PhD Seminar (ETH ML H 43) *November 24th, 2016*

Search for Electroweak Production of Supersymmetry in Final States with Multiple Leptons at the CMS Experiment

an executive summary

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Outline

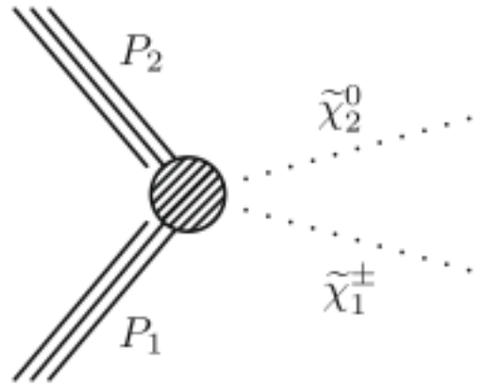
- Supersymmetry
- The CMS Experiment at the CERN LHC
- Signatures of EWK SUSY
- Search Strategy
- Results With Early 2016 Data
- Future Plans

Supersymmetry (SUSY)

- standard model (SM) has several open questions
  - hierarchy problem, flavor mixing, dark matter, dark energy, …
- need a theory beyond the SM
- supersymmetry (SUSY) one of them, able to deliver answers to many questions
  - hierarchy problem, dark matter candidate, unification?, …
- minimal-supersymmetric SM (MSSM) doubles the particle spectrum of SM
- SUSY searches
  - direct: search for new particles
  - indirect: deviations from SM (e.g. cross sections different to SM prediction)
- SUSY not yet experimentally observed

What do we Look for?

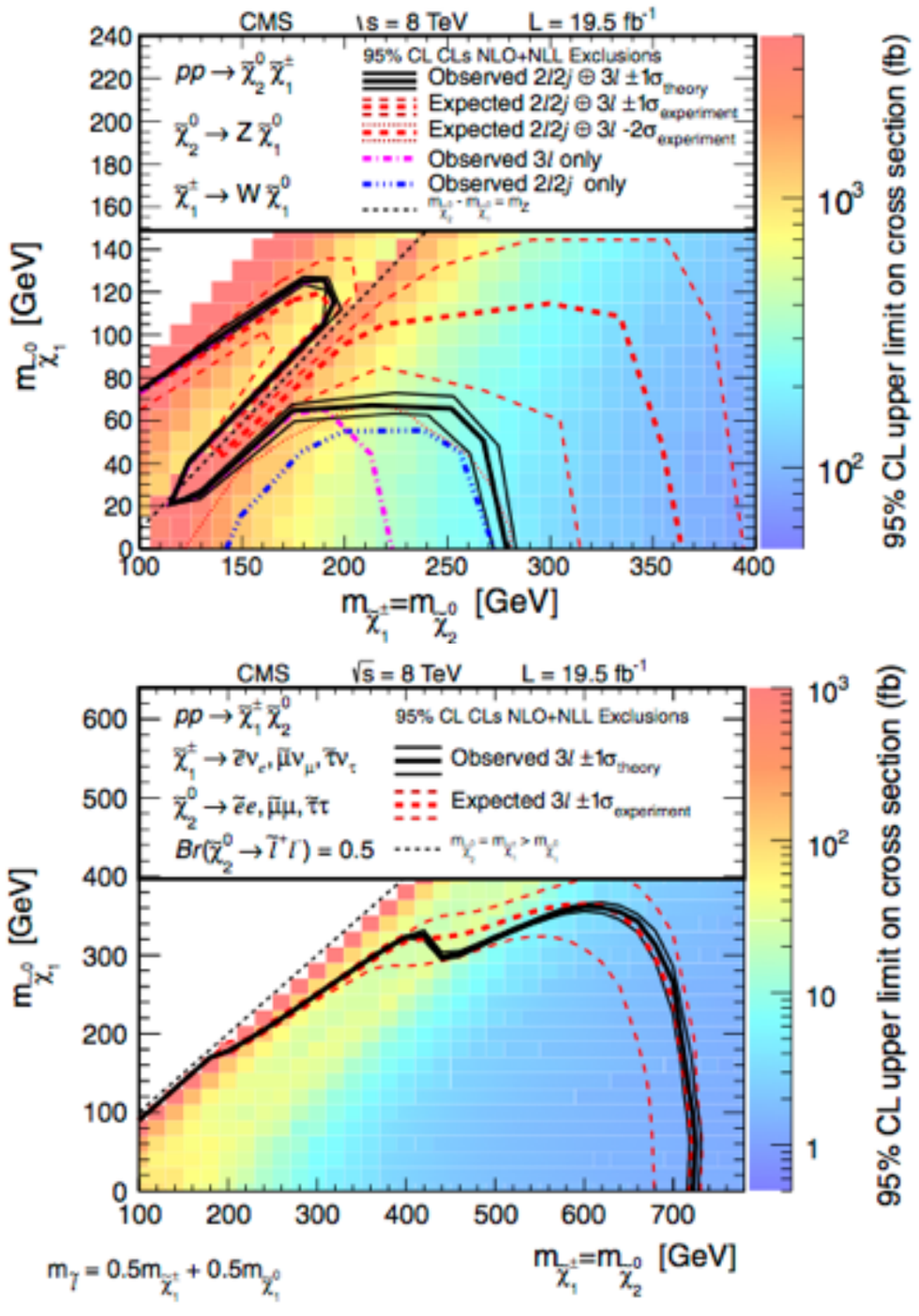
- what is electroweak SUSY?
  - production of particles interacting via the electroweak force
  - here: search for pair production of charginos (C1) and neutralinos (N2)
- why search for electroweak SUSY?
  - if gluinos / squarks are very massive, electroweak SUSY may dominate
  - naturalness: gaugino mass is of the order of H boson mass
- why conducting a leptonic search?
  - C1 and N2 may have significant branching ratios to W, Z or sleptons, which can decay to leptons
  - depending on the specific model, can have a number of hard and isolated leptons in the final state
  - low standard model backgrounds producing these leptonic final states
  - expect less additional hadronic activity than for gluino-gluino production (clean leptonic final states)
- what do we look for?
  - 3 principal final states: 2 leptons of same sign, 3 leptons or more than 3 leptons



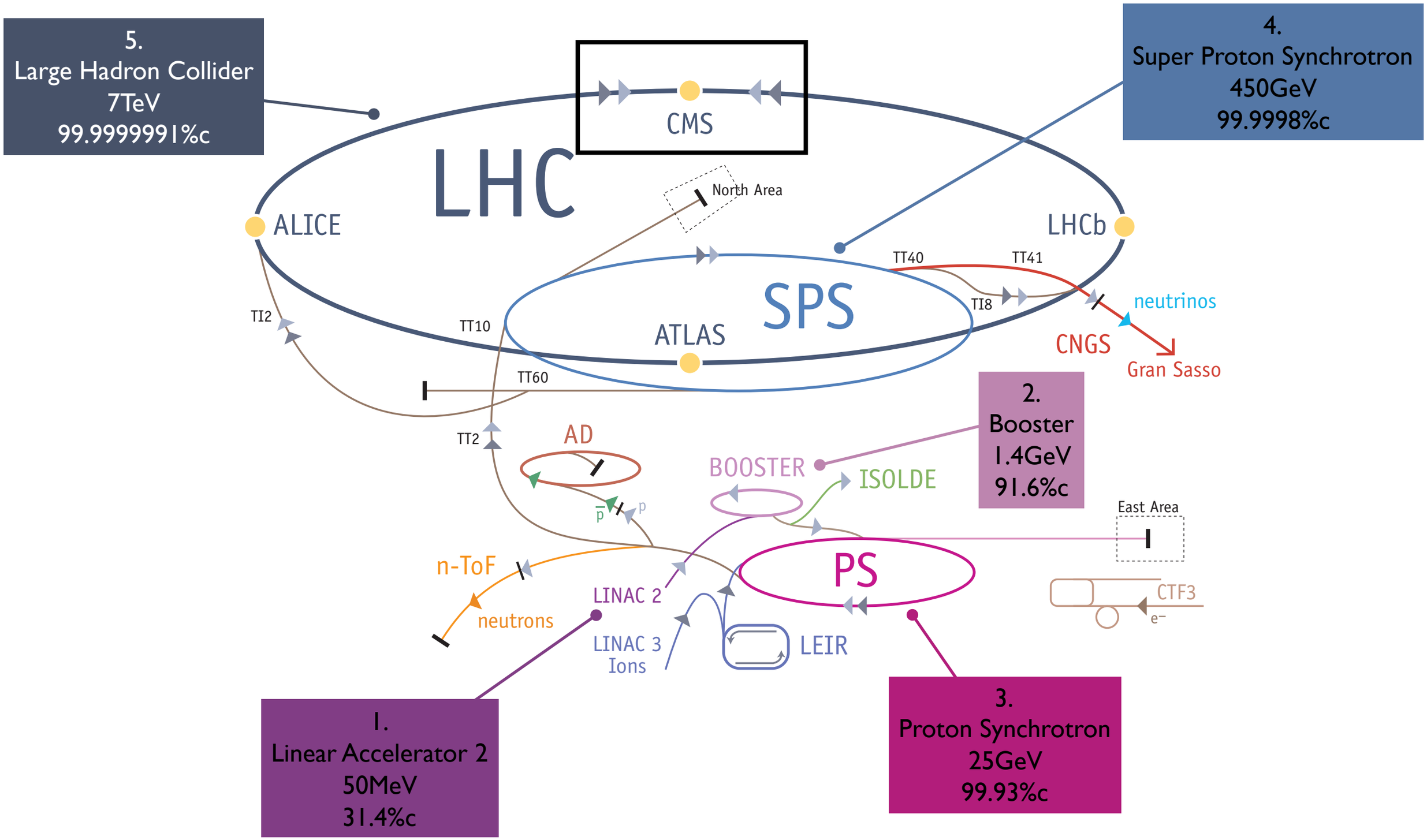
C1N2 production

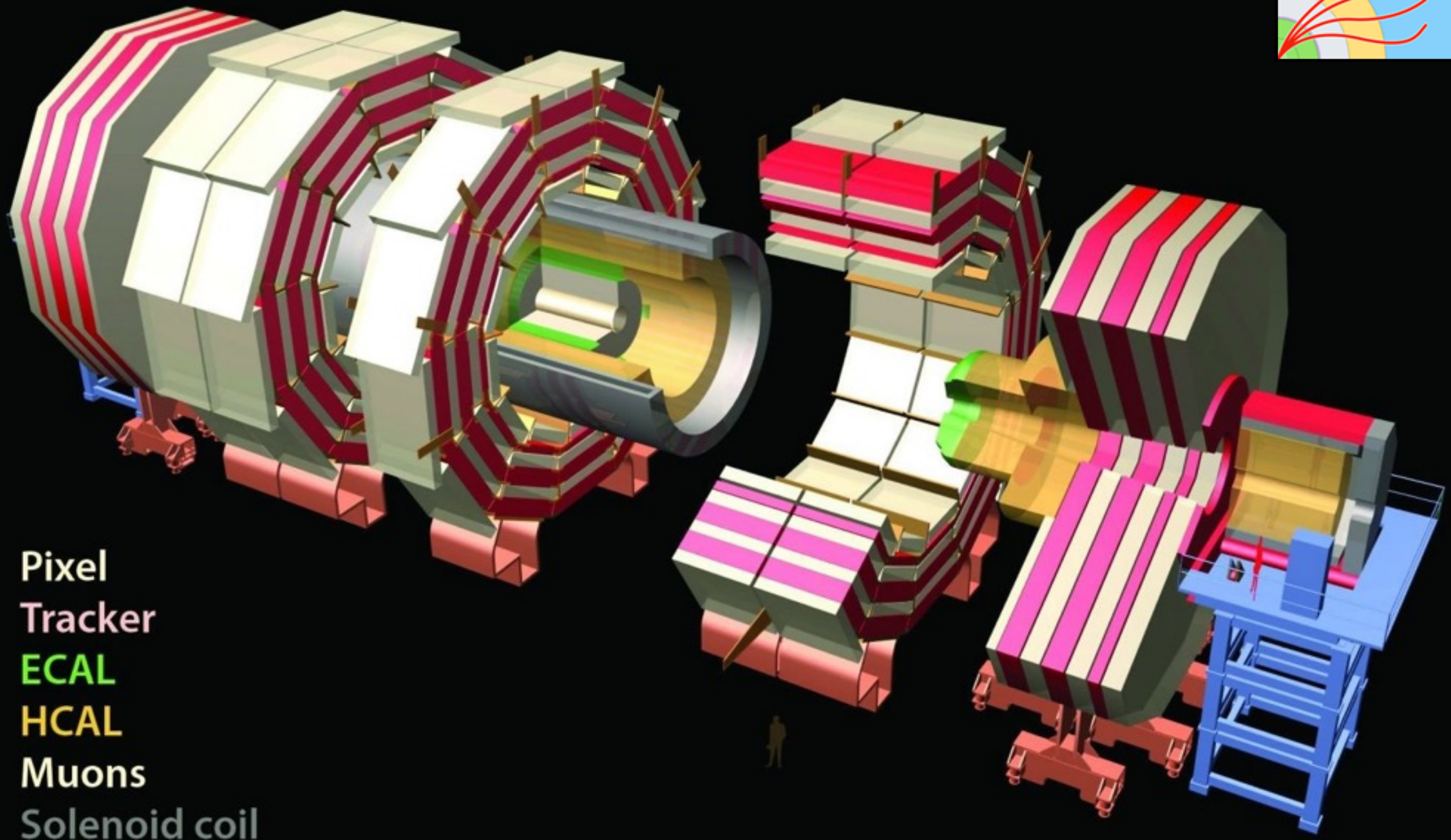
8TeV Results - Benchmark for 13TeV Scenario

- 2009-2012 center-of-mass energy $\sqrt{s}$ = 8TeV
- search for EWK SUSY already done:
  - combination with results from other analyses
  - no evidence for SUSY found (pity!)
  - exclusion of sparticle masses up to ~700GeV
- since 2015: $\sqrt{s}$ = 13TeV
- early searches focus on strong SUSY production (due to larger xsec)
- 2016 is the interesting period for EWK SUSY
  - more data gives sensitivity to low-xsec models
  - early 2016 data: already presented at ICHEP2016
  - **full 2016 dataset: being analyzed now!**



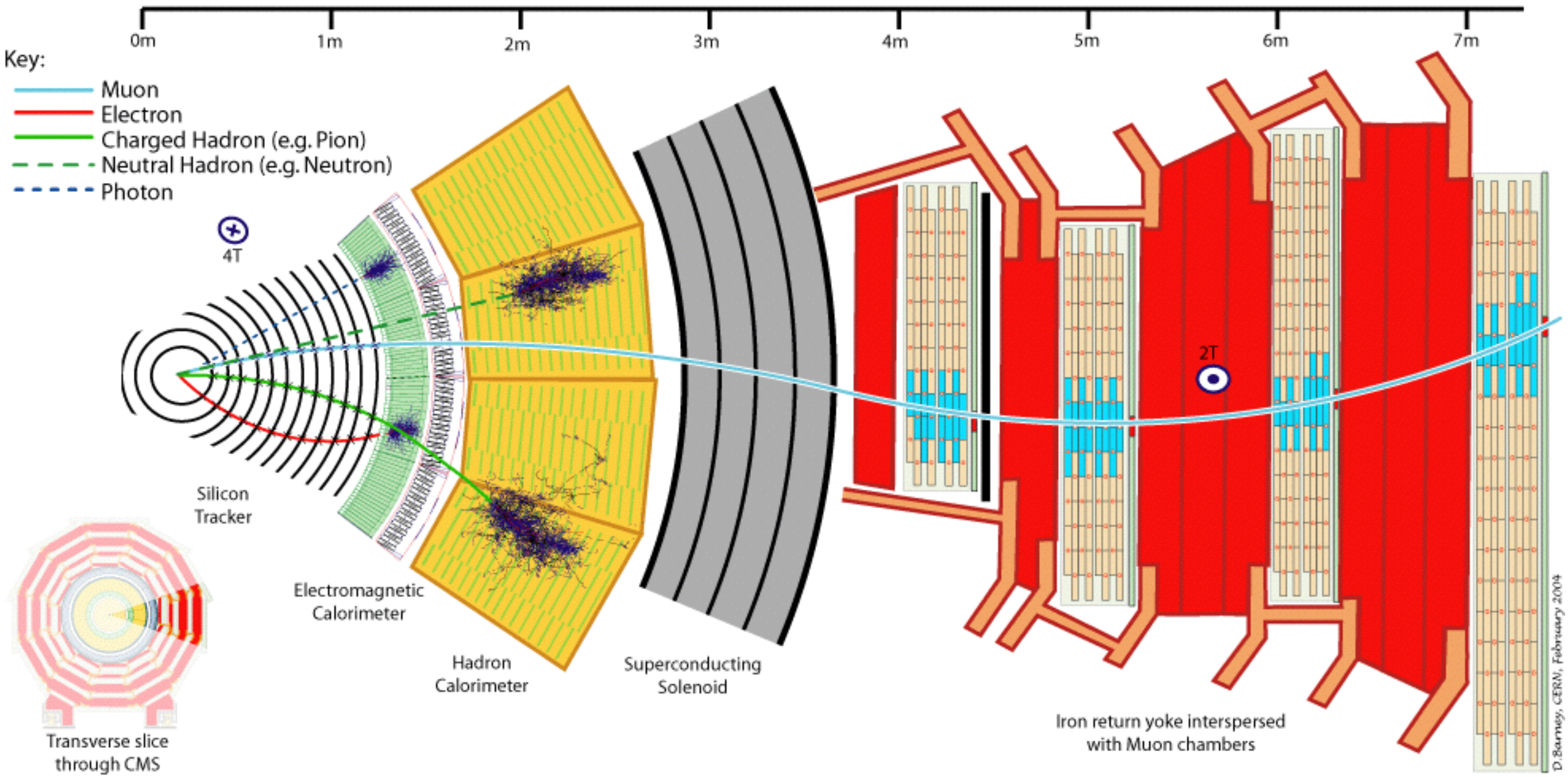
LHC Accelerator Chain





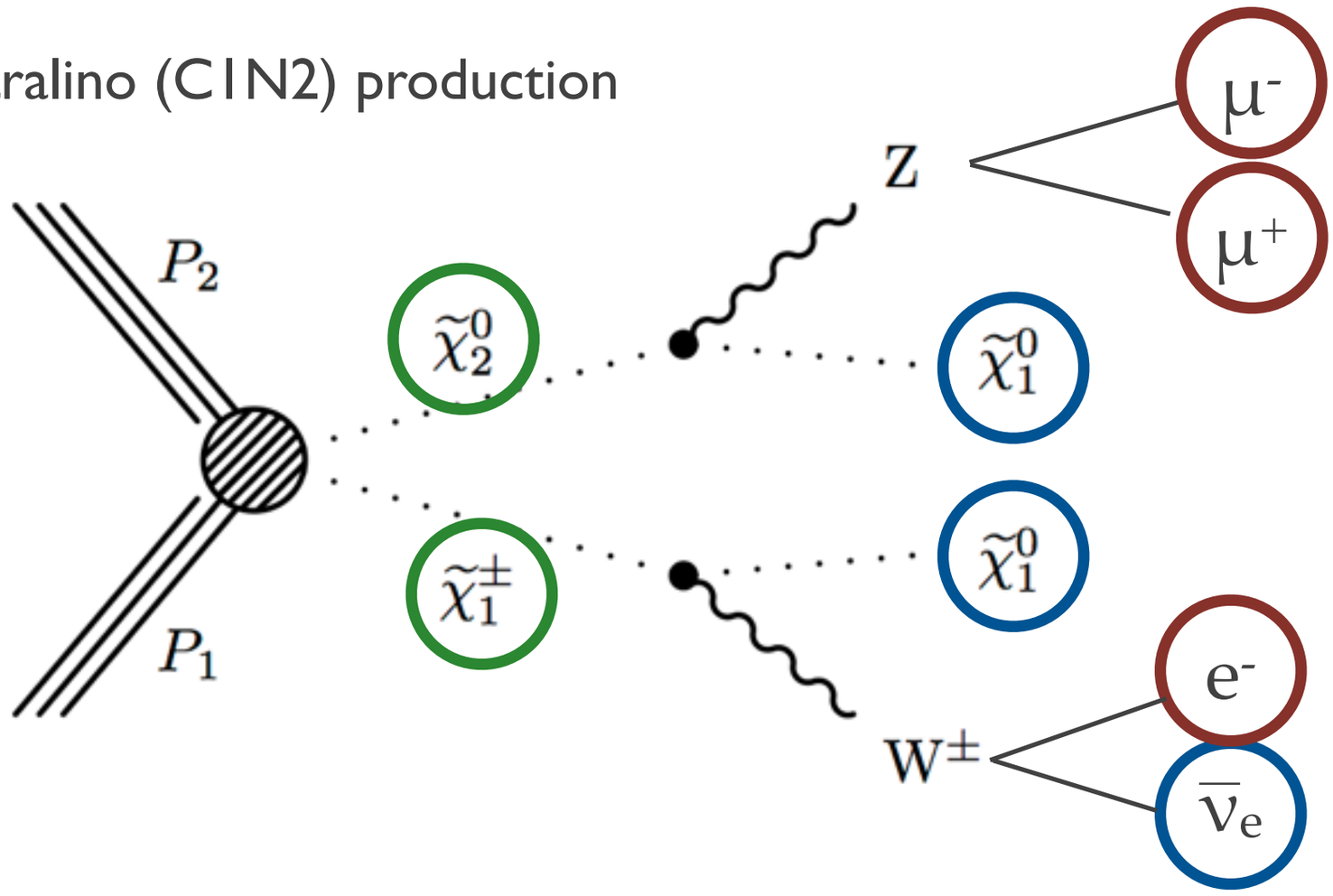
Total weight 12500 t, Overall diameter 15 m, Overall length 21.6 m, Magnetic field 4 Tesla

CMS Detection Principle



EWK SUSY Signature

e.g. chargino-neutralino (C1N2) production

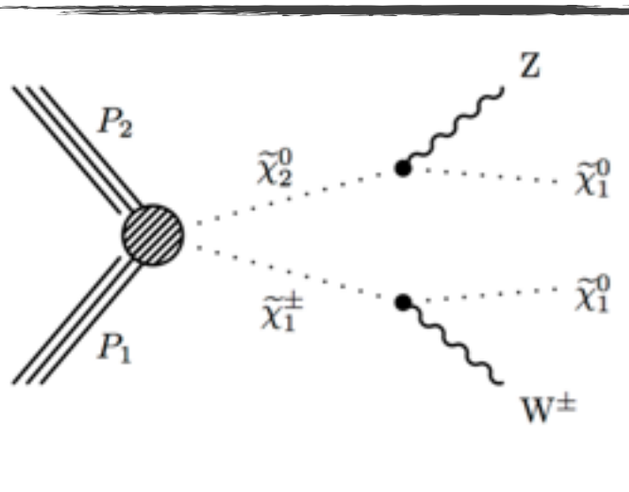


Typical signature of a leptonic SUSY process:

- **multiple hard and isolated charged leptons** in the central part of the detector
- these leptons are prompt, i.e. produced by W, Z or **sparticles**
- large **missing energy** in the plane transverse to the beam (MET) due to unidentifiable particles

assuming R-parity conservation

Three „Classes“ of Models

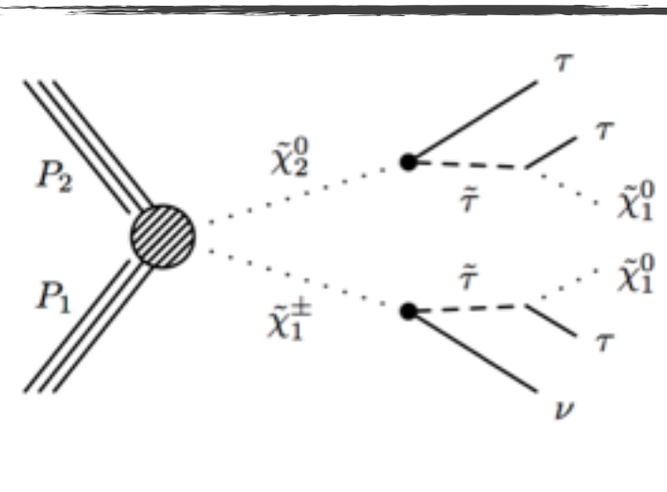


C1N2 production

flavor-democratic decay via W and Z bosons to all three lepton flavors

sensitive to Wino component of sleptons

largest sensitivity: 3 light flavor leptons

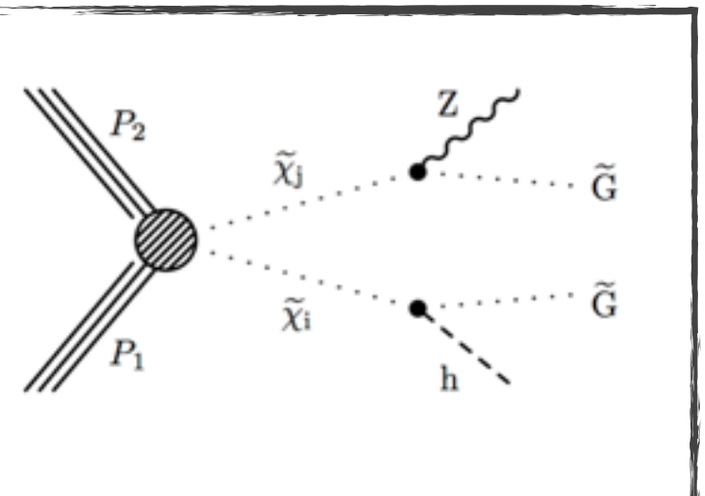


C1N2 production

decay only to taus

assume right-handed sleptons (which would prefer to decay to taus)

largest sensitivity: 1 light lepton + 2 tau



N2N3 production

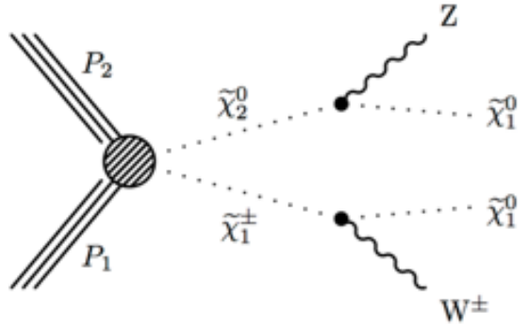
flavor-democratic decay via Z bosons to all three lepton flavors

sensitive to Higgsino component of sleptons

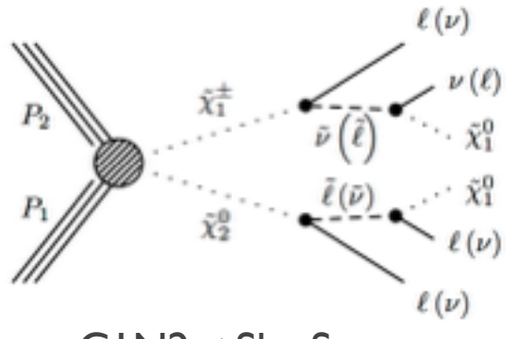
largest sensitivity: 4 leptons any flavor

All Models Considered in this Analysis

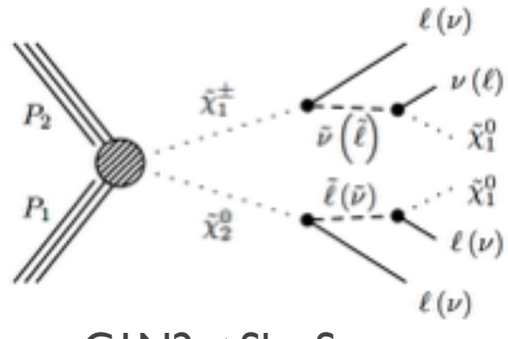
leading models: already sensitive with early data



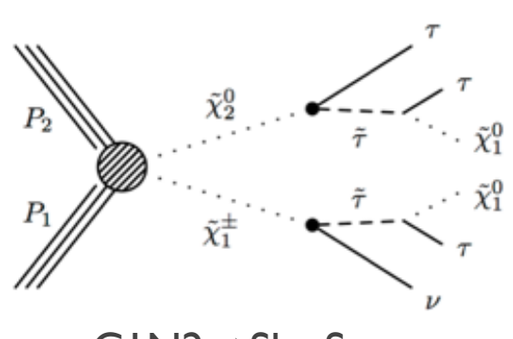
C1N2→WZ



C1N2→SlepSneu
(flavor-democratic, x=0.5)

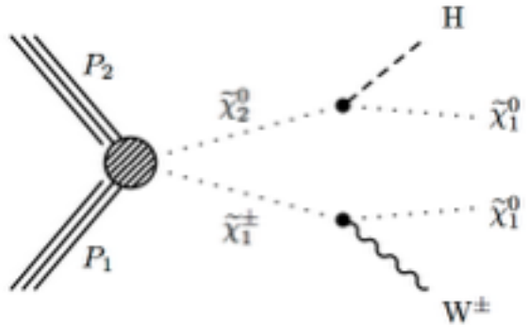


C1N2→SlepSneu
(flavor-democratic, x=0.05)

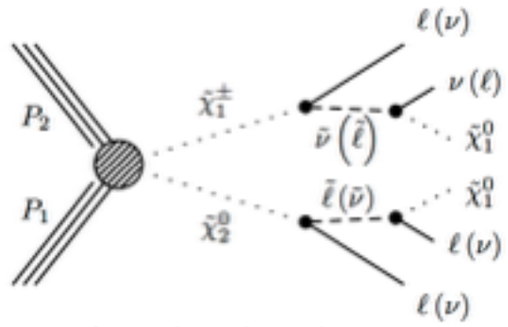


C1N2→SlepSneu
(tau-dominated decay, x=0.5)

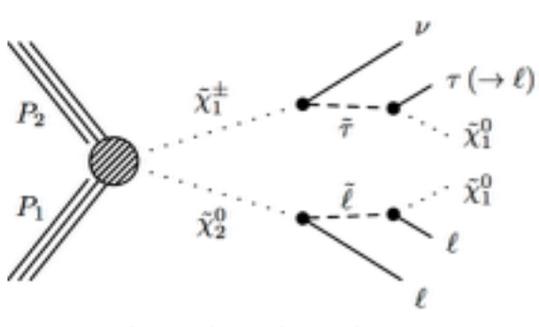
subleading models: becoming important for full dataset



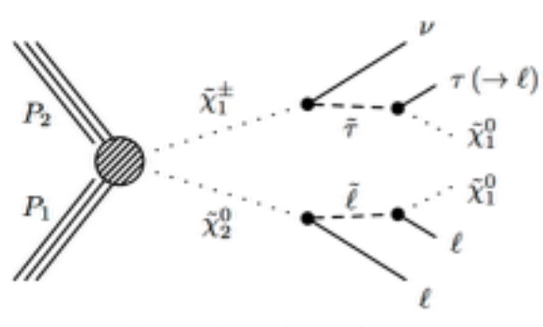
C1N2→WH



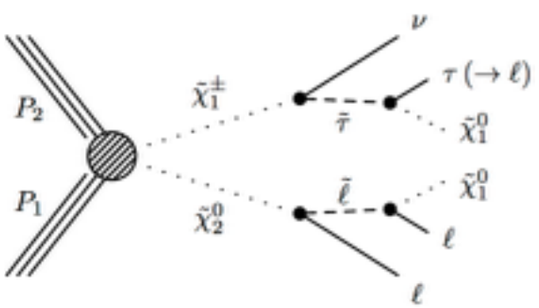
C1N2→SlepSneu
(flavor-democratic, x=0.95)



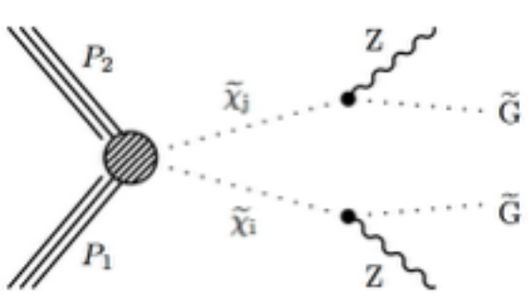
C1N2→SlepSneu
(tau-enriched, x=0.5)



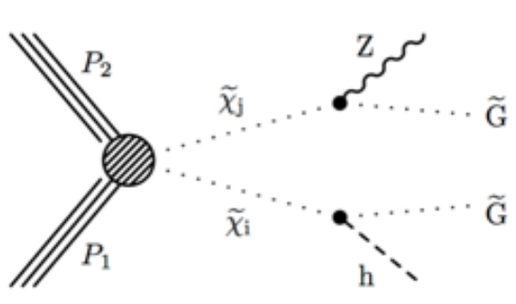
C1N2→SlepSneu
(tau-enriched, x=0.05)



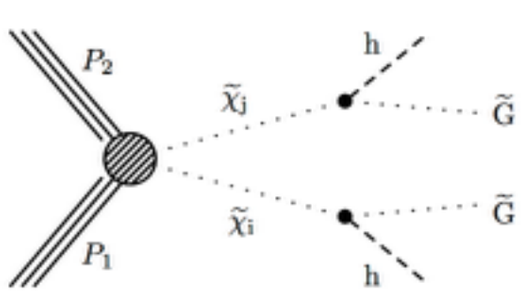
C1N2→SlepSneu
(tau-enriched, x=0.95)



N2N3→ZZ



N2N3→HZ



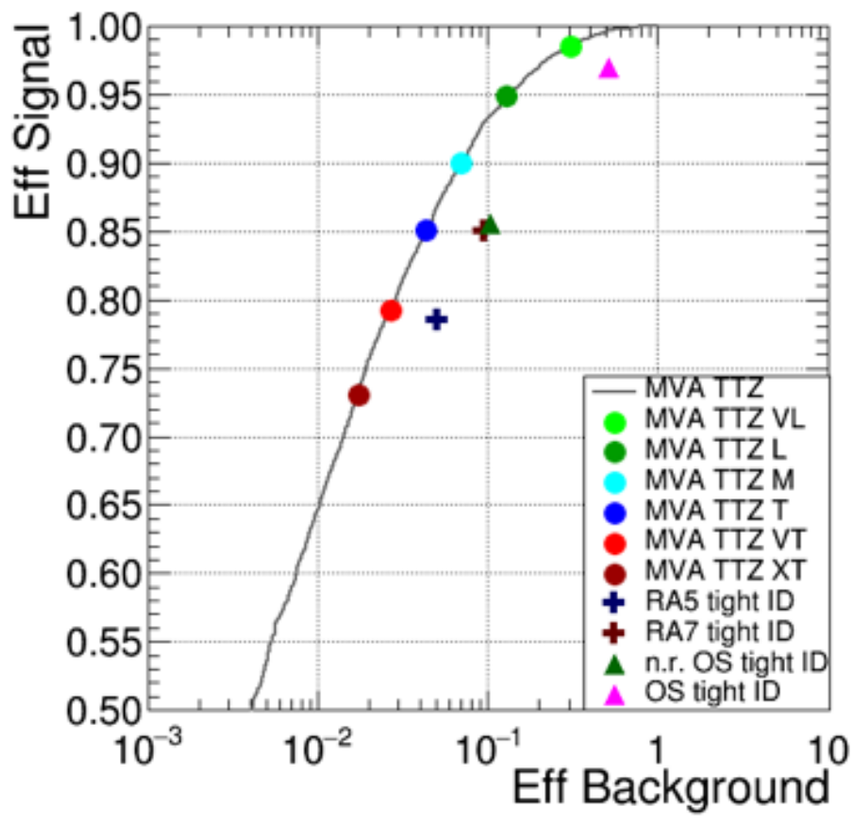
N2N3→HH

Search Strategy

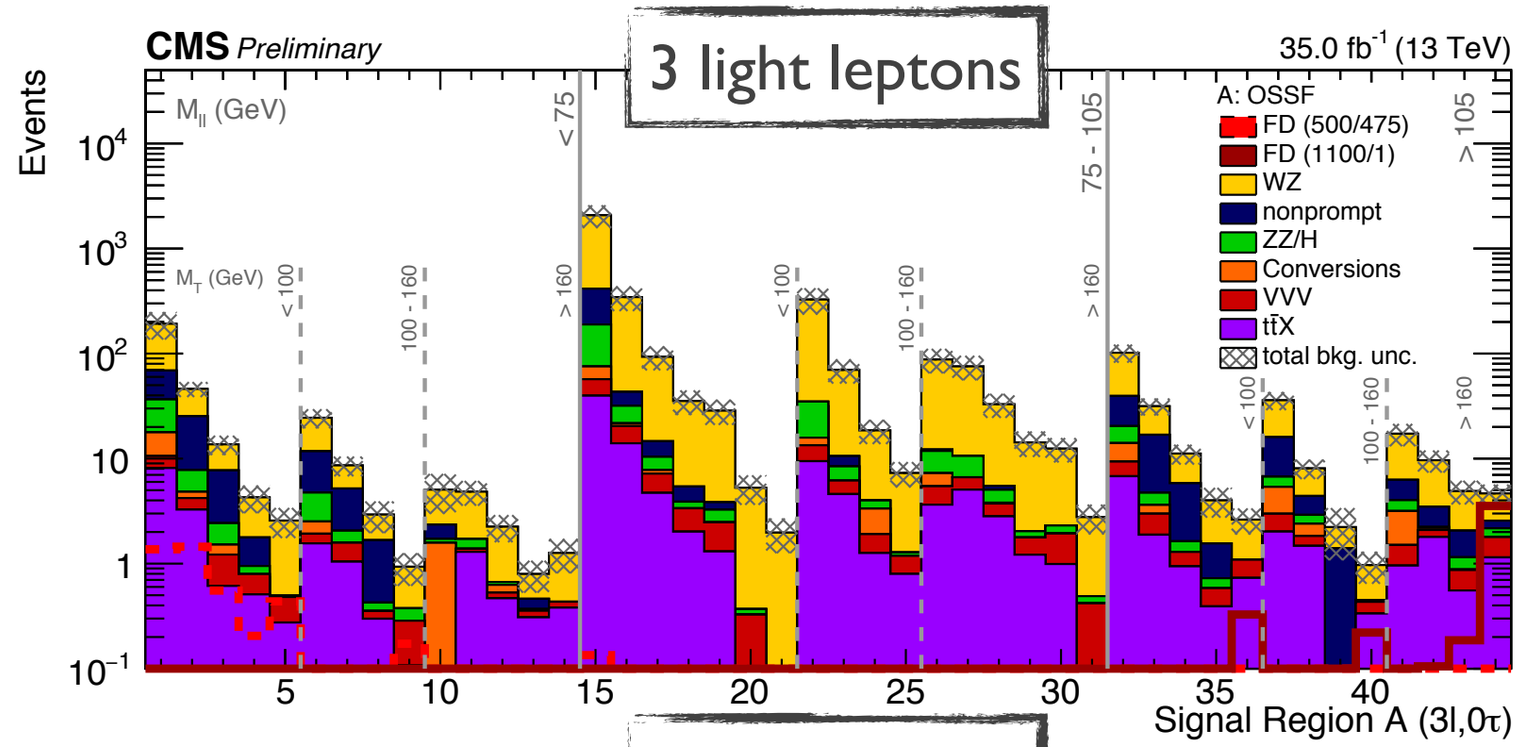
- so-called „cut-and-count analysis“
- define important kinematic objects:
  - electrons, muons, jets, MET
- define regions of phase space (~150 „signal regions“, SR) according to key observables:
  - MET (missing energy), Mll (invariant mass of lepton pair), MT (transverse mass), MT2(two hardest leptons)
- count the number of events in each SR
- compare to the expected number of background events per SR
- hypothesis test: could background alone produce the observed number of events?
- result either significance (observation) or upper limit (exclusion) at 95% confidence level

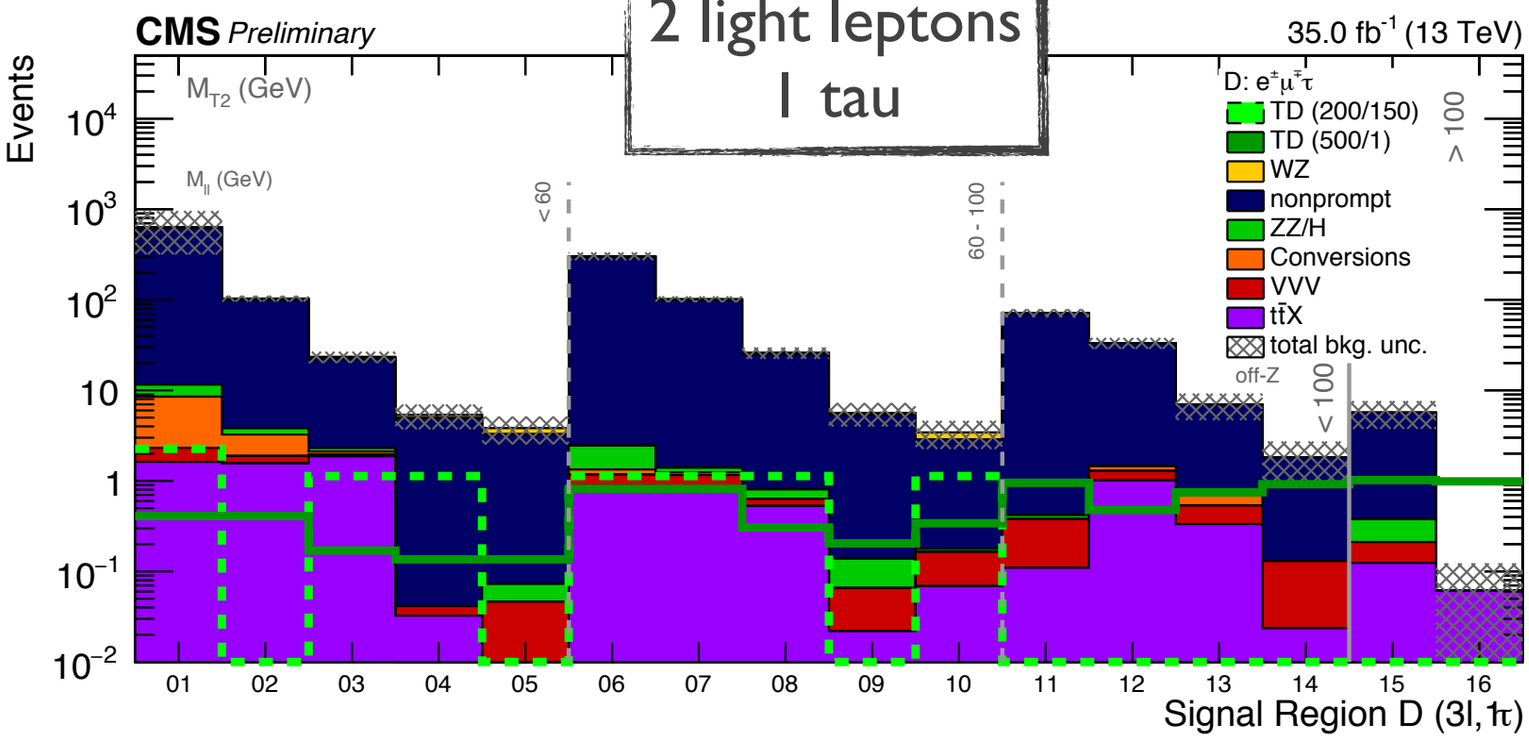
Lepton Identification

- sources of leptons
  - prompt = a lepton produced at primary vertex in a decay of W or Z boson (or sparticle decay)
  - nonprompt = due to misreconstruction of the leptons in the detector
- source of nonprompt leptons depends on the flavor
  - nonprompt electron = mostly light-flavor jets (pions)
  - nonprompt muons = mostly genuine muon within a heavy-flavor jet
  - nonprompt taus = mostly jets
- designed an Multivariate Analysis method (MVA) to distinguish prompt leptons from nonprompt leptons
  - significant gain in signal acceptance / background rejection w.r.t. „conventional“ identification of leptons
- residual nonprompt lepton background needs to be estimated with dedicated method

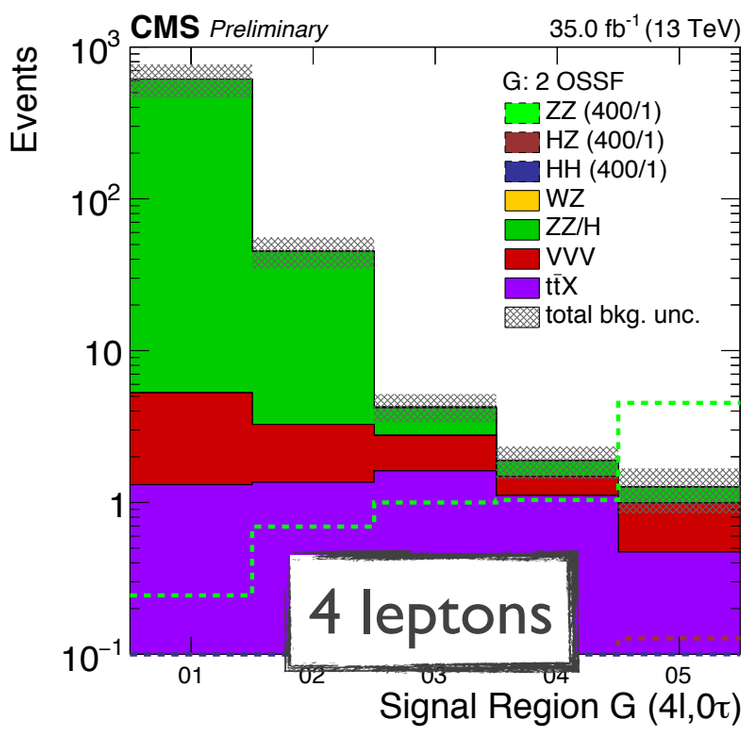


Background Composition



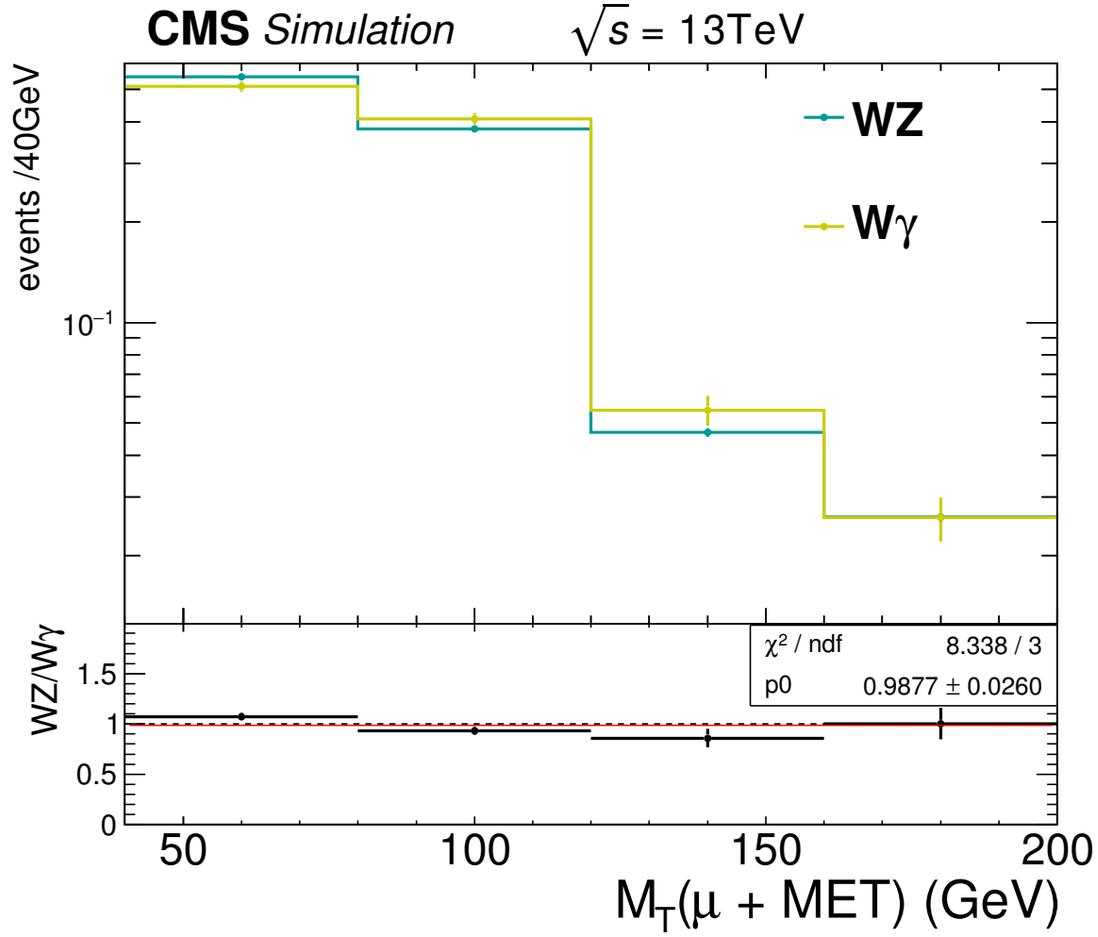


- expected background composition in different final states (taken from simulated events)
- behold of the log scale!

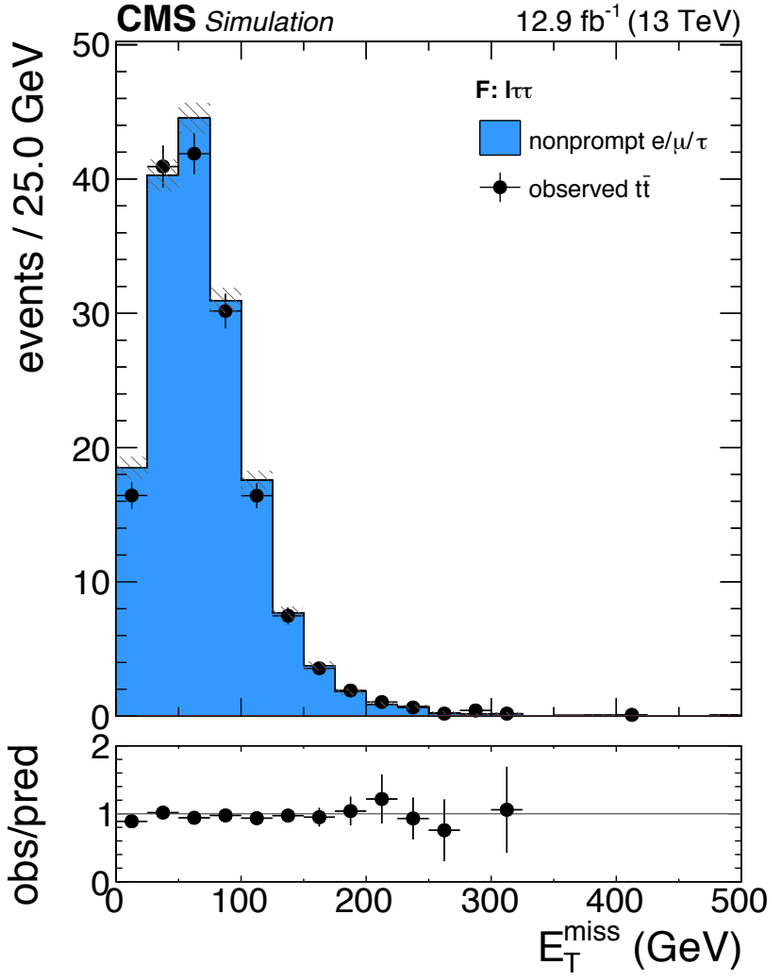


Background Estimation

- most important backgrounds:
  - 3 light leptons: standard model WZ
  - 3 leptons with taus: residual nonprompt lepton background
  - 4 leptons: standard model ZZ
- WZ estimation
  - estimate from simulated events
  - assess normalization in WZ control region
  - systematic uncertainties extracted from the Wγ shape
- ZZ estimation
  - estimate from simulated events



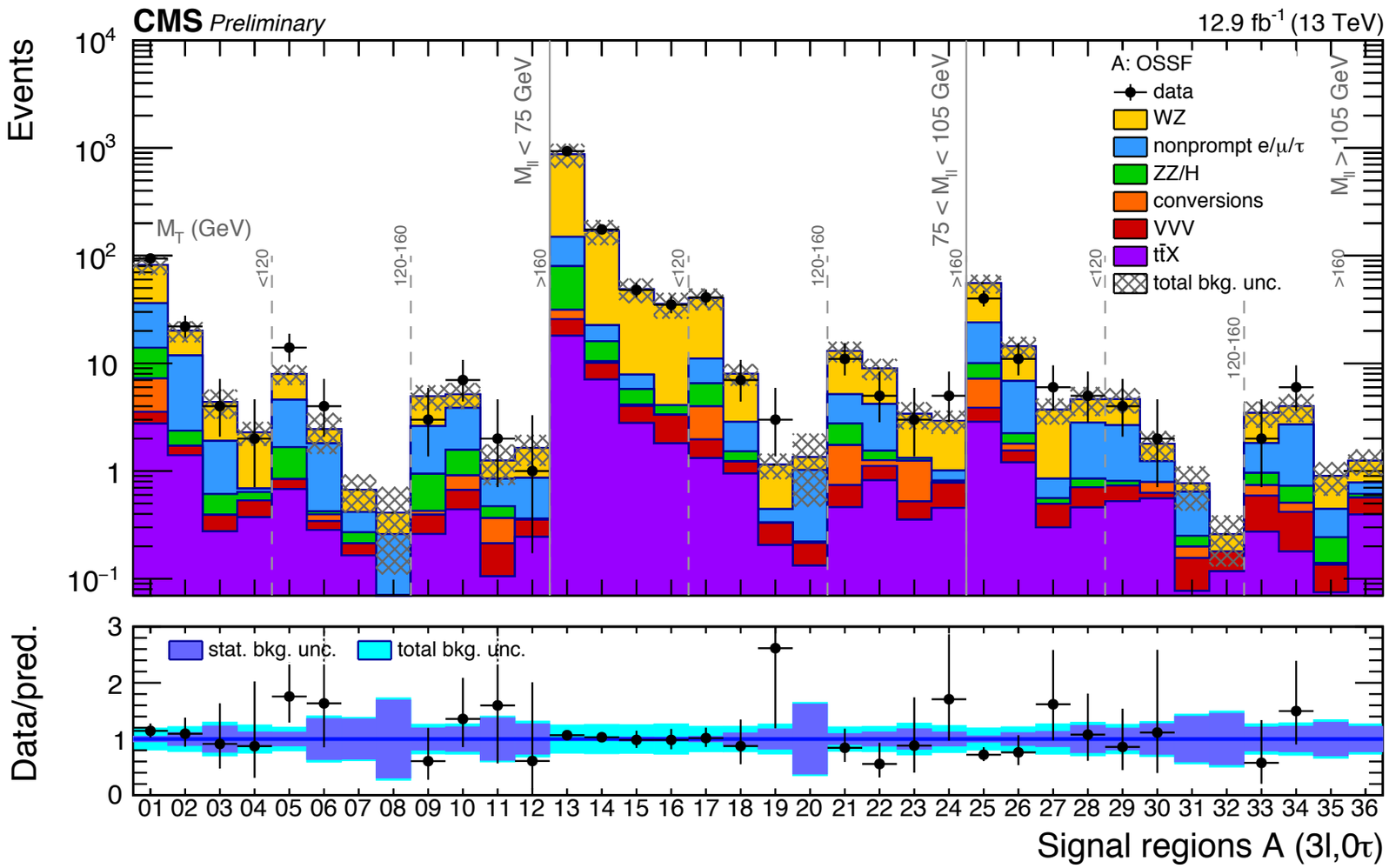
Background Estimation

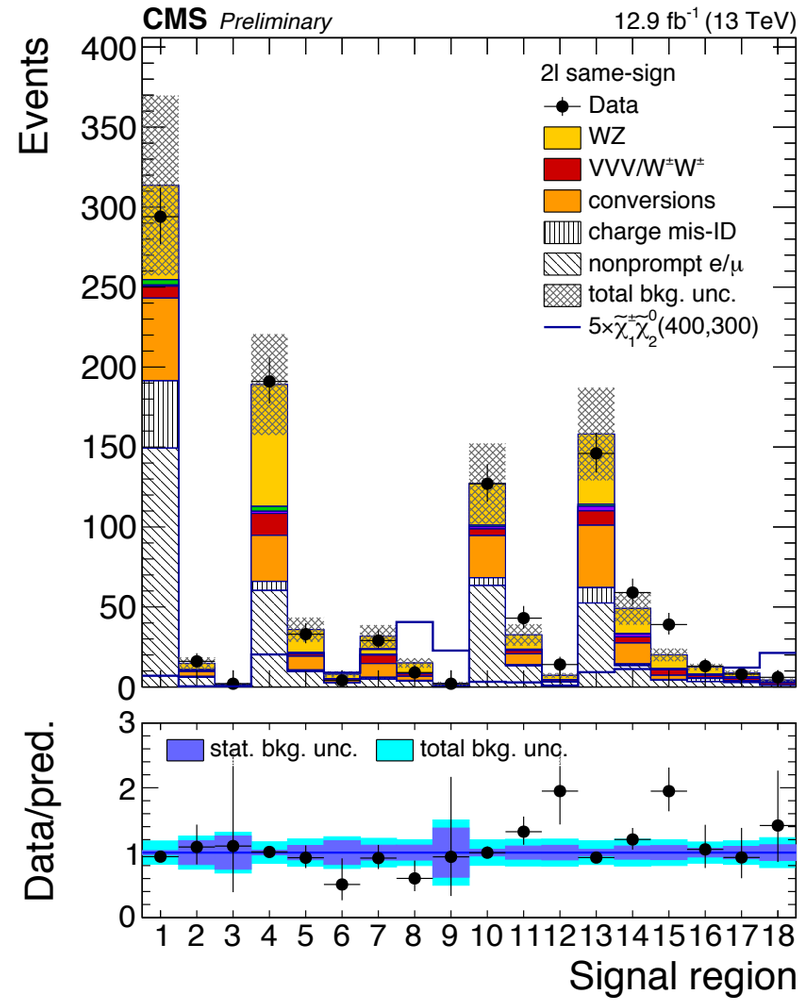


- most important backgrounds:
  - 3 light leptons: standard model WZ
  - 3 leptons with taus: residual nonprompt lepton background
  - 4 leptons: standard model ZZ
- nonprompt backgrounds
  - data-driven „tight-to-loose method“
  - measure probability for a nonprompt lepton to be identified as a „good lepton“ in a dedicated measurement region
  - use this probability in order to estimate background contribution
  - „closure test“: compare data-driven estimation to estimation using generator information
- other backgrounds (photon conversion, rare SM processes)
  - estimate from simulated events (partially using control regions for normalization)

Results With Early 2016 Data

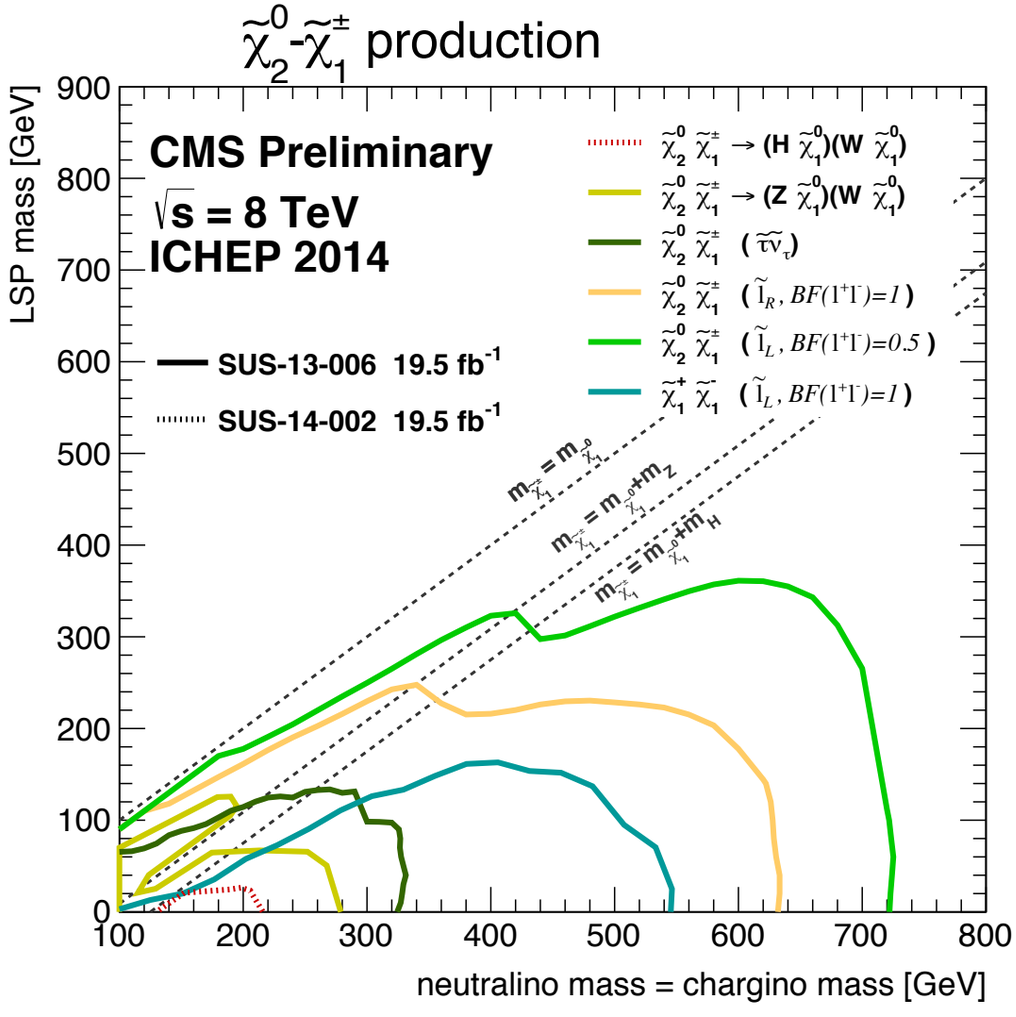
- Physics Analysis Summary (PAS) available: http://cds.cern.ch/record/2205168?ln=en
  - paper in preparation, to be out soon
- presented at ICHEP2016

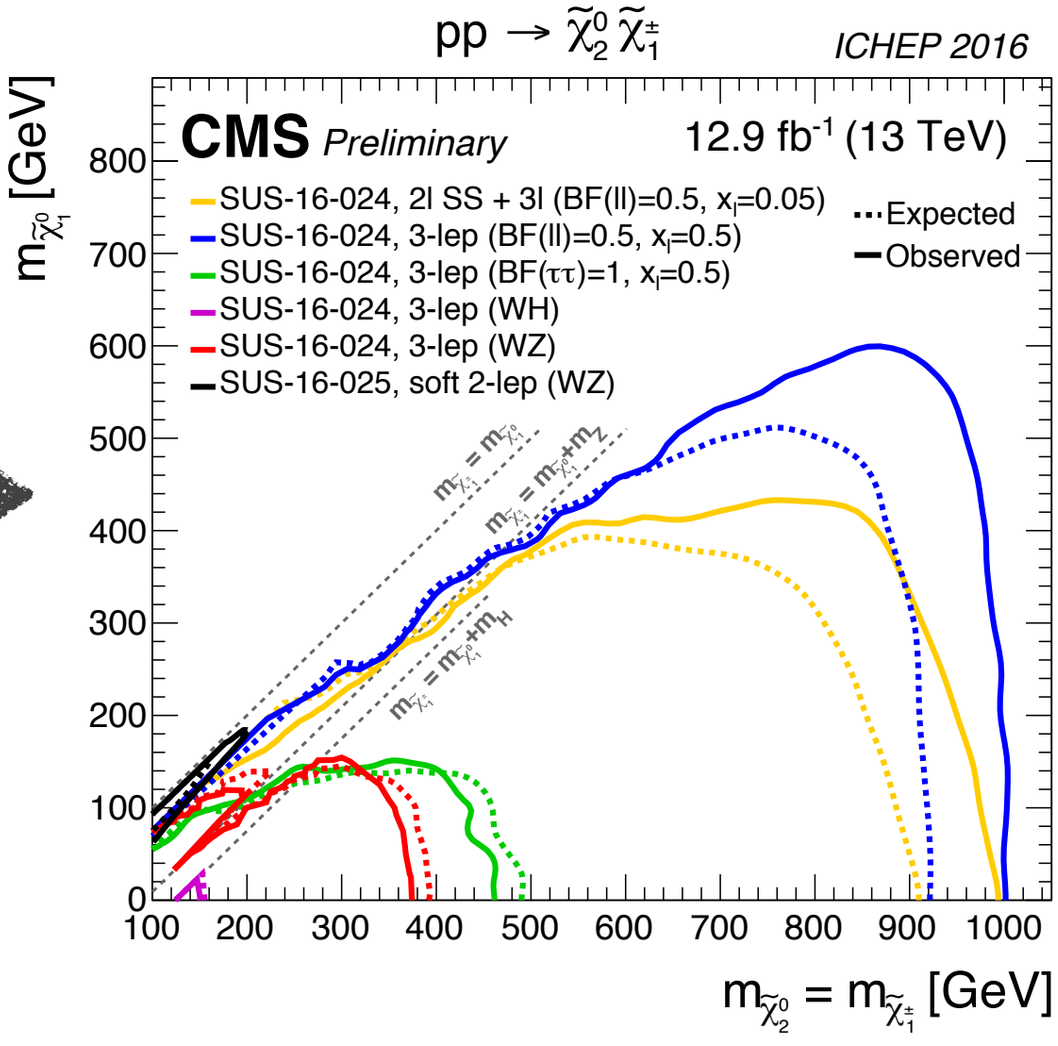




Interpretations

- no evidence for EWK SUSY found in early 2016 data
- setting exclusion limits on sparticle masses and model xsec





Summary and Future Plans

- SUSY is a promising candidate to answer open questions of SM
- searching for EWK production of SUSY with multiple leptons
  - different simplified models available targeting different slepton scenarios
  - discussed search strategy and critical points
  - results with early 13TeV data exclude sparticle masses up to 1TeV
- search is repeated with full 2016 data set
  - will be sensitive to Higgsino models
  - combine results with other analyses (as done for 8TeV search)
  - push exclusion limits even higher (or finally **find SUSY?**)

End

The ECOP Leptonic Team

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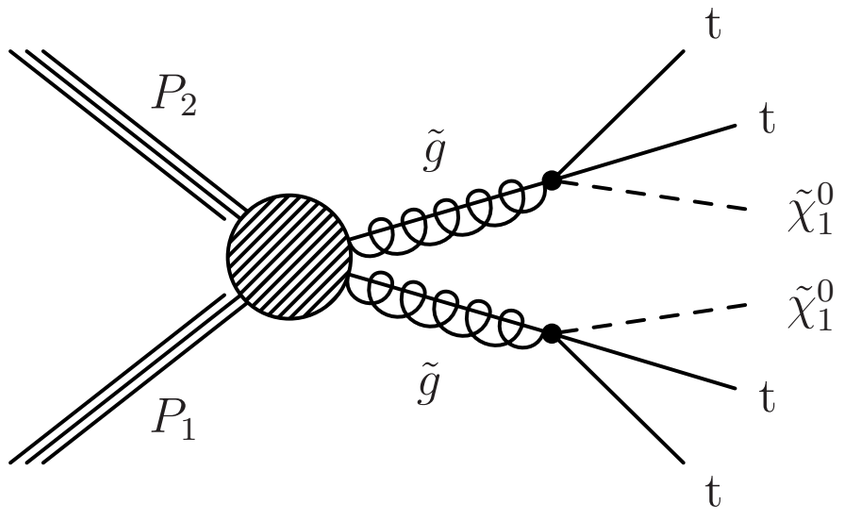
Appendix

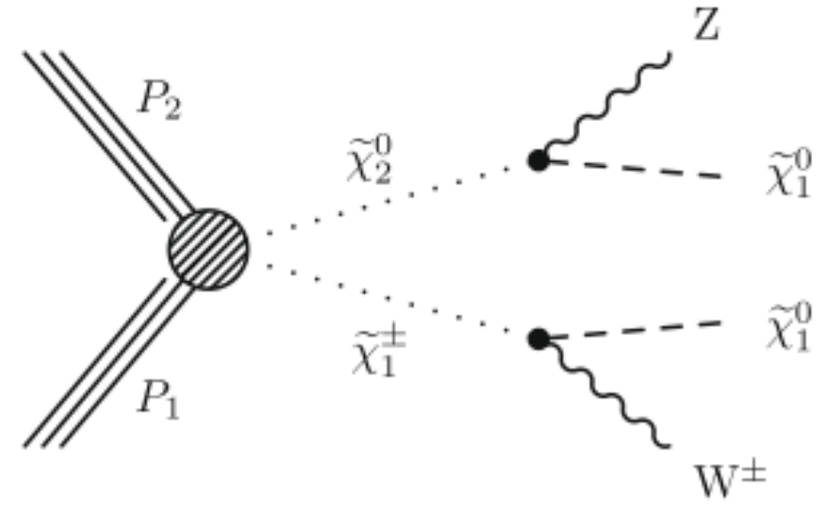
EWK SUSY vs. Strong Production

- different signatures in EWK SUSY w.r.t. strong production
- e.g. compare T1tttt (leading model for RA5 SSDL analysis) to TChiNeuWZ (one of the leading models for EWK SUSY trilepton analysis)



gluino-gluino production

- up to 4 hard, isolated, central leptons from W decays
- also a number of hard, central (b-) jets
- large MET from stable LSP (+ ν from W)

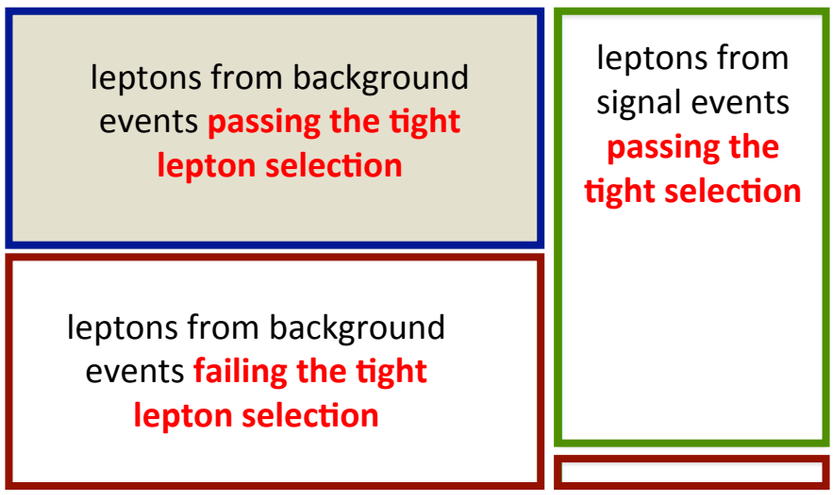


chargino-neutralino production

- 3 hard, isolated, central leptons from W and Z decays
- no additional jets
- large MET from stable LSP (+ ν from W)

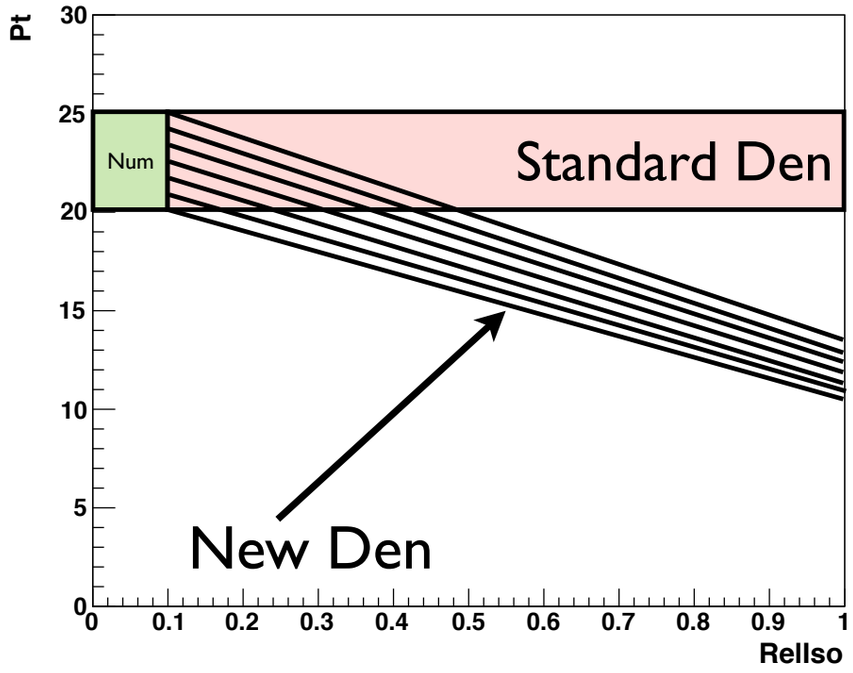
Nonprompt Background Estimation

- fake leptons
  - TT+Jets, DY+Jets or WW+Jets produces 1-2 jets passing lepton ID (=fake lepton)
  - use data-driven technique „**fake ratio method**“ to estimate this background
  - fake ratio (FR): probability for a fake to pass the tight lepton ID given it has passed the fakable ID
  - measure the number of loose leptons in a control region → gives estimate of the fakes in SR
  - we can benefit from many improvements in this method for RA5 and RA7 analyses (e.g. cone correction)



fake events = # events with loose-not-tight leptons x FR/(1-FR)

simplified FR method in single-lepton events



cone corrected FR denominator