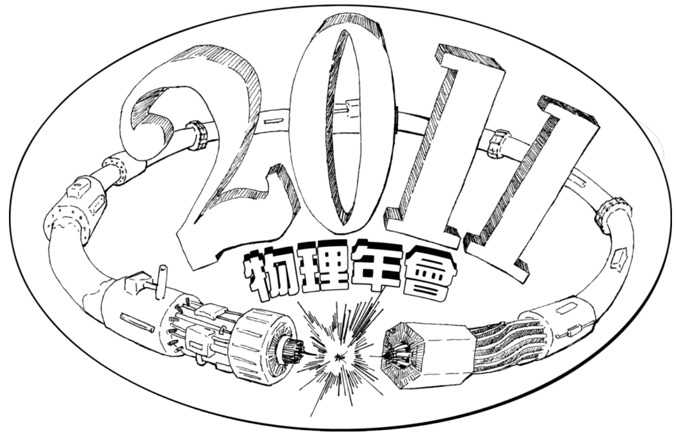
Wγ and Zγ Production at ATLAS



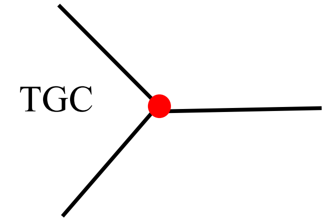
PSROC 2011

January 25th-27th, 2011

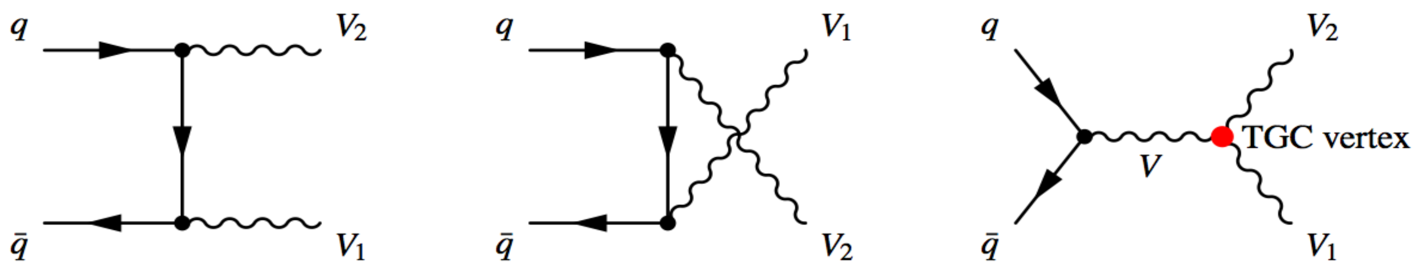
Song-Ming Wang
Academia Sinica

ATLAS Collaborations

Introduction

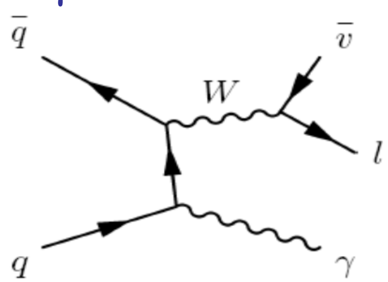


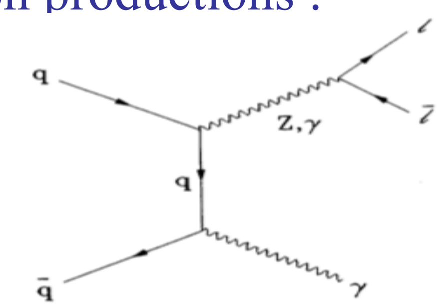
- In Standard Model (SM) non-abelian nature of $SU(2)_L \times U(1)_Y$ allow gauge bosons to interact with one another
  - Coupling between 3 gauge bosons ⇒ Triple Gauge-Boson Coupling (TGC)
- The study of these gauge couplings can be performed through the measurement of di-boson productions
- At LHC di-boson can be produced through :



t-channel　　*u*-channel　　*s*-channel

- Wγ, Zγ are two of such di-boson productions :





- Measurement of di-boson productions at LHC provides an important test of high energy behavior of EWK interactions, and is an key milestone for initial physics program

Gauge Couplings

- SM only allows charged coupling (WWZ,WWγ), does not allow pure neutral coupling (ZZZ, ZZγ, Z$\gamma\gamma$, $\gamma\gamma\gamma$) since Z/γ has no charge nor weak isospin
- Physics beyond SM can introduce anomalous TGC which may allow neutral couplings, or increased the charged TGC coupling strength
- Effective Lagrangians which characterized the charged and neutral TGC, introduced a few anomalous coupling parameters (assuming C,P symmetry conservation and QED gauge invariance)

Charged TGC:

- λ_γ , λ_Z
- $\Delta\kappa_\gamma=\kappa_\gamma-1$, $\Delta\kappa_Z=\kappa_Z-1$, $\Delta g^Z{}_1=g^Z{}_1-1$
- SM at tree level: $\lambda_\gamma=\lambda_Z=\Delta\kappa_\gamma=\Delta\kappa_Z=\Delta g^Z{}_1=0$

Neutral TGC:

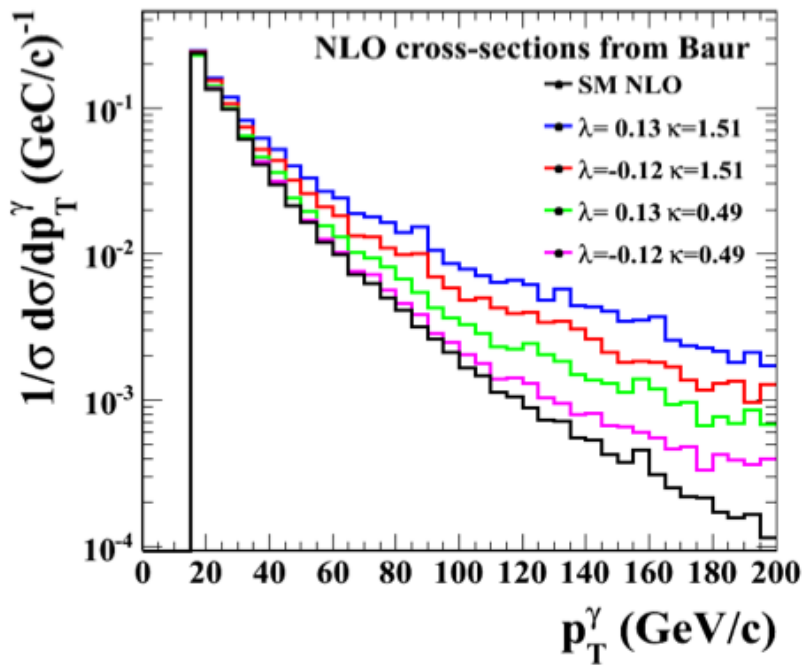
- $f^Z{}_4$, $f^Z{}_5$, $f^\gamma{}_4$, $f^\gamma{}_5$
- SM at tree level: $f^Z{}_4 = f^Z{}_5 = f^\gamma{}_4 = f^\gamma{}_5 =0$

Gauge Couplings

Final State	WZ	Wγ	WW	ZZ	Zγ
SM	W± W± Z TGC	W± W± γ TGC	W+ Z/γ W- TGC	✗	✗
an.TGC	W± W± Z TGC	W± W± γ TGC	W+ Z/γ W- TGC	Z γ/Z Z TGC	γ γ/Z Z TGC

- Each diboson production can probe one or more TGC:
  - Wγ : WWγ vertex
  - Zγ : ZZγ, Zγγ vertex
- Measures the anomalous coupling parameters

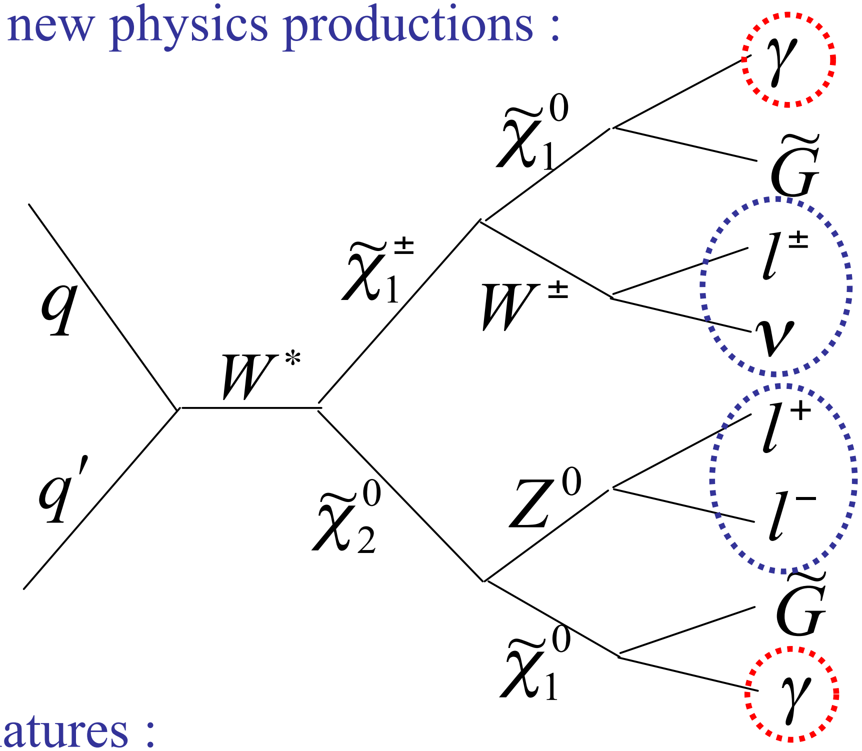
- Presence of anomalous TGC could enhance diboson production rate, particularly at high transverse momentum of bosons
- Search for new physics through measuring the anomalous TGCs



Diboson and Searches

•Diboson (Wγ,Zγ) final state can appear in new physics productions :

- **SUSY**
  - $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{\chi}_1^0 \rightarrow l^{\pm}\nu\gamma\tilde{G}$
  - $\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0 \rightarrow l^+l^-\gamma\tilde{G}$



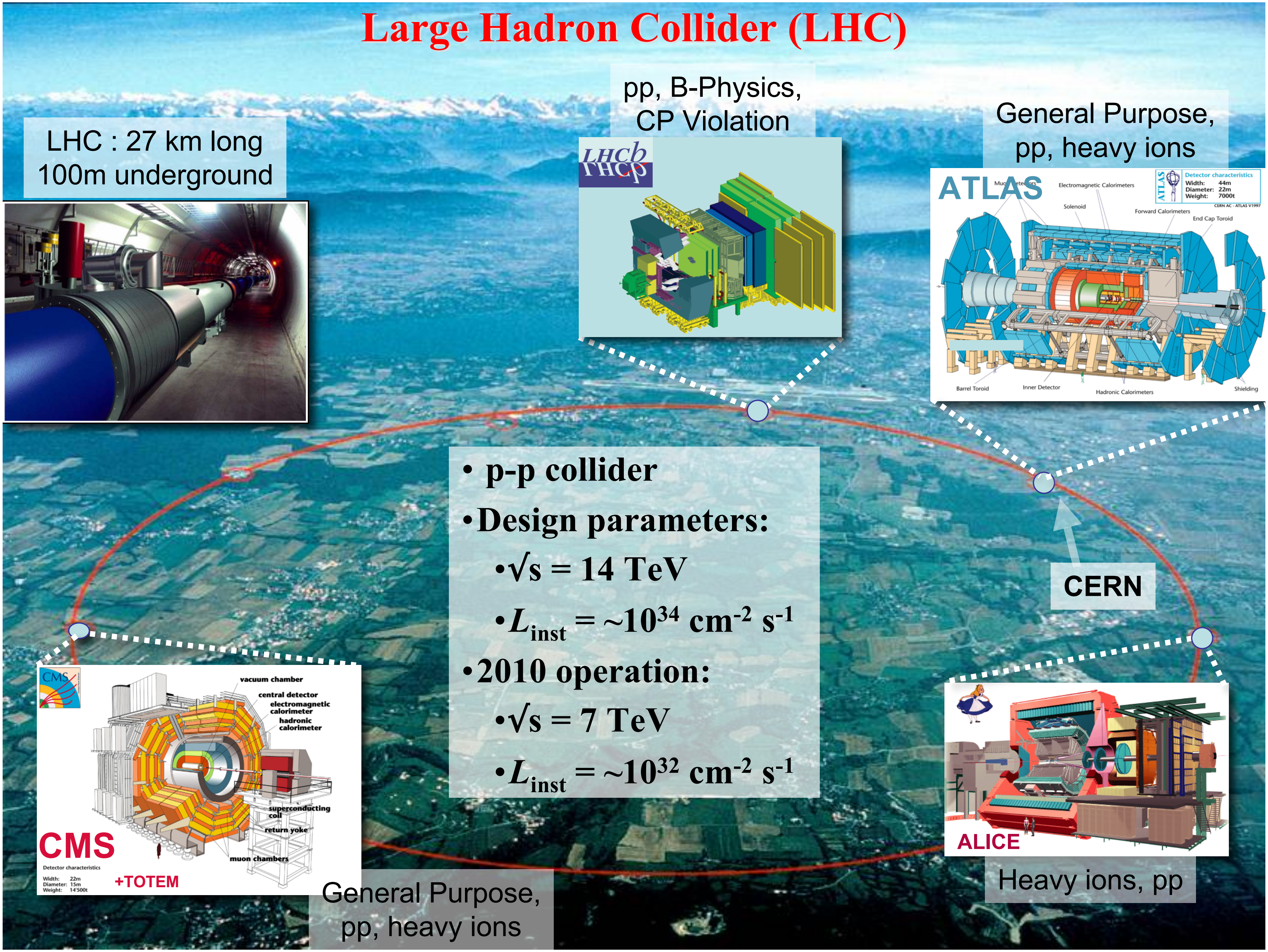
•Diboson (Wγ,Zγ) faking new physics signatures :

- **$W^{\pm}\gamma \rightarrow l^{\pm}\nu\gamma \rightarrow l^{\pm}\nu l^+l^-$**
- **$Z\gamma \rightarrow l^+l^-\gamma \rightarrow l^+l^-l^+l^-$**

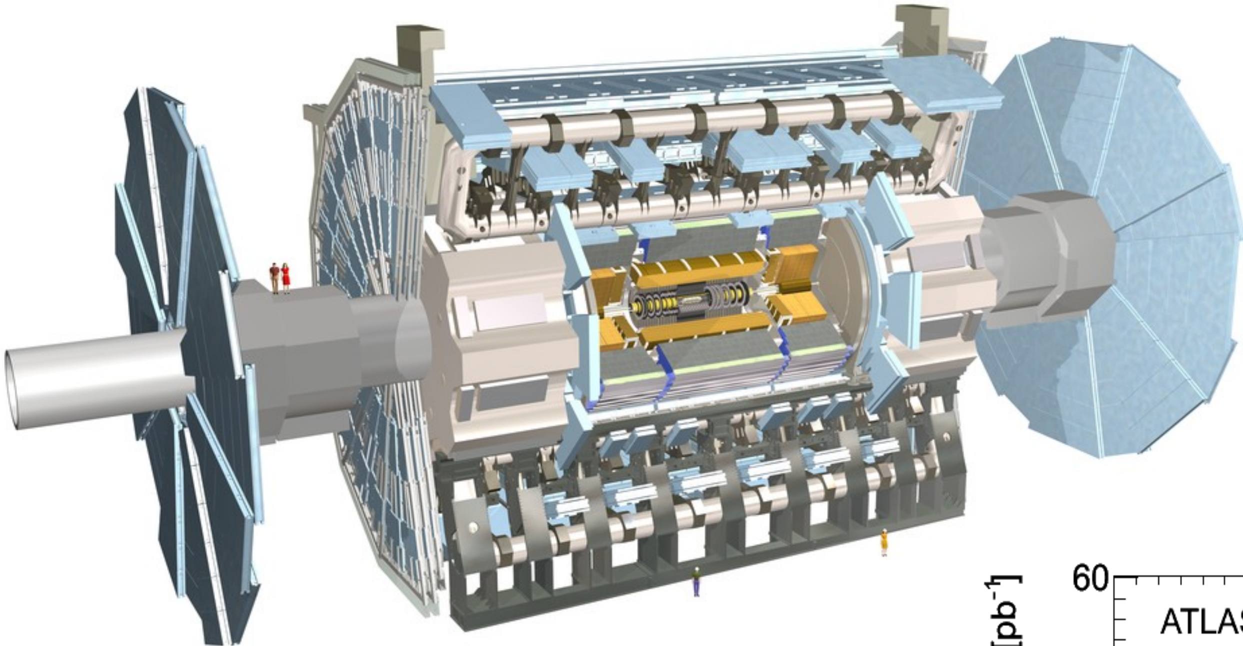
•Photon conversion leads to same-sign multi-lepton signature

•Background to searches for new physics in this final state

⇒ Important to understand these production processes !

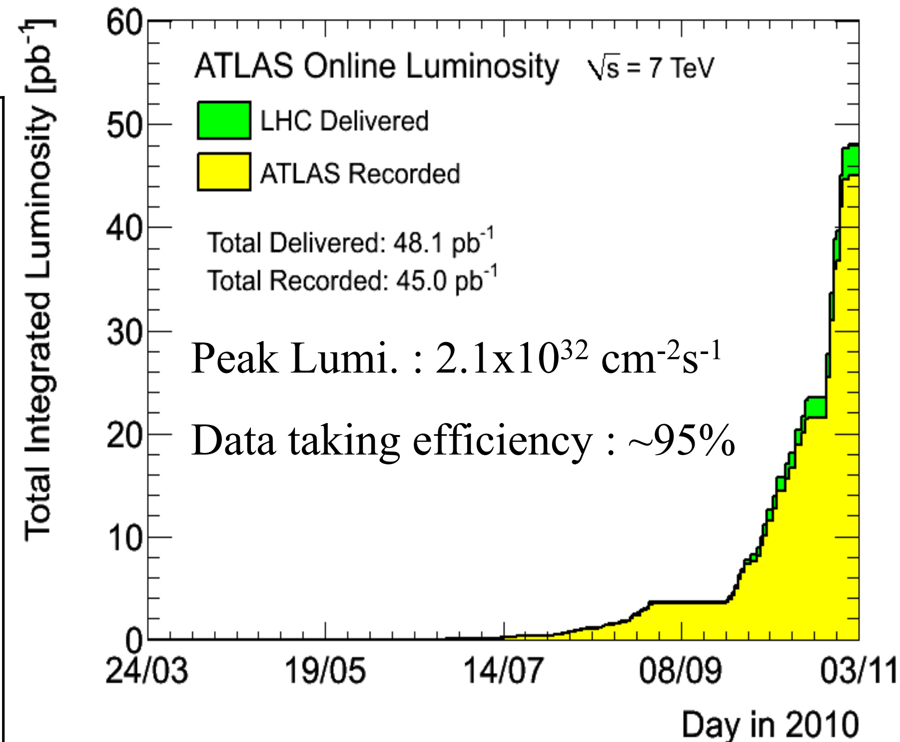

Large Hadron Collider (LHC)
LHC : 27 km long
100m underground
pp, B-Physics,
CP Violation
LHCb
General Purpose,
pp, heavy ions
ATLAS
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding
• p-p collider
• Design parameters:
• $\sqrt{s}$ = 14 TeV
• L_{inst} = ~10^{34} cm^{-2} s^{-1}
• 2010 operation:
• $\sqrt{s}$ = 7 TeV
• L_{inst} = ~10^{32} cm^{-2} s^{-1}
CERN
vacuum chamber
central detector
electromagnetic calorimeter
hadronic calorimeter
superconducting coil
return yoke
muon chambers
CMS
+TOTEM
General Purpose,
pp, heavy ions
ALICE
Heavy ions, pp

ATLAS Detector and Luminosity



B field: 2T solenoid, 4T toroid

Inner tracker : |η| coverage	2.5
$\sigma(P_T)/P_T$ at P_T=100 GeV	3.8%
EM calorimeter: |η| coverage	3.2
$\sigma(E)/E$	$10\%/\sqrt{E}+0.7\%$
HAD calorimeter: |η| coverage	4.9
$\sigma(E)/E$ (EM+HAD combined)	$50\%/\sqrt{E}+3\%$
Muon system: |η| coverage	2.7
$\sigma(P_T)/P_T$ at P_T=1 TeV (standalone)	12% ($\|\eta\|<1.5$)



Peak Lumi. : 2.1×10^{32} cm^{-2}s^{-1}

Data taking efficiency : ~95%

$W\gamma$, $Z\gamma$ Production at Hadron Colliders

Predicted cross sections :

Diboson mode	$\sqrt{s}$=1.96 TeV σ(ppbar) [pb]	$\sqrt{s}$=7 TeV σ(pp) [pb]
$W^{\pm}\gamma$	19.3*	69.0**
$Z\gamma$	4.7*	13.8**

* : $E_T(\gamma)>7$ GeV, $\Delta(l,\gamma)>0.7$, $l=e$ or μ

** : $E_T(\gamma)>10$ GeV, $\Delta(l,\gamma)>0.5$, $l=e$ or μ

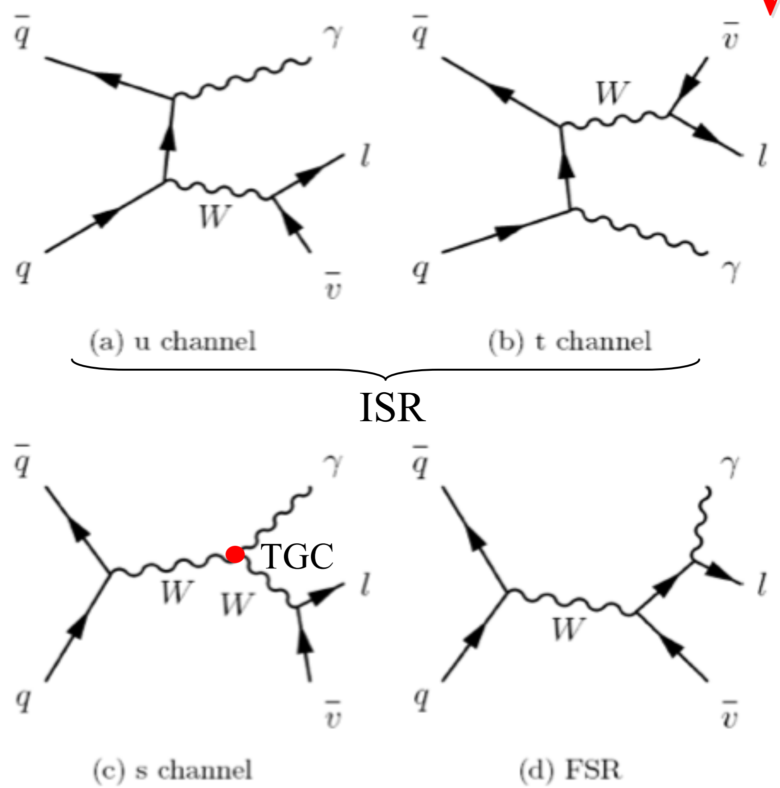
Measured cross sections :

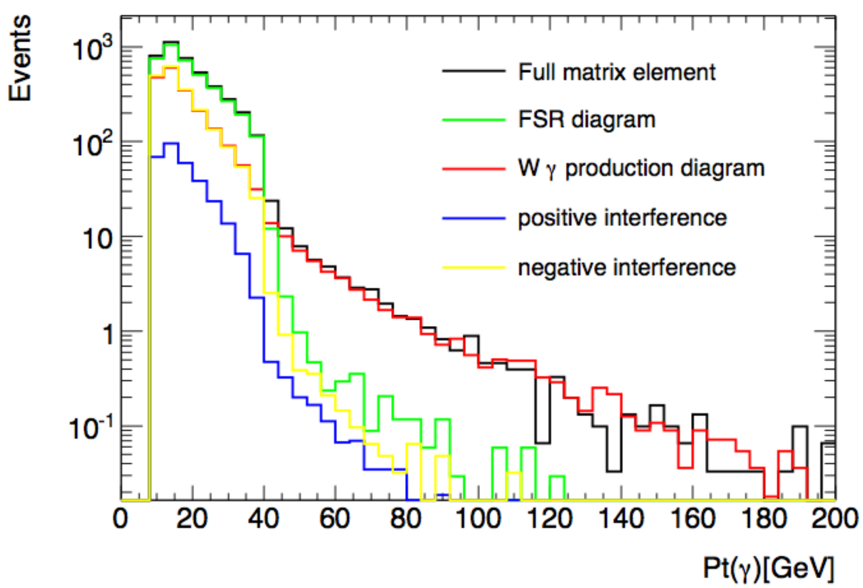
Diboson mode	$\sqrt{s}$=1.96 TeV σ(ppbar) [pb]	$\sqrt{s}$=7 TeV σ(pp) [pb]
$W^{\pm}\gamma$	18.0±2.8* (CDF, 1.1 fb^{-1}) 14.8±2.1* (D0, 0.16 fb^{-1})	?
$Z\gamma$	4.6±0.5* (CDF, 1.1 fb^{-1}(ee), 2.0 fb^{-1}($\mu\mu$)) 4.96±0.42* (D0, 1.1 fb^{-1})	?

- Production rate at LHC is ~3 times of Tevatron
  - Greatly enhance detection sensitivity to anomalous triple-gauge-boson couplings

Wγ Production

- Perform measurement in e, μ decays
- Final state consists:
  - High p_T isolated e, μ
  - Isolated γ
  - Missing E_T due to escaping ν
- Main background:
  - W+jets : jet fakes as γ
  - Z(ee,μμ)+γ/jet (one lepton not Id, jet mis-Id as γ)
  - t-tbar

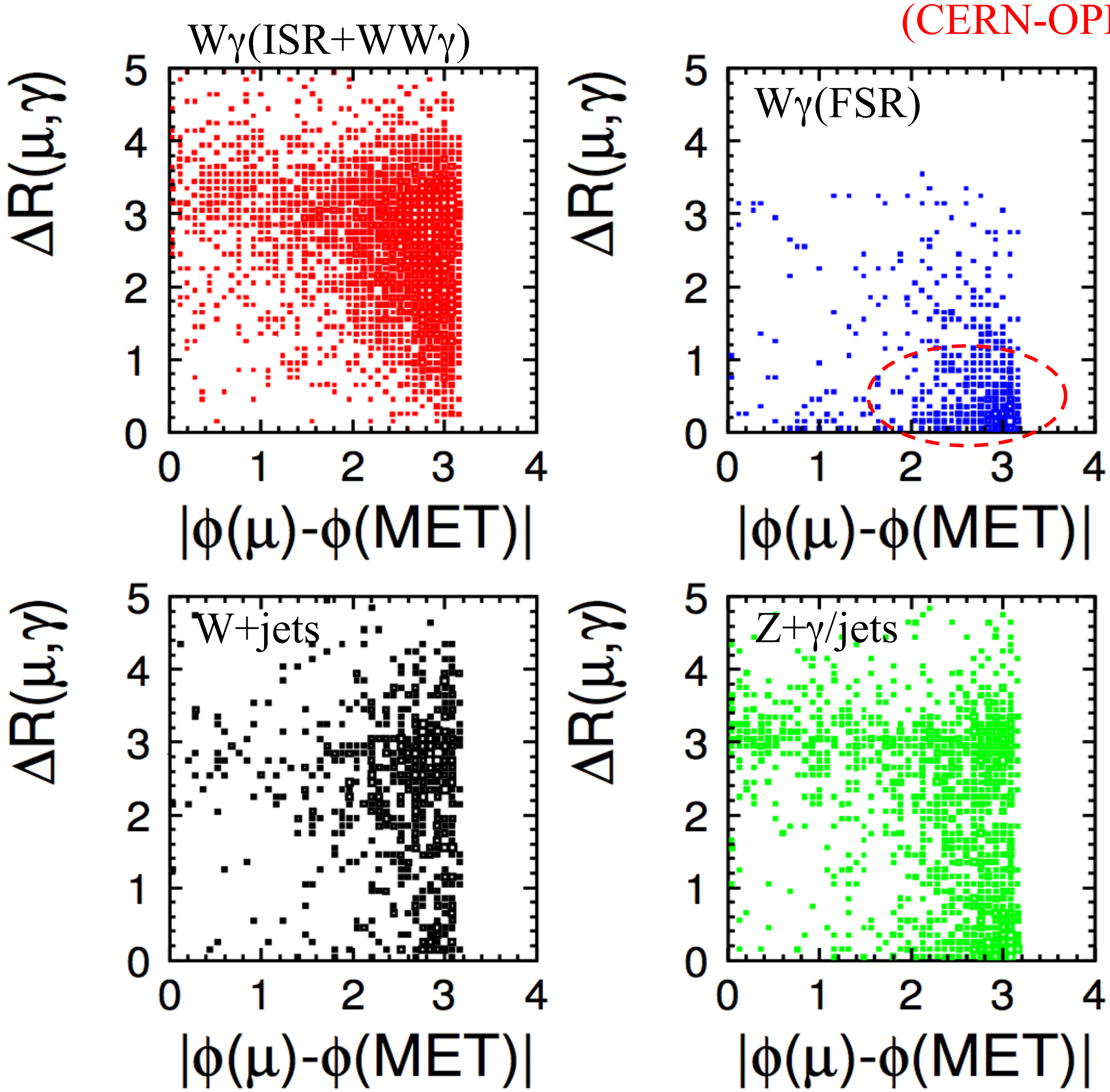




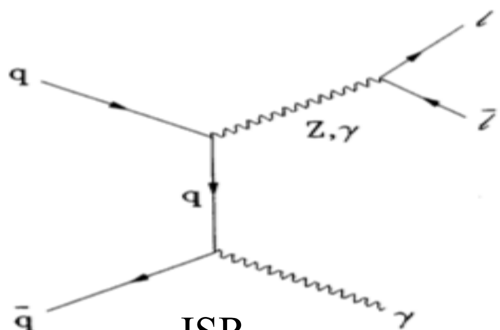
- $E_T(\gamma)$ from FSR drops rapidly after ~40 GeV , limited by the momentum carries by the lepton
- Higher $E_T(\gamma)$ region is dominated by the ISR and WWγ vertex

Wγ Production

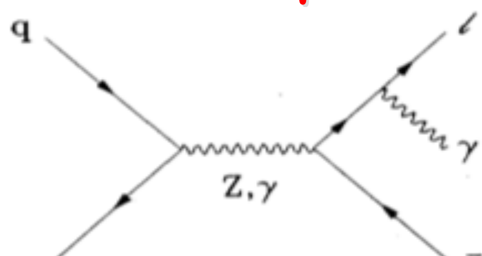
(CERN-OPEN-2008-020)



Zγ Production

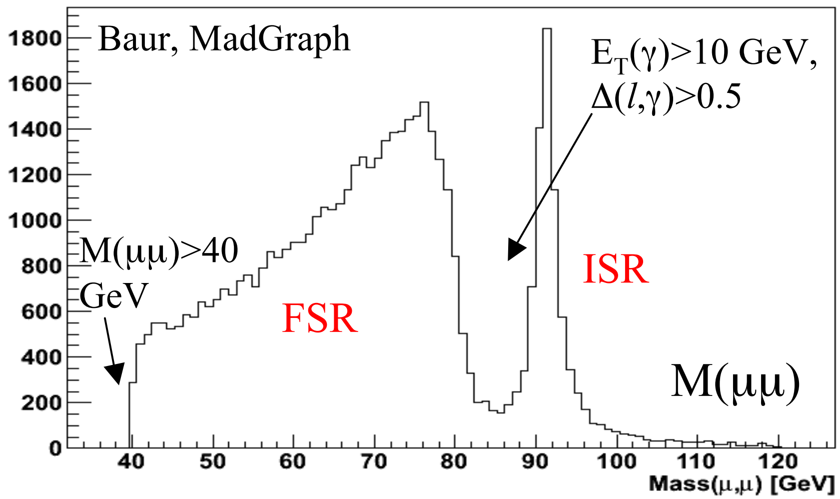


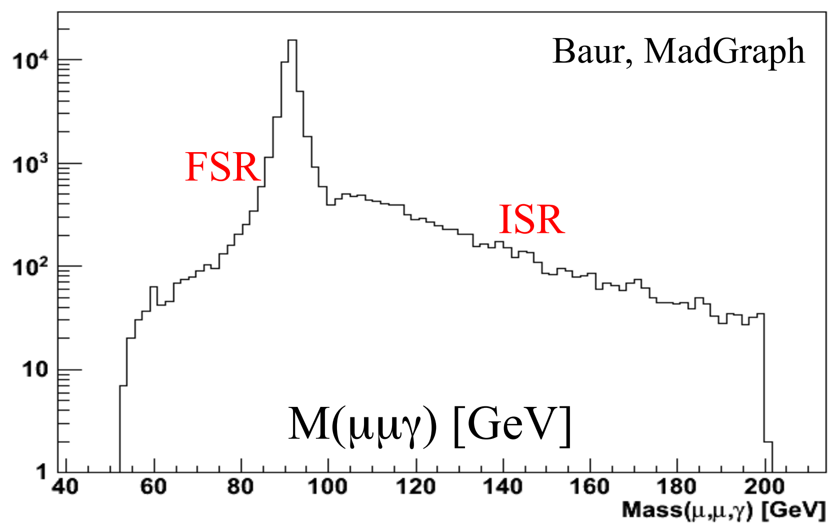
ISR

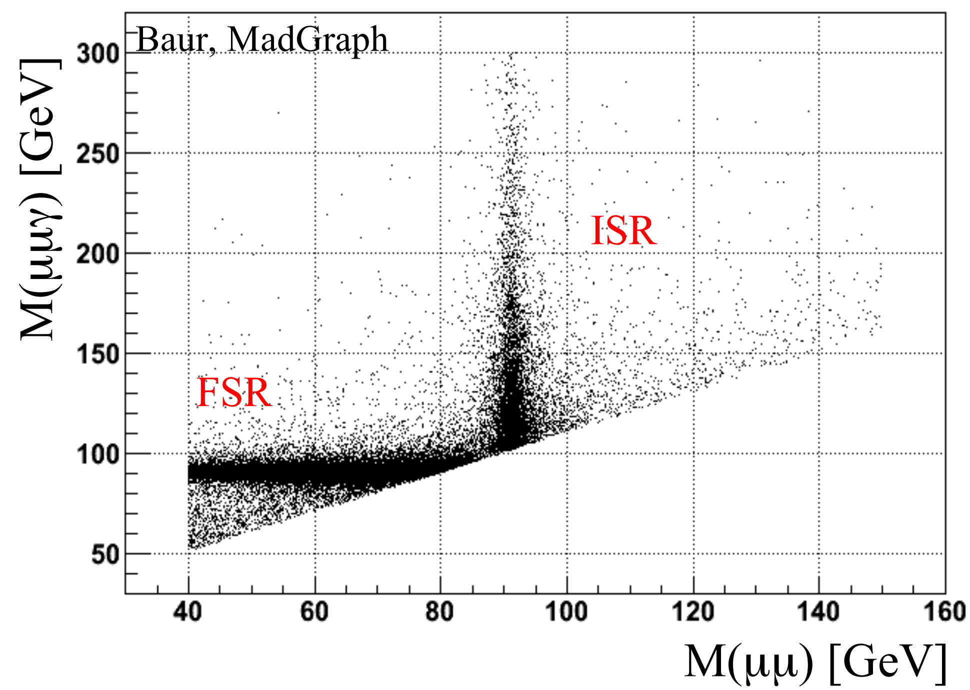


FSR

- Perform measurement in e, μ decays
- Final state consists:
  - A pair of e^+e^- , $\mu^+\mu^-$
  - Isolated γ
- Main background:
  - Z+jets : jet fakes as γ
  - t-tbar



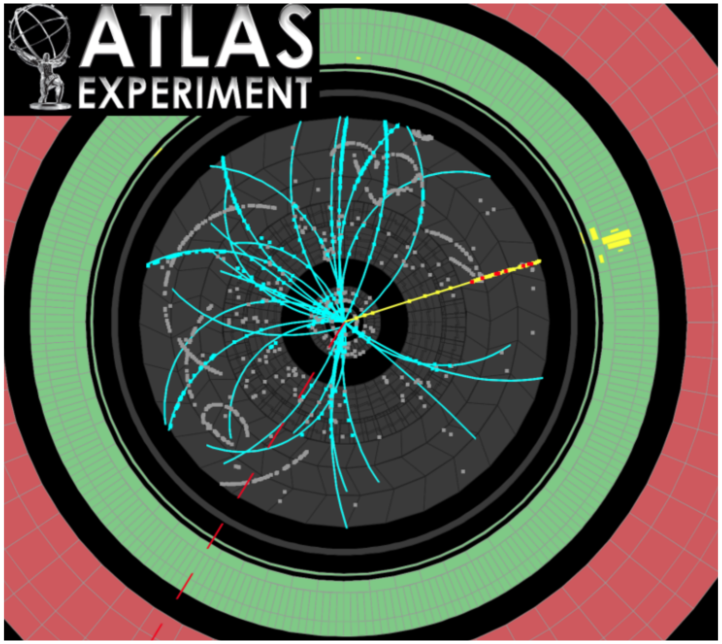




Understanding Physics Objects

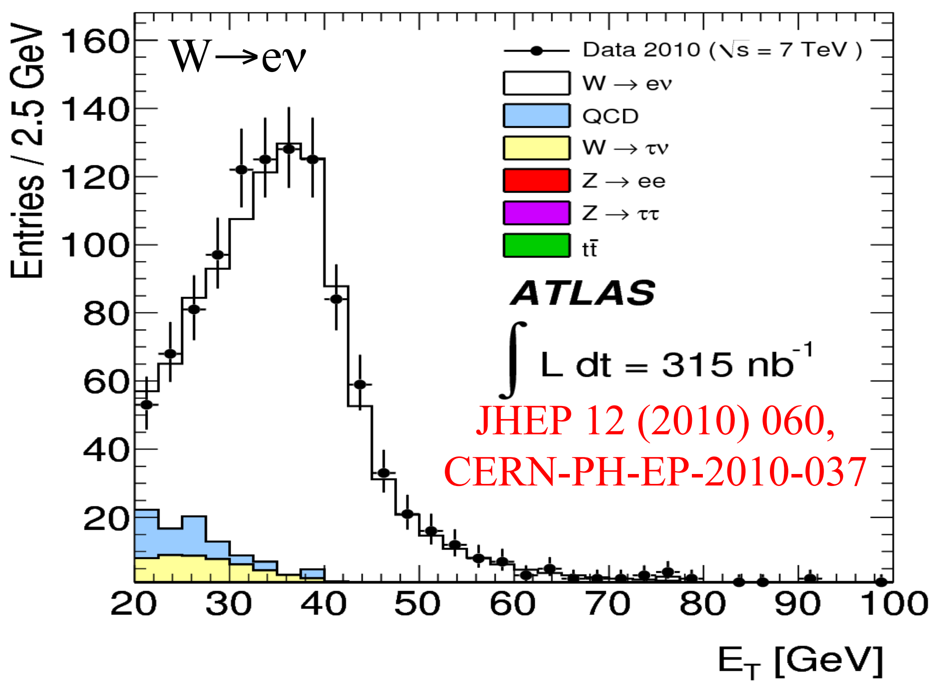
- Physics objects in Wγ, Zγ measurements that need to be well understood are :
  - Leptons : e, μ
  - Missing E_T
  - Photon
- Inclusive W and Z productions are :
  - Standard candles for calibrating the detector
    - $Z \rightarrow l^+l^-$:
      - Measure the EM energy scale of calorimeter and the momentum scale/resolution of tracks
      - Measure the lepton identification and trigger efficiencies
    - $W \rightarrow l\nu$:
      - Calibrate high pt lepton, study Missing E_T performance
  - Major background in the Wγ, Zγ measurements

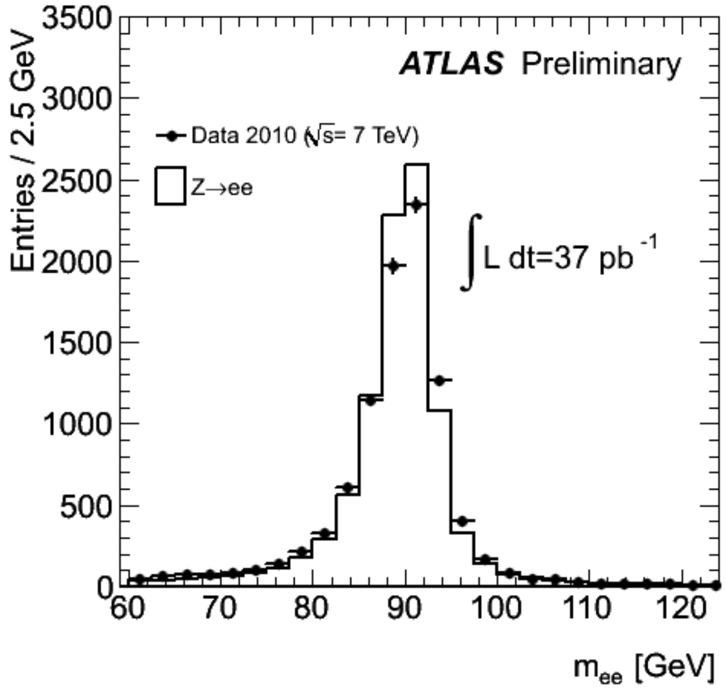
Electron Identification



Identification Types:

- **Loose** : cut on hadronic leakage, shower shapes in 2nd EM sampling
- **Medium** : cut on shower shapes in 1st sampling, cluster/track match
- **Tight** : cut on threshold of transition radiation tracker (TRT), track quality, conversion veto (ID efficiency ~75%)





Electron Identification

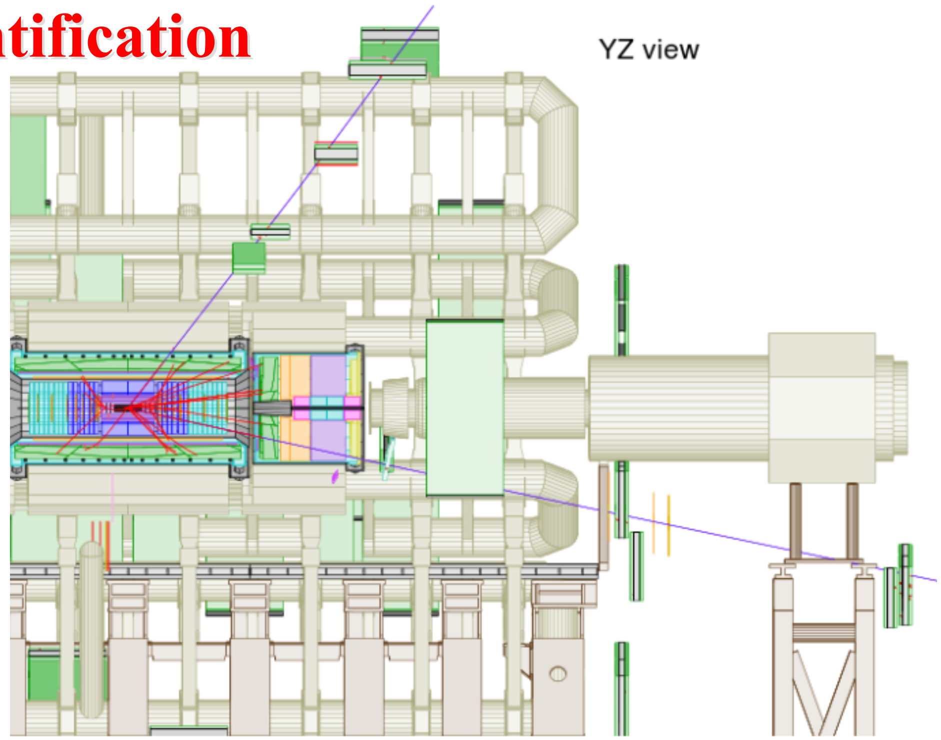
Academia Sinica contribution in W(e,ν) measurement (~315 nb^{-1}) : JHEP 12 (2010) 060, CERN-PH-EP-2010-037

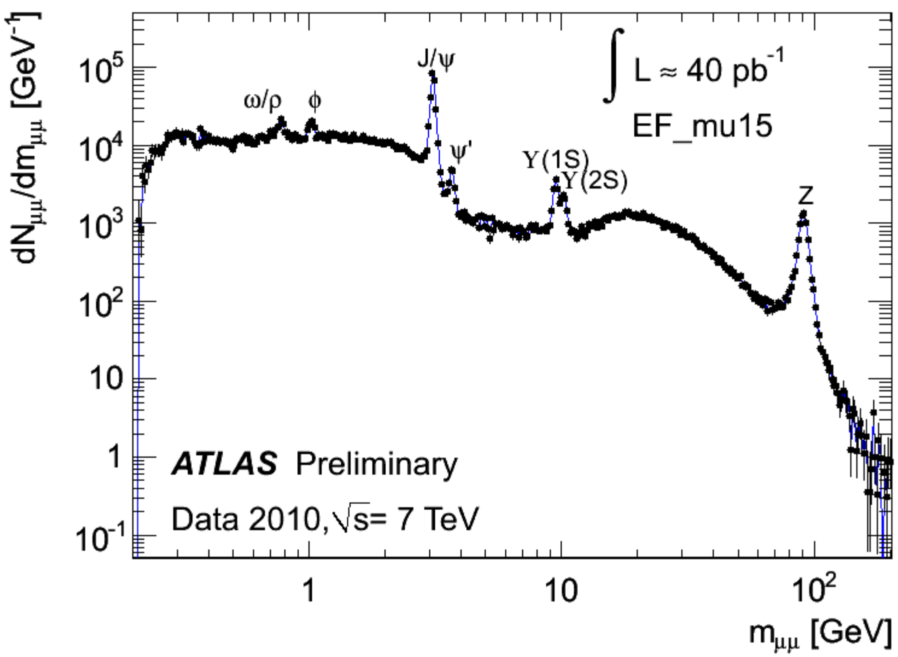
Electron Identification & Trigger efficiency :

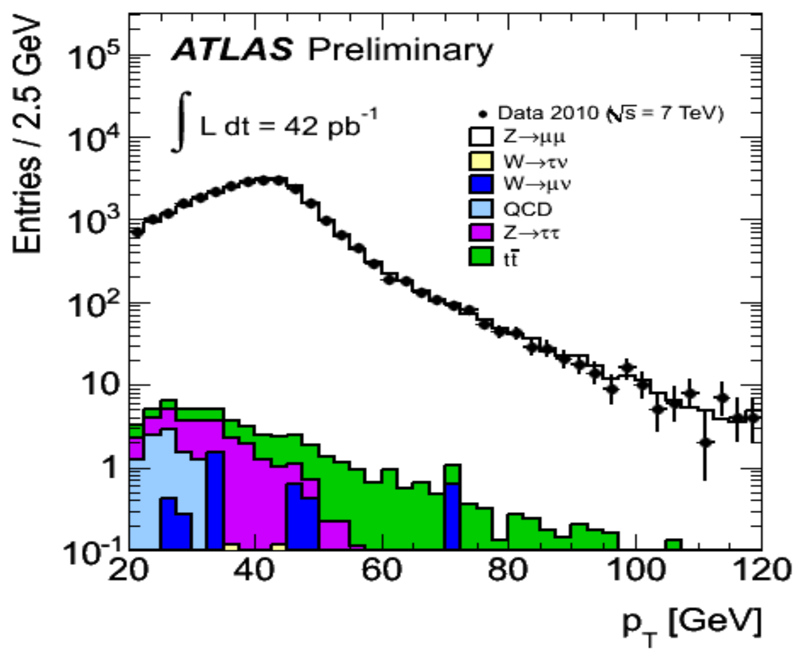
- Common method use "Tag-&-Probe" method on Z→ee decay to select high purity electron sample
  - Disadvantage : low statistic, low Et range of electron
- A.S. employed alternative method to extract high purity electron sample :
  - Use events passing high missing E_T trigger
  - Apply topology cuts (e.g. $\Delta\phi$(MET,jet)) to reduce QCD di-jet background
  - Require loose match between track and EM cluster
    - Select high pt electrons from W decay
    - Selection has little bias to the identification cuts that we want to study
  - Advantage : higher statistic, higher reach in Et of electron
  - Disadvantage : not as pure as "Tag-&-Probe" on Z→ee decay
  - Main measurement of the electron ID efficiency (~5% systematic uncertainty)

Muon Identification

- Several muon identification available
- Most commonly used algorithm in high pt analyses requires
  - matching of an inner detector track to a muon segment found in the muon spectrometer
  - Deposit a minimum ionizing particle like signature in the calorimeter
- Id efficiency : ~89%

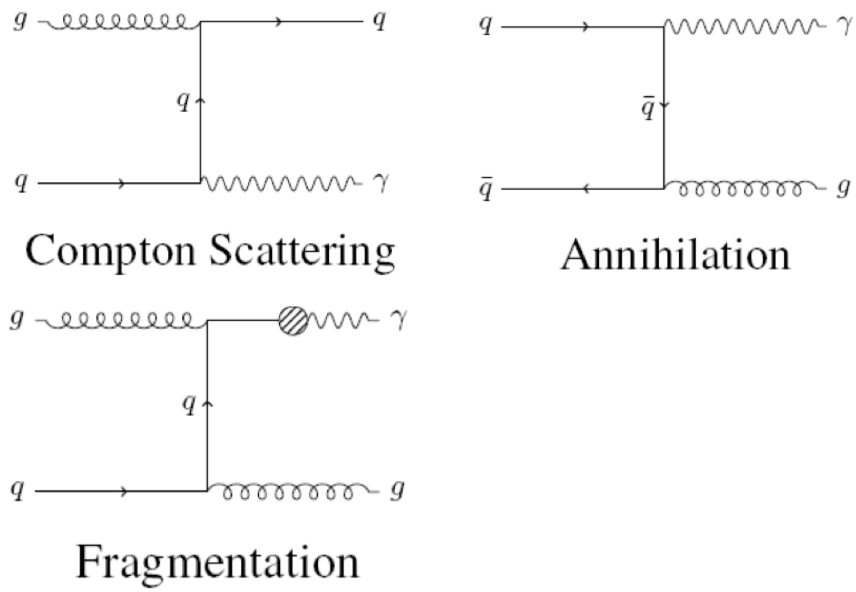




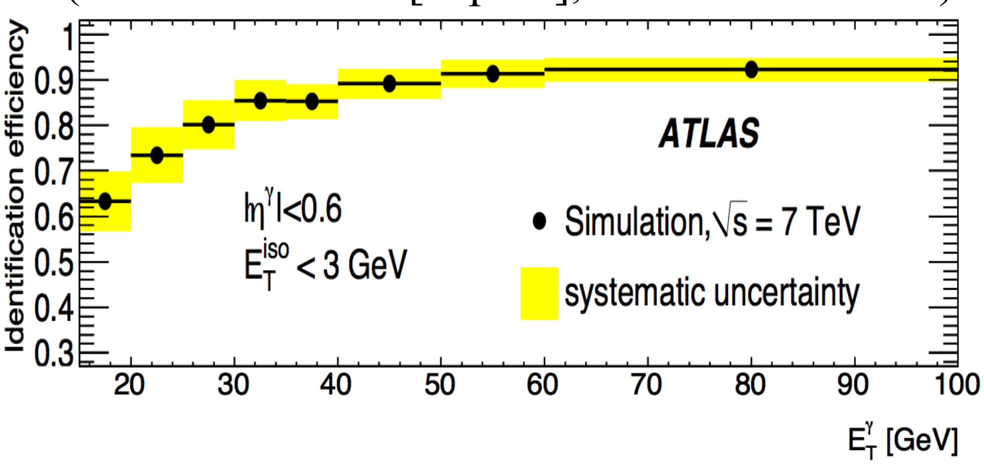


Photon Identification

•γ identification studied on direct γ production



(arXiv:1012.4389[hep-ex], submitted to PRD)



γ Reconstruction :

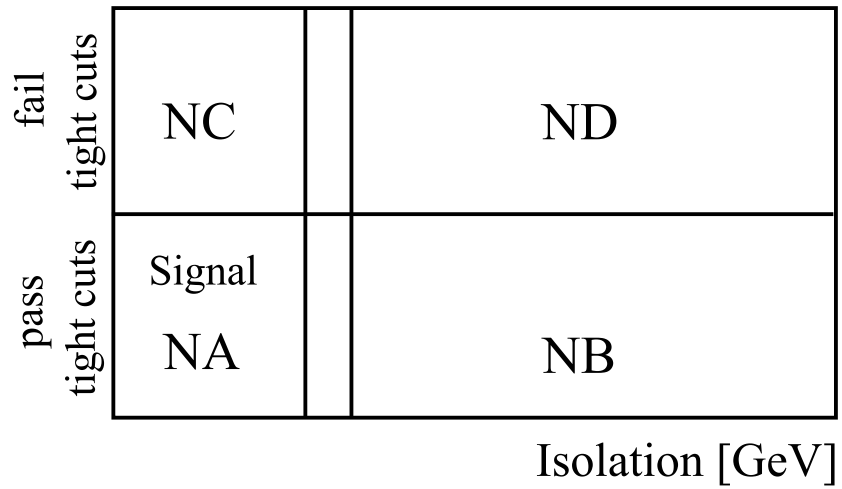
- Require small hadronic leakage and narrow energy profile
- Cut on variables to discriminate single γ from near by showers (e.g. remove π^0)

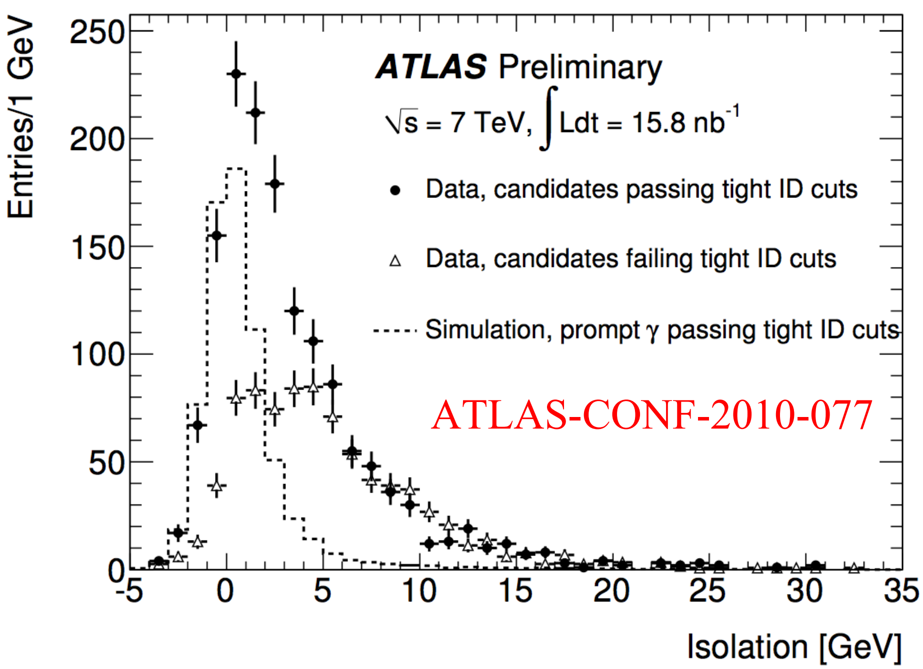
- Identification efficiency >~80% for Et(γ)>25 GeV

Photon Identification

Academia Sinica contribution in direct photon measurement:

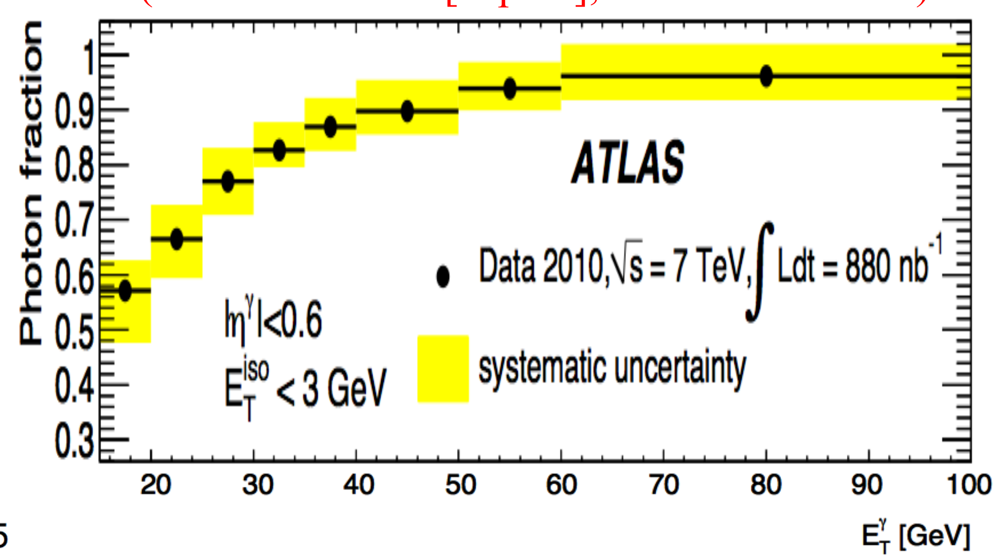
- Developed a 2-D side band method to estimate fraction of background faking isolated proton photon in signal region
- Assume isolation profile for background is the same for tight and non-tight regions
- Correct for leakage of signal into control regions (B,C,D)
- $N^{signal}_A = N_A - N_B * (N_C / N_D)$





Technique used in the direct-γ paper

(arXiv:1012.4389[hep-ex], submitted to PRD)



Missing E_T Reconstruction

- Missing E_T (E_t^{miss}) is constructed from energy deposited in all calorimeter cells

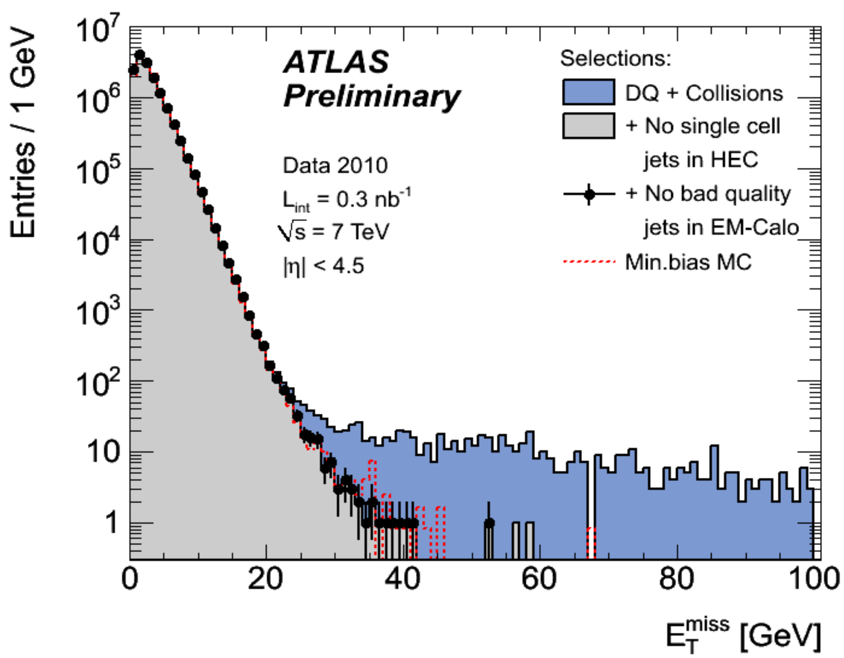
$$E_{\mathrm{x}}^{\mathrm{miss}} = -\sum_{i=1}^{N_{\mathrm{cell}}} E_i \sin\theta_i \cos\phi_i \,,$$

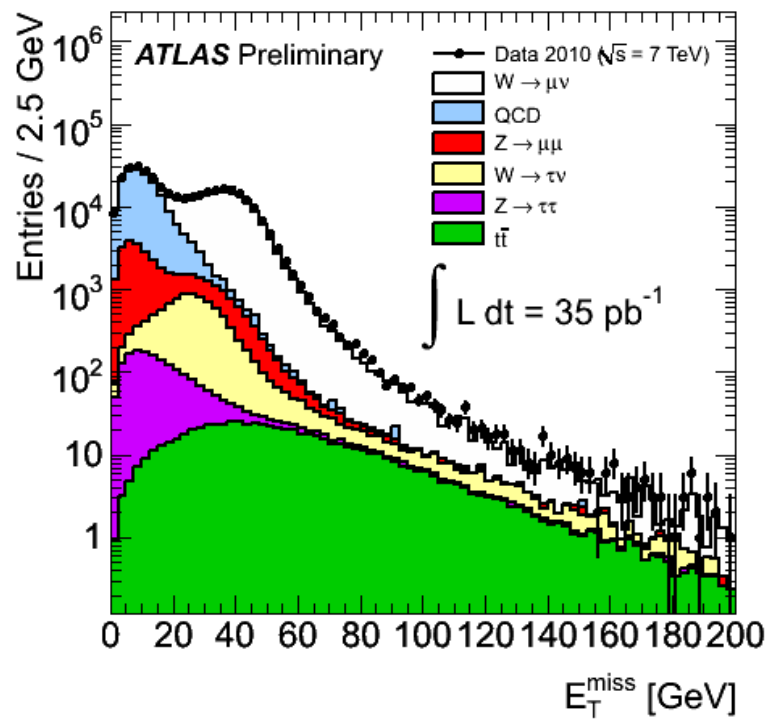
$$E_{\mathrm{y}}^{\mathrm{miss}} = -\sum_{i=1}^{N_{\mathrm{cell}}} E_i \sin\theta_i \sin\phi_i \,,$$

$$E_{\mathrm{T}}^{\mathrm{miss}} = \sqrt{(E_{\mathrm{x}}^{\mathrm{miss}})^2 + (E_{\mathrm{y}}^{\mathrm{miss}})^2} \,,$$

- Measurement is corrected for the presence of muons and the energy lost in the cryostat
- Event is removed in the present of bad jets
  - caused by noise
  - out-of-time energy deposition in calorimeter

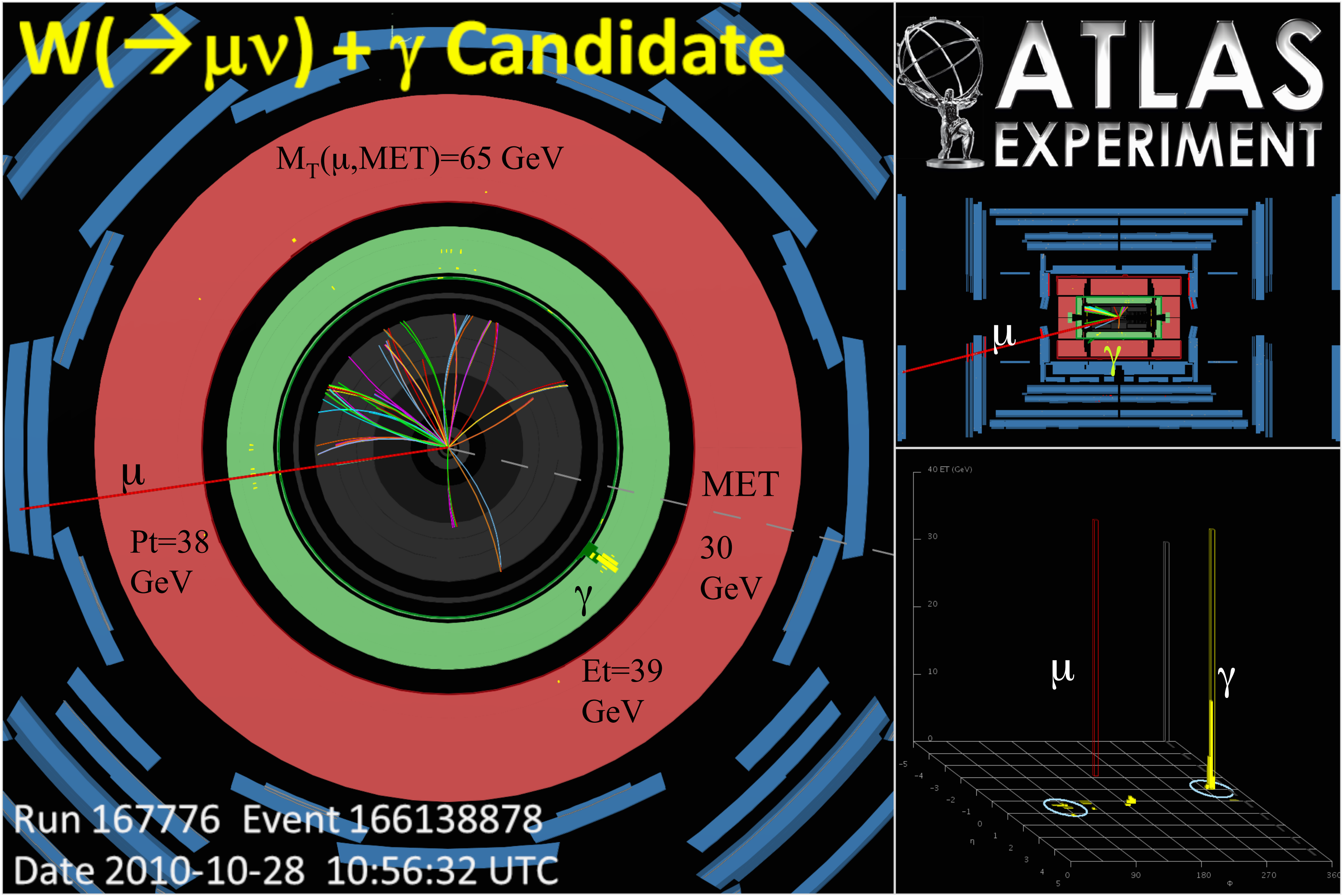
- Study performance of missing E_T measurement in minimum biased (fake E_t^{miss}) and inclusive W (real E_t^{miss}) productions

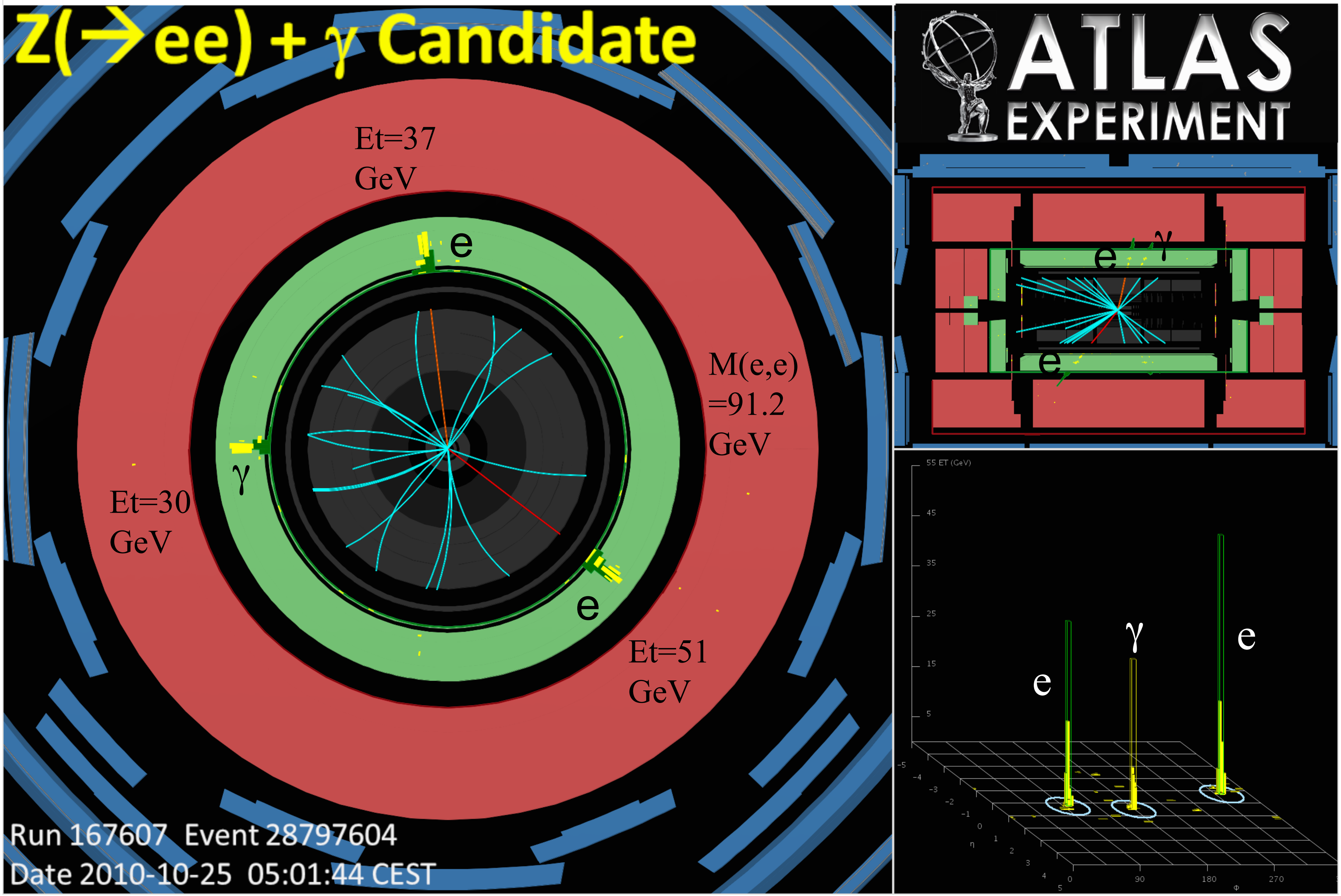




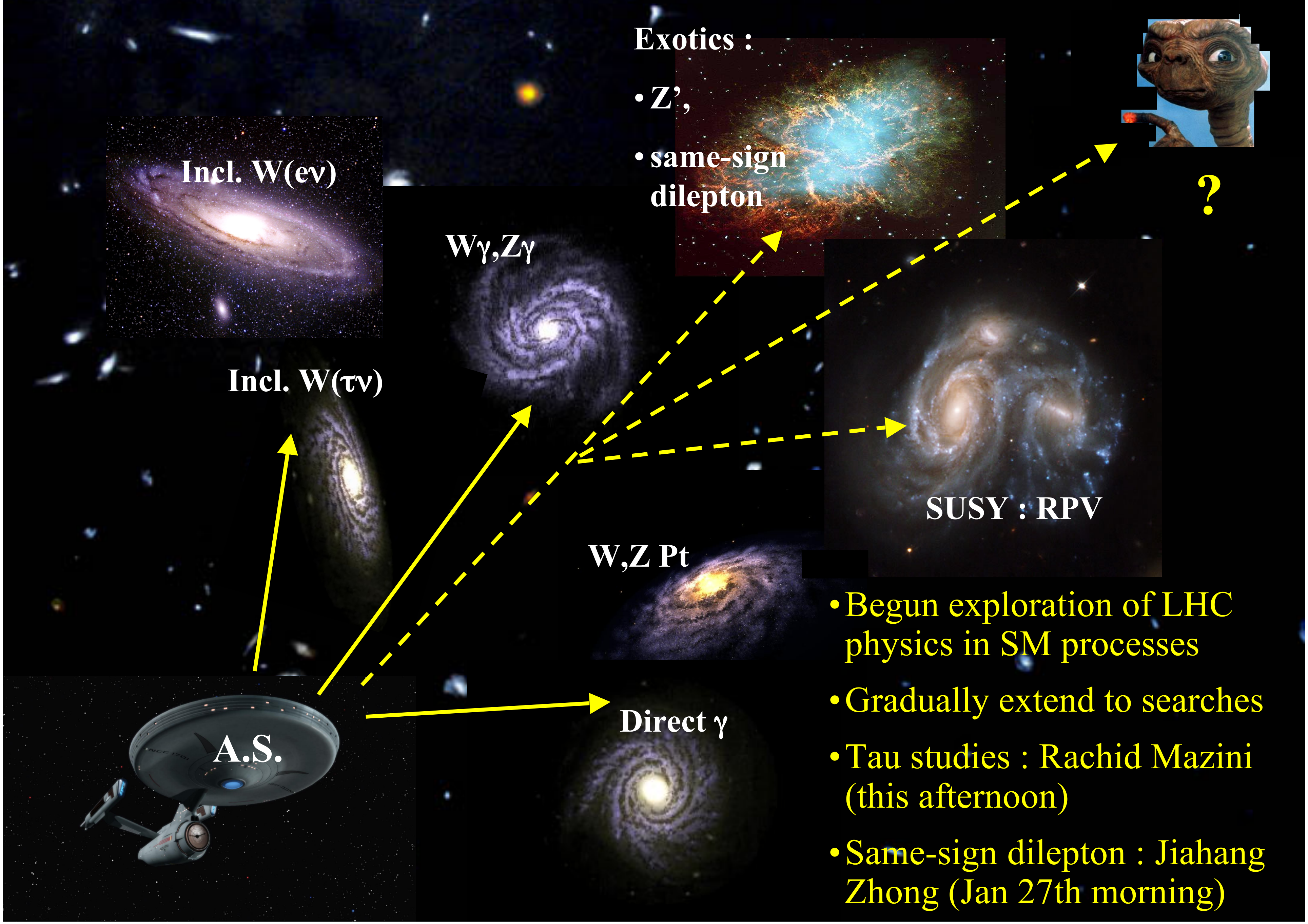
Status of Wγ, Zγ Analyses

- We perform the analyses in both electron and muon decay channels
- At final stage of the analysis and are undergoing reviews by the collaboration
- Have seen experimental signature of their productions


W(→μν) + γ Candidate
M_T(μ,MET)=65 GeV
μ
Pt=38 GeV
MET
30 GeV
γ
Et=39 GeV
Run 167776 Event 166138878
Date 2010-10-28 10:56:32 UTC
ATLAS EXPERIMENT
μ
γ
40 ET (GeV)
30
20
10
0
μ
γ
η
0
90
180
270
φ


Z(→ee) + γ Candidate
Et=37 GeV
e
M(e,e) =91.2 GeV
γ
Et=30 GeV
e
Et=51 GeV
Run 167607 Event 28797604
Date 2010-10-25 05:01:44 CEST
ATLAS EXPERIMENT
e
γ
e
e
γ
e

Other Academia Sinica Physics Analyses at ATLAS



- Begun exploration of LHC physics in SM processes
- Gradually extend to searches
- Tau studies : Rachid Mazini (this afternoon)
- Same-sign dilepton : Jiahang Zhong (Jan 27th morning)

Summary

- Academia Sinica started its first physics analyses on measuring of Standard Model processes
- Experiences in earlier SM measurements have contributed to the Wγ, Zγ analyses
- Have observed candidate events of Wγ, Zγ production in the leptonic decay channels
- Analyses under review by the ATLAS collaboration
- Group has begun to brunch off into performing searches
- Polishing our analyses techniques to be ready for the next data collection period in March 2011 !

BackUp

Expected Sensitivity

- Expected Wγ, Zγ signal, backgrounds and sensitivity for 1 fb^{-1} at $\sqrt{s}$=14 TeV
  (from simulation studies : CERN-OPEN-2008-020)

Diboson mode	Signal	Background	Signal eff.	σ_{stat}^{signal}	p-value	Sig.
$W\gamma \to e\nu\gamma$	1604 ± 65	1180 ± 120	5.7% (BDT)	2.5%	significance > 30	
$W\gamma \to \mu\nu\gamma$	2166 ± 88	1340 ± 130	7.6% (BDT)	2.1%	significance > 30	
$Z\gamma \to e^+e^-\gamma$	367 ± 12	187 ± 19	5.4% (BDT)	5.2%	1.2×10^{-91}	20.3
$Z\gamma \to \mu^+\mu^-\gamma$	751 ± 23	429 ± 43	11% (BDT)	3.6%	5.9×10^{-171}	27.8

- Anomalous TGC limits at 95% C.L., Λ=2 TeV, ATLAS : $\sqrt{s}$ = 14 TeV, L = 10 fb^{-1}

Diboson	Assumption	$\Delta\kappa_\gamma$	λ_γ
Wγ(ATLAS)		[0.26,0.07]	[-0.05,0.02]
WW(ATLAS)		[-0.088,0.089]	[-0.074,0.165]
WW+Wγ+WZ (D0, 1 fb^{-1})	($\lambda_\gamma = \lambda_Z$, $\Delta\kappa_Z = \Delta g^Z_1 - \Delta\kappa_\gamma * \tan^2\theta_W$)	[-0.29,0.38]	[-0.08,0.08]
WW (CDF, 3.6 fb^{-1})	($\lambda_\gamma = \lambda_Z$, $\Delta\kappa_Z = \Delta g^Z_1 - \Delta\kappa_\gamma * \tan^2\theta_W$)	[-0.57,0.65]	[-0.14,0.15]
WW (LEP)	($\lambda_\gamma = \lambda_Z$, $\Delta\kappa_Z = \Delta g^Z_1 - \Delta\kappa_\gamma * \tan^2\theta_W$)	[-0.105,0.069]	[-0.059,0.026]