Search for supersymmetric phenomena at LHC with the CMS detector

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Outline

- Why Supersymmetry @ LHC
- Why you should believe CMS results
- Susy searches at CMS
  - Hadronic searches
  - Searches with leptons
  - Searches with photons
  - Exotic searches
  - Supersymmetric Higgs

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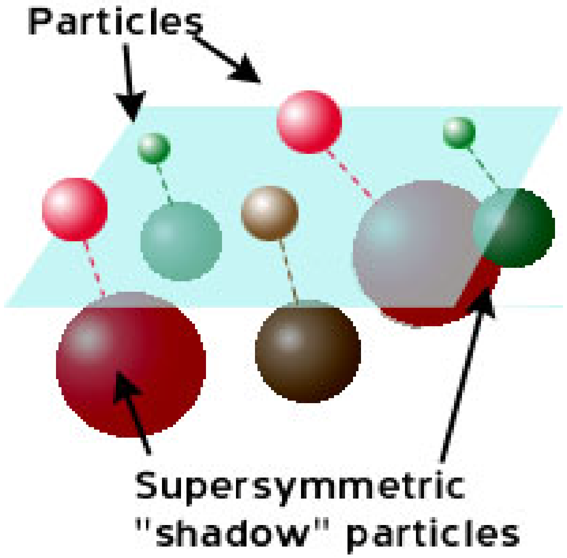
Supersymmetry

- The theory hypothesises a relationship between bosons and fermions
    - Leads to the prediction that every fermion has a bosonic super-partner and vice versa



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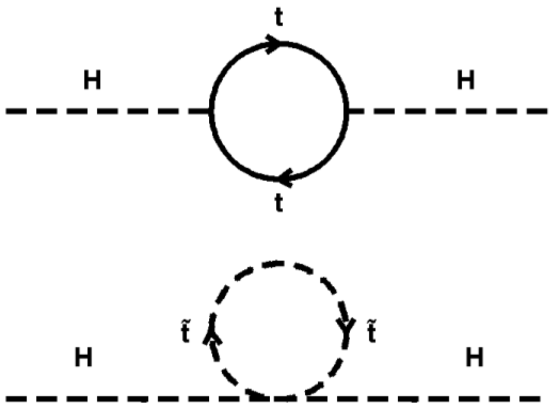

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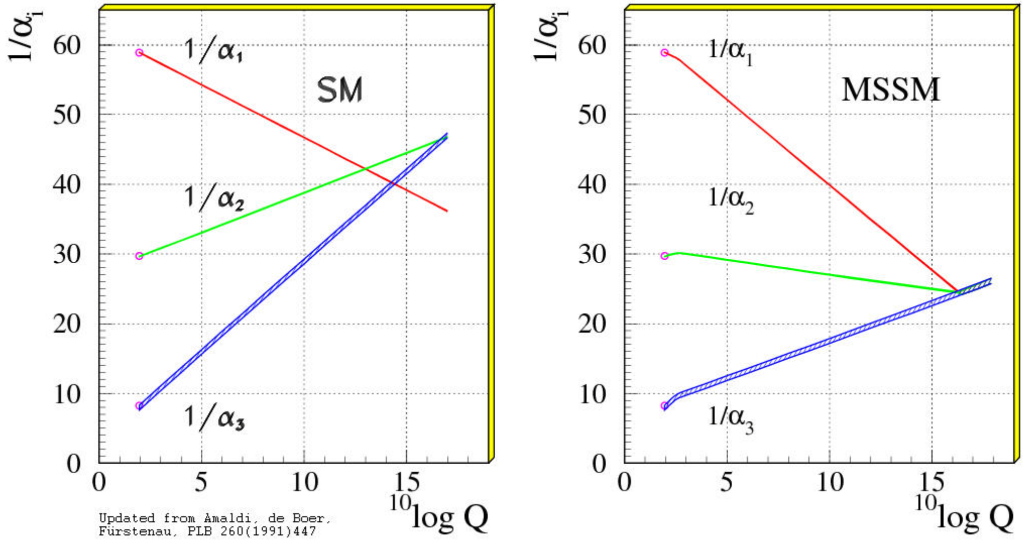

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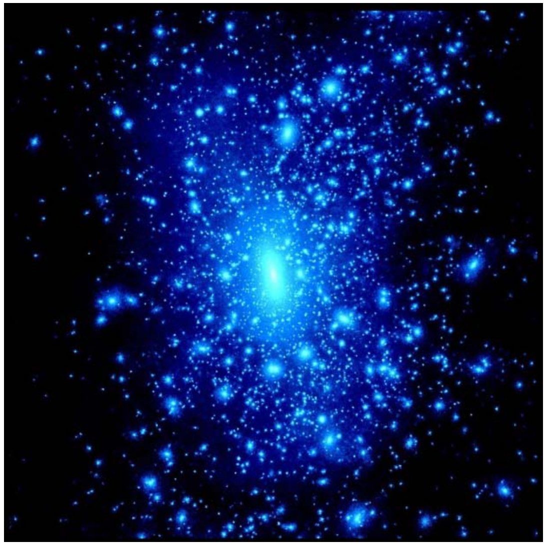

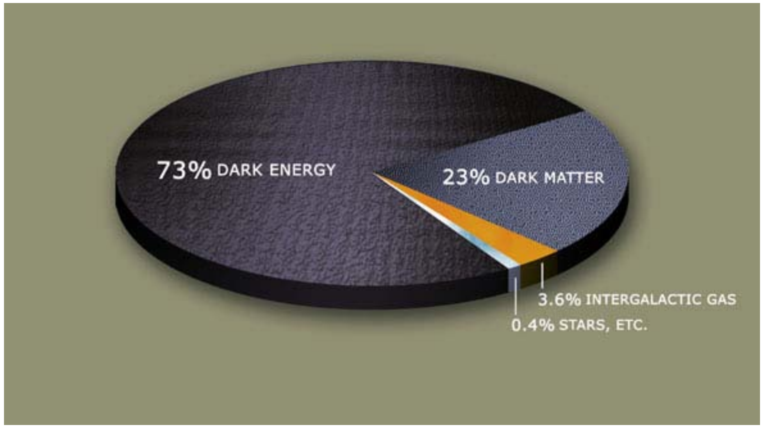

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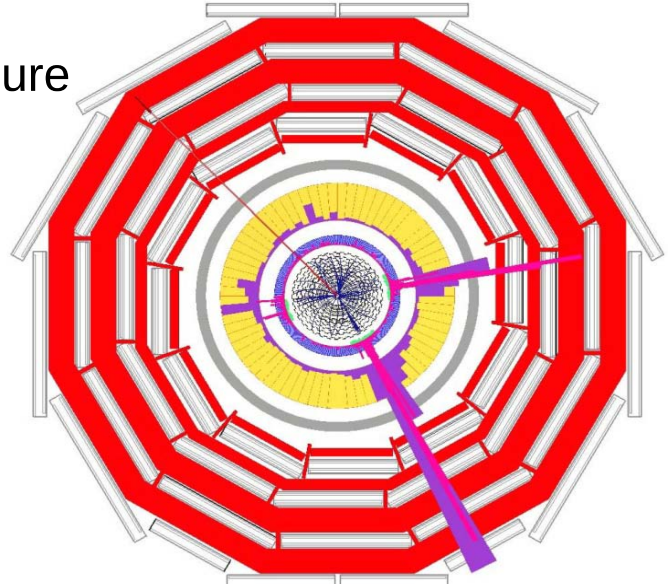

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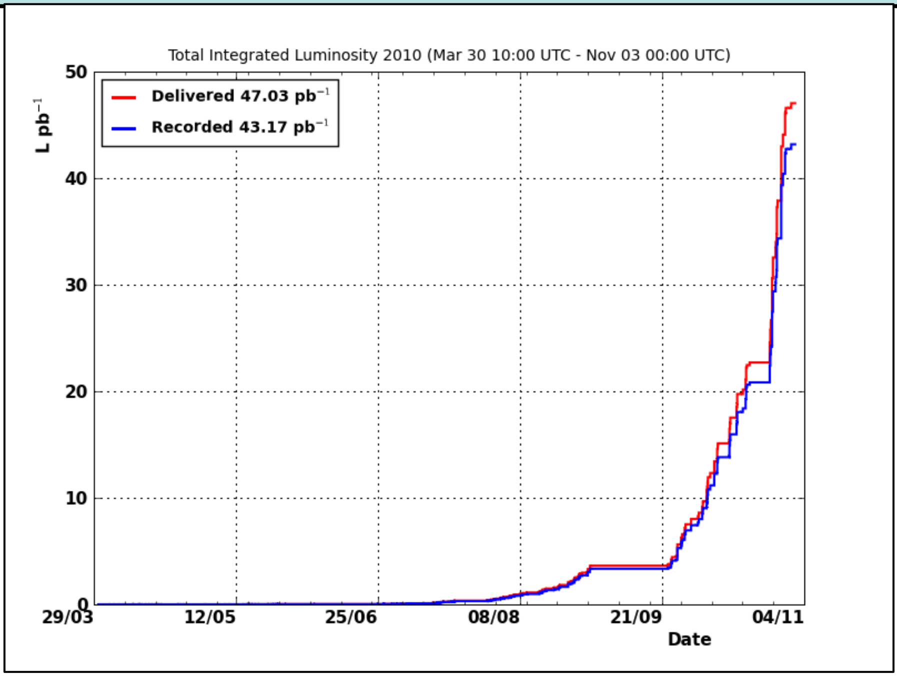
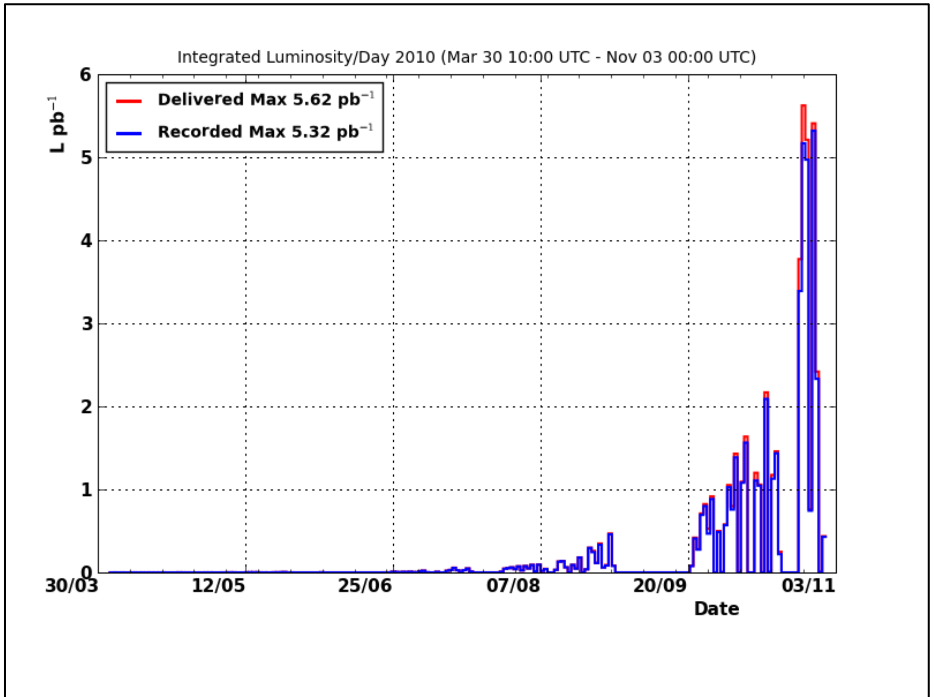
- Experimentalists love it because:
  - Plethora of new particles to discover and measure
- Symmetry not exact
  - SUSY and Standard Model particles have different masses
  - SUSY is broken ➔ what does it look like and how do we search?

LHC

- Mar-Aug: Run2010A ≈ 3pb−1
- Sep-Nov: Run2010B ≈ 40pb−1
- In total LHC Delivered 47 pb-1

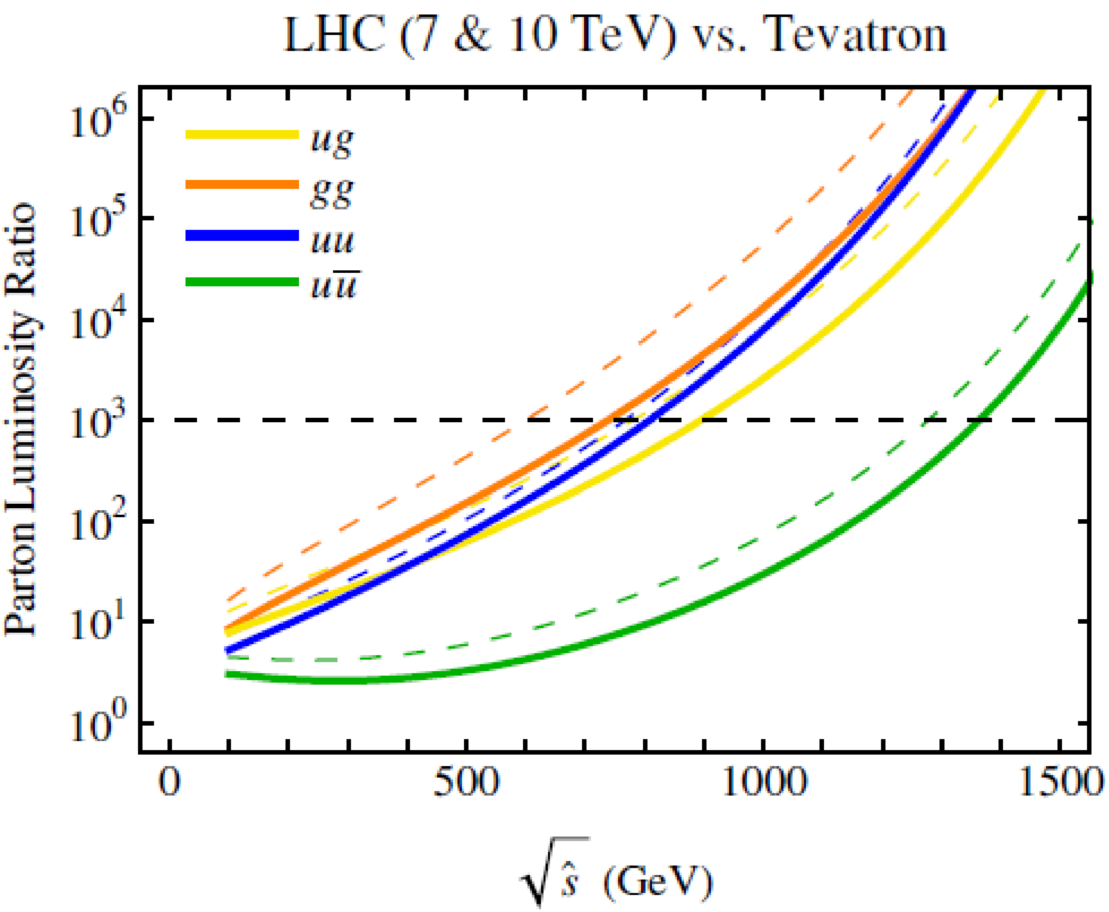




Steep performance curve
By the end of Run2010B
more than 5pb−1 per day

LHC vs TeVatron

Ratio of parton luminosities at the LHC and the TeVatron exceeds
the inverse ratio of integrated luminosities
(~100 = 5 fb-1 /50 pb-1)
for mass
scale >500-600 GeV
(gg, qg)
and 1150 GeV (qq)



Bauer et al., Phys. Lett. B **690, 280 (2010)**

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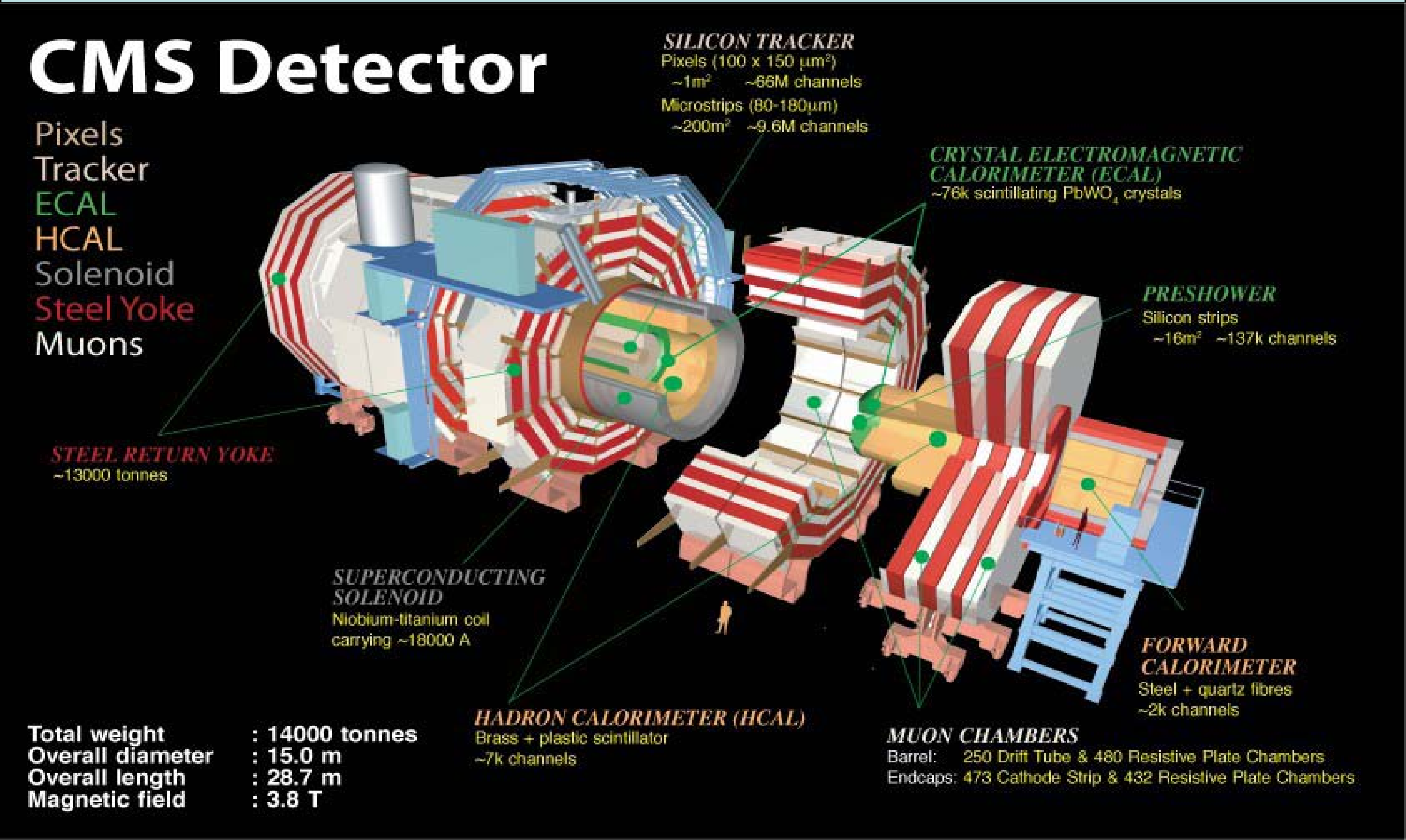
CMS detector



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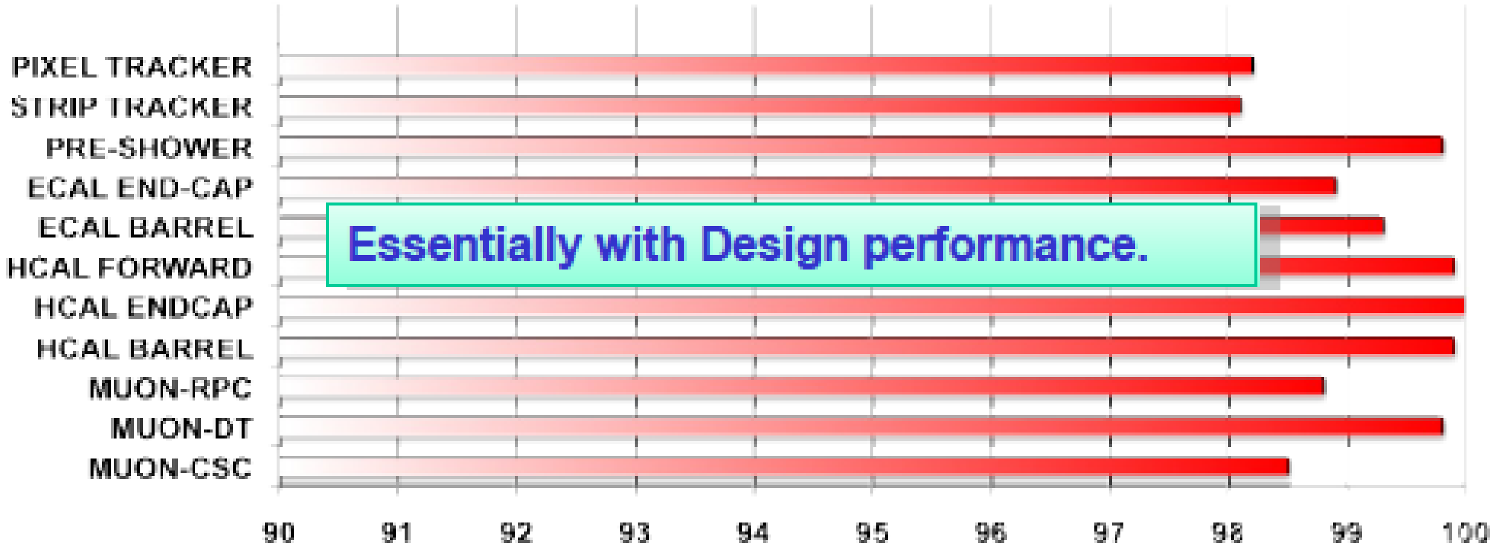


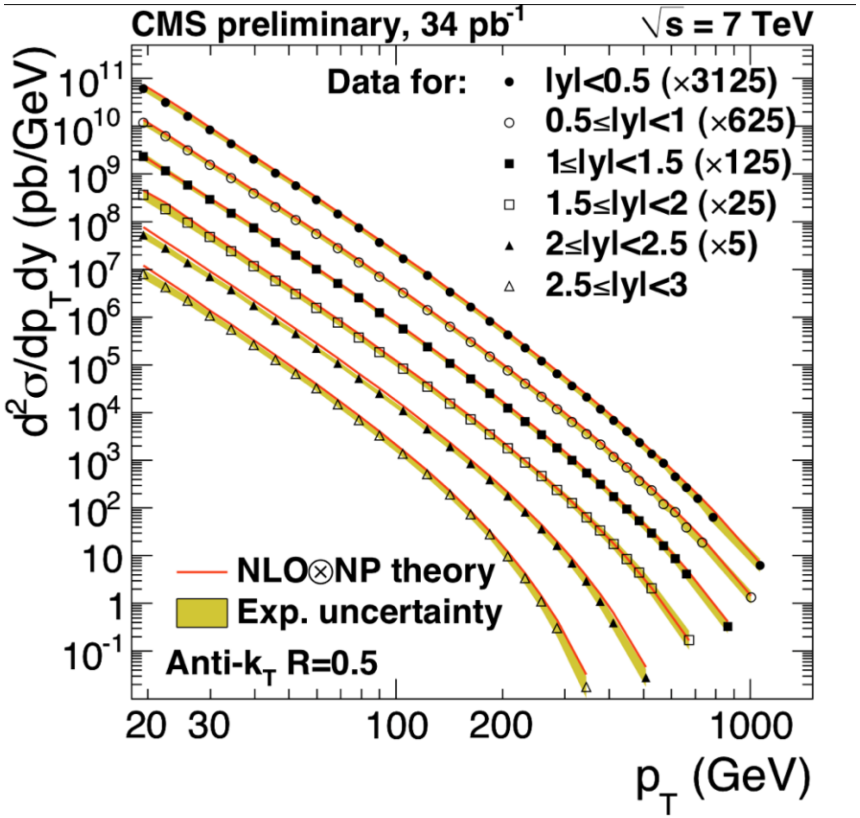
	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2

Proton-proton
LHC Delivered 47 pb-1,
CMS recorded 43 pb-1
Overall data taking efficiency 92%
~85% with all subdetectors fully operational

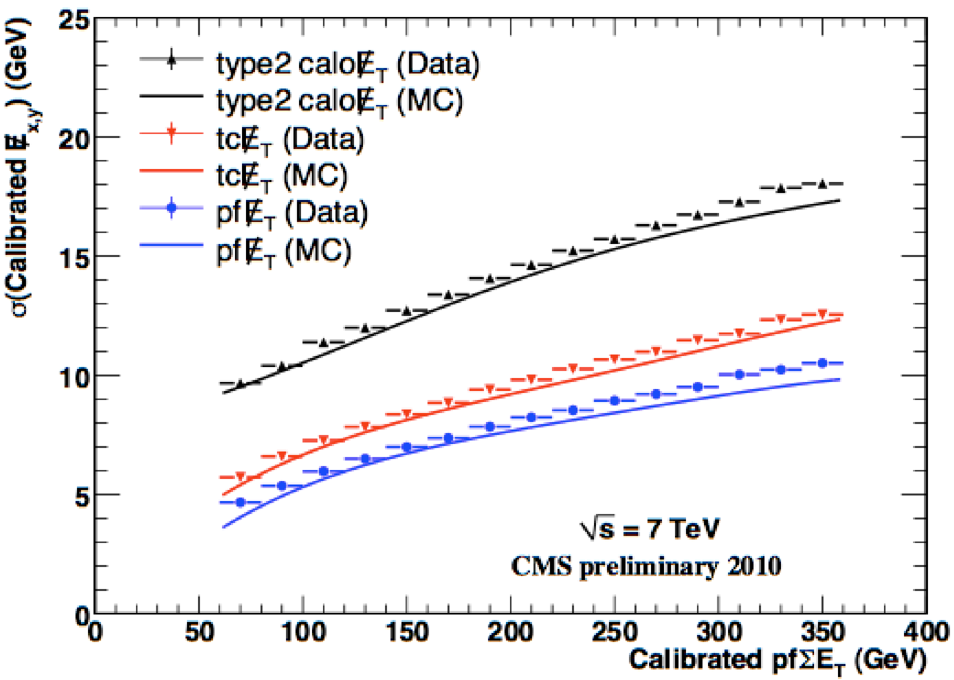
Heavy (Pb-Pb) Ions
LHC delivered ~ 10 mb-1,
CMS efficiency > 95%

Hadronic jets and MET

CMS-QCD-10-011
Measurement of the jet production cross section



CMS-PAS-JME-10-004
MET resolution

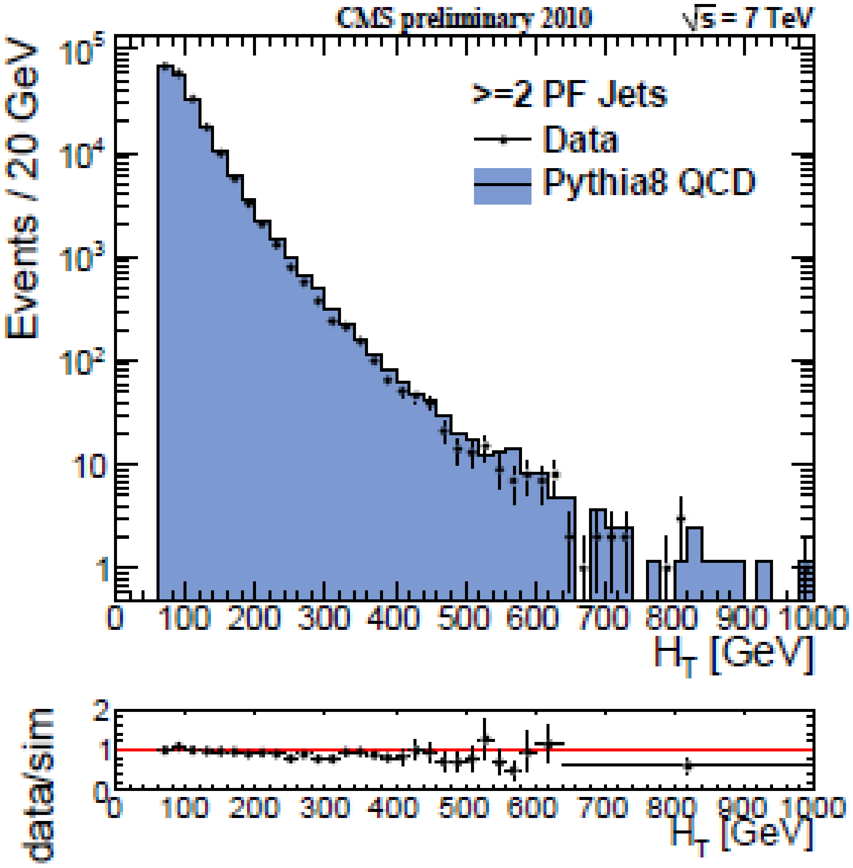


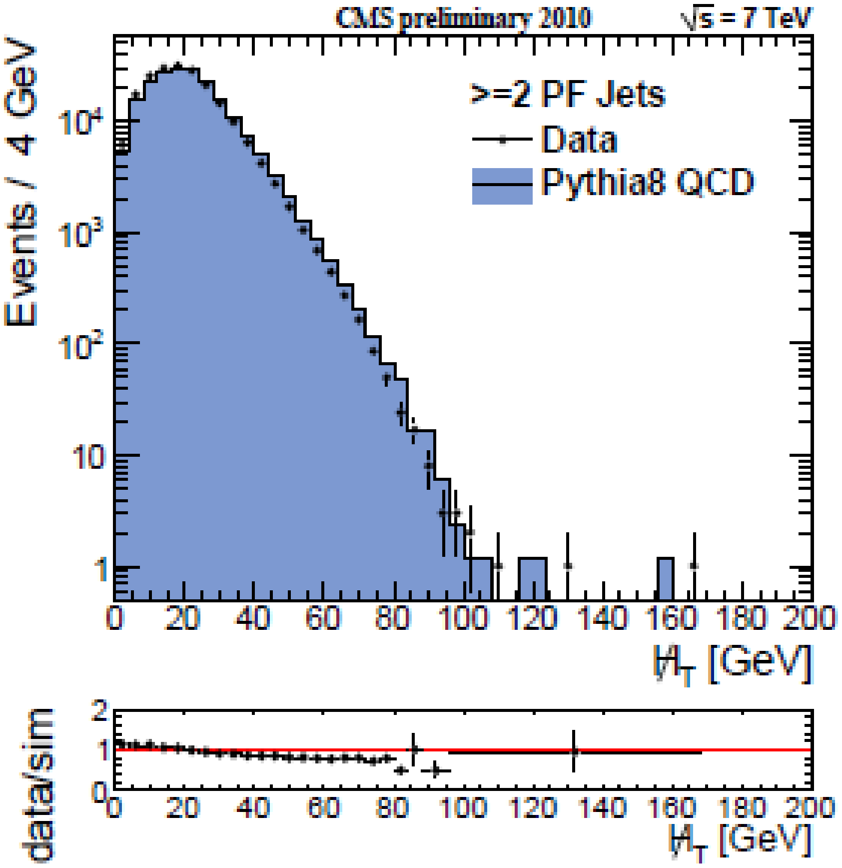
Jets and MET in good shape

HT and MHT

Deeply used in inclusive SUSY searches

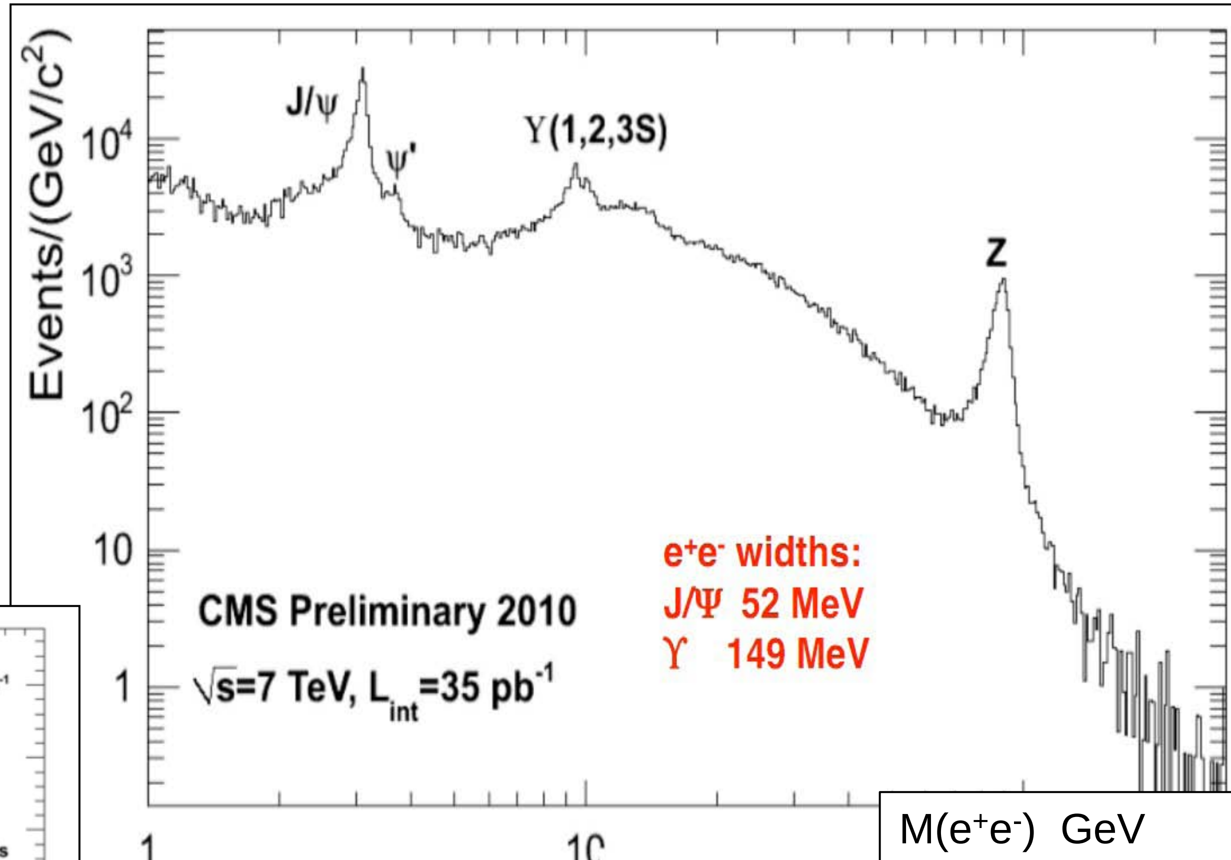
$$H_T = \sum \left| Pt_{jet} \right| \qquad MH_T = \left| \sum \vec{P}t_{jet} \right|$$

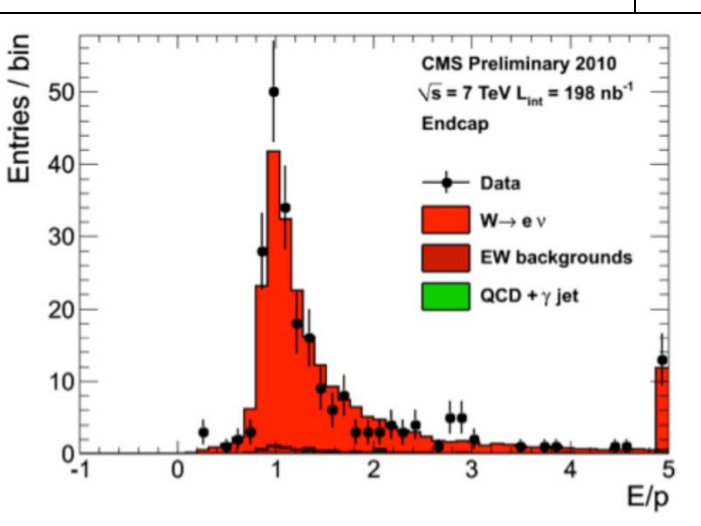




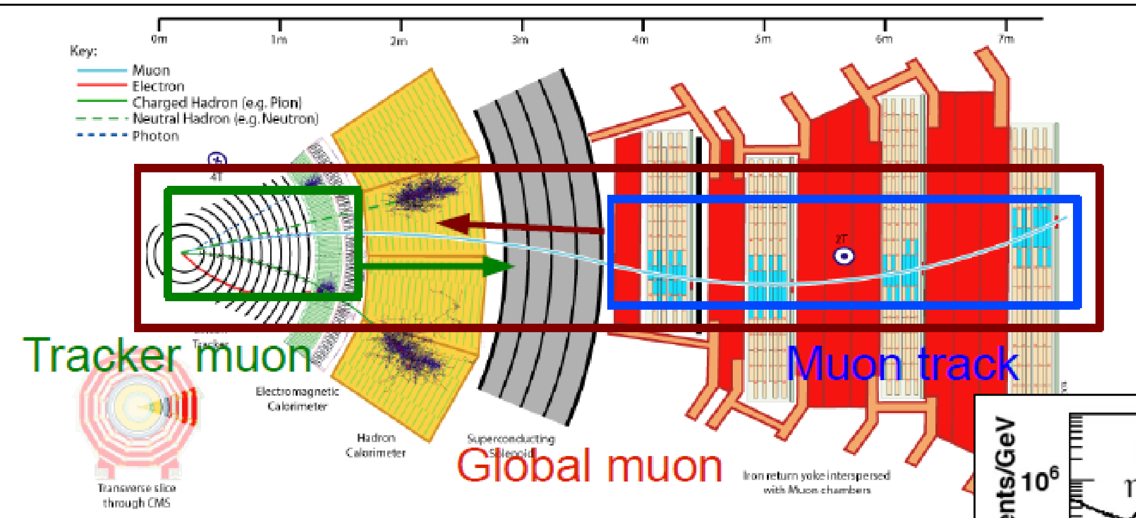
Electrons

Electron reconstruction based on ECAL and silicon tracker sub-detectors



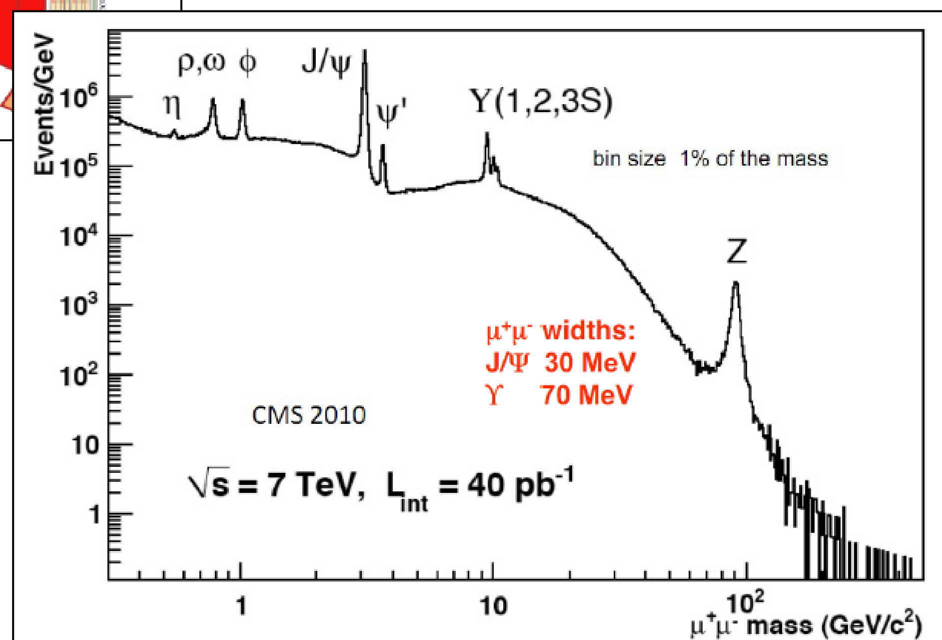


Muons



The "M" in CMS is Muon

Muon track fit including silicon track and muon chamber hits is performed



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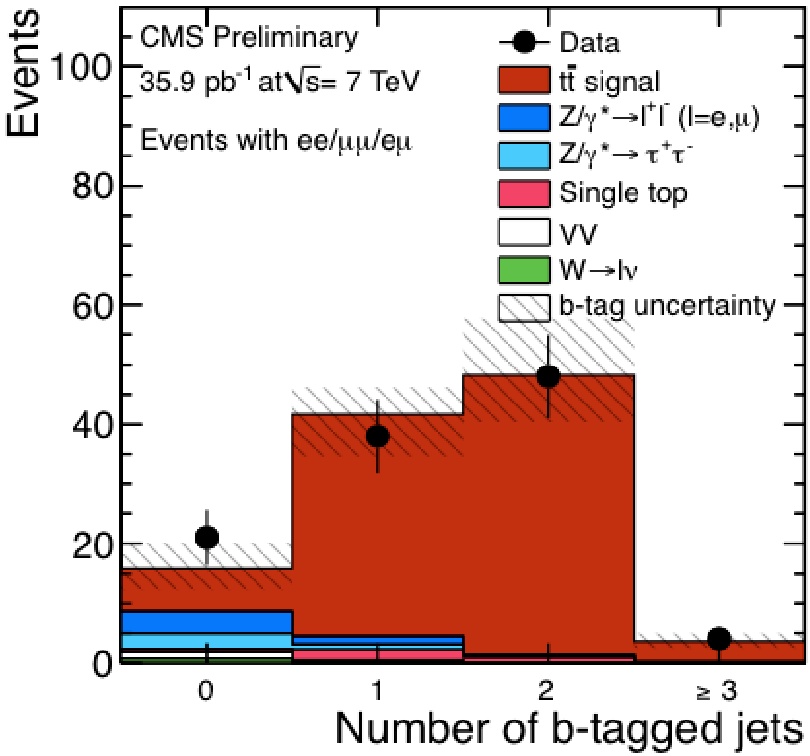
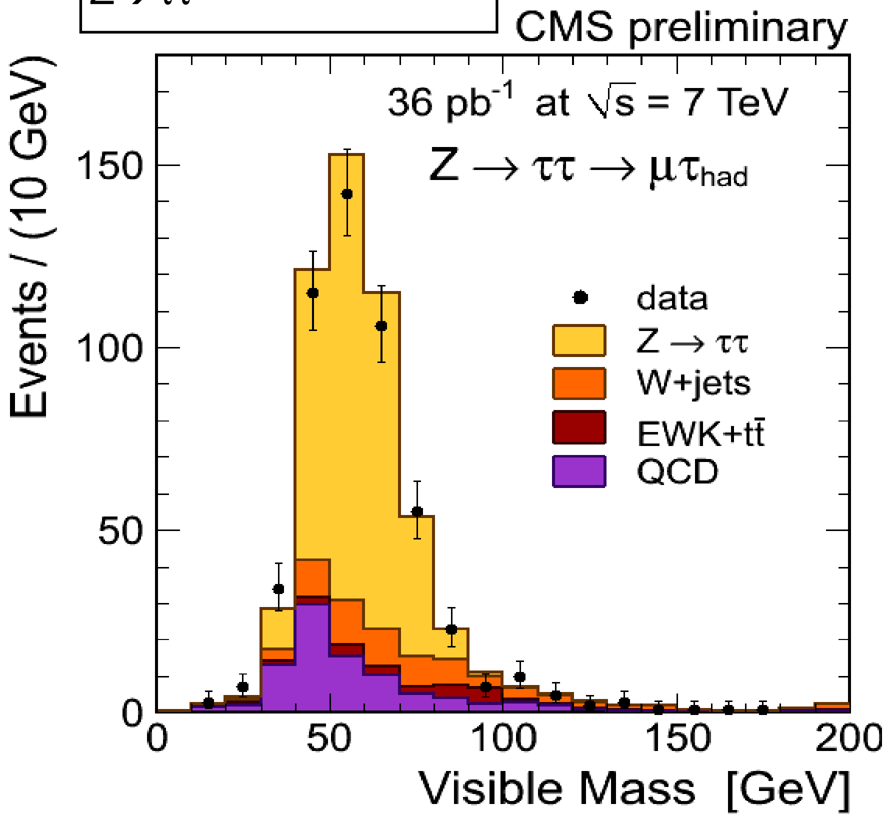
B and τ tagging

CMS-TOP-10-005
Top quark pair production

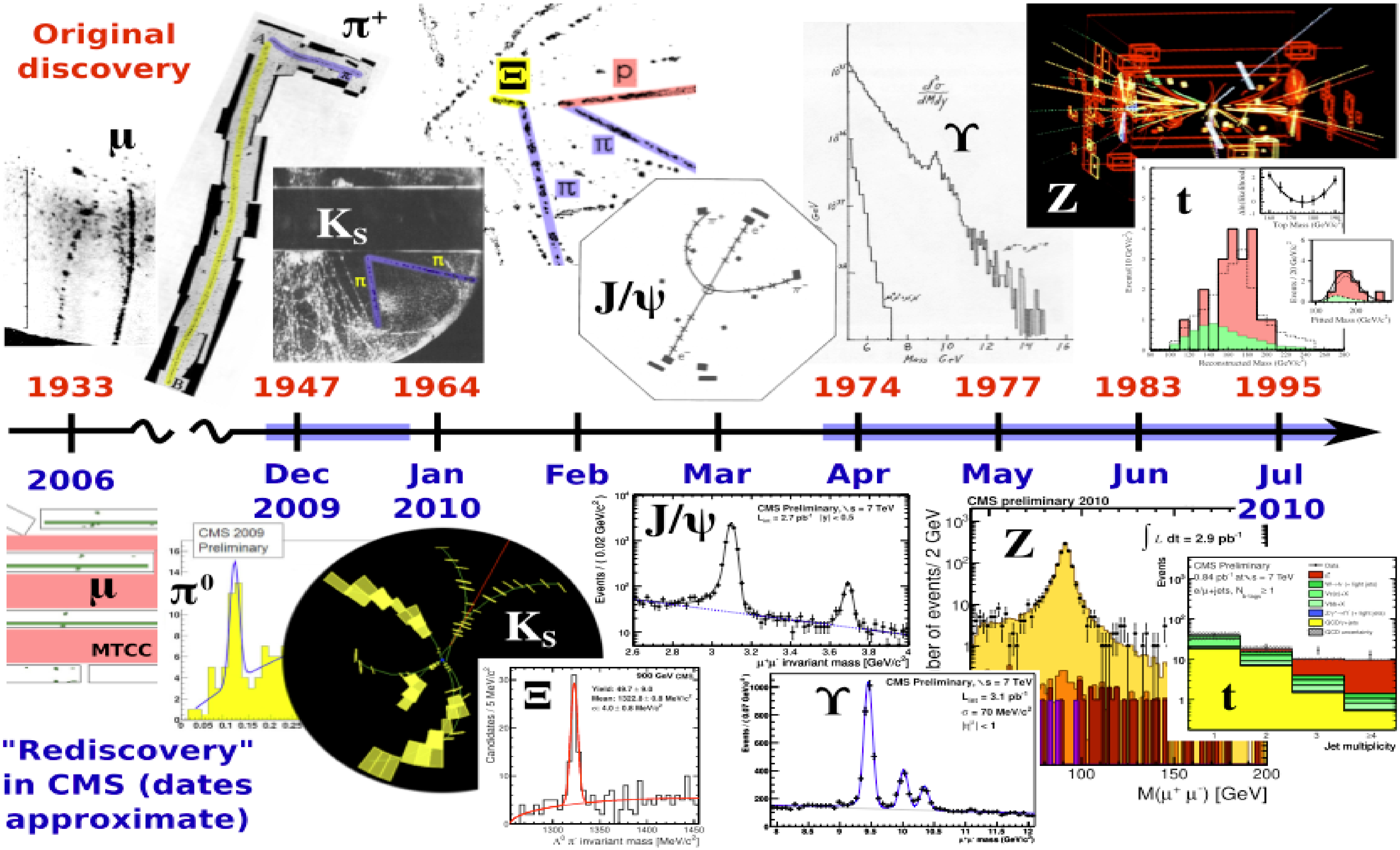


CMS-EWK-10-013
$Z \rightarrow \tau\tau$



b-tagging and τ-tagging performing well

Standard Model re-discovery



Search strategy for R-parity models (what and how?)

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

- Generic missing energy signatures
- Categorised by numbers of leptons and photons
- Many include jet requirement ➔ strong production
- All counting experiments at this point

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- Very challenging due to large amount and wide range of backgrounds
- However most sensitive search for strongly produced SUSY
- CMS pursues several complementary strategies based on kinematics and detector understanding

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- Lepton (electron or muon) requirement reduces background considerably
- Only ttbar and W+jets left ➔ topological handles

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- Adding a second lepton (electron or muon) reduced W background
- Two analyses here: inclusive and Z peak search
- Several techniques including opposite-sign opposite-flavour subtraction
- Shape information and mass edges

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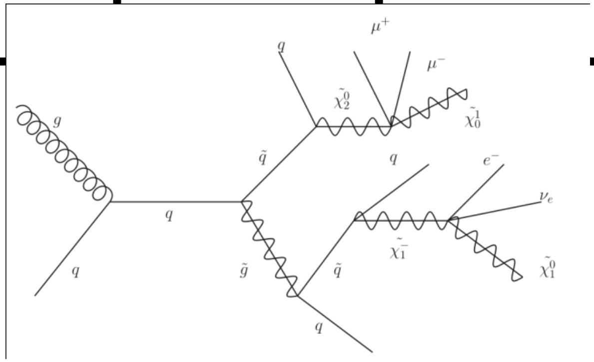

- A natural SUSY signature
- Very small Standard Model backgrounds
- Include all three generations of leptons and all cross channels

Search strategy for R-parity models (what and how?)

0-leptons	1-lepton	OSDL	SSDL	$\geq$3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

- Very clean events with very low Standard Model background
- Include all three generations of leptons and all combinations
- Search inclusively, on the Z peak, with and without MET

Search strategy for R-parity models (what and how?)

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- Many gauge-mediated models predict photons in final state
- Di-photon searches dominated by QCD multijet and γ+jet backgrounds

Search strategy (what and how?)

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- Many gauge mediated models predict photons in final state
- Lepton reduces QCD multijet and γ+jet backgrounds

Interpretation of results

- All the results are interpreted in the context of CMSSM/mSugra to be compared with results of other experiments
- Other models proposed from theorists http://www.lhcnewphysics.org to cover what can be seen in the first 50 pb^{-1}

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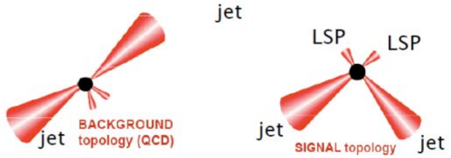
All Hadronic searches

3 complentary analyses:

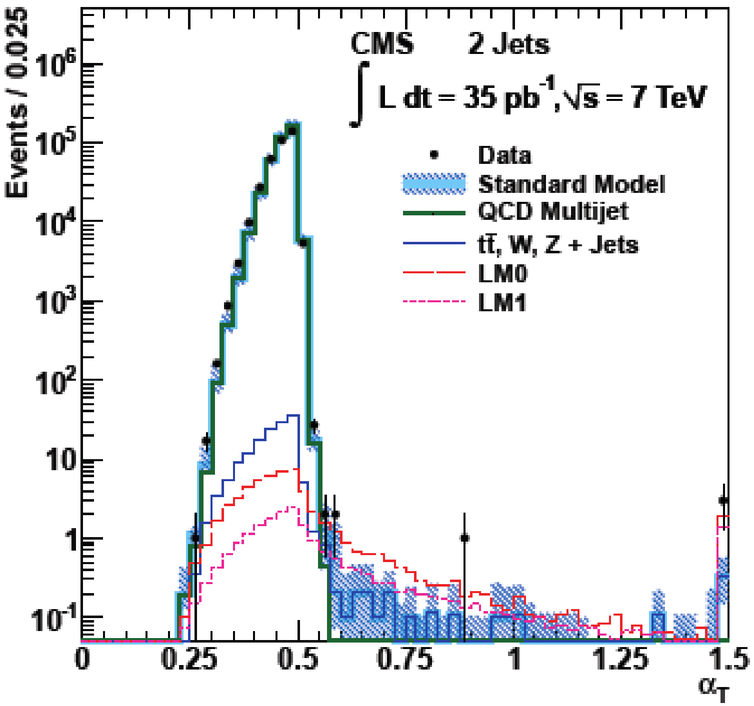
- α_T analysis
  - First LHC Susy paper
  - Already 30 citations (from spires)
  - Very robust against detector effects on jet energy measurements
- Missing energy search
  - Highly efficient for cascade topologies
  - Based on understanding the detector response in detail
- Razor analysis
  - Use of kinematic properties of heavy particles productions

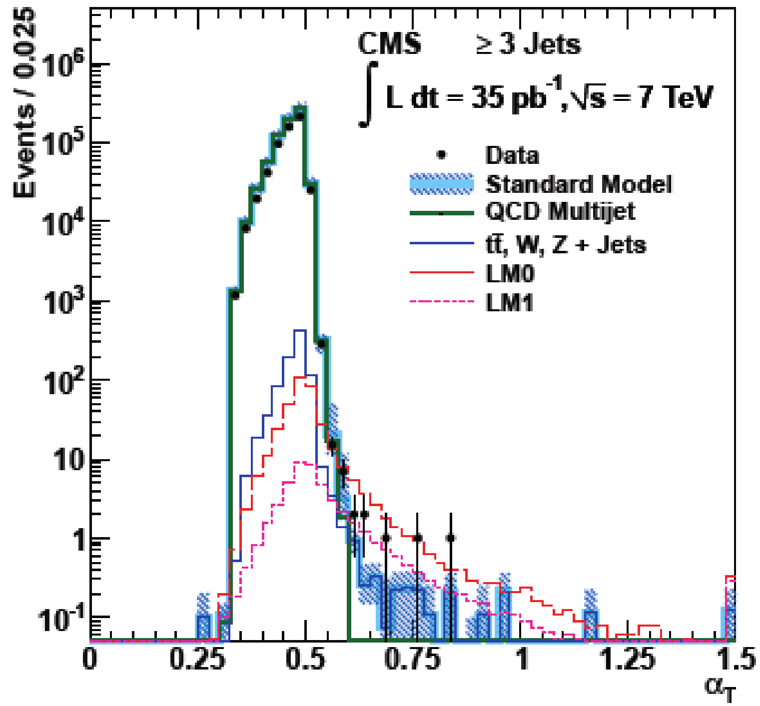
Hadronic search with α_T

$$\alpha_T = \frac{E_{T\ j2}}{M_{T\ j1j2}} = \frac{\sqrt{E_{T\ j2}/E_{T\ j1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$

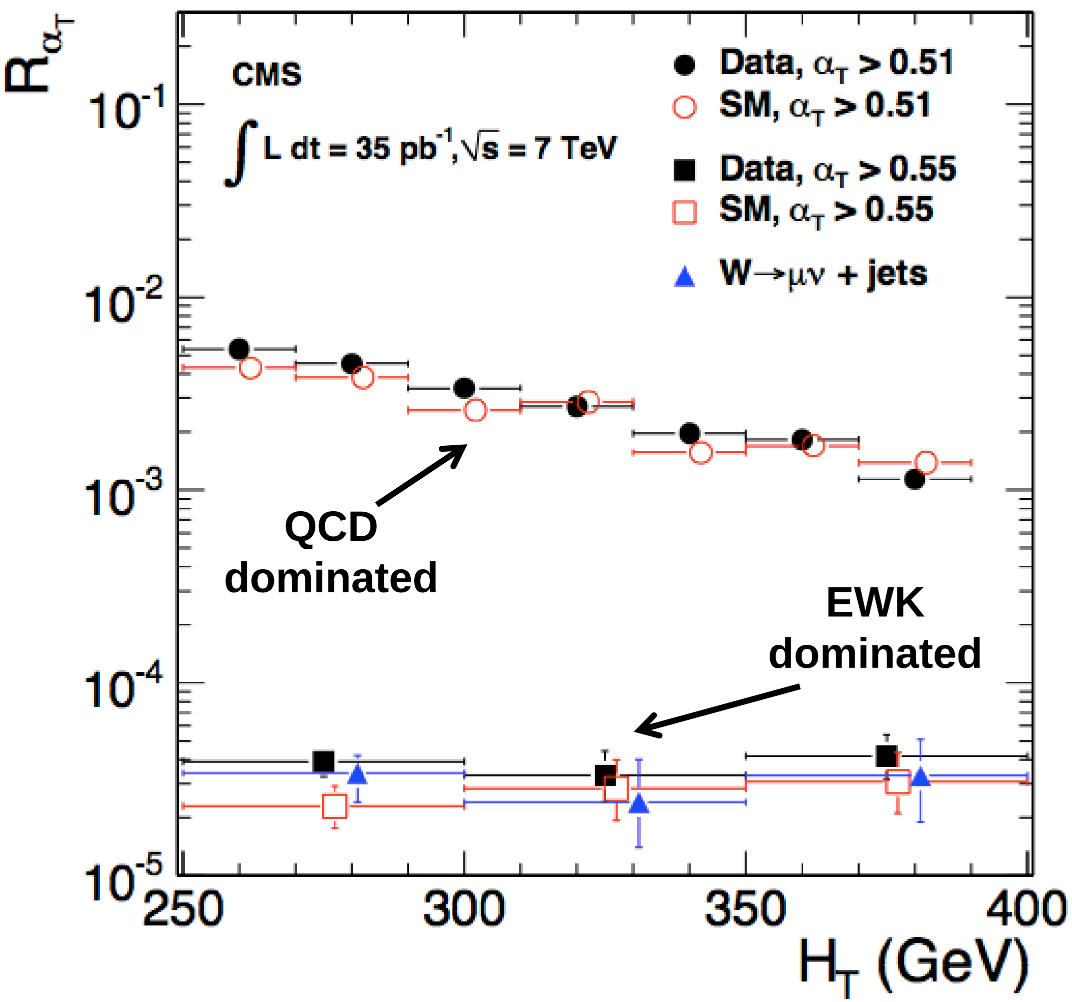


HT>350 GeV
α_T>0.55
No leptons
No photons
13 observed events





Inclusive background estimate

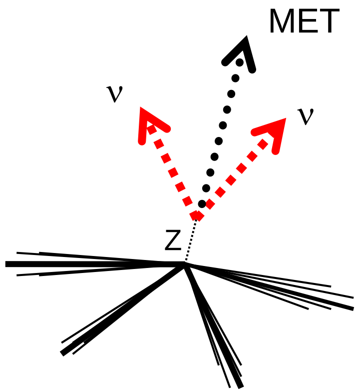


$R\alpha_T = N(\alpha_T > x)/N(\alpha_T < x)$

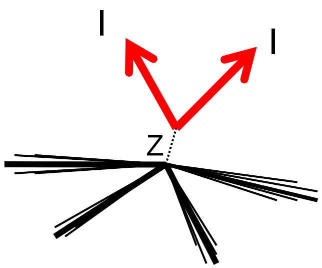
Use (almost) signal free region (lower HT bin) to measure RaT and extrapolate into signal region at HT>350GeV

Est. Bkg= $9.4^{+4.8}_{-4.0}$(stat.)±1.0(syst.)

Z → νν background



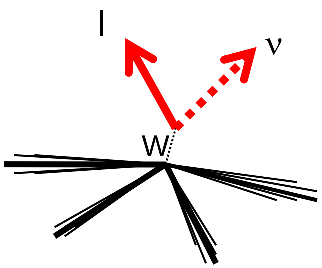
- Z → νν + jets → irreducible background
- Replacement technique pursued with all three samples
- γ+jets sample currently used, other cross check



Z → ll + jets

Strength: very clean

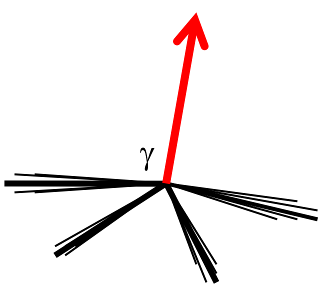
Weakness: low statistics



W → lν + jets

Strength: larger statistics

Weakness: background from SM and SUSY



γ + jets

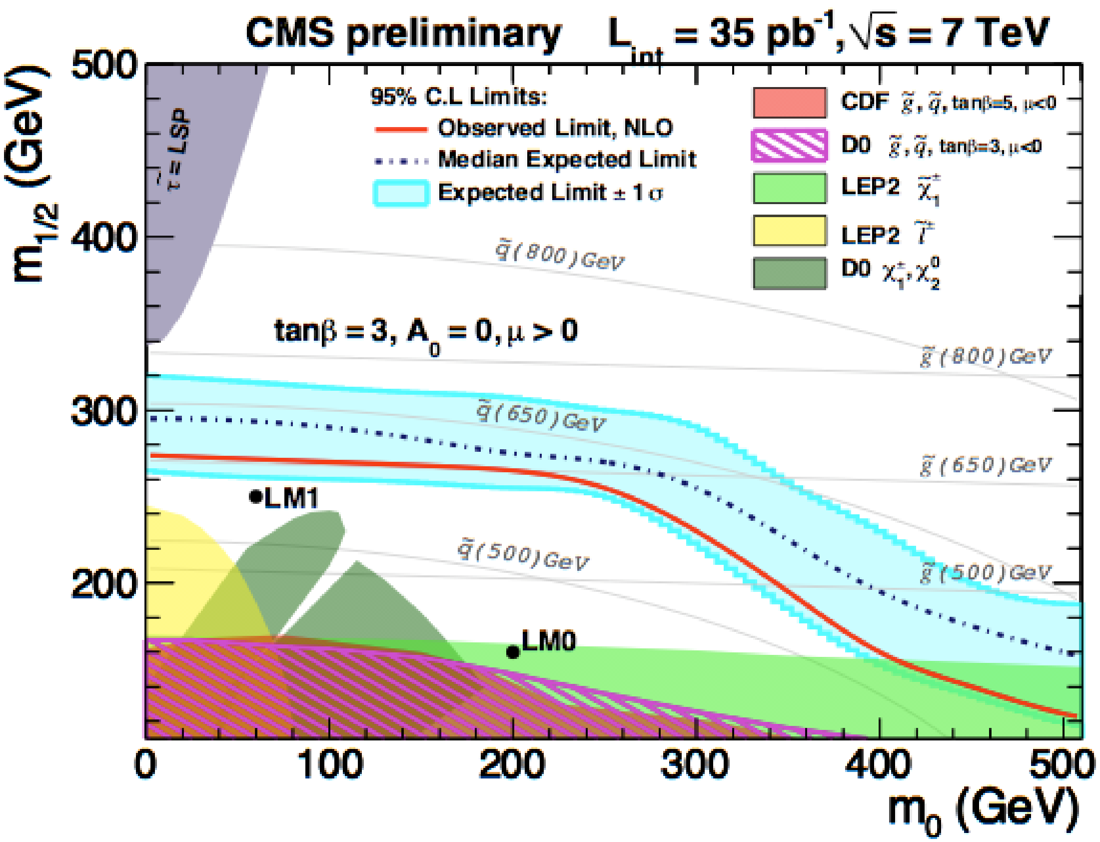
Strength: large statistics and clean at high E_T

Weakness: background at low E_T, theoretical errors

Hadronic search with α_T

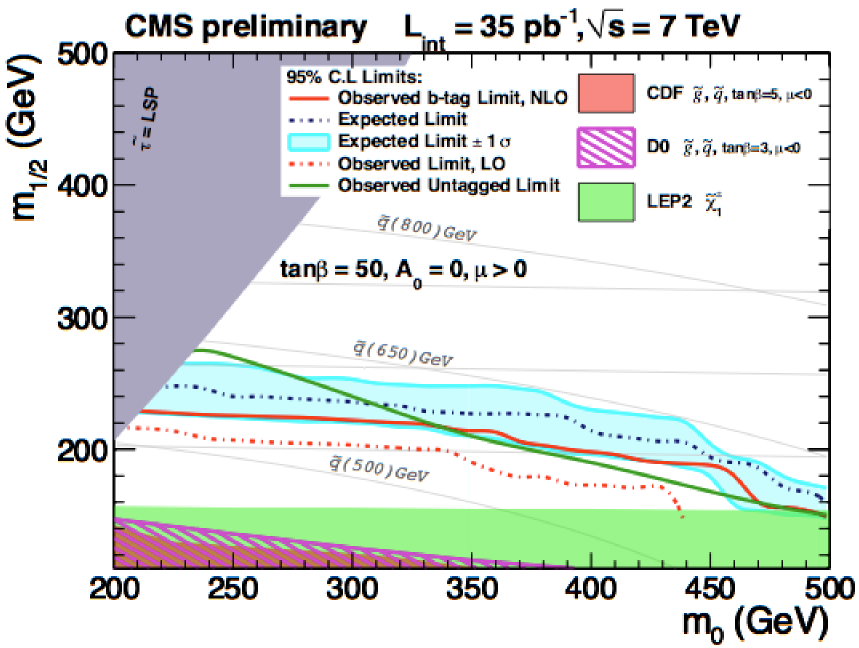
- Interpret in CMSSM for easy comparison with previous experiments
- $\tan\beta=3$ $A_0=0$ $\mu>0$
- Significant extension of excluded region over Tevatron experiments

arXiv:1101.1628

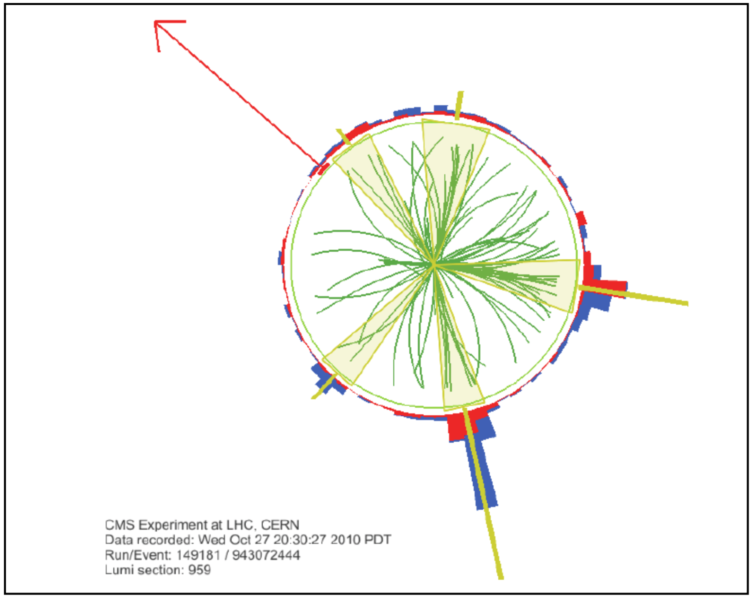


Hadronic search α_T + b-tag

CMS-SUS-10-011



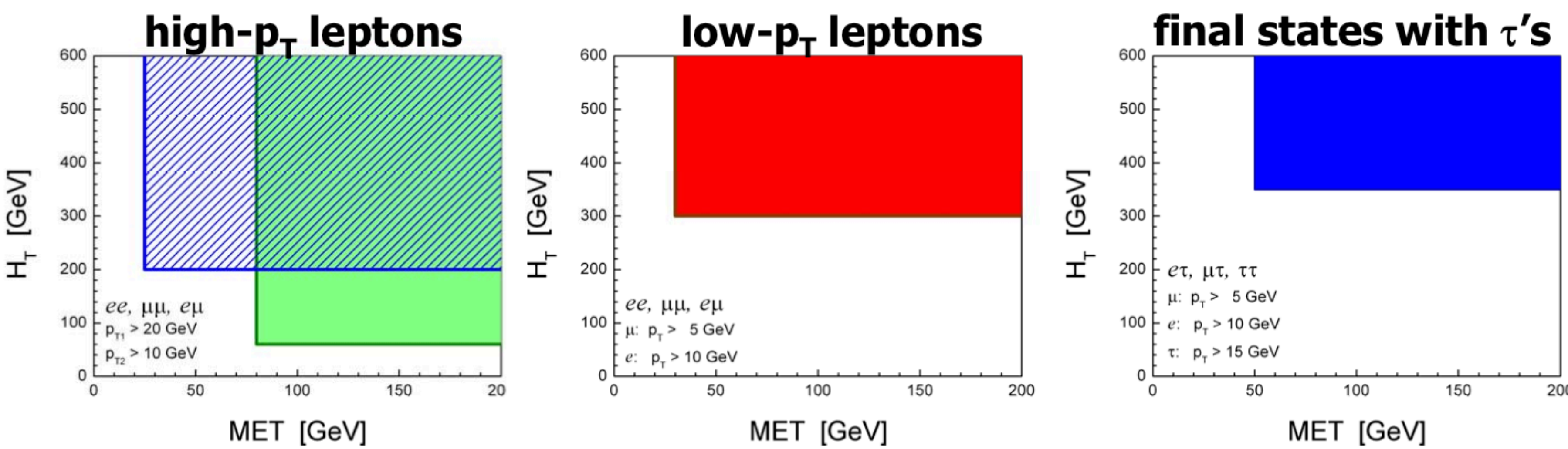
- Same as search with α_T but add the requirement that one of the jets must be b-tagged
- Reduces non-top backgrounds
- Increased sensitivity for b-rich models



1 event observed in data
Expect $0.33^{+0.43}_{-0.33}$ (stat) ± 0.13 (syst) events

Same-sign dilepton search

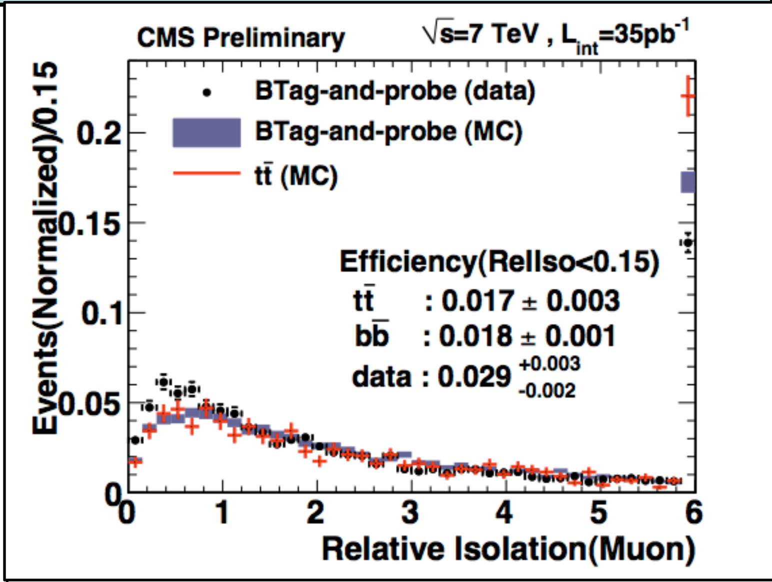
- Isolated same-sign lepton signature essentially absent in the Standard Model
- Search in all three lepton species and four search regions

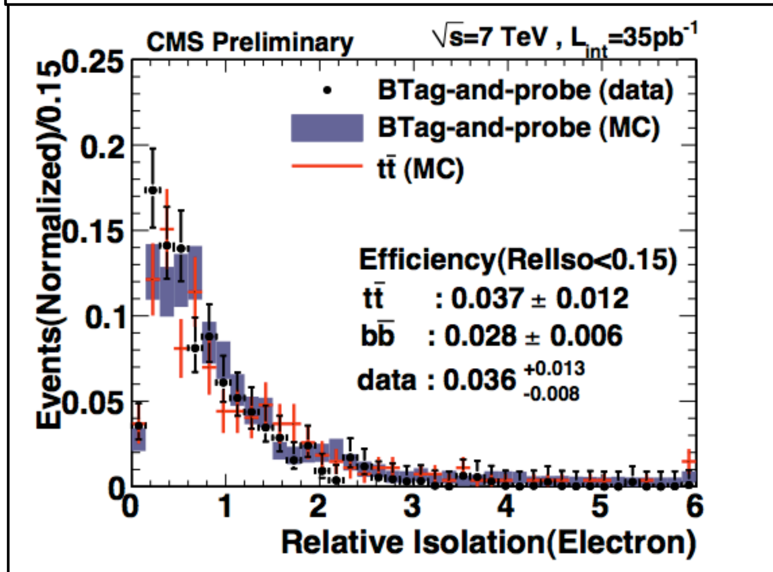


- Dominant backgrounds
  - ttbar: one isolated lepton from W, one from semi-lep b/c decay in jet
  - QCD: larger for hadronic τ final states

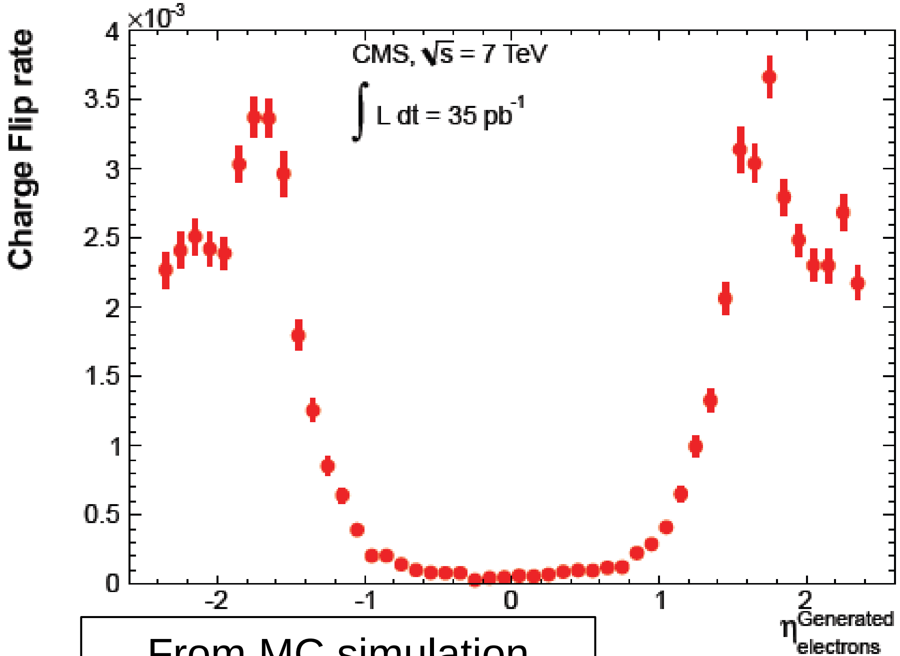
Background from ttbar

- Use tag and probe in bbbar (QCD) events to measure isolation efficiency
- Reweight this distribution to that of ttbar using simulation
- Use this isolation efficiency to determine background

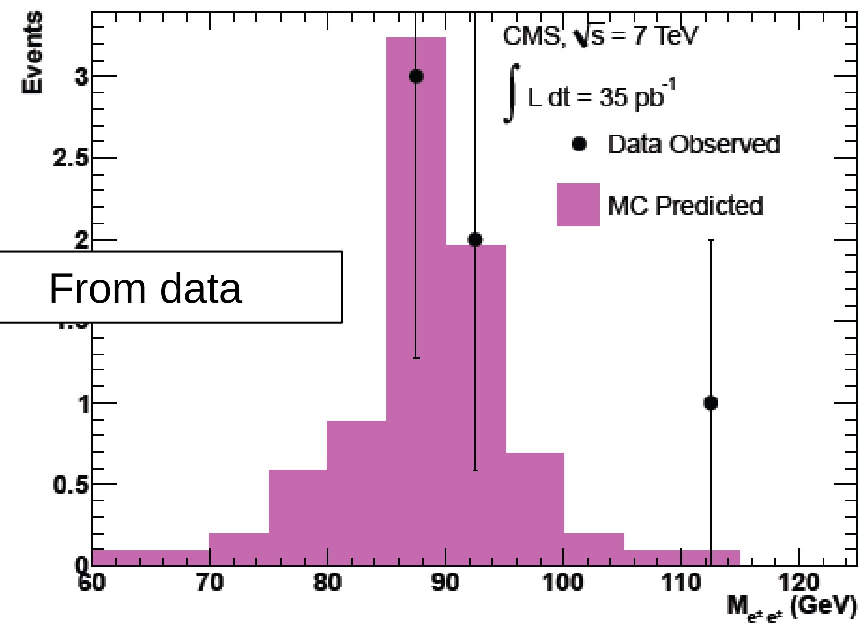




Background from electron charge flip



From MC simulation



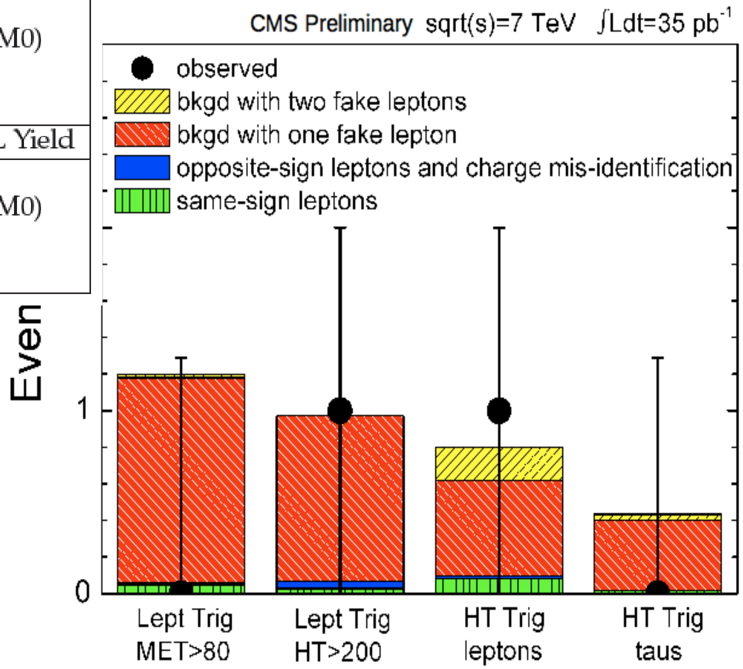
From data

Measure the rate of SS Z→ee events in data: 5
Measure the rate of OS Z→ee events in data: 3642

take the average flip rate <ε>=0.5·(5/3642)=0.0007 and
apply it to the observed isolated OS *ee/eμ events (+HT, +MET)*

Same Sign Dilepton search

Search Region	ee	$\mu\mu$	$e\mu$	total	95% C.L. UL Yield
Lepton Trigger					
$\not{E}_T > 80$ GeV					
MC	0.05	0.07	0.23	0.35	(7.3 for LM0)
BG predicted	**0.23 ± 0.35**	**0.23 ± 0.26**	**0.74 ± 0.55**	**1.2 ± 0.8**	
observed	**0**	**0**	**0**	**0**	**3.1**
$H_T > 200$ GeV					
MC	0.04	0.10	0.17	0.32	(9.6 for LM0)
BG predicted	**0.71 ± 0.58**	**0.01 ± 0.24**	**0.25 ± 0.27**	**0.97 ± 0.74**	
observed	**0**	**0**	**1**	**1**	**4.4**
H_T Trigger					
Low-p_T					
MC	0.05	0.16	0.21	0.41	(9.1 for LM0)
BG predicted	**0.10 ± 0.07**	**0.30 ± 0.13**	**0.40 ± 0.18**	**0.80 ± 0.31**	
observed	**1**	**0**	**0**	**1**	**4.5**
	$e\tau$	$\mu\tau$	$\tau\tau$	total	95% C.L. UL Yield
τ enriched					
MC	0.36	0.47	0.08	0.91	(2.0 for LM0)
BG predicted	**0.10 ± 0.10**	**0.17 ± 0.14**	**0.02 ± 0.01**	**0.29 ± 0.17**	
observed	**0**	**0**	**0**	**0**	**3.4**



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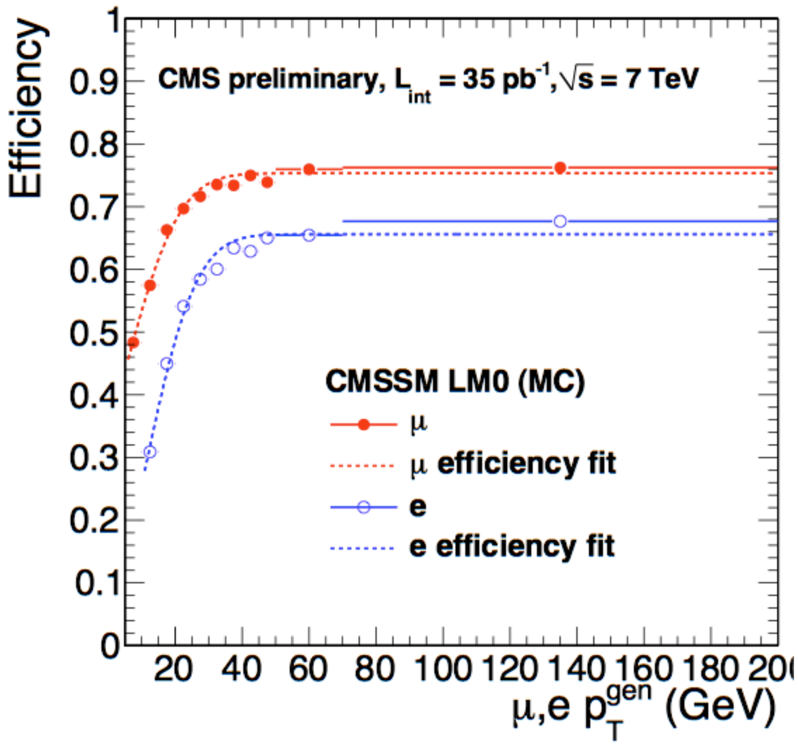
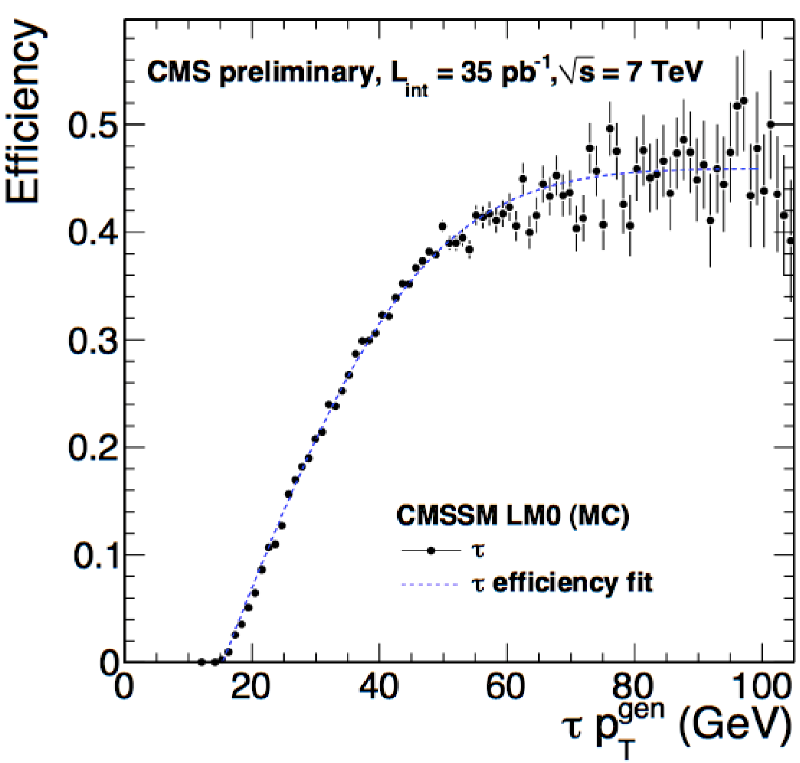
Input for theorists

Each theorist can test her/his model against cms SSDL results.

Acceptance,Lepton reconstruction efficiency,
HT and MHT resolution are given in the paper





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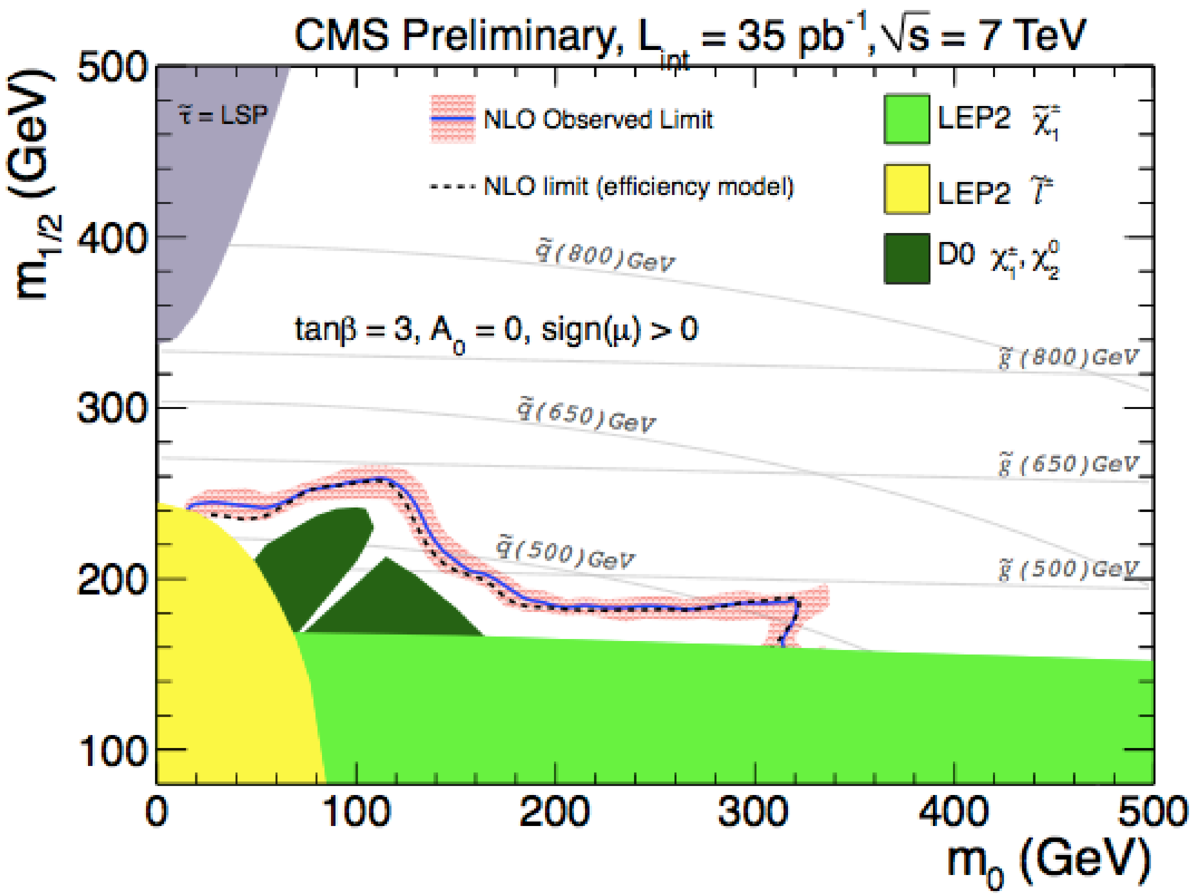
Limits in CMSSM



Limits in CMSSM beyond previous TeVatron searches

Efficiency model exclusions agree very well with the exclusions obtained with MC simulations.

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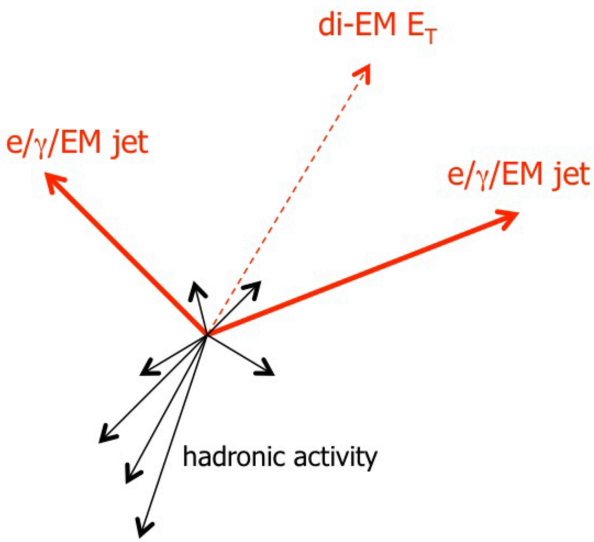
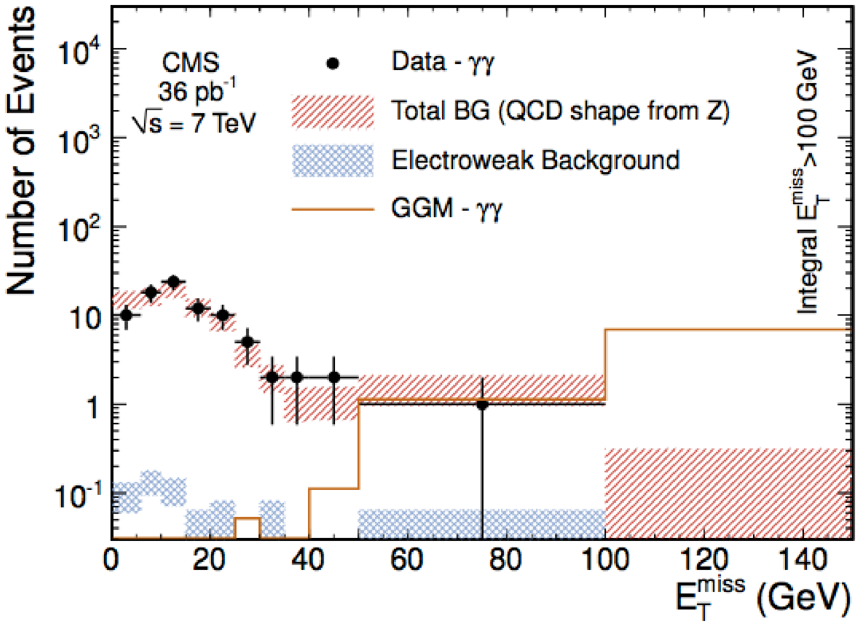
Searches with photons

arxiv:1103.0953

- Selection
  - Two isolated photons with $P_{T\gamma}$ > 30 GeV and $|\eta_\gamma|$ < 1.4
  - Shower shape ID cuts and H/E veto (<5%)
  - Distinguish electrons and photons by track in pixel detector
  - At least one jet E_T>30 GeV (cleans up beam and cosmic backgrounds)
  - MET> 50 GeV
- Background
  - QCD photo-production + MET mismeasurement
    - Measured from data with hadronic recoil method (next slide)
  - Fake photons
    - $e\gamma$ sample rescaled by $e \rightarrow \gamma$ factor

QCD backgrounds



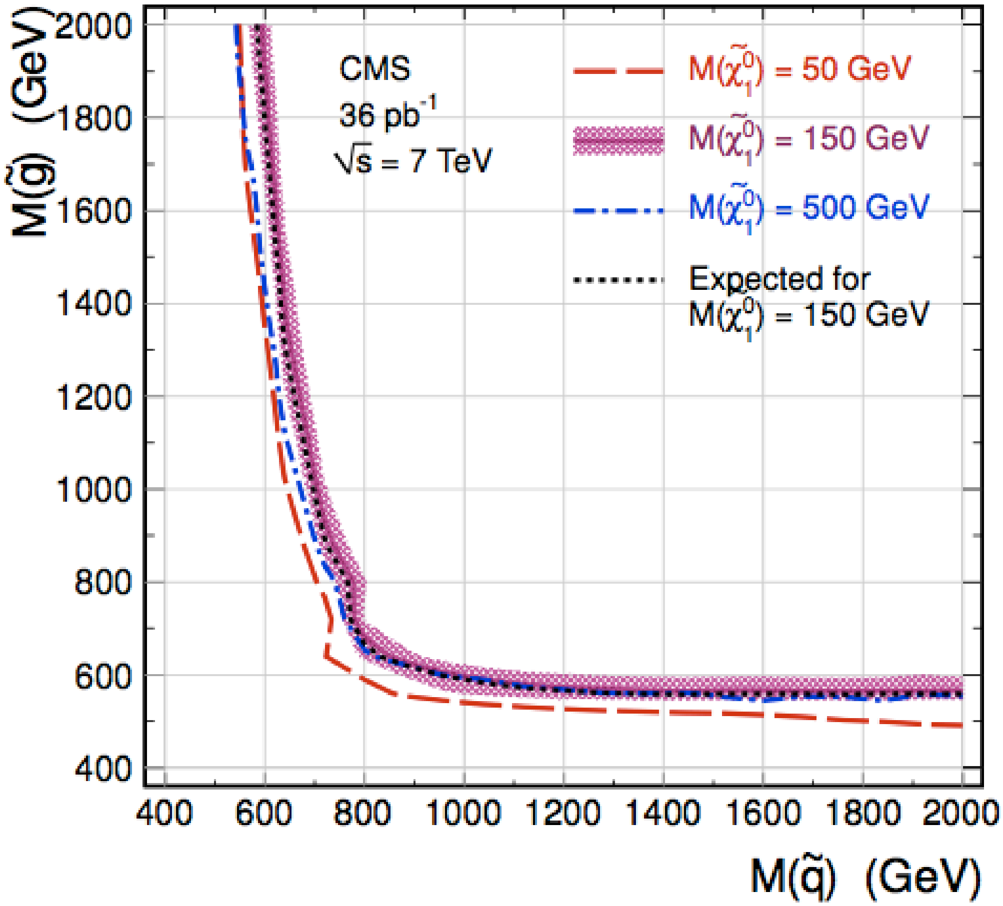


- EM objects better measured than hadronic objects
- MET dominated by hadronic resolution
- Reweight control samples to signal γγ E_T spectrum
- Normalise at low MET (<20 GeV)

Diphoton search

- Consider GGM model with neutralino (bino), gluino, and squark decaying to jets + two photons + two Gravitinos
- Upper limits between 0.5 and 1.1 pb depending on masses

1 observed event
Bkg. Estimate= 1.2 ± 0.8



Search for long-lived particles

- Predicted in many SUSY models
- Two complementary searches with 2010 data:
  1. Massive charged long-lived particles leaving highly ionizing tracks in the tracker (and the muon system)
  2. Long-lived strongly interacting particles stopping in the detector and decaying out-of-time with the collisions

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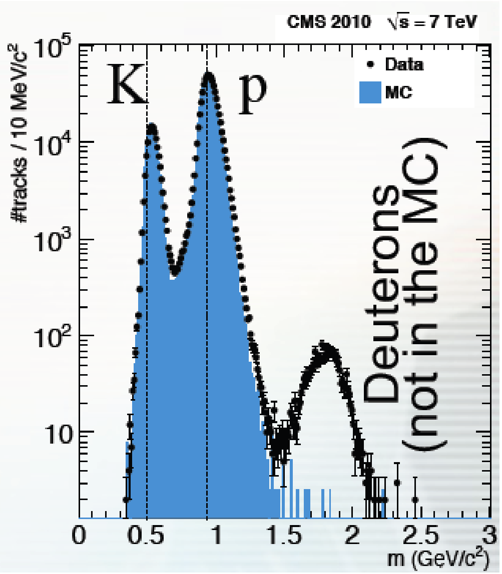
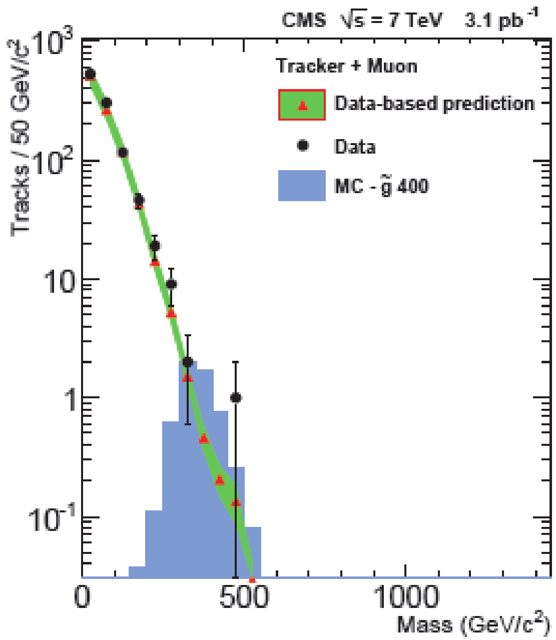
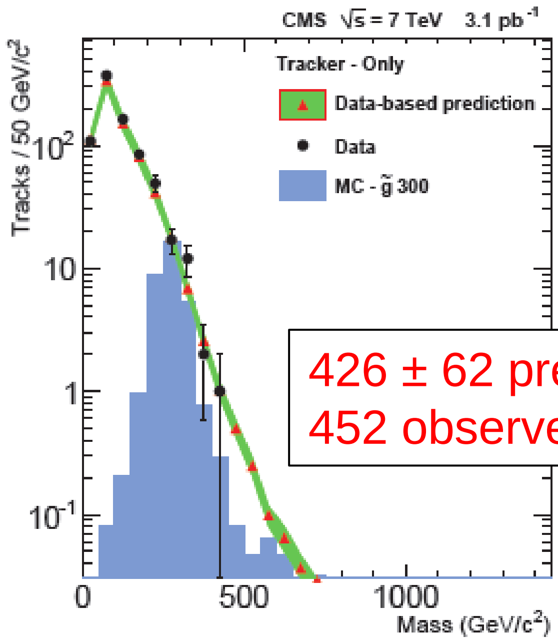
Heavy stable charged particles

- Track mass from Bethe-Block equation inversion
- Mass > 75 GeV
- Background distribution from data





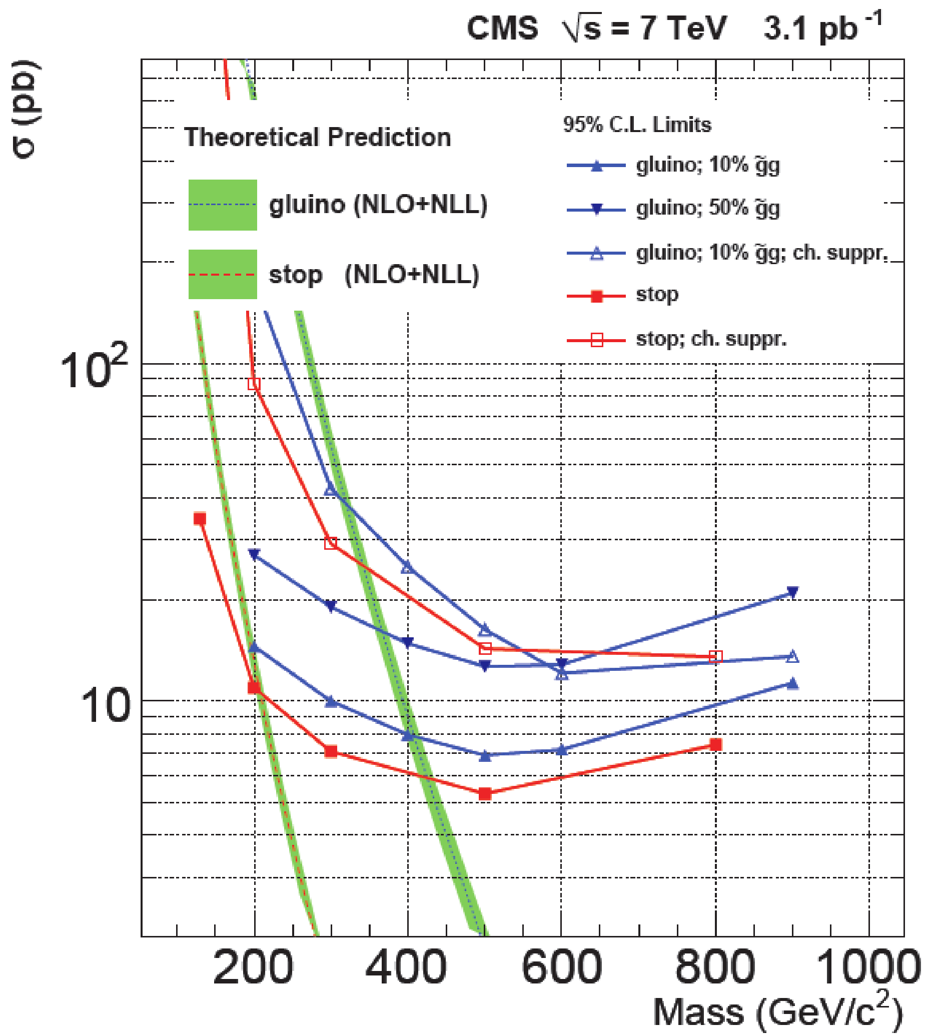


426 ± 62 predicted
452 observed

Heavy stable charged particles

Limits on the gluino mass of 357-398 GeV for the fraction f of gg hadronization between 0.5 and 0.1

The analogous stop limit
is 202 GeV



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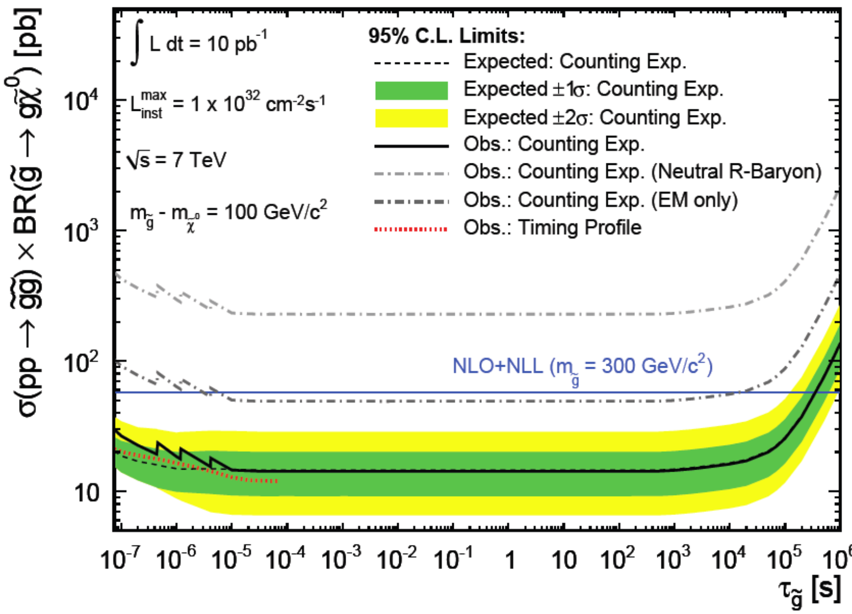
Search for stopped gluinos

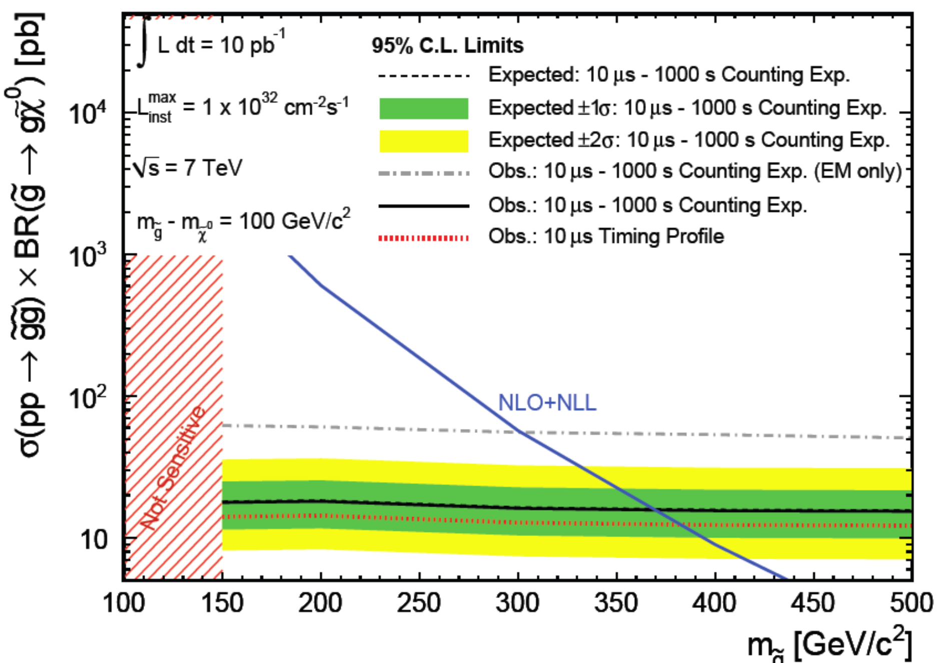
- Sensitive to slow-moving ($\beta < 0.4$)long-lived particles that hadronize and then stop in the dense material of the CMS detector
- Once stopped, they can decay microseconds, seconds, or days later, potentially giving a spectacular signal when there is no beam passing through CMS
- Designed and commissioned special no-beam trigger
- Look for jets in the calorimeters
- Main background from cosmic rays, beam halo and detectore noise
- Background estimated from cut factorization

Lifetime [s]	Expected Background ($\pm$ stat. $\pm$ syst.)	Observed
1×10^{-7}	$0.8 \pm 0.2 \pm 0.2$	2
1×10^{-6}	$1.9 \pm 0.4 \pm 0.5$	3
1×10^{-5}	$4.9 \pm 1.0 \pm 1.3$	5
1×10^{6}	$4.9 \pm 1.0 \pm 1.3$	5

Search for stopped gluinos



M(g)>382 GeV (τ = 10 μs)



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MSSM Higgs searches

- In the Minimal Supersymmetric Standard Model (MSSM) two Higgs doublets ➔ five Higgs bosons
  - Three neutral: h (light scalar), H (heavy scalar) & A (neutral CP odd)
  - Two charged: $H^{\pm}$

$\phi \rightarrow \tau\tau$ search

CMS-HIG-10-002

- Search for pp ➔ ϕ + X
  - ϕ = h,H,A mass degenerate depending on regime
- Higgs decays to tau-pairs with BR~10%
  - (b-quark pairs higher BR but huge background from QCD)
- Three decay channels considered:
  - H ➔ $\tau\tau$ ➔ e-μ
  - H ➔ $\tau\tau$ ➔ e-τ_h (τ_h=hadronic decay)
  - H ➔ $\tau\tau$ ➔ μ-τ_h

Process	$\mu\tau_h$	$e\tau_h$	$e\mu$
$Z \rightarrow \tau\tau$	329±77	190±44	88±5
$t\bar{t}$	6±3	2.6±1.3	7.1±1.3
$Z \rightarrow \ell\ell$, $jet \rightarrow \tau_h$	6.4±2.4	15±6.2	
$Z \rightarrow \ell\ell$, $\ell \rightarrow \tau_h$	13.3±3.6	119±28	
$W \rightarrow \ell\nu$	54.9±4.8	30.6±3.1	3.9±1.2
$W \rightarrow \tau_\ell\nu$	14.7±1.3	7.0±0.7	
QCD	132±14	181±23	
WW/WZ/ZZ	1.6±0.8	0.8±0.4	3.0±0.4
Total	558±79	546±57	102±5
Observed	540	517	101
Signal Efficiency (m_A=120 GeV/c^2)	0.0253	0.0156	0.00561

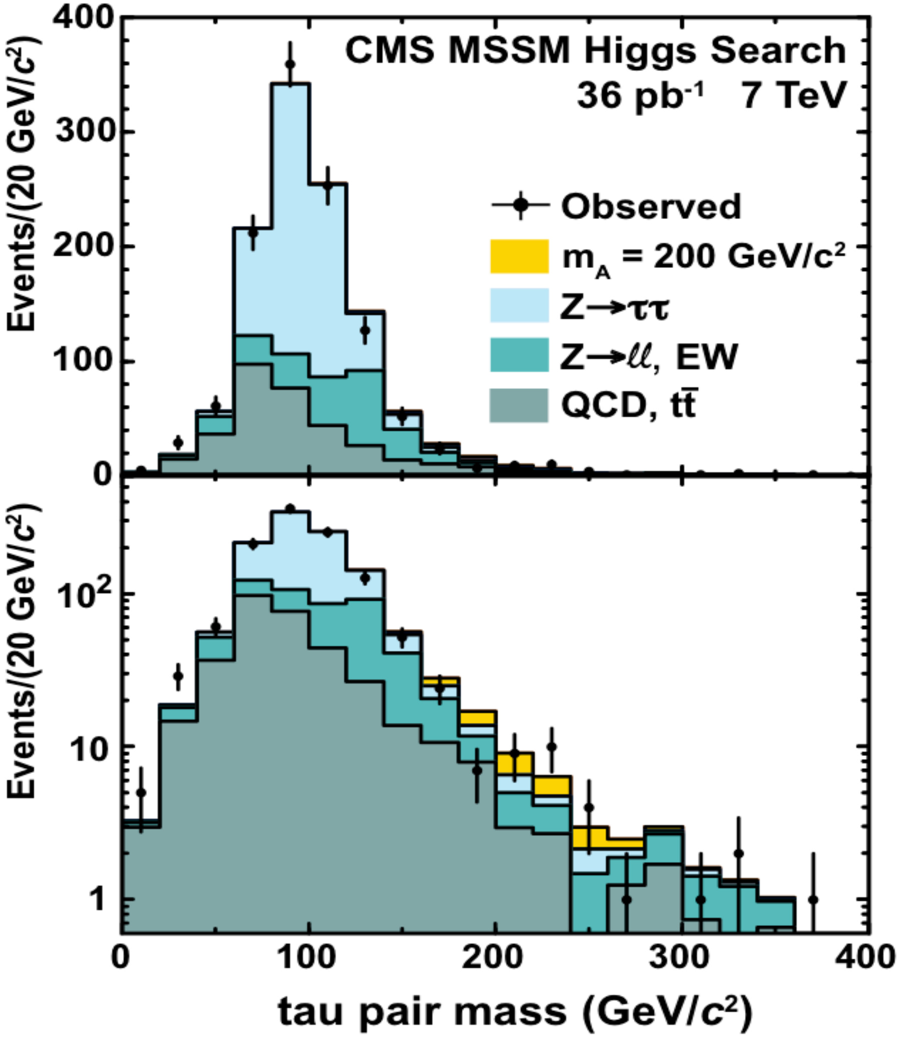
- Selection:
  - Electron/muon pT> 15 GeV
  - τ_h p_T>20 GeV
  - l-τ_h: $M_T=\sqrt{2p_T^l \cdot MET \cdot (1-\cos\Delta\phi)}$ < 40 GeV
  - e-μ: M_T < 50 GeV

Backgrounds from QCD multi-jets determined in two ways:

1. From ratio of SS to OS dilepton events
2. From tau fake rate studies in QCD multi-jet sample

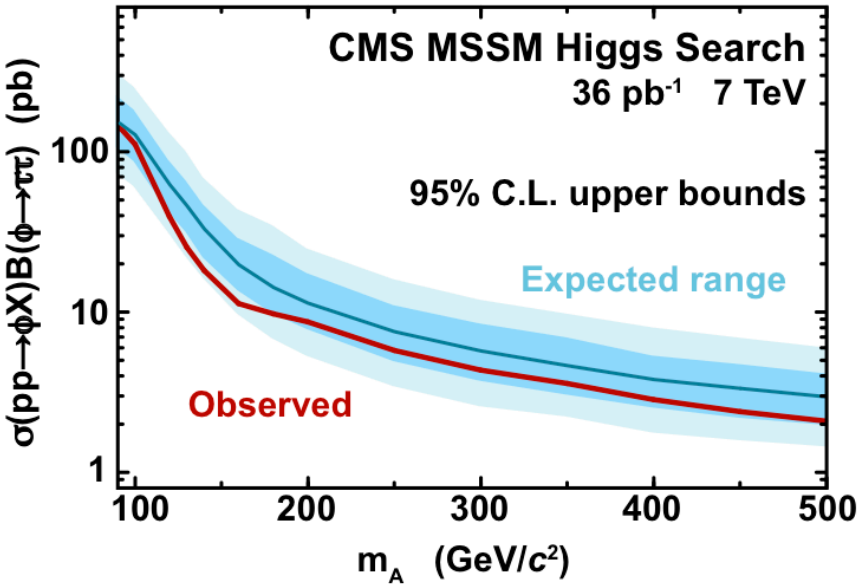
ττ pair mass reconstruction

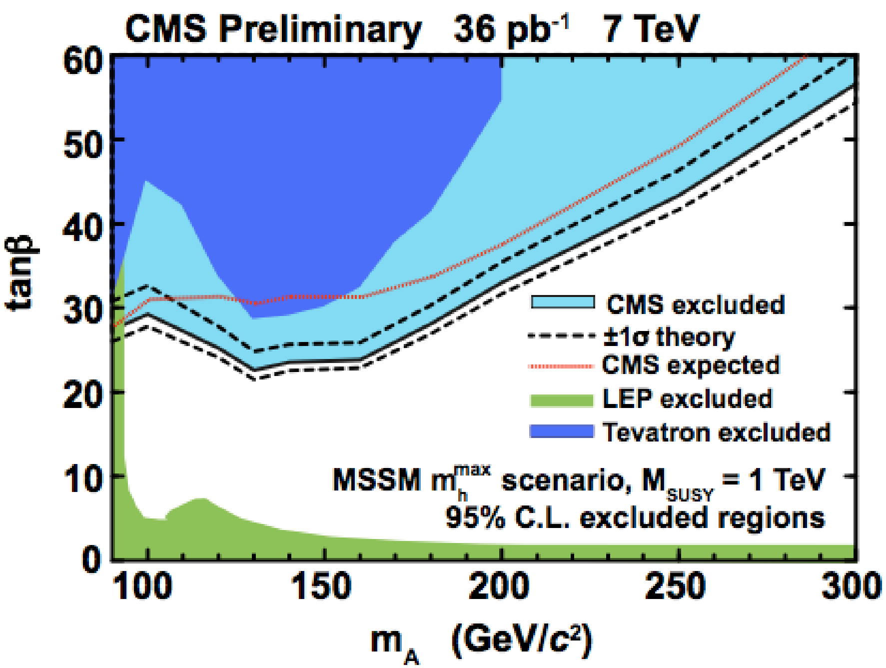
- Likelihood fit to τ momenta
- Use all available kinematic information and probability density for τ p_T spectra
- Improvement in resolution compared to visible mass



$\phi \rightarrow \tau\tau$ limits

Limit on σxBR for tanβ=30



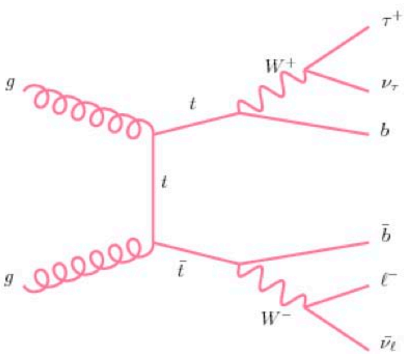


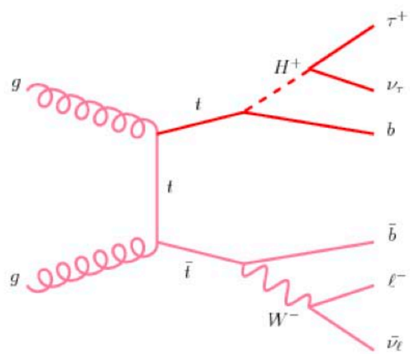
Excluded region in MSSM m_h^{max} scenario

Significantly extends previous limits

Charged Higgs search

- Charged MSSM Higgs bosons may contribute to ttbar decays





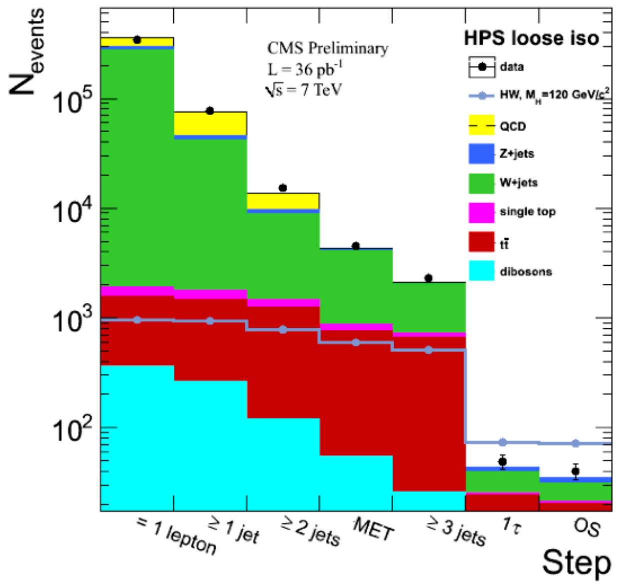
Substitute $H^\pm$ for $W^\pm$ in ttbar decays to τ

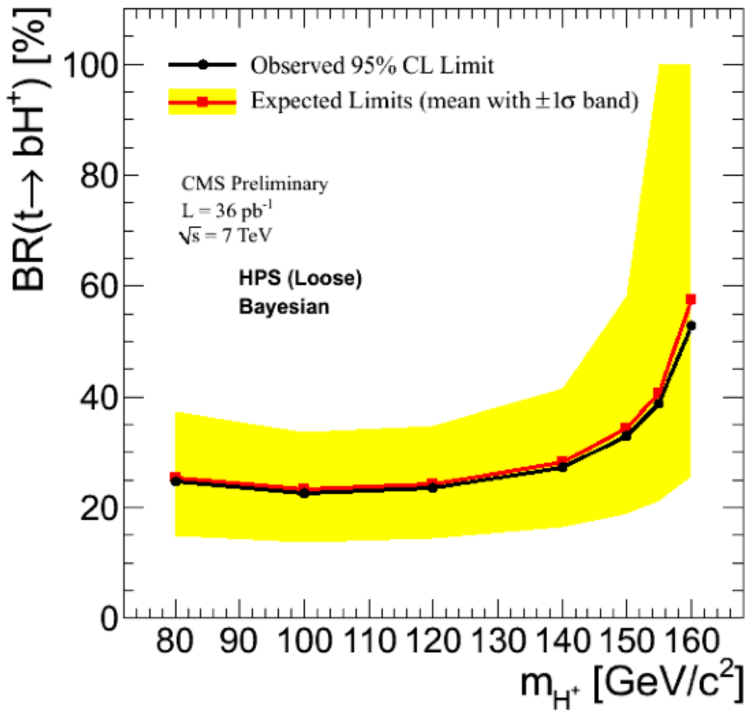
- Selection as for ttbar cross section measurement [CMS PAS-TOP-10-002]
  - One electron (muon) with $p_T > 30$ (20) GeV
  - At least two jets $E_T > 30$ GeV
  - MET > 40 GeV
  - Hadronic τ $p_T > 20$ GeV

CMS-HIG-11-002

- Backgrounds in two categories:
  - Fake hadronic τ: use fake rate method to estimate from data
  - Real hadronic τ: use simulation to estimate background

Charged Higgs





- 40 observed events
- 38±3±6 expected from SM
- No signal observed
  - Set 95% C.L on BR (t→bH$^+$) assuming BR(H$^+$→ $\tau^+ \nu$)=1
  - Limit ~0.25-0.30 for 80 GeV < m_H^+ < 140 GeV

Summary

- LHC and CMS are performing very well
- A lot of results on susy searches
- CMS is covering a lot of SUSY topologies
- Unfortunately no observations
- LHC extended the TeVatron limits for many models
- Exciting discoveries could happen in 2011/2012
- We are ready to make discoveries!

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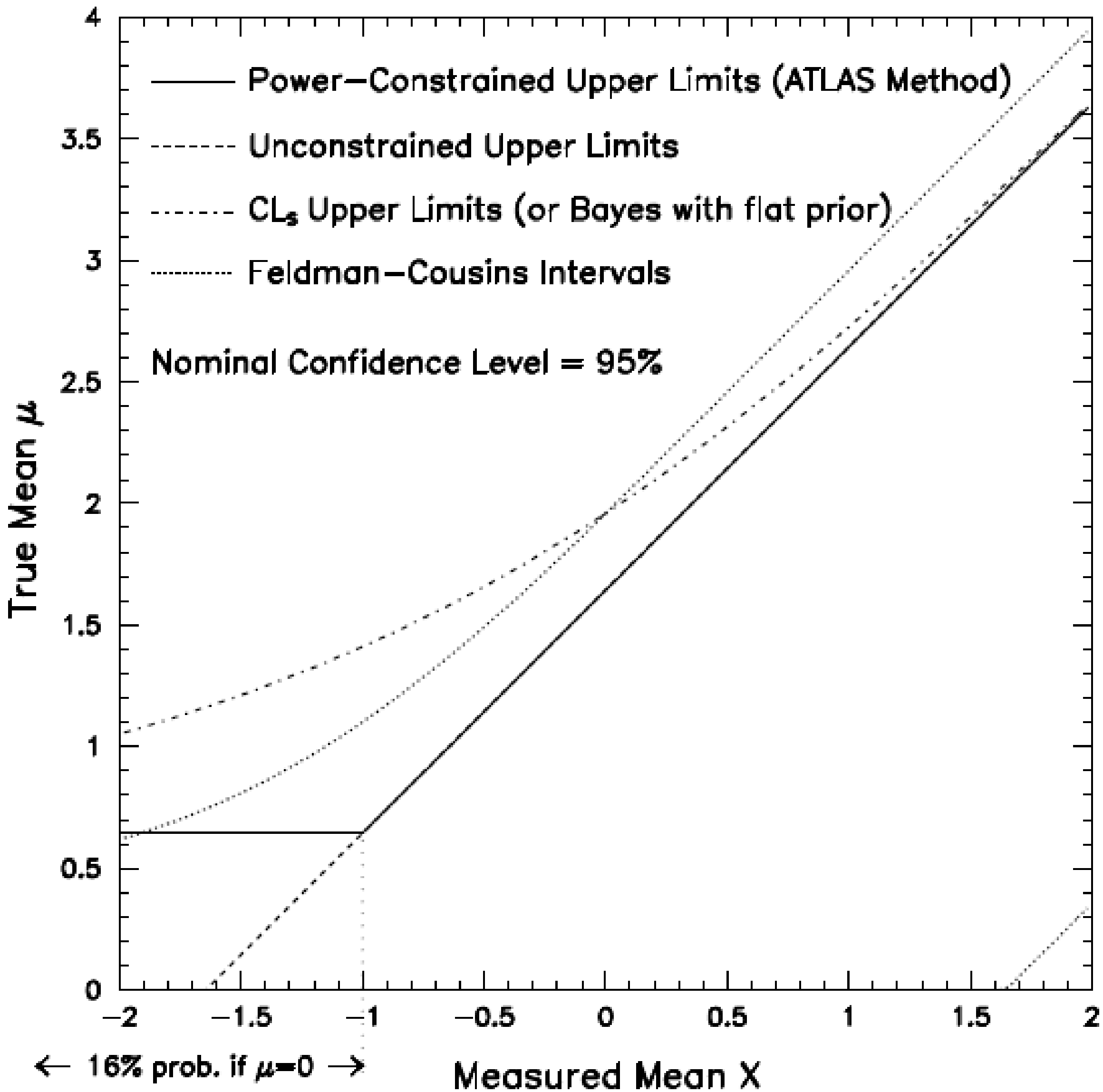
Back-up

Intervals and Limits for a Physically Bounded μ

- Prototype: measurement x is unbiased Gaussian estimate of μ. (Let ⌠=1.) What is 95% C.L. Upper Limit (UL)?
- 1986: Six methods for UL surveyed by V. Highland (VH) include U.L. = max(0, x + 1.64) and U.L. = max(0,x) + 1.64.
- RPP 1986: Bayesian: uniform prior on the mean μ for μ≥0, prior prob = 0 for ⌠<0. (VH's other five not mentioned.)
- 1994,96: 3 ad-hoc frequentist recipes, one using max(x,0).
- 1998: Feldman & Cousins (FC) "Unified Approach" in (Kendall and Stuart) replaces ad hoc frequentist
- 2002: CL_S from LEP added to Bayesian and FC.
- CMS Statistics Committee recommends using (at least) one of the three (red) methods in 2002-present PDG RPP.
- ATLAS SC method implies U.L. = max(0, x + 1.64) before power constraint (PC), U.L. = max(-1,x) + 1.64 after PC.

Comparison of ATLAS PCL with the three methods in PDG



(Atlas unconstrained U.L. is zero, not null, for x < -1.64)

ATLAS PCL re-opens discussion on use of diagonal line along with ad hoc constraint, out of favor for many years, not recommended by CMS SC.

CMS and ATLAS SC's are reviewing arguments and what has been learned in 25+ years. Academic statisticians have commented as well.

Just tip of iceberg: Poisson example brings in other issues. Nuisance parameters yet more. Choice of test statistic varies.

SUSY phenomenology

Breaking mechanism and R-parity determines **phenomenology** and the **search strategy**

Generic MSSM

MSUGRA/CMSSM

GMSB, GGM

AMSB

Split-SUSY

RPV-scenarios

....

In R-parity conserving scenarios, $\tilde{\chi}_1^0$(or $\tilde{\nu}$) is LSP.
Signatures:
Missing E_T + jets (+ leptons)

Exploit unbalanced momentum from LSP

Gravitino very light (<< MeV) → is the LSP. Neutralino can be NLSP:

$$\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$$

Signatures (R-parity cons.):
Missing E_T+2γ (+lepton/jets)

Depending on the mass spectrum if small $\tilde{\chi}^\pm - \tilde{\chi}_1^0$ mass difference, long-lived charginos expected
Signatures:
displaced vertex kinked tracks

If R-parity not conserved, search for resonances

Dedicated techniques

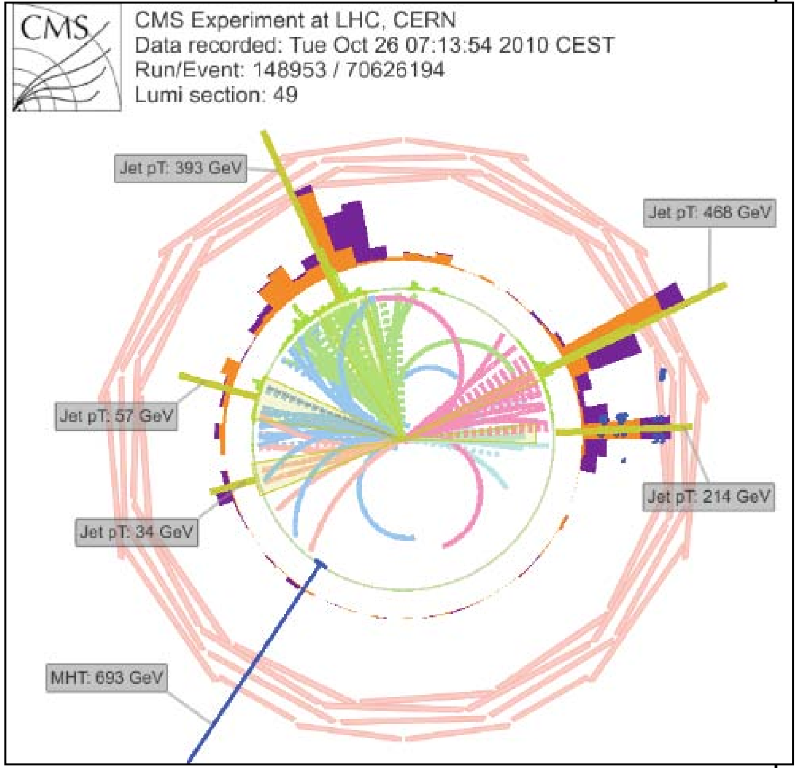
squarks/gluinos heavy
Typical signatures:
Long-Lived / quasi stable particles (R-hadrons)

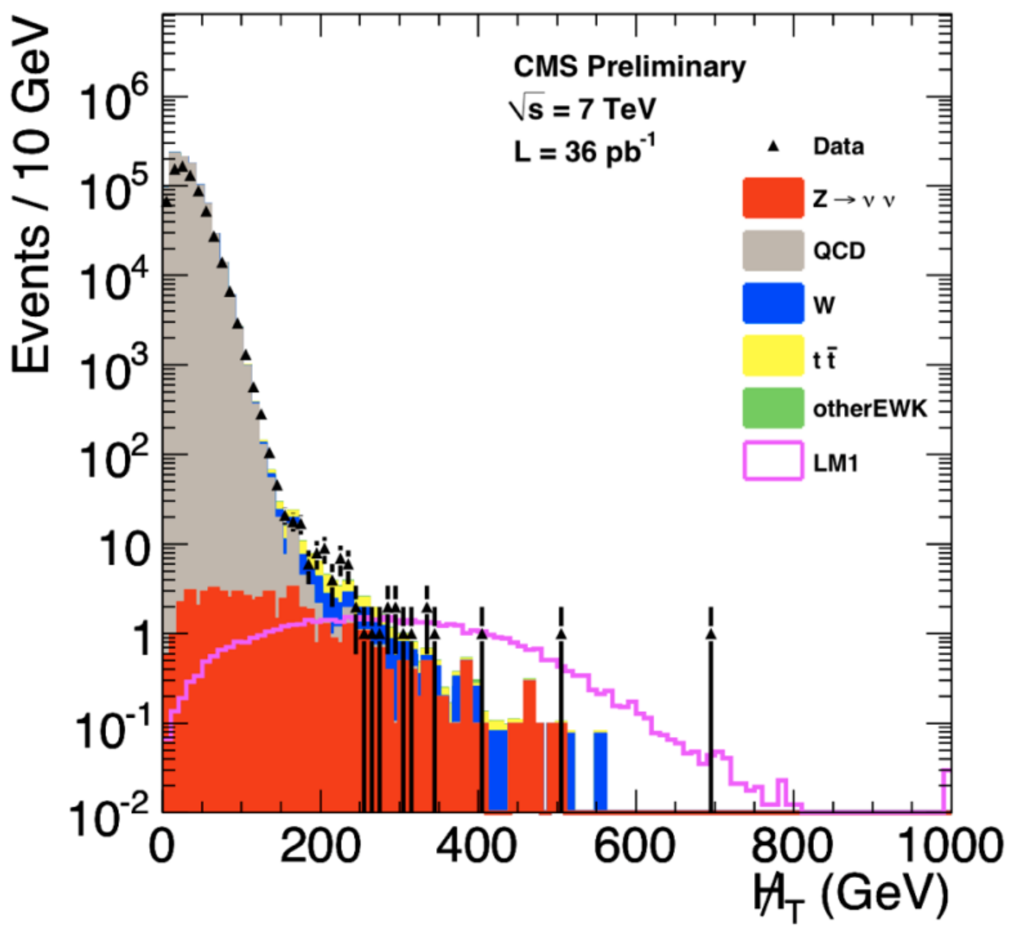
Hadronic search with missing energy

- $N_{jets50} > 2$
- $H_T > 300$ GeV
- MHT > 150 GeV
- No Leptons

15 observed events

CMS-SUS-10-005



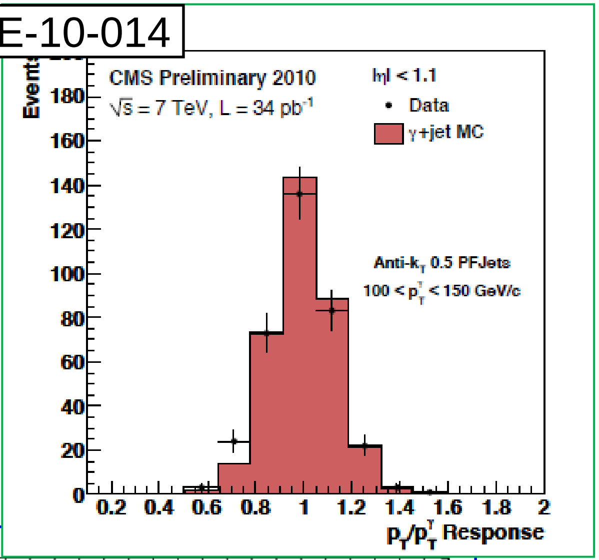


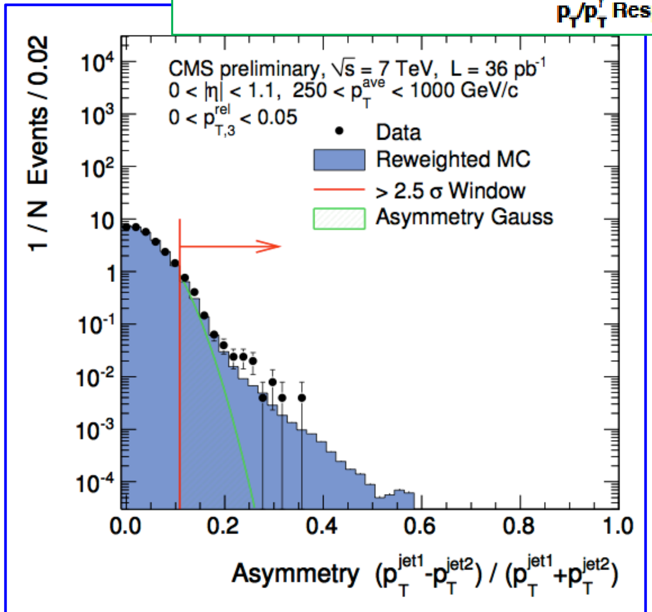
Multi-jet QCD background

- Jet energy response from data γ+jets (core) and di-jets (non-gaussian tails)
- Jet energy response is applied to a “seed jet sample” to predict the high MHT tails
- Seed jet sample obtained by rebalancing multi-jet sample
- EWK component negligible

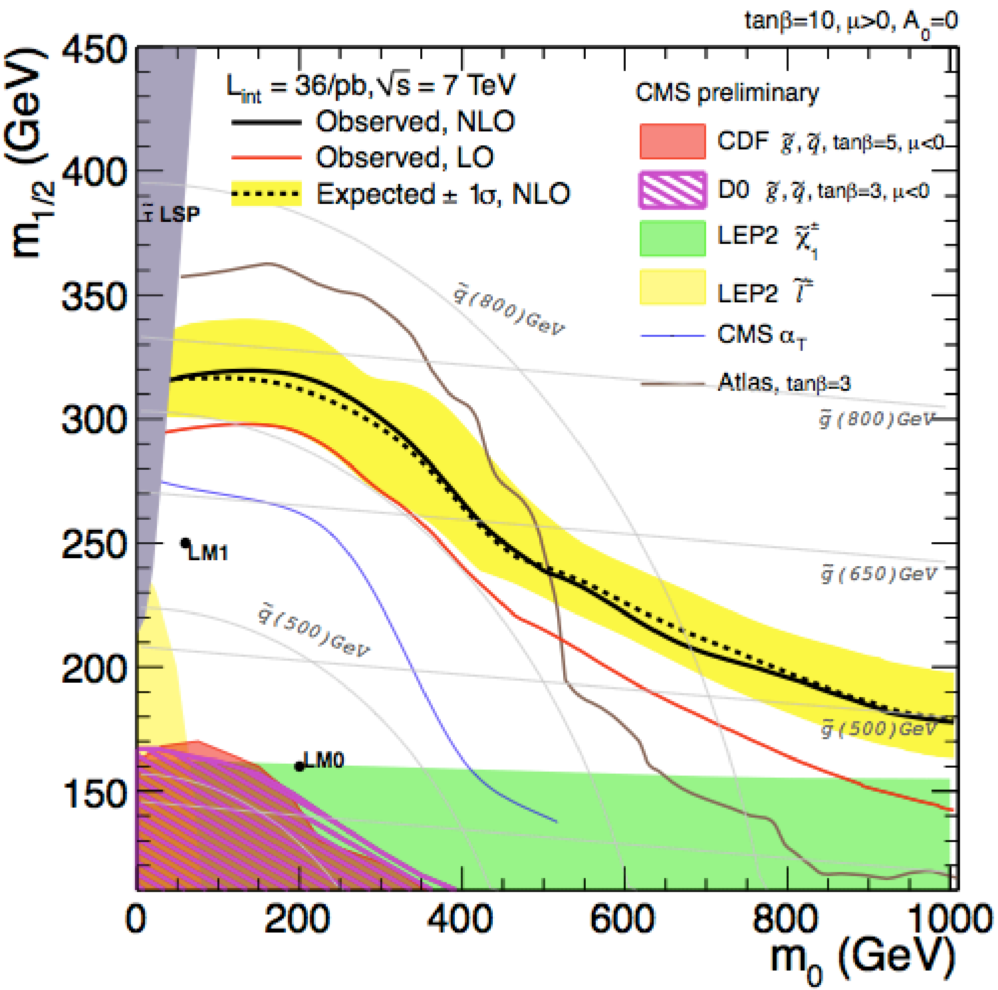
bkg estimate=19.0±3.6

CMS-JME-10-014





Hadronic search with missing energy



- Results expressed in terms of 95% C.L. in CMSSM
- Extends limit from α_T search and Tevatron

Hadronic search with "Razor"

- The "Razor" variables: M_R and R

arXiv:1006.2727

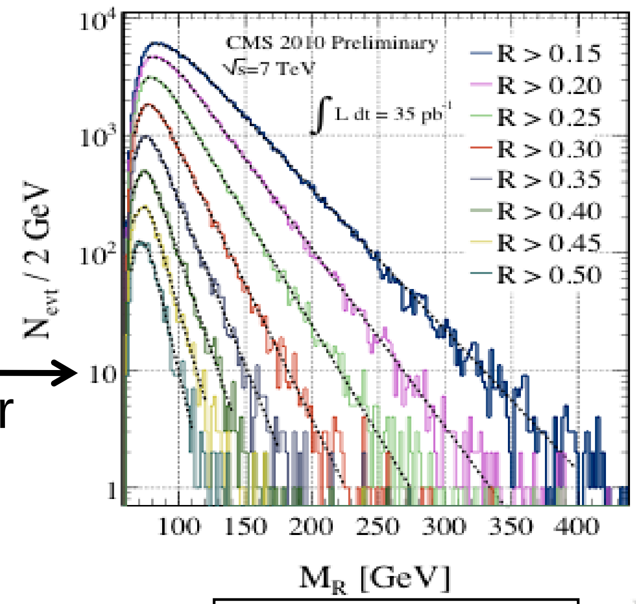
  - Designed to characterise pair-production of heavy particles
  - Combine all particles into two hemispheres and boost back to rest frame
  - M_R is a measure of the mass and peaks at the scale of the production

$$M_R = \frac{M_{\tilde{q}}^2 - M_{\chi}^2}{M_{\tilde{q}}}$$

  - M_R^T averaged transverse mass with endpoint M_R
  - R then the ratio M_R/M_R^T

- For non-signal events M_R distribution after R cut shows exponential scaling behaviour

QCD simulation



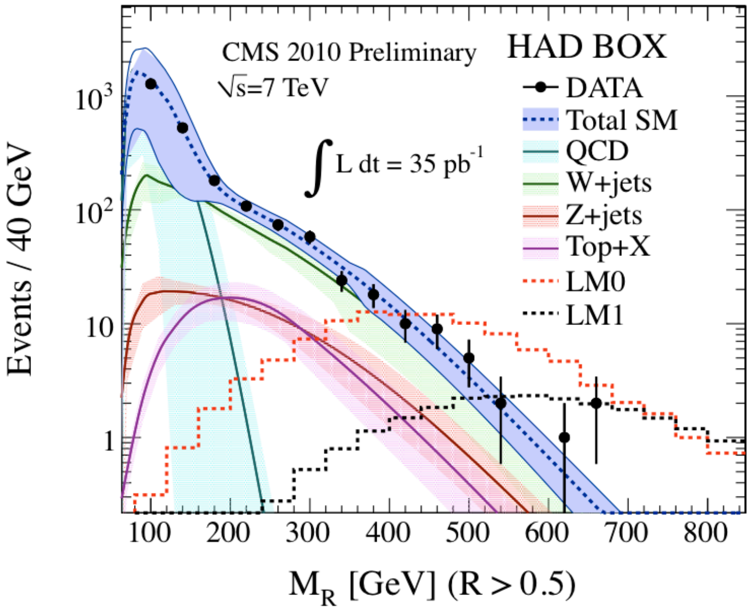
CMS-SUS-10-009

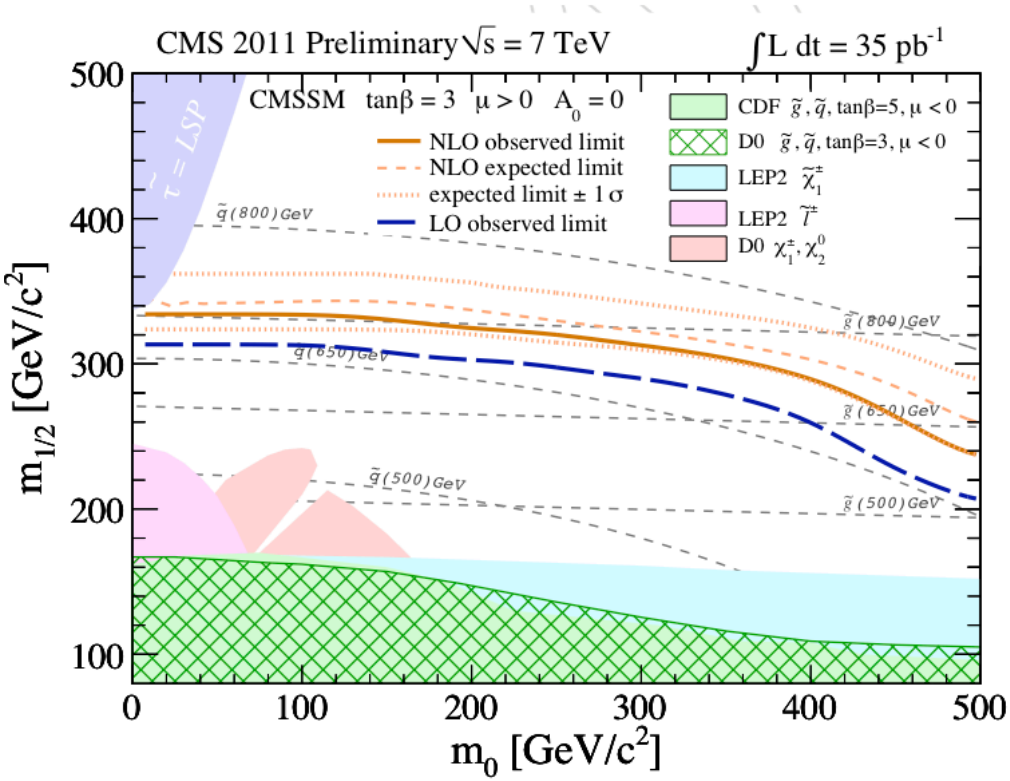
Hadronic search with "Razor"

- $N_{jets30} \geq 2$
- R>0.5
- M_R>500 Gev

7 observed events

Similar limits to jets+MHT analysis





Only low M_R regions used to determine backgrounds

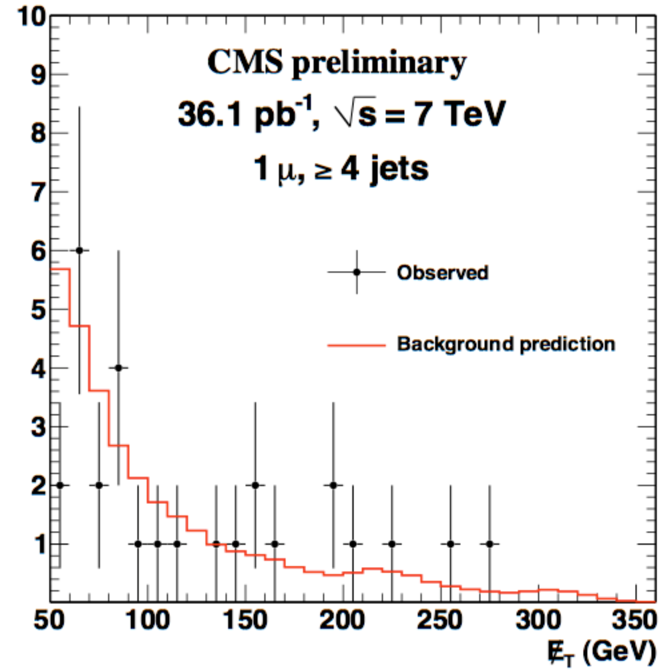
Bkg estimate=5.5 ± 1.4

Search in single lepton events

CMS-SUS-10-006

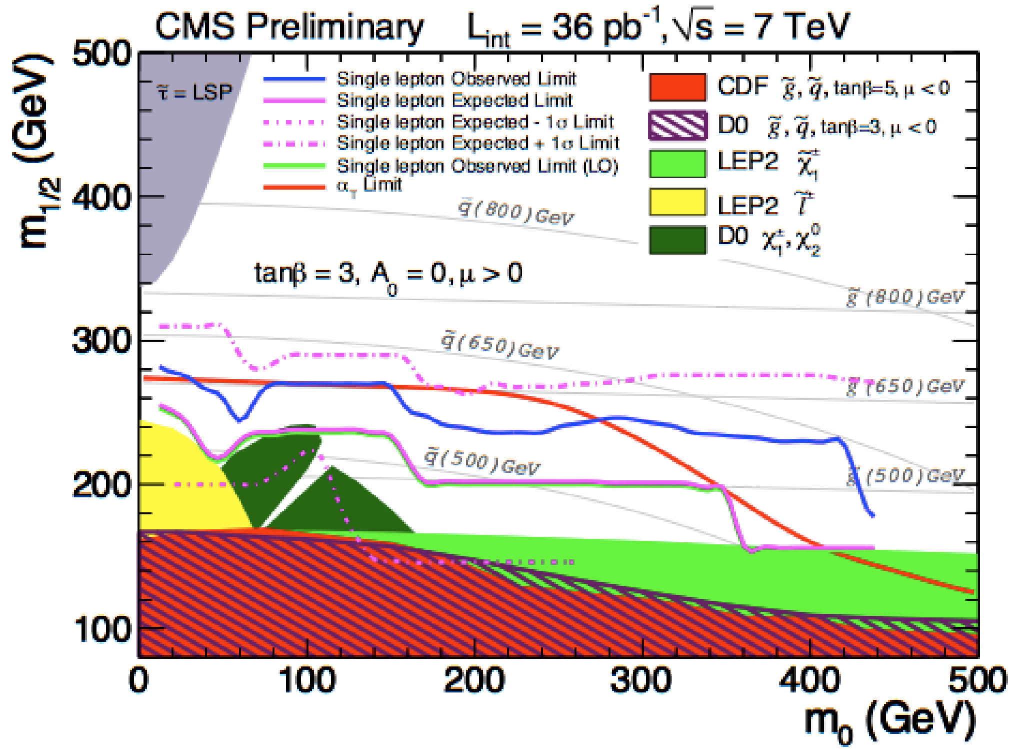
- $N_{jets20} \geq 4$
- 1 isolated electron or muon pt>20 GeV
- HT>500 GeV
- MET>250 GeV
- 2 observed events in μ+jets+MET
- 0 observed events in e+jets+MET

Main background sources are W+jets and tt events estimated directly from data. Exploit the fact that for W decays the charged lepton and neutrino p_T spectra are on average approximately the same



Results and interpretation

Sample	$\ell = \mu$	$\ell = e$
Predicted SM 1 ℓ	1.7 ± 1.4	1.2 ± 1.0
Predicted SM dilepton	$0.0^{+0.8}_{-0.0}$	$0.0^{+0.6}_{-0.0}$
Predicted single τ	0.29 ± 0.22	$0.32^{+0.38}_{-0.32}$
Predicted QCD background	0.09 ± 0.09	$0.0^{+0.16}_{-0.0}$
Total predicted SM	2.1 ± 1.5	1.5 ± 1.2
Observed signal region	2	0

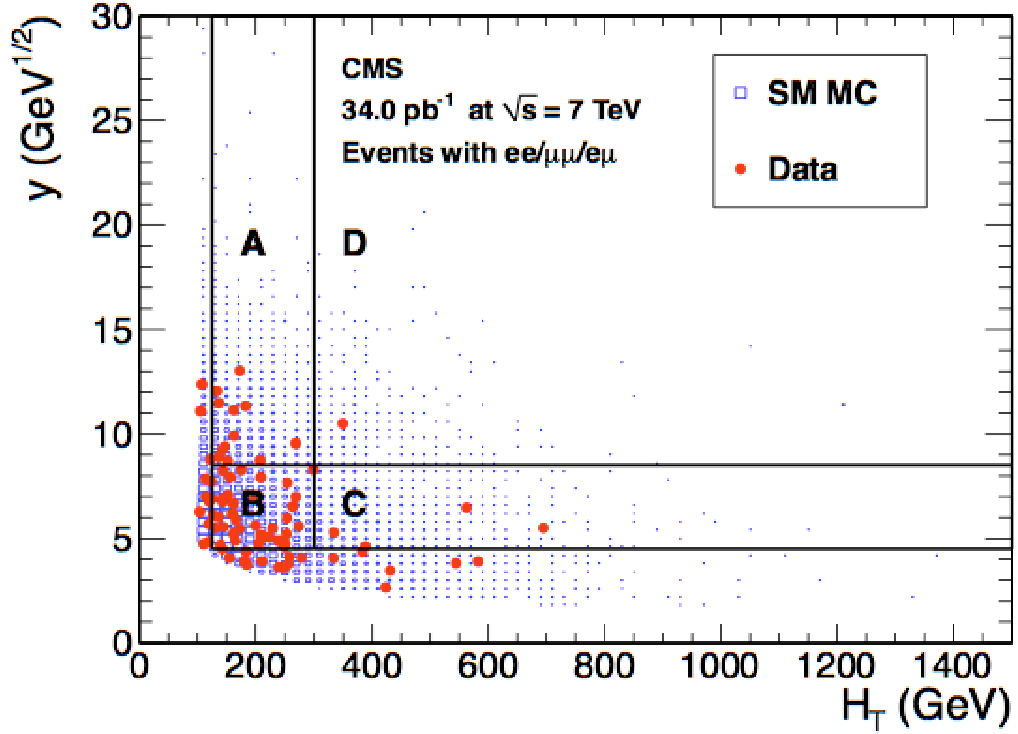


Limit similar to hadronic α_T search in CMSSM

Opposite-sign dilepton search

- Adding a second lepton rejects W+jets leaving mostly top background
- Two isolated leptons (e or μ); one with p_T>20 GeV, other with p_T>10 GeV
- Veto same-flavour pairs in Z mass window and m_{ll}<10 GeV
- N_{jets30} >2
- H_T > 300 GeV
- Y=MET/ √HT > 8.5 √GeV

arxiv:1103.1348



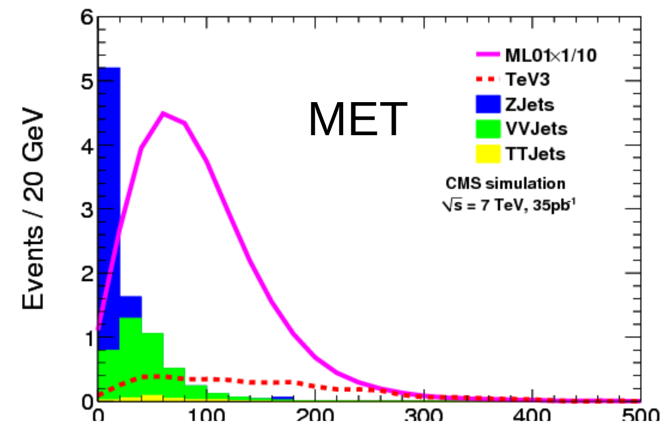
D signal region, ABC background regions
ABCD/matrix method
Background in D=A*C/B

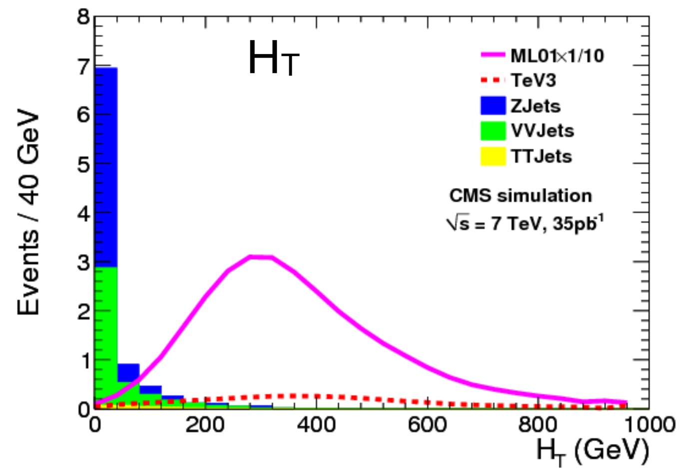
Multi-lepton search

CMS-SUS-10-008

- Baseline
  - At least three leptons (e,μ,τ) with p_T thresholds from 8 GeV
  - Require one non-τ lepton (trigger)

- Two final selections
  - MET > 50 GeV
  - H_T > 200 GeV
- Backgrounds:
  - WZ+Jets, ZZ+Jets, ttbar
    estimated from simulation
  - Z+Jets, WW+Jets, W+Jets, QCD
    estimated from data

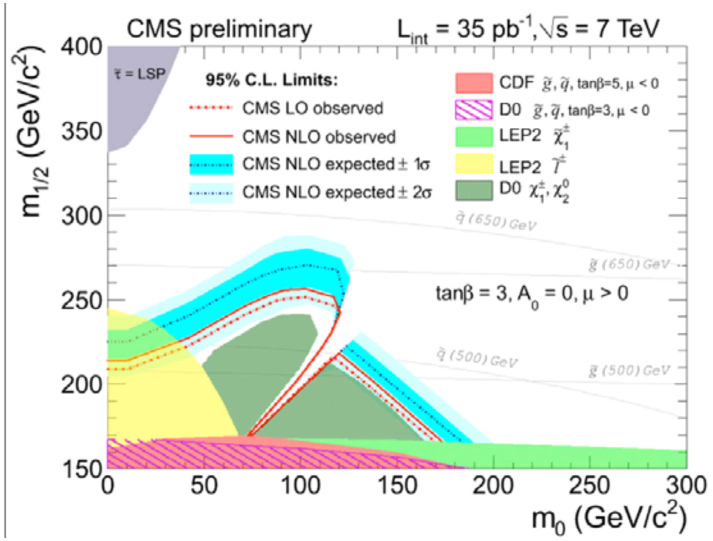


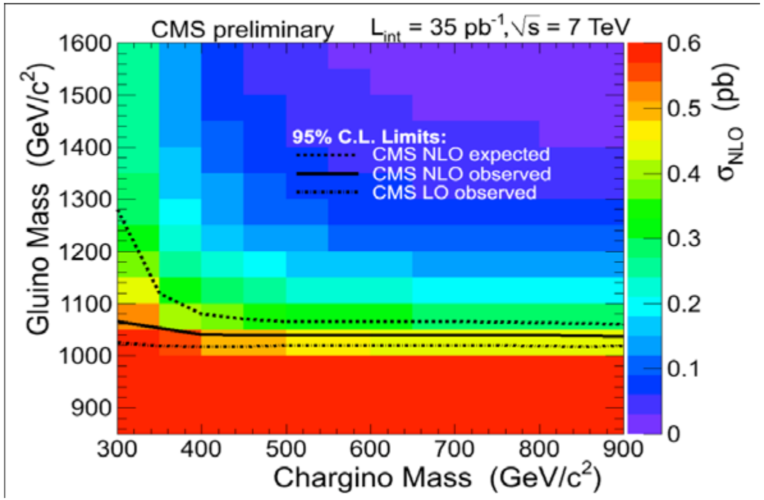


Multi-lepton search

- 55 exclusive channels combined statistically to give final result
- No excess observed

- Set limits in CMSSM for comparison with previous expts.
- Also consider more phenomenological interpretation in GGM model
- Multi-lepton signatures also arise naturally in co-NLSP model with mass degenerate sleptons decaying to leptons and Gravitino

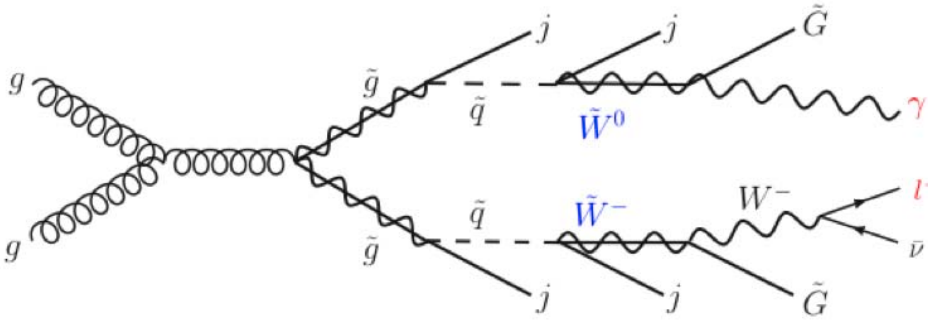




Lepton + photon search

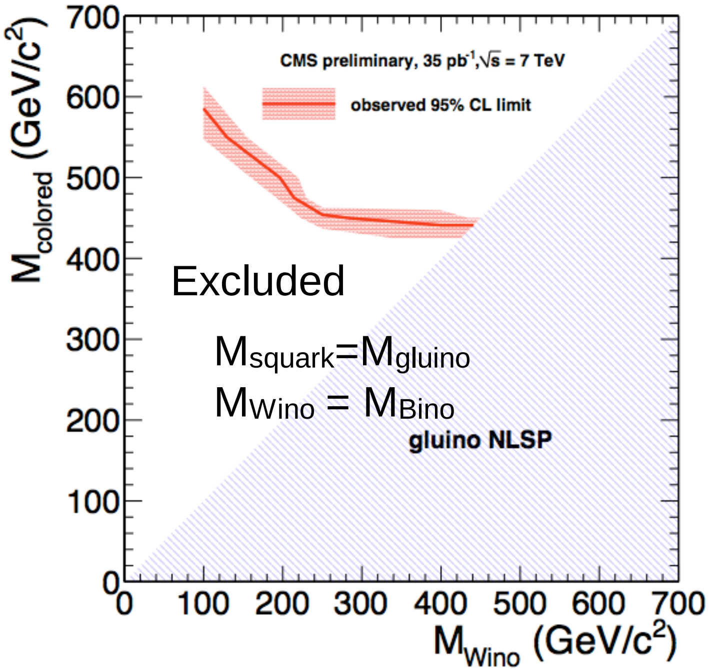
CMS-SUS-11-002

If wino and bino are mass degenerate NLSPs then di-photon signature replaced by lepton+photon signature.



- Isolated lepton (e or μ) with p_T
- Isolated photon with p_T>30 GeV
- MET>100 GeV
- Dominant background is Wγ
  - Cross section measured by CMS [CMS EWK-10-008]
  - Taken from simulation

	Observed	BKG estimate
γ+μ+MET	1	1.7±0.4
γ+e+MET	1	1.6±0.4



Doubly charged Higgs

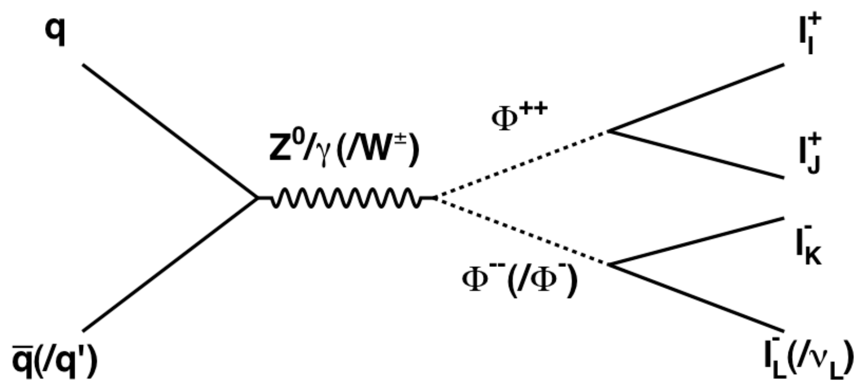
– Extend Standard Model adding scalar triplet: $\Phi^{\pm\pm}$, $\Phi^{\pm}$ and Φ^{0}

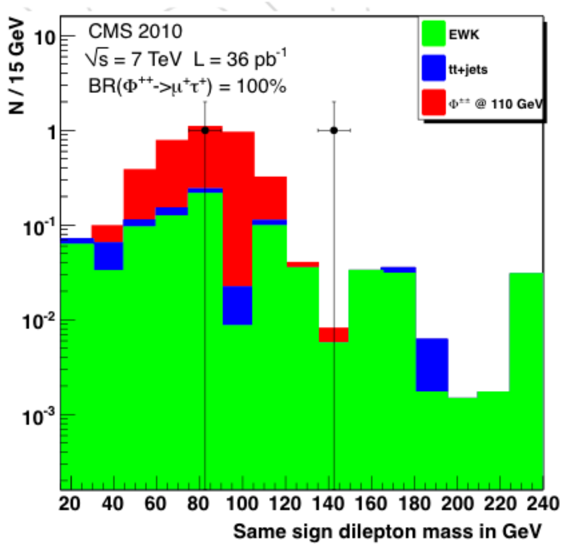
– Triplet responsible for neutrino masses

– Consider model where BR($\Phi^{\pm\pm} \rightarrow ll$)=100

– Final states with three or four isolated leptons (earlier multi-lepton search)

– Look for resonance peaks in dilepton mass distributions





CMS-HIG-11-001