SUSY @ CMS

Saeid Paktinat

(IPM, Tehran)

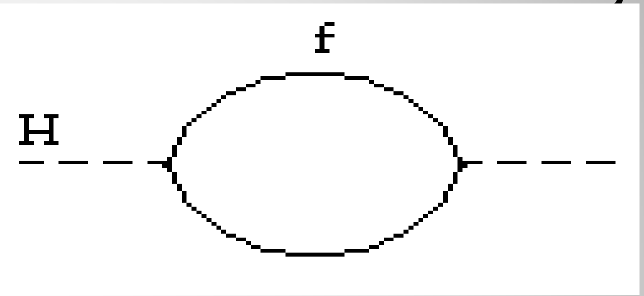
On behalf of the CMS Collaborations

outline

- SUSY
- Common Signatures
- Some Examples
- Conclusion

Why SUperSYmmetry(1)

SM describes a lot of experimental results very precisely, but



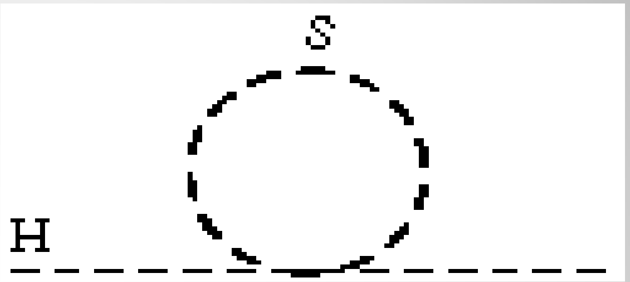
Fermionic loop corrections to higgs mass diverge quadratically:

$$\Delta m_H^2 = c\lambda_f^2[-\Lambda^2 + b]$$

Λ is a cut-off scale (upper limit for SM validity
→ $M_{pl} = 2.4*10^{18}$ GeV).
Huge disparity between *EW* scale and M_{pl} is not natural (Hierarchy Problem)

Why SUperSYmmetry(2)

If another scalar couples to higgs



new correction is

$$\Delta m_H^2 = c_2 \lambda_S [\Lambda^2 + b_2]$$

Proper couplings → This correction can cancel the quadratic divergencies.
SUSY introduces new particles that cancel quadratic div and fill the scale between *EW* and M_{pl}(solves the hierarchy problem).

SUSY particle content

Every SM particle has a SUSY partner (sparticle) that are exactly same, but differ in spin by ½ .

Names		spin 0	spin 1/2	$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$
squarks, quarks	Q	$(\tilde{u}_L \quad \tilde{d}_L)$	$(u_L \quad d_L)$	$(3, 2, \frac{1}{6})$
(×3 families)	U^c	$\tilde{u}_R^*$	$u_R^\dagger$	$(\bar{3}, 1, -\frac{2}{3})$
	D^c	$\tilde{d}_R^*$	$d_R^\dagger$	$(\bar{3}, 1, \frac{1}{3})$
sleptons, leptons	L	$(\tilde{\nu} \quad \tilde{e}_L)$	$(\nu \quad e_L)$	$(1, 2, -\frac{1}{2})$
(×3 families)	E^c	$\tilde{e}_R^*$	$e_R^\dagger$	$(1, 1, 1)$
Higgs, higgsinos	H_u	$(H_u^+ \quad H_u^0)$	$(\tilde{H}_u^+ \quad \tilde{H}_u^0)$	$(1, 2, \frac{1}{2})$
	H_d	$(H_d^0 \quad H_d^-)$	$(\tilde{H}_d^0 \quad \tilde{H}_d^-)$	$(1, 2, -\frac{1}{2})$

Names	spin 1/2	spin 1	$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$
gluino, gluon	$\tilde{g}$	g	$(8, 1, 0)$
wino, W	$\tilde{W}^\pm, \tilde{W}^0$	$W^\pm, W^0$	$(1, 3, 0)$
bino, B	$\tilde{B}^0$	B^0	$(1, 1, 0)$

Important Features

- $R=(-1)^{2S+3B+L}$
- Consider R-parity conservation only
  → pair-production of sparticles
- Lightest SUSY particle (LSP) stable
  → dark matter candidate
- Hadron collider: squark/gluino production is dominant (if not too heavy)

SUSY & mSUGRA

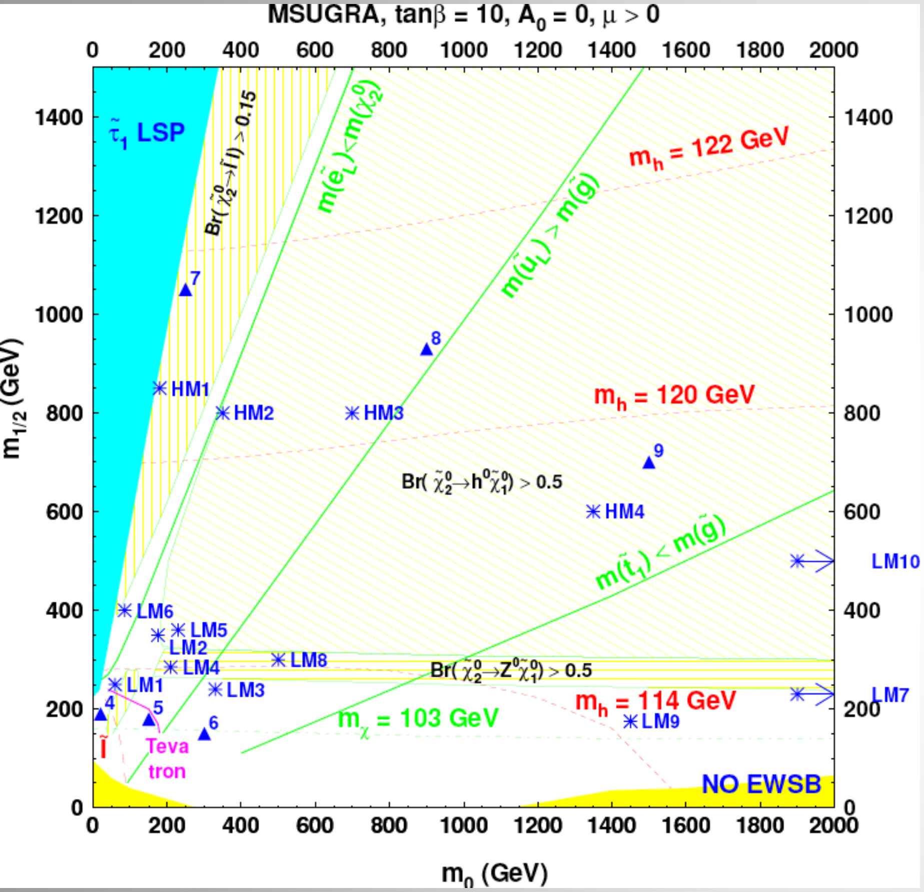
- SUSY particles have not been discovered, so they don't have exactly same mass as their SM partners.

→SUSY is a broken symmetry.

- There are different scenarios in the market, describing this symmetry breaking.
- In mSUGRA, SUperGRAvity does it.
- The mSUGRA, reduces the 127 parameters of general SUSY models to 5 parameters:

m_0, $m_{1/2}$: (common scalar and gaugino mass at GUT scale)
A: (common gaugino coupling at GUT scale)
$\tan\beta$: ratio of vev of H_u and H_d
sign(μ): μ being the higgs mixing parameter.

CMS SUSY Benchmark Points

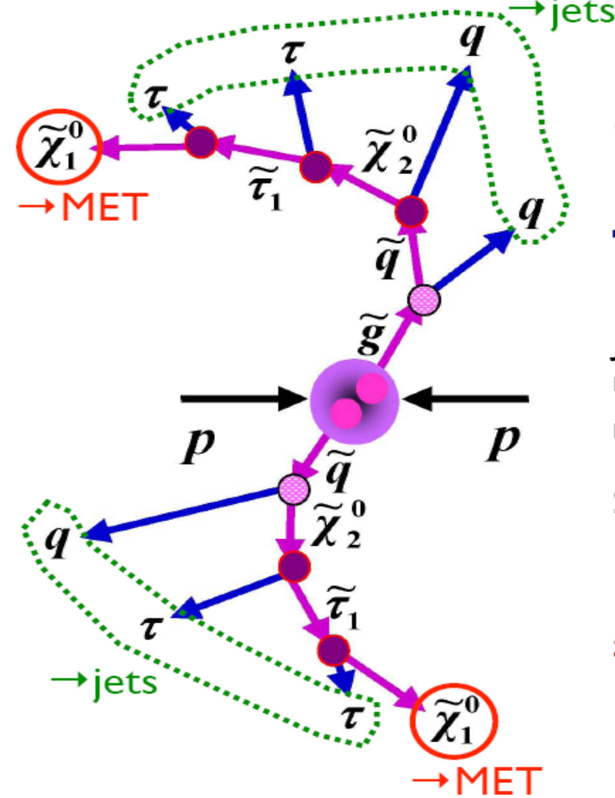


LM/HM = Low/High Mass
All points are beyond current Tevatron limits
High mass points are close to the ultimate LHC reach

Point	m_0	$m_{1/2}$	$\tan\beta$	$\mathrm{sgn}(\mu)$	A_0
LM1	60	250	10	+	0
LM2	185	350	35	+	0
LM3	330	240	20	+	0
LM4	210	285	10	+	0
LM5	230	360	10	+	0
LM6	85	400	10	+	0
LM7	3000	230	10	+	0
LM8	500	300	10	+	-300
LM9	1450	175	50	+	0
LM10	3000	500	10	+	0
HM1	180	850	10	+	0
HM2	350	800	35	+	0
HM3	700	800	10	+	0
HM4	1350	600	10	+	0

Point LM1 MSUGRA:
m_g=611, m_{X01}= 94, m_{b1}=514, m_{b2}=535, m_{t1}=236

SUSY Common Signatures



•**2 LSP**

➔ Large missing ET (MET): O(> 100GeV)

difficult to measure precisely at start-up

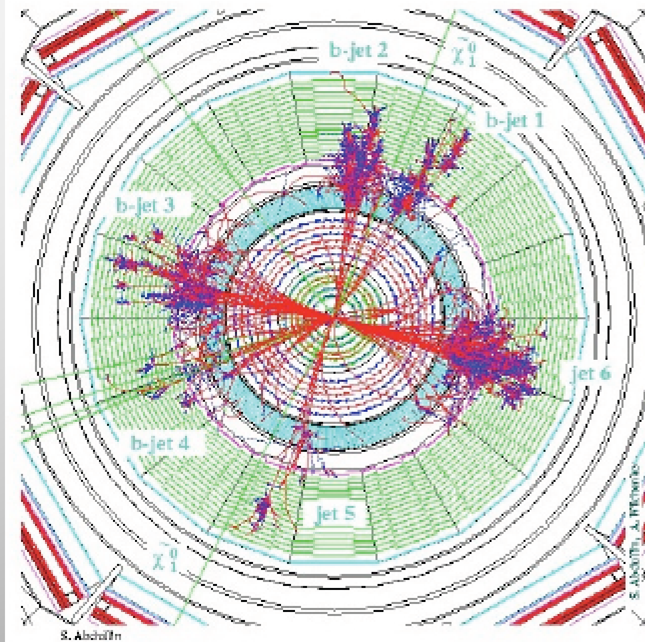
•**decay chains**

➔ ≥ 3 hard Jets O(>100-200GeV)

➔ N isolated leptons

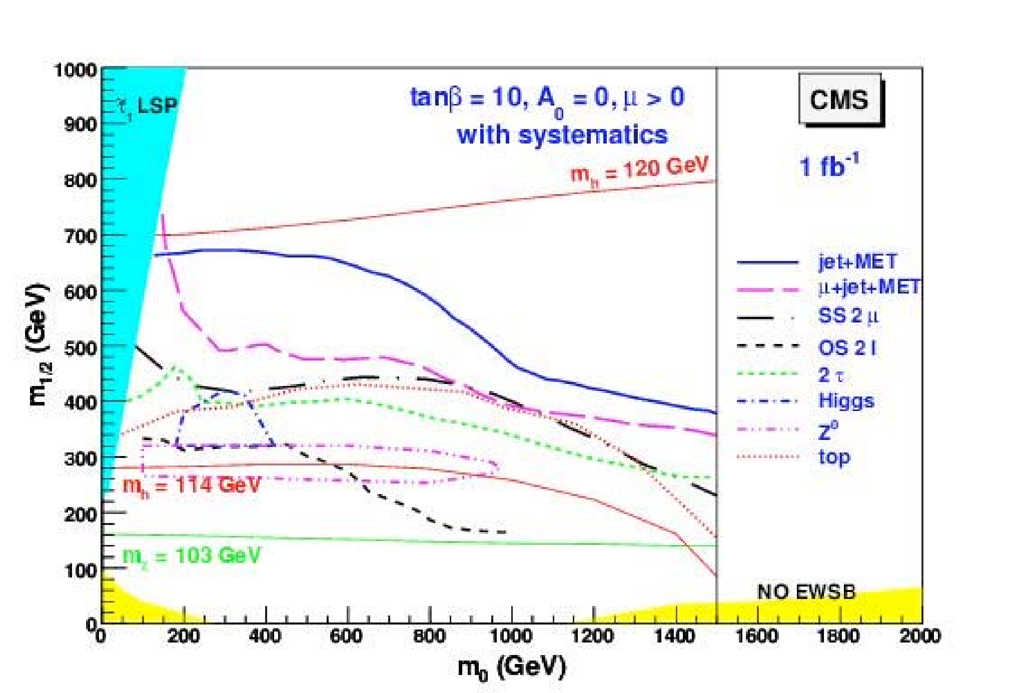
reduced QCD with growing N

•**Expected backgrounds**: W+jets, Z+jets, tt+jets, di-boson, single t, multi-jets (QCD)

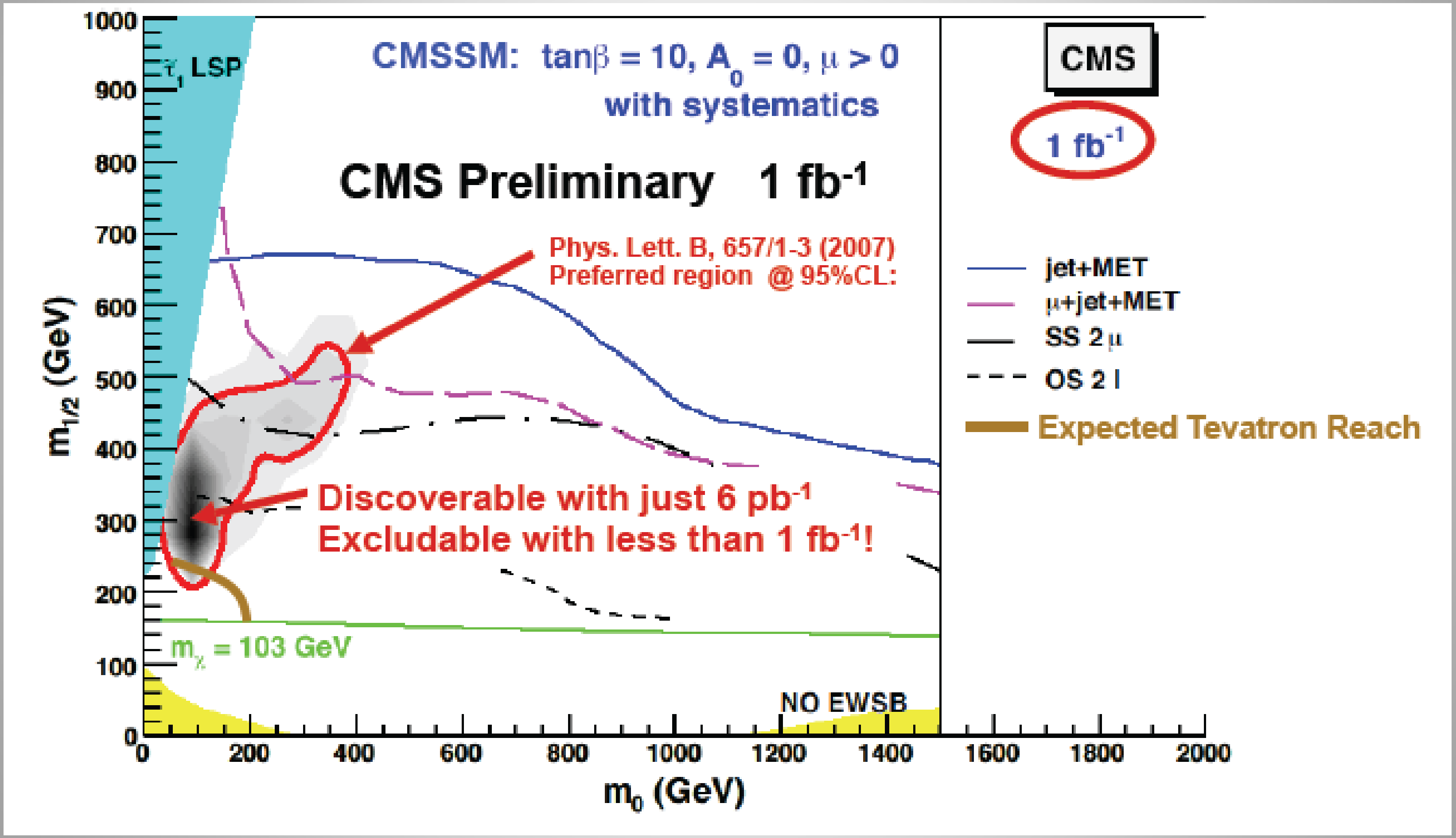


Past Activities

- A huge effort was done in the whole collaboration to evaluate the physics performance of the complete detector which ended up to Physics TDR II. SUSY/BSM group had an important contribution.



Preferred SUSY Parameter Space



CMS Reach for New Physics (14 TeV)

Model	Mass reach	Luminosity (fb^{-1})	Early Systematic Challenges
Contact Interaction	$\Lambda < 2.8$ TeV	0.01	Jet Eff., Energy Scale
Z'			Alignment
ALRM	M ~ 1 TeV	0.01	
SSM	M ~ 1 TeV	0.02	
LRM	M ~ 1 TeV	0.03	
E6, SO(10)	M ~ 1 TeV	0.03 – 0.1	
Excited Quark	M ~0.7 – 3.6 TeV	0.1	Jet Energy Scale
Axigluon or Colouron	M ~0.7 – 3.5 TeV	0.1	Jet Energy Scale
E6 diquarks	M ~0.7 – 4.0 TeV	0.1	Jet Energy Scale
Technirho	M ~0.7 – 2.4 TeV	0.1	Jet Energy Scale
ADD Virtual G_{KK}	M_D~ 4.3 - 3 TeV, n = 3-6	0.1	Alignment
	M_D~ 5 - 4 TeV, n = 3-6	1	
ADD Direct G_{KK}	M_D~ 1.5-1.0 TeV, n = 3-6	0.1	MET, Jet/photon Scale
SUSY	M ~1.5 – 1.8 TeV	1	MET, Jet Energy Scale, Multi-Jet backgrounds, Standard Model backgrounds
Jet+MET+0 lepton	M ~0.5 TeV	0.01	
Jet+MET+1 lepton	M ~0.5 TeV	0.1	
Jet+MET+2 leptons	M ~0.5 TeV	0.1	
mUED	M ~0.3 TeV	0.01	ibid
	M ~ 0.6 TeV	1	
RS1			
di-jets	M_{G1}~0.7- 0.8 TeV, c=0.1	0.1	Jet Energy Scale
di-muons	M_{G1}~0.8- 2.3 TeV, c=0.01-0.1	1	Alignment

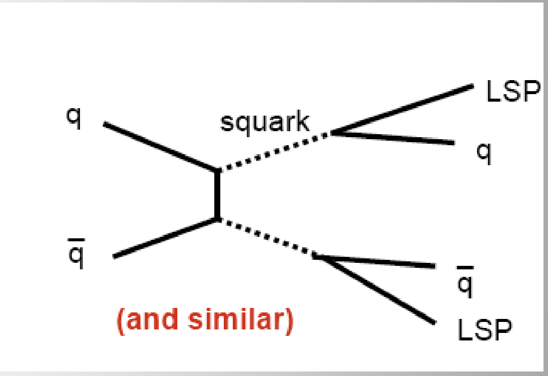
Disclaimer

- In this talk only the latest post PTDRII results are reviewed. They focus on the data driven methods with the early data.
- **We are getting ready for data.**
- **To know about the search for SUSY by electron, muon and top see the talks by H. Bakhshian, A. Fahim and B. Safarzadeh, respectively. They are not repeated here.**

SUSY in Dijet final states

- New CMS study: PAS-SUS-08/005
  - CMS PTDR II focused on inclusive SUSY searches with ≥ 3 jets + MET

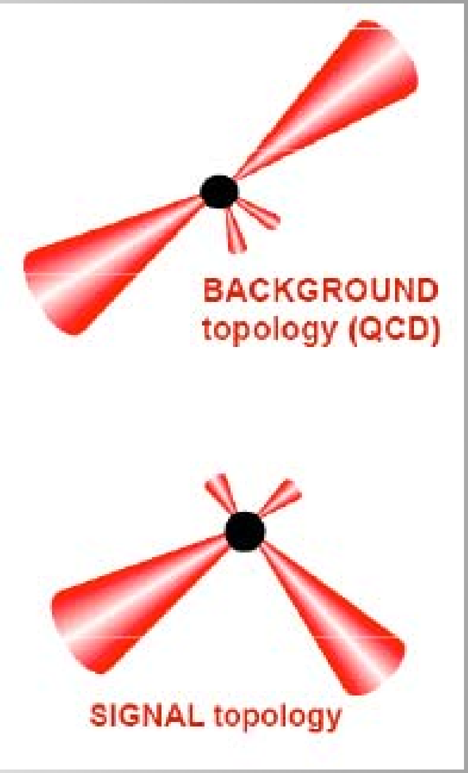
- Motivated in addition by recent paper by
  - L. Randall, D.Tucker-Smith (Phys.Rev.Lett.101:221803,2008)
- Idea:
  - Squarks pair produced and directly decaying to quarks and neutralinos
- Event topology
  - Only two jets + missing energy
- Background:
  - QCD dijet events
    - No real missing momentum
  - $Z \to \nu\nu$ events
    - Irreducible background due to real missing E_T
  - $W \to l\nu$
    - Leads to missing Et when lepton not reconstructed or out of acceptance



Event Selection (1)

- Trigger
  - di-jet trigger
    - two jets with pt > 150 GeV
- Preselection:
  - Jet Selection
    - 2 jets with pt > 50 GeV, F_{em}< 0.9
    - 3rd jet veto: pt < 50 GeV
    - $\Delta\varphi(\mathrm{MHT}, \mathrm{jet}_{1,2,3}) > 0.3$ rad

    MHT = - ($p_T^{Jet1} + p_T^{Jet2}$) (Jet based missing E_T)
    - $|\eta_{j1}| < 2.5$
  - Lepton veto's:
    - no e, μ with pt >10 GeV



Event Selection (2)

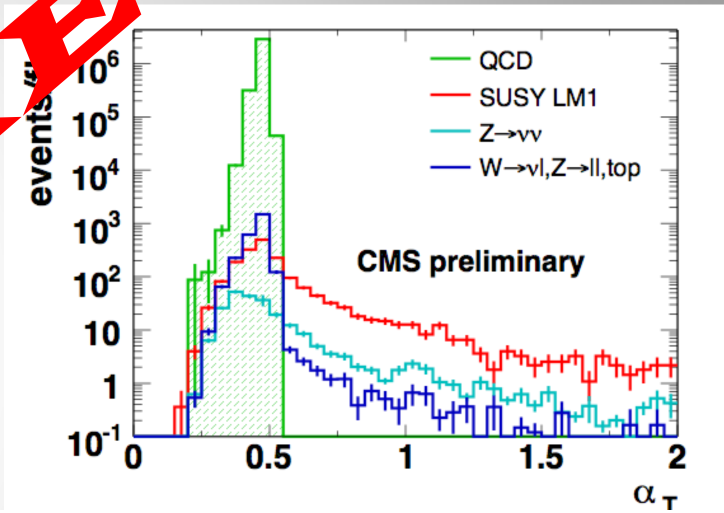
- HT > 500 GeV

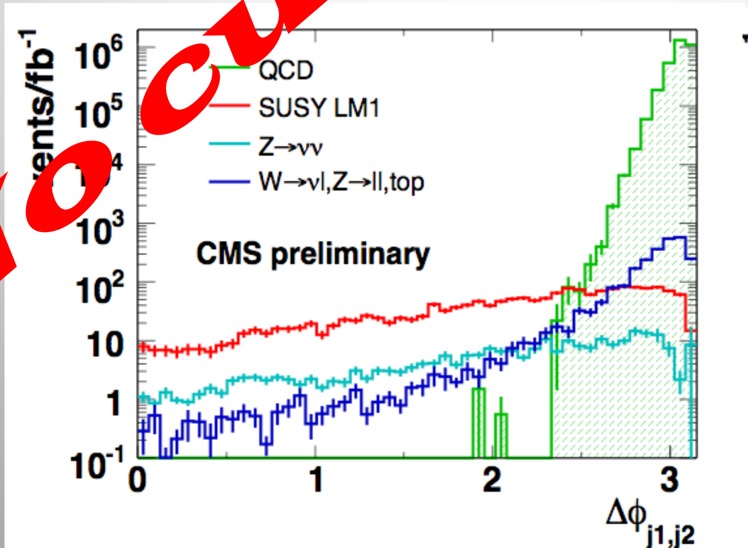
  (HT = $P_T^{Jet1} + P_T^{Jet2}$)
- α (α_T) > 0.55
- ($\Delta\phi < 2\pi/3$)

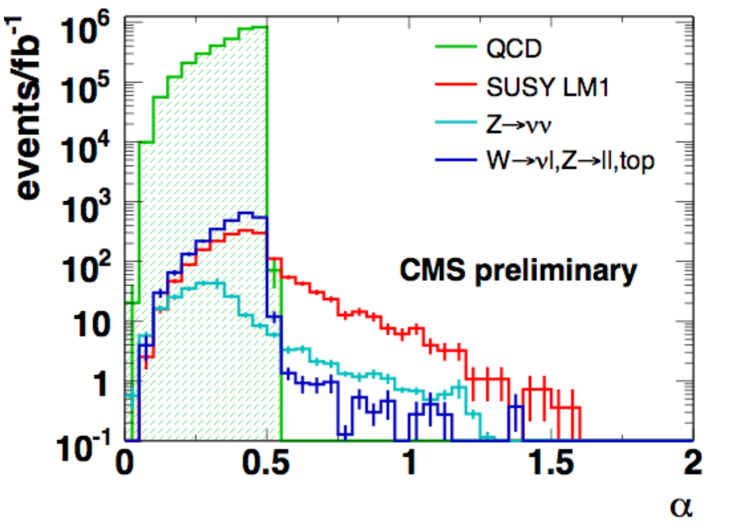
$$\alpha = E_T^{j2} / M_{inv}^{j1,j2}$$

$$\alpha_T = E_T^{j2} / M_{inv\,T}^{j1,j2}$$

No cut on MET!







Signal & Background yields

- Expected event yields for $1fb^{-1}$

Selection cut	QCD	$t\bar{t}$,W,Z	$Z \rightarrow \nu\bar{\nu}$	LM1
Trigger	1.1×10^8	147892	1807	25772
Preselection	3.4×10^7	9820	878	2408
$HT > 500$ GeV	3.2×10^6	2404	243	1784
$\alpha > 0.55$	0	7.2	19.7	227.6
$\alpha_T > 0.55$	0	19.9	58.2	439.6
$\Delta\phi_{j1,j2} < 2\pi/3$	0	18.7	57.2	432.4

=> Signal/Background = 5.6

- Variation of jet energy scale and resolution
  - 10% gaussian smearing of jet p_T's and of 0.1 rad of φ measurement
  - Scaling of jet energy by ± 5%
  - Scaling of jet energy by ± 3% for endcap/forward ($|\eta|>1.4$)
- Stable S/B for all variations

Data-Driven Background Studies

- LHC data explores a new energy regime
  - Monte Carlo simulations doubtful at best
  - develop data-driven techniques
  - identify data control samples
- Two main sources of background:
- QCD
  - Seems to be under control but huge cross-section
  - MC uncertainties due to higher order QCD effects
  - Third jet veto should minimize higher order effects
- $Z \rightarrow \nu\nu$
  - represents an irreducible background
  - two jets + real missing E_T
  - Ideally study $Z \rightarrow \mu\mu$ events but not enough statistics in the early days
  - Other control samples:
  - W + Jets
  - Photon + Jets

ABCD Method

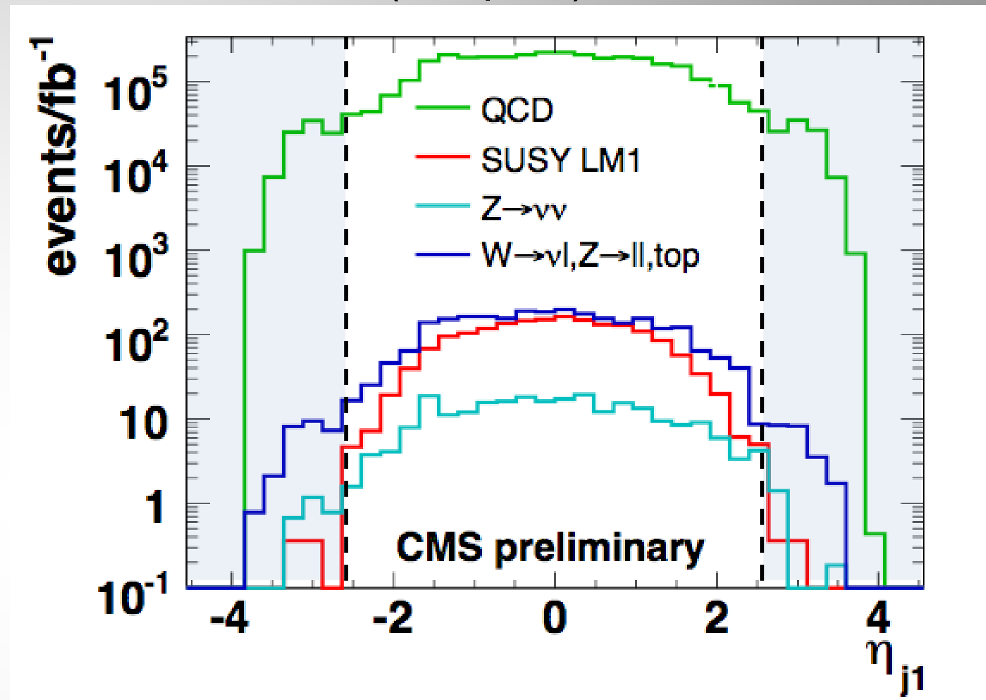
Idea: define signal enriched and depleted regions by splitting data sample in events with first jet in barrel and forward region

- SUSY jets are more central
- Use ratio of events $R_a = \alpha_T > 0.55 / \alpha_T < 0.55$ in (signal depleted) forward η region to predict background in (signal enriched) barrel region.

α

	B(Signal+BG)	C(BG)
0.55	A(BG+some signal) ~2 million QCD+~2K tt/W/Z+~1k SUSY	D(BG)
	2.5	|η|

Pre-selection (no η cut) + HT > 500 GeV



R = C/D: assumed to be constant over η and nearly signal free

also: constant for all background contributions individually

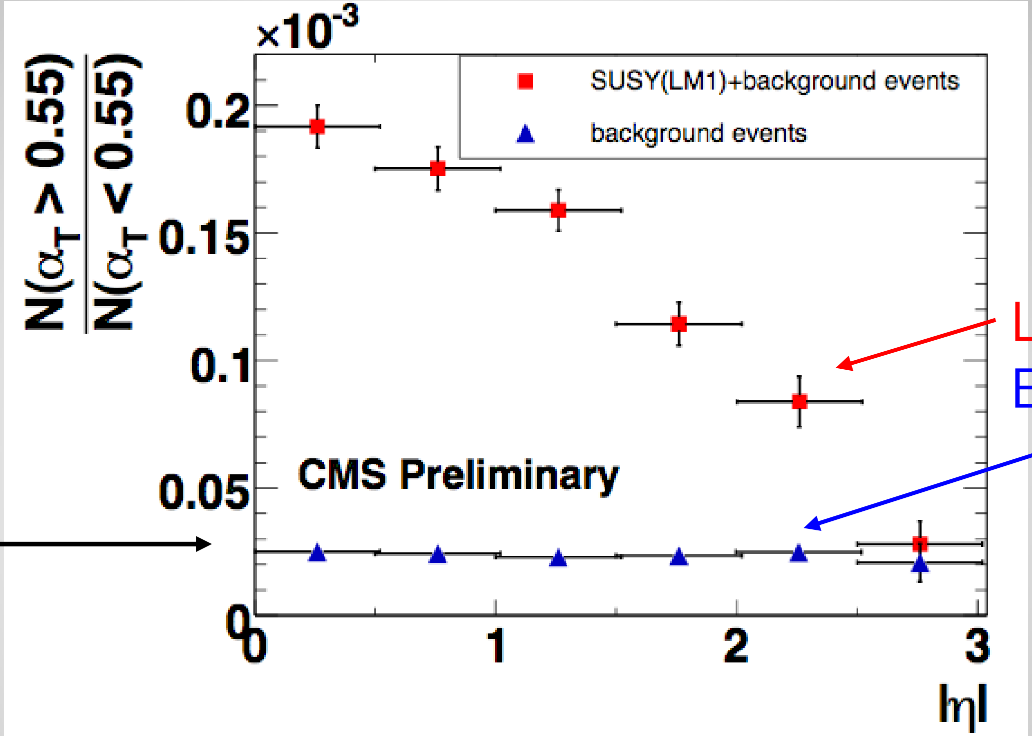
Then, background in B can be obtained as:

B = A * R

See also: Background Modeling in New Physics Searches Using Forward Events at LHC. Victor Pavlunin, David Stuart, Phys.Rev.D78:035012,2008.

Verifying the Method

Pre-selection (no $|\eta|$ cut) + HT > 500 GeV



LM1+BK

Background only

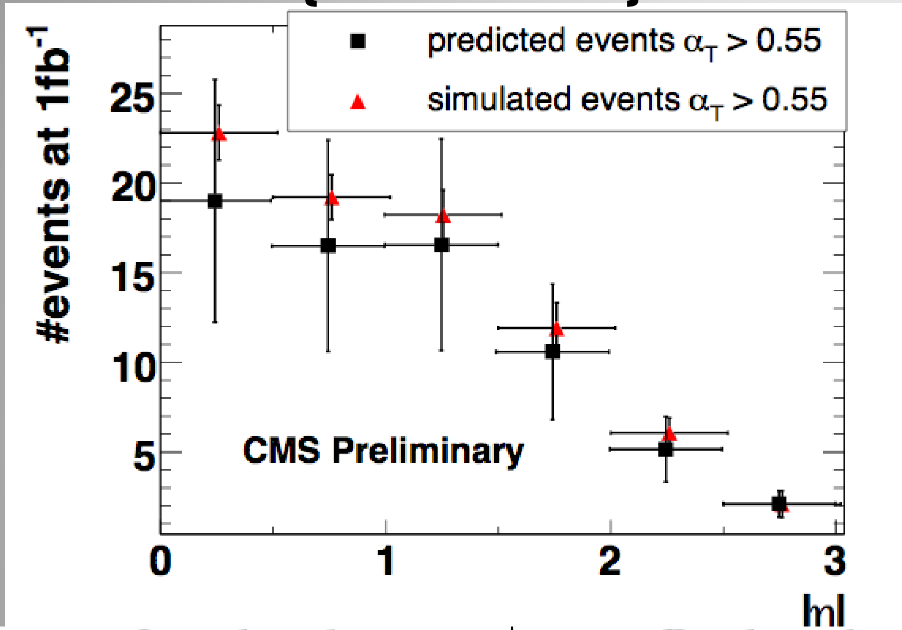
Verified that flat for all Bkgd contributions

- R_α flat for background as function of $|\eta_{j1}|$
- α_T and $|\eta_{j1}|$ can be used for ABCD-matrix method

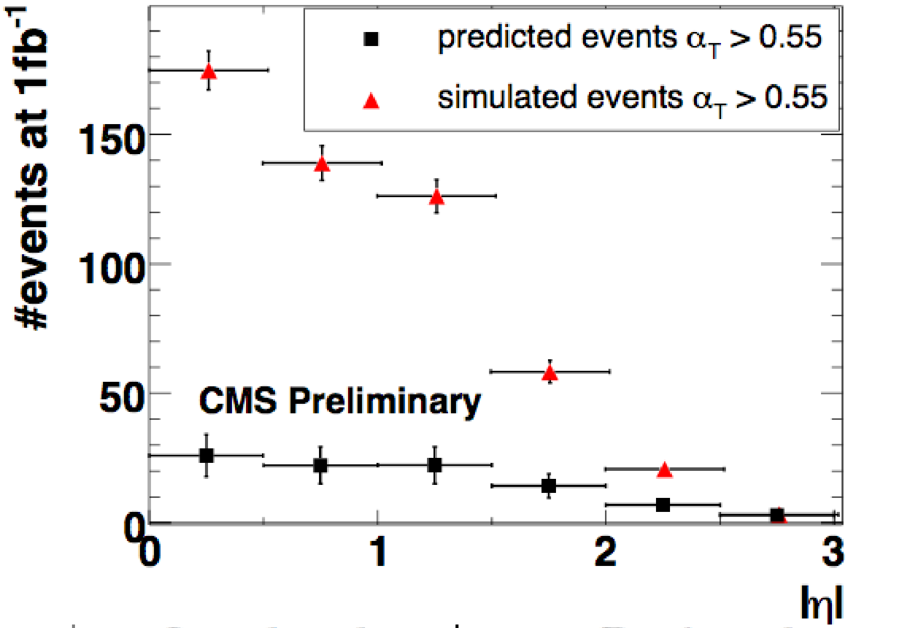
✸ Measure $R\alpha_T$ in $2.5 < |\eta| < 3.0$ region.

Background Estimation

without SUSY
(closure test)



with LM1 SUSY
"contamination"

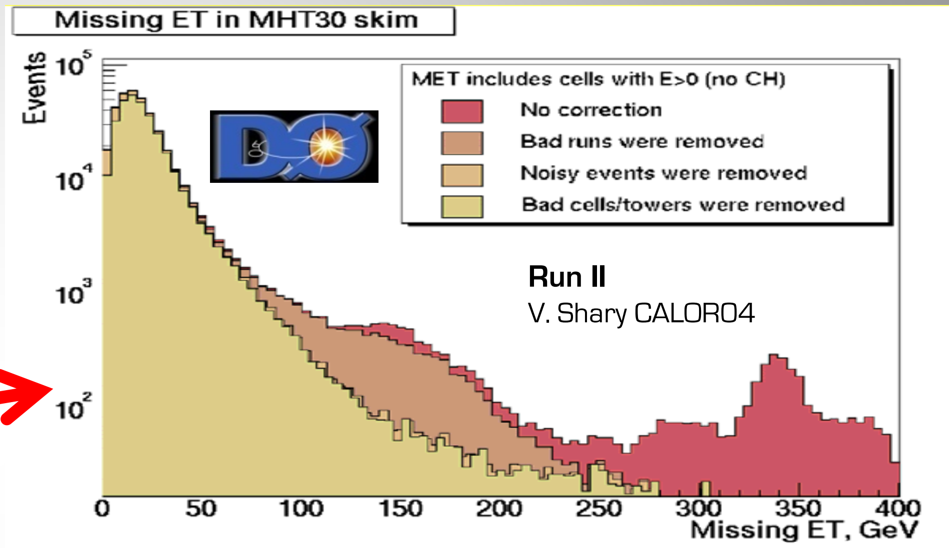


Simulated background ($\alpha_T > 0.55$ and $\|\eta\| < 2.5$)	Predicted background no SUSY contribution	Simulated background and SUSY(LM1)	Predicted background SUSY (LM1) contamination
$77 \pm 3\ (\pm 8)$	$68 \pm 24\ (\pm 43)$	$517 \pm 13\ (\pm 22)$	$91 \pm 30\ (\pm 51)$

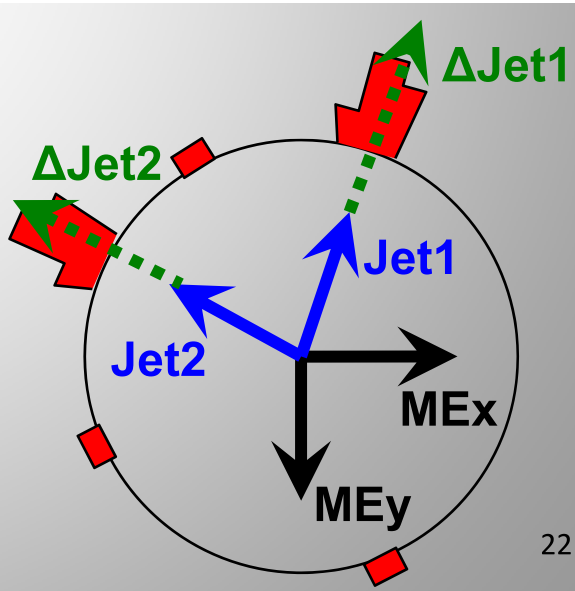
Predicted BKGD agrees well with simulated BKGD
SUSY LM1 leads to **significant** excess in signal region
Method also verified with systematic variations

Important MET

- Most of the SUSY searches rely on MET.
- Wrong MET can easily mimic SUSY.



- By definition, wrongly measured jets can make MET.



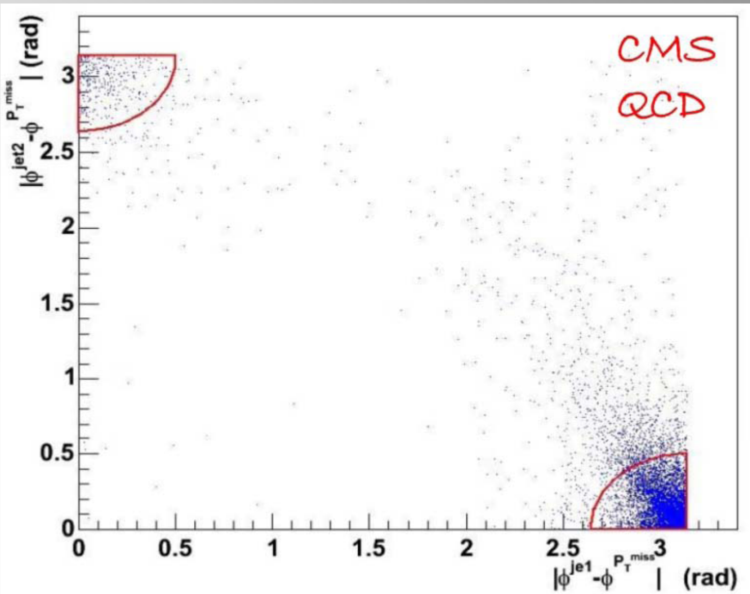
QCD Fake MET Suppression

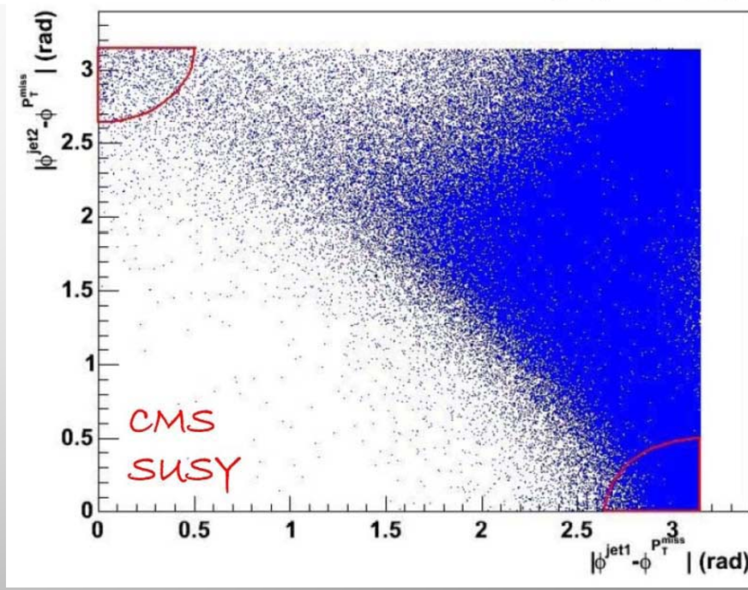
$$R_{1,2} = \sqrt{\Delta\varphi_{1,2}^2 + (\pi - \varphi_{1,2}^2)} > 0.5$$

where $\varphi_{1,2} = |\varphi_{\mathrm{jet1,jet2}} - \varphi_{\mathrm{MET}}|$

- Event EMF $\dfrac{\sum_{jets} p_T^j \cdot EMF^j}{\sum_{jets} p_T^j} > 0.1$
- Event Charge Fraction $\dfrac{\sum_{tracks} p_T^t}{p_T^{jet}} > 0.175$

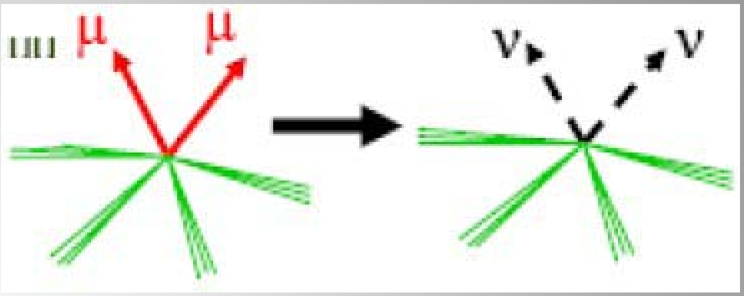
Cuts from the fully hadronic SUSY search in PTDRII.

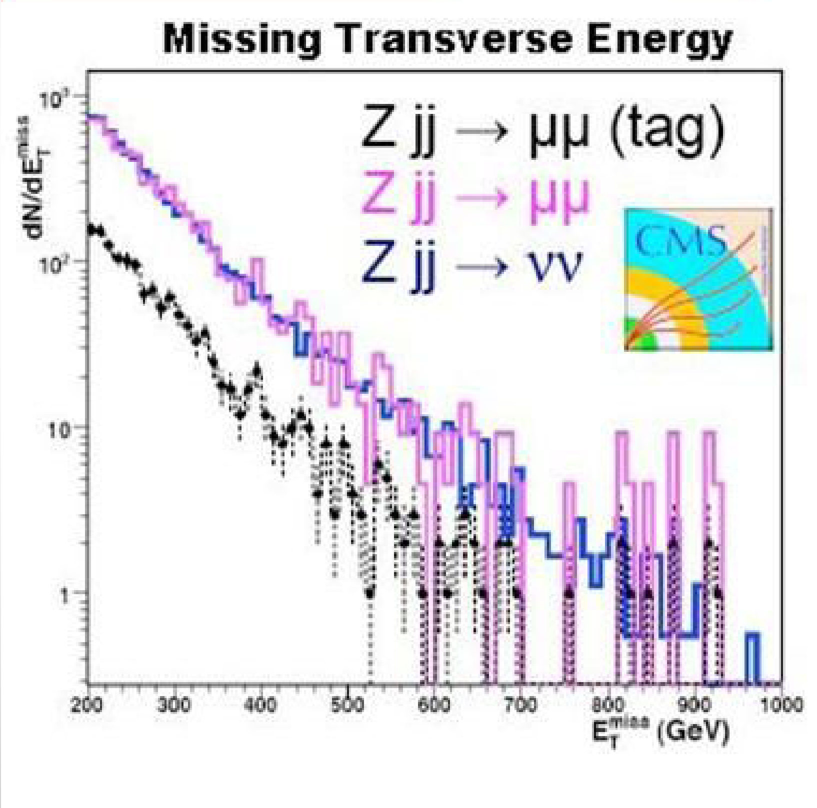




Irreducible Background: Z → νν

Z→νν + jets events have the same kinematic characteristic as Z→μμ + jets events, therefore, number of Z→νν + jets can be estimated using number of Z→μμ + jets events observed in data.





Black: M_Z tagged

Pink: M_Z tagged / tag efficiency

Blue: Z-> νν is normalized to pink(data)

Total uncertainty ~20% for 1fb-1 stat. limited statistics!

Br(Z→μμ) = 1/6 Br(Z→νν)

Z → νν measurement with photons

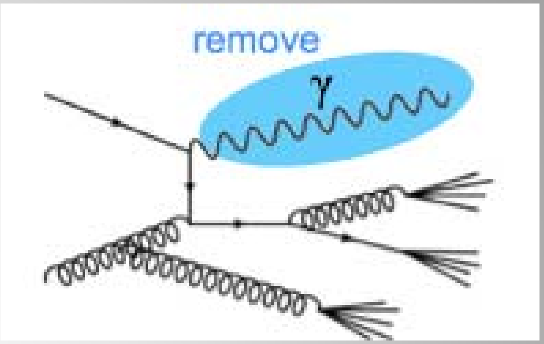
The photon spectrum is corrected for photon selection efficiencies, then scaled down

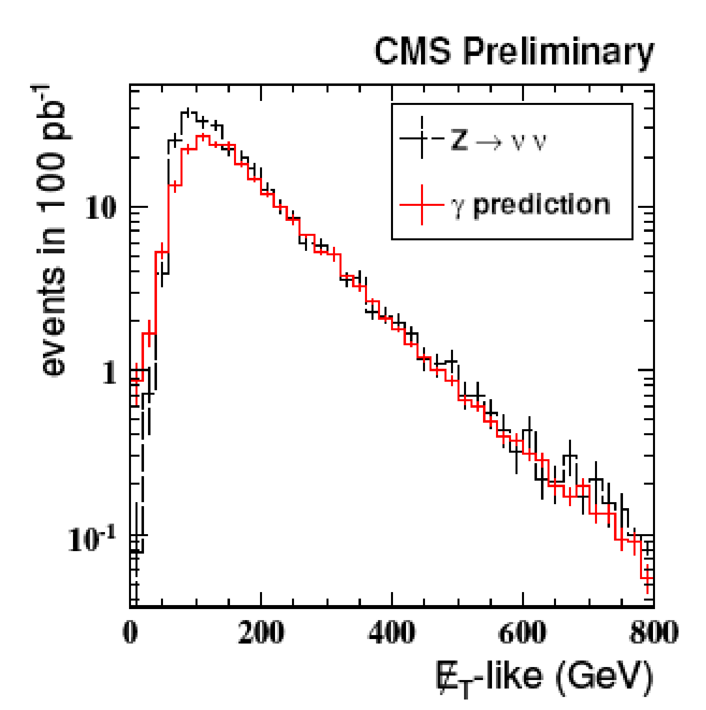
to the Z →νν branching ratio, and finally corrected for the theoretical differences with

Z →νν events as extracted from ALPGEN.

All corrections are evaluated

and applied in the barrel and endcap separately.



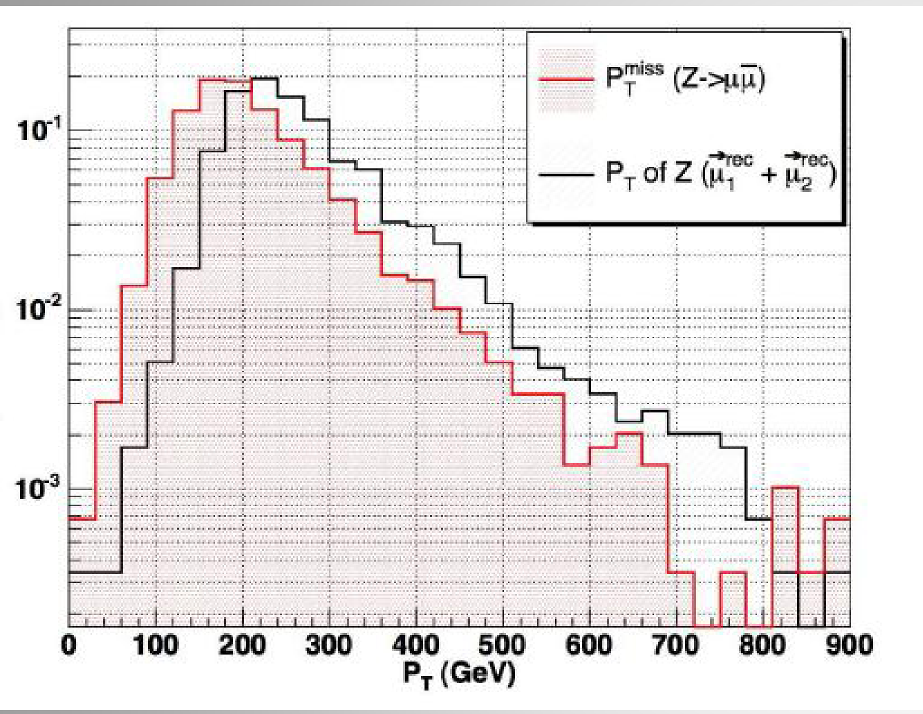


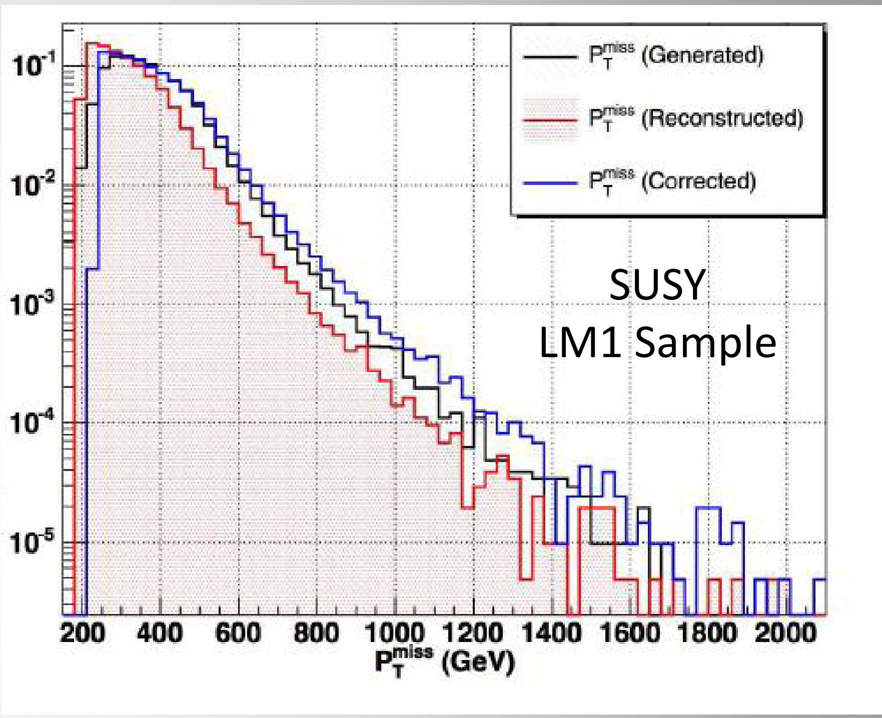
$Z \to \nu\nu$ background estimate (100 pb^{-1})	
MC-truth	35
From γ+jets	29 ± 3 (stat) ±5 (sys)
From W+jets	35 ± 10 (stat) ±8 (sys) ±3 (theory)

E_T^{miss} Calibration with Z(→μμ) + Jets(1)

- Expect agreement for E_T^{miss} and P_T of Z since muons have minor energy deposits in calorimeter.
- Muons from Global Muon Reconstruction (GMR) can be used.
- The ratio of the two in the Z P_T bins, where we have enough events, can be used to extract a calibration constant. (To be able to use events in the tail for large E_T^{miss} we need more than 1.5 fb^{-1}collection.)

E_T^{miss} Calibration with Z(→μμ) + Jets(2)





- **A promising calibration method for raw ETmiss. Need to improve it for the tail.**

If SUSY is discovered, its spectroscopy is a challenging task for LHC experiments!

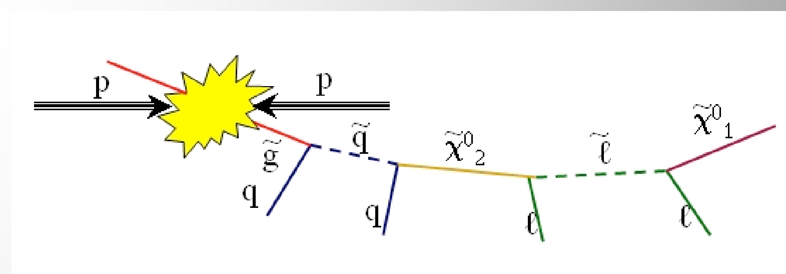
SUSY Parameter Estimation

- No mass peaks due to LSP/MET

→ measure shapes and endpoints!

- Important example: Opposite Sign, Same flavor

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q (\rightarrow \tilde{\ell}^{\pm} \ell^{\mp} q) \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^- q$$



- Endpoint:

$$m_{\ell\ell}^{max} = m_{\tilde{\chi}_2^o} \sqrt{1 - \frac{m_{\tilde{\ell}_R}^2}{m_{\tilde{\chi}_2^o}^2}} \sqrt{1 - \frac{m_{\tilde{\chi}_1^o}^2}{m_{\tilde{\ell}_R}^2}}$$

Dilepton Mass Edge

- Data-driven background estimate
- tt and diboson background
- from eμ data (Br(ee) + Br(μμ) = Br(μe))
- Unbinned fit to data (7 parameters)

$$F(m) = N_{sig}S(m) + N_{bkg}B(m) + N_Z Z(m)$$

Signal Model

Bkg from data

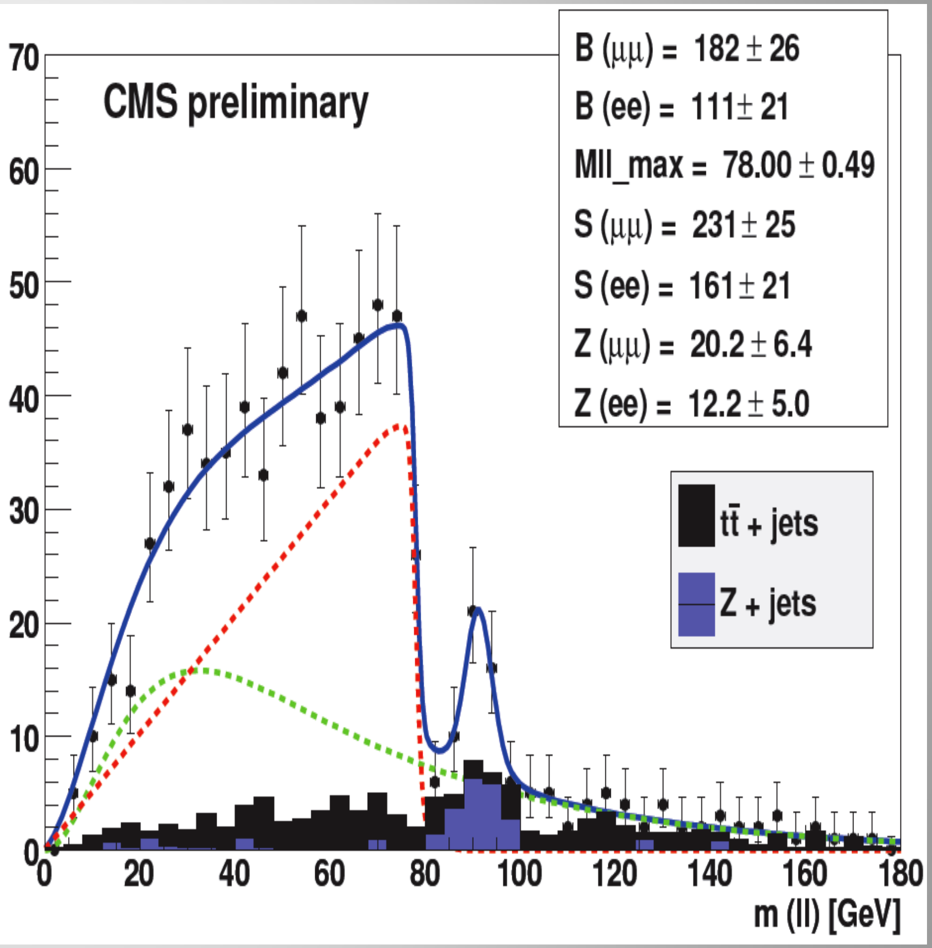
Z peak

Dilepton Mass Edge

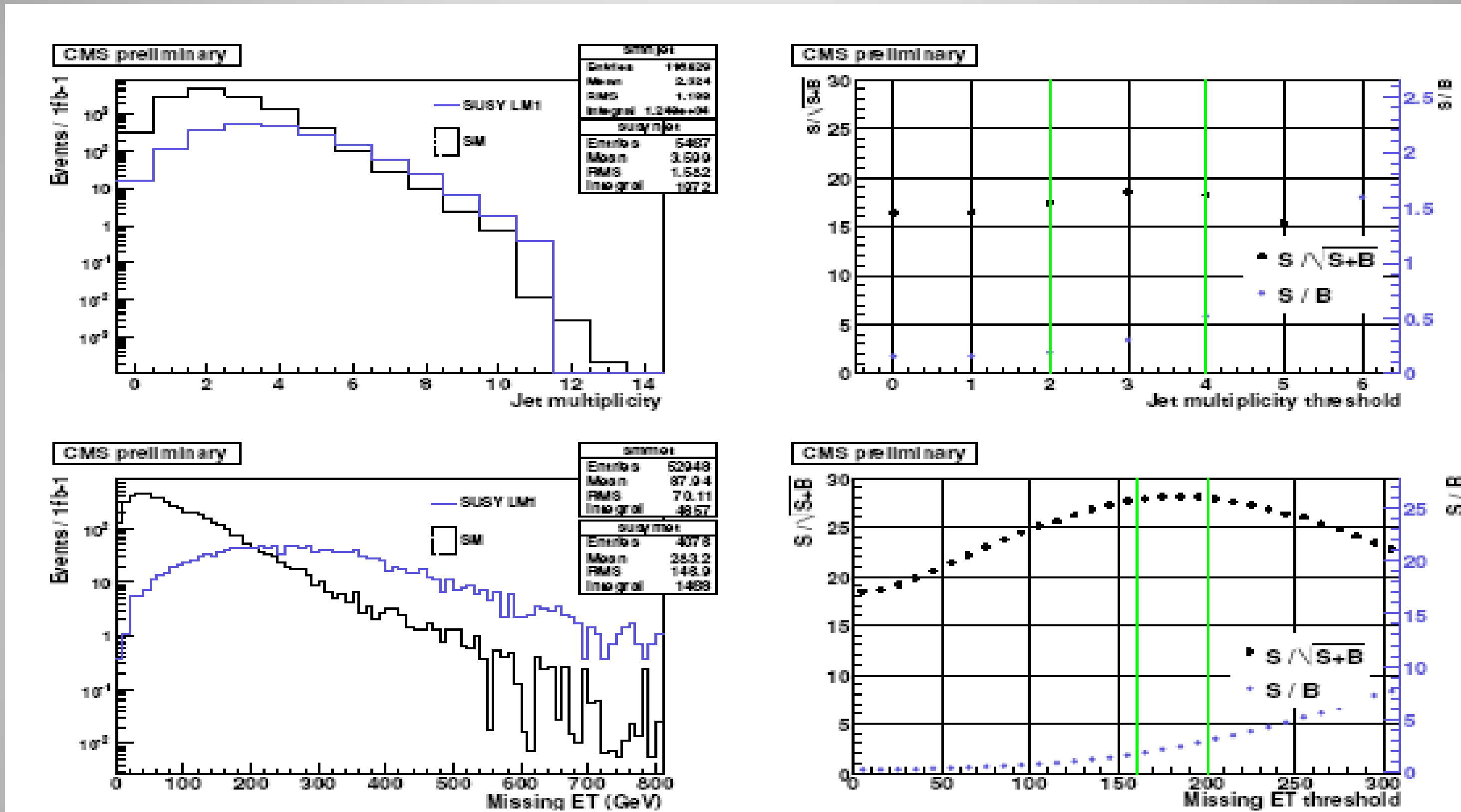
$$m_{\ell\ell}^{max}(TH) = 78.15\ GeV/c^2$$

$$\Delta m_{ee}^{max} = \pm 1.07(stat.) \pm 0.36(syst.)GeV$$

$$\Delta m_{\mu\mu}^{max} = \pm 0.75(stat.) \pm 0.18(syst.)GeV$$



Cut Optimization for Dilepton mass edge



Cuts are optimized to have both high significance and reliable S/B. It was a recommendation from statisticians.

Conclusion

- CMS has performed many SUSY oriented studies and results were published in PTDR-Vol. II.
- New generation of analysis with emphasis on data driven methods are (being) done.
- Different searches (leptonic, hadronic, No MET cut and with a MET cut) are prepared to run on the real data.
- CMS experiment is ready to see the SUSY if it exists.

Thank you for your attention