Search for SUSY in soft opposite-sign dilepton final state

Compact Muon Solenoid experiment at CERN's LHC

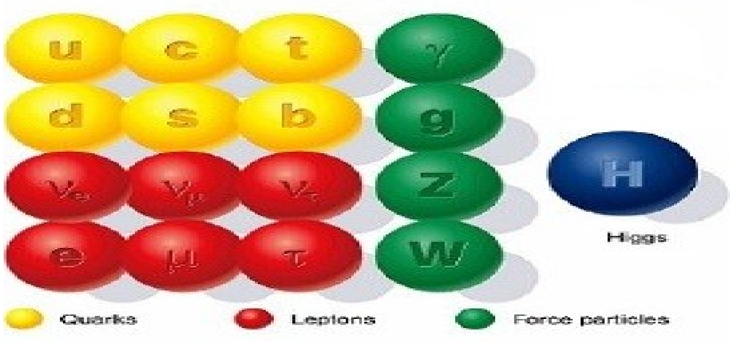
HELLENIC REPUBLIC
National and Kapodistrian University of Athens

G.Karathanasis for the CMS collaboration

SUper SYmmetry

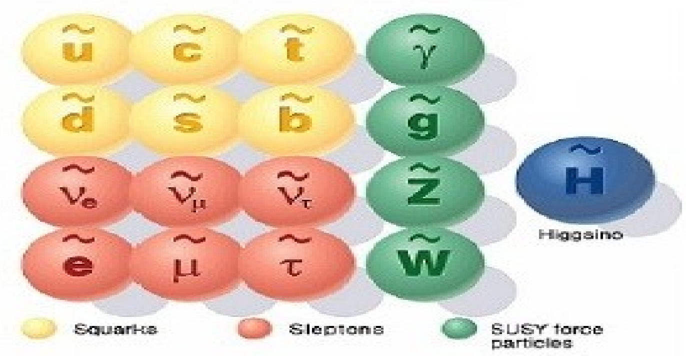
What is Super Symmetry?

- Super Symmetry (SUSY): One of the most appealing extensions of Standard Model (SM).
- New symmetry of nature: Predicts super partners whose spin differs by ½ with respect to SM.



Standard particles

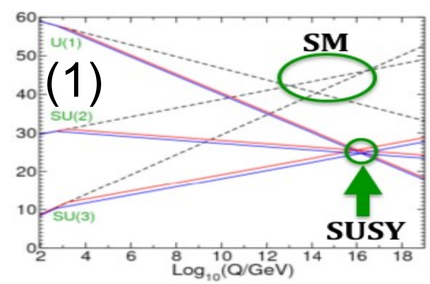
Spin Based Symmetry



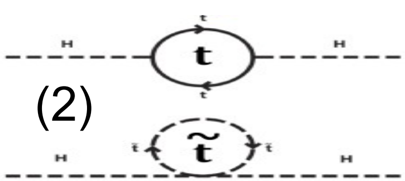
SUSY particles

Why is it appealing?

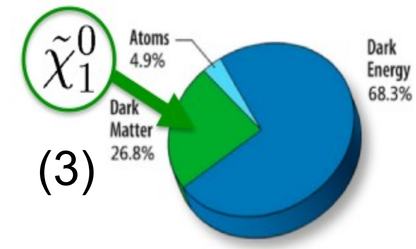
(1) Unification of gauge couplings.



(2) Top squark contributions cancel SM contributions.



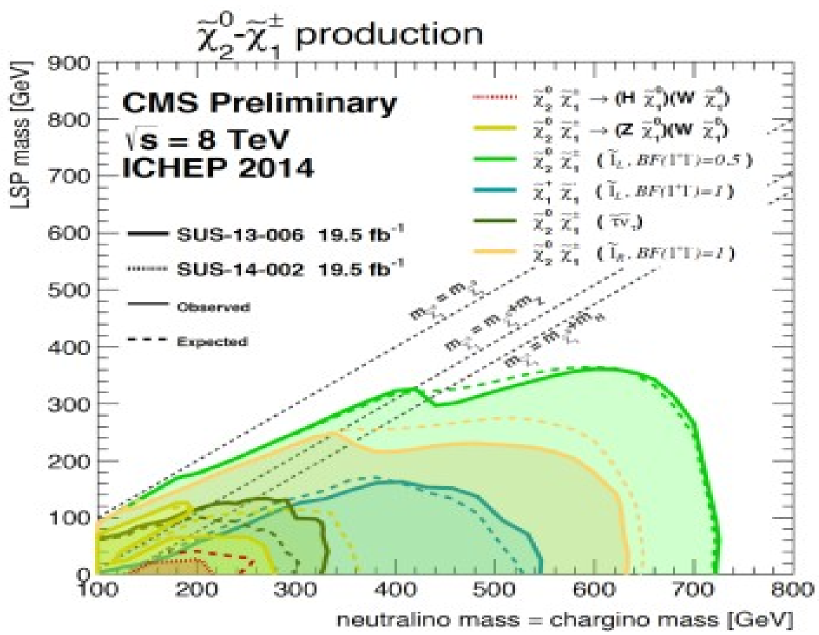
(3) Lightest Supersymetric Particle (LSP) provide a plausible candidate for Dark Matter.

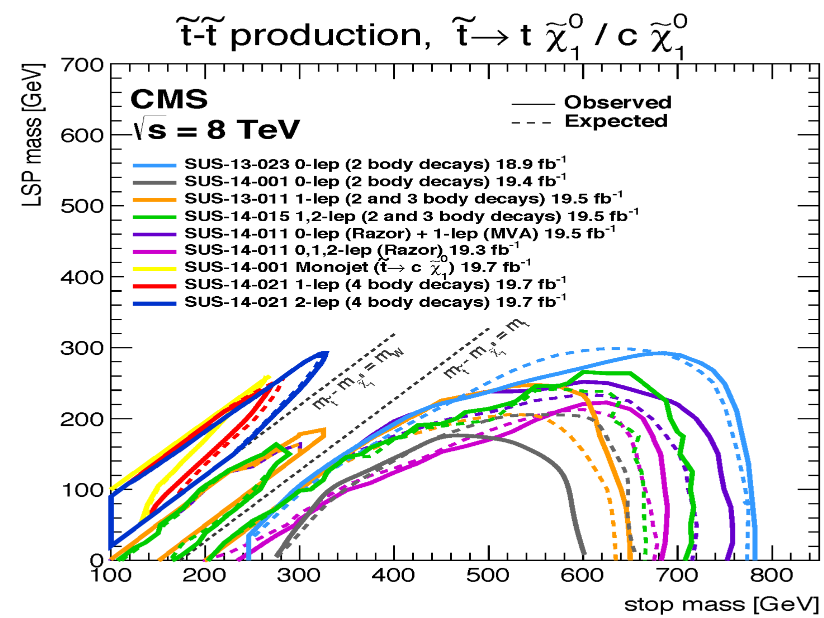


SUSY: So far...

Extensive studies at 8TeV: <u>no evidence</u>!!!

Exclusion limits set in a large area of parametric space...





Nevertheless, there is significant room for SUSY. As examples of how SUSY could have escaped thus far:

- Not enough data to be visible yet (e.g. low BR for studied channels, low couplings)

- Super partners are abundantly produced, elude current searches (e.g. compressed spectrum)

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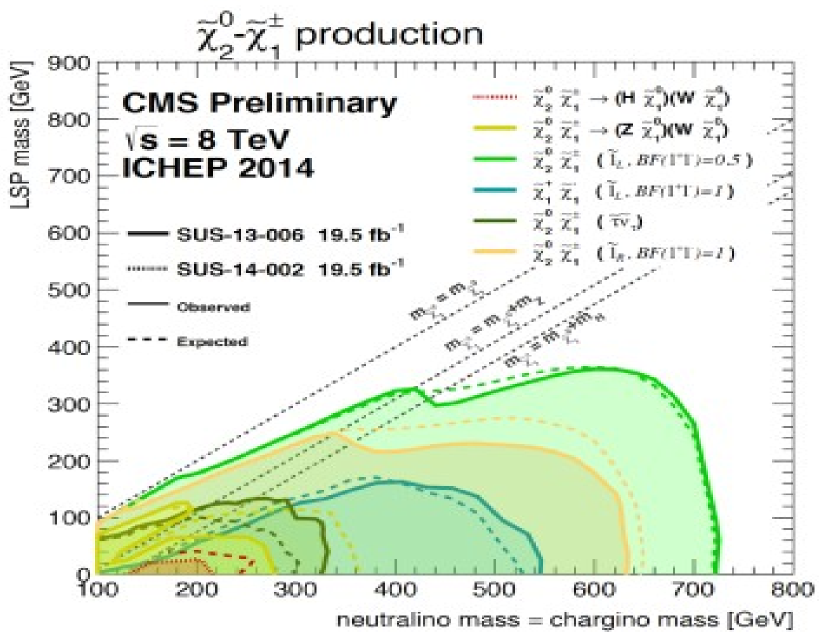

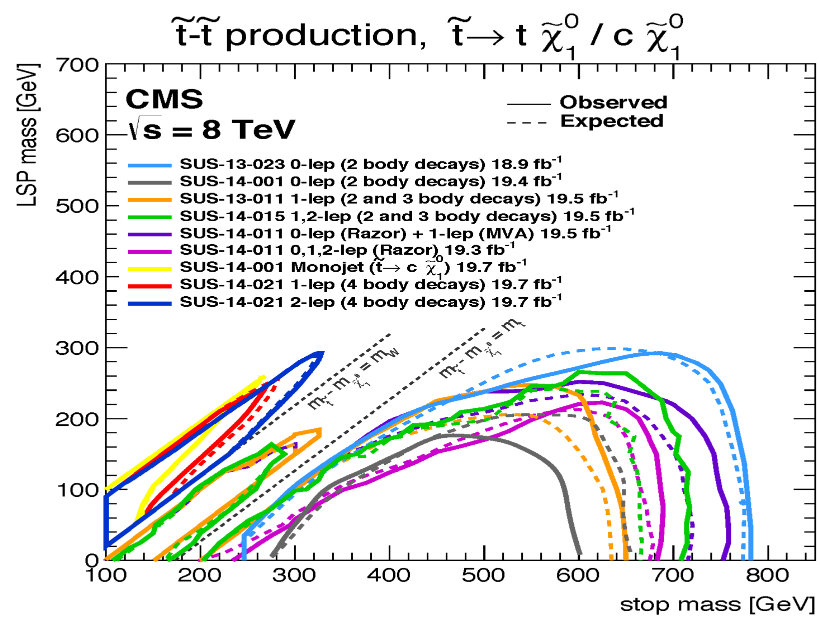

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New searches in “difficult” regions

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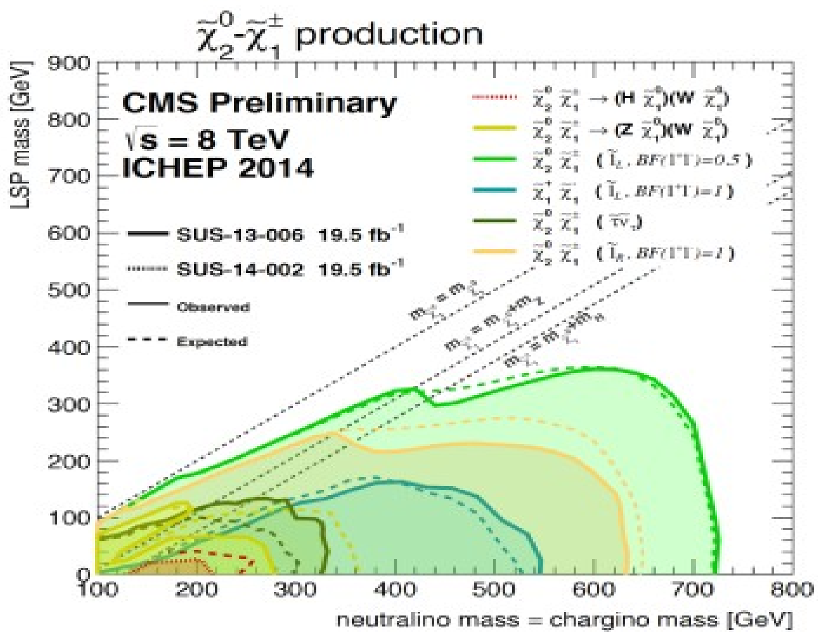

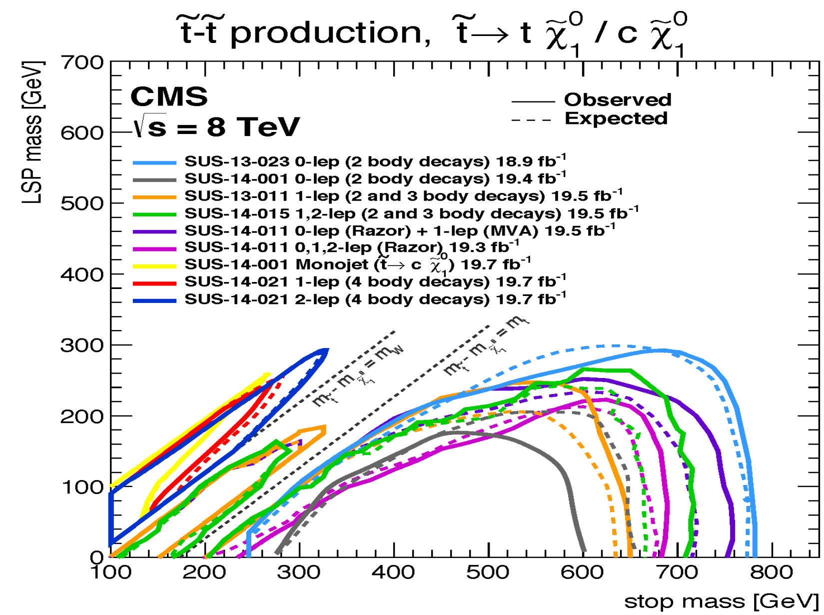

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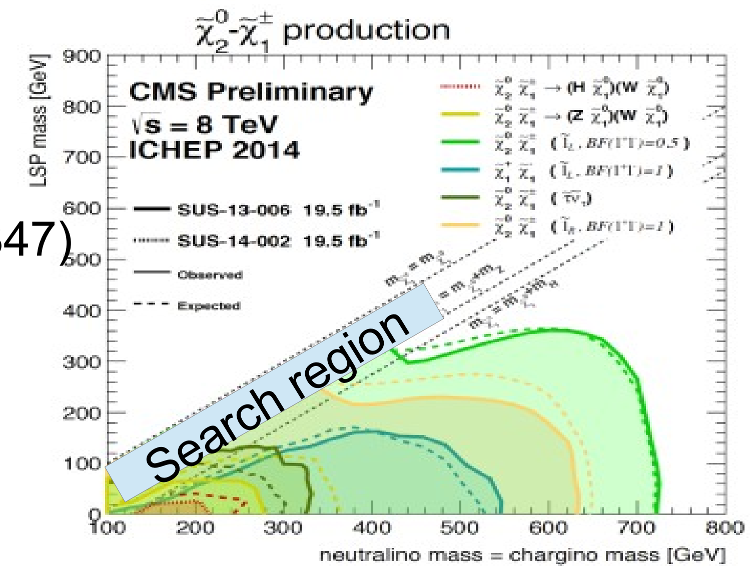
New searches in “difficult” regions

Focus of current analysis

Compressed (spectrum) SUSY

What is compressed spectrum SUSY?

- SUSY scenario in which Δm(NLSP,LSP) is small (<50GeV)
- Well motivated from theory:
    - Gives right relic density for DM (Phys.Rev. D70,015007)
    - Low Δm (stop,LSP) motivated in literature (arxiv:1212.6847)



Main difficulty:
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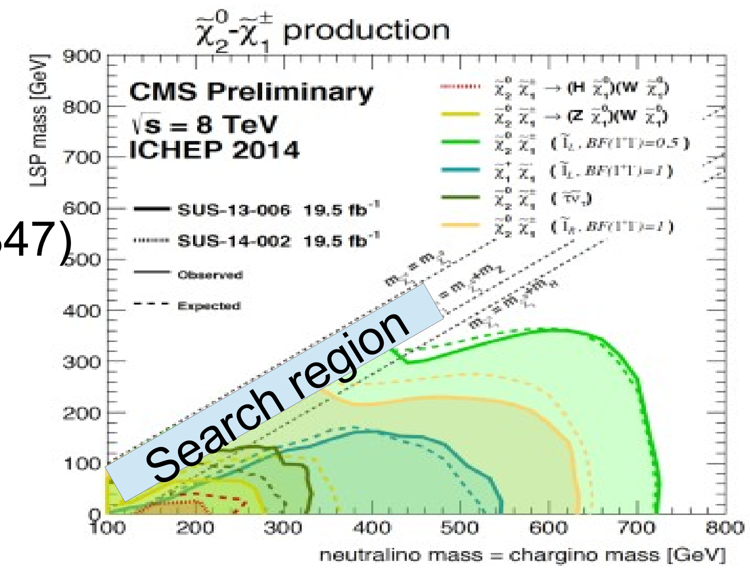

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- Final objects will include soft visible objects and the invisible LSP
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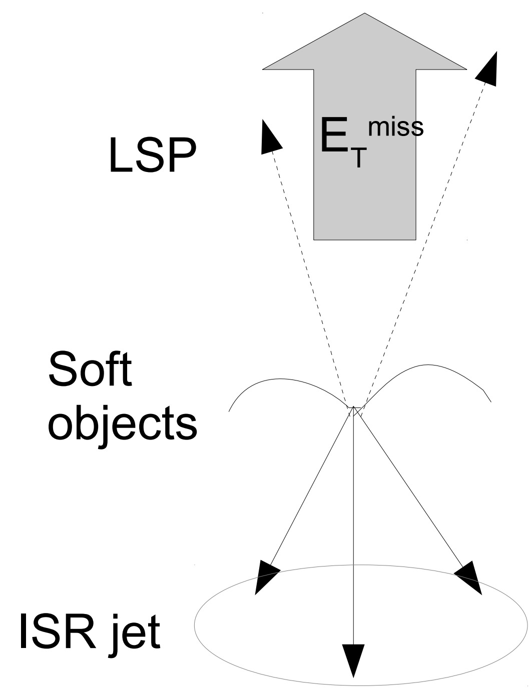
Solution:

- Require an ISR jet in the event.

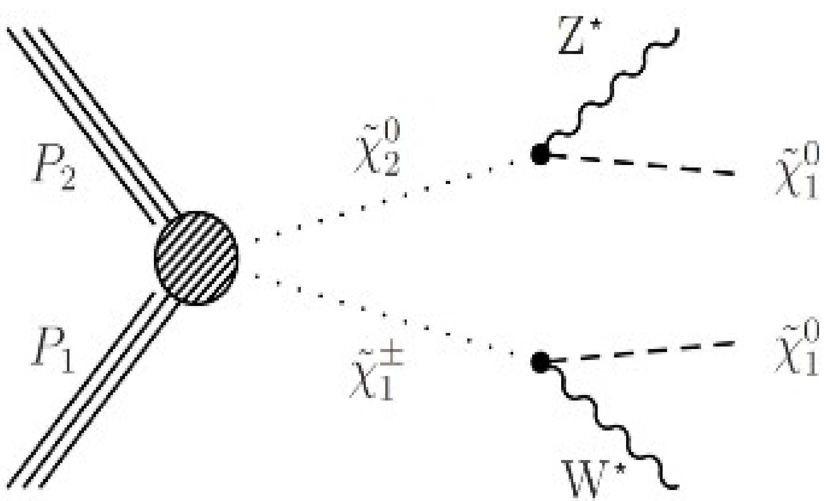
- LSP will be boosted, creating moderate E_T^{miss}

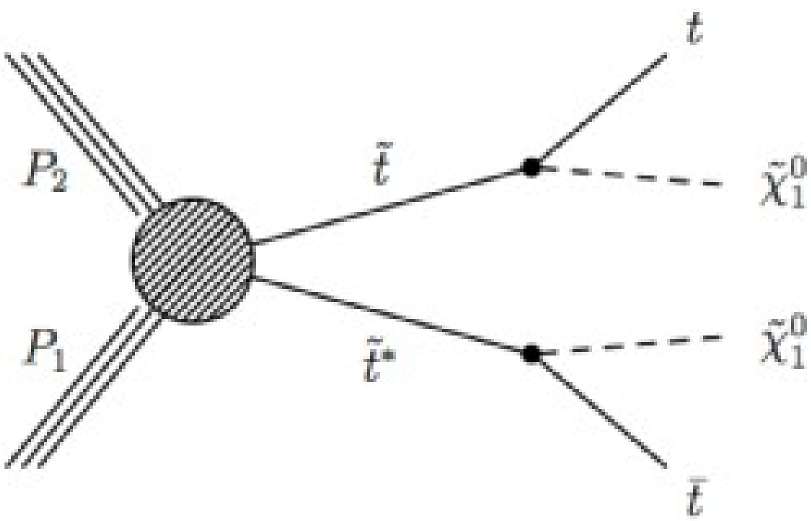
- Something that we can trigger on!



Targeted Signatures

EWKinos:
- Super partners (Bino-Wino-Higgsino) mix to form mass eigenstates.
- Mass eigestates (EWKinos) are divided in two categories charginos ($\tilde{\chi}_1^{\pm}$,$\tilde{\chi}_2^{\pm}$) and neutralinos ($\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$,$\tilde{\chi}_3^0$,$\tilde{\chi}_4^0$).
- In this analysis we search for $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$, or $\tilde{t}$ production.





Details of the signature:
- Compressed particle mass spectrum (Δm<50 GeV).
- Moderate E_T^{miss}, soft leptons, ISR selection.
- Search for: Chargino-neutralino production and stop.
- Typical LSP search mass: 150 GeV for $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$, and 350 GeV for $\tilde{t}$.
- Physics analysis summary reference: SUS 16-048 (link)

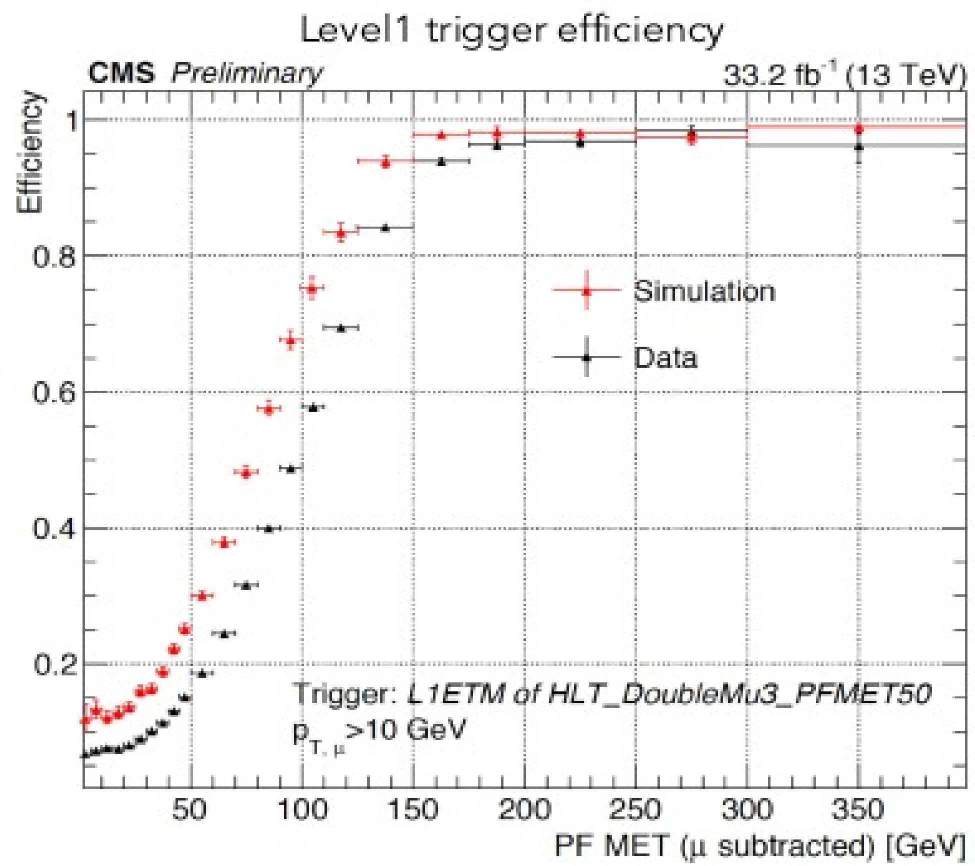
Trigger

We search for events with:
- Soft leptons (μ,e)
- Moderate E_T^{miss}
- ISR-jet

Created a tailor-made trigger for soft μ

Benefits of new trigger:
- Reduce thresholds for $P_T(\mu)$ and E_T^{miss}
- Search a completely new phase space going to very small Δm

Details of new trigger:
- E_T^{miss} > 50 GeV
- $P_T(\mu)$ > 3 GeV
- Active for 33.2 fb^{-1} out of 35.9 fb^{-1}
- 80% efficiency (mostly to distance of closest approach (DCA) between leptons inefficiency)
- Gained 2 times more sensitivity (with respect to existing triggers).
- Existing triggers: Inclusive E_T^{miss} triggers with threshold of E_T^{miss} >120 GeV



* Difference between simulation/Data: Lower ETM paths disabled in Data

Event Selection

Signal region definition:

- $P_T(\mu)$: [5 GeV, 30 GeV]
- E_T^{miss} > 125 GeV

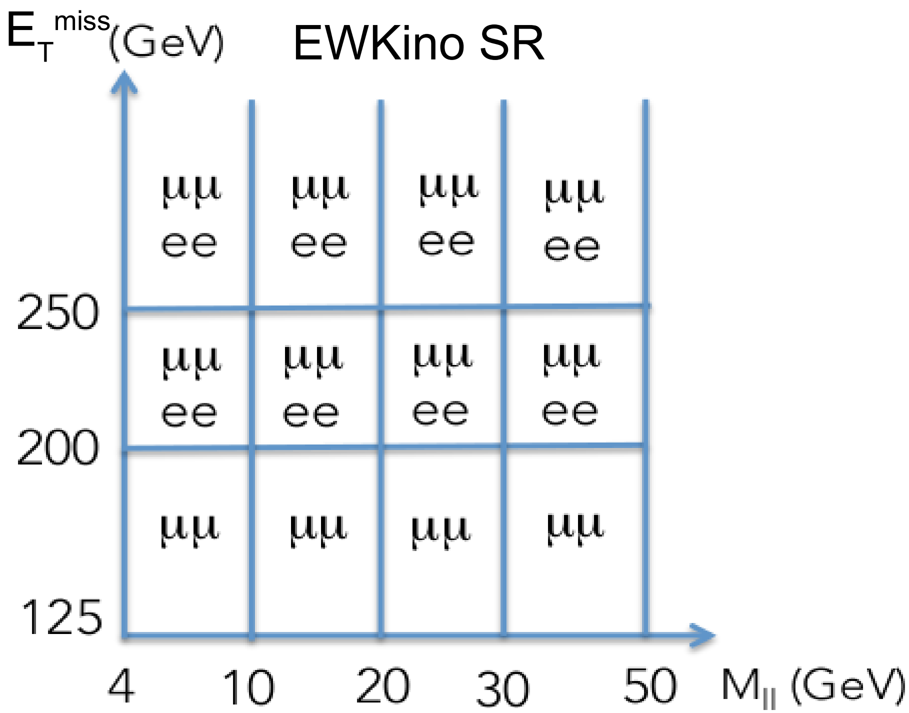
To be on the plateau of the trigger

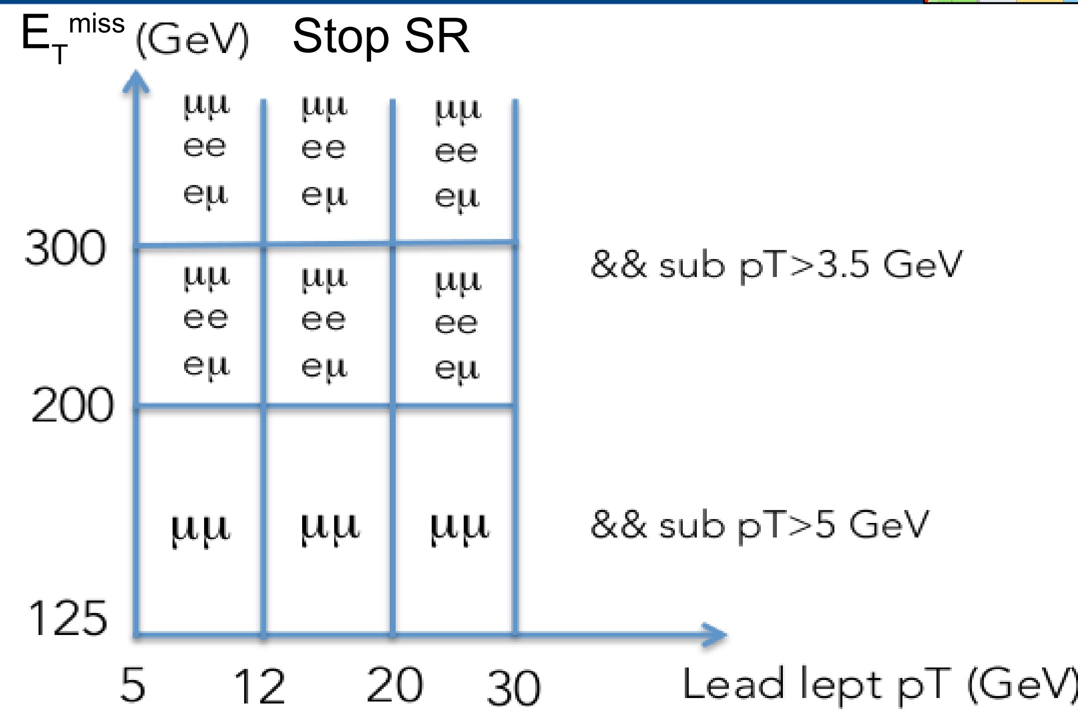
- E_T^{miss}/H_T:
  - $H_T = \Sigma P_T(jet_i)$
  - lower value: cuts QCD bkg but not ISR.
  - Upper value: reject J/Ψ.
- loose b-veto: reject $t\bar{t}$.
- J/Ψ and Υ inv. mass veto.
- $M_{\tau\tau}$>160 GeV or <0:
  - Decomposing E_T^{miss} in leptons direction → reconstruct initial τ → calculate M(τ,τ)
  - Reject taus boosted from Z → τ^+,τ^-.
- M_T<70GeV: For EWKino signal E_T^{miss} is aligned with the leading lepton.
- H_T >100 GeV: ISR requirement
- IP3D<0.01cm .AND. SIP3D<2.0: reject non-prompt leptons

Samples:

- Data: Collected with CMS at 35.9 fb^{-1} in 2016.
- Triggers: Inclusive E_T^{miss} and a dimuon+ E_T^{miss}. Dimuon+E_T^{miss} low E_T^{miss} threshold (33.2 fb^{-1})
- Monte Carlo: MADGraph, POWHEG

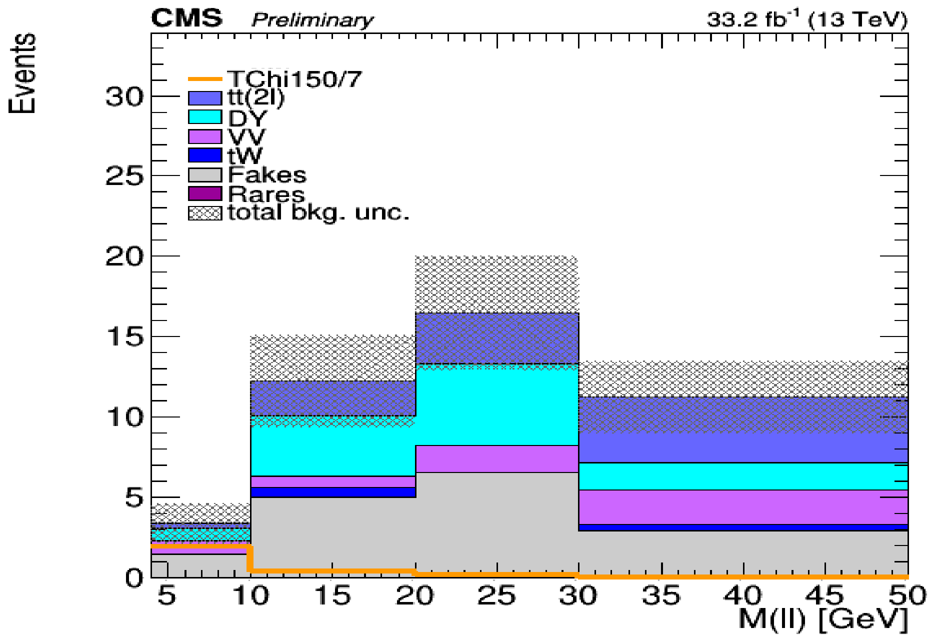
Signal Regions





- Signal regions: One EWKino-like and one Stop-like.
- EWKino-like:
  - Targets constrained Z* production from $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0$.
  - Expecting two same-flavour opposite-sign leptons with mass edge. Bins in M(ll).
- Stop-like:
  - Targets cascade decays, e.g. from stop. Expect also eμ events.
  - Bins in P_T(l1).

Background Composition



Background processes:
- TT(2l)
- DY
- VV

Prompt

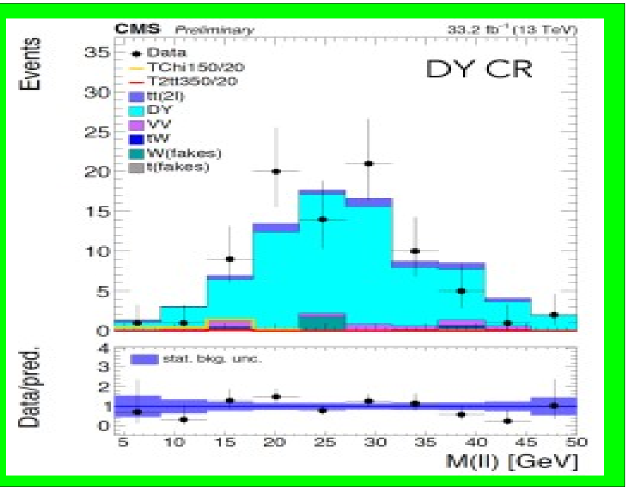
- Non-prompt leptons → Non-Prompt

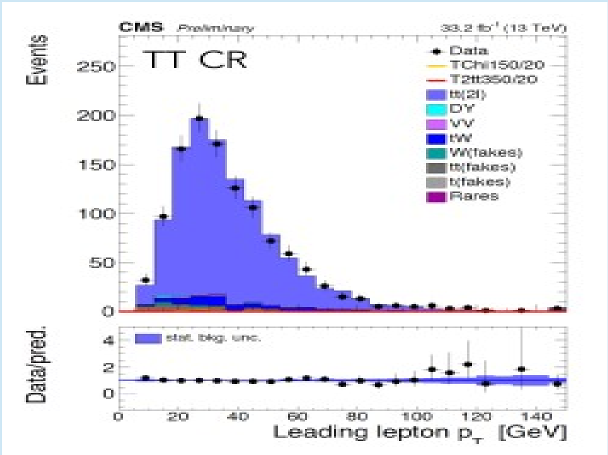
- Important backgrounds:
  - Prompt (mostly TT(2l) and DY).
  - Non-prompt leptons: mostly Wjets.
- **Strategy**:
  - **Prompt**:
    - DY, TT: Normalised to each control region (CR) and fitted simultaneously to the SR, shapes taken from MC.
    - VV: From simulation, validated with data.
  - **Non-prompt**: Tight-to-loose method.

Defining strategy:

- Estimated using Control Regions (CR), with similar phase space, signal free.

- Remove $P_T(l) < 30$ GeV cut
- $0 < M_{\tau\tau} < 160$ GeV
- Relax IP3D SIP3D





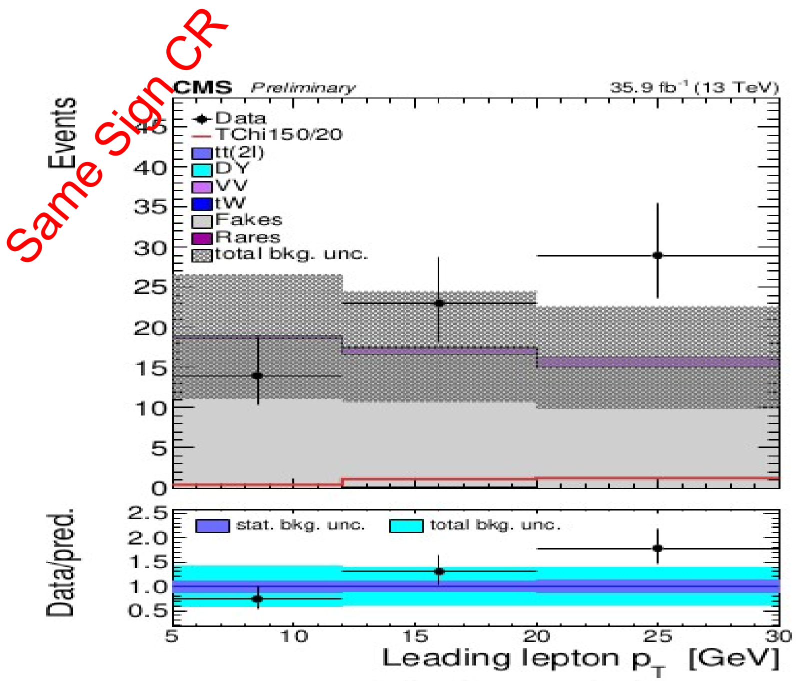
- Remove $P_T(l) < 30$ GeV cut
- At least one b-taged jet
- $P_T(b) > 40$ GeV

- Compute transfer factors (F) from simulation: $F = N_{MC}^{SR} / N_{MC}^{CR}$
- Use CR yield and F to calculate the SR contribution: $N_{data}^{SR} = F \cdot N_{Data}^{CR}$
- Done for **each process** independently.

	DY+jets CR		$t\bar{t}$ CR	
E_T^{miss}	125-200 GeV	> 200 GeV	125-200 GeV	> 200 GeV
DY+jets or $t\bar{t}$	70.1 ± 5.1	64.5 ± 3.3	1053.7 ± 9.4	535.7 ± 7.1
All SM processes	82.6 ± 5.5	75.2 ± 3.6	1170.3 ± 11.2	710.2 ± 10.6
Data	84	75	1157	680

Non-Prompt Background

- Non-prompt lepton sources: Decays of heavy flavour, π/K decays in flight, misidentified jets(e).
- Tight-to-loose rate: Probability of a non-prompt lepton to pass the tight ID criteria. Measured in a QCD enriched sample.
- Application Region (AR): Events where a lepton fails the tight ID criteria of the SR but passes a looser version (loose ID). Mostly filled with W+Jets events.
- Use Tight-to-loose rate and AR to estimate in SR.
- To constrain the uncertainty: Use an additional same sign CR.

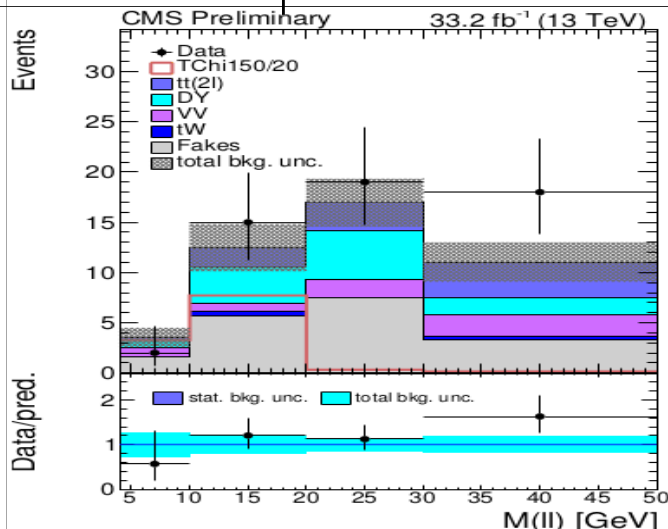
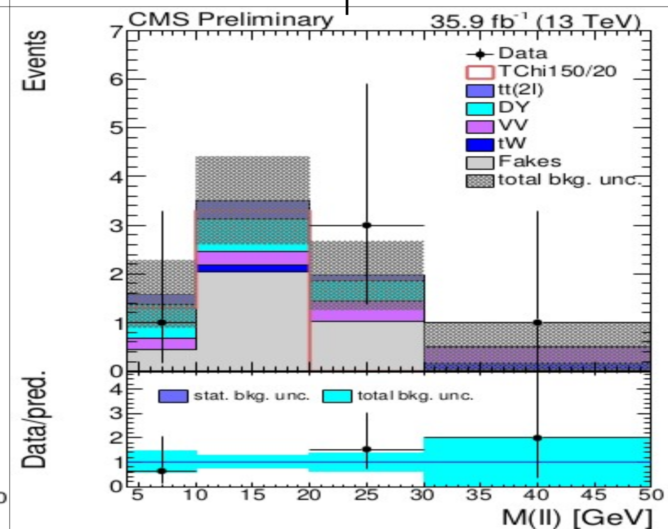
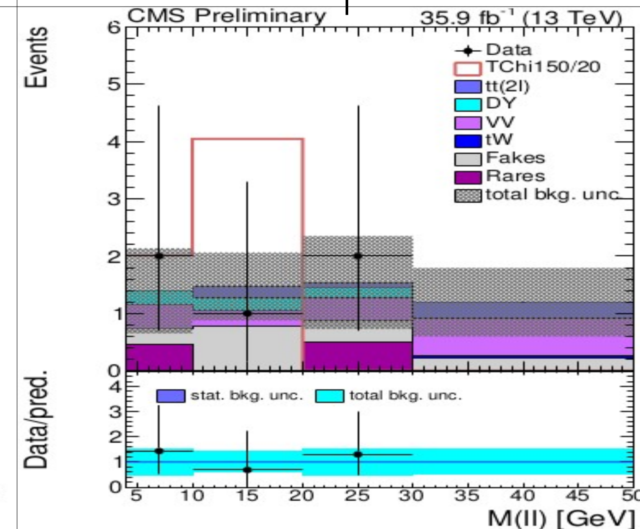
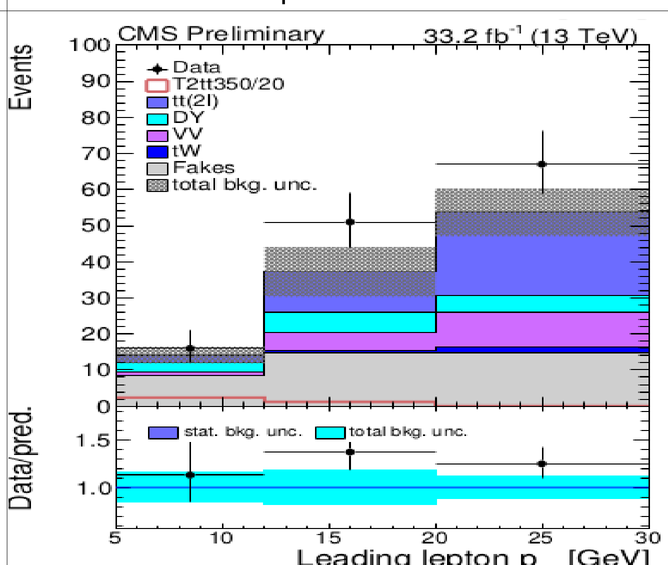
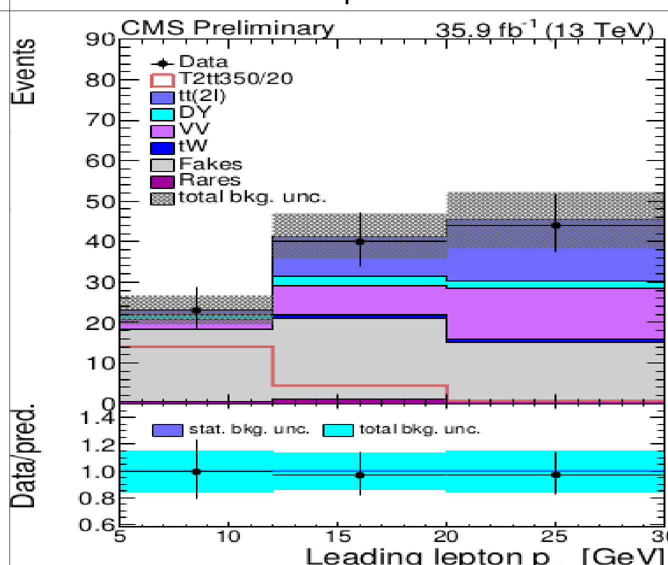
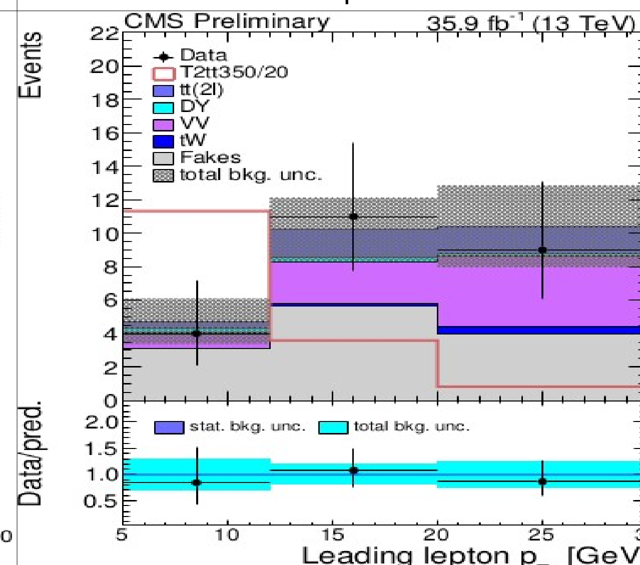


Systematic Uncertainties

Sample	Uncertainty	Method	Value
t-t(bar)	Spin Correlation	Vary the top spin correlation of top quarks by 20%	3-5%
	W helicity	Vary W polarization from top decays by 5%	
	ISR weight	Reweight top P_T based on the number of ISR jets	
DY+Jets	Hadronic recoil	Measure the recoil resolution from $Z \rightarrow \mu\mu$ events	<1%
Non-prompt	Tight-to-loose method	Closure test	40%
All	Experimental	Trigger, b-tagging, μ reconstruction	2-12%

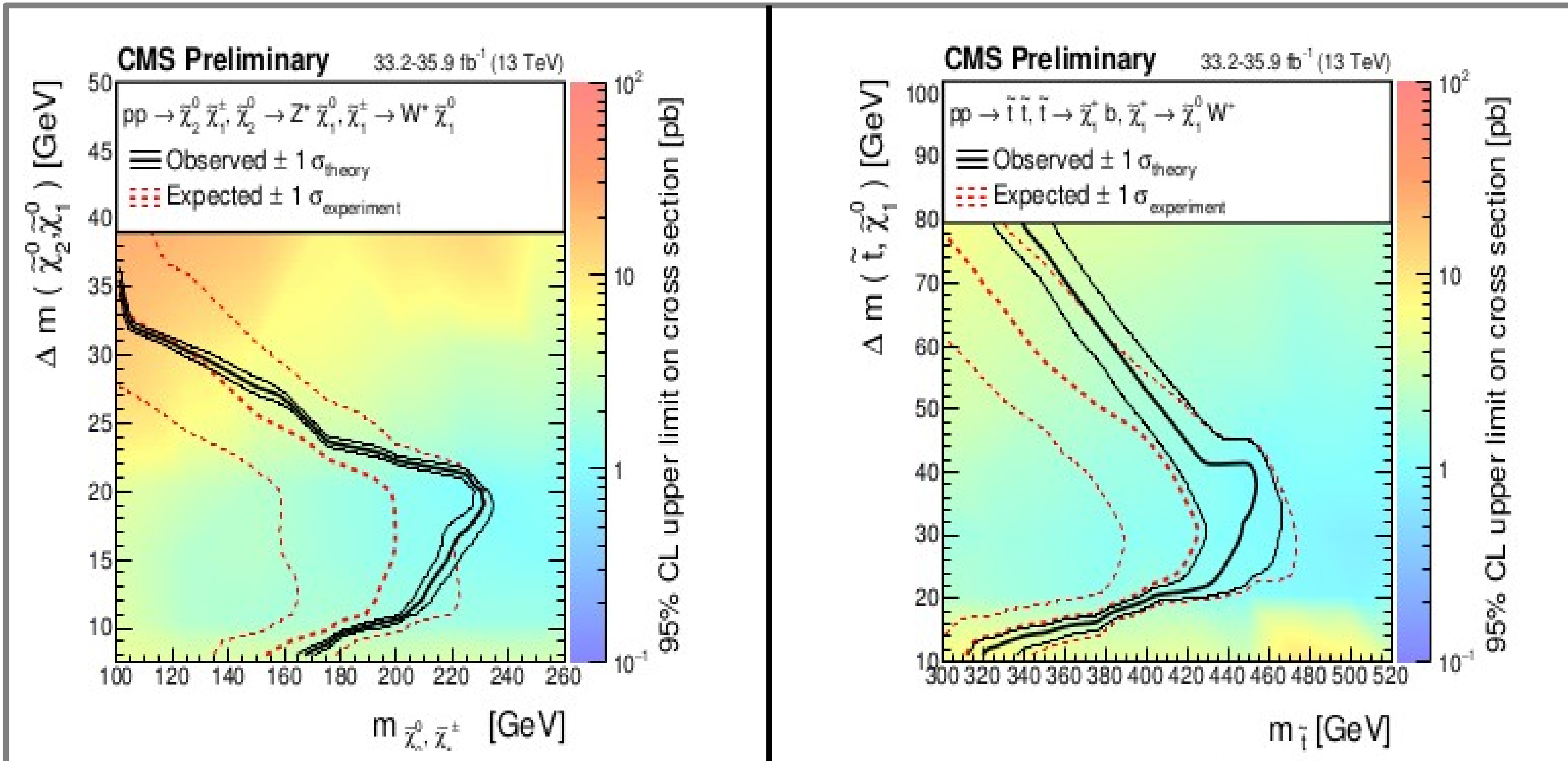
- In samples with low yields (namely dibosons, rares) we assign a flat uncertainty.
- Statistical uncertainties from CRs and SR dominate the total uncertainty.
- Statistical uncertainty more important in bins with low yields.

Results

	125 GeV<E_T^{miss}<200 GeV	200 GeV<E_T^{miss}<300 GeV	300 GeV<E_T^{miss}
EWKino			
	125 GeV<E_T^{miss}<200 GeV	200 GeV<E_T^{miss}<250 GeV	250 GeV<E_T^{miss}
Top squark			

Interpretations

- No significant excess observed → exclusion limits.
- The specially designed E_T^{miss}+soft dimuon trigger led to a substantial increase in sensitivity
- Masses up to m(χ_2^0)=230 GeV and Δm=20 GeV are excluded.



Summary

- A search for new physics in events with two low momentum opposite-sign leptons and missing transverse energy using the data collected by CMS was performed.
- No evidence of physics beyond Standard Model observed.
- Search is ongoing with current samples

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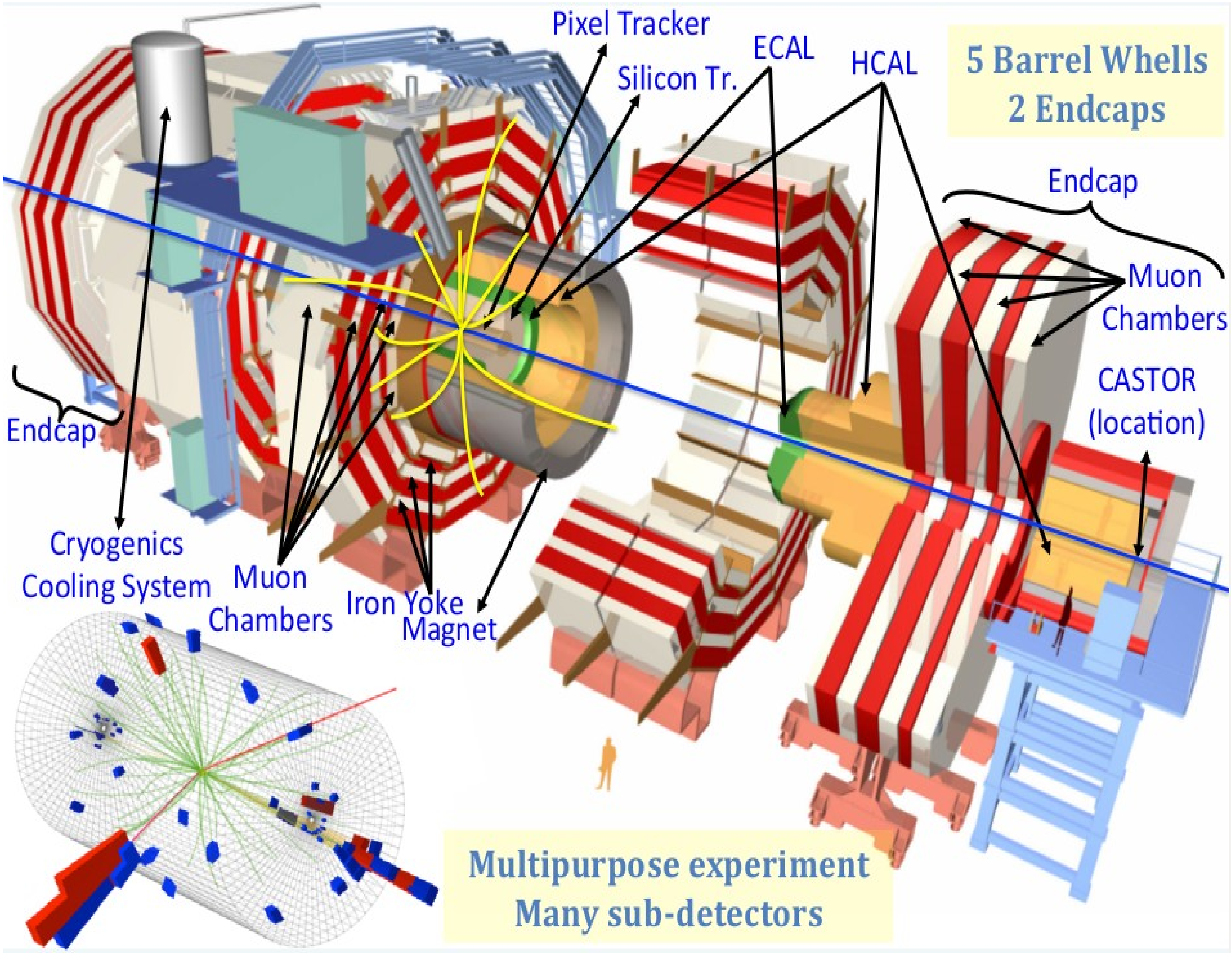
THANK YOU !

Back up

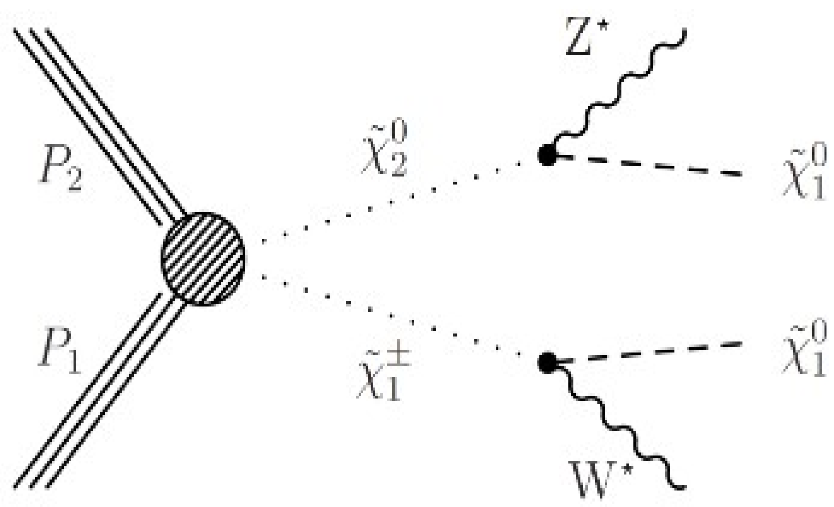
CMS Detector

CMS

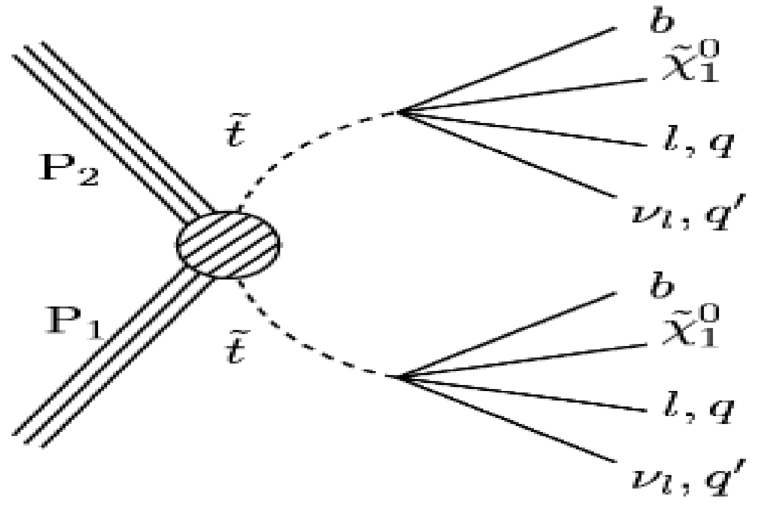
- Tracking:
  - Pixel,strip tracker
  - P_T res.: 1%(100GeV)
- ECAL:
  - PbWO4 crystals
  - E_T res.: 3%
- HCAL:
  - Sampling
  - E_T res.: 100%
- Magnet:
  - Superconducting
  - 3.8T
- Muon chambers:
  - Gas-ionization
  - 3 systems
- L1 Trigger:
  - Calorimiter, muons
  - Output: 100kHz
- HLT:
  - Reconstruction
  - Output: 400 Hz



More on SUSY



- High leptonic activity few jets
- Small cross-sections
- Small SM contribution
- Small mass splitting in natural SUSY



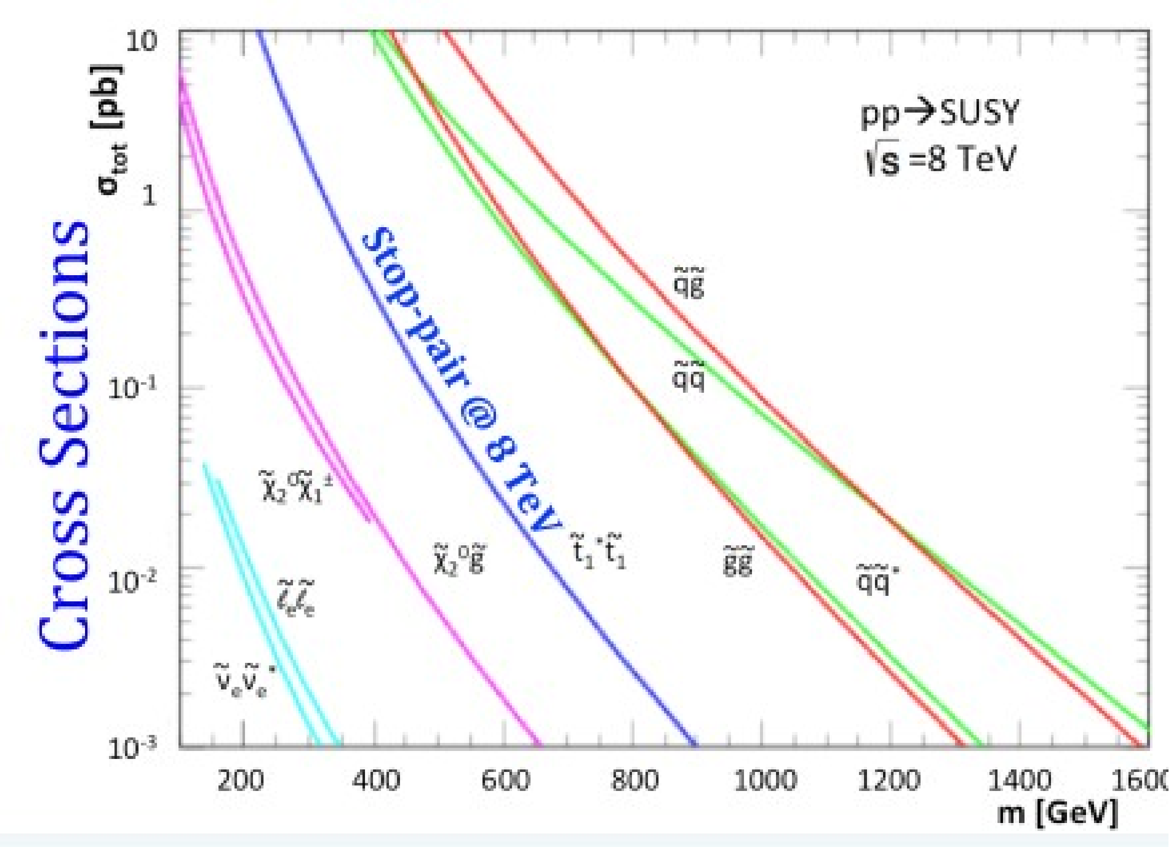
- Low mass stop required by natural SUSY
- Decays depend on Δm
- In our compressed case, 4 -body decay

MSSM

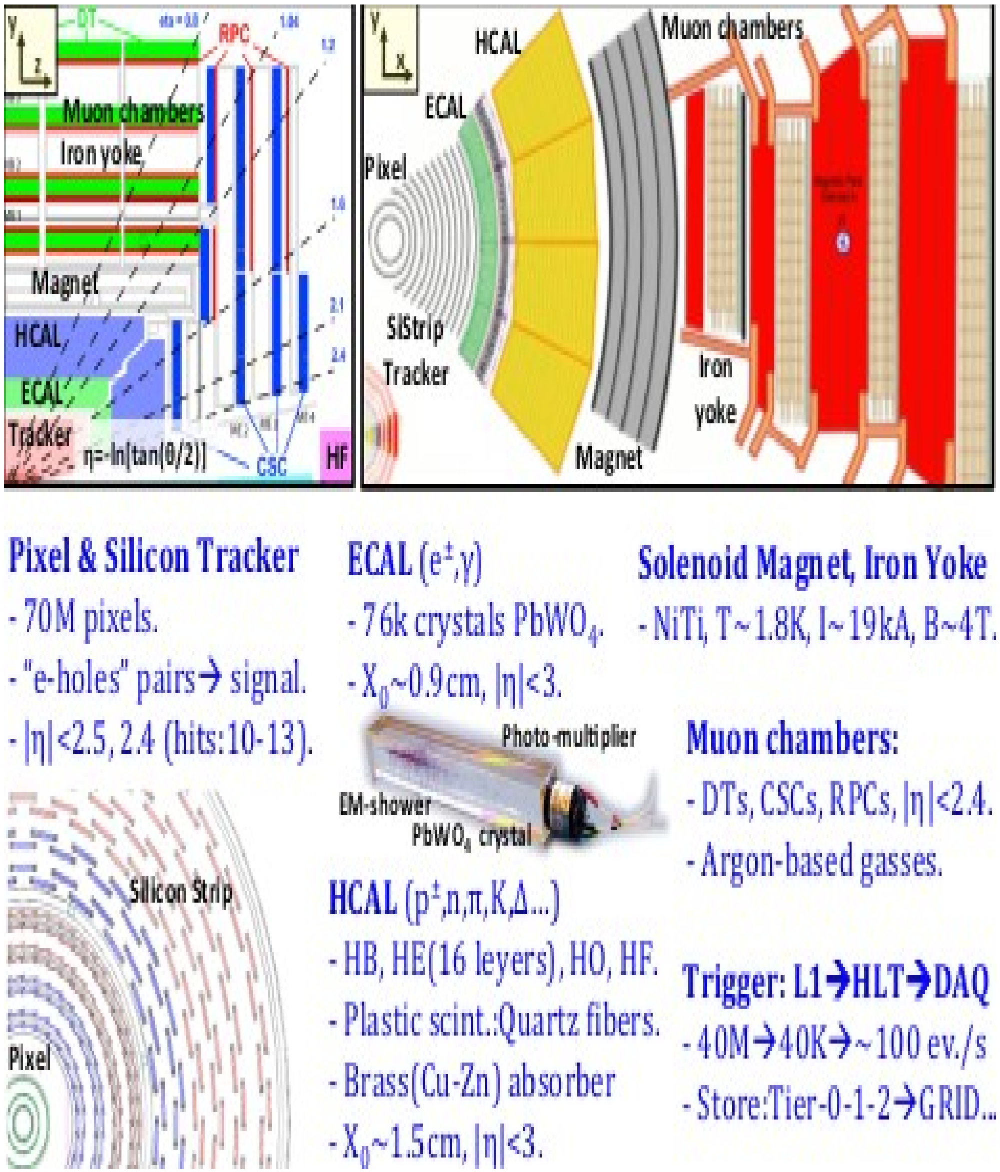
MSSM: Minimal Supersymmetric Standard Model
Content: 2Higgs doublets, Super partners

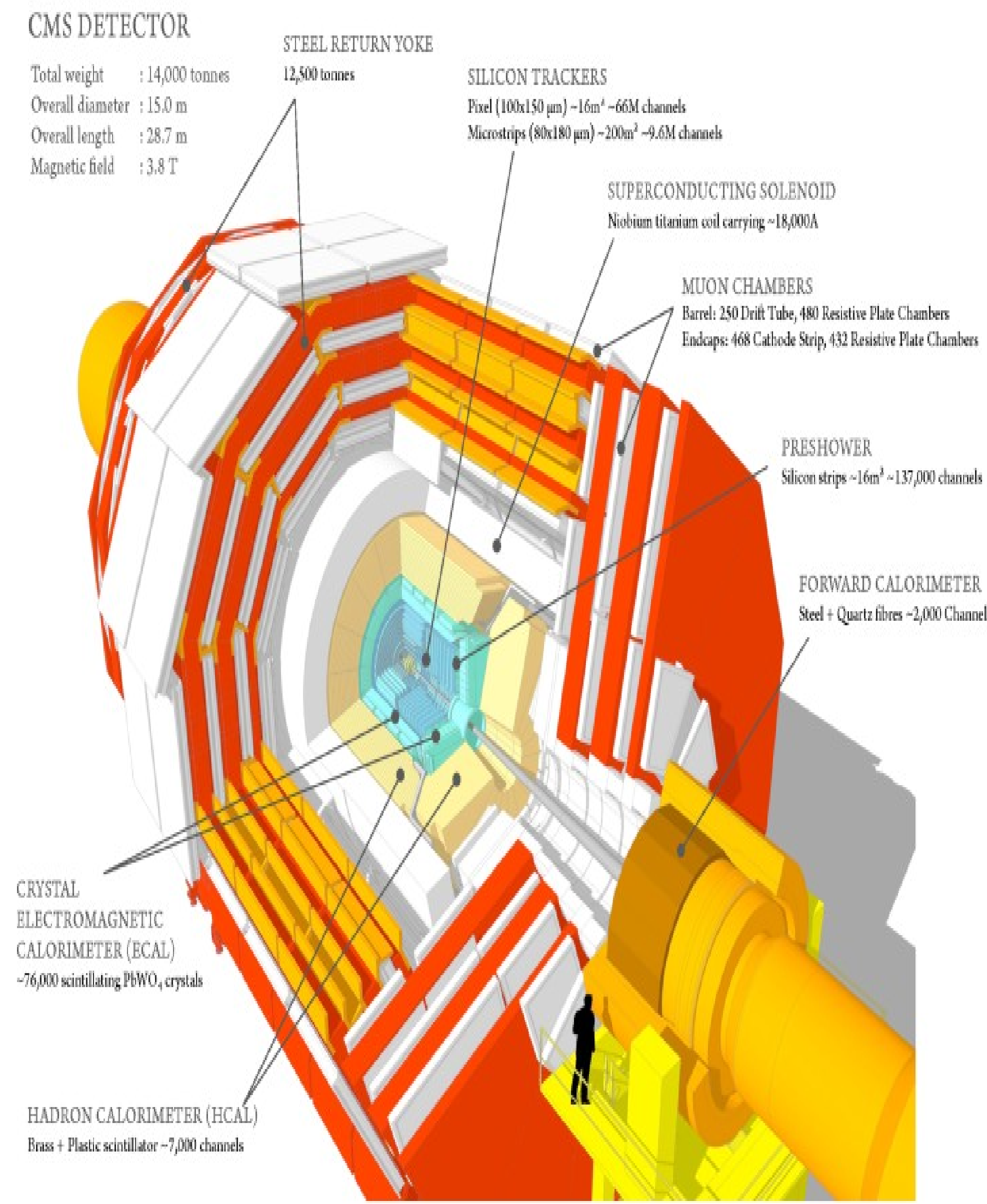
If SUSY exists: broken symmetry → mass of Super partners depend on breaking

Flavour mixing → unknown couplings



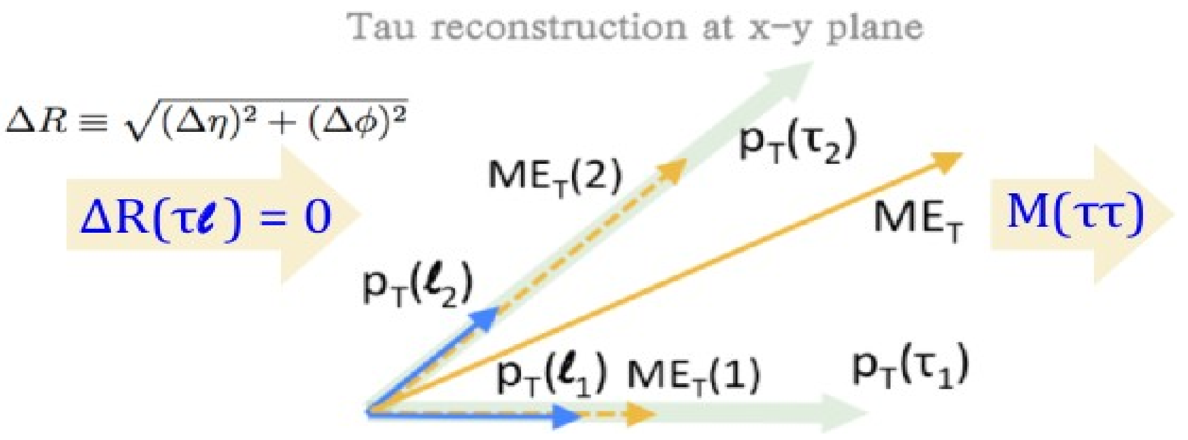
More on CMS


DT
RPC
Muon chambers
Iron yoke
Magnet
HCAL
ECAL
Tracker
η=-ln[tan(θ/2)]
CSC
HF
HCAL
ECAL
Pixel
SiStrip
Tracker
Magnet
Muon chambers
Iron
yoke
Pixel & Silicon Tracker
- 70M pixels.
- "e-holes" pairs→ signal.
- |η|<2.5, 2.4 (hits:10-13).
ECAL (e±,γ)
- 76k crystals PbWO4.
- X0~0.9cm, |η|<3.
Photo-multiplier
EM-shower
PbWO4 crystal
Solenoid Magnet, Iron Yoke
- NiTi, T~1.8K, I~19kA, B~4T.
Muon chambers:
- DTs, CSCs, RPCs, |η|<2.4.
- Argon-based gasses.
Silicon Strip
Pixel
HCAL (p±,n,π,K,Δ...)
- HB, HE(16 leyers), HO, HF.
- Plastic scint.:Quartz fibers.
- Brass(Cu-Zn) absorber
- X0~1.5cm, |η|<3.
Trigger: L1→HLT→DAQ
- 40M→40K→~100 ev./s
- Store:Tier-0-1-2→GRID...


CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Variables

M(τ τ):
1) Final lepton → same direction as tau
2) Decompose E_T^{miss} in two parts
3) Compute $P_T(\tau)=E_T^{miss} + P_T(l)$
4) $P(Z)=P(\tau\ 1) + P(\tau\ 2) = -H_T$
5) From the last two compute P(τ)
6) Compute M(τ τ)



$M_T = \sqrt{2P_T(l)*P_T(MET)*\cos\Delta\varphi(l1,E_T^{miss})}$

- For EWKino Δφ~0
- Top reduction