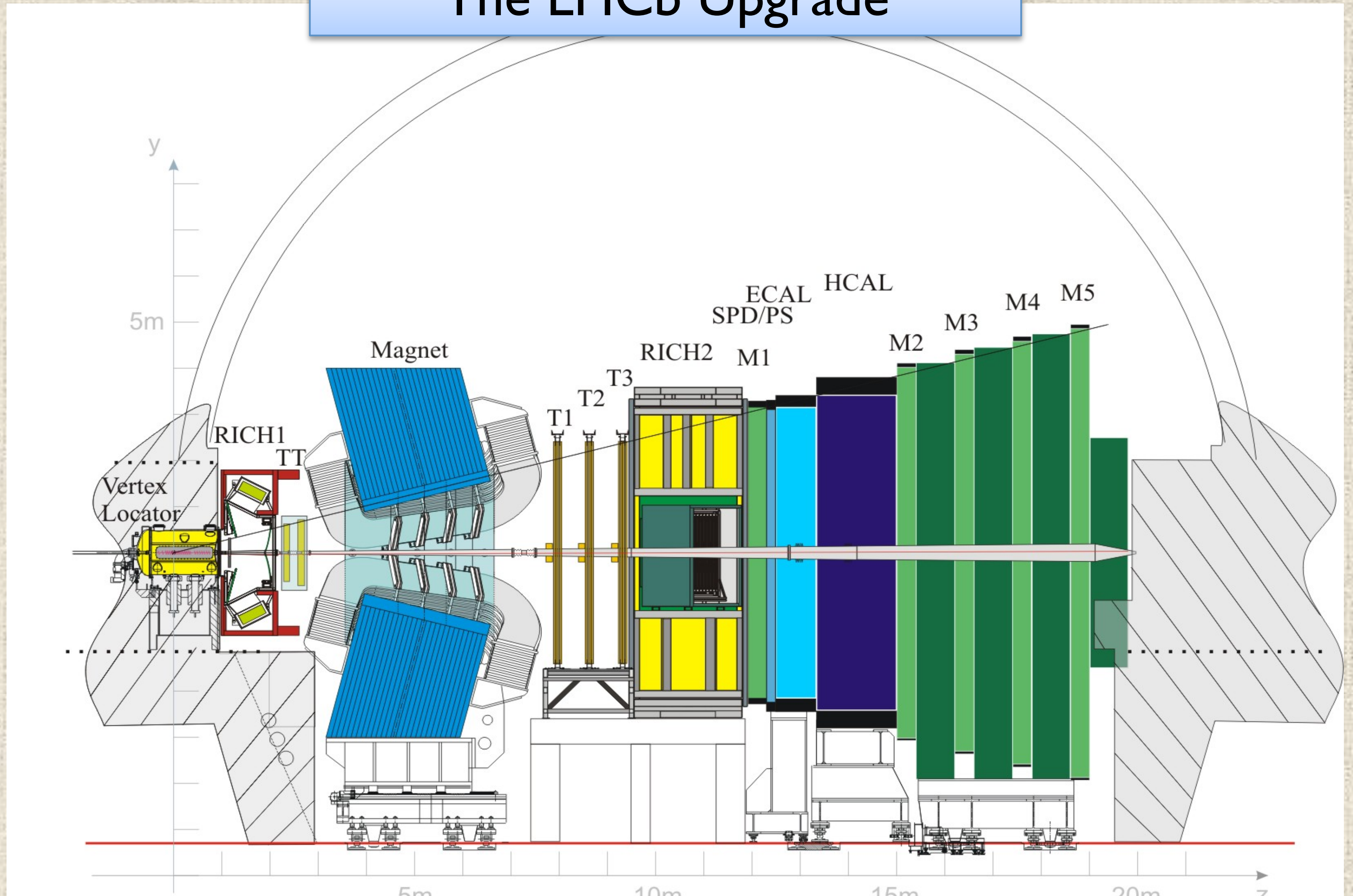
The LHCb Upgrade

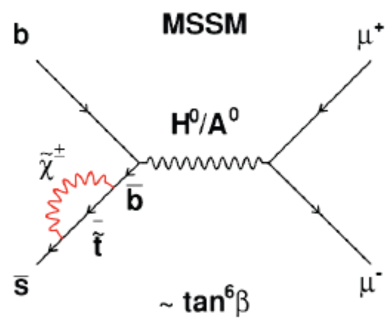


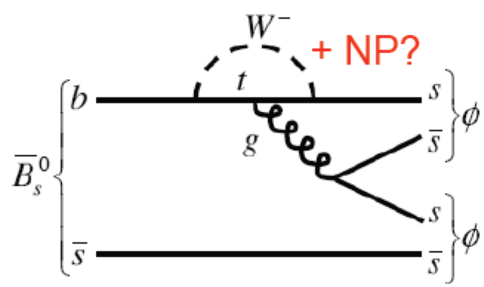
Benasque 25.05.12 – P. Campana (CERN/LNF)

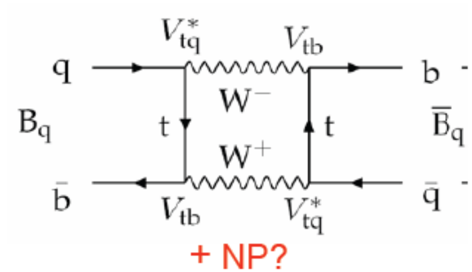
LHCb Physics Programme

- Search for New Physics which may appear in CP violation or in rare decays mediated by new particles at high mass scale via their effects in loops diagrams

- Compare CKM quantities determined in tree and loop process





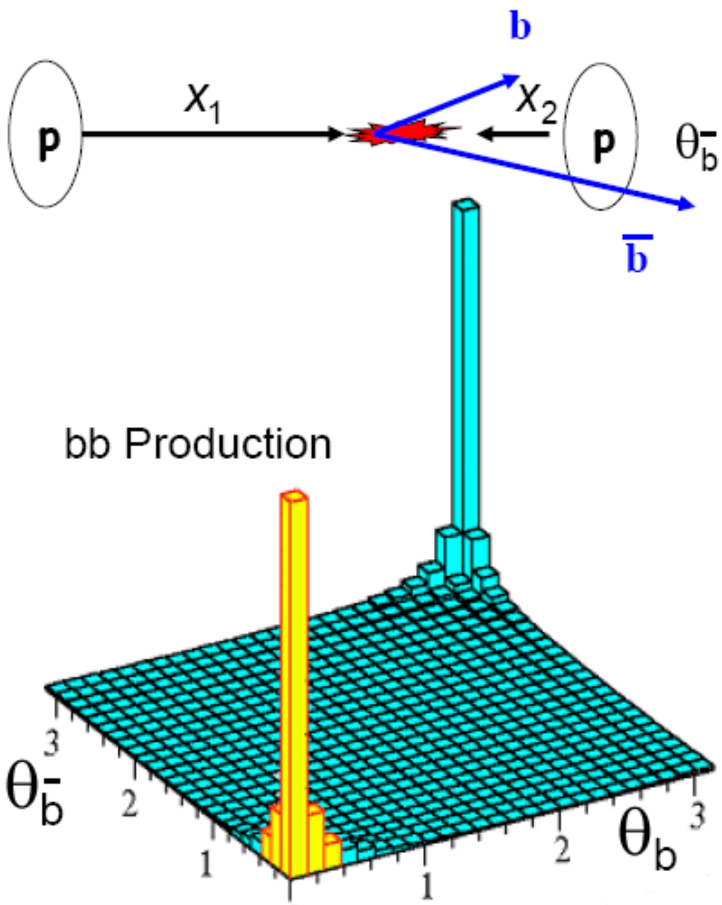


- CPV
  - B_s oscillation phase ϕ_s
  - CKM angle γ in trees and loops
  - CP Asymmetries in charm decays
- Rare decays
  - Helicity structure in $B_d \to K^*\mu\mu$, $B_s \to \phi\gamma$
  - FCNC in loops ($B_{d,s} \to \mu\mu$, $D \to \mu\mu$)

+ b and c production studies, electroweak physics, exotics, etc...

b and c quark production in the LHCb environment

Gluon-Gluon-Fusion:



- Cross sections predictions (PYTHIA)

  $\sqrt{s} =$ 7, 10, 14 TeV

  $\sigma_{inel} \sim$ (0.89, 0.95, 1) $\times$ 80 mb

  $\sigma_{bb} \sim$ (0.44, 0.67, 1) $\times$ ~500 μb

  (280 μb, measured @ 7 TeV)

- B , B^0, B_s, B_c, Λ_b …

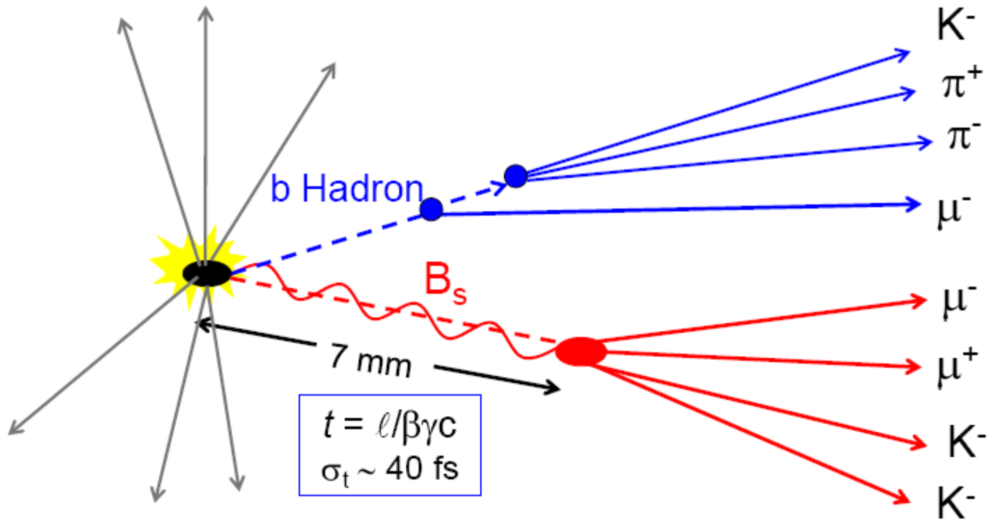
  (40% 40% 10% 10% from LEP)

- 20x larger charm production

- Design $\mathcal{L}$ ~ 2 x 10^{32} cm^{-2} s^{-1} (tuned)
  - ~ 10^{12} $b\bar{b}$ events / year (2 fb^{-1})
  - 15 kHz $b\bar{b}$-events in LHCb

LHCb acceptance : 2 < η < 5 (ATLAS and CMS: |η| < 2.5)

B meson decays topology



Excellent vertex resolution: to resolve fast B_s oscillation.

Background reduction: Very good mass resolution
Good particle identification (K/π)

High statistics: Efficient trigger for hadronic and leptonic states

At L0 level (7 TeV)

min.bias : cc : bb

250 : 20 : 1

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

B decays with $\mu\mu$	$\varepsilon_{\mathbf{(L0\ x\ HLT)}}$	~ 70-90 %
B decays with *hadrons*	$\varepsilon_{\mathbf{(L0\ x\ HLT)}}$	~ 20-45 %
Charm decays :	$\varepsilon_{\mathbf{(L0\ x\ HLT)}}$	~ 10-20 %

(efficiencies for off-line selected events)

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%

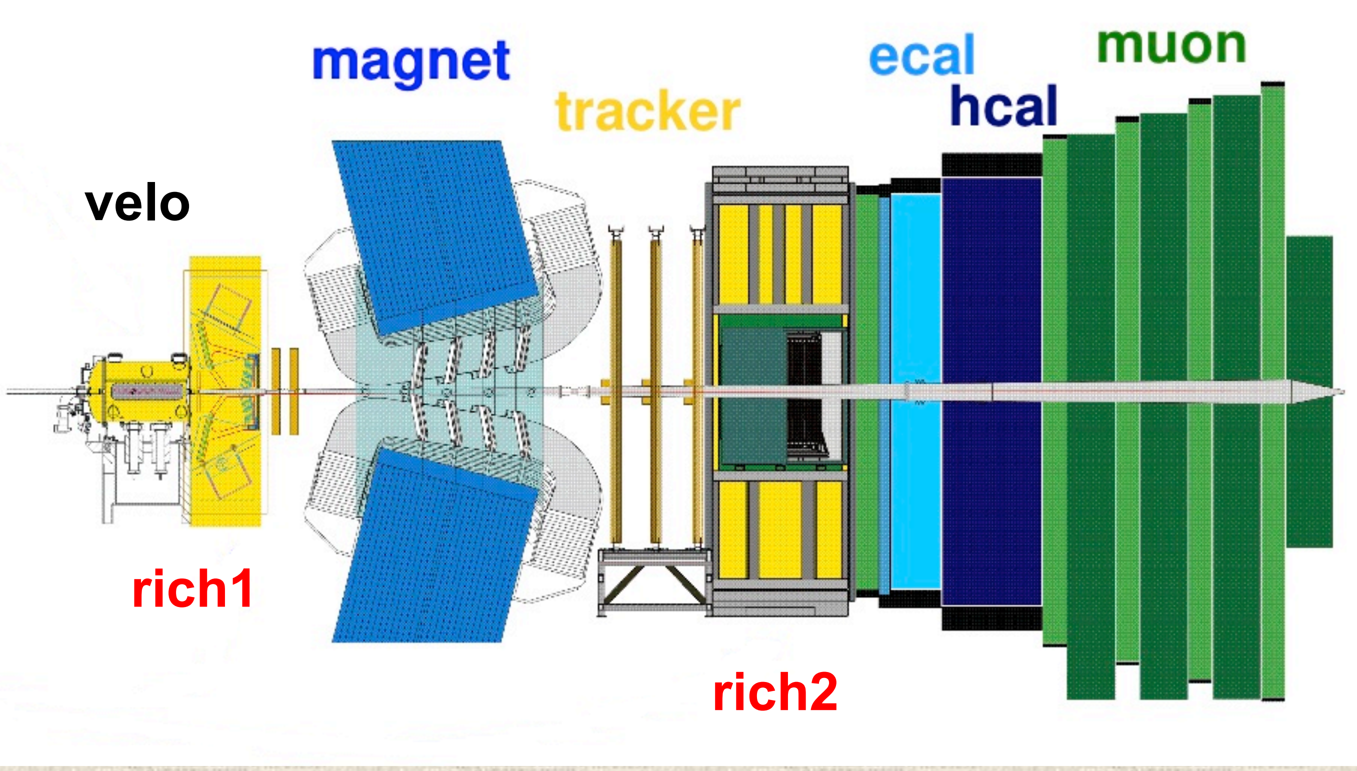
RICH2: CF_4
- π/K separation for 20<p<100 GeV

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

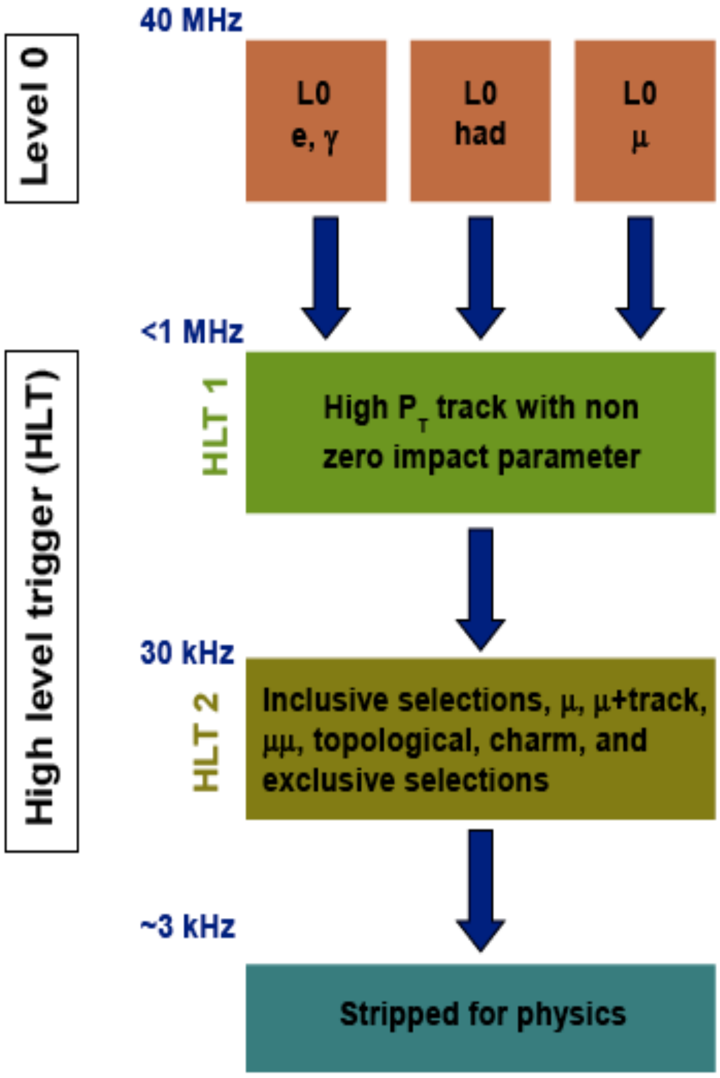
MUON
MWPC+GEM: π/μ separation

Brasil, China, France, Germany, Ireland, Italy, Netherlands, Poland, Romania, Russia, Spain, Switzerland, UK, Ukraine, US, CERN

55 institutes,
730 members



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

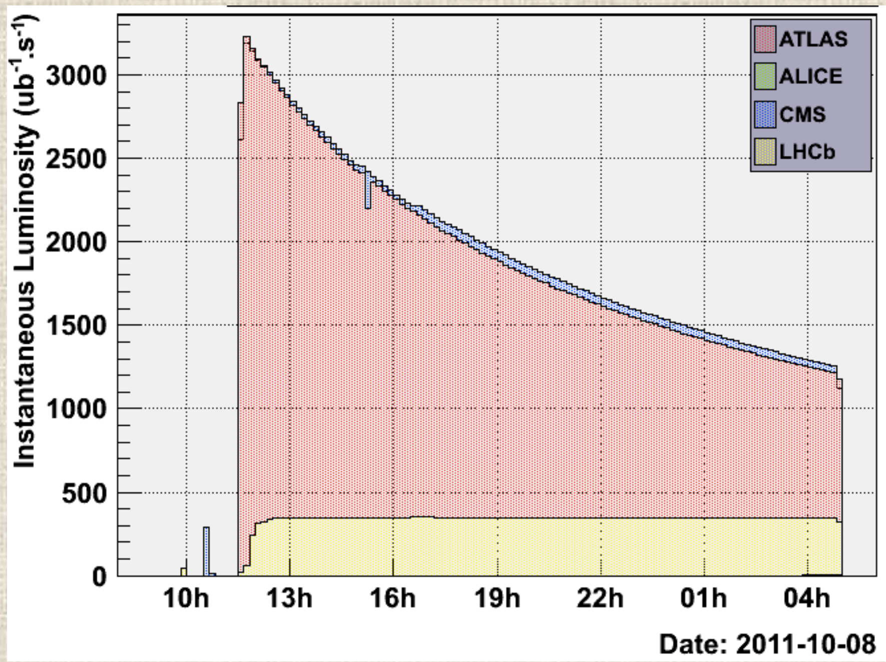
High Level Software Trigger Farm

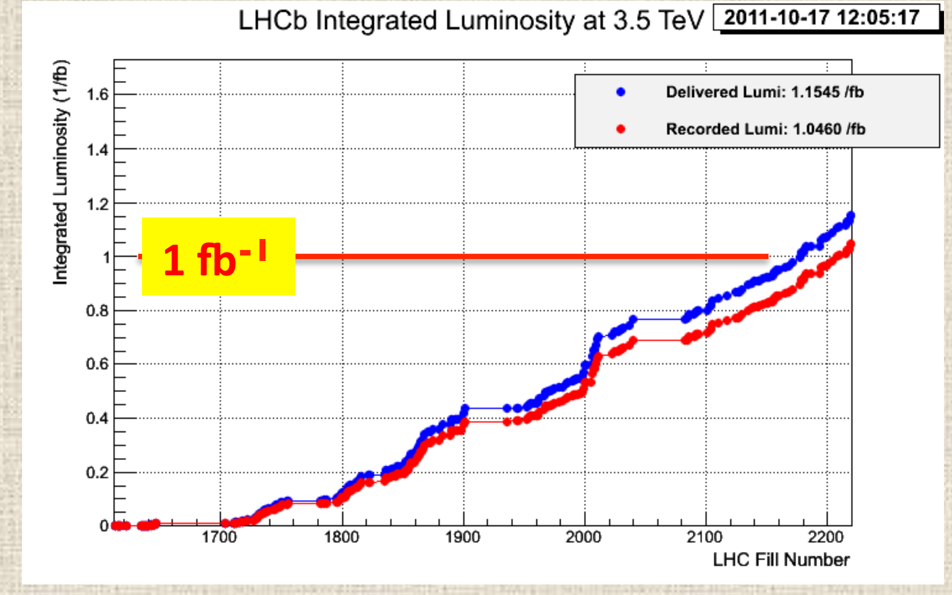
- HLT1: Add Impact parameter cuts
- HLT2: Global event reconstruction
- Physics output rate : up to 3-4 kHz
- In 2012 increase (10%) in no. of CPU installed

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

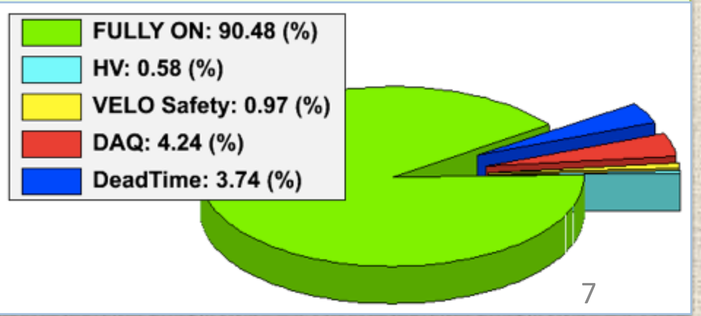
Data taking in 2011: great LHC performance, excellent running of LHCb detectors (~99% of channels operational), and the luminosity leveling





- L_{INT} > 1 fb^{-1} (on tape)
- LHCb operated at **L ~ 4 10^{32}** cm^{-2}s^{-1} (*design was 2 10^{32} cm^{-2}s^{-1}*)
- Stable trigger and pile-up (μ) ~ 1.5 (*design was 0.4*)
- Data taking efficiency ~ 90%
- Aging of detectors as planned
- L0=0.85 MHz online → 3 kHz of physics on tape

(1 kHz hadrons, 1 kHz muons, 1 kHz charm)



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)

  → useful for the future (when spacing=25 ns)

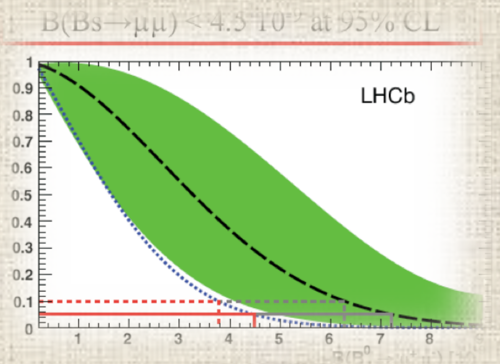
LHCb running conditions

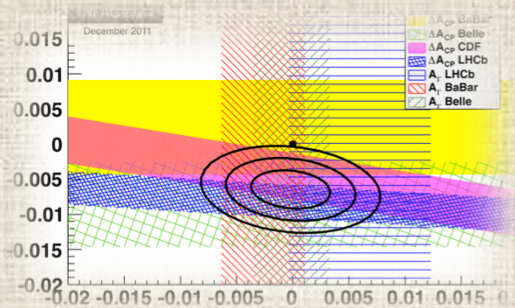
- Keep detector efficiency and data quality high
- L0 output ~ 1 MHz (maximum allowed)
- HLT output ~ 4.5 kHz (with upgraded farm [+10%] and better HLT trigger)

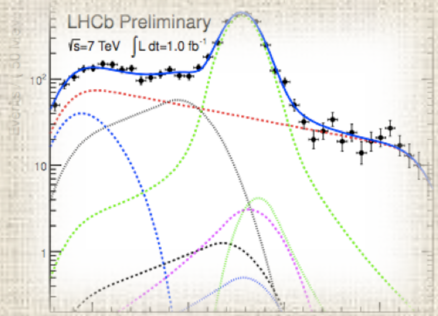
  → increase in yields of charm (K_s in HLT1) and in b-hadronic channels

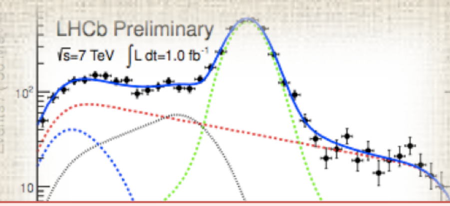
Considering the experience of 2011 → target of ≥ 1.5/fb on tape in 2012

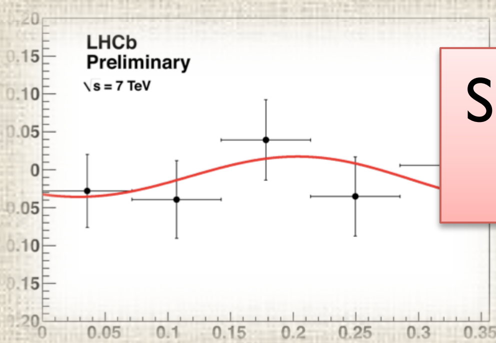
- Expected increase in event yields in 2012
- Energy (better S/B) + improved HLT + more CPU ~ +20-30% (mainly had. decays)



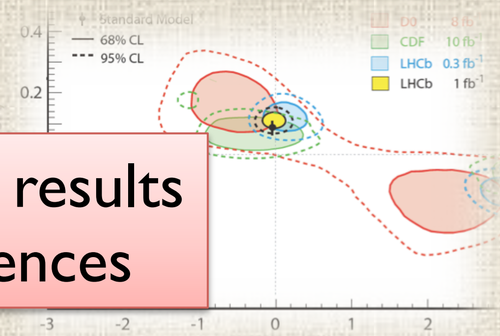


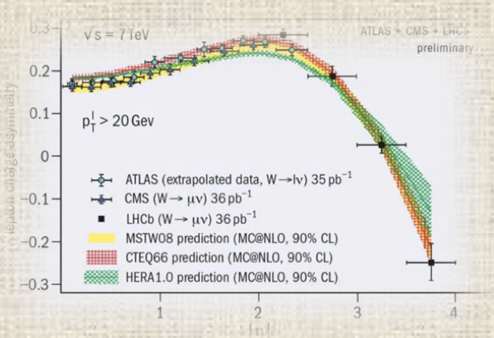


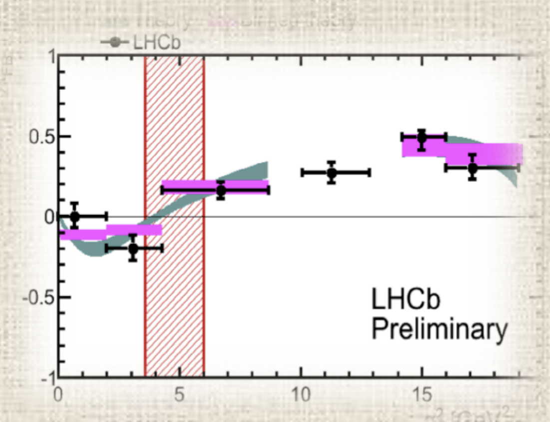


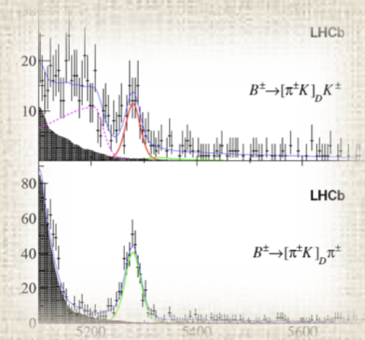


Selected Highlights of LHCb results from 2012 Winter Conferences









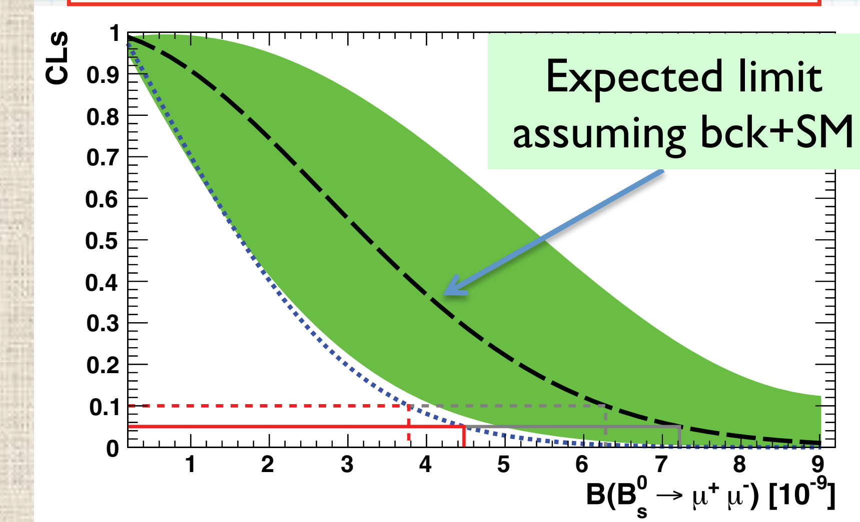
arXiv:1203.4493

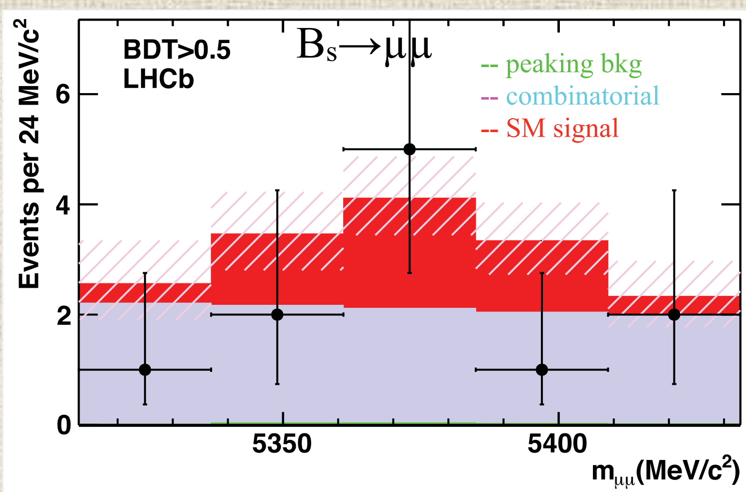
$B_{s\,(d)} \rightarrow \mu\,\mu$

Very rare decay sensitive to New Physics (in particular to models with high *tg β*)

Precise predictions in SM: BR $3.2 \pm 0.2\ 10^{-9}$
Very clean experimental signature

$B(Bs \rightarrow \mu\mu) < 4.5\ 10^{-9}$ at 95% CL





Observed limit is stronger than expected: if (true) BR equals SM, under-fluctuation of the signal

With 2.5/fb (target for 2012 data taking), still able to observe SM signal at 3 sigma

CMS had an expected limit slightly worse

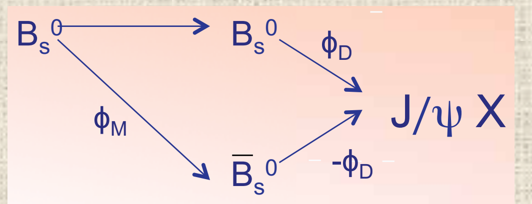
BR estimation:

simultaneous unbinned LL fit to the mass to the 8 BDT bins

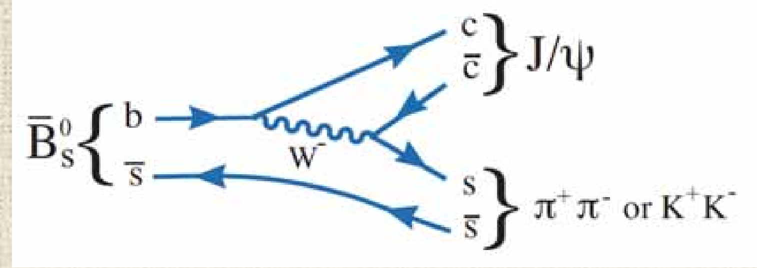
$$B(Bs \rightarrow \mu\mu) = (0.8^{+1.8}_{-1.3})\ 10^{-9}$$

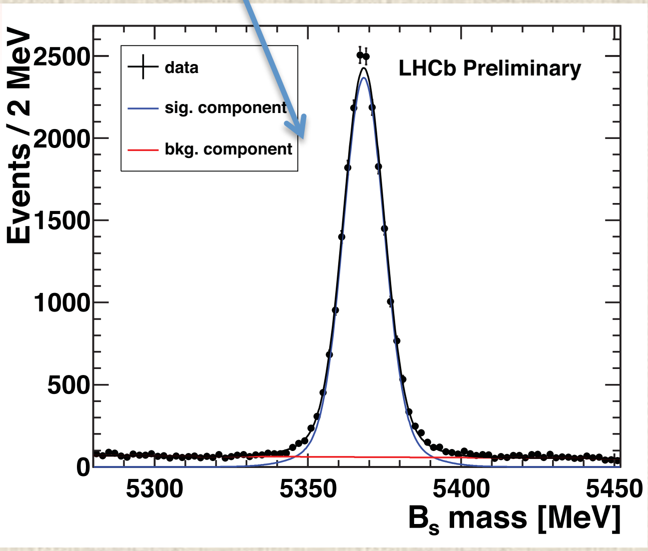
Results on CP Violation in B_s Mixing [measurements of ϕ_s and $\Delta\Gamma_s$]

- Measure relative phase difference[1] $\phi_s = \phi_M - 2\phi_D$ between two "legs"

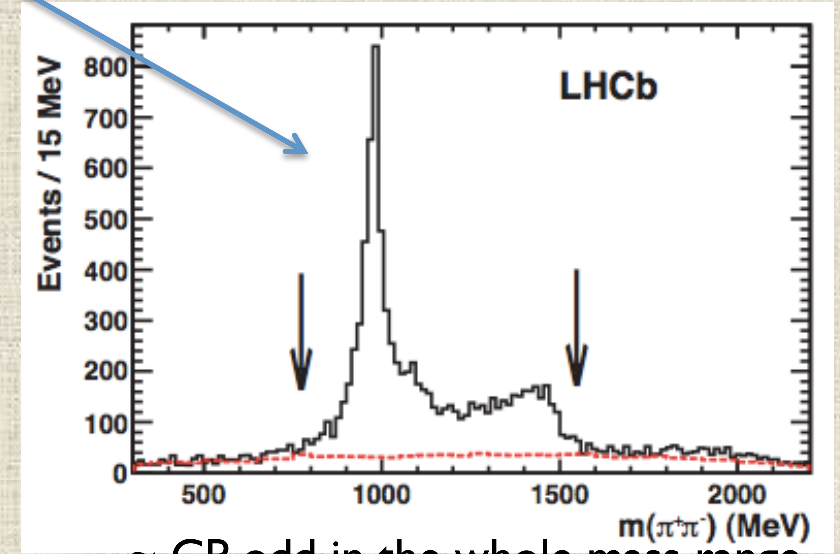


- $B_s \to J/\psi\Phi$ and $B_s \to J/\psi\pi\pi$ are very clean decays



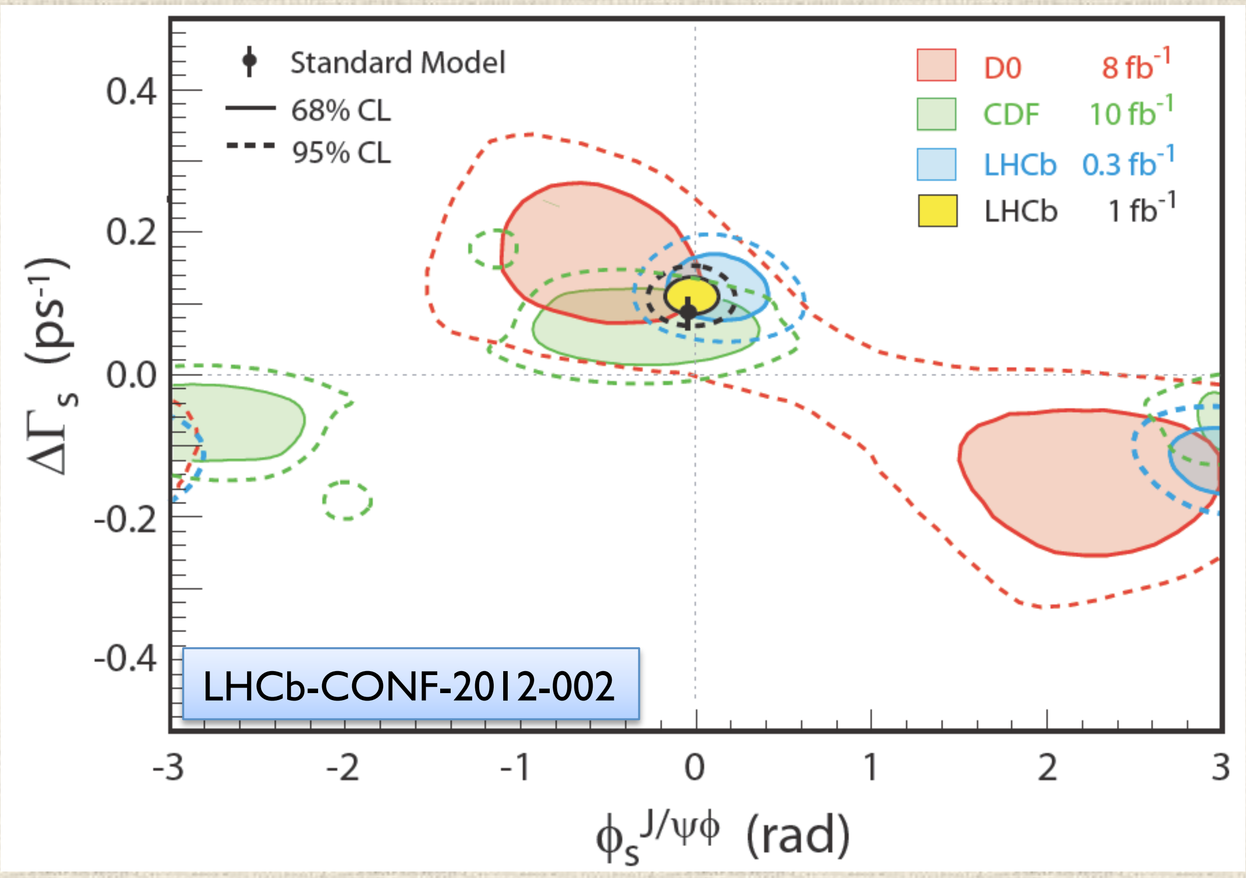


CP odd & even (angular analysis)



~ CP odd in the whole mass range

$B_s \rightarrow J/\psi\ \phi$ and $B_s \rightarrow J/\psi\ \pi\pi$ combined result



ϕ_s= -0.002 ± 0.083 ± 0.027 rad

Γ_s = 0.6580 ± 0.0054(stat.) ± 0.0066(syst.) ps^{-1}

$\Delta\Gamma_s$ = 0.116 ± 0.018(stat.) ± 0.006(syst.) ps^{-1}

CP violation in charm decays

arXiv:1112.0938

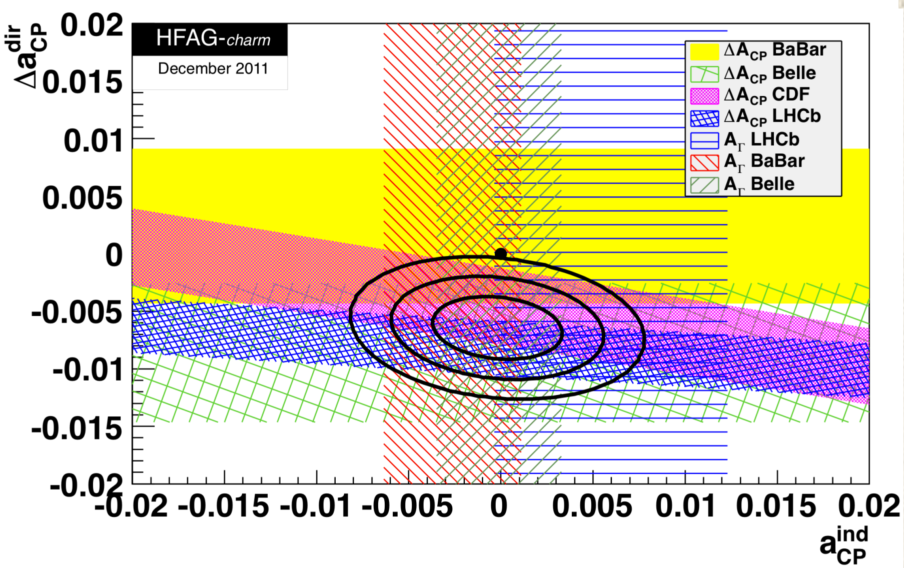
$$A_{CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D}^0 \to f)}$$

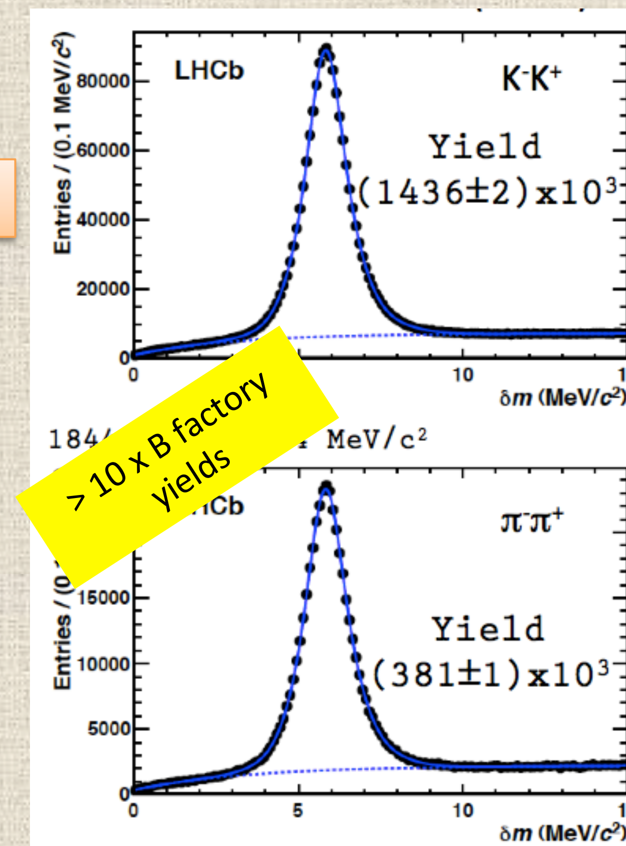
Measure CP asymmetry in time integrated single Cabibbo suppressed $D^0 \to hh$ decays with f = KK or $\pi\pi$ (D^0 tagged by $D^* \to D^0 \pi_{soft}$)

$$\Delta A_{CP} \equiv A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$$

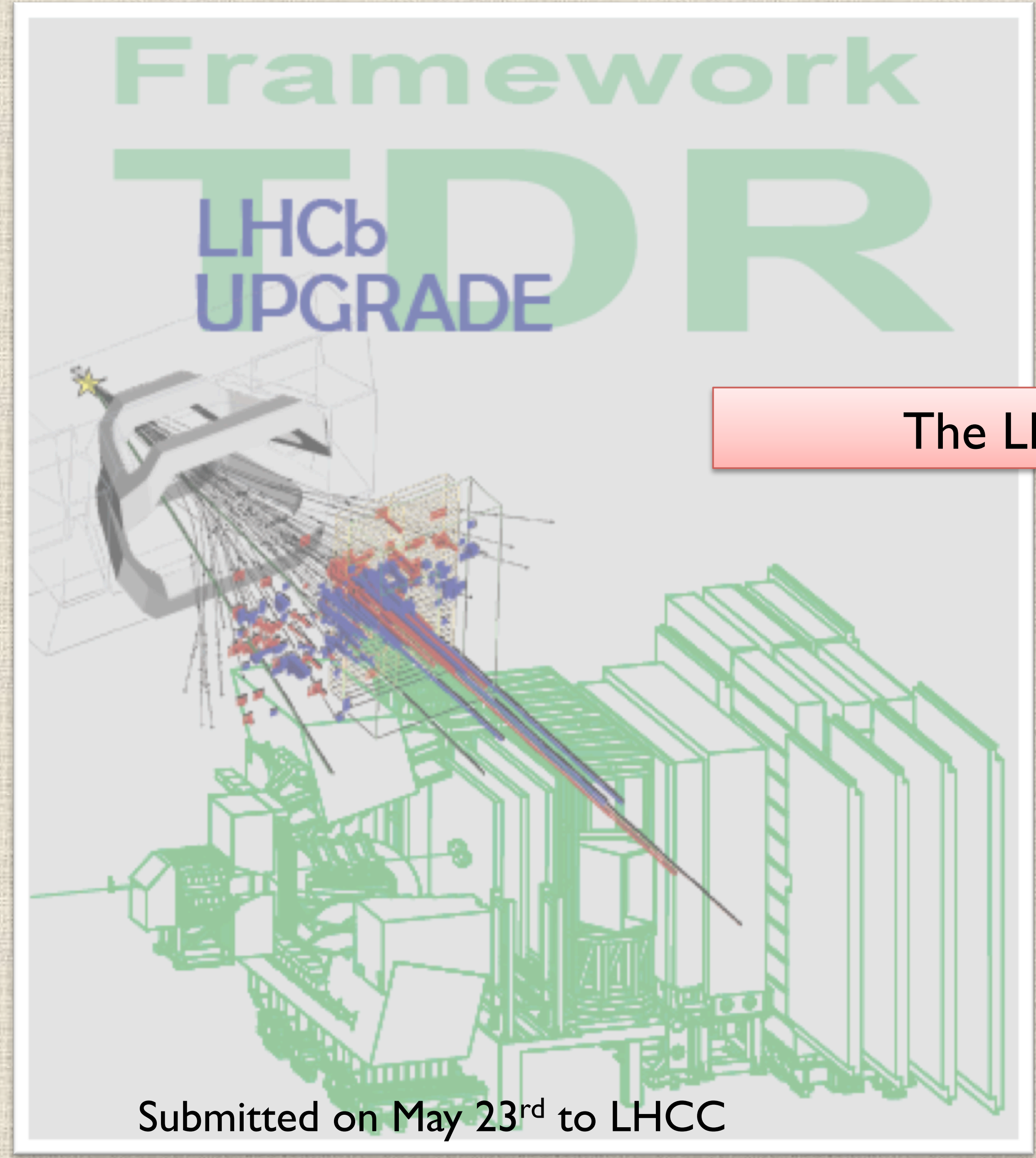
In ΔA_{CP} the production and the π asymmetries cancel

$$\Delta A_{CP} = [-0.82 \pm 0.21(\mathrm{stat.}) \pm 0.11(\mathrm{sys.})]\,\%$$





More studies are needed to confirm or disprove the effect (explained by SM?)



The LHCb Upgrade

Submitted on May 23rd to LHCC

Why the LHCb Upgrade ?

The flavor sector offers a very rich complementarity to the High Energy Frontier searches for New Physics (LHCb results enter Susy fits)

Recent LHCb results have shown the potentialities of Flavor Physics at LHC and the excellent performances of the detector

LHCb is unique for NP searches in B_s (and works well for B_d) and charm is produced and detected in large quantity !

LHCb is unique in his forward geometry (also for non flavor physics) and complements the pseudo-rapidity of Atlas and Cms

LHC is a fantastic machine (background-less !) and can be tuned to LHCb needs

HL-LHC is not necessary for LHCb upgrade, and LHCb can coexist with HL-LHC

LHCb data taking perspectives and its upgrade

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

- 2012 @8 TeV and 2015-16-17 @13 (14) TeV

By the end of 2017 ≥ **5/fb** collected (at an equivalent $\sqrt{s}$=14 TeV)

Reaching ultimate theory precision in flavor variables will need more statistics

The current LHCb limitation is in trigger rate capability. Upgrade plans:

- **1 MHz → 40 MHz readout**
- **A full software trigger**
- **Up to L ~ 2 10^{33} $cm^{-2}s^{-1}$** to collect **50/fb**

Expected annual physics yields increase (with respect to 2011):

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

Installation of upgraded LHCb during **Long Shutdown 2** (**2018**)

LHCb Upgrade: the formal steps

- *March 2011, "Letter of Intent for the LHCb Upgrade" submitted to LHCC*
  → Endorsement of physics case. Review of proposed trigger concept (40 MHz)

- *June 2011, Positive peer review of trigger concept*
  → LHCC endorses the LOI, green light for TDR preparation

- *June 2012, Submission of "Framework TDR for the LHCb Upgrade" to LHCC*
  (intermediate document describing the plan, cost and resources needed for the upgrade)

- *September 2012, Approval of "Framework TDR" expected*

- *Fall 2013, Submission of LHCb subsystems TDRs to LHCC*

… *funding applications to Agencies ongoing now* …

The schedule for the LHCb Upgrade

2012 LHCb data taking (8 TeV)

2013-14 LHC LS1 / LHCb maintenance, first infrastructures for upgrade

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

2018 **LHC LS2 / LHCb upgrade installation**

2019-21 LHCb data taking

≥ 2022 LHCb data taking @ HL-LHC

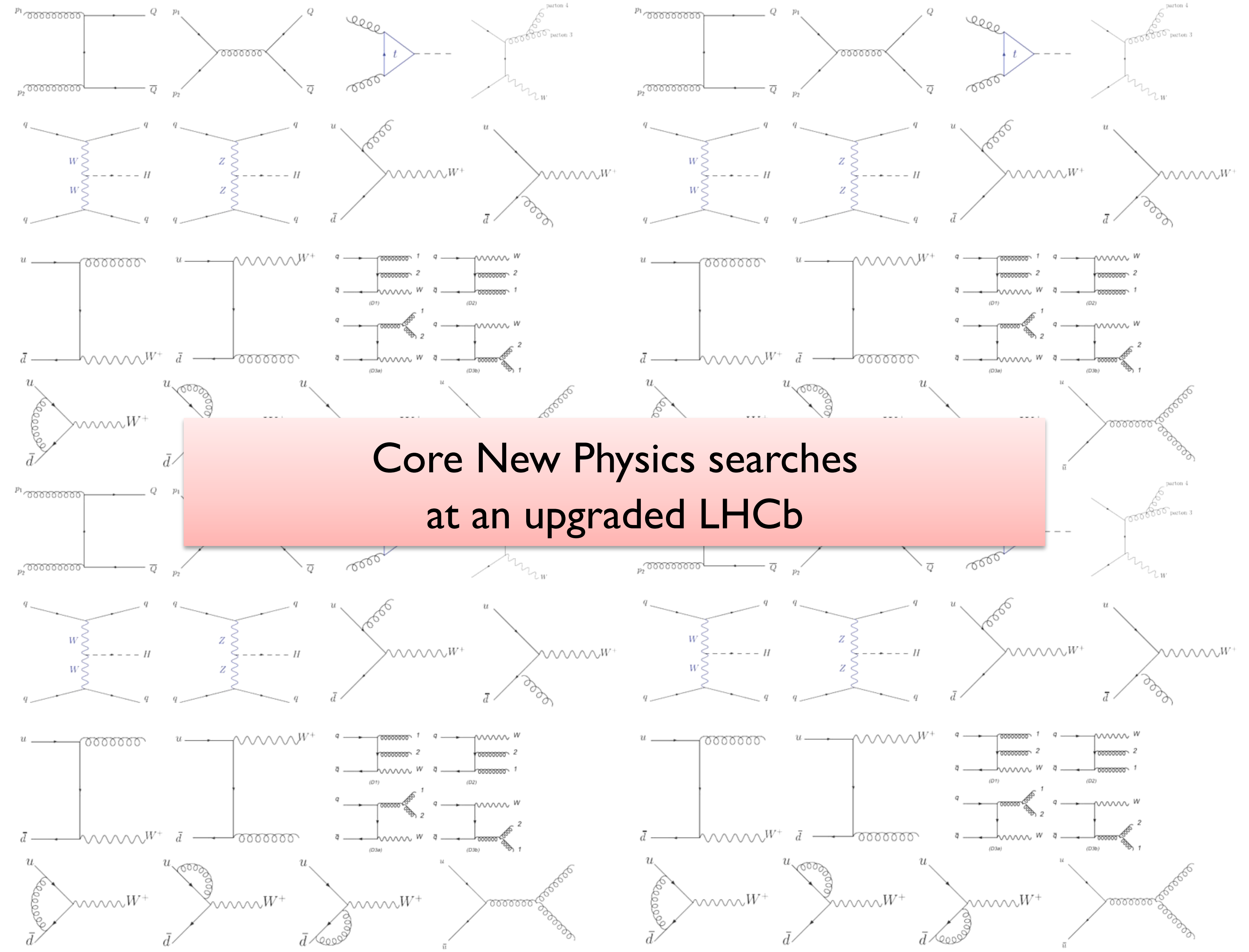
LHCb Upgrade preparation

2012-13 R&D, technology choices, subsystems TDRs

2013-14 Requests for approval/Funding/Start of productions

2015-18 Construction & installation

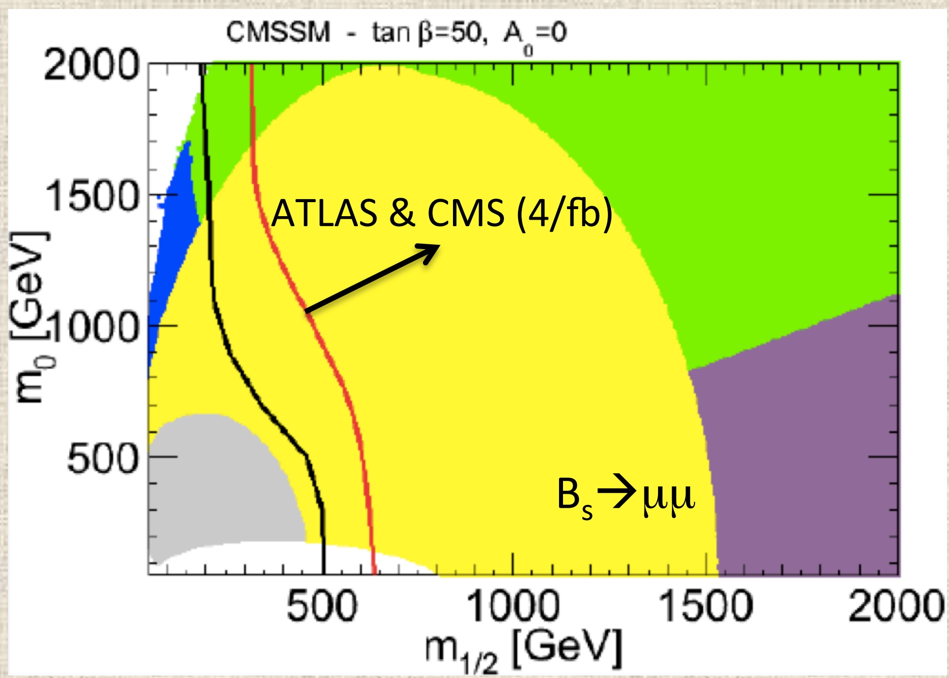
Core New Physics searches at an upgraded LHCb



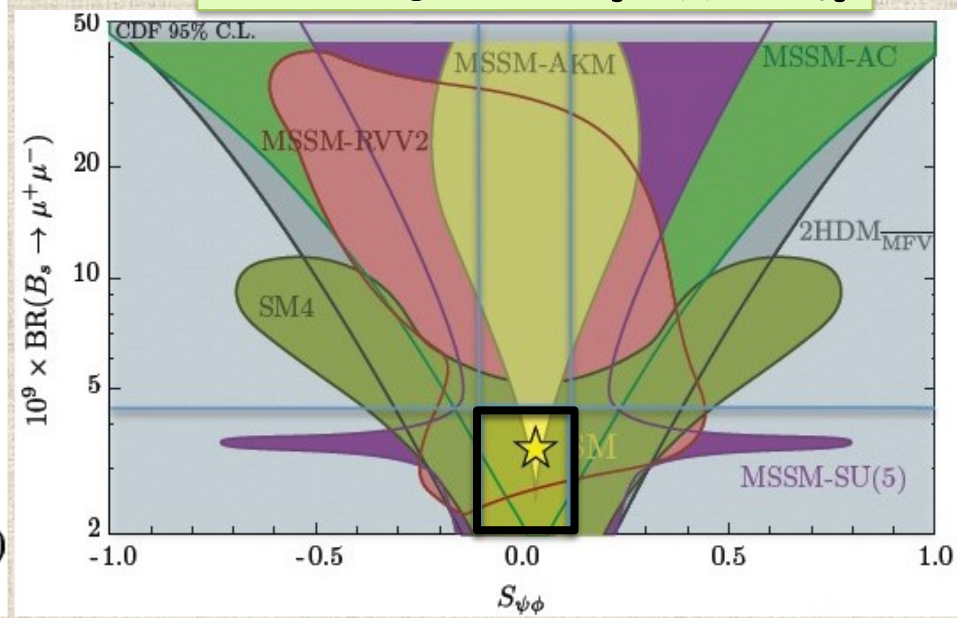
LHCb flavor results constraining New Physics

Already now BR($B_s \to \mu\mu$) puts strong bounds on mass scale (at least in high *tan* β models), complementary to direct searches in ATLAS & CMS

LHCb results enter the SUSY fits and moreover put severe bounds on several models



Allowed region from $B_s \to \mu\mu$ and ϕ_s



N. Mazhoudi, Moriond QCD2012

D. Straub [arXiv:1107.0266]

Future prospects (a personal view)

"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

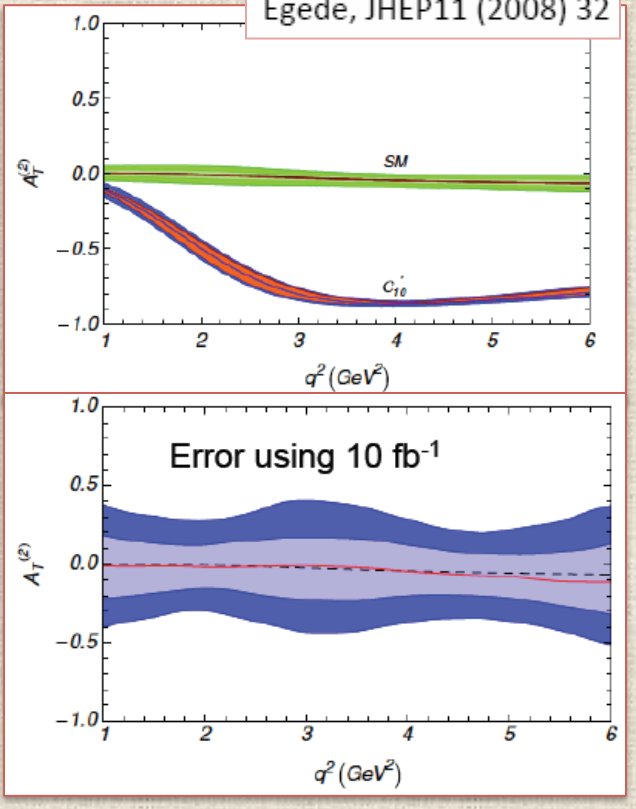
• $B_d \rightarrow K^*\mu\mu$

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 $1 < q^2 < 6\ GeV^2$

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

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

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

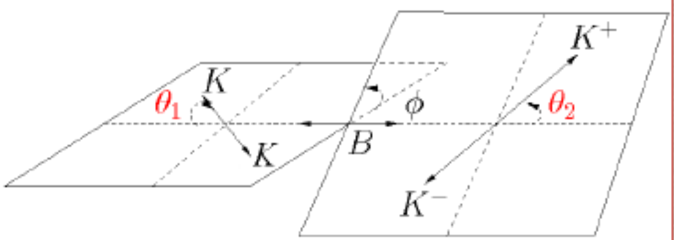


Yield (end 2017) ~ 12,000 ev
Yield (upgrade: ε x 1.5, **10^{33} cm^{-2}s^{-1}**) ≥ 8,000 ev/y

• $B_s \rightarrow \phi\phi$

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)

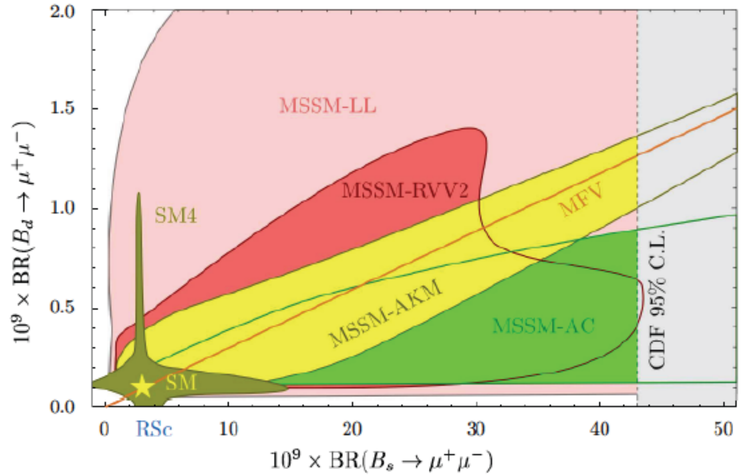


Yield (end 2017) ~ 12,000 ev
Yield (upgrade: ε x 3, **10^{33} cm^{-2}s^{-1}**) ≥ 15,000 ev/y

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

A large statistics is needed for a precise measurement of $B_{d,s} \to \mu\mu$ (in SM known at 10%) at the SM level and for discriminating theory predictions for $Br(B_s \to \mu\mu)$ / $Br(B_d \to \mu\mu)$ (known in SM at 5%)

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



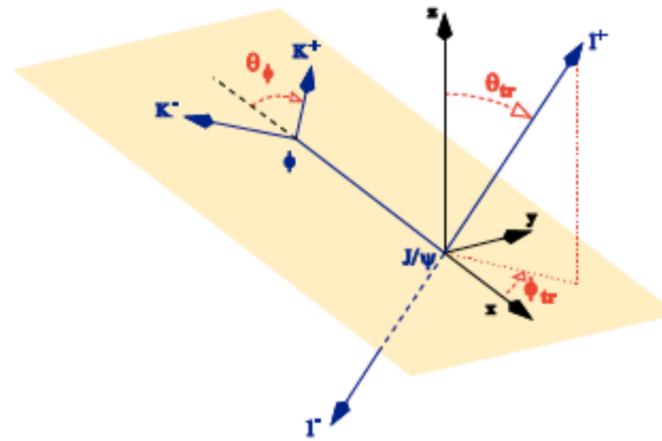
Competition with CMS & ATLAS (will depend on their capabilities of triggering and selecting signal events in high luminosity and high pile-up conditions)

Yield (end 2017) ~ 100 ev

Yield (upgrade, **10^{33} cm^{-2}s^{-1}**) ~ 50 ev/y (B_s) – 6 ev/y (B_d)

CP asymmetry in $B_s \rightarrow J/\psi\ \Phi$

- $B_s \rightarrow J/\psi\ \Phi$ measures the B_s mixing phase $-2\beta_s$ as $B \rightarrow J/\psi\ K_s$ provides the CPV phase 2β



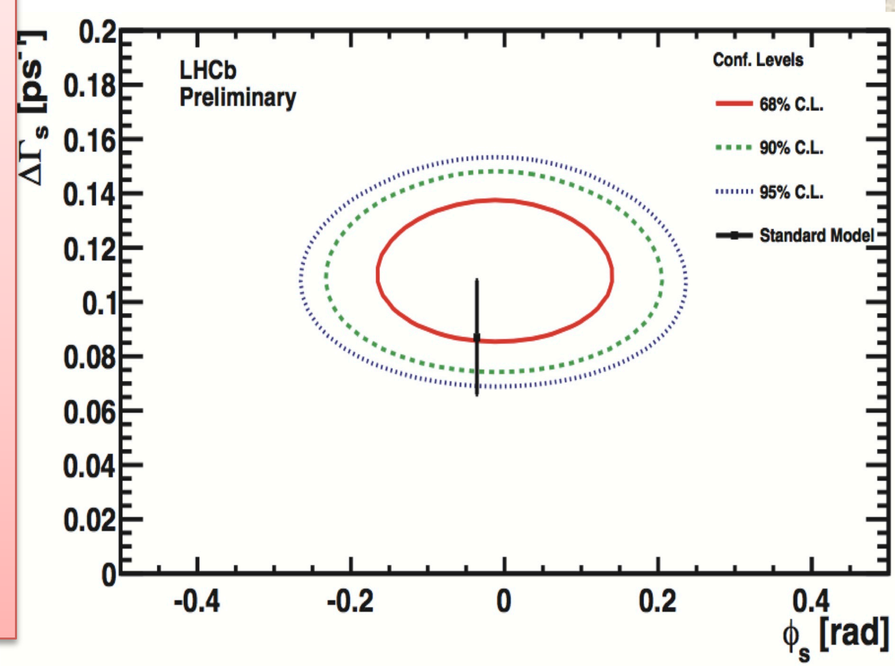
- $B_s \rightarrow J/\psi\ \Phi$ is a vector-vector final state
  - Angular analysis required
  - $\Delta\Gamma_s/\Gamma_s$ is a parameter of the fit

Clean prediction from SM (0.41± 0.01)

Yield (2017) ~ 300 kev (+ better FT) with an expected error $2\beta_s$ ± 0.03
Yield (upgrade, **10^{33} cm^{-2}s^{-1}**) ~ 150 kev/y

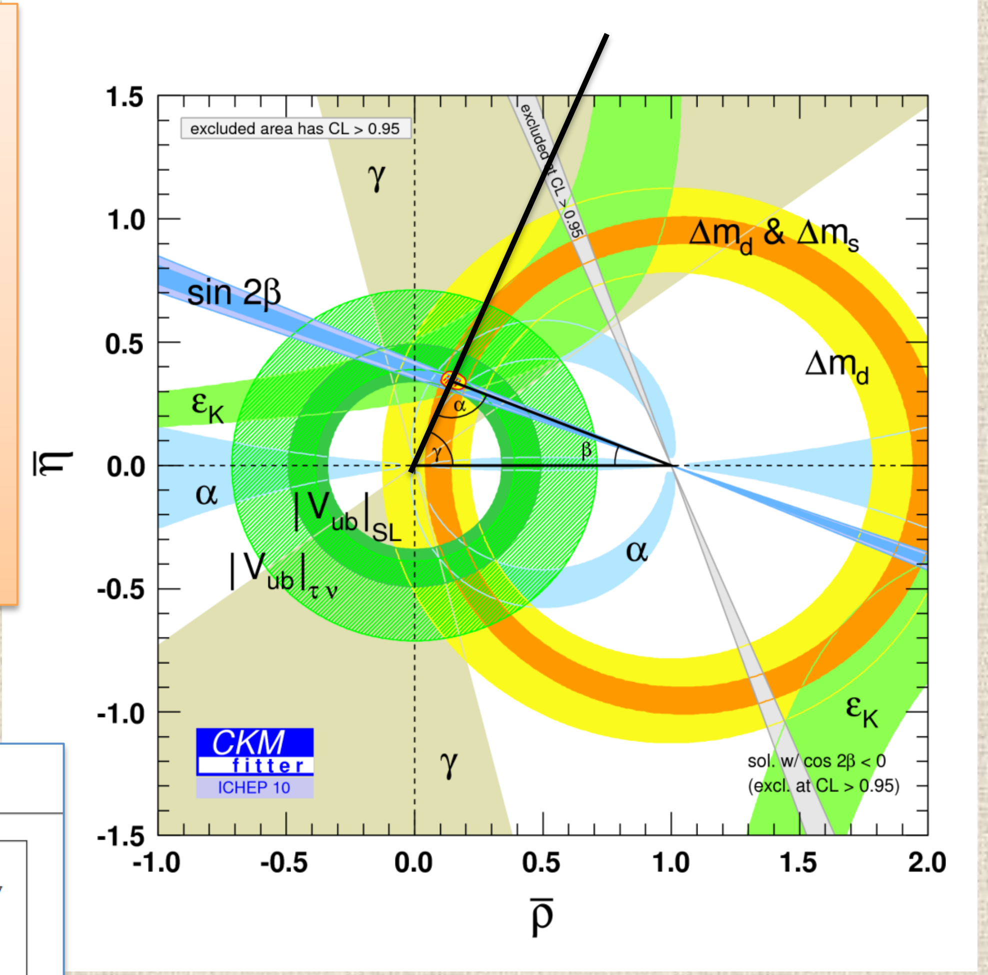
- Efficiency can profit from sw trigger
- Other final states can be considered
  ($\psi\ f_0$, $D_s\ D_s$)

- With 50 fb^{-1}, error on $2\beta_s$ is reduced to ± 0.008 (stats only)

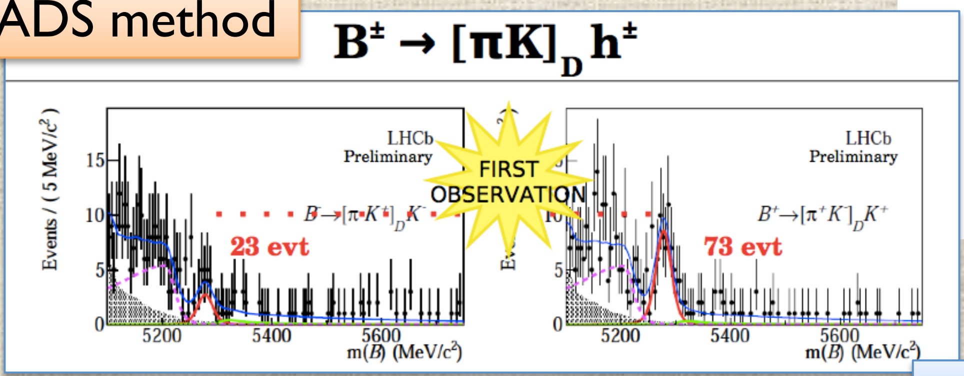


The measurement of γ at LHCb

- Present uncertainty on γ ~ 20°
- Many different ways to measure γ in LHCb (time averaged and time dependent, in trees and loops)
- With 5 fb^{-1} precision to few degrees
- Better than 1° with the upgrade in the tree-decays: strong constraint on fit to NP



ADS method



arXiv:1203.3662

$\tau \to \mu\mu\mu$

- Depending on the model $\tau \to \mu\mu\mu$ can be dominant over $\tau \to \mu\gamma$
  → e.g. Little Higgs w/ T parity or doubly charged Higgs

- Current world leading limits from Belle and BaBar of 2.1×10^{-8} and 3.3×10^{-8} respectively at 90% CL
- Approaching sensitivity needed to exclude/constrain NP models, for example:

NP model	Ref	$\tau \to \mu\mu\mu$ 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}

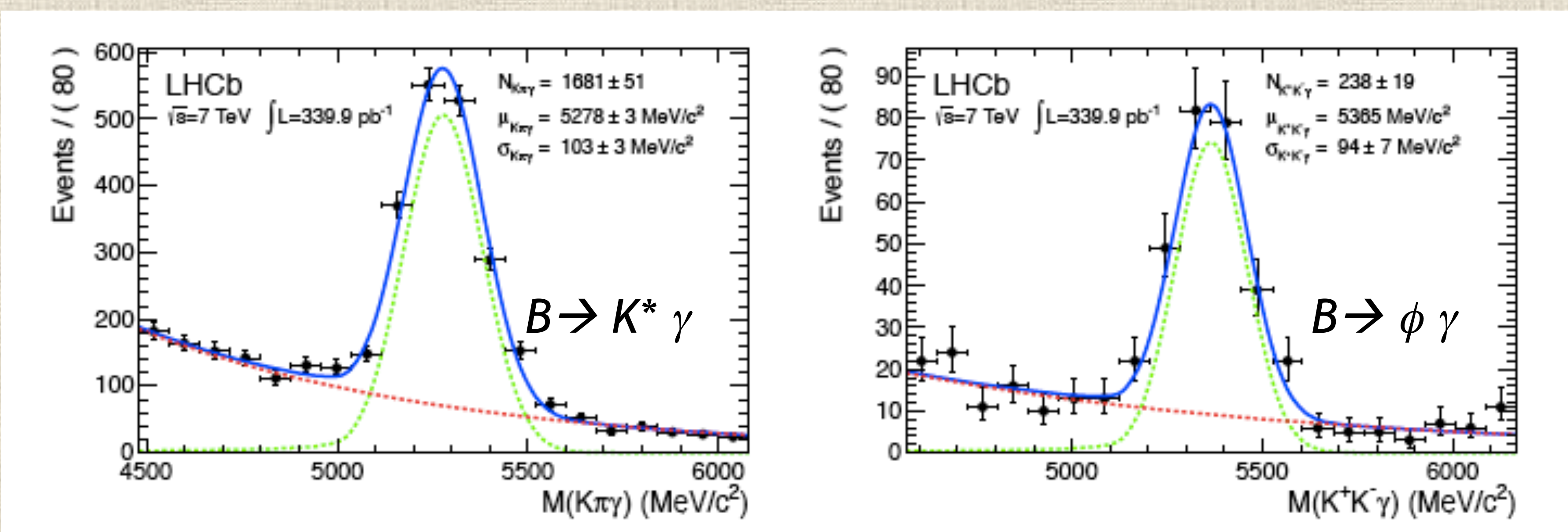
LHCb is well suited to perform this measurement, as it has a low threshold p_T for muons
Preliminaries studies with Multivariate Analysis techniques show a good potential of LHCb in this area (~ 6 10^{-8} at 90% CL with 1/fb, paper in preparation)

$b \to s\gamma : B_s \to \phi\gamma$

- $B_s \to \phi\gamma$: Time dependent decay rate
  - SM: photons are predominantly ($O(m_s/m_b)$) left polarized: no interference B_s and $\overline{B}_s$
  - Observed CP violation depends on polarization and weak phase.
    - Sizeable $\Delta\Gamma_s$ allows measurement A_Δ:

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

LHCb is performing well in photon energy resolution (those expected from MC).
The effect of pile-up (~4) on resolution to be studied



Charm Physics

- 2010:
  - With 37 pb^{-1} collected charm samples of $D^0 \rightarrow h^+h^-$ comparable to B-factories
- 2017 :
  - 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 ~ 2 kHz

Upgrade yields: 14 Tev (x2), trigger (≥4), Luminosity (≥2.5) → well beyond ≥10

At 10^{33} cm^{-2} s^{-1} , several MHz of charm events at Trigger Level 0
Samples of O(10^{10} events) for most channels
Most probably limited by HLT output: O(10 kHz)
Enormous gain in multi-body decays and with K_s in the final state

LHC is a real charm factory, allowing to access asymmetries in rare modes ($D \rightarrow V\gamma$)

Sensitivities to key flavour channels

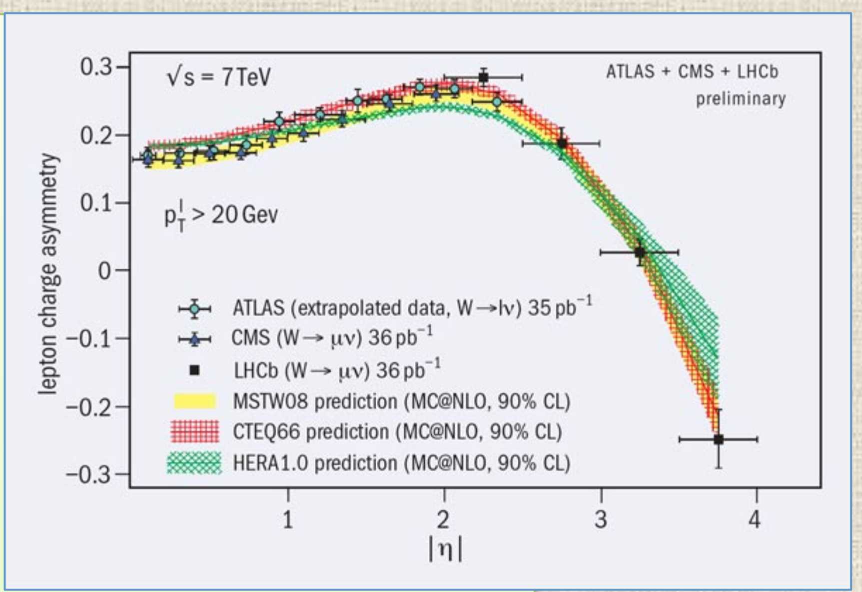
Type	Observable	Current precision	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	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	$\gamma\ (B \to D^{(*)}K^{(*)})$	$\sim 20^\circ$ [19]	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 errors will not be trivial !

Non flavor physics

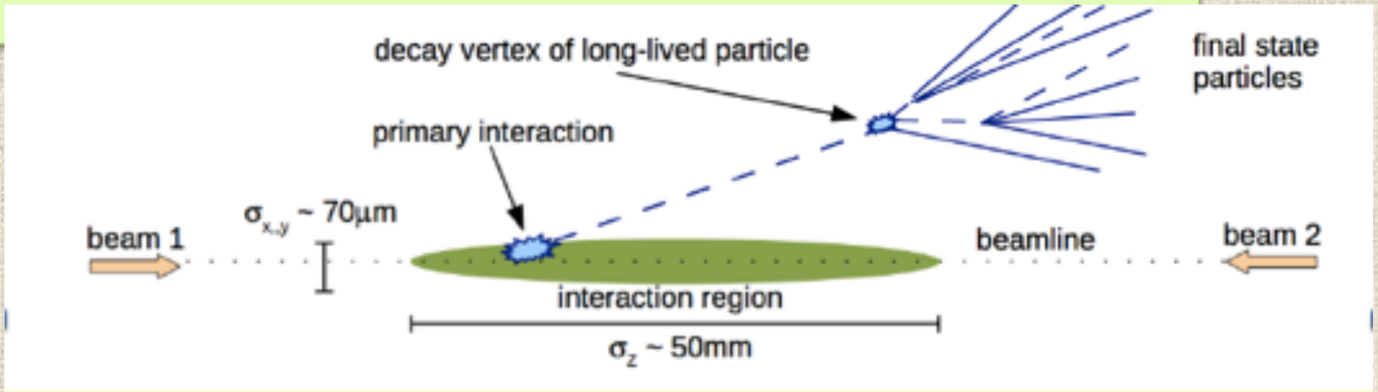
- **Electroweak physics & QCD**

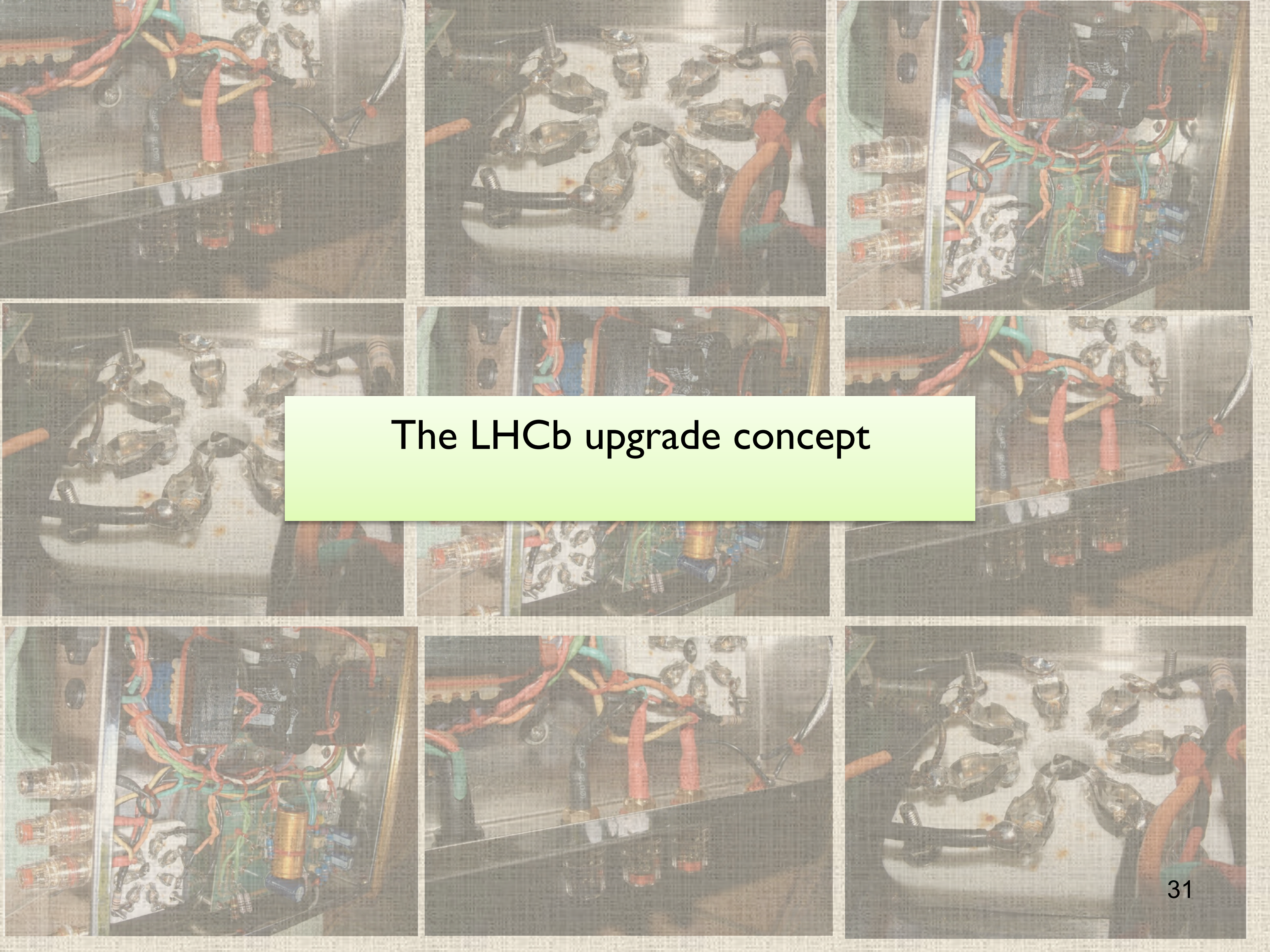
Measurement of the PDF in a unique pseudo-rapidity range
With high statistics, measurement of $\sin^2\theta_W$ at 0.0001 using A_{FB} in $Z \rightarrow$ leptons
Study of low p_T forward process
Central exclusive production



- **Exotics**

Interest for "hidden valley" models made of long lived particle decaying into b-quark jets
Higgs decaying into v-flavored hadrons ($H^0 \rightarrow \pi^0_v \pi^0_v \rightarrow$ bb jets)
Direct and indirect searches for Majorana neutrinos
For this class of events LHCb will be able to run special triggers





The LHCb upgrade concept

The present LHCb Trigger Flow

L0 bandwidth sharing and p_T thresholds are set to reduce min. bias and maximize physics output (max rate = 1 MHz)

- ~500 kHz for hadronic trigger (E_T > 3.5 GeV)
- ~200 kHz for $e/\gamma/\pi^0$ (p_T > 2.5 GeV)
- ~250 kHz for $\mu/2\mu$ (p_T > 1.4 GeV)

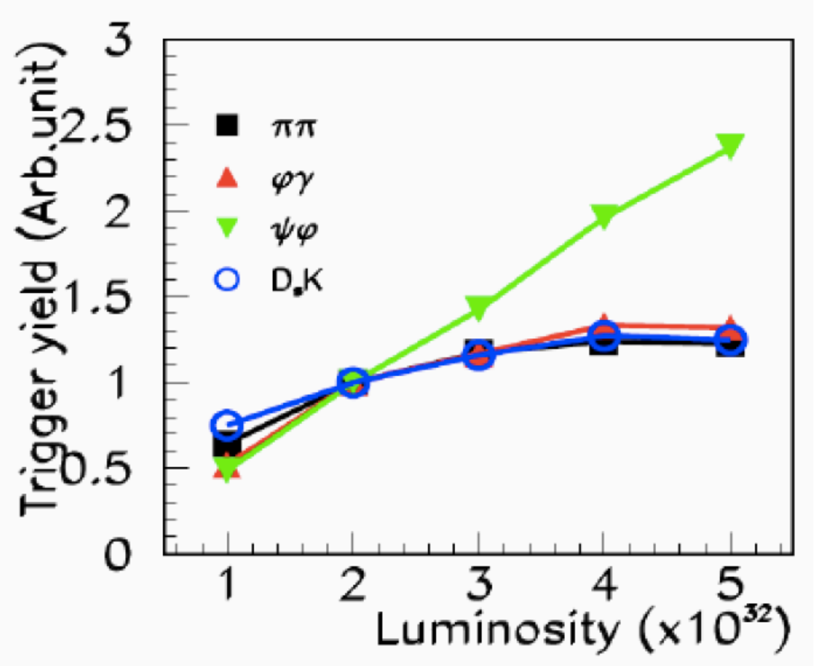
HLT1 confirms L0 using IP and a partial reconstruction of the event (→ 40 KHz)
HLT2 performs exclusive/inclusive refined selections (→ 4 kHz on tape)
L0xHLT have an efficiency of ~20-40% on hadronic and of ~ 80% on di-μ channels

With the present readout (1 MHz) 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)



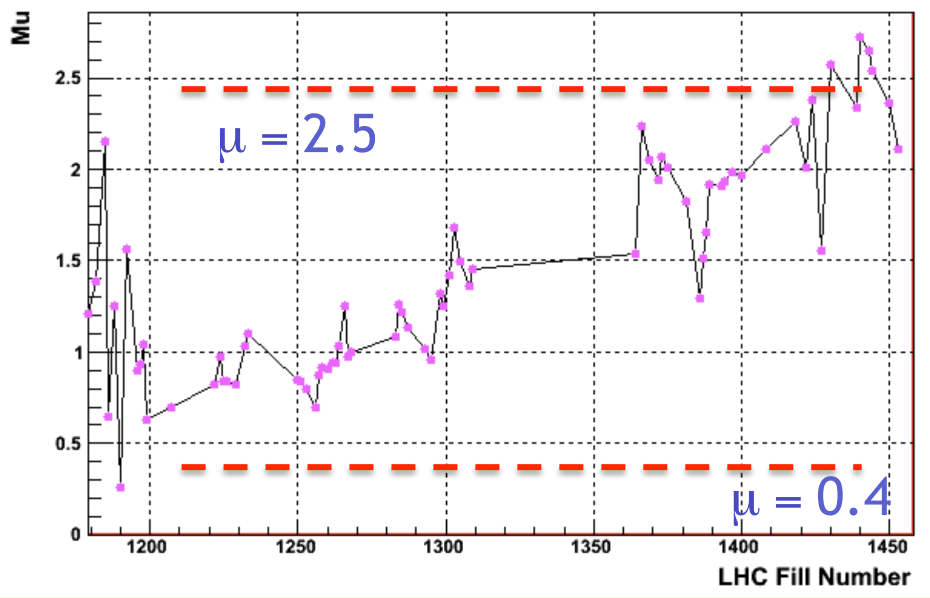
LHCb test of High Luminosity environment

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

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

At $2\ 10^{33}\ cm^{-2}\ s^{-1}$ (and $\mu = 4$) with 25 ns bunch spacing, important effects will start: spillover, occupancy and ageing



The current 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" a part of detectors (Outer Tracker, RICH, Calo, Muon)

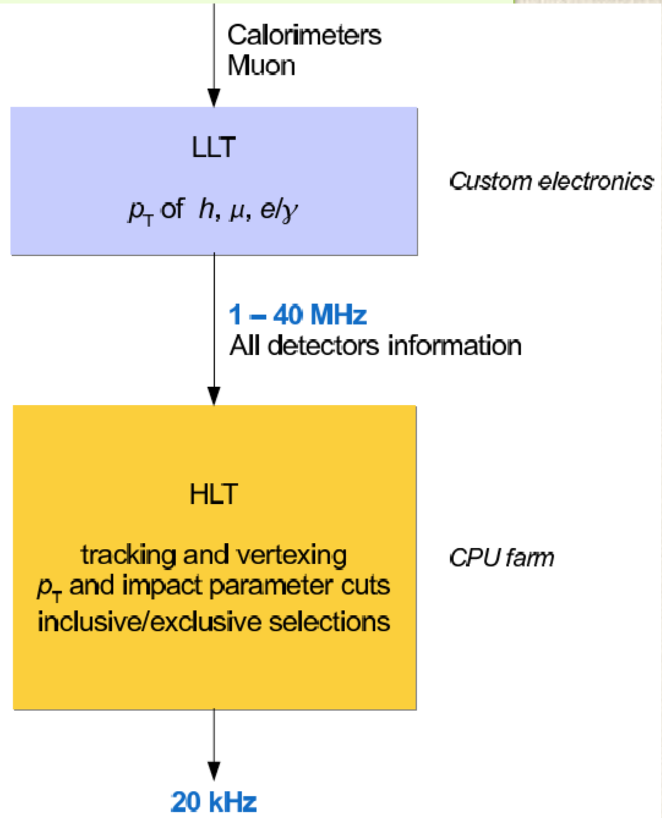
The LHCb baseline upgrade

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

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

We must ensure also the maintenance (consolidation) of several sub detectors to sustain aging/rate increase:

- Outer tracker (straw tubes)
- Calorimeters (lead, iron and scintillator)
- Muon system (MWPC and Gems)



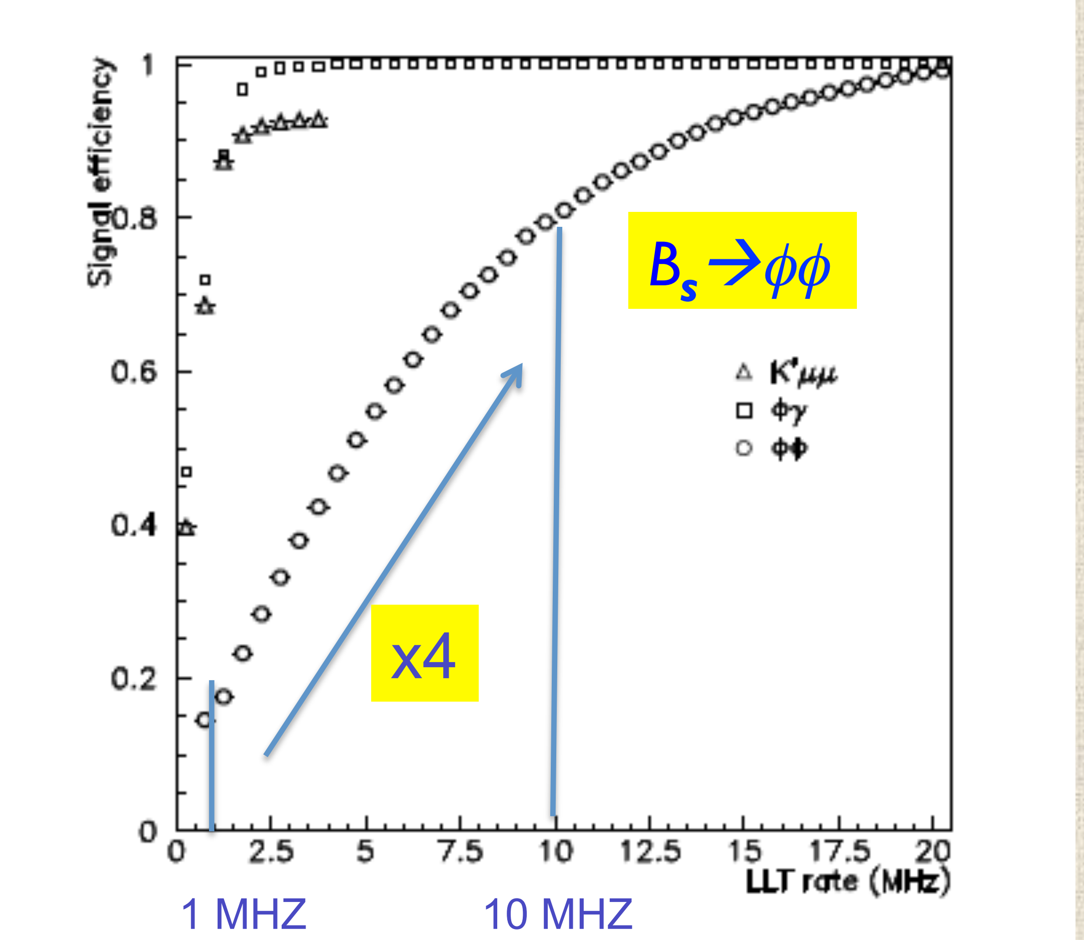
The effect of an upgraded trigger (case of $B_s \rightarrow \phi\phi$)

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

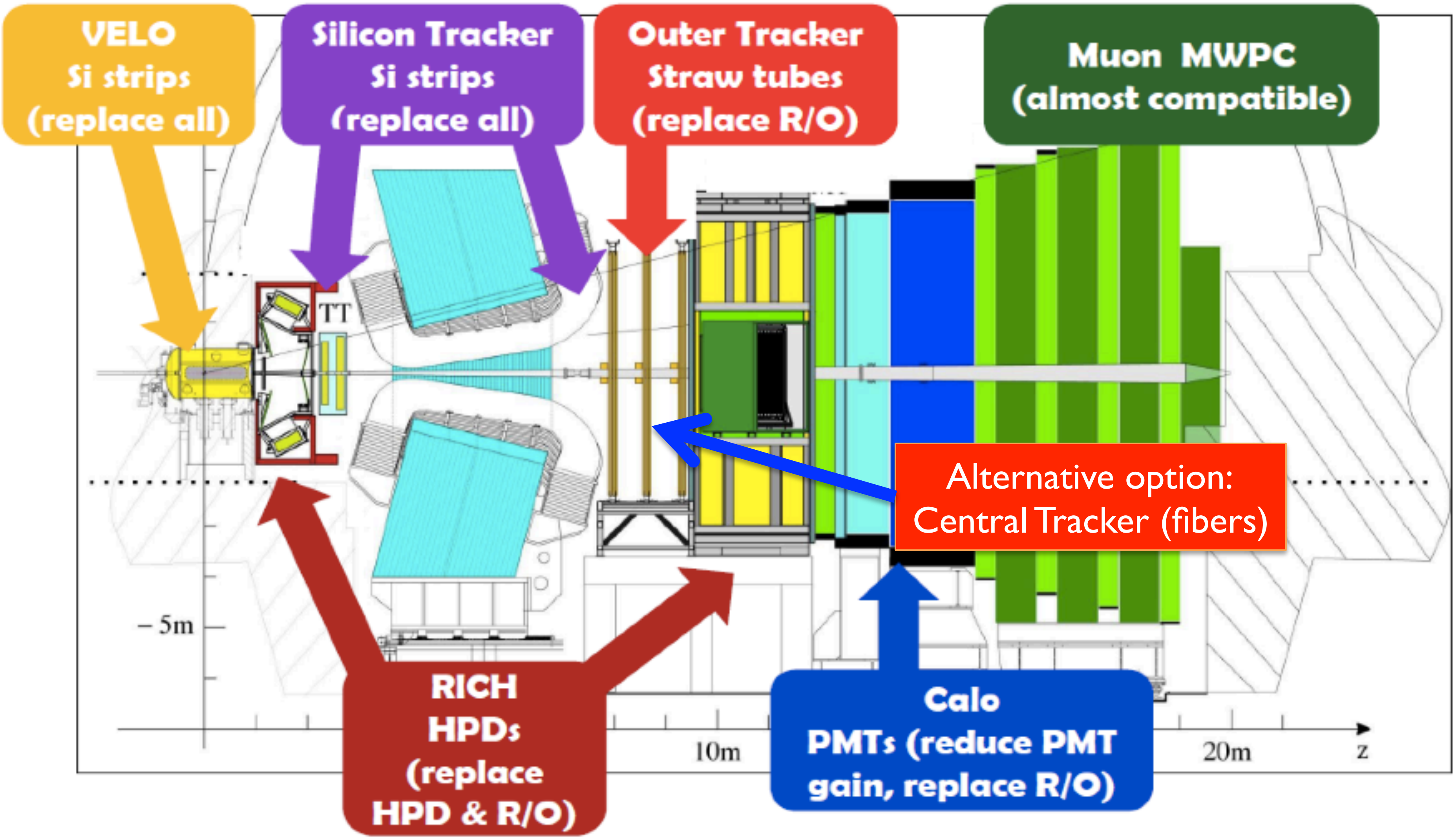
In this particular example x4 at 10 MHz of LLT (which we consider optimal for initial farm size)
Other key channels will gain ($B_s \rightarrow \phi\gamma$, $B_d \rightarrow K^*\mu\mu$, $B_s \rightarrow \psi\phi$)

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

The problem is to readout them
All, due to high purity of the sample
Now: 3 kHz data taking →
Upgrade: 20 kHz data taking (challenging)



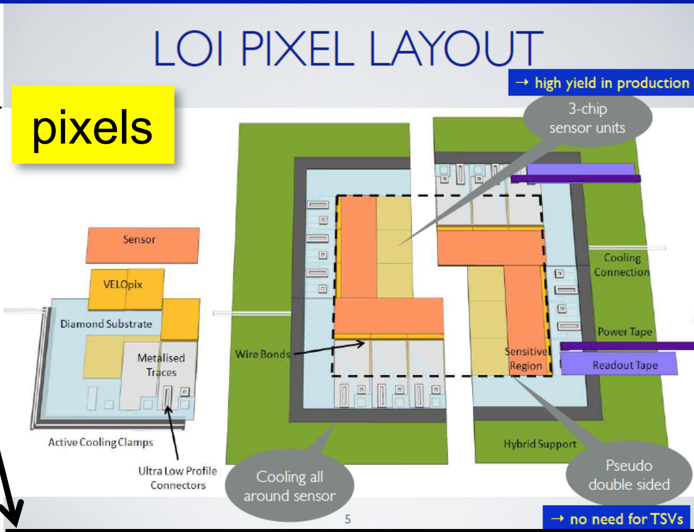
LHCb detector modifications for the upgrade

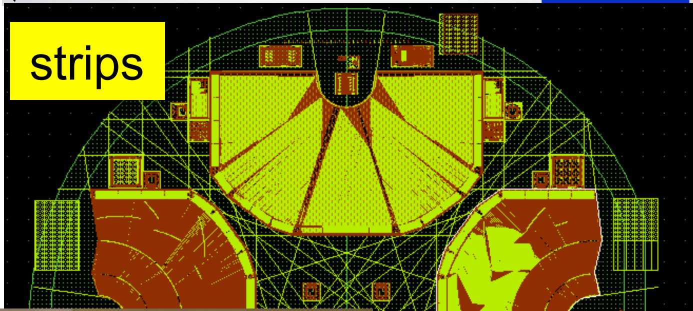


VELO

- Completely new modules and FE electronics
  - Two major options under consideration
  - Strips have been done already (very well) but 40 MHz implementation pushes boundaries
  - Pixels have good synergy with other projects (e.g. ATLAS IBL, rad hard, due 2014, NA62, mechanics, electronics, due 2013)

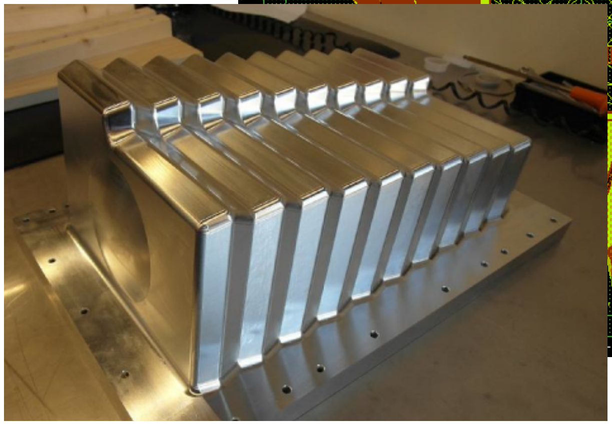
  Must be
  - Capable of dealing with huge data rate
    - > 12 Gbit/s for hottest pixel chip
    - On-chip 0-suppression
  - Able to withstand radiation levels of ~ 370 MRad or 8 x 10^{15} n_{eq}/cm^2





Common developments:

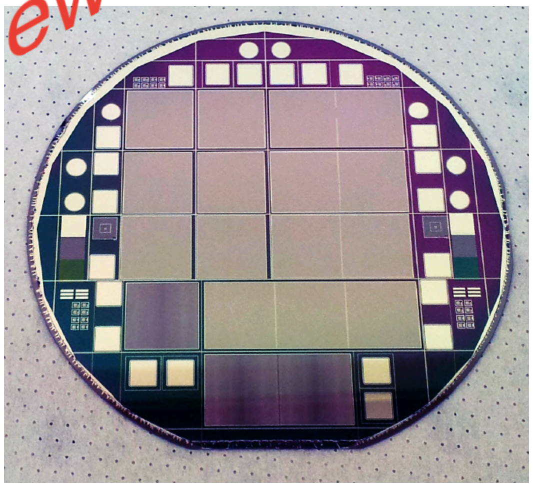
- completely new module cooling interface
- New RF foil
- All without sacrifices in material budget



Sensors

- Rad hard, slim edge planar pixel sensors in development at CNM, Micron, VTT and Hamamatsu

New

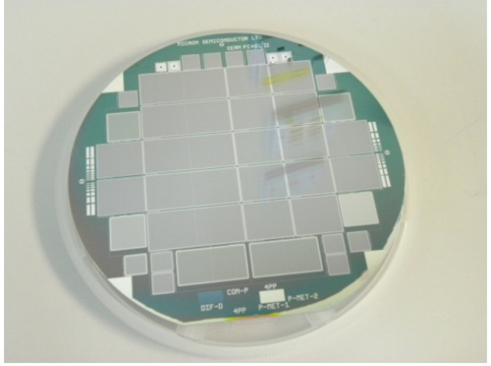


CNM-USC LHCb Medipix/Timepix wafer

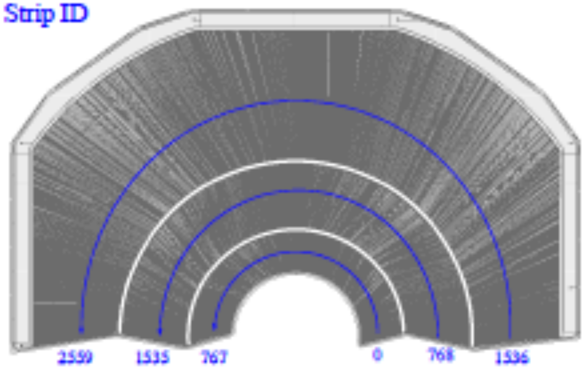
R&D on:
Multi-ASIC bump-bonding on thin sensors
Minimal guard ring design, slim edges: trenches, sidewall Al_2O_3
Minimization of dead areas inter ASICs: elongated pixels, routing

- Strip sensor Development in progress with Hamamatsu
- Production launched and sensors expected Q1 2012
- Extensive QA and testing facility under development :
  - Clean room with bonding machines, pull tester, probing stations, metrology, N2 storage etc.
  - Several fine pitch strip prototype modules manufactured and tested in Timepix testbeam as "dress rehearsal" for Hamamatsu delivery
  - Including pitch adapters designed and built

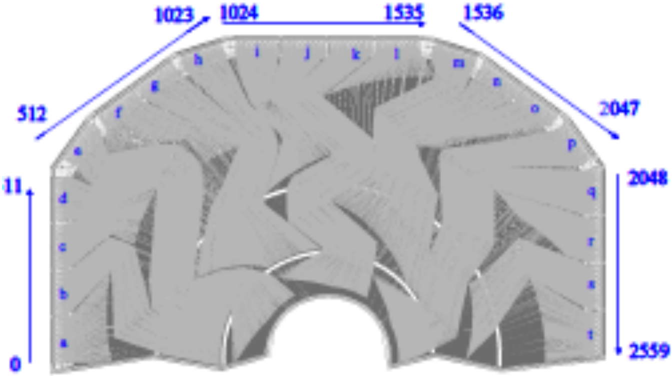
Micron wafer



Strip ID



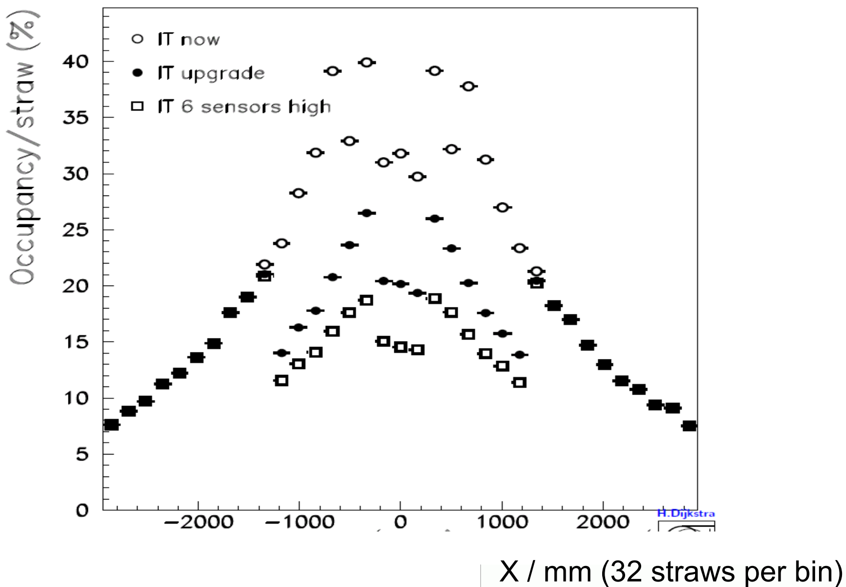
Bonding PAD ID

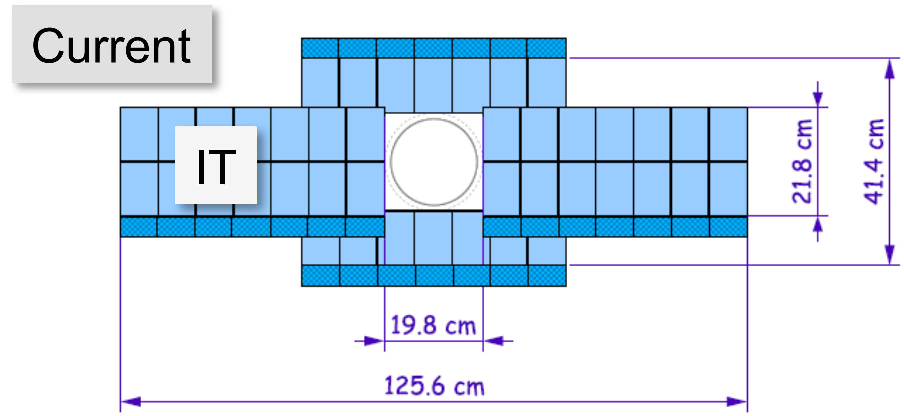


Common challenge of pix. and strips: **cooling**!

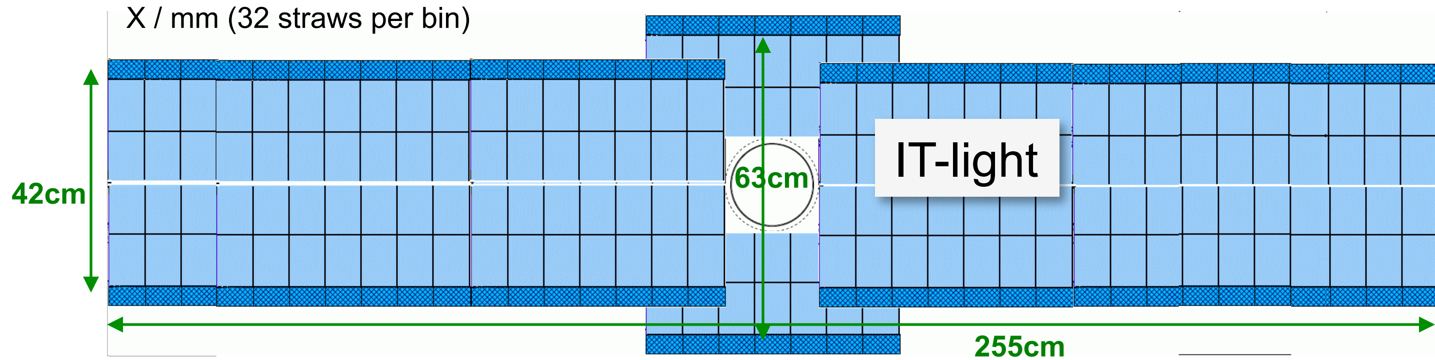
Tracking option 1: Silicon IT "IT light and large"

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





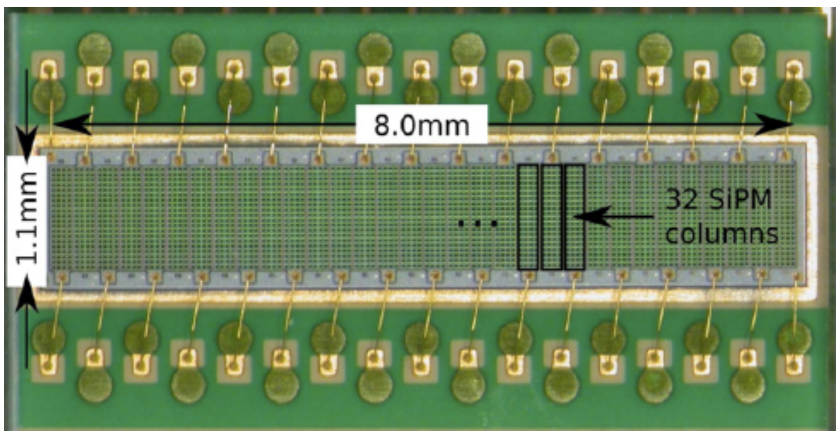
Challenges:
- Mass reduction
- Cost

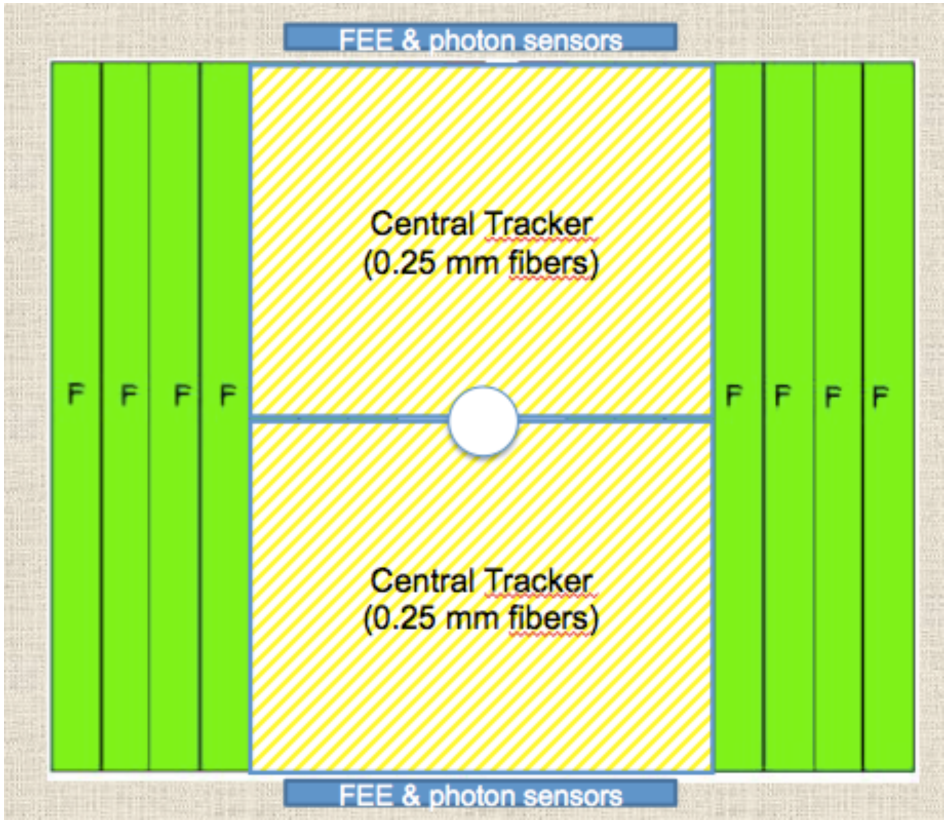


- From 126x22(41) cm to 255x42(63) cm
- Increase number of sensors/layer by nearly factor 4, $\times 3.3$ for 10 layers.
- "η" coverage: IT/(IT+OT)= $33\% \rightarrow 54\%$

Tracking option 2: SciFi Central Tracker

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

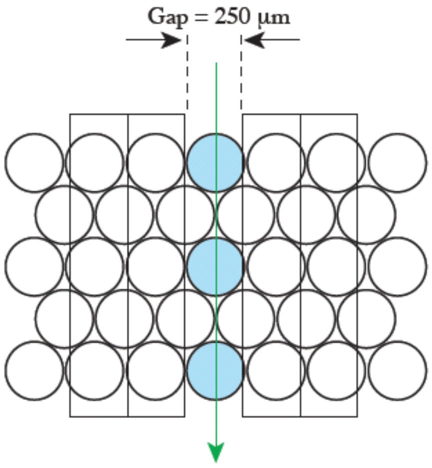




- 5 layers of densely packed 250μm diameter fibers, readout with 128-channel Silicon Photomultipliers (SiPM)
- 2×2.5m long fibers, readout on top and at bottom of stations
- No silicon IT (if it Sci.Fi. can sustain the occupancy and radiation)

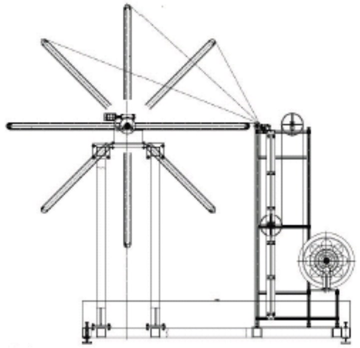
SciFi R&D

- **128-channel SiPM**
  - Hamamatsu sensors made of two 64-channel chips
    - work on minimizing inactive area between chips and sensors
  - alternative SiPM under development with KETEK
  - SiPM radiation hardness studies (see next slide)

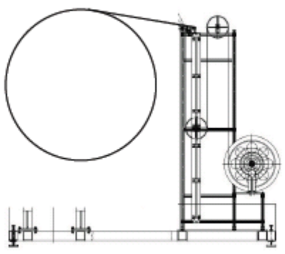


- **SciFi module**
  - 2.5m-long module production technique in development
  - existing solution developed and tested for modules up to ≈80cm long
  - ⇒ can be adapted for longer modules
  - SciFi radiation hardness under study (fibers + glue)

- flat frame



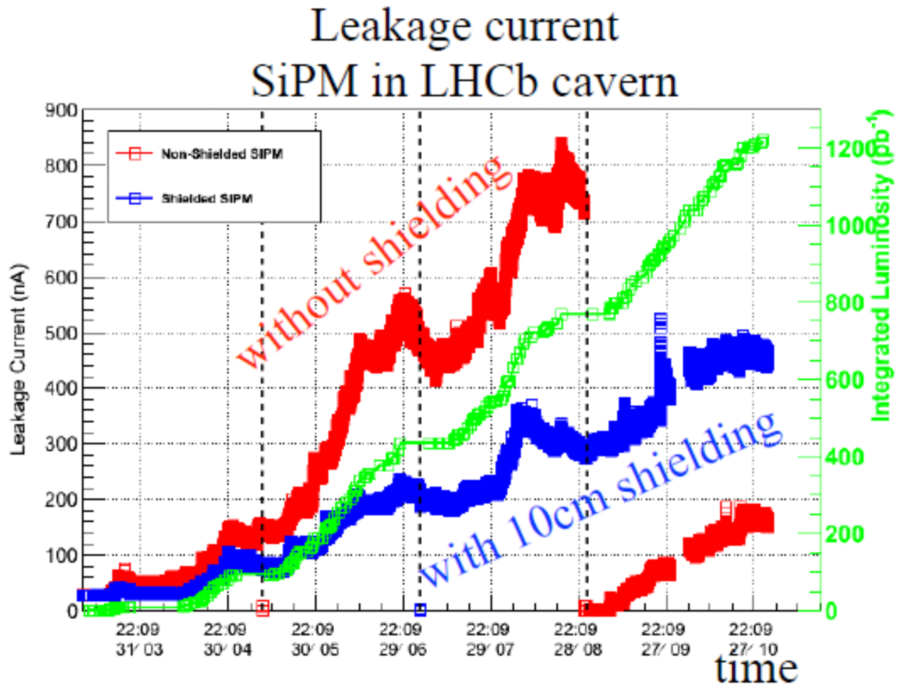
- big wheel (modified Aachen style)



- **Front-end electronics:**
  - design options under study (dependent on ongoing simulation studies)

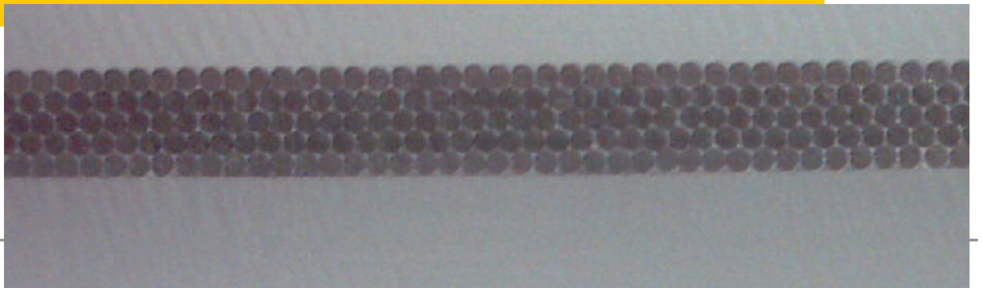
SciFi : SiPM radiation hardness

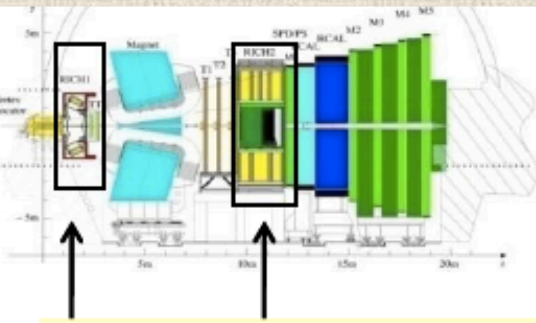
- SiPM radiation hardness is one of the main questions
- Ongoing studies:
  a) in situ SiPM samples with and without shielding
     - compare measurements with FLUKA simulations
  b) irradiation with neutrons and with protons
  c) effects of cooling



- Solution is taking shape, as a combination of:
  1. improved technology (with manufacturer)
  2. shielding (gain factor ~2 on leakage current)
  3. active cooling of SiPM (factor 2 every 8-10°C)

Test module (2.5 m length) built wiring the fiber (as a MWPC)

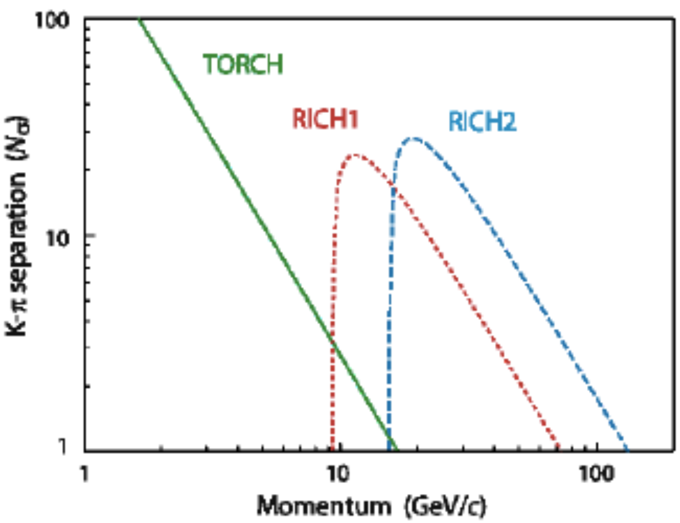




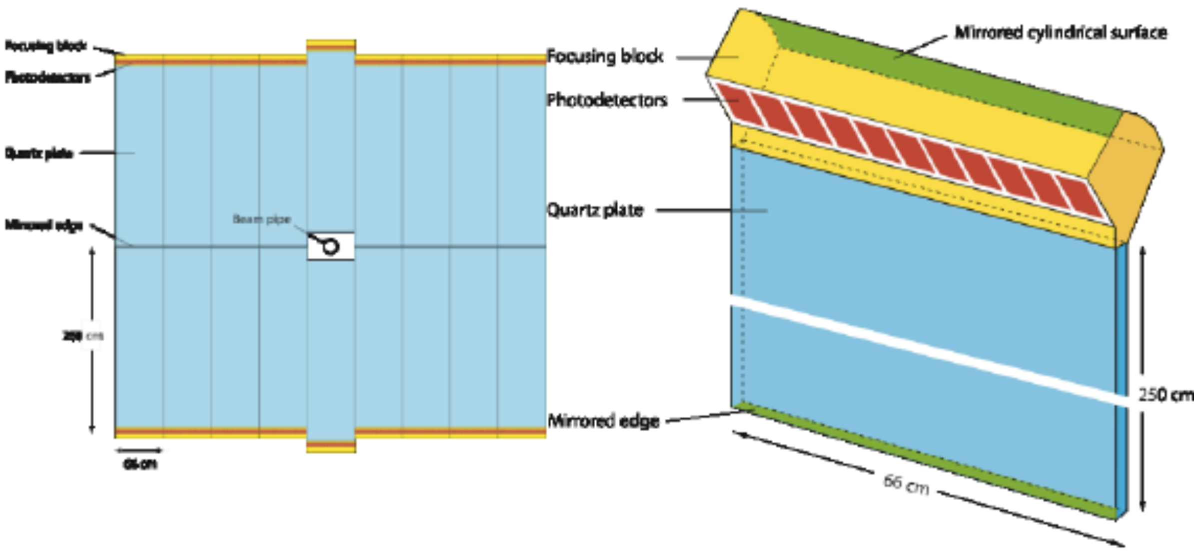
Particle ID

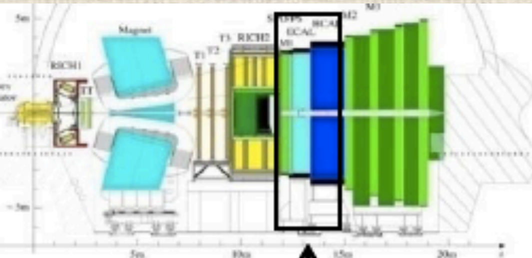
- RICH-1 and RICH-2 detectors remain
  - Readout baseline: replace pixel HPDs by MaPMTs & readout out by 40 MHz ASIC
  - Alternative: new HPD with external readout
- Low momentum tracks: replace Aerogel by Time-of-Flight detector "TORCH"
  (=Time Of internally Reflected CHerencov light)
  - 1 cm thick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

K-π separation vs p in upgrade:



TORCH detector:

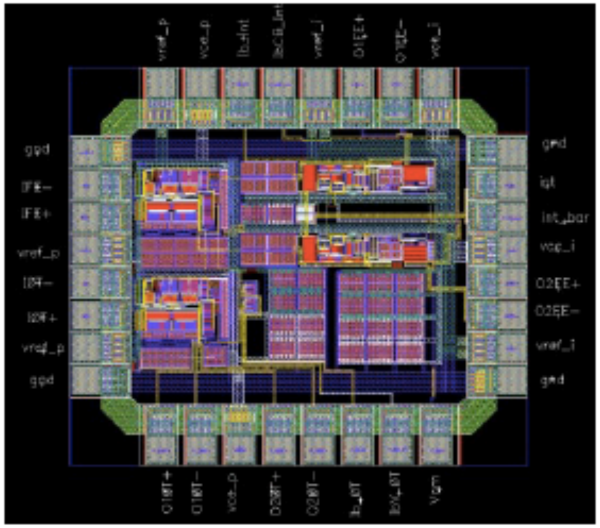




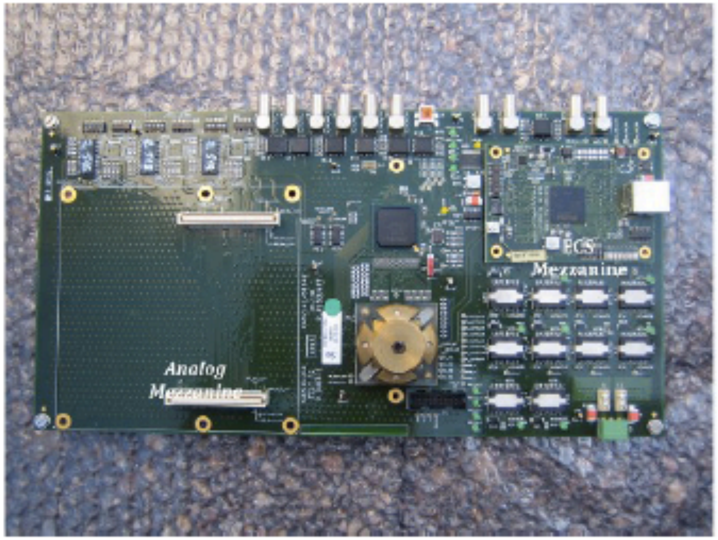
Calorimeters

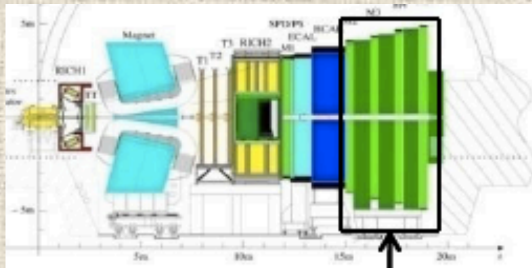
- ECAL and HCAL are maintained
  - Keep all modules & photomultipliers (reduce gain in upgrade)
- PS and SPD will be removed
  - (e/γ separation provided by tracker)
- Front End electronics modified for lower yield and to allow 40 MHz readout

ASIC prototype



New digital electronics prototype

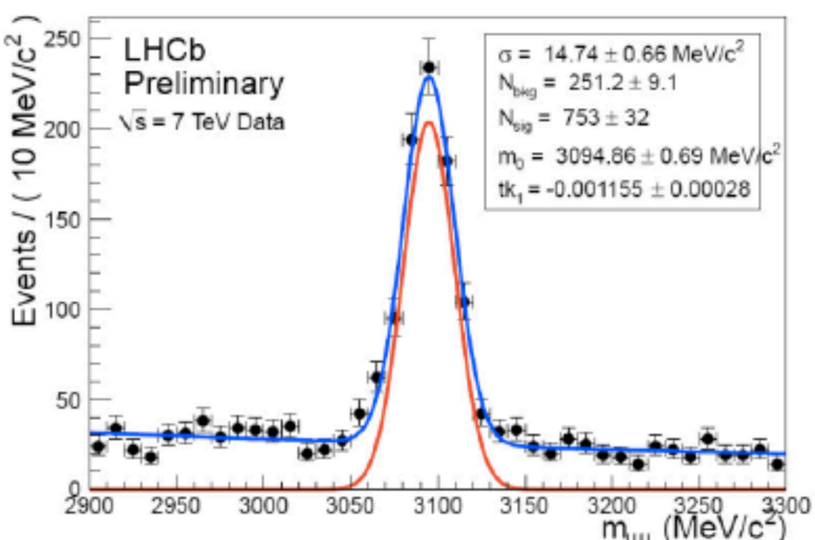




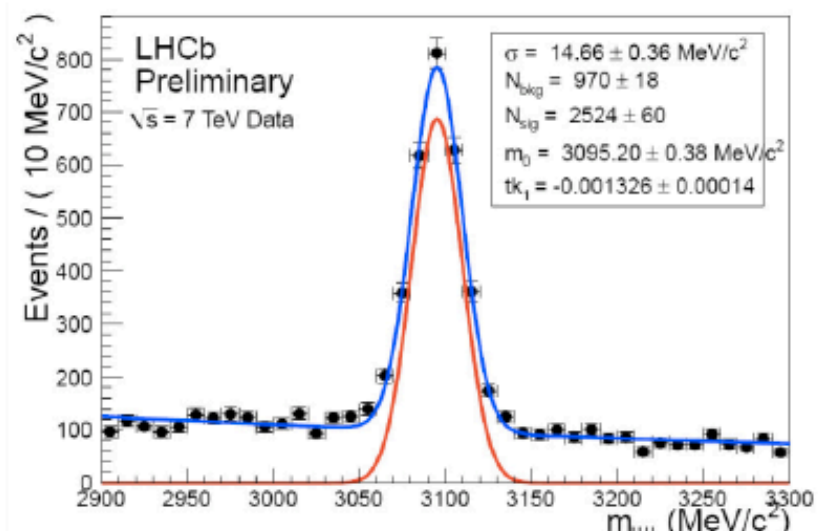
Muon Detectors

- **Muon detectors are already read out at 40 MHz in current L0 trigger**
  - Front end electronics can be kept
  - Remove detector M1
- **Performance at higher occupancy: OK**
- **Investigations:**
  - MWPC aging : tested at CERN to 10^{33} level and 50 fb^{-1},
  - Rate capabilities for HV being investigated
    - Malter like effect that can be cured by conditioning the chambers,

$J/\psi \rightarrow \mu^+\mu^-$ for single PV events



$J/\psi \rightarrow \mu^+\mu^-$ for events with <PV>=2.3



Conclusions

LHCb performed well in the 2011 data taking and in the 2012 startup (a particular thank to LHC team for the careful tuning of our instantaneous luminosity !)

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

Looking forward to increase the statistics in 2012 and later in 2015-17

Standard Model remains "un-cracked" but still large room for New Physics: LHCb is complementing ATLAS & CMS searches for Supersymmetry

Upgrade goal: reaching ultimate theoretical errors in flavor variables and search for unexpected phenomena in the forward region: ~ 50/fb needed

The upgrade of the LHCb Detector is taking shape