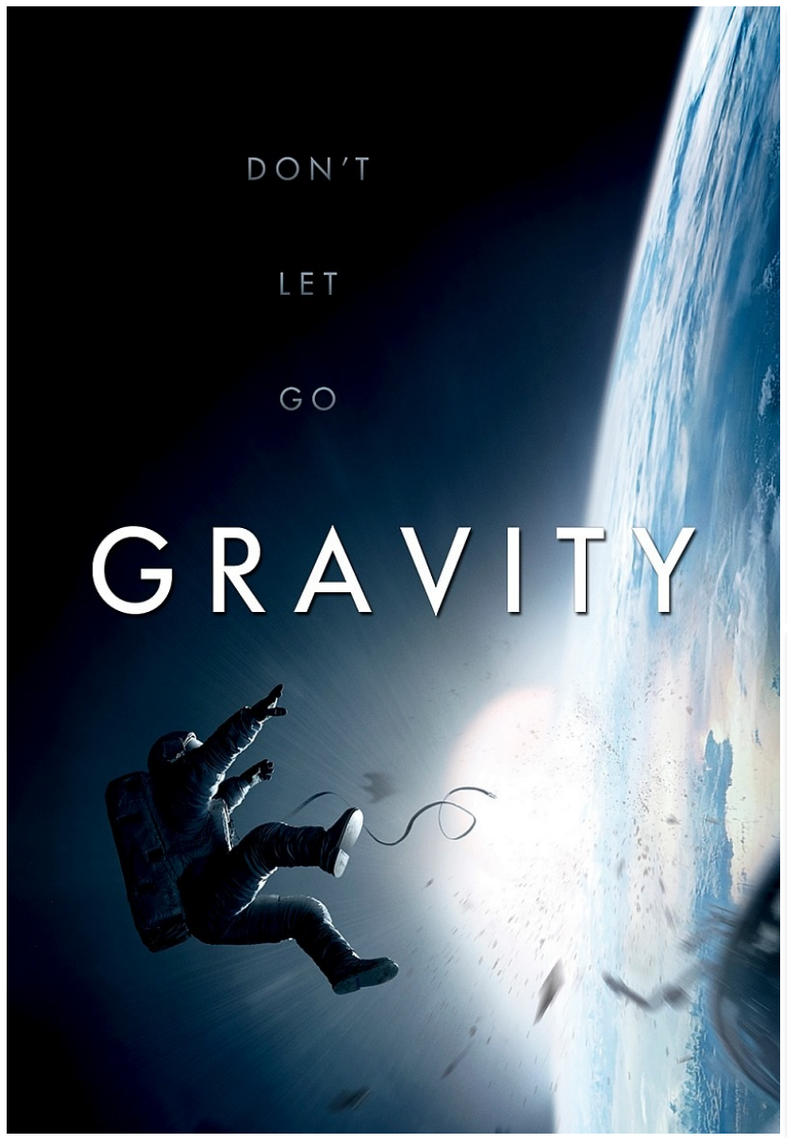
Theory of absence:
Jet vetoes for finding new physics

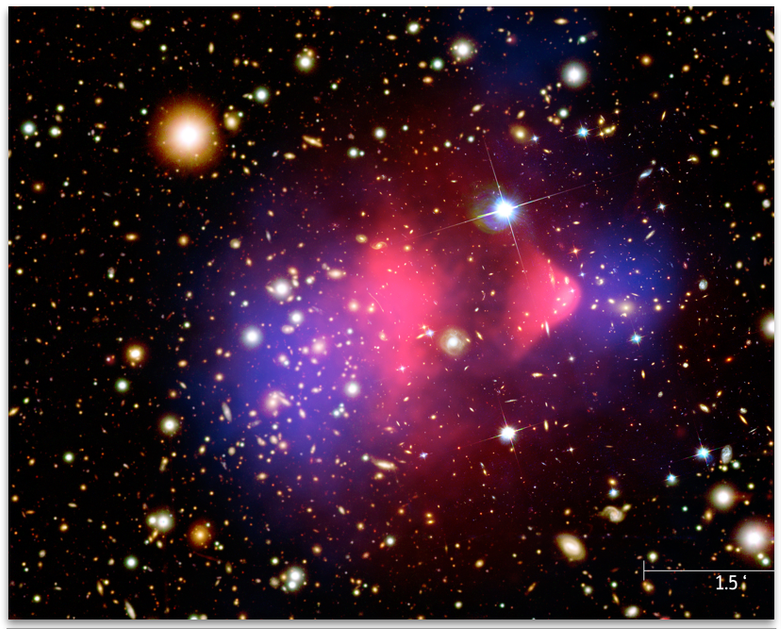
Lisa Zeune

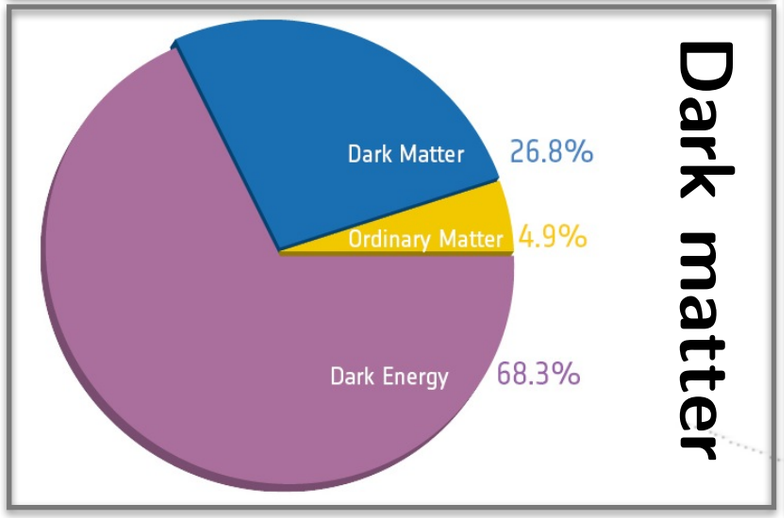
Nikhef Jamboree 2015

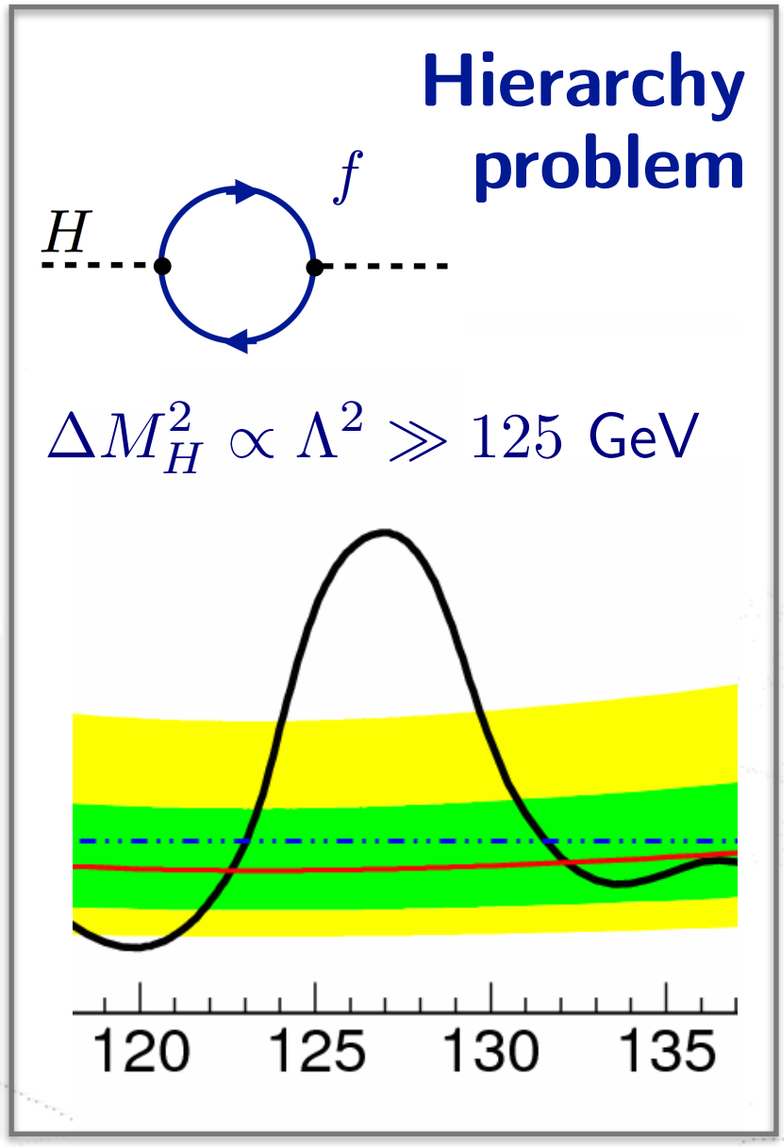
Amsterdam, 14 December 2015

New physics Beyond the Standard Model must exist









LHC run II started this year

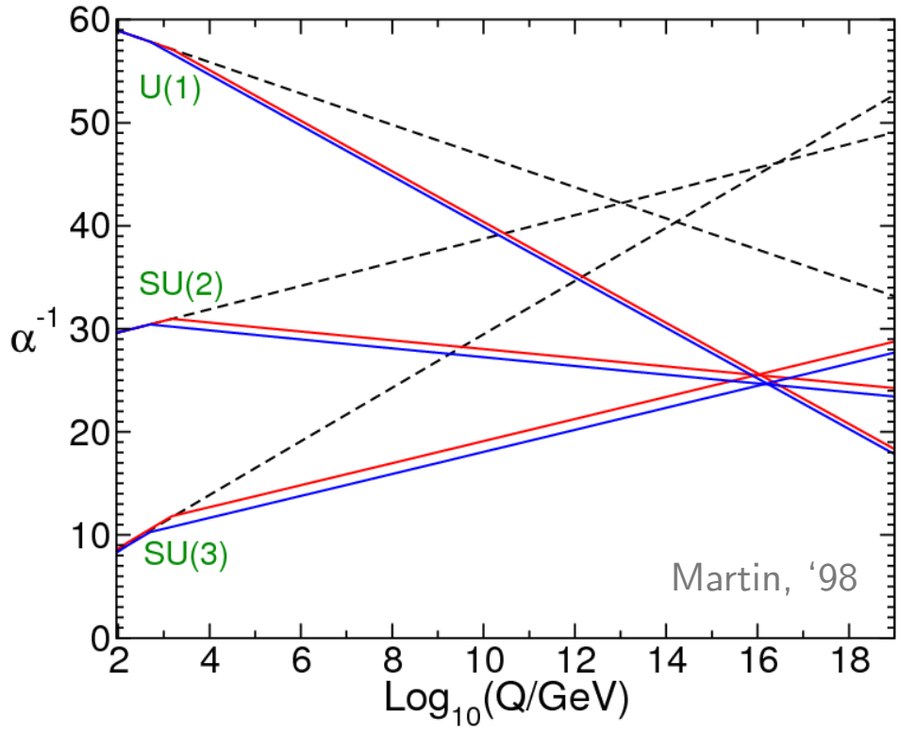
New energy range with opportunities for exciting new discoveries

Supersymmetry

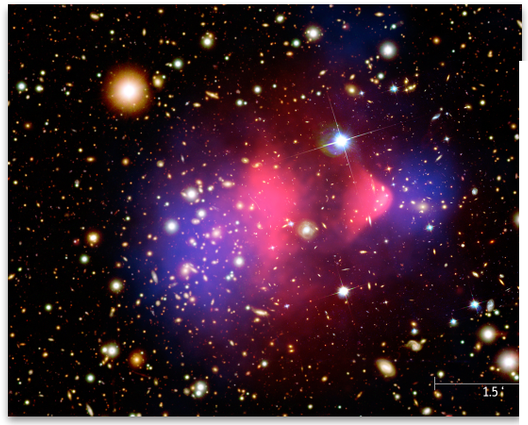
- Theoretically very appealing
  Only possible extension of the spacetime symmetries, which particle physics builds on

- Many nice features
  E.g. unification of gauge couplings

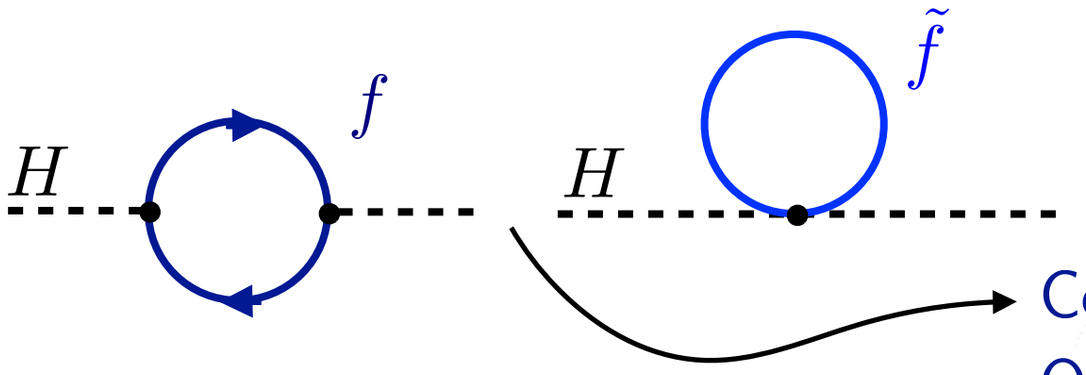
- Adresses important shortcomings of the Standard Model



↪ Provides a dark matter candidate
Lightest supersymmetric particle



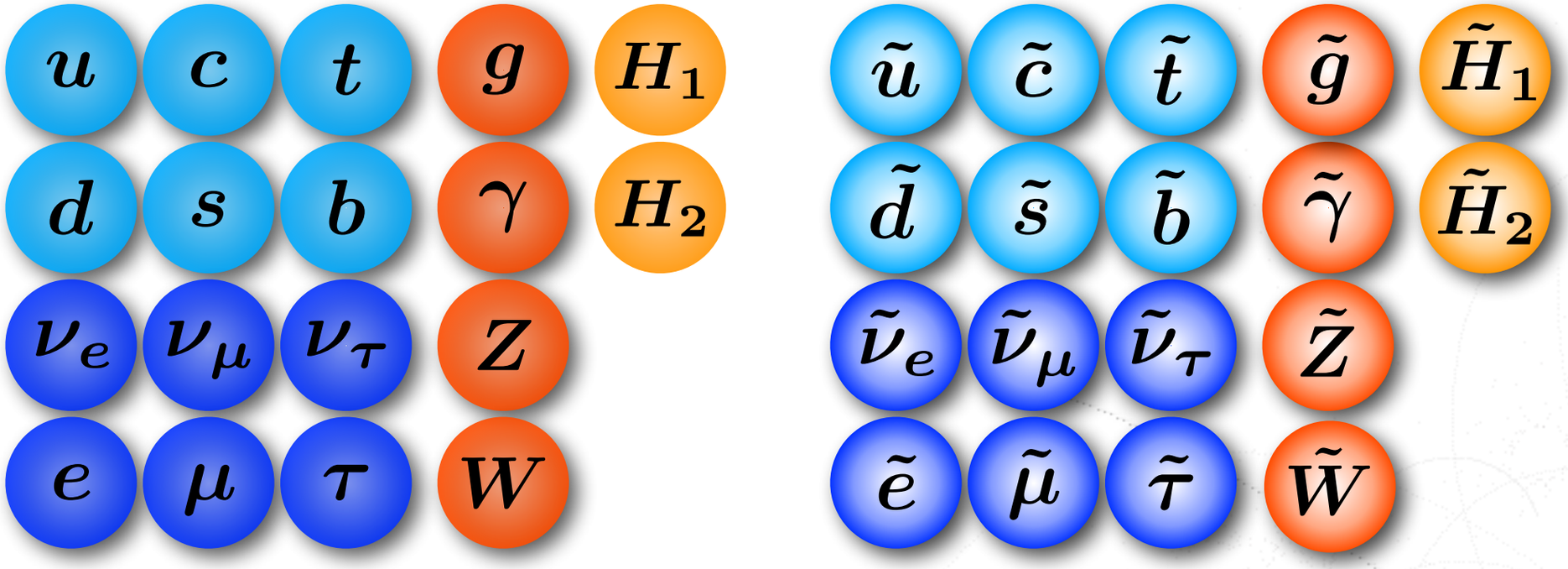
↪ Solves the hierarchy problem



Corrections enter with opposite signs:
Quadratic divergencies cancel

The Minimal Supersymmetric Model

- Supersymmetry (SUSY) transforms a bosonic state in a fermionic state and vice versa: Particle content of the SM approximately doubled
- No SUSY particles observed yet
- The LHC experiments undertake enormous efforts to search for these particles



Jet vetoes important for new physics searches

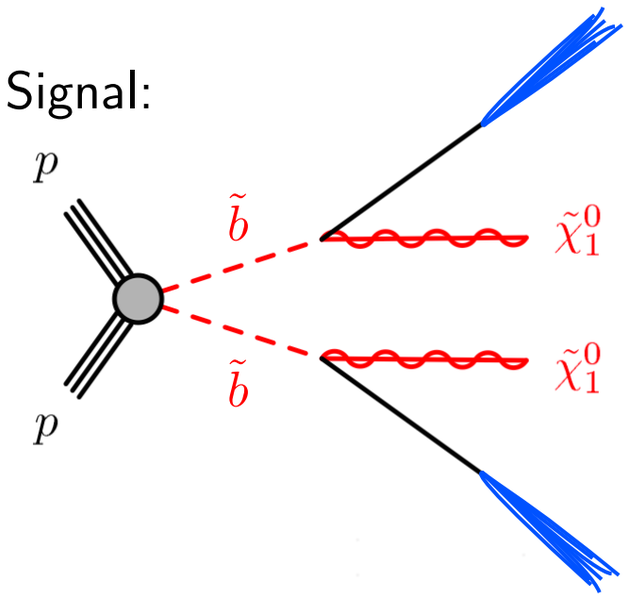
- **Main challenge:** Distinguish new physics (e.g SUSY) from overwhelming Standard Model background

ATLAS Supersymmetry (SUSY) example:

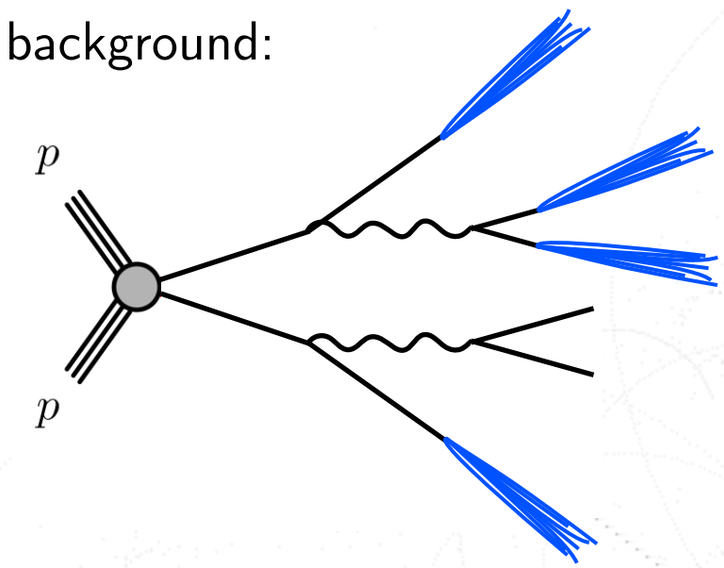
Search for sbottoms

JHEP 10 (2013) 189

Signal:



Standard Model background:



Veto third jet

Description	SRA
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150 GeV
Leading jet $p_{\mathrm{T}}(j_1)$	> 130 GeV
Second jet $p_{\mathrm{T}}(j_2)$	> 50 GeV,
Third jet $p_{\mathrm{T}}(j_3)$	**veto if > 50 GeV**

Many LHC analyses use jet vetoes...

Stop and sbottom searches

- ATLAS (1308.2631) "Search for direct third-generation squark pair production in final states with missing transverse momentum and two b-jets in 8 TeV pp collisions with the ATLAS detector"
- CMS (CMS-PAS-SUS-13-018) "Search for direct production of bottom squark pairs"
- ATLAS (1506.08616) "ATLAS Run 1 searches for direct pair production of third-generation squarks at the Large Hadron Collider"

Electroweakino searches

- ATLAS (1407.0350) "Search for the direct production of charginos, neutralinos and staus in final states with at least two hadronically decaying taus and missing transverse momentum in pp collisions at 8 TeV with the ATLAS detector"
- ATLAS (1403.5294) "Search for direct production of charginos, neutralinos and sleptons in final states with two leptons and missing transverse momentum in pp collisions at 8 TeV with the ATLAS detector"
- CMS (1405.7570) "Searches for electroweak production of charginos, neutralinos, and sleptons decaying to leptons and W, Z, and Higgs bosons in pp collisions at 8 TeV"
- ATLAS (1501.07110) "Search for direct pair production of a chargino and a neutralino decaying to the 125 GeV Higgs boson in 8 TeV pp collisions with the ATLAS detector"
- ATLAS (1509.07152) "Search for the electroweak production of supersymmetric particles in 8 TeV pp collisions with the ATLAS detector"

Other new physics searches

- CMS (CMS-PAS-SUS-14-019) "Search for dark matter and compressed mass-spectra supersymmetry with the vector boson fusion topology in pp collisions at 8 TeV"
- ATLAS (1211.6096) "Measurement of ZZ production in pp collisions at 7 TeV and limits on anomalous ZZZ and ZZγ couplings with the ATLAS detector"
- ATLAS (1404.0051)"Search for dark matter in events with a Z boson and missing transverse momentum in pp collisions at 8 TeV with the ATLAS detector"
- ATLAS (1508.04735) "Searches for scalar leptoquarks in pp collisions a 8 TeV with the ATLAS detector"
- ...

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  Collider"

Electroweakino searches

- ATLAS (1407.0350) "Search for the direct production of charginos, neutralinos and staus in final states with at least two hadronically decaying taus and missing transverse momentum in pp
- ATLAS (1403.5294) "Search for direct production of charginos, neutralinos and sleptons in final states with two leptons

Jet vetoes are even more important when a new particle is discovered, facilitating clean and precise measurements

- ATLAS (1509.07152) "Search for the electroweak production of supersymmetric particles in 8 TeV pp
  ATLAS detector"

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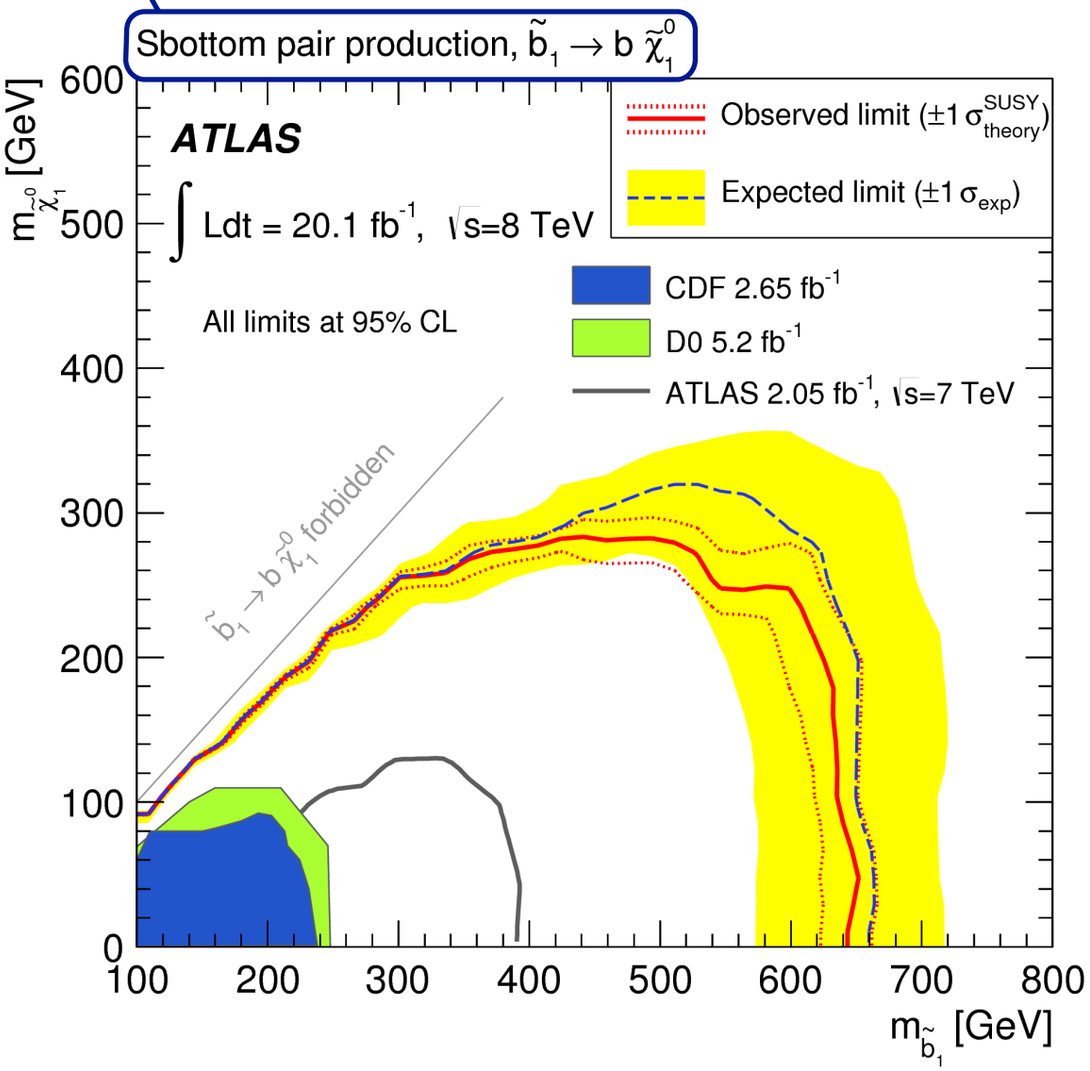
Exclusion limits

Exclusion limits presented in Simplified Models



- Exclusion limits used in many phenomenological studies
- Tools to test your favourite model against the LHC exclusion limits:

CheckMATE	Desai, Drees, Dreiner, Kim, Rolbiecki, Schmeier, Tattersall
ATOM	Kim, Papucci, Sakurai, Weiler
MadAnalysis	Bein, Chalons, Conte, Dumont, Fuks, Kulkarni, Kraml, Schmitt, Sengupta, Wymant
FastLim	Papucci, Sakurai, Weiler, LZ
SmodelS	Kraml, Kulkarni, Laa, Lessa, Magerl, Magerl, Proschofsky, Traub, Waltenberger
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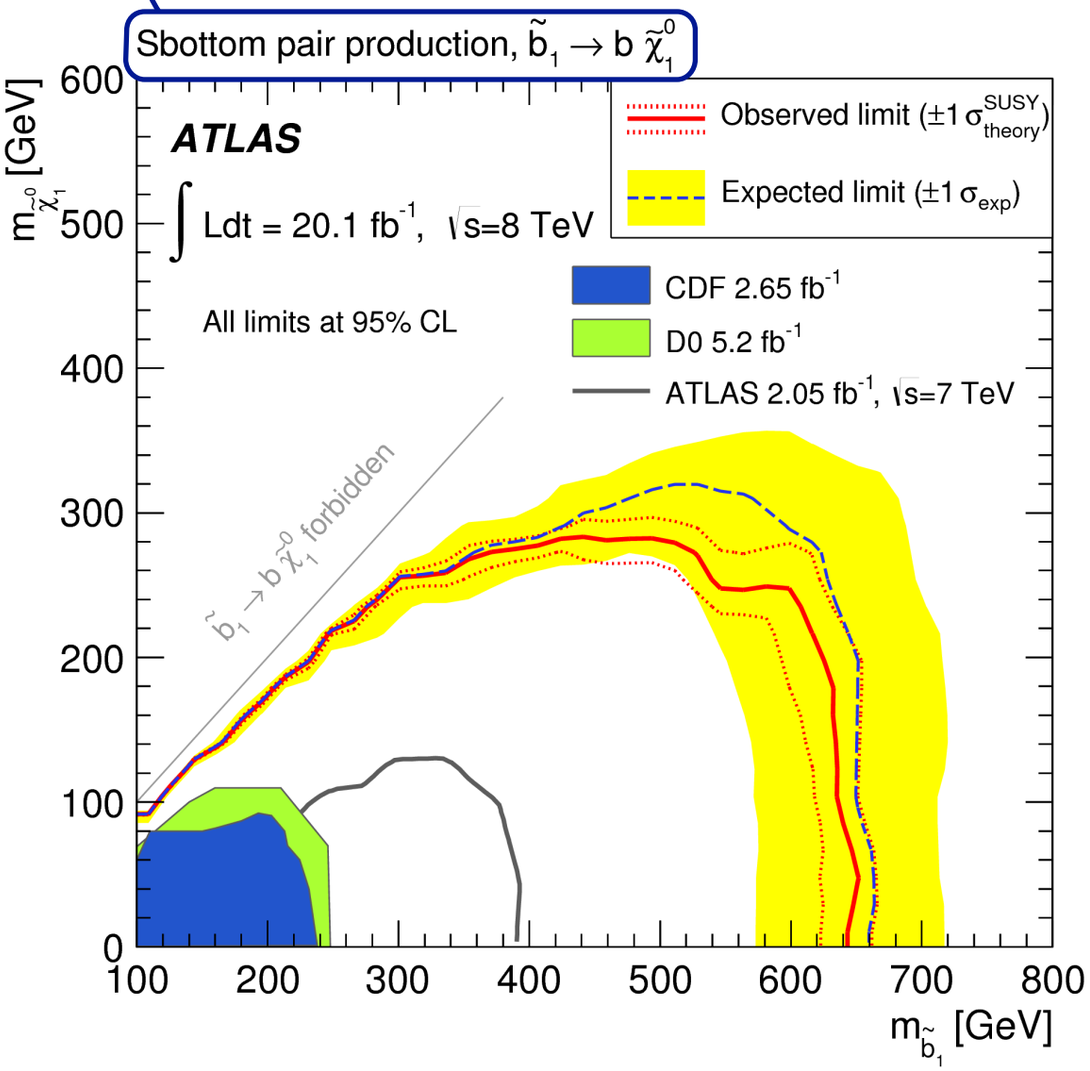

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Focus today:

- For accurate exclusion limits, precise cross section predictions with reliable uncertainties are needed

Jet vetoes require resummation

- The effect of jet vetoes on the cross section is difficult to calculate

$$\sigma(p_T^{\text{cut}}) \sim \sigma_0 \times (1 + \alpha_s\,[L^2 + L + c_1] + \alpha_s^2[L^4 + L^3 + L^2 + L + c_2] + \dots)$$

Large logarithms $L = \ln(p_T^{\text{cut}}/Q)$

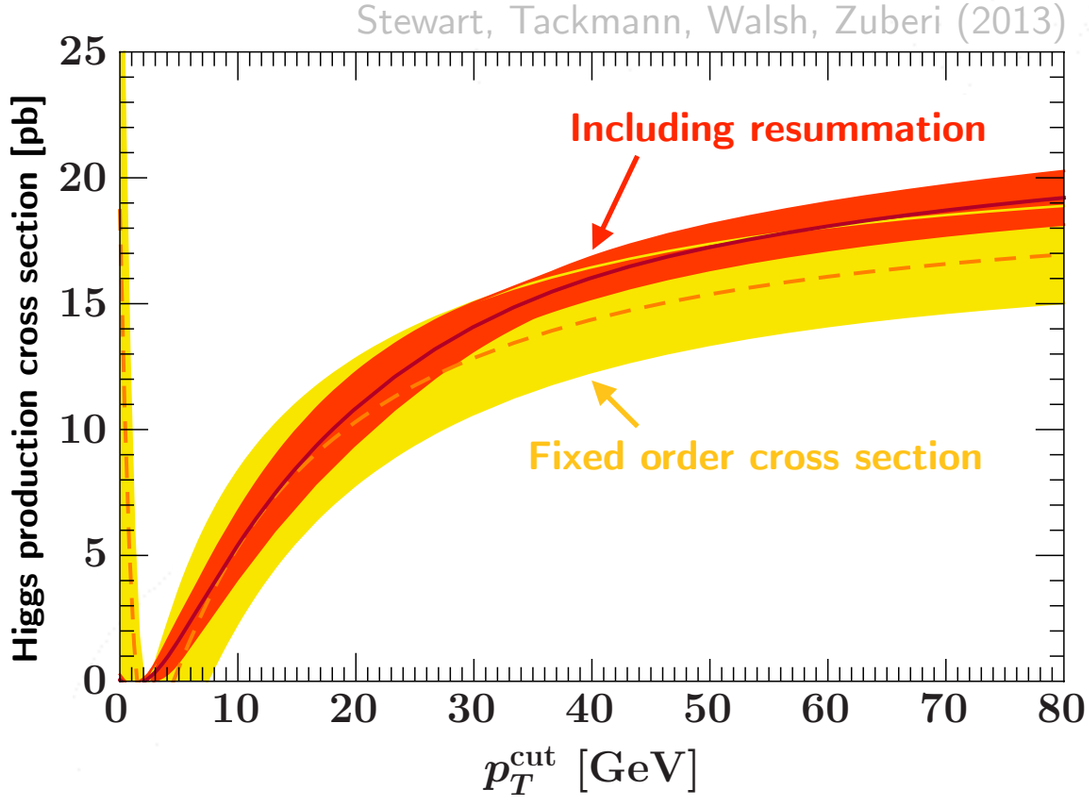
LL NLL

- For realistic and reliable cross-section predictions: **Resummation required**

- Theory uncertainties significantly reduced

Higgs production (0 jets)

Stewart, Tackmann, Walsh, Zuberi (2013)



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Large logarithms $L = \ln(p_T^{\text{cut}}/Q)$

LL NLL

- Currently experimental analyses use parton showers

  ↪ Describe the leading logarithms (LL)

  ↪ No uncertainty from jet veto

- If logarithms are large: Resummed calculation beyond LL accuracy needed

$p_T^{\text{veto}} \sim 30$ GeV

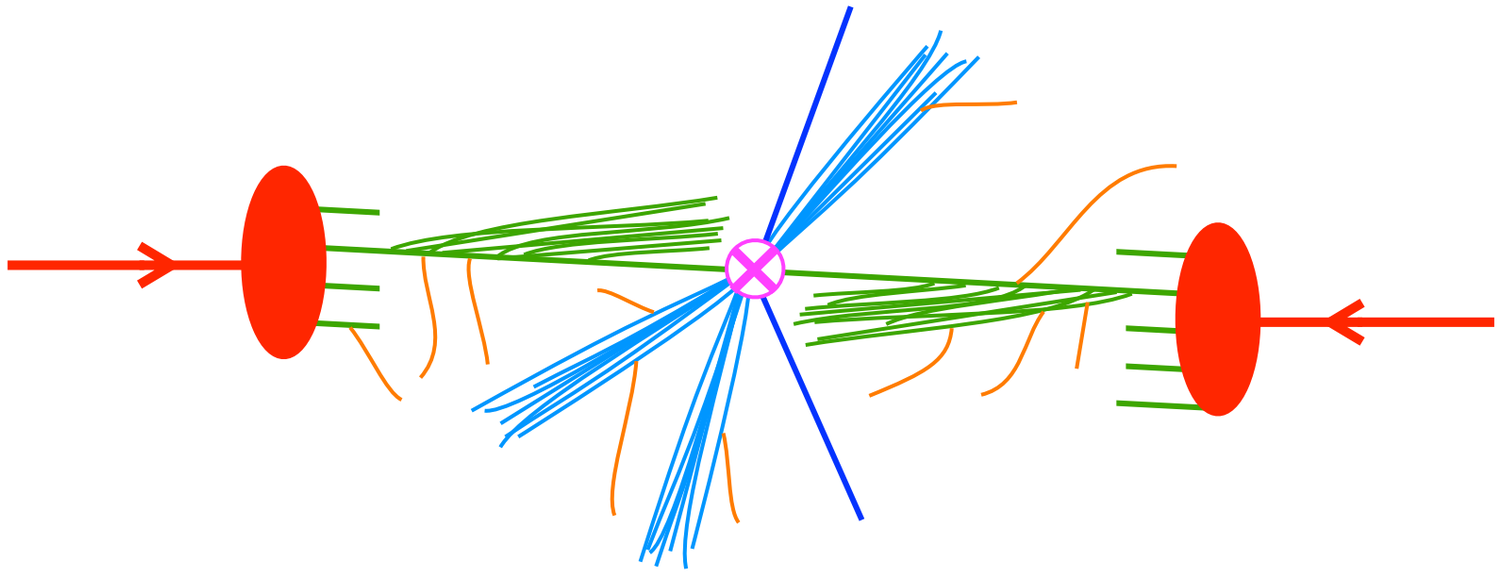
Higgs: $Q \sim 125$ GeV

New physics: $Q \sim 1000$ GeV

Jet veto effect more significant for new physics processes!

Factorization and resummation in SCET

PDFs
Initial-state radiation
Hard scattering
Final-state radiation
Soft radiation



- Calculations with multiple scales lead to large logarithms, e.g. $\alpha_s \ln^2 \frac{p_T^{\text{cut}}}{Q}$
- Factorization: separate the physics associated with the different scales

$$d\sigma = H \times BB \times S \times \prod_i J_i \quad (B = \mathcal{I} \times f)$$

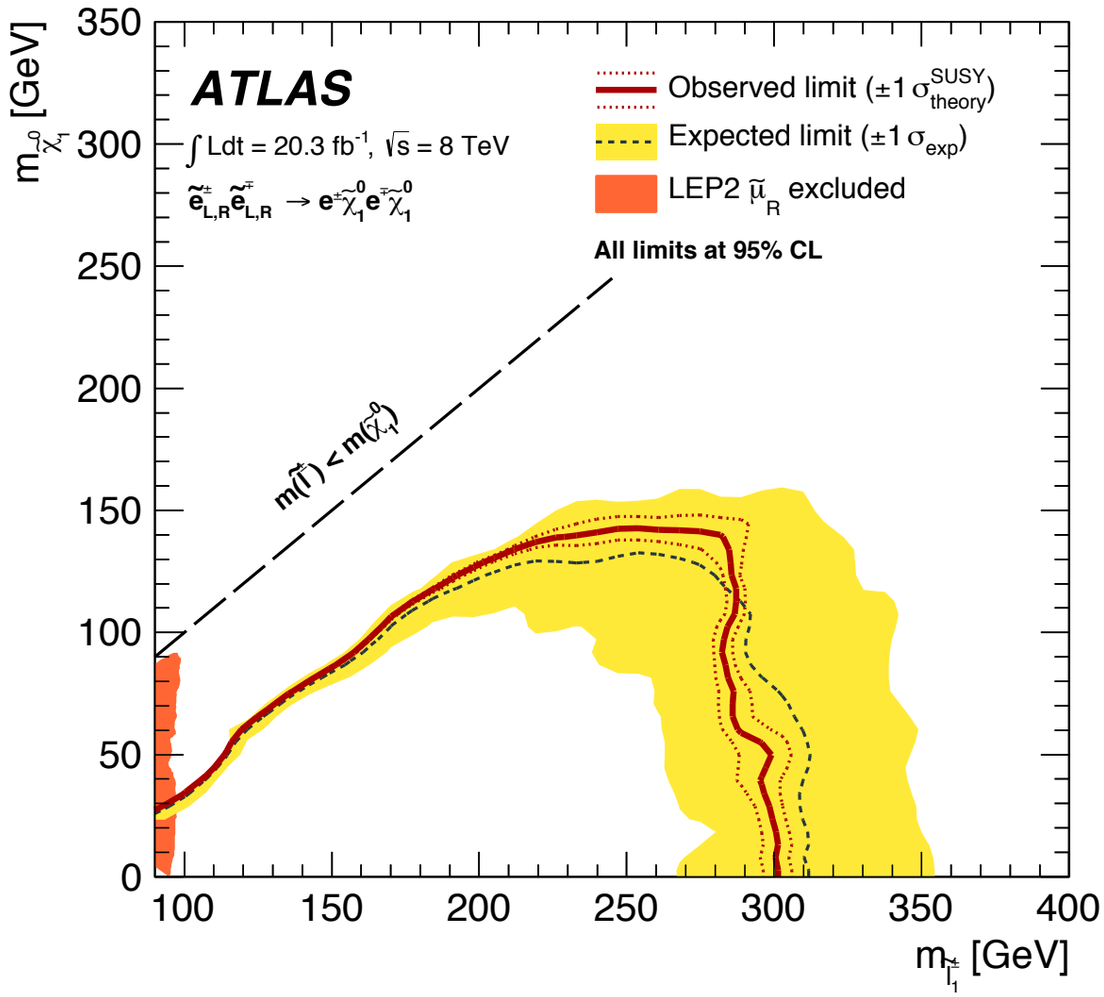
- Each component depend only on one scale, e.g. $H(Q)$ contains $\alpha_s \ln^2 \frac{\mu}{Q}$
  $\rightarrow$ Remove logs by natural scale choice $\mu = Q$
- Resummation: Use RGEs to obtain all ingredients (H, B, S, J) at a common scale

Results at 8 TeV

PRELIMINARY RESULTS

- We focus on slepton production
- Example analysis: JHEP 1405 (2014) 071
  All jets with p_T larger 20 GeV are vetoed

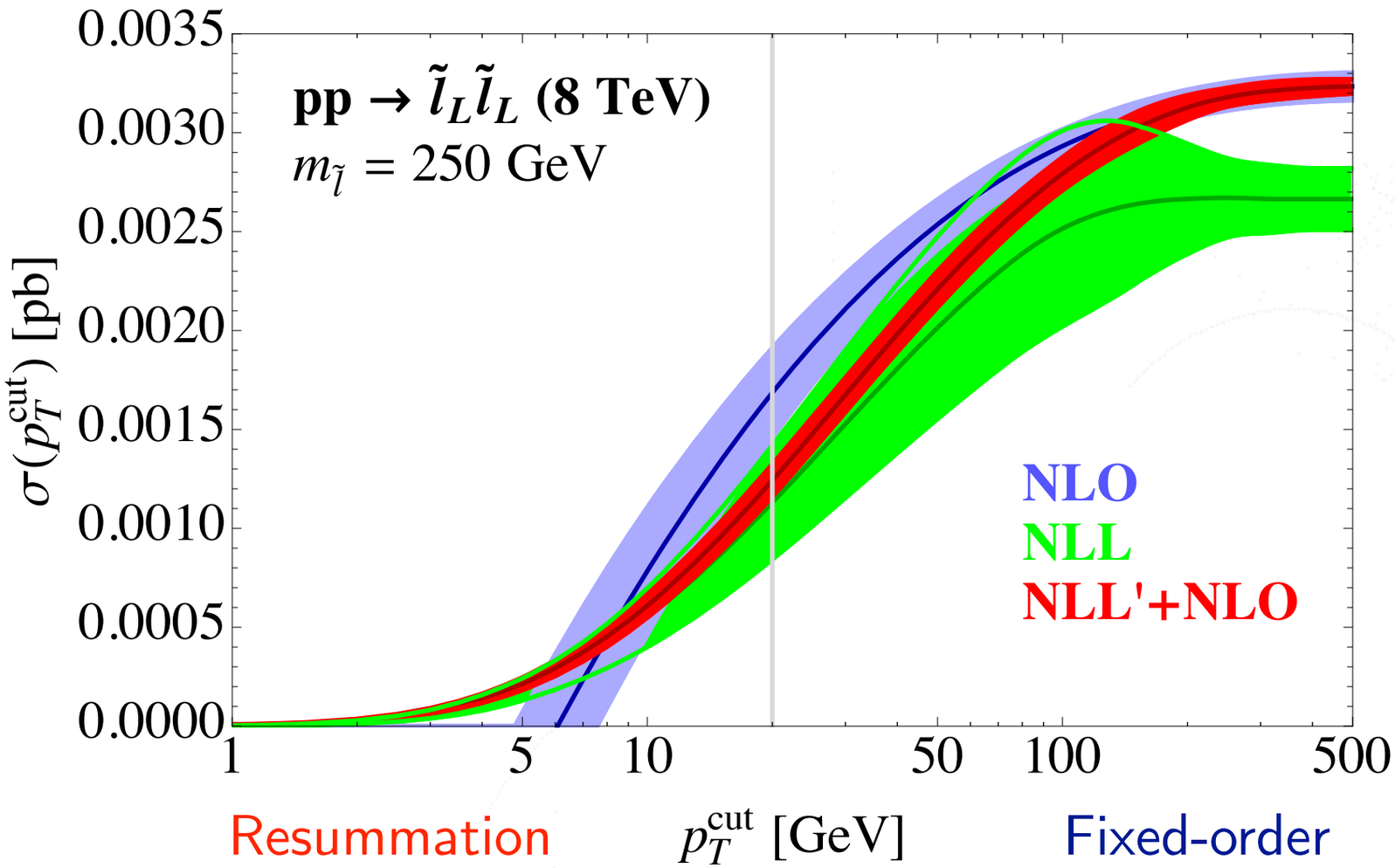
ATLAS 1403.5294



Results at 8 TeV

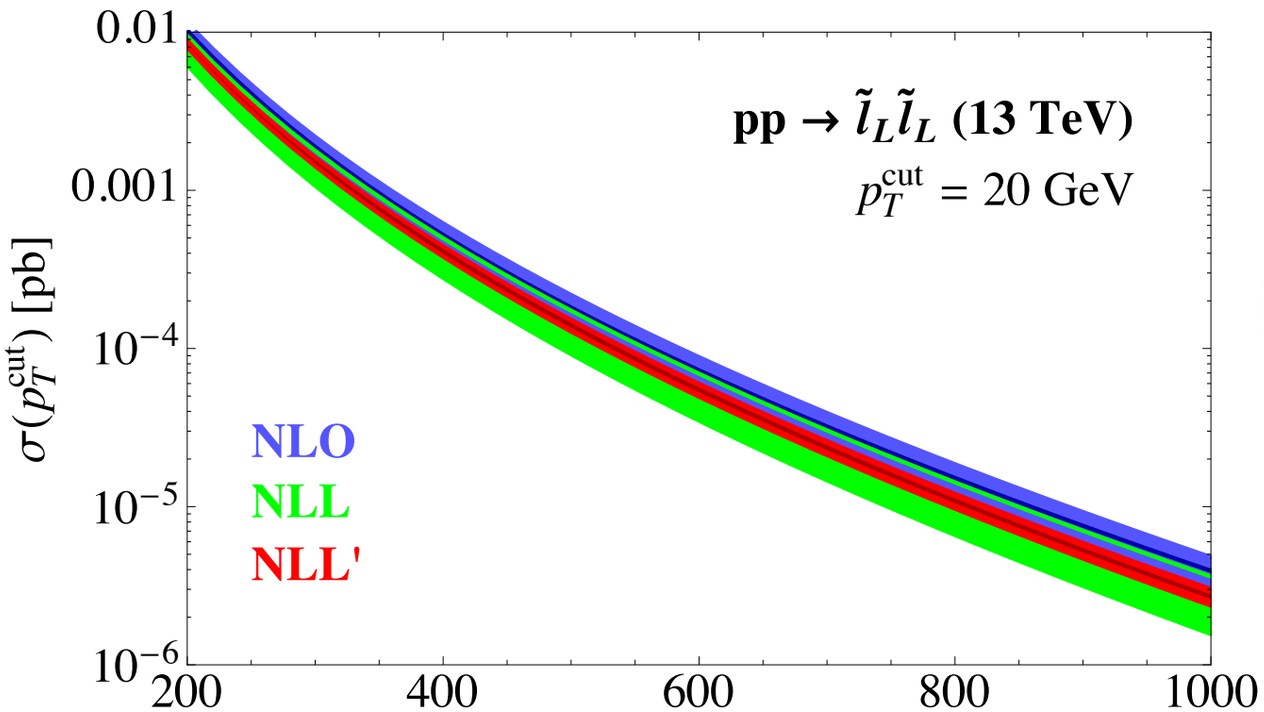
PRELIMINARY RESULTS

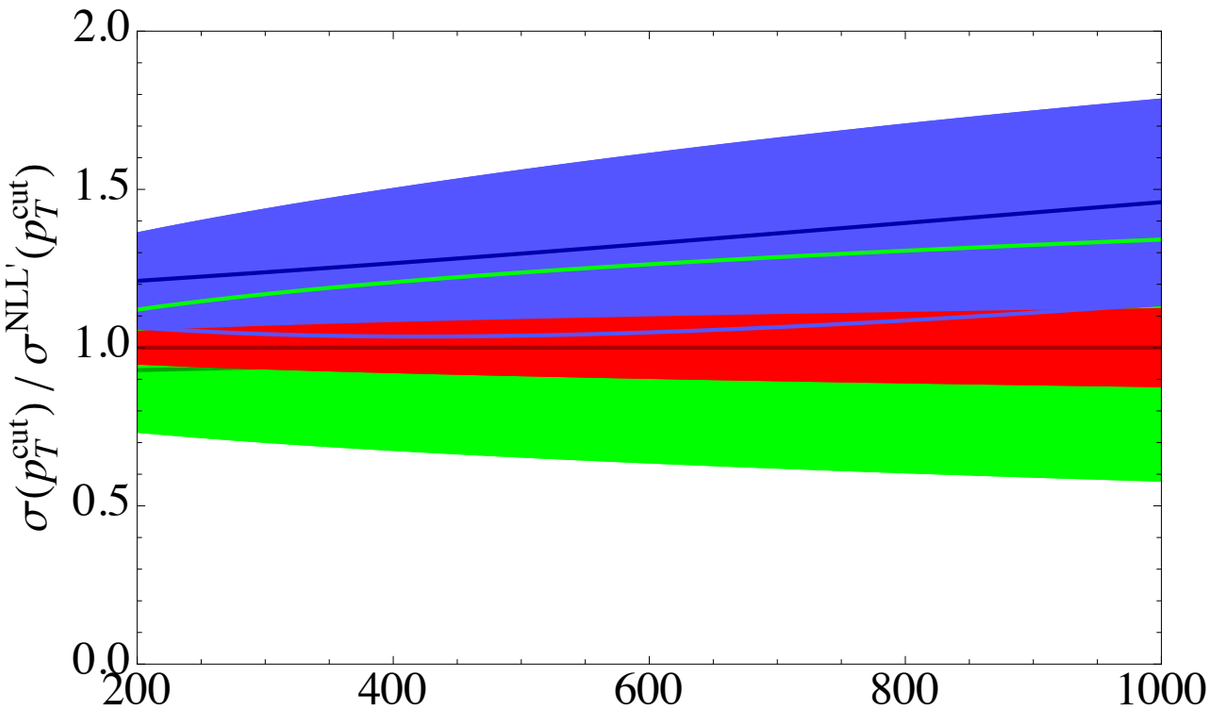
- We focus on slepton production
- Example analysis: JHEP 1405 (2014) 071
  All jets with p_T larger 20 GeV are vetoed
- Results for the resummed cross section prediction
  - ⋆ Reliable jet-veto uncertainties
  - ⋆ Shifted central value and reduced uncertainties compared to fixed-order



Results at 13 TeV

PRELIMINARY RESULTS





- LHC 13 TeV run will test heavier sleptons
- Higher slepton masses lead to larger logarithms $\ln(p_T^{\text{cut}}/Q)$ in the slepton production cross section
- Importance of jet veto resummation increases

Uncertainties

	200 GeV	1000 GeV
NL0	12 %	22 %
NLL	21 %	39 %
NLL'	5 %	12 %

Summary and outlook

- Precise cross sections including jet veto resummation important to fully exploit the LHC data:

If we don't see new physics at the LHC, they ...

... are needed to set accurate exclusion limits

... can be used to refine the search strategy

If we discover a new particle, they ...

... are essential to precisely determine the properties of the discovered particle

... can help to reveal the underlying model realised in nature

- **Next steps:**

↪ Develop framework for jet veto resummation for generic processes

↪ Calculated jet-veto resummed cross section for other relevant processes

↪ Public code providing resummed predictions