Karlsruher Institut für Technologie

Bundesministerium für Bildung und Forschung

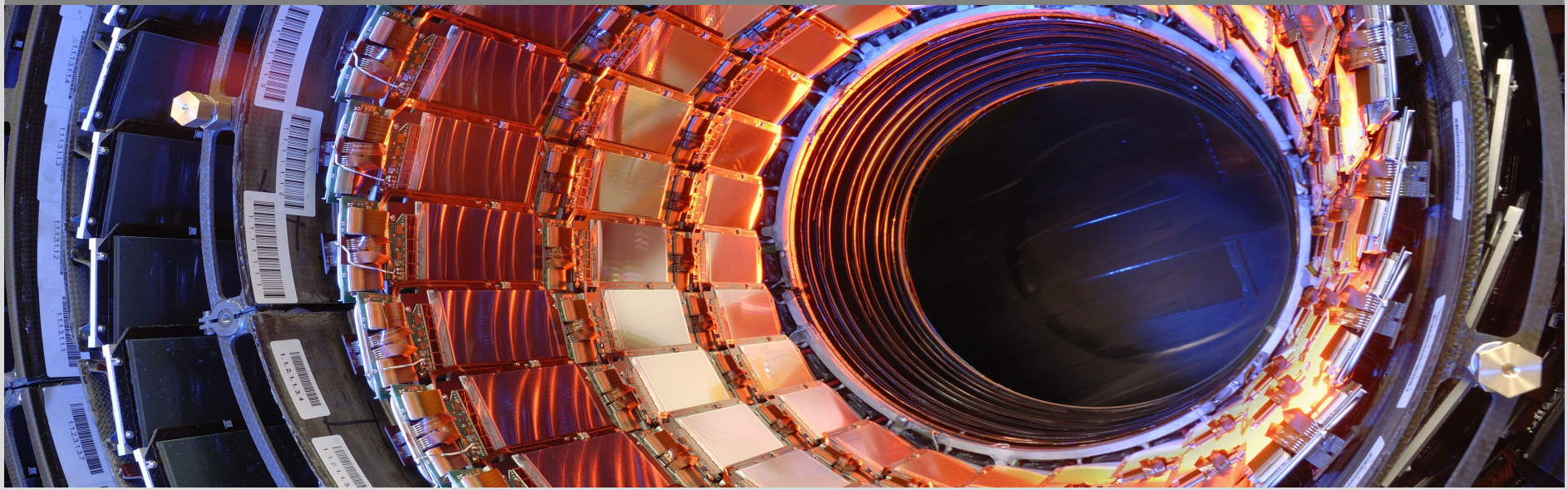
PHYSICS AT THE TERA SCALE Helmholtz Alliance

CMS Germany BMBF FSP-CMS

CMS Results of the Search for SUSY in Multilepton Finalstates

Martin Niegel on behalf of the CMS Collaboration

5th Annual Workshop of the Helmholtz Alliance “Physics at the Terascale”



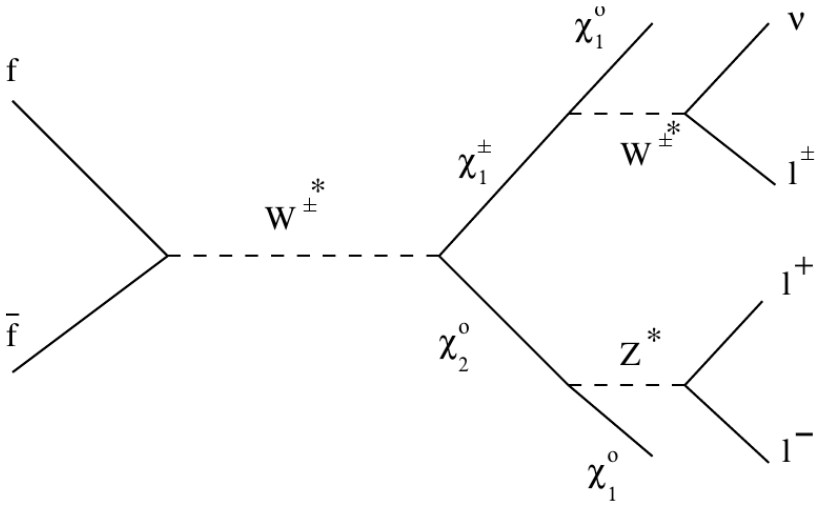
Outline

- SUSY Multilepton Production
- SM Backgrounds
- Search Strategy
- Background Prediction and Validation
- Results and Interpretation with 2.1fb-1
- Conclusion & Outlook

SUSY Multilepton Production

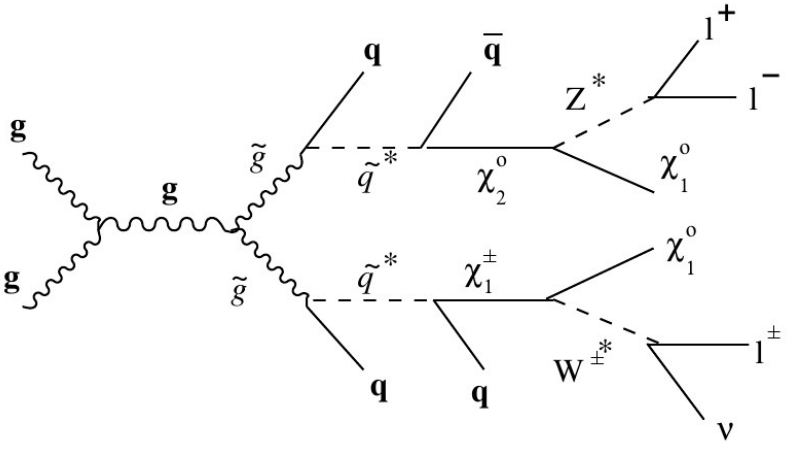
- Isolated leptons in SUSY mostly from Neutralino/Chargino decays
  - depending on mass scale: decay either via slepton or on/offshell boson
- Multileptons ($N_\ell \geq 3$) mostly from pairs of Neutralino/Charginos
- Neutralino/Chargino pairs either by direct elektroweak production or in SUSY decays

Direct electroweak production



MET and low hadronic activity

Cascade decays of squarks and gluinos



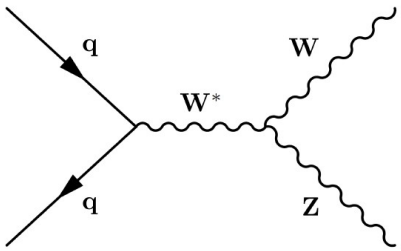
High hadronic activity and MET

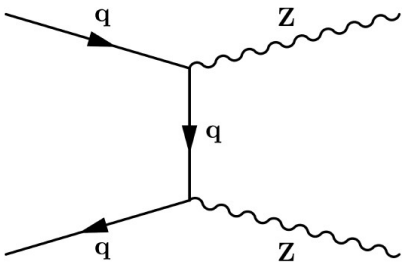
SM Backgrounds

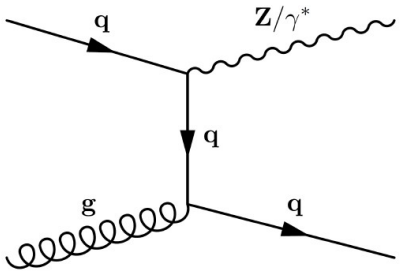
Two type of SM Backgrounds:

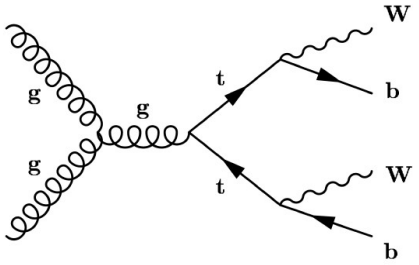
- **Direct production of dibosons (irreducible)**
  - ZZ → 4 leptons: no intrinsic MET, low hadronic activity
  - ZW → 3 leptons + neutrino: MET, low hadronic activity

- **Two leptons from bosons + fake leptons**
  - DY → ℓℓ + fake lepton: no intrinsic MET, low hadronic activity
  - ttbar → WWbb → ℓν ℓν bb + fake lepton: MET, high hadronic activity
  - WW → ℓνℓν + fake lepton: MET, low hadronic activity





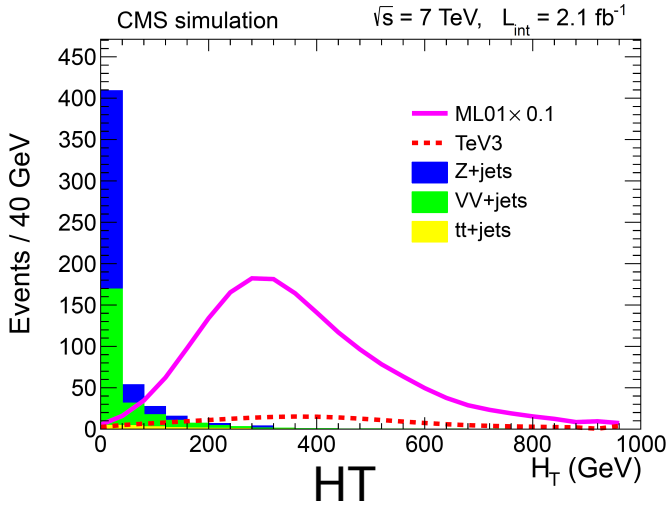




Search Strategy

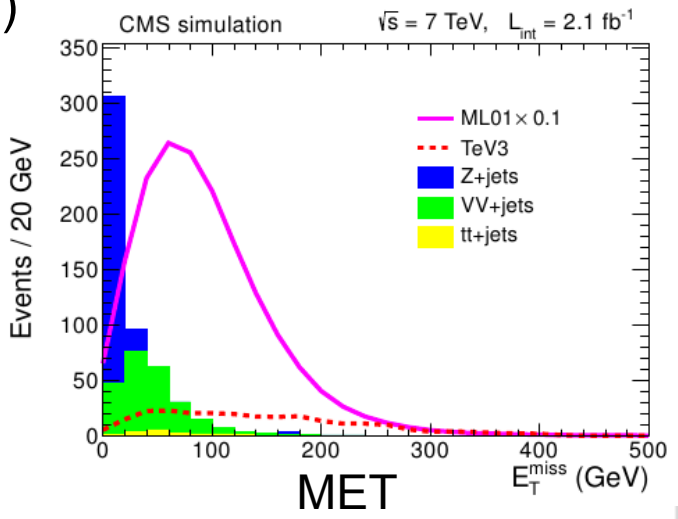
Event Selection:

- **Include 3 and more leptons (up to 2 τ's)**
- **Select single & dilepton triggers**
- **Cut events with J/Ψ,Upsilon**: $M(\ell^+\ell^-) > 12\text{GeV}$
- **Reject Z(ℓℓ + FSR)**: $M(\ell\ell\ell) \neq M(Z)$



Signal Selection:

- **Use MET, HT (Σ_{jet} ET), Z-Veto ($M(\ell^+\ell^-) \neq$ 75-105 GeV)** for opposite sign opposite flavour leptons (OSSF)
- **Be sensitive to different SUSY scenarios**
- **Split phase space in 52 different channels**
  - Number/Charge of leptons
  - Number of Taus
  - MET >/< 50 GeV
  - HT >/< 200 GeV
  - OSSF Z/noZ



Lepton Selection

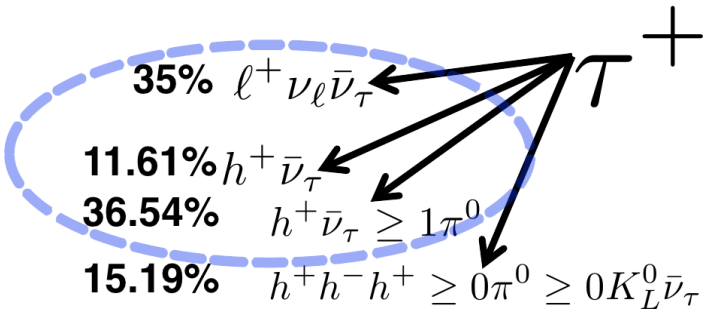
Electrons and Muons: (P_T>8 GeV in $|\eta|$ <2.1)

- Reject fakes from long-lived mesons by transverse distance to beamspot
  - Require $|d_{xy}| < 0.02$ cm
- Reject fakes from jets by relative (<0.15) and total isolation (<10GeV)
  - Isolation for e(μ) measured in tracker + calo in cone 0.4 (0.3)
- Additional requirements from trigger tresholds:

Lepton\Trigger Type	μ	e	μμ	ee	e μ
Leading e/μ	> 20	> 70	>15	>20	>20
Next-to-leading e/μ	NA	NA	>10	>10	>10

Taus: ($|\eta|$ <2.1)

- Use single prong decays
  - $h^+ + \nu$: isolated track, P_T > 8 GeV
  - $h^+ + \nu + \pi^0$'s: isolated track, P_T > 15 GeV
    - allow for electromagnetic energy in dR<0.1



SM Background Prediction: Strategy

MC Prediction for diboson and ttbar:

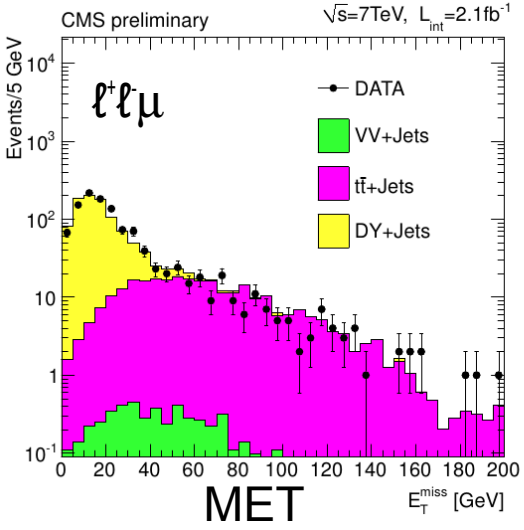
- Corrected with measured lepton selection efficiency
- **MC prediction validated in control measurements**
  - WZ: trilepton events with M($\ell^+\ell$) = M(Z) and MET
  - ttbar: Isolation sidebands of third non-isolated leptons in leptonic ttbar sample
  - ttbar: Isolation distribution of non-prompt leptons in semi-leptonic ttbar sample

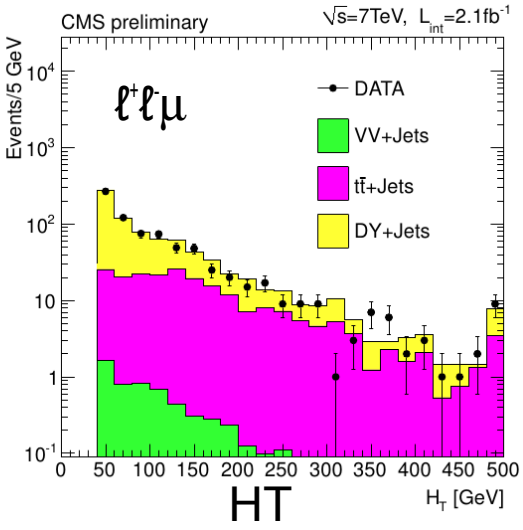
Data Driven background prediction:

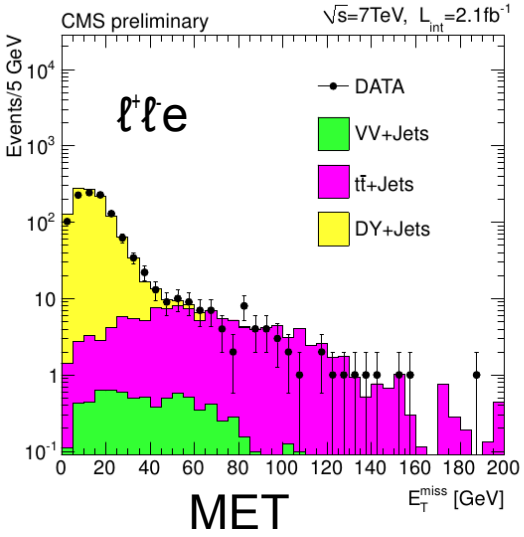
- **DY + Fake leptons from jets (counts also for WW+jets)**
  - Electrons, Muons: estimated from isolated tracks in dilepton data
  - Taus: estimated from isolation sidebands in dilepton data
  - Estimation validated in control measurements
- **Dilepton + Fake leptons from asymmetric photon conversion**
  - $\ell\ell + \gamma$, $\gamma \rightarrow \ell\ell$, one ℓ fails cut
  - Estimated from dilepton + isolated photon data

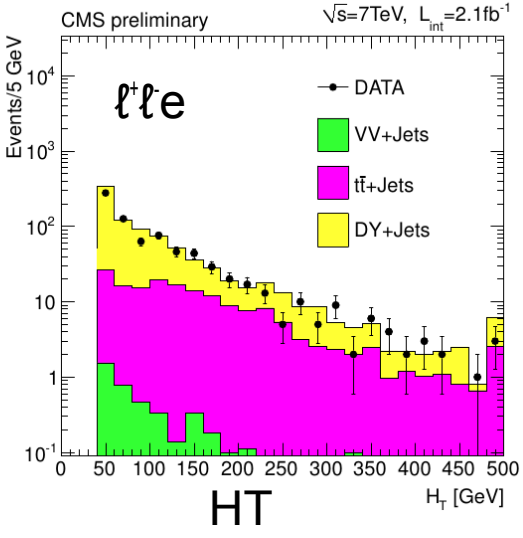
SM Background Prediction: Example

- **Control Measurements for DY and ttbar** (more methods shown in b'up)
- **Validate MC in isolation sidebands of third lepton**
- **Selection:**
  - 2 isolated leptons
  - 1 non-isolated lepton
- **Good agreement observed between data and MC**









Multilepton Search Results: 52 channels

4 leptons (e,μ)
+ MET>50GeV
+ HT<200GeV
+ Z-Veto

3 leptons (e,μ)
+ MET>50GeV
+ HT>200GeV
+ Z-Veto

3 leptons (e,μ)
+ MET>50GeV
+ HT<200GeV
+ Z-Veto

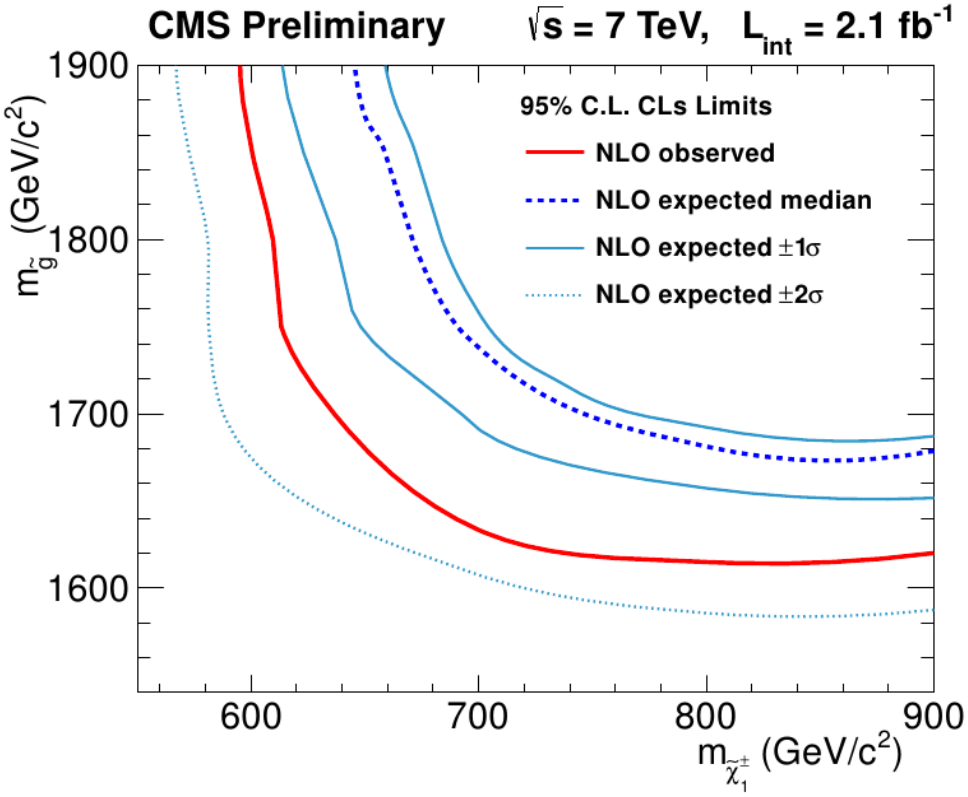
Selection	N(τ)=0 obs	N(τ)=0 expected SM	N(τ)=1 obs	N(τ)=1 expected SM	N(τ)=2 obs	N(τ)=2 expected SM
≥FOUR Lepton Results						
MET>50,H_T >200,noZ	0	0.003 ± 0.002	0	0.01 ± 0.05	0	0.30 ± 0.22
MET>50,H_T >200, Z	0	0.06 ± 0.04	0	0.13 ± 0.10	0	0.15 ± 0.23
MET>50,H_T <200,noZ	1	0.014 ± 0.005	0	0.22 ± 0.10	0	0.59 ± 0.25
MET>50,H_T <200, Z	0	0.43 ± 0.15	2	0.91 ± 0.28	0	0.34 ± 0.15
MET<50,H_T >200,noZ	0	0.0013 ± 0.0008	0	0.01 ± 0.05	0	0.18 ± 0.07
MET<50,H_T >200, Z	1	0.28 ± 0.11	0	0.13 ± 0.10	0	0.52 ± 0.19
MET<50,H_T <200,noZ	0	0.08 ± 0.03	4	0.73 ± 0.20	6	6.9 ± 3.8
MET<50,H_T <200, Z	11	9.5 ± 3.8	14	5.7 ± 1.4	39	21 ± 11
THREE Lepton Results						
MET>50,H_T >200,no-OSSF	2	0.87 ± 0.33	21	14.3 ± 4.8	12	10.4 ± 2.2
MET>50,H_T <200,no-OSSF	4	3.7 ± 1.2	88	68 ± 17	76	100 ± 17
MET<50,H_T >200,no-OSSF	1	0.50 ± 0.33	12	7.7 ± 2.3	22	24.7 ± 4.0
MET<50,H_T <200,no-OSSF	7	5.0 ± 1.7	245	208 ± 39	976	1157 ± 323
MET>50,H_T >200,noZ	5	1.9 ± 0.5	7	10.8 ± 3.3	–	–
MET>50,H_T >200, Z	8	8.1 ± 2.7	10	11.2 ± 2.5	–	–
MET>50,H_T <200,noZ	19	11.6 ± 3.2	64	52 ± 13	–	–
MET<50,H_T >200,noZ	5	2.0 ± 0.7	24	26.6 ± 3.3	–	–
MET>50,H_T <200, Z	58	57 ± 21	47	44.1 ± 7.0	–	–
MET<50,H_T >200, Z	6	8.2 ± 2.0	90	119 ± 14	–	–
MET<50,H_T <200,noZ	86	82 ± 21	2566	1965 ± 438	–	–
MET<50,H_T <200, Z	335	359 ± 89	9720	7740 ± 1698	–	–
Totals 4L	13.0	10.4 ± 3.8	20.0	7.8 ± 1.5	45	30 ± 12
Totals 3L	536	539 ± 94	12894	10267 ± 1754	1086	1291 ± 324

- Good agreement in channels with large SM background
- Some interesting channels are highlighted
- **Observation is largely consistent with SM expectation**
- **Results are used to calculate limits in CMSSM and GMSM scenarios**

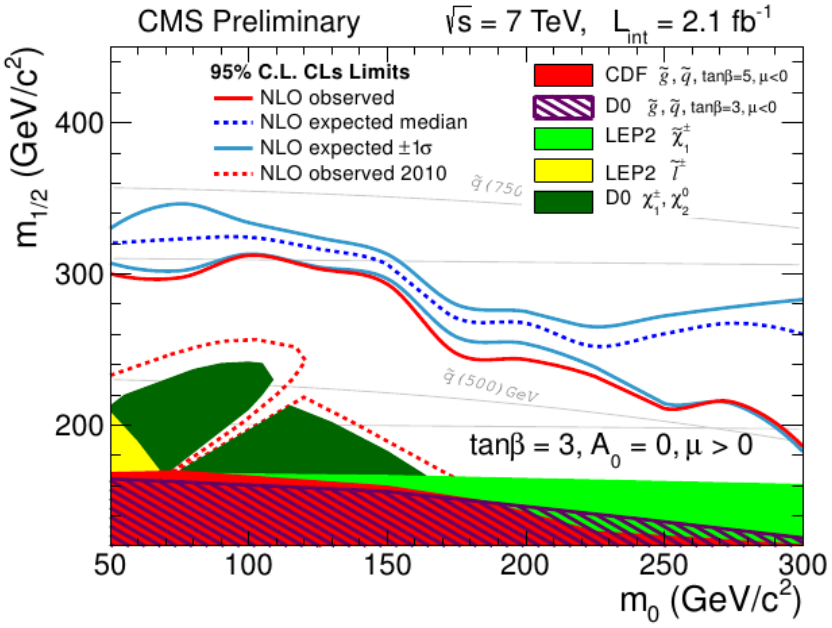
Limits in the GMSM scenario

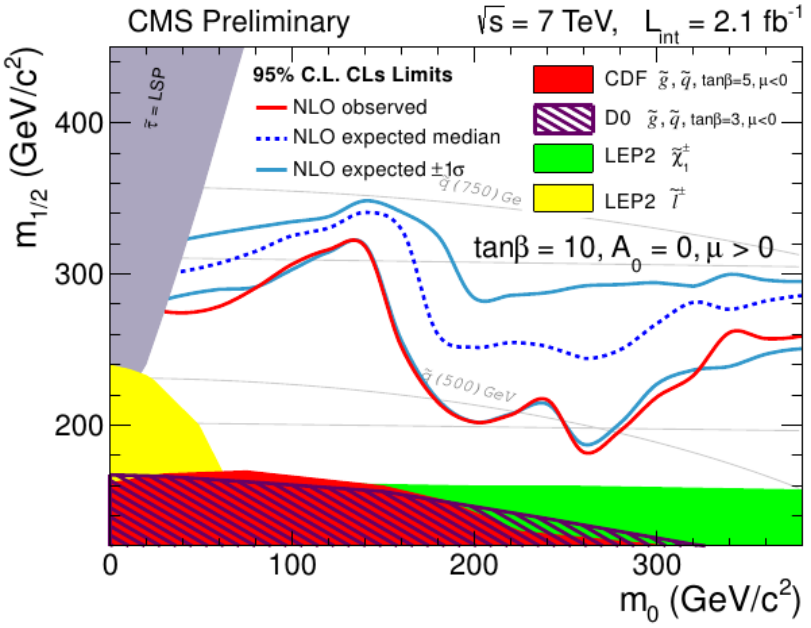
Gauge Mediated Model:

- Gravition G = LSP
- slepton co-NLSP scenario
  - $\tilde{\ell} \rightarrow \ell$+G
- Lightest Neutralino decays via sleptons to 2 leptons + G
  - $N \rightarrow \tilde{\ell}^{+}\ell^{-} \rightarrow \ell^{+}\ell^{-}$ +G
- Pair production of lightest Neutralinos lead to 4 lepton final states + MET
- Multilepton search is most sensitive to such models



Limits in the CMSSM scenario





- CMSSM scenario with A=0 and mu > 0
- Limits shown for tanβ = 3 (left) and tanβ = 10 (right)

Conclusion & Outlook

- Search for SUSY in multilepton final states using 2.1fb-1
- A variety of multilepton channels investigated
- Good agreement in channels with large SM background
- Results of multilepton search largely consistent with SM
- New parameter space in the CMSSM and GMSM excluded
- Summarized in **CMS PAS SUS-11-013**

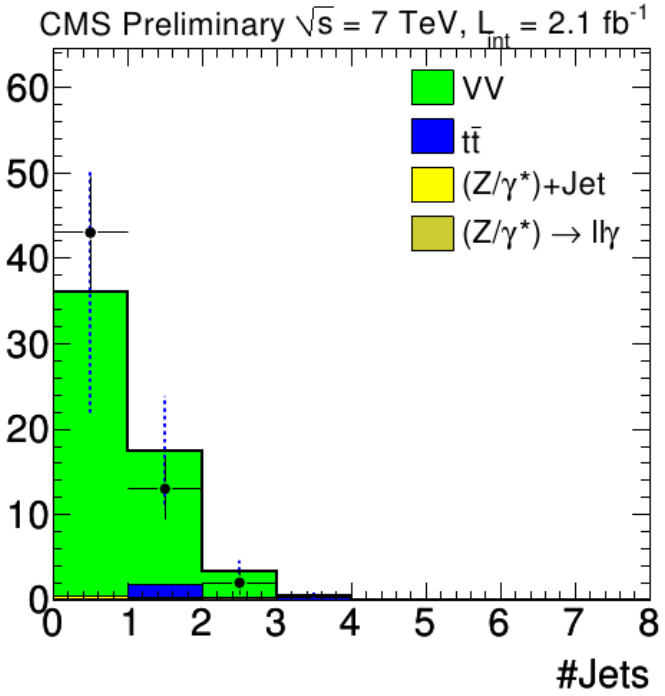
- New data (~4.7fb-1) currently being analyzed
- Results will be published soon

Backup

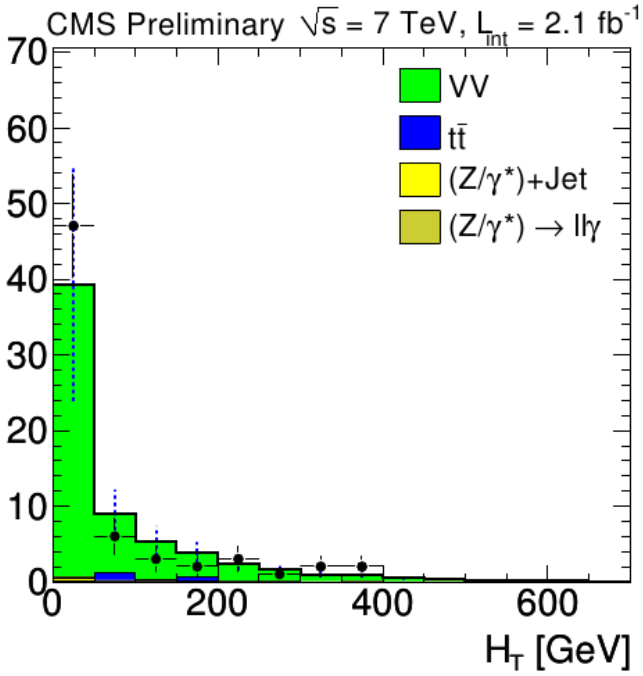
Validation of WZ MC Prediction

- Selection: 3ℓ, OSSF lepton pair with M($\ell^+\ell^-$) = M(Z) and MET>50GeV

Number of jets in WZ control sample



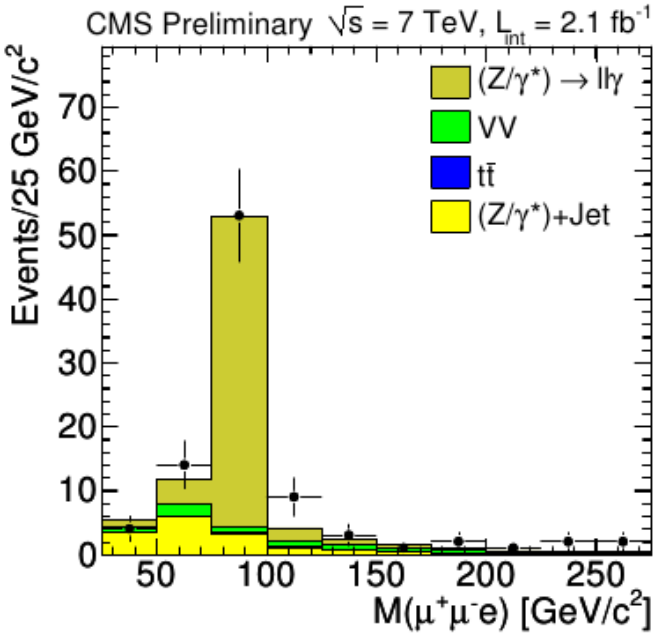
HT distribution of WZ control sample

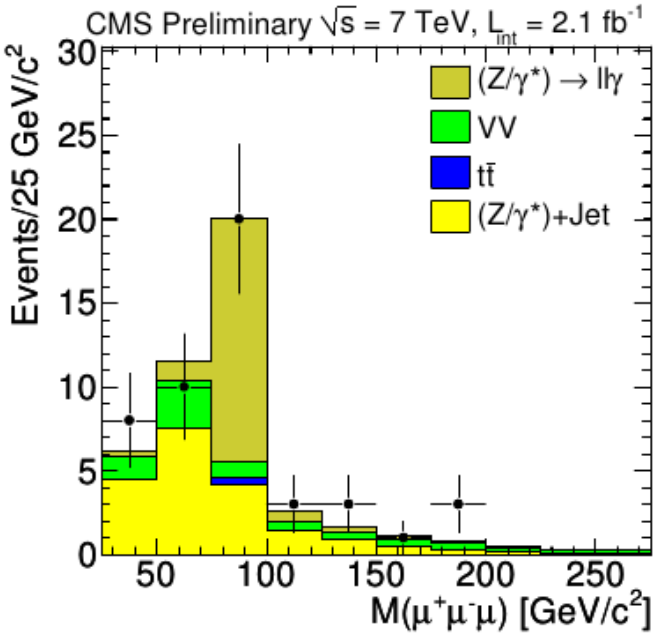


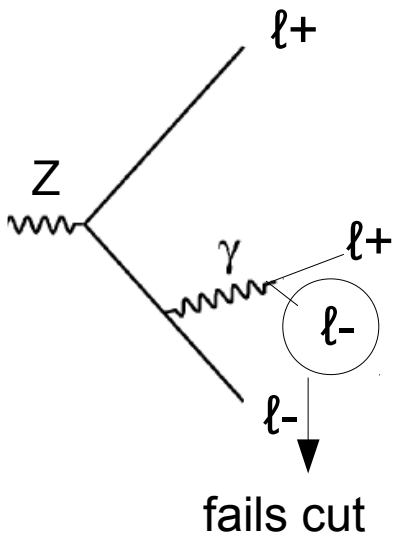
Data well described by MC within systematic uncertainties (blue dotted lines)

Leptons from Asymmetric Photon Conversion

- **External:** real photon with conversion in detector material ($\gamma \rightarrow e^+e^-$)
  - Selected by: $\ell^+\ell^-e$ with $M(\ell^+\ell^-) \neq M(Z)$ and $M(\ell^+\ell^-e) = M(Z)$
- **Internal:** virtual photon with conversion at matrix element ($\gamma \rightarrow \ell^+\ell^-$)
  - Selected by: $\ell^+\ell\mu$ with $M(\ell^+\ell^-) \neq M(Z)$ and $M(\ell^+\ell\mu) = M(Z)$
- **Data driven estimation:** measure conversion probability in data using $M(\ell\ell\ell)=M(Z)$ & $M(\ell\ell\gamma)=M(Z)$ events and apply factor to $\ell\ell\gamma$ data sample







Semi-Leptonic ttbar control sample

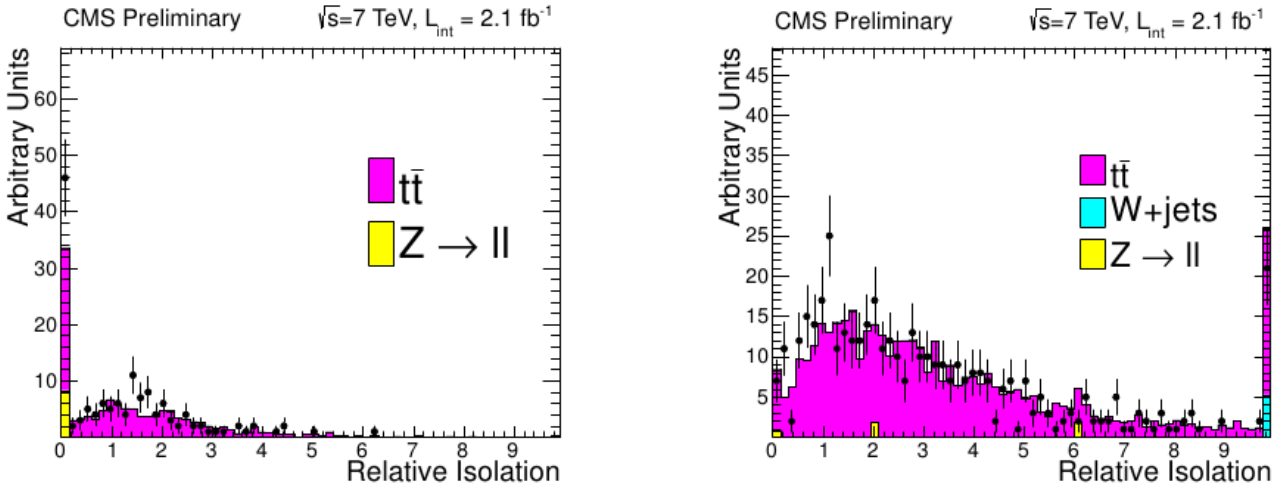
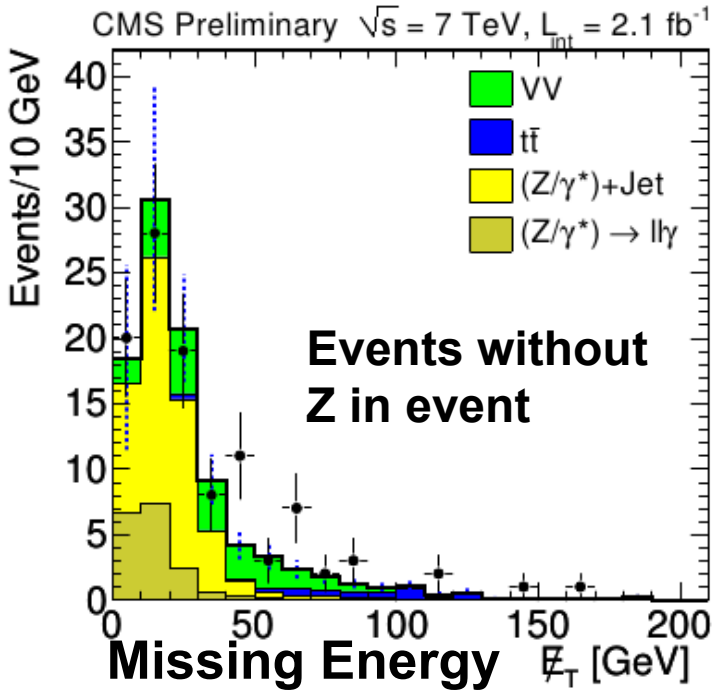


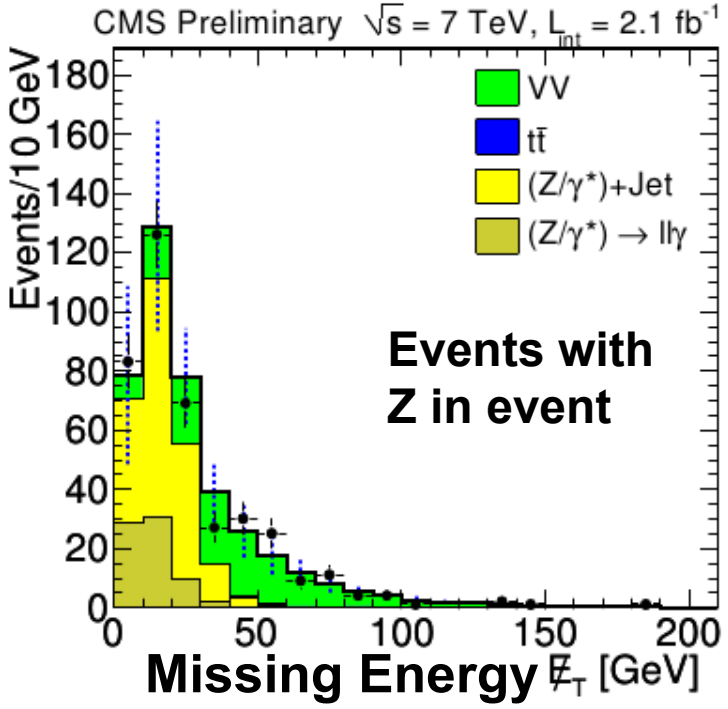
Figure 4: The isolation distribution of electrons (left) and muons (right) with large impact parameter ($d_{xy} > 0.02$ cm, primarily from jets) in a data sample enriched in $t\bar{t} \to \ell\nu bbjj$. The last bin includes the sum of all bins above this bin. The number of non-prompt isolated muons is 7, with an MC expectation of 7.5 ± 1.0.

Results: MET for Trilepton (e,μ) + HT < 200GeV

Shown results correspond to 2 of 52 multilepton channels

- MET distribution for events with Z's (right) serves as background test
- New physics could be seen in high MET region of events wo Z's (left)
- Yellow histograms show data driven prediction
- Dashed blue lines are background uncertainties

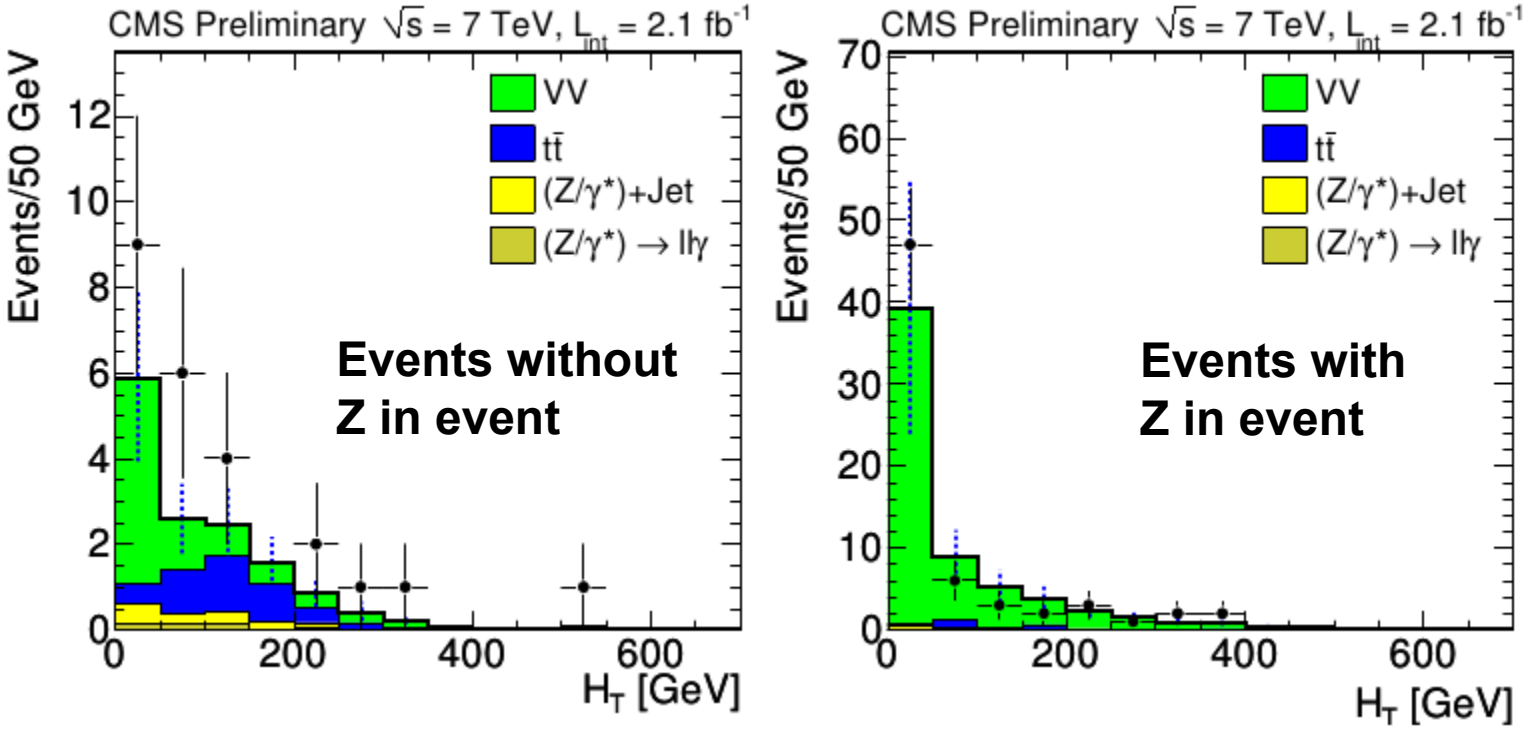




Results: HT for Trilepton (e,μ) + MET > 50 GeV

Shown results correspond to 2 of 52 multilepton channels

- HT distribution for events with Z's (right) serves as background test
- New physics could be seen in region of events wo Z's (left)
- Yellow histogramms show data driven prediction
- Dashed Blue lines are background uncertainties



Systematic Uncertainties

Source of Uncertainty	Uncertainty
Luminosity	4.5%
PDF	14%
Renormalization Scale	10%
Muon ID	0.1 %
Electron ID	0.3%
τ ID	3.7 %
Muon isolation at 8 (100) GeV/c	11% (0.2%)
Electron isolation at 8 (100) GeV/c	14% (0.6%)
Single Muon trigger efficiency	0.5%
Single Electron trigger efficiency	0.7%
Double Muon trigger efficiency	2.5%
Double Electron trigger efficiency	2%
Electron-Muon trigger efficiency	3.7%
$t\bar{t}$ background	50%
WZ background	40%
ZZ background	40%

Results for MET > 50 and Z-Veto

Channel	$\ell\ell + Jet$	$\ell\ell + \gamma$	$t\bar{t}$	VV	Total SM	Data	Signal
$OS(\ell\ell)e$	0.33±0.08	0.42±0.42	1.5±0.8	3.3±1.3	6.0±1.7	10	76±19
$OS(\ell\ell)\mu$	0.42±0.10	0.17±0.17	2.2±1.1	4.3±1.7	7.5±2.1	14	106±21
$OS(\ell\ell)\tau$	28.4±4.4	0.35±0.35	29±15	4.5±1.7	63±16	71	202±30
$\ell\ell'\tau$	24.6±6.0	1.7±1.7	38±19	7.5±2.9	73±20	88	29±10
$SS(\ell\ell)\ell'$	0.45±0.08	0.35±0.35	2.3±1.1	0.49±0.18	4.3±1.3	6	9.1±5.4
$SS(\ell\ell)\tau$	3.9±1.5	0.48±0.48	1.7±0.9	3.4±1.3	9.9±2.3	21	4.0±4.0
$\ell\tau\tau$	96±18	NA	12.3±6.2	1.7±0.6	110±19	88	24.0±9.1
$\sum \ell(\ell/\tau)(\ell/\tau)$	154±28	3.1±3.1	87±44	25.3±9.7	273±53	298	450±49
$\ell\ell\ell\ell$	0.0000±0.0006	<0.0002	<0.006	0.016±0.005	0.016±0.006	1	14.6±7.4
$\ell\ell\ell\tau$	0.00±0.07	<0.007	<0.07	0.14±0.04	0.23±0.11	0	14.8±7.7
$\ell\ell\tau\tau$	0.34±0.33	<0.005	0.27±0.13	0.14±0.04	0.89±0.40	0	7.8±5.6
$\sum \ell\ell(\ell/\tau)(\ell/\tau)$	0.34±0.34	0.00±0.00	0.27±0.13	0.29±0.08	1.14±0.42	1	37±12

Table 1: Summary of multilepton observations and expectations by lepton flavor for 2.1 fb^{-1} of luminosity with MET > 50 GeV requirement. Events with Z candidates have been removed.