Electron identification and search for SUSY with same sign leptons using 2015 ATLAS data

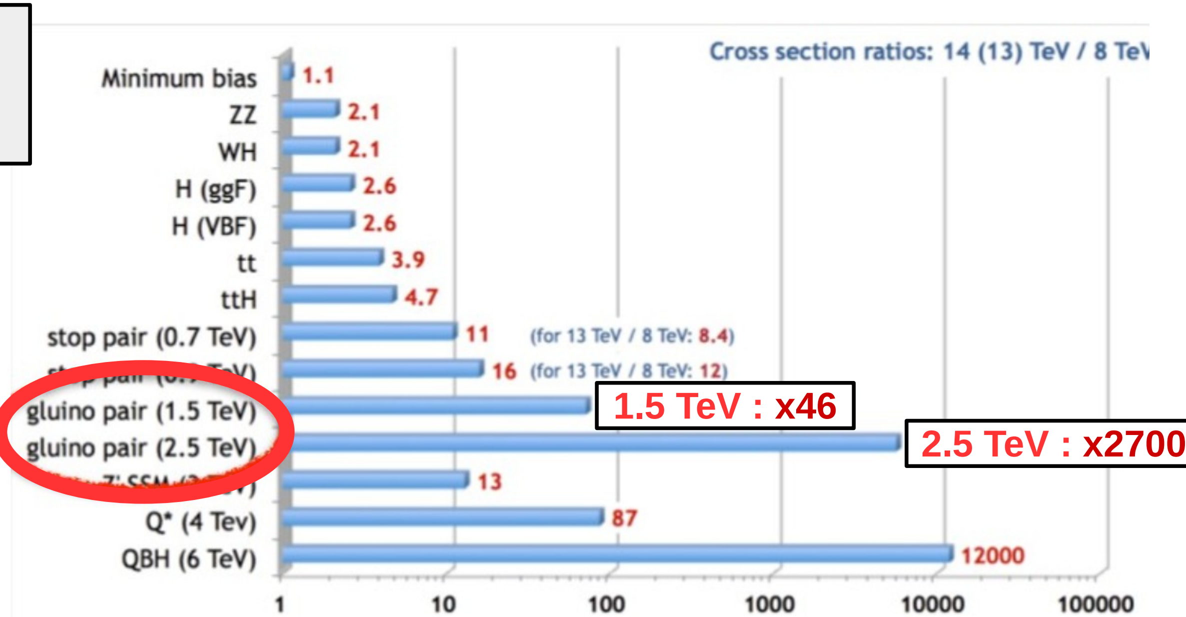
CPPM PhD seminar
Sébastien Kahn
supervisor : Fabrice Hubaut

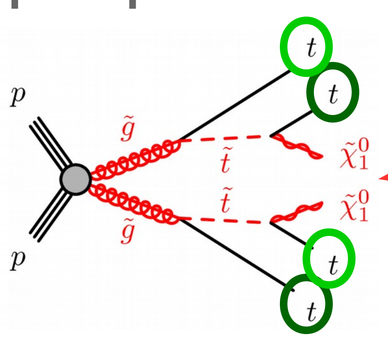
LHC Run 2 Discovery potential

- **Run-1** (2010-2012) : **Higgs discovery** but no sign for physics
- **Run-2** (2015) : p-p collision center-of-mass energy rise from **8 to 13 TeV**
  → Large production cross-section increase for heavy particles

New physics discovery potential with early Data

- **Ex :** Search for strongly produced SUSY with same sign lepton pairs





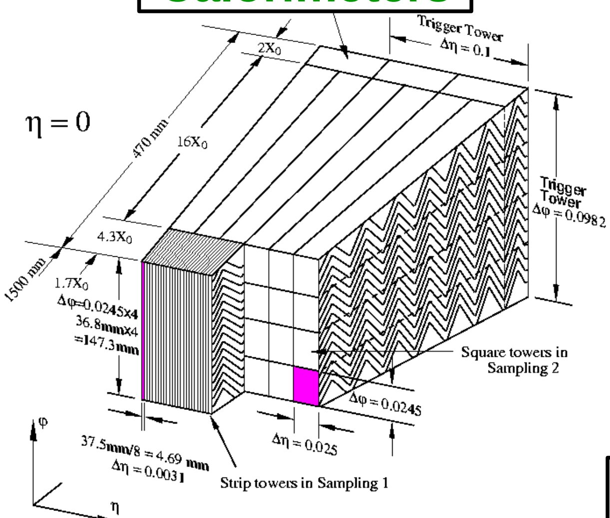
PhD work driven by Run-2 discovery potential
Part 1 : optimization of the electron identification for run 2
Part 2 : search for SUSY with same sign lepton final state

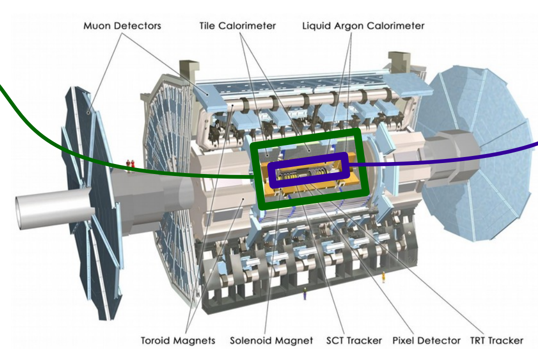
Identifying electrons with the ATLAS detector

- Electrons provides a **clear experimental signature** and are involved in a **wide variety of physical processes**

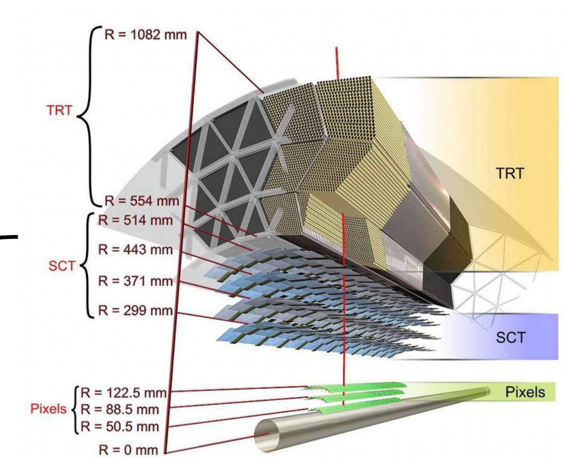
Electron identification is crucial for many physics analyses

Calorimeters





Inner tracker



Track-cluster matching

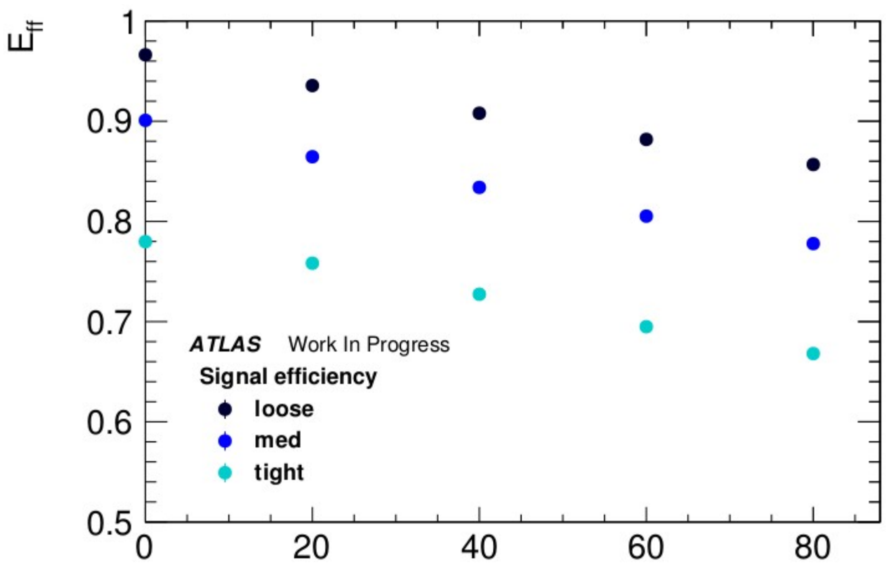
Extracted information
Fine lateral / longitudinal segmentation
→ Shower shape info

Full potential of the ATLAS detector used to identify electron against hadrons in a harsh hadronic environment

Extracted information
- presence of associated tracks
- Electron transition radiation

Motivation of the electron identification optimization

- **3 working points** designed in Run-1 to suit physics analysis needs
- Performances of the Run-1 identification menus in high pile-up regime



<number of interaction per bunch crossing> (<μ>)

Limitations of the Run-1 menus

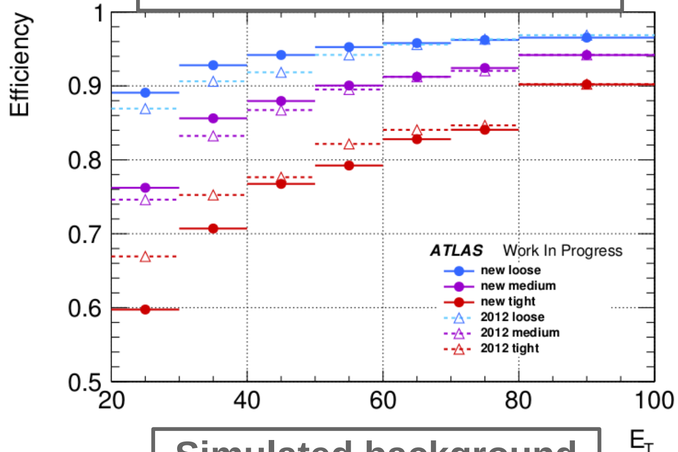
- **Efficiency loss with pile-up**
  → **higher efficiency needed**
- Energy and luminosity increase
  → **Trigger rate multiplied by 4-5**
  → Better **background rejection needed** to keep a low ~25 GeV energy thresholds

The 2012 identification menus have to be re-optimized for Run-2 high luminosity conditions

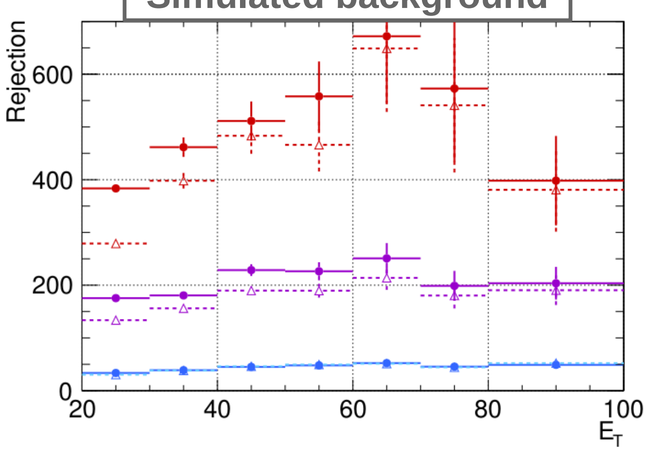
Performances of the optimized identification menus

- **Two identification techniques used :** likelihood (default) and cut-based (back-up)
- **Performance of the cut-based identification menus**

Simulated Z → ee events

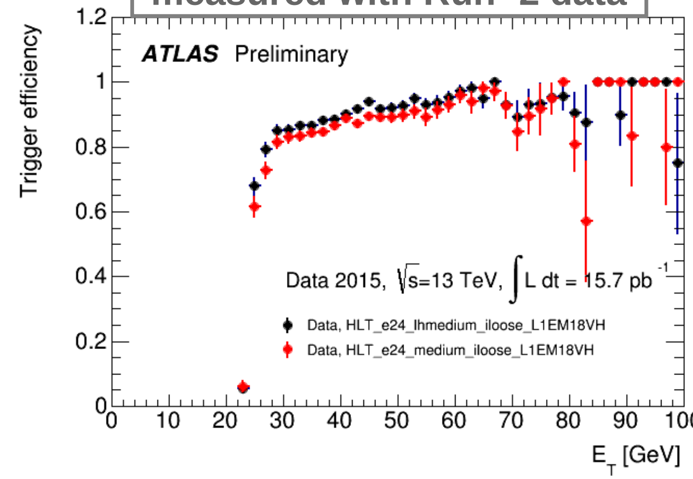


Simulated background



More detail on the the optimisation method given in last year seminar at CPPM : link

trigger performances measured with Run- 2 data

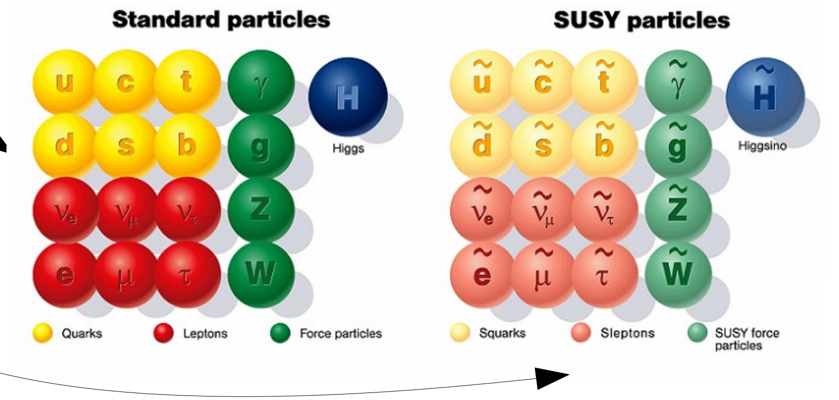


- Better performances at high pile-up
- Tight enough identification menus to define triggers with low energy thresholds

The optimized menus have been used for online and offline ATLAS software with the whole 2015 data

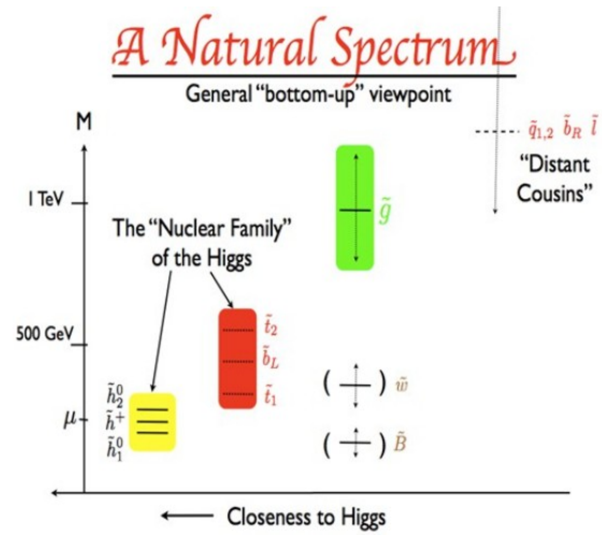
Introduction
Supersymmetry (SUSY)

- Space-time symmetry group generated by **spin 1** rotations
- Possibility to generate a space-time symmetry group with **spin ½** rotations



SUSY : generalisation of the space-time symmetry

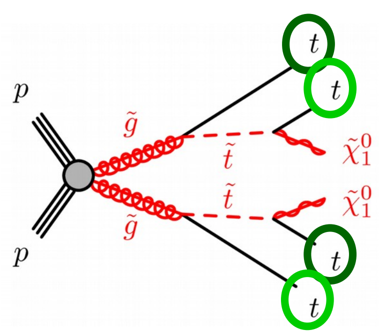
- **Strength of the theory**
  - Dark matter candidate (LSP)
  - Electro-weak and strong unification
  - Convergent Higgs mass without fine tuning (naturalness)
    - → If so, the mass of the of the **3rd generation quarks and the gluon super-partners expected at the TeV scale**



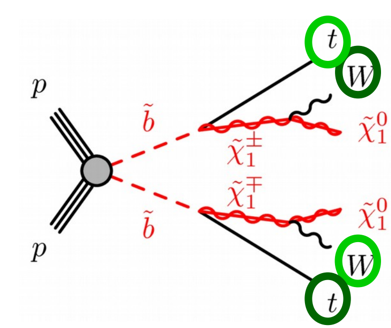
If natural SUSY, 3rd generation quark and gluon super-partners can be discovered with 2015 data

Introduction
same sign lepton final state

- **Prompt same sign leptons Standard Model production is rare :** VV, ttV, tttt
- **SUSY processes can easily produce same sign leptons**
  - SUSY particle are heavy (TeV scale) → Complex decay chains
  - Gluino (gluon superpartner) is a majorana fermion
- **The low SM contamination allow to relax the kinematic constraints**
  → A wide variety of processes can be studied covering different production modes
  → Good sensitivity to compressed SUSY mass spectra
  → Complementarity with other SUSY searches



Gluino



sbottom

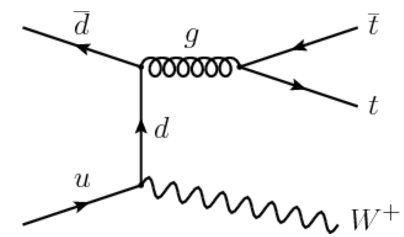
Potential same sign lepton pairs

Very powerful signature to probe production of gluinos and sbottoms

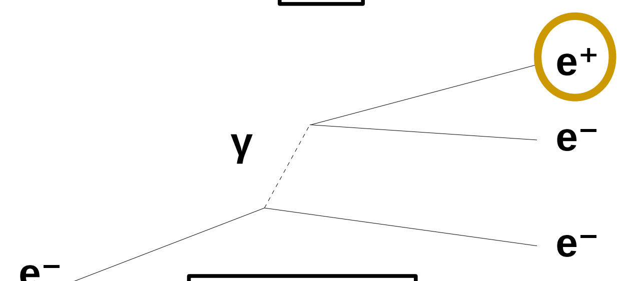
Analysis backgrounds

- **Two different kind of backgrounds contributions :**
  - **SM prompt Same sign processes : VV, ttV**
    → Estimated fully using MC simulations
    → MC estimations checked on data using dedicated Validation Regions (VR)
  - **Detector background : Fake lepton** and electron **charge flip**
    → Estimated using data driven method
- **Key background : fake prompt lepton**
  - Definition : heavy flavour / photon conversions / hadrons faking electrons
  - Mainly arises from : semi leptonic tt events

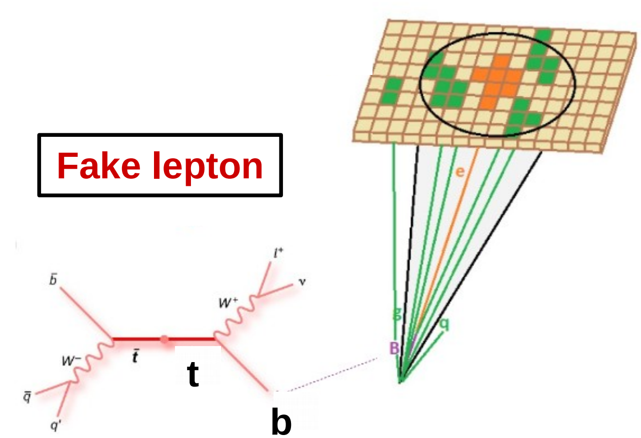
CPPM group responsible of the fake lepton background estimation
Key point of the analysis



ttW



Charge flip



Fake background estimation

- **Estimated using loose to tight (signal requirement) lepton selections**

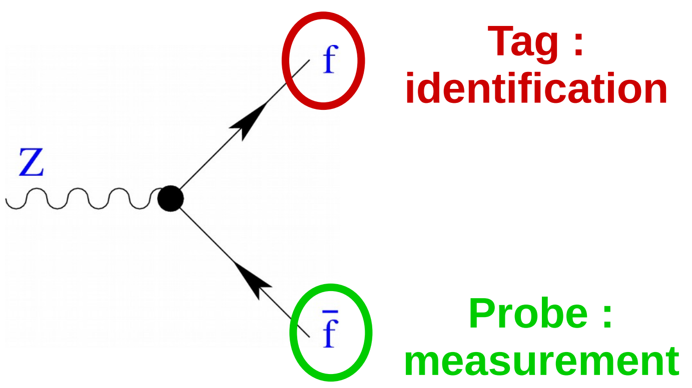
Estimated background

$$\begin{pmatrix} N_{Real} \\ N_{Fakes} \end{pmatrix} = \frac{1}{\epsilon-\zeta} \begin{pmatrix} 1-\zeta & -\zeta \\ \epsilon-1 & \epsilon \end{pmatrix} \cdot \begin{pmatrix} N_{Tight} \\ N_{Loose} \end{pmatrix}$$

Measured in the signal Regions

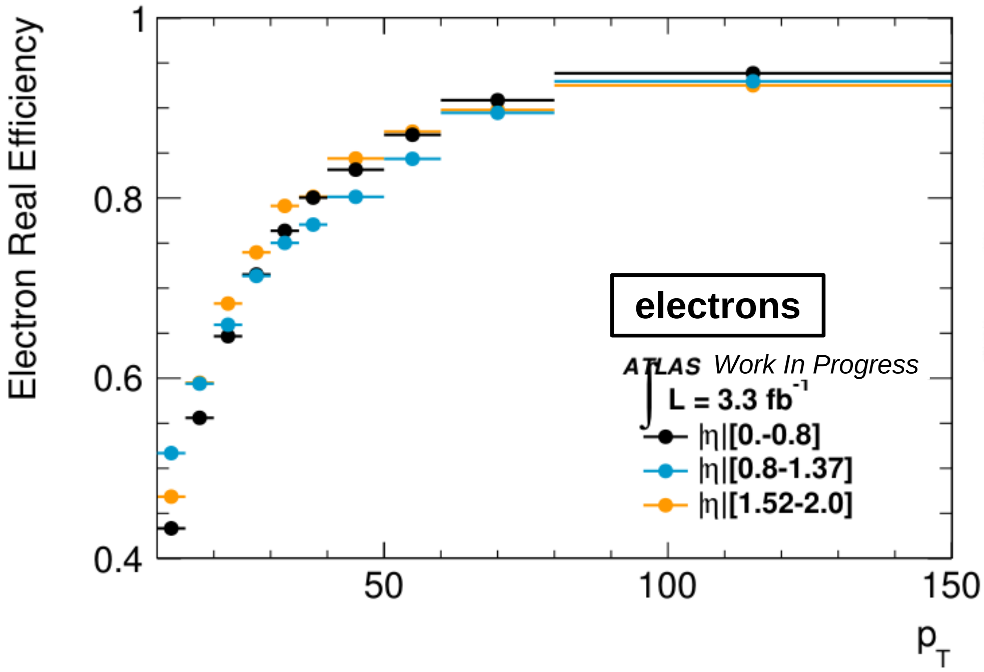
- The two main inputs are **measured in data :**
  - Fake lepton lepton efficiencies (rate) : $\zeta = (N_{Loose}/N_{Tight})_{\text{Fake leptons}}$
  - **Real lepton efficiencies** : $\varepsilon = (N_{Loose}/N_{Tight})_{\text{Real leptons}}$

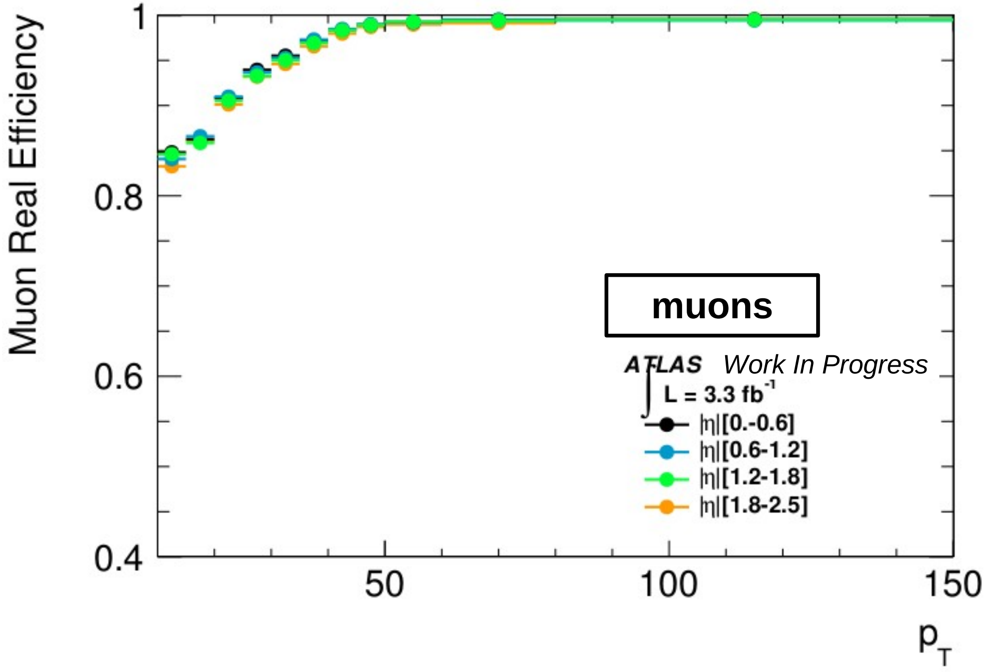
- Real lepton efficiencies measured with a **Z tag-and-proble method**
  - A **tag** lepton, used to **identify** the Z→ll event have to pass **tight identification** cuts
  - A **probe** lepton, used for the **efficiencies measurements** has to pass **loose identification** cuts



Real lepton efficiencies
Z tag-and-probe Results

- **Final Z tag-and-probe efficiencies measurements in data using the full 2015 Data**





A data to Monte Carlo agreement within o(1-2%)

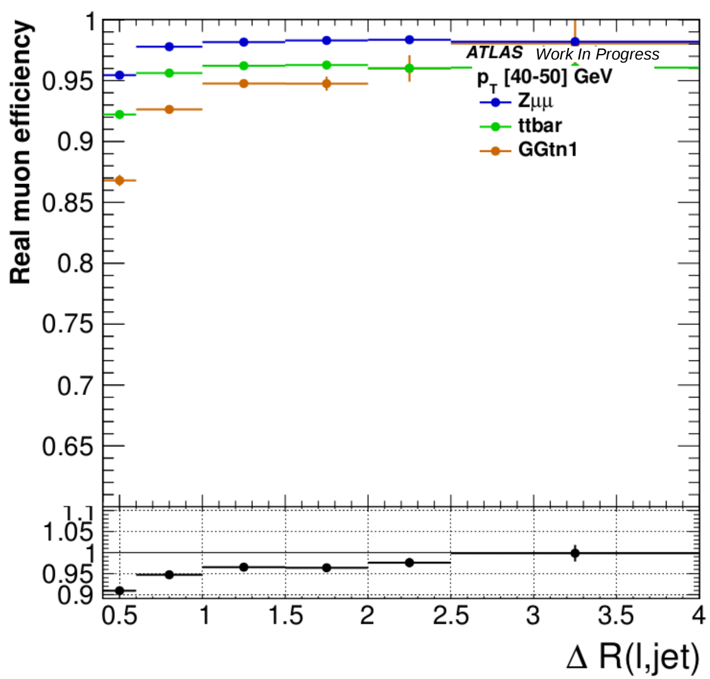
Real lepton efficiencies measurement systematics

- **Motivation :**
  - SUSY signal event topologies very different from the Z+jets ones measurement.
  - Tight isolation cuts → important topology dependency of the lepton efficiencies.

A Z+jets to signal topology extrapolation systematic is necessary to take into account these differences.

- **Estimation method**
  Ratio between Z+jets efficiencies and SUSY signal with 4 boosted tops in the final state (conservative choice)
  → around 5% systematic uncertainty at high p_T

- **Alternative lepton efficiency measurement method using tt events developed**
  method used when more data available

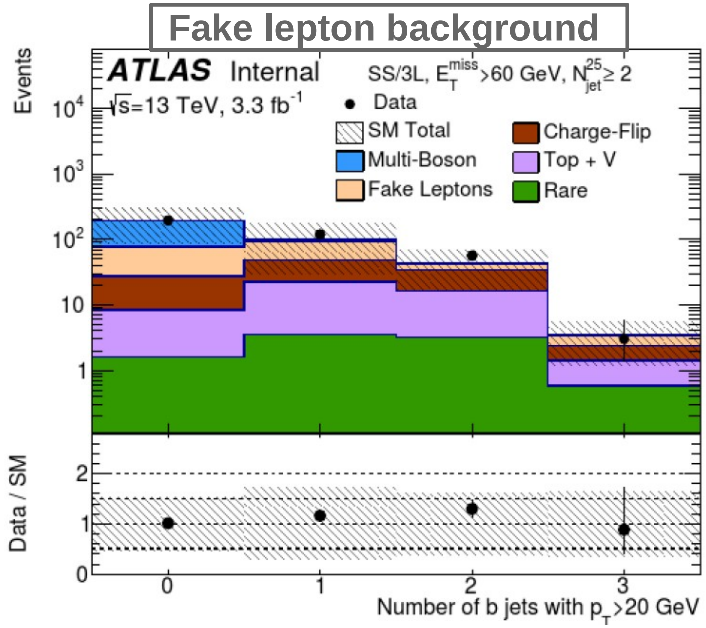


SUSY Same sign lepton Analysis summary

- **Prompt same sign and detector backgrounds estimates checked with dedicated Validation Regions**

- **The 4 following SR are probed and first discovery / exclusion plots are under finalisation**
  SR categorisation based on (b-)jet multiplicity

Signal region	N_{lept}	$N^{20}_{b\text{jets}}$	N^{50}_{jets}	E_T^{miss} [GeV]	m_{eff} [GeV]
SR3b	≥ 2	≥ 3	-	>125	>650
SR1b	≥ 2	≥ 1	≥ 4	>150	>550
SR0b5j	≥ 2	=0	≥ 5	>125	>650
SR0b3j	≥ 3	=0	≥ 3	>200	>550



Public results will be released next Tuesday

Conclusions

I/ Electron identification

– Run-2 cut-based electron identification menus optimized and use by the ATLAS community for the 2015 data.

II/ search for strongly produced SUSY with same sign lepton

– First results will released with the 2015 run 2 data next Tuesday

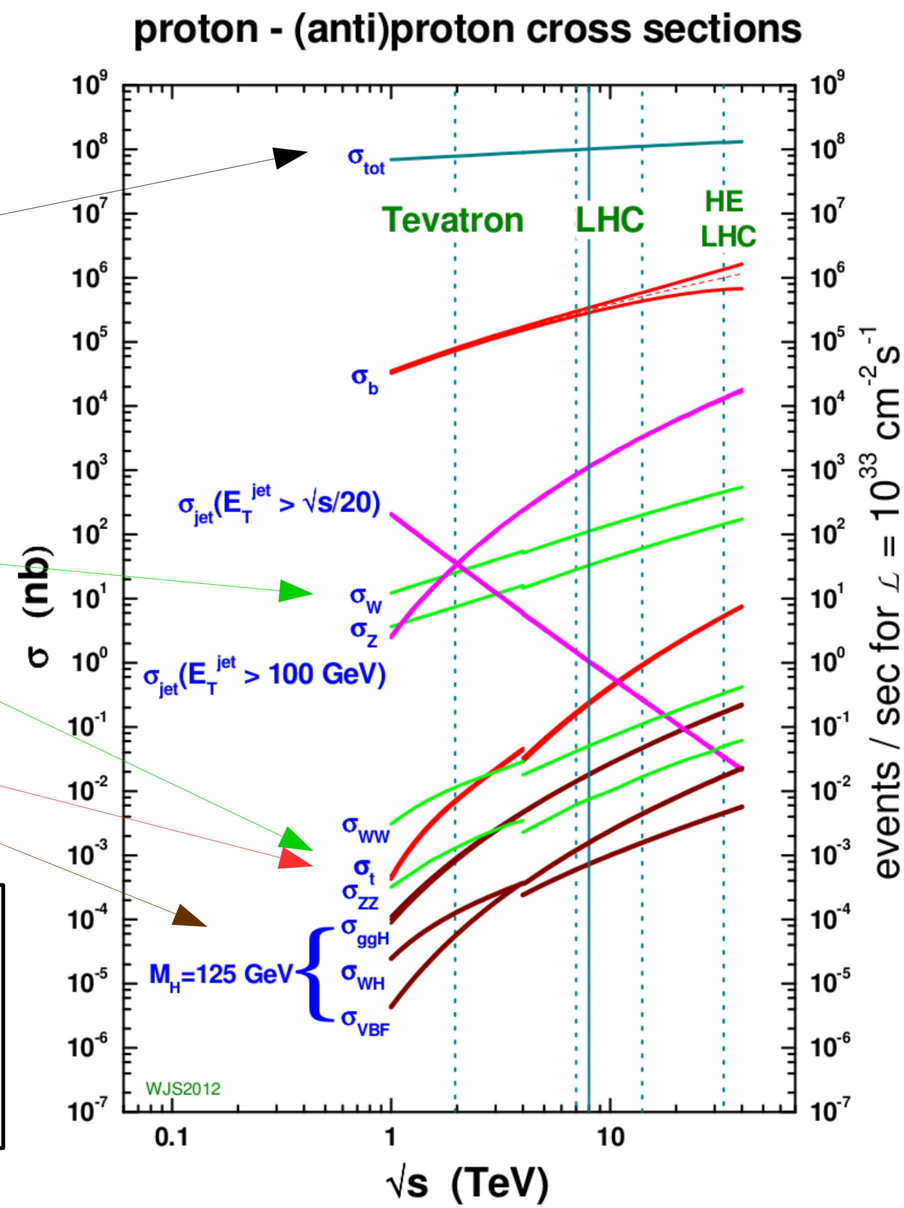
– Fist SUSY results with the full 2015 data

– Paper to be finalized and submitted in January

Back-up
Part I : Electron identification

Importance of the leptons for LHC physics

- **Leptons give a very different experimental signature from the one from QCD processes**
  -> Very clear experimental signature
- **Cross section of those processes at least 10^6 smaller than the one form QCD**
  -> Very useful to define triggers
- **Leptons can tag processes of high interest :**
  - **Z/W physics :** Z(+jets) / W(+jets)
    Dibosons
  - **Top physics :** tt(+jets) , single top
  - **Higgs :** H -> ZZ*-> 4l / H - > WW* -> 2l2ν
  - **New physics :** SUSY / exotic



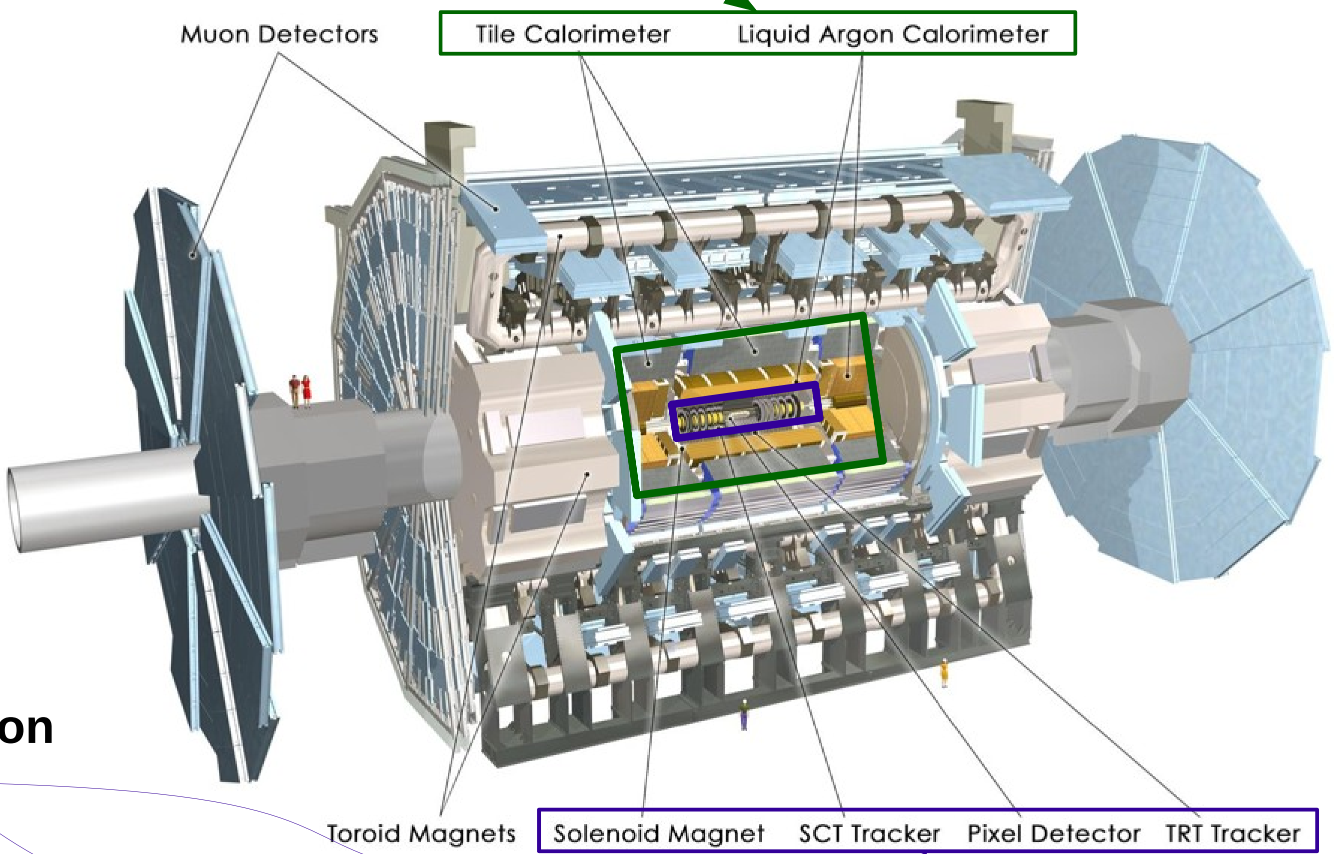
Electron marker of interest in the harsh pp collision hadronic environment
-> Electron identification is crucial for many physics analyses in LHC experiment

How to detect electron using the ATLAS detectors

- **Using the showering process :**
  -> Calorimeters
  - Stops the electrons and Measure their **energy**
  - Give **shower shape** information

- **Using the track :**
  -> Inner Tracker
  - Reconstruct the **track** of the electron
  - Measure the **charge**
  - Identify the **primary vertex**

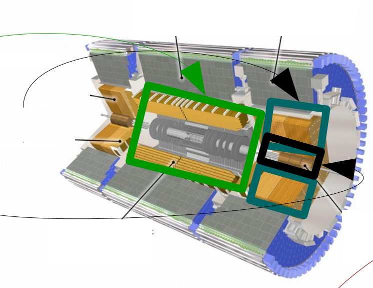
- **Using the transition radiation**
  -> TRT tracker
  - Additionnal e / π discrimination



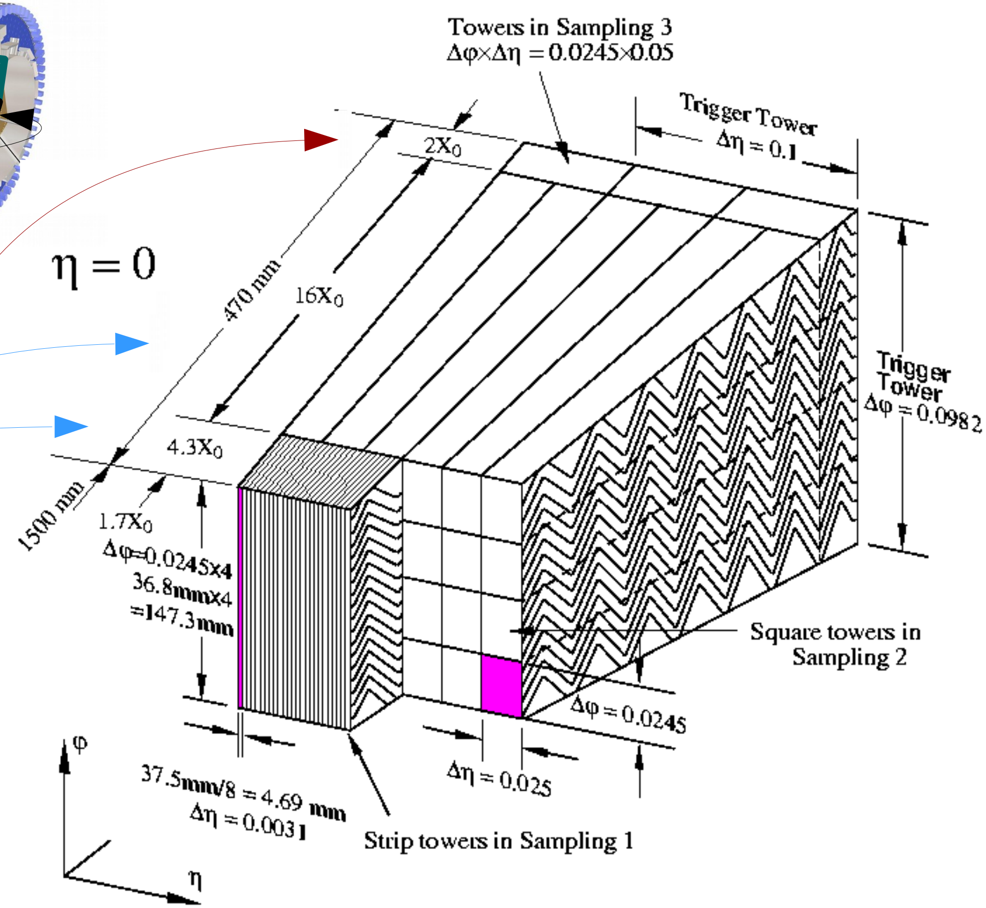
The ATLAS detector gives a large panel of information to identify electrons

The electromagnetic calorimeter

- **Global geometry :**
  - **Barrel : |η| < 1.475**
  - **End-cap :** 1.375 < |η| < 3.2
  - **Forward :** 3.2 < |η| < 4.9



- **Operating principle :**
  - Passive material : Pb
  - Active material : liquid argon
  - Accordion structure
    - -> Excellent hermiticity along Φ



- **Structure : 3 layers**
  - **Pre-sampler**
  - **1st layer :**
    fine η binning
    -> good γ / π⁰ discrimination
  - **2nd layer :**
    fine Φ binning
    - deep layer
    -> Most of the energy deposit
  - **3rd layer :**
    -> coarser η and Φ binning

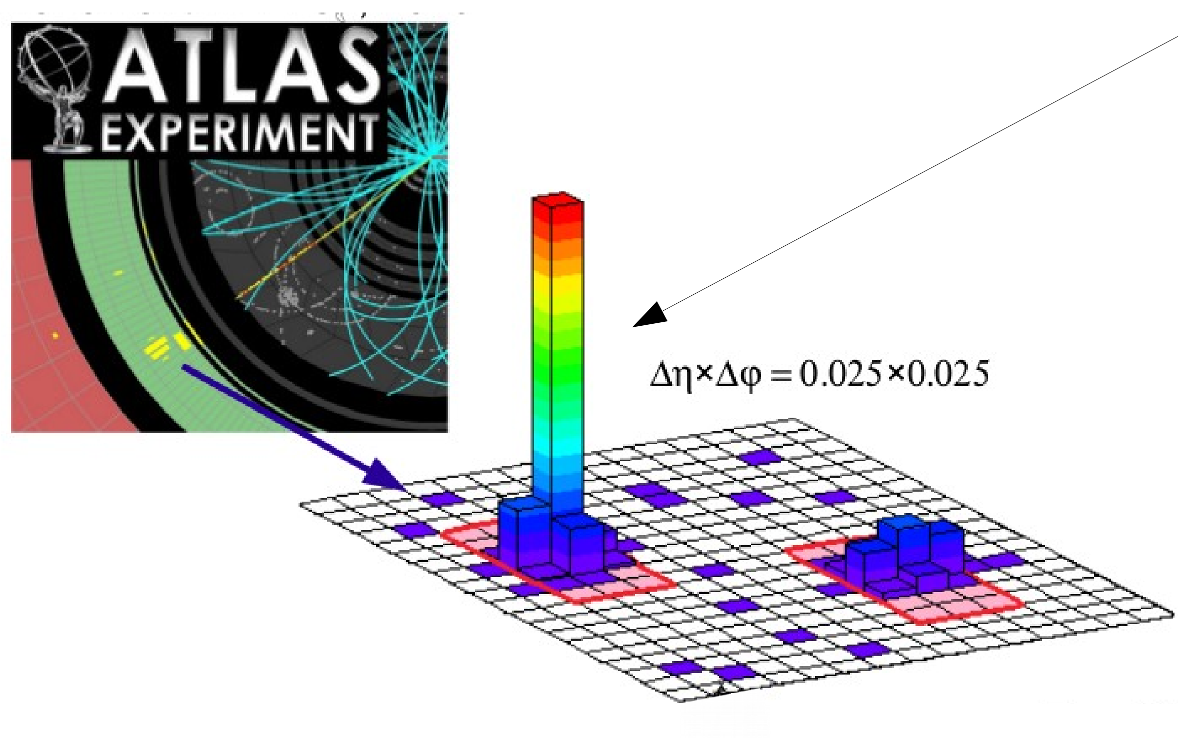
LATERAL INFO

LONGITUDINAL INFO

Large granularity, with transverse and longitudinal segmentation
-> Very useful for electron identification

Electron reconstruction

W -> eν event



- **Step 1 : Identification of energy clusters**
  in the electromagnetic calorimeter
  in a fixed ΔΦ and Δη window (in red)
- **Step 2 : Association of a track with the cluster**
  - found track :
  -> electron
  - No track found
  -> photon
- **Step 3 : Computation od the final physical parameters**
  ex : 4 momentum / charge etc ...

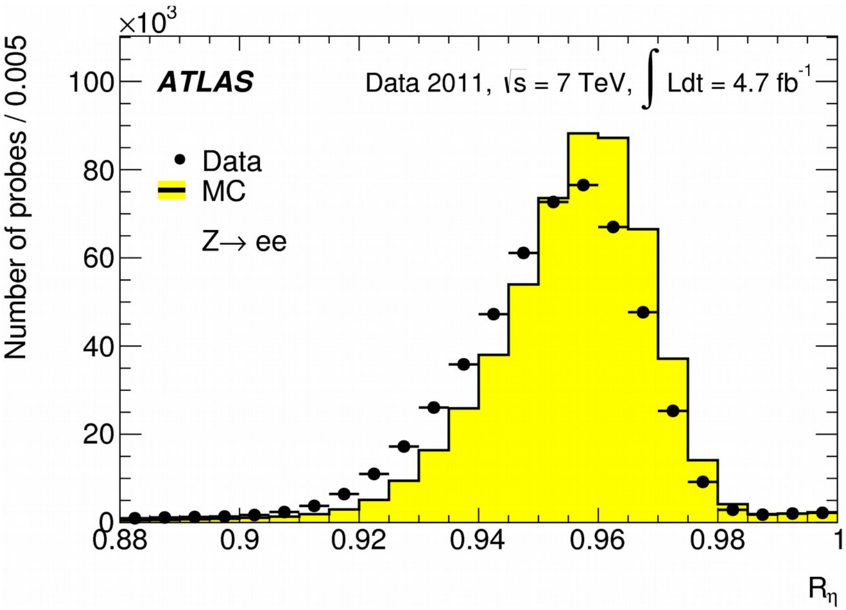
- **Hadrons are ~10^6 more abudant that electron in LHC.**
  -> Not enough rejection with the reconstruction

Further discrimination is needed
-> electron identification

Optimization method

- **We need to use high pile-up Monte Carlo samples :**
  - Electron signal : Zee at <μ> = 0 / 20 / 40 / 60 / 80 and Bs = 25 ns
  - Background sample : JF17 at <μ> = 0 / 20 / 40 / 60 / 80 and Bs = 25 ns

- **However, important shower shapes mis-modeling seen in Run 1 :**
  - Data → Monte Carlo shifting computed with 2012 data applied **(See ref n°2, slide 11)**
  - Loosen some potentially problematic cuts



- **The cuts are optimized using an algorithm that uses :**
  - The TMVA Cuts method
  - Further manual tuning

- **This optimization has been performed for :**
  - 10 η bins (|η| < 2.47)
  - 7 Et bins (Et > 20 GeV)

After one year of work to develop the tools, extract and test the menus, we propose the following re-optimized menus

Electron identification

- **Use different discriminating variables to reach further discrimination from background**
- **Wide variety of analysis in ATLAS**
  - Some are limited by **statistics**
    -> high **signal efficiency** is needed
  - Some are limited by the **fakes** electrons
    -> high **background rejection** is needed
- **To better cope with needs of the analysis 3 identification criterion are defined :**
  -> Loose / Medium / Tight
- **2 different strategy :**
  - Likelihood PID :
    -> Good performances
    -> Sensitive to mis-modeling

Good for later data taking

  - Cut Based PID :
    -> More robust to mis-modeling
    -> Worse performances

Good for early data taking

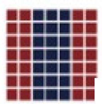
- **In 2015 the LHC will produce collision at higher energy / luminosity**

Is the 2012 cut-based menu adapted for run 2 high luminosity configuration ?

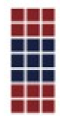
Electron Identification variables Summary

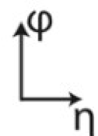
- **Here is a small presentation of the calorimeter based electron identification discriminating variables :**

$$R_\eta = \frac{E^{S2}_{3\times7}}{E^{S2}_{7\times7}}$$



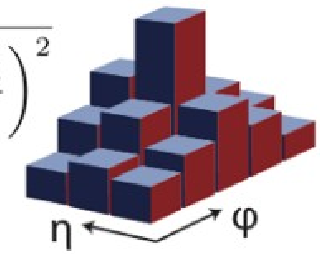
$$R_\phi = \frac{E^{S2}_{3\times3}}{E^{S2}_{3\times7}}$$



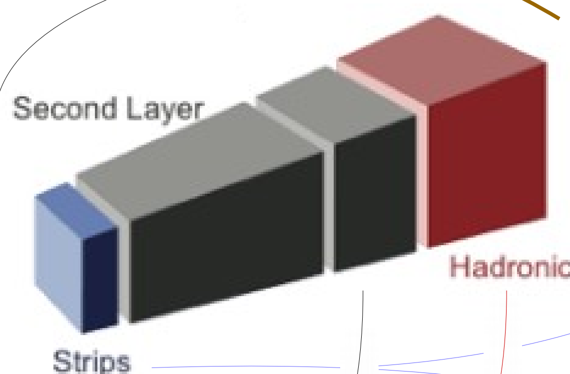


$$w_{\eta,2} = \sqrt{\frac{\sum E_i \eta_i^2}{\sum E_i} - \left(\frac{\sum E_i \eta_i}{\sum E_i}\right)^2}$$

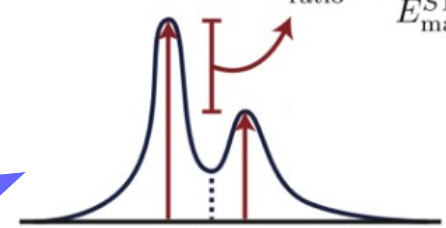
Width in a 3×5 (Δη×Δφ) region of cells in the second layer.



Calorimeters information

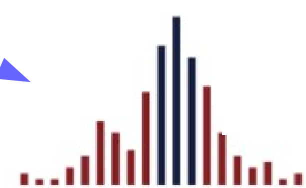


$$E_{\text{ratio}} = \frac{E^{S1}_{\max,1} - E^{S1}_{\max,2}}{E^{S1}_{\max,1} + E^{S1}_{\max,2}}$$



Track-Cluster matching

Position	**Δη ΔΦ**
Energy	**E/p**



$$\omega_{s\,tot} = \sqrt{\frac{\sum E_i (i - i_{max})^2}{\sum E_i}}$$

ωstot uses 20 strips in η

Tracking information

TRT

$$F_{HT} = \frac{n_{TRT\ \ HT\ \ hits}}{n_{TRT\ \ Hits}}$$

Silicone tracker

$$n_{Si\ \ Hits} \quad n_{Pix\ \ Hits}$$
$$n_{b\ \ layer\ \ Hits}$$

$$R_{\text{Had}} = \frac{E_T^{\text{Had}}}{E_T}$$

$$f_3 = \frac{E_{S3}}{E_{eCal}}$$

A large variety of information exploiting the full power of the detector

ID menus cut contents

Loose menu

Used variables :
Shower shape : Eratio / ωstot / ωη2 / Rη / Rhad(1)
track-cluster matching : Δη
track quality : nSi / nPix / **nBlayer**

Medium menu

Used variables:
Shower shape : Eratio / ωstot / ωη2 / Rη / **RΦ** / f3 / Rhad(1)
TRT : F HT
track-cluster matching : Δη
track quality : nSi / nPix / nBlayer

Main changes :
- Rhad is looser
- F HT is now tighter and binned in Et
- Eratio is tigher for Et[20-30] GeV
- +1 on the nSi / nPix cuts
- d0 reasonably tighten

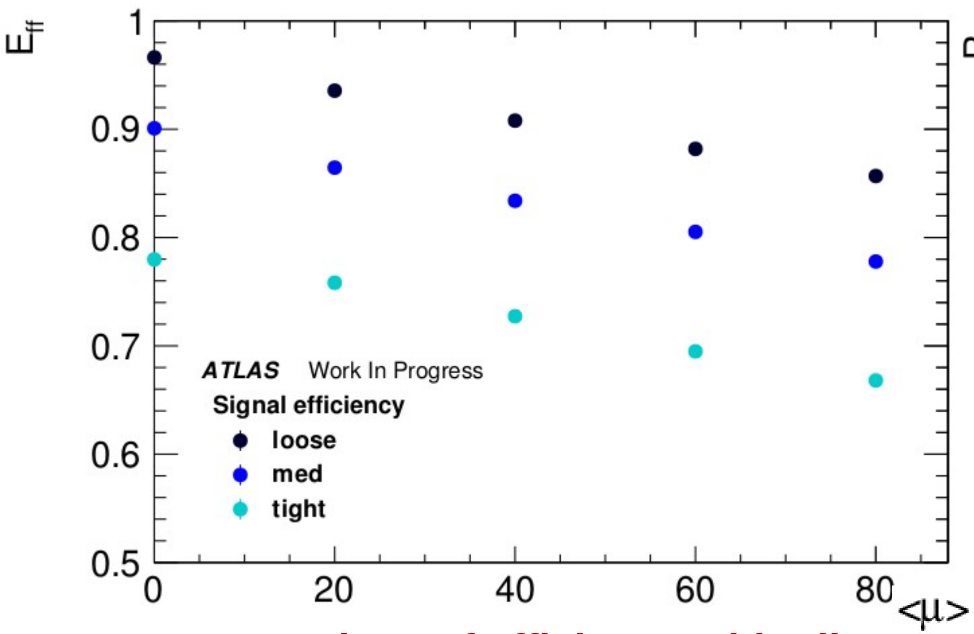
Tight menu

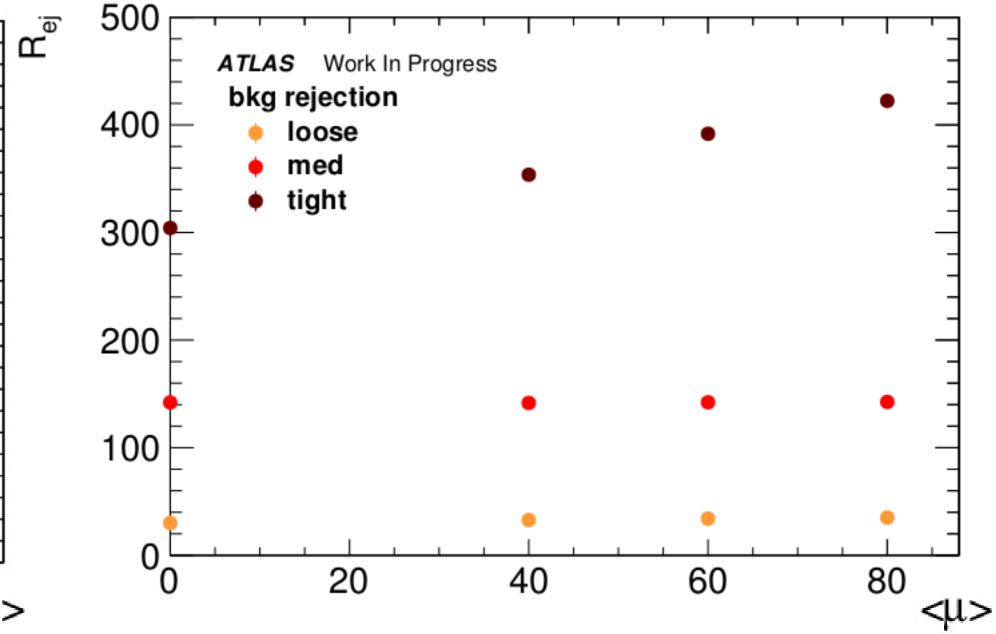
Used variables :
Shower shape : Eratio / ωstot / ωη2 / Rη / **RΦ** / f3 / Rhad(1)
track-cluster matching : Δη **/ ΔΦ / E/p**
TRT : F HT / nTRT
track quality : nSi / nPix / nBlayer

- **Green : New cuts with respect to 2012 isEM++ menus**
- **Red : Offline only cuts**

Why re-optimizing
The electron identification

- **Here are the offline performances of the 2012 identification menu :**





Important loss of efficiency with pile-up :
<mu> = 0 -> <mu> = 40 : ~ 5 % of loss

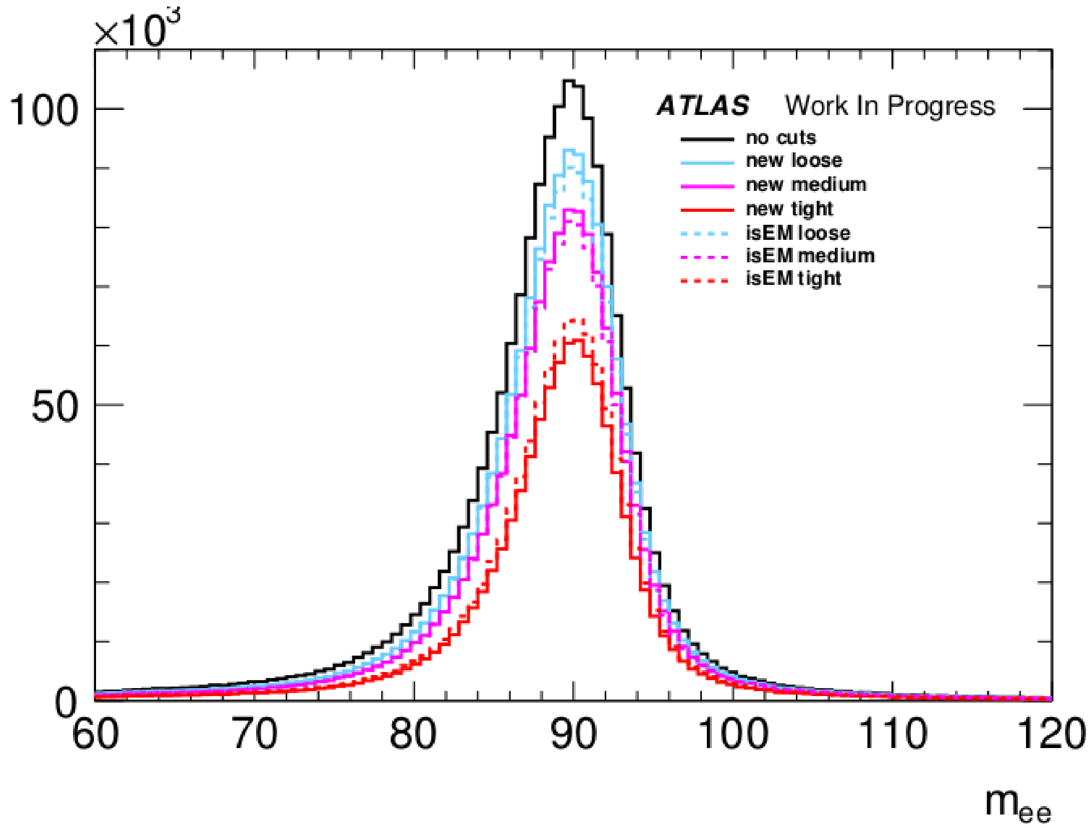
Acceptable background rejection

- **Online performances :**
  - The allowed bandwidth for single electron trigger for 2015 : **~200 Hz.**
  - The energy and the luminosity will both increase
    - -> 2015 trigger rate **4-5 time higher**
    - -> 2012 single electron trigger in 2015 high lumi/Energy conditions : **~ 1 kHz**

The 2012 identification menus needs to be re-optimized for 2015 high luminosity conditions

Are our menus degrading the physical content ?

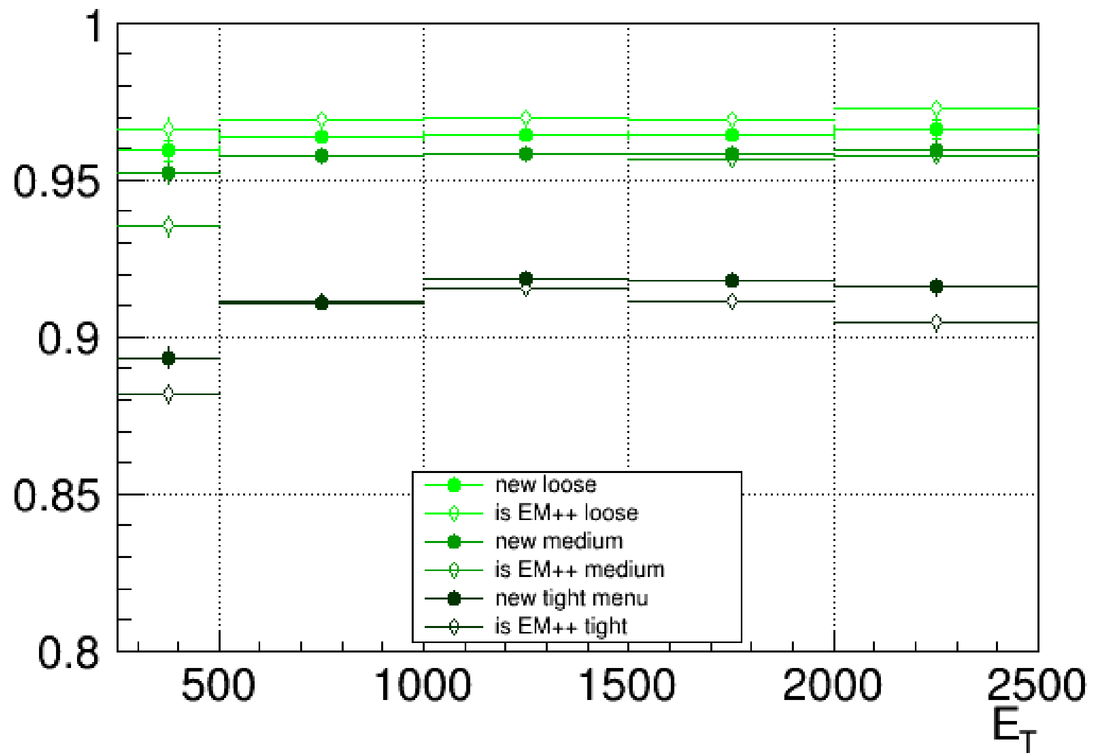
- **Invariant mass of electron pairs coming from a Z -> ee process**



No drop of efficiency @ very high Et
-> Very important for new physics

Are our menus adapted for new physics searches ?

- **New physics searches are crutial for the begining of the 2015 data taking**
- **Many new physics signals are tagged with very high Energy leptons**
  -> We want to keep high efficiency for TeV electrons



No drop of efficiency @ very high Et
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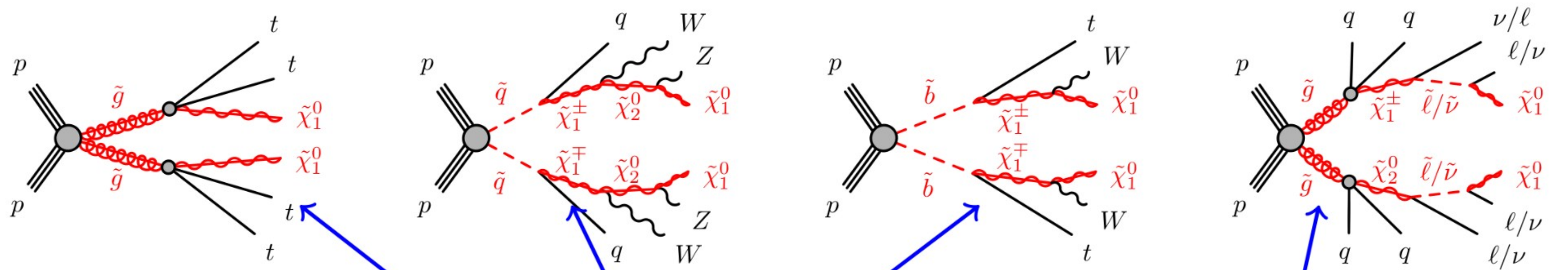
Back-up
Part II : search for SUSY with 2 same sign leptons

Introduction
Run1 Signal Regions (SR)

- **Five exclusive SR categorized using**
  - b-jet multiplicity
  - 2 same sign leptons or 3 leptons

- **m_{eff} cut → discovery**
- **m_{eff} fit → exclusions**



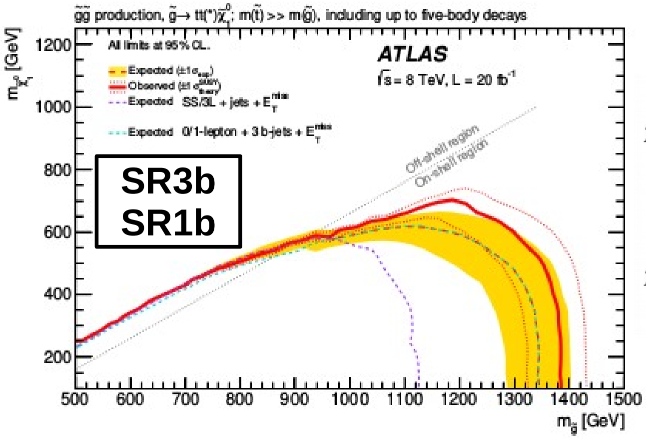
Requirement	Signal region				
	SR3b	**SR0b**	**SR1b**	**SR3Llow**	**SR3Lhigh**
Leptons	SS or 3L	SS	SS	3L	3L
$N_{b-\text{jet}}$	≥ 3	=0	≥ 1	-	-
$N_{\text{jet}} \geq$	5	3	3	4	4
$E_{\text{T}}^{\text{miss}}$ [GeV]		> 150	> 150	$50 < E_{\text{T}}^{\text{miss}} < 150$	> 150
m_{T} [GeV] $>$	-	100	-	-	-
Veto	-	-	SR3b	Z boson, SR3b	SR3b
m_{eff} [GeV] $>$	350	400	700	400	400

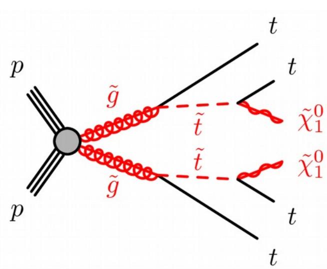
Not Etmiss cut → can be used to constrain RPV models

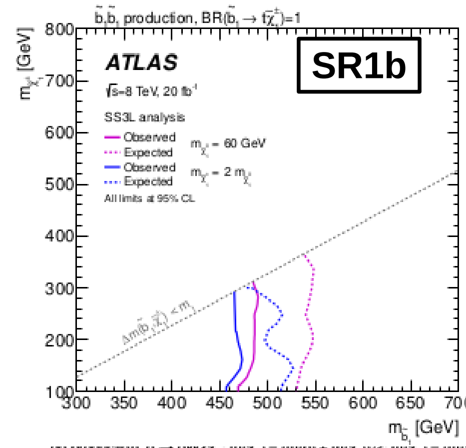
The run 1 signal regions allowed to cover efficiently a large variety of SUSY models

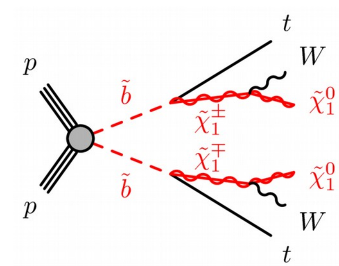
Introduction
Run1 Results (SR)

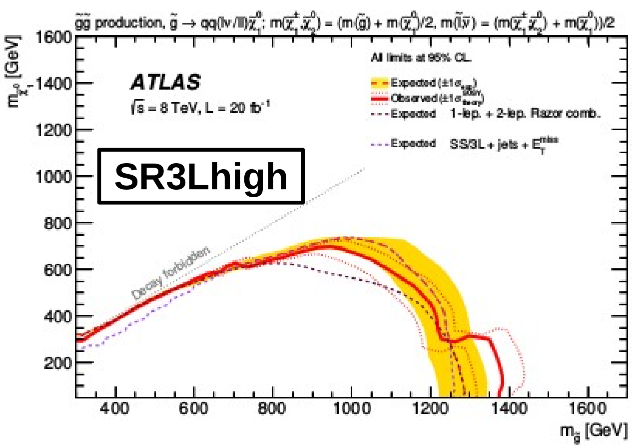
- **No discovery so far :** Strong SUSY searches summary paper **link**
- **Chosen Run 1 exclusion plots :** Same sign lepton run 1 paper **link**

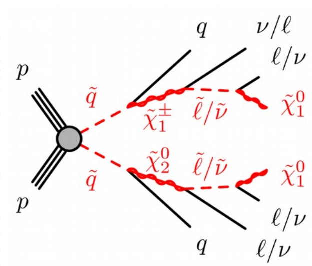


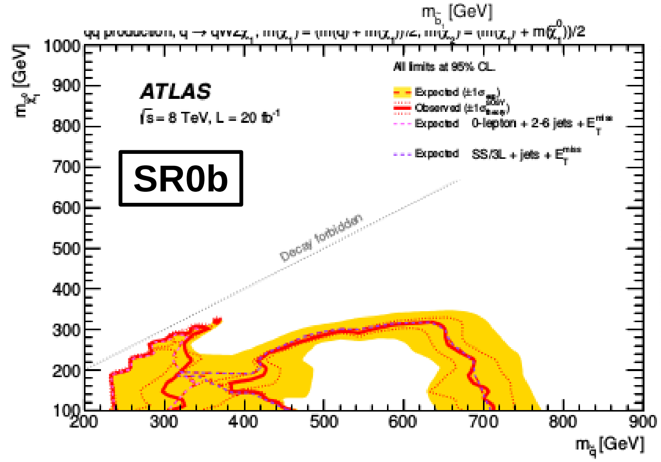


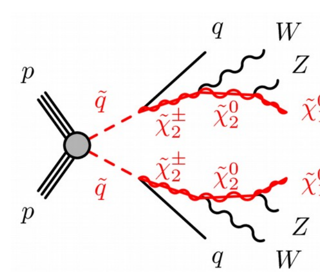








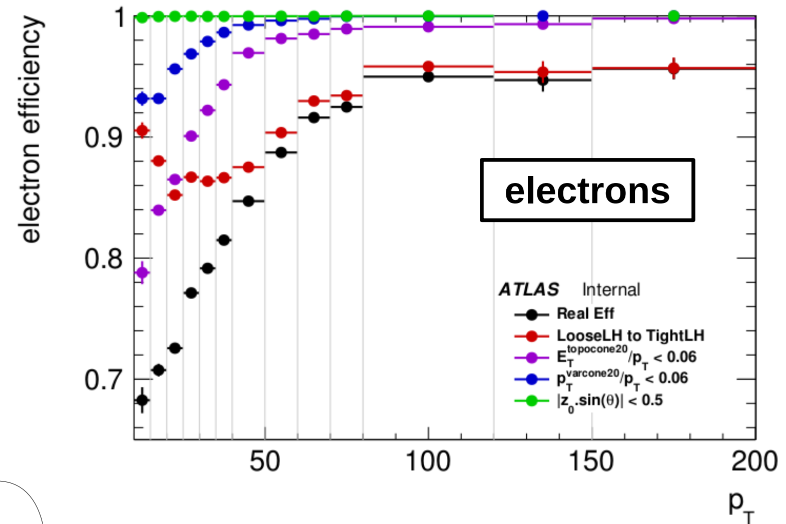


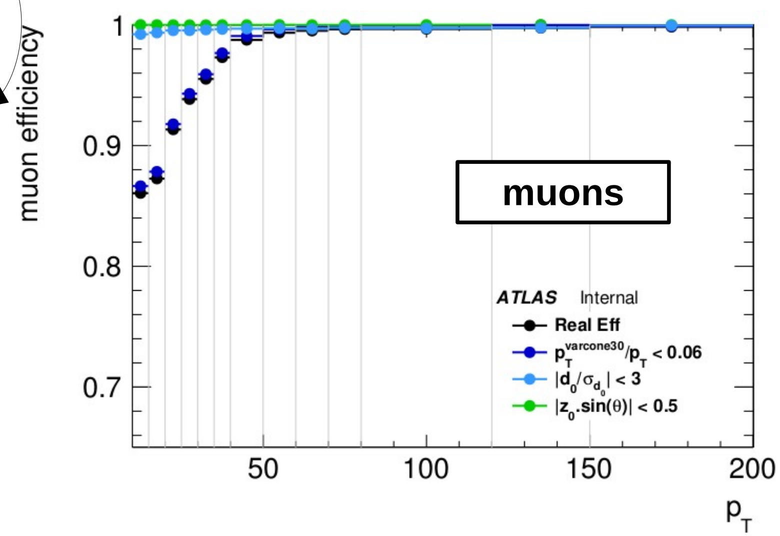


Real lepton efficiencies Description

- **Real lepton efficiency corresponds to the baseline (pre-selected) to signal leptons efficiencies**

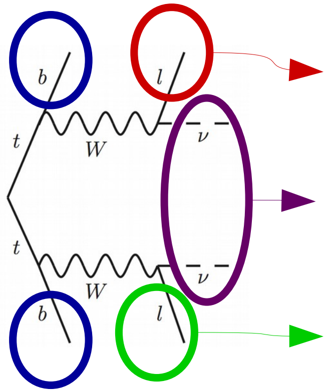
	Pre-selected Electron	Pre-selected Muon
Acceptance	$p_T > 10$ GeV, $\|\eta^{\text{clust}}\| < 2.47$ except $1.37 < \|\eta^{\text{clust}}\| < 1.52$	$p_T > 10$ GeV, $\|\eta\| < 2.5$
Quality	`LooseLLH`	`xAOD::Muon::Medium`
ℓ-jet Isolation	$\Delta R(e, jet) > 0.4$	$\Delta R(\mu, jet) > 0.4$
Impact parameter	$\|d_0/\sigma(d_0)\| < 5.0$	
	Signal Electron	**Signal Muon**
Quality	`TightLLH` $\|\eta\| < 2.0$	- -
Isolation	"FixedCutTight "	"FixedCutTightTrackOnly"
Impact parameter	$\|z_0 \cdot sin(\theta)\| < 0.5$ mm	$\|z_0 \cdot sin(\theta)\| < 0.5$ mm $\|d_0/\sigma(d_0)\| < 3.0$
	$p_T^{varcone20} / p_T < 0.06$ $E_T^{topocone20} / p_T < 0.06$	$p_T^{varcone30} / p_T < 0.06$





Dominant effect
electron : looseLH to tightLH ID
muon : track isolation

Real lepton efficiencies
ttbar tag-and-probe



- **Large b-jet multiplicity in SR1-3b**
→ topologies closer to ttbar than Z+jets
→ a ttbar tag-and-probe method has been developed to reduce the extrapolation systematics

- **Event selection**
  - Exactly 2 leptons with p_T > 30 GeV
  → Rejection against W+jets / ttZ
  - A least 1 b-jet
  → Rejection against W+jets / VV
  - E^T_{miss} > 30 and GeV for ee/μμ events
  → Rejection against Z+jets
  - Events with 70 < m_{ll} < 100 GeV removed for ee/μμ events
  → Rejection against Z+jets / ttV

- **Lepton selection**
  - **tag lepton, used to identify the ttbar event, has to pass :**
    - Signal lepton definitions cuts
    - Single lepton trigger match
  - **A probe lepton, used for the efficiencies measurements has to pass :**
    - Baseline lepton definition cuts

Closer to SUSY signal efficiencies (smaller systematics) expected with ttbar T&P