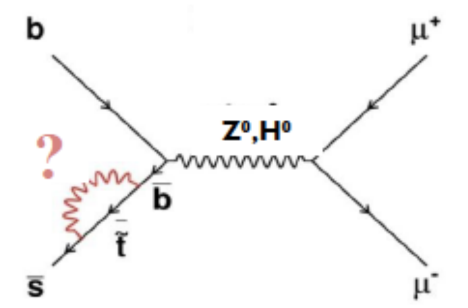
Selected Topics in B-Physics at LHC

1. Motivations for B-physics at LHC
2. Experimental aspects for B-physics at LHC
3. Examples of relevant analyses
4. Conclusion

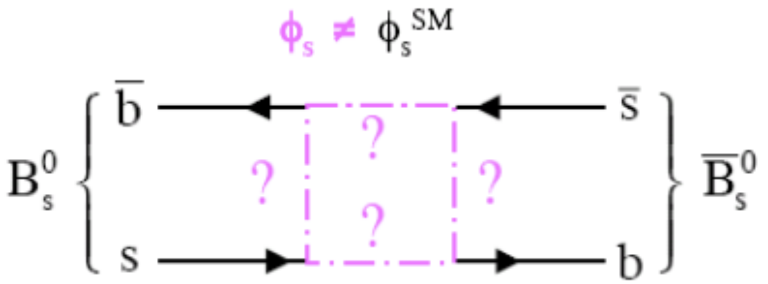
N.B.: personal free collection from ICHEP2012 so almost everything is “very preliminary”

1. Motivations for B-physics at LHC

- due to production of all B-states →can test prediction for all sectors (meson, baryon), new spectroscopy
- B's decay via diagram (tree, box, Penguin) which allows to test several fundamental aspects like mixing, CP violation, etc.. → deviation can show evidence for New Physics



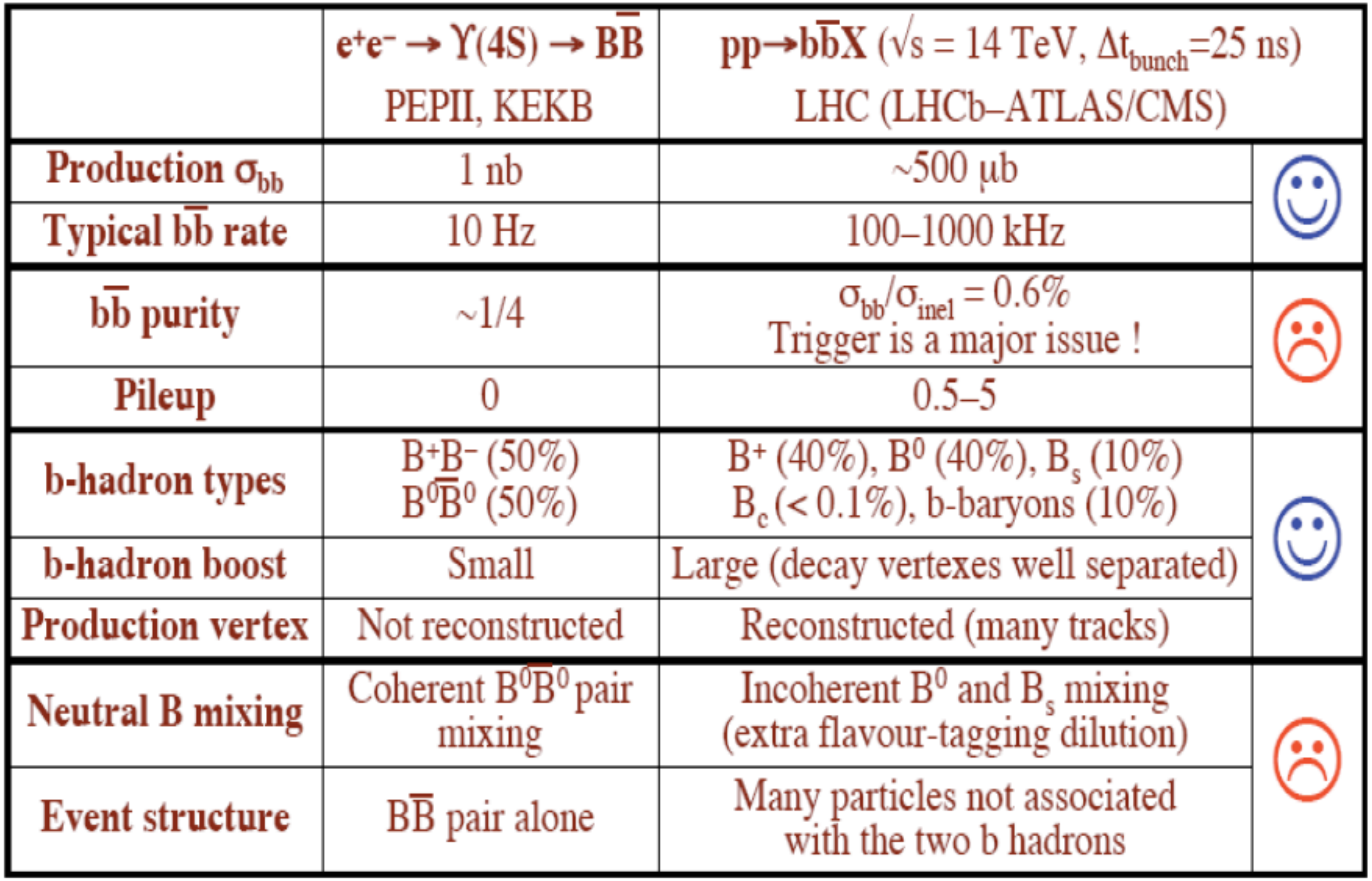
$B_s \rightarrow \mu^+\mu^-$ Higgs “Penguin”



B_s–$\bar{B}_s$ oscillations: “Box” diagram

2. Experimental aspects of B physics at LHC

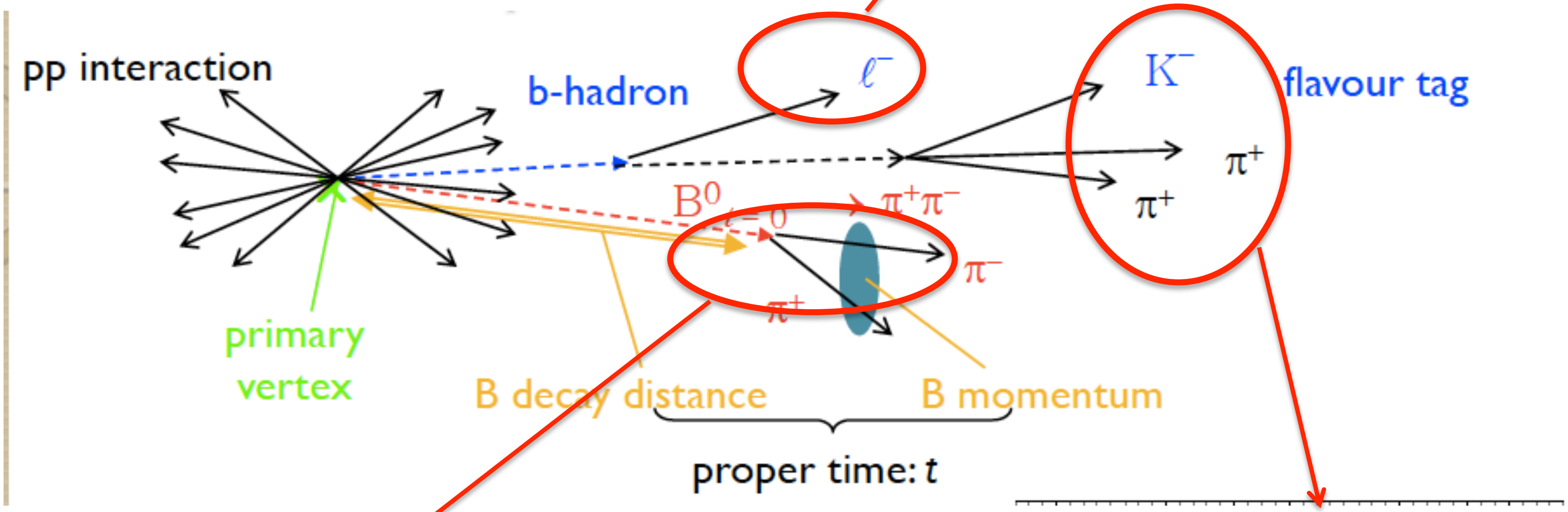
Experiments: LHCb dedicated but also ATLAS and CMS very competitive



	$e^+e^- \to \Upsilon(4S) \to B\bar{B}$ PEPII, KEKB	$pp \to b\bar{b}X$ ($\sqrt{s} = 14$ TeV, $\Delta t_{bunch} = 25$ ns) LHC (LHCb–ATLAS/CMS)	
Production σ_{bb}	1 nb	~500 μb	☺
Typical $b\bar{b}$ rate	10 Hz	100–1000 kHz	
$b\bar{b}$ purity	~1/4	$\sigma_{bb}/\sigma_{inel} = 0.6\%$ Trigger is a major issue !	☹
Pileup	0	0.5–5	
b-hadron types	B^+B^- (50%) $B^0\bar{B}^0$ (50%)	B^+ (40%), B^0 (40%), B_s (10%) B_c (< 0.1%), b-baryons (10%)	☺
b-hadron boost	Small	Large (decay vertexes well separated)	
Production vertex	Not reconstructed	Reconstructed (many tracks)	
Neutral B mixing	Coherent $B^0\bar{B}^0$ pair mixing	Incoherent B^0 and B_s mixing (extra flavour-tagging dilution)	☹
Event structure	$B\bar{B}$ pair alone	Many particles not associated with the two b hadrons	

2.2 Typical b-bbar event at LHC:

Lepton high Pt
→Trigger
→Tag b or b-bar

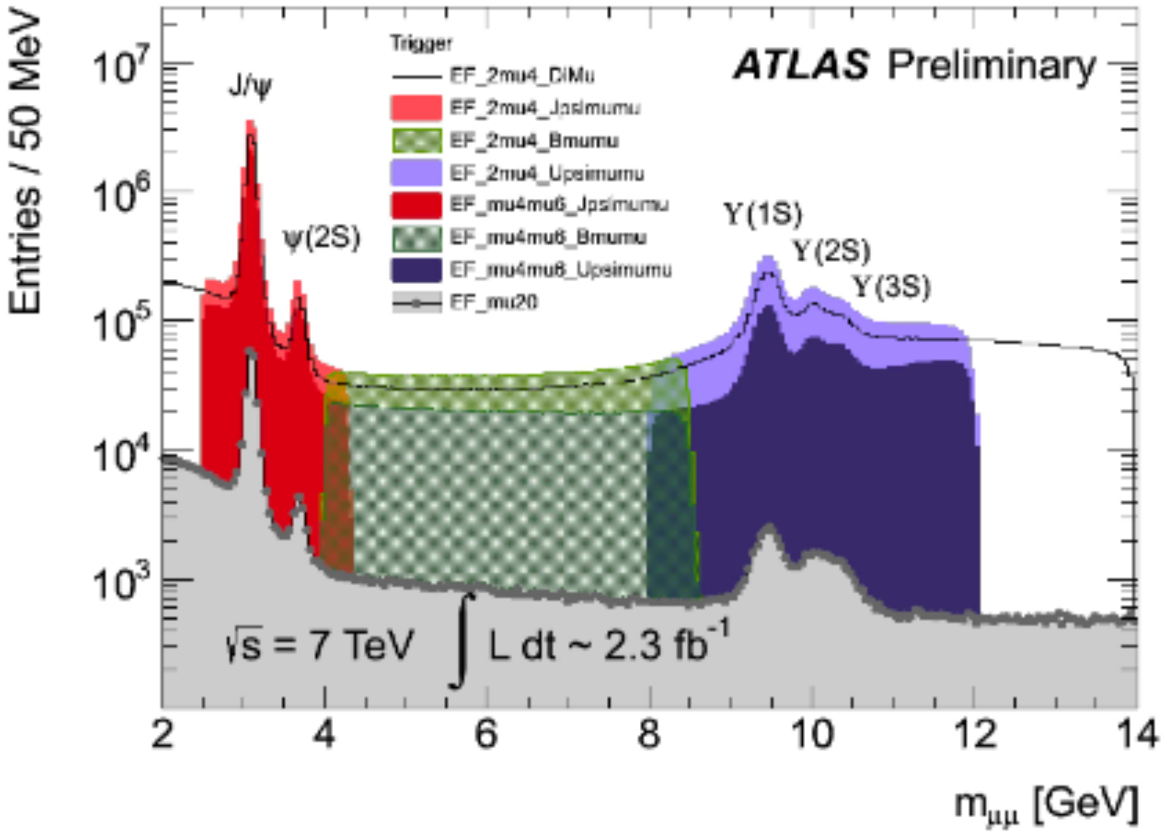


Fully reconstructed
B-hadron
→backg. Red.
→ proper time

D^0,D^+,D_s fully
reconstructed
→backg. Red.
→ Tag b or b-bar

2.3 Trigger for B-physics at LHC:

- ATLAS trigger
  - Output rate ~300Hz
  - Three levels of selection
  - Based on Regions-of-Interest
- B-Trigger
  - High p_T trigger priority for general-pourposes experiment (Higgs, SUSY etc.)
  - Keep low p_T trigger thresholds at high luminosity
  - Total bandwidth is the main limitation
- Di-muon trigger is the key

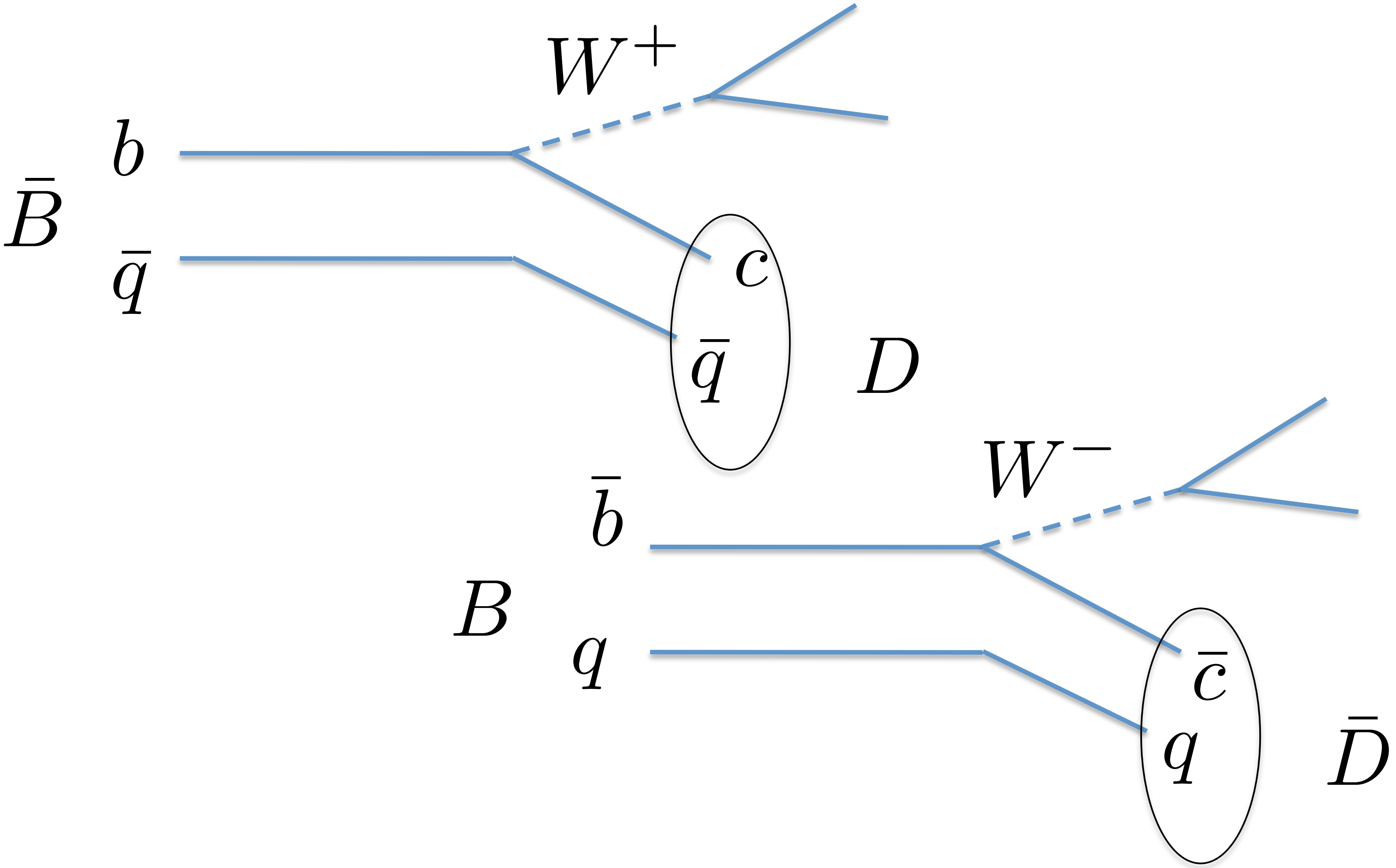


→ at high luminosity B –triggers become "problematic", increase Pt cut or multiplicity

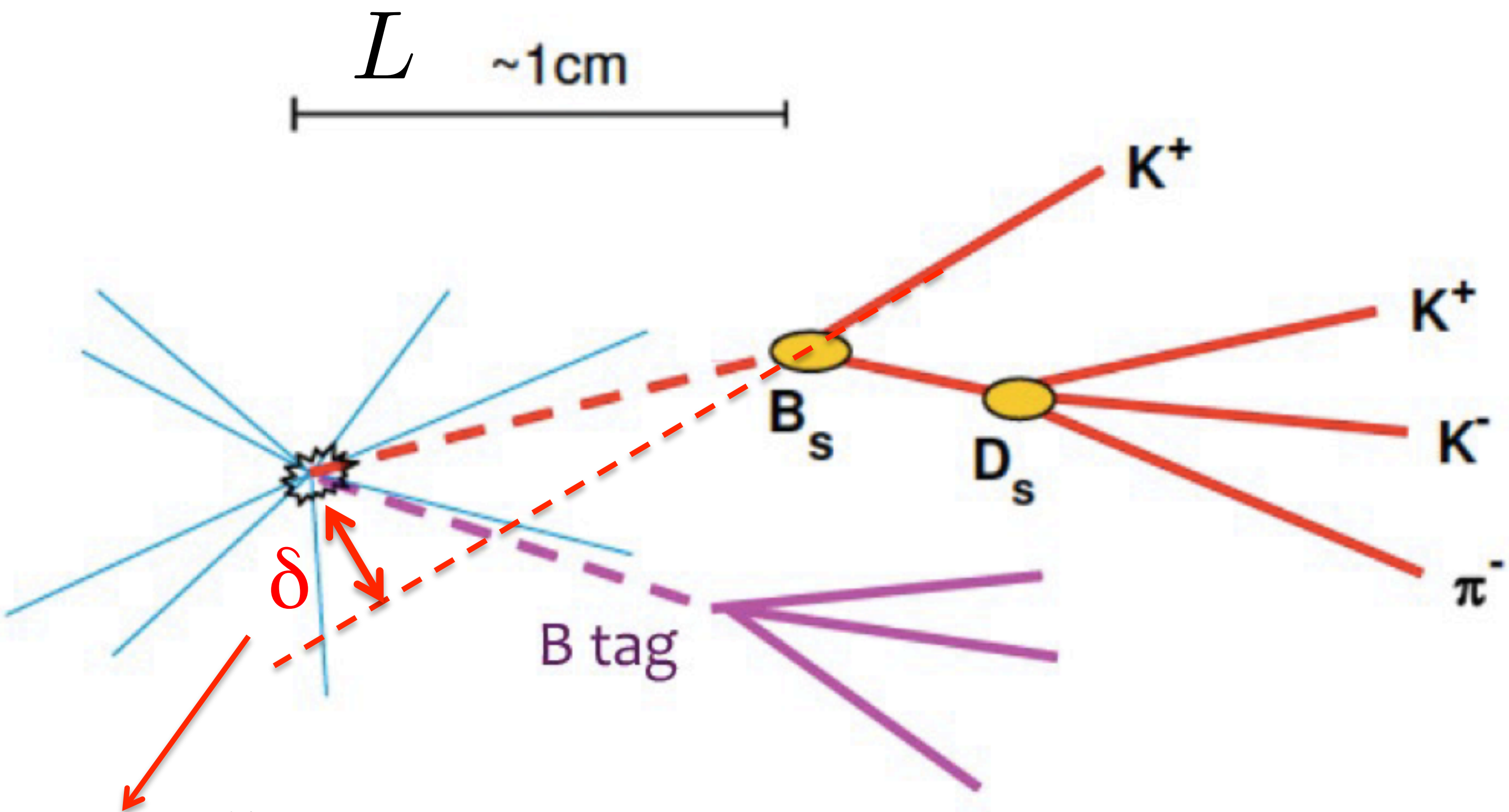
2.4 Use of fully reconstructed “decay” products

→D^0,D^+, D_s, J/ψ, ϕ, K*, etc…for background reduction

→allows the tagging of the type of B-hadron



2.5 $\tau_B \approx 1{,}5$ ps → displaced vertex



parametro d'impatto

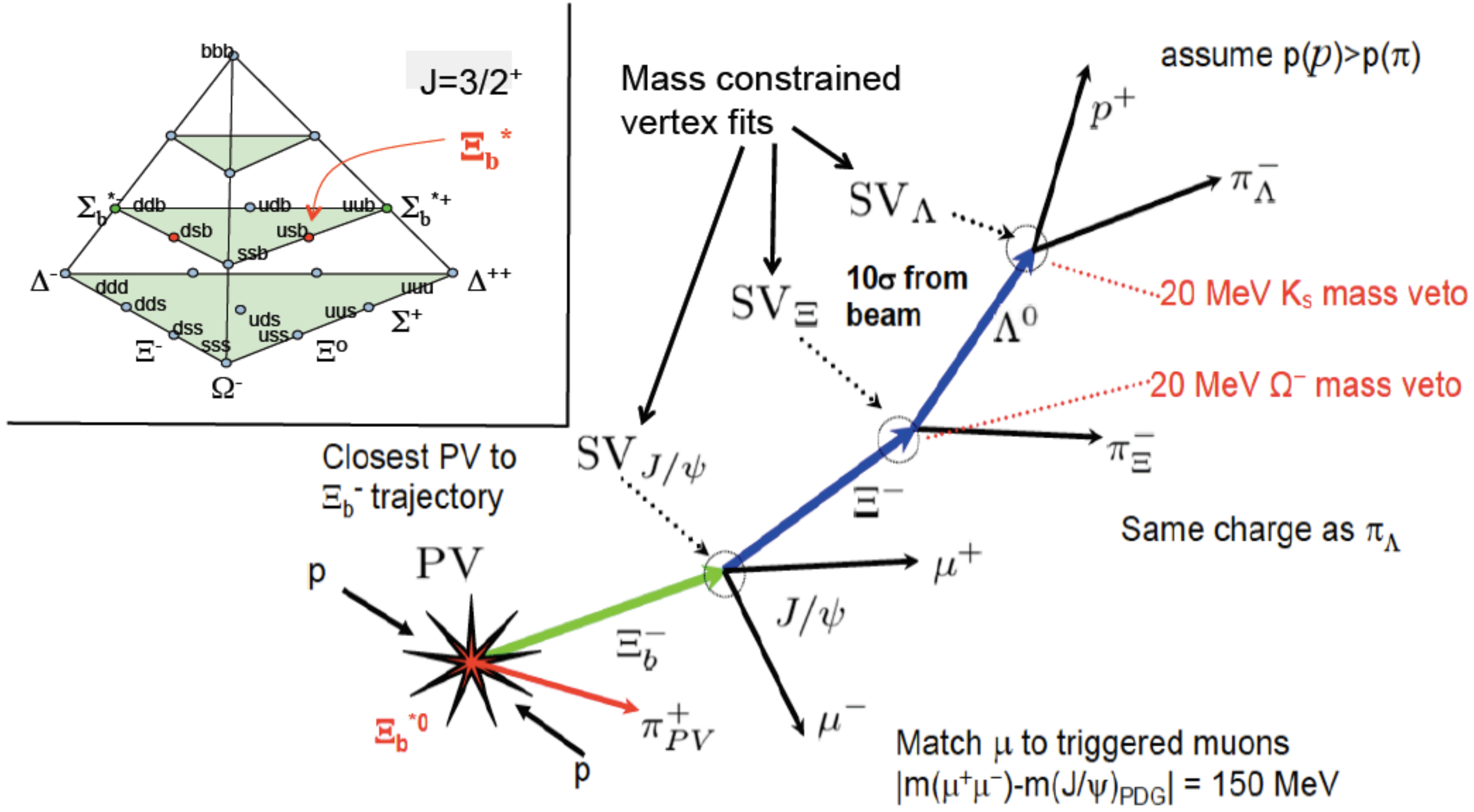
$$\delta \sim c \cdot \tau \sim 450 \mu m$$

tempo proprio

$$t = \frac{L \cdot m}{p} \xrightarrow{transv.} t \approx \frac{L_{xy} \cdot m}{p_T}$$

3.1 Discovery of new states

Discovery of Ξ_b^* baryon CMS



J=3/2$^+$

Mass constrained vertex fits

assume $p(p)>p(\pi)$

10σ from beam

20 MeV K_S mass veto

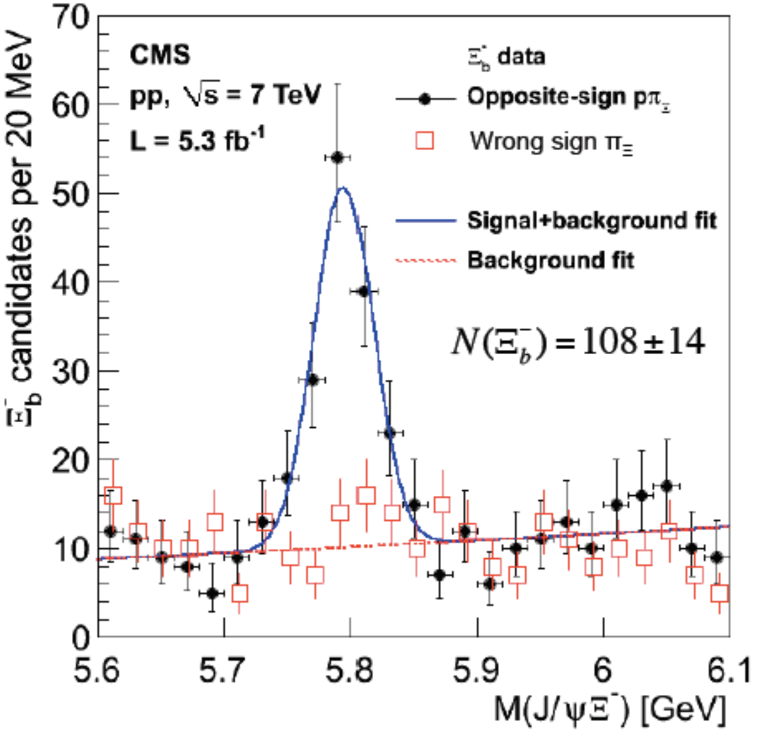
20 MeV Ω^- mass veto

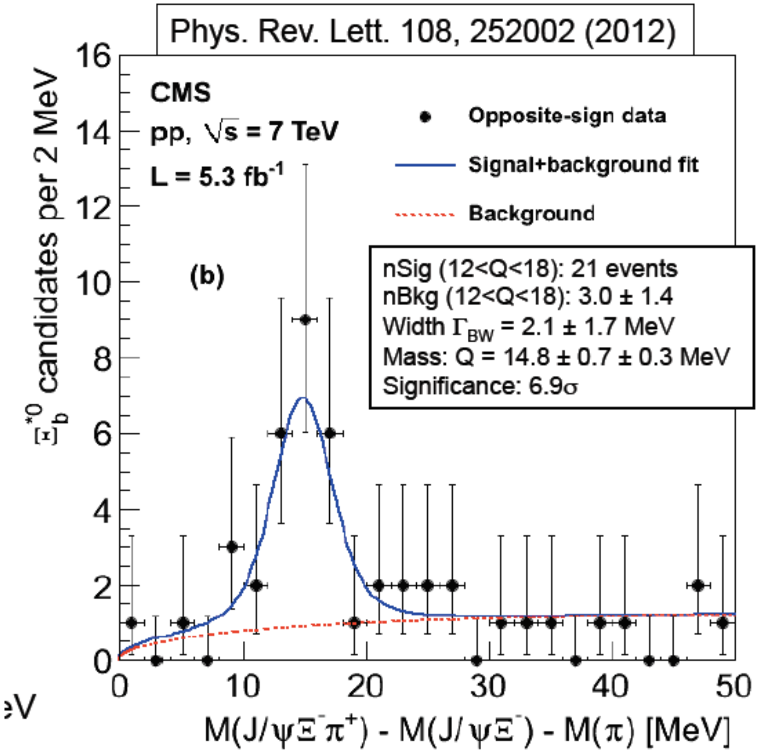
Same charge as π_Λ

Closest PV to Ξ_b^- trajectory

Match μ to triggered muons
$|m(\mu^+\mu^-)-m(J/\psi)_{PDG}| = 150$ MeV

$\Xi_b^- \to J/\Psi(\mu^-\mu^+)\Xi^-(\Lambda\pi^-)$ with $\Lambda \to p\pi^-$



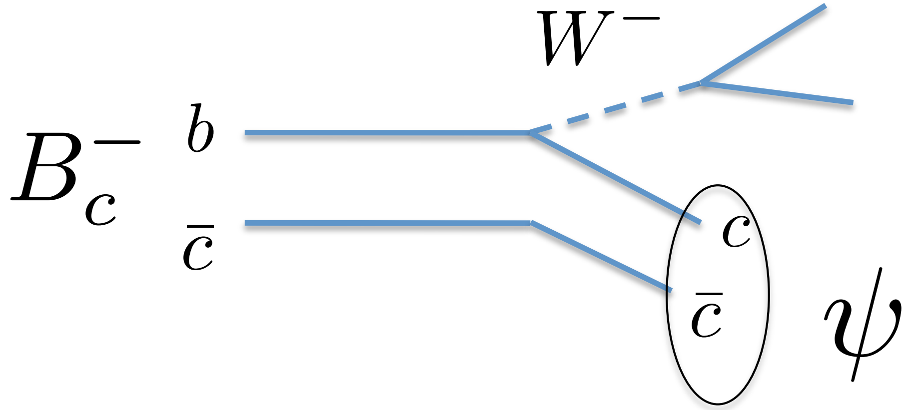


- ☐ Measured mass =

$m(\Xi_b^*) = 5945.0 \pm 0.7 \pm 0.3 \pm 2.7$ (PDG) MeV

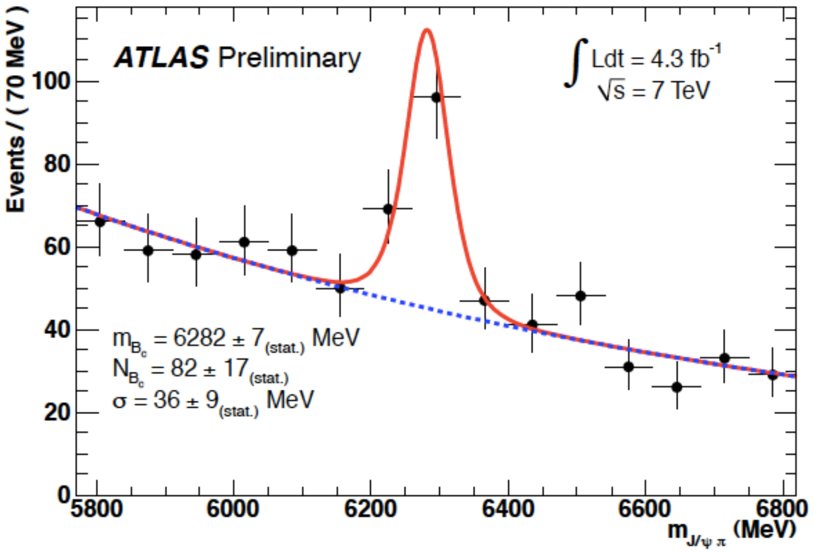
Plot difference of invariant mass
→ “cancel” resolution effects (first order)

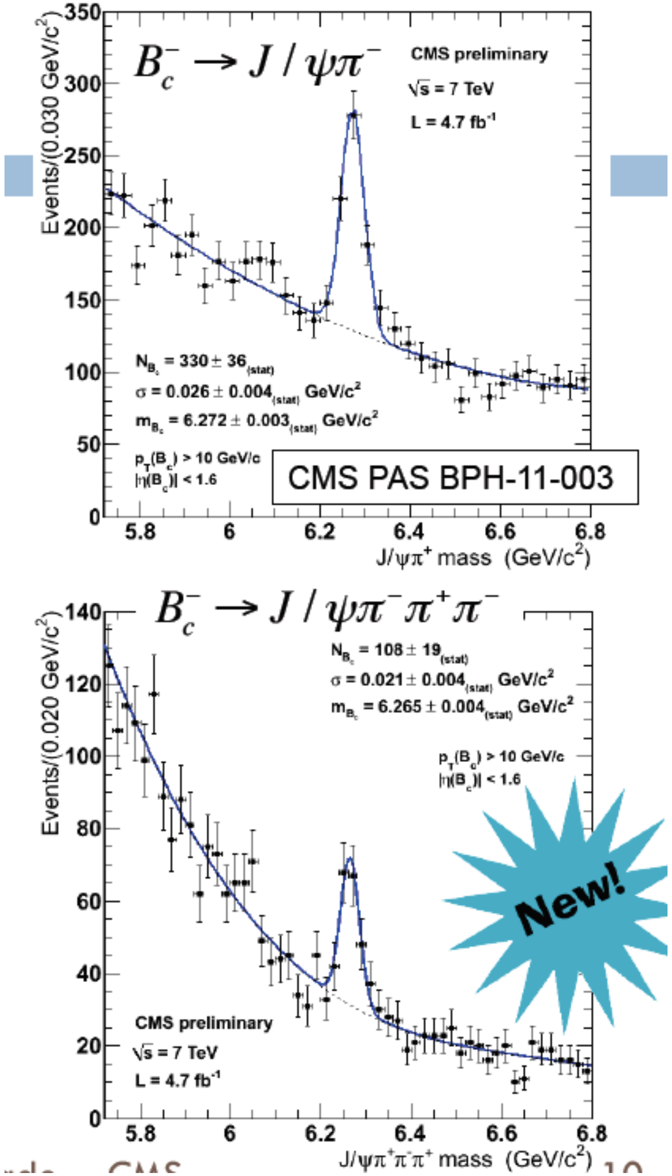
3.2 B_c observation



$$\tau_b \sim 1,5\text{ps} \leftrightarrow \tau_c \sim 0,4\text{ps}$$

B_c observation

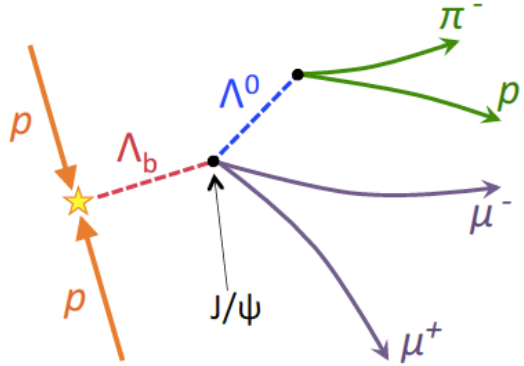


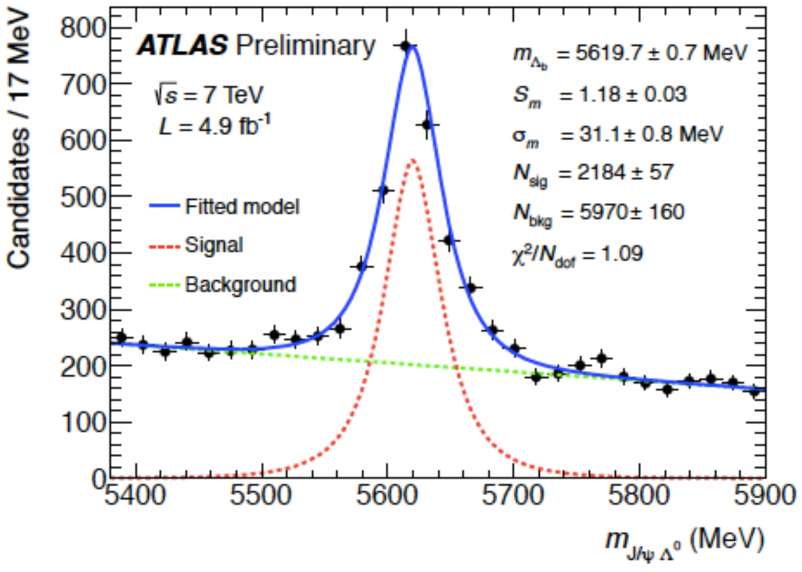


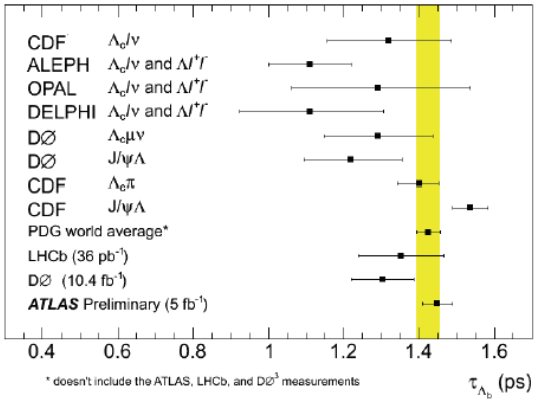
- ATLAS-CONF-2012-028
- B_c is observed in $B_c \to J/\psi(\mu^+\mu^-)\ \pi$.
- Result: $m(B_c) = 6282 \pm 7_{stat}$ MeV (PDG value: 6277 ± 6 MeV)

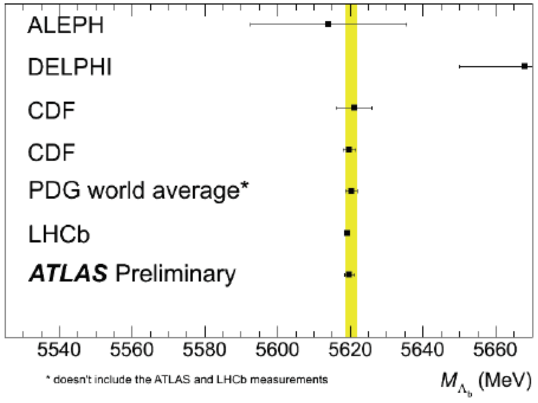
3.3 Λ_b mass and lifetime

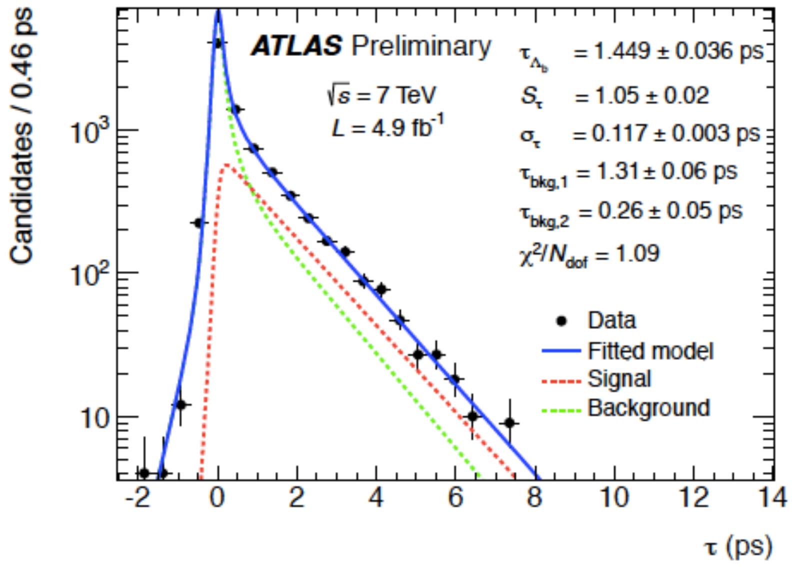
→ better understanding of the baryonic sector which is “unaccessible” at B –factories



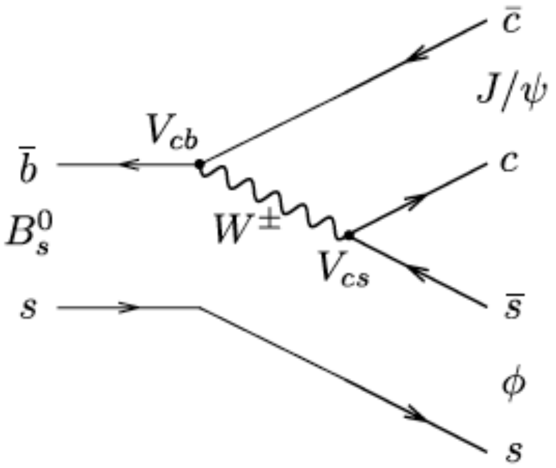


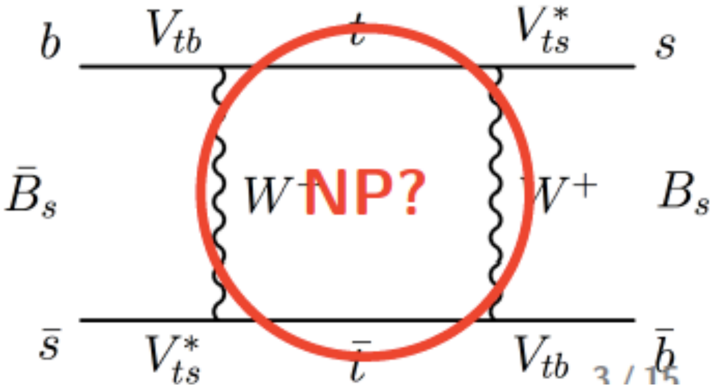


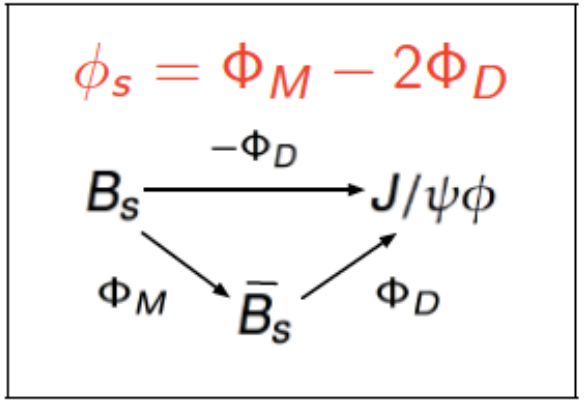




3.4 $B_s \rightarrow J/\psi\ \phi$ decay







$$\phi_s = \Phi_M - 2\Phi_D$$

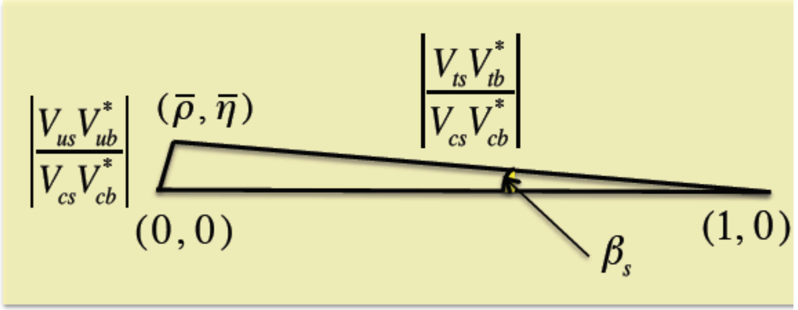
$$\begin{tikzcd}
B_s \arrow[rr, "-\Phi_D"] \arrow[dr, "\Phi_M"'] & & J/\psi\phi \\
& \bar{B}_s \arrow[ur, "\Phi_D"'] &
\end{tikzcd}$$

Due to flavor changing couplings to common states, the time evolution of the meson B_S and $\bar{B}_S$ is described by the superposition of B_H and B_L states, with masses $m_S \pm \Delta m_S/2$ and lifetimes $\Gamma_S \mp \Delta\Gamma_S/2$.

These states deviate from defined values $CP = \pm 1$, as described in the SM by the mixing phase φ_s :

$$\varphi_s = -2\beta_s ,$$

$$\beta_s = \arg[-(V_{ts}V_{tb}^*)/(V_{cs}V_{cb}^*)]$$



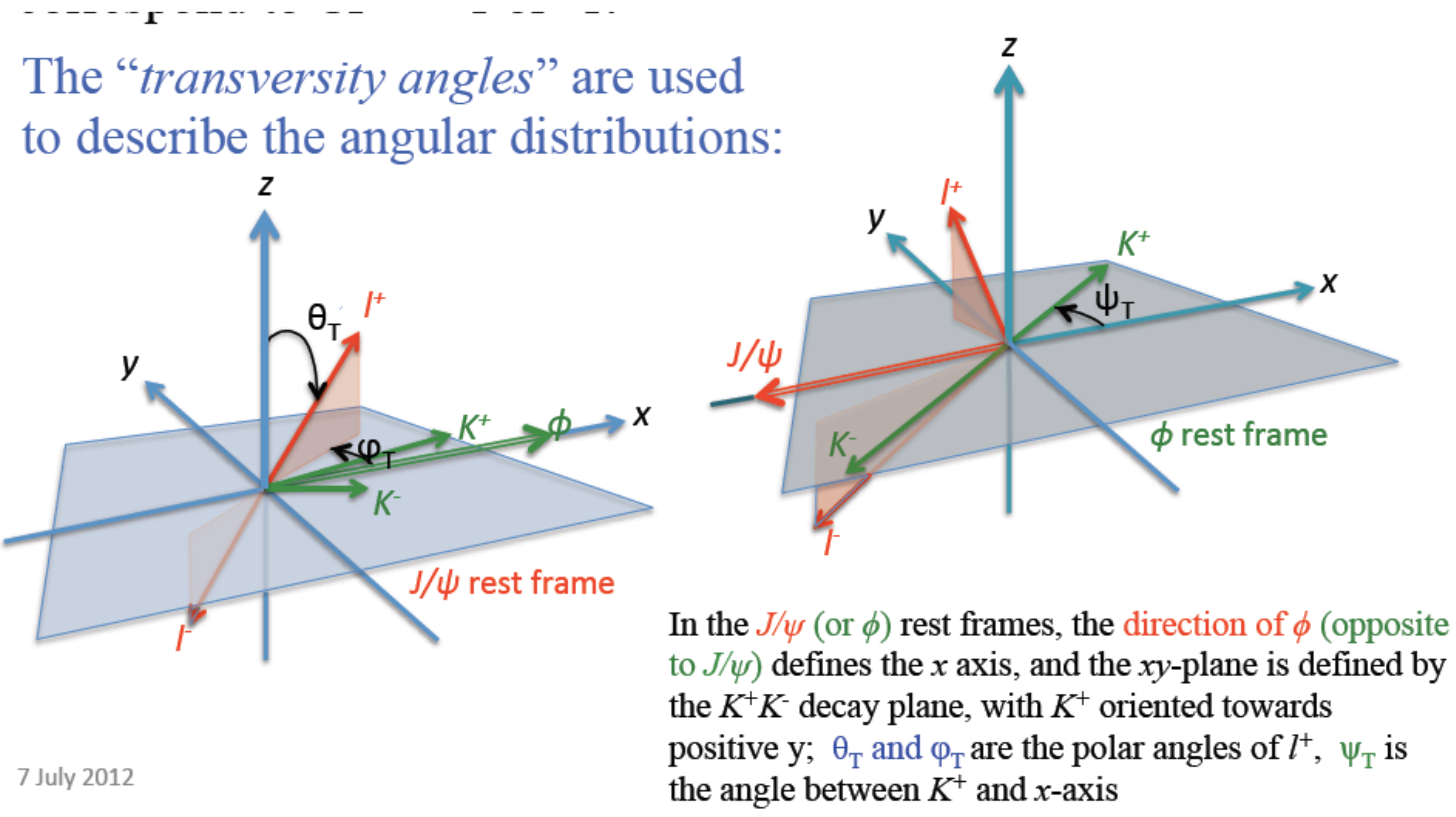
SM prediction (fit): $\varphi_s = -0.0368 \pm 0.0018$ rad

$\Delta\Gamma_S = 0.082 \pm 0.021\ \text{ps}^{-1}$

New Physics might add an additional contribution to φ_s , and might change the ratio $\Delta\Gamma_S / \Delta m_S$.

→ invariant mass plot

→ Proper time distribution for the “different” components



The “*transversity angles*” are used to describe the angular distributions:

In the J/ψ (or ϕ) rest frames, the direction of ϕ (opposite to J/ψ) defines the x axis, and the xy-plane is defined by the K^+K^- decay plane, with K^+ oriented towards positive y; θ_T and φ_T are the polar angles of l^+, ψ_T is the angle between K^+ and x-axis

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Different decay amplitudes correspond to angular amplitudes of defined *CP*. The overall time- and angle-dependent probability is:

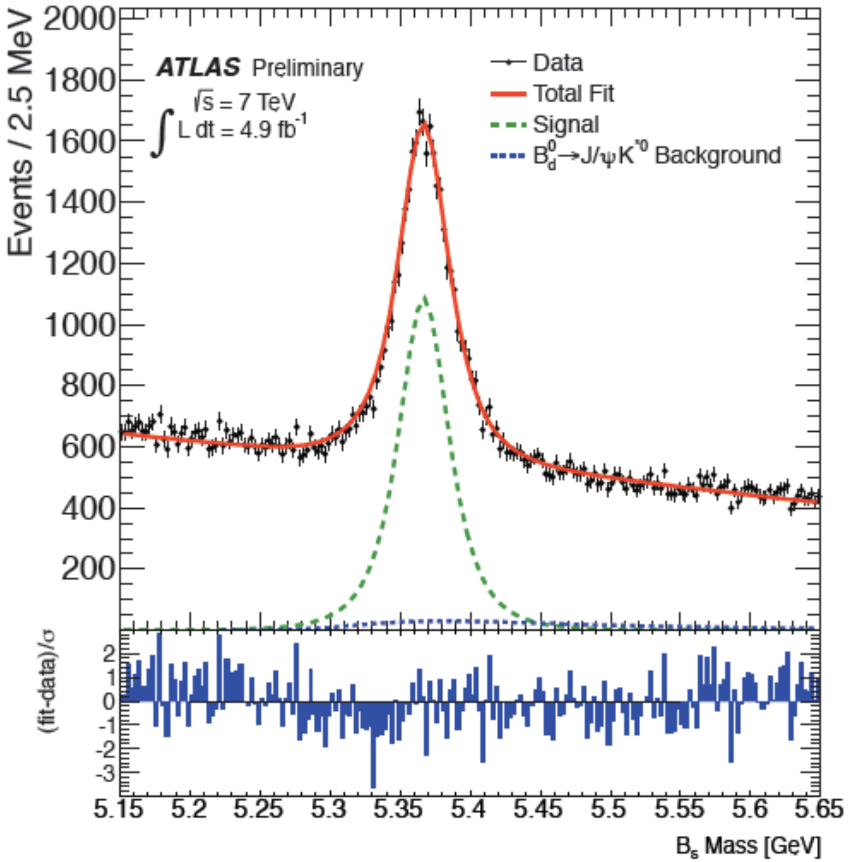
$$\frac{d^4\Gamma}{dt\,d\Omega} = \sum_k \mathcal{O}^{(k)}(t) g^{(k)}(\theta_T, \psi_T, \varphi_T)$$

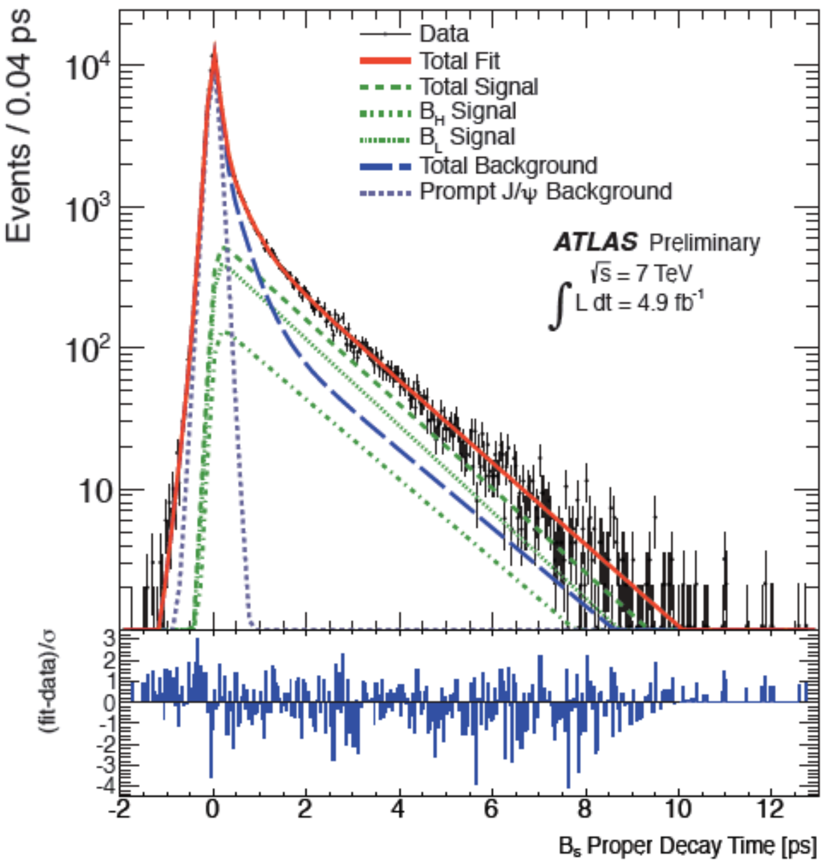
k	$\mathcal{O}^{(k)}(t)$	$g^{(k)}(\theta_T, \psi_T, \varphi_T)$	
1	$\frac{1}{2}\lvert A_0(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t}\right]$	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\varphi_T)$	CP= +1
2	$\frac{1}{2}\lvert A_\parallel(0)\rvert^2 \left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t}\right]$	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\varphi_T)$	CP= +1
3	$\frac{1}{2}\lvert A_\perp(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t}\right]$	$\sin^2\psi_T\sin^2\theta_T$	CP= −1
4	$\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\parallel(0)\rvert\cos\delta_{\parallel}$ $\left[(1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t}\right]$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\varphi_T$	Interference terms
5	$\frac{1}{2}\lvert A_\parallel(0)\rvert\lvert A_\perp(0)\rvert\left(e^{-\Gamma_{\mathrm{H}}^{(s)}t} - e^{-\Gamma_{\mathrm{L}}^{(s)}t}\right)\cos(\delta_\perp-\delta_{\parallel})\sin\phi_s$	$\sin^2\psi_T\sin 2\theta_T\sin\varphi_T$	
6	$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_\perp(0)\rvert\left(e^{-\Gamma_{\mathrm{H}}^{(s)}t} - e^{-\Gamma_{\mathrm{L}}^{(s)}t}\right)\cos\delta_\perp\sin\phi_s$	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\cos\varphi_T$	
7	$\frac{1}{2}\lvert A_S(0)\rvert^2 \left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t}\right]$	$\frac{2}{3}\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$	Terms related to non-resonant and f^0 amplitude for K^+K^- (S-wave)
8	$-\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\parallel(0)\rvert\left(e^{-\Gamma_{\mathrm{H}}^{(s)}t} - e^{-\Gamma_{\mathrm{L}}^{(s)}t}\right)\sin(\delta_\parallel-\delta_S)\sin\phi_s$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\varphi_T$	
9	$\frac{1}{2}\lvert A_S(0)\rvert\lvert A_\perp(0)\rvert$ $\left[(1-\cos\phi_s)\, e^{-\Gamma_{\mathrm{L}}^{(s)}t} + (1+\cos\phi_s)\, e^{-\Gamma_{\mathrm{H}}^{(s)}t}\right]\sin(\delta_\perp-\delta_S)$	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\varphi_T$	
10	$-\frac{1}{2}\lvert A_0(0)\rvert\lvert A_S(0)\rvert\sin(-\delta_S)\left(e^{-\Gamma_{\mathrm{H}}^{(s)}t} - e^{-\Gamma_{\mathrm{L}}^{(s)}t}\right)\sin\phi_s$	$\frac{4}{3}\sqrt{3}\cos\psi_T\left(1-\sin^2\theta_T\cos^2\varphi_T\right)$	

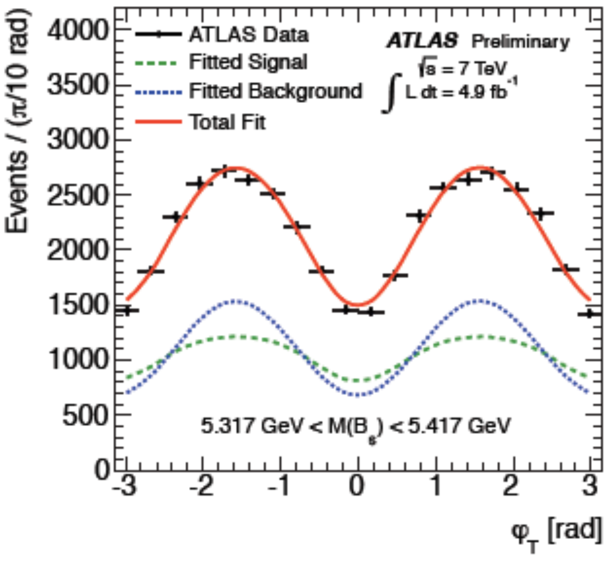
$$\ln\ \mathcal{L} = \sum_{i=1}^{N}\{w_i\cdot\ln(f_{\mathrm{s}}\cdot\boxed{\mathcal{F}_{\mathrm{s}}(m_i,t_i,\Omega_i)} + f_{\mathrm{s}}\cdot f_{\mathrm{B}^0}\cdot\boxed{\mathcal{F}_{\mathrm{B}^0}(m_i,t_i,\Omega_i)}$$

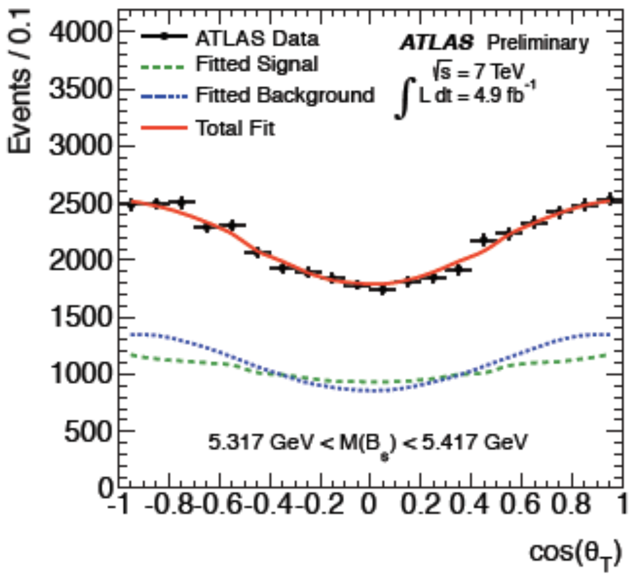
$$+(1-f_{\mathrm{s}}\cdot(1+f_{\mathrm{B}^0}))\boxed{\mathcal{F}_{\mathrm{bkg}}(m_i,t_i,\Omega_i)})\} + \ln P(\delta_\perp)$$

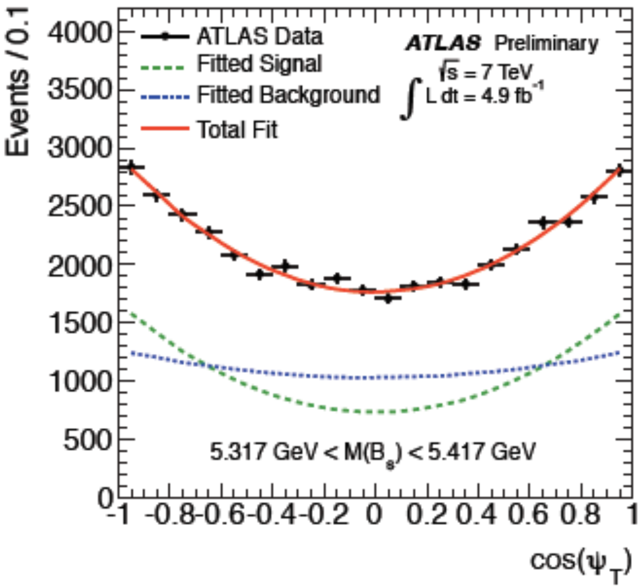
Terms describing:

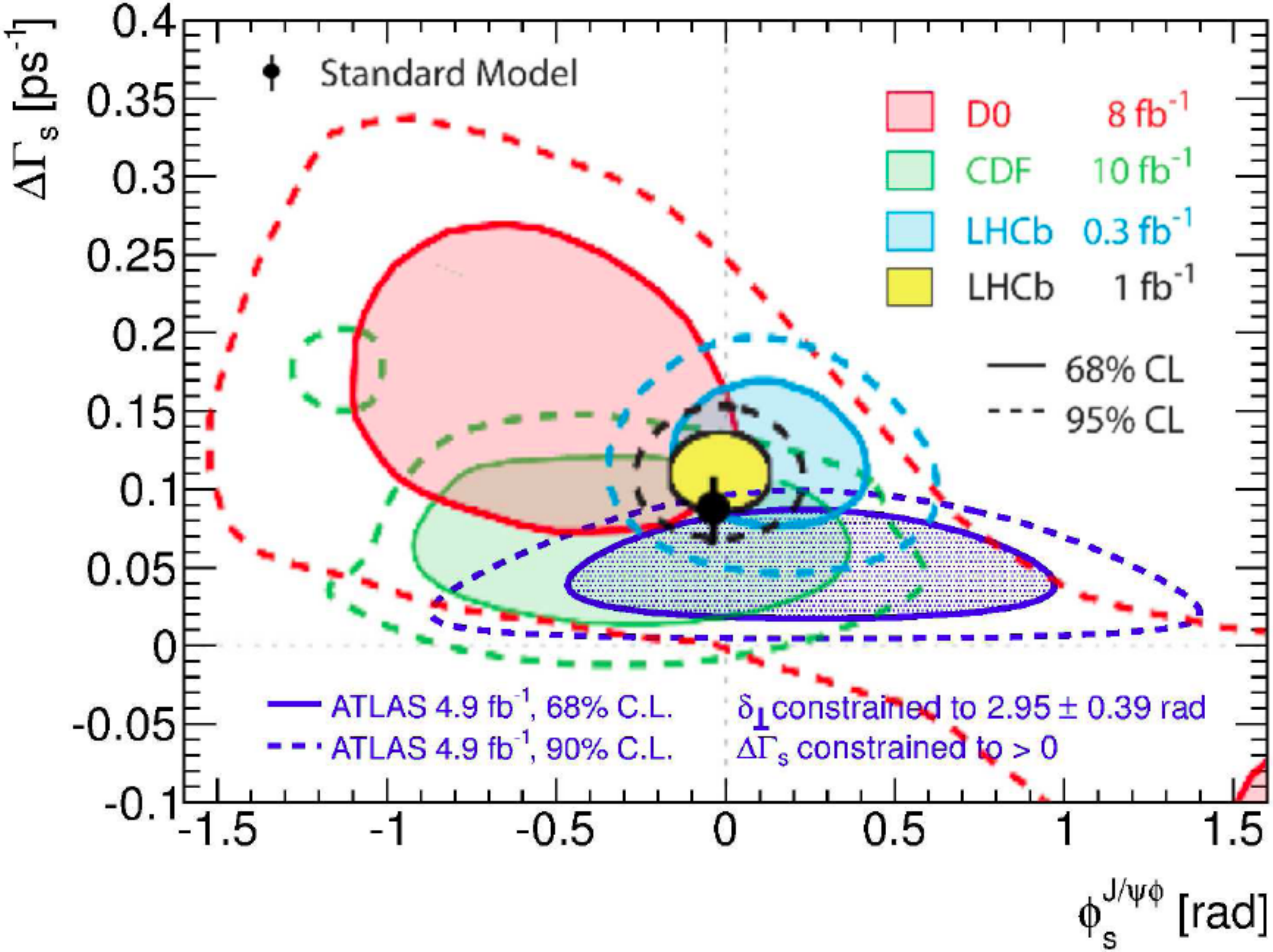

ATLAS Preliminary
$\sqrt{s}$ = 7 TeV
$\int L\,dt = 4.9\ \mathrm{fb}^{-1}$
Data
Total Fit
Signal
$B_d^0 \to J/\psi K^{*0}$ Background
Events / 2.5 MeV
2000
1800
1600
1400
1200
1000
800
600
400
200
(fit-data)/σ
2
1
0
-1
-2
-3
5.15
5.2
5.25
5.3
5.35
5.4
5.45
5.5
5.55
5.6
5.65
B_s Mass [GeV]


Data
Total Fit
Total Signal
B_H Signal
B_L Signal
Total Background
Prompt J/ψ Background
ATLAS Preliminary
$\sqrt{s}$ = 7 TeV
$\int L\,dt = 4.9\ \mathrm{fb}^{-1}$
Events / 0.04 ps
10^4
10^3
10^2
10
(fit-data)/σ
3
2
1
0
-1
-2
-3
-4
-2
0
2
4
6
8
10
12
B_s Proper Decay Time [ps]


ATLAS Data
Fitted Signal
Fitted Background
Total Fit
ATLAS Preliminary
$\sqrt{s}$ = 7 TeV
$\int L\,dt = 4.9\ \mathrm{fb}^{-1}$
Events / (π/10 rad)
4000
3500
3000
2500
2000
1500
1000
500
0
5.317 GeV < M(B_s) < 5.417 GeV
-3
-2
-1
0
1
2
3
φ_T [rad]


ATLAS Data
Fitted Signal
Fitted Background
Total Fit
ATLAS Preliminary
$\sqrt{s}$ = 7 TeV
$\int L\,dt = 4.9\ \mathrm{fb}^{-1}$
Events / 0.1
4000
3500
3000
2500
2000
1500
1000
500
0
5.317 GeV < M(B_s) < 5.417 GeV
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
cos(θ_T)

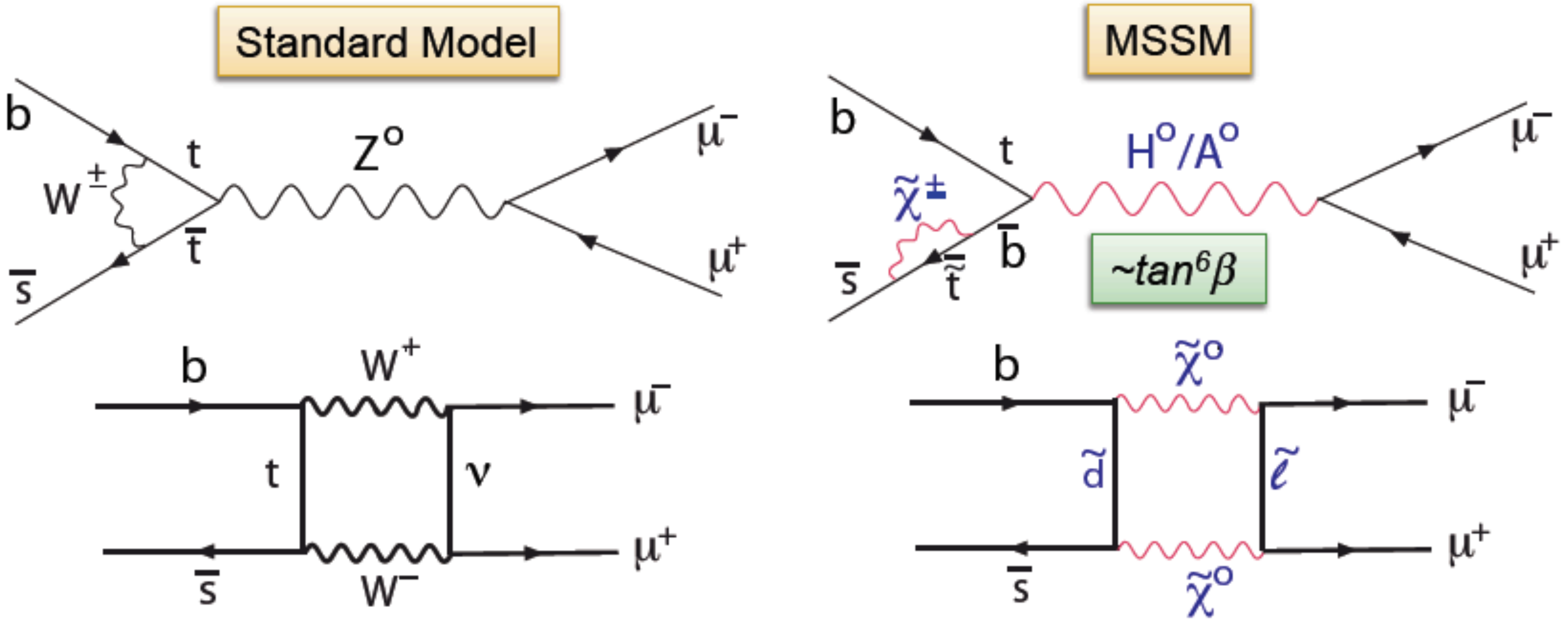

ATLAS Data
Fitted Signal
Fitted Background
Total Fit
ATLAS Preliminary
$\sqrt{s}$ = 7 TeV
$\int L\,dt = 4.9\ \mathrm{fb}^{-1}$
Events / 0.1
4000
3500
3000
2500
2000
1500
1000
500
0
5.317 GeV < M(B_s) < 5.417 GeV
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
cos(ψ_T)


Standard Model
D0 8 fb^{-1}
CDF 10 fb^{-1}
LHCb 0.3 fb^{-1}
LHCb 1 fb^{-1}
68% CL
95% CL
ATLAS 4.9 fb^{-1}, 68% C.L.
ATLAS 4.9 fb^{-1}, 90% C.L.
$\delta_\perp$ constrained to 2.95 ± 0.39 rad
$\Delta\Gamma_s$ constrained to > 0
$\Delta\Gamma_s$ [ps^{-1}]
$\phi_s^{J/\psi\phi}$ [rad]
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-1.5
-1
-0.5
0
0.5
1
1.5

3.4 $B_s \rightarrow \mu^+ \mu^-$ decay

- SM branching ratio is $(3.2 \pm 0.2) \times 10^{-9}$ [Buras arXiv: 1012.1447], NP can make large contributions.

Note, K. De Brun arXive:1204.1737 show that B theory needs to be raised by $1/(1-y_s)$



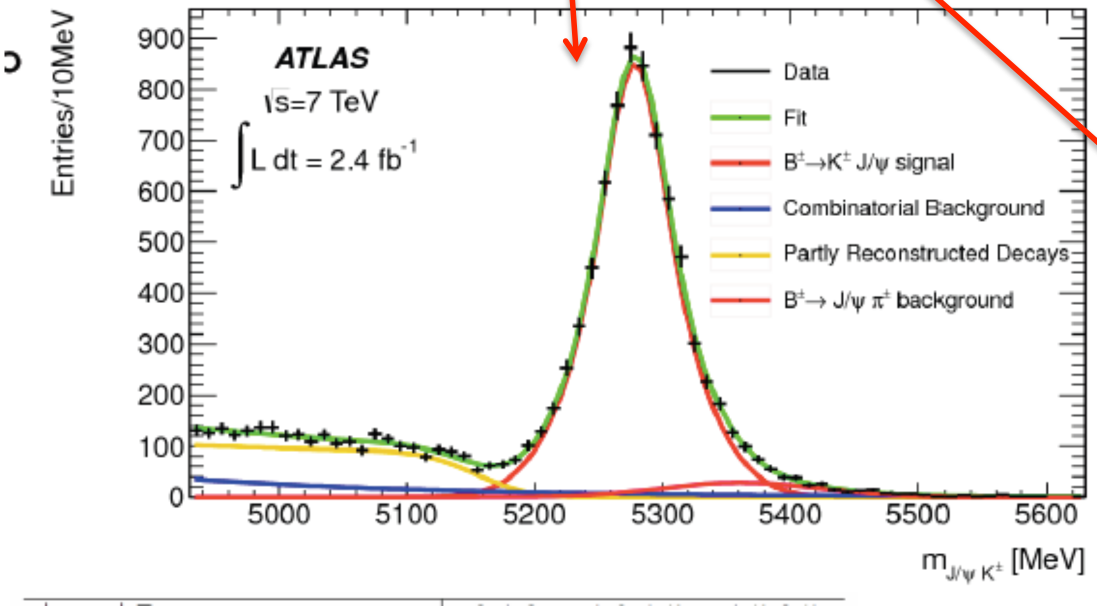
- Many NP models possible, not just Super-Sym

→ Very challenging decay!

Analysis strategy via a reference channel well measured with similar “kinematics”

→ cancel several systematics effects

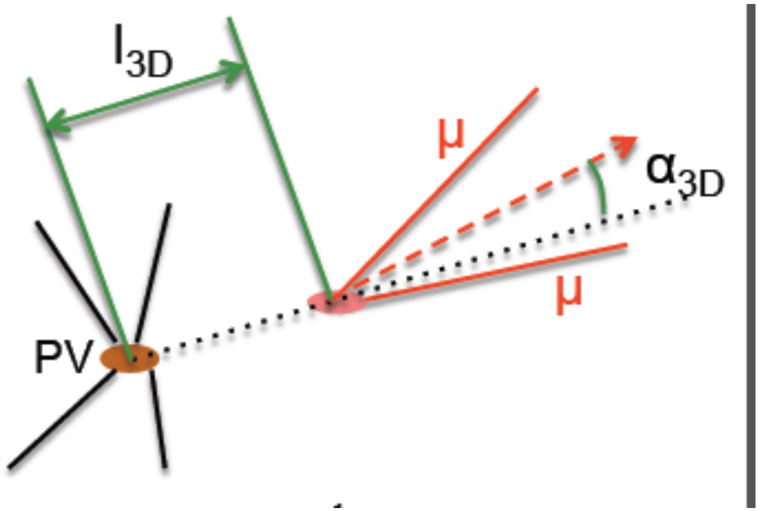
$$BR(B_s \to \mu\mu) = \frac{N_{B_s \to \mu\mu}}{N_{J/\psi K^\pm}} \cdot \frac{\alpha_{J/\psi K^\pm}\, \varepsilon^{tot}_{J/\psi K^\pm}}{\alpha_{B_s \to \mu\mu}\, \varepsilon^{tot}_{B_s \to \mu\mu}} \cdot \frac{f_u}{f_s} \cdot BR(B^\pm \to J/\psi K^\pm)$$



From PDG

Isolate tiny signal over huge backgr.

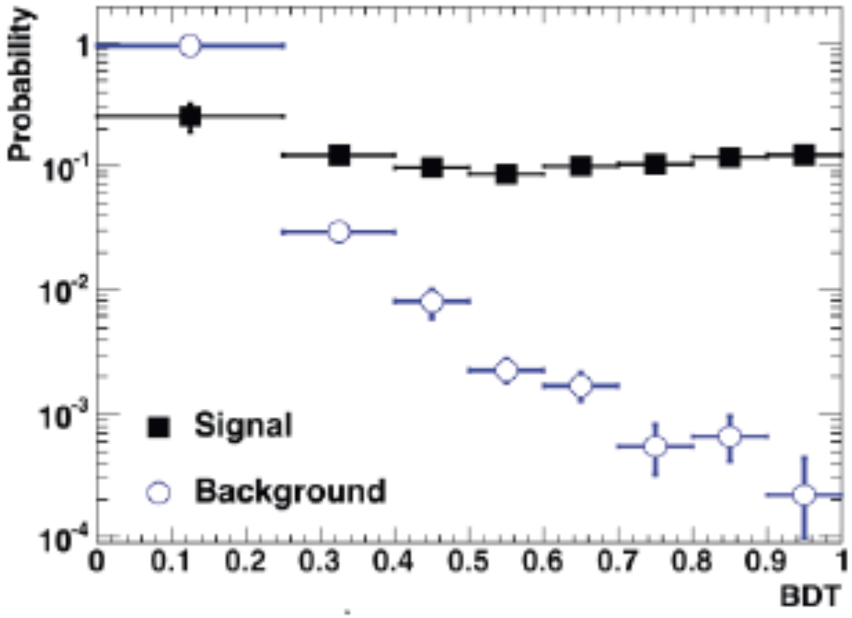
3.4 $B_s \rightarrow \mu^+ \mu^-$ decay



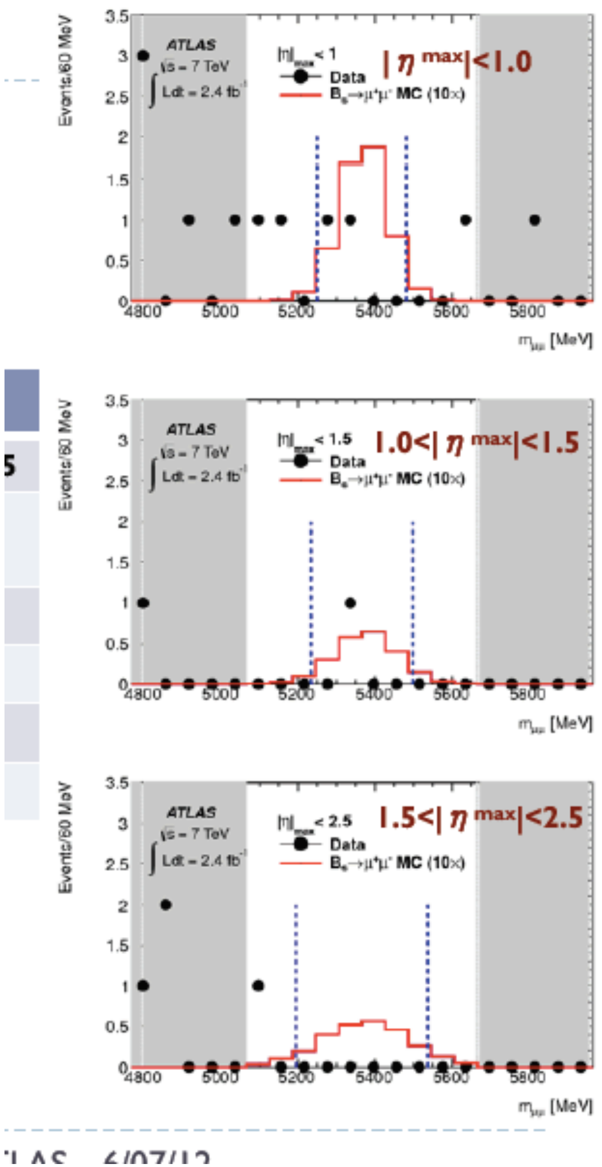
Add more cuts:

- impact parameter of muons
- muon isolation and momentum
- B momentum
- decay distance and proper time
- angle for two body decay

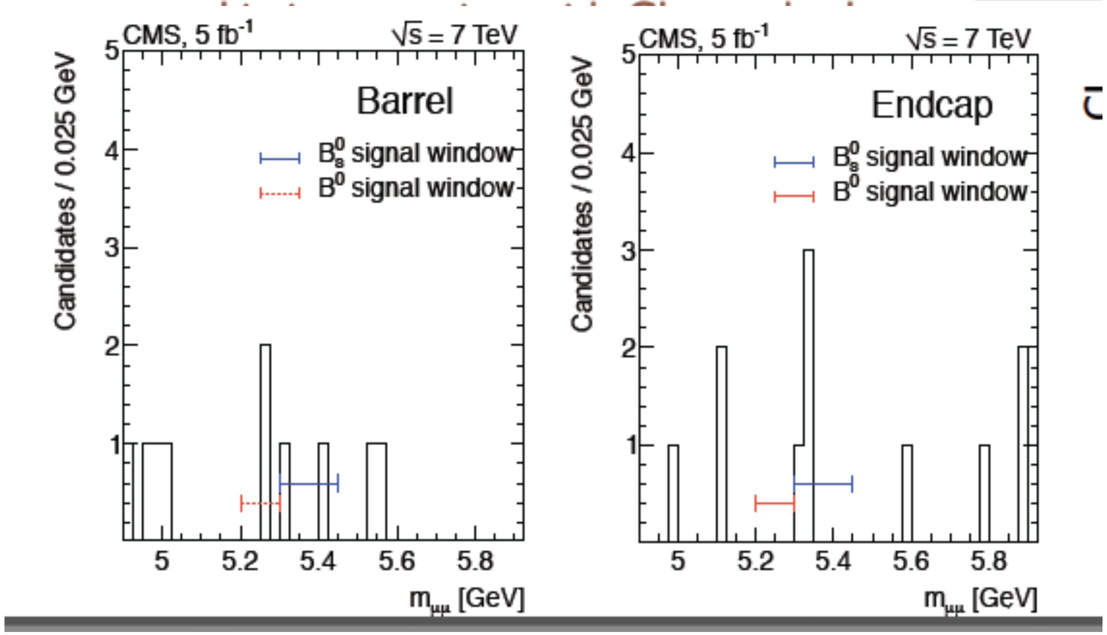
Combination of the various “ingredients” → multivariate analysis (BDT ~15 variables) to be optimized on MonteCarlo



3.4 $B_s \rightarrow \mu^+ \mu^-$ decay

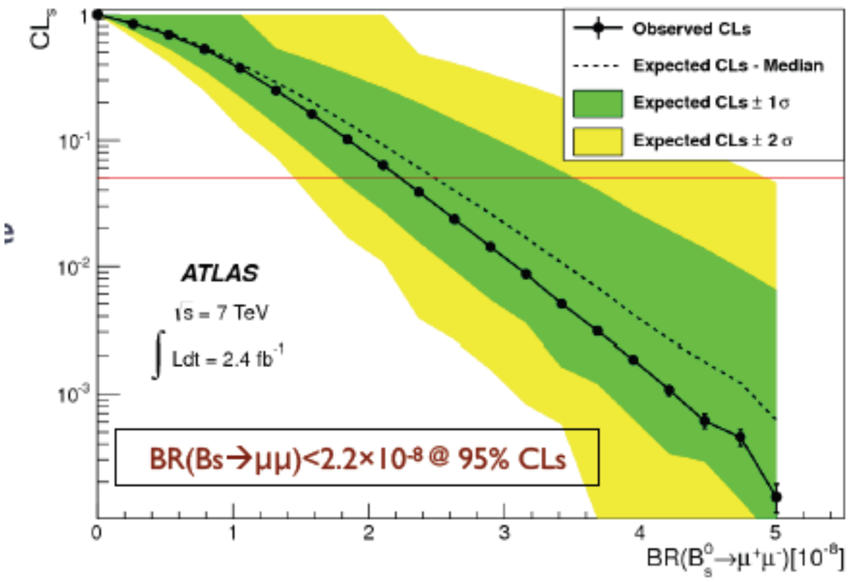


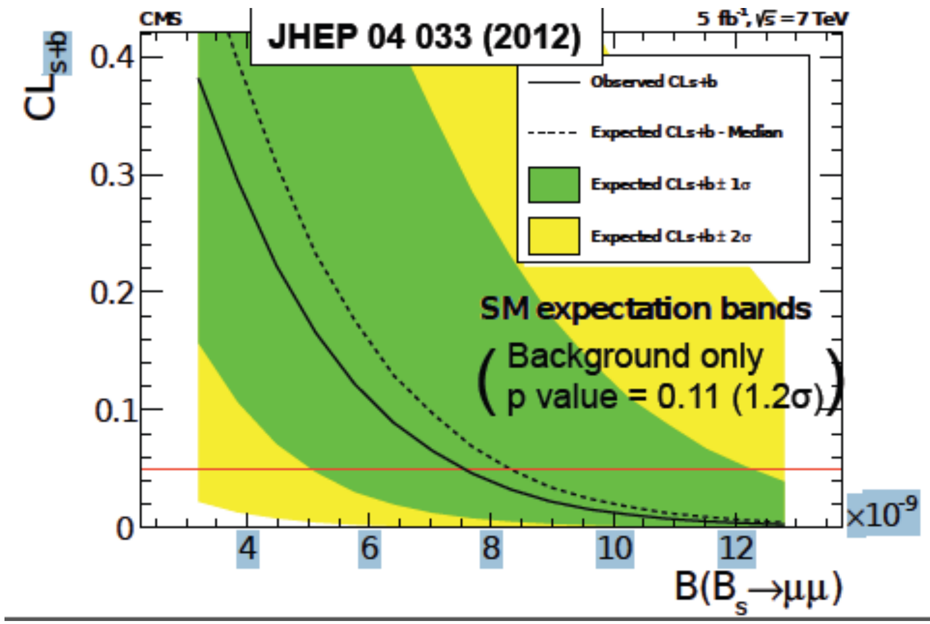
- Unbiassed
  - Blind analysis
    - signal region (±300MeV around B^0_s mass) blinded
    - Use MC to model data
  - Background data in sidebands split in two
    - 50% to optimize selection cuts
    - 50% to measure the bkg yield after cuts optimization
- Signal extraction
  - Event count in signal region
  - Background estimation from sidebands

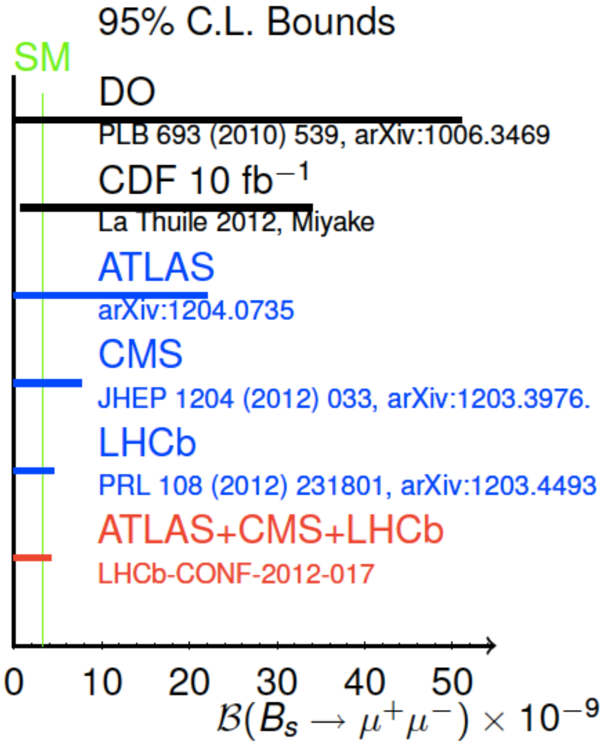


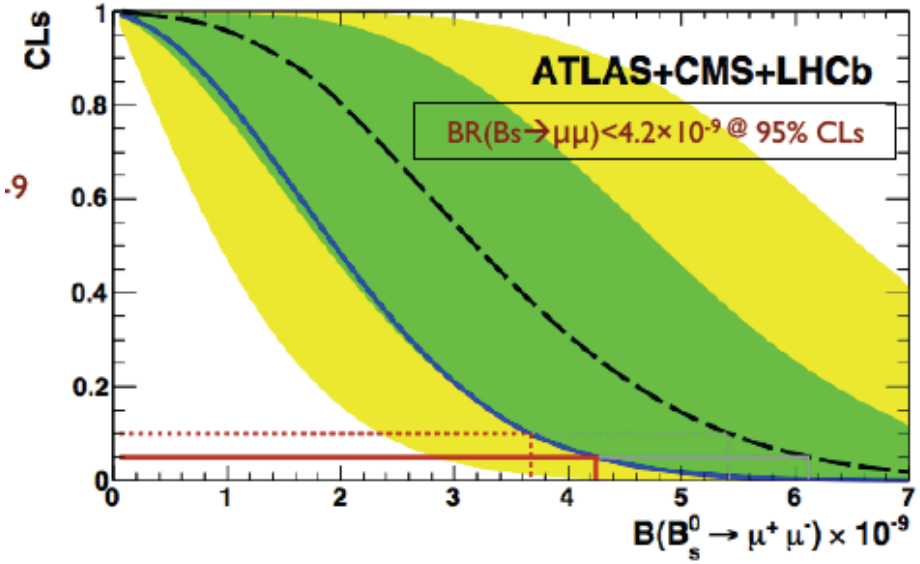
Extraction of limits of “known” signal in presence of background → CLs method

3.4 $B_s \rightarrow \mu^+ \mu^-$ decay









4. Conclusions

1. B-physics is a very important at LHC and fully complementary to B-factories
2. A lot of interesting results with 2011 data already and with 2012 data in next future
3. Hopefully we could get some NP hints soon.