Detector and Physics simulation

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Luminosity measurement at muon collider

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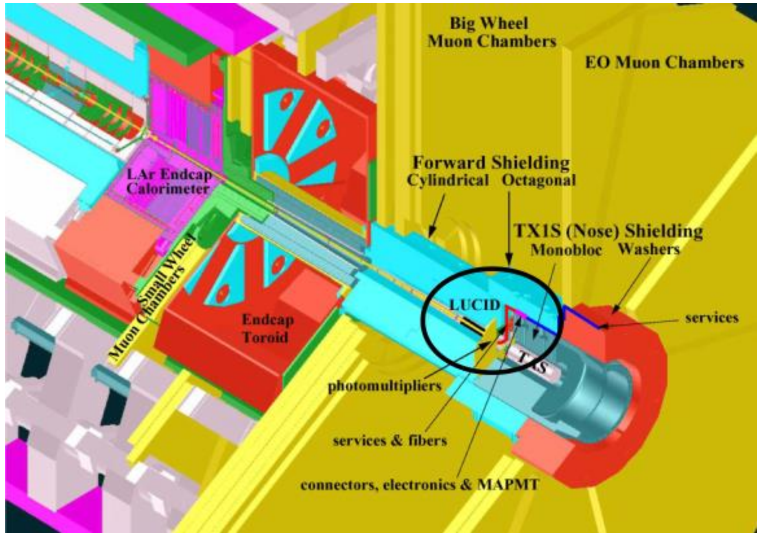
Luminosity Measurements: method 1

- Precise determination of the integrated luminosity target uncertainty is of crucial importance for any physics cross section measurement. In a two beams collider

$$L = \frac{N_1 \cdot N_2 \cdot f \cdot n_b}{A_{eff}}$$

n_b : number of colliding bunches, f : revolution frequency in the collider ➞ known by the machine
N_1, N_2: average number of particle per bunch, A_{eff} : effective area of the luminous region ➞ to be measured

- Dedicated detectors, luminometers, are used in combination to "van der Meer" scan method to determine N_1, N_2 and A_{eff} . For example ATLAS

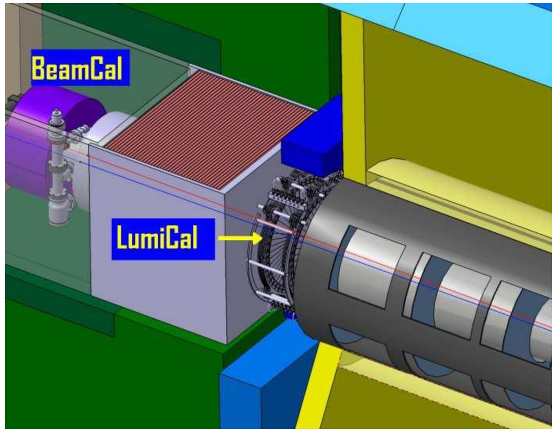


Luminosity Measurements: method 2 at e^+e^-

Experiments like KLOE, Babar, Belle, BES and, recently, Belle2 and BESIII, measure the integrated luminosity by counting the number of events, N, of a process whose cross-section is theoretically known with high precision, σ_{th} exploiting: $N=L\cdot\sigma_{\text{th}}$

The mostly used process: Bhabha scattering, $e^+e^- \rightarrow e^+e^-$ mainly in the forward region.

ILC and CLIC have dedicated detector in the forward regions to reconstruct e^+e^- pairs



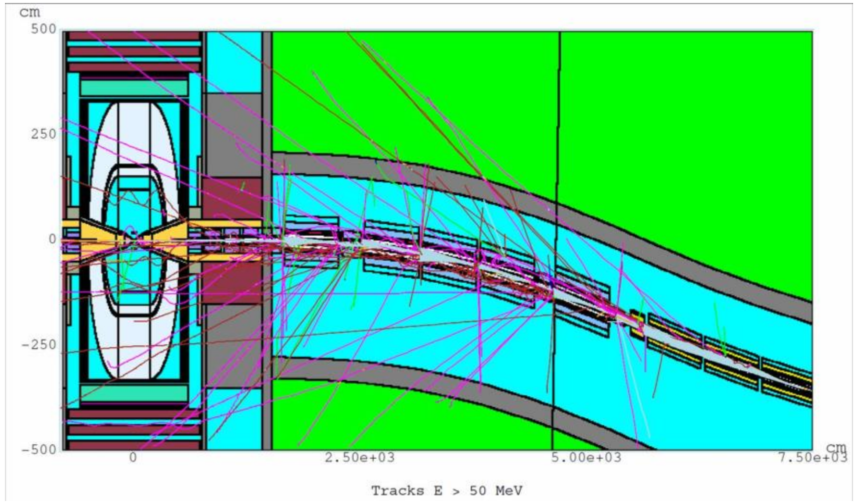
Source of uncertainty	$\Delta L/L$ (500 GeV)	$\Delta L/L$ (1 TeV)
Bhabha cross-section σ_B	$5.4\cdot10^{-4}$	$5.4\cdot10^{-4}$
Polar angle resolution σ_θ	$1.6\cdot10^{-4}$	$1.6\cdot10^{-4}$
Bias of polar angle $\Delta\theta$	$1.6\cdot10^{-4}$	$1.6\cdot10^{-4}$
IP lateral position uncertainty	$1\cdot10^{-4}$	$1\cdot10^{-4}$
Energy resolution a_{res}	$1.0\cdot10^{-4}$	$1.0\cdot10^{-4}$
Energy scale	$1.0\cdot10^{-3}$	$1.0\cdot10^{-3}$
Beam polarization	$1.9\cdot10^{-4}$	$1.9\cdot10^{-4}$
Physics background B/S	$2.2\cdot10^{-3}$	$0.8\cdot10^{-3}$
Beamstrahlung + ISR[1]	$-1.1\cdot10^{-3}$	$-0.7\cdot10^{-3}$
Beamstrahlung + ISR[2]	$0.4\cdot10^{-3}$	$0.7\cdot10^{-3}$
EMD[1]	$-2.4\cdot10^{-3}$	$-1.1\cdot10^{-3}$
EMD[2]	$0.5\cdot10^{-3}$	$0.2\cdot10^{-3}$
$(\Delta L/L)^1$	$4.3\cdot10^{-3}$	$2.3\cdot10^{-3}$
$(\Delta L/L)^2$	$2.6\cdot10^{-3}$	$1.6\cdot10^{-3}$

Physics background and beamstrhlung are among the dominant sources of systematic errors

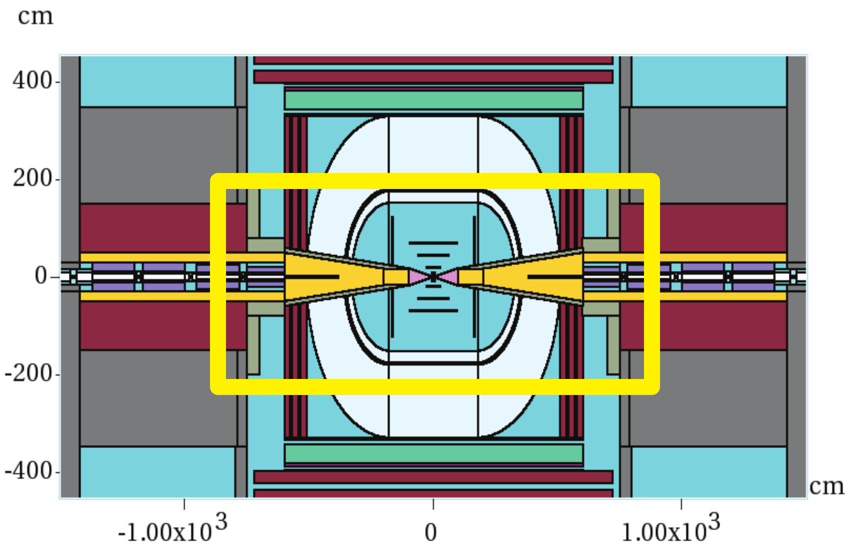
Muon Collider: Beam-Induced Background

At muon collider the two mentioned methods can not be used because of the detector configuration.

Detector performance at a Muon Collider could be strongly limited by the rate of background particles arriving at each subdetector due to muon decays.



Nozzles have been designed to mitigate the effect of a such background.



Luminosity measurement at Muon Collider

Proposal: reconstruct $\mu^+ \mu^- \to \mu^+ \mu^-$ events at large angle with respect to the beam line to obtain

$$L = \frac{N}{\sigma_{th}}$$

Questions:

1. do we have enough μ-Bhabha events at large angle?
2. Is the precision of the theoretical cross section enough to measure L?

Plan:

a. Produce a sample of events $\mu^+ \mu^- \to \mu^+ \mu^-$ at $\sqrt{s}$=1.5TeV, $\sqrt{s}$=3.0 TeV and $\sqrt{s}$=10 TeV by using a tree-level Monte Carlo generator and study the reconstruction efficiency at large angle by using the full detector simulation and identify additional kinematical requirements that can help to obtain a more precise theoretical prediction.
b. Perform the same studies with Mu-BabaYaga event generator.
c. Evaluate the theoretical precision on the Bhabha cross section.
d. Determine the expected precision on the luminosity.

Status of the activities: preparation of the dataset

A sample of $\mu^+ \mu^- \rightarrow \mu^+ \mu^-$ at $\sqrt{s}$=1.5TeV has been produced with Pythia and analyzed at Monte Carlo level to understand how many events we have in the "central" region.

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*-------  PYTHIA Event and Cross Section Statistics  -------------------------------------------------------------*
|                                                                                                                 |
| Subprocess                                    Code |            Number of events       |      sigma +- delta    |
|                                                    |       Tried   Selected   Accepted |     (estimated) (mb)   |
|                                                    |                                   |                        |
|-----------------------------------------------------------------------------------------------------------------|
|                                                    |                                   |                        |
| f fbar -> gamma gamma                          204 |        6331       2788          0 |  0.000e+00  0.000e+00 |
| f f' -> f f' (t-channel gamma*/Z0)             211 |  1531041922  885384204      99669 |  3.085e-08  9.771e-11 |
| f_1 f_2 -> f_3 f_4 (t-channel W+-)             212 |     1385941     169276          0 |  0.000e+00  0.000e+00 |
| f fbar -> gamma*/Z0                            221 |        1704       1623        158 |  4.925e-11  3.723e-12 |
| f fbar -> gamma*/Z0 gamma*/Z0                  231 |        7548        358         22 |  7.268e-12  1.512e-12 |
| f fbar -> W+ W-                                233 |       46301       5162         28 |  8.702e-12  1.641e-12 |
| f fbar -> gamma*/Z0 gamma                      243 |       24073       2768         88 |  2.783e-11  2.930e-12 |
| f fbar -> H (SM)                               901 |           0          0          0 |  0.000e+00  0.000e+00 |
| f fbar -> H0 Z0 (SM)                           904 |          99         26          3 |  6.897e-13  3.837e-13 |
| f f' -> H0 f f'(Z0 Z0 fusion) (SM)             906 |         331        113         27 |  7.090e-12  1.237e-12 |
| f_1 f_2 -> H0 f_3 f_4 (W+ W- fusion) (SM)      907 |        2697        977          5 |  1.599e-12  7.138e-13 |
|                                                    |                                   |                        |
| sum                                                |  1532516947  885567295     100000 |  3.095e-08  9.786e-11 |
|                                                                                                                 |
*-------  End PYTHIA Event and Cross Section Statistics ------------------------------------------------------------*
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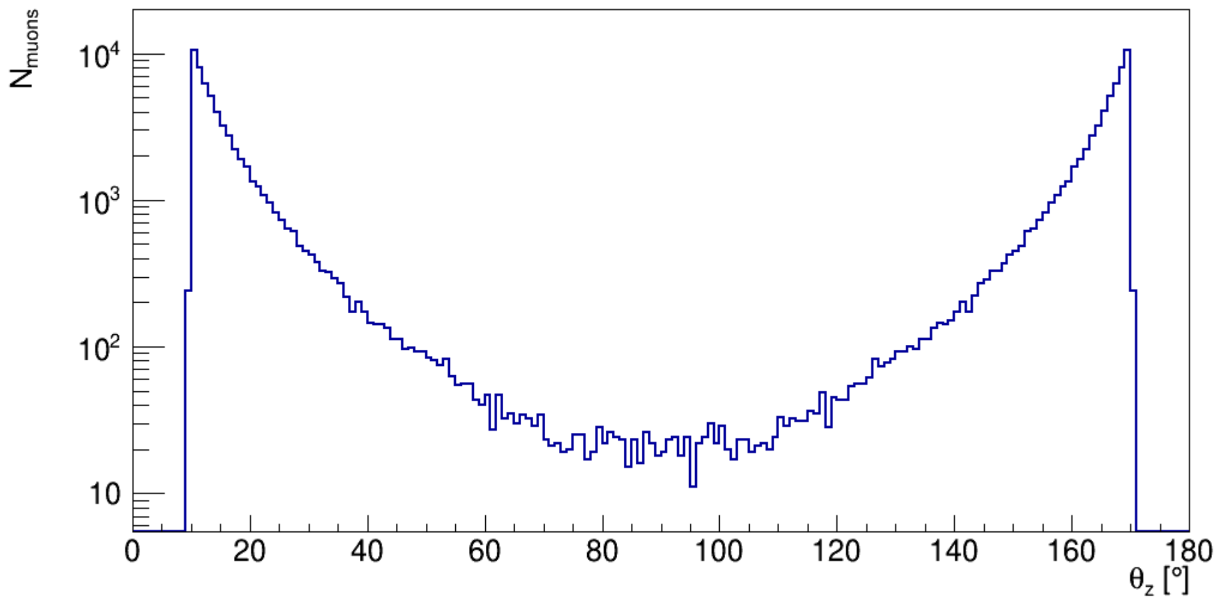
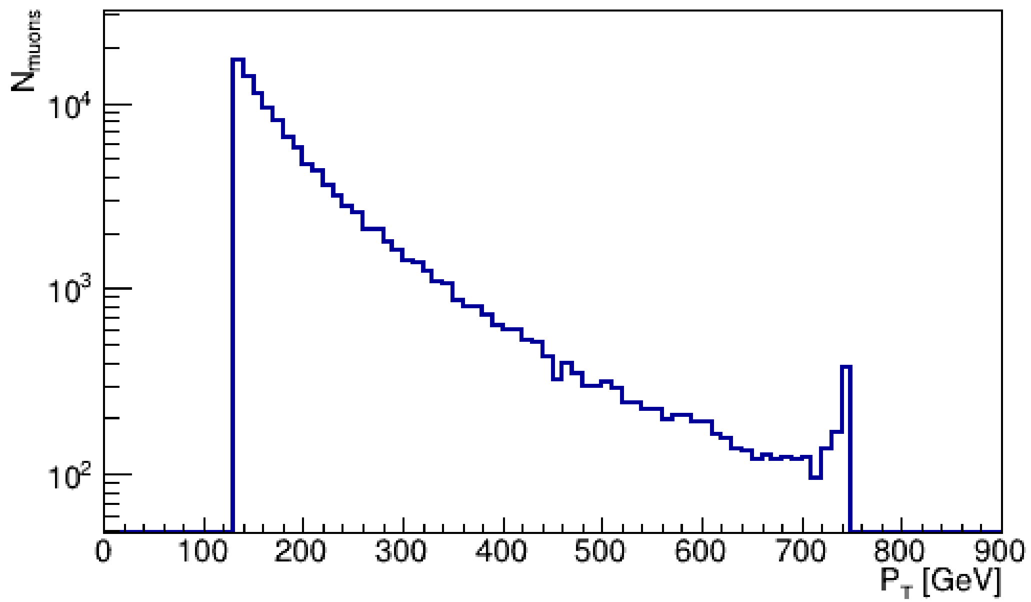
Status of the activities: first look at data

Accepting all muons in the detector acceptance with P_t>130 GeV



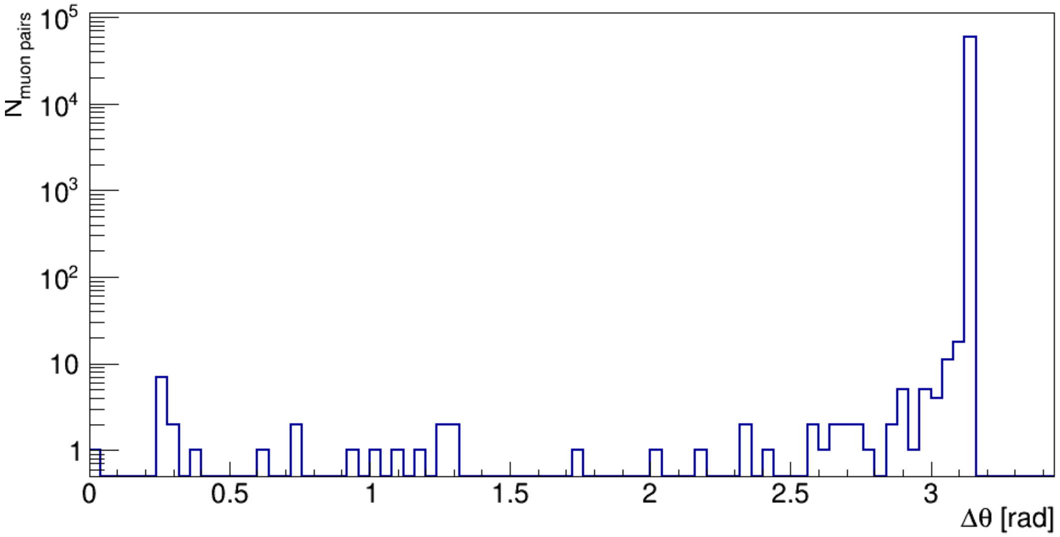
θ angle of muons with respect to the z axis in the detector acceptance



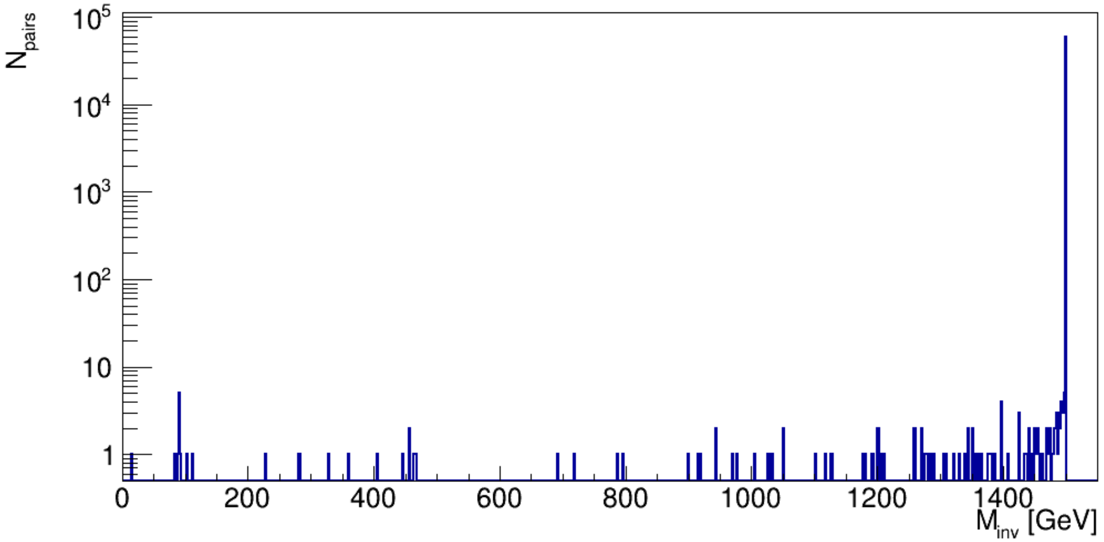
Transverse momentum of muons in the detector acceptance

Status of the activities: first look at data

Analysis on the muons's pairs in the detector acceptance with P_t>130 GeV



$\Delta\theta$ between the muons in the detector acceptance

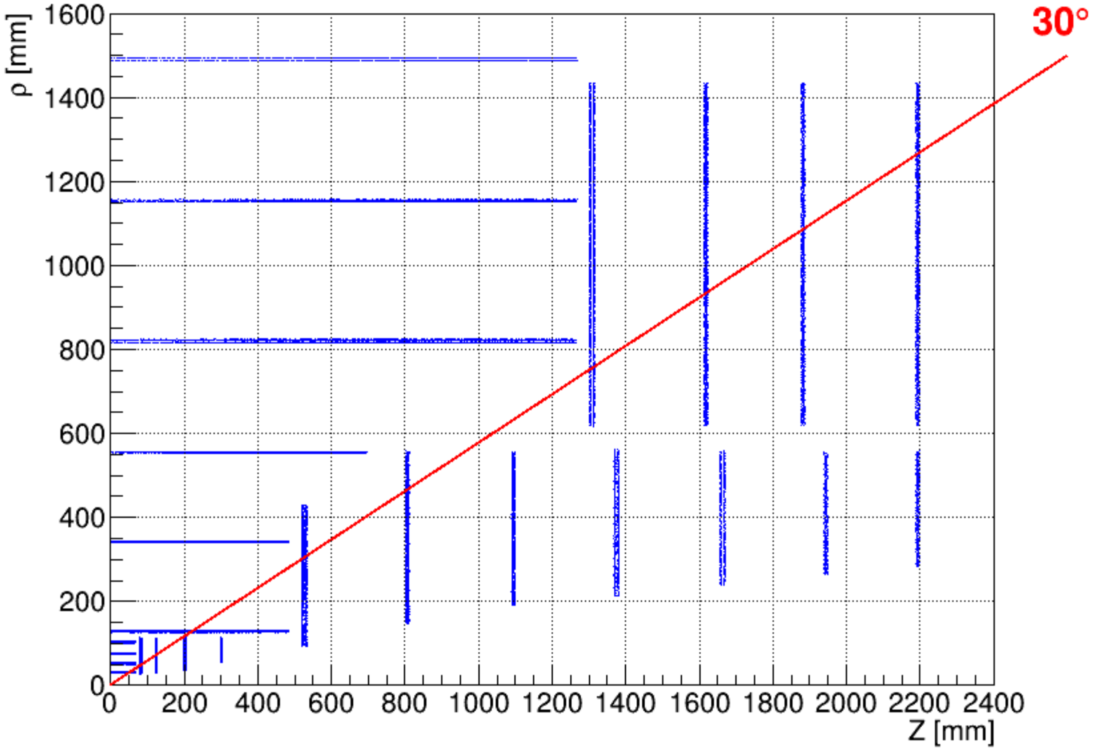


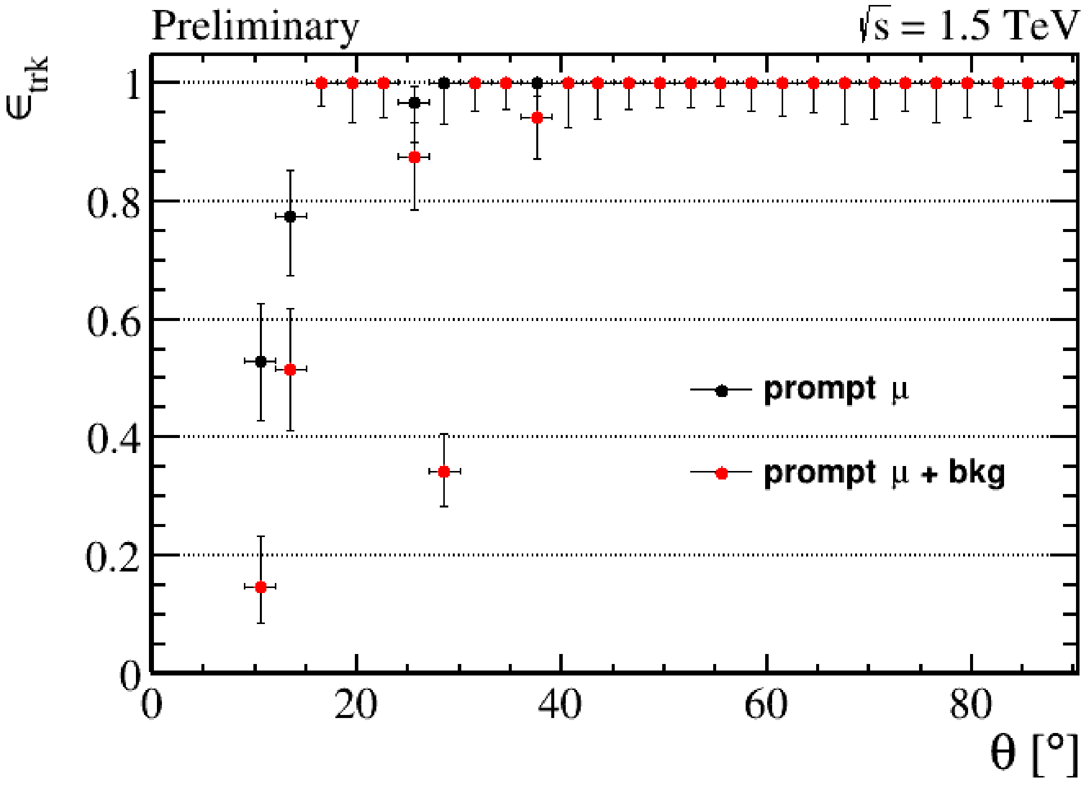
Invariant mass of the muons

Assuming a Snowmass year = 10^7seconds
$\mathscr{L}$=1.25•10^{34} $cm^{-2}s^{-1}$
Total events: 2.3 M

Status of the activities: Identify "safe" detector regions

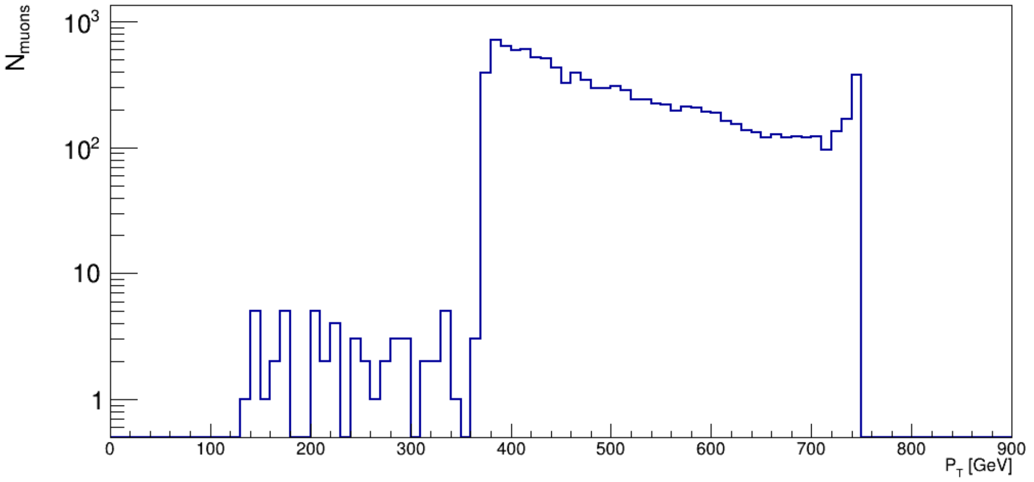
In order to avoid the crowded regions affected by beam-induced background muons $30^o < \theta < 150^o$ are selected in addition to P_t>130 GeV





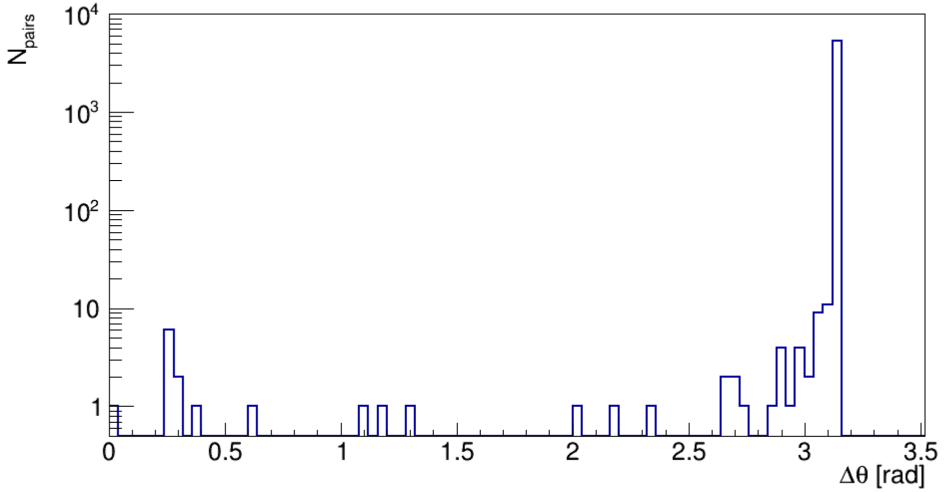
Status of the activities count useful events

Muons with $30^o < \theta < 150^o$ are selected and P_t>130 GeV

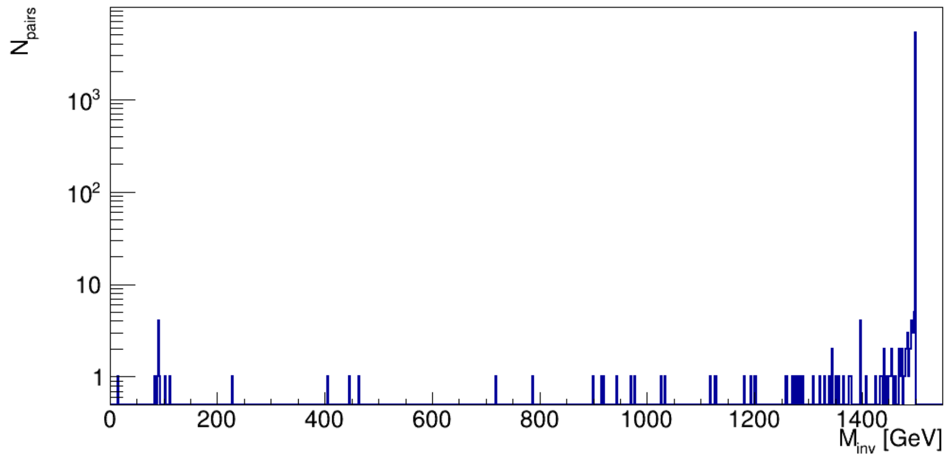


Transverse momentum of muons in the detector acceptance

$\Delta\theta$ between the muons



Invariant mass of the muons



Assuming a Snowmass year = 10^7seconds

$\mathscr{L}=1.25 \cdot 10^{34}\ cm^{-2}s^{-1}$

Total events: 213 K

$$\frac{\Delta\mathcal{L}}{\mathcal{L}} \sim \frac{1}{\sqrt{N}} = 0.002$$

Summary

- A method to measure the luminosity at Muon Collider is proposed based on μ-Bhabha at large angle.

- By looking at the number of events produced by using Pythia it seems the number of events is enough to determine the luminosity with a reasonable precision (usually ~1%) at least at $\sqrt{s}$=1.5TeV.

- The next steps:
  - Re-do the exercise with the full detector simulation.
  - Perform the same analysis at $\sqrt{s}$ =3.0 TeV and $\sqrt{s}$=10 TeV.
  - Use mu-BabaYaga to generate $\mu^+ \mu^- \rightarrow \mu^+ \mu^-$ samples and identify the best kinematic cuts to select Bhabha events.
  - Determine the theoretical precision on the cross section at the different center of mass energies.