EF04 Topical Group Community Meeting

Friday Dec 4, 2020, 10:00 AM → 11:20 AM US/Eastern

Muon Collider: study of methods for the luminosity measurement

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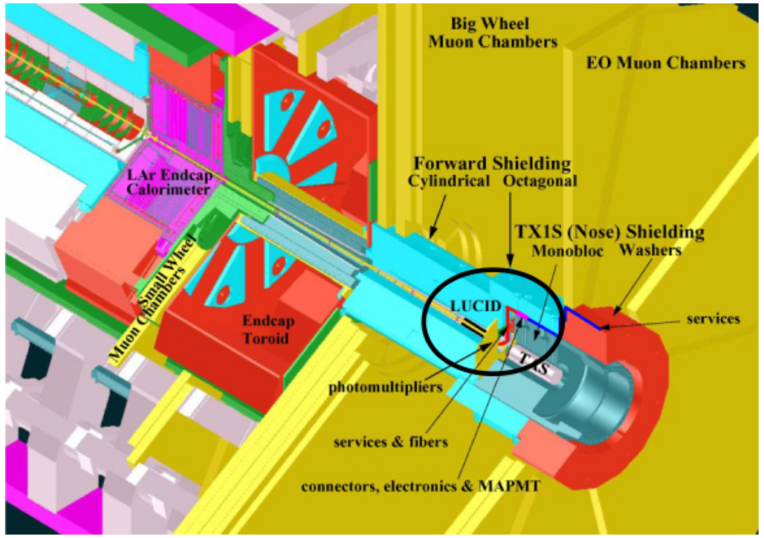
Luminosity Measurements: method 1

- 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

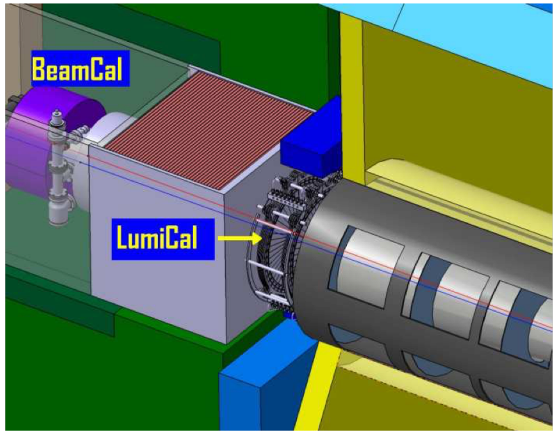


Luminosity Measurements: method 2 at e^+e^-

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: $N=L\cdot\sigma_{\mathrm{th}}$

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

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



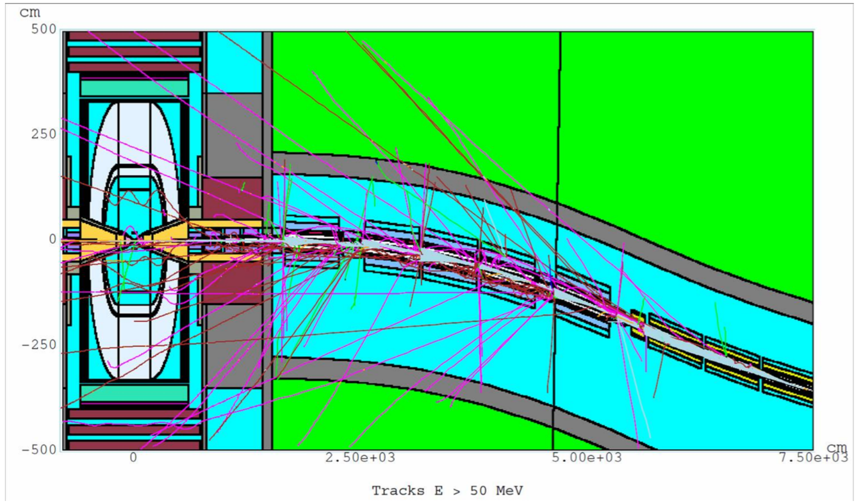
Source of uncertainty	$\Delta L/L$ (500 GeV)	$\Delta L/L$ (1 TeV)
Bhabha cross-section σ_B	$5.4\cdot 10^{-4}$	$5.4\cdot 10^{-4}$
Polar angle resolution σ_θ	$1.6\cdot 10^{-4}$	$1.6\cdot 10^{-4}$
Bias of polar angle $\Delta\theta$	$1.6\cdot 10^{-4}$	$1.6\cdot 10^{-4}$
IP lateral position uncertainty	$1\cdot 10^{-4}$	$1\cdot 10^{-4}$
Energy resolution a_{res}	$1.0\cdot 10^{-4}$	$1.0\cdot 10^{-4}$
Energy scale	$1.0\cdot 10^{-3}$	$1.0\cdot 10^{-3}$
Beam polarization	$1.9\cdot 10^{-4}$	$1.9\cdot 10^{-4}$
Physics background B/S	$2.2\cdot 10^{-3}$	$0.8\cdot 10^{-3}$
Beamstrahlung + ISR^{1}	$-1.1\cdot 10^{-3}$	$-0.7\cdot 10^{-3}$
Beamstrahlung + ISR^{2}	$0.4\cdot 10^{-3}$	$0.7\cdot 10^{-3}$
EMD^{1}	$-2.4\cdot 10^{-3}$	$-1.1\cdot 10^{-3}$
EMD^{2}	$0.5\cdot 10^{-3}$	$0.2\cdot 10^{-3}$
$(\Delta L/L)^1$	$4.3\cdot 10^{-3}$	$2.3\cdot 10^{-3}$
$(\Delta L/L)^2$	$2.6\cdot 10^{-3}$	$1.6\cdot 10^{-3}$

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

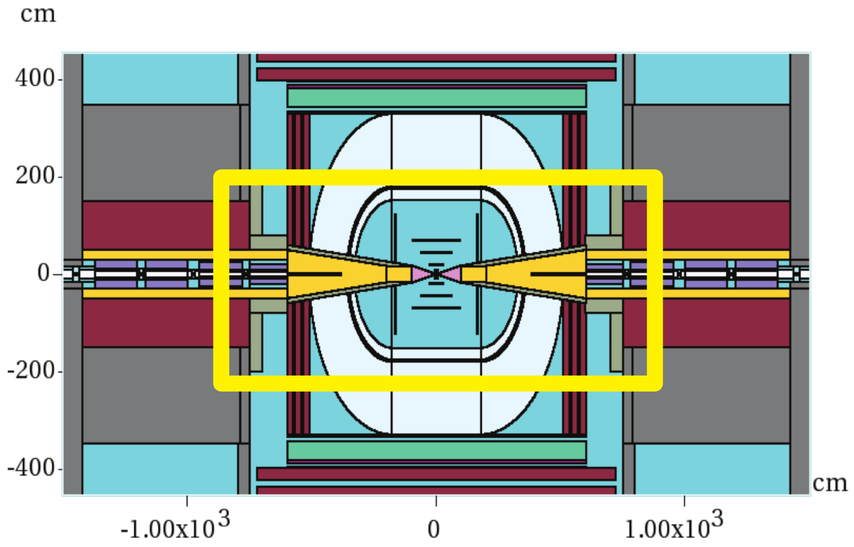
Muon Collider: Beam-Induced Background

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.

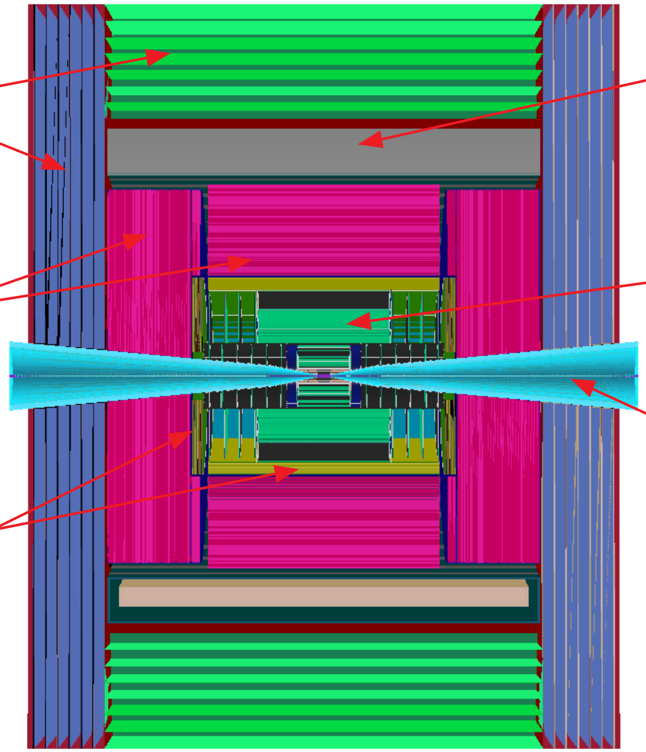


Nozzles have been designed to mitigate the effect of a such background.



Detector for $\sqrt{s}$ =1.5 TeV Collisions

CLIC Detector technologies adopted with important modifications to cope with BIB



Vertex Detector (VXD)

- 4 double-sensor barrel layers 25x25μm^2
- 4+4 double-sensor disks 25x25μm^2

Inner Tracker (IT)

- 3 barrel layers 50x50μm^2
- 7+7 disks ”

Outer Tracker(OT)

- 3 barrel layers 50x50μm^2
- 4+4 disks ”

Electromagnetic Calorimeter (ECAL)

- 40 layers W absorber and silicon pad sensors, 5x5 mm^2

Hadron Calorimeter (HCAL)

- 60 layers steel absorber & plastic scintillating tiles, 30x30 mm^2

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 the 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.

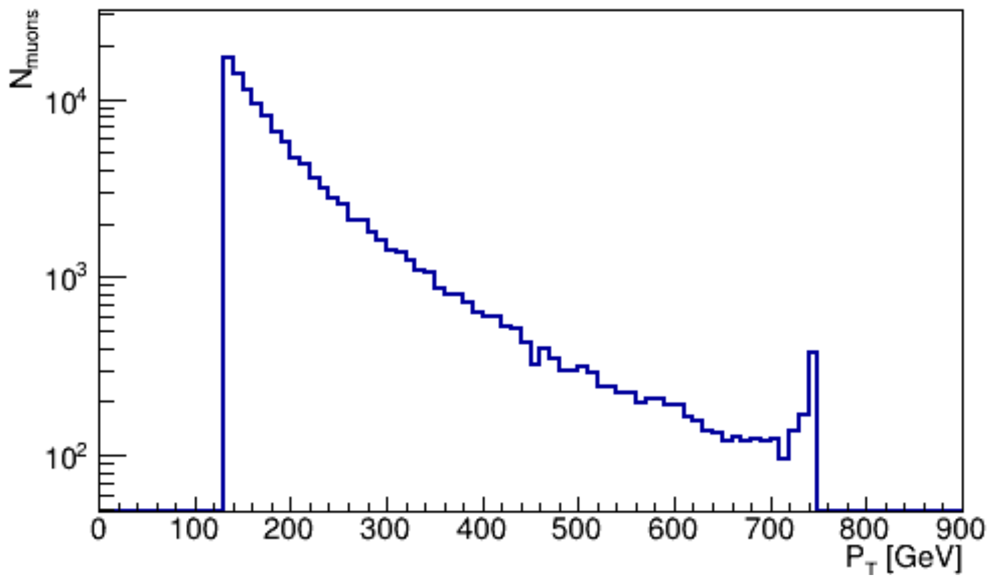
PYTHIA Event and Cross Section Statistics

Subprocess	Code	Number of events: Tried	Selected	Accepted	sigma +- delta (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

Status of the activities: first look at data

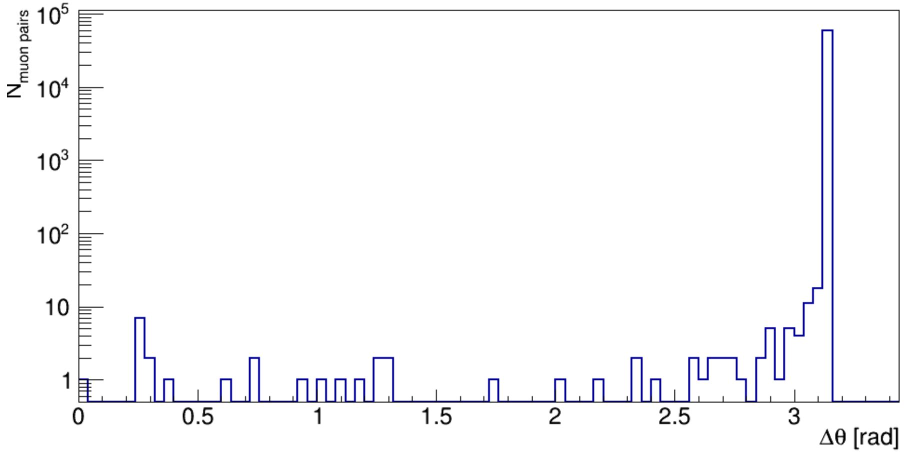
Accepting all muons in the detector acceptance with P_t>130 GeV



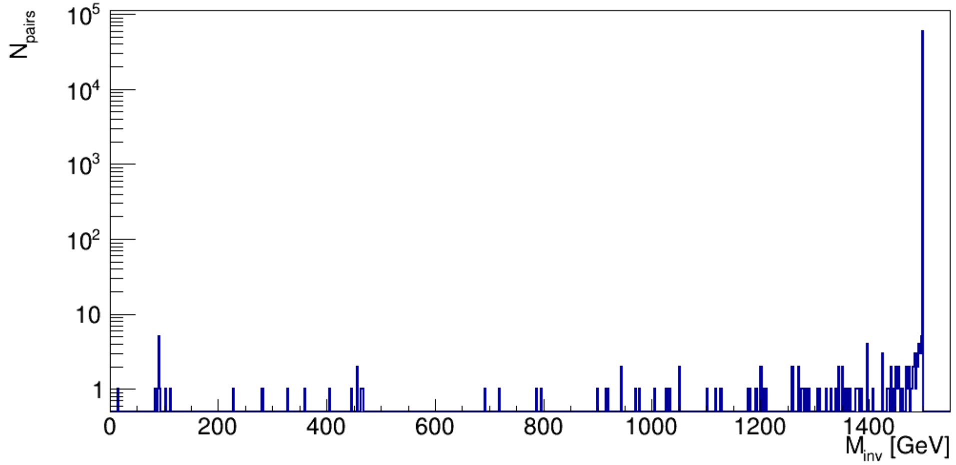
Transverse momentum of muons in the detector acceptance

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

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

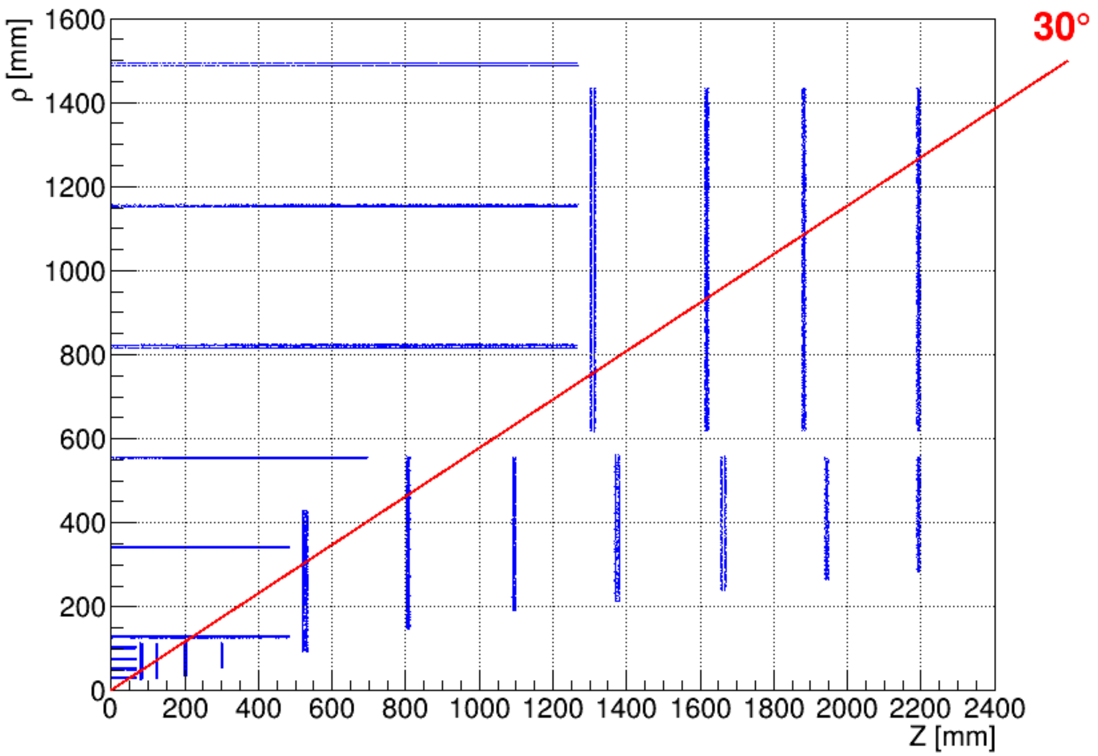


Invariant mass of the muons



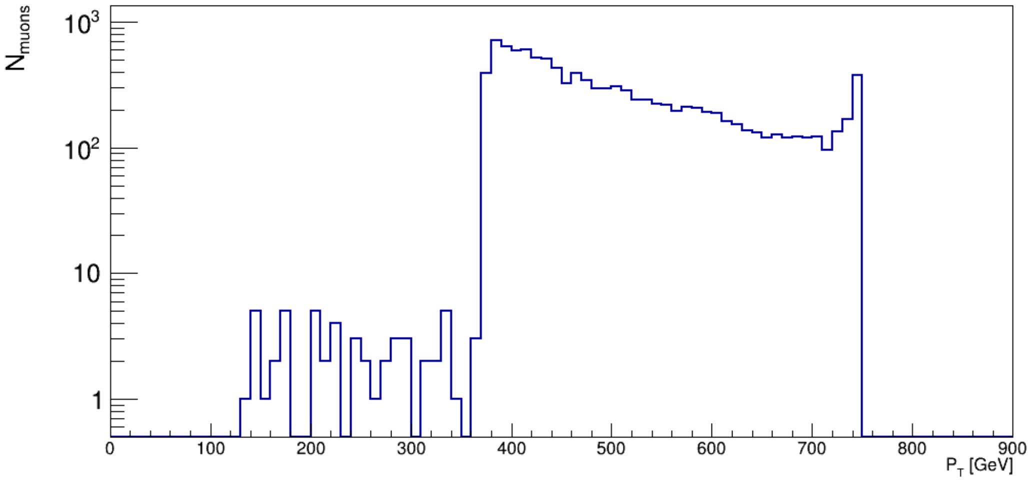
Status of the activities: Identify “safe” detector regions

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



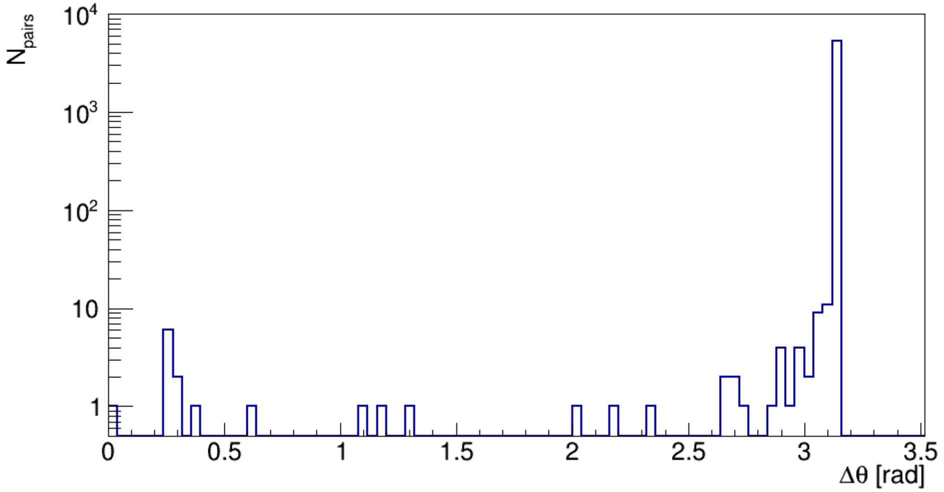
Status of the activities count useful events

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

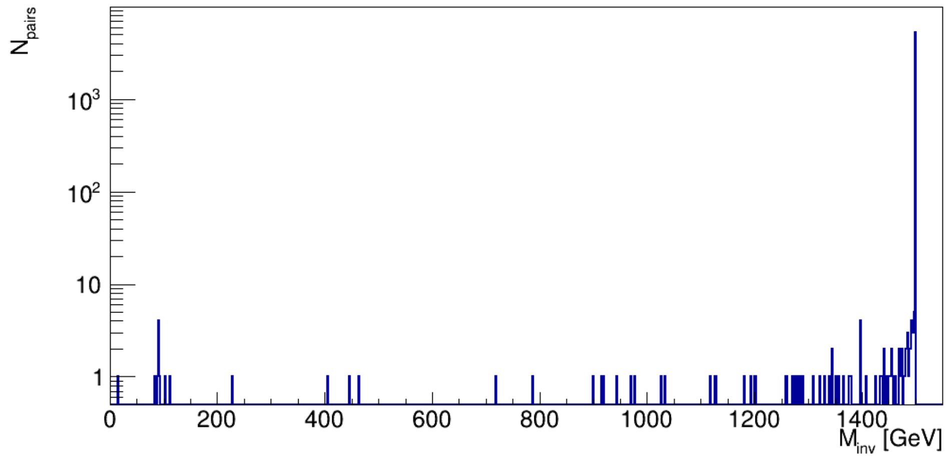


Transverse momentum of muons in the detector acceptance

$\Delta\theta$ between the muons



Invariant mass of the muons



Assuming a Snowmass year = 10^7seconds
$\mathcal{L}$=$1.25 \bullet 10^{34}$ $cm^{-2}s^{-1}$
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 $\mu^+ \mu^- \to \mu^+ \mu^-$ 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.