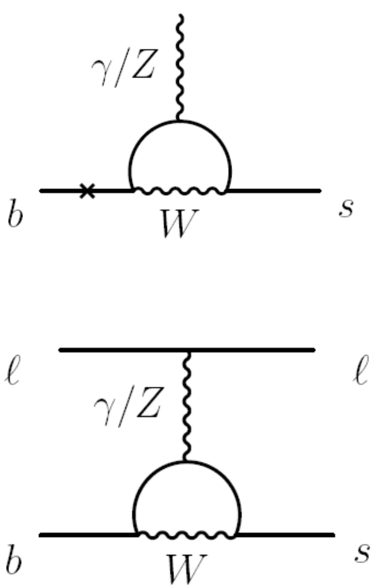
$$A(B\rightarrow\mu\mu K) = \langle\mu\mu K|H_{eff}|B\rangle \sim G_F V_{tb} V^*_{ts} \sum C_i \langle\mu\mu K|O_i|B\rangle$$

Rare decays: OPE

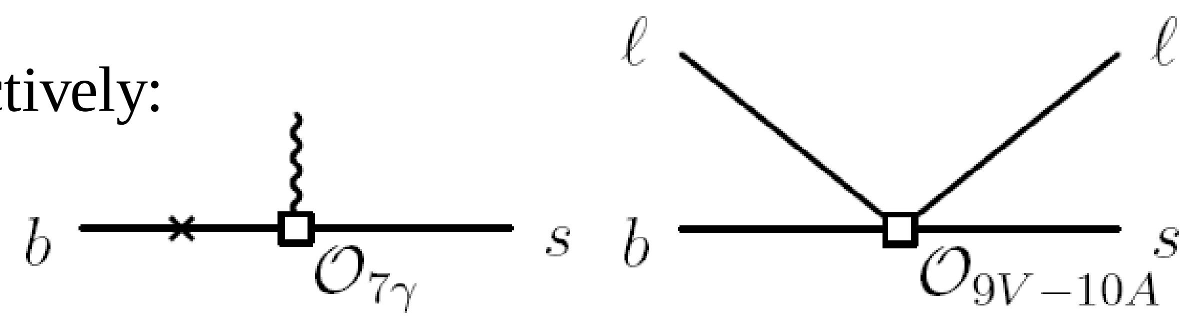
- *Flavour changing neutral currents (FCNC)*
- *Probe V-A structure of SM*
- *In HQET expressed in terms of Wilson coefficients*
- *NP can appear as new operators, or with modified coefficients!*



$$H_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu, M_{heavy}) \mathcal{O}_i(\mu)$$



effectively:



e.g. W.Altmannshofer et al., JHEP 0901:019,2009

Rare decays: OPE

- *Flavour changing neutral currents (FCNC)*
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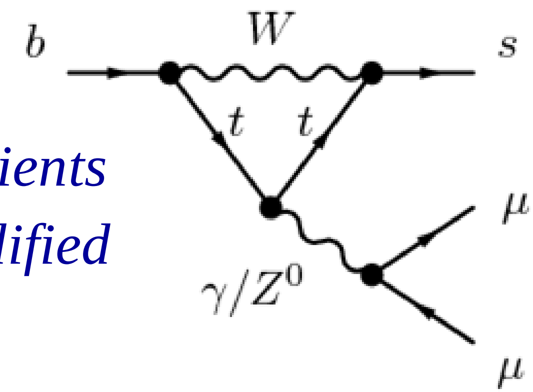
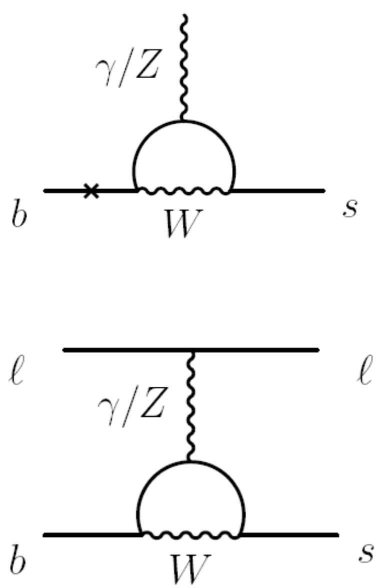


$$H_{\rm eff} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu, M_{heavy}) \mathcal{O}_i(\mu)$$



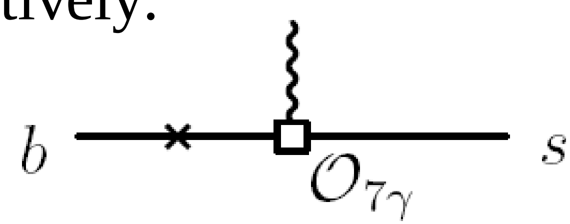
$B^0_{(s)} \to K^*(\varphi)\gamma$	$B^0 \to K^*\mu\mu$	$B^0_s \to \mu\mu$
$\mathcal{O}_{7\gamma}$	$\mathcal{O}_{7\gamma}, \mathcal{O}_{9V}, \mathcal{O}_{10A}, \mathcal{O}_S, \mathcal{O}_P$	$\mathcal{O}_{10A}, \mathcal{O}_S, \mathcal{O}_P$

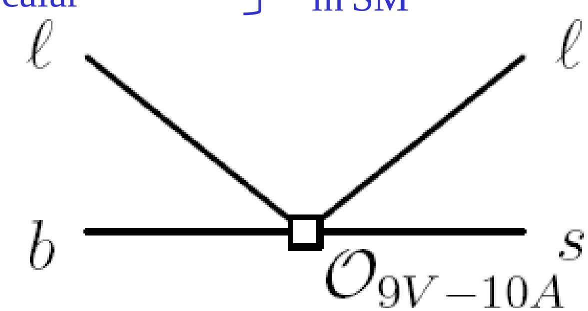
In principle both left- and righthanded, $\mathcal{O}_{7\gamma}$ and $\mathcal{O}_{7\gamma}$'

$\mathcal{O}_S$: Scalar current (Higgs)
$\mathcal{O}_P$: Pseudo-scalar

Highly suppressed in SM

effectively:

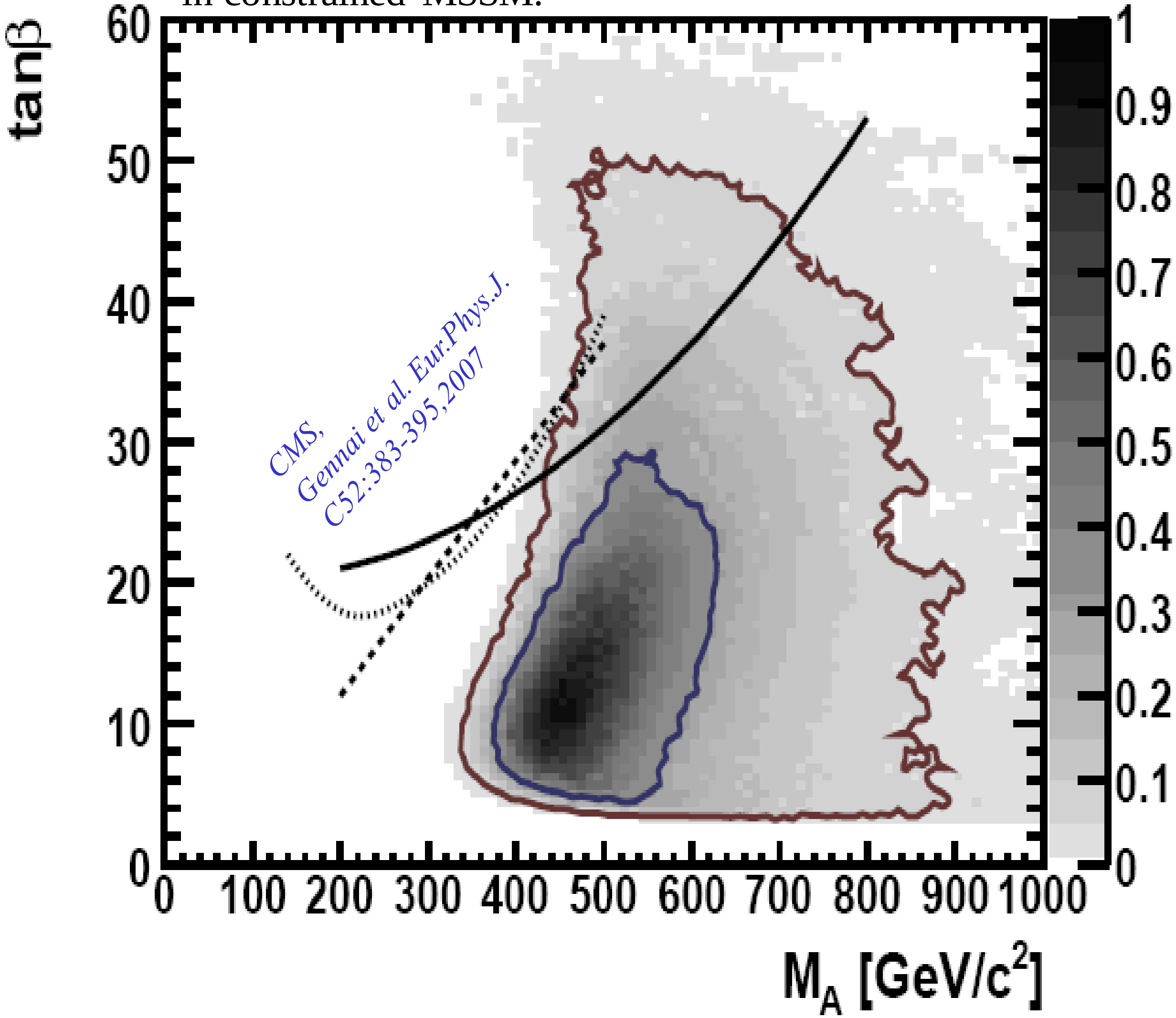




e.g. W.Altmannshofer et al., JHEP 0901:019,2009

Intermezzo 2: Allowed MSSM parameter space

Allowed parameter space from fit in constrained MSSM:



constraints. These include precision electroweak data, the anomalous magnetic moment of the muon,

- **$(g-2)_\mu$,**

B-physics observables (the rates for

- **BR($b \to s\gamma$) and**
- **BR($B_u \to \tau\nu_\tau$),**
- **B_s mixing,**

and the upper limit on

- **BR($B_s \to \mu^+\mu^-$)),**
- the **bound on the lightest MSSM Higgs** boson mass, M_h, and the cold dark matter (CDM) density inferred from
- **astrophysical and cosmological data**, assuming that this is dominated by the relic density of the lightest neutralino, χ_{h2}.

shown are the 5-σ discovery contours for observing the heavy MSSM Higgs bosons H,A in the three decay channels ***H,A → $\tau^+\tau^-$ →***

1) ***jets (solid line),***
2) ***jet+μ (dashed line),***
3) ***jet+e (dotted line)***

at the LHC. The discovery contours have been obtained using an analysis that assumed 30 or 60 fb^{-1} collected with the CMS detector.

O.Buchmueller et al. Eur.Phys.J.C64:391-415,2009