Measurement of the QED FSR from Z $pp \rightarrow Z \rightarrow \mu\mu\gamma$ in ATLAS

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Outline

- Motivation: QED final state radiation

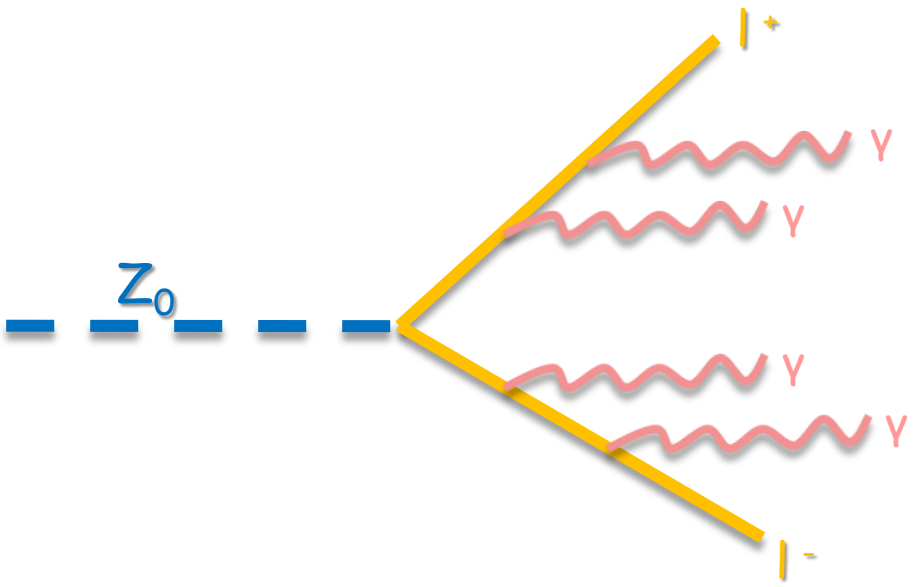
- Event selection
- Background rejection
- Photon performance: Linearity/Uniformity
- Systematic uncertainties

- Final yields and cross-section measurement of FSR
- Improvement on the Z invariant mass
- Improvement on H->(4μ) invariant mass

- Summary

Motivation

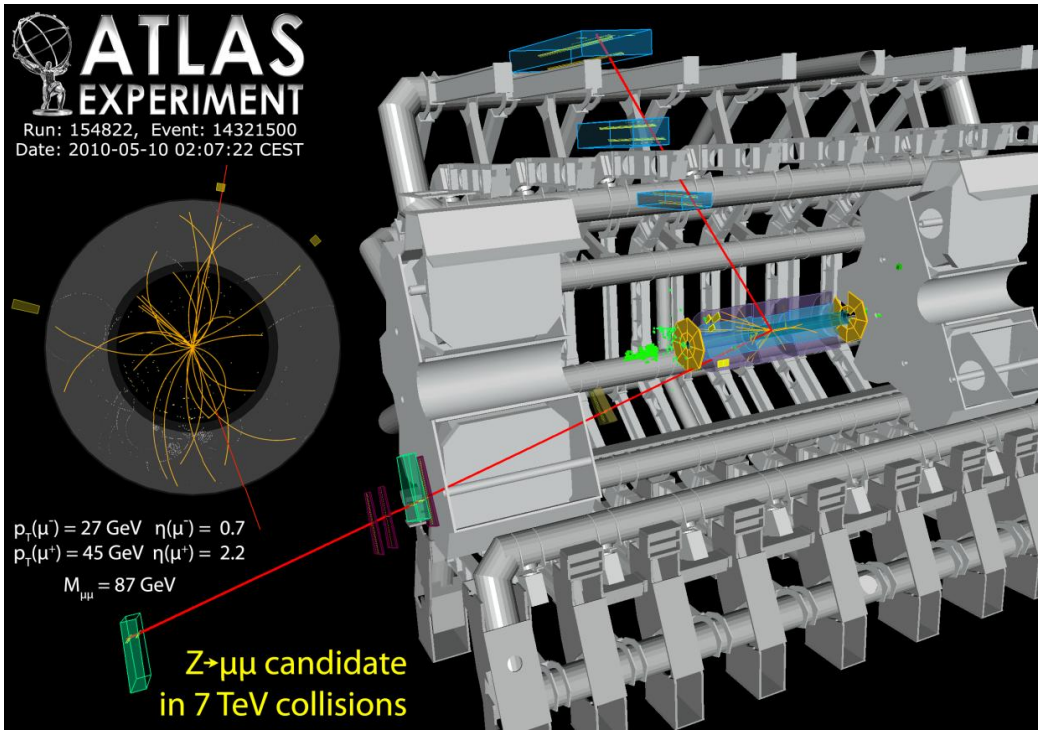
- QED final state radiation (FSR)



- Study photon QED radiation from Z leptonic decay.
- Measure Z->μμγ xsection.
- Improve the invariant mass of Z->μμ.
- Improve the high mass Higgs->ZZ->4l, in which large tails have been observed.

FSR(Z->μμγ) event selection

Plot: First candidate for an event with a Z boson decaying to two muons seen in 7 TeV collision data.

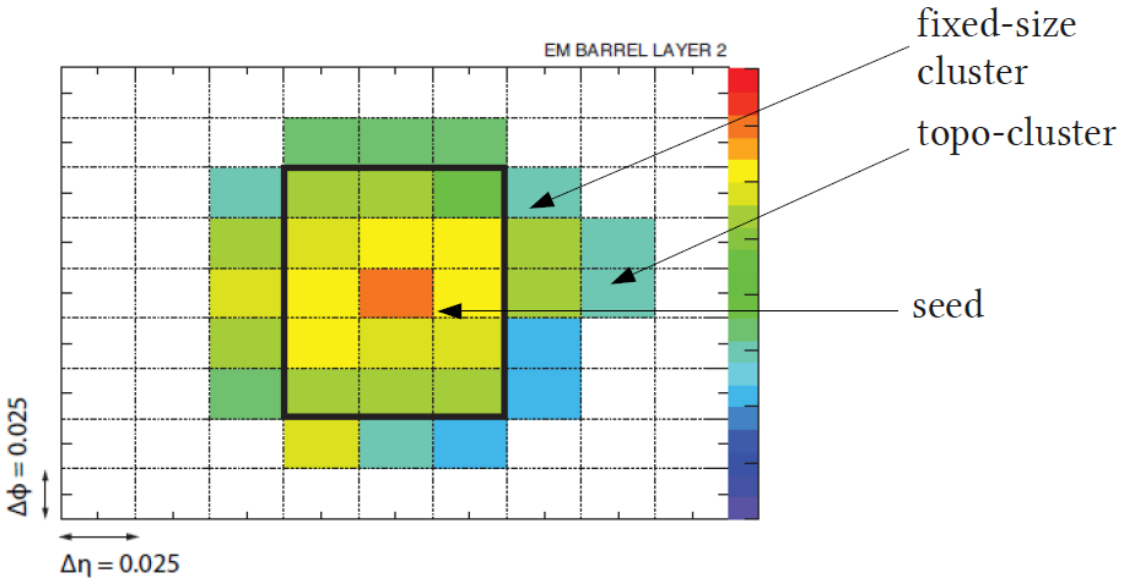


Find a high quality Z->μμ candidate(left) for one event.

Around the μ neutral lines(defined by μ momentum at IP), open a cone(ΔR~0.2).

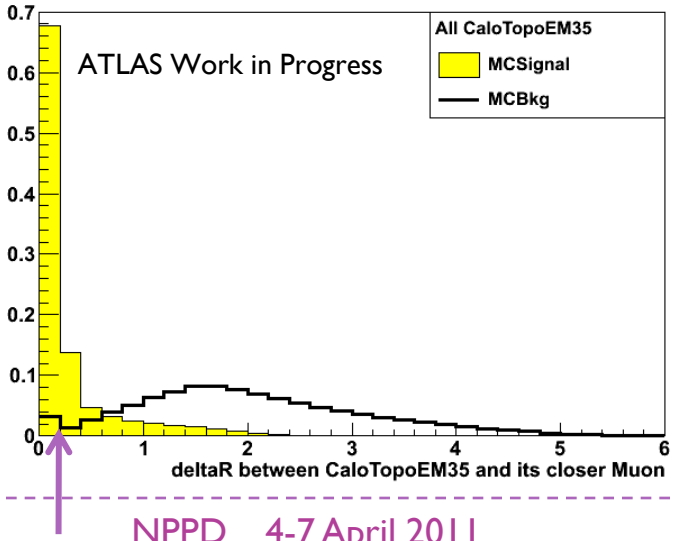
Pick the most energetic **CaloTopocluster** in the EM calorimeter as **Rec_{fsr}**.

CaloTopoEM35: cluster for low-P_T e/γ identification



- Approach E_T below 3GeV (comparing to standard Egamma SWclustering)
- Well calibrated by long-weights MC (comparing to TopoClustering)

We looked into all CaloTopEM35Clusters for events passing Z->μμ selection. Most of the signal FSR events are inside cone 0.2 around the closer μ.

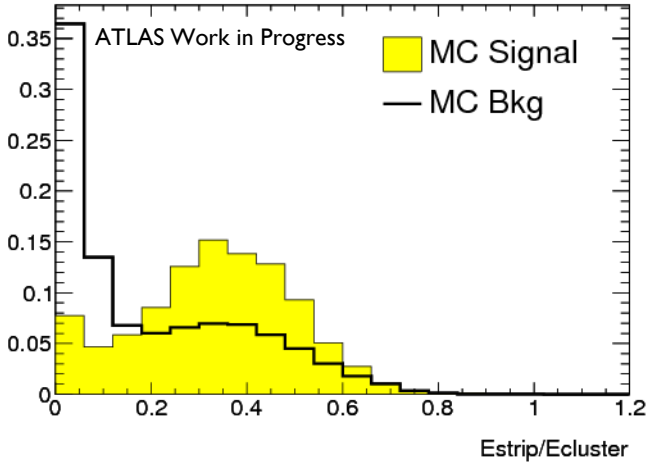


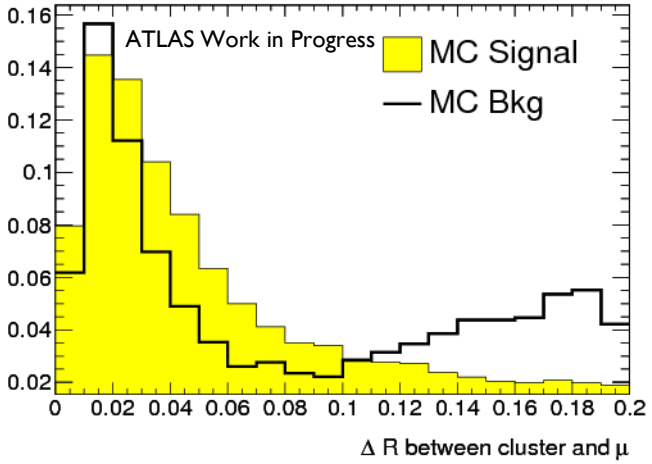
FSR background rejection

Background description

- fake FSR coming from Z->μμ events, the energy μ left in the cluster biases the FSR photon energy.(dominant)
- other Z->μμ backgrounds, mainly Wμu, Zττ and QCD events.(small)

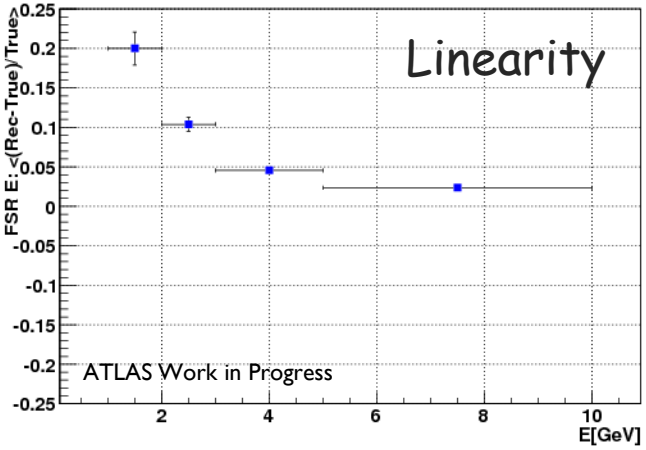
Analysis Cutflow (reduce fake FSR)	
Cut1	Et* > 1GeV
Cut2	$f_1 = (E_{strip}/E_{cluster}) > 0.15$
Cut3	deltaR between cluster and μ < 0.15

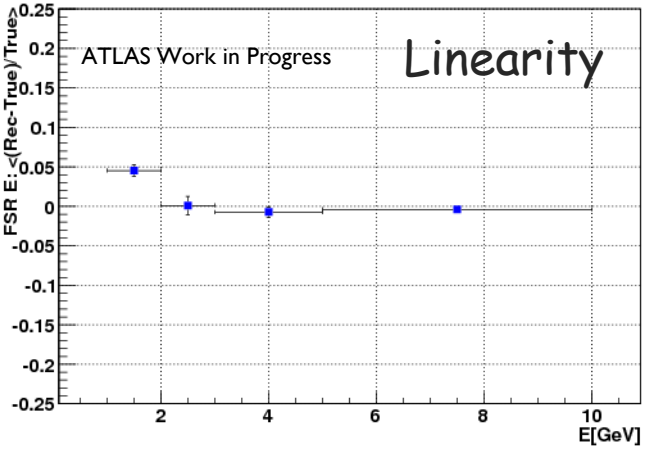


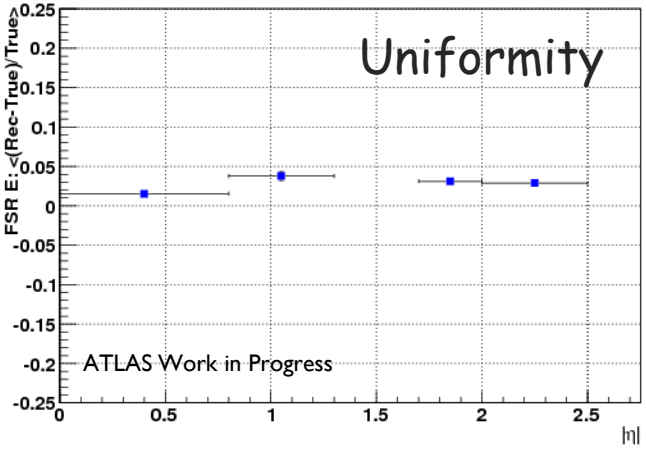


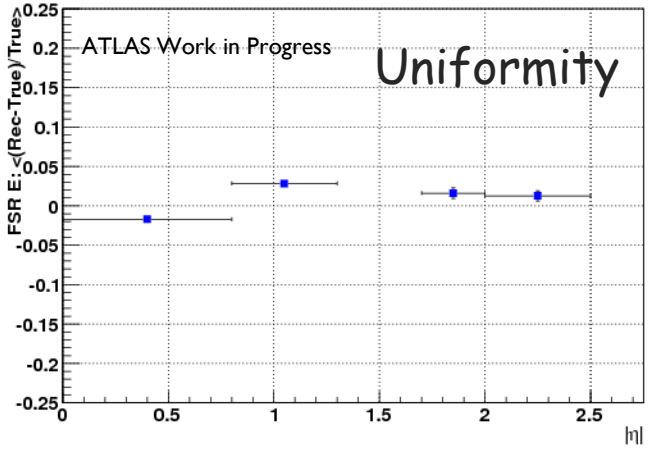
FSR photon performance: Linearity/Uniformity before/after energy correction

E_γ is overcorrected when using $E_{cluster}$ due to the energy of μ, which can be corrected by subtracting the average energy μ lost in the LAr.









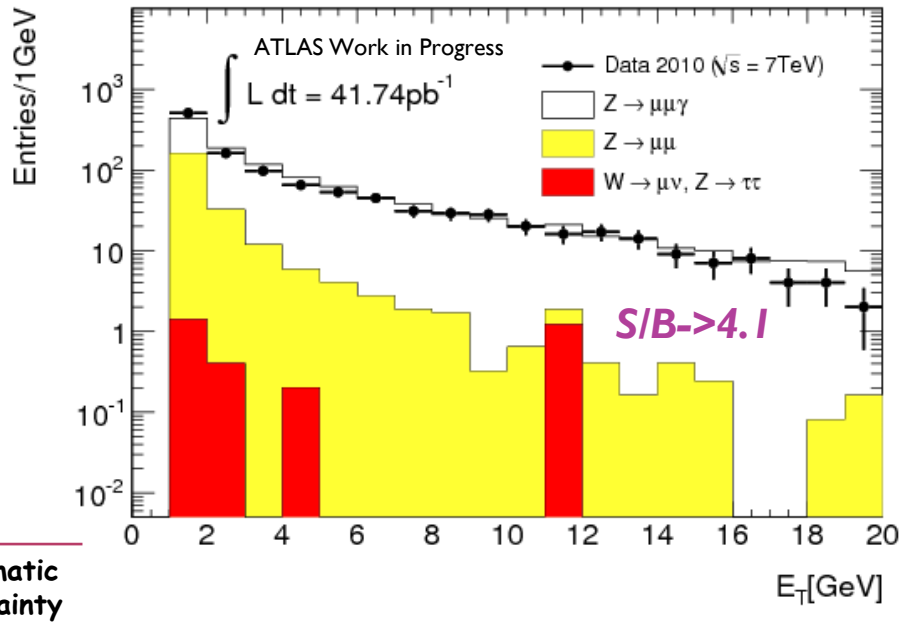
Final Z->μμγ yields for L=41.74pb^{-1}

The final event yield of Data is 1142.

ATLAS Work in Progress

$\sigma_{Z->\mu\mu\gamma \text{ measured from Data}} = 0.567nb$

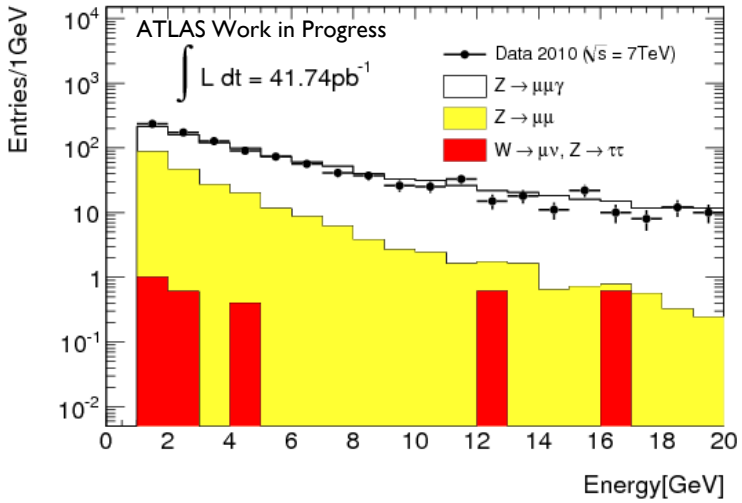
$\sigma_{Z->\mu\mu\gamma \text{ theoretical from MC}} = 0.582nb$



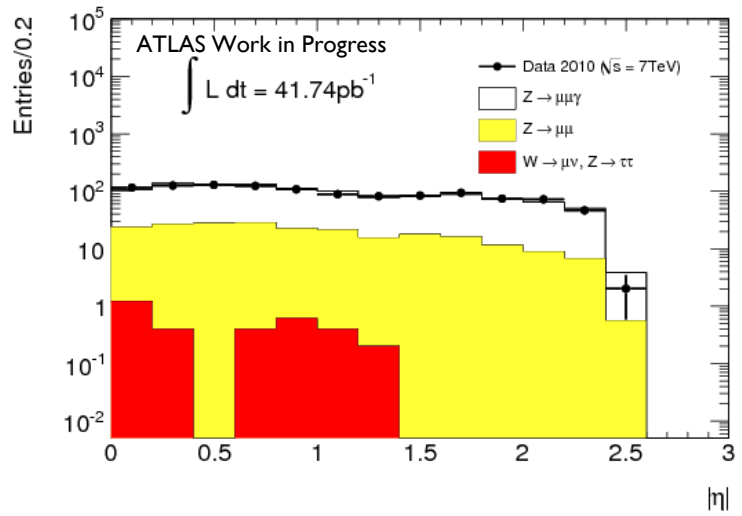
Cut description ATLAS Work in Progress	Method	Systematic Uncertainty
$Et_{cluster}$ > 1GeV	Data Driven	±1%
Other Analysis Cuts	Data Driven	±1%
Background Normalization	Data Driven	±2%
Total FSR(Z->μμγ) selection		±2.4%
Z selection(based on WZ note)	Data Driven	±6.2%
Total uncertainty (other than Lumi)		±6.6%
Luminosity uncertainty		±11%

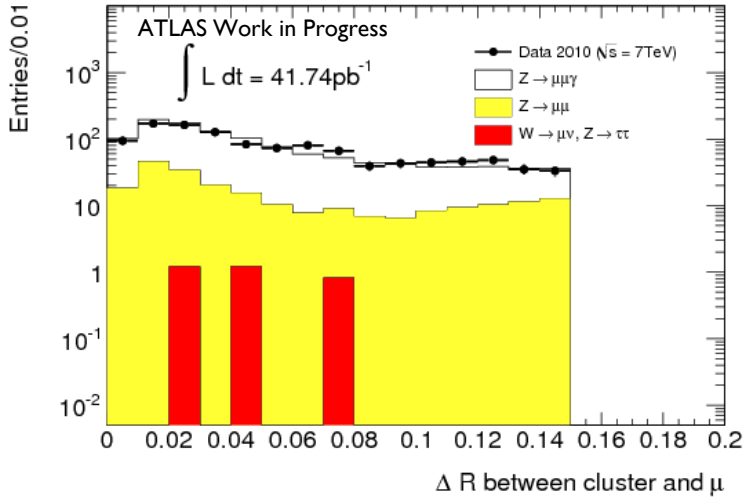
← Uncertainties for R=(Z->μμγ /Z->μμ) Which is insensitive to other systematics.

Final energy/|η|/dR distributions

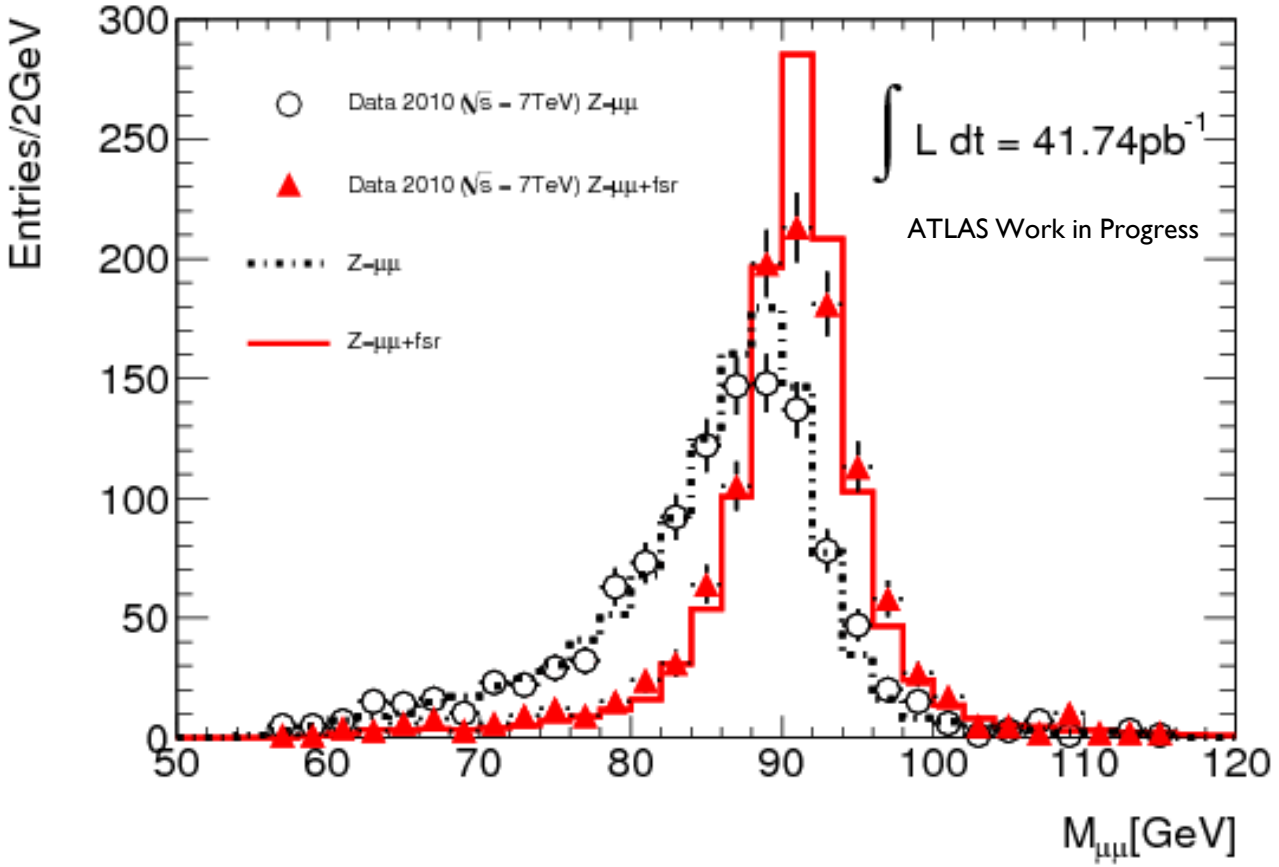


Signal and background are normalized to the expected number of events for 41.74pb^{-1}.





Improving the resolution and scale of the Z invariant mass



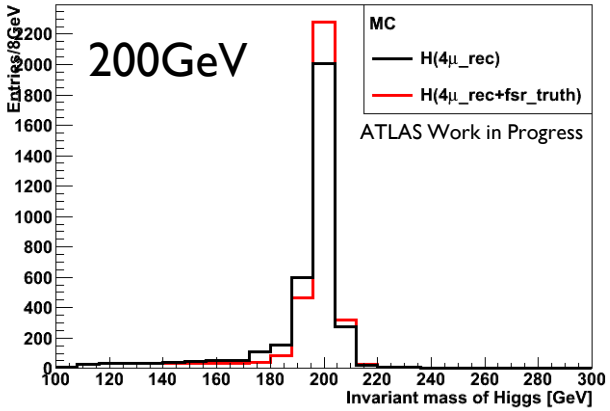
Invariant mass distribution of Z for events passing FSR analysis cuts:
Black dashdotted line/black point: Z mass calculated by Z=μμ from MC/Data
Red solid line/red point: Z mass calculated by Z=μμ+Rec_{fsr} from MC/Data

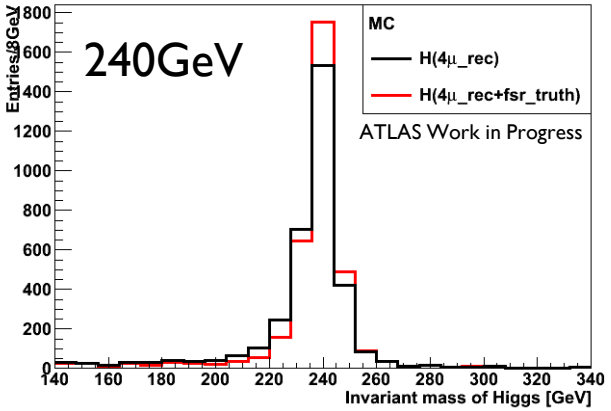
FSR contribution to the invariant mass of Higgs(→4μ)

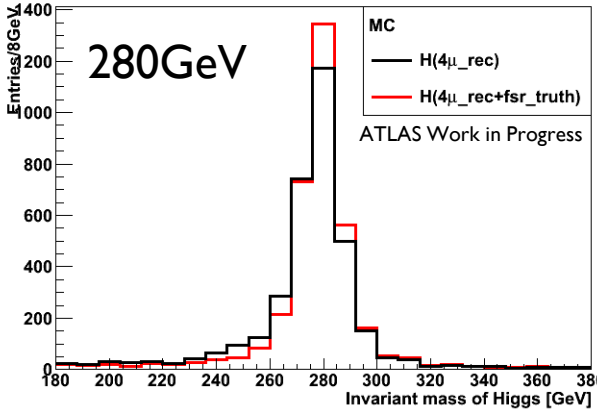
- For inclusive Z→μμ, we can correct at least 1/10 of the events.
- For Higgs→4μ, there are more FSR photons with even higher energy. We applied the similar method (cone0.3, Et>1GeV, using egamma electrons and photons) to the high mass Higgs and we found a significant reduction of the tails and improvement in the resolution. The events we corrected is ~20%.
- Samples: mc10H4l with mass range of Higgs:200~360GeV.

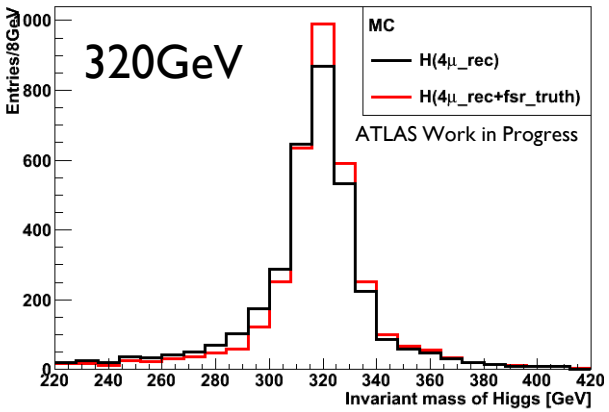
Higgs=4μ$_{recon}$(+FSR$_{truth}$) for 4μ events

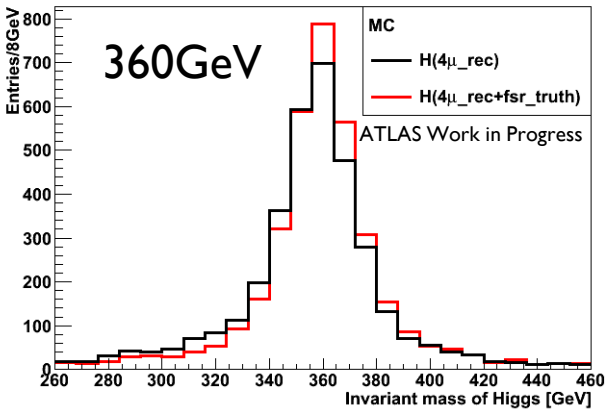
Improved Higgs Mass when adding truth FSR ← the best we can do!





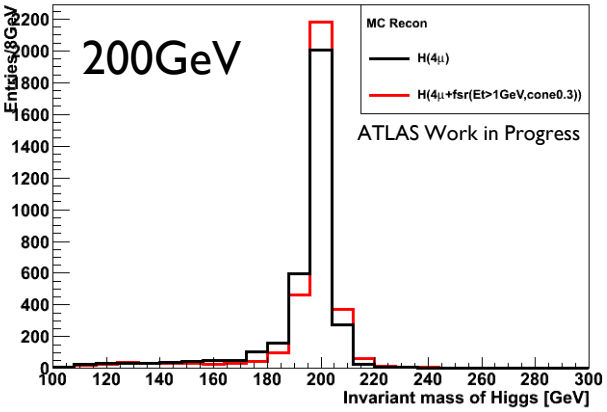


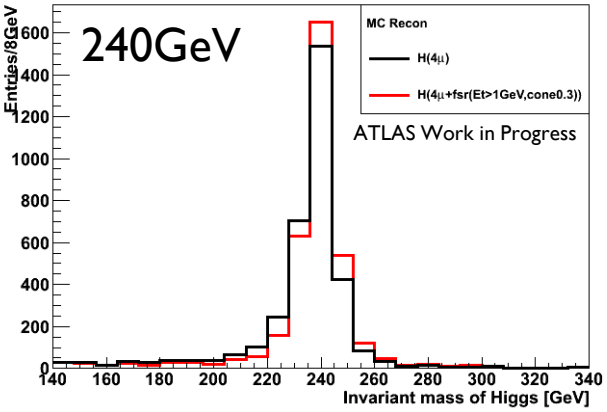


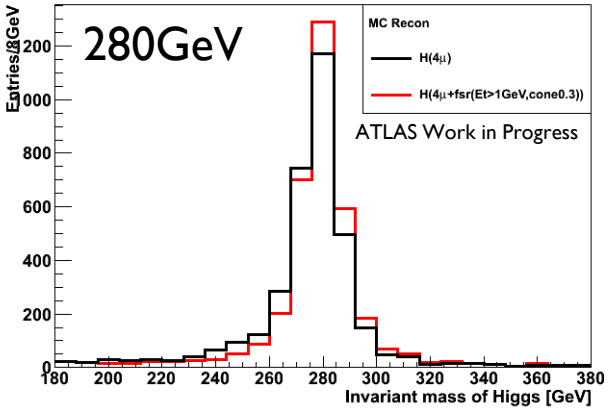


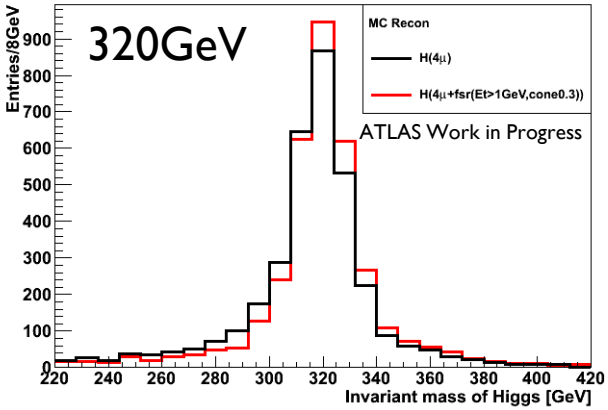
Higgs=4μ$_{recon}$(+FSR$_{recon}$) for 4μ events

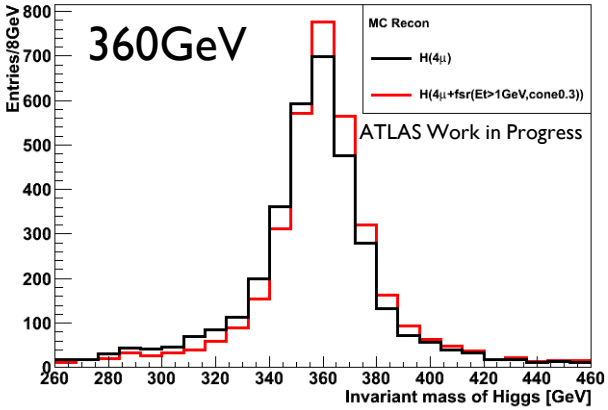
Improved Higgs Mass when adding recon FSR ← what we can do now!





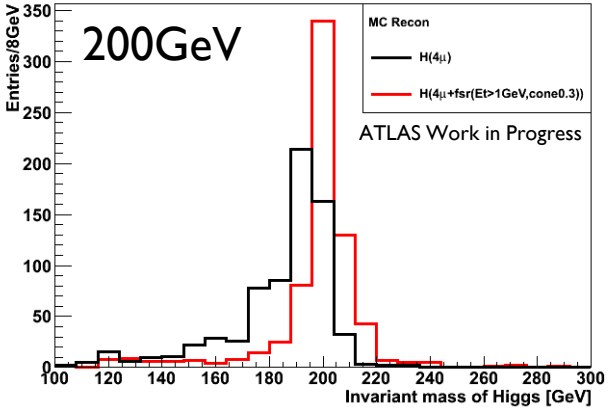


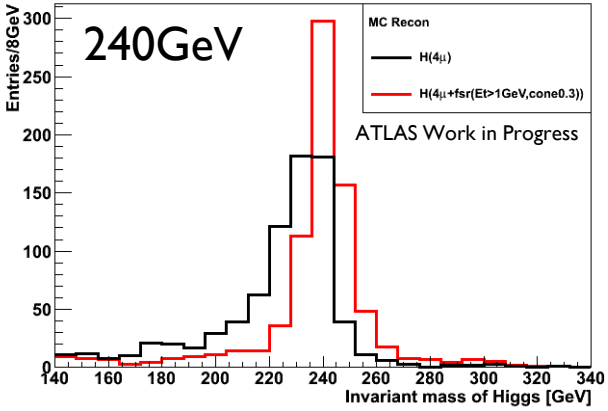


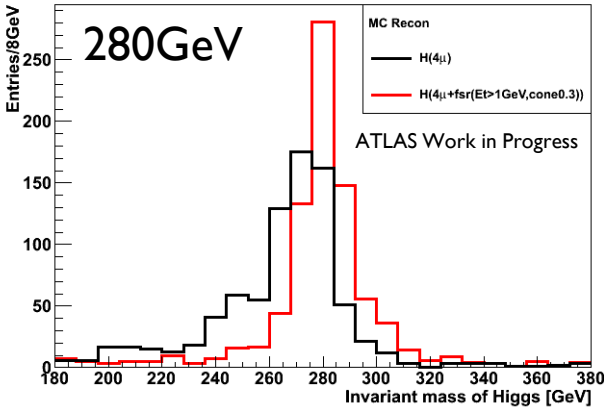


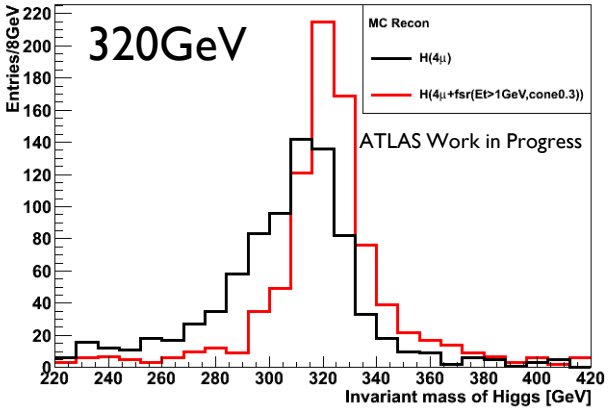
Higgs=4μ_{recon}(+FSR$_{recon}$) for corrected events

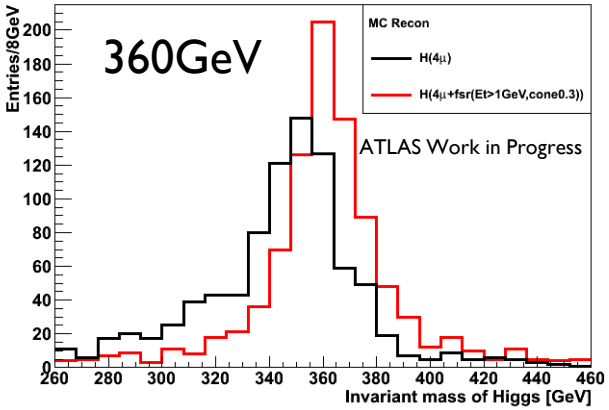
Improved Higgs Mass for corrected events only ← the real improvement











Summary

- The first measurement of the QED FSR from Z as well as the study of the systematic uncertainties have been done with the full 2010 dataset.
- For the measurement we used CaloTopoCluster that have a reach at energies as low as 500MeV. The Atlas Egamma group have approved our proposal to include this as one of the official egamma clusters.
- For the Z events with reconstructed FSR photons, the method improves significantly the Z->μμ invariant mass, thus confirming the high signal purity after event selection.
- Significant gains in the invariant mass of Higgs(→4μ) have been observed when adding FSR, which is crucial for the upcoming Higgs search.

Backup

FSR event selection

- Collision event selection
- Primary vertex: $N_{vtx} \geq 1$ with $N_{tracks} \geq 3$, $|Z_{vtx}| < 150mm$
- Trigger: EF_mu10

- High-P_T event selection
- Muon selection: Combined tracks, $P_T > 15GeV$, $|\eta| < 2.4$
- Muon quality: $P_T^{MS} > 10GeV$, $|P_T^{MS} - P_T^{ID}| < 15GeV$, $|Z_o - Z_{vtx}| < 10mm$

- Z->μμ event selection (both muons)
- Tight kinematics: $P_T > 20GeV$, $|\eta| < 2.4$
- Muon quality: (as above)
- ID isolation: $\sum P_T^{ID}/P_T < 0.2$
- Charge: $c_1 * c_2 < 0$
- Invariant Mass: $55 < M_{\mu\mu} < 116GeV$

Similar to SM Z→μμ

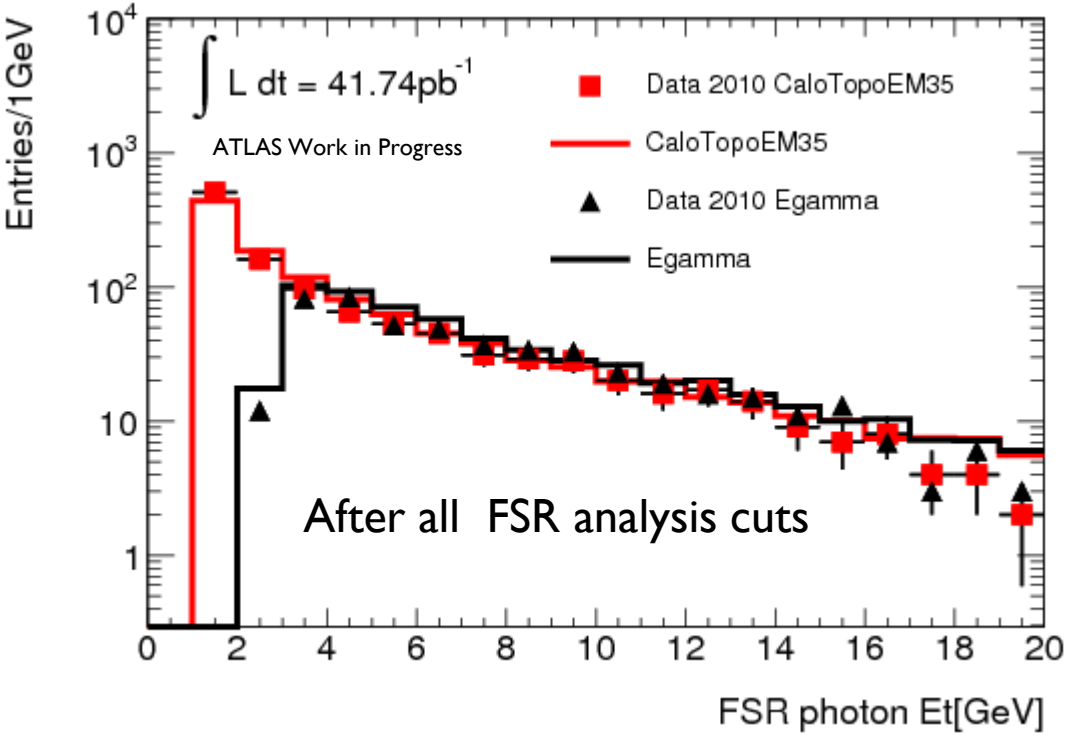
- Z→μμγ (FSR) selection
- in this selection, we are using ***CaloTopoEM35*** *: a fixed size cluster with 3*5 cells seeded by EMTopoCluster430. (has already been used in the π^0->γγ analysis)*
- for each "good Z candidate" event, loop over all *CaloTopoEM35* inside a cone of 0.2 around the μ neutral line(defined by the μ momentum at the IP), select the most energetic one as our FSR photon candidate.

Data sets and MC samples

- Data: L_{int}~ 41.74pb^{-1} (follows SM W/Z group)
- L1_MU10: ABCDE1-E3
- EF_mu10_MG: E4-G1
- EF_mu13_MG: G2-I1(up to run 167576)
- EF_mu13_MG_tight: I1(from run 167607)-I2

- MC: mc09 "Pythia+Photos"
- EF_mu10

CaloTopoEM35(red) versus EgammaSW(black)



- The same clusters as for π^0 analysis
- Official calibration used for π^0
- Everything out of the box.

Data shows that CaloTopoCluster is efficient at pt<3-4 GeV where SW stops.
Caution: CaloTopoEM35 is not well calibrated for high energies (E>10GeV)
Std egamma can be used above 4 GeV, but caution: most FSR's in electron collection.

Expected yield of FSR events from MC

All numbers in the table are normalized to 1 nb^{-1}.

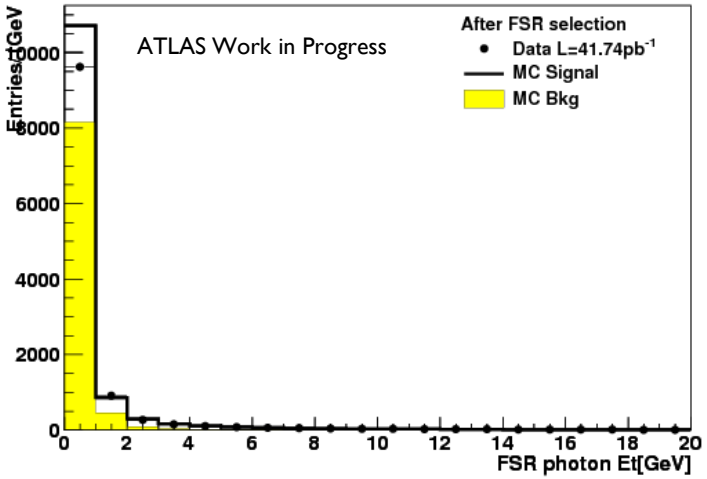
ATLAS Work in Progress

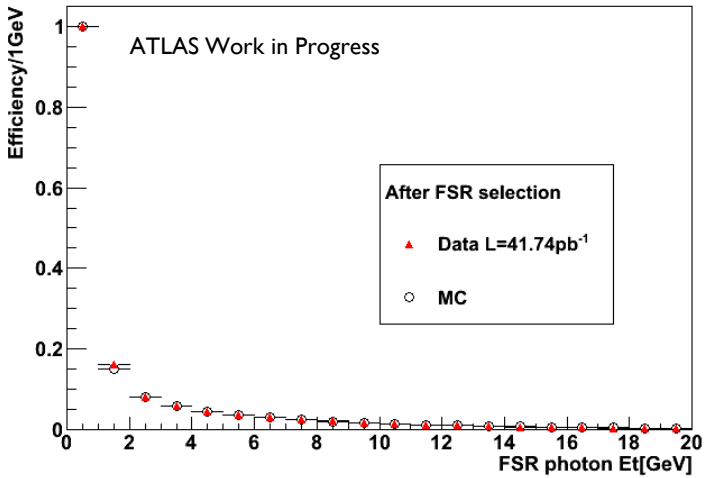
/nb^{-1}	FSR selection	Analysis cut 1	Analysis cut2	Analysis cut3
MC truth	0.093	0.030	0.025	0.023
MC bkg total	0.218	1.65E-02	7.29E-03	5.56E-03
MC bkg1 (Z->μμ)	0.217	1.63E-02	7.21E-03	5.48E-03
MC bkg2 (Wμυ, Zττ,QCD)	5.93E-04	1.27E-04	8.80E-05	8.31E-05

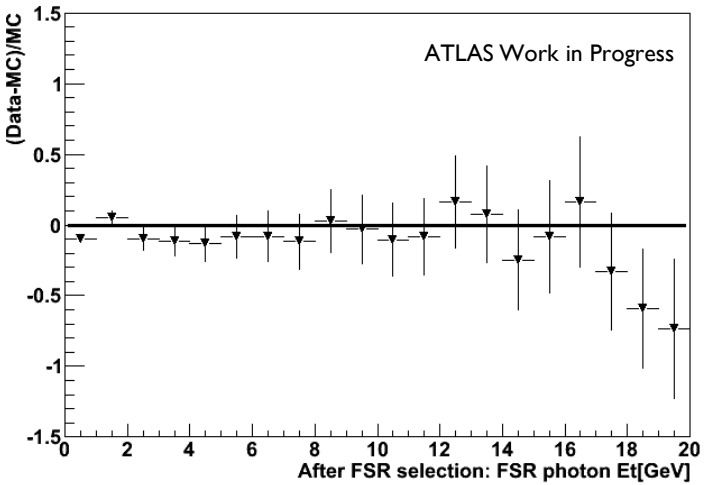
S/B->4.1

For Data(Period A to I) with L_{int} ~41.74pb^{-1}, we expect ~1185FSR candidates.

Systematic uncertainties: Et>1GeV







Energy scale of ±5% gives a ±1% systematic uncertainty.

Systematic uncertainties: Background normalization