Search for charged long-lived heavy particles with the ATLAS experiment at the LHC

Elisa Guido

- INFN Genova & CERN -

Incontri di Fisica delle Alte Energie Ferrara, 12 Aprile 2012

Outline

- ✓ Theoretical motivations
- ✓ Experimental techniques
- ✓ ATLAS results
  - ✓ Pixel+Tracker+Tile-based analysis — **Phys.Lett. B701 1-19 (2011)**
  - ✓ Muon Spectrometer-based analysis — **Phys.Lett. B703 428-446 (2011)**
  - ✓ Pixel-based analysis — **NEW!!** — **ATLAS-CONF-2012-022 (2012)**
- ✓ Future prospects

Theoretical motivations

✓ **Stable Massive Particles** (SMPs) predicted by many BSM scenarios, including several different SUSY models

✓ R-hadrons are **coloured** SMPs: bound states formed by **squarks and gluinos** hadronizing with a light SM quarks system, several **electric charges** (and the electric charge can change due to nuclear scattering with the detector)

✓ **Long-lived** for this search

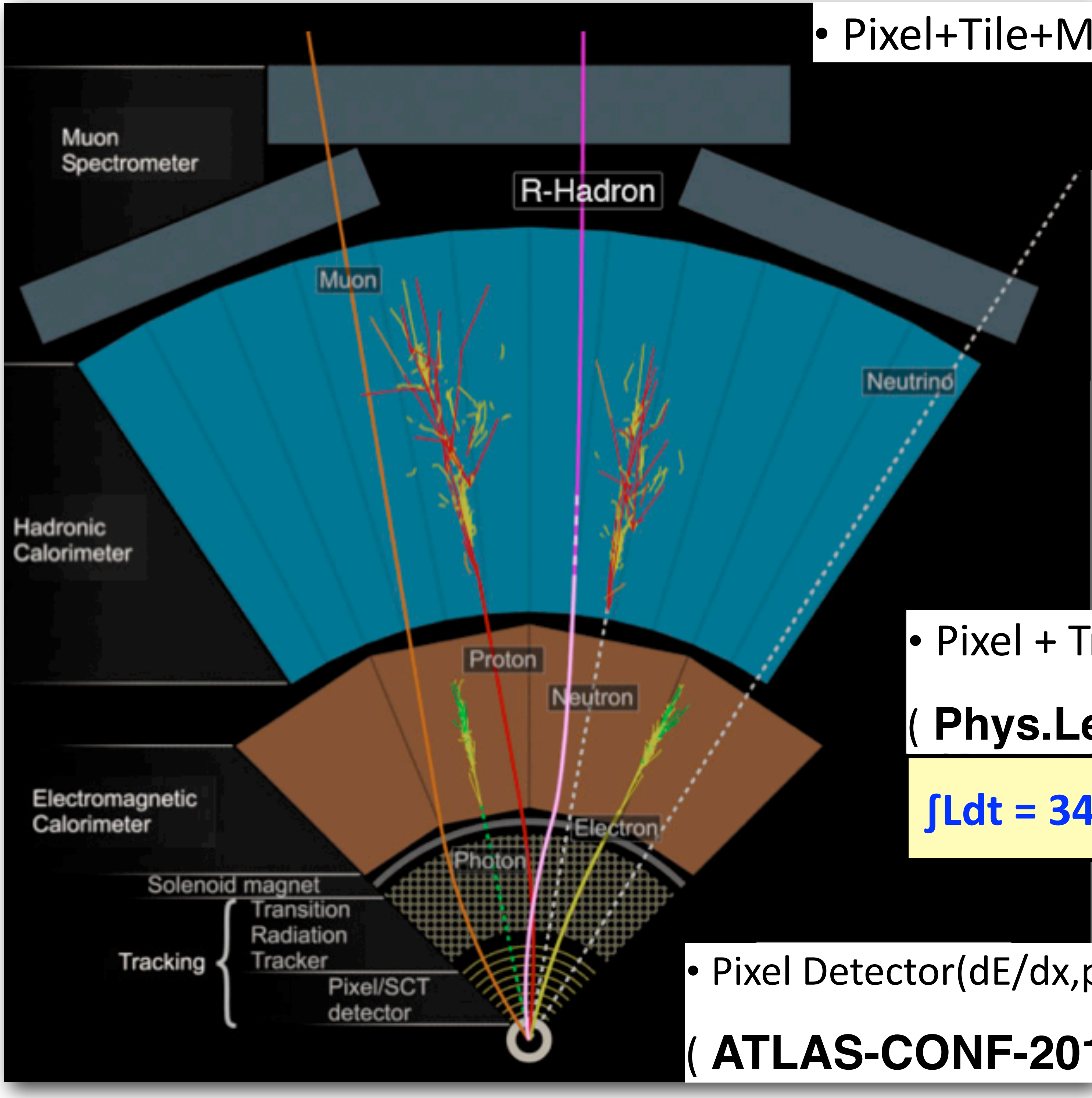
	composition	notation
R-mesons	$R = \tilde{g}q\bar{q}, (\tilde{q}\bar{q})$	R^+, R^-, R^0
R-baryons	$R = \tilde{g}qqq, (\tilde{q}qq)$	R^{++}, R^+, R^-, R^0
R-gluinoballs	$R = \tilde{g}g$	R^0

arXiv:hep-ph/0611040

SMP	LSP	Scenario	Conditions
$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	MSSM	$\tilde{\tau}_1$ mass (determined by $m^2_{\tilde{\tau}_{L,R}}$, μ, $\tan\beta$, and A_τ) close to $\tilde{\chi}_1^0$ mass.
	$\tilde{G}$	GMSB	Large N, small M, and/or large $\tan\beta$.
		$\tilde{g}$MSB	No detailed phenomenology studies, see [23].
		SUGRA	Supergravity with a gravitino LSP, see [24].
	$\tilde{\tau}_1$	MSSM	Small $m_{\tilde{\tau}_{L,R}}$ and/or large $\tan\beta$ and/or very large A_τ.
		AMSB	Small m_0, large $\tan\beta$.
		$\tilde{g}$MSB	Generic in minimal models.
$\tilde{\ell}_{i1}$	$\tilde{G}$	GMSB	$\tilde{\tau}_1$ NLSP (see above). $\tilde{e}_1$ and $\tilde{\mu}_1$ co-NLSP and also SMP for small $\tan\beta$ and μ.
	$\tilde{\tau}_1$	$\tilde{g}$MSB	$\tilde{e}_1$ and $\tilde{\mu}_1$ co-LSP and also SMP when stau mixing small.
$\tilde{\chi}_1^+$	$\tilde{\chi}_1^0$	MSSM	$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \lesssim m_{\pi^+}$. Very large $M_{1,2} \gtrsim 2$ TeV $\gg |\mu|$ (Higgsino region) or non-universal gaugino masses $M_1 \gtrsim 4M_2$, with the latter condition relaxed to $M_1 \gtrsim M_2$ for $M_2 \ll |\mu|$. Natural in O-II models, where simultaneously also the $\tilde{g}$ can be long-lived near $\delta_{GS} = -3$.
		AMSB	$M_1 > M_2$ natural. m_0 not too small. See MSSM above.
$\tilde{g}$	$\tilde{\chi}_1^0$	MSSM	Very large $m^2_{\tilde{q}} \gg M_3$, e.g. split SUSY.
	$\tilde{G}$	GMSB	SUSY GUT extensions [25–27].
	$\tilde{g}$	MSSM	Very small $M_3 \ll M_{1,2}$, O-II models near $\delta_{GS} = -3$.
		GMSB	SUSY GUT extensions [25–29].
$\tilde{t}_1$	$\tilde{\chi}_1^0$	MSSM	Non-universal squark and gaugino masses. Small $m^2_{\tilde{q}}$ and M_3, small $\tan\beta$, large A_t.
$\tilde{b}_1$			Small $m^2_{\tilde{q}}$ and M_3, large $\tan\beta$ and/or large $A_b \gg A_t$.

Experimental techniques

✓ Generic signature: **slow** (β<1 and highly ionizing) and **high-p_T particles**: measurement done by different ATLAS subdetectors



- Pixel+Tile+Muon combined analysis in the pipeline

$\int Ldt = 5fb^{-1}$

- Muon Spectrometer (β,μ-like)

(**Phys.Lett. B703 428-446 (2011)**)

$\int Ldt = 37pb^{-1}$

- Pixel + Tracker + Tile Calorimeter (β)

(**Phys.Lett. B701 1-19 (2011)**)

$\int Ldt = 34pb^{-1}$

- Pixel Detector(dE/dx,p)+SCT(p) $\int Ldt = 2fb^{-1}$ → in the pipeline → $\int Ldt = 5fb^{-1}$

(**ATLAS-CONF-2012-022 (2012)**)

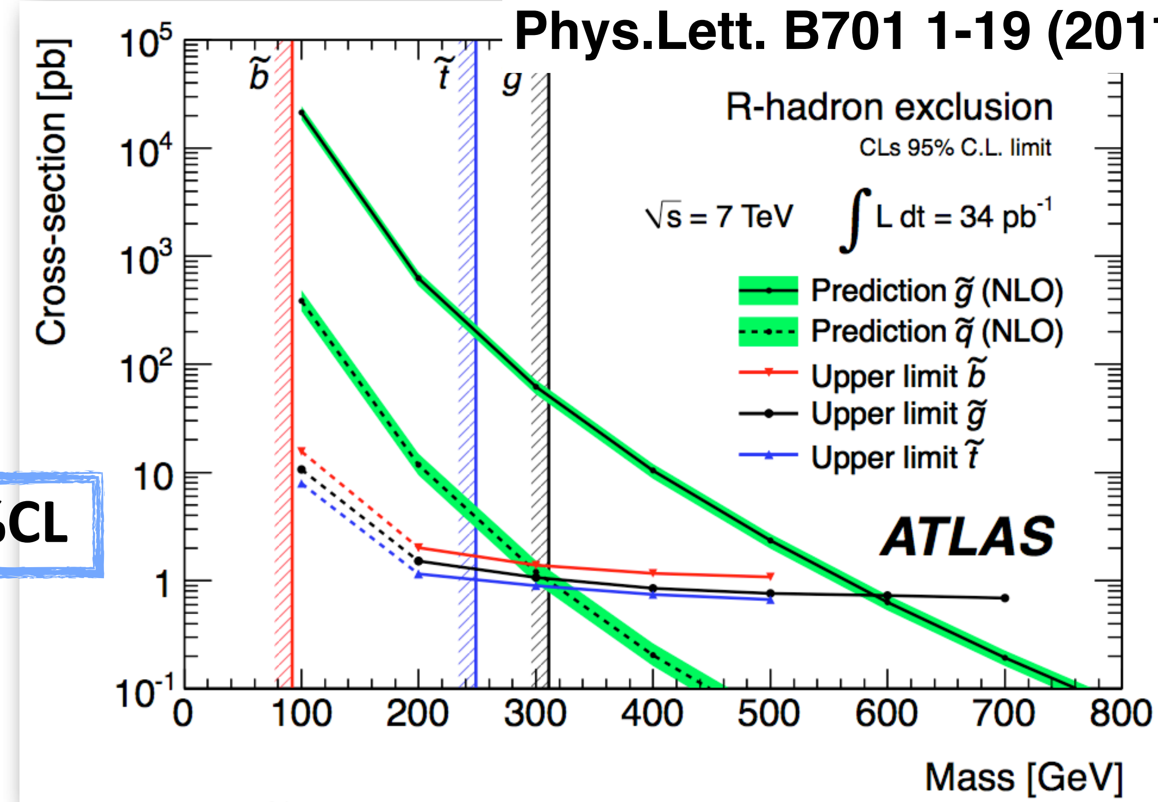
Previous ATLAS results

- Pixel + Tracker + Tile Calorimeter:

✓ Measurement of time-of-flight (Tile calorimeter) and specific ionization energy loss (Inner Detector)

m($\tilde{g}$)>586 GeV @95%CL

Phys.Lett. B701 1-19 (2011)

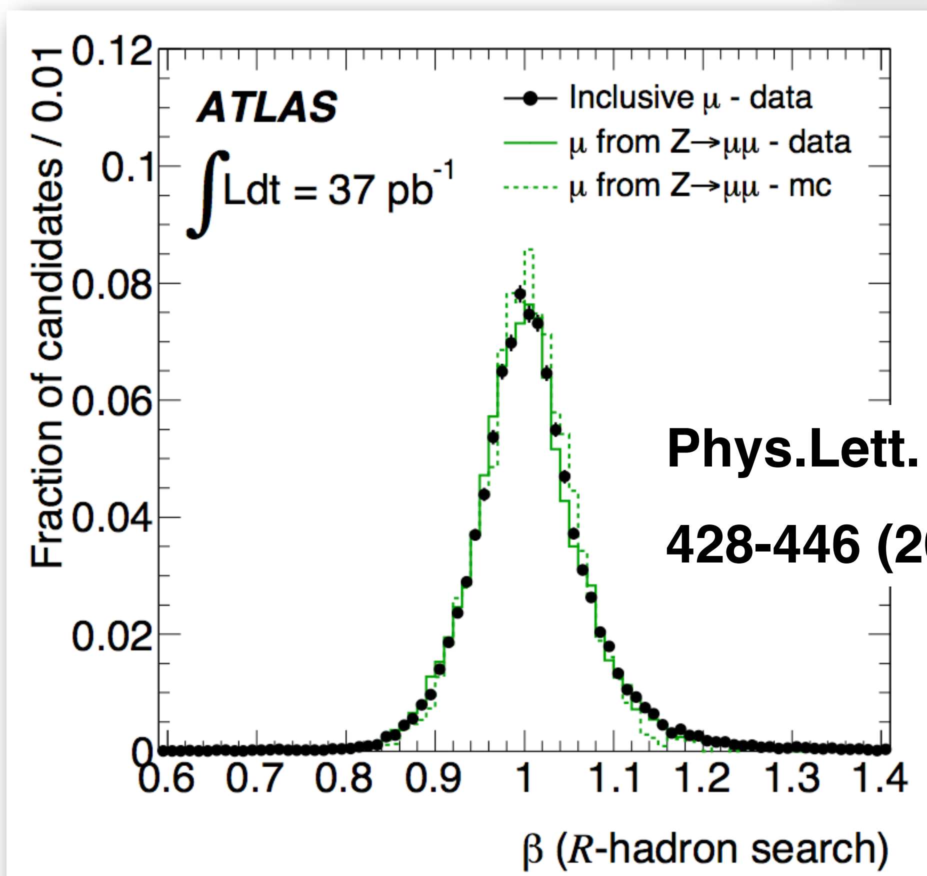


- Muon Spectrometer:

✓ Complementary (looking for R-hadrons even without an ID track)

✓ More sensitive to larger gluino-ball (neutral) fractions

✓ Signature similar to muons, except for timing



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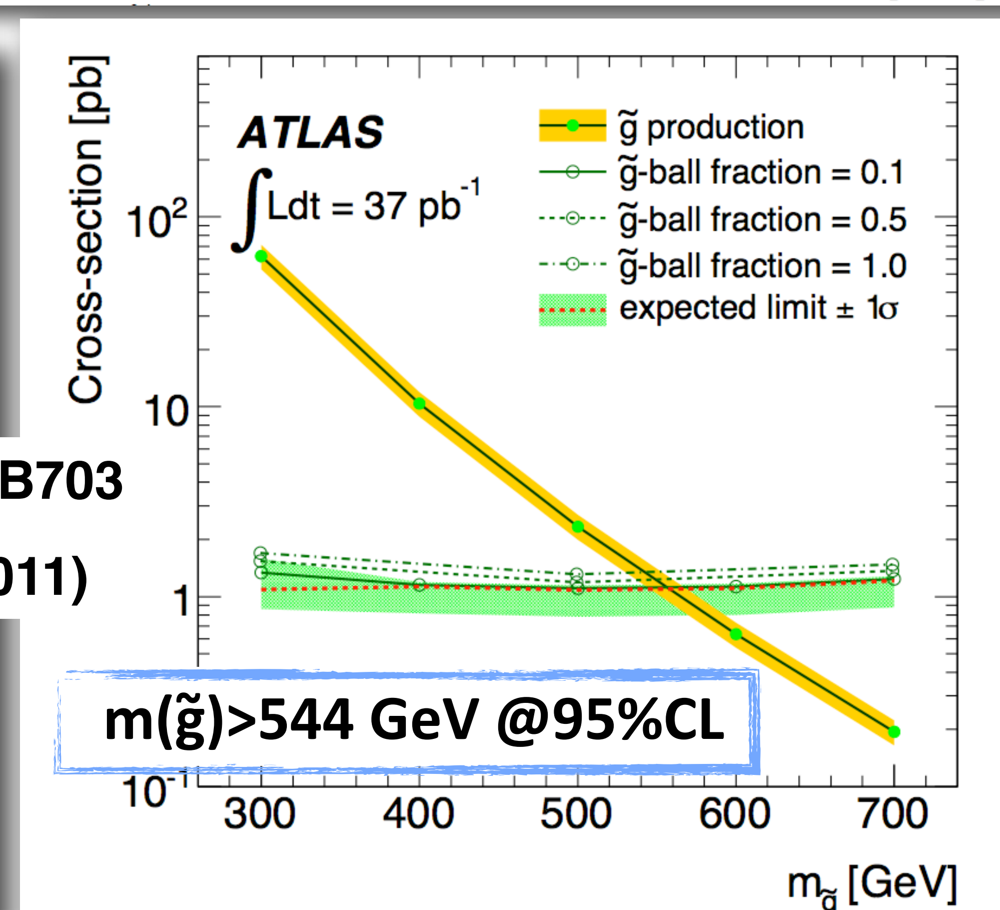
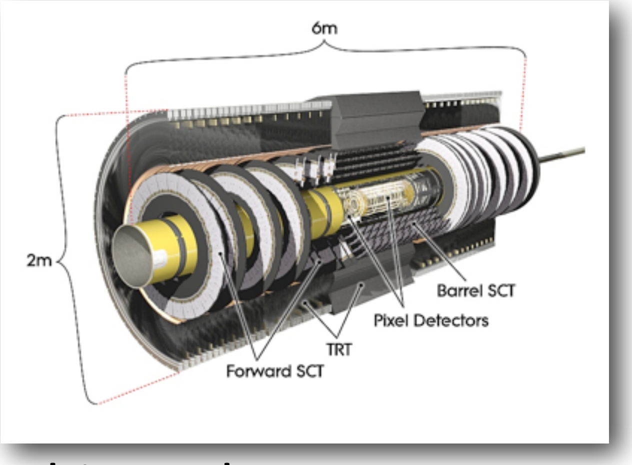


m($\tilde{g}$)>544 GeV @95%CL

Latest ATLAS result (Pixel analysis)



✓ We do not explicitly require any confirmation of the signal out of the ID (**Pixel+SCT**):

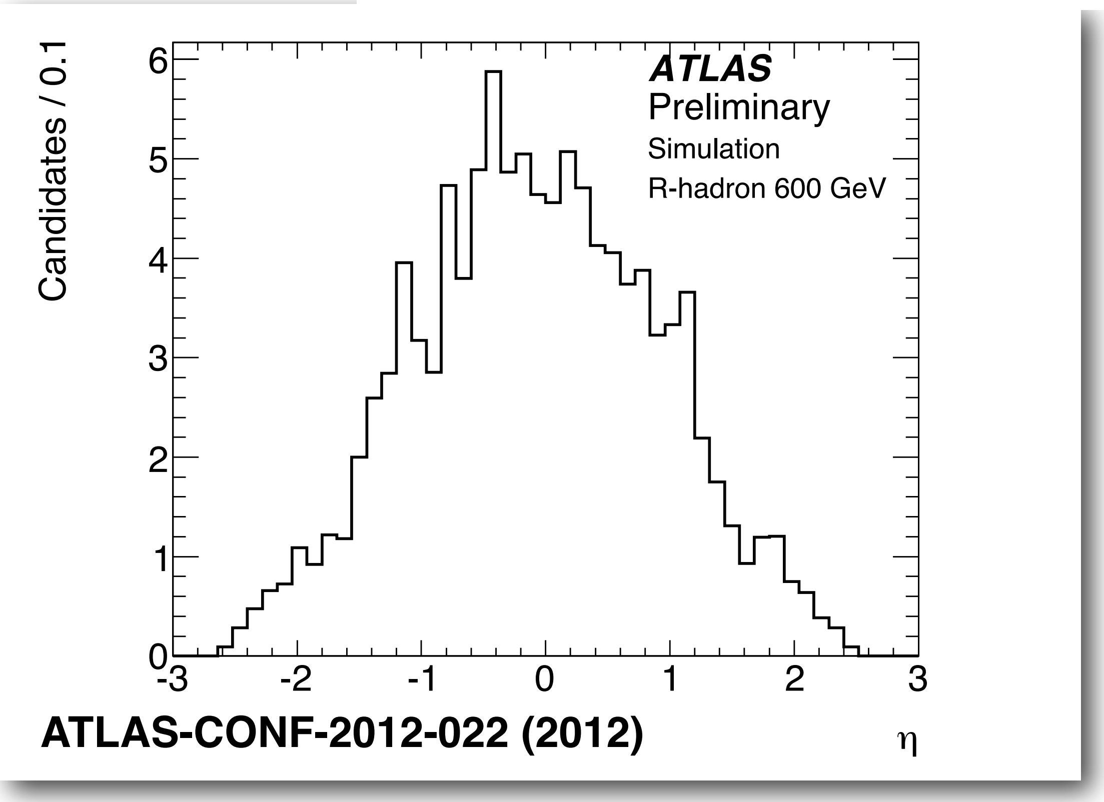
-> **open to models different from R-hadrons** production, i.e. decaying before reaching other subdetectors, or scattering

-> SUSY models predict the possibility for R-hadrons to interact with material and become **neutral**

✓ Even when considering **stable R-hadrons**, the Pixel-only measurement is competitive with the combined one, thanks to:

- Signal efficiency not affected by calorimeter requirements
- Higher geometrical acceptance (|η|<2.5 vs. |η|<1.7)
- Good background rejection capability (track isolation cut)
- Refined background estimation (dE/dx dependence on p and η)

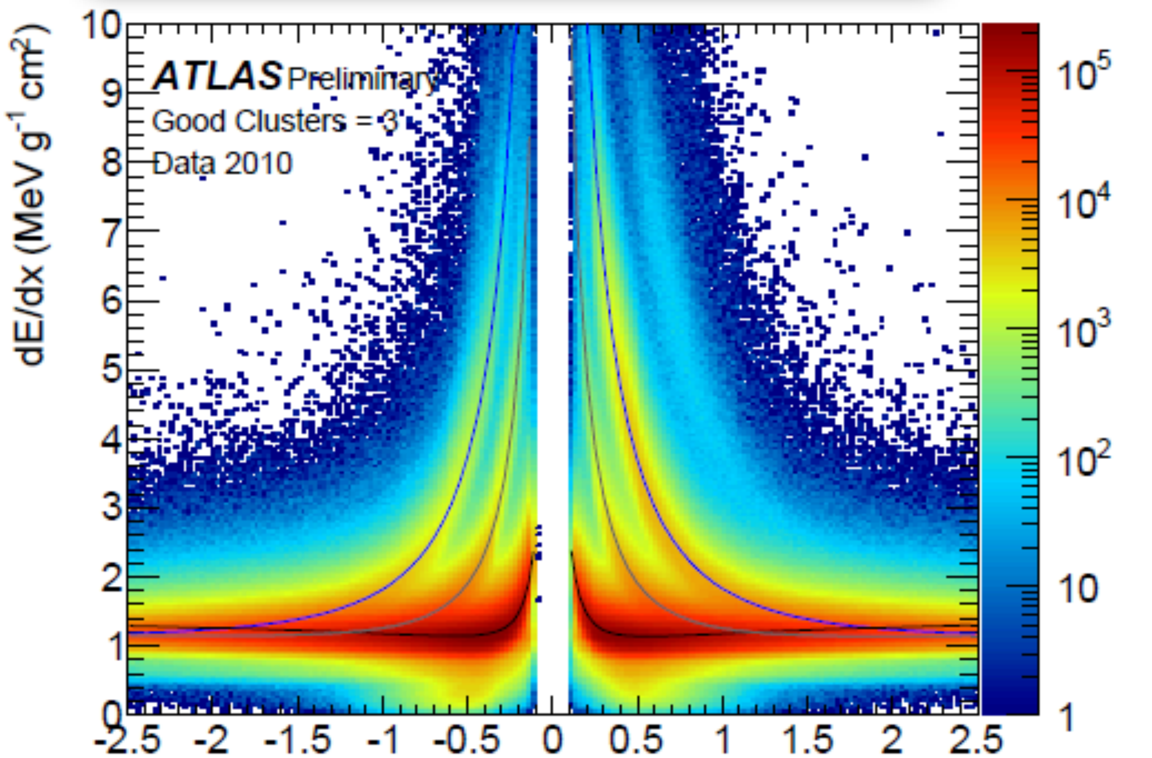
Gluino R-hadron simulated sample



Strategy

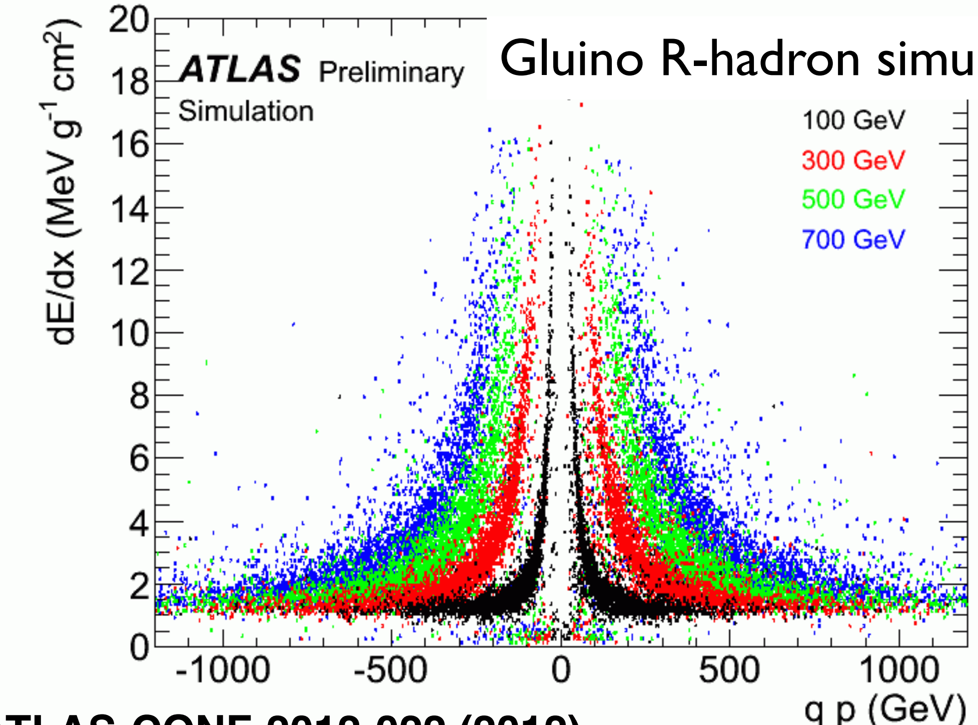
✓ R-hadrons have large p_T and large ionization in Pixel, well above the MIP release

dE/dx(MIP)~1.2MeVg^{-1}cm^{2}



ATLAS-CONF-2011-016 (2011)

Gluino R-hadron simulated samples



ATLAS-CONF-2012-022 (2012)

✓ Measurement not available at trigger level -> other signatures must be used

✓ The strong nature of gluino production mechanisms and the associated QCD radiation is exploited: gluon-gluon fusion, where ISR gives rise to jets

✓ Jets + modest energy deposition of the heavy objects -> **missing transverse energy** (E_T^{miss})

Trigger efficiency **~20%** on a wide range of masses

Mass measurement with the Pixel

✓ Particles identified fitting each dE/dx and momentum measurement to an empirical Bethe-Bloch distribution and deducing their mass value

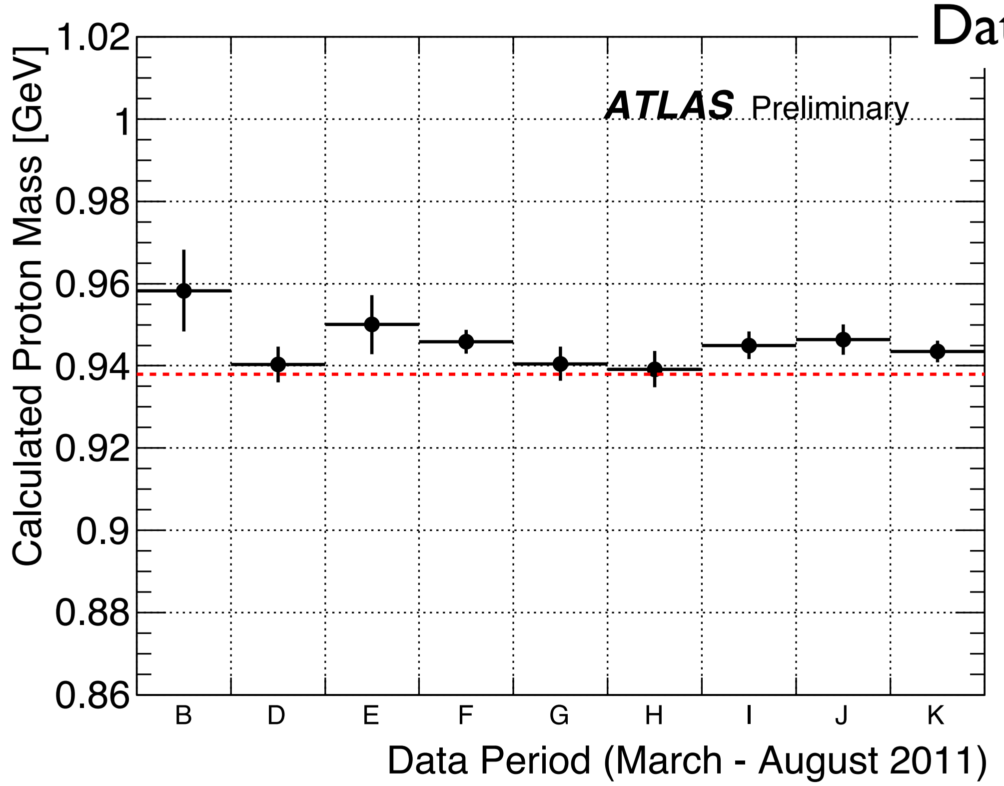
✓ 5-parameters function to describe the most probable value dependence on β:

$$\mathscr{M}_{\frac{dE}{dx}}(\beta) = \frac{p_1}{\beta^{p_3}} \ln(1 + (p_2 \beta\gamma)^{p_5}) - p_4$$

✓ Procedure continuously monitored through measurement of SM particles (protons) -> good stability

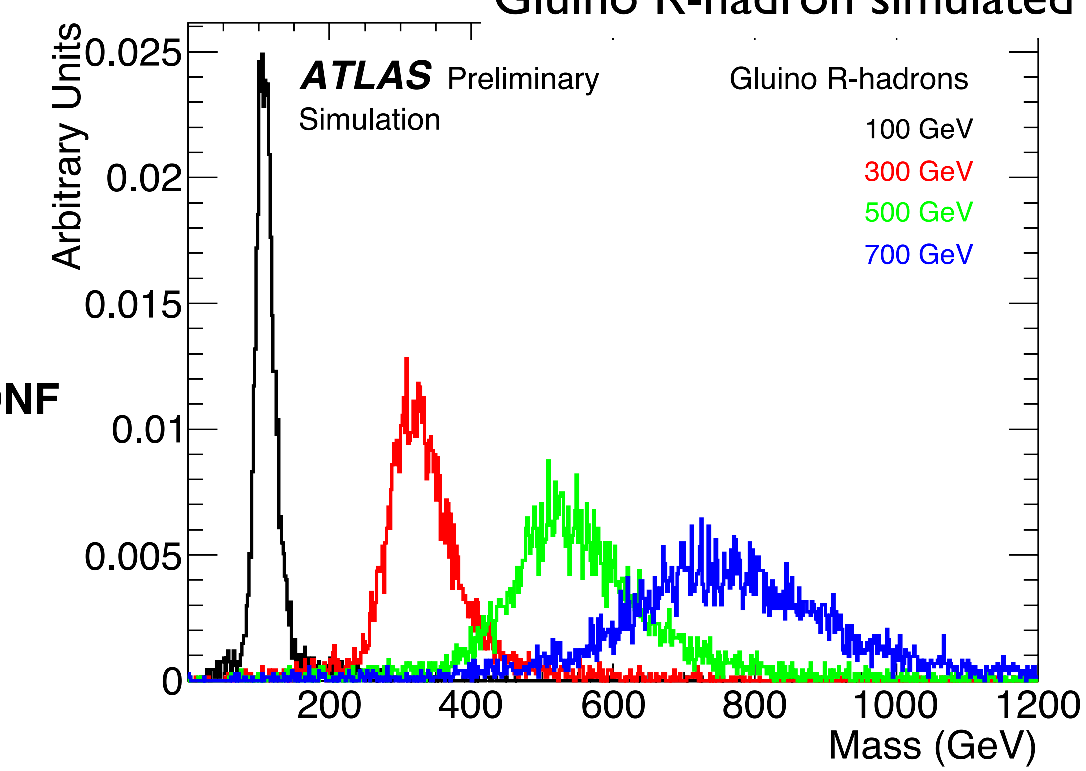
✓ Mass resolution decreasing with increasing mass values (because Δp/p increasing with p)

Data 2011



ATLAS-CONF
-2012-022

Gluino R-hadron simulated sample



Event selection

✓ Event level:

✓ offline confirmation of the trigger **E_T^{miss} offline > 85 GeV**

✓ at least 1 primary vertex (PV) with a minimum number of associated tracks = 5

✓ Track level: to have at least one track with:

✓ **p_T>50 GeV** + n.Pixel hits >=3 (and nBLayer hits >=1) and n.SCT hits >=6 and request to come from the PV

✓ **isolation**: no other tracks with p_T>5 GeV in a cone of radius **ΔR<0.25**

✓ **p>100 GeV**

✓ **high ionization:** **$dE/dx > 1.800 - 0.045|\eta| + 0.115|\eta|^2 - 0.033|\eta|^3$ MeV/g cm^{-2}**

(a η-dependent cut to take into account dE/dx-p-η correlations and to ensure a constant signal-to-noise ratio)

✓ In case of multiple tracks surviving the selection, the one with highest transverse momentum is kept as R-hadron candidate (to simplify normalization)

Total signal efficiency ~**2-9%** on [200,1000] GeV range

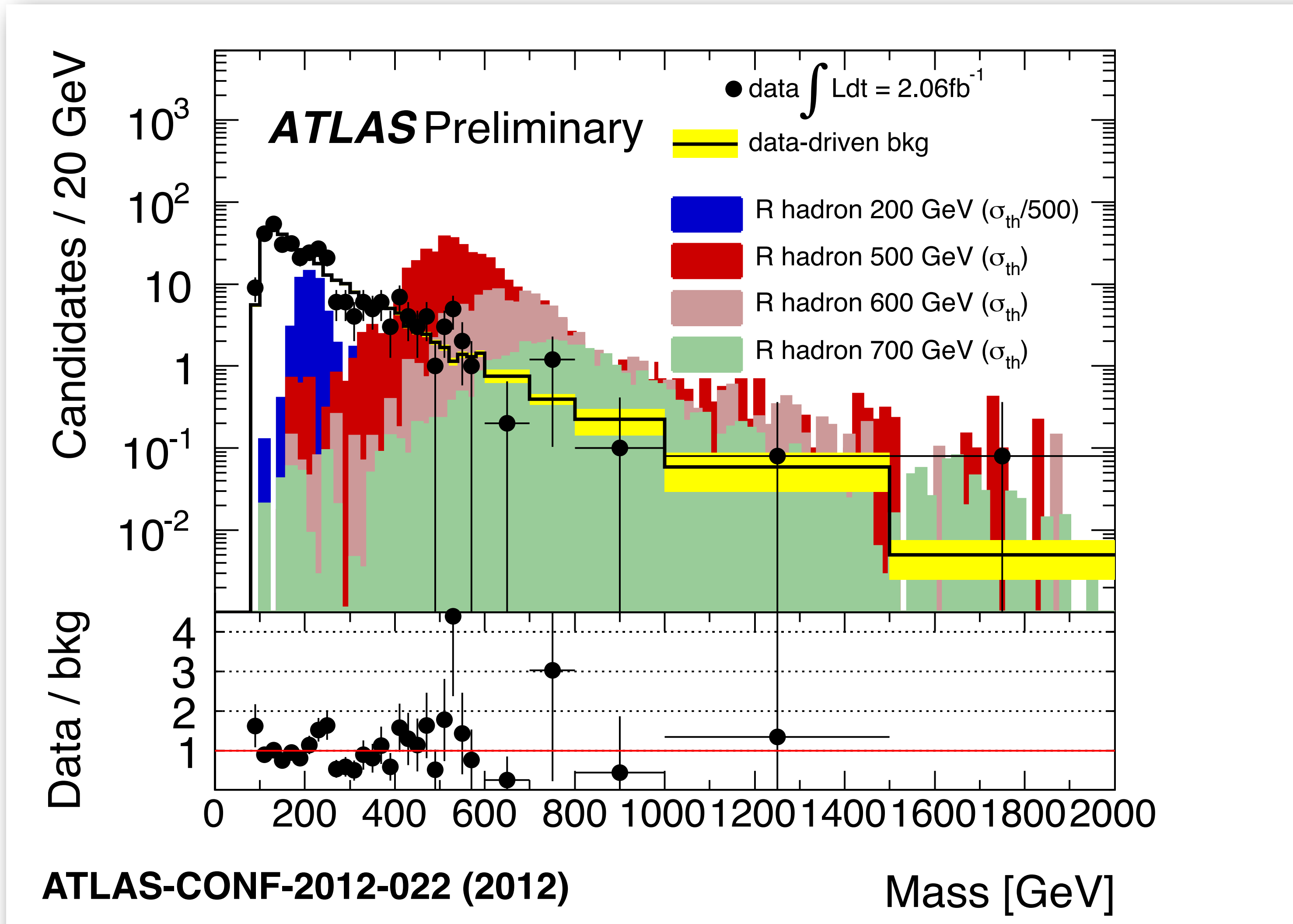
Background estimation

✓ Data-driven approach: we use data to parameterize the key variables (p, η and dE/dx) and their inter-dependences, and then we generate a high-statistics random sample based on them, and reproducing data behaviour

✓ 2 data samples used (**both selected in a way to reduce signal contamination**, requiring either low ionization or low momentum)

✓ Normalization of the background mass spectrum to data BEFORE the ionization cut (smaller uncertainty), and considering Mass<140 GeV (again to avoid possible signal contaminations)

The error on the background distribution is (bin by bin) the sum in quadrature of statistical, normalization, and systematic errors



Systematic uncertainties

Some of them varying with mass (200-1000 GeV)

✓ Uncertainties affecting:

Systematic Uncertainties on Efficiency		[%]
QCD Accuracy	(theoretical)	± 8.5
Ratio of charged R-hadrons		± 0.2
Scattering models		± 11
Trigger turn-on	(experimental)	$\pm 4 \div \pm 3$
MET scale		$-8.6 \div -3.4; +1$
Pile-up		± 2
Ionization Parametrization		$-9 \div -2$
Momentum Parametrization		± 1
LAr Inefficiency		± 1
Total uncertainty on Efficiency		$19 \div 14$
Systematic Uncertainties on Background		**[%]**
Binning p,η and $\eta(p)$		$-2 \div +4$
Smoothing		$-2 \div +3$
dE/dx CB		$-1 \div +3$
dE/dx CB+exp		$-1 \div +3$
Pile-up		$-2 \div +2$
Total uncertainty on Background		$1 \div 10$
Other uncertainties		
Luminosity		± 3.7
Prospino NLO	(theoretical cross-section)	± 15
PDFs		± 5

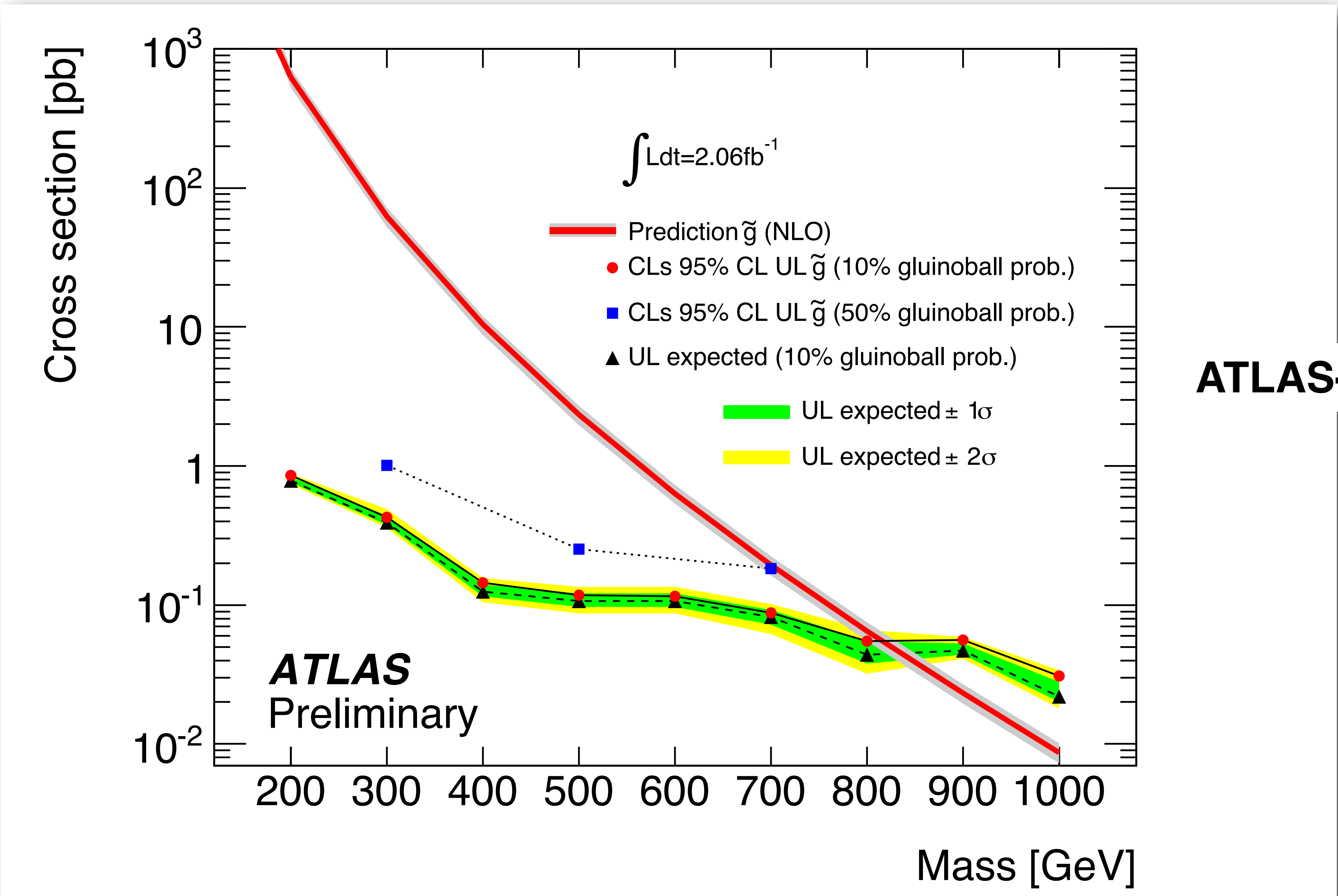
ATLAS preliminary

ATLAS-CONF-2012-022 (2012)

Results

✓ Input: signal, background and data mass spectra [0,2000] GeV

✓ Frequentist scan of the signal CL, as a function of R-hadron cross-section



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A gluino R-hadron with Mass<810 GeV is excluded at the 95% CL

Conclusions

✓ Search for charged SMPs performed by ATLAS using several signatures and experimental techniques

✓ Their combination allows to check different SUSY models and to increase sensitivity in the overlapping region

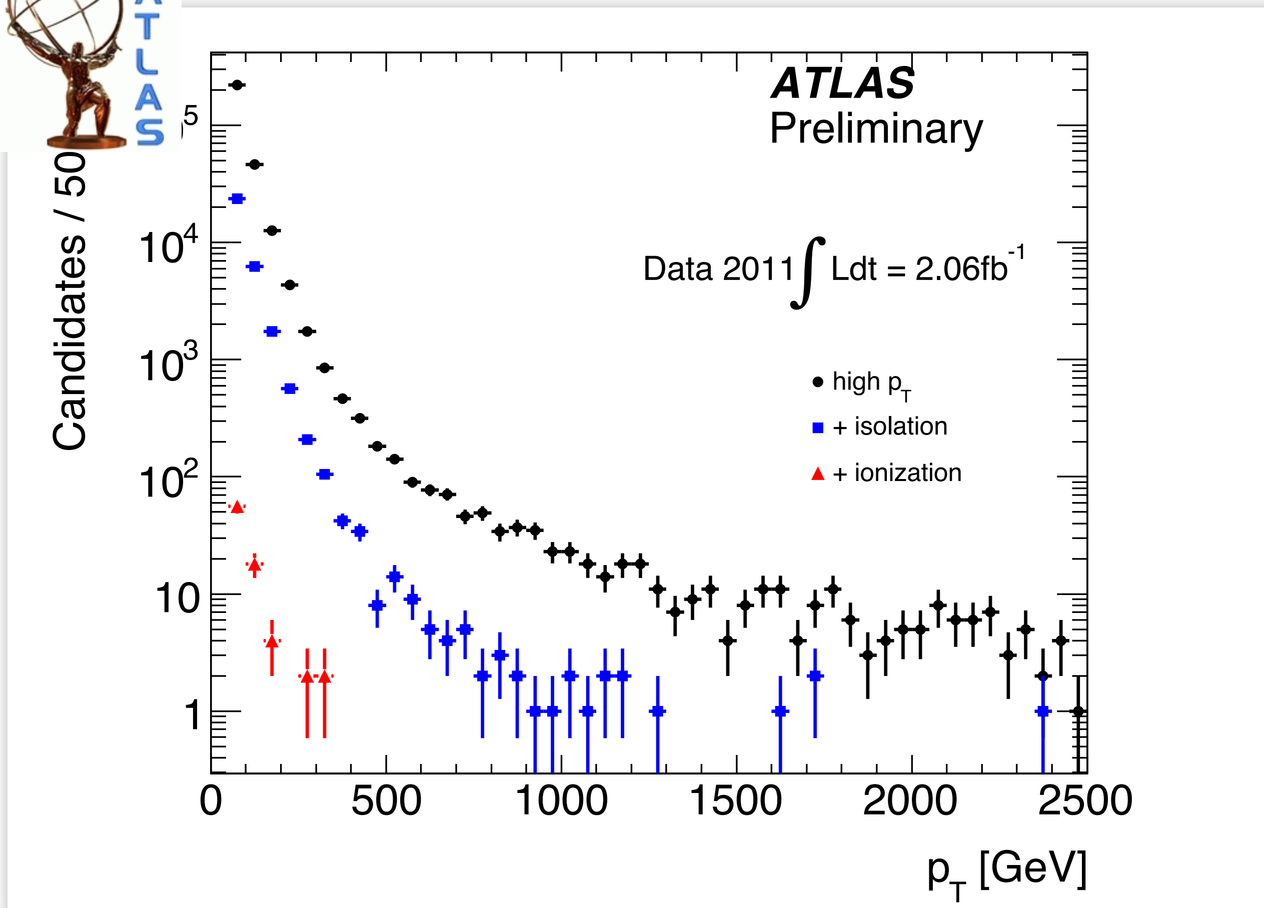
✓ Recent result using only the Pixel detector:

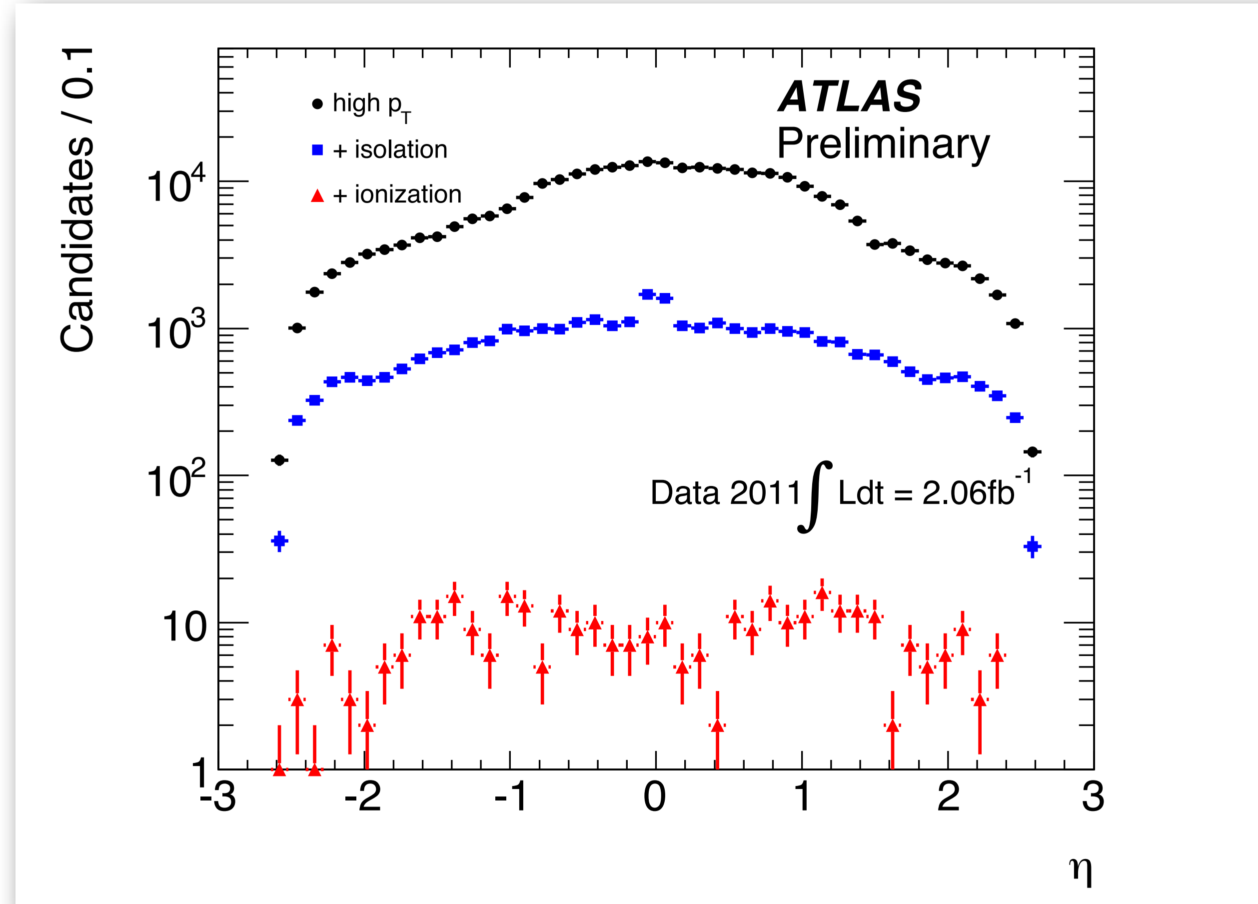
- ✓ **a gluino R-hadron with Mass<810 GeV is excluded at the 95% CL**
- ✓ update to full 2011 statistics soon
- ✓ other models (metastable R-hadrons and charginos) can be considered

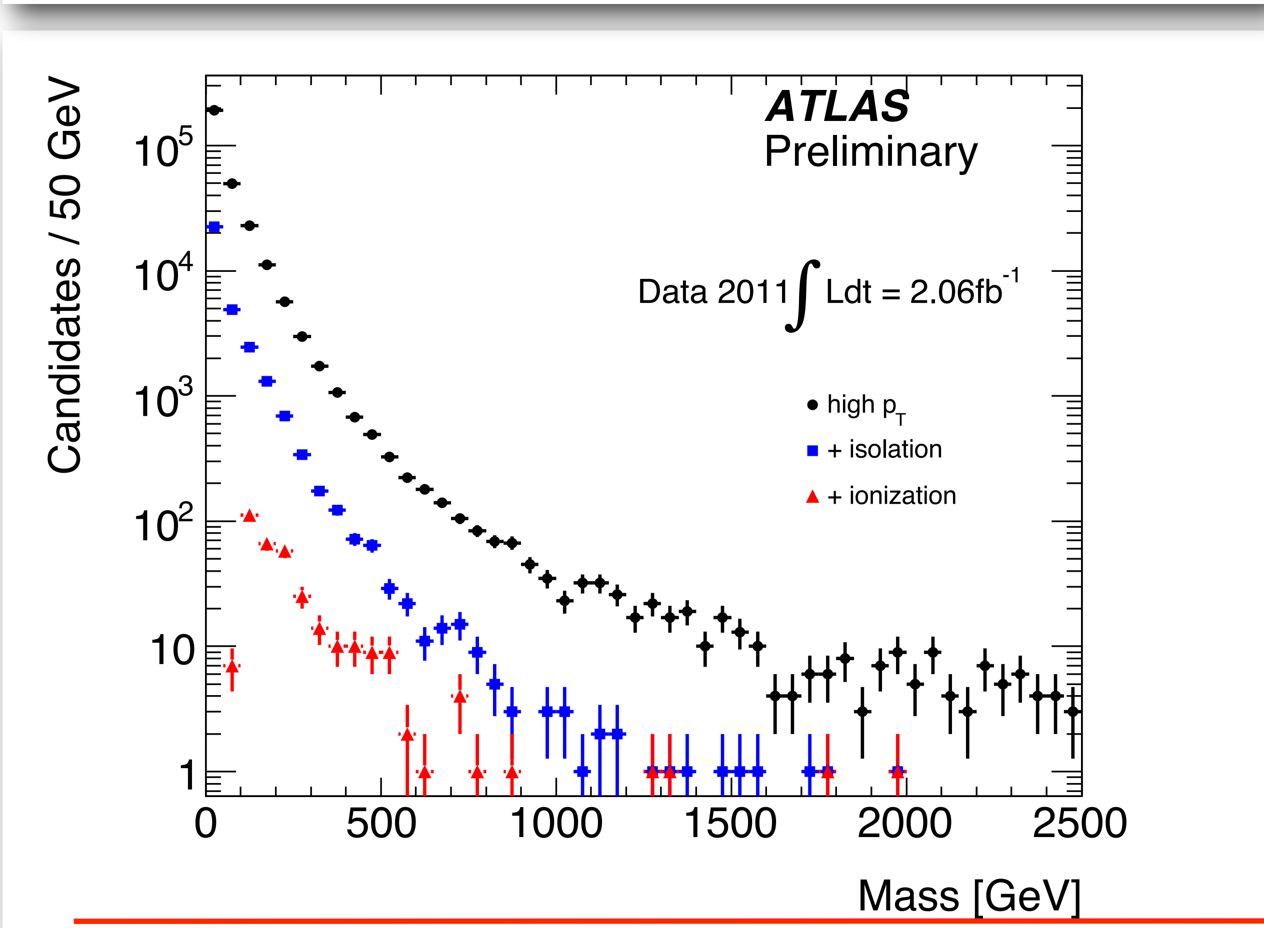
✓ Pixel+Calorimeter and Muon Spectrometer approaches produced results with 2010 data, and will give updates soon

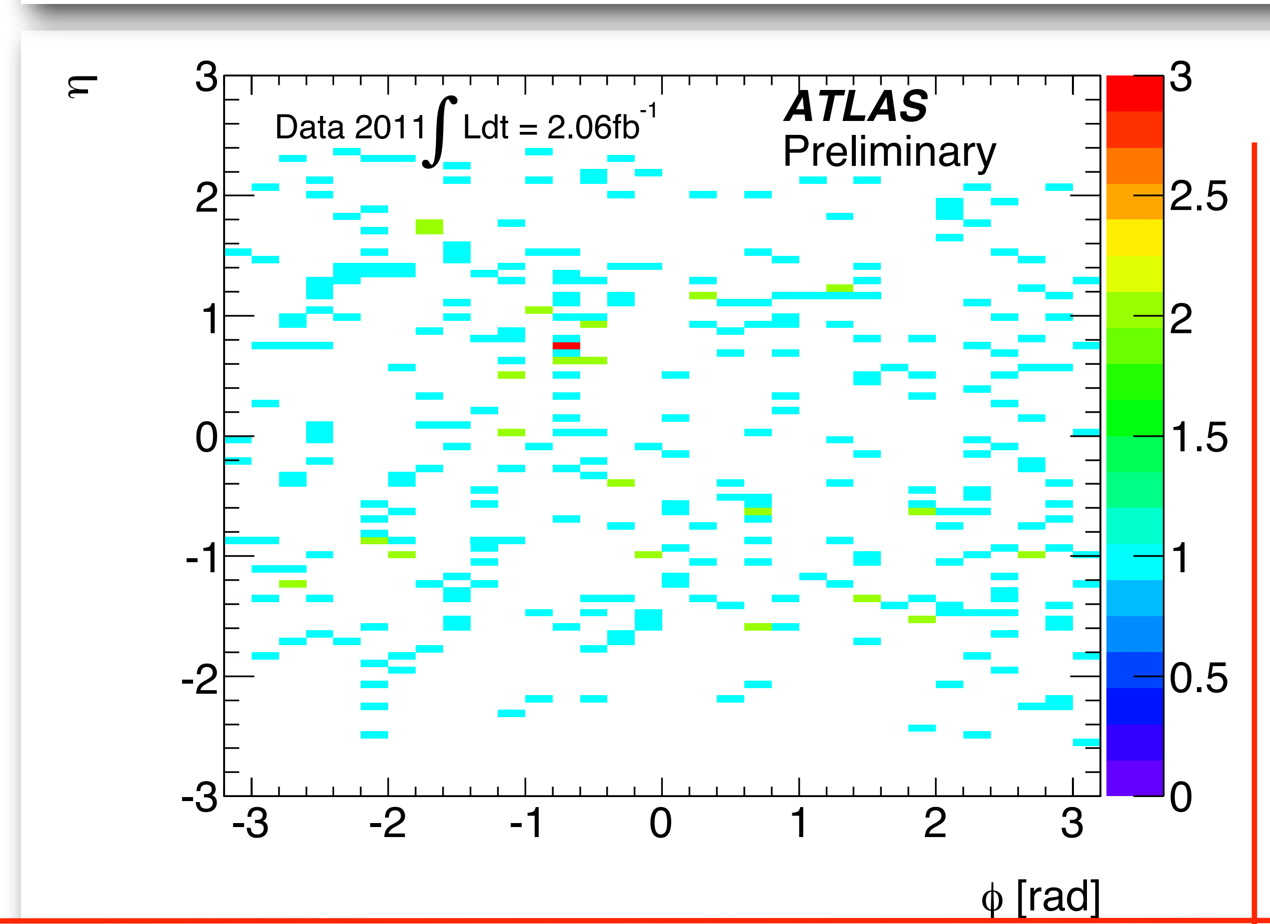
✓ Combination of all the approaches planned

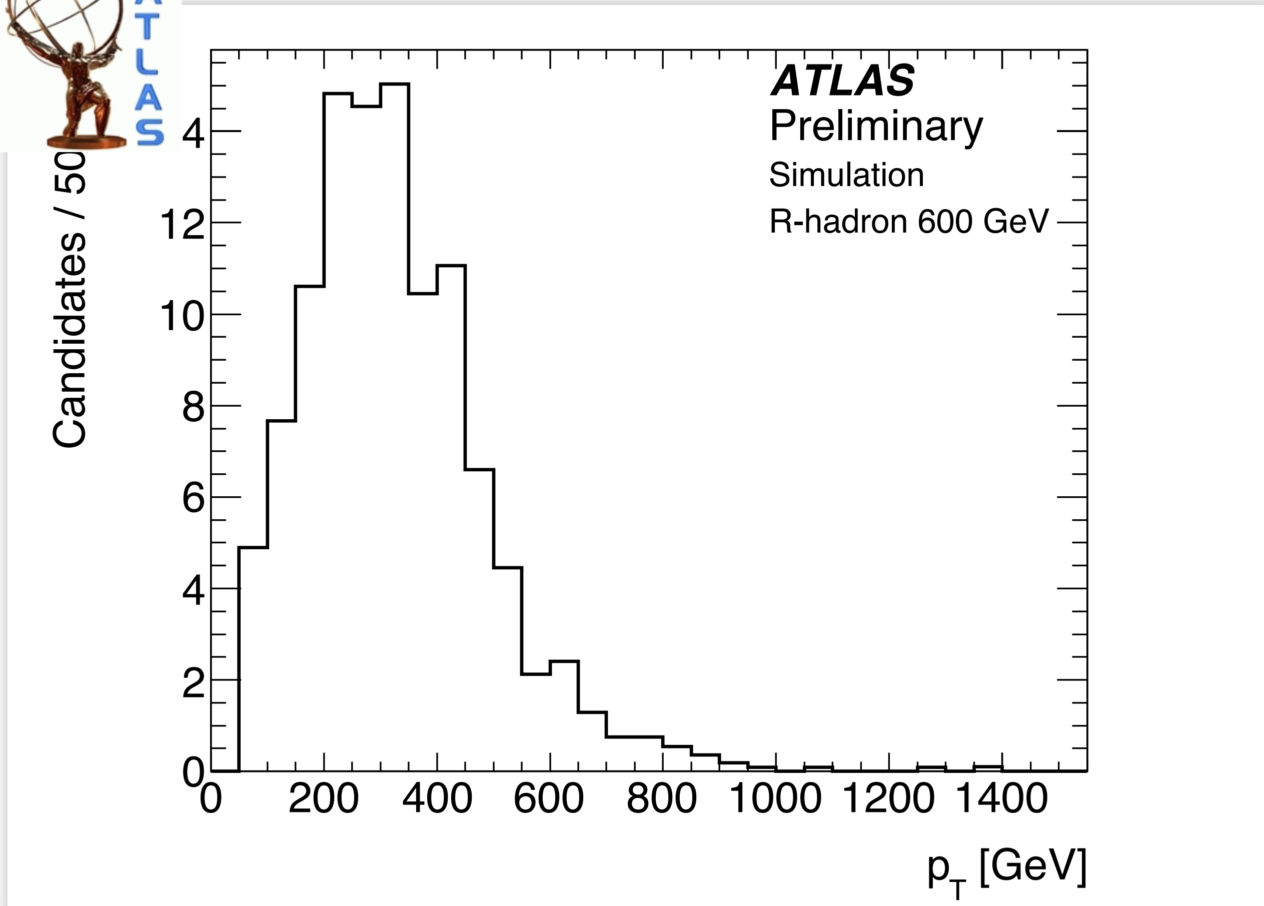
BACKUP

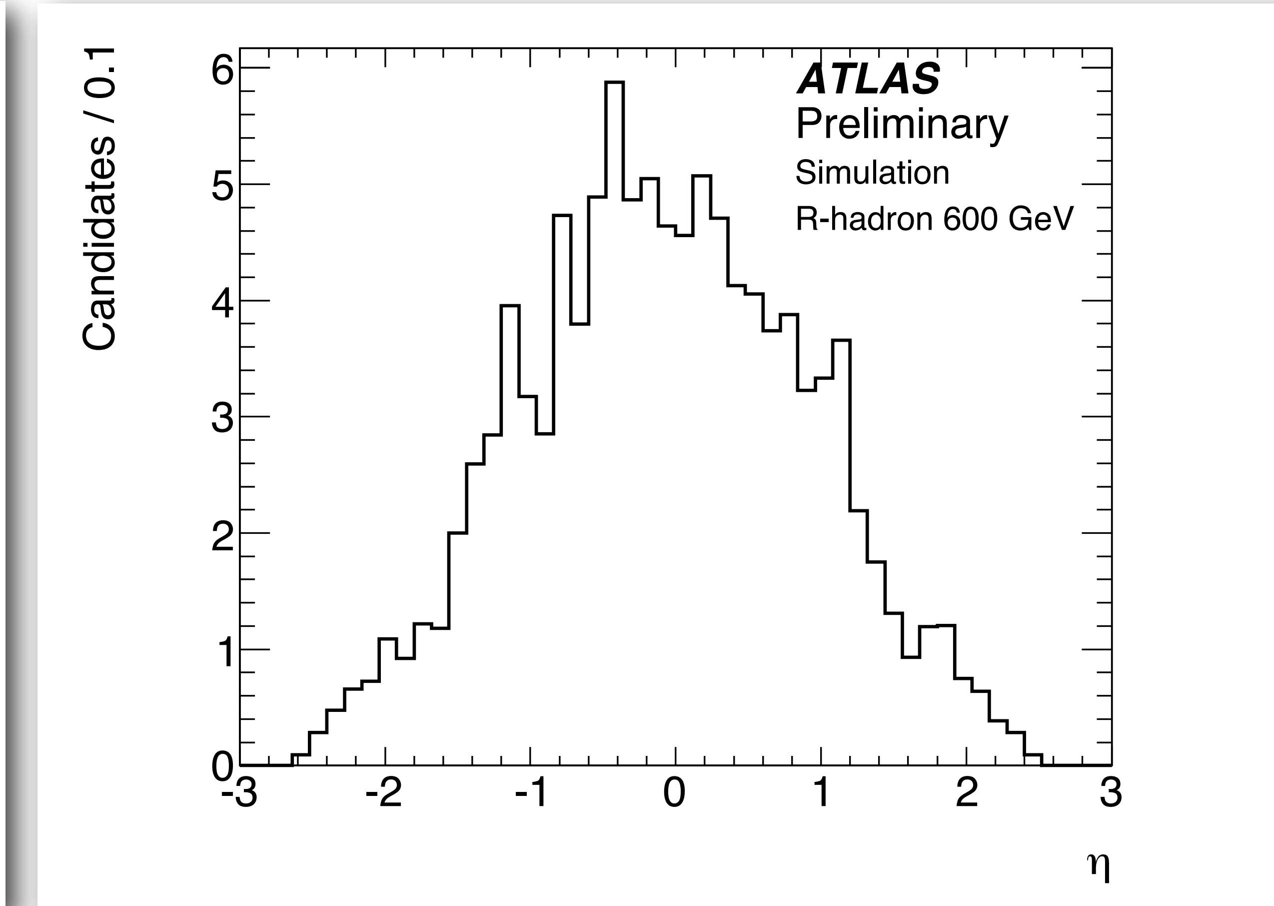

ATLAS
Preliminary
Data 2011 ∫Ldt = 2.06fb-1
high pT
+ isolation
+ ionization
Candidates / 50
pT [GeV]

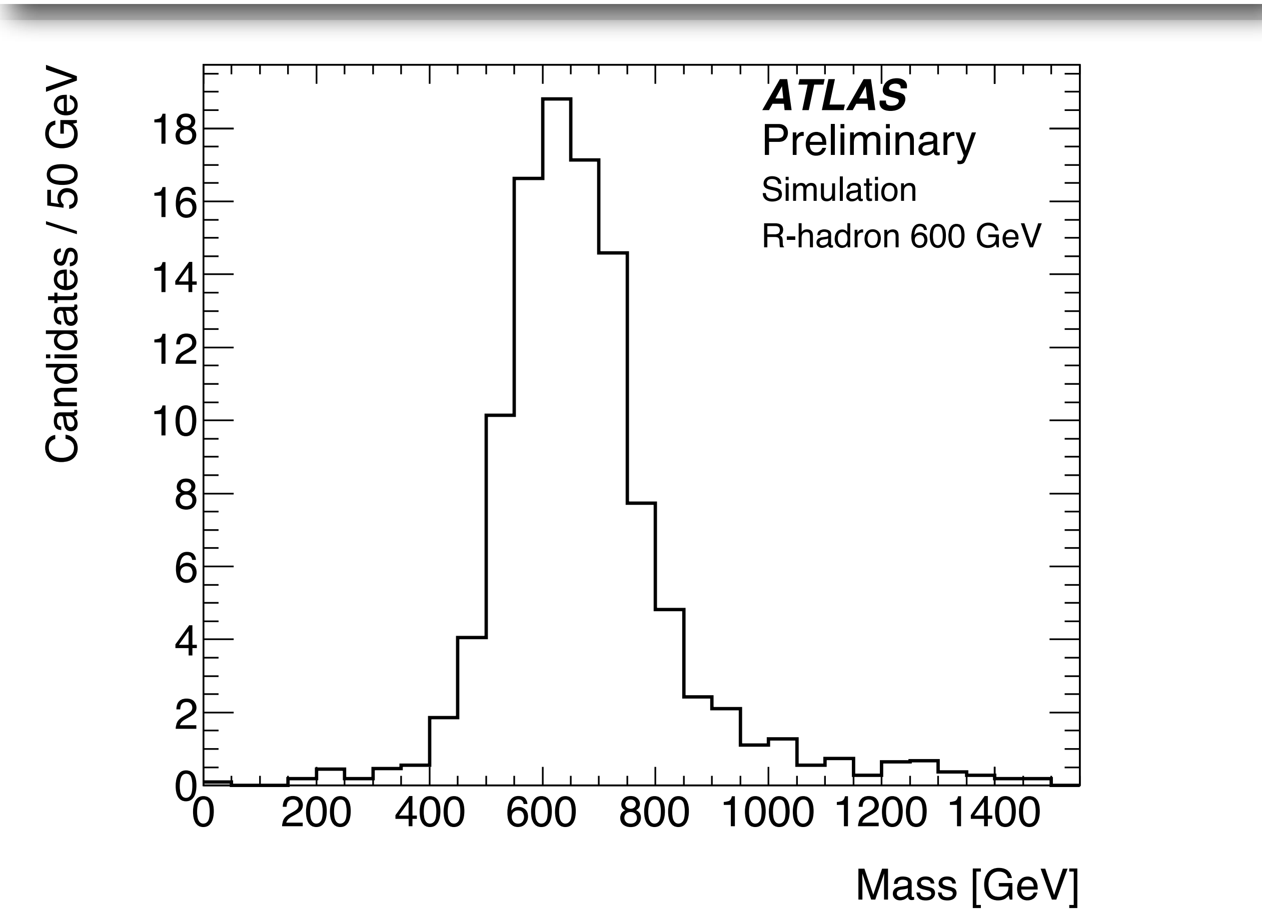

ATLAS
Preliminary
high pT
+ isolation
+ ionization
Data 2011 ∫Ldt = 2.06fb-1
Candidates / 0.1
η

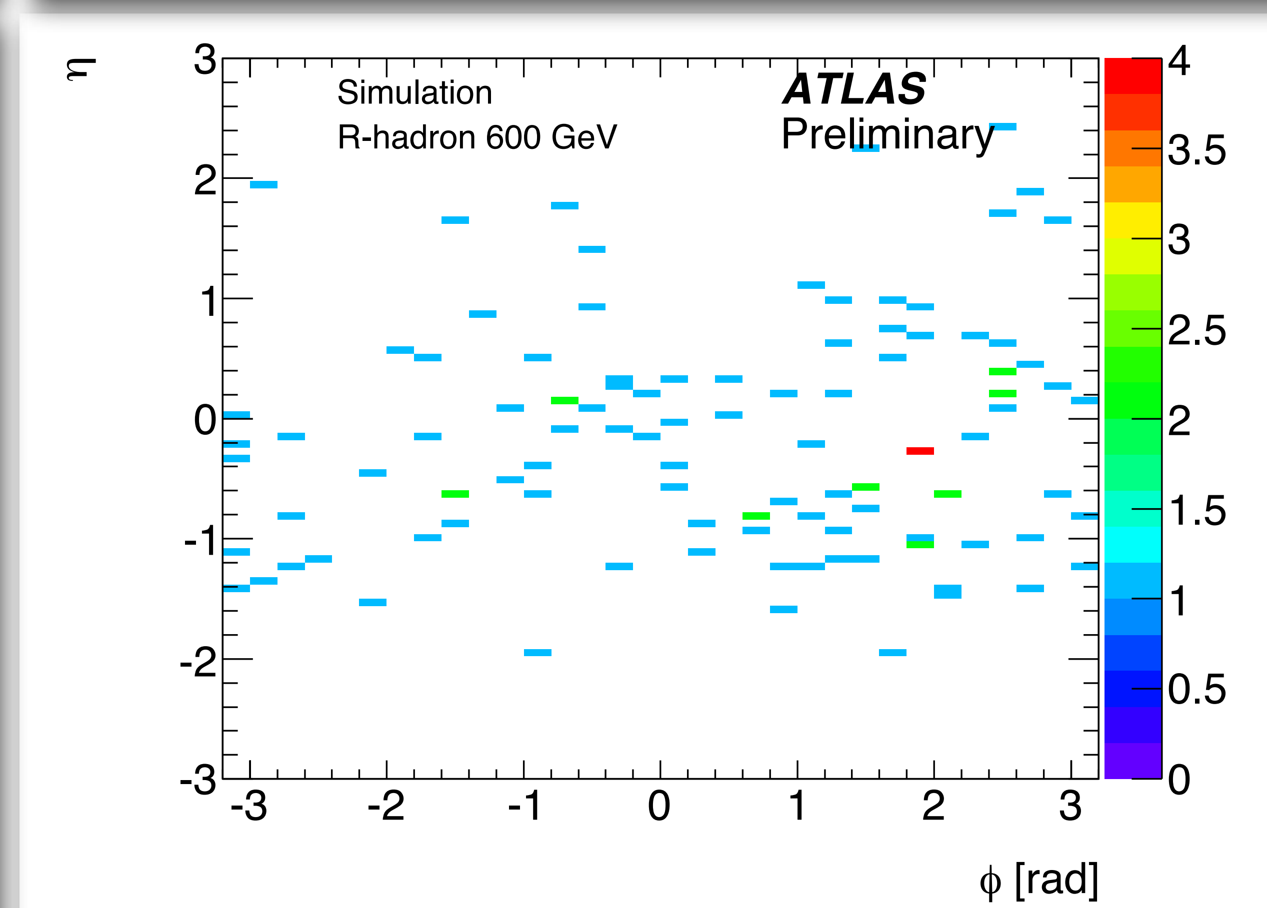

ATLAS
Preliminary
Data 2011 ∫Ldt = 2.06fb-1
high pT
+ isolation
+ ionization
Candidates / 50 GeV
Mass [GeV]


Data 2011 ∫Ldt = 2.06fb-1
ATLAS
Preliminary
η
ϕ [rad]


ATLAS
Preliminary
Simulation
R-hadron 600 GeV
Candidates / 50
0 2 4 6 8 10 12 4
0 200 400 600 800 1000 1200 1400
p_T [GeV]


ATLAS
Preliminary
Simulation
R-hadron 600 GeV
Candidates / 0.1
0 1 2 3 4 5 6
-3 -2 -1 0 1 2 3
η


ATLAS
Preliminary
Simulation
R-hadron 600 GeV
Candidates / 50 GeV
0 2 4 6 8 10 12 14 16 18
0 200 400 600 800 1000 1200 1400
Mass [GeV]


Simulation
R-hadron 600 GeV
ATLAS
Preliminary
η
-3 -2 -1 0 1 2 3
-3 -2 -1 0 1 2 3
φ [rad]
0 0.5 1 1.5 2 2.5 3 3.5 4

Mass measurement with the Pixel

ATLAS-CONF-2011-016 (2011)