Long exercise: detector design tune for final states with low-p_T muons

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Goal

- Define a **realistic detector layout** and tune it in order to enhance the detection of **low-p_T muons**
- Test **available choices**
  - Play with them
  - Check detector performance
- Try **different solutions**
  - Describe and motivate them

Benchmark physics channel

- **$B^0/B_s \rightarrow \mu^+\mu^-$ decays**
  - Very rare process
  - Small signal and very high background

- Observation of B_s resonance already achieved with Run 1 data

- The real challenge will be the **observation of the $B^0 \rightarrow \mu\mu$ process**
  - Almost degenerate peaks:
    $m(B^0) \approx 5280$ MeV, $m(B_s) \approx 5360$ MeV   ($\Delta m \approx 80$ MeV)
  - B_s yield ~9 times higher than B^0
  - B_s peak is effectively the main background for the B^0 search!
  - **Separation of the two peaks** will be paramount

Datasets

- Only **signal datasets** from MC production for the Technical Proposal will be used
  - BdToMuMu
  - BsToMuMu

- Only the generator information has been extracted from these samples and saved in **HepMC format**
  - These can be given to Delphes as input

- Samples have been produced with these cuts at the generator level
  - $p_T(\mu) > 2.5$ GeV
  - $|\eta(\mu)| < 2.5$

Step 1: run Delphes and check output

- Define a **Delphes datacard** with the help of **TkLayout**
- **Run Delphes** over the samples
- **Check resolutions, yields, etc.**
  - Do they match your design?
  - Are they good enough for the physics needs?

Step 2: evaluate the B_s/B^0 performance

- Find the **di-μ invariant mass** spectra from the Delphes output
- Define which **event selection criteria** you want to apply
  - You will probably not have all the information available in the Delphes' root trees
  - Need to make **simplifying assumptions** in order to get some estimates
  - Justify them (Calculations? Published material? MC estimates?)
- Evaluate the results in terms of **B^0/B_s separation** and **signal yield**
  - Is the resolution good everywhere? Can you improve it in the regions where it is worse (e.g. **in the endcaps**)?
  - Can you improve the acceptance and enhance the yield?

Some notes

- The exercise involves **no pile-up** to make it faster
  - The real detector will have to deal with considerable PU
  - Can you think of any significant effect of PU to your results?

- The results you will obtain are based on a fast simulation of the detector and its response
  - The reference results in FTR PAG studies are done with more refined techniques and sometimes use full simulation
  - **They could be hard to directly compare with yours**

- What you are asked to complete by Friday is just an exercise based on the performance of the tracker and muon detectors
  - In general, always keep in mind that **the tools that you will use are simple and real life is complicated**
  - **Use your common sense to be sure that the results make sense to you**

Example: plotting mass peaks

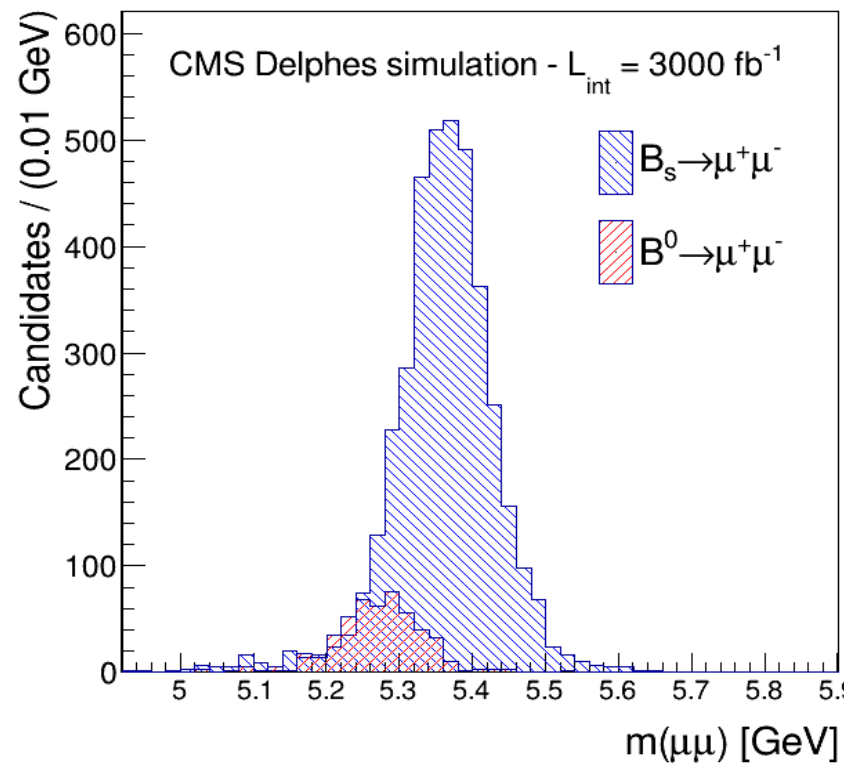
- Selection efficiency, normalizations, etc., scaled from Run-1 measurement
- Expected events
  - **$B_s \rightarrow \mu\mu$: ~4000**
  - **$B^0 \rightarrow \mu\mu$: ~460**

- Width of each resonance **σ = 60 MeV**
- Simple calculation of the "resolving power" of CMS:

$\sigma_{tot} = \sqrt{[\sigma^2(B_s)+\sigma^2(B^0)]}$

$= \sqrt{(2\times\sigma^2)} \approx 85$ MeV

  - Comparable with $\Delta(m)$!



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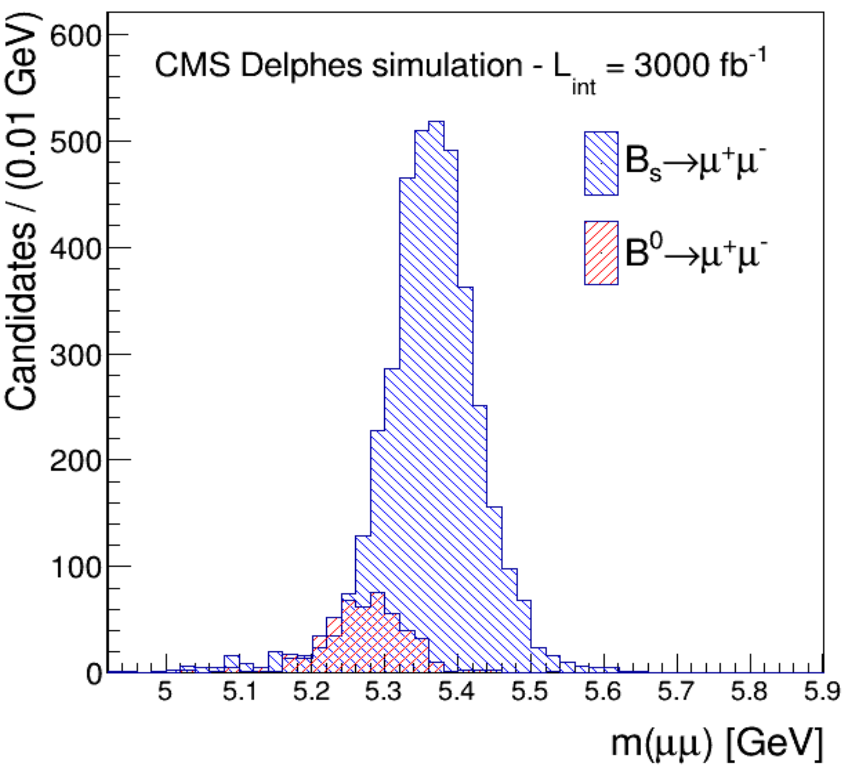

- **Resolution shown above is at the limit for the discrimination between the two peaks**
- **Can you do better?**

More notes

- **Presenting the results** is as important as extracting them
    - Allocate enough time to prepare a good talk
    - Be clear and concise
    - Show a refined analysis (e.g. including correct error propagation)
- Focus on the main point but be ready to **defend also the details of your work**
    - Include any external sources of information
    - Motivate all the choices you made

Delphes setup

```
git clone https://github.com/sethzenz/Delphes.git
git checkout tags/31Jul2014
cd Delphes
./configure
sed -i '/lFWCoreFWLite/ s/$/ -lGenVector/' Makefile
make clean
make
```

Tools

- Input datasets (ASCII-HepMC files):

  /nfs/dust/cms/group/cups2014/longexercises/BdToMuMu_14TeVPythia6/
  /nfs/dust/cms/group/cups2014/longexercises/BsToMuMu_14TeVPythia6/

- Example Delphes card:

  /nfs/dust/cms/group/cups2014/longexercises/DESYCards/CMS_UpgradeSchool_BASE.tcl

- Example analysis macro

  Delphes/examples/Example1.C
  Delphes/examples/Example1.cpp

- Signal samples are not very big (~50K events each) so you will not need to parallelize your jobs
  - To go even faster, run on small subsamples first
  - If you don't want Delphes to run everything, strip down the card to what you really need

Cuts and assumptions used in the example

- Muon p_T > 4 GeV
- B candidate p_T > 5 GeV
- Full $|\eta|$ range
- Signal efficiency degradation by ~35% with respect to the Run-1 analysis

Bibliography

1) Public material:

- Run 1 B->mumu results:
  - CMS Collaboration, "*Measurement of the $B_s^0 \to \mu^+\mu^-$ branching fraction and search for $B^0 \to \mu^+\mu^-$ with the CMS experiment*", Phys. Rev. Lett. **111** (2013) 101804; arXiv:1307.5025; CMS-BPH-13-004-003; CERN-PH-EP-2013-129.
  - CMS and LHCb Collaborations, "*Combination of results on the rare decays $B_{(s)}^0 \to \mu^+\mu^-$ from the CMS and LHCb experiments*", arXiv:1411.4413; CMS-PAS-BPH-13-007 ; LHCb-CONF-2013-012 ; CERN-LHCb-CONF-2013-012
- HL-LHC, Run 2, etc., predictions:
  - CMS Collaboration, "*CMS reach in B_s to dimuon and B to dimuon branching fractions for the new LHC runs*", CMS-PAS-FTR-13-022
  - Approved slides with updated results: https://twiki.cern.ch/twiki/bin/viewauth/CMS/TpPublicResultsECFA (row "BPH"). It contains the most recent plots

2) CMS-private material:

- CMS Analysis Note with details of the latest analysis of the Phase-2 performance: http://cms.cern.ch/iCMS/jsp/openfile.jsp?tp=draft&files=AN2014_186_v4.pdf (updated)
- PAS under preparation with new analysis of HL-LHC performance: http://cms.cern.ch/iCMS/analysisadmin/versions?analysis=FTR-14-015 (not fully up to date)
- CMS Phase-2 Upgrade Technical Proposal, paragraph 10.5: "*B Physics*" (not updated)