The LHCb High Level Trigger and its upgrade

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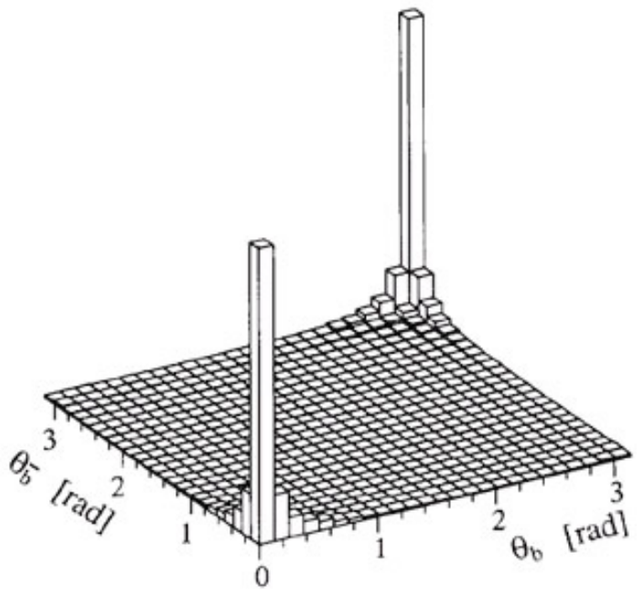
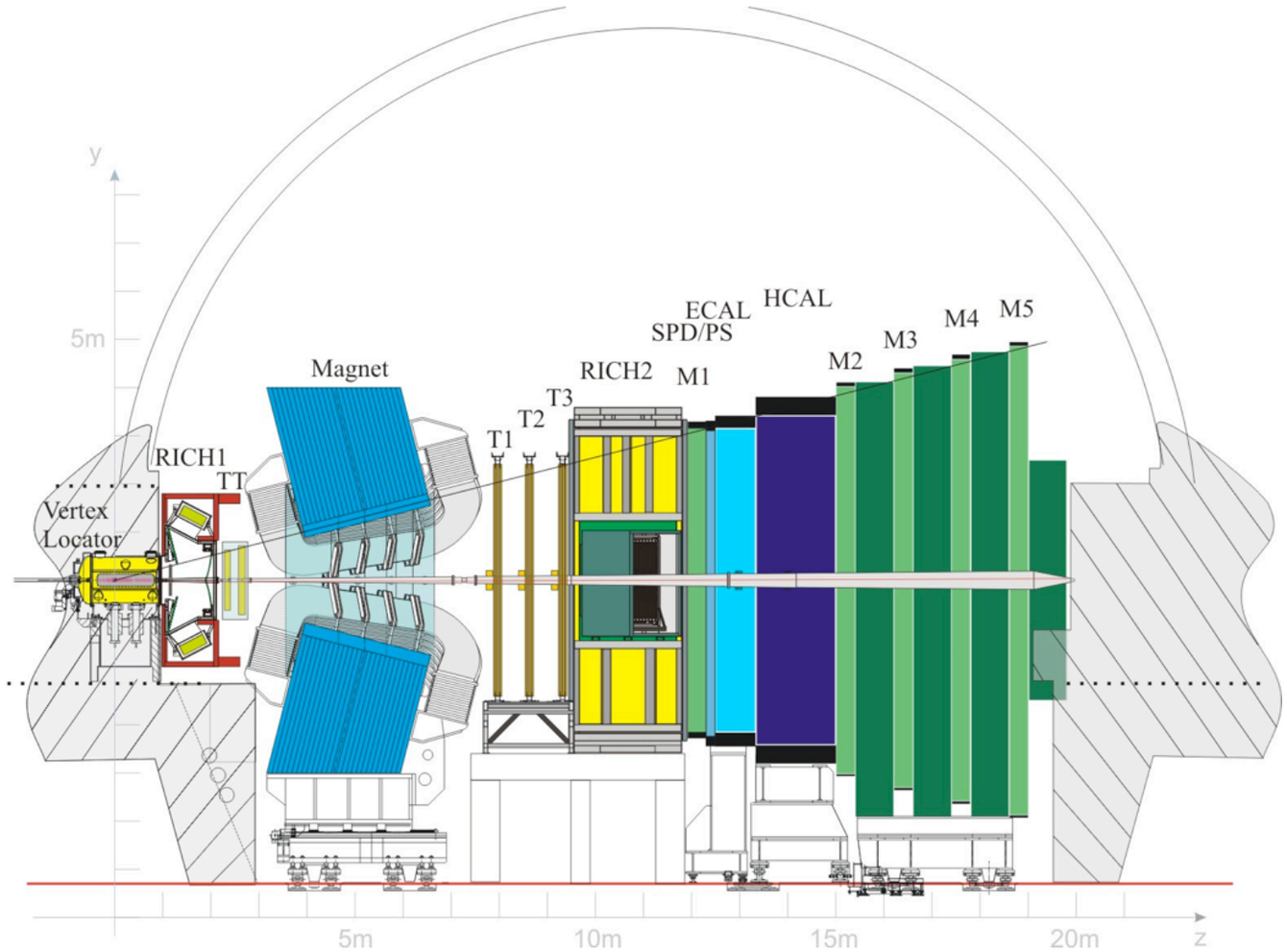
On behalf of the LHCb collaboration

12th Pisa meeting on Advanced Detectors

21st May 2012

The LHCb detector





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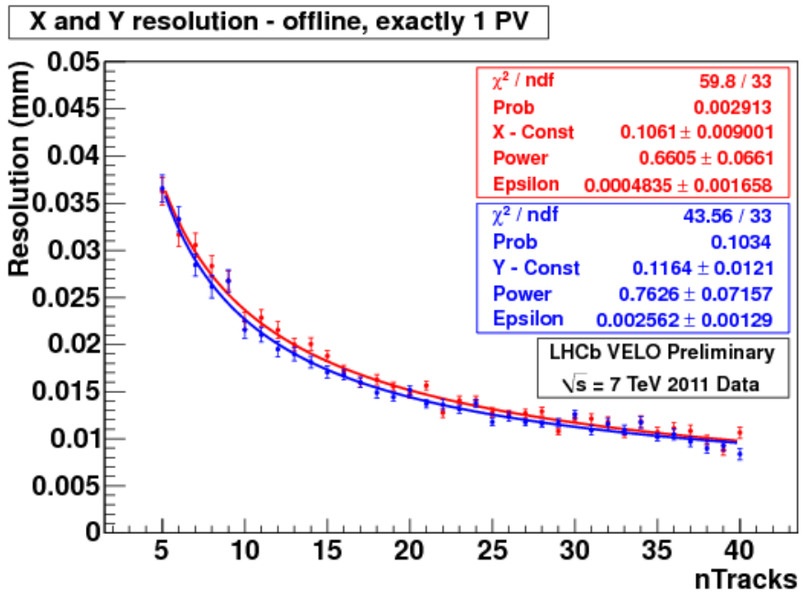

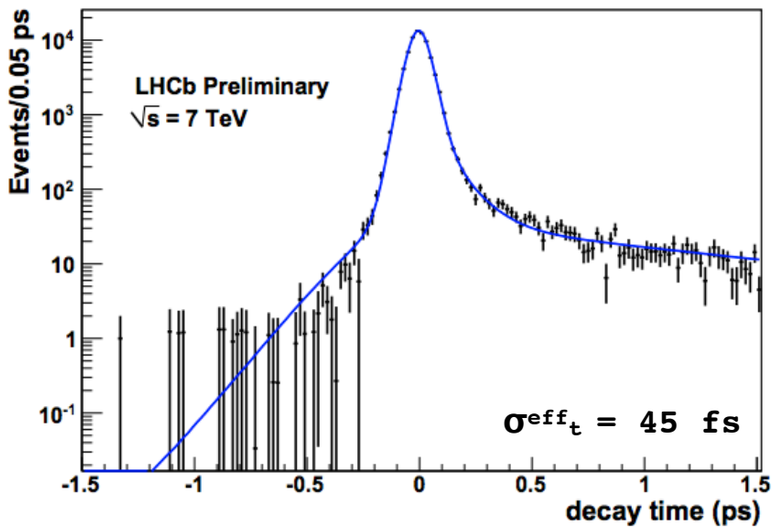

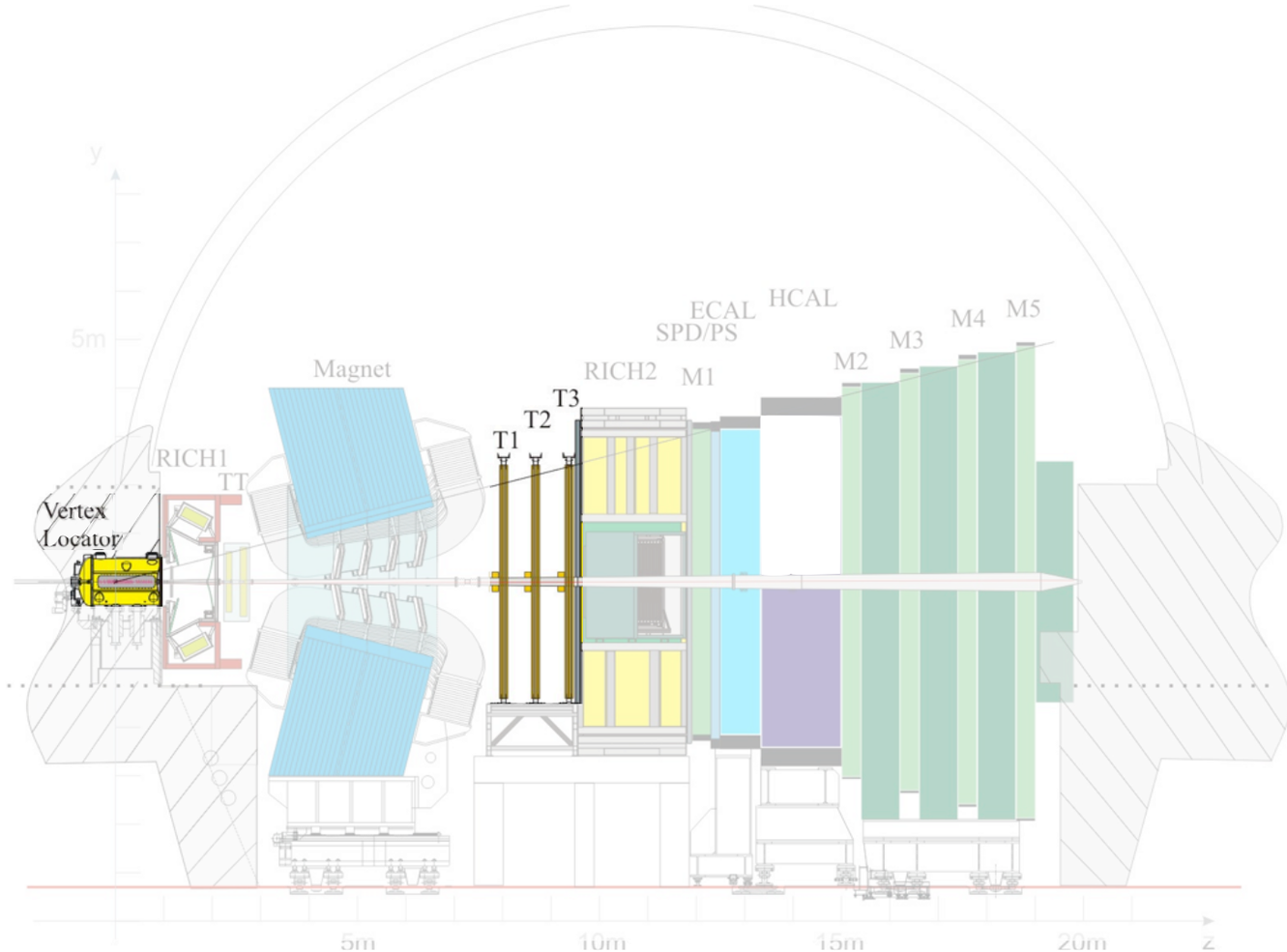

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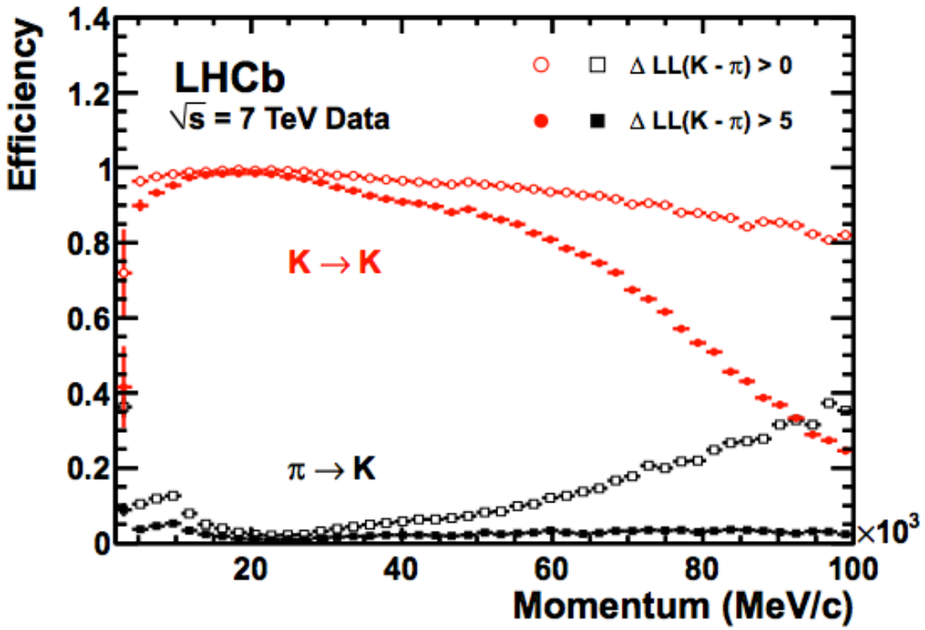
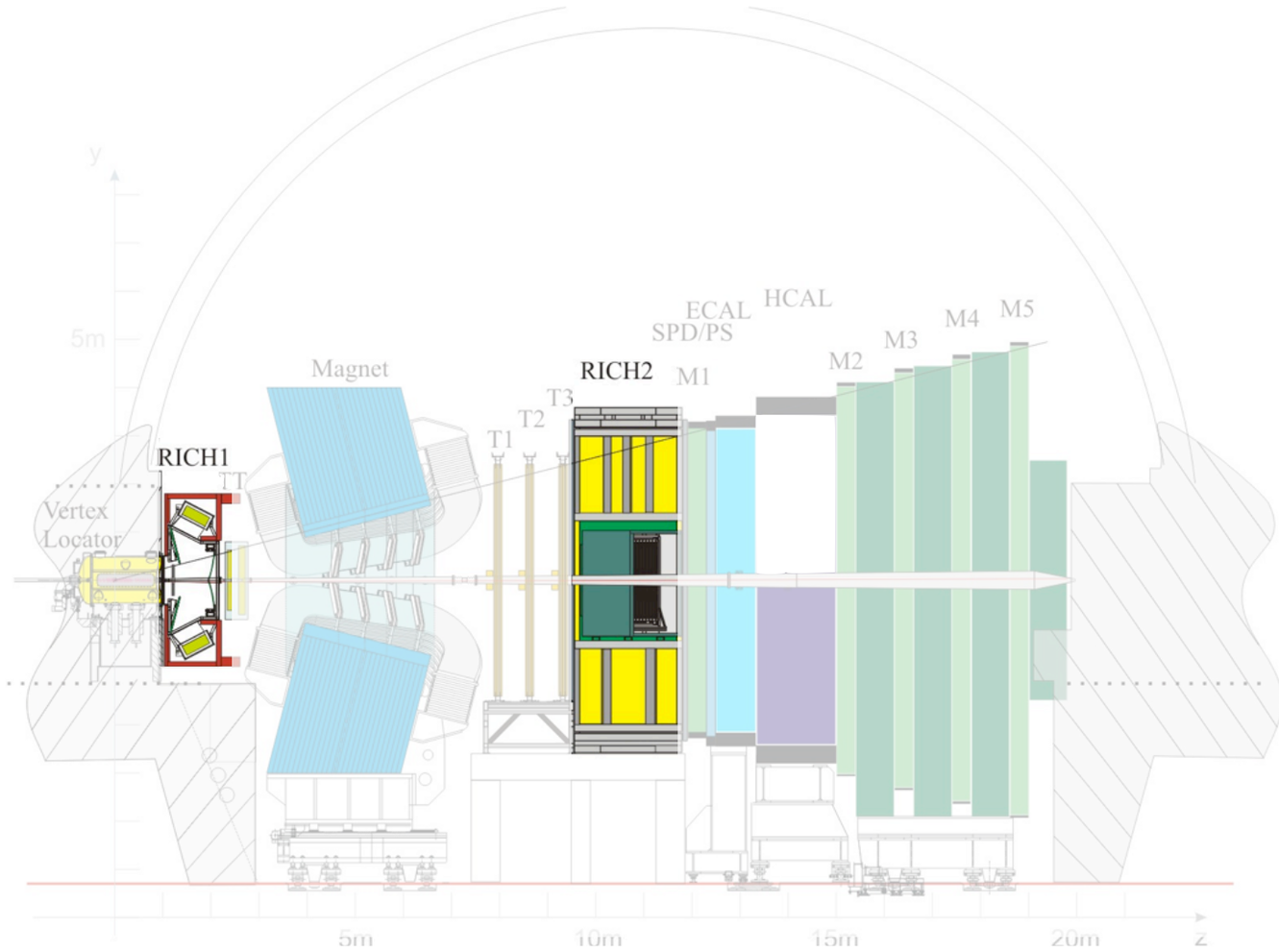
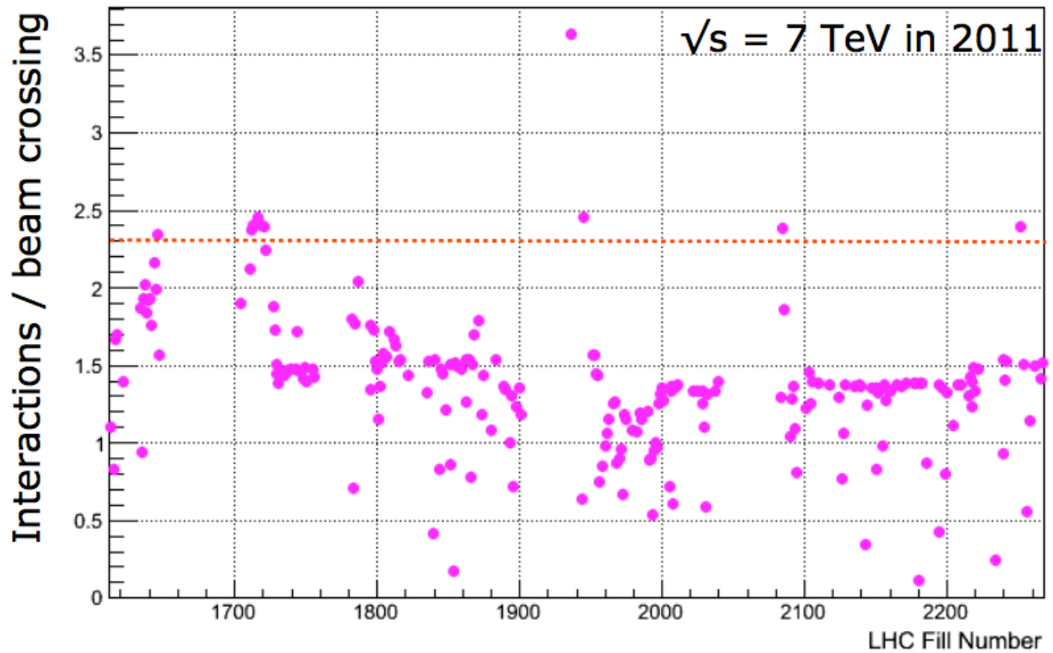




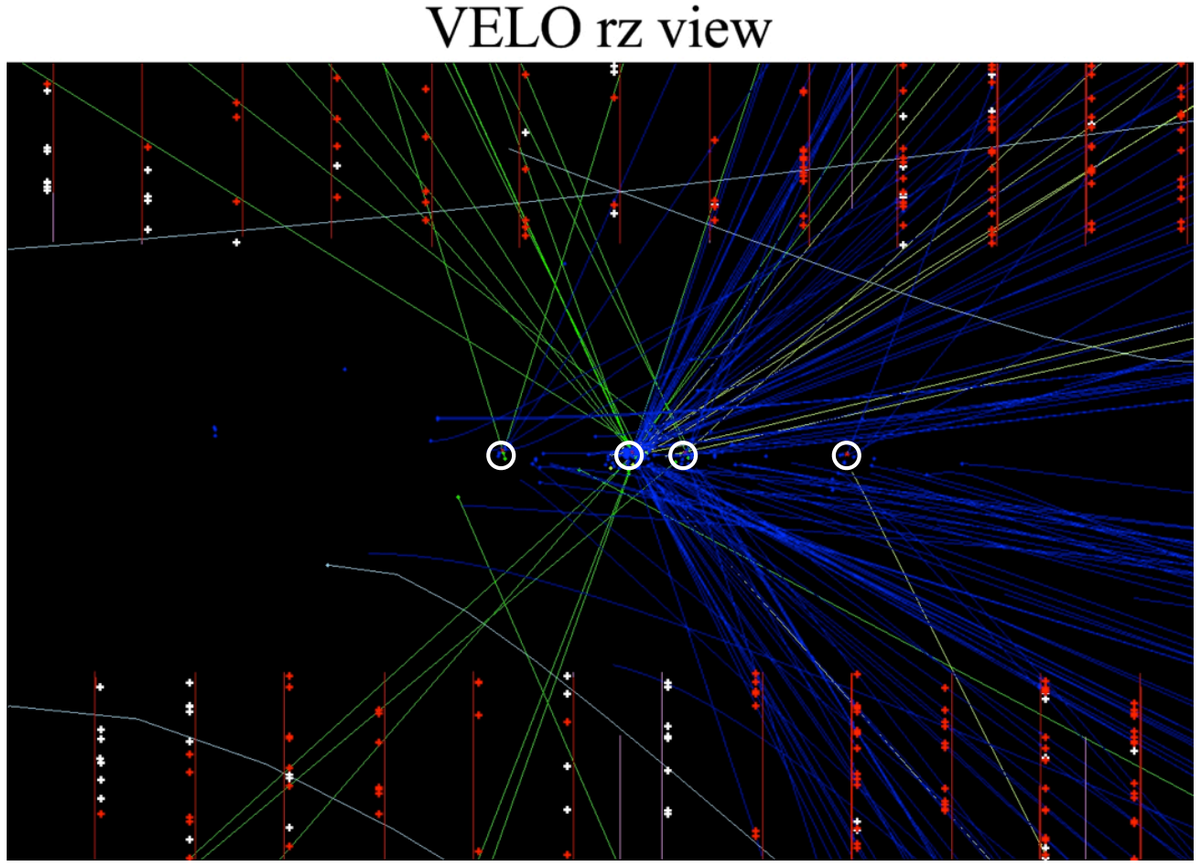
The LHCb detector upgrade

- Collect **50 fb^{-1}**
- Increase the annual yield by a factor 5 for leptonic channels and by a factor 10 for hadronic channels
- Reach experimental sensitivities comparable or better than theoretical uncertainties
- Enlarged core physics program:
  - Leptons flavour physics [Majorana neutrino, LV in $\tau^{\pm}$ decays]
  - Electroweak physics [$\sin 2\theta_{\mathrm{eff}}^{\mathrm{lept}}$, M_W]
  - Exotic search [hidden valleys,...]
  - QCD [central exclusive production]
- Constant luminosity $\mathscr{L}$ **= 1×10^{33} cm^{-2}s^{-1}** with 25 ns bunch spacing.

  design upgraded sub-system to sustain a peak luminosity of $\mathscr{L}_{\mathrm{peak}}$ = 2×10^{33} cm^{-2}s^{-1}
- Interactions / beam crossing ~ 2.3
  Already gained expertise running LHCb in such conditions:



The LHC environment



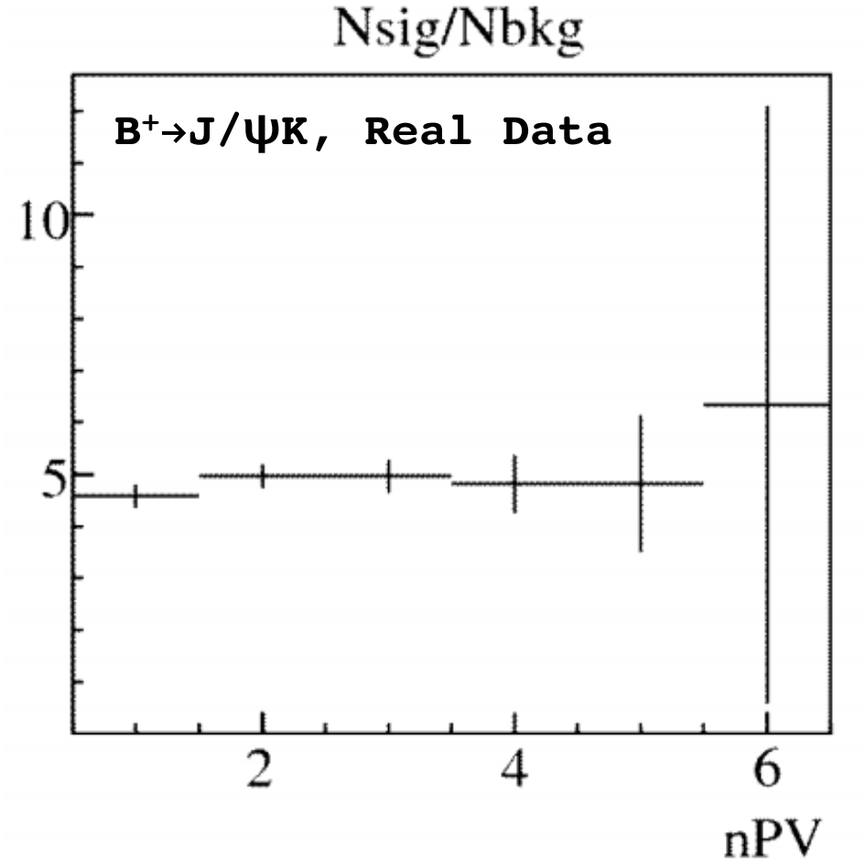
The LHC produces 15 MHz of proton-proton (pp) collisions

In order to maximize integrated luminosity, it is necessary to accept events with multiple pp interactions in a single bunch crossing

Event with four interactions is shown on the left

We have been running with an average of ~1.5 interactions per bunch crossing in 2011/12

The LHC environment



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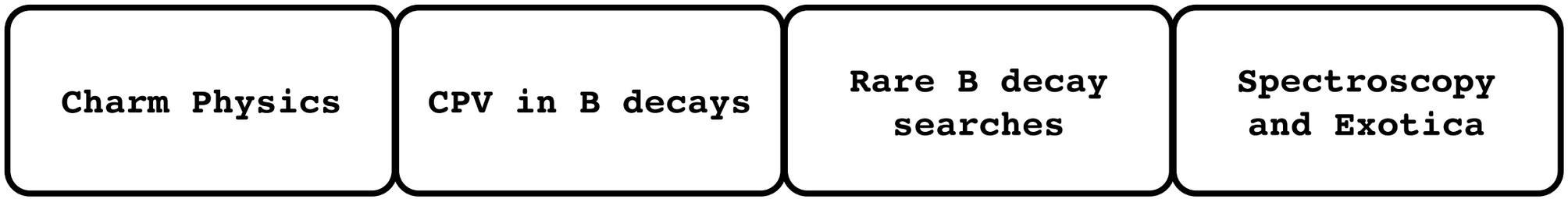
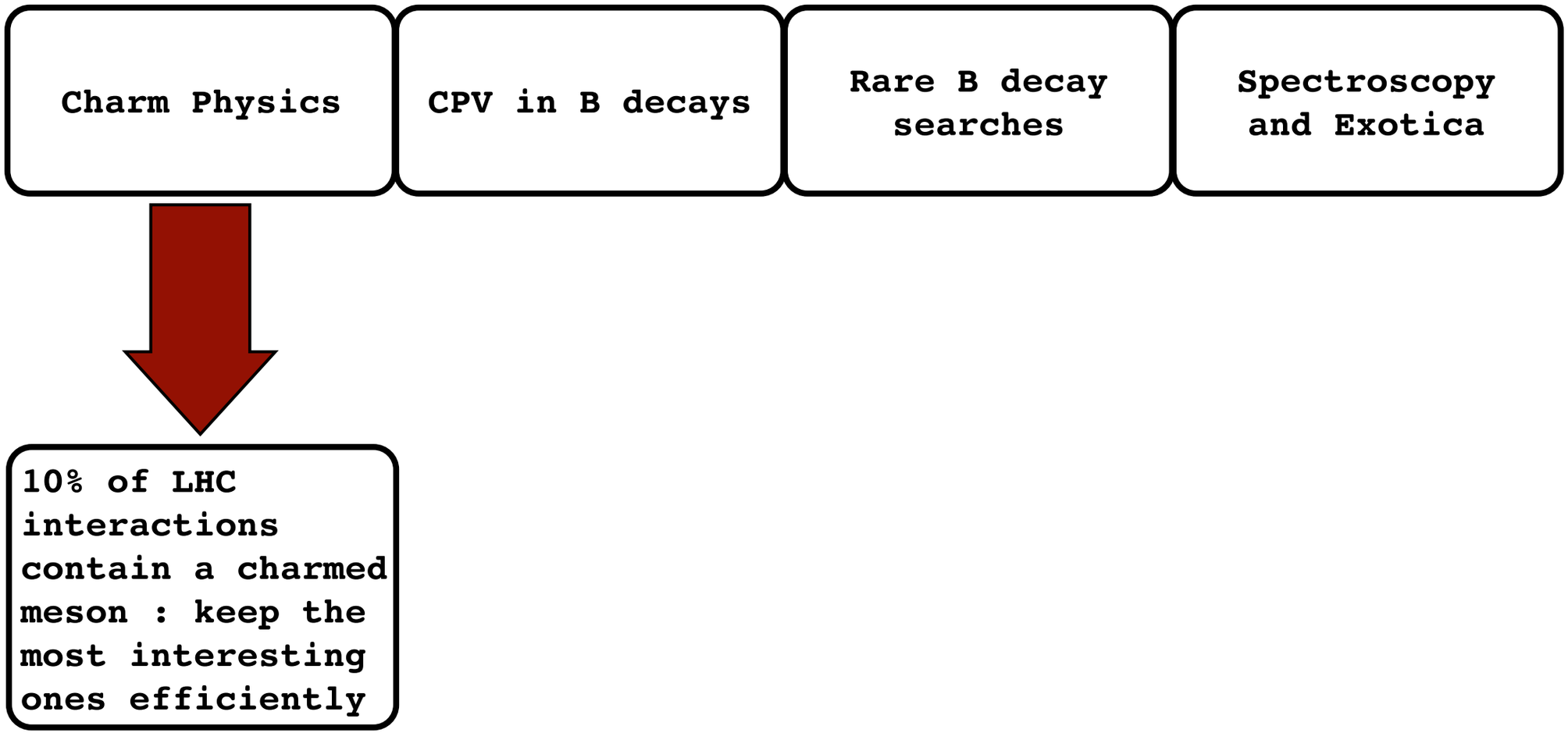
Signal purities are stable with the number of interactions in an event

The LHCb physics programme…



Note : clearly not the entire physics programme, see the LHCb upgrade LOI for more details

…and its demands on the trigger



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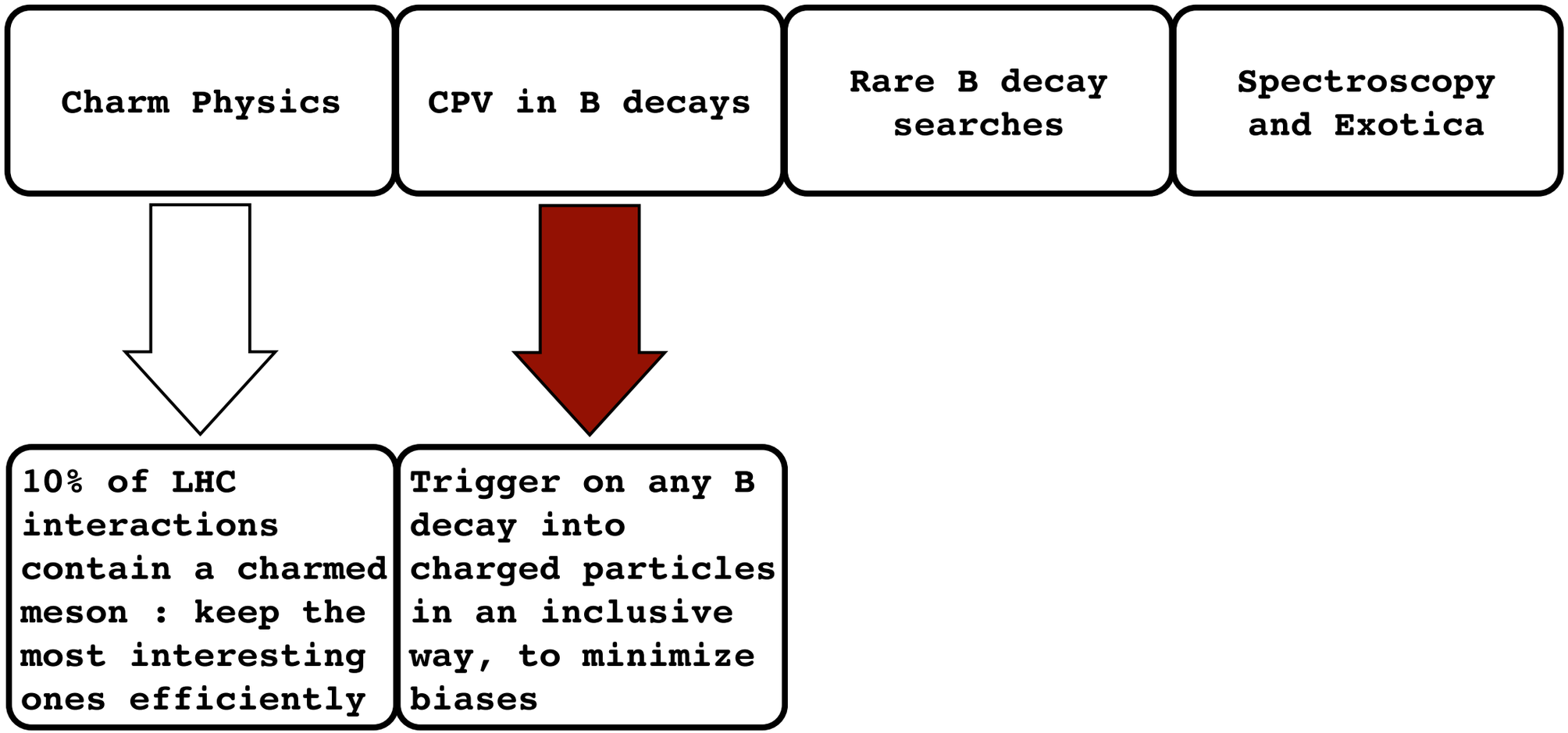

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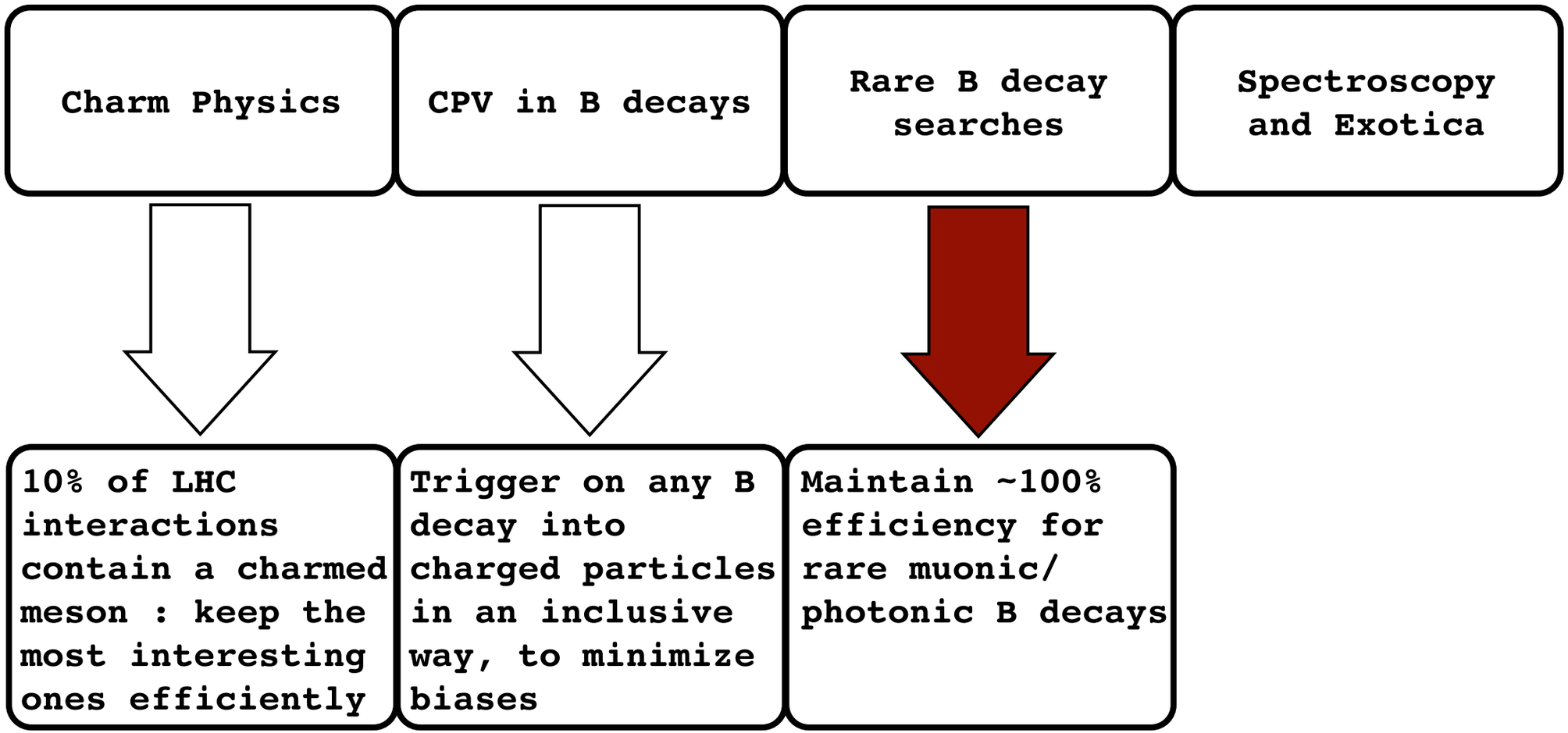

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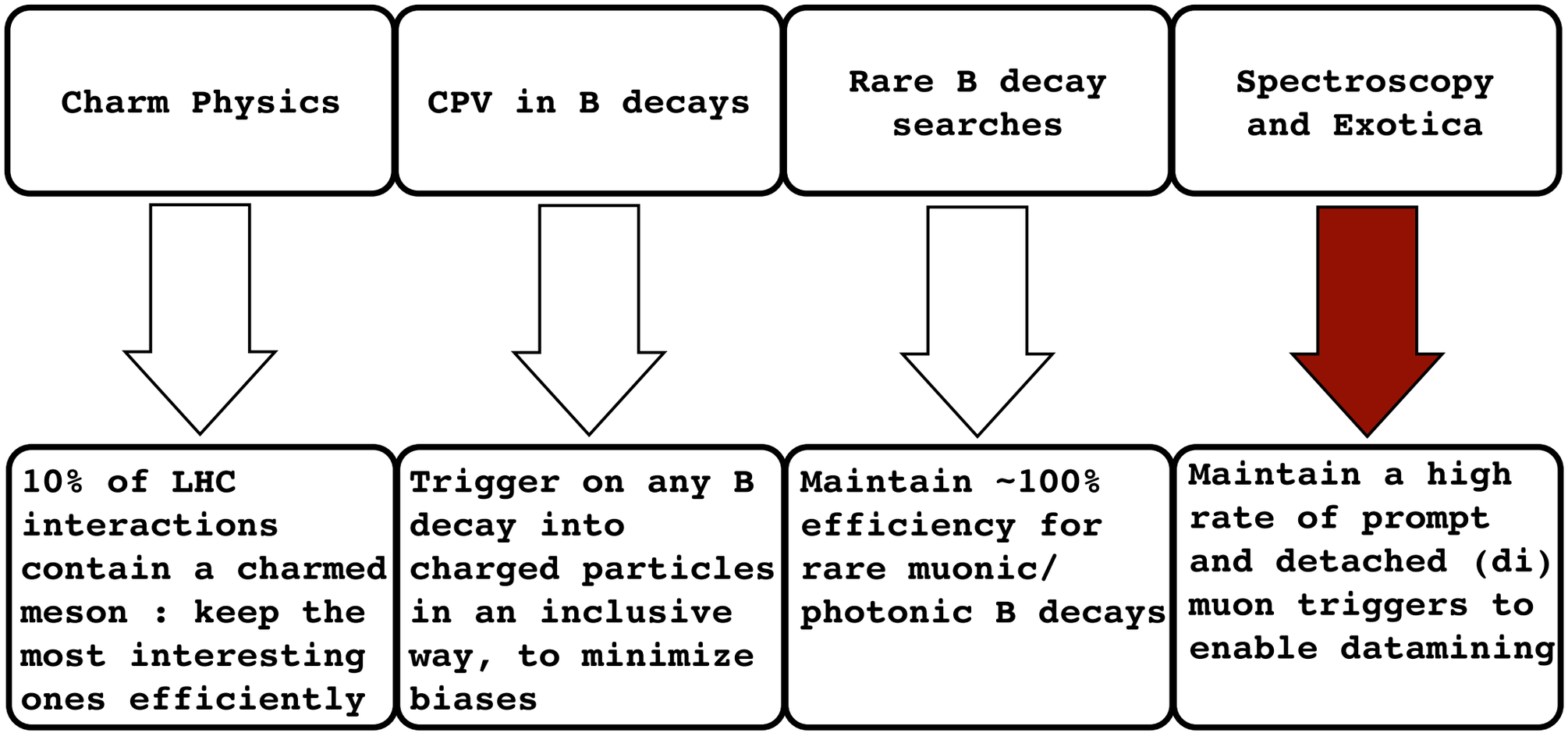

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…and its demands on the trigger

Charm Physics	CPV in B decays	Rare B decay searches	Spectroscopy and Exotica

And all this must fit into an output rate of ~4 kHz!

KEY CHALLENGE : discriminate against prompt charm (300 kHz in the LHCb acceptance) while keeping the most interesting prompt charm!

10% of LHC interactions contain a charmed meson : keep the most interesting ones efficiently	Trigger on any B decay into charged particles in an inclusive way, to minimize biases	Maintain ~100% efficiency for rare muonic/ photonic B decays	Maintain a high rate of prompt and detached (di) muon triggers to enable datamining

Note : clearly not the entire physics programme, see the LHCb upgrade LOI for more details

Triggering at the LHC at $4 \cdot 10^{32}\,cm^{-2}s^{-1}$

15 MHz pp interactions

1 MHZ Detector readout

450 kHz $h^{\pm}$	350 kHz μ	120 kHz e/γ	80 kHz $\mu\mu$

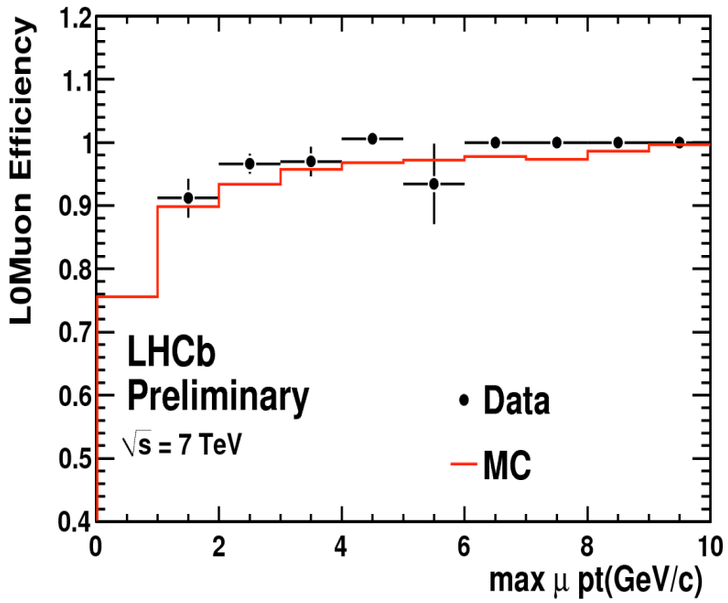
Software trigger :

- 29000 Logical CPU cores
- Access to the full event information
- Use offline reconstruction software tuned for HLT time constraints

4 kHz data output

We can only read out the full detector information at 1 MHz, hence need a hardware trigger

Trigger on high transverse momentum and energy deposits in the calorimeters and muon chambers



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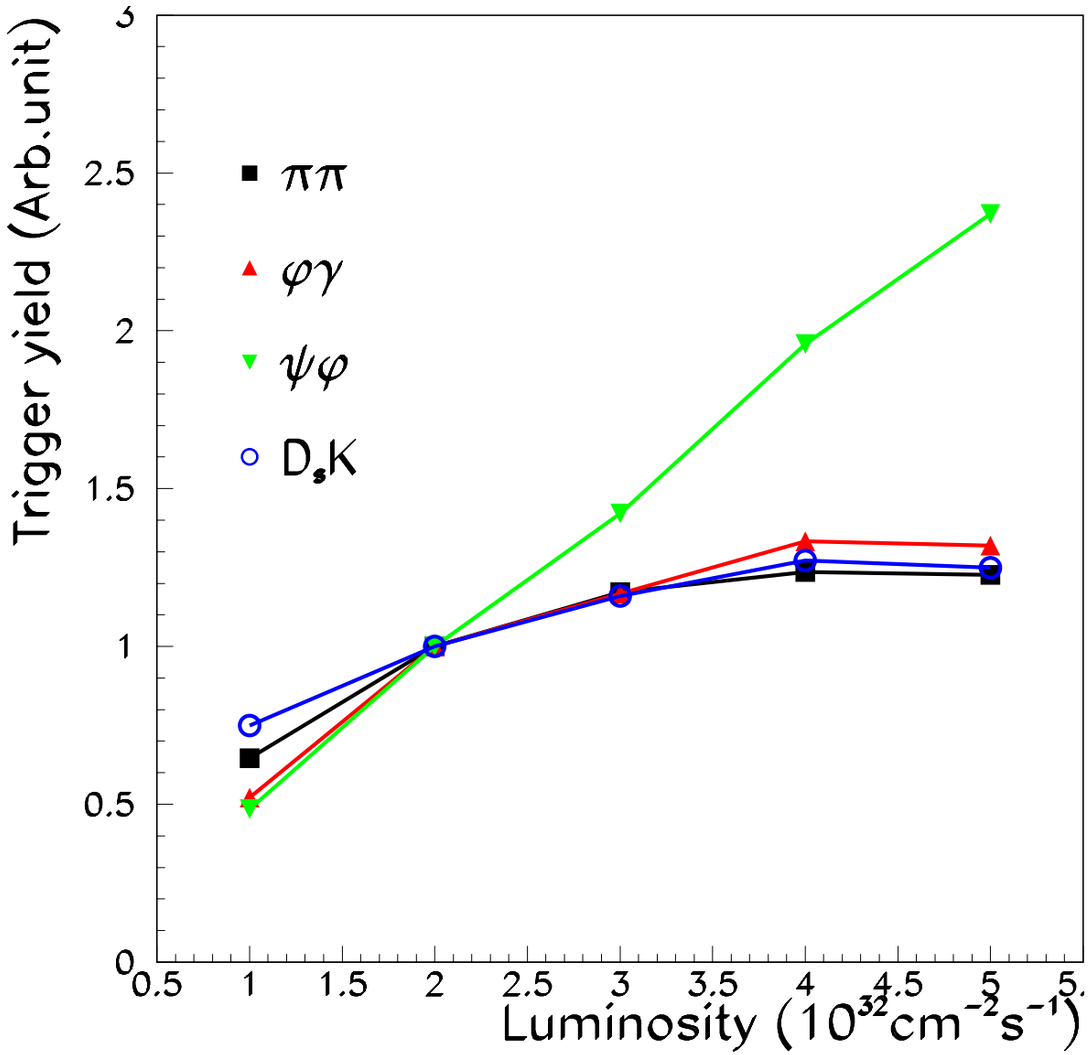

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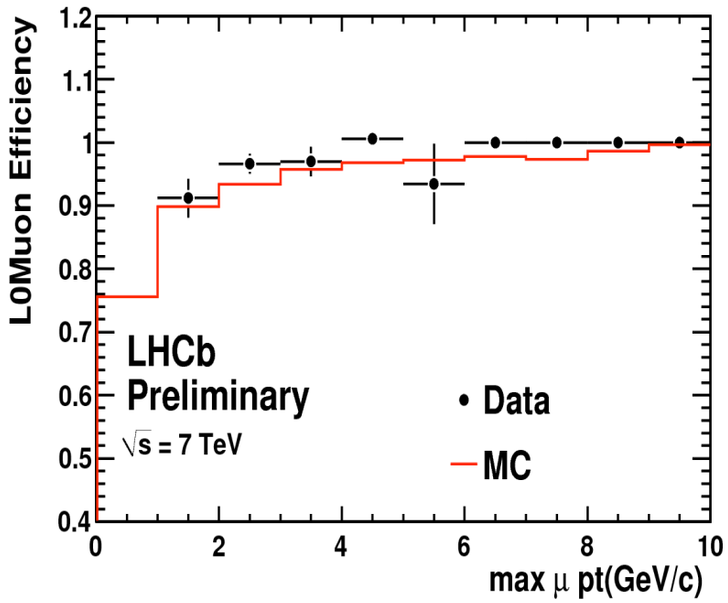
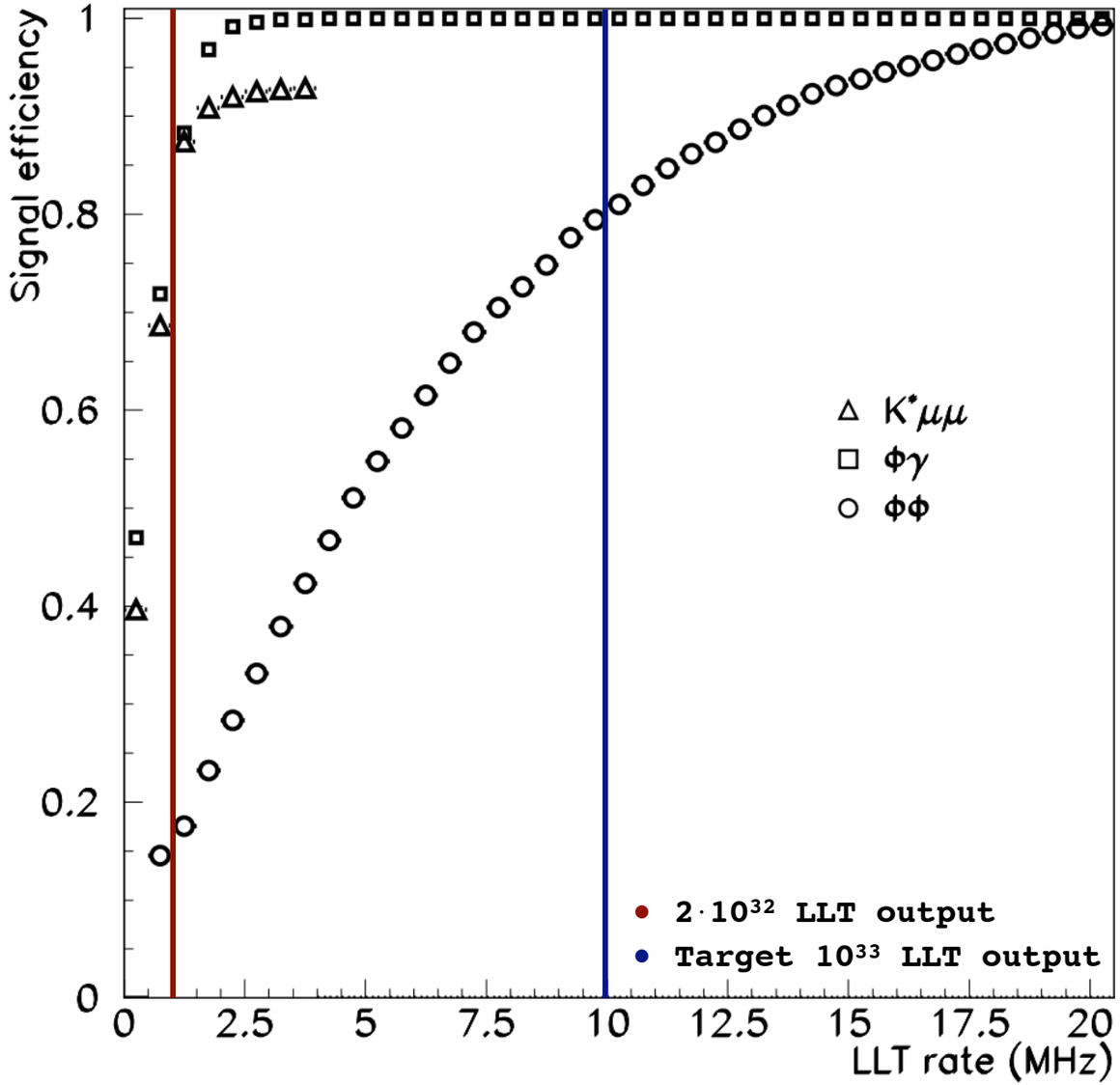


Triggering at the LHC at $10^{33}\,cm^{-2}s^{-1}$



The 1 MHz detector readout is the bottleneck in the current DAQ chain

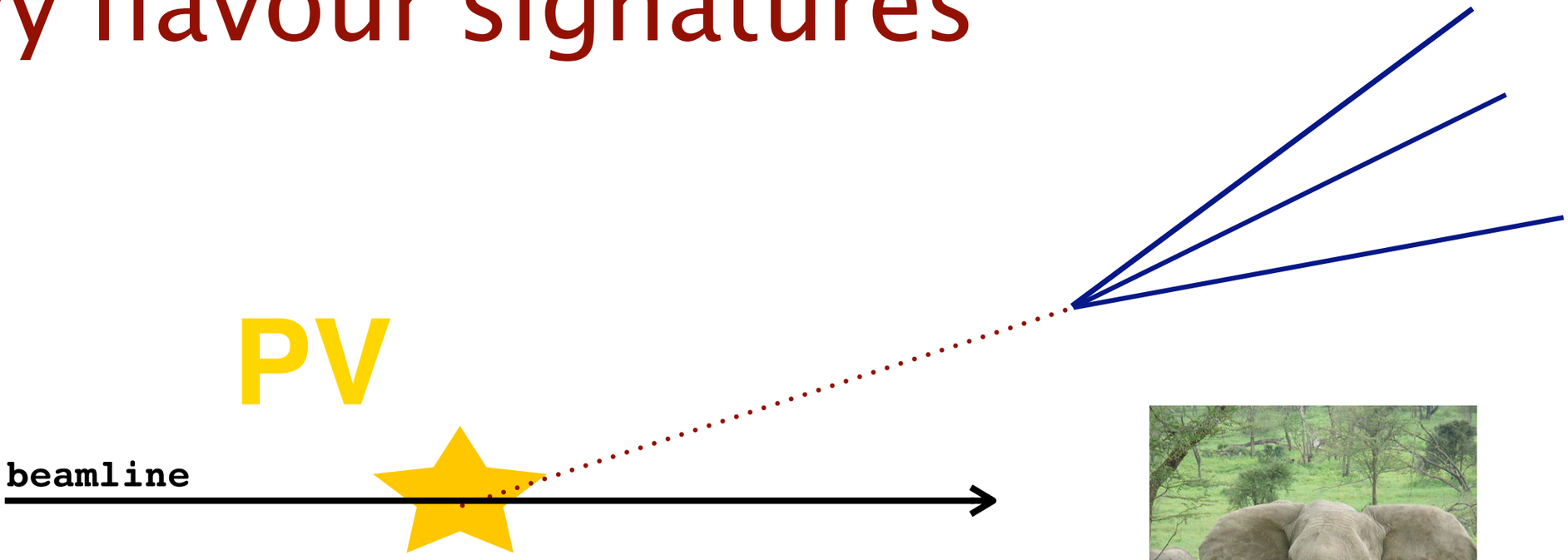
Particularly limiting for hadronic decay modes, and would become more limiting as the luminosity rises due to pileup

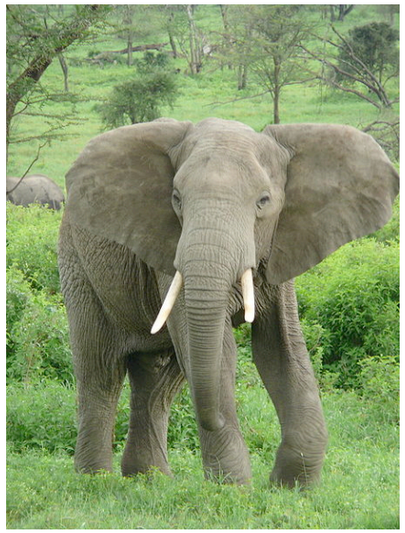
Therefore LHCb will upgrade all subdetectors to read out at 40 MHz

And then scale the actual detector readout according to the available CPU capacity in the HLT farm

Make the L0 (LLT) trigger less and less important as the upgrade progresses

Heavy flavour signatures



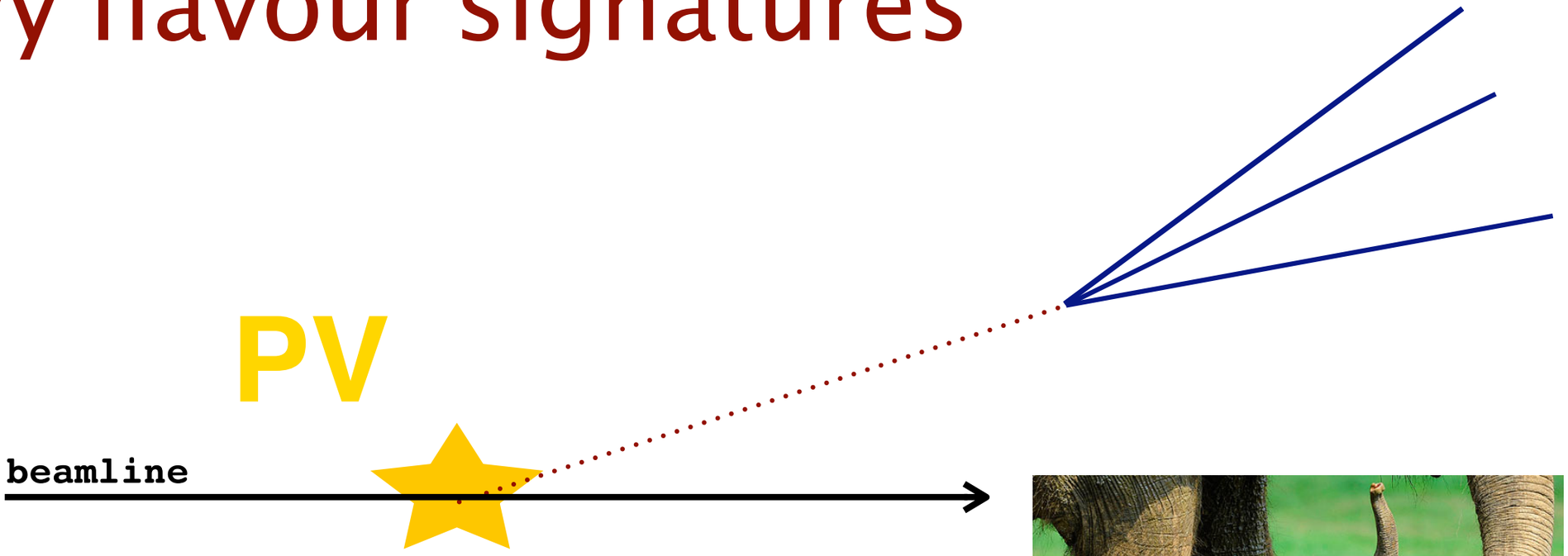


B meson signatures :

- **Large child transverse momentum**
- **Large child impact parameter or vertex displacement**
- **DiMuon candidate**

"A B is the elephant of the particle zoo: it is very heavy and lives a long time" -- T. Schietinger

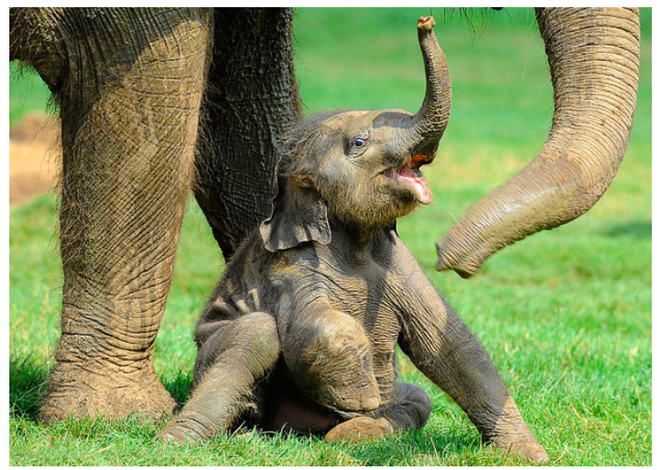
Heavy flavour signatures



D meson signatures :

Large child transverse momentum

Large child impact parameter or vertex displacement



First two criteria largely apply also to the baby elephants of the particle zoo, the charm mesons

Displaced track trigger

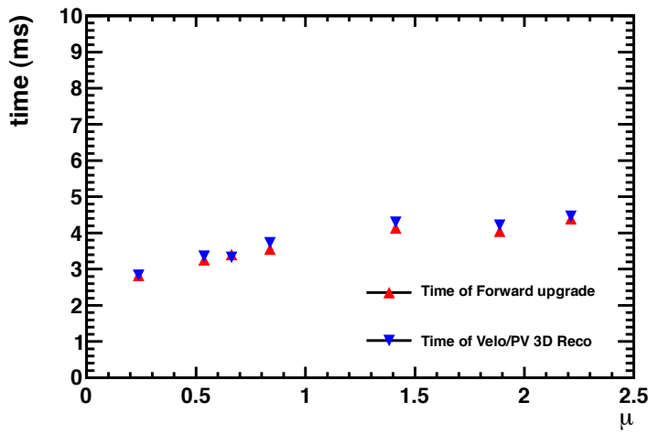
Full reconstruction of tracks in vertex locator

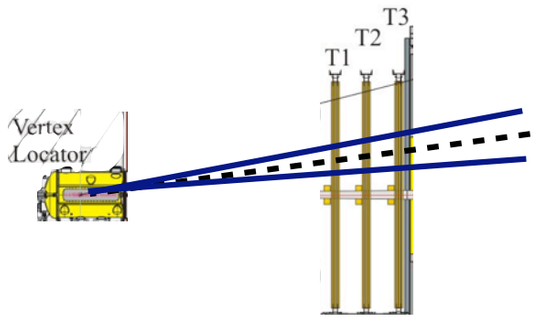
⇓

Select displaced tracks

⇓

Reconstruction of displaced tracks in regions of interest





Region of interest defined by assumed track P/P_T, 10/1.25 GeV in 2011

See LHCb public notes
LHCb-PUB-2011-003
LHCb-PUB-2011-016

DiMuon trigger

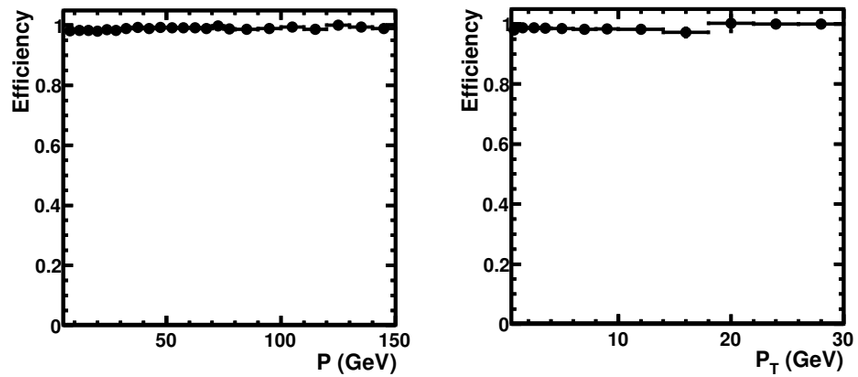
Full reconstruction of tracks in vertex locator

⇓

Match VELO tracks to muon hits

⇓

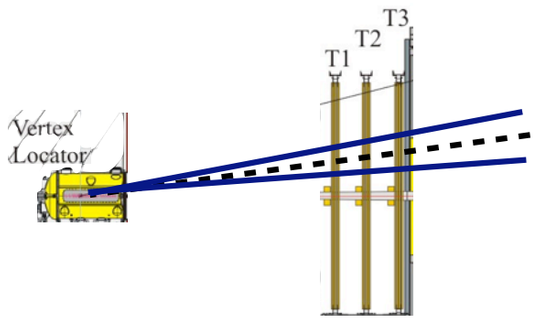
Reconstruction of muon-matched tracks in regions of interest



(a) p (b) p_T

Figure 4: Efficiency of the HLT1 Velo to muon hit matching algorithm.

Muon-matching kills as more tracks than the IP cut, can afford softer P/P_T cuts later



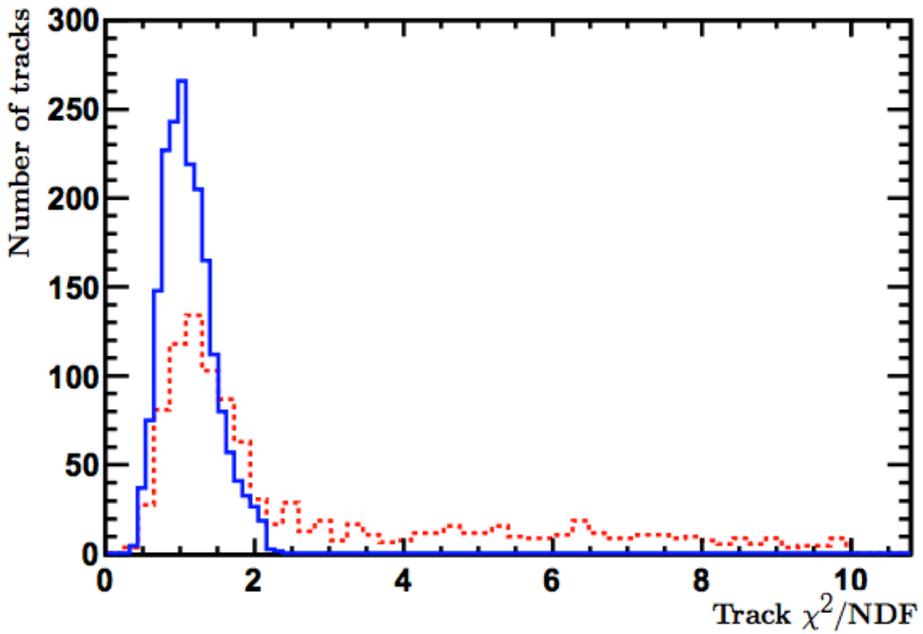
Region of interest defined by assumed track P/P_T, 6/0.5 GeV in 2011

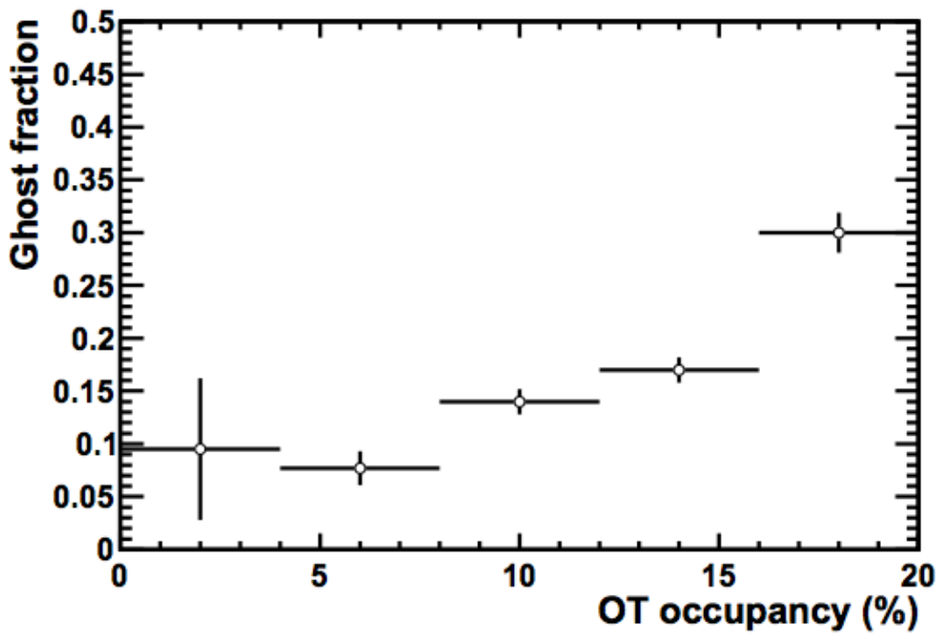
See LHCb public notes LHCb-PUB-2011-017

Ghost killing

Use criteria based on the length of the tracks as well as the Kalman fit chi2 to reject ghosts

Important that this is stable as the occupancy rises : fraction of ghost candidates firing the trigger remains under 20% with 15% occupancy in the tracking system

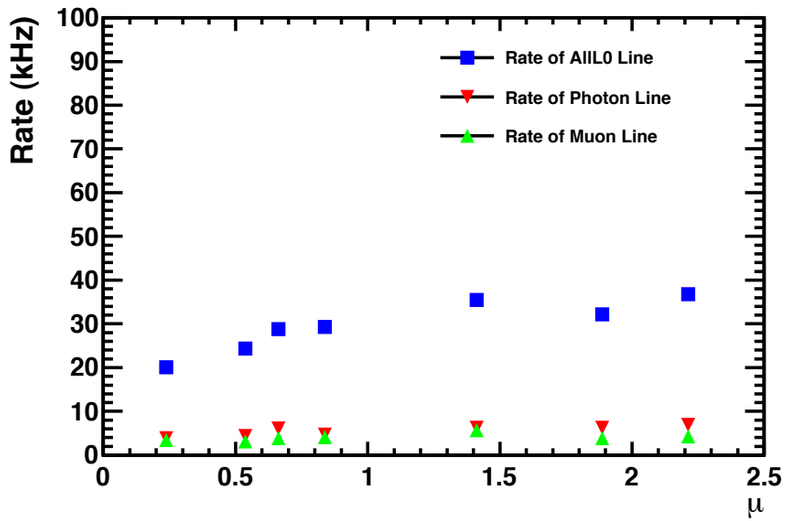




Rates and efficiencies

Efficiency **(TOS)**	$B^0 \to J/\psi K^{*0}$	$B^+ \to J/\psi K^+$	$B^0 \to D^+\pi^-$	$B^+ \to D^0\pi^-$
Hlt1TrackAllL0	$(78 \pm 5)\%$	$(79 \pm 2.5)\%$	$(83 \pm 2)\%$	$(84 \pm 2)\%$
Hlt1TrackMuon	$(81 \pm 5)\%$	$(76 \pm 2.5)\%$	N/A	N/A
Hlt1Track(Muon or AllL0)	$(88 \pm 5)\%$	$(86 \pm 2.5)\%$	N/A	N/A

Muon-ID allows softer IP/PT cuts and increases efficiency for muon modes



Rate on left is given with respect to 1 MHz of LLT triggers

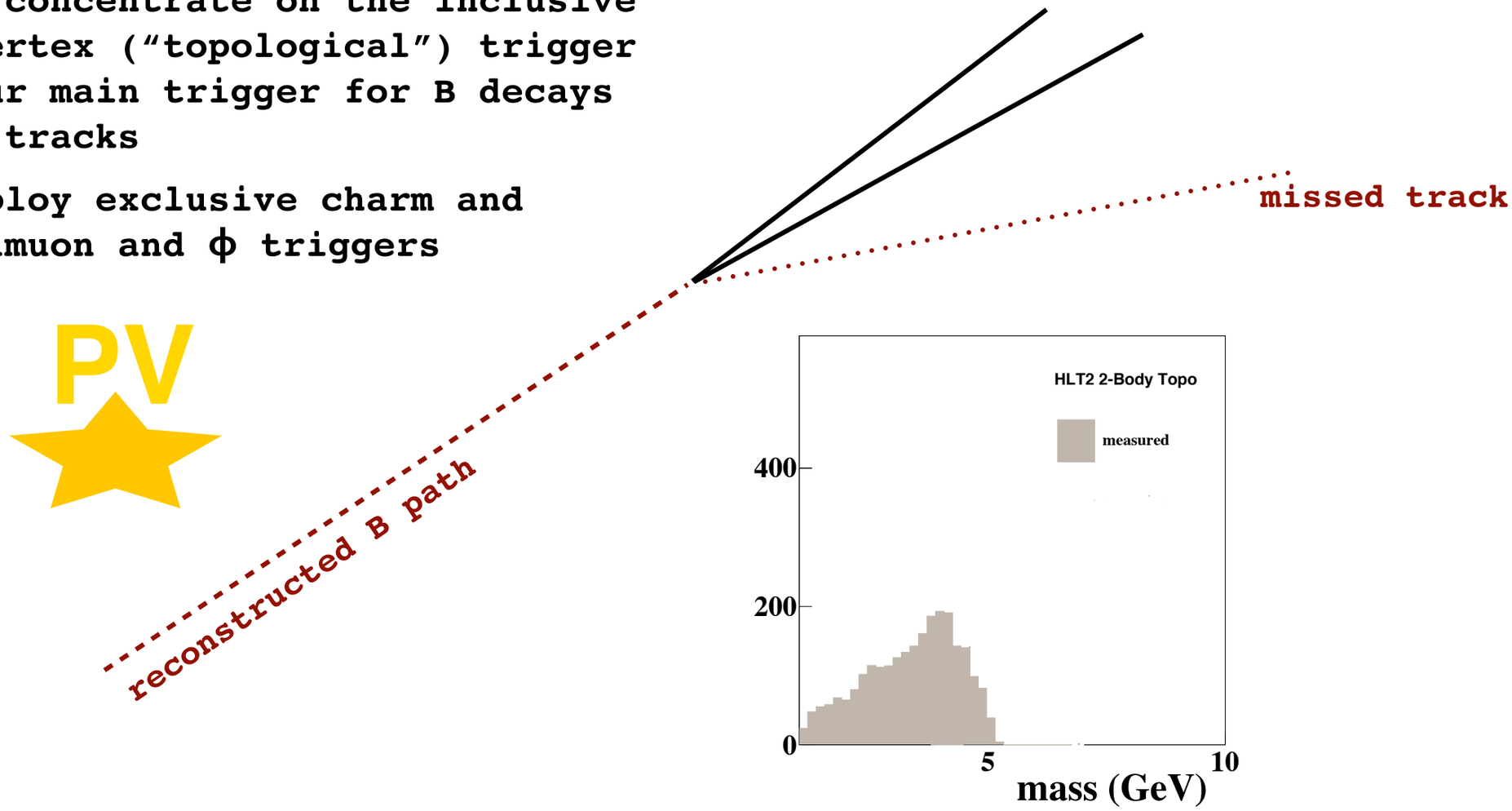
Hence a reduction of around a factor 20 is possible by looking for a detached track or a dimuon candidate

Need another factor 10 reduction in the output rate, but now have time to perform an "offline-like" reconstruction of the surviving events

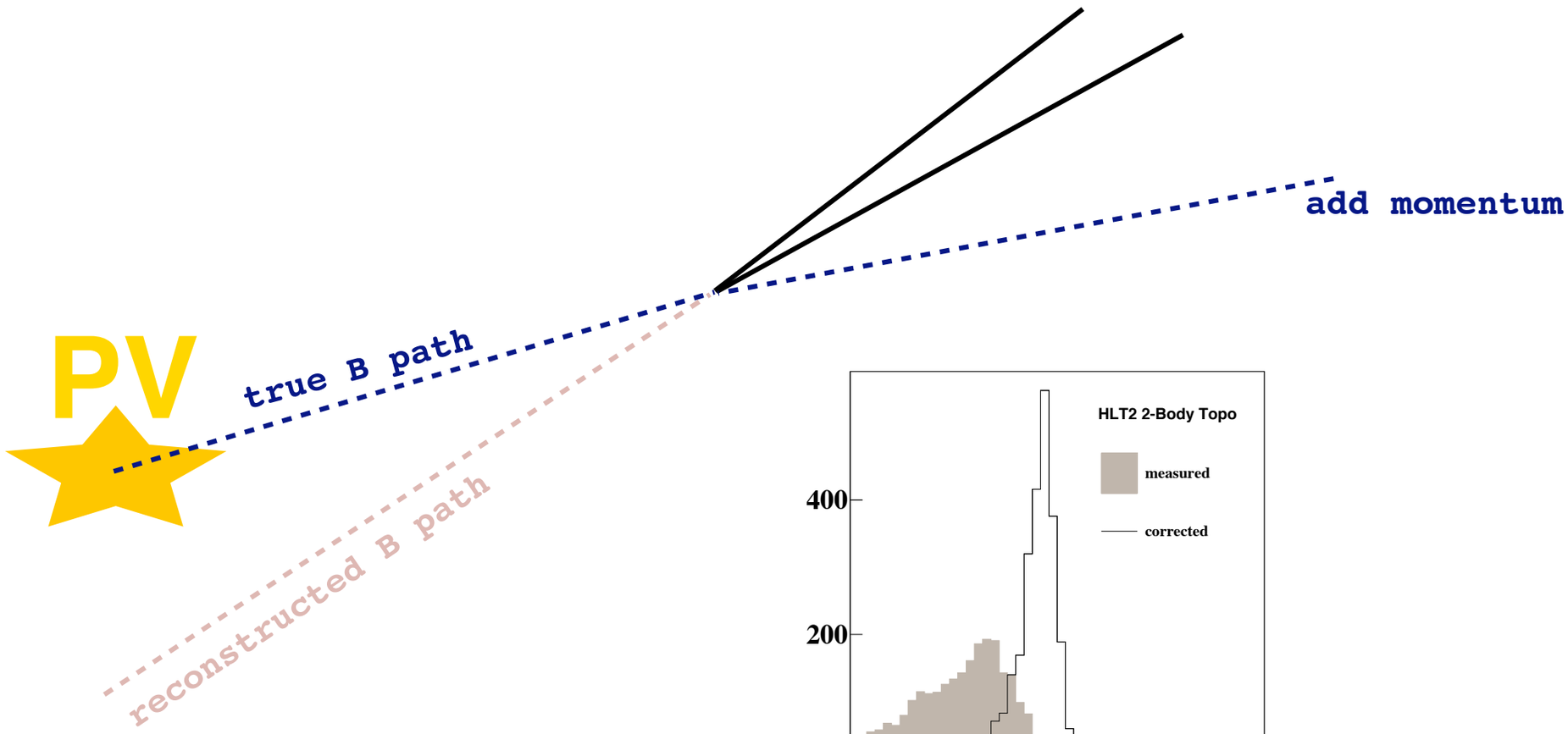
The topological trigger

I will now concentrate on the inclusive detached vertex ("topological") trigger which is our main trigger for B decays to charged tracks

We also deploy exclusive charm and detached dimuon and ϕ triggers

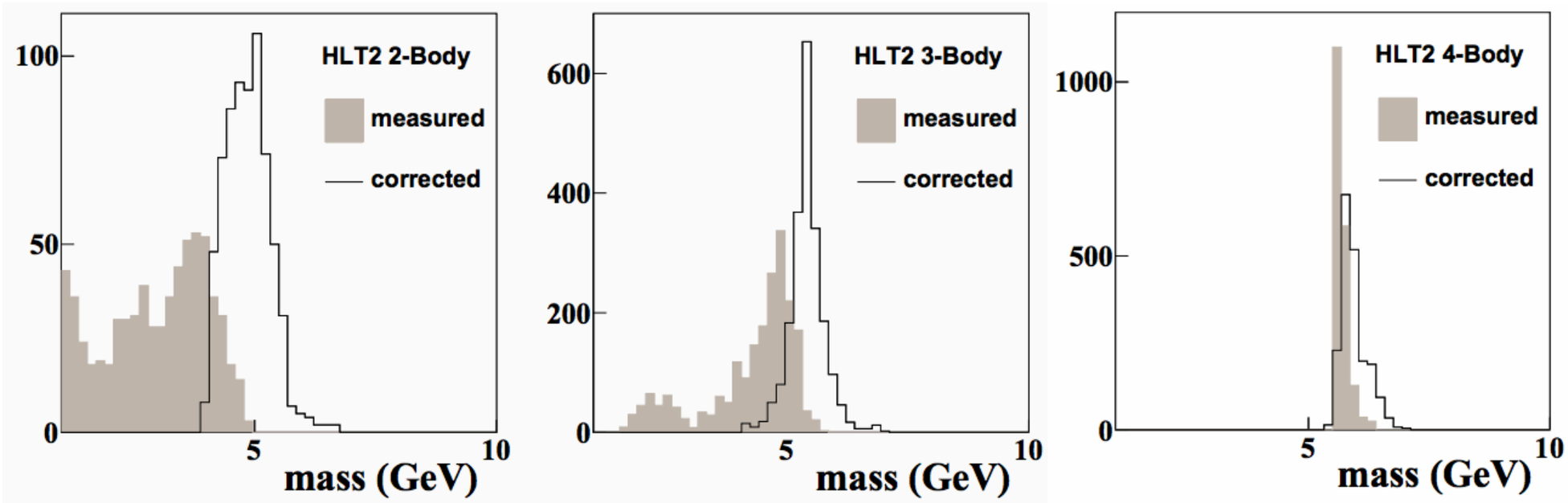


The topological trigger



$$m_{\text{corrected}} = \sqrt{m^2 + |p'_{T\text{missing}}|^2} + |p'_{T\text{missing}}|$$

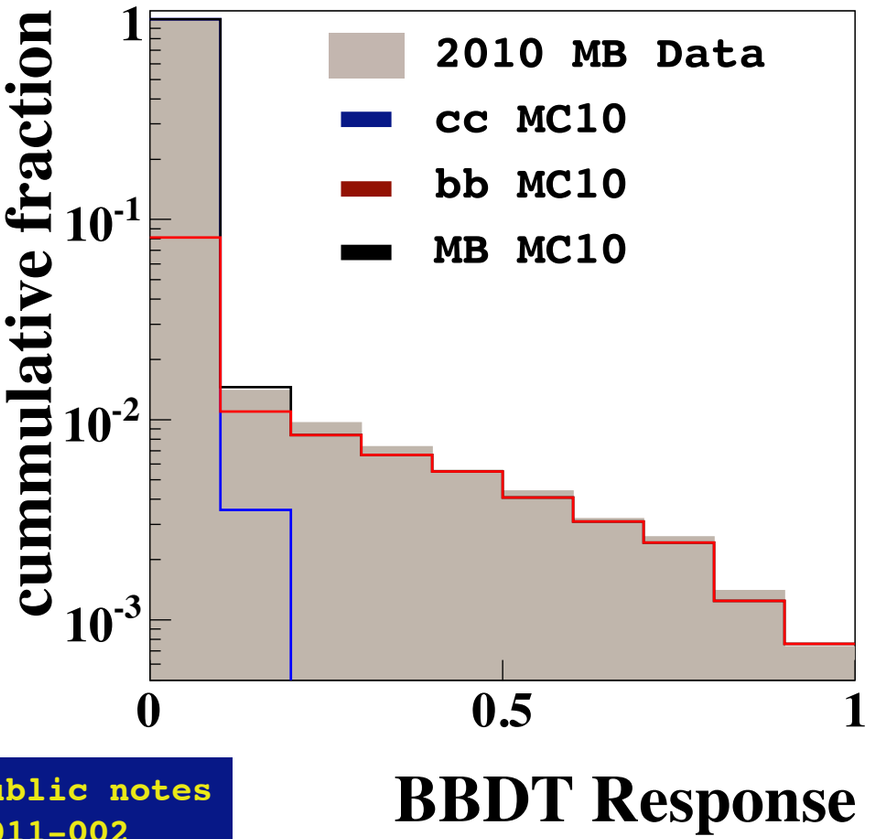
The topological trigger

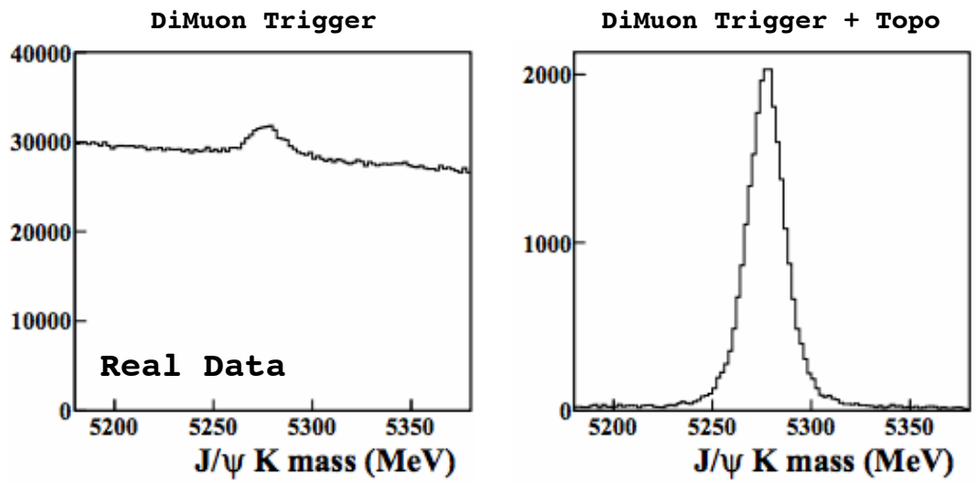


Corrected mass of B→K*μμ in 2,3,4 track topological triggers

The topological trigger

The corrected mass is a good variable, but not good enough to deal with pileup on its own : deploy a boosted decision tree to discriminate between signal and background displaced vertices.





Left : J/ψK candidates with a dimuon trigger and no detachment required

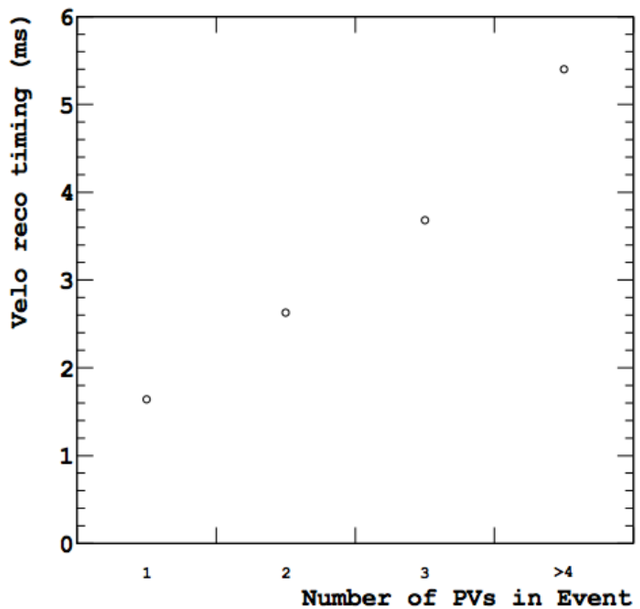
Right : the subset of these candidates which pass the topological trigger

See LHCb public notes
LHCb-PUB-2011-002
LHCb-PUB-2011-016

Back to the future

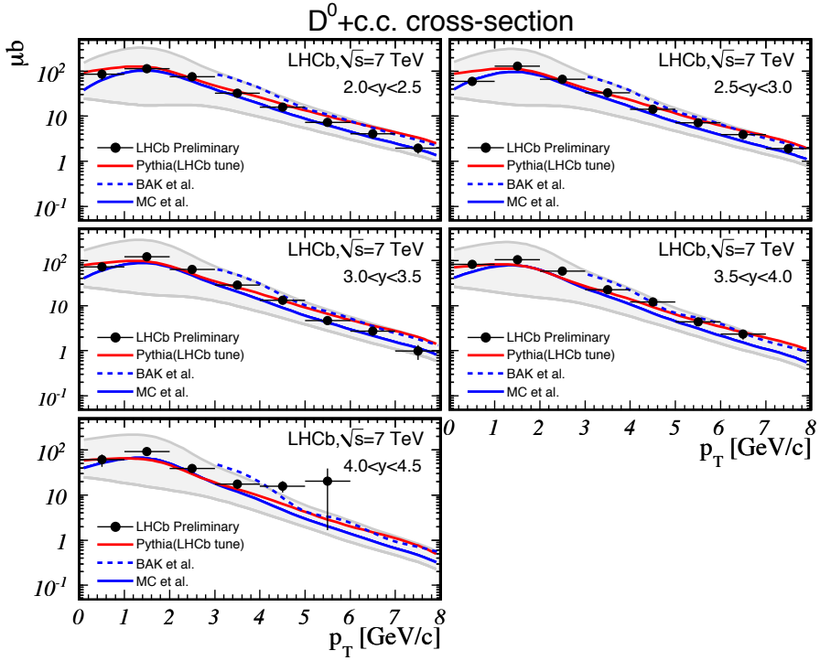
The trigger plan for the upgrade is very simple: set the output rate of the LLT to whatever size farm we can afford to buy at any given moment. Since the upgrade will run with twice the number of bunches in the LHC compared to now, the average number of interactions per bunch crossing will stay roughly the same, and hence so will the HLT timing.

We profit roughly linearly for hadronic modes from 1 to 10 MHz LLT output. HLT output rate will be under control even if we assume no further improvements are made to the current algorithms.



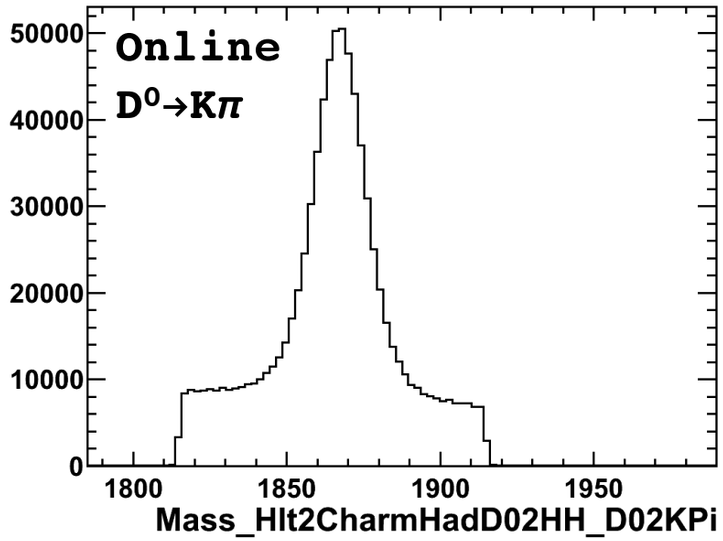
EFF size	5×2011	10×2011
LLT-rate (MHz)	5.1	10.5
HLT1-rate (kHz)	270	570
HLT2-rate (kHz)	16	26
Total signal efficiency		
$B_s \to \phi\phi$	0.29	0.50
$B^0 \to K^*\mu\mu$	0.75	0.85
$B_s \to \phi\gamma$	0.43	0.53

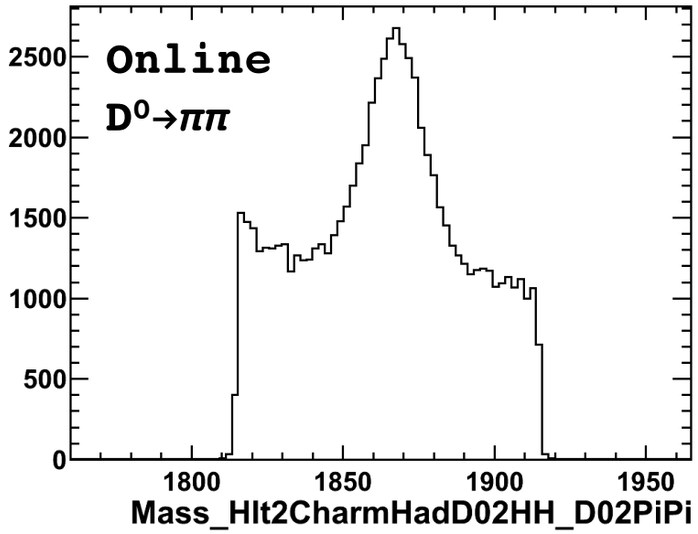
The charm challenge



Open charm cross section at 7 TeV is already huge

σ = 6.10 ± 0.93 mb





Charm triggers are dominated by signal

Efficiency of charm triggers is largely limited by the allowed output rate. For example at 14 TeV and 10^{33} $cm^{-2}s^{-1}$, the LHC will produce something like 20 kHz of $D^0 \to K\pi$ decays which can be fully reconstructed in the LHCb acceptance!

An ongoing challenge will be to keep the most interesting charm events as efficiently as possible

Outlook

The LHCb trigger is working very well, and has enabled us to collect the world's largest samples of D and B mesons already in the first full year of datataking

E.g. see on the right the rarest B decay ever observed, B→πμμ

Upgrade will deliver 100/200 times the yield for muonic/hadronic decays respectively

The basic principle of a track trigger followed by a multivariate B-vertex selection has been validated to hold for the upgrade

In order to unlock the full potential of these algorithms, need to be able to handle a 10 MHz input rate to the farm : a major technological challenge