B-физика на LHC
Статус и перспективы поиска новой физики

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ИЯИ РАН

Оглавление

- **Экспериментальный статус и глобальный фит SM модели и основные направления поиска НФ с тяжелыми кварками**

- **LHCb is B-meson experiment for search NP in CPV and rare decays**
  - **Основные параметры и экспериментальные методы**

- **Физическая программа и ключевые результаты по поиску НФ**
  - ϕ_s, A^q_{SL}, $B_s \to \mu\mu$, $B \to K^*\mu\mu$

- **Заключение**

Параметризация СКМ матрицы

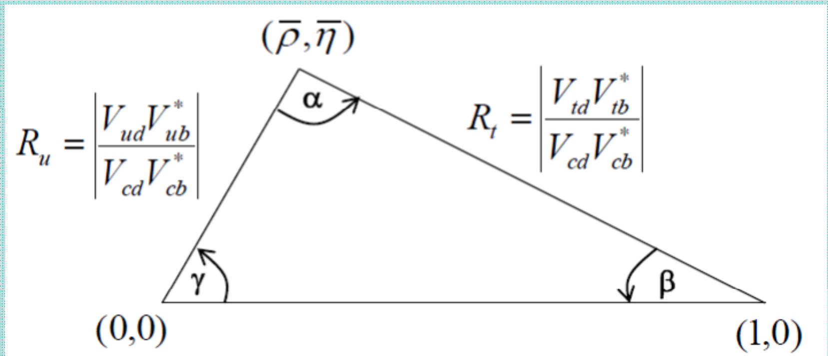
- СКМ матрица: унитарность → 4 действительных свободных параметра – **A, λ, ρ, η**. Фазоинвариантная параметризация, сохраняющая унитарность до любого порядка по λ (Wolfenstein parametrisation with Jarlskog like phase invariants ; Charles et al. EPG C41,1-131(2005))

$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar\rho + i\bar\eta = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

$$V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

  - λ измерена из значений $|V_{ud}|$ и $|V_{us}|$, берущихся из суперразрешенного ядерного β-распада и полулептонных распадов K-мезонов.
  - **A** определяется из значений $|V_{cb}|$ и λ.
  - **ρ, η** - определяются из измерений углов и сторон B_d унитарного треугольника.

- B_d унитарный треугольник: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

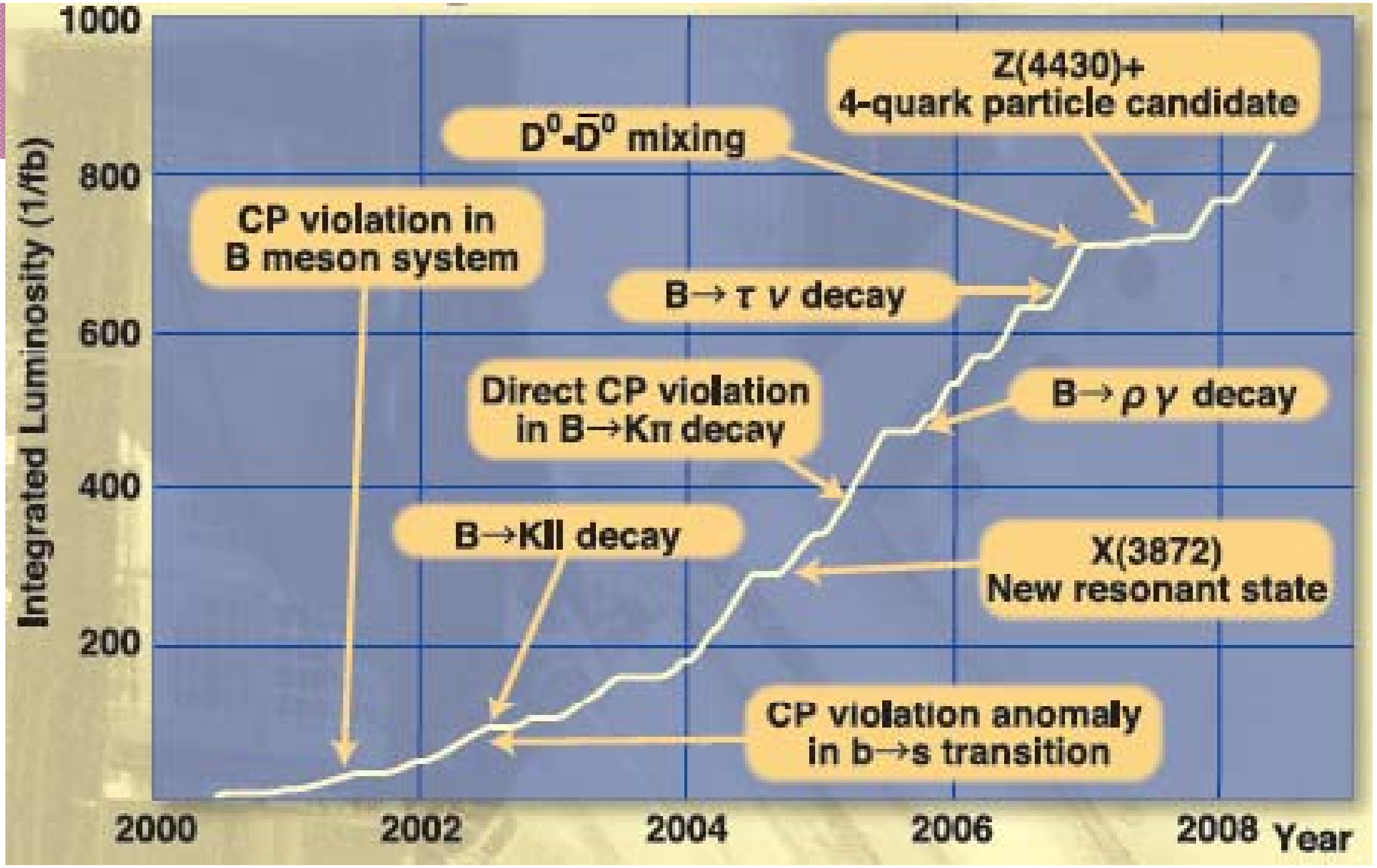


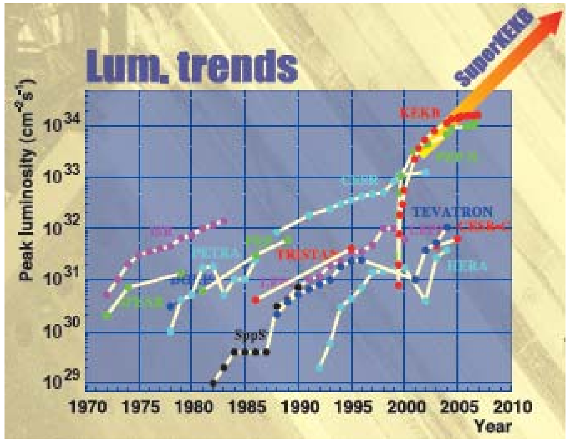
$$\alpha = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right], \quad \beta = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right],$$

$$\gamma = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right], \quad \beta_s = -\arg\left[-\frac{V_{cs}V_{cb}^*}{V_{ts}V_{tb}^*}\right]$$

BELLE

В последние 10 лет огромное количество данных получено на B-фабриках, уточняющих параметры B_d треугольника.





Total cross section and trigger rates with $L = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
Hadron production from continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\rm lab} \geq 17^\circ$)	44	350 $^{(a)}$
$\gamma\gamma$ ($\theta_{\rm lab} \geq 17^\circ$)	2.4	19 $^{(a)}$
2γ processes ($\theta_{\rm lab} \geq 17^\circ$, $p_t \geq 0.1$ GeV$/c$)	~ 80	~ 15000
Total	~ 130	~ 20000

$^{(a)}$ rate is pre-scaled by a factor of 1/100

Экспериментальный статус СКМ матрицы

Спасибо В-фабрикам и Теватрону: огромный прогресс достигнут за последние годы в измерениях параметров СКМ матрицы.

Observables

$|V_{ud}|, |V_{us}|$

$|V_{cb}|, |V_{ub}|$

$\mathcal{B}[B \to \tau\, \nu]$

$\Delta m_d, \Delta m_s$

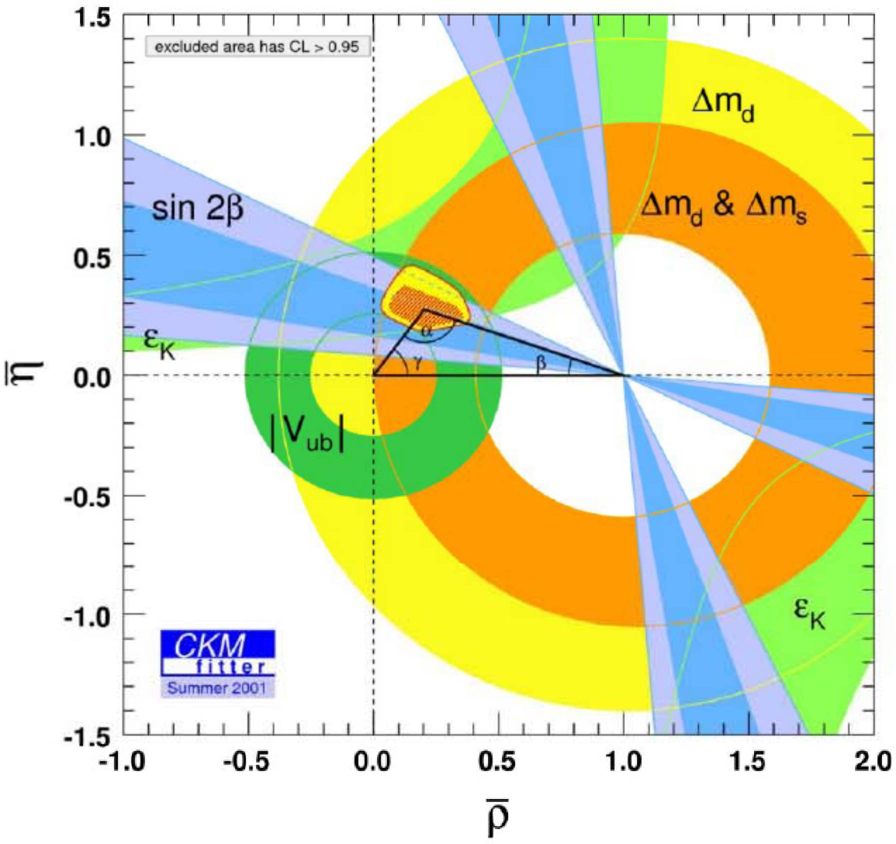
$|\varepsilon_K|$

$\alpha, \sin(2\beta_{cc}), \gamma$

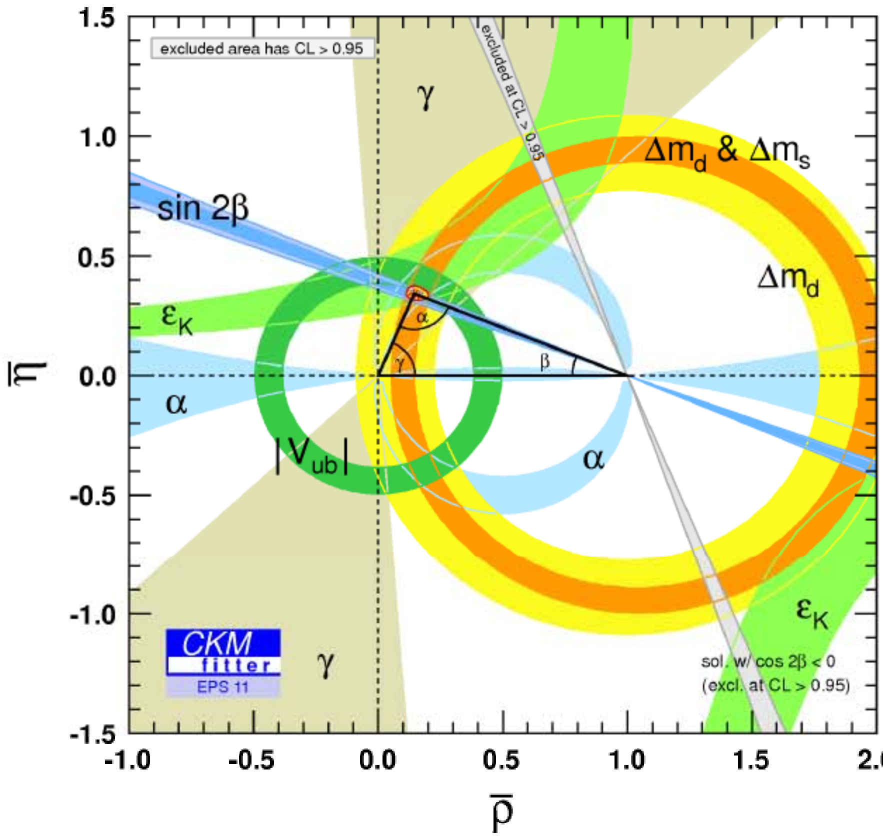
$$\bar{\rho} = 0.144^{+0.027}_{-0.018}, \quad \bar{\eta} = 0.343^{+0.014}_{-0.014}$$

$$A = 0.816^{+0.011}_{-0.021}, \quad \lambda = 0.22518^{+0.00036}_{-0.00077}$$

EPS 2001

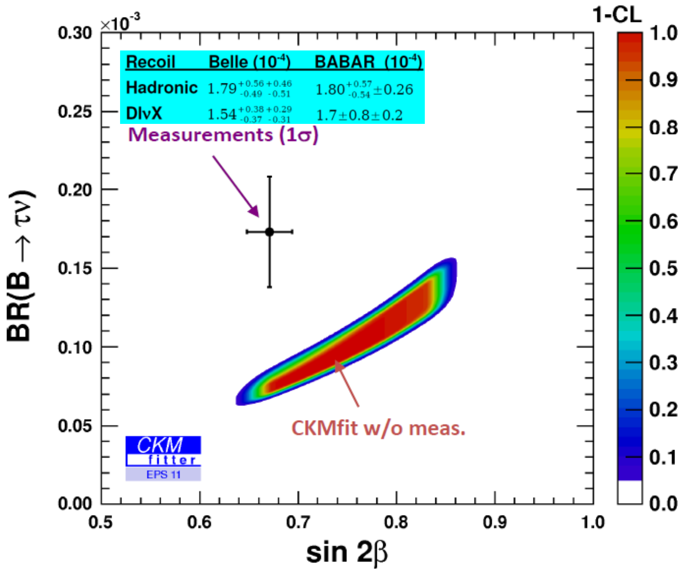


EPS 2011



Предсказания CKMfitter 2011

В целом согласие предсказаний с экспериментом, но ...
Продолжается противоречие между BR[$B\to\tau\nu$] и $\sin(2\beta_{cc})$.
Исключение одной из этих наблюдаемых из фита уменьшает χ^2_{min} на 2.6 σ, т.е. в рамках стандартной модели либо BR[$B\to\tau\nu$] слишком велик, либо $\sin(2\beta_{cc})$ слишком мал.



Observable	Measurement	Prediction	Pull (σ)
Charged Leptonic Decays			
$\mathcal{B}(B^+\to\tau^+\nu_\tau)$	$(16.8\pm3.1)\cdot10^{-5}$	$(7.57\ ^{+0.98}_{-0.61})\cdot10^{-5}$	2.8
$\mathcal{B}(B^+\to\mu^+\nu_\mu)$	$<10^{-6}$	$(3.74\ ^{+0.44}_{-0.38})\cdot10^{-7}$	-
$\mathcal{B}(D_s^+\to\tau^+\nu_\tau)$	$(5.29\pm0.28)\cdot10^{-2}$	$(5.44\ ^{+0.05}_{-0.17})\cdot10^{-2}$	0.5
$\mathcal{B}(D_s^+\to\mu^+\nu_\mu)$	$(5.90\pm0.33)\cdot10^{-3}$	$(5.39\ ^{+0.21}_{-0.22})\cdot10^{-3}$	1.3
$\mathcal{B}(D^+\to\mu^+\nu_\mu)$	$(3.82\pm0.32\pm0.09)\cdot10^{-4}$	$(4.18\ ^{+0.13}_{-0.20})\cdot10^{-4}$	0.6
Neutral Leptonic B decays			
$\mathcal{B}(B_s^0\to\tau^+\tau^-)$	-	$(7.73\ ^{+0.37}_{-0.65})\cdot10^{-7}$	-
$\mathcal{B}(B_s^0\to\mu^+\mu^-)$	$<32\cdot10^{-9}$	$(3.64\ ^{+0.17}_{-0.31})\cdot10^{-9}$	-
$\mathcal{B}(B_s^0\to e^+e^-)$	$<2.8\cdot10^{-7}$	$(8.54\ ^{+0.40}_{-0.72})\cdot10^{-14}$	-
$\mathcal{B}(B_d^0\to\tau^+\tau^-)$	$<4.1\cdot10^{-3}$	$(2.36\ ^{+0.12}_{-0.21})\cdot10^{-8}$	-
$\mathcal{B}(B_d^0\to\mu^+\mu^-)$	$<6\cdot10^{-9}$	$(1.13\ ^{+0.06}_{-0.11})\cdot10^{-10}$	-
$\mathcal{B}(B_d^0\to e^+e^-)$	$<8.3\cdot10^{-9}$	$(2.64\ ^{+0.13}_{-0.24})\cdot10^{-15}$	-
$B_q-\bar{B}_q$ mixing observables			
$\Delta\Gamma_s/\Gamma_s$	$0.092^{+0.051}_{-0.054}$	$0.179\ ^{+0.067}_{-0.071}$	0.5
$a^d_{\rm SL}$	$(-47\pm46)\cdot10^{-4}$	$(\text{-}6.5\ ^{+1.9}_{-1.7})\cdot10^{-4}$	0.8
$a^s_{\rm SL}$	$(-17\pm91^{+12}_{-23})\cdot10^{-4}$	$(0.29\ ^{+0.09}_{-0.08})\cdot10^{-4}$	0.2
$a^s_{\rm SL}-a^d_{\rm SL}$	-	$(6.8\ ^{+1.9}_{-1.7})\cdot10^{-4}$	-
$\sin(2\beta)$	0.678 ± 0.020	$0.832\ ^{+0.013}_{-0.033}$	2.7
$2\beta_s$	$[0.04;1.04]\cup[2.16;3.10]$ $0.76\ ^{+0.36}_{-0.38}\pm0.02$	$0.0363\ ^{+0.0016}_{-0.0015}$	-
Radiative B decays			
$\mathcal{B}(B_d\to K^*(892)\gamma)$	$(43.3\pm1.8)\cdot10^{-6}$	$(64\ ^{+22}_{-21})\cdot10^{-6}$	1.2
$\mathcal{B}(B^-\to K^{*-}(892)\gamma)$	$(42.1\pm1.5)\cdot10^{-6}$	$(66\ ^{+21}_{-20})\cdot10^{-6}$	1.1
$\mathcal{B}(B_s\to\phi\gamma)$	$(57^{+21}_{-18})\cdot10^{-6}$	$(65\ ^{+31}_{-24})\cdot10^{-6}$	0.1
$\mathcal{B}(B\to X_s\gamma)/\ \mathcal{B}(B\to X_c\ell\nu)$	$(3.346\pm0.247)\cdot10^{-3}$	$(3.03\ ^{+0.34}_{-0.32})\cdot10^{-3}$	0.2
Rare K decays			
$\mathcal{B}(K^+\to\pi^+\nu\bar{\nu})$	$(1.75^{+1.15}_{-1.05})\cdot10^{-10}$	$(0.854\ ^{+0.116}_{-0.098})\cdot10^{-10}$	0.8
$\mathcal{B}(K_L\to\pi^0\nu\bar{\nu})$	-	$(0.277\ ^{+0.028}_{-0.035})\cdot10^{-10}$	-

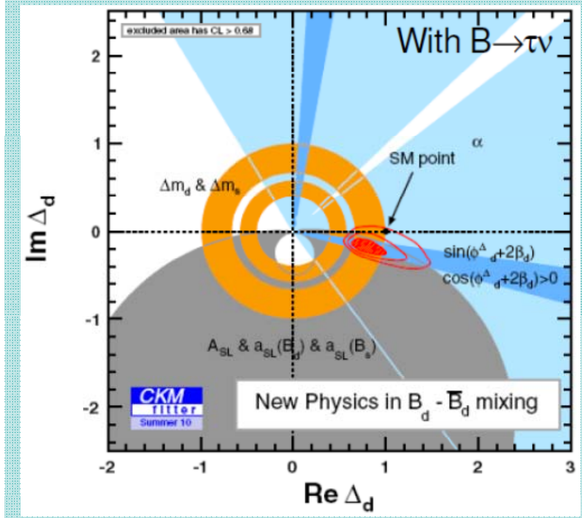
Выводы из СКМ фитирования

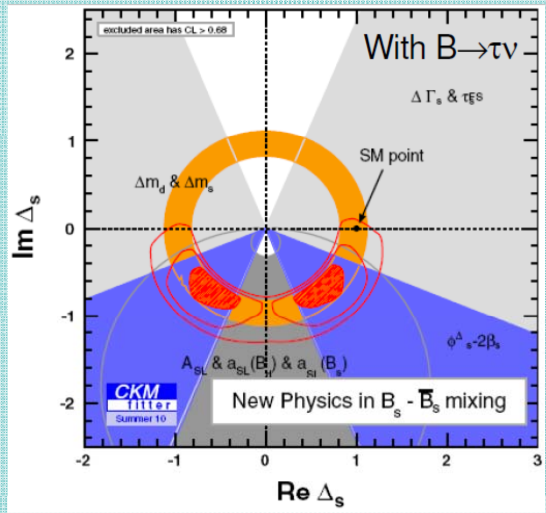
- Механизм СКМ очевидно работает, но есть место для Новой Физики в механизме смешивания в обоих B_d и B_s мезонах: как показывает анализ, дополнительные фазы смешивания могут компенсировать имеющееся противоречие между $BR[B \to \tau\nu]$ и $\sin(2\beta_{cc})$.
- Противоречия в наблюдаемых подталкивают к перепроверке и обновлению измерений, в первую очередь тех, что на подходе: ϕ_s, A^q_{SL}, $B_s \to \mu\mu$, $B \to K^*\mu\mu$.

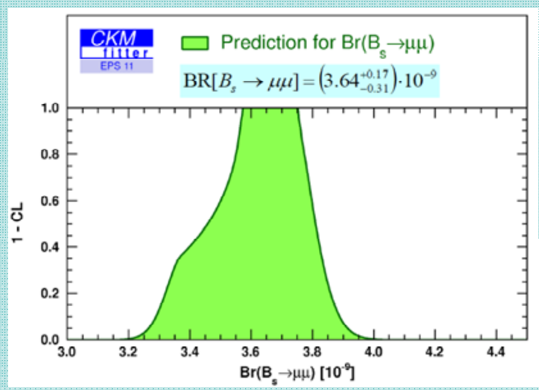
Ждем обновления результатов с Тэватрона и LHC!

$$\Phi_d^{NP} = (-12.9^{+3.8}_{-2.7})^\circ$$

$$\Phi_s^{NP} = (-59^{+18}_{-12} \cup -127^{+12}_{-19})^\circ$$







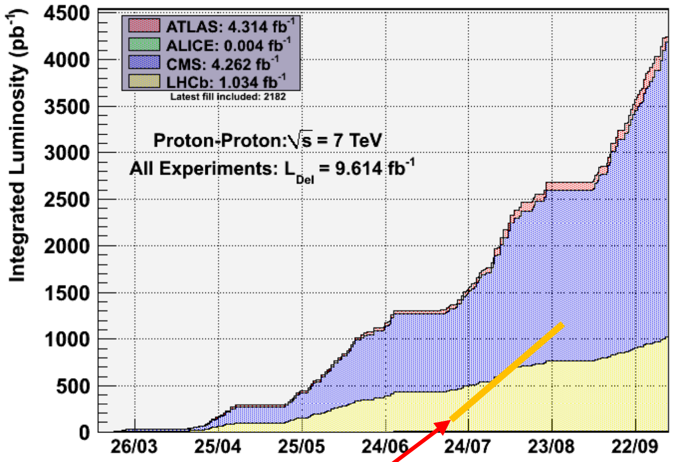
$$\Delta_q \equiv |\Delta_q| \cdot e^{i\phi_q^\Delta} \equiv M_{12}^q / M_{12}^{SM,q}$$

LHCb Collaboration:
755 Members, from 55 Institutes in 15 Countries

LHCb experiment for studies of B-meson CPV and rare decays

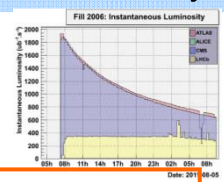
LHCb operation

LHCb collected ~37 pb^{-1} in 2010 and already ~ 940 pb^{-1} recorded in 2011
By end of 2011 LHCb hopes to collect >1 fb^{-1}



dL/dt ~ 100 pb^{-1}/week !

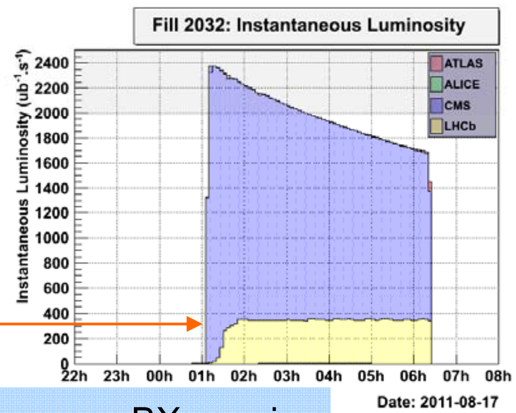
- LHC reached nominal peak luminosity of $3.2 \cdot 10^{33}$ $cm^{-2}s^{-1}$ with number of bunches is ~1380 from ~2600.
- LHCb recording >1pb^{-1}/hour running at $L \sim 3.5 \cdot 10^{32}$ $cm^{-2}sec^{-1}$ in auto-leveling mode
- GPD luminosity/fill is 4-10 times higher than LHCb

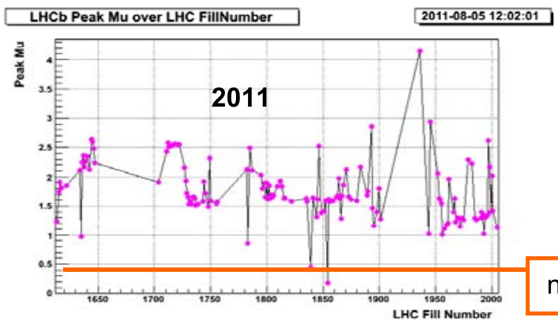


LHC performs well!

~30 pb-1 for LHCb in 29 h in single fill !

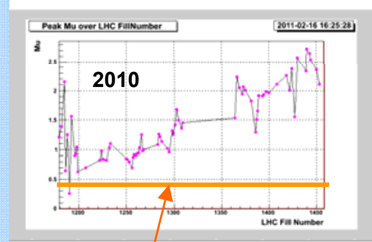
LHCb luminosity auto-leveling





nominal μ =0.4

- Visual average number of vertexes per BX now is ~×3 times larger than nominal μ =0.4 (**in 2010 ~×6 larger**)
- 1 PV gives ~30 tracks/rapidity unit
- Higher μ means higher track multiplicity, that is dangerous for reconstruction



nominal μ =0.4

LHC as B - factory

- Very high luminosity – 3.2*10^{33}(nominal-10^{34})$cm^{-2}sec^{-1}$
- High production cross-section (@3.5TeV):
  - ~300μb (pp → $b\bar{b}$ X) and ~6.1mb (pp → $c\bar{c}$ X)
  - But also ~65 mb for minimum-bias
- Annual yield (in LHCb) – > 10^{12}BB-pair and 20xDD

Tevatron:
instant luminosity reached ~4*10^{32}/cm^2/s and total L~12/fb. Cross-sections bb is 3 times lower than at LHC.

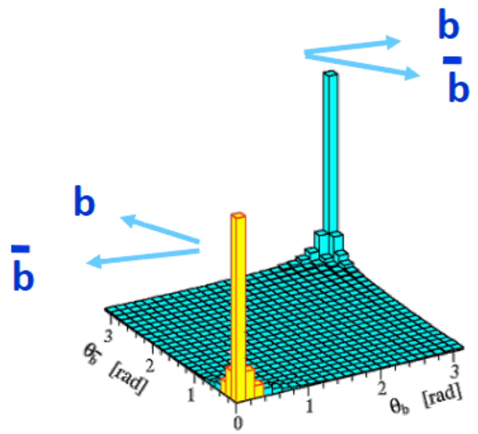
In LHCb:
~1 of 200 collisions with b-quark !
~1 of 10 - with c-quark !

All b-species:
B^+ : B^0 : B^0_s : Λ^0_b : B_c
40%:40%:10%:10%:0.1%

To reduce L0 rate > 10 MHz to 2-3 kHz VERY selective trigger is necessary!
Trigger on low p_T tracks with efficient PID

B-pairs are produced mainly in forward and backward directions:

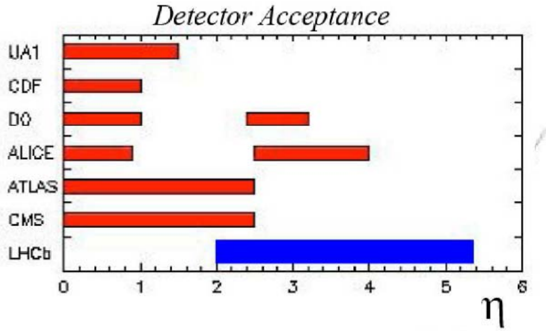
Single-arm forward spectrometer covering ~4% of open angle has ~40% acceptance.

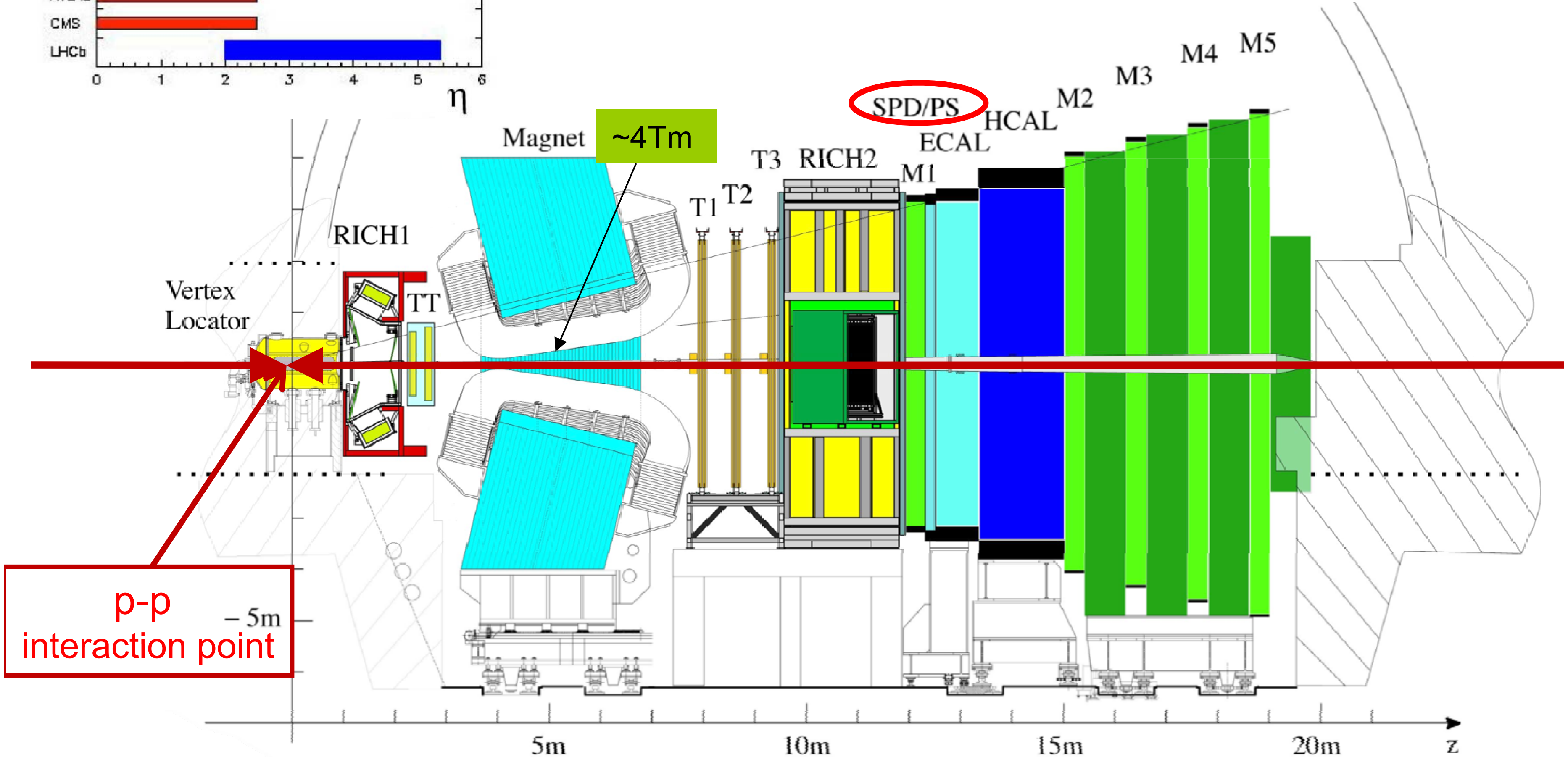


LHCb detector

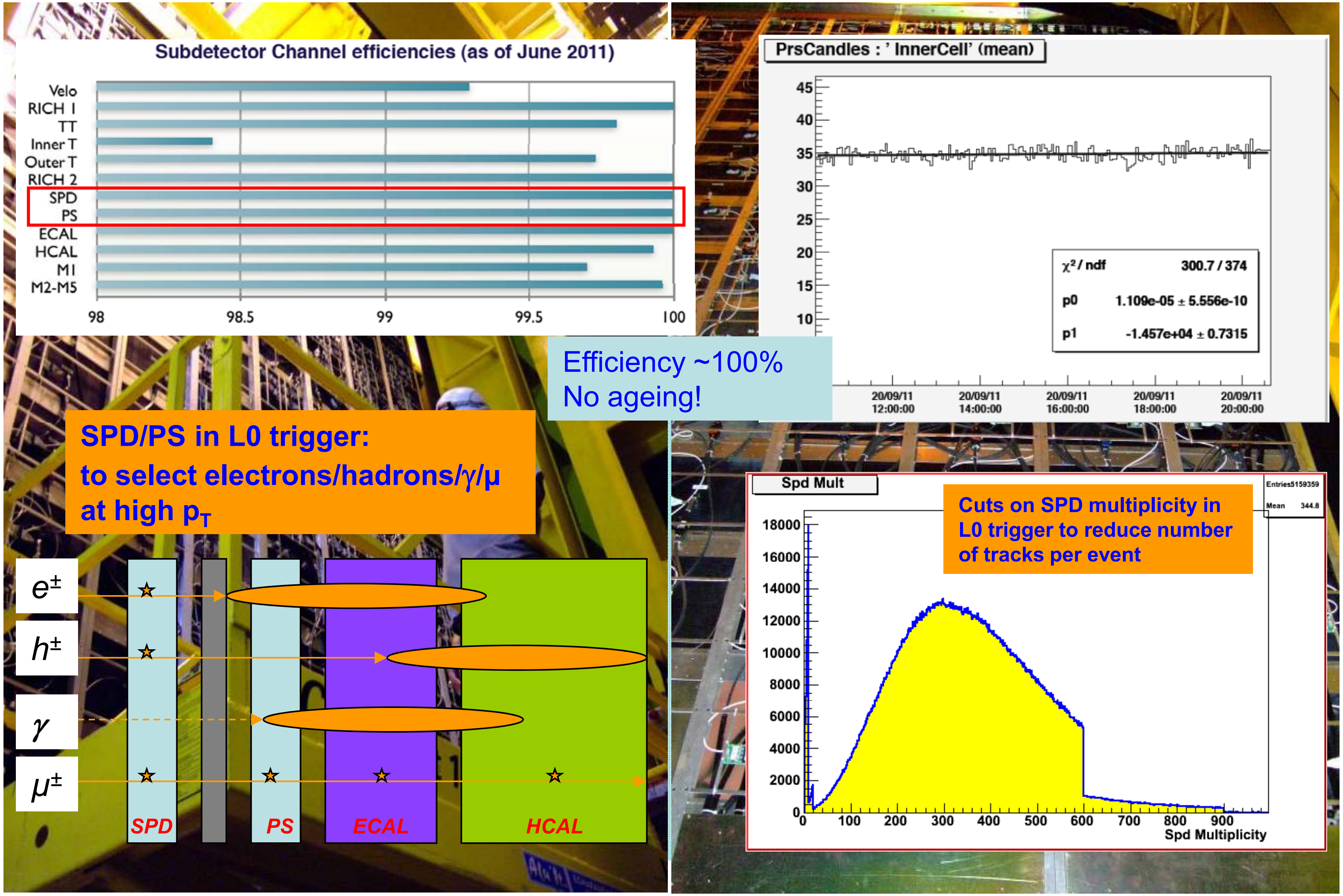
LHCb is forward spectrometer optimized for studies of CPV and B-meson rare decays

LHCb key performances:
Vertex/proper time resolution : VELO
PID: RICH, Calorimeter, Muon system
Mass resolution: Tracker



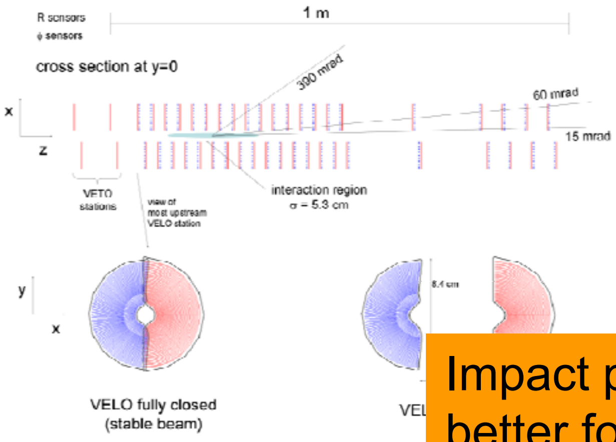


Preshower/SPD built in INR (Moscow)



Vertex / Time resolution

LHCb lifetime measurements using 36 pb^{-1} of 2010 data – **world class**!



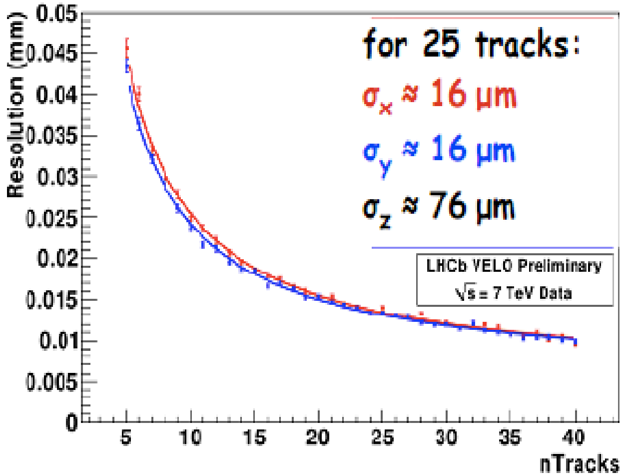
Both statistical and systematical errors are expected to be significantly improved with 2011 data!

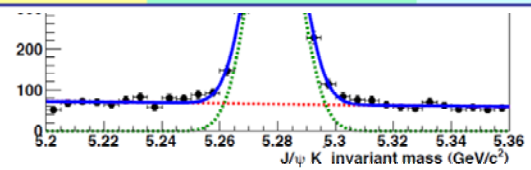
	LHCb-CONF-2011-001 [ps]	PDG [ps]
$\tau(B^+ \to J/\psi K^+)$	$= 1.689 \pm 0.022\ (\text{stat.}) \pm 0.047\ (\text{syst.})$	1.638 ± 0.011
$\tau(B^0 \to J/\psi K^{*0})$	$= 1.512 \pm 0.032\ (\text{stat.}) \pm 0.042\ (\text{syst.})$	1.525 ± 0.009
$\tau(B^0 \to J/\psi K^0_S)$	$= 1.558 \pm 0.056\ (\text{stat.}) \pm 0.022\ (\text{syst.})$	1.525 ± 0.009
$\tau^{\text{single}}(B^0_s \to J/\psi \phi)$	$= 1.447 \pm 0.064\ (\text{stat.}) \pm 0.056\ (\text{syst.})$	1.477 ± 0.046
[illegible]	[illegible] (syst.)	1.391 ± 0.038

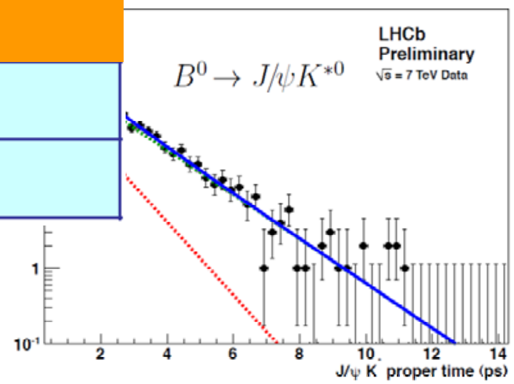
Impact parameter resolution @p_T=2GeV is better for LHCb than for CMS&ATLAS:

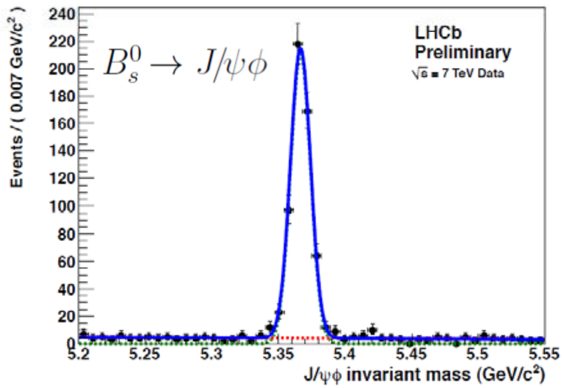
@2GeV	ATLAS	CMS	LHCb
σ (IP)	60 μm	50 μm	25 μm

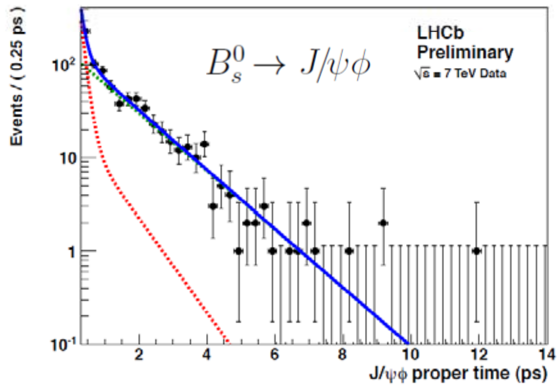
Vertex Locator (V…
provides excellen…
time resolution o…











Mass resolution

Mass resolution is based on precise momentum measurement with LHCb magnet and tracker: $\Delta p/p<0.5\%$ up to 100 GeV/c

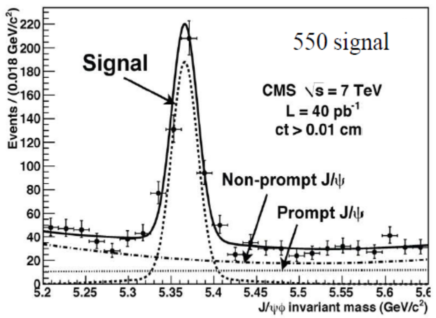
With 2010 data!

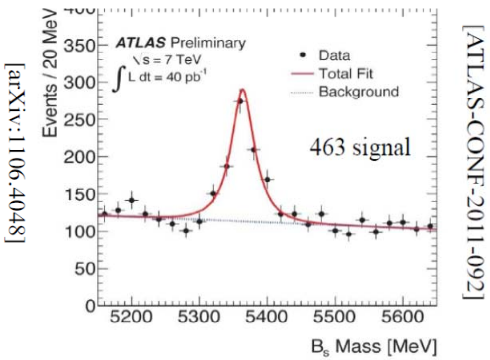
LHCb-CONF-2011-027: masses [MeV/c^2]

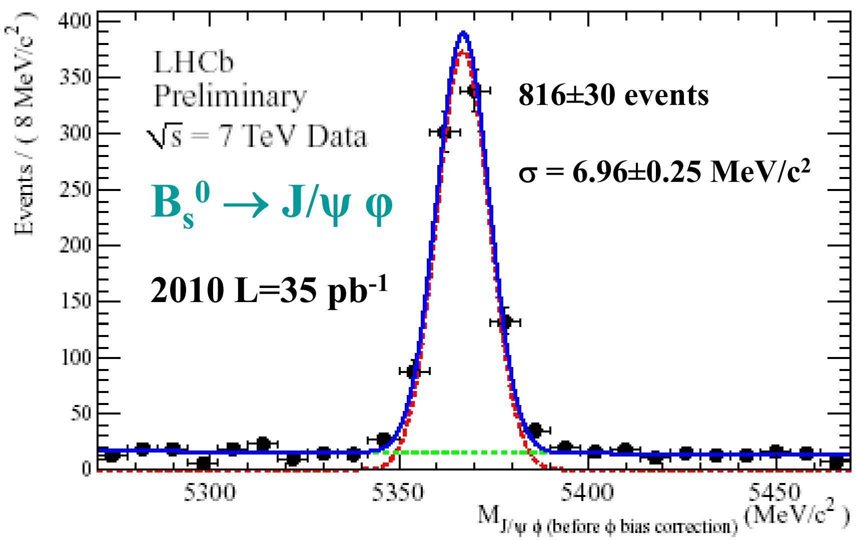
	LHCb-CONF-2011-027	PDG [MeV/c^2]
$M(B^+ \to J/\psi K^+)$	$= 5279.27 \pm 0.11\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.17 ± 0.29
$M(B^0 \to J/\psi K^{*0})$	$= 5279.54 \pm 0.15\,(\text{stat}) \pm 0.16\,(\text{syst})$	5279.50 ± 0.30
$M(B^0 \to J/\psi K^0_S)$	$= 5279.61 \pm 0.29\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.50 ± 0.30
$M(B^0_s \to J/\psi \phi)$	$= 5366.60 \pm 0.28\,(\text{stat}) \pm 0.21\,(\text{syst})$	5366.30 ± 0.60
$M(\Lambda_b \to J/\psi \Lambda)$	$= 5619.49 \pm 0.70\,(\text{stat}) \pm 0.19\,(\text{syst})$	5620.2 ± 1.6
$M(B^+_c \to J/\psi \pi^+)$	$= 6268.0 \pm 4.0\,(\text{stat}) \pm 0.6\,(\text{syst})$	6277 ± 6

World-best mass measurements!

Mass resolution of $B_s(J/\psi\ \varphi)$:
LHCb ~7 MeV
Atlas/CMS ~ 20 MeV + background

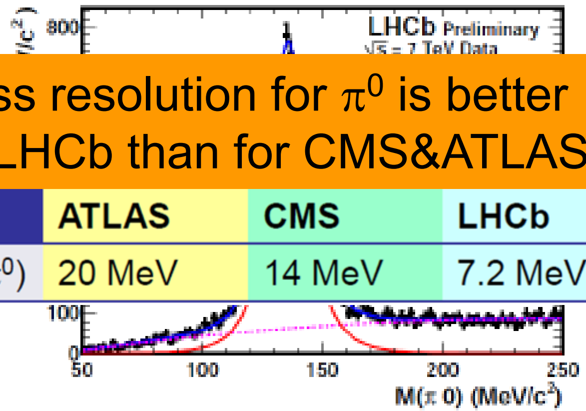






Particle Identification

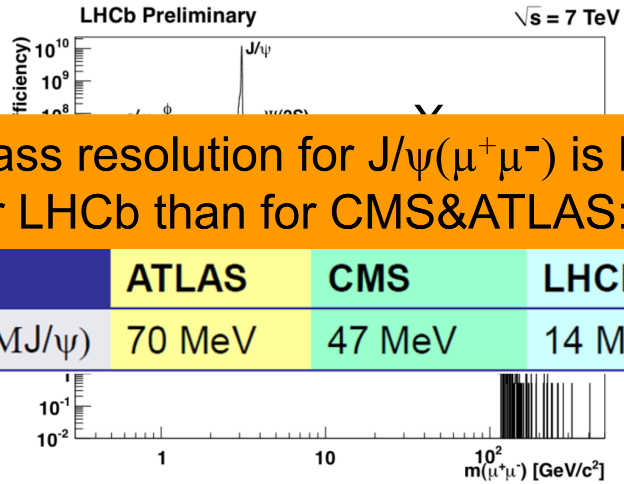
photon/electron/hadron PID – SPD/PRS/ECAL/HCAL



Mass resolution for π^0 is better for LHCb than for CMS&ATLAS:

	ATLAS	CMS	LHCb
$\sigma(M\pi^0)$	20 MeV	14 MeV	7.2 MeV

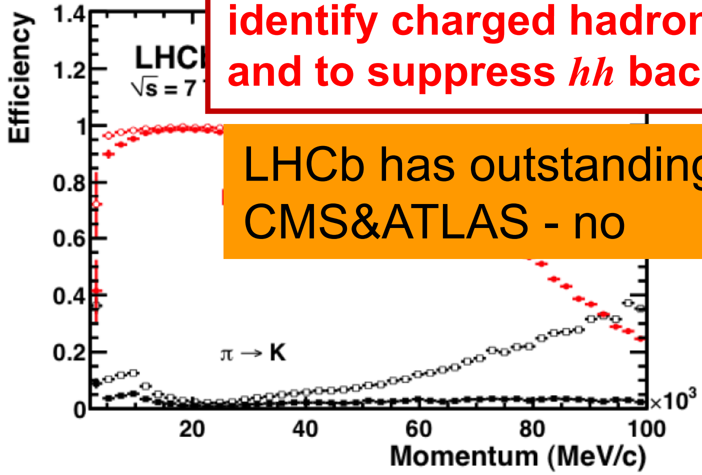
Muon PID – Muon system



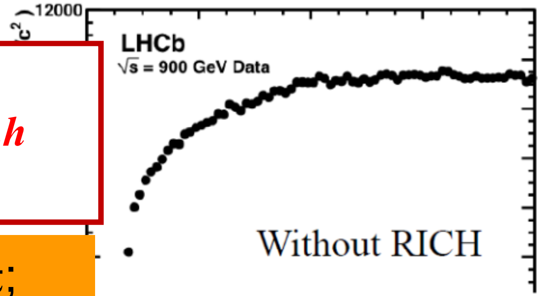
Mass resolution for $J/\psi(\mu^+\mu^-)$ is better for LHCb than for CMS&ATLAS:

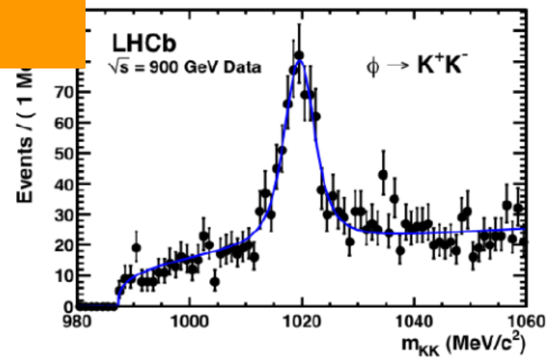
	ATLAS	CMS	LHCb
$\sigma\ (MJ/\psi)$	70 MeV	47 MeV	14 MeV

Hadron PID – RICH1 and RICH2



RICH PID is absolutely necessary to identify charged hadrons in $B,\Phi \to hh$ and to suppress hh background





LHCb has outstanding PID for K/π; CMS&ATLAS - no

CPV measurements and flavour tagging

- ***Measurement of CPV*** despite of huge data sample & reconstruction precision relies most heavily on **flavour tagging** based on **correlation of** daughter particles **charges** and **flavour of tagging** B_{tag}-meson. Often there is used a charge of lepton or kaon (pion) coming from B_{tag}-decay.
- Tagging is never perfect → observable assymetry is always lower than real one.
- Tagging is deluted by
  - Mixing of B_{tag} (for B^0 or B_s)
  - In semileptonic decay through charm due to wrong sign of lepton: $b \to c(\overline{c}) \to l$
  - Other particles from underlying event
  - Misidentification
- If ω is a wrong tag fraction, then measured asymmetry is smaller by dilution coefficient $D=1-2\cdot\omega$:

$$A_{measured} = \frac{\overline{N}(1-\omega) + N\omega - (\overline{N}\omega + N(1-\omega))}{\overline{N}+N} = (1-2\omega)\frac{\overline{N}-N}{\overline{N}+N} = DA_{true}$$

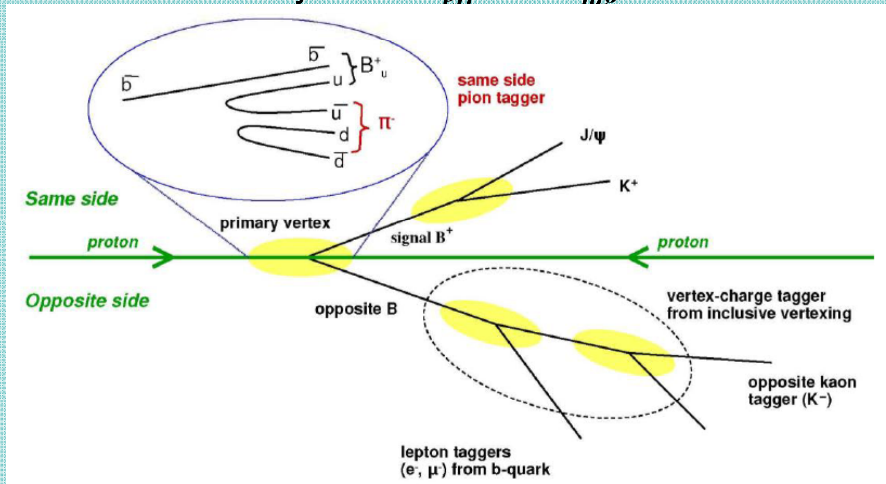
- If ε_{tag} is tagging efficiency, then effective statistics is lower by factor $\varepsilon_{eff}=D^2\cdot\varepsilon_{tag}$.

LHCb tagging power ε_{eff}:

Opposite site (OS)	(3.2±0.8)%
Same site (SS)	(1.3±0.4)%

B-factories gain in flavour tagging

ε_{eff} ~30%



LHCb physics program and key measurements

LHCb is optimized for study of CP-violation and rare decays in B-mesons.

LHCb physics program includes measurements:

- CP-violation in B^+, B^0, B_s
  - Prospects for γ-angle measurement
    - Tree-level processes ($B \to DX$),
    - Loop processes (charmless B decays)
  - Direct CP-violation ($B \to K\pi$)
  - Mixing induced CPV (ϕ_s)
- Rare decays &NP
  - $B_d \to K^* \mu\mu$
  - $B_s \to \mu\mu$
  - ...
- Quarkonia studies ($X(3872), X(4140), \chi_c, \chi_b$,..)
- Physics with charm (CPV,..)
- Soft QCD
- Electroweak physics (W,Z)

Highlights in his talk:

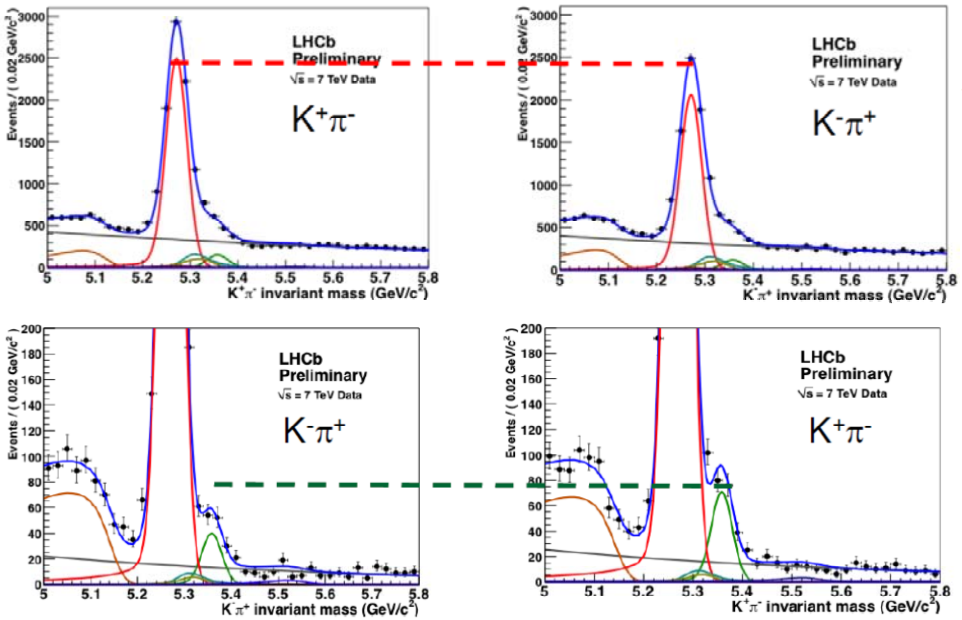
ϕ_s, $B_s \to \mu\mu$, $B \to K^*\mu\mu$ + A^q_{SL},…

Direct CP asymmetry measurement in $B^0_{d,s} \to K\pi$

LHCb with L=320pb^{-1} of 2011 data already has done:

$B^0 \to K\pi$ - the most precise single measurement and first 5σ observation at hadron machine!

$B^0_s \to K\pi$ - the first evidence of CP-violation in B_s decay!



$$A_{CP} = [\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)]/[\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)]$$

Raw asymmetry (has to be corrected for detector and production asymmetry)

LHCb-CONF-2011-042

$A_{cp}(B^0 \to K\pi)$ = -0.088±0.011(stat) ±0.008(syst)

To be compared with world average: $-0.098^{+0.012}_{-0.011}$

$A_{cp}(B_s \to K\pi)$ = 0.27±0.08(stat) ±0.02(syst)

First LHCb result (with 37pb^{-1} data of 2010)

LHCb-CONF-2011-011

$A_{cp}(B^0 \to K^+\pi^-)$= -0.074±0.033(stat) ±0.008(syst)

$A_{cp}(B^0_s \to K^-\pi^+)$= -0.15±0.19(stat) ±0.02(syst)

HFAG:

$A_{cp}(B^0 \to K^+\pi^-)$= $-0.098^{+0.012}_{-0.011}$

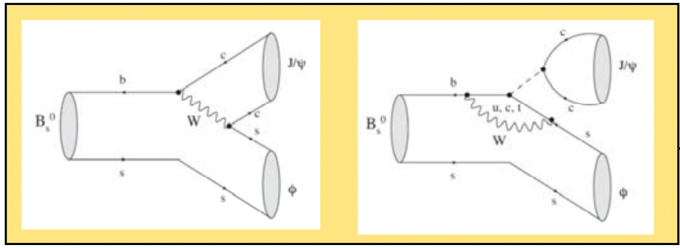
CDF:

$A_{cp}(B^0_s \to K^-\pi^+)$= 0.39±0.15(stat) ±0.08(syst)

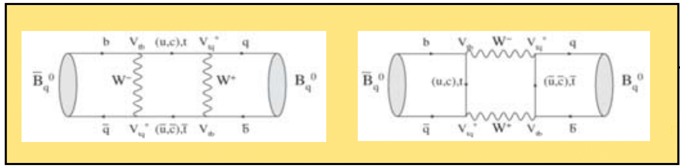
CP-violation in B_s mixing: $B_s \to J/\psi\Phi$

- Dominant contribution – tree-level diagram
- Contribution from "penguin" is small (10^{-3} – 10^{-4})
- Interference between direct decay and decay via mixing gives CPV phase: $\phi_s = \phi_M - 2\phi_D$
- In Standard Model $\phi_s \approx 2\beta_s = -2arg(V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx -0.0363 \pm 0.0017\ rad$
- Search New Physics in mixing: $\phi_s = \phi_s^{SM} + \boldsymbol{\phi_s^{NP}}$

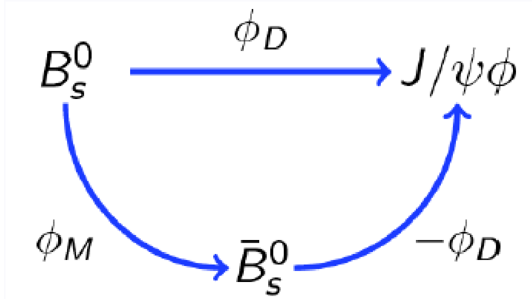
$$A_{CP} \equiv \frac{N(\overline{B} \to f) - N(B \to f)}{N(\overline{B} \to f) + N(B \to f)} \sim \eta_f \sin\phi_s \sin(\Delta m_s t)$$



Decay ϕ_D



Mixing ϕ_M



NP can modify mixing phase

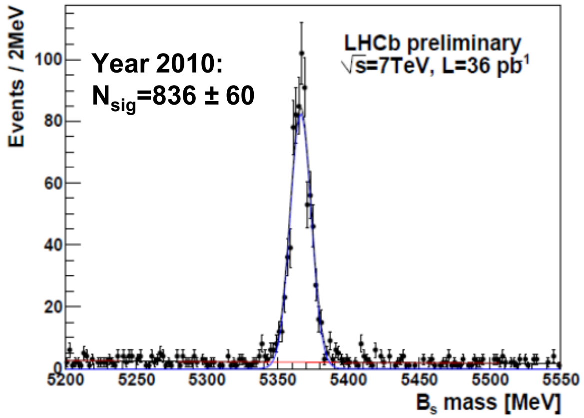
Strategy to measure ϕ_s:

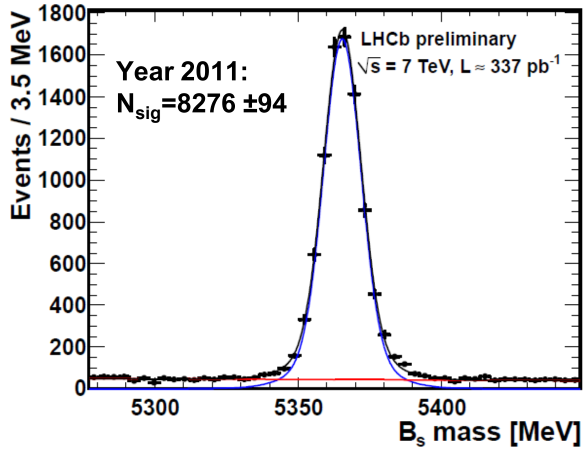
- Trigger and select $B_s \to J/\psi\Phi$ events
- measure proper time
- Measure transversity angles of final decay products to disentangle CP -odd and –even states
- Tag initial flavor
- Fit ϕ_s with other unknown parameters

$$\varepsilon_{tag}\mathcal{D}^2 = (2.08 \pm 0.41)\%$$

CP-violation phase in B_s-mixing: $B_s \to J/\psi\Phi$

- **LHCb provides the world most precise measurement with 0.337 fb^{-1} of 2011**



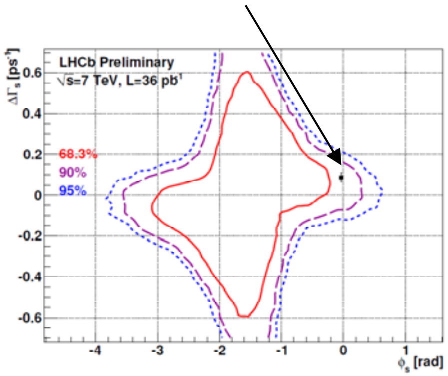


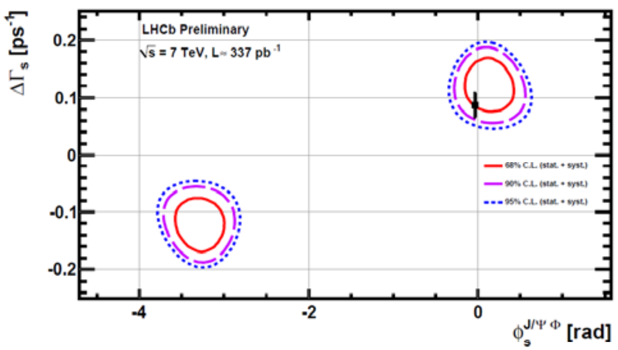
LHCb-CONF-2011-006: data 2010 L=36 pb^{-1}

LHCb-CONF-2011-049: data 2011 L=337 pb^{-1}

$$\begin{aligned} \phi_s^{J/\psi\phi} &= 0.13 \pm 0.18\ (\text{stat}) \pm 0.07\ (\text{sys})\ \text{rad}, \\ \Gamma_s &= 0.656 \pm 0.009\ (\text{stat}) \pm 0.008\ (\text{sys})\ \text{ps}^{-1}, \\ \Delta\Gamma_s &= 0.123 \pm 0.029\ (\text{stat}) \pm 0.011\ (\text{sys})\ \text{ps}^{-1}. \end{aligned}$$

Standard Model value, probability = 22%(1.2σ)

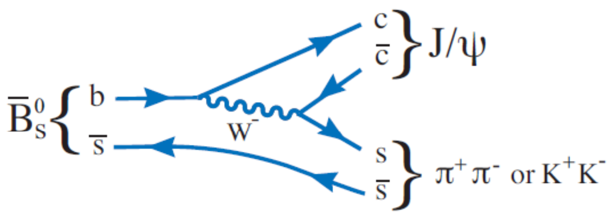




Expecting with full 2011 data set soon!

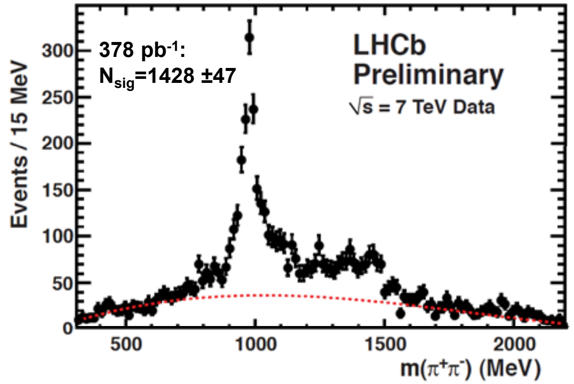
CP-violation phase in B_s-mixing: $B_s \to J/\psi f_0(980)$

- **LHCb first measurement of mixing phase in $B_s \to J/\psi f_0(980)$ with 0.378 fb^{-1} of 2011**



$$R^{f_0}_{\text{effective}} \equiv \frac{\mathcal{B}(B_s^0 \to J/\psi f_0,\ f_0 \to \pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi \phi,\ \phi \to K^+K^-)} = (21.7 \pm 1.1 \pm 0.7)\%$$

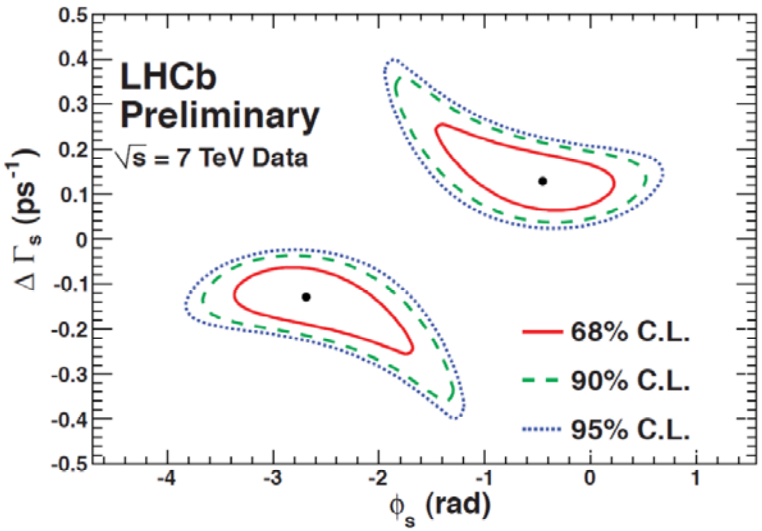
for $|m(\pi^+\pi^-) - 980\ \text{MeV}| < 90$ MeV.

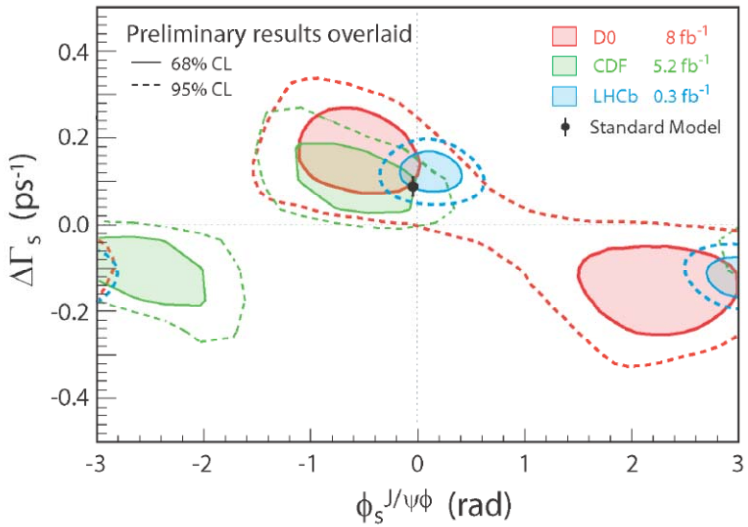


LHCb-CONF-2011-056: combined data

$\phi_s = 0.03 \pm 0.16\ (\text{stat}) \pm 0.07\ (\text{sys})$ rad

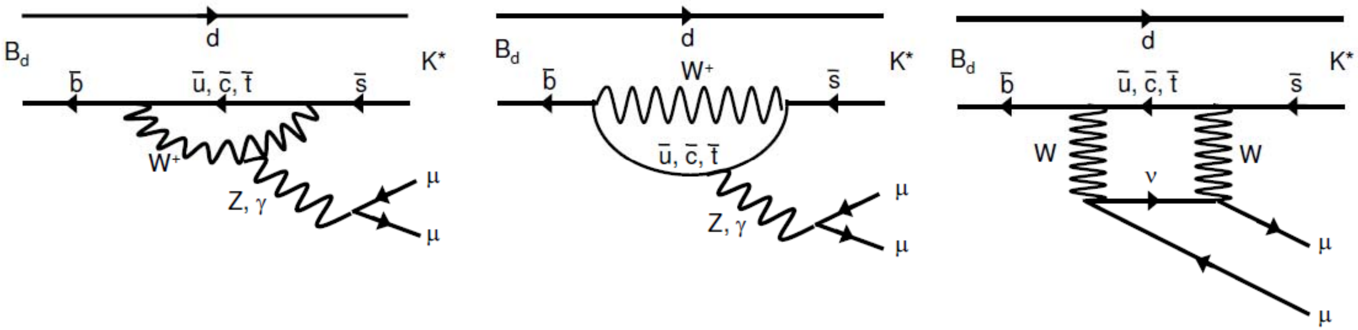
LHCb-CONF-2011-051: data 2011 L=378 pb^{-1}



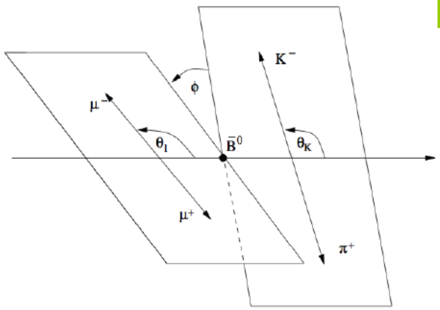


Expecting more updates in 2011!

Search for NP effects in $B_d \to K^*\mu\mu$

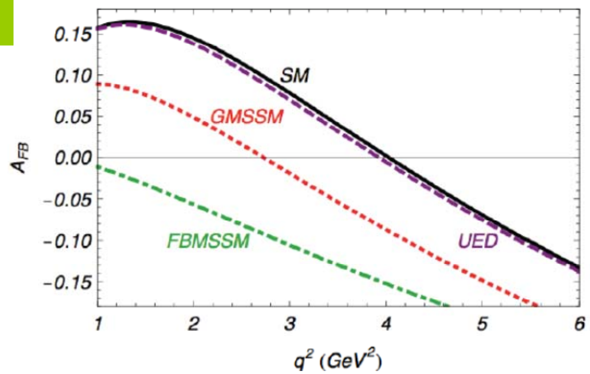


- In SM via FCNC (box and penguin diagrams)
- Helicity structure is sensitive to right-handed and new scalar operators
- The most known observable sensitive to NP is A_{FB}



NP can modify helicity structure

$$A_{FB}(q^2) = \frac{N(\cos\theta_\ell > 0) - N(\cos\theta_\ell < 0)}{N(\cos\theta_\ell > 0) + N(\cos\theta_\ell < 0)}$$



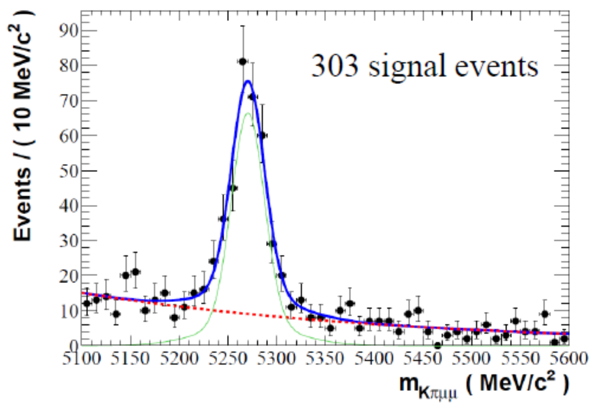
- Zero-crossing point $A_{FB}(q^2)$=0 is predicted in SM
- ***LHCb can reach precision for ZCP $\Delta q^2 < 0.5$ GeV^2 at 2 fb^{-1}***

Search for NP in rare decays: $B_d \to K^*\mu\mu$

- ***LHCb has largest data sample in the world***

Analysis strategy:

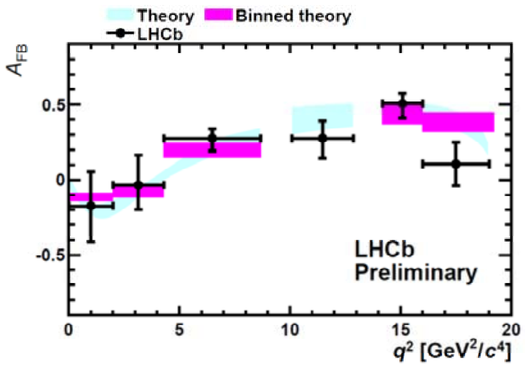
- Events selection using Boosted Decision Tree (composition of topological and kinematical observables)
- Correction for non-uniformity of reconstruction and selection
- MC check with control channels
- Validation using $B_d \to J/\psi K^*$
- Fit the angular observables

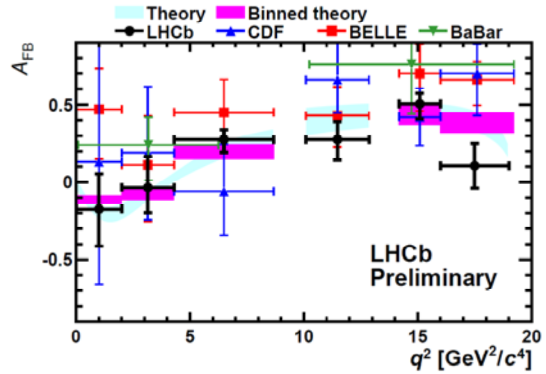


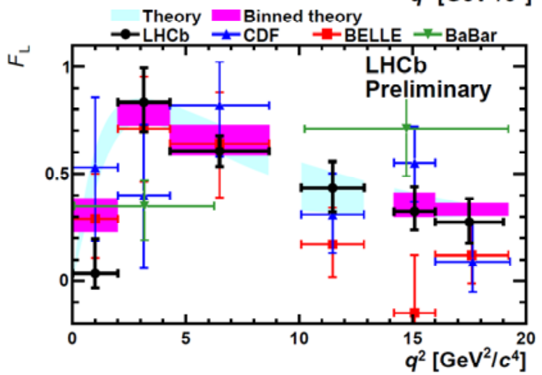
[LHCbCONF-2011-038]

LHCb with 309 pb^{-1} achieved (preliminary) the most precise measurement to date

LHCb-CONF-2011-038







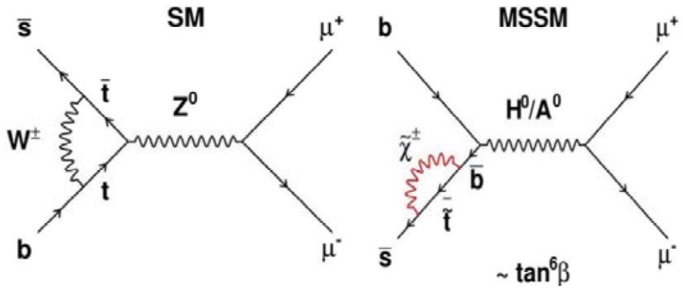
BaBar [PRD 79 (2009)], Belle [PRL 103 (2009)], CDF [PRL 106 (2011)]

Results are consistent with SM prediction for forward-backward asymmetry A_{FB}, longitudinal polarization FL and differential brunching fraction dBF/dq^2:

$$A_{FB} = -0.10^{+0.14}_{-0.14} \pm 0.05$$
$$F_L = 0.57^{+0.11}_{-0.10} \pm 0.03$$
$$\mathrm{d}BF/\mathrm{d}q^2 = 0.39 \pm 0.06 \pm 0.02$$

Statistical errors are dominated now and will be improved with more data. Systematical error is also expected to be improved with more statistics.

Golden mode: $B_{s,d} \to \mu\mu$



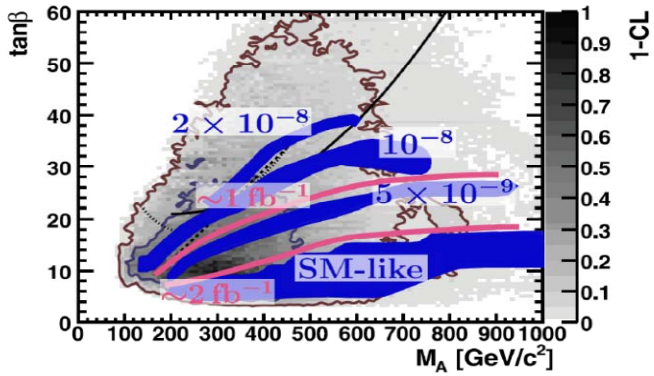
- Ultra rare decays in SM (FCNC and helicity suppressed)
- SM predicts (via box and penguin diagrams):

  BR($B_s \to \mu\mu$) = (3.2 ± 0.2) · 10^{-9}

  BR($B_d \to \mu\mu$) = (1.1 ± 0.1) · 10^{-10}

NP can modify decay branching value

$$Br^{MSSM}(Bq \to l^+l^-) \propto \frac{m_b^2 m_l^2 \tan^6\beta}{M_{A0}^4}$$



LHCb with ~1 fb^{-1} allows a considerable constrain on MSSM

Rare decays: $B_{s,d} \to \mu\mu$

CDF reported the observation:

BR($B_s \to \mu\mu$) = (1.8 $^{+1.1}_{-0.9}$) · 10 $^{-8}$

arxiv: 1107.2304

LHCB: With ~300 pb-1 of data at SM level after selection:

~3.2 $B_s \to \mu\mu$ and ~0.32 $B_d \to \mu\mu$ events

LHCb: most-precise measurement!

- LHCb presents preliminary result with 300 pb^{-1}

LHCb-CONF-2011-037:

BR($B_s^0 \to \mu\mu$) = 1.3 (1.6) · 10 $^{-8}$ at 90%(95%)C.L.

BR($B^0 \to \mu\mu$) = 4.2 (5.2) · 10 $^{-9}$ at 90%(95%)C.L.

- Combining with preliminary result with 37 pb^{-1}

PLB 699(2011) 330,[hep-ex/1103.2165]

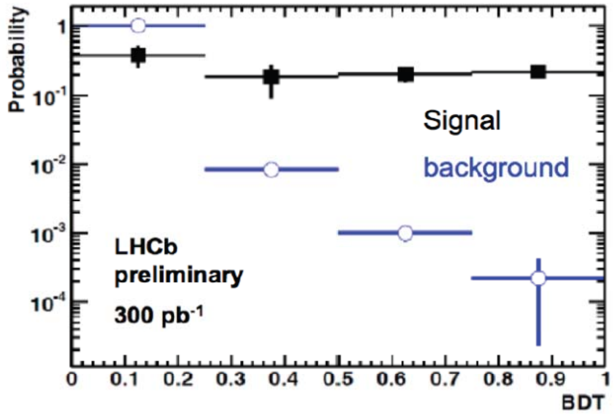
BR($B_s^0 \to \mu\mu$) = 1.2 (1.5) · 10 $^{-8}$ at 90%(95%)C.L.

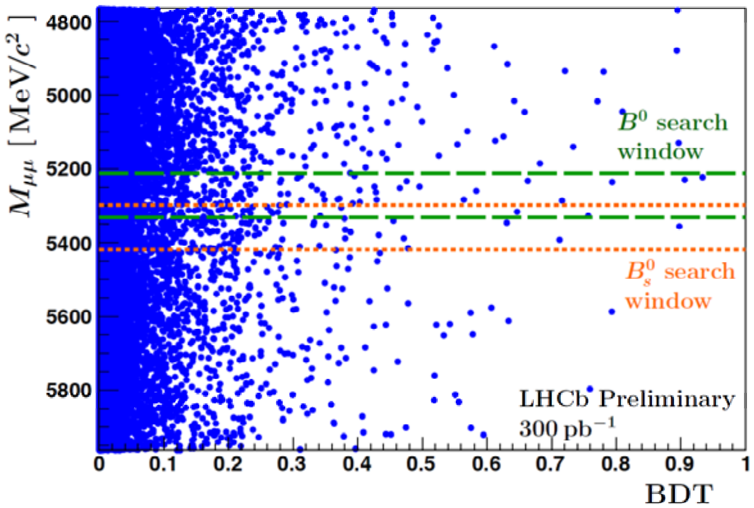
- Combining with CMS observation

LHCb-CONF-2011-047:

BR($B_s^0 \to \mu\mu$) = 0.9 (1.1) · 10 $^{-8}$ at 90%(95%)C.L.

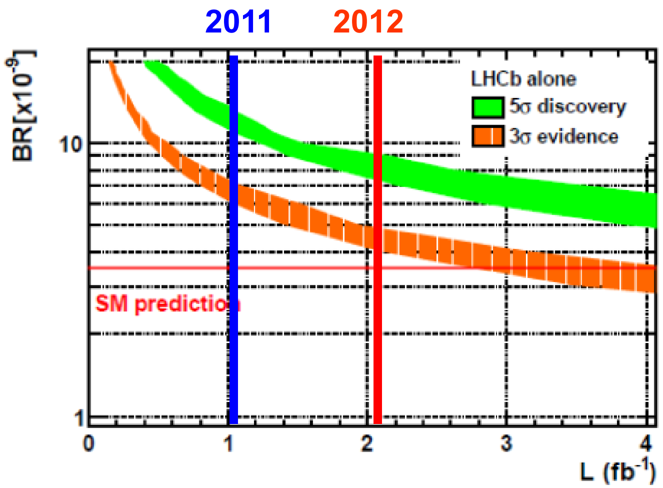
Excess seen by CDF is not confirmed

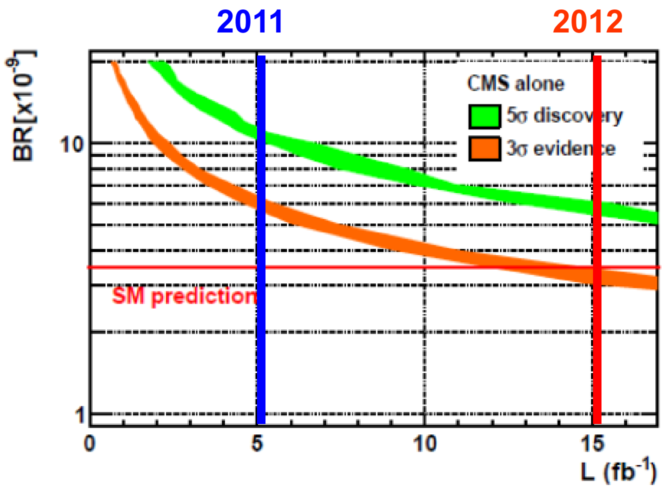




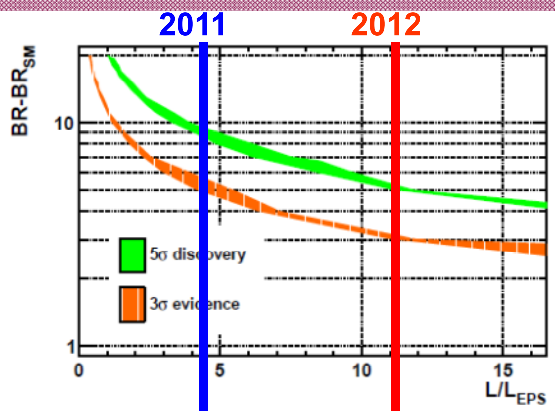
CMS vs LHCb prospect: $B_{s,d} \to \mu\mu$

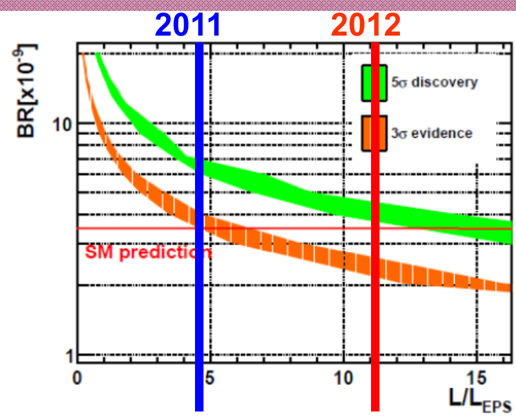
- CMS/LHCb luminosity factor is ~4 now and can increase in 2012
- CMS performance for large number of primary vertices > 12 ?
- Caution: **prediction is based on assumption, that background is like it was before summer 2011!**





CMS+LHCb arxiv:1108.3018





D0 result on A^q_{SL}

CPV in *B* semileptonic decays

D0: Evidence for anomalous like-sign dimuon charge asymmetry

$$A^b_{sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

$$A^b_{sl} = (-0.787 \pm 0.172\ (\text{stat}) \pm 0.093\ (\text{syst}))\%$$

$$A^b_{sl}(\text{SM}) = (-0.028^{+0.005}_{-0.006})\%$$

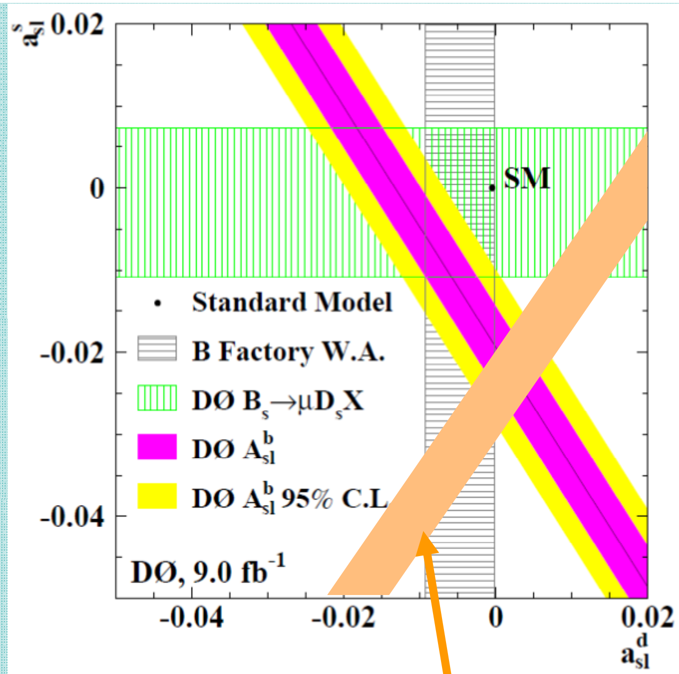
3.9σ

SM prediction (HFAG):

$$A^b_{sl} = C_d a^d_{sl} + C_s a^s_{sl}$$

$$a^q_{sl} = \frac{\Delta\Gamma_q}{\Delta M_q} \tan\phi_q$$

$$C_d = 0.594 \pm 0.022$$
$$C_s = 0.406 \pm 0.022$$



D0 Collaboration, arXiv:1106.6308

Supposed LHCb measurement:

$B_s \to D_s^- \mu^+ \nu$ and $B^0 \to D^- \mu^+ \nu$

The same final state $K^+K^-\pi^-\mu^+$

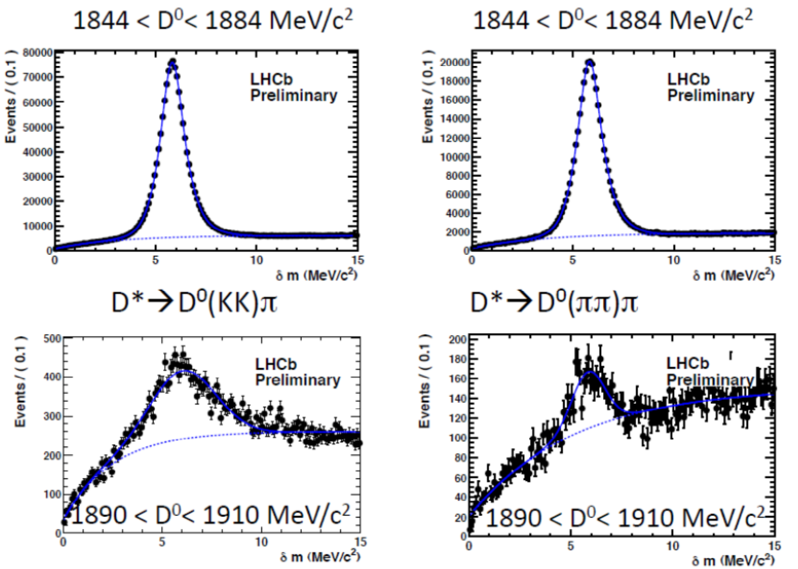
Measure difference between B_s and B^0:

$$\Delta A_{fs} = \frac{a^s_{fs} - a^d_{fs}}{2}$$

Analysis in progress

A_{CP} in D^0 system

- D0-mixing is established, but no CPV is seen yet. In SM expected to be small ($<10^{-3}$)
- Very large statistics is available in LHCb: more than 10^6 of $D^{*+} \to D^0(K^+K^-)\pi^+$
- Measurement of $\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$ is very robust: detection and production asymmetries are cancelled
- LHCb result with 37 pb^{-1} of 2010 data $\Delta A_{CP} = (-0.28 \pm 0.70 \pm 0.25)\%$
- New analysis under approval: 670 pb^{-1} in 2011



Fitted yields using 250/pb of data

Mode	Mass window (MeV/c^2)	Yield
$K^- K^+$	1844–1884	$813,980 \pm 1270$
$K^- K^+$	1890–1910	$4,700 \pm 260$
$\pi^- \pi^+$	1844–1884	$223,930 \pm 690$
$\pi^- \pi^+$	1890–1910	840 ± 95

CDF with 6 fb^{-1} *(CDF note 10296)*

$$A_{CP}(D^0 \to \pi^+\pi^-) = [+0.22 \pm 0.24\ (stat.) \pm 0.11\ (syst.)]\%$$
$$A_{CP}(D^0 \to K^+K^-) = [-0.24 \pm 0.22\ (stat.) \pm 0.10\ (syst.)]\%$$

BaBar with 386 fb^{-1} *PRL100,061803*

$$a_{CP}^{KK} = (0.00 \pm 0.34(\text{stat}) \pm 0.13(\text{syst}))\%$$
$$a_{CP}^{\pi\pi} = (-0.24 \pm 0.52(\text{stat}) \pm 0.22(\text{syst}))\%$$

Belle with 386 fb^{-1} *PRL100,061803*

$$A_{CP}^{KK} - A_{CP}^{\pi\pi} = (-0.86 \pm 0.60 \pm 0.07)\%$$

LHCb prospects for upgrade

LHCb sensitivities for key observables

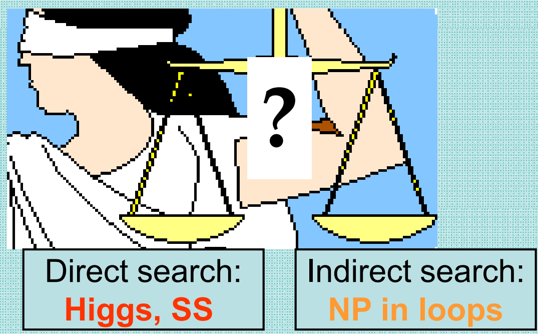
Type	Observable	Current precision	LHCb (5 fb^{-1})	Upgrade (50 fb^{-1})	Theory uncertainty
Gluonic penguin	$S(B_s \to \phi\phi)$	-	0.08	0.02	0.02
	$S(B_s \to K^{*0}\bar{K}^{*0})$	-	0.07	0.02	< 0.02
	$S(B^0 \to \phi K^0_S)$	0.17	0.15	0.03	0.02
B_s mixing	$2\beta_s\ (B_s \to J/\psi\phi)$	0.35	0.019	0.006	~ 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
	$s_0\, A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	-	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	$\gamma\ (B \to D^{(*)}K^{(*)})$	$\sim 20^\circ$	$\sim 4^\circ$	0.9°	negligible
	$\gamma\ (B_s \to D_s K)$	-	$\sim 7^\circ$	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}	-
	$A_{CP}^{dir}(KK) - A_{CP}^{dir}(\pi\pi)$	4.3×10^{-3}	4×10^{-4}	8×10^{-5}	-

CERN-LHCC-2011-001

Conclusion

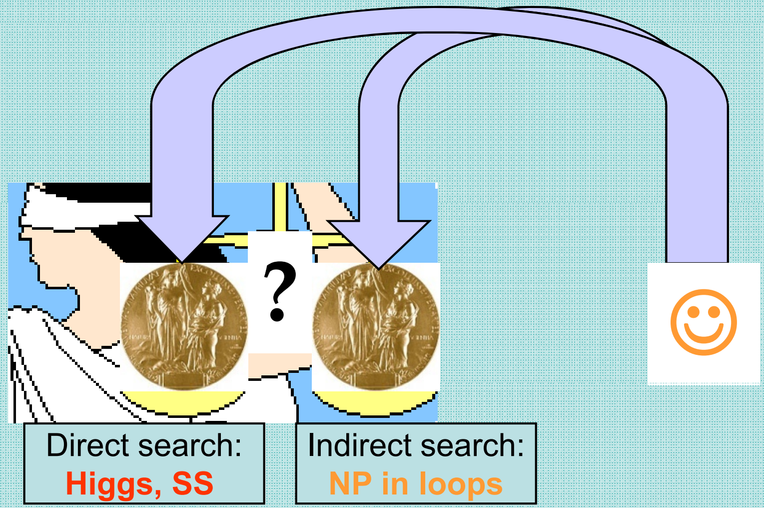
- **Last decade – precise tests of CKM in B-sector and full success of SM**
- B-factories and Tevatron have done great job in B-mesons: mixing, CPV, CKM-angles, but still a room for NP:

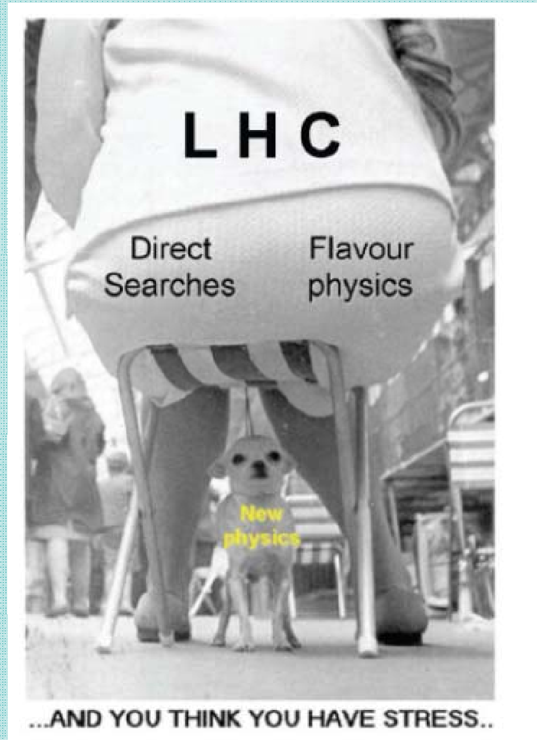
  BR[$B \to \tau\nu$] and $\sin(2\beta_{cc})$, ϕ_s, $B_d \to K^*\mu\mu$, $B_s \to \mu\mu$, γ-angle, ΔA^q_{sl} …
- **Now this is a job for (*Super!*)LHCb and for SuperB-factories**
- **New Physics can be just around the corner**
- **LHCb expecting ~1 fb^{-1} of data this year and many most-precise measurements very soon! Waiting for winter conferences!**
- **LHCb searches for New Physics with unprecedented precision!**
- But CMS&ATLAS too!



Физики нервничают

- **Где же Новая Физика?**
- **Но не только физики нервничают...**





[Vincenzo Chiochia, workshop on Implications of LHC results, CERN, 1 Sep 2011]

Поздравляем юбиляра!
Желаем новых успехов в науке!

BACK-UP

First observations of B-decays in LHCb

- **$B_s \to DK^*$ LHCb-CONF-2011-008**
- **$B \to DK\pi\pi$ CS-mode, can be used for γ-measurements LHCb-CONF-2011-024**
- **$B \to \psi(2s)\varphi$ LHCb-CONF-2011-014 – mixing CP**
- **$B_s \to J/\psi K^*$ penguin-suppressed LHCb-CONF-2011-025**
- **$B_s \to K^{*bar}K^*$ time-dependent CP LHCb-CONF-2011-019**
- $\overline{B_s} \to D_{s2}^{*+} X \mu^- \overline{\upsilon}$ **PLB 698(2011)14**
- **$B_s \to J/\psi\ f_0(980)$ mixing phase PLB 698(2011)115**
- **$B_s \to J/\psi\ f_2'(1525)$ mixing phase LHCb-CONF-2011-035**
- **$B_c \to J/\psi\ \pi\pi\pi$ first observation LHCb-CONF-2011-040**

Наблюдаемые и методы измерения

Phys.param.	*Exp. observable*	*Theory method/ingredients*
$\|V_{ud}\|$	Superallowed β decays	*Towner & Hardy*, PRC 77, 025501 (2008)
$\|V_{us}\|$	K_{l3} (WA Flavianet)	$f_+^{K\pi}(0)=0.964(5)$ (most precise: RBC-UKQCD)
$\|V_{cb}\|$	HFAG incl.+excl. $B\to X_c l\nu$	$40.59(38)(58)\times10^{-3}$
$\|V_{ub}\|$	HFAG incl.+excl. $B\to X_u l\nu$	(specif. uncer. budget): $3.87(9)(46)\times10^{-3}$
Δm_d	last HFAG WA B_d-B_d mixing	$B_{Bs}/B_{Bd}+f_{Bs}/f_{Bd}+f_{Bs}+B_{Bs}$
Δm_s	CDF B_s-B_s mixing	$B_{Bs}+f_{Bs}+f_{Bd}$
$B^+\to\tau^+\nu$	last 08 WA: BaBar/Belle	f_{Bs}/f_{Bd} & f_{Bs}
$\|\varepsilon_K\|$	K^0-K^0 (PDG08: KLOE, NA48,KTeV)	PDG param. (*Buchalla et al. '96*) + $B_K=0.721(5)(40)$
β/ϕ_1	latest WA HFAG charmonium	-
α/ϕ_2	last WA $\pi\pi/\rho\pi/\rho\rho$	isospin SU(2) (GL)
γ/ϕ_3	latest WA HFAG $B^-\to D^{(*)}K^{(*)-}$	GLW/ADS/GGSZ

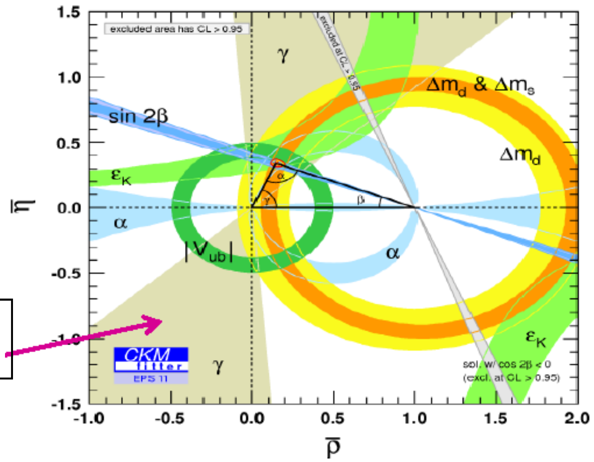
γ-angle measurements

CKM – matrix is measured very precisely.
Great jobs done by B-factories and others.
Less constrained γ-angle :

combinated "trees" & "loops": $\gamma = (67\pm4)°$
from "trees" only: $\gamma = (73^{+22}_{-25})°$

Prospects for γ-measurements with "trees":
(based on Gronau-London-Wyler & Atwood-Dunietz-Soni methods + time-dependent + Dalitz-plot analysis)

PLB270,75(1991); PRL78,3257(1997)



- To combine $B_s \to D_s^\pm K^\pm$, $B^0 \to DK^{*0}$ and $B^\pm \to DK^\pm$ $\to \sigma(\gamma)\sim5°$ with 2 fb^{-1}

$B_s \to D_s^- K^+$ ($D_s^+ K^-$) decays

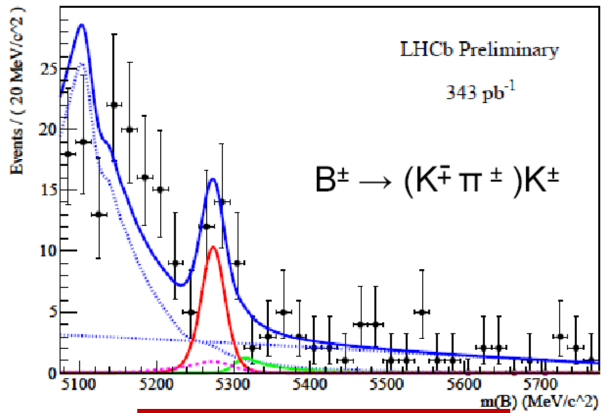
- under study, **time-dependent** analysis ($A_{cp} \to \gamma - \phi_M$)
- ϕ_M – B_s mixing phase well constrained in $B_s \to J/\psi\Phi$
  - at first step Δm_s measurement using $B_s \to D_s\pi$

$B^\pm \to DK^\pm$ decays using common mode for D^0&$\bar{D}^0 \to$ **$K^+\pi^-$**

Mode more suppressed for D^0 and favored for $\bar{D}^0$
maximizes interference: **$D^0 \to K^+\pi^-$ (DCS) and $\bar{D}^0 \to K^+\pi^-$ (CF)**

But total branching very small (~10^{-7})

LHCb-CONF-2011-044



World-class measurement!

Preliminary: evidence for suppressed ADS mode at 4.0σ with 343 pb^{-1}.
Ratio to favored mode:

$$R_{ADS}^{DK} = (1.66 \pm 0.39 \pm 0.24) \times 10^{-2}$$

$$A_{ADS}^{DK} = -0.39 \pm 0.17 \pm 0.02$$

World average (without LHCb):
1.6 ± 0.3
-0.58 ± 0.21

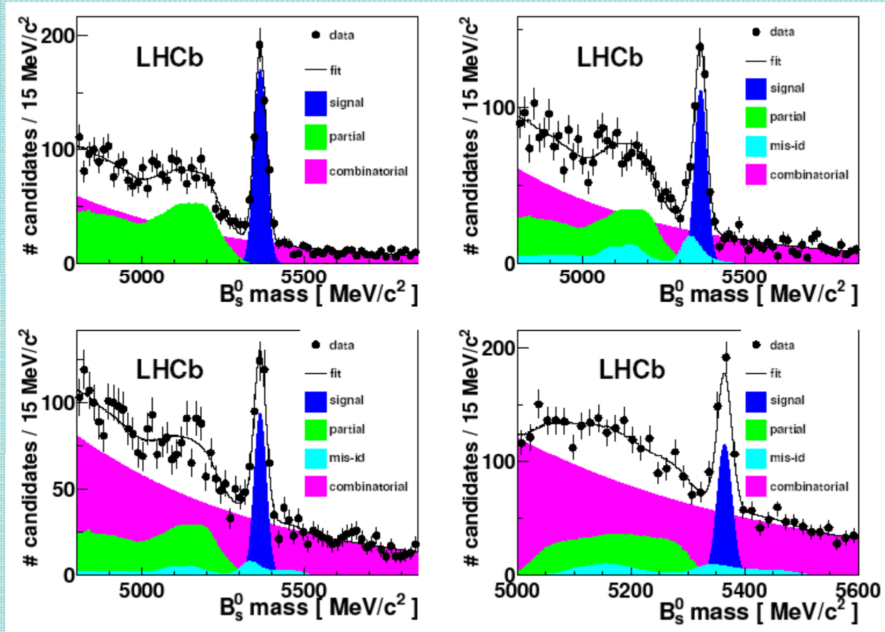
World-class measurement!

Measurement of Δm_s

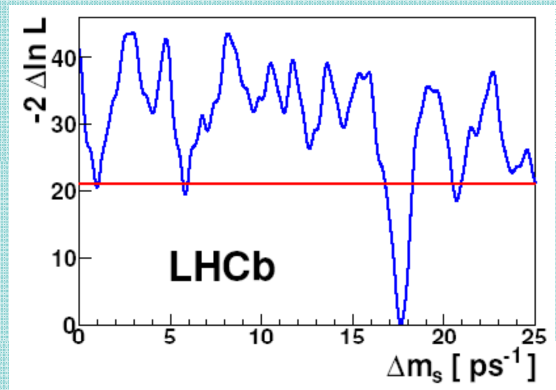
decay mode	# signal candidates
$B_s \to D_s^-(\phi\pi^-)\pi^+$	515 ± 25
$B_s \to D_s^-(K^*K)\pi^+$	338 ± 27
$B_s \to D_s^-(K^+K^-\pi^-)\pi^+$	283 ± 27
$B_s \to D_s^-(K^+K^-\pi^-)3\pi$	245 ± 46

- Δm_s – mixing frequency in B_s
- Used ~1381 B^0_s decays from 2010 data:
- Combining the 4 decays allows suppress decay-specific features
- To be used in time-dependent CPV studies

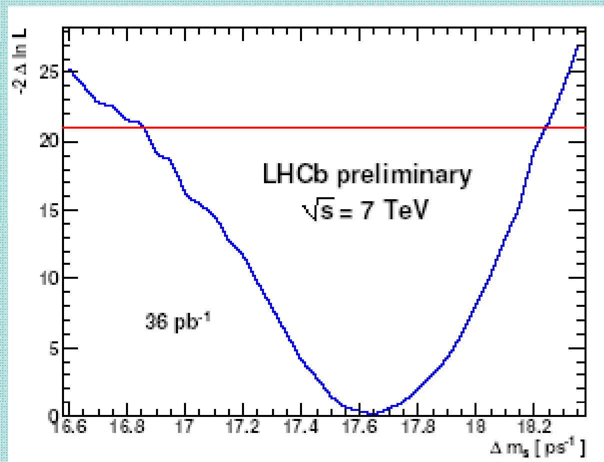
$B_s^0 \to D_s^-(\phi\pi^-)\pi^+$ $B_s^0 \to D_s^-(K^*K^-)\pi^+$



$B_s^0 \to D_s^-(K^+K^-\pi^-)\pi^+$ $B_s^0 \to D_s^-3\pi$



Likelihood scan for Δms



LHCb-CONF-2011-005, CERN-PAPER-2011-010

$$\Delta m_s = 17.63 \pm 0.11\ (\text{stat}) \pm 0.03\ (\text{syst})\ \text{ps}^{-1}$$

World average: $\Delta m_s = 17.77 \pm 0.10 \pm 0.07\ \text{ps}^{-1}$

Other channels relevant for ϕ_s measurement

"**Penguin**" diagram dominated ***can help to control penguin effect in Bs→J/ψΦ for ϕ_s extraction*** :

- $B_s \to \Phi\Phi$
- $B_s \to K^* \overline{K^*}$ - **The first observation !** Can help to extract β_s and γ — **LHCb-CONF-2011-019**
- $B_s \to J/\psi K^*$ — **LHCb-CONF-2011-025**
- $B_s \to K^+ K^-$ - **Most precise lifetime measurement !** — **LHCb-CONF-2011-018**

Box diagram dominated ***can be used for ϕ_s measurement*** :

- $B_s \to J/\psi f_0(980)$ - **The first observation !** **CP-odd eigenstate** — **Phys. Lett. B 698 (2011) 115**
- $B_s \to J/\psi f_2'(1525)$ - **The first observation !** — **LHCb-CONF-2011-035**

Other channels relevant for ϕ_s

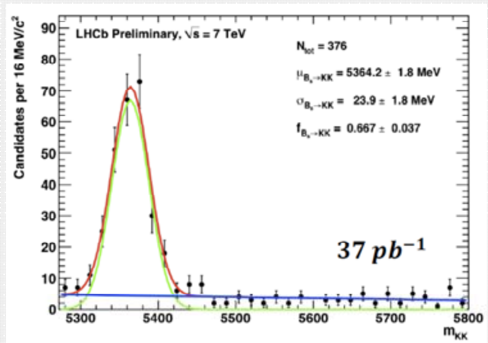
- "**Penguin**" diagram dominated: $B_s \to \bar{\Phi}\Phi$ $B_s \to K^* K^*$ $B_s \to J/\psi K^*$ $B_s \to K^+ K^-$

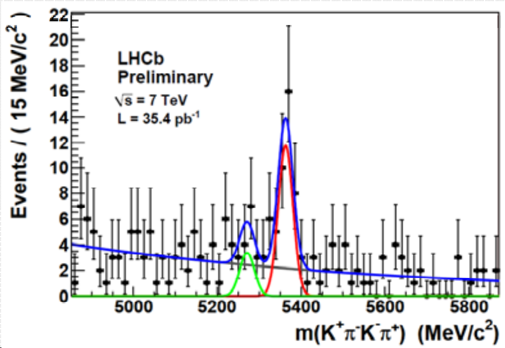
LHCb-CONF-2011-018

Most precise lifetime measurement of $B_s \to K^+ K^-$

$$\tau_{B_s^0} = 1.440 \pm 0.096\ (\mathrm{stat})\ \pm\ 0.010\ (\mathrm{syst})\ \ \mathrm{ps}$$

Can be used to put constrains on ϕ_s and $\Delta\Gamma_s$





LHCb-CONF-2011-019

The first observation of $B_s \to \bar{K}^* K^*$

$$\mathcal{B}\left(B_s^0 \to K^{*0}\bar{K}^{*0}\right) = (1.95 \pm 0.47(stat.) \pm 0.51(syst.) \pm 0.29\,(f_d/f_s)) \times 10^{-5}$$

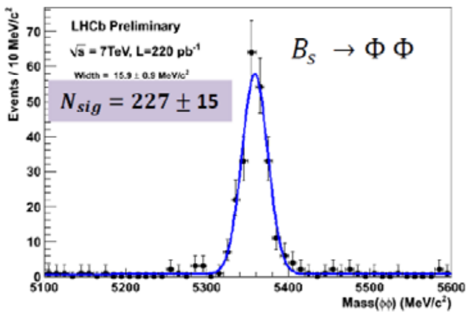
Can help to extract β_s and γ

LHCb-CONF-2011-025

Assuming all events are from $K^* \to K\pi$ for mass $|M(K\pi)-M(K^*)|<150$ MeV

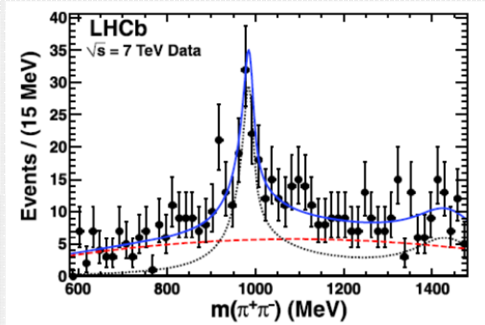
$$\mathcal{B}(B_s^0 \to J/\psi \bar{K}^{*0}) = (3.5^{+1.1}_{-1.0}(stat.) \pm 0.9(syst.)) \times 10^{-5}$$

Can help to control penguin effect in $Bs \to J/\psi\Phi$ for ϕ_s extraction



Other channels sensitive for ϕ_s

- **Box** diagram dominated: $B_s \to J/\psi f_0(980)$ $B_s \to J/\psi f_2'(1525)$



Phys. Lett. B 698 (2011) 115

CP odd eigenstate

The first observation of $B_s \to J/\psi f_0(980)$

$$R_{f_0/\phi} \equiv \frac{\Gamma(B_s^0 \to J/\psi f_0,\, f_0 \to \pi^+\pi^-)}{\Gamma(B_s^0 \to J/\psi \phi,\, \phi \to K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$

Statistics of 2010 ~34 pb^{-1}

LHCb-CONF-2011-035

Can be used for ϕ_s measurement

The first observation of $B_s \to J/\psi f_2'(1525)$

$$R^{f_0}_{\text{effective}} \equiv \frac{\mathcal{B}(B_s^0 \to J/\psi f_0,\ f_0 \to \pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi \phi,\ \phi \to K^+K^-)} = (21.7 \pm 1.1 \pm 0.7)\%$$

for $|m(\pi^+\pi^-) - 980\text{ MeV}| < 90$ MeV.

$$R^{f_2'}_{\text{effective}} \equiv \frac{\mathcal{B}(B_s^0 \to J/\psi f_2'(1525),\ f_2'(1525) \to K^+K^-)}{\mathcal{B}(B_s^0 \to J/\psi \phi,\ \phi \to K^+K^-)} = (19.4 \pm 1.8 \pm 1.1)\%$$

for $|m(K^+K^-) - 1525\text{ MeV}| < 125$ MeV.

Statistics of 2010 ~34 pb^{-1} + 125 pb^{-1} of 2011