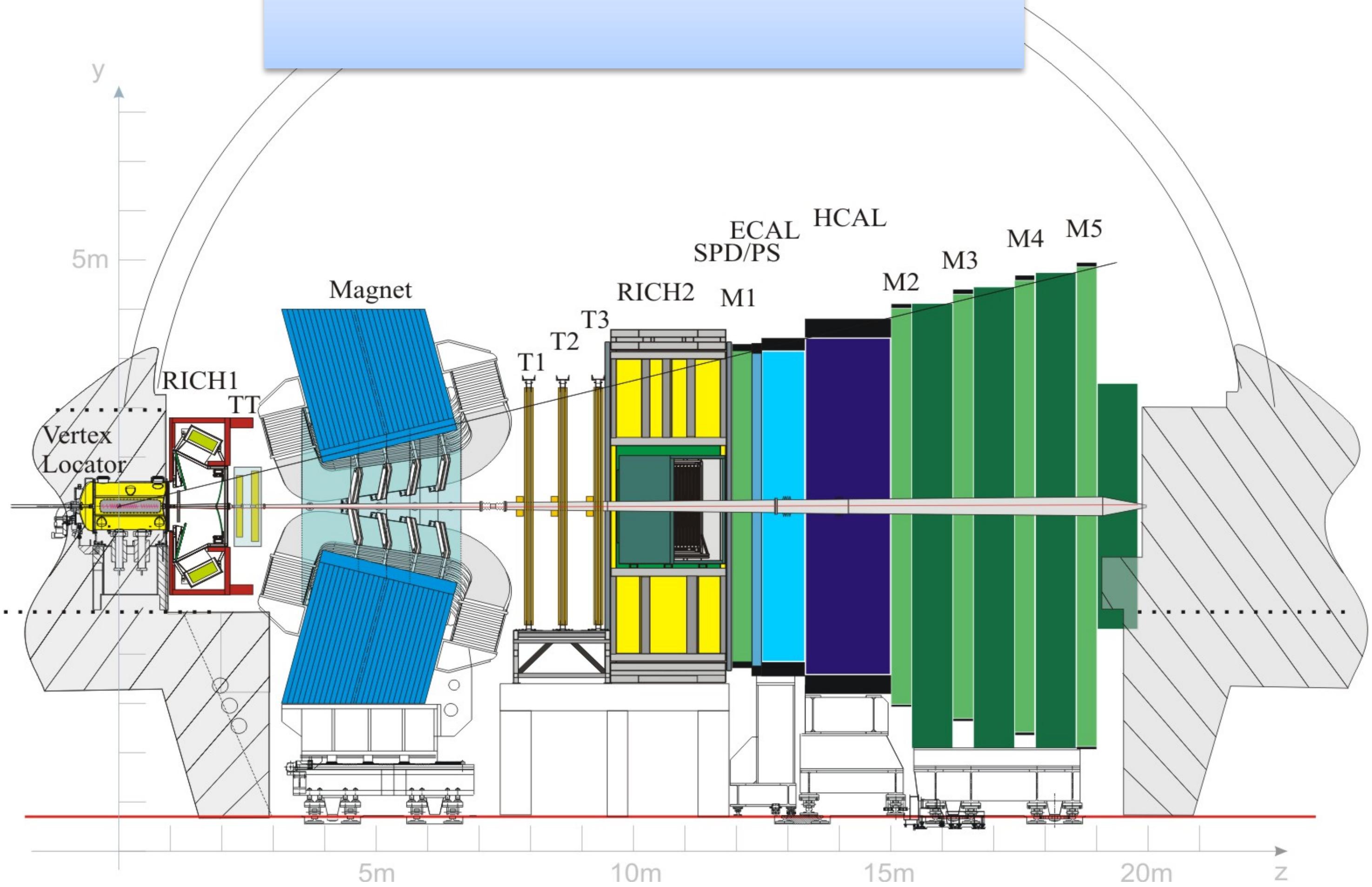
L’upgrade di LHCb



CSN1 – Firenze 21.11.11 – P. Campana (CERN/LNF)

The LHCb data taking perspectives

Based on 2011 experience, and running at 4 10^{32} $cm^{-2}s^{-1}$, LHCb can collect ~1.5/fb per year (in 5 10^{6} s at ε=0.25)

- 2.5/fb at 7 TeV and 4.5/fb at 14 TeV (σ_{bb}=0.3 mb @7 TeV, 0.6 mb @14 TeV)

In 2017 → x 12 the present sample

Understanding New Physics phenomena will need more statistics. Upgrade Plan

- L = 1-2 10^{33} $cm^{-2}s^{-1}$ → 4-8 fb^{-1} per year

To profit of an increase in luminosity, it is required to overcome the current hardware limitation of 1 MHz L0,
→ reading-out all the sub detectors at 40 MHz,
and to deploy a FULLY software and flexible HLT trigger

This will more than double the yields for hadronic triggers ($B_s \to \phi\phi$, DK, charm, etc..), collecting ≥ 10 times more events

Why the LHCb Upgrade ?

The flavor sector offers a very rich complementarity to the High Energy Frontier searches for New Physics

Recent LHCb results have shown the potentialities of Flavor Physics at LHC

LHCb is unique for NP searches in B_s (and works well for B_d and charm)

LHCb is unique in his forward geometry (also for non flavor physics)

LHC is a fantastic machine and can be tuned to LHCb needs. S-LHC is not necessary for LHCb upgrade

LHCb upgrade has a moderate cost and a well defined time plan

The Collaboration is preparing to do the job

The LHCb LOI

The LHCb upgrade : a bit of history

- *January 2007, Edinburgh Upgrade Workshop*: choice of 40 MHz
- *April 2008, Expression of Interest*
- *March 2011, Letter of Intent (baseline proposal) to LHCC*
  Endorsement of physics case
  Review of proposed trigger concept (40 MHz)
- *June 2011, Positive review of trigger concept*
  LHCC endorses the LOI, green light for TDR (due in 2013)
  Intermediate document describing due early in 2012

Physics Case:

The Committee congratulates LHCb for the excellent work done on the physics case for the upgrade. It finds the arguments for flavour physics with 50 fb^{-1} very compelling. This amount of data allows measurements at the level of the theoretically achievable precision for many quantities sensitive to new physics. With 5 fb^{-1} of collected data, most searches for deviations from the Standard Model (SM) predictions will be turned into precision measurements of the SM value with the LHCb upgrade. The level of accuracy achievable is comparable, in case of overlap, with that foreseen at future SuperB factories with 50 ab^{-1}; this makes the upgraded LHCb experiment a well-matched competitor and a very important complement.

Organising LHCb towards TDR

In July 2011, LHCb management has setup a team to bring subprojects to TDR in a coordinated way, to define milestones, and all the necessary steps towards technological choices

A. Schopper (Coordinator), M. Ferroluzzi & S. Hansmann Menzemer (Tracking), R. LeGac (Electronics & DAQ), G. Wilkinson (PID)

Workshops on Tracking, PID and DAQ are being organised, open also to new groups. A set of options for various items already identified

Driving requests: upgrade to ~2 10^{33} $cm^{-2}s^{-1}$, ready by 2018, ~ 50 MSF

In the meantime an Upgrade Resource Board (1 representative/nation) has started his work for

- Assessment of resources needed (money and manpower)
- Assessment of Institutes' interests
- Coordination of financial requests to FA

A (very tentative) schedule for LHC/LHCb

2011-2012 LHCb data taking

2013-2014 LHC repair / LHCb maintenance, first infrastructures for upgrade

2015-2017 LHCb data taking

2018 LHC shutdown / LHCb upgrade installation

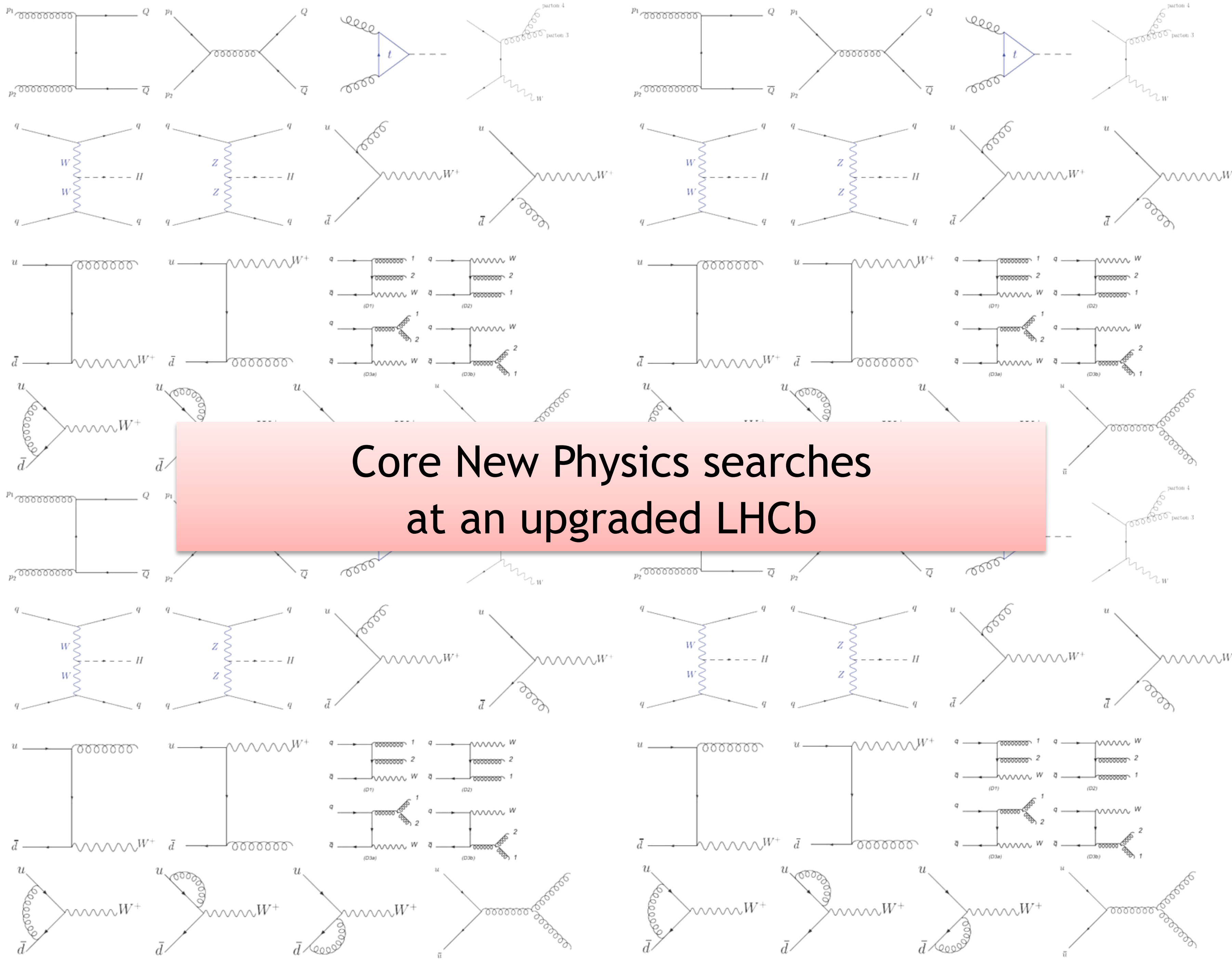
✓ LHCb Upgrade preparation

2011-2013 R&D, technological choices, TDR preparation and its approval

2013-2014 Funding requests for approval

2014-2017 Construction

Core New Physics searches at an upgraded LHCb



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 ← LHCb (? to be checked)
- $B_{s,d} \to \mu\mu$ ← 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

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

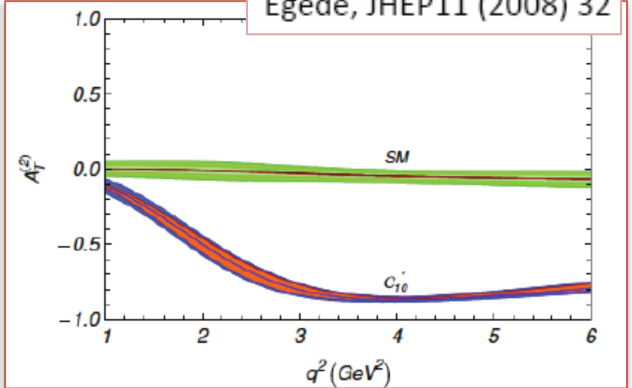
With a larger statistics, study of further observables (transverse asymmetries: $A_T^{(2)}$, $A_T^{(3)}$, $A_T^{(4)}$) sensitive to NP (especially C_7), and free of hadronic errors in the region $1 < q^2 < 6\ GeV^2$

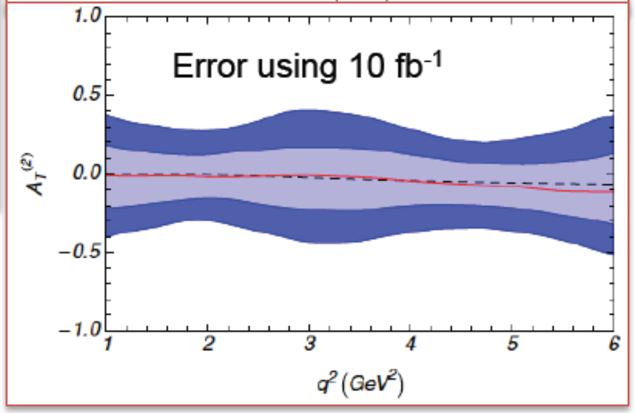
$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2},$$

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

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

Egede, JHEP11 (2008) 32

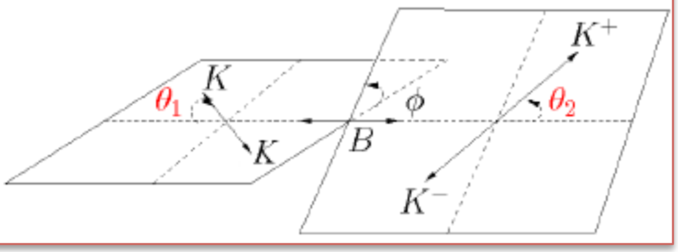




- $B_s \to \phi\phi$

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

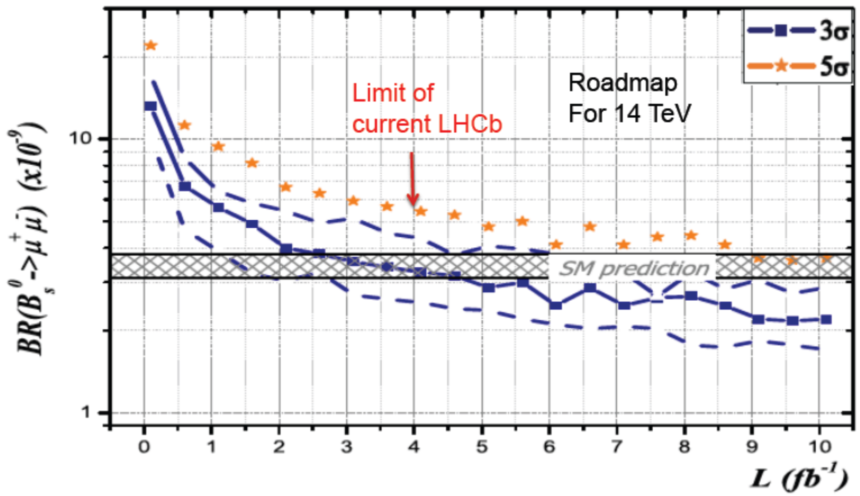
Knowledge of β_s^{eff} mixing phase in penguins σ≈0.015 (SM=0)



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

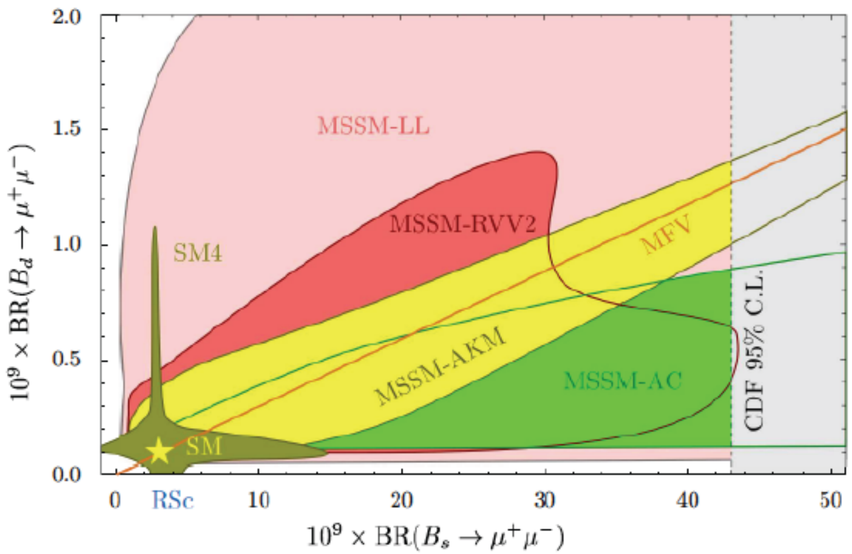
A large statistics is needed for a precise measurement of $B_{d,s} \to \mu\mu$ at the SM level and for discriminating among theory predictions for $Br(B_s \to \mu\mu) / Br(B_d \to \mu\mu)$

- Will take Upgrade to reach SM sensitivity



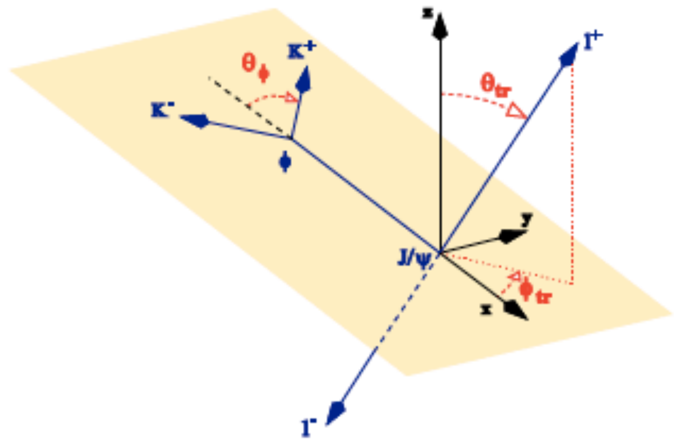
- Reach SM sensitivity and beyond with Upgrade

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



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

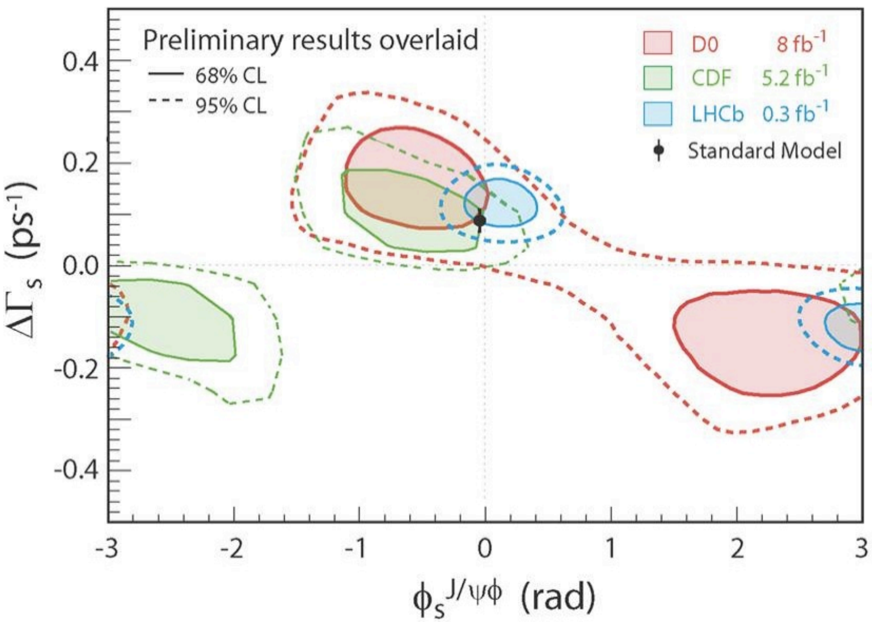
- $B_s \rightarrow J/\psi\ \Phi$ measures the B_s mixing phase $-2\beta_s$ as $B \rightarrow J/\psi\ K_s$ provides the CPV phase 2β



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

- LHCb should get 300 k events with 5 fb-1 with an expected error $2\beta_s\ \pm 0.02$

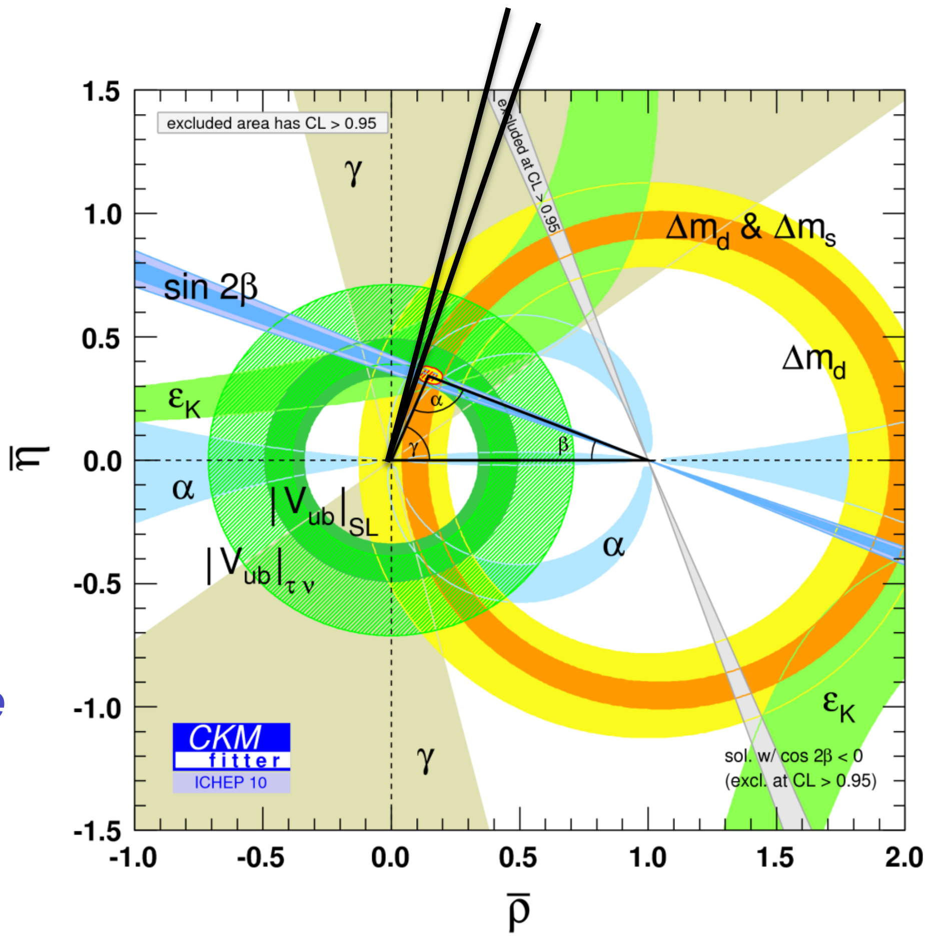
  Other final states can be considered ($\psi\ f_0$, $D_s\ D_s$)



- With 50 fb-1 errors on $2\beta_s$ is reduced to $\pm$ 0.006 (stats only)
  - May imagine to distinguish among several supersymmetry models

The measurement of γ at LHCb

- *Present uncertainty on γ ~ 20°*
- *Many different ways to measure γ in LHCb (time average and time dependent, 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*



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

- 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 make this measurement at the LHC due to low muon p_t trigger threshold

MC cut based approach study gives $\leq 4 \times 10^{-8}$ with 2/fb at 90% CL (Geometrical Likelihood or Multivariate approaches give much better results → analysis ongoing for winter conferences)

The LHCb upgrade sample (50/fb) could reach ~ 10^{-9}

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

- $B_s \rightarrow \phi\gamma$: 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:
  - Phase 1: expect 5500 $B_s \rightarrow \phi\gamma$/year; photon polarisation measurement to 0.10
  - Phase 2: expect 40000 $B_s \rightarrow \phi\gamma$/year; precision to percent level

Charm Physics

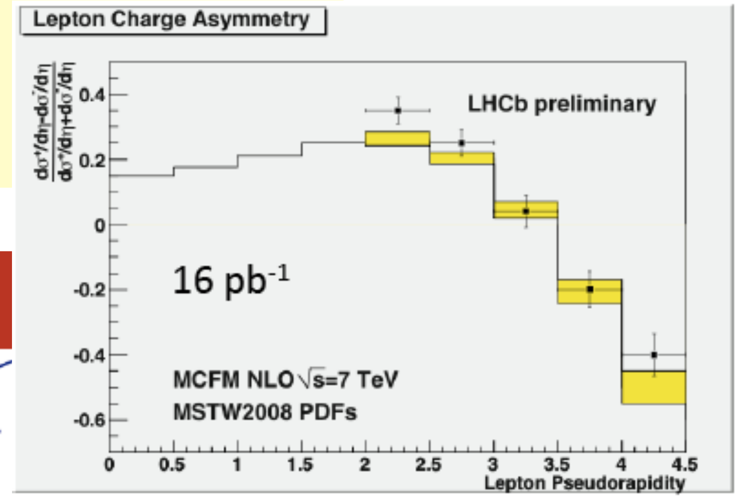
- 2010:
  - With 37 pb^{-1} collected charm samples of $D^0 \rightarrow h^+h^-$ comparable to B-factories
- Phase-1:
  - Good efficiency for 2-body decays, lower eff for higher multiplicity due to E_T trigger in L0
- Phase-2:
  - Full software trigger allowing selection of topology of interest
  - High 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: $D \rightarrow e\,\mu$

Sensitivities to key flavour channels

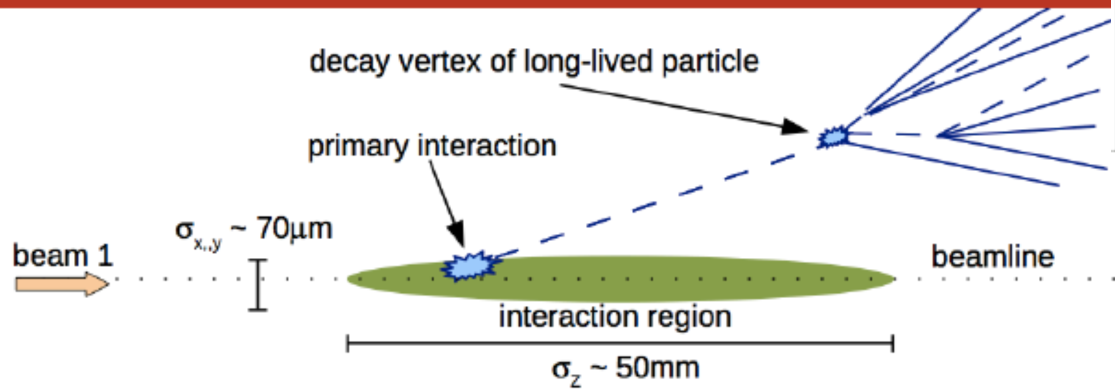
Type	Observable	Current precision	LHCb (5 fb^{-1})	Upgrade (50 fb^{-1})	Theory uncertainty
Gluonic penguin	$S(B_s \to \phi\phi)$	-	0.08	0.02	0.02
	$S(B_s \to K^{*0}\bar{K}^{*0})$	-	0.07	0.02	< 0.02
	$S(B^0 \to \phi K^0_S)$	0.17	0.15	0.03	0.02
B_s mixing	$2\beta_s$ $(B_s \to J/\psi\phi)$	0.35	0.019	0.006	~ 0.003
Right-handed currents	$S(B_s \to \phi\gamma)$	-	0.07	0.02	< 0.01
	$\mathcal{A}^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	-	0.14	0.03	0.02
E/W penguin	$A_T^{(2)}(B^0 \to K^{*0}\mu^+\mu^-)$	-	0.14	0.04	0.05
	s_0 $A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	-	4%	1%	7%
Higgs penguin	$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	30%	8%	$< 10\%$
	$\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s\to\mu^+\mu^-)}$	-	-	$\sim 35\%$	$\sim 5\%$
Unitarity triangle angles	γ $(B \to D^{(*)}K^{(*)})$	$\sim 20°$	$\sim 4°$	0.9°	negligible
	γ $(B_s \to D_s K)$	-	$\sim 7°$	1.5°	negligible
	β $(B^0 \to J/\psi\, K^0)$	1°	0.5°	0.2°	negligible
Charm CPV	A_Γ	2.5×10^{-3}	2×10^{-4}	4×10^{-5}	-
	$A_{CP}^{dir}(KK) - A_{CP}^{dir}(\pi\pi)$	4.3×10^{-3}	4×10^{-4}	8×10^{-5}	-

Electroweak Physics

- LHCb can contribute until ILC/CLIC becomes operational
  - $\sin^2 \theta_{eff}^{lept}$: measure A_{FB} of leptons in Z-decays
    - Due to $q\bar{q}$ production, the raw A_{FB} asymmetry is factor 5 larger than @ LEP
    - Upgrade: statistical precision $\sin^2 \theta_{eff}^{lept} \sim 0.0001$
      - Systematics (PDF's) to be understood
  - M_W measurement at LHC is challenging.
    - LHCb can contribute by measuring PDFs

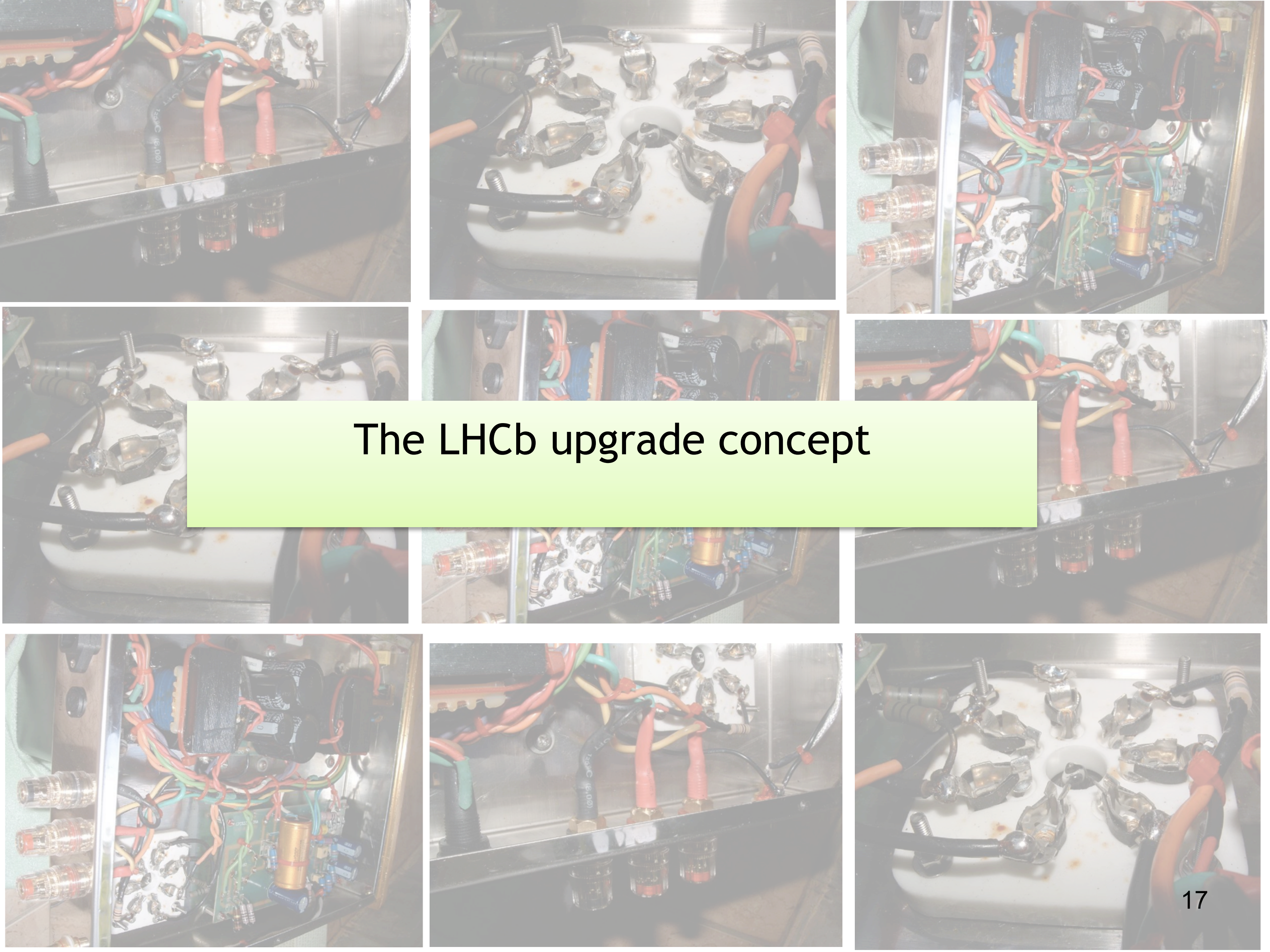


Exotics



- Hierarchy problem: why is Higgs mass not at Planck scale?
  - Many models (Susy, Xtra dimensions, Technicolour, Little Higgs) predict new states at TeV Z', 4th generation, leptoquarks, Hidden Valley particles
- Hidden Valley particles carry "v" quantum number and can be low mass
  - Lightest v-particle is a dark matter candidate
  - V-neutral particles might have long lifetime and decay, e.g. to $b\bar{b}$
  - V flavoured particles could be produced by Higgs;
    - Decay of Higgs to two π_v^0 particles could even lead to Higgs discovery

The LHCb upgrade concept



The present LHCb Trigger Flow

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

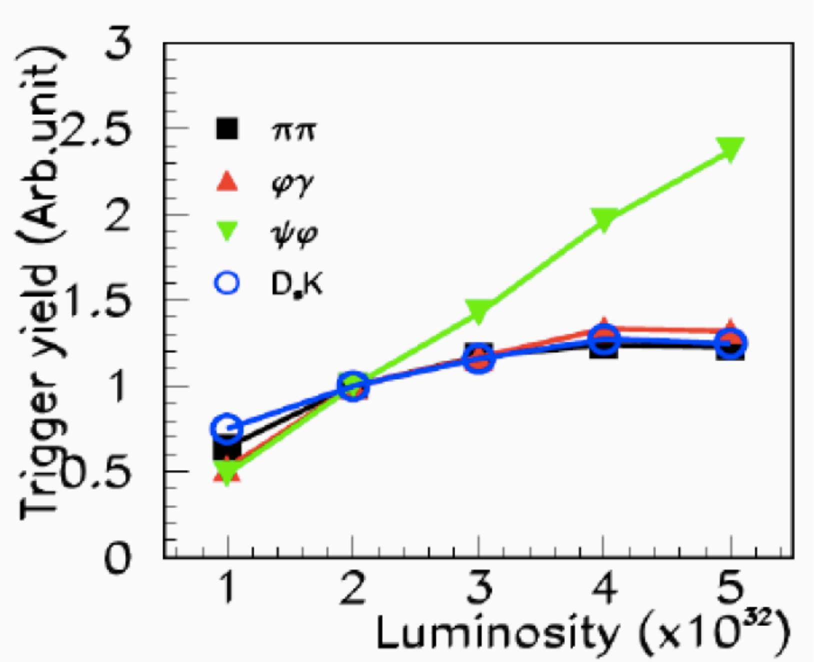
- 700 kHz for hadronic trigger ($E_T > 3.5$ GeV)
- 150 kHz for $e/\gamma/\pi^0$ ($p_T > 2.5$ GeV)
- 150 kHz for $\mu/2\mu$ ($p_T > 1.4$ GeV)

HLT1 confirms L0 using IP and a partial reconstruction of the event (→ 40 KHz)
HLT2 performs exclusive/inclusive refined selections (→ 3 kHz on tape)
L0xHLT have an efficiency of ~20-40% on hadronic and of ~ 80% on di-μ channels

An increase in luminosity (→ 10^{33} cm^{-2} s^{-1}) does not increase the yield in hadr. chann.
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)



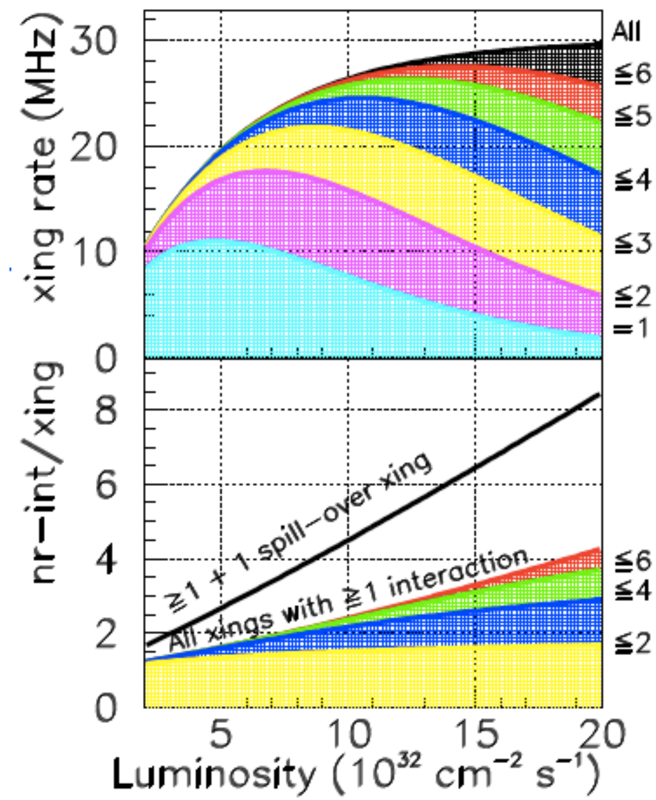
Running LHCb at high Luminosity

Baseline Luminosity for upgrade is 10^{33} cm^{-2} s^{-1} with 25 ns spacing (2800 bunches)

Consequences on data taking:
- 25 MHz of crossings with ≥ 1 visible interaction
- Average no. of visible interactions/x-ing ~ 2.5
- Spillover effects become relevant

LHCb upgrade strategy:
- Acquire all sub-detectors at 40 MHz
- Deploy a LLT at ≥ 5 MHz (increase the hadron yield)
- Send data with LLT_yes to a large farm

Effects on yields:
- Luminosity x 5 on all channels
- Efficiency x 2 on most of hadronic channels

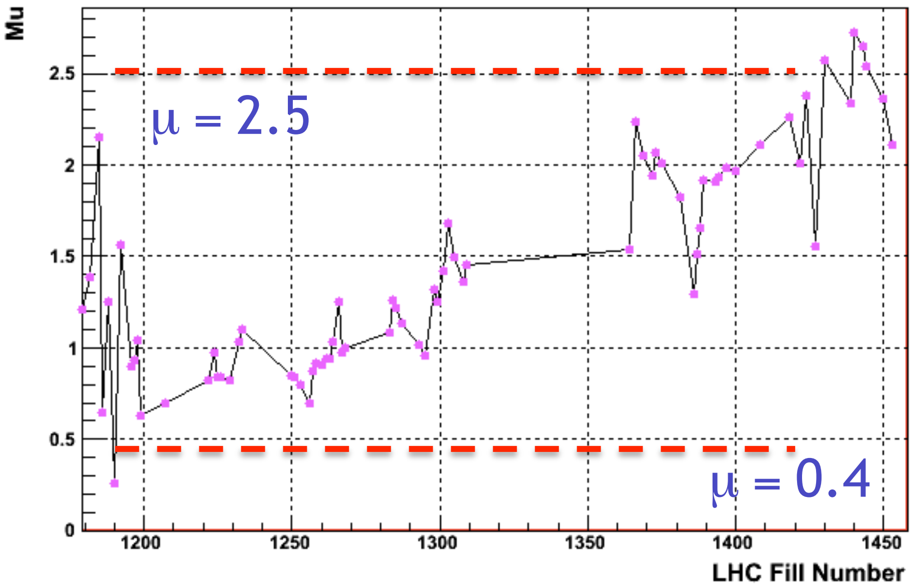


→ Goal : collect ~ 5/fb/year (for a total of 30-50/fb)

Remark: S-LHC is not needed for the upgrade and its operation can be made compatible with LHCb

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 meant to run at $\mu = 0.4$

But at 10^{33} $cm^{-2} s^{-1}$ with 25 ns spacing important effects will start: spillover and ageing of detectors

Presently 10^{33} $cm^{-2} s^{-1}$ seems a reasonable compromise to keep untouched a large part of detectors (Outer Tracker, RICH, Calo, Muon)

Running at 2 10^{33} $cm^{-2} s^{-1}$ would mean $\mu = 4$, outside the capabilities of the present <u>baseline detector upgrade</u>

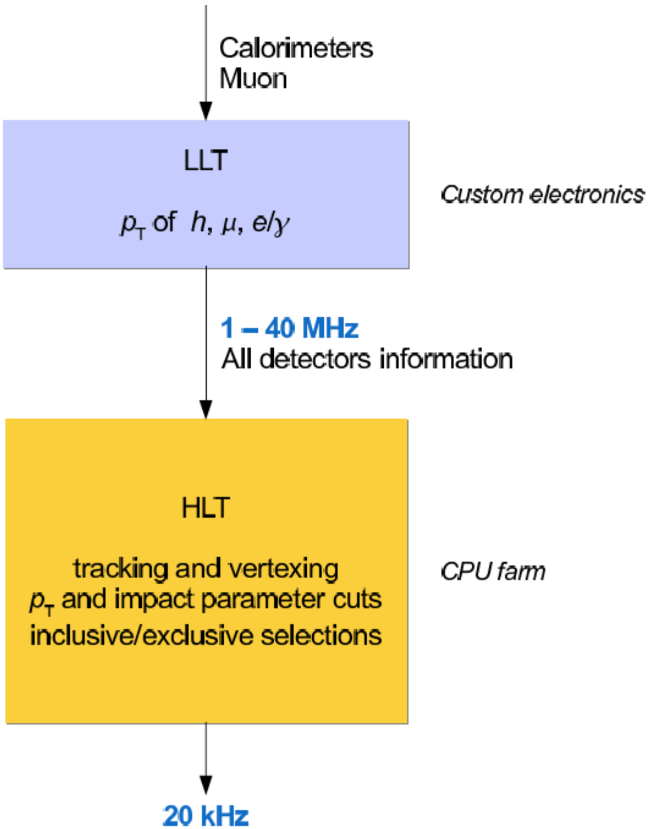
The LHCb baseline upgrade

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 Inner Tracking system (silicon or scintillating fibers)
- new RICH photosensors (multianodes PMT)
- a Low Level Trigger (LLT)
- a large HLT farm (to cope with O(5-10 MHz) of events in input)

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

- Outer tracker
- Calorimeters
- Muon system



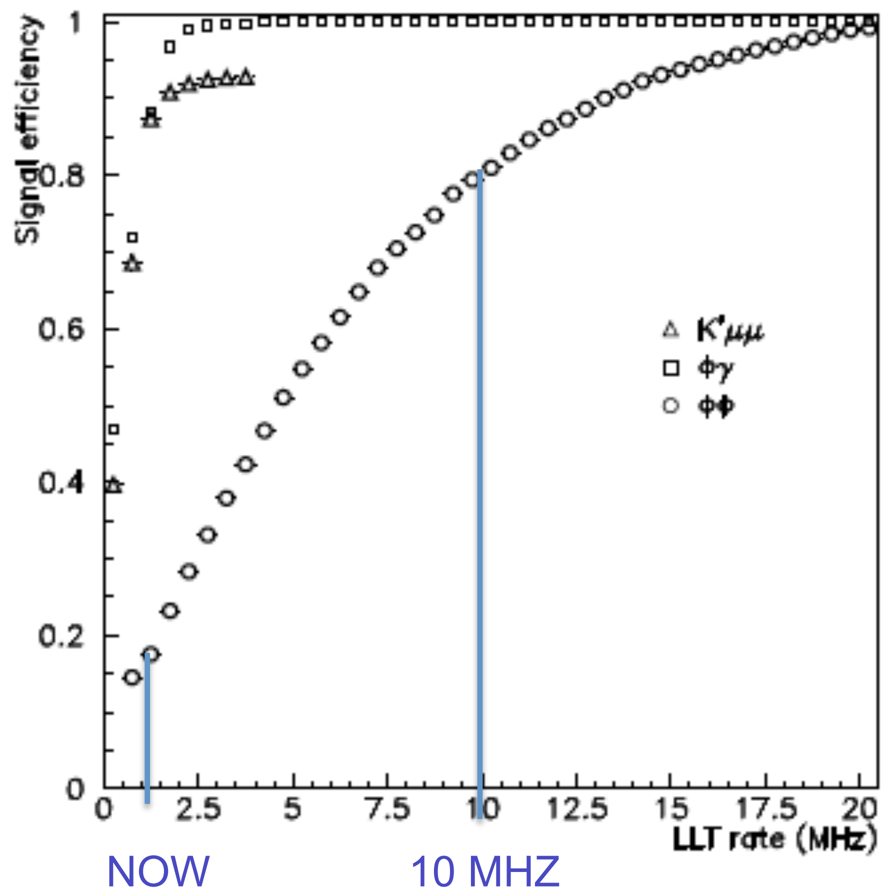
The effect of an upgraded trigger (case of $B_s \rightarrow \phi\phi$)

Strong improvement in physics yields due to lower ET cut

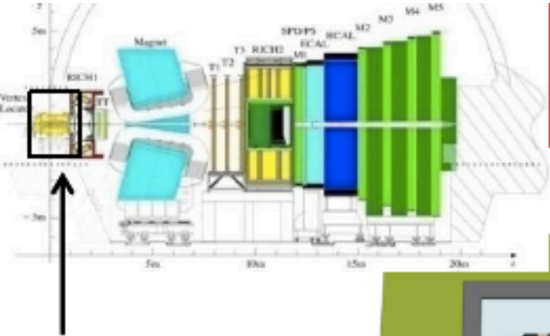
In this particular example x4 at 10 MHz of LLT (which we consider optimal for farm size)

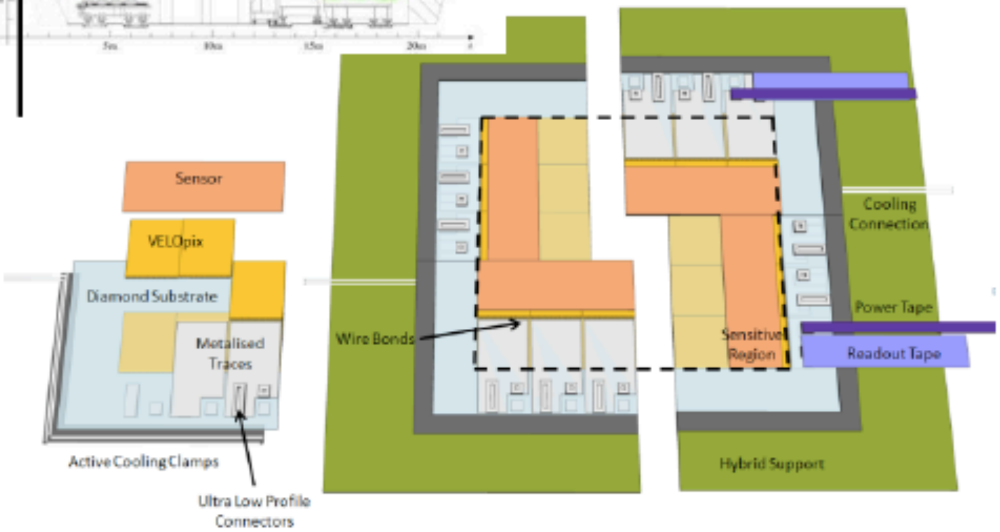
Other hadronic channels will gain

Charm lines will gain up a factor X 10 thanks to low ET cut, in particular for multibody decays
The problem is to readout them all due to high purity

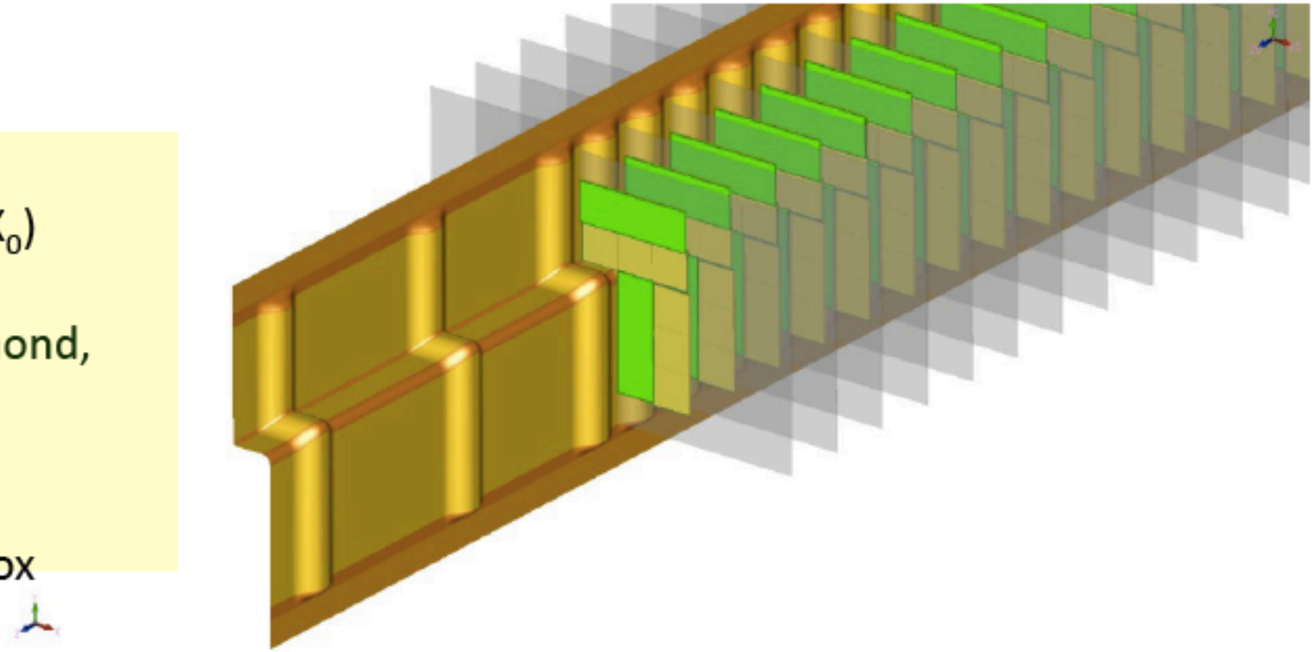


Velo Upgrade





- New Velo @40 MHz readout
  - Baseline option: pixel detector: VELOPIX based on Timepix chip
    - 55 µm x 55 µm pixel size
  - Alternative option: strip detector



- R&D program
  - Module structure (X_0)
  - Sensor options
    - Planar Si, Diamond, 3D
  - CO_2 cooling
  - Electronics
  - RF-foil of vacuum box

VELO (2 options)

Pixels
PRO – very good tracking
CON – higher mass, cooling, new technology

Strips
PRO – very good resolution, easier to build
CON – higher ghosts, radiation hardness, FEE chip (R&D just started)

Common activities
RF foil – Cooling – HV/LV – Motion - Readout

Time scale - TDR early 2014 (at maximum)

Interested groups
Nikhef – CERN – Santiago – Moscow – Krakow – Rio UFRJ - Tsinguha
Warwick - Liverpool – Manchester - Bristol – Glasgow

CENTRAL TRACKER (2.5 options)

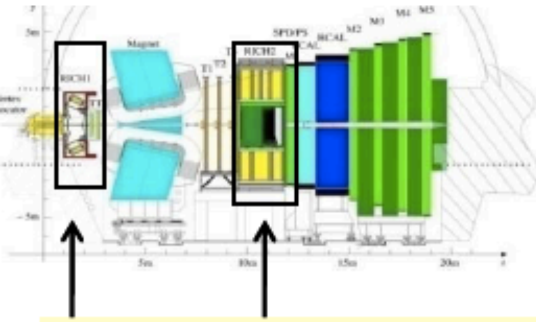
THIN FIBERS
PRO – very good tracking (uniformity), low mass
CON – SiPM radiation hardness

2a - IT (big)+Outer tracker (straws)
PRO – very good resolution, easier to build (known technologies)
CON – high IT area (x4), light mechanics for the IT

2b - IT (small)+Outer tracker (thick fibers)
PRO – very good resolution
CON – light mechanics for the IT, 3 tracking technologies

Time scale – TDR by end of 2013

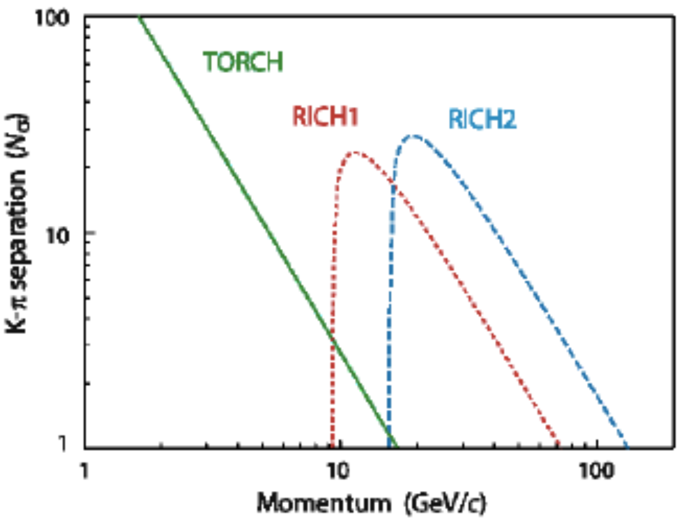
Interested groups
Dortmund – Lausanne – Zurich – Barcelona – Imperial – Russia – CERN – Clermont Ferrand – Frascati – Rio CBPF



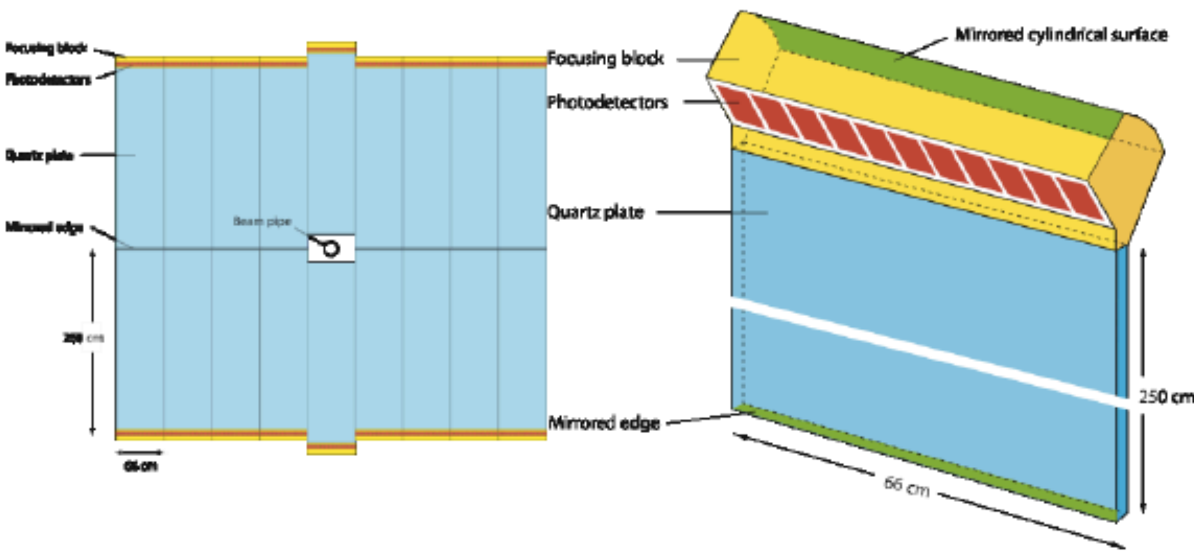
Particle ID

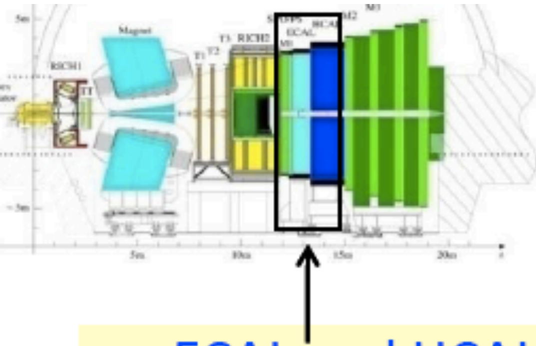
- RICH-1 and RICH-2 detectors remain
  - Readout baseline: replace pixel HPDs by MaPMTs & readout out by 40 MHz ASIC
  - Alternative: new HPD with external readout
- Low momentum tracks: replace Aerogel by Time-of-Flight detector "TORCH" (=Time Of internally Reflected CHerencov light)
  - 1 cm thick 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:

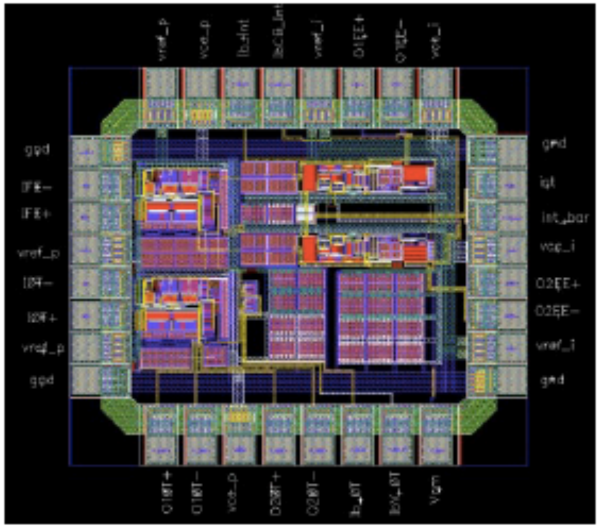




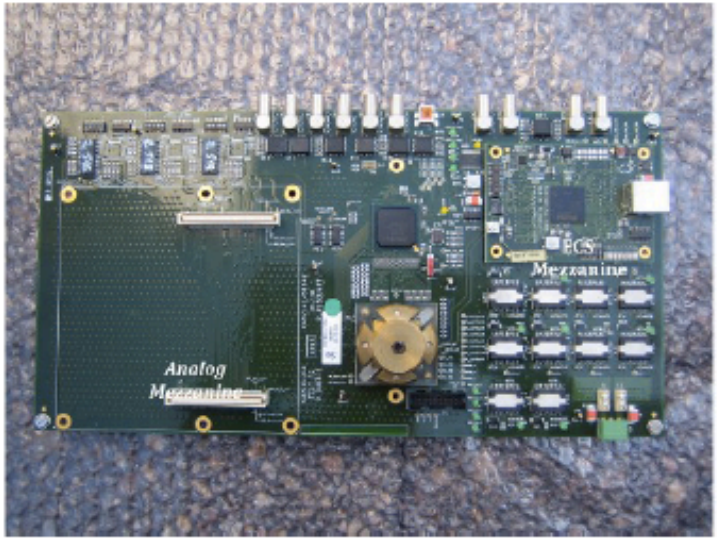
Calorimeters

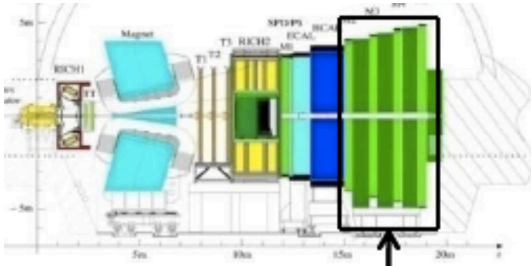
- ECAL and HCAL are maintained
  - Keep all modules & photomultipliers (reduce gain in upgrade)
- PS and SPD will be removed
  - (e/γ separation provided by tracker)
- Front End electronics modified for lower yield and to allow 40 MHz readout

ASIC prototype



New digital electronics prototype

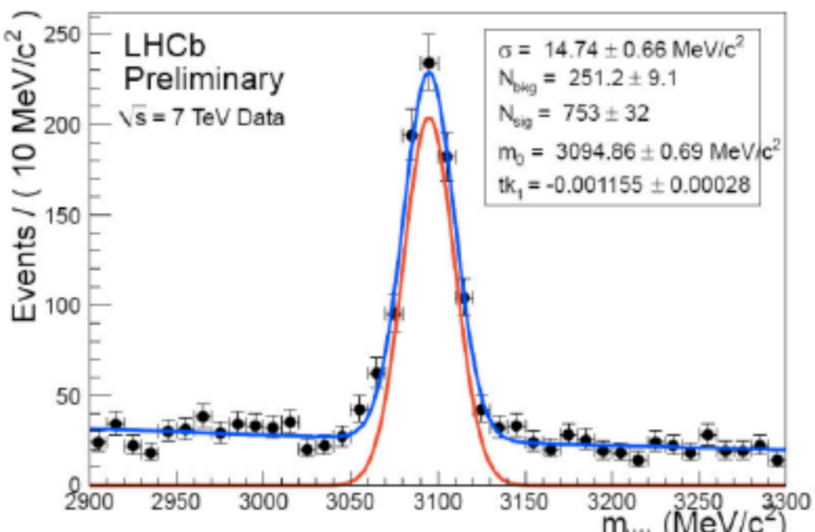




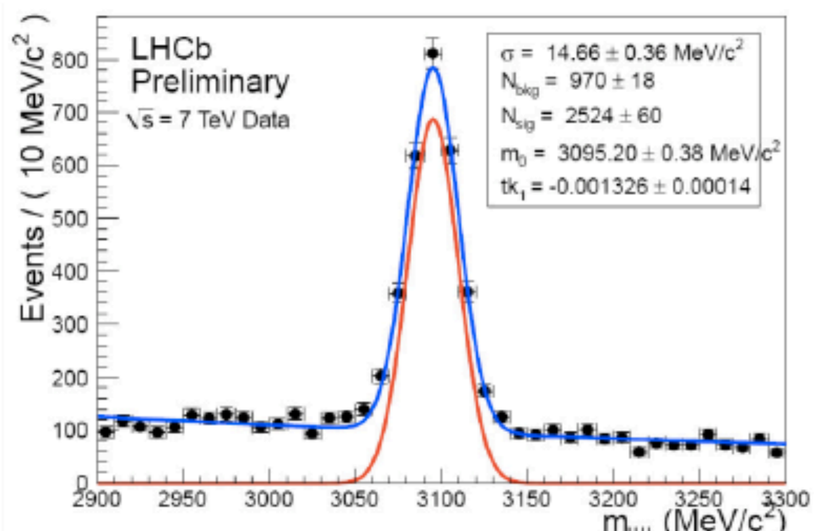
Muon Detectors

- 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,

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



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



Le attivita’ di R&D per l’upgrade dei gruppi italiani

Gli impegni dei gruppi italiani

I gruppi italiani sono interessati ad una prosecuzione dell' attivita' di LHCb oltre la "fase 1" (che presumibilmente si concludera' nel 2017, per quanto oggi e' possibile capire dalla schedula di LHC).

C'e' un interesse specifico verso l'upgrade e il mantenimento in funzione (con i relativi impegni) primariamente per i rivelatori di responsabilita' italiana.

Nel prossimo periodo si chiariranno possibili interessi verso altre specifiche attivita' di R&D di LHCb, anche per eventuali nuovi gruppi. Le opportunita' interessanti non mancano e la Collaborazione e' aperta.

Tempi, modi, impegni finanziari e risorse umane di tale partecipazione verranno definiti con la preparazione dei TDR.

Conclusioni

LHCb ha dimostrato con la qualita' dei primi dati di avere una grande potenzialita' di scoperta di Nuova Fisica in processi in avanti, anche in condizioni nettamente peggiori di pile-up (di un fattore 6).
Questo ci fa pensare che una prosecuzione della presa dati a piu' alta intensita' sia praticabile, una volta risolto il problema della banda passante.

Cio' mette in condizioni LHCb di presentare un caso di Fisica nell'ambito dello studio del flavor di altissimo profilo scientifico, con tempi certi e con costi contenuti, ad una macchina che sta dimostrando un'efficienza altissima.
L'LHCC e il CERN condividono questa posizione.

L'upgrade a 40 MHz ha conseguenze importanti sul rivelatore, ma le scelte tecnologiche non sembrano irrealistiche.

Come al solito sara' cruciale la disponibilita' di risorse umane e finanziarie per un effettivo sviluppo del progetto.