W/Z+Jets Production as Background for SUSY Searches at CMS

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OUTLINE

- SUSY Studies at CMS
- W/Z+Jets at LHC
- Z+Jets Candle Normalization and W/Z Ratio
- E_T^{miss} Calibration with Z+Jets
- W/Z + Jets Rejection with Indirect Lepton Veto
- Expected CMS SUSY Reach
- Conclusions

Motivation and Introduction

- There are many experimental studies(!) for mSUGRA driven SUSY models in CMS.
- W/Z + Jets production is one of the backgrounds in these studies that requires extra attention.
- Tevatron experience provides us valuable information.

How do we deal with W/Z+Jets data in a SUSY analysis?

SUSY Studies at CMS

PTDR-Vol. II was published in June 2006[1]. More than 60 pages of SUSY analysis and references for the detailed analysis notes. They cover SUSY, extra dimensions, etc.

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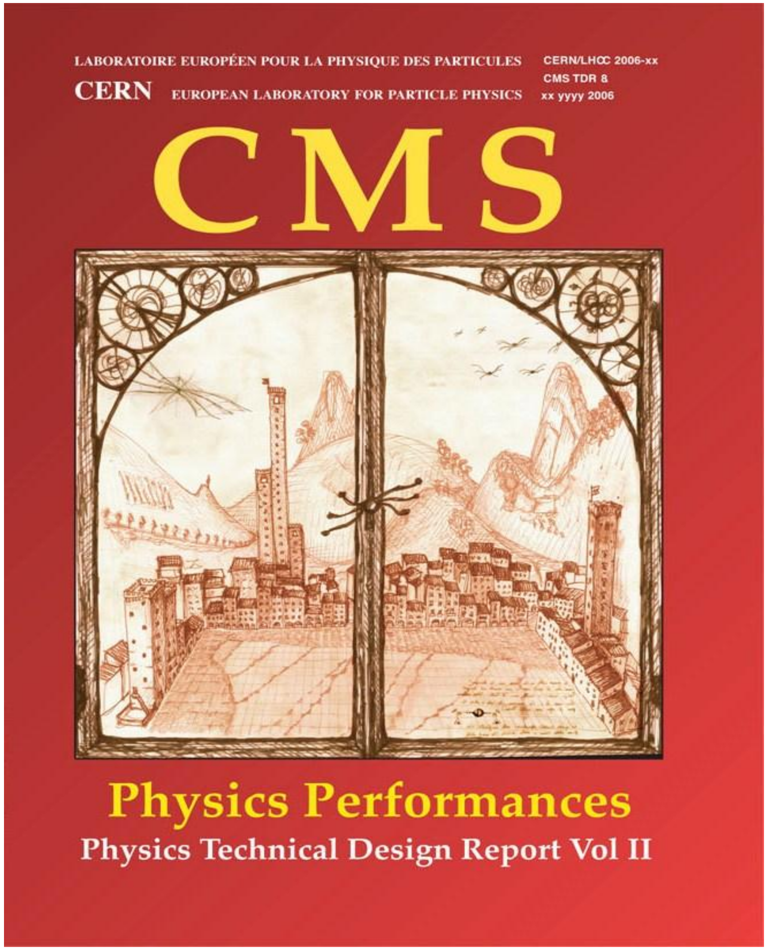


Assorted SUSY Studies from PTDR-Vol. II

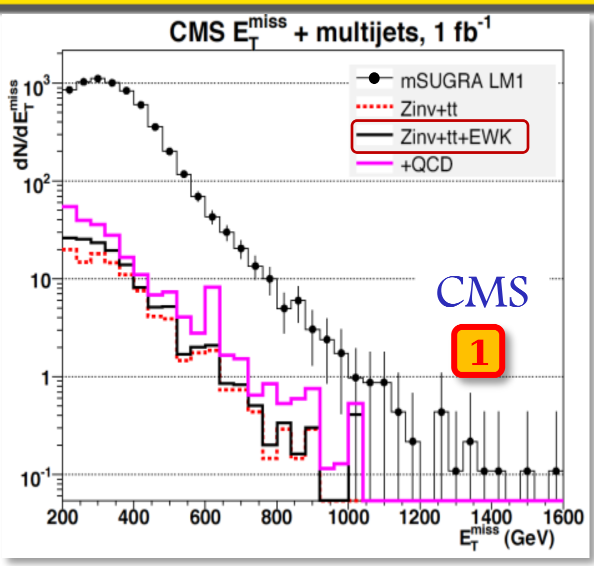
1 **Inclusive multi-jets + E_T^{miss}**

2 **Inclusive μ + multi-jets + E_T^{miss}**

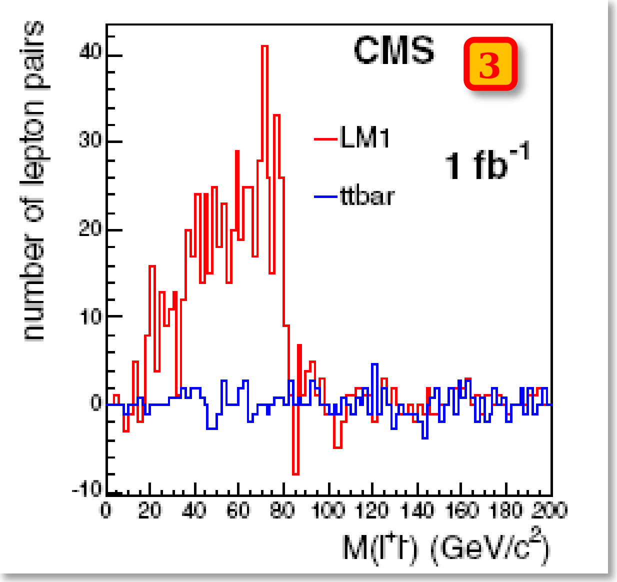
3 **Inclusive OS di-leptons + multi-jets + E_T^{miss}**

4 **Inclusive SS di-μ + multi-jets + E_T^{miss}**

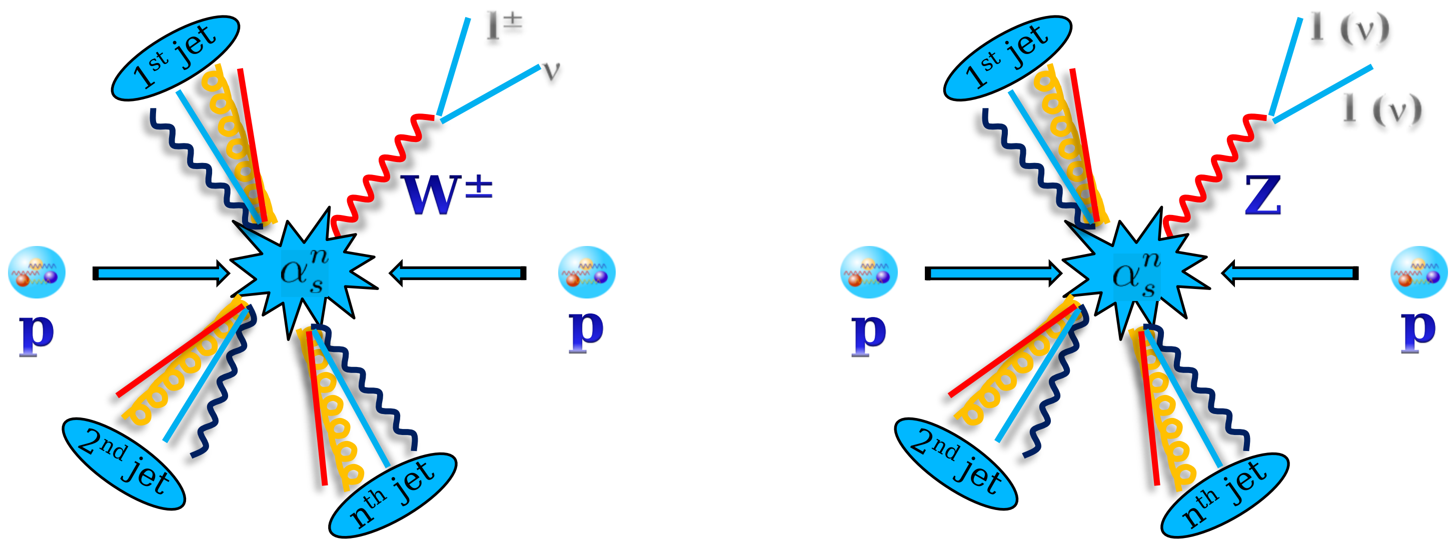
5 **Inclusive di-τ + multi-jets + E_T^{miss}**



- ✓ LM1 will be observable with 1 fb^{-1} data.
- ✓ High mass points will require more data collection.



W/Z + Jets as Background for SUSY



High jet multiplicities, missing transverse energy and leptons in W/Z + Jets production. Background for SUSY and other new physics processes.

$\sigma(pp \rightarrow W/Z + Jets) \propto \alpha_s^n$ at lowest order. Therefore they (especially Z(leptonic)+Jets) provide a powerful estimation tools for data and MC.

In order W/Z + Jets data to be useful for detector calibrations, MC estimations and theoretical predictions, we need as accurate as possible MC tools for W/Z+ Jets processes for LHC.

W/Z + Jets Studies at CMS as SUSY BG

In regard to SUSY search[1,3]

- ✓ Candle normalization with $Z(\rightarrow\mu\mu)$ + Jets
- ✓ W + Jets normalization by using W/Z ratio
- ✓ Raw E_T^{miss} calibration by using $Z(\rightarrow\mu\mu)$ + Jets
- ✓ Rejection of W/Z events with Indirect Lepton Veto (ILV) from SUSY background

studies had been performed(mostly PYTHIA was used).

i ***Studies are being re-visited and improved by using current CMS software and newer generator versions (with ALPGEN and MADGRAPH) !***

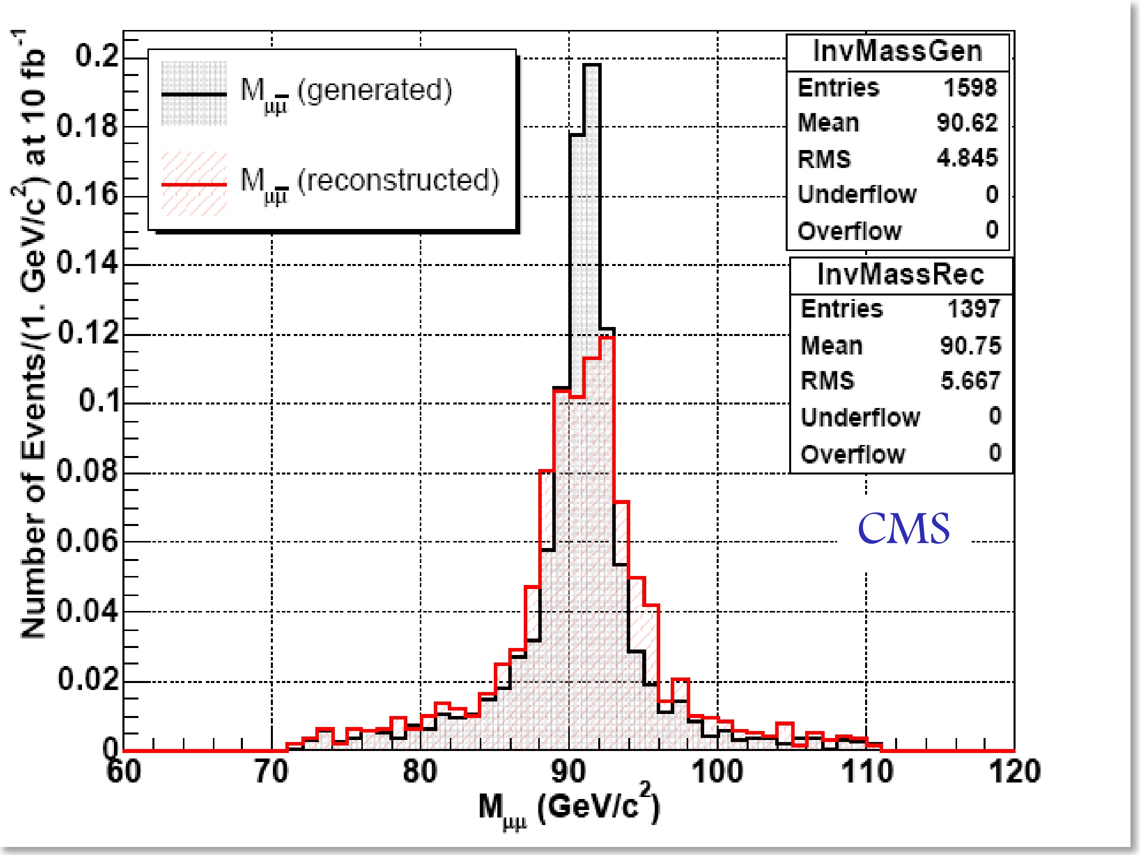
Z(→μμ) + Jets Standard Candle Normalization(I)

Need to collect clean Z(→μμ) + ≥ 2 jets events from data.
(MC events are used as if they are real data.)

Selection of events:

(Production: PYTHIA(V6.215)
Z+Jets with 400 < $\hat{p}_T$ < 700 GeV, σ≈8.8 fb^{-1})

- ≥ 2 jets with E_T ≥ 30 GeV and |η|≤3.0
- E_T^{miss} > 200 GeV
- 2 muons from Global Muon Reconstructor [4]
- Z mass window by using two muons with M_Z-20 GeV < $M_{\mu\mu}$<M_Z+20 GeV



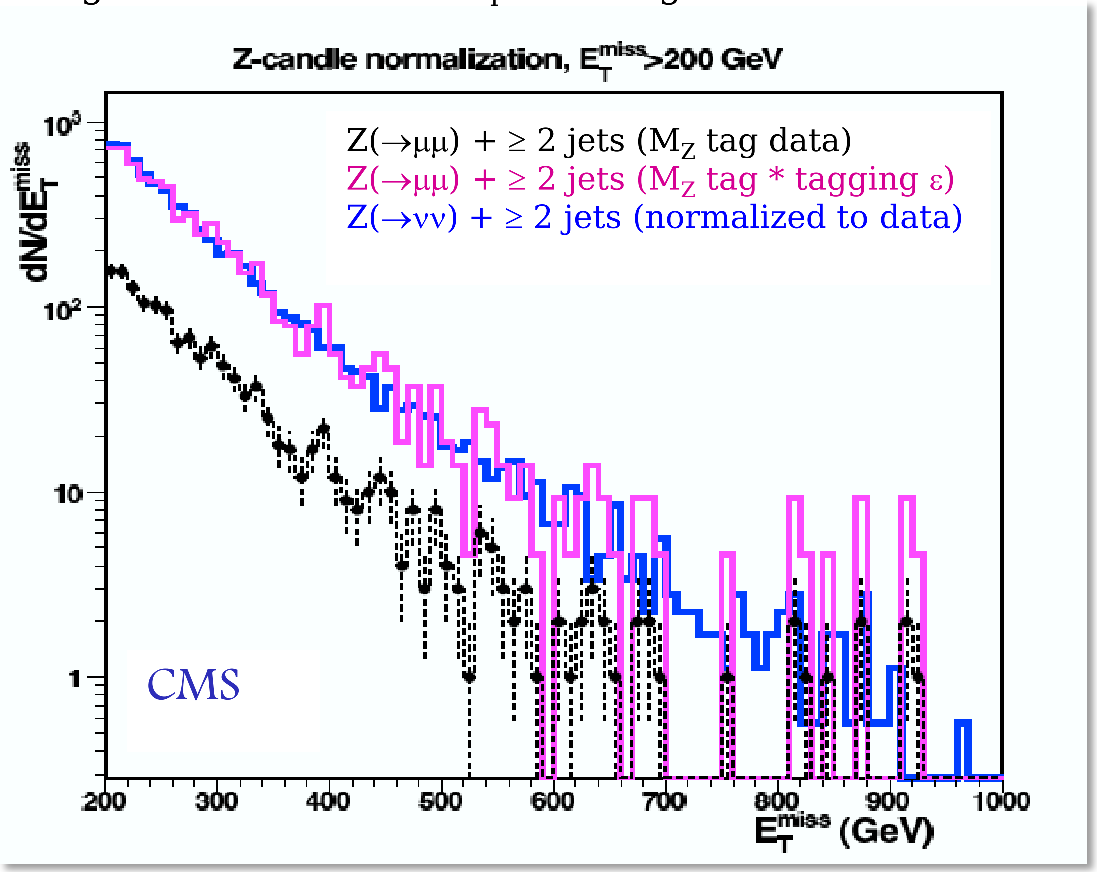
5% precision Z+Jets sample can be obtained by < 1.5 fb^{-1}

$Z(\rightarrow\mu\mu)$ + Jets Standard Candle Normalization(II)

Estimation of $Z(\rightarrow\nu\nu)$ + Jets

$Z(\rightarrow\nu\nu) + \geq 3$ jets is a significant source of E_T^{miss} background for SUSY.

$Z(\rightarrow\nu\nu) + \geq 2$ jets MC is normalized back to $Z(\rightarrow\mu\mu) + \geq 2$ jets "data" by using Z-mass tagging and analysis efficiency.

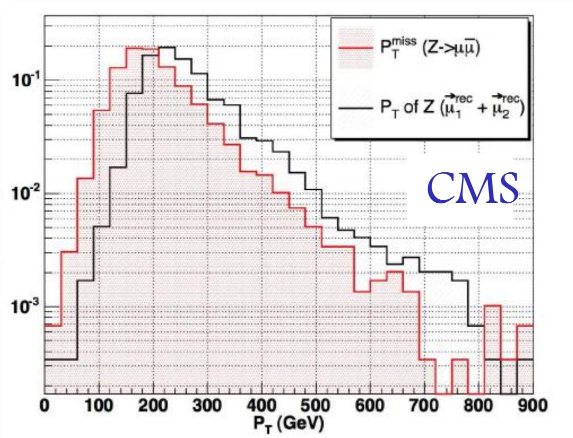


E_T^{miss} shape from simulation of $Z(\rightarrow\nu\nu)$ should be similar to the shape from $Z(\rightarrow\mu\mu)$ data.

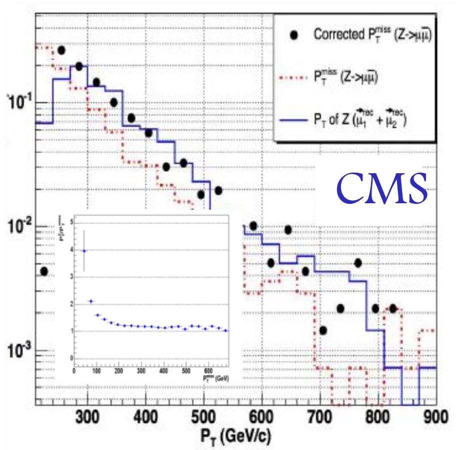
E_T^{miss} Calibration with $Z(\to\mu\mu)$ + Jets(I)

Expect agreement for E_T^{miss} p_T of Z since muons have minor energy deposits in calorimeter. Muons from Global Muon Reconstruction (GMR) can be used.

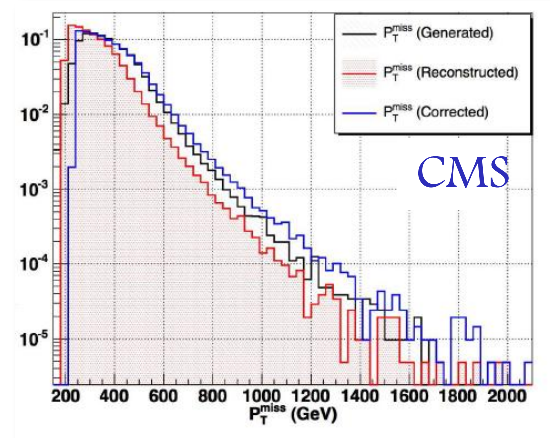
$Z(\to\mu\mu) + \geq 2$ Jets Sample



$Z(\to\mu\mu) + \geq 2$ Jets Sample



SUSY LM1 Sample



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.)

✓ ***A promising calibration method for raw E_T^{miss}. Need to improve it for the tail.***

Z(→μμ) + Jets Standard Candle Normalization(III)

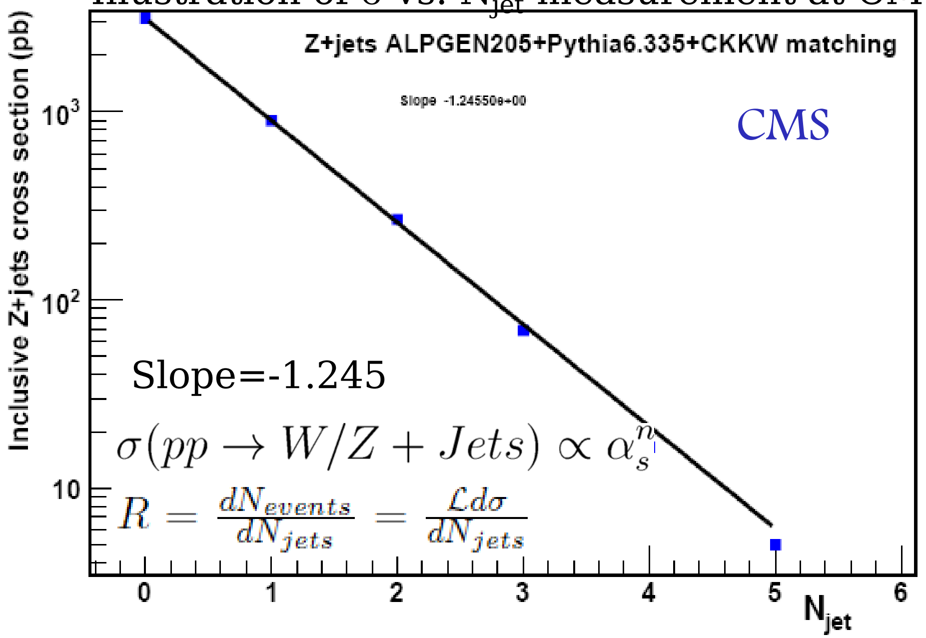
Estimation of W/Z + n-jets by Z +(n-1)-jets and R^{μ}_{WZ}

The cross-section and jet-multiplicity relation at lowest order, lepton universality assumption and

$$\rho \equiv \frac{\sigma(pp \to W(\to \mu\nu) + jets)}{\sigma(pp \to Z(\to \mu^+\mu^-) + jets)}$$

allow us to make estimations.

Illustration of σ vs. N_{jet} measurement at CMS



Some Numbers*:

$$R^{\mu}_{W,Z} = \frac{\sigma(W(\to \mu\nu + \geq 2\text{jets}))}{\sigma(Z(\to \mu\mu + \geq 2\text{jets}))} \approx 6.58(6.99)^{\#}$$

$$\frac{\sigma(Z(\to \mu\mu + \geq 2\text{jets}))}{\sigma(Z(\to \mu\mu + \geq 3\text{jets}))} \approx 2.3$$ PYTHIA+CMS

$$\frac{\sigma(Z(\to \mu\mu + \geq 2\text{jets}))}{\sigma(Z(\to \mu\mu + \geq 3\text{jets}))} \approx 3.8$$ ALPGEN+ PYTHIA(+CKKW) + CMS

* Only for demonstration to show the analysis results.
# This is the number when cross-sections from PYTHIA are used.

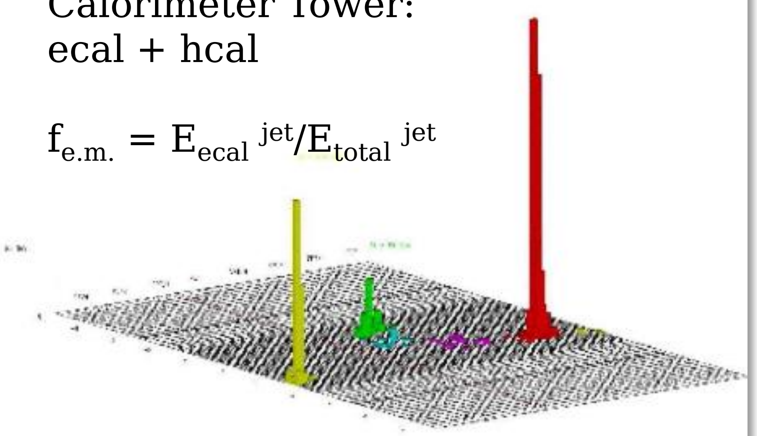
Need to have good control on syst. of lumi, unct. on the measurement of R, and ρ(N_{jet}).May need to tune MC to data for kinematic distributions.

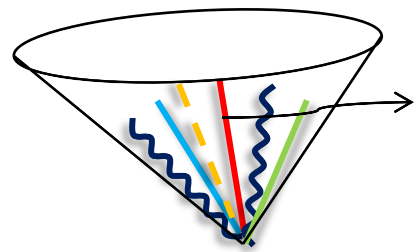
W/Z + Jets BG Rejection with ILV(I)

Some SUSY analysis require to reject leptons (i.e. multi-jets + E_T^{miss})
Indirect Lepton Veto (ILV) can be used: Combination of the e.m. fraction of first two leading jets with isolated leading track.

Calorimeter Tower:
ecal + hcal

$f_{e.m.} = E_{ecal}^{\ jet} / E_{total}^{\ jet}$





Track with $p_T > 15$ GeV is isolated, if

$$\frac{\Sigma p_T^i}{p_T^{ltrk}} \leq 10\%$$

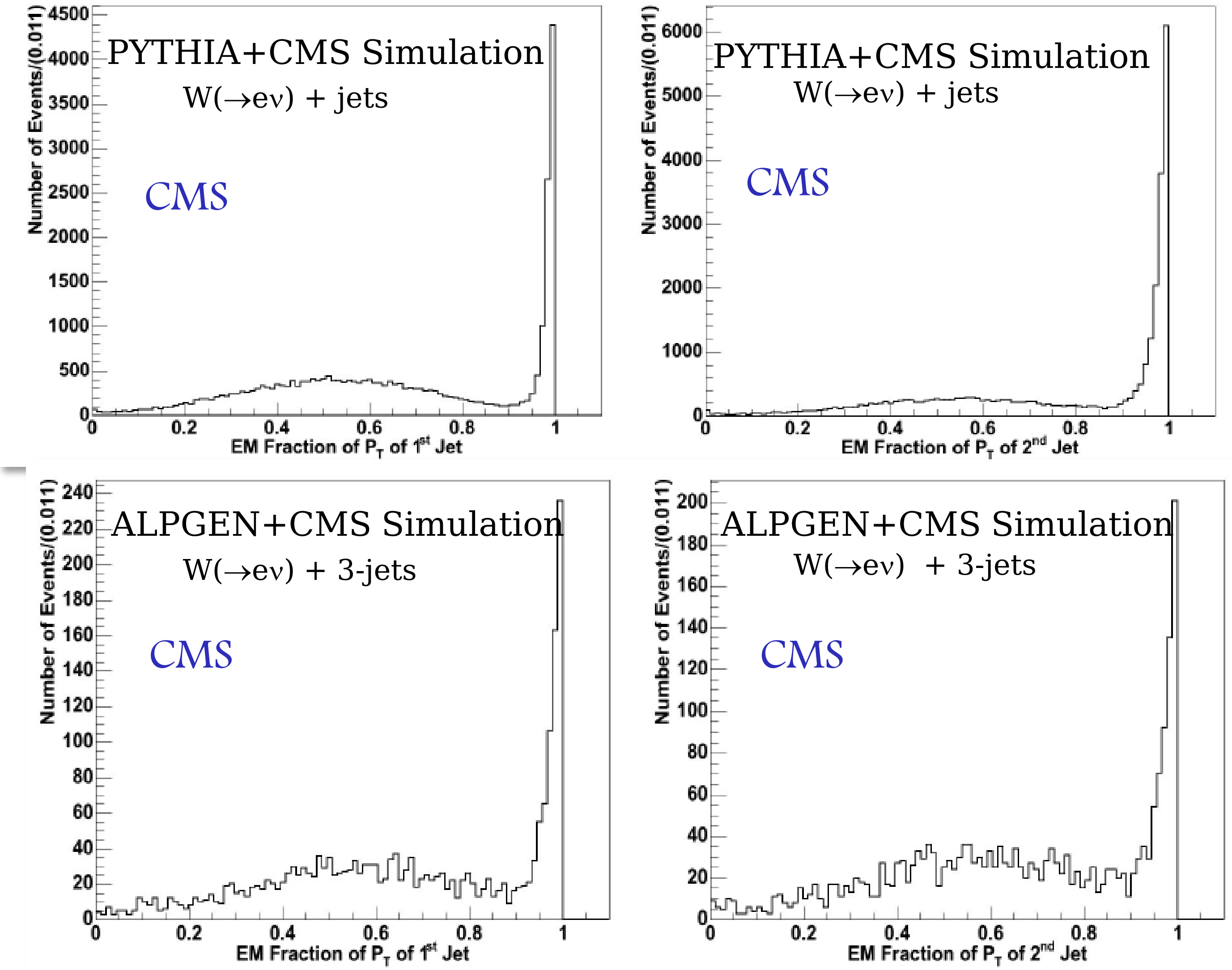
within $\Delta R < 0.35$ of the track.

ILV:= $[f_{e.m.}$ (1st jet) < 0.9 _AND_ $f_{e.m.}$ (2nd jet) $< 0.9]$ _AND_ $(Iso^{ltrk} = 0)$

How will it behave for different MC generators?

W/Z + Jets BG Rejection with ILV(II)

$f_{e.m.}$ **for two leading jets for W + jets sample**

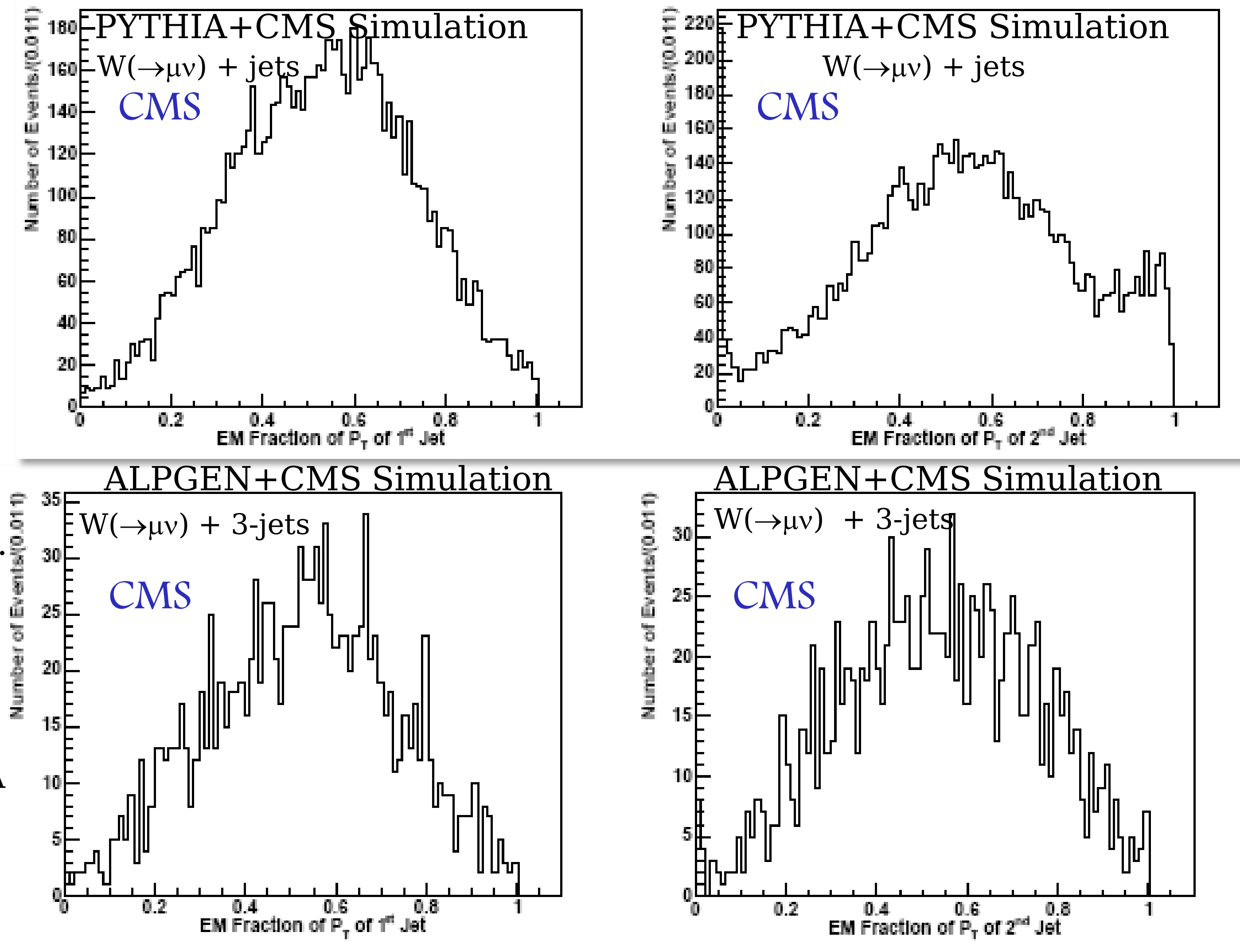


- ✓ PYTHIA and ALPGEN give consistent results.
- ✓ The jet related part of ILV is expected to be useful also with MC based on matrix element calculations.

i PYTHIA: V6.215
ALPGEN: V2.05
interfaced with PYTHIA V6.227 (+CKKW)

W/Z + Jets BG Rejection with ILV(III)

$f_{e.m.}$ **for two leading jets for W + jets sample**

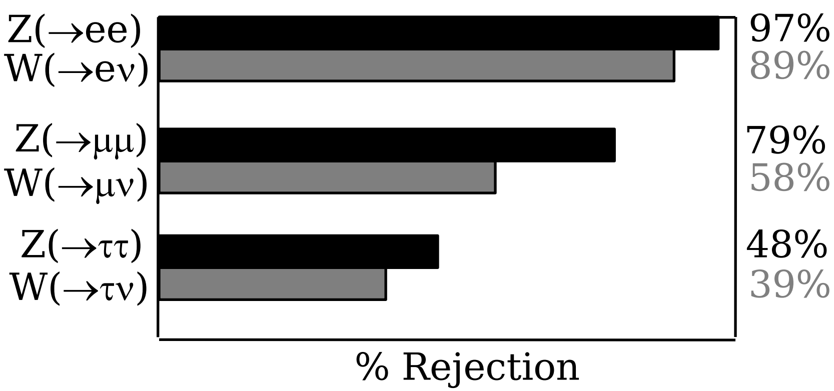


- ✓ PYTHIA and ALPGEN give consistent results.
- ✓ The jet related part of ILV is expected to be useful also with MC based on matrix element calculations.

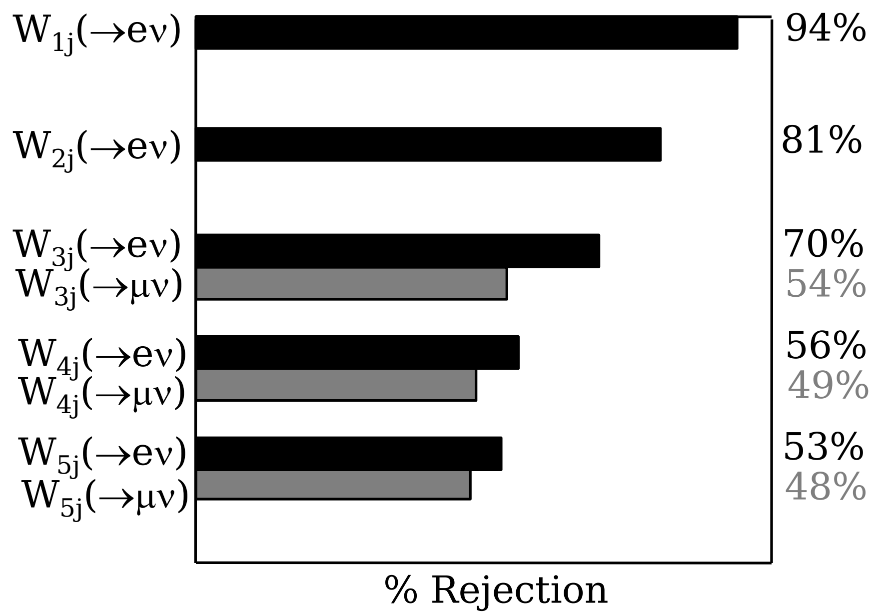
i PYTHIA: V6.215
ALPGEN: V2.05
interfaced with PYTHIA V6.227 (+CKKW)

W/Z + Jets BG Rejection with ILV(IV)

W/Z + ≥ 2 Jets (PYTHIA+CMS Simulation)



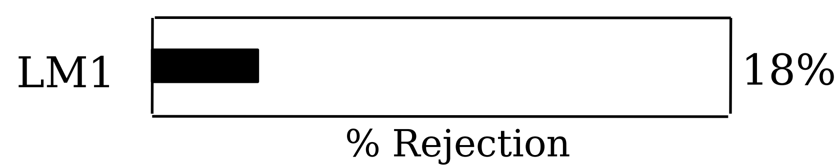
W + ≥ 2 Jets (ALPGEN+CMS Simulation)



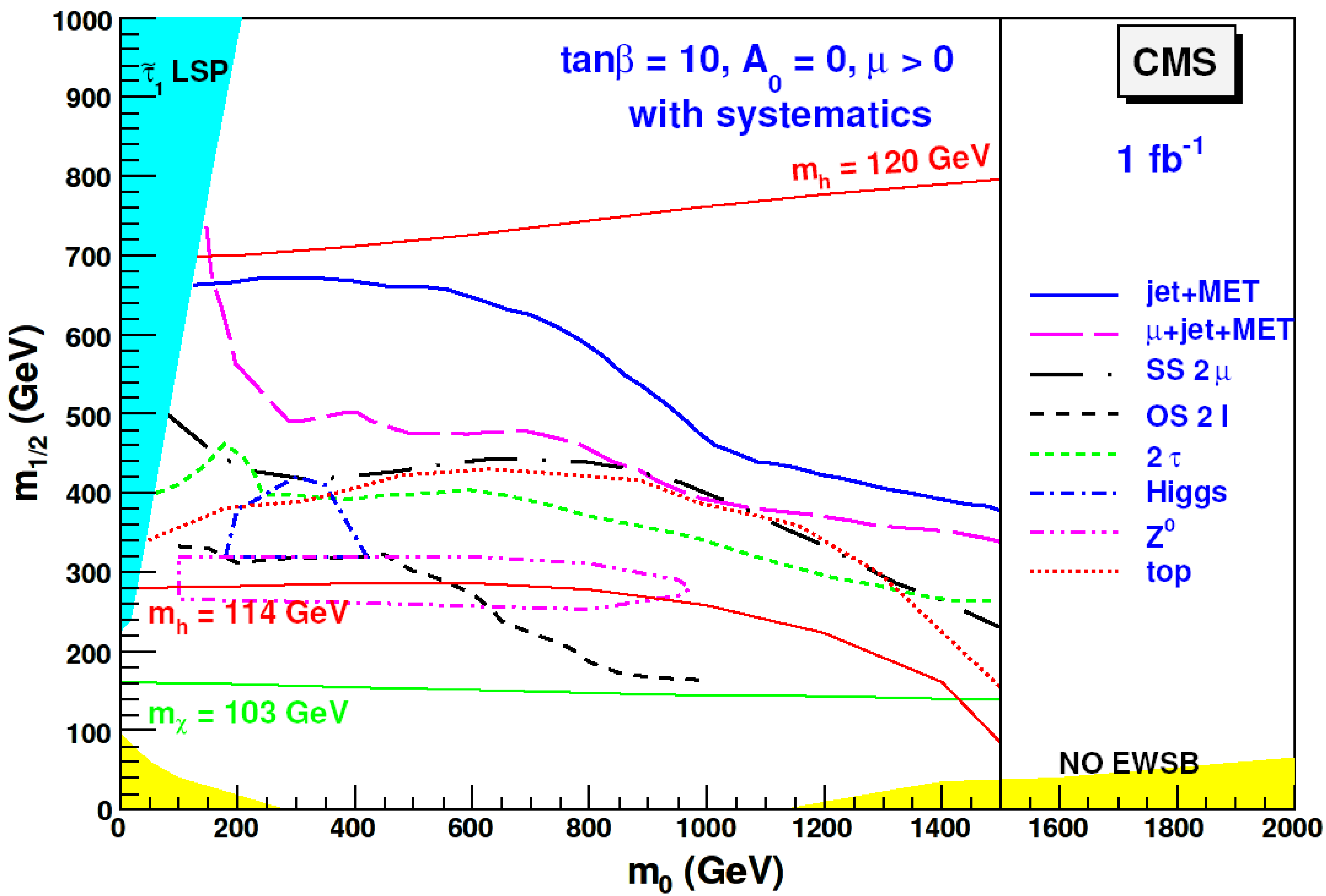
A Strong tool, may need to improve it.

- ✓ Rejection efficiency decreases with increased lepton mass.
- ✓ The rejection efficiency decreases with increased jet multiplicity.
- ✓ ALPGEN and PYTHIA give comparable results for low jet multiplicities.

PYTHIA+ISASUSY +CMS Simulation



Expected CMS Reach for 1 fb^{-1}



Conclusions

- CMS has performed many SUSY oriented studies and results are published in PTDR-Vol. II.
- Much of the emphasis was put on data driven methods.
- W/Z + Jets is one of the major backgrounds for SUSY and CMS has been doing analysis for rejections as well as usage of them.
  - Normalization of MC to data.
  - Estimation of $Z(\to\nu\nu)$ + Jets by using $Z(\to\mu\mu)$ + Jets.
  - Estimation of W + Jets by using lepton universality and W/Z cross-section measurements.
  - Missing transverse energy calibration by using $Z(\to\mu\mu)$ + Jets.
  - Rejection by using Indirect Lepton Veto.

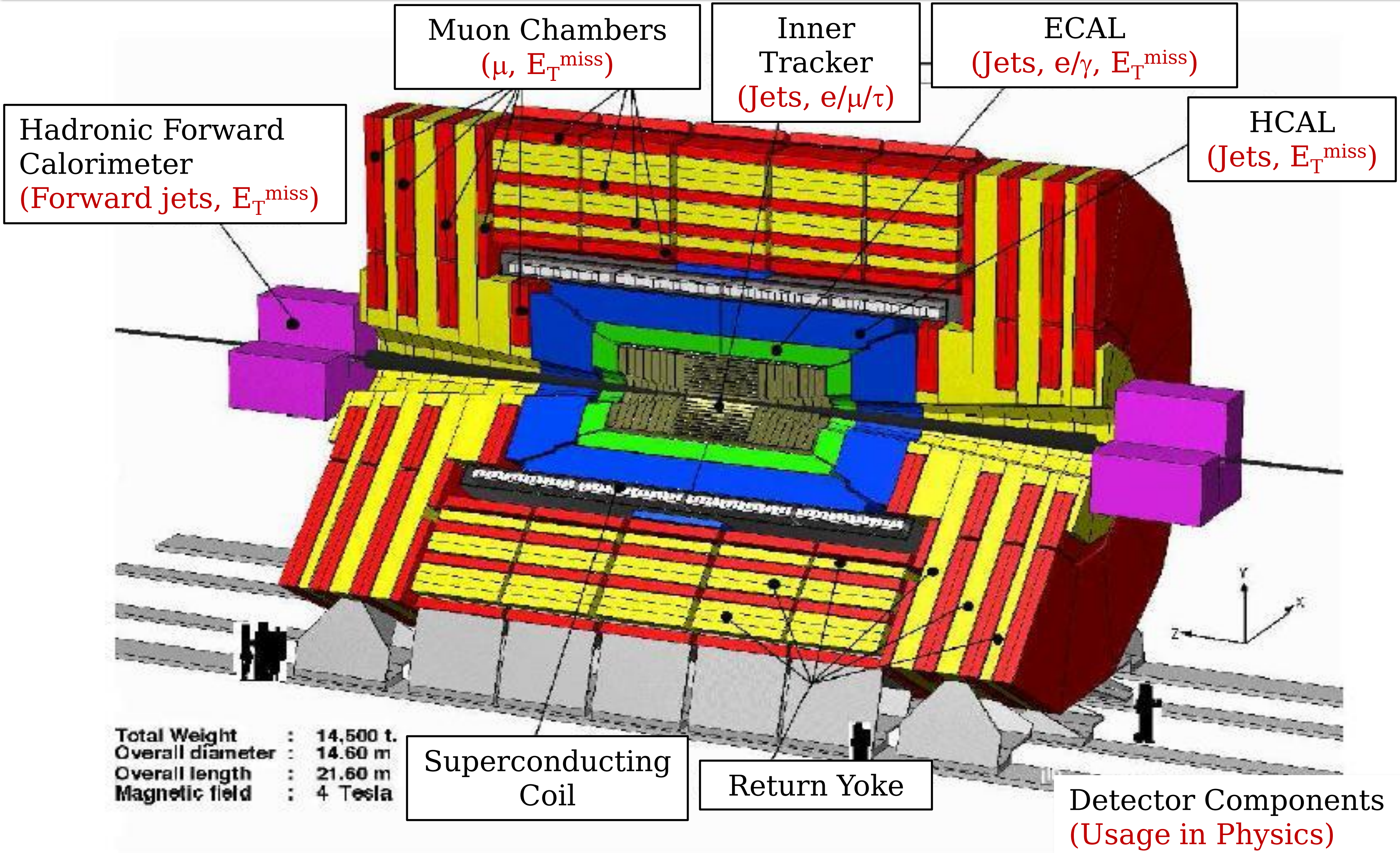
Background estimation is of key importance for the discoveries at LHC! We are eager to perform comprehensive studies with MC generators together with data when LHC starts.

Details and References

1. J. Phys. G: Nucl. Part. Phys. 34 (2007) 995 and http://cmsdoc.cern.ch/cms/cpt/tdr/ptdr2_LHCC.pdf
2. T. Yetkin, "Search for SUSY in Missing Transverse Energy Plus Multi-Jet Topologies at √s=14 TeV and Geant4 Simulation of the CMS Hadronic Forward Calorimeter in the 2004 Test Beam", Ph.D. Thesis, University of Cukurova, 2006.
3. S. Abdullin and A. Drozdetskiy, *hep-ph/0605143* .
4. *http://cmsdoc.cern.ch/cms/cpt/tdr/ptdr1_final_colour.pdf*

BACKUP SLIDES

CMS Detector



SUSY Signature at LHC

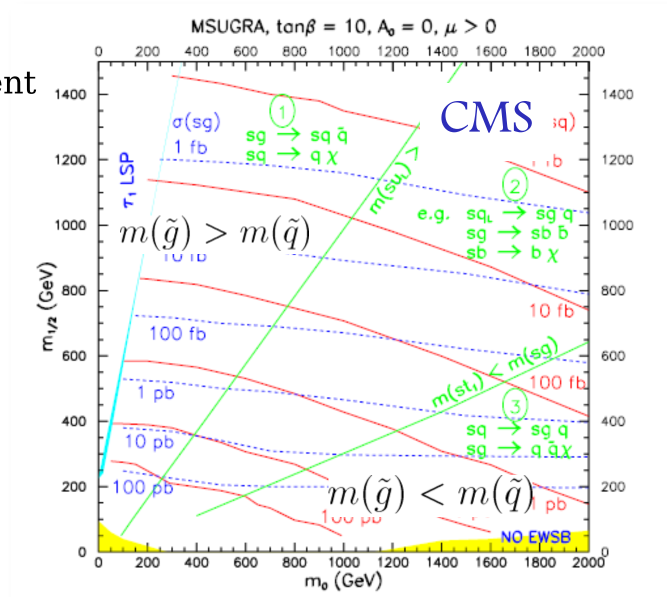
- Expect pair production of gluinos/squarks or squark/gluino/chargino/neutralino productions.

- Cascade decays of sparticles and R-Parity conservation (for Dark Matter Candidates form theory) make the signature of SUSY:

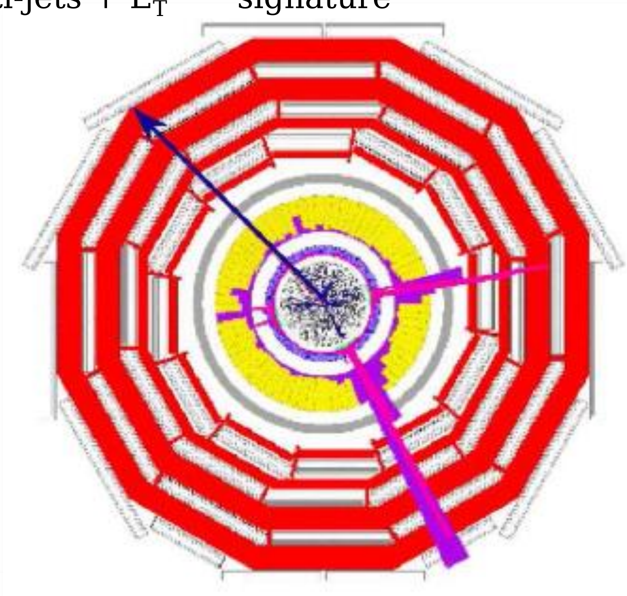
$$pp \to Jets + E_T^{miss} + \dots$$

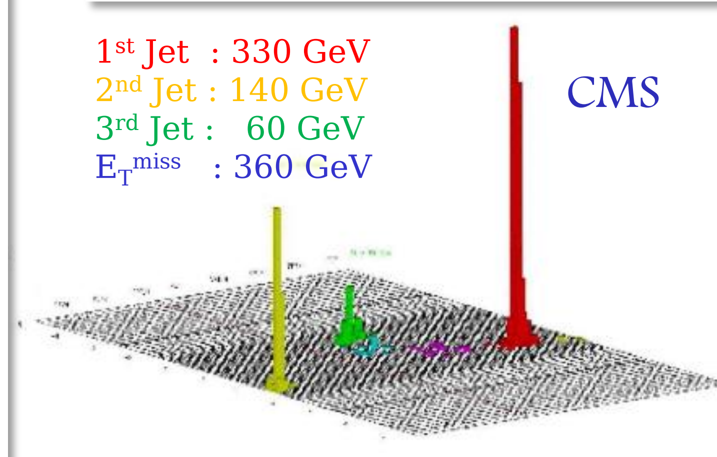
- Three mass regions. Different analysis strategies.

- PTDR-Vol. II shows the experimental approach and readiness[1].



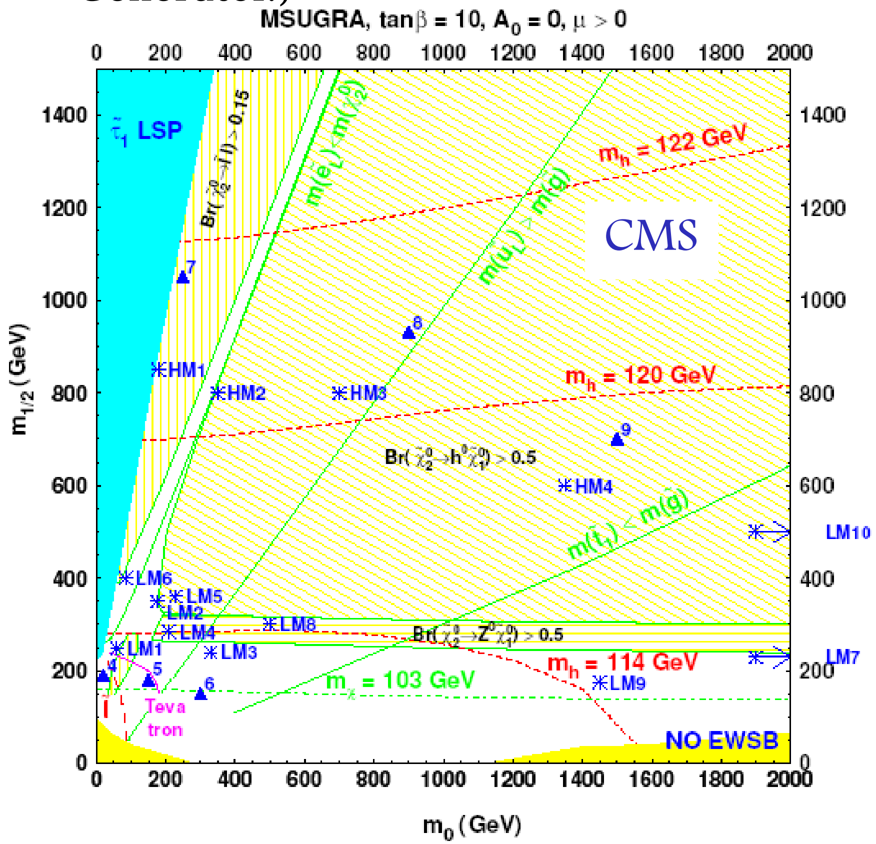
Example event from LM1 SUSY sample with multi-jets + E_T^{miss} signature





SUSY Analysis at CMS

Different benchmark points have been studied at PTDR-Vol. II to develop analysis strategies and to show discovery potential. (PYTHIA + ISASUSY was used as MC Generator.)



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

LM1 benchmark point is used to optimize analysis and 5σ discovery reach. Other points, depending on analysis scopes, are also used for full analysis.

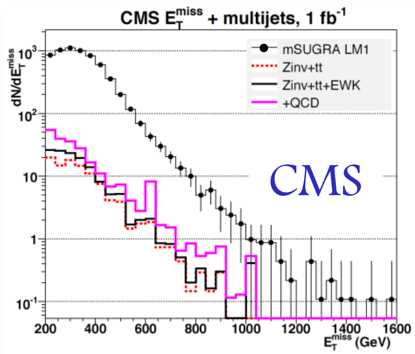
Assorted SUSY Studies from PTDR-Vol. II

Inc. multi-jets + E_T^{miss}

Trigger: L1 and HLT jet-met@95%ε

Cuts are optimized based on LM1 benchmark.

- E_T^{miss} > 200 GeV
- ≥3 jets with E_T> 180, 110, and 30 GeV, and |η|< 1.7, 3, and 3
- Indirect Lepton Veto
- Various cuts on Δϕ between jets and E_T^{miss}
- $H_T(=E_T^{2nd\,j} + E_T^{3rd\,j} + E_T^{4th\,j} + E_T^{miss}) > 500$ GeV



Conclusions:

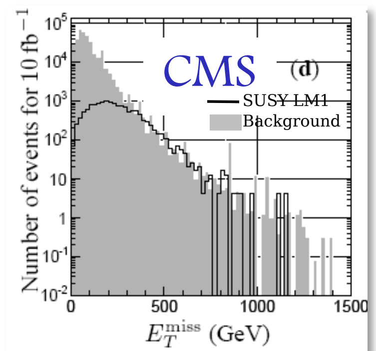
- ✓ LM1 will be observable with 1 fb^{-1} data with S/B=6319/244.5 by giving 13% signal efficiency.
- ✓ 5σ discovery is achievable with ~6 fb^{-1} data.

Inc. μ + multi-jets + E_T^{miss}

Trigger: single or di-muons

Cuts are optimized based on LM1 benchmark point and used a genetic algorithm (GARCON[2])

- ≥1 iso. μ with p_T > 30 GeV
- E_T^{miss} > 130 GeV
- ≥3 jets with E_T> 440, 440, and 50 GeV, and |η|< 1.9, 1.5, and 3
- Various cuts on Δϕ between jets and E_T^{miss}



Conclusions:

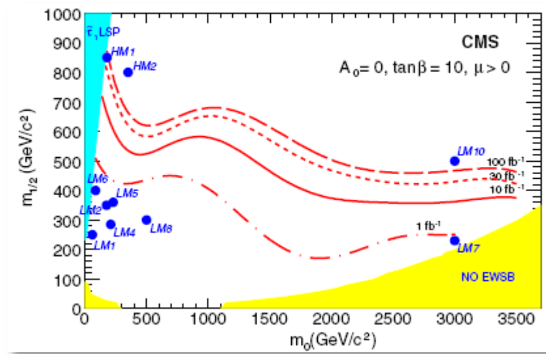
- ✓ LM1 will be observable with 10 fb^{-1} data with S/B=311/2.5 by giving > 34 σ significance.
- ✓ Low mass region, based on optimization, will be observed up to 1.5 TeV/c^2.
- ✓ High mass region beyond 2 TeV/c^2 can be probed with 60 fb^{-1} data.

Inc. SS di-μ + multi-jets + E_T^{miss}

Trigger: di-muon HLT @98%ε

Cuts are optimized based on LM1 benchmark point and used a genetic algorithm (GARCON[2])

- ≥2 iso. SS μ with p_T > 10 GeV
- $\Delta R(\mu_i, \mu_j) \geq 0.01$ (μ iso. by tracker and calo.)
- E_T^{miss} > 200 GeV
- ≥3 jets with E_T> 175, 130, and 55 GeV



Conclusions:

- ✓ LM1 will be observable with 10 fb^{-1} data with S/B=341/1.5 by giving > 37σ significance.
- ✓ Low mass region, based on optimization, will be observed with 16σ < Signif. < 37σ. (except LM10)
- ✓ High mass region (HM1,HM1) require more than 10 fb^{-1} data to claim 5σ discovery.

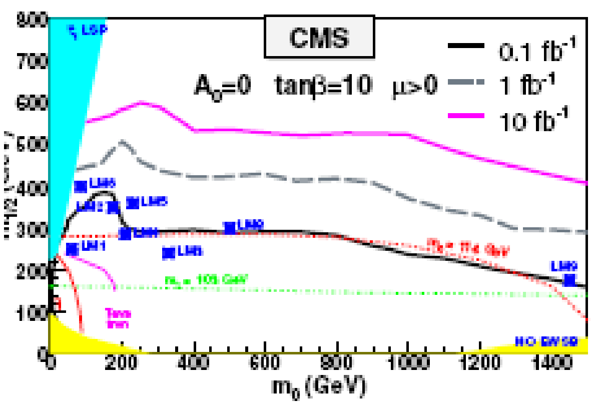
Assorted SUSY Studies from PTDR-Vol. II(con'td)

Inc. di-τ + multi-jets + E_T^{miss}

Trigger: L1 and HLT jet-met

Cuts are optimized based on LM2 benchmark point.

- ≥2 τ candidates
- $\Delta R(\tau_i, \tau_j) < 2$
- $E_T^{miss} > 150$ GeV
- ≥2 jets with $E_T > 150$



Conclusions:

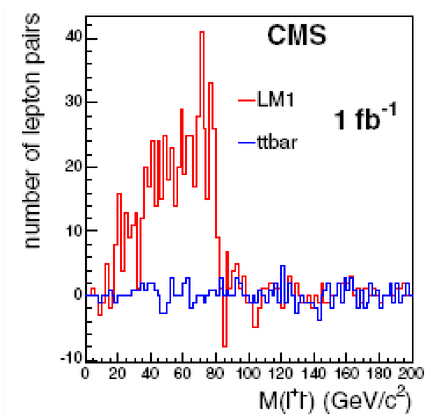
- LM1 will be observable with ~13 fb^{-1} data with S/B=2735/938 with 3% signal selection efficiency.
- Low mass region, based on optimization, will be observed with5σ by using < 1 fb^{-1} data .

Inc. OS di-leptons + multi-jets + E_T^{miss}

Trigger: L1 and HLT single isolated muon

Cuts are optimized based on LM1 benchmark.

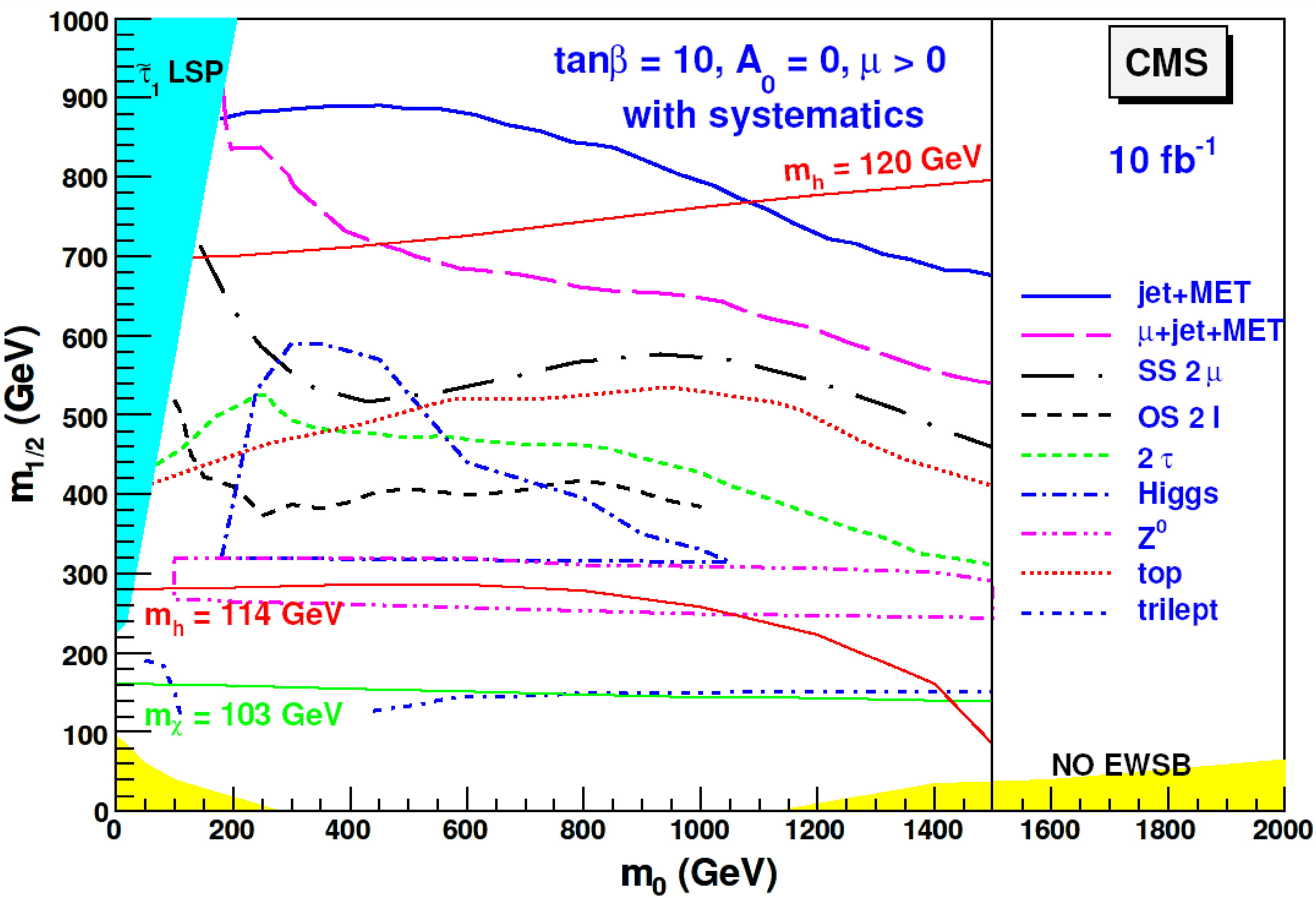
- ≥2 iso. SFOS isolated leptons with $p_T > 10$ GeV
- $\Delta R(l_i, l_j) \geq 0.02$ (0.15) for ee (μμ) pair.
- $E_T^{miss} > 200$ GeV
- ≥2 jets with $E_T > 100$, 60 with $|\eta| < 3$.



Conclusions:

- M_{ll} for LM1 shows a clear edge for 1 fb^{-1}.
- S/B=4.1 with 1.6% signal efficiency.
- 5σ discovery is achievable with 14 pb^{-1} .

Expected CMS Reach for 10 fb^{-1}



Cross-Sections

Pythia

Sample	X-Sec(fb)	Gen.($\times 10^3$)	Used ($\times 10^3$)
Z + jets ($75 < \hat{p}_T < 125$)	1.25×10^5	149	147
Z + jets ($125 < \hat{p}_T < 200$)	2.70×10^4	99	93
Z + jets ($200 < \hat{p}_T < 350$)	5.43×10^3	50	48
Z + jets ($350 < \hat{p}_T < 550$)	6.44×10^2	36	34
W + jets ($75 < \hat{p}_T < 125$)	9.45×10^5	285	282
W + jets ($125 < \hat{p}_T < 200$)	2.15×10^5	181	164
W + jets ($200 < \hat{p}_T < 350$)	4.38×10^4	97	88
W + jets ($350 < \hat{p}_T < 550$)	4.28×10^3	79	77

ALPGEN interfaced with PYHTIA and CKKW Matching

Sample	X-Sec(fb)	Gen.($\times 10^3$)
$W(\rightarrow \mu, e + \nu)$ + 0 jet	1.03×10^7	100
$W(\rightarrow \mu, e + \nu)$ + 1 jet	2.52×10^6	58
$W(\rightarrow \mu, e + \nu)$ + 2 jets	7.38×10^5	8.23
$W(\rightarrow \mu, e + \nu)$ + 3 jets	1.96×10^5	6.74
$W(\rightarrow \mu, e + \nu)$ + 4 jets	5.13×10^4	1.29
$W(\rightarrow \mu, e + \nu)$ + 5 jets	1.39×10^4	0.48

W/Z + Jets BG Rejection with ILV(IV)

PYTHIA+CMS Simulation

	Baseline Requirements	EMF(1)&&EMF(2)	$Iso^{ltrk}=0$	Both
Sample	(N_{events})	(%)	(%)	(%)
$W(\to e+\nu)+\geq 2$ jets	28090	86.04	39.25	89.32
$W(\to \mu+\nu)+\geq 2$ jets	8038	10.69	53.42	58.17
$W(\to \tau+\nu)+\geq 2$ jets	19324	23.08	20.27	39.28
$Z(\to e+e)+\geq 2$ jets	19855	94.57	57.29	97.11
$Z(\to \mu+\mu)+\geq 2$ jets	5474	15.16	75.44	79.06
$Z(\to \tau+\tau)+\geq 2$ jets	16742	26.32	28.71	48.27

ALPGEN+CMS Simulation

	Baseline Requirements	EMF(1)&&EMF(2)	$Iso^{ltrk}=0$	Both
Sample	(N_{events})	(%)	(%)	(%)
$W_{1j}(\to e+\nu)+\geq 2$ jets	4015	90.96	45.28	94.15
$W_{2j}(\to e+\nu)+\geq 2$ jets	2281	74.26	38.67	80.8
$W_{3j}(\to e+\nu)+\geq 2$ jets	2233	60.41	35.33	70.04
$W_{4j}(\to e+\nu)+\geq 2$ jets	491	46.03	30.55	56.01
$W_{5j}(\to e+\nu)+\geq 2$ jets	262	40.08	30.15	53.05
$W_{3j}(\to \mu+\nu)+\geq 2$ jets	1283	7.01	51.67	54.01
$W_{4j}(\to \mu+\nu)+\geq 2$ jets	352	4.26	47.44	48.86
$W_{5j}(\to \mu+\nu)+\geq 2$ jets	226	4.24	45.13	47.79

PYTHIA+ISASUSY +CMS Simulation

LM1	357555	12.77	7.42	18.28

A Strong tool, need to improve it.

- ✓ Leading track isolation is expected to be independent from jet multiplicity and MC used.
- ✓ $f_{e.m.}$ is affected by increased number of jets and different flavors.
- ✓ The rejection efficiency changes for different decays of W/Z
- ✓ Tracking only at central region (will result in background).

Baseline selections: ≥1 P.V., ≥ 2-jets with $p_T \geq 30$ GeV and $|\eta| \leq 3$, $|\eta^{1st}$ jet $| \leq 1.7$