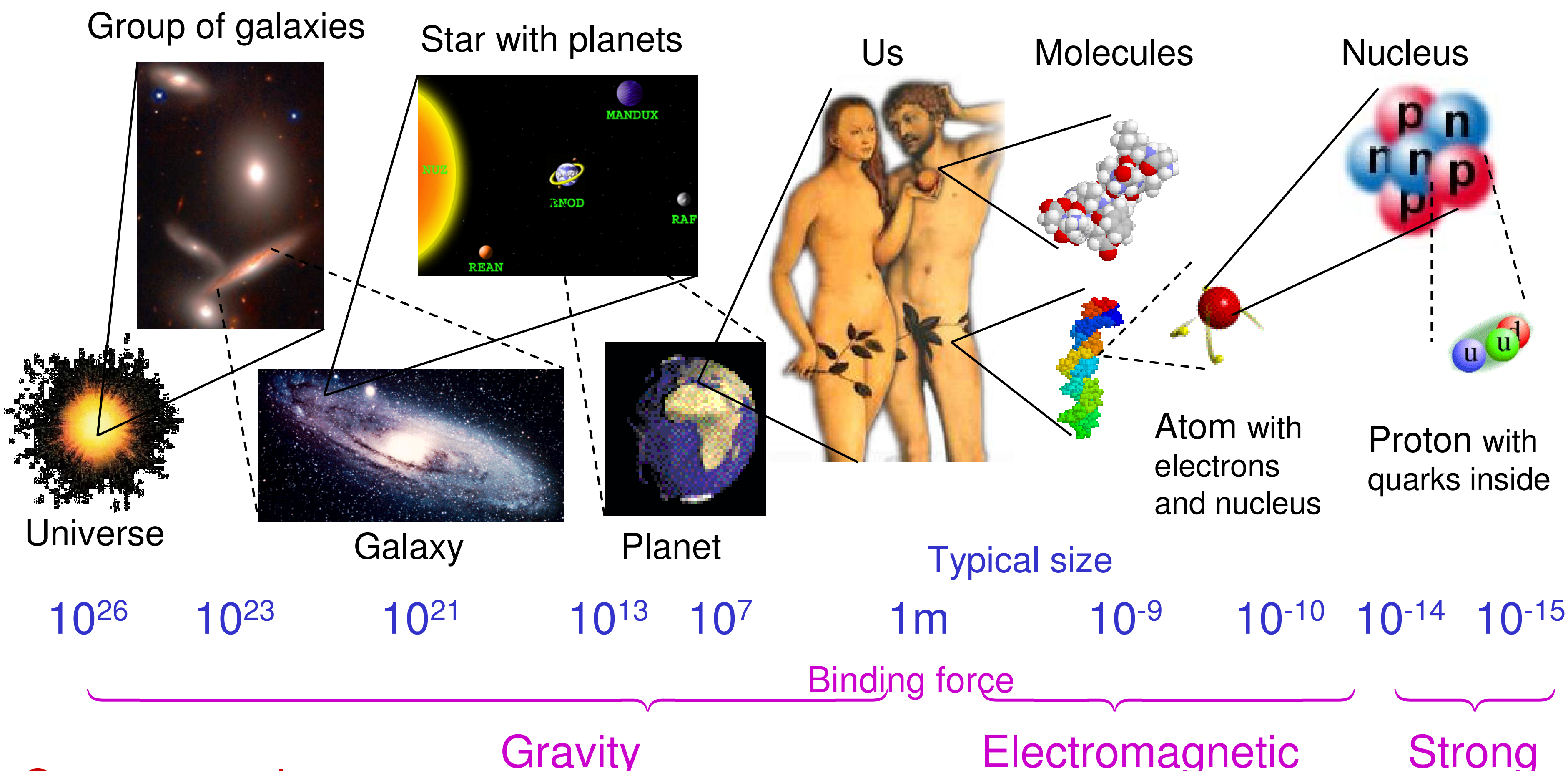
Status of the LHCb experiment.

Physics of heavy flavor loops.
First results from LHCb.
Prospects for near and farther future.

Tomasz Skwarnicki

Syracuse University

Fundamental Forces (Standard Model)



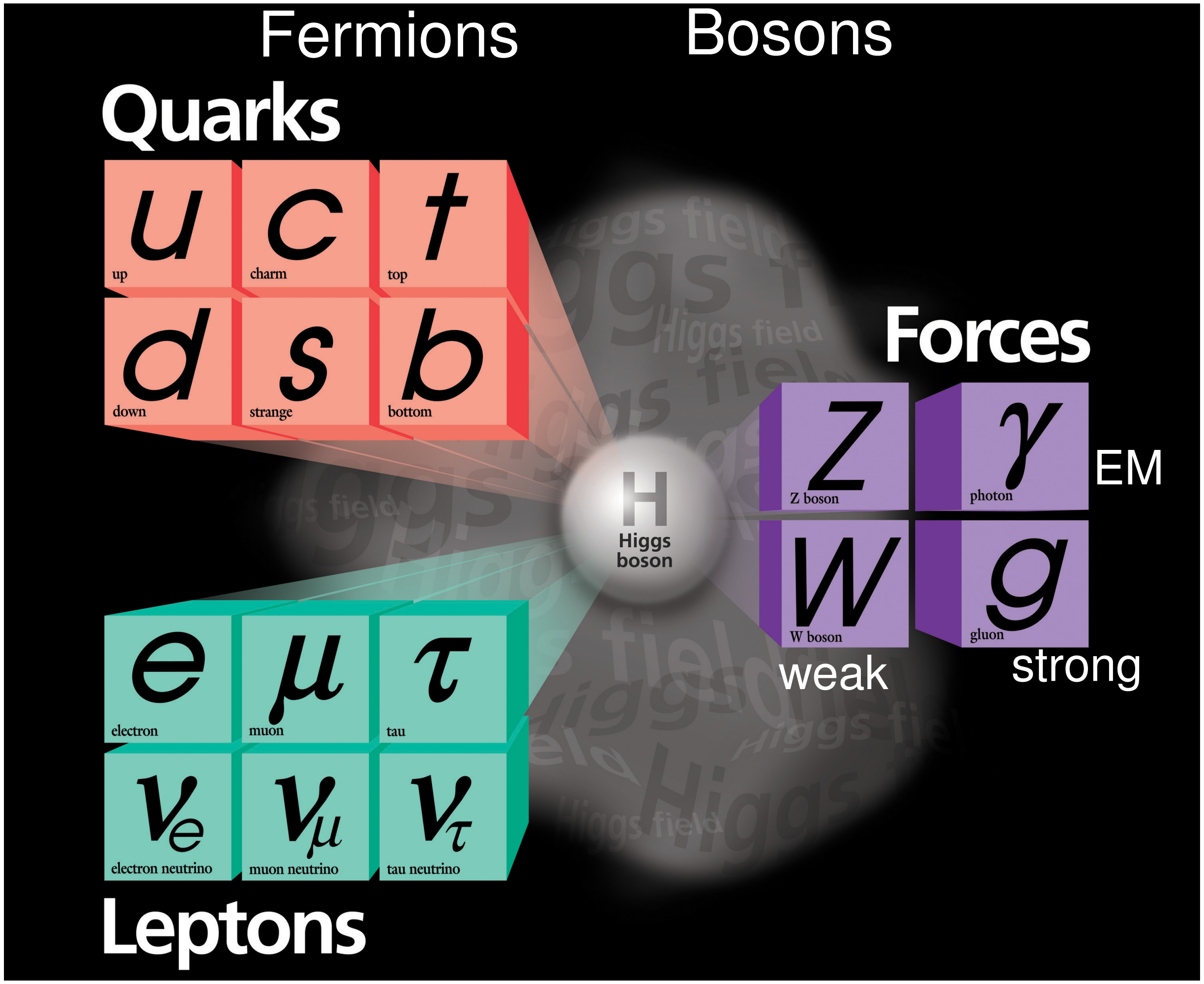
So many phenomena,
so few fundamental particles,
so few forces!

Can we simplify our understanding even further?
GUTs

+ Weak decays of heavier quarks and leptons

Electroweak

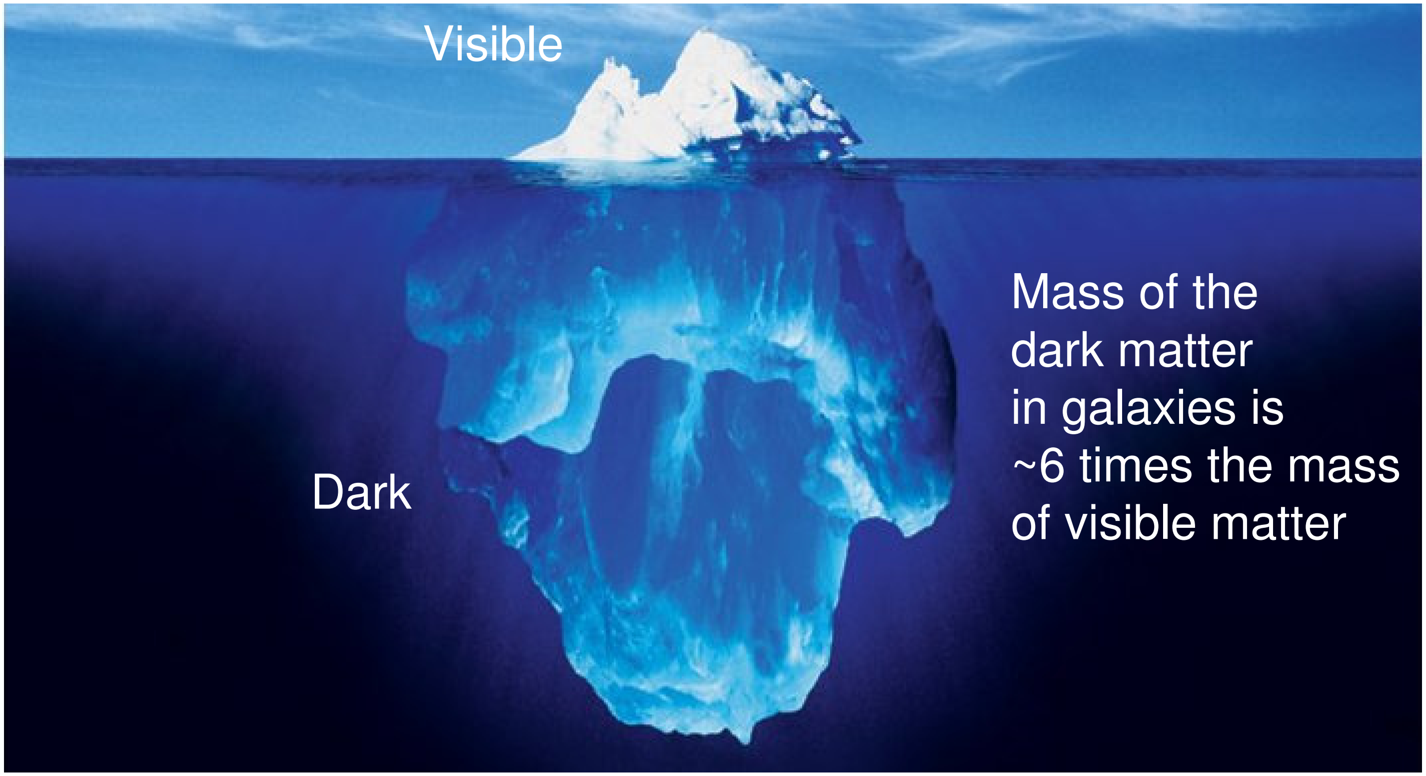
One force in SM still to be confirmed



Higgs discovery is the main goal of LHC: pp collider with 7000 GeV x 7000 GeV

- Higgs boson breaks electroweak symmetry making W,Z bosons massive (80, 91 GeV), γ massless.
- Also gives mass to all other elementary particles.

Dark matter

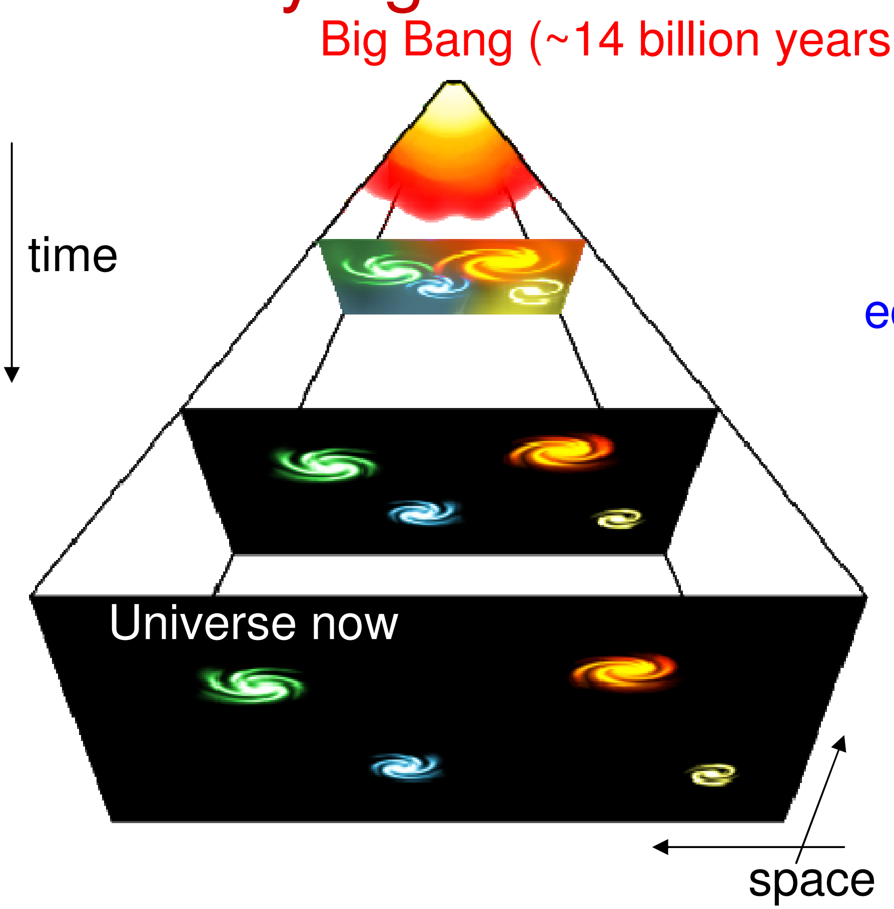


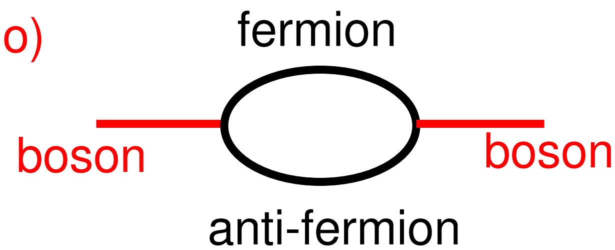
Established by studies of gravitational forces measured in galaxies.

Not in SM!

- Most likely, the dark matter is due to a yet unknown stable elementary particle (which could be light or heavy), interacting with other particles by exchanging very heavy boson(s) (new force).
- There is now even a bigger problem: the Universe expands much faster than allow by our theory of gravity (Dark Energy).

Baryo-genesis





equal number of fermions and anti-fermions

only fermions survived
(anti-fermions disappeared)

- Standard Model forces don’t provide enough symmetry violation to explain disappearance of the anti-matter (we should not have been here!)
- Likely explanation: unknown forces at high energies with large (“CP-”)symmetry violation

Generation problem

end of 19th centaury

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			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

Explained by atomic structure (nucleus + + electrons, QM and electromagnetic forces)

mid 20th centaury

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

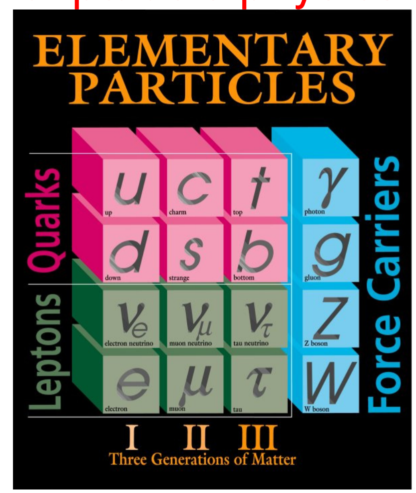
	$Q=-1$	$Q=0$	$Q=+1$	$Q=+2$
$S=0$	Δ^-	Δ^0	Δ^+	Δ^{++}
$S=-1$	Σ^{*-}	Σ^{*0}	Σ^{*+}	
$S=-2$	Ξ^{*-}	Ξ^{*0}		
$S=-3$	Ω^-			

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

Explained by existence of quarks and nature of strong interactions

now

Standard Model of particle physics



Explained by ?????

- Standard Model account for 3 generations of quarks and fermions is merely a period table!

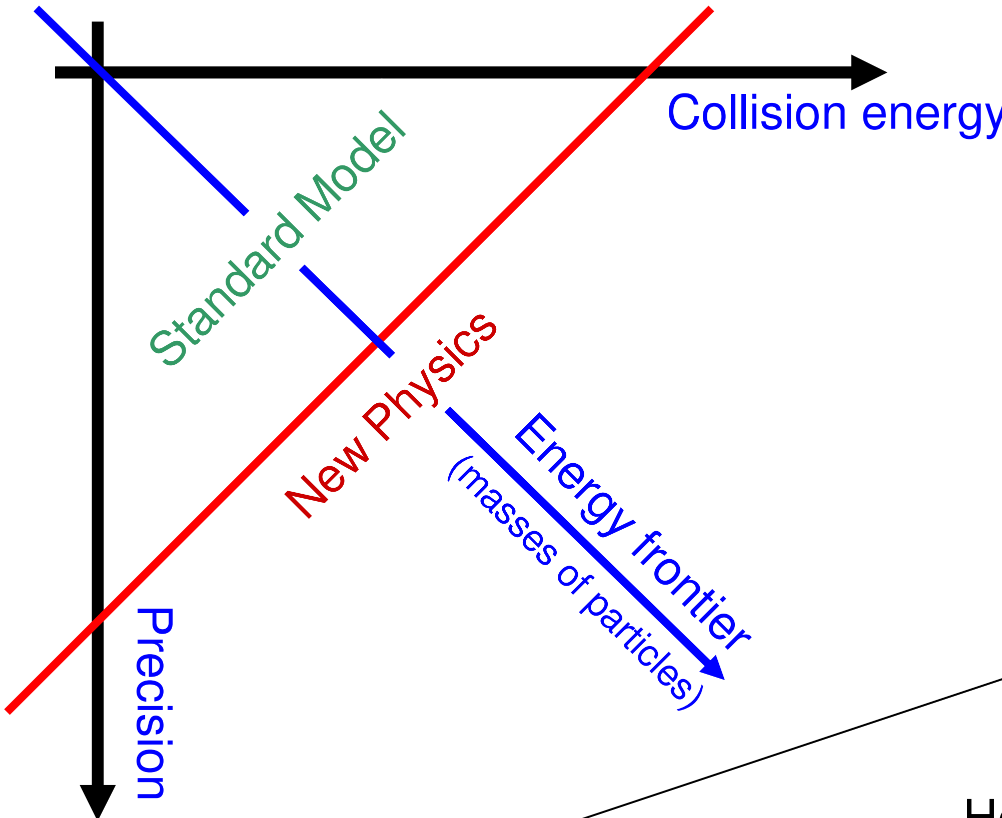
New Physics (NP)

Forces not accounted for
in Standard Model
exist in the nature!

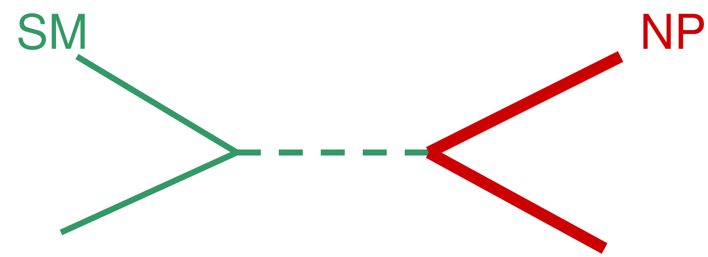
We just don't know what they are.

Need to probe higher energy scales.

Two complementary ways of advancing “energy frontier”

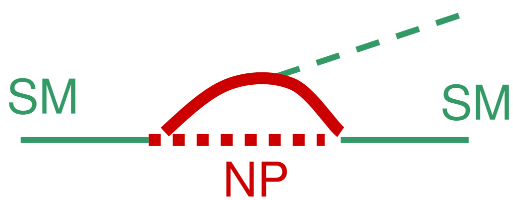


Tree diagrams, for example



Want high CM energy to exceed the production threshold

Loop diagrams, for example

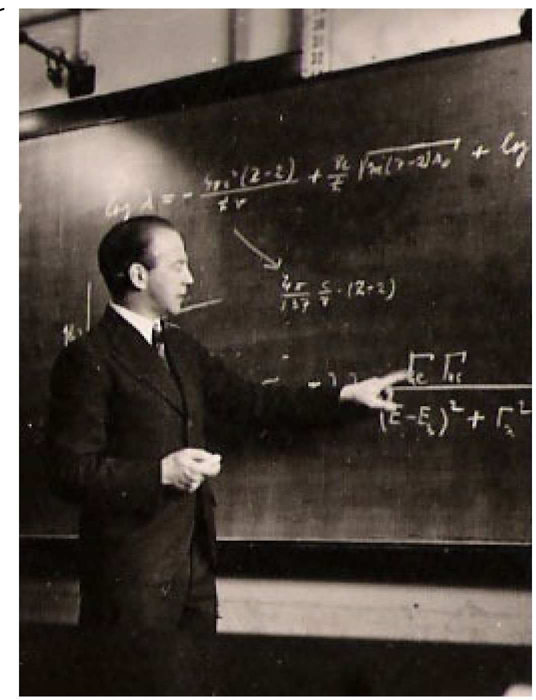


Want high precision since NP particles are highly virtual here, thus probabilities small

Heisenberg’s uncertainty principle:

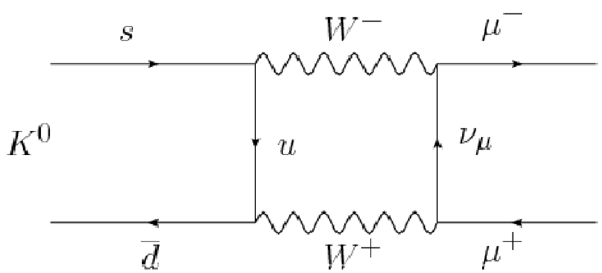
$$\Delta E\ \Delta t = \hbar/2$$

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



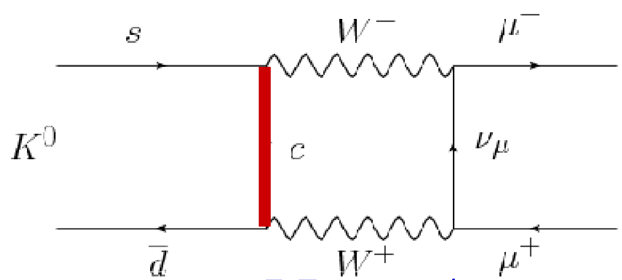
Loops: GIM mechanism 1970

- Standard Model at that time:
  - Known quarks **u,d,s** (eigenstates of strong interactions)
  - weak current (W) coupling **u** and **d'** = **d** cosθ + **s** sinθ
    . (θ – Cabibbo angle: cosθ=0.97 sinθ=0.22)
- Glashow-Iliopoulos-Maiani mechanism:
  - There is also a weak current between **c** (NP!) and **s'** = - **d** sinθ + **s** cosθ
  - Automatically no Flavor Changing Neutral Currents ($s \to d$) at tree level (desired to stay consistent with known results)
  - **c** quark in the FCNC box diagram (loop!) for $K^0_L \to \mu^+\mu^-$ decay cancels the "large" contribution from **u** quark box, and explains why not observed at 10^{-4} level



BR ~ 10^{-4}

+



BR « 10^{-4}

Observed in 1973
BR ~ 10^{-8}

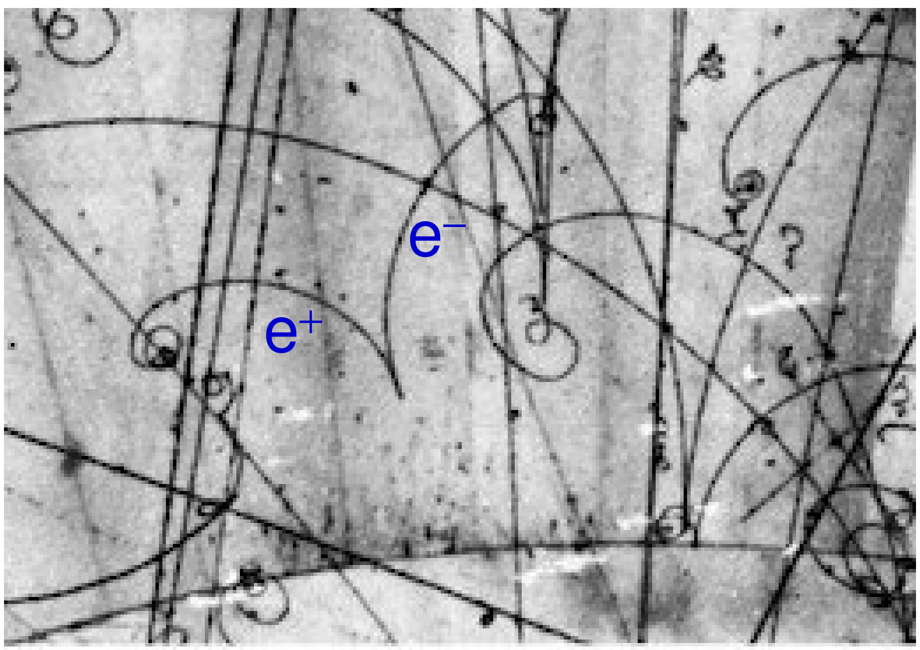
Initial non-observation of this decay meant effectively first indirect observation of c !

c quark later observed directly via tree diagram in 1974 (Ting,Richter - J/ψ)

Loops: CP violation in K^0 decays (1964)

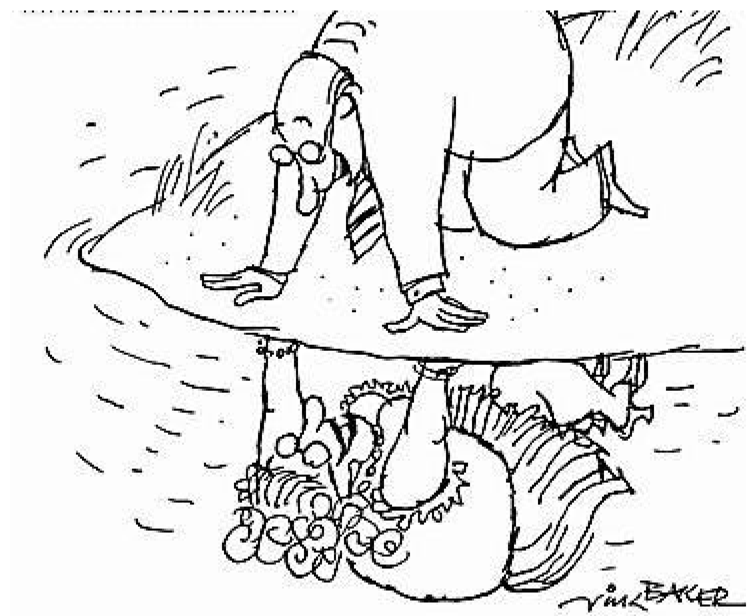
- Standard Model at that time:
  - Electromagnetic and strong interactions **conserve** C and P symmetries
  - Weak interactions **violate** P (Wu 1956) but **conserve** CP symmetry

C symmetry



$\gamma N \to e^+e^- N$

Violation of P symmetry



"Hi, gorgeous!"

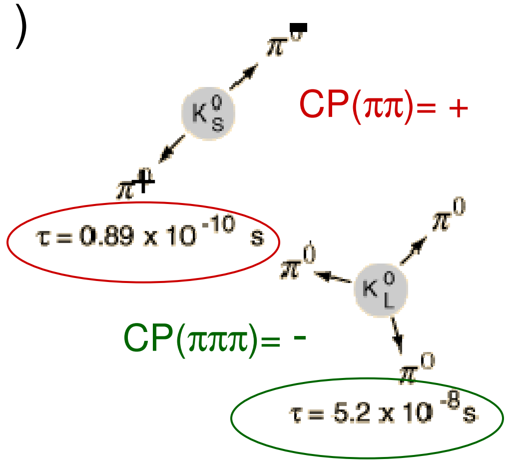
Loops: CP violation in K^0 decays

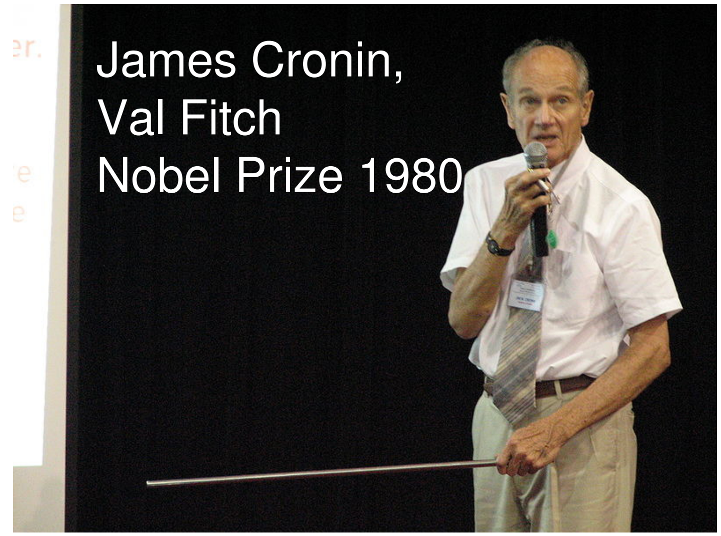
- Cronin-Fitch experiment 1964 (BNL):

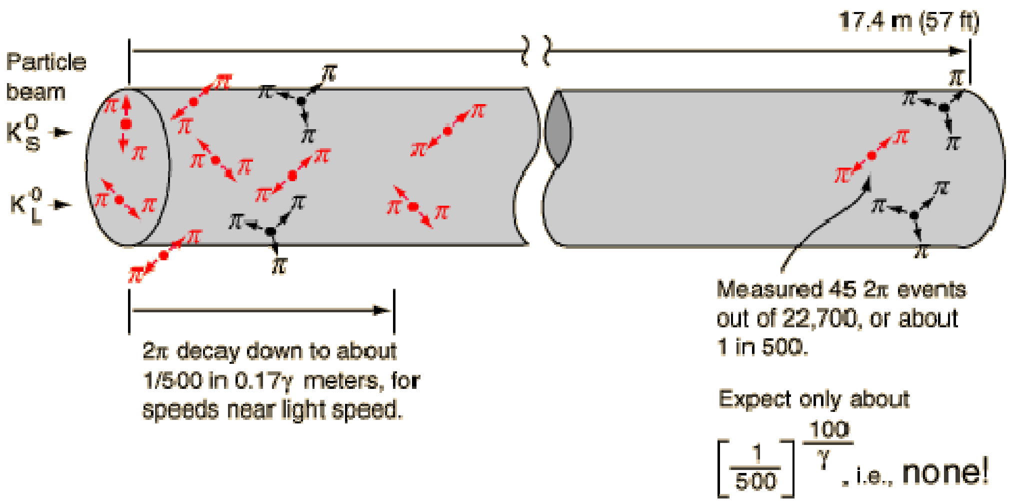
$K^0 = (d\,\bar{s})$ $\quad \overline{K^0} = (\bar{d}\,s)$

$$K_S^0 = \frac{1}{\sqrt{2}}(K^0 + \bar{K}^0) \quad \text{CP= +}$$

$$K_L^0 = \frac{1}{\sqrt{2}}(K^0 - \bar{K}^0) \quad \text{CP= -}$$







- Decays of K^0_L mesons to ππ **violate** CP symmetry!
- Evidence for new type of force – “5th force” (NP)?

K^0_s decay quickly

K^0_L not expected to decay to ππ but it does at 0.2% level

Loops: CP violation in K^0 decays

- Kobayashi, Maskwa 1972:
  - proposed 3 quark generations to explain the Cronin-Fitch experiment without the 5th force (before the 2nd generation c quark was discovered!)

Cabibbo + GIM

$$\begin{pmatrix} u \\ c \end{pmatrix} \xleftarrow{\text{weak force}} W \longrightarrow \begin{pmatrix} d' \\ s' \end{pmatrix} = V \begin{pmatrix} d \\ s \end{pmatrix}$$

+ Kobayashi,Maskawa

$$\begin{pmatrix} u \\ c \\ t \end{pmatrix} \xleftarrow{\text{weak force}} W \longrightarrow \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V \begin{pmatrix} d \\ s \\ b \end{pmatrix} \longleftarrow \text{NP!}$$

To conserve probability the quark mixing matrix V must be unitary:

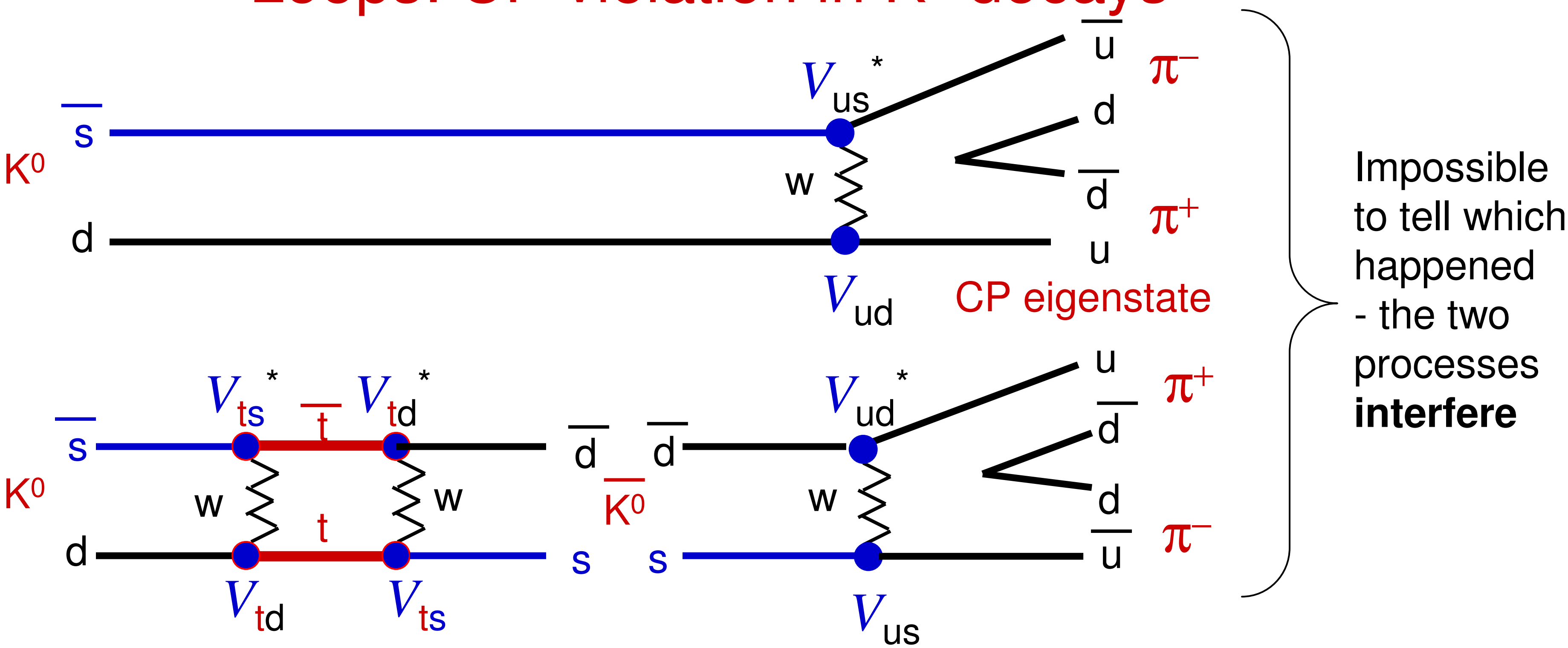
$$VV^\dagger = V^\dagger V = 1$$

V has **1 free parameter**:
rotation angle between flavors - Cabibbo angle!
All V_{ji} elements can be made real.

V has **4 free parameter**:
e.g. 3 rotation angles (Euler angles) + 4th must be in a complex phase.

  - the complex phases of V_{ji} not observable unless two amplitudes (i.e. processes) interfere

Loops: CP violation in K^0 decays



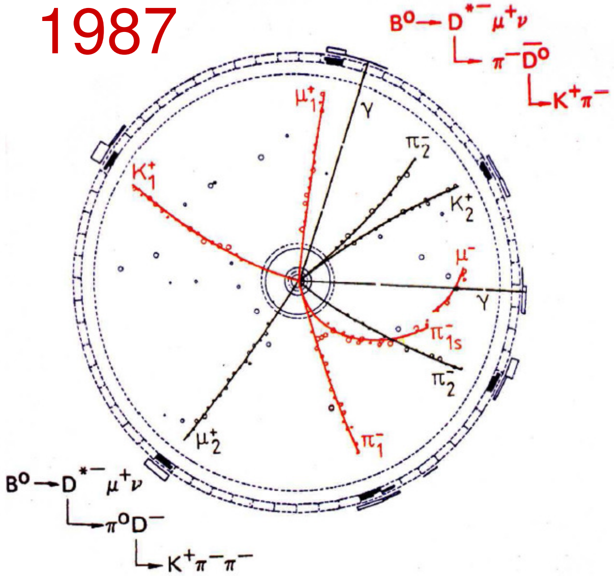
Box diagram responsible for K^0-$\overline{K^0}$ mixing

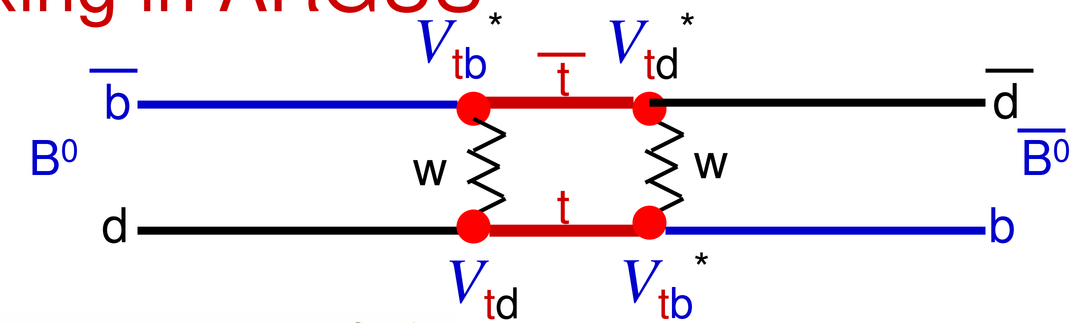
(mixing + decay: "indirect" CPV)

- The interference term produces CP violation and depends on the complex phase of the mixing diagram (ϕ_M) minus phase of decay diagram ($\phi_A \approx 0$)
- **Observation of CP violation in K^0 decays to $\pi\pi$ was effectively the first indirect observation of t quark**
- t quark observed directly via tree diagram in 1995 (CDF&D0); b quark in 1977 (Lederman Υ)

Loops: B^0-$\overline{B^0}$ Mixing in ARGUS

1987





$$r = \frac{N(B^0B^0) + N(\overline{B}^0\overline{B}^0)}{N(B^0\overline{B}^0)} = 0.21 \pm 0.08$$

DESY: DORIS E_{CM}=10 GeV

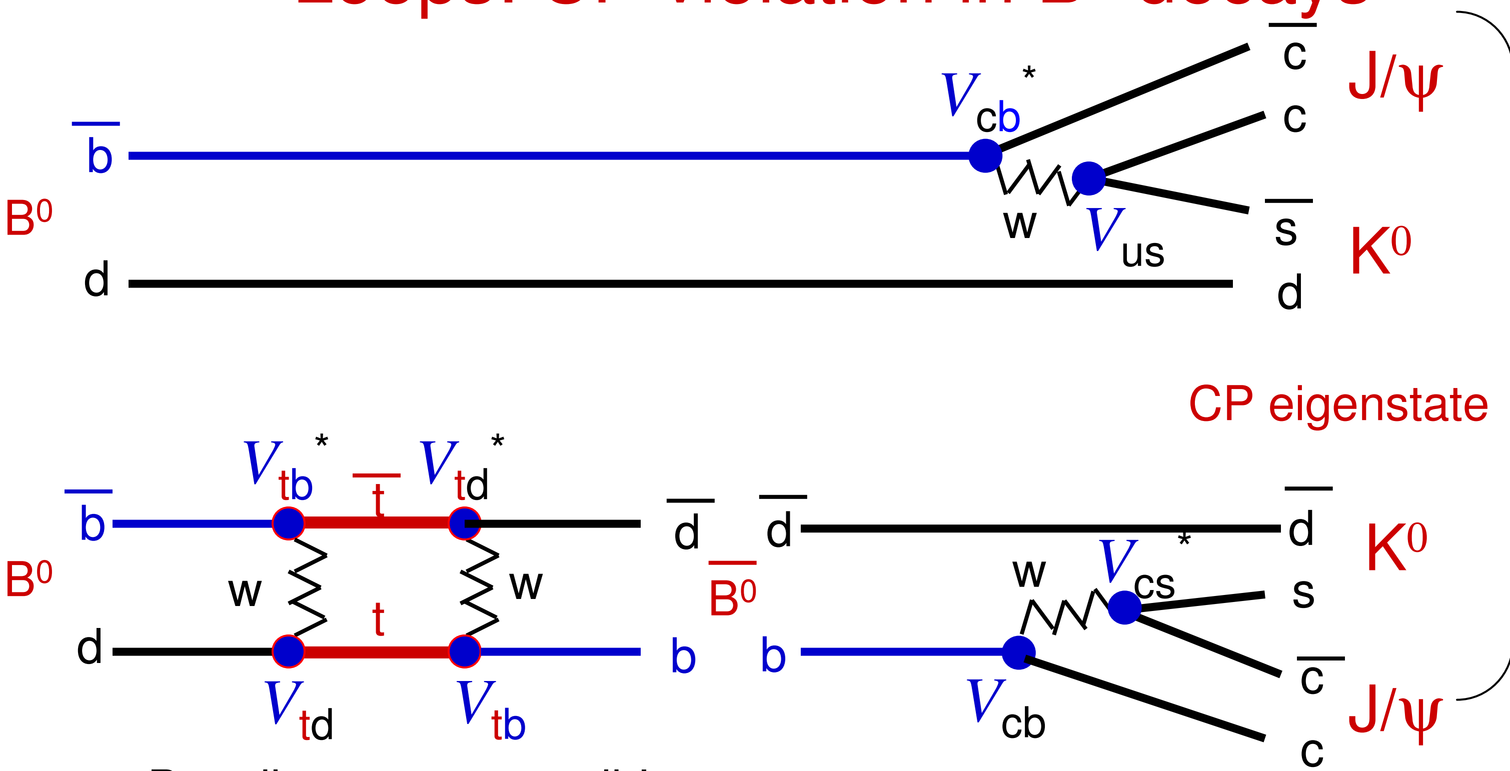
$e^+e^- \to \Upsilon(4S) \to B^0\overline{B^0}$

- **Big surprise** - expected to be small before the ARGUS measurement
- Sensitive to $|V_{td}|$ and top quark mass $r \sim m_t^4$
- From the ARGUS measurement m_t>50 GeV contrary to the believes of that time.

- In these times at DESY DORIS was a sideshow to higher energy PETRA!
  - e^+e^- colliders which failed to find top via direct searches:
    - PETRA (1978-90 2x17GeV), PEP (1980-90 2x14GeV), TRISTAN(1987-90 2x32 GeV), SLC (2x50GeV), LEP(1989-02 2x90GeV)
  - PEP & TRISTAN were later (~2000) rebuilt to run at Υ(4S) and search for New Physics in loops! **Is top&W the only thing in the box?**

- t finally discovered at Tevatron (FNAL) by CDF&D0 in 1995: m_t=171 GeV

Loops: CP violation in B^0 decays



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

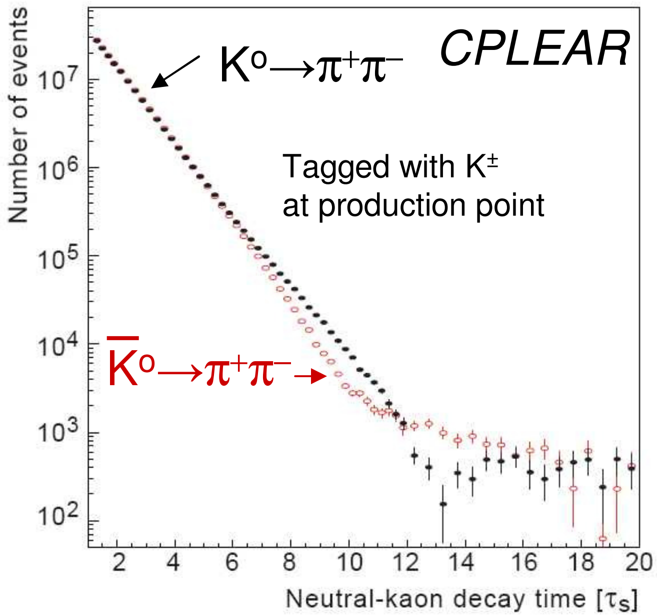
Box diagram responsible for B^0-$\overline{B^0}$ mixing

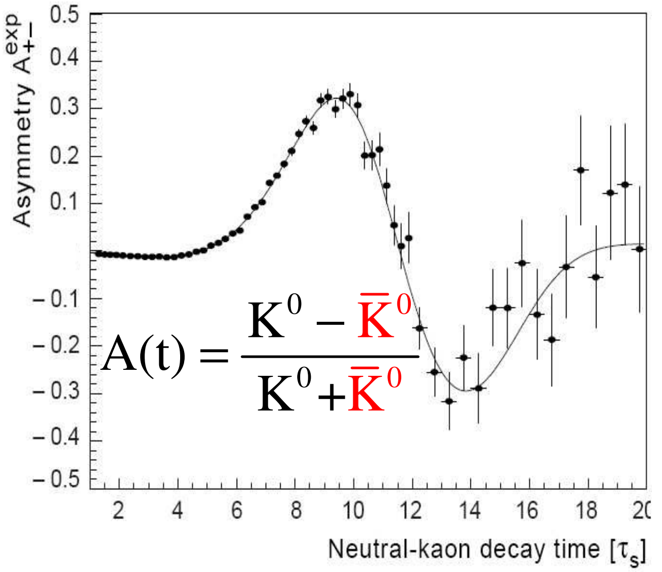
(mixing + decay: “indirect” CPV)

- Sizeable mixing frequency made this measurement feasible
- Because of rather short B^0 lifetime it was necessary to build asymmetric e^+e^- colliders, to make them live longer in the lab frame (PEP II: BaBar, KEK-B: Belle)

Indirect CPV in B^0 decays

Modern version of Cronin-Fitch





$$A(t) = \frac{K^0 - \overline{K}^0}{K^0 + \overline{K}^0}$$

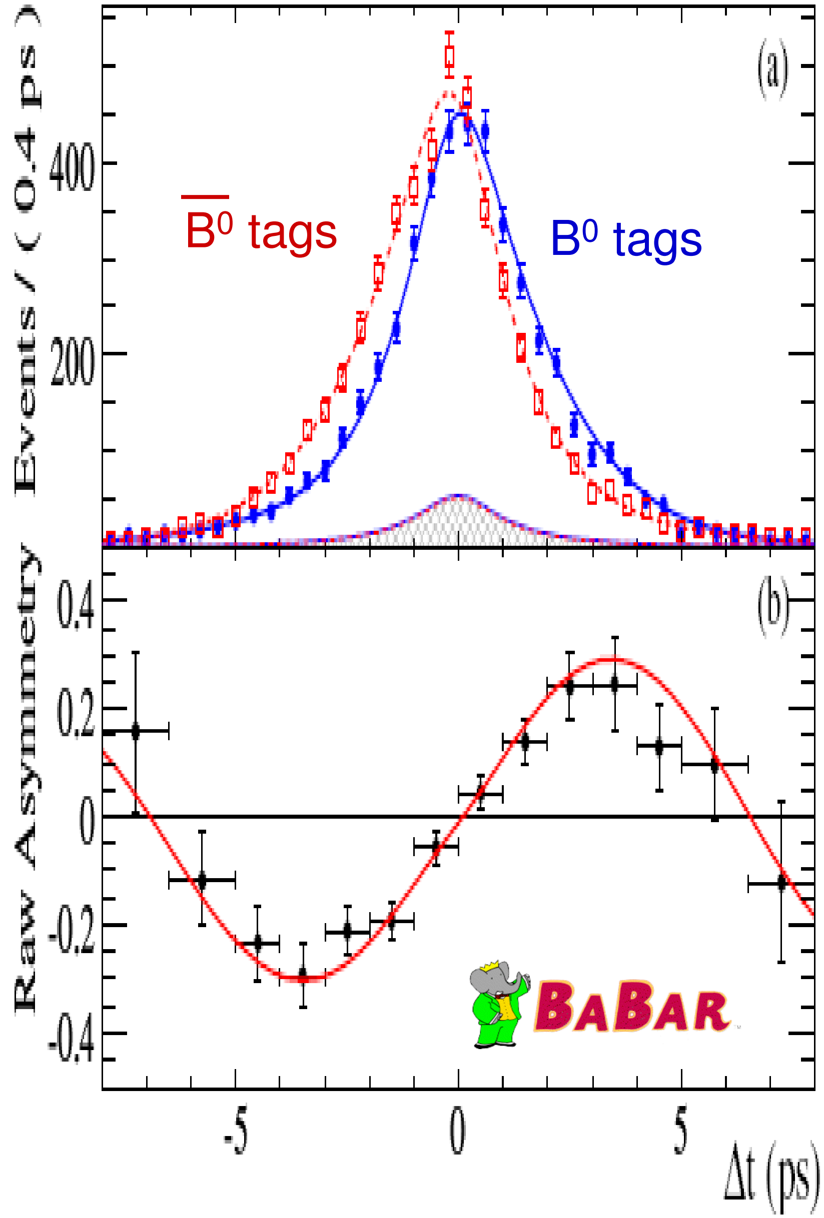
For B's measure Δt between B^0 & $\overline{B}^0$ decay in $e^+e^- \to B^0\overline{B}^0$

$\Delta\Gamma = \Gamma_S - \Gamma_L$

← large

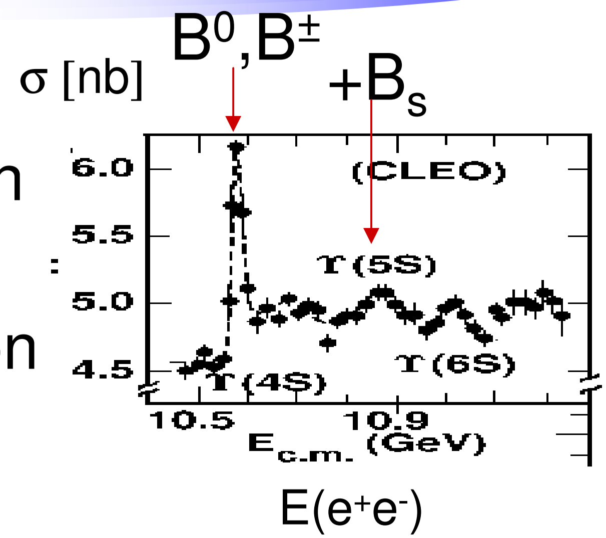
very small →

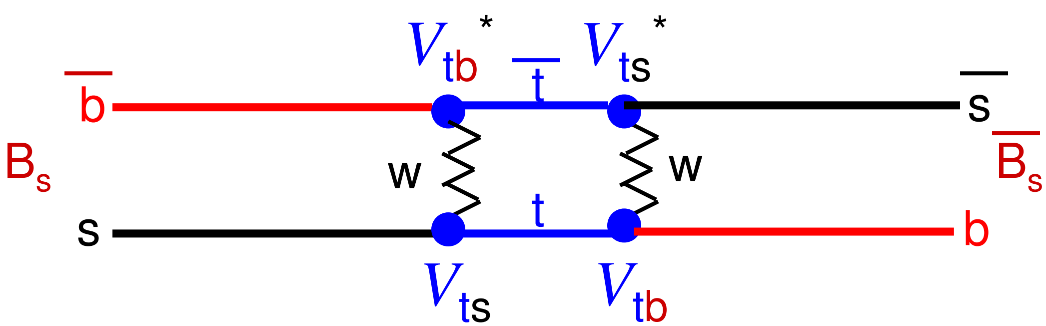
$B^o \to J/\psi\, K^0_S$ + similar

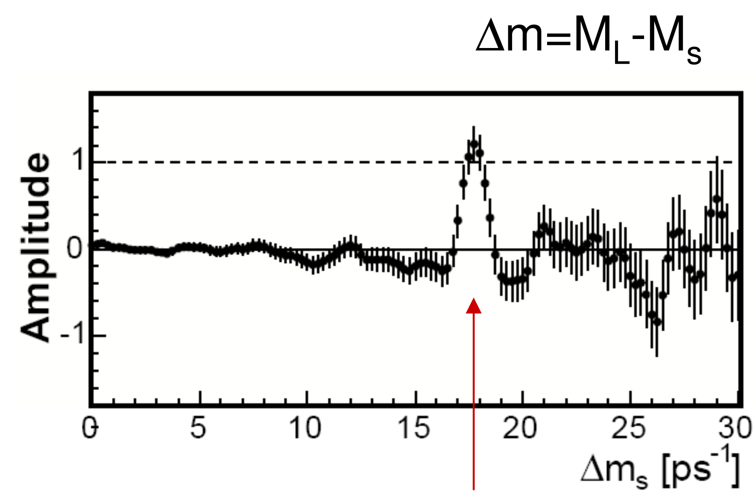


Bs-$\overline{\text{Bs}}$ mixing

- In e^+e^- B_s produced only above ϒ(4S). Production cross-section much smaller than for B^0,$B^\pm$ at the ϒ(4S) peak.
- Large numbers of B_s's produced at Tevatron (and LHC): $\sigma_{b\bar{b}}(pp) \sim 10^5\, \sigma_{b\bar{b}}(e^+e^-)$
- CDF at Tevatron measured B_s-$\overline{B}_s$ mixing frequency in 2006







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

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%

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

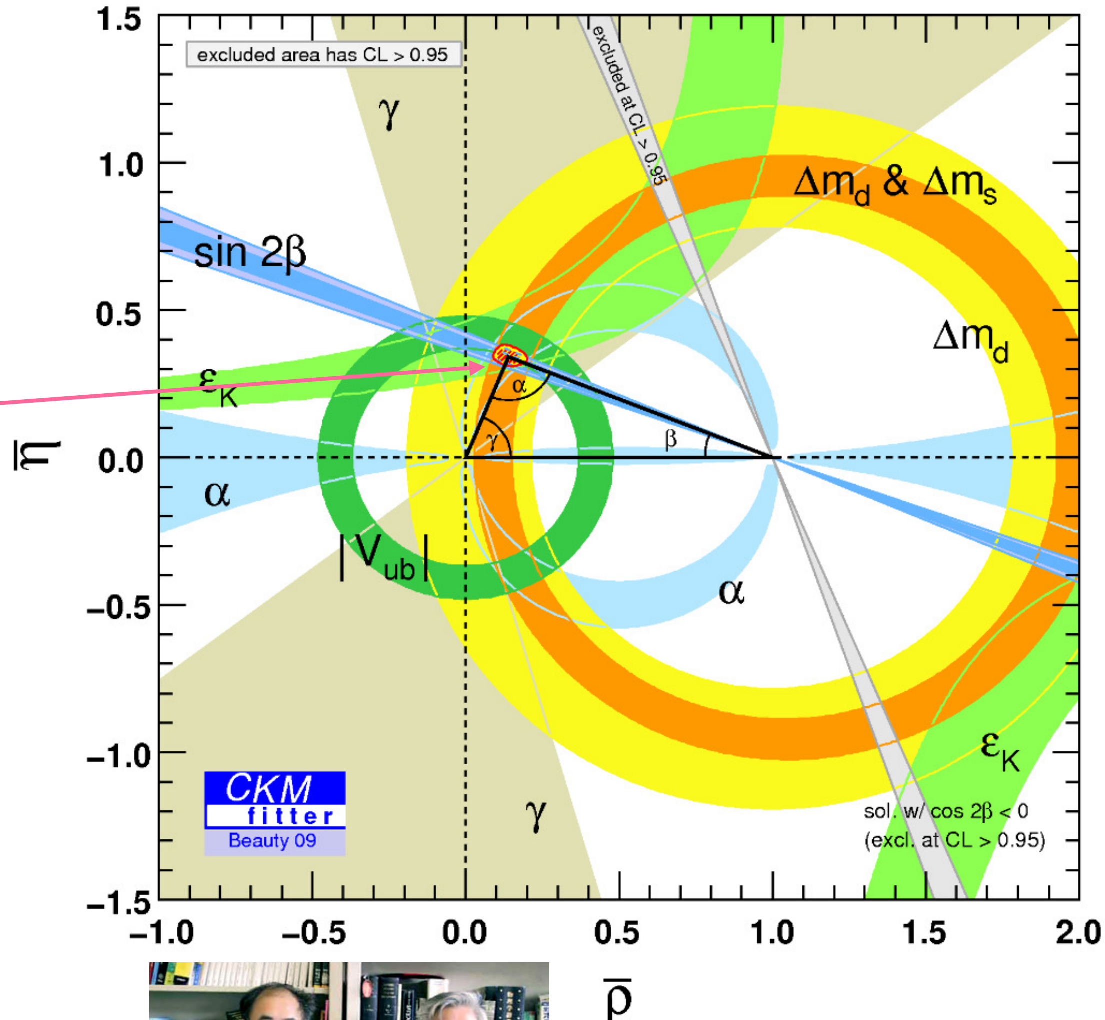
$$\delta V=\begin{pmatrix} 0 & 0 & 0 \\ -iA^2\lambda^5\eta & 0 & 0 \\ A\lambda^5(\rho+i\eta)/2 & -A\lambda^4(1/2-\rho-i\eta) & 0 \end{pmatrix}$$

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

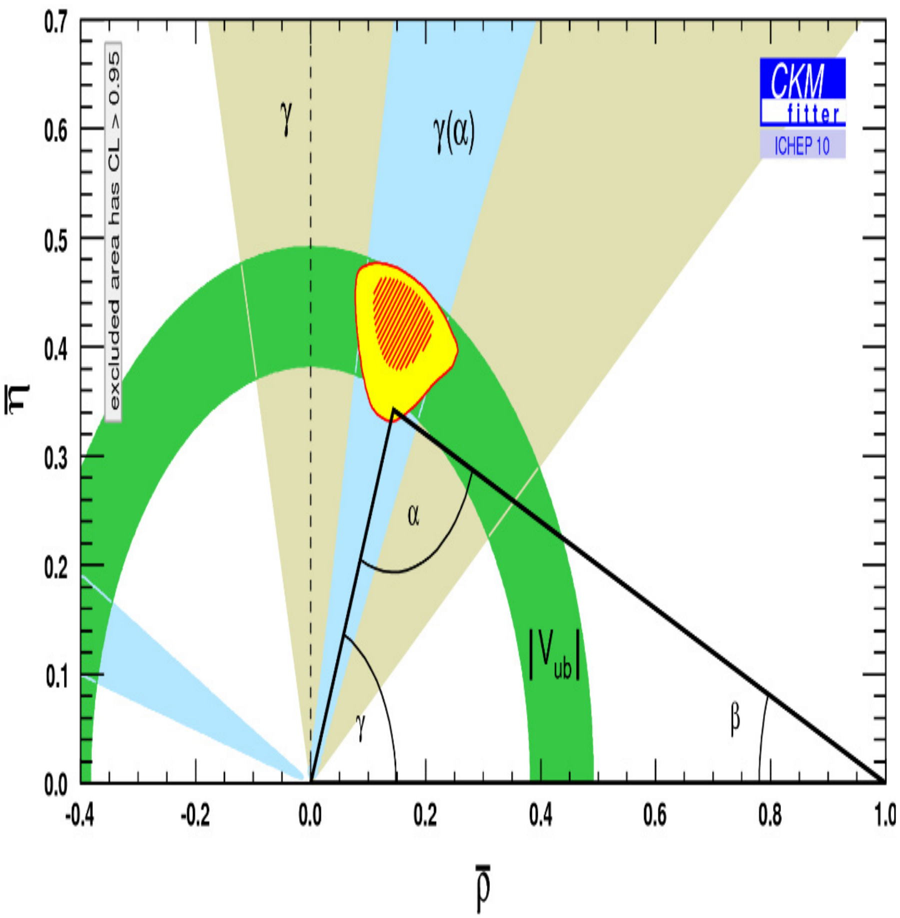


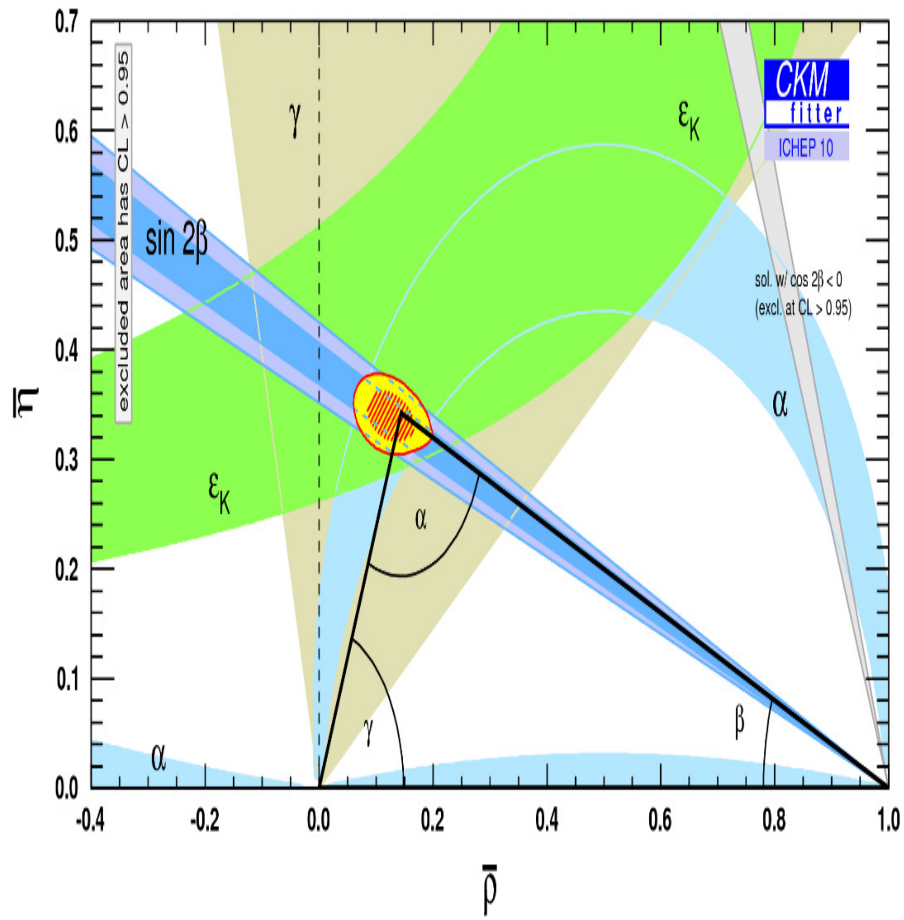
Kobayashi & Maskawa
Nobel Prize 2008

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

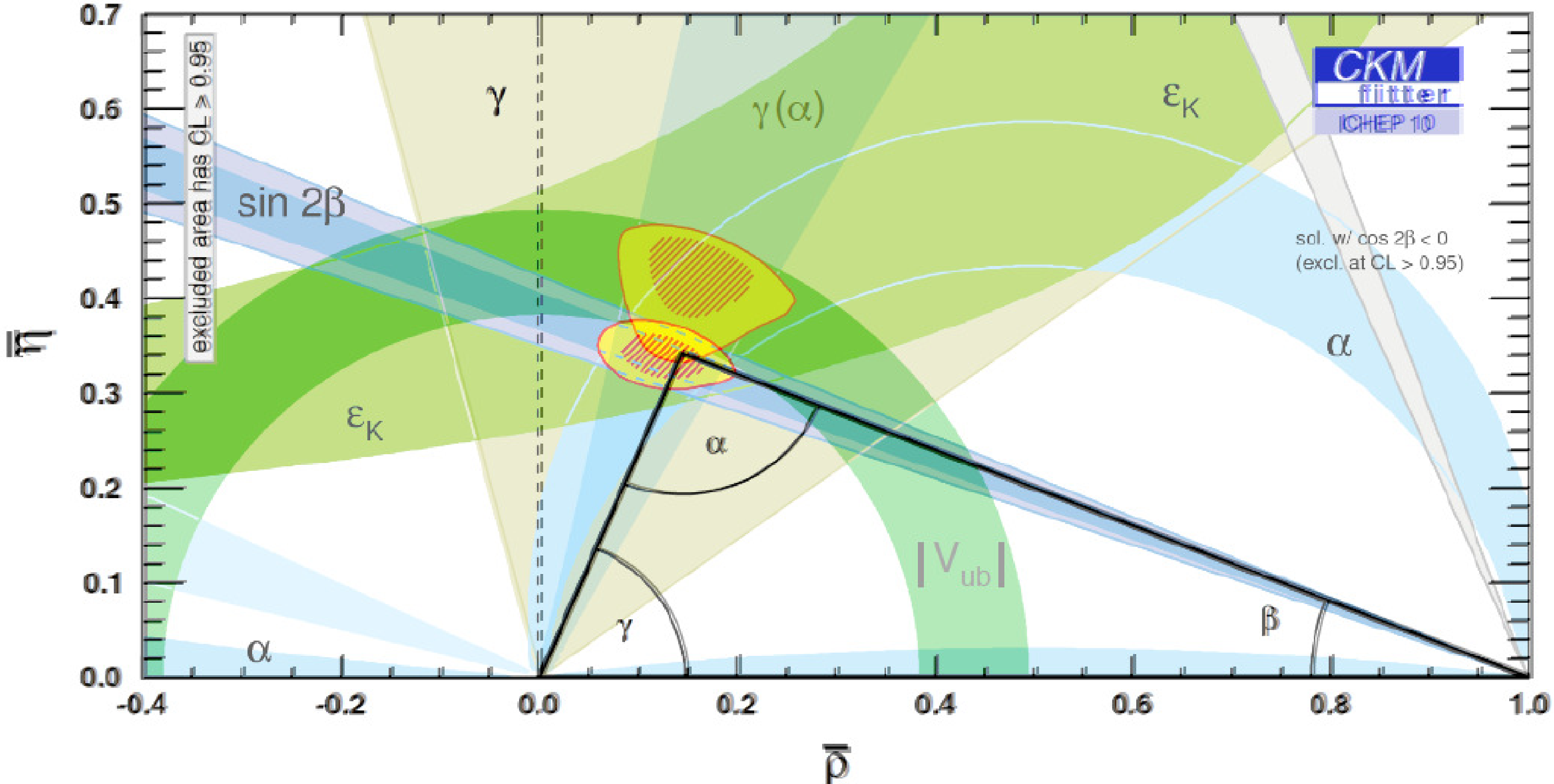




(γ poorly determined)

Separating trees and loops

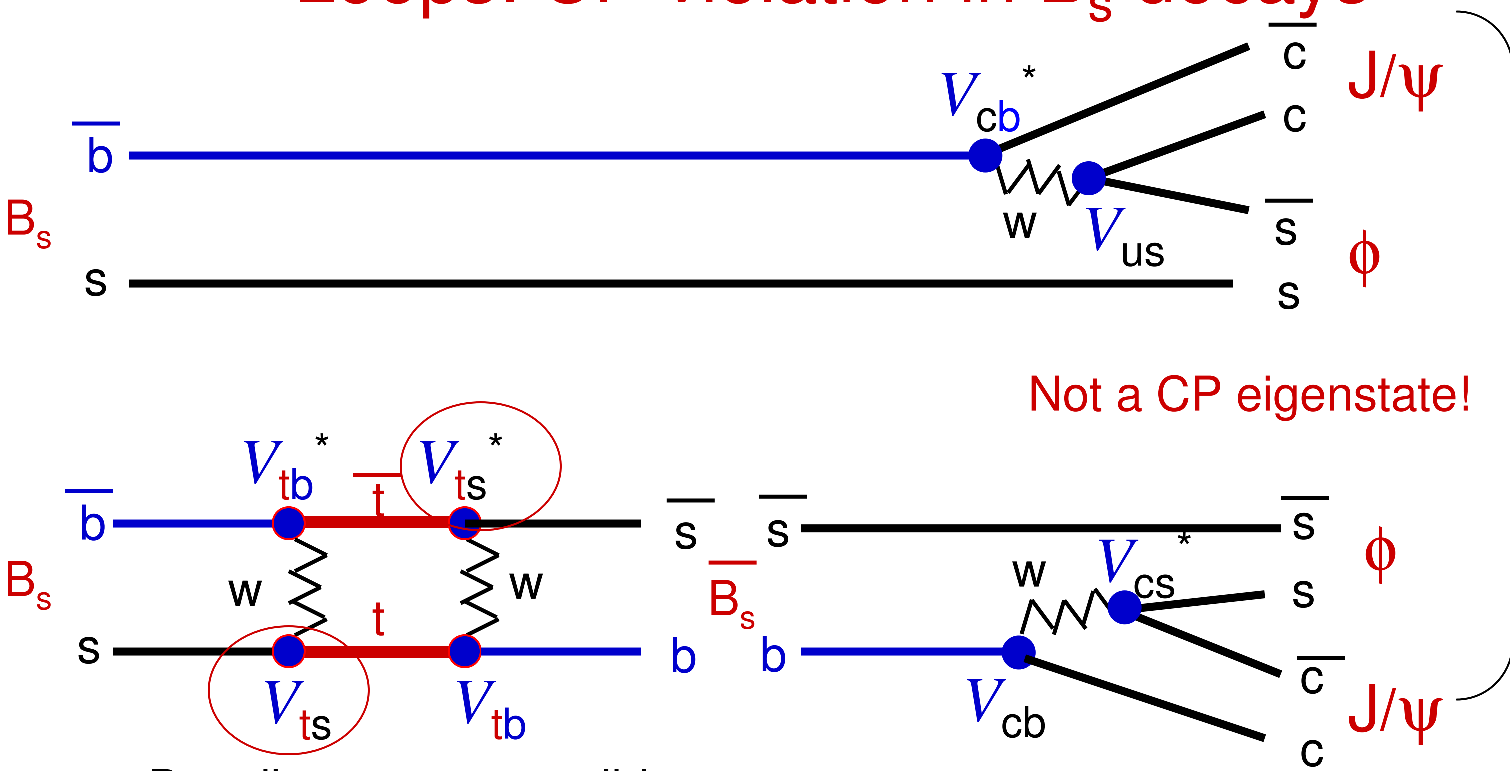
- Tree diagrams are unlikely to be affected by physics beyond the SM
- Loops are more sensitive to NP - CPV in B^0 and K^0 mixing only



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



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

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

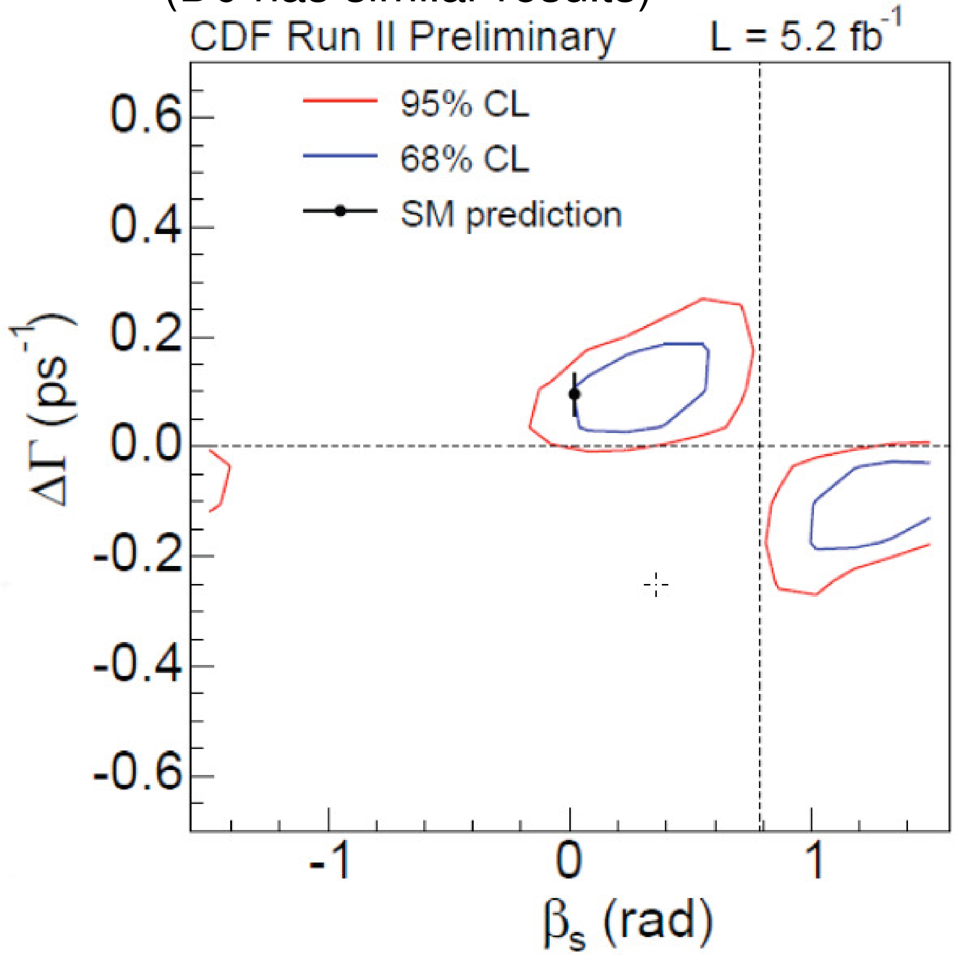
(mixing + decay: "indirect" CPV)

- 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)



$= -\phi_s/2$

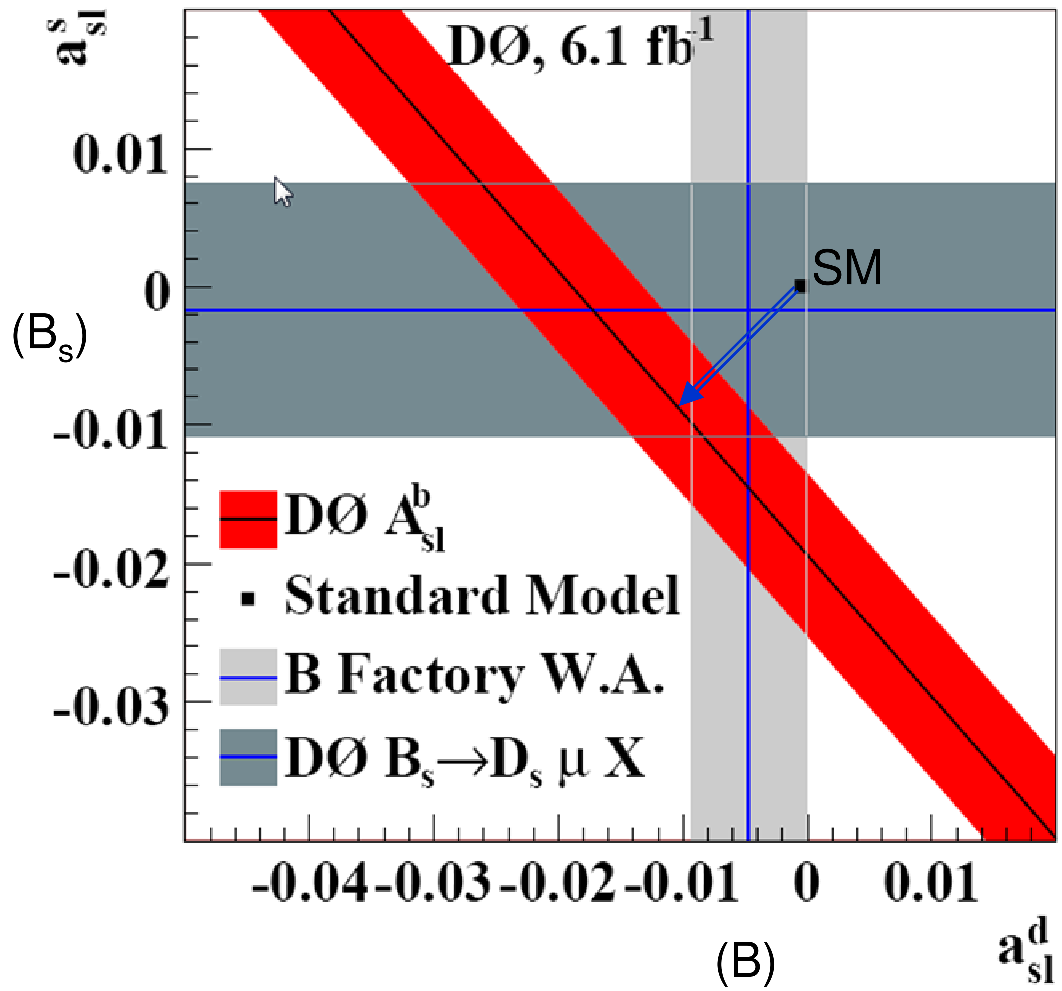
Pretty sizable integrated luminosity for hadron collider!

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

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

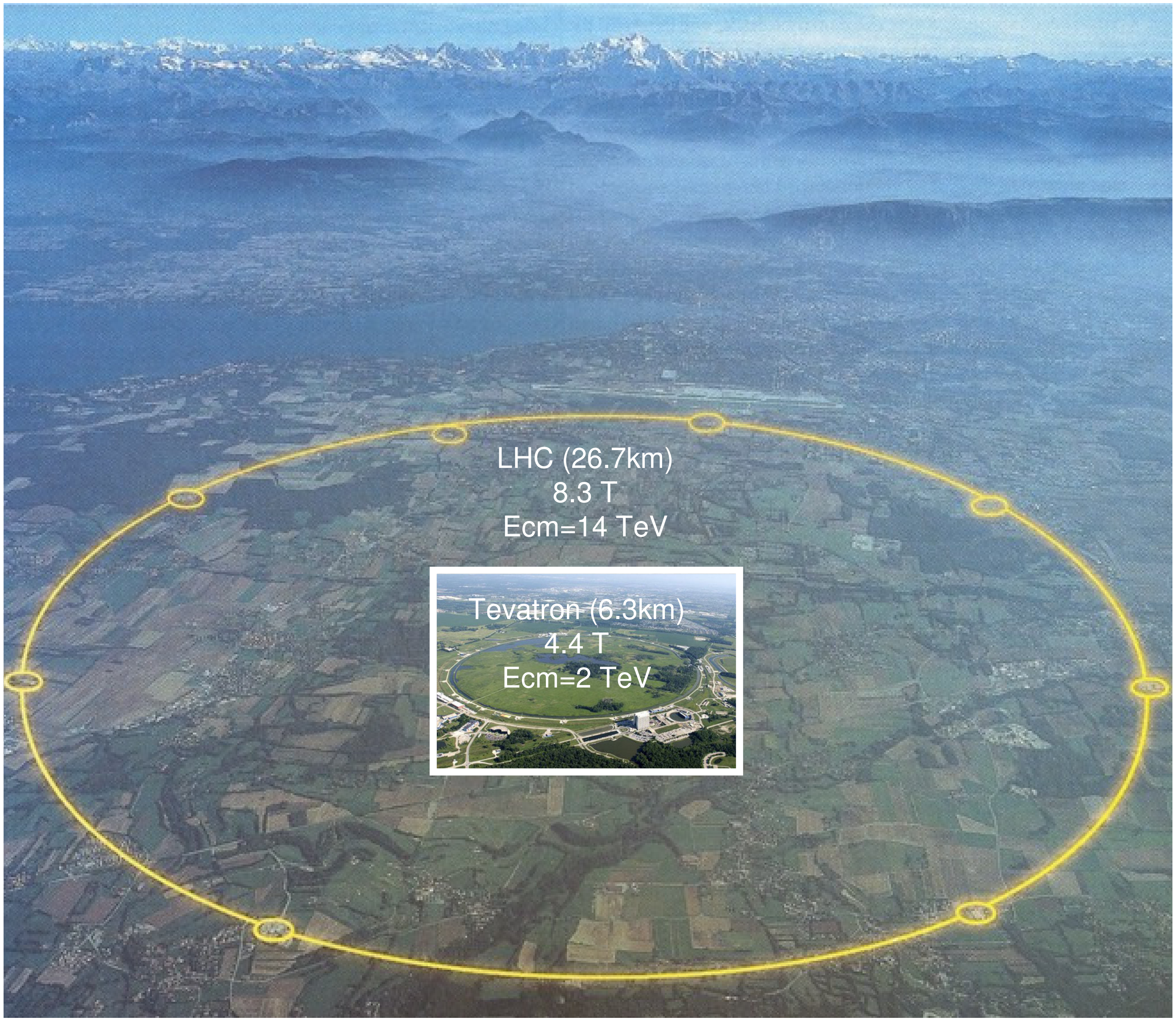


- 3.2σ deviations from the SM !
- Anomalous CPV- 5th force?

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

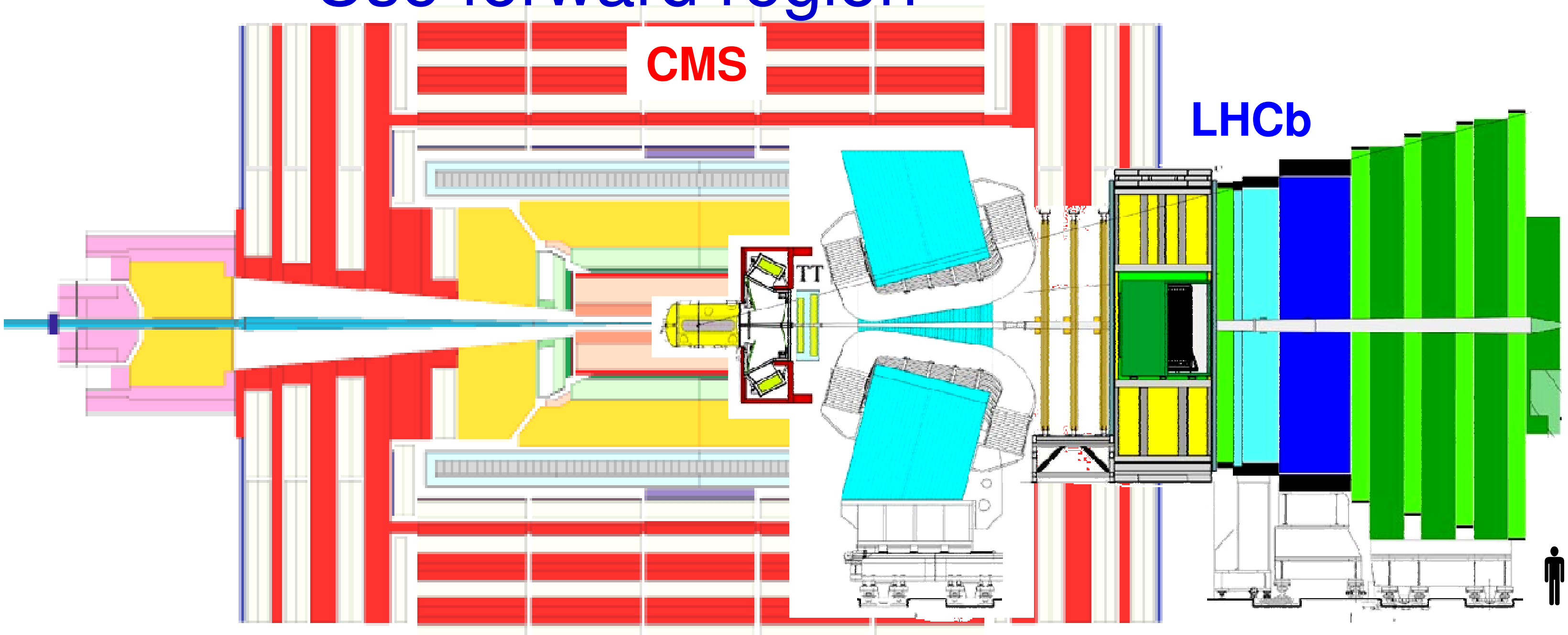
* but only in Europe
~~(BTeV)~~

Increase $b\bar{b}$ 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**

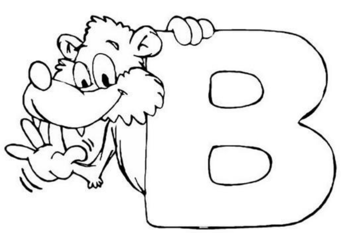
Use forward region



- Capture both b and $\bar{b}$ in **affordable** (75M CHF) solid angle (at $\mathcal{L}$=2x10^{32}/cm^{2}s, we get 10^{12} B hadrons in 10^7 sec; 20kHz)
- Single arm to have space for more detector layers: Particle ID (K/π/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 (40 fs)

B trigger happy!

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



	CDF	LHCb (future running)
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**	**2 000 Hz**
Event size	250 kB	35 kB
Type	Computer farm	Computer Farm (full event reco)
Fraction of bandwidth for heavy flavors	small	all

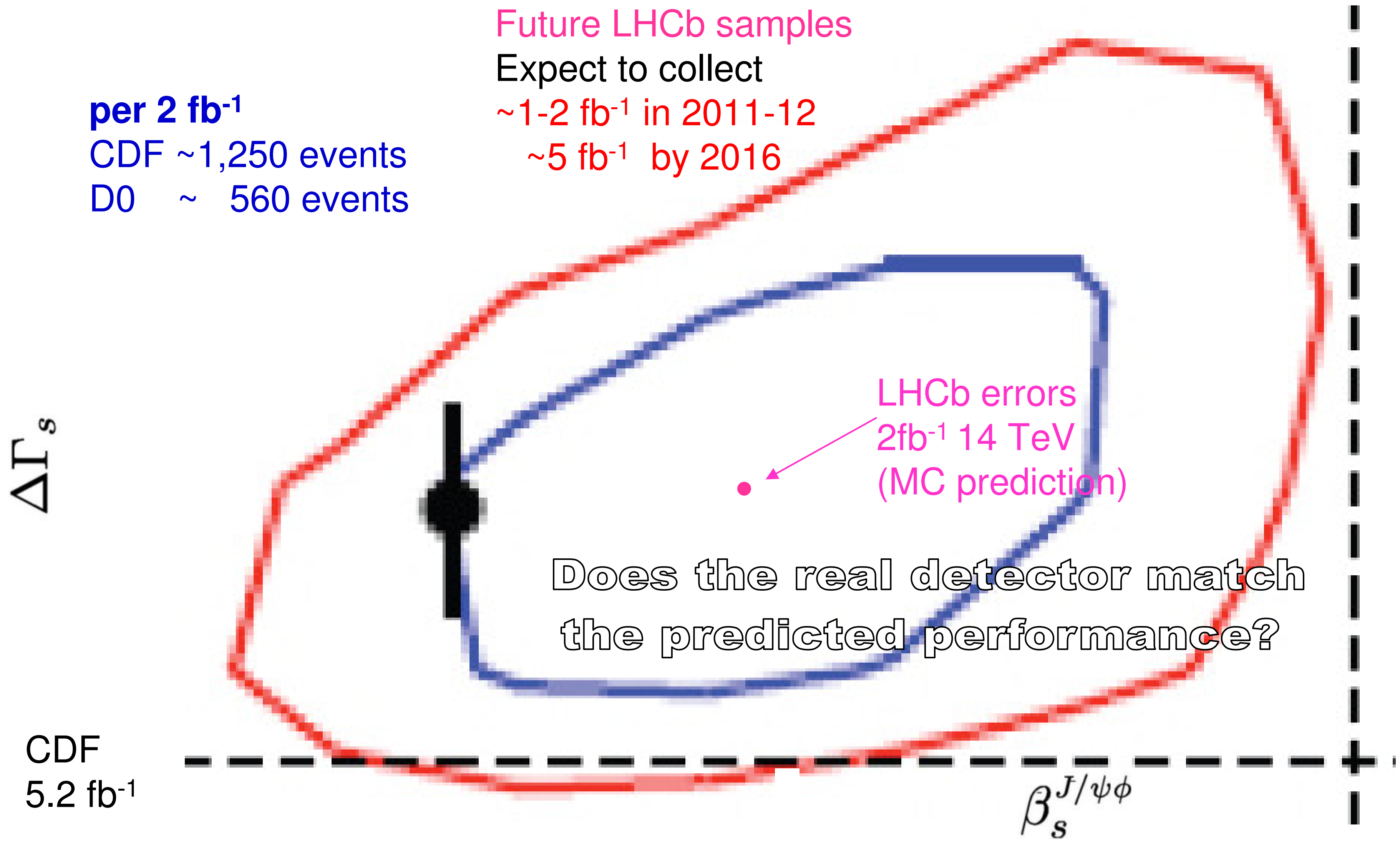
- LHCb is the first dedicated hadron collider b-experiment

LHCb sensitivity to β_s

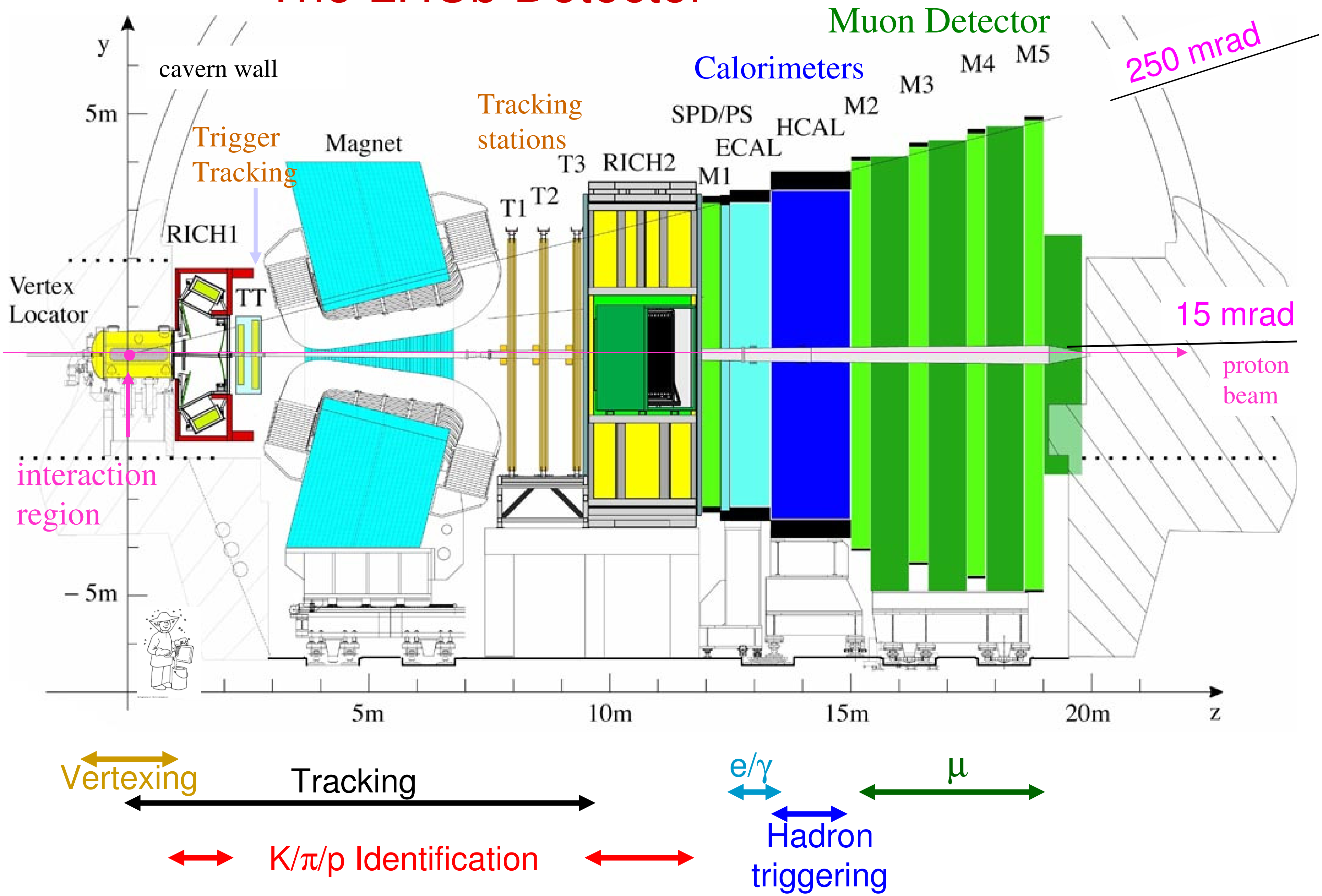
- LHCb will get 131,000 such events in 2 fb^{-1} at 14 TeV. Projected errors are ±0.03 rad in $2\beta_S$ & ±0.013 in $\Delta\Gamma_S/\Gamma_S$

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

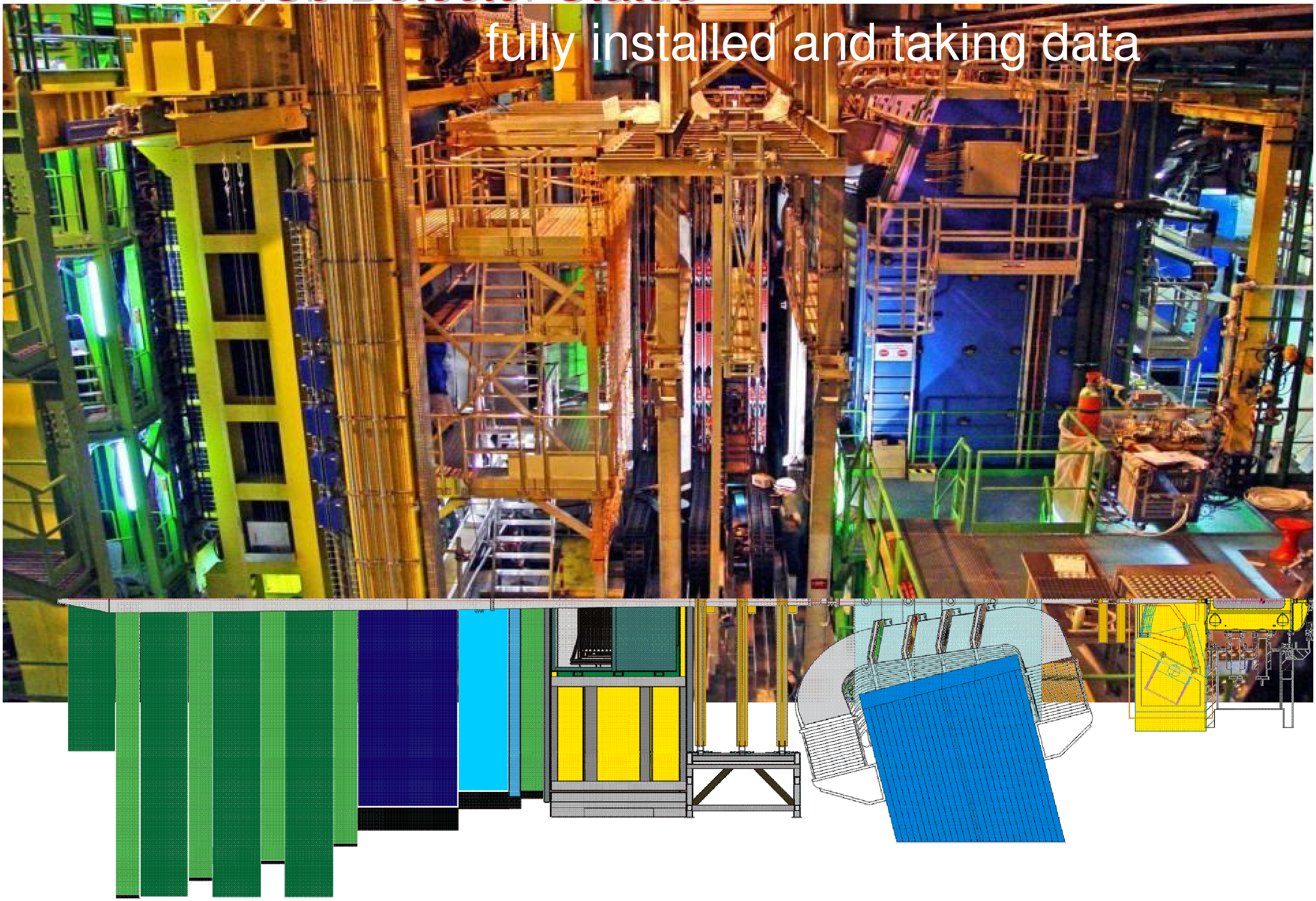
Future LHCb samples
Expect to collect
~1-2 fb^{-1} in 2011-12
~5 fb^{-1} by 2016



The LHCb Detector



LHCb Detector Status

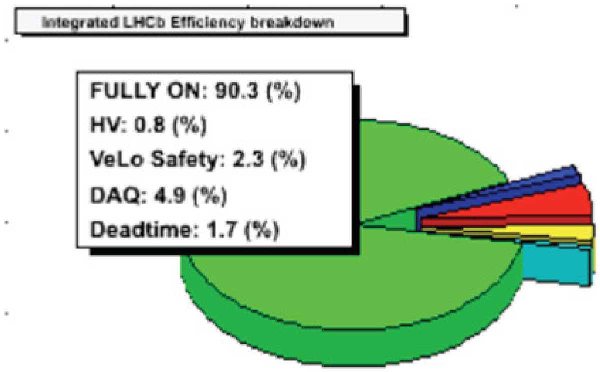


2010 data samples

For updates see:
http://lpc.web.cern.ch/lpc/lumiplots.htm

42.15 pb^{-1} delivered

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



Conversions:

1 pb^{-1} = 1/1000 fb^{-1}

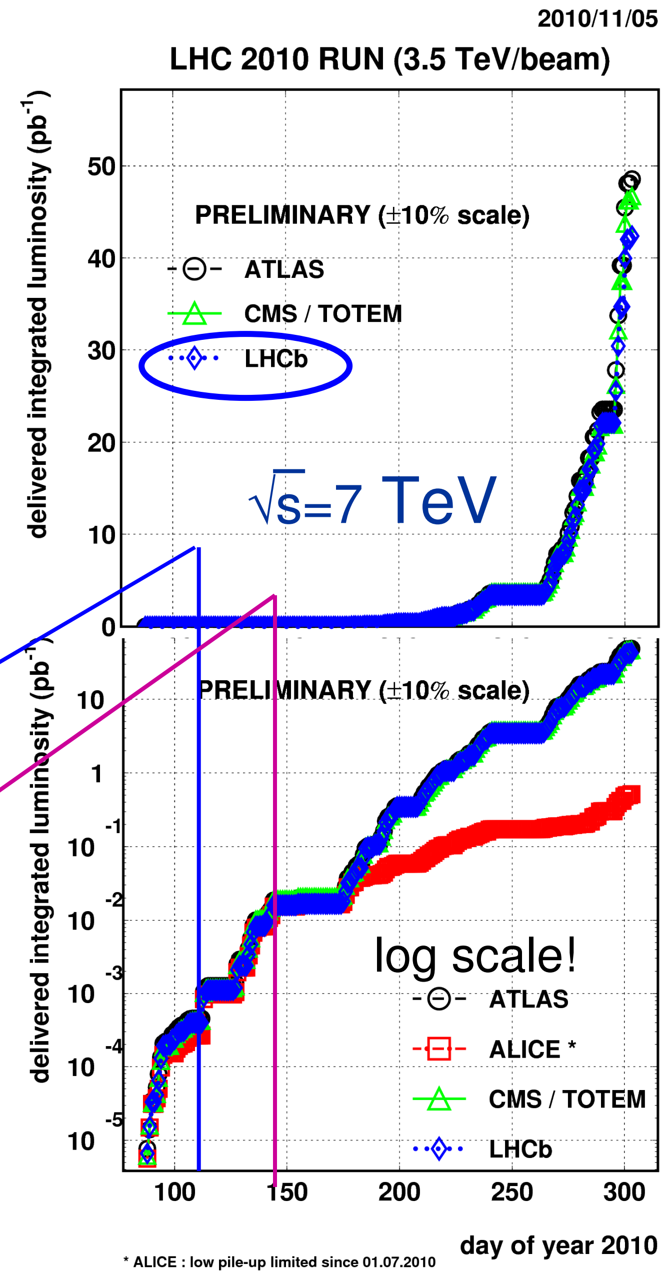
1 nb^{-1} = 1/1000 pb^{-1}

- Numerical results presented in this talk are based on a negligible fraction (<1/1000) of the data recorded up to date

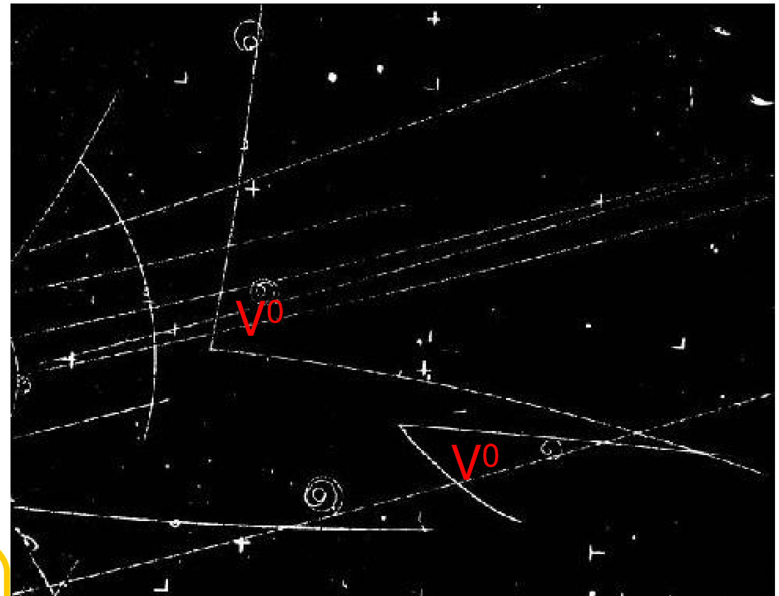
0.3-3 nb^{-1} min.bias trigger

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

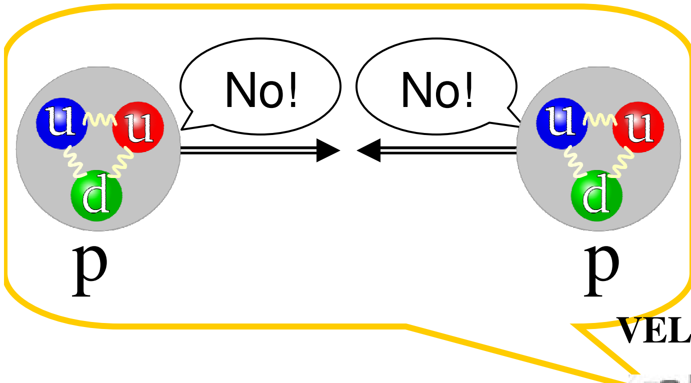
Also ~0.2 nb^{-1} (min.bias trigger) at $\sqrt{s}$=0.9 TeV



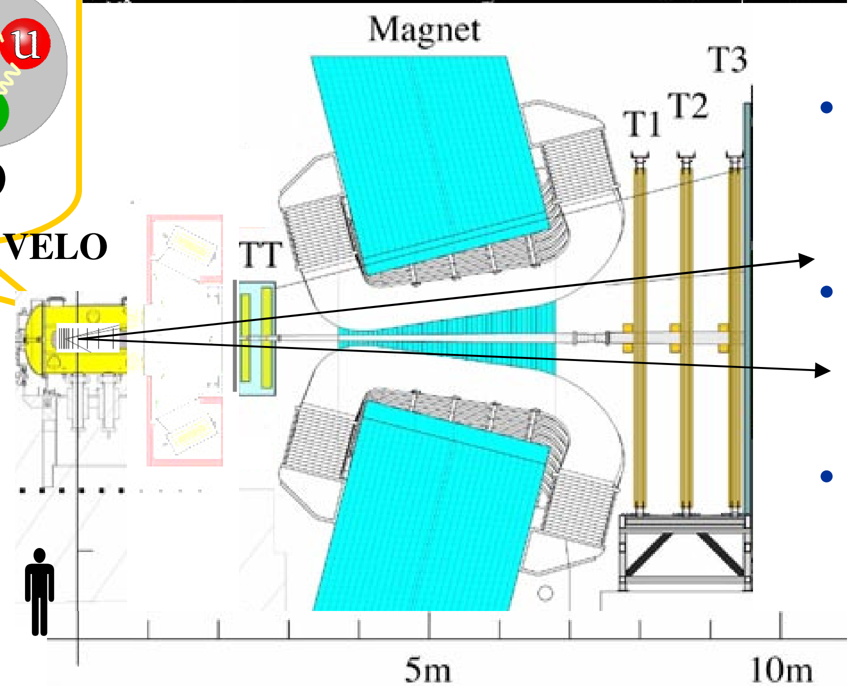
Tracking system test - Strange V^0s



$$\Lambda \rightarrow p\pi^-$$
$$\overline{\Lambda} \rightarrow \overline{p}\pi^+$$
$$K^0_S \rightarrow \pi^+\pi^-$$



Good probe for fragmentation processes



- Long lifetime → clean signals with no PID
- Copiously produced (1 per event)
- Good exercise of the **tracking system** in early data

Λ analysis (selection)

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- Opposite sign charged tracks missing the primary vertex (PV), creating a secondary vertex pointing back to the PV, with $M(\pi^+\pi^-)$ inconsistent with K^0_S
- Contribution of diffractive processes suppressed by PV reconstruction

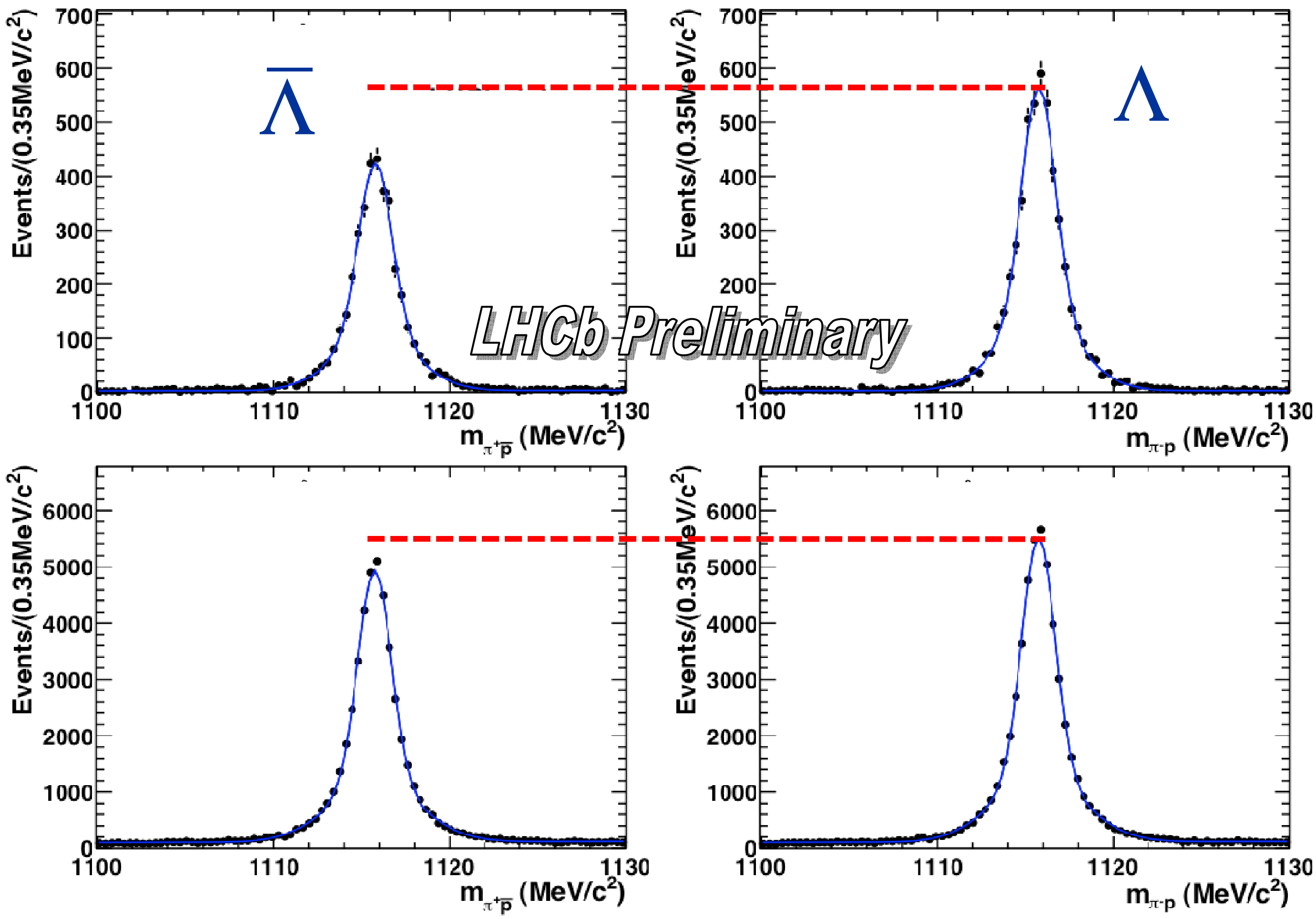
0.9 TeV

$\int L \sim 0.3\ nb^{-1}$

$\sqrt{s}$

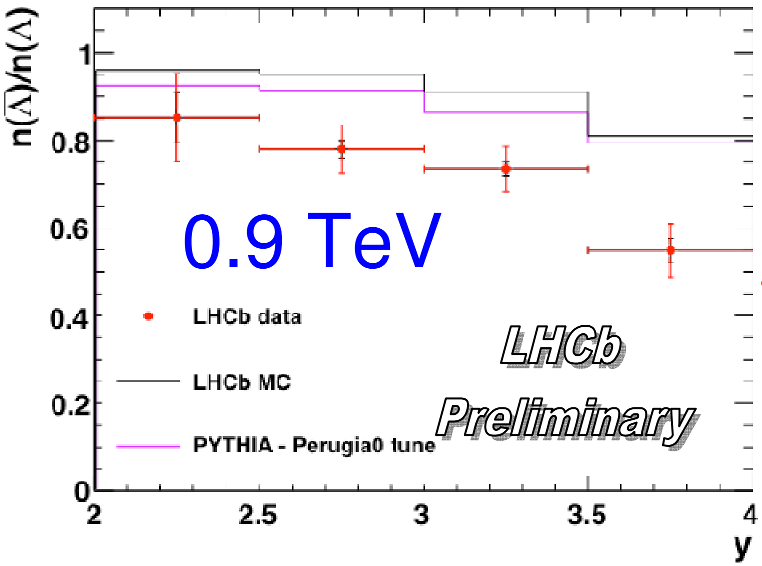
7.0 TeV

$\int L \sim 0.2\ nb^{-1}$



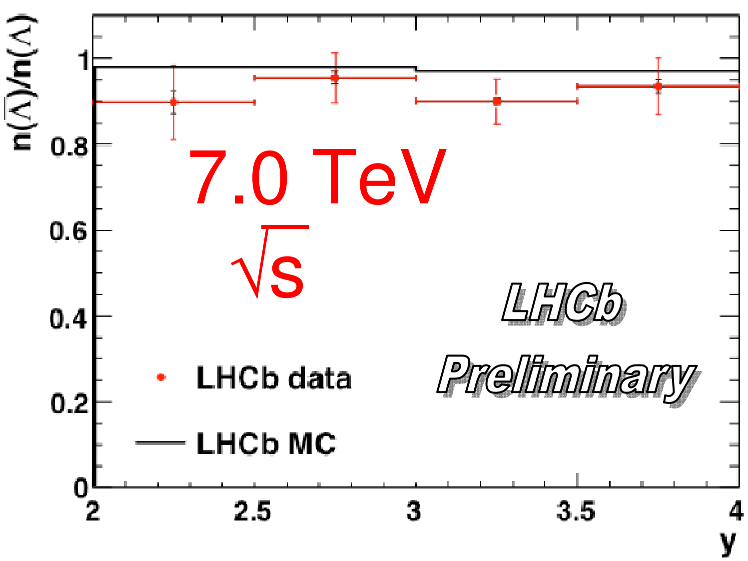
Λ analysis (results)

Efficiency corrected ratio, in rapidity bins:

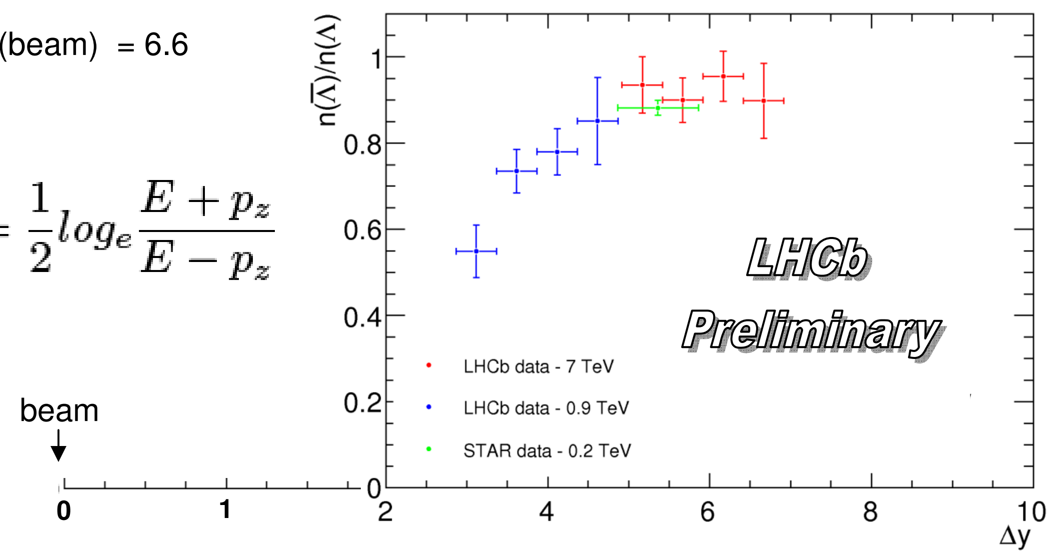


- At 0.9 TeV:
  - **Previously unexplored region very close to the beam**
  - **Effect of the beam baryon number propagating to Λ clearly visible (can distinguish different models of colour flow)**
  - Data tend to be lower than both PYTHIA tunes
- At 7.0 TeV
  - Data in fair agreement with the predictions, and the previous measurement
  - Further away from the beam, less asymmetry

y(beam) = 6.6



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



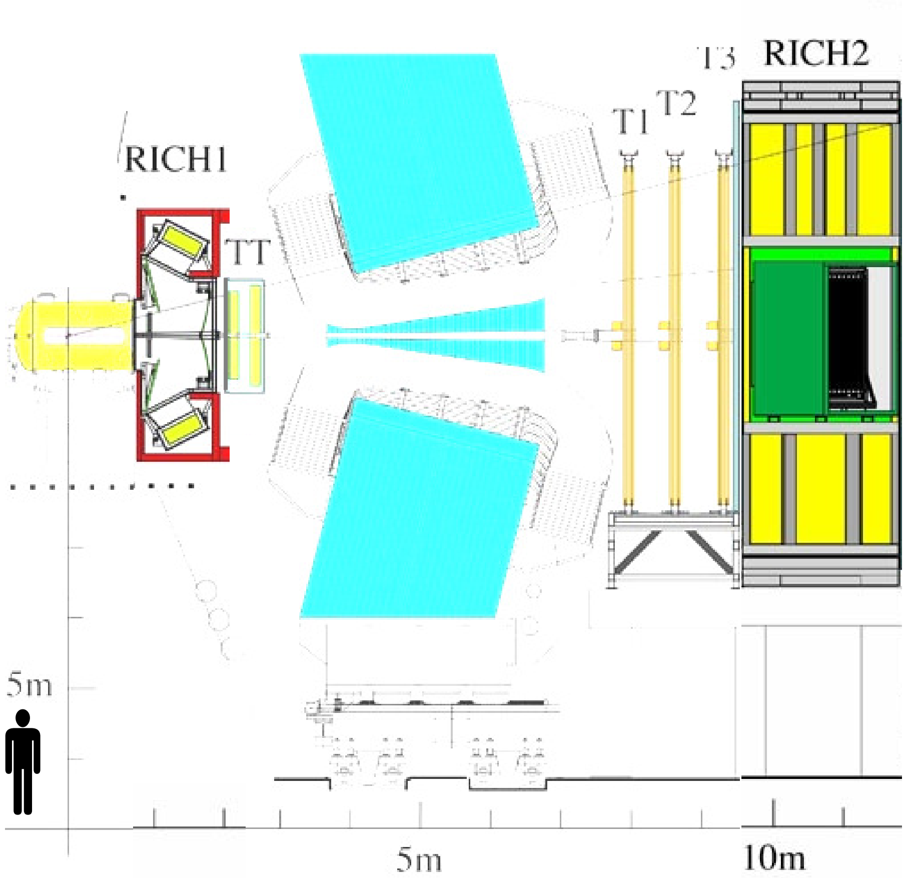
y(beam) = 8.3

Δy = y(beam) – y(Λ)

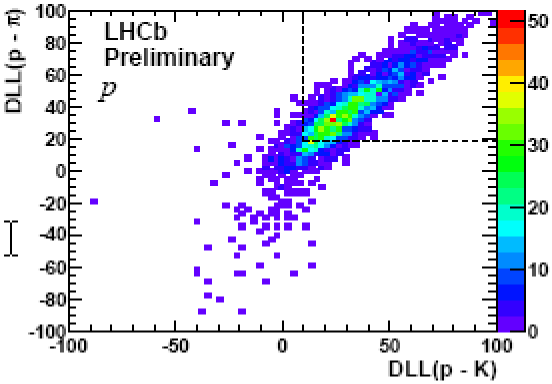
RICH test - p/$\overline{\text{p}}$ analysis

Calibration signals

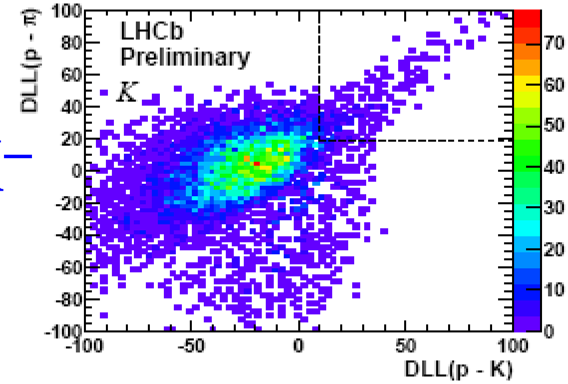
- Separate p/K/π using the **RICH detectors.**



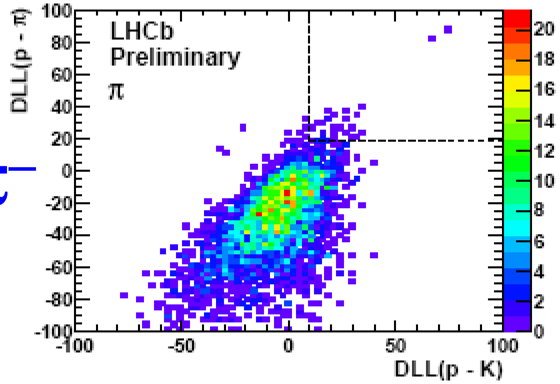
$\Lambda \rightarrow p\pi^-$



$\phi \rightarrow K^+K^-$

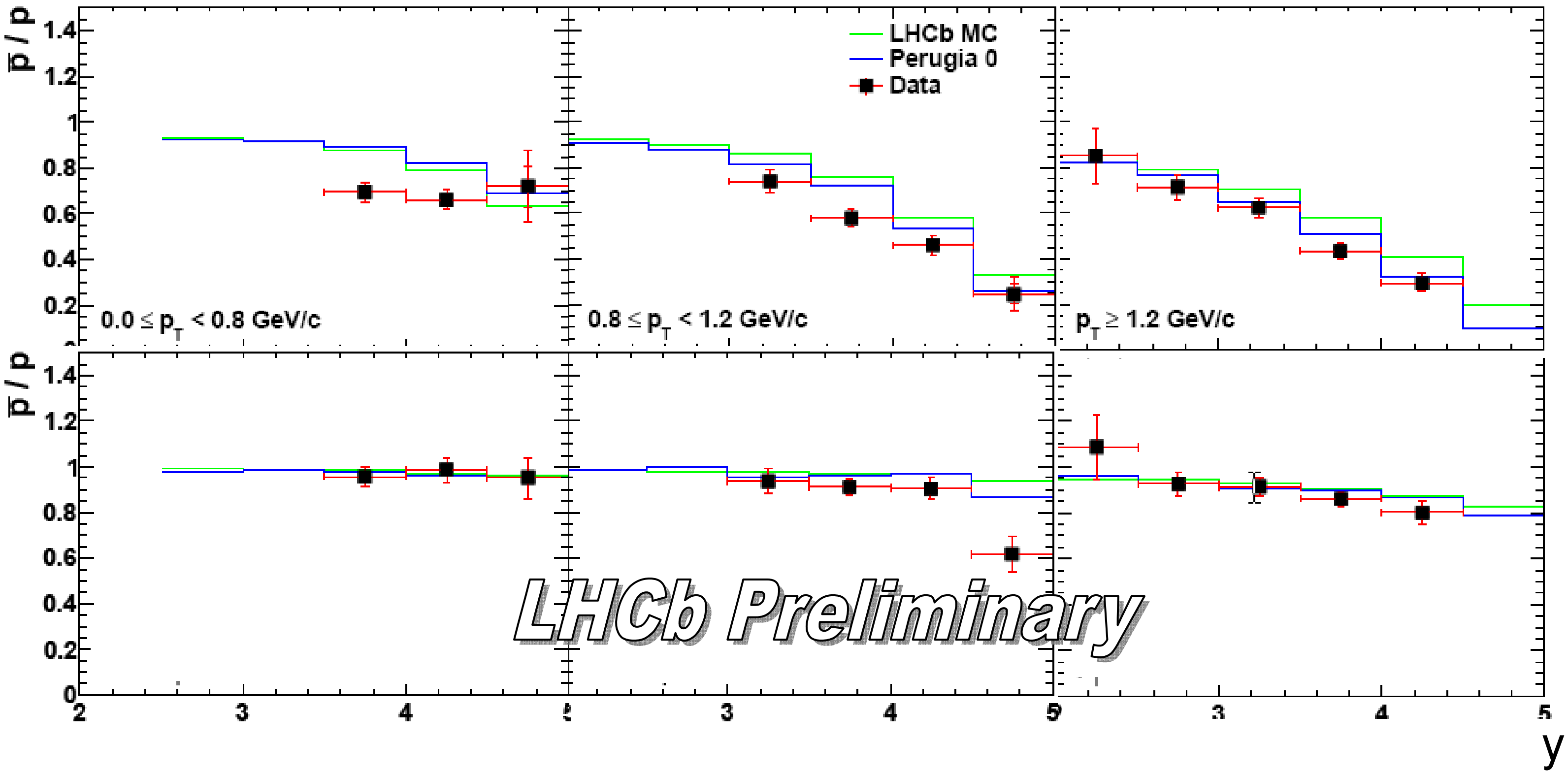


$K^0_S \rightarrow \pi^+\pi^-$



LHCb-CONF-2010-09

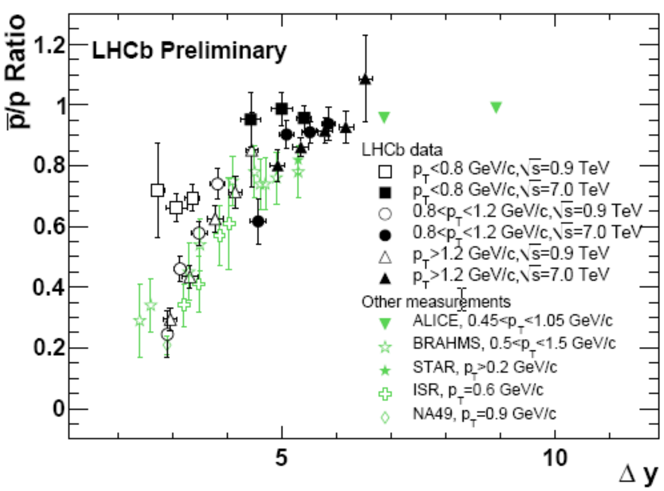
$\bar{p}/p$ analysis (results)



0.9 TeV

$\sqrt{s}$

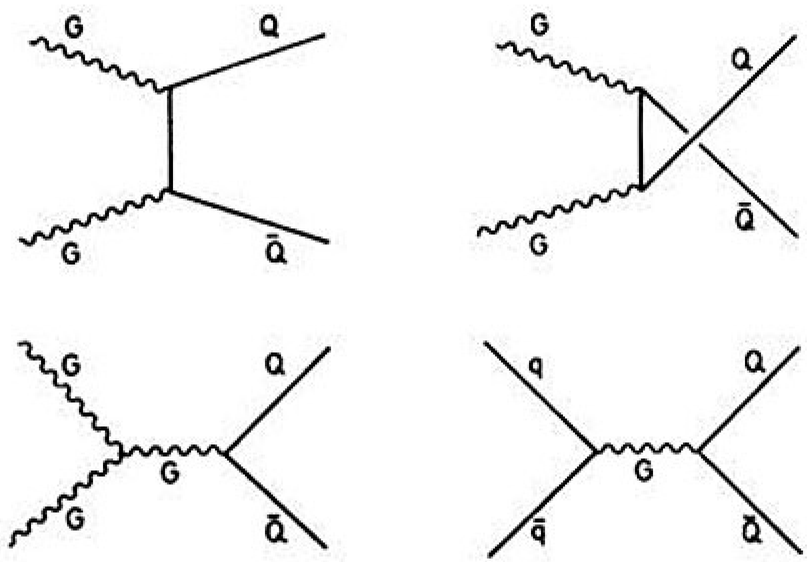
7.0 TeV



- Data in fair agreement with the predictions and with the other experiments

Charm cross-sections

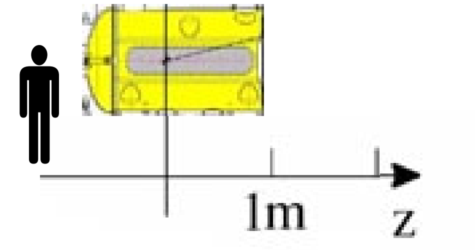
- Forward direction is unexplored domain.
- LHCb core program includes exciting charm physics topics (mixing, CP-violation, rare decays).
- Testing hard production mechanisms also relevant for b-quarks

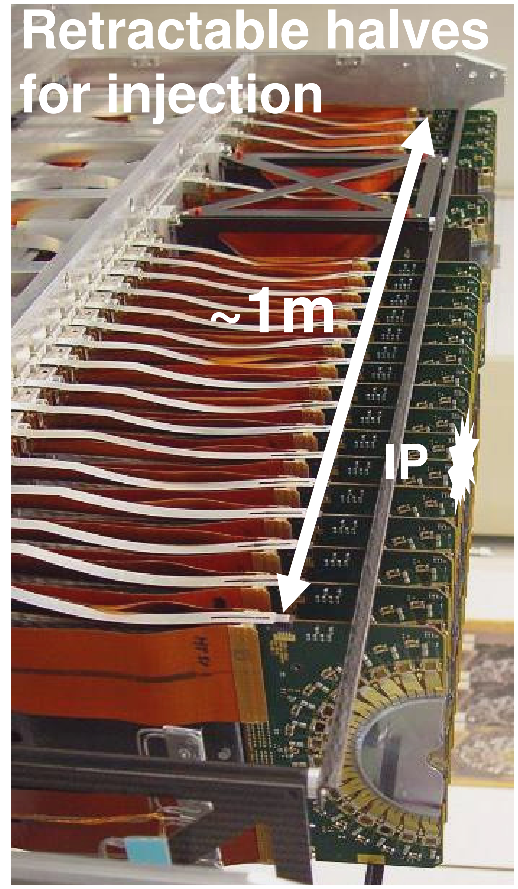


- Practicing analysis techniques also applicable to b-physics

Open charm selection

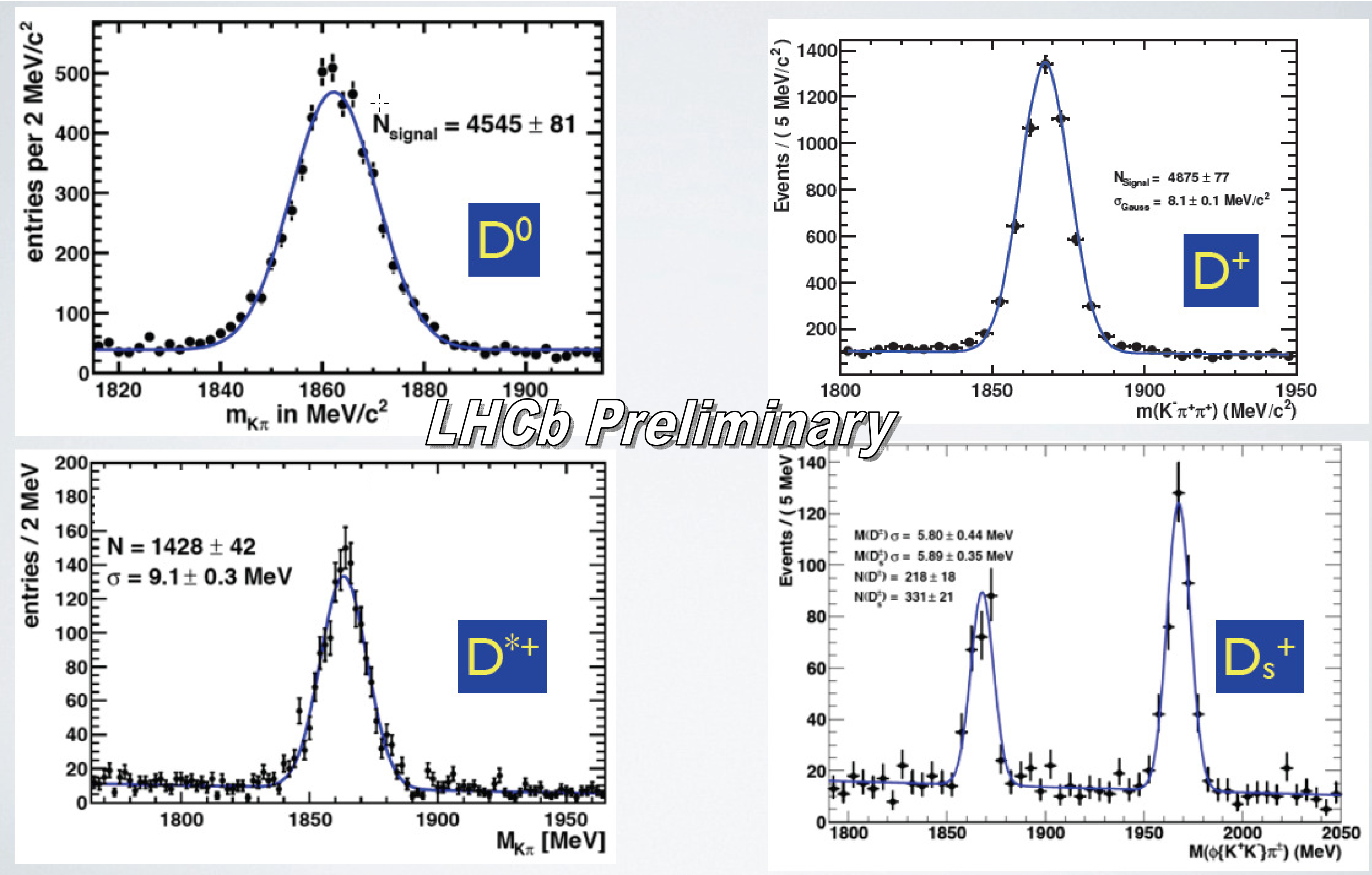
- Short but detectable lifetime:
  - $c\tau$ = 2.7cm K^0_S, 7.9cm Λ
    . rate ~ 1/1 per event
  - $c\tau$ = 0.12cm D^0
    . rate ~ 1/10 per event
  - $c\tau$ = 0.46cm B^0
    . rate ~ 1/100 per event
- Use excellent resolution of VELO to reject light quark backgrounds:
  - Daughter charged tracks must:
    - miss PV
    - meet each other to form secondary vertex
  - The charm meson must point to PV
- RICH also plays an important role in many modes (c $\to$ s; charged K ID)



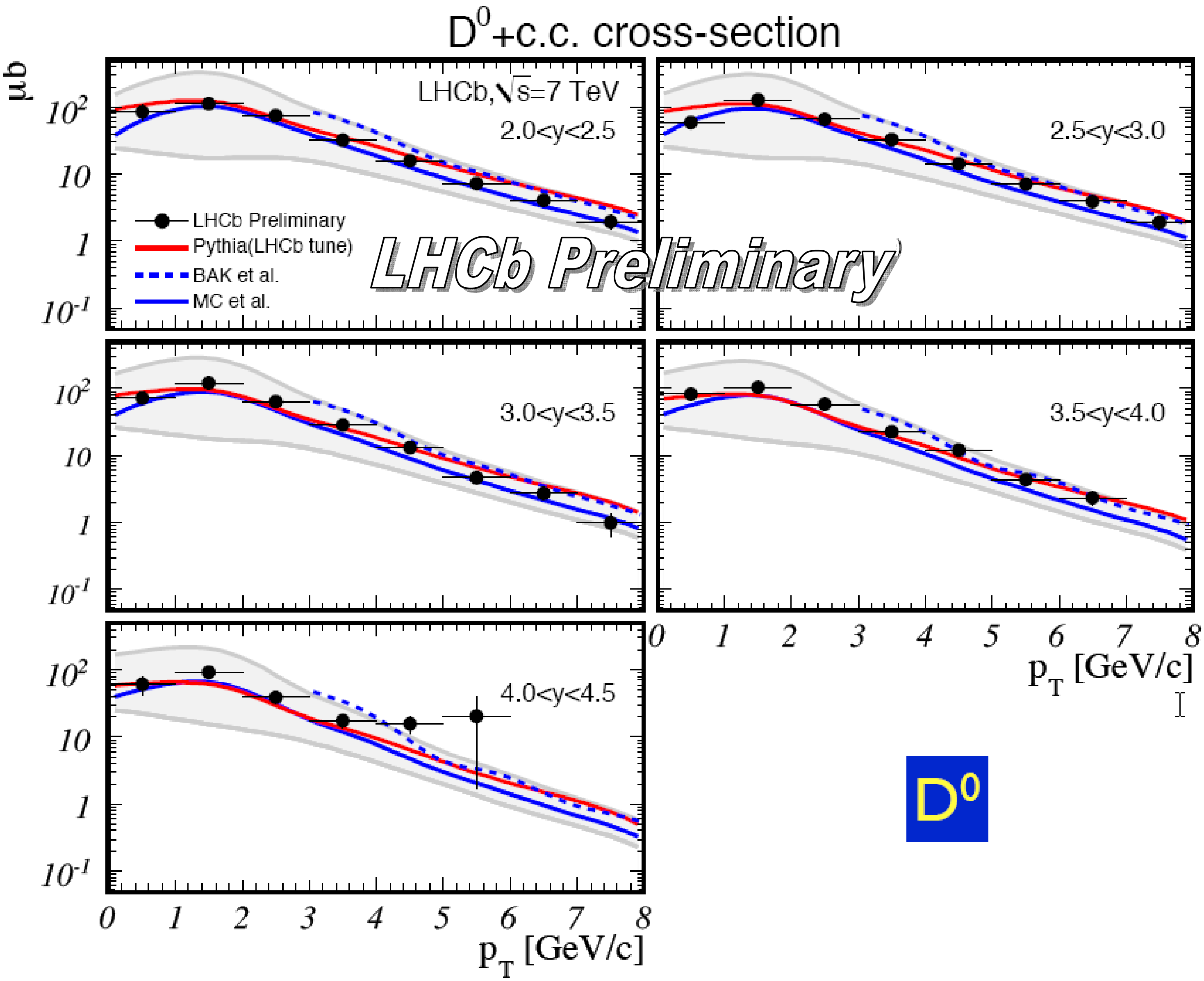


Charm signals

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



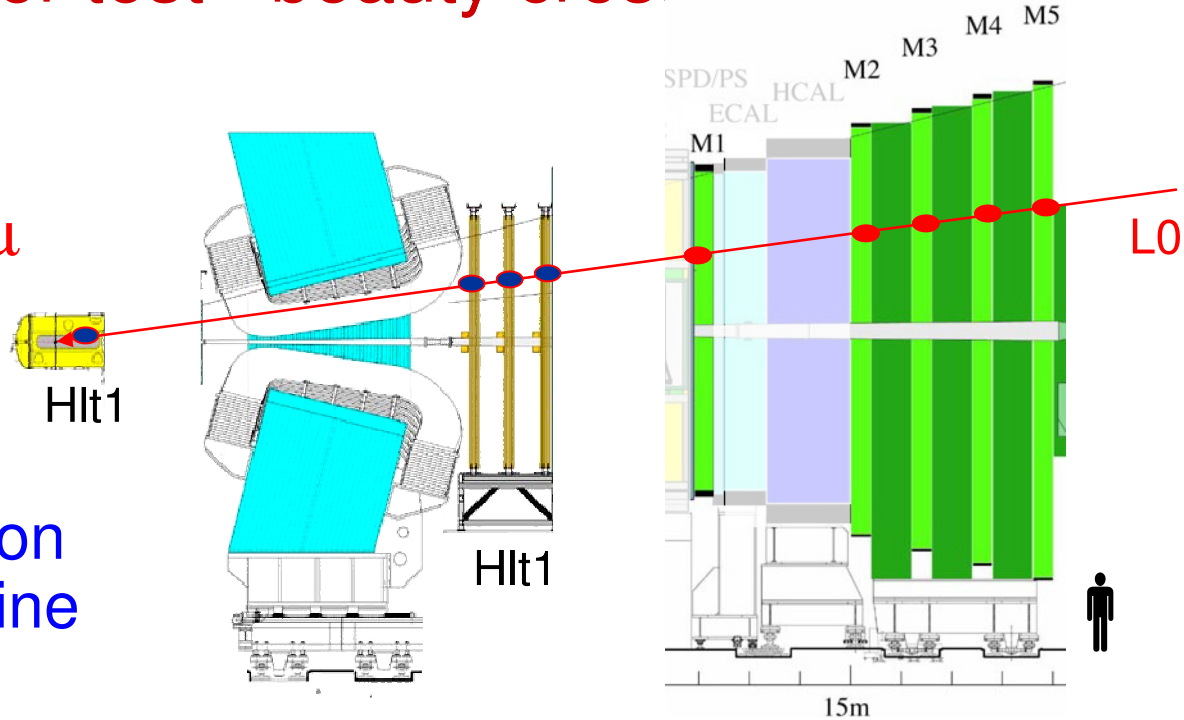
D^0 cross-section results



- Good agreement with the expectations

Mu detector test - beauty cross-section

- $b \rightarrow c\mu^- \nu$ ~10%
  - combine D with μ

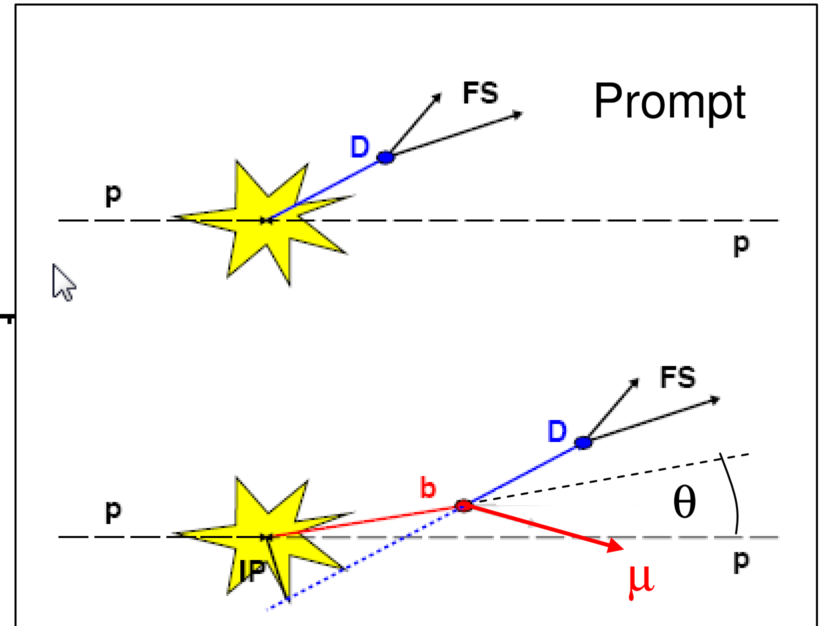


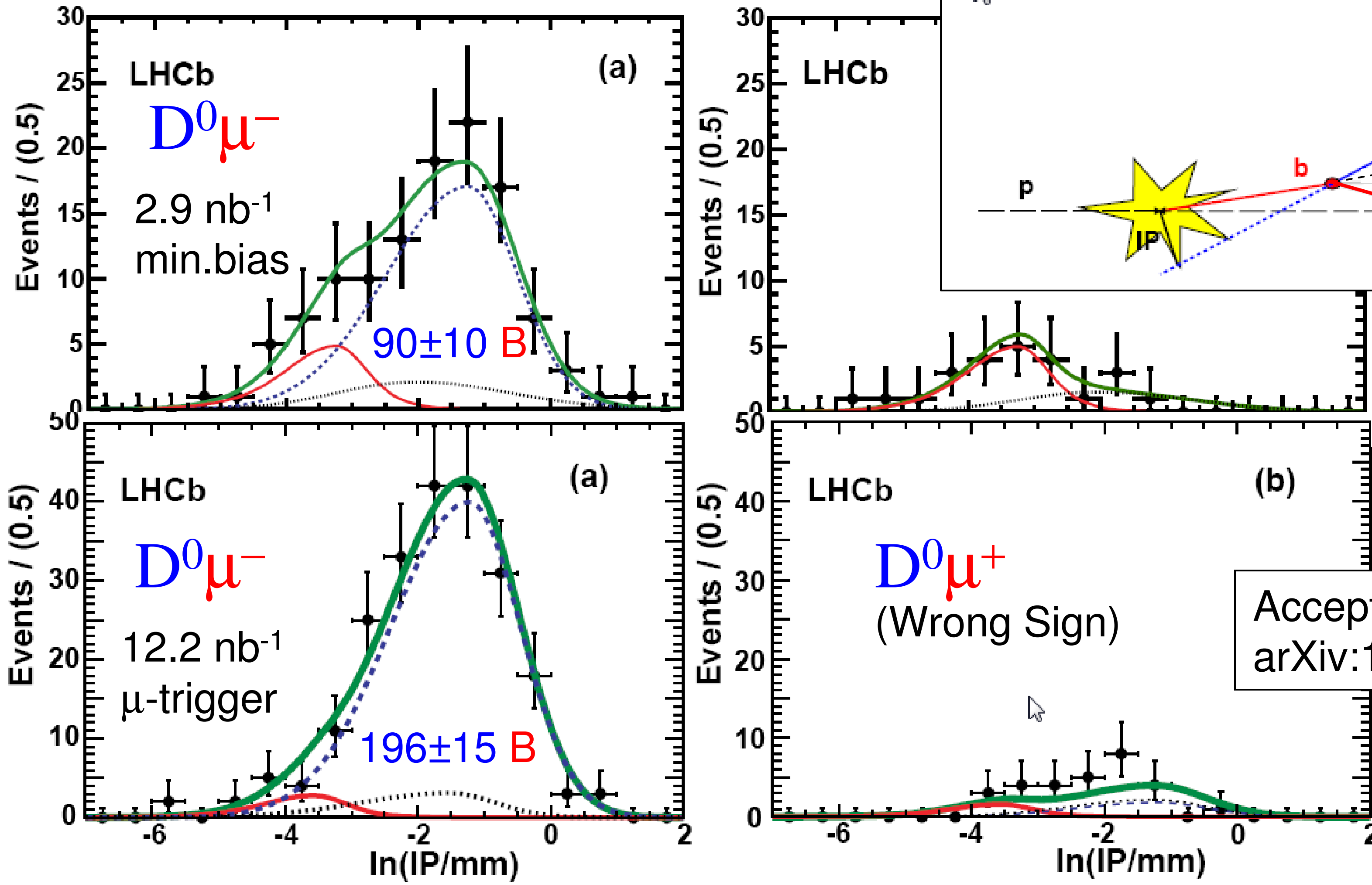
- Muon detector:
  - Low reconstruction thresholds in offline and trigger:
    - p>3 GeV, p_t>0.5 GeV
  - Single- (and di-) muon triggers: p_{t1} $(+p_{t2})$ > 1.3 GeV

- Two data samples:
  - 2.9 nb^{-1} of minimum bias trigger (>=1 Track)
  - 12.2 nb^{-1} single muon trigger

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

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

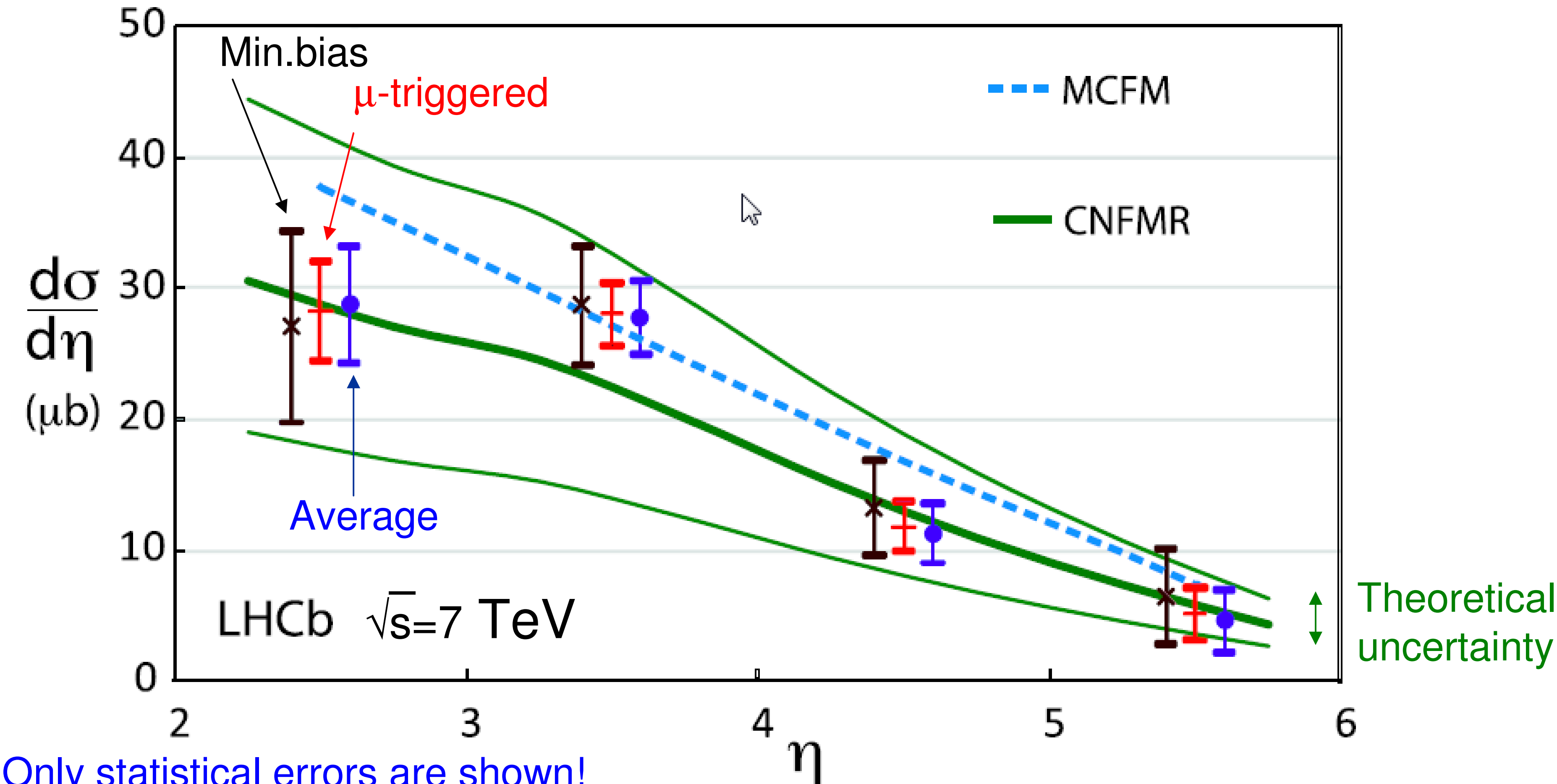




$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

Accepted by PLB
arXiv:1009.2731

$B \rightarrow D^0 \mu^- \nu X$ results



Only statistical errors are shown!

Systematic error: 17% (dominant errors: 10% luminosity, 10% tracking)

- We explored new energy and η domain
- Data consistent with the QCD calculations

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

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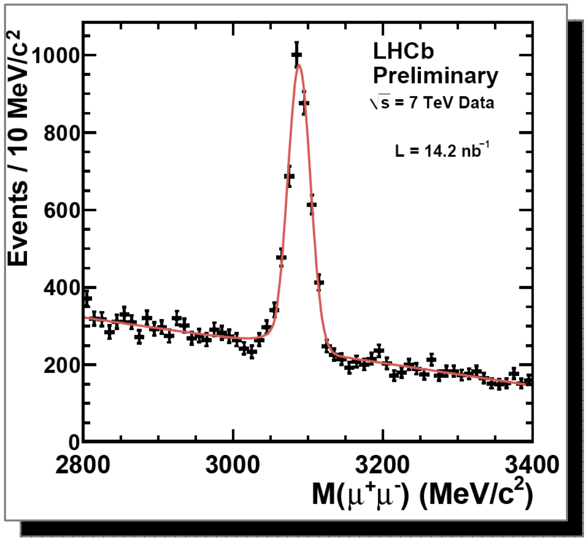
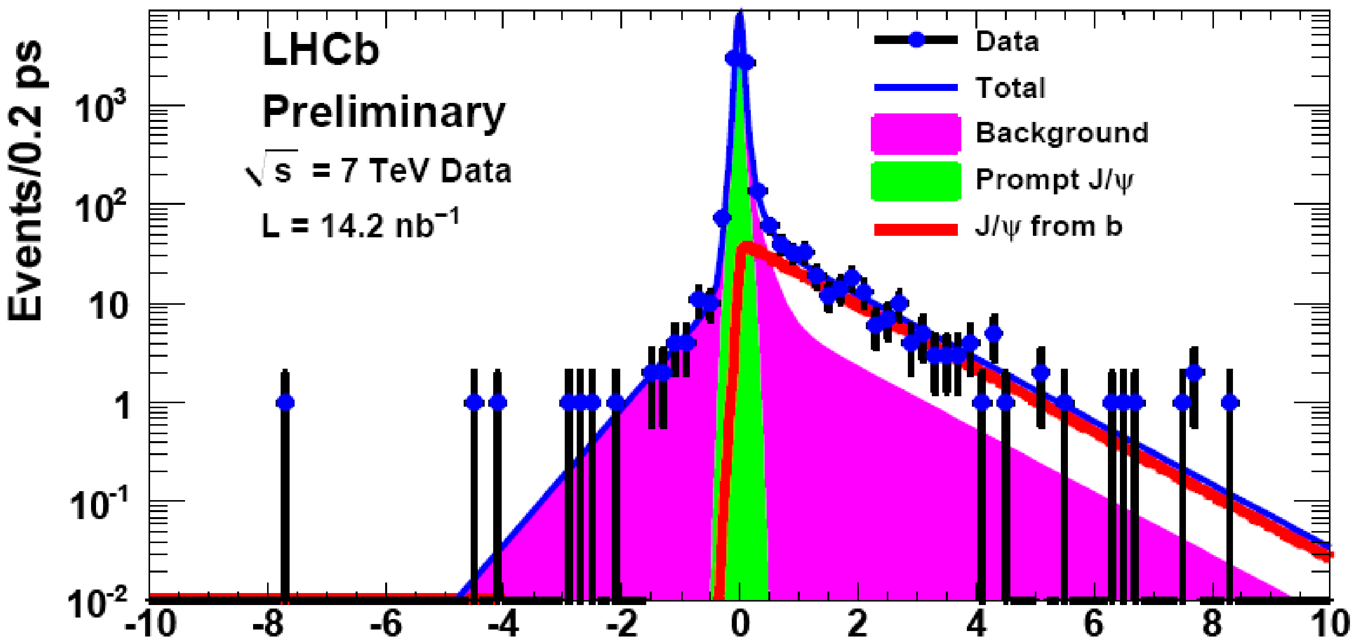
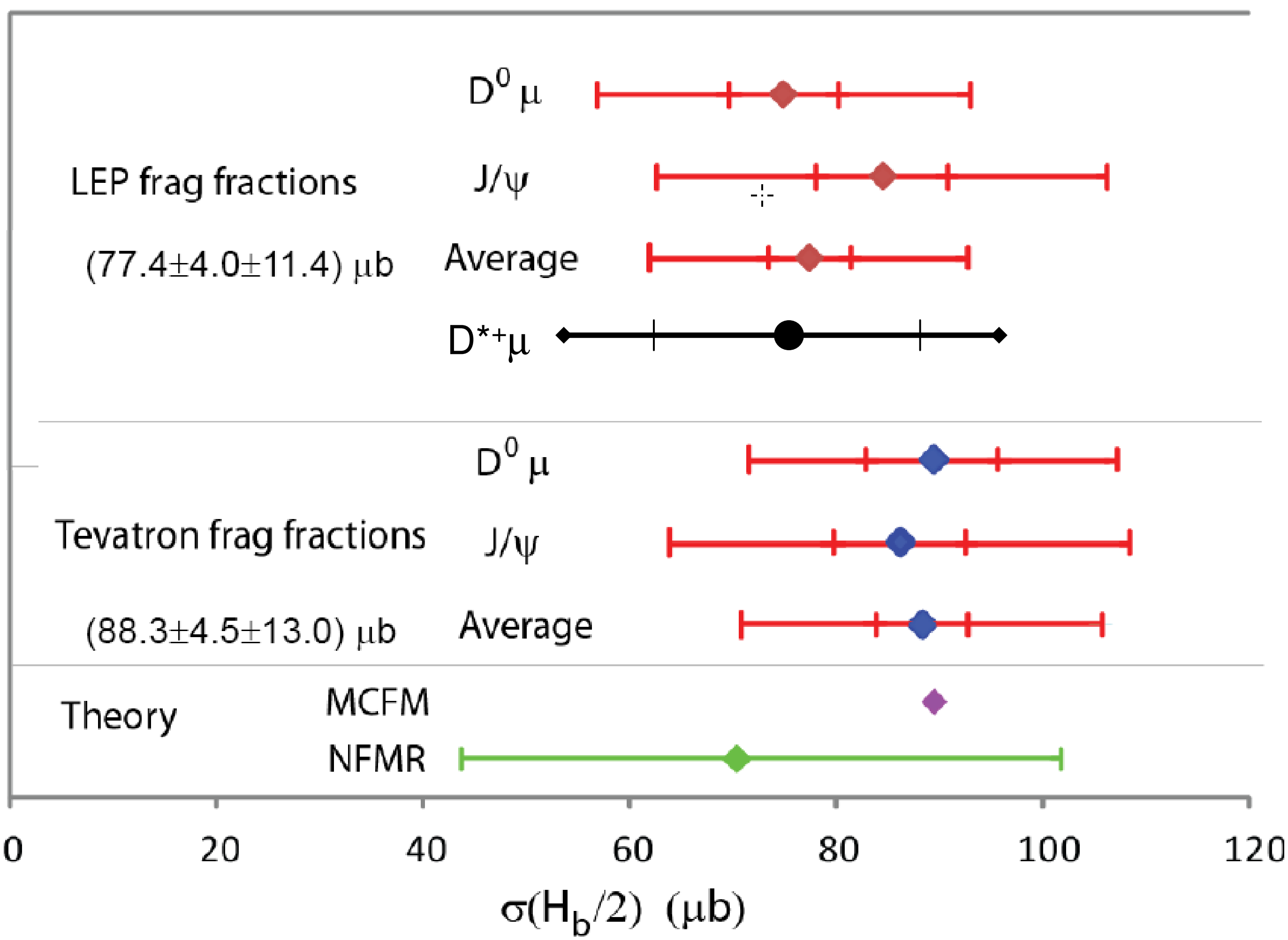
- $BR_{vis} \sim 1.3 \times 10^{-3}$





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

Average beauty cross-section



- $2 < \eta < 6$

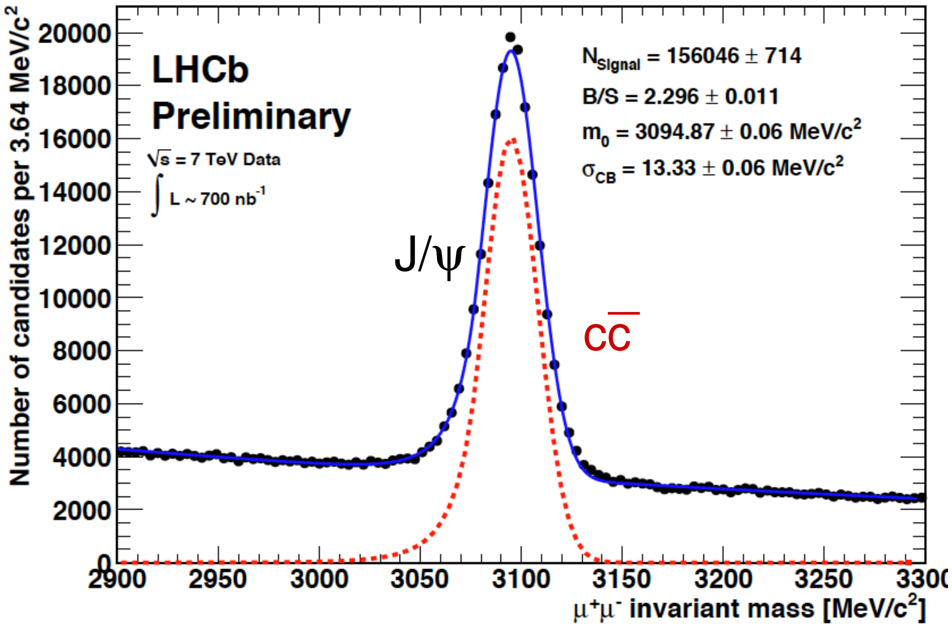
Using Pythia to extrapolate to 4π

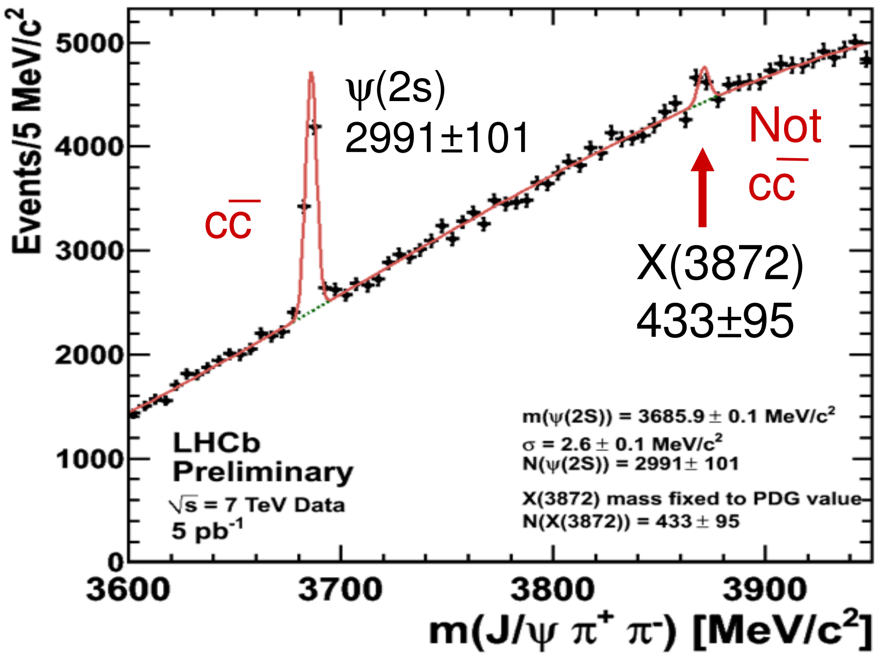
- Total

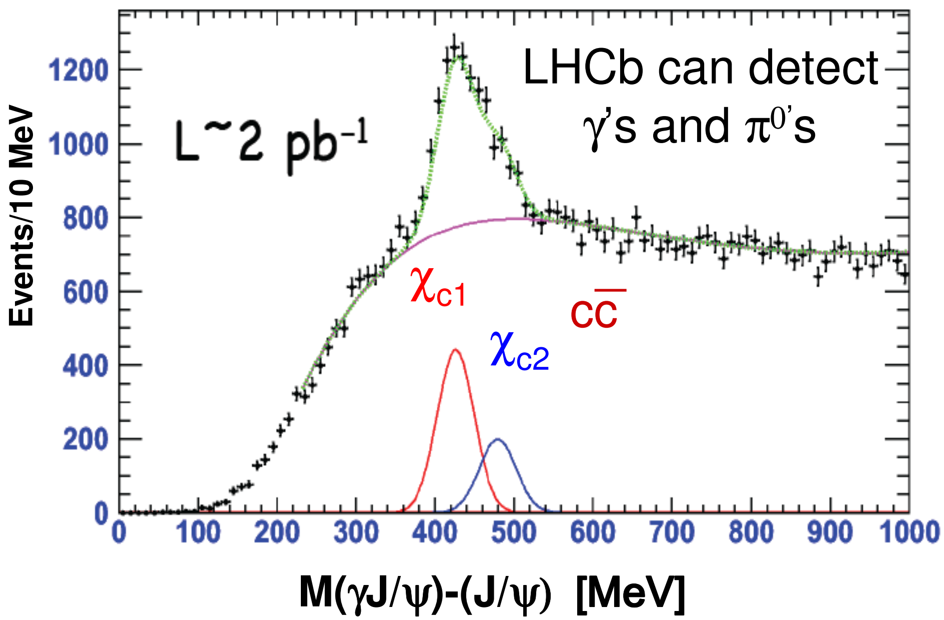
σ = (292±15±43) μb LEP frag

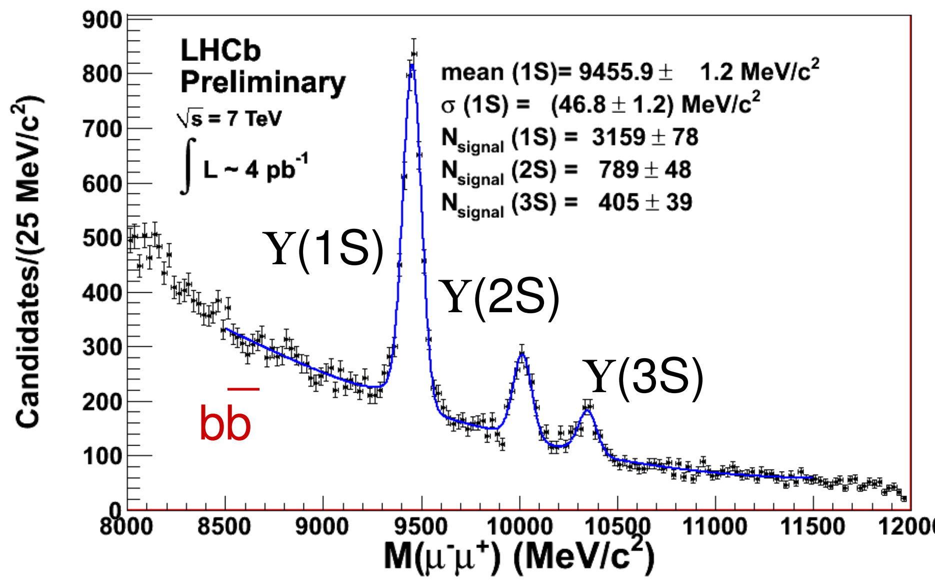
Close to the value we had been using in our estimates of b-physics sensitivity!

More quarkonia in LHCb







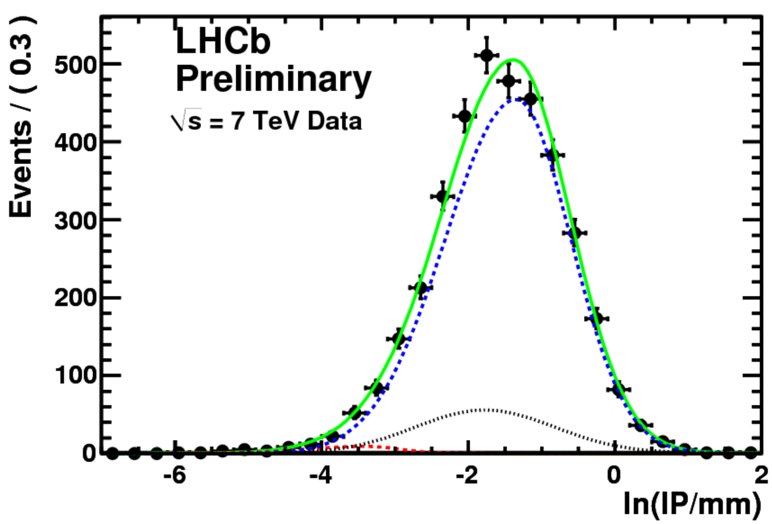


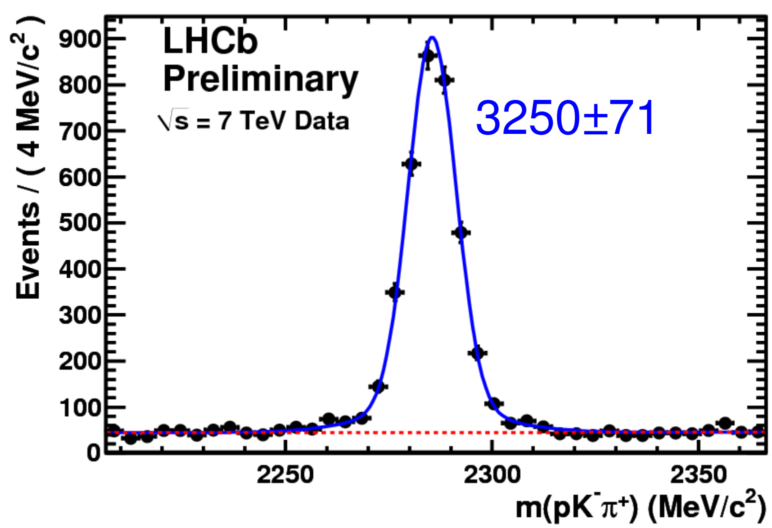
b→cμνX future prospects

- The $D^0\mu$ technique can be exploited to measure also $b \to D^+, D_s, \Lambda_c\ \mu X$ decays.
- Gives access to several b semileptonic measurements, including b-hadrons fragmentation fractions (f_d, f_u, f_s)

Example:

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

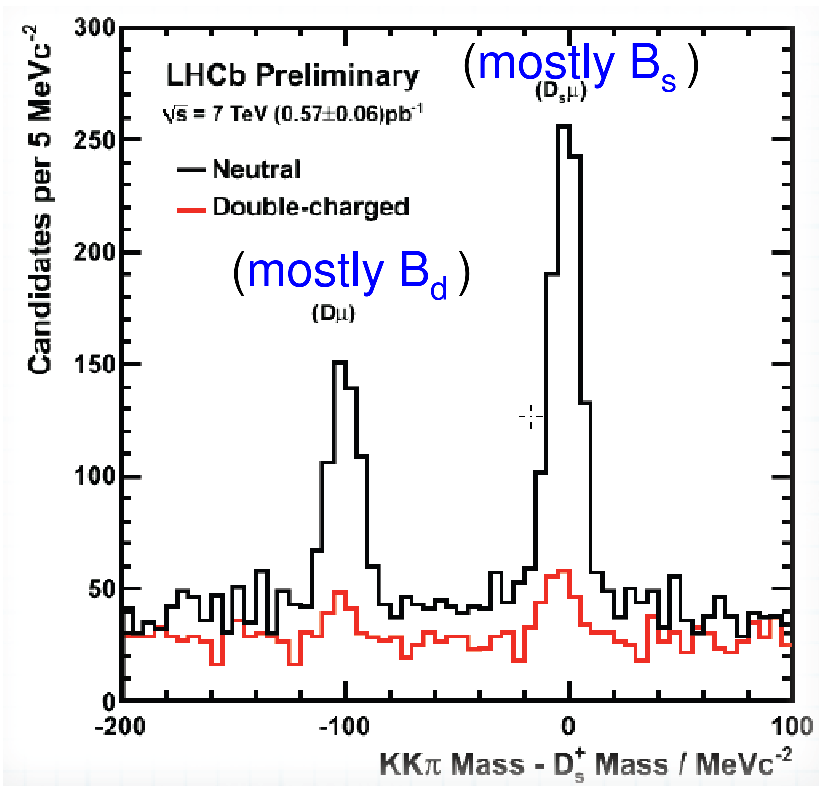


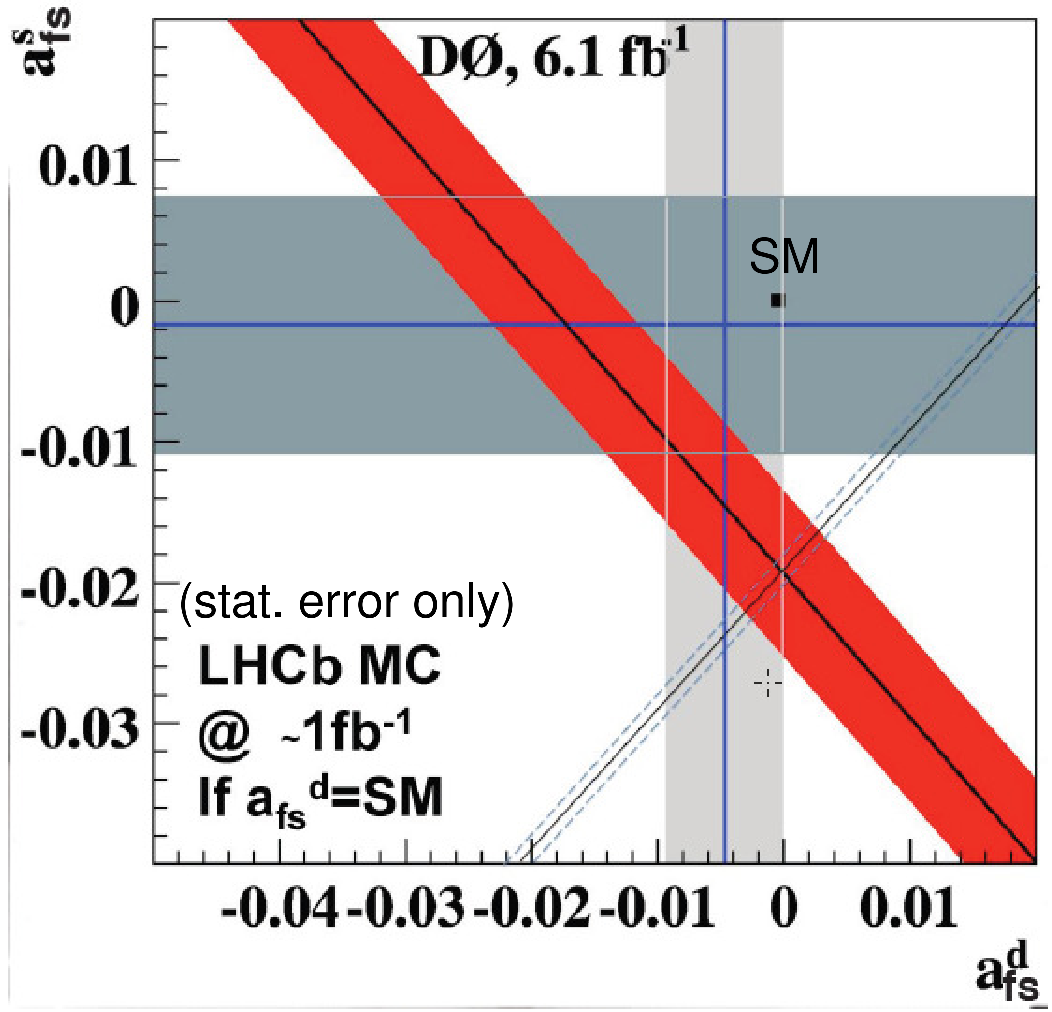


~2 pb^{-1}

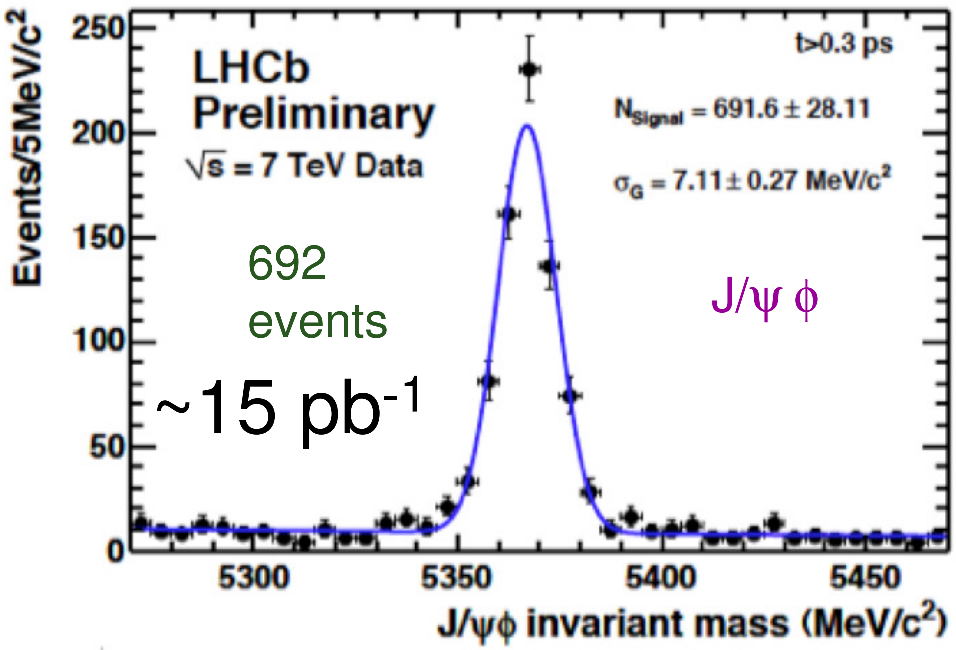
Flavor asymmetry

- LHCb plans to measure exclusive $D_{(q)}^{\pm}\mu^{\mp}$ rates
  - Ignore time dependence to remove production asymmetry (~10^{-2})
  - Compute difference in the asymmetry between B_s,B_d to remove detector asymmetries (~10^{-2})

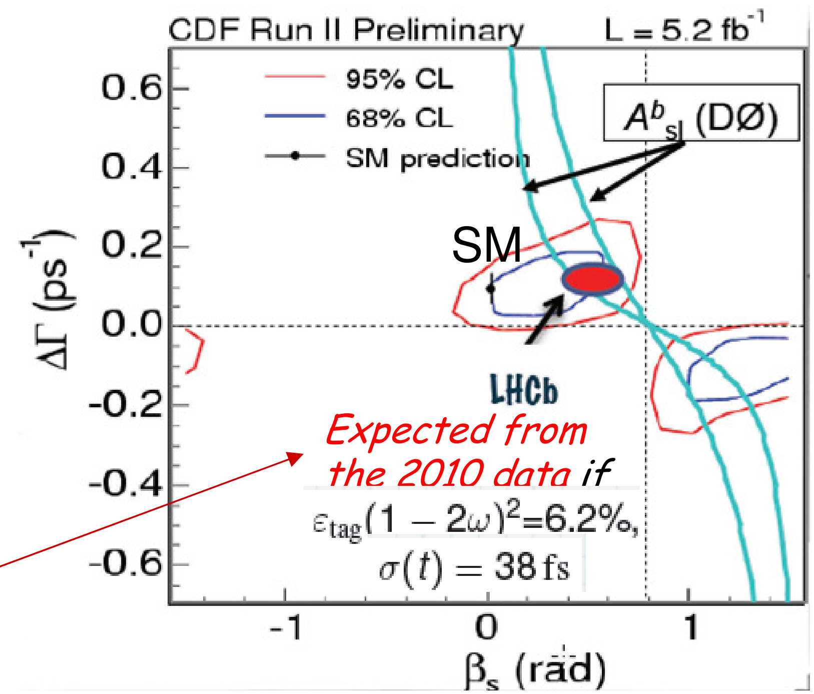


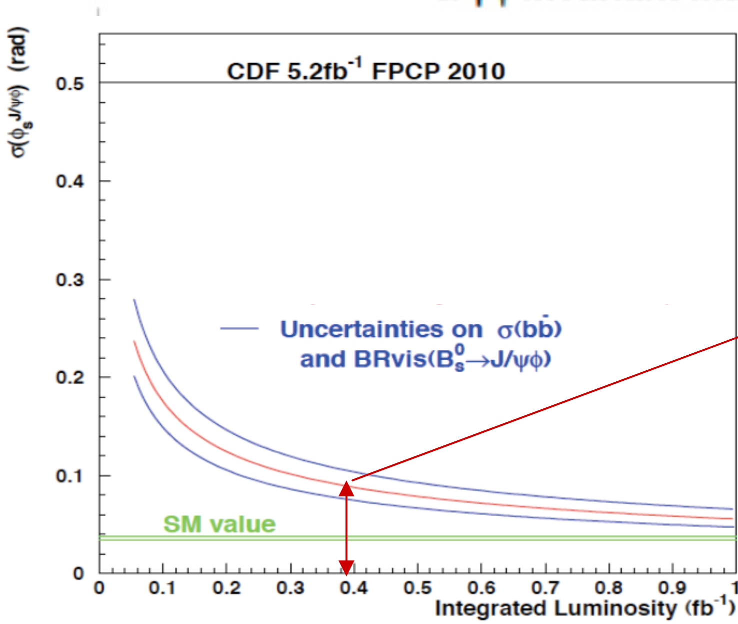


$B_s \to J/\psi\ \phi$



- Signal yield consistent with the MC expectations!





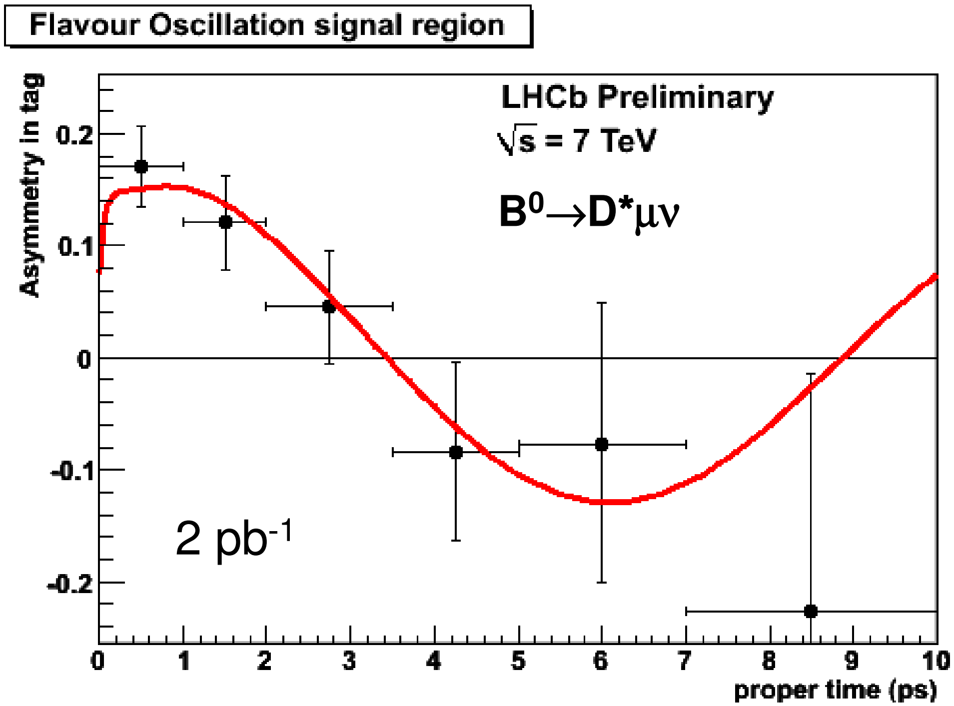
One of the best predicted CPV phases in the SM.

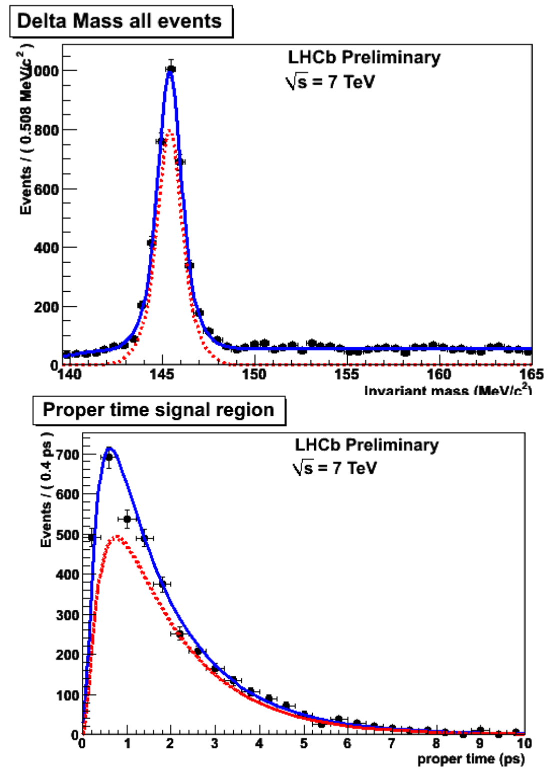
LHCb has sensitivity to observe SM CPV with a few fb^{-1}.

Need ~50-100 fb^{-1} (Super LHCb?) to fully exploit this window to NP.

First B^0 oscillation seen

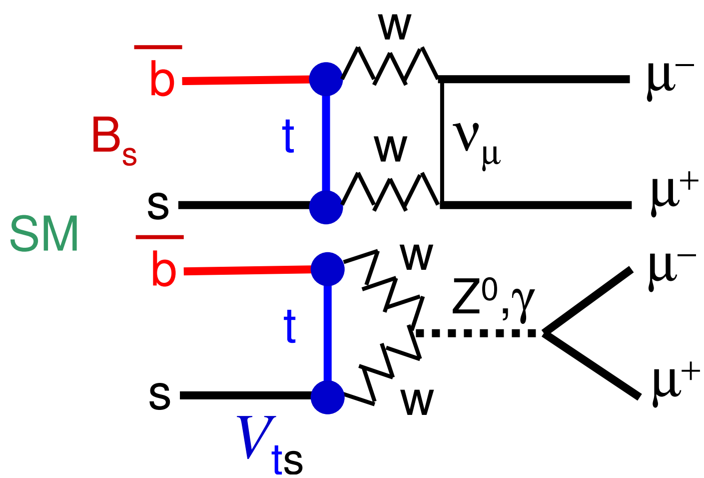
- First signal of flavour oscillation from $B^0_d \to D^{*-}(D^0\pi^-)\mu^+\nu$ events .





- "Out of the box" un-calibrated tagging performance (algorithm tuning, tagger combination etc..) already at 60% of expected performance.
- Proper time resolution at present ~20% worse than expected

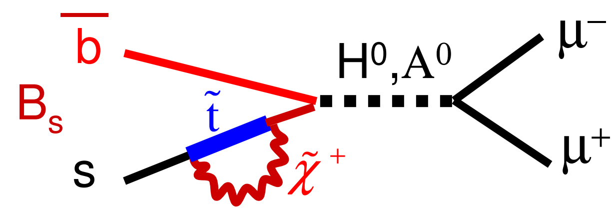
Loops in LHCb: BR($B_S \to \mu^+\mu^-$)



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

Small with small theoretical error!

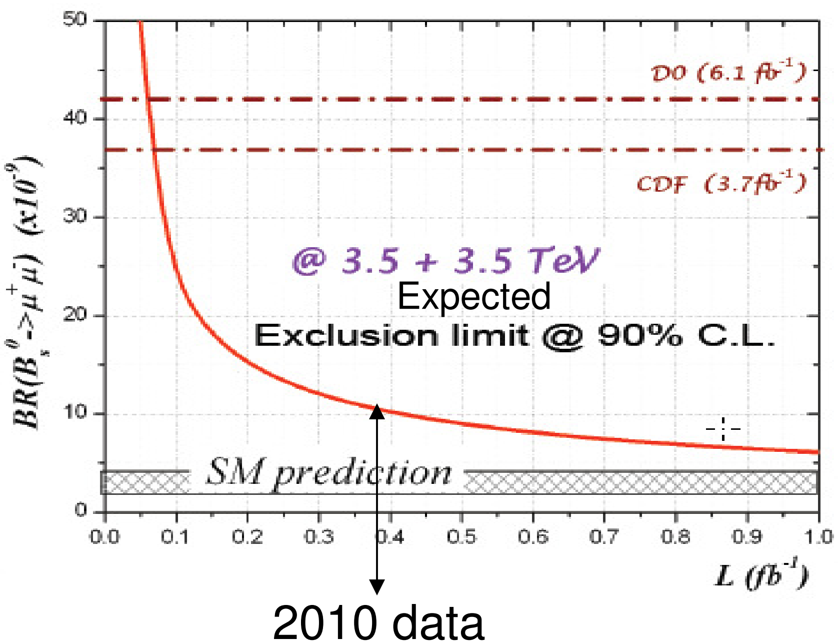
NP
e.g. SUSY



~ $\tan^6\beta$

Could be strongly enhanced.

In some models negative interference with the SM.



Bkg: $b \to \mu^- X$ & $b \to \mu^+ X$ is under control.

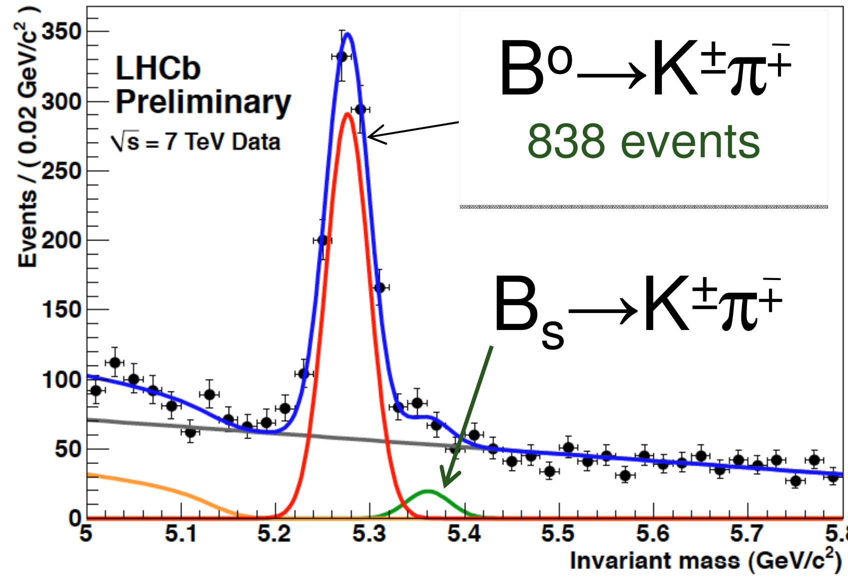
LHCb can observe SM value with a few fb^{-1}

Need ~50-100 fb^{-1} to reach theoretical limitations (Super-LHCb ?)

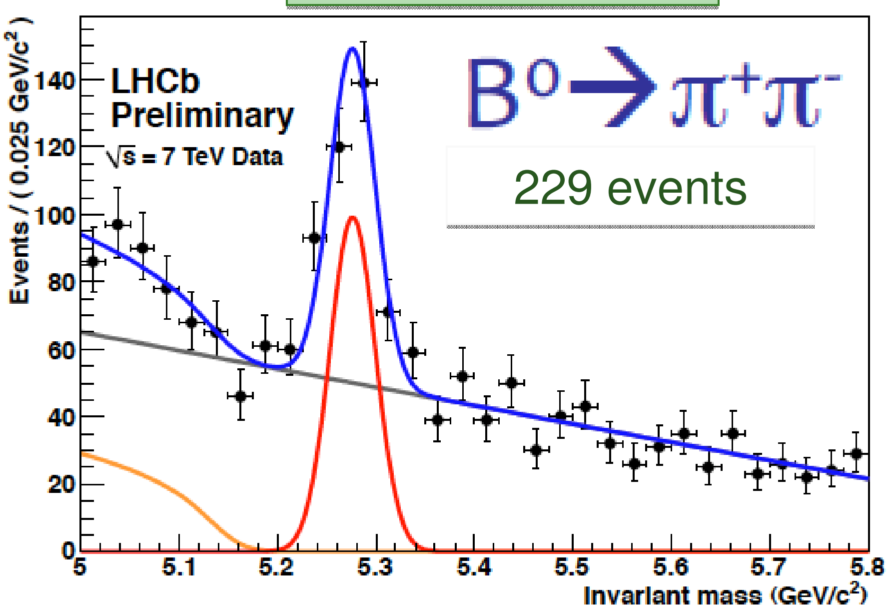
B→πK, ππ, KK

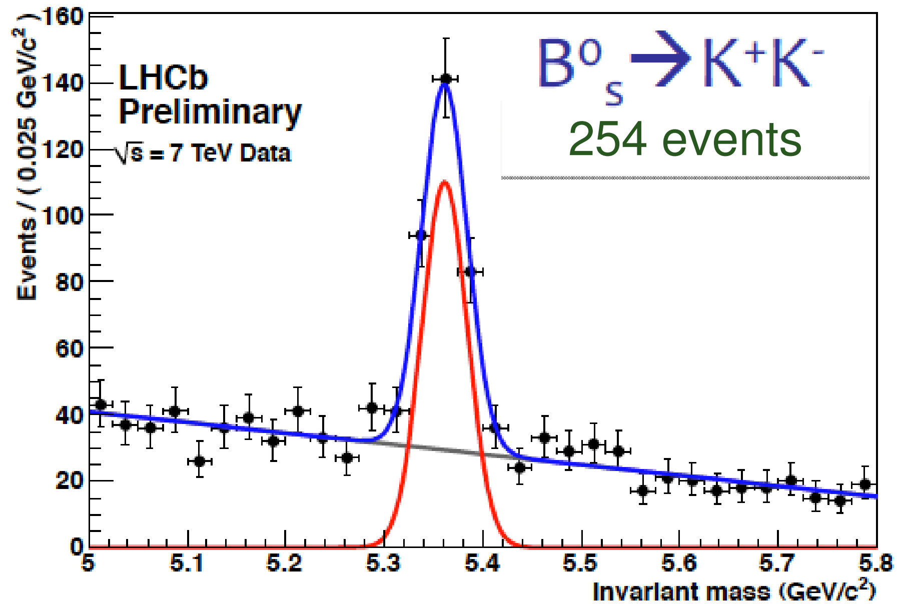
(RICH detectors essential)

- 35 pb^{-1}, "loose cuts"
- We will get as many Kπ in 0.5-0.7 fb^{-1} as Belle in 1000 fb^{-1}



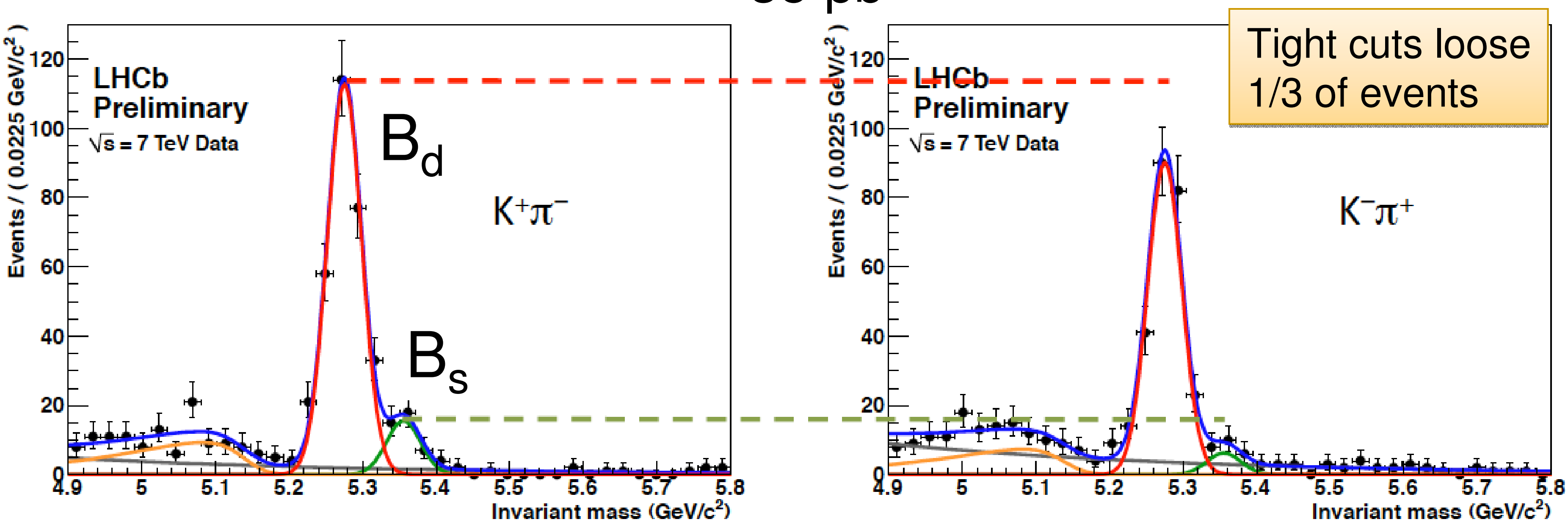
$B(B \rightarrow \pi^+\pi^-) = 5\mathrm{x}10^{-6}$





B→πK: CPV

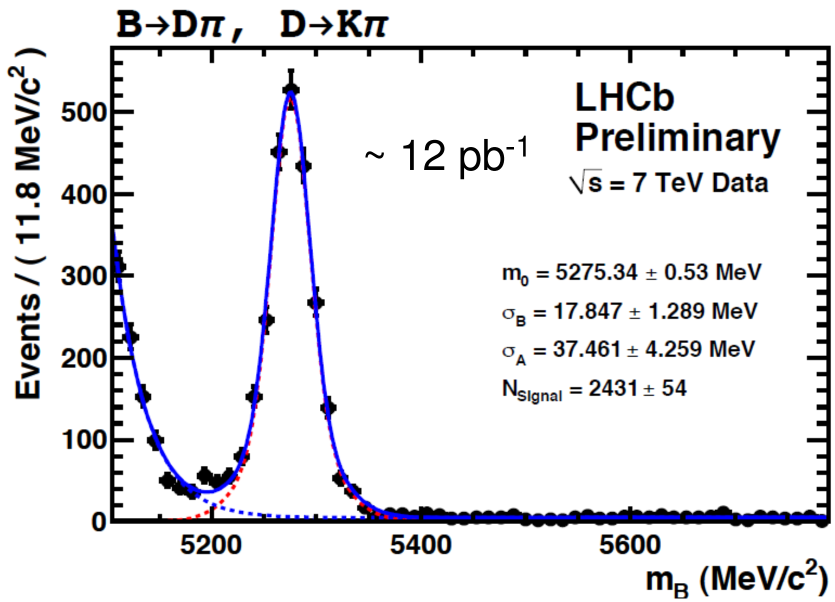
~35 pb^{-1}

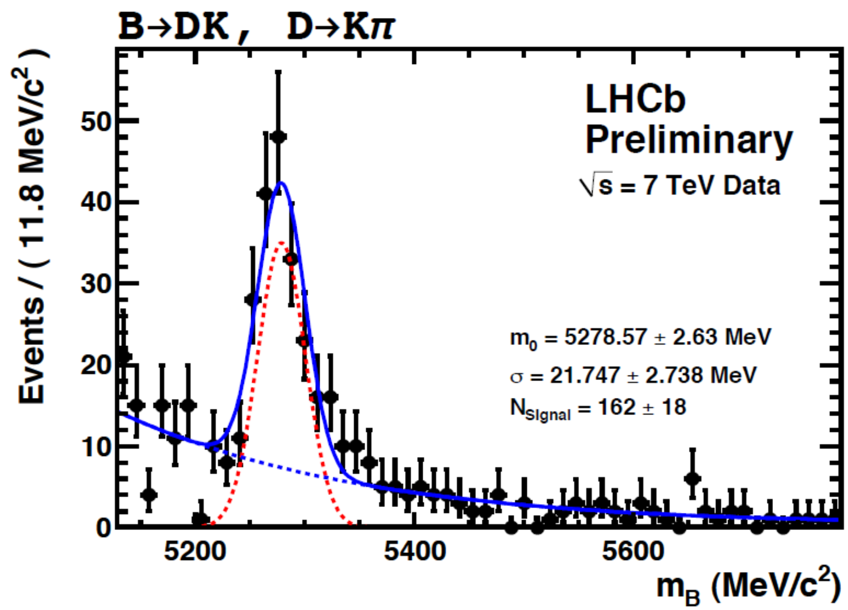


- Obvious direct CPV in both (interference of tree and loop decay processes)
- Using loose cuts $A_{CP}(B^o)$= -0.134±0.041 stat error only, no corrections (HFAG: -0.098±0.012 world average)
- Using tight cuts $A_{CP}(B_s)$= -0.43±0.17 stat error only, no corrections (CDF: 0.39±0.15±0.08 in 1 fb^{-1})

B→DX: a precision measurement of γ

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



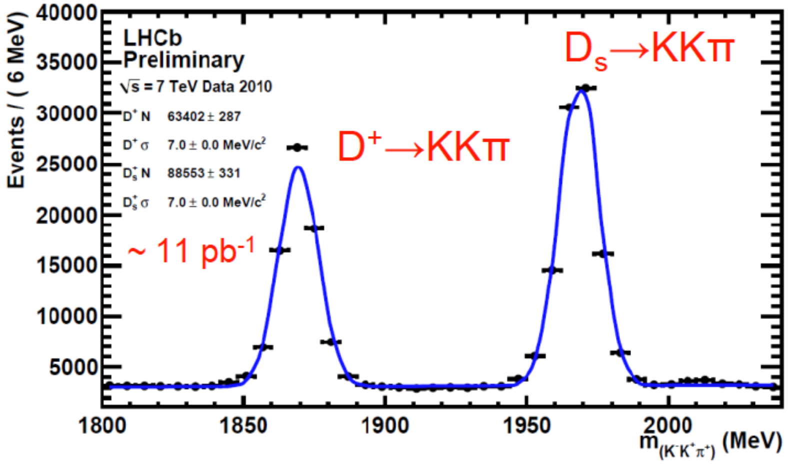


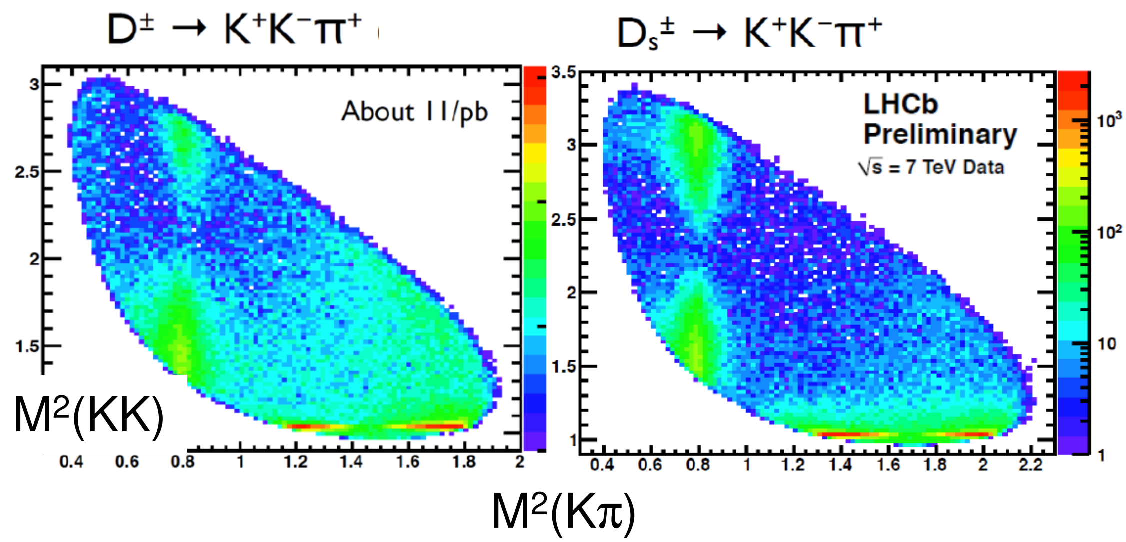
Sample ~37 pb^{-1} around ¼ size of B-factory yields.

Tree level determination of γ. This is the phase of the CKM element V_{ub}.
The most poorly measured angle accessible at B-factories.
We can measure it to 4-5° with 2 fb^{-1} (2011-2012?).

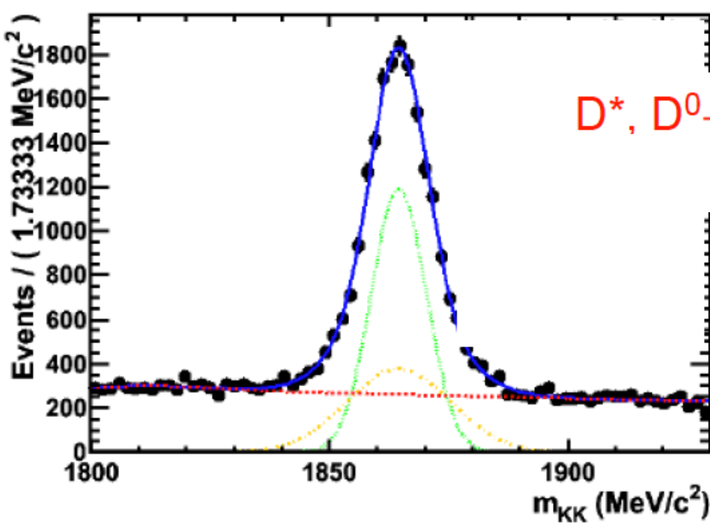
Important to improve to the 1° level with ~50 fb^{-1} (Super LHCb?).

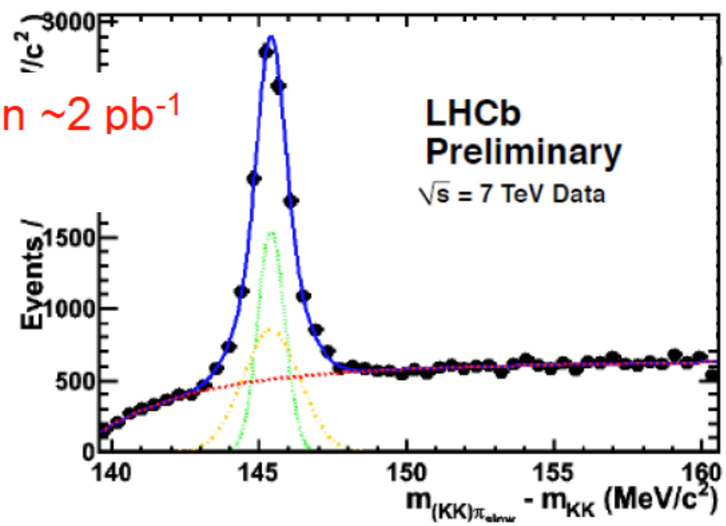
Great Prospects in Charm





D^*, $D^0 \to KK$ in ~2 pb^{-1}



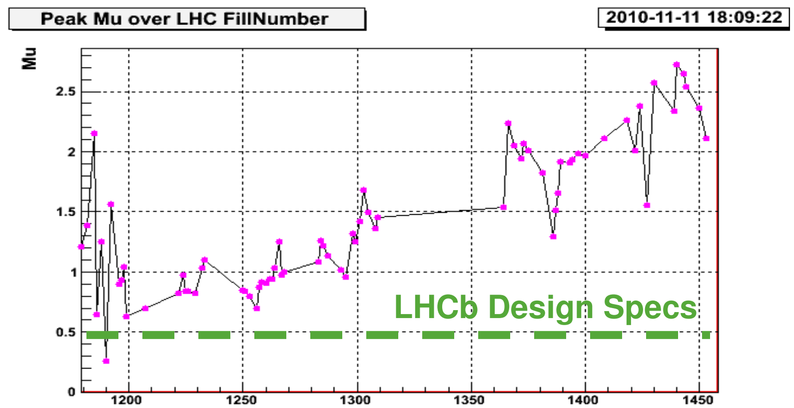


Sample sizes in low multiplicity modes
already similar to those of B-factories !

Limitations of the present LHCb detector

- The existing detector was optimized for low pile-up conditions (i.e. number of pp interactions per bunch crossing - μ).
  μ_{design}~0.5 with 2622 bunches in LHC: L_{design}~2x10^{32} $cm^{-2}s^{-1}$
- This year we collected data with L reaching L_{design} but with only 344 bunches: μ ~2.0-2.5

Average number of visible interactions per crossing



- Sensitivity of all analyses but $B_s \rightarrow \mu\mu$ does not benefit from further increase in μ. This will limit our luminosity to L_{max}~5x10^{32} $cm^{-2}s^{-1}$ even for 2622 bunch operations. Also radiation hardness issues for higher L operations.
- Design luminosity of LHC is 10^{34} $cm^{-2}s^{-1}$. We will defocus beams when we reach L_{max} (or μ_{max}).
- Hope to collect ~5 fb^{-1} with the existing detector.
- To reach ultimate sensitivity (limited by either theoretical or systematic limitations) in many modes need 50-100 fb^{-1}. Must upgrade the LHCb detector to reach it. (Does not require LHC upgrade!)

LHCb upgrade

- Replace strip VELO detector with radiation hard pixel VELO
- Need to overcome L0 triggering limitations for hadronic modes:
  - Readout all detector at 40 MHz and go to fully software triggers (new photodetectors in RICH detectors, new TT,IT and new readout in OT)
- Re-optimize tracking devices (TT,IT+OT) for higher μ
- Possibly also improve low momentum PID performance - aerogel radiation in RICH1 replaced by TORCH (RICH detector with ToF measurement).
- Detailed design is being studied.
- LOI still this year. Installation in 2016?

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.

From Wikipidia:
Seers, wizards, sorcerers, psychics, gypsies, fortune tellers, and all other types of diviners also used crystal balls to "see" into the past, present, or future.