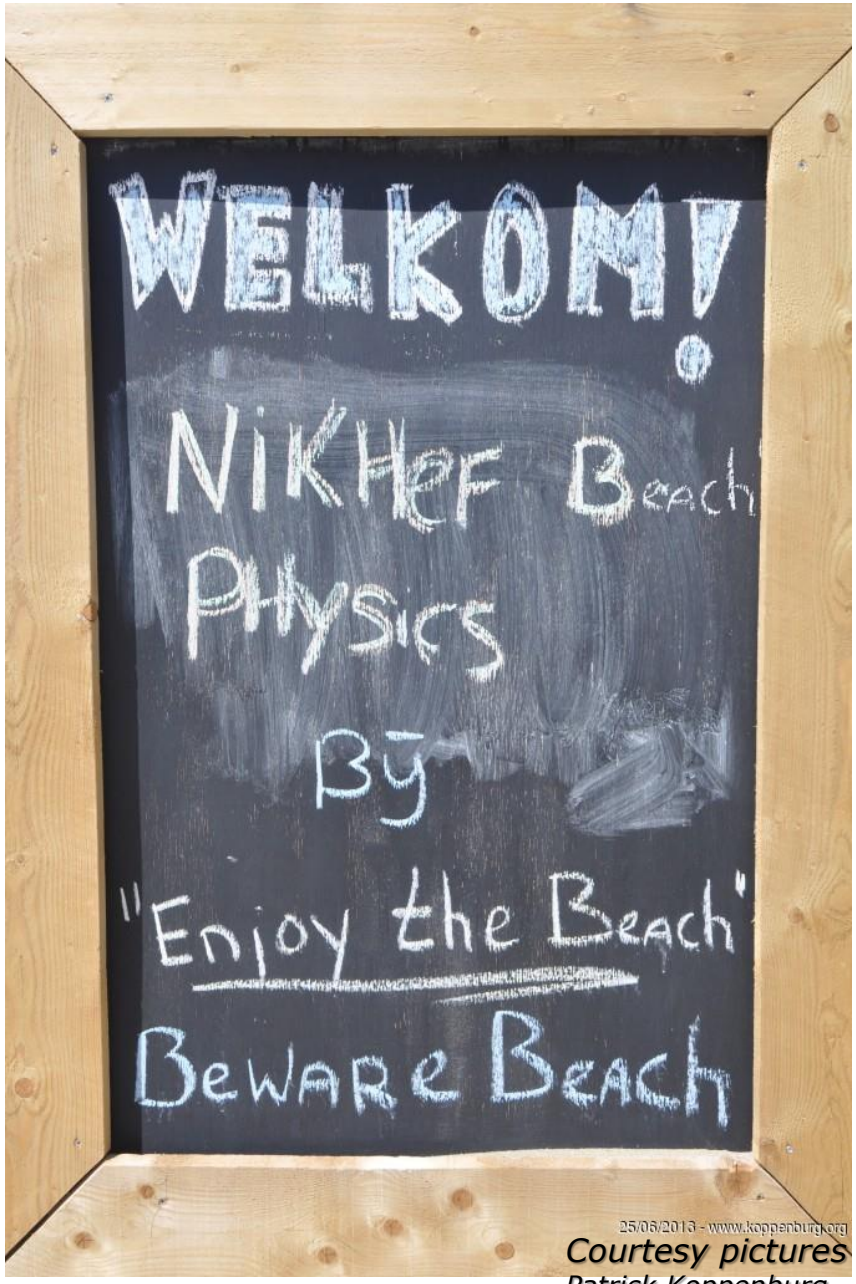
Introduction & Overview

Niels Tuning

Beach Physics group



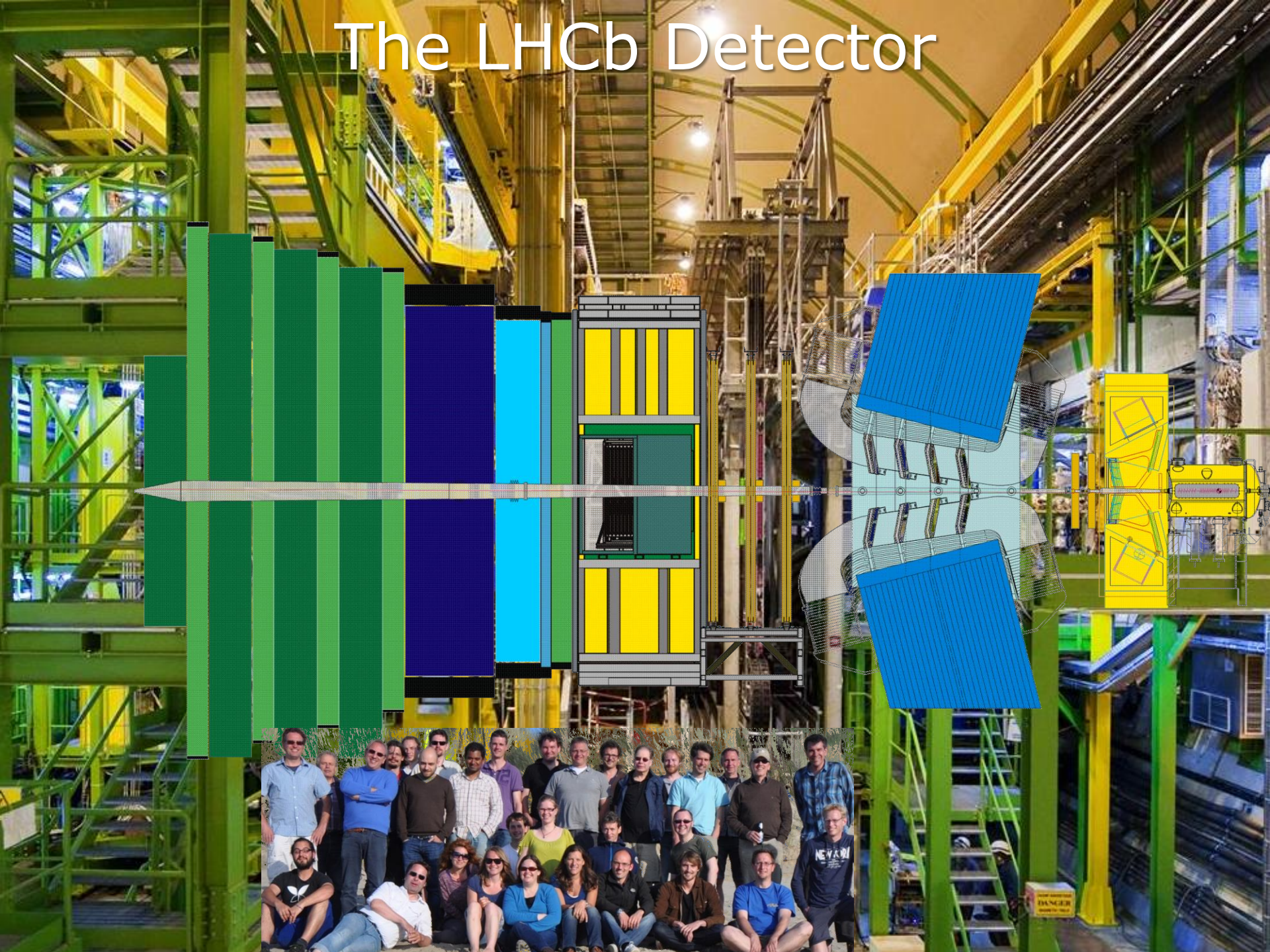
Courtesy pictures
Patrick Koppenburg
www.koppenburg.org

Outline

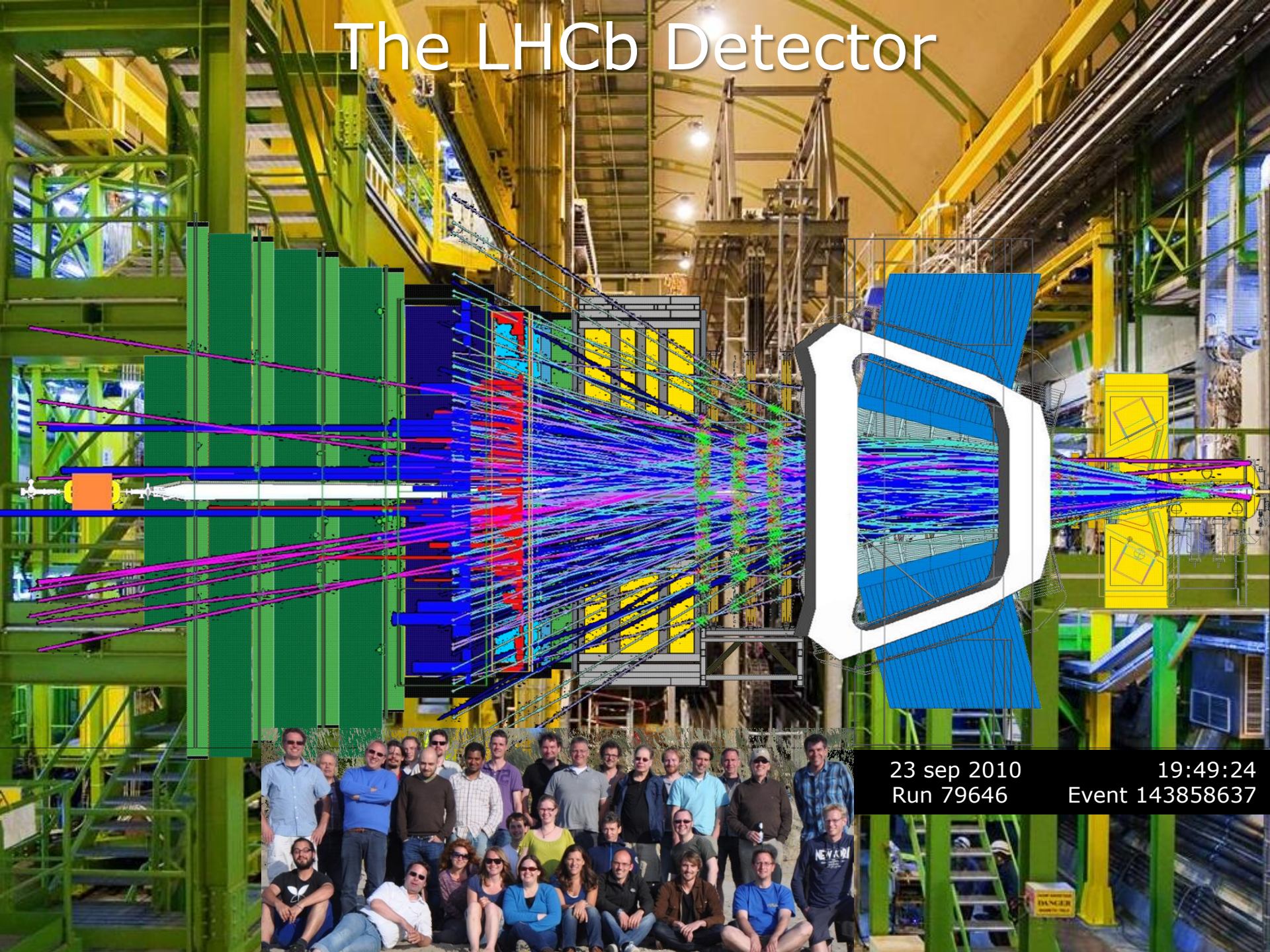
1) The group
2) Highlights from LHCb
   - New physics in loops? $B^0 \to K^{*0} \mu^+ \mu^-$
   - First CP violation in B_s^0 system $B_s^0 \to K^+ \pi^-$
3) Highlights from the group
   - Rarest decay $B_s^0 \to \mu^+ \mu^-$ — Siim
   - CP violation in B_s^0 system $B_s^0 \to J/\Psi\phi$ — Roel
   - DØ Anomaly? $B_{(s)}^0 \to D_{(s)}^- \mu^+ X$
   - Unitarity angle γ $B_s^0 \to D_s^- K^+$ — Niels
   - Exotics $X \to Y$ — Maurizio
4) LHCb upgrade — Eddy

The LHCb Detector

The LHCb Detector



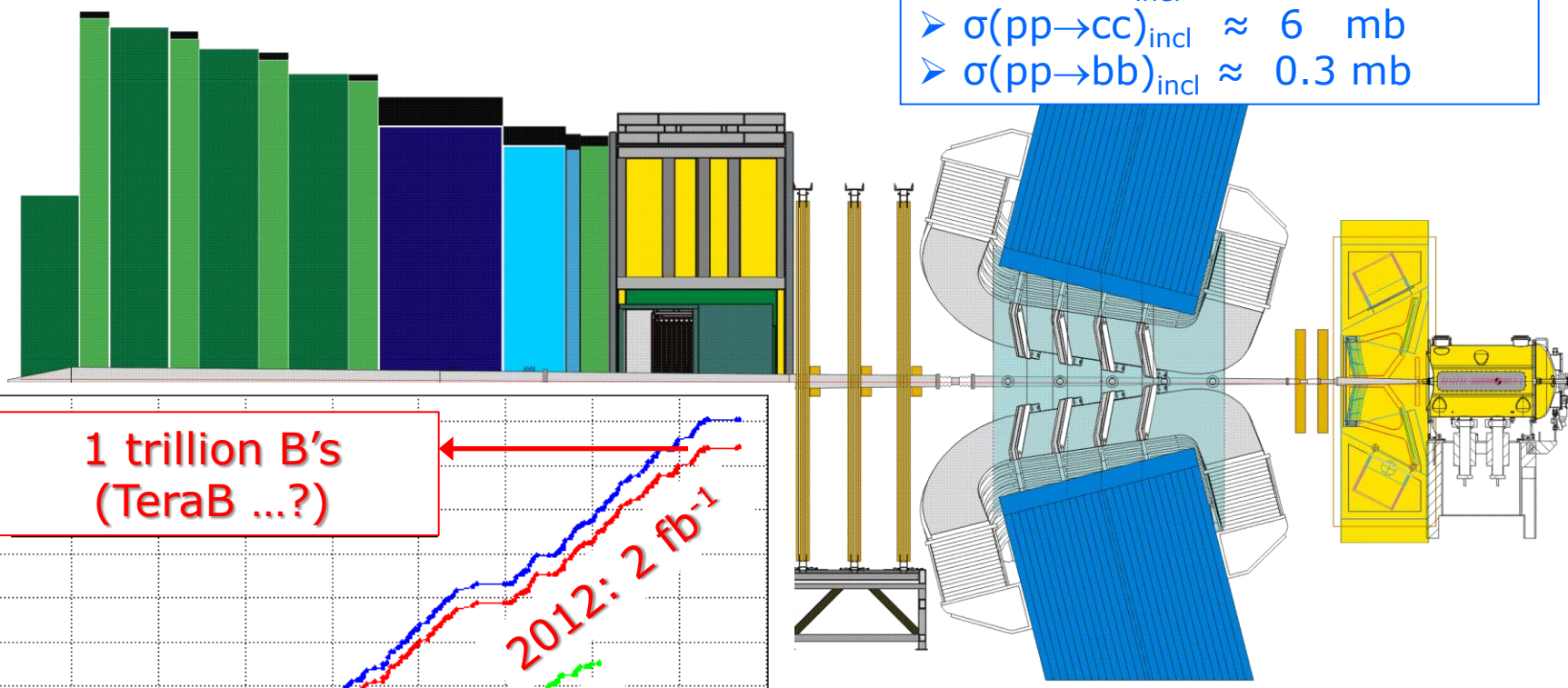
The LHCb Detector

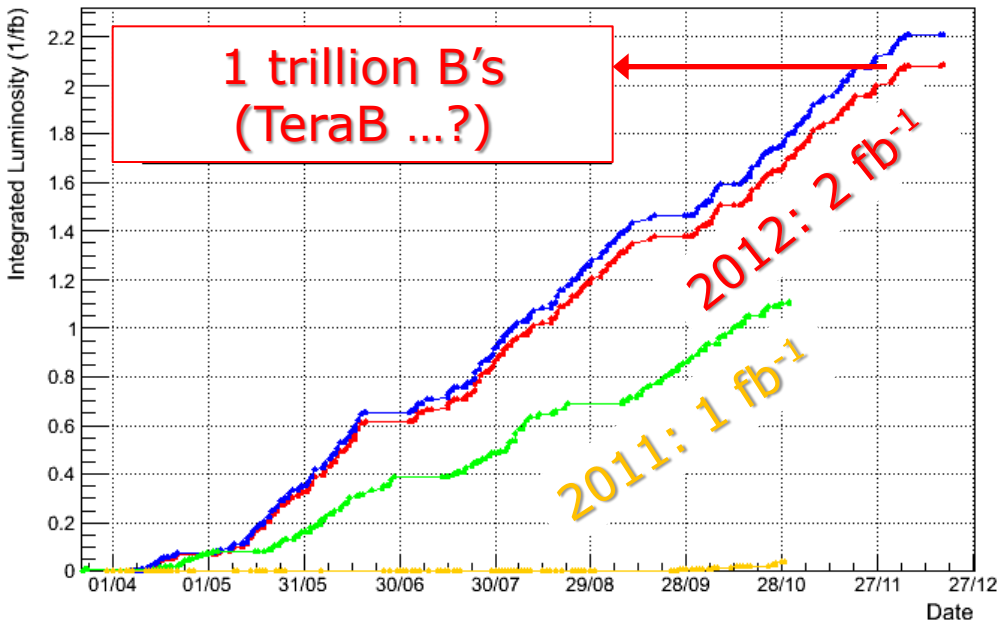


23 sep 2010 19:49:24
Run 79646 Event 143858637

The LHCb Detector

Forward arm spectrometer
- $2<\eta<5$
- $\sigma(pp\rightarrow X)_{inel} \approx 60$ mb
- $\sigma(pp\rightarrow cc)_{incl} \approx 6$ mb
- $\sigma(pp\rightarrow bb)_{incl} \approx 0.3$ mb





- Produce 3×10^{11} B's per fb^{-1}

NB: ε ~1%

Beach Physics Group

Happy Management

Coordinators in LHCb

LHCb Upgrade

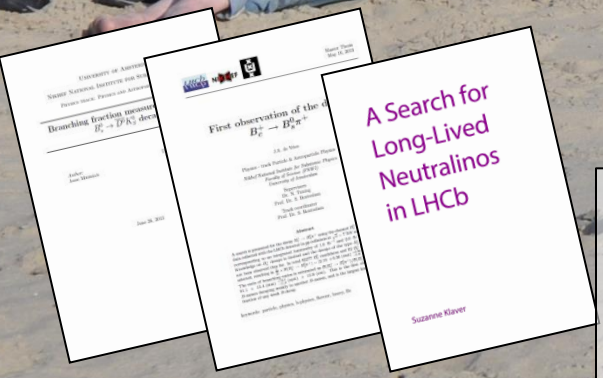
Career moves in 2013

MSc. Jacco de Vries

Fellow Victor Coco

MSc. Suzanne Klaver

Dr Serena Oggero

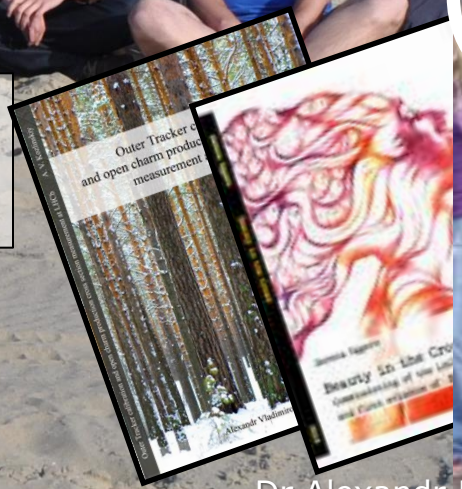


2 PhD theses:

- Alexandr Kozlinskiy
- Serena Oggero

3 master theses:

- Jesse Mesman
- Jacco de Vries
- Suzanne Klaver



Dr Alexandr Kozlinskiy

New

MSc: Lennaert Bel

PhD: Jacco de Vries

Jeroen van Tilburg

Hella Snoek

Groningen

+ 3 Master students

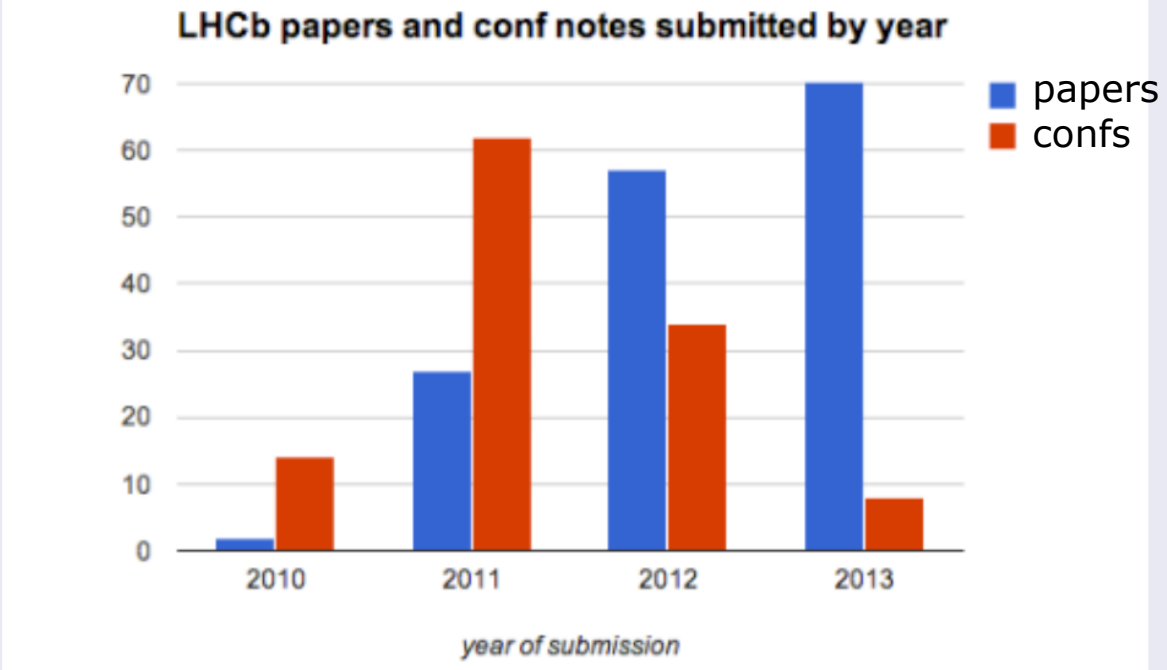
[61] *KVI-University of Groningen, Groningen, The Netherlands, associated to* [40]

[40] *Nikhef National Institute for Subatomic Physics, Amsterdam, The Netherlands*
[41] *Nikhef National Institute for Subatomic Physics and VU University Amsterdam, Amsterdam, The Netherlands*

2013: a fruitful year!

76 papers in 2013

Physics publications

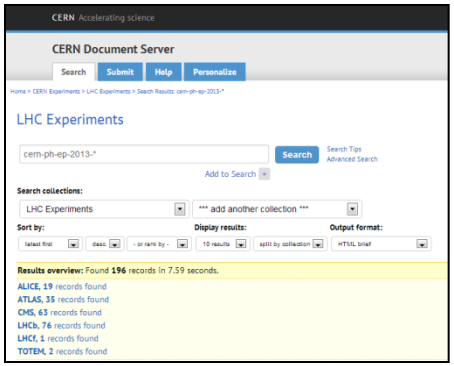


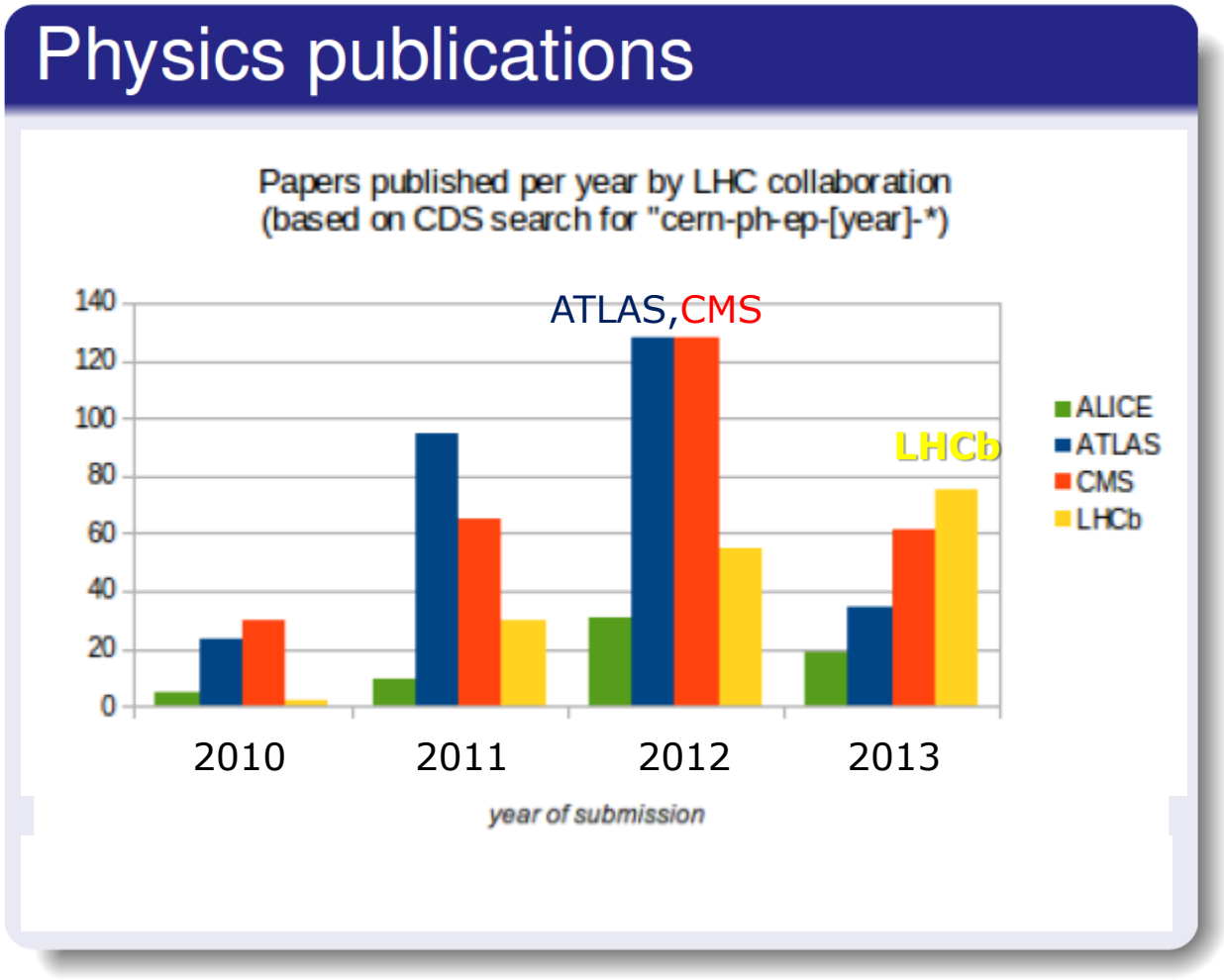
161 papers in total.

(I will indicate our group achievements with:)

2013: a fruitful year!

Catching up:





2013: a fruitful year!

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  - Unitarity angle γ $B_s^0 \to D_s^- K^+$
  - [illegible] $X \to Y$

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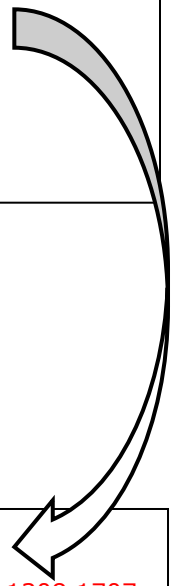

Monumental Papers in 2013:

1)	Measurement of form-factor independent observables in the decay $B^0 \to K^{*0}\mu^+\mu^-$	arXiv:1308.1707
2)	First observation of CP violation in the decays of B_s mesons	arXiv:1304.6173
3)	Measurement of the $B_s^0 \to \mu^+\mu^-$ branching fraction and search for $B^0 \to \mu^+\mu^-$ decays at the LHCb experiment	arXiv:1307.5024
4)	Measurement of CP violation and the B^0_s meson decay width difference with $B^0_s \to J/\psi K^+K^-$ and $B^0_s \to J/\psi\pi^+\pi^-$ decays	arXiv:1304.2600
5)	Precision measurement of the B^0_s - $\bar{B}^0_s$ oscillation frequency with the decay $B^0_s \to D^-_s\pi^+$	arXiv:1304.4741
6)	Measurement of the CKM angle γ from a combination of $B \to Dh$ analyses	arXiv:1305.2050

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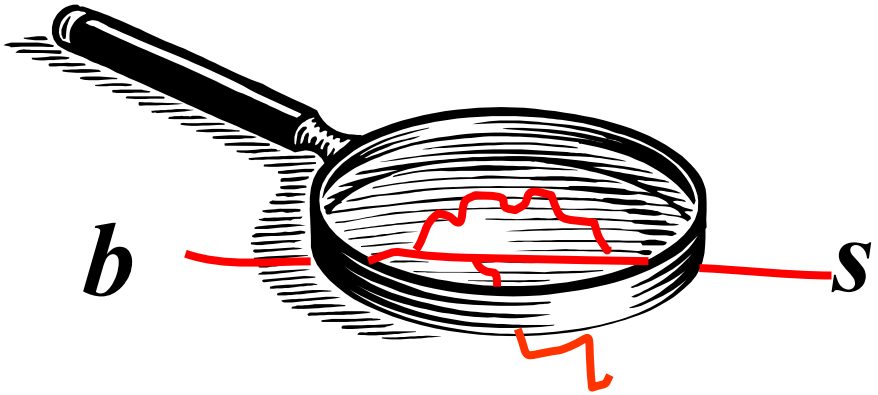
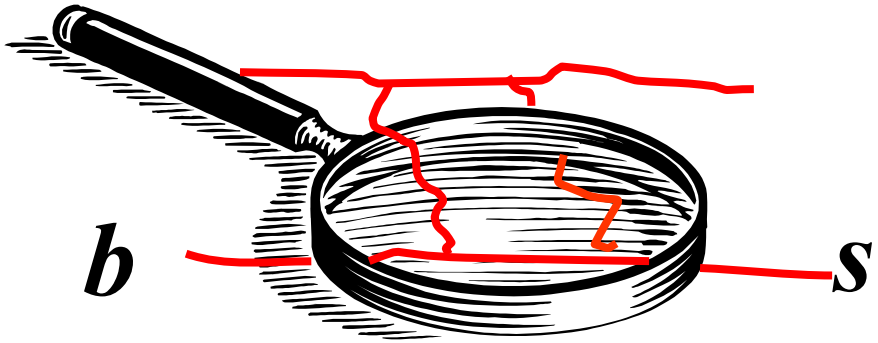
B to what? [bi tu' dʒe saj paj ke]

- That's the strength of LHCb:

  many decays, many loops, many observables, many searches





Flavour physics: Corner stone of Standard Model

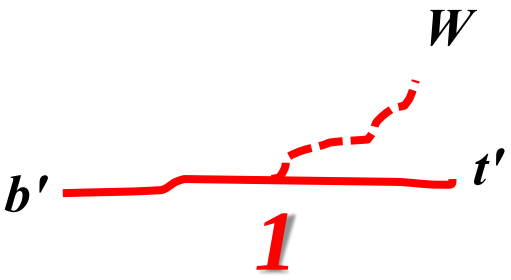
Yukawa couplings (Higgs – fermions)

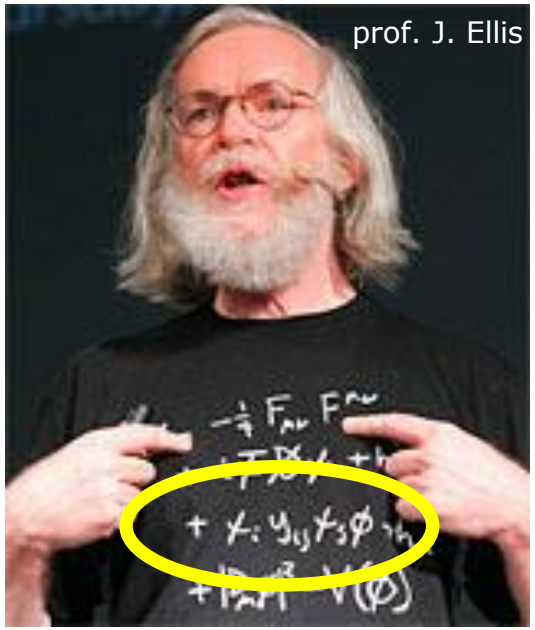
Change quark basis

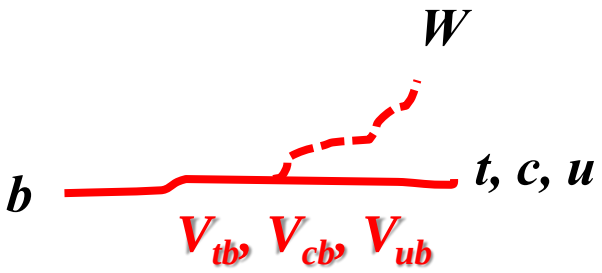
Diagonal Yukawa matrix

$$L_{Yukawa} = Y_{ij}\bar{\psi}_i\phi\psi_j \longrightarrow \begin{pmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{pmatrix} \bar{Q}_{L,i}\phi\, q_{R,j}$$

$$\begin{pmatrix} m_d & 0 & 0 \\ 0 & m_s & 0 \\ 0 & 0 & m_b \end{pmatrix}$$







"Flavour diagonal" charge currents

"Flavour changing" charge currents

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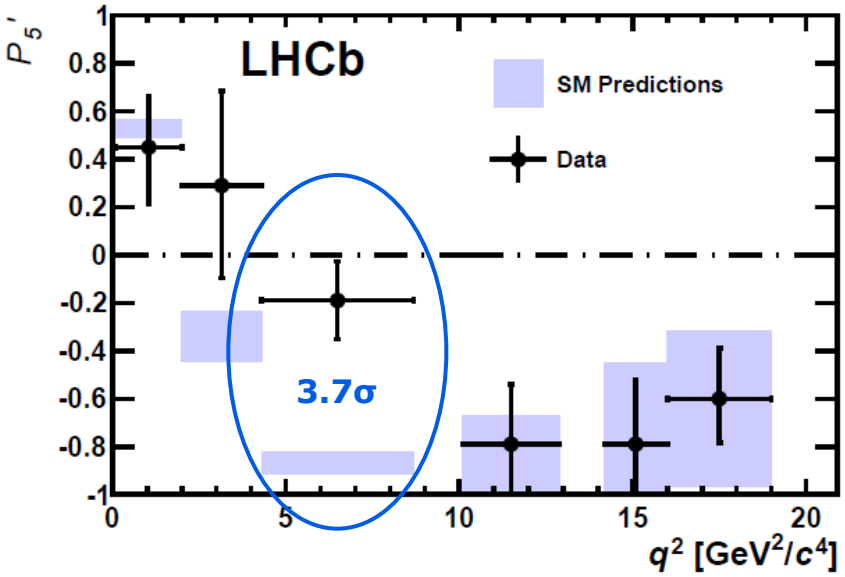
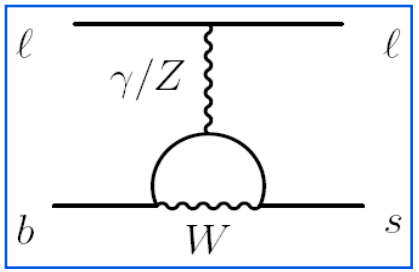
"A prime example of new physics?"

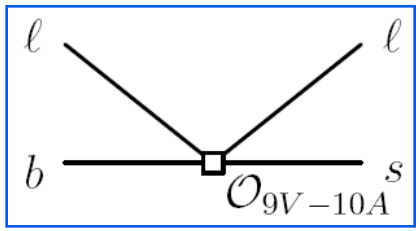


Modified C_9?

Hint of Z' ?



HQET



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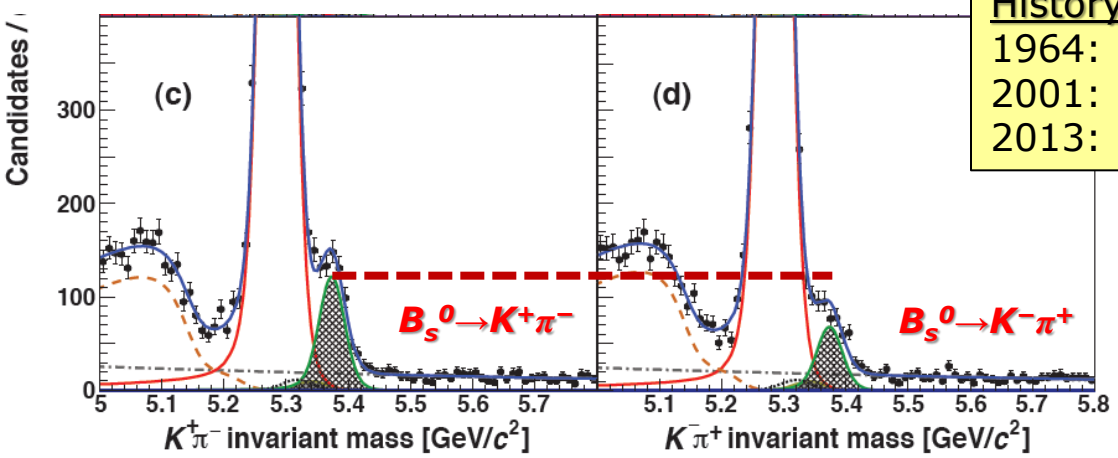
Historical?

$$A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.04\,(\text{stat}) \pm 0.01\,(\text{syst})$$



History:
1964: Discovery of CPV with K^0 (Prize 1980)
2001: Discovery of CPV with B^0 (Prize 2008)
2013: Discovery of CPV with B^0_s

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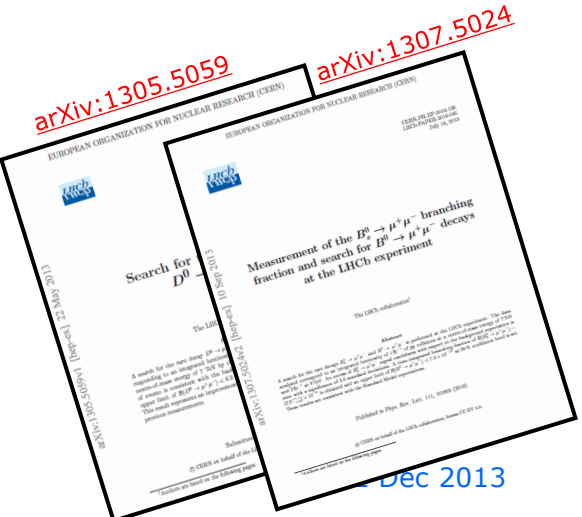

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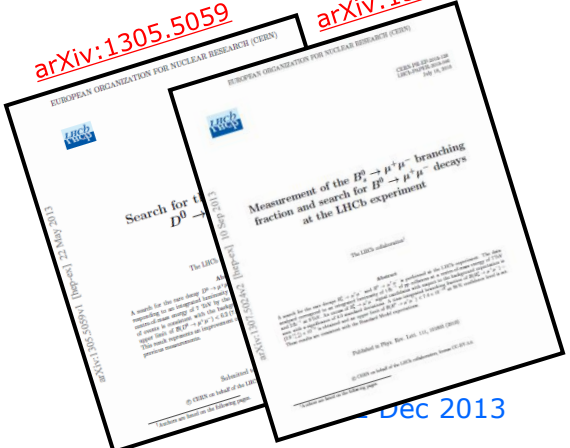
See Siim's Tolk!

$B_s^0 \to \mu\mu$ team



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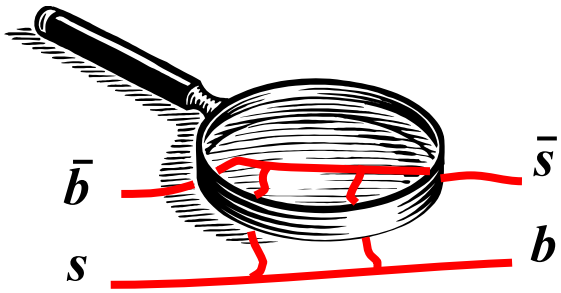

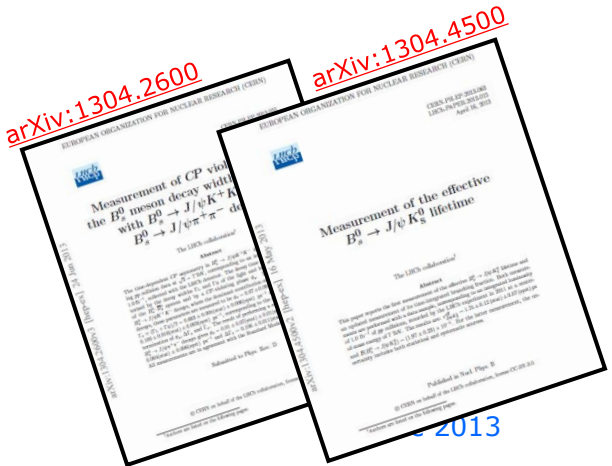

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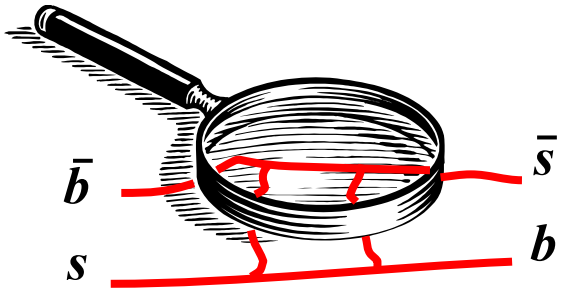
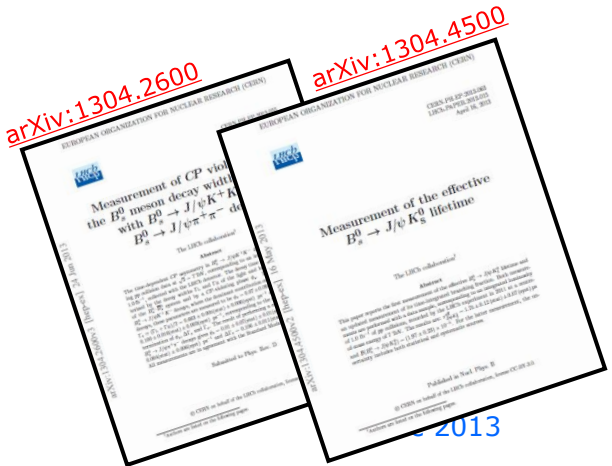


See Roel's Tolk!



$B_s^0 \to J/\psi X$ team

2013

Bfys overview

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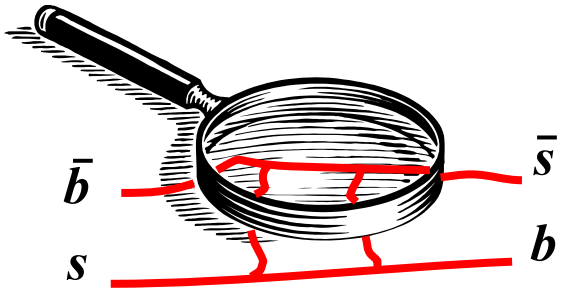

"Two anomalies ?"

A_{sl} ▪ DØ: $P(B_s^0 \to \overline{B}_s^0) \neq P(\overline{B}_s^0 \to B_s^0)$ **?**

ΔA_{CP} ▪ LHCb: $N(D^0 \to \pi\pi)/N(\overline{D}^0 \to \pi\pi) \neq N(D^0 \to KK)/N(\overline{D}^0 \to KK)$ **?**

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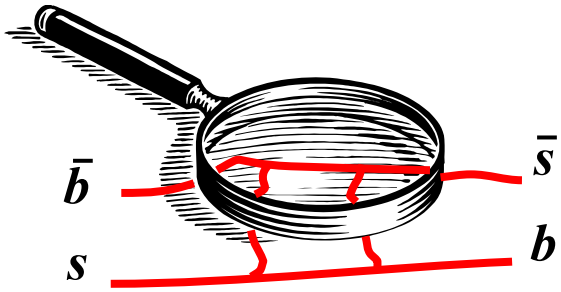
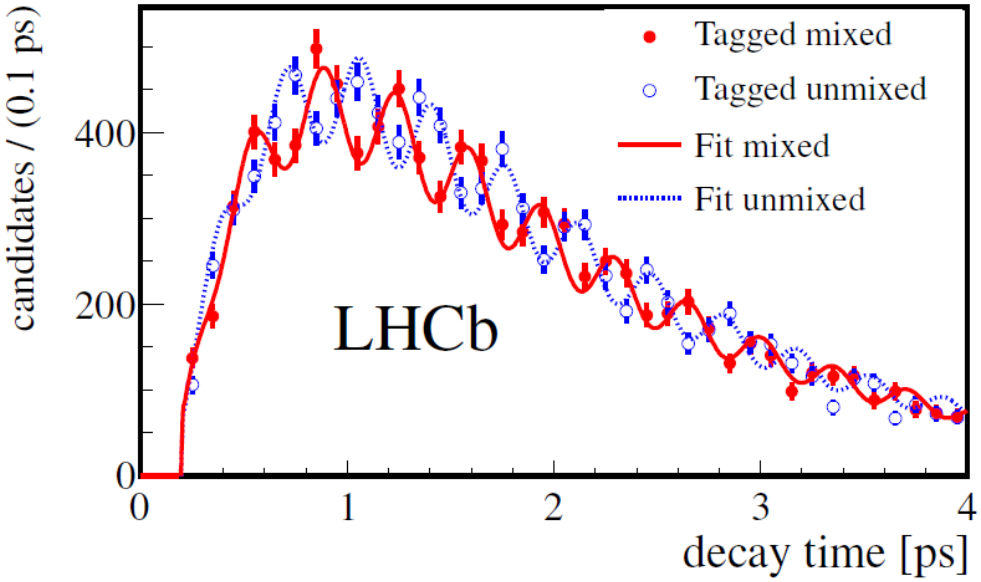
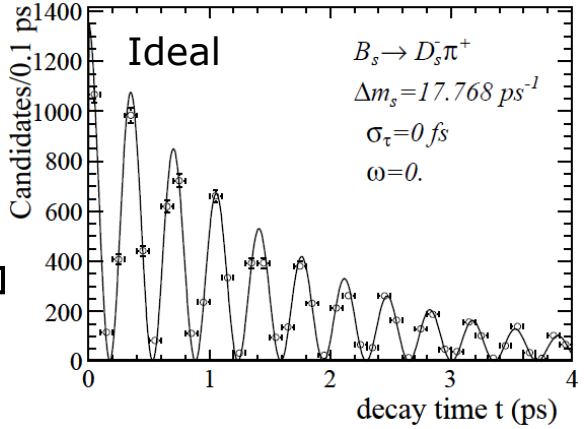


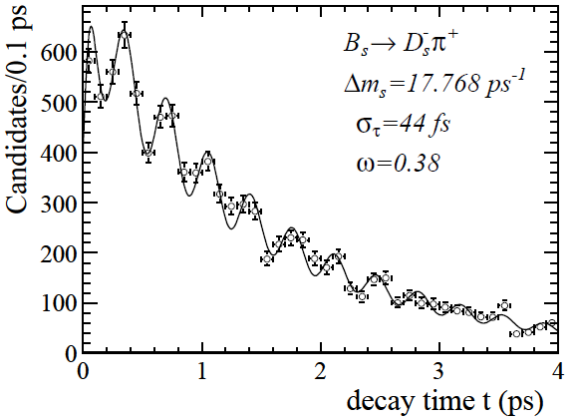
The text-book plot: $P(B_s^0 \to \bar{B}_s^0)(t)$



Tagging, resolution



Acceptance



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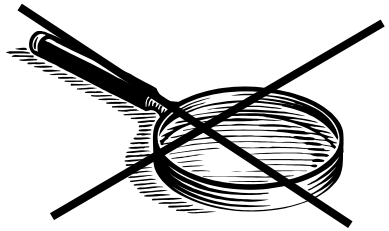

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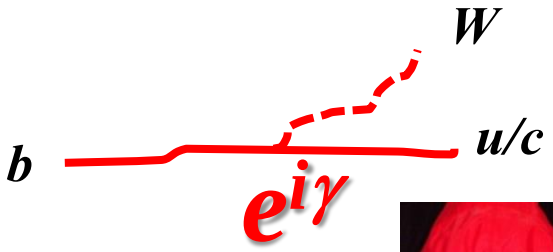

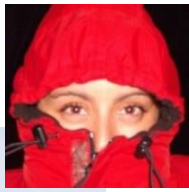

$B_s^0 \to D_s K$ team

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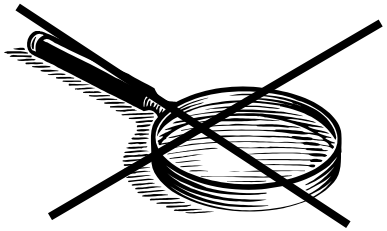
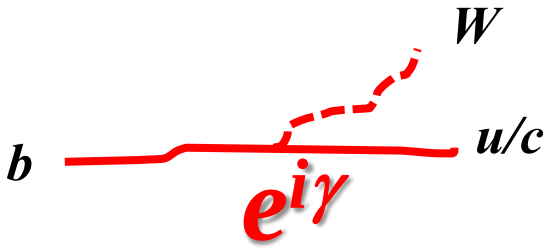
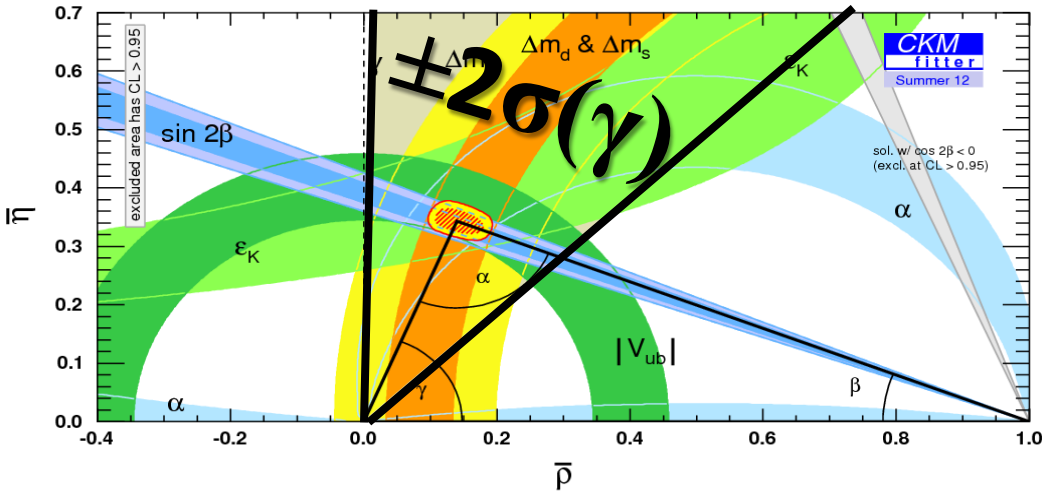
  - Exotics $X \to Y$

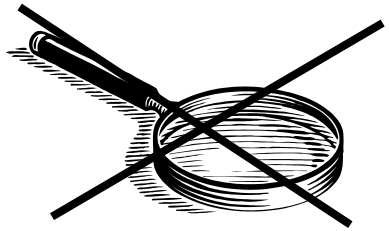




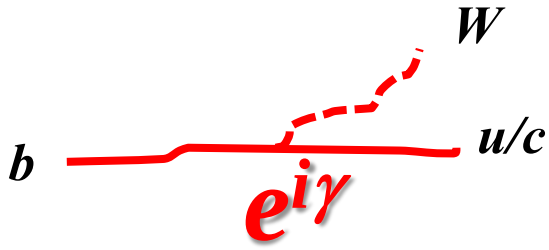
Least known parameter in unitarity triangle:



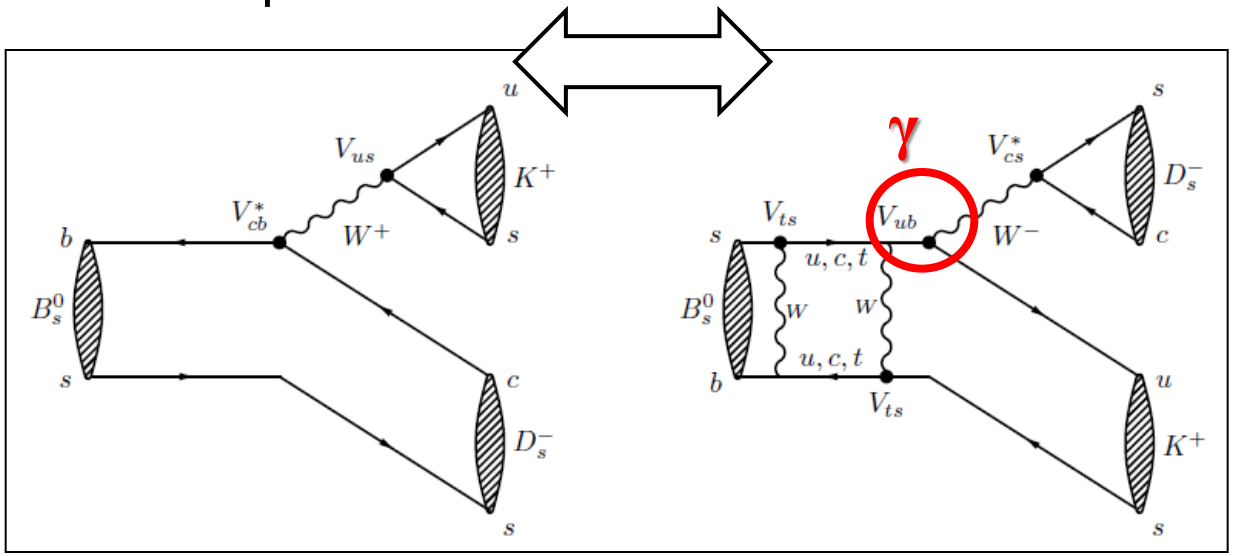
Determination of γ with $B_s^0 \to D_s^- K^+$



$\Gamma(B_s^0 \to D_s^- K^+) = |A_1 + A_2 e^{i\gamma+\delta}|^2$

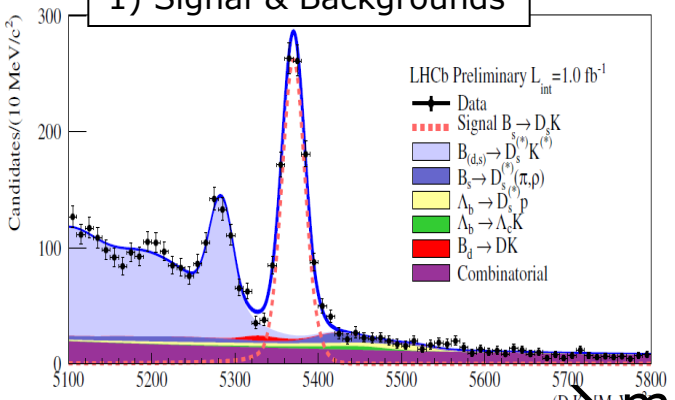


Relative phase:



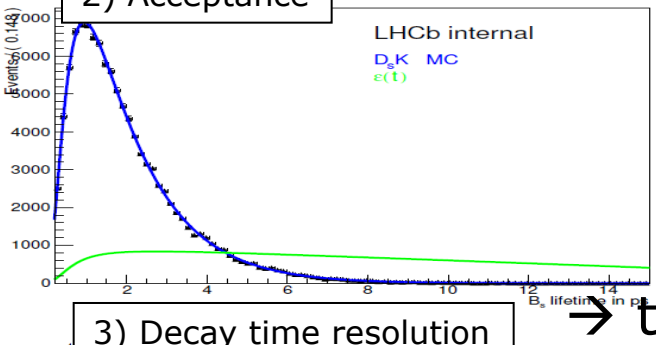
Determination of γ with $B_s^0 \to D_s^- K^+$

1) Signal & Backgrounds



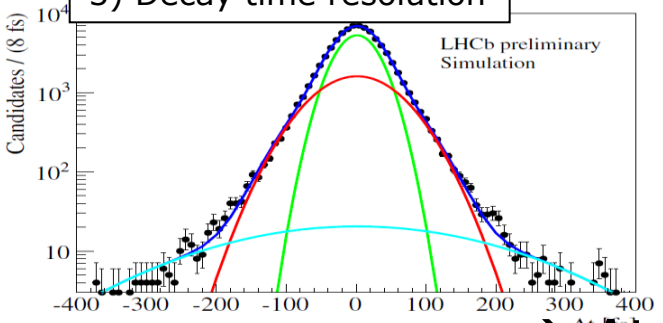
→ m

2) Acceptance



→ t

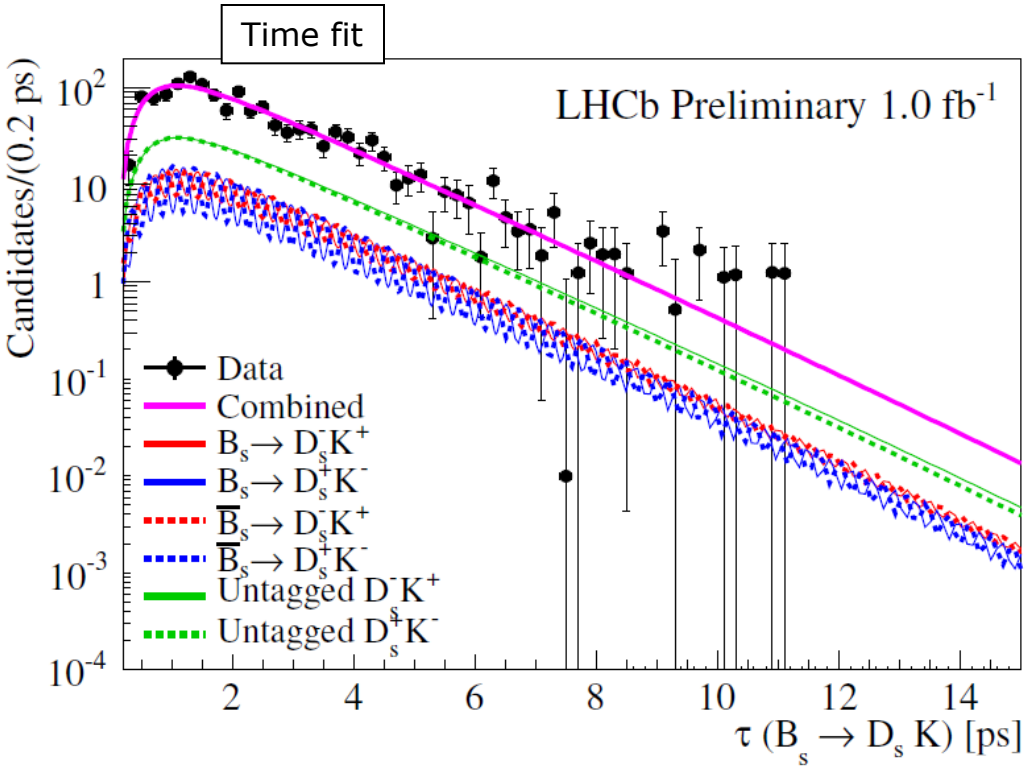
3) Decay time resolution



→ Δt

4) Flavour Tagging

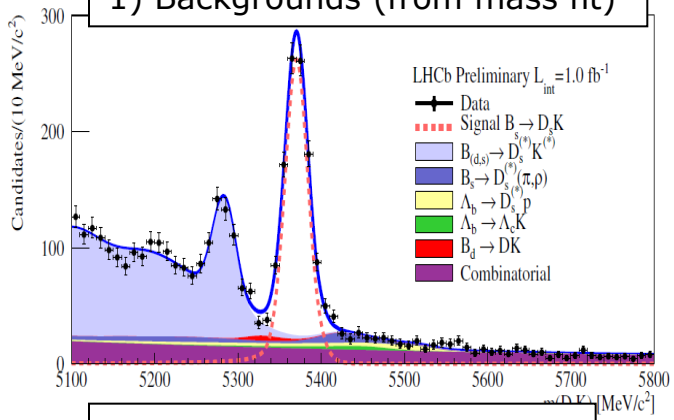
Time fit



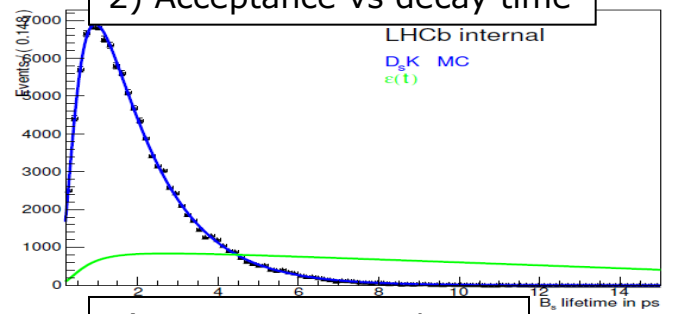
- Expect γ with ~ 28^0 precision
- Improve with 2012 data
- LHCb average now: $67^0 \pm 12^0$

Determination of γ

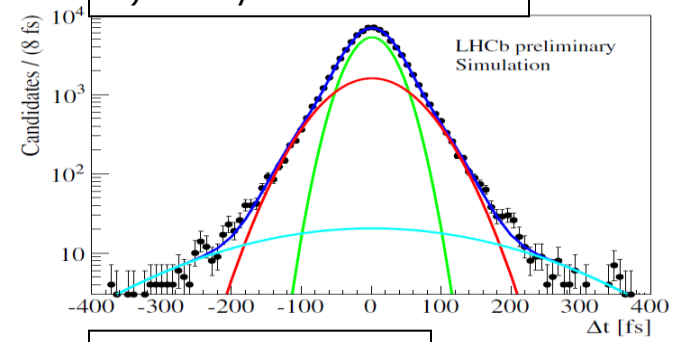
1) Backgrounds (from mass fit)



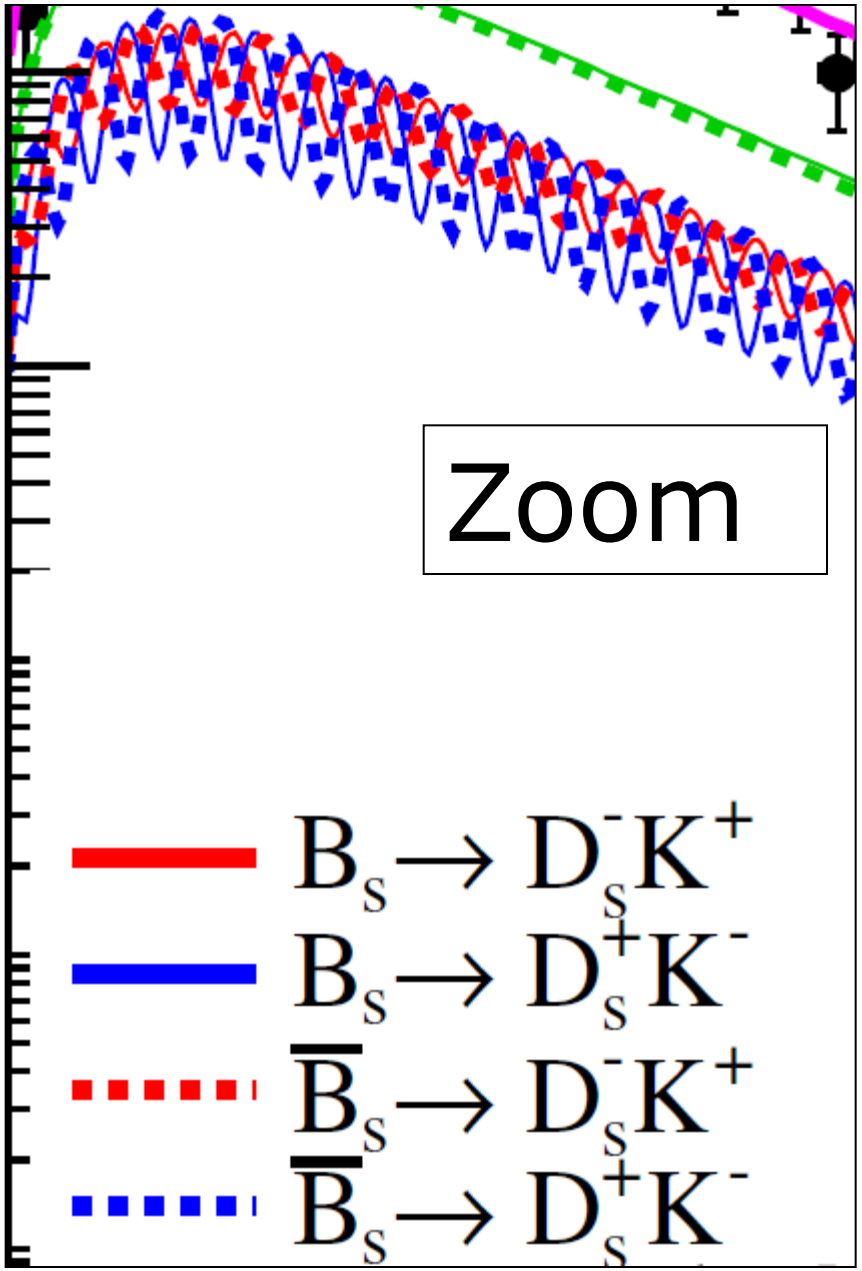
2) Acceptance vs decay time



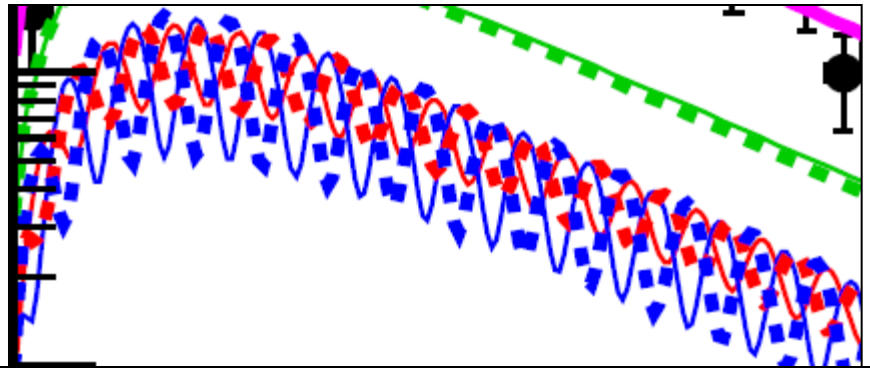
3) Decay time resolution



4) Flavour Tagging



Determination of γ

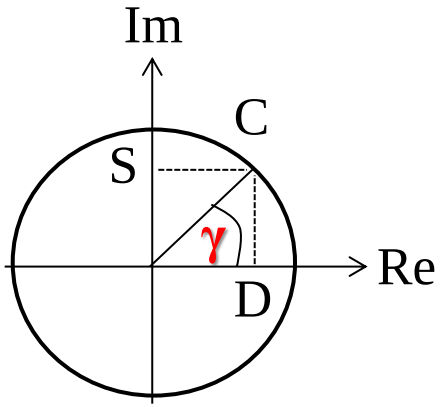


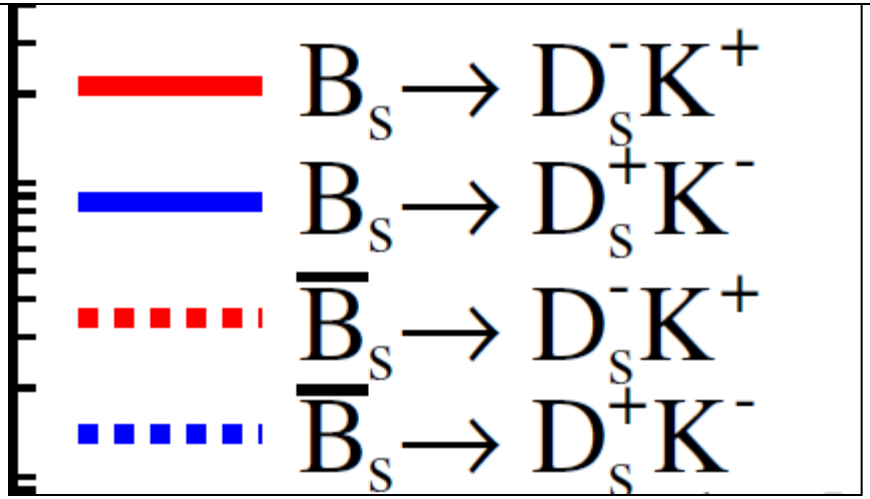
$$\frac{d\Gamma_{B_s^0\to f}(t)}{dt\, e^{-\Gamma t}} \sim |A_f|^2(1+|\lambda_f|^2)\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right)+D_f\sinh\left(\frac{\Delta\Gamma t}{2}\right)+C_f\cos(\Delta m t)-S_f\sin(\Delta m t)\right)$$

$$\frac{d\Gamma_{\bar{B}_s^0\to f}(t)}{dt\, e^{-\Gamma t}} \sim |A_f|^2\left|\frac{p}{q}\right|^2(1+|\lambda_f|^2)\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right)+D_f\sinh\left(\frac{\Delta\Gamma t}{2}\right)-C_f\cos(\Delta m t)+S_f\sin(\Delta m t)\right)$$

$$\frac{d\Gamma_{\bar{B}_s^0\to \bar{f}}(t)}{dt\, e^{-\Gamma t}} \sim |\bar{A}_{\bar{f}}|^2(1+|\bar{\lambda}_{\bar{f}}|^2)\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right)+D_{\bar{f}}\sinh\left(\frac{\Delta\Gamma t}{2}\right)+C_{\bar{f}}\cos(\Delta m t)-S_{\bar{f}}\sin(\Delta m t)\right)$$

$$\frac{d\Gamma_{B_s^0\to \bar{f}}(t)}{dt\, e^{-\Gamma t}} \sim |\bar{A}_{\bar{f}}|^2\left|\frac{q}{p}\right|^2(1+|\bar{\lambda}_{\bar{f}}|^2)\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right)+D_{\bar{f}}\sinh\left(\frac{\Delta\Gamma t}{2}\right)-C_{\bar{f}}\cos(\Delta m t)+S_{\bar{f}}\sin(\Delta m t)\right)$$





"Side products" of b → Dh analyses

1) Measurement of BR($B_s^0 \to D_s^- K^+$), BR($B_s^0 \to D_s^- \pi^+$)
   - Too small with 1 fb^{-1}?
     (see De Bruyn, Fleischer et al, arXiv:1208.6463)

2) Measurement of f_s/f_d with $B_s^0 \to D_s^- \pi^+$
   - Largest systematic unc. for $B_s^0 \to \mu^+\mu^-$
     (see Fleischer, Serra et al, arXiv:1004.3982)

3) Measurement of BR($B_c^+ \to B_s^0 \pi^+$)
   - First weak B-to-B decay, largest weak BR(B), *source* of B_s^0 mesons?

4) Measurement of $f_{\Lambda b}/f_d$ and BR($\Lambda_b^0 \to \Lambda_c^- \pi^+$)
   - Reference BR for Λ_b^0 physics, PDG on Λ_b^0 is empty:

Λ_b^0 DECAY MODES		Fraction (Γ_i/Γ)
$J/\psi(1S)\Lambda \times$ B($b \to \Lambda_b^0$)		$(5.8 \pm 0.8) \times 10^{-5}$
$\Lambda_c^+ \pi^-$		$(5.7^{+4.0}_{-2.6}) \times 10^{-3}$
$\Lambda_c^+ a_1(1260)^-$		seen
$\Lambda_c^+ \pi^+ \pi^- \pi^-$		$(8 \ ^{+5}_{-4}) \times 10^{-3}$
$\Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything	[y]	(9.8±2.2) %

Highlights

- This is what LHCb was built for!
  - New Physics in loops? $B^0 \to K^{*0}\mu^+\mu^-$
  - First CP violation in B_s^0 system $B_s^0 \to K^+\pi^-$
  - Rarest decays $B_s^0 \to \mu^+\mu^-$
  - Time dependent CP violation in B_s^0 $B_s^0 \to J/\Psi\phi$
  - Anomaly? $B_{(s)}^0 \to D_{(s)}^-\mu^+X$
  - Unitarity angle γ $B_s^0 \to D_s^-K^+$
  - Exotics $X \to Y$

"LHCb is the forward GPD detector"

See Maurizio's Tolk

Exotic team

Conclusions

1) 2013 fruitful year for LHCb and our group

2) Highlights from LHCb
   - New physics in loops?
   - First CP violation in B_s^0 system

3) Highlights from the group
   - Rarest decay
   - CP violation in B_s^0 system
   - DØ Anomaly?
   - Unitarity angle γ
   - Exotics

$B^0 \to K^{*0}\mu^+\mu^-$	Z' ?	
$B_s^0 \to K^+\pi^-$	historical	
$B_s^0 \to \mu^+\mu^-$	BR	Siim
$B_s^0 \to J/\Psi\phi$	Φ_s	Roel
$B_{(s)}^0 \to D_{(s)}^- \mu^+ X$	A_{sl}	
$B_s^0 \to D_s^- K^+$	γ	
$X \to Y$	NP ?	Maurizio

4) All results statistics limited, upgrade will improve — Eddy

Backup

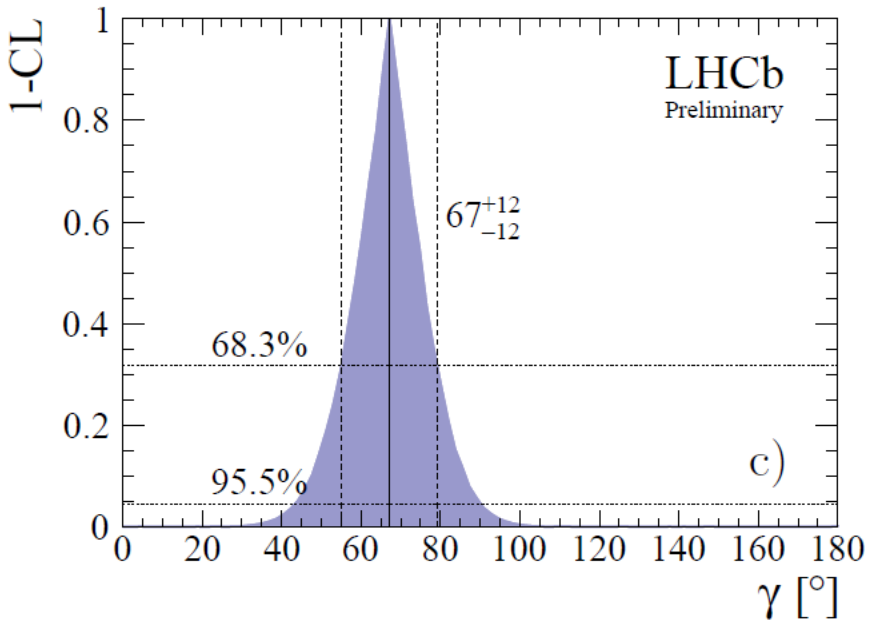
Determination of γ

1) Measurement of the CKM angle γ from a combination of B→Dh analyses — arXiv:1305.2050
   - Improved constraints on γ from $B^{\pm}\to DK^{\pm}$ decays including first results on 2012 data — LHCb-CONF-2013-006

- Relative weak phase of two amplitudes in $B^{\pm}\to DK^{\pm}$ decays: γ
- Combine 4 measurements (with CLEO input) to determine γ
  - $B^{\pm}\to D(K_S^0\pi^+\pi^-)K^{\pm}$ (2 fb^{-1}, "GGSZ") — LHCb-CONF-2013-004
  - $B^{\pm}\to D(K_S^0\pi^+\pi^-)K^{\pm}$ (1 fb^{-1}, "GGSZ") — LHCb, PL B718 (2012) 43
  - $B^{\pm}\to D(h^+h^-)K^{\pm}$ (1 fb^{-1}, "ADS" & "GLW") — LHCb, PL B712 (2012) 203
  - $B^{\pm}\to D(\pi^+K^-\pi^+\pi^-)K^{\pm}$ (1 fb^{-1}, "ADS") — LHCb, PL B723 (2013) 44

$$\gamma = (67 \pm 12)^\circ \text{ at } 68\% \text{ CL}$$

Comparison	γ	± 1σ
Belle	68	$^{+15}_{-14}$
BaBar	69	$^{+17}_{-16}$
LHCb	67	±12



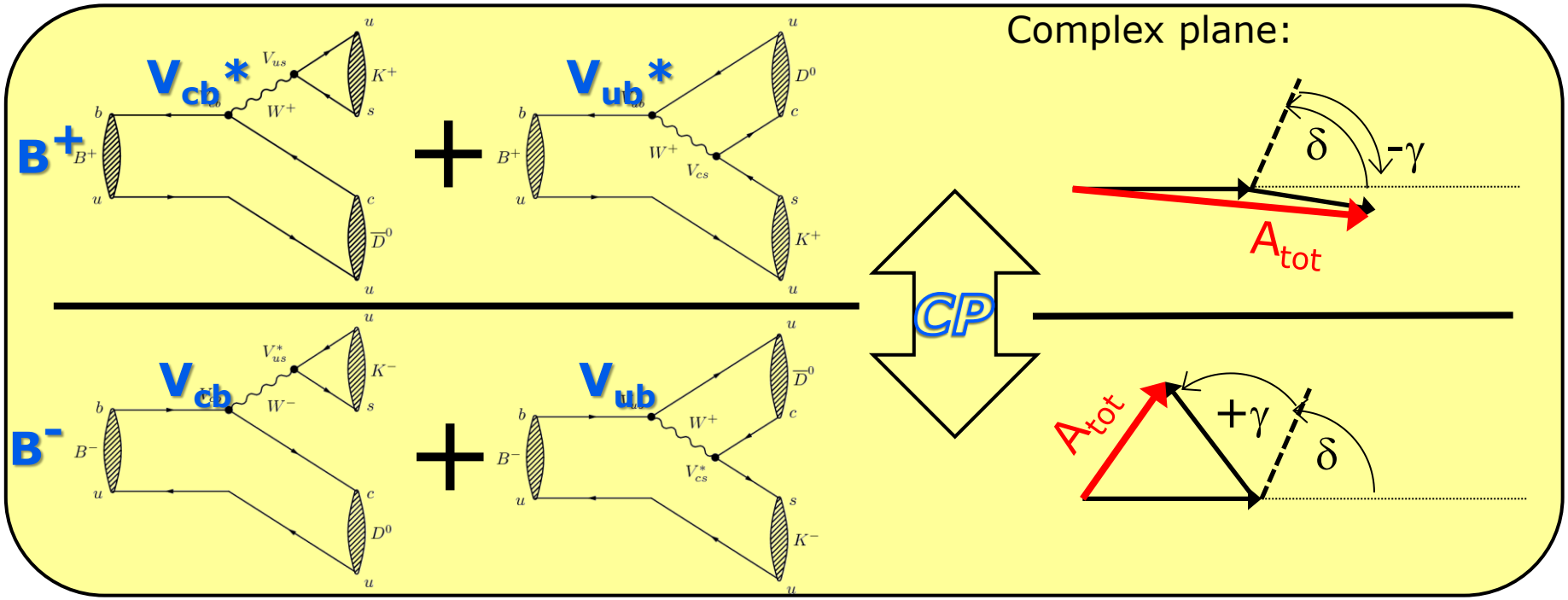
➢ With all data analyzed, foresee a precision of ~7°

Determination of γ

1) Measurement of the CKM angle γ from a combination of B→Dh analyses arXiv:1305.2050

- Relative weak phase of two amplitudes in $B^{\pm} \to DK^{\pm}$ decays: γ

What can happen when *two* amplitudes contribute to a decay:

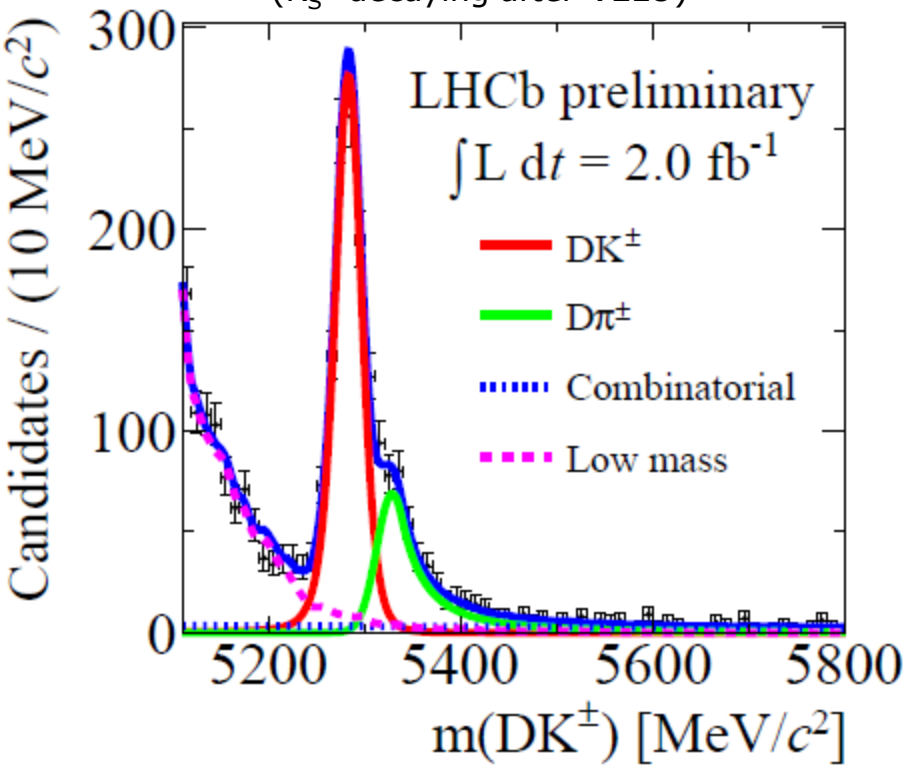


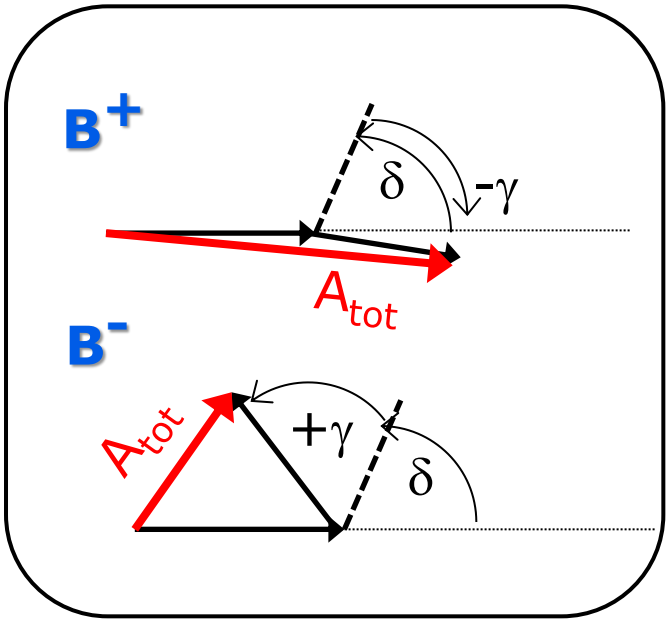
Determination of γ

1)	Measurement of the CKM angle γ from a combination of B→Dh analyses	arXiv:1305.2050
▪	Model-independent measurement of CP violation parameters in $B^{\pm}\to(K^0_S h^+h^-)_D K^{\pm}$ decays	LHCb-CONF-2013-004

- Relative weak phase of two amplitudes in $B^{\pm}\to DK^{\pm}$ decays: γ
- Compare $B^-\to D(K_S^0\pi^+\pi^-)K^-$ with $B^+\to D(K_S^0\pi^+\pi^-)K^+$

(K_S^0 decaying *after* VELO)





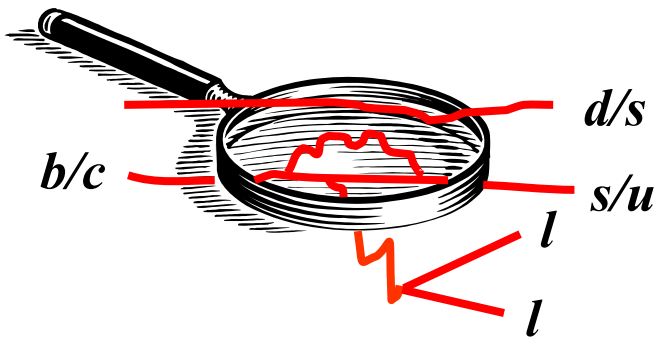
"How can a complex number affect the total amplitude?"

LHCb: a place to find penguins

Electroweak penguins ($B^0 \to K^{*0}\mu^+\mu^-$ and friends)

2) Differential branching fraction and angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ arXiv:1304.6325

- Many EW penguin decays studied:
  - Differential branching fraction and angular analysis of the decay $B^0_s \to \phi\mu^+\mu^-$ arXiv:1305.2168
  - Search for $D^+_{(s)} \to \pi^+\mu^+\mu^-$ and $D^+_{(s)} \to \pi^-\mu^+\mu^+$ decays arXiv:1304.6365
  - Measurement of the $B^0 \to K^{*0}e^+e^-$ branching fraction at low dilepton mass arXiv:1304.3035



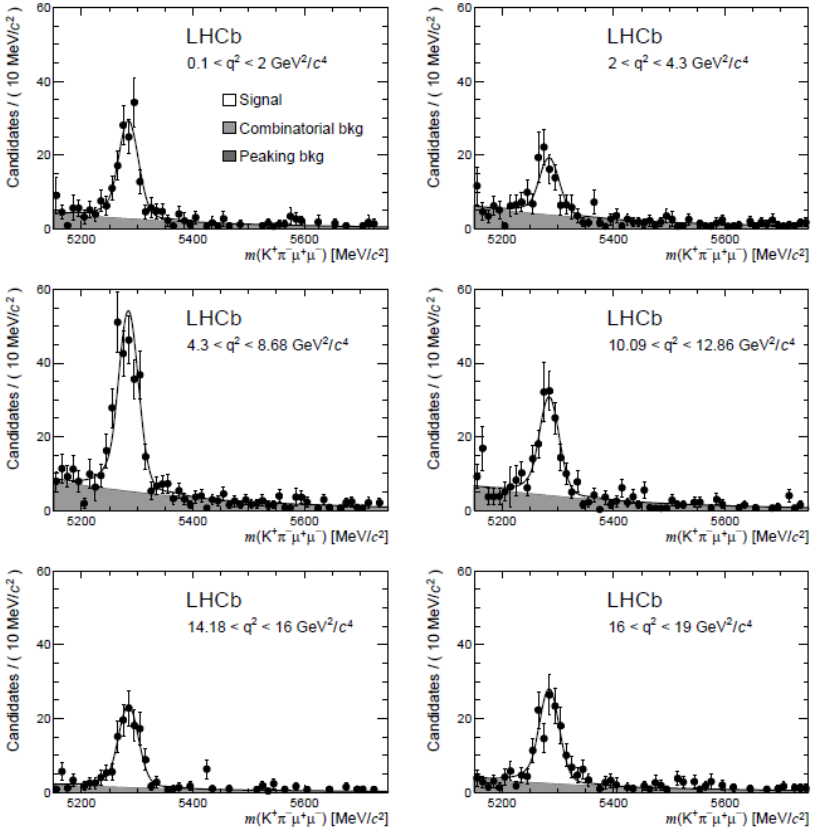
- Very rich "laboratory" !
- Many decays & observables
- New particles affect couplings
  - Modify SM couplings, like C_7, C_9, C_{10}
  - Add righthanded couplings, like C'_7, C'_9, C'_{10}
  - Add other couplings, like $C^{(\prime)}_S$, $C^{(\prime)}_P$

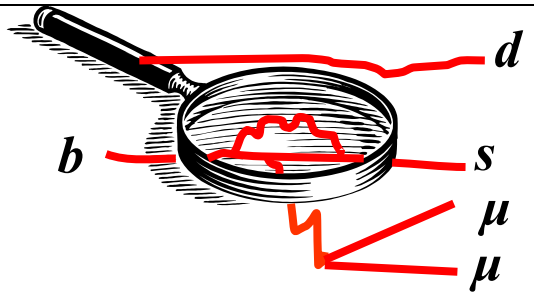
➢ Large variety of possible modifications to observations!

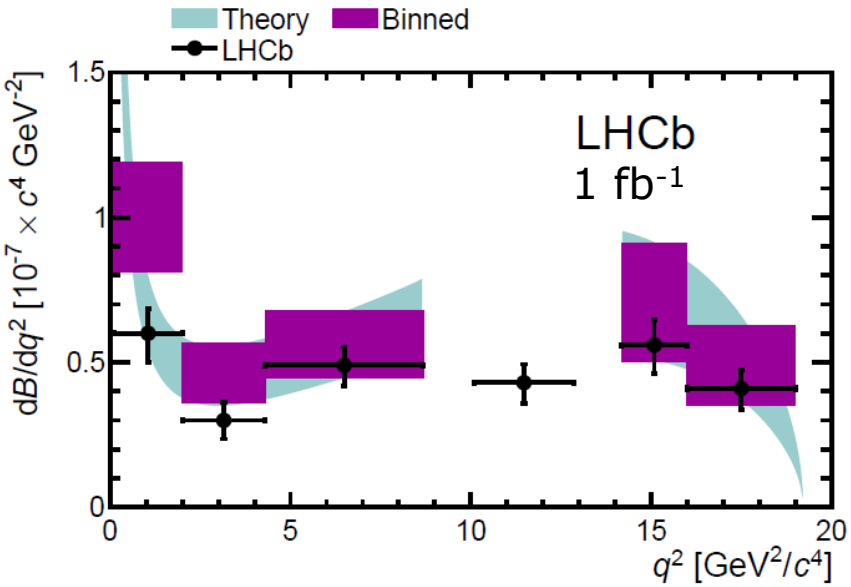
$$\mathcal{H}_{\text{eff}} = -G_F \cdot \alpha/\sqrt{2\pi} \cdot V_{tb}V_{ts}^* \sum_i (C_i\mathcal{O}_i + C_i'\mathcal{O}_i')$$

Electroweak penguins: $B^0 \to K^{*0}\mu^+\mu^-$

2) Differential branching fraction and angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ arXiv:1304.6325



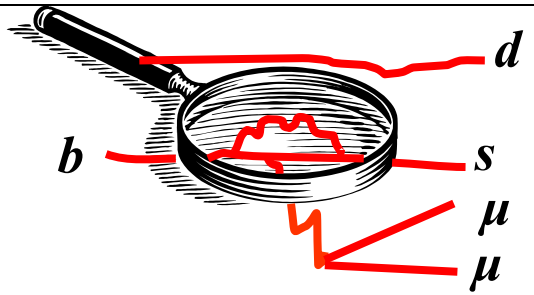


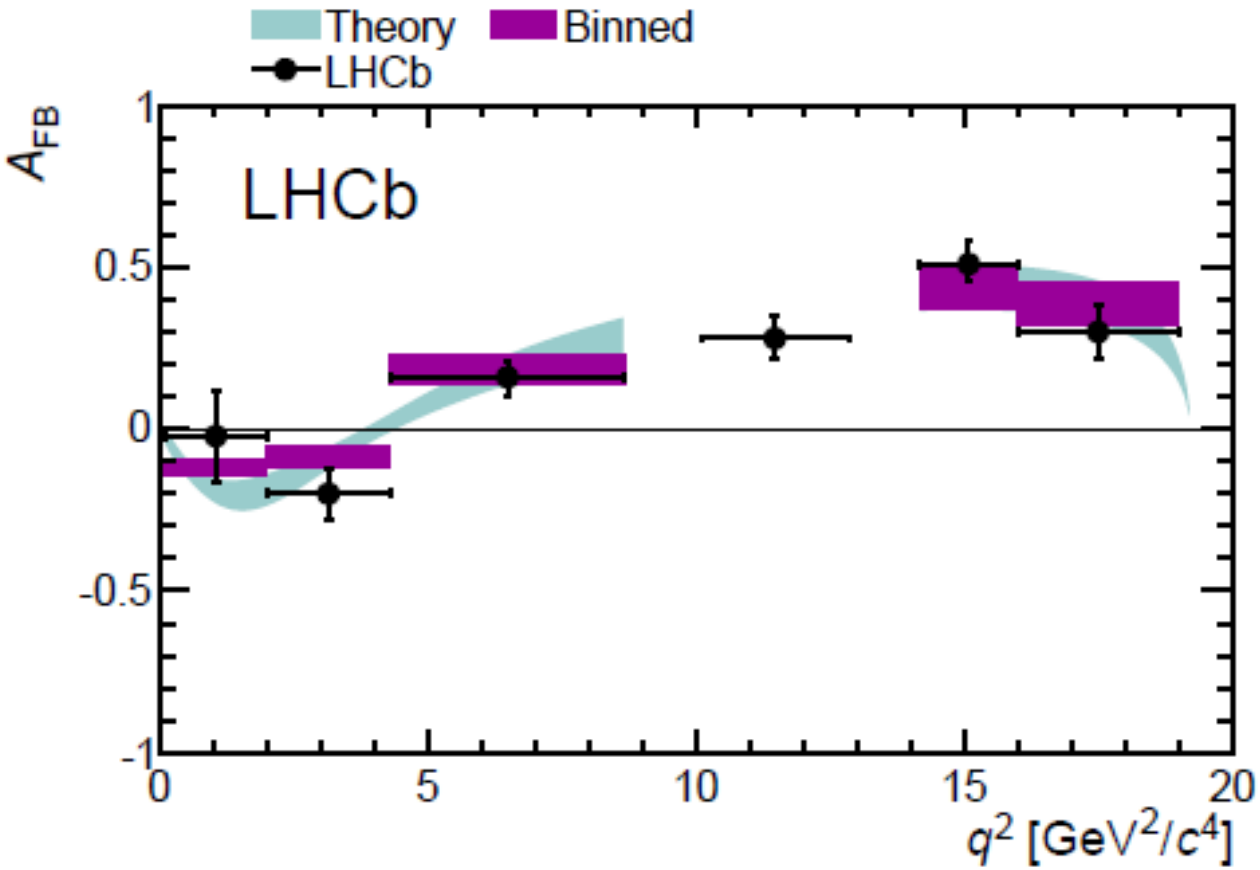


- Accurate measurement of $d\Gamma/dq^2$
- In agreement with SM

Electroweak penguins: $B^0 \to K^{*0}\mu^+\mu^-$

2) Differential branching fraction and angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ arXiv:1304.6325





- In agreement with B-factories, CDF, ATLAS and CMS

Electroweak penguins: $B^0 \to K^{*0}\mu^+\mu^-$

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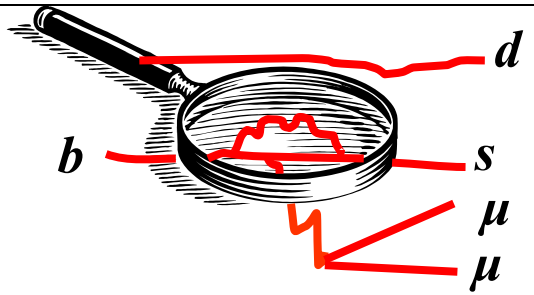

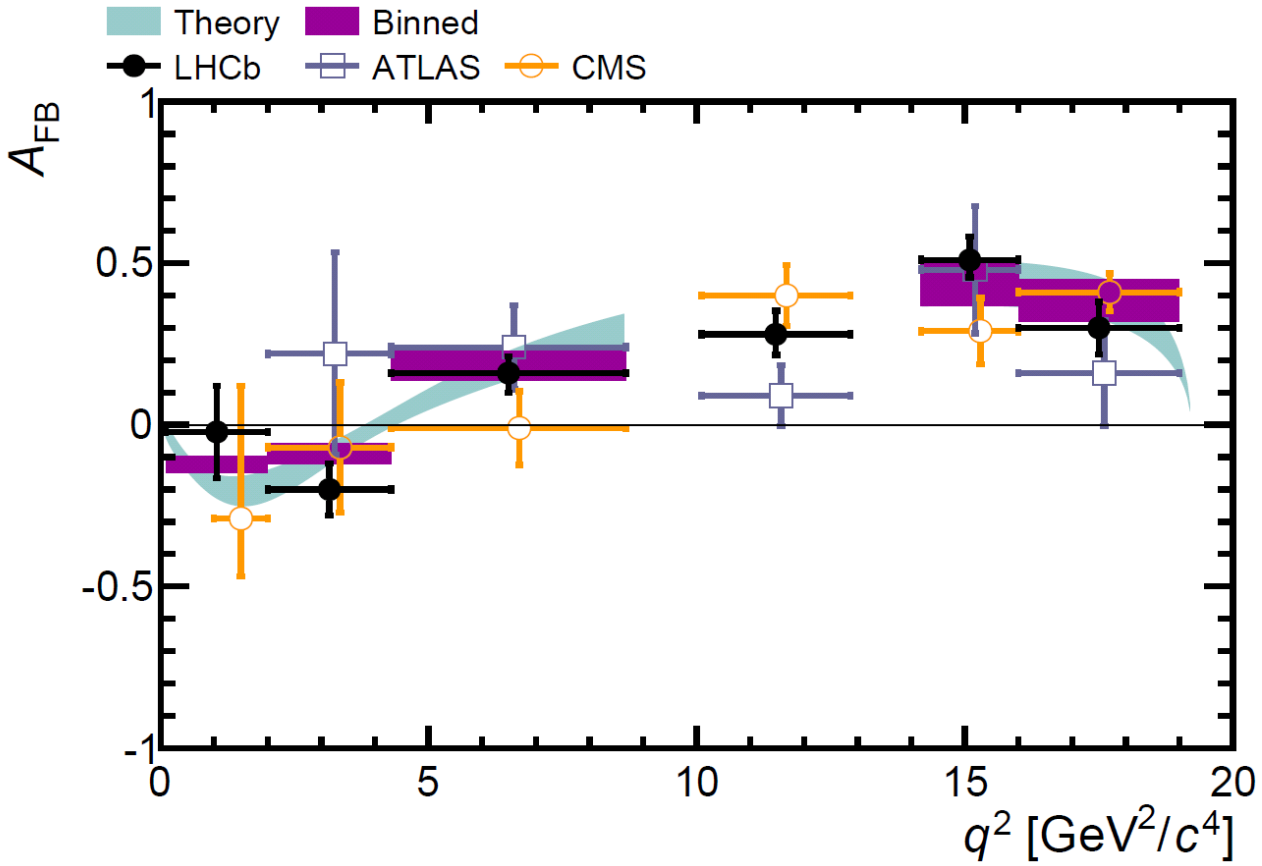

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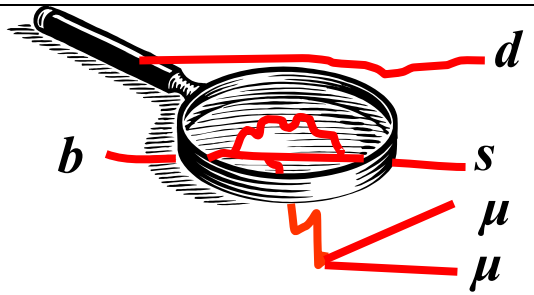
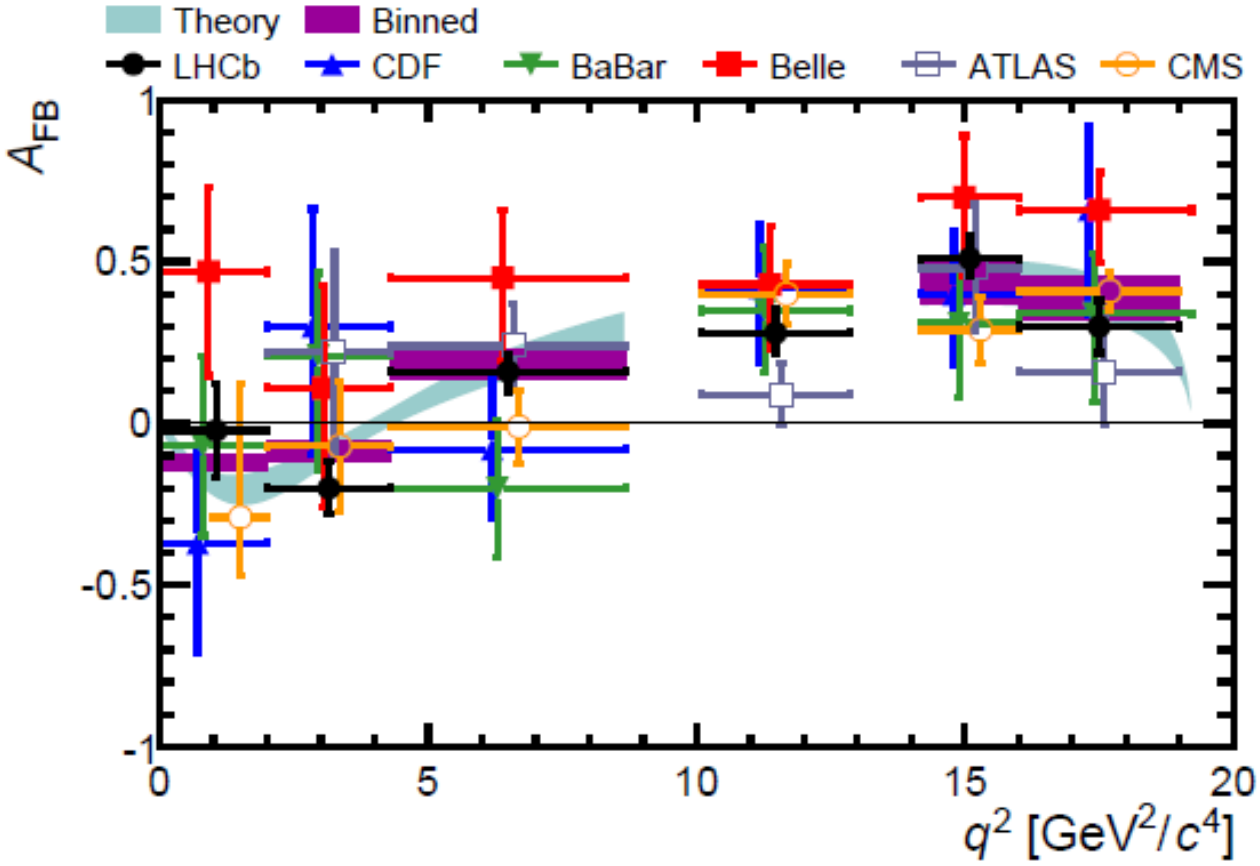


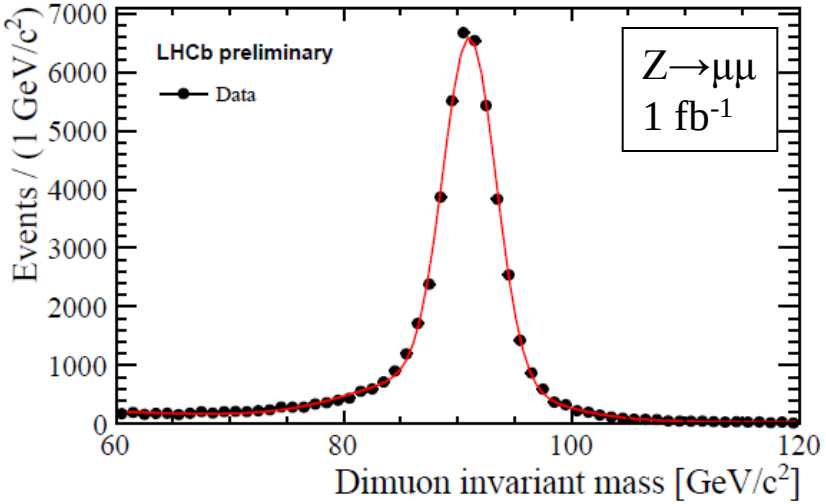


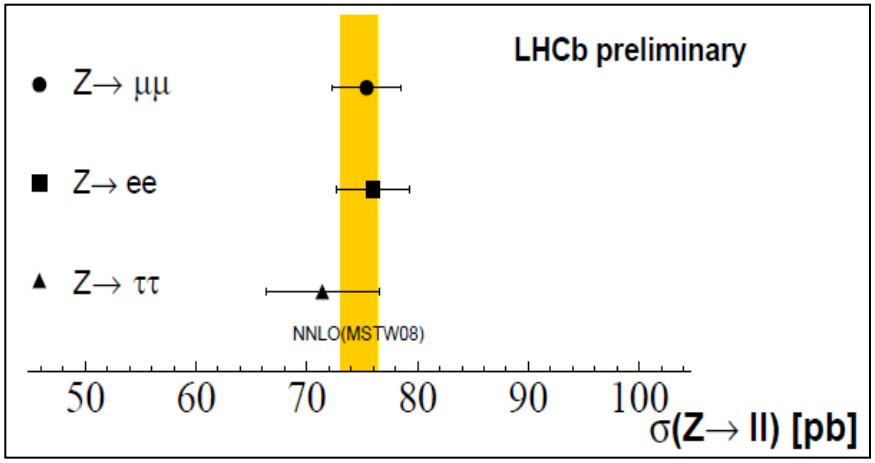
- In agreement with B-factories, CDF, ATLAS and CMS

LHCb: "forward GPD"

- Measurement of the cross-section for $Z \to \mu\mu$ production with 1 fb^{-1} of pp collisions at $\sqrt{s}$=7 TeV LHCb-CONF-2013-007
- Graphical comparison of the LHCb measurements of W and Z boson production with ATLAS and CMS LHCb-CONF-2013-005

- Test the SM
- Constrain the pdf's
- Scrutinize lepton universality





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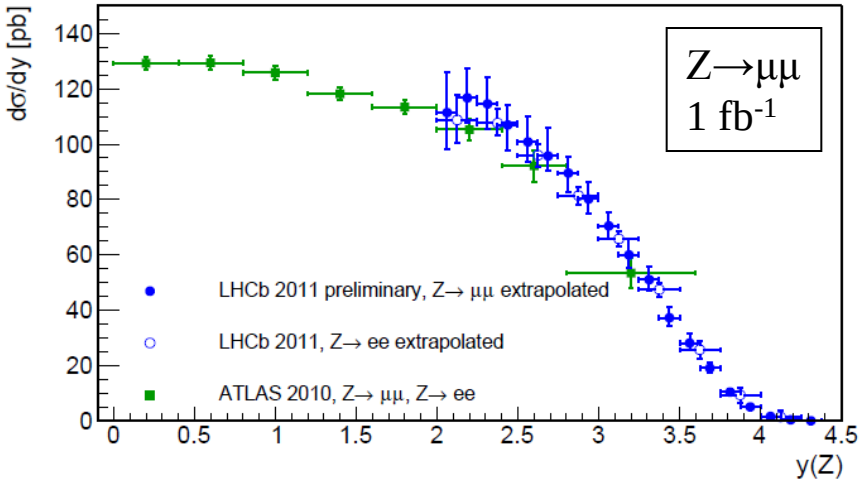
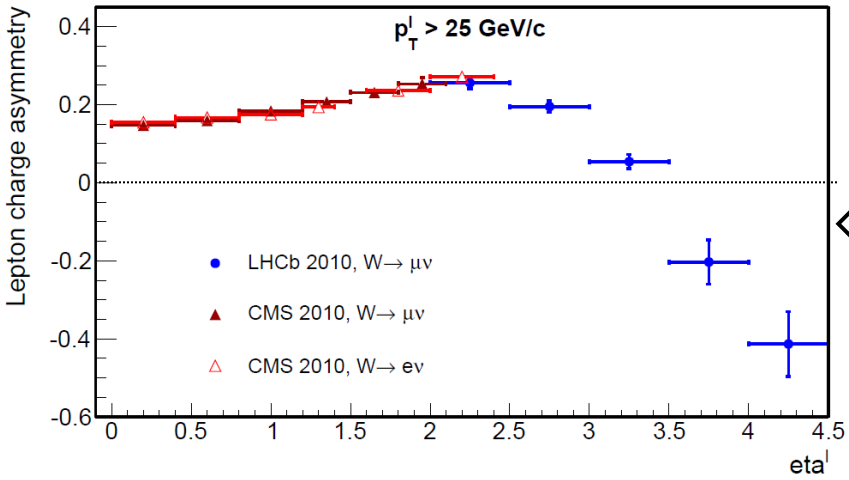
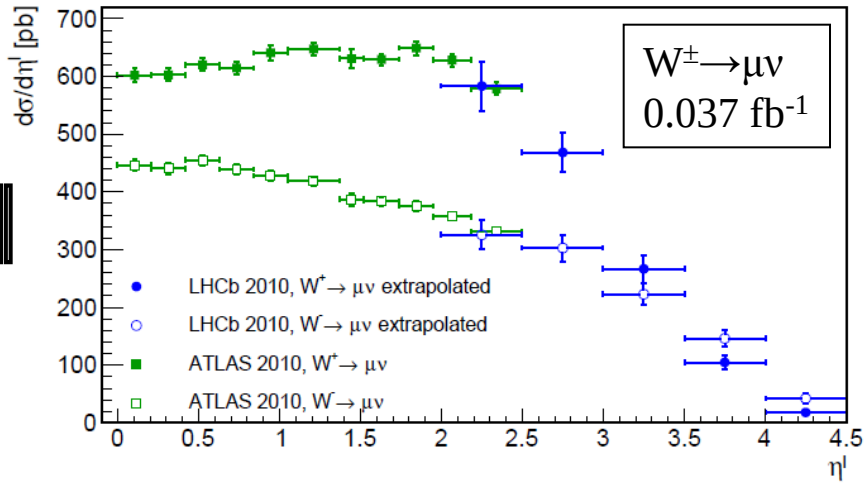
➢ LHCb becomes "Forward GPD"



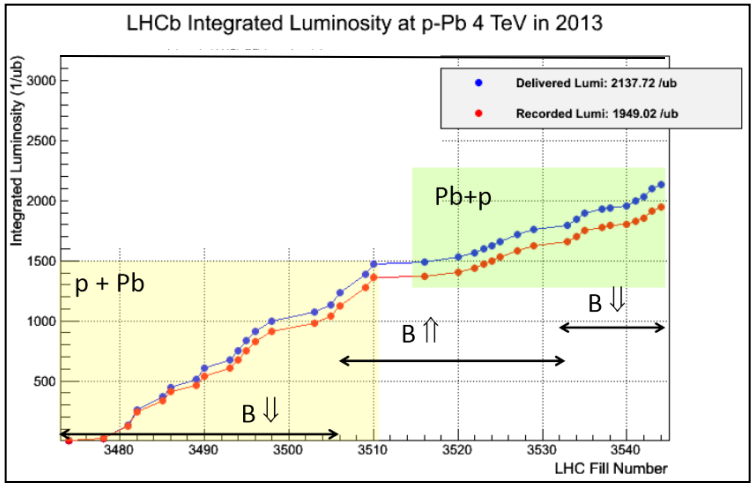




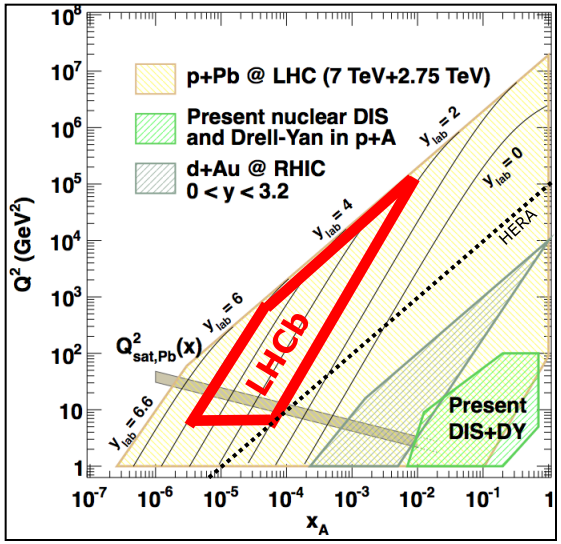
LHCb and heavy ions

Study of the J/ψ production cross-section in proton-lead collisions at $\sqrt{s_{NN}}$=5 TeV LHCb-CONF-2013-008

- Collected 2 nb^{-1} of pA+Ap data
  - Results based on
    0.75 nb^{-1} pA and 0.3 nb^{-1} Ap



- Unique acceptance coverage
  - pp: $2 < \eta < 5$
  - pA: $1.5 < \eta < 4.5$
  - Ap: $-5.5 < \eta < -2.5$



LHCb and heavy ions

Study of the J/ψ production cross-section in proton-lead collisions at $\sqrt{s_{NN}}$=5 TeV LHCb-CONF-2013-008

- Measured J/ψ production
  1) Prompt and from-b
  2) pA, Ap
  3) Nuclear suppression (wrt pp)
- Cross section vs √s
  - Scaled by 1/A
  - In common rapidity range: 2.5<|y|<4
- Nuclear attenuation
  - Agreement with theoretical predictions
  - Precision insufficient to prove saturation