SUSY Searches at the LHC

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on behalf of the ATLAS and CMS Collaborations

3rd LC Forum
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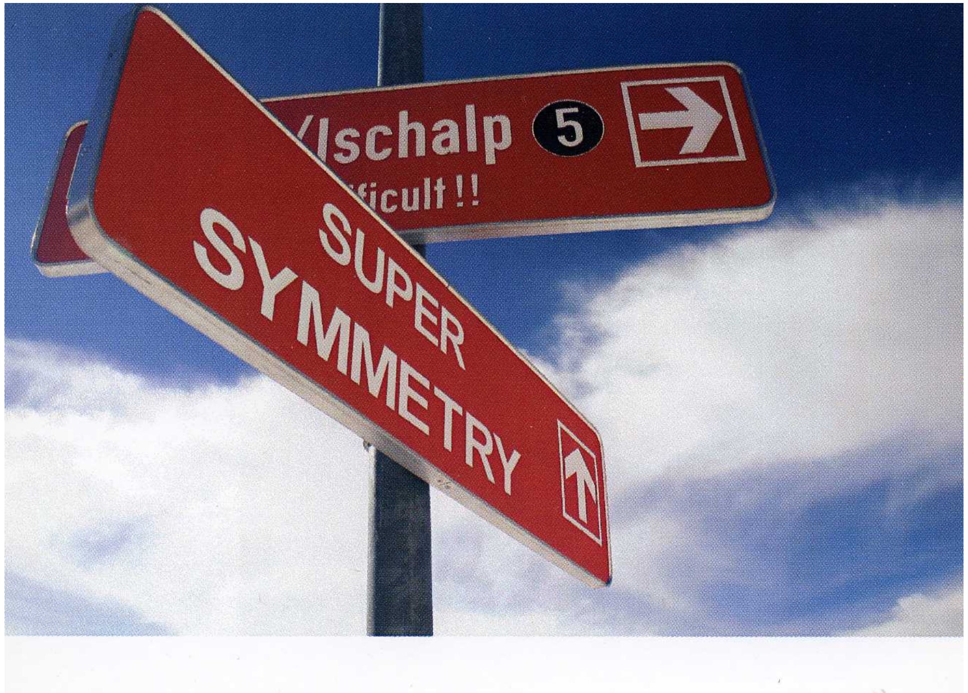
Outline

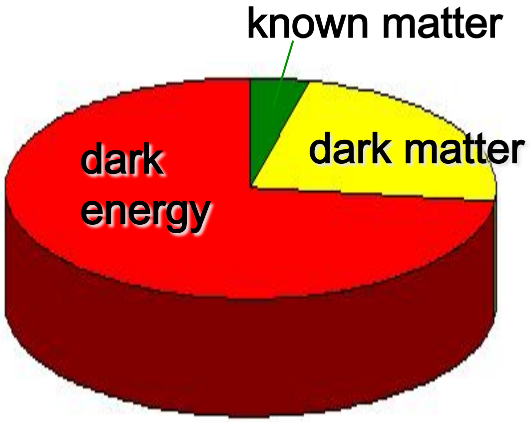
Introduction

- Hadronic searches
- Leptonic searches
- Searches with photons
- Long-lived particles
- Summary and outlook



Why SUSY?

- SUSY has solutions to (almost) all open questions:
  - Unification with gravity (Superstring theory)
  - Unification of the gauge couplings
  - Solution of the hierarchy problem
  - Candidate for dark matter particle

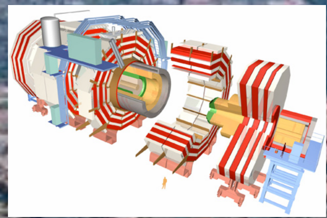


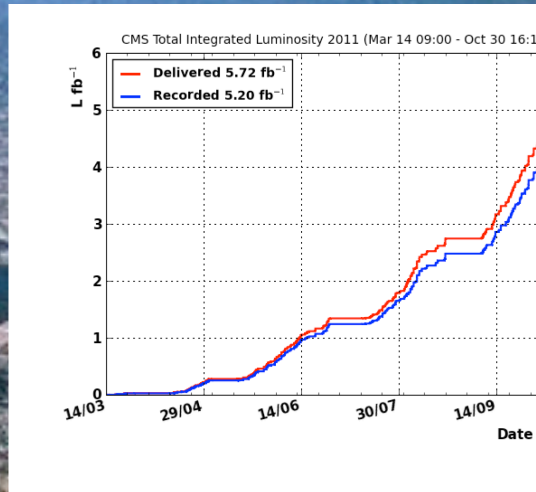
- SUSY relates bosons to fermions and vice versa
  - No SUSY particles with same masses as SM partners found → broken symmetry
  - SUSY partners heavier than SM particles, but expected to be at least (partly) lighter than 1TeV

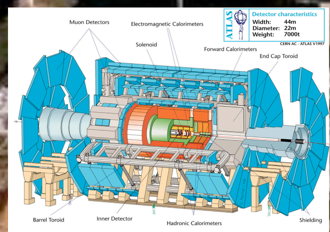
→ Search them at the LHC!!!

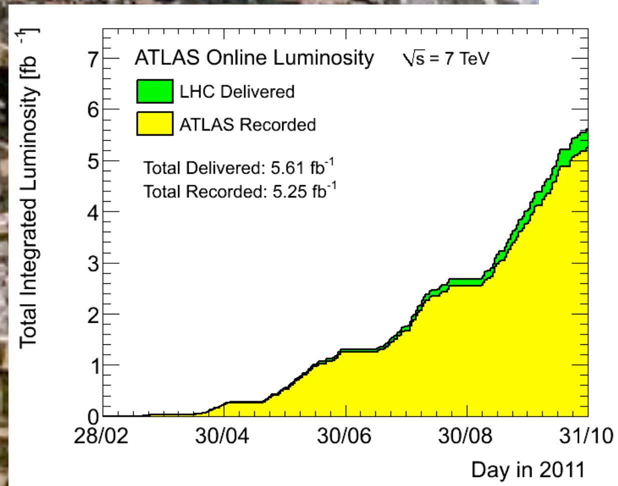
LHC, ATLAS and CMS

- Very successful running in 2011
- ~5.7 fb^{-1} delivered per experiment
- Most analyses presented here based on smaller subset of data



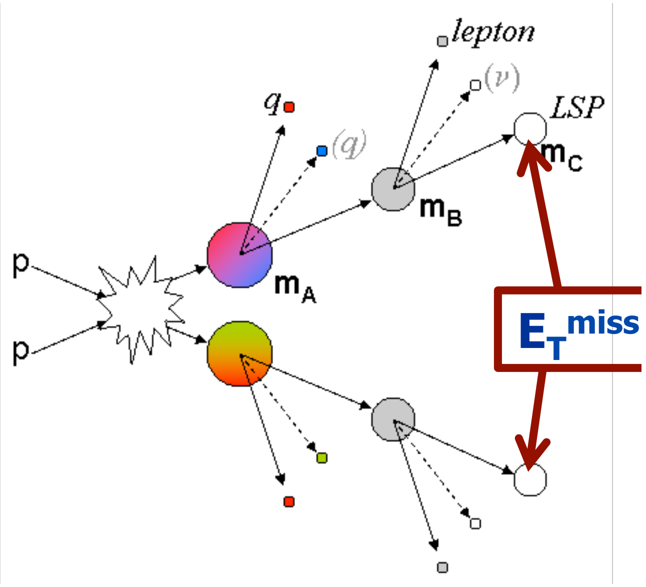






Search Strategy

- **Topology based searches, not optimized for any particular SUSY model**
- Most searches probe tails of $\mathbf{E_T^{miss}}$ distribution
- Try to cover as much phase space as possible (e.g. as low lepton p_T as possible)
- Estimate backgrounds from data (data-driven bkg estimate) to minimize reliance on MC (e.g. for detector (mis)reconstruction effects)
- Exclude area in common benchmark scenarios, e.g. cMSSM and simplified models

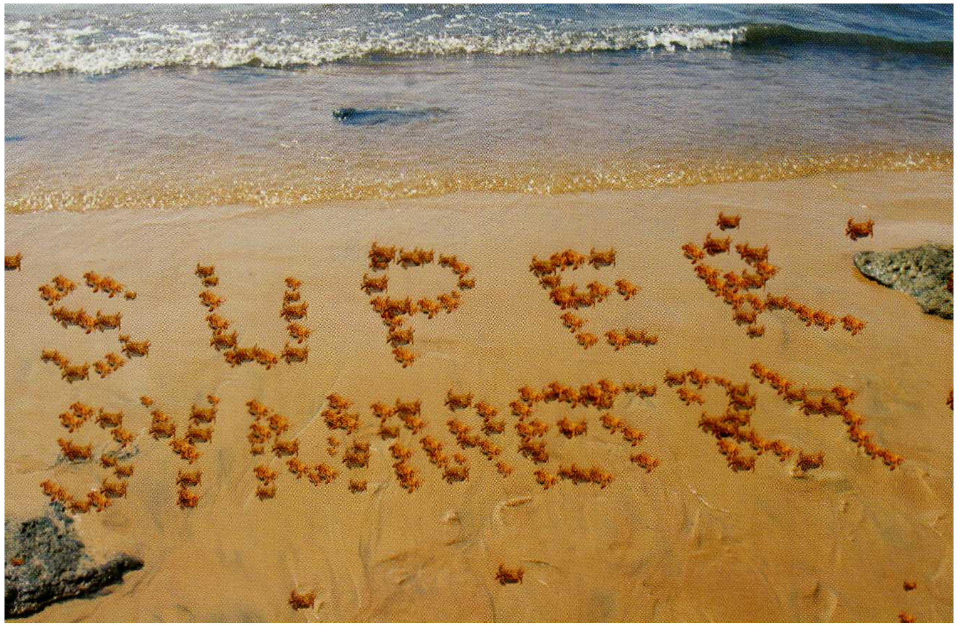


0 leptons	**1 lepton**	**OSDL**	**SSDL**	**≥3 lep.**	**2 γ**	**1 γ+ 1 lep.**
Jets + E_T^{miss} (+special variables)	Single lepton+ jets+E_T^{miss}	Opposite sign di-leptons+ jets+E_T^{miss}	Same-sign di-leptons + jets +E_T^{miss}	Multi-leptons	Di-photon +jets +E_T^{miss}	Photon +lepton +E_T^{miss}

- Add b-tag requirement in order to be more sensitive to light 3rd generation squarks

Where we are...

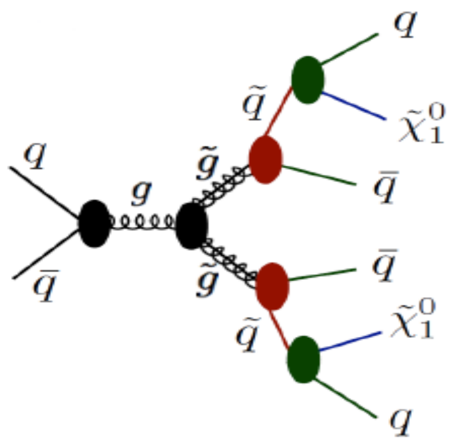
- The CMS Experiment
- **Hadronic searches**
  - Inclusive hadronic analysis
    - Search with many jets
    - Direct sbottom production
- Leptonic searches
- Searches with photons
- RPV SUSY
- Long-lived particles



Inclusive All-Hadronic Search: Introduction

Signature:
Many jets and large missing transverse energy

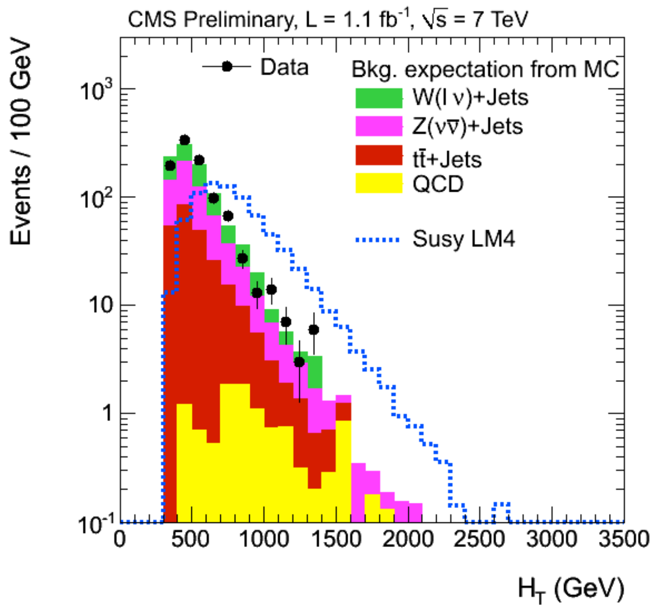
- Least model-dependent analysis
- Large backgrounds:
  - Z+jets with Z→ νν (irreducible)
  - W+jets and ttbar with W → lν and lost lepton or τ → hadrons + ν
  - QCD multijet events with large missing transverse momentum due to:
    - Leptonic decays of heavy flavor hadrons inside jets
    - Jet energy mis-measurement
    - Instrumental noise
    - Non-functioning detector components

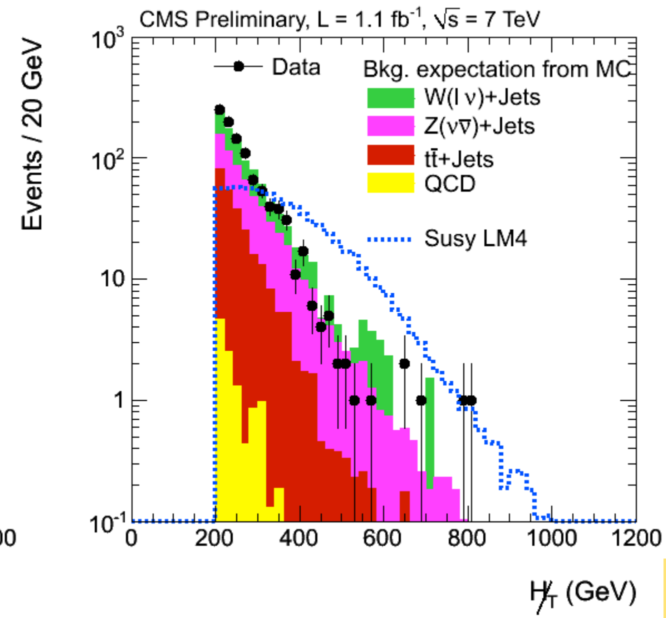


Phys. Lett. B698:196-218 (2011)
CMS PAS SUS-11-004

Inclusive All-Hadronic Search: Event Selection

- **Baseline selection**
  - At least 3 jets with $p_T^{jet} > 50$ GeV and $|\eta| < 2.5$
  - $|\Delta\Phi(\vec{J}_{1,2}, \vec{H}_T^{miss})| > 0.5$ and $|\Delta\Phi(\vec{J}_3, \vec{H}_T^{miss})| > 0.3$ to veto events where H_T^{miss} is aligned in transverse plane with one of the 3 leading jets
  - Veto on isolated muons and electrons
  - $H_T > 350$ GeV
  - $H_T^{miss} > 200$ GeV





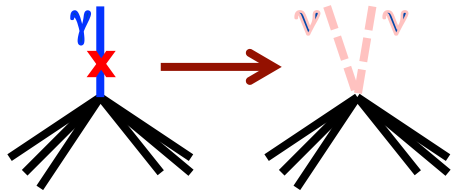
$$H_T = \Sigma|\vec{p}_T^{\,jet}|$$

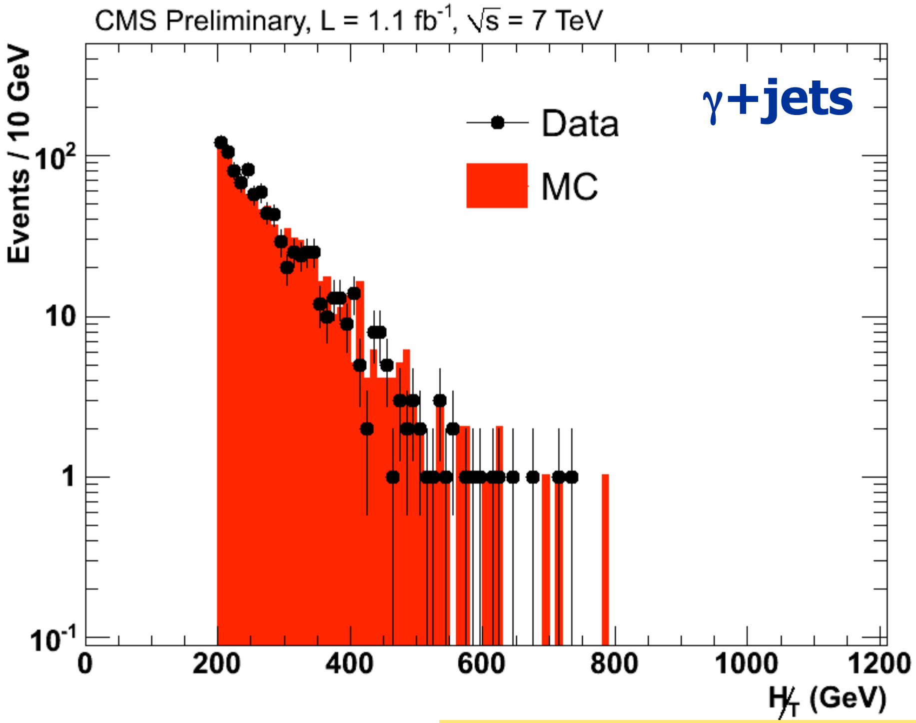
$$\vec{H}_T^{miss} = -\Sigma\,\vec{p}_T^{\,jet}$$

CMS PAS SUS-11-004

Inclusive All-Hadronic Search: Background Estimation for Z → νν

- **Background estimation with γ+jets :**
- Strategy:
  - Declare photon invisible to emulate neutrinos
  - Then re-calculate E_T^{miss} for this event
  - Correct for the photon reconstruction efficiency and neutrino branching ratio



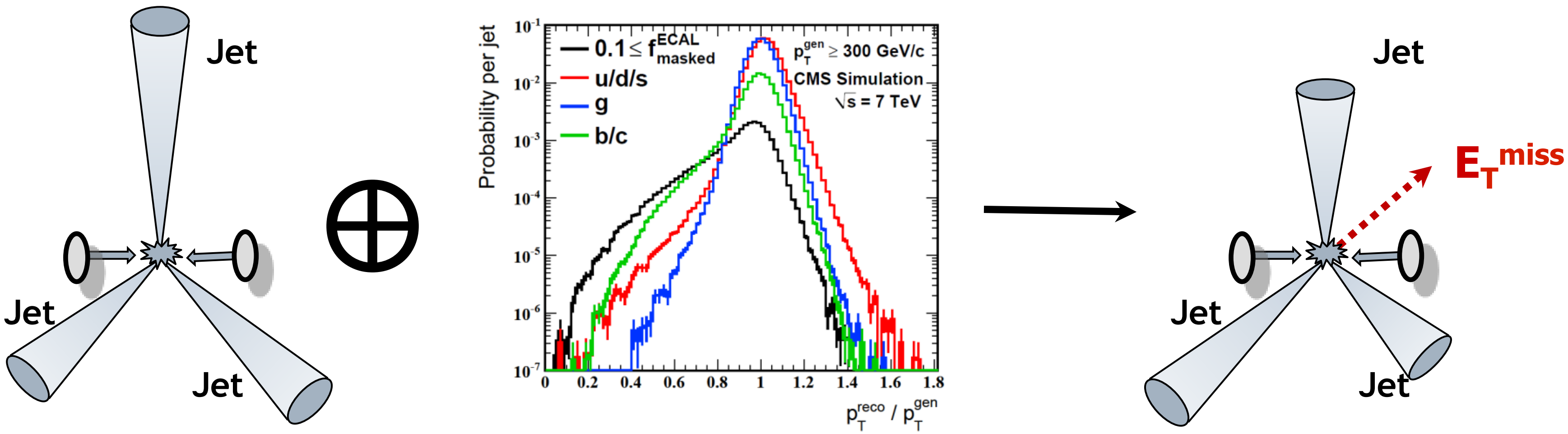


→ Crosscheck with Z→μμ+jets: Low statistics in signal region, but comparable result in baseline selection

CMS PAS SUS-11-004

Inclusive All-Hadronic Search: QCD Background Estimation

- Most difficult background, derived here by 'Rebalance & Smear' method:
  - Rebalance all jets to overall p_T balance (=kind of 'generator level jet', robust against seed jet mis-measurements and non-QCD processes)
  - Smear p_T of each seed jet by a factor derived from jet resolution distribution (from simulation, and corrected for data/MC differences)
- Smearing of the jets results in artificially created E_T^{miss} used to estimate the real E_T^{miss} distribution

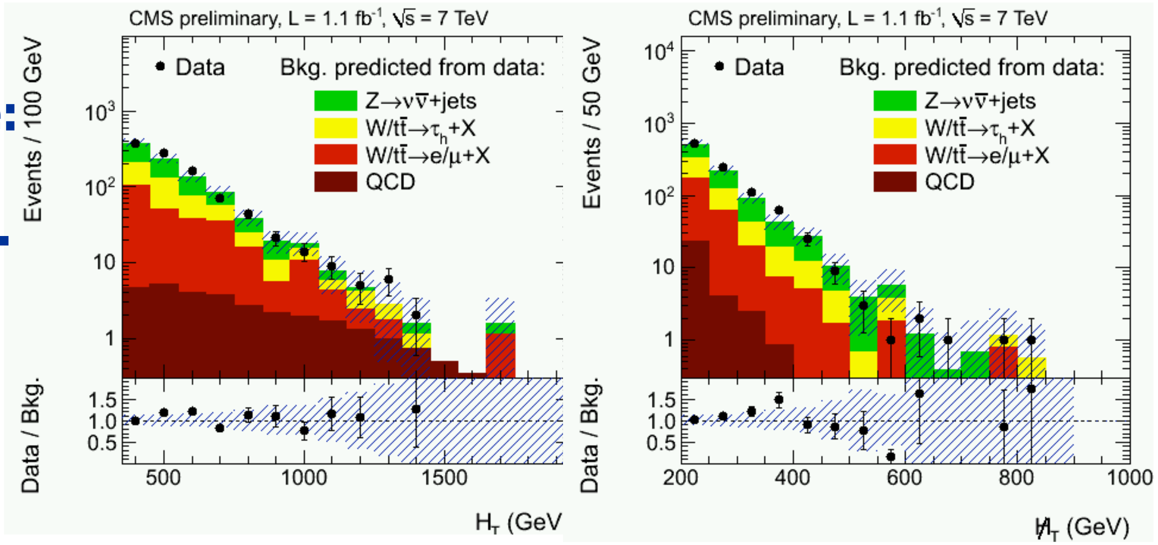


CMS PAS SUS-11-004

Inclusive All-Hadronic Search: Results

Method	Baseline H_T > 350 GeV and H_T^{miss} > 200 GeV	Medium H_T > 500 GeV and H_T^{miss} > 350 GeV	High H_T H_T > 800 GeV and H_T^{miss} > 200 GeV	High H_T^{miss} H_T > 800 GeV and H_T^{miss} > 500 GeV
$Z \rightarrow \nu\nu$ from γ+jets	376.3 ± 12.3 ± 79.2	42.6 ± 4.4 ± 8.9	24.9 ± 3.5 ± 5.2	2.4±1.1 ± 0.5
tt/W → e,μ+X	$243.5 \pm 19.8^{+30.0}_{-30.9}$	12.7 ± 3.3 ± 1.5	$22.5 \pm 6.7^{+3.0}_{-3.1}$	0.8±0.8 ± 0.1
tt/W → τ_{hadr}+X	263 ±8 ± 7.4	17 ± 2 ± 0.7	18 ± 2 ± 0.5	0.73 ± 0.73 ± 0.04
QCD	$30.9 \pm 35.2^{+16.6}_{-6.2}$	$1.3 \pm 1.3^{+0.6}_{-0.4}$	$13.5 \pm 4.1^{+7.3}_{-4.3}$	$0.09 \pm 0.31^{+0.05}_{-0.04}$
Total background	927.5 ±103.1	73.9 ±11.9	79.4 ±12.2	4.6 ±1.5
Observed in data	986	78	70	3

Here: Bkg pred. from data

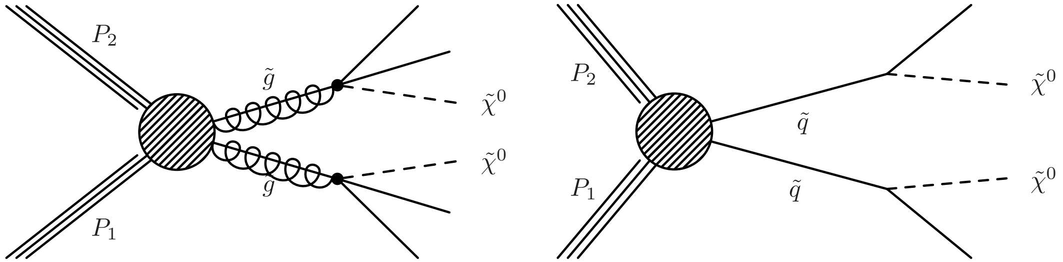


No excess observed!

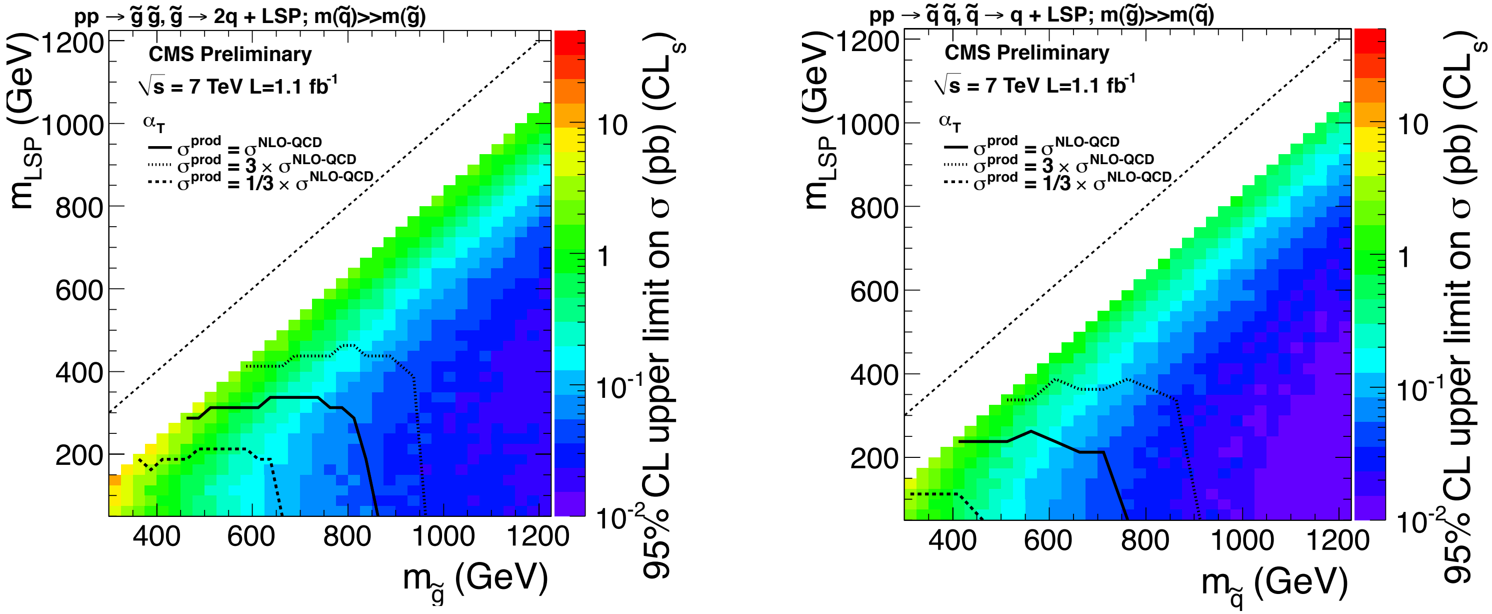
CMS PAS SUS-11-004

Hadronic Analysis: Interpretation

- Simplified models (on-shell effective theory): intermediate step between a complete theory and experimental signature
- Use limited set of new hypothetical particles and decays to produce a given topological signature



From data in CMS PAS SUS-11-003



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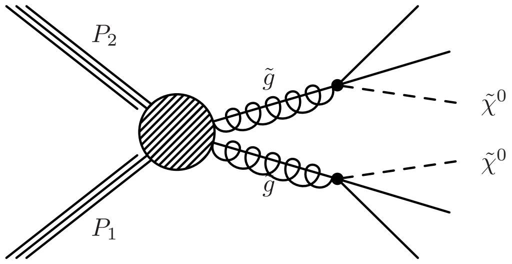
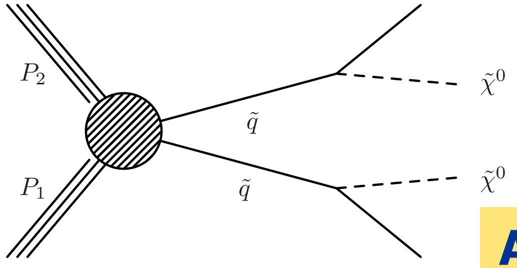
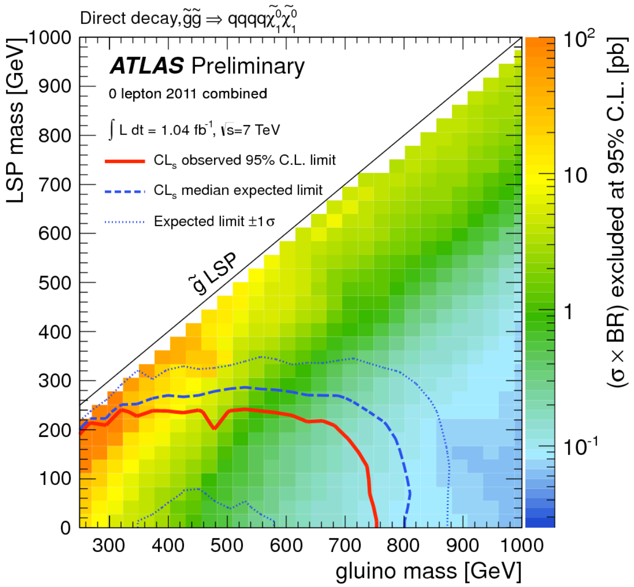
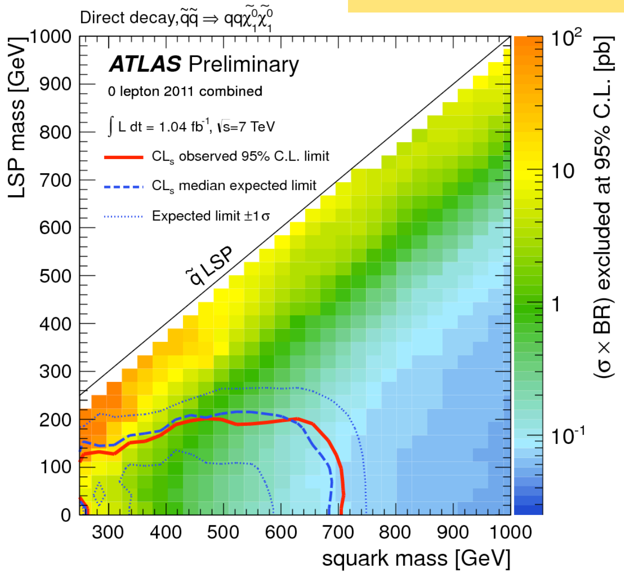


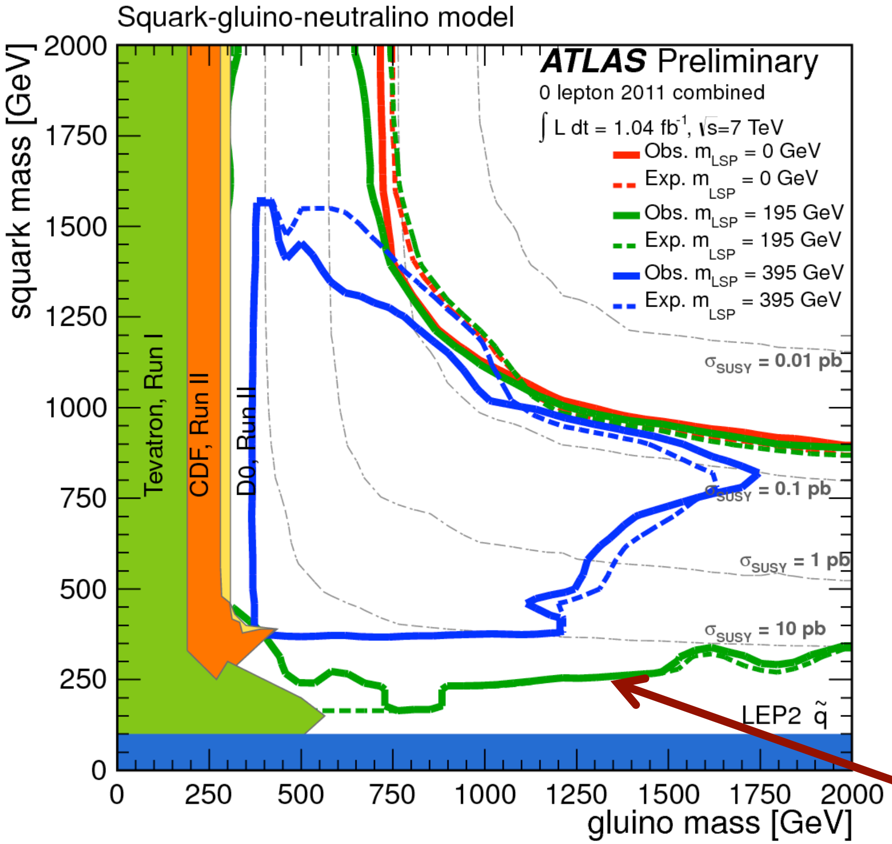


ATLAS-CONF-2011-155





Hadronic Analysis: Interpretation from ATLAS



- Production of 1st and 2nd generation squarks and gluinos with direct two-body ($\tilde{q}_{L,R} \rightarrow q\,\tilde{\chi}_1^0$) or three-body decays ($\tilde{g} \rightarrow qq\,\tilde{\chi}_1^0$)
- When kinematically allowed, the heavier strong sparticles may decay via the lighter ones
- Planes in the squark and gluino masses are probed with $(m_{\tilde{\chi}_1^0}+5\ \text{GeV}) \leq m_{\tilde{q},\tilde{g}} \leq 2$ TeV
- All other particles masses set to 5 TeV

Note: lower limit because $m_{gluino} > m_{LSP}$ and $m_{squark} > m_{LSP}$

ATLAS-CONF-2011-155

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All-Hadronic Search with ≥ 6 Jets: Introduction

- Events with larger jet multiplicities → increased sensitivity to models predicting:
  - Many-body decays
  - Sequential cascade decays to many strongly interacting particles
  - SUSY models that have gluinos with masses near the TeV scale and relatively heavy squarks
- Need to carefully examine SM background with high jet multiplicities

- **4 Signal regions** defined by $E_T^{miss}/\sqrt{H_T} > 3.5\sqrt{\mathrm{GeV}}$:
  - Jets have to be central ($|\eta|<2.8$) and separated from each other by $\Delta R>0.6$

Signal region	7j55	8j55	6j80	7j80
Jet p_T	> 55 GeV	> 55 GeV	> 80 GeV	> 80 GeV
Number of Jets	≥ 7	≥ 8	≥ 6	≥ 7

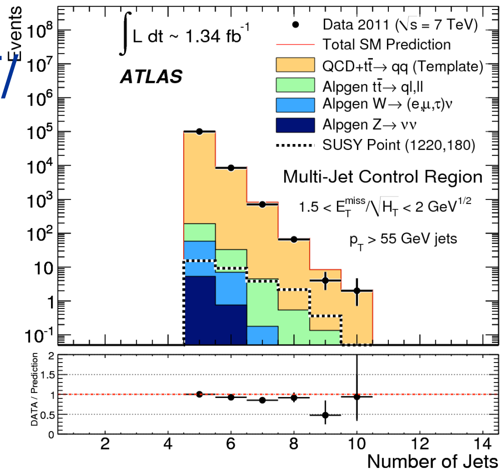
ATLAS CERN-PH-EP-2011-155, Submitted to JHEP

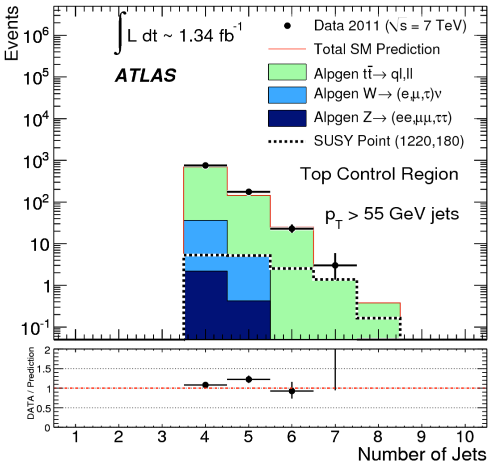
All-Hadronic Search with ≥ 6 Jets: Background determination

- Control regions: Multi-jet, top, Z, W
- Transfer factors to extrapolate to signal region

CERN-PH-EP-2011-155, Submitted to JHEP

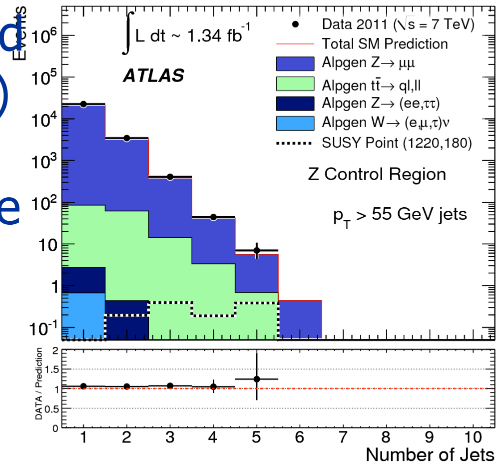
✧ 1.5 √GeV < MET/ √H_T < 2 √GeV with overlaid templates from MET/√HT< 1.5 √GeV

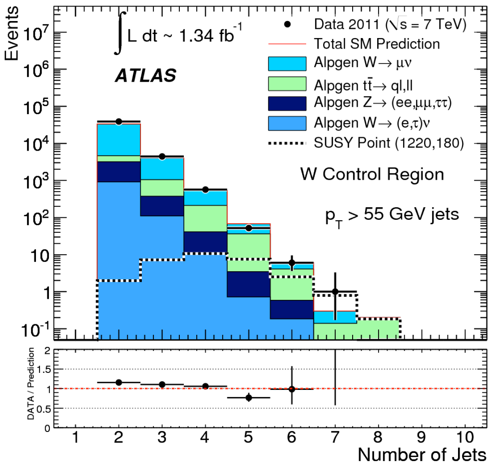




✧ ≥1 b-tagged jet
✧ one single isolated muon with p_T>20 GeV and |η|<2.4,
✧ 40<m_T<100 GeV

✧ Z→νν is predicted from MC (ALPGEN)
✧ MC is verified on μμ control sample



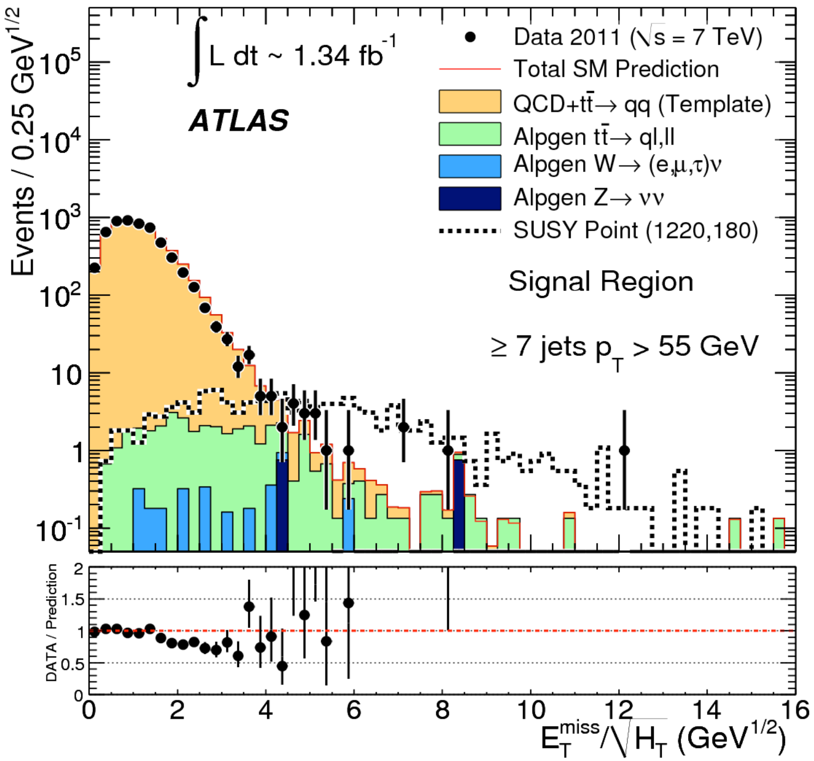


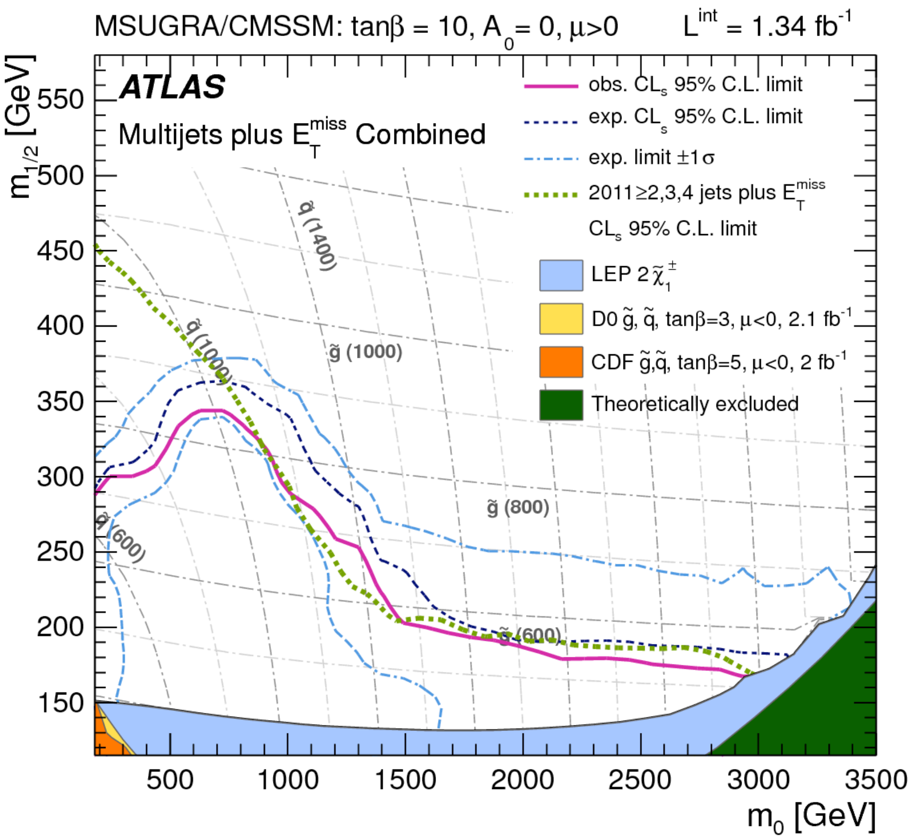
✧ one single isolated muon with p_T>20 GeV and |η|<2.4,
✧ 40<m_T<100 GeV

All-Hadronic Search with ≥ 6 Jets: Result

- No sign for new physics in signal regions
- → Set exclusion limit in cMSSM

CERN-PH-EP-2011-155, Submitted to JHEP





No excess observed!

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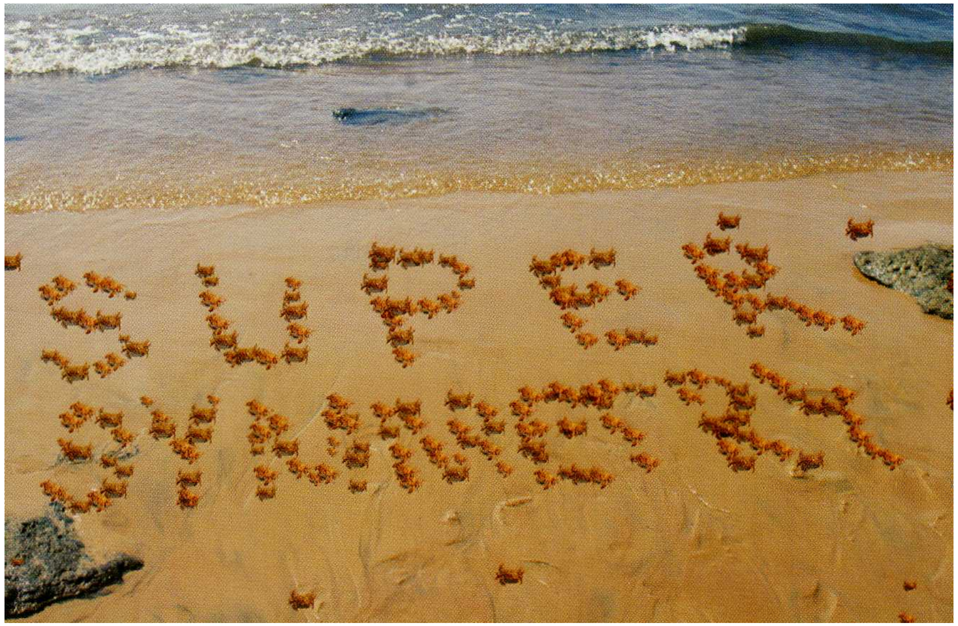
- Leptonic searches
- Searches with photons
- Long-lived particles



Direct sbottom production: Introduction and Selection

- MSSM: left- and right-handed squarks mix proportional to mass of corresponding SM quark → large mixing can yield one light stop and sbottom mass eigenstate (significantly lighter than the other squarks)
- Here: search for $\tilde{b} \to b\tilde{\chi}_1^0$

- **Selection**
  - At least 2 b-tagged jets with $p_T^{jet1(jet2)} > 130\ (50)$ GeV and $|\eta| < 2.5$
  - Veto events with muons, electrons or jets with $p_T^{jet} > 50$
  - $E_T^{miss}/(E_T^{miss} + H_T) > 0.25$
  - 3rd jet has to be separated from E_T^{miss} by 0.2 in azimuth
  - $E_T^{miss} > 130$ GeV
  - Calculate **boost-corrected contransverse** mass for 2 identical particles into 2 visible (v_i) and 2 invisible particles:

$$m_{CT} = \left(\left[E_T(v_1) + E_T(v_2)\right]^2 - \left[\vec{p}_T(v_1) + \vec{p}_T(v_2)\right]^2\right)^{1/2}$$

  - Expect endpoint in m_{CT} at $\left(m_{\tilde{b}_1}^2 - m_{\tilde{\chi}_1^0}^2\right) / m_{\tilde{b}_1}$

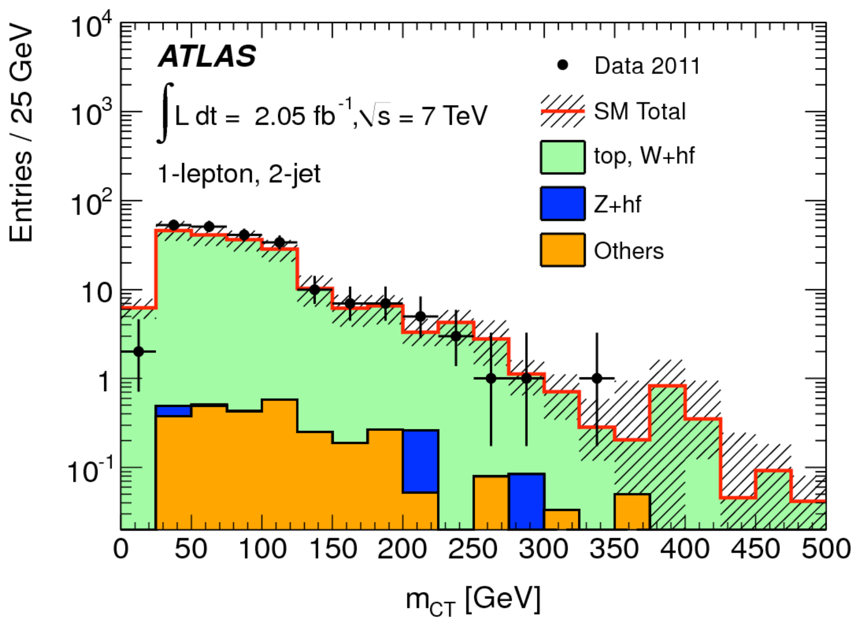
ATLAS arXiv:1112.3832 Submitted to PRL

→ Define **3 signal regions**: m_{CT} >100, 150, 200 GeV

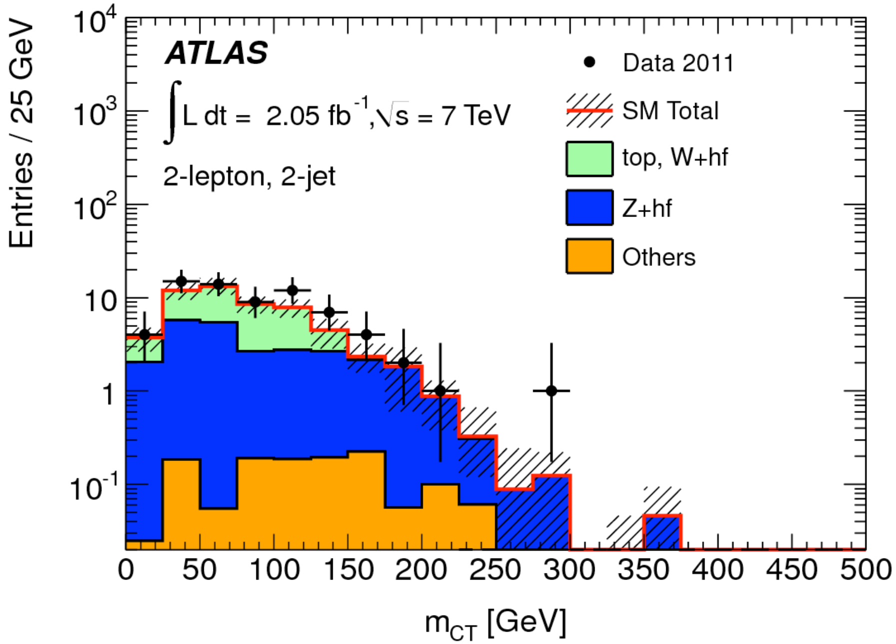
Direct sbottom production: Background Estimation

- Main backgrounds:
  - ttbar
  - W+heavy flavor with W→ $\nu\tau$
  - Z +heavy flavor with Z→$\nu\nu$
  - → Estimation from control regions

ATLAS arXiv:1112.3832 Submitted to PRL



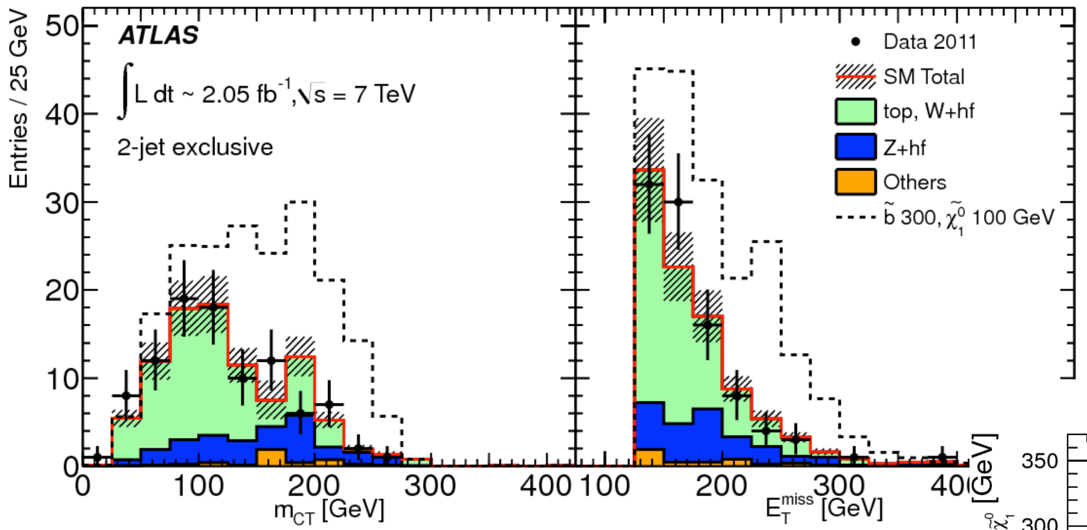
1 lepton control region



2 lepton control region

Direct sbottom production: Result

No excess observed!



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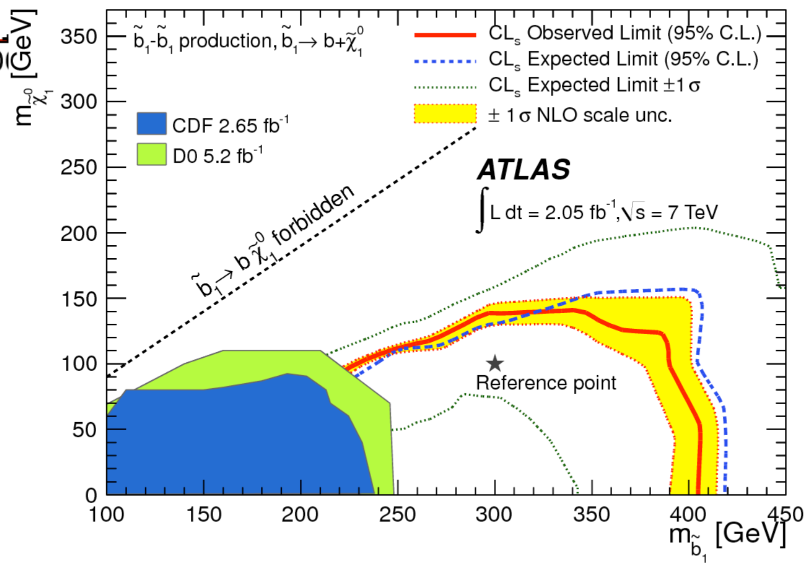
- Exclusion limit in the sbottom-neutralino mass plane
- Reference point corresponds to the MSSM scenario with $m_{sbottom}$ = 300 GeV and $m_{neutralino}$= 100 GeV

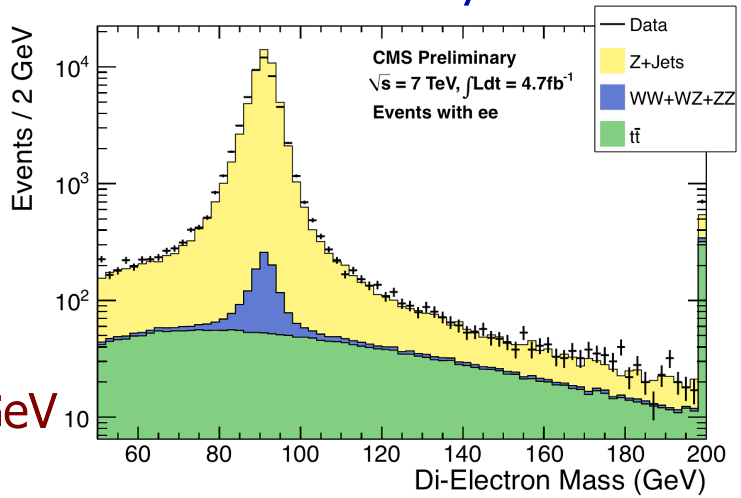


Where we are…

- The CMS Experiment
- Hadronic searches
- **Leptonic searches**
  - Searches with Z + jets + E_T^{miss}
  - Searches with four leptons
  - RPV SUSY
- Searches with photons
- RPV SUSY
- Long-lived particles

Opposite Sign Di-Leptons: Event Selection on Z-region

- New physics expected to connect to EW sector, e.g. $\chi_2^0 \rightarrow Z\ \chi_1^0$
- **Baseline selection**
  - $p_T^{lep1,lep2} > 20$ GeV, $|\eta| < 2.4$ (μ) and $|\eta| < 2.5$ (e)
  - Relative isolation : $I = \Sigma(E_{T(Cal.)}+P_{T(Tracker)})/p_T^{lep} < 0.15$ for leptons
  - At least 2(3) jets with $P_T > 30$ GeV, $|\eta| < 3$ and $\Delta R=0.4$ away from leptons
  - $|m_{lep,lep} - m_Z| < 10(20)$ GeV



- **Two search strategies**
  - ***E_T^{miss} measurement:***
    - E_T^{miss} > 30 / 60 /100 / 200 / 300 GeV
  - ***Jet-Z balance method:***
    - At least 3 jets with $P_T > 30$ GeV, $|\eta| < 3$ and $\Delta R=0.4$ away from leptons
    - $JZB = |\Sigma\ \vec{p}_T^{\,jets}| - |\vec{p}_T^{\,Z}| > 50 / 100 / 150 / 200 / 250$ GeV

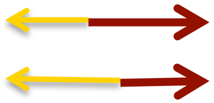
CMS PAS SUS-11-021

Opposite Sign Di-Leptons: Background Determination (Z-region)

- **Jet-Z balance method:**

  $JZB = |\Sigma \vec{p}_T^{\,jets}| - |\vec{p}_T^{\,Z}|$

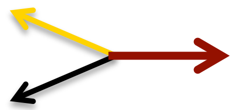
  SM Z + jet

  JZB > 0

  JZB < 0

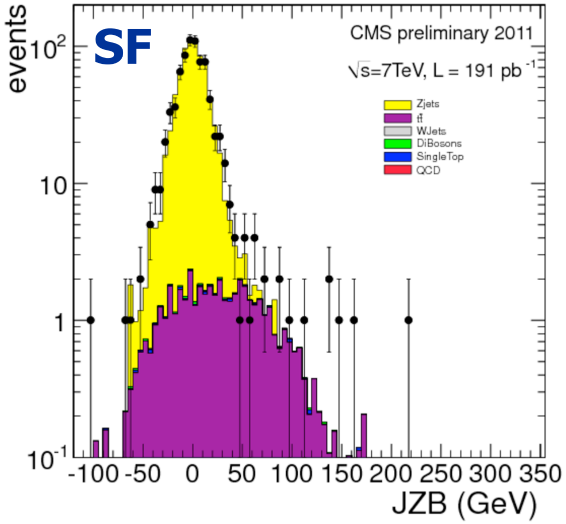
  Signal Z + jet + E_T^{miss}

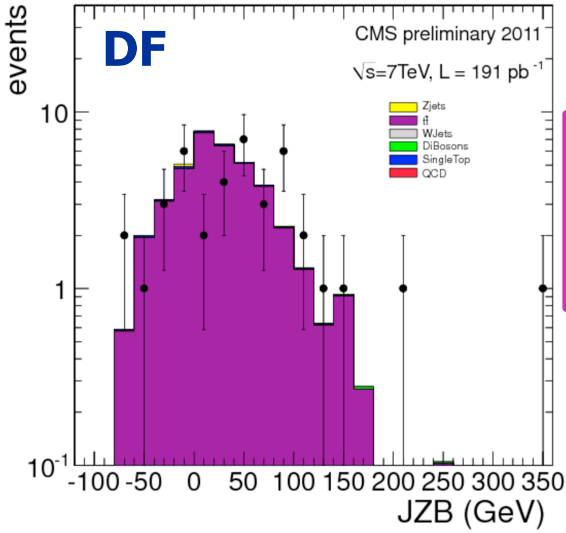
  

  JZB > 0

- Total SM background in JZB > 0 estimated in two control regions:

SM Z+jets from same flavor





ttbar from different flavor

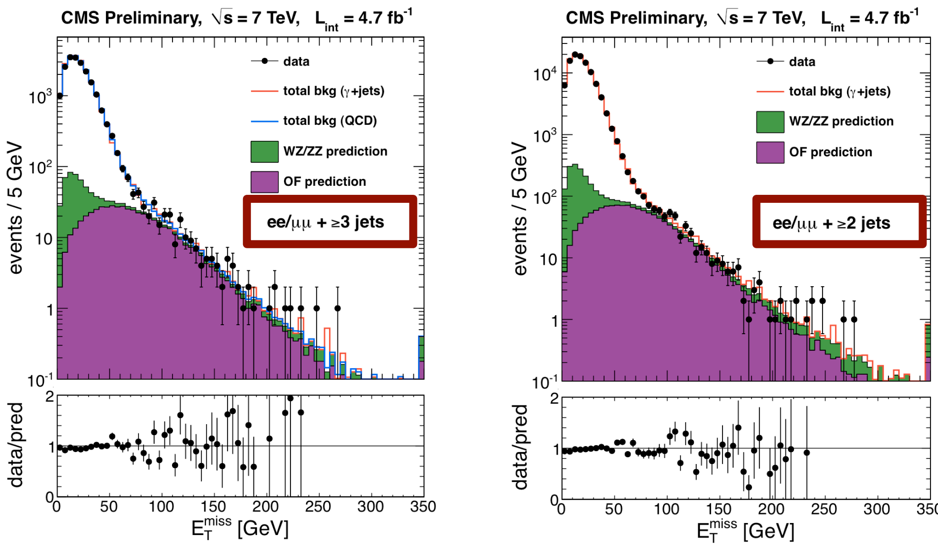
$$JZB^{pred}_{bkg} = \left| JZB^{neg}_{SF} - JZB^{neg}_{DF} \right| + JZB^{pos}_{DF}$$

CMS PAS SUS-11-012
CMS PAS SUS-11-017

Opposite Sign Di-Leptons: Results (Z-region)

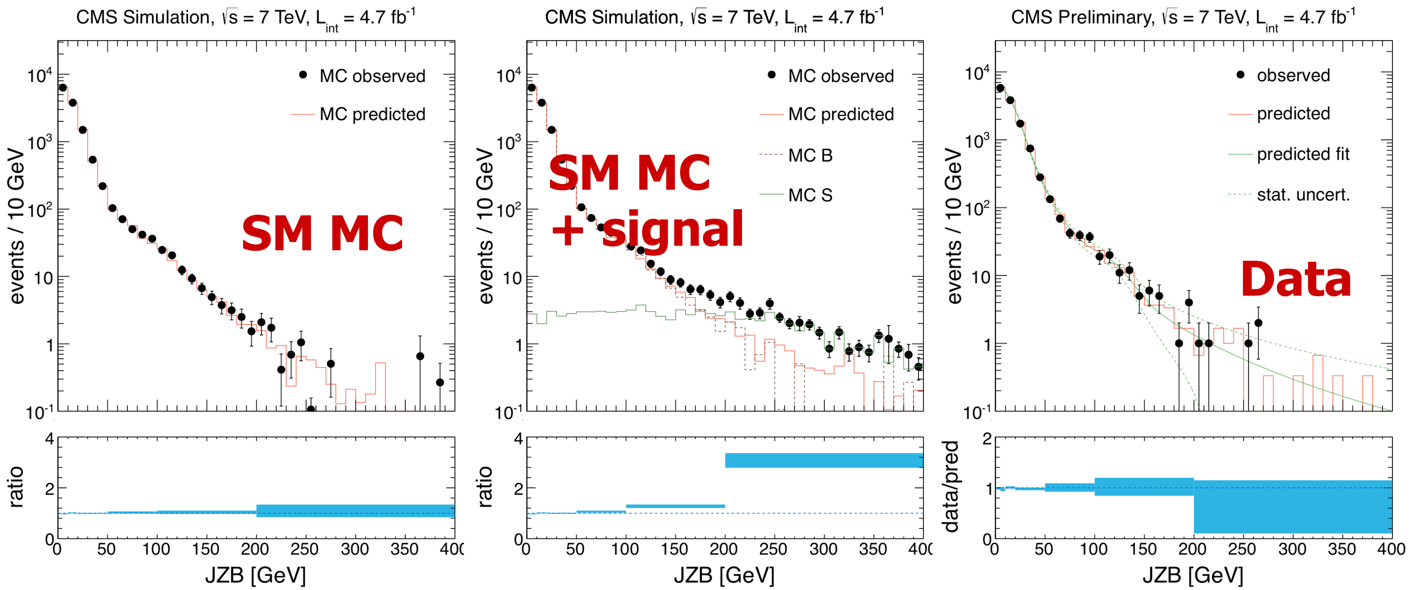
CMS PAS SUS-11-021

- **E_T^{miss} measurement:**



First result with full 2011 data
… still no excess observed!

- **JZB**



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Search with four leptons: Introduction

4-lepton signatures can occur in R_P conserving and R_P violating scenarios

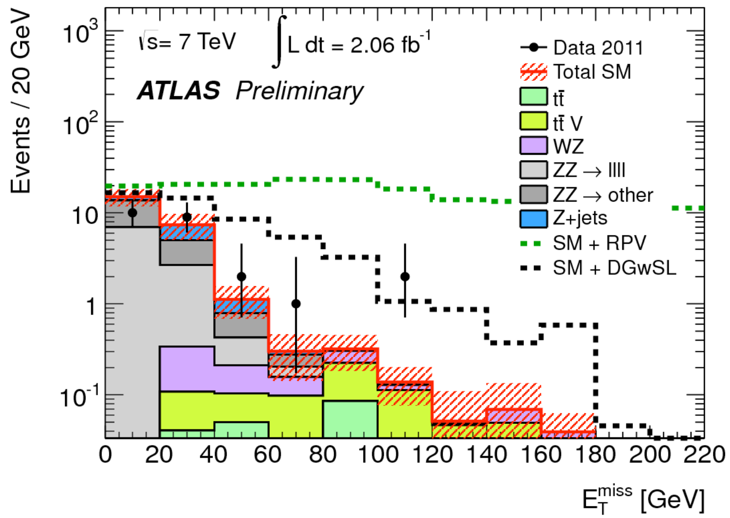
- Reminder: $R_P = (-1)^{2S+3B+L}$ with S: Spin, B: baryon number, L: lepton number
  - Introduced to keep the proton stable
  - $R_P=1$: SM particle
  - $R_P=-1$: SUSY particle
- If R-parity is conserved (RPC)
  - SUSY particles produced in pairs
  - Single SUSY particles cannot decay into just SM particles
  - Lightest SUSY particle (LSP) absolutely stable
- If R-parity is violated (RPV)
  - More couplings:

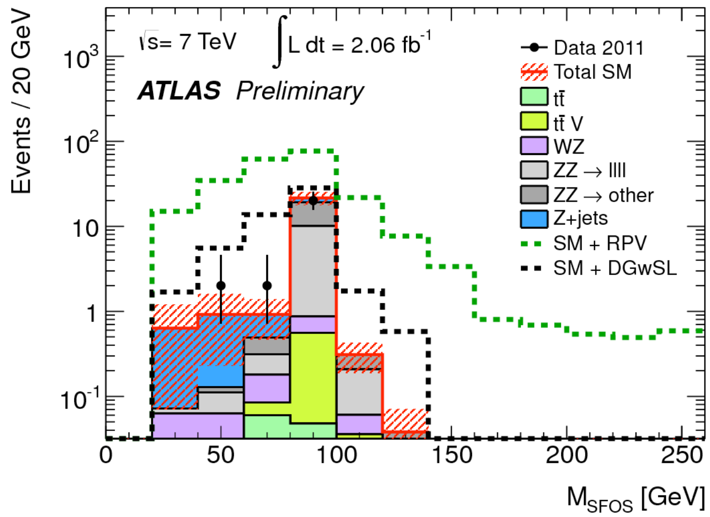
$$W_{\not R p} = \overbrace{\lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^C_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^C_k + \underbrace{\epsilon_i\hat{L}_i\hat{H}_u}_{\text{bilinear terms}}}^{\text{L-number violating terms}} + \underbrace{\lambda''_{ijk}\hat{U}^C_i\hat{D}^C_j\hat{D}^C_k}_{\text{B-number violating terms}}$$

  - But: some couplings have to be small in order to keep the proton stable

Search with four leptons: Result

- **2 signal regions**
  - 4 leptons + E_T^{miss} > 50 GeV
  - 4 leptons + E_T^{miss} > 50 GeV + veto on same-flavor opposite-sign leptons with $m_{inv} = m_Z \pm 10$ GeV
- Background from events with at least 2 prompt leptons estimated from control regions





RPV model: $m_{1/2}$ =400 GeV, tan β =22, m_0=A_0=0, sign(μ) =1 and λ_{121}= 0.032 (0.048) at the GUT (EW) scale
RPC model: direct gauginos with sleptons: bino mass m_1=100 GeV, wino mass m_2=250 GeV, higgsino mass μ=160 GeV and tanβ =6

No excess observed!

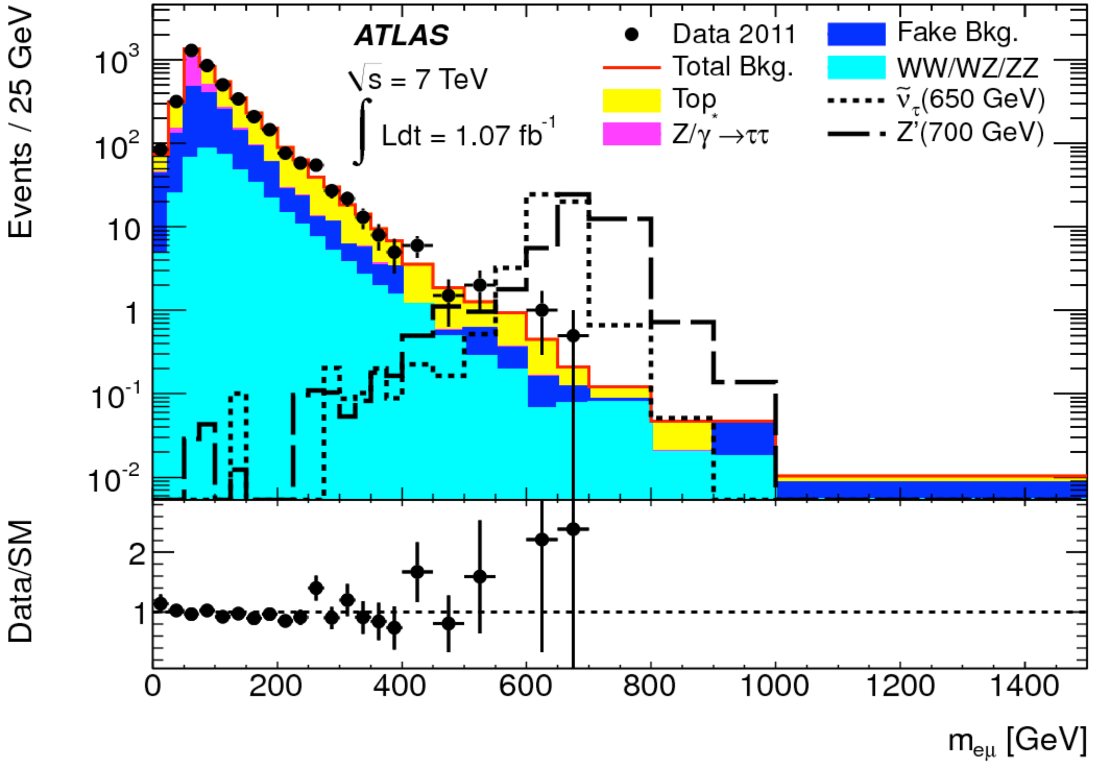
ATLAS-CONF-2012-001

Where we are…

- The CMS Experiment
- Hadronic searches
- **Leptonic searches**
  - Searches with Z + jets + E_T^{miss}
  - Searches with four leptons
  - RPV SUSY
- Searches with photons

RPV SUSY: Introduction

- Sneutrinos are expected to decay into e and μ in RPV SUSY
- **Event selection**
  - Isolated e ($|\eta|<1.37$ or $1.52<|\eta|<2.47$) and μ ($|\eta|<2.4$) with $p_T>25$ GeV with opposite charge
- **Backgrounds**
  - $Z/\gamma^* \rightarrow \tau\tau$, ttbar, ZZ, WW, ZW, single top
  - Events with 'fake' leptons: W/Z+γ, W/Z+jets, multijet events

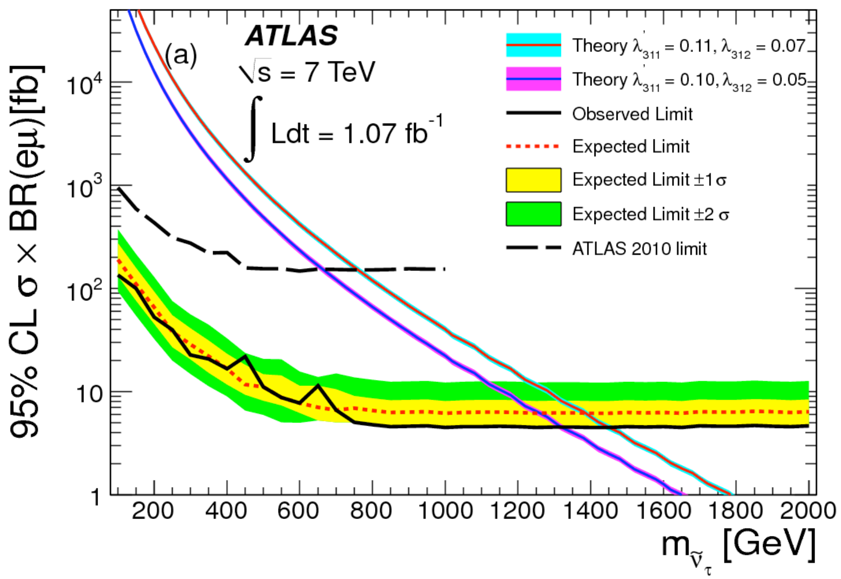


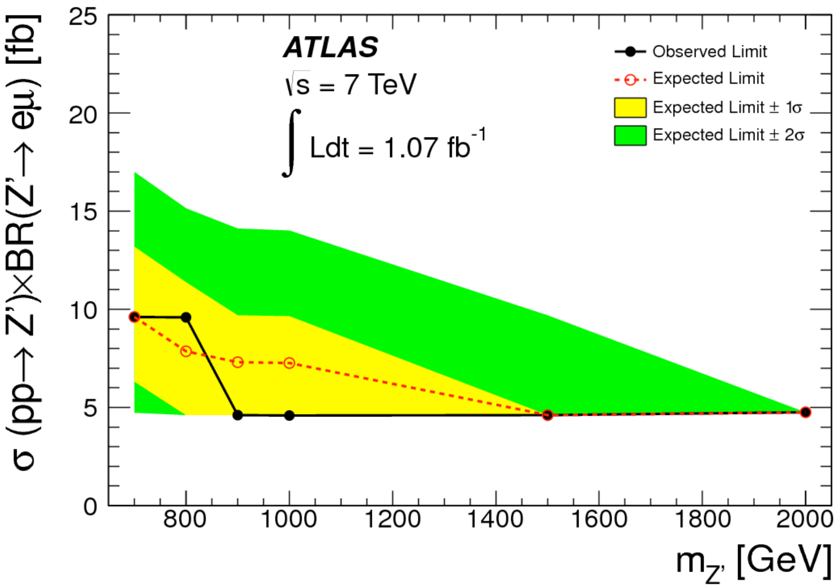
ATLAS
EPJC 71 (2011) 1809

RPV SUSY: Result

No excess observed!

→ Set limit





- $\sigma(pp \rightarrow \tilde{\nu}_\tau) \times BR(\tilde{\nu}_\tau \rightarrow e\mu)$

$\sigma(pp \rightarrow Z') \times BR(Z' \rightarrow e\mu)$

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EPJC 71 (2011) 1809

Where we are …

- The CMS Experiment
- Hadronic searches
- Leptonic searches
- **Searches with photons**
  → Search with di-photons
- Long-lived particles

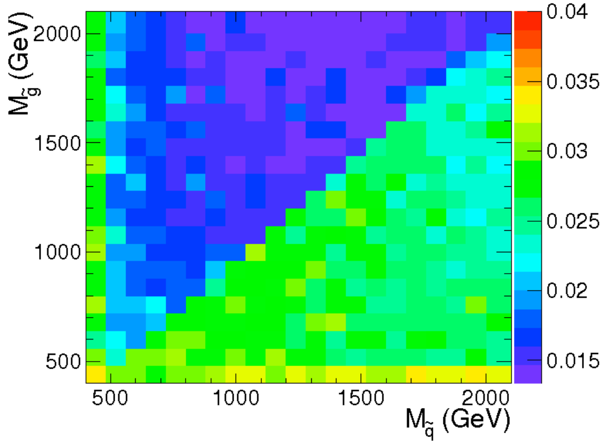
Searches with Di-Photons: Results

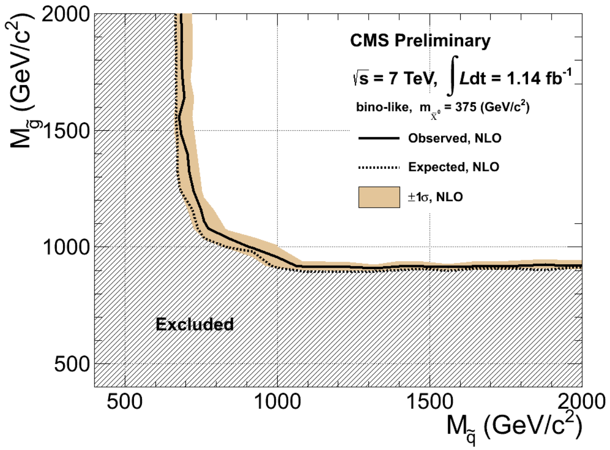
Di-photon analysis interpreted in GMSB model: Gravitino is LSP, neutralino is NLSP

Sample (CMS)	$E_T^{miss} > 50$ GeV	$E_T^{miss} > 100$ GeV
Total predicted SM	11.3 ± 1.9 ± 0.8	1.5 ± 0.8 ± 0.6
Data	9	0

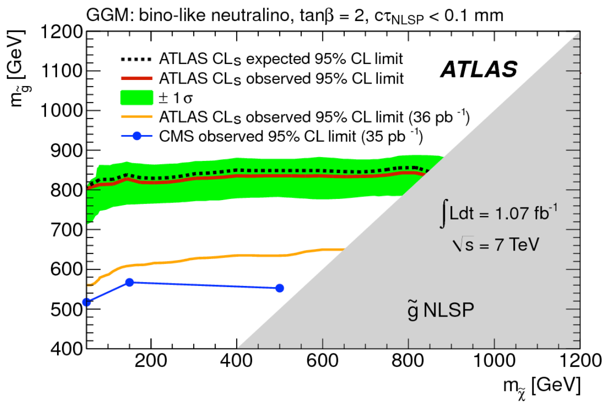
No excess observed!

- 95% CL upper limits on the cross section in gluino-squark mass space for a neutralino mass of 375 GeV
- 95% CL exclusion contours in gluino-squark mass space for a neutralino mass of 375 GeV
- 95% CL exclusion contours in gluino-neutralino mass space





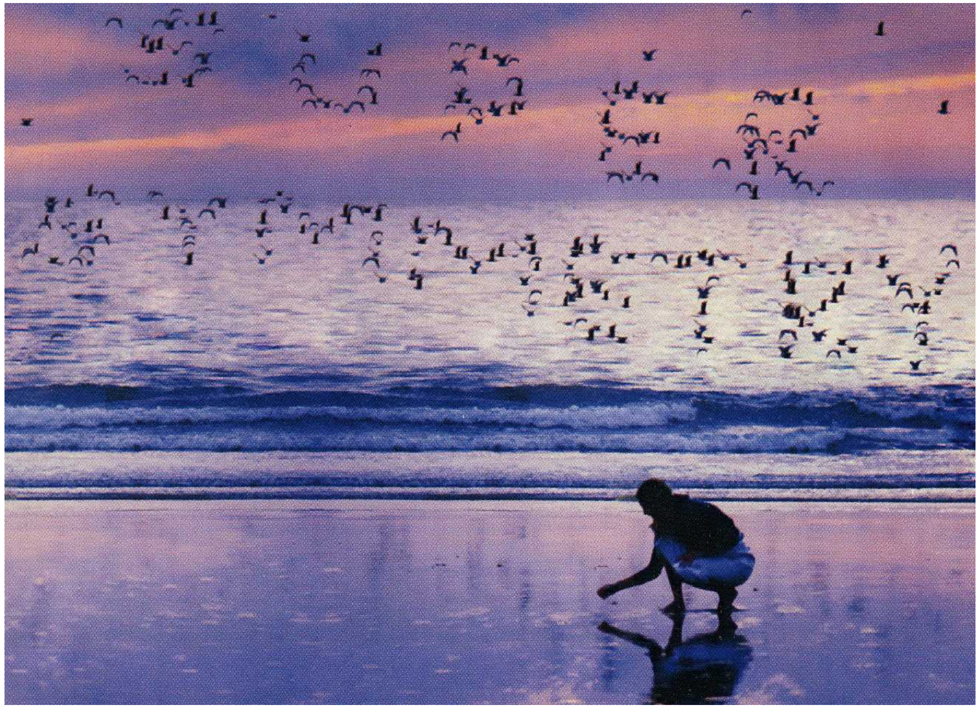
CMS PAS SUS-11-009



ATLAS arXiv:1111.4116 Submitted to PLB

Where we are...

- The CMS Experiment
- Hadronic searches
- Leptonic searches
- Searches with photons
- **Long-lived particles**



Long-lived Particles: Introduction

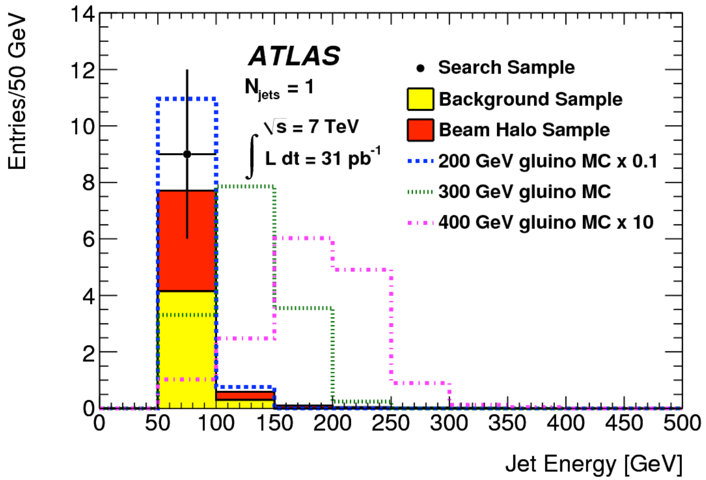
- Predicted by several theories, e.g. split-SUSY, gauge-mediated SUSY breaking, UED
- Split-SUSY: gluino decay suppressed by large squark mass
- Hadronization: long-lived gluinos bind with SM quarks/gluons ("R-hadrons")
- R-hadrons scatter via the nuclear force → exchange partons with the detector material (e.g. $\tilde{g}q\bar{q} \rightarrow \tilde{g}qqq$) → charge-flip between electrically neutral, singly- and doubly-charged states in detector
- R-hadrons might be produced near threshold → slow (β<1) → large ionisation → might be stopped and decay late → search in empty bunches
- Decay via $\tilde{g} \rightarrow g\tilde{\chi}_1^0$ or $\tilde{g} \rightarrow \bar{q}q\tilde{\chi}_1^0$

- **Background in empty bunches:**
  - Cosmic-ray muons, beam-halo muons, proton-proton collisions, proton-gas collisions, calorimeter noise

- **2 signal channels:**
  - Single-jet channel
  - Multi-jet channel (due to very high-energetic R-hadrons)

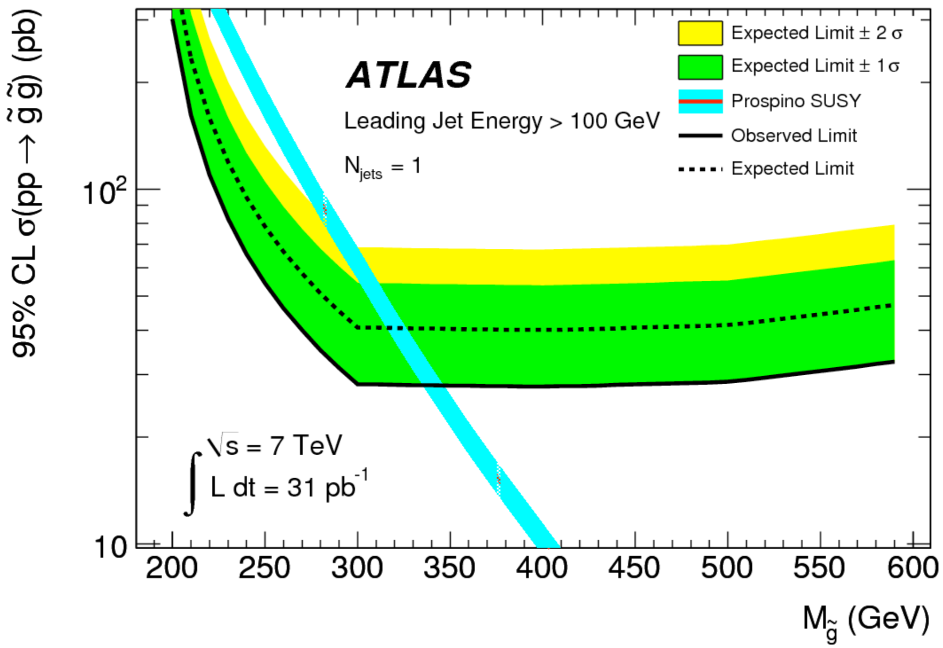
Long-lived Particles: Result

- Limit on R-hadrons decaying to a gluon and LSP ($m\chi_1^0$ =100 GeV) with lifetime between 10^{-5} to 10^3 seconds



Jet energy for the single jet channel, for selected events before the leading jet energy requirement p_T>100 GeV

No excess observed!

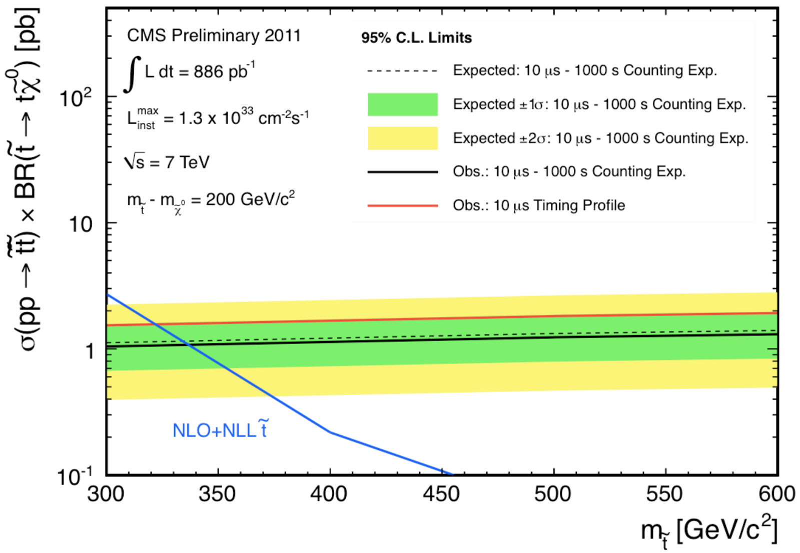


Limit on gluino mass for $m\chi_1^0$ =100 GeV

ATLAS
arXiv 1201.5595
Submitted to EPJC

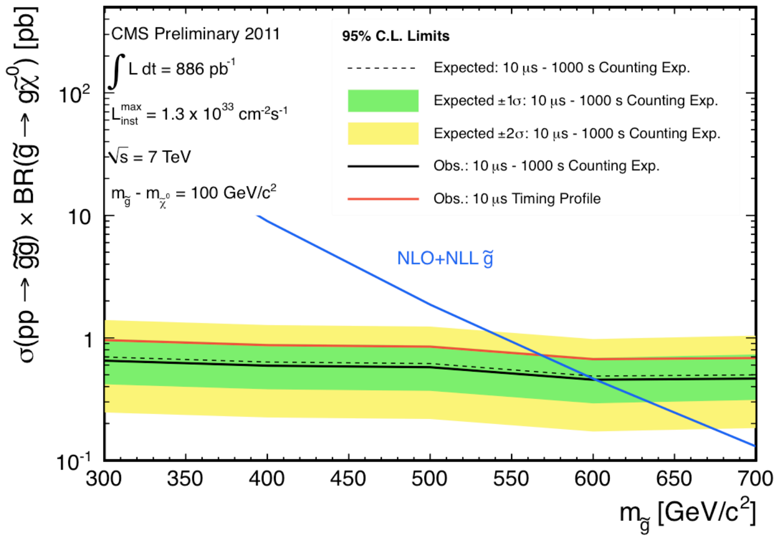
Long-lived Particles: Result

- Similar results from CMS



Limit on stop anti-stop mass for $m\chi_1^0$ =100 GeV

No excess observed!



Limit on gluino mass for $m\chi_1^0$ =100 GeV

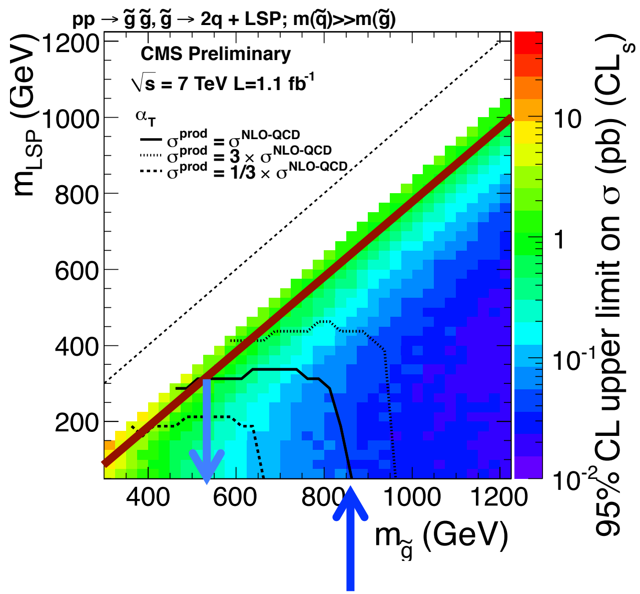
CMS PAS EXO-11-020

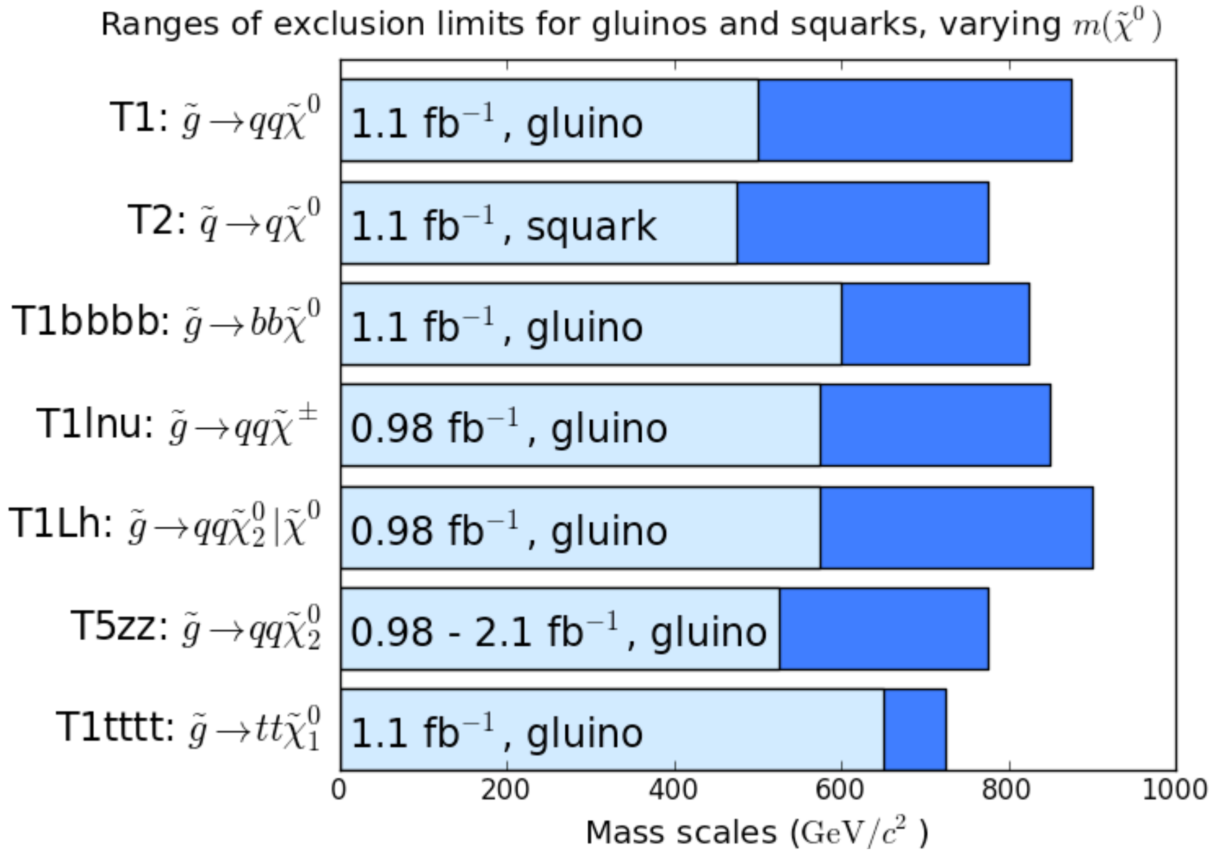
Summary CMS: Interpretation with Simplified Models

- For limits on m(gluino): m(squark)>>m(gluino) and vice verso

$$\sigma^{prod} = \sigma^{NLO\text{-}QCD}$$

$$m(\tilde{\chi}^{\pm}),\ m(\tilde{\chi}^{0}_{2}) = \frac{m(\tilde{g}) + m(\tilde{\chi}^{0})}{2}$$

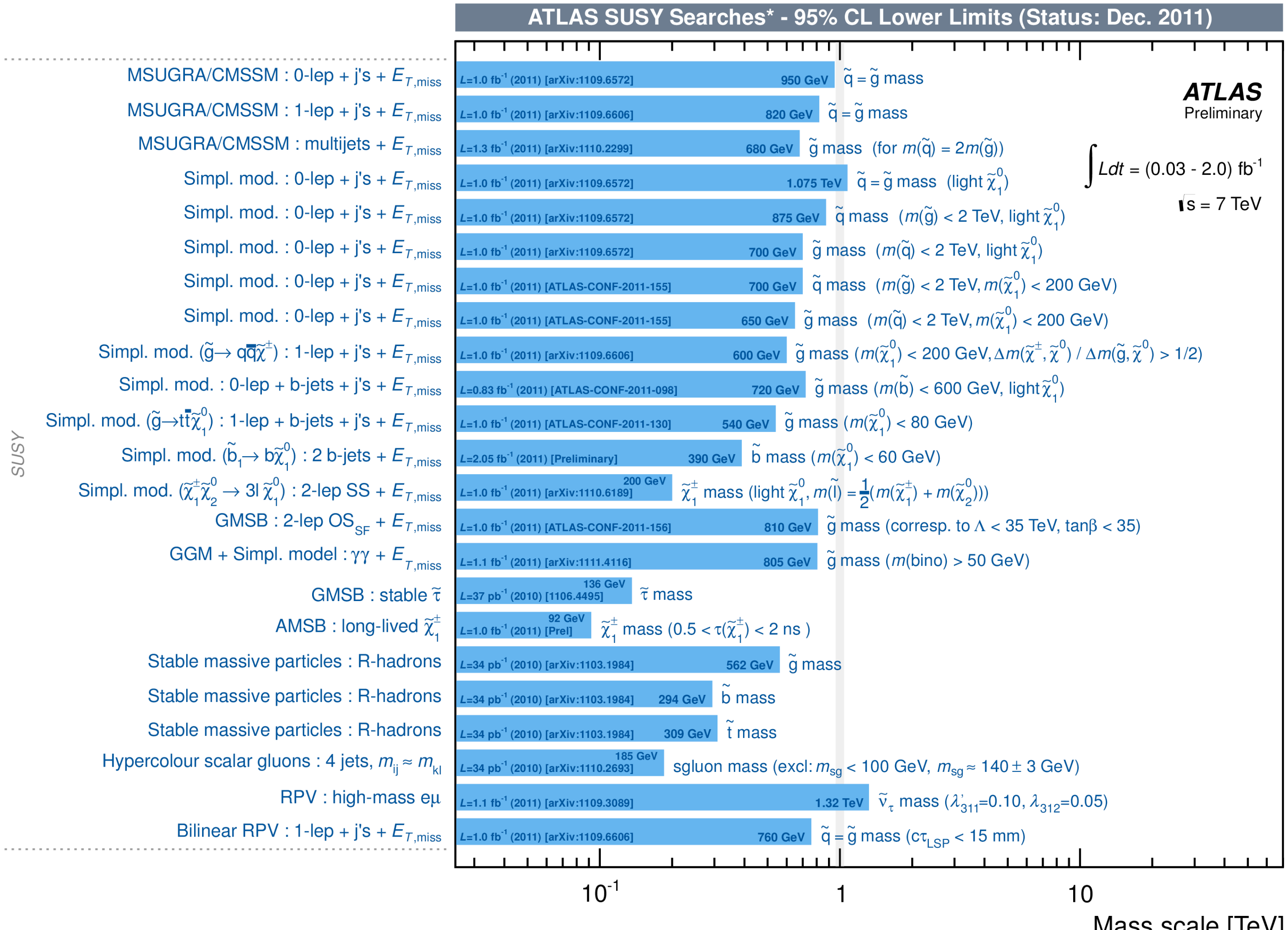




$m(\chi^0)$=m(gluino)-200GeV
(light blue)

$m(\chi^0)$=0
(dark blue)

Summary ATLAS: Interpretation with Simplified Models

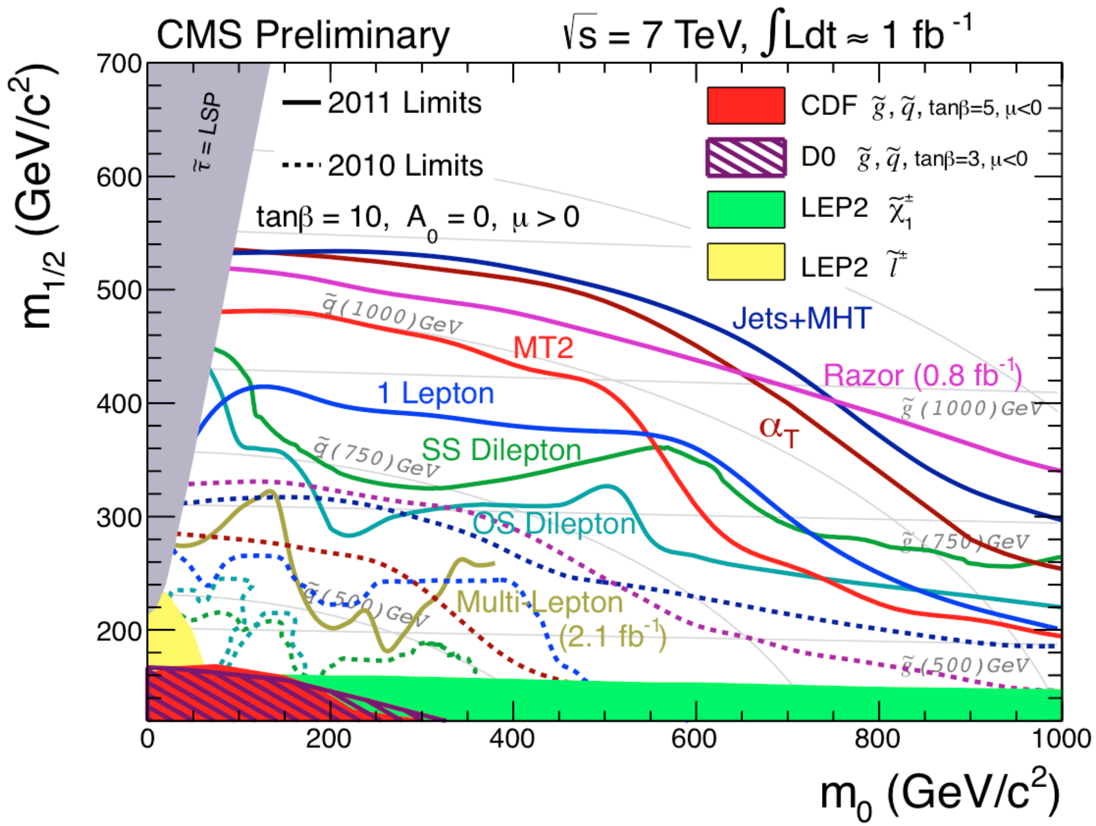


*Only a selection of the available results leading to mass limits shown

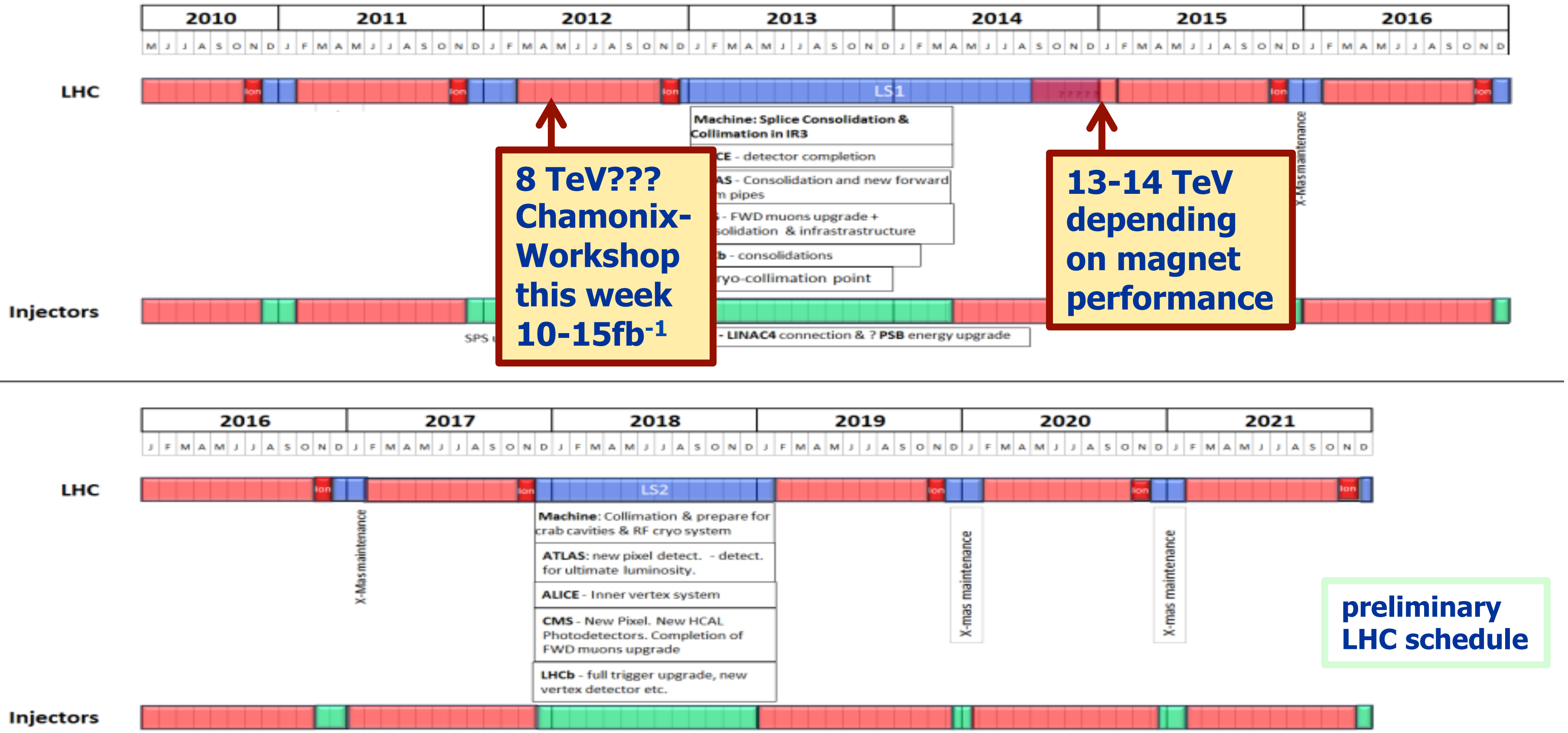
Summary

- Results from many analyses have been presented based on 2011 data
- None of the analyses has observed any significant deviation from the Standard Model ☹
- Exclusion limits have been set
  - Using cMSSM
  - In simplified models

Many more results with full 2011 data expected for Moriond…



Outlook – next years…



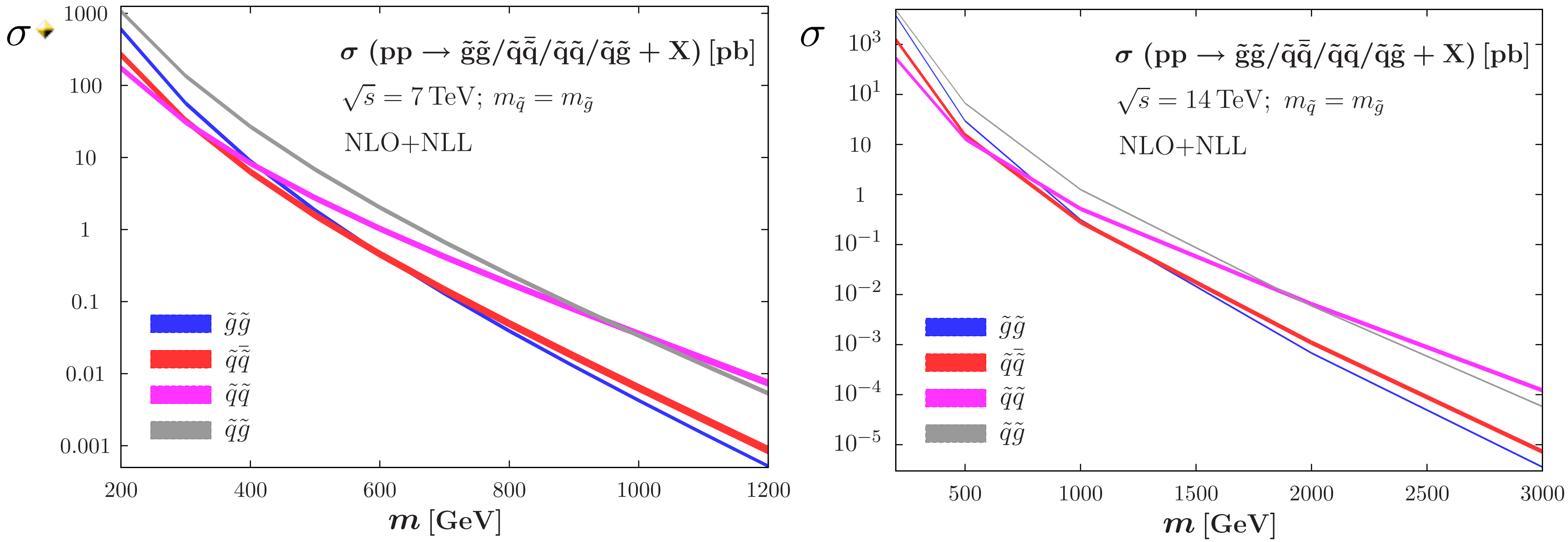
- Higher energy → higher cross-sections
- Reach for higher sparticle masses

Outlook – next years...

- Higher energy → higher cross-sections
- Reach for higher sparticle masses

NLO+NLL QCD cross section

[Beenakker, Höpker, Spira, Zerwas '96; Beenakker, Brensing, MK, Laenen, Kulesza, Niessen '09]

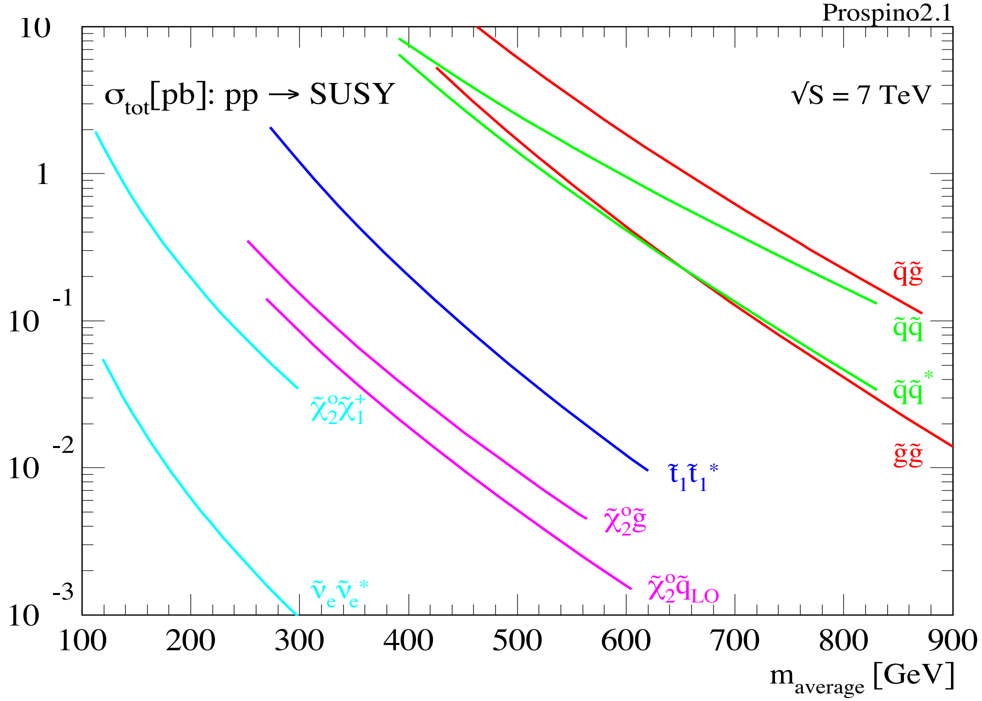


7 TeV → 14 TeV

σ(m≈500 GeV) ≈ 20 pb → σ(m≈1000 GeV) ≈ 2.5 pb

Outlook – next years...

- Experiments will continue "standard" analysis, and in addition tune analyses to have better reach for special models, e.g. 3rd generation searches, EWkino production

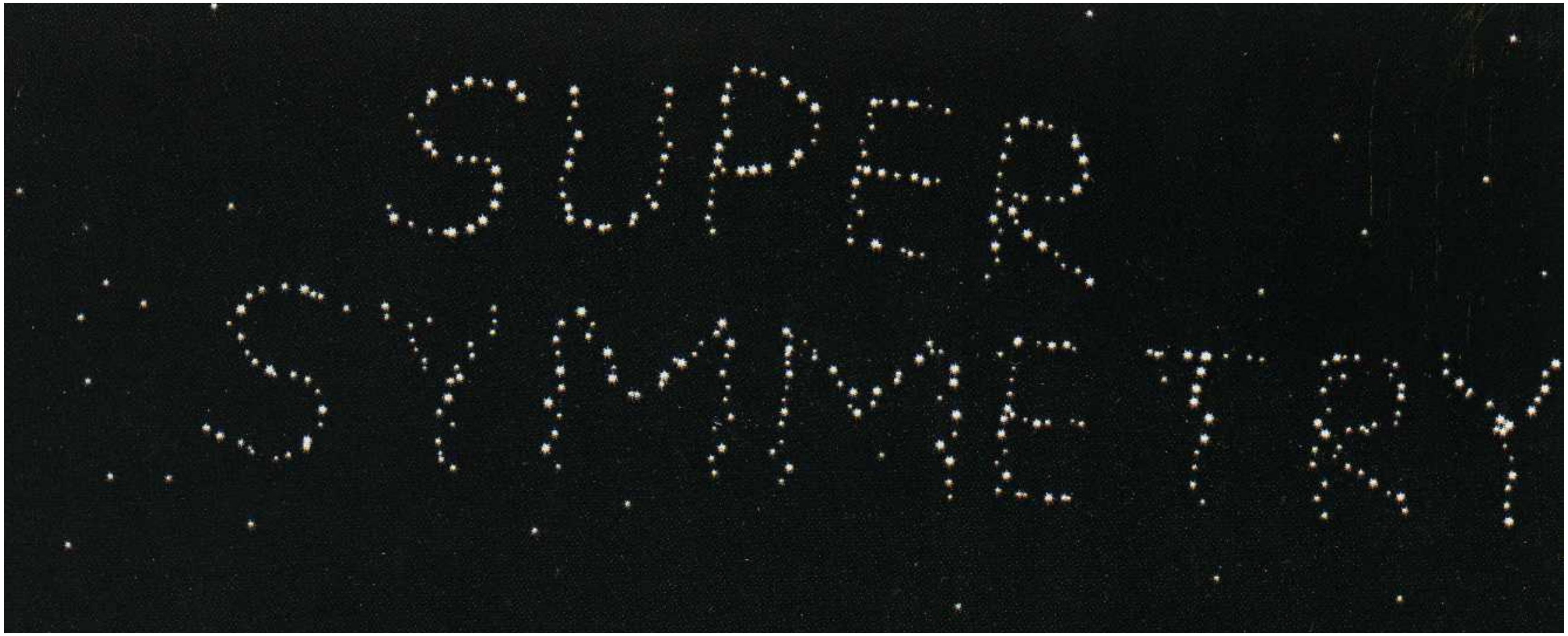


Production cross-sections

Much more interesting data to come – stay tuned...

Thank you for listening

Backup slides

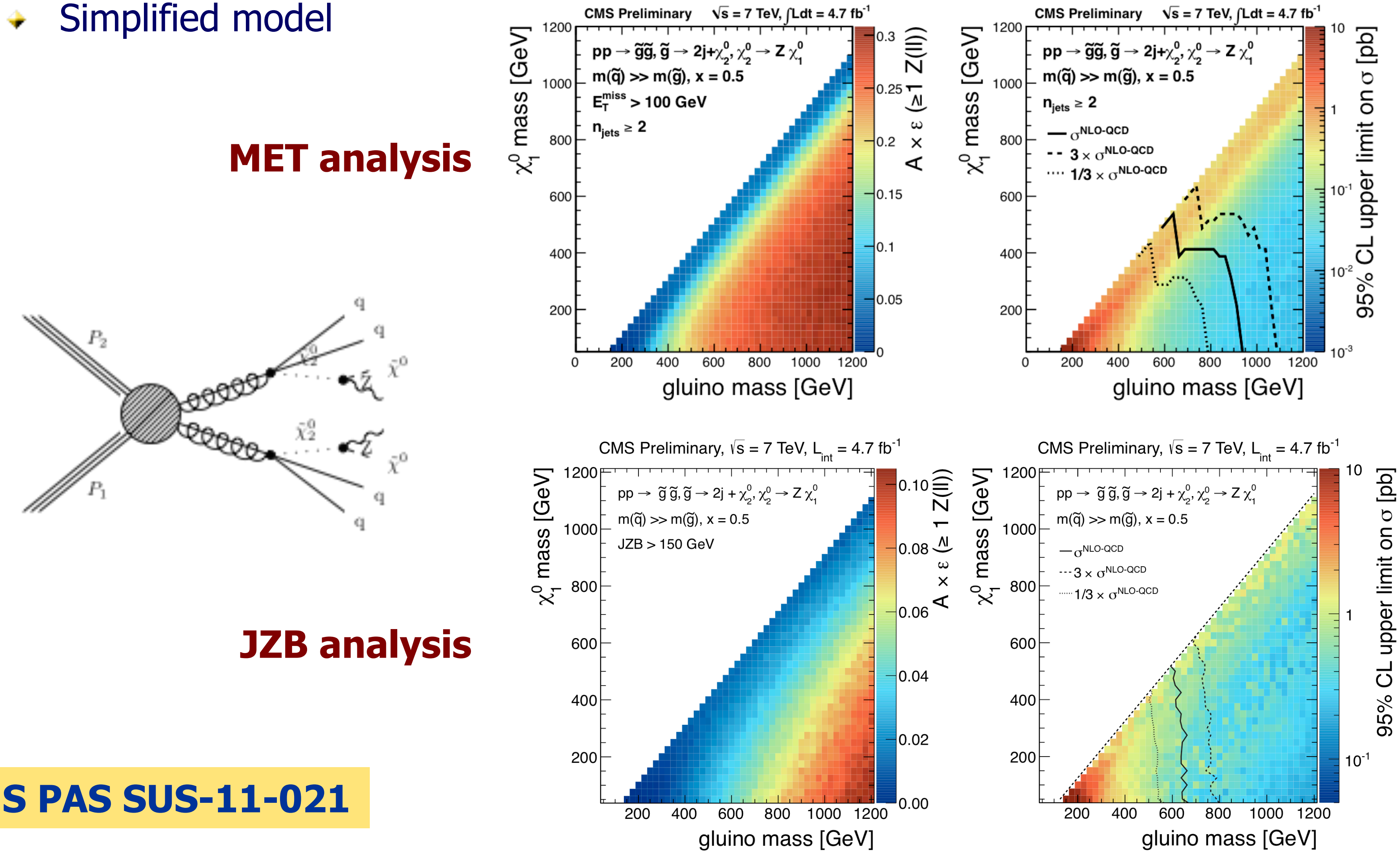


Opposite Sign Di-Leptons: Interpretation

- Simplified model

MET analysis

JZB analysis



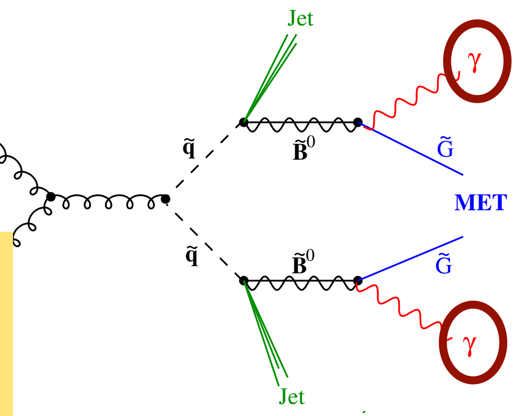
CMS PAS SUS-11-021

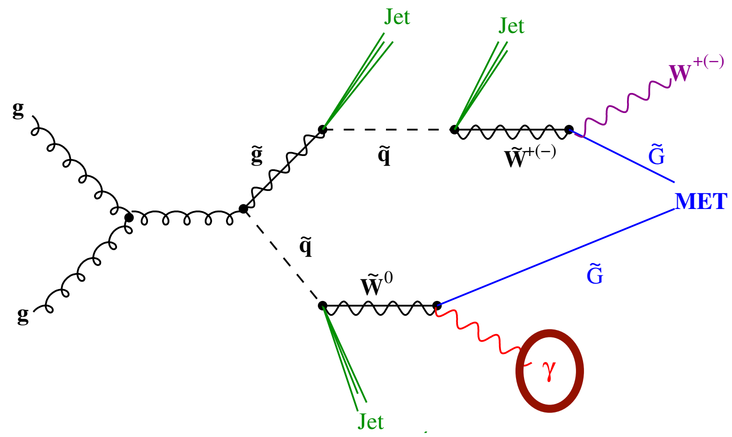
Searches with Photons: Introduction

In General Gauge Mediated SUSY

- Gravitino is LSP
- Neutralino is NLSP
  - Neutralinos: mix of Binos, neutral Winos, and Higgsinos
  - In CMS up to now: interpretation via a “Bino-like” neutralino model, with $\chi_0^1 \rightarrow \gamma + G$ (undetected G $\Rightarrow E_T^{miss}$)
  - Conserve R parity ⇒ two neutralinos ⇒ di-photon analysis
- NEW: Add simplified model where the Wino is less massive than the Bino, resulting in a neutralino-chargino co-NLSP
  - Photons not as common as in Bino-like case, but still occuring, most frequently at lower neutralino mass ⇒ single photon analysis

Phys. Rev. Lett. 106, 211802 (2011)
CMS PAS SUS-11-009

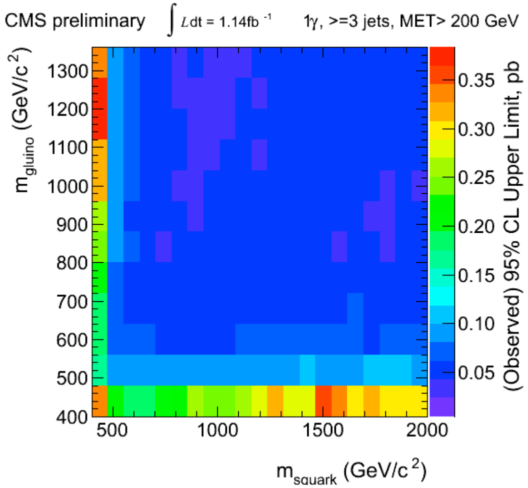


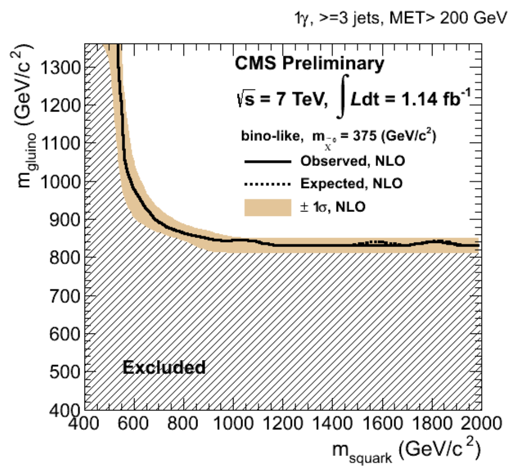


Searches with Single Photons: Results

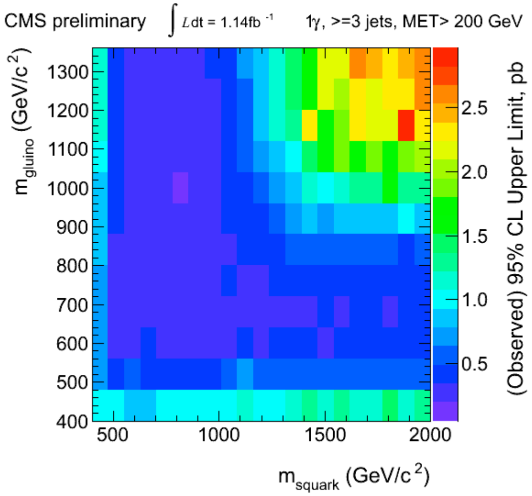
95% CL upper limit in gluino-squark mass space

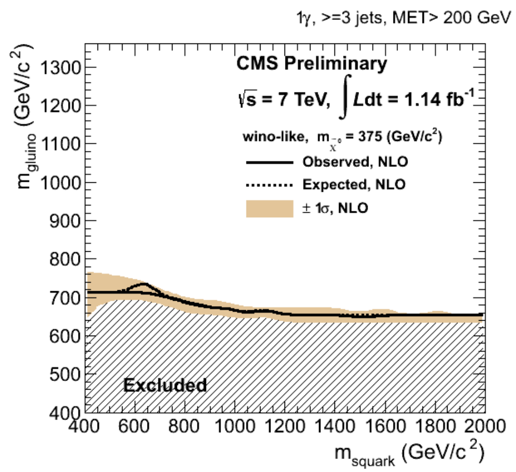
95% CL exclusion contours in gluino-squark mass space





- Bino-like





- Wino-like

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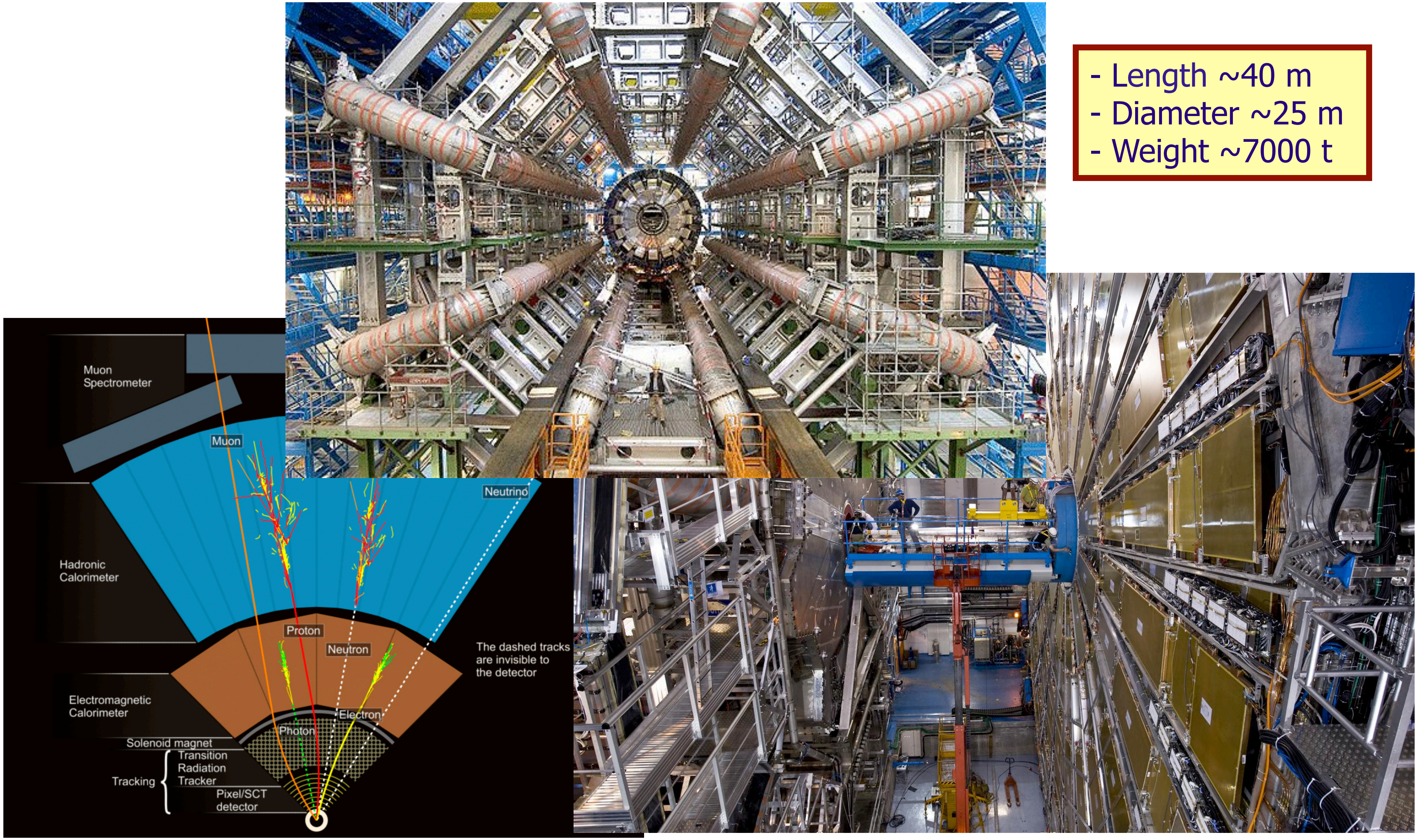
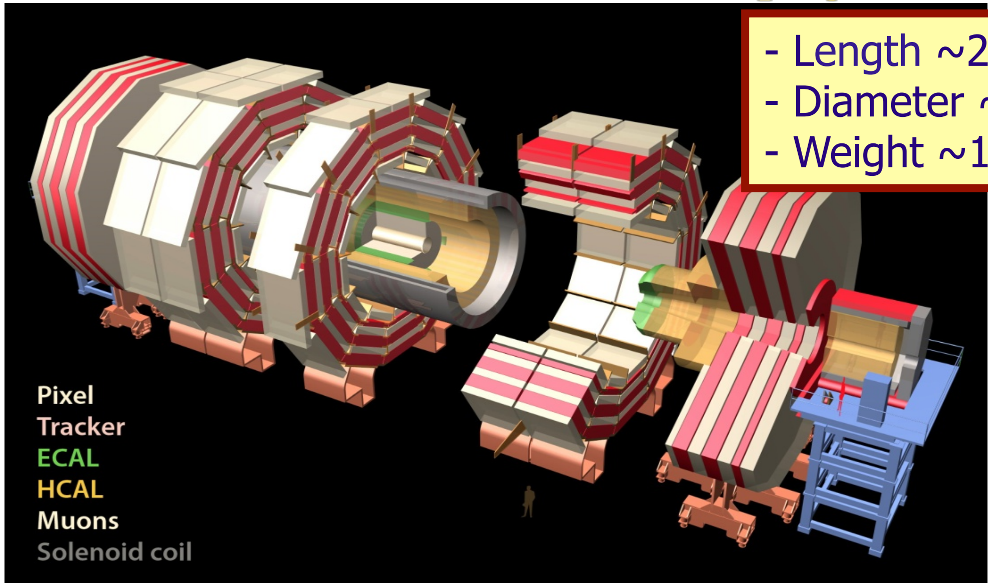
A Toroidal LHC ApparatuS

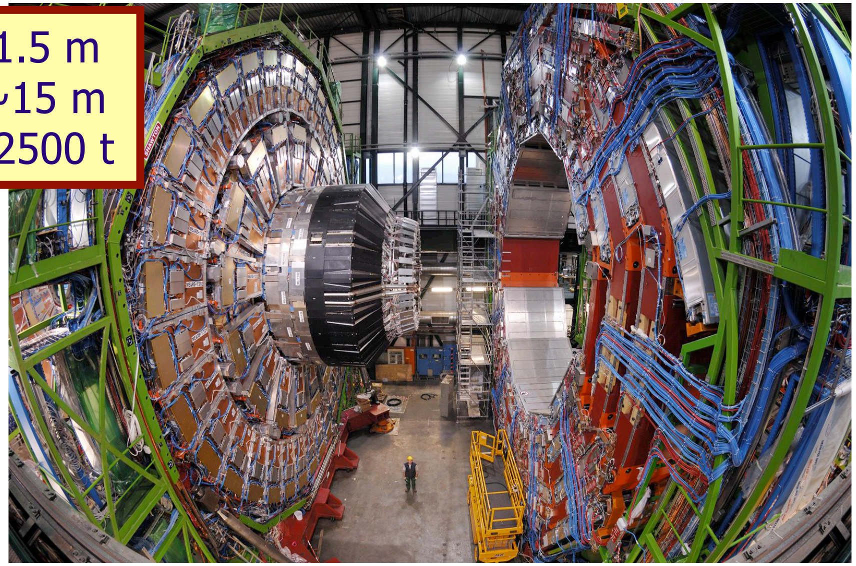


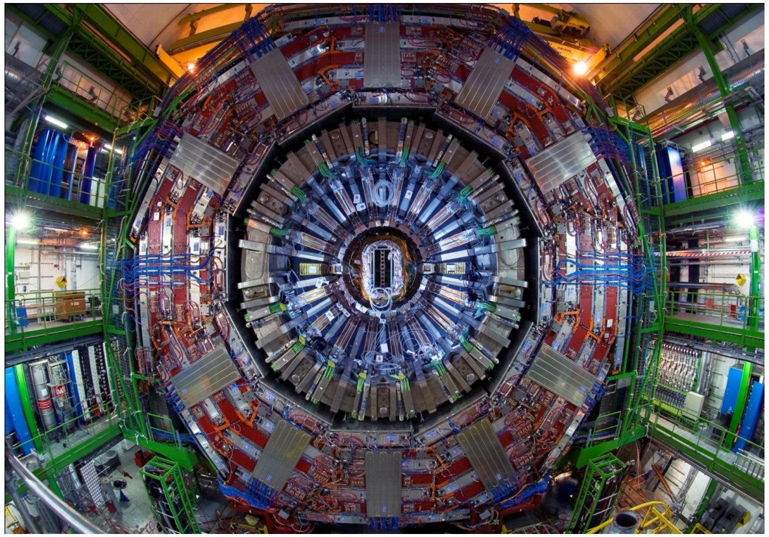
- Length ~40 m
- Diameter ~25 m
- Weight ~7000 t

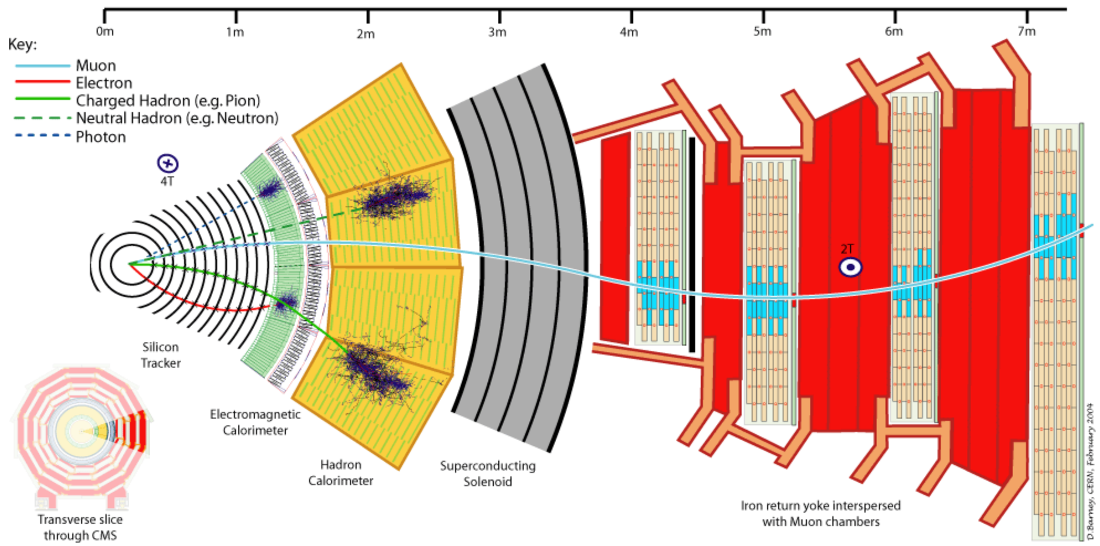
Compact Muon Solenoid (CMS)

- Length ~21.5 m
- Diameter ~15 m
- Weight ~12500 t





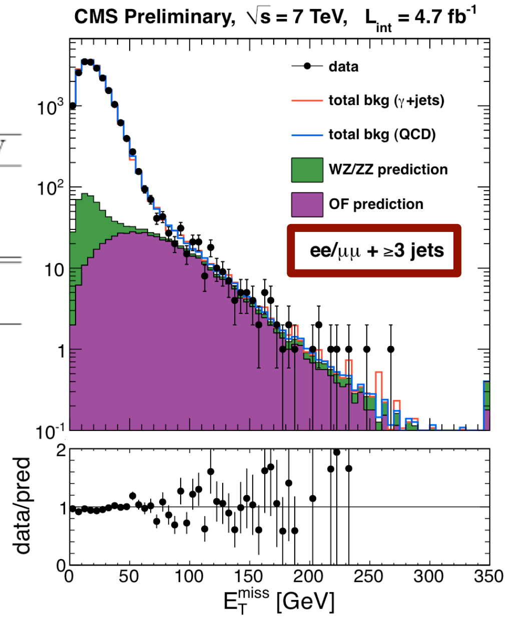


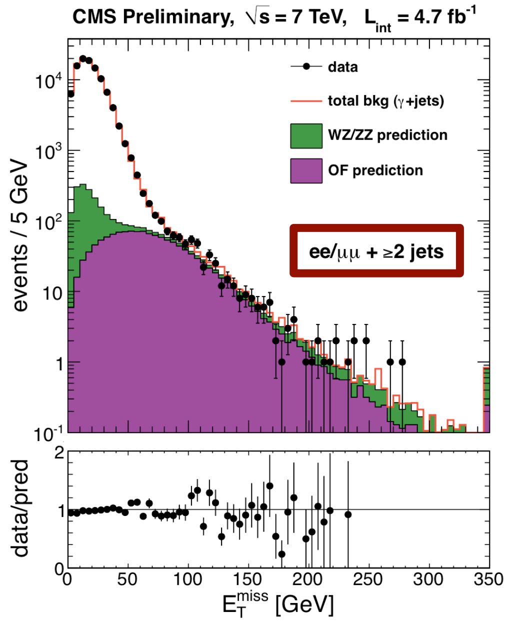


Opposite Sign Di-Leptons: Results (Z-region)

- E_T^{miss} **measurement:**

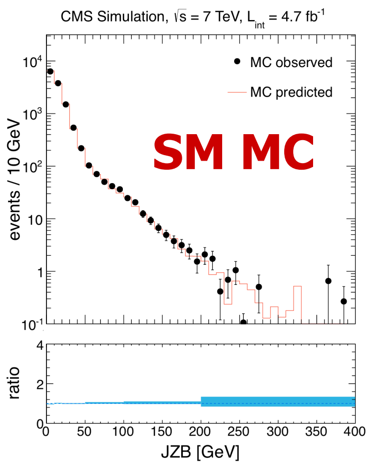
	E_T^{miss} 100 – 200 GeV	E_T^{miss} 200 – 300 GeV	E_T^{miss} > 300 GeV
Z bkg	33 ± 12	1.9 ± 0.8	0.4 ± 0.3
OF bkg	215 ± 20	10 ± 3.0	1.6 ± 0.6
VZ bkg	27 ± 14	4.0 ± 2.0	1.1 ± 0.7
total bkg	**276 ± 27**	**16 ± 3.0**	**3.1 ± 1.0**
data	**276 (134,142)**	**14 (8,6)**	**0**

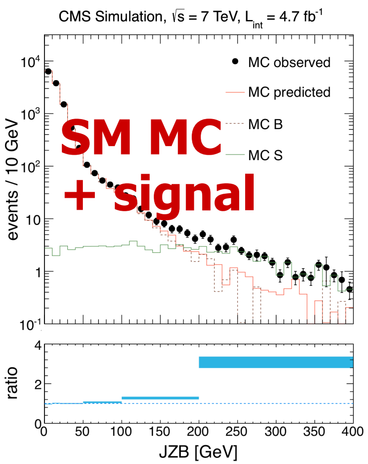


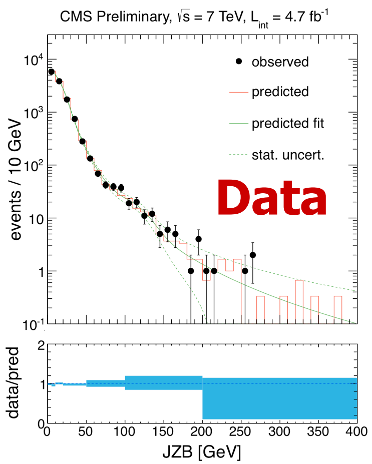


No excess observed!

- **Jet-Z balance method:**



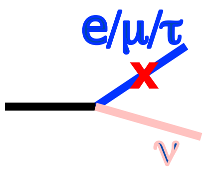




	JZB > 50 GeV	100 GeV	150 GeV	200 GeV	250 GeV
Z bkg	$97 \pm 13 \pm 38$	$8 \pm 3 \pm 3$	$2.7 \pm 1.8 \pm 0.8$	$1.0 \pm 1.0 \pm 0.25$	0
flavor-symmetric	$311 \pm 10 \pm 45$	$81 \pm 5 \pm 12$	$19 \pm 3 \pm 3$	$7 \pm 2 \pm 1$	$2.0 \pm 0.8 \pm 0.3$
total bkg	$408 \pm 16 \pm 59$	$89 \pm 6 \pm 12$	$22 \pm 3 \pm 3$	$8 \pm 2 \pm 1$	$2.0 \pm 0.8 \pm 0.3$
data	**408 (203,205)**	**88 (52,36)**	**21 (13,8)**	**5 (3,2)**	**3 (2,1)**
upper limit	114	32	14	6	6
LM4	57 ± 2	48 ± 2	38 ± 1	27 ± 1	17 ± 1
LM8	21 ± 1	18 ± 1	15 ± 1	11.0 ± 0.5	7.0 ± 0.4

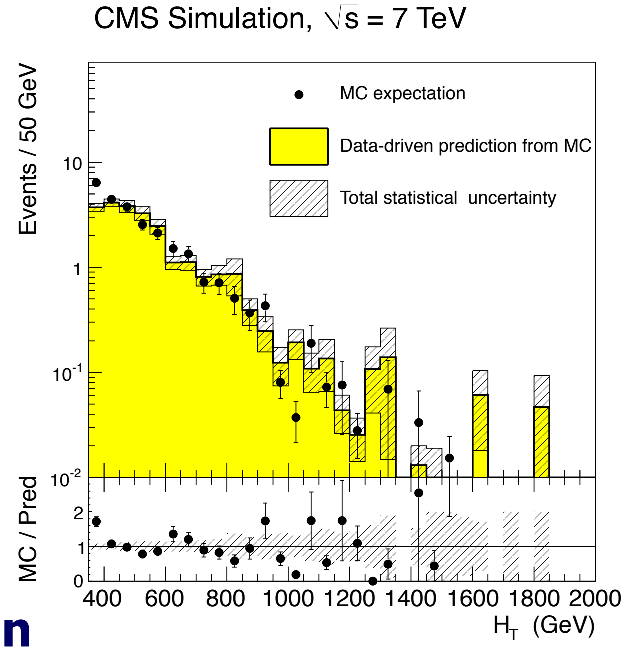
CMS PAS SUS-11-021

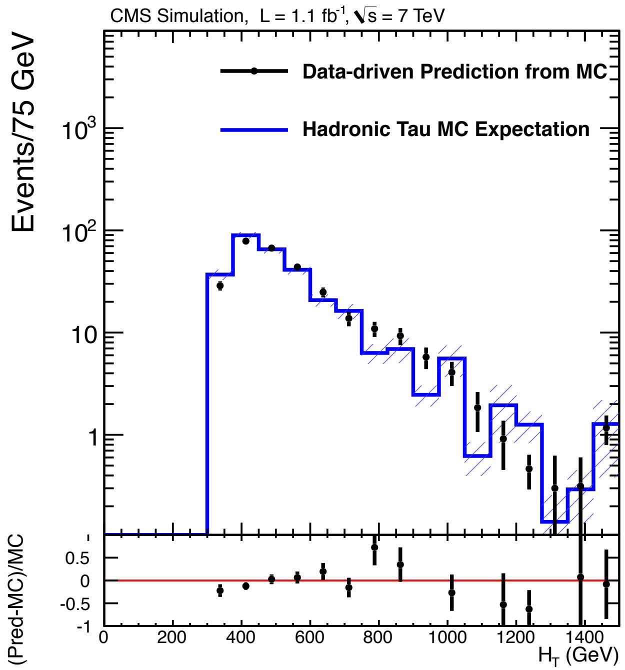
Inclusive All-Hadronic Search: W and Top Background Estimation



Lost Lepton Background Estimation

- Muon control sample with $M_T < 100$ GeV with $M_T = \sqrt{(2 p_T^{\mu} E_T^{miss} (1-\cos\phi))}$ used to model:
  - Non-isolated (but identified) leptons
  - Non-identified leptons (ratio id/non-id taken from Monte Carlo)





τ Background Estimation

- Determined with a muon control sample
- Substitute μ with τ jet using response template to model the fraction of visible momentum
- Recalculate all quantities like H_T

CMS PAS SUS-11-004

Searches with Photons: Event Selection

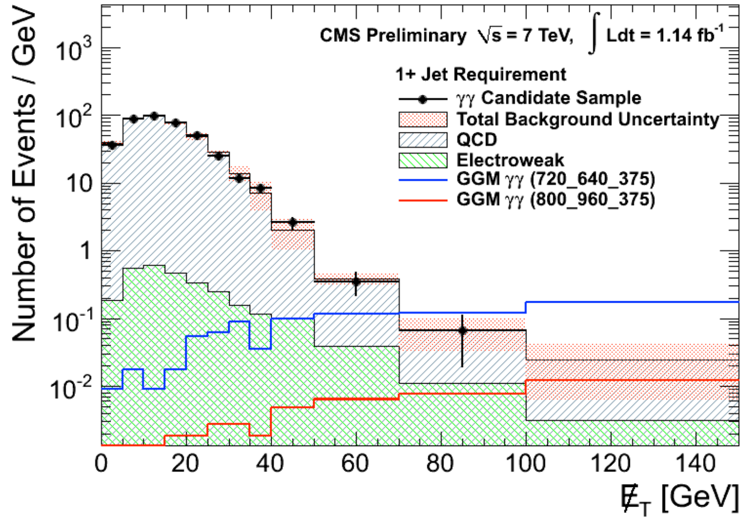
- **Di-photon analysis:**
  - At least 2 photons in barrel with $p_T^{\gamma 1} > 45$ GeV, $p_T^{\gamma 2} > 30$ GeV
  - At least 1 jet with $p_T > 30$ GeV, $|\eta|<2.6$
  - *Loose signal region:* $E_T^{miss} > 50$ GeV
  - *Tight signal region:* $E_T^{miss} > 100$ GeV

- **Single photon analysis:**
  - Exactly 1 photon in barrel with $p_T^{\gamma} > 75$ GeV (due to trigger constraint)
  - $H_T > 400$ GeV (also from trigger)
  - At least 3 jets with $p_T > 30$ GeV, $|\eta|<2.6$
  - $E_T^{miss} > 200$ GeV

CMS PAS SUS-11-009

Searches with Di-Photons: Background Determination

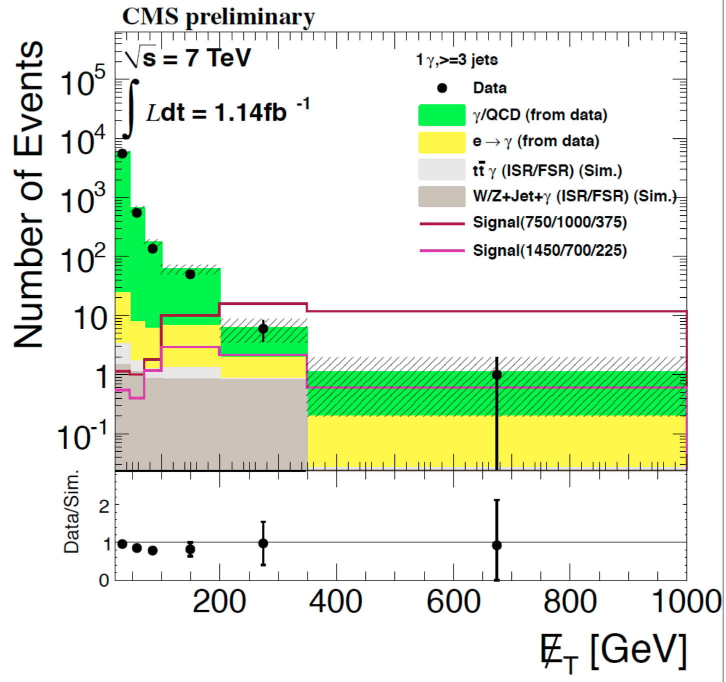
- **QCD background (no true E_T^{miss})**
  - Mis-measurement of E_T^{miss} in QCD processes and/or photon mis-identification:
    - Direct di-photon production
    - γ+jets and multijets, with jets mimicking photons
  - Background determined from samples with 2 fake γ or 2 electrons
- **Electroweak background with true E_T^{miss}**
  - Background from events with real or fake photon and W → νe (where e is misidentified as γ)
- **Fake rate determination**
  - Measure rate of events in Z region in eγ and ee sample:
    $f_{e\to\gamma}$ = 0.014 ± 0.0004 (stat.) ± 0.002 (syst.)



CMS PAS SUS-11-009

Searches with Single Photons: Background Determination

- Background determination similar to di-photon case
- Additional backgrounds: initial state radiation (ISR) and final state radiation (FSR) of photons:
  - ISR and FSR in events with electrons in final state covered by EW background prediction from data
  - Remaining contributions from SM process are very small – taken from Monte Carlo simulation with a systematic uncertainty of 100%.



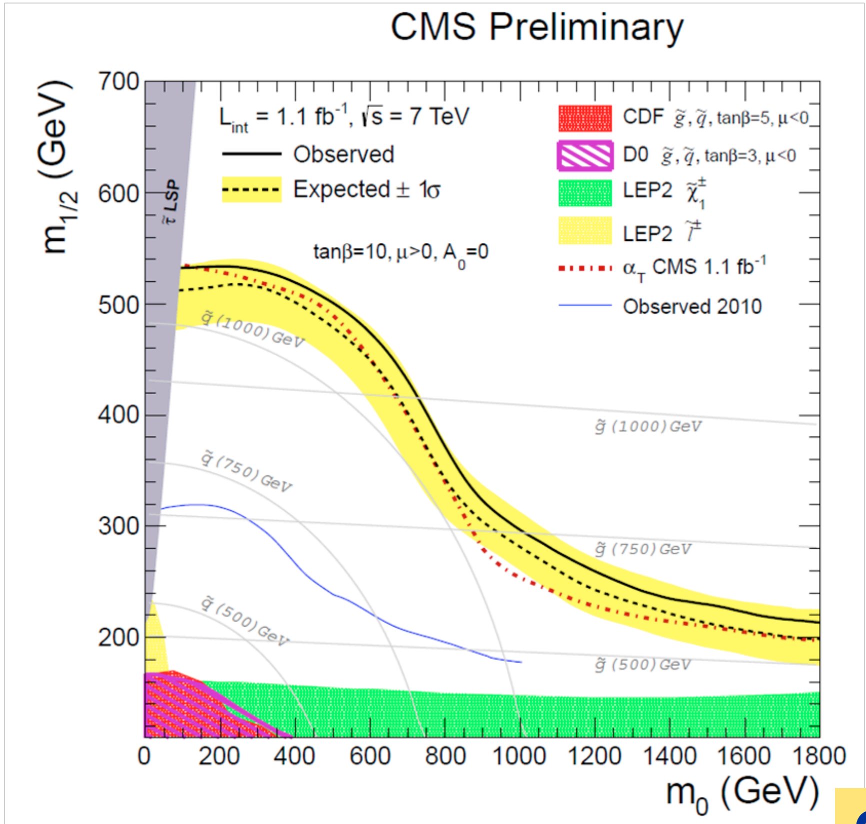
Sample	Event yield	(stat.)	(syst.)
Data	7		
QCD (est. from data)	5.16	±2.58	±0.62
EWK $e \to \gamma$ (est. from data)	1.22	±0.13	±0.04
FSR/ISR ($W \to \mu/\tau\nu, Z \to \nu\nu$) (Sim.)	0.80	±0.31	±0.80
FSR/ISR ($t\bar{t} \to \mu/\tau\nu + X$) (Sim.)	0.07	±0.05	±0.07
Total SM background estimate	7.24	±2.6	±1.53

No excess observed!

CMS PAS SUS-11-009

Inclusive All-Hadronic Search: Exclusion Plot

- Observed and expected 95% CL exclusion limit in the CMSSM m_0-$m_{1/2}$ plane using the signal cross sections calculated at NLO
- Contours are the combination of the different selections, such that the shown contours are the envelope with respect to best sensitivity



CMS PAS SUS-11-004