LHCb future plans

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on behalf of the 11 LHCb UK groups:
Birmingham, Bristol, Cambridge, Edinburgh, Glasgow, Imperial College London, Liverpool,Oxford, Manchester, STFC/RAL, Warwick

Brief summary of the current status

- *Detector is robust and functioning successfully in high multiplicity environment far beyond the nominal conditions*

  - $L_{inst} \approx 3.5 \times 10^{32}\ cm^{-2}s^{-1}$ *(designed for* 2×10^{32}*)*
  - μ *(average number of interactions per BX) up to 2.5 (designed for* $\mu \sim 0.5$*)*

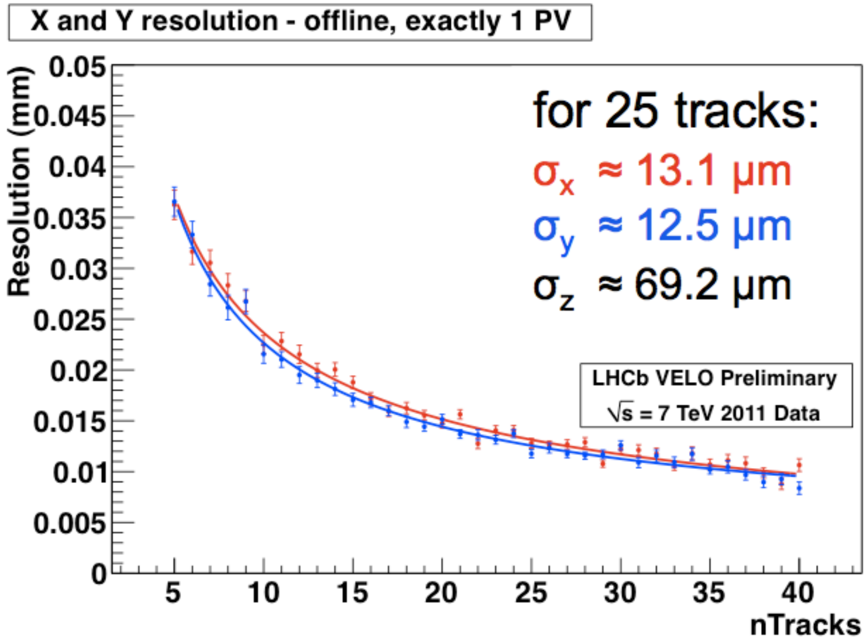
  Performance validated with data:

  - ***superior mass and vertex resolution (best amongst LHC detectors)***
  - ***excellent PID (RICH is unique)***
  - *proper time resolution*
  - *most efficient and flexible trigger for low* p_t *objects*

- *Collected 400* pb^{-1} *of data (37* pb^{-1} *in 2010)*
  Reaching 1 fb^{-1} *in 2011 is very realistic*

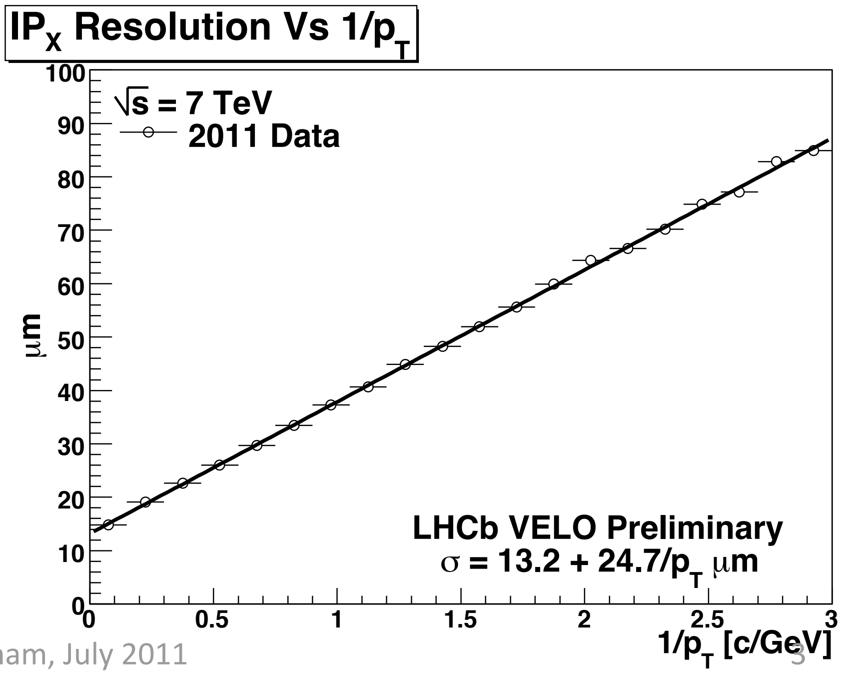
- ***Wide physics programme complementary to GPDs.***
  World best sensitivity reach for LHCb golden channels is guaranteed in 2011

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



Primary vertex resolution:
~ 13 (70) μm in transversal
(longitudinal plane)

Best IP resolution ~15 μm

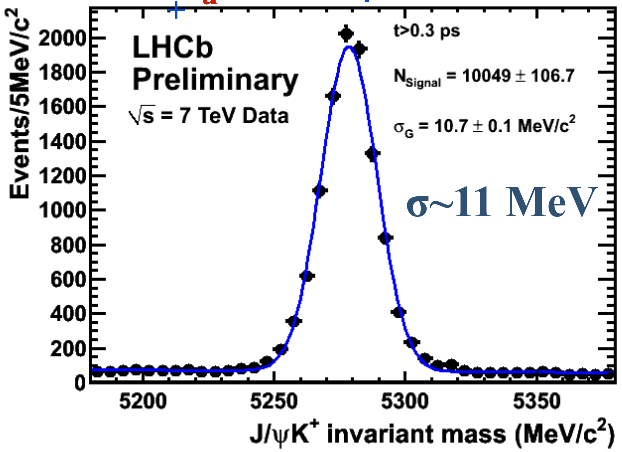


Superior LHCb mass resolution

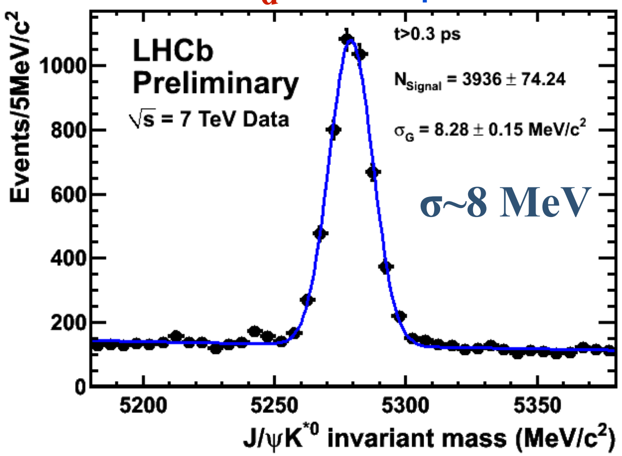
Comparison with GPDs:

- *CMS: σ~16 MeV*
- *ATLAS: σ~26 MeV*

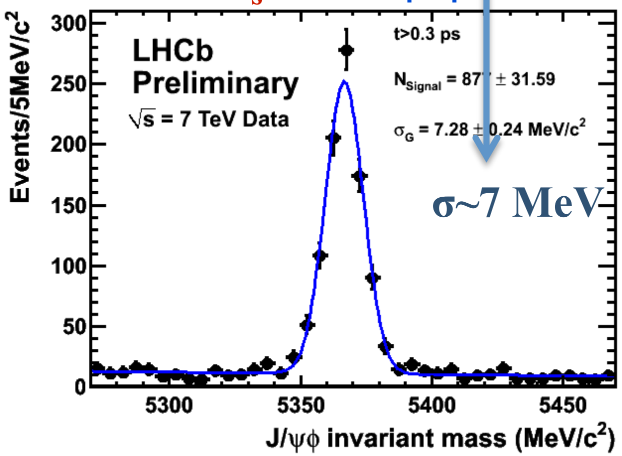
$B_u^+ \rightarrow J/\psi\ K$



$B_d^0 \rightarrow J/\psi\ K^*$

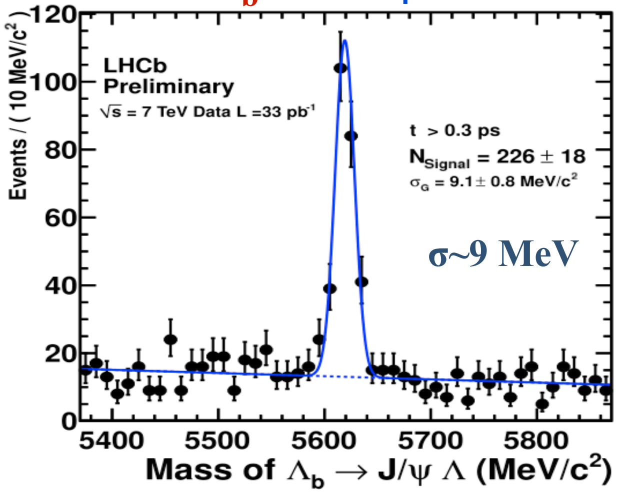


$B_s^0 \rightarrow J/\psi\ \varphi$



Signals are as clean as at the e^+e^- - machines !!!

$\Lambda_b^0 \rightarrow J/\psi\ \Lambda$

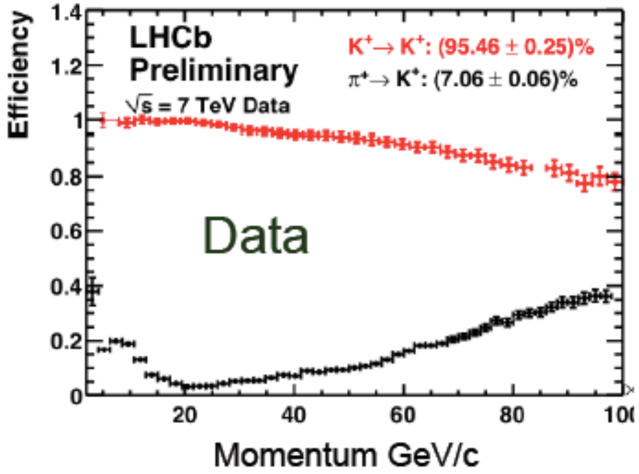


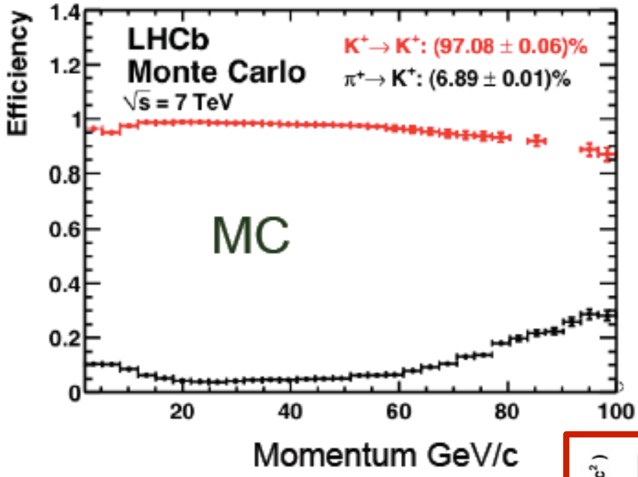
World best mass measurements for B_u, B_d, B_s and Λ_b

[LHCb-CONF-2011-027]

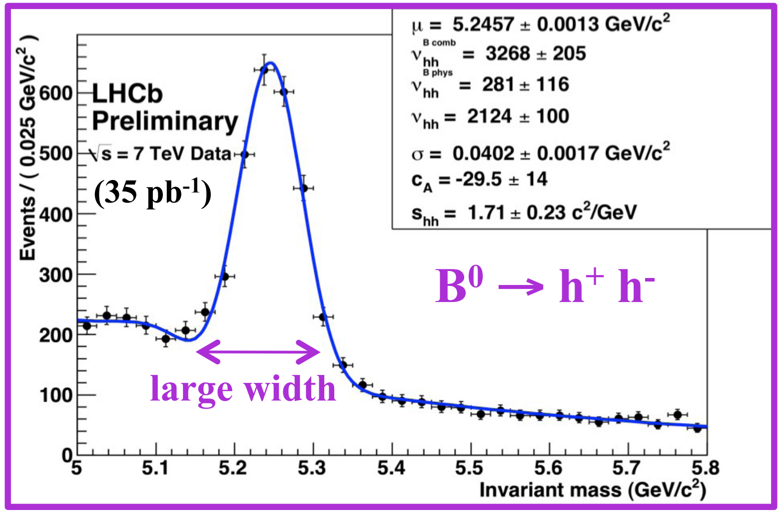
Channel		LHCb mass [MeV/c^2]	PDG [MeV/c^2]
$M(B^+ \rightarrow J/\psi K^+)$	=	$5279.27 \pm 0.11\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.17 ± 0.29
$M(B^0 \rightarrow J/\psi K^{*0})$	=	$5279.54 \pm 0.15\,(\text{stat}) \pm 0.16\,(\text{syst})$	5279.50 ± 0.30
$M(B^0 \rightarrow J/\psi K^0_S)$	=	$5279.61 \pm 0.29\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.50 ± 0.30
$M(B^0_s \rightarrow J/\psi \phi)$	=	$5366.60 \pm 0.28\,(\text{stat}) \pm 0.21\,(\text{syst})$	5366.30 ± 0.60
$M(\Lambda_b \rightarrow J/\psi \Lambda)$	=	$5619.49 \pm 0.70\,(\text{stat}) \pm 0.19\,(\text{syst})$	5620.2 ± 1.6
$M(B^+_c \rightarrow J/\psi \pi^+)$	=	$6268.0 \pm 4.0\,(\text{stat}) \pm 0.6\,(\text{syst})$	6277 ± 6

PID RICH performance



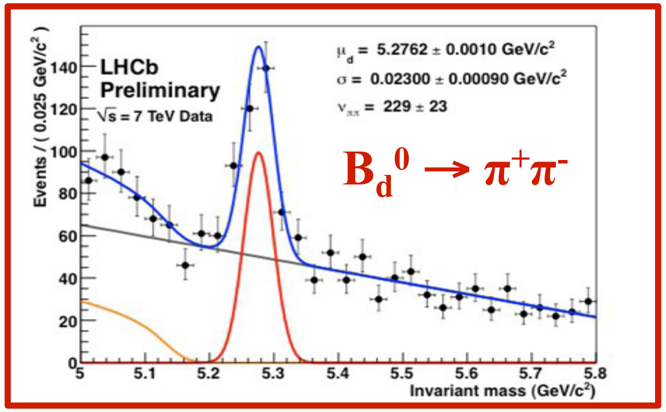


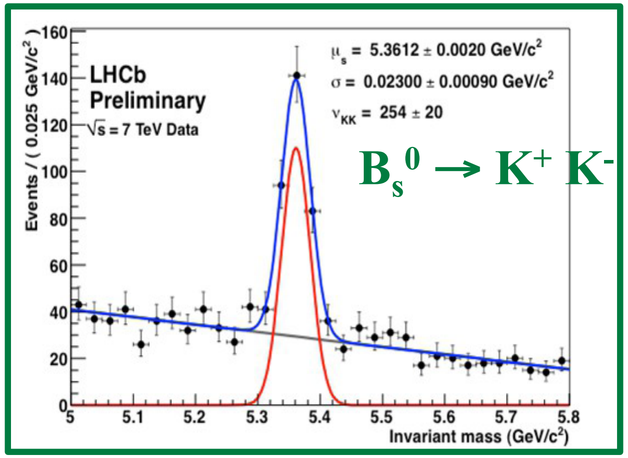
No particle identification → any 2 hadrons!



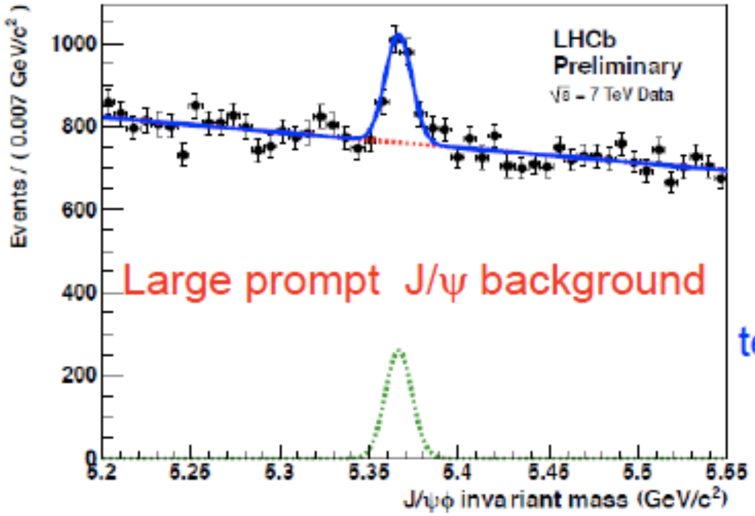
PID of 2π

PID of 2K



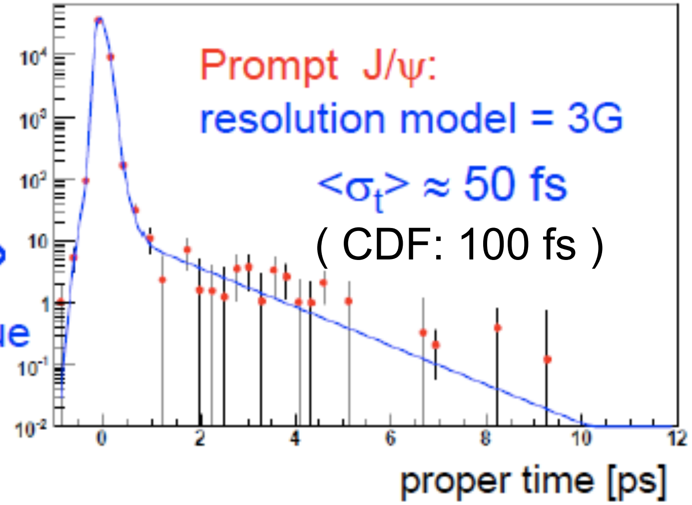


Proper time resolution and flavour tagging



sPlot

technique



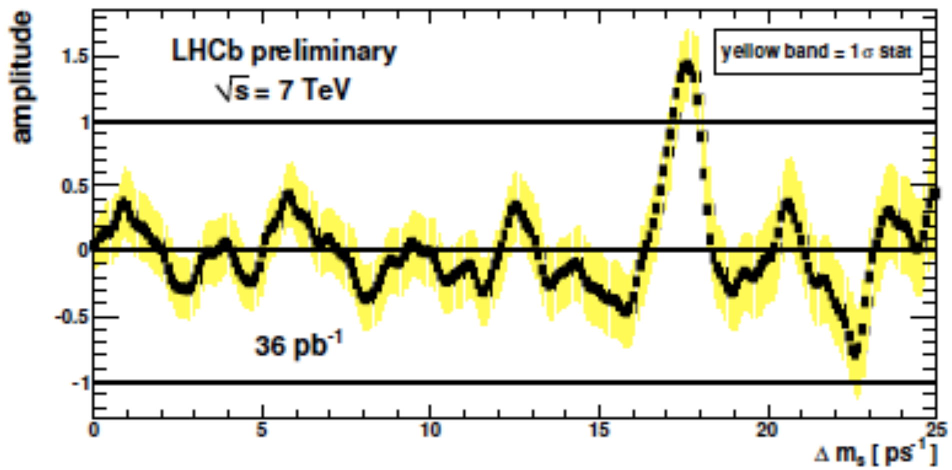
Δm_s = 17.63 ± 0.11 ± 0.04 ps^{-1}

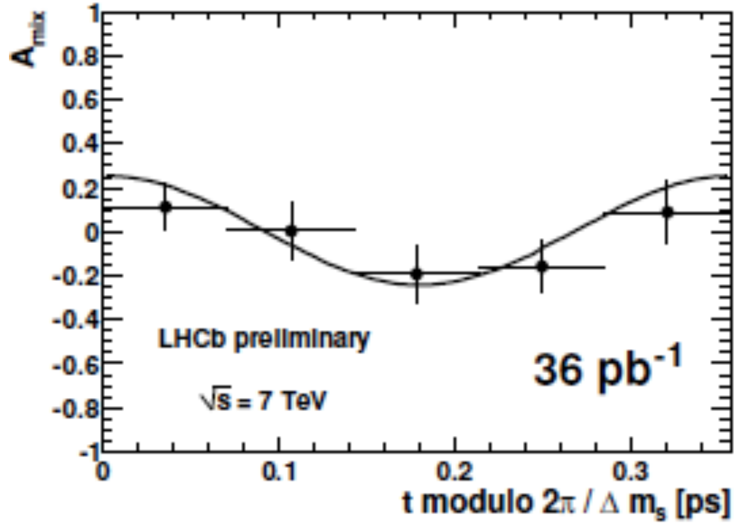
CDF: Δm_s = 17.67 ± 0.10 ± 0.07 ps^{-1}

Small syst. uncertainty thanks to excellent proper time resolution

$B_s^0 - \bar{B}_s^0$ oscillations

asymmetry modulo $2\pi / \Delta m_s$





Flavour tagging power ~3% (→ 6%)

LHCb physics objectives

Discover New Physics

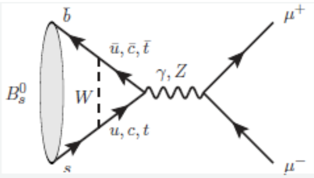
Strategy: study observables which test loop diagrams
Make a test which involves quarks of all three generations
→Explore both $B_{u,d}$ and B_s sectors, b-baryons and charm

Key measurements:

- *CP Violation in beauty and charm to search for NP phases (ϕ_s in $B_s \rightarrow J/\psi\phi$ & $\phi\phi$, γ in hadronic channels mediated by trees and loops)*
- *Search for super rare decays enhanced by NP (e.g. $B_s \rightarrow \mu\mu$, $D \rightarrow \mu\mu$)*
- *Test of NP helicity structure (e.g. $B \rightarrow K^*\mu\mu$, $B_s \rightarrow \phi\gamma$)*

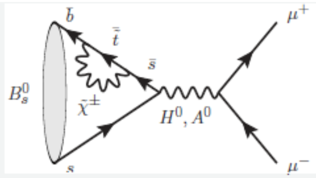
Sensitivity reach for golden channels: $B_s \rightarrow \mu\mu$

(UK contribution to the mass scale calibration)



FCNC, helicity suppression

SM expectation: $(3.2 \pm 0.2) \times 10^{-9}$

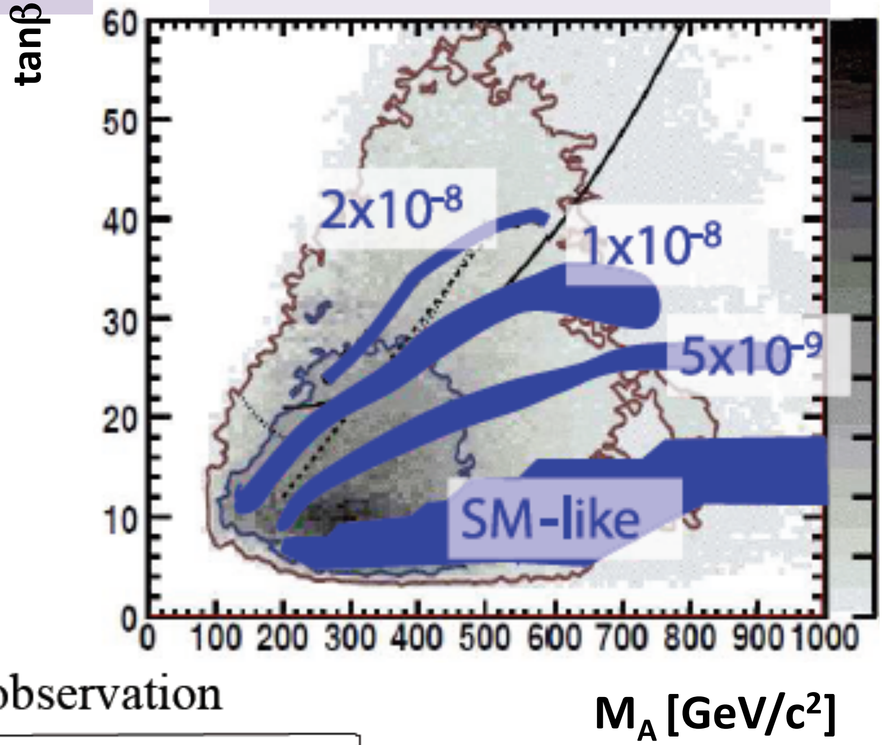


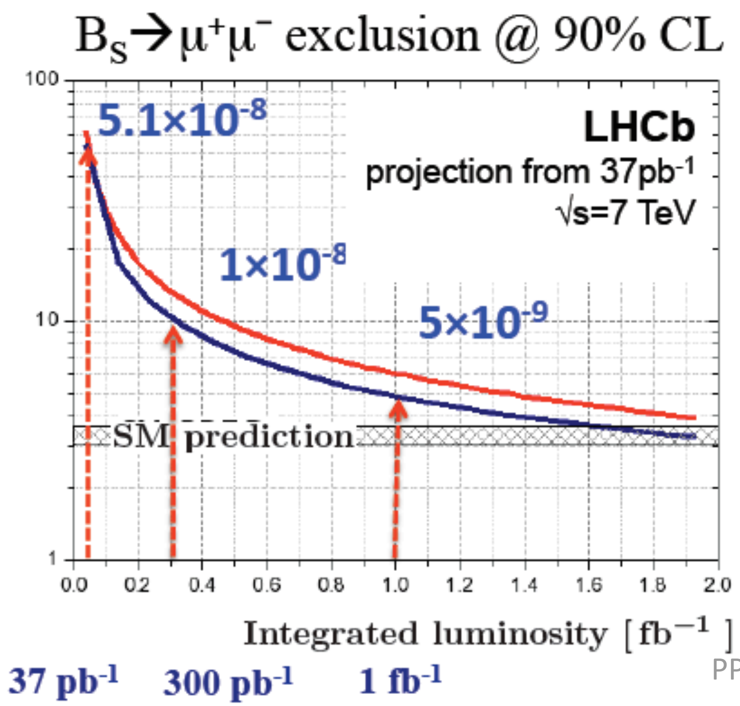
Sensitive to NP contributions

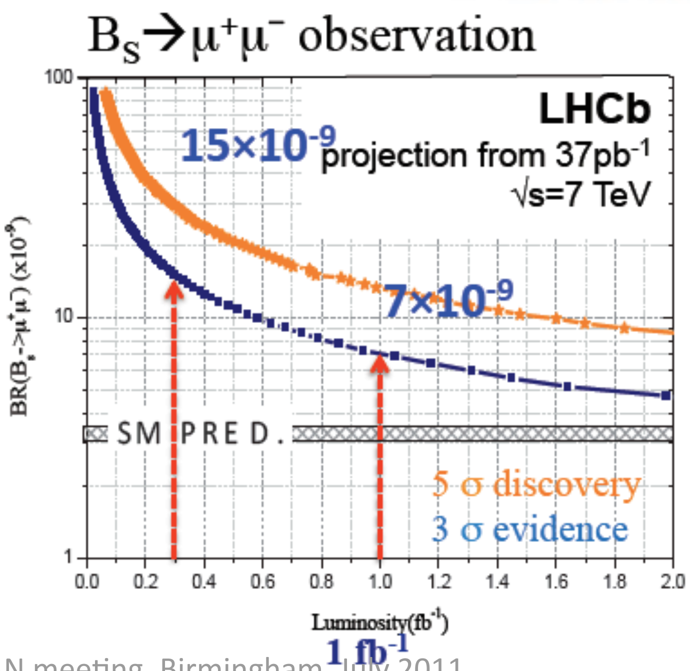
MSSM: $Br(B_s \rightarrow \mu^+\mu^-) \simeq \frac{\tan^6 \beta}{M_A^4}$

	Luminosity	Limit @ 90% CL
CDF	$3.7 fb^{-1}$	36×10^{-9}
D0	$6.1\ fb^{-1}$	42×10^{-9}
LHCb	$0.037 fb^{-1}$	43×10^{-9}

Strong impact on viable SUSY scenarios







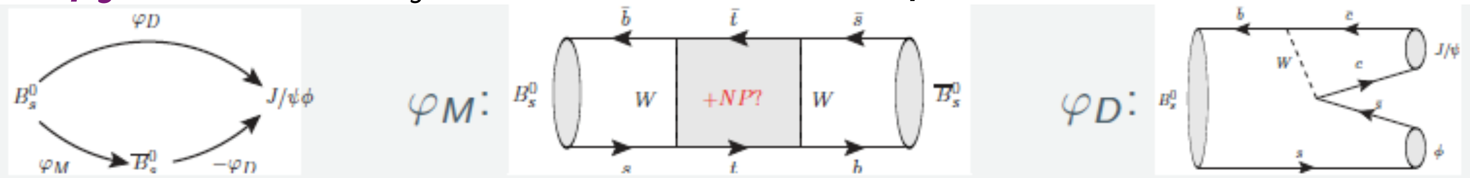
SM test with 10% accuracy requires ~$50 fb^{-1}$

Search for $B_d \rightarrow \mu\mu$ requires even larger data sample !

Sensitivity reach for golden channels: ϕ_s in $B_s \to J/\psi\phi$ & $\phi\phi$

(strong / leading contribution of UK groups)

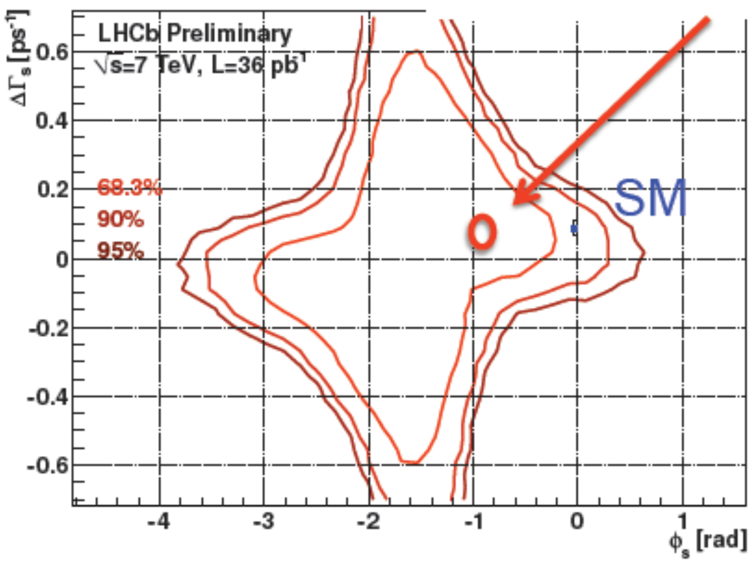
$\phi_s^{J/\psi\phi}$ = **$-2\beta_s$** *in SM is the B_s meson counterpart of 2β* (**penguin contribution ≤ 10^{-3}**)



$\phi_s^{J/\psi\phi}$ *is not really constrained so far*

Theoretical uncertainty is very small: *$-2\beta_s$ = - 0.0368±0.0017 (CKMfitter 2007)*

0.13 rad sensitivity with 1 fb^{-1}



$\phi_s \in [-2.7, -0.5]$ rad @68% c.l.

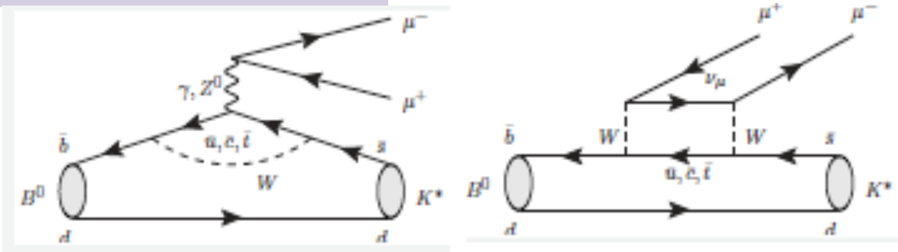
$\phi_s \in [-3.5, 0.2]$ rad @95% c.l.

Measurement of the ϕ_s expected in SM to precision < 20% of SM value requires 50 fb^{-1}

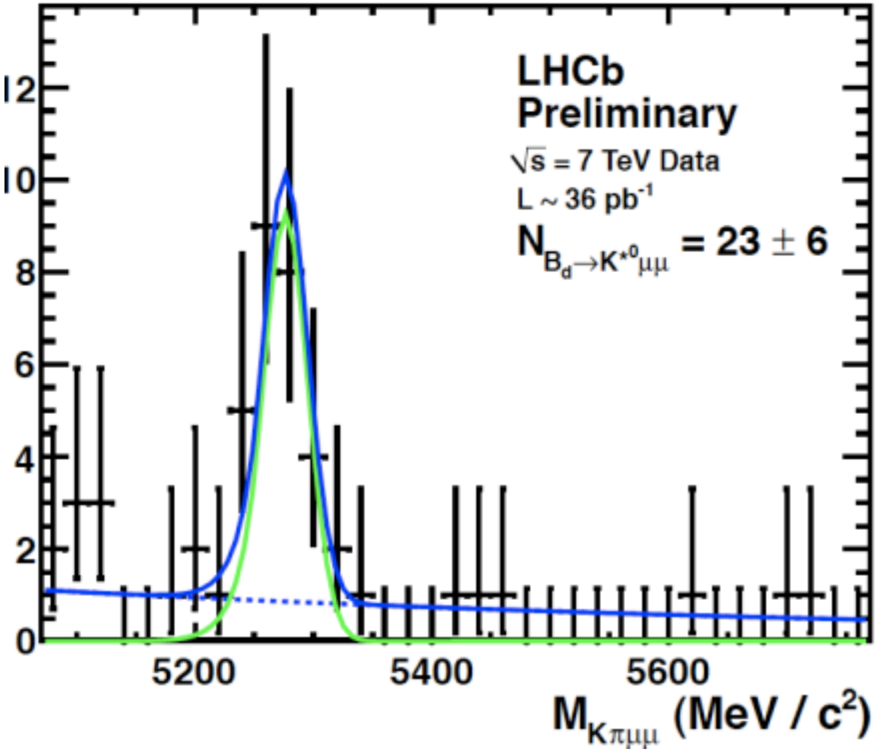
Similar test for the NP phases in penguin diagrams using $B_s \to \phi\phi$ requires even larger data sample !

Sensitivity reach for golden channels: $B_d \to K^*\mu\mu$
(leading contribution of UK groups)

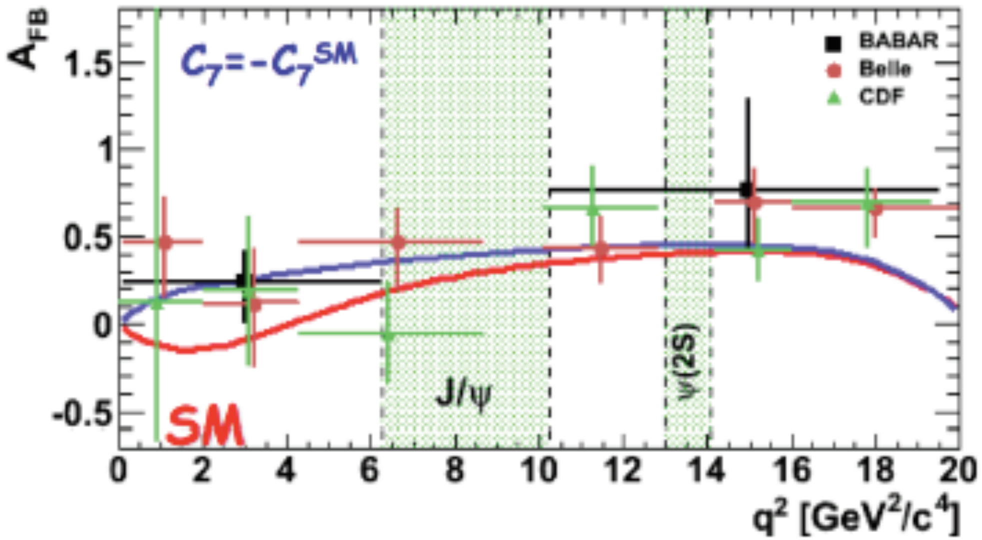
$$\mathrm{FCNC},\ Br = (1.05^{+0.16}_{-0.13}) \times 10^{-6}$$



As seen in LHCb with 36 pb^{-1}



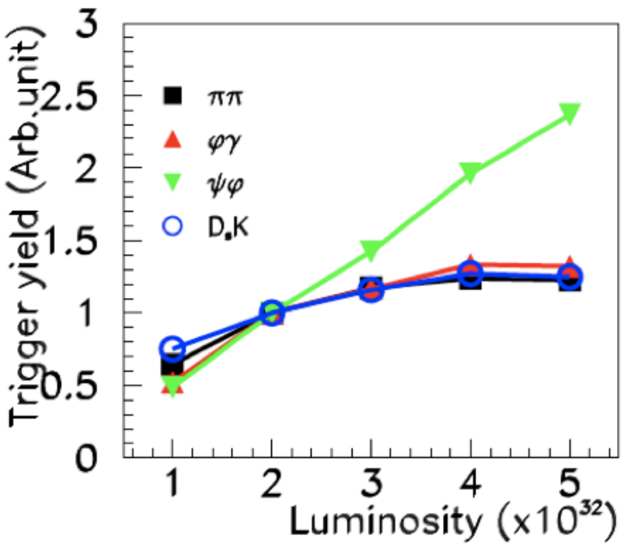
Intriguing hint is emerging with current data → LHCb expects ~1500 signal events in 2011 and should clarify existing situation. Expecting accuracy in A_{FB} zero crossing point is 0.8 GeV^2



Full transversity amplitudes analysis requires large data sample of ~50 fb^{-1}

Future LHCb upgrade

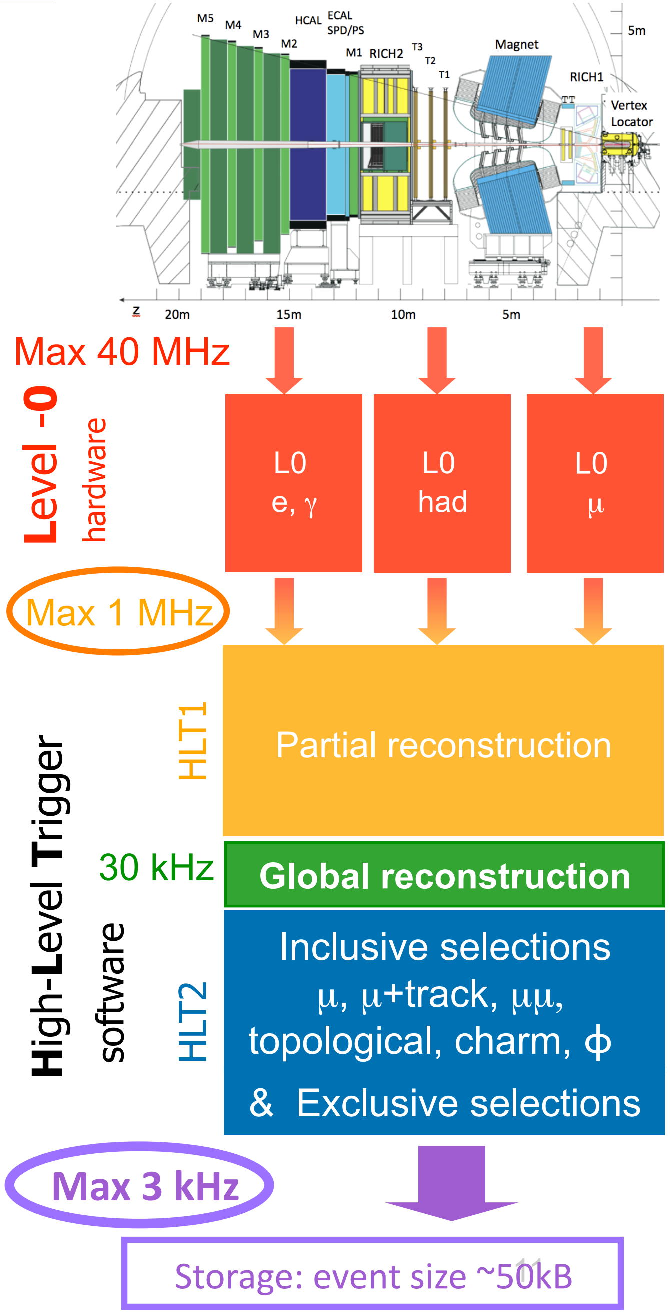
- Excellent performance of current detector in hadronic environment demonstrated
- Current detector can accumulate ~1 fb^{-1}; running luminosity levelled at 3.5×10^{32} $cm^{-2}s^{-1}$ with μ ~ 1.5 and event logging rate of ~3 kHz
- After recording ~5 fb^{-1} time to double stats is too slow ➔ increase $\mathcal{L}$ ➔ Level-0 trigger loses efficiency because the <u>DAQ readout limited to 1MHz</u>, E_T -cut raised...



Solution:

40MHz DAQ readout rate

Fully software trigger



LHCb Upgrade strategy

- *LHCb detector readout at 40MHz with a fully software based trigger:*
  - *Upgrade of all sub-detector Front-End electronics to 40 MHz readout*

- *Rebuild of all silicon detectors attached to the current 1MHz electronics*
  - *VELO, IT, TT, RICH photo-detectors*

- *Remove some detectors due to increased occupancies or no necessity at higher luminosity*
  - *RICH1-aerogel, M1, possibly PS&SPD*

- *Eventually improved PID at low momenta:*
  - *Build a new detector: TORCH*

- ***Tight time schedule** → try to optimize:*
  - *Cost*
  - *Manpower*
  - *Time (R&D, production, installation)*

- *Re-use existing electronics & infrastructure as much as possible*

- *Develop common solutions for use by all sub-detectors*
  - *e.g.: use GBT @ 4.8 Gbit/s with zero suppression ~ 13,000 links with 8,300 optical fibers already installed in LHCb*

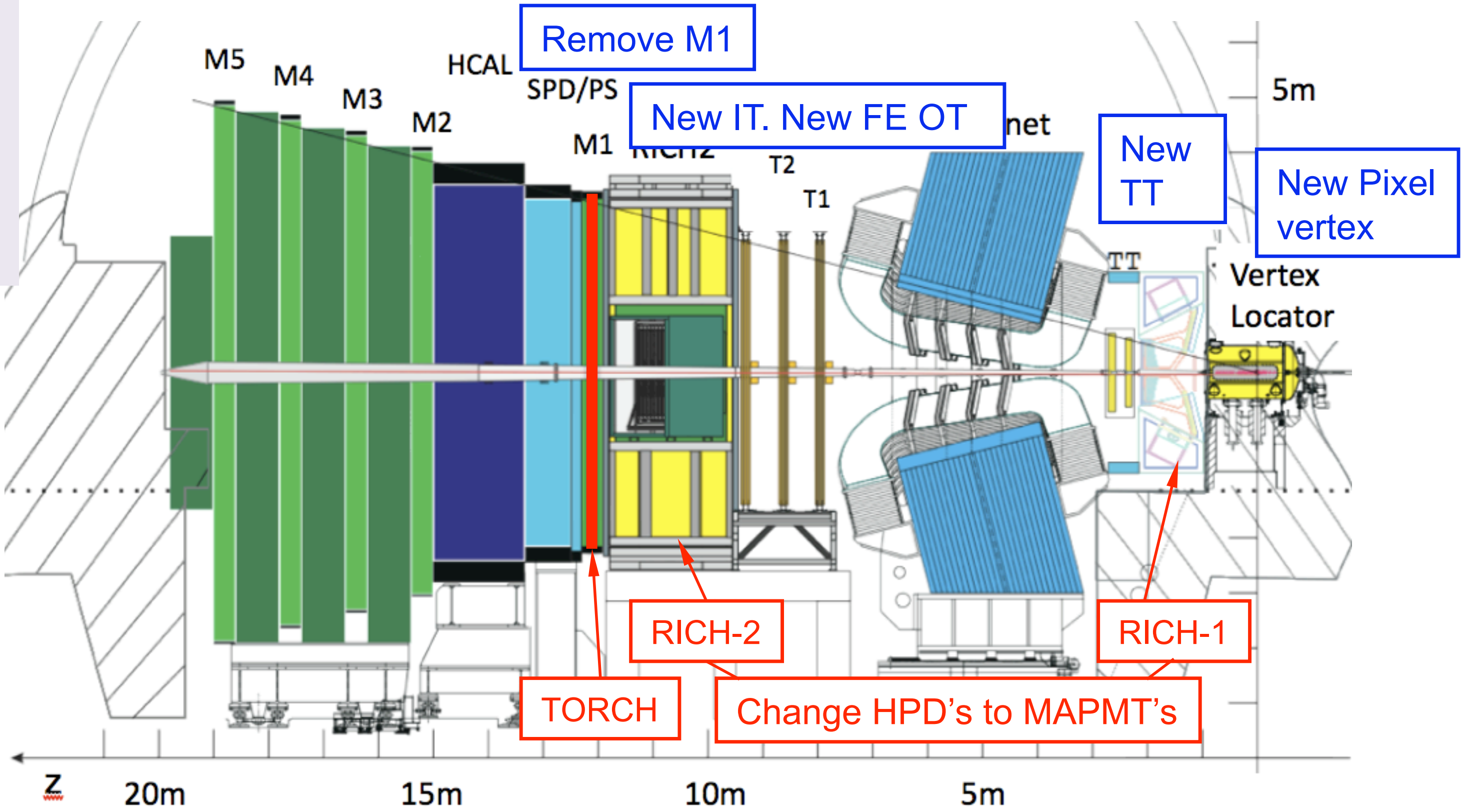
Collect $50\ fb^{-1}$:

$\sim 5\ fb^{-1}/year$

$\sqrt{s} = 14$ TeV

$\mathcal{L} = 10^{33}\ cm^{-2}s^{-1}$

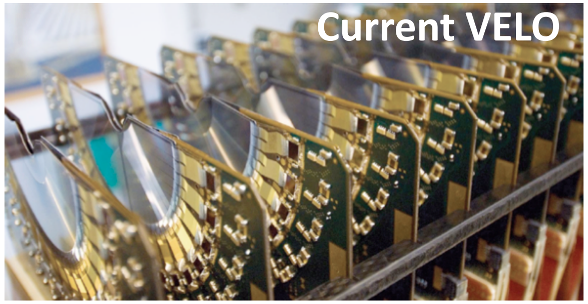
Upgraded LHCb



GPD in the forward region with fully flexible software trigger

Key elements of the upgrade:

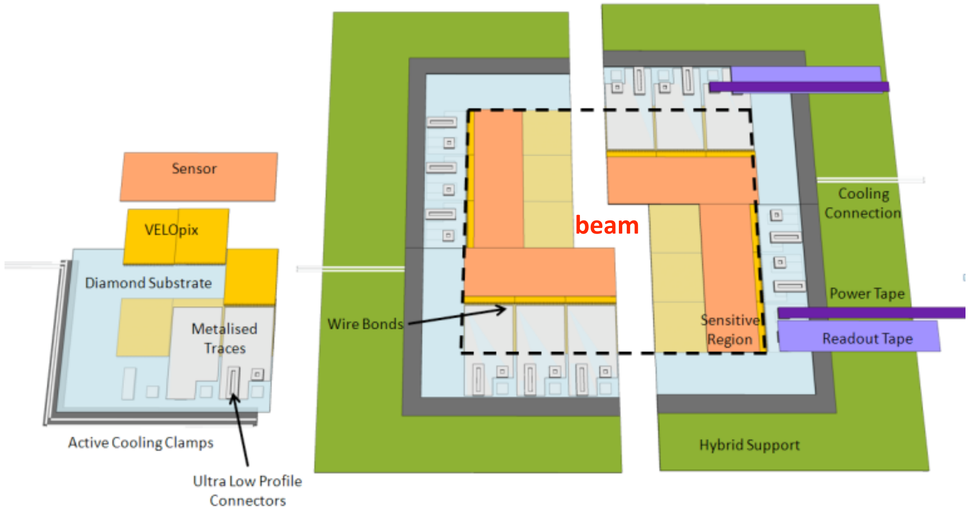
- *Readout @ 40 MHz → New electronics (and replacement RICH photodetectors)*
- *Improved tracking → New Vertex Detector & New IT / TT with particular aim to improve material budget within LHCb acceptance*

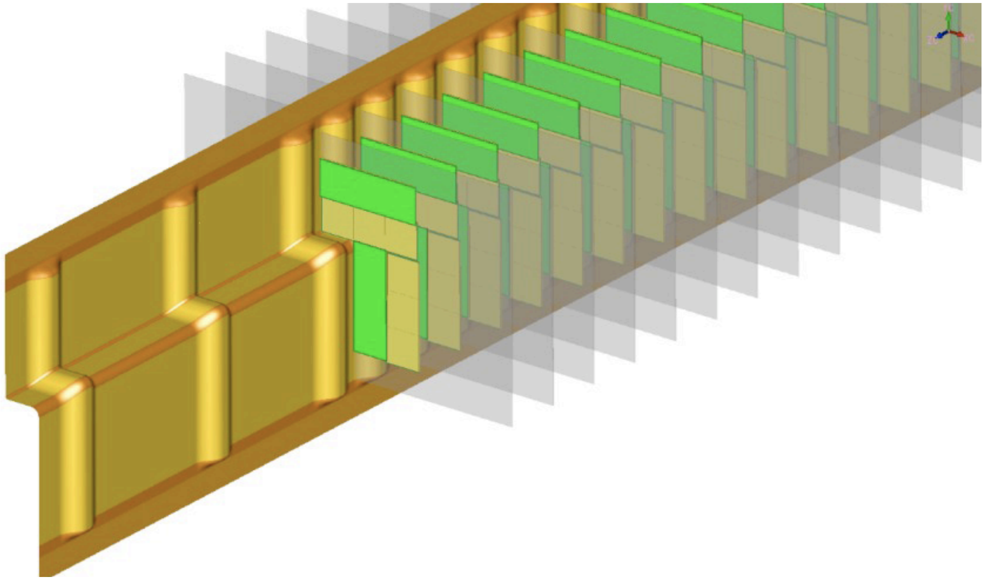


New Vertex detector
(impossible without strong UK involvement)

NEW VELO @ 40MHz Readout

- Challenges: Data rates <$rate_{max}$> = 200MHz cm^{-2}
  $Irradiations_{max}$= 5.10^{15} 1 MeV $n_{eq}cm^{-2}$
  Low material budget
- Baseline option:
  PIXEL Detector: VELOPIX based on TimePix
  - 55 µm x 55 µm pixel size
  - CVD Diamond substrate
- Alternative option: Strip detector





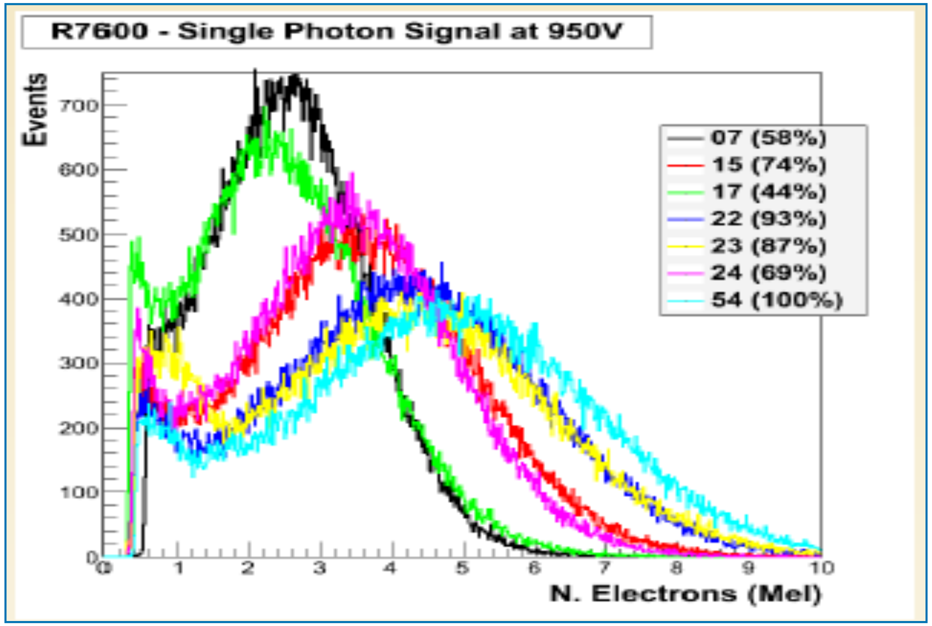
R&D ongoing

- Module layout and mechanics
- Sensor options:
  - Planar Si, 3D, Diamond
- CO_2 cooling
- FE electronics
- RF-foil of vacuum box

Upgrade of the PID (impossible without strong UK involvement)

- RICH-1 and RICH-2 detectors are retained, replace HPDs (1 MHz internal Readout):
  - Baseline readout: replace pixel HPDs by MaPMTs & readout with 40 MHz custom ASIC
- Baseline MaPMTs (Hamamatsu):

R7600 vs R11265 (baseline):
8x8 pixels, 2.0x2.0 mm^2, 2.3 mm pitch (2.9 mm)
18.1x18.1 mm^2 active area (23.5x23.5 mm^2)
Fractional coverage: 50% (80%)



R7600 characterization:
- Channel to channel gain variation
- Excellent cross-talk (below 1%)
- ~10% gain reduction in 50 gauss B_L-field (25 gauss max B_L-field in LHCb)

UK groups are also strongly involved to R&D for the TORCH:
Time of Flight detector based on 1 cm quartz plate, for PID of low momenta hadrons (replacing Aerogel) combined with DIRC technology

Deliberations from LHCC

- *" LHCb has presented a very detailed LOI describing its upgrade plan The physics case is based on a planned int. luminosity of 50 fb^{-1} This can be achieved by running luminosity leveled at $L \geq 10^{33}\ cm^{-2}s^{-1}$; with μ=2.3*

- *The case for flavour physics with 50 fb^{-1} was found to be very compelling*

  - This amount of data allows measurements at the level of theor. achievable precision for many quantities sensitive to NP

  - The level of accuracy achievable is comparable, in case of overlap, with that foreseen at future SuperB factories with 50 ab^{-1}; ***→ this makes LHCb a well-matched competitor and a very important complement "***
  Many channels are unique for LHCb

- *" Physics capabilities in the area of lepton flavour violation, EW and exotic physics are also noted as a welcome addition to the LHCb physics potential "*

- ***LHCb was strongly encouraged to proceed towards TDR rapidly at the LHCC meeting in June 2011 !***

- ***Presentation to the SPC in June 2011. Very positive reaction***

Feedback from PPAN to LHCb Statement of Interest:

1. *"PPAN noted that LHCb was the sole flavour physics experiment currently funded by STFC and that, to exploit fully the flavour physics potential of the LHC, the LHCb experiment would require an upgrade for operation at higher luminosities"*

2. *"PPAN felt that a clear demonstration of strong scientific results from LHCb still remained to be made. A a result a decision on any future upgrade for LHCb might not yet be timely."*

3. *"…PPAN felt that it was premature to recommend the submission of a full proposal at this time."*

4. *"PPAN felt it was important to retain the skills and capabilities that would be required for any future LHCb upgrade."*

Planned schedule

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

Long shutdown
Splice repairs,
LHC → 13-14 TeV

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

Injector and LHC
Phase I upgrades

2019-2021
Ramping up to 10^{34}
Up to 100 fb^{-1} delivered per year

Towards High
Luminosity LHC

LHC had a very bright startup:

2010: 250 bunches with ca. 2.6 10^{13} p per beam

2011: 1092 bunches and beyond

Luminosity > $10 \times 10^{32} cm^2$

Plan to run at 7 TeV for 2011 and 2012+

18 month shutdown 2013-2014:

to repair splices → 13-14 TeV

GPDs 1st phase upgrade (e.g. ATLAS b-layer)

Next shutdown ~ 2018:

Full luminosity upgrade of LHC

GPDs 2nd phase upgrade for "nominal" lumi

LHCb full upgrade to 40MHz R/O

Installation of Upgraded LHCb

LHCb Upgrade TDR in 2013 at latest
Intensive R&D activities are vital now !

Contribution of the UK groups to the current LHCb & Future plans

Current (11 UK groups are LHCb members):

- Leading role in construction and operation of the two key sub-detectors: VELO and RICH; UK provides ~20% external computing power for LHCb analysis

- Leading role of UK physicists (past, current and future)
***Elected positions**: CB chair, spokesperson, two physics coordinators*
***Conveners of the two major physics working groups**: Rare Decays and CPV (as well as coordinators of all physics working groups including charm, production, spectroscopy and EW-physics)*
EB Chair
Project leaders: VELO, RICH, Computing
Upgrade coordinator

Funding wise the UK contribution to the current LHCb was at the level of ~15%

Future strongly depends on funding possibilities
Landscape is well prepared → Time to decide now !!!

For the reference planned cost of LHCb upgrade is ~40-50 Mln CHFR and the cost of current LHCb is 75 Mln CHFR

Conclusions

- *The concept of forward spectrometer for flavour physics at LHC has been proven with data. LHCb is producing world-class measurements*
- *LHCb will reach world best sensitivity in key beauty and charm channels which could lead to a discovery of NP using ~5 fb^{-1} of data or before*
- *However full exploration of flavour and other low P_T and EW physics at LHC requires much larger data sample. LHCb upgrade provides a golden opportunity to collect ~50 fb^{-1} of excellent quality data within the LHC lifetime*
- *The LHCC has concluded that LHCb upgrade strategy is challenging but well motivated and will work*
- *The upgrade requires immediate allocation of funds and manpower since intensive R&D phase has to be started asap in order to prepare TDR in 2013*
- ***The 11 UK groups are playing a leading role in LHCb. Any LHCb future is hard to plan without our strong participation in the LHCb upgrade.*** *Even modest investment in 2011 will help to fulfill our goals*