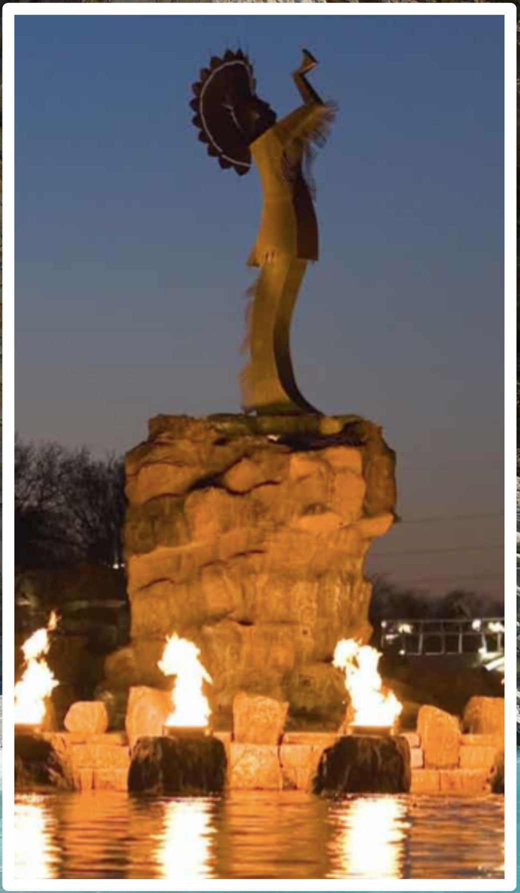
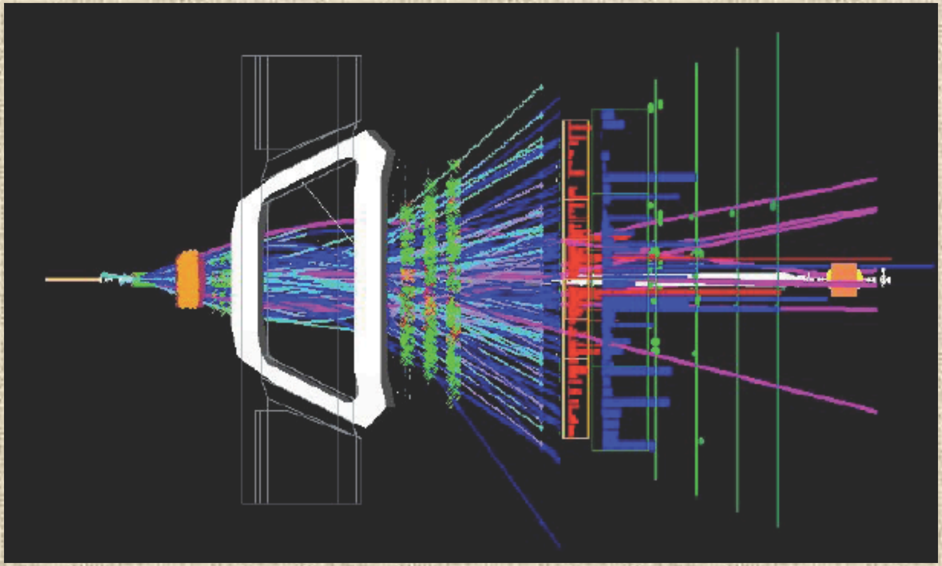


Recent results from LHCb and future prospects

P. Campana (CERN & Frascati)

24/07/2012 - BEACH 2012 – Wichita, KS

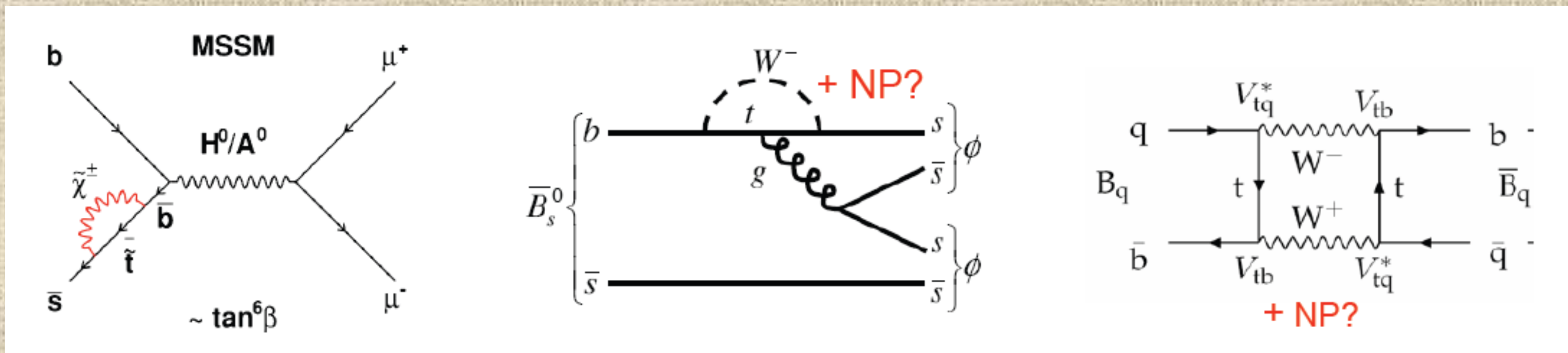
Outline of the talk:



- The LHCb physics programme
- The experiment and the data taking in 2012
- The detector performances: trigger, tracking, particle identification
- Highlights on LHCb results & implications for New Physics searches
- Prospects for the LHCb Upgrade
- Conclusions

LHCb Physics Programme

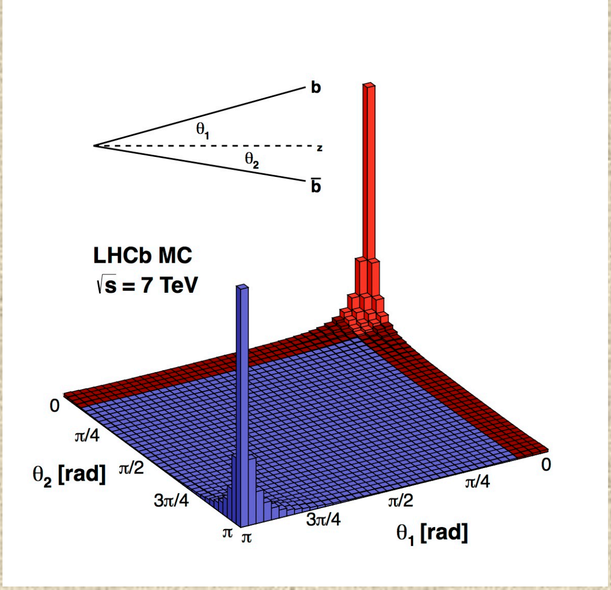
Search for New Physics (NP) which may appear in CP violation or in rare decays mediated by new particles at high mass scale - via their effects in loop diagrams (e.g.: compare CKM quantities determined in tree and loop process)



Approach complementary to direct searches in ATLAS & CMS: once NP discovery will be made, NP non trivial flavor structure has to be determined

- CPV
  - B_s oscillation phase ϕ_s
  - CKM angle γ in tree and loop mediated decays
  - CP Asymmetries in charm decays
- Rare decays
  - Helicity structure in $B_d \rightarrow K^*\mu\mu$, $B_s \rightarrow \phi\gamma$
  - FCNC in loops ($B_{d,s} \rightarrow \mu\mu$, $D \rightarrow \mu\mu$)

+ b and c production studies, spectroscopy, forward electro-weak physics, exotica, etc...



b and c quark production in LHCb

- Cross section predictions (PYTHIA8)

$\sigma_{\mathbf{inelastic}}$ ~ 70-80 mb
$\sigma_{\mathbf{bb}}$ = 252 μb / 292 μb / 527 μb [7 – 8 – 14 TeV]

Measured at 7 TeV ~ 280 μb - PLB 694 (2010) 209
(~70 μb in LHCb acceptance)

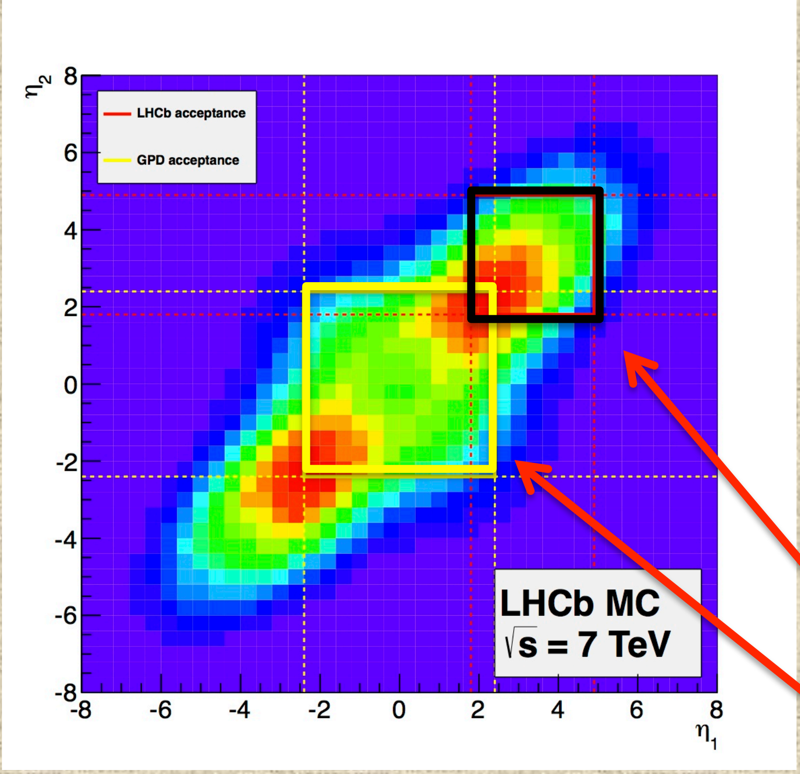
- b-hadrons $B^{\pm}$, B^{0} , B_{s} , B_{c} , Λ_{b} …

produced at LHC (~40%, ~40%, ~10%, …)

- Design luminosity: $L \sim 2\ 10^{32}\ cm^{-2}\ s^{-1}$

(operated since end of 2011 at 4 10^{32} cm^{-2} s^{-1})
Pileup with 50 ns bunch spacing <μ> ~ 1.7

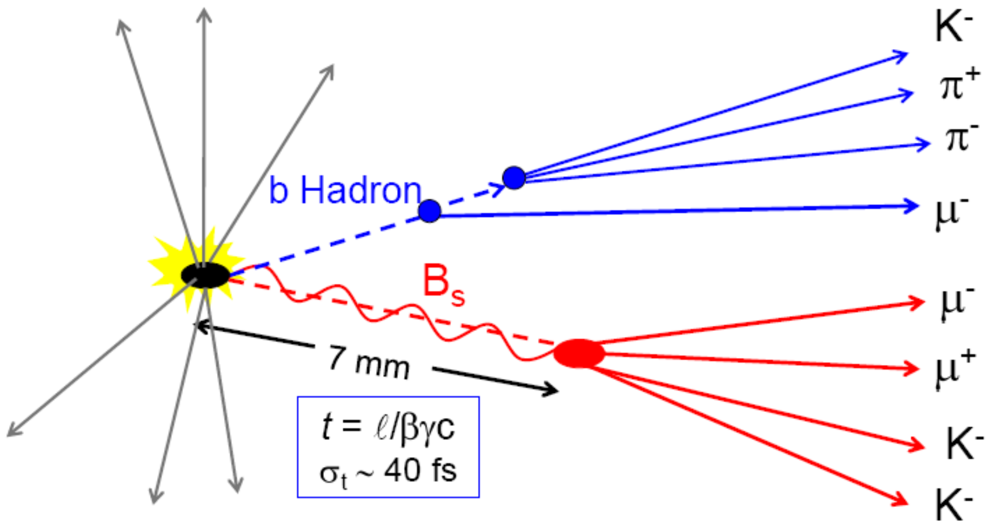
~ 30 kHz of bb events in LHCb [7 TeV]
~ 1 10^{11} bb events in LHCb [7 TeV, 1.5/fb]



LHCb acceptance : 2 < η < 5

ATLAS and CMS: |η| < 2.5

B meson decays topology



At L0 trigger level (7 TeV)

min.bias : cc : bb

250 : 20 : 1

Excellent vertex resolution: to resolve fast B_s oscillation. → VELO

Background reduction: Very good mass resolution → Tracking

Good particle identification (K/π) → RICH, CALO, Muon

High statistics: Efficient trigger for hadronic and leptonic states → L0 x HLT

- VELO
- Tracking
- RICH
- CALO
- Muon
- L0 x HLT

B decays with *μμ*	$\varepsilon_{(\mathbf{L0\ x\ HLT})}$	~ 70-90 %
B decays with *hadrons*	$\varepsilon_{(\mathbf{L0\ x\ HLT})}$	~ 20-50 %
Charm decays :	$\varepsilon_{(\mathbf{L0\ x\ HLT})}$	~ 10-20 %

(efficiencies for off-line selected events)

Flavor tagging plays a key role

σ_{cc} ~ 6 mb:
LHC is a charm factory !

The LHCb Detector

VELO: 21 (R+φ) silicon stations
- Movable:7mm when stable beams

RICH1: C_4F_{10} + AEROGEL
- π/K separation for 2<p<60 GeV

Tracking: Si + straw tubes + 4Tm
- $\delta p/p$=0.45%

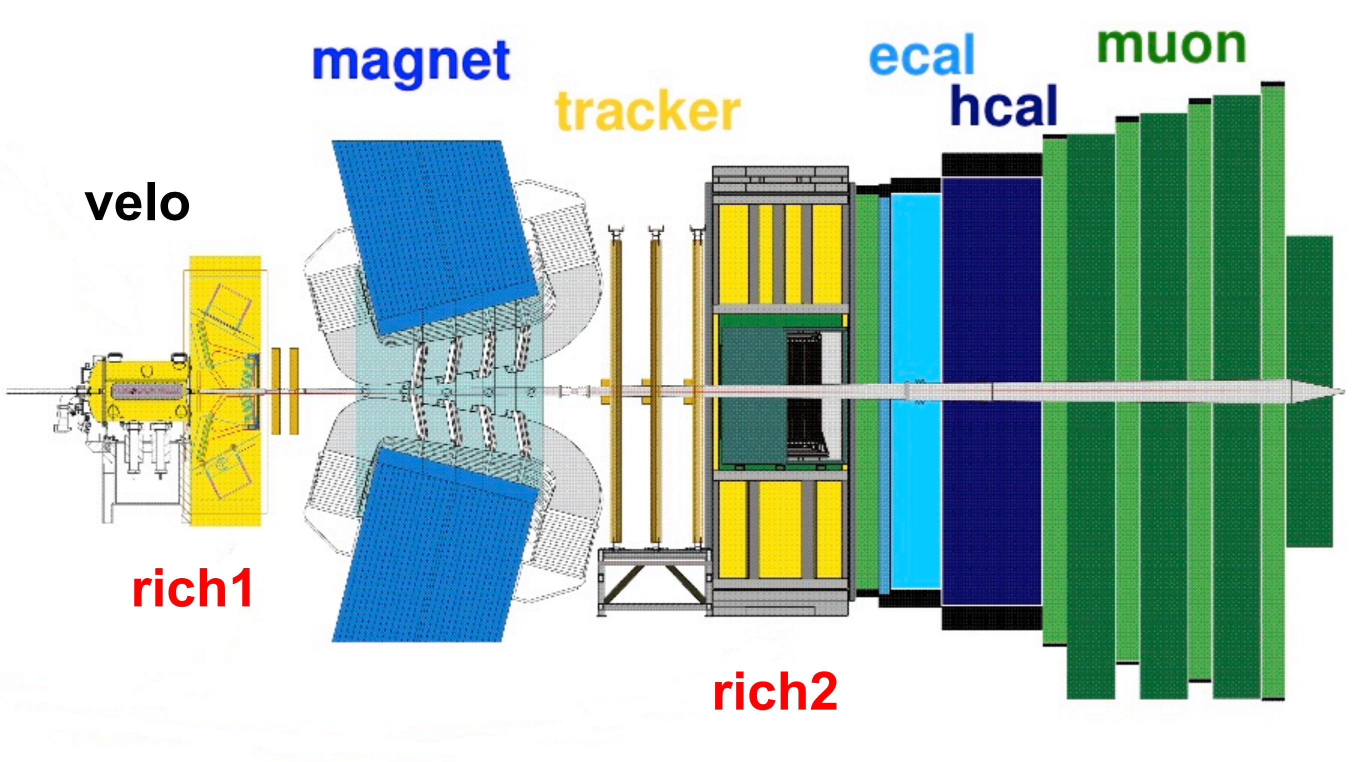
RICH2: CF_4
- π/K separation for 20<p<100 GeV

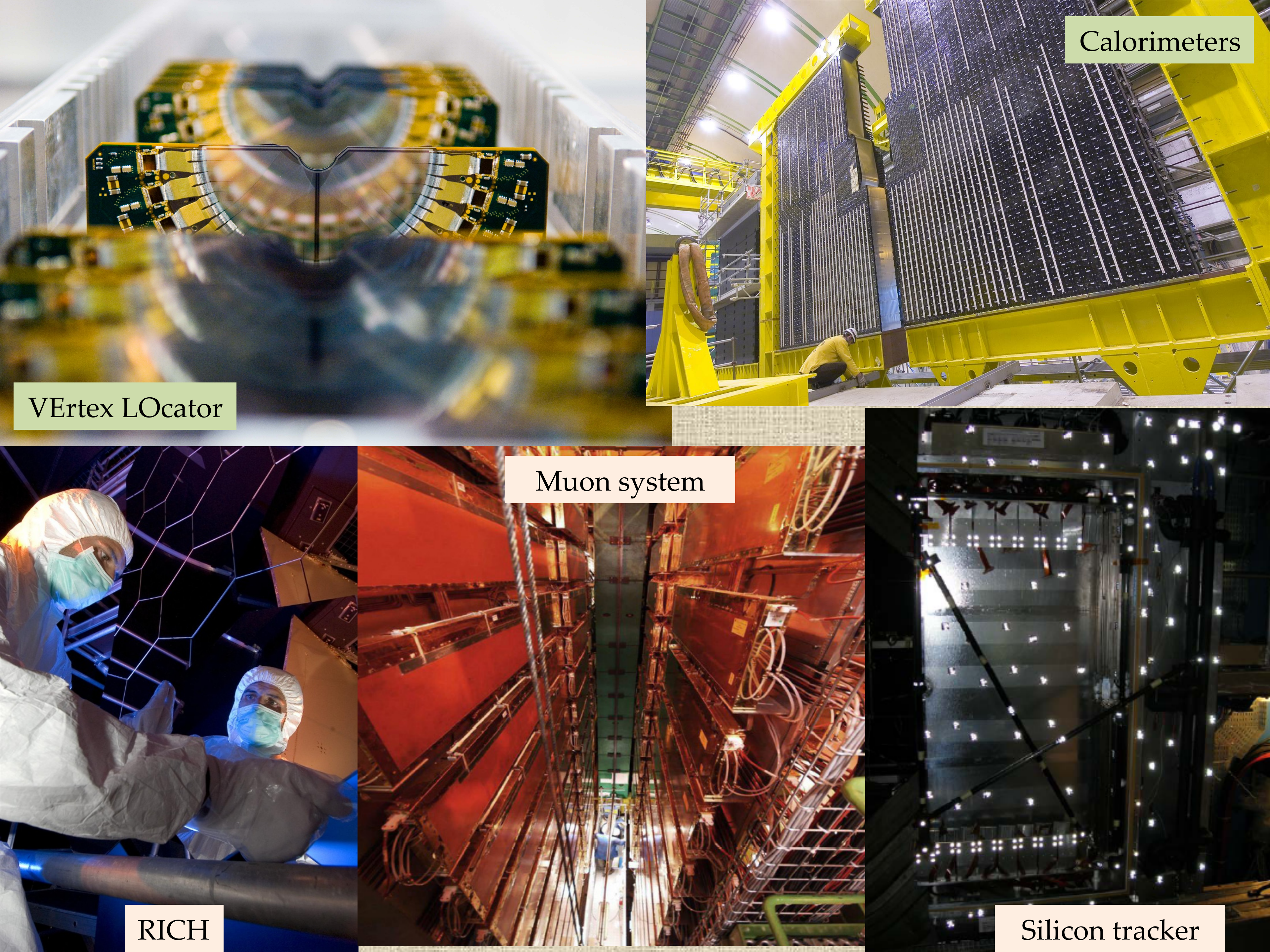
CALO:
- ECAL: lead+scintillating tiles
- HCAL: iron+scintillation tiles

MUON
MWPC+GEM: π/μ separation

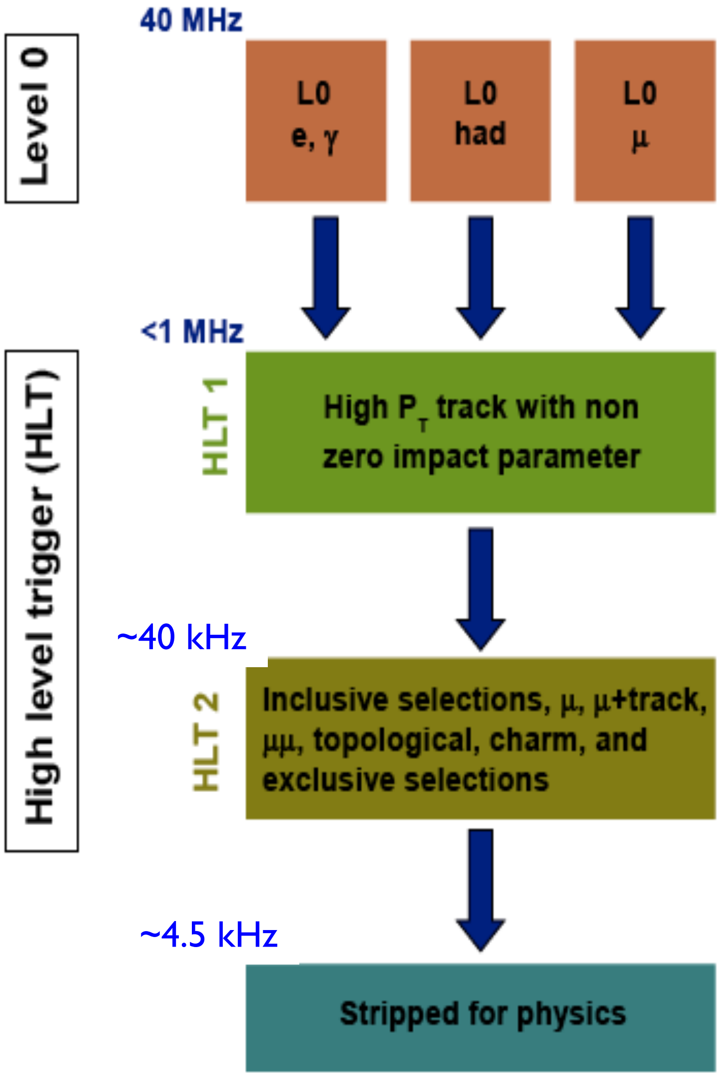
Brasil, China, France, Germany, Ireland, Italy, Netherlands, Pakistan, Poland, Romania, Russia, Spain, Switzerland, UK, Ukraine, US, CERN
59 institutes,
~ 750 members

58 papers
~ 100 conf. contr.




VErtex LOcator
Calorimeters
RICH
Muon system
Silicon tracker

LHCb Trigger



L0 Hardware Trigger 40 MHz → 1 MHz

- Search for high p_T , μ, e, γ, hadron candidates
  CALO p_T > 3.6 GeV, MUON p_T > 1.4 GeV

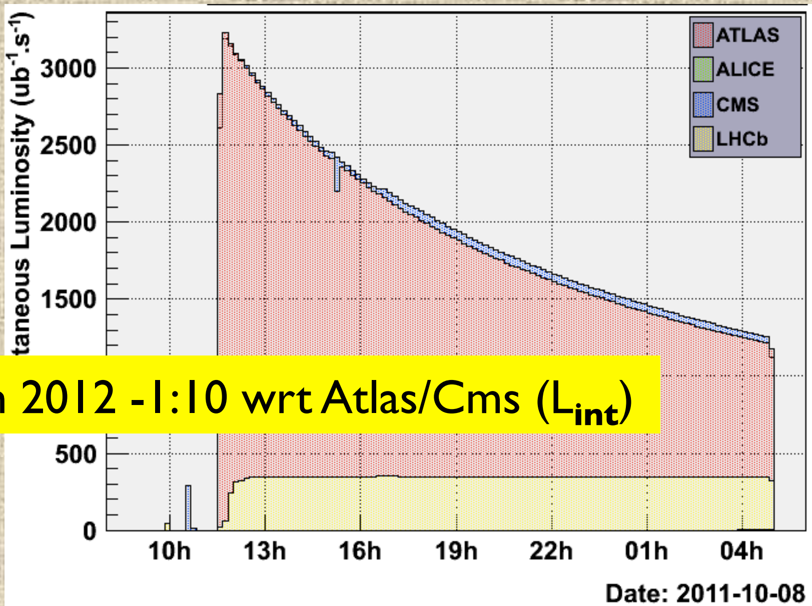
High Level Software Trigger Farm

- HLT1: Add Impact parameter cuts
- HLT2: Global event reconstruction
- Physics output rate : up to 4.5 kHz
- In 2012 increase (+10%) in no. of CPU installed
  + deferred trigger implemented (+20% in CPU)

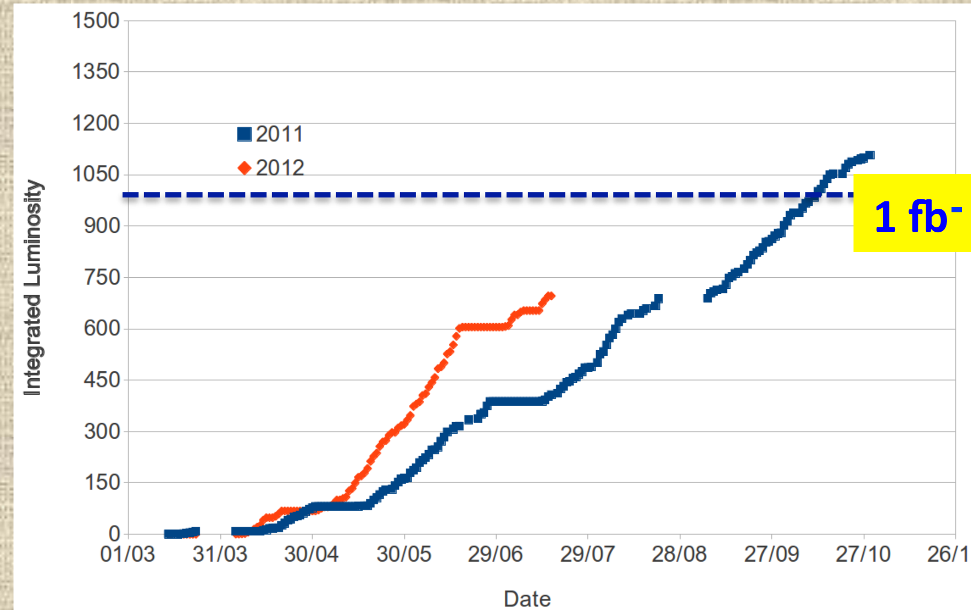
HLT needs operational flexibility

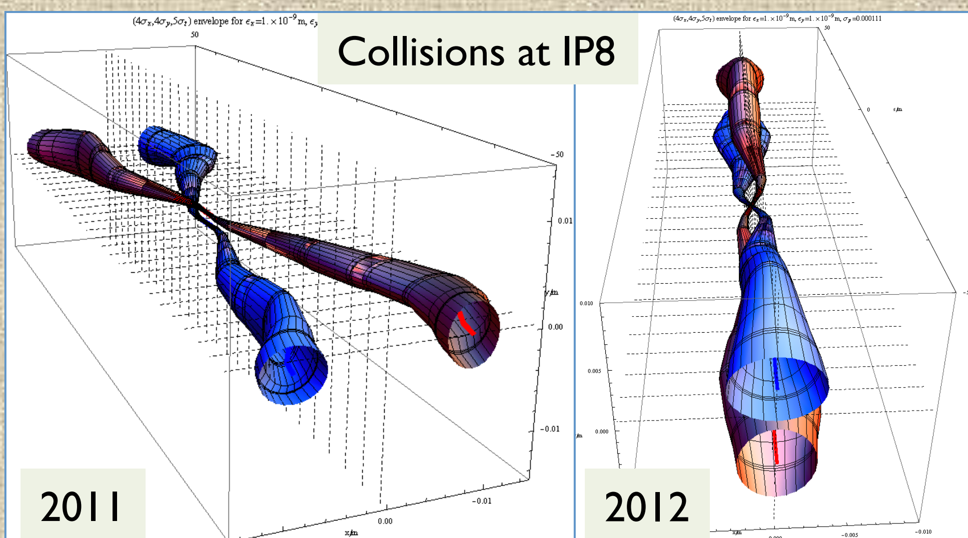
- Trigger Configuration Key (TCK) to distribute the configuration to 1000 nodes simultaneously when optimizing parameters during LHC fill
- Match the increased no. of pile-up events (μ)
- Global Even Cuts applied to reduce event complexity at high μ

Great LHC performance, excellent running of LHCb detectors (~99% of channels operational, ~95% data taking efficiency), and the luminosity leveling at L ~ 4 10^{32} $cm^{-2}s^{-1}$



in 2012 -1:10 wrt Atlas/Cms (L_{int})





In 2012:

collisions in LHCb done in the VERTICAL plane, so to minimize systematics effects during magnet swaps (polarity UP/ DOWN)

on HORIZONTHAL plane, beam angle crossing are different for UP/DOWN magnet configuration

Prospects for LHCb data taking in 2012

LHC running conditions

- $\sqrt{s}$ = 8 TeV (b-bbar cross section increases ~15%)
- L ~ 4 10^{32} $cm^{-2}s^{-1}$ (in LHCb)
- Bunch spacing 50 ns (ok, this level of pileup is not an issue for LHCb)
- LHC crossing angle in LHCb in the vertical plane (fully symmetric with magnet swaps)

LHCb running conditions

- Keep detector efficiency and data quality high
- L0 output ~ 1 MHz (maximum allowed)
- HLT output ~ 4.5 kHz (with upgraded farm [+10%] and better HLT trigger)
  → increase in yields of charm (K_s in HLT1) and in b-hadronic channels
- Deferred HLT event processing during LHC inter-fills (planning to gain at least another 20% in CPU power)

Based on the experience of 2011 → target of ≥ 2.2/fb on tape in 2012 (also including p-p run extension)

- Expected increase in event yields in 2012:
  energy (better S/B) + improved HLT + more CPU → ~20% (even more for charm)

Detector aging well under control

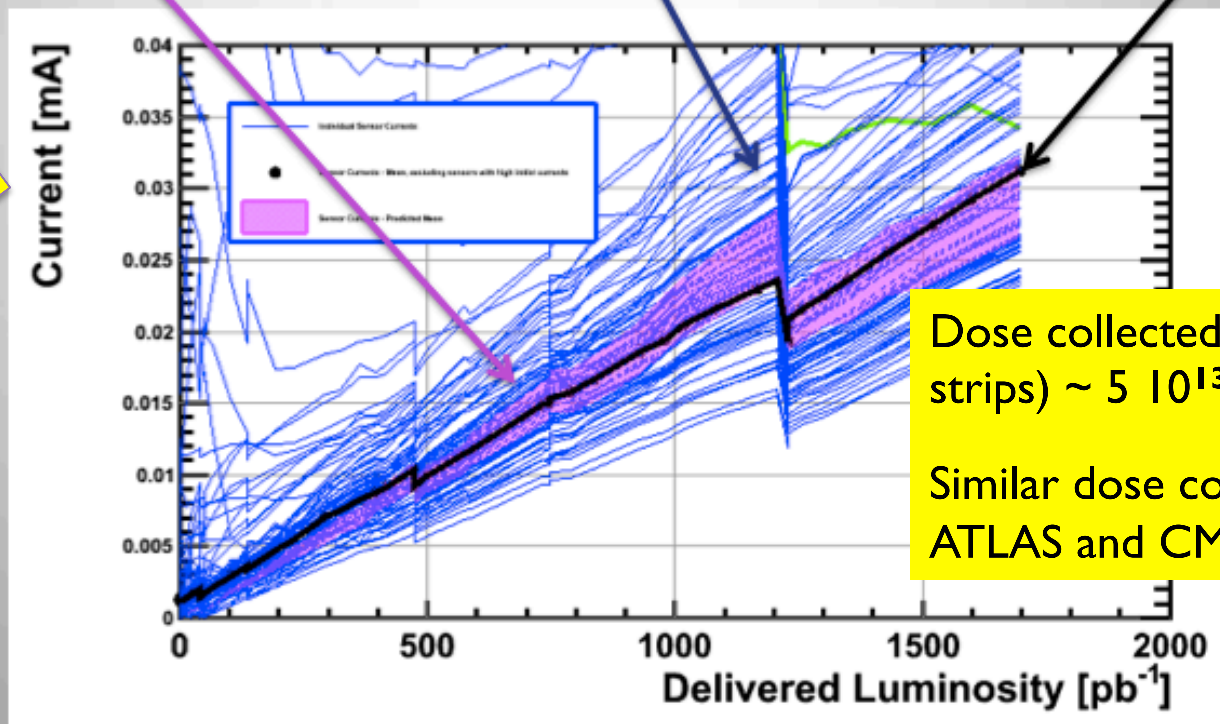
- Sensor leakage current monitored regularly
  - Simple and direct monitoring of the radiation damage

Well described by predictions

Annealing clearly visible

Increase in multiplicity @ 8 TeV

VELO
(ok up to 20/fb)

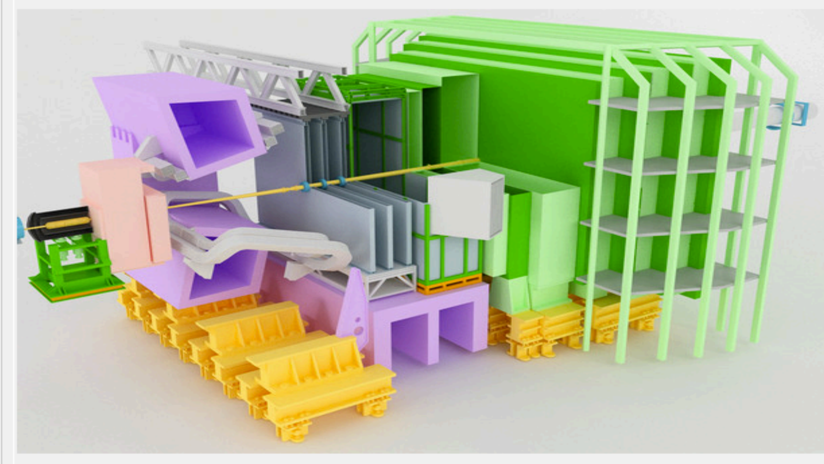


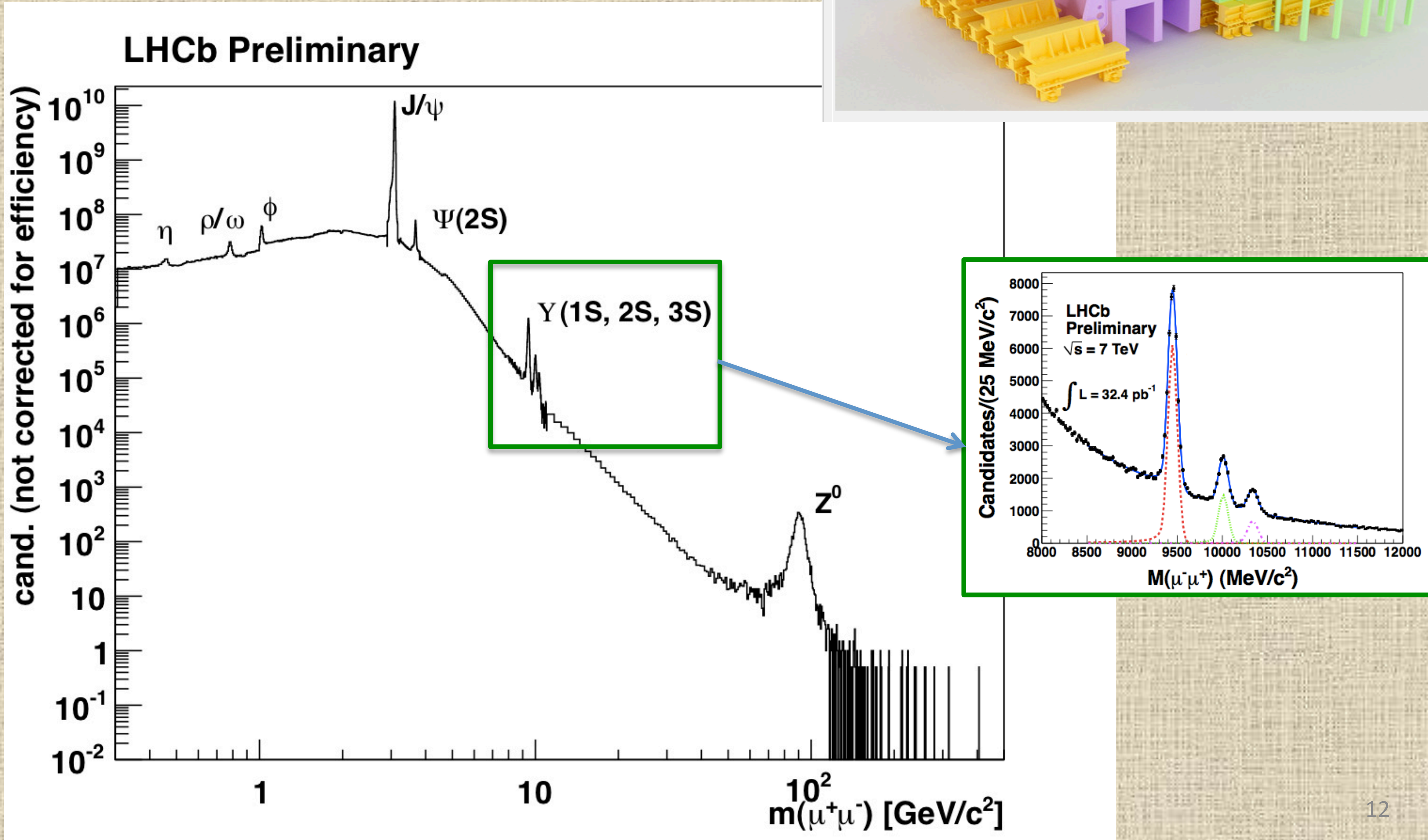
Dose collected (in innermost strips) ~ 5 10^{13} neq/cm^2

Similar dose collected by ATLAS and CMS in ~20 /fb

AGEING still OK also for other tracking systems and calorimeters

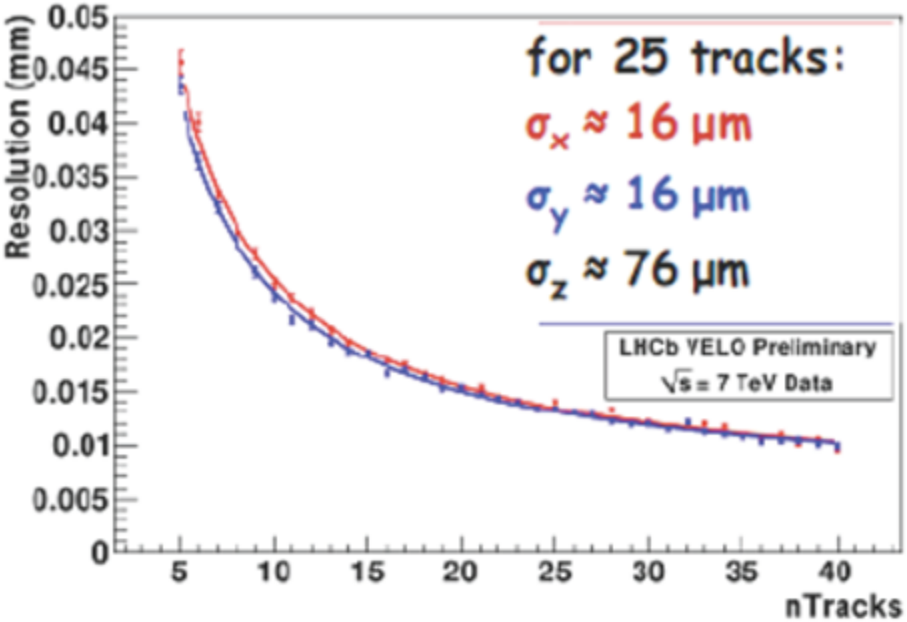
LHCb: a general purpose, high resolution spectrometer in the forward direction





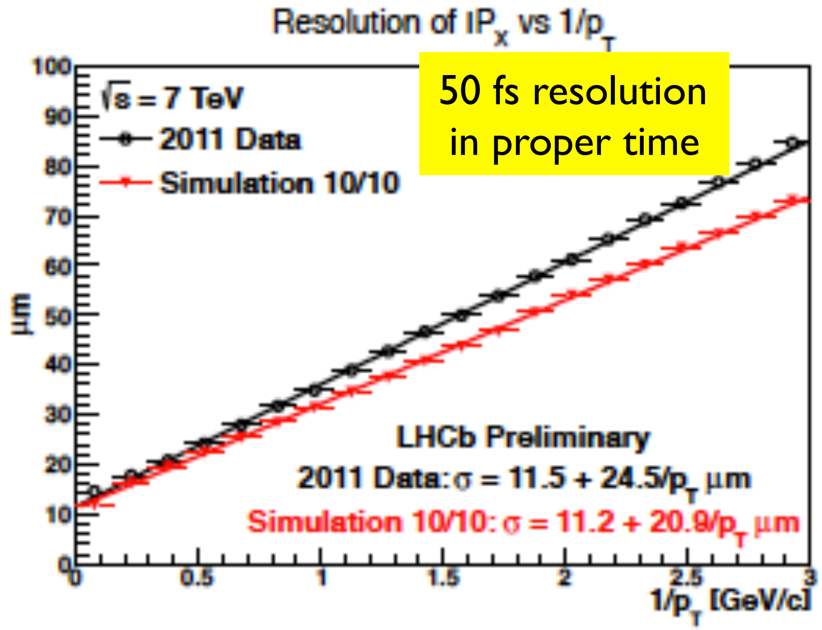
Primary Vertex (PV) & Impact Parameter (IP) resolution

PV resolution evaluated in data using random splitting of the tracks in two halves and comparing vertices of equal multiplicity



Resolution for PV with 25 tracks

Data: 16 μm for X & Y and 76 μm for Z
MC: 11 μm for X & Y and 60 μm for Z



IP resolution ~ 11.5 μm for the highest p_T bins

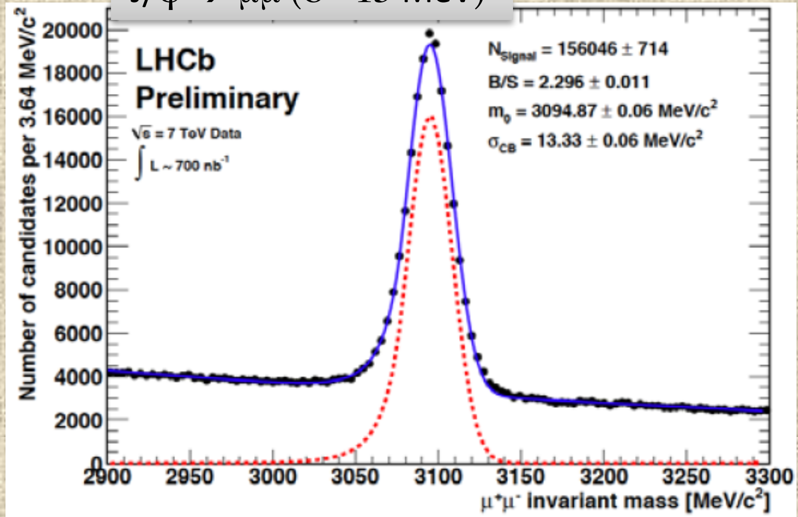
- *slope determined by multiple scattering, not an alignment effect*
- *improvement of material description is ongoing*

Tracking and Invariant Mass resolutions

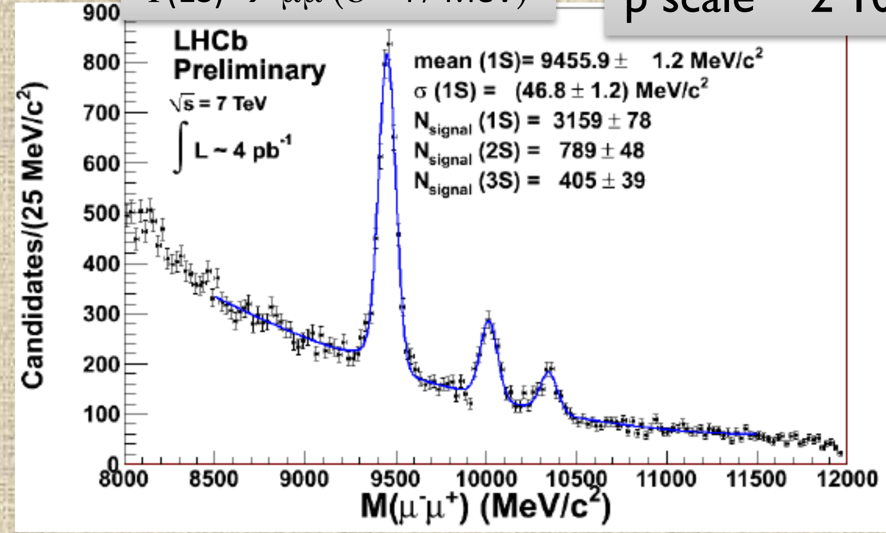
$\sigma_p/p \sim 0.4 - 0.6\ \%$

p scale ~ 2 10^{-4}

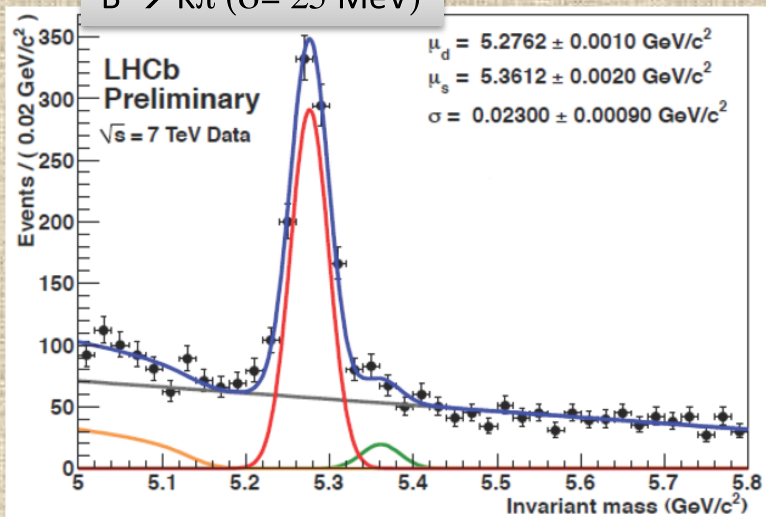
$J/\psi \rightarrow \mu\mu$ (σ= 13 MeV)



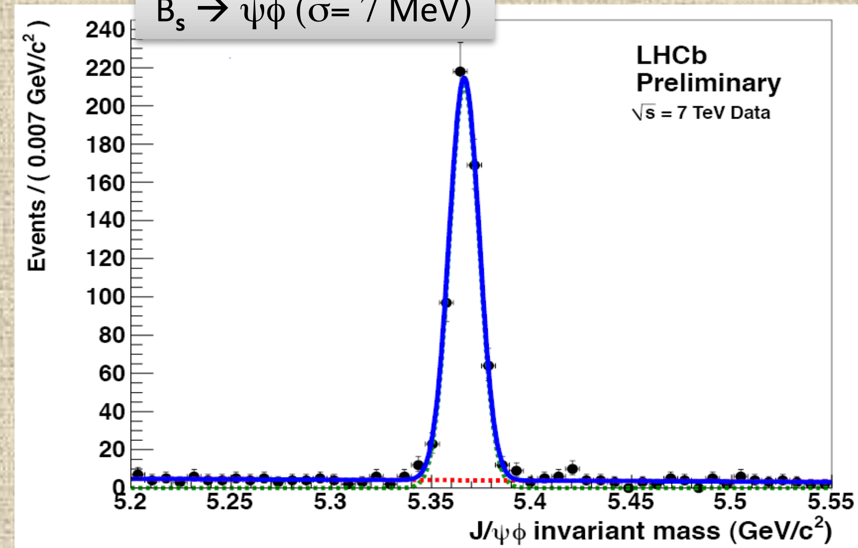
$\Upsilon(1S) \rightarrow \mu\mu$ (σ= 47 MeV)



$B \rightarrow K\pi$ (σ= 25 MeV)

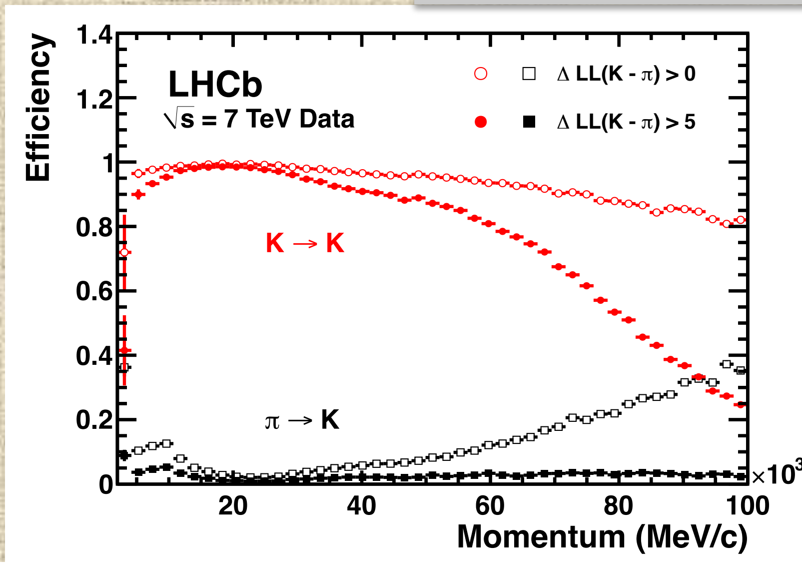


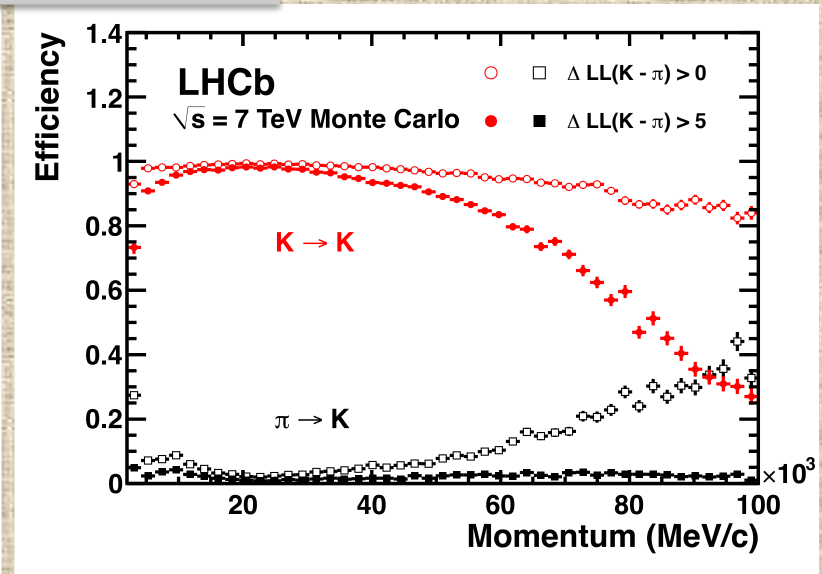
$B_s \rightarrow \psi\phi$ (σ= 7 MeV)

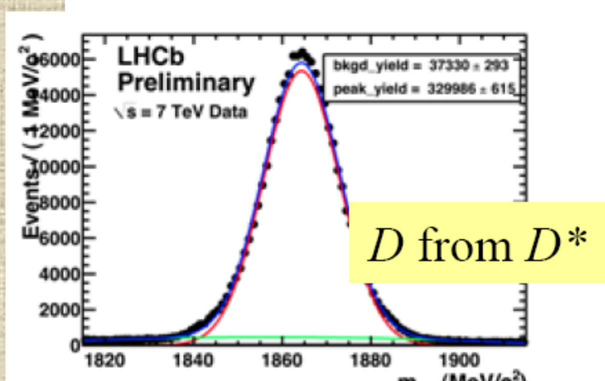


Resolutions very near to MC: world best b-hadron mass measurements (arXiv 1112.4896)

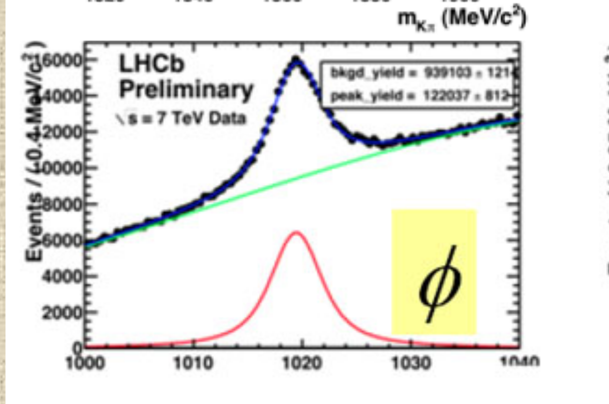
Particle Identification : kaons

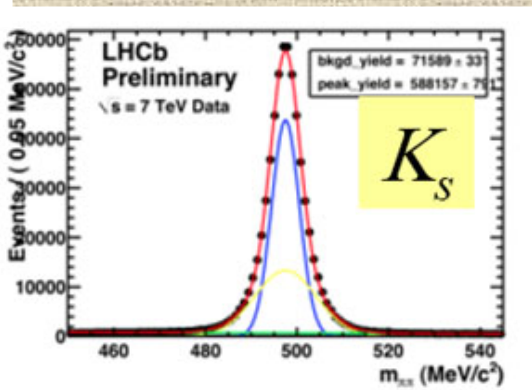


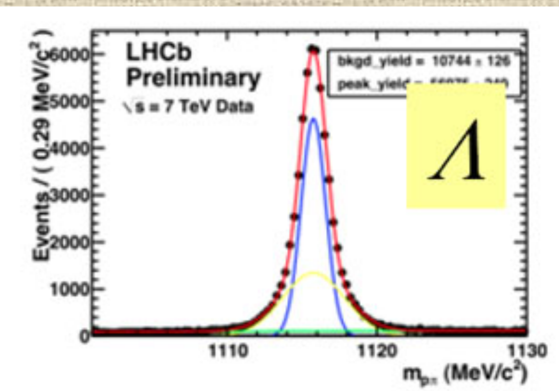




- Large samples of clean final states for PID calibration, efficiency and purity determination based on data
- RICH performances near to the MC expectations

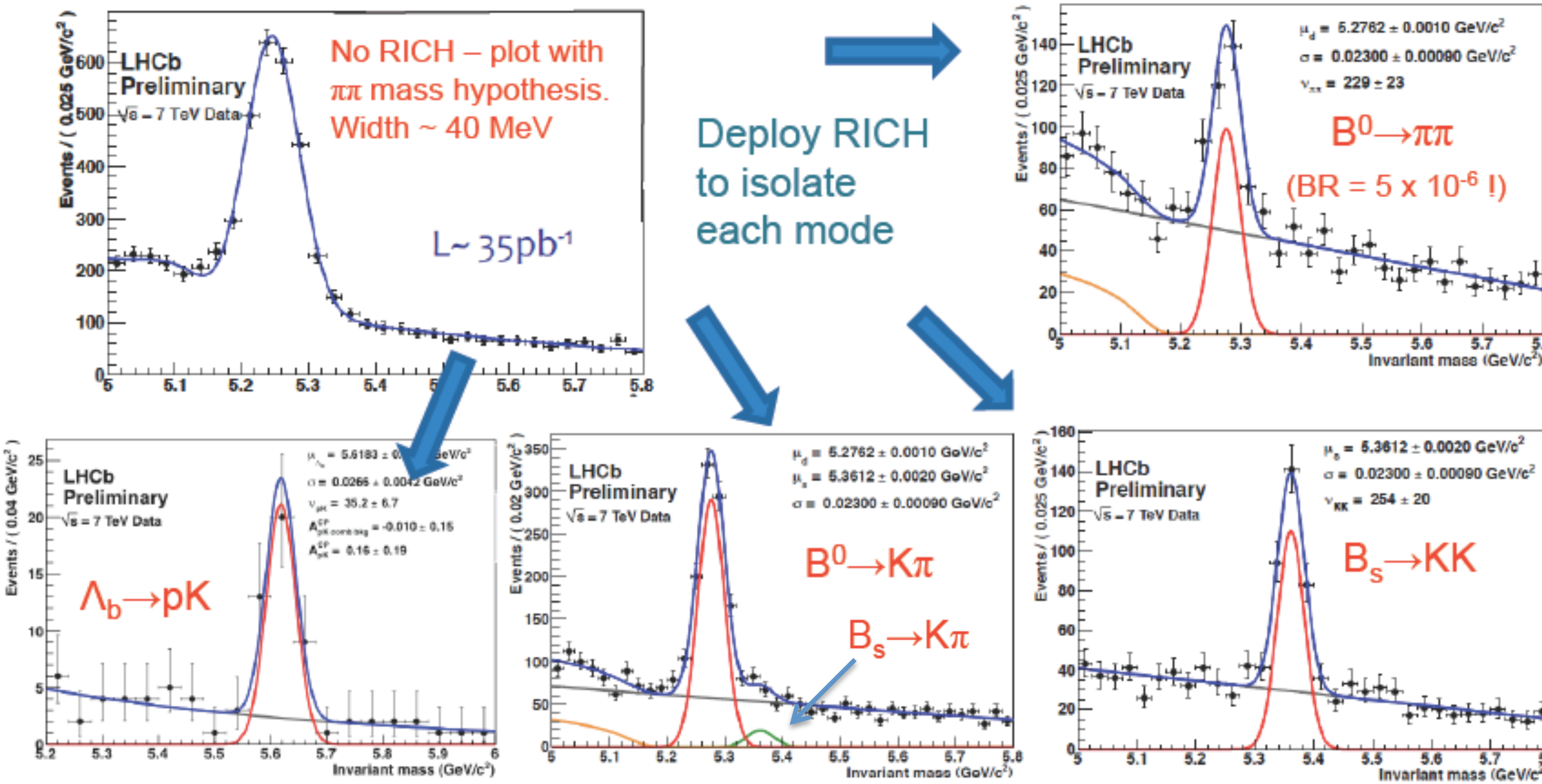






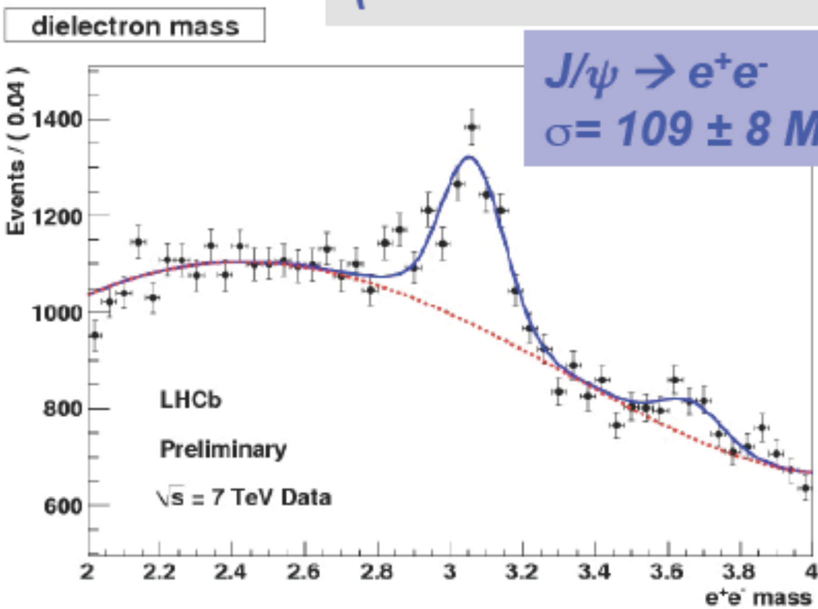
Kaon ID: the smoking gun ($B \to hh$)

- Charmless B decays → Sensitive probes of CKM matrix with potential to reveal NP through penguins



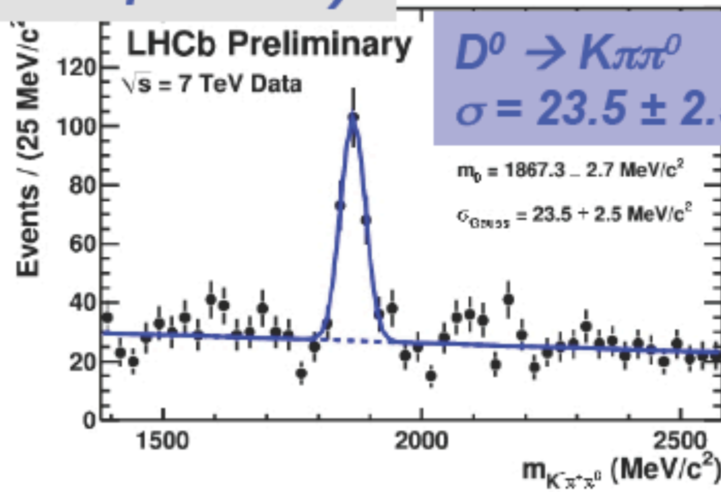
PID with Calorimeter

(Identification of electrons and photons)



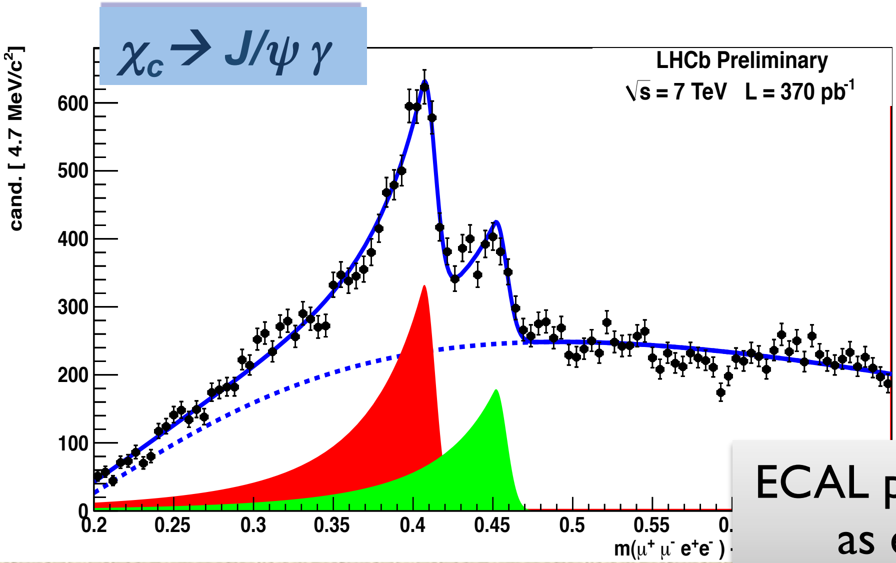
$J/\psi \rightarrow e^+e^-$

$\sigma = 109 \pm 8$ MeV

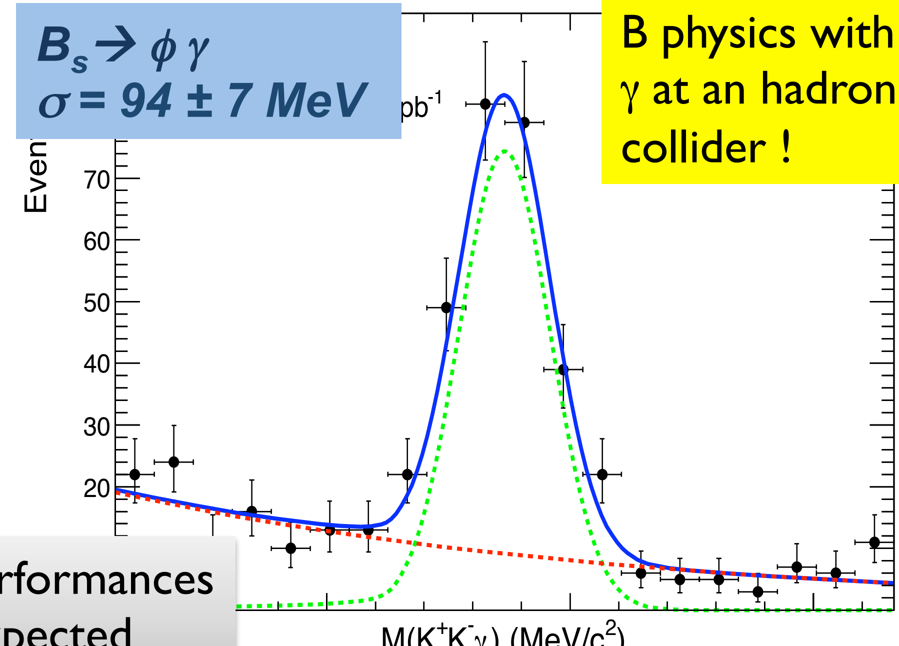


$D^0 \rightarrow K\pi\pi^0$

$\sigma = 23.5 \pm 2.5$ MeV



$\chi_c \rightarrow J/\psi\, \gamma$



$B_s \rightarrow \phi\, \gamma$

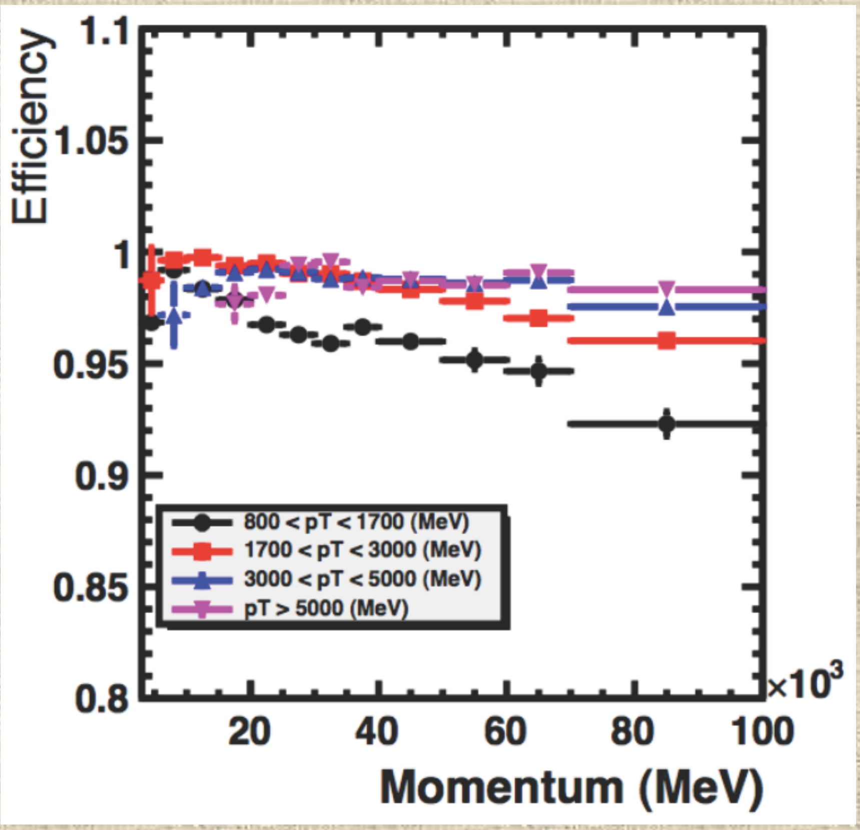
$\sigma = 94 \pm 7$ MeV

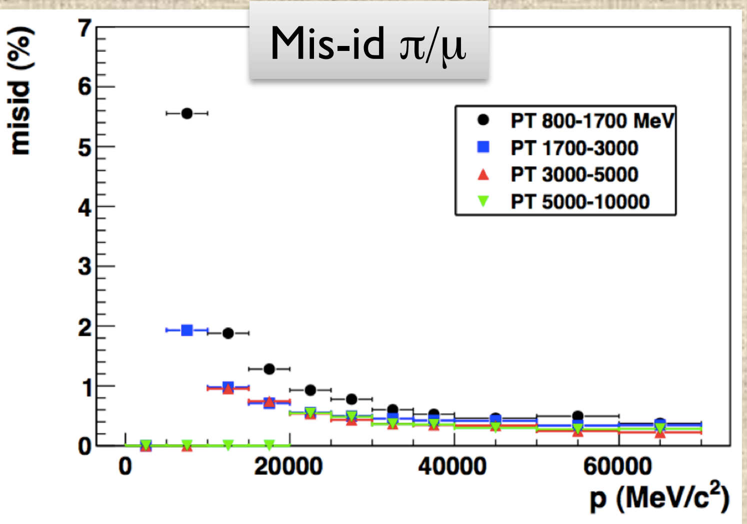
B physics with γ at an hadron collider !

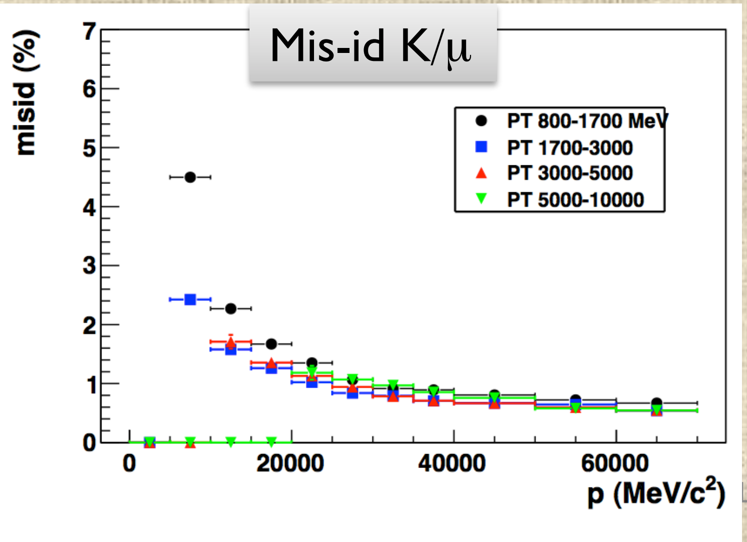
ECAL performances as expected

PID with muons

π/μ, K/μ and p/μ mis-identification rates have been determined with large samples of $K_S \rightarrow \pi\pi$, $\phi \rightarrow KK$ and $\Lambda \rightarrow p\pi$ decays



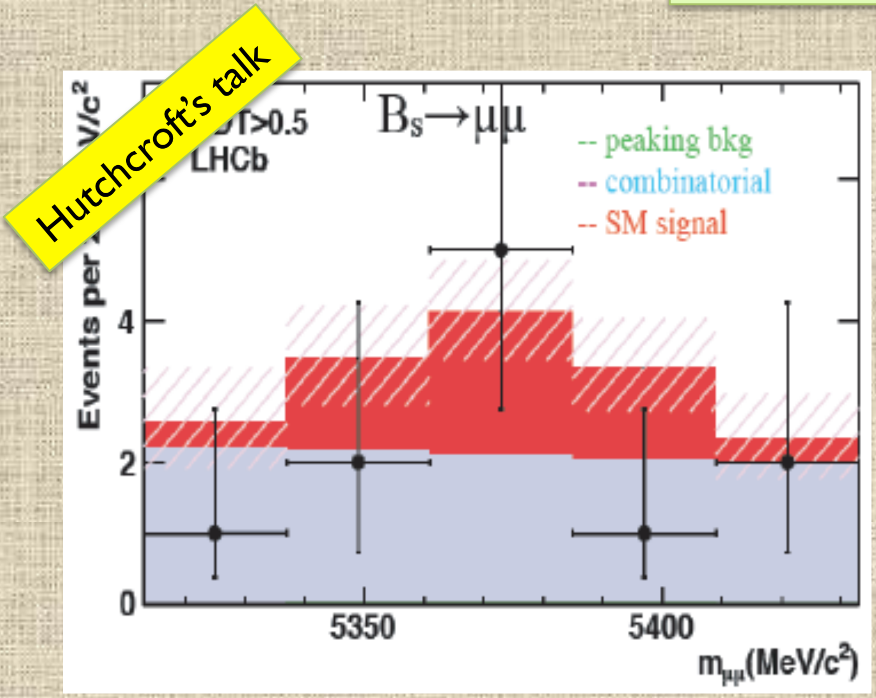




MUON performances as expected
ID good up to very low p_T ($\tau \rightarrow \mu\mu\mu$)

LHCb recent results (I)

PRL 108 (2012) 231801

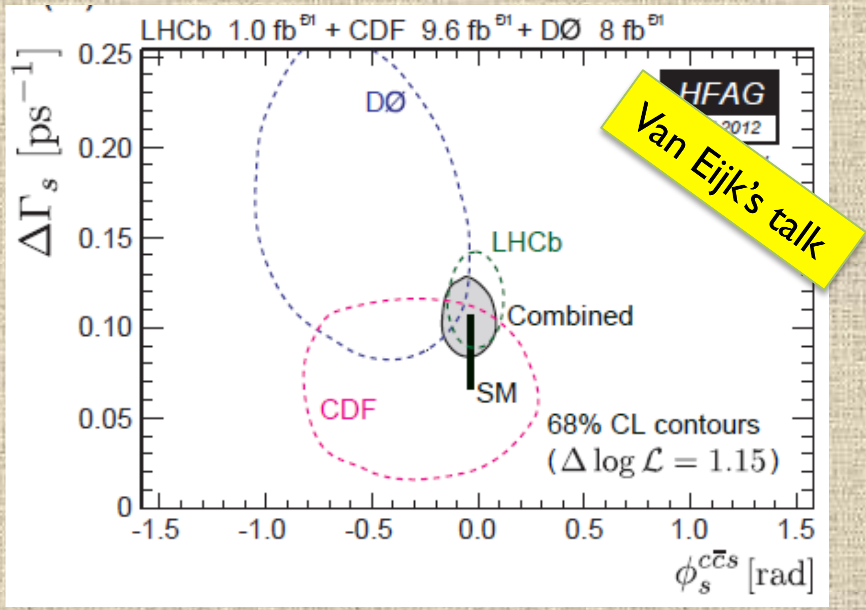


The rare decay $B_s \to \mu^+\mu^-$
BR < 4.5 x10^{-9} @ 95%CL (LHCb)
(Atlas/Cms/LHCb combination BR < 4.2 x10^{-9})

Very rare decay sensitive to New Physics
Precise predictions in SM: BR = 3.2±0.2 10^{-9}
Very clean experimental signature
At EPS2011, CDF reported BR in excess

Measurement of the B_s mixing phase ϕ_s from $B_s \to J/\psi\phi$ and $B_s \to J/\psi\pi\pi$

First measurement of $\Delta\Gamma_s$ and removal of ϕ_s sign ambiguity
Anomaly seen by CDF and D0 not confirmed by LHCb

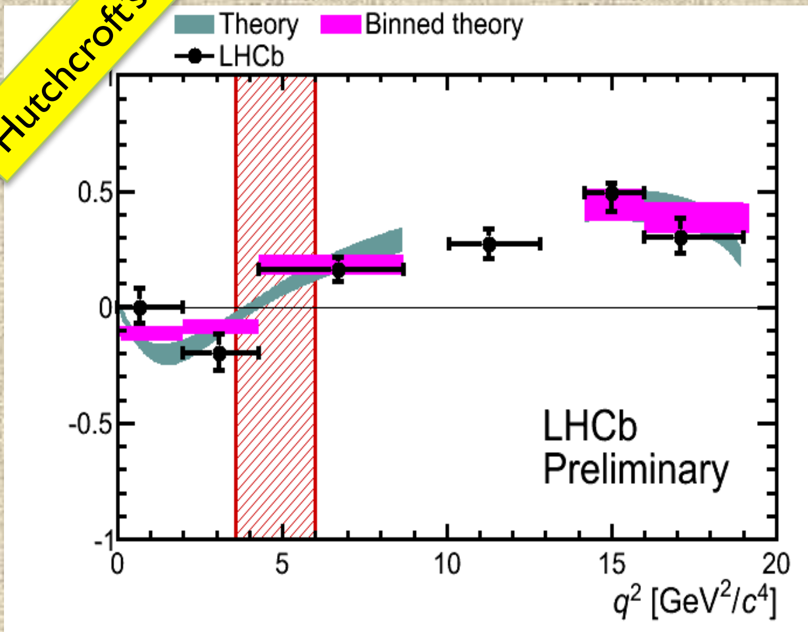


LHCb-CONF-2012-002

LHCb recent results (II)

LHCb-CONF-2012-008

Hutchcroft's talk



Rare decay $B \rightarrow K^* \mu^+\mu^-$

Measurement of A_{FB} $q_0^2 = (4.9^{+1.1}_{-1.3})\ \mathrm{GeV}^2/c^4$

(and of other angular variables, sensitive to RH currents)

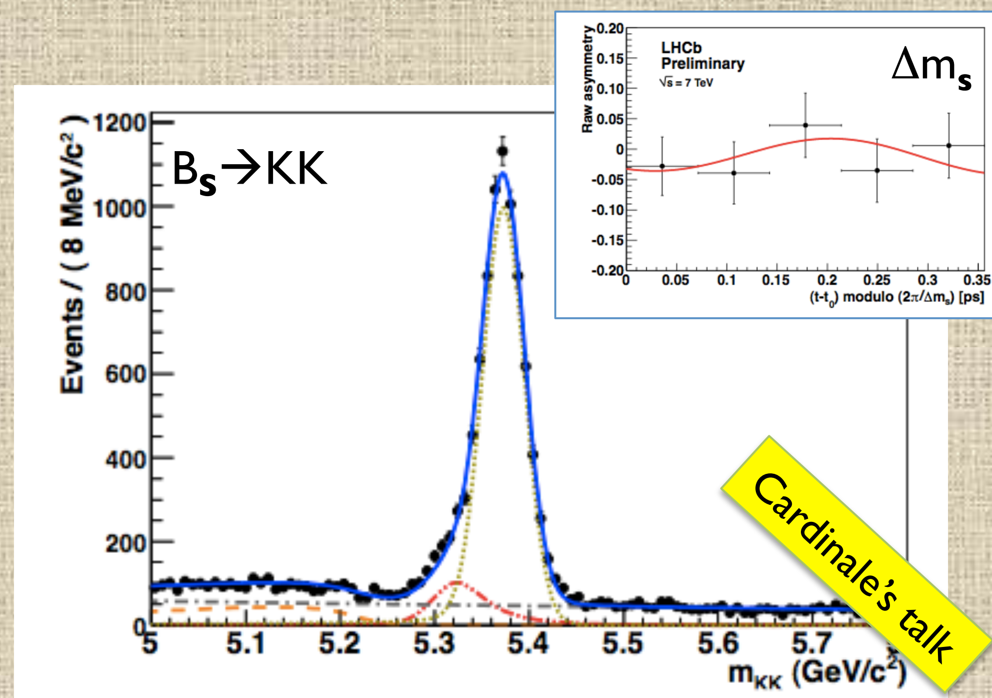
Hint of anomalous distribution of events from B factories and CDF - ruled out by LHCb data

First time dependent CP asymmetries with $B_{d(s)}$ ($B^0 \rightarrow \pi\pi$ and $B_s \rightarrow KK$)

and

measurement of BR of suppressed decay modes ($B_s \rightarrow \pi\pi$ and $B^0 \rightarrow KK$).

First step toward γ with loops

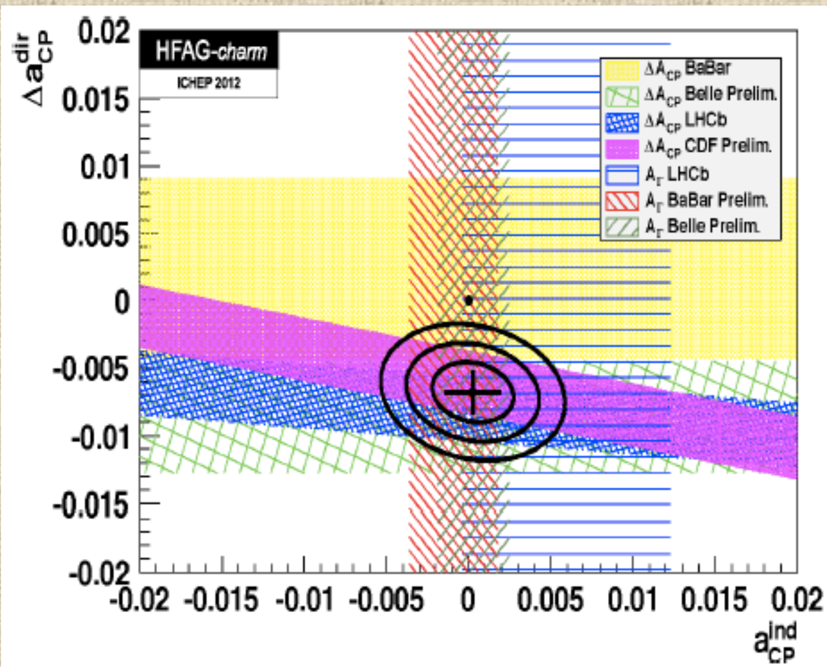


Cardinale's talk

arXiv 1206.2794

LHCb recent results (III)

PRL 108 (2012) 111602



CPV in charm SCS decays ($D^0 \rightarrow h^+h^-$)

Hint of CPV≠0 from LHCb, CDF, Belle
HFAG fit from ICHEP 2012
$A^{CP}_{dir} = (-0.678 \pm 0.147)$

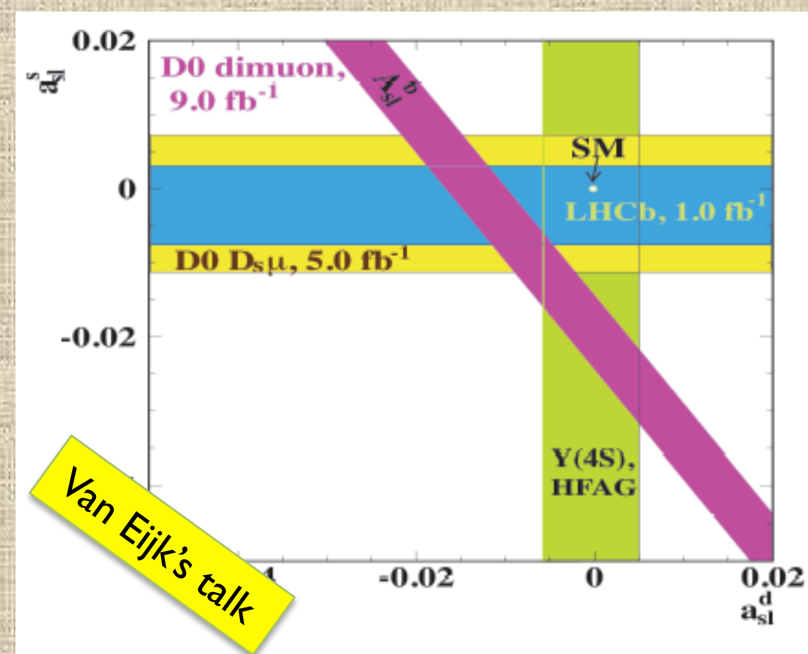
NP or explicable within SM ?
More data & confirmation in other D channels needed

D0 anomaly in A^b_{SL} in b double semi-leptonic decays (~4σ away from SM)

LHCb finds value in agreement with SM

$$a^s_{sl} = (-0.24 \pm 0.54 \pm 0.33)\%$$

D0 result still compatible at ~2σ



LHCb-CONF-2012-022

Not only flavor physics at LHCb (I)

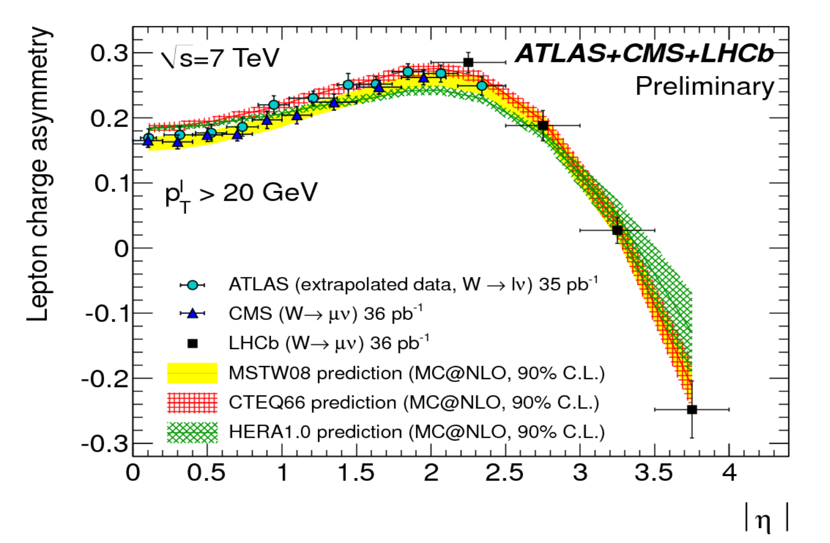
arXiv 1204.1620

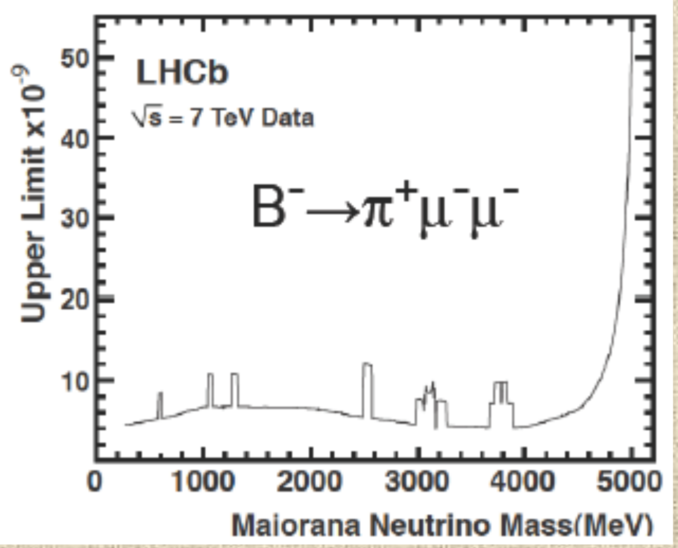
Electroweak physics

LHCb forward acceptance provides very interesting PDF studies

- take large-x / small-x from pp
- two distinct regions in (x,Q^2)
- inaccessible to other experiments

Complementarity w.r.t. ATLAS & CMS





PRD 85 (2012) 112004

Majorana neutrinos & exotica

Look for $N \rightarrow W^+\mu^-$ on shell decays of heavy ν

Set limits to mass and production couplings

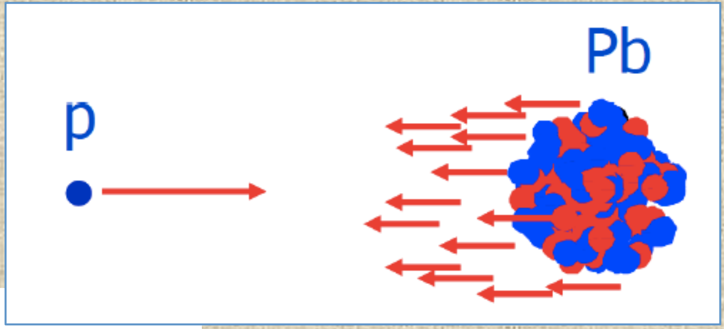
LHCb well suited for long lived particles detection

More results also from quarkonia production & spectroscopy (see talk of P. DeSimone)

Not only flavor physics at LHCb (II)

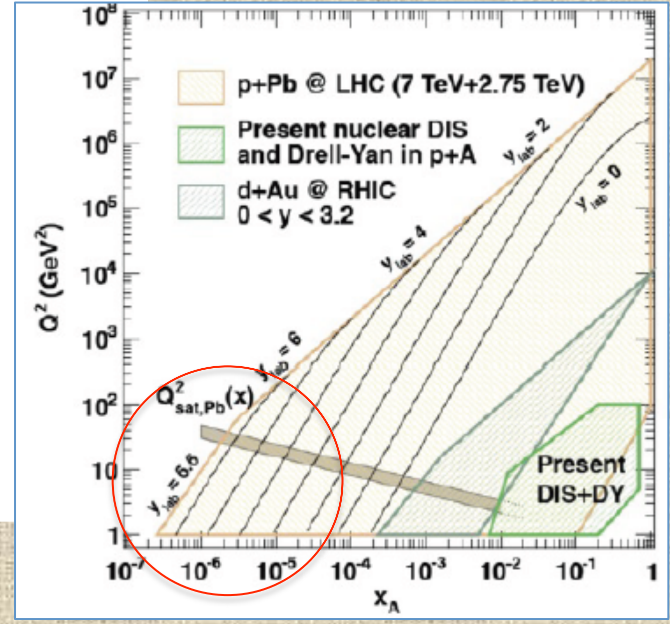
LHCb will take data in p-A run in 2013

Limited luminosity (~10^{26} cm^{-2} s^{-1}) but interesting kinematic domain (PID equipped) in forward region



→ *LHCb is able to contribute to pp and pA physics:*

- soft QCD measurements
  - → particle multiplicities and production ratios
  - → strangeness production ($V^0, \phi, K^*, \ldots$) and Λ-polarization
  - → energy flow and underlying event measurememts
- J/ψ-related measurements
  - → production cross sections of charmonium states
  - → polarization studies
- "advanced" topics
  - → low mass DY and in general physics probing low-x
  - → isolated photon- and jet-production
  - → open charm, Υ-production, b-cross-section, . . .

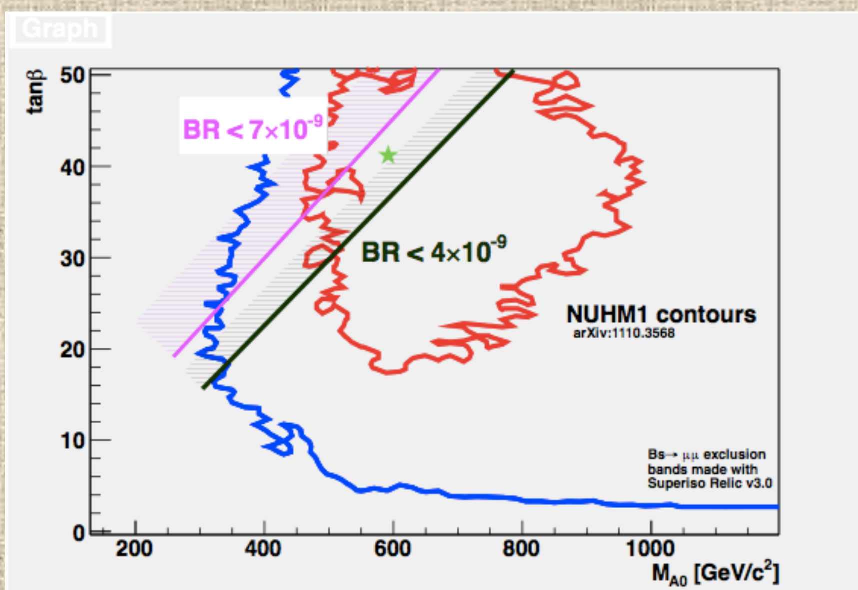


Implications of LHCb results on New Physics (I)

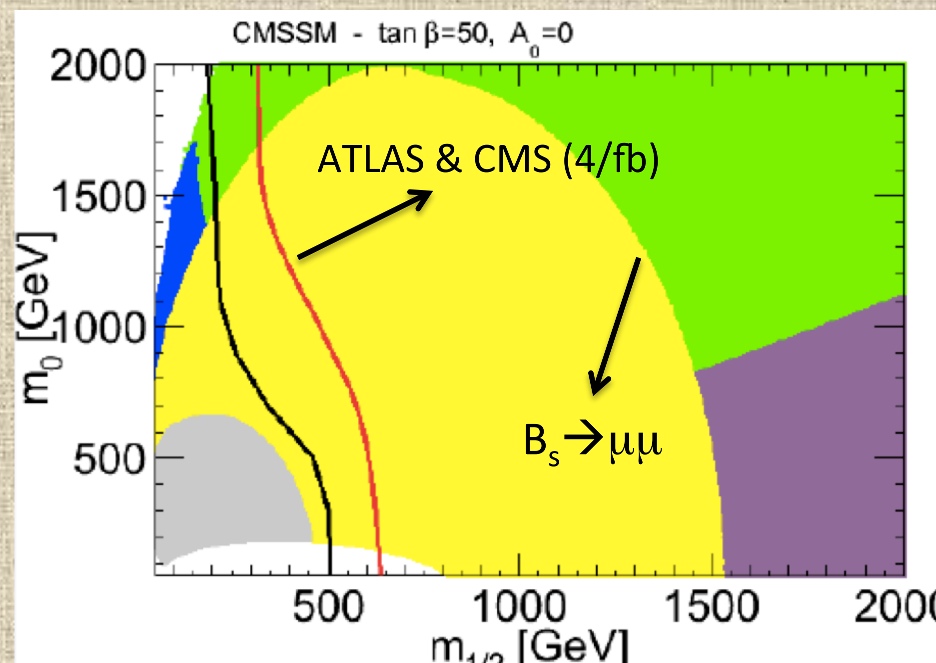
→ Hints of SM deviations of previous measurements have not been confirmed. However, more precise measurements are mandatory

- BR($B_s \to \mu\mu$) sets strong bounds on mass scales in SUSY (at least in high *tan* β models), complementary to direct searches in ATLAS and CMS
- LHCb results enter the SUSY and CKM fits, starting to impose severe bounds on several models and flavor variables

These implications will increase with the full data sample 2011-2012 (> 3/fb)

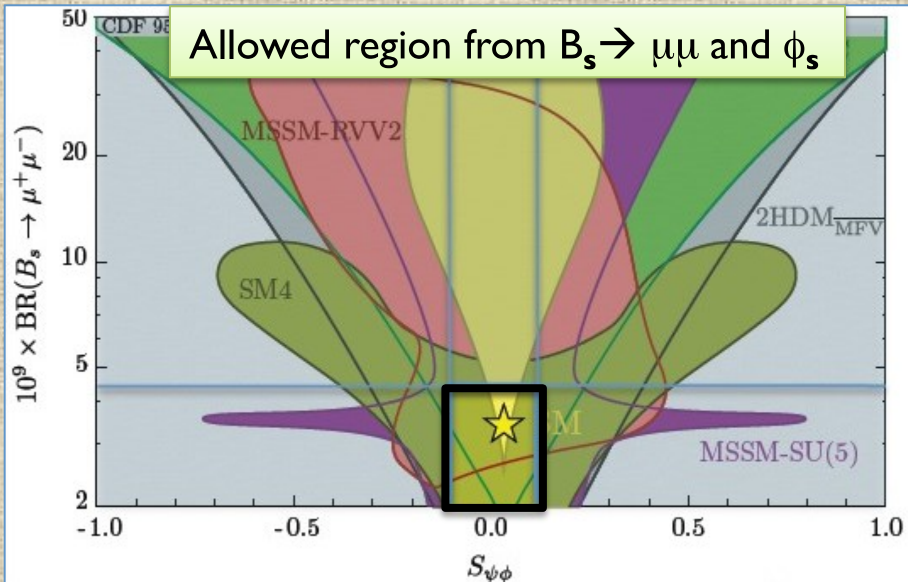


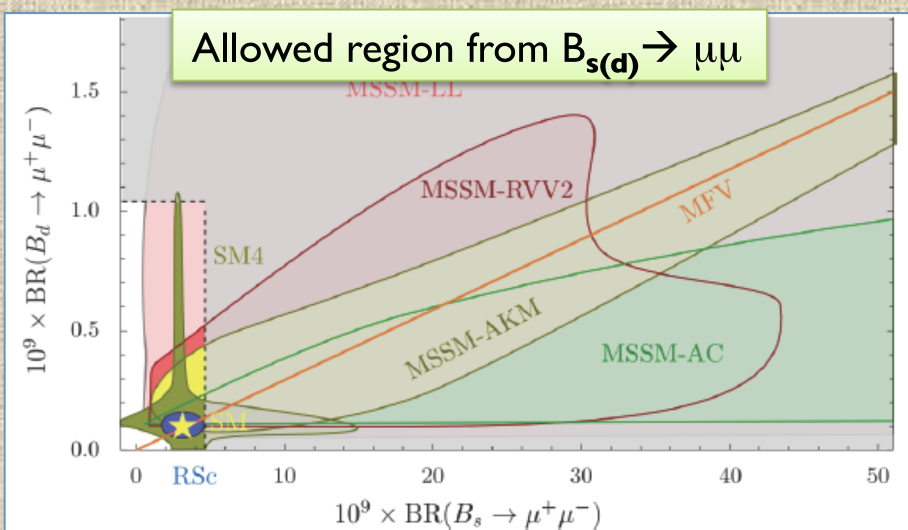
arXiv 1201.5359

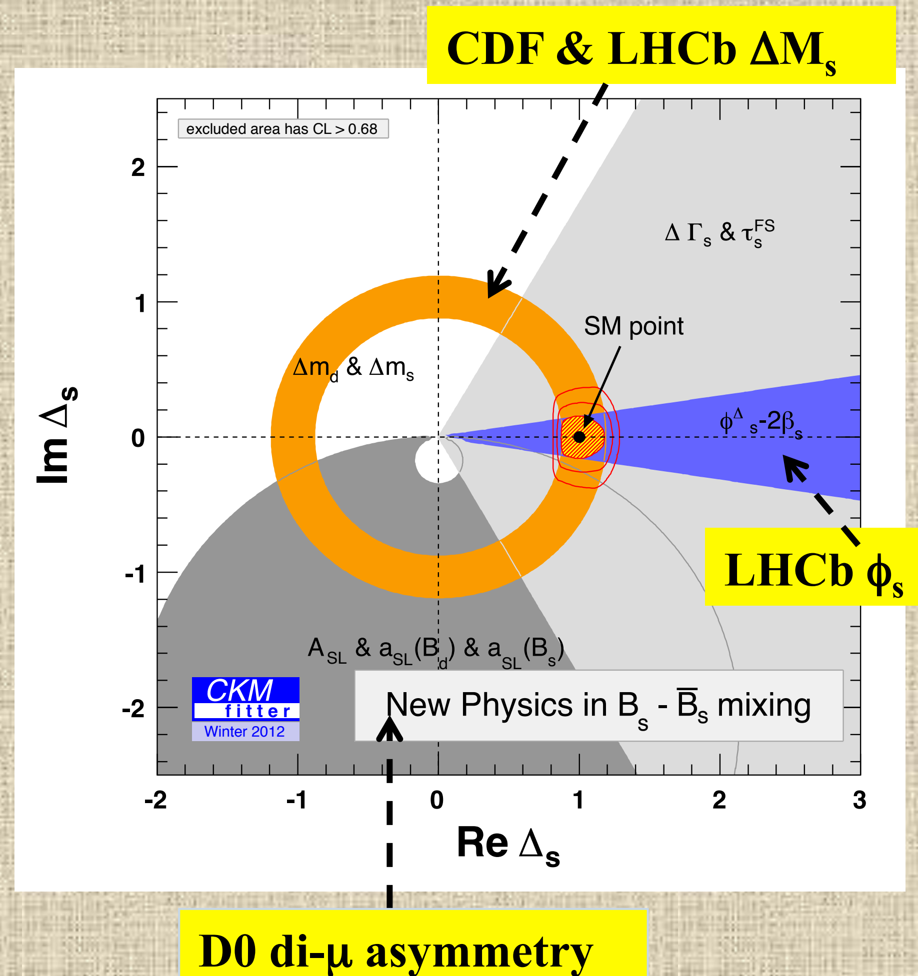


N. Mazhoudi, Moriond QCD2012

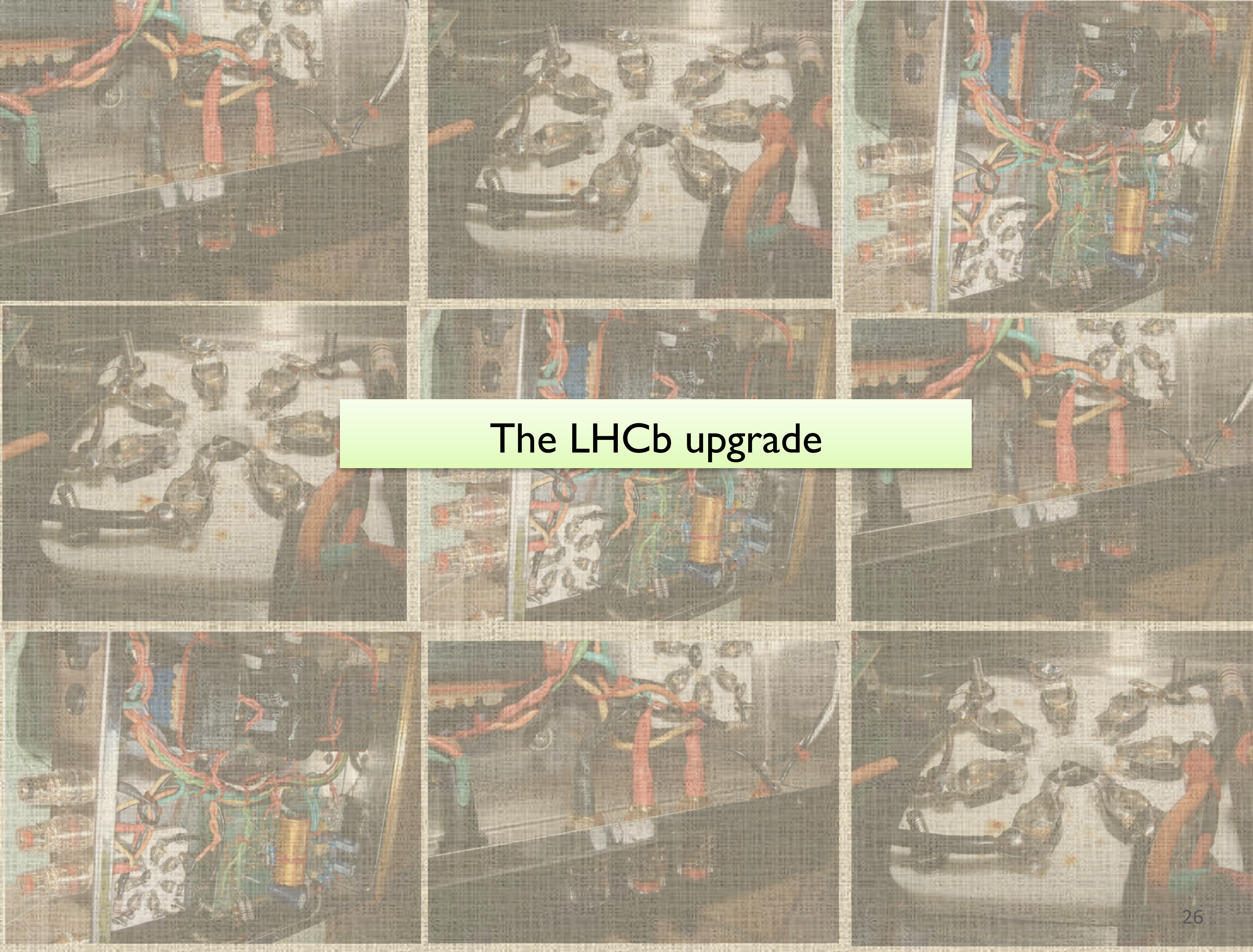
Implications of LHCb results on New Physics (II)







D. Straub [arXiv 1107.0266] and Moriond2012



The LHCb upgrade

Why the LHCb Upgrade ?

- The flavor sector offers a very rich complementarity to the High Energy Frontier (ATLAS & CMS) searches for New Physics
- Recent LHCb results have shown the potentialities of Flavor Physics at LHC and the good performances of the detector
- LHCb is unique for NP searches in B_s (and works well also for B_d).
  Huge sample of charm available.
  Complementary also in respect to Super-B factories
- LHCb is unique in his forward geometry (and also for "exotica" New Physics searches)
- High Luminosity LHC (HL-LHC) is not necessary for LHCb upgrade, and LHC operation can be tuned to LHCb needs via luminosity leveling

LHCb data taking perspectives and its upgrade

Based on 2011 experience LHCb can collect ~ 1.5/fb per "normal" LHC year

- **2012 @8 TeV and 2015-16-17 @13 TeV**

By the end of 2017 → **~ 7/fb** collected.
Reaching ultimate theory precision in flavor variables will need more statistics.
Current LHCb limitation is in L0 trigger rate capability (< 1 MHz) that does not allow to profit from an increase in luminosity

Upgrade plans:

- **1 MHz → 40 MHz readout**
- **Full software trigger** (better yield for charm and hadronic triggers)
- **Up to L ~ 2 10^{33} $cm^{-2}s^{-1}$** to collect **50/fb**

Expected yields increase (w.r.t. 2011):

- **x10** in muonic channels
- more than **x20** in hadronic channels ($B_s \rightarrow \phi\phi$, DK, charm, etc...)

Framework TDR submitted to LHCC (June 2012) with first evaluation of upgrade cost (~ 55 MSF) and of time schedule

A (very tentative) schedule for LHC

2012 LHCb data taking (8 TeV)

2013-14 Long Shutd. 1 / LHCb maintenance, first infrastructures for upgrade

2015-17 LHCb data taking (13-14 TeV)

2018-19 Long Shutd. 2 / LHCb upgrade installation [Atlas/Cms upgrades phase 1]

2019-21 LHCb data taking (14 TeV)

≥ 2022 HL-LHC [Atlas/Cms upgrades phase 2]

LHCb Upgrade preparation

2012-13 R&D, technological choices, preparation of subsystems TDRs

2014 Requests for approval/Funding/Procurements

2015-19 Construction & installation

Future prospects (a personal view)

A flavor theorist shopping list

"Minimalistic" list of key (quark-) flavour-physics observables:

- γ from tree ($B \to DK$, ...) ← LHCb
- $|V_{ub}|$ from exclusive semilept. B decays
- $B_{s,d} \to \mu\mu$ ← LHCb
- CPV in B_s mixing ← LHCb
- $B \to K^*\mu\mu$ (angular analysis) ← LHCb
- $B \to \tau\nu$, $\mu\nu$
- $K \to \pi\nu\nu$
- CPV in D mixing ← LHCb

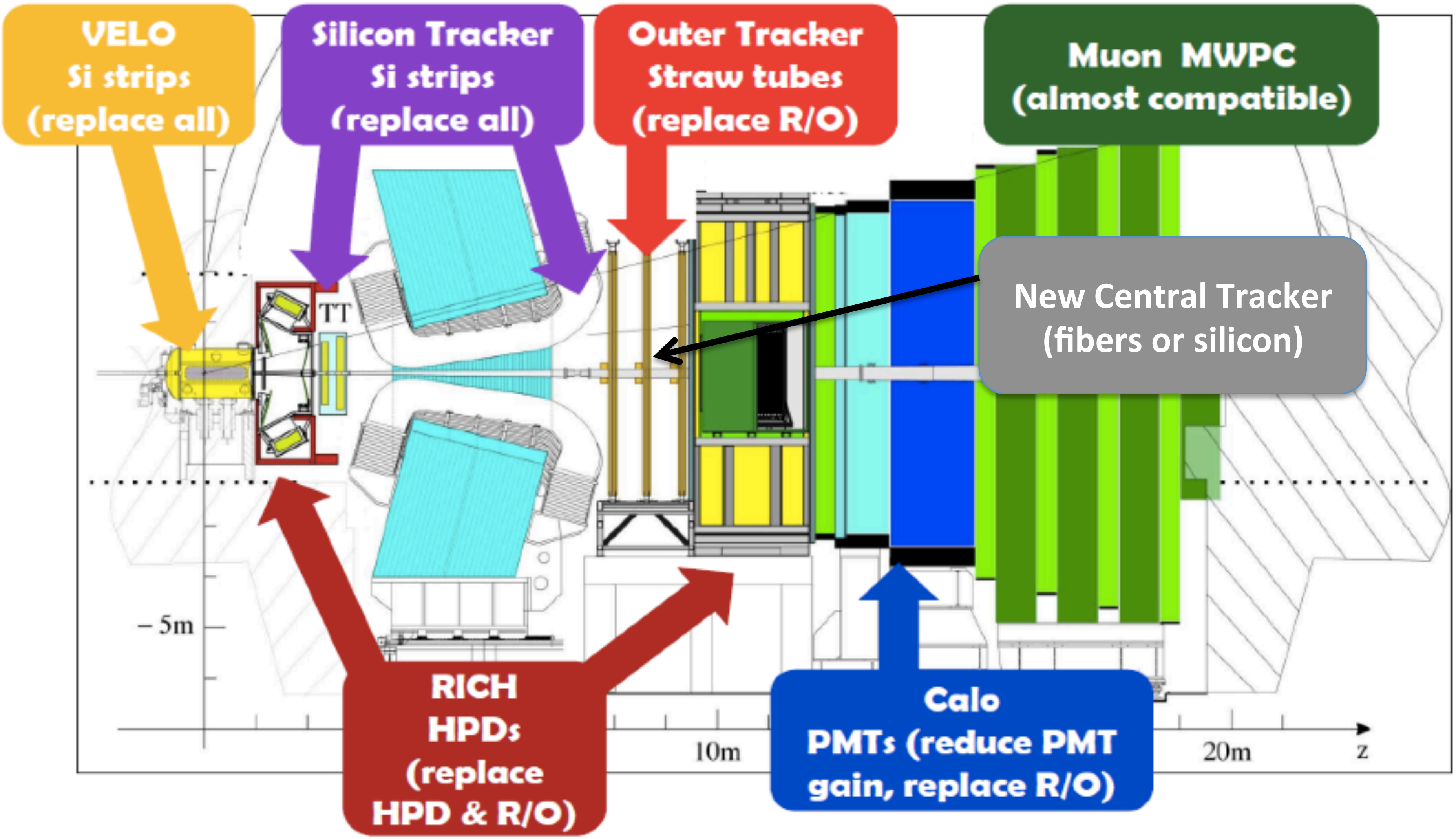
Ultimate LHCb Upgrade goal: reach limit of theory precision
+
Broadening physics spectrum: search NP in forward region

Sensitivities to key flavour channels

Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\, A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	~ 10–$12°$ [19, 20]	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi\, K_S^0)$	0.8° [18]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

Fighting against systematical uncertainties will not be trivial !

LHCb detector modifications for the upgrade



The present LHCb Trigger Flow

L0 bandwidth sharing and p_T thresholds are set to reduce Min. Bias and maximise the physics output (max rate = 1 MHz)

- 600 kHz for hadronic trigger (E_T > 3.5 GeV)
- 150 kHz for $e/\gamma/\pi^0$ (p_T > 2.5 GeV)
- 250 kHz for $\mu/2\mu$ (p_T > 1.4 GeV)

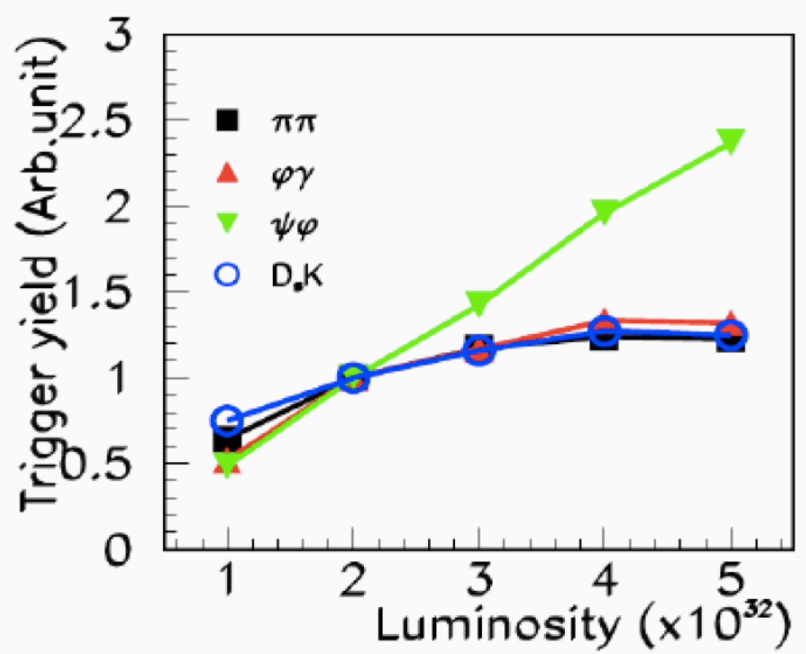
HLT1 confirms L0 using IP and a partial reconstruction of the event (→ 40 KHz)
HLT2 performs exclusive/inclusive refined selections (→ 4.5 kHz on tape)
L0xHLT have an efficiency of ~20-50% on hadronic and of ~ 70-90% on di-μ channels

An increase in luminosity ($\geq 10^{33}$ cm^{-2} s^{-1}) does not increase the yield in hadronic channels

Two main reasons:

- a stronger E_T cut to cope with 1 MHz
- tougher conditions for tracking (pileup)

A more flexible trigger and a higher L0 bandwidth are needed
(→ readout all detectors at 40 MHz)



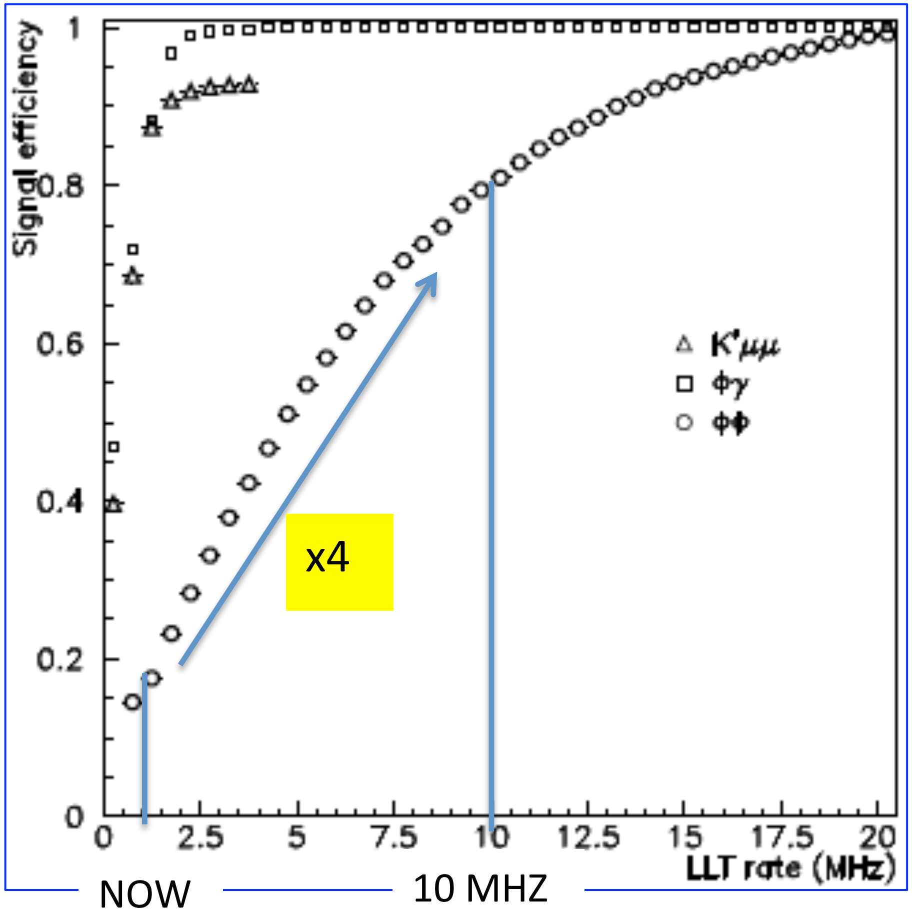
The effect of an upgraded trigger (case of $B_s \rightarrow \phi\phi$)

Strong improvement in physics yields due to lower pT, E_T cut

In this particular example x4 at 10 MHz of LLT (which we consider optimal for initial farm size)
Other key channels will gain
($B_s \rightarrow \phi\gamma$, $B_d \rightarrow K^*\mu\mu$, $B_s \rightarrow \psi\phi$)

Charm lines will gain up a factor x10, thanks to low E_T cut, in particular for multi-body decays

The problem is to readout them all due to high purity
Now 4.5 kHz data taking →
upgrade 20 kHz data taking (challenging)



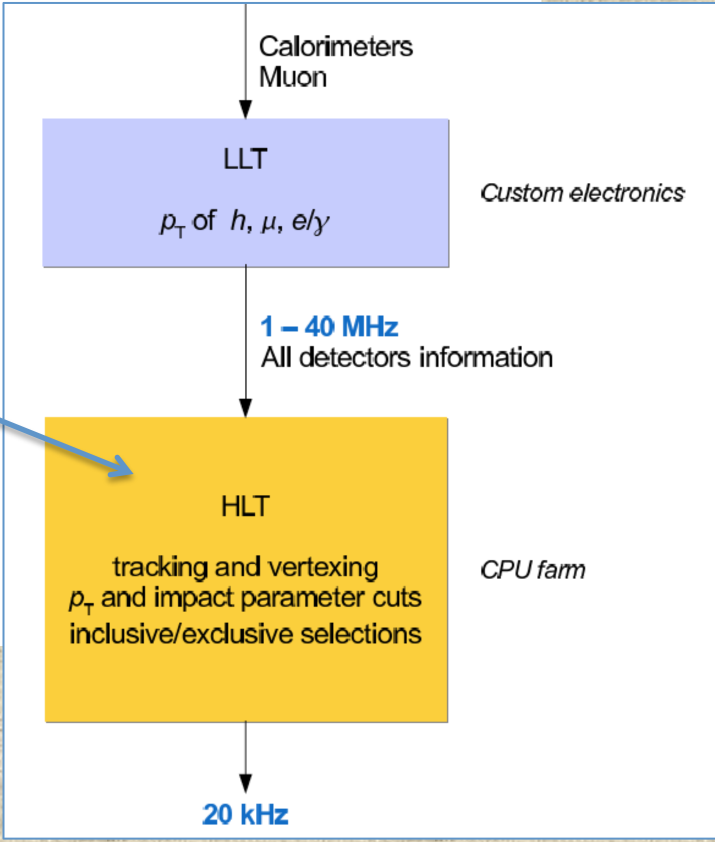
The LHCb baseline upgrade

The transition to 40 MHz needs the replacement of all electronics (except CALO and MUON) and of the following detectors:

- a new VELO detector (pixels or short strips)
- a new Inner Tracking system (silicon or scintillating fibers)
- new RICH photo-sensors (multianodes PMT)
- a Low Level hardware Trigger (LLT)
- a large HLT farm (to cope with O(>10 MHz) of events in input)

Fast tracking/vertex reconstruction within HLT at 40 MHz (CHALLENGING !)

Outer Tracker, Calorimeters, Muon system: adjustments for 40 MHz readout (mainly on electronics)



VELO

- Completely new modules and FE electronics

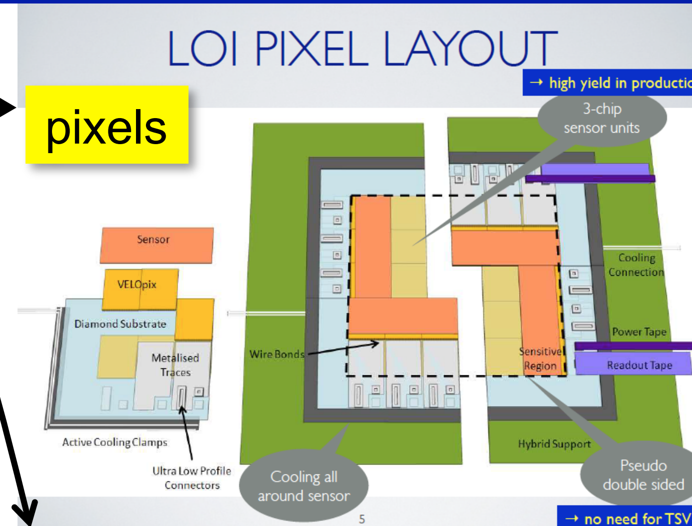
  Two major options under consideration

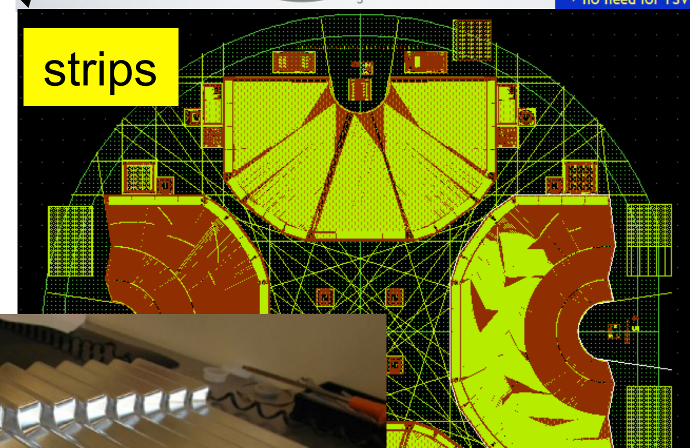
  – STRIPS (40 MHz implementation pushes Boundaries)

  – PIXEL (based on Timepix R&D)

  Must be

  - Capable of dealing with huge data rate
    - > 12 Gbit/s for hottest pixel chip
    - On-chip 0-suppression
  - Able to withstand radiation levels of ~ 370 MRad or 8 x 10^{15} n_{eq}/cm^2



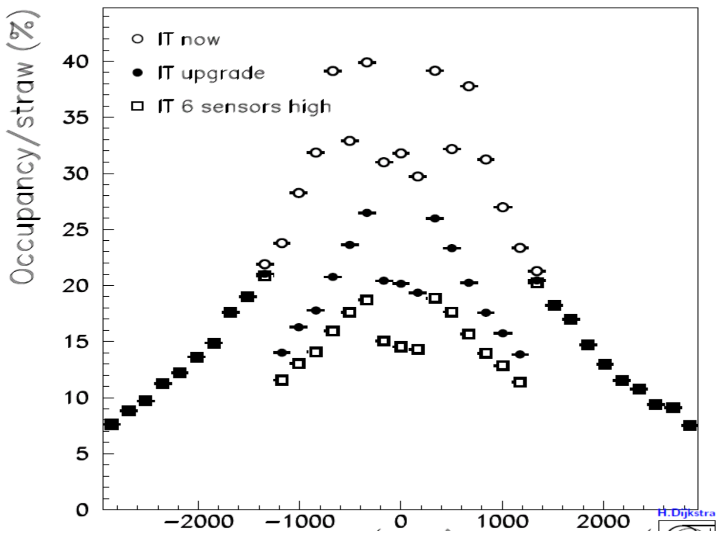


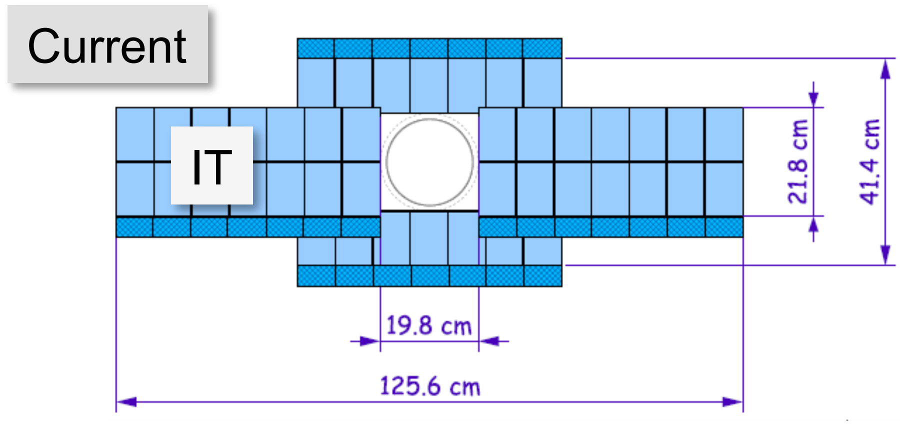
Common developments:

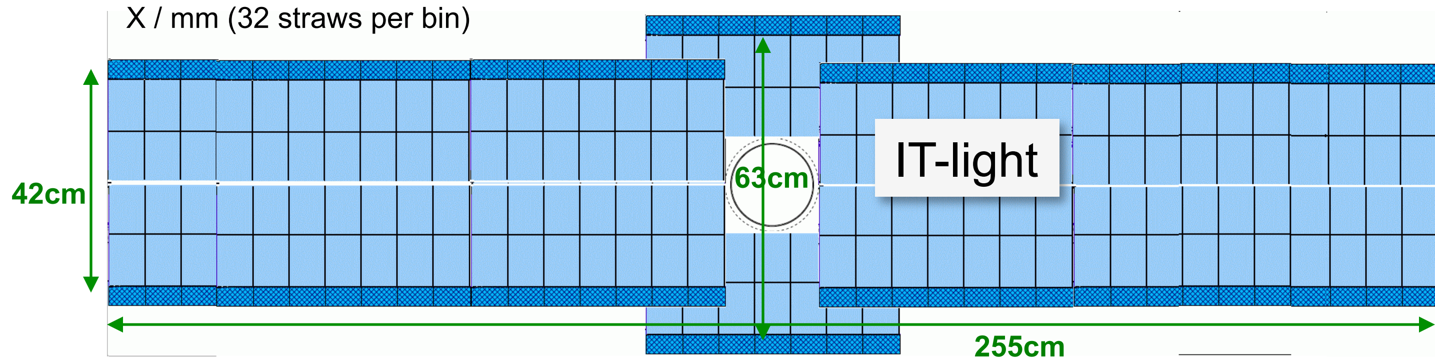
- completely new module cooling interface
- New RF foil
- All without sacrifices in material budget
- Nearer to BEAM (improve vertexing) ?

Tracking option 1: Silicon IT "IT light and large"

- Increase size + decrease mass of IT to cure the OT occupancy problem





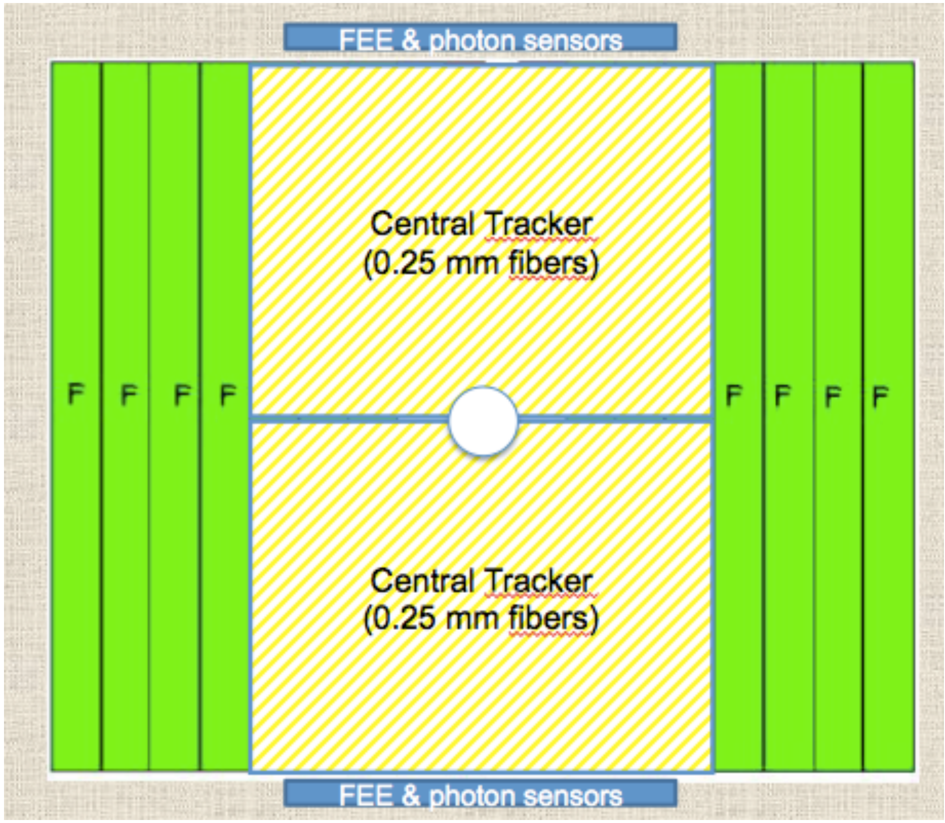


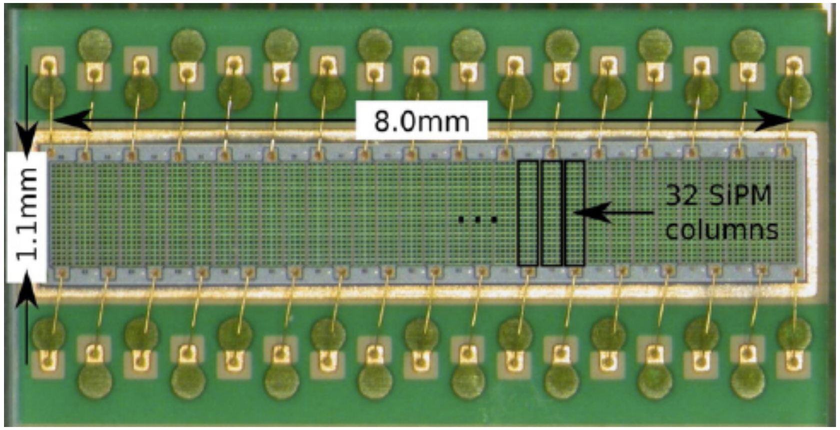
Challenges:
- Mass reduction
- Cost

- From 126x22(41) cm to 255x42(63) cm
- Increase number of sensors/layer by nearly factor 4, $\times 3.3$ for 10 layers.
- "η" coverage: IT/(IT+OT)= $33\% \to 54\%$

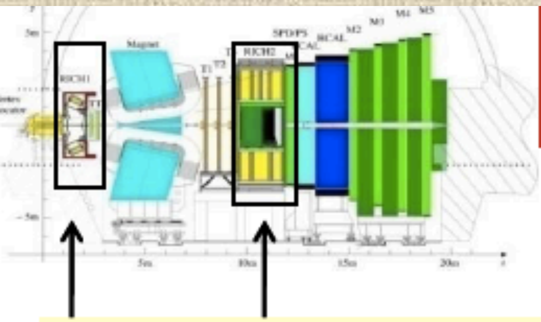
Tracking option 2: SciFi Central Tracker

- Central tracker with new scintillating fibers modules (Sci.Fi.) + current external OT (straw tubes)





- 5 layers of densely packed 250μm diameter fibers, readout with 128-channel Silicon Photomultipliers (SiPM)
- 2×2.5m long fibers, readout on top and at bottom of stations
- Challenge : if it Sci.Fi. can sustain the occupancy and radiation

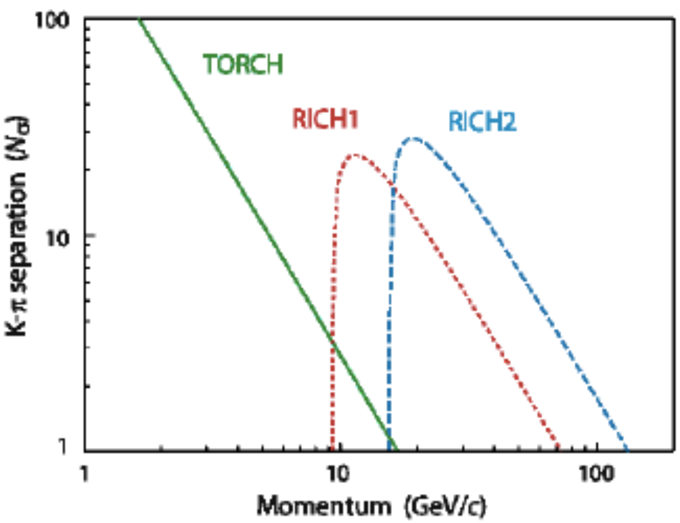


Particle ID

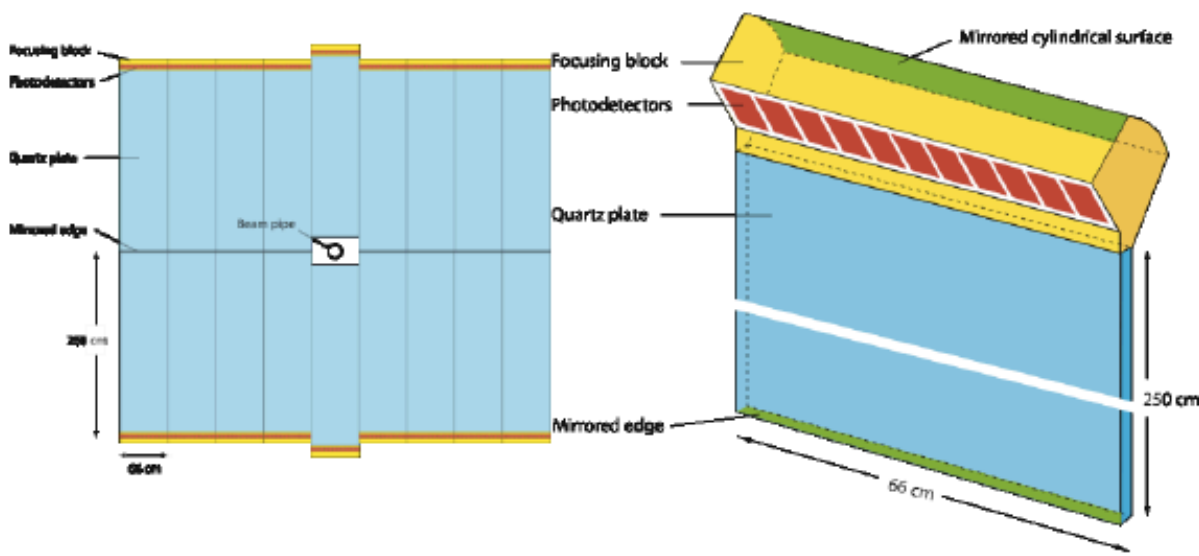
- RICH-1 and RICH-2 detectors remain
  - Readout baseline: replace pixel HPDs by MaPMTs & readout out by 40 MHz ASIC
  - Alternative: new HPD with external readout
- Low momentum tracks: replace Aerogel by Time-of-Flight detector “TORCH”
  (=Time Of internally Reflected CHerencov light)
  - 1 cm thick quarz plate combining technology of time-of-flight and DIRC
  - Measure ToF of tracks with 10-15 ps (~70 ps per foton).

TORCH not included in the baseline upgrade plan

K-π separation vs p in upgrade:



TORCH detector:



Conclusions

Thanks to LHC performances and to luminosity leveling technique **LHCb** has collected over 1 fb^{-1} in the 2011 run, 0.75 fb^{-1} in 2012 - and is planning to more than triple the statistics

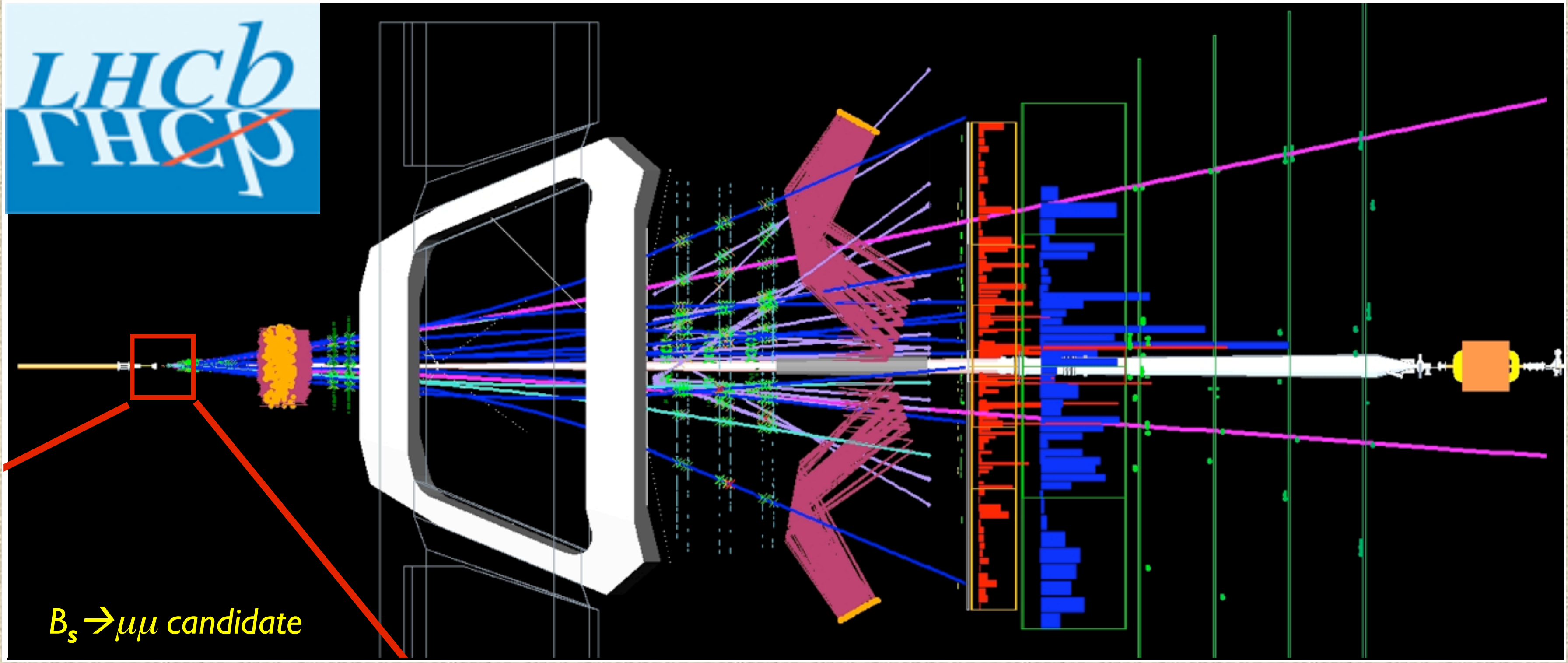
Analyses in the core physics channels are well advanced, with areas of "world record" measurements: $B_s \rightarrow J/\psi\ \phi$, $B_s \rightarrow \mu\mu$, $B_d \rightarrow K^* \mu\mu$, B_s mixing and charm physics. A large amount of other channels under study

Standard Model shows its solidity but still room available for New Physics: **LHCb** is complementing ATLAS & CMS searches for Supersymmetry

Very good perspectives for future new measurements in CPV in b and c decays, CKM angle γ , radiative and rare decays, and in non-flavor physics

The 40 MHz **LHCb** upgrade will allow to fully exploit an higher luminosity from LHC and to enhance the efforts for New Physics searches in the next decade

Thank you !



" There is no excellent beauty that hath not some strangeness in the proportion (F. Bacon) "

Backup slides

D0 anomaly in B mixing

D0 - measurement of A^b_{SL} in b double semi-leptonic decays (~4σ away from SM)

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

Indication from D0 that anomaly may comes from B_S (from studies of impact parameter)

$$a^d_{sl} = (-0.12 \pm 0.52)\%$$
$$a^s_{sl} = (-1.81 \pm 1.06)\%$$

Measurement of a^s_{SL} in $B_S \to D_S^- \mu^+ \nu$ ($D_S \to \phi\pi$) events

$$a^s_{sl} = (-1.08 \pm 0.72 \pm 0.17)\%$$

LHCb measurement: use same technique of D0 with single semi-leptonic B_S decays

Magnet periodically reversed

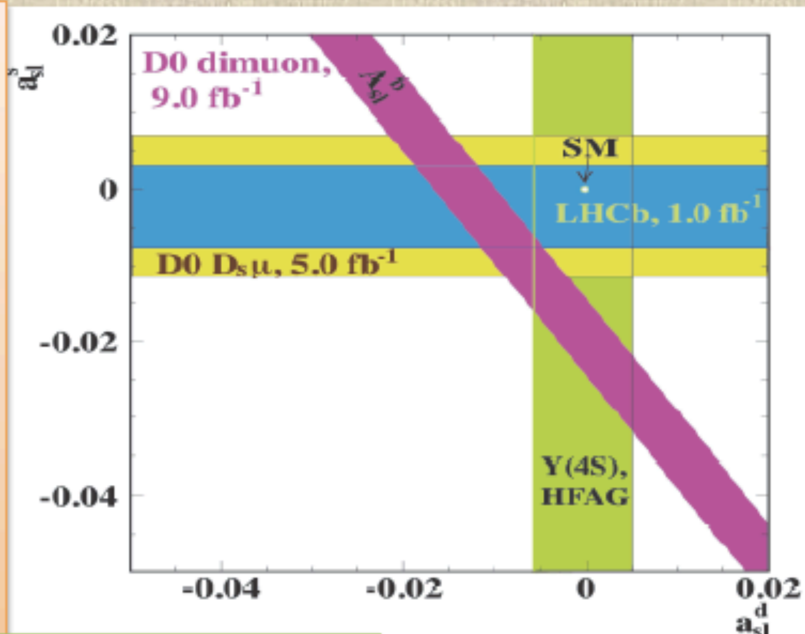
Effects of B_S production asymmetry reduced by fast oscillations

Calibration samples used to study detector trigger, track and muon ID biases

LHCb finds $a^s_{sl} = (-0.24 \pm 0.54 \pm 0.33)\%$

In agreement with SM

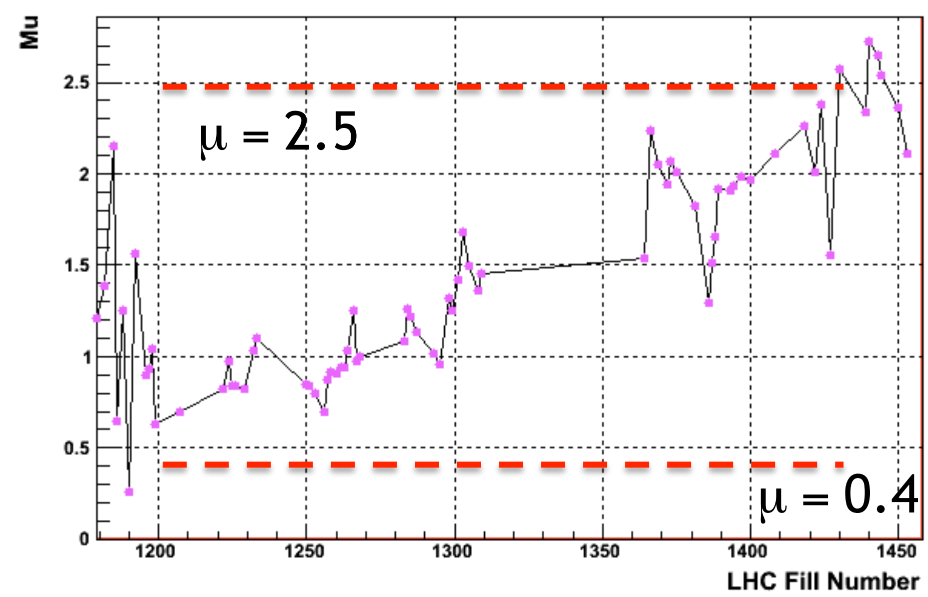
D0 result still compatible at ~2σ



Presented at ICHEP 2012

LHCb test of High Luminosity environment

In 2010 LHCb has already experienced (due to the startup of LHC with high currents but small number of bunches) High Luminosity conditions i.e. events with (relatively) high pile-up ($\mu = 2.5$), in conditions similar to the upgrade one



- Good tracking capabilities
- Small deterioration of S/B

Have allowed LHCb to perform good Measurements even in these harsh conditions

Note: LHCb was meant to run at $\mu = 0.4$

Average no. of visible interactions/crossing ~ 4 at L = 2 10^{33} cm^{-2} s^{-1} (25 ns BX)
Rate of visible interactions ~ 30 MHz

The current baseline detector upgrade is taking into account these effects and is looking for a configuration able to stand UP to 2 10^{33} cm^{-2} s^{-1} keeping untouched some parts of the detector (part of Outer Tracker, RICH, Calo, Muon)

- $B_d \to K^* \mu\mu$

With a larger statistics, study of further observables (transverse asymmetries: $A_T^{(2)}$, $A_T^{(3)}$, $A_T^{(4)}$) sensitive to NP (especially C_7), and free of hadronic errors in the region $1 < q^2 < 6\ GeV^2$

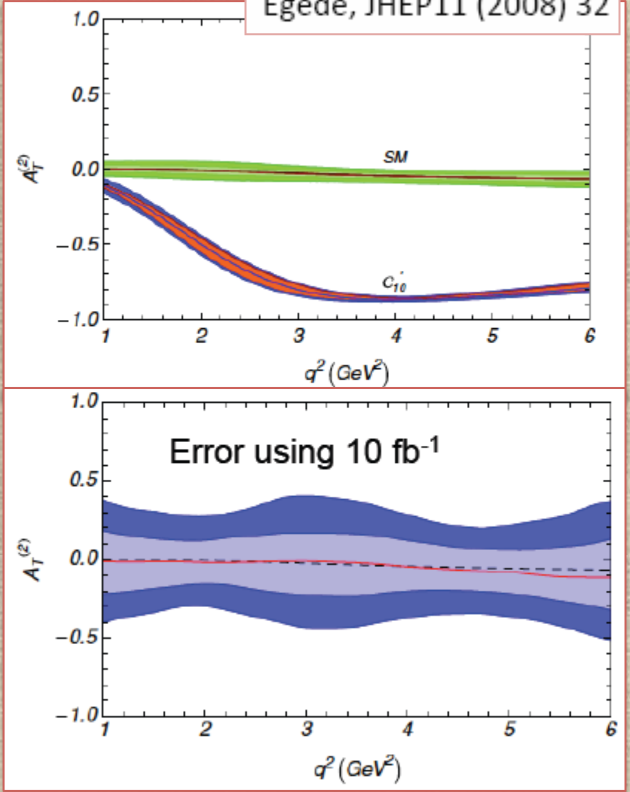
$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2},$$

$$A_T^{(3)} = \frac{|A_{0L}A_{\parallel L}^* - A_{0R}^* A_{\parallel R}|}{\sqrt{|A_0|^2 |A_\perp|^2}},$$

$$A_T^{(4)} = \frac{|A_{0L}A_{\perp L}^* - A_{0R}^* A_{\perp R}|}{|A_{0L}^* A_{\parallel L} + A_{0R}A_{\parallel R}^*|},$$

Yield (end 2017) ~ 12,000 ev
Yield (upgrade: ε x 1.5, 10^{33} cm^{-2}s^{-1}) ≥ 8,000 ev/y

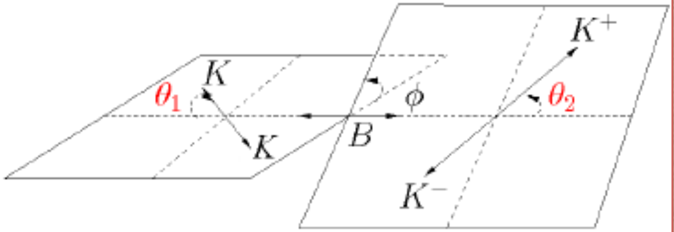
Egede, JHEP11 (2008) 32



- $B_s \to \phi\phi$

Fully hadronic decay.
Time dependent CPV: full angular fits needed (statistics)

Knowledge of β_s^{eff} mixing phase in penguins σ=0.02 (SM=0)



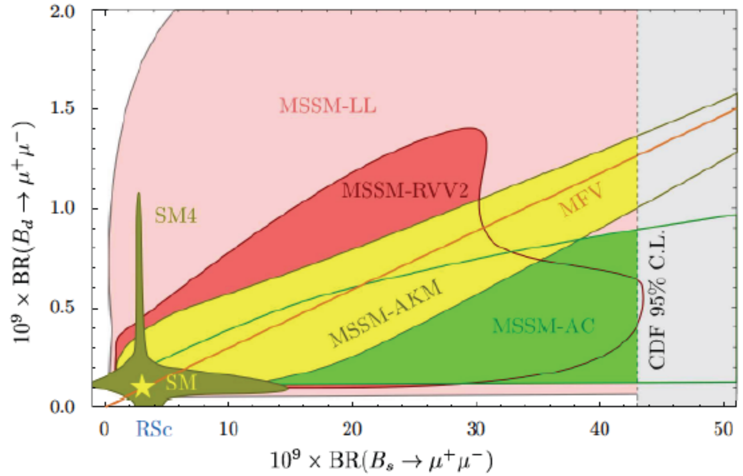
Yield (end 2017) ~ 12,000 ev
Yield (upgrade: ε x 3, 10^{33} cm^{-2}s^{-1}) ≥ 15,000 ev/y

$B^0 \to \mu^+\mu^-$

A large statistics is needed for a precise measurement of $B_{d,s} \to \mu\mu$ at the SM level and for discriminating NP theory predictions for

$Br(B_s \to \mu\mu) / Br(B_d \to \mu\mu)$ known quite precisely in SM

- In fact correlation between B_d & B_s $\mu^+\mu^-$ could be crucial

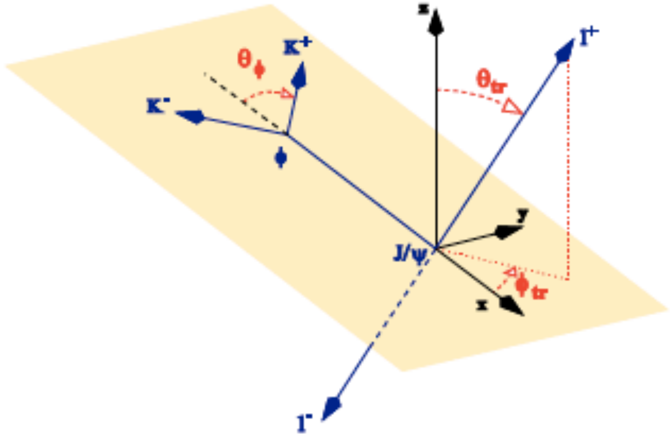


Strong competition with CMS & ATLAS
(will depend on their capabilities of triggering and selecting signal events in high luminosity and high pile-up conditions)

Yield (end 2017) ~ 100 ev
Yield (upgrade, 10^{33} $cm^{-2}s^{-1}$) ~ 40 ev/y

CP asymmetry in $B_s \to J/\psi\, \Phi$

- $B_s \to J/\psi\, \Phi$ measures the B_s mixing phase $-2\beta_s$ as $B \to J/\psi\, K_s$ provides the CPV phase 2β
- $B_s \to J/\psi\, \Phi$ is a vector-vector final state

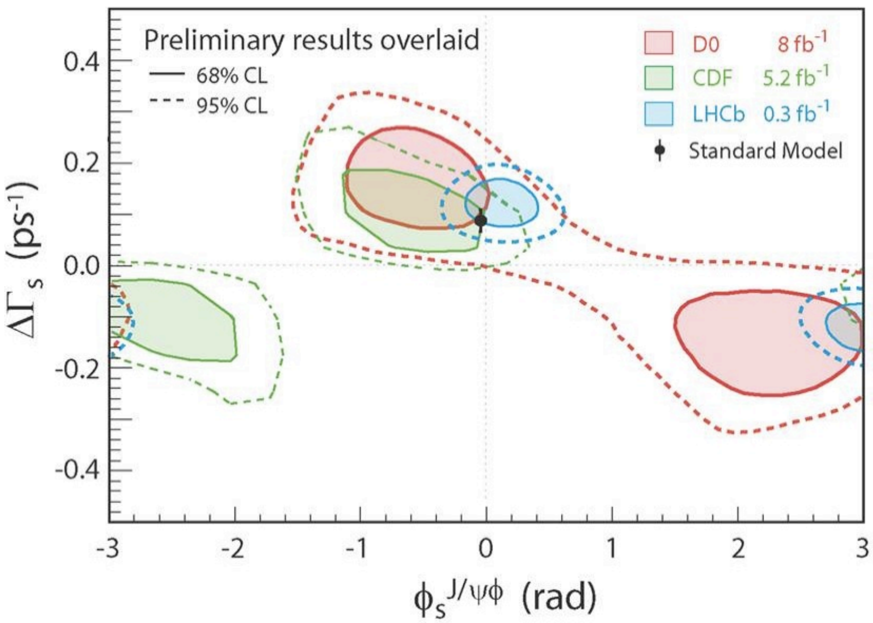


SM predictions for $2\beta_s$ very precise ~0.003

- Efficiency can profit from software trigger (+20-30%)
- Other final states can be considered ($\psi\, f_0$, $D_s\, D_s$)

Yield (2017) ~ 300 kev (+ better FT) with an expected error on $2\beta_s$ ± 0.02
Yield (upgrade, 10^{33} $cm^{-2}s^{-1}$) ~ 150 kev/y

- With 50 fb^{-1}, error on $2\beta_s$ is reduced to ± 0.006 (stats only)



$\tau \rightarrow \mu\mu\mu$

Present limits (Belle, BaBar) ~ 2-3 10^{-8} (90% CL) [reachable by LHCb with O(2/fb)]
Approaching sensitivity to exclude/contraints NP models
Complementary to $\tau \rightarrow \mu\,\gamma$ searches

NP model	Ref	$\tau \rightarrow \mu\mu\mu$ BR
SM + heavy majorana ν_R	Cvetic, Dib, Kim, Kim, PRD 66 (2002)	10^{-10}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003)	10^{-10}
mSUGRA + seesaw	Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002)	10^{-9}

LHCb is well suited to make this measurement due to muon low p_T threshold
Geometrical Likelihood or Multivariate approaches ongoing
The LHCb upgrade sample (50/fb) could reach ~ 10^{-9}

B_d / B_s radiative decays

Photon Energy resolutions are those expected from MC in a pileup 5x the one foreseen. This item to be studied for the upgrade (high L could spoil it)
S ($B_s \rightarrow \phi\,\psi$) and $A_{\Delta\Gamma_s}$ could be measured at 2-3 % level

Yield (end 2017) ~ 10000 ev
Yield (upgrade: ε x 2, ~ 10^{33} cm^{-2}s^{-1}) ~ 8000 ev/y
(yields for $B \rightarrow K^* \gamma$: ~ x 7 those of $B_s \rightarrow \phi\,\gamma$)

Charm Physics

- 2010:
  - With 37 pb^{-1} collected charm samples of $D^0 \rightarrow h^+h^-$ comparable to B-factories
- 2012-17 :
  - Good efficiency for 2-body decays, lower eff for higher multiplicity due to E_T trigger in L0
- Upgrade
  - Full software trigger allowing selection of topology of interest
  - High statistic available for CPV study in mixing and decay:
    - Lifetime asymmetry $D^0 \rightarrow K^+K^-$ and $\overline{D^0} \rightarrow K^+K^-$ probes CPV in D mixing
    - Difference in time integrated CP asymmetry $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ probes CPV in decay of D
    - Rare charm decay: $D \rightarrow \mu^+\mu^-$, lepton flavour violation: $D \rightarrow e\ \mu$

$D^0 \rightarrow hh$ tagged events (@ 7 TeV) : 5M ($K\pi$), 2.5M (KK), 0.7M ($\pi\pi$) /fb^{-1}
Present bandwidth for charm ~ 1kHz

Upgrade: 14 Tev (x2), trigger (~ x4), Luminosity ($\geq$ x2.5) → well beyond x10

Most probably limited by HLT2 output: O(10 kHz)

Enormous gains in multi-body decays and with K_s in the final state
LHC is a real charm factory (!)