It's nice to be here rather than in Norwich

LHCb

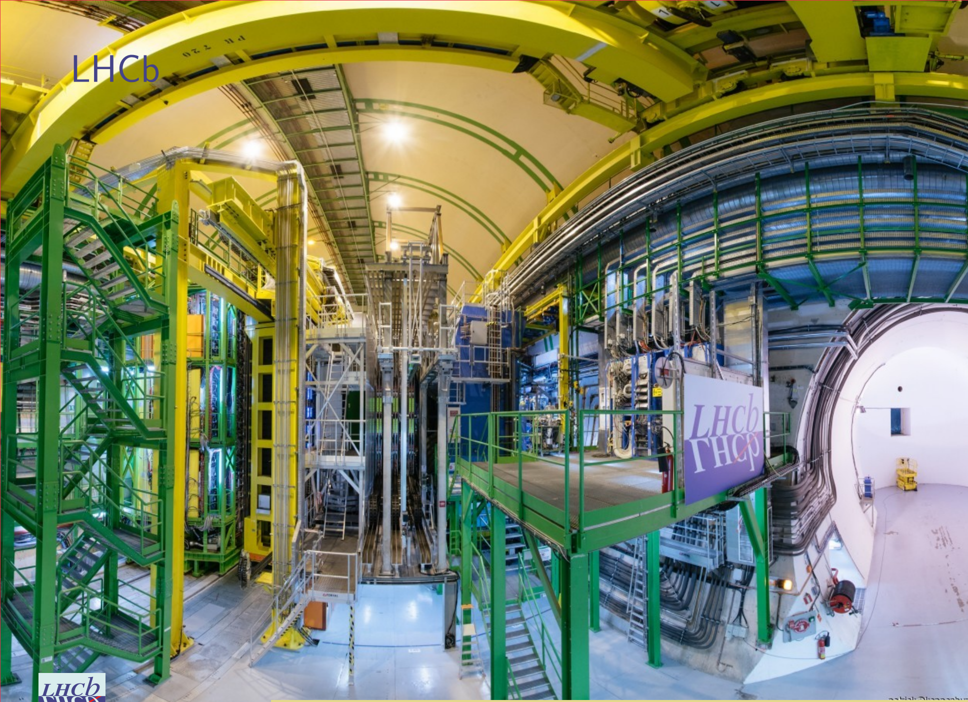
- **Patrick Koppenburg:** Introduction
- **Mick Mulder:** Non-universality in rare beauty decays
- **Laurent Dufour:** High-precision *CP*-violation measurements
- **Sean Benson:** Real-time analysis now and in the upgrade

Jamboree — 12/12/2017

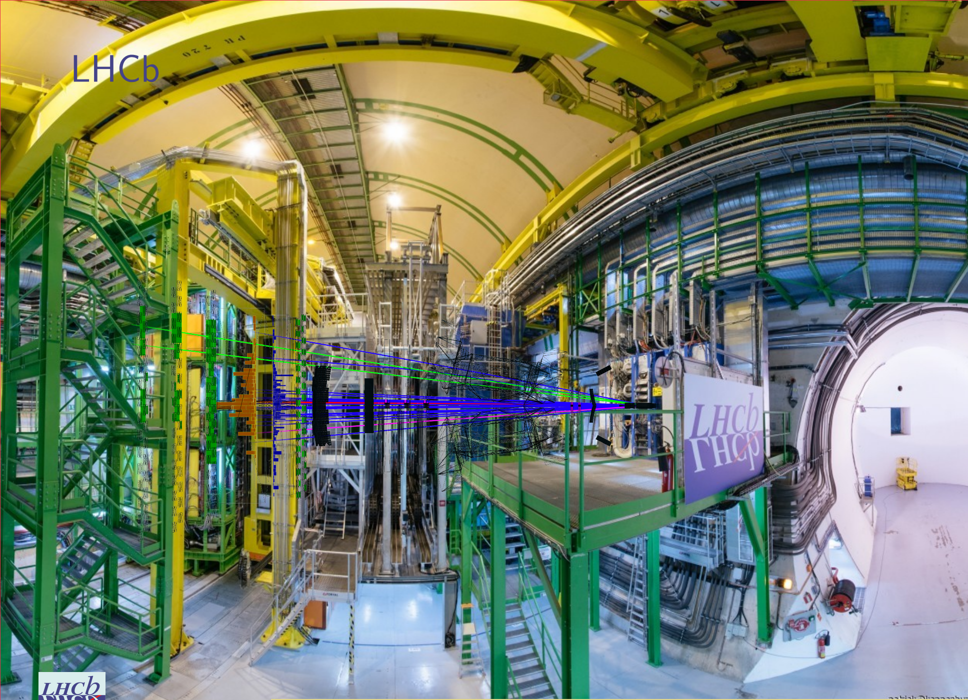
Patrick Koppenburg

Nikhef

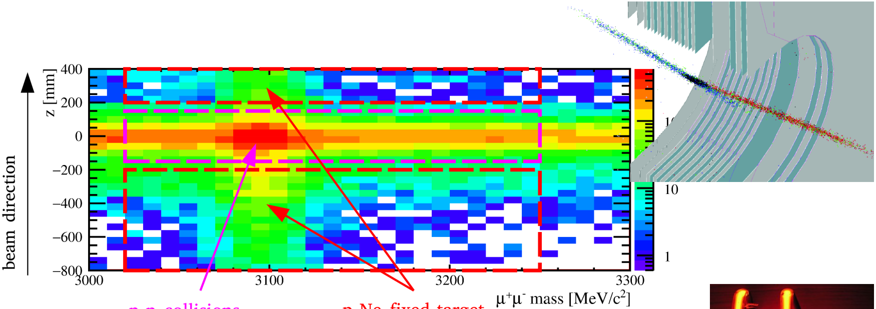
LHCb

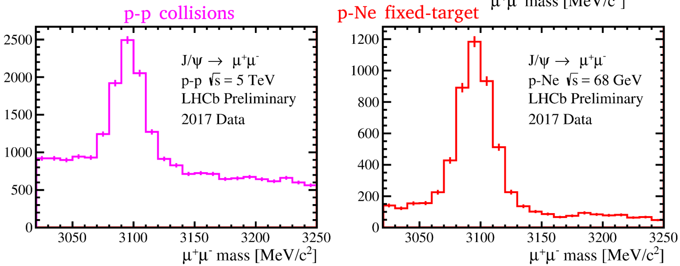


LHCb

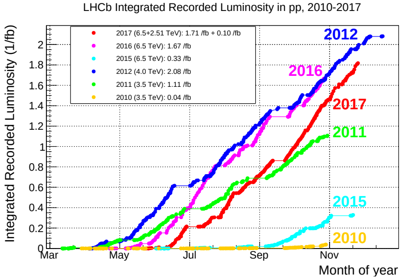


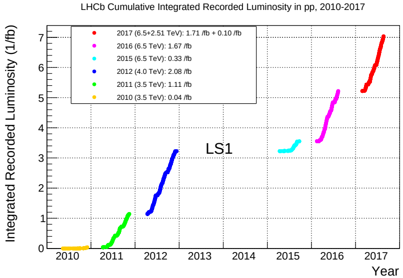
Injecting neon

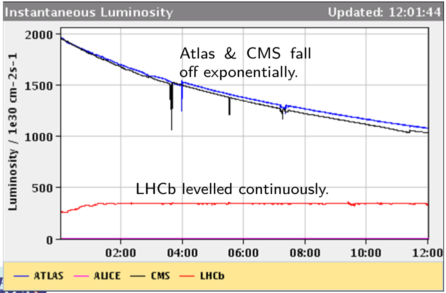




2017 HARVEST







- We have collected $7\,\mathrm{fb}^{-1}$ {7TeV:1,8TeV:2,13TeV:4}
- We keep our luminosity constant ($4 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$) by offsetting the beams
  - → ALICE, ATLAS and CMS are also doing that

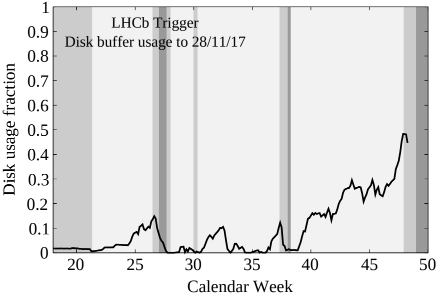
→ Stable trigger conditions

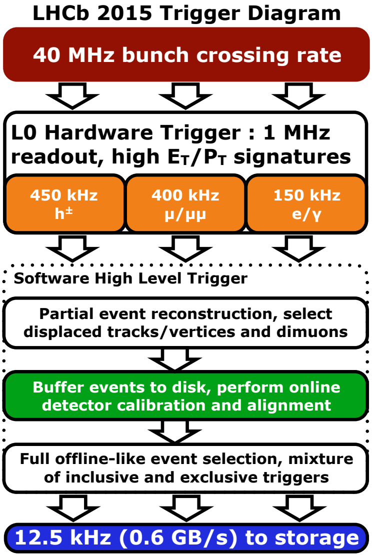
➜ See Sean's talk

LHCb Trigger in Run 2

Events are buffered on disk (10 PB) while calibrations are being run.

- ➜ Offline-quality trigger objects available for analysis.
- Disk = CPU. The full reconstruction can also be run during LHC downtime.



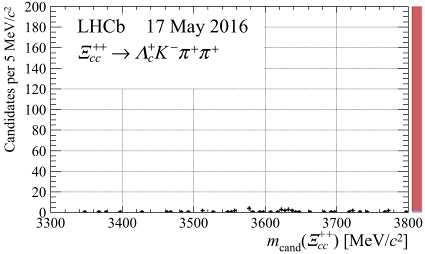


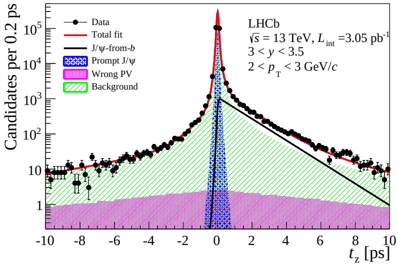
➜ See Sean's talk

LHCb Trigger in Run 2

New in Run 2: Introducing the TURBO stream

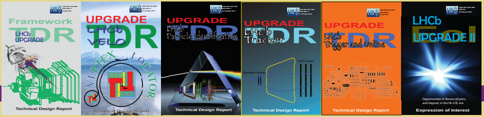
- 5 kHz of 12 kHz go to TURBO:
- Only trigger information is saved: tracks and vertices that caused the event to trigger
  - ➜ No raw event — no offline reconstruction
- ✔ Smaller events, faster analysis
- Used for high-yield exclusive trigger lines : J/ψ [JHEP 10 (2015) 172], charm [JHEP 03 (2016) 159], spectroscopy [PRL 119 (2017) 112001]





J/ψ pseudo-proper-time.

LHCb Upgrade



$\mathcal{L} = 2{\cdot}10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ requires some new detectors and 40 MHz read-out clock new electronics

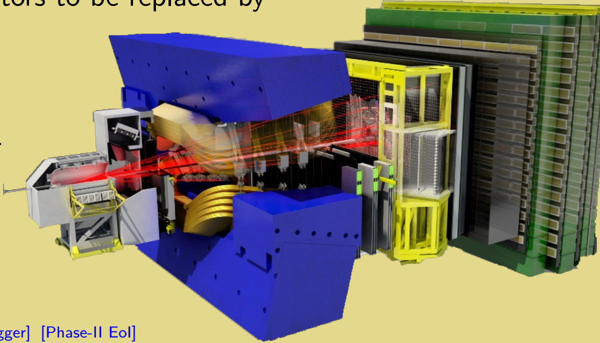
VELO: New pixel vertex detector Nikhef

TRACKERS: New scintillating fibre tracker Nikhef
The upstream tracker is also replaced

PID: Hybrid photodetectors to be replaced by multi-anode PMTs

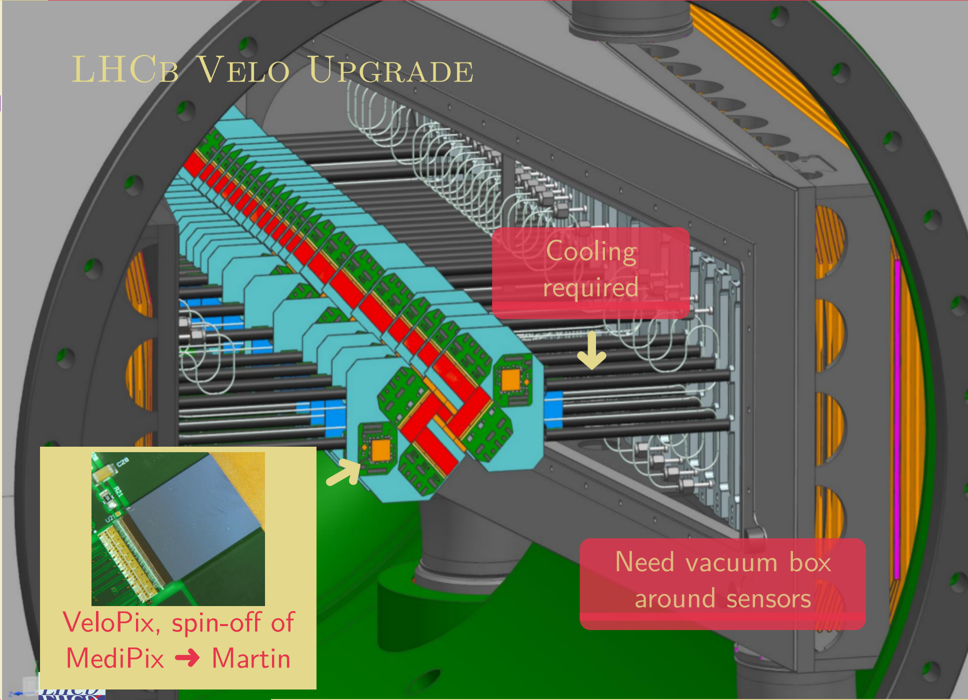
➜ 50 fb^{-1} by Run 4.

✔ We are preparing another upgrade for Run 5
➜ 300 fb^{-1}



[Upgrade TDR] [Velo] [PID] [Sci-Fi] [Trigger] [Phase-II EoI]

LHCb Velo Upgrade



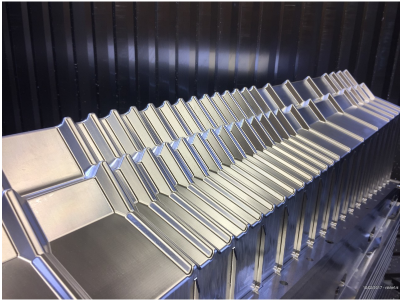
VeloPix, spin-off of MediPix ➜ Martin

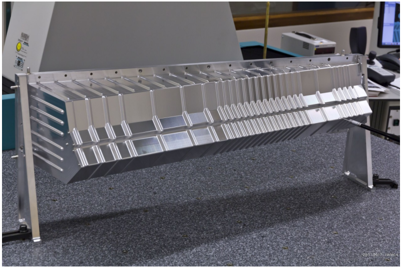
Vacuum Box

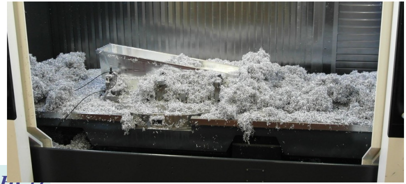
New velo vacuum boxes being 3D-forged

- Now 500 μm, being etched to 250 μm

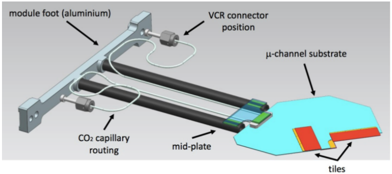
[Martin Doets, Willem Kuilman, Johan Kos, Tjeerd Ketel, Krista de Roo, Berend Munneke, Wouter Hulsbergen]



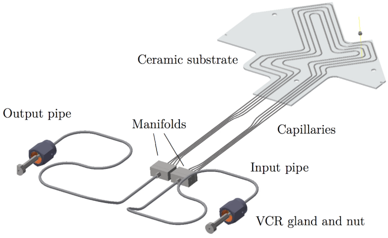




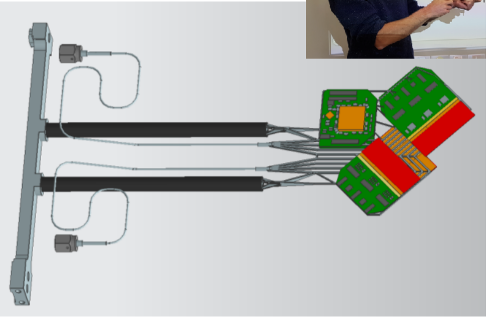
Cooling



A: Microchannels — the chosen option



B: Ceramic

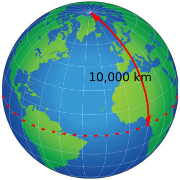


Z: Titanium

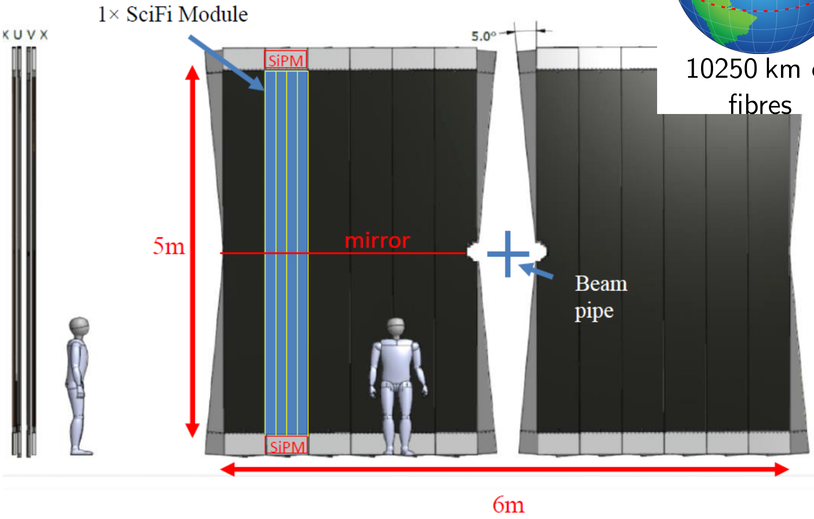
Managed to get CO_2 channels printed in titanium to work!

[Freek Sanders, Krista de Roo, Erno Roeland, Martijn van Overbeek, Ton Damen, Robert Hart, Jan David Schipper, Wim Gotink, Wouter Hulsbergen]

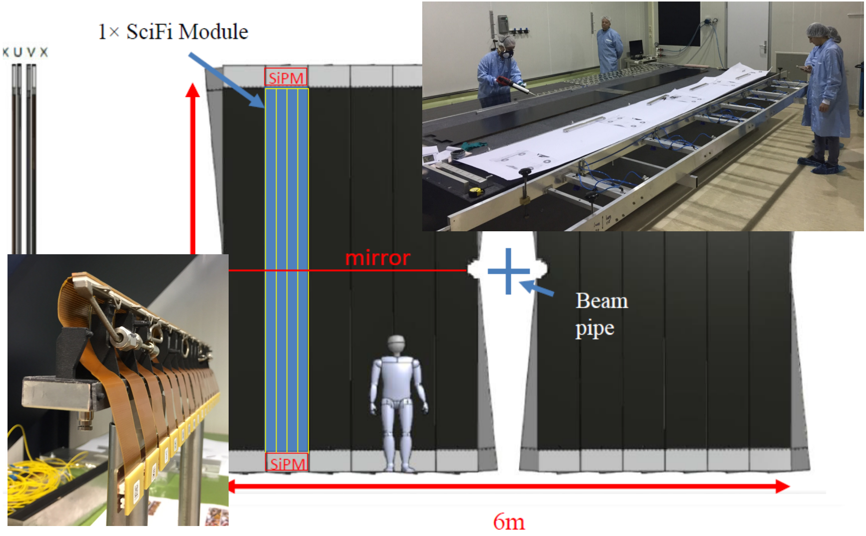
Sci-Fi Tracker



10250 km of fibres

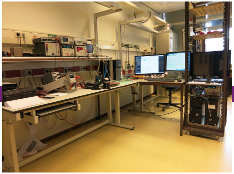


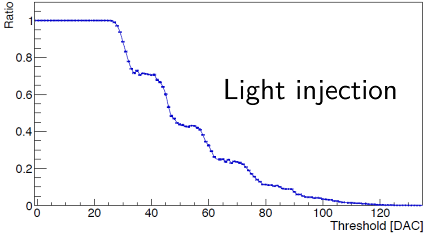
Sci-Fi Tracker: Fibre mats

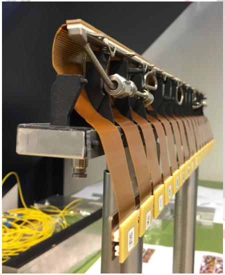


SIPM Box

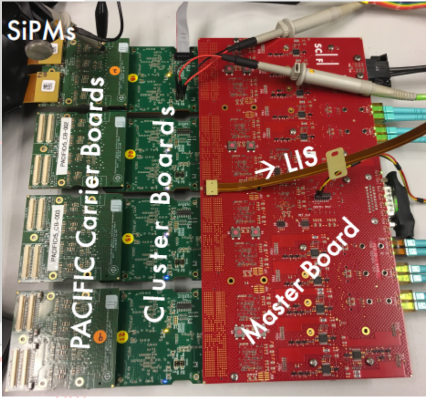
Sci-Fi Tracker: Electronics





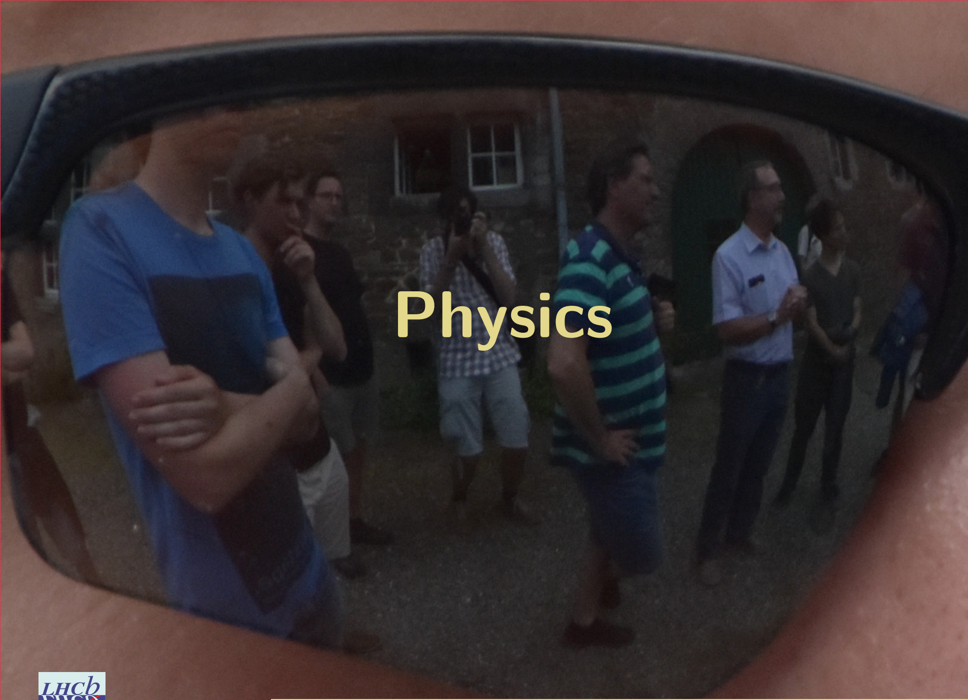


SIPM Box



First full SIPM → FE → DAQ system

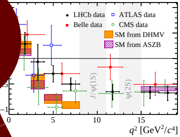
Physics



➜ See Mick's talk right after this

Anomalies

Angular (P'_5)

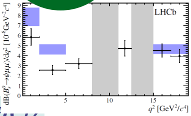


Global fits of $b \to s\ell^+\ell^-$ transitions indicate deviations from the SM of 3 to 6 σ, depending on treatment of QCD uncertainties.

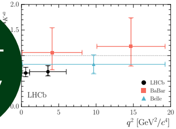
$b \to s\ell^+\ell^-$ FCNC

Flavour anomalies

BFs



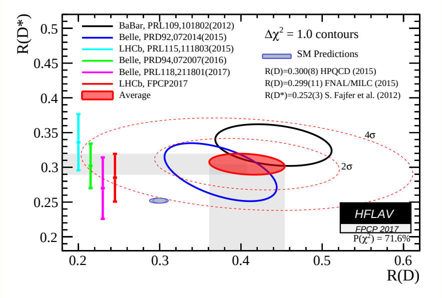
e–μ universality



[JHEP 02 (2016) 104] [ATLAS-CONF-2017-023] [CMS-PAS-BPH-15-008] [Belle, PRL118 111801] [JHEP 09 (2015) 179] [JHEP 06 (2014) 133] [JHEP 11 (2016) 047] [JHEP 06 (2015) 115] [JHEP 08 (2017) 055] [PRL 113 (2014) 151601]

[Geng et al., PRD96 093006] [Altmannshofer et al., PRD96 055008] [D'Amico et al., JHEP09(2017)010] [Ciuchini et al., EPJC77 688] [Capedevila et al, arXiv:1704.05340]

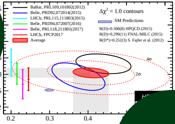
Anomalies



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

➜ 4σ from SM

R_D



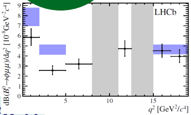
R_{D^*}

$b \to c\ell\nu$ trees

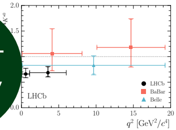
…our …alies

$R_{J/\psi}$

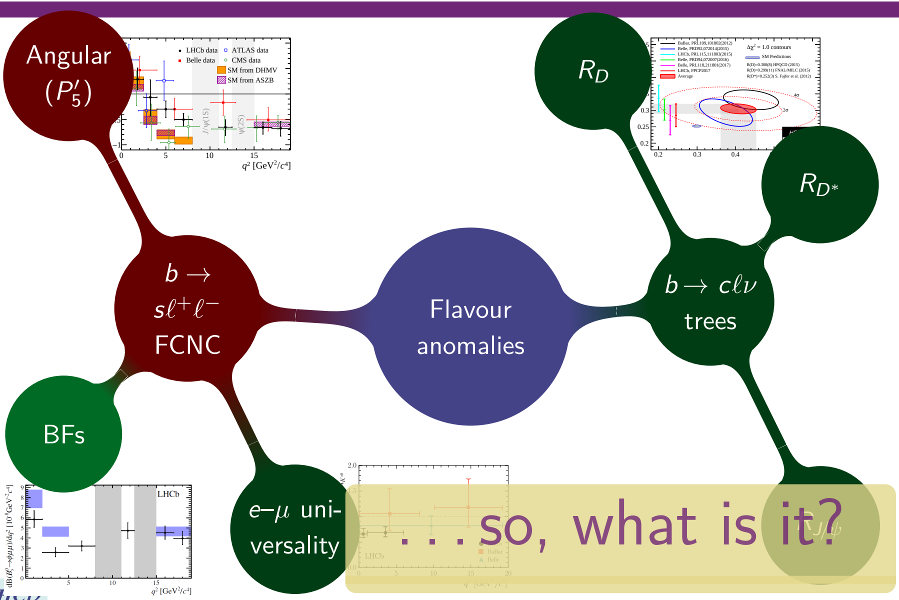
BFs



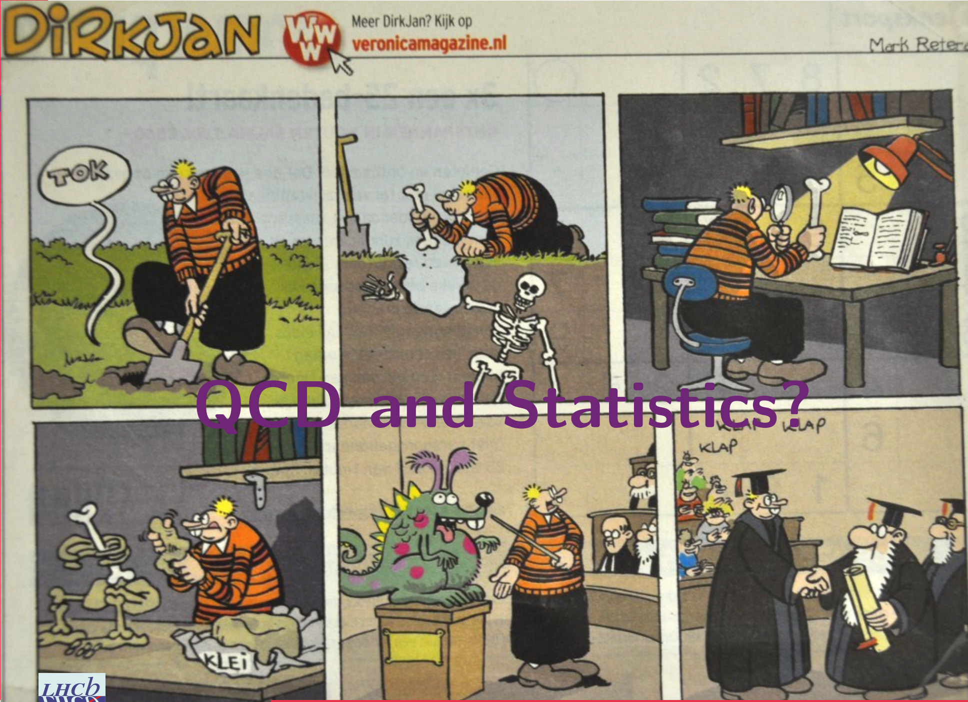
e–μ universality



Anomalies


Angular (P'_5)
R_D
R_{D^*}
$b \to s\ell^+\ell^-$ FCNC
Flavour anomalies
$b \to c\ell\nu$ trees
BFs
e–μ universality
$R_{J/\psi}$
. . . so, what is it?

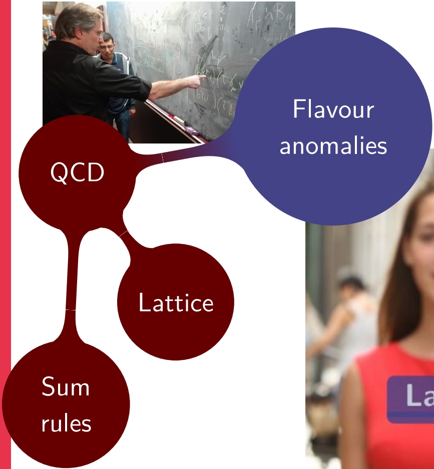
QCD and Statistics?




LIVE
breakyourown
BREAKING NEWS
NEW PHYSICS IN LEPTONS
11:57
THIS CHANGES OUR VIEW OF THE UNIVERSE SAYS DR. NIELS TUNING

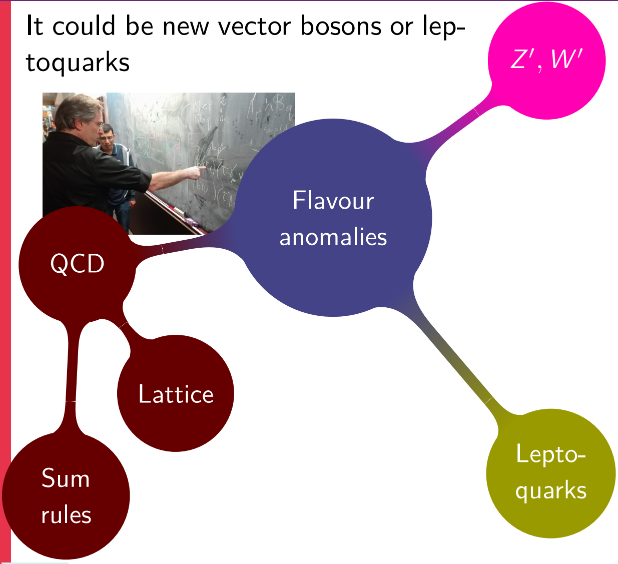
Anomalies

We need a better precision in QCD.



Anomalies

It could be new vector bosons or lep-toquarks



Anomalies

Why is there no *CP* violation beyond the CKM matrix?

Flavour anomalies

QCD

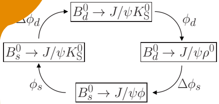
Lattice

Sum rules

Z', W'

CPV?

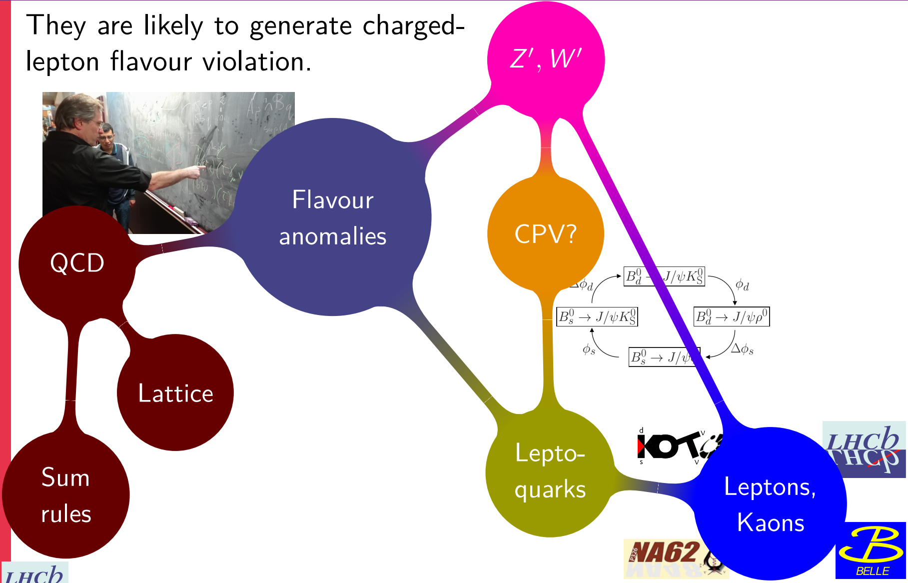
Lepto-quarks



Precision tests with Fleischer et al.

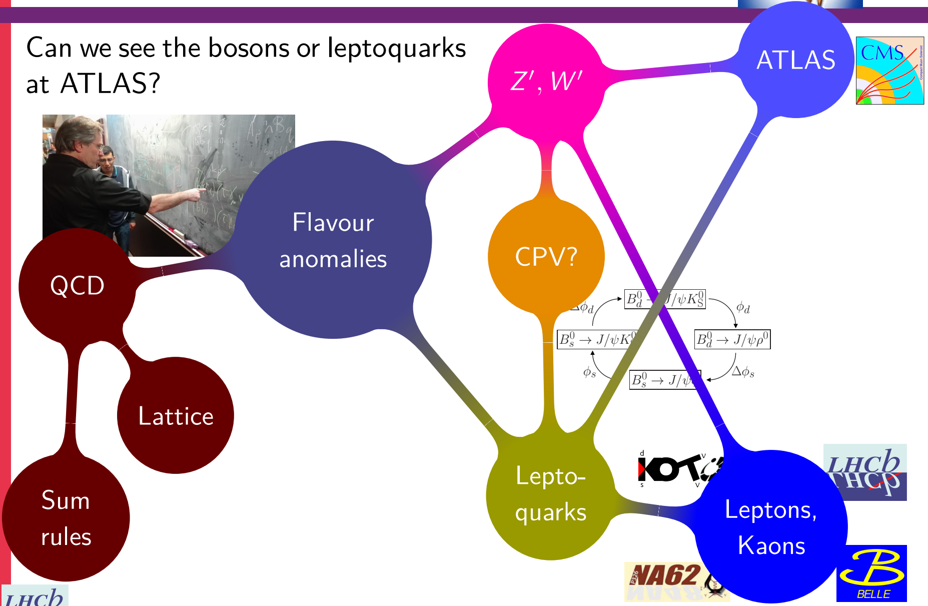
Anomalies

They are likely to generate charged-lepton flavour violation.



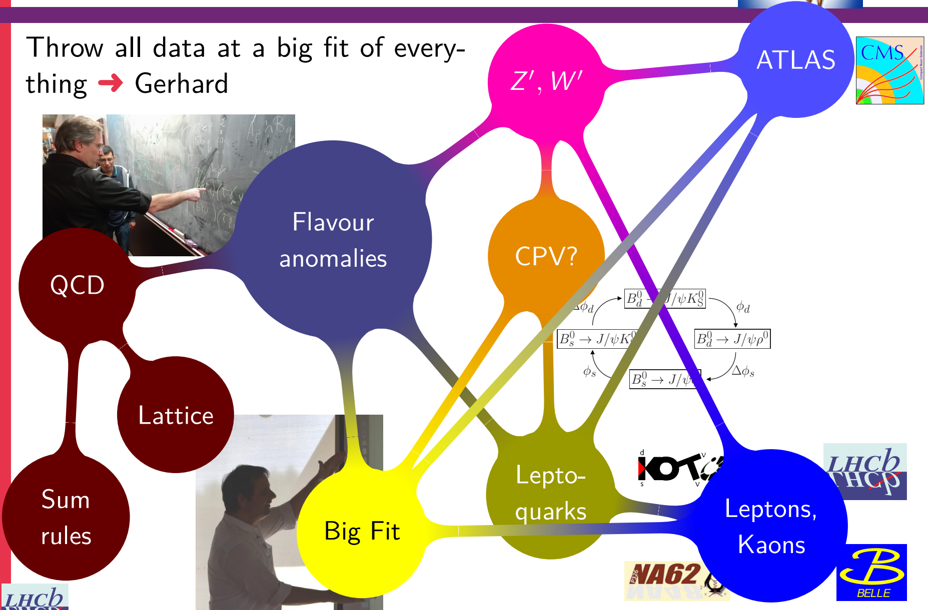
Anomalies

Can we see the bosons or leptoquarks at ATLAS?



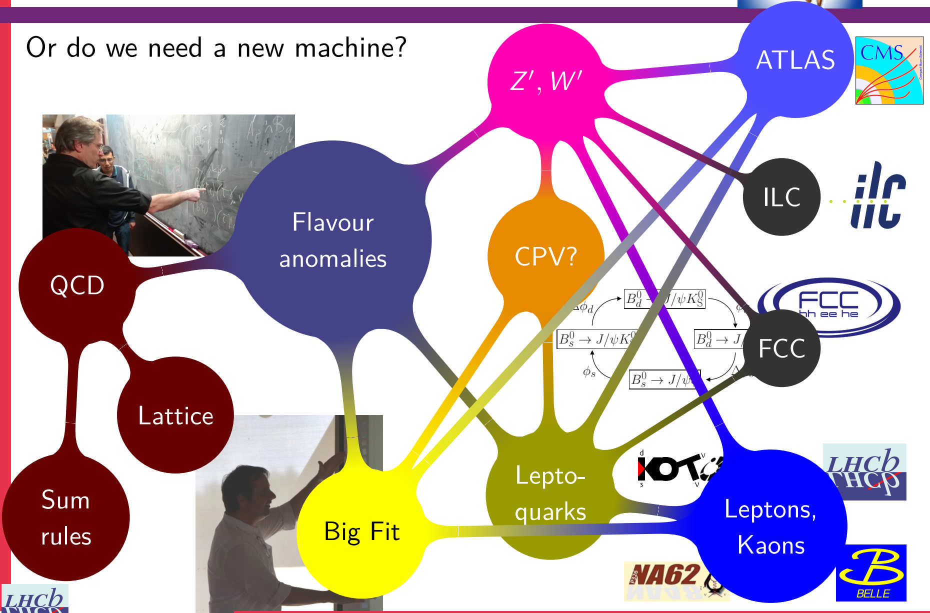
ANOMALIES

Throw all data at a big fit of everything ➜ Gerhard



Anomalies

Or do we need a new machine?

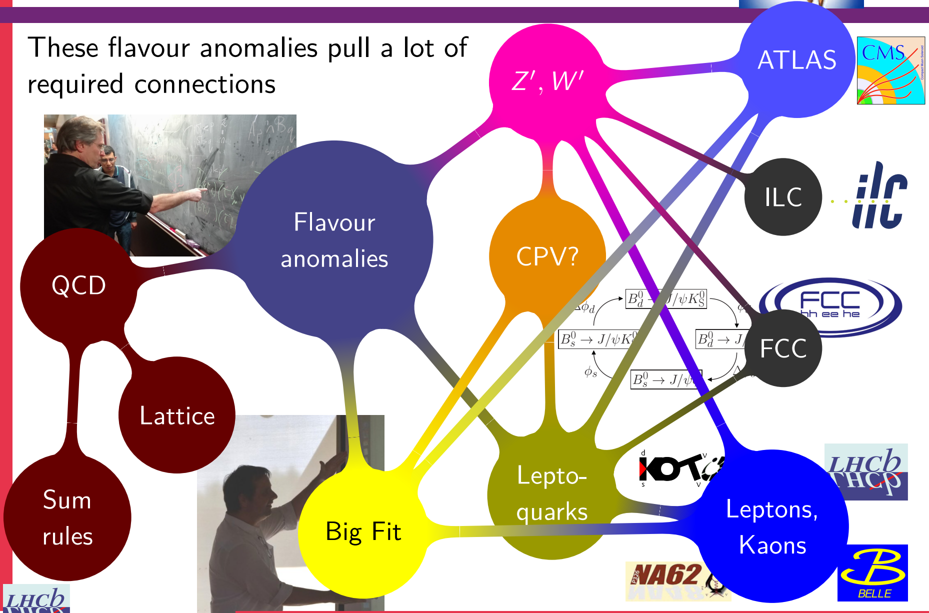


Anomalies

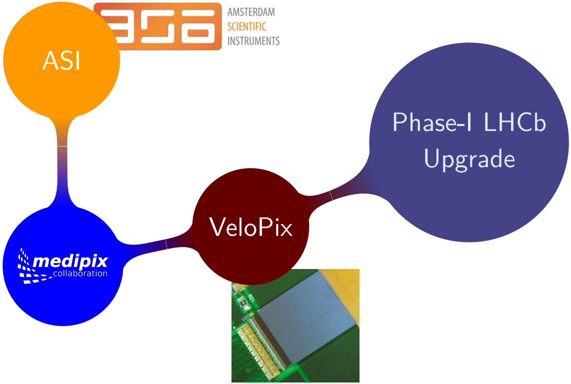
Was that too fast?
Come to the "what's going on with leptons" focus sessie at Veldhoven
24 January, 13h30, Parkzaal 4.
Speakers: Greg Ciezarek, Gerco Onderwater, Svjetlana Fajfer (Ljubljana), Tristan du Pree

Connections

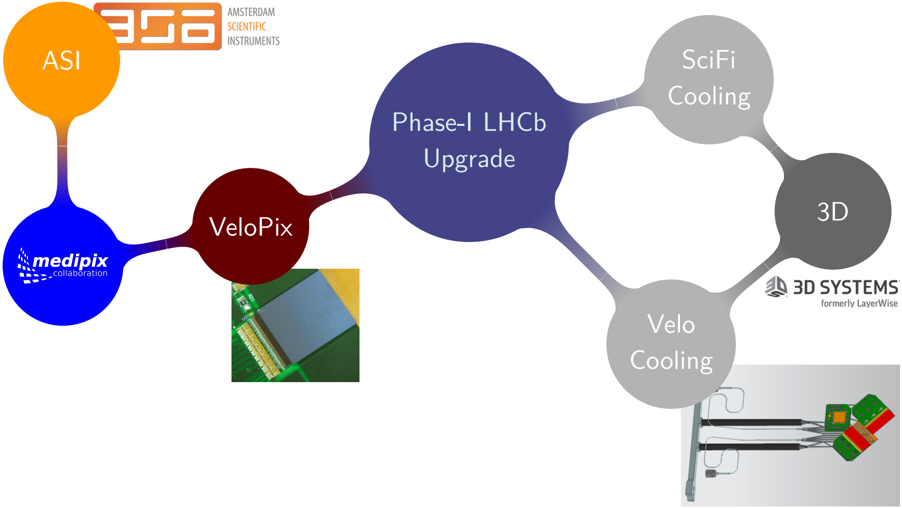
These flavour anomalies pull a lot of required connections



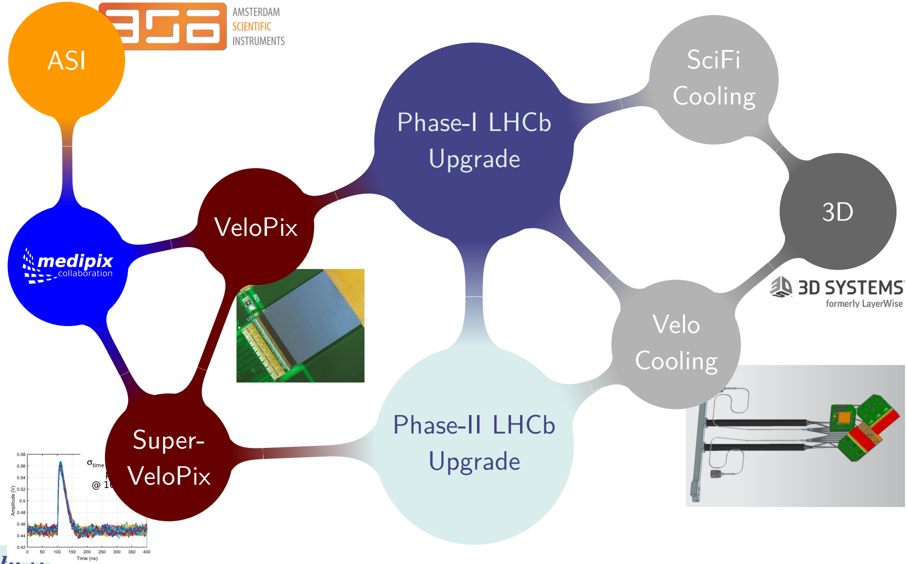
Hardware connections



Hardware connections



Hardware connections



BFYS Outing

BFYS Outing


VERBODEN TOEGANG
ART. 461 WETB.v.STRAFR.

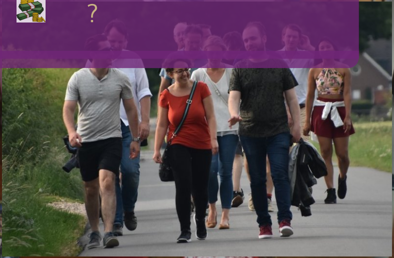

30/05/2017 - patrick@koppenburg.ch

bfys Outing

Year	bfys theme	Jamboree theme
2016	Horizons	Vista25
2017	Commonalities	Connections

BFYS Outing

Year	bfys theme	Jamboree theme
2016	Horizons	Vista25
2017	Commonalities	Connections
2018	Infinite resources to LHCb	?

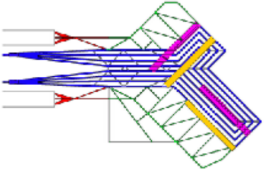


Backup

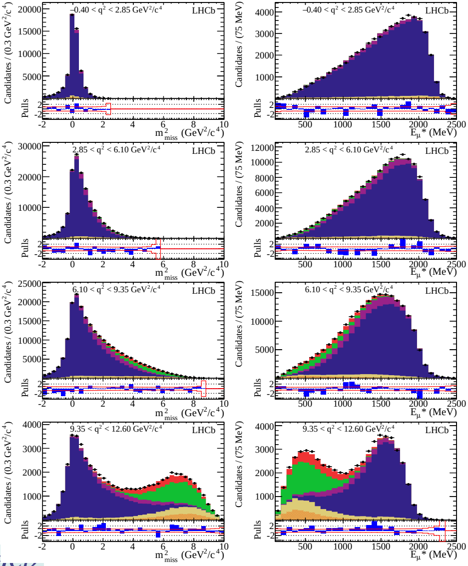
Option Z

Plan Z design still very interesting for future!

- Foot as for plan A,B
- no midplate: substrate directly glued into legs
- no separate “cooling connector”; cooling pipes connected by welding or brazing
- channel dimensions 1 x 1 mm
- Choice of 4 channels with equal spacing
  - Same number as for plan-B
  - reasonable match to plan-A radiation length
- Printed restrictions on inlet
- Bespoke supports for hybrids and bond pad area (C-side, N-side)
- 14 substrates produced over three submissions and 6 modules built for cooling/flow/deformation tests (!)
- Leak tests, pressure tests = OK
- Timeline and cost very favourable

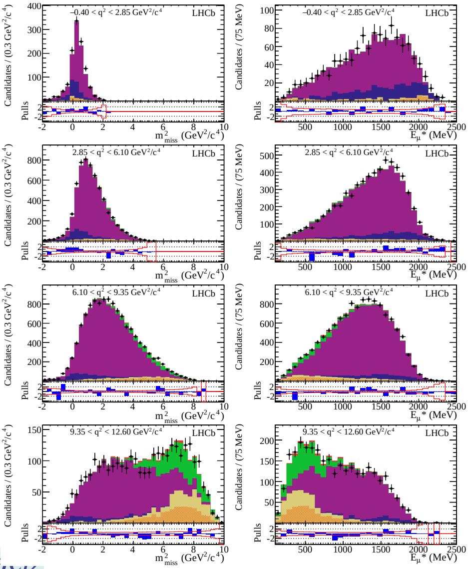


$\overline{B}^0 \to D^{*+}\tau\nu$ at LHCb



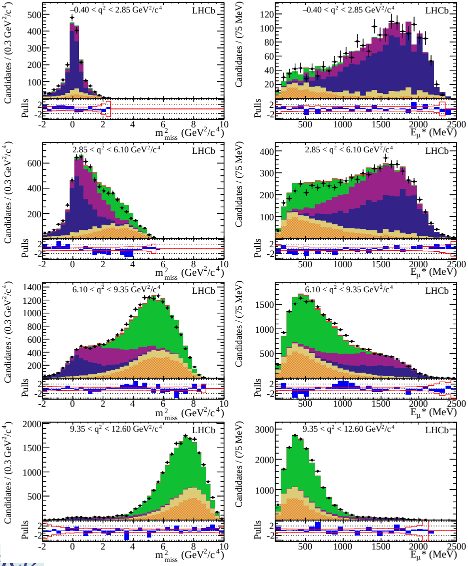
- Select D^* with $D^0 \to K^-\pi^+$ and μ^-, forming a good vertex separated from PVs, and isolated using dedicated MVA
- $B^0 \to D^{*+}\tau^-\overline{\nu}$ with $\tau^- \to \mu^-\nu\overline{\nu}$ and $B^0 \to D^{*+}\mu^-\overline{\nu}$ have same final state.
- Disentangled by kinematical variables : q^2, E^*_μ, m^2_{miss}.
  - The B momentum is approximated from the boost of the reconstructed system.
- A template fit in q^2 bins determines signal yields

$\overline{B}^0 \to D^{*+}\tau\nu$ at LHCb



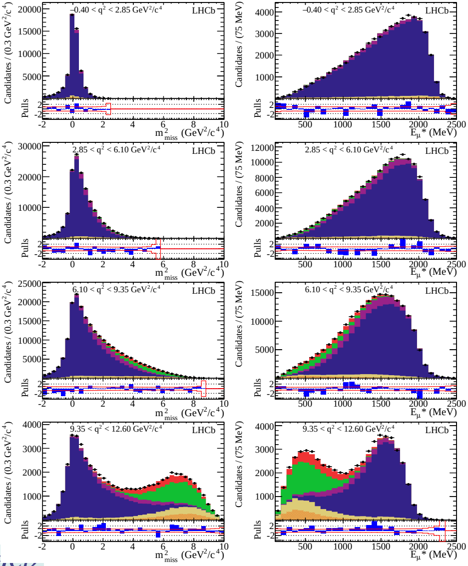
- $B^0 \to D^{*+}\tau^-\overline{\nu}$ with $\tau^- \to \mu^-\nu\overline{\nu}$ and $B^0 \to D^{*+}\mu^-\overline{\nu}$ have same final state.
- Disentangled by kinematical variables : $q^2 = (p_B - p_D)^2$, E^*_μ, $m^2_{\text{miss}} = (p_B - p_D - p_\mu)^2$.
- A template fit in q^2 bins determines signal yields
- Reverting isolation veto gives $B \to (D_1, D_2^*, D_1')\mu\overline{\nu}$ shapes

$\overline{B}^0 \to D^{*+}\tau\nu$ at LHCb



- $B^0 \to D^{*+}\tau^-\overline{\nu}$ with $\tau^- \to \mu^-\nu\overline{\nu}$ and $B^0 \to D^{*+}\mu^-\overline{\nu}$ have same final state.
- Disentangled by kinematical variables : q^2, E^*_μ, m^2_{miss}.
- A template fit in q^2 bins determines signal yields
- Reverting isolation and requiring a kaon selects $B^0 \to D^* H_c(\to \mu\overline{\nu}X)$ shapes

$\overline{B}^0 \to D^{*+}\tau\nu$ at LHCb



- $B^0 \to D^{*+}\tau^-\overline{\nu}$ with $\tau^- \to \mu^-\nu\overline{\nu}$ and $B^0 \to D^{*+}\mu^-\overline{\nu}$ have same final state.
- Disentangled by kinematical variables : q^2, E^*_μ, m^2_{miss}.
- A template fit in q^2 bins determines signal yields
- Get 36300 ± 1600 $B \to D^{*+}\mu^-\overline{\nu}$ decays and $R_{D^*} = 0.336 \pm 0.027 \pm 0.030$
  - Dominant systematics are MC stats and mis-ID μ shapes

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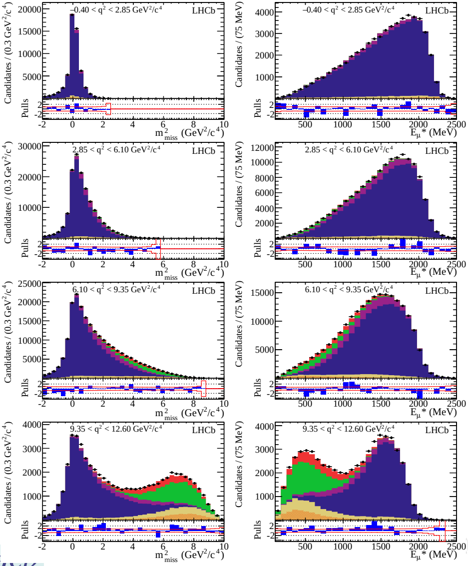

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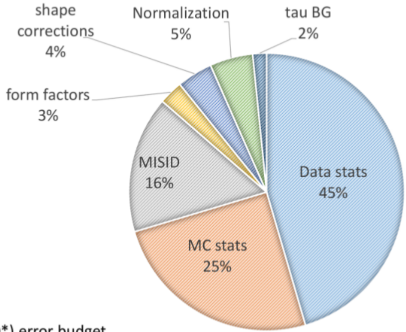
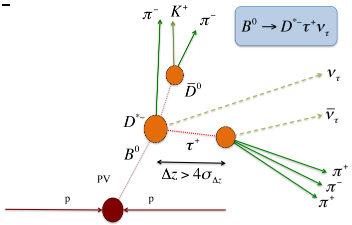


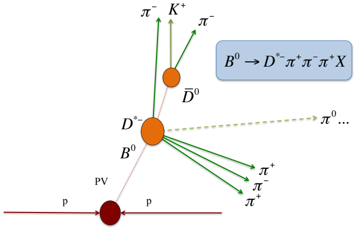
D*) error budget

$B^0 \to D^{*-}\tau^+\nu_\tau$ WITH $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\overline{\nu}_\tau$

The ratio $\mathcal{R}(D^*) = \frac{\mathcal{B}(B\to D^*\tau^+\nu_\tau)}{\mathcal{B}(B\to D^*\mu^+\nu_\mu)}$ is measured above the SM.

- So far all measurements used $\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$, which provides the same final state as $(B\to D^*\mu^+\nu_\mu$
- Here for the first time, $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\overline{\nu}_\tau$ is used.
- The main background is $B^0 \to D^{*-}\pi^+\pi^-\pi^-$. The two are separated exploiting the τ^+ lifetime.
- A BDT is used for that purpose

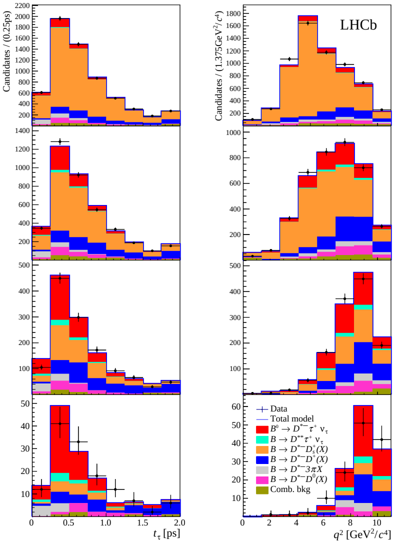




$B^0 \to D^{*-}\tau^+\nu_\tau$ WITH $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\overline{\nu}_\tau$

Signal and backgrounds are determined by a three-dimensional binned fit to t_τ, q^2 and BDT output.

- signal yield: 1273 ± 85.



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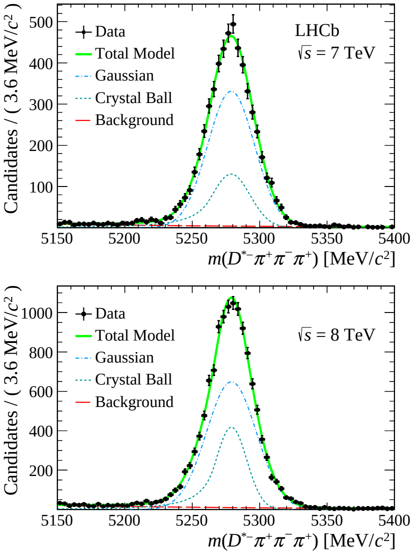
Signal and backgrounds are determined by a three-dimensional binned fit to t_τ, q^2 and BDT output.

- signal yield: 1273 ± 85.
- Normalised to $B^0 \to D^{*-}\pi^+\pi^-\pi^+$ [PRD 87 (2013) 092001], yielding $\mathcal{B}(B \to D^*\tau^+\nu_\tau) = (1.40 \pm 0.09 \pm 0.12 \pm 0.10)\%$

$\mathcal{R}(D^*) = 0.286 \pm 0.019 \pm 0.025 \pm 0.021$, 1σ above the SM (0.252 ± 0.003 [Faijfer et al.]) and consistent with the world average.



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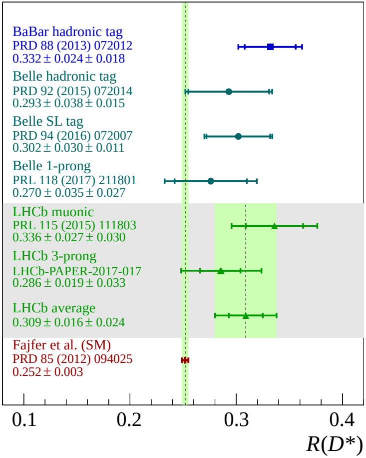
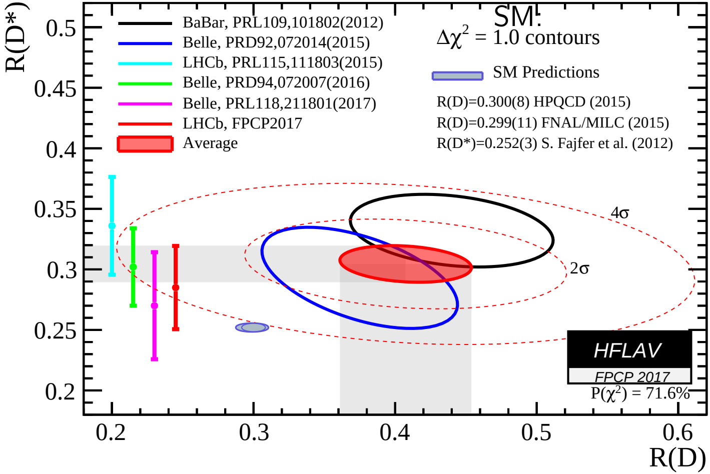


The world average becomes $\mathcal{R}(D^*)^{\text{WA}} = 0.304 \pm 0.013 \pm 0.007$

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



BABAR [PRL 109 101802 (2012)], [PRD 88 072012 (2013), arXiv:1303.0571] Belle [PRD 92 072014 (2015)] [Moriond EW, arXiv:1603.06711], LHCb [PRL 115 (2015) 111803] [arXiv:1708.08856].
Theory [Na et al., PRD 92 054410 (2015)], [Faijfer et al., PRD 85 094025 (2012)]

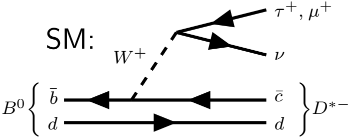
$B \to D^{(*)}\tau\nu$ HFLAV AVERAGE

The ratio

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau^+\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\mu^+\nu_\mu)}$$

tests lepton universality.

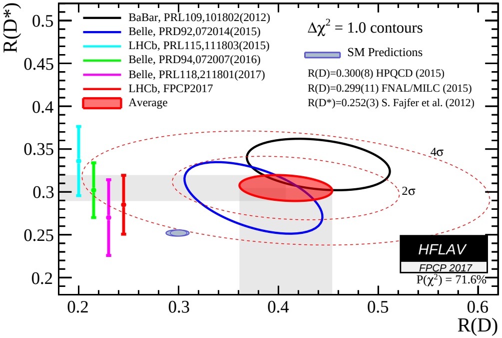
SM:



In the SM it differs from unity due to phase-space (and phase space affecting form factors).

Experimental average is 4σ from SM prediction.

New vector bosons? Leptoquarks?



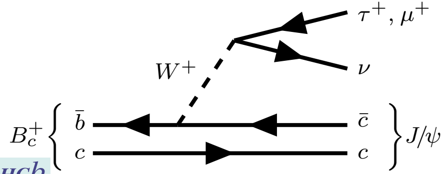
BABAR [PRL 109 101802 (2012)], [PRD 88 072012 (2013), arXiv:1303.0571] Belle [PRD 92 072014 (2015)] [Moriond EW, arXiv:1603.06711], LHCb [PRL 115 (2015) 111803] [arXiv:1708.08856].
Theory [Na et al., PRD 92 054410 (2015)], [Faijfer et al., PRD 85 094025 (2012)]

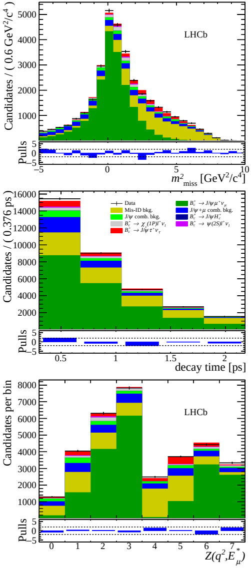
Study of $B_c^+ \to J/\psi \tau^+ \nu_\tau$

LHCb measured $R(D^{*+})$ with $\tau^+ \to \mu^+ \nu \bar{\nu}$ [PRL 115 (2015) 111803] and $\tau^+ \to \pi^+ \pi^- \pi^+$ [arXiv:1708.08856]

What about $B_c^+ \to J/\psi \tau^+ (\mu^+ \nu \bar{\nu}) \nu$?

- Three-dimensional template fit in missing mass (m_{miss}), decay time (τ) and coarse E^*, q^2 bins (Z)
- ✔ Surprising signal excess (3σ)
- Measure $R(J/\psi) = 0.71 \pm 0.17 \pm 0.18$, which is 2σ above the SM





Physics analyses

$B_s^0 \to \phi\phi$ (soon): *CP* violation in $b \to s$ penguins

$B_s^0 \to J/\psi\,\phi$ (soon): *CP* violation in B_s^0 mixing ($b \to t$)

$B_s^0 \to D_s^\pm K^\mp$ [LHCb-PAPER-2017-047]: *CP* violation in $b \to u$ trees

D_s^+ production asymmetry (soon): ➜ See Laurent

$B_s^0 \to e^\pm \mu^\mp$ [arXiv:1710.04111]: Lepton-flavour violation Long-lived jets [Eur. Phys. J. C77 (2017) 812]:]

$B_s^0 \to \mu^+\mu^-$ [PRL 118 (2017) 191801]: Best BF

LHCb Trigger in Run 3

LHCb 2015 Trigger Diagram

40 MHz bunch crossing rate

↓

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

450 kHz	400 kHz	150 kHz
$h^{\pm}$	$\mu/\mu\mu$	e/γ

↓

Software High Level Trigger

- Partial event reconstruction, select displaced tracks/vertices and dimuons
- ↓ Buffer events to disk, perform online detector calibration and alignment
- ↓ Full offline-like event selection, mixture of inclusive and exclusive triggers

↓

12.5 kHz (0.6 GB/s) to storage

→

LHCb Upgrade Trigger Diagram

30 MHz inelastic event rate (full rate event building)

↓

Software High Level Trigger

- Full event reconstruction, inclusive and exclusive kinematic/geometric selections
- ↓ Buffer events to disk, perform online detector calibration and alignment
- ↓ Add offline precision particle identification and track quality information to selections

  Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

↓

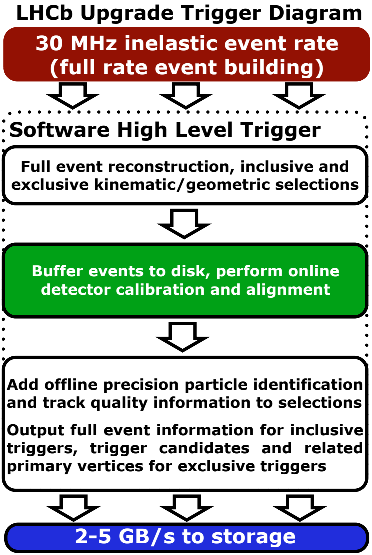
2-5 GB/s to storage

LHCb Trigger in Run 3

New in Run III: No hardware (L0) trigger

- 30 MHz non-empty events go to event filter farm
- Full event reconstruction at 30 MHz
- Full calibration of preselected events
- Offline-like selections

→ 2–5 GB/s to storage (some of that TURBO)



[Trigger TDR]