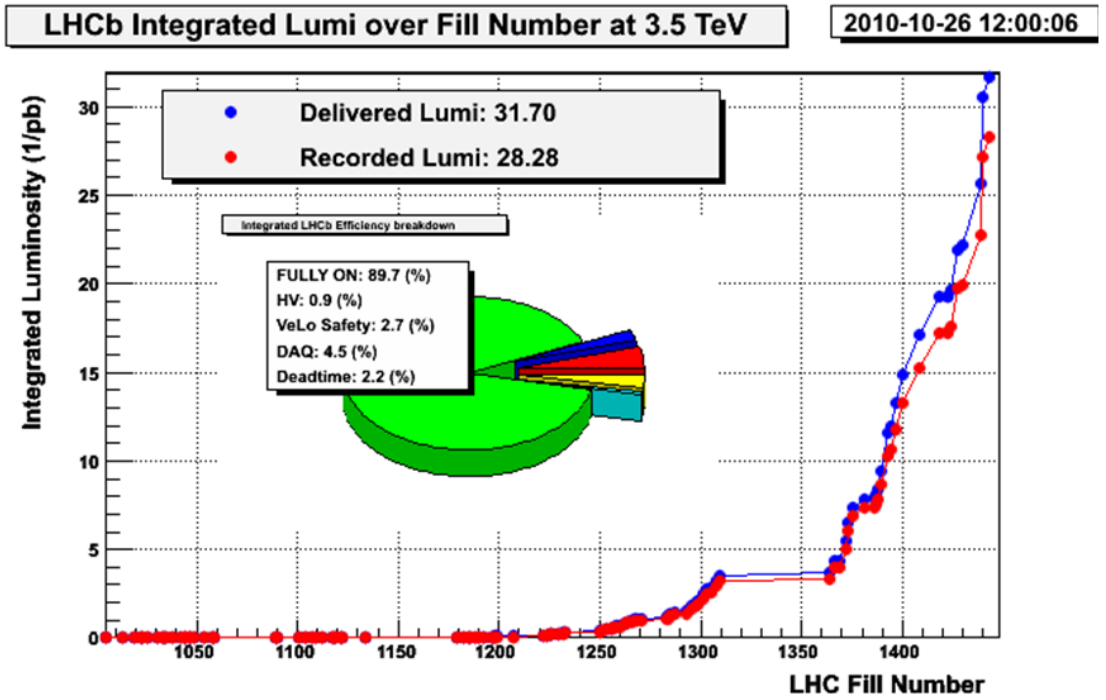
S. Stone

LHCb Physics

The LHCb Collaboration

- 800 Physicists
- 54 Institutes
- 15 Countries
- Basking in light of 2008 Nobel Prize to Kobayshi, Maskawa & Nambu, "for the discovery of the origin of the broken symmetry which predicts the existence of at least 3 families of quarks"



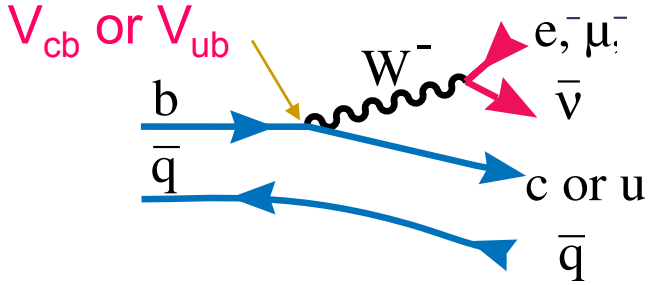
Quark Mixing & the CKM Matrix

$$
\begin{array}{cc} & \longrightarrow \text{mass} \\ & \begin{array}{ccc} d & s & b \end{array} \\ \begin{array}{c} u \\ c \\ t \\ (q=-1/3) \end{array} & V = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \end{array}
\quad (q=2/3) \downarrow \text{mass}
$$

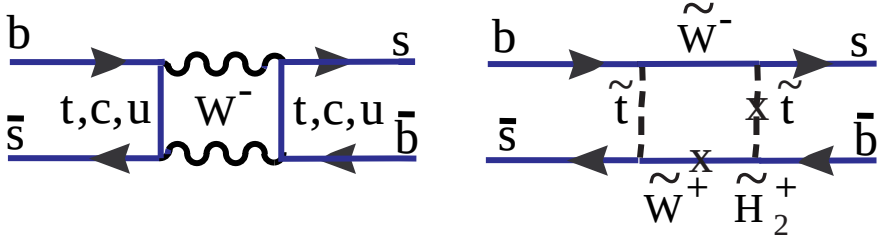
- A, λ, ρ and η are in the Standard Model fundamental constants of nature like G, or α_{EM}
- η multiplies i and is responsible for CP violation
- We know λ=0.22 (V_{us}), A~0.8; constraints on ρ & η

Limits on New Physics

- It is oft said that we have not seen New Physics, yet what we observe is the sum of Standard Model + New Physics. How to set limits on NP?
- Assume that tree level diagrams are dominated by SM and loop diagrams could contain NP



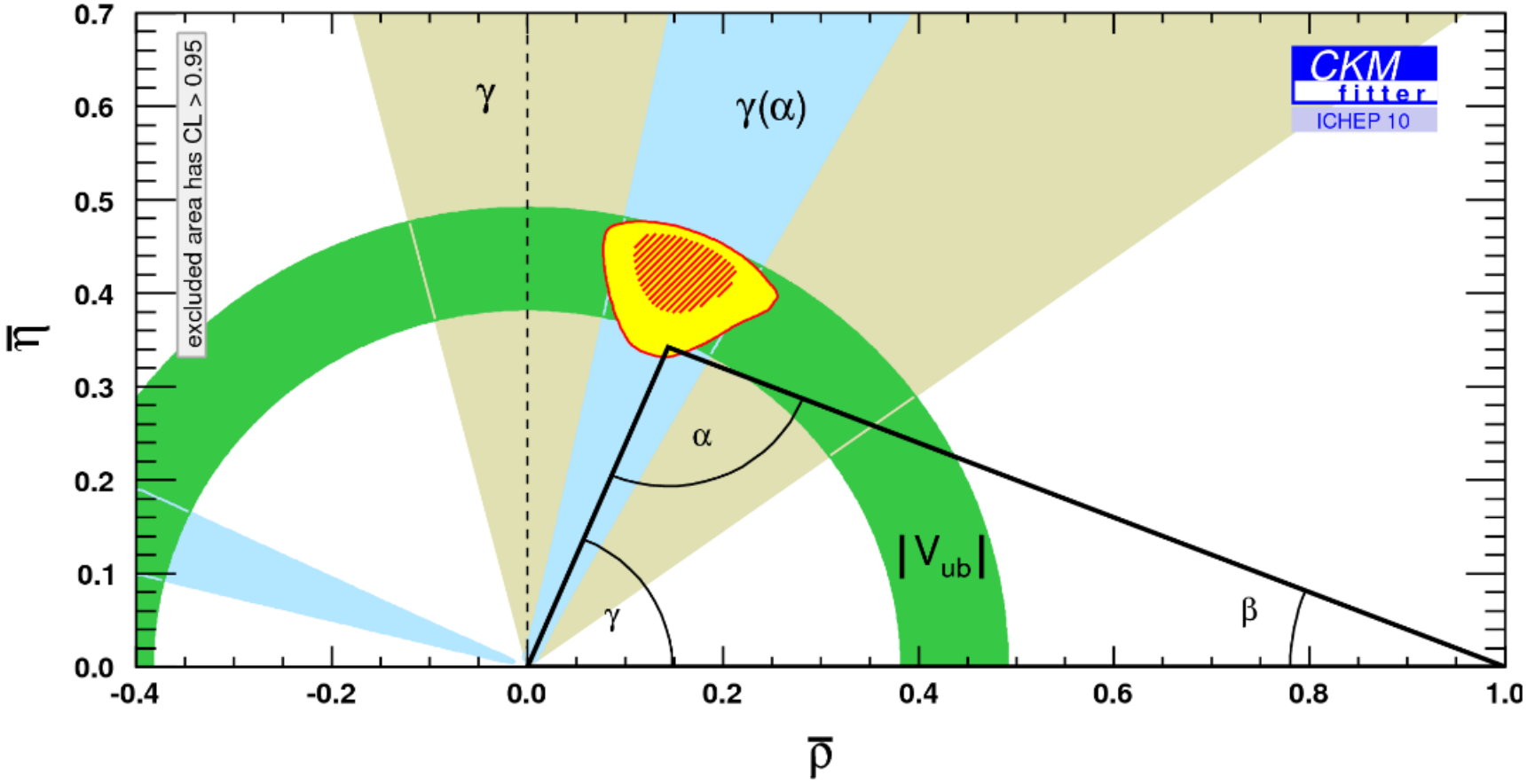
Tree diagram example



Loop diagram example

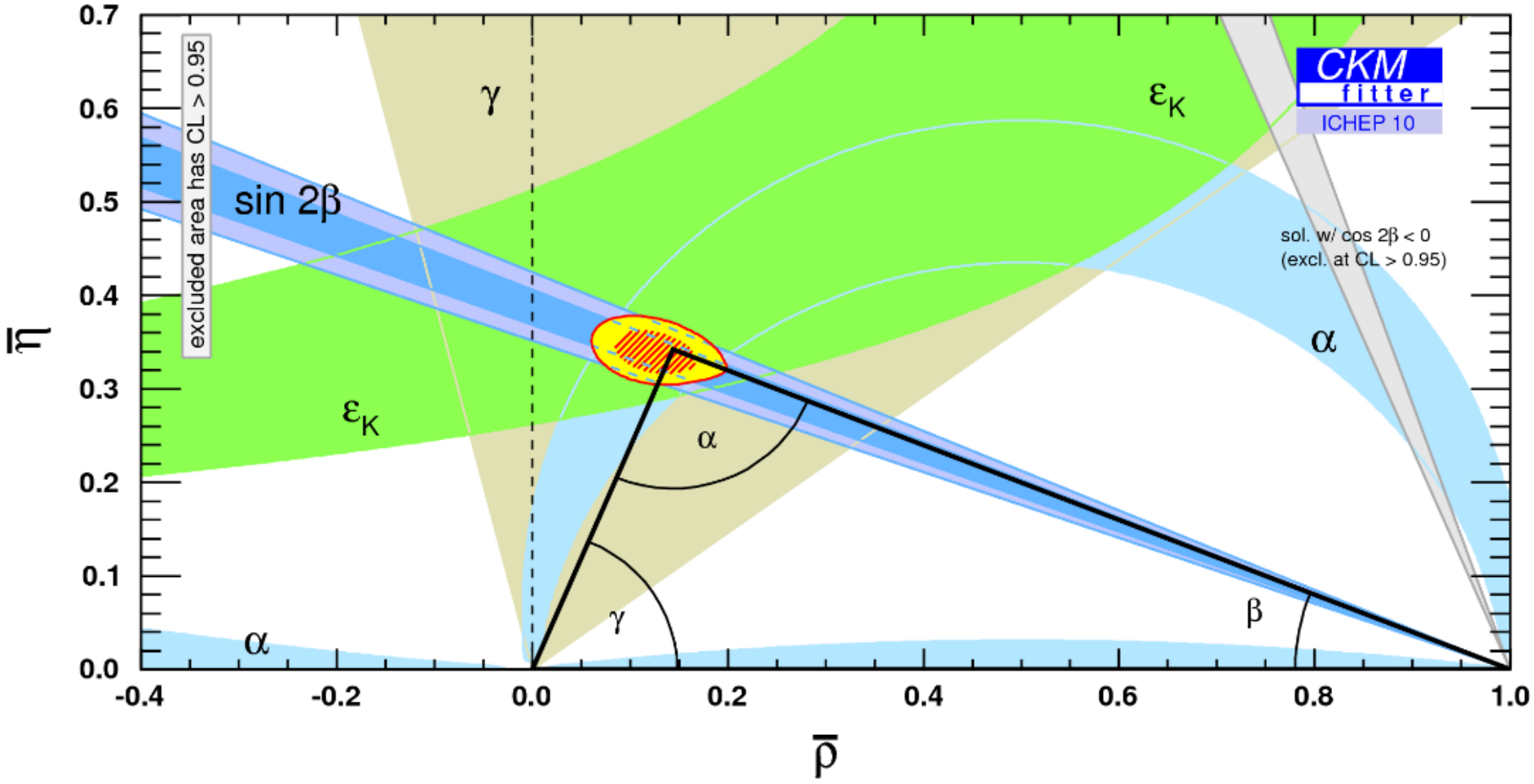
What are limits on NP from quark decays?

- Tree diagrams are unlikely to be affected by physics beyond the Standard Model

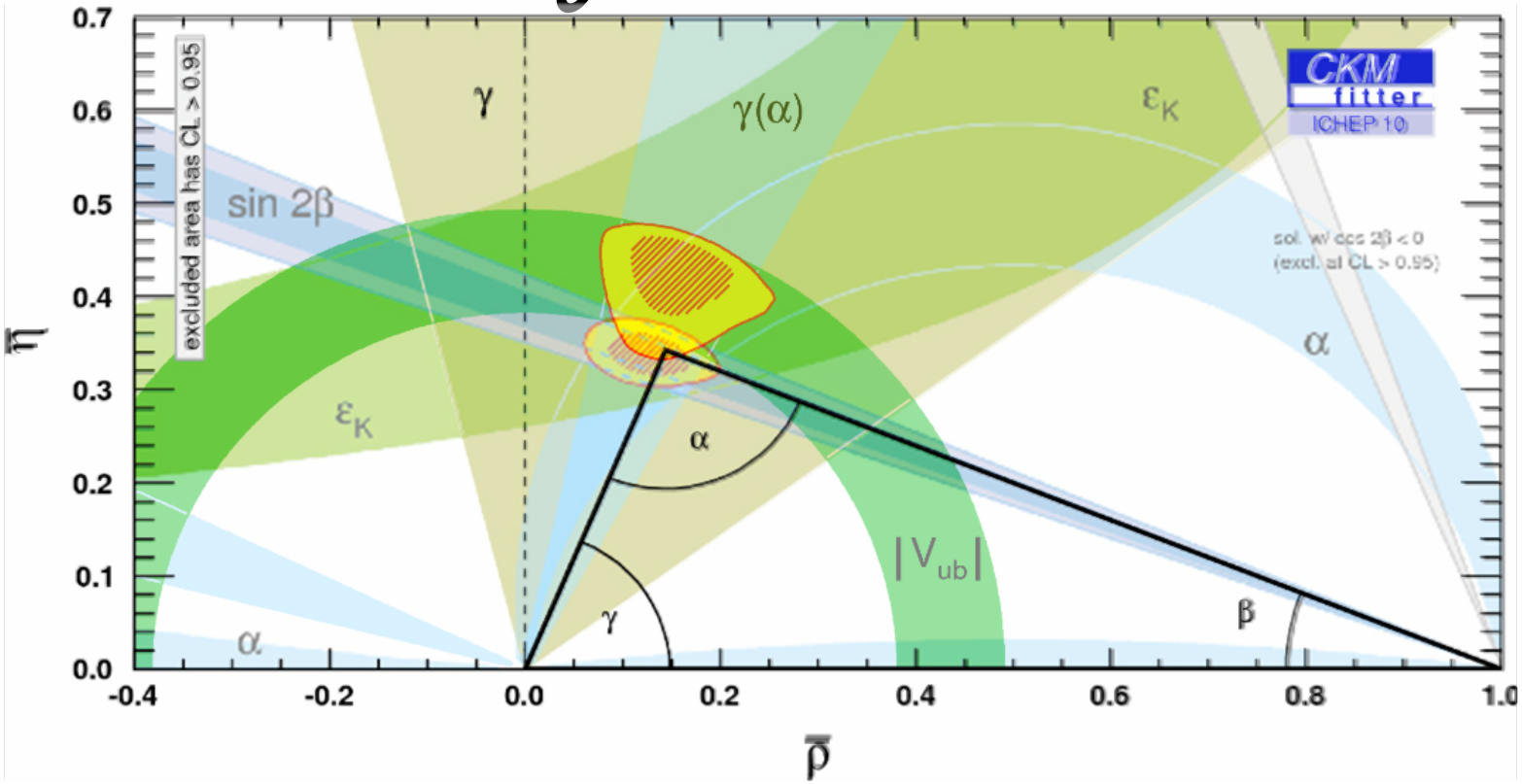


CP Violation in B^0 & K^0 Only

- Absorptive (Imaginary) of mixing diagram should be sensitive to New Physics. Lets compare

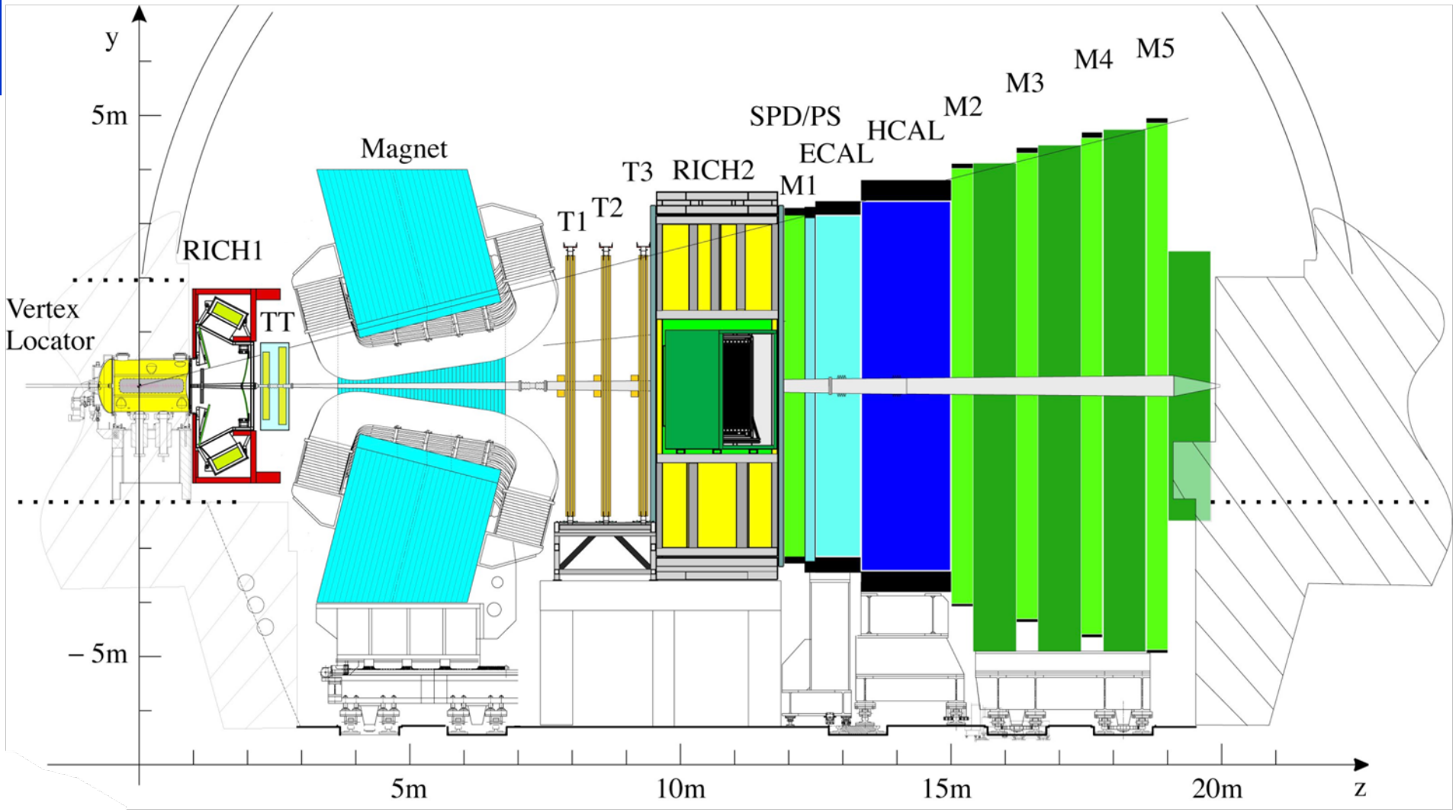


They are Consistent

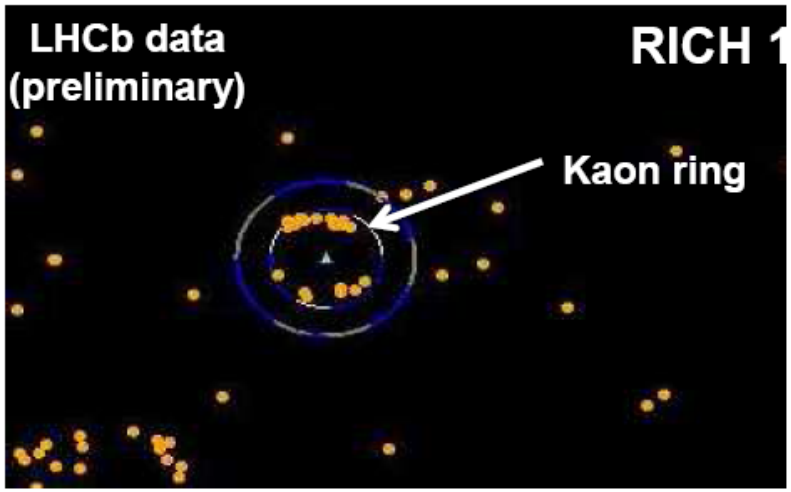


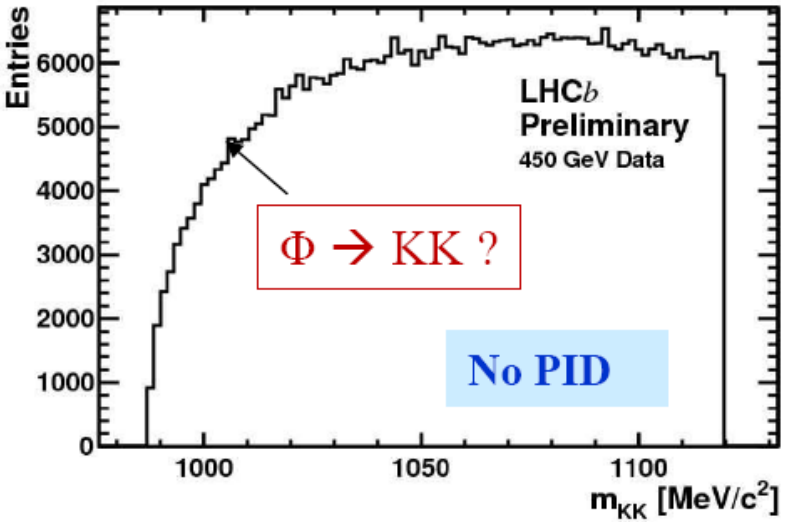
- But consistency is only at the 5% level
- Same for B_s – CP violation in $J/\psi\,\phi$ (not including D0 A_{sl}) $\Rightarrow$limits on NP are not so strong

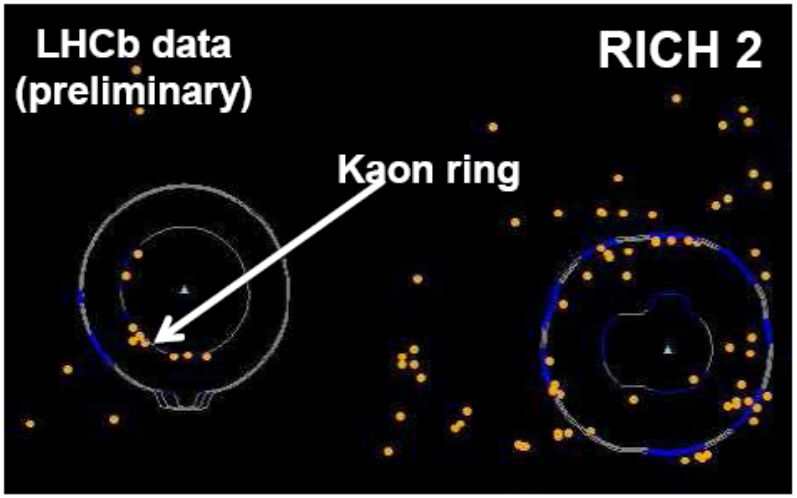
The LHCb Detector

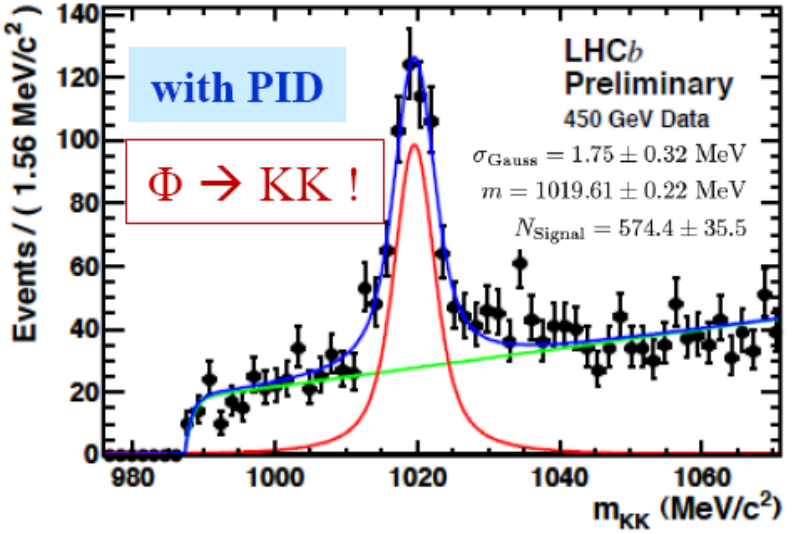


Particle Identification





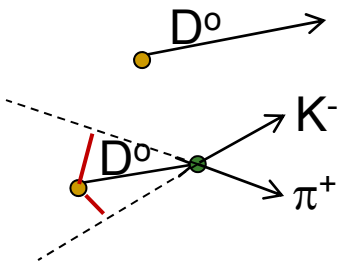




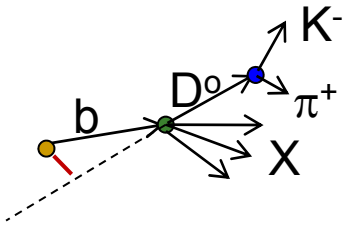
Measurement of $\sigma(pp \to b\bar{b}X)$ using $b \to D^0 X \mu^- \nu$

Strategy

- Consider pp $\rightarrow c\bar{c}X$, $c \rightarrow D^o$ X (Prompt)
  - The D^o should point at the vertex, so IP should = 0
  - Now suppose $D^o \rightarrow K^-\pi^+$, then $K^-\pi^+$ have large IP's, in general, i.e. distributions are not peaked at zero



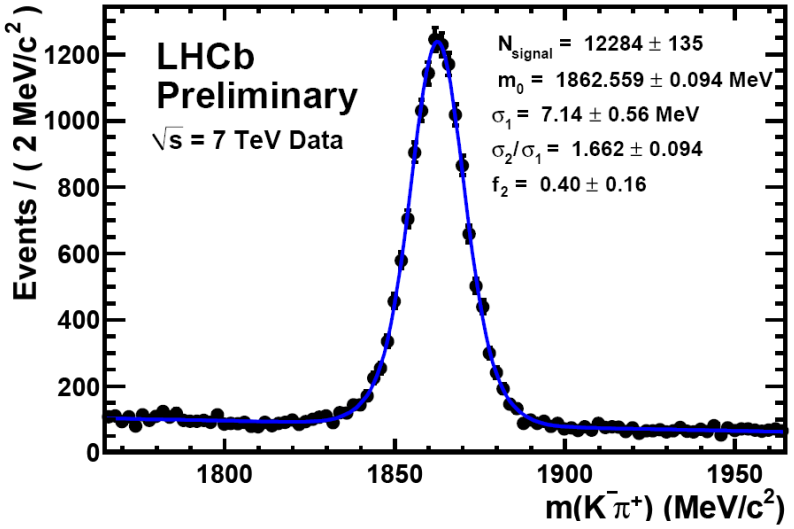
- Consider pp $\rightarrow b\bar{b}X$, $b \rightarrow D^o$ X (DfB)
  - Now the D^o has significant IP
  - The $K^-\pi^+$ even larger than before



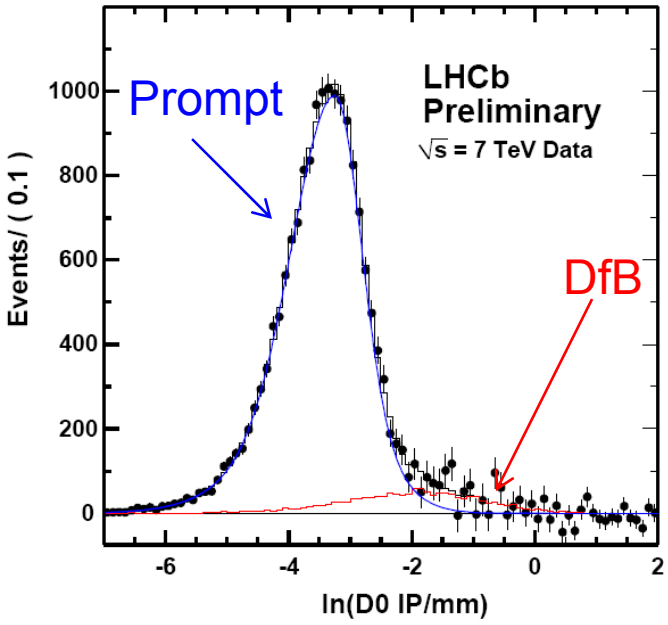
- We know $B(b \rightarrow D^o X \mu^- \nu) = (6.82 \pm 0.35)\%$ (LEP)
- Require minimum p_t so that IP is well defined
- Make sure D^o candidate is separated from primary

Analysis with Untriggered Sample, ~3 nb^{-1}

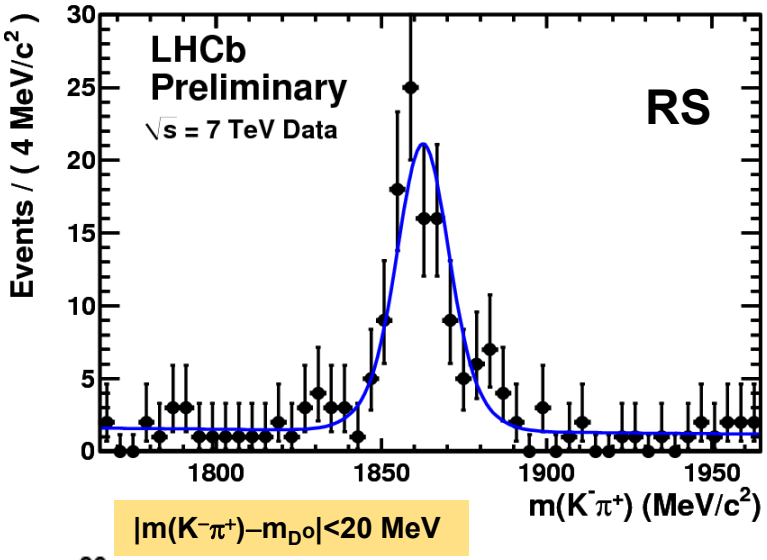
- $K^-\pi^+$ mass spectrum used to define signal shape

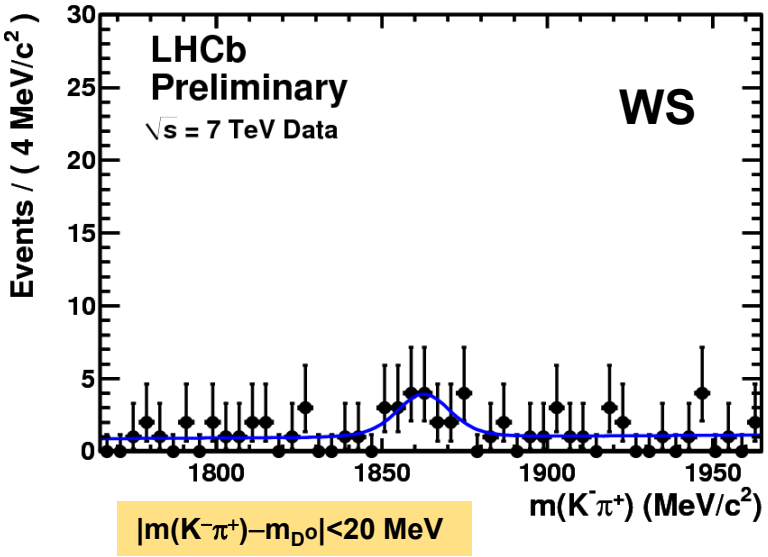


- IP distribution used to separate Prompt & DfB



Fits to $D^0\mu$


LHCb
Preliminary
√s = 7 TeV Data
RS
Events / (4 MeV/c²)
m(K⁻π⁺) (MeV/c²)
|m(K⁻π⁺)–m_D0|<20 MeV


LHCb
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m(K⁻π⁺) (MeV/c²)
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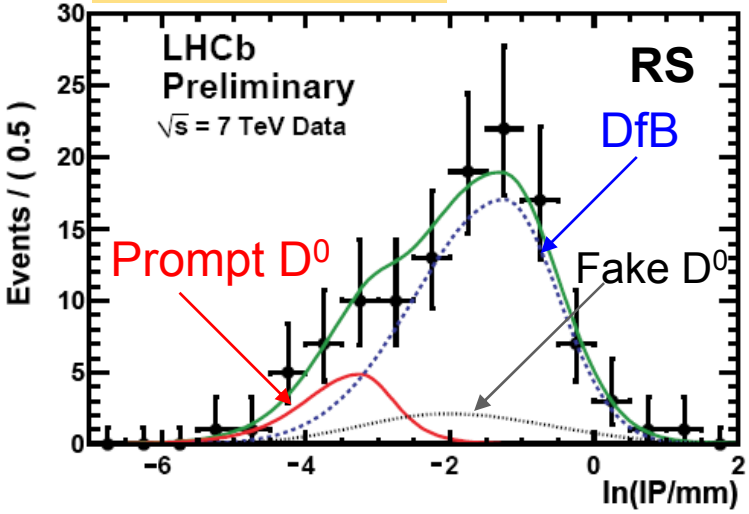
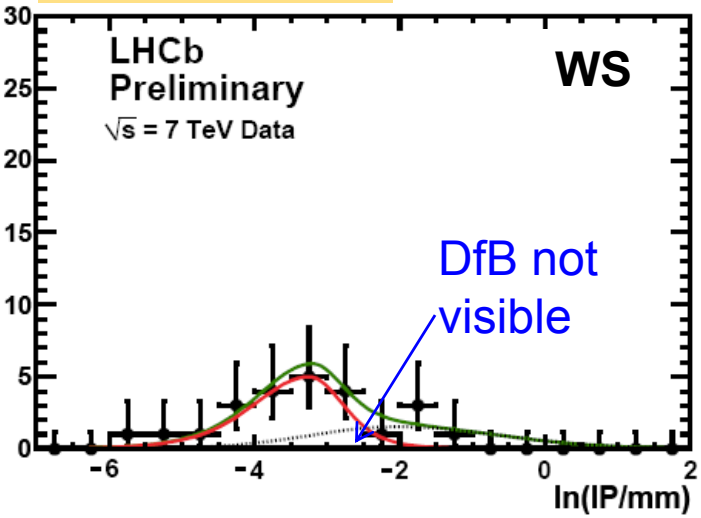

LHCb
Preliminary
√s = 7 TeV Data
RS
DfB
Prompt D⁰
Fake D⁰
Events / (0.5)
ln(IP/mm)


LHCb
Preliminary
√s = 7 TeV Data
WS
DfB not
visible
ln(IP/mm)

Systematic Errors

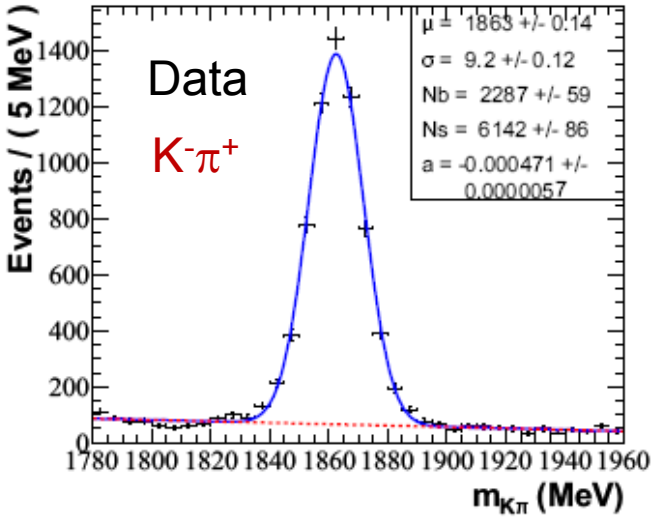
- Determined from data whenever possible
- Ex: Tracking efficiency

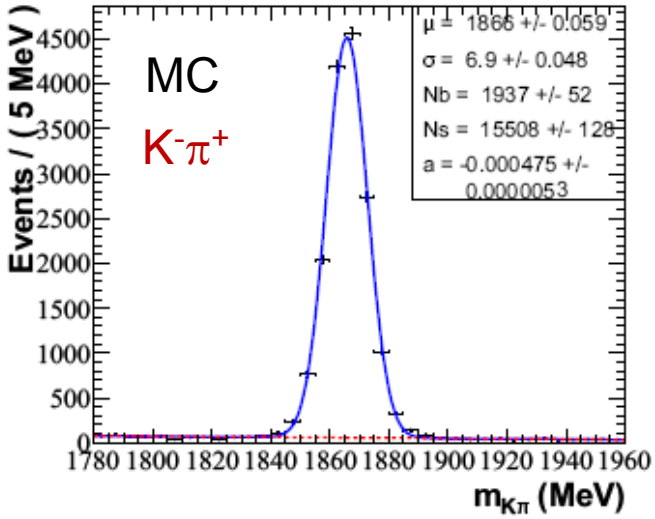
Source	Error (%)
Luminosity	10.0
Tracking efficiency	10.0
$\mathcal{B}(b \to D^0 X \mu^- \bar{\nu})$	5.1
Assumed branching fractions	4.4
LEP fragmentation fractions	4.2
Generated b p_T distribution	3.0
Muon identification	2.5
χ^2_{IP} cut	2.5
MC statistics	1.5
Prompt and Dfb shapes	1.4
$\mathcal{B}(D^0 \to K^- \pi^+)$	1.3
$D^0 \mu^-$ vertex χ^2 cut	1.2
Kaon identification	1.2
Muon fakes	1.0
D^0 mass cut	1.0
D^0 vertex χ^2 cut	0.6
D^0 flight distance cut	0.4
Pion identification	0.3
Total	17.3%

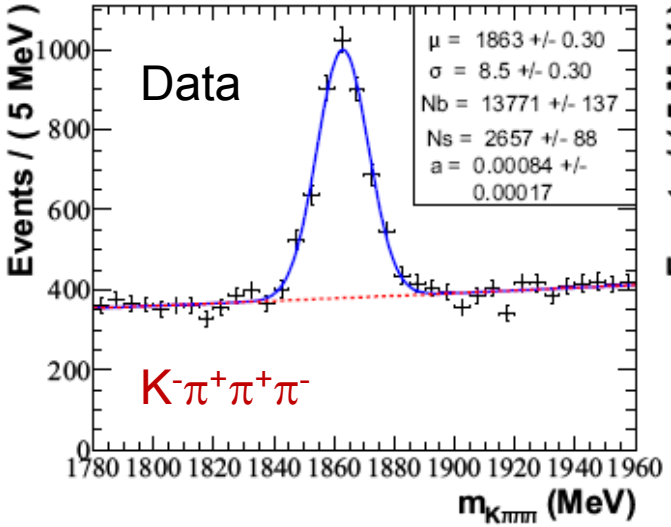
Tracking efficiency

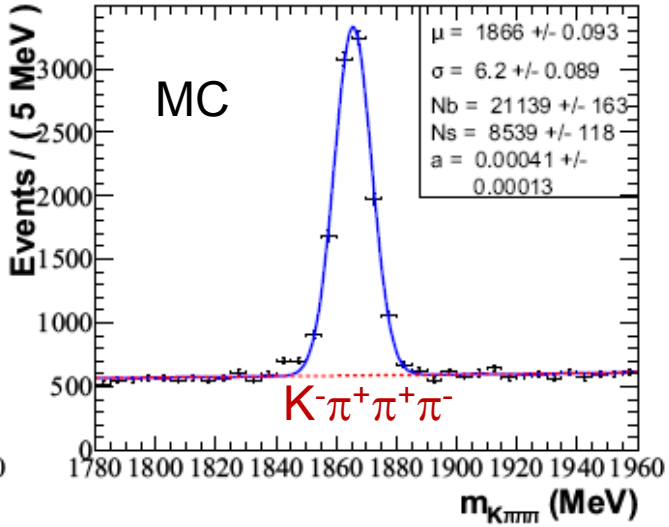
- Ratio of K3π/Kπ data/MC gives 1.00±0.03 per track

LHCb ~3 nb^{-1}







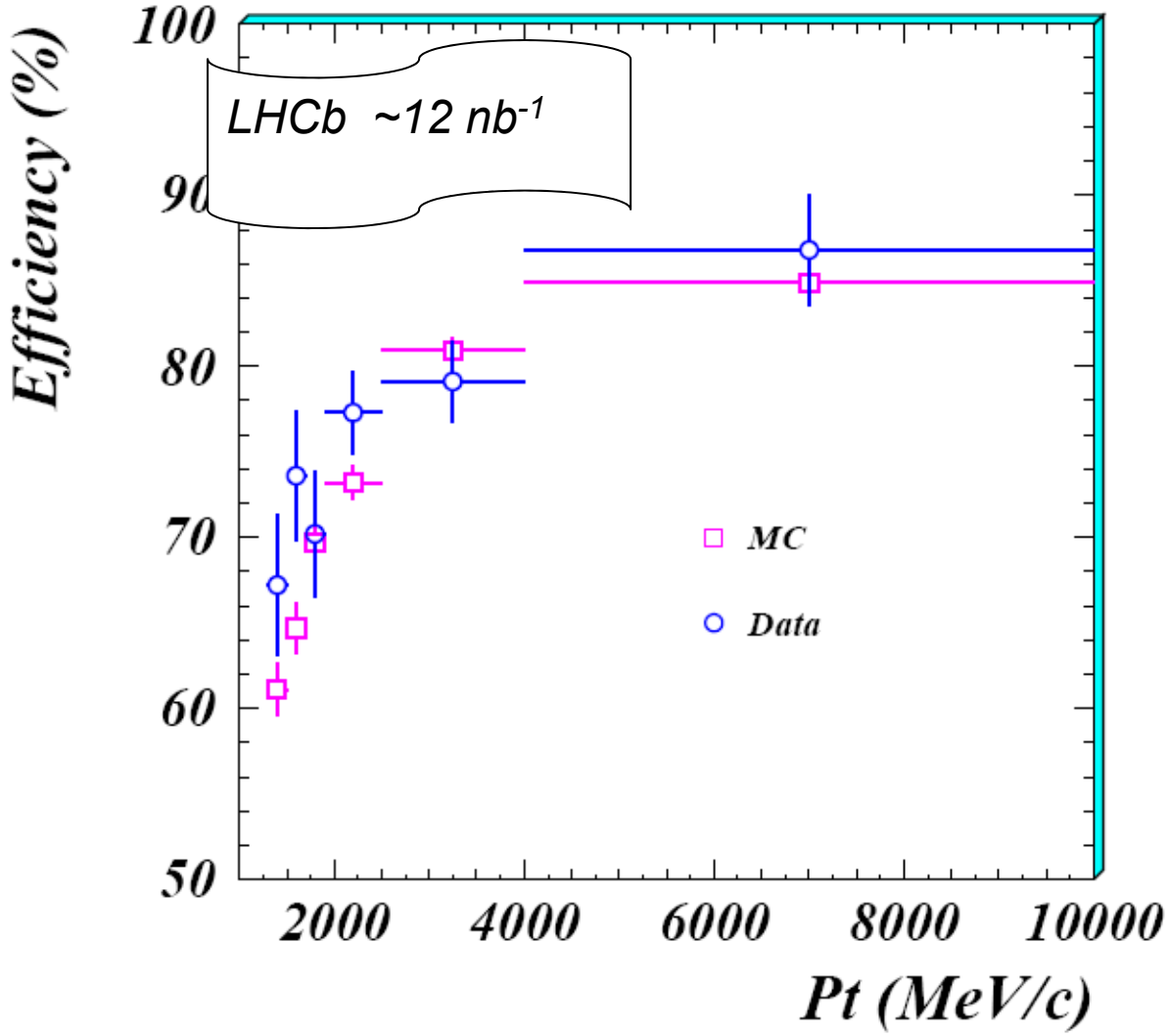


HLT1 Triggered additional 12 nb^{-1}

Use single muon trigger with p_t>1.3 GeV/c (0.5 GeV/c in untriggered sample)

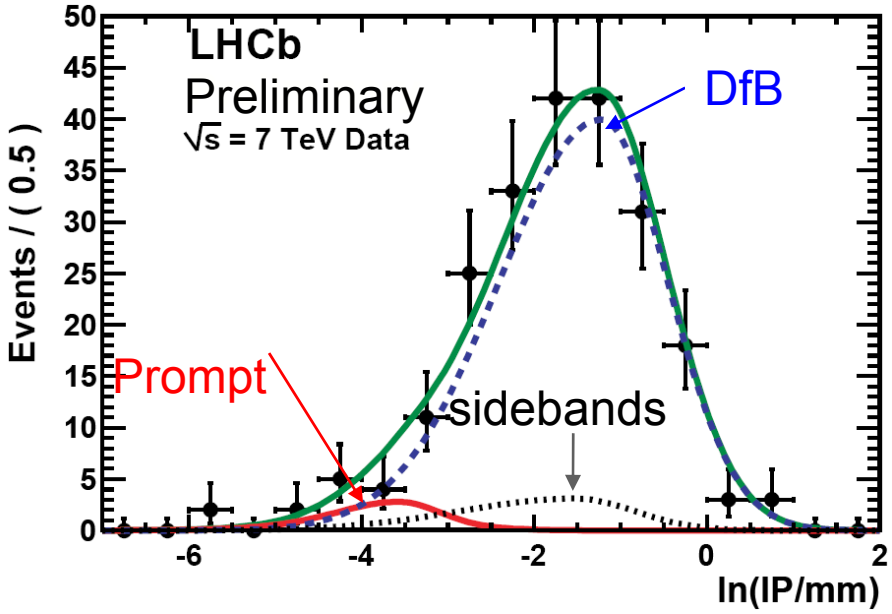
Trigger eff checked with data

- Evaluated using other triggers that fired independently of the single muon trigger that we use for our signal (TIS)



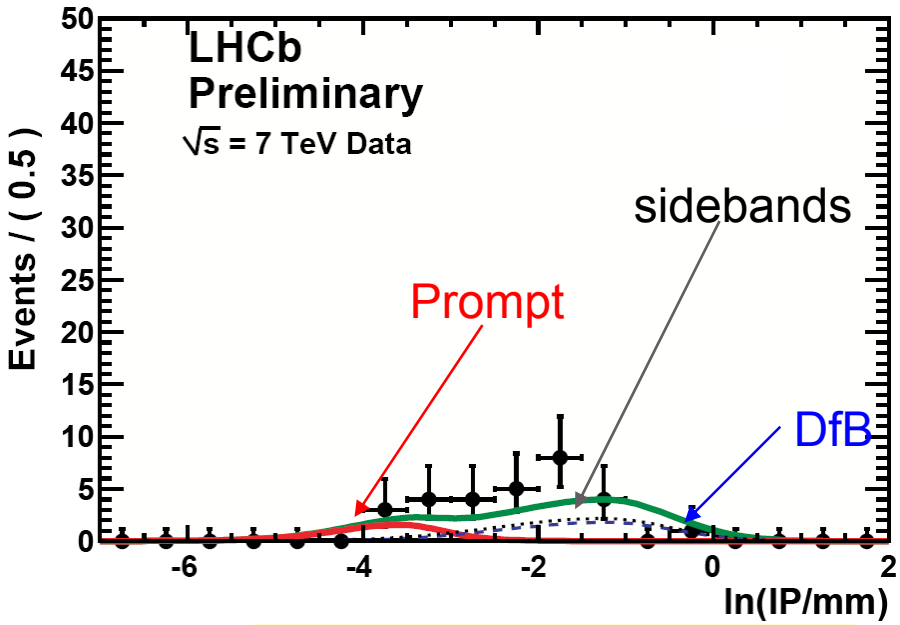
IP distributions from 12/nb

RS



195±15 events

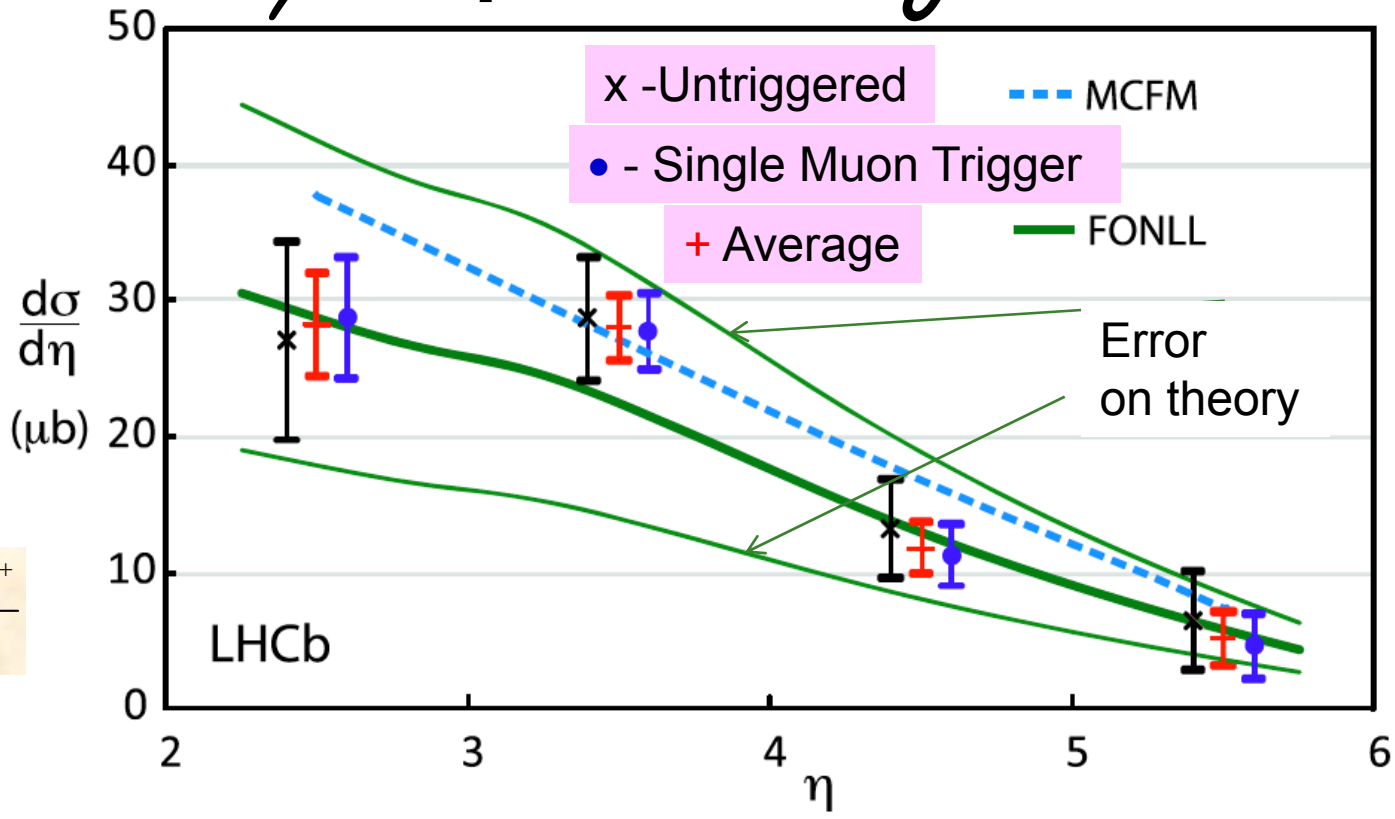
WS



WS: 8.8±5.1 events

$2 < \eta < 6$

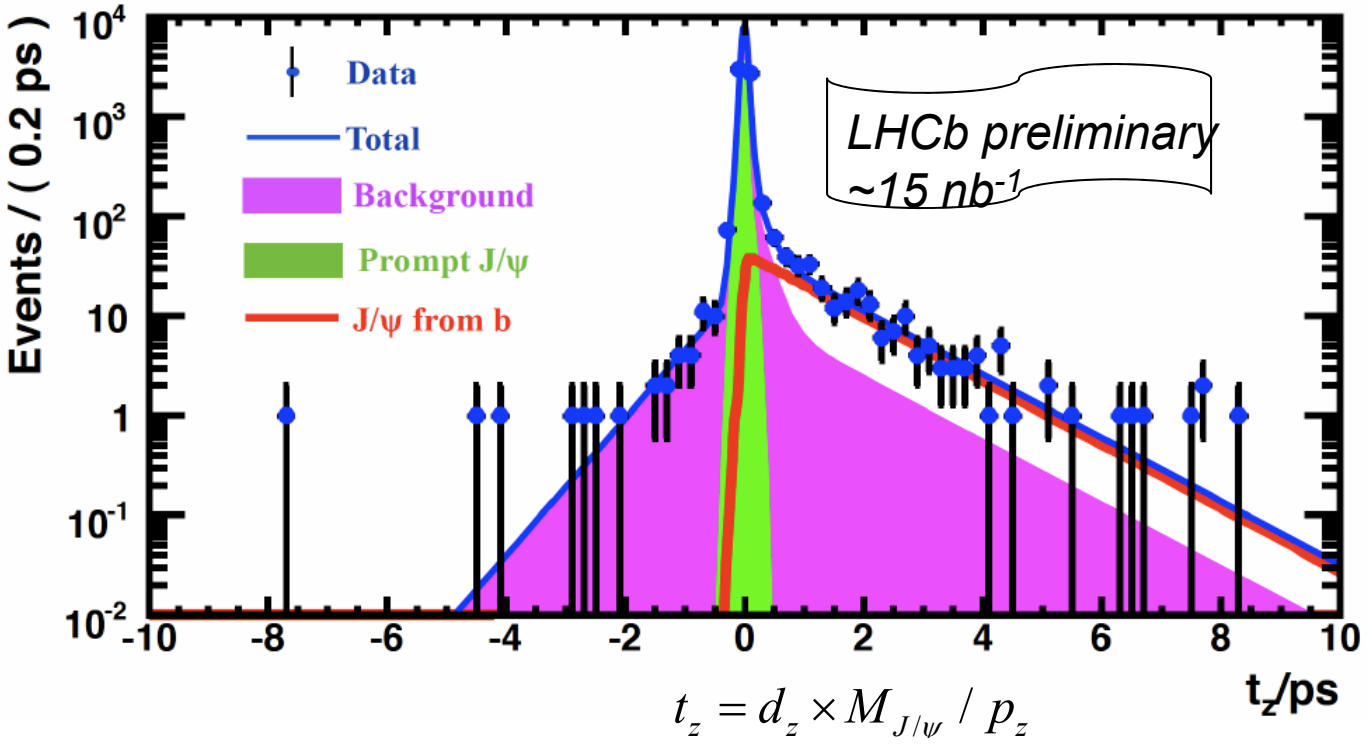
$d\sigma/d\eta$ Summary



$$\sigma = \frac{\#\text{ of detected } D^0\mu^- \ \&\ \bar{D}^0\mu^+}{L \text{ x efficiency x } 2}$$

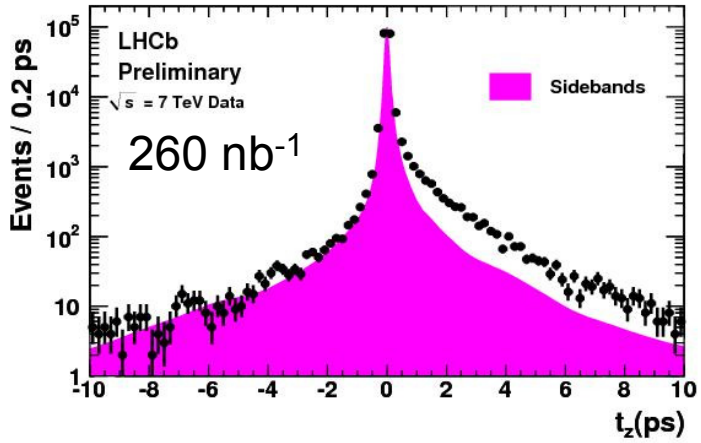
- In $2<\eta<6$, $(75.3\pm5.4\pm13.0)$ μb LEP frag
- In $2<\eta<6$, 89.6 μb Tevatron frag

$\sigma(pp \to b\bar{b}X)$ using $b \to J/\psi X$



$$t_z = d_z \times M_{J/\psi} / p_z$$

- In $2<\eta<6$, $(84.5 \pm 6.3 \pm 15.6)$ μb LEP frag
- In $2<\eta<6$, 86.2 μb Tevatron frag



$\sigma(pp \to b\bar{b}X)$ Over all phase space

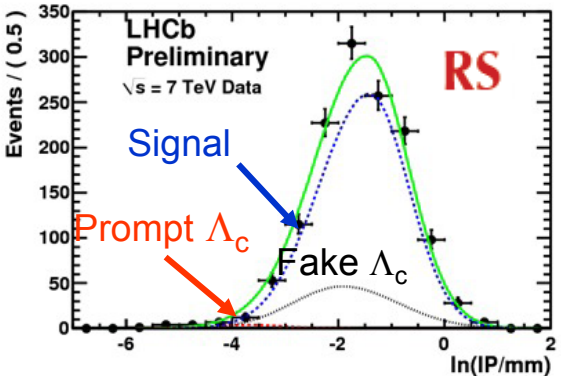
- In $2<\eta<6$ (Average)
  - $(78.2 \pm 4.1 \pm 12.3)$ μb LEP frag
- To get over all η multiply by 3.77 (Pythia), 3.63 (MCFM), 3.73 (FONLL)
- $\sigma = (295 \pm 15 \pm 46)$ μb LEP frag
- $\sigma = 330$ μb Tevatron frag functions
- Theory: MCFM 332 μb, FONLL 254 μb

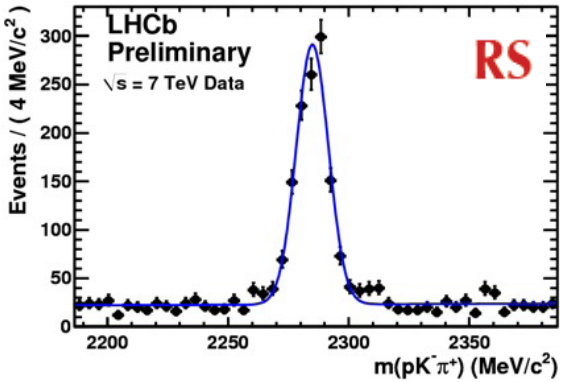
Soon other modes

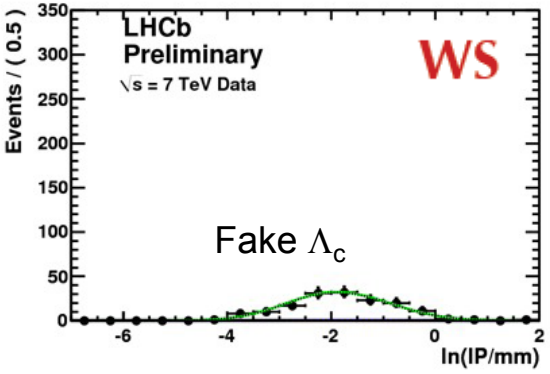
- $b \to D^0 X \mu^- \nu$, $D^+ X \mu^- \nu$, $b \to D_s X \mu^- \nu$ & $\Lambda_b \to \Lambda_c \mu \nu X$

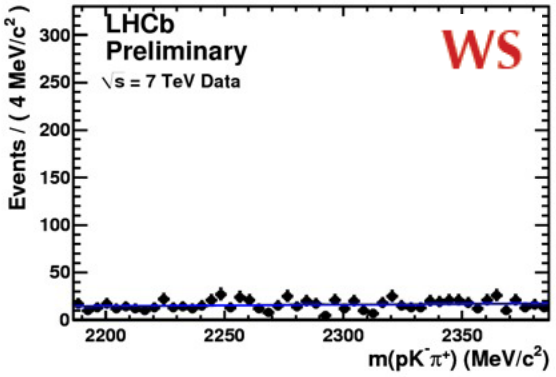
~0.8 pb^{-1}

$\Lambda_c^+ \to p^+ K^- \pi^+$ (BR=5.0±1.3%)



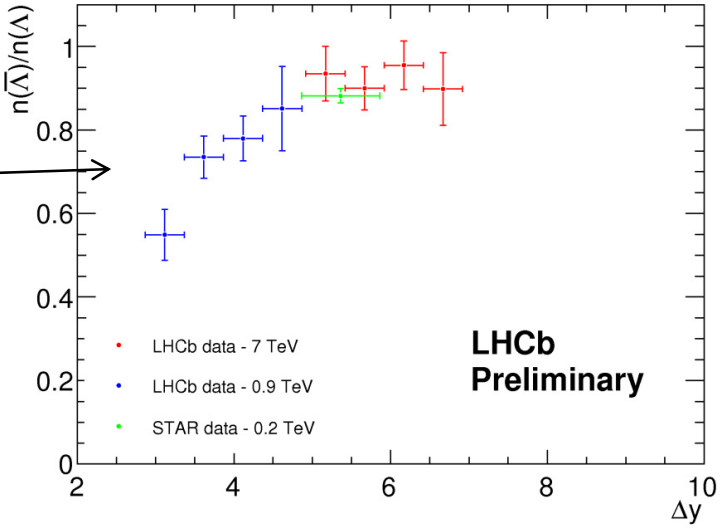


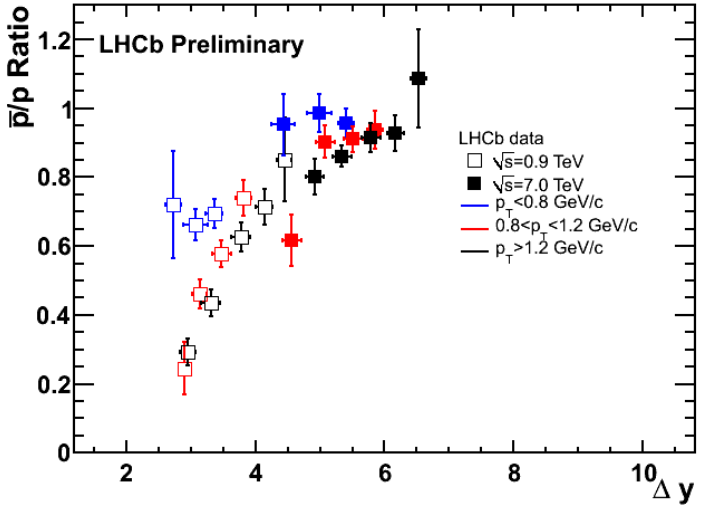


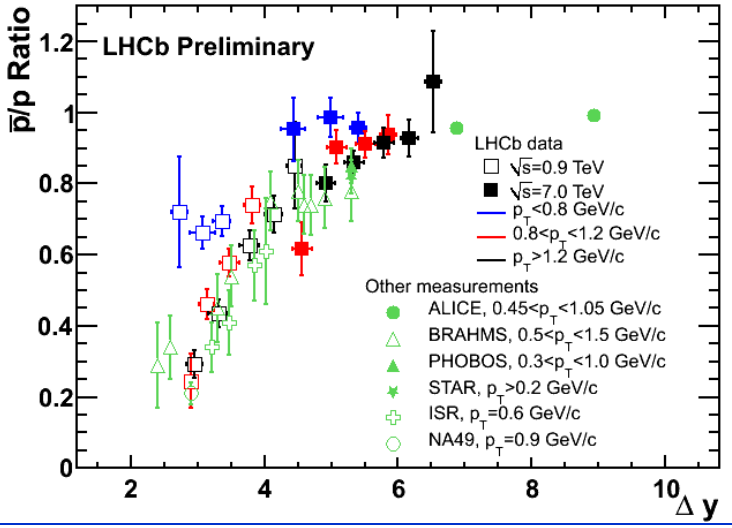


Other results: Remembering the beam

- $\Delta y \equiv y_{beam} - y_{hadron}$
- Measure $\bar{\Lambda}/\Lambda$ & $\bar{p}/p$

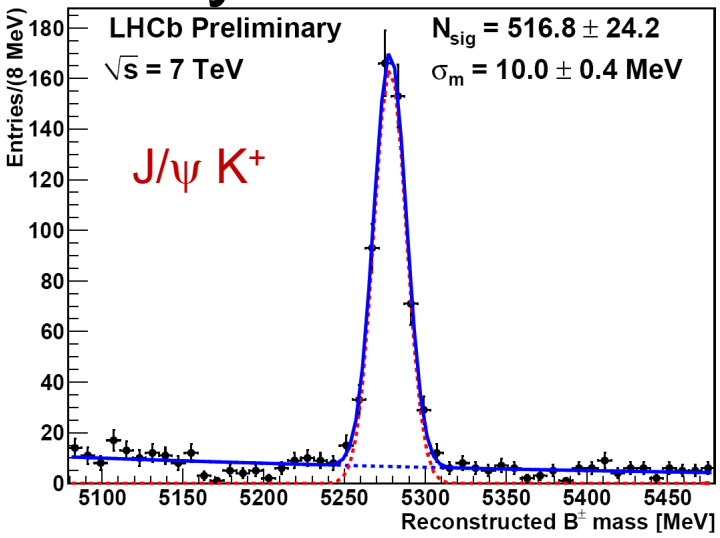


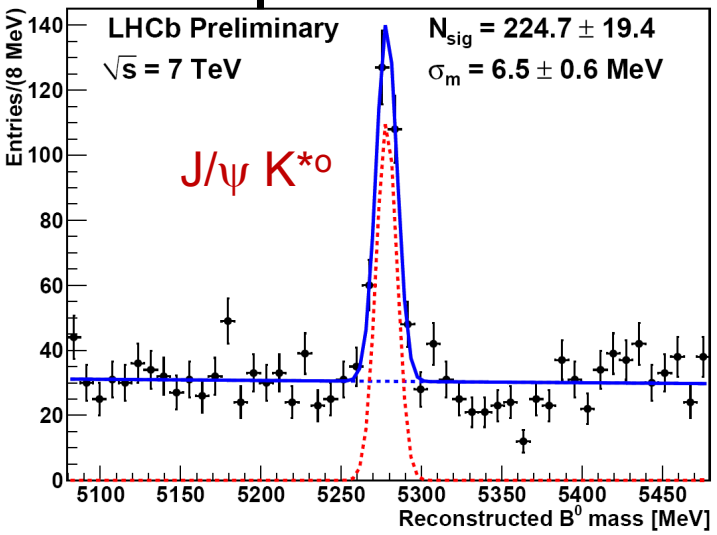


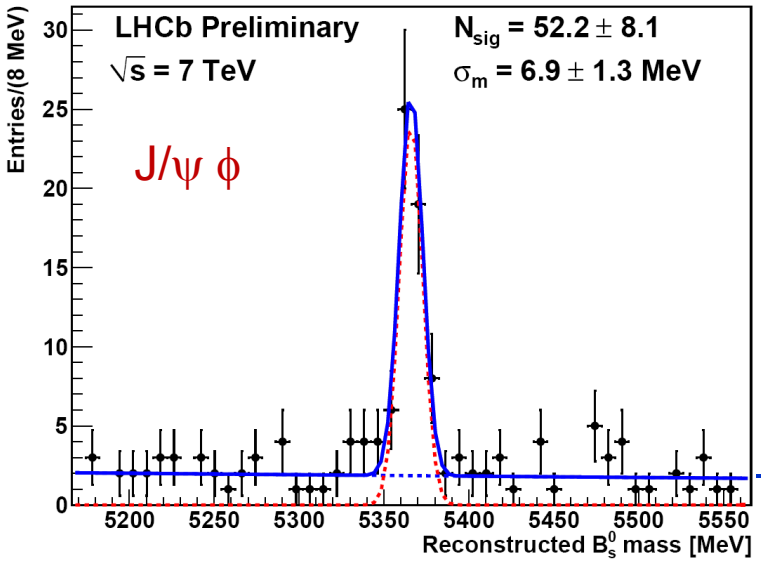


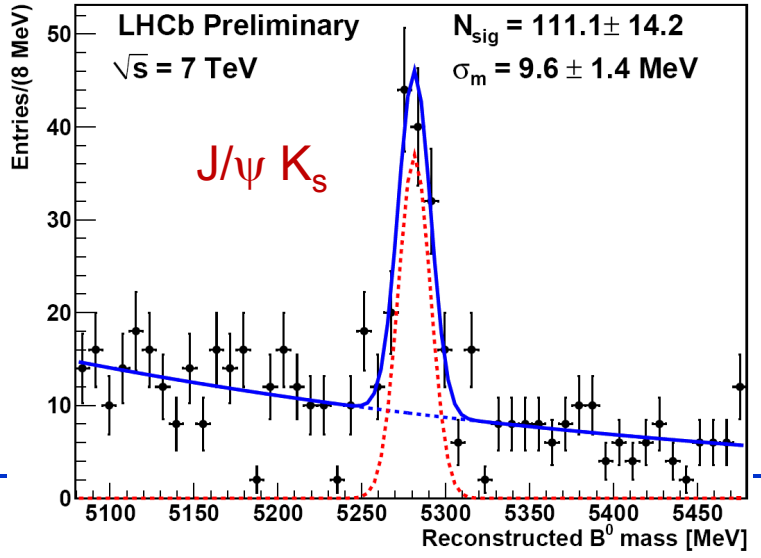
Exclusive $B \to J/\psi h$

- Fully reconstructed B's ~3 pb^{-1}

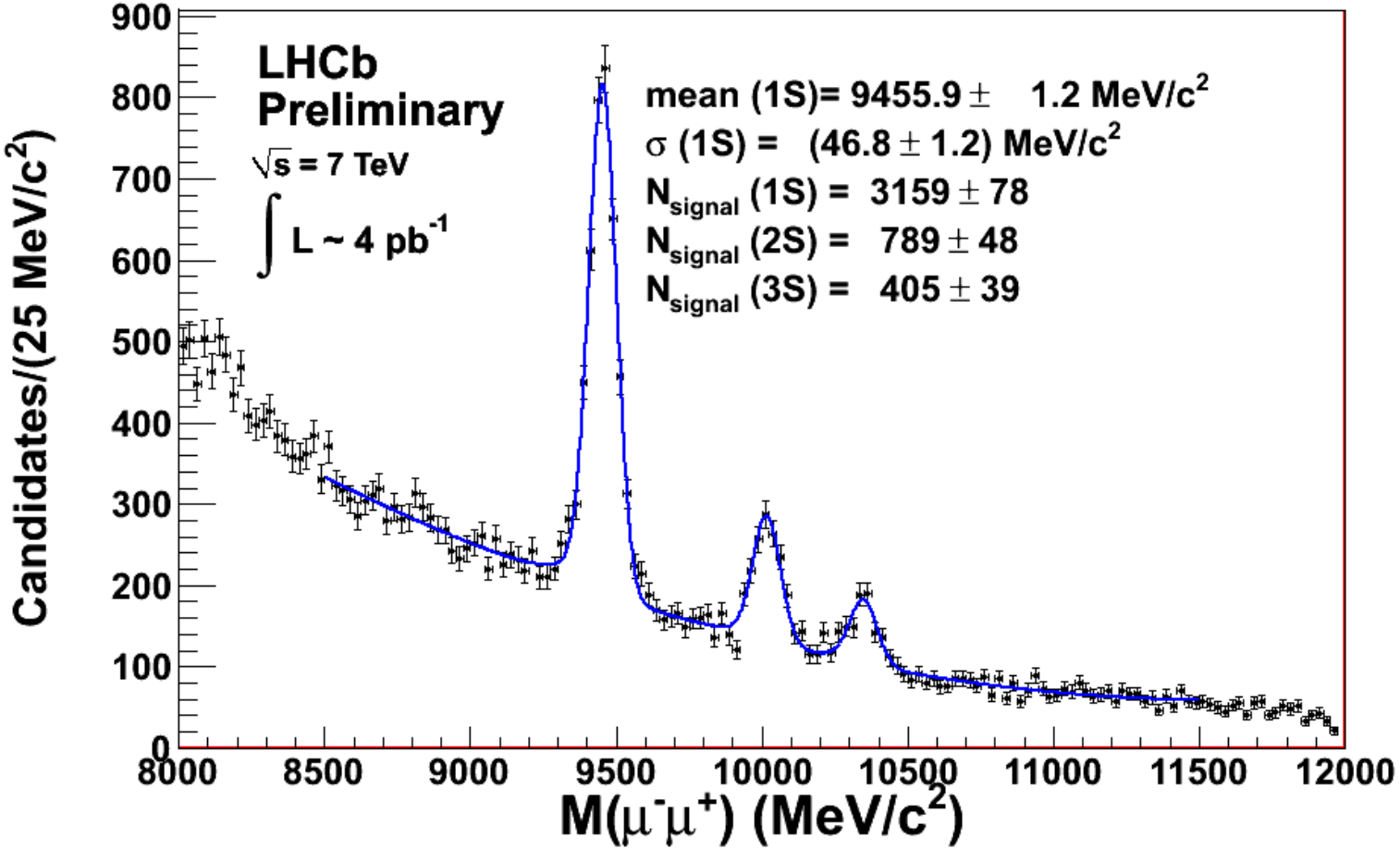




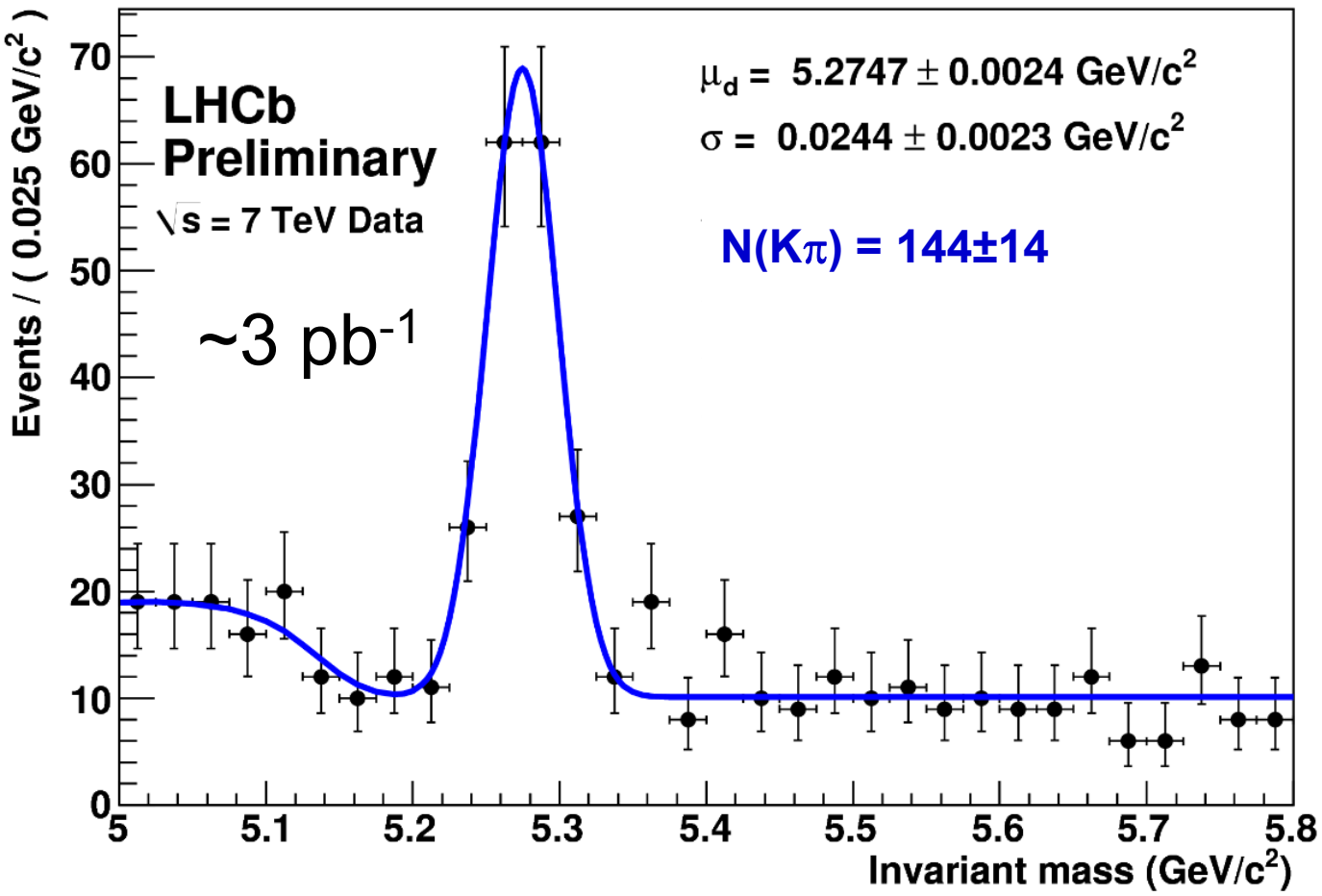




Upsilons too



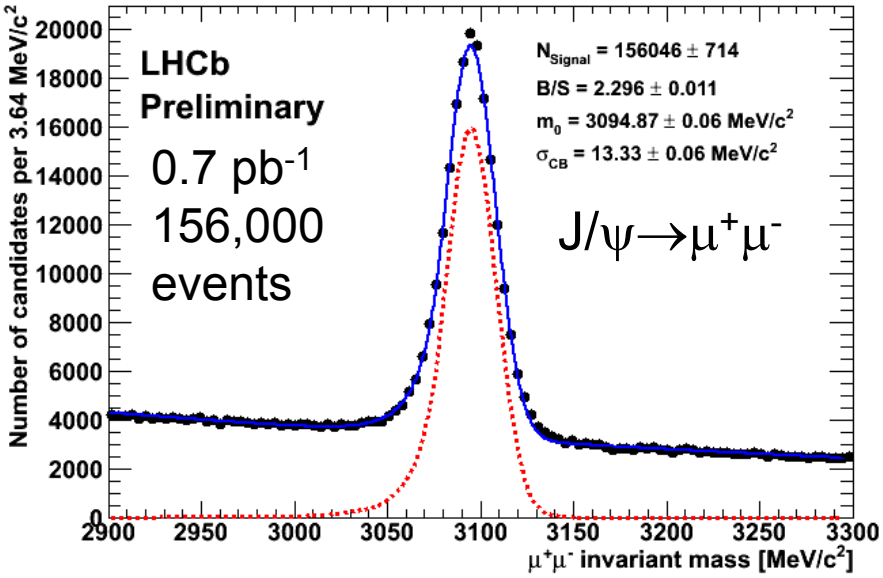
$B \to K^- \pi^+$

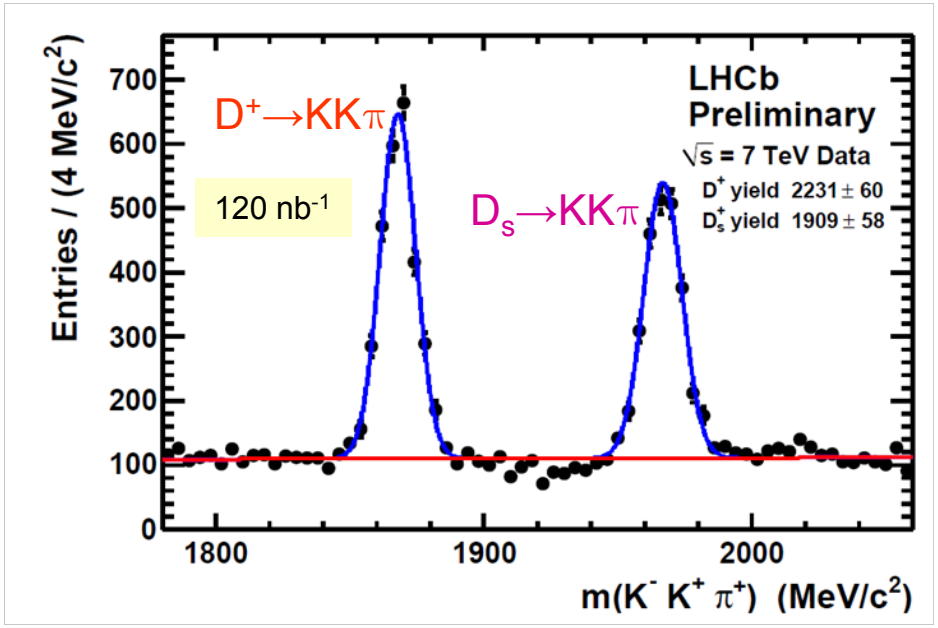


- Extrapolates to 50,000/fb^{-1}
- B-factories have ~10,000 in 1000 fb^{-1}

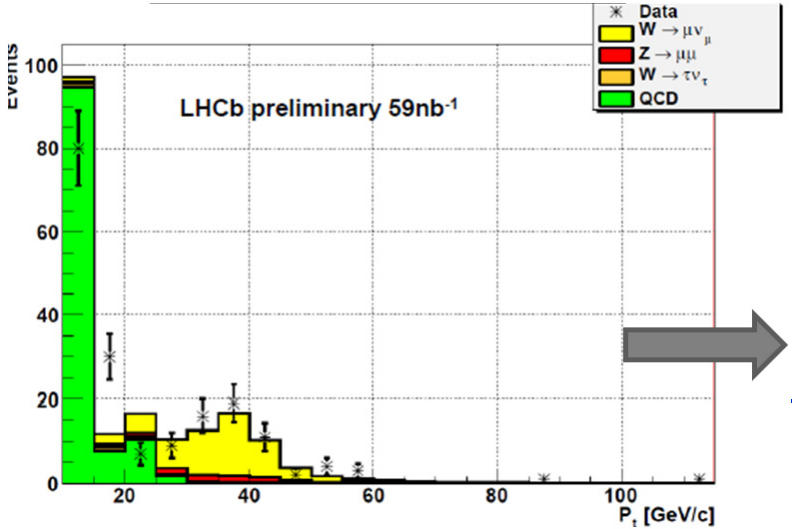
Many more interesting results available

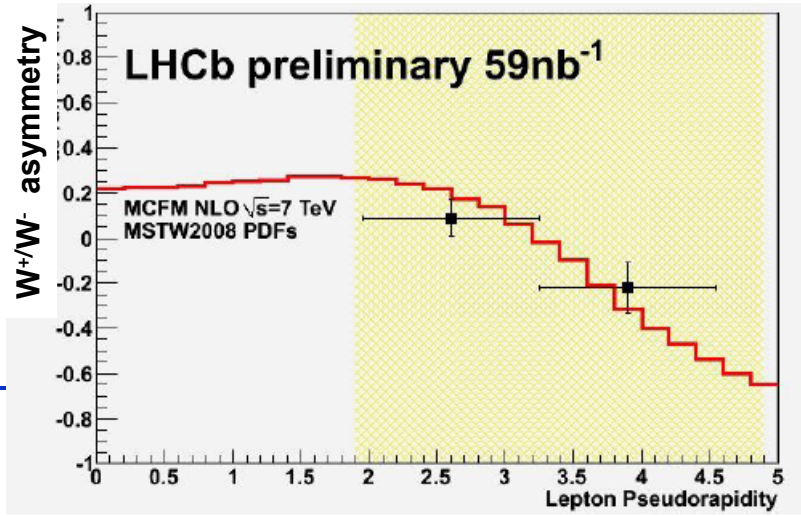
Other results





- $W^+ \rightarrow \mu^+ \nu$





Some Interesting Near Future Measurements & Sensitivities

LHCb expectations: $\geq 40\ pb^{-1}$ in 2010

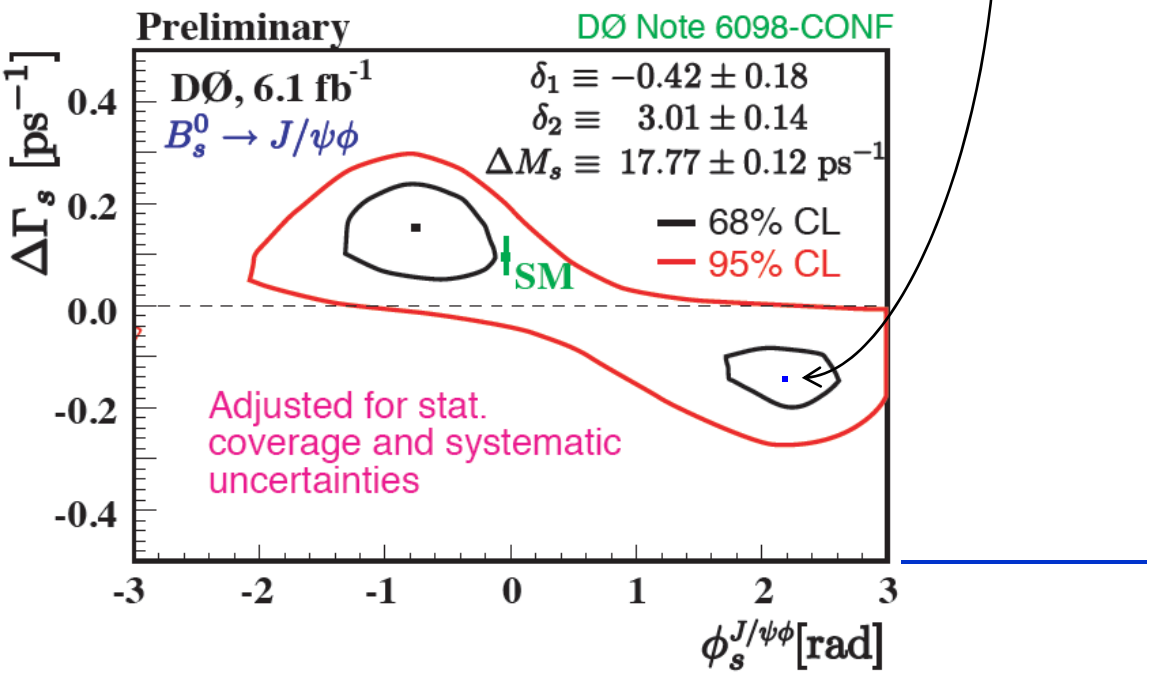
~ $2\ fb^{-1}$ for nominal yr

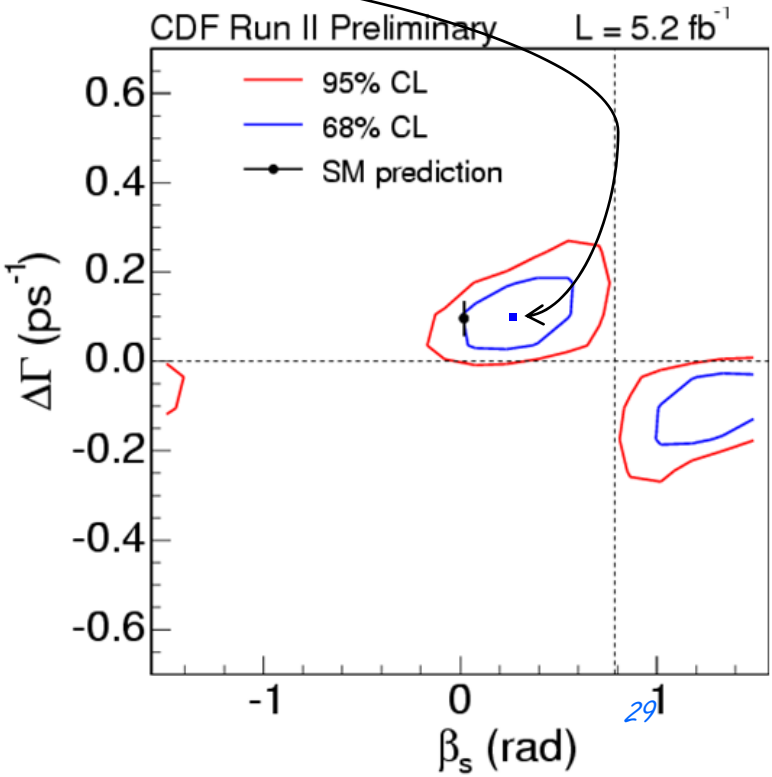
~ $6\ fb^{-1}$ for "1st run"

~$60\ fb^{-1}$ for upgrade

CP Asymmetry in $B_S \rightarrow J/\psi\,\phi$

- Just as $B^o \rightarrow J/\psi\, K_S$ measures CPV phase 2β, $B_S \rightarrow J/\psi\,\phi$ measures CPV B_S mixing phase $-2\beta_S$
- The width difference $\Delta\Gamma_S/\Gamma_S$ also enters in the fit
- LHCb will get 60,000 such events in 2 fb^{-1}. Projected errors are ±0.07 rad in $2\beta_S$ & ±0.026 in $\Delta\Gamma_S/\Gamma_S$. [Will also use $J/\psi\, f_o(980)$]





$B_s \to \phi\gamma$: Right-Handed currents

- Define $\tan\psi \equiv \left|\frac{\mathcal{A}\left(\bar{B}_{(s)} \to \Phi^{\mathcal{CP}}\gamma_R\right)}{\mathcal{A}\left(\bar{B}_{(s)} \to \Phi^{\mathcal{CP}}\gamma_L\right)}\right|$, zero in SM
- Theory

$$\Gamma_{B^0_{(s)}\to\Phi^{\mathcal{CP}}\gamma}(t) = |A|^2 e^{-\Gamma_{(s)}t}\left(\cosh\frac{\Delta\Gamma_{(s)}t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_{(s)}t}{2} + \mathcal{C}\cos\Delta m_{(s)}t - \mathcal{S}\sin\Delta m_{(s)}t\right)$$

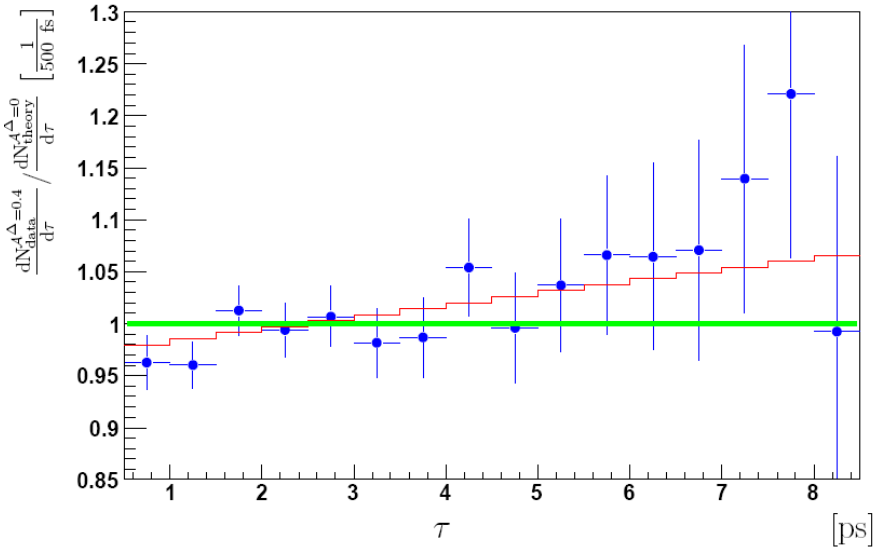
$$\Gamma_{\bar{B}^0_{(s)}\to\Phi^{\mathcal{CP}}\gamma}(t) = |A|^2 e^{-\Gamma_{(s)}t}\left(\cosh\frac{\Delta\Gamma_{(s)}t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_{(s)}t}{2} - \mathcal{C}\cos\Delta m_{(s)}t + \mathcal{S}\sin\Delta m_{(s)}t\right)$$

where $A^{\Delta}=\sin2\psi$

- Sum them
- Sensitivity

(assume $\Delta\Gamma_S/\Gamma_S=0.12$)

- $\sigma(\sin2\psi)=0.22$ $2fb^{-1}$
- $\sigma(\sin2\psi)=0.10$ $10fb^{-1}$
- $\sigma(\sin2\psi)=0.02$ $100fb^{-1}$

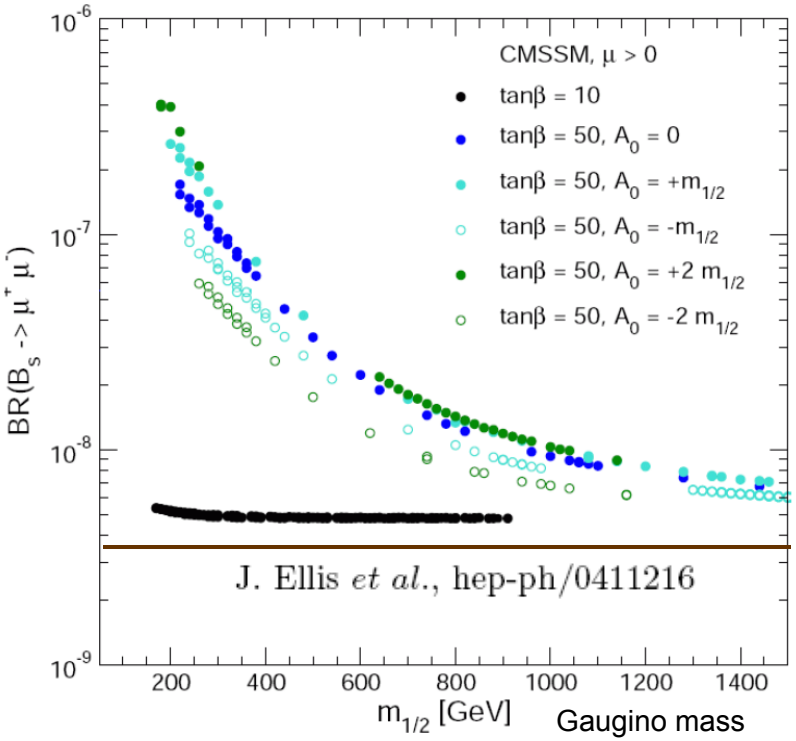


$A^{\Delta}=0.4$

$A^{\Delta}=0$

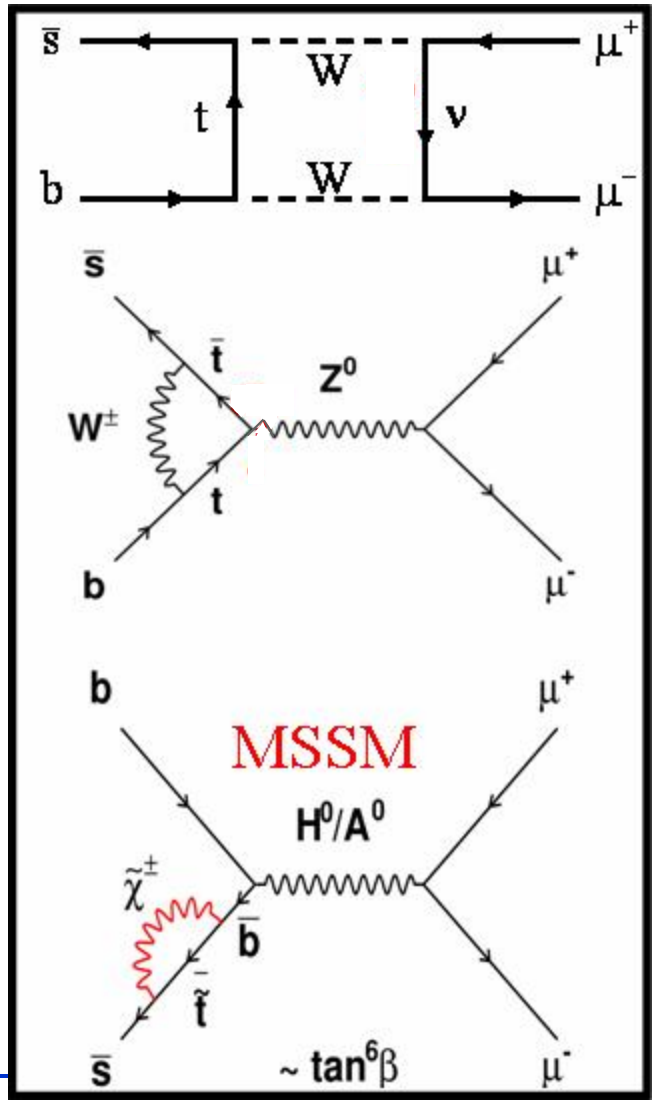
$B_s \to \mu^+\mu^-$ & Supersymmetry

- Branching Ratio very sensitive to SUSY
- In MSSM goes as $\tan^6\beta$



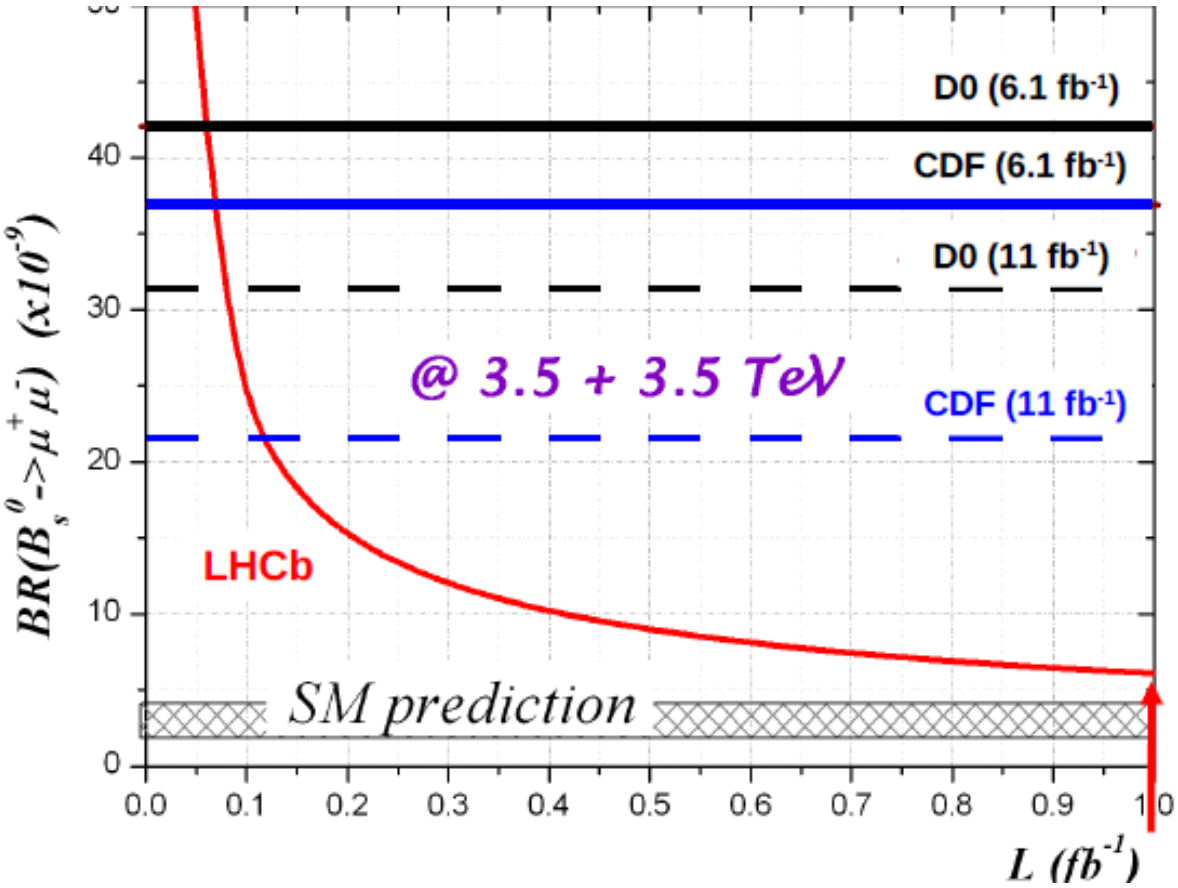
SM

Gaugino mass



$B_s \to \mu^+\mu^-$

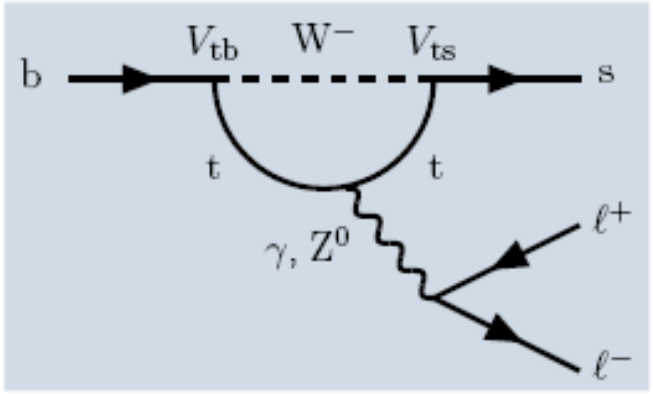
Exclusion limit at 90% CL at √s=7 TeV



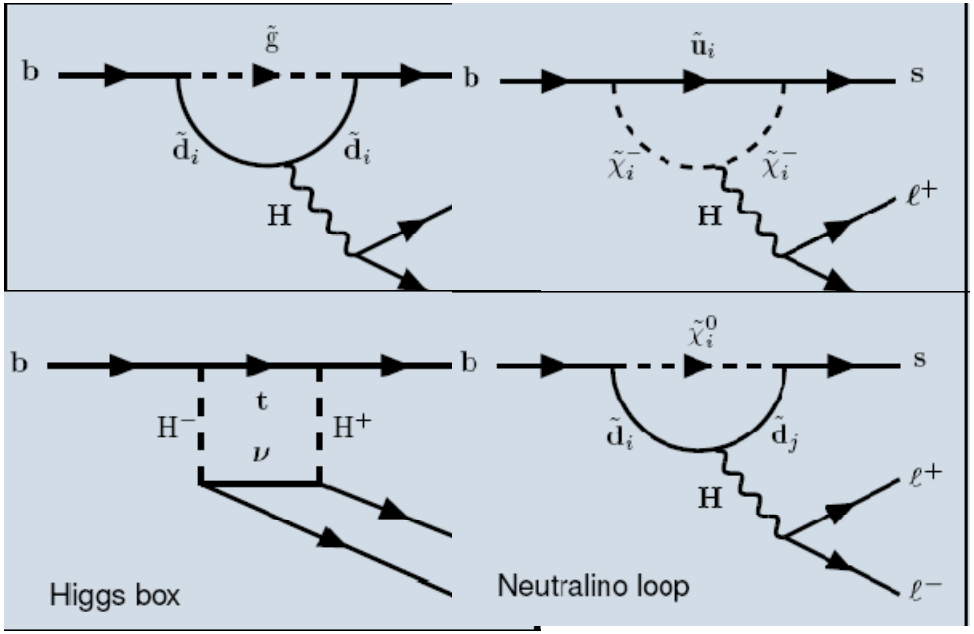
- Expectation uses measured $b\bar{b}$ cross-section
- ~10 fb^{-1} needed to make significant measurement at SM level

$B \to K^* \mu^+ \mu^-$

Standard Model



Supersymmetry

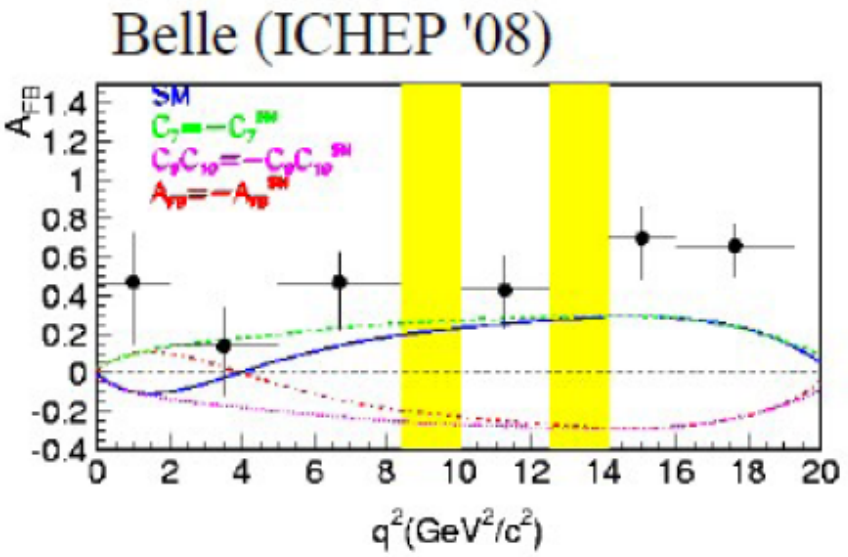


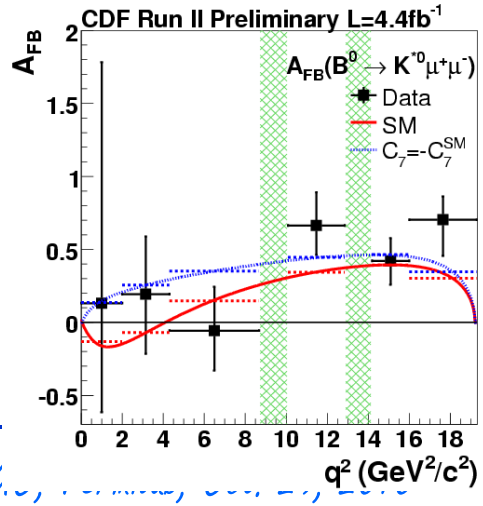
- Forward-backward asymmetry A_{FB}

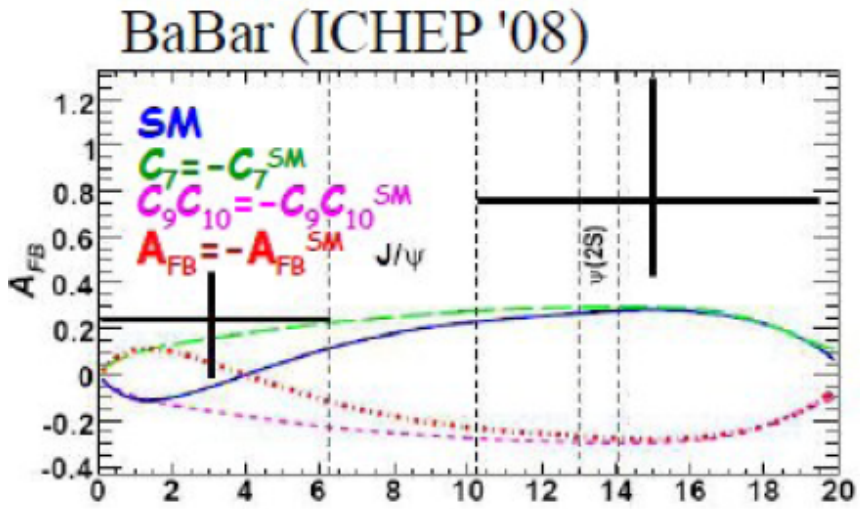
  distribution of particular interest: varies between SM & different NP models

A_{FB} in $B \to K^* \mu^+ \mu^-$

- State-of-the art is 625 fb^{-1} Belle analysis ~ 250 K*$\ell\ell$
  arXiv:0904.07701
- CDF have ~20 events in 1 fb^{-1} arXiv:0804.3908
- LHCb expects ~360 in 300 pb^{-1}(with $\mu^+\mu^-$ only)





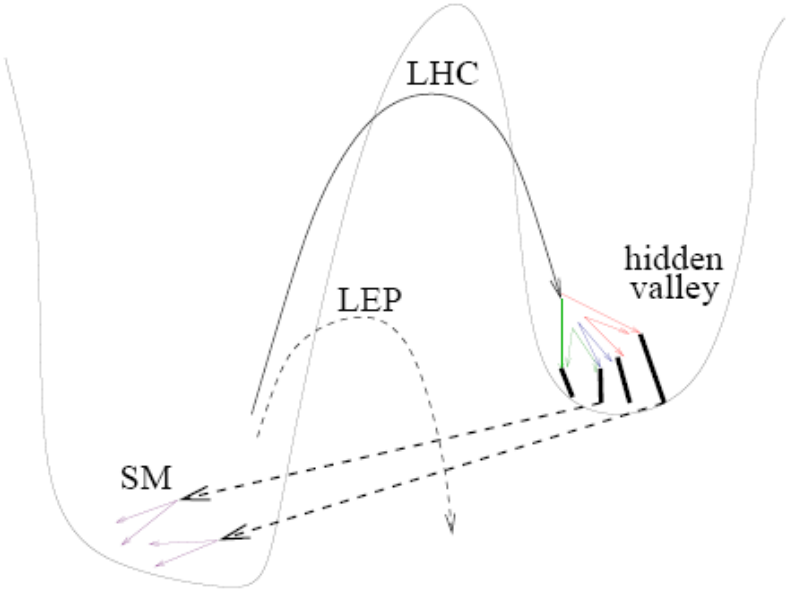


Exotic Searches

- LHCb complements the ATLAS/CMS solid angle by concentrating at large η and low p_t
- Sensitive to "Exotic" particles decaying into lepton or quark jets, especially with lifetimes in the range of $500>\tau>1$ ps.
- We will show one example, that of "Hidden Valley" Higgs decay

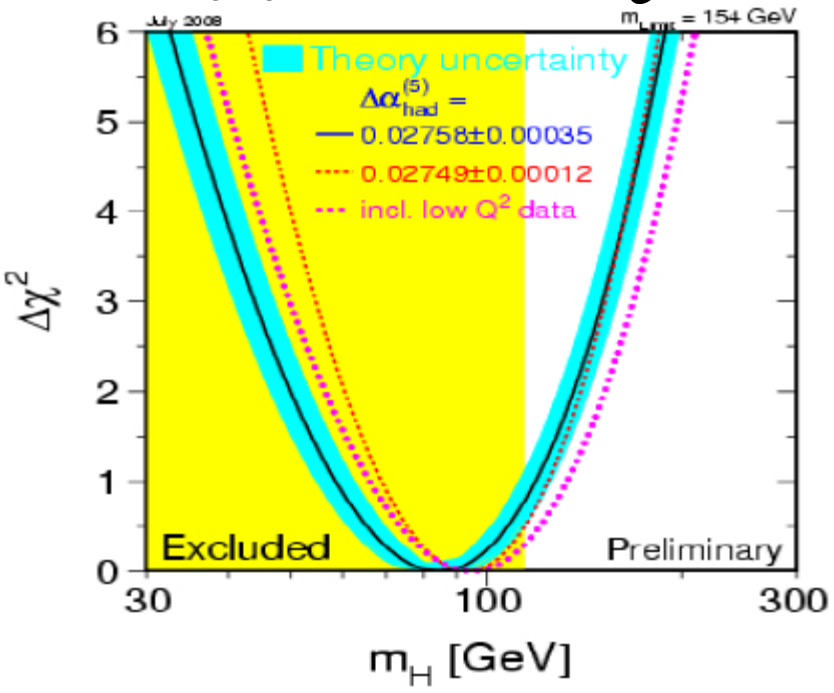
Search for Hidden Valleys

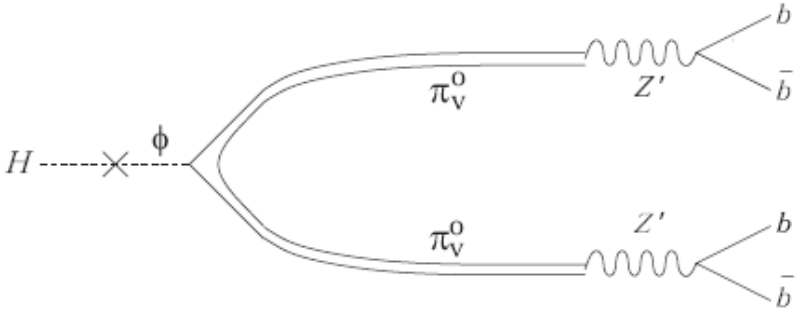
- New heavy Gauge sectors can augment the Standard Model (SM) as well SUSY etc..
- These sectors arise naturally in String theory
- It takes Energy to excite them
- They couple to SM via Z′ or heavy particle loops
- From Strassler & Zurek [hep-ph/604261]



Search for Exotic Higgs Decays

- Recall tension between predicted SM Higgs mass using Electroweak data & direct LEP limit
- Limit is based on SM decays, would be void if there were other modes
- Hidden Valley provides new scalars π^o_v, allowing $H^o \rightarrow \pi^o_v \pi^o_v \rightarrow b\bar{b}$, with long lifetimes possible.



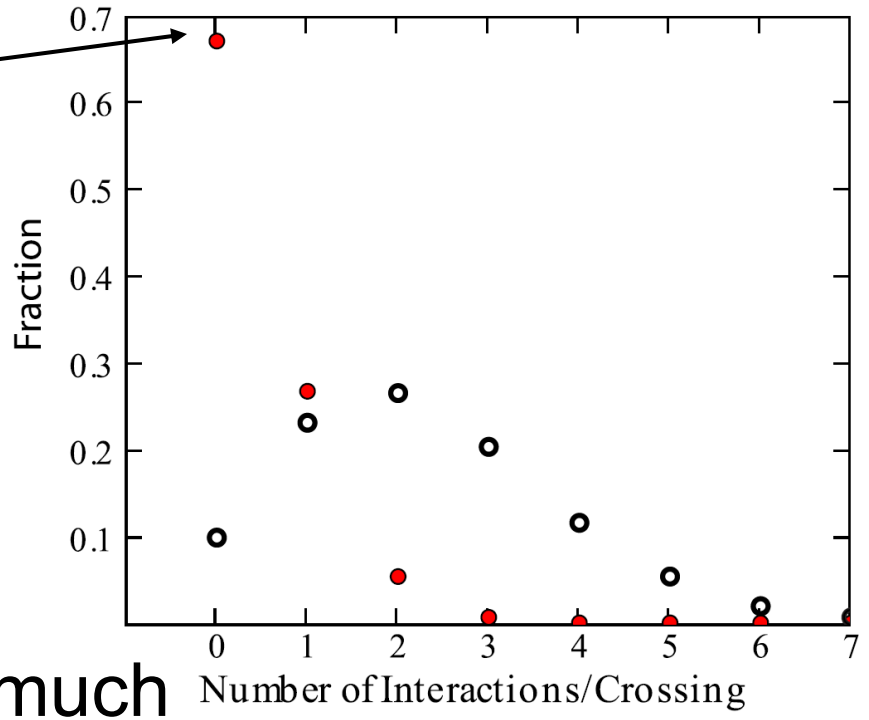


The LHCb Upgrade

- Run at 5x higher luminosity
- Improve hadron trigger eff.
- Requires that detector be read out at 40 MHz crossing rate
  $\Rightarrow$ new front end electronics for most of the detector
- More radiation damage and trigger speed necessitates a new VELO based on pixels
- Basically build a better magnifying glass!

Running Conditions

- Nominal: luminosity 2×10^{32} cm^{-2}/s at beginning of run
- Take σ = 60 mb, [σ(total) - σ(elastic) - σ(diffractive)]
- Account for only 29.5 MHz of two filled bunches
- Most xings don't have an interaction
- At L=10^{33} have int. in most crossings
- Recent running with <int>=~2 allowed by 10x fewer bunches. Learned much



Conlusions

- LHCb is off to a great start
- Detector performing well including trigger
- Data processing using GRID on track
- $\sigma(pp \rightarrow b\bar{b}X)$=~300 μb at 7 TeV, larger than our original estimates
- Looking forward to more results soon
- Flavor physics adds an important complimentarity to the LHC search for New Physics
- LHCb probes other physics in $2<\eta<6$ region

The Future

- Yogi Berra: “Its difficult to make predictions, especially about the future”
- Possibilities:

ATLAS CMS high p_T physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

- Fourth possibility too depressing to list, but LHCb measurements could set the scale of where we would have to go next

The End

General Justification for Flavor Physics

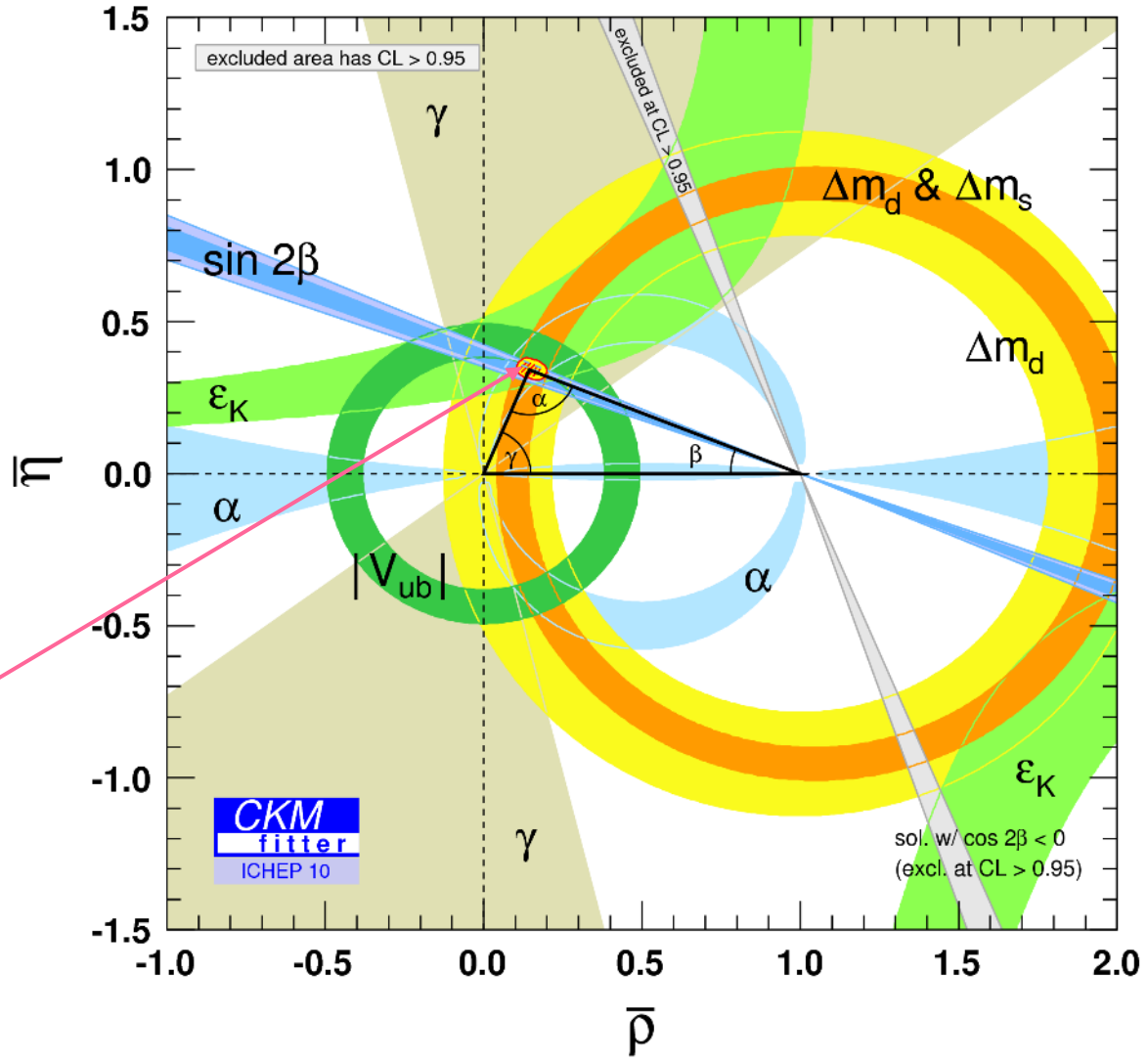
- Expect New Physics will be seen at LHC
  - Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem (why $M_{Higgs} << M_{Planck}$)
- However, it will be difficult to characterize this physics
- How the new particles interfere virtually in the decays of b's (& c's) with W's & Z's can tell us a great deal about their nature, especially their phases

Flavor Problems

- Why do the fermions have their specific masses? Why are the masses in general smaller than the electroweak scale?
- Are there only 3 generations? If so, why?
- Why do the mixing angles (the CKM matrix elements) have their specific values?
- Is there a new theory that relates the CKM matrix elements to masses?
- What is the relationship between the CKM matrix and the neutrino mixing matrix?

Current Status of CP & Other Measurements

- SM CKM parameters are: A~0.8, λ=0.22, ρ & η
- CKM Fitter results using CP violation in $J/\psi\ K_S$, $\rho^+\rho^-$, DK^-, K_L, & V_{ub}, V_{cb} & ΔM_q
- The overlap region includes CL>95%
- Similar situation using UTFIT
- Measurements "consistent"



Note: $\overline{\rho} = \rho(1-\lambda^2/2)$
$\overline{\eta} = \eta(1-\lambda^2/2)$

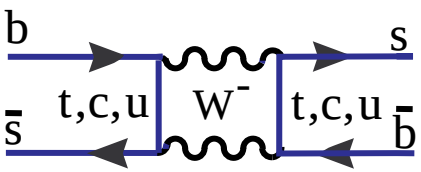
New Physics Models

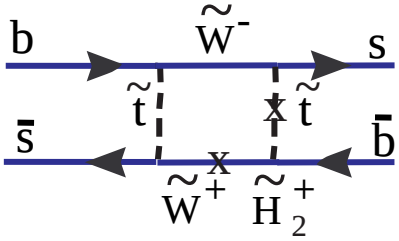
- There is, in fact, still lots of room for “generic” NP
- What do specific models predict?
  - Supersymmetry: many, many different models
  - Extra Dimensions: ″
  - Little Higgs: ″
  - Left-Right symmetric models ″
  - 4th Generation models ″
- NP **must** affect every process; the amount tells us what the NP is (“DNA footprint”)
- Lets go through some examples, many other interesting cases exist

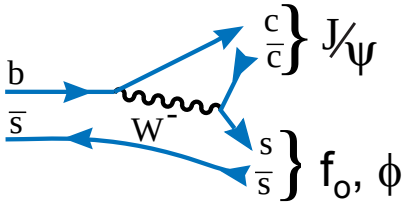
Supersymmetry: MSSM

- MSSM from Hinchcliff & Kersting (hep-ph/0003090)
- Contributions to B_s mixing

$B_s \rightarrow J/\psi f_o$ or ϕ





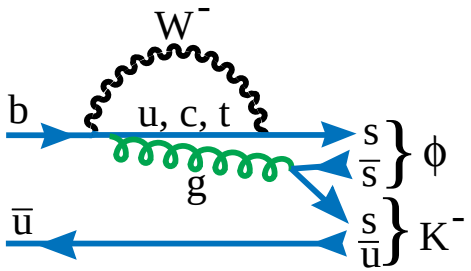


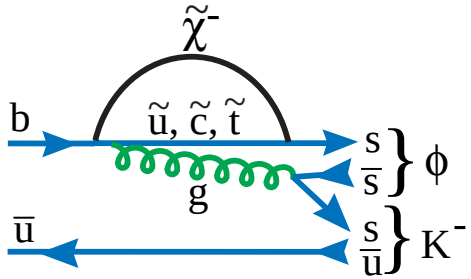
measures CP violating $\angle -2\beta_s$

CP asymmetry $\approx 0.1 \sin\phi_\mu \cos\phi_A \sin(\Delta m_s t)$, ~10 x SM

- Contributions to direct CP violating decay

$B^- \rightarrow \phi K^-$





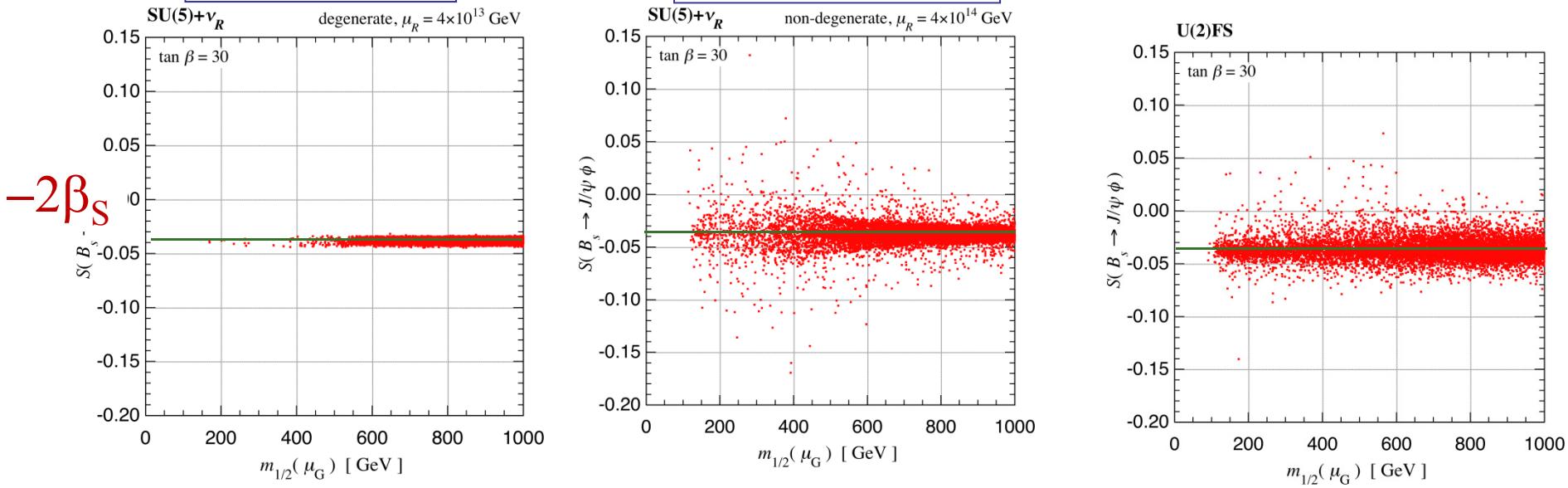
Asym=$(M_W/m_{squark})^2 \sin(\phi_\mu)$, ~0 in SM

Supersymmetry: SU(5)

SU(5) GUT Degenerate

SU(5) GUT Non-degenerate

U(2) FS

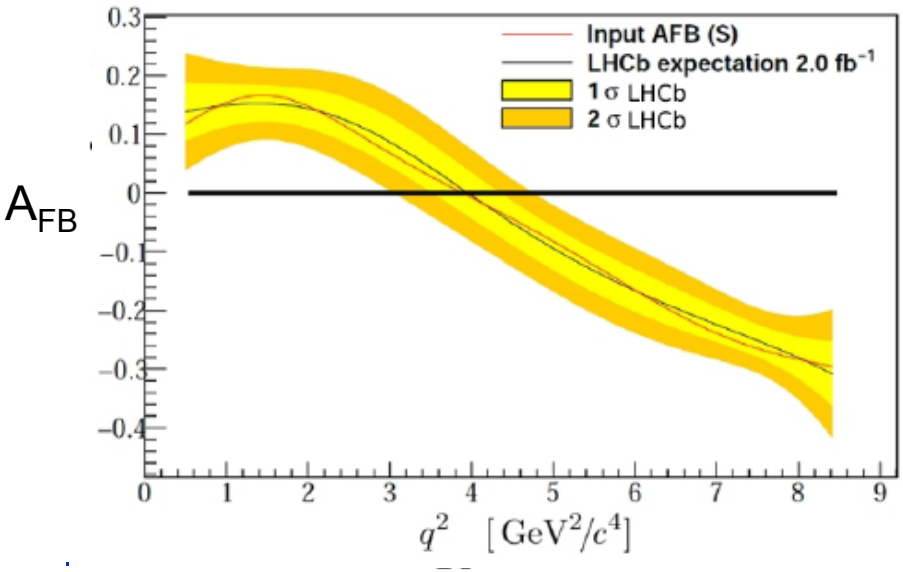


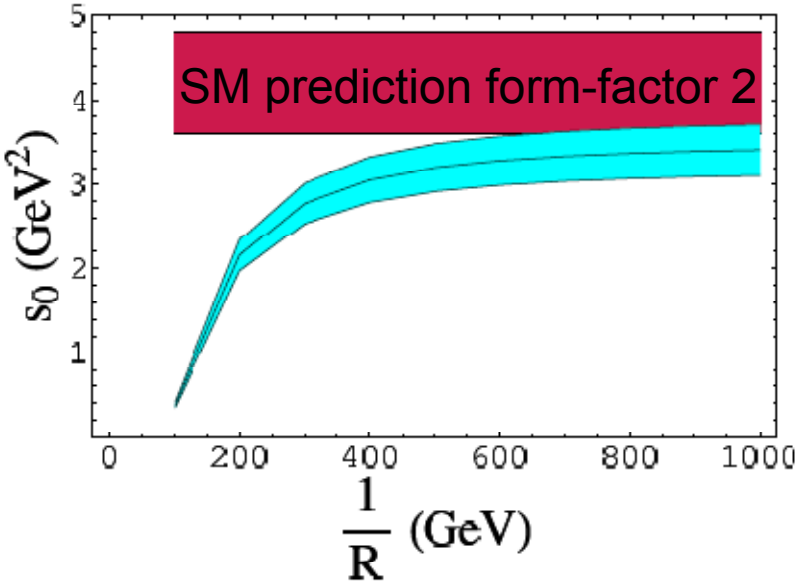
$-2\beta_S$

- $-2\beta_S$ can deviate from the "SM" value of -0.036 in SU(5) GUT non-degenerate case, and the U(2) model. From Okada's talk at BNMII, Nara Women's Univ. Dec., 2006

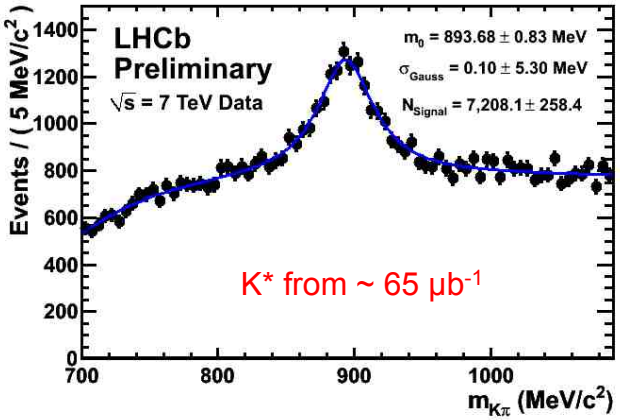
Extra Dimensions

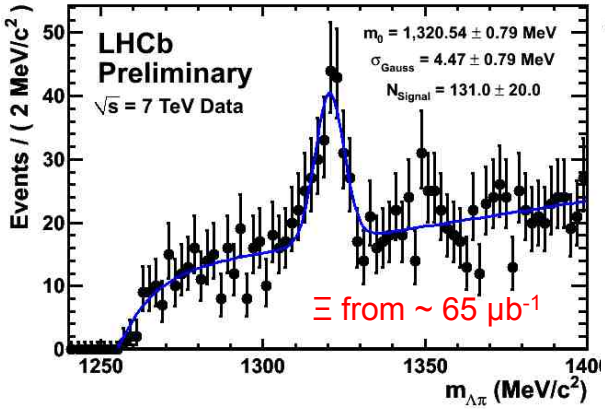
- Using ACD model of 1 universal extra dimension, a MFV model, Colangelo et al predict a shift in the zero of the forward-backward asymmetry in $B \to K^* \mu^+ \mu^-$
- *Insensitive to choice of form-factors. Can SM calculations improve?*

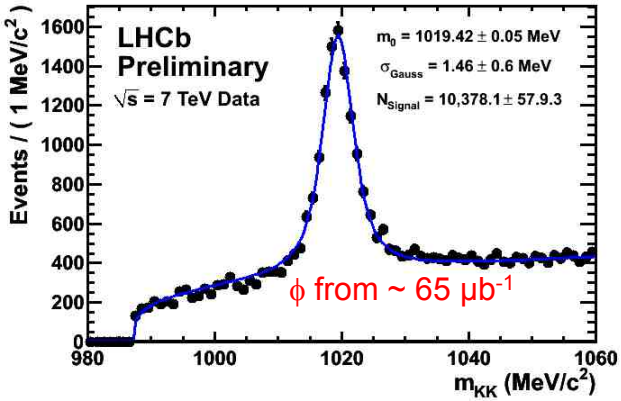




Some Nice Mass Plots

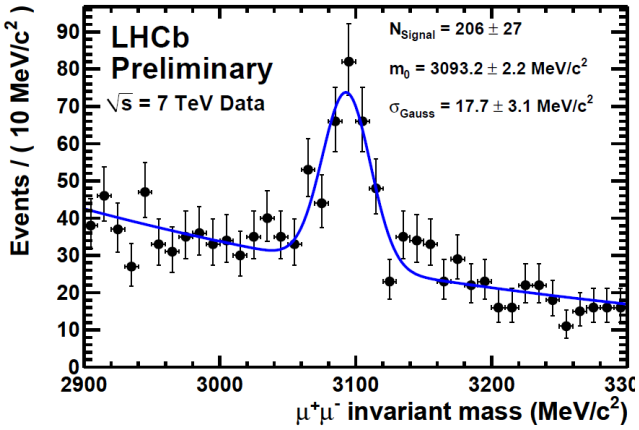




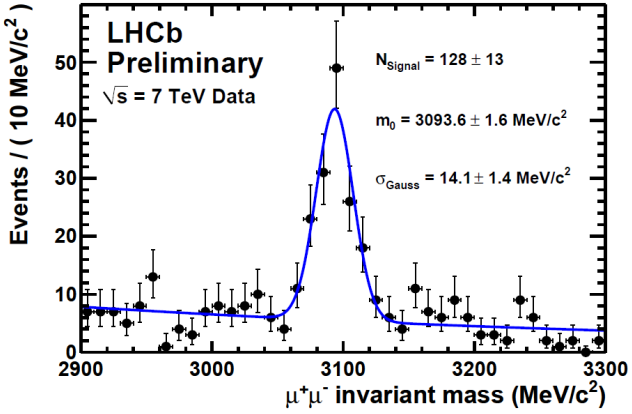


J/ψ from ~ 800 nb^{-1}

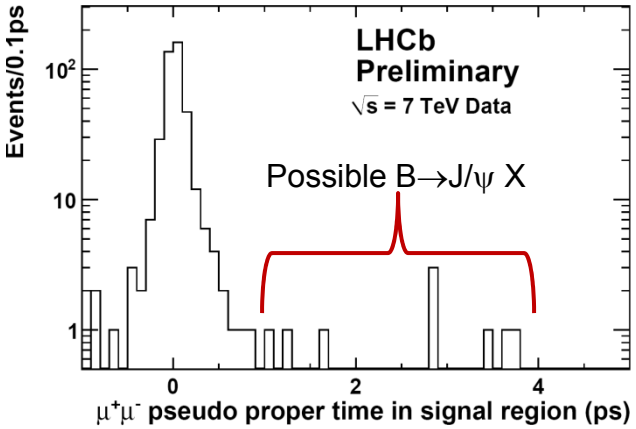
Loose selection



Tight Selection

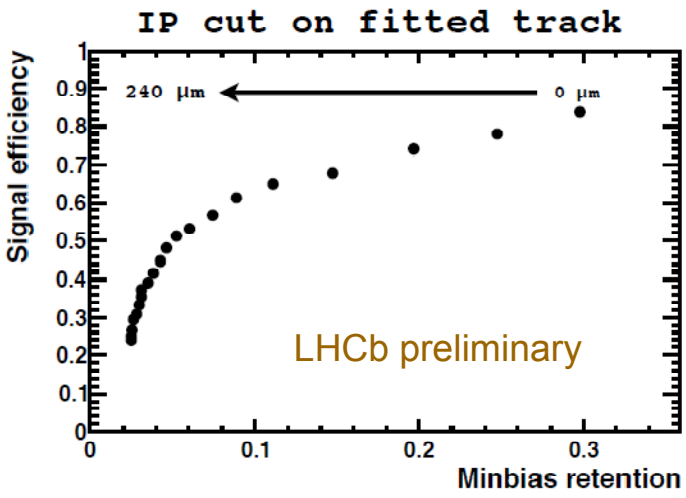


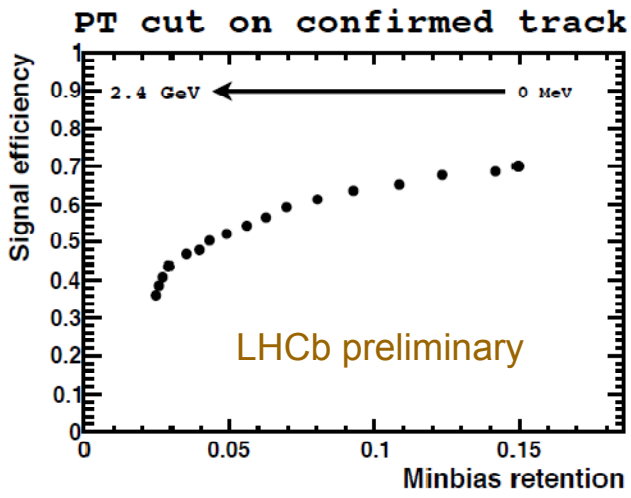
Time Resolution



Hadron Trigger Checks

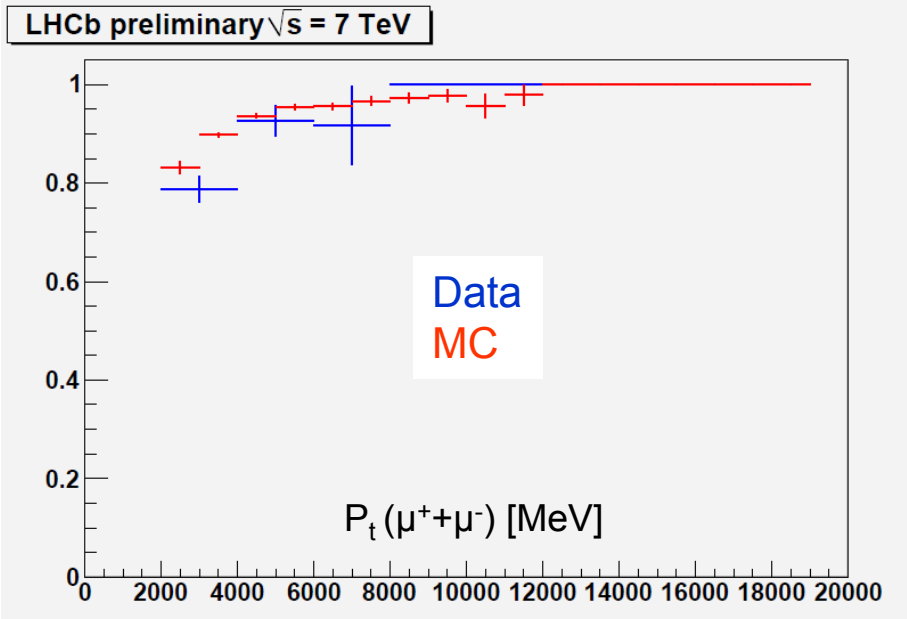
- Take D*, $D^0 \rightarrow K\pi$ signal collected in minimum bias events & evaluate preliminary L0*HLT1 performance
- Performance curves of single-hadron HLT1 line on data: $\varepsilon_{trigL0*HLT1}$(data) = 60 $\pm$ 4 % vs MC 66%

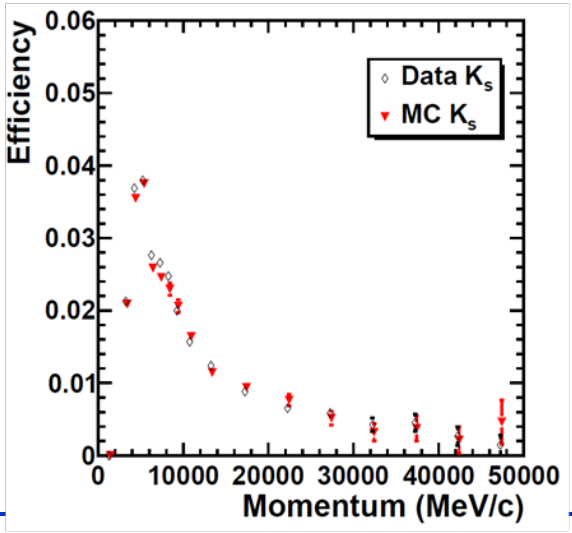




Muon Checks

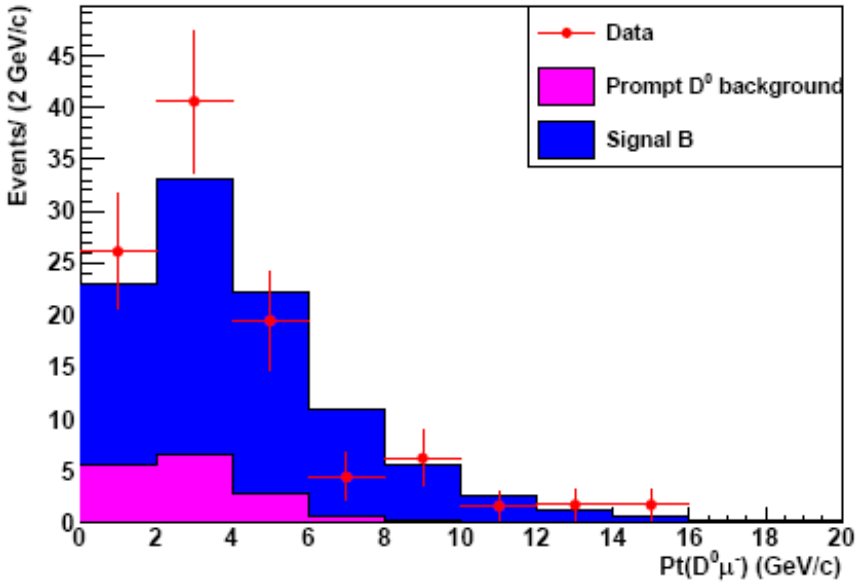
- Measure performance of L0*HLT1 trigger for J/ψ→μμ
- Data = (82±1) %
- MC = 91%
- fake rate

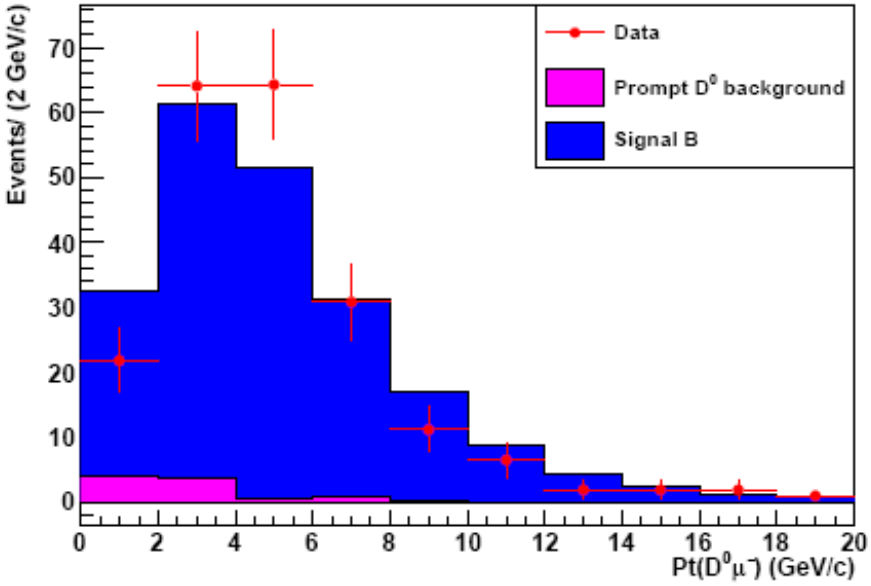




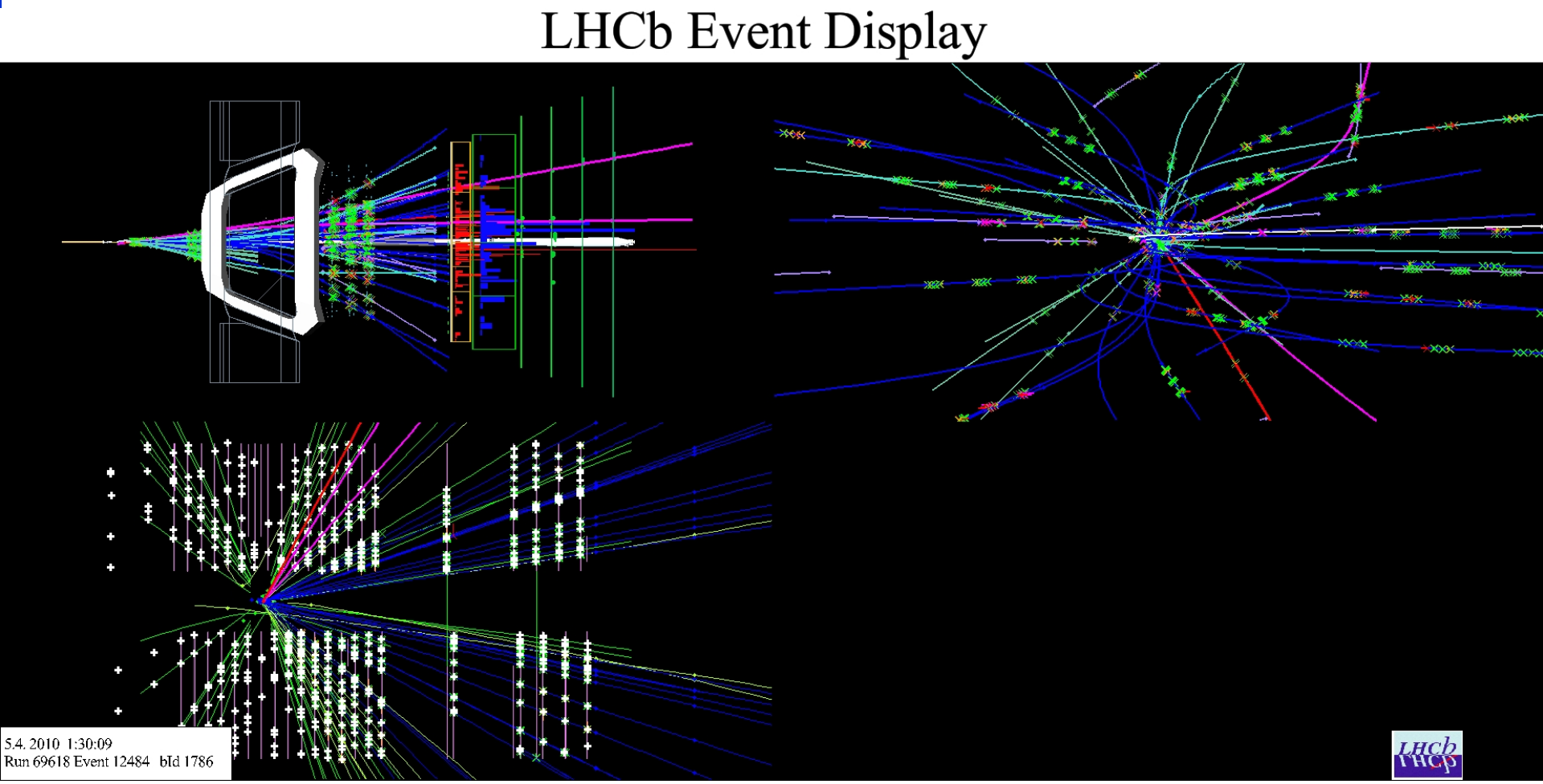
p_t

- Checked that $p_t(D^o + \mu^-)$ agrees with Monte Carlo simulation of b production x detector acceptance

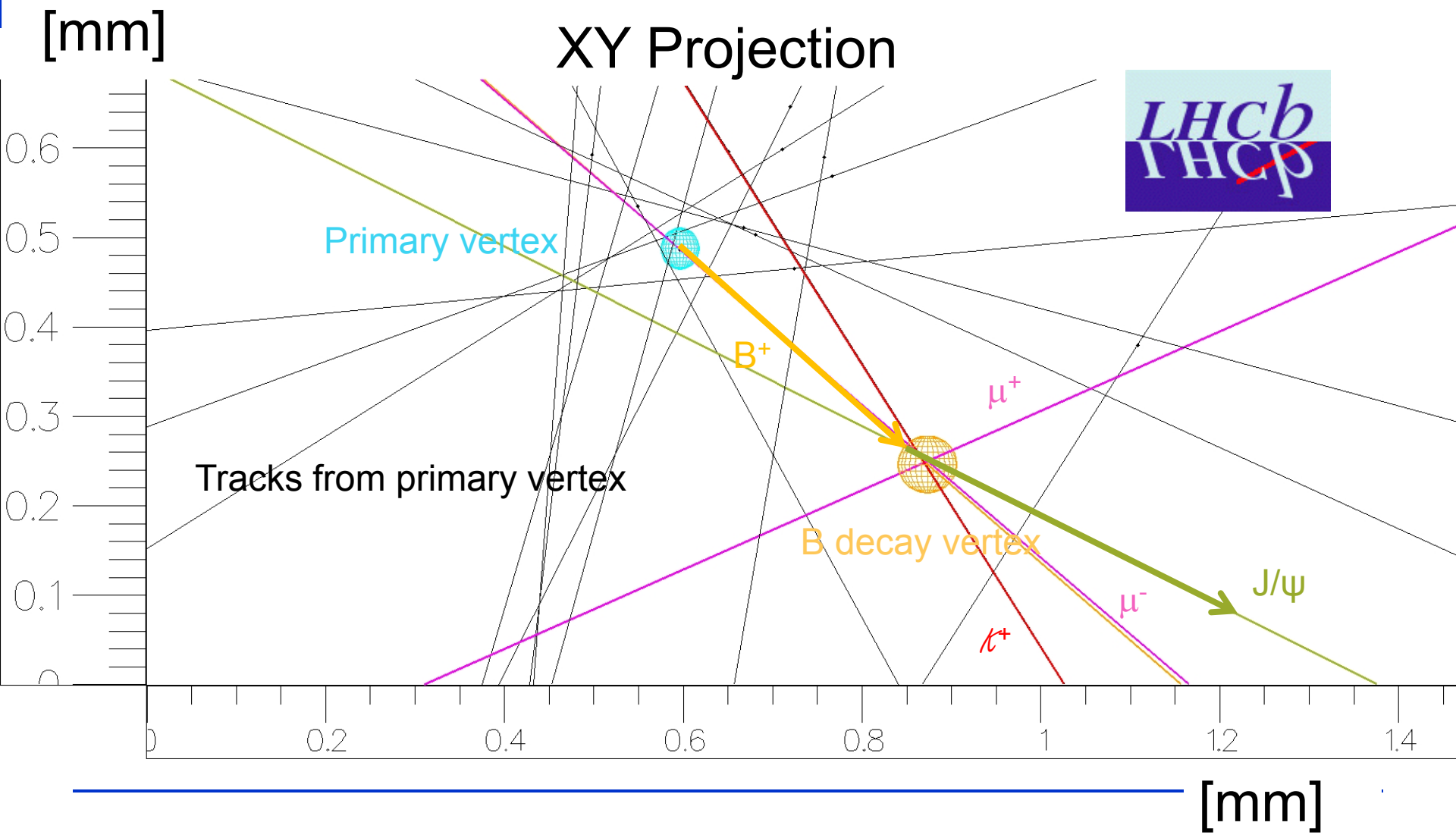




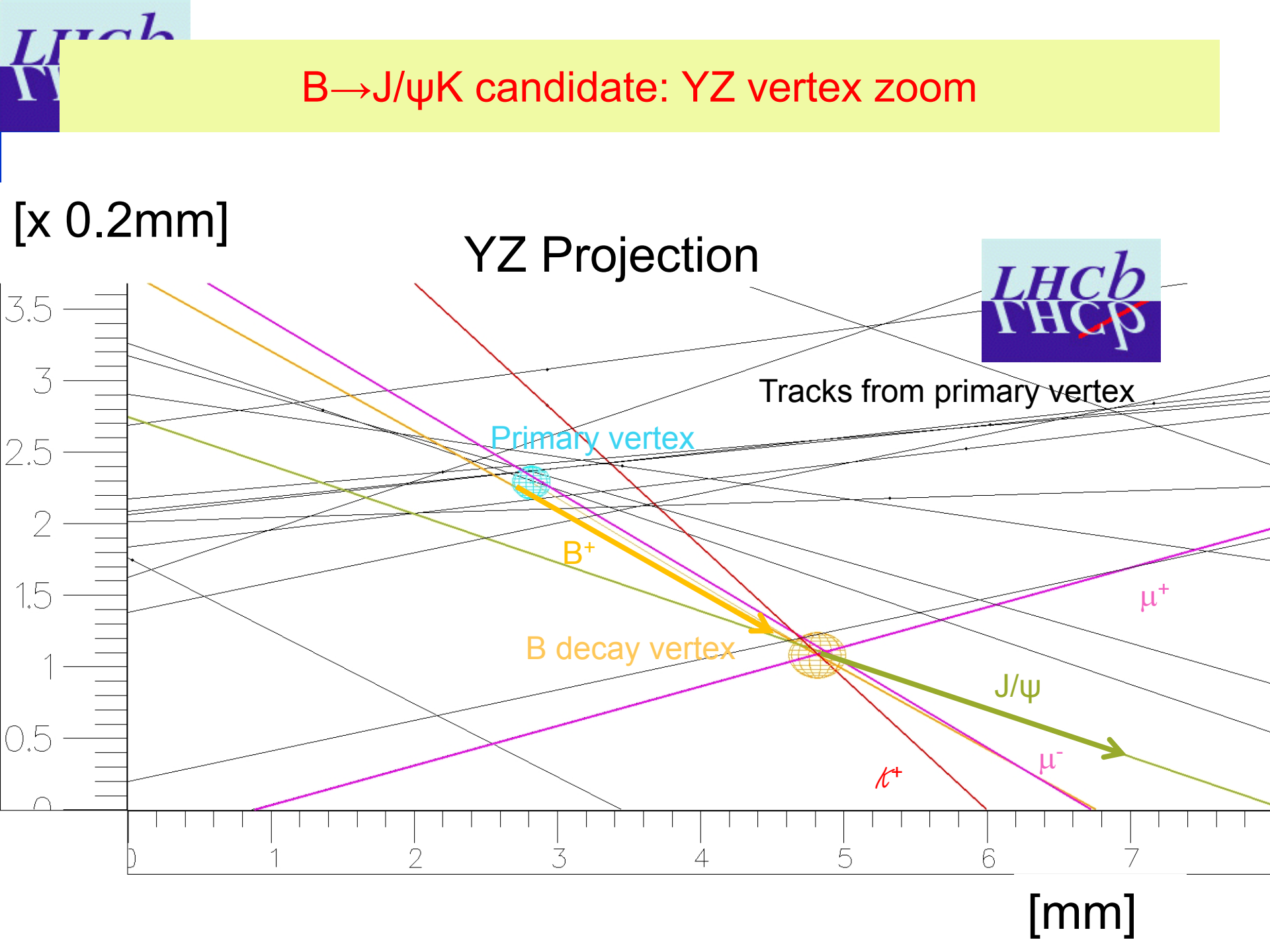
B→J/ψK candidate: global view (muons are magenta, kaon is red)



B→J/ψK candidate: XY vertex zoom

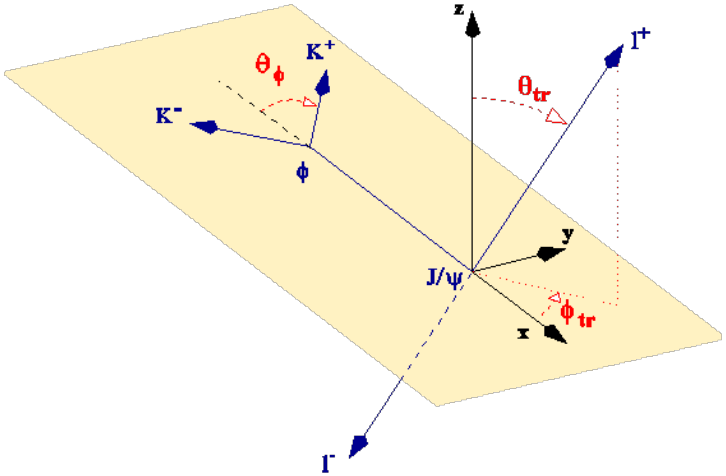


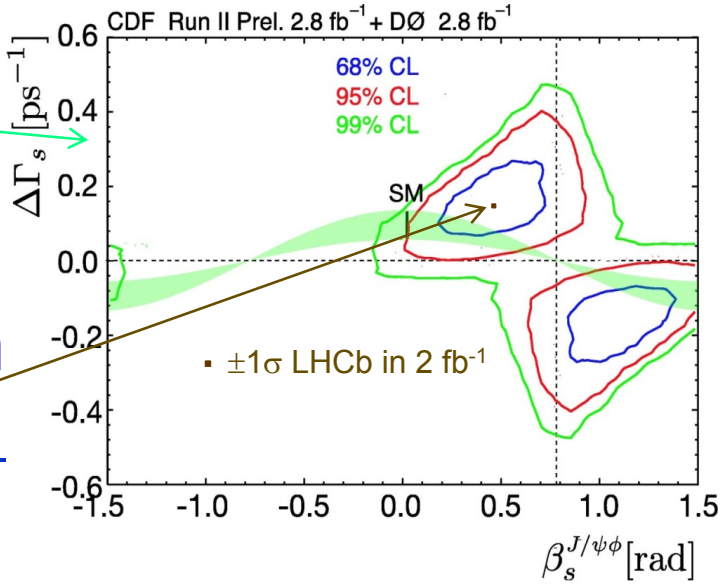
B→J/ψK candidate: YZ vertex zoom



CP Asymmetry in $B_S \rightarrow J/\psi\,\phi$

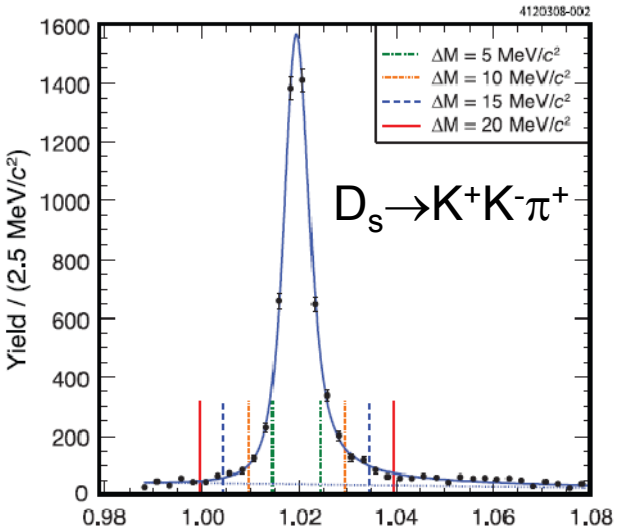
- Just as $B^o \rightarrow J/\psi\, K_S$ measures CPV phase 2β $B_S \rightarrow J/\psi\,\phi$ measures CPV B_S mixing phase $-2\beta_S$
- Since this is a Vector-Vector final state, must do an angular (transversity) analysis
- The width difference $\Delta\Gamma_S/\Gamma_S$ also enters in the fit
- Combined CDF & D0 results
- LHCb will get 60,000 such events in 2 fb^{-1}. Projected errors are ±0.07 rad in $2\beta_S$ & ±0.026 in $\Delta\Gamma_S/\Gamma_S$. [Will also use $J/\psi\, f_o(980)$]





β_s Using $B_s \to J/\psi\, f_0(980)$

- Problem with $J/\psi\ \phi$: S-wave
- Stone & Zhang estimate 10%, can be dealt with, but increases complexity and error (arXiv:0812.2832)
- CLEO also measures



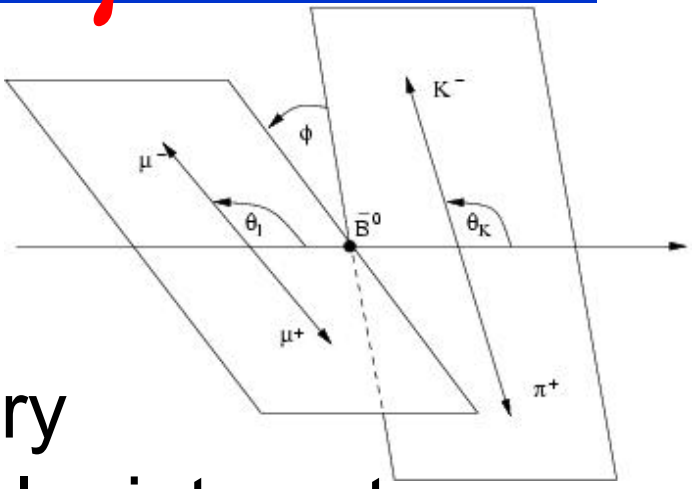
$$\mathcal{B}(D_s^+ \to f_0(980)e^+\nu,\ f_0 \to \pi^+\pi^-) = (0.20 \pm 0.03 \pm 0.01)\%$$

$$\mathcal{B}(D_s^+ \to \phi e^+\nu,\ \phi \to K^+K^-) = (1.16 \pm 0.11 \pm 0.06)\%$$

- Estimate: $\mathcal{B}(B_s \to J/\psi\, f_o \to J/\psi\, \pi^+\pi^-)/\mathcal{B}(B_s \to J/\psi\, \phi \to J/\psi\, K^+K^-)$ =20-40% [Note $M(B_s)$-$M(J/\psi) \approx M(D_s)$]
- This is a CP Eigenstate, so can get independent measurement of somewhat worse accuracy

$B \to K^* \mu^+ \mu^-$

- Described by three angles (θ_l, ϕ, θ_K) and di-μ invariant mass q^2



- Forward-backward asymmetry A_{FB} of θ_l distribution of particular interest:
  - Varies between different NP models →
  - At $A_{FB} = 0$, the dominant theoretical uncertainty from $B_d \to K^*$ form-factors cancels at LO

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

Other Angular Variables in $K^*\mu^+\mu^-$

- Supersymmetry (Egede, et al... arXiv:0807.2589)
- Use functions of the transverse polarization

$$A_{\perp L,R} = \sqrt{2}Nm_B(1-\hat{s})\left[(\mathcal{C}_9^{(\mathrm{eff})} \mp \mathcal{C}_{10}) + \frac{2\hat{m}_b}{\hat{s}}(\mathcal{C}_7^{(\mathrm{eff})} + \mathcal{C}_7^{\prime(\mathrm{eff})})\right]\xi_\perp(E_{K^*}),$$

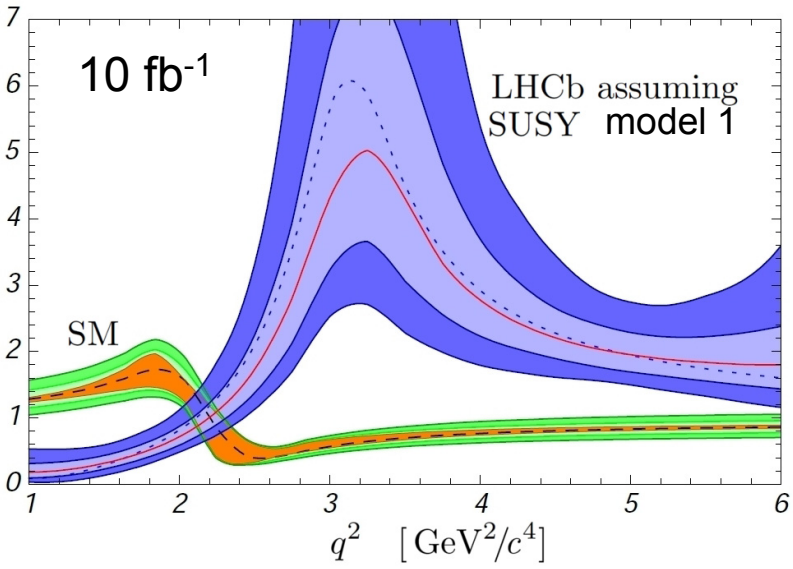
$$A_{\parallel L,R} = -\sqrt{2}Nm_B(1-\hat{s})\left[(\mathcal{C}_9^{(\mathrm{eff})} \mp \mathcal{C}_{10}) + \frac{2\hat{m}_b}{\hat{s}}(\mathcal{C}_7^{(\mathrm{eff})} - \mathcal{C}_7^{\prime(\mathrm{eff})})\right]\xi_\perp(E_{K^*}),$$

$$A_{0L,R} = -\frac{Nm_B}{2\hat{m}_{K^*}\sqrt{\hat{s}}}(1-\hat{s})^2\left[(\mathcal{C}_9^{(\mathrm{eff})} \mp \mathcal{C}_{10}) + 2\hat{m}_b(\mathcal{C}_7^{(\mathrm{eff})} - \mathcal{C}_7^{\prime(\mathrm{eff})})\right]\xi_\parallel(E_{K^*}),$$

ξ_i are form factors

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

$A_T^{(4)}$



With more ∫L can distinguish between different SUSY models in some cases

One Ex: LHCb Sensitivities for $2\beta_S$

	0.3 fb^{-1}	**2.0 fb^{-1}**	**10 fb^{-1}**	**100 fb^{-1}**
Error in $-2\beta_s$	$\pm$0.08	$\pm$0.03	$\pm$0.013	$\pm$0.004
#σ wrt SM value: -.0368	0.5	1.3	2.8	8.8

- With 100 fb^{-1} (LHCb upgrade) error in $-2\beta_S$ decreases to $\pm$0.004 (only $\mathcal{L}$ improvement), useful to distinguish among Supersymmetry (or other) models (see Okada slide), where the differences are on the order of ~0.02

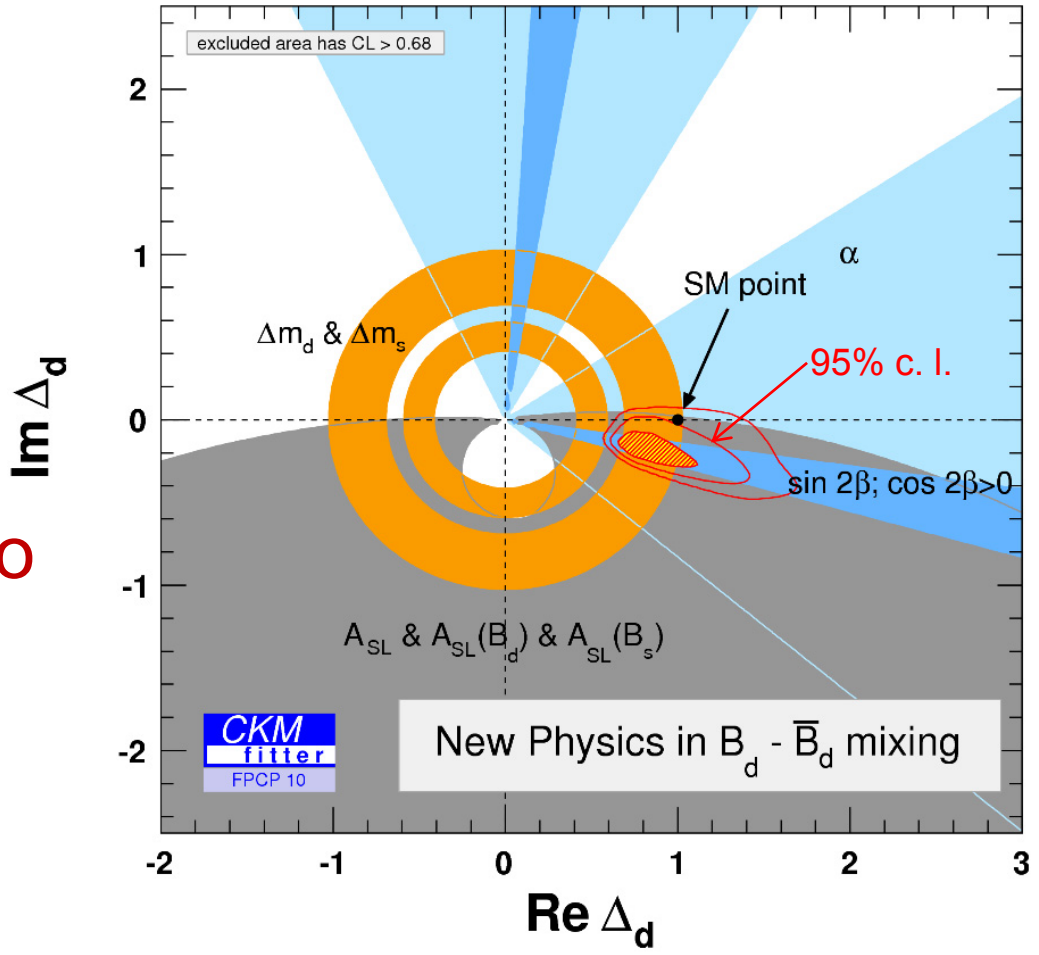
Conclusions

- We hope to see the effects of new particles observed by ATLAS & CMS in "flavor" variables in 10 fb^{-1}
- Upgrading will allow us to precisely measure these effects

Upgraded Sensitivities (100 fb^{-1})	
Observable	Sensitivity
CPV($B_s \to \phi\phi$)	0.01-0.02
CPV($B_d \to \phi K_s$)	0.025-0.035
CPV($B_s \to J/\psi\phi$) ($2\beta_s$)	0.003
CPV($B_d \to J/\psi K_s$) (2β)	0.003-0.010
CPV($B \to DK$) (γ)	<1°
CPV($B_s \to D_s K$) (γ)	1-2°
$\mathcal{B}(B_s \to \mu^+\mu^-)$	5-10% of SM
$A_{FB}(B \to K^*\mu^+\mu^-)$	Zero to $\pm$0.07 GeV^2
CPV($B_s \to \phi\gamma$)	0.016-0.025
Charm mixing x'^2	2×10^{-5}
Charm mixing y'	2.8×10^{-4}
Charm CP y_{CP}	1.5×10^{-4}

Limits on New Physics From B^o Mixing

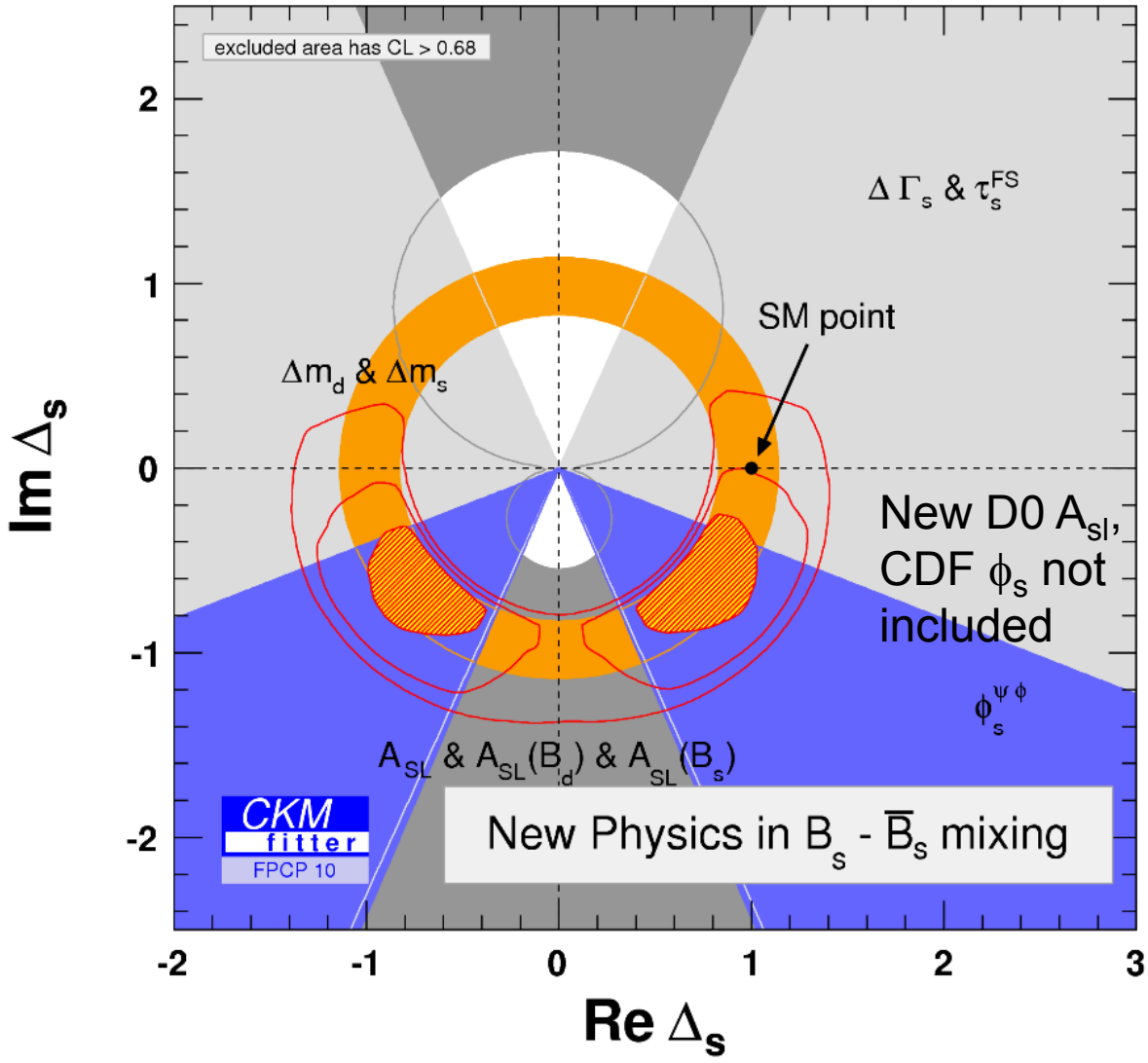
- Is there NP in B^o-$\bar{B}^o$ mixing?
- $$\left\langle B^o \left| H^{SM+NP}_{\Delta B=2} \right| \bar{B}^o \right\rangle = \Delta_d^{NP} \left\langle B^o \left| H^{SM}_{\Delta B=2} \right| \bar{B}^o \right\rangle$$
  $$\Delta_d^{NP} = \mathrm{Re}\,\Delta_d + i\,\mathrm{Im}\Delta_d$$
- Assume NP in tree decays is negligible, so no NP in $|V_{ij}|$, γ from $B^- \to D^o K^-$.
- Allow NP in Δm, weak phases, A_{SL}, & $\Delta\Gamma$.



- Room for new physics, in fact SM is only at 5% c.l.

Limits on New Physics From B_S Mixing

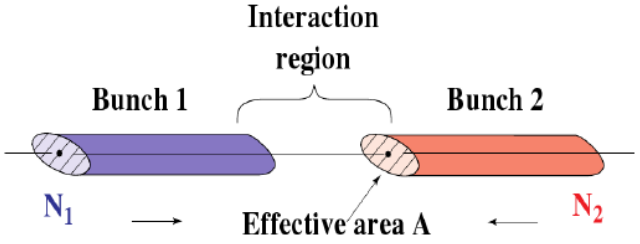
- Similarly for B_S
  - One CP Violation measurement using $B_S \rightarrow J/\psi\ \phi$
- Here again SM is only at 5% c.l.
- Much more room for NP due to less precise measurements



Luminosity

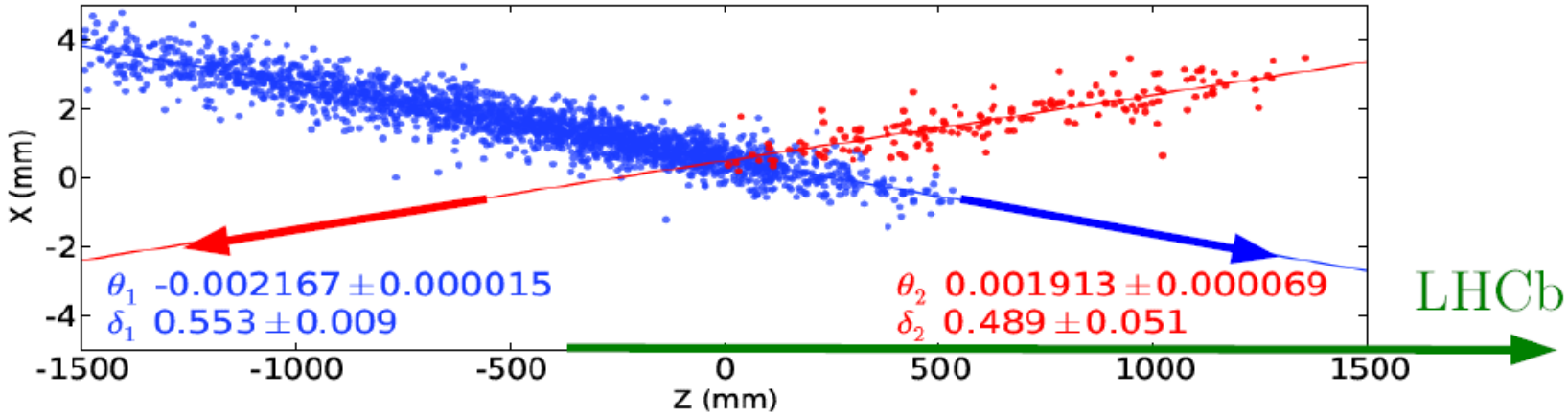
$$\mathcal{L} = \frac{N_1\, N_2\, f}{A_{\text{eff}}}$$

$$\frac{1}{A_{\text{eff}}} = \underbrace{\int g_1(x,y)\, g_2(x,y)\, dx\, dy}_{\text{overlap integral}}$$

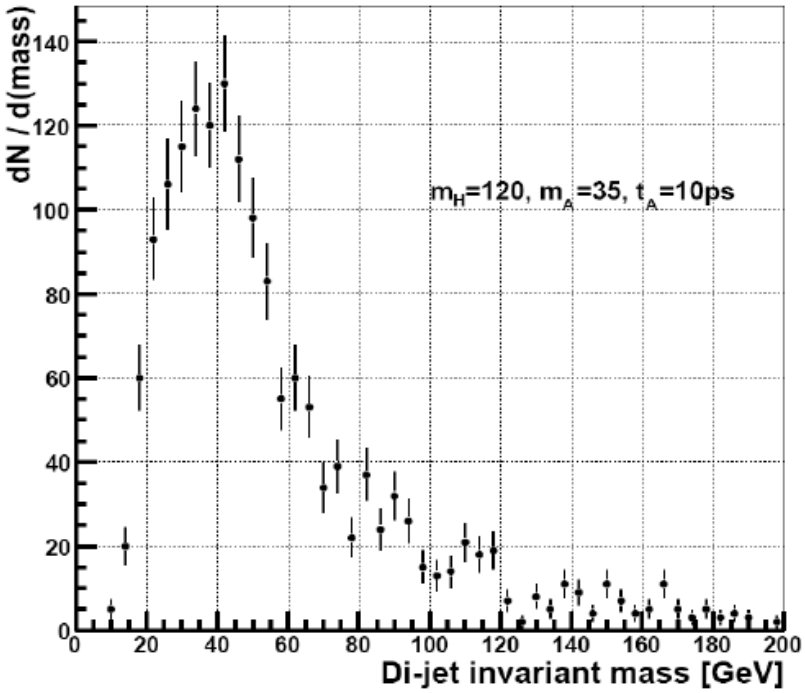


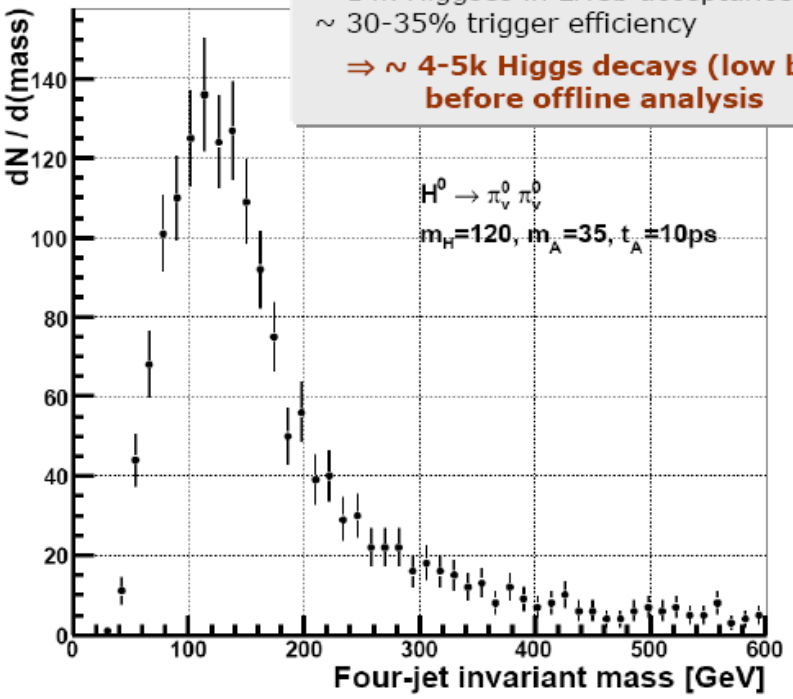
$\Rightarrow$ Gaussian shape beams: $\mathcal{L} = \dfrac{N_1\, N_2\, f}{4\pi\sigma_x\sigma_y}$

- Profile from beam-gas collisions



Mass Resolutions

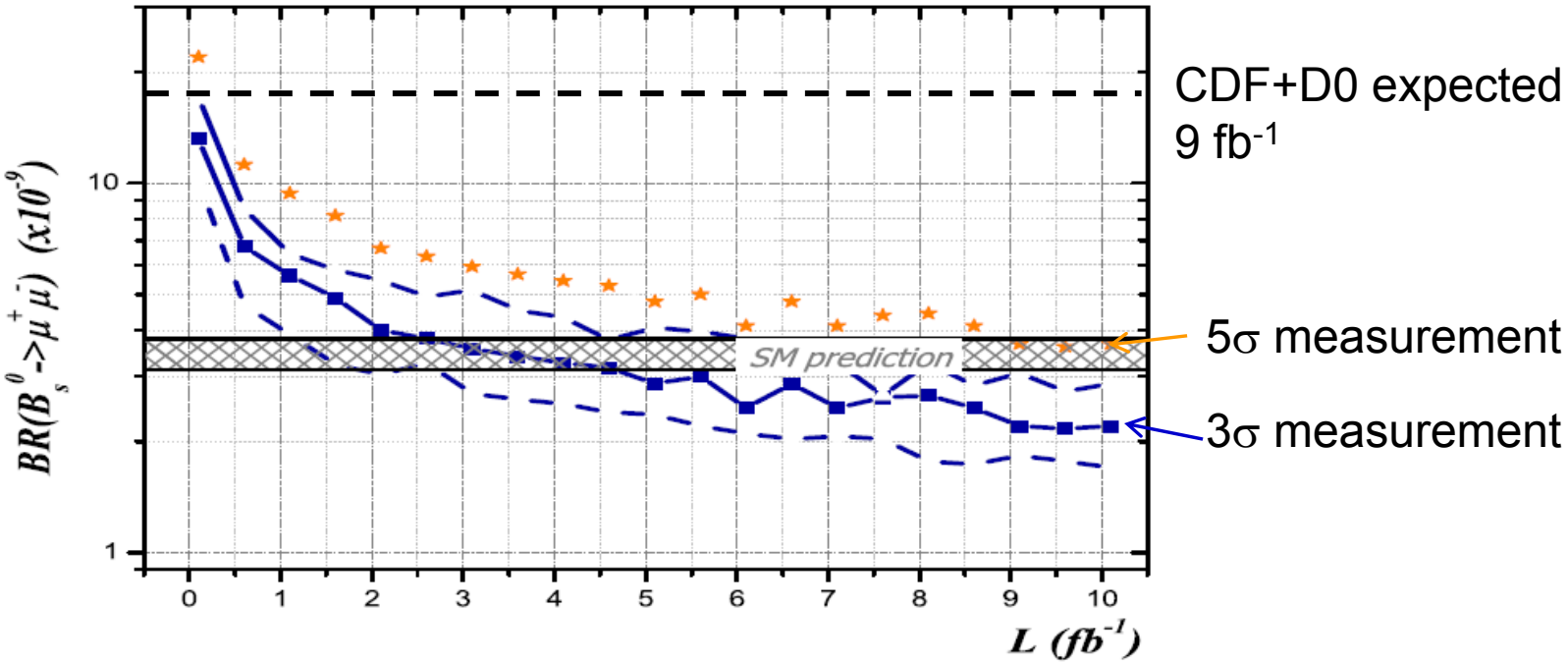




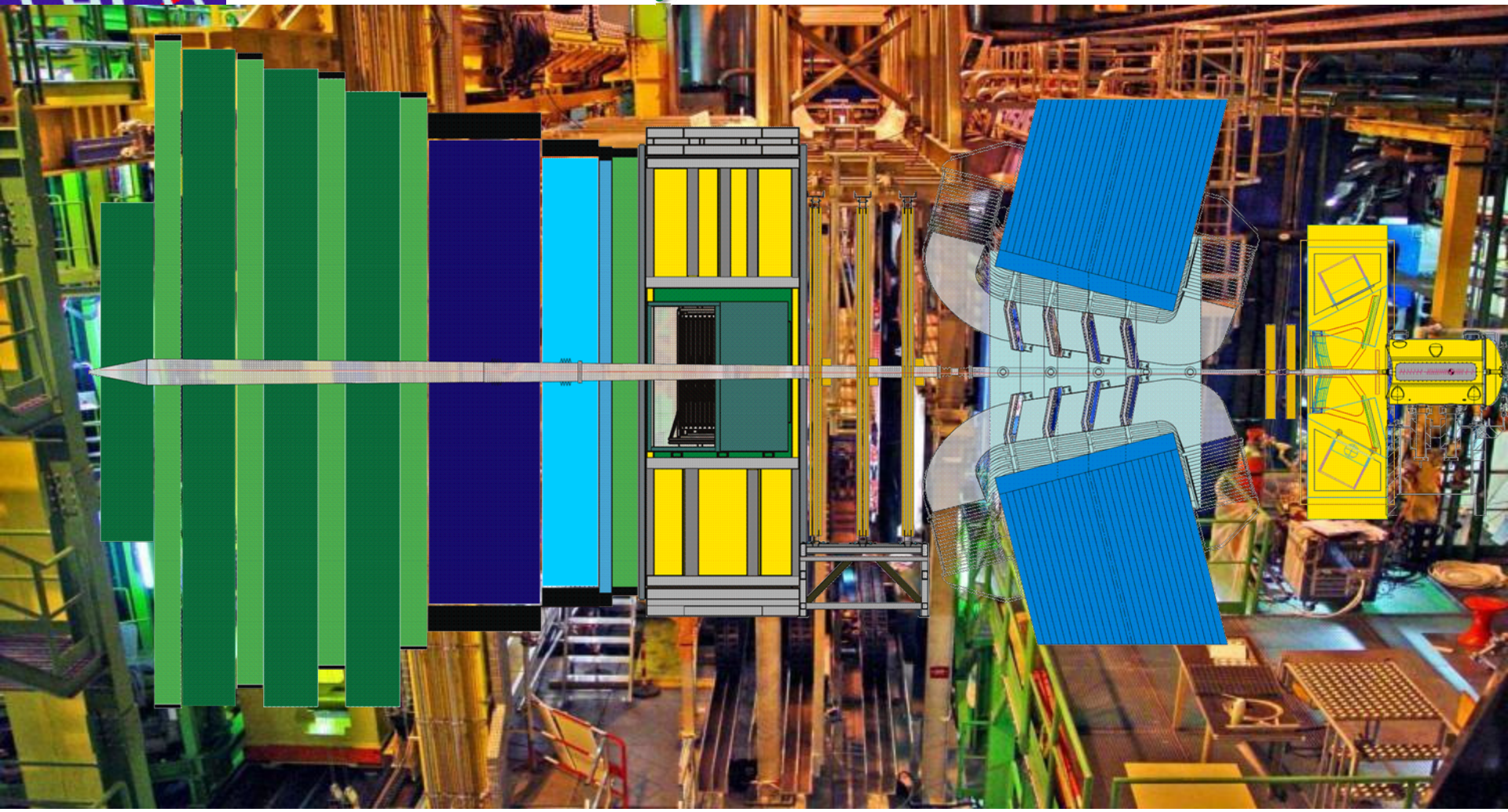
- Expect a few thousand reconstructed decays in 2 fb^{-1}

$B_s \to \mu^+\mu^-$

- With 10 fb^{-1} barely able to make significant SM level measurement
- Precision measurement requires 60 fb^{-1}

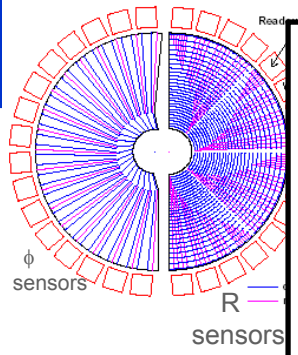


Detector Workings

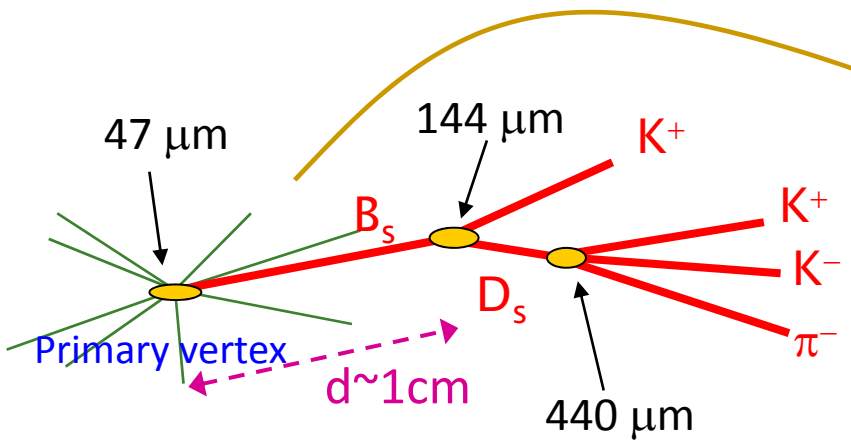


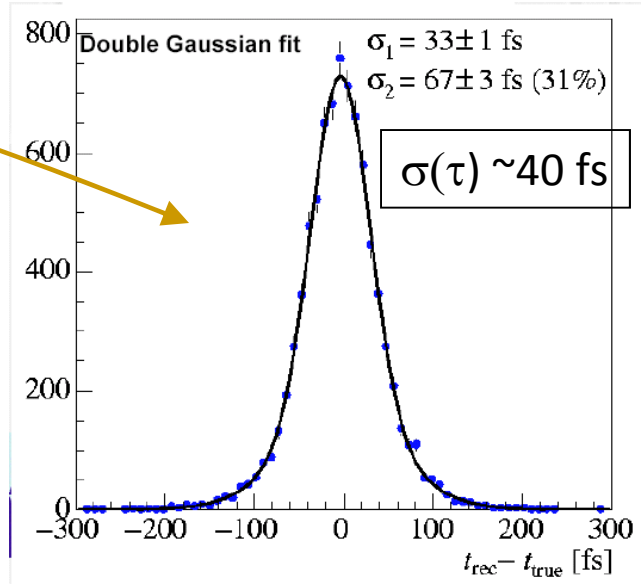
LHCb detector ~ fully installed and commissioned → walk through the detector using the example of a $B_s \rightarrow D_s K$ decay

B-Vertex Measurement

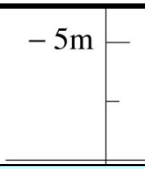


Example: $B_s \rightarrow D_s K$





Decay time resolution = 40 fs



Vertex Locator (Velo)

Silicon strip detector with

~ 5 μm hit resolution

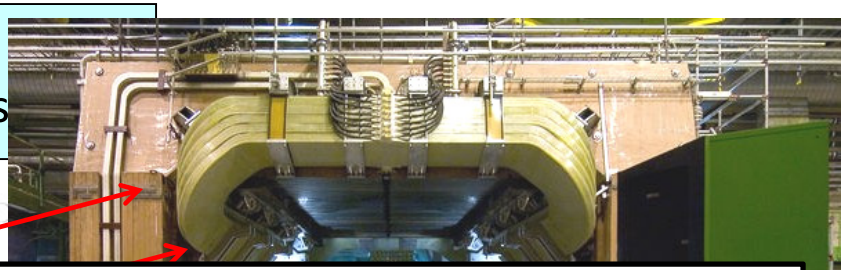
→ 30 μm IP resolution

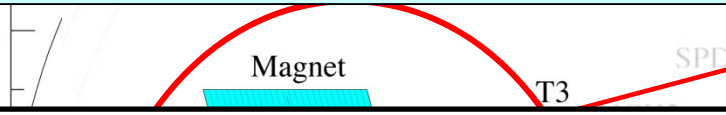
Vertexing:

- trigger on impact parameter
- measurement of decay distance (time)

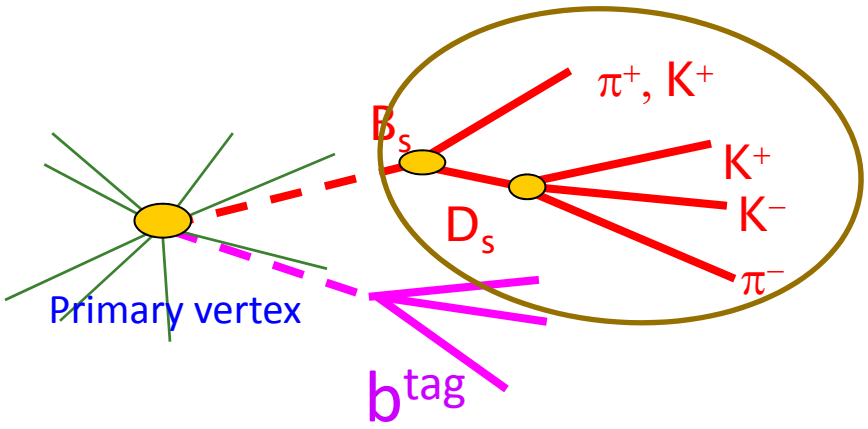
Momentum and Mass measurement

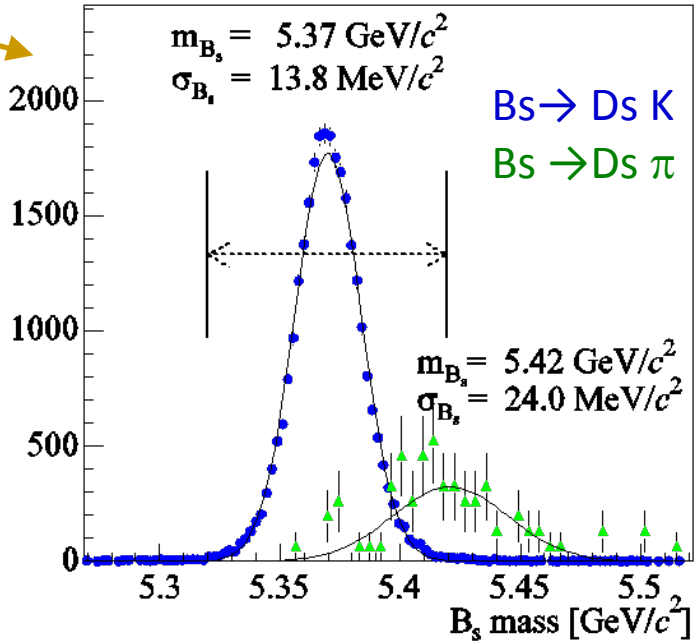
Momentum meas. + direction (VELO):
Mass resolution for background suppres

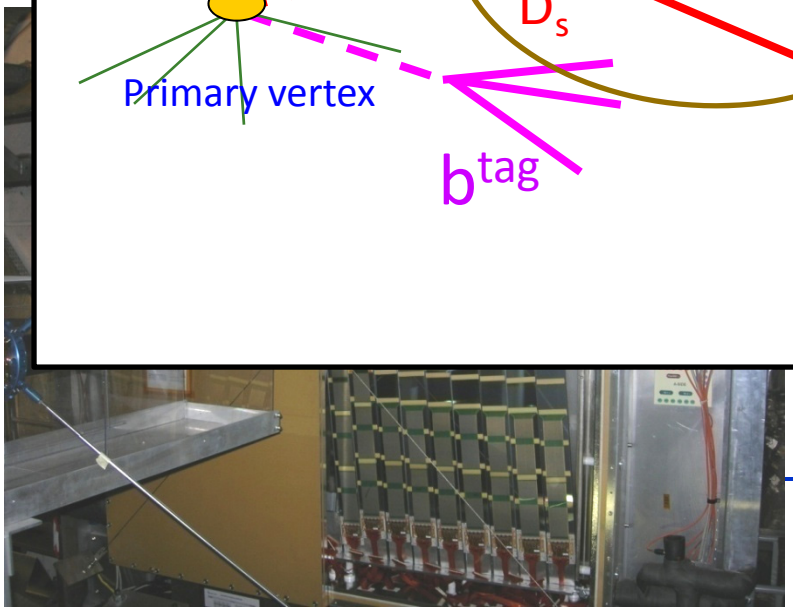




Mass resolution
σ ~14 MeV

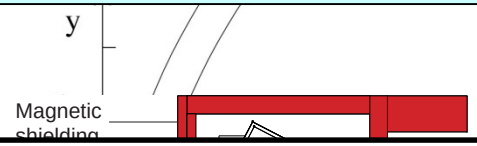


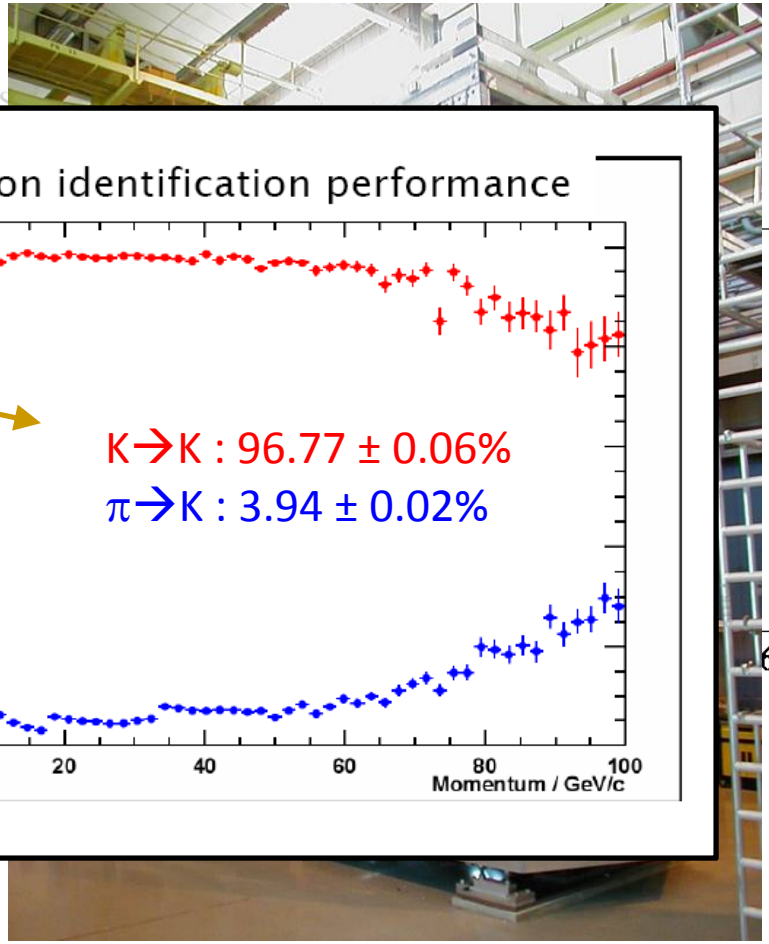




Hadron Identification

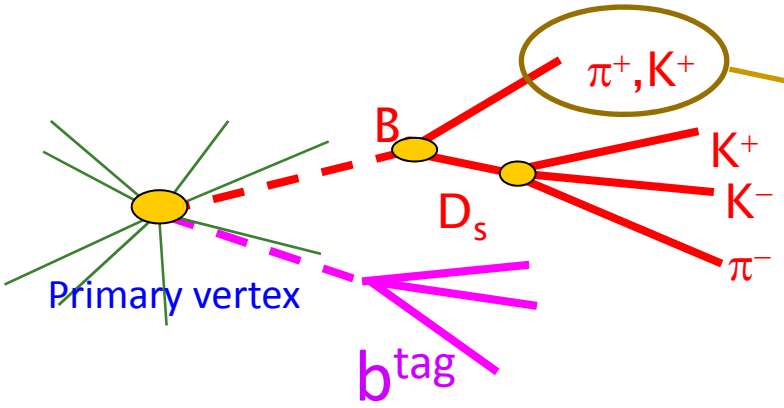
RICH: K/π identification using Cherenkov light emission angle





Bs → Ds K

SS flavour tagging

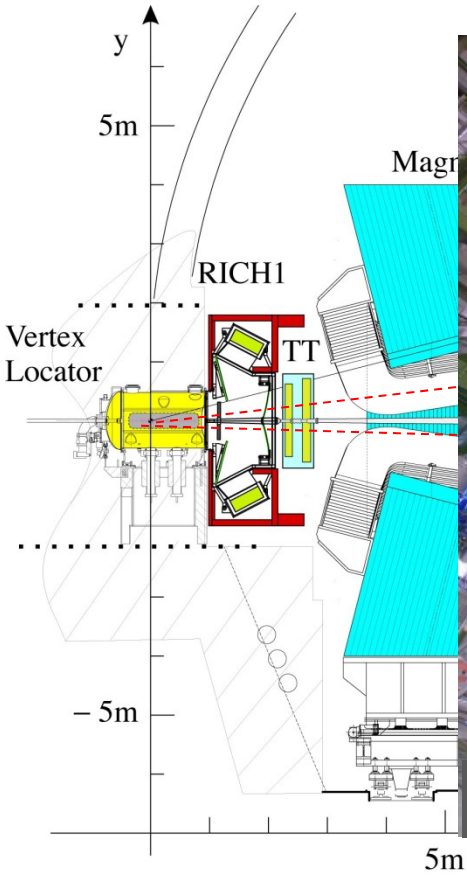


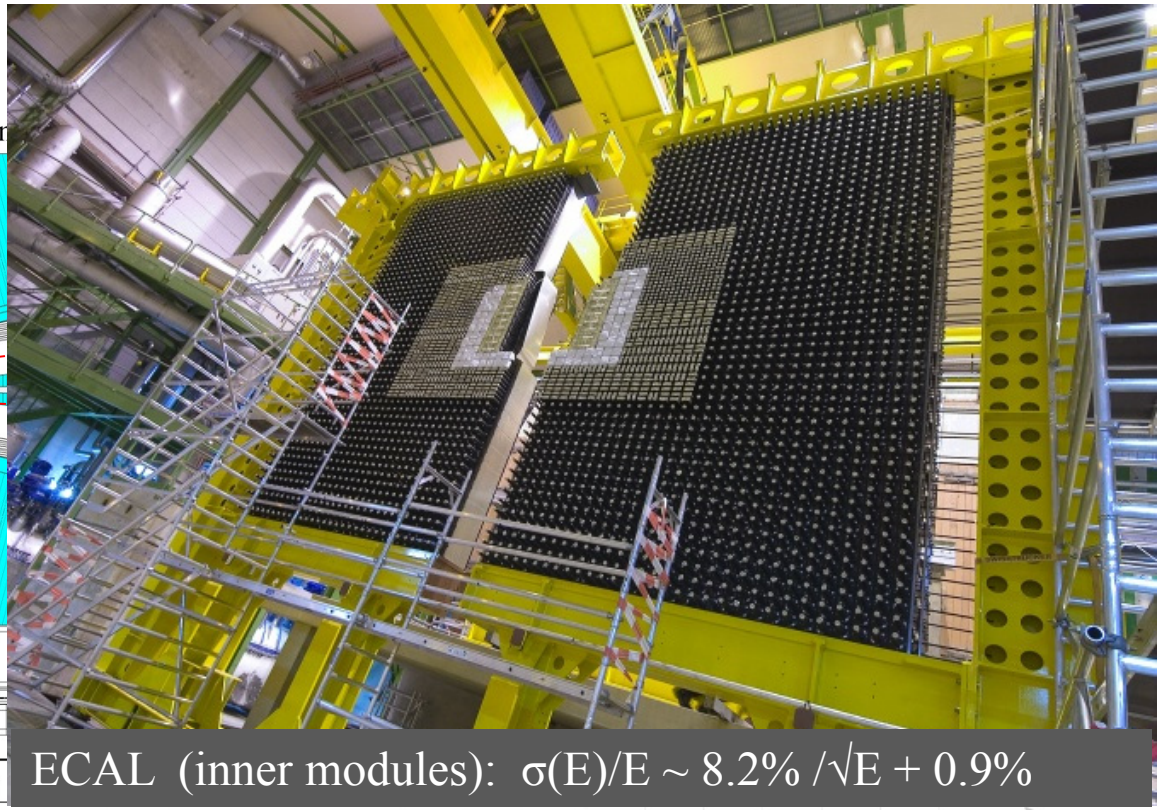
RICH1: 5 cm aerogel n=1.03

4 m^3 C_4F_{10} n=1.0014

RICH2: 100 m3 CF_4 n=1.0005

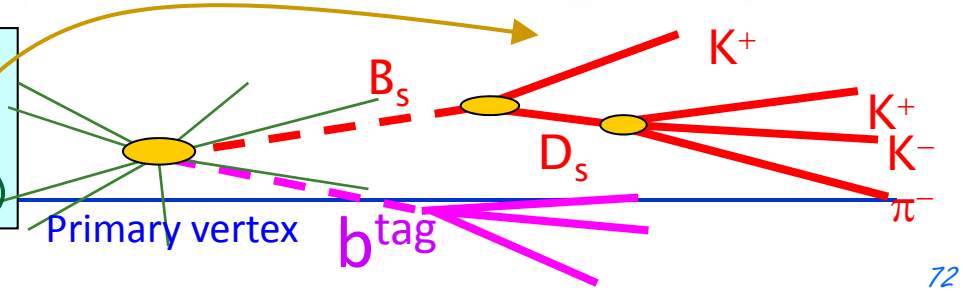
Calorimetry



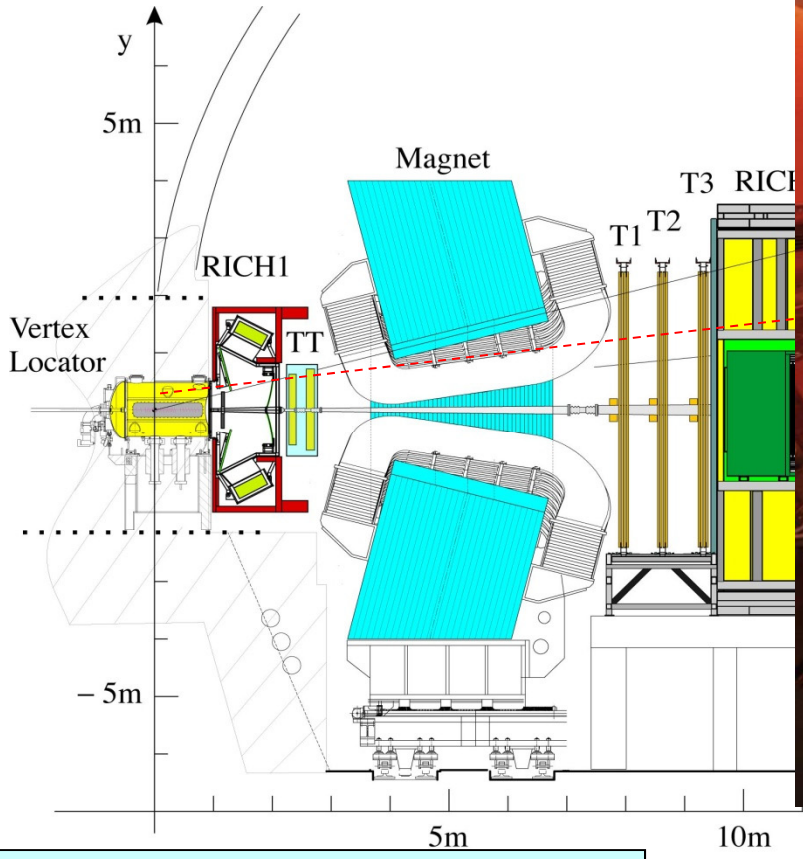


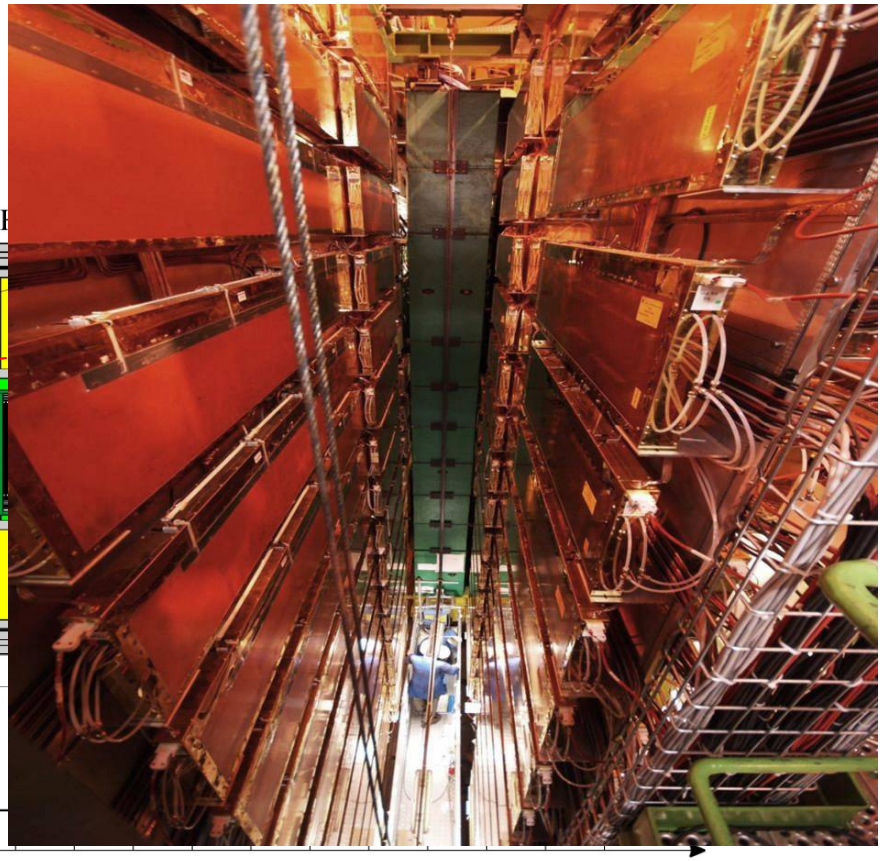
ECAL (inner modules): $\sigma(E)/E \sim 8.2\% /\sqrt{E} + 0.9\%$

Calorimeter system :
- Identify electrons, hadrons, π^0 ,γ
- Level 0 trigger: high E_T electron and hadron



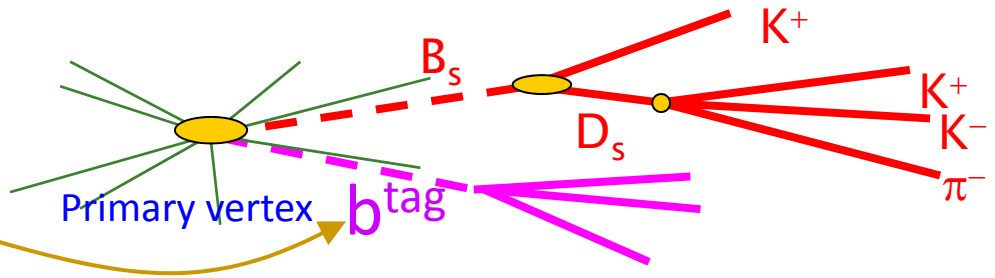
Muon detection



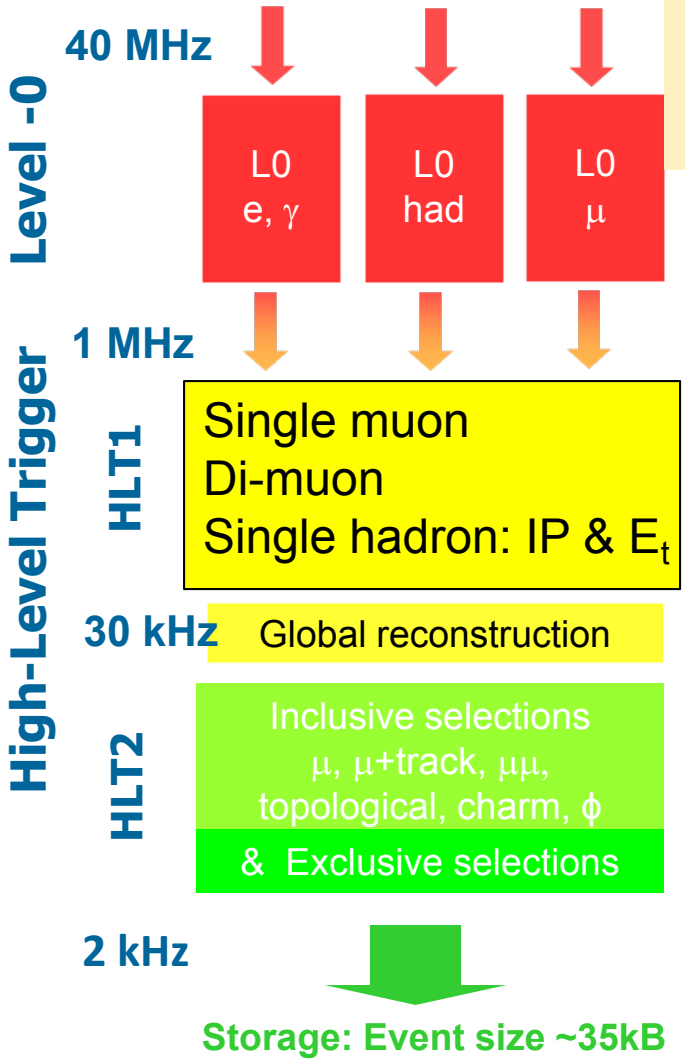


Muon system:

- Level 0 trigger: High P_t muons
- OS flavour tagging



Triggering



Trigger is crucial as $\sigma_{b\bar{b}}$ is less than 1% of total inelastic cross section and B decays of interest typically have $\mathcal{B} < 10^{-5}$

- **Hardware level (L0)**

  Search for high-p_T μ, e, γ and hadron candidates

- **Software level (High Level Trigger, HLT)**

  Farm with $\mathcal{O}$(2000) multi-core processors

  HLT1: Confirm L0 candidate with more complete info, add impact parameter and lifetime cuts

  HLT2: B reconstruction + selections

	ε(L0)	ε(HLT1)	ε(HLT2)
Electromagnetic	70 %	> ~80 %	> ~90 %
Hadronic	50 %		
Muon	90 %		