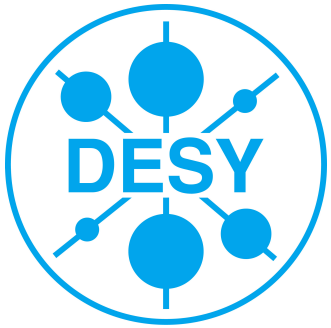


Search for supersymmetry with τ leptons in the CMS experiment

Ilya Bobovnikov, Alexis Kalogeropoulos,

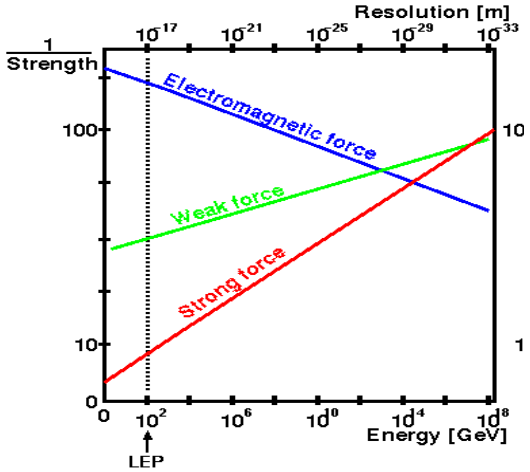
Isabell Melzer-Pellmann, Alexei Raspereza

55th Course of the International School of Subnuclear Physics, Erice, 14-23 June 2017

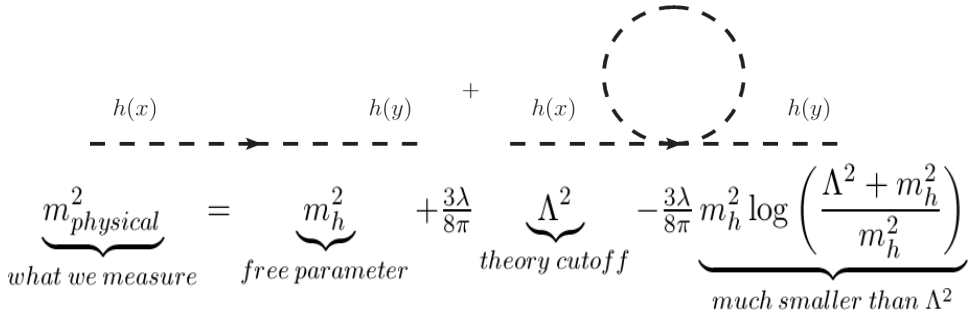
Motivation for SUSY

Problems

Gauge coupling unification



Hierarchy problem

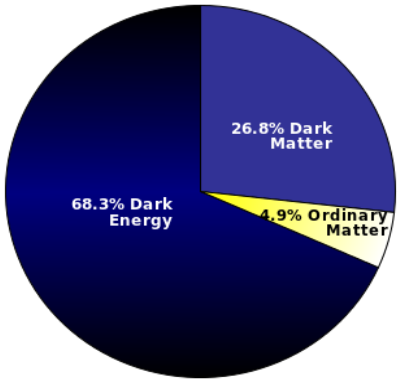


$$\underbrace{m^2_{physical}}_{\text{what we measure}} = \underbrace{m_h^2}_{\text{free parameter}} + \frac{3\lambda}{8\pi}\underbrace{\Lambda^2}_{\text{theory cutoff}} - \frac{3\lambda}{8\pi} m_h^2 \log\left(\frac{\Lambda^2 + m_h^2}{m_h^2}\right)$$

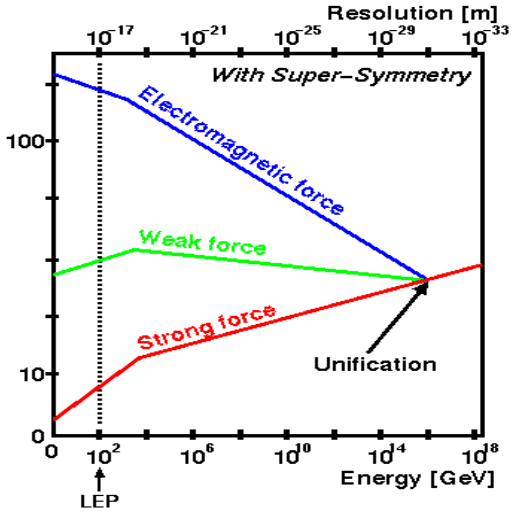
$\underbrace{\quad\quad}_{\text{much smaller than } \Lambda^2}$

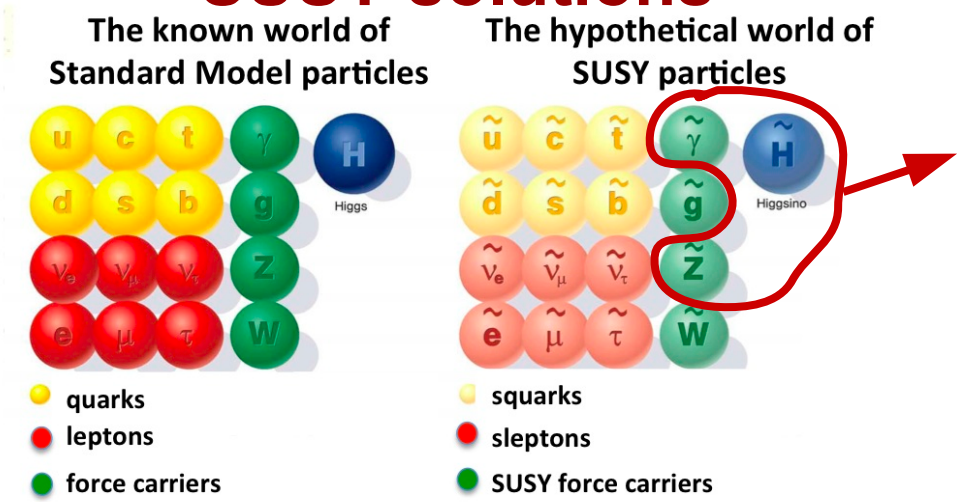
Fine tuning (for Plank Scale):
$O(10^{19}\ GeV)^2 - O(10^{19}\ GeV)^2 = O(10^2\ GeV)^2$

Dark matter

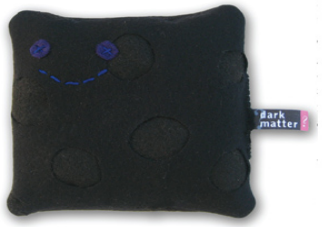


SUSY solutions





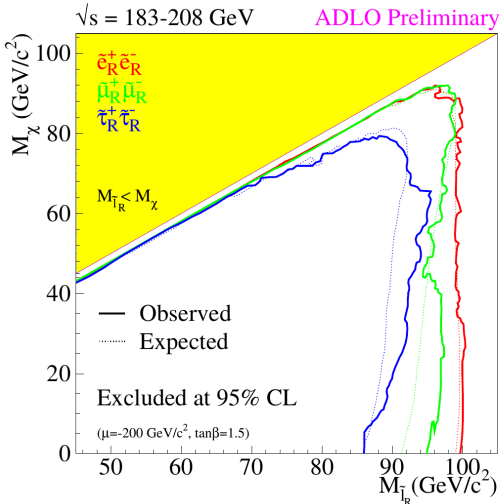
In case R parity conservation Lightest Supersymmetric Particle (LSP) can be good candidate to be dark matter



Loop from particle and sparticle cancel each other

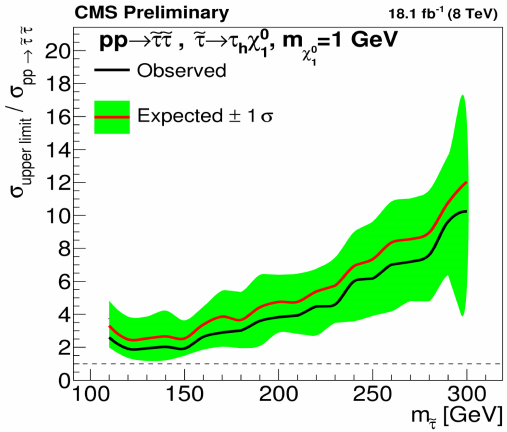
Motivation

LEP results

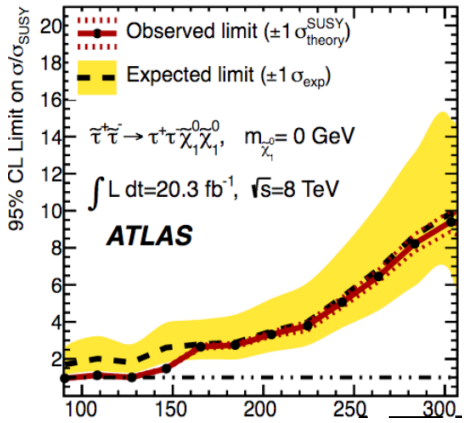


LEP put strong limits on slepton masses

LHC Run1 results



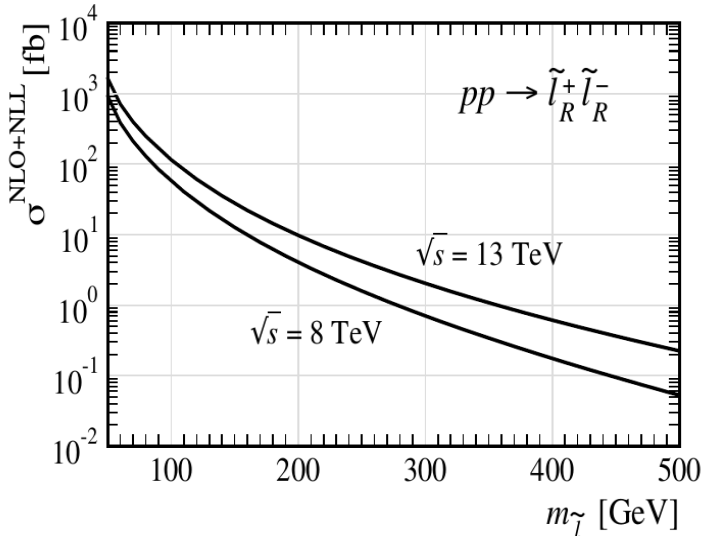
CMS (SUS:14-022)

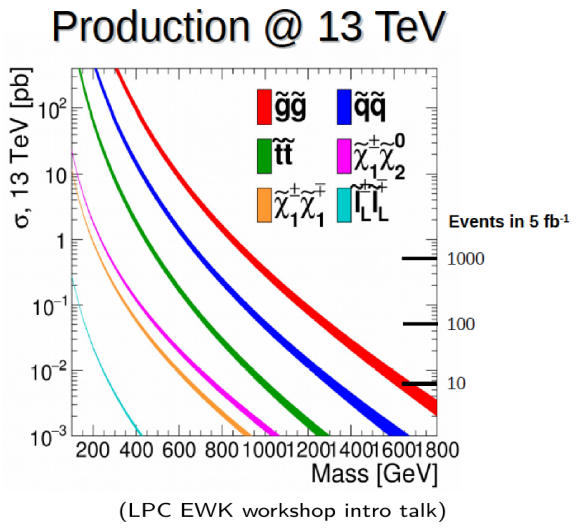


ATLAS (arxiv:1407.0350)

Only one point excluded at 8TeV @ 20 fb^{-1}

SUSY LHC cross sections

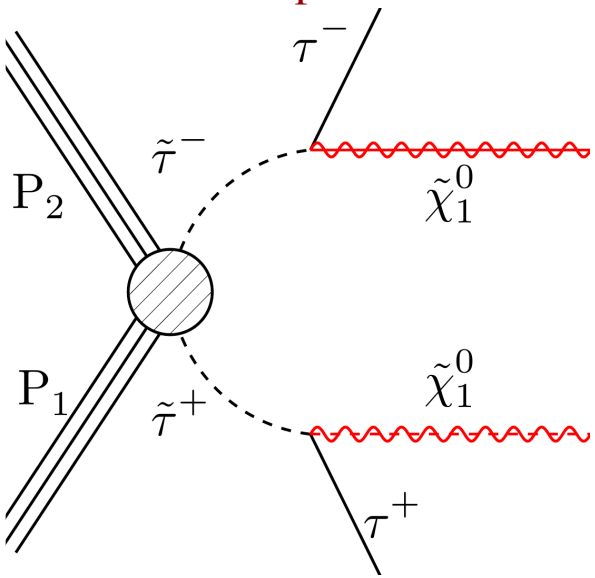




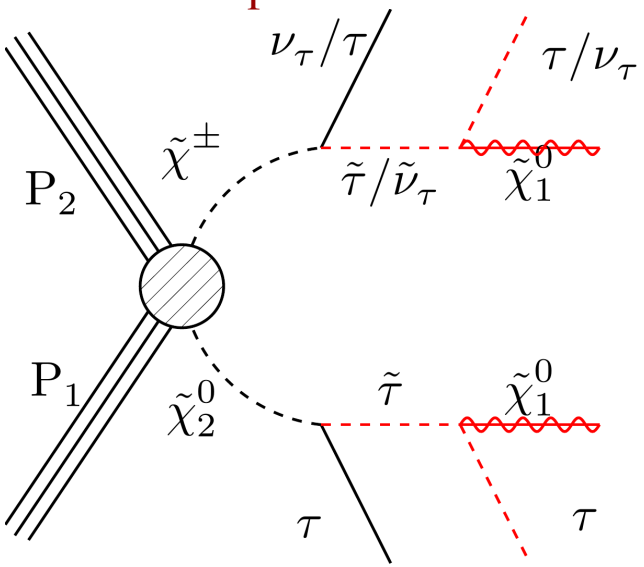
The cross section is the lowest of all SUSY particles

Models and topologies

direct stau production



chargino-neutralino pair production



Experimental signature

- Missing transverse energy depends on model parameters
- Small number of jets and no b-tagged jets

Channel	Signature	$\mathcal{BR}$
$0-\ell$	$2\tau_h+\not{E}_T$	$0.65^2 = 0.42$
$1-\ell$	$\tau_\ell\tau_h+\not{E}_T$	$2 \times (0.35 \cdot 0.65) = 0.46$
$2-\ell$	$2\tau_\ell+\not{E}_T$	$0.35^2 = 0.12$

Covered by this analysis

$\mu\tau_h$, $e\tau_h$, $e\mu$

Event selection

- 35.9 fb^{-1}of 13 TeV p-p collisions data taken during 2016
- For μτ, eτ channels
  - well identified isolated muon or electron, that fires single lepton trigger
  - well identified isolated τ-lepton
  - opposite charge
  - $0.3 < \Delta R < 3.5$
- For eμ channel
  - Well identified isolated muon and electron, that fire cross trigger (two lepton trigger)
  - opposite charge
  - $\Delta R > 0.3$
- 3rd lepton veto and dilepton veto
- Njet ≤ 1 and Nb-tag = 0
- $20 < M_T < 60$ GeV or $M_T > 120$ GeV (μτ, eτ)

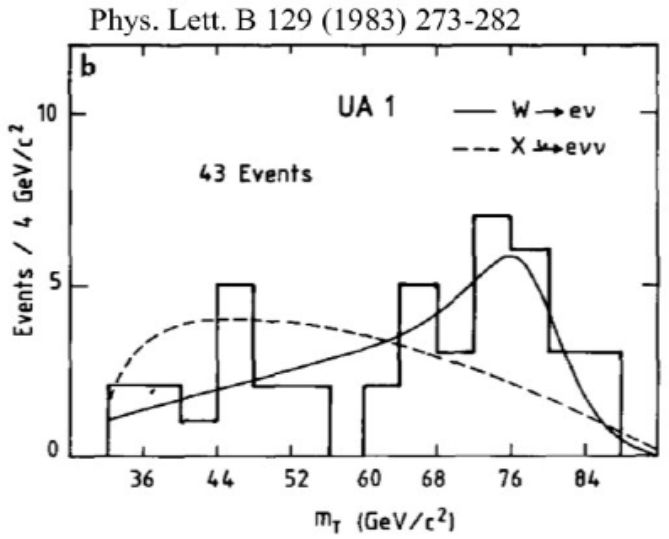
  (to suppress Wjets bkg.)
- Mll < 30 GeV and 100 GeV < Mll < 250 GeV (eμ)

  (to suppress DY bkg.)

$\Delta R_2 = \Delta\varphi_2 + \Delta\eta_2$, where Δφ and Δη are distances between leptons in (φ,η) plane)

$$M_T = \sqrt{2P_T^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - cos(\Delta\Phi(\ell, E_{\mathrm{T}}^{\mathrm{miss}}))}$$

M_T was initially introduced at UA1 to measure M_W ($M_T < M_W$)



Additional cuts to increase signal to background ratio are applied (called as **Signal Region cuts**)

Background estimation

Bkg.	Shape	Norm	Selection of CR
TTJets	MC(corrected)	CR	μ-e + cuts (94% pur.),Norm~1.04
WJets	MC(corrected)	CR	μ-τ + cuts (89% pur.),Norm~0.91
DYJets	MC(corrected)	CR	μ-μ +cuts (99% pur.): Norm~0.96
Rest	MC(corrected)	-	-
QCD	Region A	C/D	**A** Same Sign, Nominal relIso **B**, Opposite Sign, Nominal relIso(SR) **C** ,Opposite Sign, Inverted relIso **D**, Same Sign, Inverted relIso

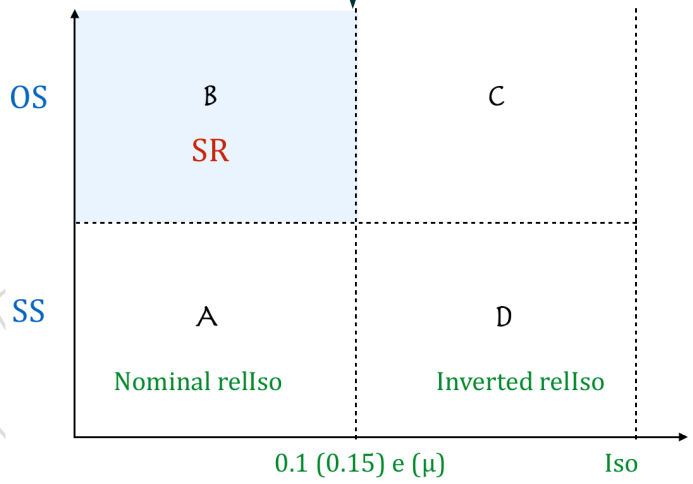
Very limited number of events from QCD MC

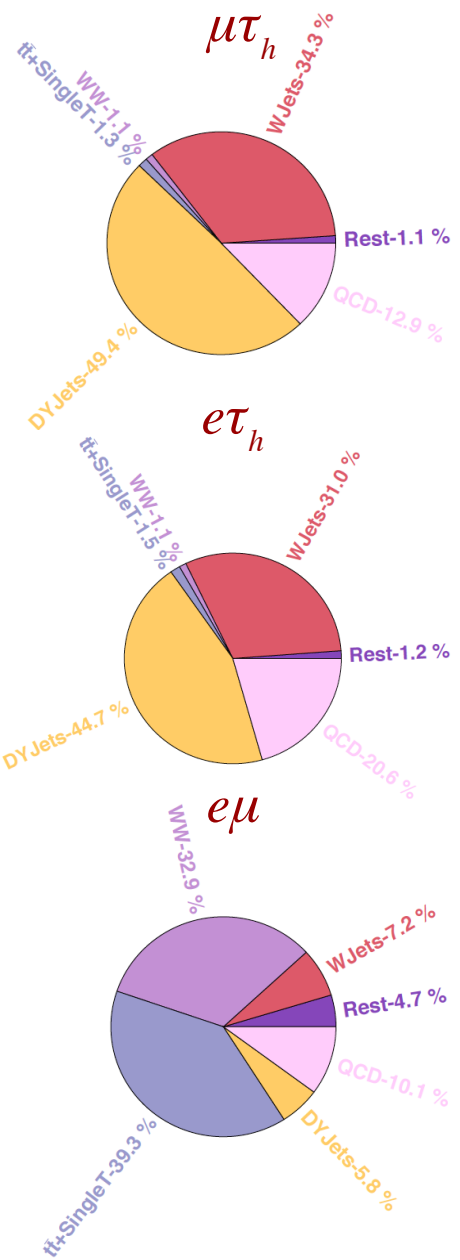
Subtract all other processes in each region (taken from MC)

$$S^{\mathrm{QCD}} = S^{\mathrm{data}} - S^{\mathrm{MC}}_{\text{non-QCD}}$$

$$N^{\mathrm{QCD}} = N^{\mathrm{data}} - N^{\mathrm{MC}}_{\text{non-QCD}}$$

QCD calculation: $S^{\mathrm{QCD}}_{\mathrm{SR}} = S^{\mathrm{QCD}}_{\mathrm{A}} \frac{N^{\mathrm{QCD}}_{\mathrm{C}}}{N^{\mathrm{QCD}}_{\mathrm{D}}}$

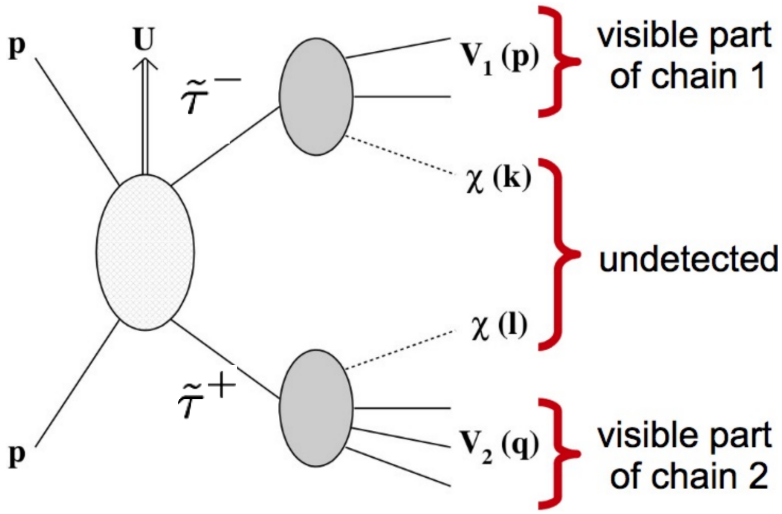




Search variables

- E_T^{miss} – missing transverse energy
- M_{T2} – "stransverse" mass

$$M_{T2}^2 = \min_{\vec{k}_T+\vec{l}_T=\text{tot miss } \vec{p}_T} \left\{ \max\left[M_T^2(\text{chain 1}), M_T^2(\text{chain 2}) \right] \right\} \leq m^2_{\tilde{\tau}}$$



- D_ζ – Discriminant used in legacy Higgs searches

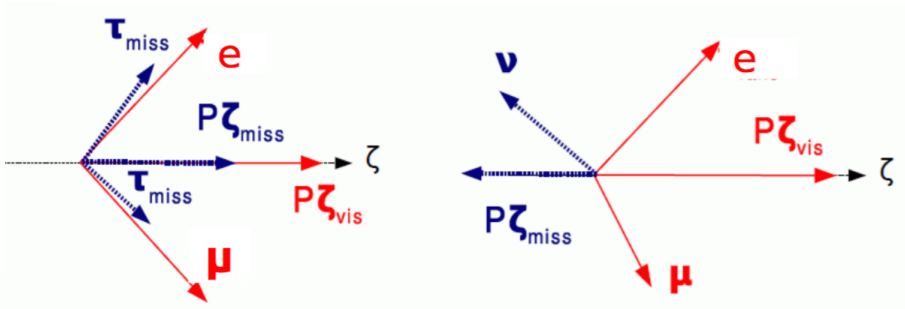
$$D_\zeta = P_{\zeta,\text{mis}} - \alpha \cdot P_{\zeta,\text{vis}}$$

$$P_{\zeta,\text{mis}} = \vec{p}_{T,\text{mis}} \cdot \vec{\zeta}, \quad P_{\zeta,\text{vis}} = (\vec{p}_{T,e} + \vec{p}_{T,\mu}) \cdot \vec{\zeta}$$

ζ – bisector between the direction of the electron and that of the muon

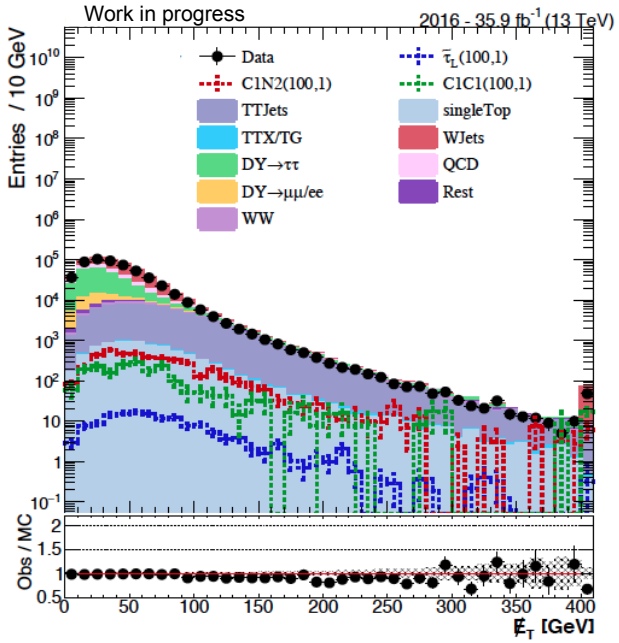
α = 0.85 (optimized value)

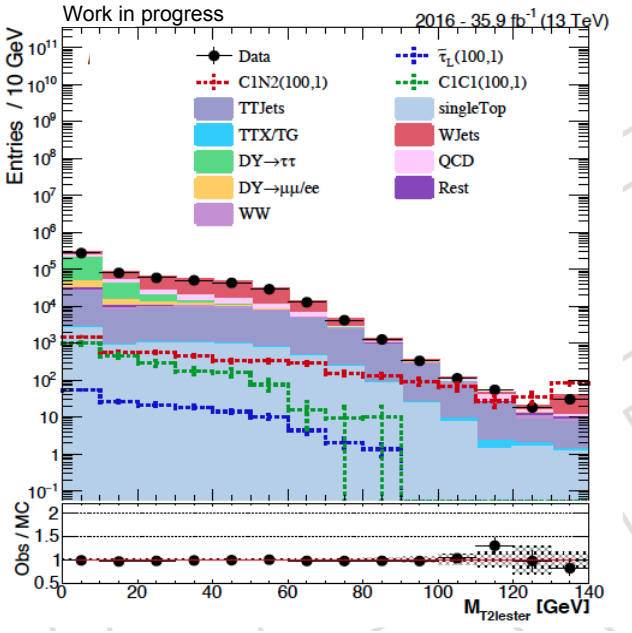
DYJets **TTJets,WJets (signal)**



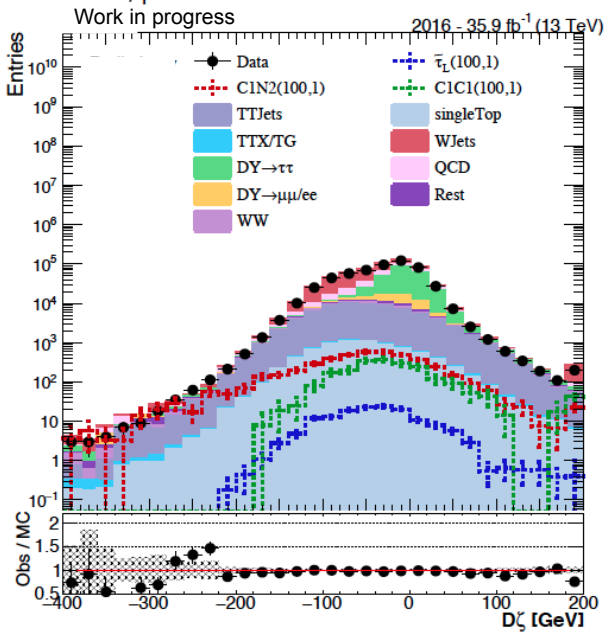
Control plots ($\mu\tau_h$)

Distributions after baseline selection



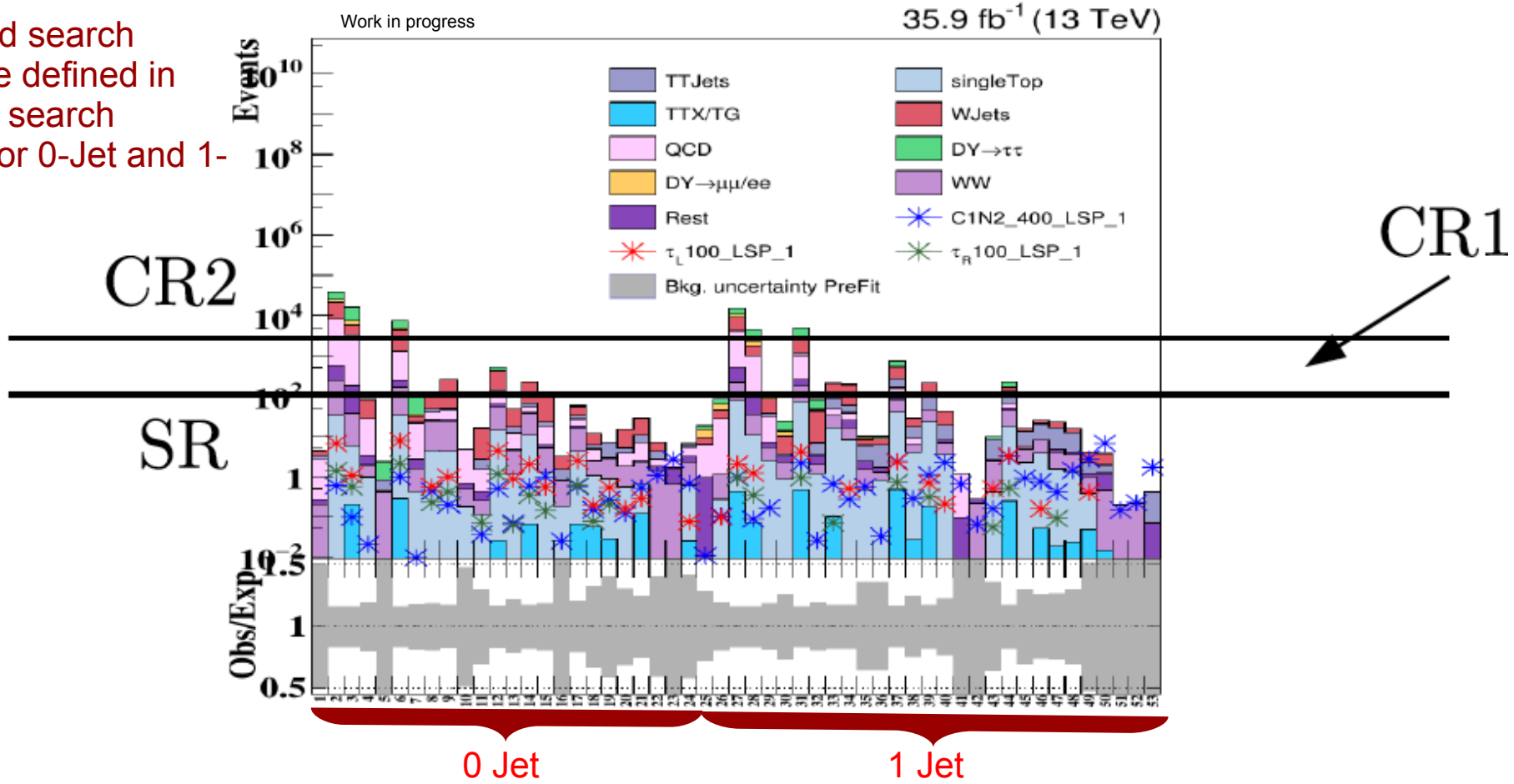


Agreement between Data and MC looks good



Search region definition

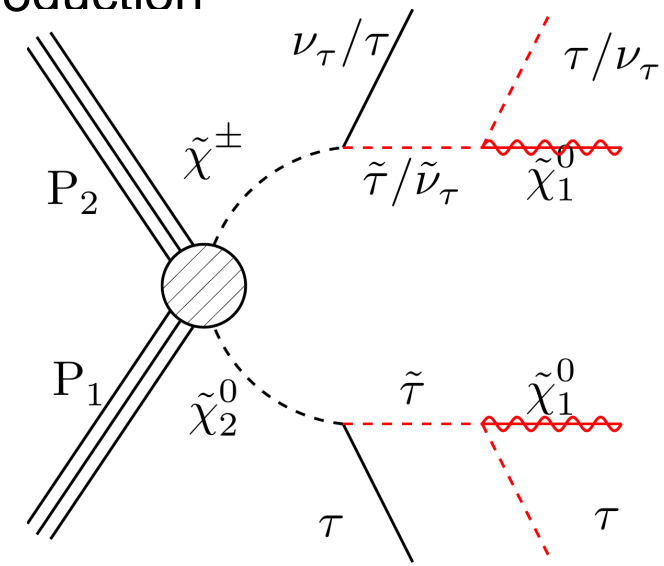
Control and search regions are defined in bins of the search variables for 0-Jet and 1-Jet events



- Control Region 2 (CR2) : bins with $N_B > 1000$
- Control Region 1 (CR1) : bins with $100 < N_B \leq 1000$
- Search Region (SR) : bins with $N_B \leq 100$
- Use regions CR1 and CR2 to commission fits and validate uncertainty
- Extract limits with simultaneous fit of CR1 + SR

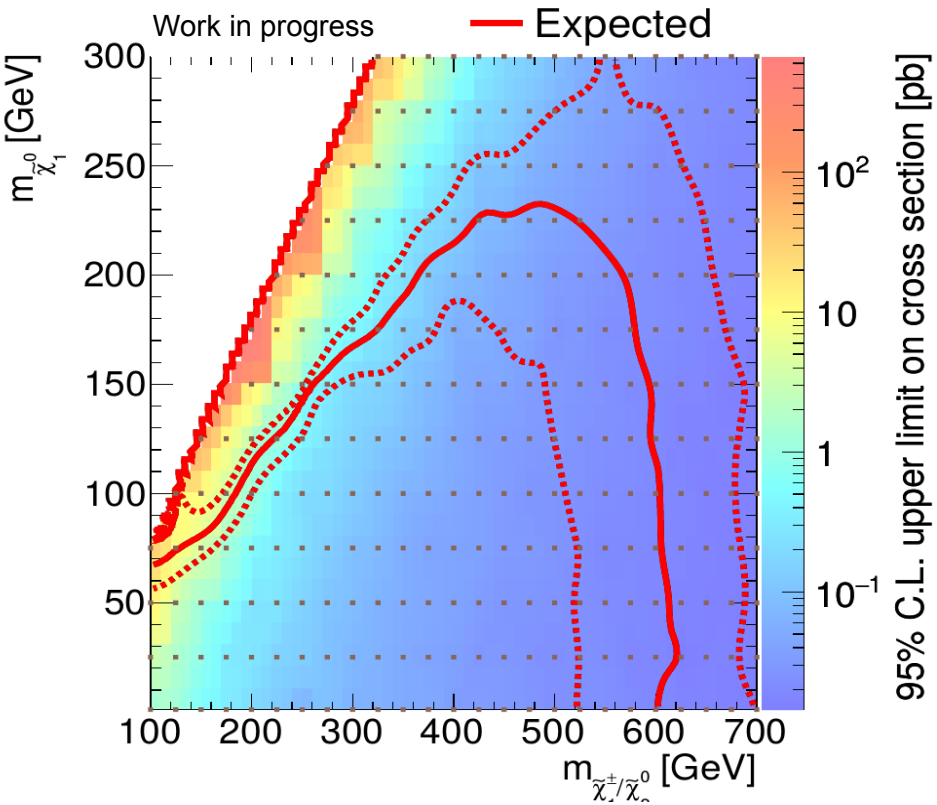
Interpretation

The results of the search are interpreted in the context of chargino-neutralino production



$$m_{\tilde{\chi}^{\pm}_1} = m_{\tilde{\chi}^0_2}$$

$$m_{\tilde{\tau}} = (m_{\tilde{\chi}^0_2} + m_{\tilde{\chi}^0_1})/2$$



Only expected limits are calculated since data are blinded

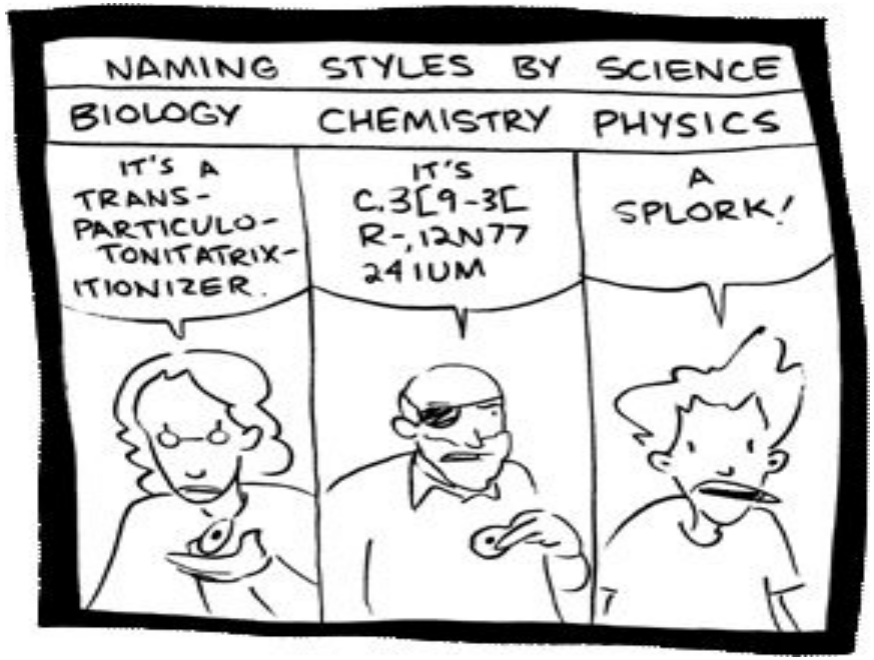
No sensitivity to direct $\tilde{\tau}$ production has been achieved

Conclusion

- Search for SUSY in events with τ leptons in the final state with 13 TeV data taken in 2016
- Various background estimation techniques
- Signal region optimization
- Results are interpreted in terms of simplified SUSY model and expected exclusion limits are calculated
- Plan to improve selection technique be sensitive to direct $\tilde{\tau}$ production and combine with all hadronic ($\tau_h \tau_h$) channel

Stay tuned!

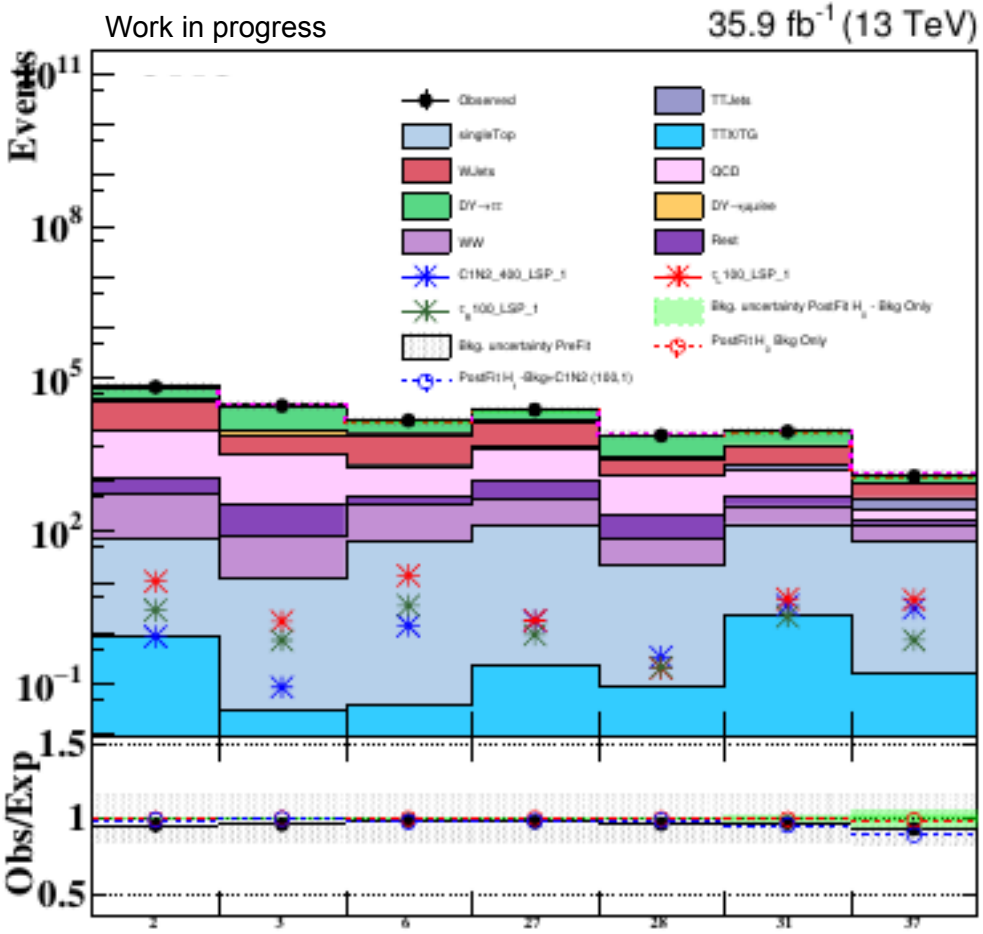
Thank you for attention



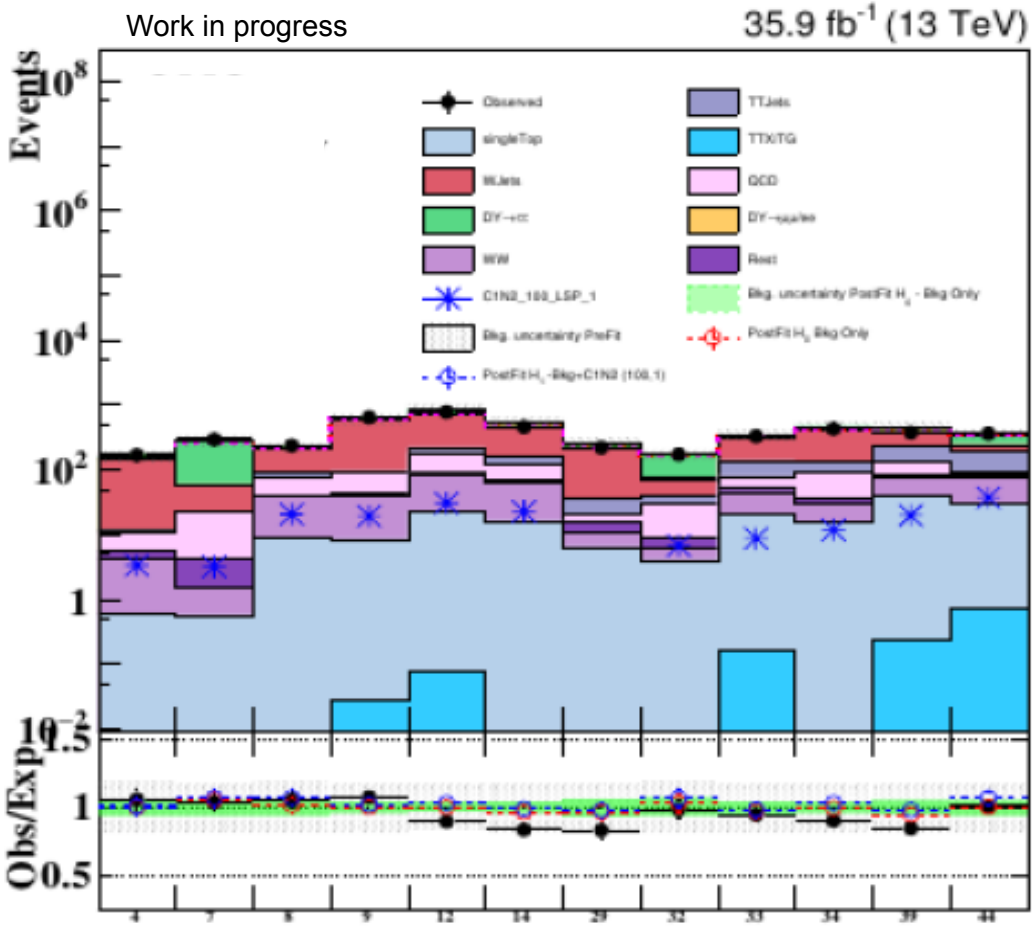
Backup

Commissioning of fits ($\mu\tau_h$)

CR 2



CR 1



Control regions are well described by the background prediction, and fluctuations are within the statistical and systematic uncertainties.
The influence of the signal contamination is marginal.

Binning

p_T^{miss}	M_{T2}	$D\zeta$	#SR 1-24	Category
<40	<40	<-100	1	0-Jets events
		>-100 & <0	2	
		>0	3	
	>40	>-500	4	
>40 & <80	<40	<-100	5	
		>-100 & <50	6	
		>50	7	
	>40 & <80	<-100	8	
		>-100	9	
	>80	>-500	10	
>80 & <120	<40	<-100	11	
		>-100	12	
	>40 & <80	<-150	13	
		>-150	14	
	>80	>-500	15	
>120 & <250	<40	<-100	16	
		>-100	17	
	>40 & <80	<-150	18	
		>-150 <-100	19	
		>-100	20	
	>80 & <100	>-500	21	
	>100 & <120	>-500	22	
	>120	>-500	23	
>250	>0	>-500	24	

p_T^{miss}	M_{T2}	$D\zeta$	#SR 25-53	Category
<40	<40	<-150	25	1-Jet events
		>-150 & <-100	26	
		>-100 & <0	27	
		>0	28	
	>40	>-500	29	
>40 & <80	<40	<-100	30	
		>-100 & <50	31	
		>50	32	
	>40 & <80	<-100	33	
		>-100	34	
	>80	>-500	35	
>80 & <120	<40	<-100	36	
		>-100	37	
	>40 & <80	<-150	38	
		>-150	39	
	>80 & <120	>-500	40	
	>120	>-500	41	
>120 & <250	<40	<-150	42	
		>-150 & <-100	43	
		>-100	44	
	>40 & <80	<-150	45	
		>-150 <-100	46	
		>-100	47	
	>80 & <100	>-500	48	
	>100 & <120	>-500	49	
	>120	>-500	50	
>250	>80 <100	>-500	51	
	>100 & <120	>-500	52	
	>120	>-500	53	

selection

Baseline selection

- Two leptons ($\mu\tau$, eτ, or eμ)
- No additional leptons (e or μ)
- $n_{\text{jet}} \leq 1$, where jets must have $p_{\text{T}} > 20\,\text{GeV}$ and $|\eta| < 2.4$
- $n_{\text{b-tag}} = 0$, with the medium WP (0.8484) of CSVv2
- $20 < M_{\text{T}} < 60\,\text{GeV}$ or $M_{\text{T}} > 120\,\text{GeV}$ ($\mu\tau$, eτ)
- $M_{\ell\ell} < 30\,\text{GeV}$ and $90\,\text{GeV} < M_{\ell\ell} < 250\,\text{GeV}$ (eμ)

Signal region selection (SRcuts)

optimized for generic SUSY search with τ's

- $\Delta|\eta|(\ell_1, \ell_2) < 2$
- $M_{\ell_1\ell_2} > 20\,\text{GeV}$
- $M_{\text{Tsum}} > 30\,\text{GeV}$
- $p_{\text{T}}(\ell_{1,2}) < 200\,\text{GeV}$ (eμ)
- $\Delta|\eta|(J_0, \ell_{1,2}) < 3$ (1-jet category only)
- $\Delta R(J_0, \tau) < 4$ ($\mu\tau$, eτ) (1-jet category only)

J_0 stands for hadronic jet

$$M_{\text{Tsum}} = M_{\text{T}}(\ell_1, E_{\text{T}}^{\text{mis}}) + M_{\text{T}}(\ell_2, E_{\text{T}}^{\text{mis}})$$

Additional selection criteria optimized to search for direct stau pair production

- $|d_z(\mu, e)| < 0.04\,\text{cm}$
- $|d_{xy}(\mu, e)| < 0.02\,\text{cm}$
- $Iso(\tau) > 0.85$ ($\mu\tau$, eτ)
- $\Delta|\eta|(\ell_1, \ell_2) < 1.5$
- $\Delta\Phi(\ell_1, \ell_2) > 1.5$
- $2 < \Delta R(\ell_1, \ell_2) < 3.2$
- $M_{\ell_1\ell_2} > 50\,\text{GeV}$
- $M_{\text{Tsum}} > 50\,\text{GeV}$

Corrections

- **Trigger and Lepton scale factors** (efficiencies have been obtained with *Tag & Probe* method from Z → μμ and Z → ee selection)
- **Muon and Electrons Tau fake rate**: these are obtained from the TAU POG.
- **Tau fake rate**: Measuring the jets→tau fake from a Wjets enriched CR Applying nominal preselection of μ-τ
- **Top p_T reweighting**: to improve modelling of the top quark p_T spectrum
- **Z recoil corrections**: corrections to the the parallel and perpendicular parts of the E_T^{miss} (extracted from Z → μμ selection, applied to Z-jets and W-jets events)
- **Z p_T corrections**: applied to describe the disagreement of data and simulation at high Z p_T