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Searching for supersymmetry using hadronically decaying tau leptons

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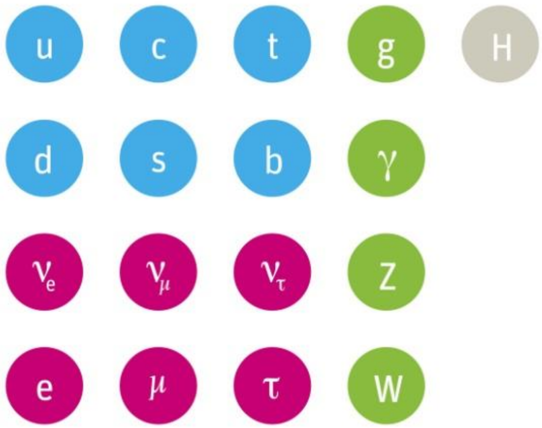
FOR PRECISION TESTS
OF FUNDAMENTAL
SYMMETRIES

What is supersymmetry?

- Standard model of particle physics
  - Describes the known matter
    + 3 interactions
    to very high precision



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    e.g. what is dark matter?

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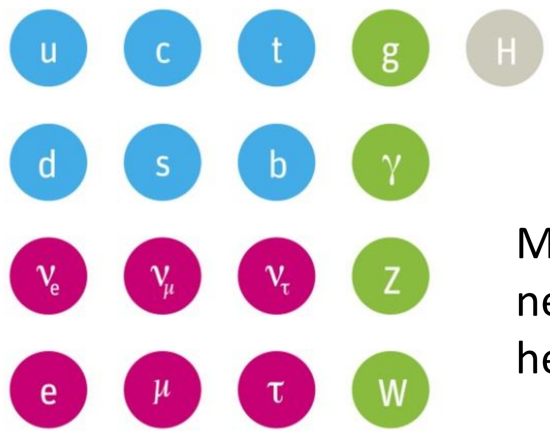
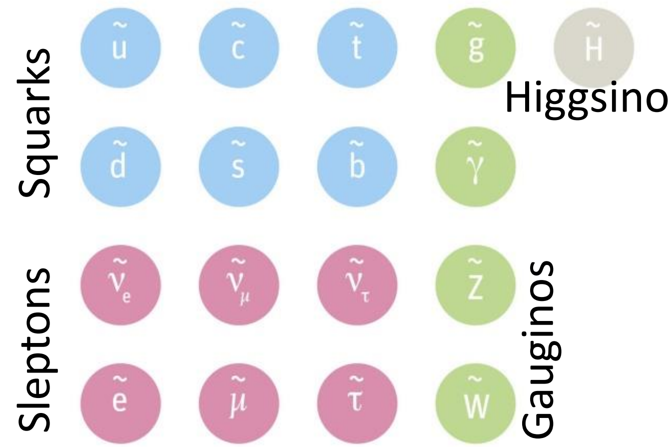


Maybe adding a new symmetry helps

SUPERSYMMETRY (SUSY)



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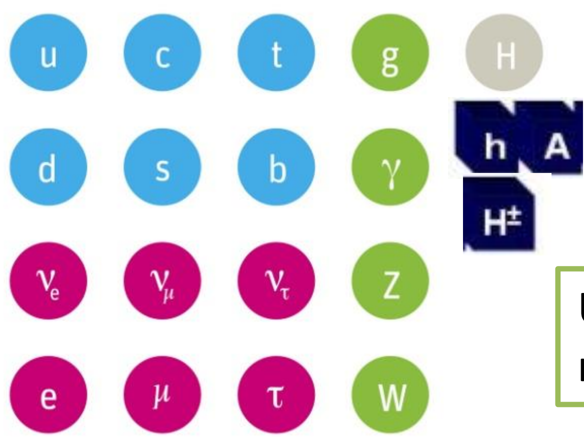
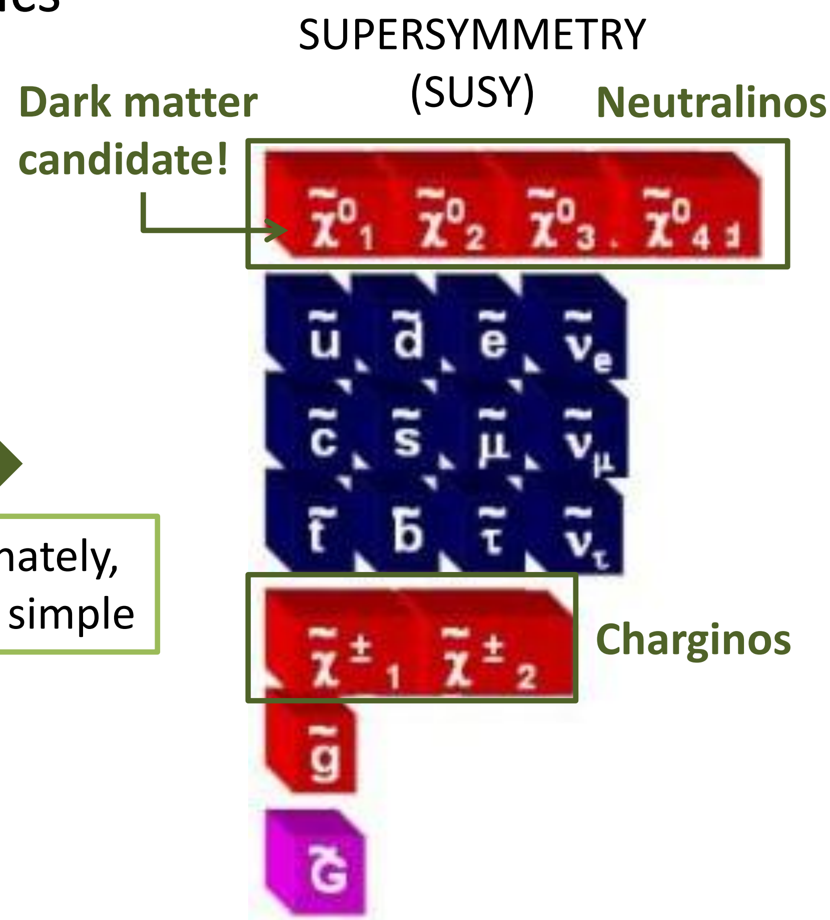


Unfortunately, not that simple



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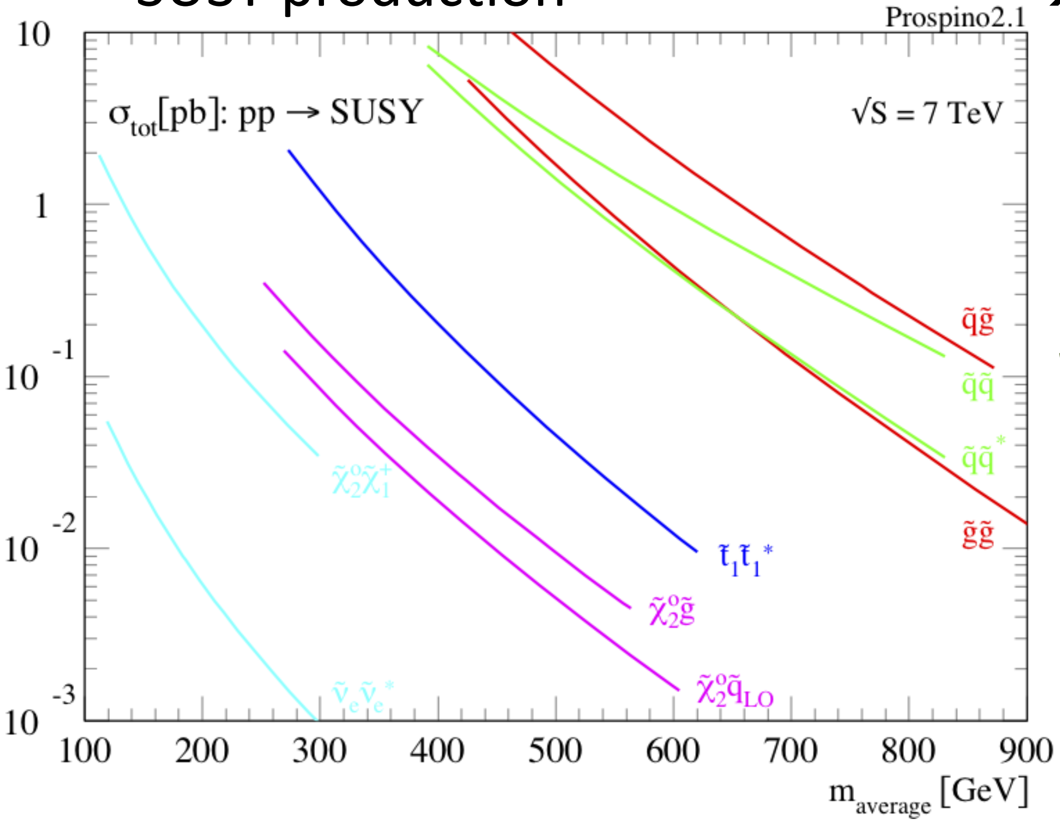
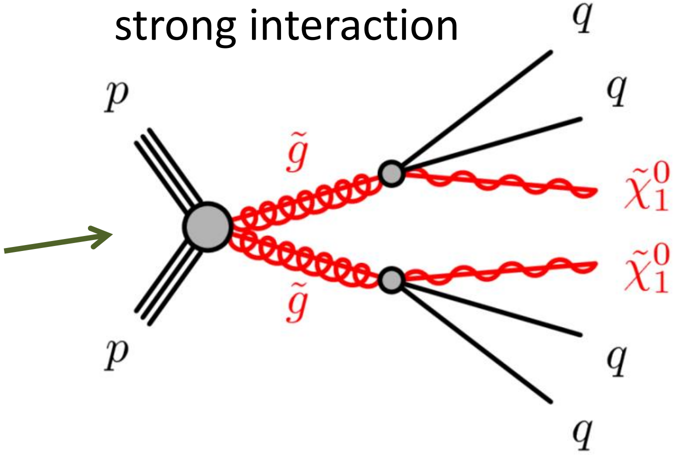
How could we see SUSY @ LHC?

- SUSY production → colliding protons



→ Squark/Gluino production via strong interaction



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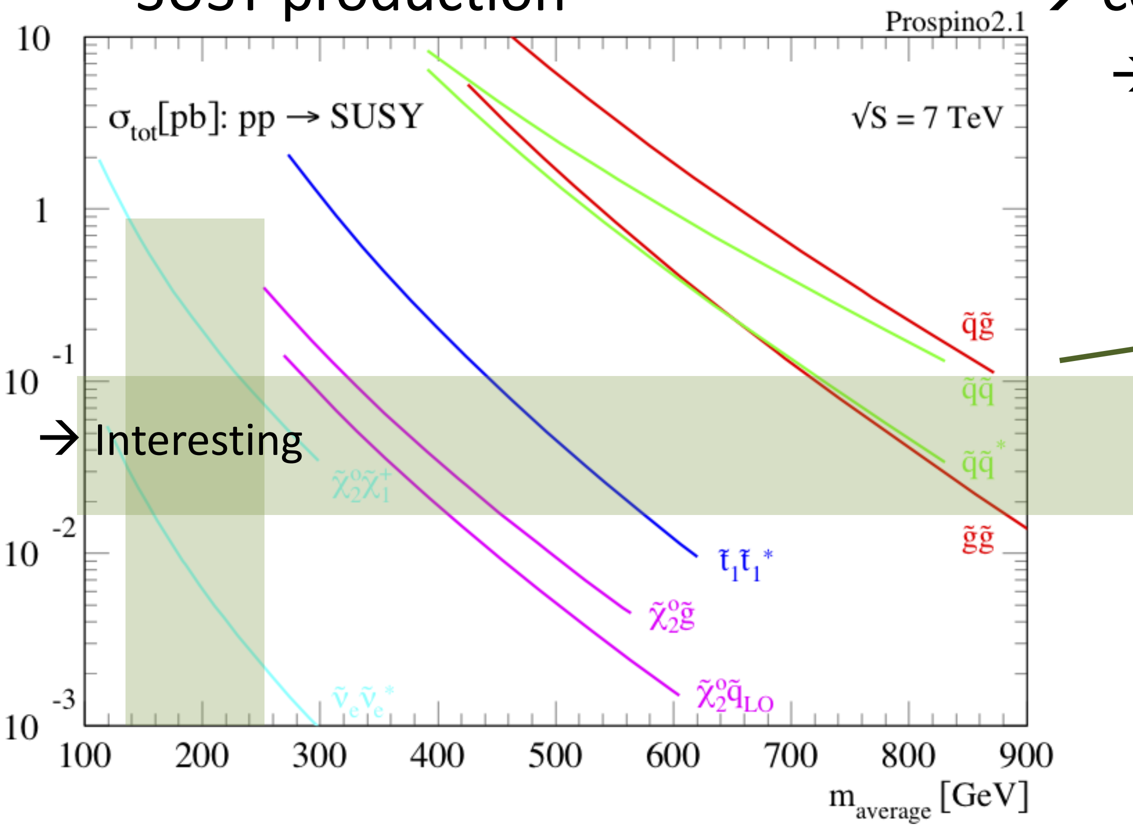
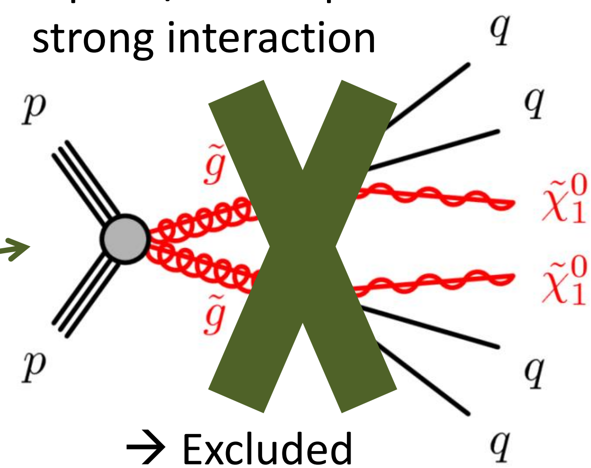


→ Interesting

→ Squark/Gluino production via strong interaction



→ Excluded up to O(TeV)

How could we see SUSY @ LHC?

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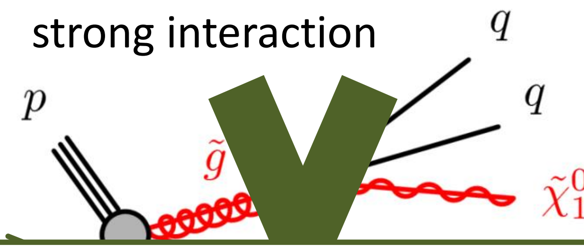

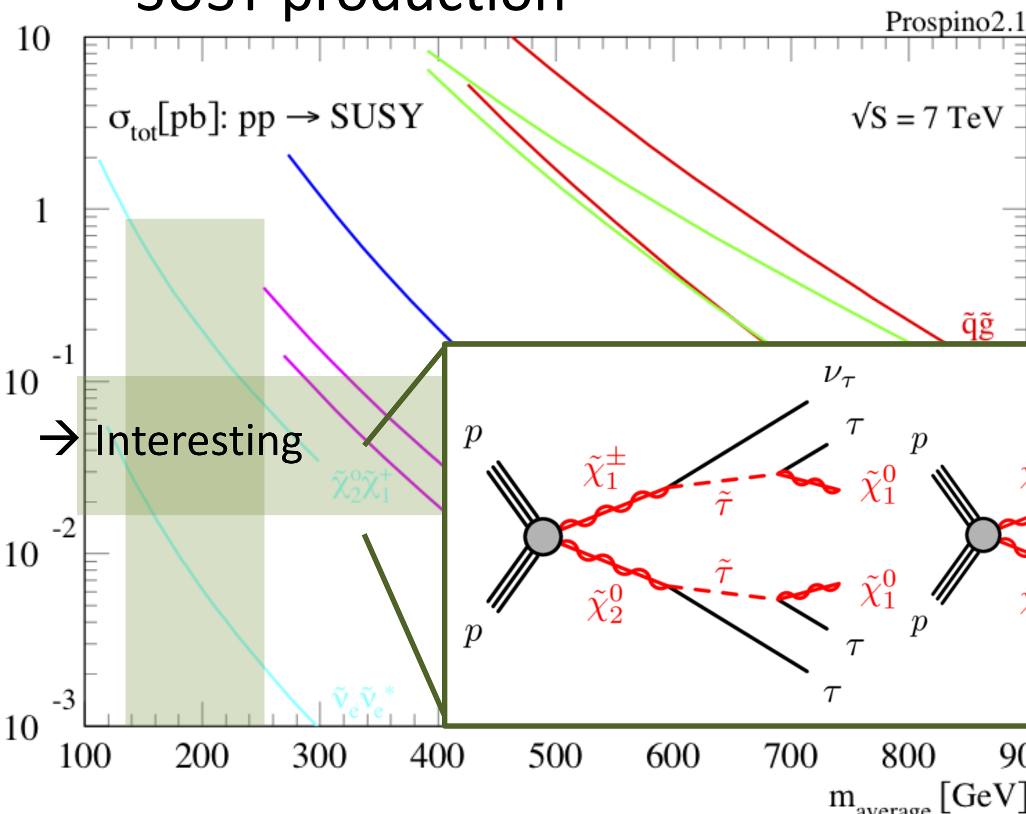

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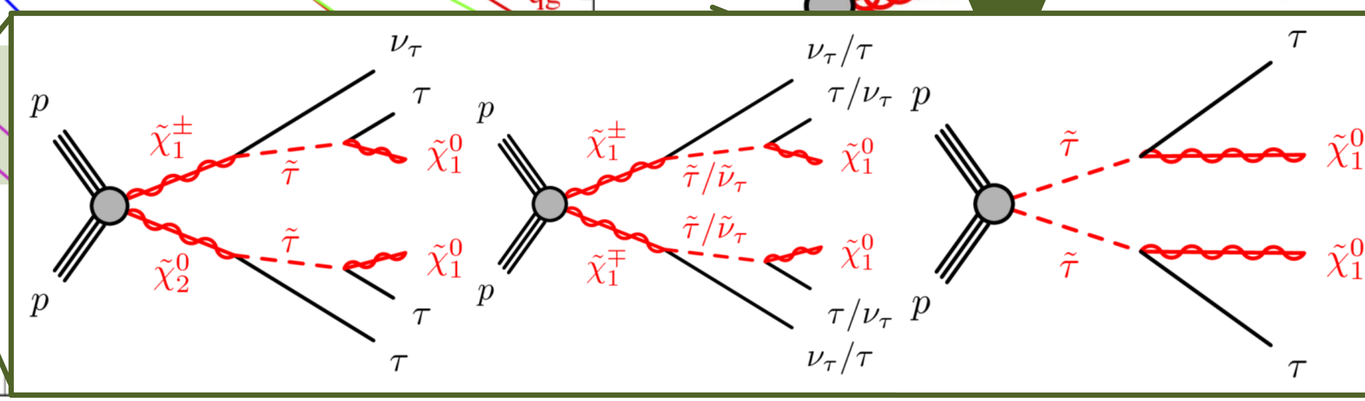
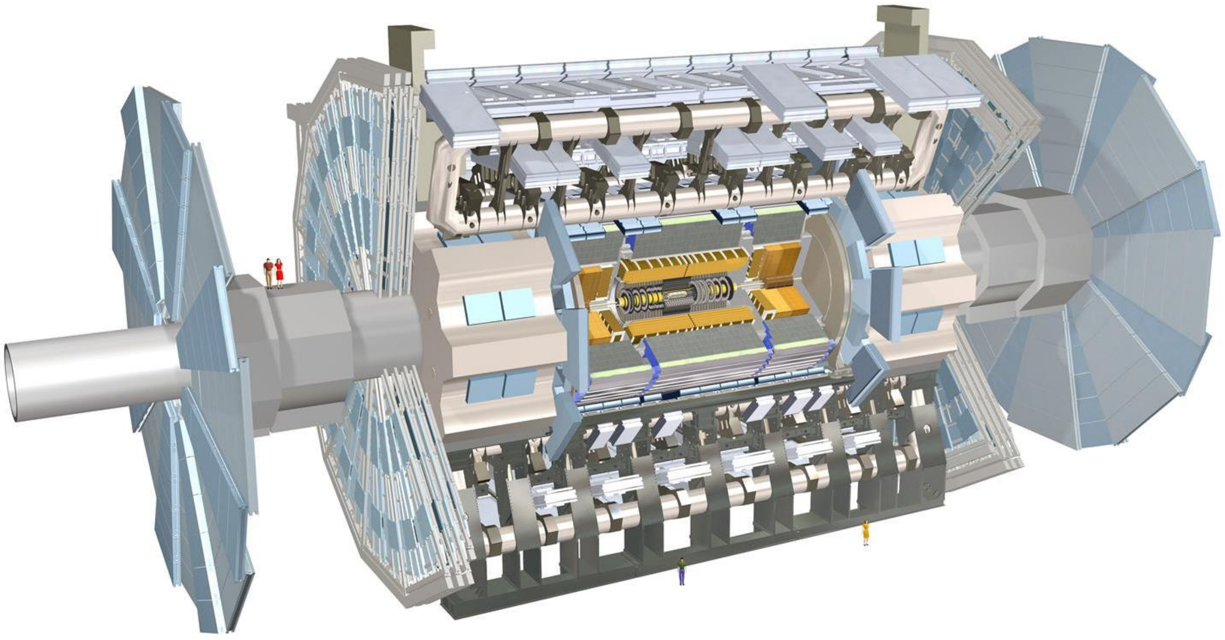


→ Direct electroweak production of chargino, neutralino and sleptons

→ Final state with τ's, E_T^{miss} and O(0) jets

What do we measure?

- ATLAS detector



Multipurpose detector
→ Onion shell structure
  - Inner detector – tracking
  - Calorimeters
  - Muon system

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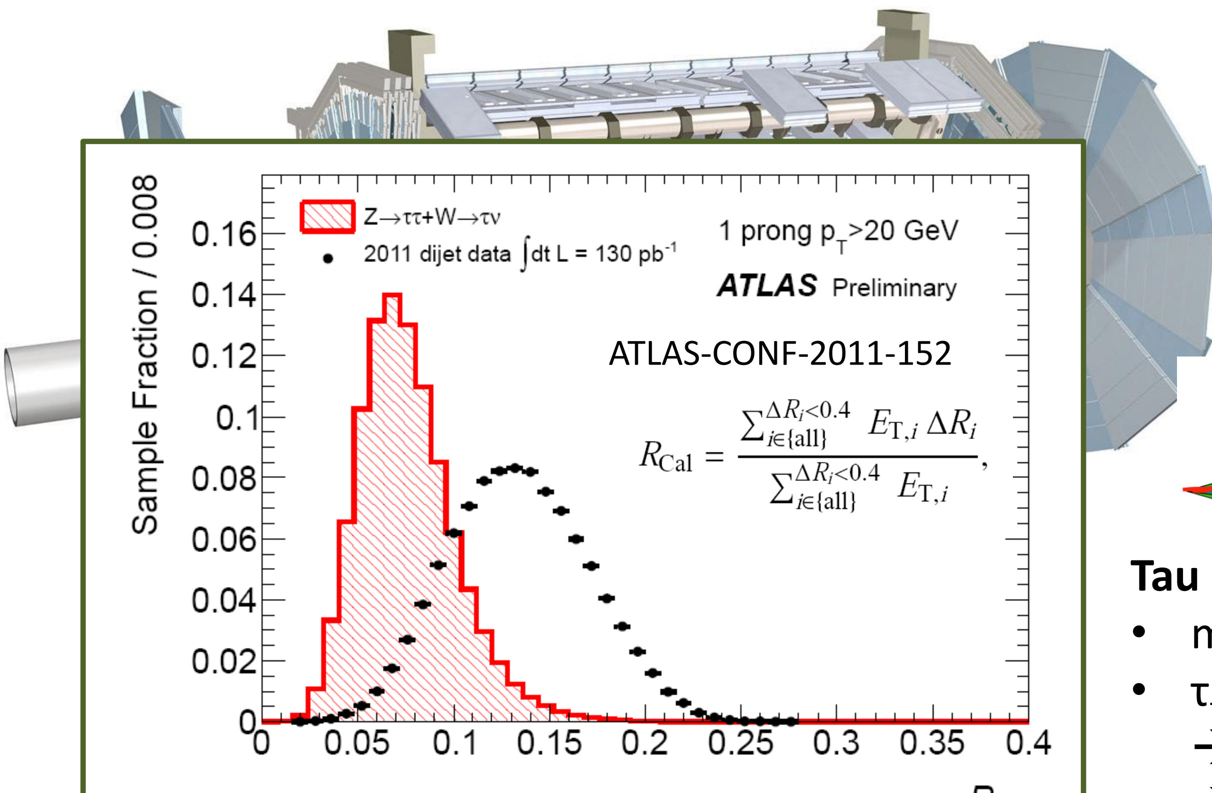

→ Discrimination from jets → multivariate

Multipurpose detector
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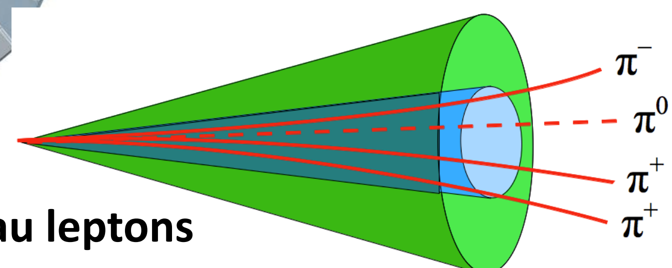

Tau leptons
- m_τ = 1.78GeV
- $\tau_\tau = 2.9*10^{-13}$s
  → decay length 87.1µm
  → inside beam pipe
- $BR_{hadrons}$ = 65%

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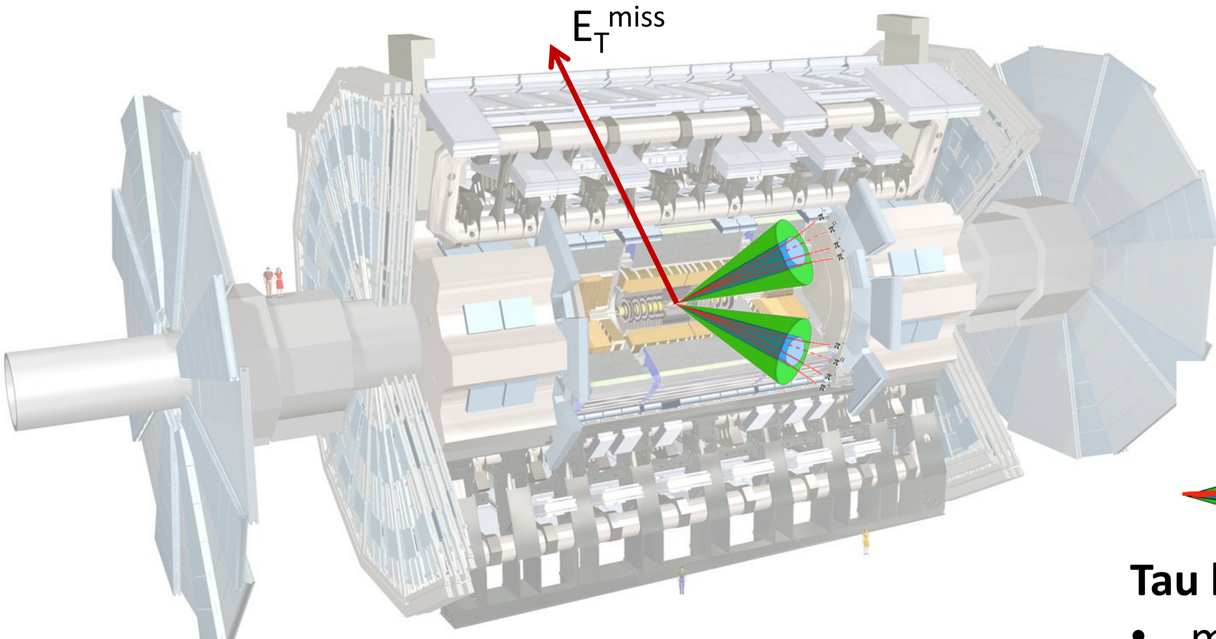

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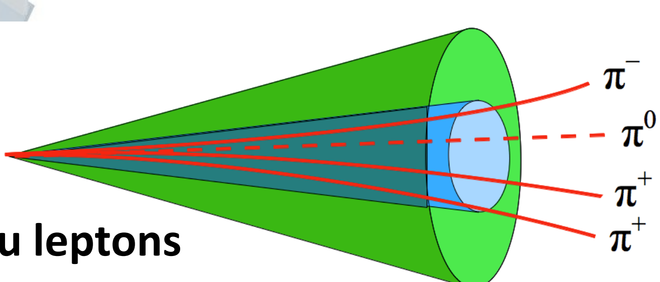

Final state signature

- ≥ 2 τ_{had}
- Large E_T^{miss}
- Not much else

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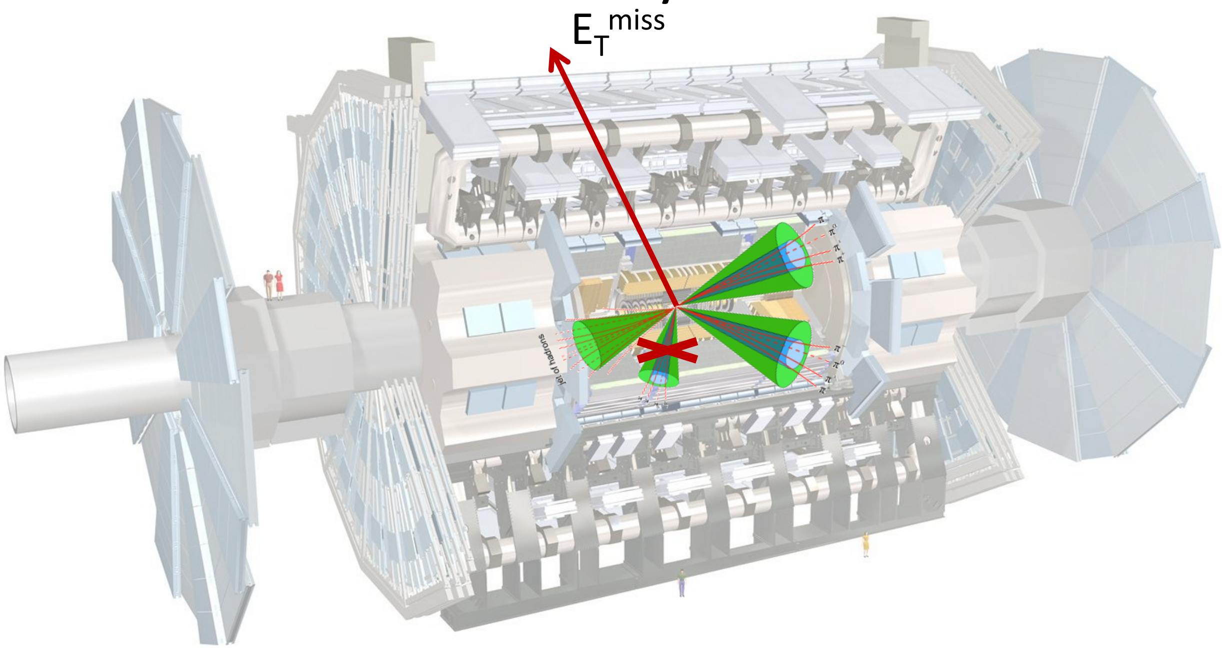
How do we quantify our signature?

- Cut-and-Count Analysis



Cut

- Define electrons, muons, taus and jets
- Compute variables like E_T^{miss}, m_{T2}, etc
- Select events according to criteria e.g. ≥ 2 τ's

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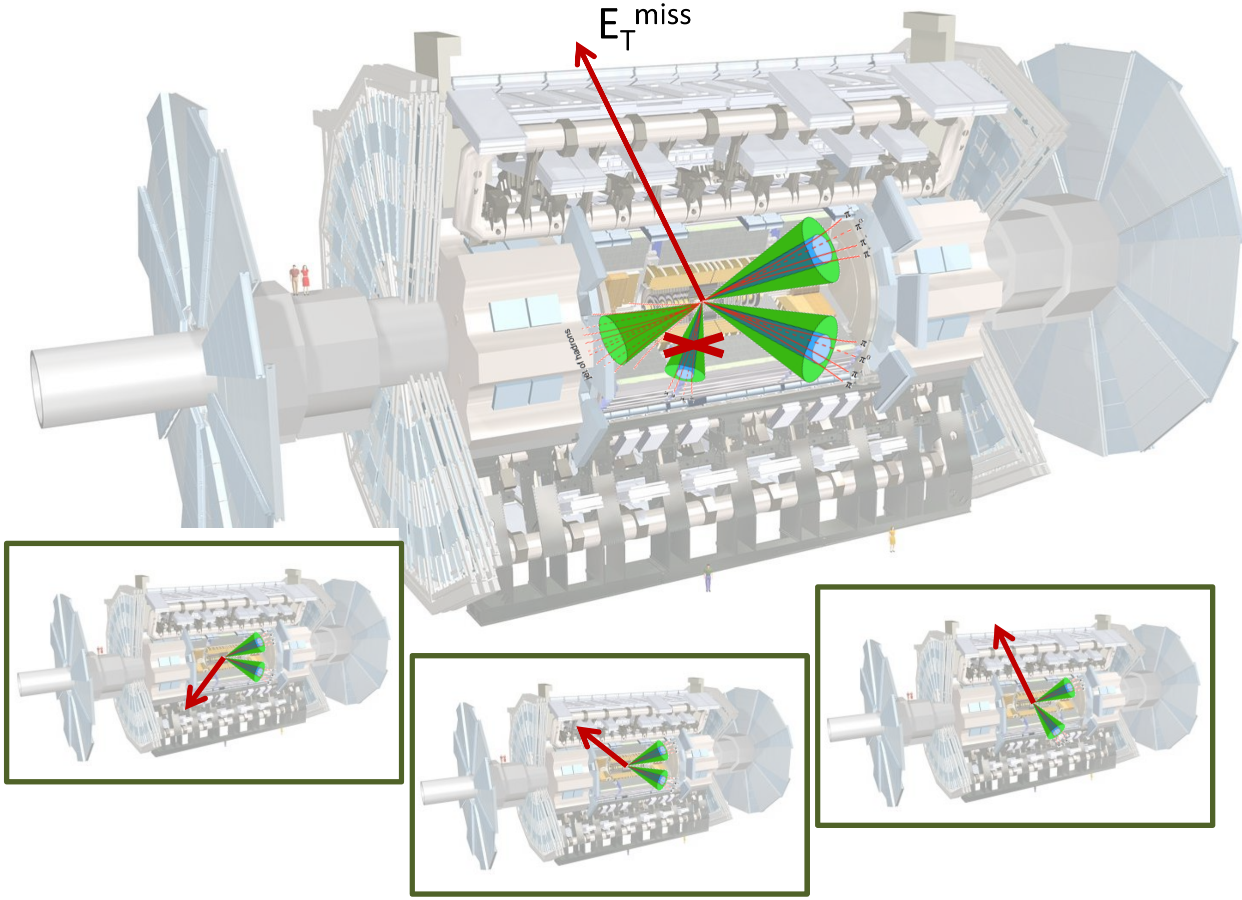


Cut

- Define electrons, muons, taus and jets
- Compute variables like E_T^{miss}, m_{T2}, etc
- Select events according to criteria e.g. ≥ 2 τ‘s

Count

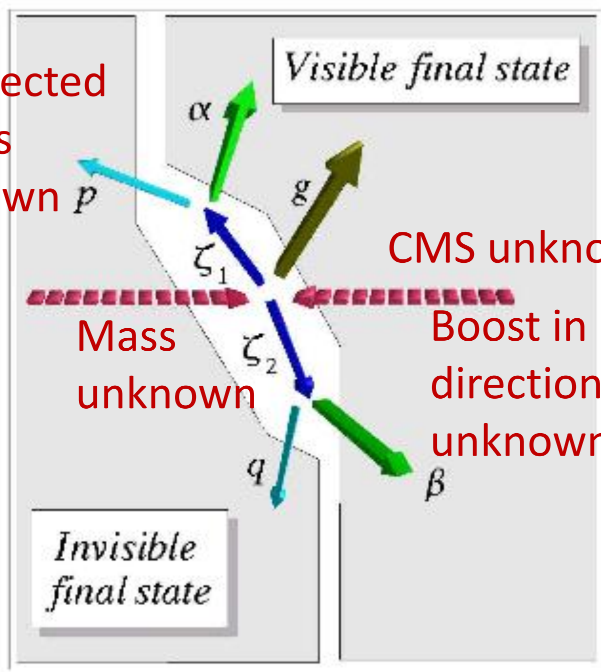
- Count events passing the criteria

→ **Compare**

- Compare expectation from standard model to measured data

What do we need m_{T2} for?

- "Invariant mass" of invisible particles (partially) decaying to invisible particles



→ Consider decay with 1 invisible particle: $\tilde{\tau}^+ \to \chi_1^0 \tau^+$

→ $m_{\tilde{\tau}}^2 = m_\tau^2 + m_{\chi_1^0}^2 + 2[\mathrm{E}_\mathrm{T}^\tau \mathrm{E}_\mathrm{T}^{\chi_1^0} \cosh(\Delta y) - \mathbf{p}_\mathrm{T}^\tau \cdot \mathbf{p}_\mathrm{T}^{\chi_1^0}]$ with y=rapidity(*)

→ Transverse mass m_T^2: leave out $\cosh(\Delta y)$.

→ Since $\cosh(\Delta y) \geq 1$ → $m_T^2 \leq m_{\tilde{\tau}}^2$

http://arxiv.org/pdf/hep-ph/0304226.pdf

(*) rapidity $y = \frac{1}{2}\ln(\frac{E+p_z}{E-p_z})$

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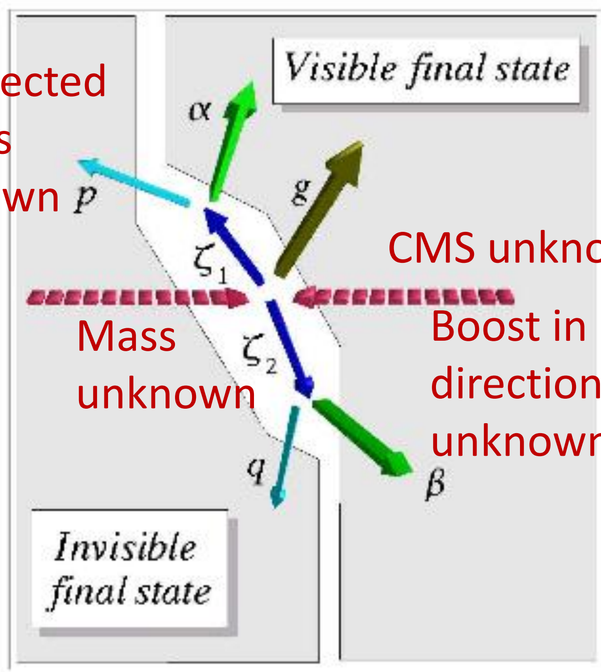

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→ **2*decay** → $\tilde{\tau}^+\tilde{\tau}^- \to \tau^+\tau^-\chi_1^0\chi_1^0$

→ 2 χ_1^0 contribute to E_T^{miss}

→ Split E_T^{miss} into $E_T^{miss} = q_T^{(1)} + q_T^{(2)}$ such that

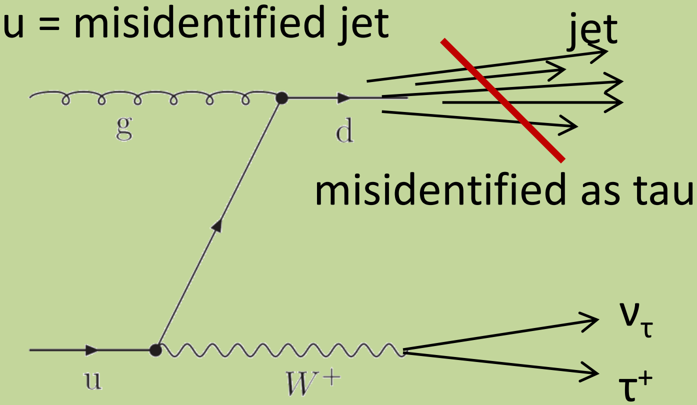
$$m_{T2}^2(\chi) = \min_{q_T^{(1)}+q_T^{(2)}=E_T^{miss}} [\max\left\{m_T^2\left(p_T^{\tau^{(1)}}, q_T^{(1)}; \chi\right), m_T^2(p_T^{\tau^{(2)}}, q_T^{(2)}; \chi)\right\}]$$

How many events do we expect from standard model processes?

- Processes which look like our signal

QCD multijet and W+jet

tau = misidentified jet



E_T^{miss} = additional artefact from instrumental effects or W-decay

→ Largest background (30-80%)

→ Use data to estimate due to incorrect fake tau modelling in simulation

→ **ABCD method**

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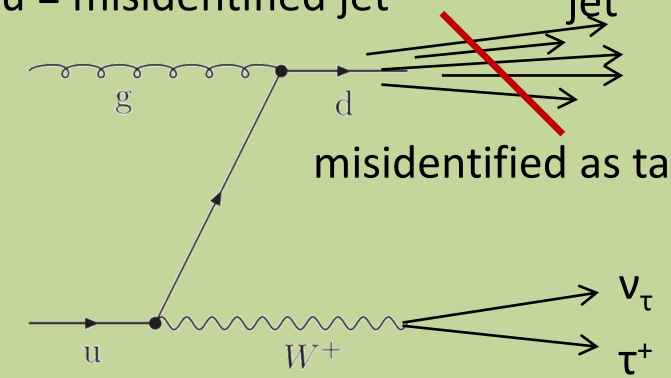

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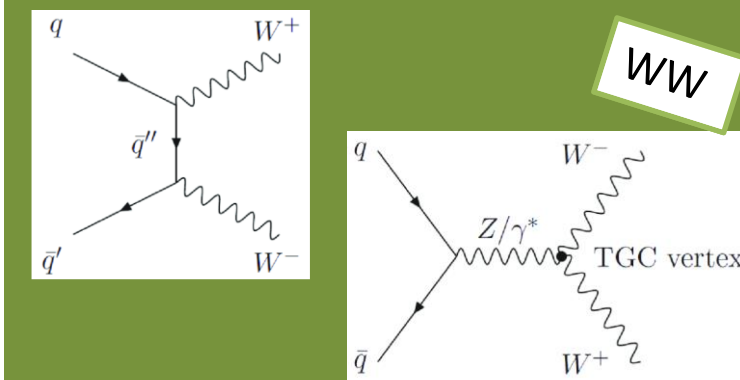
Diboson, Z+jet, top

tau = real tau from particle decay



E_T^{miss} = neutrinos e.g. from W-decay

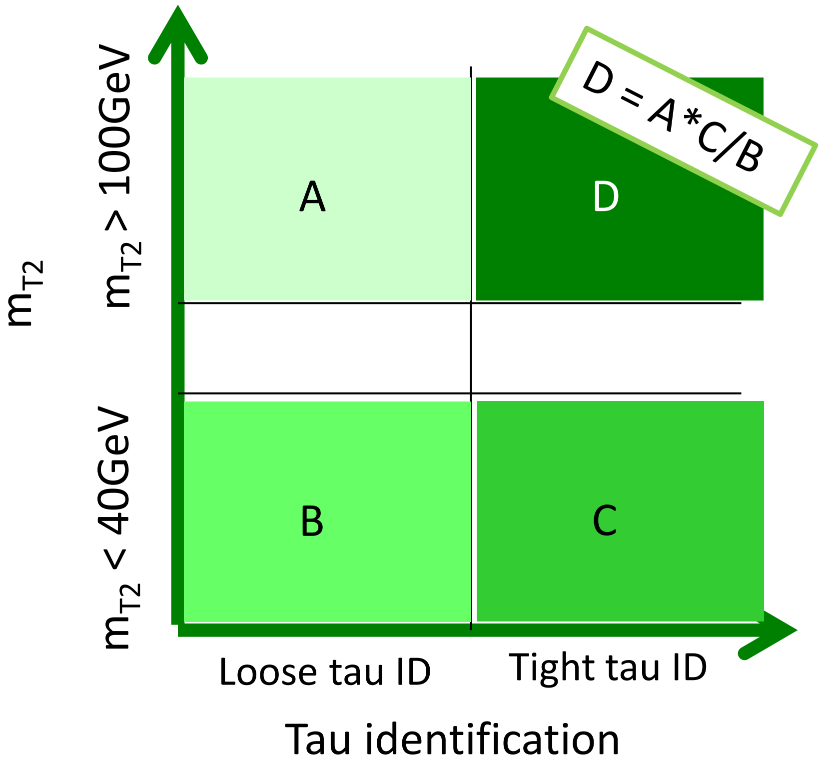
→ Diboson = 2nd largest (15-35%)

→ Estimate from simulation → many systematics sources to be considered

→ Validation of simulation in specific phase space regions with data

How does the ABCD method work?

- Divide phase space into 3 background A,B,C + 1 signal region D



- Pair of uncorrelated variables: tau ID and e.g. m_{T2}
- Regions A, B, C dominated by background which is to be estimated
- Events in region D via rule of proportion

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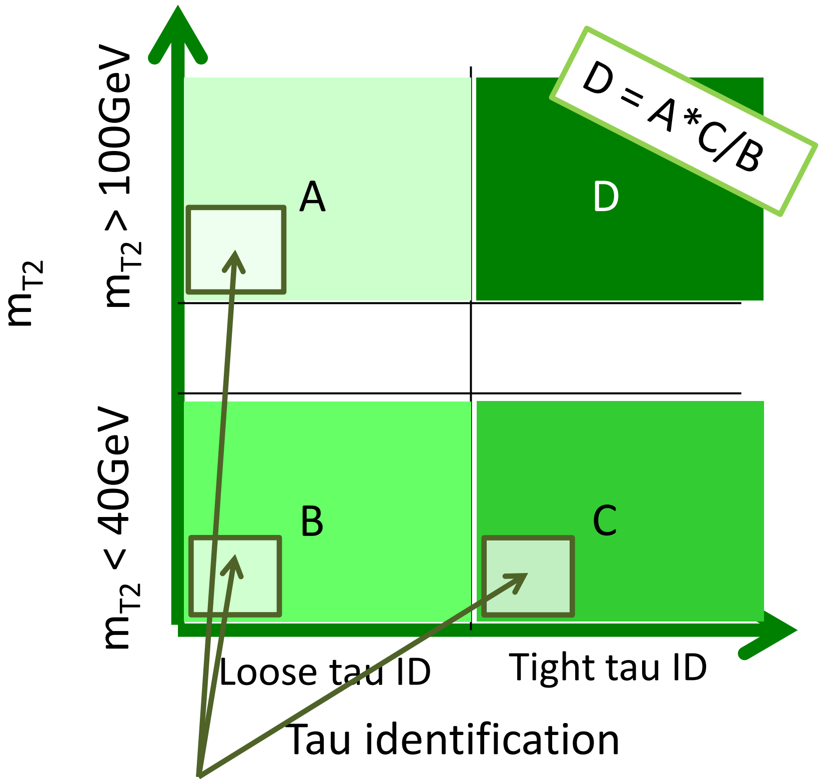

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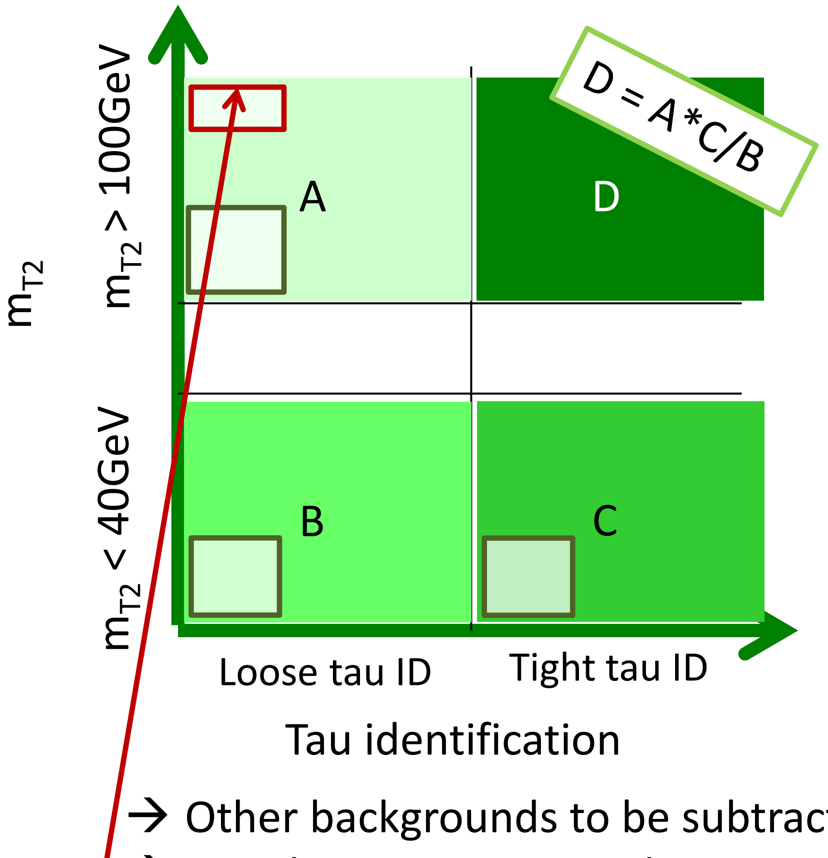

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→ Other backgrounds to be subtracted
→ Signal contamination take into account

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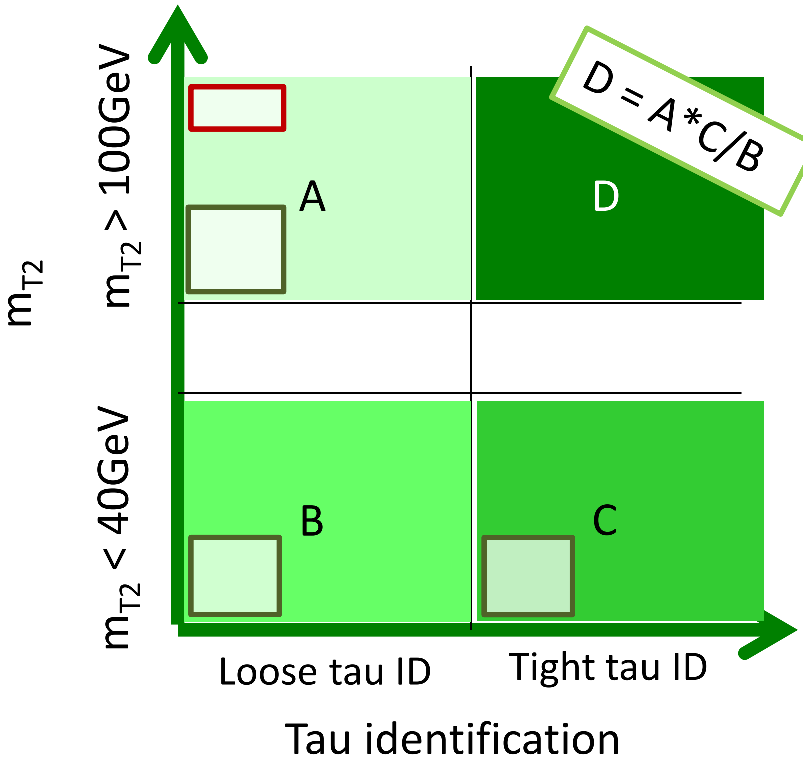

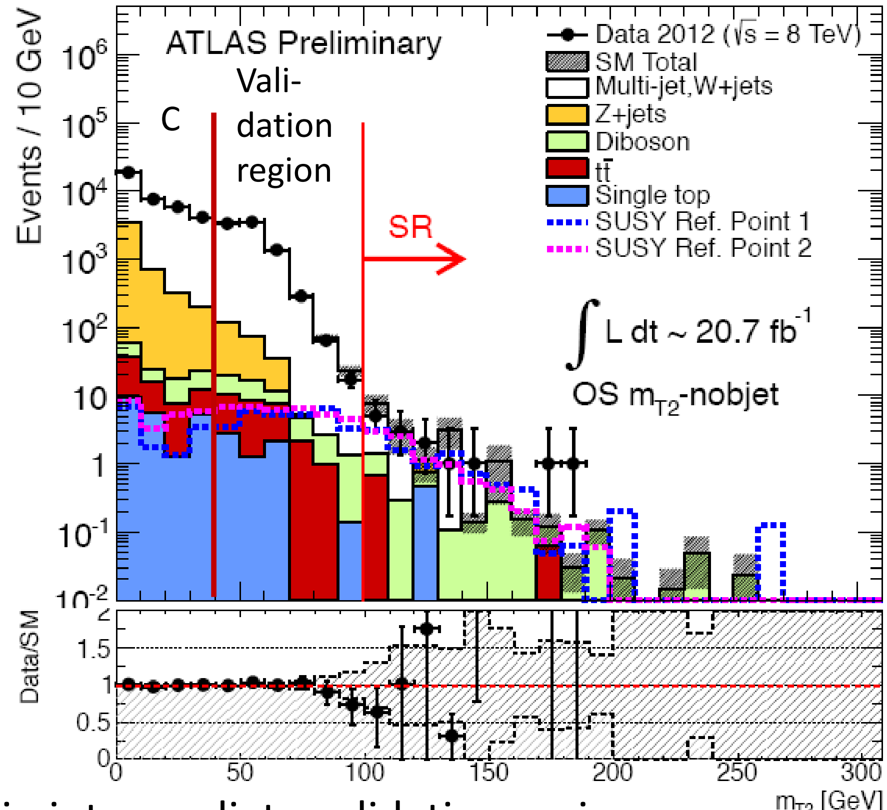

→ Agreement between data and estimates in intermediate validation region

→ **Compare obtained number of expected standard model events in signal region to data**

How do the Monte Carlo estimates work, e.g. for diboson?

- Principle idea
  - Use number of events predicted in the signal regions
  - **But** signal regions = extreme phase space for diboson processes → range of very low Monte Carlo statistics

  → Produce as much Monte Carlo as possible

  → Statistically combine existing Monte Carlo to reduce statistical uncertainties

Straight forward

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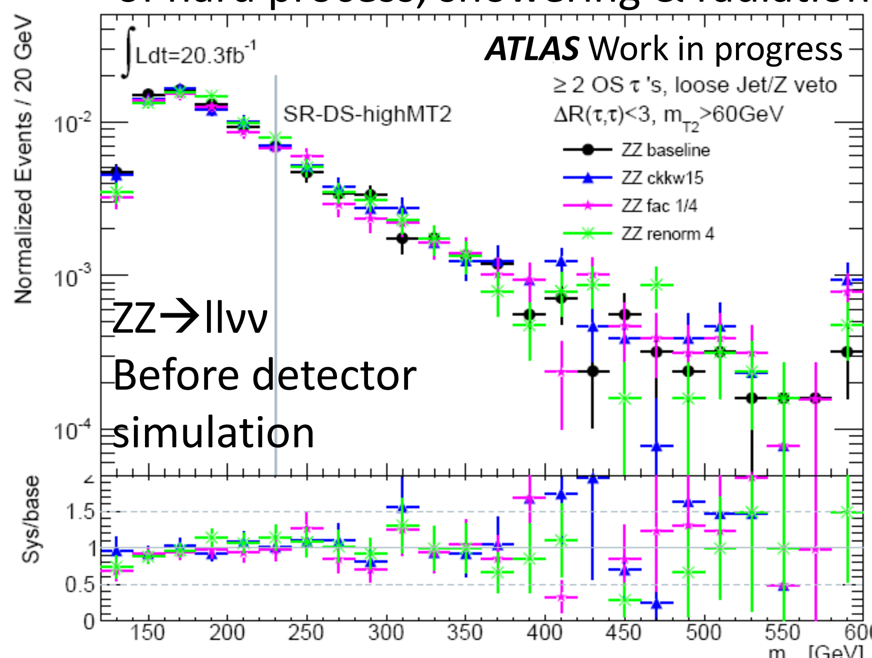
→Systematic uncertainties

- Experimental uncertainties from reconstruction, e.g. tau energy scale
- Theoretical uncertainties from simulation, e.g. scales for separation of hard process, showering & radiation



What if we don‘t see a difference between our expectation and data?

- Results from March 2013

Process	Example signal region
Expected standard model events	17 ± 4(stat) ± 3(sys)
Measured in data	14
Expected from 2 SUSY points	9.2 ± 1.2
	8.9 ± 0.7

Updated with improved signal regions now but not published yet

Observation
→ Probably no SUSY

→ But up to which parameter values are we sure we don‘t see SUSY?

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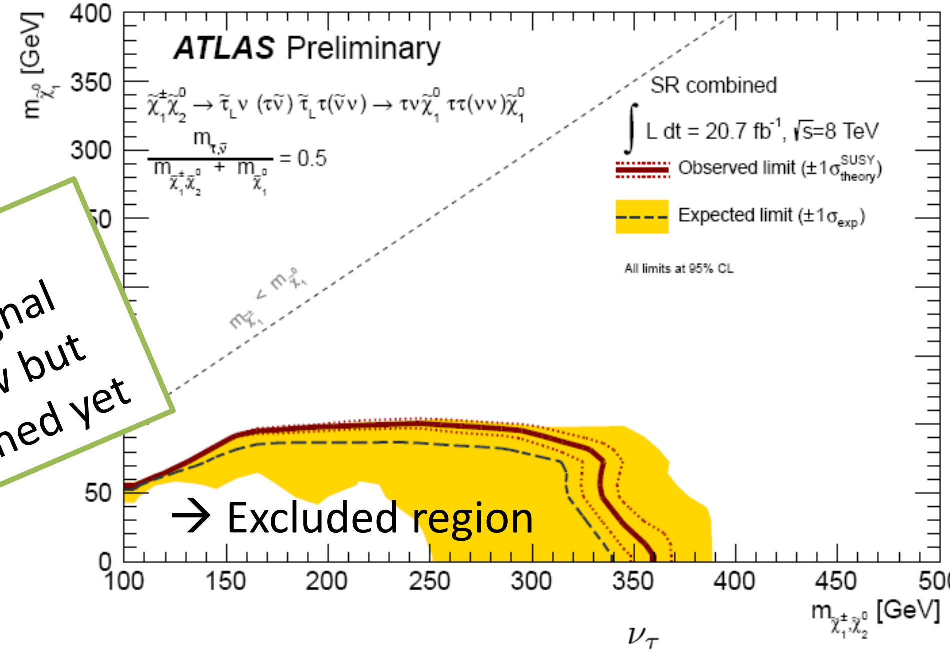

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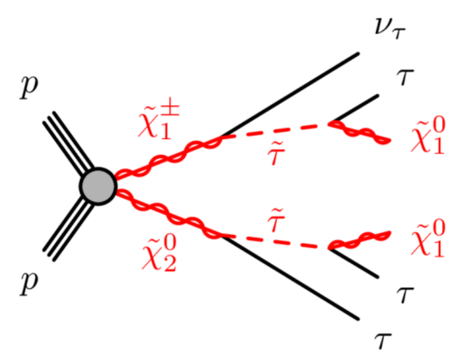
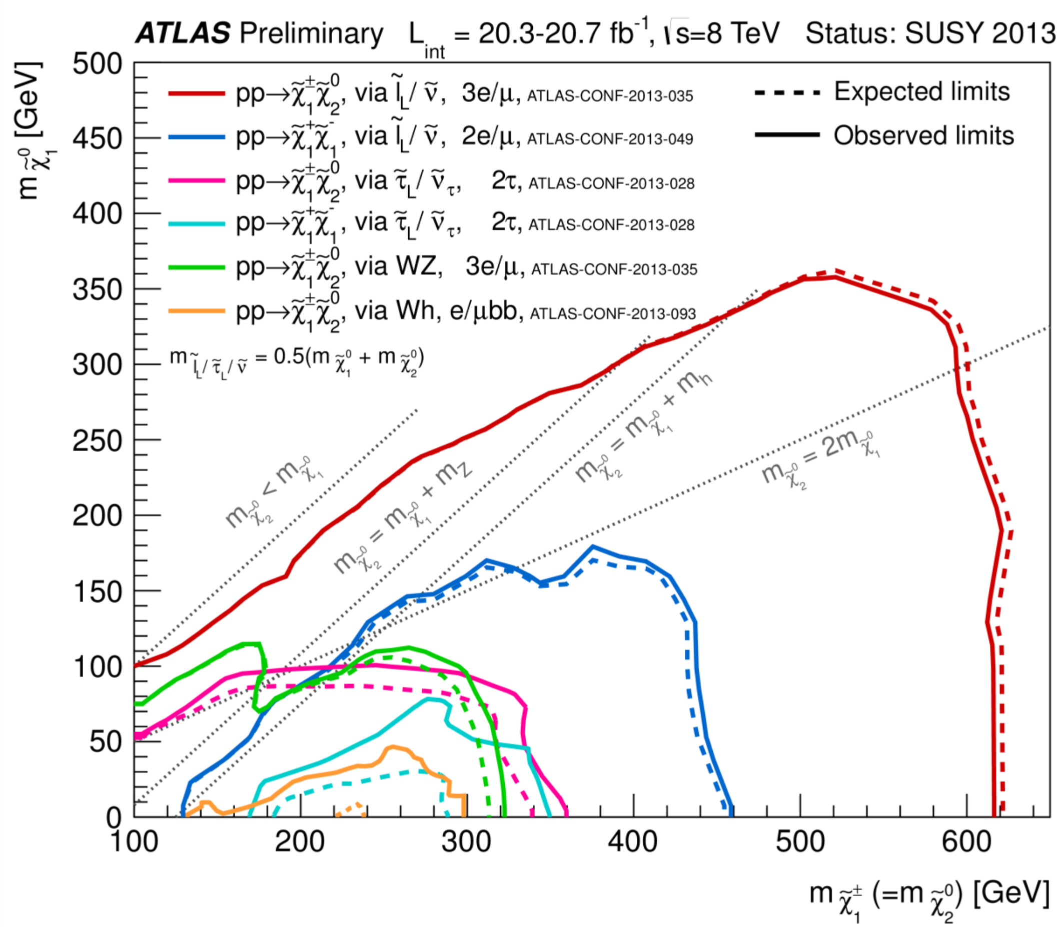
Reminder



Where is SUSY?

- Different analyses searching for SUSY electroweak production



→ Large part of the haystack is searched, but so far no SUSY found

→ Continue with the remaining part