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Measurement of $Z\gamma \to \mu^+\mu^-\gamma$

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On behalf of the CMS Collaboration

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Bonn
PHYSICS AT THE TERASCALE
08.12.2011

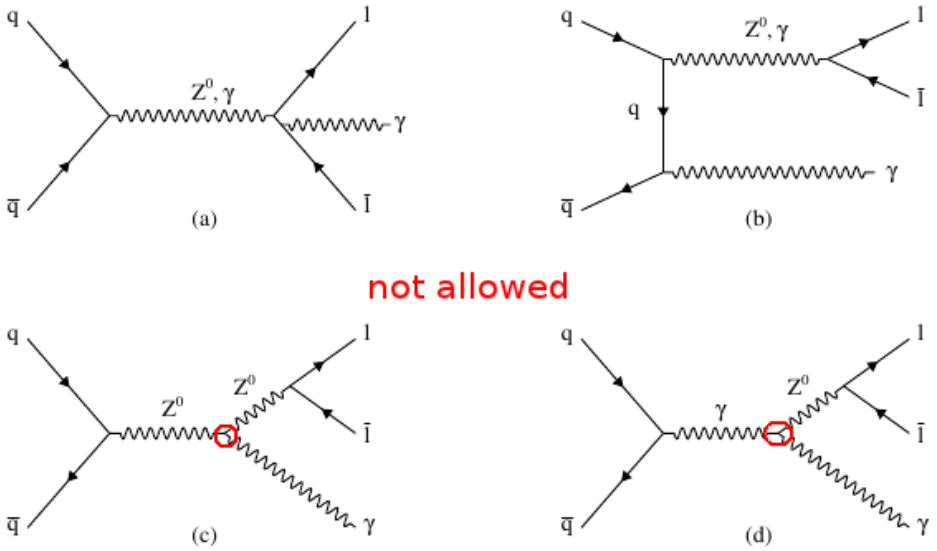
Overview

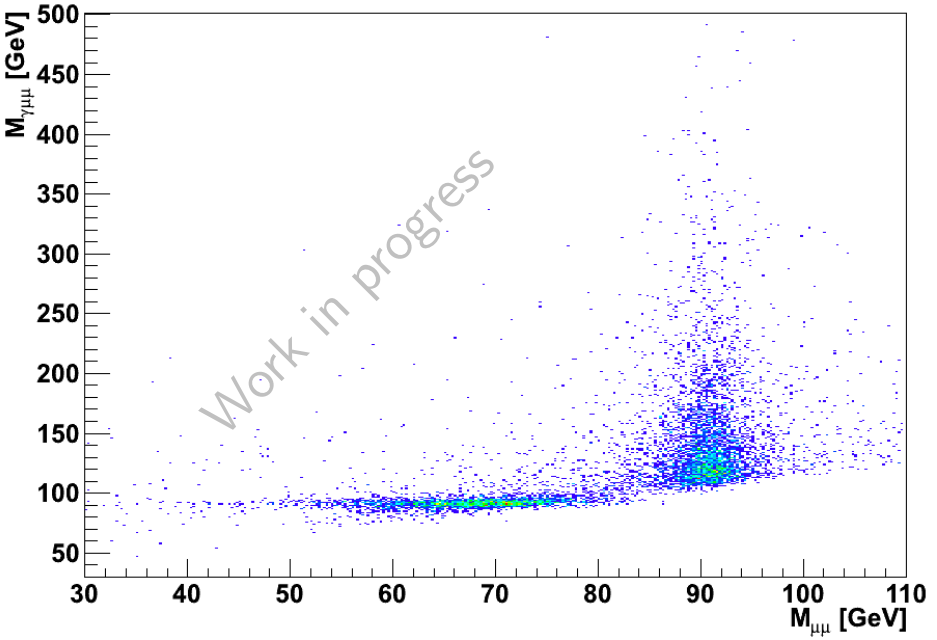
Content

- Motivation
- What can be learnt from FSR
  - Photon ID efficiency
  - Photon energy scale
- Measurement of ISR cross section

Motivation

- Standard model $U(1) \times SU(2)$ gauge invariance fixes the couplings of gauge bosons, $\Rightarrow Z - \gamma$ not allowed.
- Measured photons radiated by incoming quarks (ISR) and outgoing muons (FSR) which can be kinematically separated.
- An enhancement (especially of high E_t-photons) would mean an anomalous coupling beyond the standard model.





Event Selection

Dataset: DoubleMu ($4683\,\mathrm{pb}^{-1}$), Trigger: Double Muon

Muons

- Opp. charged muons
- $P_t > 20\,\mathrm{GeV}$
- $|\eta| < 2.4$
- Muon ID.

FSR

- $30\,\mathrm{GeV} < M_{\mu\mu} < 80\,\mathrm{GeV}$
- $70\,\mathrm{GeV} < M_{\mu\mu\gamma} < 110\,\mathrm{GeV}$
- Muon: relative track isolation < 0.15

$\rightarrow$ clean sample of photons for detailed studies of photon reconstruction.

Photons

- $|\eta_{sc}| < 2.5$, gap excluded
- $E_t > 15\,\mathrm{GeV}$
- Full photon ID

Signal

- $\Delta R(\mu, \gamma) > 0.7$
- $M_{\mu\mu} > 50\,\mathrm{GeV}$
- Muon: relative combined (ECal, HCal, Track) isolation < 0.1

$\rightarrow$ interesting region for new physics.

Object IDs

Photon EB(EE)

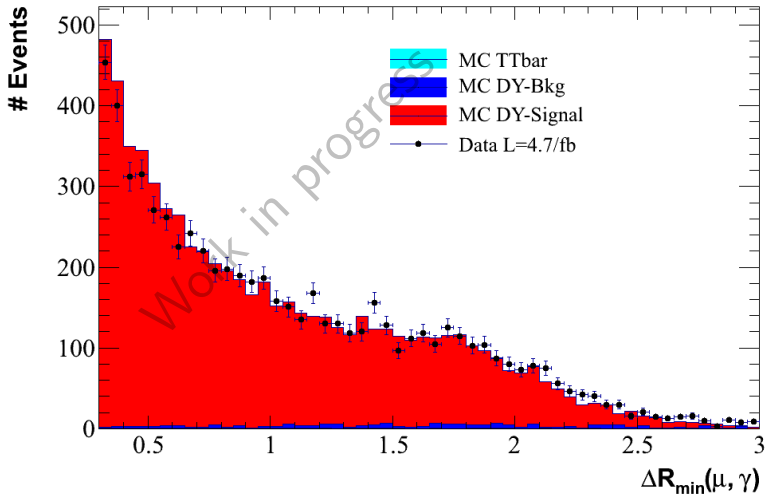
- Pixel Seed Veto
- $E_{HCal}/E_{ECal} < 0.05(0.05)$
- $I_{TRK,\Delta R<0.4} < 2.0 + 0.001E_t + 0.167\rho(2.0 + 0.001E_t + 0.032\rho)$
- $I_{ECal,\Delta R<0.4} < 4.2 + 0.006E_t + 0.183\rho(4.2 + 0.006E_t + 0.090\rho)$
- $I_{HCal,\Delta R<0.4} < 2.2 + 0.0025E_t + 0.062\rho(2.2 + 0.0025E_t + 0.180\rho)$

Muon

- Global and Tracker Muon
- $\chi^2/ndof < 10$
- > 10 Tracker hits
- > 1 Pixel hits
- $D_{xy} < 0.2\,\text{mm}$, $D_z < 1\,\text{mm}$

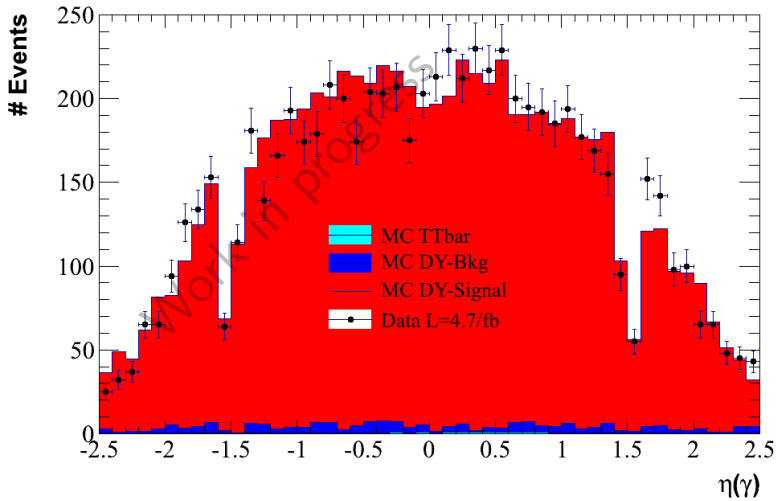
ρ: median of jet P_t in event per area.

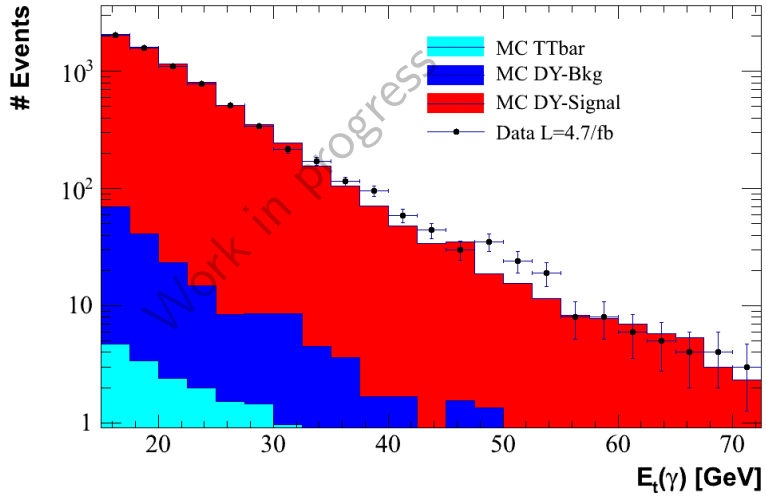
FSR Photon Distributions



Comparison of FSR-Distribution with Pythias photon simulation shows good agreement.

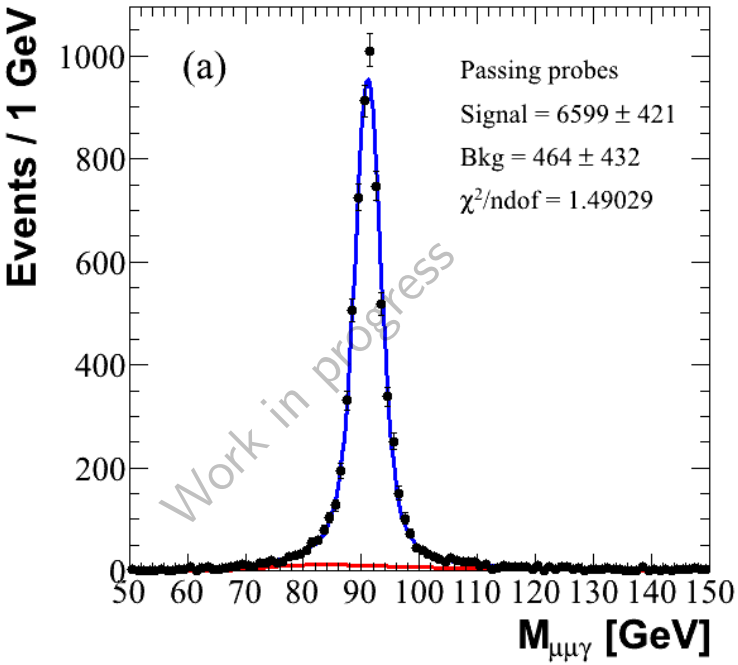
$\Delta R_{min}(\mu, \gamma) > 0.25 \Downarrow$

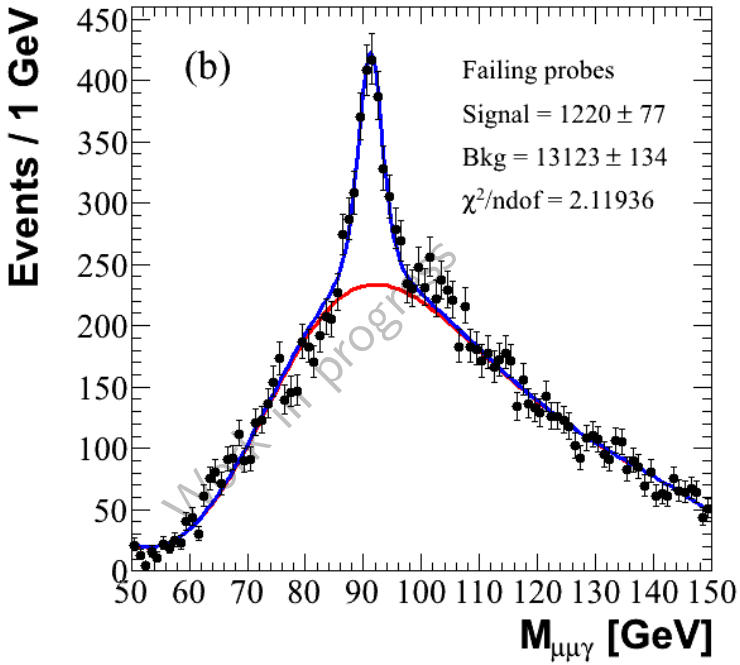




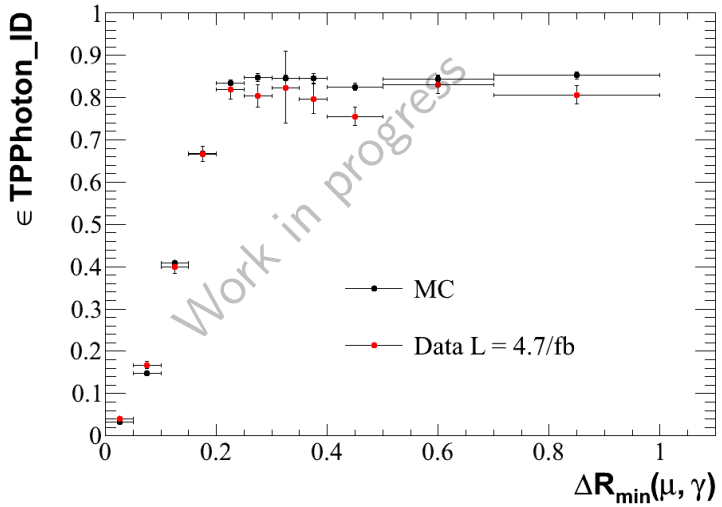
Photon ID efficiency using FSR I

- $M_{\mu\mu\gamma}$ distribution shows Z-Peak which can be used for Tag&Probe
- Tag: DiMuon system
- Probe: loose Photon object

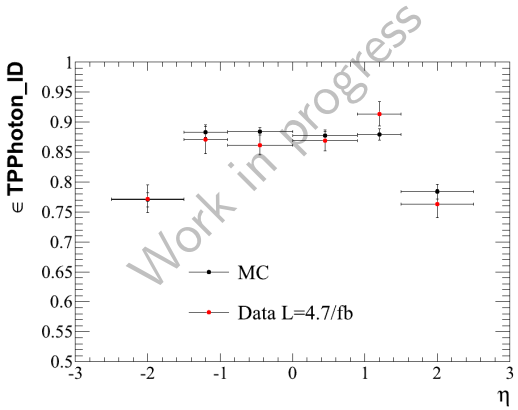


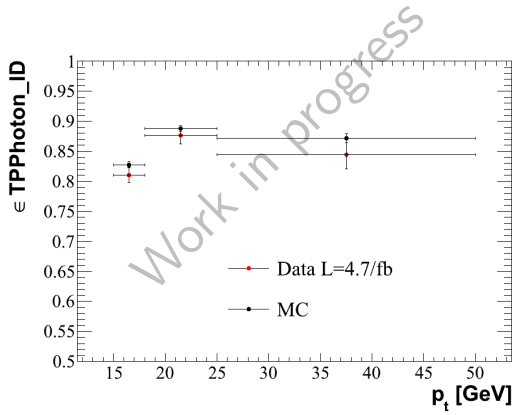


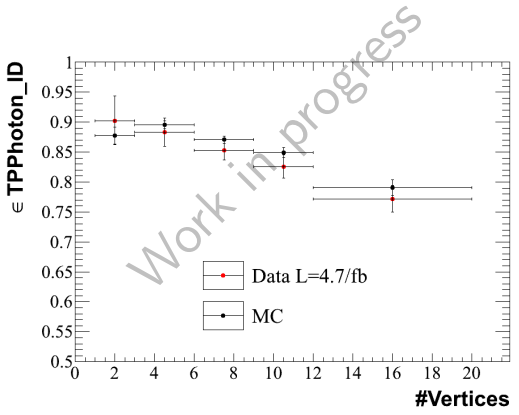
Photon ID efficiency using FSR II



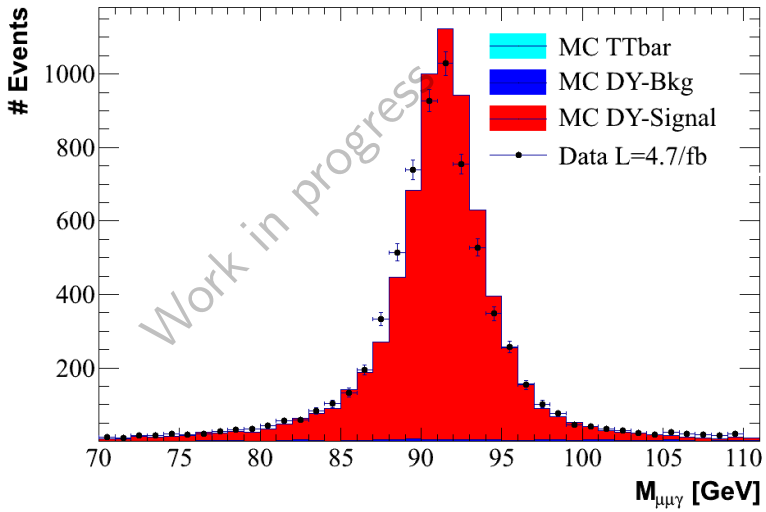
- ID affected by $\Delta R_{min}(\mu, \gamma)$ $\Rightarrow$ cut $\Delta R_{min}(\mu, \gamma) > 0.25$
- Photon ID efficiency: $\epsilon_{DA}/\epsilon_{MC} = 97.4 \pm 1.3\,\%$.

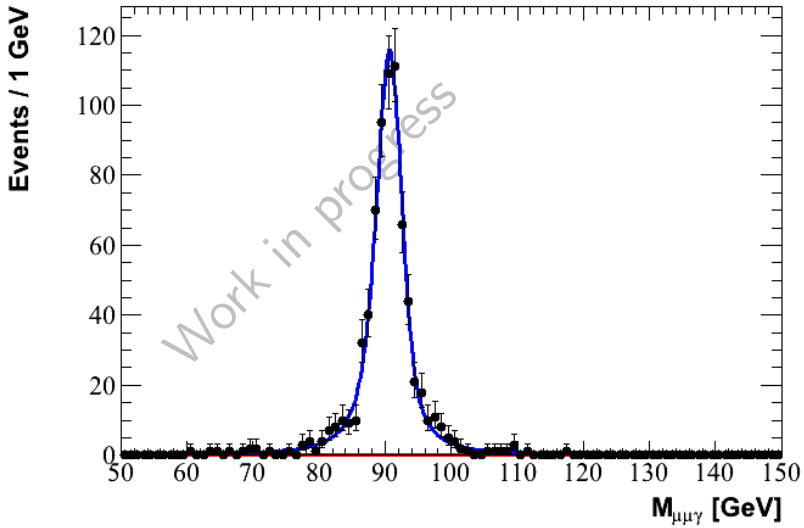


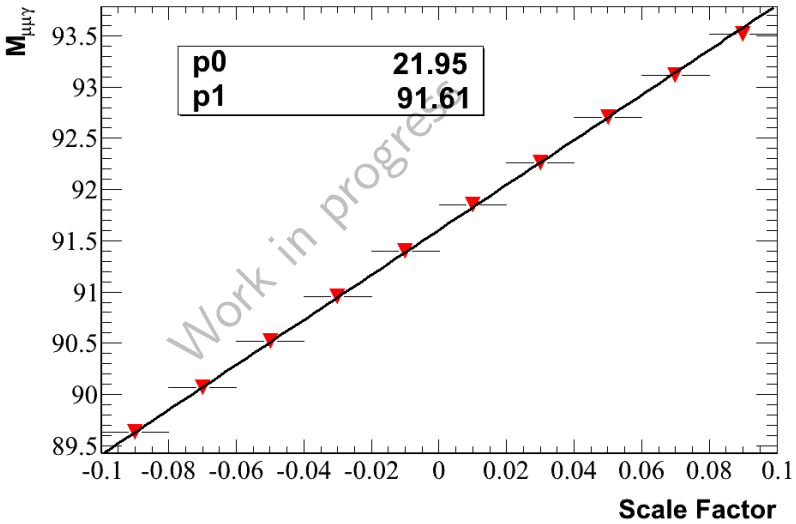




Photon Energy Scale I

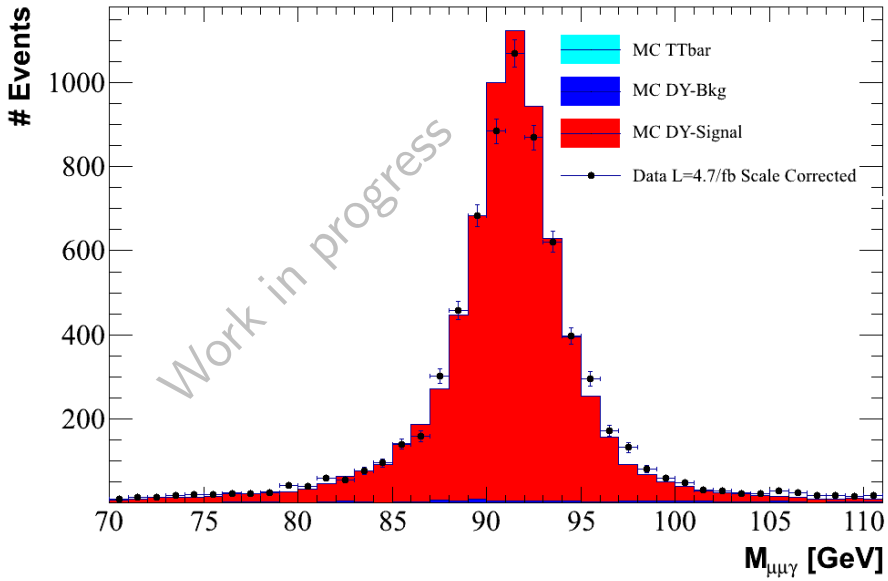






Photon energy scale in MC varied, $M_{\mu\mu\gamma}$-peak position compared to data.
$\Rightarrow$ energy correction factor photon to match MC (scale of muon is correct.)

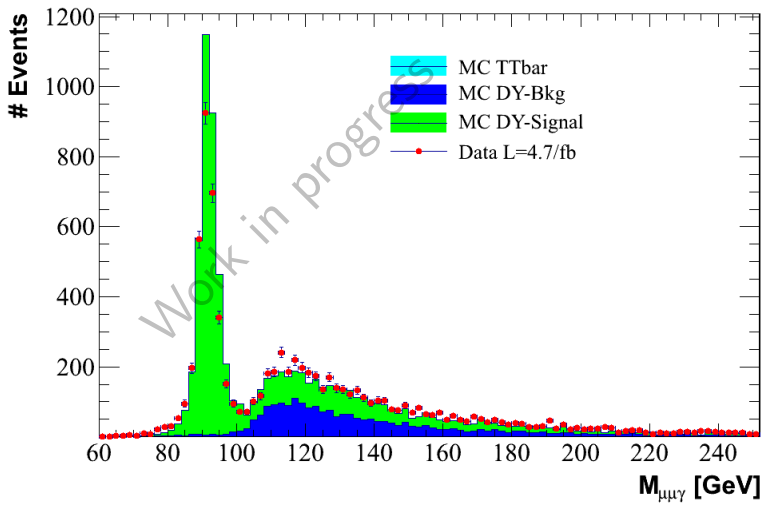
Photon Energy Scale II



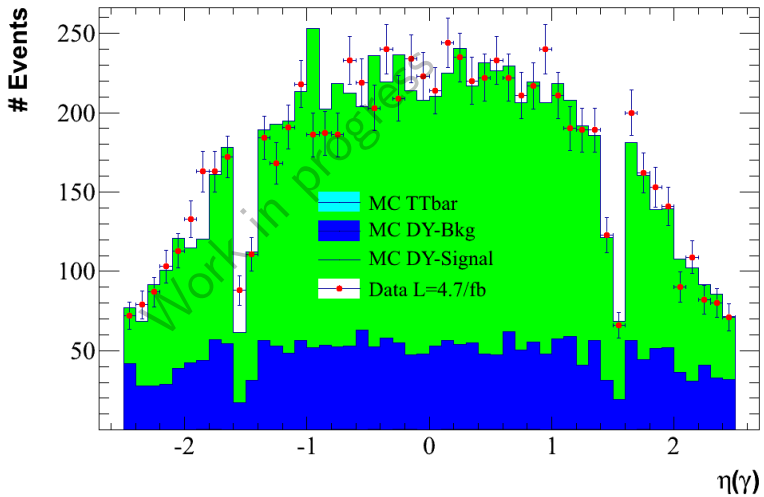
This procedure is done for ECal Barrel(EB) and Ecal Endcap(EE), as well as for direct(D) and interacting(I) photons separately.

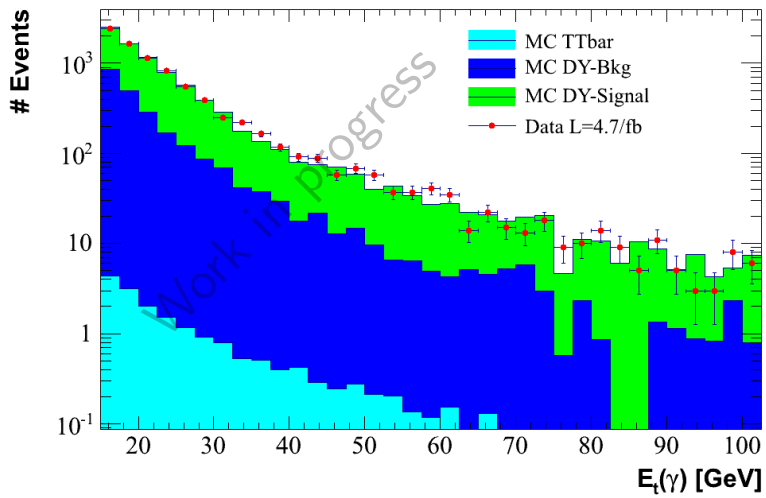
Run	EB D[%]	EE D[%]	EB I[%]	EB I[%]
160431 - 167078	-1.18	-2.10	-2.33	-0.61
167078 - 170828	0.74	-3.73	-2.33	-4.77
170828 - 173236	-0.94	-4.13	-0.24	-1.87
173236 - 180252	-1.84	-0.43	-1.97	-0.43

ISR Photon Distributions



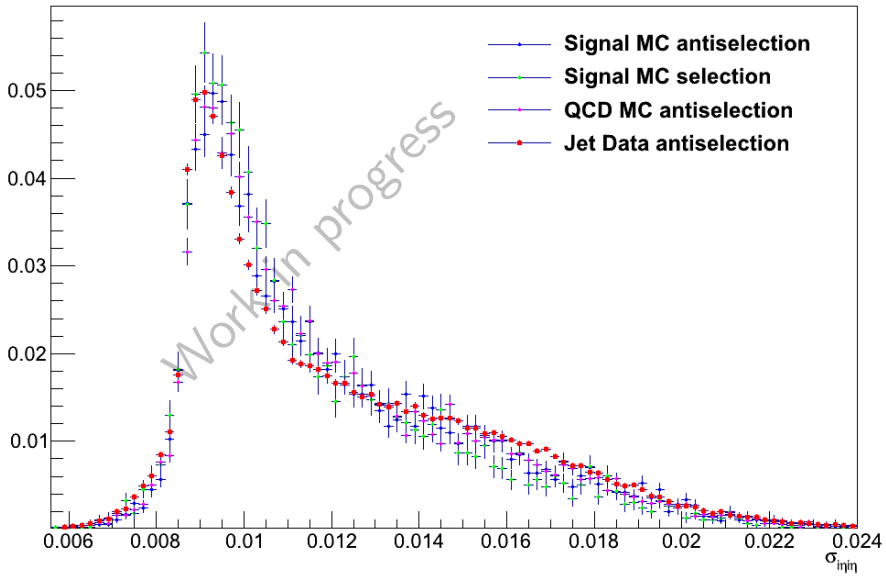
Comparison of ISR-Distribution with Madgraph Monte-Carlo





Signal extraction I

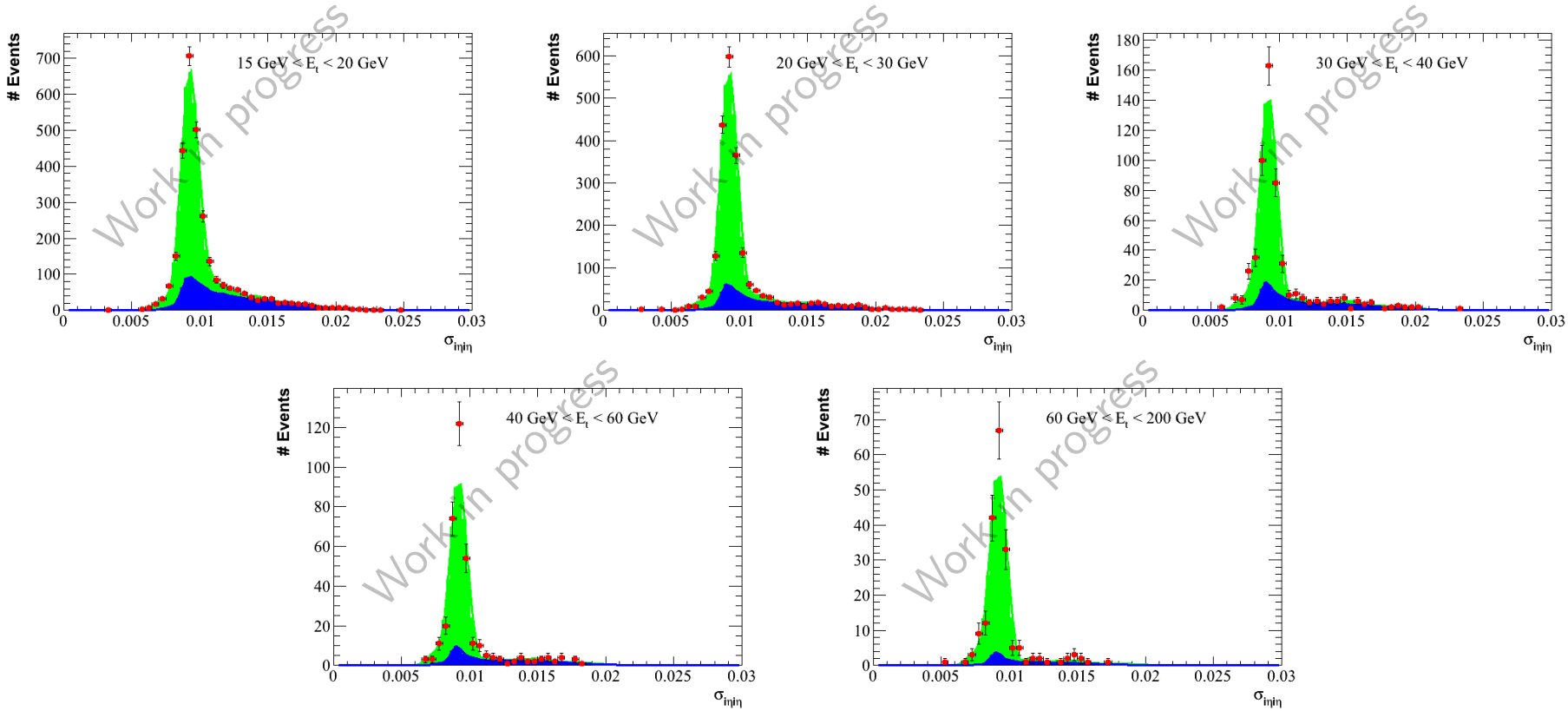
- In contrast to FSR strong contamination of fake photons due to π^0 and other neutral hadrons.
- $\sigma_{i\eta i\eta}$-templates (cluster shape variable) are used to extract the signal.
- **BKG:** from jet data by inverting the track isolation cut of the photon.
- **Signal:** from data FSR.



- $\sigma_{i\eta i\eta}$ and I_{TRK} have a very weak correlation.

Signal extraction I

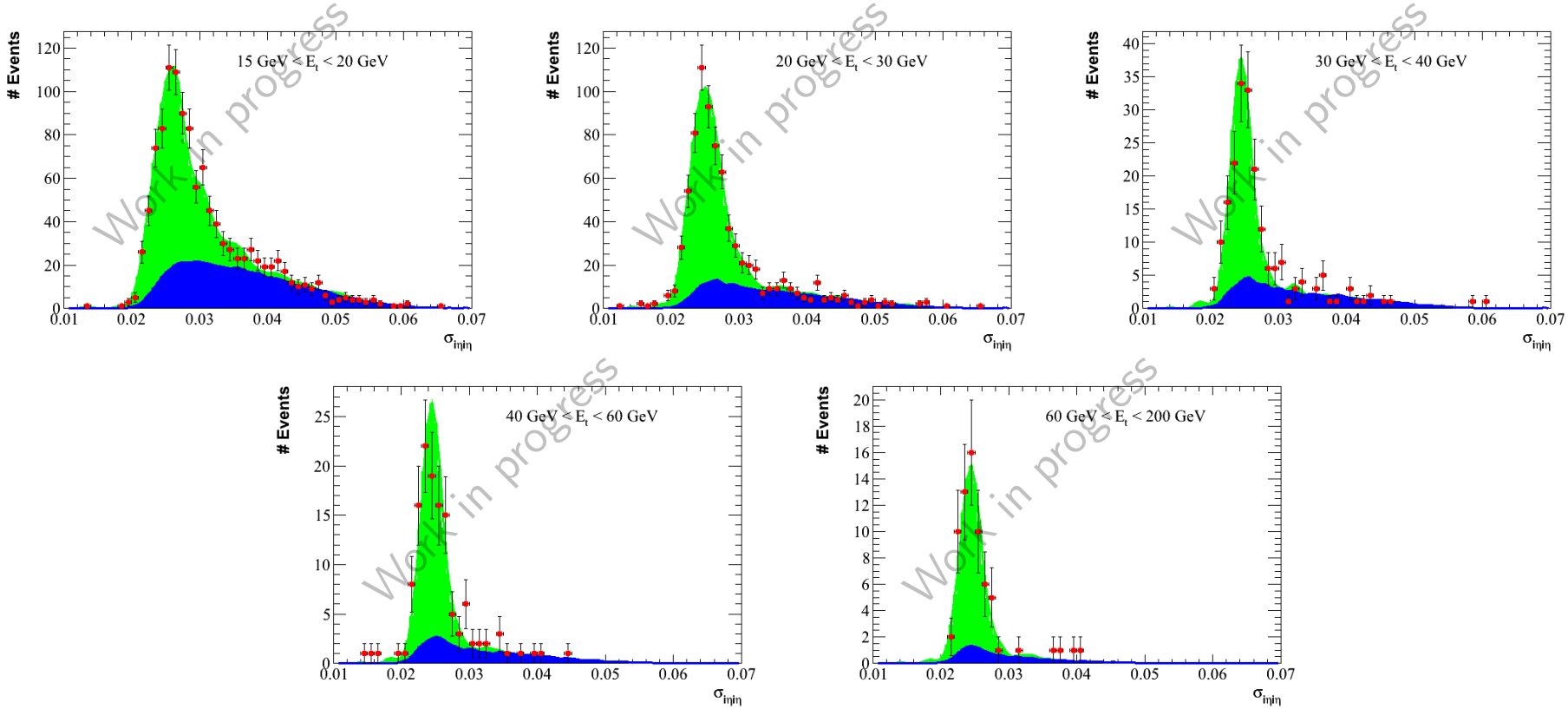
Template fit ECal barrel (signal, fake photons)



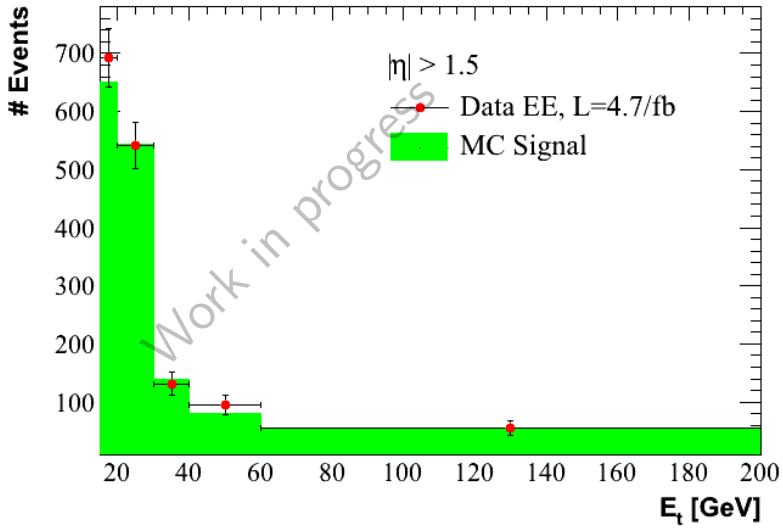
-Unbinned extended maximum likelihood method used.

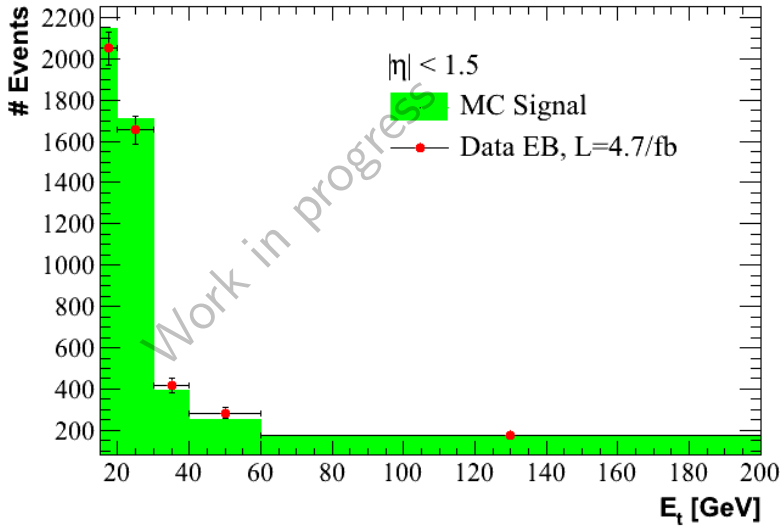
Signal extraction I

Template fit ECal endcap (signal, fake photons)



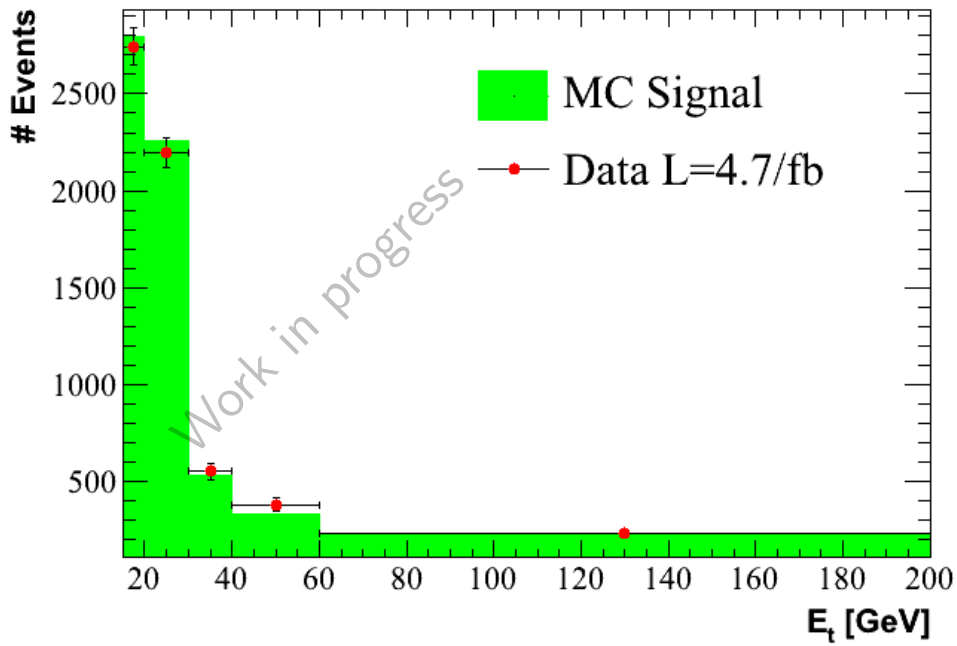
Signal extraction I





- Luminosity: $4683 \pm 187\,\mathrm{pb}^{-1}$
- $N_{sig} = 6095 \pm 137$
  $(EE : 1519 \pm 70, EB : 4577 \pm 117)$
- Photon reco uncertainty: 1.4 %
- Acceptance: 80.7 %
- Total efficiency: 29.9 %
- Difference due to photon scale: 2.3 %

Signal extraction I



Phase space: $\Delta R_{min}(\mu, \gamma) > 0.7$, $M_{\mu\mu} > 50\,\text{GeV}$ and $E_t(\gamma) > 15\,\text{GeV}$:

$$\sigma_{\mu\mu\gamma} = 5.74 \pm 0.17(stat.) \pm 0.16(sys.) \pm 0.23(lumi.)\,\text{pb}$$

Not all uncertainties included yet.

$\Rightarrow$Good agreement with NLO (MCFM) expectation of $5.447 \pm 0.006\,\text{pb}\Leftarrow$

Conclusion

FSR

Clean sample of photon with simple kinematic cuts:

- Photon reconstruction efficiency.
- Photon scale correction.

ISR

- Large number of fake photon but data driven templates for $\sigma_{i\eta i\eta}$ available.
- Cross section is in good agreement with MC prediction.
- Work on limits on AGC still ongoing.