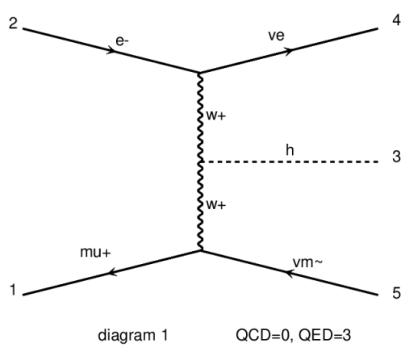
MUON COLLIDER

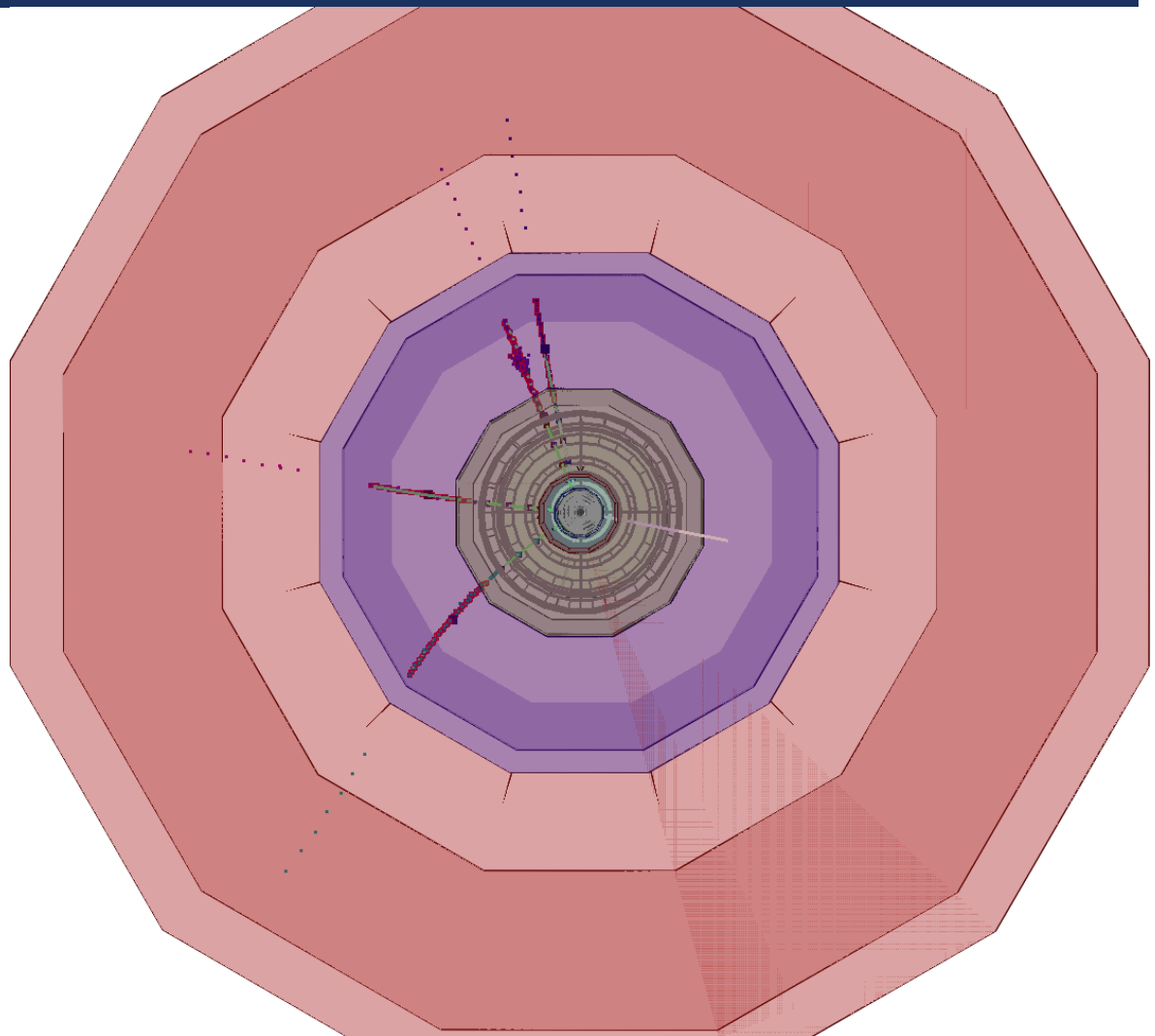
$$\mu^+\mu^- \rightarrow \mathrm{H} \rightarrow \mathrm{ZZ} \rightarrow 4\mu$$

$$WW fusion$$



Preliminary results

$\sqrt{s}$ = 1.5 TeV and 3 TeV studies



Angela Zaza, Anna Colaleo, Filippo Errico,
Paola Mastrapasqua, Rosma Venditti

LAST PRESENTATION

Samples

	Physical process	#Events	Cross section (fb)
Signal	$\mu^+\mu^- \rightarrow \mathrm{H} \rightarrow Z^*\mathrm{Z} \rightarrow 4\mu$	4000	$9.291 \cdot 10^{-3}$
Irreducible bkg	$\mu^+\mu^- \rightarrow \mathrm{Z}\mu^+\mu^-\nu_\mu\overline{\nu_\mu}$ (*) $\mathrm{Z} \rightarrow \mu^+\mu^-$	4000	$7.972 \cdot 10^{-2}$
	$\mu^+\mu^- \rightarrow \mathrm{Z}\mu^+\mu^-$ $\mathrm{Z} \rightarrow \mu^+\mu^-$	4000	1.877

$\sqrt{s}$ = 1.5 TeV

Software release: v02-05-MC

Magnetic Field: 3.57 T

Muon Barrel: -1.34 T

Double Layer Filter not enabled

(*) in order to avoid $\mu^+\mu^-$ annihilation, we produced $\mu^+e^- \rightarrow \mathrm{Z}\mu^+\mu^-\nu_e\overline{\nu_\mu}$ with MadGraph (Fabio Maltoni suggestion)

Sample production UPDATE

Different process produced for the irreducible bkg study:

$$\tau^{+}e^{-} \rightarrow 4\mu\, \bar{\nu}_{\tau}\, \nu_{e} \text{ (*)}$$

Now, we do not require anymore a real Z boson in the final state.

In order to have a better statistics, some cuts are applied at the generator level:

- Pt > 5 GeV
- $\eta < 3.0$
- 10 < invMass($\mu^{+}\mu^{-}$) < 200 GeV

The cross section obtained by MadGraph has been already scaled down, taking into account the selection efficiencies for the applied cuts.

(*) Fabio Maltoni suggestion

Samples 1.5 TeV

	Physical process	#Events	Cross section (fb)
Signal	$\mu^+\mu^- \rightarrow \mathrm{H} \rightarrow Z^*\mathrm{Z} \rightarrow 4\mu$ No selection	10000	$9.291 \cdot 10^{-3}$
Irreducible bkg	$\tau^+ e^- \rightarrow 4\mu\, \bar{\nu}_\tau\, \nu_e$ Selection: Pt > 5 GeV $\eta < 3.0$ 10 < invMass($\mu^+\mu^-$) < 200 GeV	9998	$1.407 \cdot 10^{-2}$

$\sqrt{s}$ = 1.5 TeV
Lumi: $500\ fb^{-1}$

Software release: v02-05-MC
Magnetic Field: 3.57 T
Muon Barrel: -1.34 T
Double Layer Filter not enabled

Samples 3 TeV

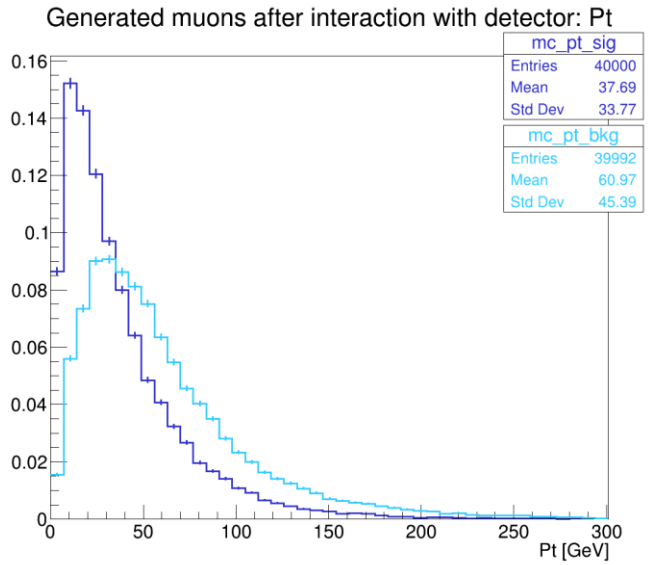
	Physical process	#Events	Cross section (fb)
Signal	$\mu^+\mu^- \rightarrow \mathrm{H} \rightarrow Z^*\mathrm{Z} \rightarrow 4\mu$ No selection	4000	$1.47 \cdot 10^{-2}$
Irreducible bkg	$\tau^+ e^- \rightarrow 4\mu\, \bar{\nu}_\tau\, \nu_e$ Selection: Pt > 5 GeV $\eta < 3.0$ 10 < invMass($\mu^+\mu^-$) < 200 GeV	9999	$2.89 \cdot 10^{-2}$

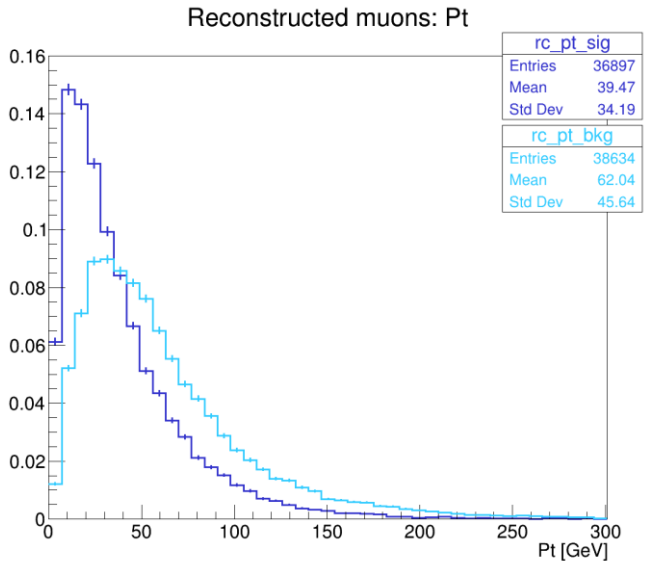
$\sqrt{s}$ = 3 TeV
Lumi: $1300\ fb^{-1}$

Software release: v02-05-MC
Magnetic Field: 3.57 T
Muon Barrel: -1.34 T
Double Layer Filter not enabled

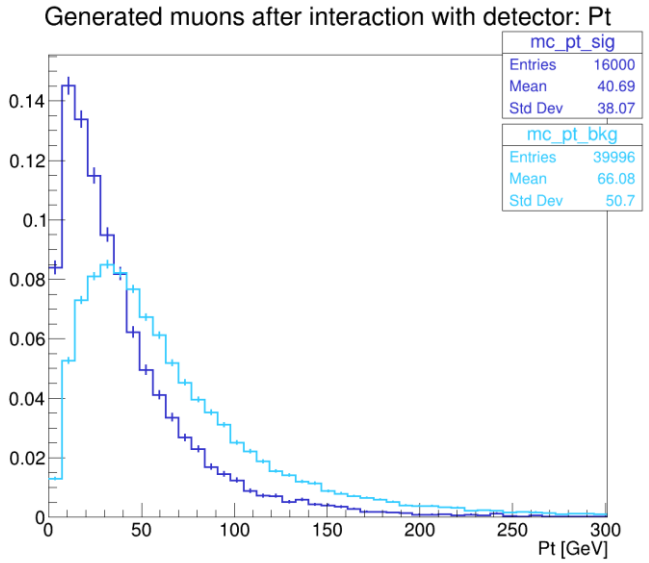
Transverse Momentum: comparison between Generated and Reconstructed Muons

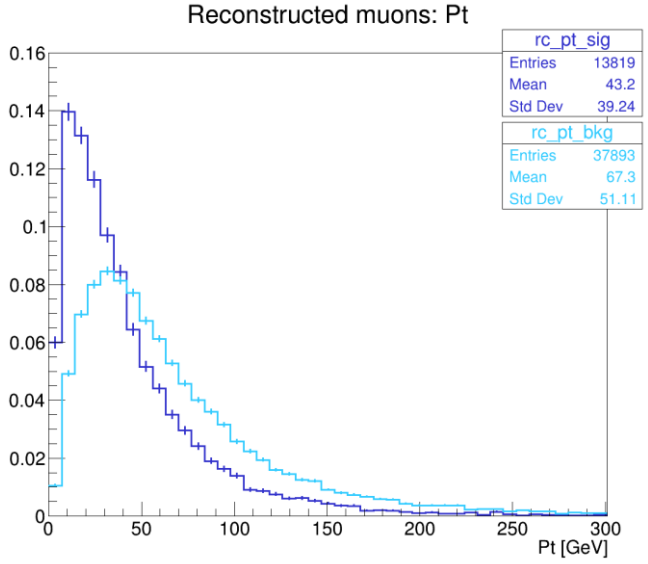
1.5 TeV





3 TeV



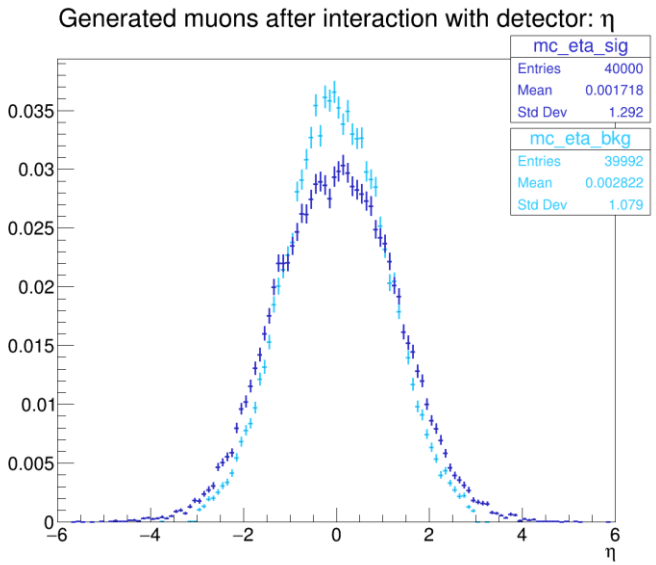


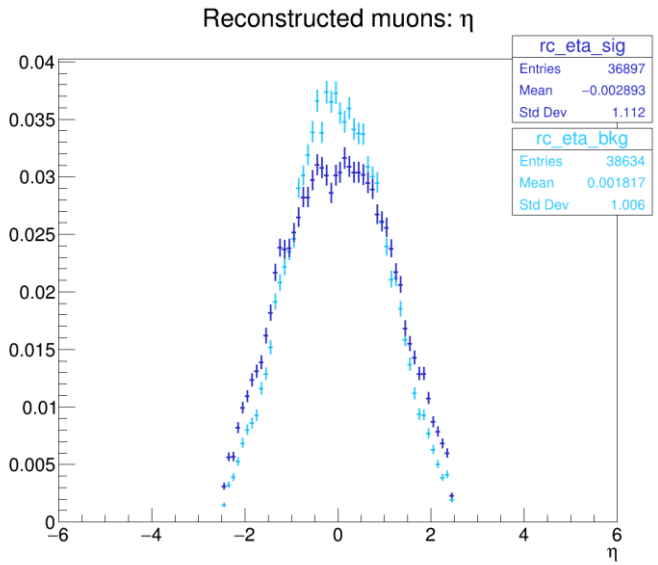
Histograms are normalized to 1

Reconstructed Muons: Particle Flow output collection.

Pseudorapidity: comparison between Generated and Reconstructed Muons

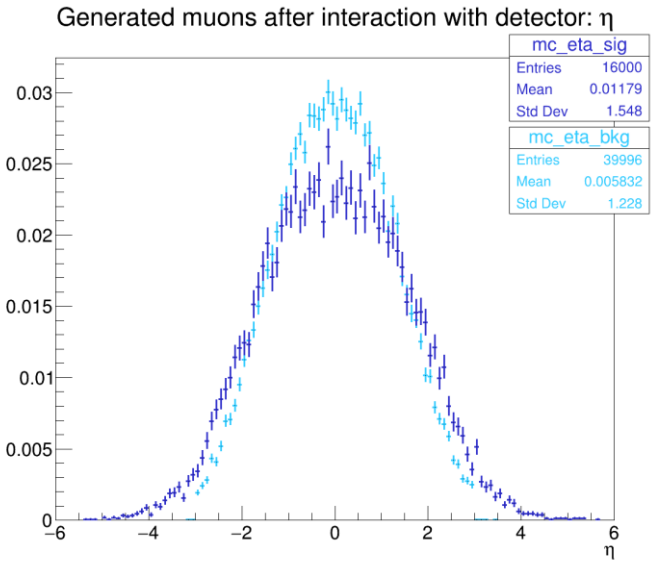
1.5 TeV

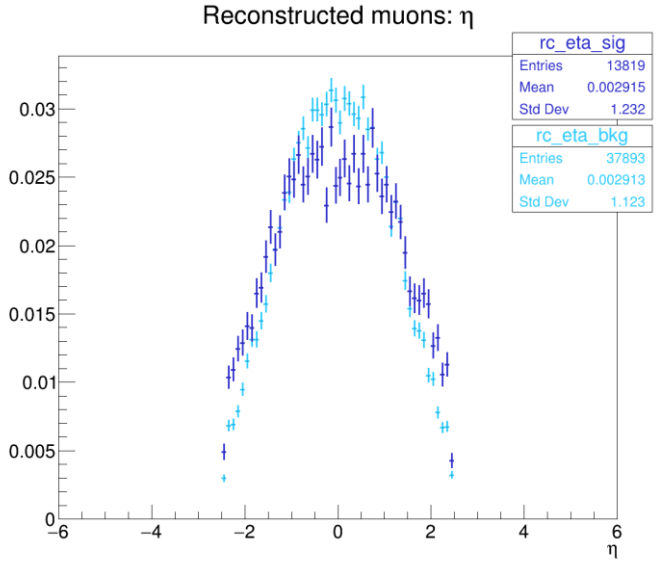




Histograms are normalized to 1

3 TeV

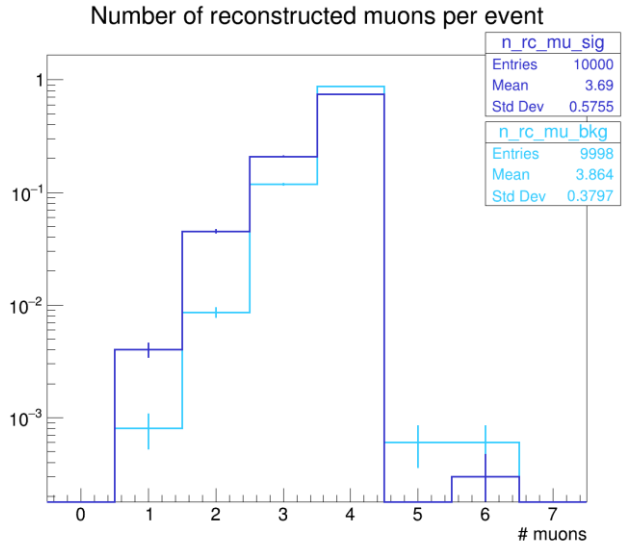




Reconstructed Muons: Particle Flow output collection.

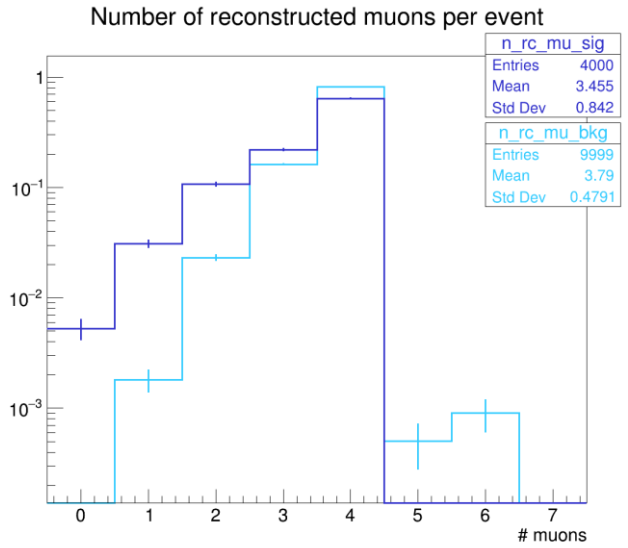
Number of Reconstructed Muons per event

1.5 TeV



# Reco muons	signal	bkg
0	1	0
1	40	8
2	451	86
3	2083	1180
<4	2575	1274
% wrt the total number of Gen events	**25.75%**	**12.74%**

3 TeV



# Reco muons	signal	bkg
0	21	0
1	123	18
2	427	231
3	874	1610
<4	1445	1859
% wrt the total number of Gen events	**36.13%**	**18.59%**

Histograms are normalized to 1

Selection of good final state muons

Table A

	SIGNAL				BACKGROUND			
Selection	**#muons**	**Absolute efficiency**	**Relative efficiency**	**#evts**	**#muons**	**Absolute efficiency**	**Relative efficiency**	**#evts**
GEN	40000			10000	39992			9998
$\|\eta\| < 2.5$	36897 ± 192	0.9224 ± 0.0013	0.9224 ± 0.0013	7425 ± 86	38634 ± 197	0.9660 ± 0.0009	0.9660 ± 0.0009	8724 ± 93
$P_T > 5GeV$	35782 ± 189	0.8946 ± 0.0015	0.9698 ± 0.0009	6511 ± 81	38590 ± 196	0.9649 ± 0.0009	0.9989 ± 0.0001	8688 ± 93
$D_0 < 2\ mm$	35776 ± 189	0.8944 ± 0.0015	0.9998 ± 0.0001	6506 ± 81	38583 ± 196	0.9648 ± 0.0009	0.9998 ± 0.0001	8682 ± 93
$Z_0 < 10\ mm$	35762 ± 189	0.8941 ± 0.0015	0.9996 ± 0.0001	6496 ± 81	38580 ± 196	0.9647 ± 0.0009	0.9999 ± 0.0001	8679 ± 93

From now on, only reconstructed muons passing the selection in Table A will be considered.

Selection of good final state muons

Table A

	SIGNAL				BACKGROUND			
Selection	**#muons**	**Absolute efficiency**	**Relative efficiency**	**#evts**	**#muons**	**Absolute efficiency**	**Relative efficiency**	**#evts**
GEN	16000			4000	39996			9999
$\|\eta\| < 2.5$	13819 ± 118	0.8637 ± 0.0027	0.8639 ± 0.0027	2555 ± 50	37893 ± 195	0.9474 ± 0.0011	0.9474 ± 0.0011	8140 ± 90.22
$P_T > 5GeV$	13384 ± 116	0.8365 ± 0.0029	0.9685 ± 0.0015	2235 ± 47	37833 ± 195	0.9459 ± 0.0011	0.9984 ± 0.0002	8090 ± 89.94
$D_0 < 2\ mm$	13377 ±116	0.8361 ± 0.0029	0.9995 ± 0.0002	2231 ± 47	37829 ± 194	0.9458 ± 0.0011	0.9999 ± 0.0001	8087 ± 89.93
$Z_0 < 10\ mm$	13373 ± 116	0.8358 ± 0.0029	0.9997 ± 0.0001	2229 ± 47	37822 ± 194	0.9456 ± 0.0011	0.9998 ± 0.0001	8080 ± 89.89

From now on, only reconstructed muons passing the selection in Table A will be considered.

ZZ Candidate Selection: inspired to CMS analysis

- Z candidates: pairs of selected muons of opposite charge that satisfy
  $12 < InvMass\ (\mu^+\mu^-) < 120\ GeV$

- ZZ candidates: pairs of non-overlapping Z candidates
  Z_1: Z candidate with reconstructed mass $m_{\mu^+\mu^-}$ closest to the nominal Z boson mass
  Z_2: the other Z candidate

  ZZ candidates are required to satisfy:
  - $\Delta R > 0.02$ between each of the 4 muons
  - At least 2 muons with:
    $P_{T,i} > 20\ GeV$
    $P_{T,j} > 10\ GeV$
  - $Z_1 mass > 40\ GeV$
  - $InvMass\ (4\mu) > 70\ GeV$

1.5 TeV

Selection of Events

Table B

Selection	SIGNAL #events	SIGNAL Absolute efficiency	SIGNAL Relative efficiency	BACKGROUND #events	BACKGROUND Absolute efficiency	BACKGROUND Relative efficiency
GEN	10000			9998		
At least 4 good final state muons	6496 ± 81			8679 ± 93		
Opposite sign muon pairs	6496 ± 81	1.00 ± 0.00	1.00 ± 0.00	8677 ± 93	0.9998 ± 0.0002	0.9998 ± 0.0002
$\Delta R > 0.02$ between each of the 4 muons	6485 ± 80	0.9983 ± 0.0005	0.9983 ± 0.0005	8675 ± 93	0.9995 ± 0.0002	0.9998 ± 0.0002
At least 2 muons with: $P_{T,i} > 20\ GeV$ $P_{T,j} > 10\ GeV$	6478 ± 80	0.9972 ± 0.0006	0.9989 ± 0.0004	8672 ± 92	0.9992 ± 0.0003	0.9997 ±0.0002
$12 < InvMass\ (\mu^+\mu^-) < 120\ GeV$	6465 ± 80	0.9952 ± 0.0008	0.9980 ± 0.0005	8476 ± 92	0.9766 ± 0.0016	0.9774 ± 0.0016
$Z_1 mass > 40\ GeV$	6420 ± 80	0.9883 ± 0.0013	0.9930 ± 0.0010	8447 ± 92	0.9733 ± 0.0017	0.9966 ± 0.0006
$InvMass\ (4\mu) > 70\ GeV$	6419 ± 80	0.9881 ± 0.0013	0.9998 ±0.0016	8446 ± 92	0.9732 ± 0.0017	0.9999 ± 0.0001

From now on, only events passing the selection in Table B will be considered.

3 TeV

Selection of Events

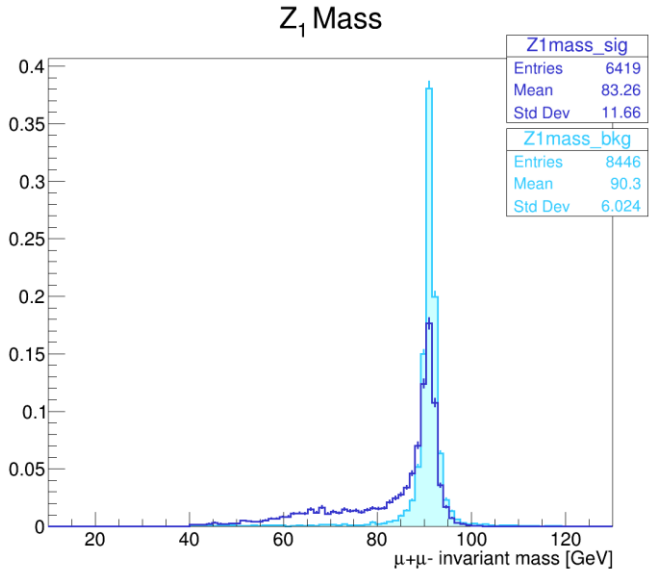
Table B

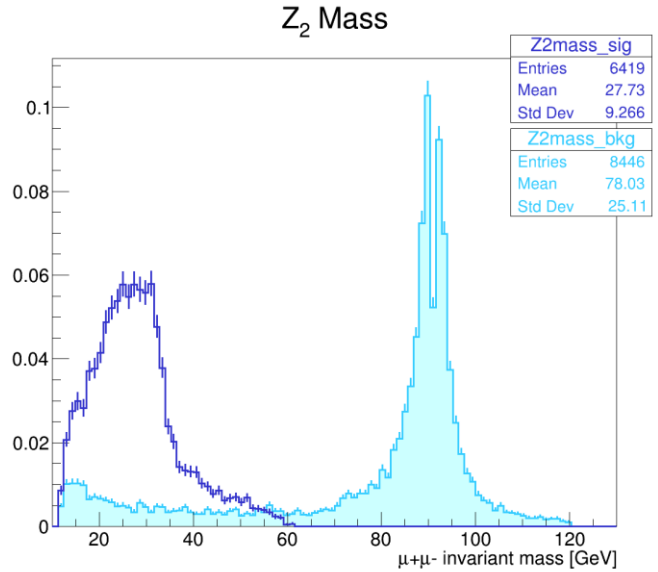
Selection	SIGNAL #events	SIGNAL Absolute efficiency	SIGNAL Relative efficiency	BACKGROUND #events	BACKGROUND Absolute efficiency	BACKGROUND Relative efficiency
GEN	4000			9999		
At least 4 good final state muons	2229 ± 47			8080 ± 90		
Opposite sign muon pairs	2229 ± 47	1.00 ± 0.00	1.00 ± 0.00	8080 ± 90	1.00 ± 0.00	1.00 ± 0.00
$\Delta R > 0.02$ between each of the 4 muons	2227 ± 47	0.9991 ± 0.0006	0.9991 ± 0.0006	8080 ± 90	1.00 ± 0.00	1.00 ± 0.00
At least 2 muons with: $P_{T,i} > 20\ GeV$ $P_{T,j} > 10\ GeV$	2224 ± 47	0.9978 ± 0.0009	0.9987 ± 0.0007	8077 ± 89	0.9996 ± 0.0002	0.9996 ± 0.0002
$12 < InvMass\ (\mu^+\mu^-) < 120\ GeV$	2217 ± 47	0.9946 ± 0.0014	0.9969 ± 0.0012	7888 ± 89	0.9762 ± 0.0017	0.9766 ± 0.0017
$Z_1 mass > 40\ GeV$	2196 ± 47	0.9852 ± 0.0024	0.9905 ± 0.0021	7857 ± 89	0.9724 ± 0.0018	0.9961 ± 0.0007
$InvMass\ (4\mu) > 70\ GeV$	2196 ± 47	0.9852 ± 0.0024	1.00 ± 0.00	7857 ± 89	0.9724 ± 0.0018	1.00 ± 0.00

From now on, only events passing the selection in Table B will be considered.

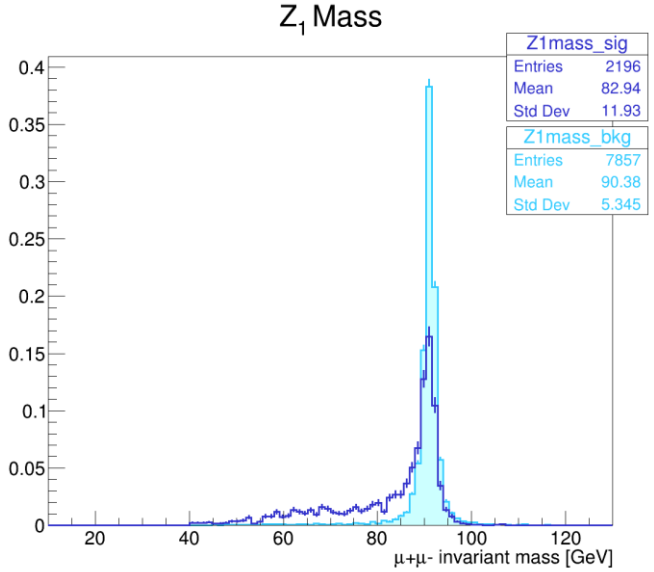
Z_1 and Z_2 Mass

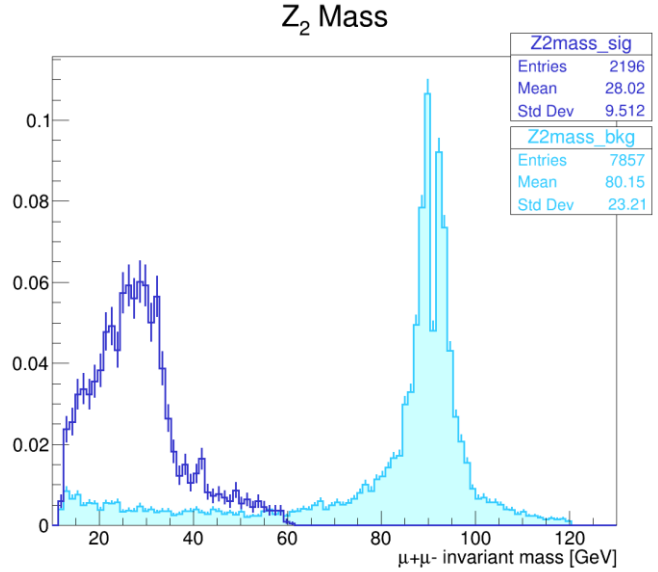
1.5 TeV





3 TeV

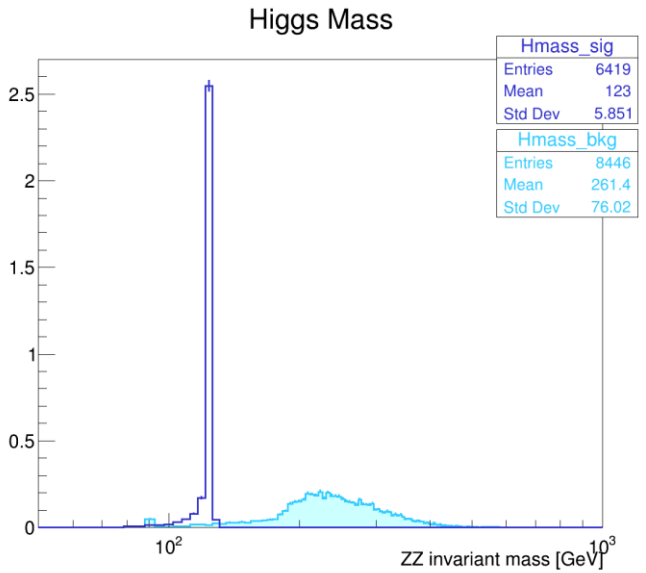


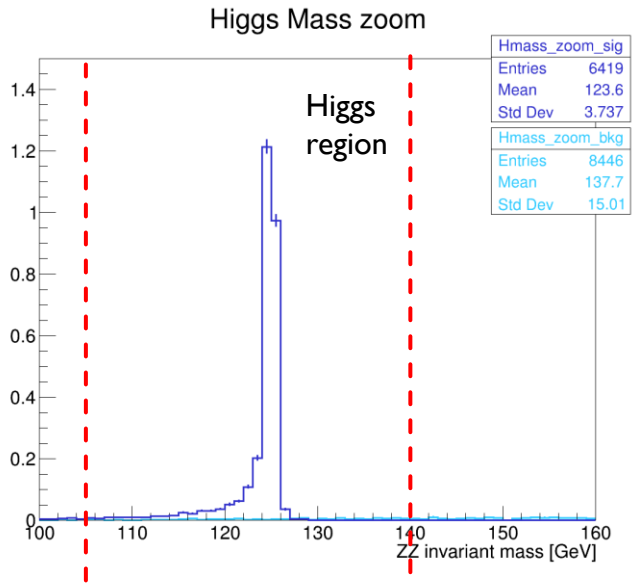


Histograms are normalized to 1

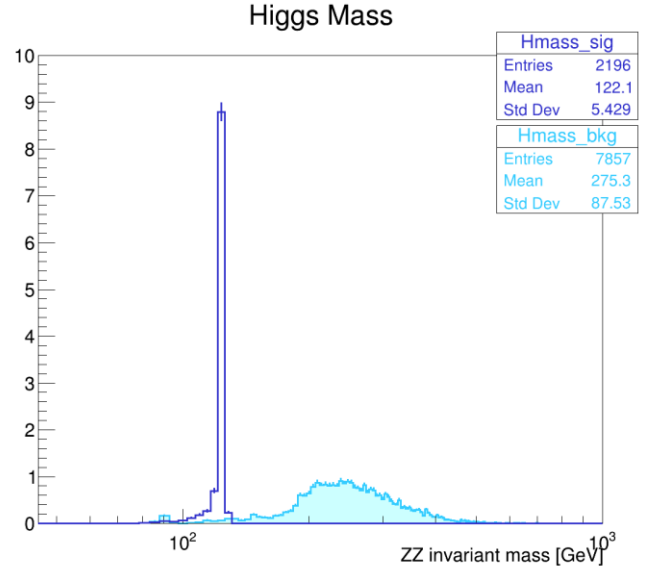
Higgs Mass

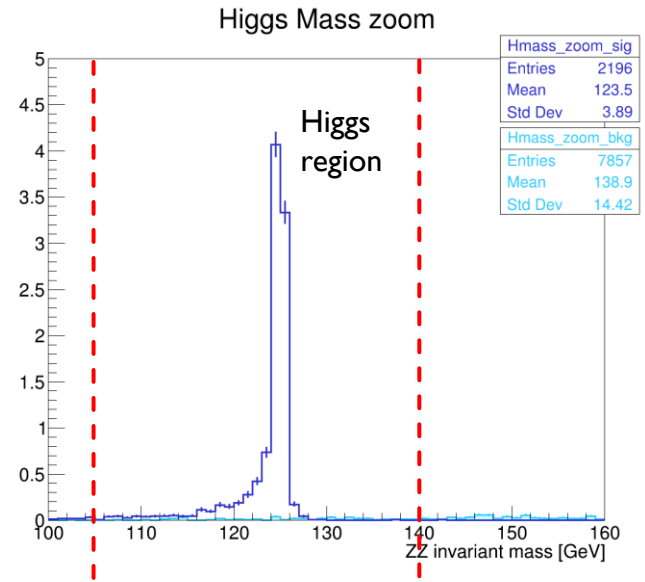
1.5 TeV





3 TeV





Histograms are normalized to cross section, integrated luminosity and number of events

Theoretical predictions

$$\mu^+\mu^- \rightarrow \mathrm{H} \rightarrow Z^*\mathrm{Z} \rightarrow 4\mu$$

$$\mathrm{BR}(H \rightarrow 4\mu) = BR(H \rightarrow ZZ) \cdot BR(Z \rightarrow \mu^+\mu^-)^2 = 2.99 \cdot 10^{-5}$$

1.5 TeV

	SIGNAL
Inclusive Cross Section (fb) $\mu^+\mu^- \rightarrow \mathrm{H}$ (VBF)	310
Cross section (fb)	$9.29 \cdot 10^{-3}$
Integrated Luminosity (fb^{-1})	500

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S} \xrightarrow[B\rightarrow 0]{} \frac{1}{\sqrt{S}} = \frac{1}{\sqrt{XS * Lumi}} = 46.40\%$$

Acceptance and selection efficiency → 1.00

$$\rightarrow \frac{\Delta\sigma}{\sigma} \sim 46.4\%$$

3 TeV

	SIGNAL
Inclusive Cross Section (fb) $\mu^+\mu^- \rightarrow \mathrm{H}$ (VBF)	500
Cross section (fb)	$1.47 \cdot 10^{-2}$
Integrated Luminosity (fb^{-1})	1300

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S} \xrightarrow[B\rightarrow 0]{} \frac{1}{\sqrt{S}} = \frac{1}{\sqrt{XS * Lumi}} = 22.88\%$$

Acceptance and selection efficiency → 1.00

$$\rightarrow \frac{\Delta\sigma}{\sigma} \sim 22.88\%$$

PRELIMINARY RESULTS
→ **ongoing study**

Preliminary Results

1.5 TeV

	SIGNAL	BKG
Cross section (fb)	$9.291 \cdot 10^{-3}$	$1.407 \cdot 10^{-2}$
Integrated Luminosity (fb^{-1})	500	

Events in the Higgs region (105 -140 GeV)

	#events	efficiency	Normalized
SIGNAL	6242 ± 69	0.6242 ± 0.0048	2.8997
BKG	187 ± 13	0.0187 ± 0.0014	0.1318

$$S/\sqrt{B} = 7.988$$

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S} = 60.04\%$$

$$\frac{\Delta g_{HZZ}}{g_{HZZ}} = \frac{1}{2}\sqrt{\left(\frac{\Delta\sigma}{\sigma}\right)^2 + \left[\frac{\Delta\left(\frac{g^2_{HWW}}{\Gamma_H}\right)}{\left(\frac{g^2_{HWW}}{\Gamma_H}\right)}\right]^2} = 30.06\%$$

3 TeV

	SIGNAL	BKG
Cross section (fb)	$1.47 \cdot 10^{-2}$	$2.89 \cdot 10^{-2}$
Integrated Luminosity (fb^{-1})	1300	

Events in the Higgs region (105 -140 GeV)

	#events	efficiency	Normalized
SIGNAL	2139 ± 46	0.5348 ± 0.0079	10.2191
BKG	121 ± 11	0.0121 ± 0.0011	0.4552

$$S/\sqrt{B} = 15.145$$

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S} = 31.97\%$$

$$\frac{\Delta g_{HZZ}}{g_{HZZ}} = \frac{1}{2}\sqrt{\left(\frac{\Delta\sigma}{\sigma}\right)^2 + \left[\frac{\Delta\left(\frac{g^2_{HWW}}{\Gamma_H}\right)}{\left(\frac{g^2_{HWW}}{\Gamma_H}\right)}\right]^2} = 16.04\%$$

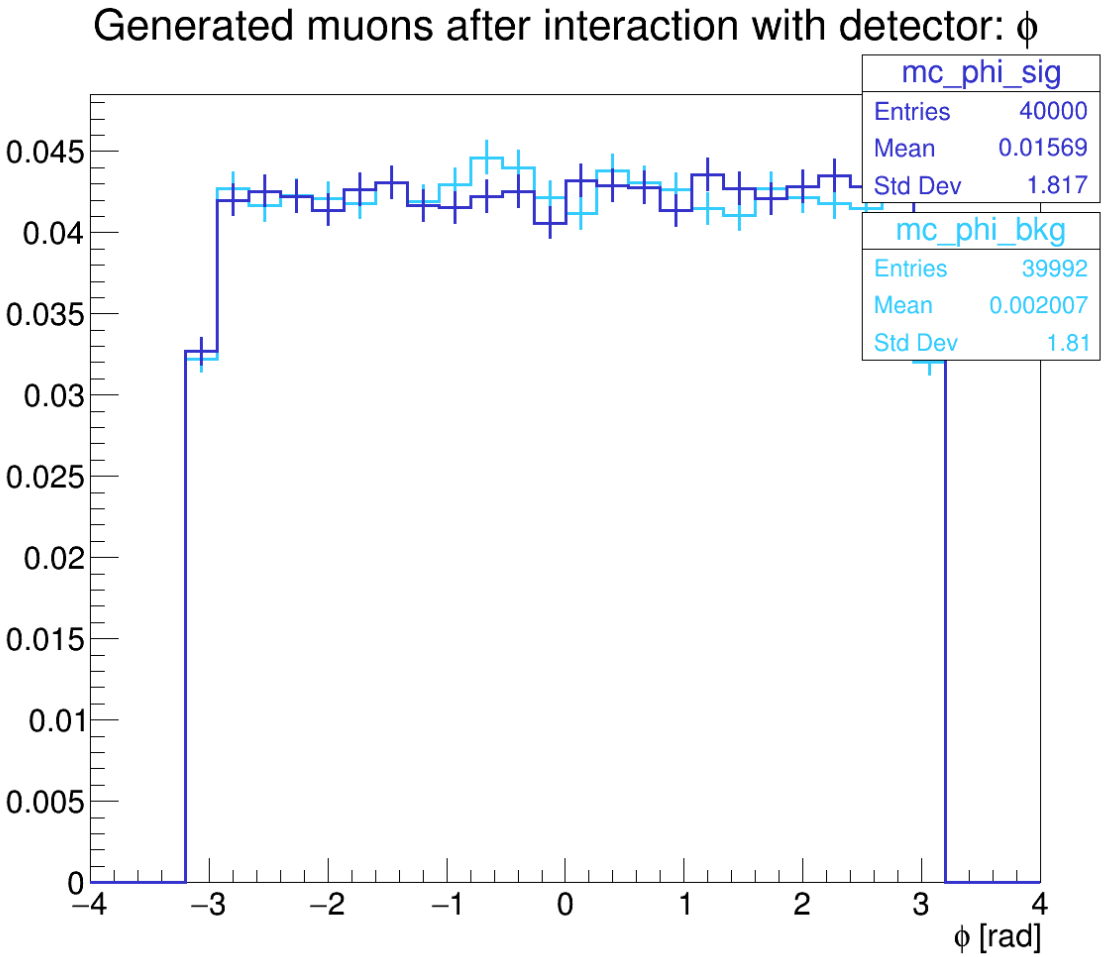
Inclusive final state $(4\mu, 4e, 2\mu 2e) \rightarrow \frac{\Delta g_{HZZ}}{g_{HZZ}} \sim 8\%$

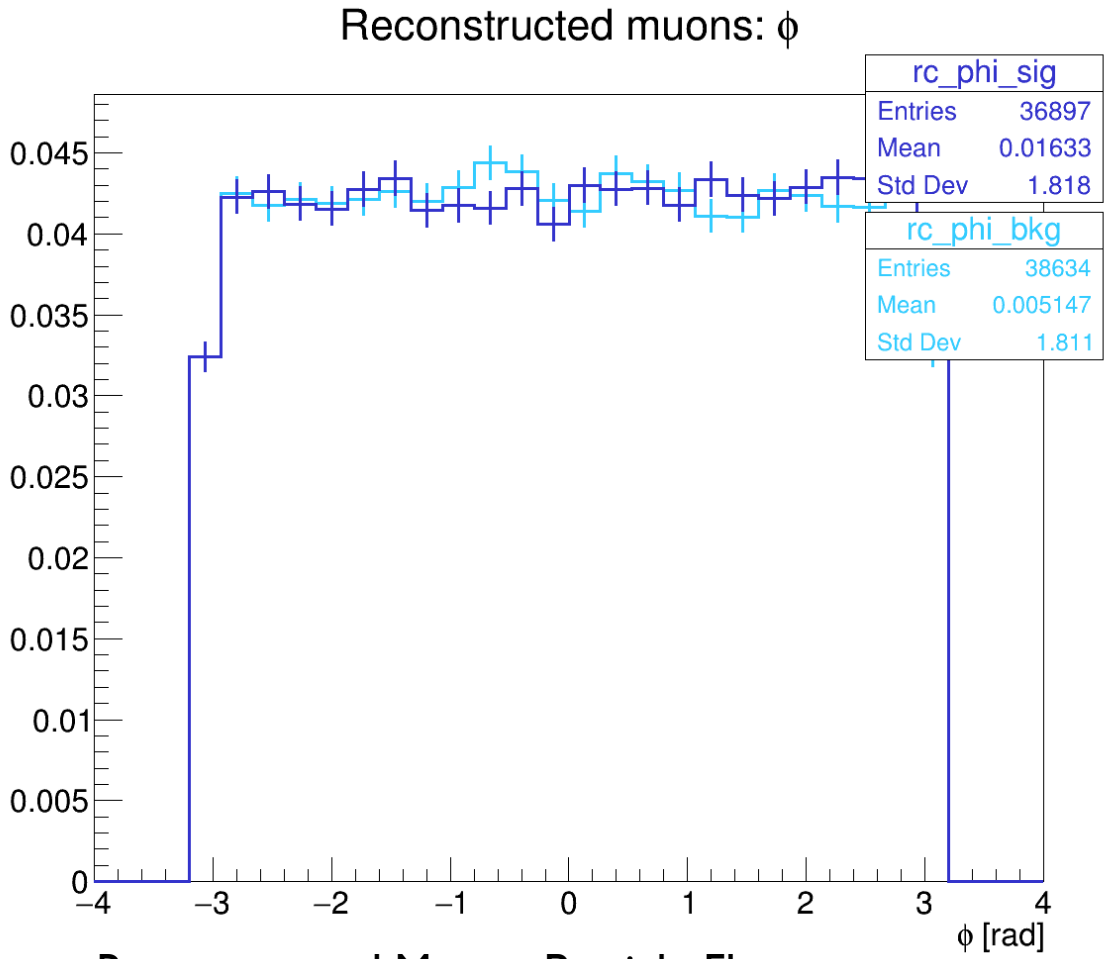
THANK YOU!

BACK UP

1.5 TeV

Azimuthal Angle: comparison between Generated and Reconstructed Muons



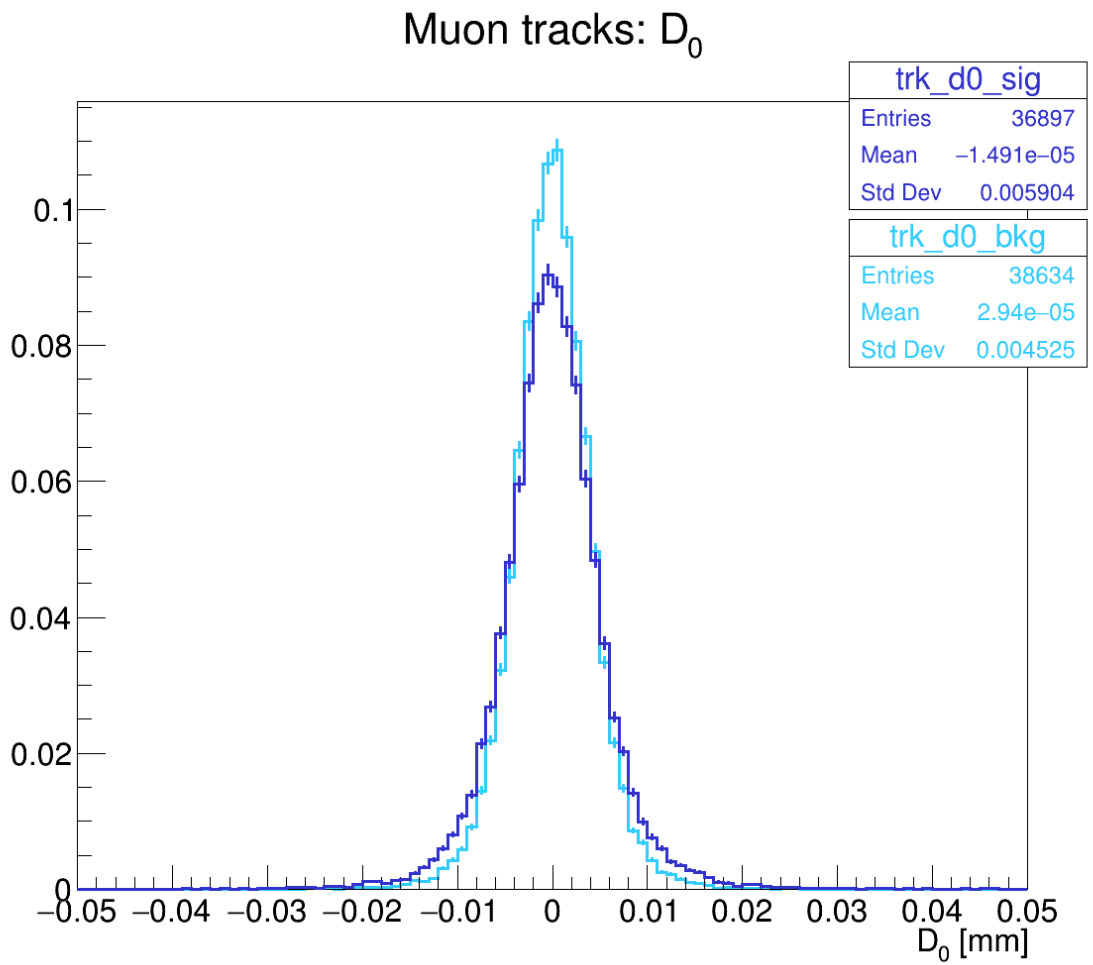


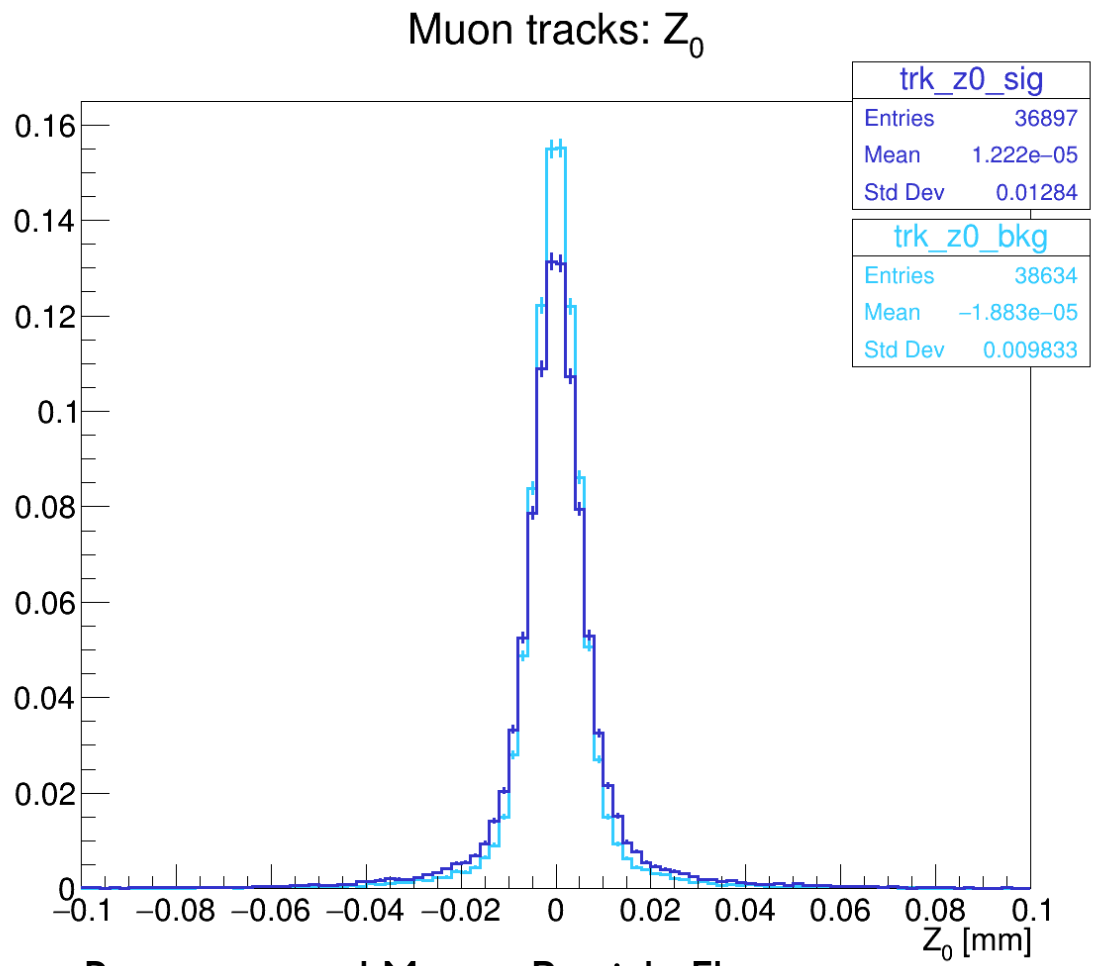
Reconstructed Muons: Particle Flow output collection.

Histograms are normalized to 1

1.5 TeV

Muon trak Parameters: D0 and Z0



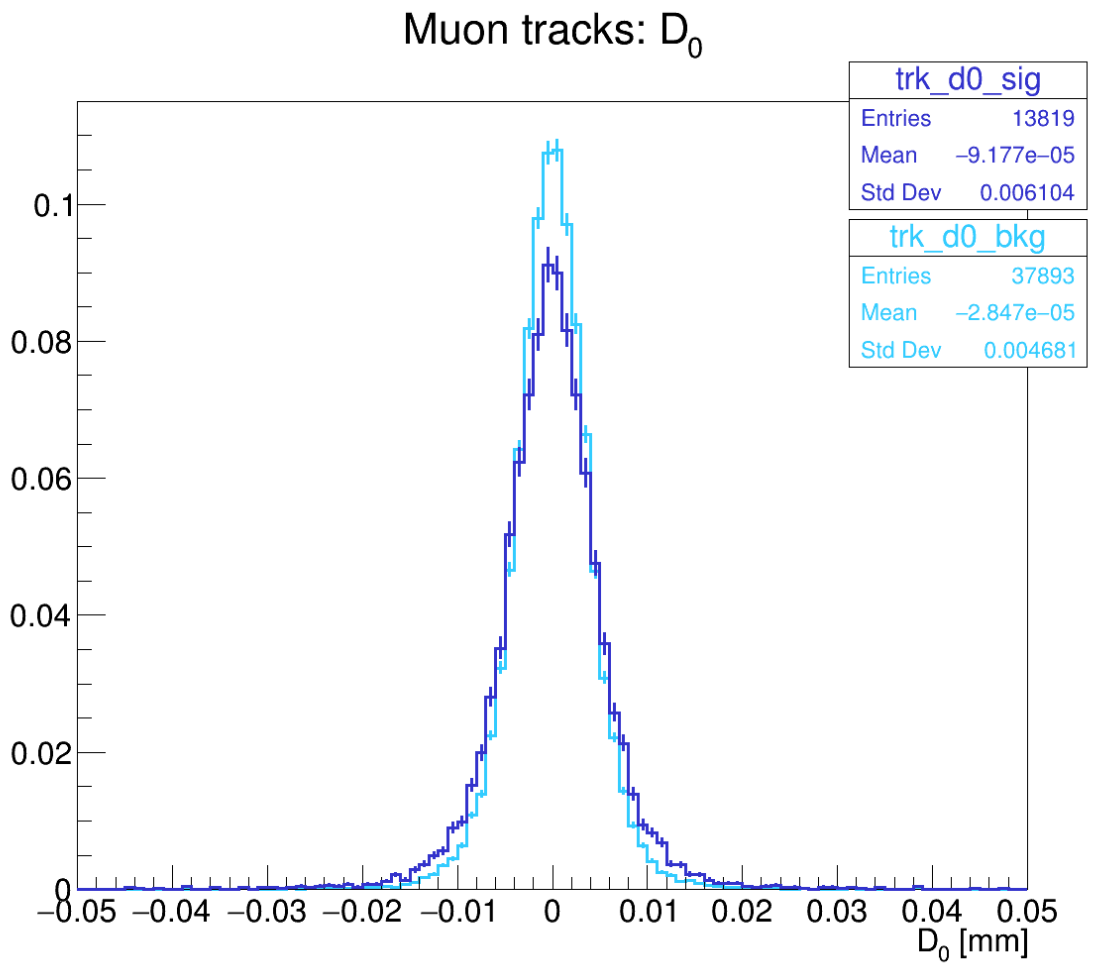


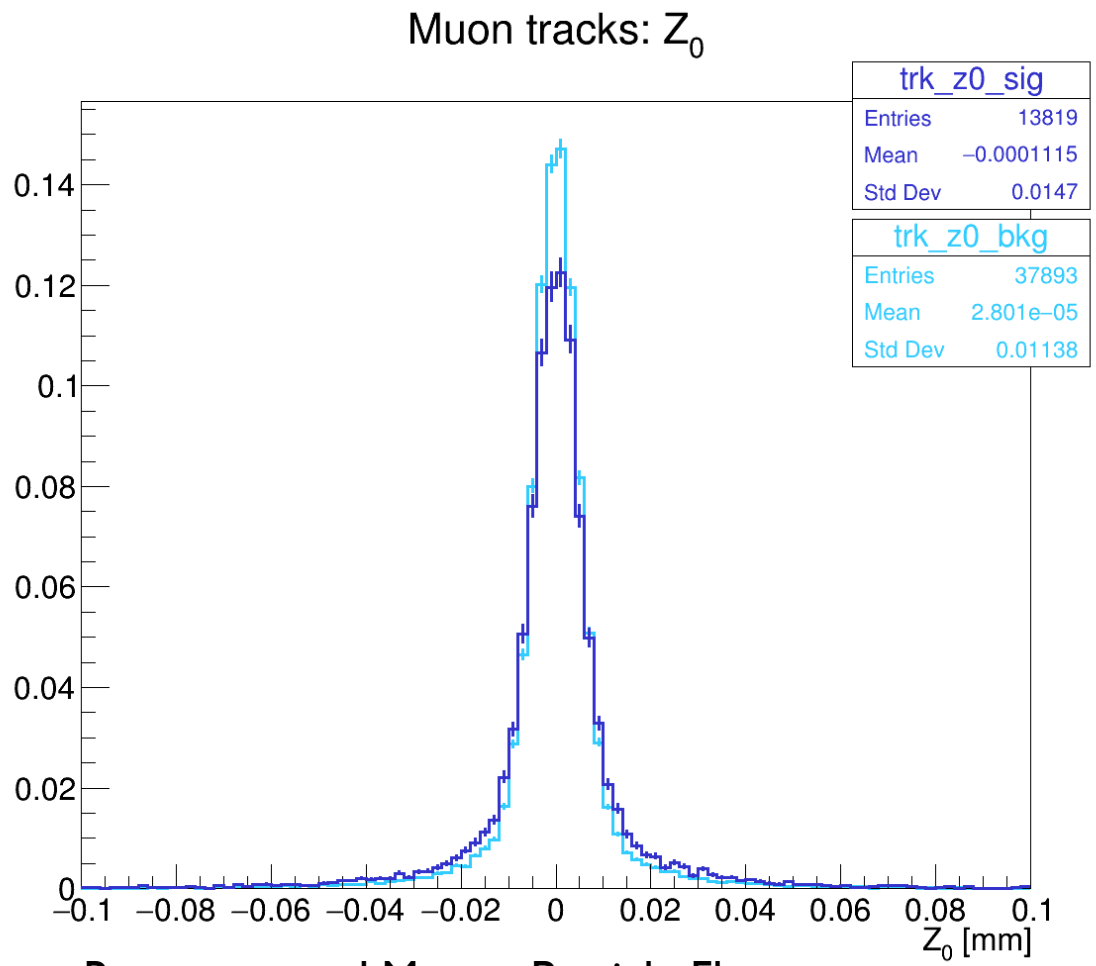
Reconstructed Muons: Particle Flow output collection.

Histograms are normalized to 1

3 TeV

Muon trak Parameters: D0 and Z0





Reconstructed Muons: Particle Flow output collection.

Histograms are normalized to 1

Theoretical predictions

3 TeV

$\mu^+\mu^- \rightarrow H \rightarrow Z^*Z \rightarrow 4\mu$

BR($H \rightarrow 4\mu$) = $BR(H \rightarrow ZZ) \cdot BR(Z \rightarrow \mu^+\mu^-)^2 = 2.99 \cdot 10^{-5}$

	SIGNAL
Inclusive Cross Section (fb) $\mu^+\mu^- \rightarrow H$ (VBF)	500
Cross section (fb)	$1.47 \cdot 10^{-2}$
Integrated Luminosity (fb^{-1})	1300

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S} \xrightarrow{B \rightarrow 0} \frac{1}{\sqrt{S}} = \frac{1}{\sqrt{XS * Lumi}} = 22.88\%$$

Acceptance and selection efficiency → 1.00

$$\rightarrow \frac{\Delta\sigma}{\sigma} \sim 22.88\%$$

$\mu^+\mu^- \rightarrow H \rightarrow bb$

BR($H \rightarrow bb$)= 0.58

	SIGNAL
Inclusive Cross Section (fb) $\mu^+\mu^- \rightarrow H$ (VBF)	500
Cross section (fb)	290
Integrated Luminosity (fb^{-1})	1300

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S} \xrightarrow{B \rightarrow 0} \frac{1}{\sqrt{S}} = \frac{1}{\sqrt{XS * Lumi}} = 0.2\%$$

Acceptance and selection efficiency → 1.00

$$\rightarrow \frac{\Delta\sigma}{\sigma} \sim 0.2\%$$