Track Reconstruction Efficiency studies for Run 3

Early measurements 2022

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14th March 2022

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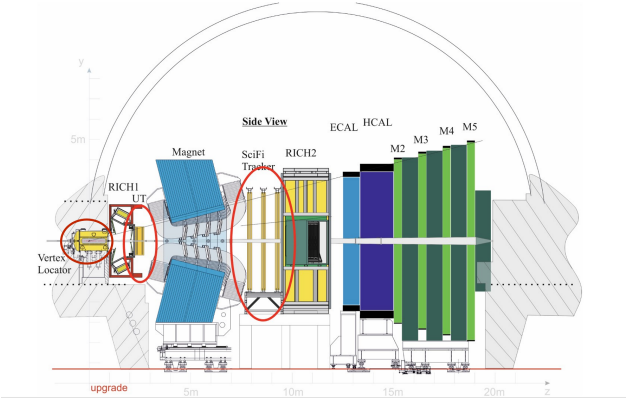
BEYOND STANDARD MODEL

FSP LHCb
Erforschung von Universum und Materie

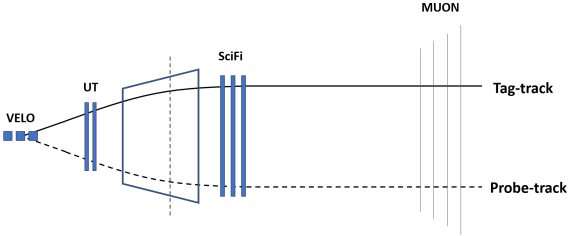
Track Reconstruction Efficiency at LHCb

- precise measurement of efficiencies essential for e.g. branching fractions
- measure efficiencies of different tracking sub-detectors:
  - relevant in Run 2: Velo, T, IT, OT
  - relevant in Run 3: Velo, *UT*, SciFi
- produce calibration tables independent from Stripping lines
- efficiency only for **tracks having enough hits in muon stations**



The tag-and-probe method

- use **tag-and-probe method** with displaced $J/\psi \to \mu\mu$ from $b \to J/\psi X$
- fully reconstructed **tag muon** + partially reconstructed **probe muon**
- try matching probe muon to a fully reconstructed long track

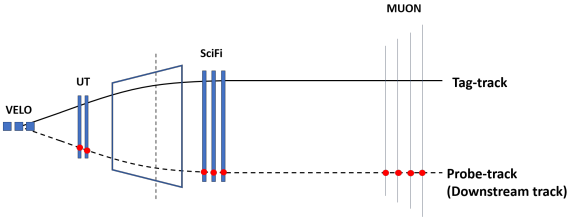


$$\epsilon_{\textit{Track Reconstruction Efficiency}} = \frac{N_{J/\psi \text{ yield with probe matched to long}}}{N_{J/\psi \text{ yield with probe and tag}}} \tag{1}$$

Trigger lines

(see MR!967):

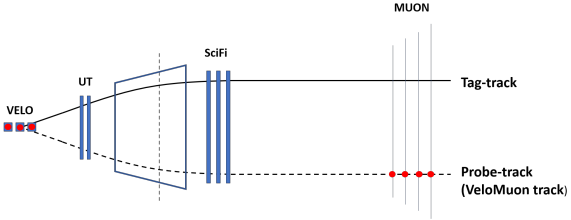
1. **Downstream method** (Run 2: Velo method): probe reconstructed from UT, SciFi and Muon hits



Trigger lines

(see MR!967):

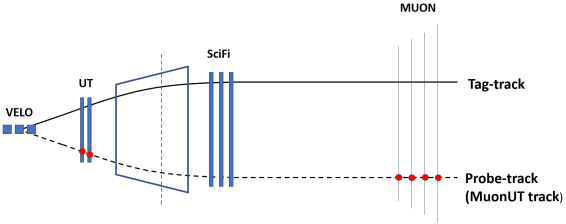
1. Downstream method (Run 2: Velo method): probe reconstructed from UT, SciFi and Muon hits
2. **VeloMuon method** (Run 2: T station method): probe reconstructed from Velo and Muon hits



Trigger lines

(see MR!967):

1. Downstream method (Run 2: Velo method): probe reconstructed from UT, SciFi and Muon hits
2. VeloMuon method (Run 2: T station method): probe reconstructed from Velo and Muon hits
3. **MuonUT method** (Run 2: Long method): probe reconstructed from UT and Muon hits

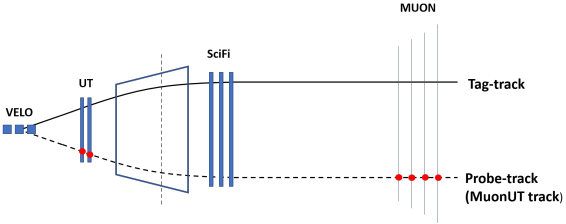


Trigger lines

(see MR!967):

1. Downstream method (Run 2: Velo method): probe reconstructed from UT, SciFi and Muon hits
2. VeloMuon method (Run 2: T station method): probe reconstructed from Velo and Muon hits
3. MuonUT method (Run 2: Long method): probe reconstructed from UT and Muon hits

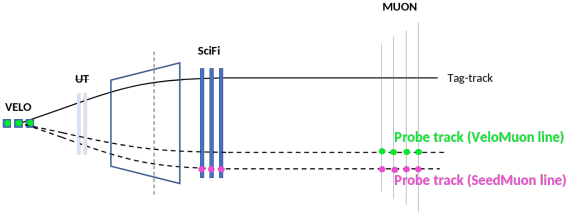
Run2: Velo and T station methods combined →weighted average with Long method to determine and reduce systematics



Trigger lines

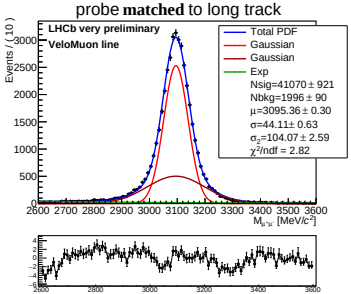
what to do without UT (see MR!1236):

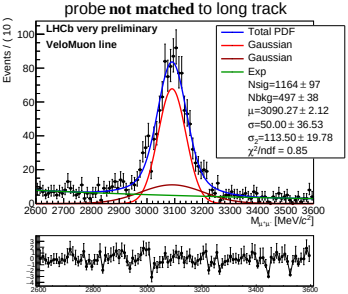
1. ~~Downstream method (Run 2: Velo method): probe reconstructed from UT, SciFi and Muon hits~~
2. **VeloMuon method** (Run 2: T station method): probe reconstructed from Velo and Muon hits →**for probing SciFi**
3. ~~MuonUT method (Run 2: Long method): probe reconstructed from UT and Muon hits~~
4. **SeedMuon method**: probe reconstructed from SciFi and Muon hits→**for probing Velo**



Yield extraction

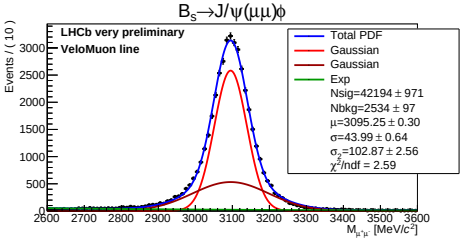
- plot J/ψ invariant mass distribution from $B_s \to J/\psi(\mu\mu)\phi$ signal Monte Carlo of:
  - **matched** candidates (probe matched to a long track)
  - **not matched** candidates (probe not matched to a long track)
- simultaneous fit to both (Double Gaussian/Double Crystal Ball (S) + Exponential (B))

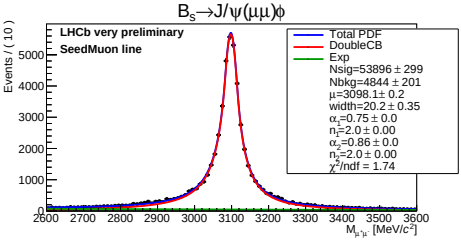




$$\epsilon_{Track\ Reconstruction\ Efficiency} = \frac{N_{sig,matched}}{N_{sig,matched} + N_{sig,not\ matched}} \tag{2}$$

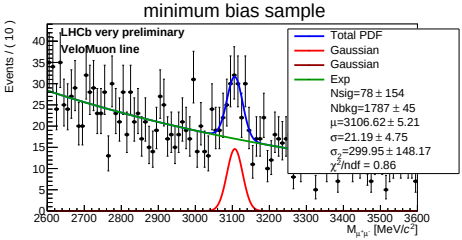
Invariant mass distribution of the signal sample

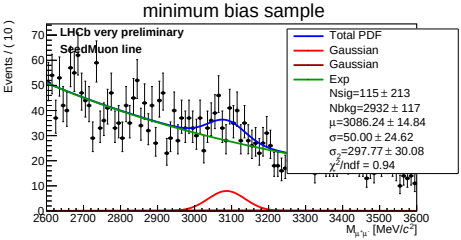




- all J/ψ passing the cuts plotted
- use Double Crystal Ball or Double Gaussian for signal shape
- Exponential distribution for background shape

Invariant mass distribution of the minimum bias sample





- all J/ψ passing the cuts plotted
- clear peak for VeloMuon line $\rightarrow$ SciFi can be probed without problems
- SeedMuon line needs bigger minimum bias sample to make definite statement

TrackCalib2 status

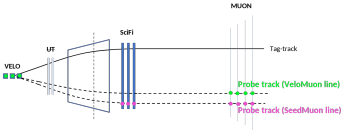
- Same logic as previous TrackCalib version, application is able to perform 3 different tasks:
  - **prepare:** skim tuples and store trees with standard naming
  - **fit:** perform fit in bins of kinematics and multiplicity for efficiency determination
  - **plot:** prepare final plots with MC corrections and efficiency comparison
- the new code is independent from ROOT (root files still used for tuple storage)
- latest version of the code is here
- code under developement, functionality testing & improvements in progress with old datasets

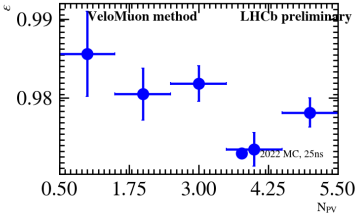
```
version: 0.1
authors: many
contacts: Flavio Archilli (flavio.archilli@cern.ch), Raphael Skuza (raphael.skuza@cern.ch)
[INFO]          ##################################################################
[INFO]          #                                                                #
[INFO]          #                              FIT                               #
[INFO]          #                                                                #
[INFO]          ##################################################################
```

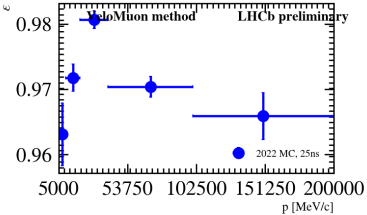
```
python3.9 trackcalib.py -h
usage: trackcalib.py [-h] {prepare,fit,plot} ...

Do the tracking efficiency fit for a given:
        a) Year of data-taking (required argument)
        b) Method to use ("Long","T", "Velo") (if not selected all methods will be run)
        c) Data/MC (if none are selected both will be used)
        d) Optional: Set of variables (default: P, Eta, #SPD hits, #PVs)
        e) Optional: Set of 2d variables (default: P-Eta)
        f) Optional: the binning scheme of set variables (<var1>:[bin list 1];<var2>:...)

        For a full list of arguments, do: 'python trackcalib.py -h'


optional arguments:
  -h, --help          show this help message and exit

tasks:
  {prepare,fit,plot}
```

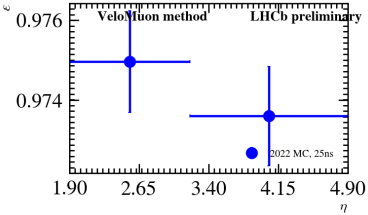
VeloMuon method status

VeloMuon method - use VeloMuon track as probe
run over $B_s \to J/\psi(\mu\mu)\phi$ MC sample





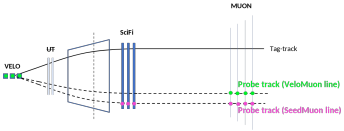


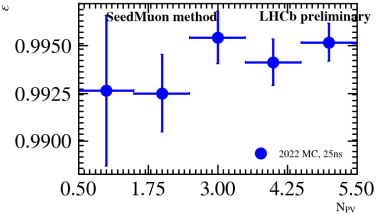


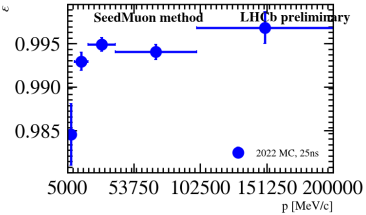
- plots produced with TrackCalib2

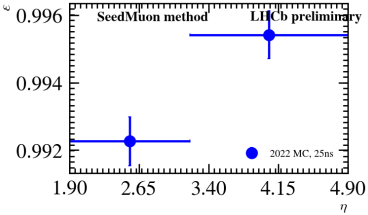
SeedMuon method status

SeedMuon method - use SeedMuon track as probe
run over $B_s \to J/\psi(\mu\mu)\phi$ MC sample





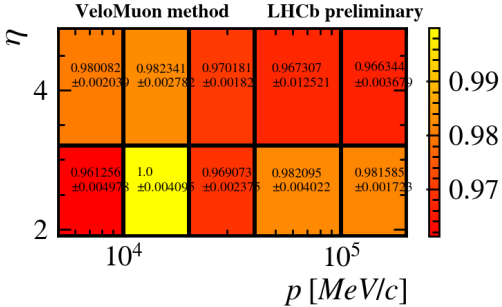


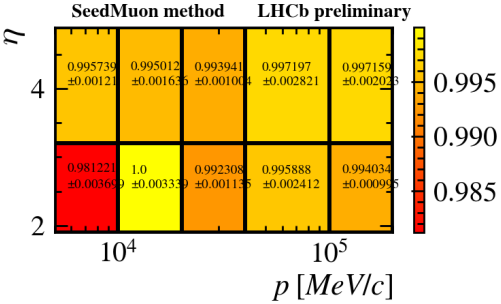


- plots produced with TrackCalib2

Track Reconstruction Efficiency tables

Track Reconstruction Efficiency tables (not calibration tables) for current $B_s \to J/\psi\,(\mu\mu)\phi$ MC sample (178705 events $\approx 1.34\,\mathrm{pb}^{-1}$)





- plots produced with TrackCalib2

Estimated uncertainty

rough estimation of **expected uncertainty** on efficiency @100 pb^{-1} based on upgrade signal MC:

	VeloMuon	SeedMuon
worst bin	0.145%	0.078%
best bin	0.020%	0.012%

Table: Statistical uncertainty on Track Reconstruction Efficiency (without background)

- efficiency of a long track to be reconstructed if it left hits in the muon stations
- Track Reconstruction Efficiency not limited by statistics according to signal MC sample
- size of minbias sample limits study of background level
- additional consideration necessary for hadronic interactions
- does not account for geometrical acceptance, selection efficiency, material and physics effects
- for more information, see TrackCalib twiki
- calibration tables of data/MC ratio will be provided

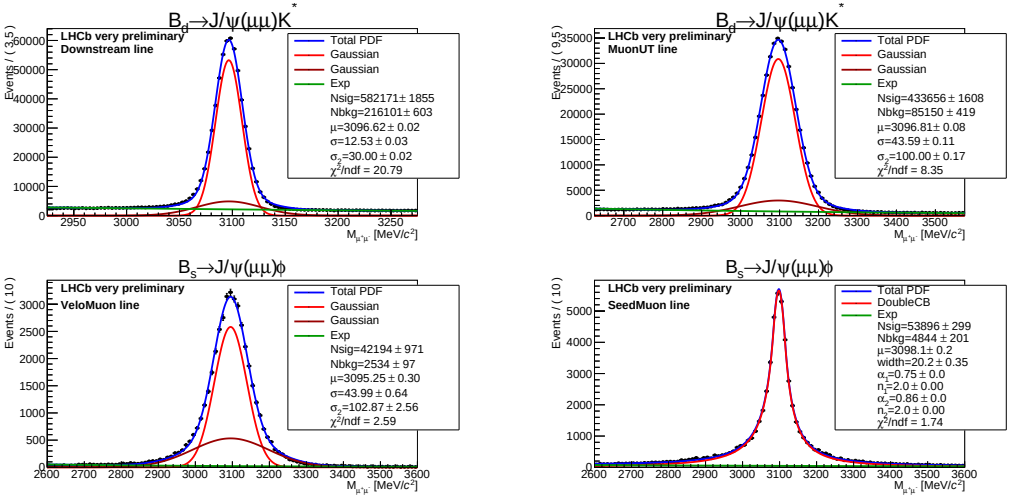
Summary & Outlook

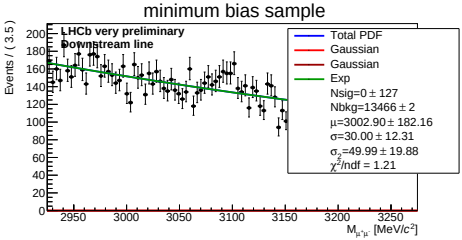
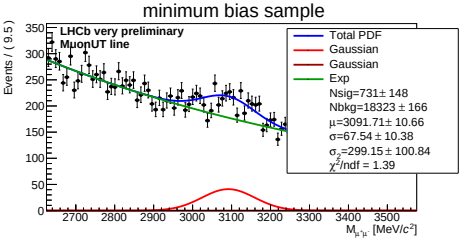
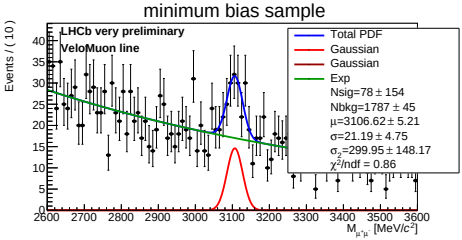
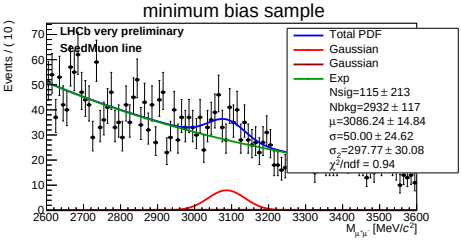
- Done
  - all trigger lines for Track Reconstruction efficiency implemented (Downstream, VeloMuon, MuonUT)
  - trigger lines in place for Run without UT (VeloMuon, SeedMuon)
  - bigger minimum bias sample needed
  - uncertainty hopefully not limited by statistics (if yield can be extracted)
  - TrackCalib2 tool generally ready
  - TrackCalib2 provides calibration tables in bins of kinematics and multiplicity for all Runs
- In Progress
  - refactoring of TrackCalib2 code without ROOT still under development
  - implementation of transition between Moore and TrackCalib2 tool
- Next Steps
  - adapt calculations for run with partial Velo and possibly not fully closed SciFi
  - implement online monitoring
  - hadronic & material interactions to study for systematics with regard to MC/data differences

Backup

Invariant mass distribution of the signal sample

(note different mass ranges!)



Invariant mass distribution of the minimum bias sample

(note different mass ranges!)