A measurement of the Z cross section at LHCb + Searches for new physics at CMS.

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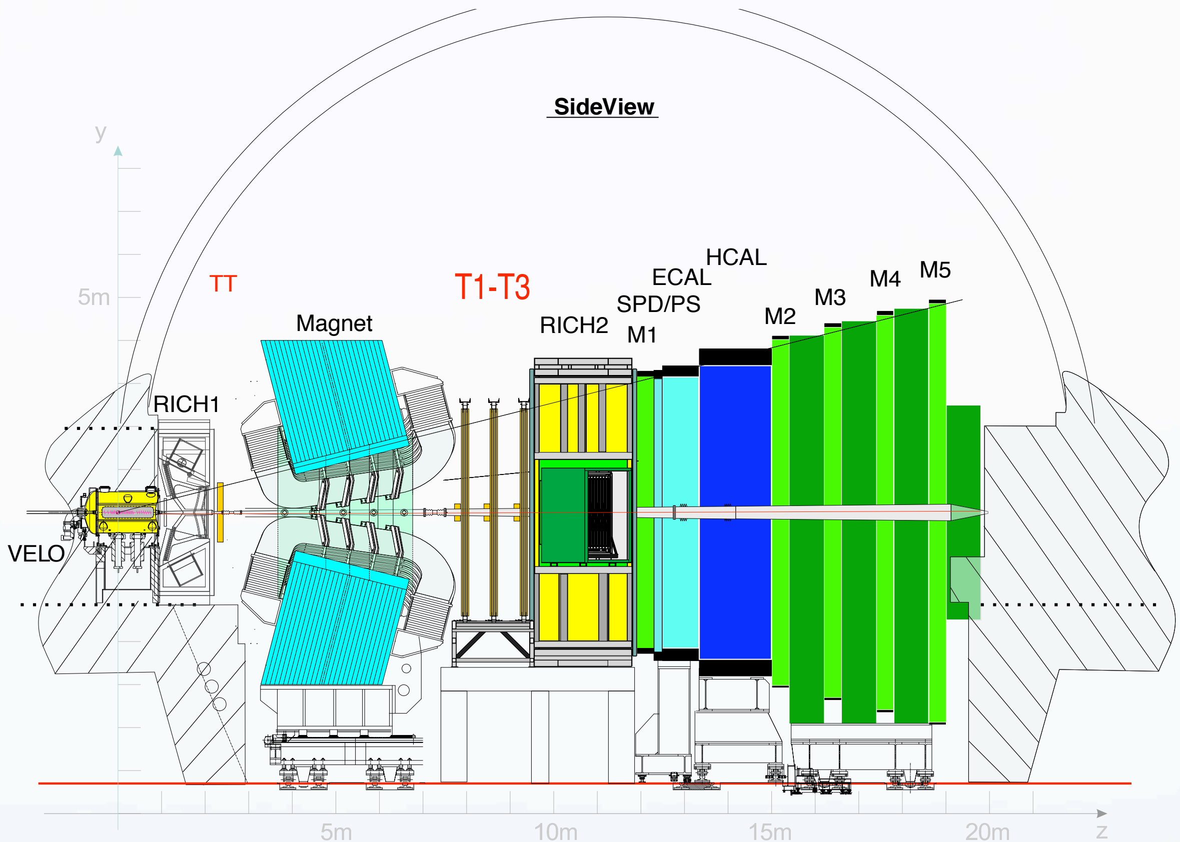
Today's talk

- 1. My research at LHCb
  - The LHCb experiment
  - Z->$\mu^+\mu^-$ cross section measurement.
  - Calibration studies of the VELO detector.

- 2. Searches for new physics at CMS
  - Z' searches
  - ttbar asymmetry measurements
  - b' searches

LHCb

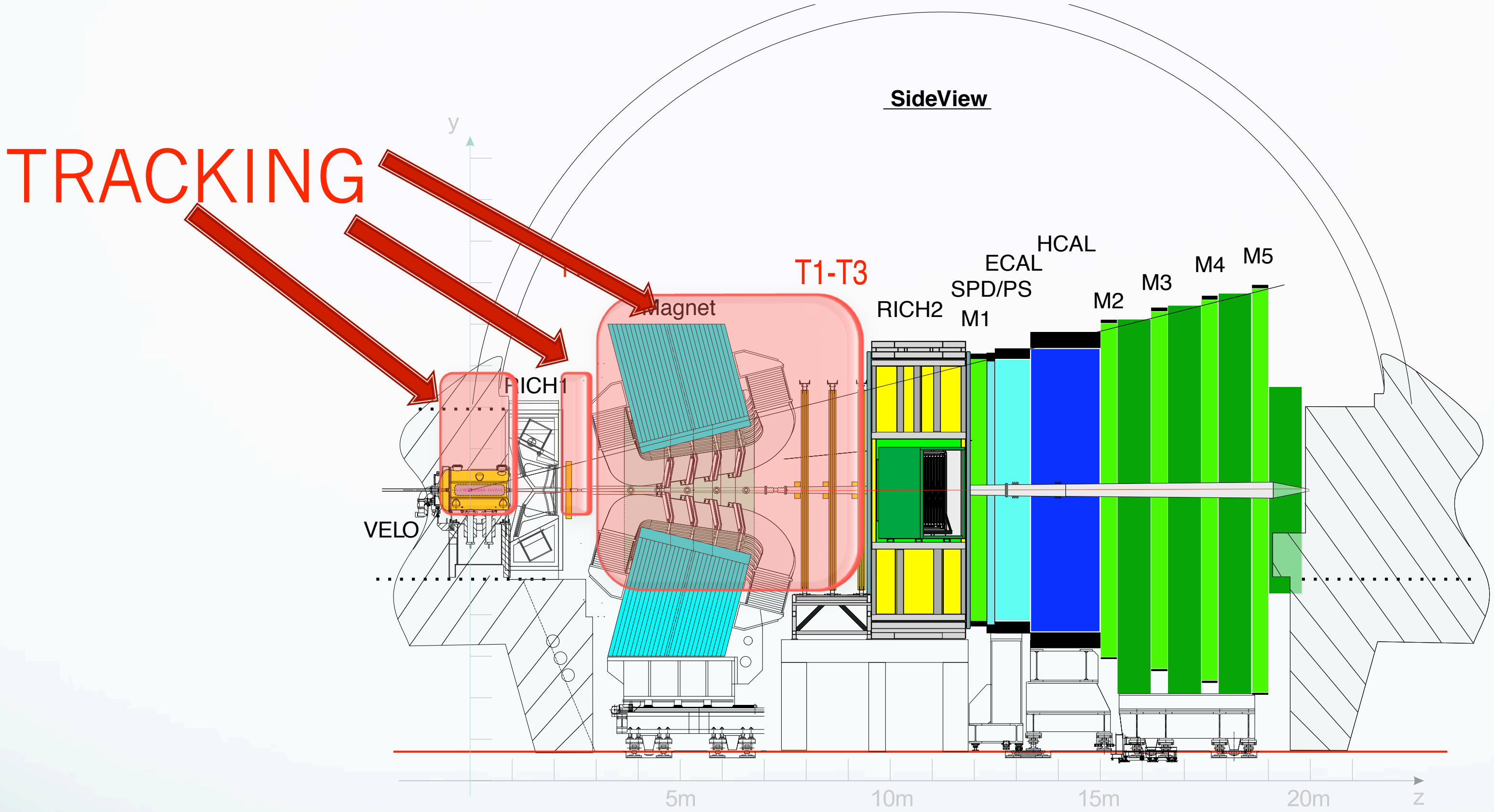
LHCb: a forward spectrometer



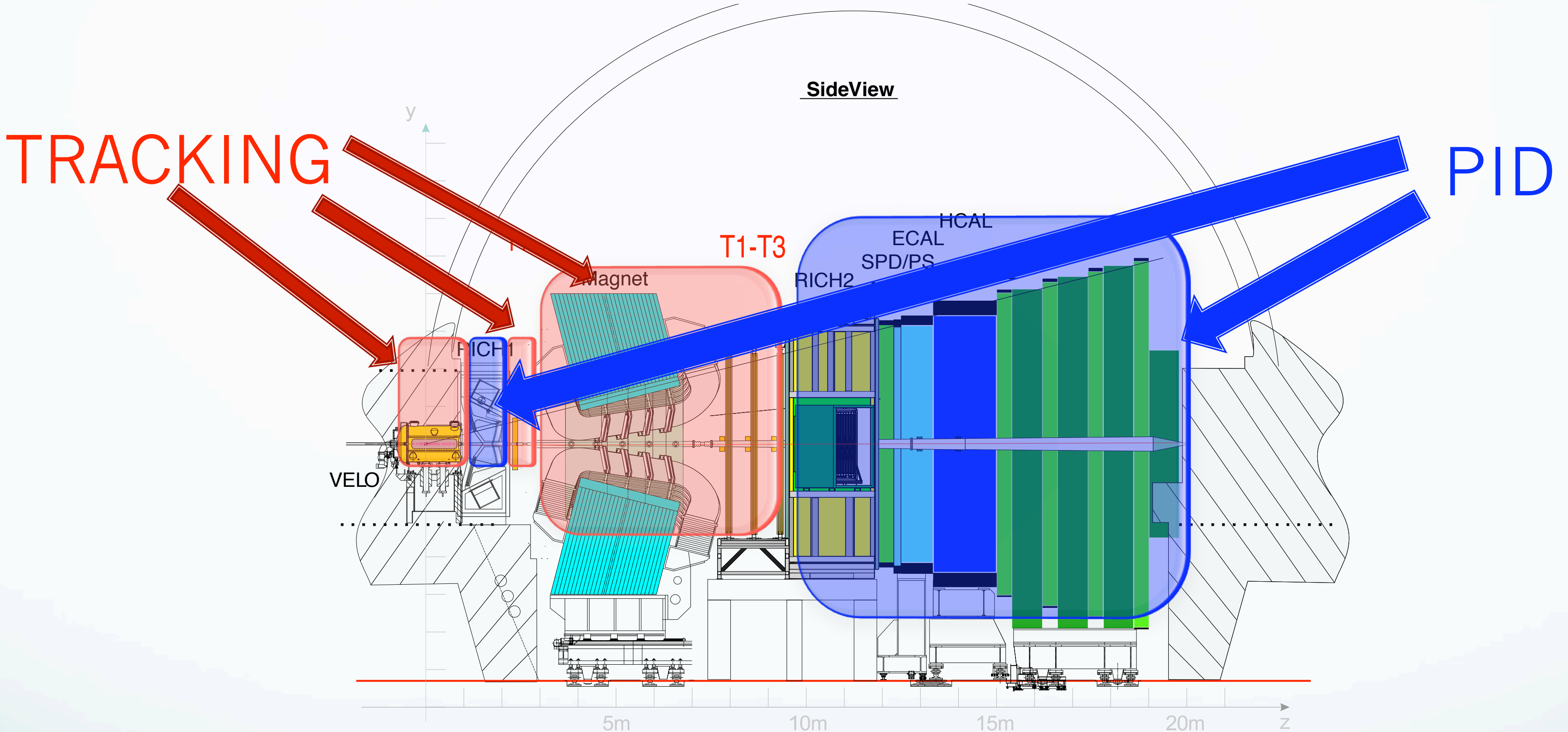
Full detector coverage in the range **(1.9 < η <4.9)**

Optimised for b-physics, but provides unique opportunity to probe the **electroweak** sector.

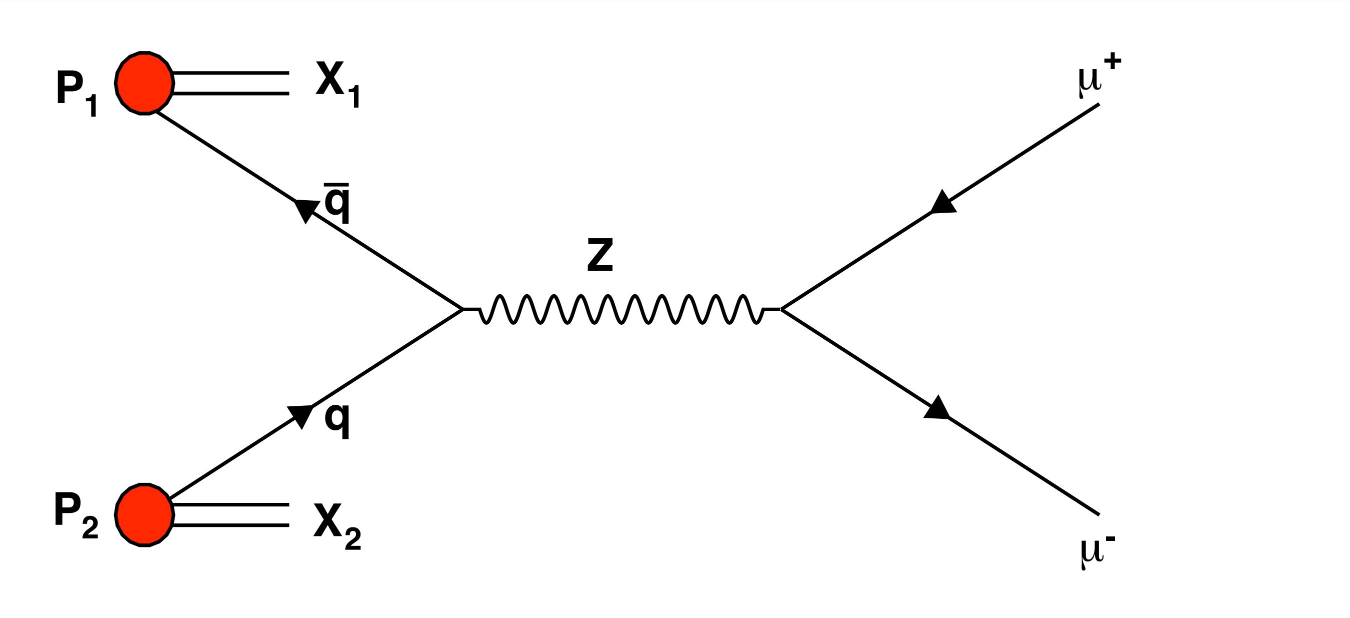
LHCb: a forward spectrometer



LHCb: a forward spectrometer



Leading order Z boson production at the LHC



Measuring σ.Br($Z \to \mu^+\mu^-$) at LHCb

1. Total cross section

2. Differential cross section as a function of boson rapidity.

Theoretically:

$$\hat{\sigma}_{pp\to Z} = \int dx_1 dx_2 \hat{\sigma}_{q\bar{q}\to Z} \sum_q [\mathcal{F}_{\frac{q}{p1}}(x_1, Q^2)\mathcal{F}_{\frac{q}{p2}}(x_2, Q^2) + (q \leftrightarrow \bar{q})]$$

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Parton level cross section, predicted by the Standard Model

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Parton level cross section, predicted by the Standard Model

Function which describes the momentum sharing of the partons

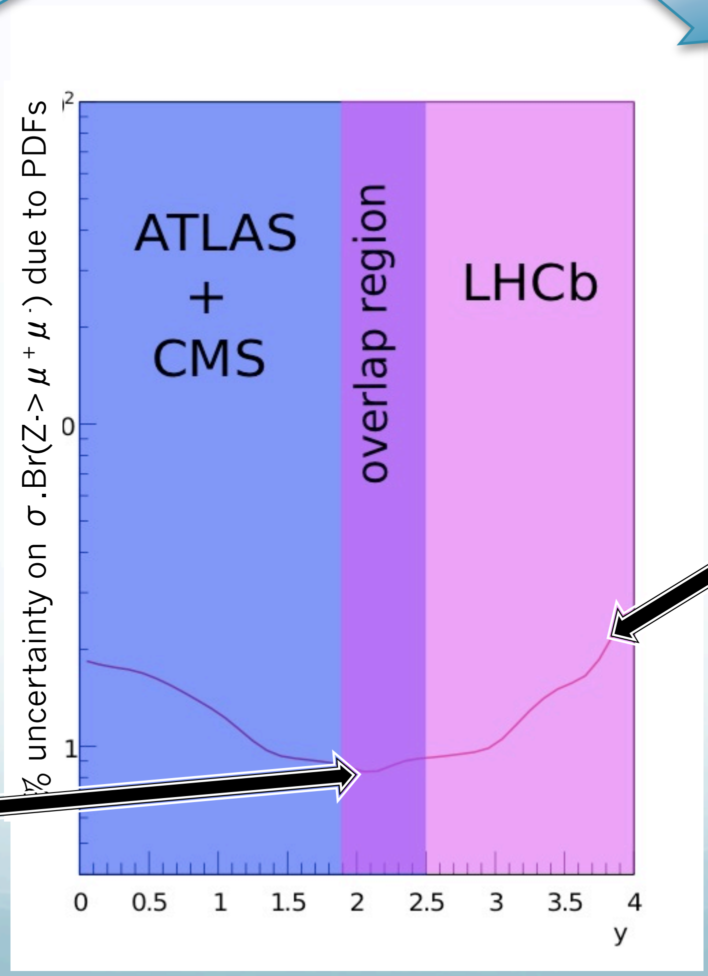
Measuring σ.Br($Z \rightarrow \mu^+\mu^-$) at LHCb

Motivations

Test the SM to 1%

In kinematic regions where uncertainties on σ.Br($Z \rightarrow \mu^+\mu^-$) due to PDFs are low, the measurement tests the SM.

Region of minimum uncertainty (1%) is accessible to LHCb, ATLAS and CMS => cross checks.



Constrain PDFs

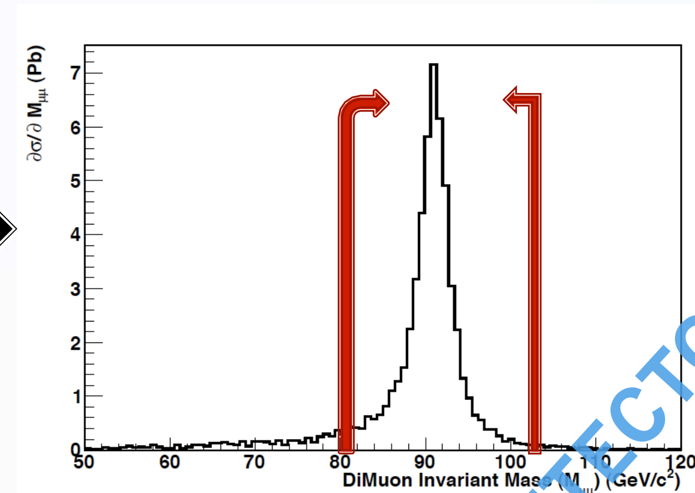
The (y > 2.5) region is unique to LHCb.

Here the uncertainties are higher (2-4%).

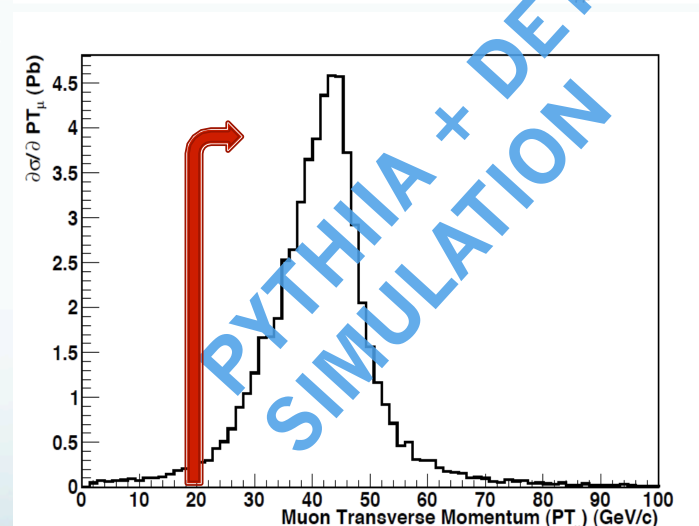
In this region the measurement can reduce PDF uncertainty.

Selecting the signal

Offline signal selection strategy is based on the large **di-muon invariant mass** and **muon transverse momenta** of the di-muons arising from the Z decay.



For simplicity and robustness, the requirements are composed of three requirements only:

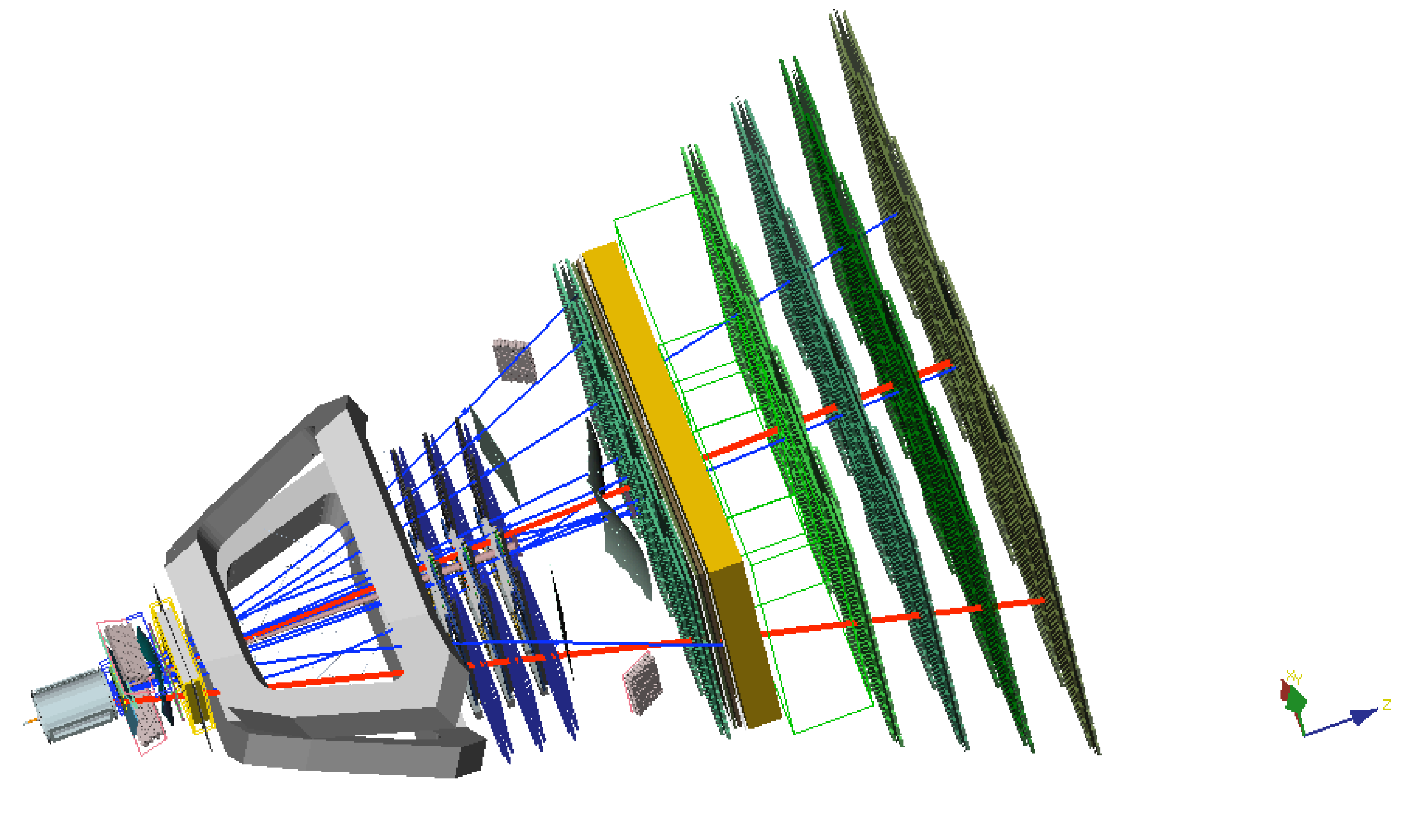


2 oppositely charged muons, with $2 < \eta_{\mu} < 4.5$

muon transverse momenta > 20 GeV

81 GeV <di-muon invariant mass <101 GeV

First Z candidate at LHCb May 2010

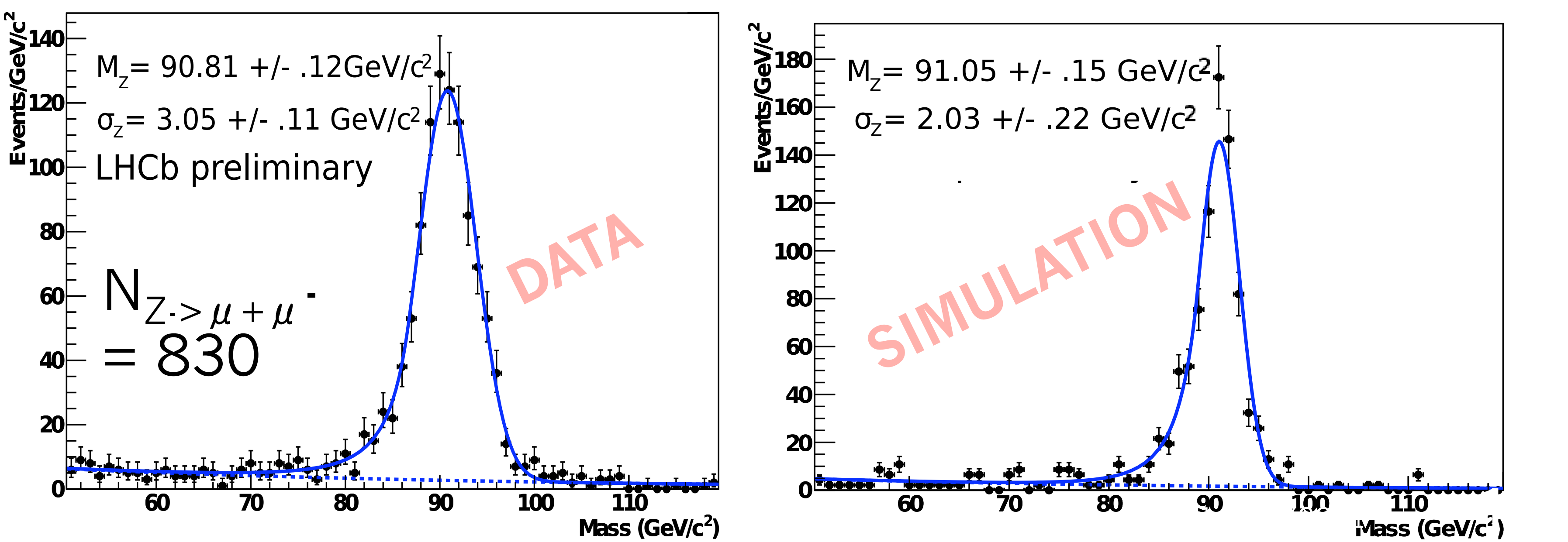


Signal Yield

Data: 16.5 ± 1.7 pb^{-1} of 7 TeV data recorded by LHCb in 2010.

Application of the selection scheme to this data yields <u>830</u> signal candidates

Di-muon invariant mass distributions of candidates:



Making a cross section measurement

$$\sigma.Br(Z\to\mu^+\mu^-) = \frac{N_{Z\to\mu^+\mu^-} - N_{background}}{\varepsilon_{detector} \times \varepsilon_{selection} \times \text{Int. Lumi}}$$

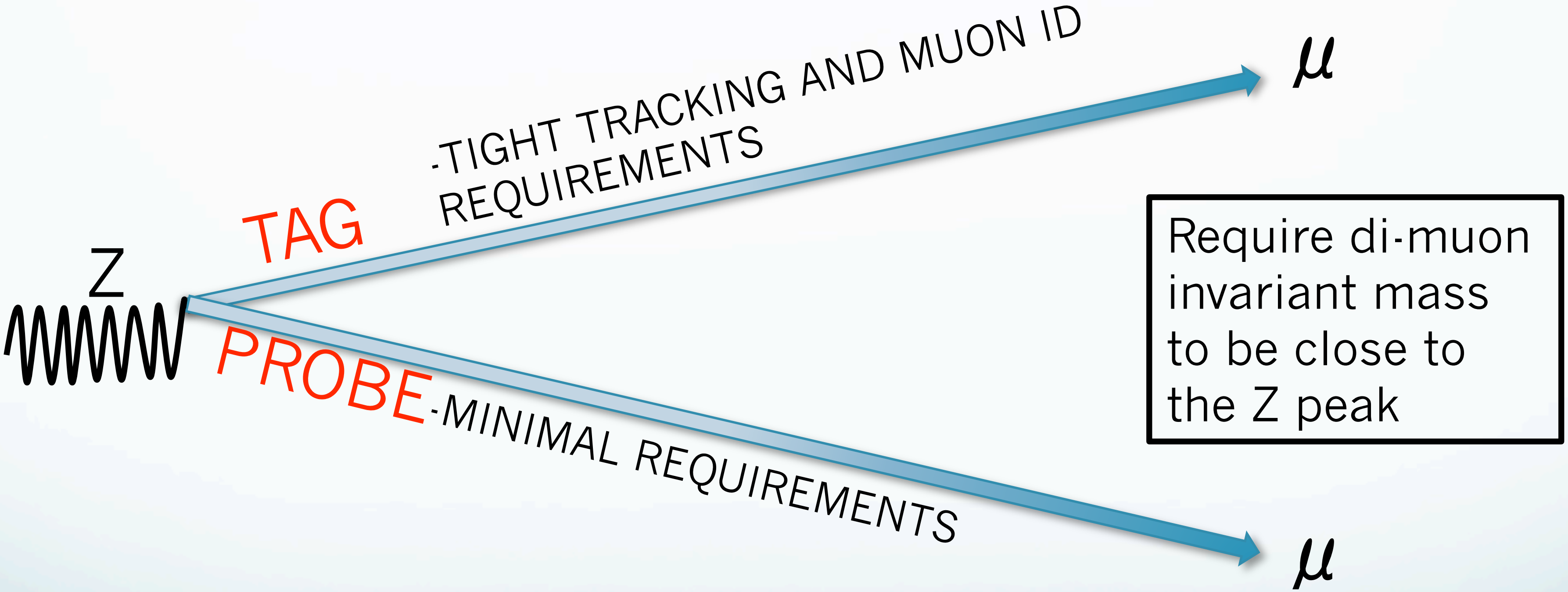
- One needs to know the efficiencies with which $Z\to\mu^+\mu^-$ events are reconstructed, triggered and selected.

$$\varepsilon_{detector} = \varepsilon_{tracking} \times \varepsilon_{muonID} \times \varepsilon_{trigger}$$

- Data-driven **Tag & Probe** method is used for most efficiency measurements.

Tag & Probe

- A data-driven method for measuring detector efficiencies.

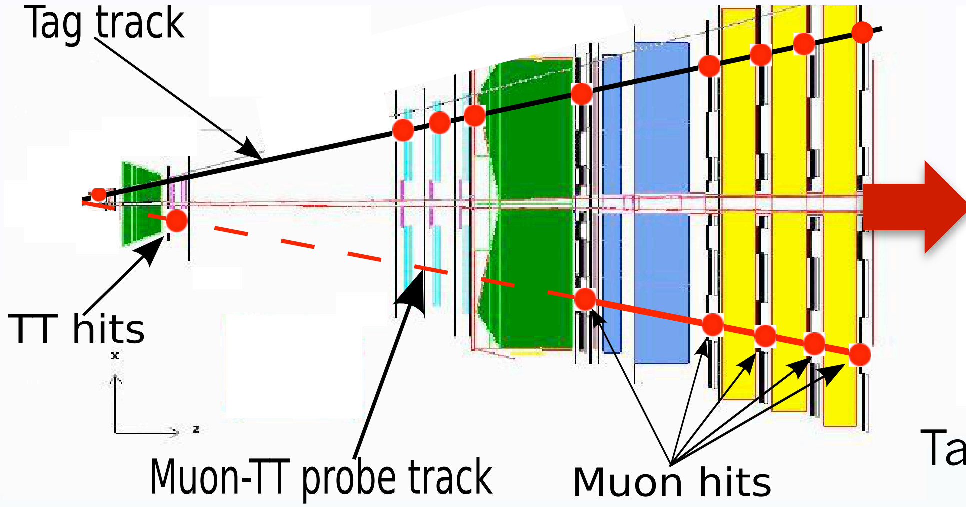


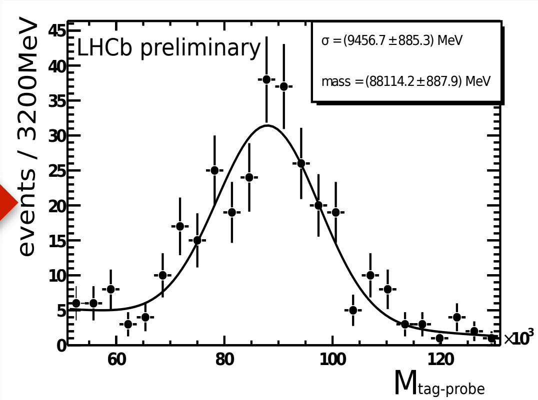
We assume Tag-Probe combinations are all real Z events. Efficiency given by fraction of probes passing requirement under scrutiny.

ε tracking

Tags –well reconstructed and tight muon identification requirements.

Probes reconstructed independently of the tracking system.





Tag-probe combinations

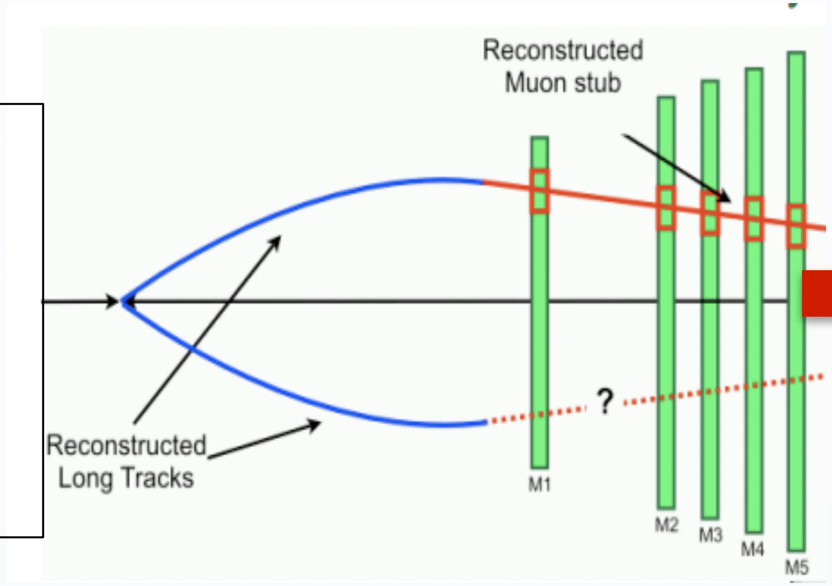
Fraction of probes that were fully reconstructed in tracking system gives single muon tracking efficiency.

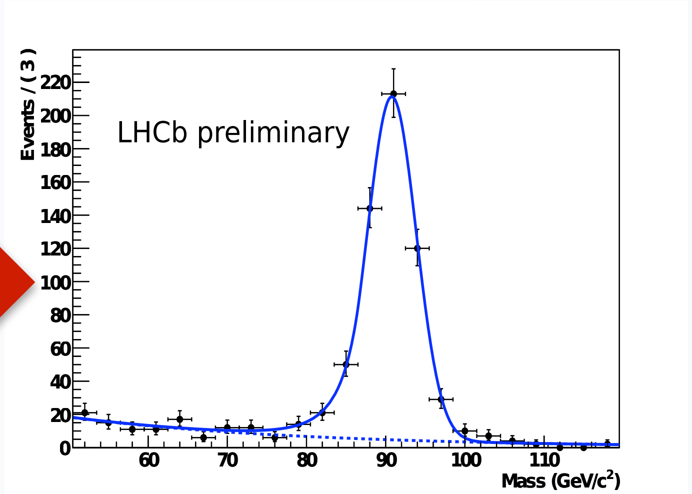
$$\varepsilon_{\text{tracking}} = .83 \pm .04$$

ε muon ID

Tags – well identified muons

Probes – track with no muon ID requirements.





Tag-probe combinations

We assume all tag-probe combinations under the Z peak are real muons.

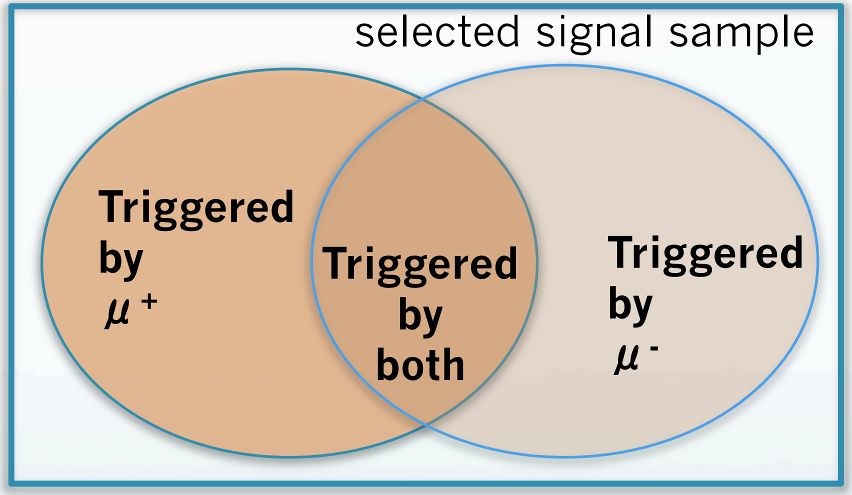
The single muon ID efficiency is given by the fraction of probes which pass muon ID requirements.

$$\varepsilon_{muonID} = .96 \pm .01$$

$\varepsilon_{\text{trigger}}$ (l)

- LHCb trigger: hardware trigger (L0) and two-stage software trigger (HLT1 & HLT2)

$$\varepsilon^{\mu^+} = \frac{\text{\#triggered by both}}{\text{\#triggered by } \mu^-}$$

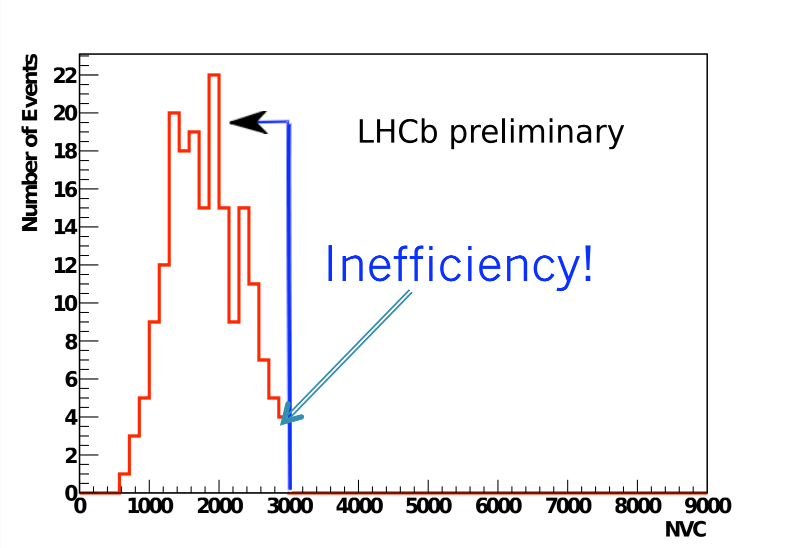


$$\varepsilon^{\mu^-} = \frac{\text{\#triggered by both}}{\text{\#triggered by } \mu^+}$$

Result: $\varepsilon_{\text{trigger(l)}} = .96 \pm .01$

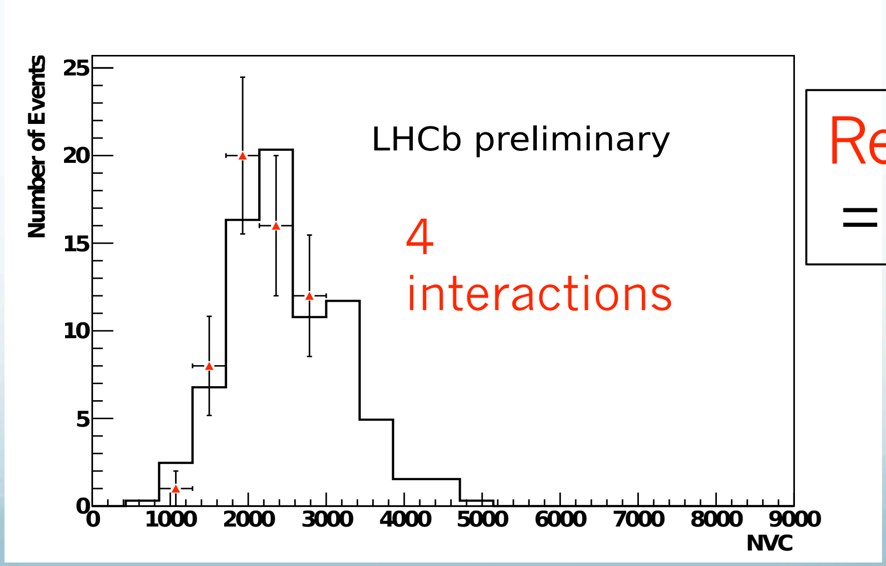
$\varepsilon_{trigger}$ (II)

- Trigger imposes Global Event Cuts like #VeloClusters <3000.
- Efficiencies on signal events depend on number of pp interactions in event.



Predict distributions by mixing signal events with *minimum bias* events.

Prediction =>



Results: $\varepsilon_{trigger\ (II)} = .93 \pm .01$

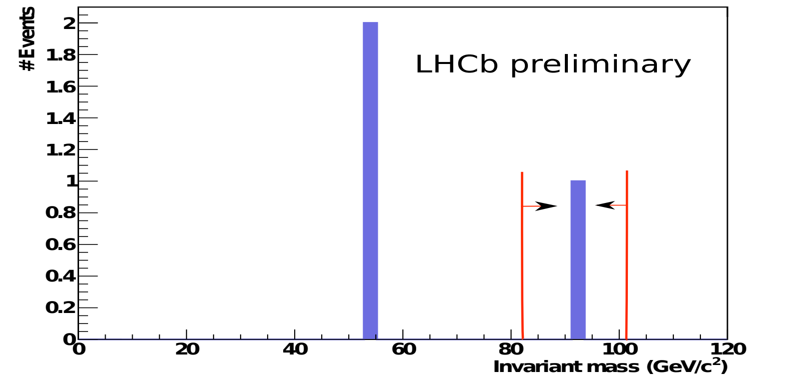
Backgrounds

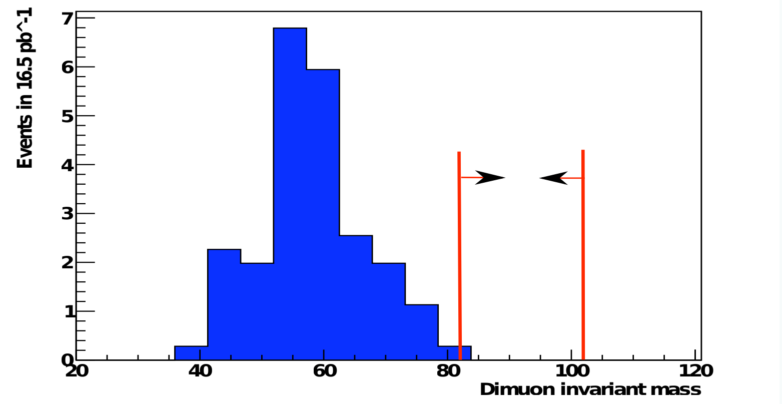
3 background processes expected to dominate.

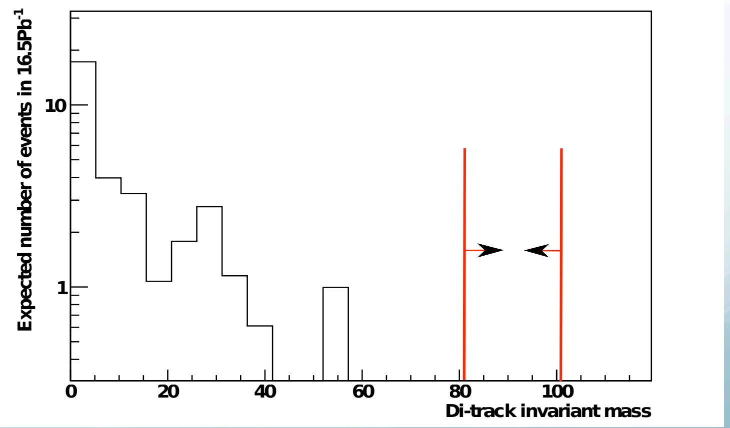
- **Heavy quark** - estimated using anti-cut on the signal events, estimated level = 1.2 ± 1.1 events.

- $Z \to \tau^+\tau^-$ - taken from simulation, estimated level = .2 ± .2 events.

- **Hadron mis-ID** - taken from data by parameterising the probability of mis-ID, expected level = 0 events.





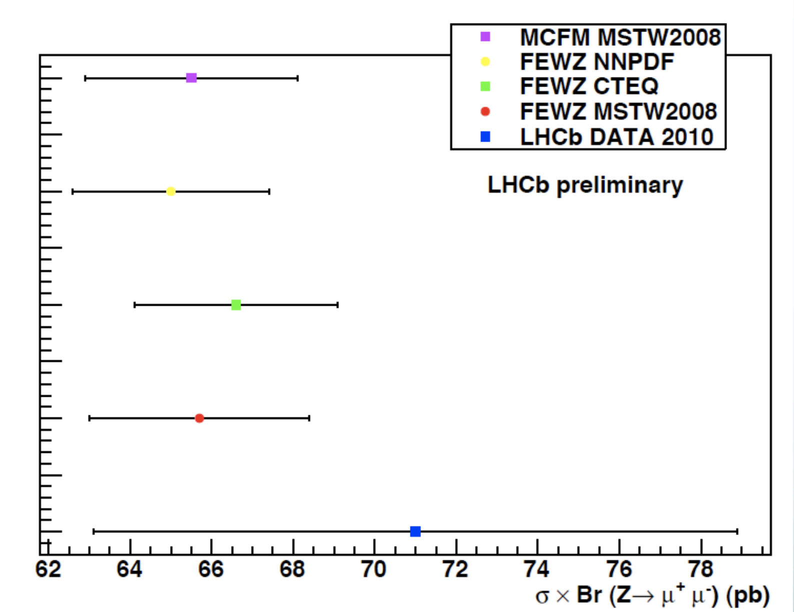


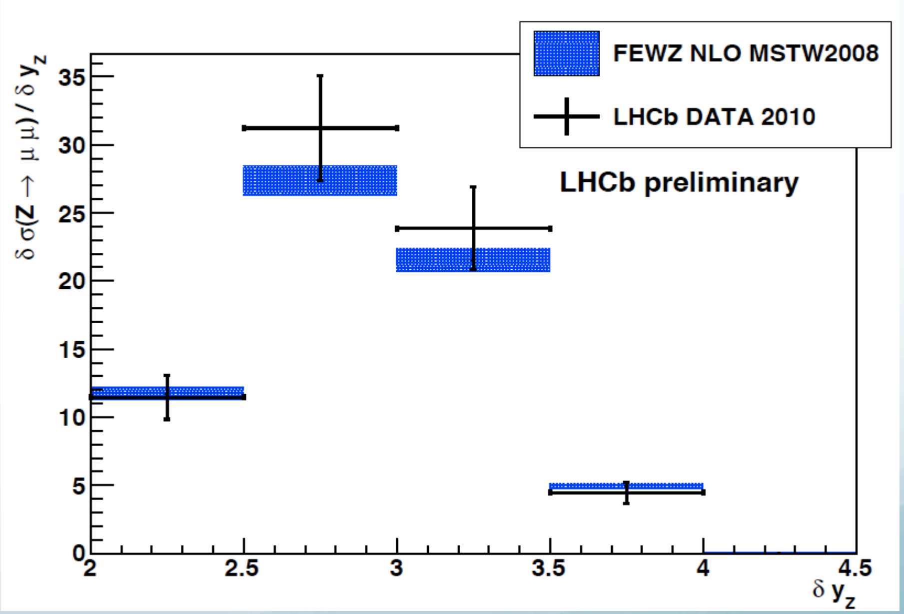
Results

- We set $\varepsilon_{selection} = 1$, and quote results in the kinematic region specified by the cuts ($2 < \eta_\mu < 4.5$ $P_T > 20$ GeV, 81GeV $< \eta_\mu <$ 101GeV).

σ.Br($Z \to \mu^+\mu^-$) = 71 ± 2 (stat.) ± 3 (sys.) ±7(lumi.) pb

Comparing to theory: predictions produced using FEWZ and MCFM @ NLO in α_s with NLO PDF sets

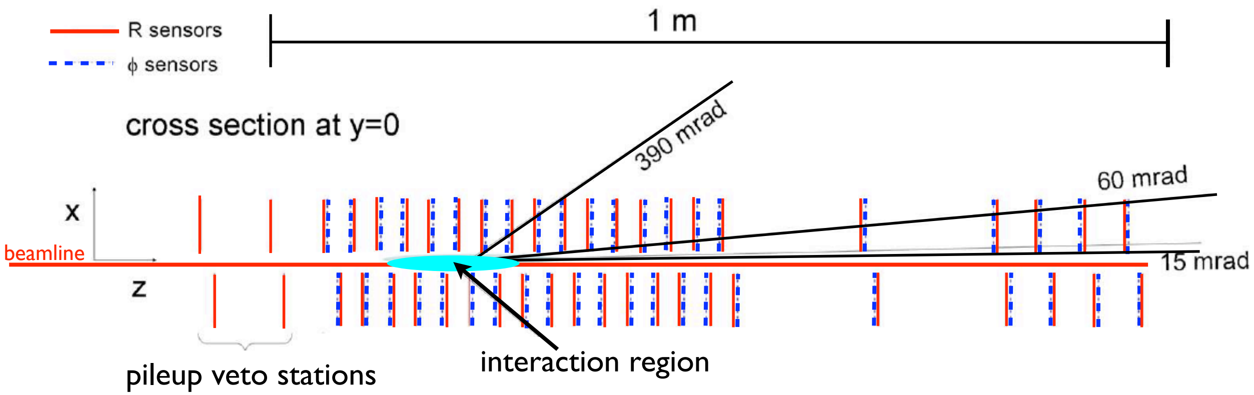




Calibration of the VELO

Calibration of the VELO

- VELO consists of 84 silicon micro-strip sensors arranged in two retractable halves.



Two sensor types: provide information on the radial (r) and azimuthal (phi) track coordinates.

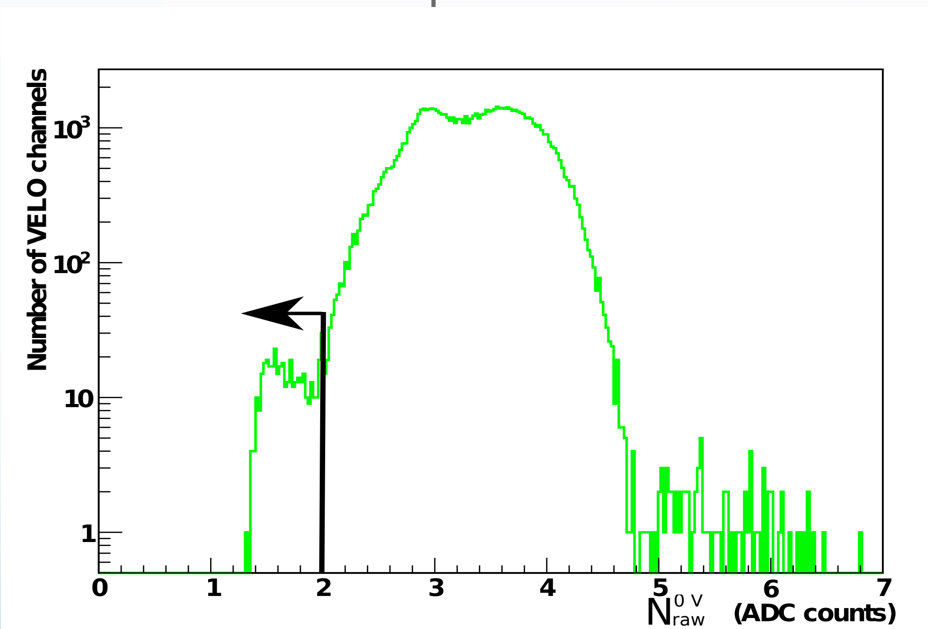
VELO fully closed

VELO fully open

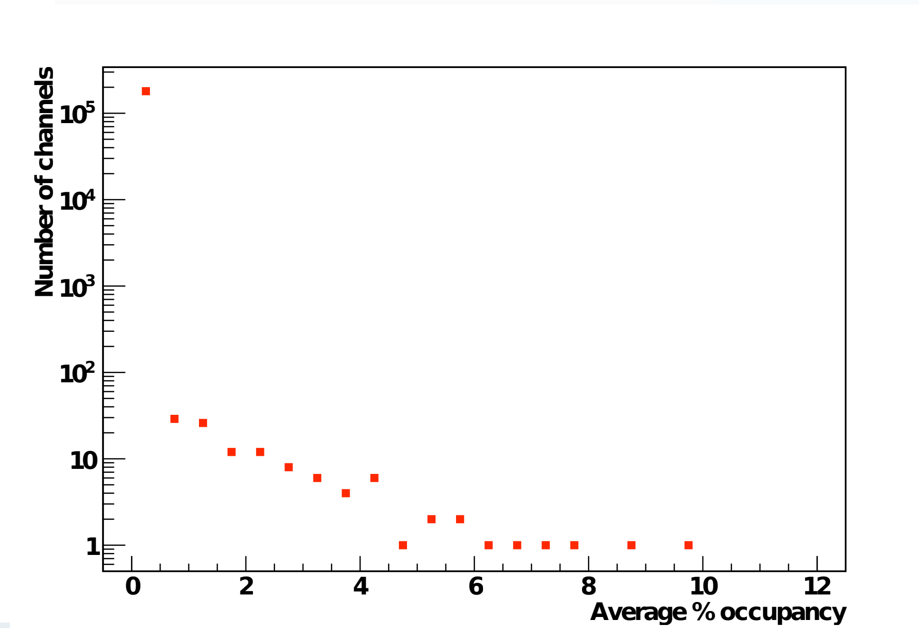
Provides excellent vertexing capabilities to LHCb -> IP resolution ~ 15 um

Calibration of the VELO

- Faulty VELO strips contribute to inefficiency in track reconstruction.
- Number of these channels monitored over detector's lifetime: possible radiation damage effects



Dead channels characterised by noise

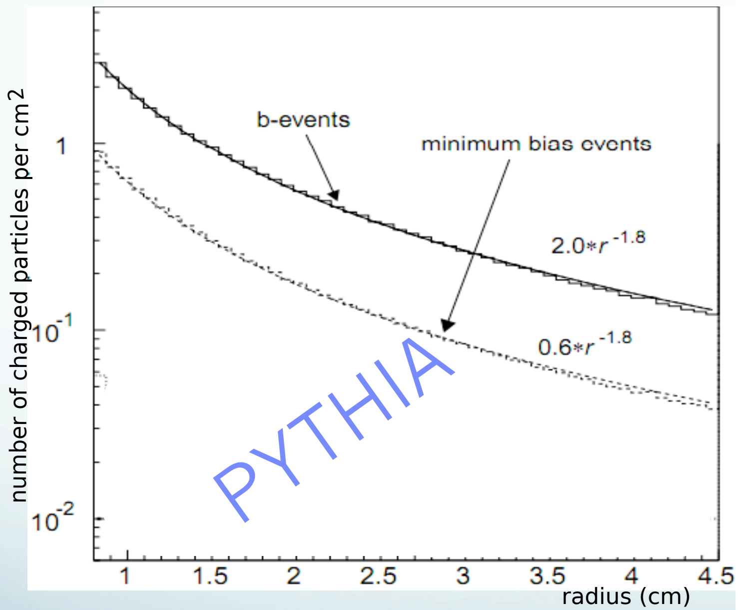


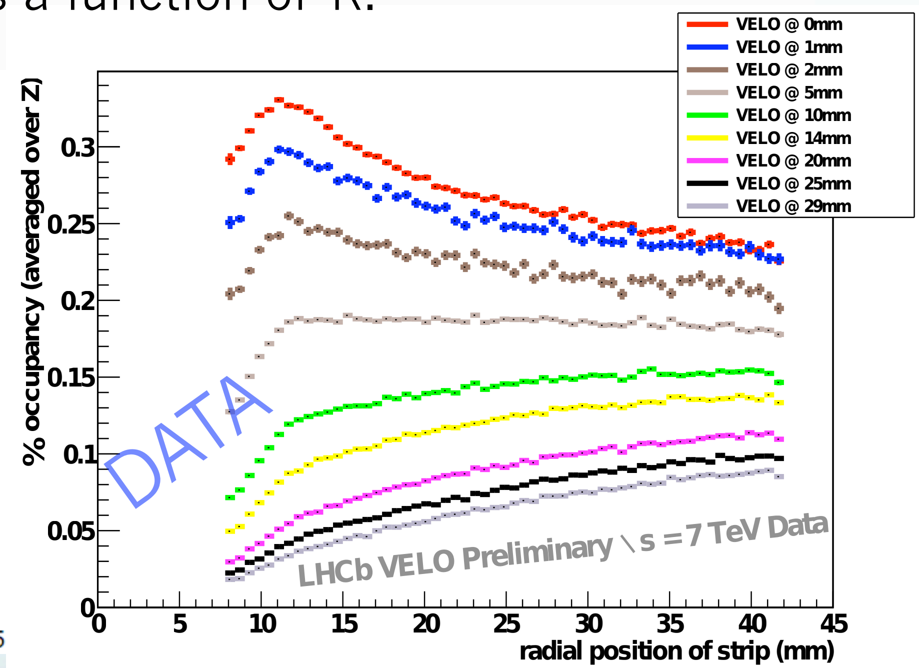
Hot channels characterised by occupancy

Calibration of the VELO

- Investigation of macroscopic occupancy behaviour in proton collisions.

R sensors should compensate the $R^{-1.8}$ particle multiplicity dependence and be uniformly occupied as a function of R.



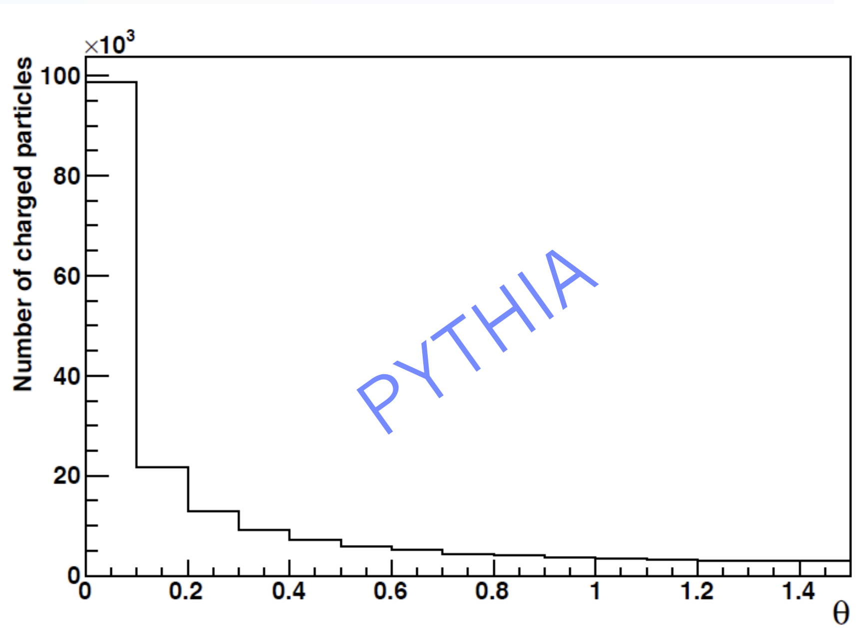


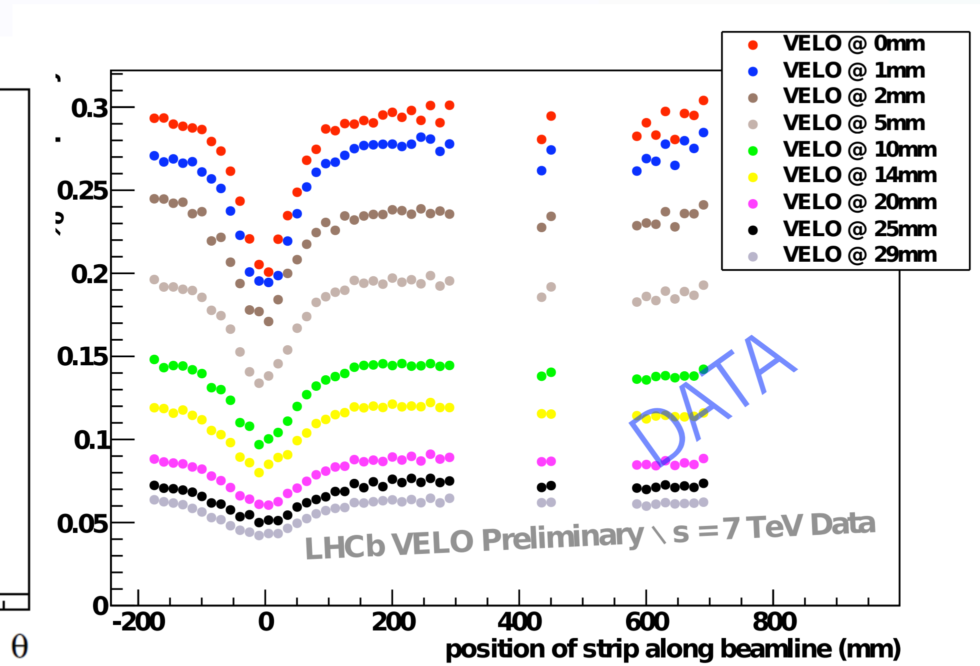
Dependence measured at a range of VELO positions (different colours).

Occupancy seen to <u>increase</u> as detector is closed.

Calibration of the VELO

- What about the dependence on position along the beamline?



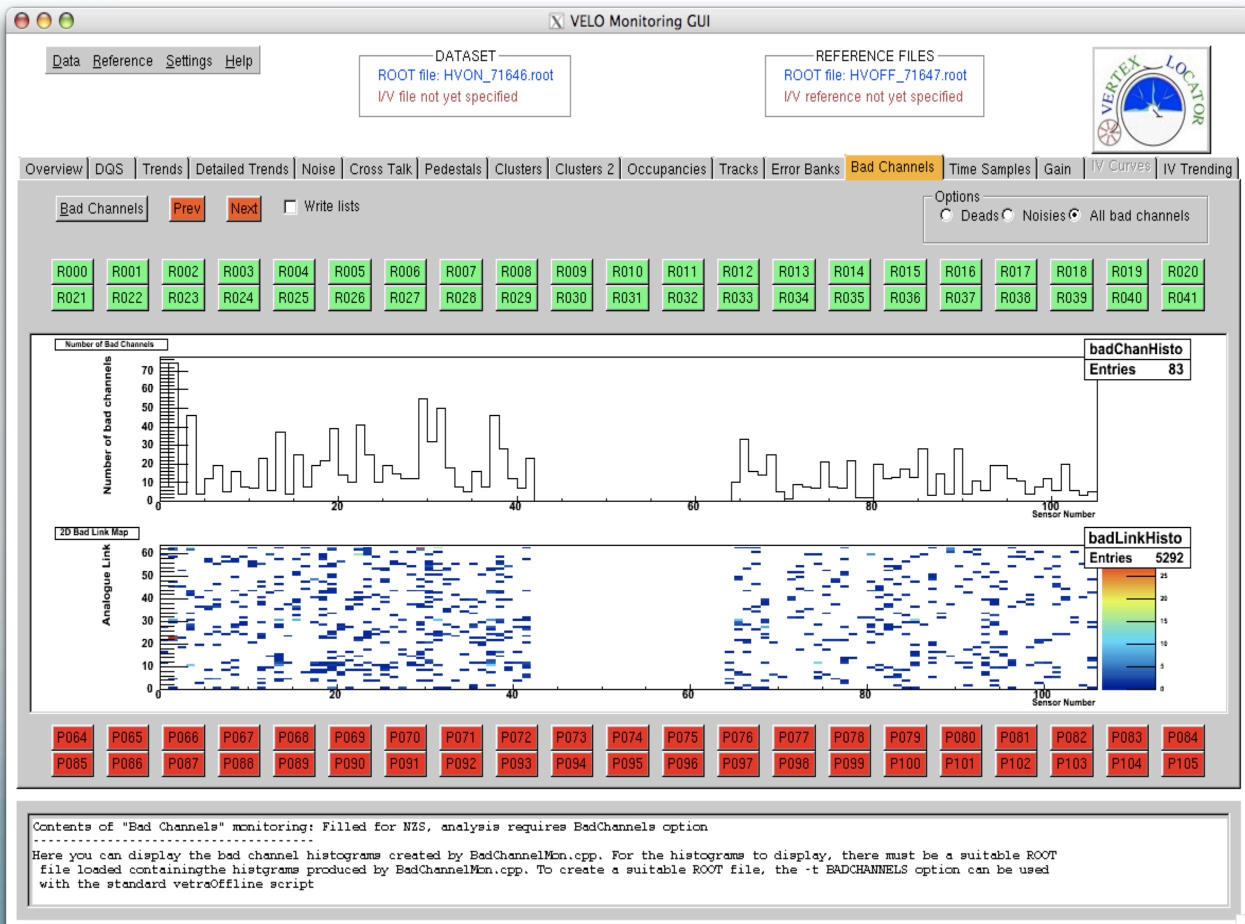


VELO occupancy mostly flat as a function of position along the beamline.

Drop in occupancy around the interaction point reflects track multiplicity distribution.

Calibration of the VELO

- Development of VELO monitoring suite: software application which allows detector monitoring by shifters.



Numbers of faulty channels can be recorded.

Occupancy of the detector can be closely inspected.

Summary of Phd work:

- Measured Z cross section with an uncertainty of 11%
  - Detector efficiencies with Tag & Probe.
  - Data-driven background estimations.
  - Results agree with NLO predictions.
- Contributed to the calibration of the VELO detector.
  - Occupancy behaviour of detector agrees with expectations.

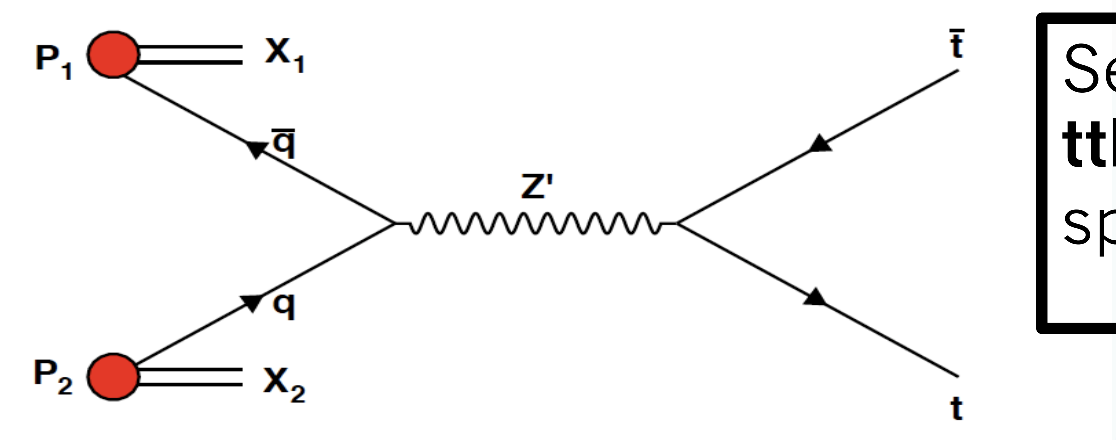
Searches for new physics at CMS

Topics of interest

- Topics chosen reflect experience and physics interests of the speaker.
- List is not exhaustive!
- Three topics discussed:
  - Z' searches,
  - ttbar asymmetries,
  - searches for b' and t' quarks

Z' searches

- CMS will access a ttbar sample of unprecedented size.
- Large event samples allow searches for new physics e.g. Z'



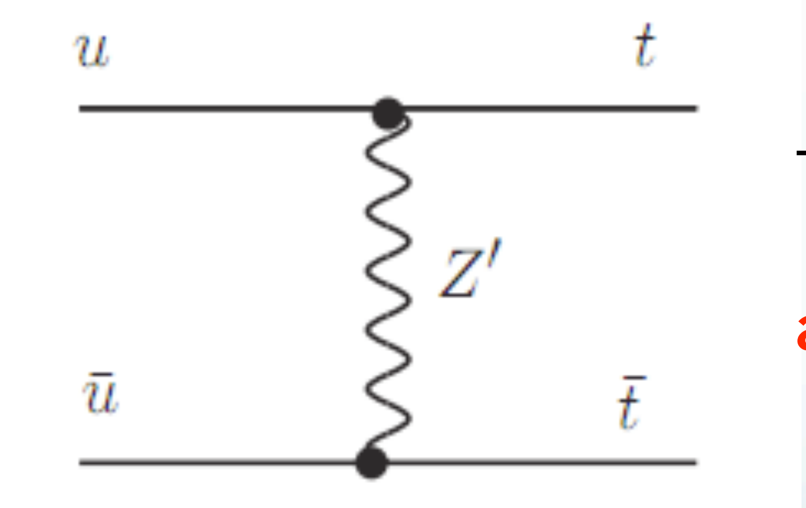
Search in **ttbar** mass spectrum

Compliments searches for high mass $\mu^+\mu^-$, $\mathbf{e^+ e^-}$ or $\gamma\gamma$ resonances.

ttbar asymmetry

Evidence for the Z’ can be found elsewhere->

Z’ exchange can result in significant same-signed top quark pair production => **distinctive signature**

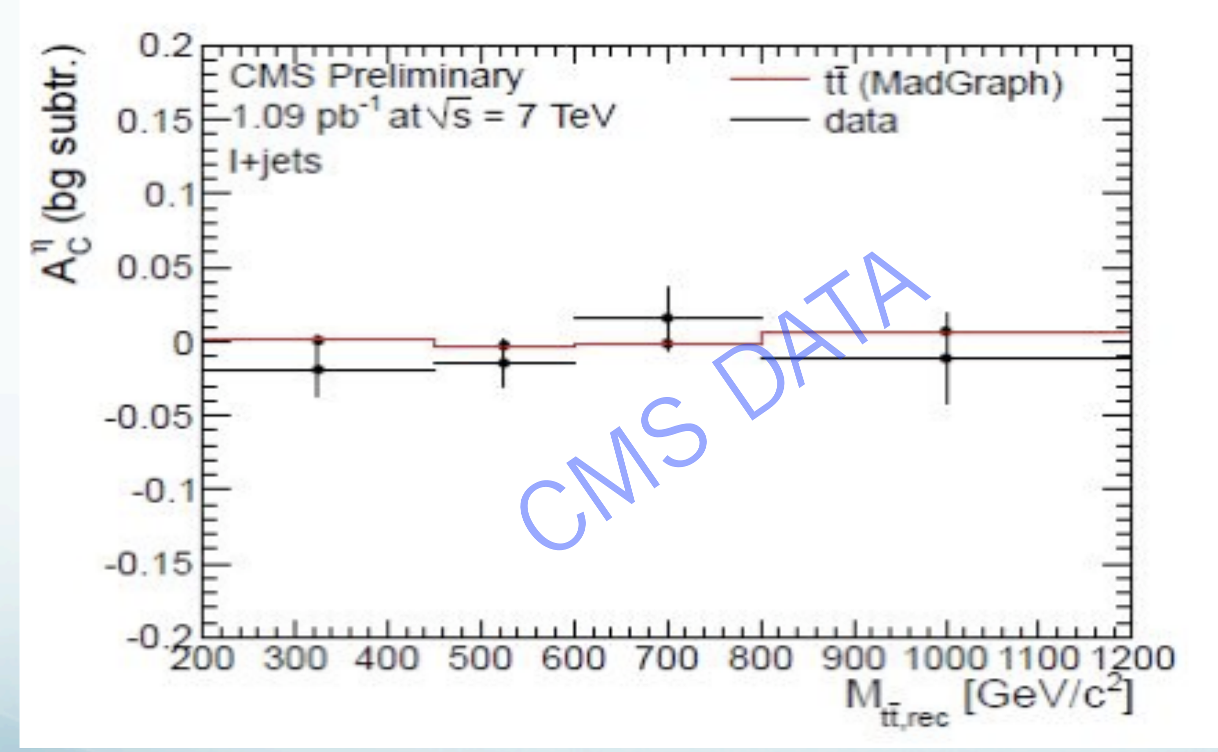


This diagram can cause **forward-backward ttbar asymmetry**

This study is of particular personal interest as it proposed to measure the effect in the forward region at LHCb.

ttbar asymmetry

- Anomalous asymmetry measured at D0 and CDF, ~2-3 σ deviation from SM, depending on ttbar mass .

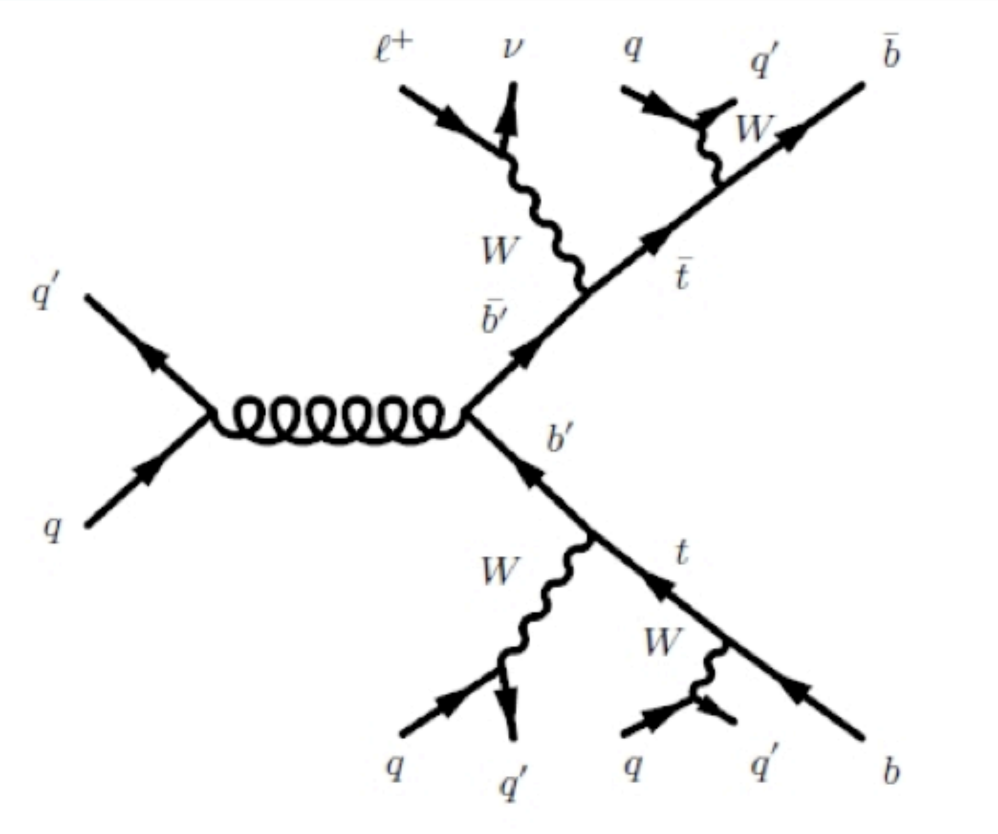


Status: Latest CMS results <u>consistent with SM</u>.

Future:
Refine measurement with more data.
Proper unfolding in asymmetry variable and invariant mass to investigate effect further.

b’ and t’ searches

- A 4^{th} generation quark produced at the LHC would manifest itself in a spectacular decay containing numerous heavy objects.

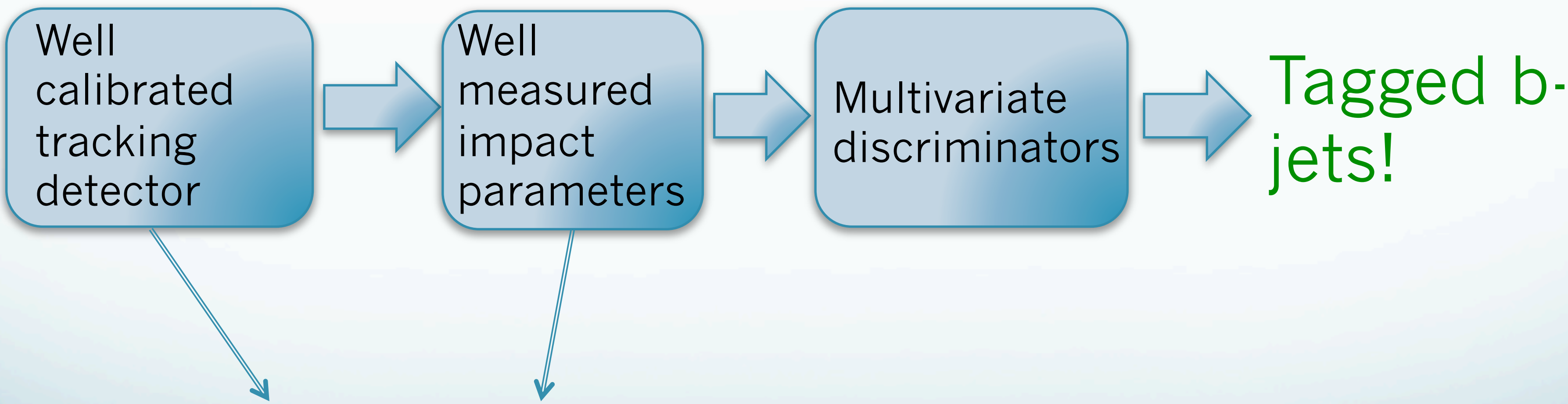


Numerous jets, a lepton and missing transverse energy!

b’ with mass < 495 GeV already excluded using 1fb^{-1}

B-tagging

- Excellent b-tagging capabilities are essential to all of these studies. e.g. BR(t->Wb) ~ 100%
- B-tagging begins with well calibrated tracking detectors and well understood impact parameter resolutions.



My experience with the VELO can help me contribute to the optimisation of the b-tagging procedure at CMS.

Conclusions

- My Phd work was on electroweak physics at LHCb.

- I gained experience in measuring high momentum leptons and calibration of tracking detectors.

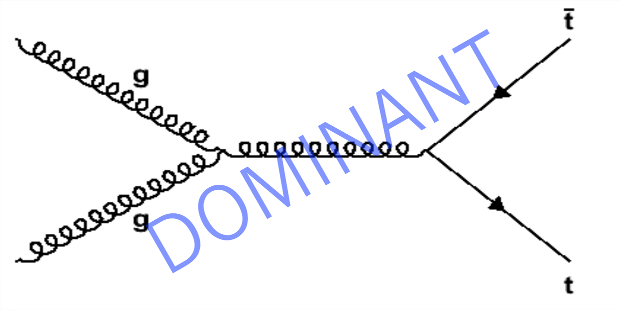
- This experience has led to an interest in various new physics searches at CMS.

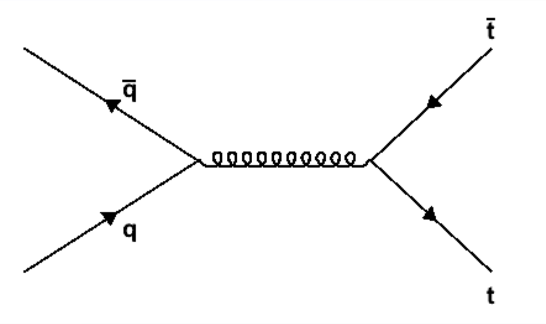
Plan of work

- Contributing to any HEP experiment requires an intimate knowledge of the software environment – I gained much experience with HEP software as author of the LHCb electroweak trigger and stripping code.
  - **First task: Familiarise myself with CMS software environment.**
- As BR(t->Wb) ~ 100%, each of the top studies mentioned demand b-tagging capabilities. B-tagging begins with well calibrated trackers and well understood impact parameters – I have applicable experience from VELO work.
  - **Second task: Improve b-tagging procedures at CMS**
- Top studies mentioned all require strong data analysis and interpretation skills- I have developed these skills in Z cross section measurement.
  - **Third task: contribute to top studies, especially unfolded, large statistics A(ttbar) measurement.**

Top quark studies at CMS (I)

- **LHC:** ttbar pairs produced via gluon or quark fusion.





- **LHC:** single top quarks also produced via electroweak interaction.

- Measurements: σ_t, σ_{tt}, σ_{tt}/σ_Z , σ_{tt}/σ_W provide tests of the SM => results published, studies are becoming mature.