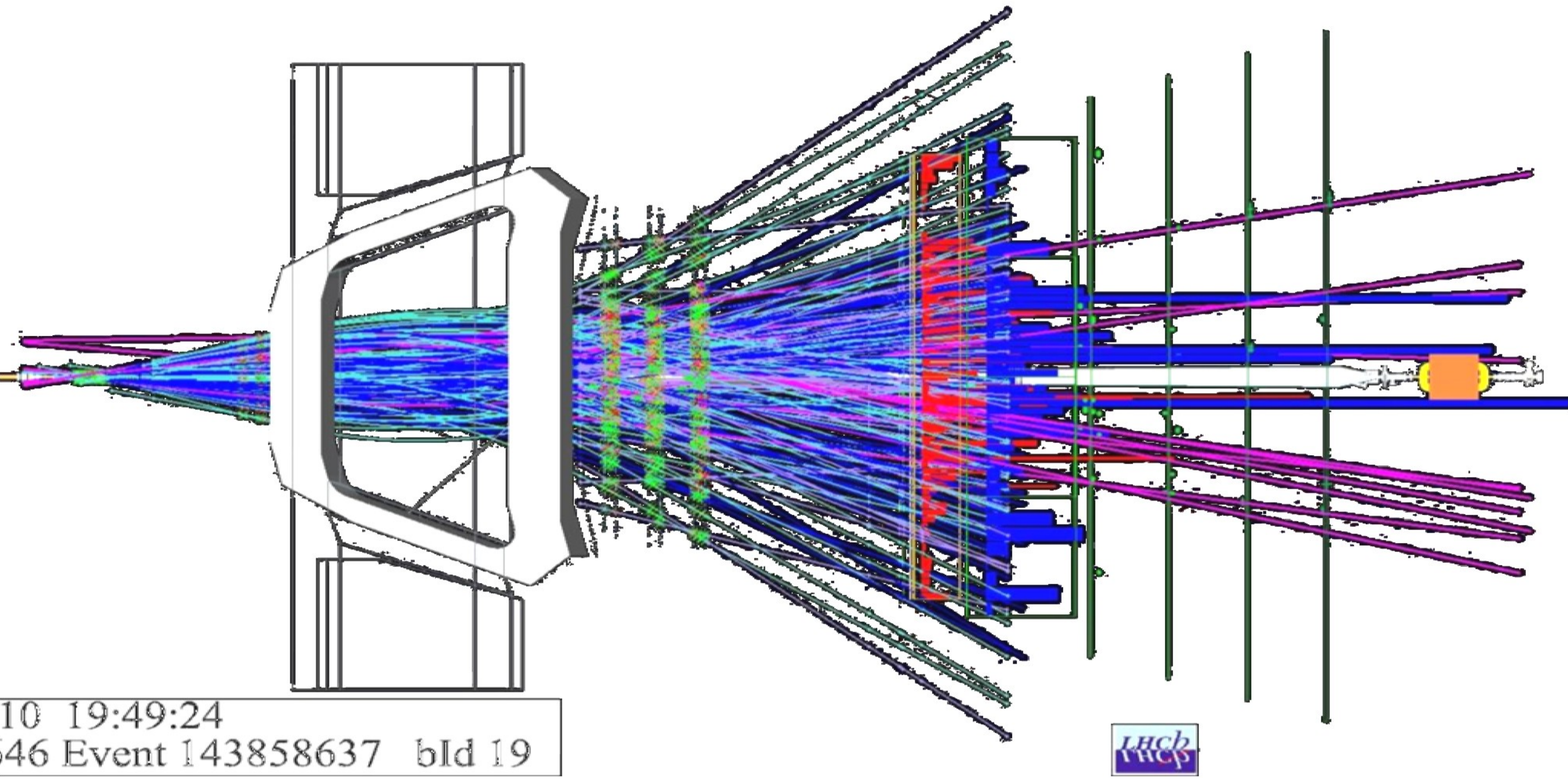
The LHCb Upgrade



On behalf of the LHCb Collaboration

Outline

LHCb performance
LHCb limitations
Upgrade Physics Programme
Upgrade Detector

Referees' view of Physics programme
"Case for flavour physics with 50 fb^{-1} compelling"

At good bookshops near to you

LHCb – Day 1 flavour physics experiment

Forward spectrometer designed to exploit huge bb cross section at the LHC

- 10^{12} *bb* produced in 2 years at $L=2\cdot10^{32}$ $cm^{-2}s^{-1}$
- B hadrons of all species are produced (B_u^+, B_u^-, B_d^0, B_d^0, B_c^+, B_c^-, B_s^0, B_s^0, Λ_b , etc.)

bb production correlated and sharply peaked forward-backward

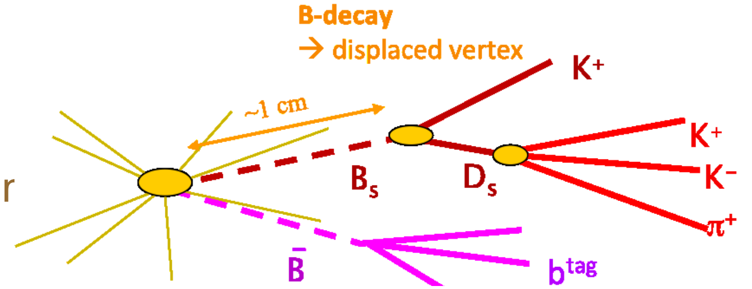
- Single arm forward spectrometer with $2 < \eta < 6$ – coverage very complementary to ATLAS and CMS

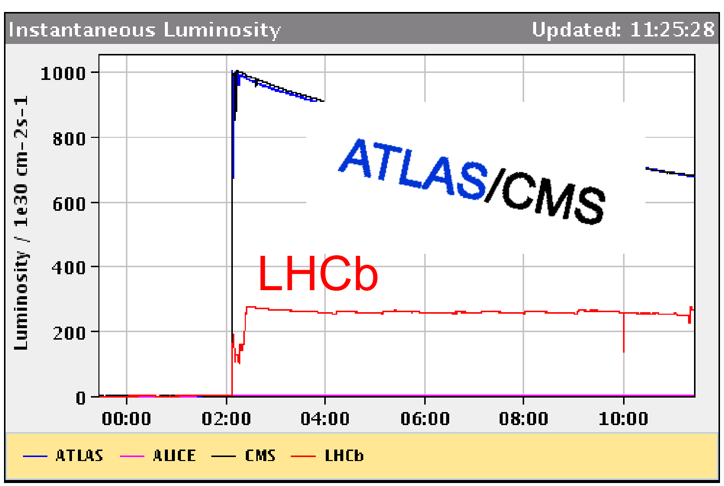
Exploits long flight distance of B hadrons

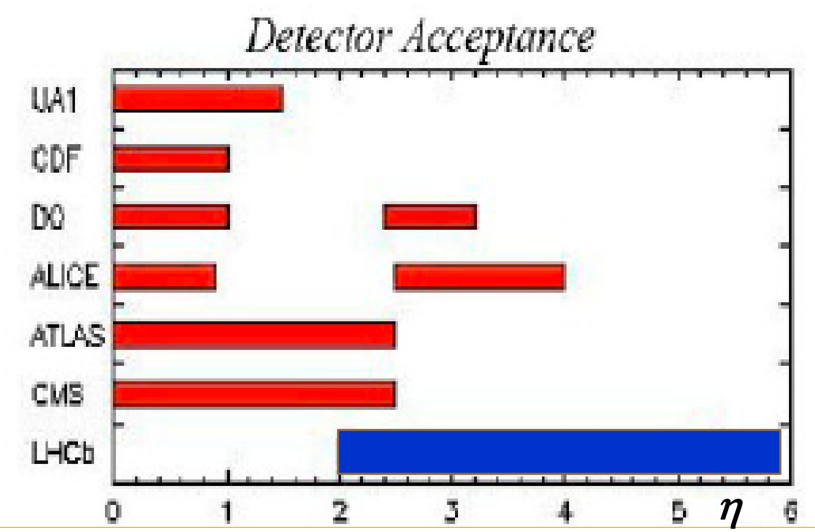
- Time-dependent CP violation measurements

LHCb is designed to run at a luminosity of choice

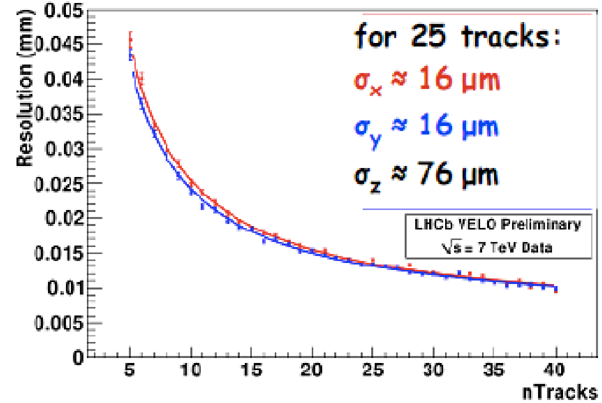
- Luminosity levelling keeps the operation point optir
- LHCb is already operating at > design luminosity







LHCb Performance



Vertex Reconstruction

- Primary Vertex: 16 μm in x and y
- Impact Parameter: 14.4 μm + 19.5/p_T μm
- Proper time resolution: $<\sigma_t>$ ~ 50 fs

PID

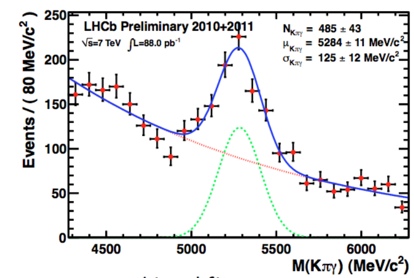
- Functions well for Hadrons, γ, μ

Mass resolution

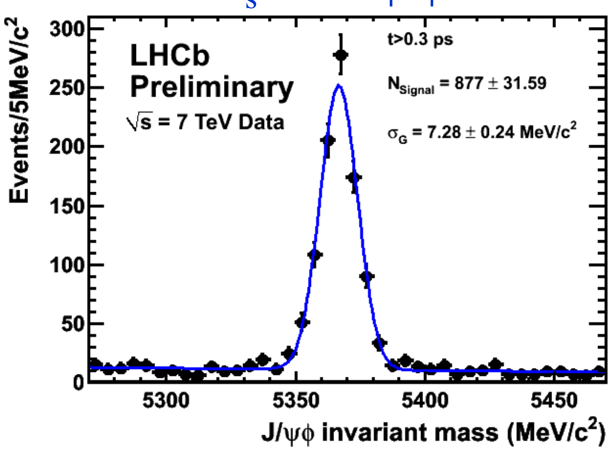
- Typical resolutions of 7-11 MeV

$B^0 \rightarrow K^* \gamma$

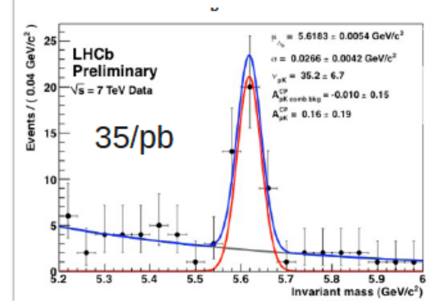
2010 + 2011 data (88/pb)

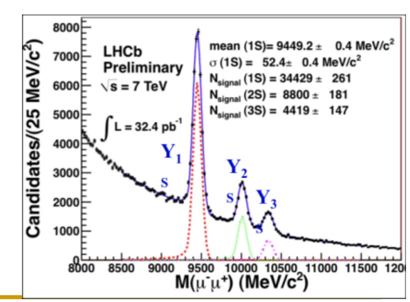


$B_s^0 \rightarrow J/\psi\ \varphi$



$\Lambda_b \rightarrow p K$





LHCb physics programme: well underway

Excellent trigger and reconstruction performance

$Br(B_s \to \mu^+\mu^-) < 5.6 \times 10^{-8}$ @ 95% C.L.

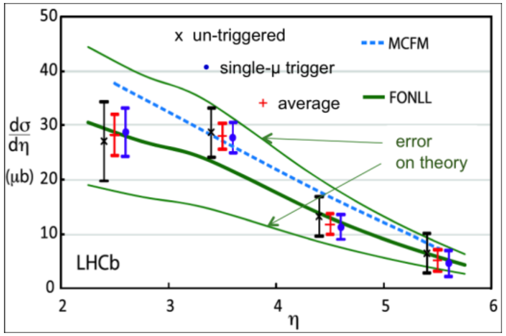
Production cross sections in beauty and charm

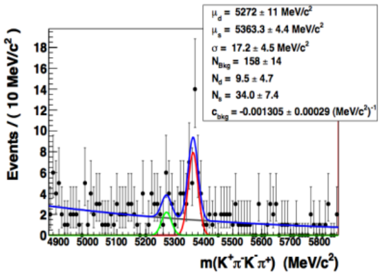
Clean Δm_s measurement at Tevatron precision and with 2x smaller systematic error

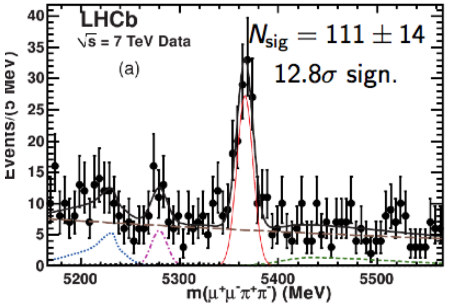
First observations: $B_s \to J/\psi f_0$, $B_s \to D_s K^{*0}$, $B_s \to K^{0*} K^{0*}$ …

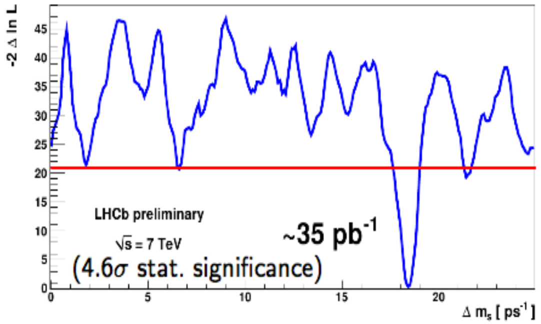
Huge yields in critical channels

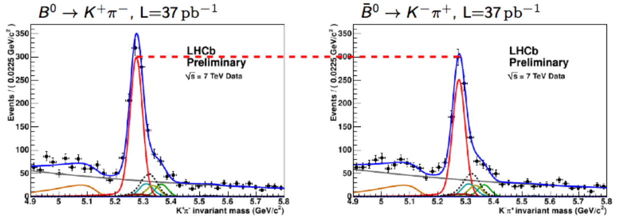
Ingredients in place for core CPV programme











Direct CPV in $B \to K^{\pm}\pi^{\mp}$

Future Prospects for LHCb

After accumulating ~5 fb^{-1} time to double stats is too low

So, why not just turn up the luminosity?

Current L0 trigger: High p_T in HCAL, ECAL & muon

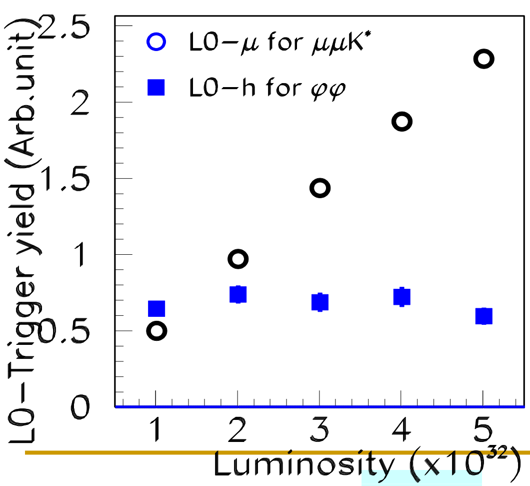
Experiment capable of reading out at up to 1 MHz

High level trigger outputs at ~2 kHz

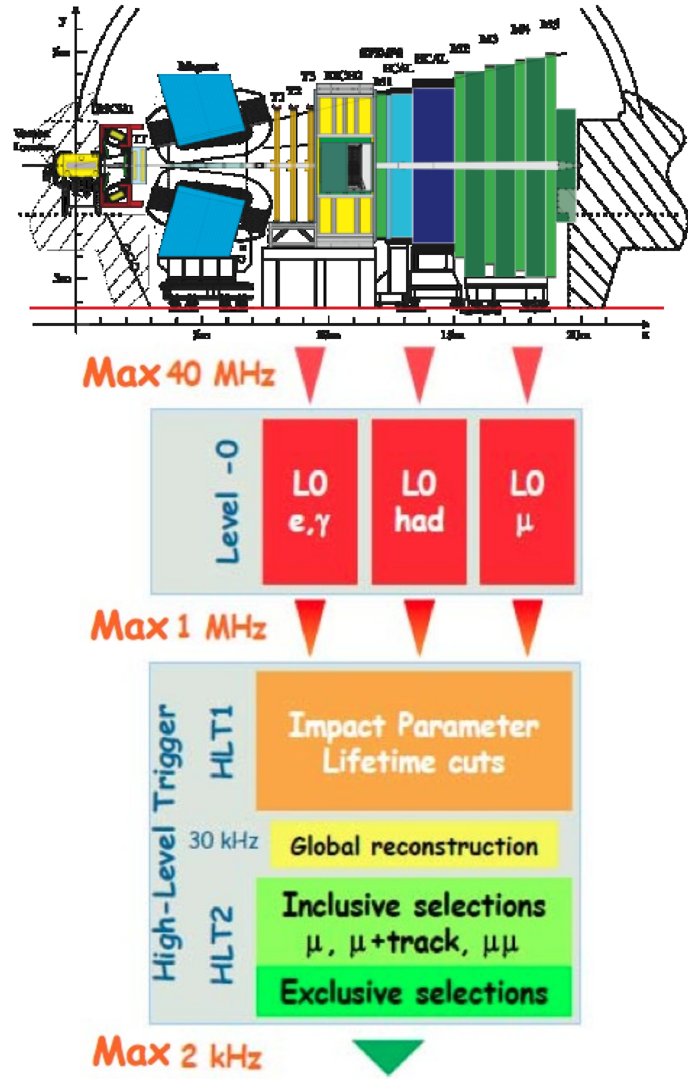
With the information currently available at L0:

Efficiency for hadronic channels flattens out at

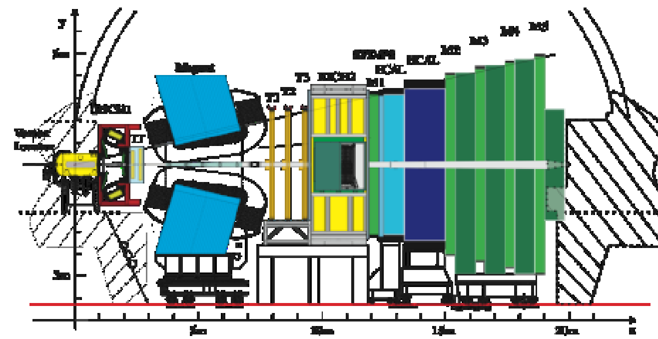
L ~ $2\text{-}3 \cdot 10^{32}$ cm^{-2} s^{-1} (E_T-cut!)



Our current limitation
Is the trigger!



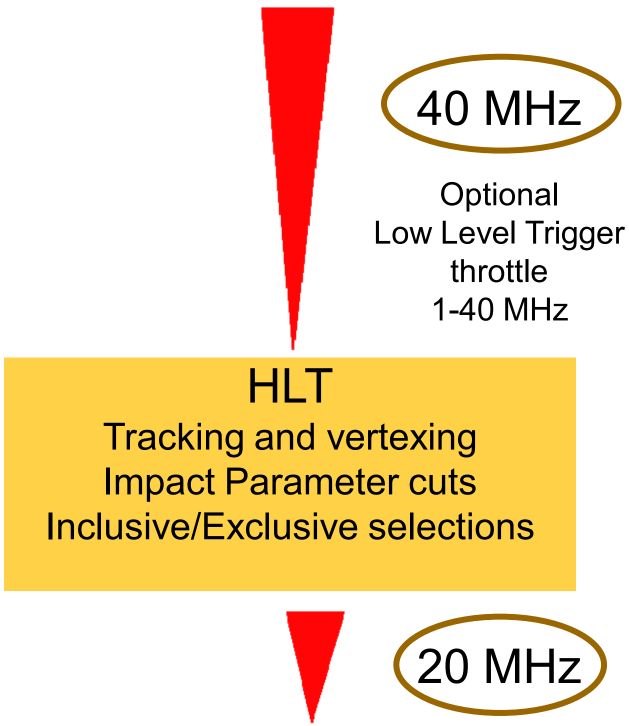
Solution: Upgrade detector to 40MHz readout



Upgrade Trigger fully software based
Runs in stageable Event Filter Farm
Up to **40 MHz input rate and 20 kHz output rate**
Trigger has access to all event information

Run at **5 times LHCb** lumi (→ L ~ 10^{33} cm^{-2} s^{-1})
Gain in signal rates **up to factor 9** for hadronic modes

Efficiency	Farm Size = 5 x 2011	Farm Size = 10 x 2011
$B_s \rightarrow \phi\phi$	29%	50%
$B^0 \rightarrow K^*\mu\mu$	75%	85%
$B_s \rightarrow \phi\gamma$	43%	53%



Outlook for first decade of LHC: 2010-2020

LHC had a very bright startup:

2010: 250 bunches with ca. 2.6 10^{13} ppb

2011: 768 bunches and beyond

Luminosity > 10 10^{32}cm^{2}

Plan to run at 7 TeV for 2011 and 2012+

18 month shutdown in 2013-2014 to repair splices

Next shut down ~ 2018

Installation of Upgraded LHCb

2010-2012+
Ramping up to fewx10^{33} @ 7TeV
Up to 5 fb-1 delivered

Long shutdown
Splice repairs

2015-2016/7
Ramping up to 10^{34}
Up to 100 fb-1 delivered

Injector and LHC
Phase I upgrades

2018-2020/1
Ramping up to 10^{34}
Up to 100 fb-1 delievered per year

Towards High
Luminosity LHC

5 to 50 fb^{-1} : From Exploration to Explanation

LHCb: pioneering exploratory measurements

- $B_s \rightarrow \mu^+\mu^-$ down to SM value
- Measurement of $2\beta_s$ to SM value
- $B \rightarrow K^*\mu^+\mu^-$ crossing point
- Measurement of γ to 3^o
- Evidence of non-SM photon polarisation

And together with ATLAS and CMS uncover the cracks in the SM??

LHCb upgrade will put the pieces together and explain what they mean e.g.

- Precise measurement of $B_s \rightarrow \mu^+\mu^-$
- $2\beta_s$ to 20% of SM value
- $B \rightarrow K^*\mu^+\mu^-$ full kinematics

And there's more….

… and open up a new world of exploration and precision measurements to distinguish between different models

Early Bronze Age Or Late Canaanite?

$B_s \rightarrow \phi\phi$, $K^{0*}K^{0*}$ penguins
$B_s \rightarrow \phi\gamma$
Measure γ to $< 1^o$
Search for $B_d \rightarrow \mu^+\mu^-$
Charm CPV search below 10^{-4}
A_{fs} hadronic modes
Physics beyond flavour
etc. etc.

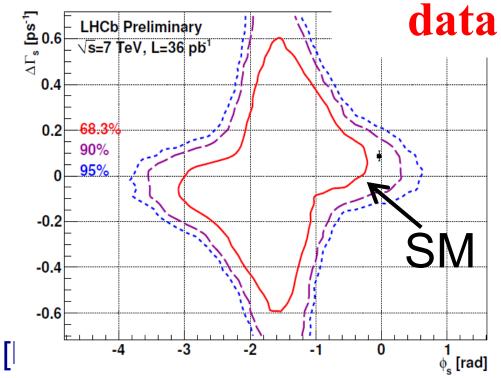
β_s with >> 5 fb^{-1}

NP may or may not be lurking just around the corner

LHCb results show that SM uncertainty can be reached within 5 fb^{-1} and either find or rule out large anomaly

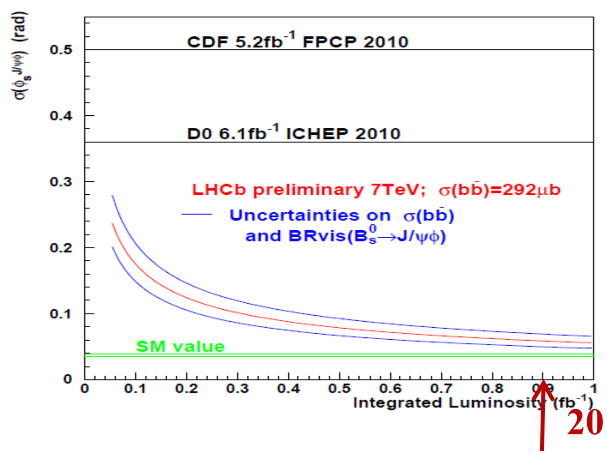
$\phi_s \in$ [-2.7, -0.5] rad at 68% CL
$\phi_s \in$ [-3.5, 0.2] rad at 95% CL

2010 data

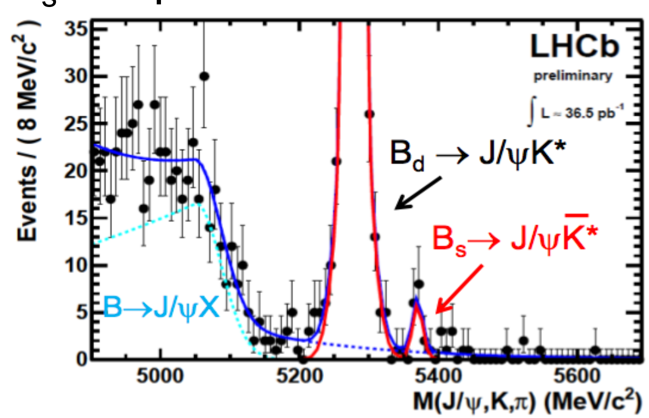


LHCb Upgrade will improve and enrich this measurement

- add pure CP states: $B_s \to D_s^+ D_s^-$ and $B_s \to J/\psi\, f_0$
- fit S-wave K^+K^- contributions (5-10%)
- reduce SM uncertainties due to (suppressed) penguin contribution by using $B_s \to J/\psi\, K^*$ and penguin-free $B_s \to D^0\, \Phi$ decays



$B_s \to J/\psi\, K^*$: **LHCb-CONF-2011-025**



CP violation in mixing via $A_{fs}(B_s)$

Asymmetry larger than 10^{-4} would be clear NP signal

- D0: $A_{sl}^{b} = -0.00957 \pm 0.00251$ (stat) ± 0.00146 (syst) $\approx (a_{fs}^{s} + a_{fs}^{d}) / 2$

  [Phys. Rev. D82 (2010) 032001; Phys. Rev. Lett. 105 (2010) 081801]

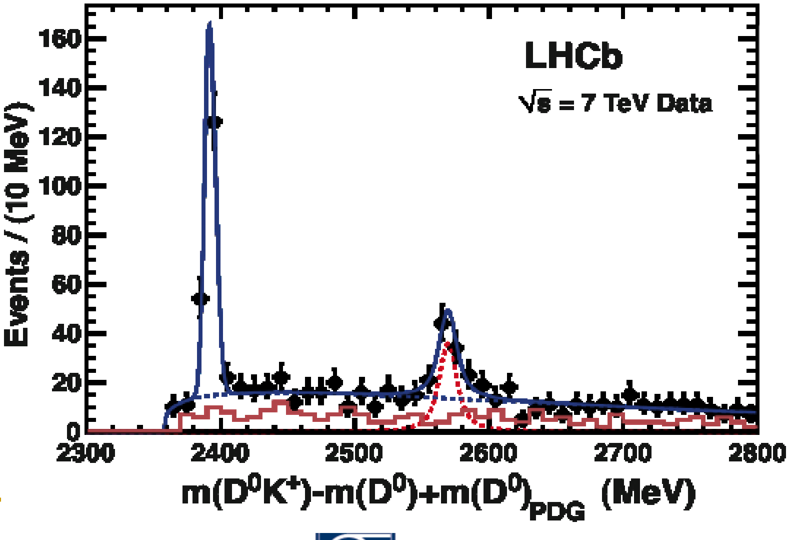
LHCb: flavour specific semileptonic decays

- measure $A_{fs}(B_s) - A_{fs}(B^0)$ via $B_s \rightarrow D_s^- \mu^+ X$ and $B \rightarrow D^- \mu^+ X$
- ✓ identical final state B^0 and B_s to reduce biases due to detector asymmetry

LHCb upgrade:

- measure separately $A_{fs}(B^0)$ and $A_{fs}(B_s)$ with hadronic decays
- flavour specific decay via $B_s \rightarrow D_s^- \pi^+$ with $D_s^- \rightarrow K^+ K^- \pi^-$
- ✓ suppress detector asymmetry with fully charge symmetric final state
- ✓ requires high statistics and flexible trigger with high efficiency for hadronic channels

First Observation of $B_s \rightarrow D_{s2}^{*+} X \mu^- \nu$:



Charmless hadronic B-decays

→ rare penguin decay topologies sensitive to NP

LHCb:

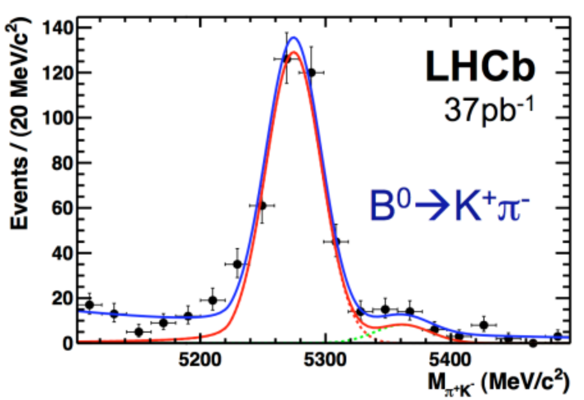
- direct CP violation in B_s and Λ_b
- time dependent CPV in $B_s \rightarrow K^+K^-$
- observe channels $B_s \rightarrow K^{*0}K^{*0}$, $B_s \rightarrow \phi\phi$

→ $\sigma(\phi_{CP}) \sim 0.08$ with 5 fb^{-1}

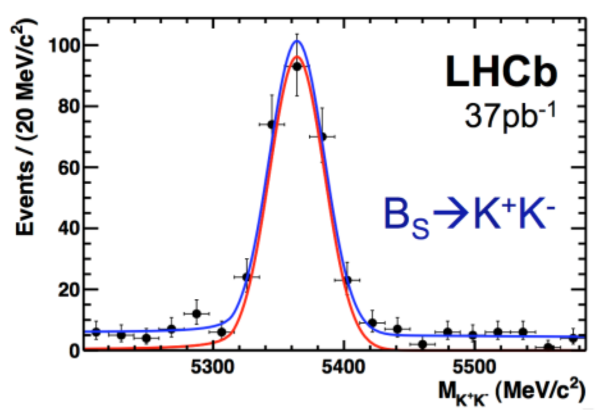
LHCb Upgrade:

- precision time dependent CPV in penguin dominated $B_s \rightarrow \overline{K}^{*0}K^{*0}$, $B_s \rightarrow \phi\phi$: $\sigma \sim 0.02$
  - ✓ SM predicts CP < 2% due to cancellation of mixing and decay phases
  - ✓ control S-wave contributions from non-resonant $B_s \rightarrow \Phi K^+K^-$ and $B_s \rightarrow \Phi f_0$
- CP asymmetry in $B^0 \rightarrow \phi K_s$ with $\sigma \sim 0.03$

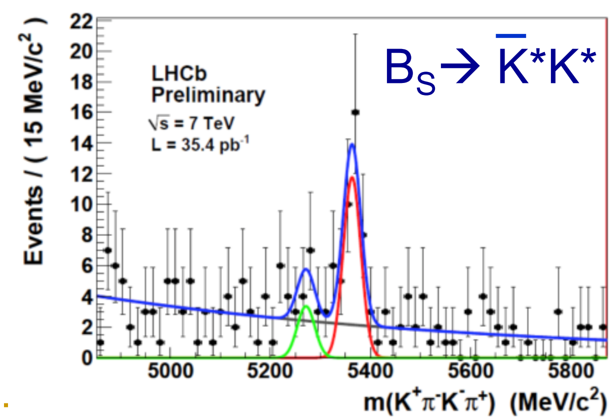
LHCb-CONF-2011-011



LHCb-CONF-2011-011



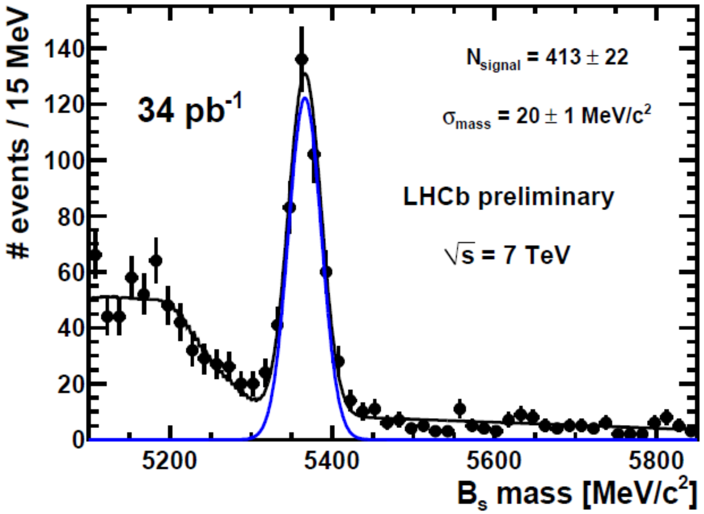
LHCb-CONF-2011-019



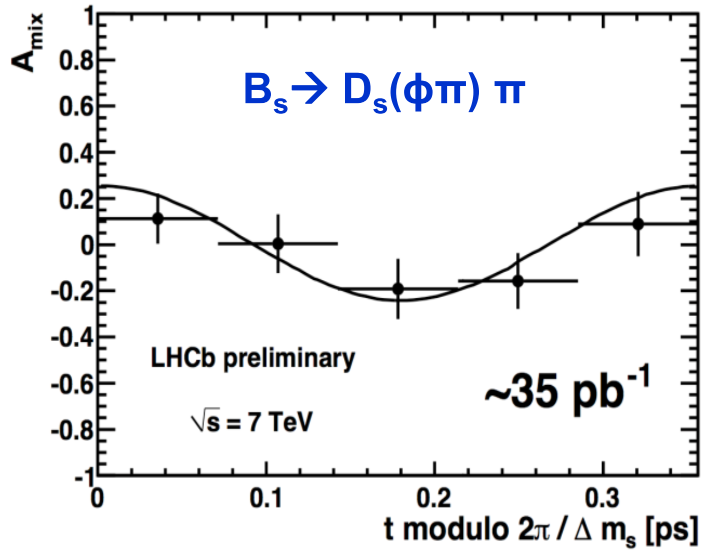
Precision CKM metrology at upgraded LHCb

2010 data give confidence that we can measure γ very well – around 3^{o} with 5 fb^{-1}
Key LHCb measurements in B->DK modes

$B_s \rightarrow D_s(\phi\pi)\ \pi$



LHCb-CONF-2011-005



This will be a huge improvement on present status, and will match current error from SM prediction. But as lattice QCD improves so will SM prediction....

Upgrade, with software trigger, will allow us to reduce uncertainty to 1^{o} or better
Essential to match the indirect constraint on γ which will improve with lattice
Calculations on V_{ub} and $\Delta m_d/\Delta m_s$

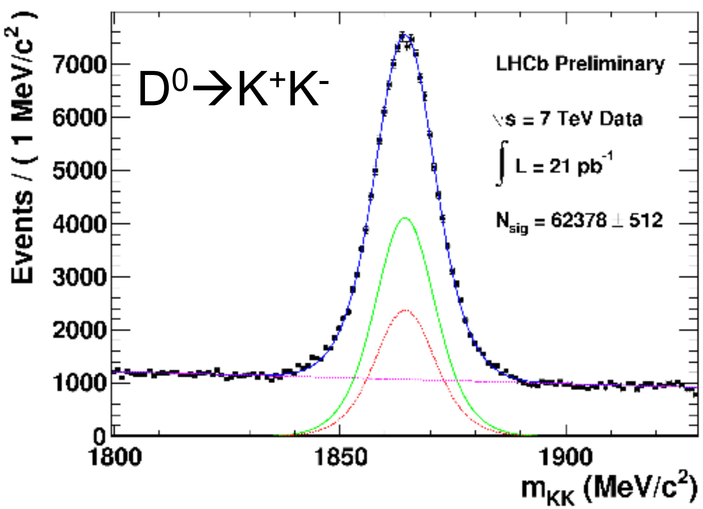
Charm Physics

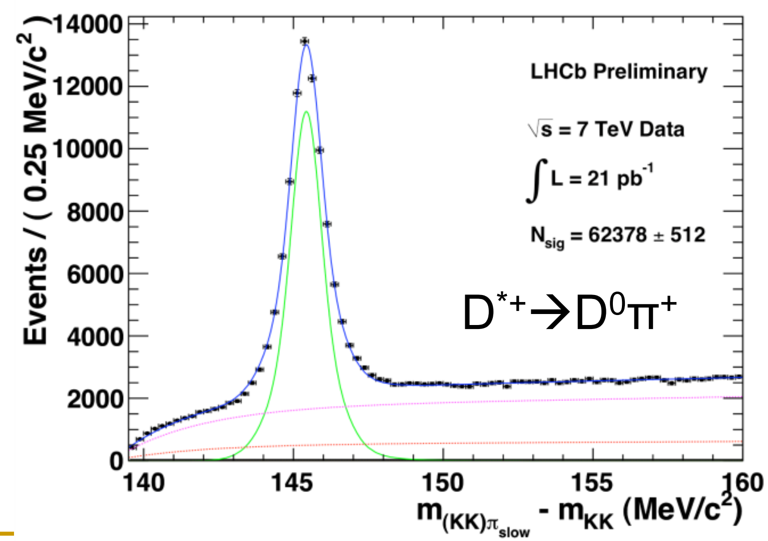
2010:

- with 37 pb^{-1} collected charm samples of $D^0 \rightarrow h^+h^-$ comparable to B-factories
- good efficiency for 2-body decays, lower eff. for higher multiplicity due to E_T trigger in L0

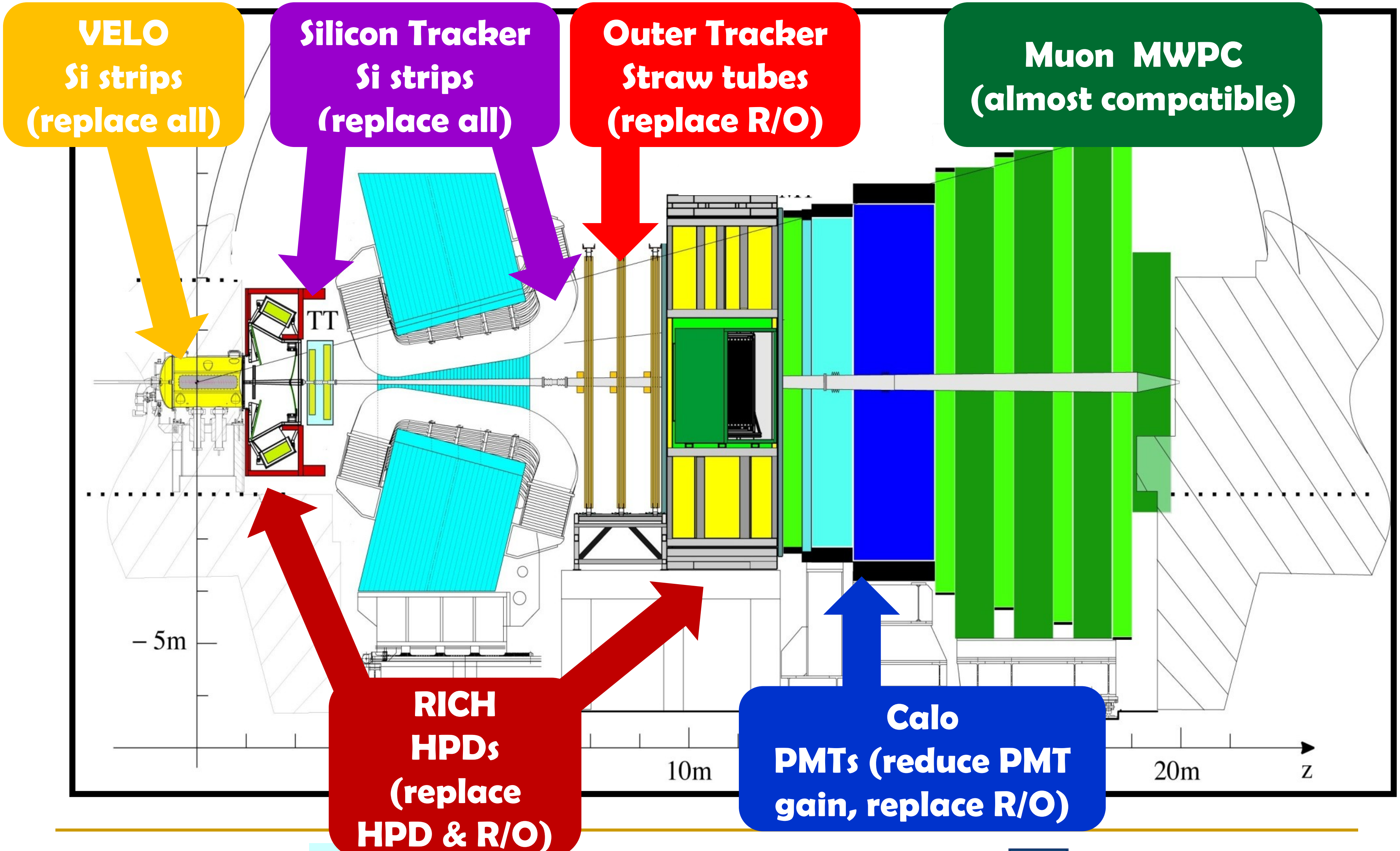
Upgrade:

- 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 $D^0 \rightarrow K^+K^-$ probes CPV in D *mixing*
  - ✓ difference in raw time integrated CP asymmetry $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ probes *direct* CPV in decay of D
  - ✓ very rare charm decay: $D \rightarrow \mu^+\mu^-$, lepton flavour violation: $D \rightarrow e\ \mu$





LHCb upgrade to 40 MHz



Detector Upgrade environment: Pileup

Nominal LHCb operation

$\mathcal{L}$~2x10^{32} cm^{-1}s^{-2} with 25 ns bunch xings

Event rate ~ 10 MHz and μ~0.42

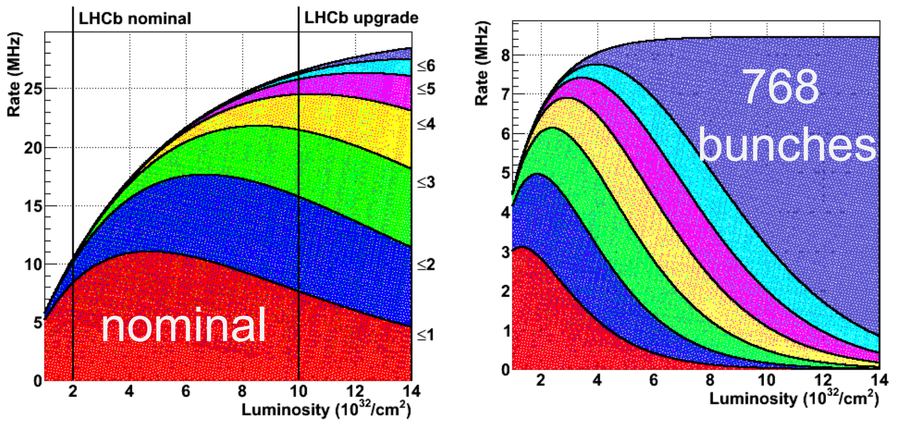
Upgrade

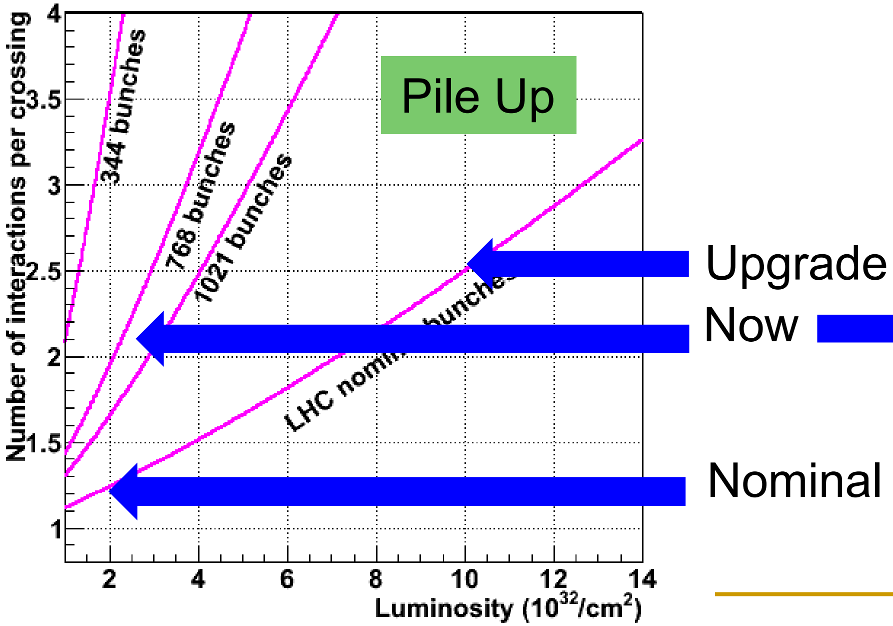
Fill up empty bunch crossings

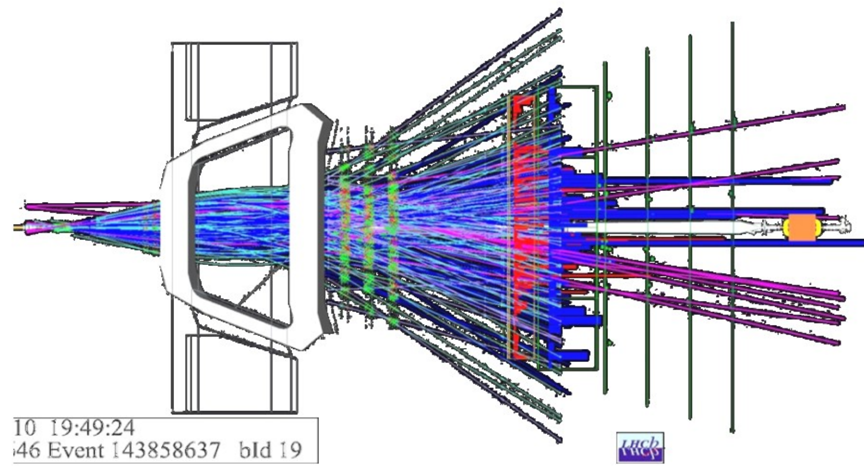
At $\mathcal{L}$~10^{33} cm^{-2}s^{-1} μ~2.13

Current operation

LHC has < 2622 bunches so the pileup~2



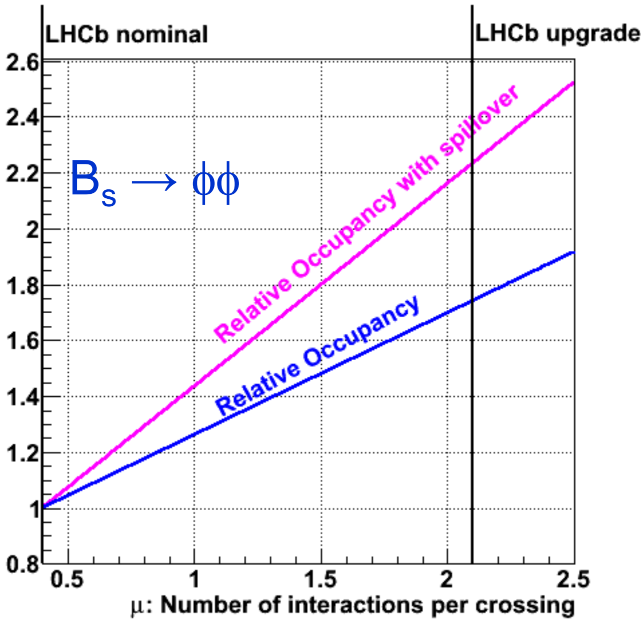




Detector Environment: Occupancy and Irradiation

Tracking and Occupancy:

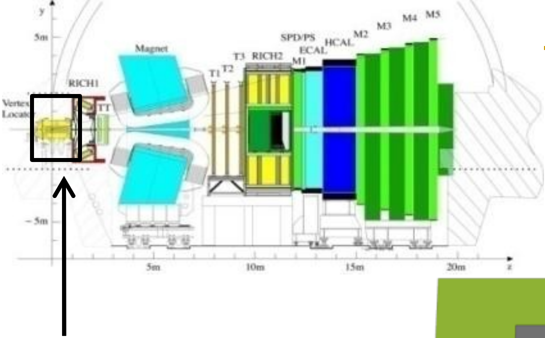
- Si can be operated without spillover
- Outer Tracker straws: occupancy at limit
- Good PR experience now from 50 ns running
- Increase area coverage of IT and use faster gas
- Move to scintillating fibres



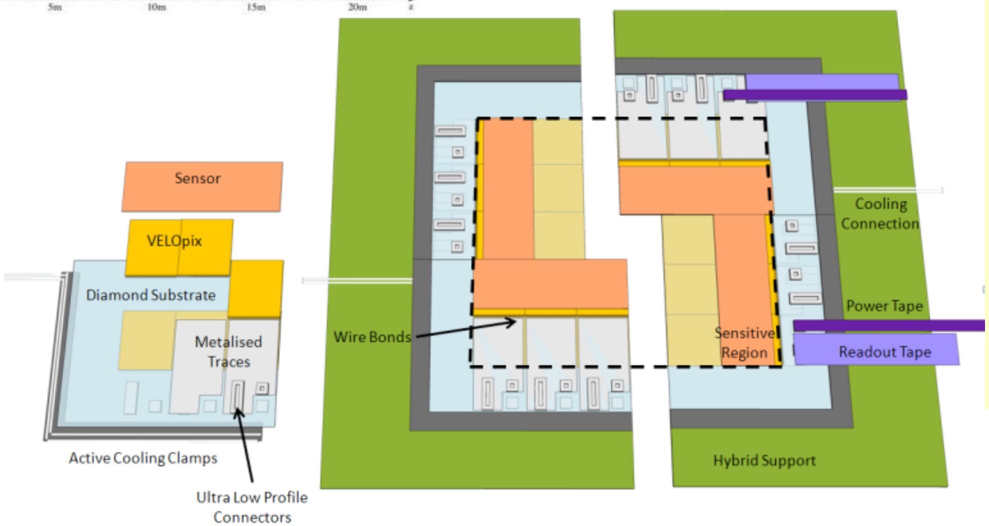
Material Budget an important issue (occupancy, momentum resolution)

Irradiation:

- Integrated dose up by a factor 10
- Affects mainly large η (trackers, inner part of calorimeter)
- Silicon will anyway be replaced and cooling optimised
- Experience from current experiment will guide decisions



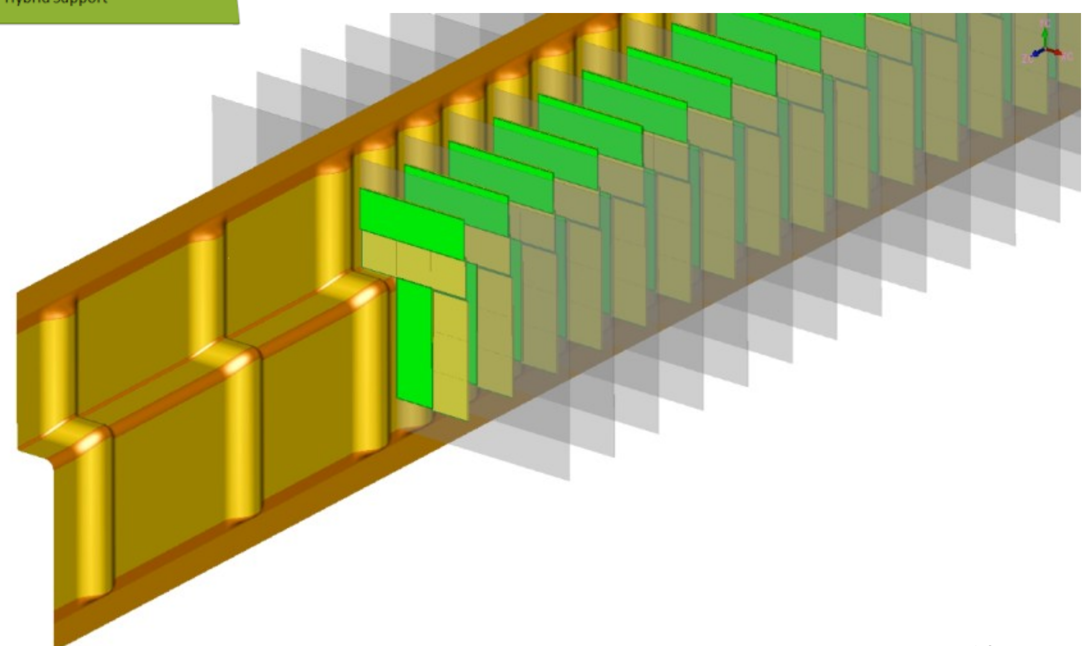
Vertexing



New Velo @40 MHz readout

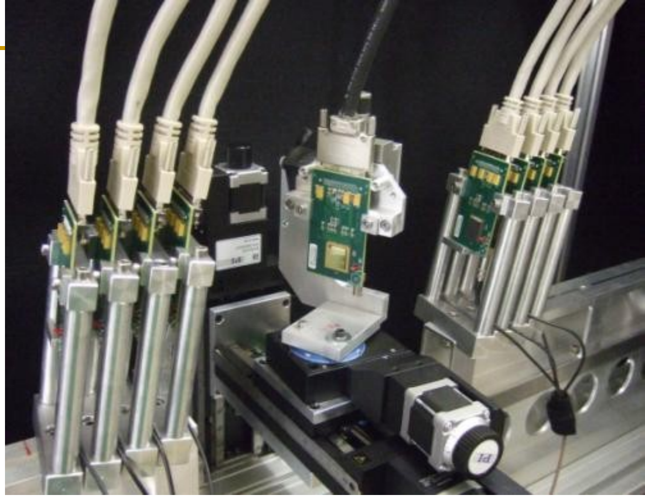
- Main challenge: data rates and irradiation
- Pixel detector: VELOPIX based on Timepix chip
  - 55 µm x 55 µm pixel size
  - Diamond module substrate
- Strip detector option with 30 µm minimum pitch

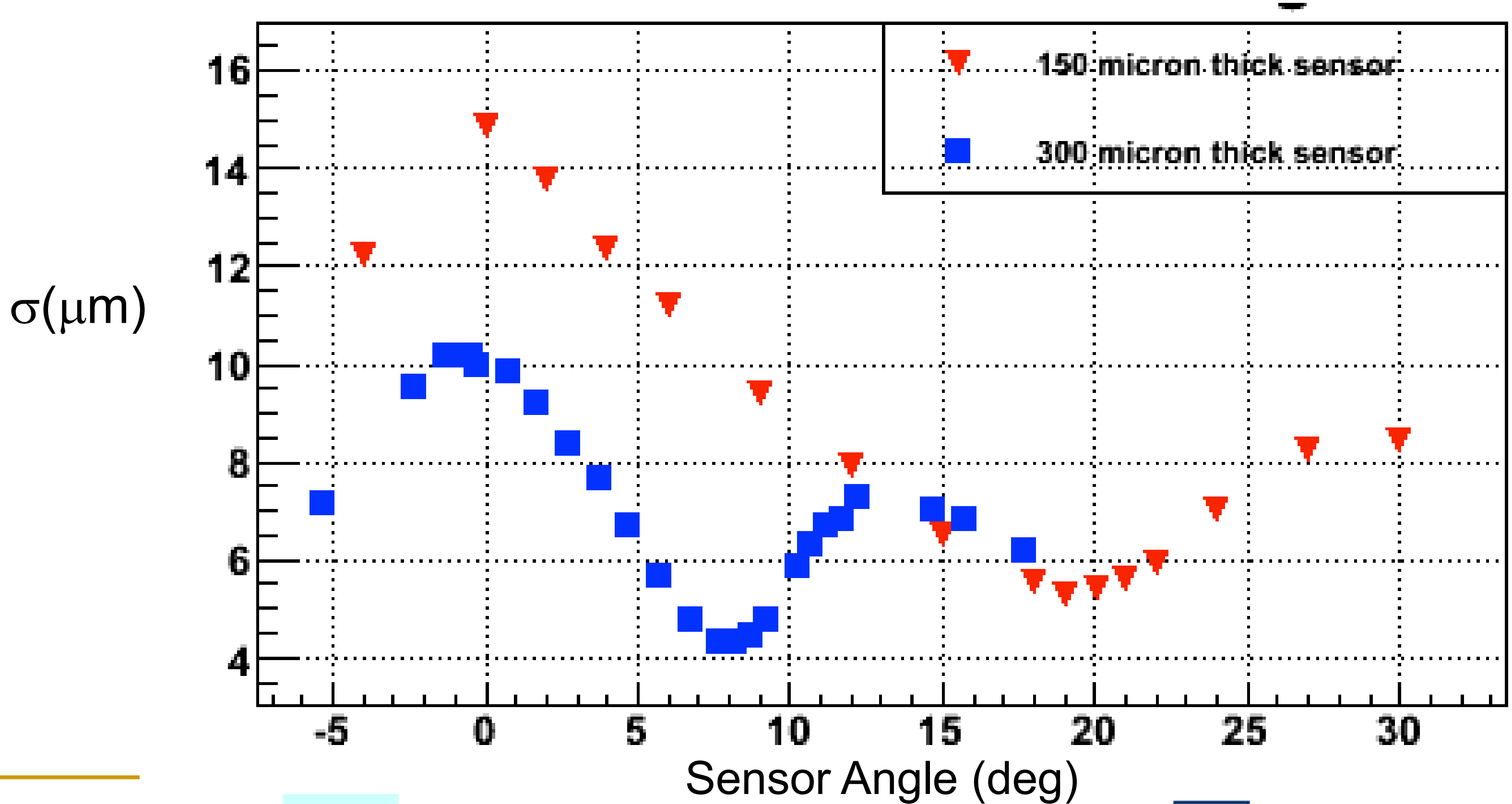
- R&D program
  - Module structure
  - Sensor options
    - Planar Si, Diamond, 3D
  - CO_2 cooling
  - Electronics
  - RF-foil of vacuum box

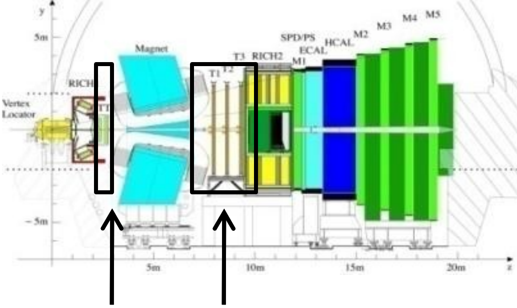


Velo-pixel R&D .

- Test beam timepix telescope
- Results:

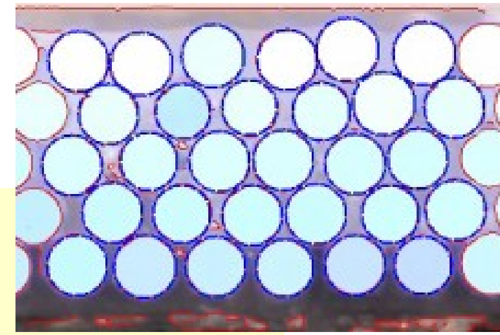






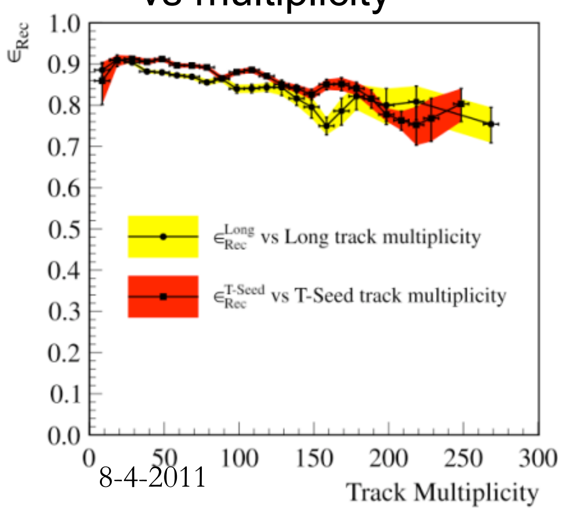
Tracking

IT fibers:

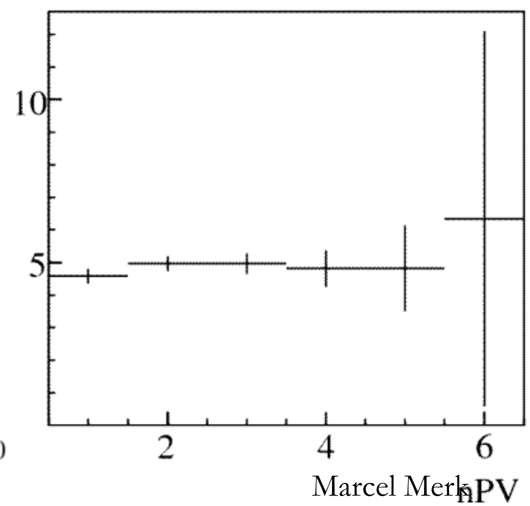


- Current tracker works with upgrade level pile-up
- Keep OT straw detector
  - Detector aging in hot area is still an unknown
  - Consider module replacements with 1mm Scintillating Fiber Tracker in hottest region
  - Replace on-detector electronics by 40 MHz version (FPGA-TDCs)
- IT and TT detectors must be replaced (1 MHz electronics integrated)
  - Options: Silicon strips and 0.25 mm Scintillating Fiber Tracker

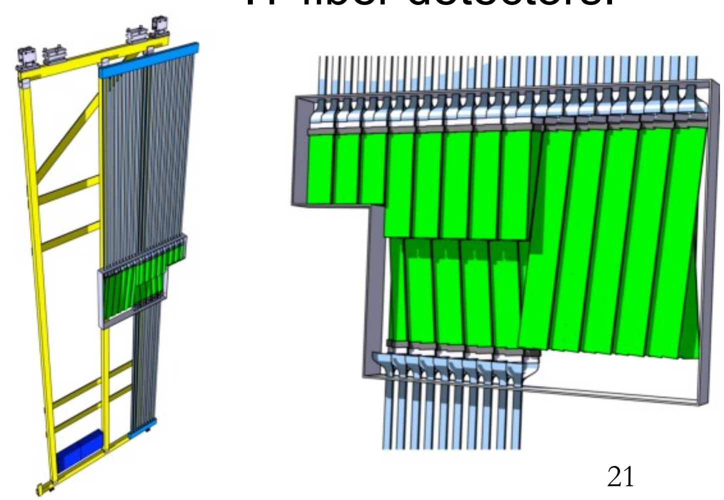
Tracking efficiency vs multiplicity

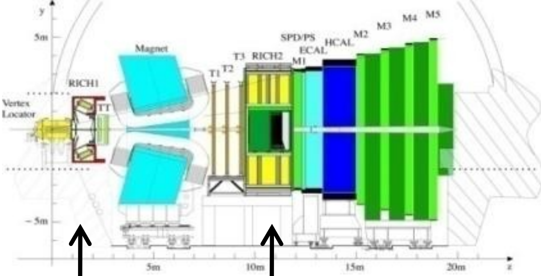


Nsig/Nbkg for B→J/ψK^+



IT-fiber detectors:

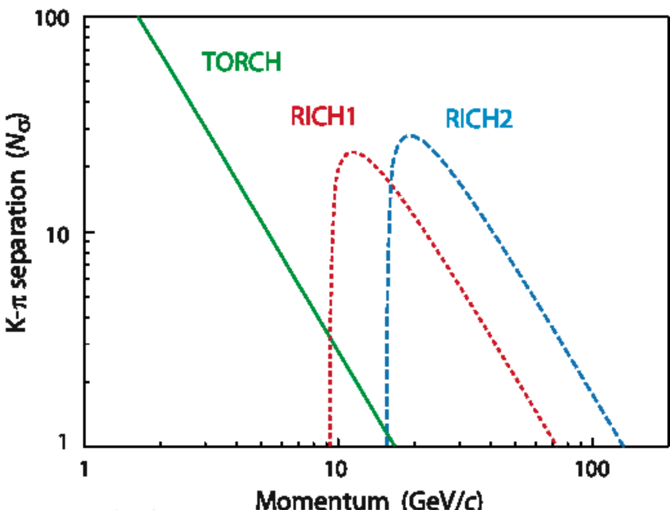




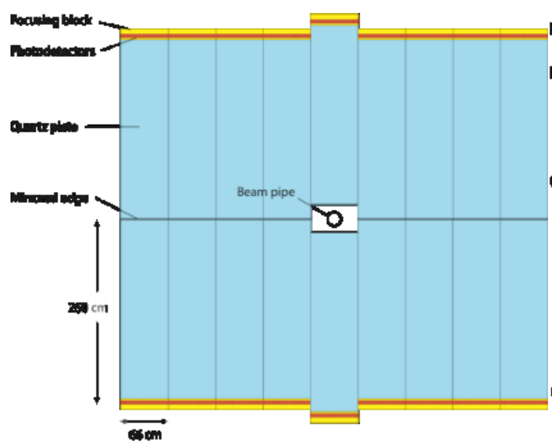
Particle ID

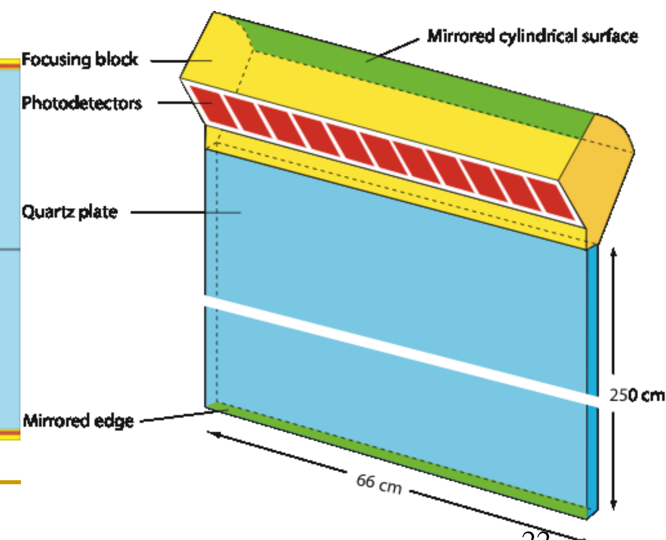
- RICH-1 and RICH-2 detectors remain
  - Readout baseline: replace pixel HPDs by MaPMTs & readout out by 40 MHz ASIC
  - Alternative: new HPD with external readout
- Low momentum tracks: replace Aerogel by Time-of-Flight detector "TORCH" (=Time Of internally Reflected CHerencov light)
  - 1 cm thick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

K-π separation vs p in upgrade:



TORCH detector:





Conclusions

LHCb plans to upgrade in 2018

- Read out entire detector at 40 MHz with a fully software based trigger
- Massive statistical power together with access to B_s sector
- Independent of LHC luminosity upgrade

The LHCb experiment is already operating very successfully in a high multiplicity environment

- Excellent vertexing, PID and tracking performances give confidence that the upgrade will be successful

LHCb upgrade is a next generation flavour experiment

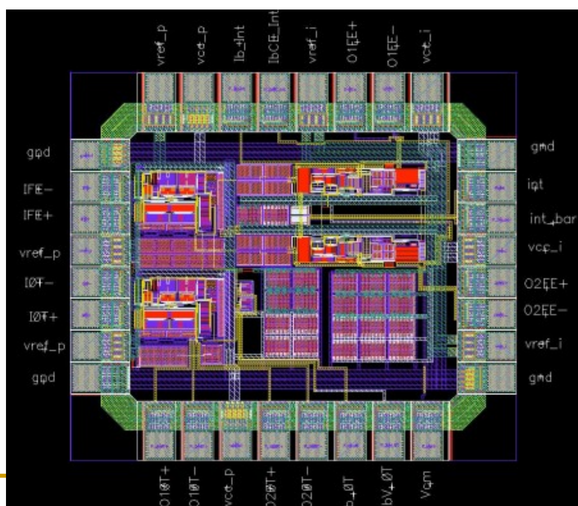
LHCb upgrade provides unique and complementary capabilities for New Physics studies beyond flavour physics

Backup

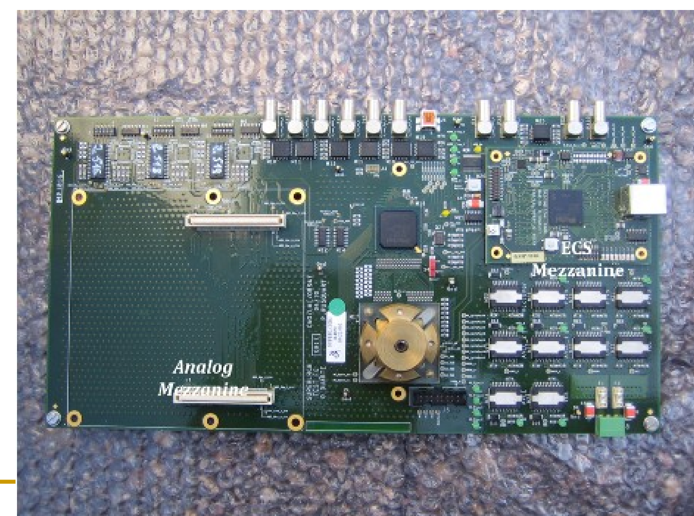
Calorimeters

- 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



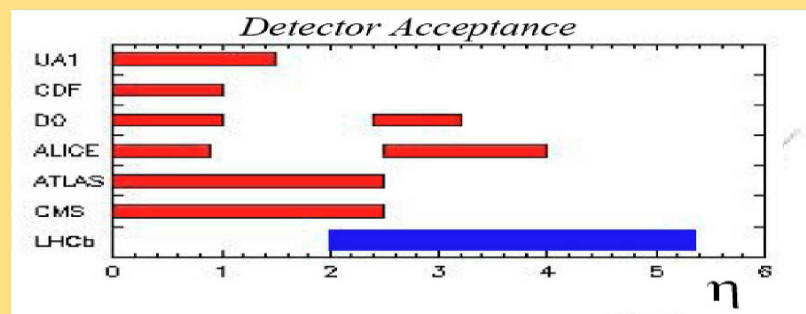
LHCb Upgrade Physics case
Why go from 5 fb^{-1} to 50 fb^{-1}?

From discovery to precision

- $B_s \to J/\psi\ \phi$ CP violating phase:
  - SM error now
  - precision measurement at upgrade
- Angular asymmetries in $B^o \to K^{*o}\ \mu^+\mu^-$
  - Zero crossing point now
  - Deploy new observables, full kinematic distributions at upgrade
- $B_S \to \mu^+\mu^-$
  - Measure SM value or large deviation now
  - Precision measurement at upgrade and extend to $B \to \mu^+\mu^-$
- Tree level γ measurement
  - 4-5° measurement now
  - Precision measurement at upgrade to match theory evolution

New discovery potential

- Huge statistics give discovery potential for "null" measurements (e.g. CPV in D° mixing)
- Angular coverage very complementary to ATLAS and CMS – and long VELO allows us to measure long lived particles
- Flexible software trigger allows us to focus on NP hinted at or discovered at LHC
- Exotic particle searches, non SM Higgs….



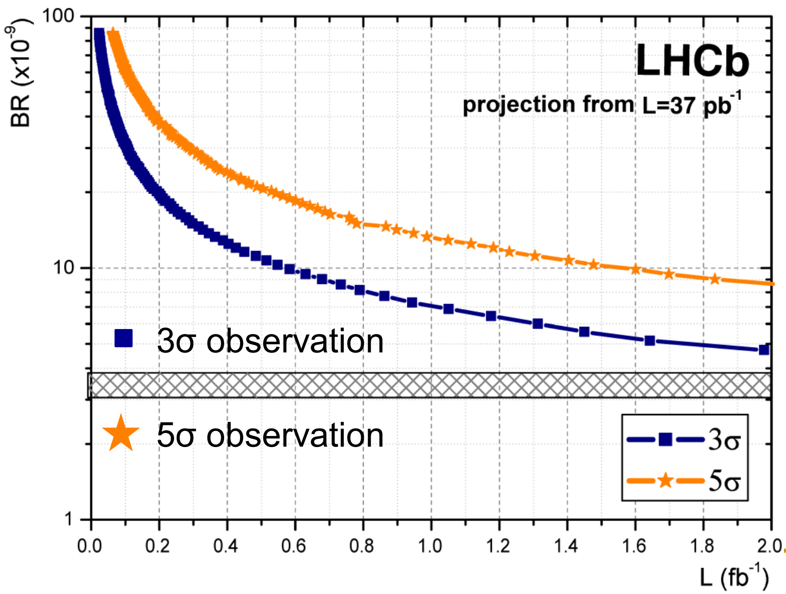
$B_{s,d} \rightarrow \mu^+\mu^-$

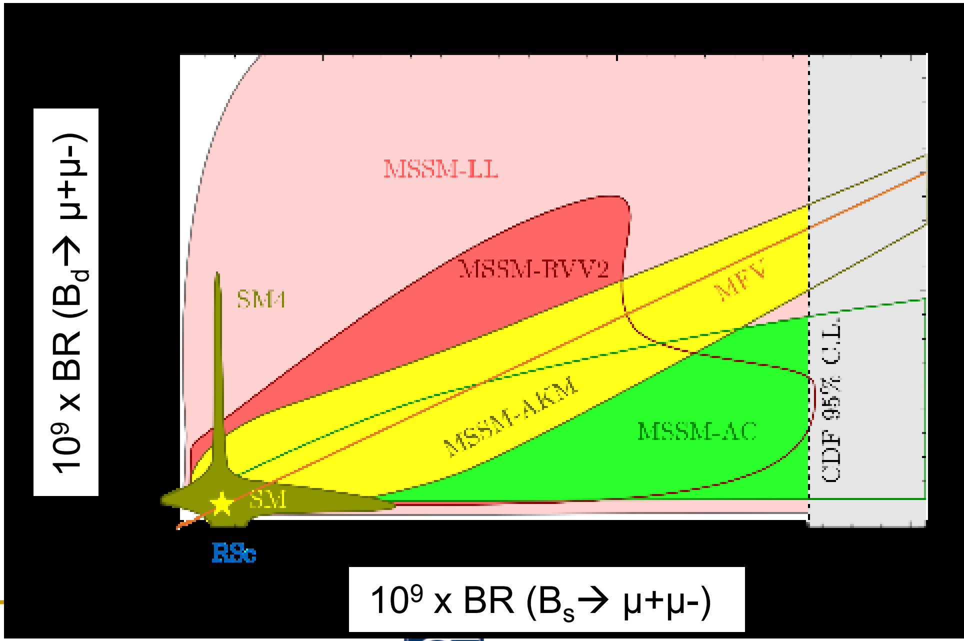
LHCb: exploit statistical power

- sensitivity of current limit in agreement with roadmap: $43 \cdot 10^{-9}$ @ 90% C.L. with 40 pb^{-1}
- expect 5σ observation down to SM value with ~3 fb^{-1} at 14 TeV cms-energy
- fragmentation fraction f_s/f_d measured with semileptonic decays to 10% (stat. limited)

LHCb Upgrade

- SM BR($B_s \rightarrow \mu^+\mu^-$) can be measured to 8% precision @ 50 fb^{-1}
  - ✓ strong constraints for NP models
- measure ratio BR($B_d \rightarrow \mu^+\mu^-$) over BR($B_s \rightarrow \mu^+\mu^-$) to ~35% level (SM uncertainty ~5%)
  - ✓ challenge: low BR $B_d \rightarrow \mu^+\mu^-$ and larger background from $B \rightarrow \pi\pi$

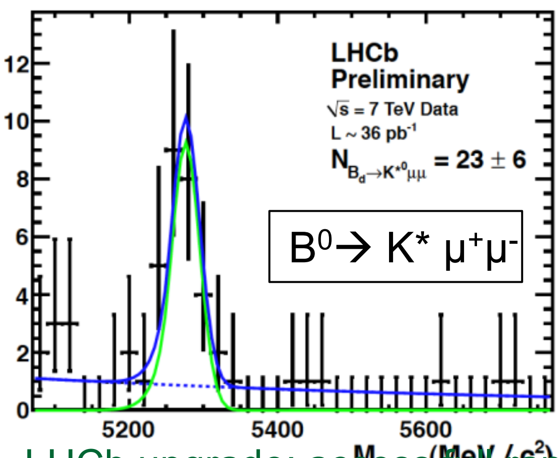


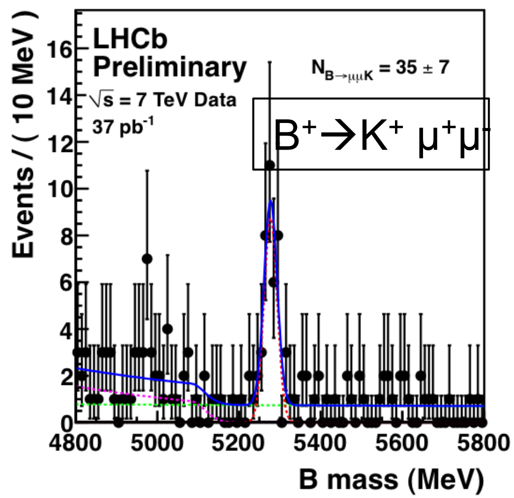


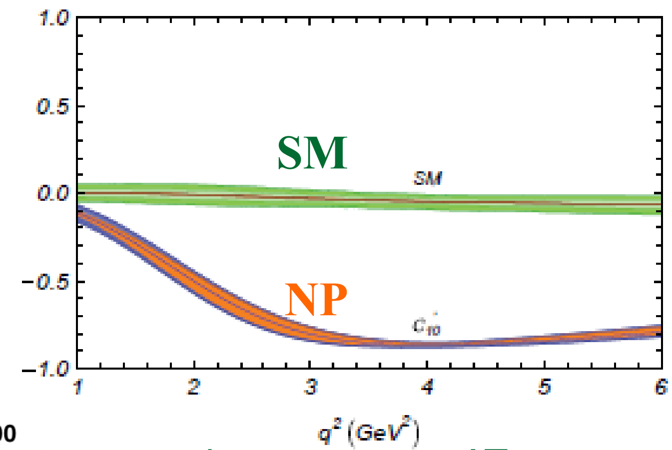
$B_0 \rightarrow K^* \ell^+ \ell^-$ and $b \rightarrow s\gamma^{(*)}$

$B_0 \rightarrow K^*\mu^+\mu^-$ and related channels ($B^0 \rightarrow K^*\mu^+\mu^-$, $B^+ \rightarrow K^+\mu^+\mu^-$, $B_s \rightarrow \phi\, \mu^+\mu^-$, $\Lambda_b \rightarrow \Lambda^{(*)}\mu^+\mu^-$) sensitive to NP via angular distribution

Principal task for current experiment is to map out the the crossing point







LHCb upgrade: access full range . transversity asymmetry AT

- ➢ $A_T^{(2)}$ is sensitive to new right handed currents
- ➢ $BR(B^+ \rightarrow K^+e^+e^-) / BR(B^+ \rightarrow K^+\mu^+\mu^-)$ sensitive to Neutral Higgs Bosons

Photon polarisation in exclusive $b \rightarrow s\gamma^{(*)}$

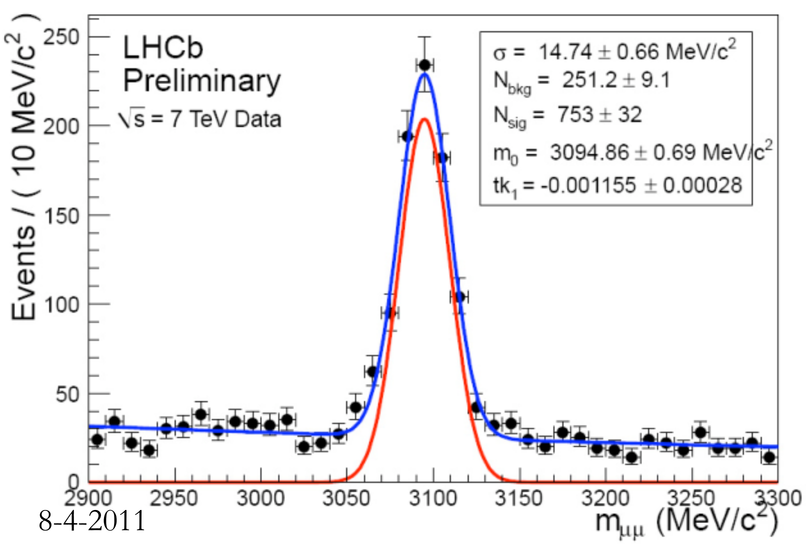
$B_s \rightarrow \Phi\gamma$: stat limited with 5 fb^{-1}. Measure polarisation to % level at upgrade

Similar story for $B^0 \rightarrow K^{*0}e^+e^-$, $B^+ \rightarrow K_1^+(K\pi\pi)\gamma$, $B^+ \rightarrow \Phi K^+\gamma$

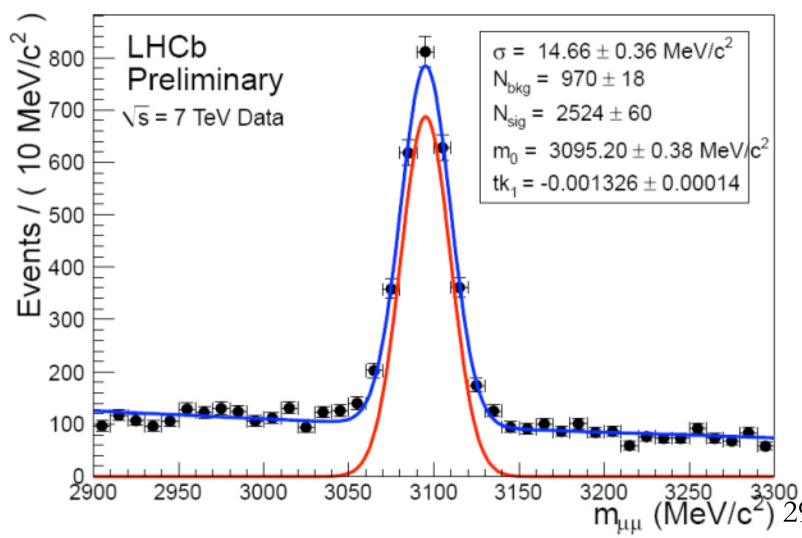
Muon Detectors

- 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/ψ → $\mu^+ \mu^-$ for single PV events



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



Operational Experience : 2010 (pileup)
2011 (pileup and start of spillover)

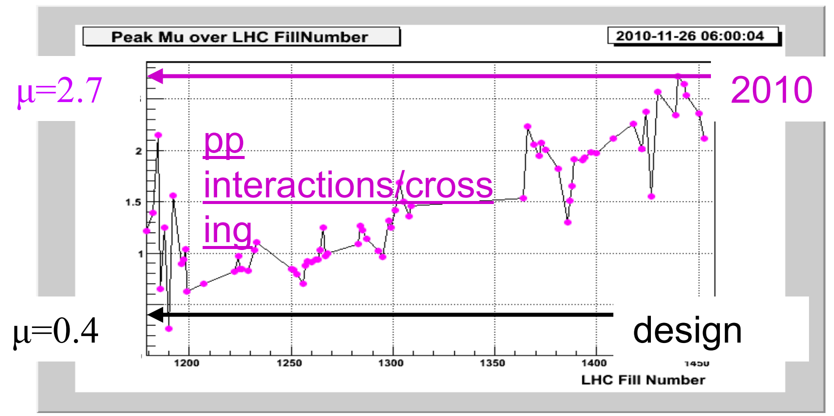
For a given luminosity μ also depends on the number of colliding bunches

So far LHC has operated well below maximum capacity of 2600 bunches

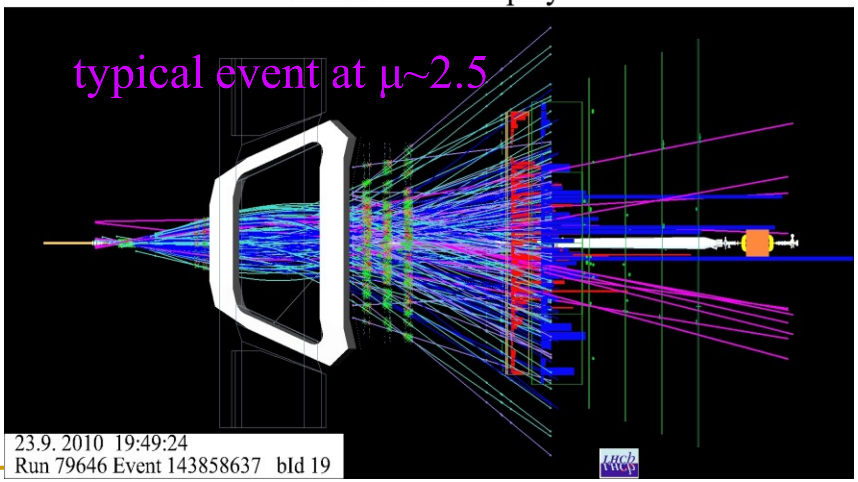
- 2010 run:
- L=1.6 ·10[32] ; n_b = 344 → μ_{max} = 2.7
  - > 6 times nominal!
  - Events are high multiplicity with multiple vertices
  - Tracking and reconstruction has functioned very well
  - 2011 run:
    - 50 ns operation for the first time
    - Spillover seen in straw tubes
    - Occupancy under study

Current data taking is already teaching us about the upgrade!

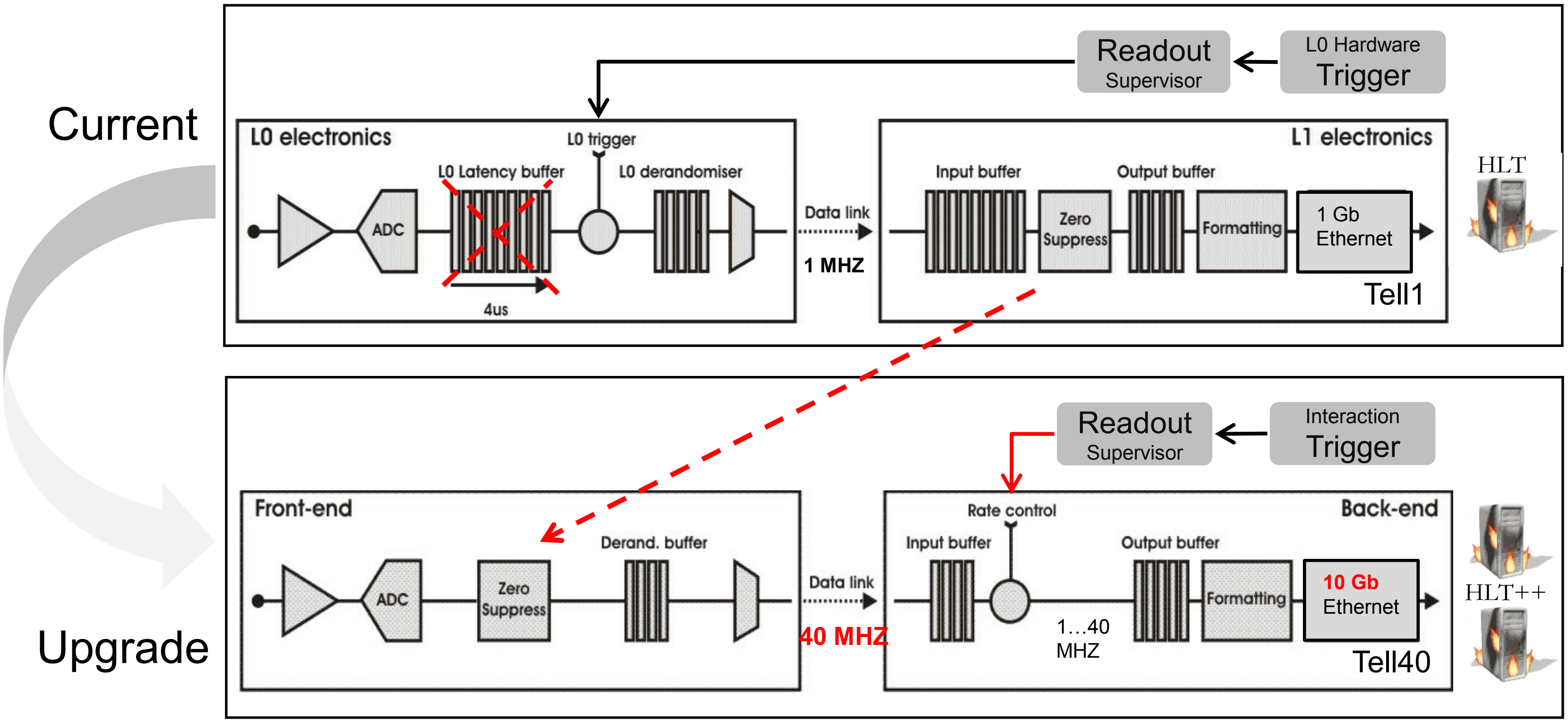
$$L = n_b \cdot L_b \; \alpha \; n_b \cdot \mu$$



LHCb Event Display



LHCb Upgrade Readout Scheme



Solution: Execute trigger algorithms on ALL data in software -> more sophisticated trigger

A new **DAQ** system must transfer all, zero-suppressed front-end data straight into a large computer farm, through a huge optical network & router.
VELO to be completely replaced

Physics beyond flavour

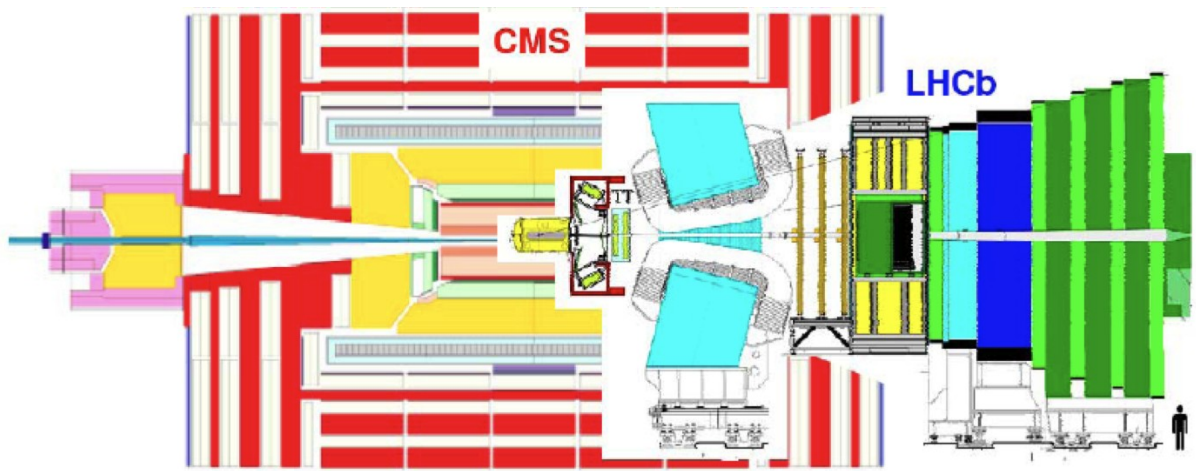
Forward acceptance means that a priori LHCb is complementary to ATLAS and CMS in many important physics topics beyond flavour

This attribute is enhanced by LHCb's unique vertexing and PID capabilities

Further advantages will come from fully flexible trigger & ability to run at high lumi

Some areas where LHCb can contribute:

- EW physics
- Search physics and exotics
- QCD



Electroweak Physics

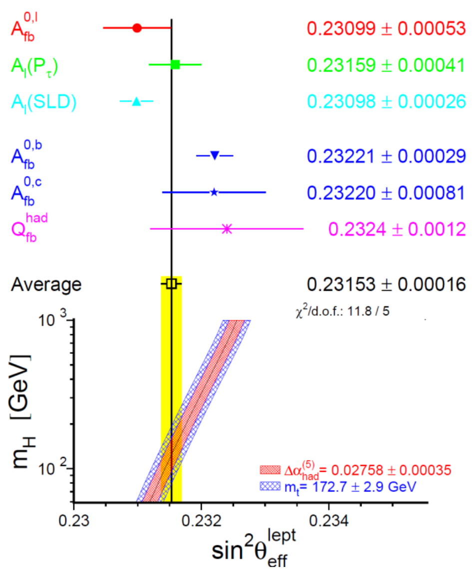
LHCb can contribute up to ILC/CLIC

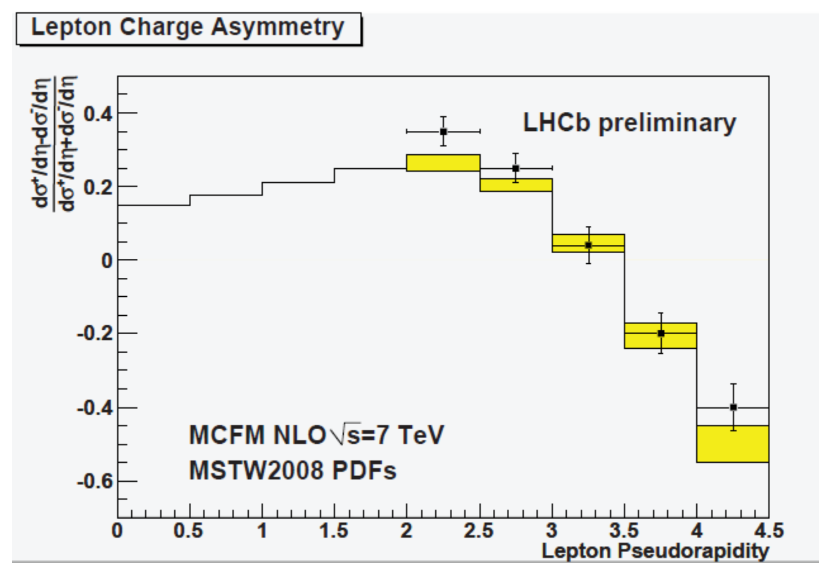
Determine $\sin^2\theta_{eff}^{lept}$ by measuring A_{FB} of leptons in Z decays

Measurement diluted by unknown direction of quark and anti quark – situation eased in forward direction

LHCb upgrade: 2.5 x better precision than LEP/SLD

LHCb can also contribute to M_W programme by constraining PDFs





Other upgrade B-physics topics

Other B-physics topics need upgrade for useful measurements to be made

Rare hadronic B decays

- Pure annihilation diagrams $B^+ \to D^* K^{*0}$ and $B^+ \to D_s^+ \Phi$ could be observed at SM BFs. Unique insights into dynamics of hadronic B decays.
- Isospin violating decays: $B_s \to \Phi \rho^0$ and $B_s \to \Phi \pi^0$ – provide clean handle on electroweak Penguins, are observable at SM level, but also sensitive to NP
- Decays like $B^+ \to K^+ K^+ \pi^-$, $K^- \pi^+ \pi^+$ negligibly small in SM, but not in NP

All benefit from software trigger !

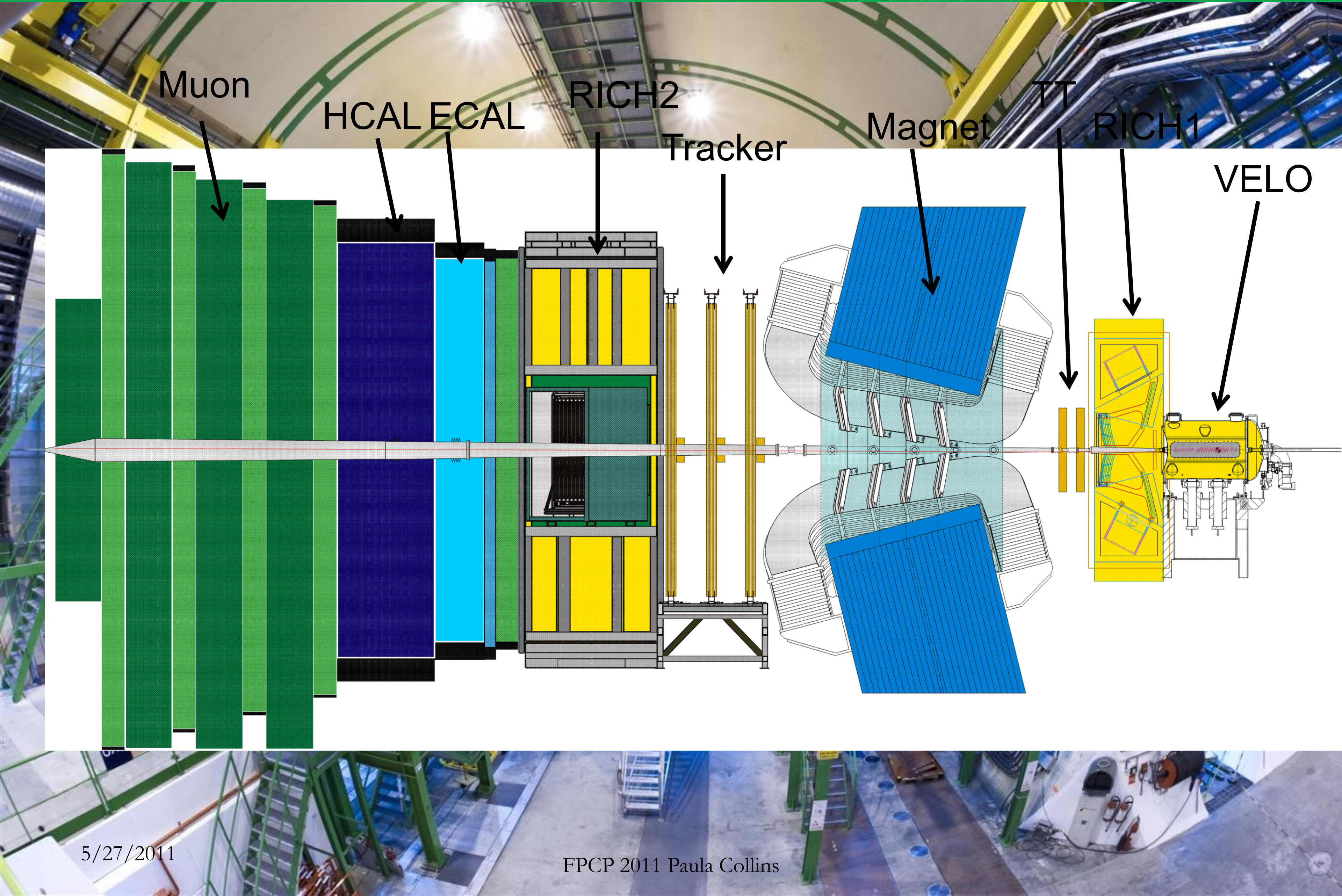
$B \to D^{(*)} \tau \nu$

Similar to B-factory flagship mode $B \to \tau \nu$, but with more observables

Sensitive to charged Higgs

Branching ratio high, but efficiency low. Distinctive topology would benefit from flexible trigger of upgrade.

LHCb: in design And in reality



FPCP LHCb Luminosity

Friday to Friday more data than in all 2010!!

- Monday 18 pb^{-1}
  - Quarkonium, CKM angles
- Tuesday 9 pb^{-1}
  - CPV, Top
- Wednesday 5 pb^{-1}
  - Charm, Neutrinos
- Thursday 0 pb^{-1}
  - Rare b decays, NP Low&High E
- Friday x pb^{-1}
  - The Future

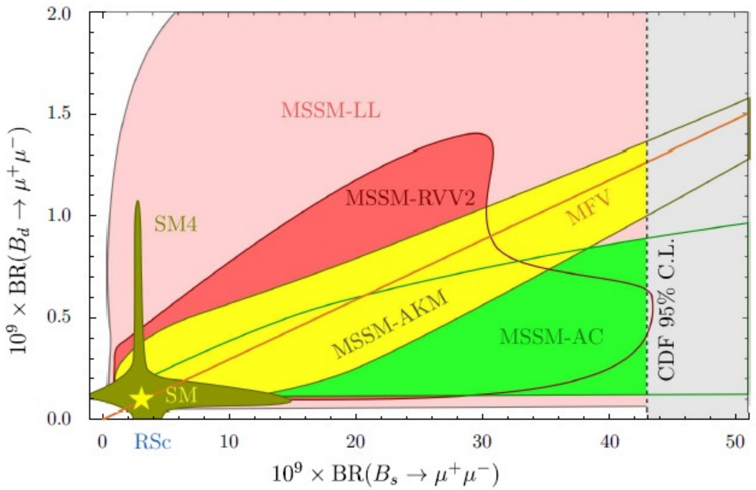
Impact on New Physics Models

LHCb upgrade will provide measurements essential to understand physics landscape that the coming decade will unveil..

Minimal Flavour Violation (MFV) hypothesis

All sources of flavour- and CP-violation in quarks will be same as SM. In this case searches for NP will be fruitless in CPV, but not in rare decays

e.g. In MFV BR($B_s \to \mu\mu$) *can* differ from SM but *not* BR($B_d \to \mu\mu$)/BR($B_s \to \mu\mu$)



SM with 4-families (SM4)

Add 2 new quarks (t', b') plus 5 new quark-mixing parameters

New CPV possibilities that could show up in D^0, B^0 and B_s system

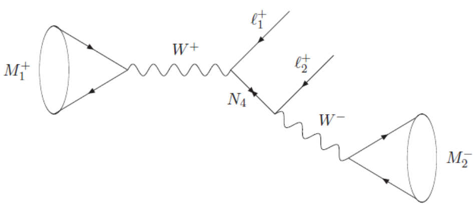
Both proposals can be disproved / strongly constrained with improved flavour data

Sensitivities to key quark 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
	$S(B^0 \to \phi K_S^0)$	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	$\gamma\ (B \to D^{(*)}K^{(*)})$	$\sim 20^\circ$	$\sim 4^\circ$	0.9°	negligible
	$\gamma\ (B_s \to D_s K)$	-	$\sim 7^\circ$	1.5°	negligible
	$\beta\ (B^0 \to J/\psi\, K^0)$	1°	0.5°	0.2°	negligible
Charm CPV	A_Γ	2.5×10^{-3}	2×10^{-4}	4×10^{-5}	-
	$A_{CP}^{dir}(KK) - A_{CP}^{dir}(\pi\pi)$	4.3×10^{-3}	4×10^{-4}	8×10^{-5}	-

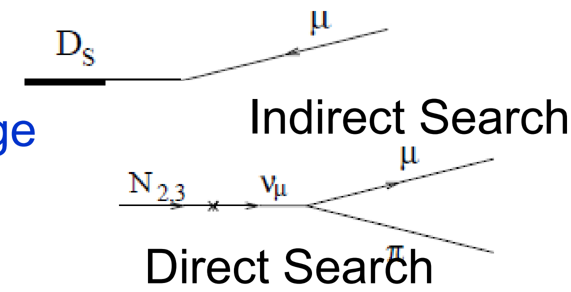
… And beyond

Lepton flavour physics
An upgraded LHCb can also illuminate the lepton sector



LFV tau decays, e.g. $\tau \to \mu\mu\mu$

Present detector will probably attain a sensitivity not much better than B-factories (2.1×10^{-8} at 90% CL). Upgrade could improve limit by an order of magnitude.

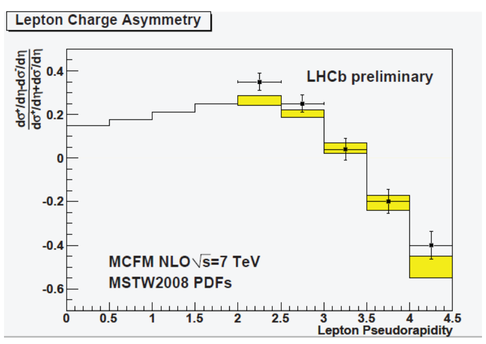


Search for heavy Majorana neutrinos in ~1 GeV mass range

Such particles a natural occurrence on many models e.g. ‘neutrino minimal SM’, produced in D,B and τ decays

Physics Beyond Flavour

EW physics



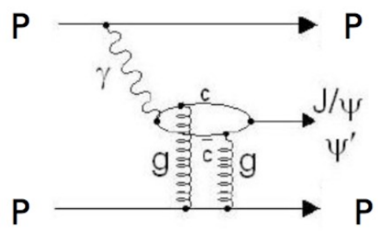
Search physics and exotics

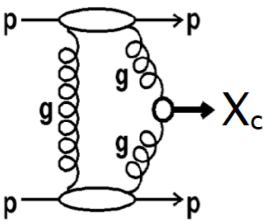
QCD

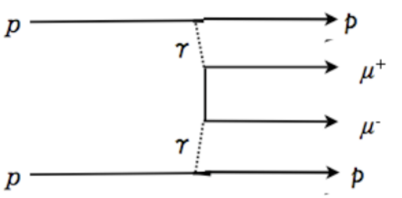
Central Exclusive Production

pp → p + X + p

rapidity gaps







- photon or pomeron exchange
- observe and study exotic particles in clean environment (exclusive χ_c is seen)
- signature: ~ no activity (even in backward silicon planes) apart from signal

LHCb Event Display