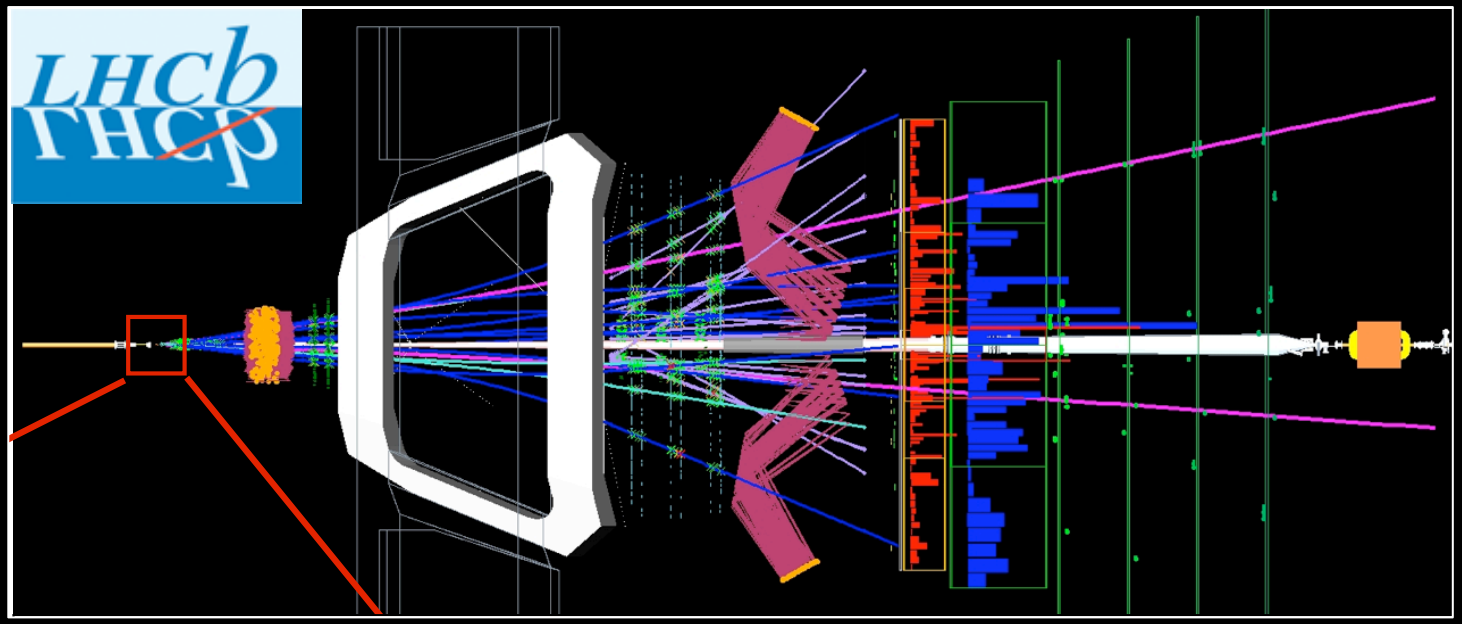
Status of the LHCb Experiment

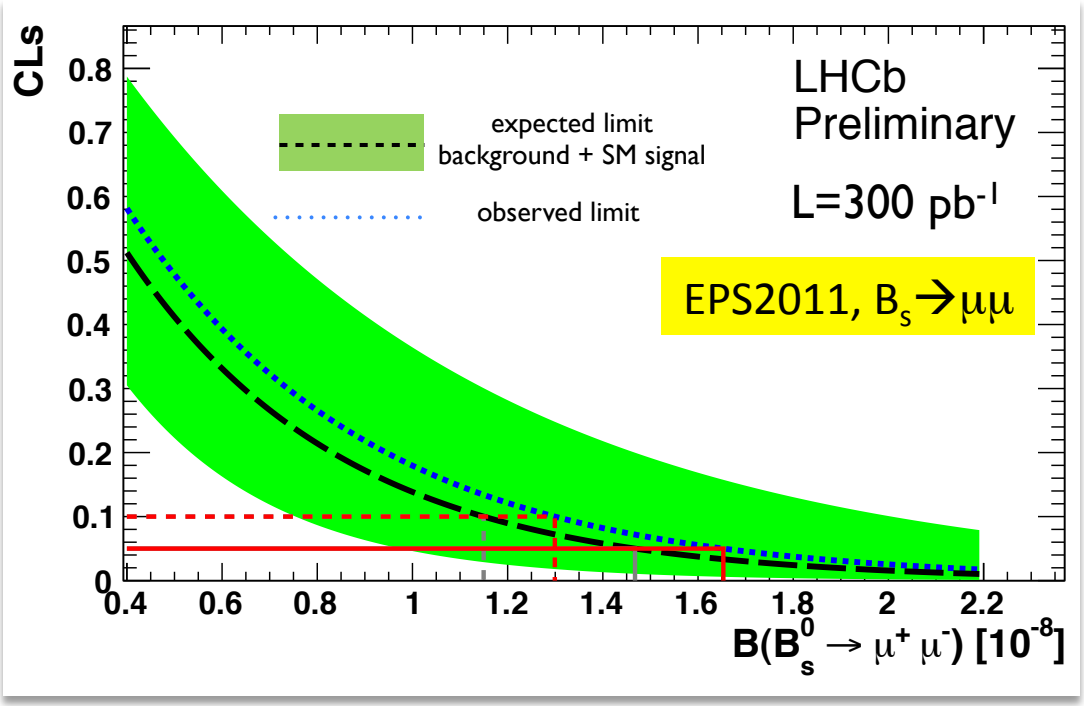


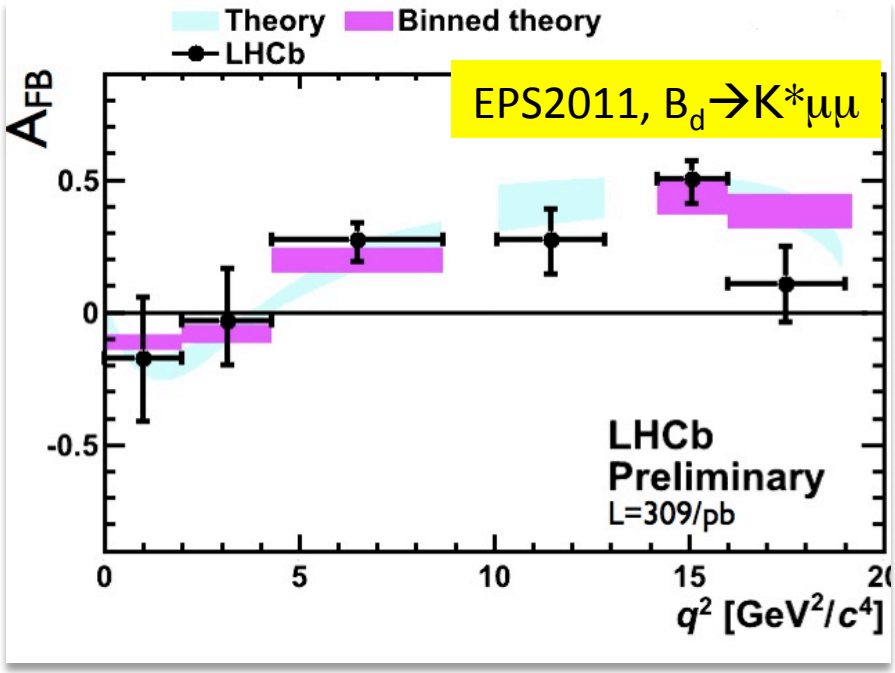
Beauty provoketh thieves sooner than gold (W. Shakespeare)

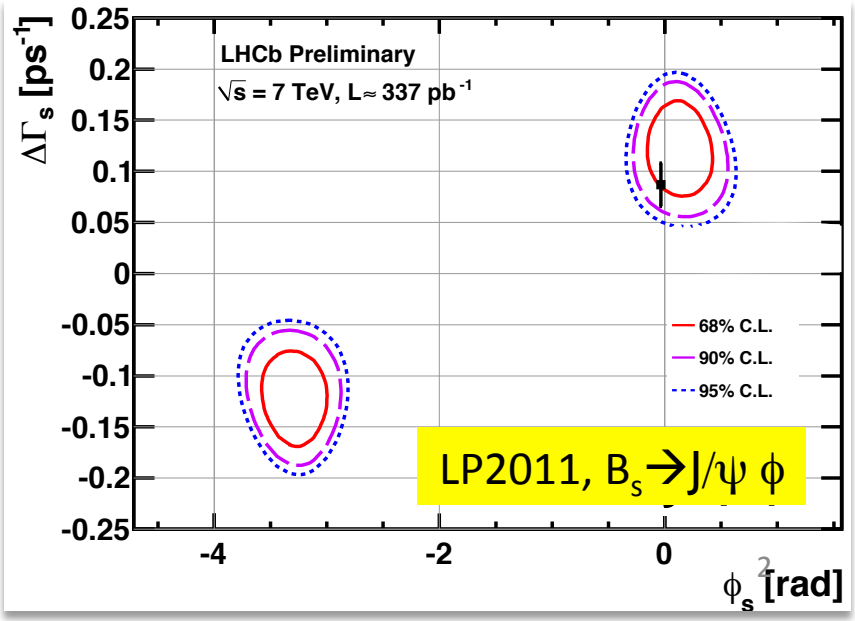
P. Campana (CERN & INFN Frascati) – RRB Meeting – October 19th, 2011

A hot summer … full of data and of physics results for the Core Program LHCb measurements

Highlights of Summer Conferences



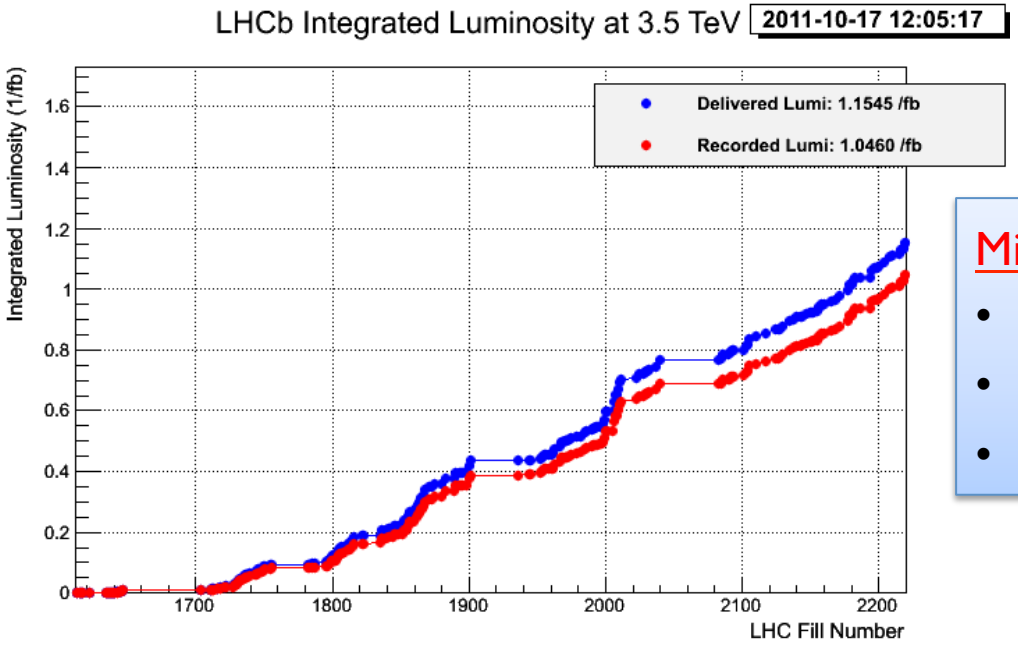




Plans at RRB Meeting, April 2011

LHCb limitations:
- ✓ *limit the number of visible pp-collisions/bunch crossing to $\mu_{max} \sim 2$ (2.5 at start-up)*
- ✓ *limit the peak luminosity to $L \sim 3 \cdot 10^{32}\ cm^{-2}\ s^{-1}$*

→ *need to increase number of bunches to ≥700 to reach "nominal" LHCb luminosity*
→ ***luminosity leveling essential to keep μ and lumi to optimal value***
→ *will run with flat luminosity throughout most of the year, so cannot "catch-up" on integrated luminosity during the year*
→ *need to continue to increase number of bunches (even at nominal lumi) to reduce μ*
→ *expect* ***≥200 pb^{-1} by end of June and ~1 fb^{-1} by the end of 2011***



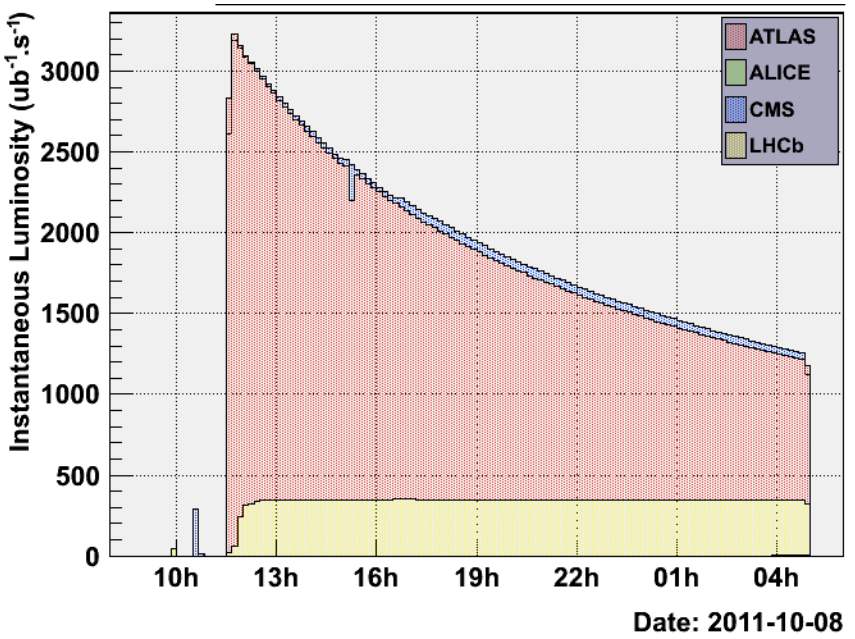
Milestones achieved:
- $L_{INT} > 1\ fb^{-1}$ (on tape)
- LHCb operated at $L \sim 3.5\ 10^{32}\ cm^{-2}s^{-1}$
- stable trigger and $\mu \sim 1.5$

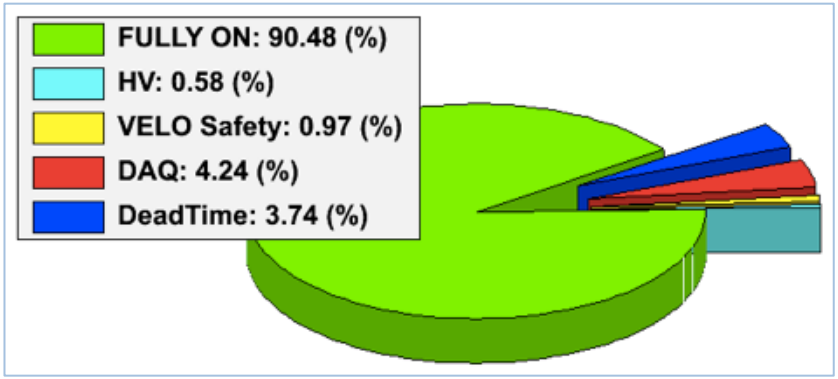
Results obtained thanks to the LHC performance, the luminosity leveling and the excellent running of LHCb detectors (~99% of channels operational)

- Ideal running conditions achieved with long fills (> 15 h; ~ 1 pb^{-1}/h)
- Best week ~ 130 pb^{-1}
- Average ~ 50-60 pb^{-1}

- L0 rate ~ 850 kHz
- Farm operating at limit of throttling
- HLT (physics) ~ 3 kHz
  - 1 kHz b→hadrons
  - 1 kHz b→muons
  - 1 kHz charm (NEW !)

- Data taking efficiency > 90%
- Quality of data ~ 99% OK





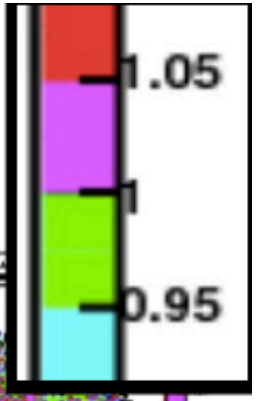
Sub detector status (all working very reliably !)

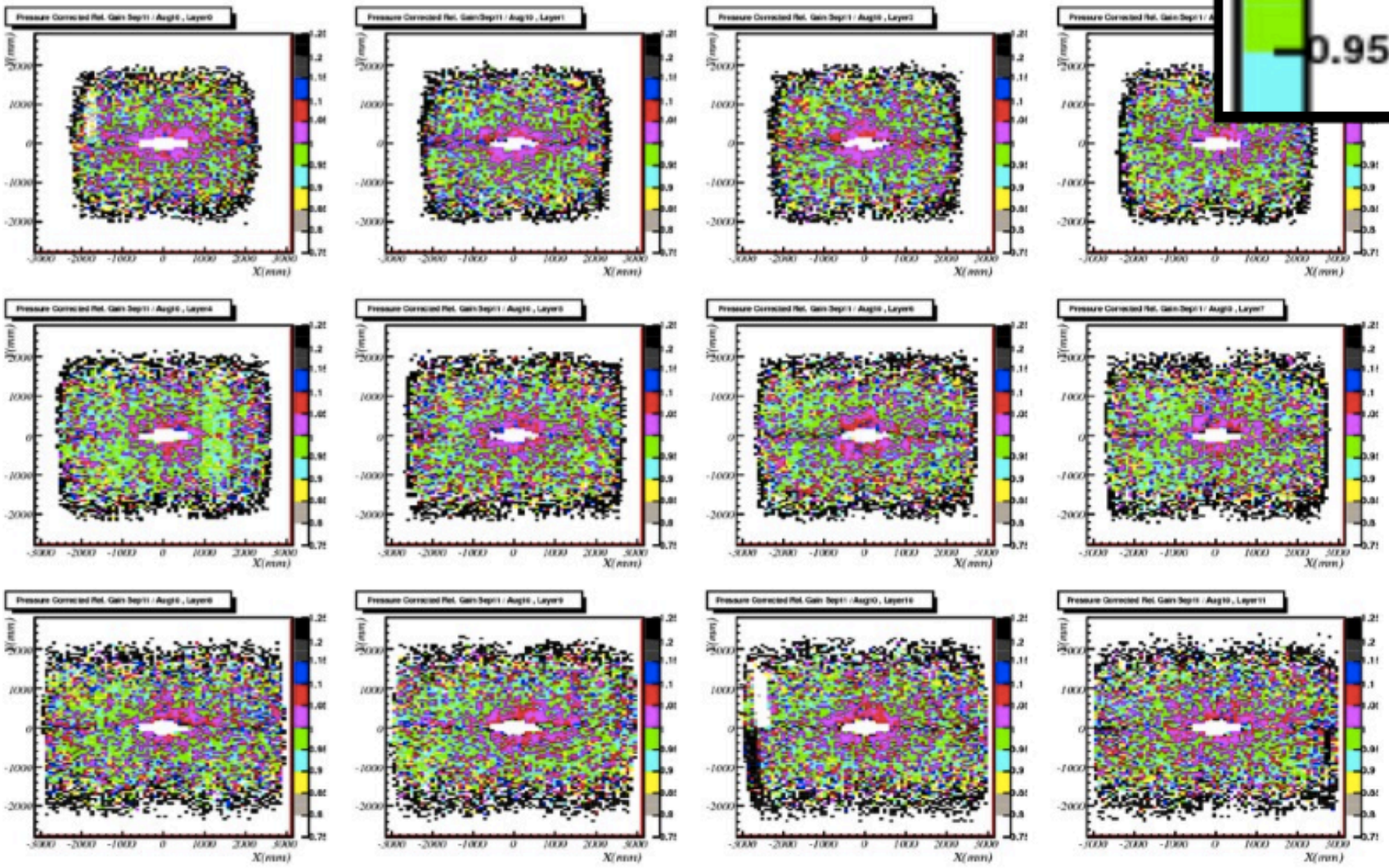
- VELO – fast and fully automatic closing; radiation effects agree with expectations
- TT/IT – currents observed in 2010 reduced by kapton shielding and by slow ramp-up of luminosity
- OT – stable operation, no sign of aging, continuous monitoring
- RICH – angle resolution equal to MC expectations; some repaired HPD show ion feedback; box for Aerogel under completion, ready for 2012 run
- CALO - showing first sign of aging, well under control: no degradation of ECAL (need to adjust PM HV), very good energy resolution after calibration
- MUON – no. of tripping chambers greatly reduced thanks to intense HV training
- ONLINE – new farm (Swiss) and new network (Cern) fully operational

Outer Tracker

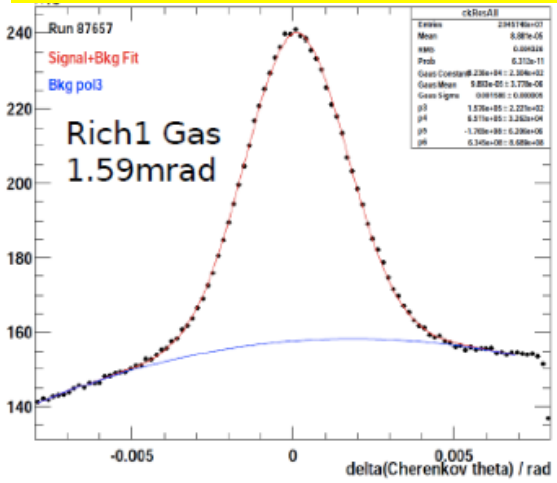
Ratio of gains Sept 2011/Ago 2010 obtained with beam scan

→ No ageing effect seen at level ~ 10%



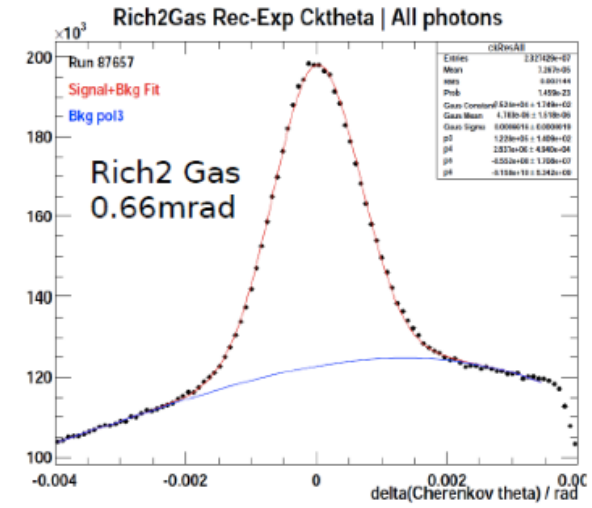


Cherenkov angle resolution



RICH 1

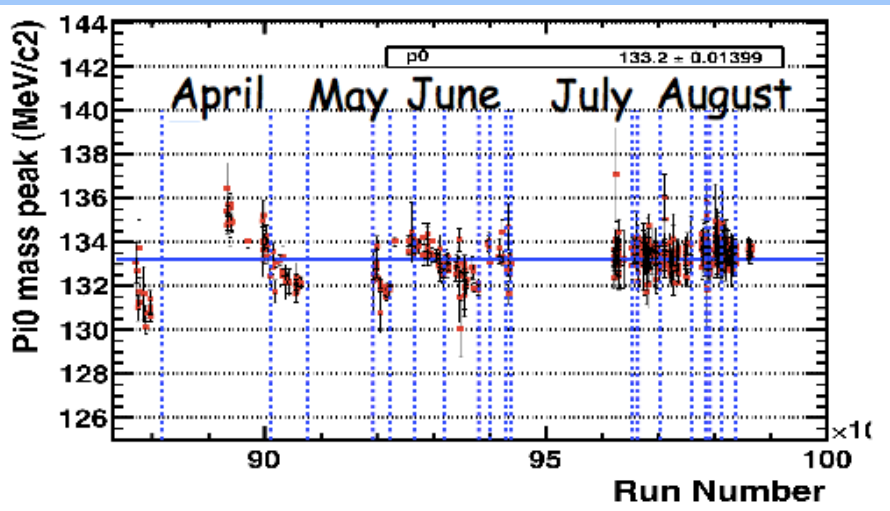
MC: 1.53 mrad



RICH 2

MC: 0.66 mrad

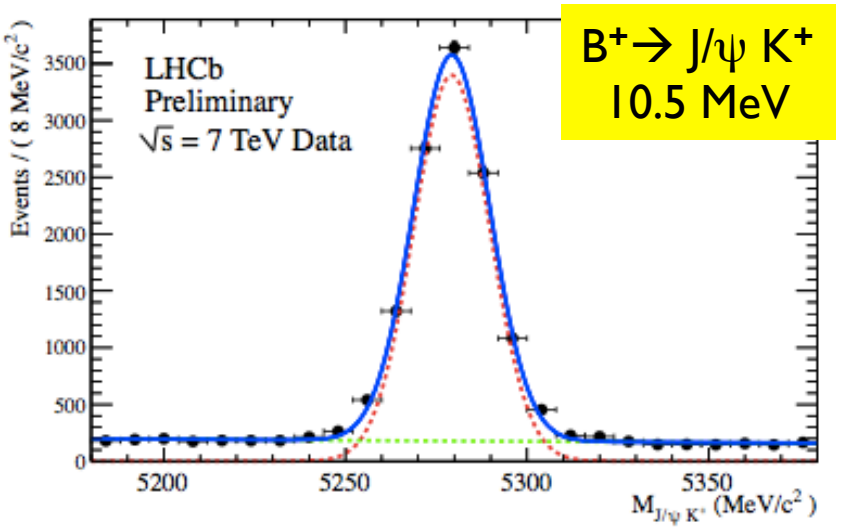
ECAL π^0 mass peak/resolution



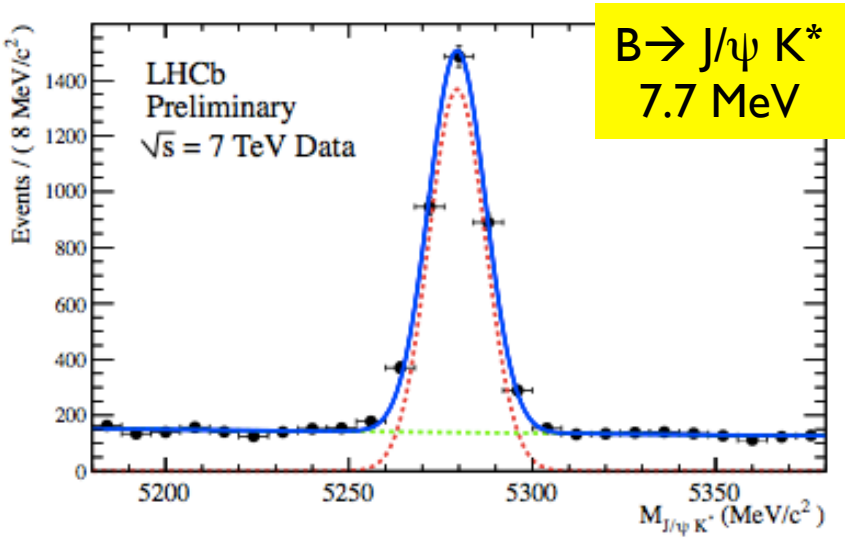
(MeV/c²)		All	
2011 early data	μ	135.07± 0.03	
	σ : σ/μ	7.60± 0.06	5.6%
2011 data (march->june)	μ	129.90± 0.02	
	σ : σ/μ	9.01± 0.04	: 6.9%
2011 data re-calibration (march->aug)	μ	133.22± 0.01	
	σ : σ/μ	7.75± 0.04	5.8%

No losses in photoelectron statistics

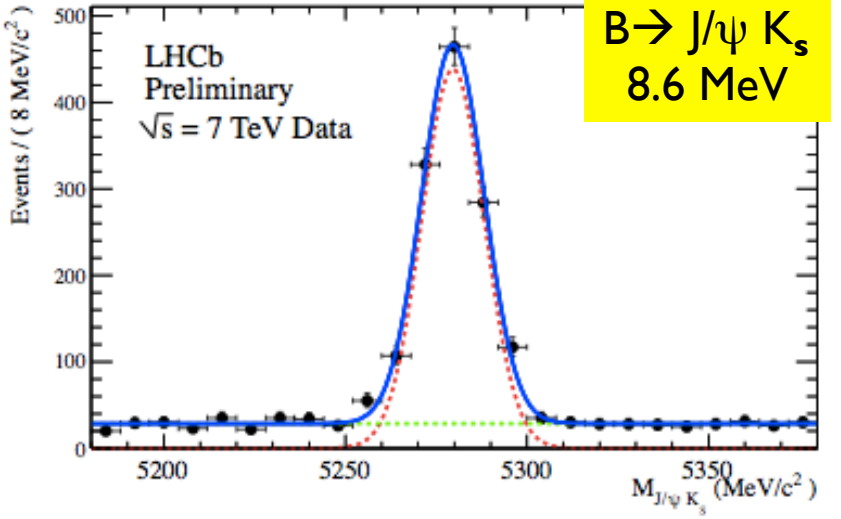
B mesons mass resolution



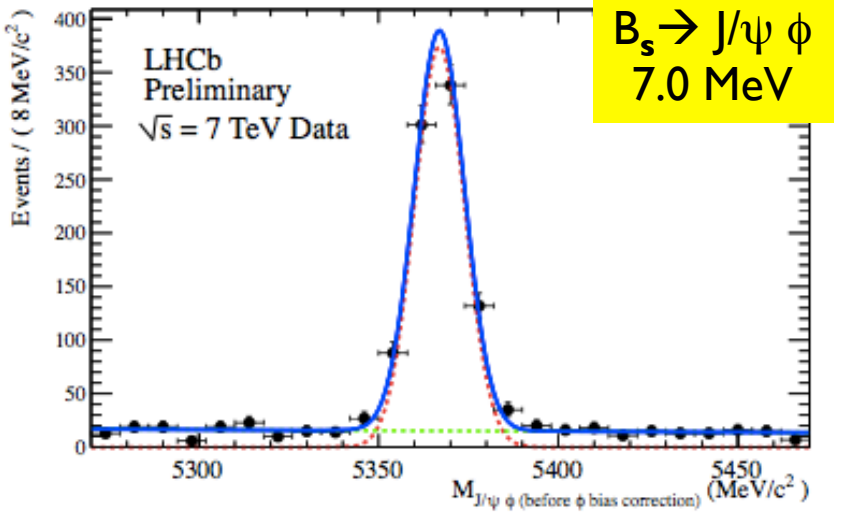
$B^+ \rightarrow J/\psi\ K^+$
10.5 MeV



$B \rightarrow J/\psi\ K^*$
7.7 MeV



$B \rightarrow J/\psi\ K_s$
8.6 MeV



$B_s \rightarrow J/\psi\ \phi$
7.0 MeV

All values very near to Monte Carlo expectations

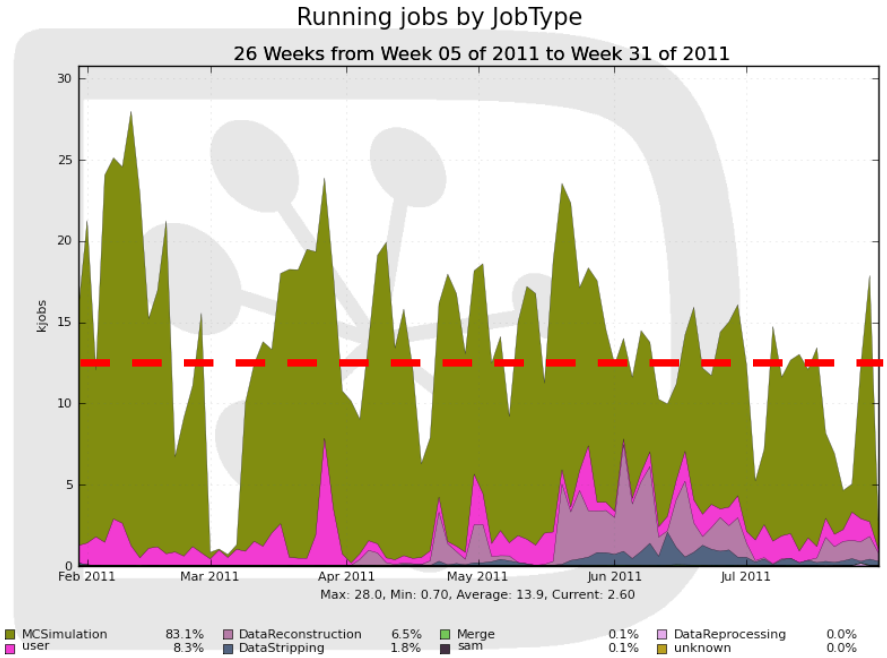
Computing & data processing

- Reconstruction output: 3 kHz with ~130 kB/event → ~ 400 MB/s

- Stripping output: 300 Hz → ~ 40 MB/s
  Draconian campaign during summer to stay within bandwidth design value and available disk space (note: charm was not in our Computing Model)

- Now ready to re-process the full 2011 dataset (~1 fb^{-1}) with the available disk space (but limited margin for Monte Carlo production)
  Reprocessing of 2011 dataset for Winter Conferences ready in December
  → Shortage of disk space to store the Physics data LHCb is producing

- Tier1 & Tier2 grid working efficiently: fair share CERN/Tier1 (no CPU limited)



$B_s \rightarrow \mu\mu$

Predicted to be very rare in the SM due to GIM & helicity suppression:

- $Br_{SM}(B_s \rightarrow \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$

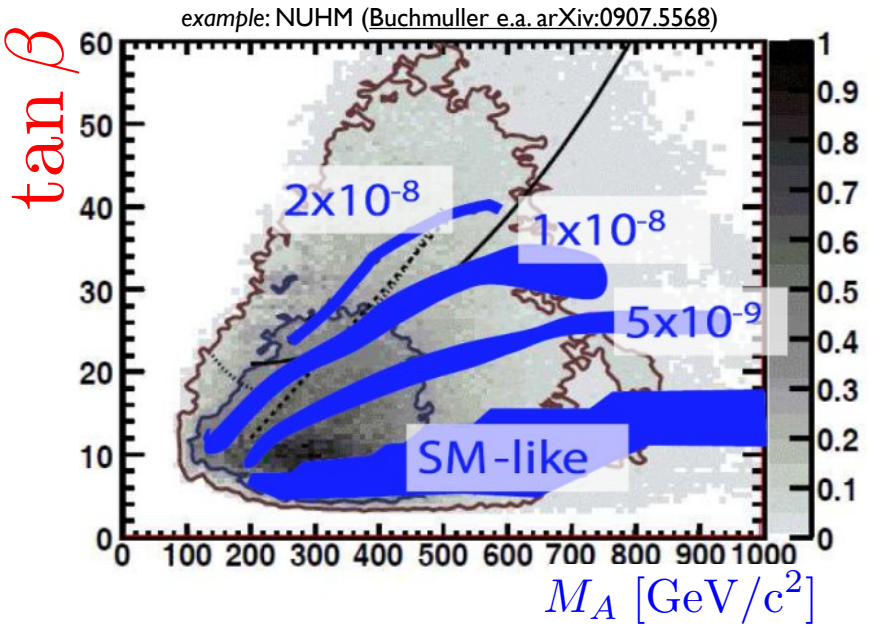
Large sensitivity to NP, eg SUSY:

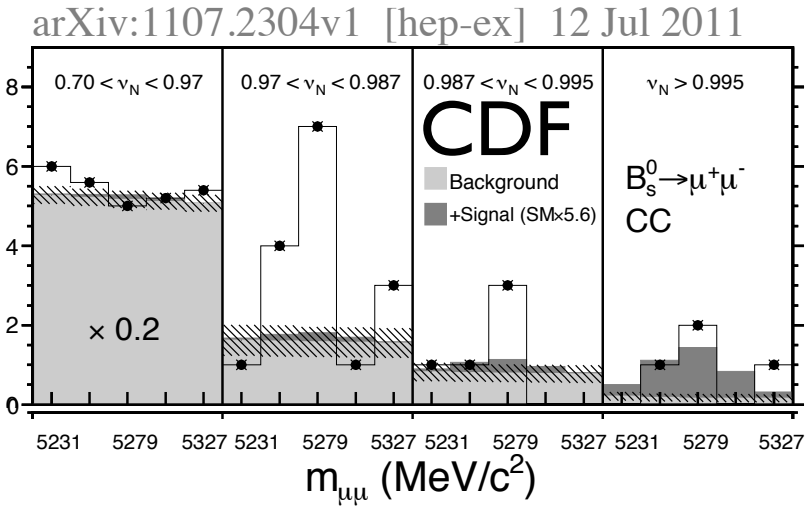
- $\mathrm{Br}_{\mathrm{MSSM}}(B_q \rightarrow \ell^+\ell^-) \propto \frac{M_b^2 M_\ell^2 \tan^6 \beta}{M_A^4}$

Good place for synergy with direct searches

CDF recently reported a hint of signal:

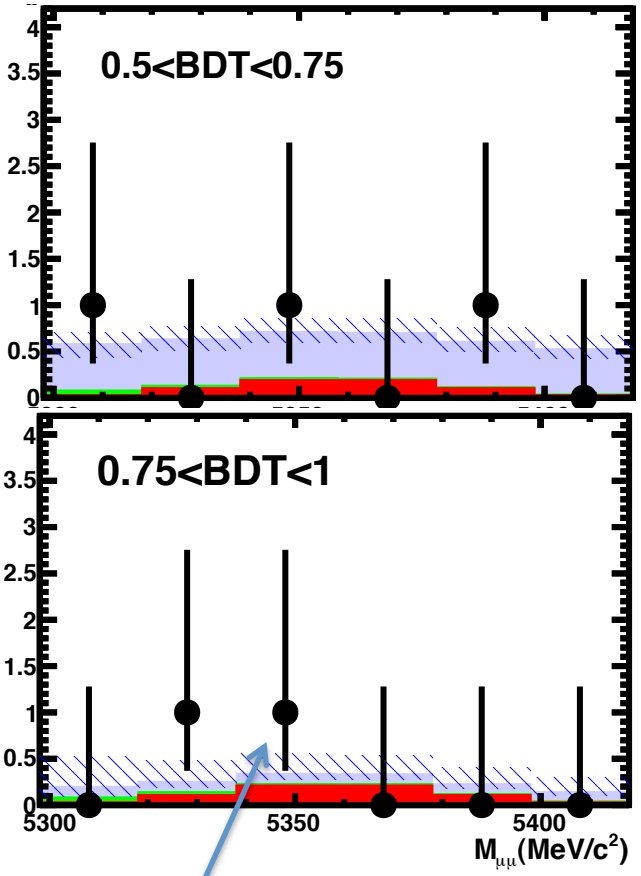
- $Br_{CDF}(B_s \rightarrow \mu\mu) = 1.8^{+1.1}_{-0.9} \times 10^{-8}$

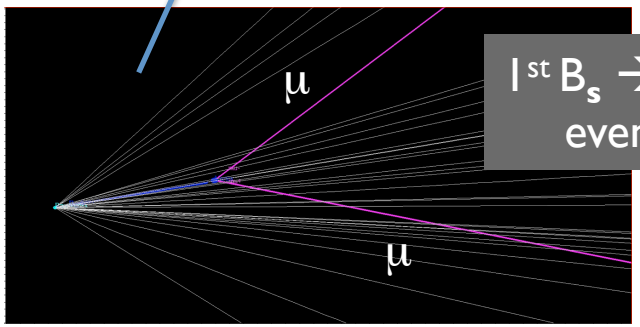




- Analysis of 300/pb using invariant mass & Boosted Decision Tree combining 9 topological & kinematical observables
  - BDT calibrated on $B \to h^+h^-$ (signal), sidebands (background)
  - Mass resolution obtained by interpolation between $J/\psi \to \mu\mu$, $\Upsilon(1S) \to \mu\mu$, shape verified using $B^0 \to K\pi$, $B_s \to KK$
- Normalization using $B^+ \to J/\psi K^+$, $B_s \to J/\psi\phi$, $B^0 \to K\pi$, and LHCb result for f_s/f_d

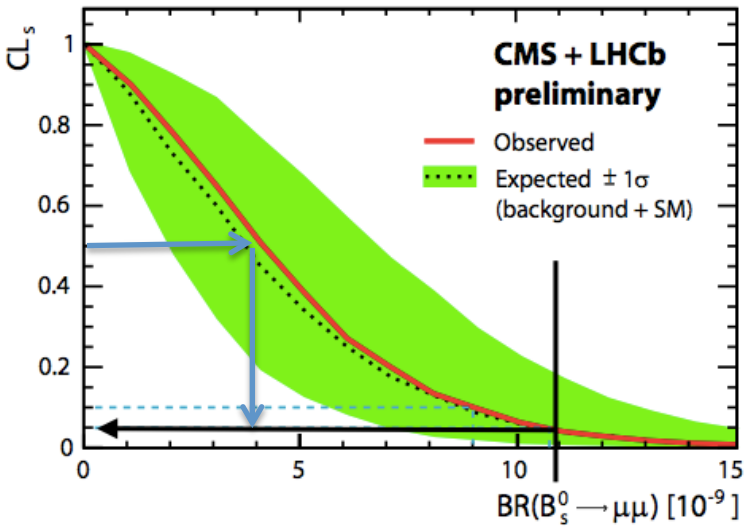
LHCb-CONF-2011-037





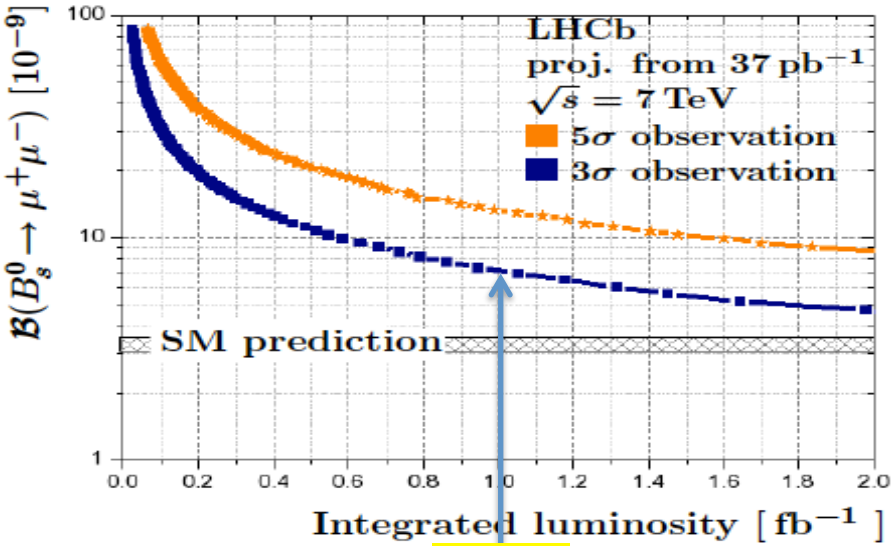
CMS, LHC*b*: $B_s \rightarrow \mu\mu$ Limits

- Expected Limit: <1.5 x 10^{-8} @ 95%CL
- p-value background only: 14%
- Br ($B_s \rightarrow \mu\mu$) < 1.6 x 10^{-8} @ 95% CL LHCb



- Combination with CMS data (1.3/fb)
- Excess see by CDF not confirmed
- Expected
 ~ 4 10^{-9}

< 11x10^{-9} @ 95% CL

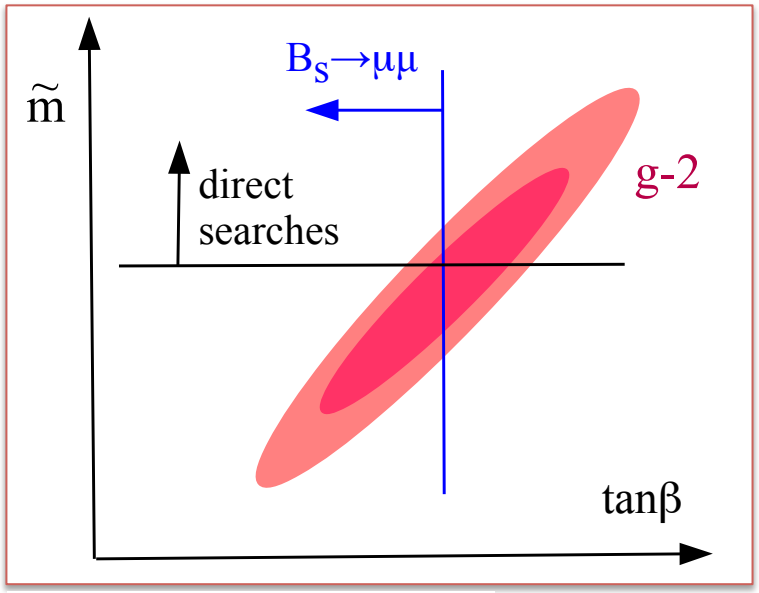


Perspectives with 1/fb statistics:

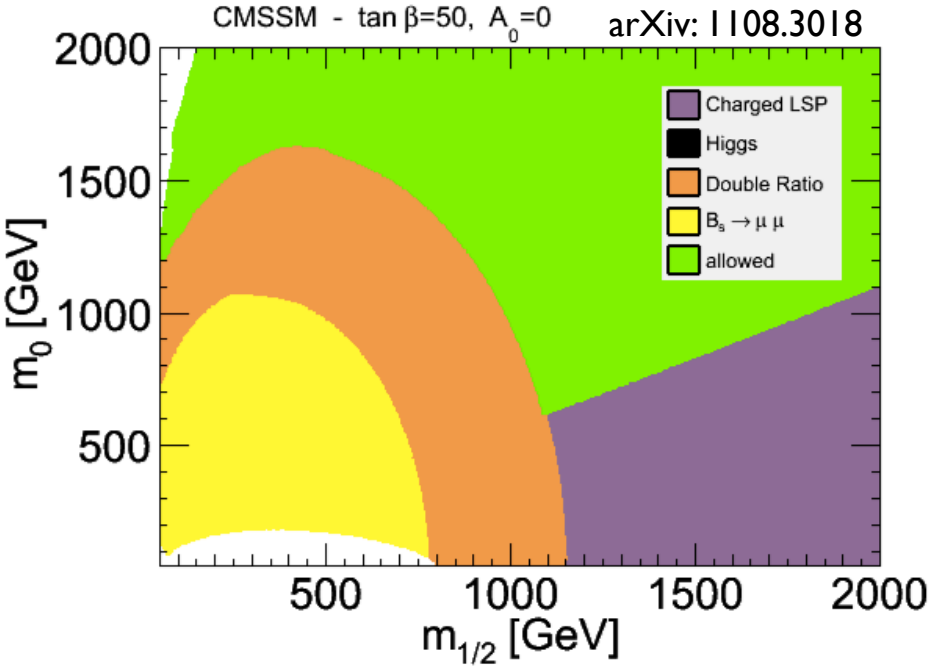
- Limit (95% CL) < 5 10^{-9} expected
- 3σ observation if BR ~ 7 10^{-9}

Measurement of $B_d \rightarrow \mu\mu$ also important [test of models : $B(B_d \rightarrow \mu\mu)/B(B_s \rightarrow \mu\mu)$]

LHCb constraining Supersymmetry

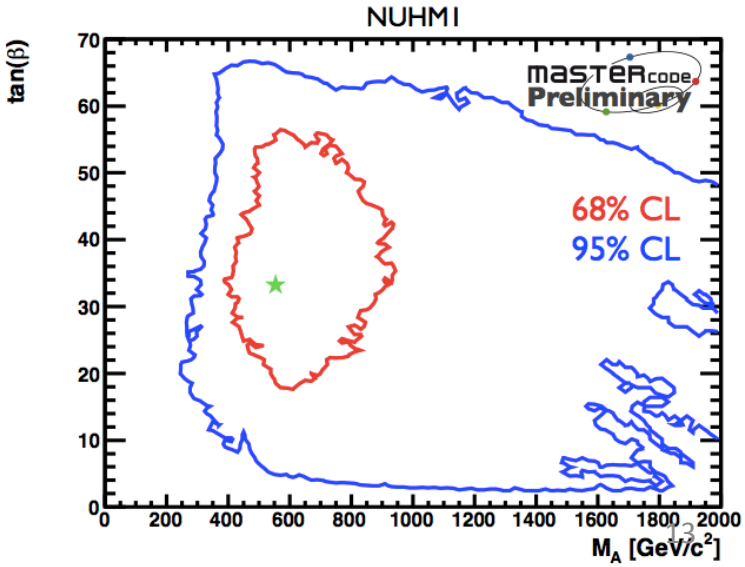


G. Isidori, ICFA Seminar, 2011



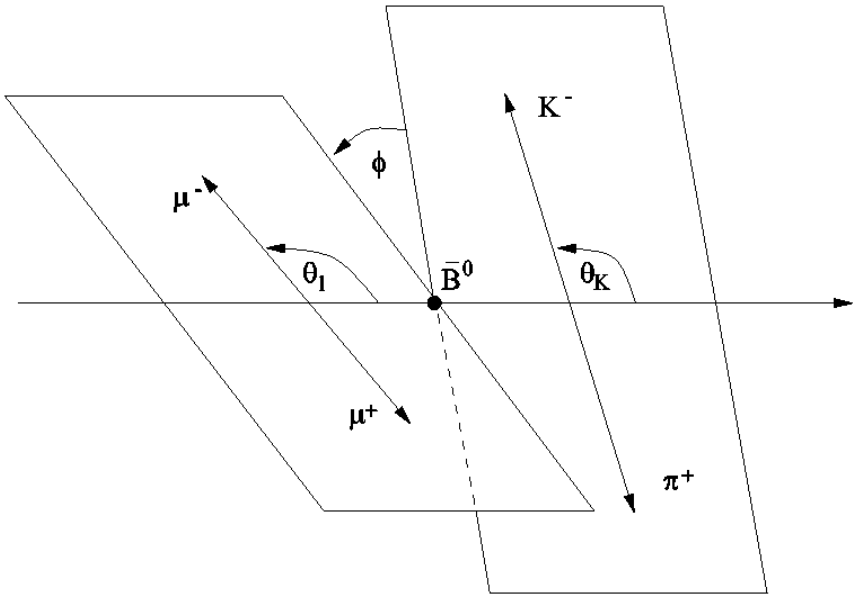
- LHC 2011 MET searches and $B_s \to \mu\mu$

- $BR(B_s \to \mu\mu)$ puts strong bounds on *tan β* at least in MSSM, complementary to direct searches and in tension with *g-2*
- LHCb result enters into SUSY models fits

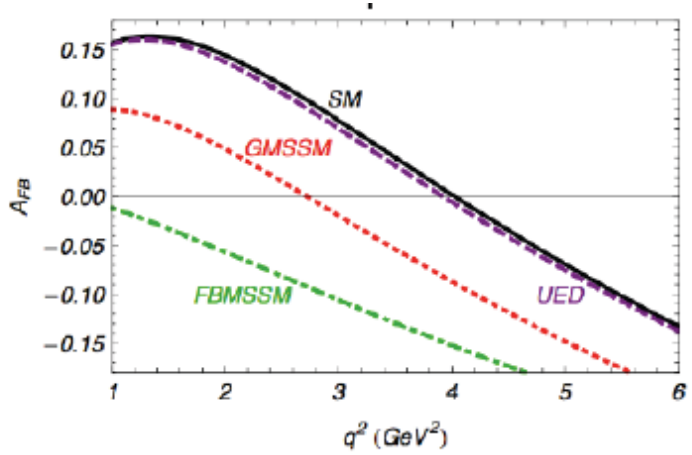


$B^0 \rightarrow K^*l^+l^-$

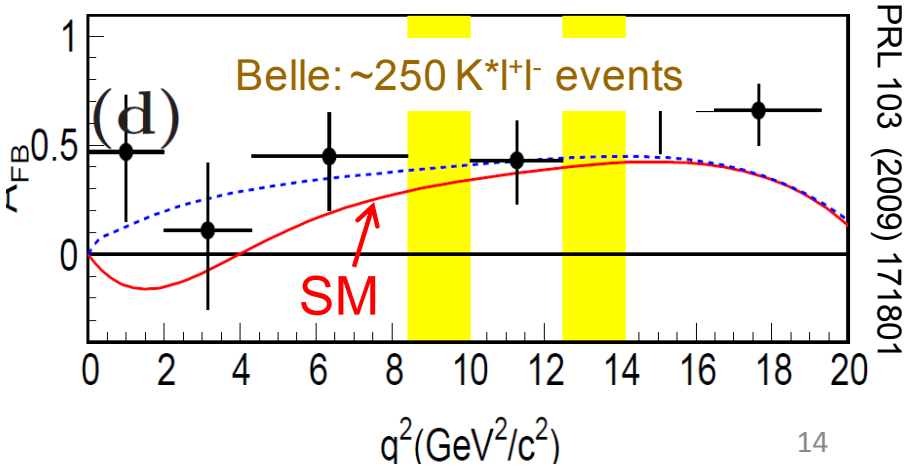
- Flavour changing neutral current decay:
  - $Br(B^0 \rightarrow K^*l^+l^-) = (3.3 \pm 1.0) \times 10^{-6}$
- Described by
  - three angles: θ_l, ϕ, θ_k
  - $\mu\mu$ invariant mass: q^2
- Excellent probe of helicity structure of New Physics
- Esp. lepton forward-backward asymmetry A_{FB} vs. q^2

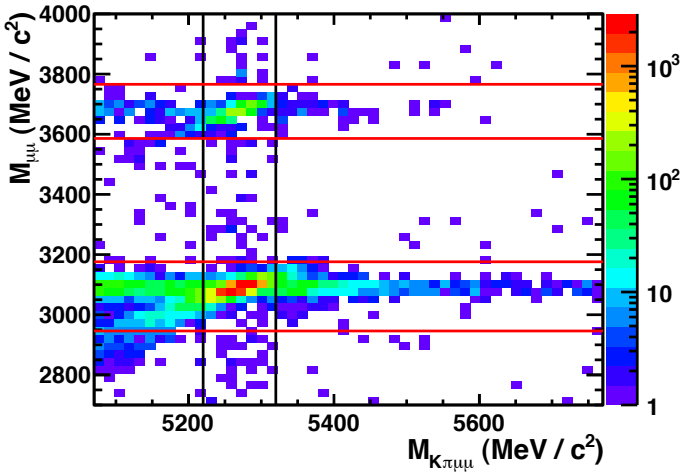


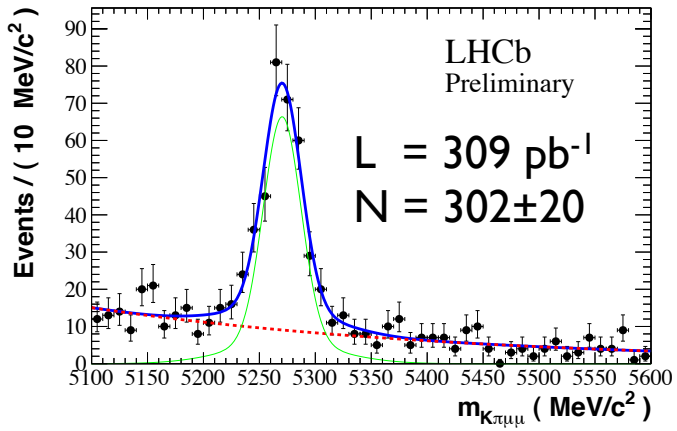
- Results from B-factories & CDF show hint of peculiar behavior at low q^2 ?



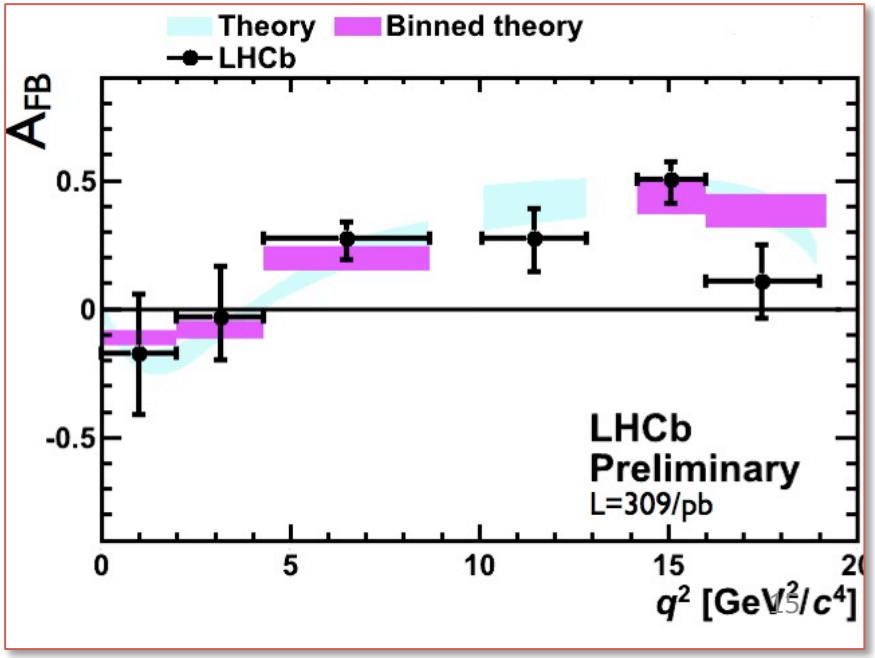
W.Altmannshofer et al. [JHEP 0901:019 (2009)]







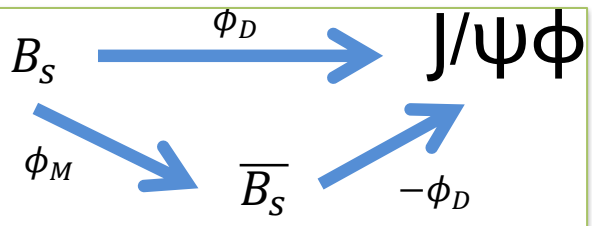
- Select data with multivariate techniques
- Very good yield and S/B (comparable to B factories)
- Fit in bins of θ_l, Φ, θ_K, and q^2
- Extract A_{FB} and F_L: systematics very small and results statistically limited



- Data in excellent agreement with SM
- Next : determine q_0^2, and variables sensitive to RH currents ($A_T^{(2)}$)

CP violation & $B_s\bar{B}_s$ Mixing Phase

Interference between mixing and decay gives rise to CP violating phase $\phi_s = \phi_M - 2\,\phi_D$



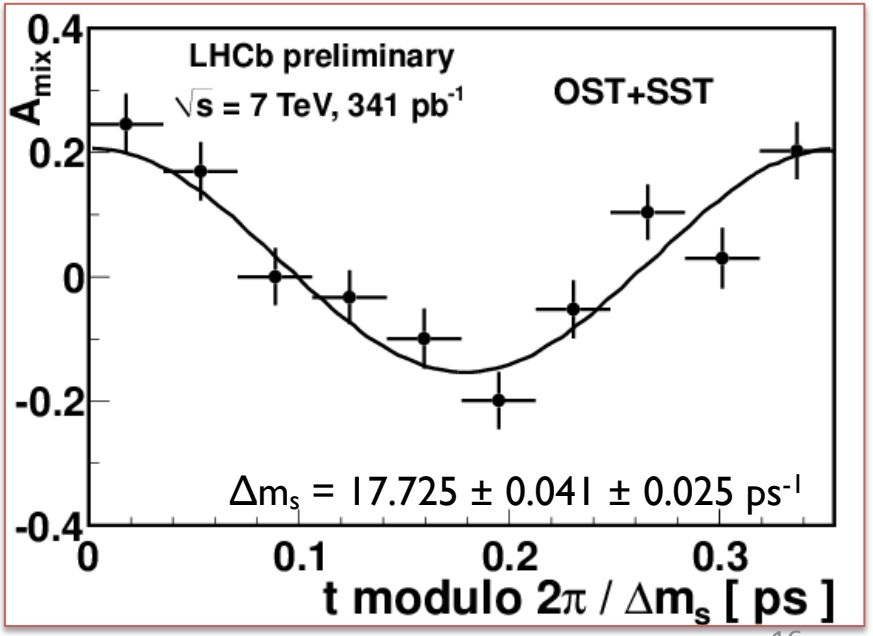
$$\phi_s \overset{\text{SM}}{=} -2\beta_s \equiv -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

Requires *time-dependent, flavour tagged, angular* analysis

Measurement of mixing Δm_s using flavor tagged decays $B_s \rightarrow D_s\,\pi$

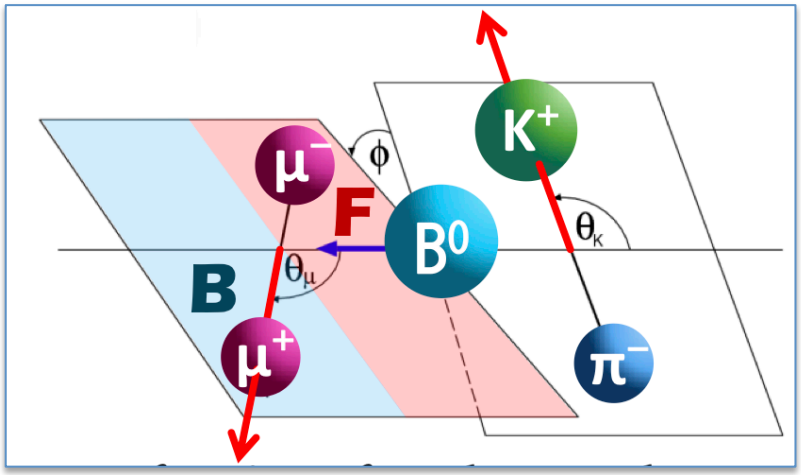
Same side and opposite side tagging exploited

LHCb has the Δm_s world best value



CP violation in $B_s \rightarrow J/\psi\phi$: ingredients

- PS → VV : 3 polarization amplitudes
  - Describe in transversity basis
    - l=1 : $A_\perp$ (CP odd)
    - l=0,2 : A_0, $A_\parallel$ (CP even)

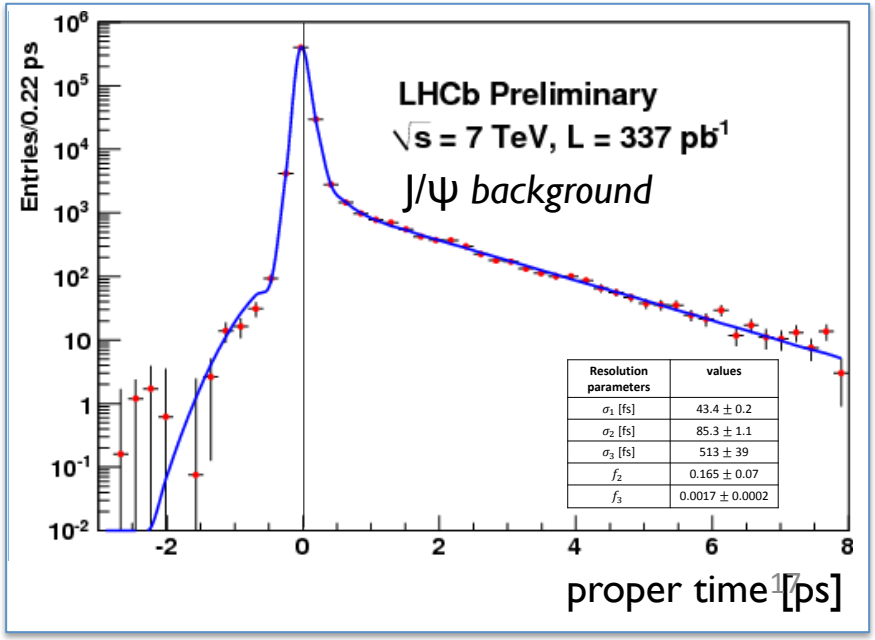


$$\vec{\lambda} = (\Gamma_s, \Delta\Gamma_s, \Delta m_s, \phi_s, |A_0|^2, |A_\perp|^2, \delta_\parallel, \delta_\perp, |A_S|^2, \delta_S)$$

Tagging power (OS only): $\varepsilon D^2 \sim 2\ \%$

Measurement of proper time resolution with the background of prompt J/ψ

Effective resolution $\sigma_t \sim 50$ fs (near to expected value)



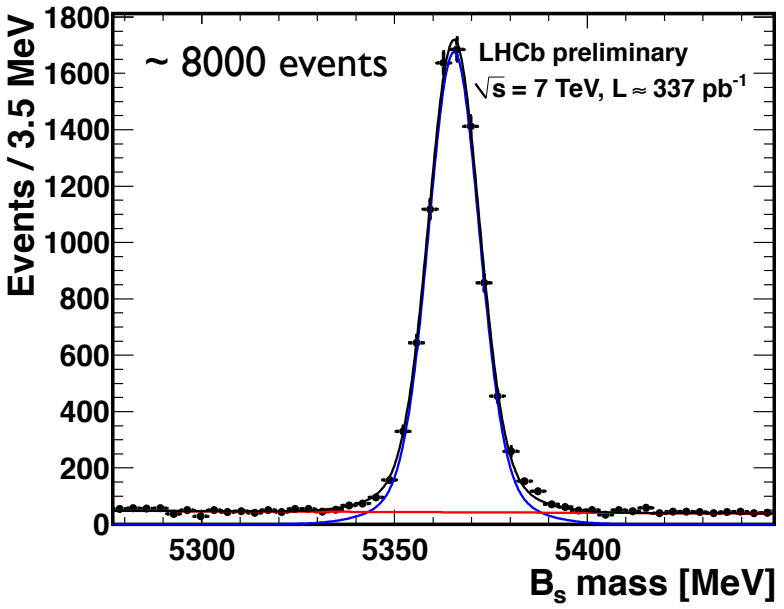
$B_s \to J/\psi\varphi$: $\Delta\Gamma_s$ vs. ϕ_s

Most precise measurement of ϕ_s

- $\phi_s = 0.13 \pm 0.18$ (stat) ± 0.07 (syst) rad
- Consistent with SM

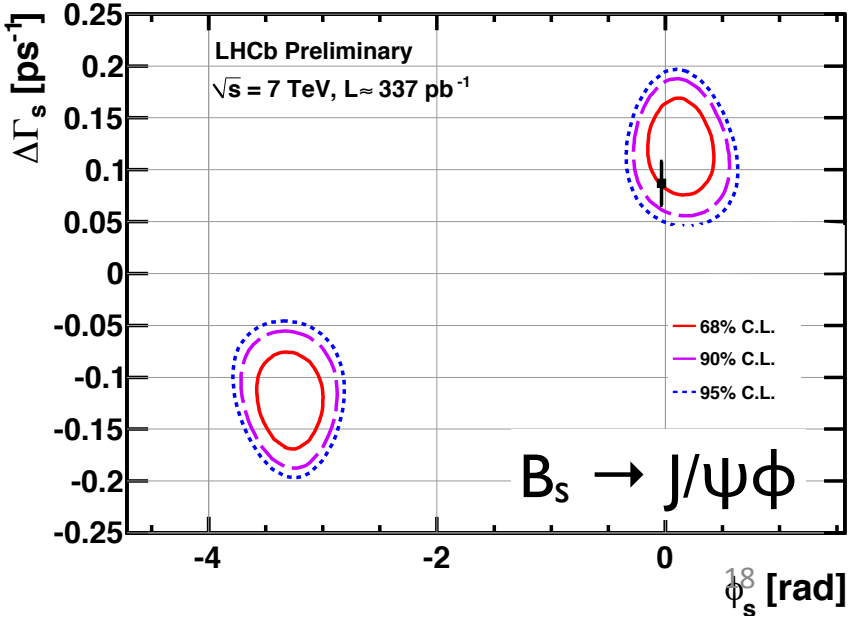
4 σ Evidence for $\Delta\Gamma_s \neq 0$:

- $\Delta\Gamma s = 0.123 \pm 0.029$ (stat) ± 0.008 (syst) ps^{-1}
- $\Gamma_s = 0.656 \pm 0.009$ (stat) ± 0.008 (syst) ps^{-1}



Independent measurement performed with $B_s \to J/\psi\, f_0$: CP eigenstate and no angular analysis needed:

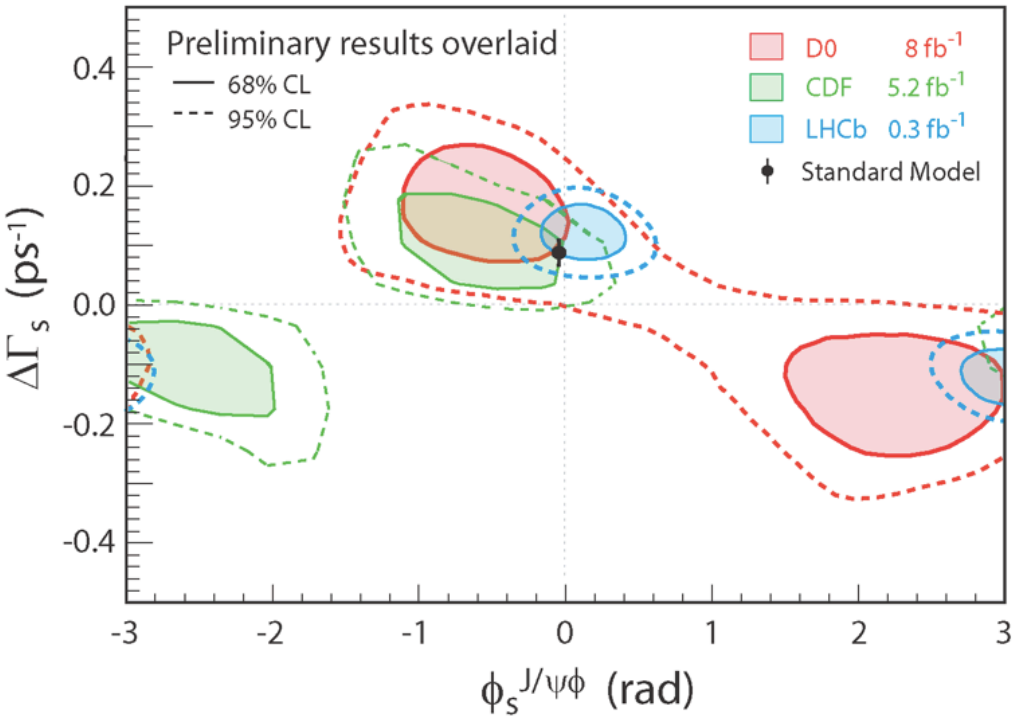
$\Phi_s = -0.44 \pm 0.44$ (stat) ± 0.02 (syst) rad

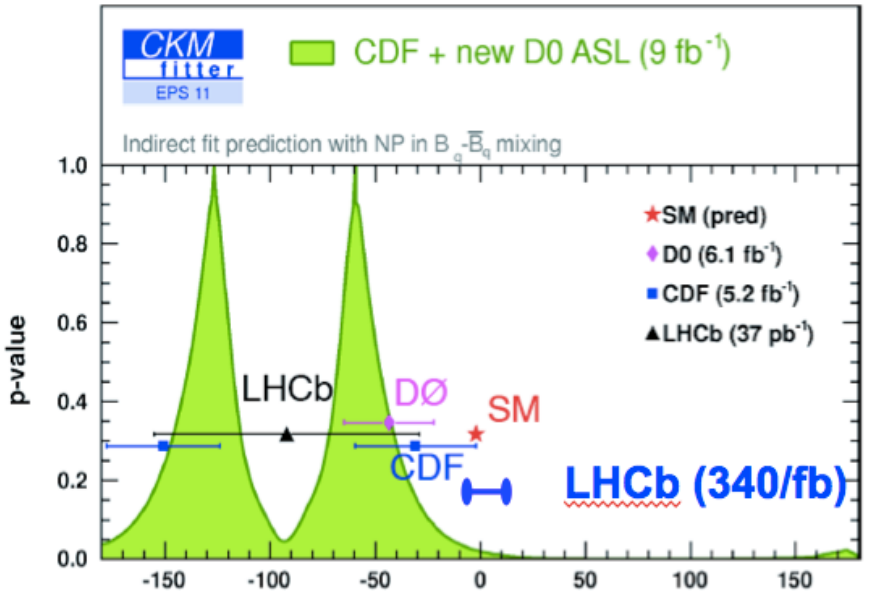


LHCb Preliminary

combined result → $\phi_s = 0.03 \pm 0.16 \pm 0.07$ rad

Status and perspectives of ϕ_s measurement





Previous tensions with SM observed by CDF and D0 not confirmed

Incompatibility with A_{SL} result from D0 (to be tested soon by LHCb)

Still a lot of room for New Physics

LHCb expects a precision of 0.1 rad with 1/fb data sample

$B^0 \to K^*\gamma$ and $B_s \to \phi\gamma$

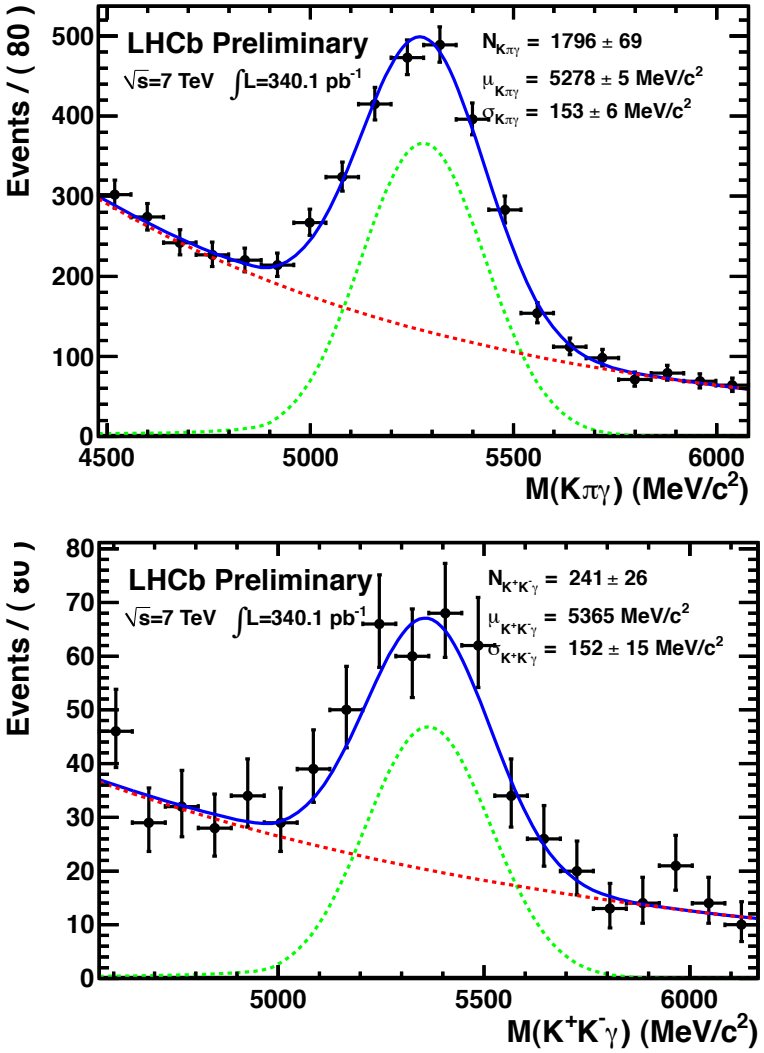
- First analysis with calorimetric objects

Largest $B_s \to \phi\gamma$ signal, measure:

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.52 \pm 0.15(\text{stat}) \pm 0.10(\text{syst}) \pm 0.12(f_s/f_d)$$

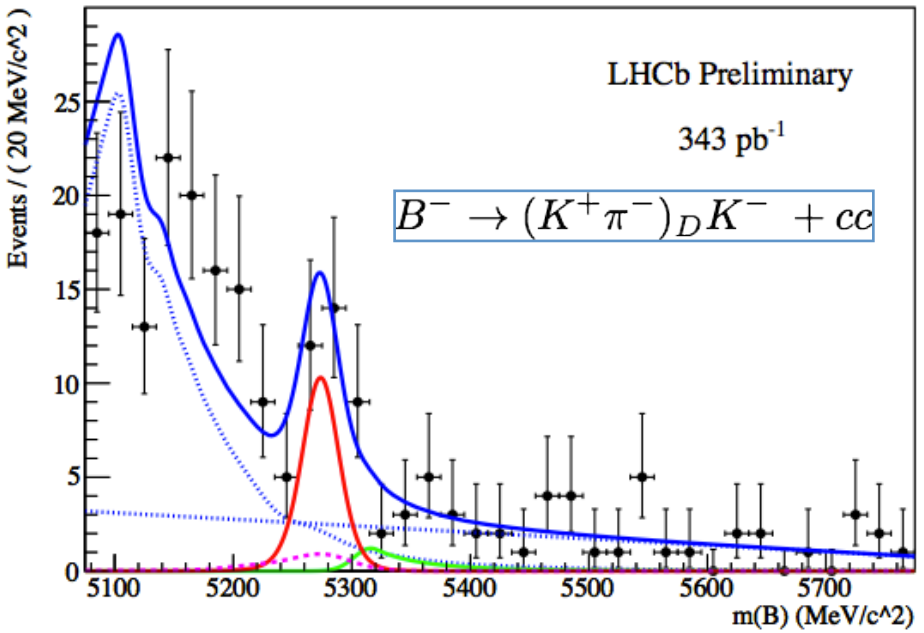
SCET predicts 1.0 ± 0.2 for this ratio
[Ali et al., EPJ C55:577 (2008)]

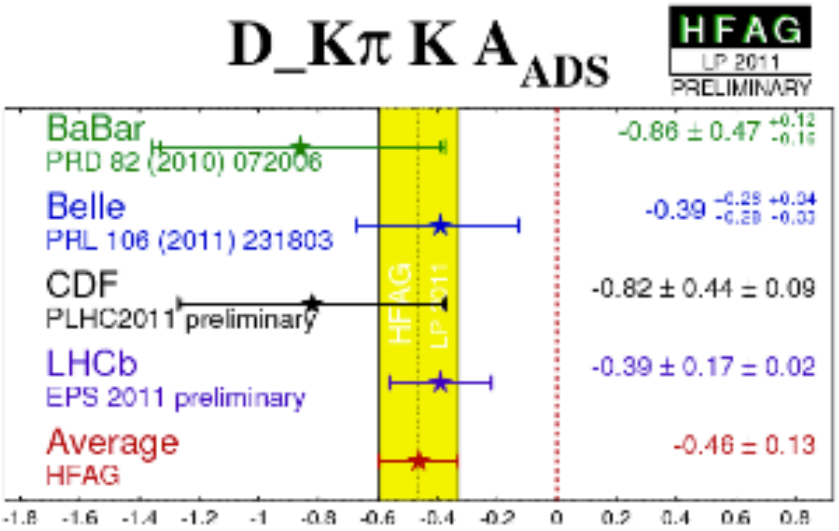
- Large improvement on mass resolution with latest ECAL calibration: 150 MeV → 100 MeV
- Next step: measure CP asymmetries



Towards the measurement of γ (tree diagrams)

- Time integrated ADS method
  (B→DK, interference between
  B and D suppressed decay modes)
- Very small branching ratio: ~ 10^{-7}
- LHCb data: world best





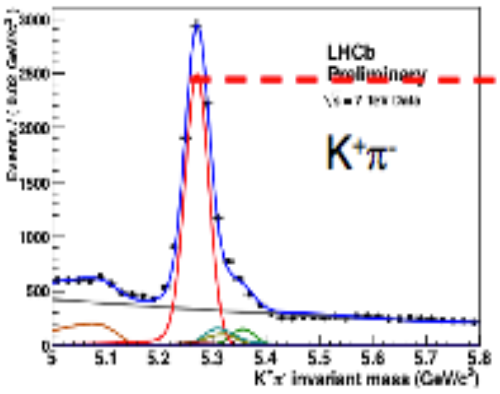
$$A = \frac{\Gamma(B^- \to f_D K^-) - \Gamma(B^+ \to \bar{f}_D K^+)}{\Gamma(B^- \to f_D K^-) + \Gamma(B^+ \to \bar{f}_D K^+)}$$

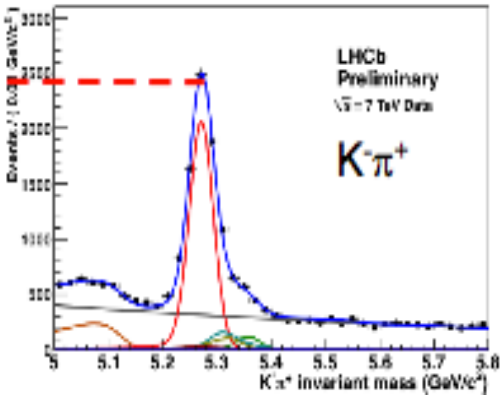
A_{ADS} = - 0.39 ± 0.17 ± 0.02

R_{ADS} =(1.66 ± 0.39 ± 0.24) 10^{-2}

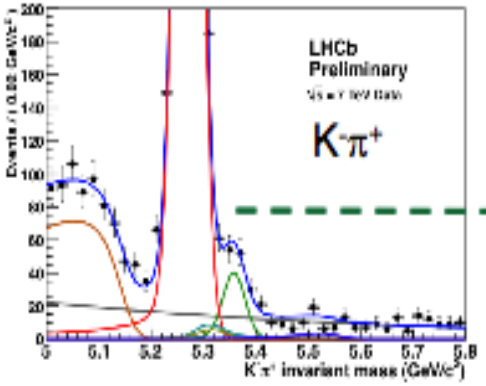
Towards the measurement of γ (loop diagrams)

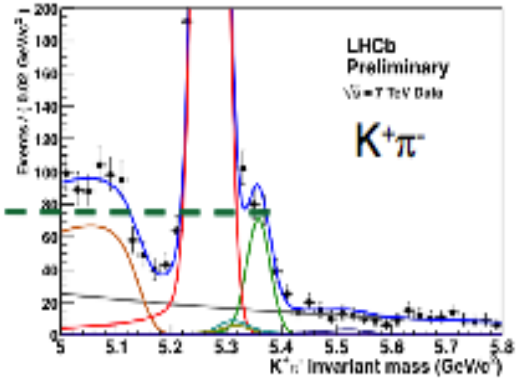
- Measurement of time integrated asymmetries in B→hh decays
- 1st evidence of CP violation in B_s system
- Best single measurement of A_{CP} (B_d) and new element for the A_{CP} "puzzle"



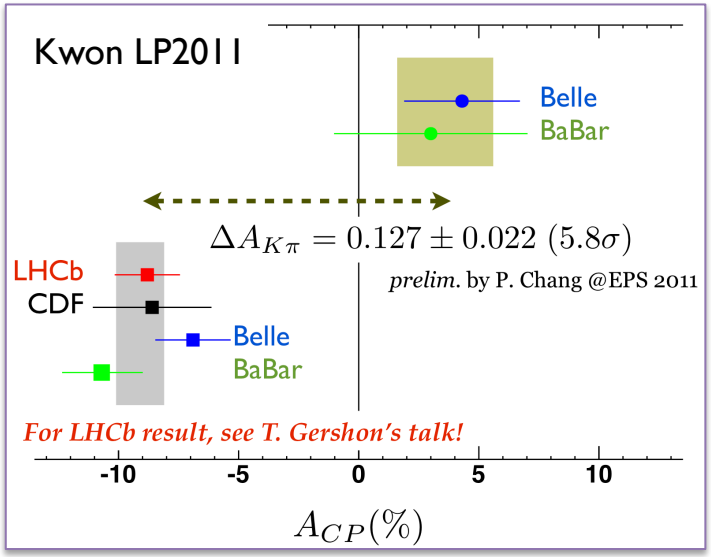


$$A_{CP}\left(B^0 \to K^+\pi^-\right) = -0.088 \pm 0.011 \pm 0.008$$





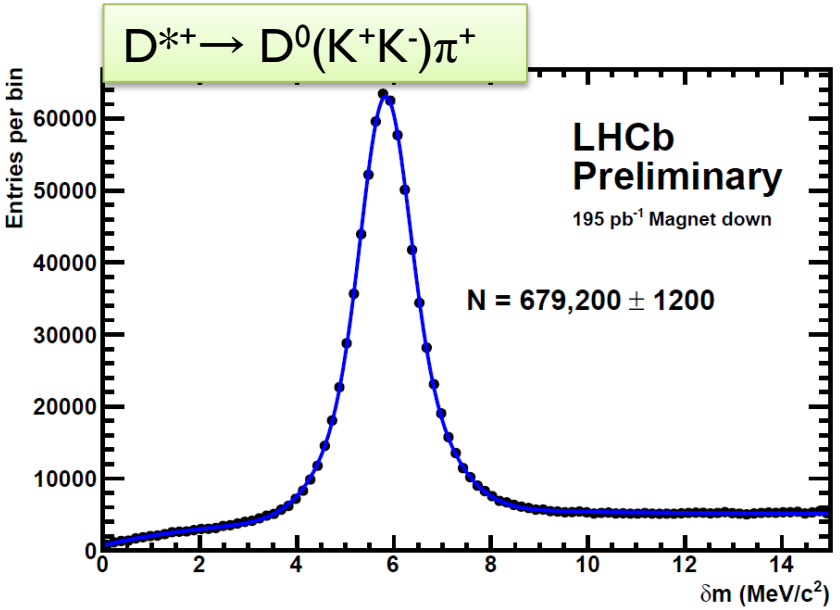
$$A_{CP}\left(B_s^0 \to \pi^+K^-\right) = 0.27 \pm 0.08 \pm 0.02$$



Next step: time dependent asymmetries

The "beauty" of charm

- LHCb can profit of the huge charm production cross section at the LHC (~6 mb): 1 kHz out of 3 kHz of the HLT output dedicated to charm
- Complication: evaluate asymmetry coming from initial pp state



A_Γ: compare D^0 and $D^0 \to KK$ lifetimes [tagged samples]

y_{CP}: compare lifetime of $D^0 \to$ CP-eigenstate, (KK or $\pi\pi$), to $D^0 \to$ non-eigenstate ($K\pi$) [untagged samples]

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$

$$y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1$$

Results presented at EPS, based ONLY on 2010 data (~35 pb^{-1})

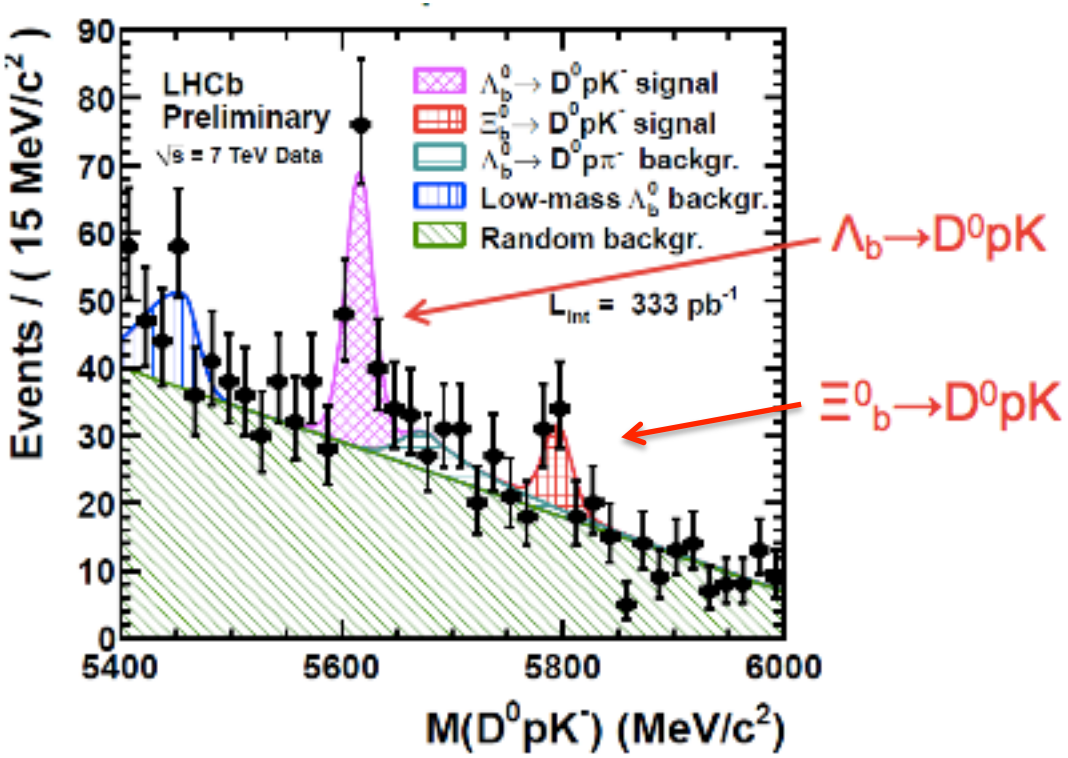
$$A_\Gamma = (-0.59 \pm 0.59 \pm 0.21)\%$$

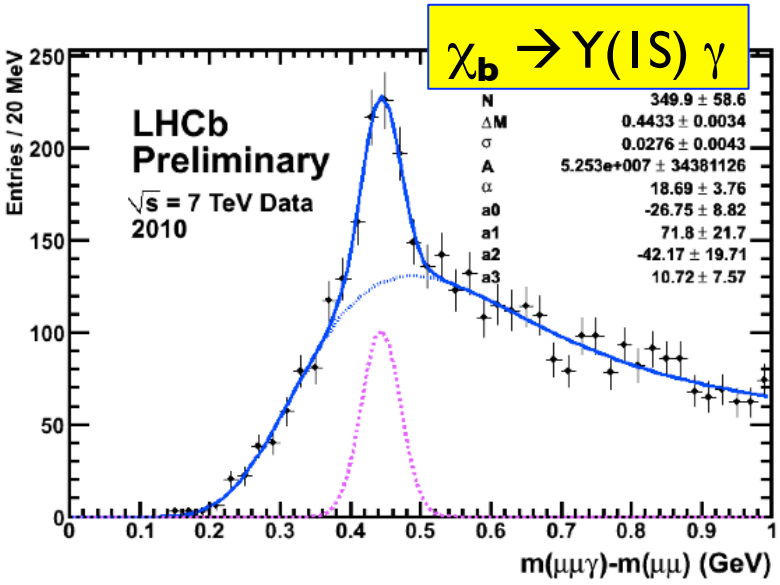
c.f. WA of $(0.12 \pm 0.25)\%$

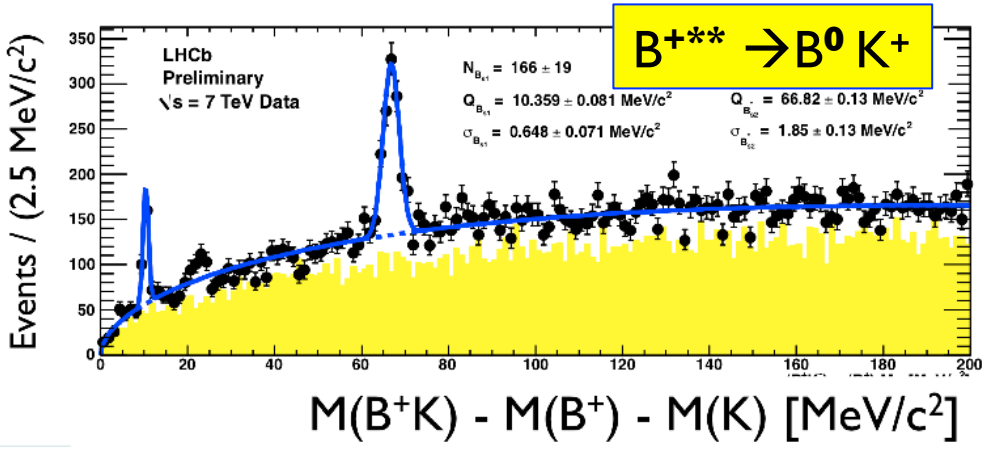
$$y_{CP} = (0.55 \pm 0.63 \pm 0.41)\%$$

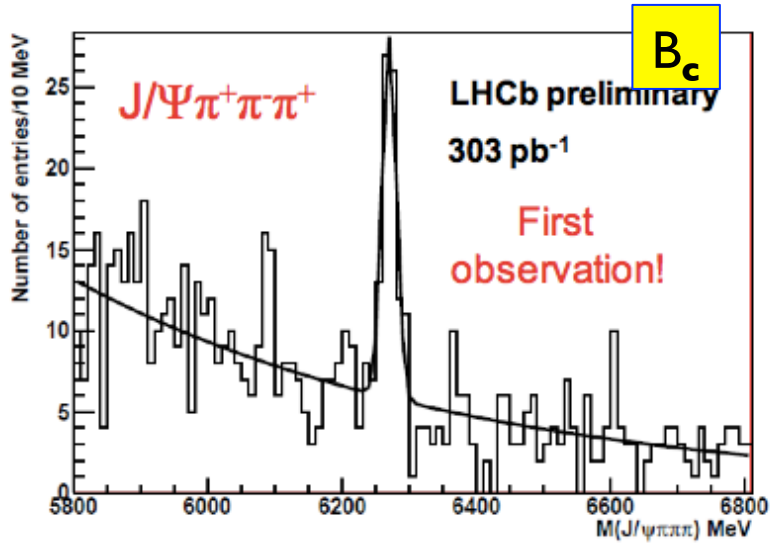
c.f. WA of $(1.11 \pm 0.22)\%$

New b-hadrons and B excited states







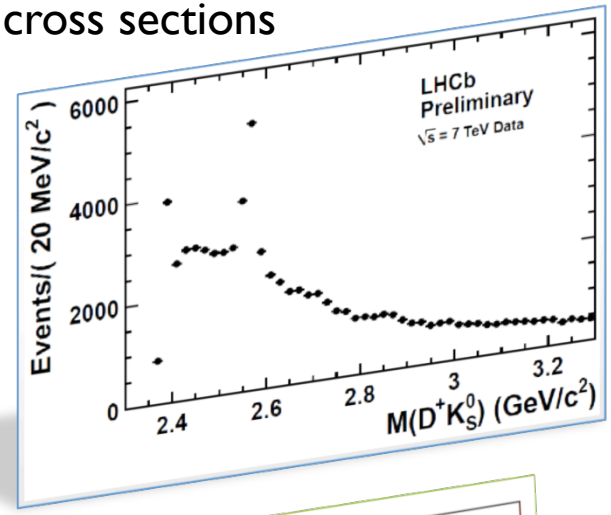


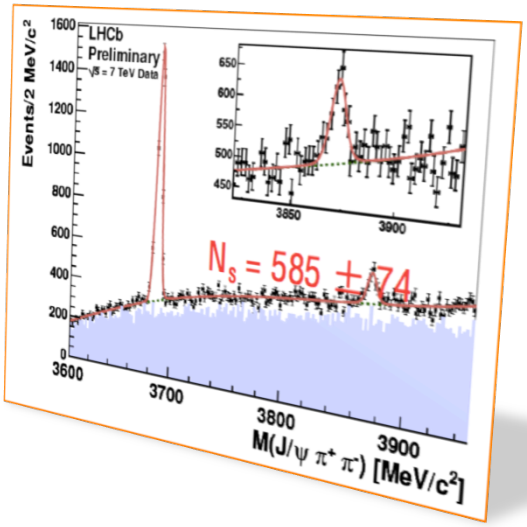
Data mining has just started !

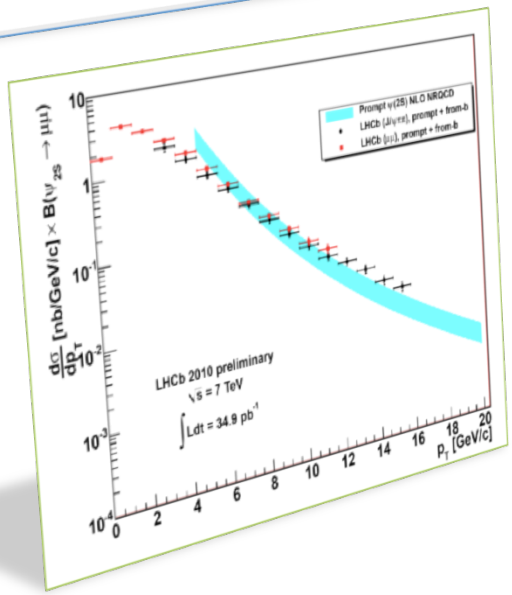
Missing items (not enough time to discuss them …)

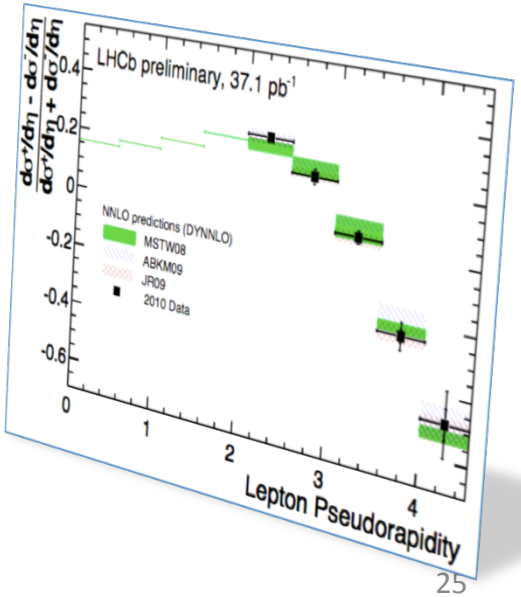
- Quarkonia and production cross sections
- Charm spectroscopy
- Electroweak Physics
- Exotica (X, Z states)
- QCD
- Majorana, long lived particles

… etc …









Status of the Upgrade (I)

April 2011: LOI submitted to LHCC

- LHCC(1): endorsement of physics case for the upgrade
- LHCC(2): setup a peer review of the 40 MHz option

June 2011: LHCC(3): positive evaluation of reviewers. "Go ahead" with TDR work and request for intermediate assessment ("framework document")

"40 MHz" upgrade scheme:

- new FEE everywhere, but MUON
- new tracking layout (VELO – TT – IT – part of OT)
- new photo sensors on RICH
- software trigger (efficiency for hadronic channels ~ double)
- consolidation for OT – CALO – MUON
- new TOF detector (TORCH)

Goals:

- Operate the detector at $\geq 10^{33}$ $cm^{-2}s^{-1}$ @ LHC with 25ns spacing
- Start of upgraded LHCb: 2019
- Collect ≥ 50/fb in 10 years with enhanced hadronic trigger

Status of the Upgrade (II)

- Upgrade Steering Group in force since 1.7.2011
  Three lines of activity: Tracking (VELO, IT, ST, OT) – PID (RICH, CALO, MUON) – Electronics & data processing. Not a replica of existing Projects
  Goals: harmonize efforts, setup milestones for technological choices, bring subsystems to TDR, define common projects
  First workshops already ongoing before end 2011

- Preparation of a "framework document" in 2012 containing:
  - List of technological options and preliminary schedule
  - Definition of milestones for having TDR(s) ready by 2013
  - Preliminary evaluation of detector cost & resources needed
  - Preliminary definition of common projects
  - List of Institutes/Funding Agencies interests

  This document should be submitted to LHCC as "Addendum to LOI"

- Intense R&D ongoing to prepare TDR (→ resources needed)

Collaboration matters

- T. Gershon (Warwick) is the new Physics Coordinator (as of 1.1.2012)
- S. Hansmann-Menzemer (Heidelberg), M. Ferroluzzi (CERN), R. LeGac (Marseille) and G. Wilkinson (Oxford) have been appointed in the Upgrade Steering Group
- A group from Rostock University became associated member (host Institute: Heidelberg University)
- A group from Cincinnati University is applying to become LHCb member (Babar - interests in charm physics, HLT and upgrade). Negotiations with LHCb well advanced. Grant application to NSF due by end of October

Conclusions

LHCb is performing very well. Thanks to LHC Team (and to luminosity leveling technique) has collected over 1 fb^{-1} in the 2011 run

Analyses in core physics channels are already well advanced, with 3 areas of "world record" measurements: $B_s \rightarrow J/\psi\,\phi$, $B_s \rightarrow \mu\mu$, $B_d \rightarrow K^* \mu\mu$

Standard Model still "uncracked" but large room for New Physics
LHCb is complementing ATLAS&CMS limits for Supersymmetry

A lot of activities and very good perspectives for "world record" measurements with 1 fb^{-1} in CPV in b and c decays, CKM angle γ , radiative and rare decays + a very large spectrum of physics items

Looking forward to increase (x 2 and even more) the statistics in 2012

Working hard to prepare LHCb future (Upgrade)

Murayama, ICFA Seminar, 2011 CERN