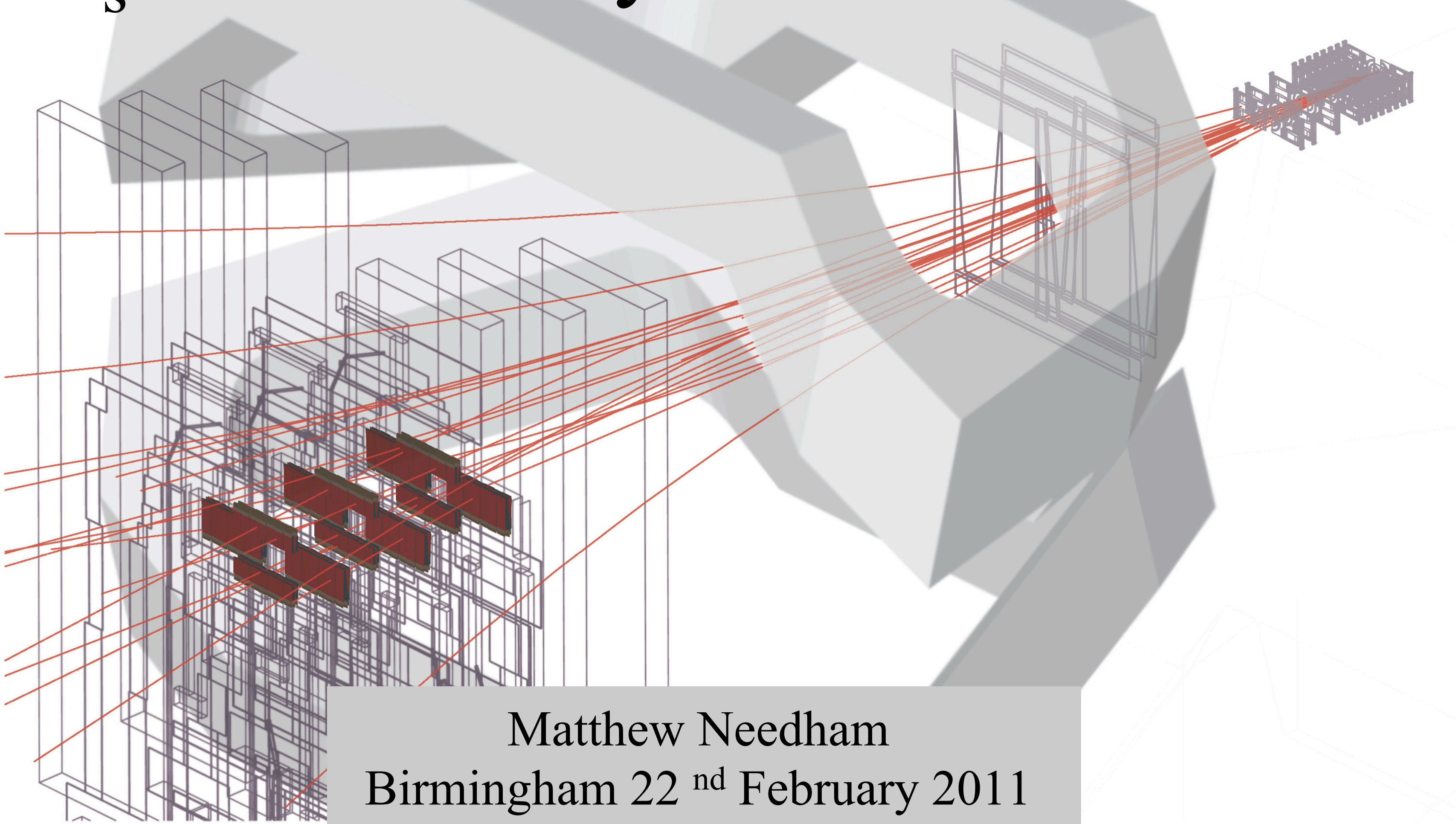
Searching for New Physics in B_s meson decays with LHCb



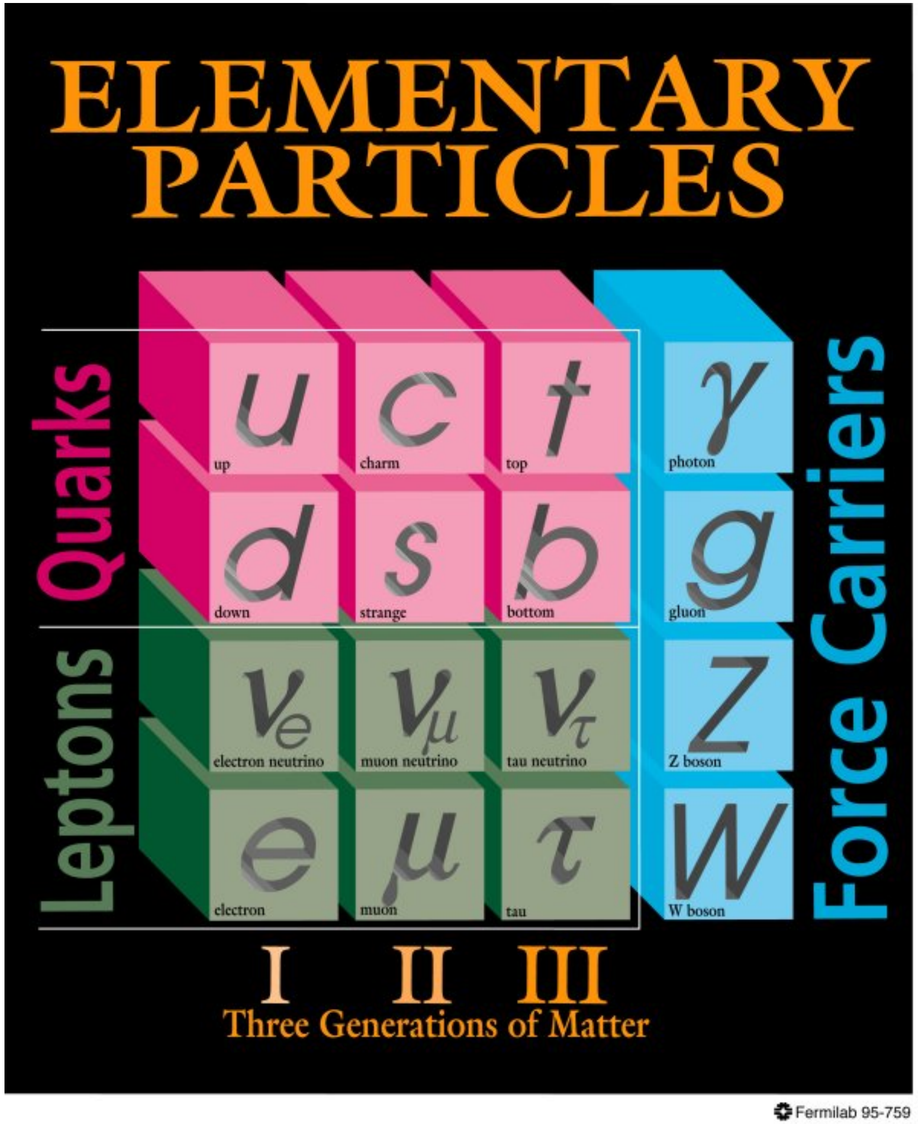
Matthew Needham
Birmingham 22 nd February 2011

Outline

Results I show today are from the time of the summer conferences with ~370 pb^{-1}. For Moriond in a few weeks time new results with full 2011 dataset expected

- New Physics in the Flavour Sector and B_s mixing
- The LHCb detector and performance
- Measurement of CP violating phase ϕ_s in $B_s \rightarrow J/\psi\phi$
  - Key probe for new physics
- ϕ_s in other decay modes
- ϕ_s: future and prospects

The Standard Model



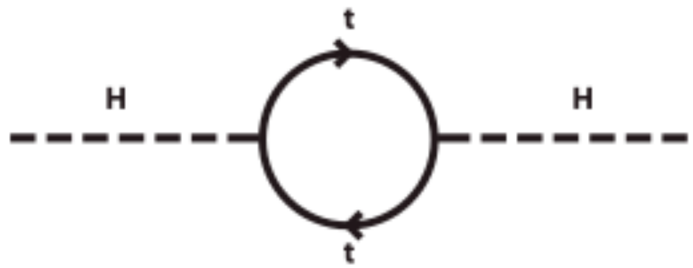
'One of the greatest masterpierces of scientific analysis ever written'

Neuberger in the Exact Sciences in Antiquity describing Ptolemy's planetary system

Can this also be said of the SM ?

Open Questions

What about the Higgs ?



Hint of 125 GeV Higgs

Light Higgs suffers large radiative corrections from the heavy top quark, ‘instability’ of the vacuum.

New Physics, such as Supersymmetry solves this, but expect to see in impact on flavour observables at LHCb

Cosmological Questions

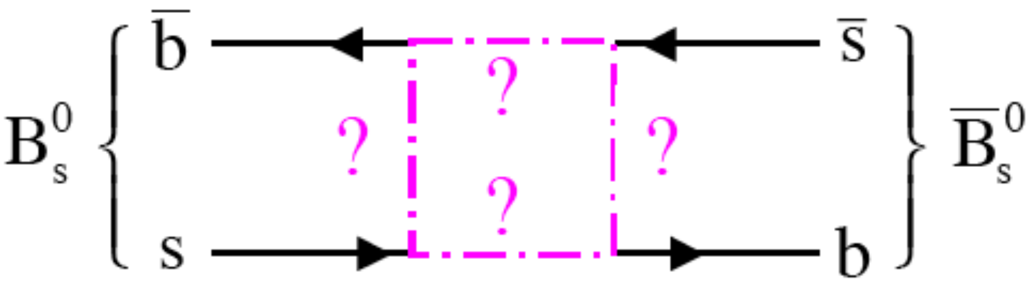
What is the origin of Dark Matter ?

Why is the Universe dominated by matter ? Where did all the anti-matter go ?

Probing New Physics

With the start of LHC operation an exciting era in the search for New Physics has begun

- Direct searches for new particles (ATLAS + CMS)
- Indirect searches (LHCb)
    - Effect of virtual particles in loop processes
    - Probe higher energy scales than direct searches



New Particles ?

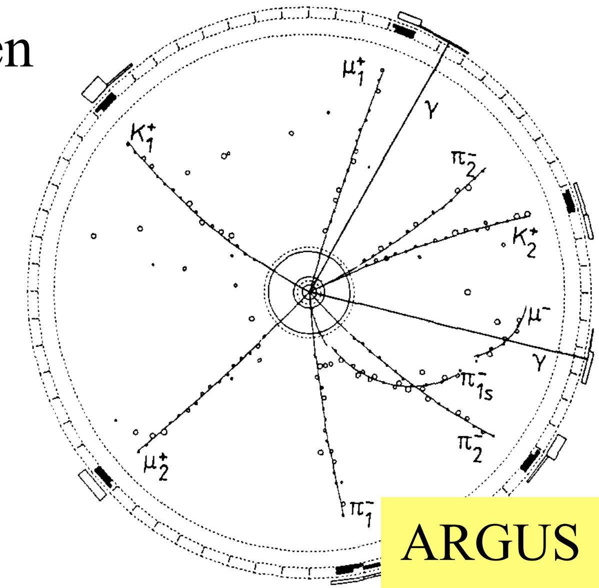
Probing New Physics

Indirect searches important in driving development of Standard Model

Early 1980s light top quark considered allowed, even evidence for 40 GeV top by UA1

Observation of B-mixing in 1987 by ARGUS experiment at DESY

$\Delta m_b \rightarrow$ m(top) > 50 GeV



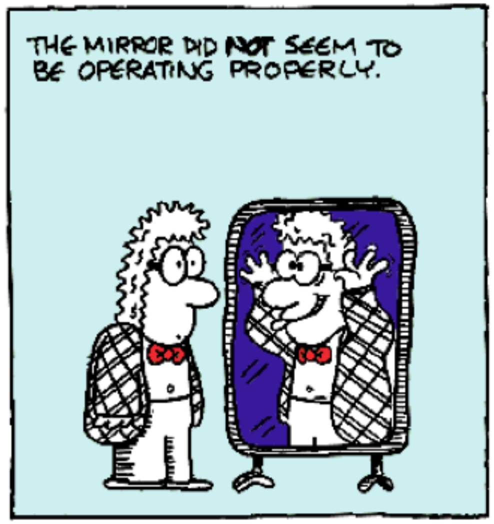
ARGUS event

Late 1960s suppression of $K_L \rightarrow \mu\mu$

Pointed to existance of Charm quark and gave prediction of its mass

CP Violation

CP violation is one of the conditions necessary to generate baryon asymmetry in the Universe



Three important discrete transformations:

P = parity spatial coordinates $x, y, z \rightarrow -x, -y, -z$
T = time reversal $t \rightarrow -t$
C = charge conjugation particles ↔ antiparticles

CPT conserved (Lorentz invariance)

Weak interaction violates CP: distinguishes matter and antimatter

CP Violation

Flavour structure of Standard Model of Particle Physics governed by the quark mixing matrix (CKM matrix)

V_{ij} complex

Weak eigenstates

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

flavour eigenstates

CP violation in the Standard Model generated by complex phase in CKM matrix

Level of CP violation in the Standard Model is insufficient to explain the observed baryon asymmetry of the universe by 10 orders of magnitude

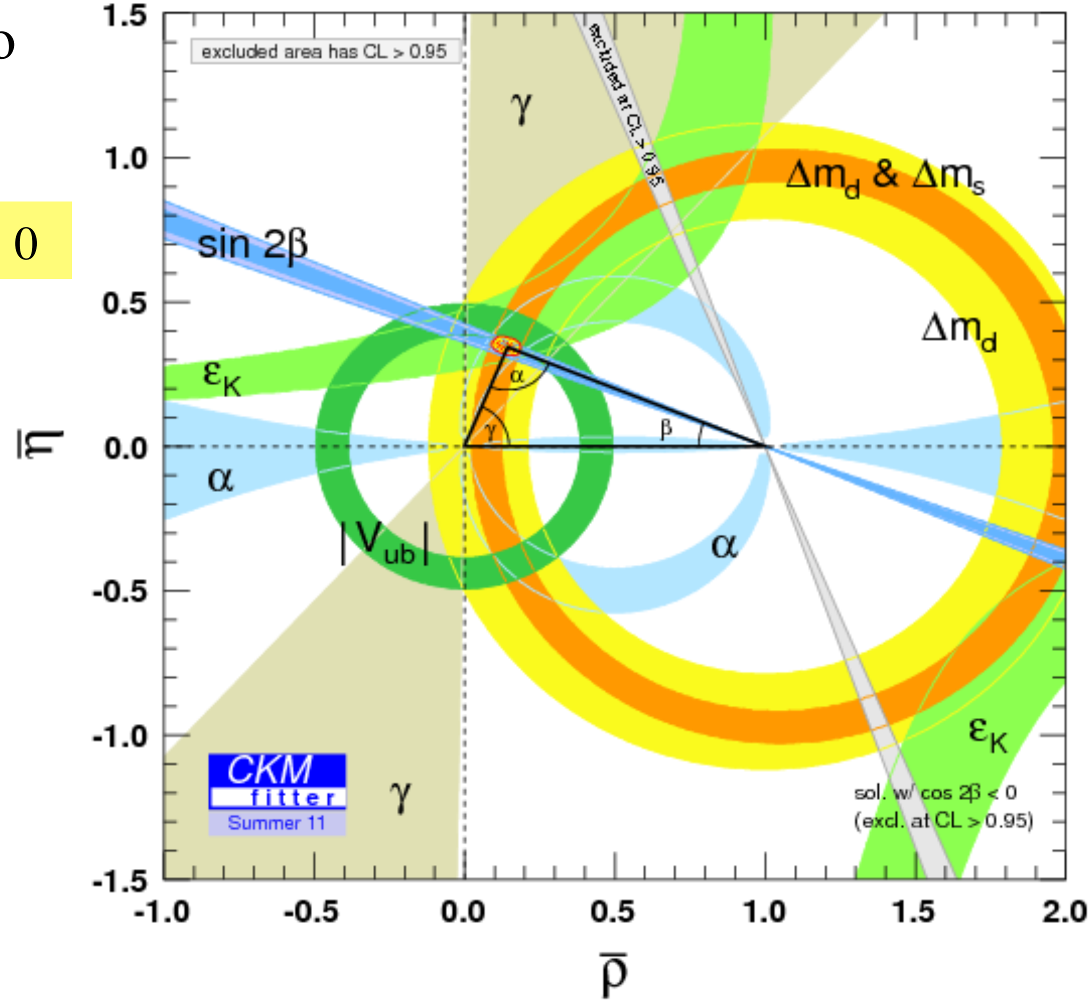
New sources of CP violation must exist. Rich flavour structure in the New Physics expected at LHC energies

Key Flavour Measurements

Unitarity of CKM matrix leads to six relations of the form:

$$V_{ud} V_{ub}^* \quad + \; V_{cd} V_{cb}^* \quad + \; V_{td} V_{tb}^* \; = \; 0$$

The ‘unitarity’ triangles



The current generation of B factories have done a superb job in constraining the parameters of the unitary triangle

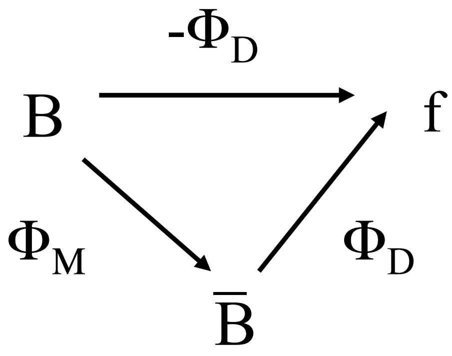
Open Flavour Questions

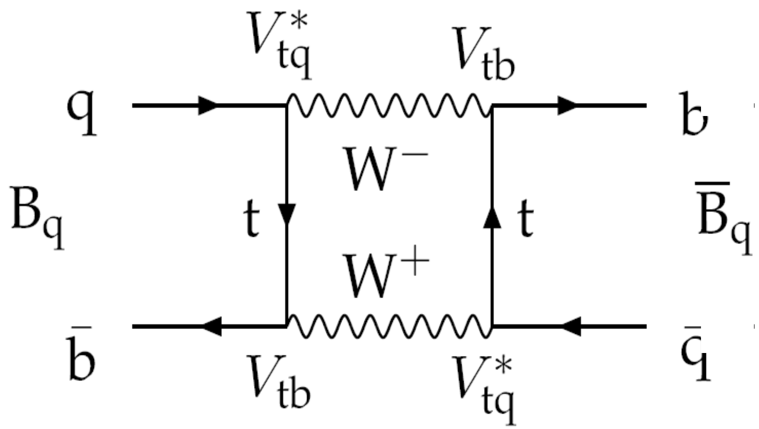
Most important open questions probing new physics:

- Measurement of the B_s mixing phase ϕ_s ⟵ Concentrate on this, one of the focuses of my research
- Precision of γ measurement of with loops and trees
- Rare decays: $B_s \rightarrow \mu\mu$
- Radiative penguins: $B \rightarrow K^*\gamma$, $B_s \rightarrow \phi\gamma$

B_s Mixing

Phase	$\phi_s = \phi_m - 2\phi_d$
Width difference	$\Delta\Gamma_s = \Gamma_L - \Gamma_H$
Mass difference	$\Delta m_s = M_H - M_L$





Flavour eigenstates mix to give physical states B_{Heavy} and B_{Light}

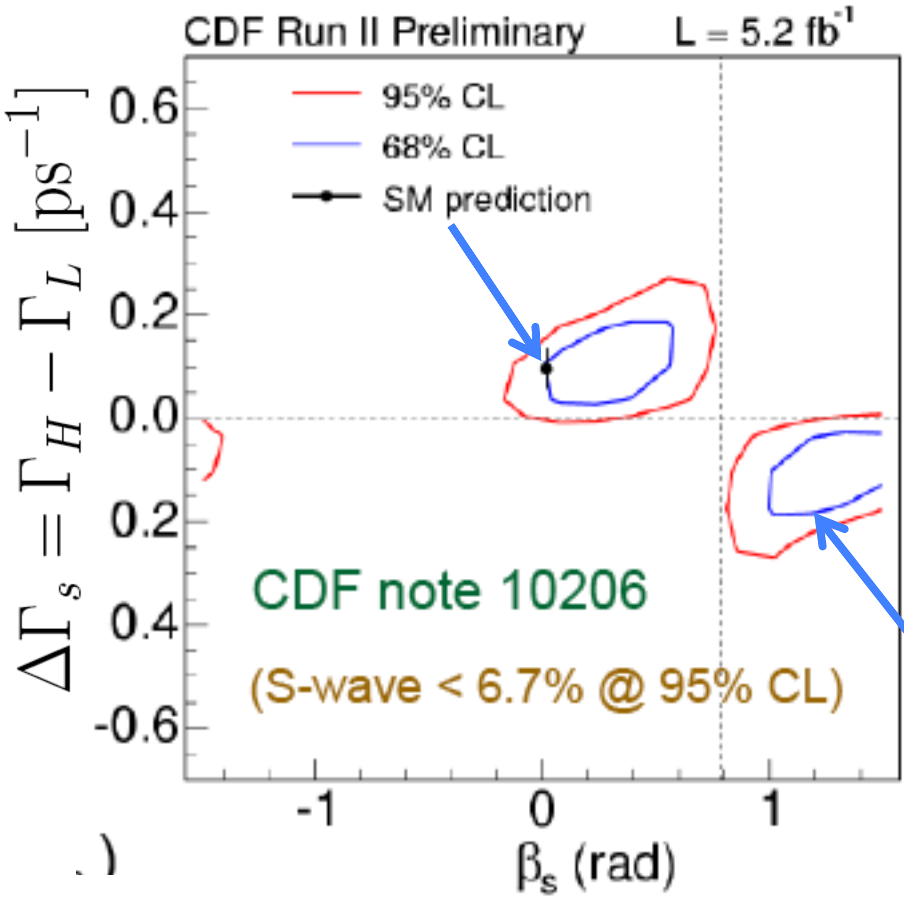
In the Standard Model expected to be small ϕ_s = - 0.04 radian

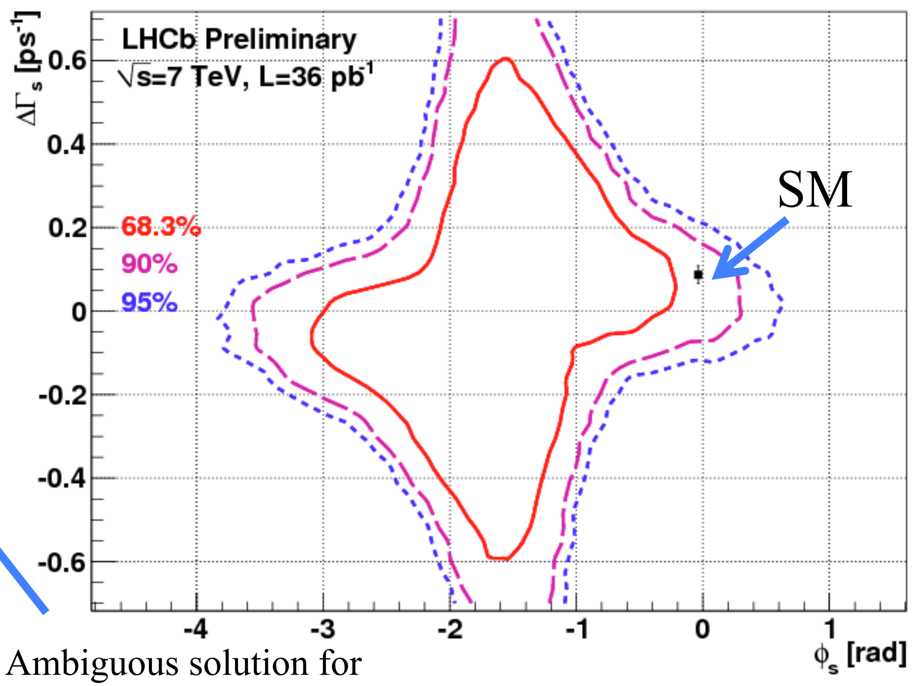
Larger values possible in models of New Physics

Way back in 2010-2011

Tevatron (CDF/D0): Both 1 σ away from Standard Model value of ϕ_s

Hint of similar trend from smaller LHCb 2010 dataset (40 pb^{-1})





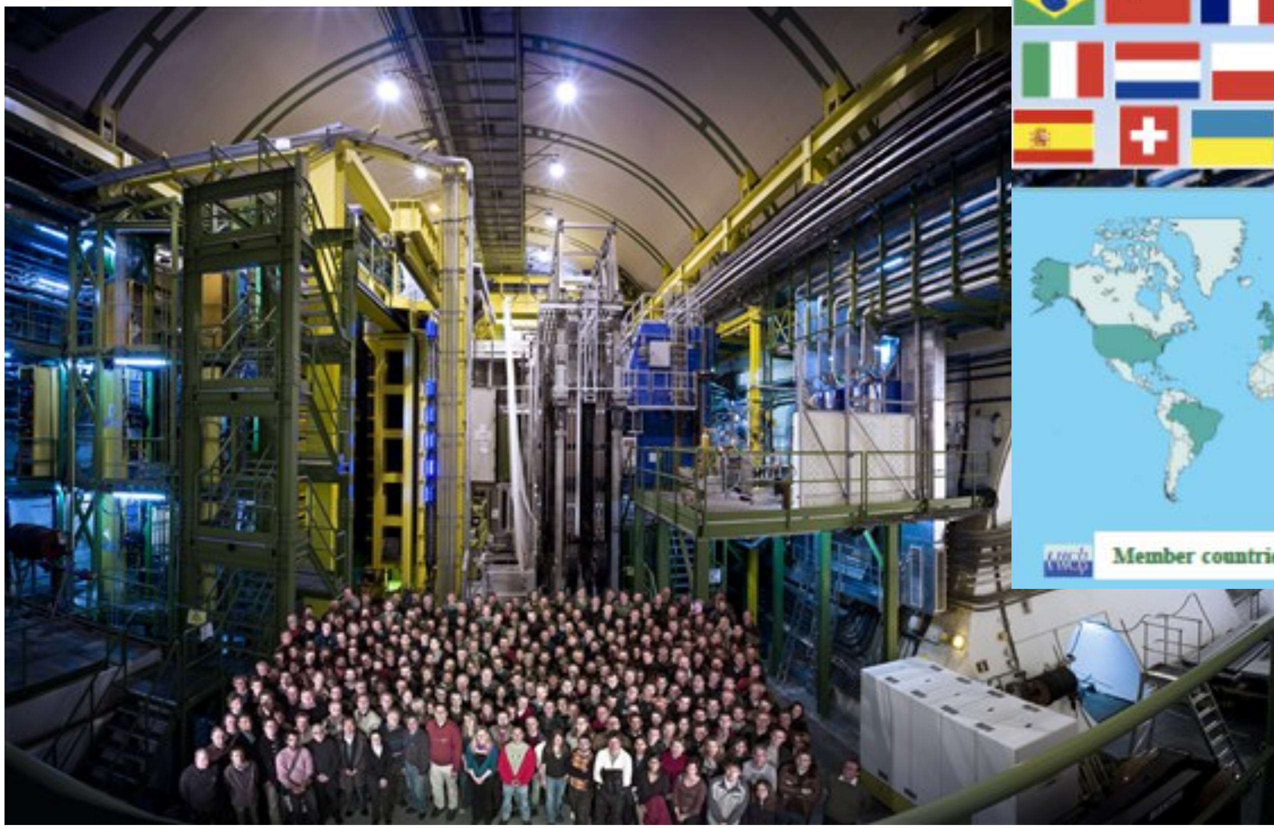
Ambiguous solution for
($\phi_s \rightarrow \pi - \phi_s$, $\Delta\Gamma_s \rightarrow -\Delta\Gamma_s$)

Intriguing but uncertainties large

LHCb

Dedicated B physics experiment at the LHC:

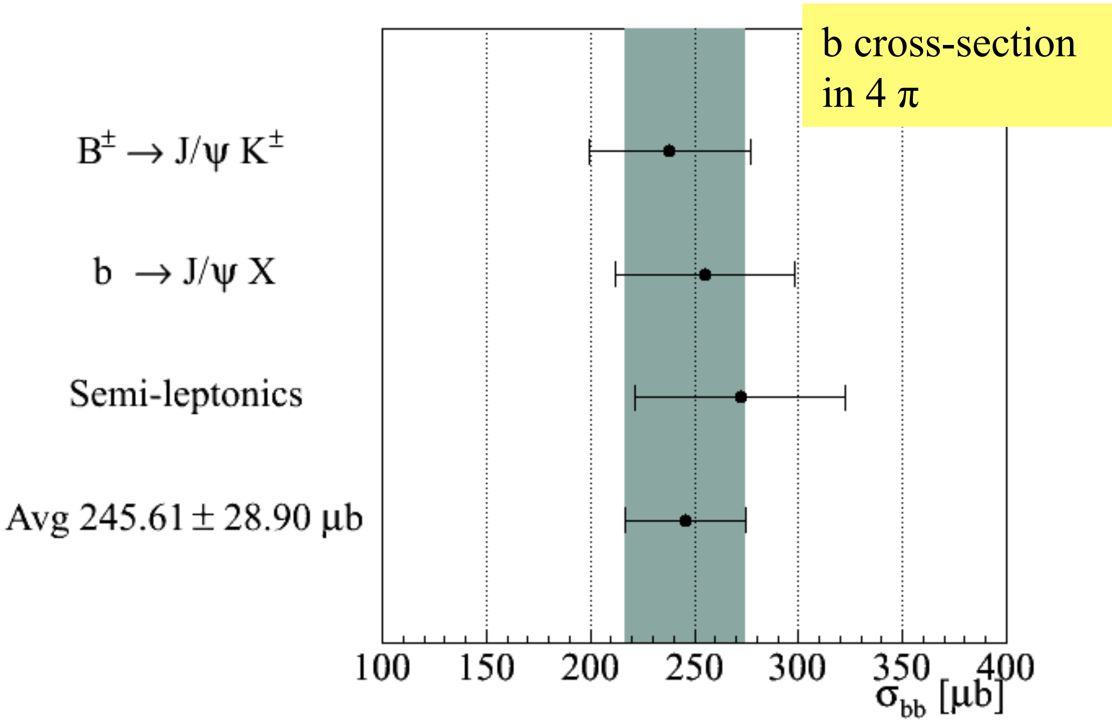
- 600 -700 Members, from 54 Institutes in 15 Countries
- Detector started physics data taking end 2009 after 15 years R+D and construction

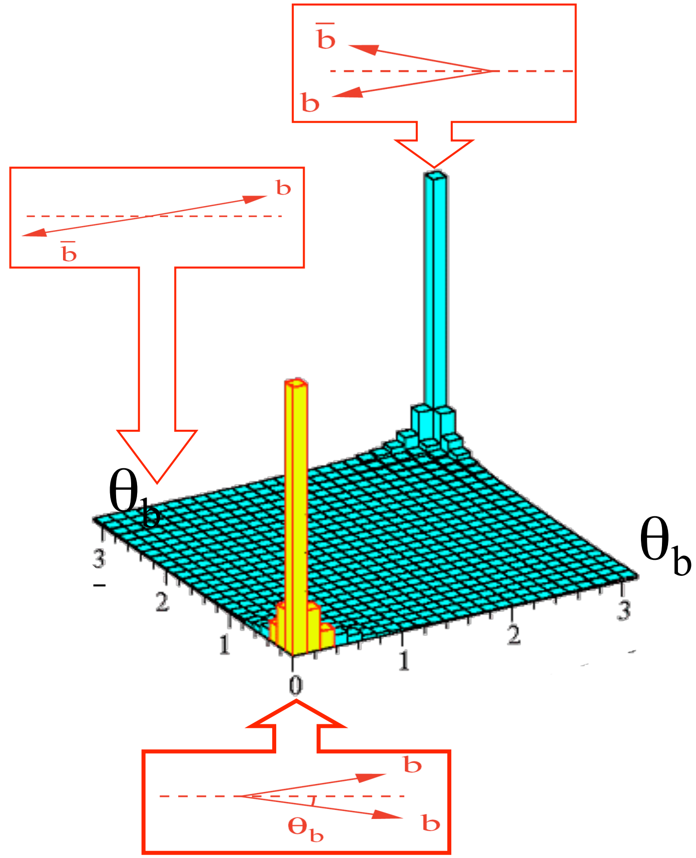


LHCb

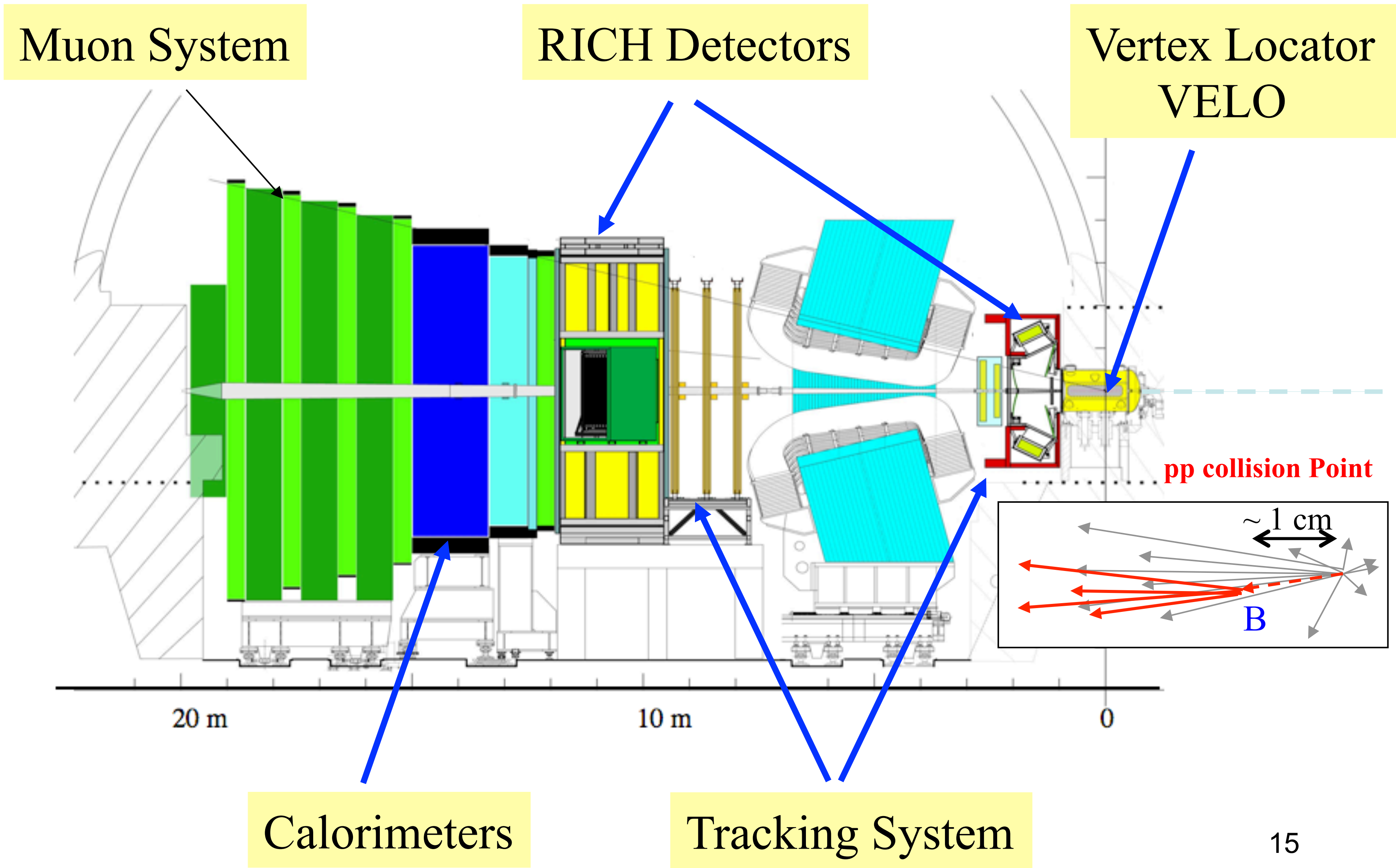
Exploit that LHC is a powerful B factory

- 10^{11} bb pairs produced in the acceptance in 2011
- All B species produced: B_d, B_s, B_u, B_c , Λ_b, Ξ_b, Ω_b
- B production peaked in the forward direction
- Experiment designed as a forward spectrometer

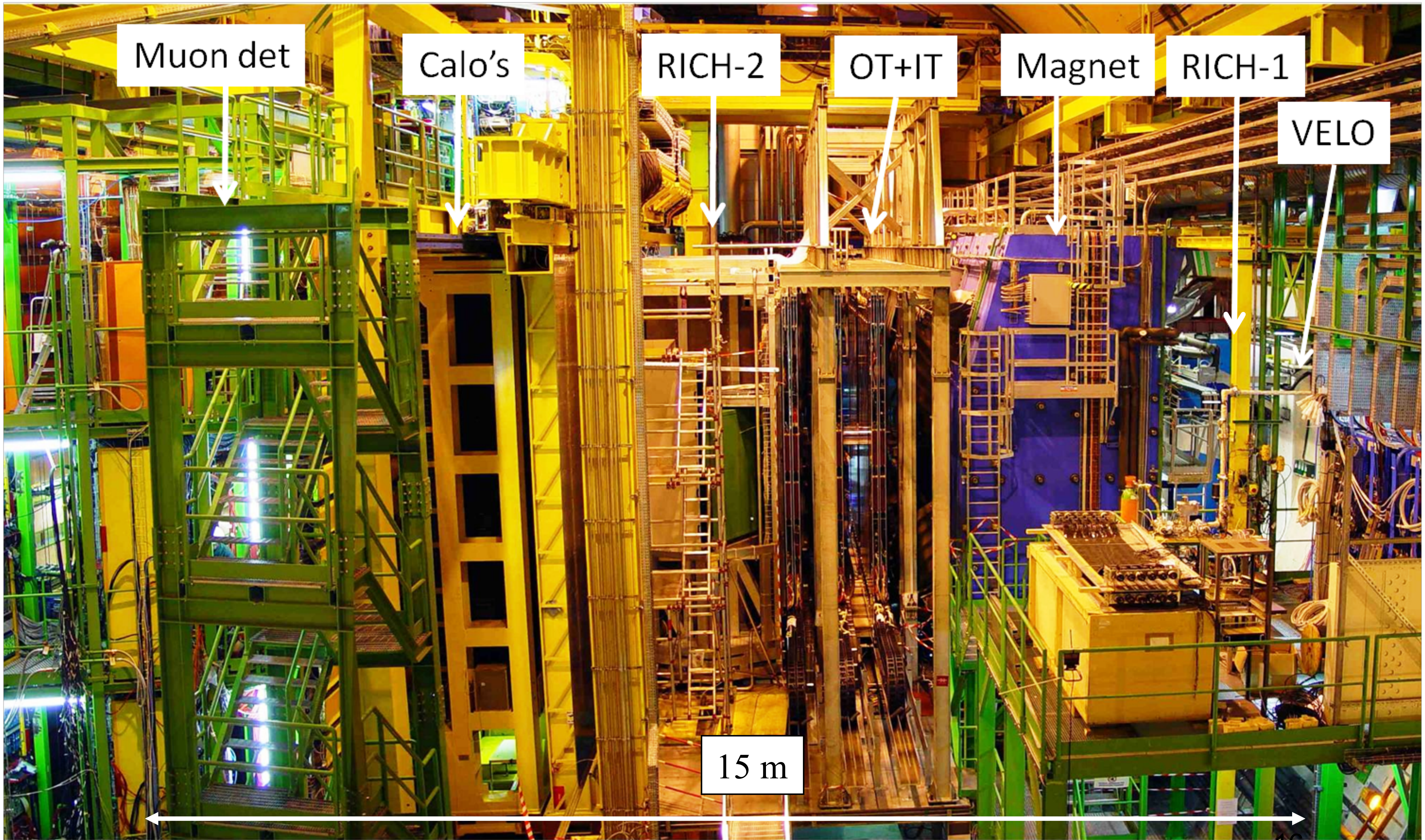




The LHCb Detector

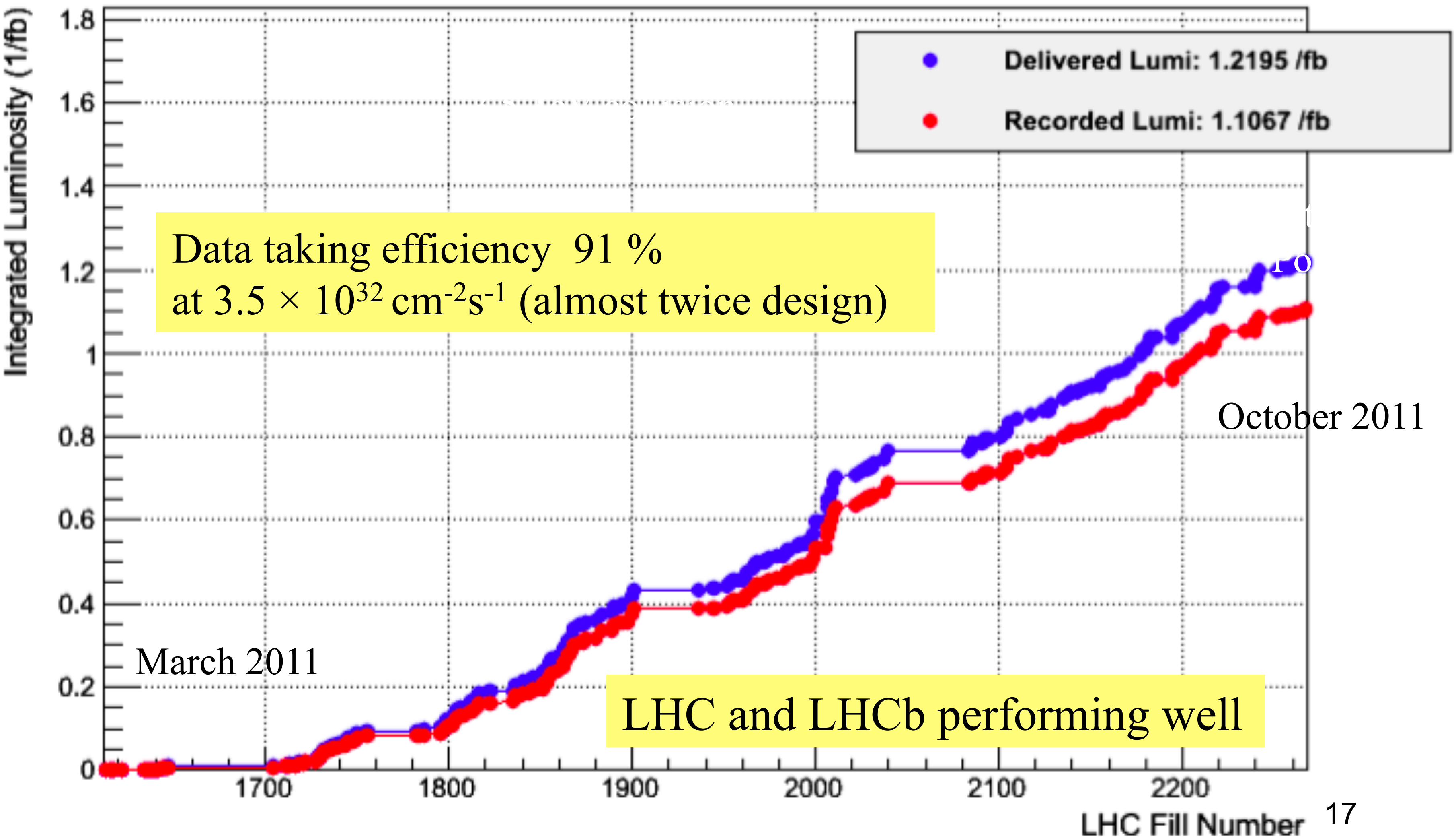


The LHCb Detector



Data taking

40 pb^{-1} collected in 2010, 1.1 fb^{-1} in 2011

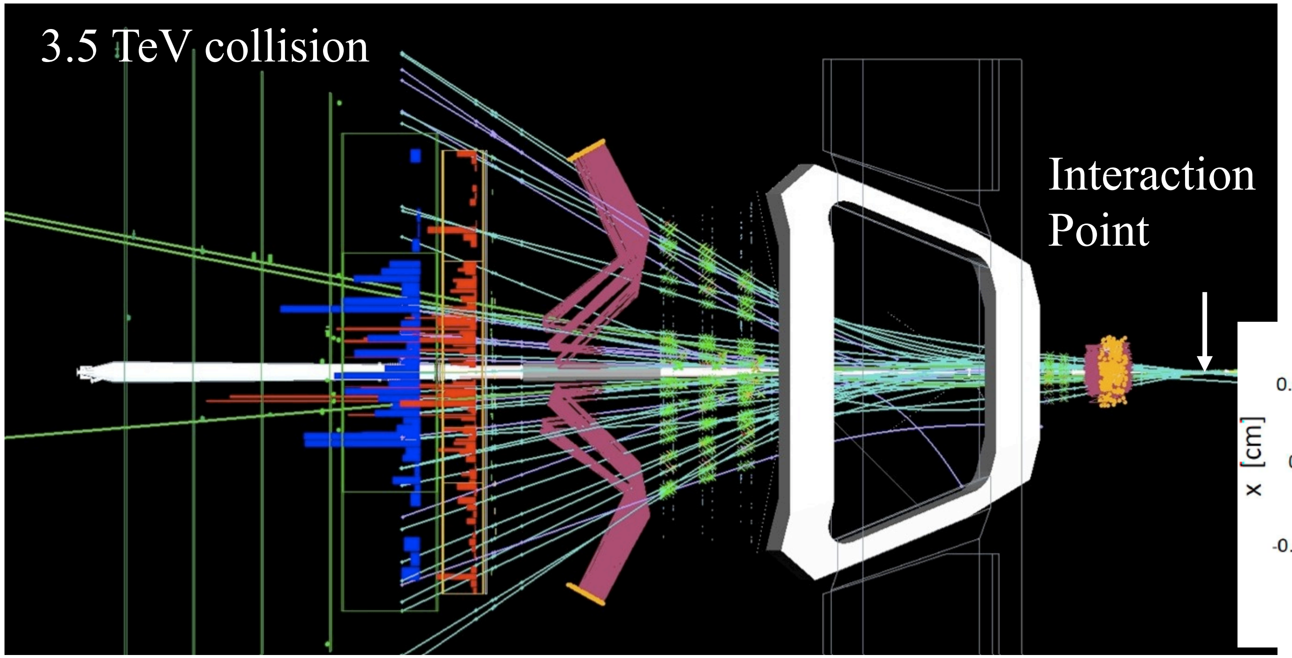


Data taking efficiency 91 %
at 3.5 × 10^{32} cm^{-2}s^{-1} (almost twice design)

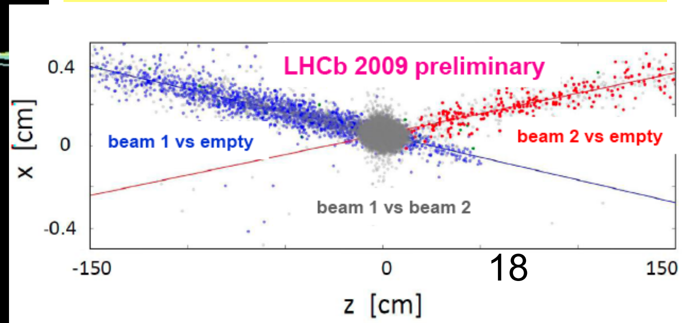
LHC and LHCb performing well

Key Ingredients

- Low luminosity compared to ATLAS + CMS (1 – 2 interactions/crossing)
- ~ 50 tracks per event from primary vertex
- ~ Only 1/200 events contains a b quark + decays of interest for CP violation have branching fractions at ~ 10^{-3} level
    - Selective online trigger to reduce from 40 MHz collision rate to 3 kHz to tape



450 GeV beam imaged by beam-gas interactions

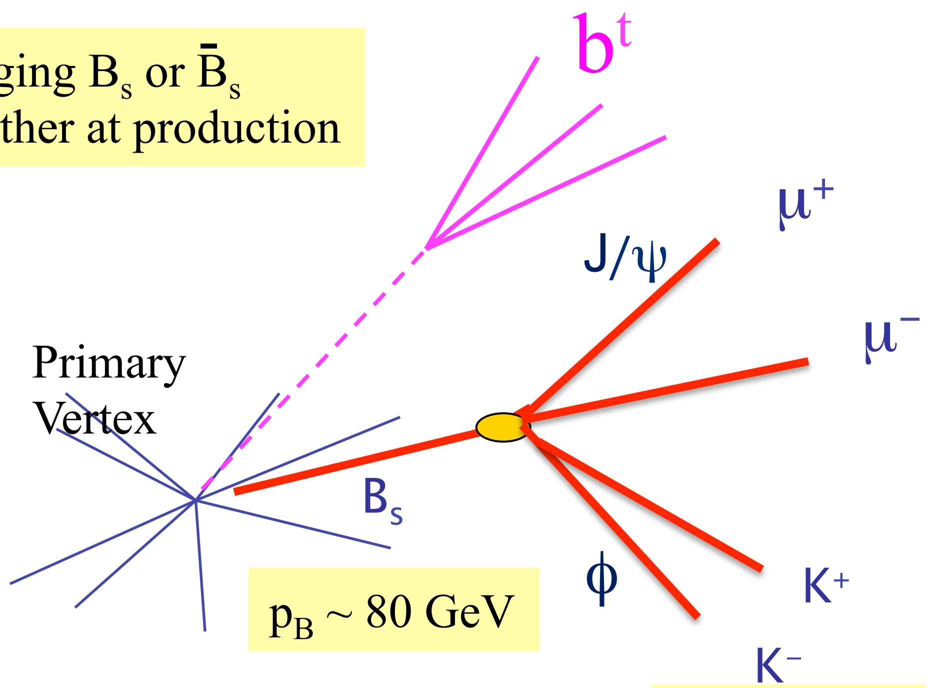


Key Ingredients

e.g. for $B_S \to J/\psi\ \phi$

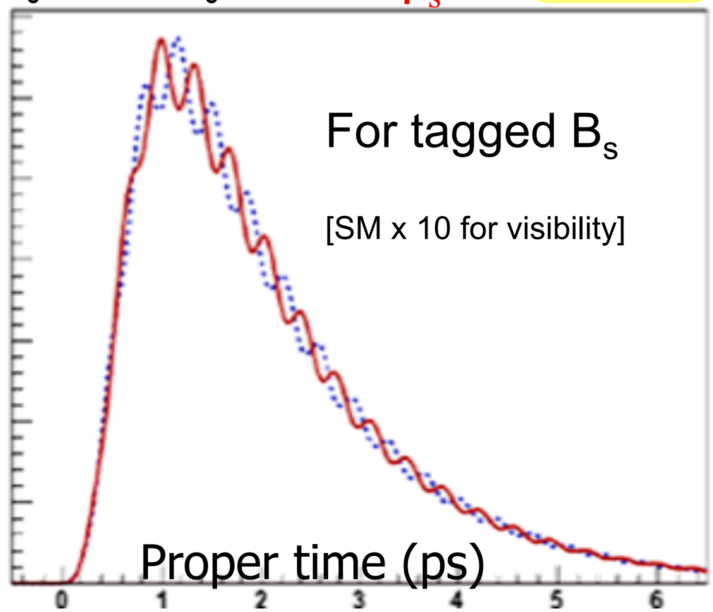
Bs Mixing

Tagging B_s or $\bar{B}_s$ whether at production



$p_B \sim 80$ GeV

Asymmetry $\propto$ **$\sin \phi_s \times \sin \Delta mt$**



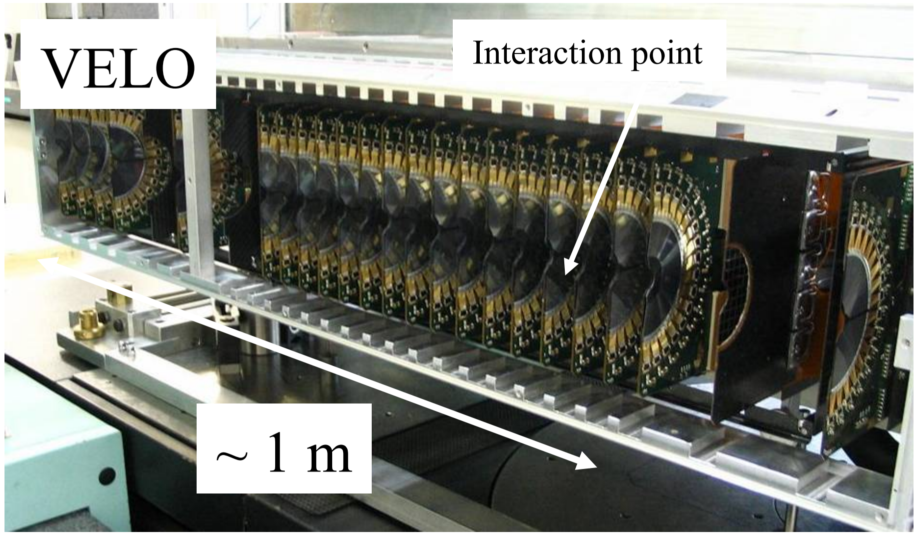
Mass + pointing constraints to reduce background

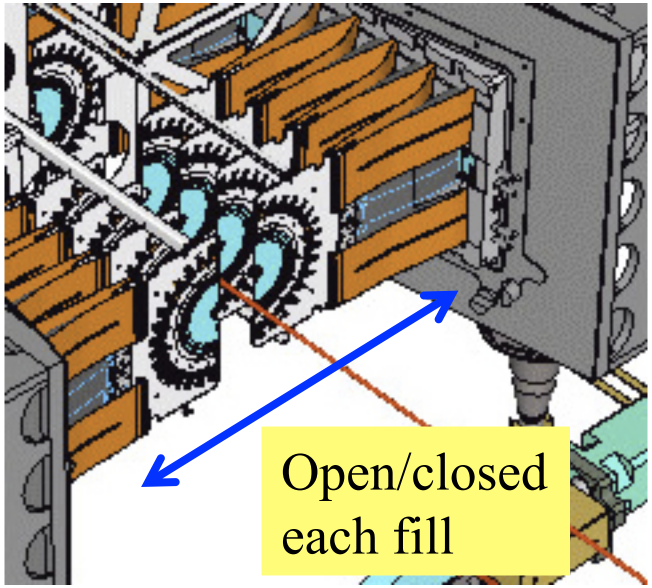
Good K/π separation

Good primary + secondary vertexing to measure proper time

Precision tracking and good particle identification crucial

Precision vertexing

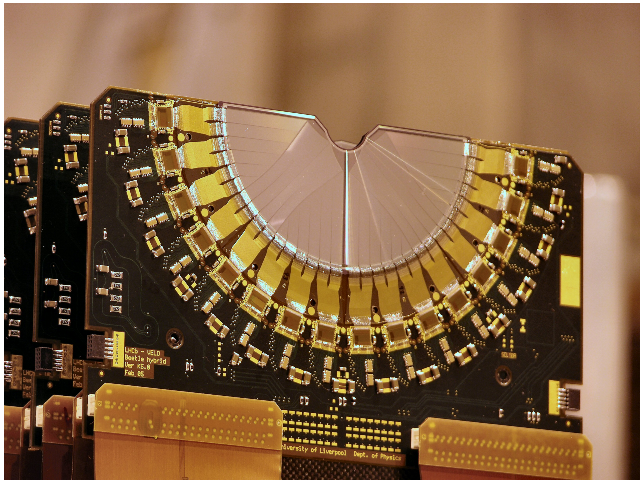




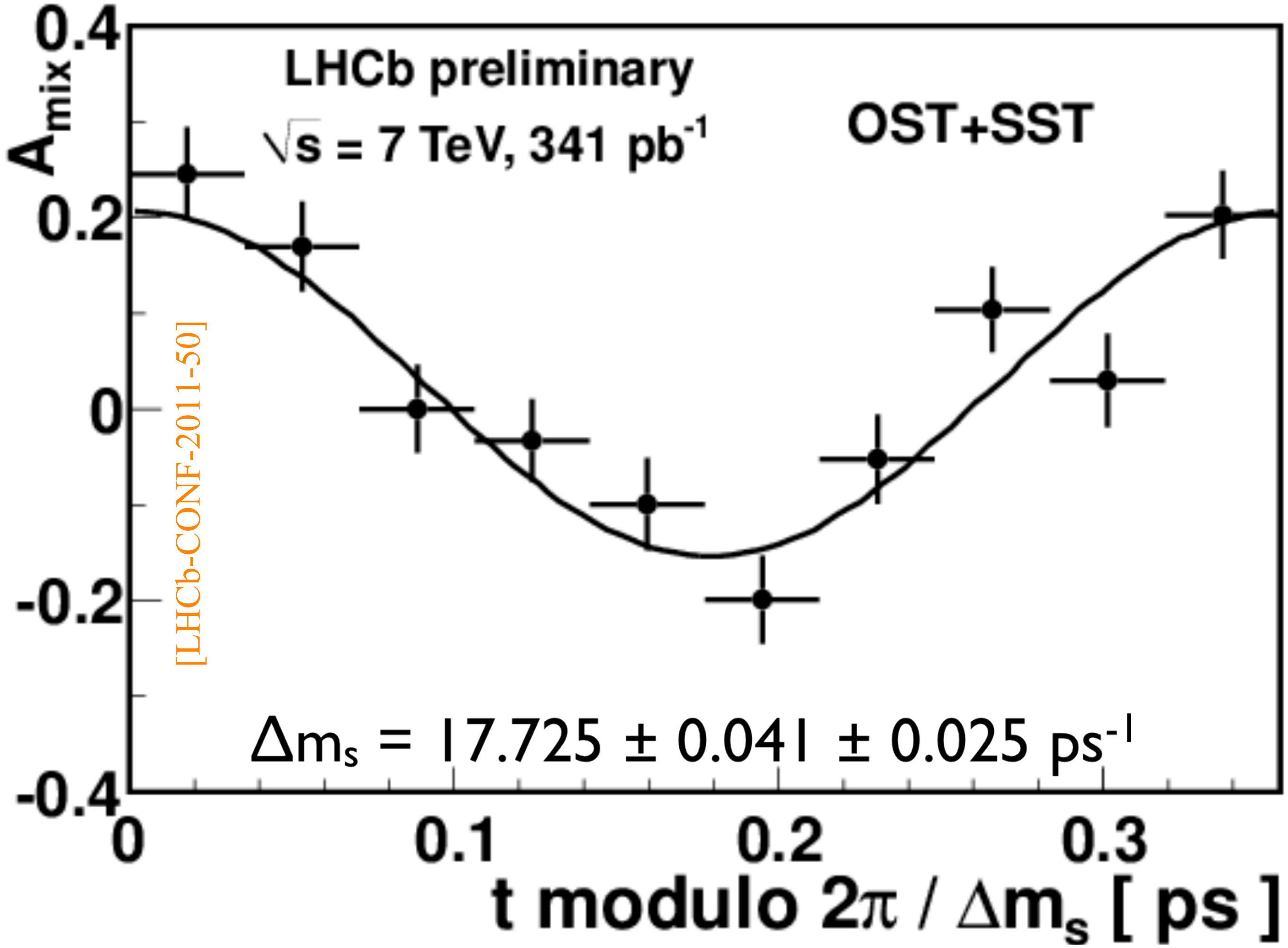
Precision silicon strip vertex detector around interaction

21 stations 300 μm thick n-on-n Silicon

Hit resolution ~ 4 μm giving precision vertex (~13 μm in x and y) and proper time resolution

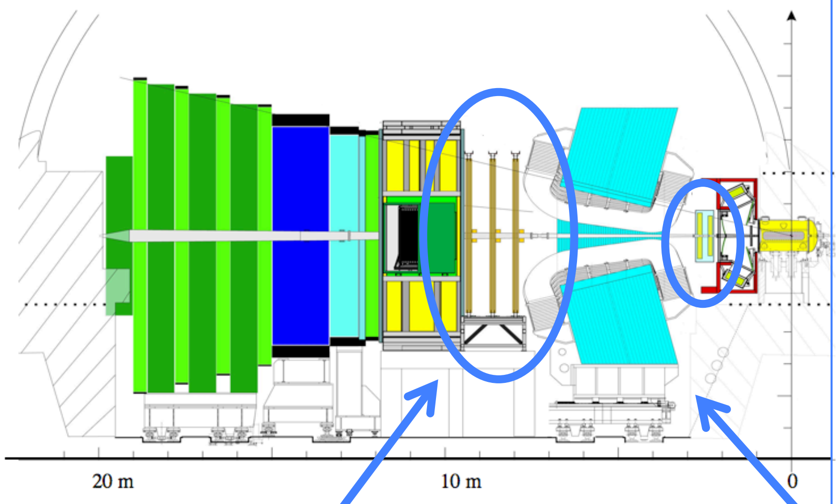


Precision vertexing



World's best measurement of of the fast B_s oscillations

Mass Resolution

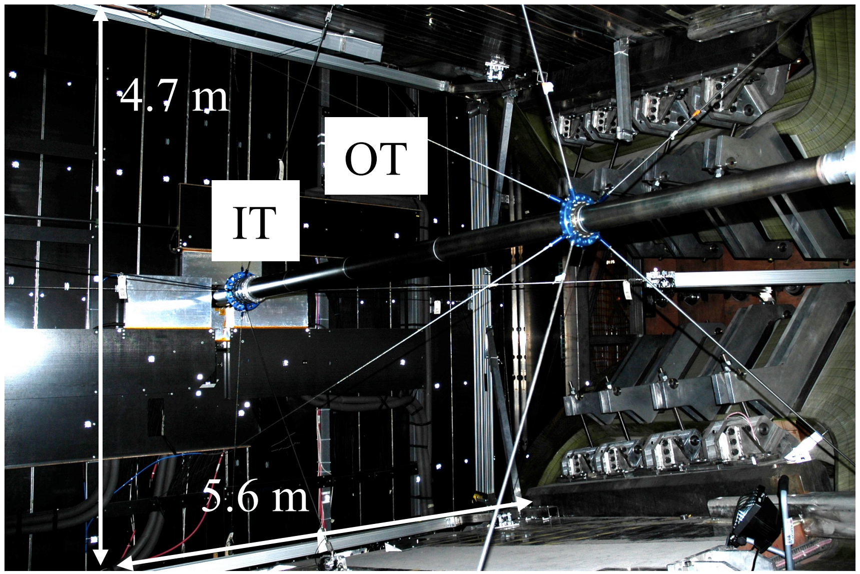


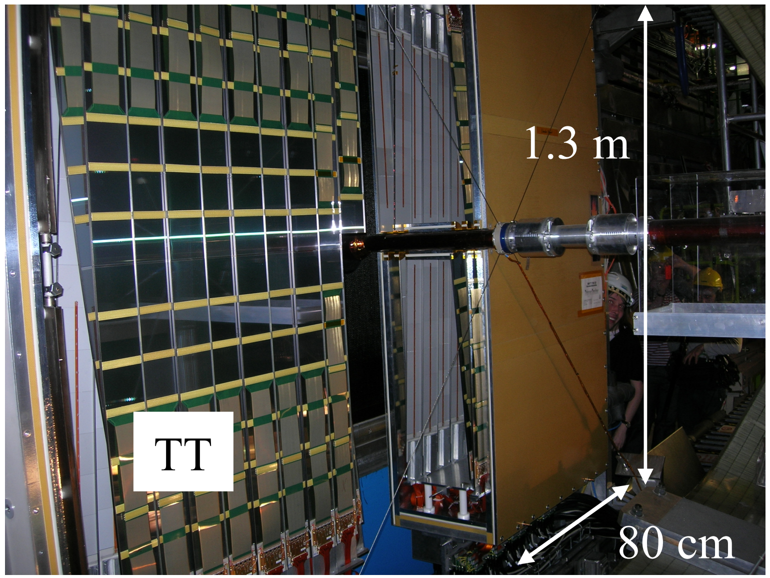
Precision tracking system

Large area silicon detector before the magnet

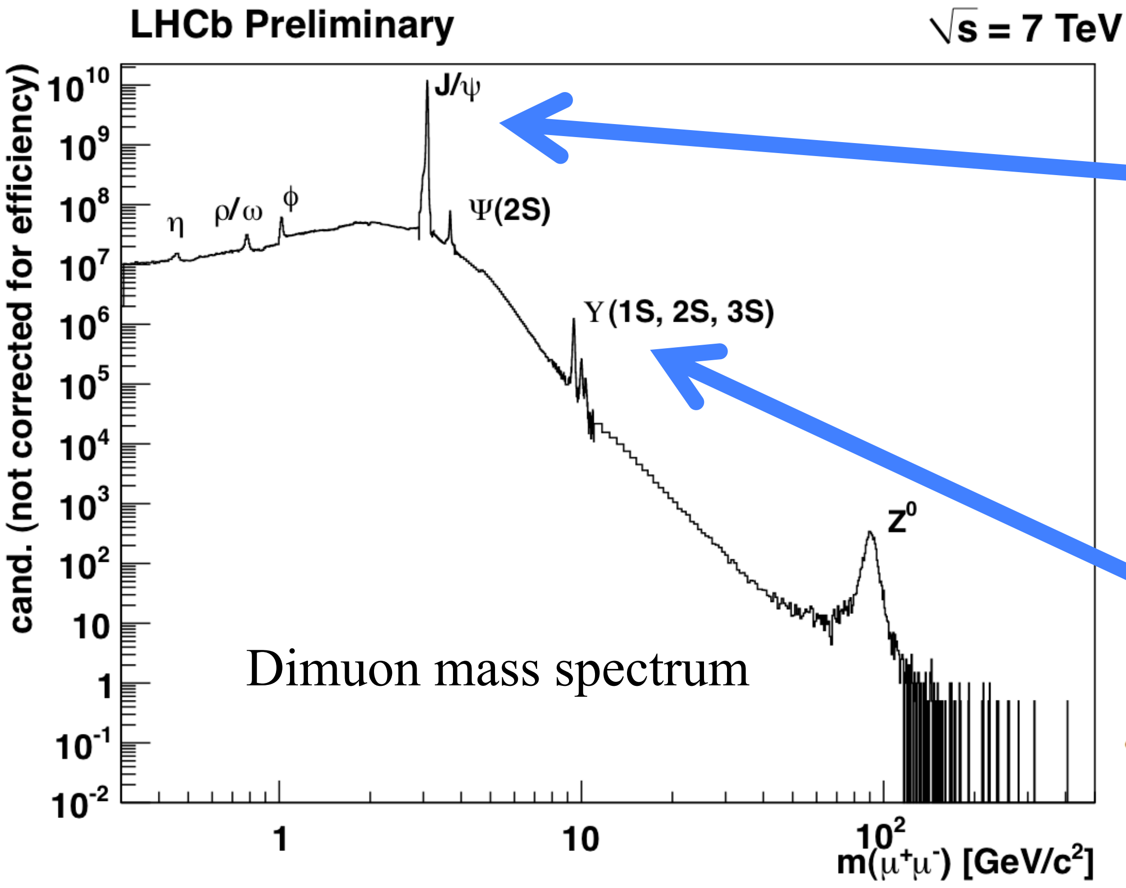
Three stations (mix of silicon strips and straws)

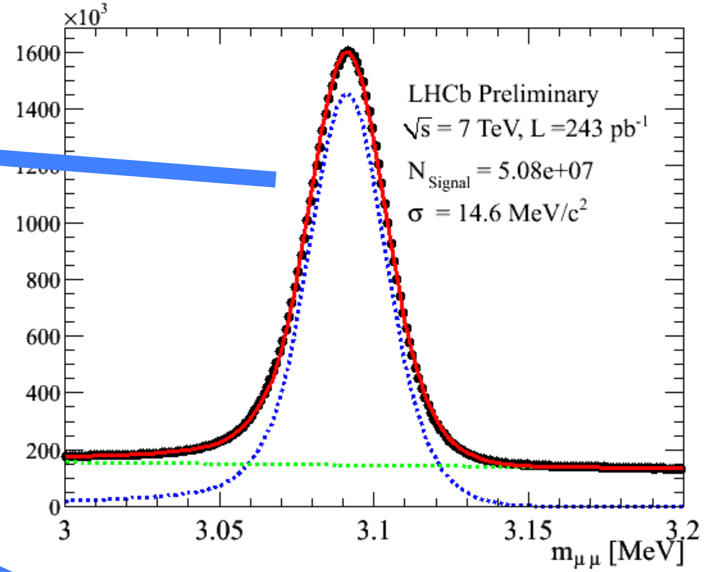
$\Delta p/p \sim 3 - 5$ per mille

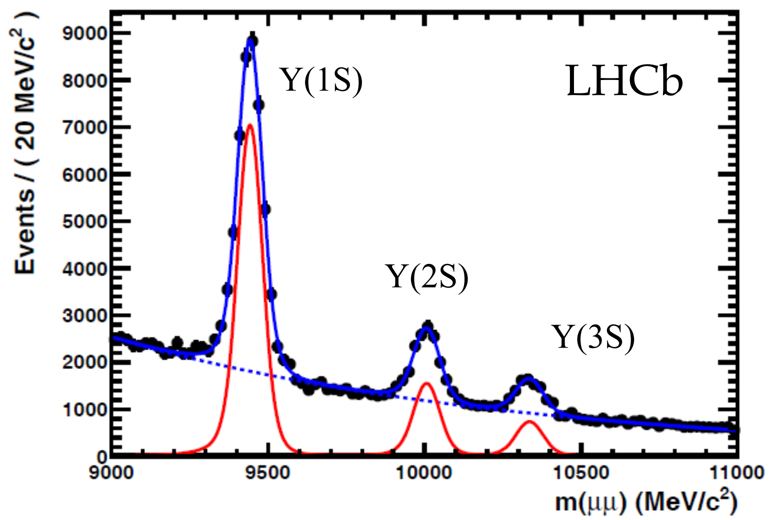




Mass Resolution



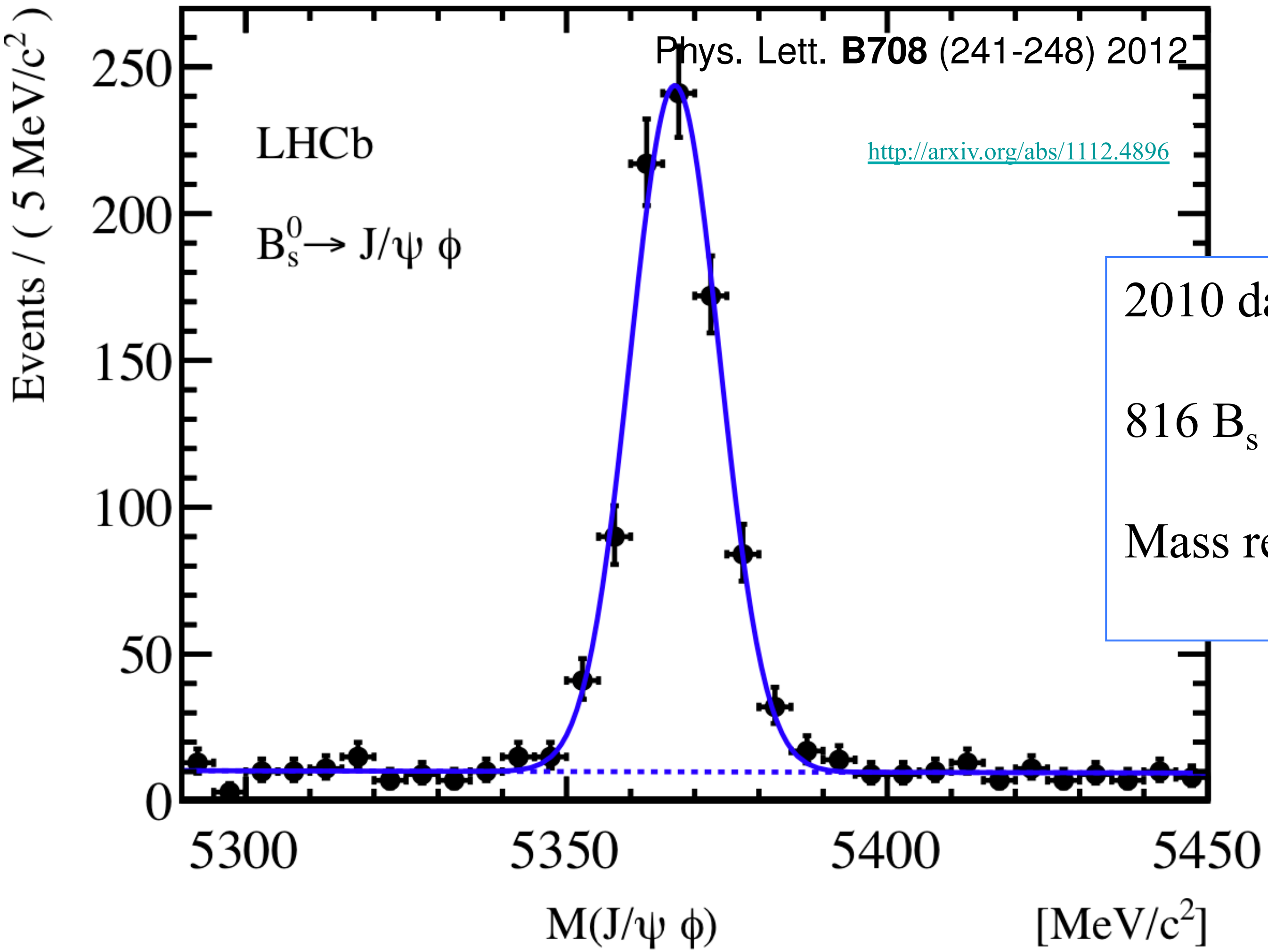




Mass resolution 14.6 MeV for the J/ψ ,
~ 50 MeV for the Υ resonances

B hadron mass measurements

Precision measurement of B hadron masses already possible



2010 dataset

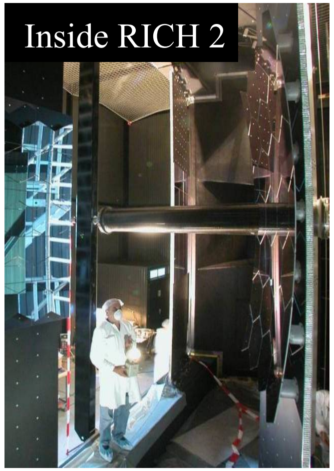
816 $B_s \to J/\psi\ \phi$ candidates

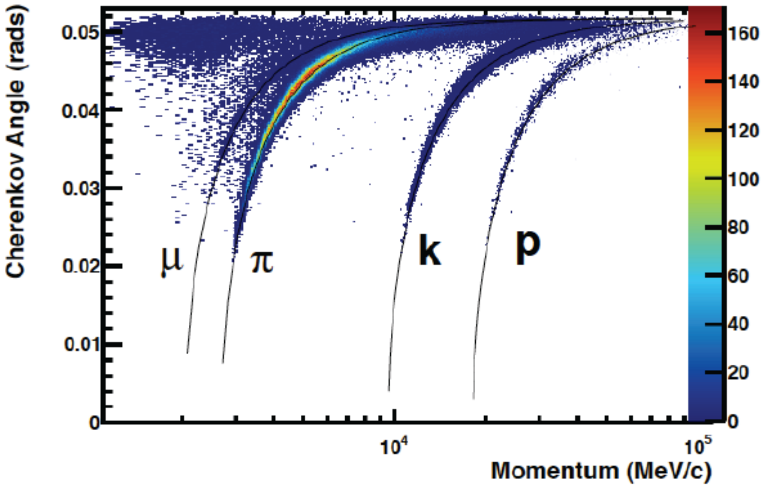
Mass resolution ~7 MeV

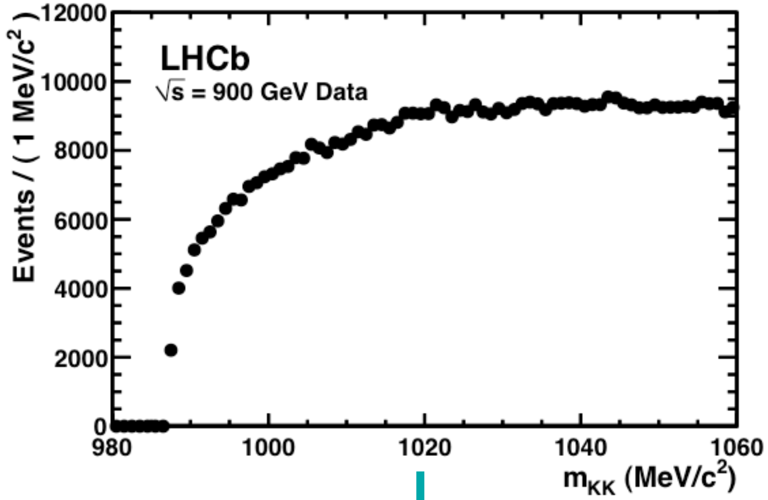
$$M(B_s^0) = 5366.90 \pm 0.28\ (stat) \pm 0.23\ (syst)\ MeV/c^2$$

Particle Identification

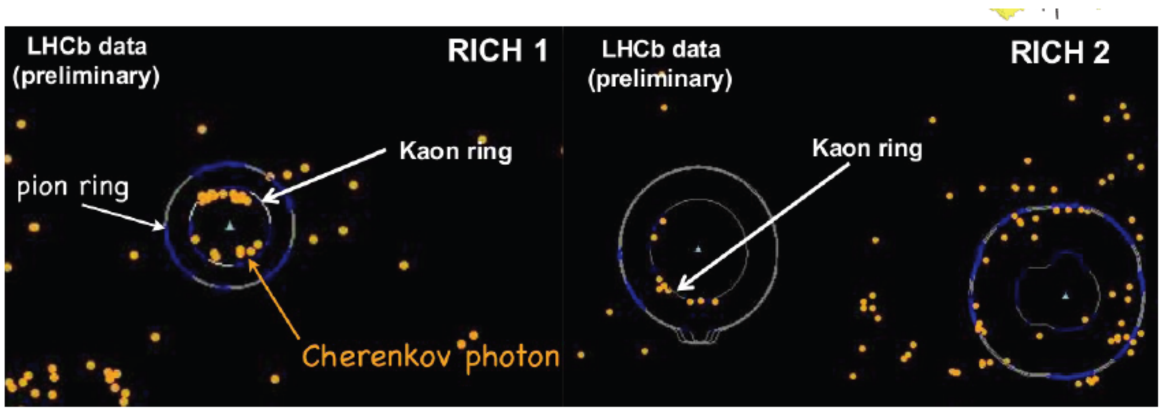
Excellent Kaon/pion separation with
two RICH detectors with three radiators

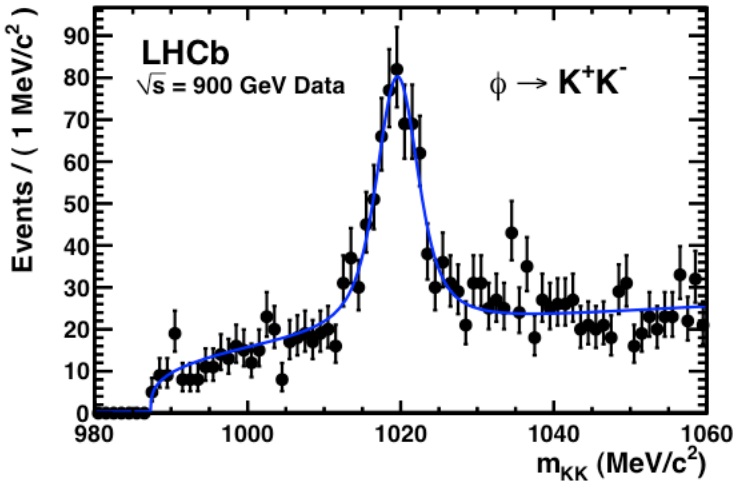






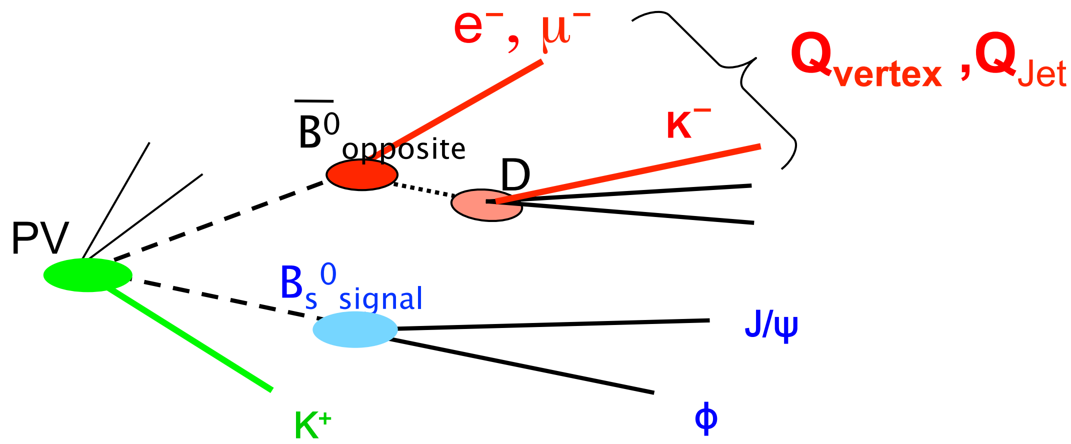
Apply
PID





Flavour Tagging

Use other b in event to tag b flavour at production



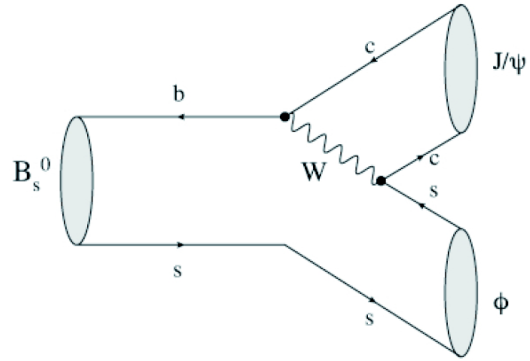
- High pt muons
- High pt electrons
- High pt kaons
- Opposite side vertex charge

Efficiency 25 %

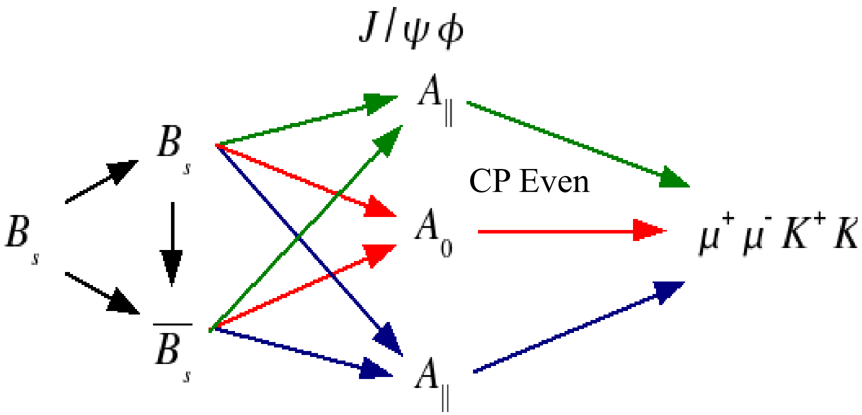
Average mistag probability $\omega = 0.36$

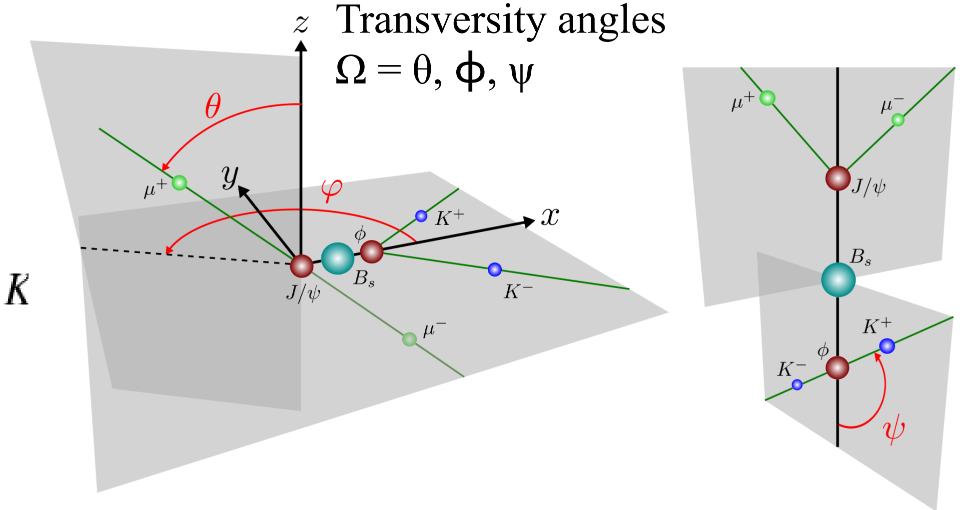
Tagging power $\varepsilon(tag)\,(1 - 2\omega)^2 = 1.91 \pm 0.23$ %

Measurement of ϕ_s in $B_s \rightarrow J/\psi\phi$



- High yield: (25 k signal events/$1fb^{-1}$ at 7 TeV)
- Admixture of CP eigenstates
  - Time dependent Angular analysis needed



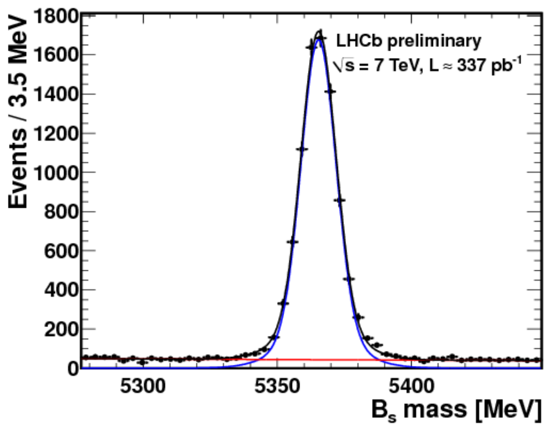


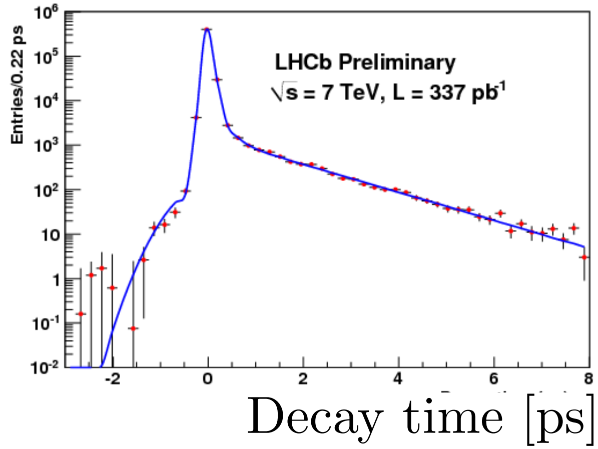
http://arxiv.org/abs/1112.3183

Results from recent PRL paper using 350 pb^{-1}

Measurement of ϕ_s in $B_s \rightarrow J/\psi\phi$

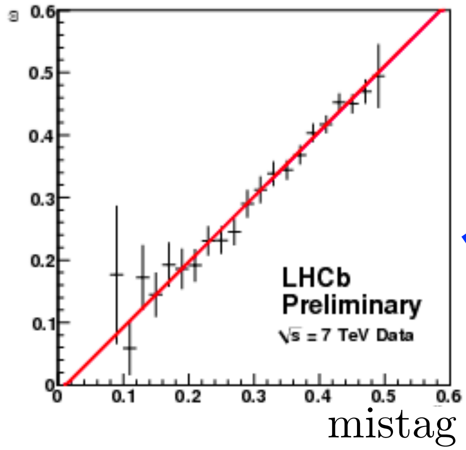
Mass distribution





Resolution model from prompt J/ψ Peak. Resolution ~ 50 fs

Unbinned maximum likelihood fit to mass, time and angles



Mistag rate measured using $B^+ \rightarrow J/\psi K^+$ calibration channel

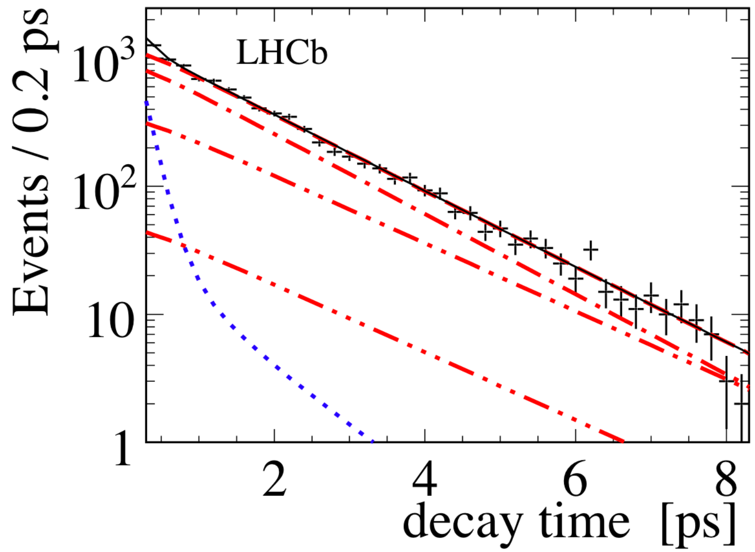
Time acceptance due to cuts in the trigger + reconstruction effects

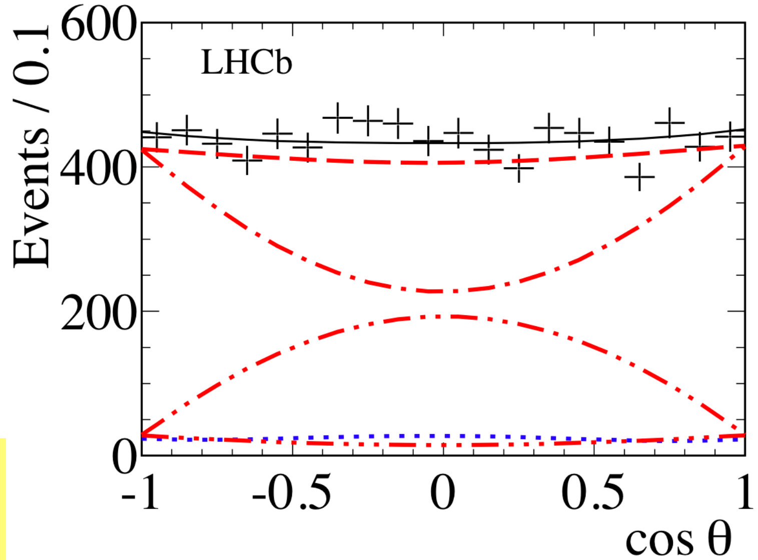
Angular acceptance for signal from simulation

Mass sidebands or sWeight technique to determine angular distribution of background

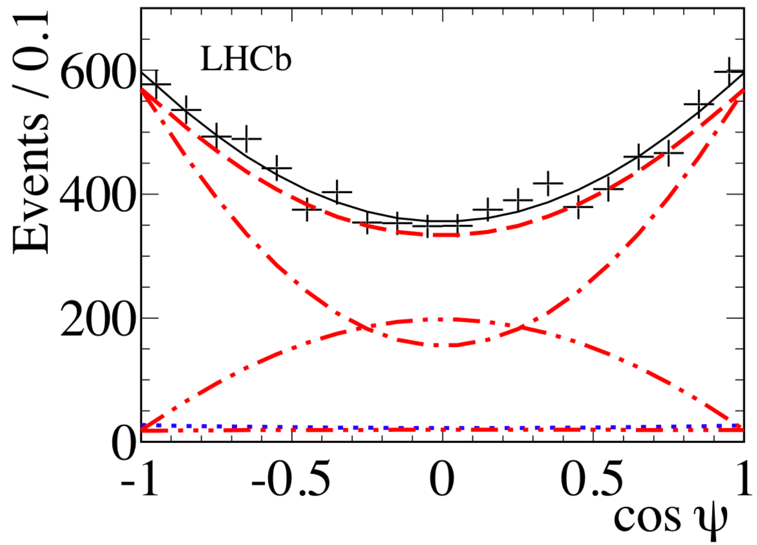
ϕ_s Result

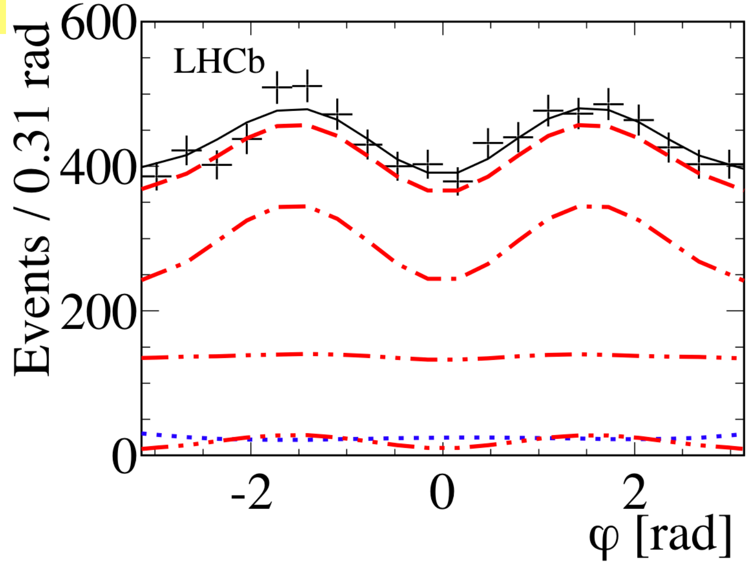
1-d projections of fit observables (time + 3 angles)





p value of fit 44 %

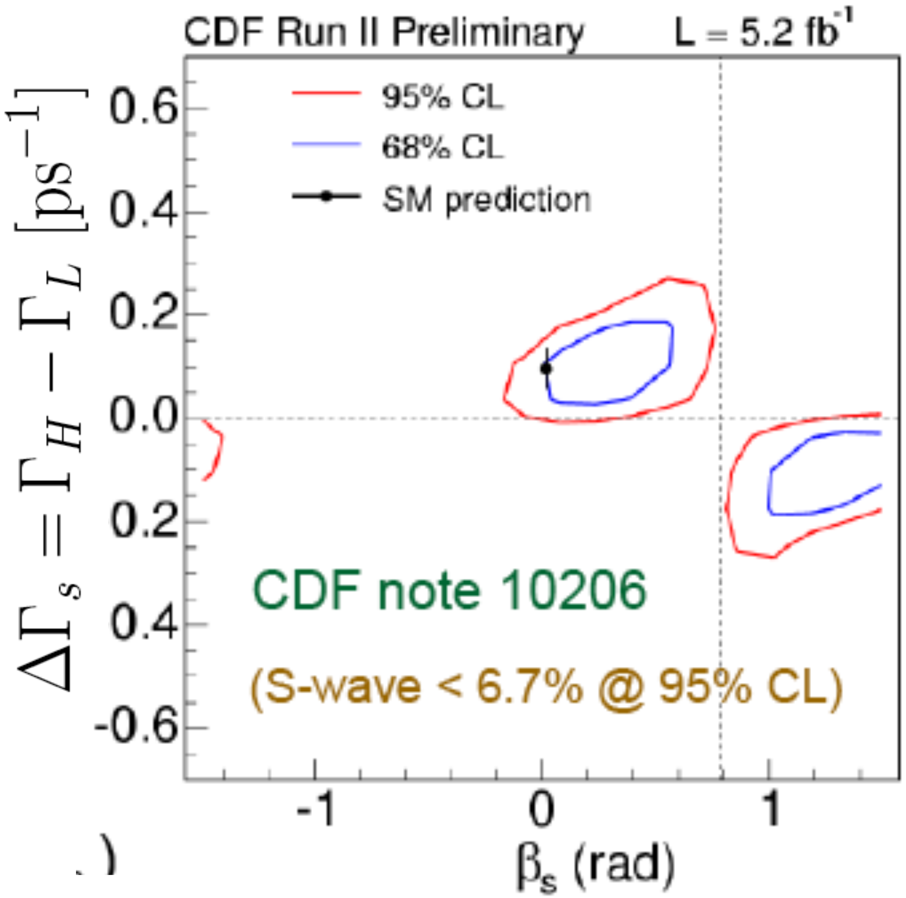


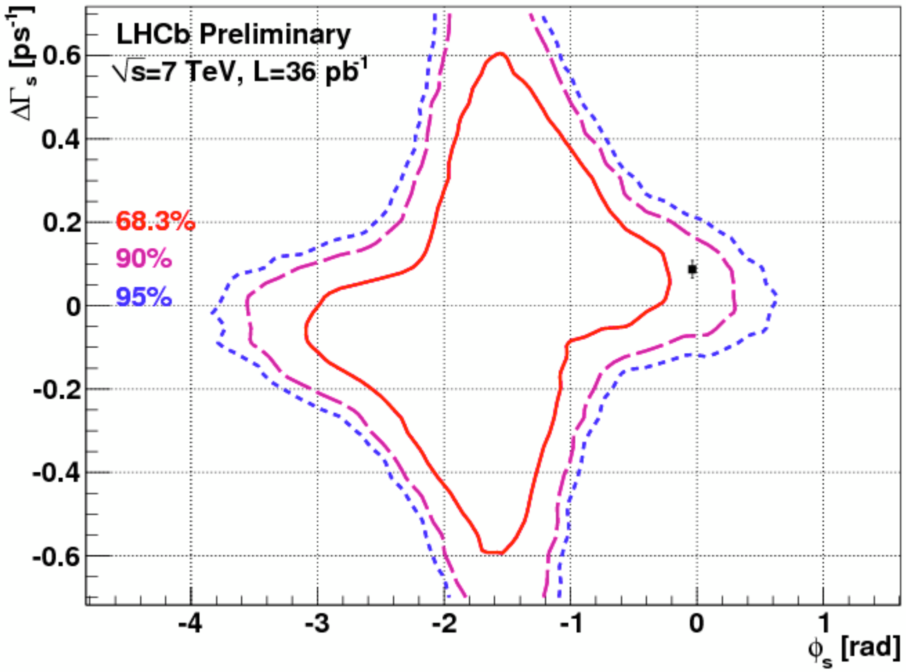


Way back in 2010-2011

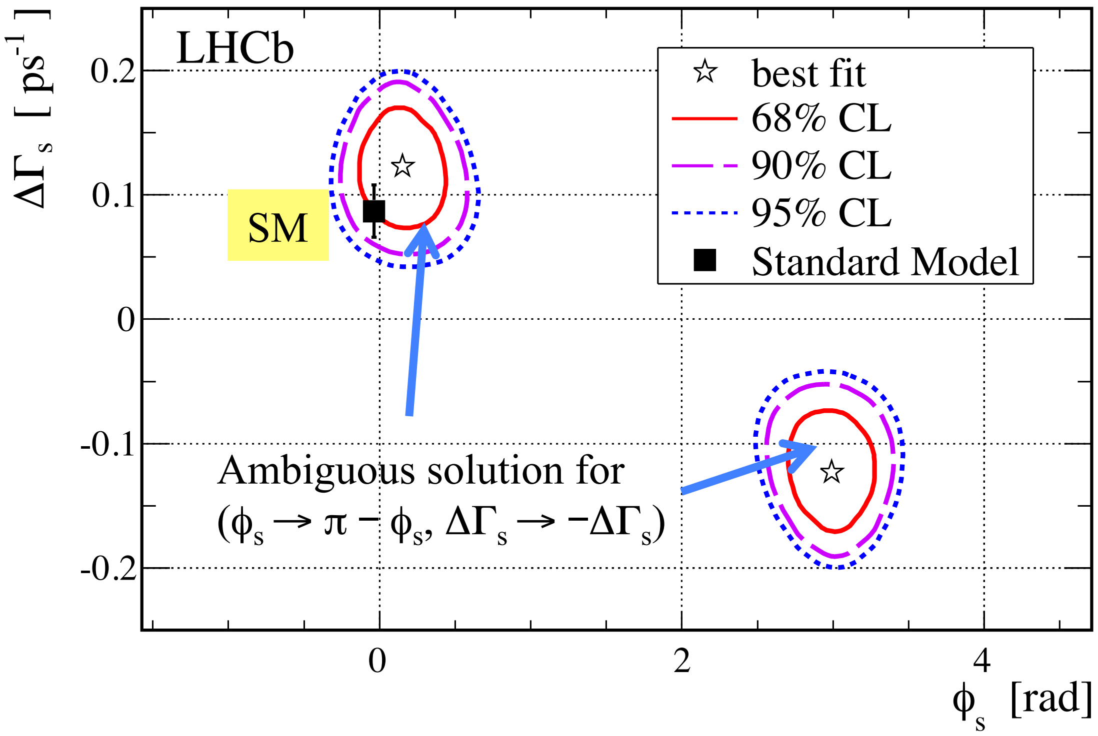
Tevatron (CDF/D0): Both 1 σ away from Standard Model value of ϕ_s

Hint of similar trend from smaller LHCb 2010 dataset (40 pb^{-1})





ϕ_s Result



Results correlated with $\Delta\Gamma_s$ = width difference of the B_s mass eigenstates
→ plotted as contours in (ϕ_s *vs* $\Delta\Gamma_s$) plane

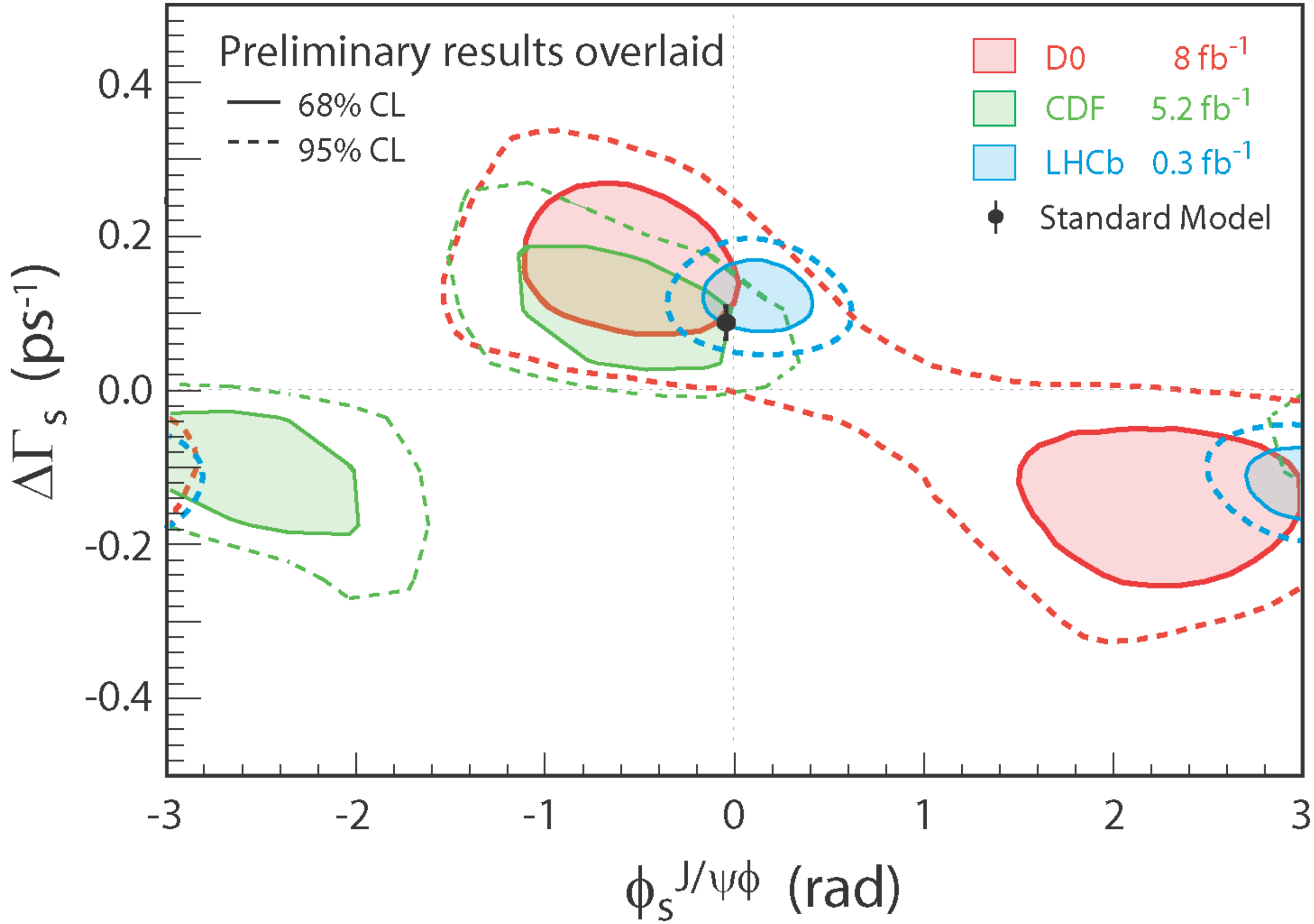
$$\phi_s = 0.15 \pm 0.18 \text{ (stat)} \pm 0.06 \text{ (syst) rad},$$

$$\Gamma_s = 0.657 \pm 0.009 \text{ (stat)} \pm 0.008 \text{ (syst) } \text{ps}^{-1},$$

$$\Delta\Gamma_s = 0.123 \pm 0.029 \text{ (stat)} \pm 0.011 \text{ (syst) } \text{ps}^{-1},$$

Result is consistent with Standard Model

Comparison with previous results



Consistent with Standard Model but still room for New Physics

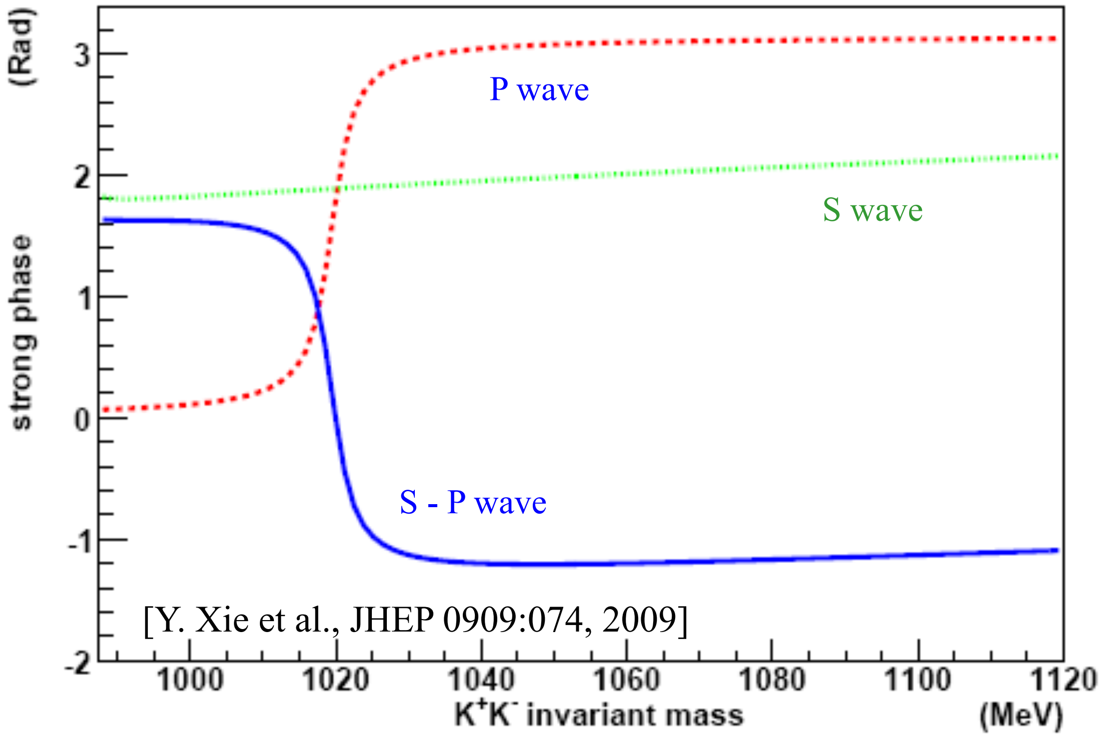
ϕ_s: Ambiguity Resolution

Use few % of S-wave non-resonance KK present in the sample

$$(\phi_s, \Delta\Gamma_s, \delta_\parallel - \delta_0, \delta_\perp - \delta_0, \delta_s - \delta_0) \longleftrightarrow (\pi - \phi_s, -\Delta\Gamma_s, \delta_0 - \delta_\parallel, \pi + \delta_0 - \delta_\perp, \delta_0 - \delta_s)$$

K^+K^- P-wave:
Phase increases rapidly across $\phi(1020)$ resonance

K^+K^- S-wave:
Phase relatively flat

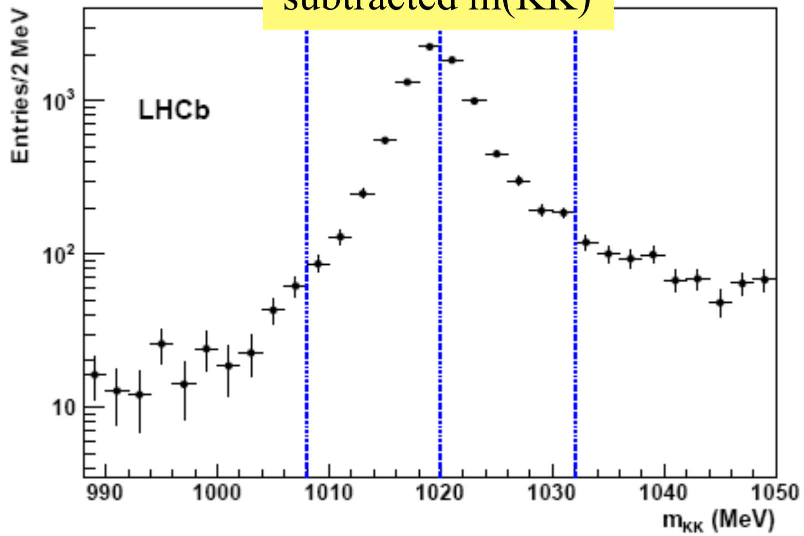


Choose the solution with a decreasing trend of δ_s- δ_P vs m_{KK} in the $\phi(1020)$ mass region

Similar to Babar measurement of sign of cos(2β), PRD 71, 032005 (2007)

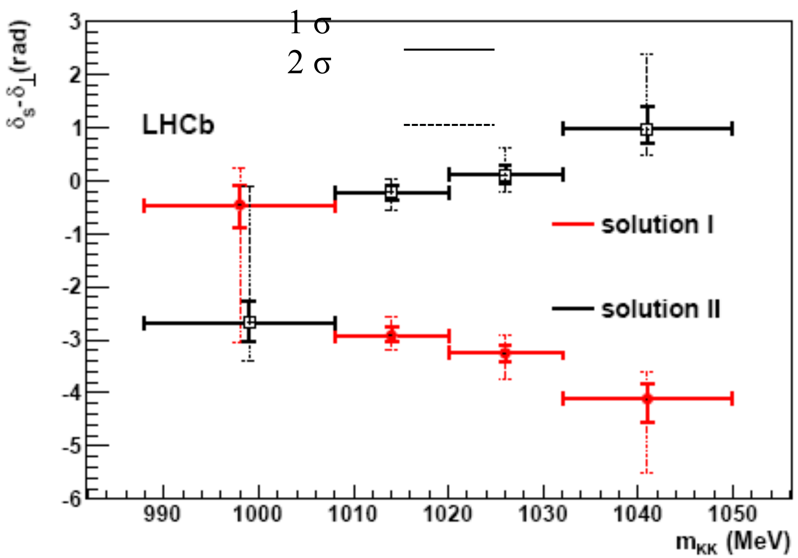
ϕ_s: Ambiguity Resolution

Background subtracted m(KK)



Open up m(KK) mass cut

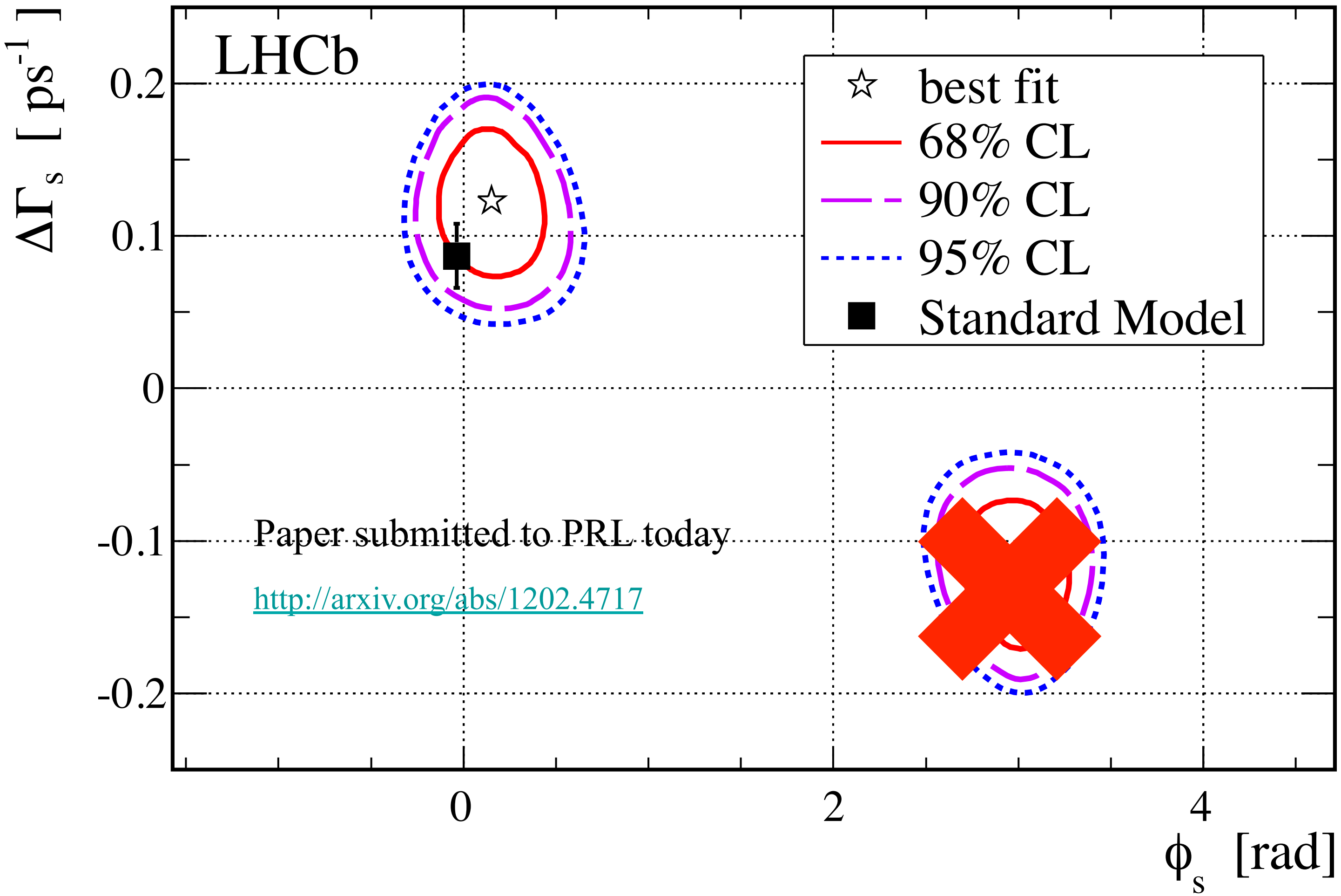
Perform analysis in four bins of m(KK) and extract phase dependence



m_{KK} interval	N_{sig}	N_{bkg}	W_p
(988, 1008) MeV	251 ± 21	1675 ± 43	0.700
(1008, 1020) MeV	4569 ± 70	2002 ± 49	0.952
(1020, 1032) MeV	3952 ± 66	2244 ± 51	0.938
(1032, 1050) MeV	726 ± 34	3442 ± 62	0.764

Solution I displays the expected decreasing trend

ϕ_s: Ambiguity Resolution



Data favour the Standard Model solution

Other Modes

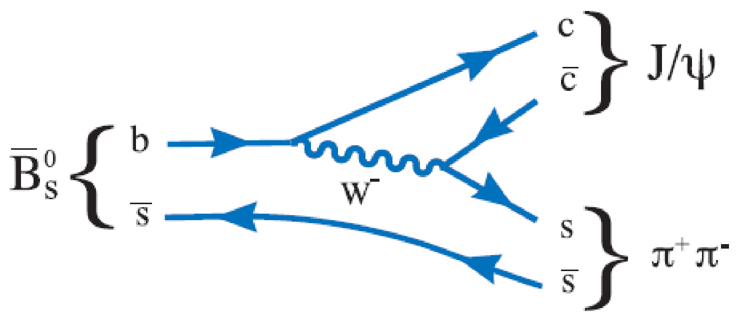
LHCb uniquely able to cross-check $B_s \rightarrow J/\psi\phi$ results using other modes

Modes that are CP eigenstates: e.g. $B_s \rightarrow J/\psi f0$

- No angular analysis needed, but lower statistics
- First result with $B_s \rightarrow J/\psi f0$ ~350 pb^{-1}

http://arxiv.org/abs/1112.3056

$$\phi_s = -0.44 \pm 0.44 \pm 0.02$$



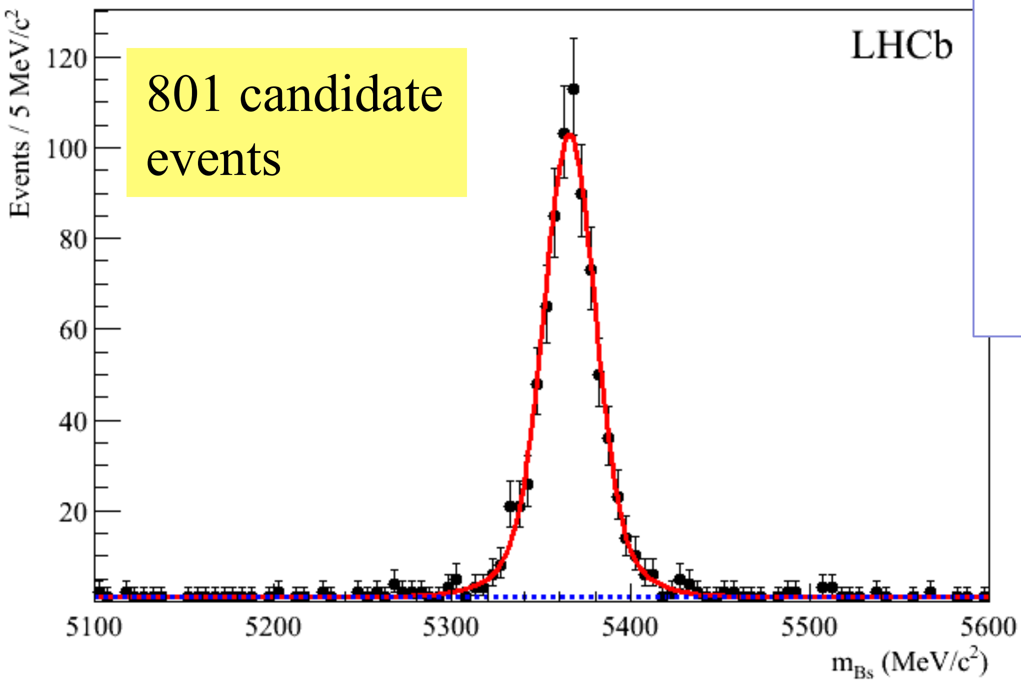
Combine with $B_s \rightarrow J/\psi/\phi$

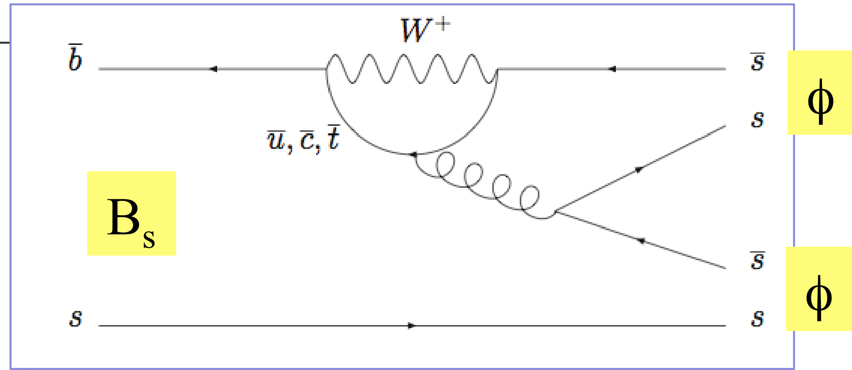
$$\phi_s = 0.07 \pm 0.17(stat) \pm 0.06(syst)\ \text{rad}$$

Other Modes: $B_s \to \phi\phi$

Decays dominated by penguins decays e.g. $B_s \to \phi\phi$

- Different sensitivity to new physics effects
- Untagged studies (presented in Summer) with ~300 events
- Paper for Winter Conferences with full 2011 dataset measuring polarization amplitudes and triple product corelations (untagged study)





Branching ratio (CDF) : $\sim 2.3 \times 10^{-5}$

Coming Soon…

New results on ϕ_s for the Winter conferences based on the full 2011 dataset

- Update in $B_s \rightarrow J/\psi\phi$ statistical precision 0.1
- Update in $B_s \rightarrow J/\psi f0$ statistical precision 0.17

Factor of two Improvement over Summer

Combined precision 0.08 on ϕ_s, strong constraint on New Physics

- Plus untagged studies in $B_s \rightarrow \phi\phi$ with full 1 fb^{-1}

Predictions for ϕ_s

M. Blanke et al., arXiv:0805.4393 [hep-ph], Little Higgs Models values up to 0.2 are reasonable

Hou et al arXiv:0810.3396 [hep-ph], 4th generation model 0.5 - 0.7

Buras arXiv:0910.1032 [hep-ph]

Model/Observable	$Br(K^+ \to \pi^+ \nu \bar{\nu})$	$Br(K_L \to \pi^0 \nu \bar{\nu})$	$Br(B_s \to \mu^+ \mu^-)$	$S_{\psi\phi}$
CMFV	20%	20%	20%	0.04
MFV	30%	30%	1000%	0.04
AC	2%	2%	1000%	1.0
RVV2	10%	10%	1000%	0.50
AKM	10%	10%	1000%	0.30
δLL	2%	2%	1000%	0.04
FBMSSM	2%	2%	1000%	0.04
GMSSM	300%	500%	1000%	1.0
LHT	150%	200%	30%	0.30
RSc	60%	150%	10%	0.75

The Future

- 2012: Collect 1.5 fb^{-1} at 8 TeV, higher luminosity, improved trigger
    - With combined 2011 and 2012 dataset and improvements in analysis will reach a precision on ϕ_s of better than 0.06 in $B_s \to J/\psi\phi$
- After the machine shutdown and energy upgrade from 2014 each year will collect ~2 fb^{-1} per year
    - Precision on ϕs will reach the Standard Model value of 0.04 in $B_s \to J/\psi\phi$.
- LHCb planning upgrade around 2018 to allow factor 100 increase in dataset size. One of the key targets precision measurement of ϕ_s in $B_s \to \phi\phi$
    - Run at $1 - 2 \times 10^{33}$ cm^{-2} s^{-1}
    - Replacement of detector front-end electronics to readout at full LHC crossing rate of 40 MHz and improve trigger

Summary

- LHCb is starting to provide answers to the most important open questions in the flavour sector

- Both the LHC and LHCb have made excellent starts

- ϕ_s measured to 0.18 precision with 350 pb^{-1}

$$\phi_s = 0.07 \pm 0.17(stat) \pm 0.06(syst)\ \text{rad}$$

- Stay tuned: precision of 0.08 on ϕ_s expected for Winter Conferences

    - Plus many other exciting new results

- Precision on ϕ_s comparable with Standard Model expectation of 0.04 by end of 2012 proton run

- First steps in a strong physics program to 2018 and beyond