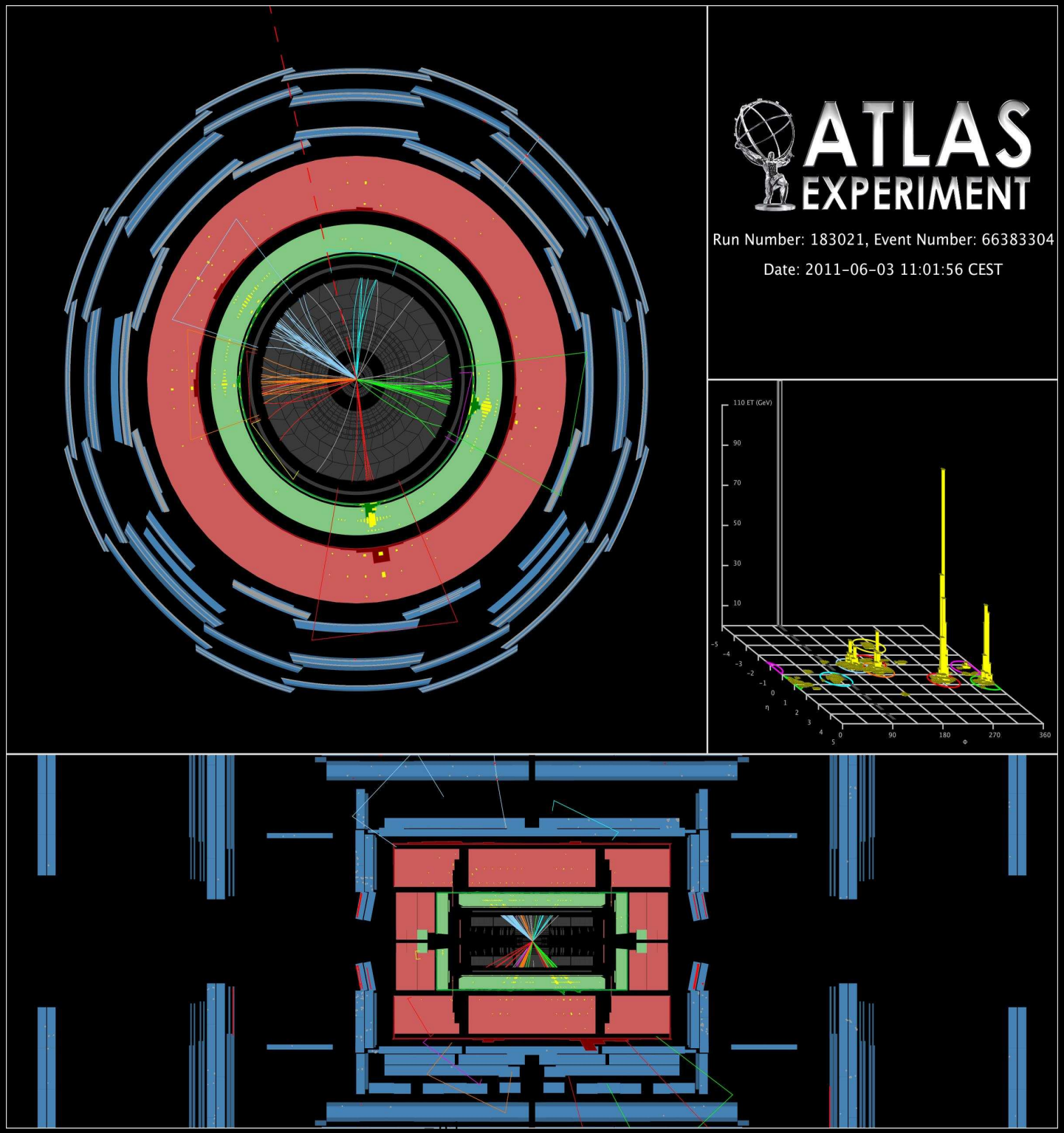
Searches for Squarks and Gluinos with ATLAS

Marc Hohlfeld
Universität Mainz

on behalf of the ATLAS Collaborations

PANIC 2011



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Outline

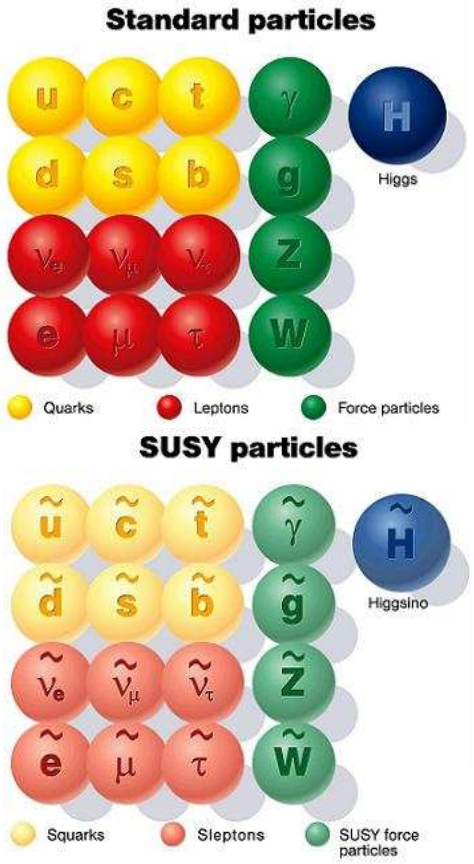
- Introduction
- Collider and detector
- Search for Supersymmetry
  - ▲ 0 lepton analysis
  - ▲ Analysis with b–jets
  - ▲ 1 lepton analysis
  - ▲ GMSB search
  - ▲ Search for R–hadrons
- Conclusion

Results presented today

$\int \mathcal{L} dt$ up to 1.04 fb^{-1}

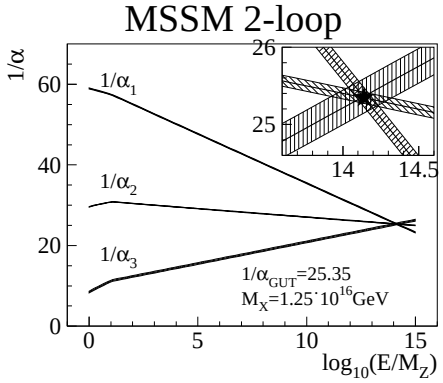
Going Beyond the Standard Model

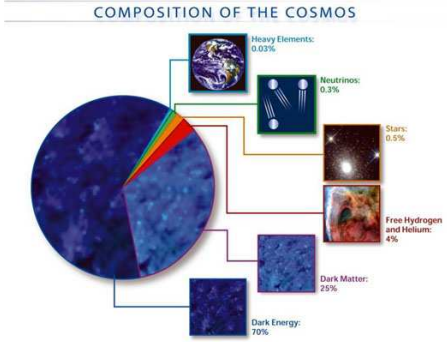
- The Standard Model is very successful...
  - ▲ ...but it cannot answer all questions and has some caveats
    - ⇒ Many ways and attempts to extend the Standard Model



- Supersymmetry
  - ▲ Extension of the Poincare group
    - ▶ Supersymmetric partner for every SM particle
    - ▶ Squarks, Gluinos, Charginos, Neutralinos,...

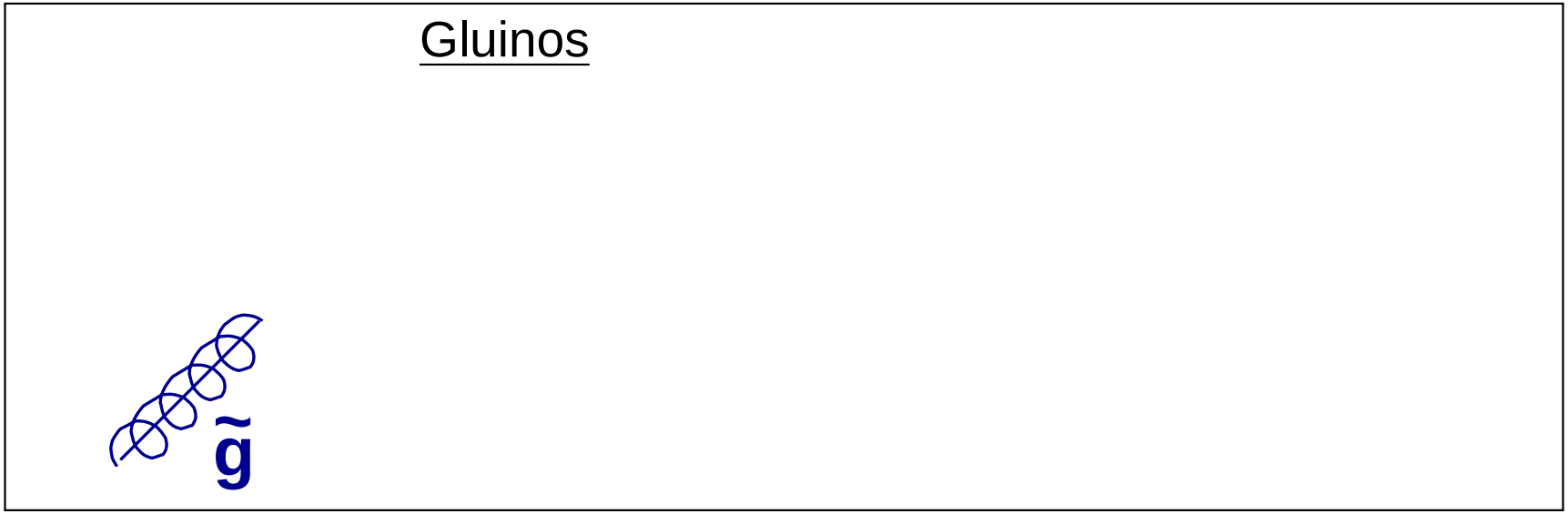
- Why Supersymmetry?
  - ▲ Cancellation of radiative corrections for the Higgs mass
  - ▲ Unification of the couplings
  - ▲ Provides a dark matter candidate





What Are We Looking For?

- Squark and Gluino production
  - ▲ Cross section basically determined by masses of squarks/gluinos
- Decay chains



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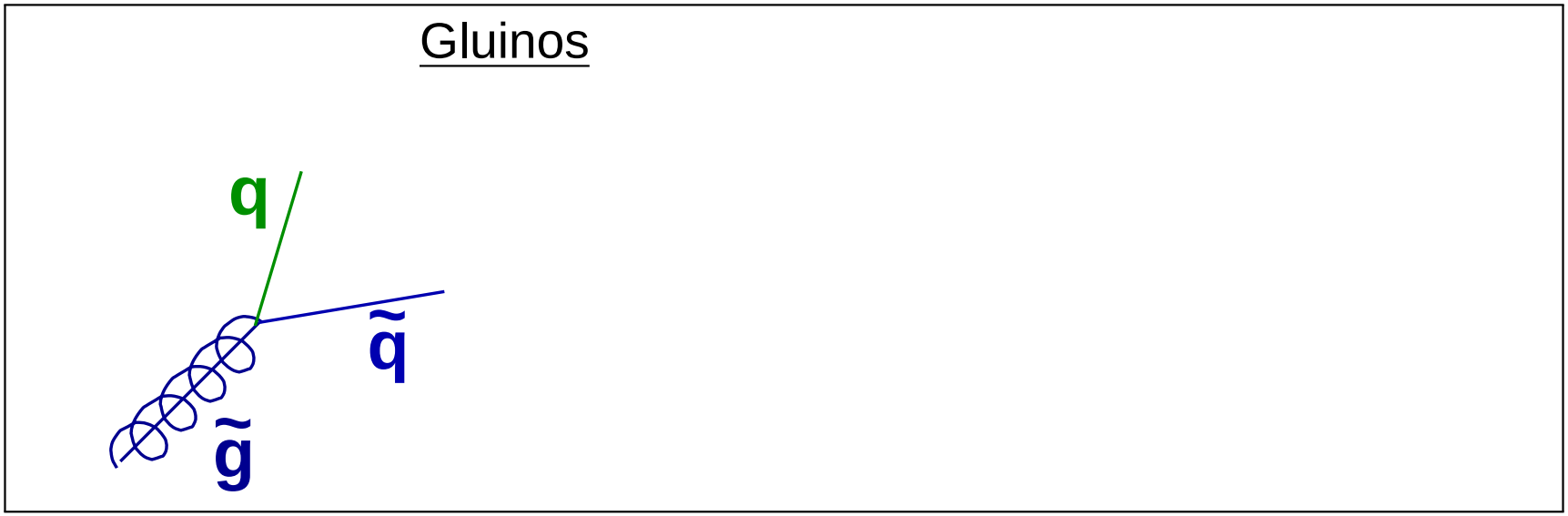

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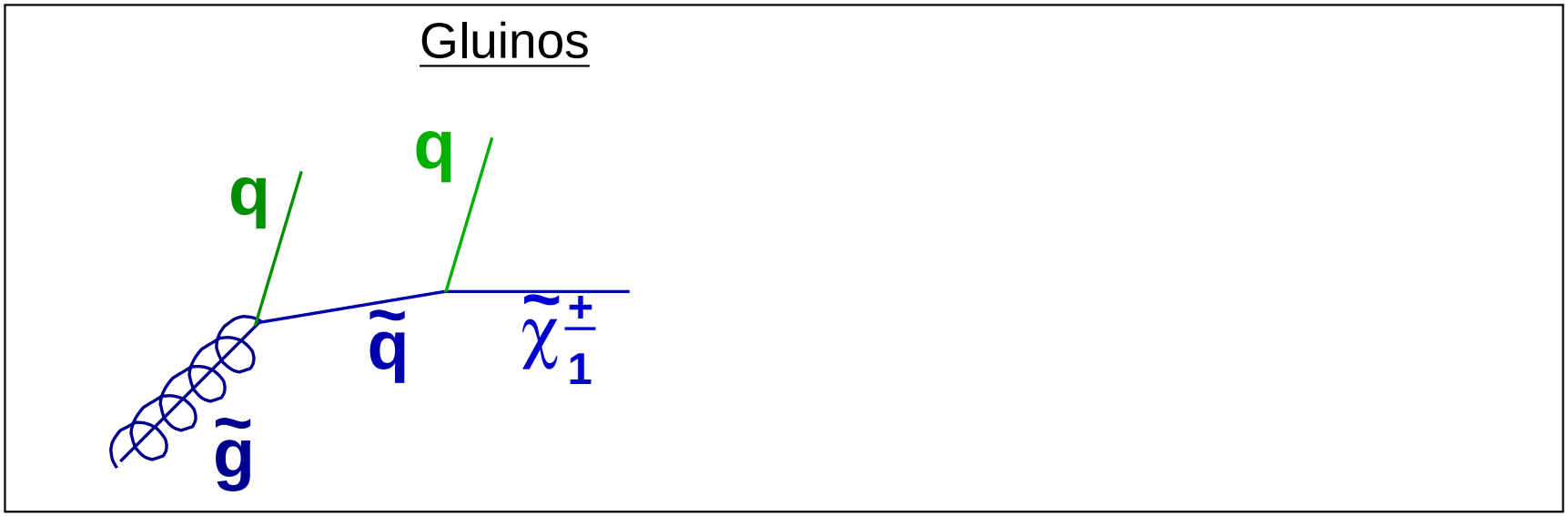

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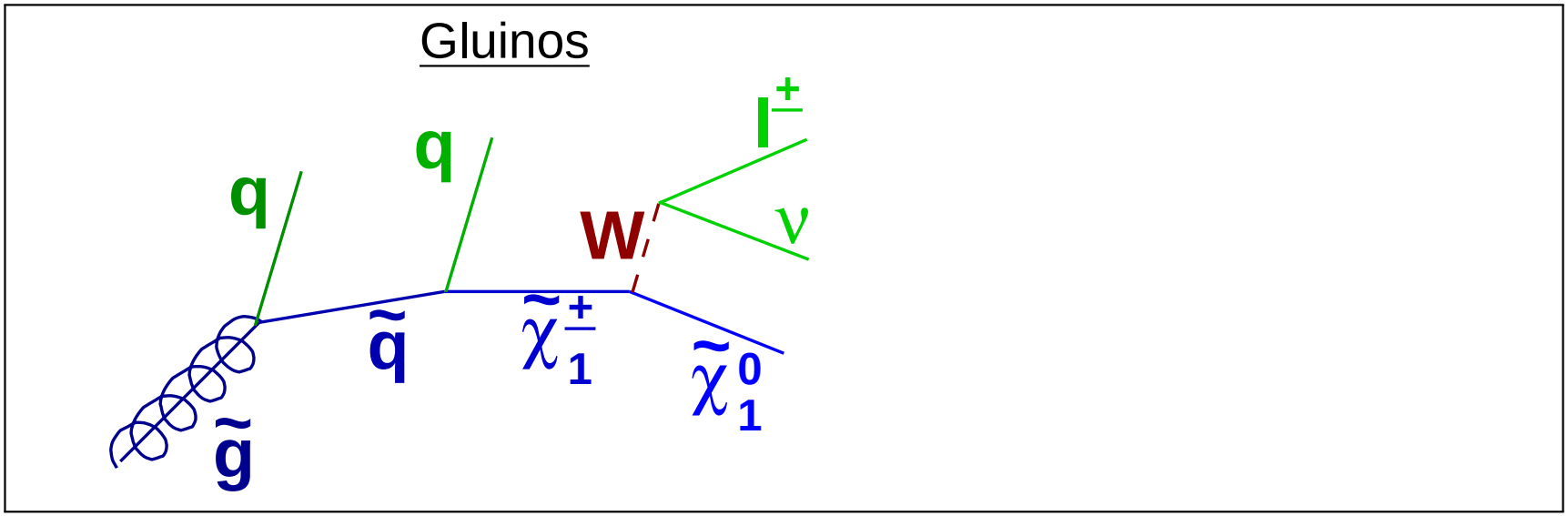

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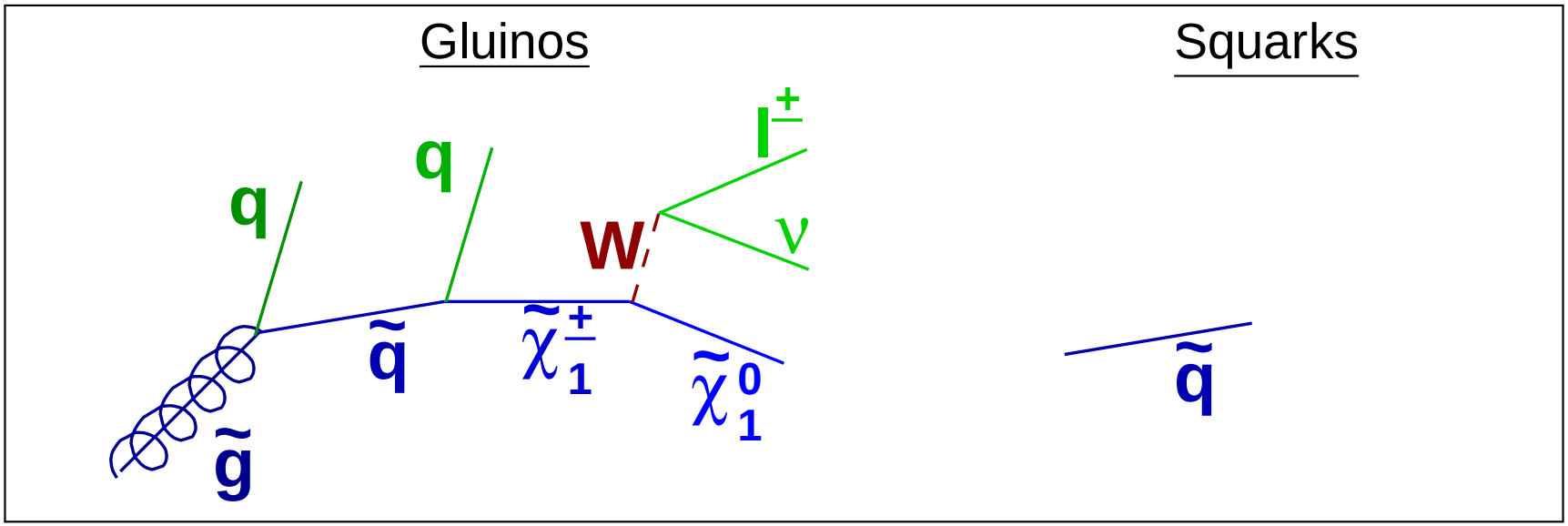

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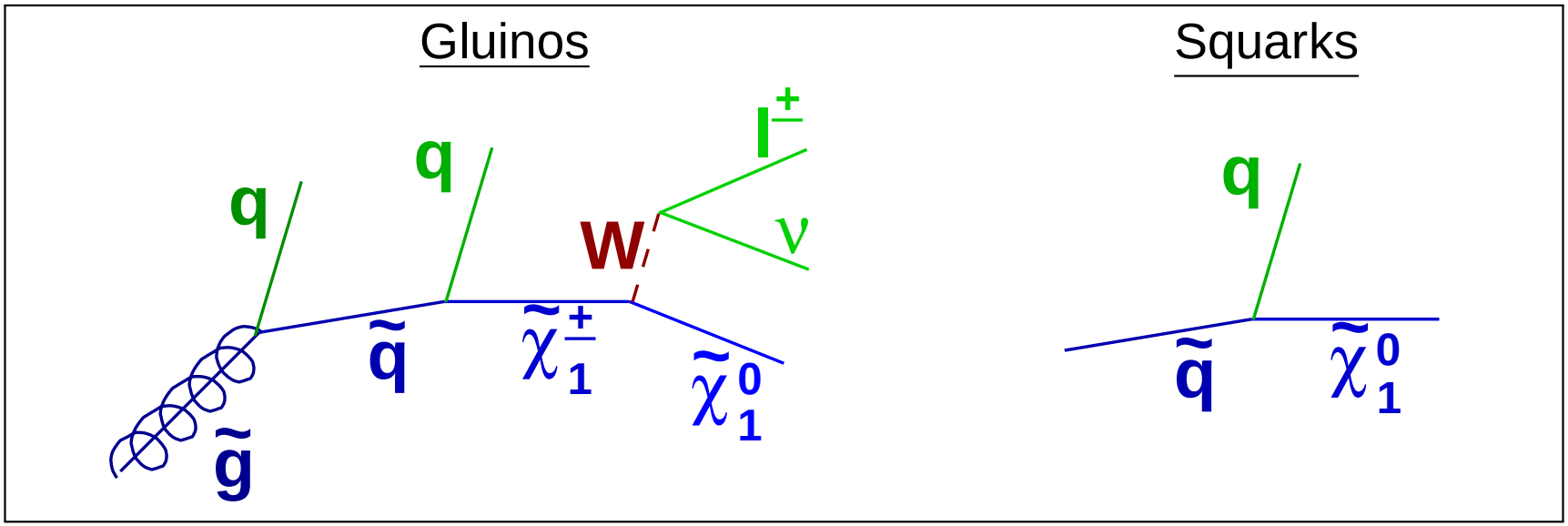

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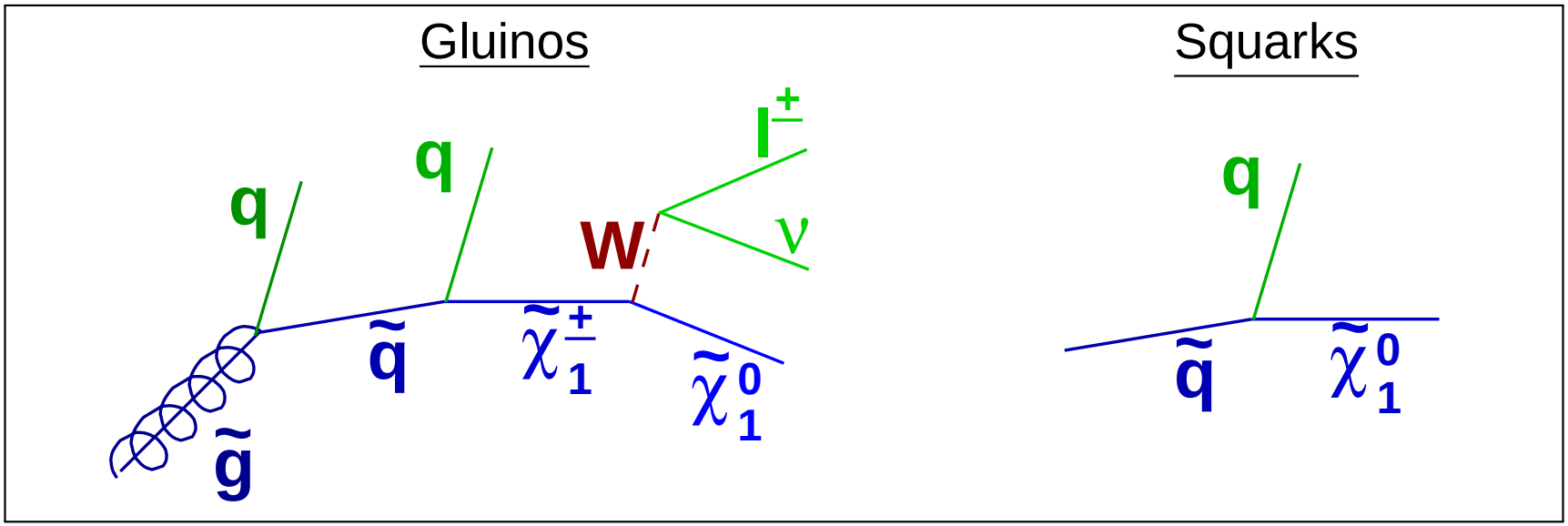
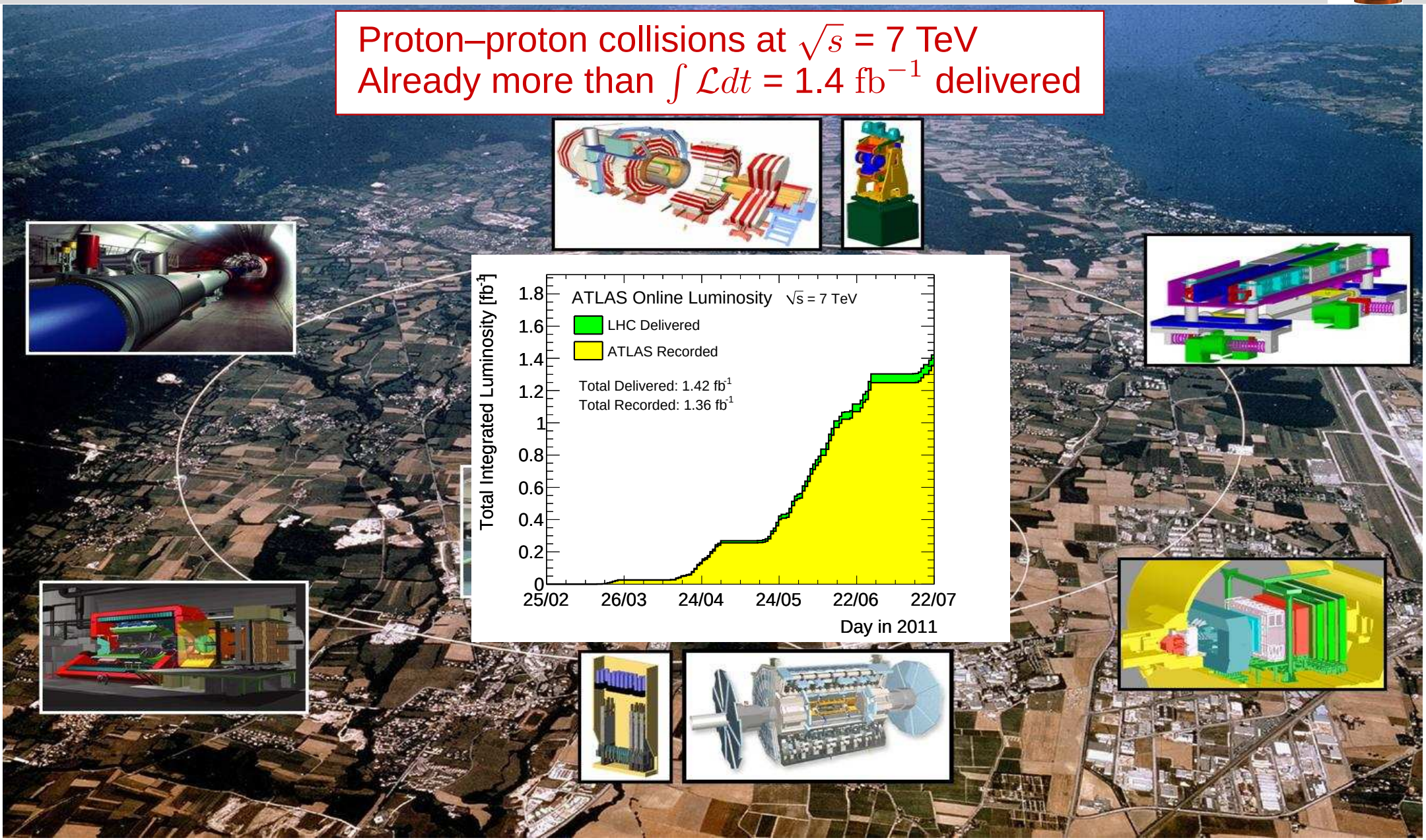


- Final state consists of
  - ▲ k leptons + n jets + missing transverse energy $\not{E}_T$ (k = 0–3, n = 2–4)
  - ▲ Dedicated analyses for third generation particles (b–jets, τ leptons)
- Searches in different final states considered here
  - ▲ GMSB models $\Rightarrow$ $\gamma\gamma$ + $\not{E}_T$ + X
  - ▲ R–hadrons $\Rightarrow$ Slow moving particles

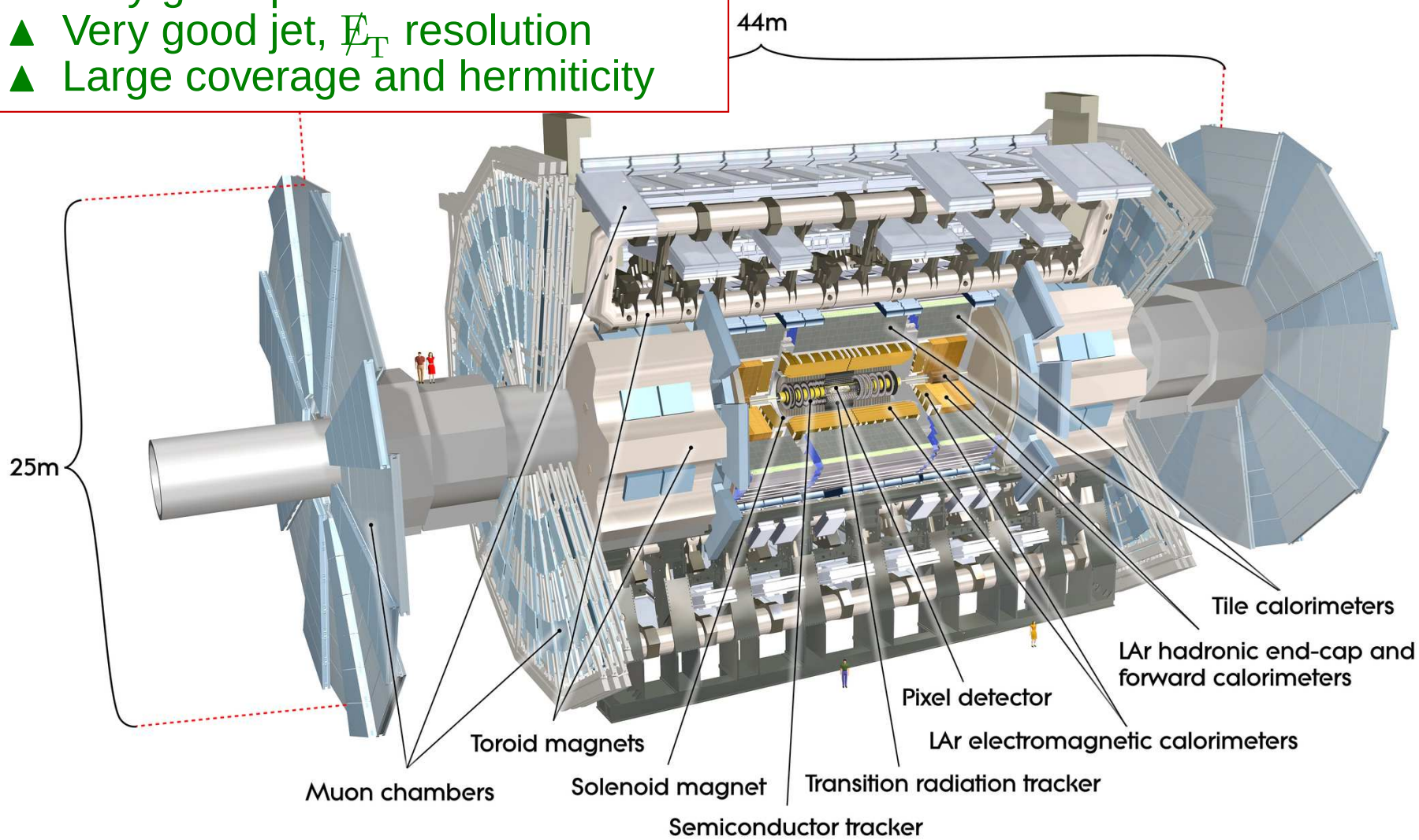
LHC

Proton–proton collisions at $\sqrt{s}$ = 7 TeV
Already more than $\int \mathcal{L} dt$ = 1.4 fb^{-1} delivered



ATLAS Detector

- Emphasis on
  - ▲ Very good particle identification
  - ▲ Very good jet, $\not{E}_T$ resolution
  - ▲ Large coverage and hermiticity



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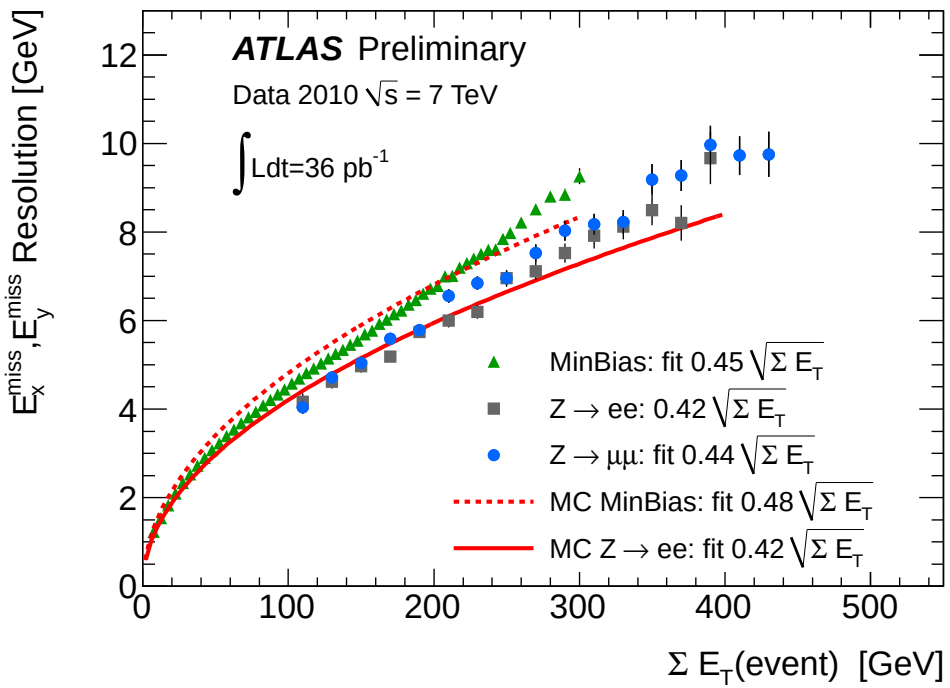
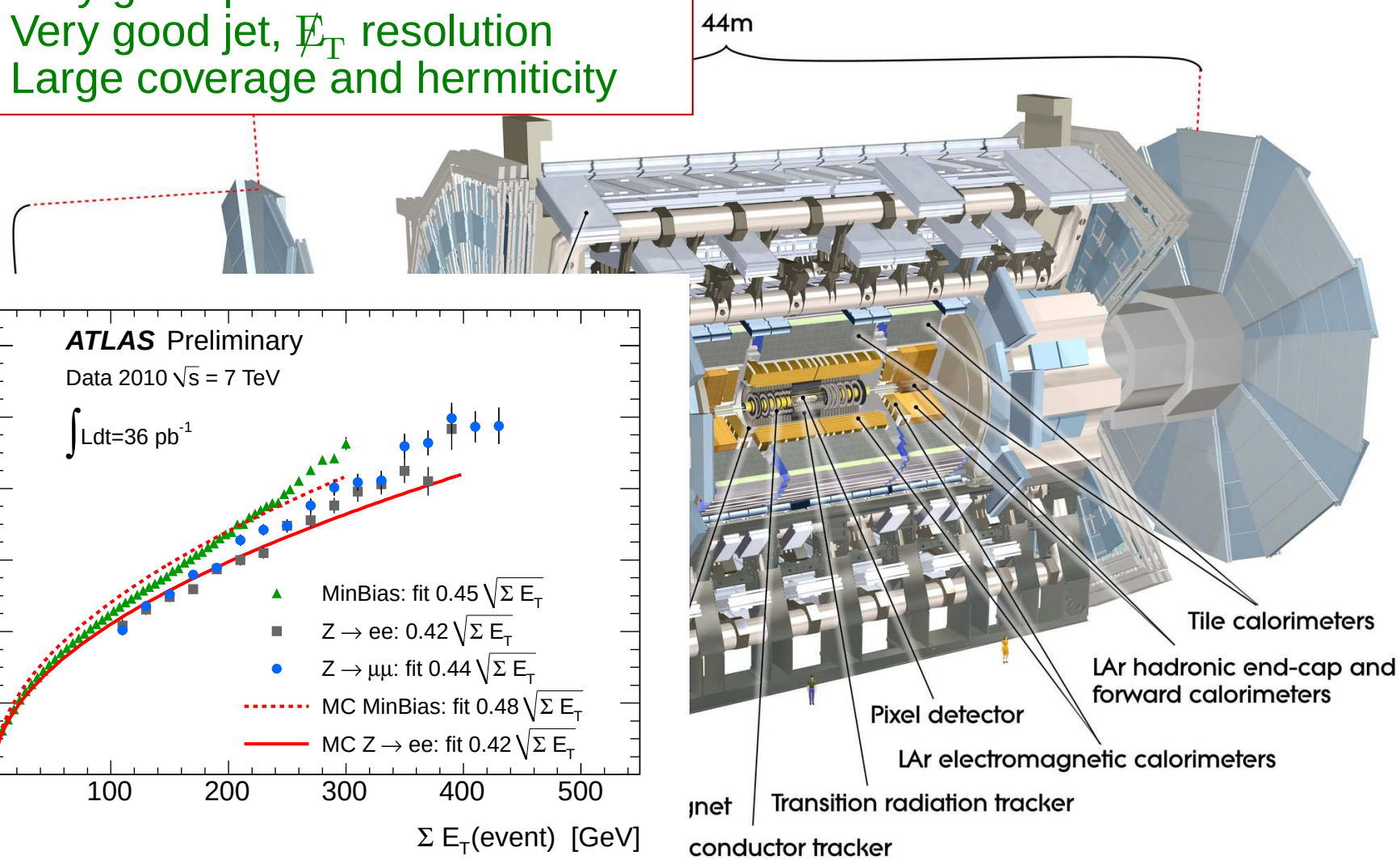




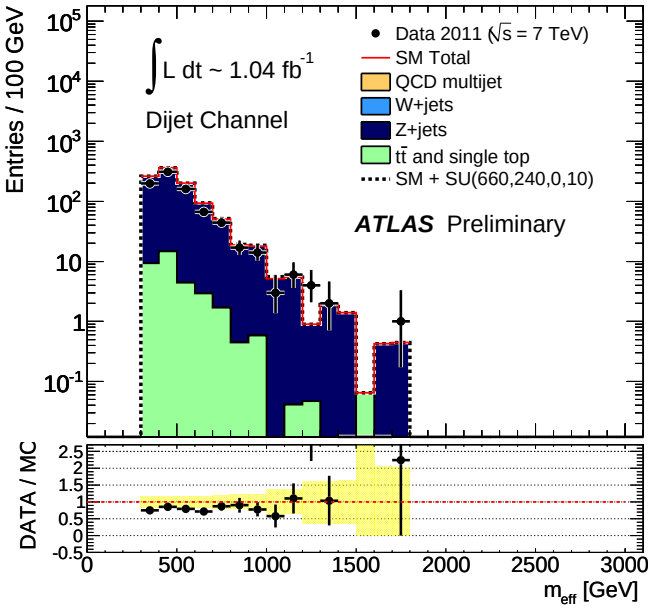
0 Lepton Channel

NEW

- 0 lepton channel is most sensitive one due to highest BR
  - Main backgrounds are Z$\rightarrow \nu\nu$+jets and W$\rightarrow \tau\nu$+jets
- Five signal regions (SR) to cover different decay topologies
  - $\tilde{q}\tilde{q} \rightarrow jj + \not{E}_T$: di-jet analysis
  - $\tilde{q}\tilde{g} \rightarrow jjj + \not{E}_T$: three jet selection
  - $\tilde{g}\tilde{g} \rightarrow jjjj + \not{E}_T$: four jet requirement
- Main discriminating variable is effective mass
  - $M_{eff} = \sum_{j=1}^{N_{jet}^{sel}} p_T^{jet_j} + \not{E}_T$
- Five control regions (CR) for every SR to estimate backgrounds
  - $Z \rightarrow \nu\nu$: Estimate from $\gamma + j$ and $Z \rightarrow ee/Z \rightarrow \mu\mu$
  - Multijets: Select events where jet and $\not{E}_T$ are aligned
  - $W \rightarrow \tau\nu$: Select $W \rightarrow e/\mu\nu$ ($\mathrm{M_T}$ cut) and anti b-tag
  - $t\bar{t}$: Same as W but with b-tag

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

$\Longrightarrow$



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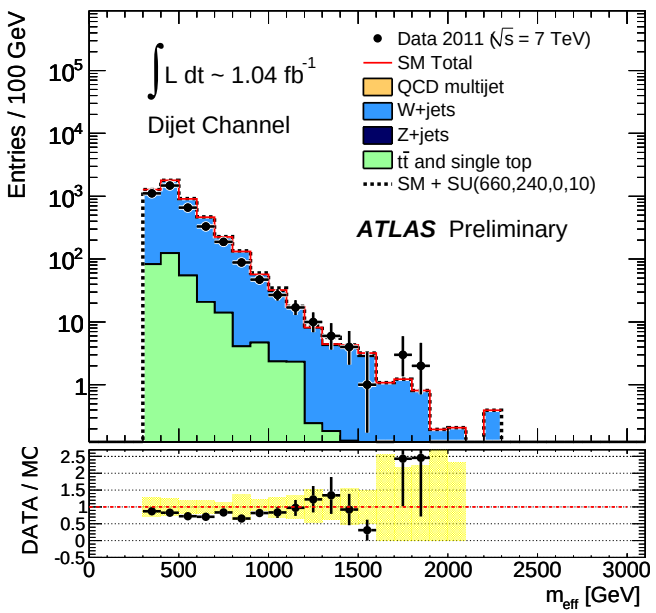

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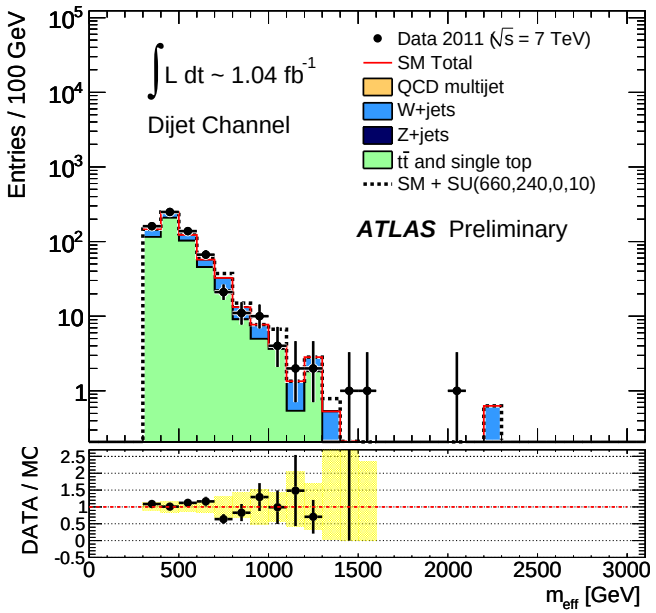


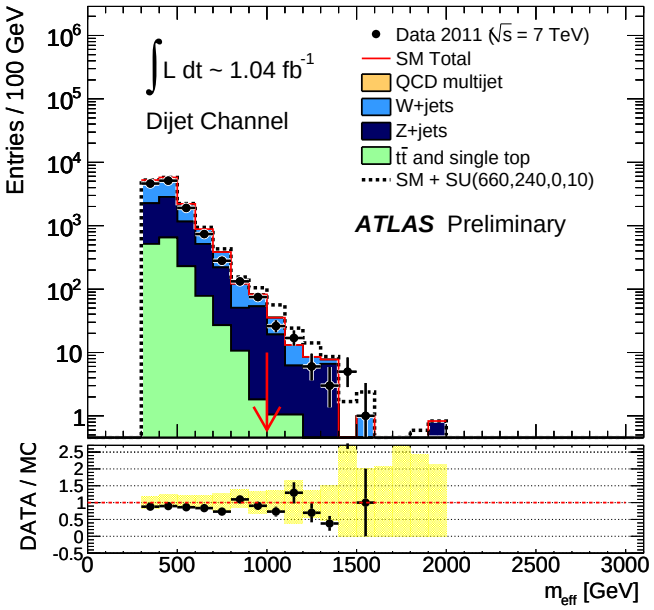
0 Lepton Channel

NEW

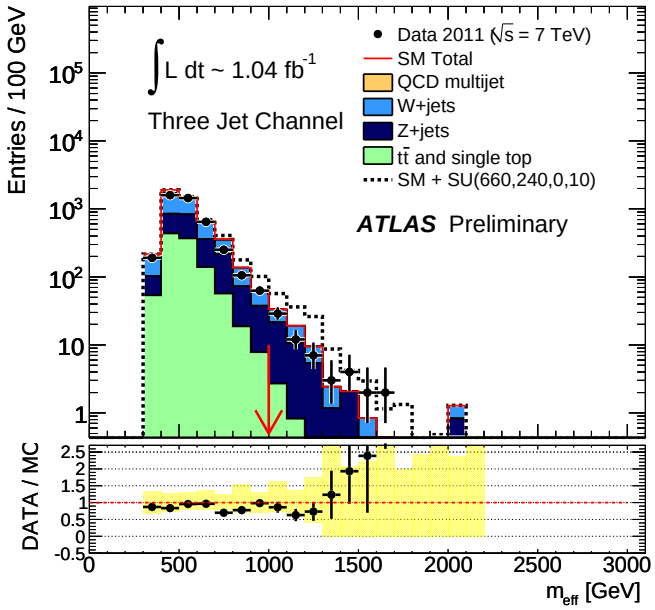
- Expected and observed events for $\int \mathcal{L}dt$ = 1.04 fb^{-1}

	Signal Region				
	$\geq$ 2 jets	$\geq$ 3 jets	$\geq$ 4 jets	$\geq$ 4 jets	High mass
dominant bkg	$Z/\gamma + j$	$Z/\gamma + j, W + j$	$t\bar{t}, W + j$	$Z/\gamma + j, W + j$	$t\bar{t}$
Total bkg	62.3±4.3±9.2	55.0±3.8±7.3	984±39±145	33.4±2.9±6.3	13.2±1.9±2.6
Data	58	59	1118	40	18

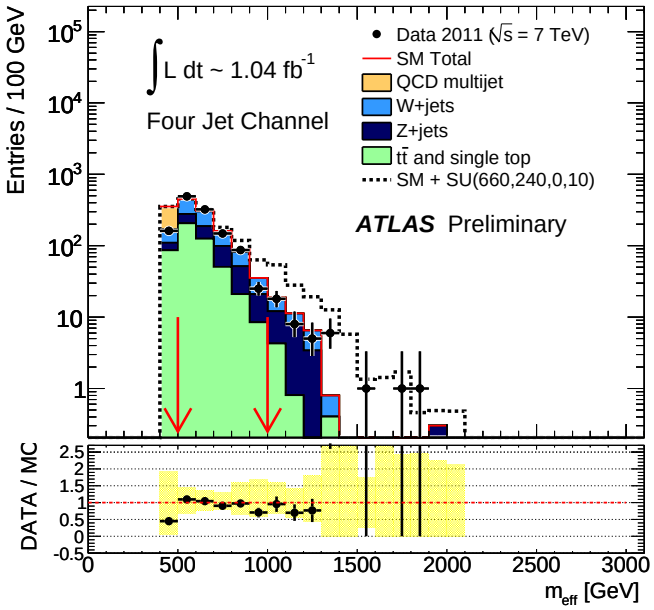
$\geq$ 2 jets



$\geq$ 3 jets



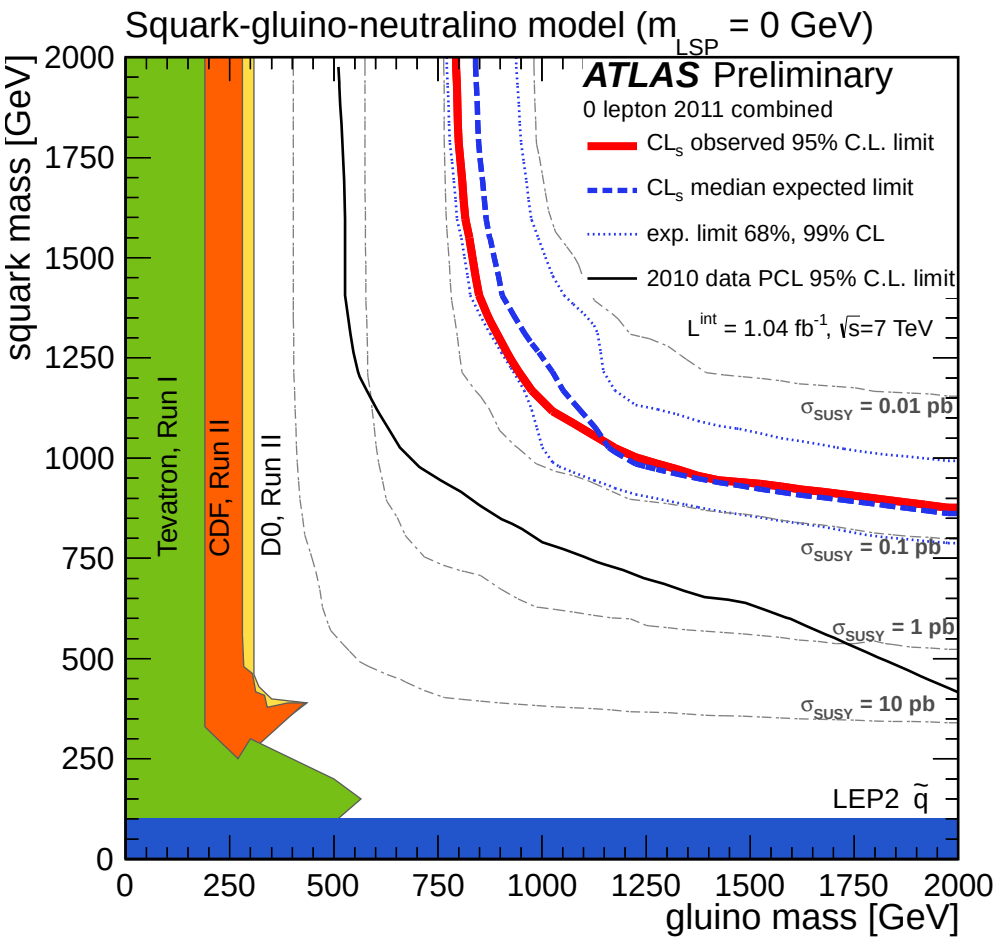
$\geq$ 4 jets



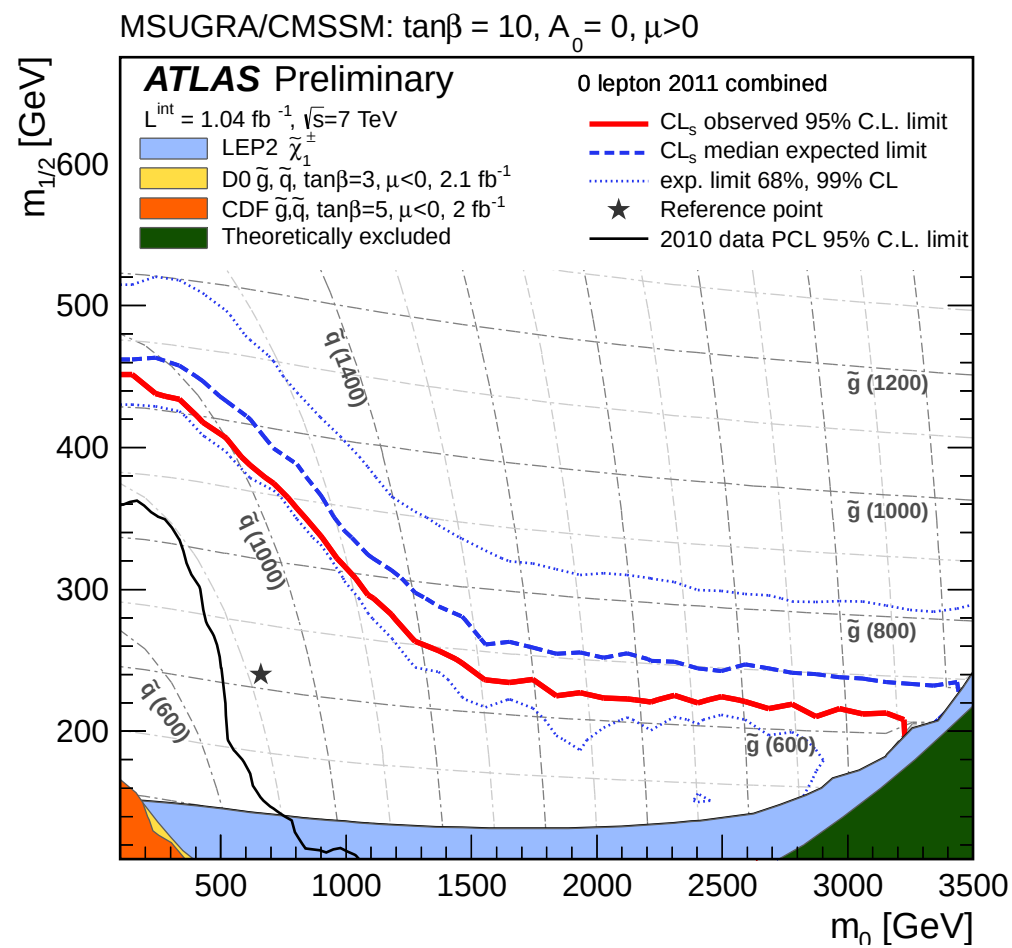
0 Lepton Channel

NEW

Squark Gluino model ($m_{\tilde{\chi}_1^0}$ = 0, $m_{non\ \tilde{q},\tilde{g}}$ = 5 TeV)



mSUGRA ($\tan\beta$ = 10)



- Limits on non SM cross section from 5 SR: $\sigma \cdot \mathcal{A} \cdot \varepsilon <$ 24, 30, 477, 32 and 17 fb
- Limits on masses: $m_{\tilde{q}} >$ 800 GeV, $m_{\tilde{g}} >$ 850 GeV
  $m_{\tilde{q}/\tilde{g}} >$ 1075 GeV for $m_{\tilde{q}} = m_{\tilde{g}}$

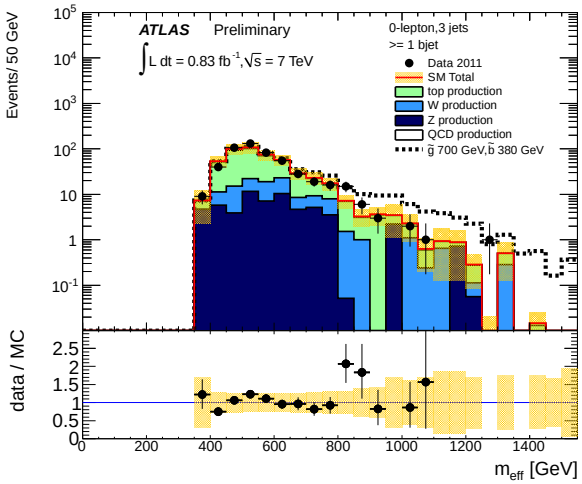
B–Jets Channel (0 Leptons)

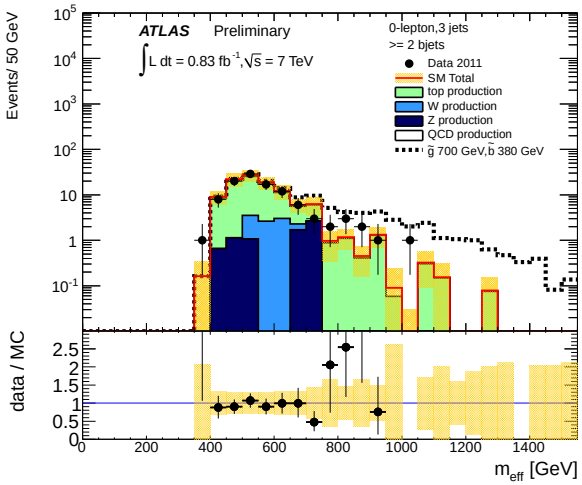
NEW

- Mixing leads to very light $\tilde{t}_1$ and $\tilde{b}_1$ mass eigenstates
  - ▲ Increased production $\Rightarrow$ b–jets in final state
- Require $\geq$ 1 b–jet among the selected jets
  - ▲ Main backgrounds are $t\bar{t}$ and W+jets
- Constrain $t\bar{t}$ and W background in CR
  - ▲ Similar procedure as in 0/1 lepton analysis
- Define four signal regions
  - ▲ Based on number of b–tags (1 or 2) and M_{eff} requirement ($>$ 500/700 GeV)

b–tags	1	1	2	2
M_{eff} (GeV)	500	700	500	700
dominant bkg	$t\bar{t}$	$t\bar{t}$, W+jets	$t\bar{t}$	$t\bar{t}$, W+jets
Total bkg	356^{+103}_{-92}	70^{+24}_{-22}	79^{+28}_{-25}	$13.0^{+5.6}_{-5.2}$
Data	361	63	76	12

$\int \mathcal{L}dt$ = 833 pb^{-1}



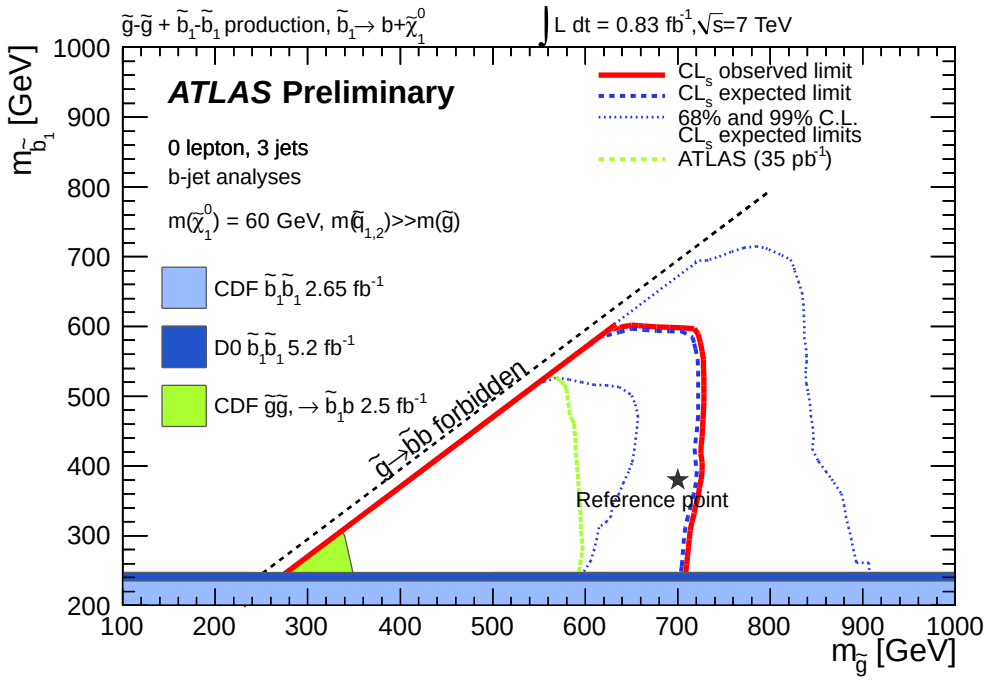


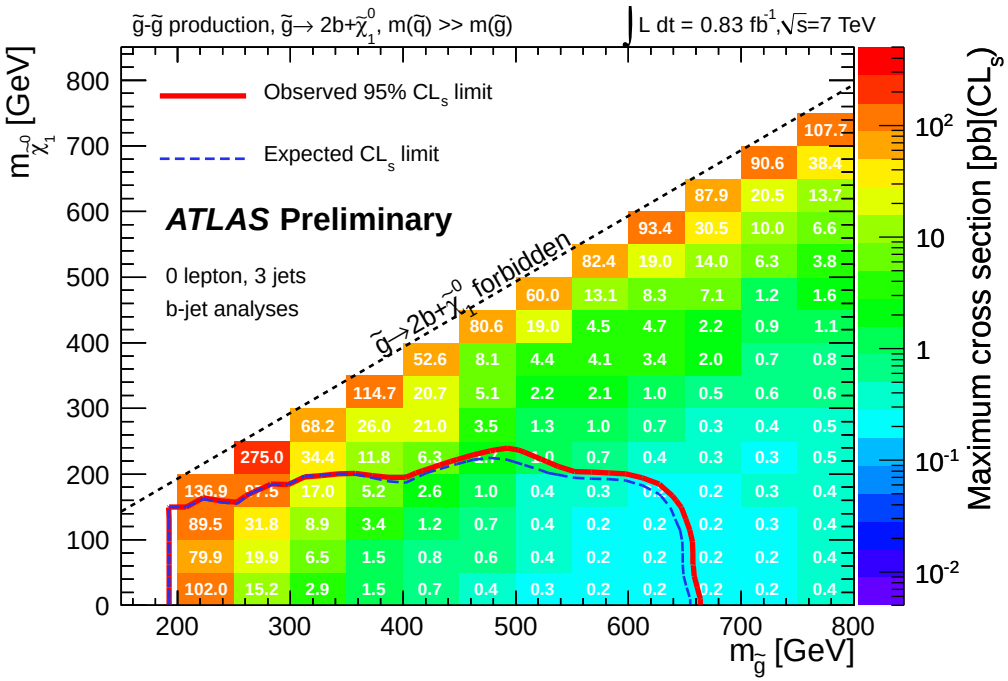
B–Jets Channel (0 Leptons)

NEW

Exclusive $\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0$ decays

No direct $\tilde{b}$ production





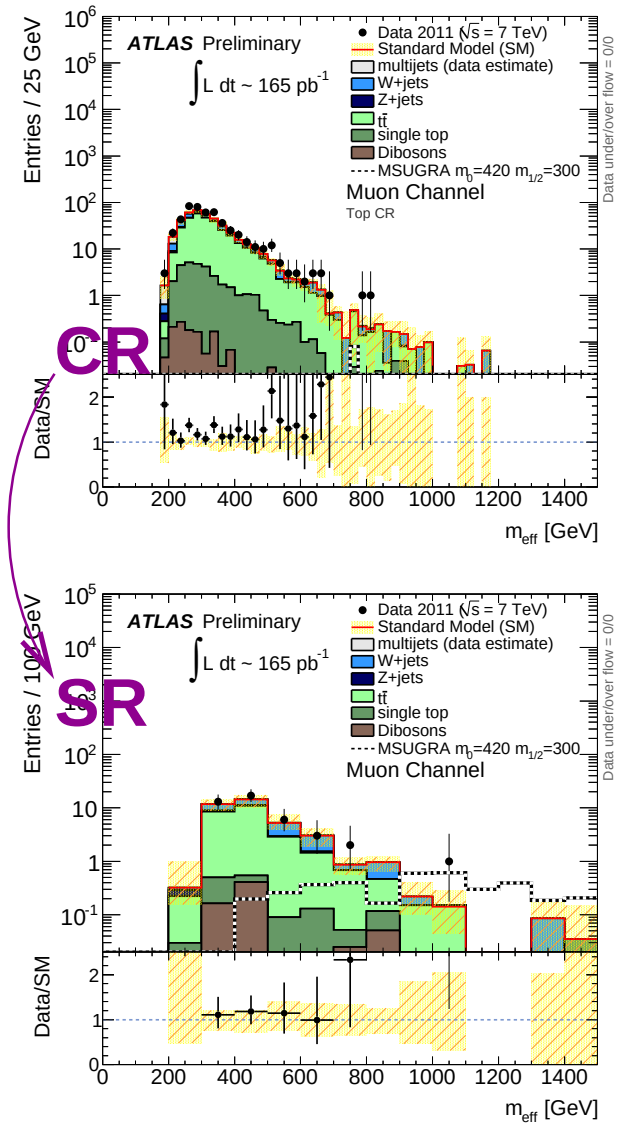
- Mass limit $m_{\tilde{\chi}_1^0} > 280$ GeV (for $m_{\tilde{g}} < 680$ GeV and $m_{\tilde{g}} - m_{\tilde{\chi}_1^0} > 100$ GeV)
- Limits in SO(10) models
  - ▲ $m_{\tilde{g}} > 570$ GeV D–term splitting model
  - ▲ $m_{\tilde{g}} > 450$ GeV Higgs splitting model

1 Lepton Channel

$\int \mathcal{L}dt$ = 165 pb^{-1}

- Require exactly one lepton + $\geq$ 3 jets + $\not{E}_{\mathrm{T}}$
  - ▲ Main backgrounds are $t\bar{t}$ and W$\rightarrow \ell\nu$+jets
- Main cuts for background suppression
  - ▲ $m_T = \sqrt{2 \cdot p_T^{\ell} \cdot \not{E}_{\mathrm{T}} \cdot (1 - \cos\Delta\phi(\ell, \not{E}_{\mathrm{T}}))} > 100$ GeV
  - ▲ $M_{eff} = p_T^{\ell} + \sum_{j=1}^{N_{jet}^{sel}} p_T^{jet_j} + \not{E}_{\mathrm{T}} > 500$ GeV
  - ▲ $\not{E}_{\mathrm{T}}$ / $M_{eff} > 0.25$
- Constrain $t\bar{t}$ and W background in CR
  - ▲ 30 GeV $< \not{E}_{\mathrm{T}} <$ 80 GeV, 40 GeV $< m_T <$ 80 GeV

Muon channel	Signal region	Top region	W region
Data	12	504	1650
Fitted $t\bar{t}$	7.2 ± 2.7 (5.7)	416 ± 29 (327)	247 ± 17 (195)
Fitted W/Z	5.0 ± 2.6 (5.0)	66 ± 16 (66)	1335 ± 48 (1336)
Fitted QCD	$0.00^{+0.13}_{-0.00}$	22.8 ± 6.1	68 ± 16
Fitted sum	12.2 ± 3.8	504 ± 22	1650 ± 41



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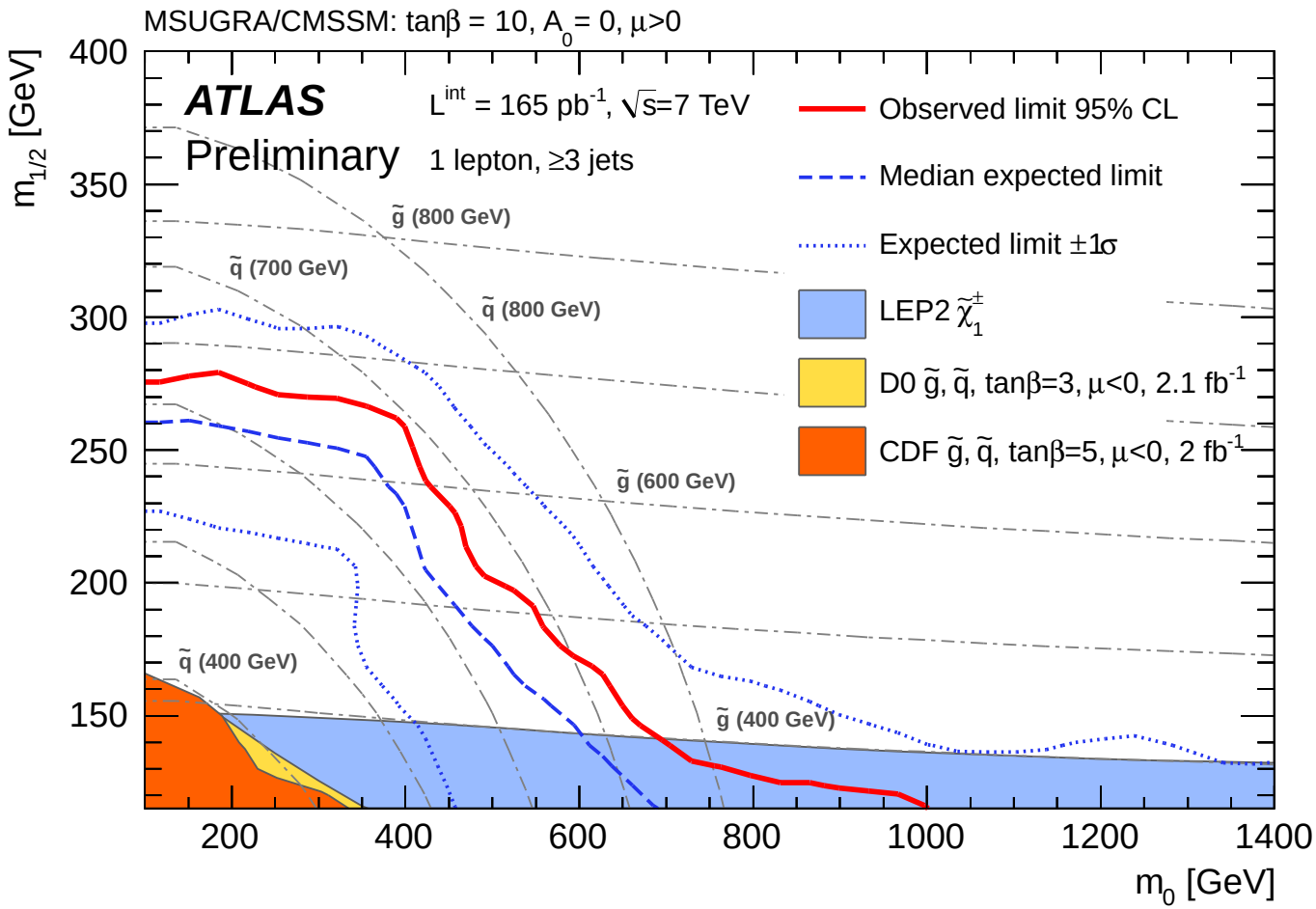


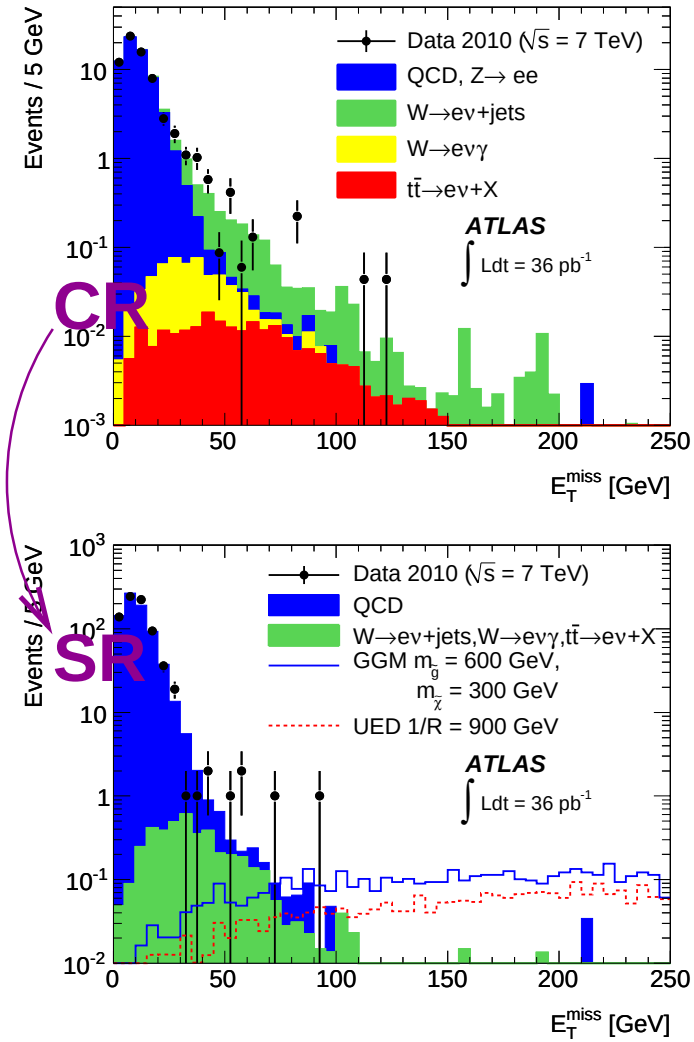
	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$ [fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_B	$p(s=0)$
Electron channel	41	6.8	$10.6^{+6.6}_{-4.7}$	0.24	0.77
Muon channel	53	8.8	$8.8^{+5.7}_{-3.8}$	0.50	0.51

$\gamma\gamma$ + $\not{E}_T$ (GMSB)

$\int \mathcal{L}dt$ = 36 pb^{-1}

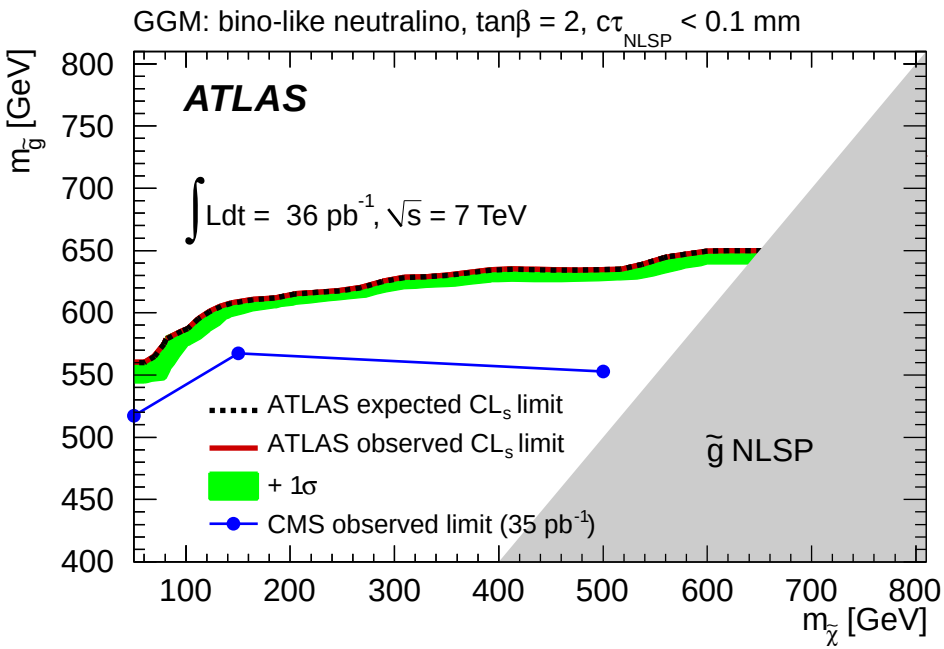
- In GMSB the NLSP decays mostly to $\gamma + \tilde{G}$
  - ▲ Final state consists of $\gamma\gamma$ + $\not{E}_T$ + X
  - ▲ Main backgrounds are QCD ($\gamma\gamma$, γj, jj) events
    - ▶ $\gamma\gamma$ modelled with $Z \to ee$+0 jet events
    - ▶ For γj use events with failed photon ID cuts
  - ▲ Additional background from W and $t\bar{t}$ events (with misidentified electrons and/or fake γ)
    - ▶ Select $e + \gamma$ events
    - ▶ Apply $e \to \gamma$ probability measured in $Z \to ee$
  - ▲ Normalize at low $\not{E}_T$ (below 20 GeV)

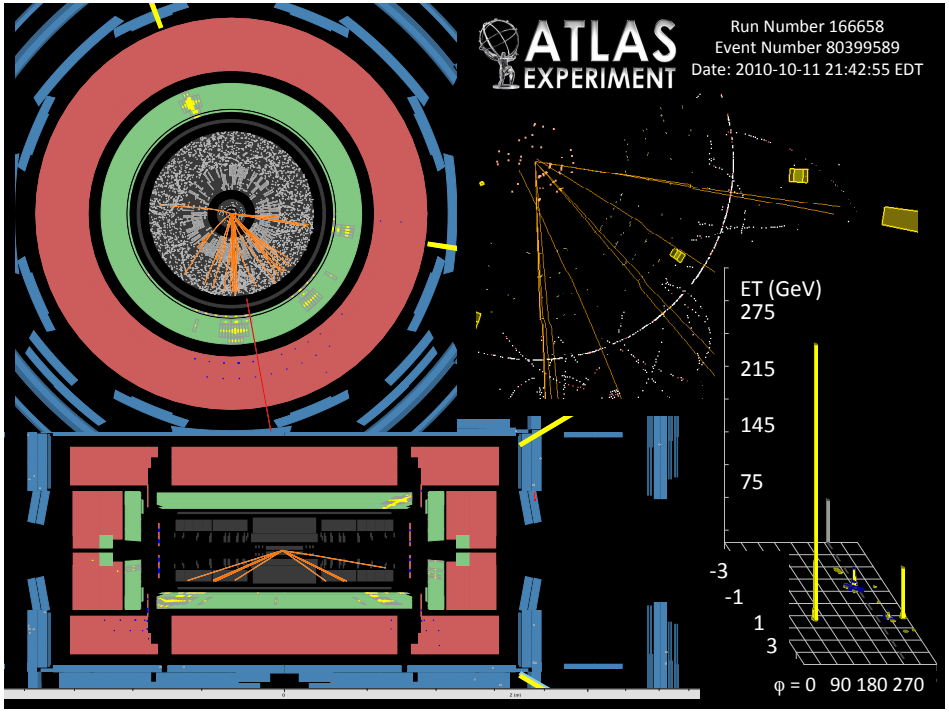
$\not{E}_T$ (GeV)	20–75	75–125	> 125
Signal	0.59±0.05	0.96±0.06	4.66±0.14
Total bkg	61.4±2.3	0.38±0.08	0.10±0.04
Data	63	1	0



$\gamma\gamma + \not{E}_T$ (GGM)

Bino–like $\tilde{\chi}_1^0$, $\tan\beta$ = 2, m_{others} = 1.5 TeV



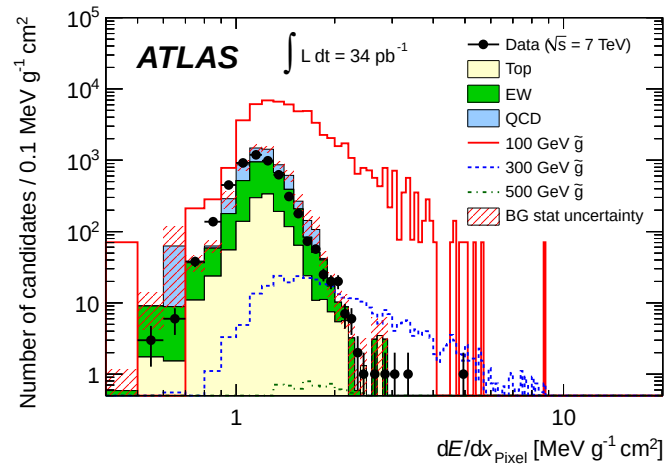


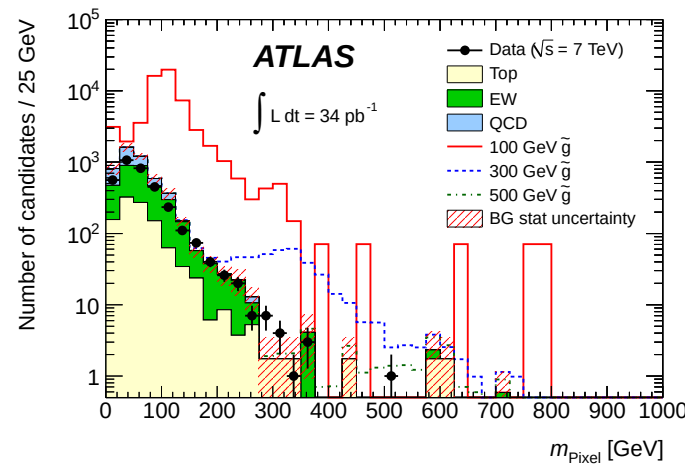
- Mass limit $m_{\tilde{g}} > 560$ GeV (for $m_{\tilde{\chi}_1^0} > 50$ GeV)
- Can also be used to set limits in UED models

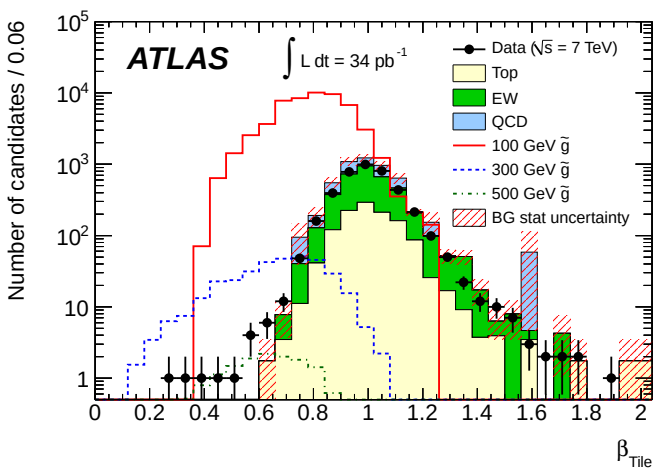
R–Hadrons

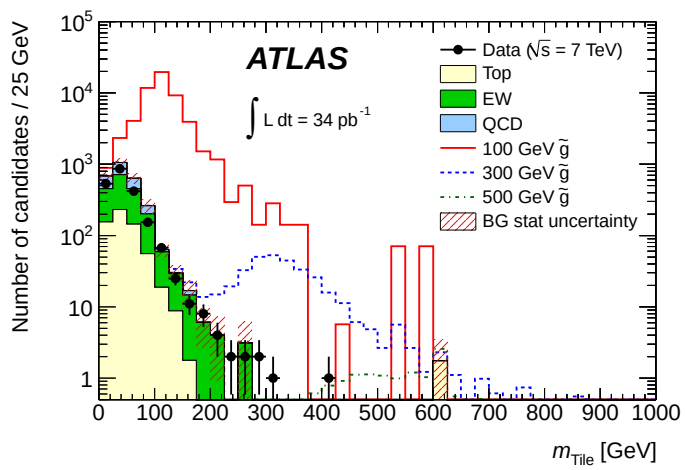
- R–hadrons: heavy objects formed from $\tilde{q}$ or $\tilde{g}$ and light SM partons
  - ▲ Penetrating and moving relatively slowly
  - ⇒ Specific ionisation energy loss dE/dx$_{pixel}$
  - ⇒ Time–of–flight measurement β_{tile}
- Event selection
  - ▲ Trigger using $\not{E}_T$
  - ▲ High p_T inner detector track matched to muon track or calorimeter cluster
- Calculate particle mass from $\beta\gamma$
  - ▲ Two mass measurements: dE/dx (pixel detector) and β (tile calorimeter)

$\int \mathcal{L}dt$ = 34 pb^{-1}



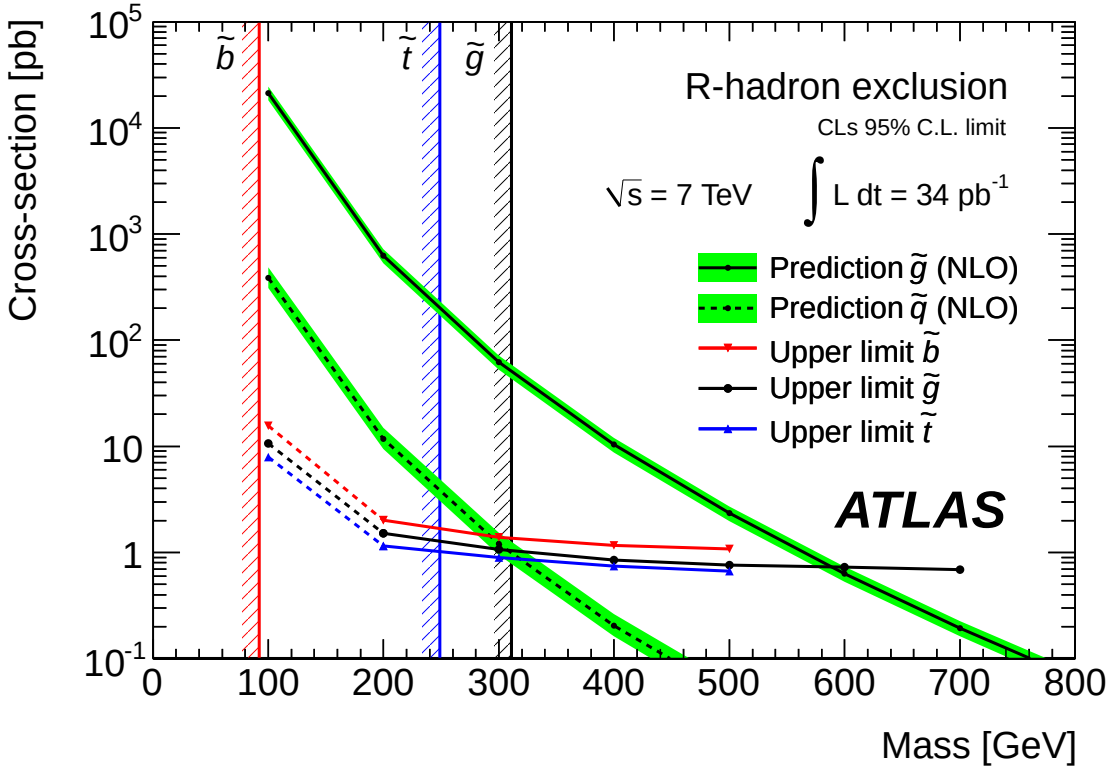






R–Hadrons

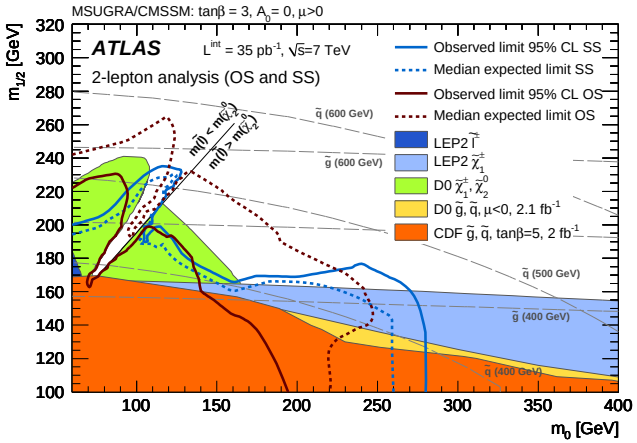
Mass (GeV) (GeV)	Signal ($\tilde{g}$)	Background	Data
100	13912	5.4	5
300	173	0.22	0
500	9.2	0.044	0
700	0.84	0.018	0



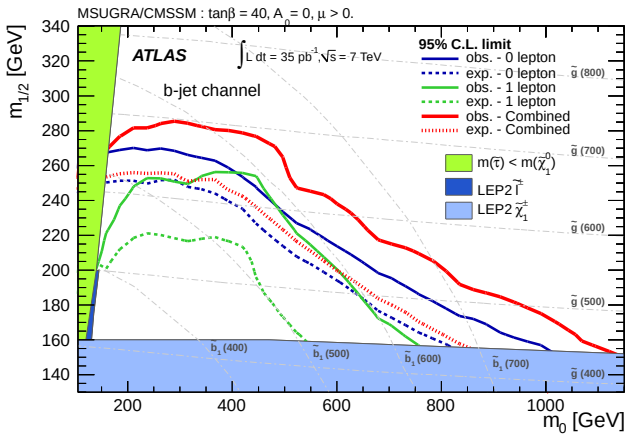
- Mass limits
  - ▲ $m >$ 294 GeV sbottom R–hadrons
  - ▲ $m >$ 309 GeV stop R–hadrons
  - ▲ $m >$ 586 GeV gluino R–hadrons

Other ATLAS SUSY Results

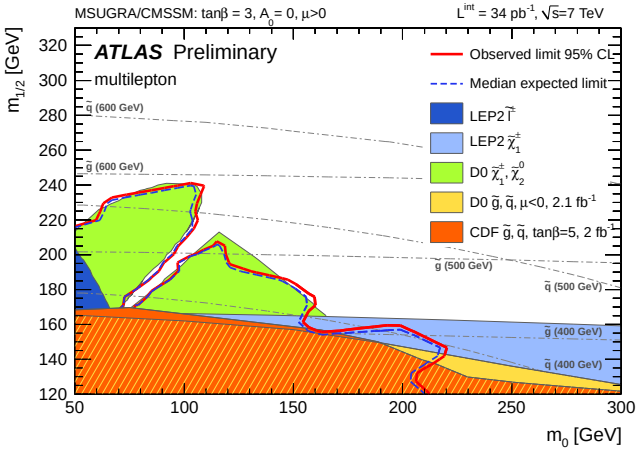
Many more results not shown in detail today



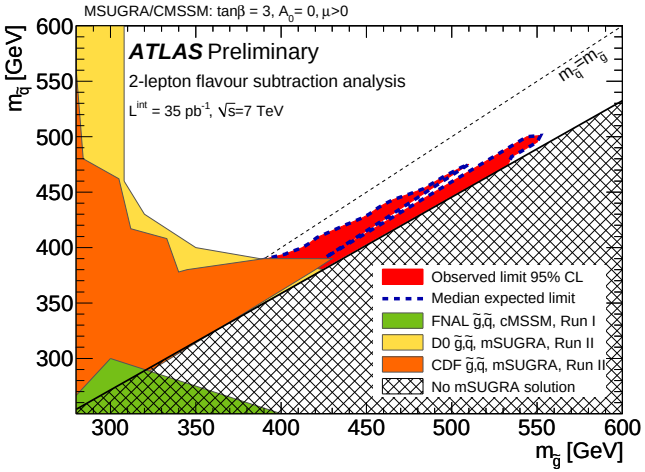
2 leptons + $\not{E}_T$ (OS)



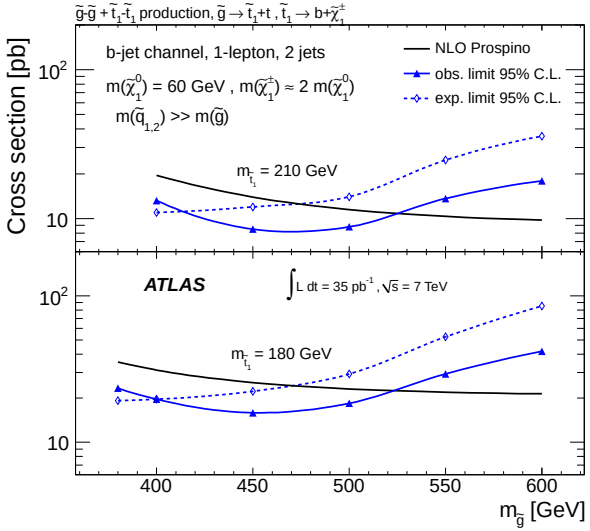
0,1 lepton + b–jet + $\not{E}_T$



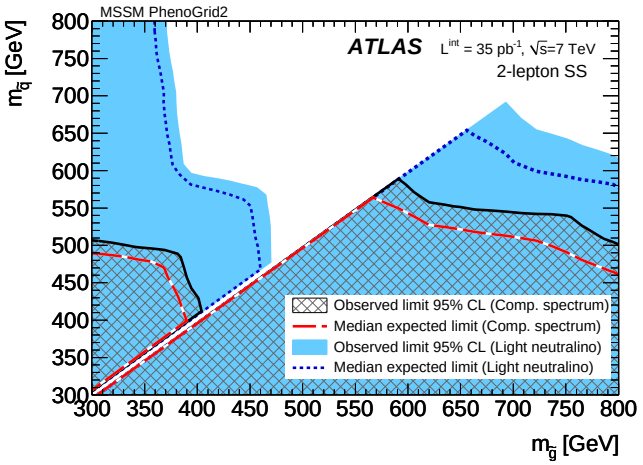
3 leptons



2 leptons + $\not{E}_T$ (SF)



1 lepton + b–jet + $\not{E}_T$



2 leptons + $\not{E}_T$ (SS)

Conclusion and Outlook

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LHC delivers large amounts of good data

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LHC delivers large amounts of good data

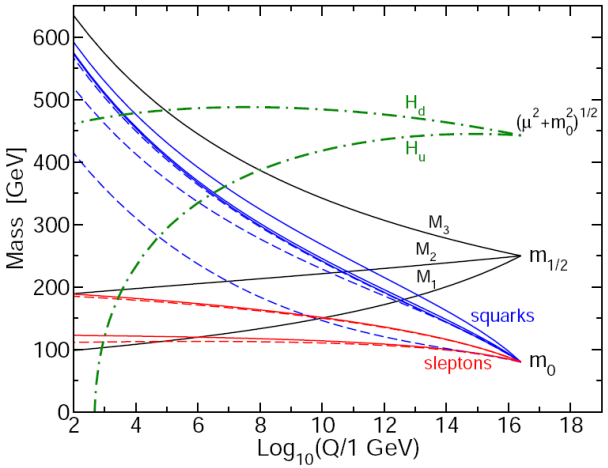
The ATLAS detector is performing well and produced already many nice results

There is still a large parameter space to be explored

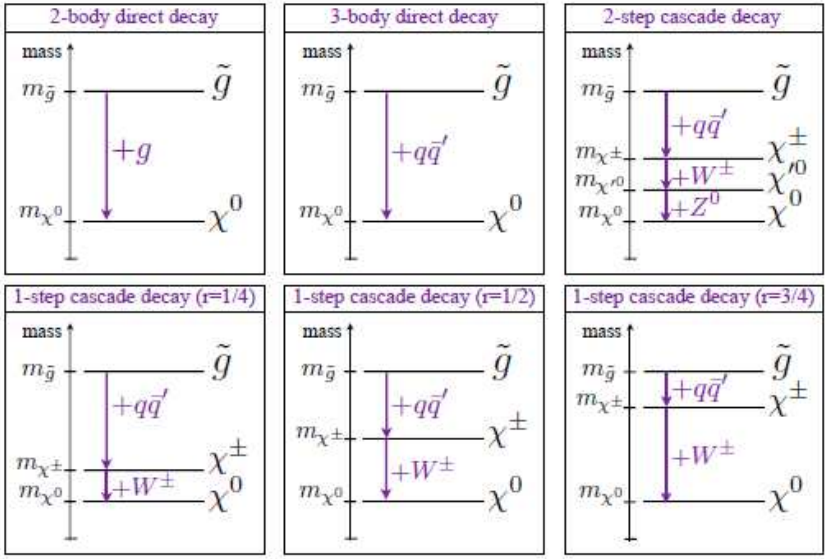
BACKUP

SUSY Model

- The reference model for SUSY searches is mSUGRA
  - ▲ Characterized by five parameters⇒ “easy”
    - ▶ Common scalar mass at GUT scale: m_0
    - ▶ Common Gaugino mass at GUT scale: $m_{1/2}$
    - ▶ Common trilinear coupling at GUT scale: A_0
    - ▶ Ratio of VEV of the neutral Higgs fields: $\tan\beta$
    - ▶ Sign of Higgs mass parameter: sign(μ)
  - ▲ R–parity conservation ⇒ stable LSP (Neutralino)



- Attempt to be less model specific
  ⇒ Simplified models
  - ▲ Pick specific production and decay chain
  - ▲ Vary masses of the particles involved in the chain
  - ▲ Can easier be interpreted in different scenarios
  - ▲ Quote limits on cross section times efficiency

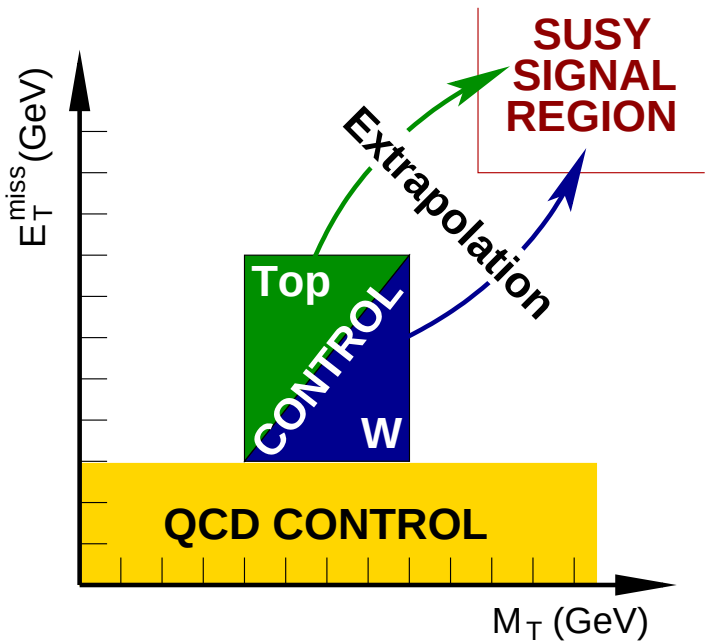


J. Wacker et al., hep-ph 1102.5338

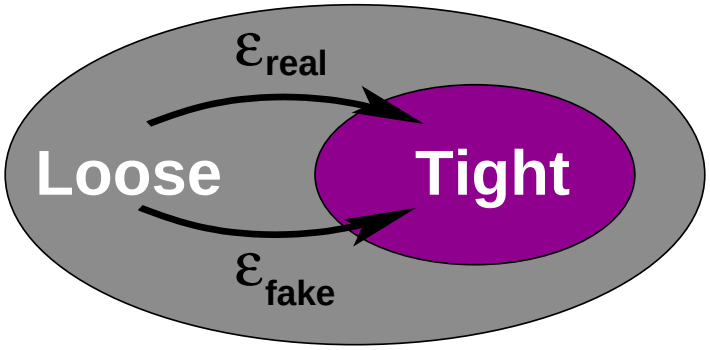
Background Strategy

W, Z, $t\bar{t}$ background

- Semi–data driven approach
- Select events in control regions (CR)
  - ▲ Normalise MC to data
- Extrapolate to signal region using MC
  - ▲ Assume shape is described correctly



QCD background



- Fully–data driven approach
- Measure real and fake efficiencies in CRs
- Apply Matrix Method to get contribution in SR