Recent Results from the LHCb

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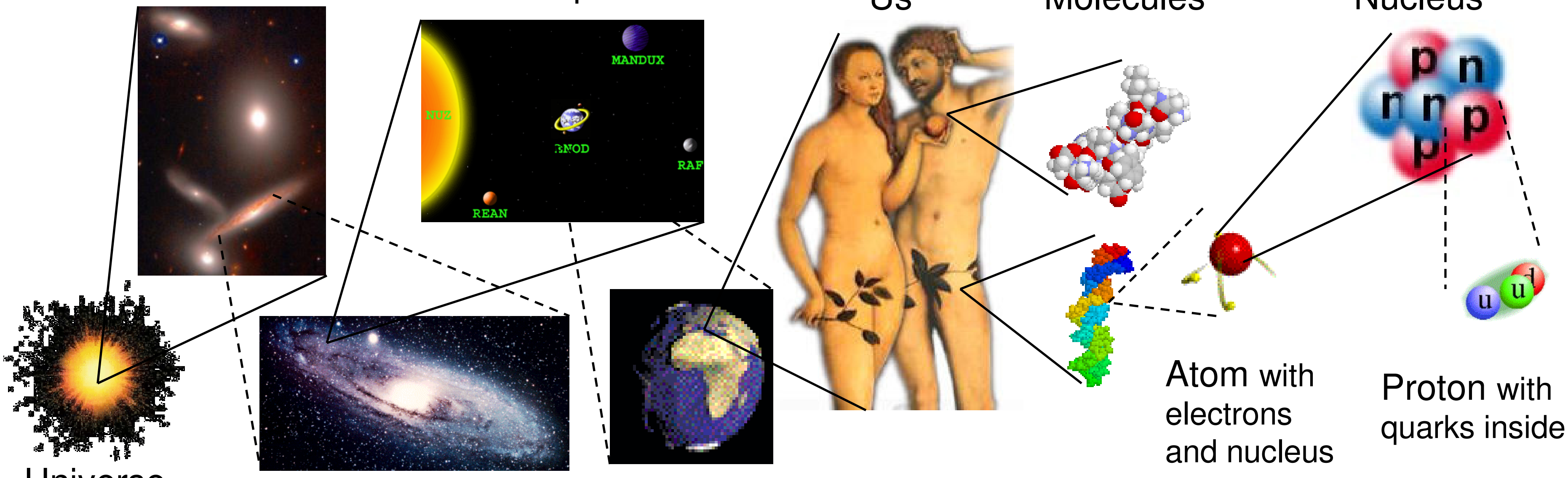
Fundamental Forces (Standard Model)



Group of galaxies

Star with planets

Us

Molecules

Nucleus

Universe

Galaxy

Planet

Atom with electrons and nucleus

Proton with quarks inside

Typical size

10^{26} 10^{23} 10^{21} 10^{13} 10^{7} 1m 10^{-9} 10^{-10} 10^{-14} 10^{-15}

Binding force

Gravity

Electromagnetic

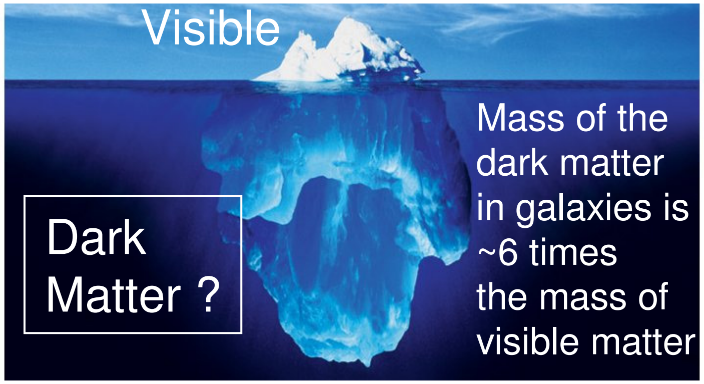
Strong

+ Weak decays of heavier quarks and leptons

Electroweak

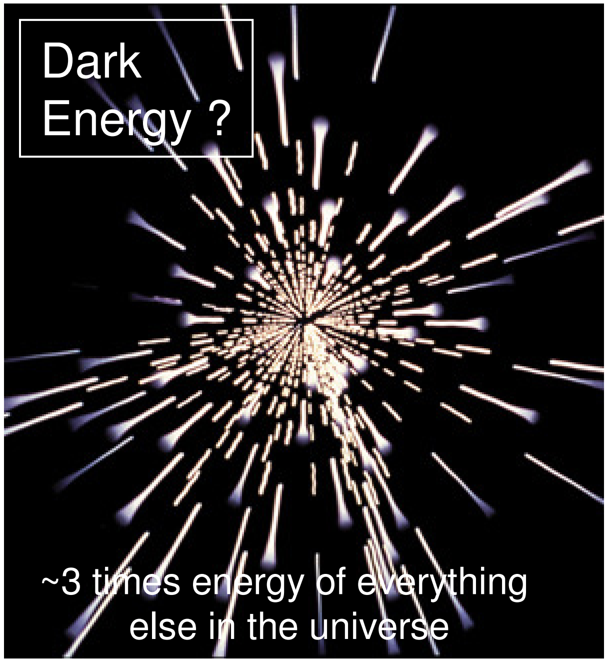
So many phenomena,
so few fundamental particles,
so few forces!

Known unknowns



Dark Matter ?

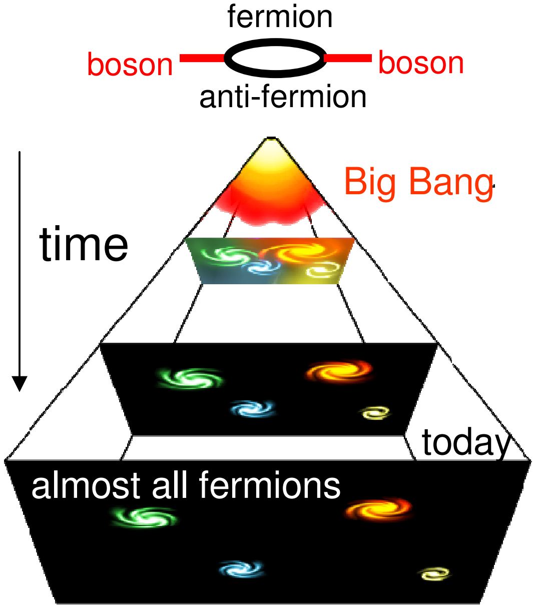
Mass of the dark matter in galaxies is ~6 times the mass of visible matter



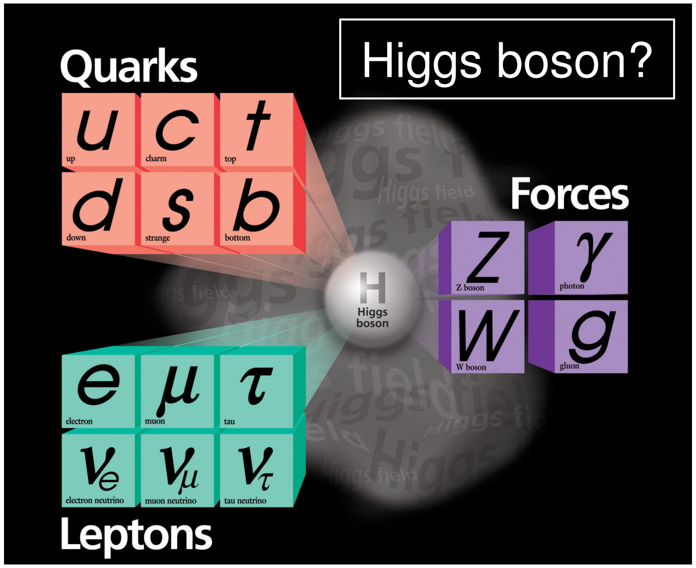
Dark Energy ?

~3 times energy of everything else in the universe

Baryogensis ?

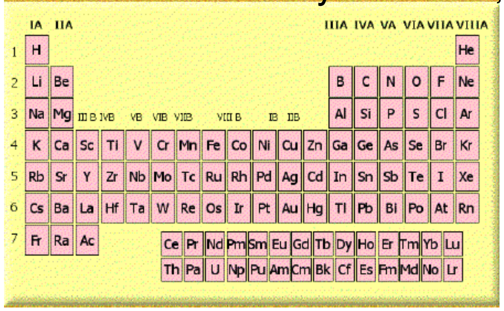


- Unknown particles and forces exist!



Higgs boson?

end of 19th centaury → atoms, QED



	IA	IIA	III B	IVB	VB	VIB	VIIB	VIII B			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	H																	He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	Ac															
				Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
				Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

mid 20th centaury → quarks, QCD

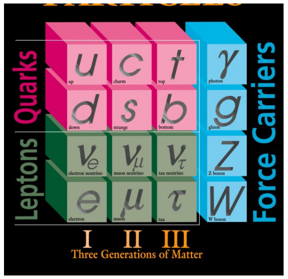
	$Q=-1$	$Q=0$	$Q=+1$
$S=+1$		K^0	K^+
$S=0$	π^+	π^0 ,η	π^+
$S=-1$	K^+	K^0	

	$Q=-1$	$Q=0$	$Q=+1$
$S=0$		n	p
$S=-1$	Σ^-	Σ^0 ,Λ	Σ^+
$S=-2$	Ξ^+	Ξ^0	

	$Q=-1$	$Q=0$	$Q=+1$	$Q=+2$
$S=0$	Δ^-	Δ^0	Δ^+	Δ^{++}
$S=-1$	Σ^{*-}	Σ^{*0}	Σ^{*+}	
$S=-2$	Ξ^{*-}	Ξ^{*0}		
$S=-3$	Ω^-			

Generation problem ?

now → ?



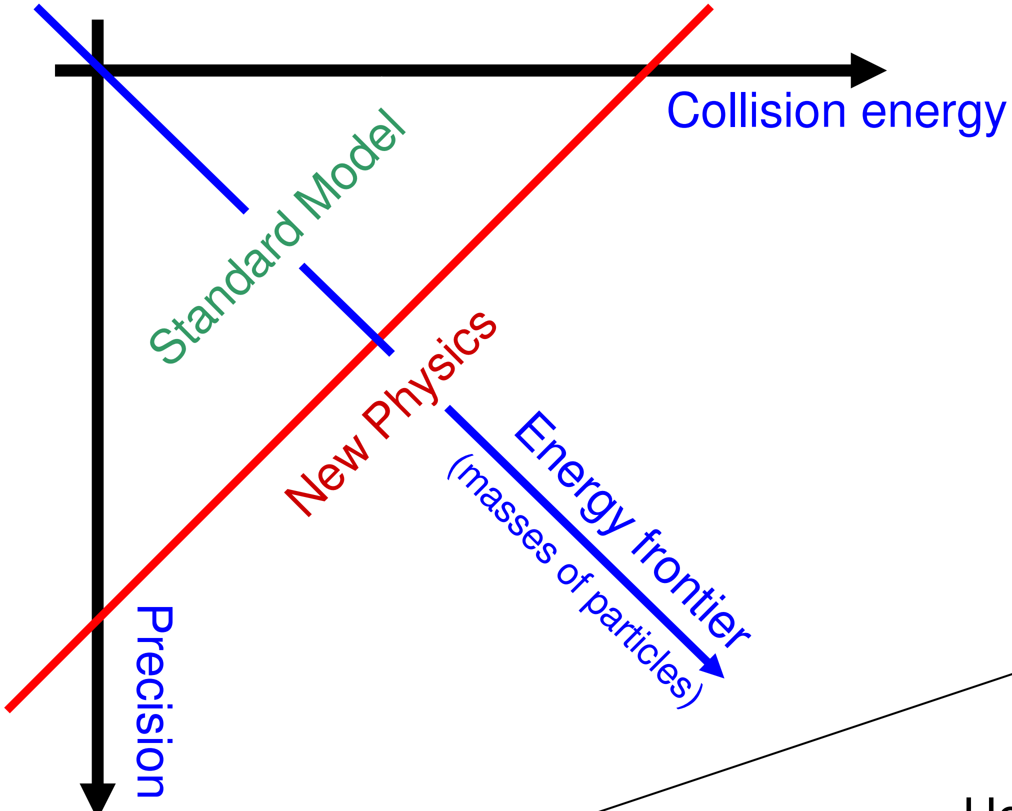
Hierarchy problem ?

$M_H << M_{Planck}$

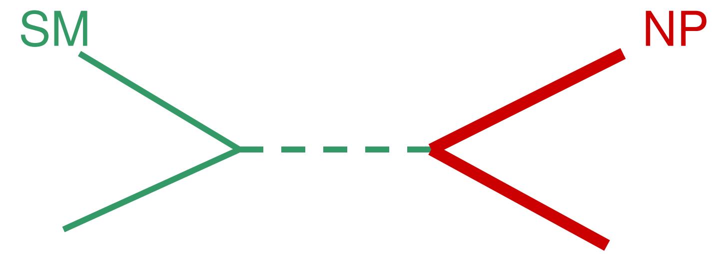
GUT?

How does gravity fits in?

Two complementary ways of advancing “energy frontier”

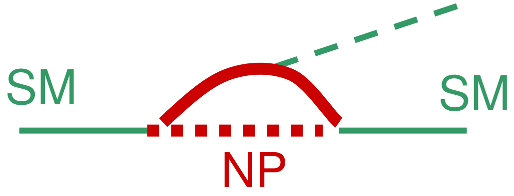


Tree diagrams, for example



Want high CM energy to exceed the production threshold

Loop diagrams, for example

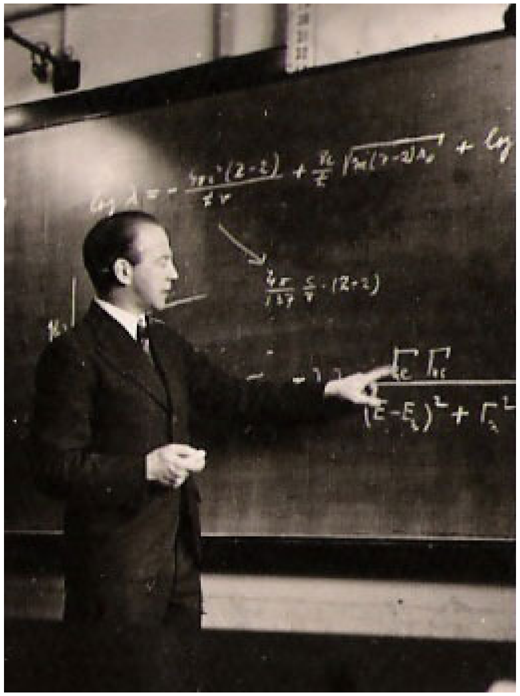


Want high precision since NP particles are highly virtual here, thus probabilities small

Heisenberg’s uncertainty principle:

$$\Delta E\,\Delta t = \hbar/2$$

i.e. $\Delta m\,\Delta t = \hbar/2$



Past successes of loops

- GIM mechanism **1970**: rare K^0 [0.5 GeV] decays → c quark
  - c observed in trees **1974** [3 GeV], Ting & Richter
- CPV in K^0-K^0 mixing **1964**, Cronin & Fitch (5th force?)
  - Kobayashi, Maskwa hypothesis **1972** → b,t quarks:
    - b observed in trees **1976** [10 GeV], Lederman
- B^0-$\overline{B^0}$ mixing **1987**, ARGUS@DORIS [10 GeV] → t heavy
  - PETRA (1978-90 34 GeV), PEP (1980-90 28 GeV), TRISTAN(1987-90 64 GeV), SLC (100 GeV), LEP(1989-02 180 GeV) fail to observe t in trees
  - t observed in trees **1995**, CDF&D0@TEVATRON [342 GeV]
- CLEO@CESR **1994**: $b \to s\gamma$ consistent with SM
  - tough constraints on 2HDM (M_{H+}>300 GeV), SUSY, LRSM
- CPV in B^0-$\overline{B^0}$ mixing and rare B decays **2001-2005**: BaBar@PEP-II, Belle@KEK-B(i.e. TRISTAN-II),
  - Confirm KM hypothesis of quark mixing
- B_s-$\overline{B_s}$ mixing **2006**, CDF@TEVATRON: ditto

CKM – emerging picture

- In SM the matrix must be unitary: 4 independent parameters to describe it (many choices how to define them)
- Wolfenstein's choice (1983) most convenient to depict its measured structure

$\lambda=0.226\pm0.001$ ($\sin\theta_C$)

$A=0.81\pm0.02$

ρ,η see next

Good to λ^3~1%

$$V = \left(\begin{array}{c|ccc} & d & s & b \\ \hline u & 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ c & -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ t & A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{array}\right) + \delta V$$

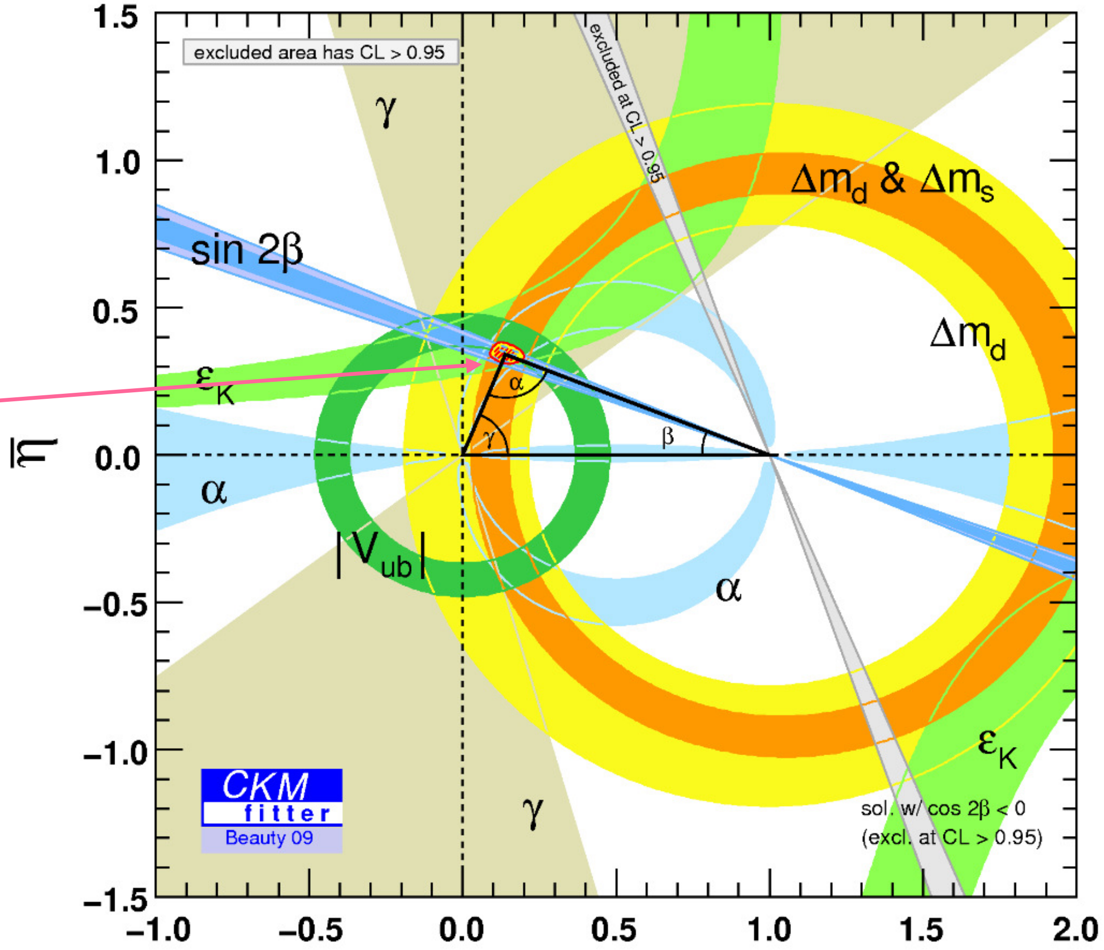
$$\delta V = \begin{pmatrix} 0 & 0 & 0 \\ -iA^2\lambda^5\eta & 0 & 0 \\ A\lambda^5(\rho+i\eta)/2 & -A\lambda^4(1/2-\rho-i\eta) & 0 \end{pmatrix}$$

Complex phase η
mostly in V_{td}, V_{ub}
then a bit in V_{ts}

$$\lambda^0 = 1$$
$$\lambda^1 = 0.23$$
$$\lambda^2 = 0.051$$
$$\lambda^3 = 0.012$$
$$\lambda^4 = 0.0026$$
$$\lambda^5 = 0.0006$$

Test of SM via CKM unitarity

- CKM Fitter results using CP violation in $J/\psi\ K_S$, $\rho^+\rho^-$, DK^-, K_L, & V_{ub}, V_{cb} & Δm_q
- Similar situation using UTFIT
- The overlap region includes CL>95%
- The fact that the overlap region exists means all measurements so far are consistent with the SM
- NP scenarios must now fit into the narrow overlap region

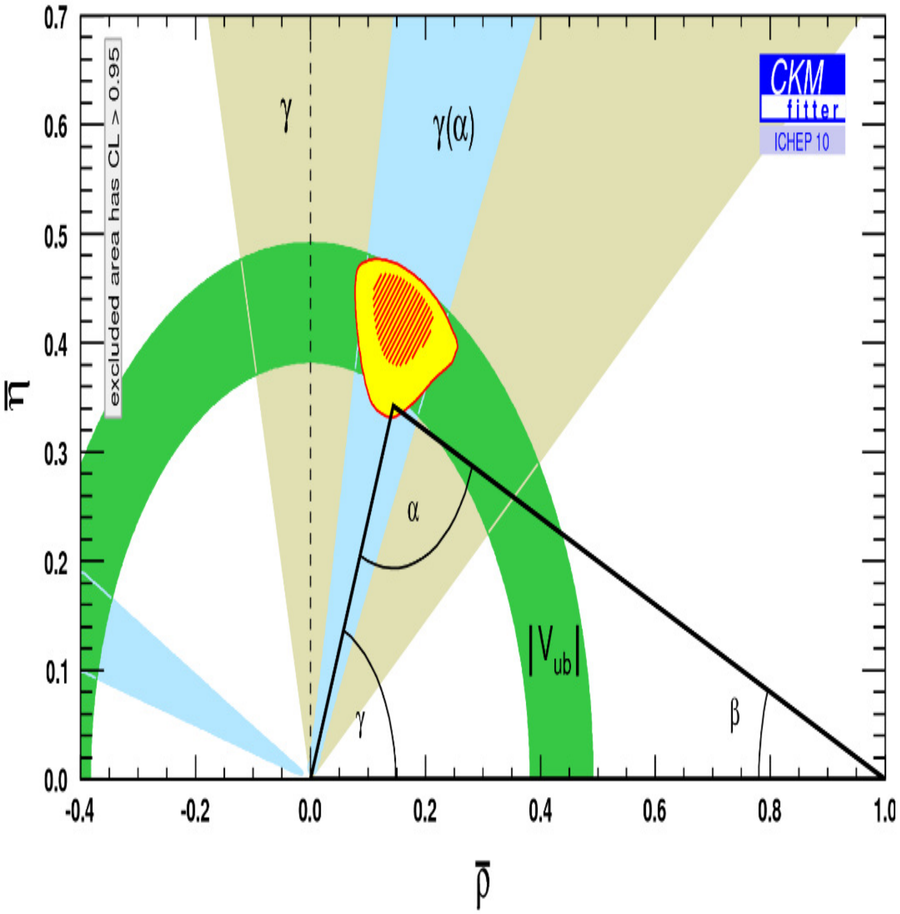


Kobayashi & Maskawa
Nobel Prize 2008

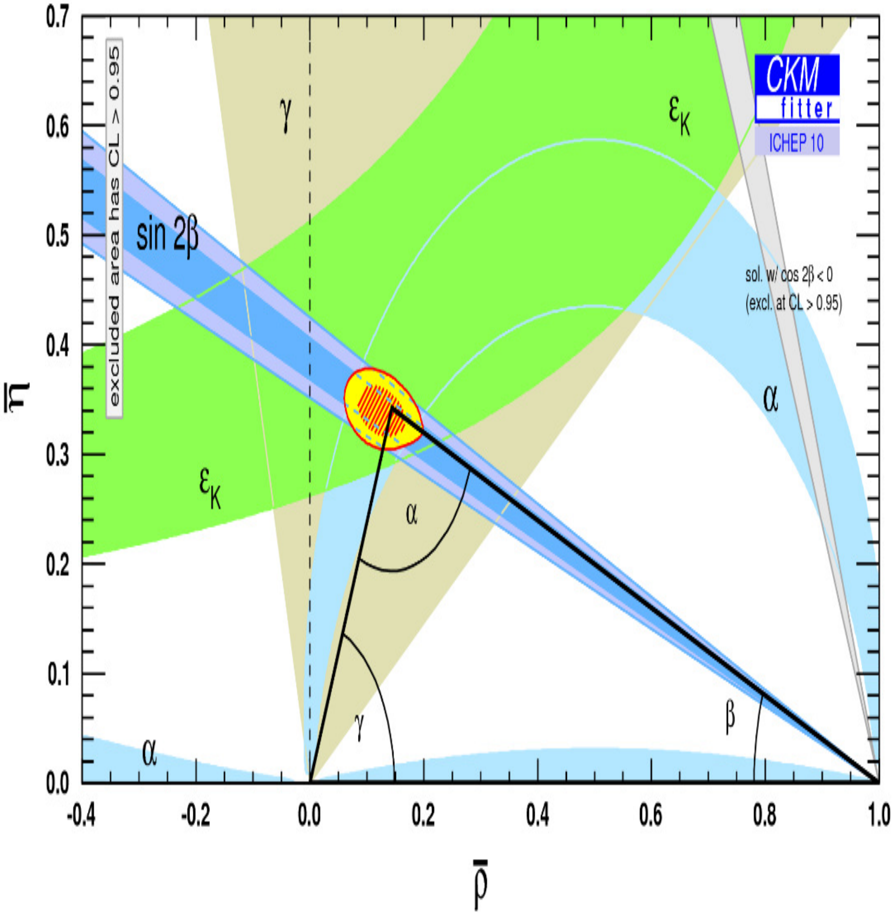
Note: $\bar{\rho} = \rho(1-\lambda^2/2)$
$\bar{\eta} = \eta(1-\lambda^2/2)$

Separating trees and loops

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



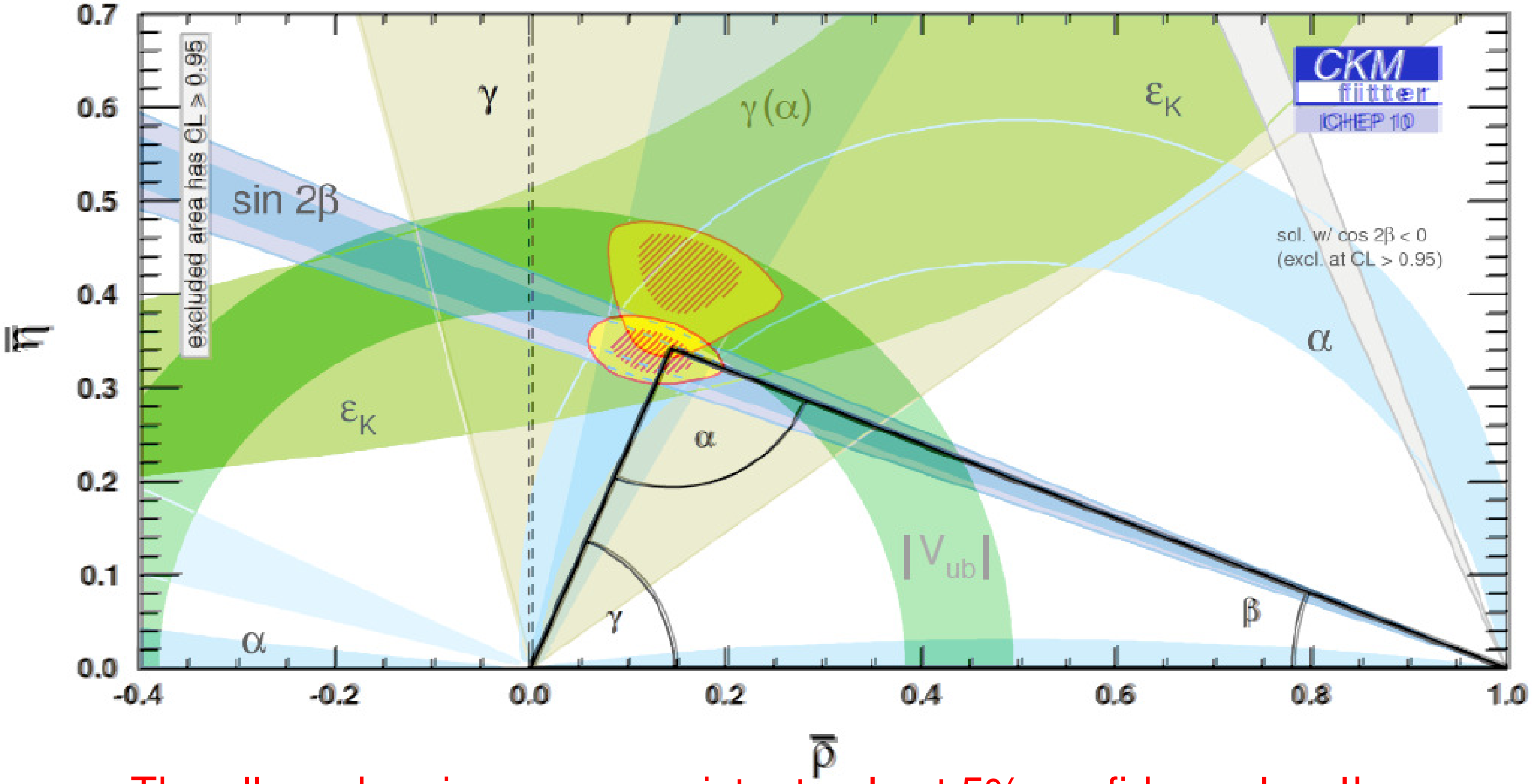
- Loops are more sensitive to NP - CPV in B^0 and K^0 mixing only



(γ poorly determined)

Separating trees and loops

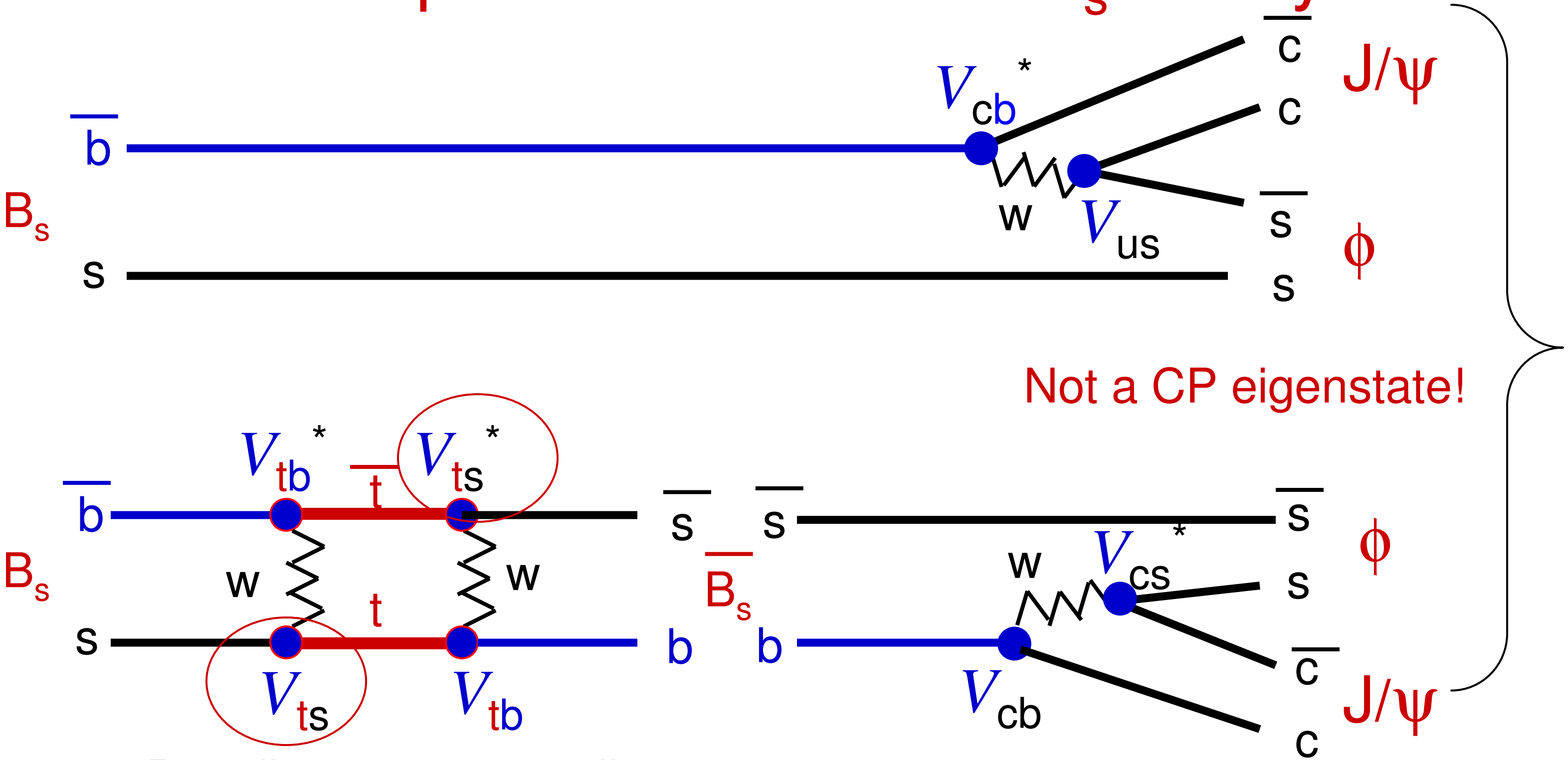
- Tree diagrams are unlikely to be affected by physics beyond the SM
- Loops are more sensitive to NP - CPV in B^0 and K^0 mixing only



The allowed regions are consistent only at 5% confidence level!

More trouble in the B_s sector – see next

Loops: CP violation in B_s decays



Not a CP eigenstate!

Impossible to tell which happened - the two processes **interfere**

Box diagram responsible for B^0-$\overline{B^0}$ mixing

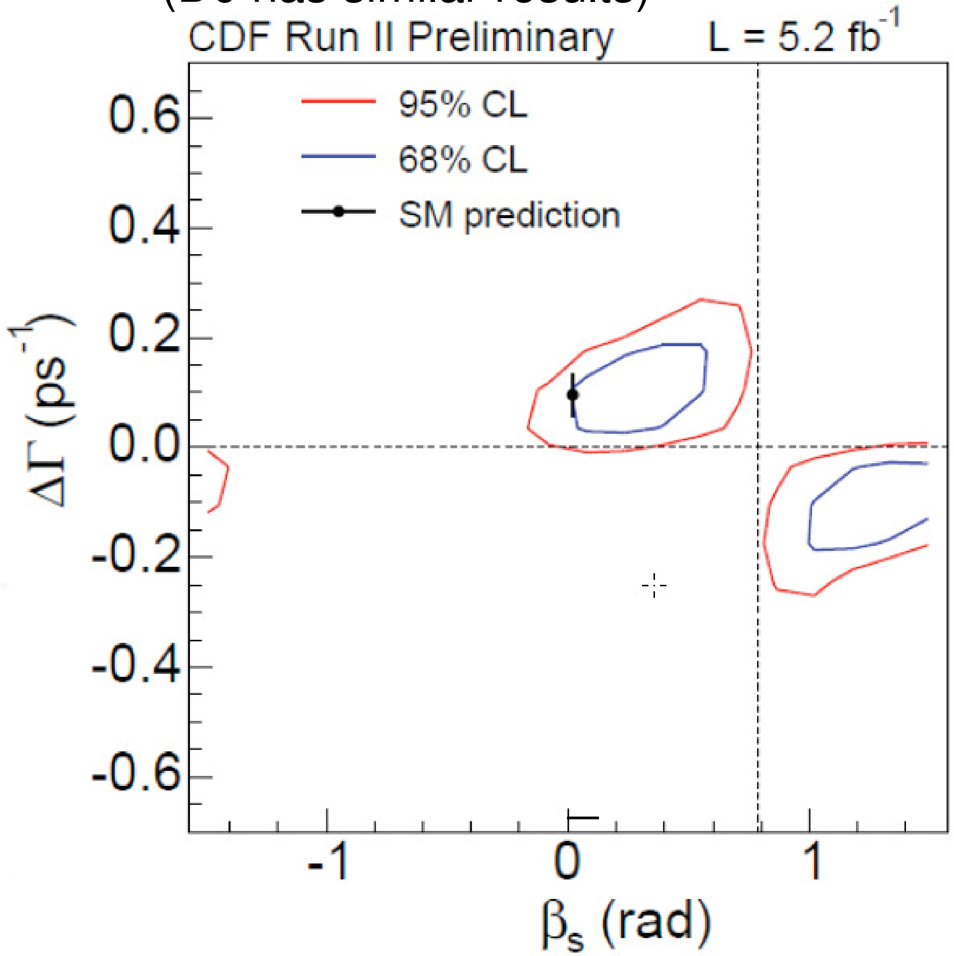
(mixing + decay: “indirect” CPV)

- The only non-negligible CKM phase is from V_{ts} ($\sim\lambda^4$) – very small. Excellent place to look for phases from NP particles!
- Different helicity amplitudes lead to different CP values of the final state. Analysis of the angular correlation is performed to deconvolute.

Phase of B_s mixing diagram

- The SM prediction of the phase depends also on $\Delta\Gamma$. Measure both from the time evolution.

(D0 has similar results)



$= -\phi_s/2$

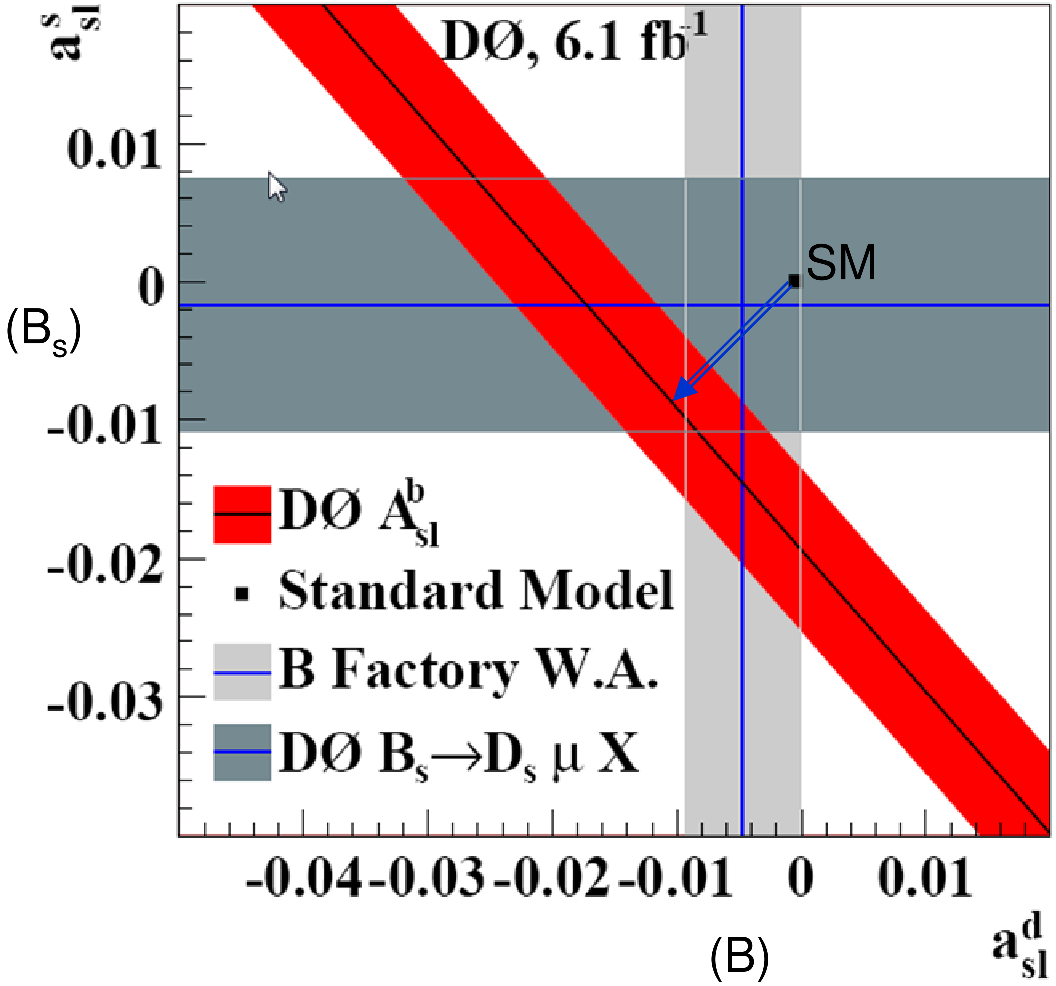
Pretty sizable integrated luminosity for hadron collider!

Would be good to shrink the experimental errors **a lot**.

Dimuon charge asymmetry – also probes $B_{(s)}\overline{B}_{(s)}$ mixing

D0 charge asymmetry measurement, using bb→μμX event

$$A^b = \frac{N^{++}-N^{--}}{N^{++}+N^{--}} = (0.494)a^s_{fs} + (0.506)a^d_{fs}$$



- 3.2σ deviations from the SM !
- Anomalous CPV- 5th force?

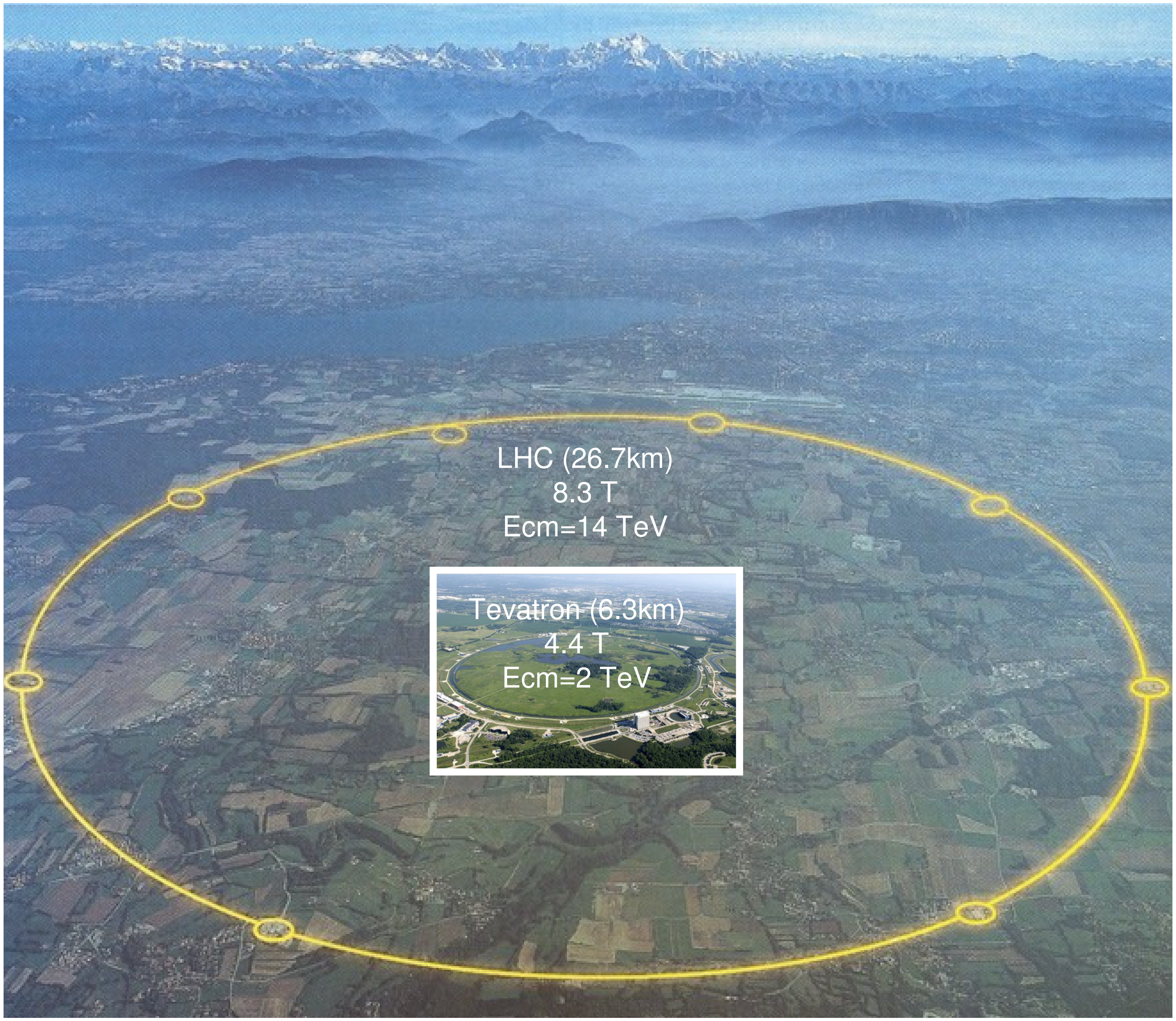
Would be good to shrink the experimental errors **a lot**.

* but only in Europe
~~(BTeV)~~

The LHCb Collaboration

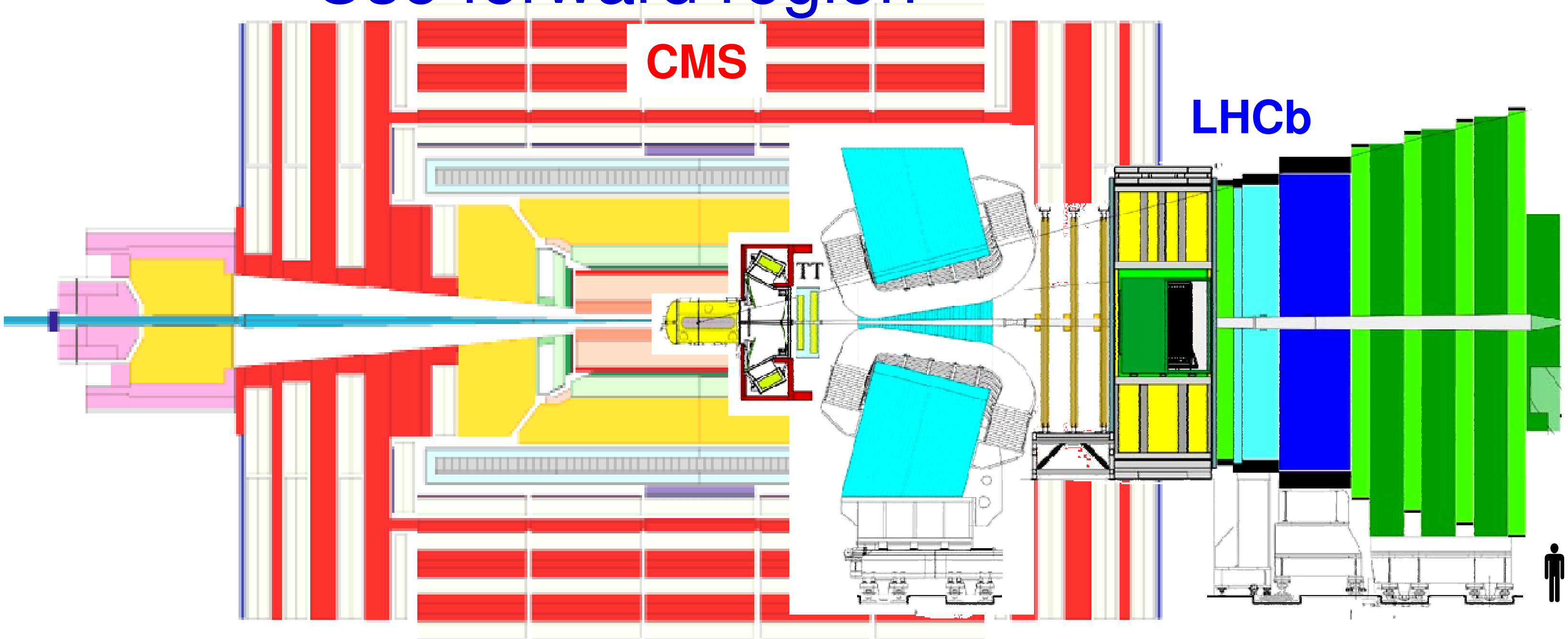
- 800 Physicists
- 54 Institutes
- 15 Countries
  - 1 Group from USA

Increased $b\bar{b}$ cross-section



- Gain a factor of ~5 in cross section at 14 TeV
- Less (~3) for initial 2 years of running, since Ecm=7 TeV
- Also gain in $b\bar{b}$ being a larger fraction of total inelastic cross-section:
  - LHC ~1% vs Tevatron ~0.3%
  - Important especially for **triggering**

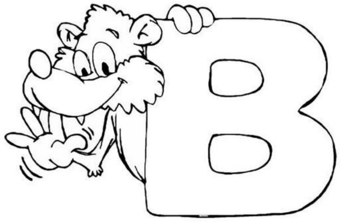
Use forward region



- Capture both b and $\overline{b}$ in **affordable** (75M CHF) solid angle (at $\mathcal{L}=2\times10^{32}/cm^2s$, we get 10^{12} B hadrons in 10^7 sec; 20kHz)
- Single arm to have space for more detector layers: Particle ID ($K/\pi/p$ separation) flavor tagging efficiency
- Large forward momentum of B daughters:
  - **Can detect/trigger on muons with much lower Pt thresholds**
  - Smaller multiple scattering in vertex detector:
    - Helps triggering on displaced vertices (B lifetime)
    - Excellent proper time resolution (50 fs)

B trigger happy!

Triggers
at
L ~ 2 10^{32} $cm^{-2}s^{-1}$



	CDF	LHCb (**design** running conditions)
Bunch crossing rate	**2 350 kHz**	**40 000 kHz**
Bunch spacing	396 ns	25 ns
Interactions / crossing	***(at 3 10^{32}) 10.0***	**(at 2 10^{32}) 1.2**
Stage 1	L1	L0
Output rate	**30 kHz**	**1 000 kHz**
Latency	5.5 μs	4.0 μs
Type	**Hardware** (tracks,mu,ecal)	**Hardware** (hcal,mu,ecal)
Single μ	Pt>4 GeV	Pt>1.3 GeV
Dimoun	Pt1>2.0 & Pt2>2.0 GeV	Pt1+Pt2>1.3 GeV
Stage 2	L2	HLT1
Output rate	**1 kHz**	**30 kHz**
Execution time	20 μs	~5 000 μs
Type	**Hardware** (tracks, IP)	**Computer Farm** (tracks,IP)
Stage 3	L3	HLT2
Output rate	**150 Hz**	**3 000 Hz**
Event size	250 kB	45 kB
Type	**Computer farm**	**Computer Farm** (full event reco)
Fraction of bandwidth for heavy flavors	small	all

- LHCb is the first dedicated hadron collider b-experiment

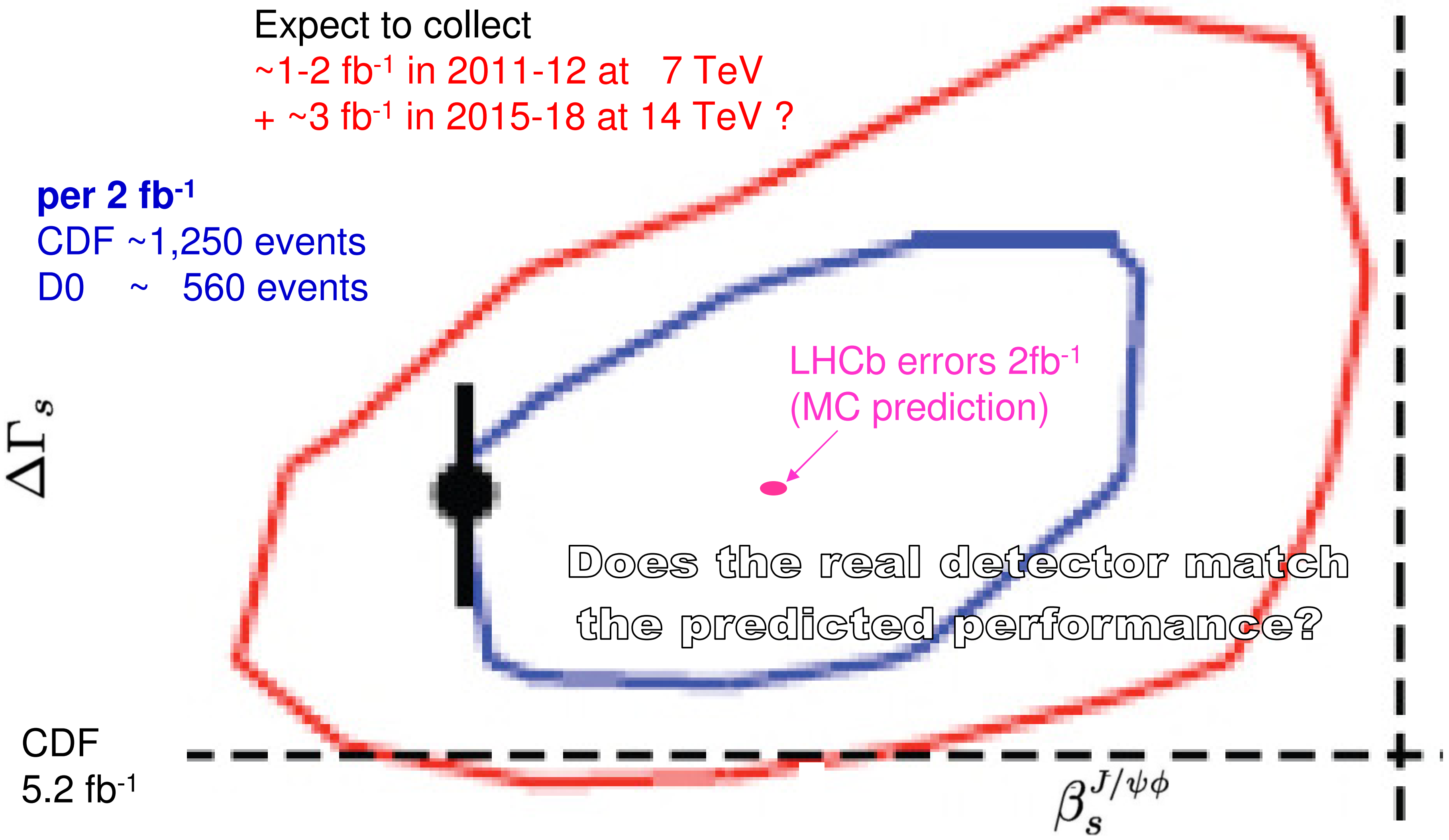

BB gun


B hunting

MC predictions for LHCb sensitivity to β_s

- Expect ~130,000 $B_s \to J/\psi\ \phi$ events in 2 fb^{-1} at 14 TeV. Projected errors are ±0.03 rad in $2\beta_S$ & ±0.013 in $\Delta\Gamma_S/\Gamma_S$

Future LHCb samples
Expect to collect
~1-2 fb^{-1} in 2011-12 at 7 TeV
+ ~3 fb^{-1} in 2015-18 at 14 TeV ?



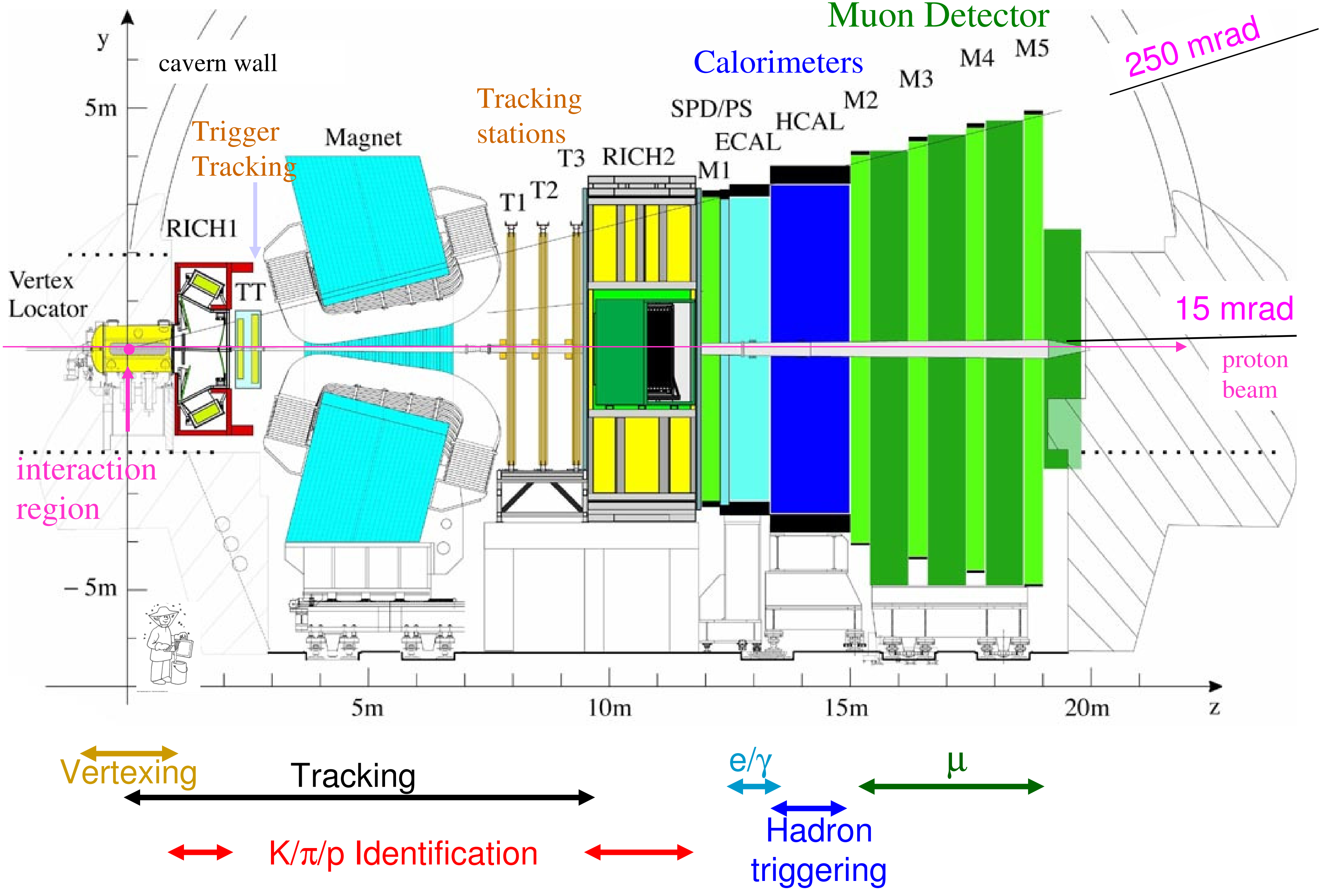
per 2 fb^{-1}
CDF ~1,250 events
D0 ~ 560 events

LHCb errors 2fb^{-1}
(MC prediction)

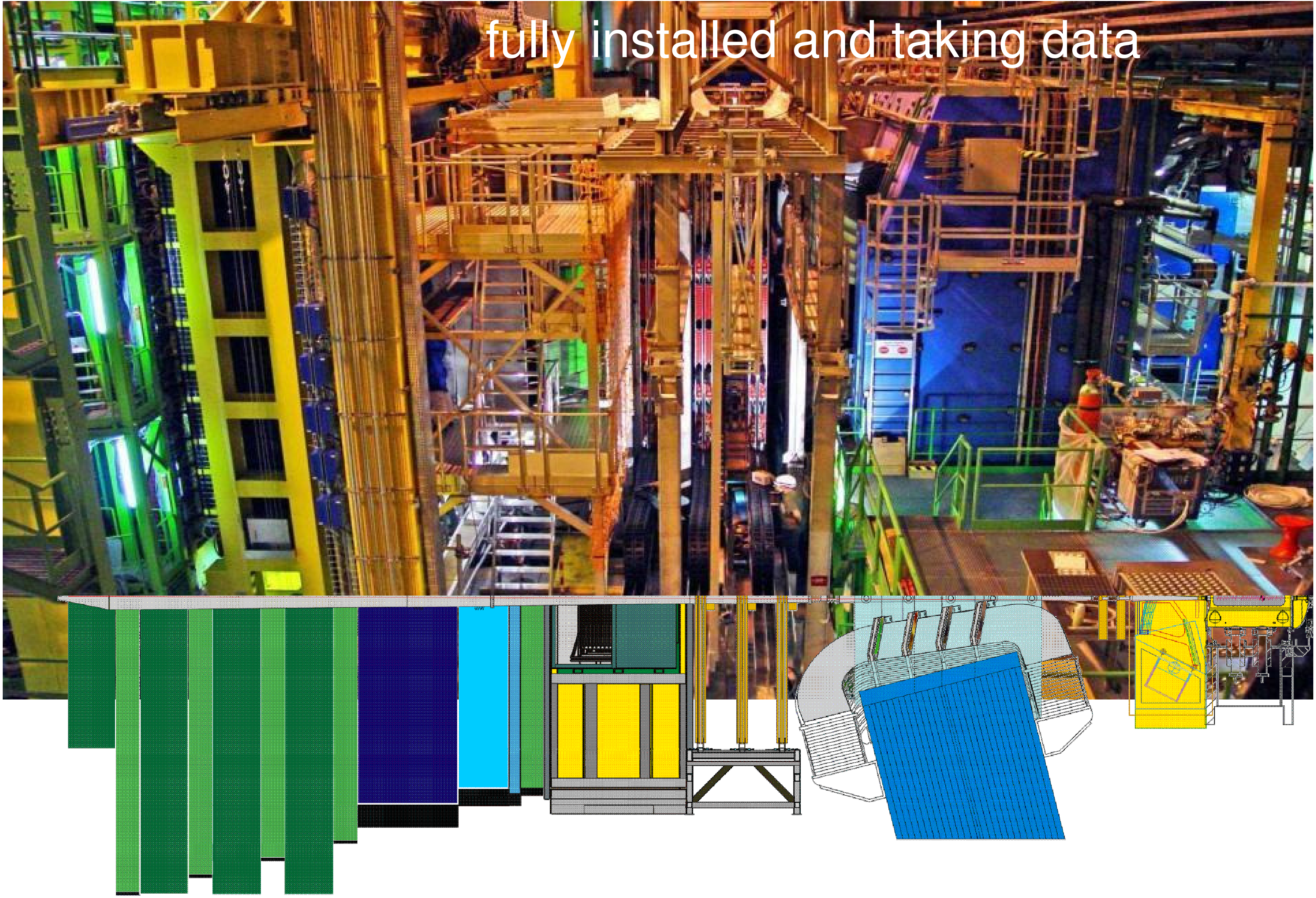
Does the real detector match the predicted performance?

CDF
5.2 fb^{-1}

The LHCb Detector



LHCb Detector Status



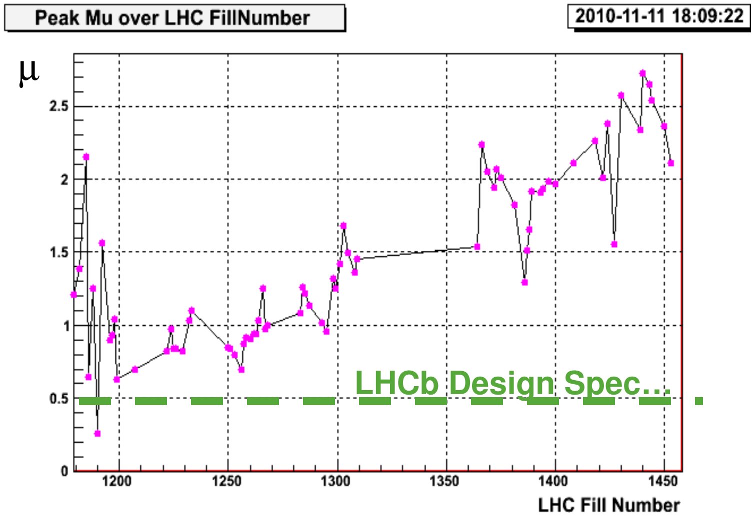
2010 data samples

42.15 pb^{-1} delivered

37.66 pb^{-1} accepted (~90% efficiency)

We reached L_{design}~2×10^{32} $\text{cm}^{-2}\text{s}^{-1}$
but with 344 instead of 2622 bunches.

μ – average number of pp
interactions per bunch crossing

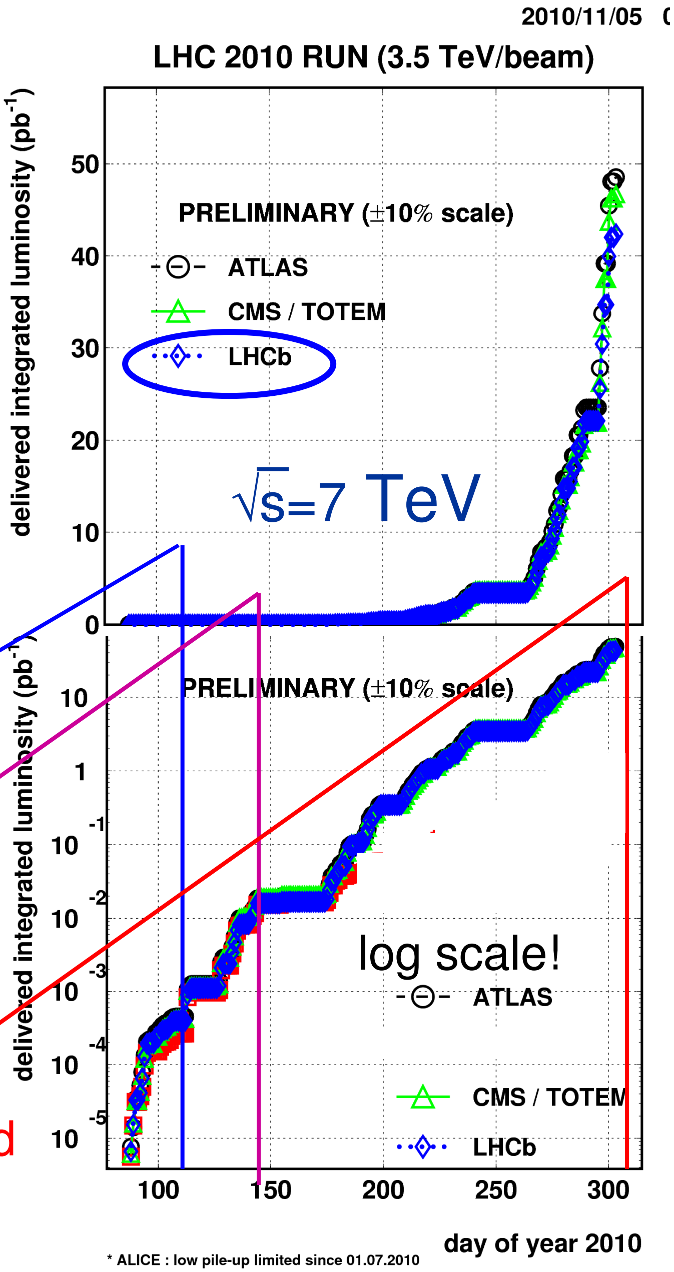


High pileup (μ), low spillover conditions.

0.3-3 nb^{-1}
min.bias trigger

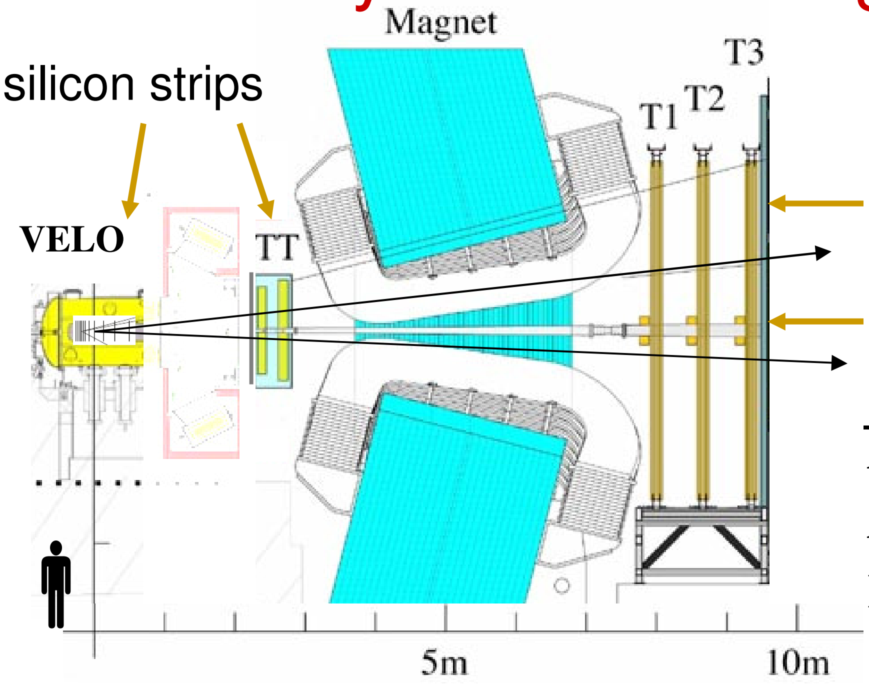
12 nb^{-1}
loose muon and
hadronic triggers

37 pb^{-1}
nominal muon and
hadronic triggers



(I will discuss early 2011 data taking later)

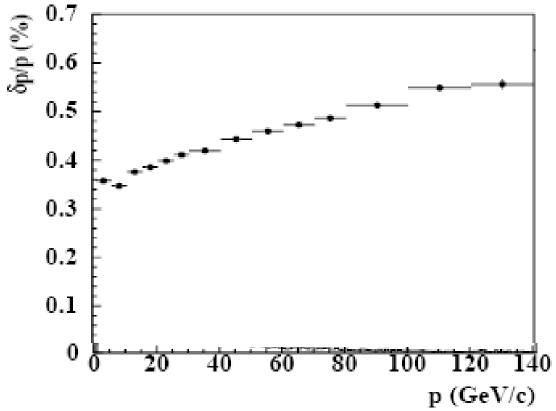
Early test of tracking - strange V^0s



silicon strips

Outer Tracker:
straw tubes

Inner Tracker:
silicon strips



$\overline{\Lambda} \rightarrow \overline{p}\pi^-$

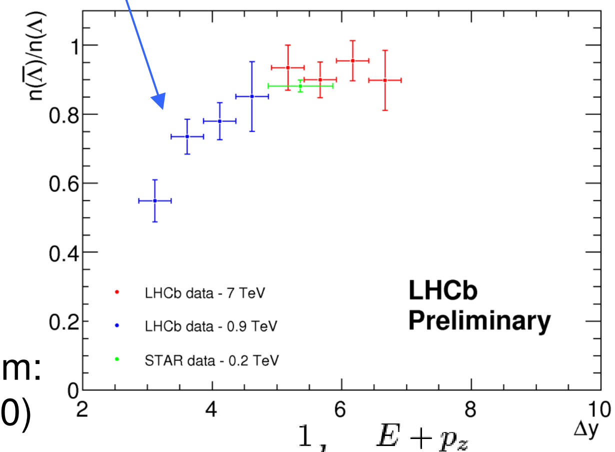
$\Lambda \rightarrow p\pi^+$

$K^0_S \rightarrow \pi^+\pi^-$

- Long lifetime → clean signals with no PID
- Copiously produced (1 per event)

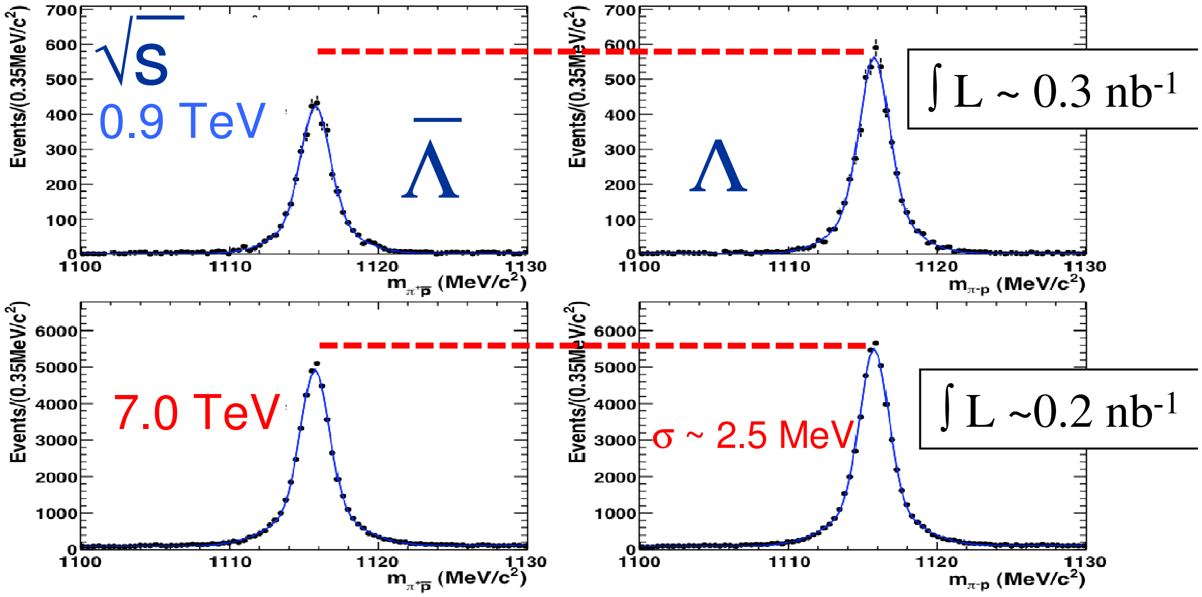
LHCb-CONF-2010-11

Baryon number of the beam propagating to Λ



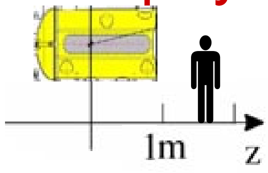
(beam: Δy=0)

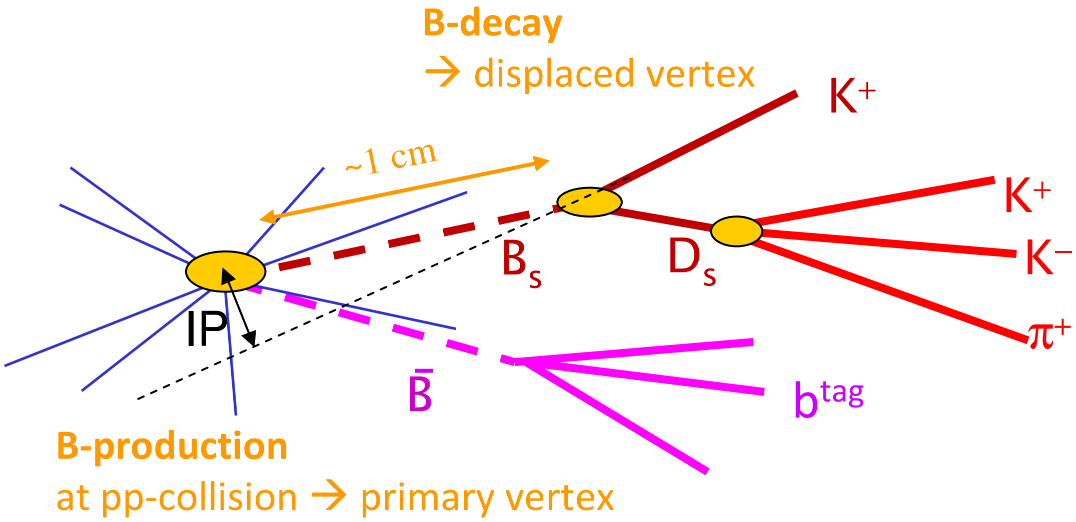
$$y = \frac{1}{2} log_e \frac{E+p_z}{E-p_z}$$



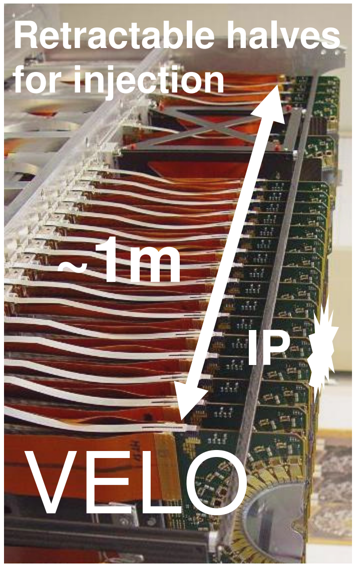
Vertex detector crucial for heavy flavor physics

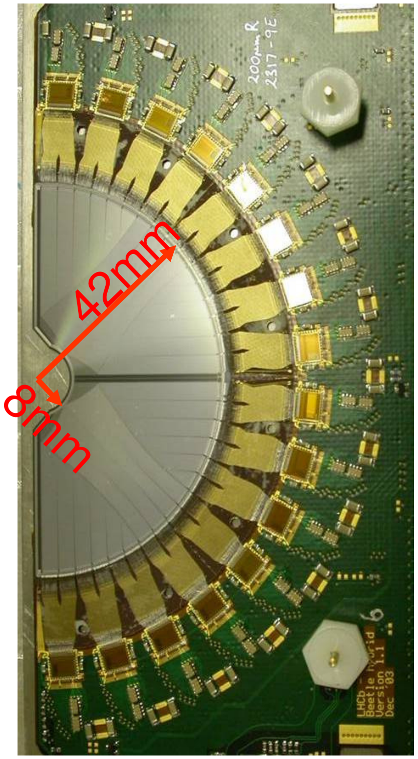
- Short but detectable lifetime → VELO
  - $c\tau$ = 2.7cm K^0_S, 7.9cm Λ; rate ~ 1/1 per event
  - $c\tau$ = 0.12 mm D^0 rate ~ 1/10 per event
    - γ ~ 10-20
  - $c\tau$ = 0.46 mm B^0 rate ~ 1/100 per event

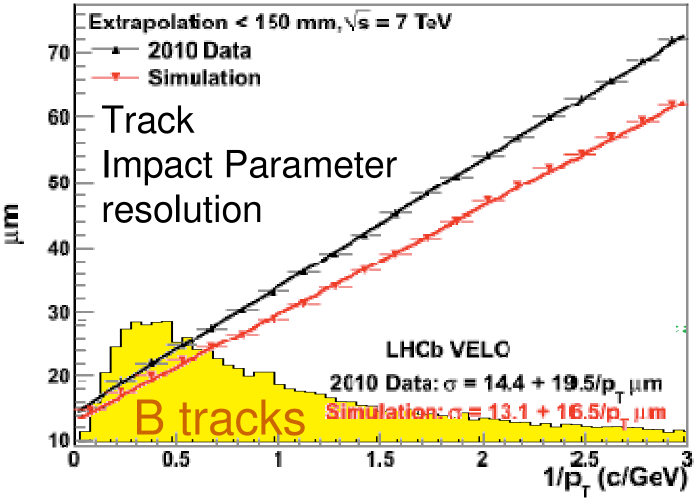


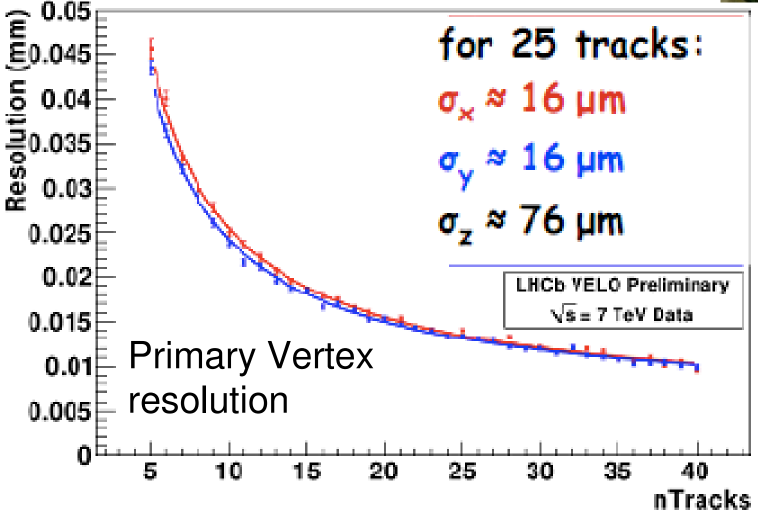

B-decay
→ displaced vertex

B-production
at pp-collision → primary vertex


Retractable halves for injection




Track Impact Parameter resolution

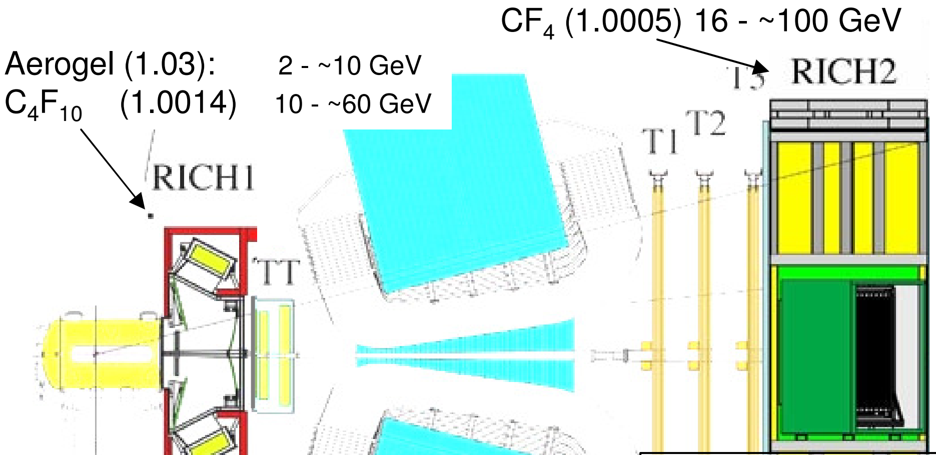

Primary Vertex resolution

for 25 tracks:
$\sigma_x \approx$ 16 μm
$\sigma_y \approx$ 16 μm
$\sigma_z \approx$ 76 μm

21 stations

R and ϕ layer each
n^+n type
2048 strips/sensor
Strip pitch varies from 40μm to 100μm
0.3mmm Al RF foil inside

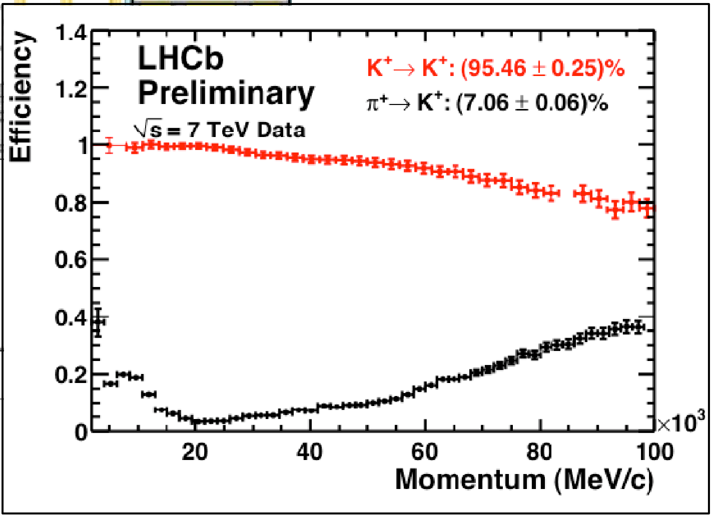
Hadron identification



CF_4 (1.0005) 16 - ~100 GeV

Aerogel (1.03): 2 - ~10 GeV

C_4F_{10} (1.0014) 10 - ~60 GeV

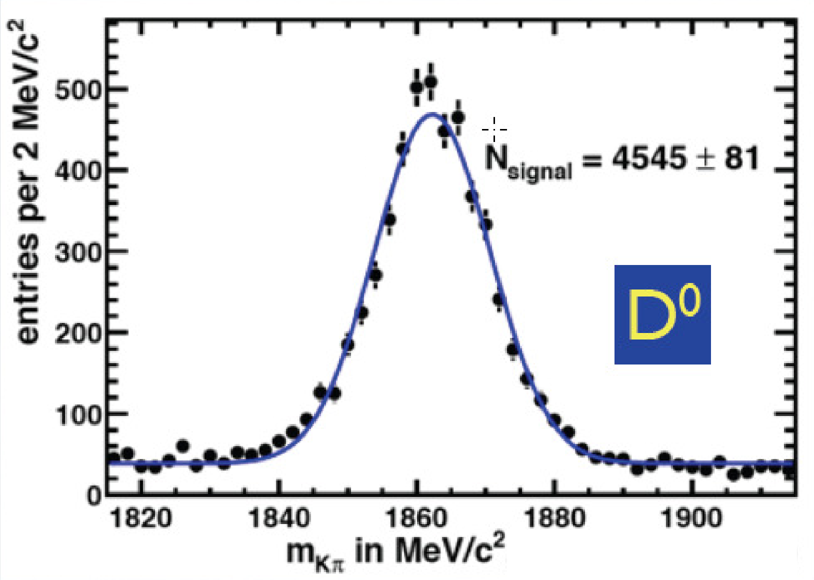


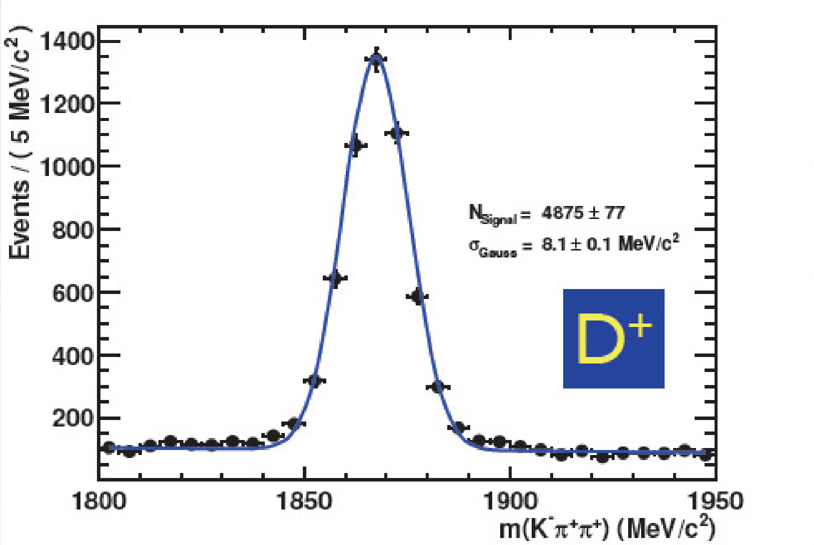
- **Good π/K/p separation is a unique feature compared to central detectors:**
  - Important for background suppression in B and D reconstruction and for **flavor tagging:** εD^2 ~ 6% (4%) for B_s (B^0)

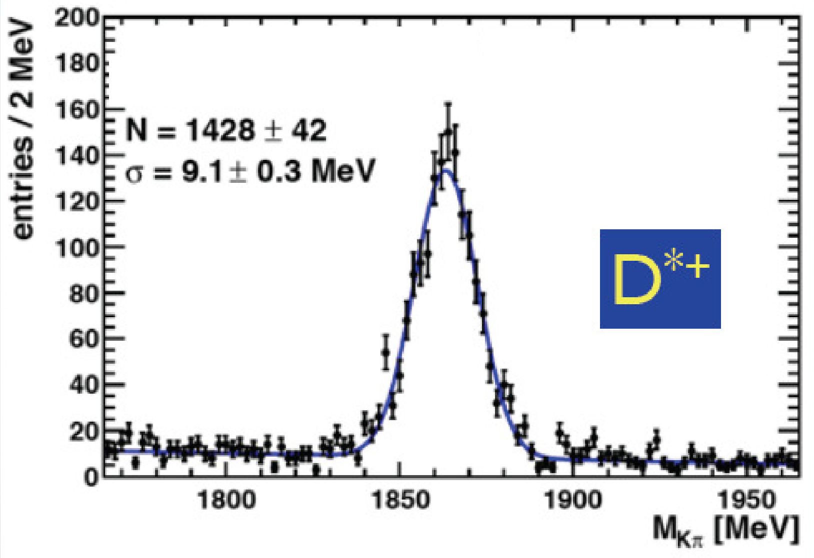
Early charm signals

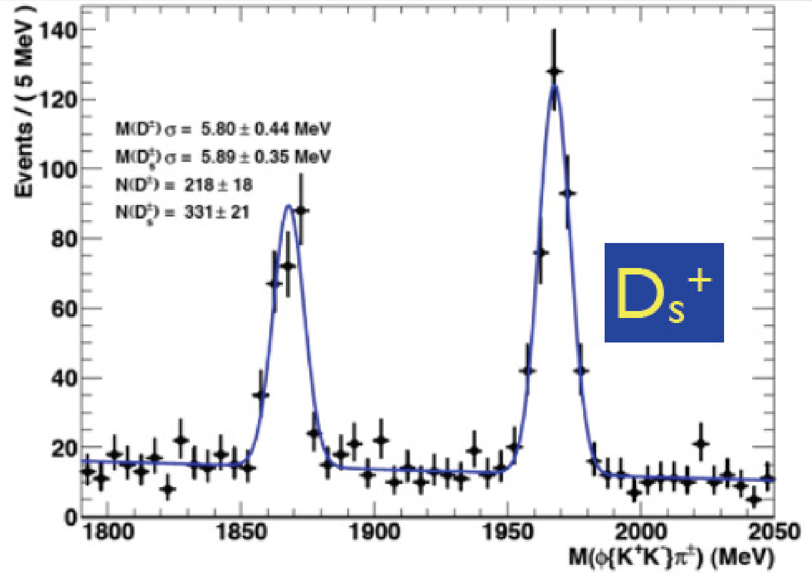
- Results with 1.8 nb^{-1} $\sqrt{s}$ =7TeV

Good mass resolution.
Clean signals (vertexing and RICHes).

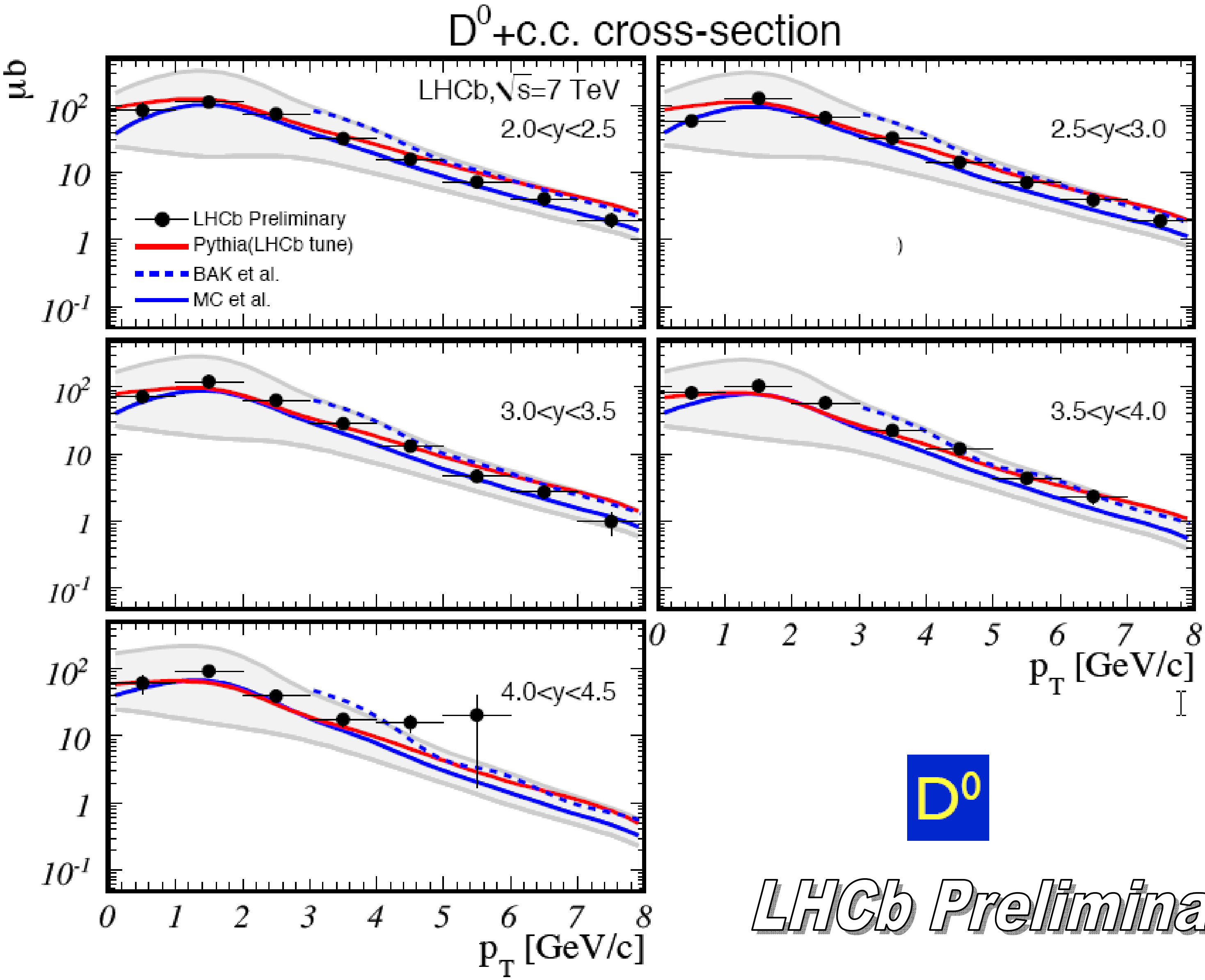








D^0 cross-section results



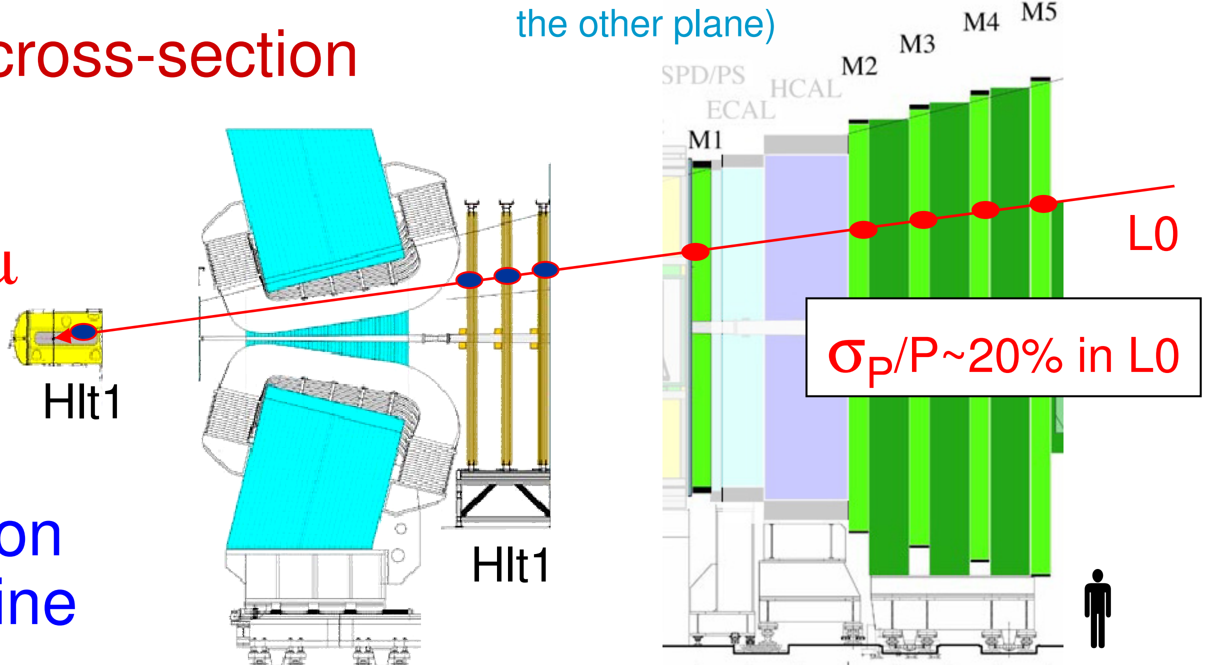
D^0

LHCb Preliminary

- Good agreement with the expectations (also for other charm mesons)

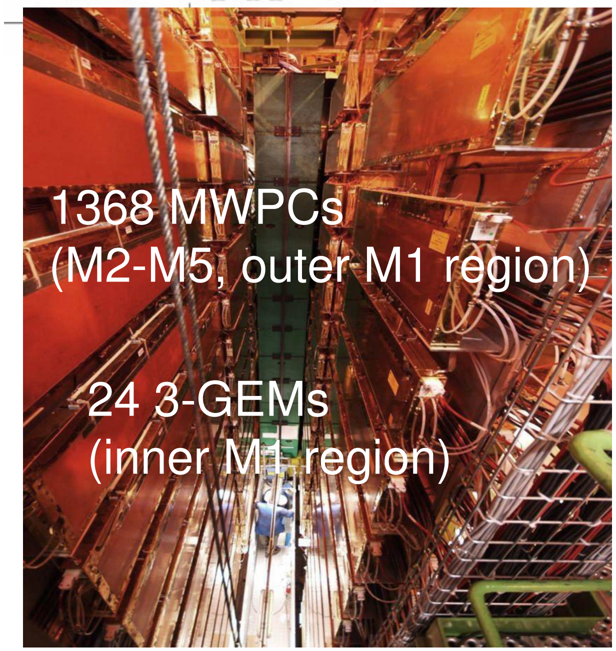
Early test of muon detector - beauty cross-section

- $b \rightarrow c\mu^{-}\nu$ ~10%
  - combine D with μ
- Muon detector:
  - Low reconstruction thresholds in offline and trigger:
    - $p>3$ GeV, $p_t>0.5$ GeV
  - Single- (and di-) muon triggers: p_{t1} $(+p_{t2}) > 1.3$ GeV
- Two data samples:
  - 2.9 nb^{-1} of minimum bias trigger (>=1 Track)
  - 12.2 nb^{-1} single muon trigger



(particles bending in the other plane)

σ_P/P~20% in L0



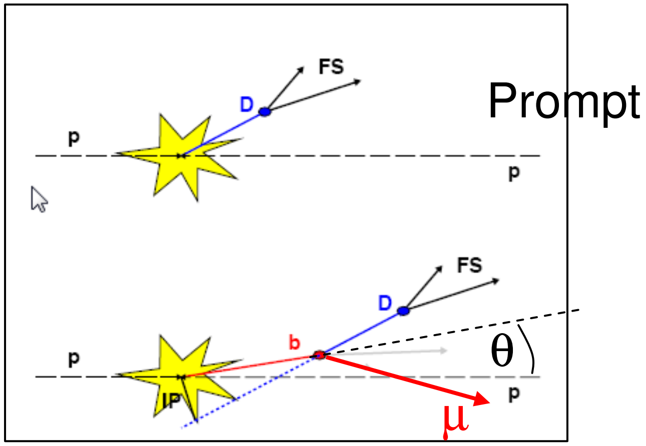
1368 MWPCs (M2-M5, outer M1 region)

24 3-GEMs (inner M1 region)

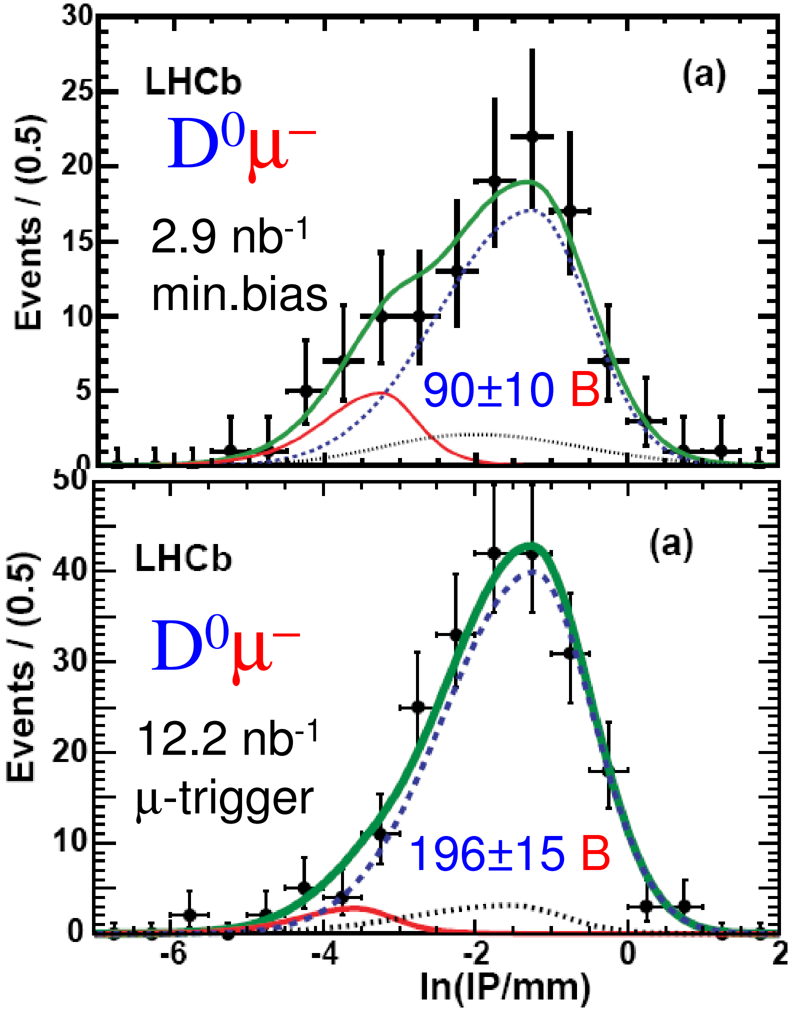
$B\rightarrow D^0\mu^-\nu X,\ D^0\rightarrow K^-\pi^+$

- $BR_{vis} \sim 8 \times 10^{-3}$
- Prompt D^0 is the dominant background!

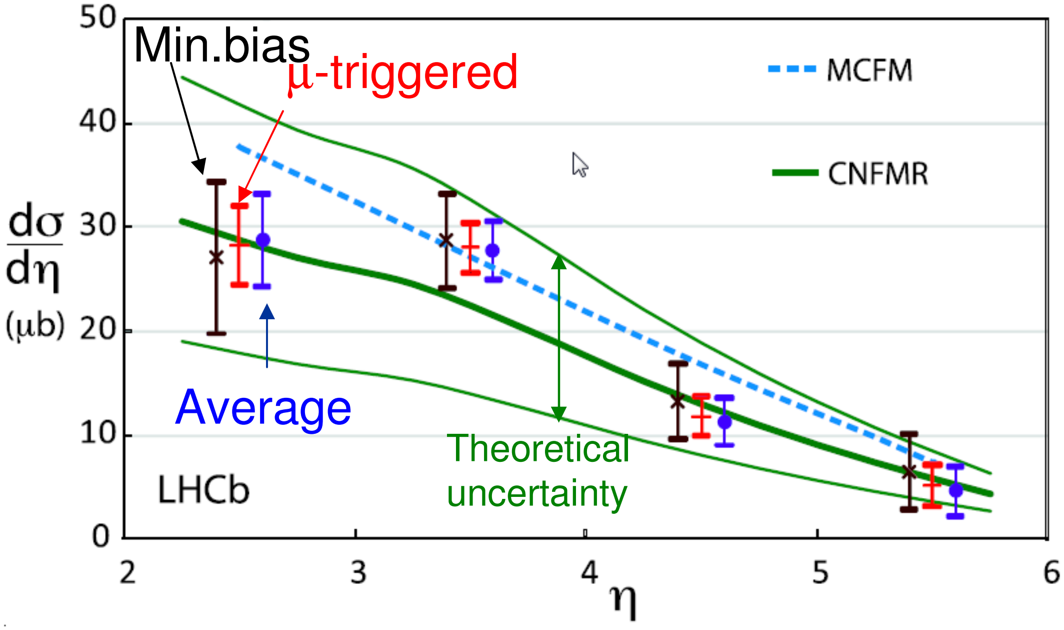
PLB694, 209 (2010).



$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

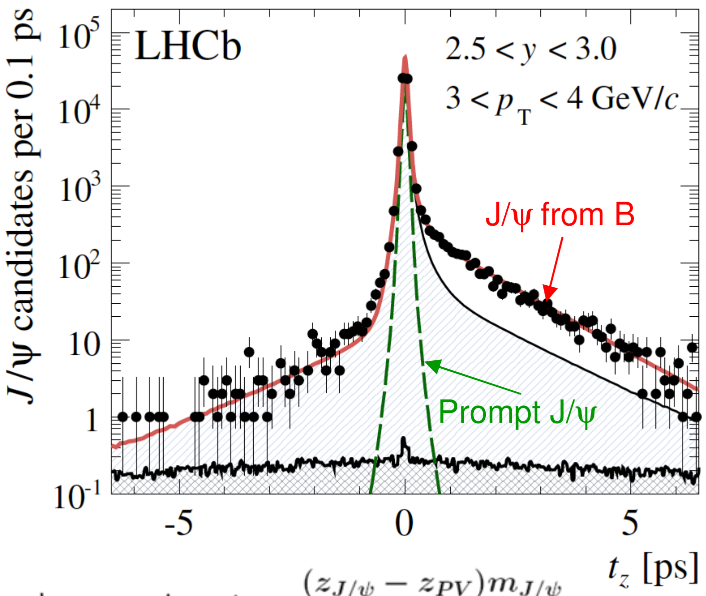


$\sigma_{4\pi}(pp\rightarrow b\overline{b}X)=284\pm20\pm49\ \mu b$

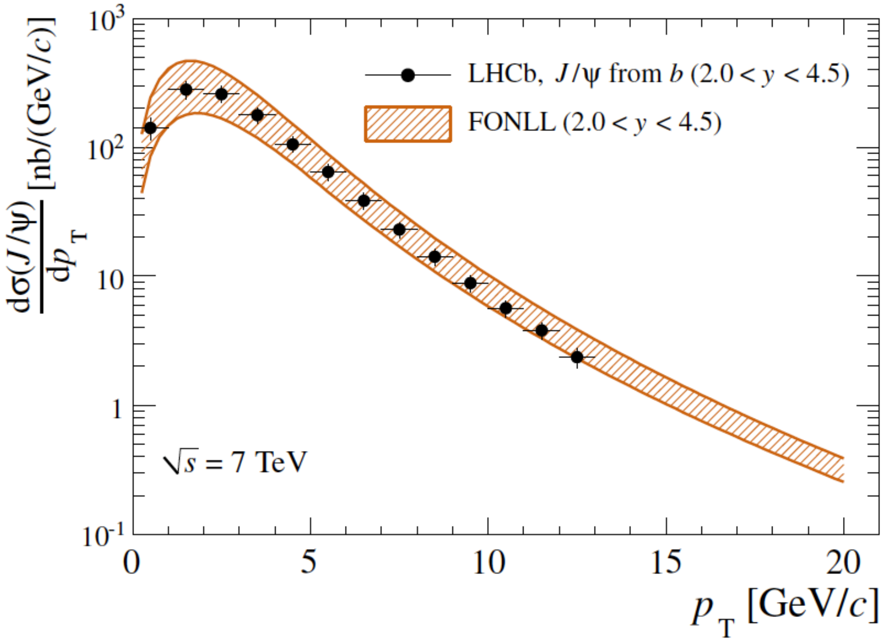


$B \to J/\psi X$, $J/\psi \to \mu^- \mu^+$

- $\mathrm{BR_{vis}} \sim 1.3 \times 10^{-3}$ 5.2 pb^{-1} *arXiv:1103.0423 submitted to EPJ C*



Pseudo proper time: $t_z = \dfrac{(z_{J/\psi} - z_{PV}) m_{J/\psi}}{p_z}$



$$\sigma_{4\pi}(pp \to b\bar{b}X) = 288 \pm 4 \pm 49\ \mu b$$

In good agreement with the previous method.

Close to the value we had used for estimates of LHCb sensitivity before data came:

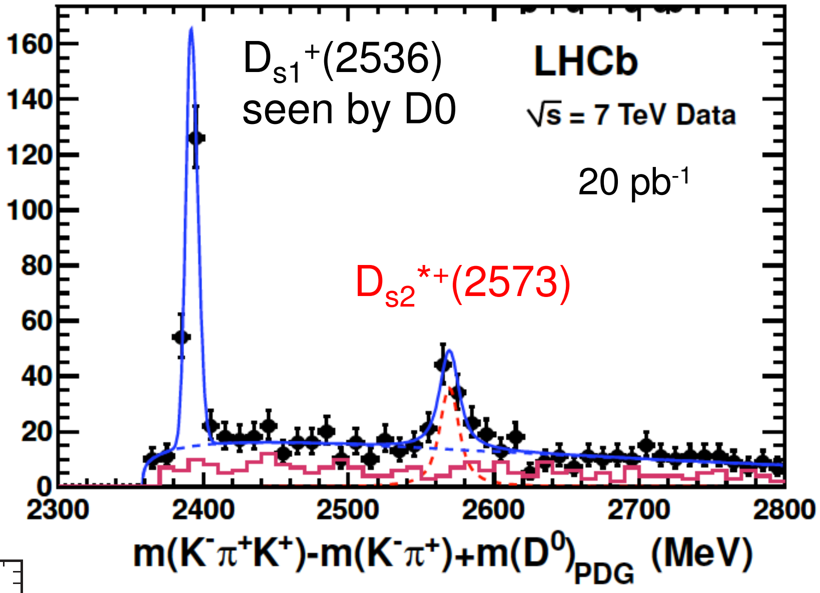
high b-cross section confirmed !

Other results with semileptonic decays

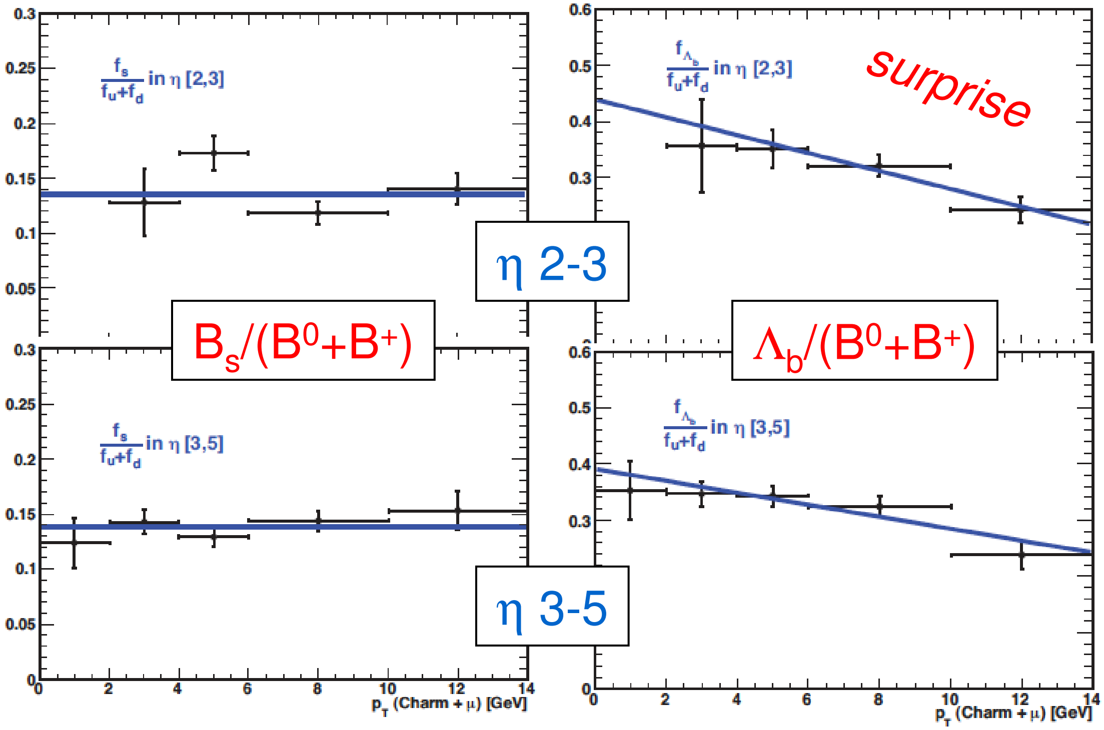
First Observation of $\overline{B}_s \to D_{s2}^{*+} X\mu^-\nu$ Decays

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_{s2}^{*+} X\mu^-\overline{\nu})}{\mathcal{B}(\overline{B}_s^0 \to X\mu^-\overline{\nu})} = (3.3 \pm 1.0 \pm 0.4)\%$$

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_{s1}^{+} X\mu^-\overline{\nu})}{\mathcal{B}(\overline{B}_s^0 \to X\mu^-\overline{\nu})} = (5.4 \pm 1.2 \pm 0.5)\%$$

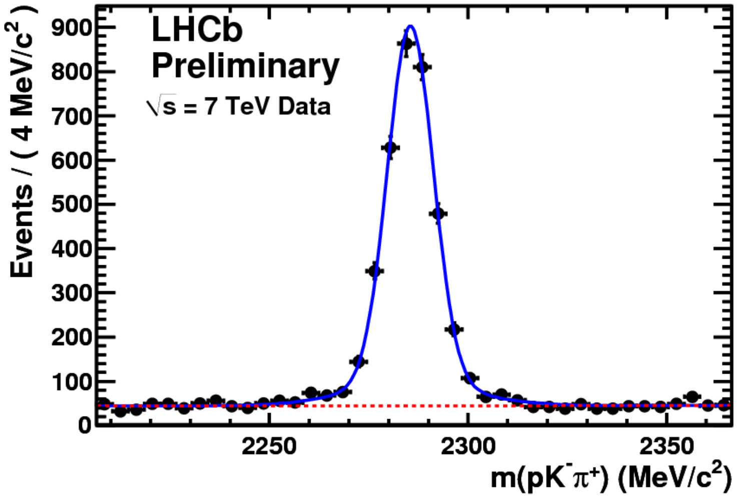


B_s and Λ_b production fractions:

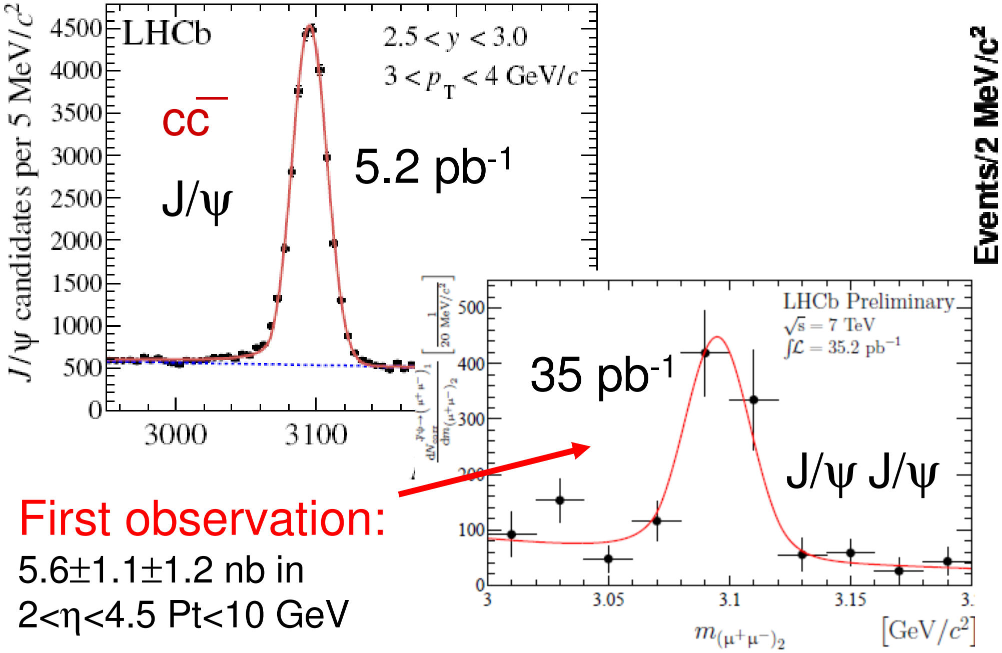


3 pb^{-1}

$\Lambda_b \to \Lambda_c \mu \nu X$



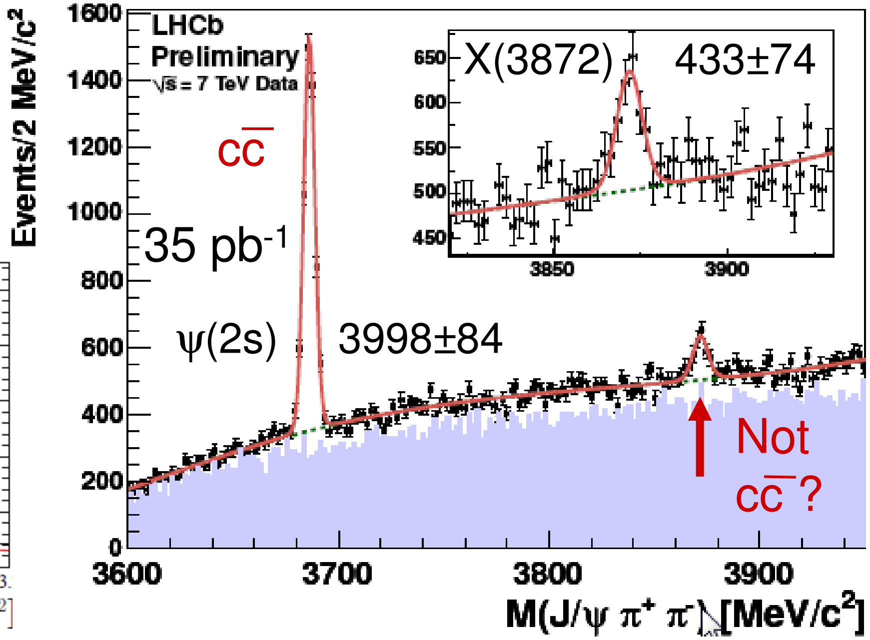
Quarkonia in LHCb (mostly prompt)

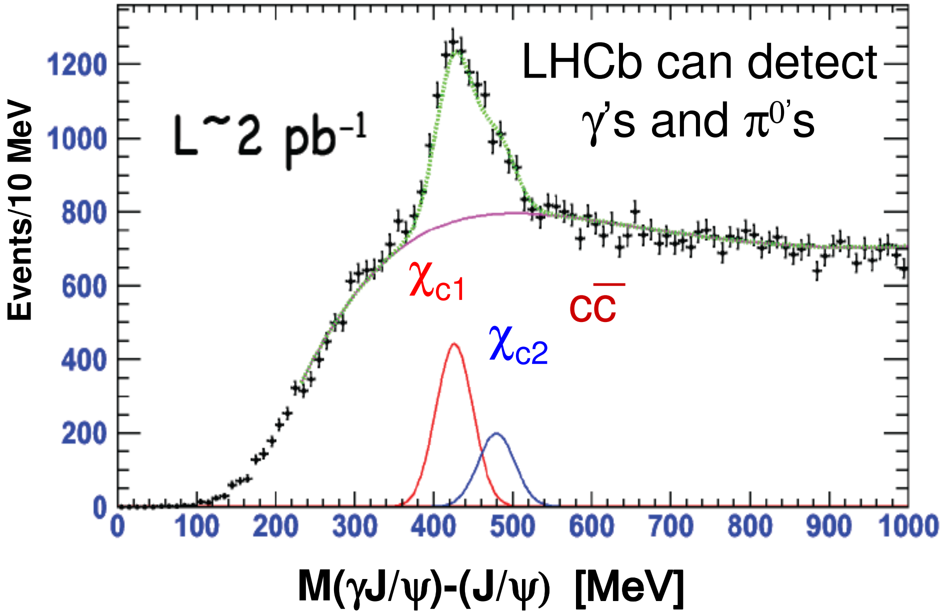


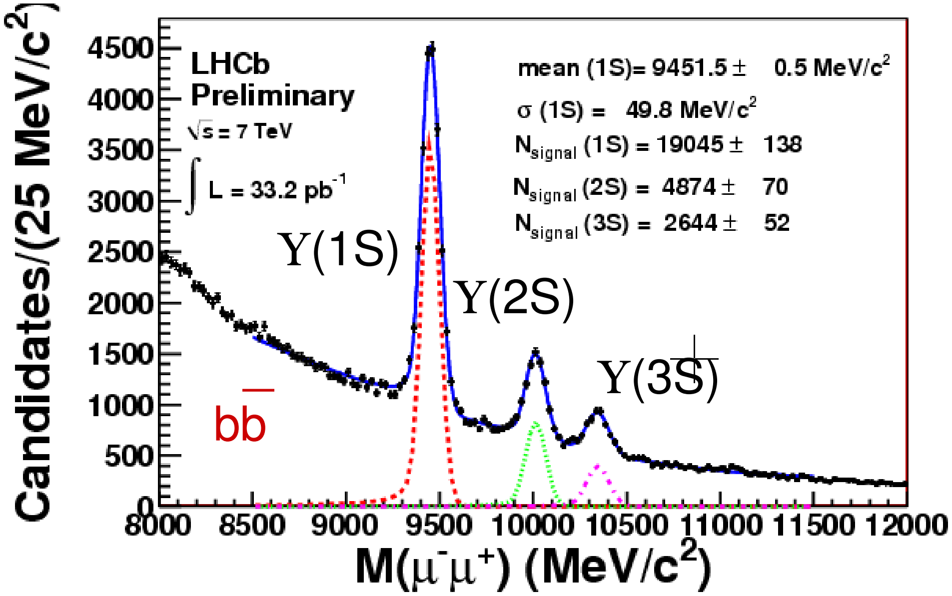
First observation:

5.6±1.1±1.2 nb in

2<η<4.5 Pt<10 GeV



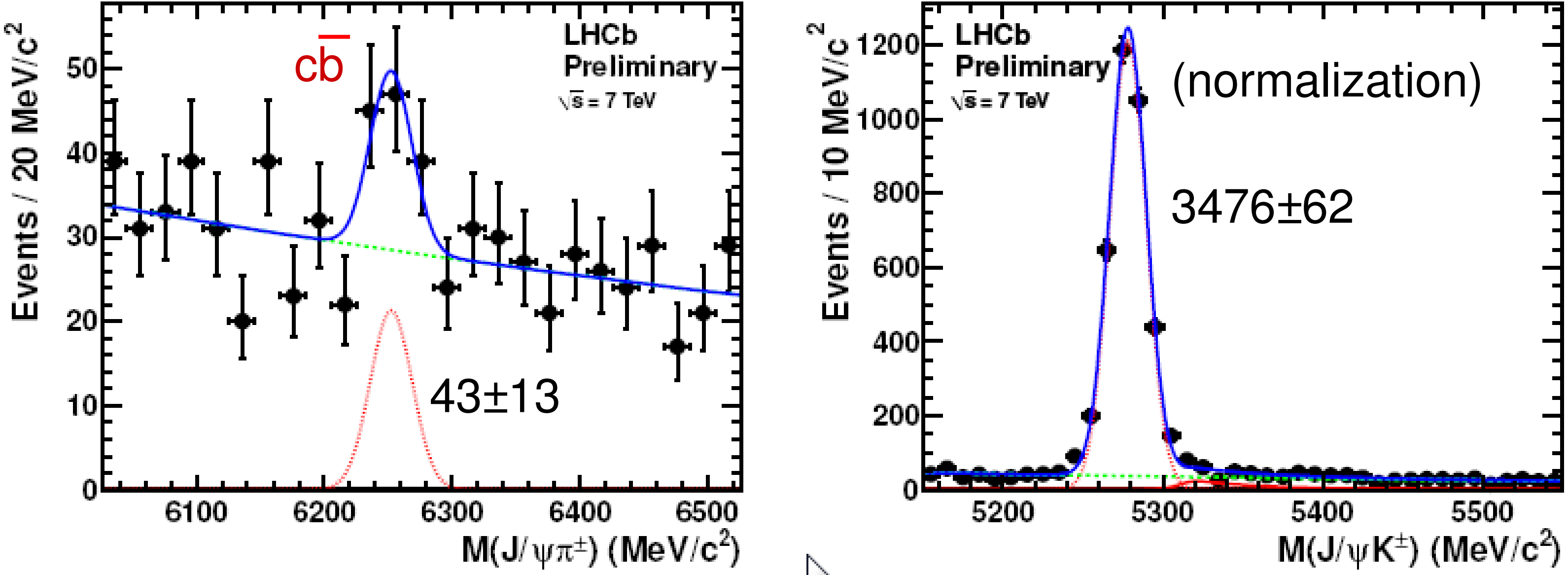




B_c

LHCb-CONF-2011-017

$B_c^+ \rightarrow J/\psi\pi^+$ $B^+ \rightarrow J/\psi K^+$



32.5 pb-1

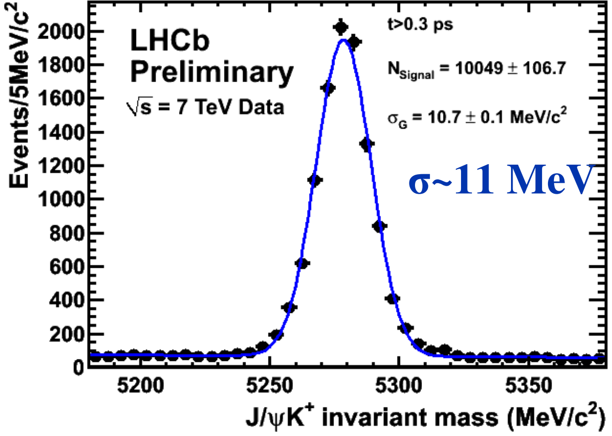
$$R_{c+} = \frac{\sigma(B_c^+) \times \mathcal{B}(B_c^+ \rightarrow J/\psi\pi^+)}{\sigma(B^+) \times \mathcal{B}(B^+ \rightarrow J/\psi K^+)} = (2.2 \pm 0.8 \pm 0.2)\%,$$

- With more data we will measure mass, lifetime, study production mechanism, detect more modes, try to find excitations

Exclusive B → J/ψ h modes

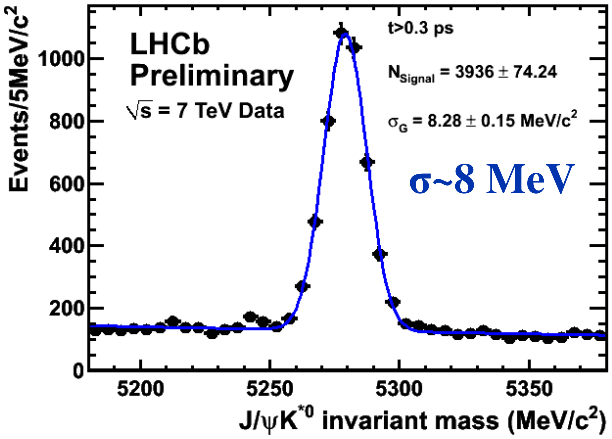
Detection of different B species: for B → J/ψ h 34 pb^{-1}

$B_u^+ \rightarrow J/\psi\ K^+$



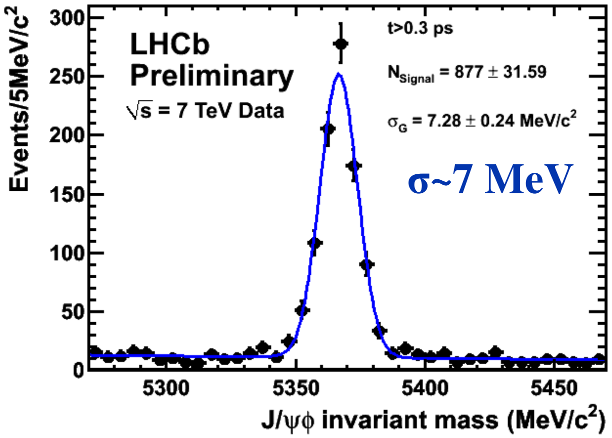
σ~11 MeV

$B_d^0 \rightarrow J/\psi\ K^*$



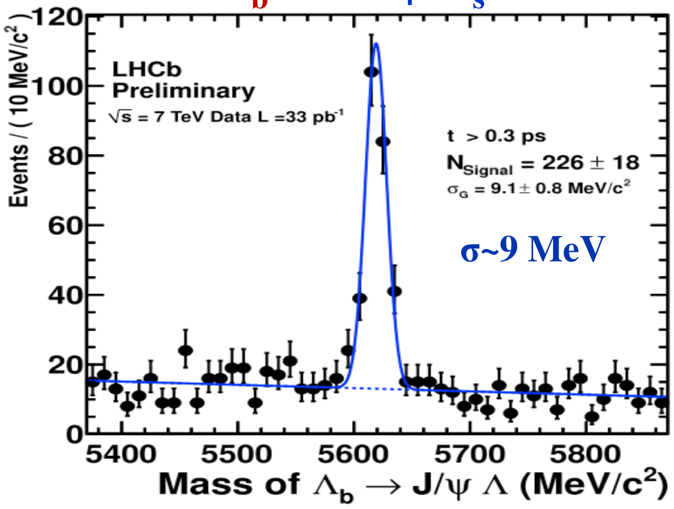
σ~8 MeV

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



σ~7 MeV

$\Lambda_b^0 \rightarrow J/\psi\ \Lambda_s$



σ~9 MeV

Comparison GPDs:

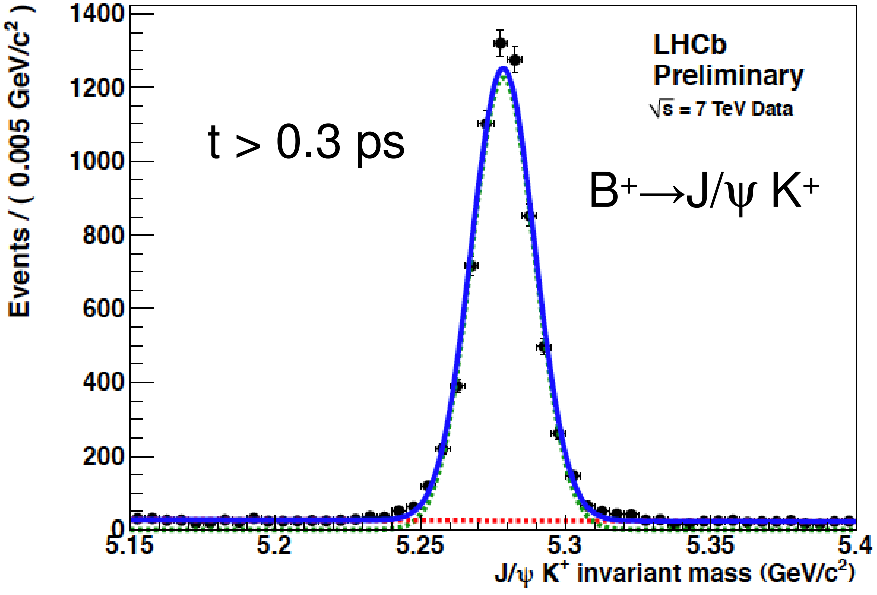
- CMS: σ~16 MeV
- ATLAS: σ~26 MeV

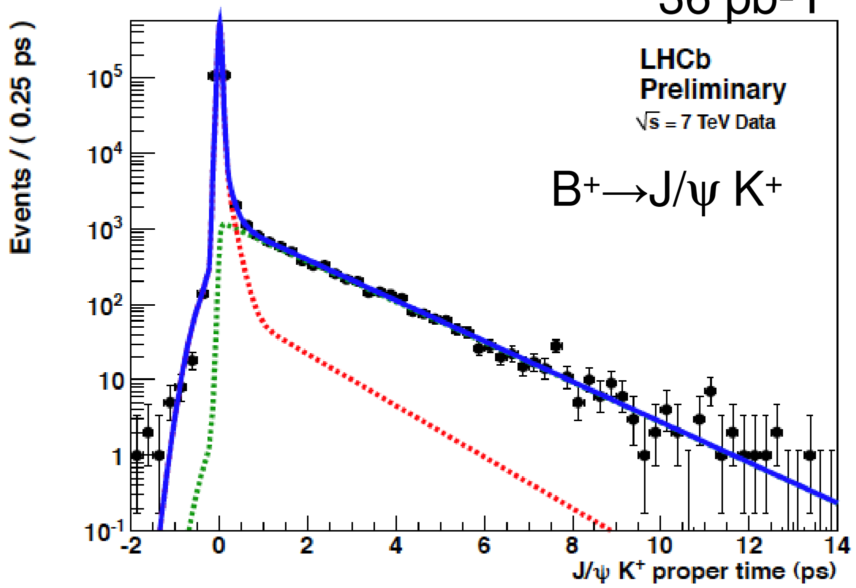
- very good mass resolution
- very low background
  (comparable to e^+e^- machines)

Lifetime measurements with B→ J/ψ h

Proper time resolution ~50 fs

36 pb-1





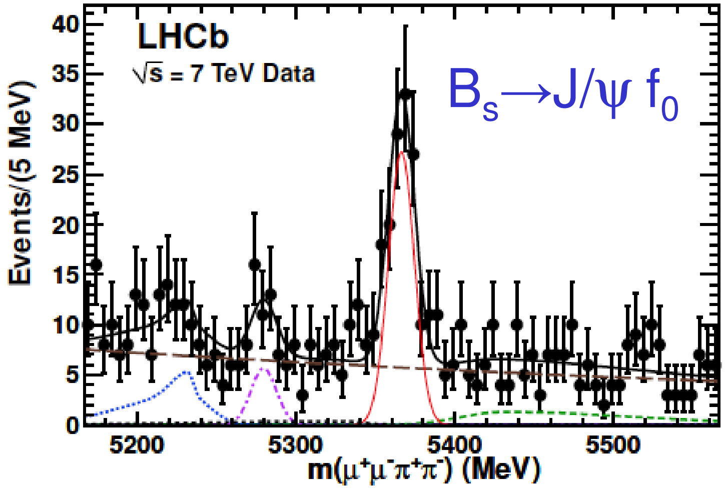
LHCb-CONF-2011-001

Channel	LHCb yield	LHCb “lifetime”(*) stat. and sys. (ps)	PDG (ps)
$B^+ \rightarrow J/\psi K^+$	6 741 ± 85	1.689 ± 0.022 ± 0.047	1.638 ± 0.011
$B^0 \rightarrow J/\psi K^{*0}$	2 668 ± 58	1.512 ± 0.032 ± 0.042	1.525 ± 0.009
$B^0 \rightarrow J/\psi K^0_S$	838 ± 31	1.558 ± 0.056 ± 0.022	1.525 ± 0.009
$B^0_s \rightarrow J/\psi \phi$	570 ± 24	1.447 ± 0.064 ± 0.056	1.477 ± 0.046
$\Lambda_b \rightarrow J/\psi \Lambda$	187 ± 16	1.353 ± 0.108 ± 0.035	$1.391^{+0.038}_{-0.037}$

Good agreement with PDG.

First observation of $B_s \rightarrow J/\psi\ f_0$

$m(J/\psi\ \pi^+\pi^-)$ within 90 MeV of 980 MeV



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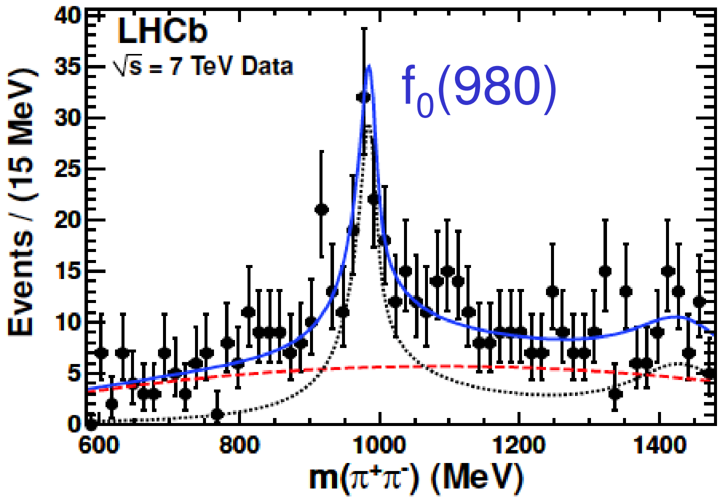
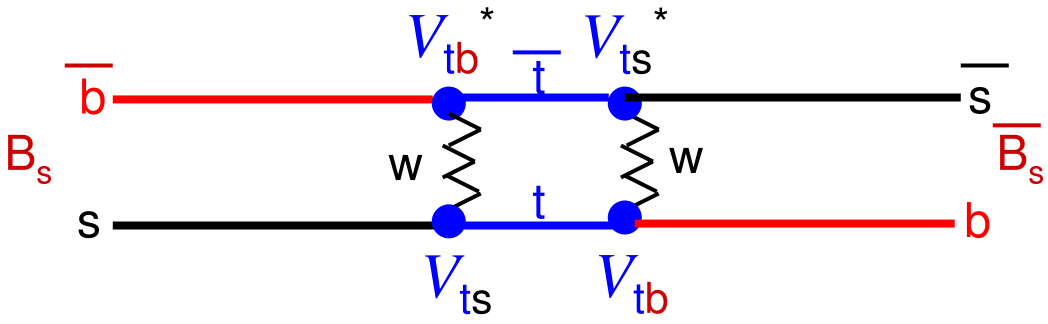
$m(\pi^+\pi^-)$ within 30 MeV of B_s mass



Confirmed by Belle & CDF

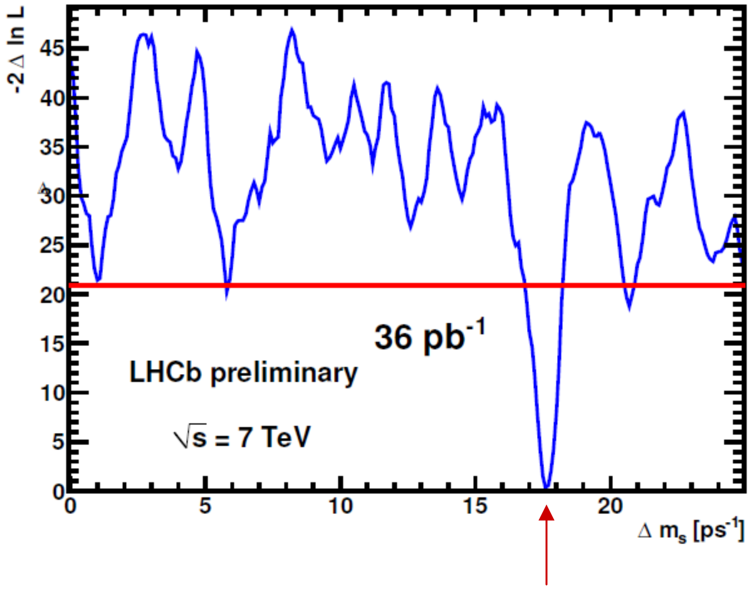
- CP-eigenstate - complementary mode for β_s measurement to $B_s \rightarrow J/\psi\ \phi$

Bs-$\overline{\text{Bs}}$ mixing



- First measured by CDF in 2006
- LHCb:

Measure Δm_s with $B_s \to D_s(KK\pi)(3)\pi$



LHCb-CONF-2011-005

$$\Delta m_s = 17.63 \pm 0.11\ (\text{stat.}) \pm 0.04\ (\text{syst.})\ \text{ps}^{-1}$$

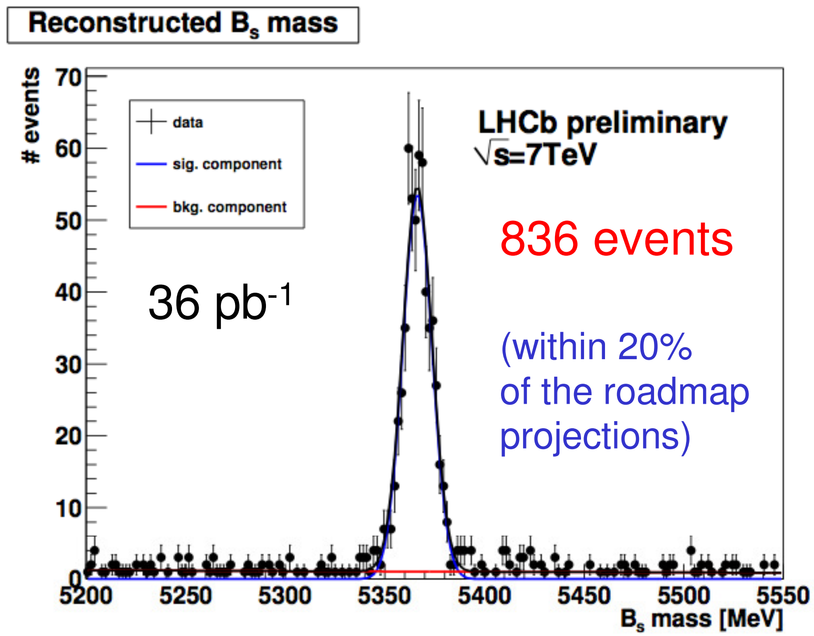
World best !

$\Delta m = M_L - M_S$

frequency of oscillations sensitive to $|V_{ts}|$

Phase of Bs-$\overline{\text{Bs}}$ mixing

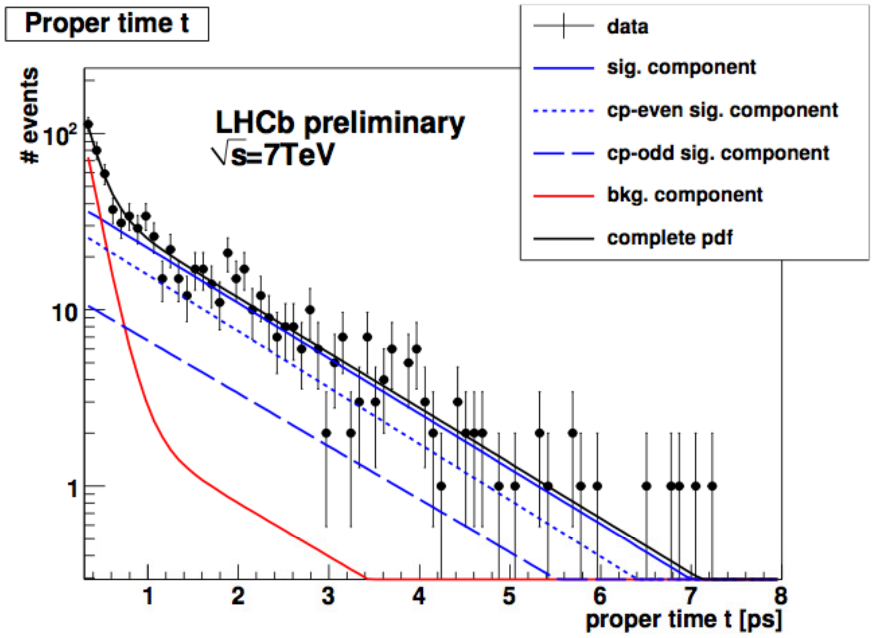
$B_s \to J/\psi\ \phi$: not an eigenstate; need angular analysis

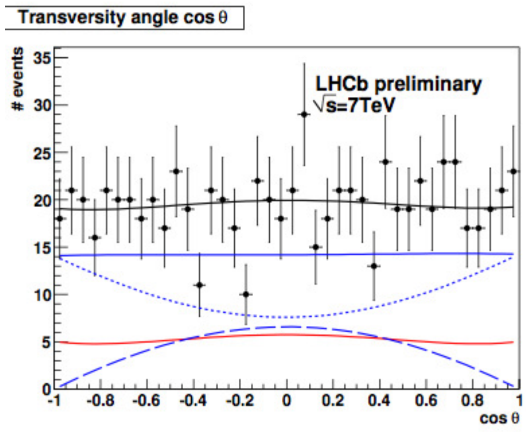


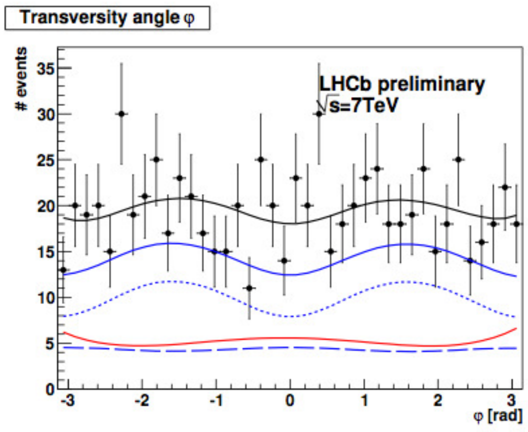
36 pb^{-1}

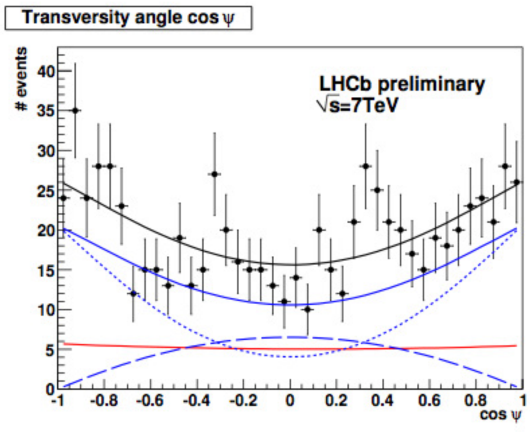
836 events

(within 20% of the roadmap projections)



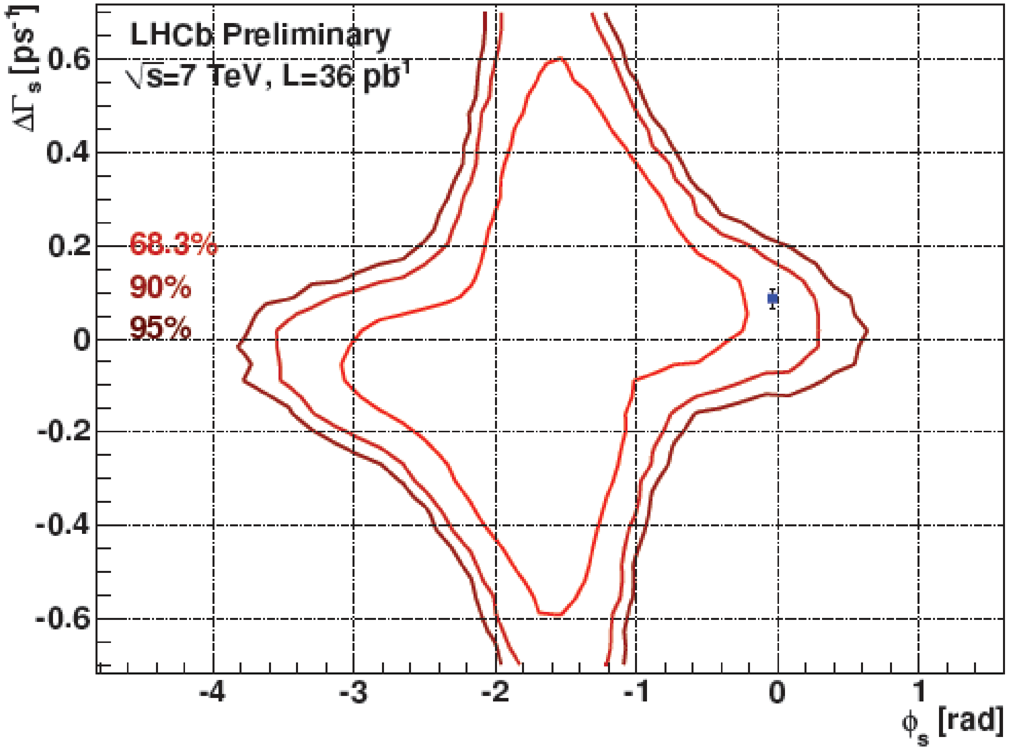






Phase of Bs-$\overline{\mathrm{Bs}}$ mixing

- Confidence Level scan
- 1.2 σ from SM
- Using opposite side flavor tagging only

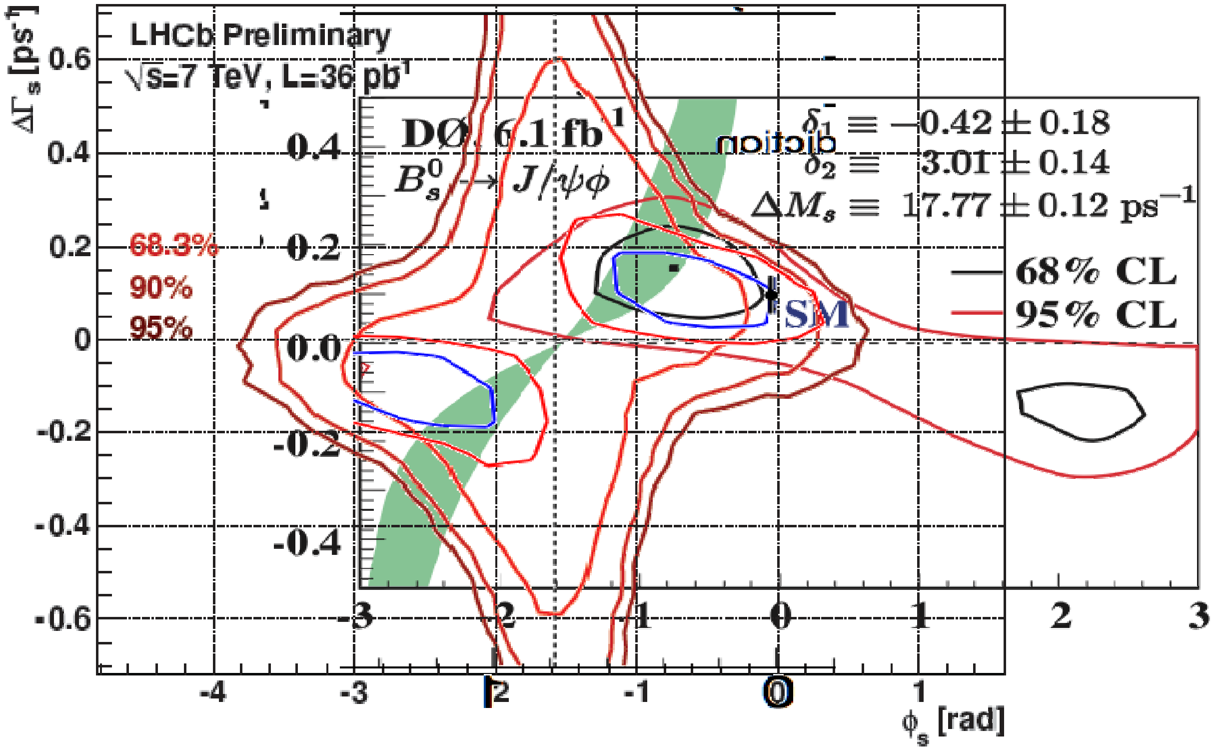


	LHCb Roadmap (36 pb^{-1})	LHCb (36 pb^{-1})	CDF (5200 pb^{-1})
# J/ψ ϕ	*1050*	836	6500
$\sigma(\tau)$ (fs)	*38*	50	100
OS tag power	*6.2%*	(2.2±0.8)%	(1.2±0.2)%
SS tag power		*working on*	(3.5±1.4)%

Phase of Bs-$\overline{\text{Bs}}$ mixing

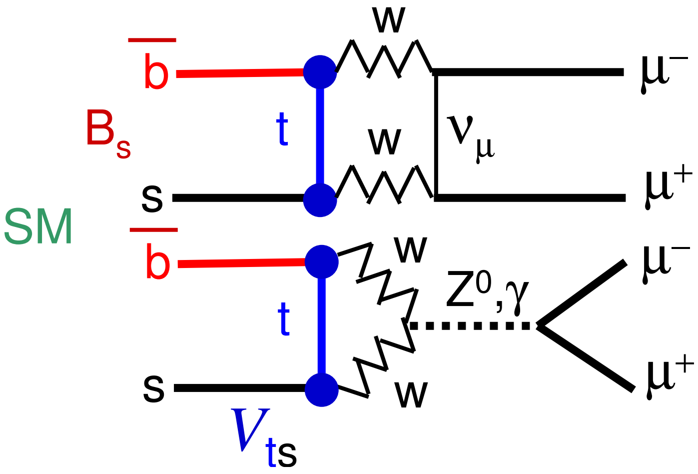
CDF 5.2 fb^{-1}

LHCb
36 pb^{-1}
OS tags
obly



- LHCb results not yet competitive without SS tagging
- More data are being logged!

BR($B_S \to \mu^+\mu^-$)

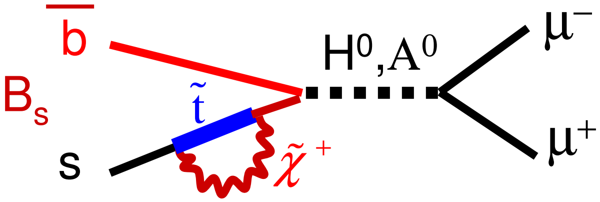


$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.35 \pm 0.32)\times 10^{-9}$

Small with small theoretical error!

NP

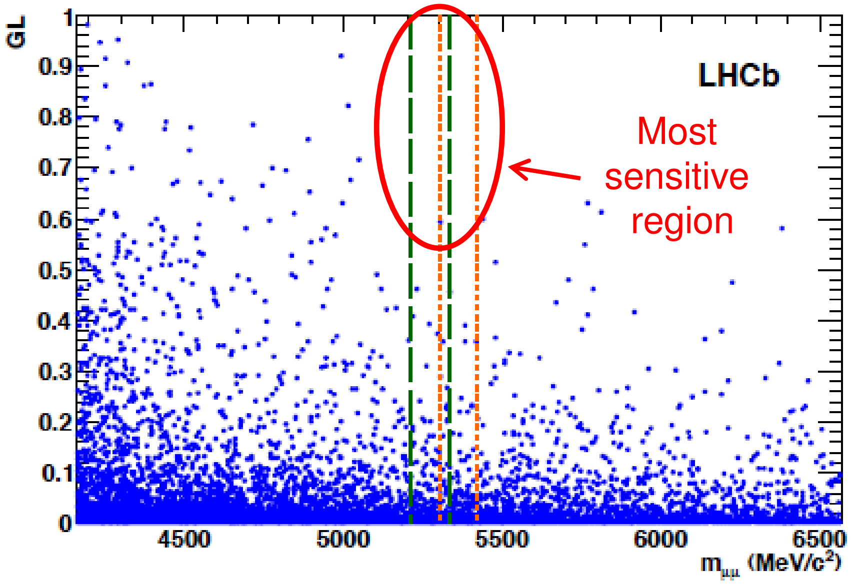
e.g. SUSY



~ $\tan^6\beta$

Could be strongly enhanced.

In some models negative interference with the SM.



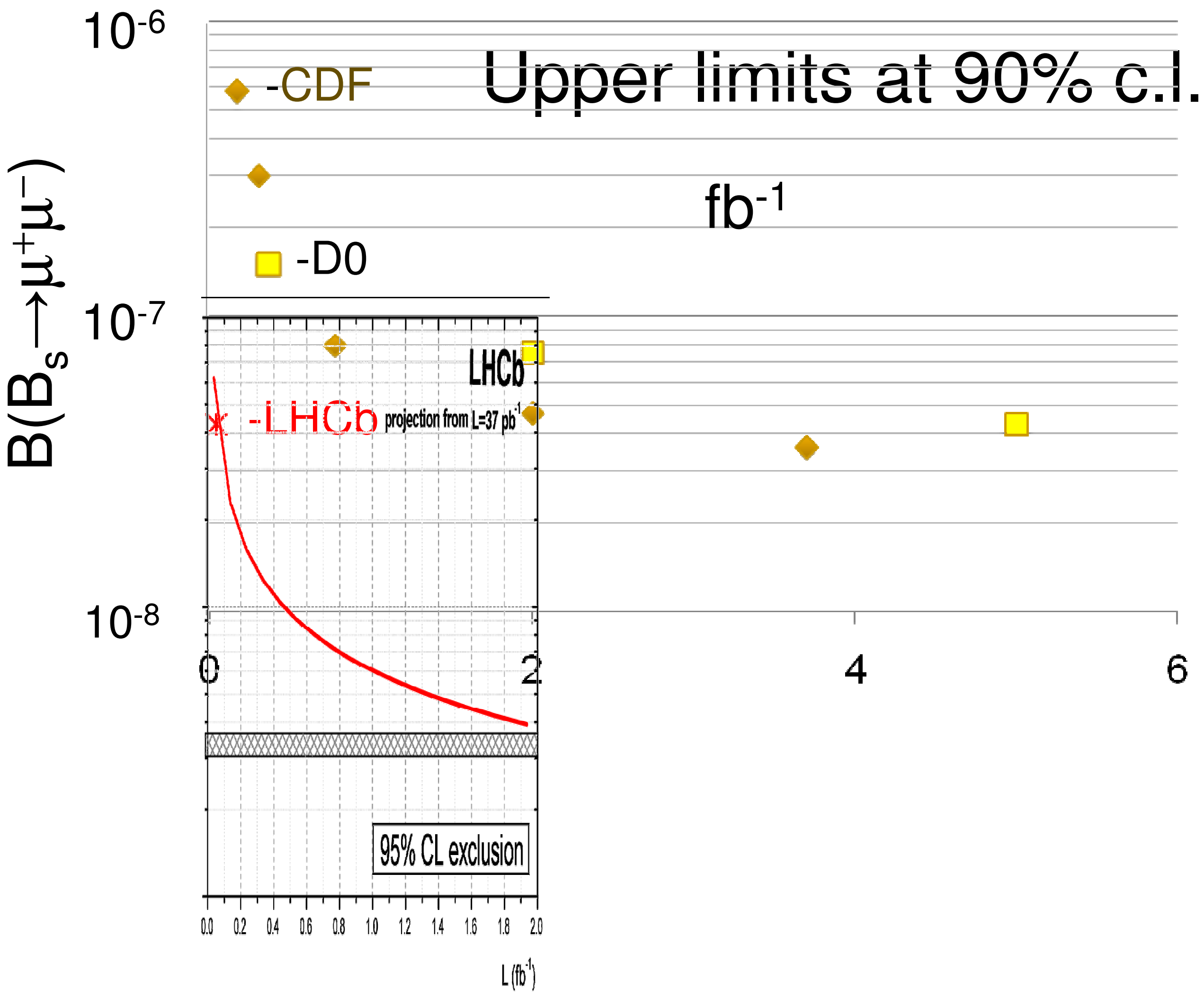
arXiv:1103.2465, accepted by PLB

BR($B_s \to \mu\mu$) < 5.6 x 10^{-8} at 95% CL

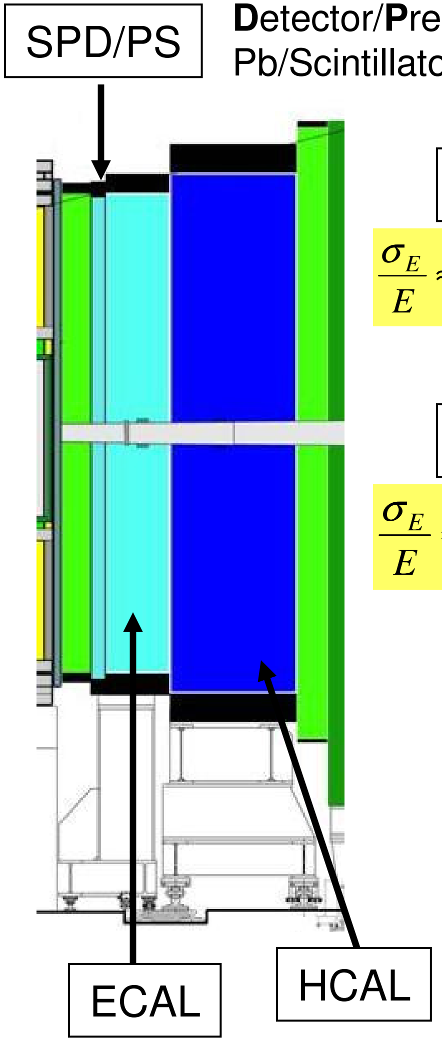
37 pb^{-1}

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

LHCb 1 year old, 37 pb^{-1}



Beyond muons: L0 calo triggers



Scintillating **P**ad
Detector/**P**re**S**hower
Pb/Scintillator, 2.5 X_0

ECAL

$$\frac{\sigma_E}{E} \approx \frac{9.5\%}{\sqrt{E}} \oplus 0.8\%$$

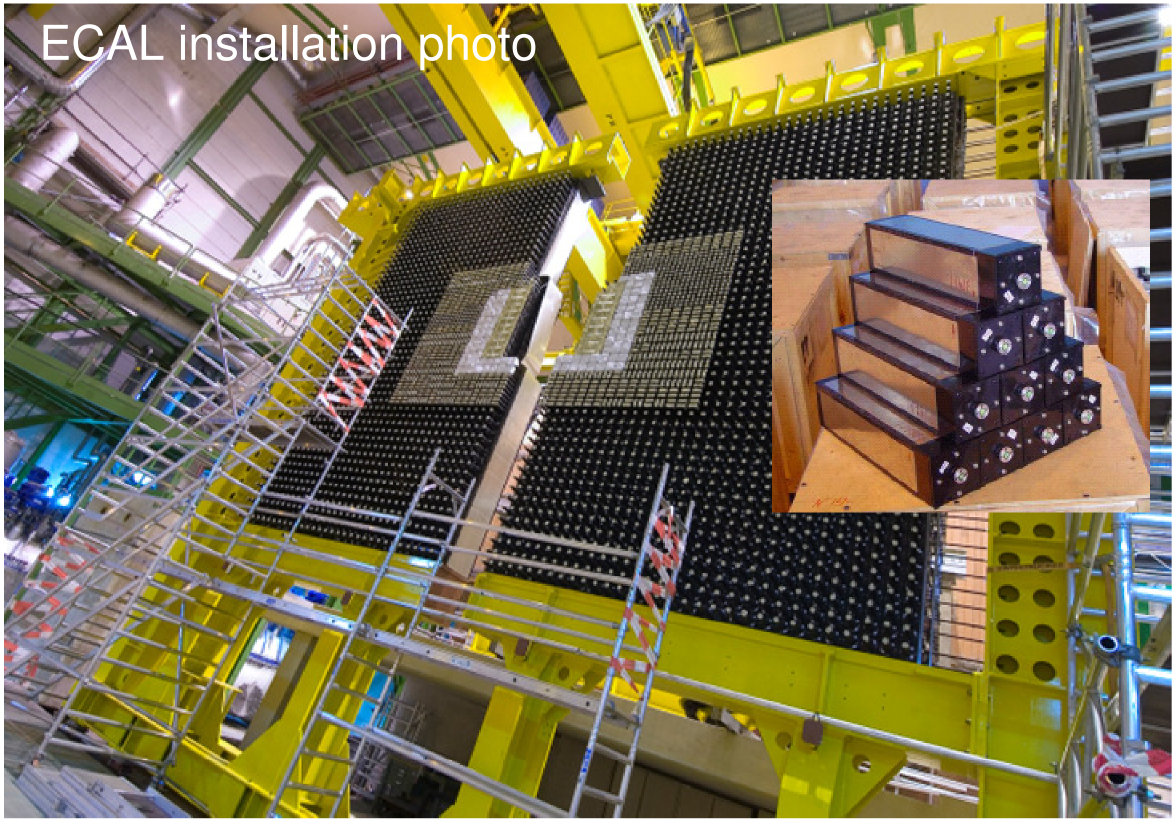
HCAL

$$\frac{\sigma_E}{E} \approx \frac{70\%}{\sqrt{E}} \oplus 10\%$$

ECAL
Pb-Scintillator
Shashlik, 25 X_0

HCAL
Fe/Scintillator
tiles, 5.6 λ_0

PMT readout

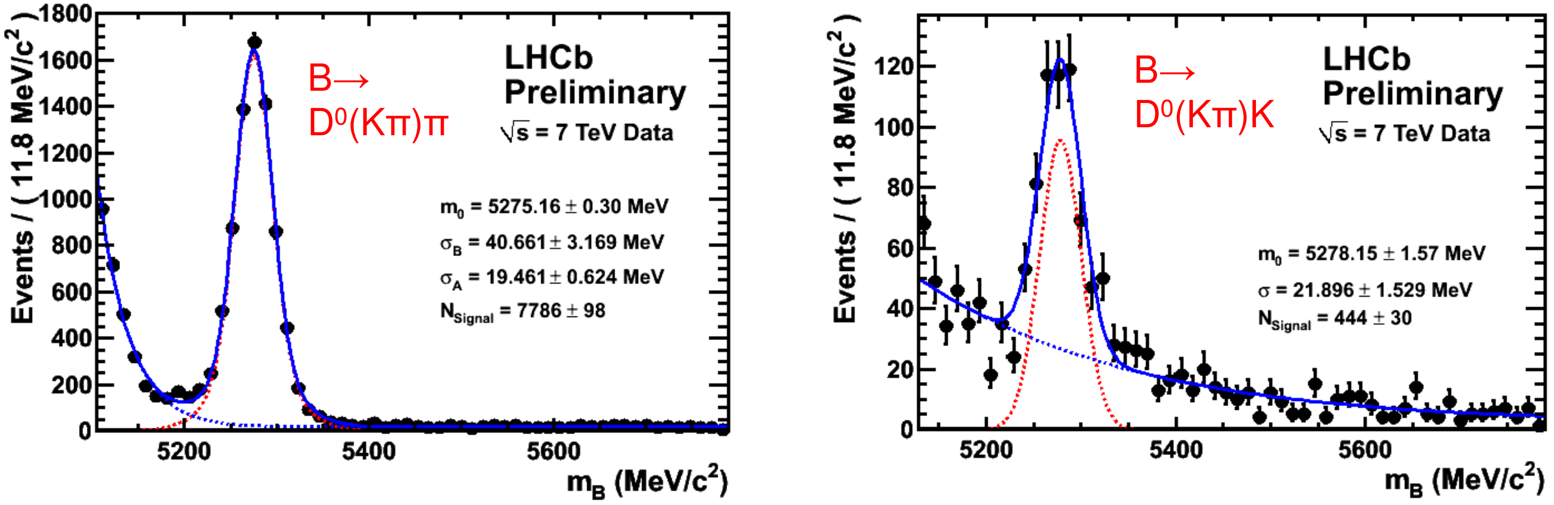


- HCAL: hadron L0 trigger (Et>~3.6 GeV)
- ECAL: e,γ L0 trigger (Et>~2.7 GeV)

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

Prospects for γ determination at LHCb

Very clean signals have emerged in B→Dπ and B→DK at ~ expected rate

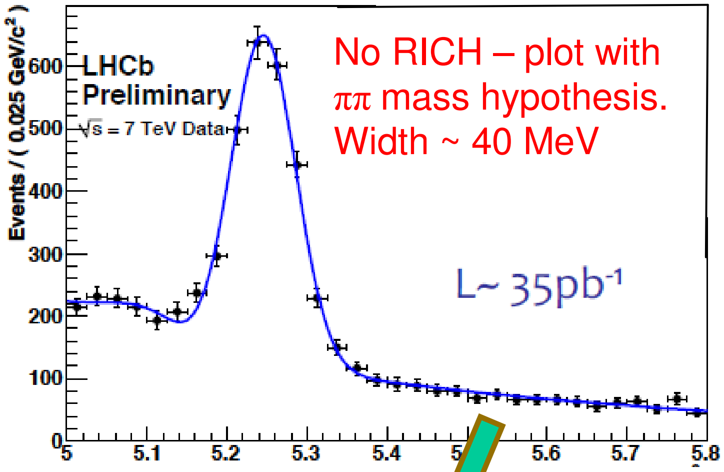


Sample with ~37 pb^{-1} around ¼ size of B-factory yields. Opportunity for precise determination of CKM angle γ in 2011-12. High efficiency, inclusive trigger, in place.

RICH in action: charmless B-decays

Two-body charmless B-decays central to LHCb physics. Significant contribution of Penguin diagrams provide entry points for new physics.

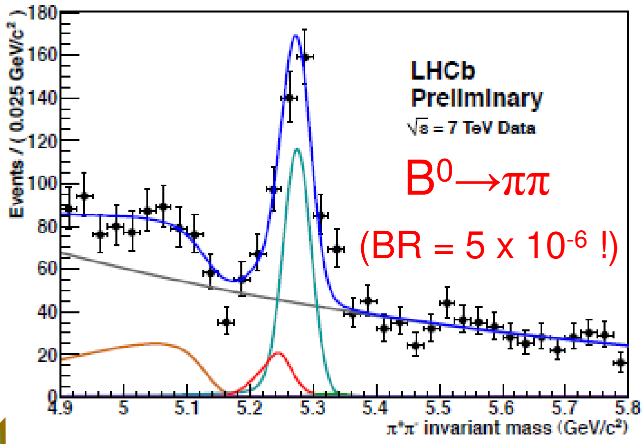
Experimentally, rely on good performance of hadron trigger and RICH system



No RICH – plot with ππ mass hypothesis. Width ~ 40 MeV

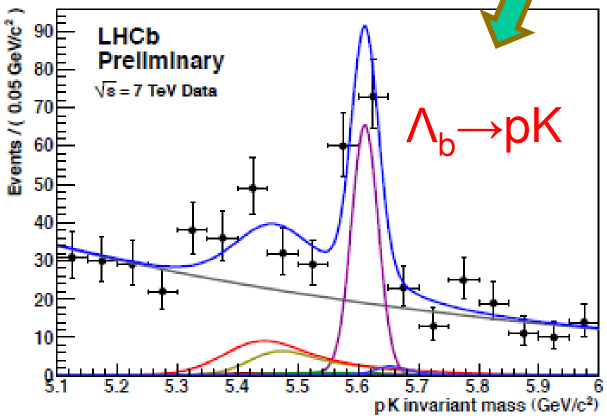
$L \sim 35 pb^{-1}$

Deploy RICH to isolate each mode

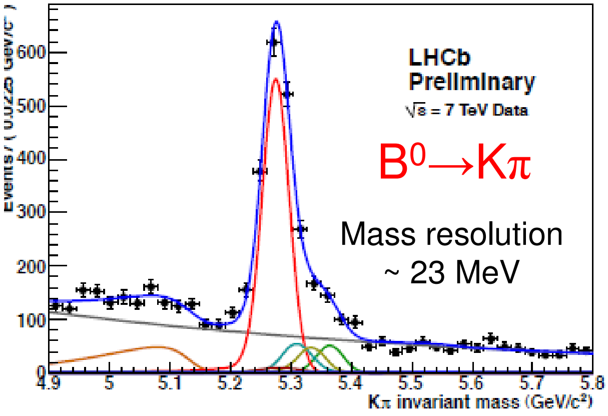


$B^0 \rightarrow \pi\pi$

(BR = 5 x 10^{-6} !)

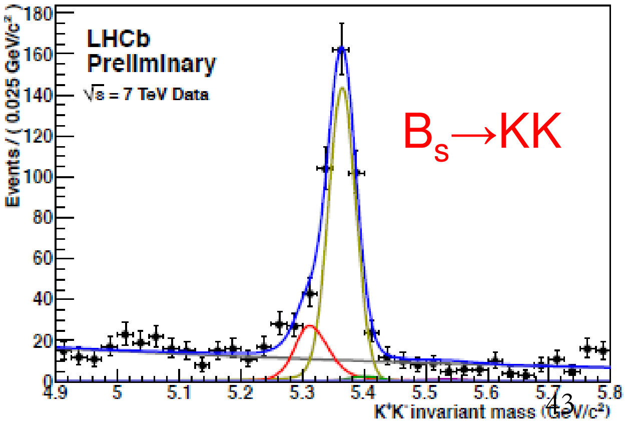


$\Lambda_b \rightarrow pK$



$B^0 \rightarrow K\pi$

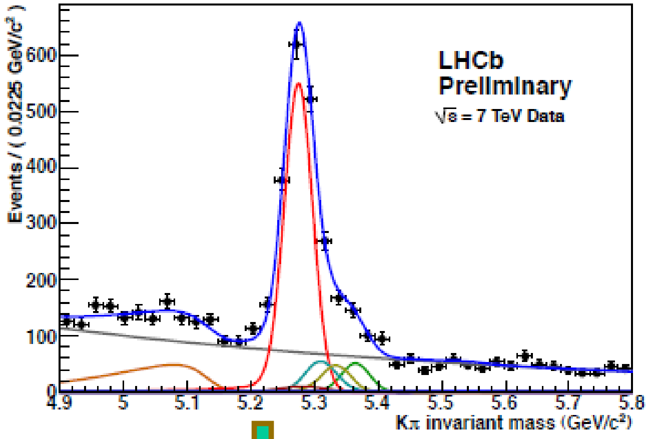
Mass resolution ~ 23 MeV



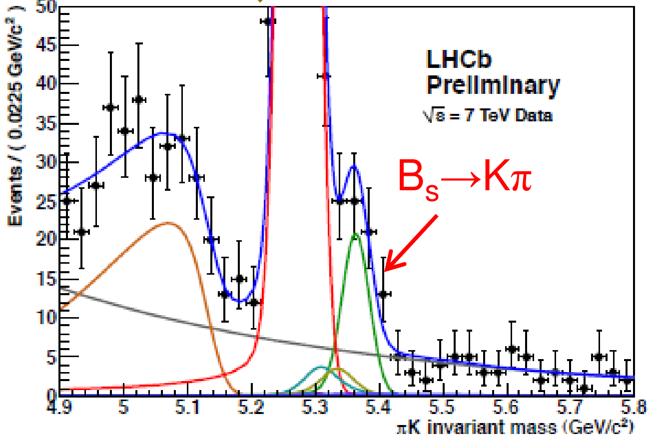
$B_s \rightarrow KK$

A closer look at B→Kπ

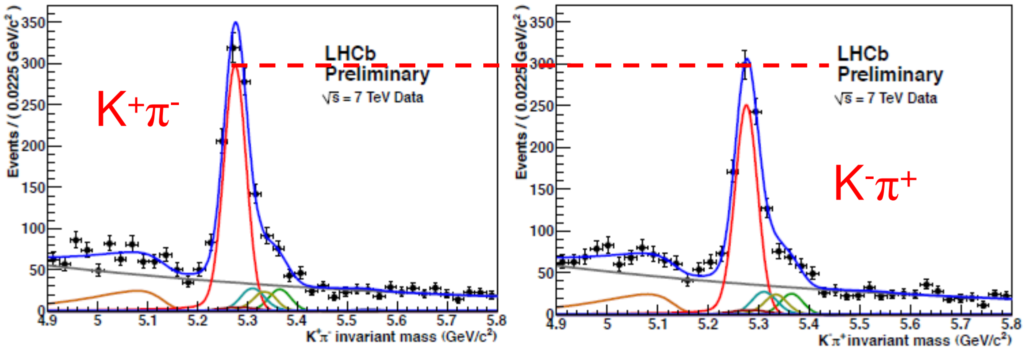
LHCb-CONF-2011-011



Tighter selection



Divide into B^0 and B^0-bar



CP-violation observed at >2σ with central value consistent with world-average:

$$A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033 \pm 0.008$$

(uncertainty presently 3x world average),
and a corresponding result for B_s→Kπ:

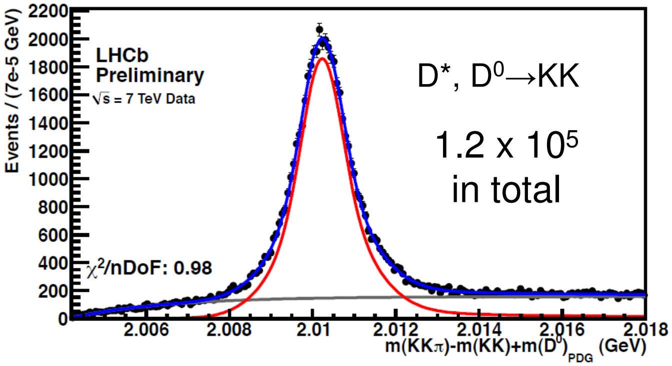
$$A_{CP}(B_s^0 \to \pi^+K^-) = 0.15 \pm 0.19 \pm 0.02$$

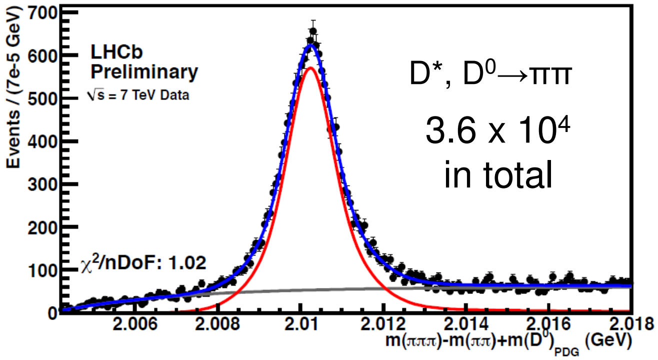
Precision very similar to CDF 1 fb^{-1} result !

Charm physics

LHCb 2010 yields in low multiplicity D decays already comparable to B-factories !
Less so for modes such as $D^0 \to K_S hh$, but trigger improvements in place for 2011.

Preliminary result for ΔA_{CP} ,difference in time integrated CP asymmetry in $D^0 \to KK$ and ππ samples – sensitive primarily to direct CP violation





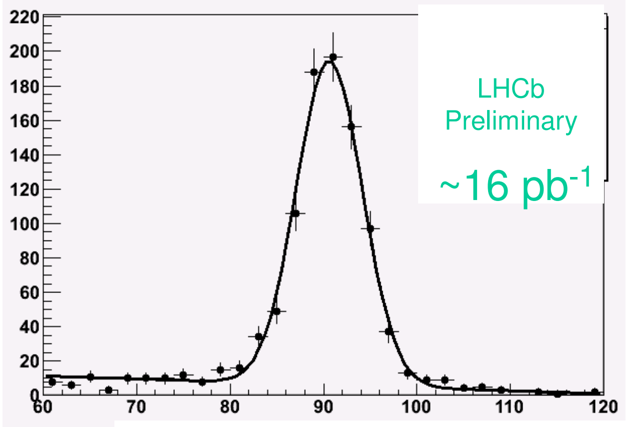
$$\Delta A_{CP} = (-0.28 \pm 0.70 \pm 0.25)\%$$

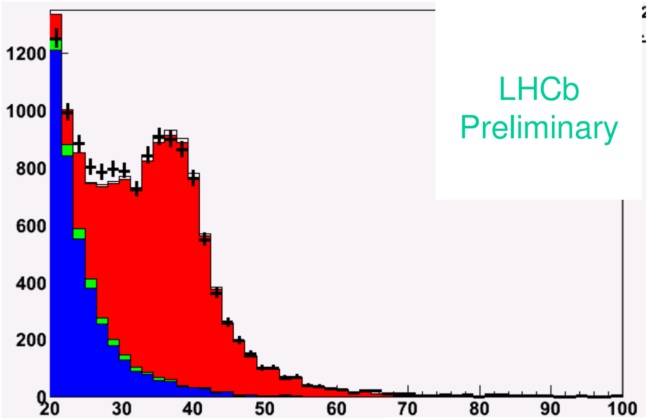
Systematic uncertainty largely statistical in nature. No limiting effect identified !

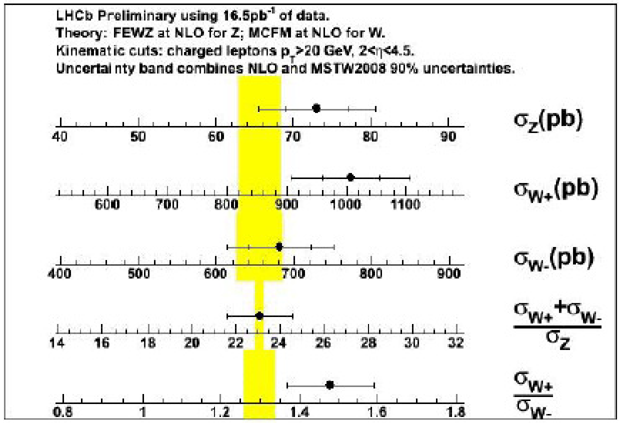
Coming *soon*, with 2010 data:
- y_{CP} and A_Γ
- CPV search in D→KKπ Dalitz space

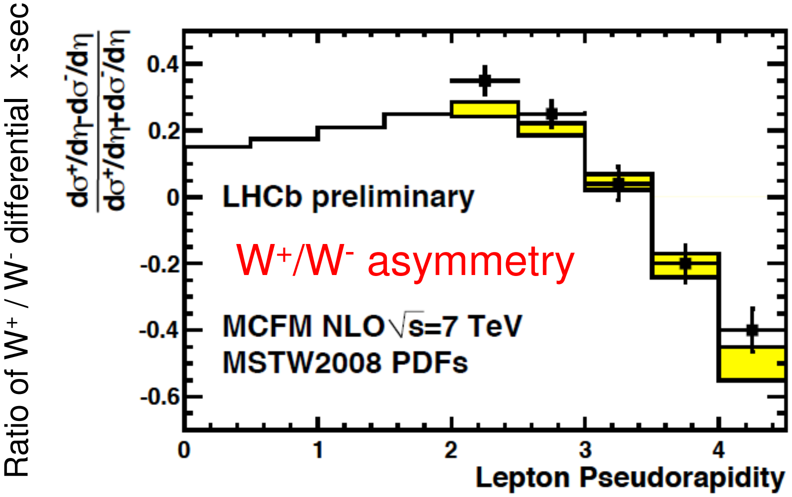
Exciting CPV, spectroscopy and rare decay possibilities in 2011.
Max. write-to-tape rate raised by 50% to 3kHz, largely to accommodate charm.

Beyond flavor physics – W/Z studies









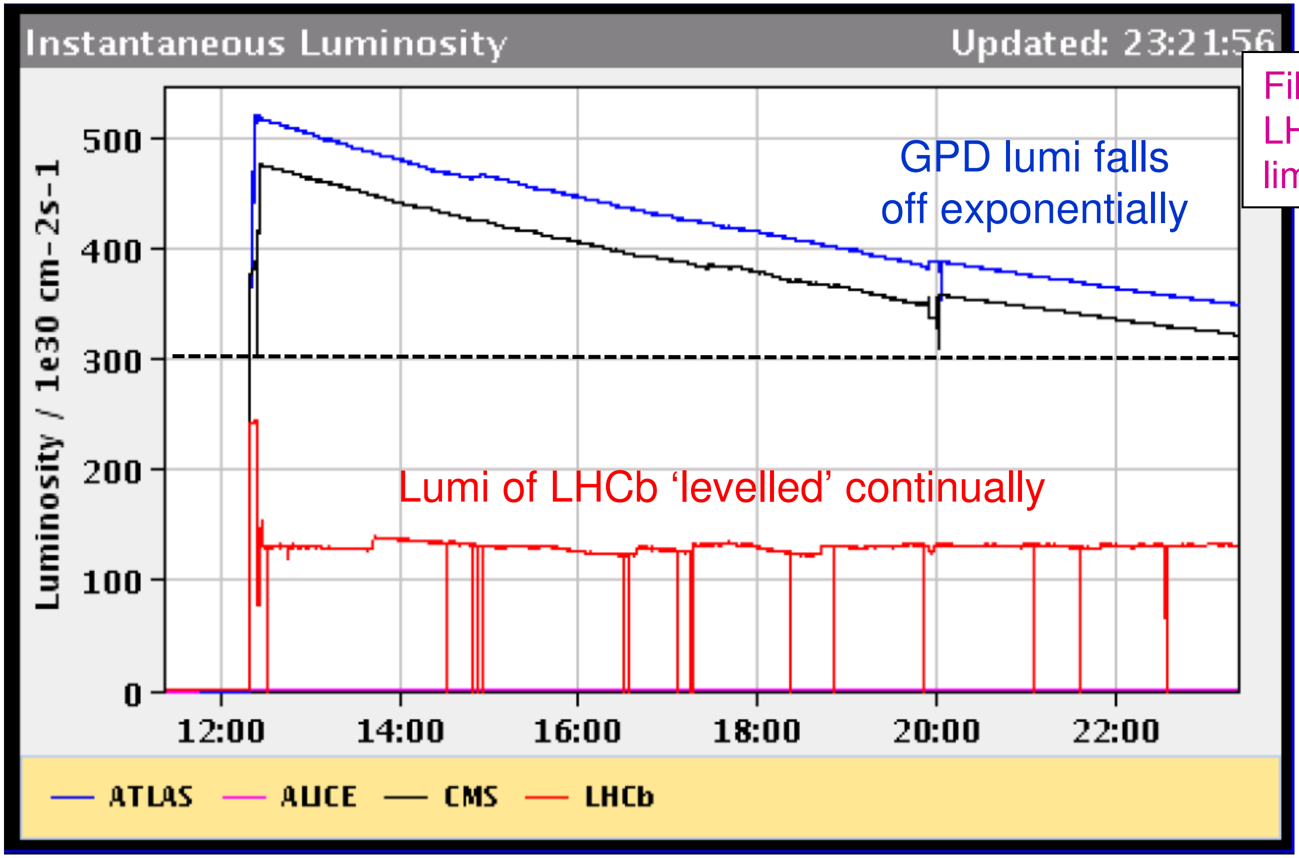
Future possibilities (near term and long term):

- Drell-Yan production of lower mass di-leptons – strong PDF constraints
- study HF content of proton: gs→Wc, gc→Zc, gb→Zb, gc→γc, gb→γb ...
- forward region best place for A_{FB} measurements, as here on average valence quarks carry most of momentum – physical axis better defined
  - precise $\sin^2\Theta_W^{eff}$ measurement with $Z^0\to\mu\mu$ (needs upgrade statistics)
  - t-tbar asymmetry??? [arXiv:1103.3747]

Luminosity leveling

Maximal value of luminosity for safe detector operations ~ 3×10^{32} $cm^{-2}s^{-1}$
Don’t gain for hadronic channels when going beyond anyway.

Beams are intentionally misaligned at LHCb to stay below this limit



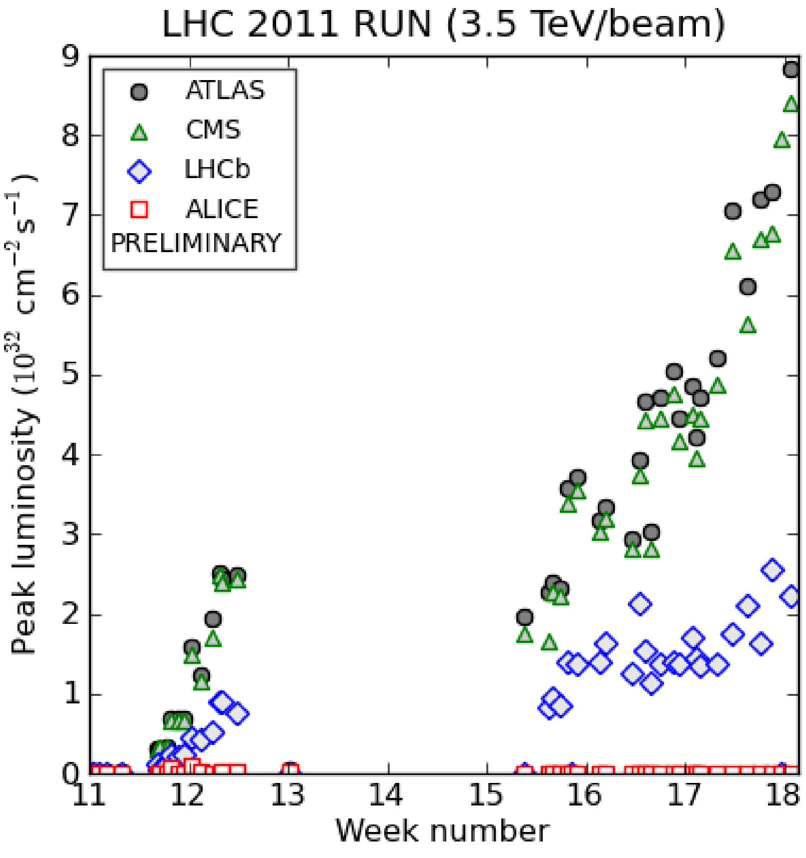
GPD lumi falls off exponentially

Lumi of LHCb ‘levelled’ continually

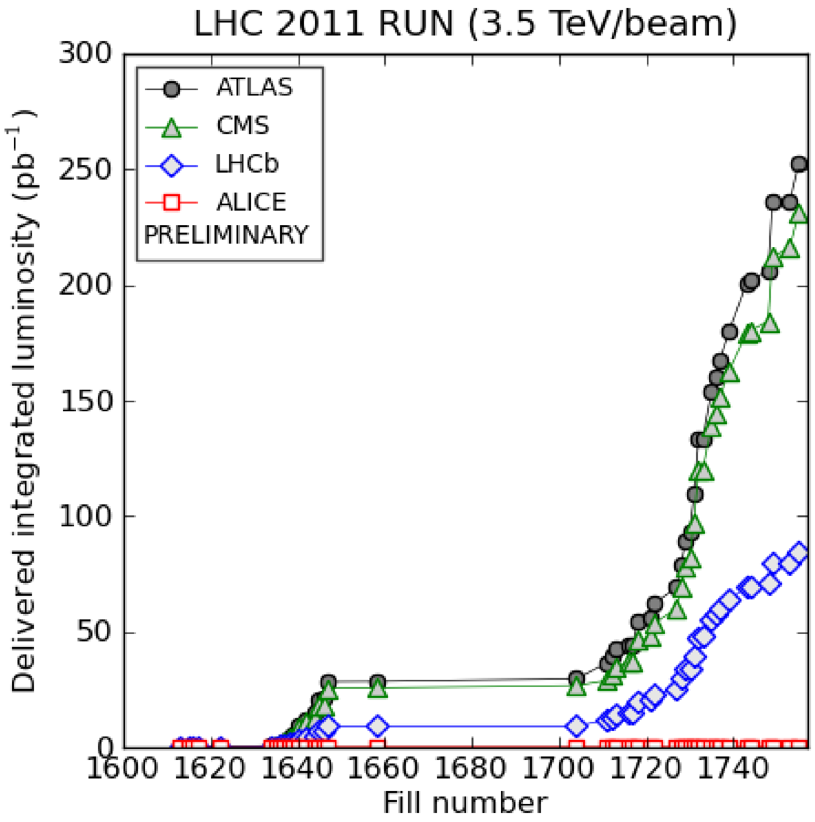
Fill from 3/23/11: 480 bunches, LHCb μ (=visible interactions/xing) limited to 1.5

Expected LHCb lumi later this year as # of bunches in the machine raises

2011 data so far



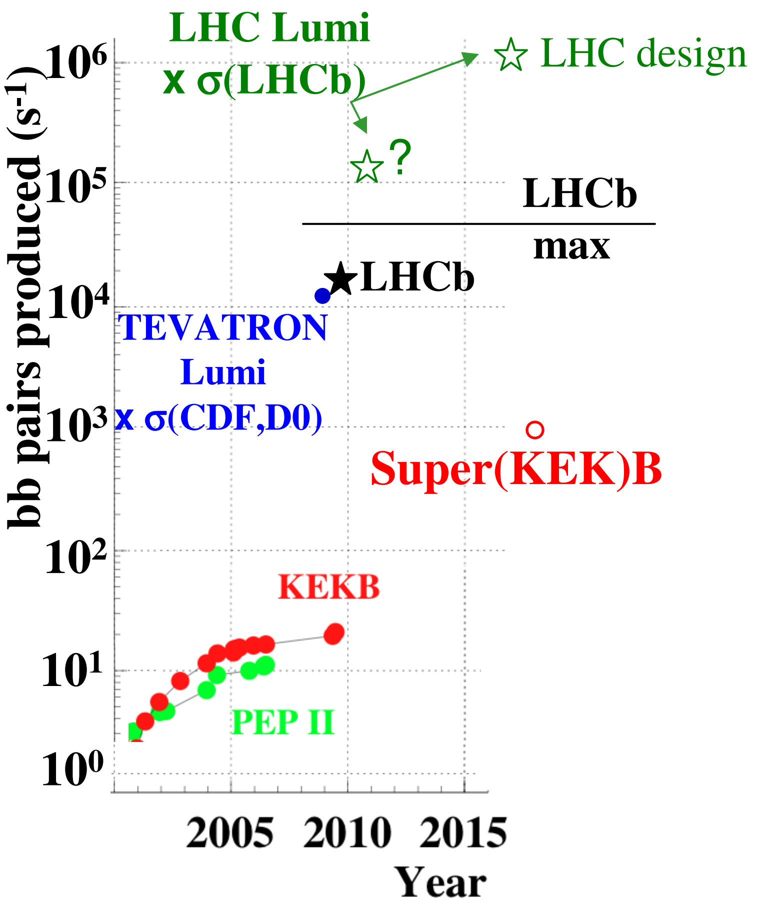
(generated 2011-05-03 11:40 including fill 1755)



(generated 2011-05-03 11:40 including fill 1755)

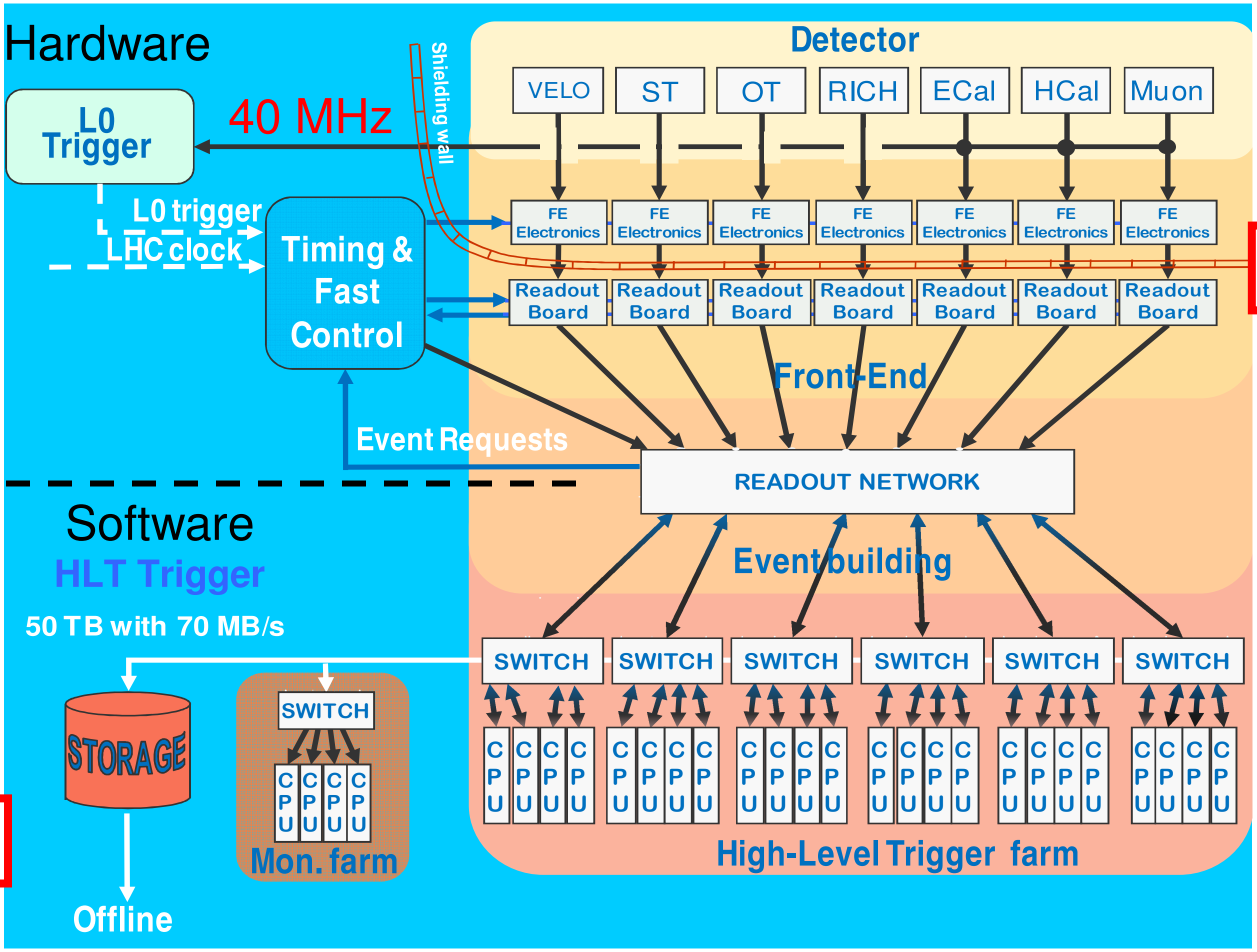
- Already twice as much data as last year
- Expect ~200 pb^{-1} for summer conferences; ~1 fb^{-1} this year

Colliders and $b\bar{b}$ rates



- LHCb reach is already limited by the detector not by LHC!
- Experiments at hadronic colliders have tremendous cross-section advantage over e^+e^-:
  - Even bigger gain for B_s and no dedicated B_s runs needed
- Worth taking advantage of full LHC potential in flavor physics:
  - We proposed an upgrade of LHCb detector to increase instantaneous luminosity by a factor of ~5 (2018 ?)

LHCb trigger & bottlenecks



1MHz

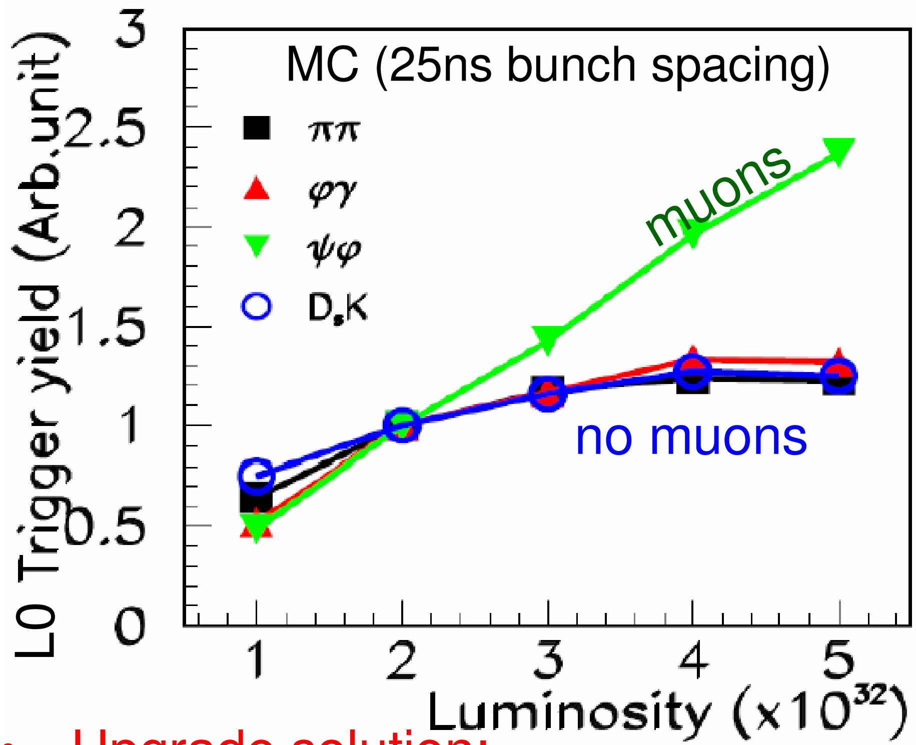
Imposed by FE readout speed

~3kHz

Imposed by offline resources

- The L0 trigger bandwidth is the most severe limitation of the present detector

L0 Trigger bandwidth bottleneck



To keep L0 output rate at 1MHz
calorimeter E_t thresholds have
to be raised with luminosity
- no gain for channels with no muons!

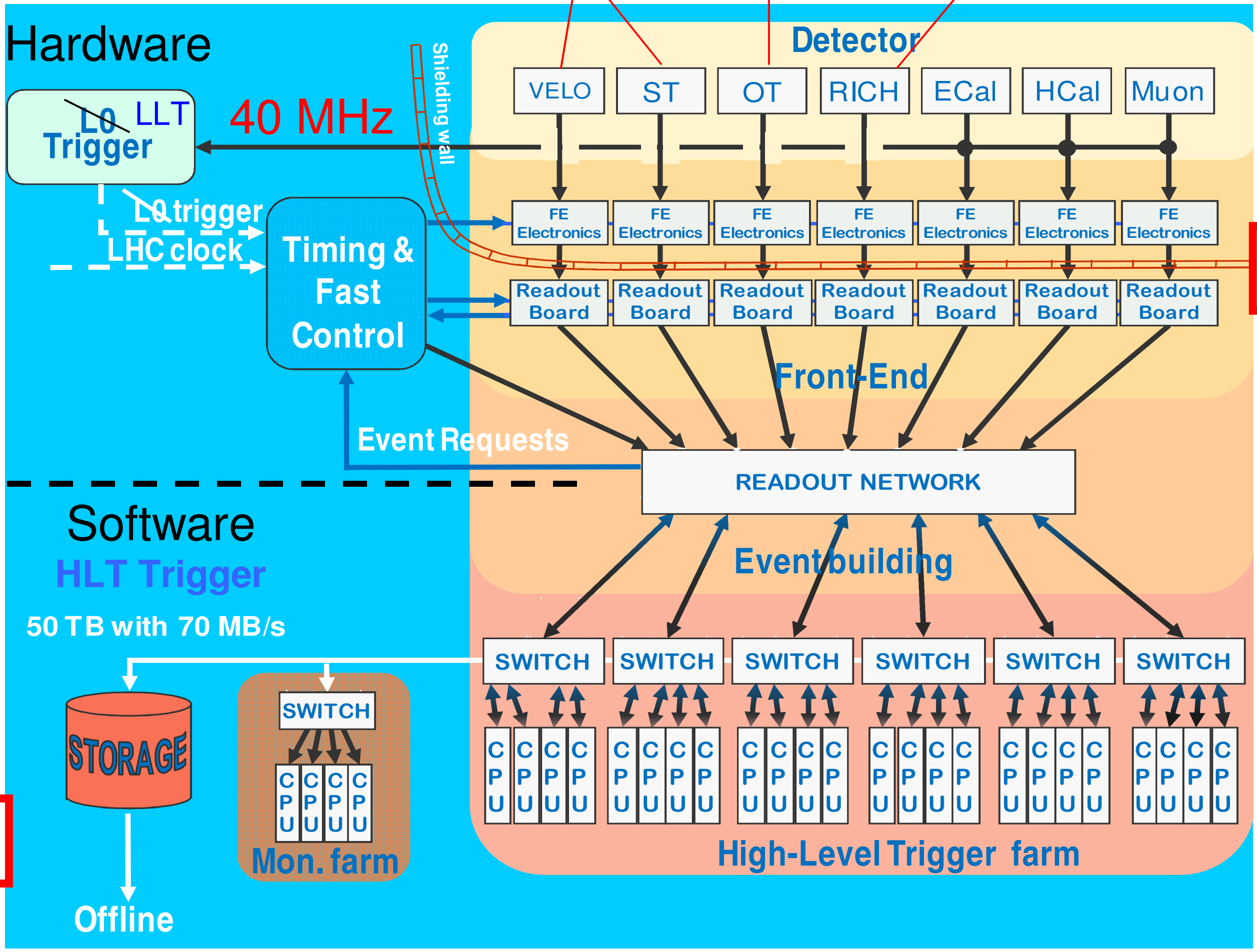
- Upgrade solution:
  - All detectors must get a readout capable of 40 MHz rate
- The actual readout speed will then be limited by HLT capacity to reduce data rate to the output trigger rate (the latter to be upgraded from 3kHz to 20kHz):
  - Preserve L0-like hardware trigger (LLT - Lower Level Trigger) to throttle readout speed to match the HLT input capacity
- Not only can reach higher luminosity but also can lower LLT calorimeter thresholds and reject backgrounds using tracking detectors in HLT – increase trigger efficiency for hadronic channels.

sLHCb trigger

Need new sensors

Need new readout

Need new photodetectors



Up to 40MHz

~~1MHz~~

~~Imposed by FE readout speed~~

Limited by HLT capacity

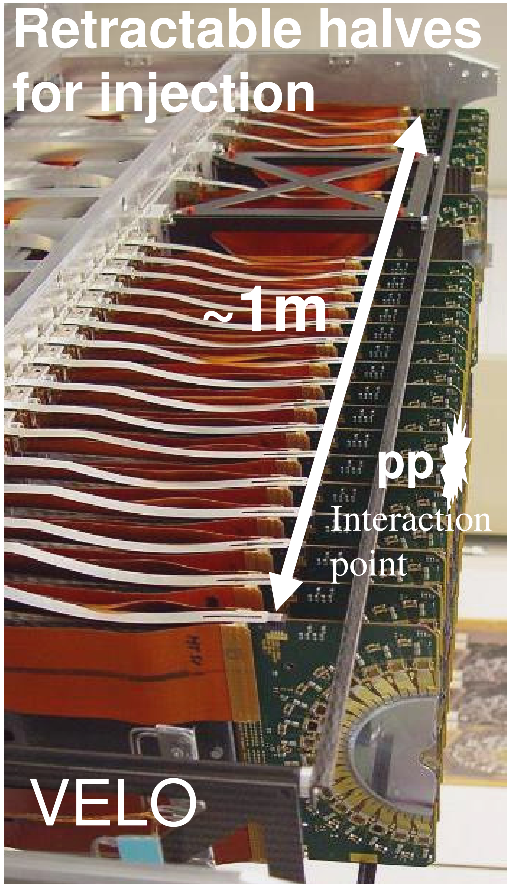
20 kHz

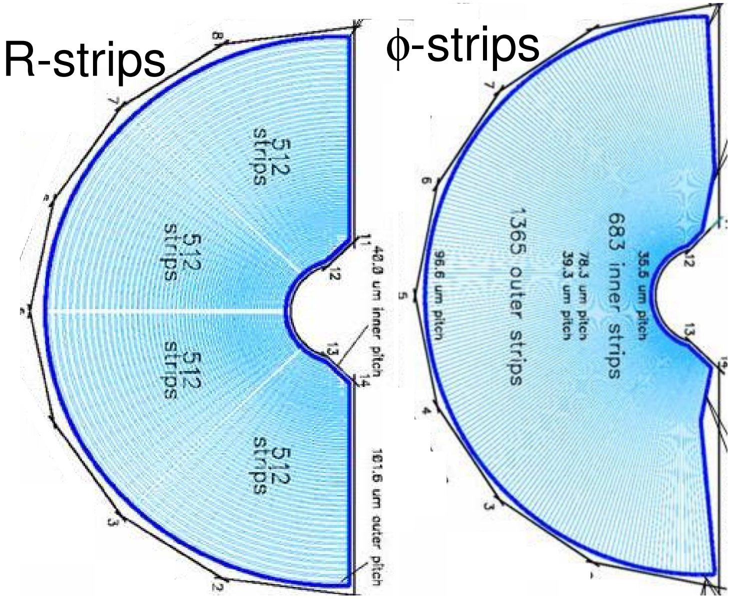
~~~2kHz~~

Imposed by offline resources

- After these changes we can collect data at 10^{33} $cm^{-2}s^{-1}$ without compromising muon trigger efficiency and with improved hadron trigger efficiencies
~~~

Vertex Detector upgrade



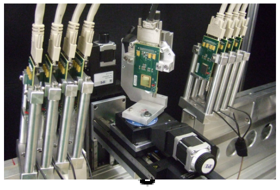


Long R,ϕ strips: **radiation damage** expected at high luminosities.

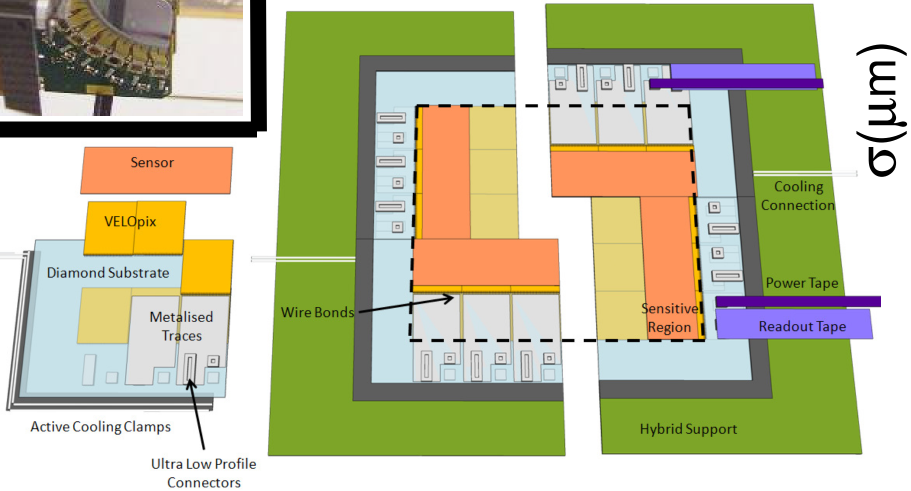
Replace with Medipix/Timepix chip bonded to 55 μm x 55 μm square pixels

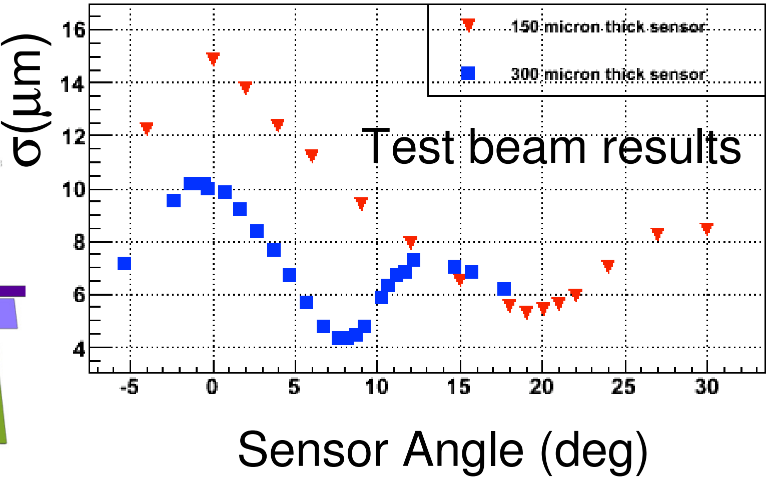
Radiation hard.

No ghosts even at very high luminosities.



VeloPix upgrade





Sensitivities to key quark flavour channels

Type	Observable	Current precision	LHCb ($5\ \mathrm{fb}^{-1}$)	sLHCb ($50\ \mathrm{fb}^{-1}$)	Theory uncertainty
Gluonic penguin	$S(B_s \to \phi\phi)$	-	0.08	0.02	0.02
	$S(B_s \to K^{*0}\bar{K}^{*0})$	-	0.07	0.02	< 0.02
	$S(B^0 \to \phi K^0_S)$	0.17	0.15	0.03	0.02
B_s mixing	$2\beta_s\ (B_s \to J/\psi\phi)$	0.35	0.019	0.006	~ 0.003
Right-handed currents	$S(B_s \to \phi\gamma)$	-	0.07	0.02	< 0.01
	$\mathcal{A}^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	-	0.14	0.03	0.02
E/W penguin	$A_T^{(2)}(B^0 \to K^{*0}\mu^+\mu^-)$	-	0.14	0.04	0.05
	$s_0\, A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	-	4%	1%	7%
Higgs penguin	$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	30%	8%	$< 10\%$
	$\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s\to\mu^+\mu^-)}$	-	-	$\sim 35\%$	$\sim 5\%$
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	$\sim 20°$	$\sim 4°$	0.9°	negligible
	$\gamma\ (B_s \to D_s K)$	-	$\sim 7°$	1.5°	negligible
	$\beta\ (B^0 \to J/\psi\, K^0)$	1°	0.5°	0.2°	negligible
Charm CPV	A_Γ	2.5×10^{-3}	2×10^{-4}	4×10^{-5}	-
	$A^{dir}_{CP}(KK) - A^{dir}_{CP}(\pi\pi)$	4.3×10^{-3}	4×10^{-4}	8×10^{-5}	-

Conclusion

- Loop processes are a crystal ball of high energy physics:
  - Spectacular successes in the past
  - Tight constraints on NP physics at energy scales extending beyond those probed by tree diagrams
  - Hunt for NP in loops at LHCb has just started. Detector works very well. Already enough data for best measurements in many channels. Much more in coming years.
  - Need Super-LHCb upgrade to exercise full physics potential.