CMS Experiment at the LHC, CERN
Data recorded: 2012-Nov-30 07:19:44.547430 GMT(08:19:44 CEST)
Run / Event: 208307 / 997510994

Long Exercise: Team 1

Search for $B^0 \rightarrow \mu\mu$

Optimization of Phase 2 CMS detector

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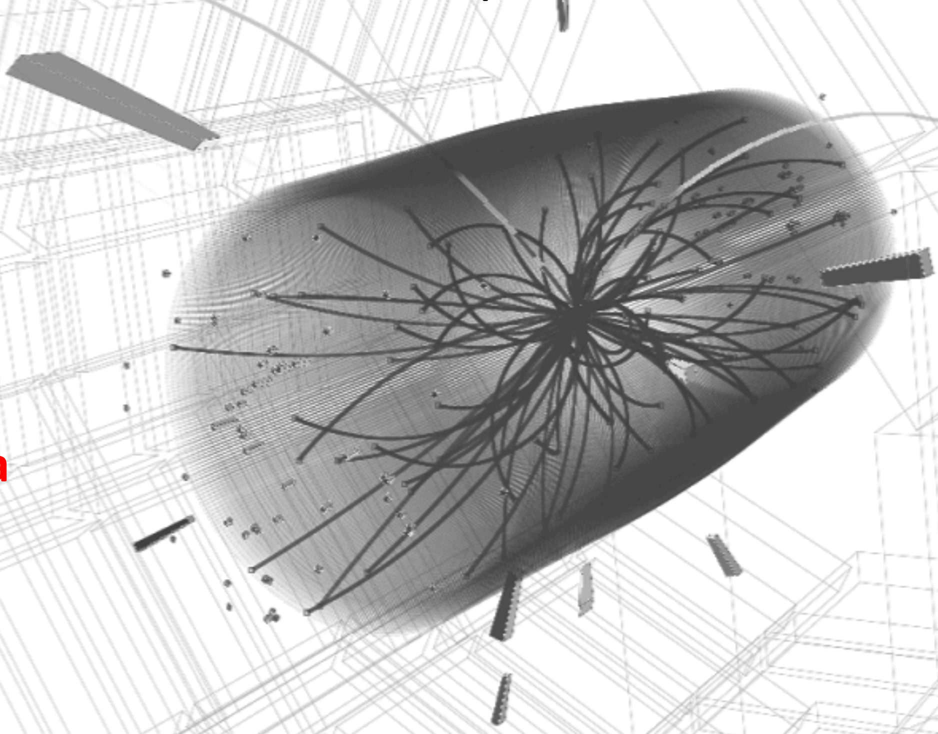
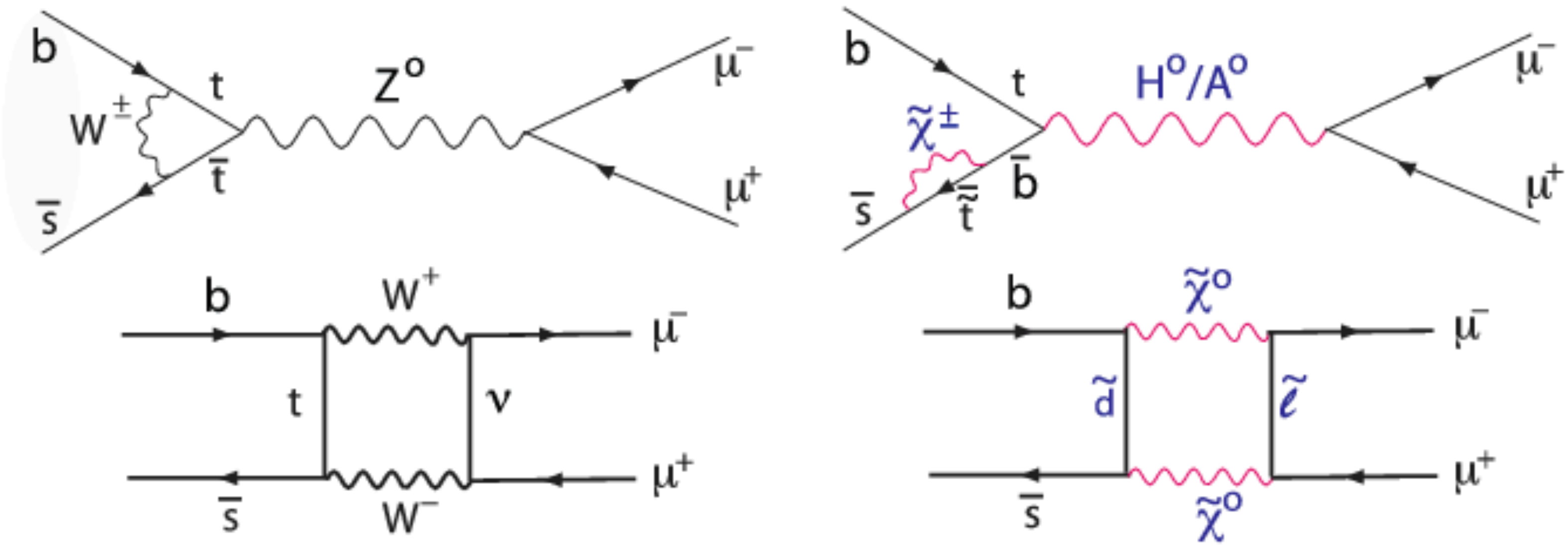


CMS Upgrade School
17-21 November, 2014
DESY Hamburg

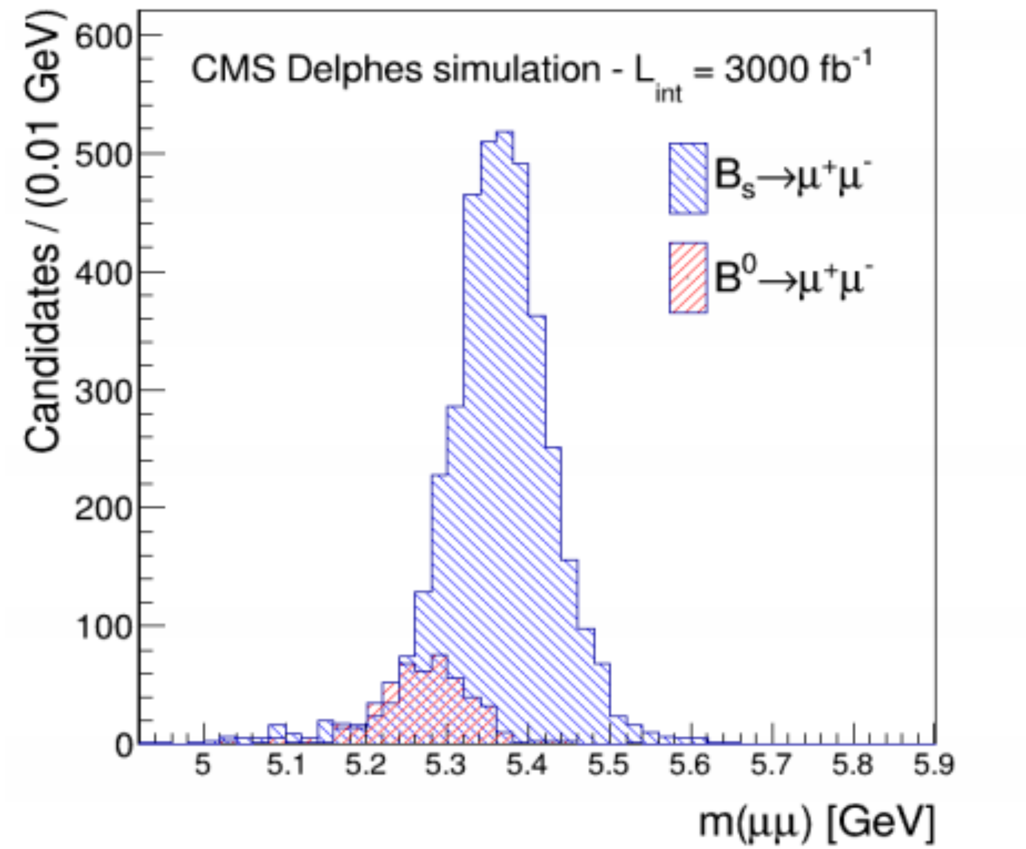
Rare decays

- Rare B decays are more sensitive to new physics than direct searches through loops !

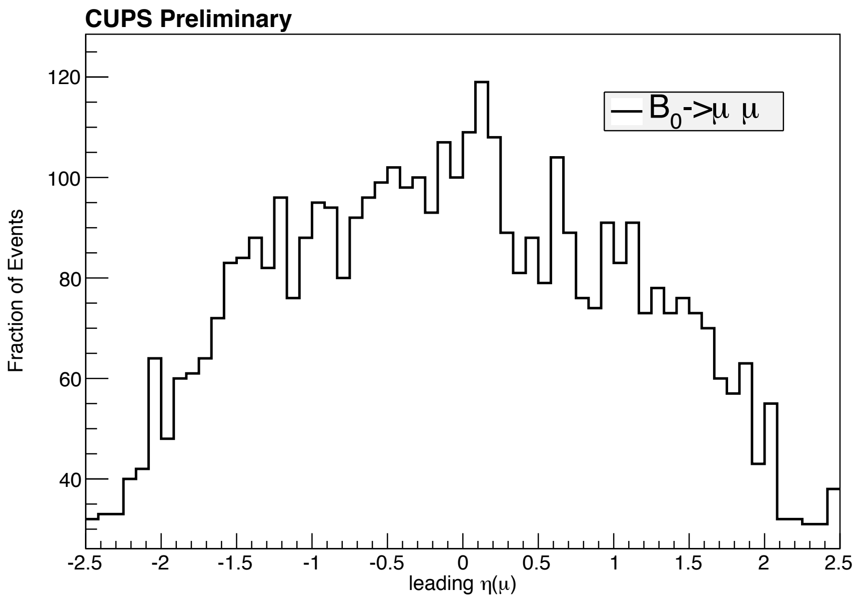


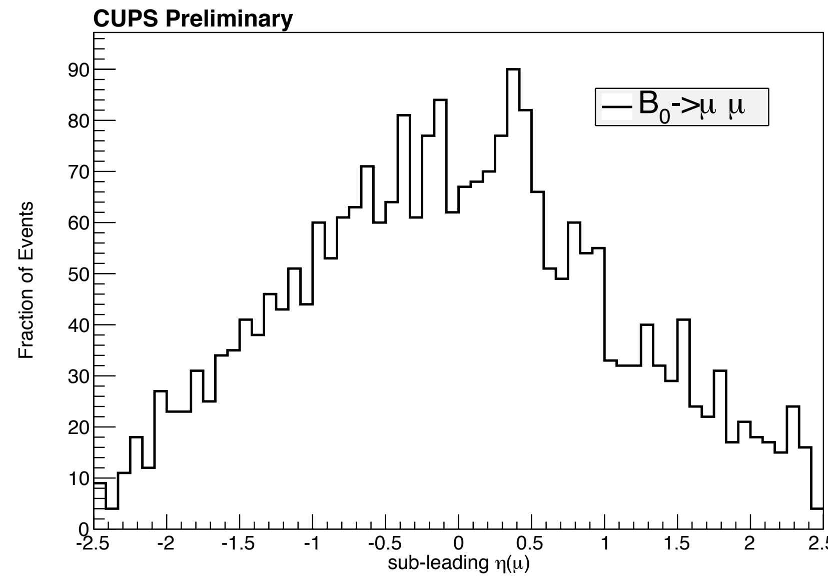
The challenge

- $B^0 \rightarrow \mu\mu$ is order of magnitude smaller than $B_s \rightarrow \mu\mu$
- Our goal is to improve $\mu\mu$ invariant mass resolution while maintaining high muon efficiency



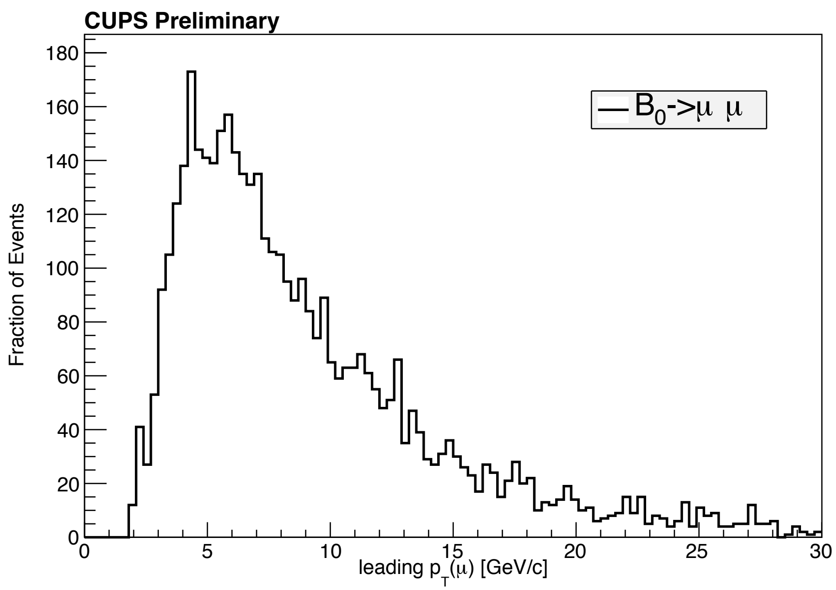
Geometric considerations

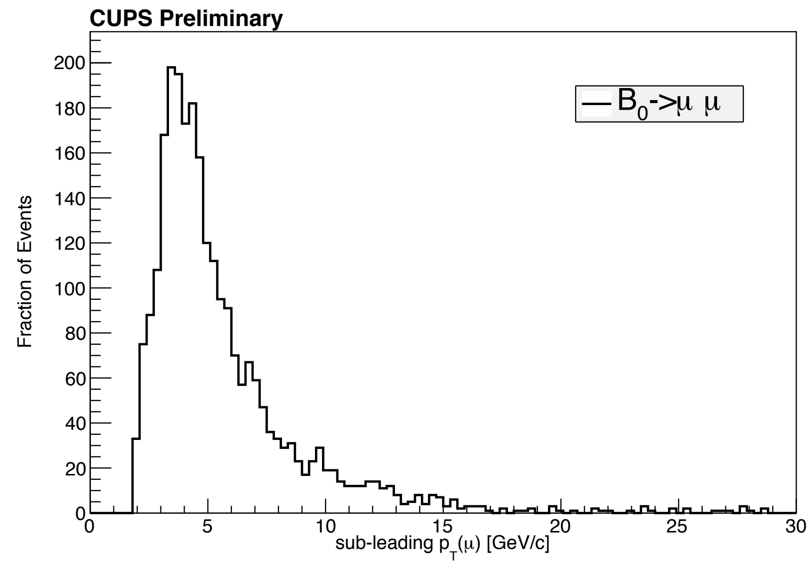




- Events are quite central
  - Almost all of muons are within | η | < 2
- We consider :
  - central | η | < 0.8 MOST IMPORTANT
  - intermediate 0.8 < | η | < 1.6 NEXT MOST IMPORTANT
  - forward regions 1.6 < | η | < 2.4

Momentum considerations



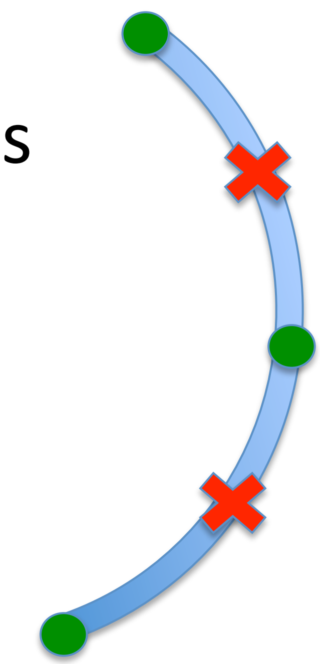


- Mean Pt :
  - Leading muon : <PT> = 5.6 GeV
  - Sub-leading muon <PT> = 5.4 GeV
- For Pt = 1- 10 GeV muons, multiple scattering reduces resolution

B → μμ signal

- Low PT muons are dominated by multiple scattering
  - Reducing tracking layers improves resolution

- Best measurement of arc curvature measures end points well and the widest part of the curvature
  - So we remove 3 barrel layers
  - And remove 2 pixel barrel layers
  - Still gives us good lever arm

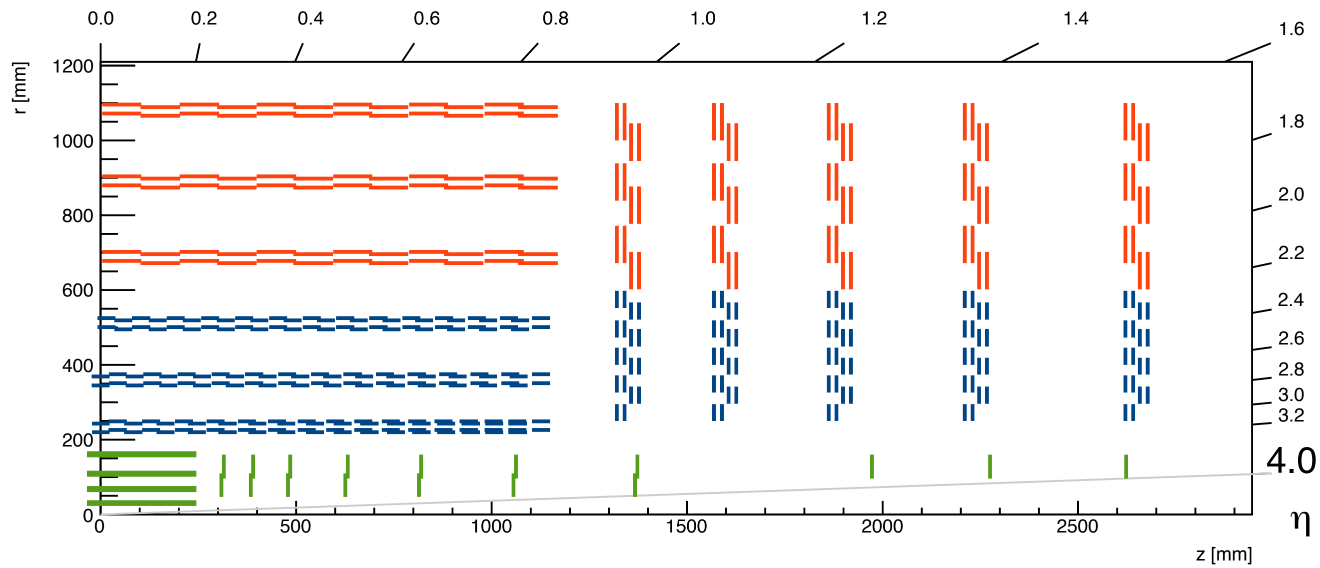


Analysis procedure

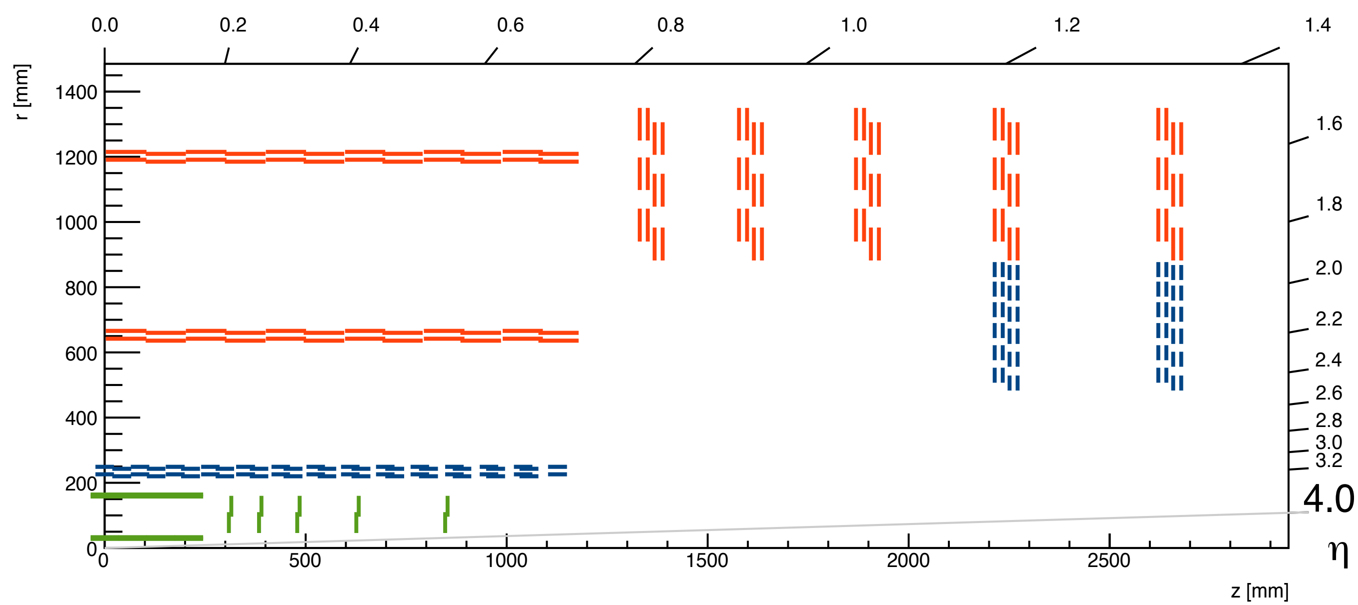
1. Design new tracker layout
   – Optimizing resolutions (PT, cot Θ) for low PT tracks
   – Calculate resolution functions & tracking efficiency
2. Input results into DELPHES simulation
3. Calculate M(μμ) mass resolution and resolving power

Team 1 design

Default : Technical Proposal

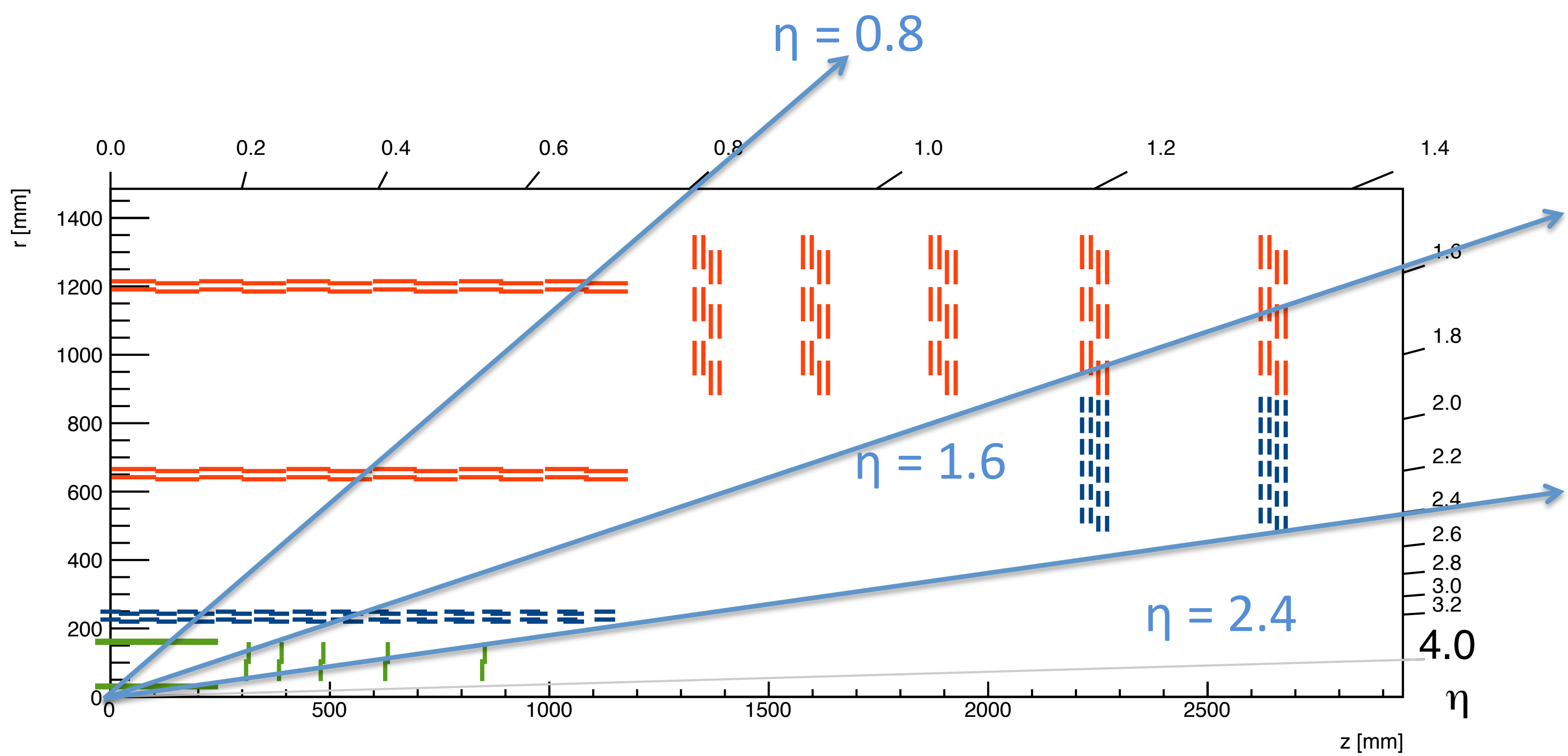


Our final design



What is changed ?

	Default	New
Number of barrel pixel layers	4	2
Number of forward pixel layers	10	5
Number of barrel tracker layers	6 (3 PS + 3 2S)	3 (1 PS + 2 2S)
Endcap tracker	5 full layers	3 partial layers + 2 full layers



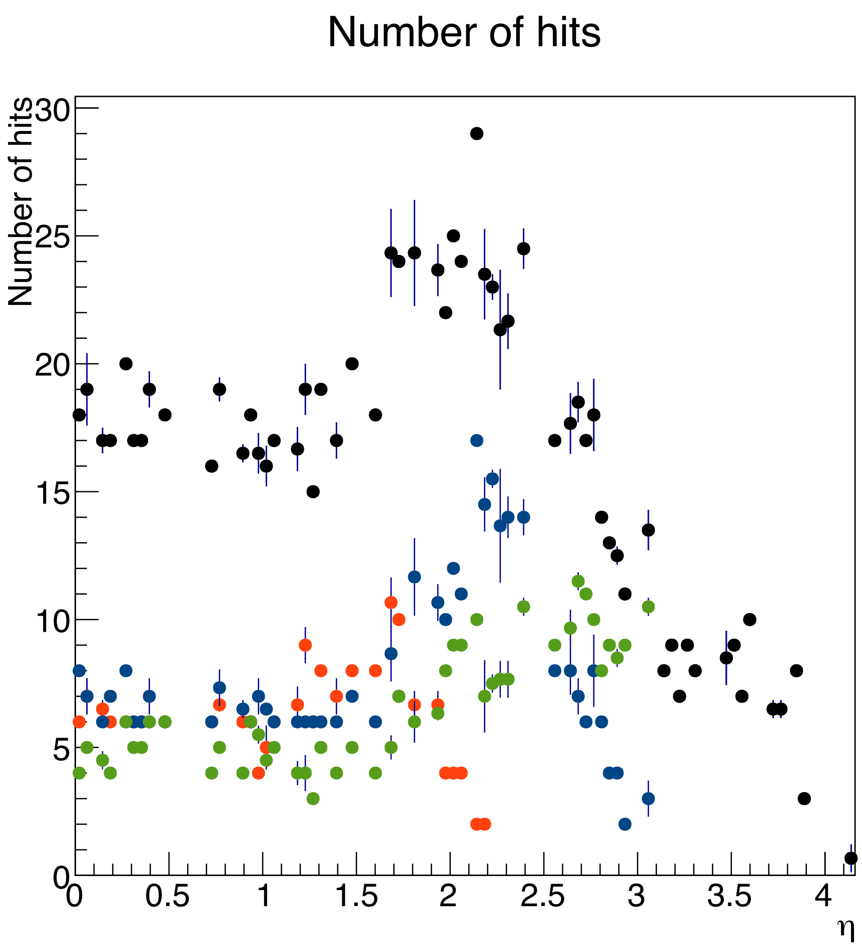
Our design ensures >= 8 hits out to η < 2.4 :
While minimizing material interactions

η = 0.8 : 8 hits

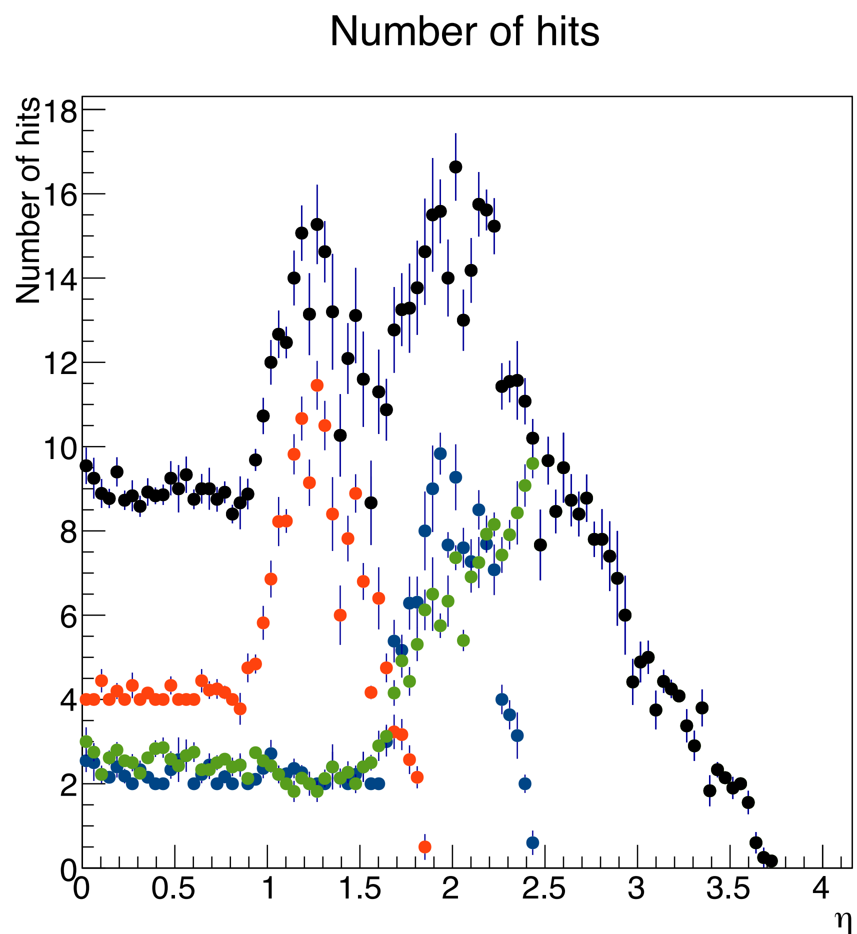
η = 1.6 : 9 hits

η = 2.4 : 8 hits

Hit coverage vs η



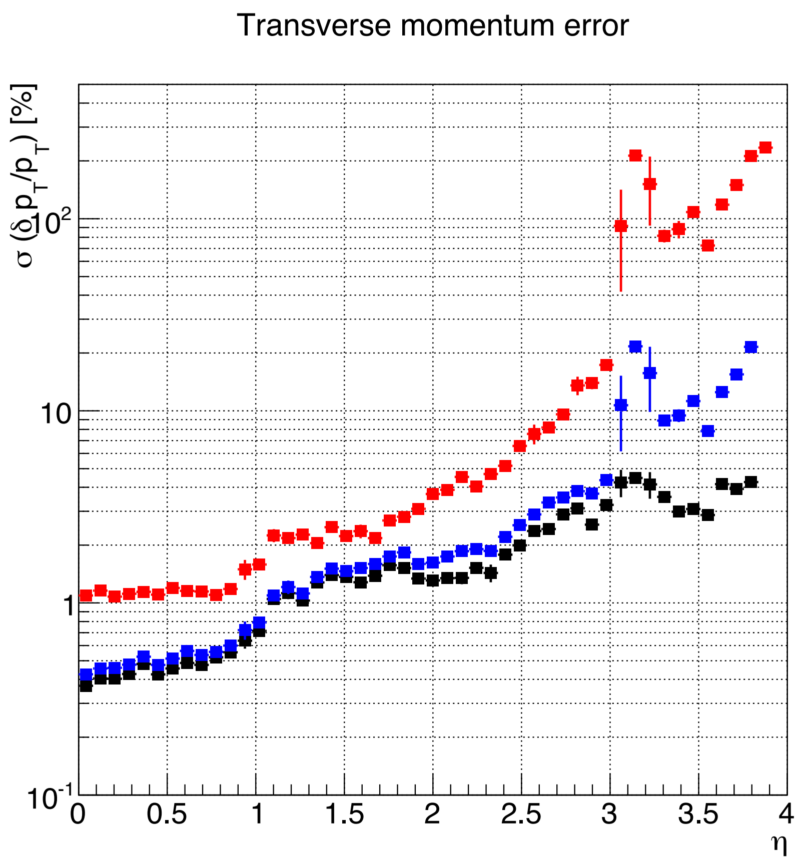
Default

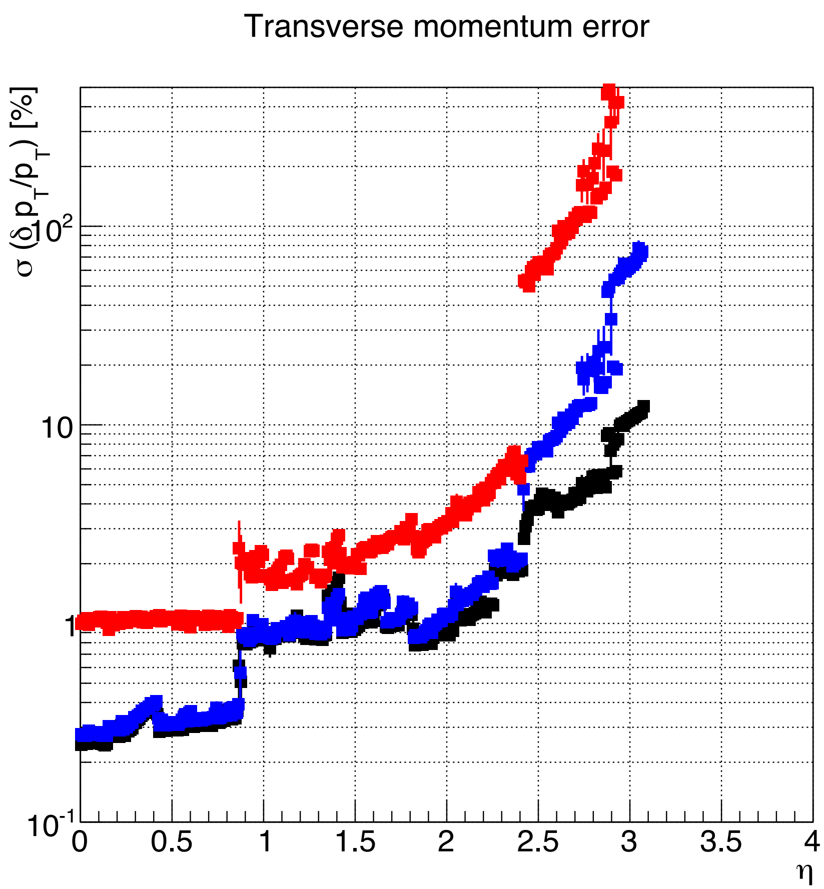


Team 1

Pt resolution vs η

- PT = 100 GeV
- PT = 10 GeV
- PT = 1 GeV





Our figure of merits

- Important :
  - PT resolution to $\eta < 2.4$
  - PZ resolution (cot theta) $\eta < 2.4$

Description	σ(δpT /pT) [%] 0 < η < 0.8	σ(δpT /pT) [%] 0.8 < η < 1.6	σ(δpT /pT) [%] 1.6 < η < 2.4	σ(δctg(θ)) [%] 0 < η < 0.8	σ(δctg(θ)) [%] 0.8 < η < 1.6	σ(δctg(θ)) [%] 1.6 < η < 2.4
Default CMS configuration: Outer: 6 layers, 5 disks, Pixel 4 layers, 10 disks	0.493	1.09	1.76	0.00036	0.00063	0.00174
Outer: 4 layers(2PS+22S), 5 disks, Pixel 4 layers, 5 disks	0.47	1.02	1.69	0.00036	0.00063	0.00174
Outer: 4 layers(2PS+22S), 5 disks, Pixel 2 layers, 5 disks	0.46	0.97	1.62	0.00034	0.00066	0.00173
Outer: 4 layers(2PS+22S), 5 disks, Pixel 2 layers, 5 disks	0.32	1.07	1.62	0.00034	0.00087	0.00173
Outer: 3 layers(1PS+22S), 5 disks, Pixel 2 layers, 5 disks	0.32	0.93	1.5	0.00034	0.00086	0.00173
Barrel: 3 layers(1PS+22S), 3 short disks, 2 long disks, Pixel 2 layers, 5 disks	0.32	0.93	1.29	0.00035	0.00095	0.00164

Now we do mass analysis

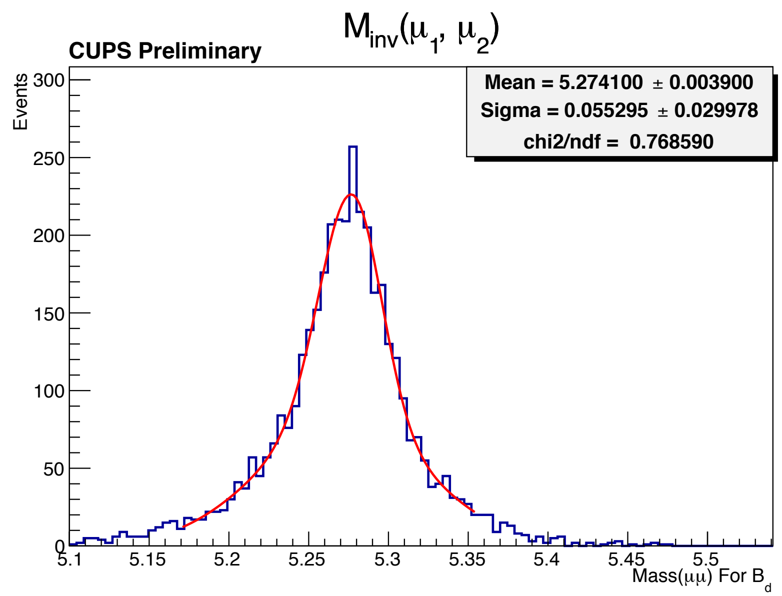
- We use DELPHES phase 2 simulation to test that we have improved Mass (μμ) resolution by separating Bs and B0 mass states

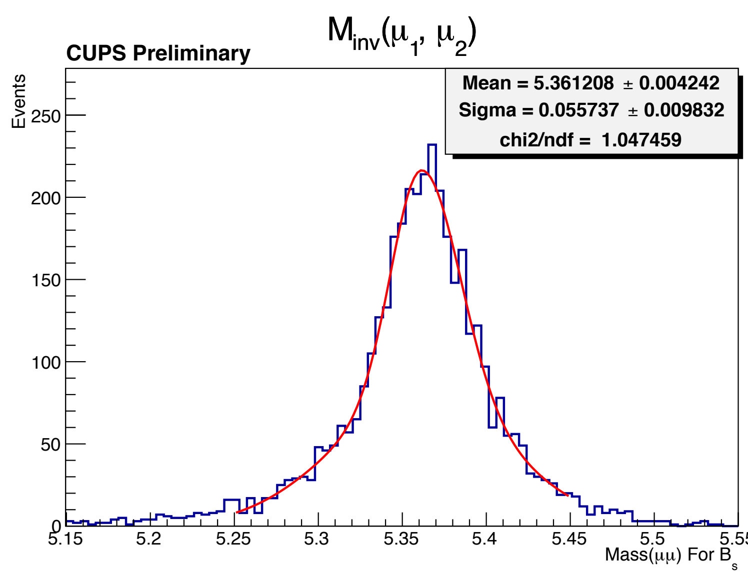
Analysis flow

- Cuts
  - Muon PT > 4 GeV
  - B Candidate PT > 5 GeV
  - Full eta range ($|\eta| < 2.4$)
- Samples
  - BdToMumu
  - BsToMumu

Fit technique

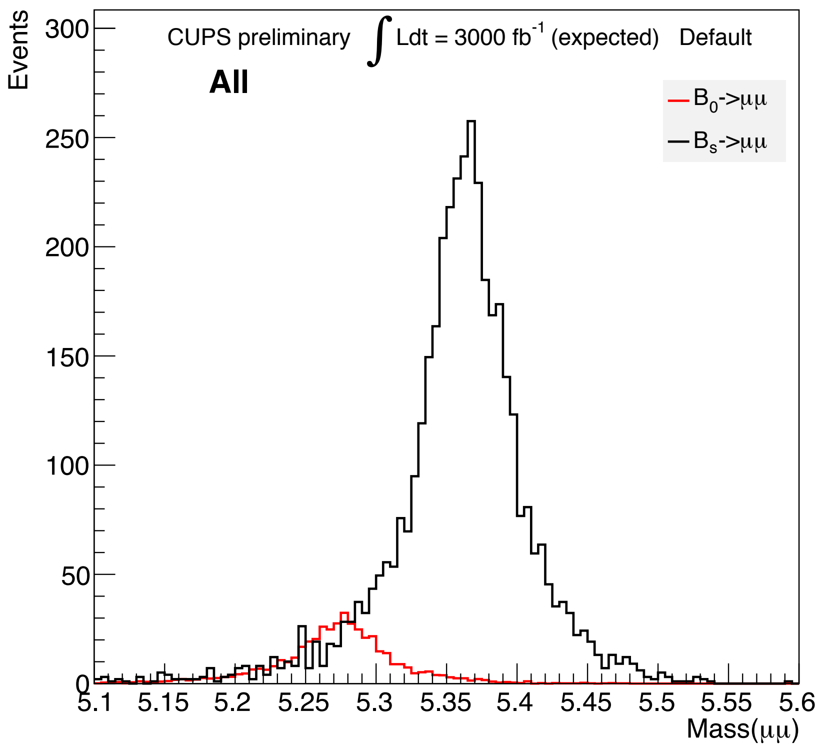
- Gaussian + asymmetric Gaussian





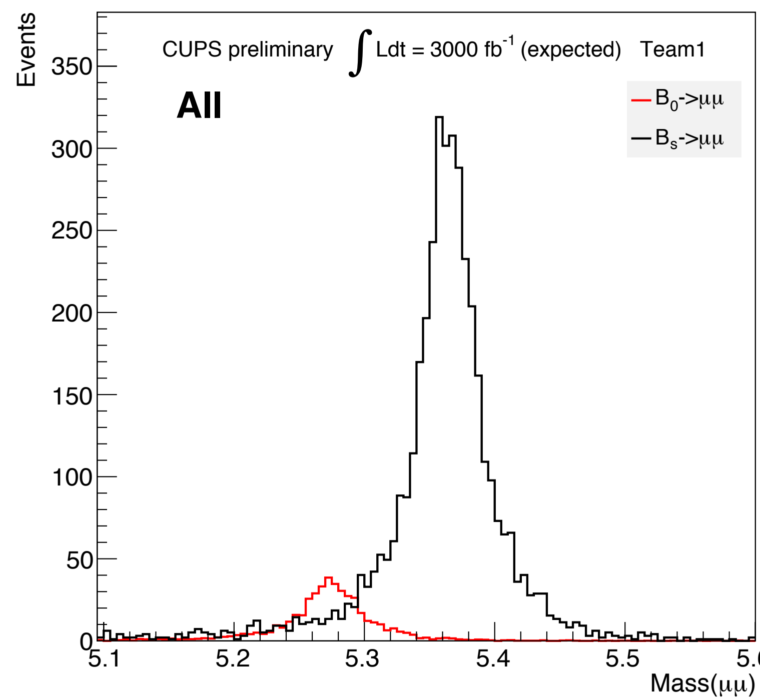
Improvement in Mass resolution

- Default



σ M B_d = 55 MeV

- Team 1



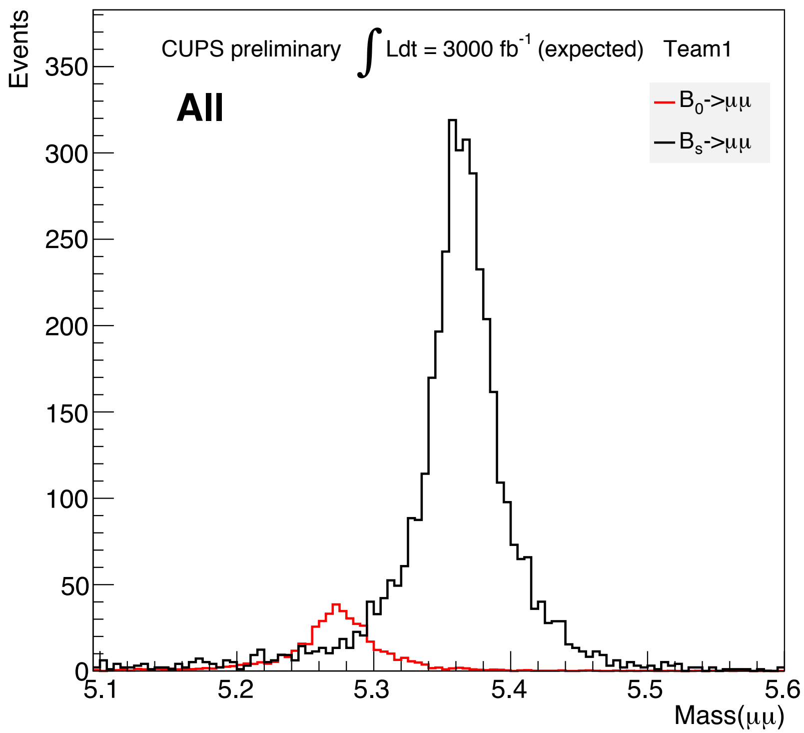
σ M B_d = 48 MeV

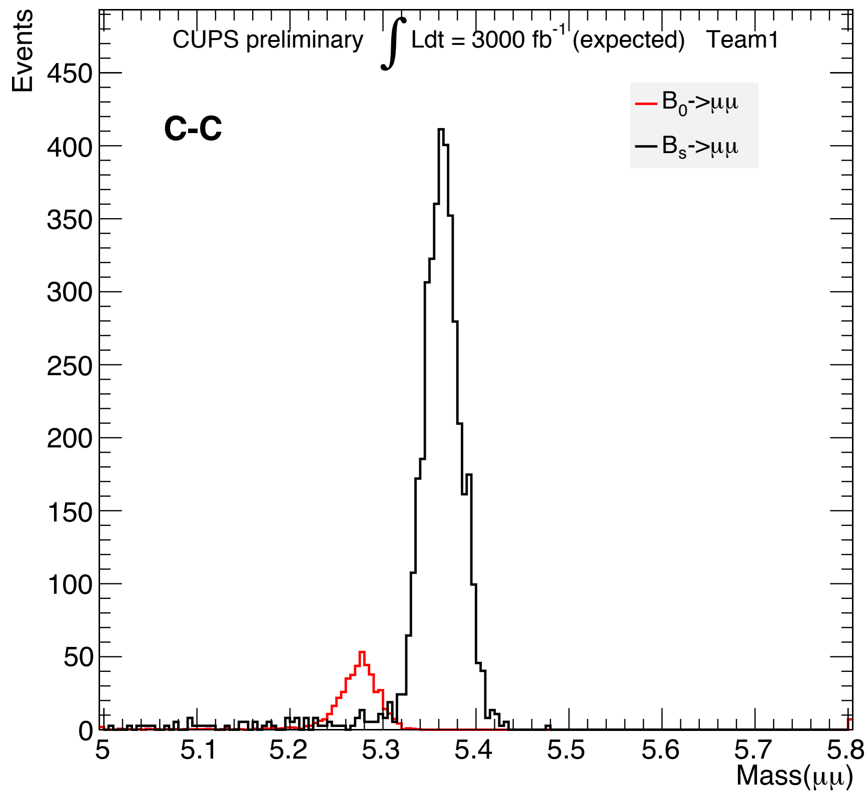
Define mas figure of merit

- Mass resolution
- $\sigma = \mathrm{sqrt}\ (\ \sigma_{Bs}^{2} + \sigma_{Bd}^{2}\ )$

Most central muons

- In our most central muons, we have excellent separation





σ M total = 62 MeV

σ M total = 22 MeV

Improvements in mass resolutions

	σ Mass (μ, μ)
Default Bs	0.056
Default Bd	0.055
Default Total	0.079
Team 1 Bs	0.036
Team 1 Bd	0.048
Team 1 Total	0.062

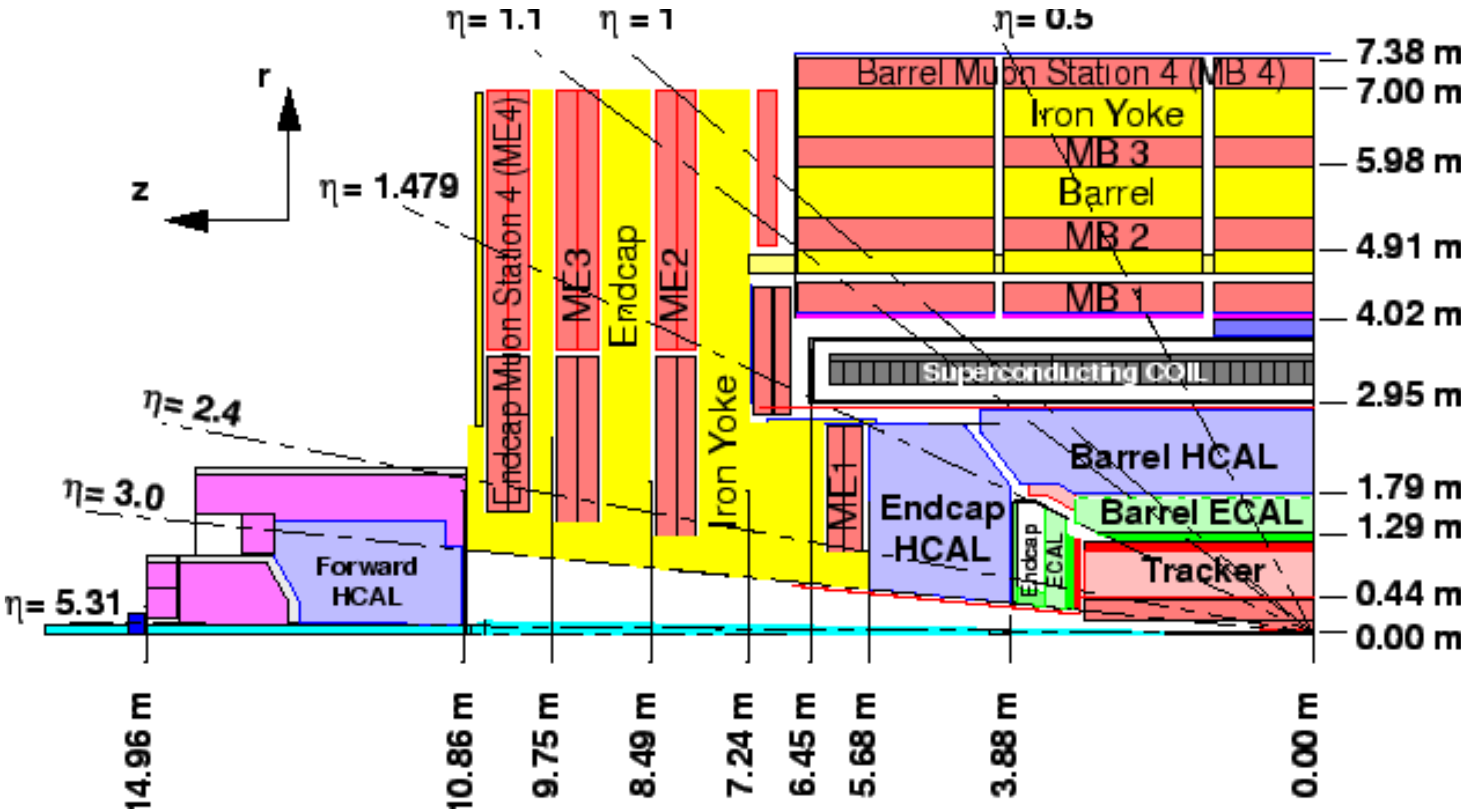
Sensor area = Cost $$$$$$$

- Our configuration saves the experiment money ! At 100 CHF / cm^2
  - Default configuration : total area 217 m^2
    - 217 MCHF
  - Our configuration : total area 189 m^2
    - 189 MCHF

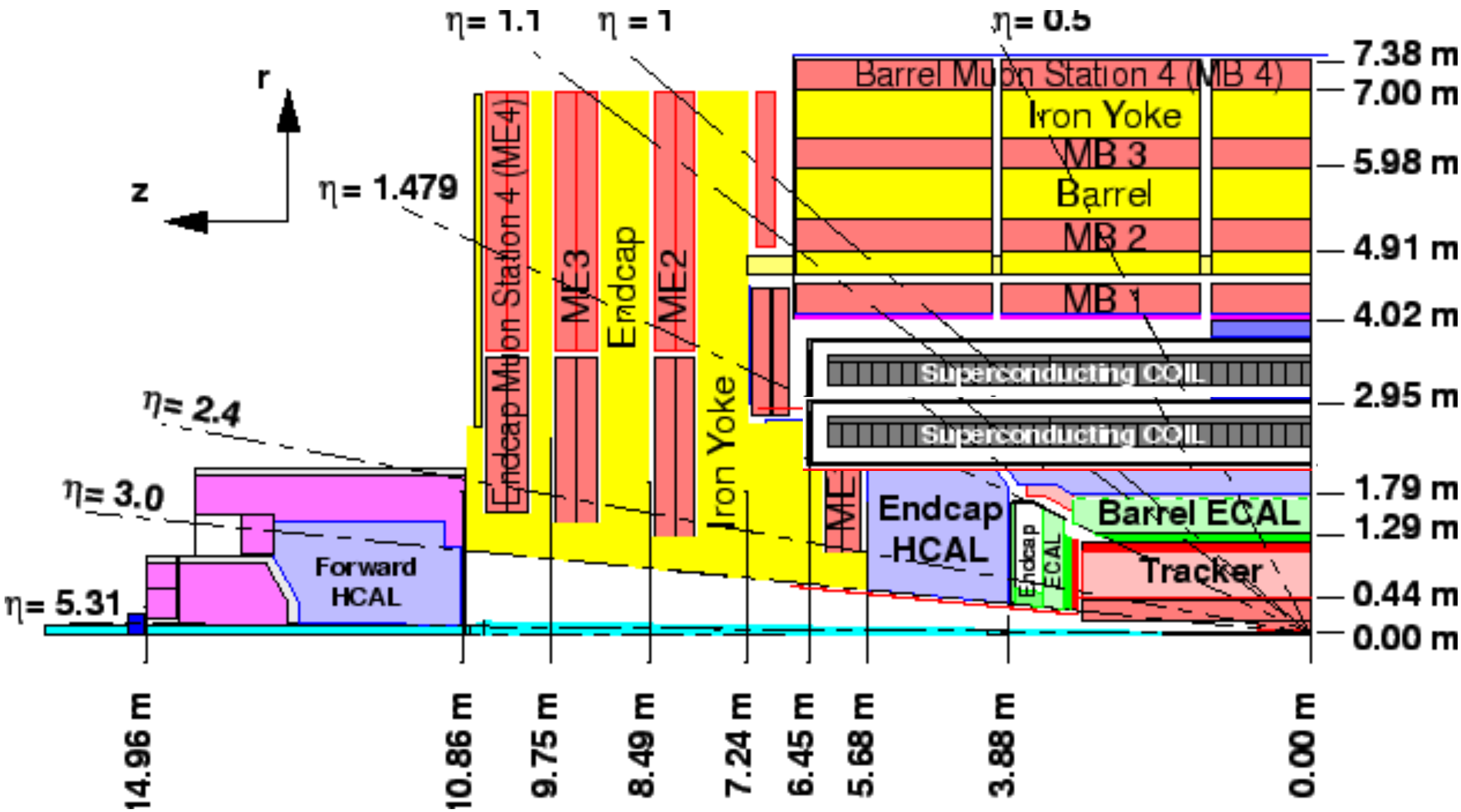
Bonus

- We also wanted to design a feature that helps the high PT analysis $Z' \rightarrow \mu\mu$

CMS detector current



CMS 2 : with 8 Tesla magnet

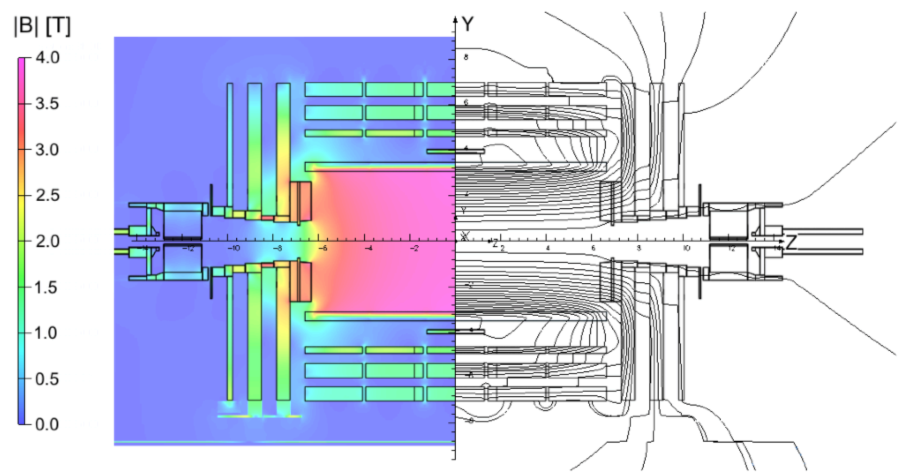


We know how to build 4 Tesla superconducting magnets, so we propose to build a new one and insert it inside the old one

8 Tesla solenoid magnet

- Requires removal of top-half of HCAL
  - However, we do not need excellent jet energy resolution for B->mumu analysis
  - We need some HCAL in order to calculate isolation of muons in order to reject fake muons
  - Removal of HCAL partially compensates additional scattering material from second solenoid

Return Yoke sufficient for additional field – but requires some further study



Bonus

- 100 GeV, with 4 T solenoid
  - Central : $\delta PT/PT = 1.04$
- 100 GeV, with 8 T solenoid
  - Central : $\delta PT/PT = 0.58$

Team 1 Conclusions

- We designed a new tracker which outperforms the Technical Proposal default configuration in the search for B0 $\rightarrow\mu\mu$
- Features :
  - Reduced number of layers
  - Carefully placed layers
  - Partial end cap trackers
- We also made a configuration to improve the Z' $\rightarrow$ $\mu\mu$ search