Physics Performance with the CMS Pixel Detector

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on behalf of the
Compact Muon Solenoid (CMS) collaboration

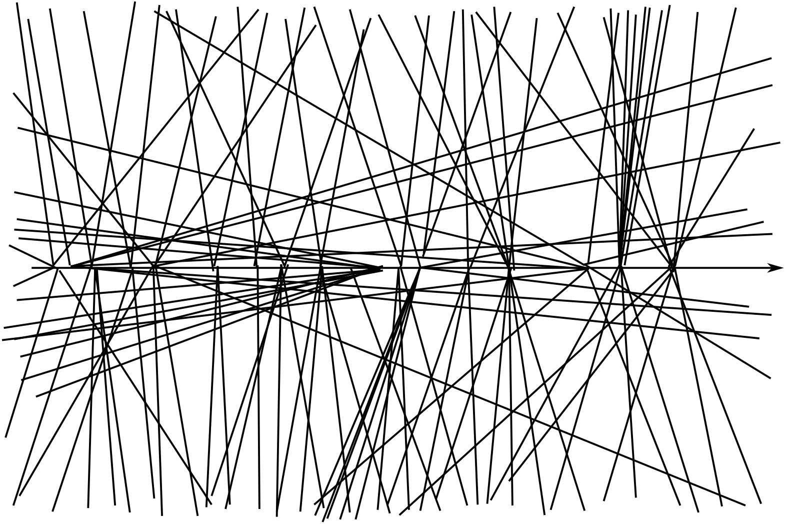
September 1, 2014

Finding the needle...

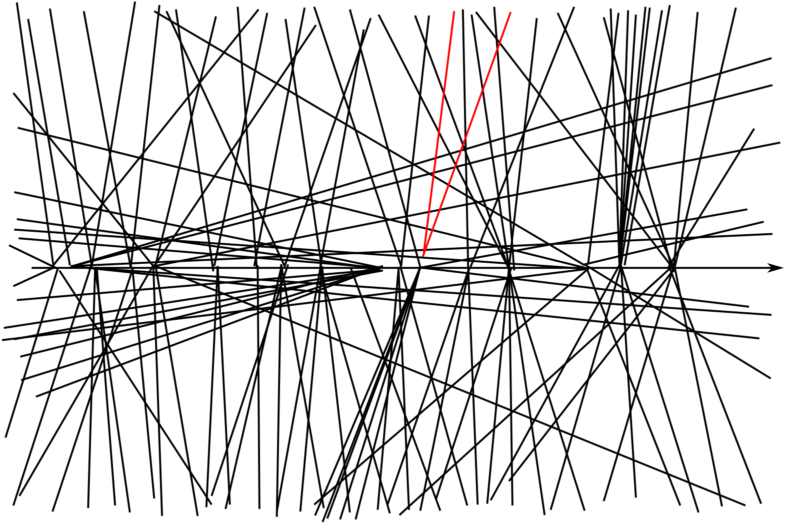
How good are you in finding the interesting event?

(No worries. Explanation will follow later)

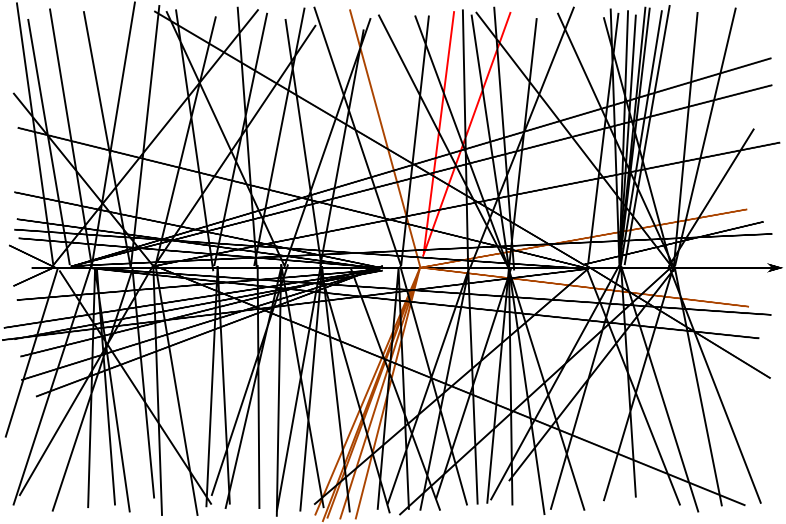
Finding the needle...



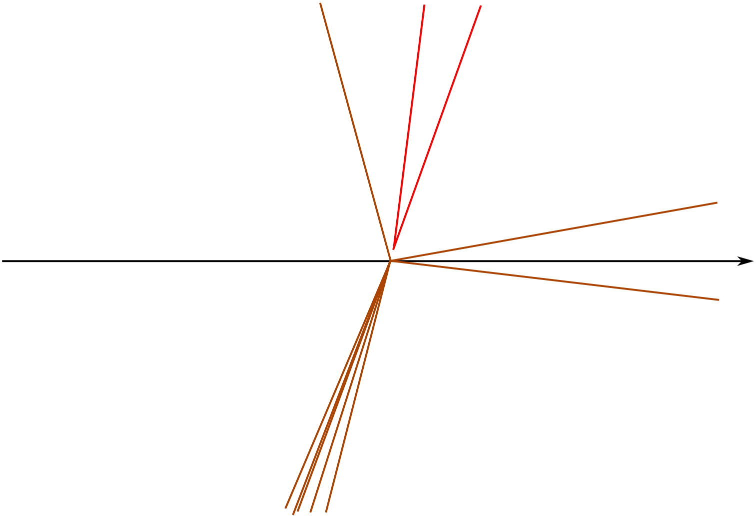
Finding the needle...



Finding the needle...



Finding the needle. . .



Finding the needle. . .

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- All recent physics results had to deal with pile-up – and succeeded. Pixel detectors were the crucial ingeredient. This is an example where the capabilities for finding **primary vertices** is key.

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- Some analyses are interested in **displaced vertices** or **secondary vertices**, like the one in my sketches or in *b*-tagging. The domain of pixels. Will show examples.
- Some property measurements are **interested in both**, the primary and the secondary vertex plus separation from pile-up. Will show an example of a lifetime analysis.

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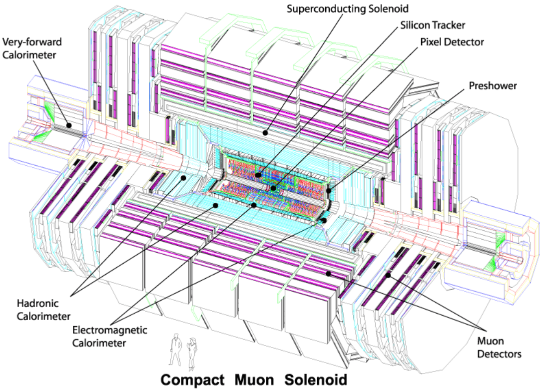
But now: getting to the real stuff.

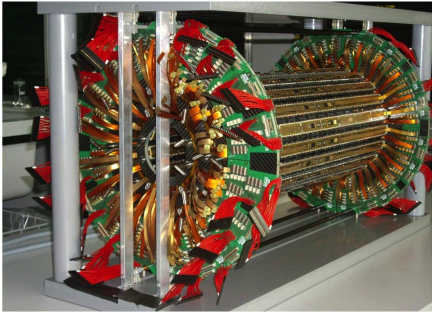
Introduction



CMS. One of the two general purpose detector experiments at Cern's Large Hadron Collider

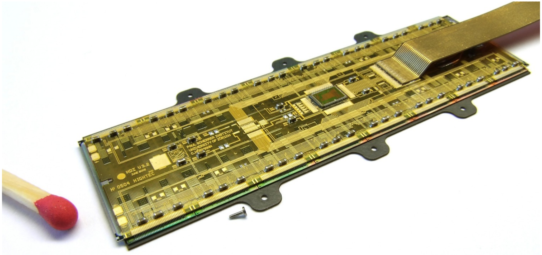
Onion structure, pixel inside.

Introduction

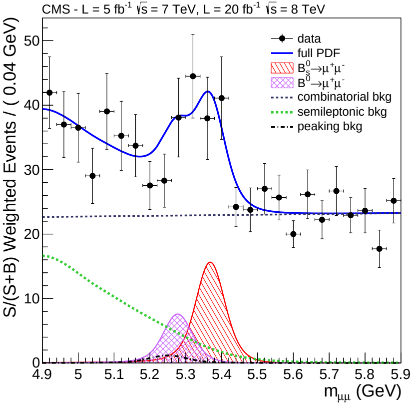


Pixel detector (barrel shown) consists of 3 barrel layers and 2×2 disks on each end

Barrel and endcap share common technology: same ROC, unit cell size $100 \times 150\,\mu\text{m}^2$



Analysis performance: $B_s \to \mu\mu$



PRL **111**, 101804 (2013)

`https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH13004`

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Analysis performance: $B_s \to \mu\mu$

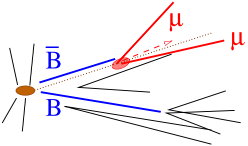
- Is a search for a rare decay, measured to be

  $$\mathrm{BF}(\mathrm{B_s^0} \to \mu^+\mu^-) = (3.0\ ^{+1.0}_{-0.9}) \times 10^{-9}$$

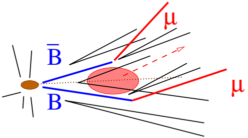
  $$\mathrm{BF}(\mathrm{B^0} \to \mu^+\mu^-) < 1.1 \times 10^{-9}$$

- Plot shows the weighted combination of all categories (barrel/endcap, BDT result bins)
- The signal consists of just two muons from a common secondary vertex, separated from the primary vertex

Sig:



Bgr:



- Precise 3d vertexing is crucial to make sure two random background muons do not merge.
- Two muons in 2d create a vertex, background separation difficult to impossible. Less resolution in z direction makes this analysis harder.

Analysis performance: $B_s \to \mu\mu$

tions of 7 and 8 TeV data and the barrel and end-cap regions of the detector. For each BDT, a number of variables is considered and only those found to be effective are included. Each of the following 12 variables, shown to be independent of pileup, are used in at least one of the BDTs: I; I_μ; $N_{\rm trk}^{\rm close}$; $d_{\rm ca}^0$; $p_T^{\mu\mu}$; $\eta_{\mu\mu}$; the B-vertex fit χ^2 per degree of freedom (dof); the $d_{\rm ca}$ between the two muon tracks; the 3D pointing angle $\alpha_{\rm 3D}$; the 3D flight length significance $\ell_{\rm 3D}/\sigma(\ell_{\rm 3D})$; the 3D impact parameter $\delta_{\rm 3D}$ of the B candidate; and its significance $\delta_{\rm 3D}/\sigma(\delta_{\rm 3D})$, where $\sigma(\delta_{\rm 3D})$ is the uncertainty on $\delta_{\rm 3D}$. The last four variables are computed with respect to the primary vertex. Good agreement between data and MC simulation is observed for these variables. In total, including the division into three sets, 12 BDTs are trained.

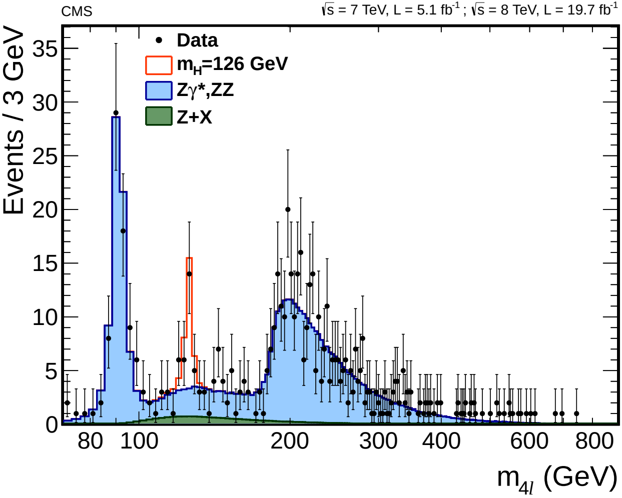
The output discriminant b of the BDT is used in two

Excerpt from the paper

Lists the variables used for the BDT. 3d vertexing plays an important role.

NB: All these variables have been demonstrated to be independent of pile-up (!)

Analysis performance: $H \to ZZ \to 4\ell$



PhysRevD.89.092007

`https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13002PubTWiki`

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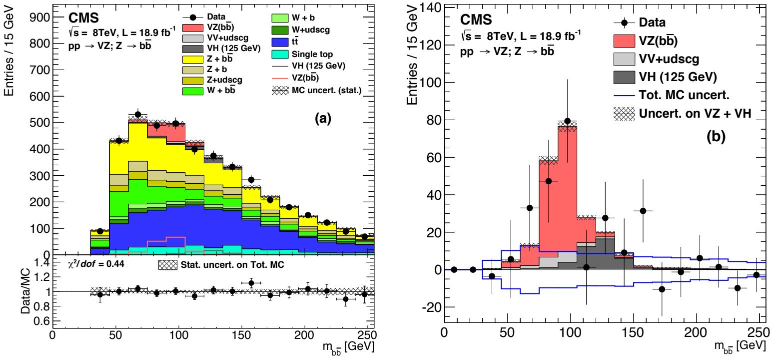
Analysis performance: $H \to ZZ \to 4\ell$

- This is the other way round: four muons need to be from primary vertex ("anti-secondary vertex detector")
- Excerpt from paper:

> In order to suppress leptons originating from in-flight decays of hadrons and muons from cosmic rays, all leptons are required to come from the same primary vertex. This is achieved by requiring $\mathrm{SIP_{3D}} < 4$, where $\mathrm{SIP_{3D}} \equiv \mathrm{IP_{3D}}/\sigma_{\mathrm{IP_{3D}}}$ is the ratio of the impact parameter of the lepton track ($\mathrm{IP_{3D}}$) in three dimensions (3D), with respect to the chosen primary vertex position, and its uncertainty.

- Plot shows combination of channels $4e$, 4μ, and $2e2\mu$

Analysis performance: $VZ \to b\bar{b}$



Eur. Phys. J. C (2014) 74:2973

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP13011

Analysis performance: $VZ \to b\bar{b}$

- Important for $H \to b\bar{b}$
- Works on b-tagged jets
- Doesn't work without a pixel detector
- But future looks hazy: trend towards higher p_T is a challenge:
  - Cluster merging happens inside jets. New algorithms help but if detectors would be capable to keep tracks from merging...
  - Fraction of b-hadrons penetrating first layer of pixels increases. Challenge for reconstruction algorithms to separate from nuclear interactions.

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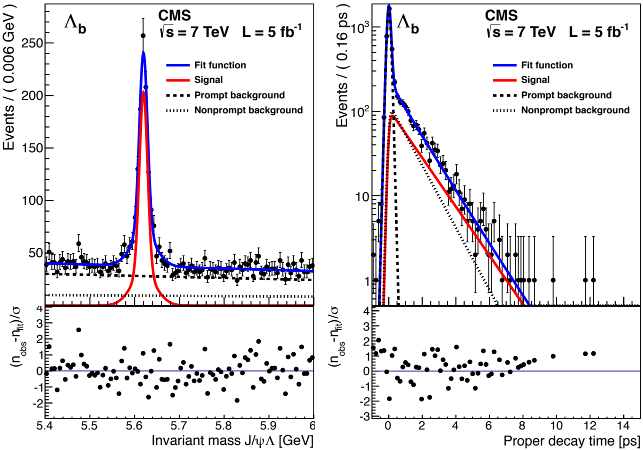
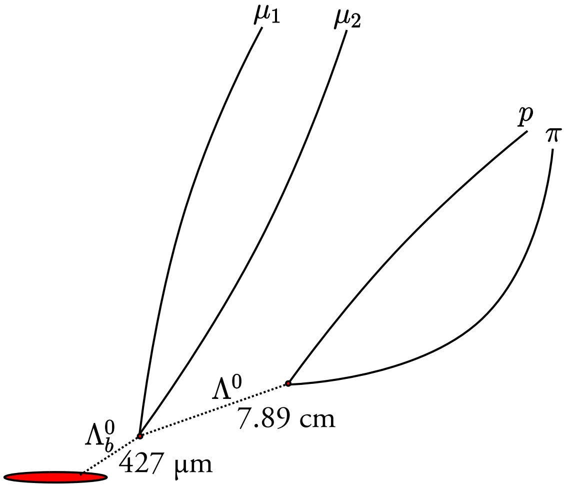
Analysis performance: Λ_b lifetime



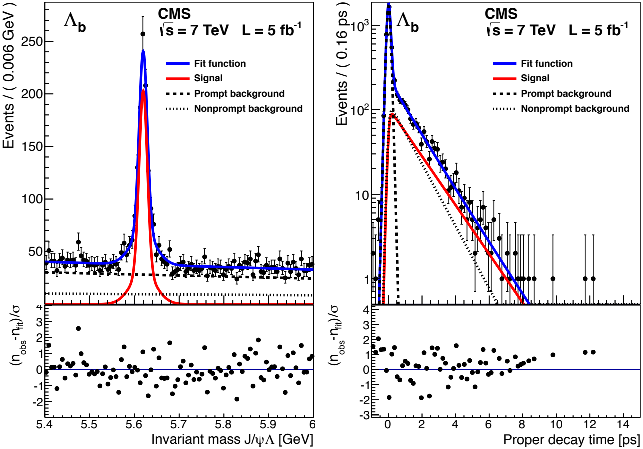
J. High Energy Phys. 07 (2013) 163

`https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11013`

Analysis performance: Λ_b lifetime



Analysis performance: Λ_b lifetime



J. High Energy Phys. 07 (2013) 163

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11013

Analysis performance

- Decay channel $\Lambda_b^0 \to J/\psi(\mu\mu)\Lambda^0(p\pi)$
- Uses three vertices:
  - Primary vertex where Λ_b^0 starts its life
  - $J/\psi \to \mu\mu$ as decay vertex of Λ_b^0
  - Λ^0 decay for event selection
- Less prominent physics but show-cases the capabilities of the detector
- Lifetime of $1.503 \pm 0.052(\text{stat.}) \pm 0.031(\text{syst.})$ ps translates to about 400 μm flight distance (unboosted)

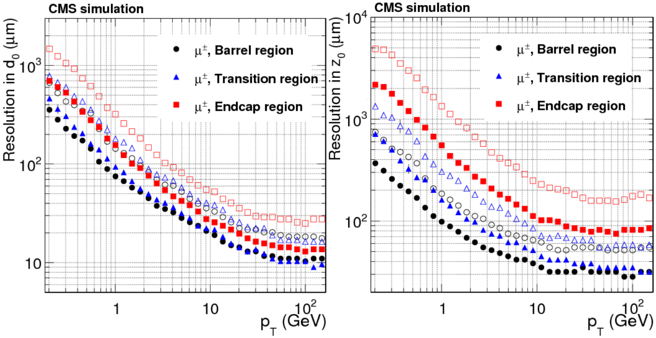
Detector performance

Allow me to wrap-up so far:

- There are much more analyses
- I think it is fair to say: most analyses rely on the pixels, be it for the measurement itself or just to mitigate pile-up
- This would not be possible without excellent performance due to good design and reliable operation
- More on operation experience in talk by János Karancsi
- More on radiation effect in talk by Viktor Veszprémi
- NB: The selection of analyses is mine, so be aware of biases.

But let's have a look at some performance plots

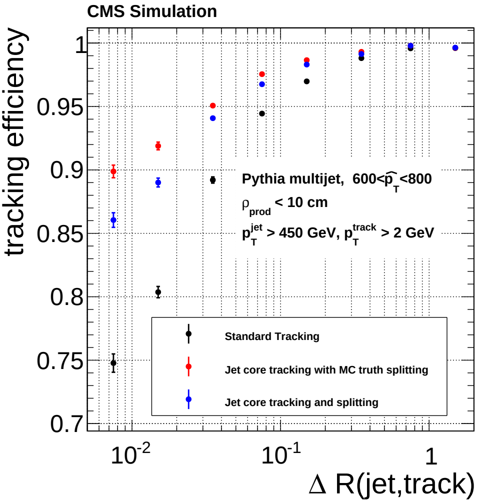
Detector performance:



Nice resolution in both directions. Solid symbols: 68%, open symbols: 90% intervals.
arXiv:1405.6569

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTRK

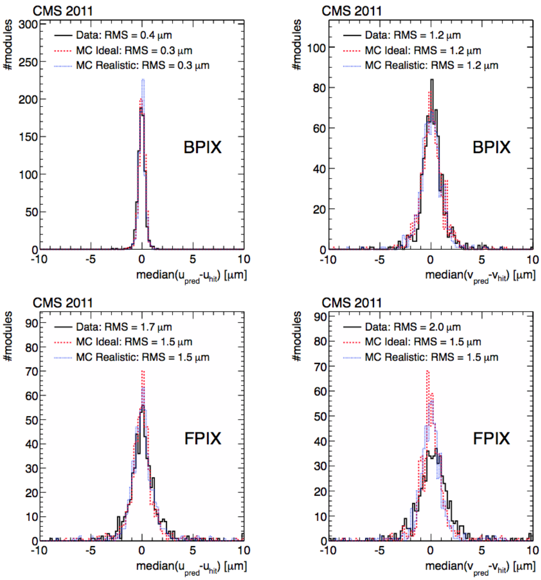
Detector performance:



Recent result from tracking in high p_T jets.

Cluster splitting algorithm allows to recover lost efficiency from merged pixel clusters in narrow jets

Detector performance



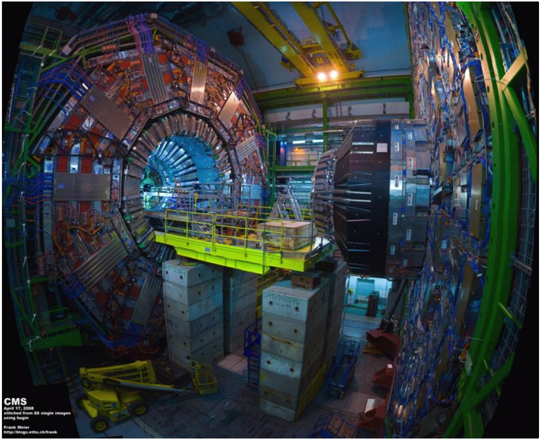
Our performance would be impossible without the incredible effort to calibrate the detector.

Alignment stands just as an example of this.

Conclusions

- The current CMS pixel detector works very well.
- Analyses shown here are a good example of this.
- Most analyses rely on pixels.
- Performance is at a very high level.
- Not possible without good design, operation, calibration, algorithms, and a lot of dedicated people.

Thank you for your attention!



Thanks go to

CMS, LHC

Pixel team

Analysis teams

Friends at PSI, UNL, USCMS