Measurement of $Z \to \mu^+\mu^-\gamma$ with first CMS data

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Overview

- **Measurement of $Z \to \mu^+\mu^-$.**
  - Event selection.
  - Comparison of Data and MC.
  - Cross Section and efficiencies from Data.
- **Measurement of γ-FSR.**
  - Selection of Muons and Photons.
  - Properties of FSR.
  - Efficiency and Cross Section.
- **Measurement of Anomalous Gauge Couplings (AGC).**
  - Introduction of AGC
  - Event selection.
  - Exclusion results.

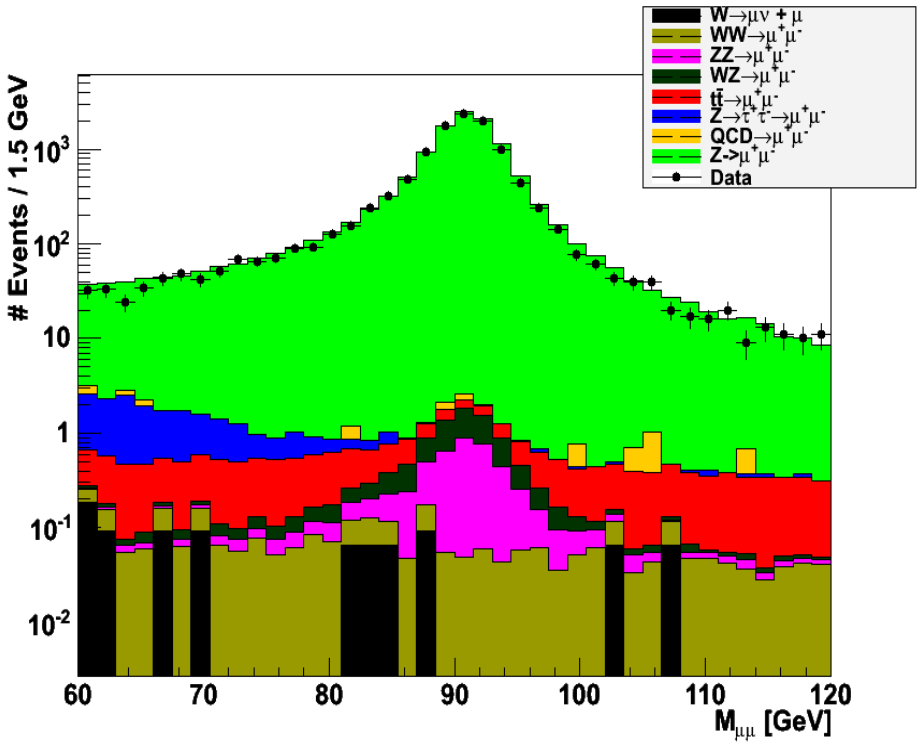
Event Selection

Used 32.4 pb^{-1}, high level single Muon trigger accepted.
Select two opposite charged Muons:

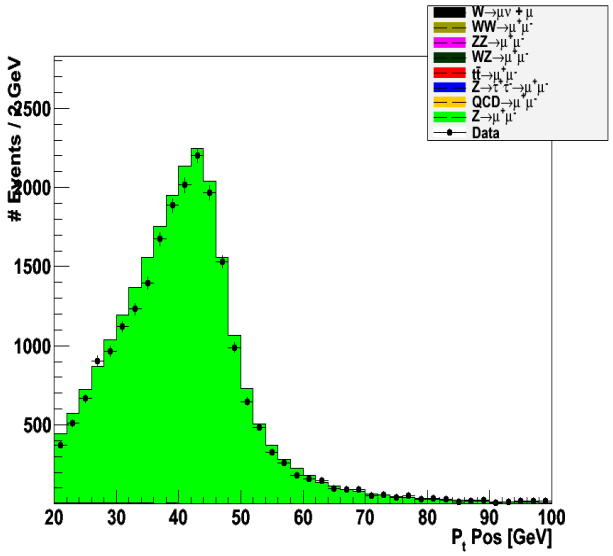
- $P_t > 20\,\mathrm{GeV}$
- $|\eta| < 2.1$
- $|d_{xy}| < 0.2\,\mathrm{cm}$
- $60\,\mathrm{GeV} < M_{\mu\mu} < 120\,\mathrm{GeV}$

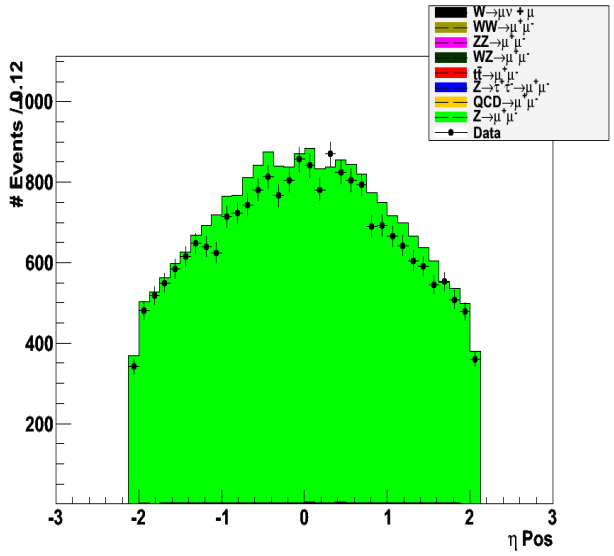
High quality Muons with Track in Tracker and Muon System

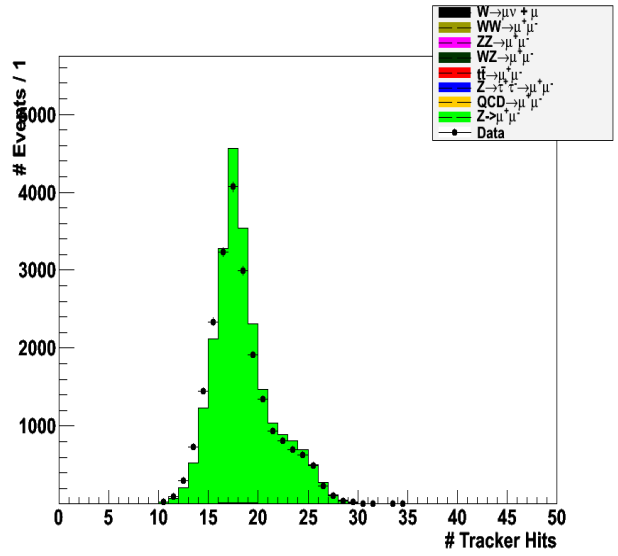
- $>= 1$ Pixel Hit
- $>= 10$ Tracker Hits
- $>= 2$ Muon Stations
- $\sum_{\Delta R=0.3} P_t(Tr)/P_t(\mu) < 0.15$

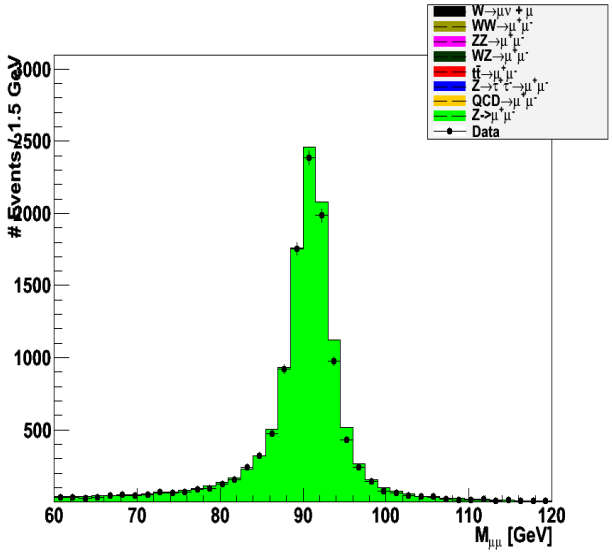


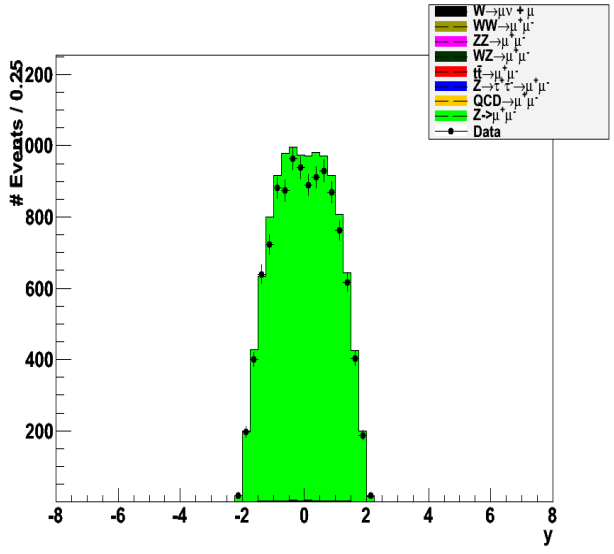
Variables of Muon and Z (MC scaled to NNLO)

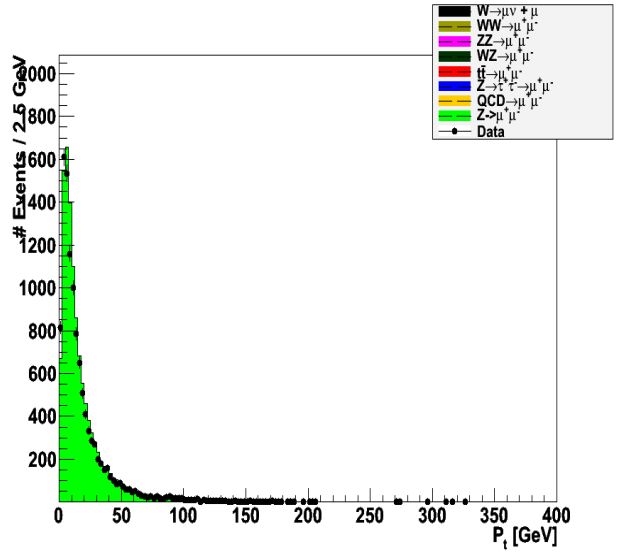






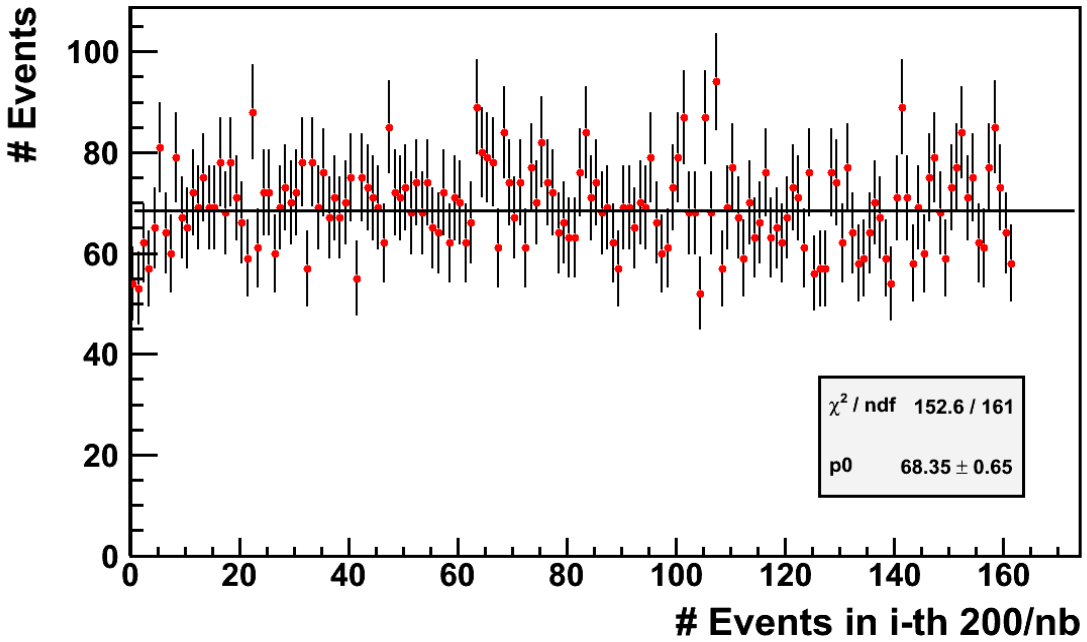






Data-Driven Efficiencies using Tag & Probe

ϵ_μ	MC T&P [%]	Data T&P [%]
Tracking (T)	99.5	99.4 ± 0.1
Muon Tracking (M)	98.0	95.0 ± 0.2
Matching (MA)	99.6	99.3 ± 0.1
ISO	99.4	99.1 ± 0.1
HLT	95.2	91.7 ± 0.3



Corrections

$$\epsilon_{tot} \sim f_i = \epsilon^2_{ISO,M,T,MA}$$

$$\epsilon_{tot} \sim f_i = 1 - (1 - \epsilon_{HLT})^2$$

$$\epsilon_{tot,DA} = \epsilon_{tot,MC} \prod_i \frac{f_{i,DA}}{f_{i,MC}}$$

$$\epsilon_{tot,MC} = 92.9\%$$

$$\Rightarrow \epsilon_{tot,DA} = 85.2 \pm 0.7\%$$

$Z^0 \to \mu^+\mu^-$ Cross Section Measurement

Theoretical prediction (FEWZ) $60 < M_{\mu\mu} < 120\,\text{GeV}$: $\sigma_{NNLO} = 975 \pm 9\,\text{pb}$
PDF uncertainty is 2% using CT10.

$$\sigma = \frac{N_{mes} - N_{BKG}}{A \epsilon_{tot} L}$$

- $N_{mes} = 11226$, $N_{BKG} = 45$ negligible from MC.
- Acceptance ($A = 41.2 \pm 0.3\,\%$) based on cuts in P_t and η.
  Uncertainty: different generators (NLO, FSR) and CT10 PDF.
- Luminosity ($L = 32.4\,\text{pb}^{-1}$).
  Uncertainty is 11%.

$$\sigma = 978 \pm 9(\text{stat.}) \pm 8(\text{sys.}) \pm 108(\text{lumi.})\,\text{pb}$$

Only the mentioned systematics are included!

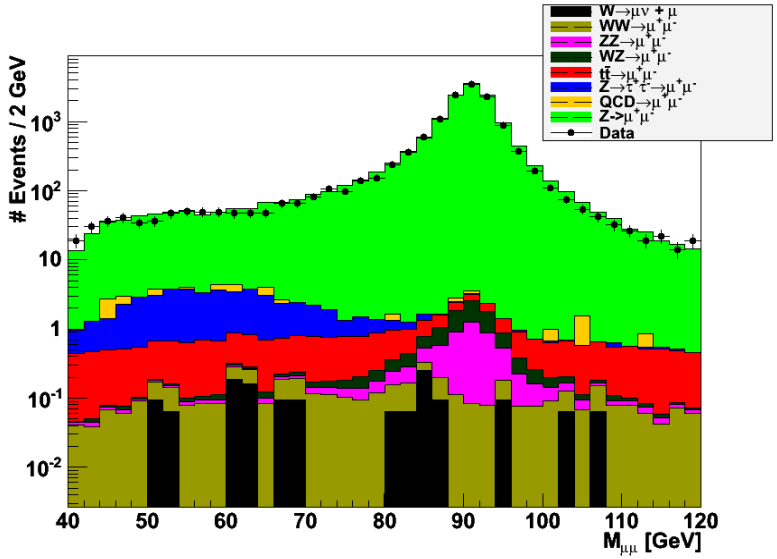
No official CMS result.

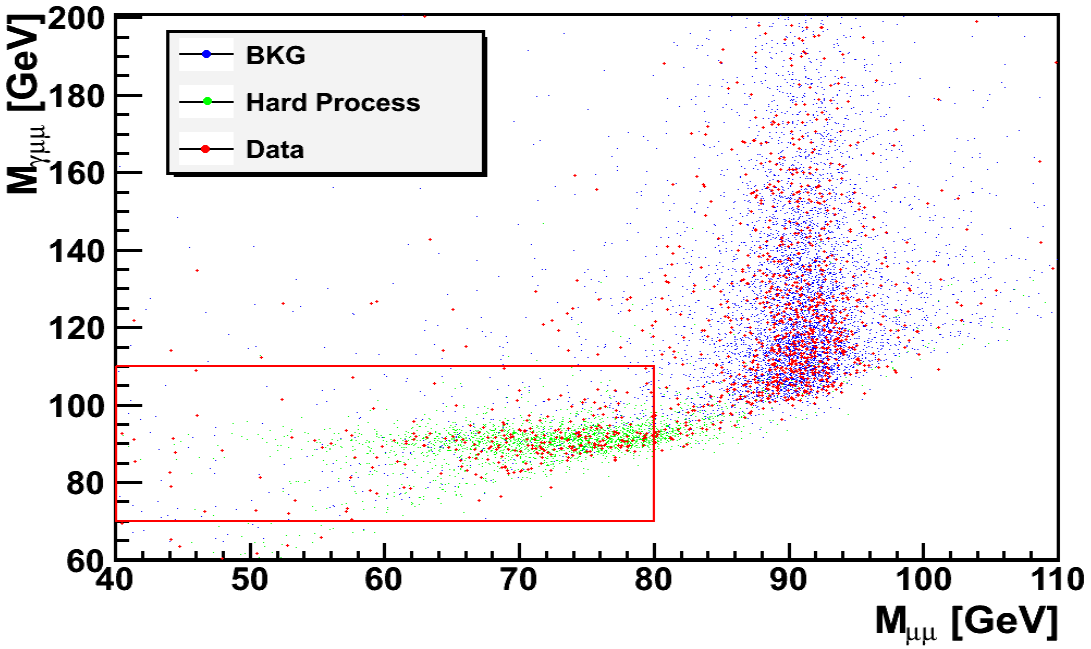
FSR Selection

Muon selection:
Same as before but
$|\eta| < 2.4$ for one Muon
Photon selection:

- Clusters for Photons SuperCluster (SC).
  $P_{t,SC} > 10\,\text{GeV}$
- $|\eta| < 2.4$
- $E_{had}/E_{em} < 0.5$

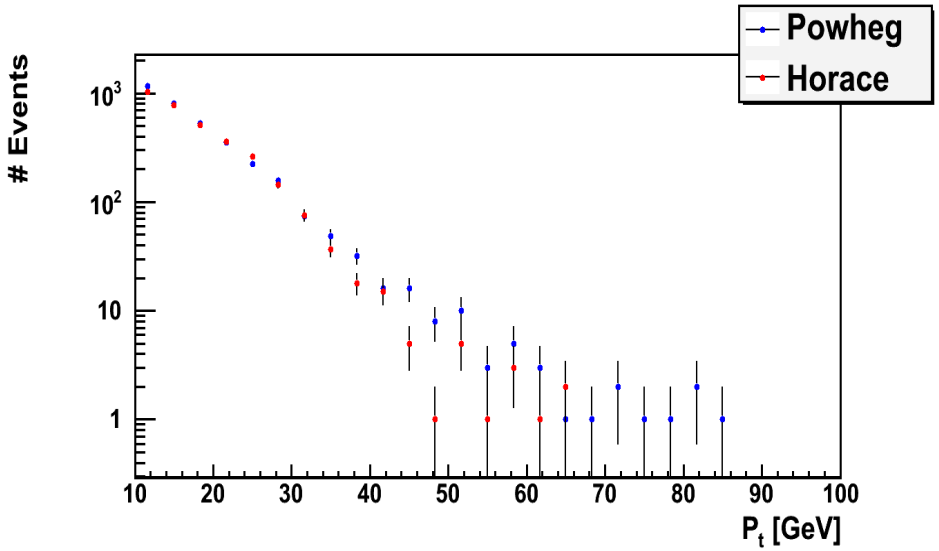
Define FSR region:
$40 < M_{\mu\mu} < 80\,\text{GeV}$
and $70 < M_{\mu\mu\gamma} < 110\,\text{GeV}$

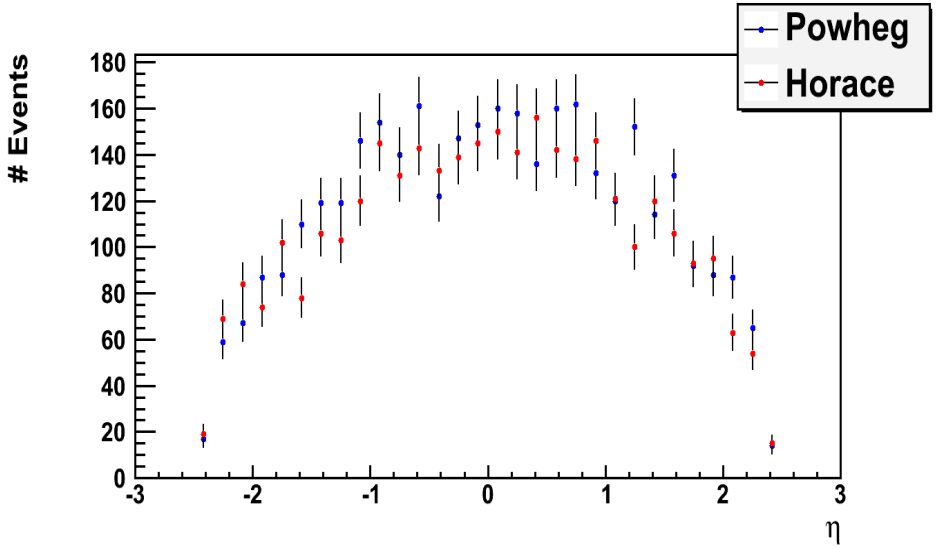


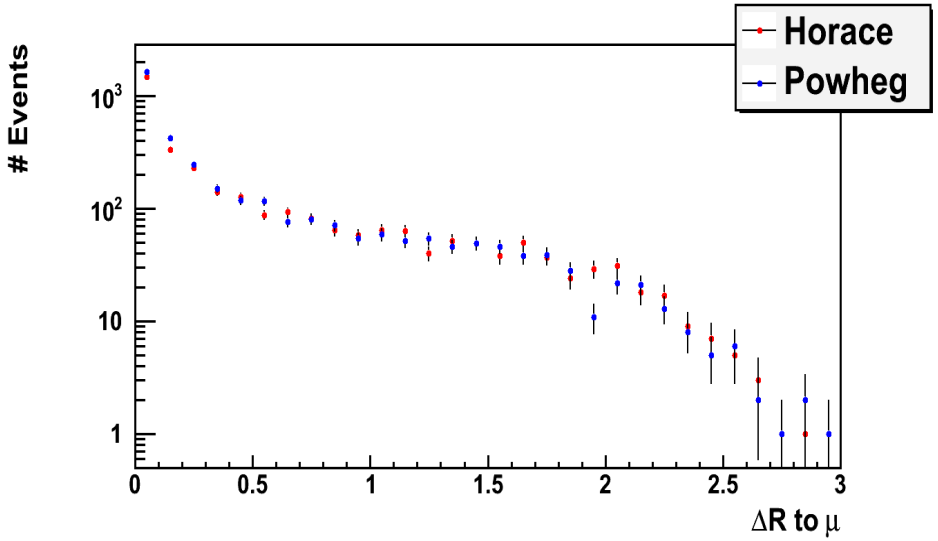


FSR on Generator-Level

Horace/Pythia6 vs. Powheg/Pythia6 (L=250 pb^{-1})

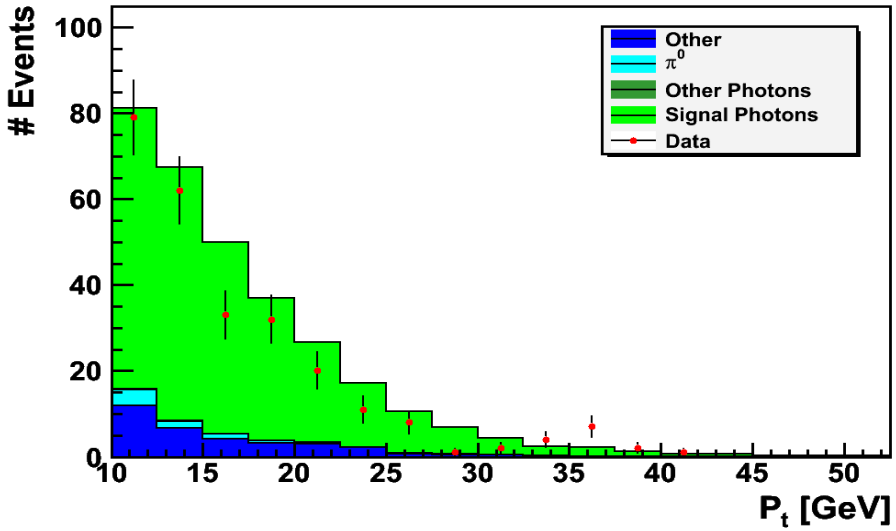


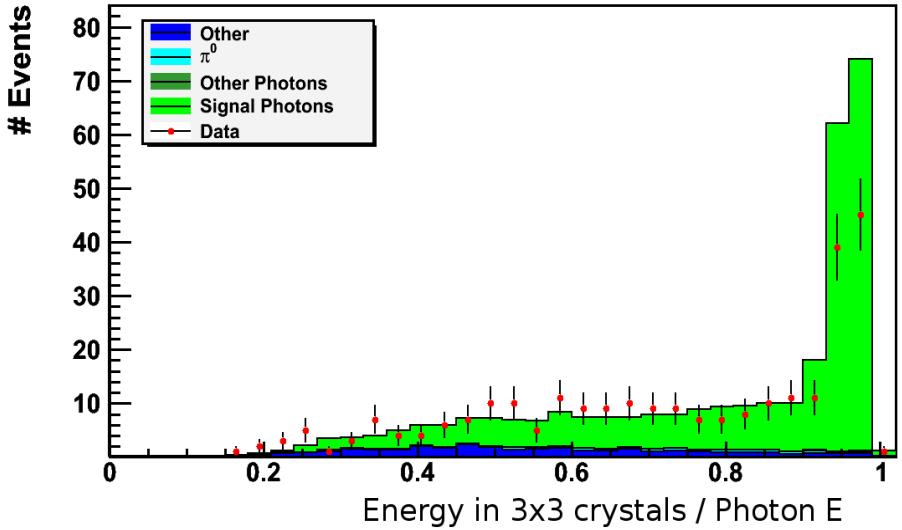


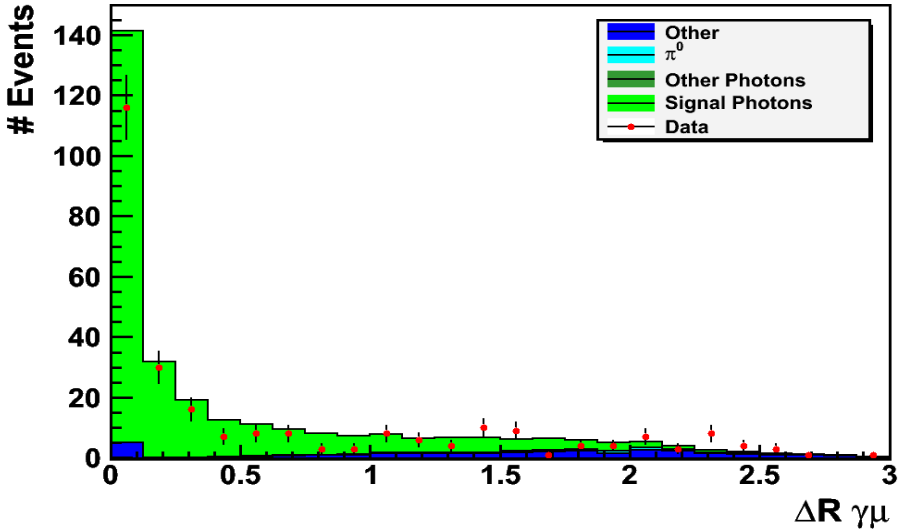


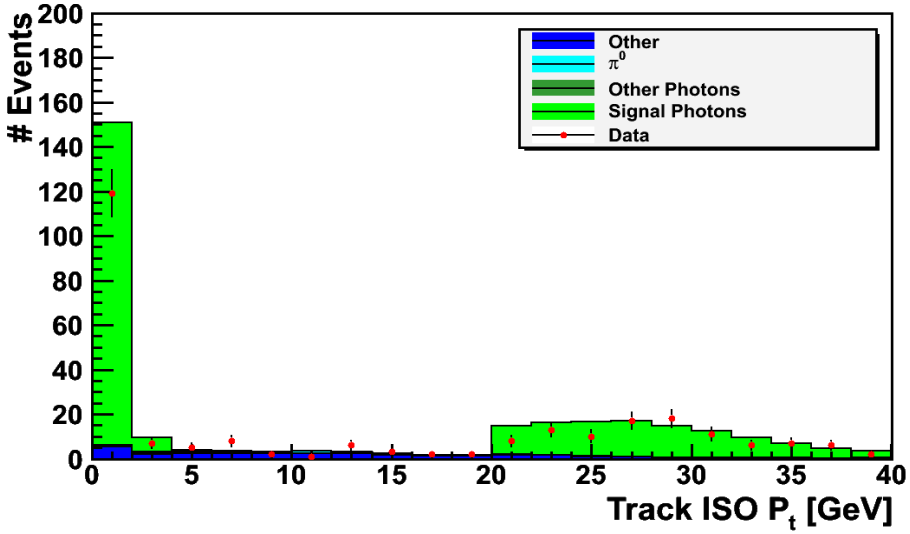
Horace: NLO-QED-Correction included.
Powheg: Pythia's shower approach of FSR.
Distributions are compatible.
Powheg (new TuneZ2) better BKG description.

FSR Photons


Other
π^0
Other Photons
Signal Photons
Data
Events
P_t [GeV]


Other
π^0
Other Photons
Signal Photons
Data
Events
Energy in 3x3 crystals / Photon E


Other
π^0
Other Photons
Signal Photons
Data
Events
$\Delta R\ \gamma\mu$


Other
π^0
Other Photons
Signal Photons
Data
Events
Track ISO P_t [GeV]

FSR Photon Identification Eff. using T&P

Tag

Muon Pair: $40 < M_{\mu\mu} < 80\,\text{GeV}$

Probe

SC: $P_t > 10\,\text{GeV}$

$70 < M_{\mu\mu SC} < 110\,\text{GeV}$

Passing Probe

SC used to build a Photon.

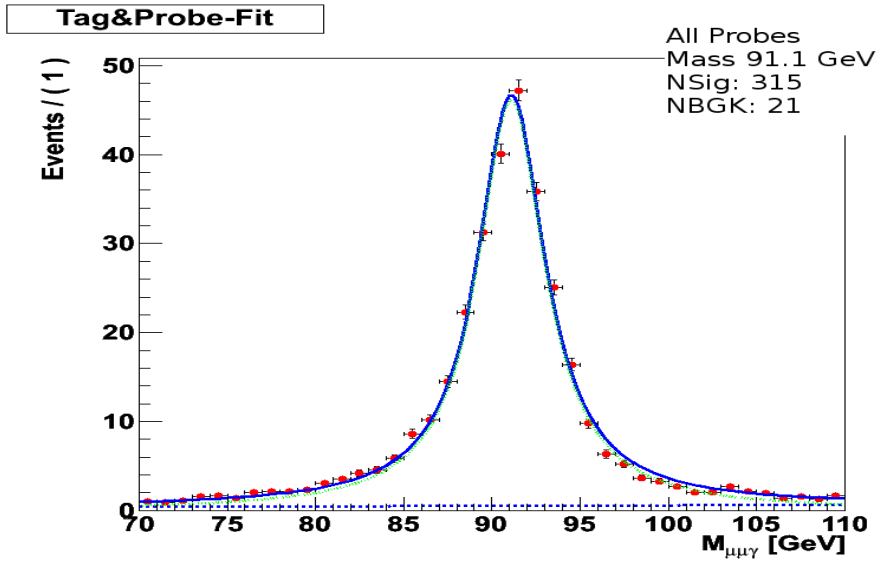
Extract number of signal events using Breit-Wigner plus straight line fit.

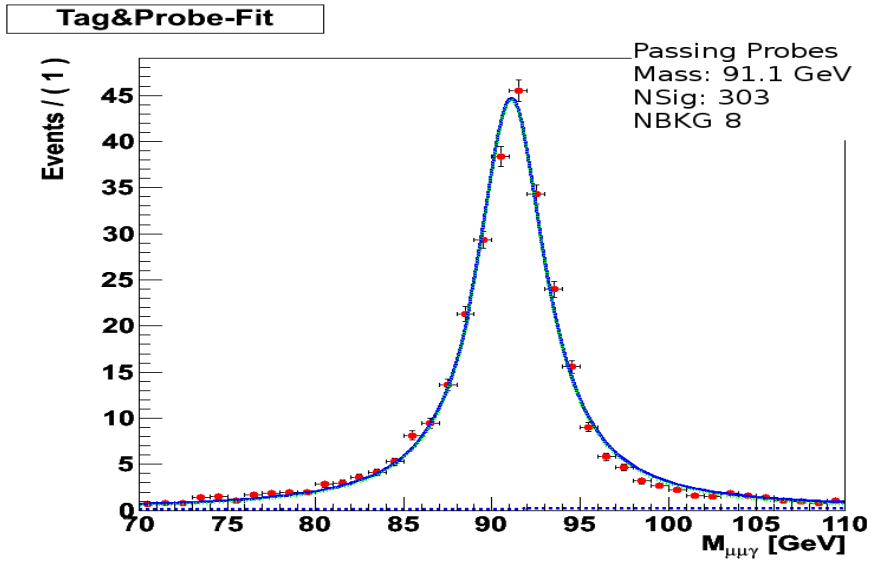
Result MC: $\epsilon_{id,MC} = 96.2\%$

Overall efficiency from MC-Truth:

$\epsilon_{MC} = 83.2\%$

Dominated by cluster efficiency.





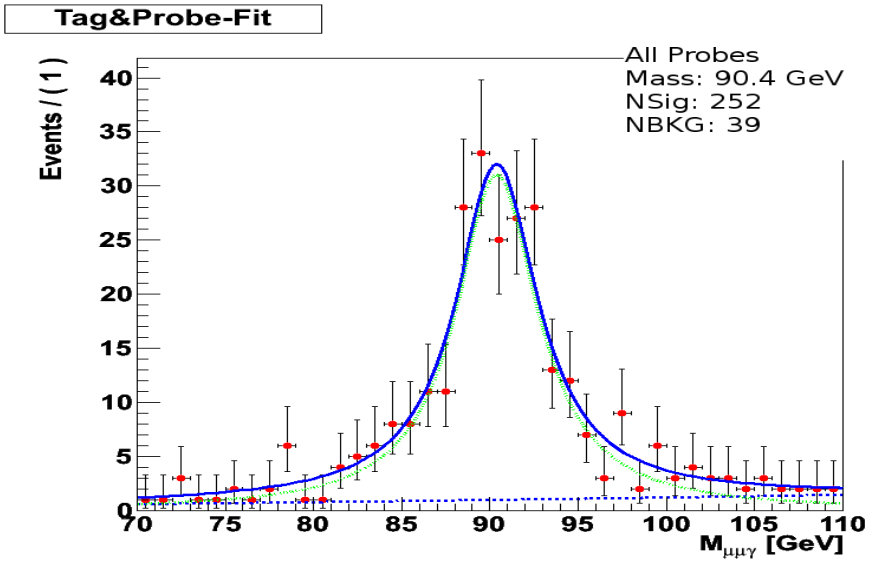
FSR Photon Cross Section Estimation

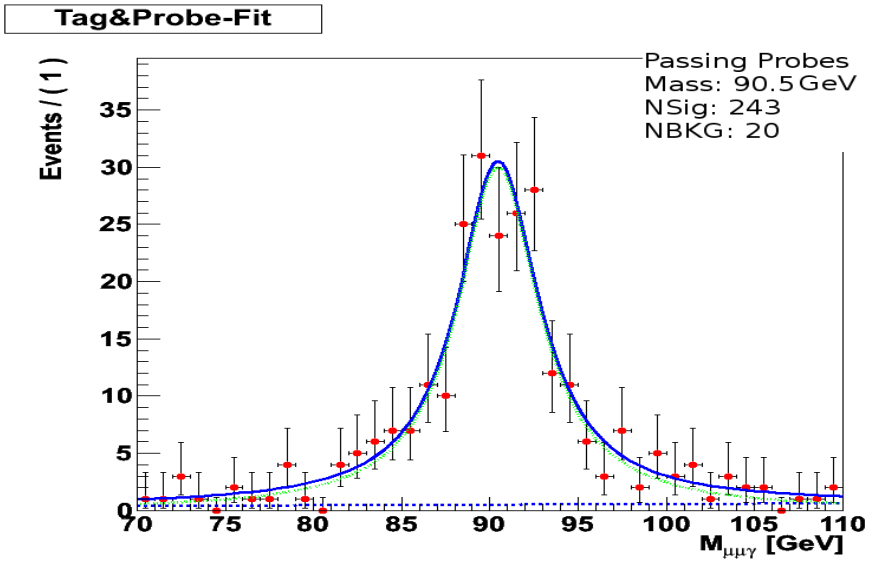
Rough estimation of Cross Section for defined kinematic region.

Result Data:
$\epsilon_{id,DA} = 96.4 \pm 1.5\%$
This is compatible with MC result.

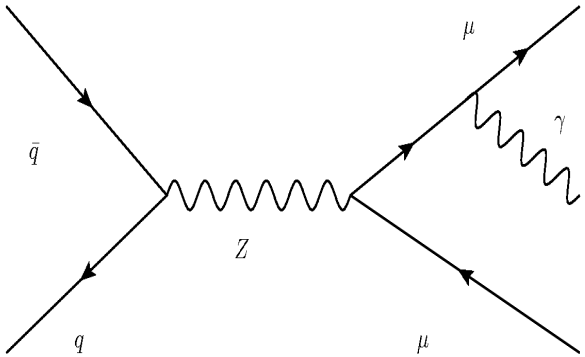
With 243 signal events:
Assume same Muon eff. as for Z.
Cross Section within cuts:
$\sigma_{FSR} = 9.9 \pm 0.6(stat.)$
$\pm 0.4(eff.) \pm 1.0(lumi.)$ pb
No official CMS result.

Monte-Carlo prediction: 10 pb

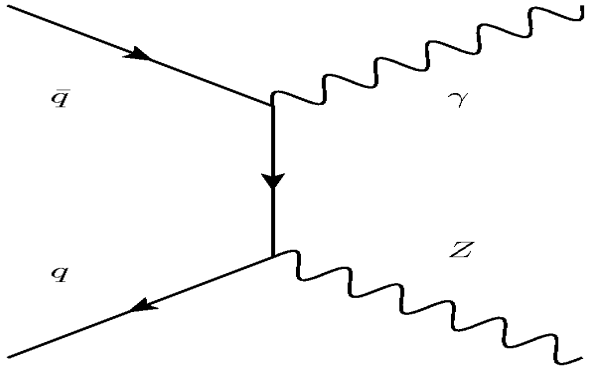




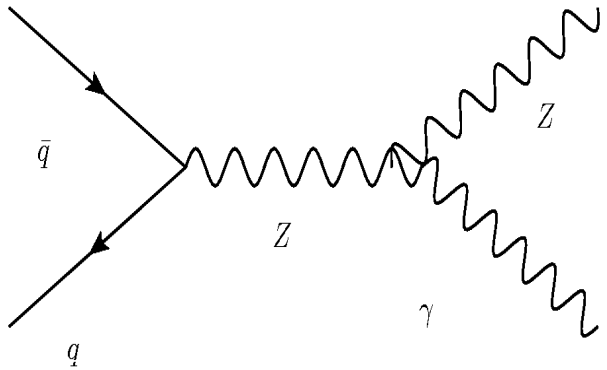
Anomalous Gauge Couplings (AGC)



SM see last part



SM

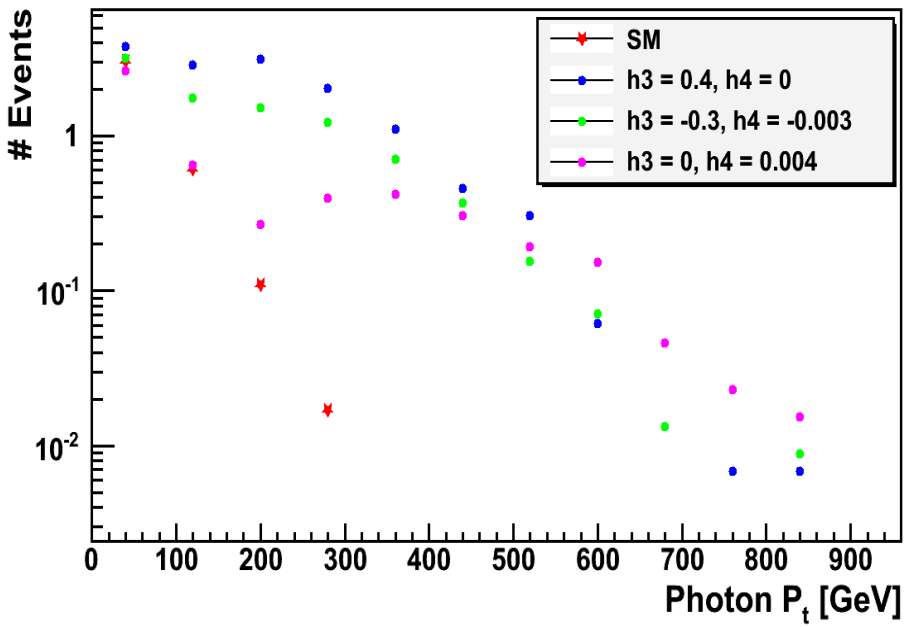


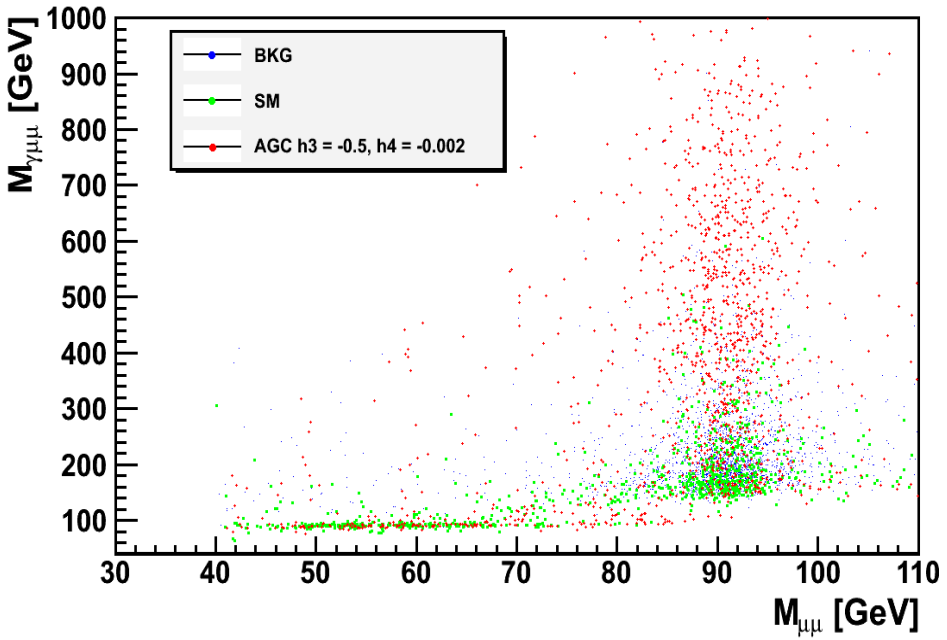
Not allowed in SM

$$\Gamma^{\alpha\beta\mu} = \frac{P^2 - q_1^2}{m_z^2}\{h_1(q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta}) + h_2\frac{P^\alpha}{m_Z^2}((P\cdot q_2)g^{\mu\beta} - q_2^\mu P^\beta)$$
$$+h_3\epsilon^{\mu\alpha\beta\rho}q_{2\rho} + h_4\frac{P^\alpha}{m_Z^2}\epsilon^{\mu\beta\rho\sigma}P_\rho q_{2\sigma}\}$$

- Most general form of vertex. P incoming Z/γ, q_1 outgoing Z, q_2 outgoing γ. [U. Baur, T.Han, J, Ohnemus]
- Four new Parameters h_i, h_1, h_2 CP-violating set to zero here.
- Scale dependent to avoid unitatity violation $h_i(s)$. All values given at Z mass.

Anomalous Gauge Couplings (AGC)



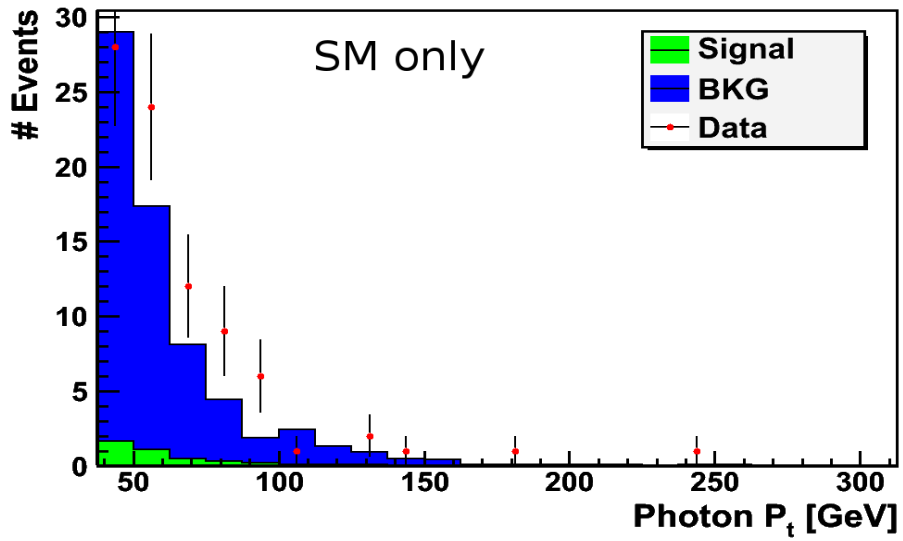


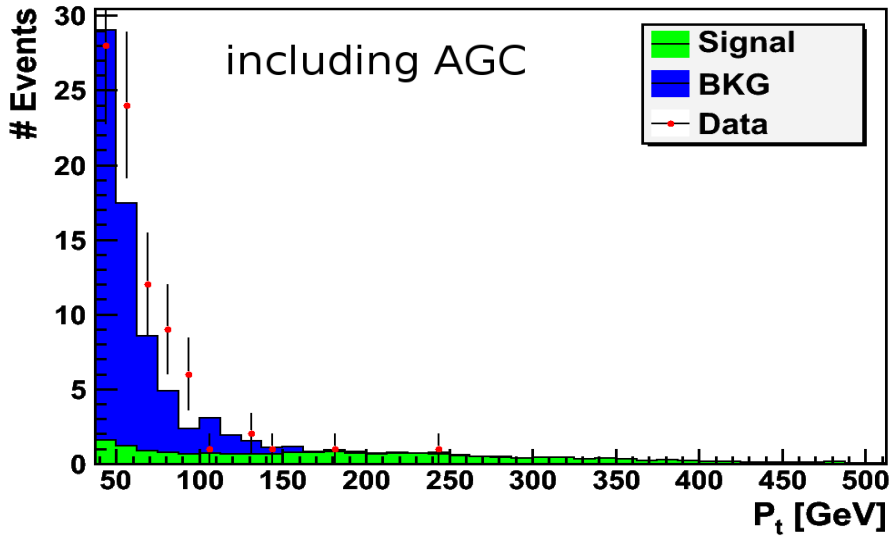
- AGC leads to a Z plus a high P_t Photon.
- AGC-Events are generated using Sherpa.

Anomalous Gauge Couplings (AGC)

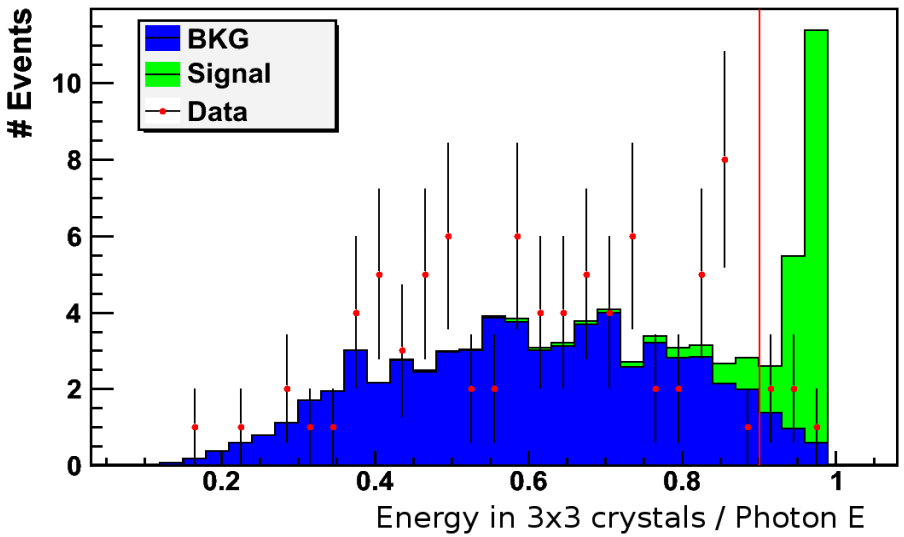
Muon Selection:
As before, but
$60\,\text{GeV} < M_{\mu\mu} < 120\,\text{GeV}$
Muon Selection:
$P_t > 40\,\text{GeV}$
$M_{\mu\mu\gamma} > 120\,\text{GeV}$

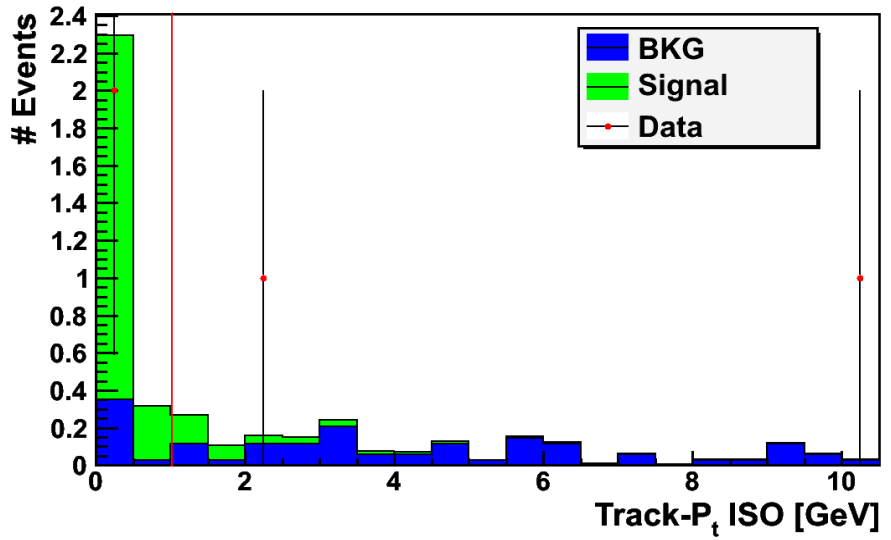
Neccessary: BKG reduction (fake Photons, Pion ...).
Seems to be higher than MC.
$\Rightarrow$ further investigation needed.

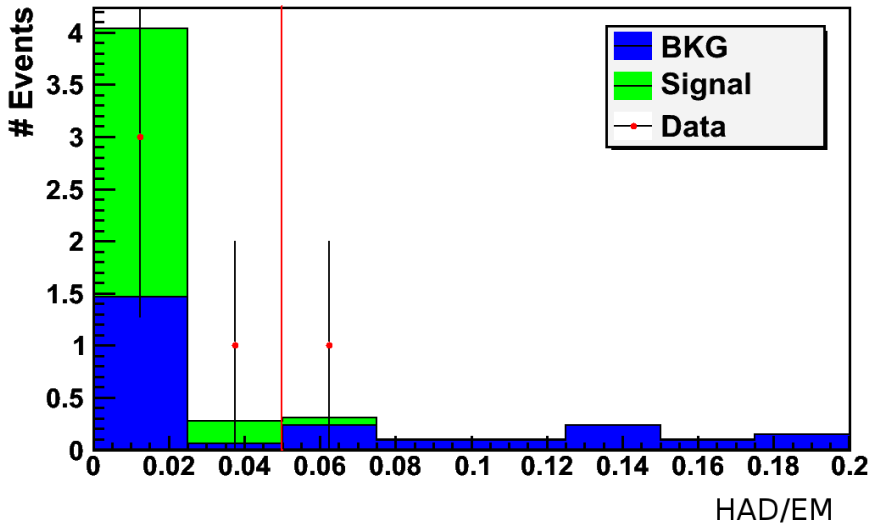




Reduction of BKG







Cuts:

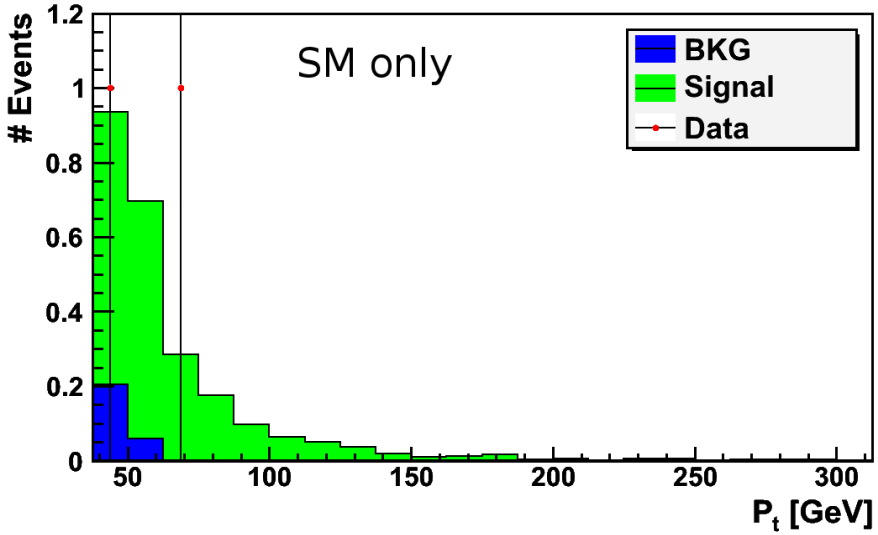
R9 > 0.9 (Energy in 3x3 ECal crystals / Photon energy)

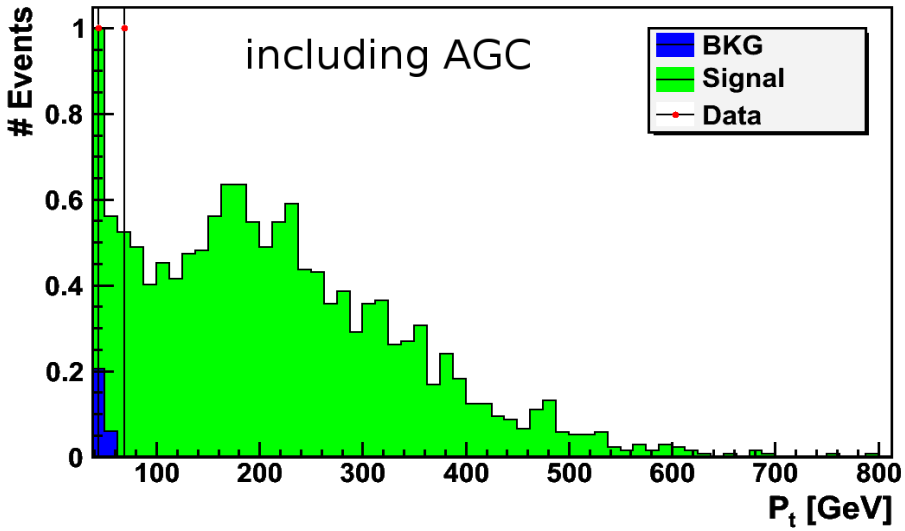
$E_{had}/E_{em} < 0.05$

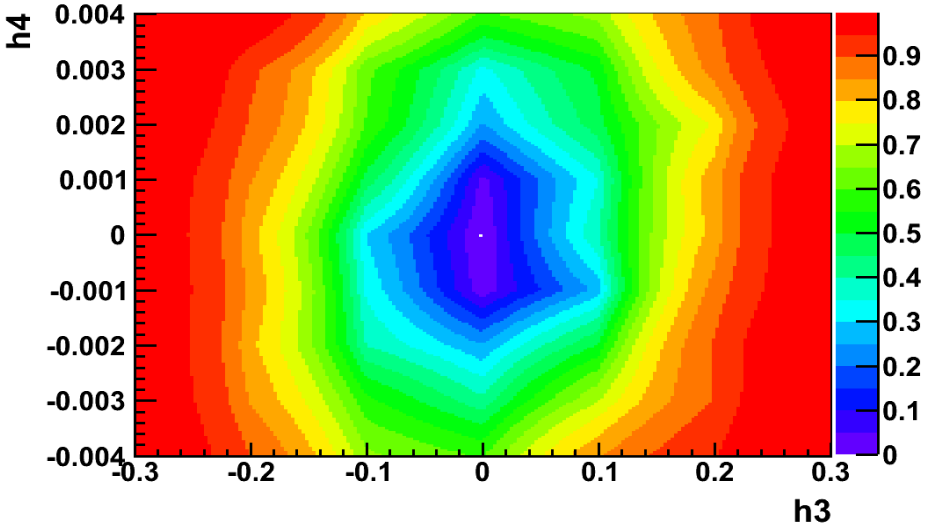
$I_{Track-P_t} < 1\,\text{GeV}$

Signal: 70%, BKG 2%

AGC Results







Results are very preliminary

Limits form CDF(95 % CL):

$-0.083 < h_3 < 0.083$

$-0.0047 < h_4 < 0.0047$

No official CMS results.

Conclusions

$$Z \rightarrow \mu^+\mu^-$$

- 11200 events measured:
  $\sigma = 978 \pm 9(stat.) \pm 8(sys.) \pm 108(lumi.)\,\text{pb}$
- Nearly no background expected.

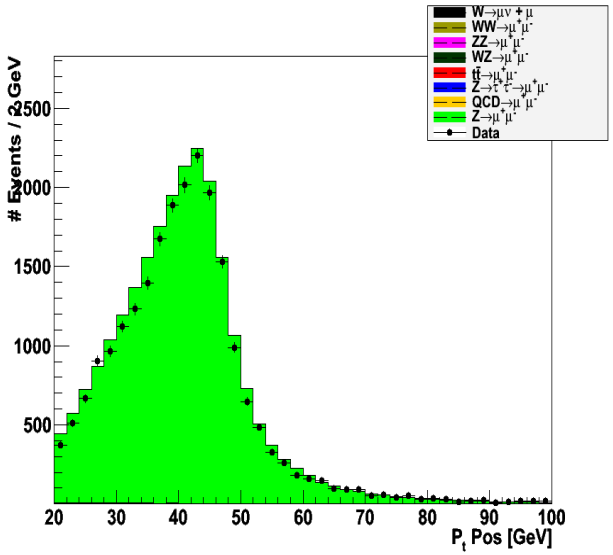
$$Z \rightarrow \mu^+\mu^-\gamma$$

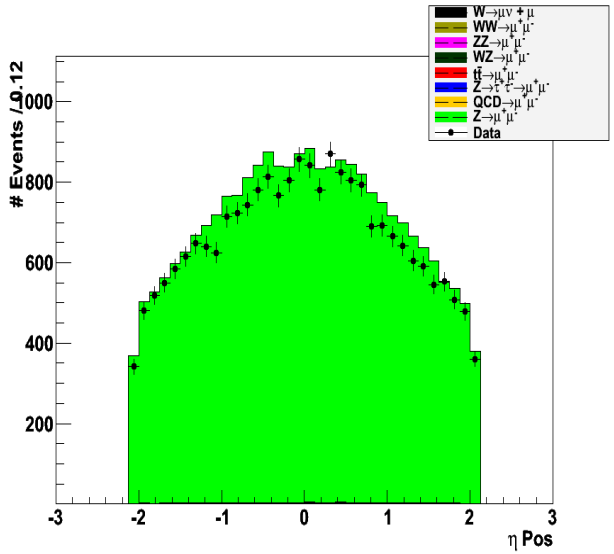
- Kinematic cuts allow to get a clean sample of FSR Photons.
- ϵ_{id} can be obtained using Tag&Probe.
- Estimation of Cross Section is in agreement with expectation.

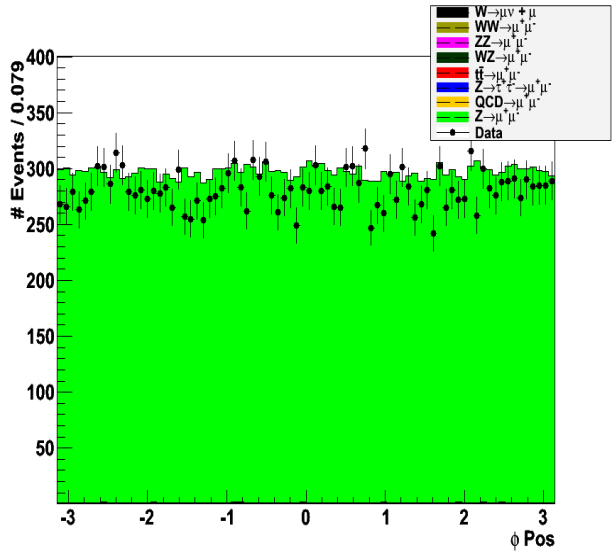
- AGC-Photons can be extracted cleanly.
- CDF limits can be reached with about $200\,\text{pb}^{-1}$.
- More detailed study of BKG is neccesary(estimation from data).

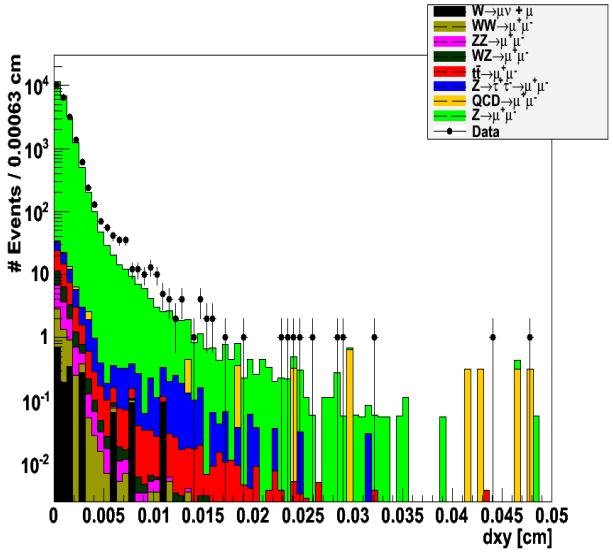
BACK UP

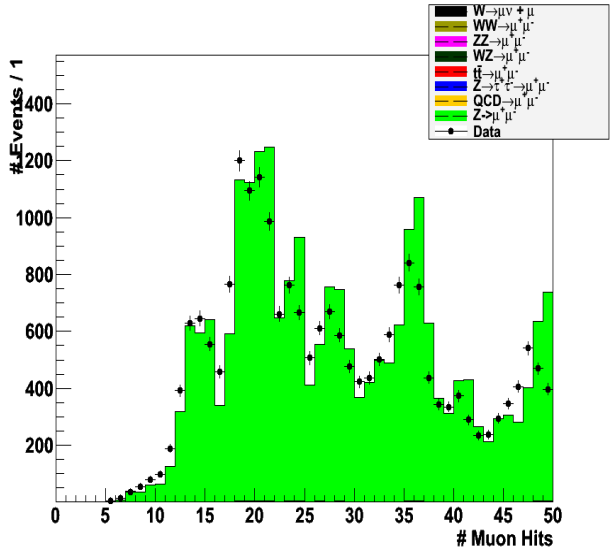
Muon Variables

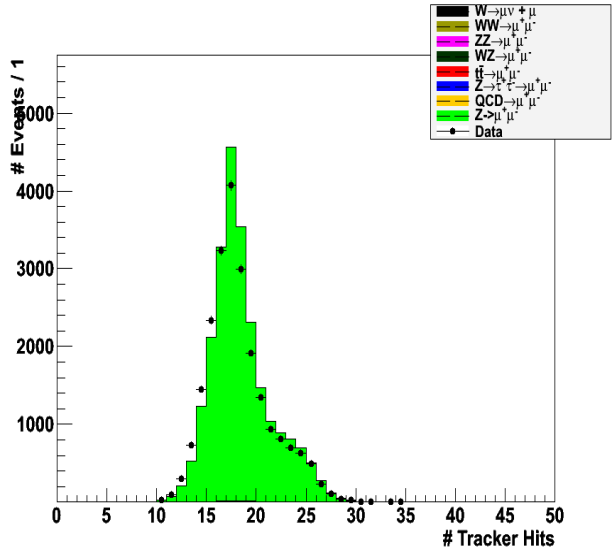












Variables of $\mu^-\mu^+$-System