Systematic uncertainties in SUSY search at LHC:
experimentalist view

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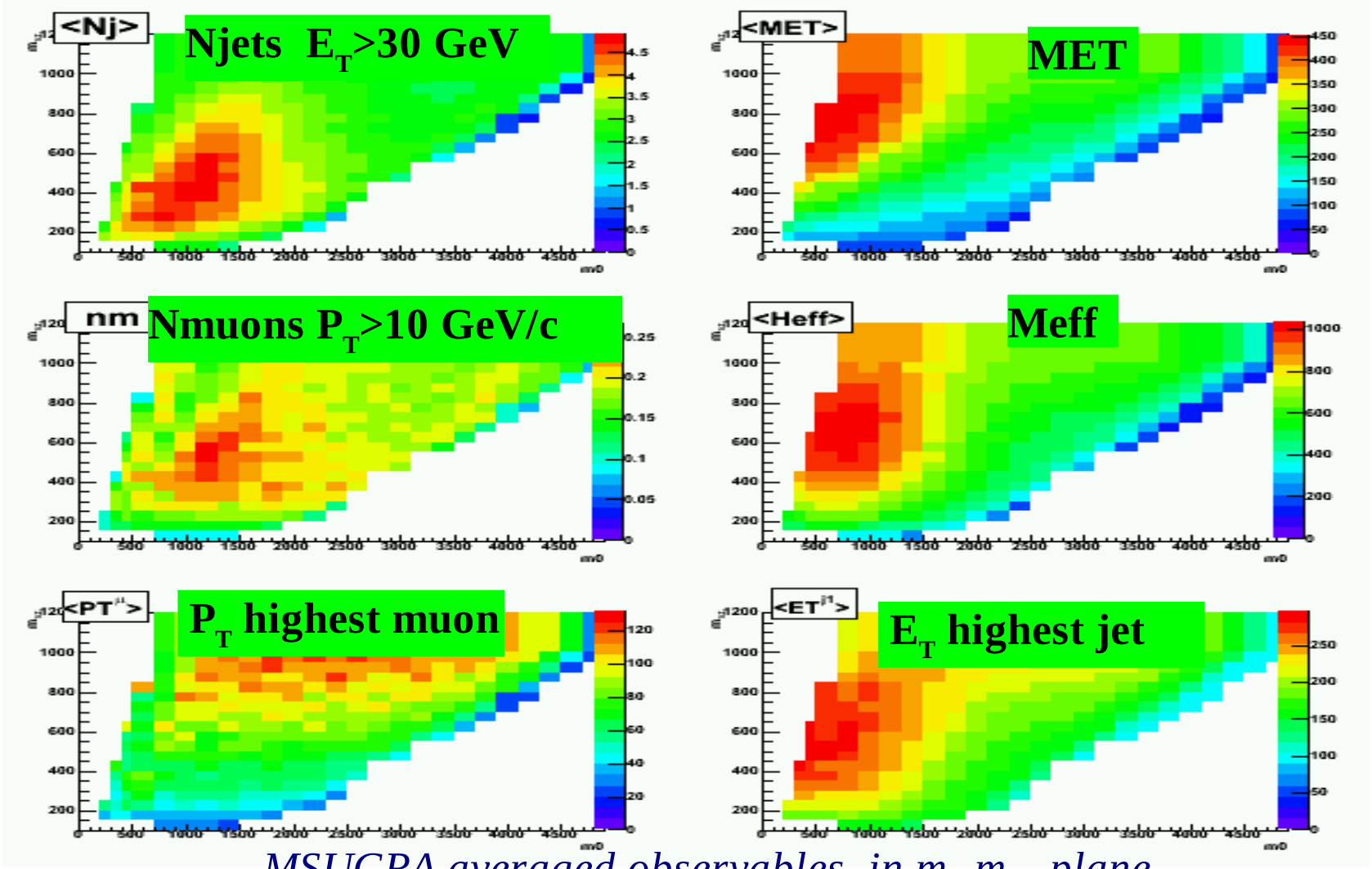
SUSY observables

Signal signature: **Jets+MET+Leptons**

mass scale: *sumET(EM+HAD), MET, Meff, jetsET(1,2,..), Leptons PT(1,2,..),..*

event topology: *N_{jets}(ET>ET0), $N_{leptons}$(PT<PT0), invariant masses and angles (jets, leptons, MET), shape(sphericity, planarity, thrust), PT asymmetry,*



CMS FastSim

tanβ=50 A_0=0

MSUGRA averaged observables in m_0-$m_{1/2}$ plane

SM backgrounds

Main SM bkg channels:

Channel		<MET>,GeV	<Nj> (>30GeV)	<Nm> (>10GeV)
Ttbar(lν)+jets	837 pb^{NLO}	64	4.4	0.18
W(lν)+jets (>50 GeV)	58 nb	74	1.8	0.15
Bbbar+jets	2 b	55	2.1	0.06
QCD (>20 GeV)	300 b	22.8	2.6	0.04
Z(ll)+jets(>20 GeV)	5.8 nb	41	2.1	0.25
Zbbar+jets	790 pb	26	1.7	0.32
ZW(3l)	52 pb ^{NLO}	41	0.6	0.4
ZZ(4l)	16 pb ^{NLO}	28	0.7	0.45
MSUGRA(m_0,m_{12},tan)				
LM1 60,250,10	62 pb ^{NLO}	224	4.2	0.25
LM9 1450,175,50	42 pb ^{NLO}	110	4.7	0.2

Different set of backgrounds for different SUSY models and topologies.

Two complimentary approaches to search beyond SM:

- *'model independent': spot any deviations from SM in one topology*
- *'model dependent': consistent check of all manifestation of a particular model in different searches(topologies).*

-> different strategy for optimization of the bkg suppression

Used in CMS so far: ***selection of the defined topology tuned to one mSUGRA point, then extrapolate to the whole mSUGRA plane***

SUSY selections

CMS Physics TDR: set of 'realistic' analysis using full CMS simulation

Most of analysis are tuned to the low mass region (LM1 m_0=60 $m_{1/2}$=250 tanβ=10)

channel	Trigger	MET,GeV	Jets (ET1,ET2,ET3)	Leptons(PT)	Nsig. 10 fb^{-1} (m0, m1/2, tanb)	N bkg. 10fb^{-1}
Jets + MET	Jet+MET	>200	>2 (180,110,30,..)*	-	6 10^4 (60,250,10)	2450 (qcd,ttbar,zj)
Jets+ MET+ μ	1 ,2	>130	>2 (440,440,50)*	1 (>30)	311 (60,250,10)	2.5 (wjets,ttbar)
SS 2μ + Jets+MET	2	>200	>2 (175,130,55)*	2 (>10)	341 (60,250,10)	1.5 (ttbar)
OSSF + MET + Jets	Jet+MET	>200	>1 (100,60,.)	OSSF(>10)	8.5 10^3 (60,250,10)	2 10^3 (ttbar,wj,zj)
OS 2τ + JET + MET	Jet+MET	>150	>1(150,150,..)	OS 2	1140 (185,350,35)	427 (ttbar)
Top + Jets+ MET	Jet+MET	>150	4(30)	e, (>5)	380 (60,250,10)	220 (ttbar)
Z + Jets + MET	2 ,2e	>255	-	2e, ,Minv=Zo	1289 (210,285,10)	440 (ttbar)
Ho + Jets + MET	Jet+MET	>200	>4(200,150,50,30) -	-	1.4 10^4 (60,250,10)	200 (ttbar)
Trileptons	2 ,2e	-	No central jets	2e, (>17,10)	53 (1450,175,35)	157 (dy,zj.ttbar)

Numbers without systematics

Significance:

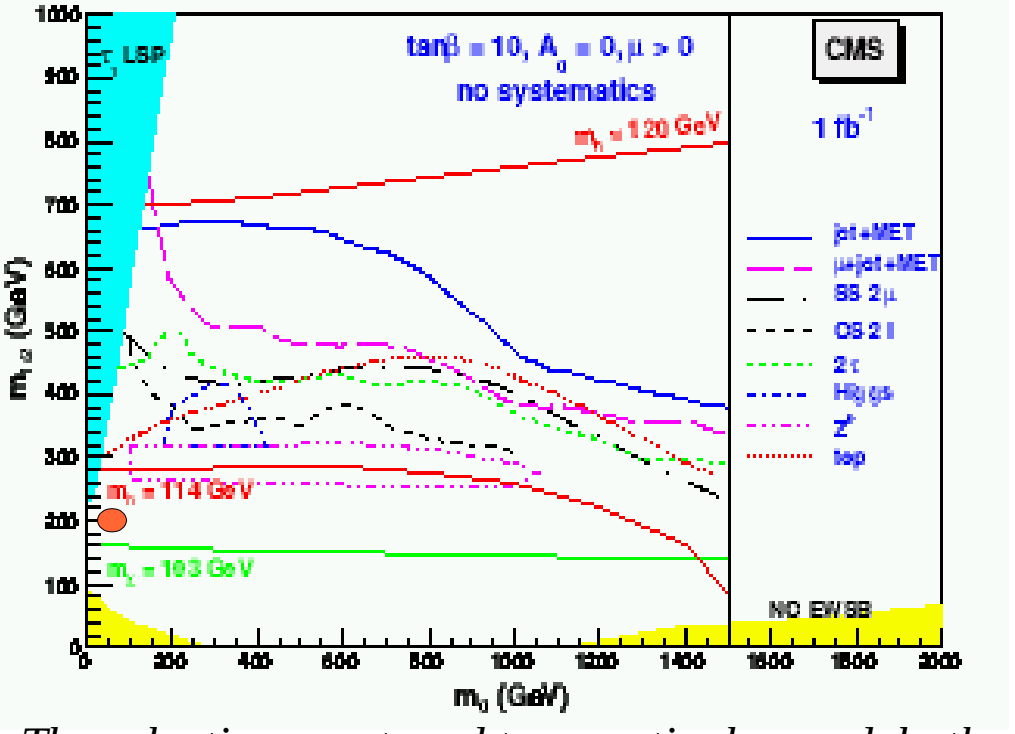
systematic σ_{sys} ~dN_{bkg}+dN_{sig} :

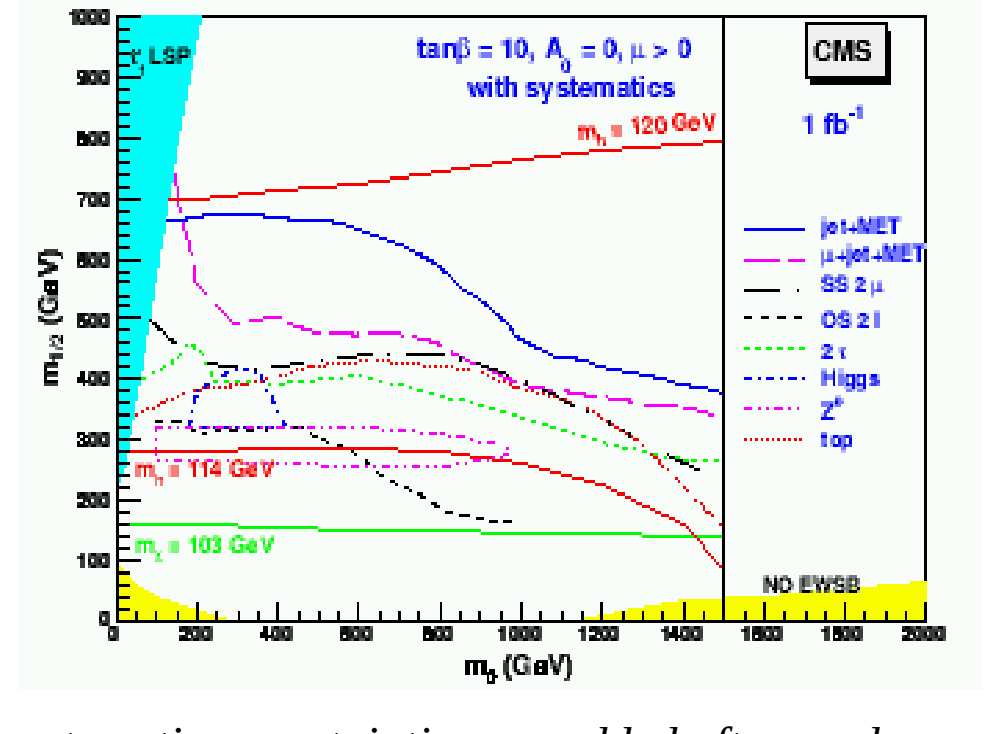
$$\frac{N_{sig}}{\sqrt{N_{bkg}+\sigma_{sys}^2}}$$

- **detector related σ_{det}** ; *luminosity, JetEnergyScale, resolutions, fakes, etc*
- **model uncertainties σ_{th}** ; ***cross sections, QCD(μ), ISR/FSR, PDF,UE, etc....***

Discovery reach

CMS discovery reach for different topologies (2006): significance>5





The selection was tuned to a particular model, the systematic uncertainties are added afterwards
Included: luminosity, cross sections, PDF and detector JES, resolution,...
QCD uncertainties are missed (for ex. ME jets can spoil analysis tuned with PS)
Uncertainties are treated differently for different analysis.

-> include systematic uncertainties in the stage of optimization of selection and consistent treatment of systematics for all analysis, i.e.:

- **Factorize the uncertainties of each observable used in selection taking into account correlations.**
- **Select /define observables and theirs ranges least prone to the uncertainties**

Data driven(dd) calibration

Use the preselected reference sample in the signalless region to verify the model and extrapolate results into the signal region., i.e. absolute 'scale' calibration. Note, the extrapolation is still sensitive to the model uncertainties.

Reference channels:

- *Z+jets: Z->l^+l^-, M_{ossf}~M_z, MET<MET0*

bkg: bbar, Wjets, ttbar, ***but also SUSY signal χ_2^0->$Z\chi_0$ (dm_χ~Mz)***

Example: selection cuts efficiencies Z(mm)+jets(Nj<3)

		Zjets 5.8E+3	Ttbar 8.4E+2	Wjets 5.8E+4	QCD 2.5E+8	Bbjets 2.9E+6
HLT	**Muons**	0.55	0.29	0.26	3.0E-3	0.02
METrecoil	**<50 GeV**	0.84	0.42	0.74	0.88	0.95
SumETj	**<55 GeV**	0.67	0.04	0.65	0.03	0.61
Njets(>30)	**<3**	0.99	0.49	0.99	0.7	0.95
Etj1	**<45 GeV**	0.99	0.66	0.98	0.8	0.99
Nμ (pt>10)	**2**	0.56	0.33	0	0.2	0.18
Ossf	**1**	0.99	0.74	0.7	0.6	0.64
PT1-PT2/PT1+PT2	**<ß.12**	0.91	0.62	0.19	0	0.73
φ(μμ)	**>130**	0.95	0.47	0.38	0	0.28
Minvossf	**70-120**	0.9	0.22	0.08	0	0.02
N event 10pb-1		**1.1E+4**	**0.2**	**1.3**	**<1**	**12.7**

- *Wjets, ttbar and qcd also can be used as reference in limited topologies*

Calibrate all observables used in SUSY selection...

Systematic uncertainties: cross sections

For optimization of SUSY selection one needs to know composition of the selected data streams. *Trigger streams: jets(200,2*150,3*85) , jets(180,125*2)+MET(60), MET(65), sumET(120), muons(11,2*3), etc.*

Cross section will be measured from data (at the end of the days) but only in particular channels, needs extrapolation to other channels.

LO/NLO/NNLO K factors:

K factors mu - scale dependency: criteria for the convergence ?
What are the uncertainties in the prediction at LHC energy and CMS(ATLAS) measuring conditions(PTj, dRjj): dK(pt, mu) for different channels ?

Example: Z(mm) +jets LO/NLO cross sections (pb)

	Sherpa 1.1.0	Alpgen 2.13	MCFM5.2 LO	MCFM NLO
0j	612	880	919	1050
1j	298	325	310	475
2j	188	156	137	212
3j	112	64	-56	
Sum	1212	1426	1366	1738

K (Zjets) ~1.27
K (Wjets)~1.22
K(ttbar)~ 1.7
K(SUSY) ~1.2-2.0 (m_{susy}<500)

SUSY:
- *NLO/NNLO calculations consistent with SUSY.*
- *uncertainties in the signal topologies(important for the model dependent search)*
- *uncertainties in the complimentary measurements (EW, DarkMatter searches).*

Systematic uncertainties: PDFs

Use LHPDF libs: 41 PDF subsets for all partons

Reweighting technique:

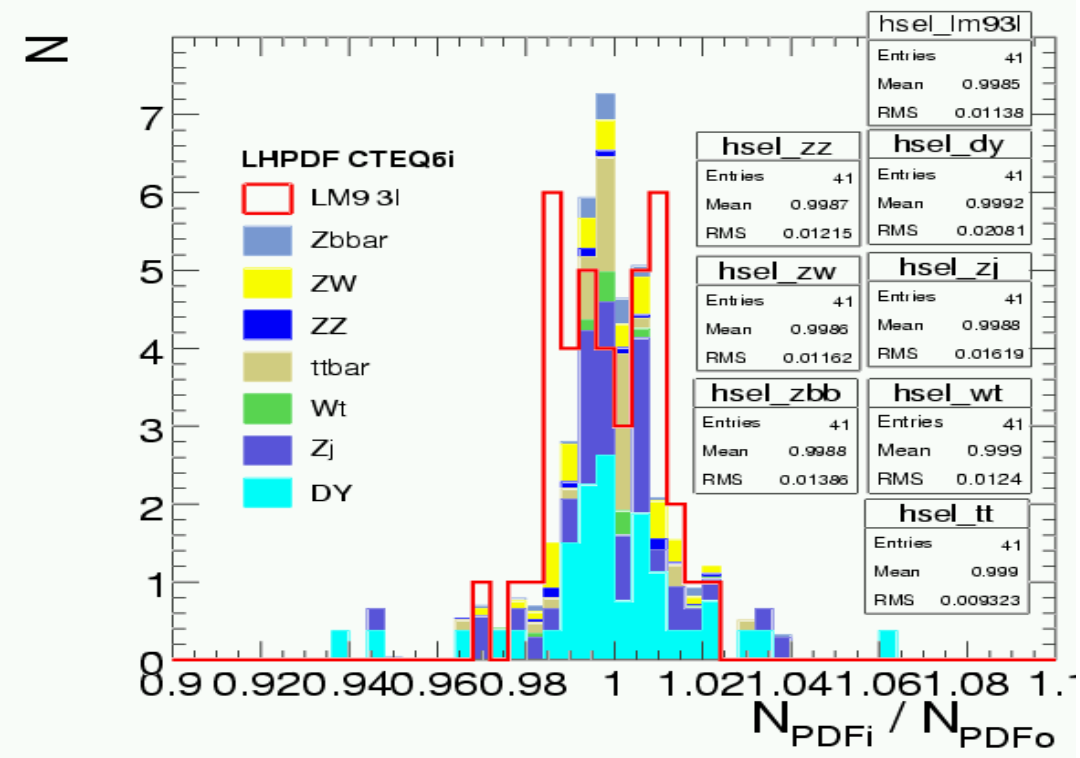
Assign for each selected event a vector of weights for each PDFi :

$W_i = PDF_i(pid1, pid2, x1, x2, Q) / PDF_0(pid1, pid2, x1, x2, Q)$; $x_{1,2} \sim p_L / s$

pid- parton (p,g) ID, PDF_0 - reference PDF

Calculate for each PDF subset : Nev=Sum W_i, and Nev_0 at reference PDF_0

normalization scale Q : running $Q^2 \sim x_1 x_2 s^2$ (divergent) or fixed $Q^2 \sim mu^2$?



Example.
mSUGRA trileptons from direct neutralino-chargino.
LHPDF 4.1.1 cteq61.LHgrid
sigma ~1.7 %
max+/- ~5% (DY)

Have to use same PDF set as used in the event generations

Systematic uncertainties: Jets ET

Ex. SUSY selection: *ETj1>150 GeV, Etj2>100, ETj3>30*

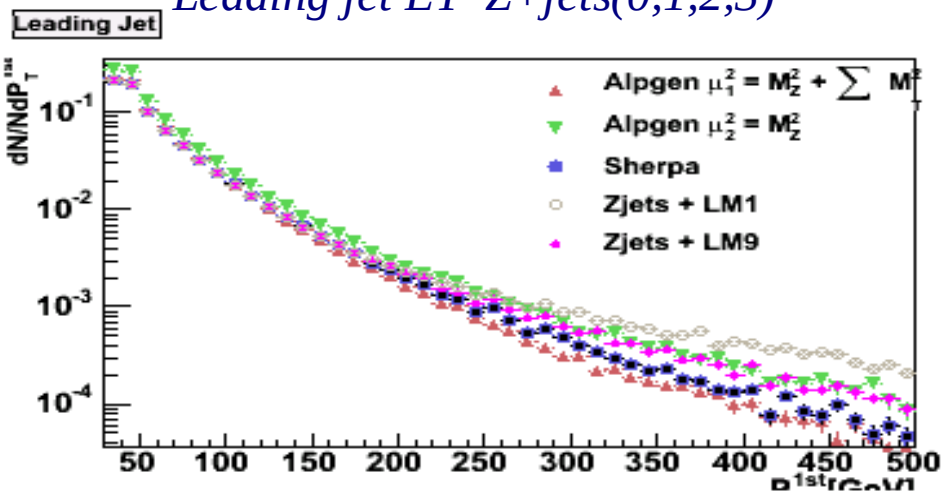
Uncertainties:

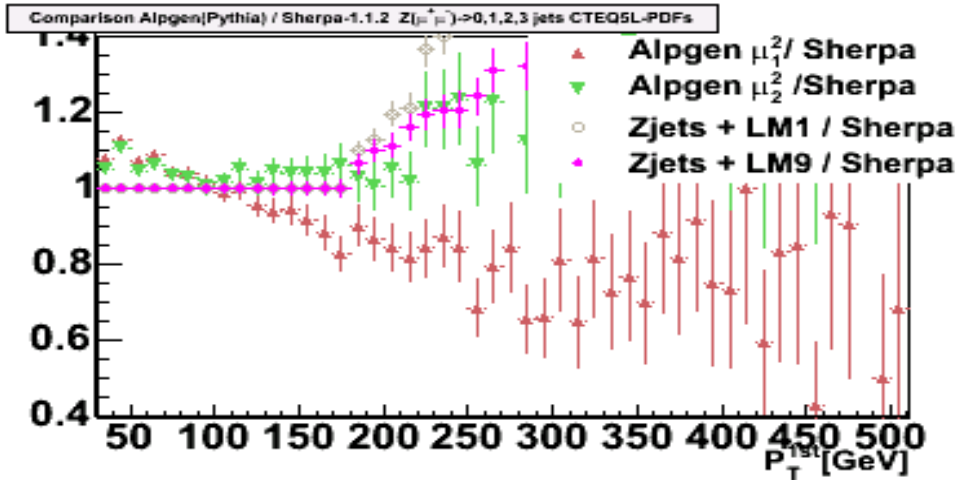
Detector: *JES (calibration: gamma-jets, Z-jets, tt(W)jets; dJES <5% at 1fb^{-1})*

Model: *jets ET tails (ME(LO/NLO), PS parameters, jets algorithms)*

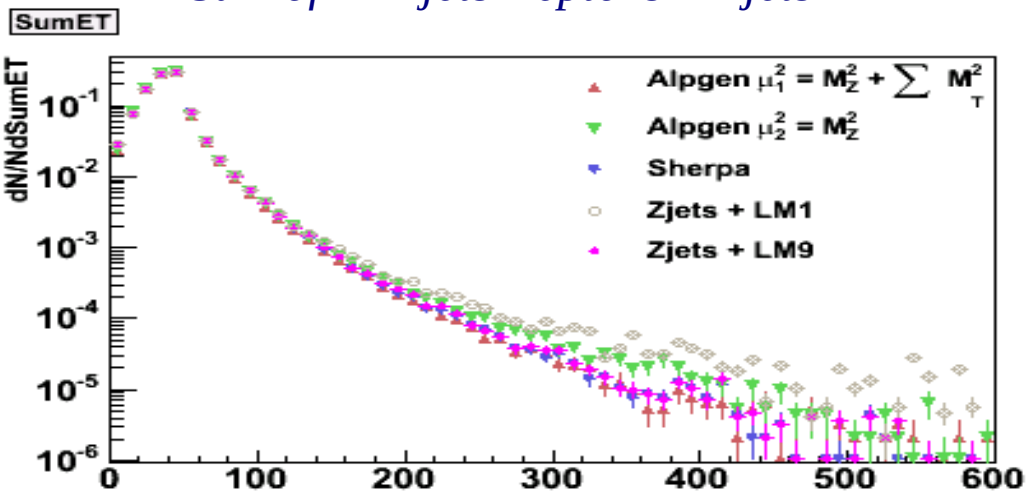
Z+Jets ET(MC) Sherpa, Alpgen(scale), mSUGRA LM9 L=1fb^{-1}

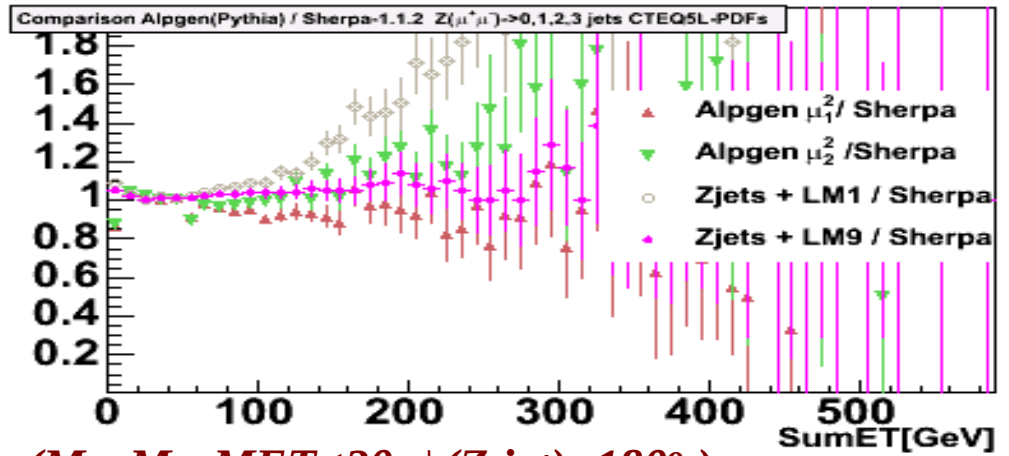
Leading jet ET Z+jets(0,1,2,3)





Sum of ET=jets+leptons Z+jets





dd calibration: *Z(ll)+one balanced jet (M_{ll}~M_Z, MET<20, ϕ(Z,jet)~180^o)*

Systematic uncertainties: Jets multiplicity

Ex: SUSY selection: N_{jet} (ET>20 GeV, eta<2) > 2

Uncertainties:

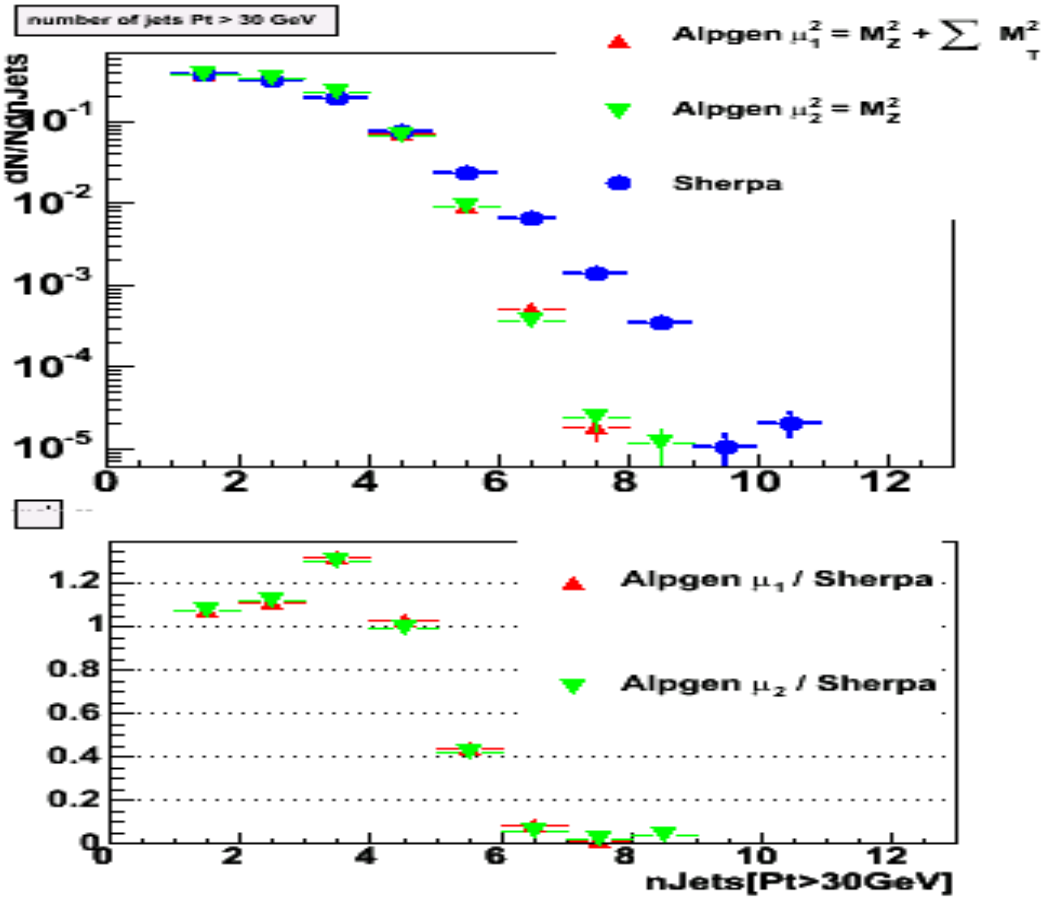
Detector: *jets algorithm, PU, beam halo, 'fake' jets*

Model: *head of jetET, shower parameters, QCD soft jets ->SR-> ME/PS matching, UE*

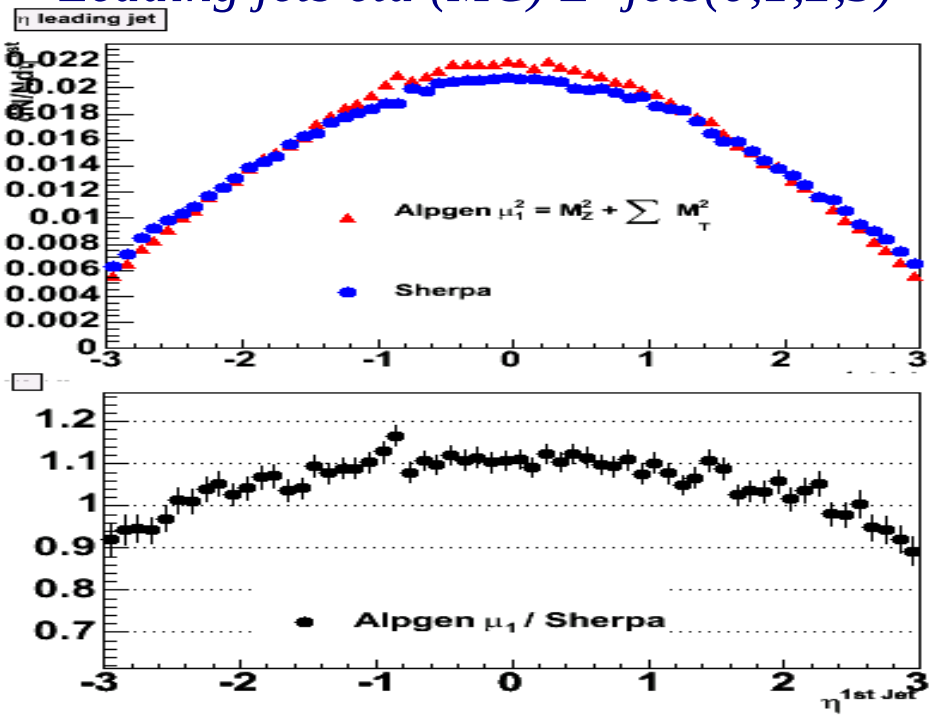
*** Verification of matching (MLM, CKKW) for SM.**
Has to be tuned for each channel?

*** Need matching for SUSY as well**
(can affect SUSY soft jets in the degenerate scenarios :$m_{\tilde{g}} \sim m_{\tilde{q}}$, Focus Point)

Njets(>30) Z+jets(0,1,2,3)



Leading jets eta (MC) Z+jets(0,1,2,3)



dd calibration: Z(ll)+Njets ($M_{ll} \sim M_Z$)

Systematic uncertainties: MET

Ex. SUSY MET >100 GeV

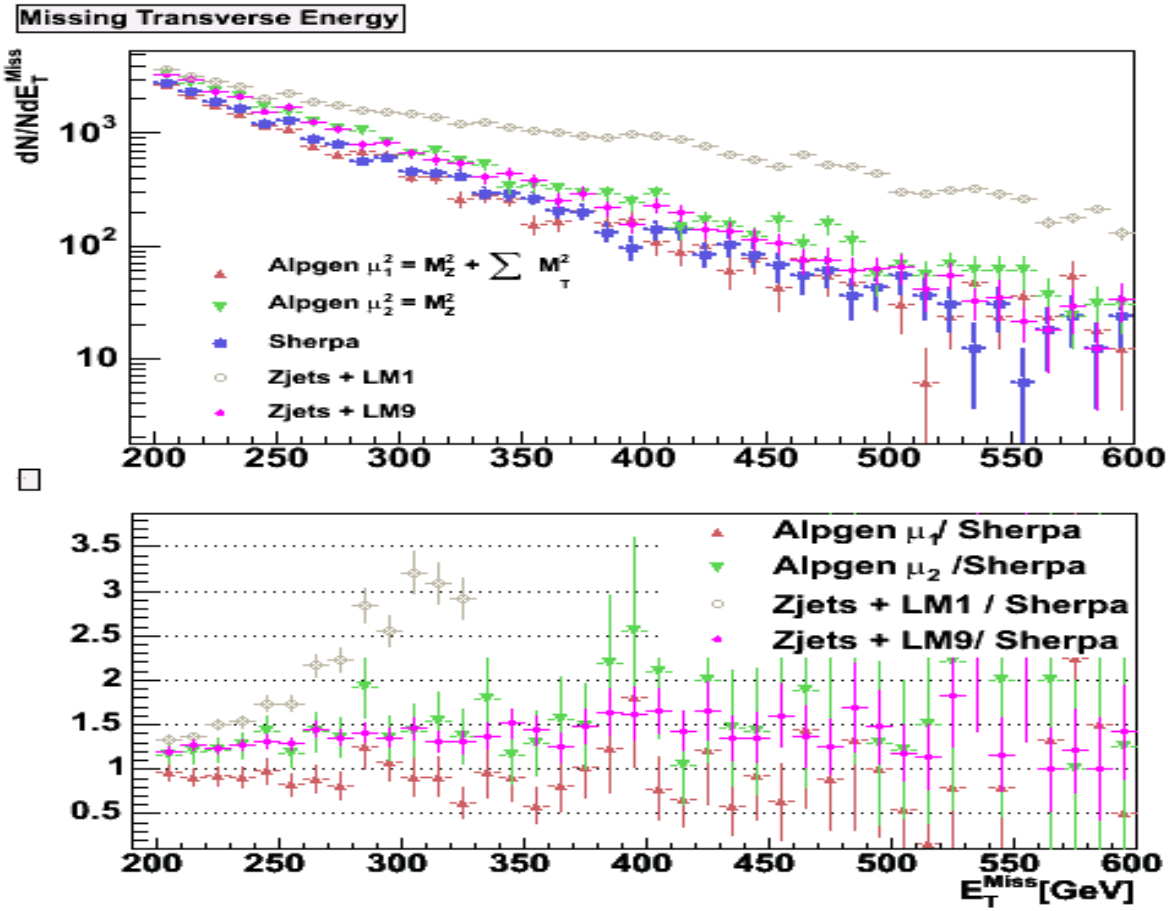
- *MET from neutrino, LSP (ME calculation)*
- *MET from jets mis reconstruction(detector sim.)*

Uncertainties:

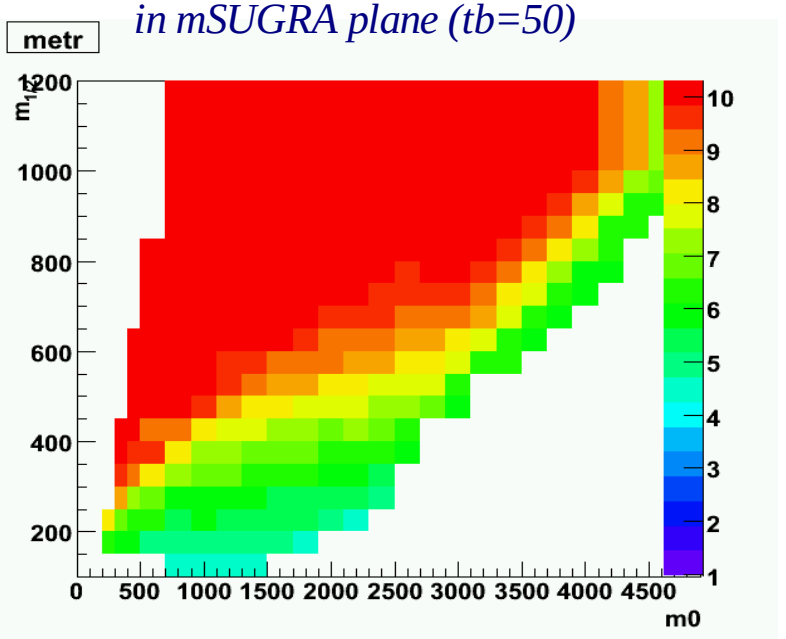
Detector: *JES, noise, jets mis reconstruction* $sigma_{MET}$*~0.95*sqrt(sumET)*

Model: *jets algorithm, jets fragmentation model*

MET at MC level for Alpgen ,Sherpa Z(mm->nunu) and mSUGRA LM9, LM1(60,250,10), L=1fb-1



MET significance: MET/sqrt(sumET) in mSUGRA plane (tb=50)



dd calibration:

select Z(mm)+Njets (M_{ll}~M_Z)

*replace Z(mm->nunu)*MC factor*

extrapolate to other channels

Systematic uncertainties: leptons

SUSY leptons: $\chi_2^0 \to ll\chi_0$, $\chi_1^\pm \to l\nu\chi_0$, $\tilde{l} \to l\chi$

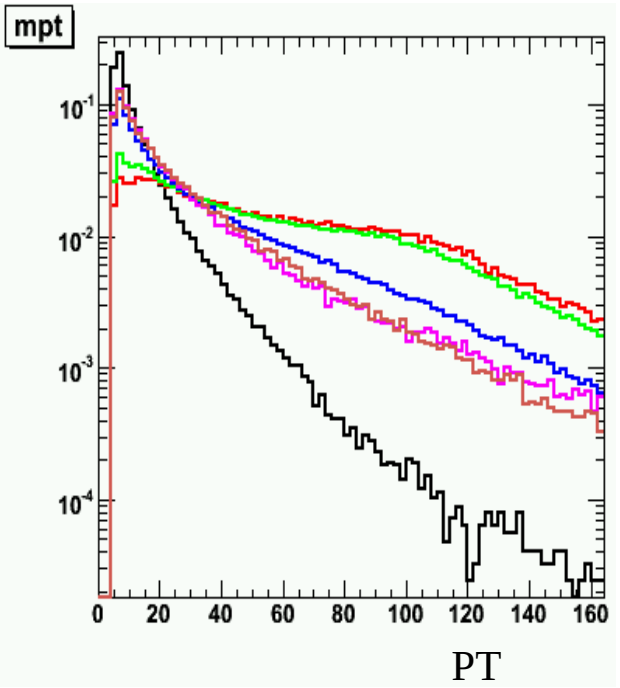
Uncertainties:

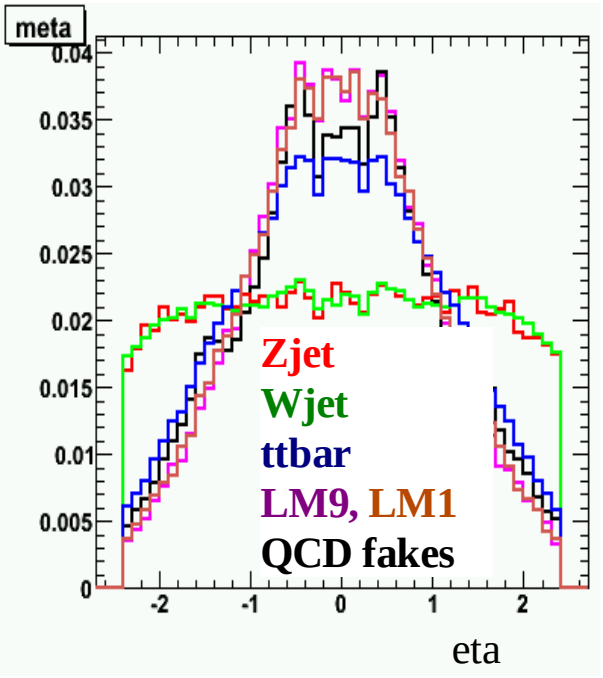
Detector: *resolution (alignment), detector 'fakes' (mostly electrons)*

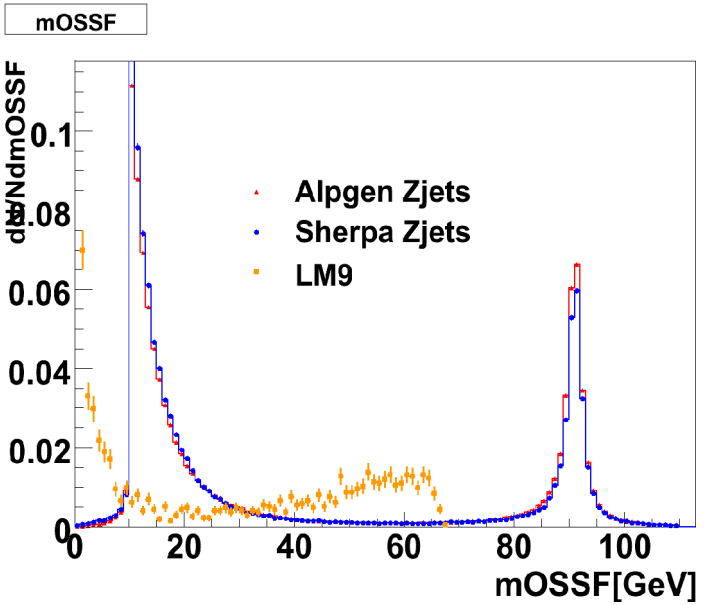
Model: *leptons at ME(invariant masses), leptons in jets (b,c,->l)*

Leading muon (ALPGEN+PYTHIA+CMSSW): Zj,Wj,ttbar,qcd,SUSY (SoftSusy). SUSY leptons are soft.

Z+jets dileptons invariant mass in Alpgen, Sherpa and LM1 (norm) can be used for Z/W suppression







dd calibration: **tag&probe method DY** ***Z***->μ(***tag***)+μ (***probe***) ***(MET<20, M_{ll}~m_Z).***

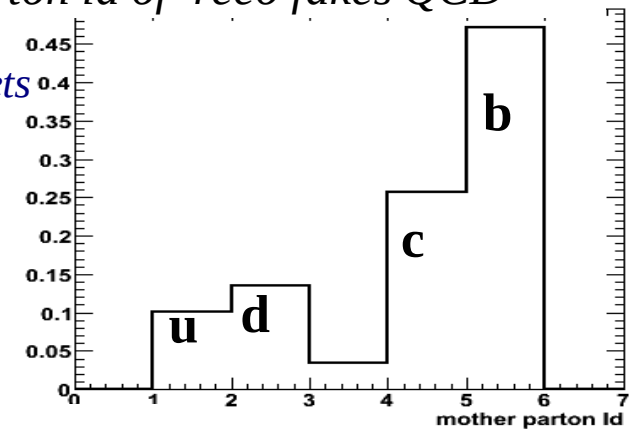
Systematic uncertainties: fake leptons

QCD jets
RecoMuons
PT>5GeV/c

All selected **100**
- notisoPt — **94** *Leptons in jets*
- isoPt — **6** *Isolated Fakes*
- identification — **0.8**

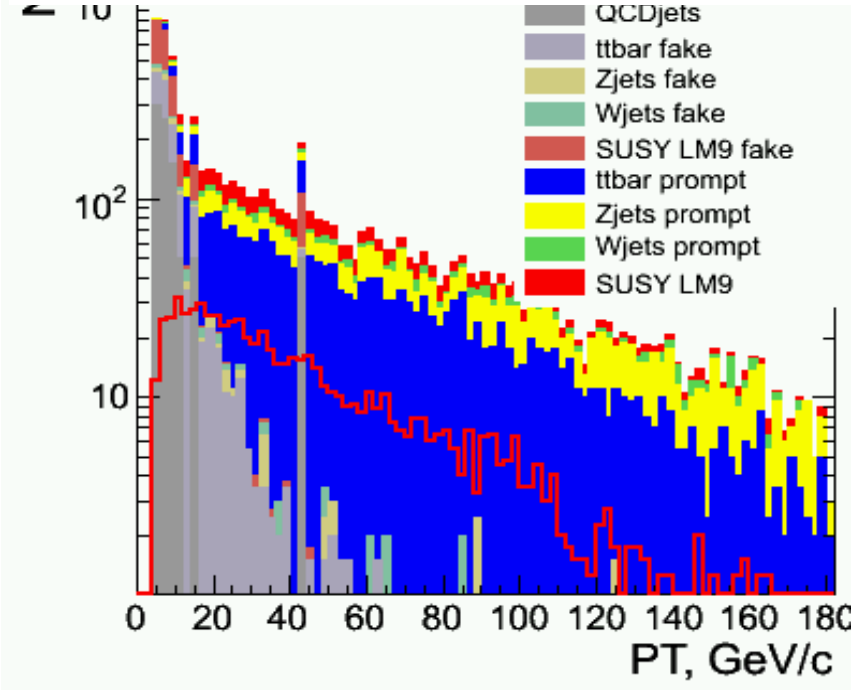
From pi,K **0.1** | From b **0.40** | From c,s,u,d **0.30**

parton id of reco fakes QCD



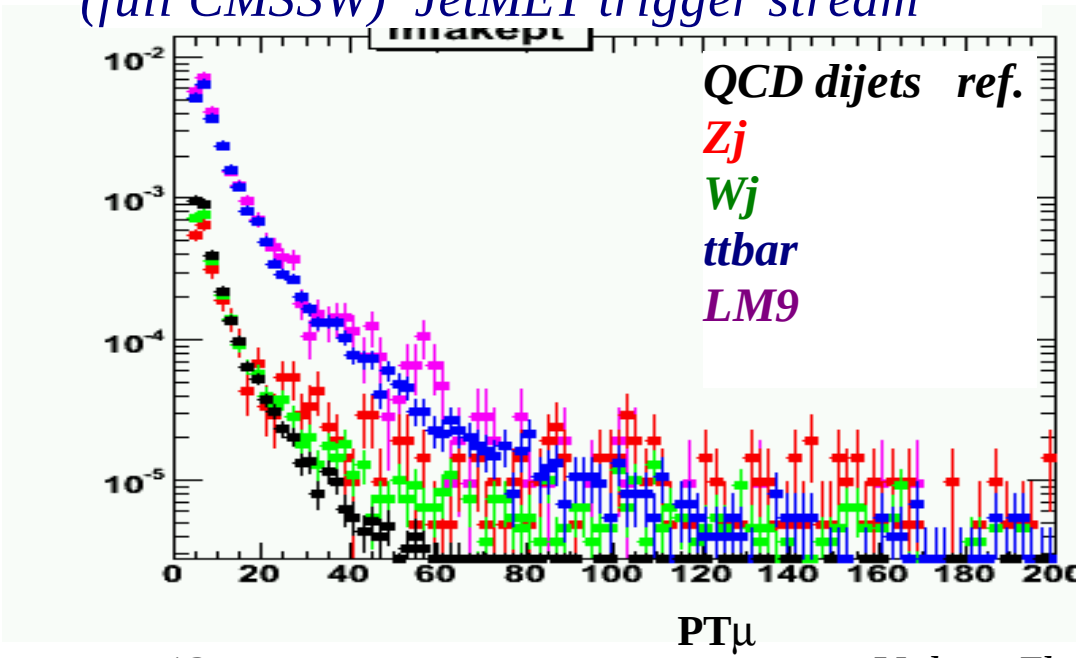
Uncertainties in fakes:
b,c jets from SR soft gluon splitting into bbar, ccbar sensitive to masses($m_{b,c}$), shower parameters, matching.

Contribution of fakes.
Muons PT in SUSY selection 1m+JetMET
(Etj1>120,ETj2>80, Nj>2, MET>100,sumET>250)
L=1fb^{-1}



dd calibration: ***use QCD dijet reference sample***
(MET<20, Nj=2,Minvt<40, Assj12<0.12, Rtj2/mj12=0.2-0.8, aplanarity<0.0026,etc). Contamination(Wj) <4 10^{-4})

Muons(isobyPT) fake rate per event
(full CMSSW) JetMET trigger stream



SUMMARY

Factorize systematic uncertainties.
detector related: study with the detector GEANT model
model related: QCD (factorization scale), SUSY models

Consider systematics during selection of observables.
Define range of observables least sensitive to the uncertainties.
Use composite parameters with the uncertainties cancellation.

Perform data driven calibration methods for each observable.
Select reference channel.
Estimate errors of extrapolation into signal region.

Benefit from collaboration with theoreticians .....

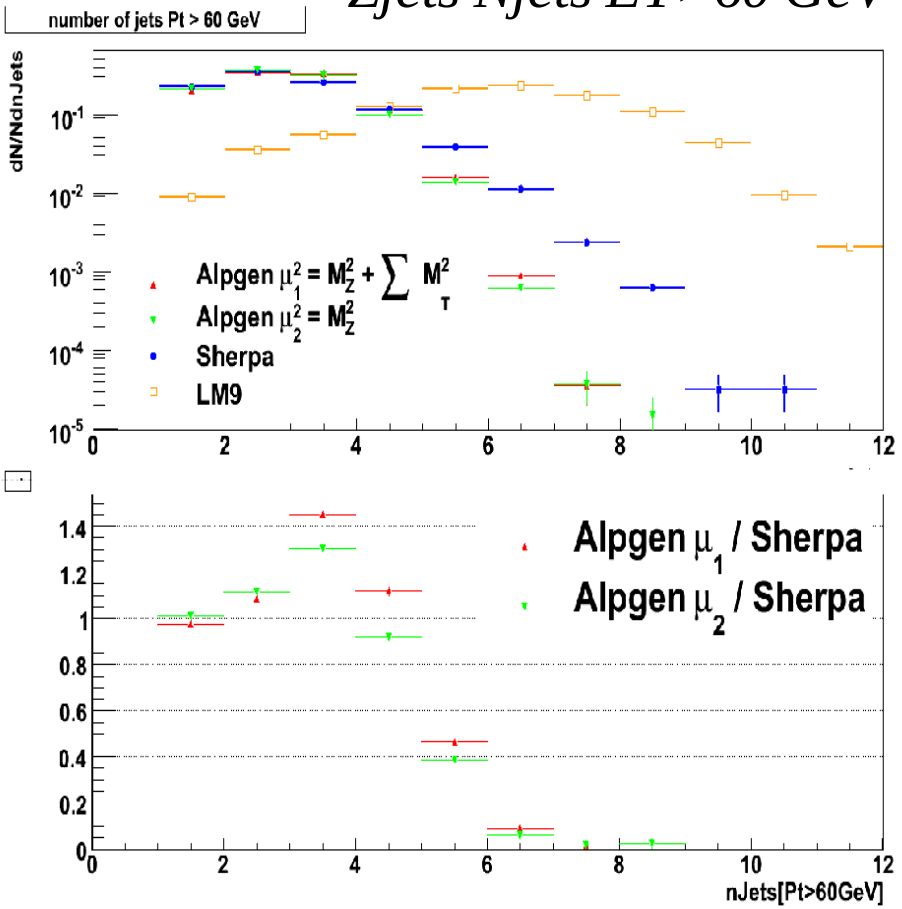
Back-up slides

MC generators:

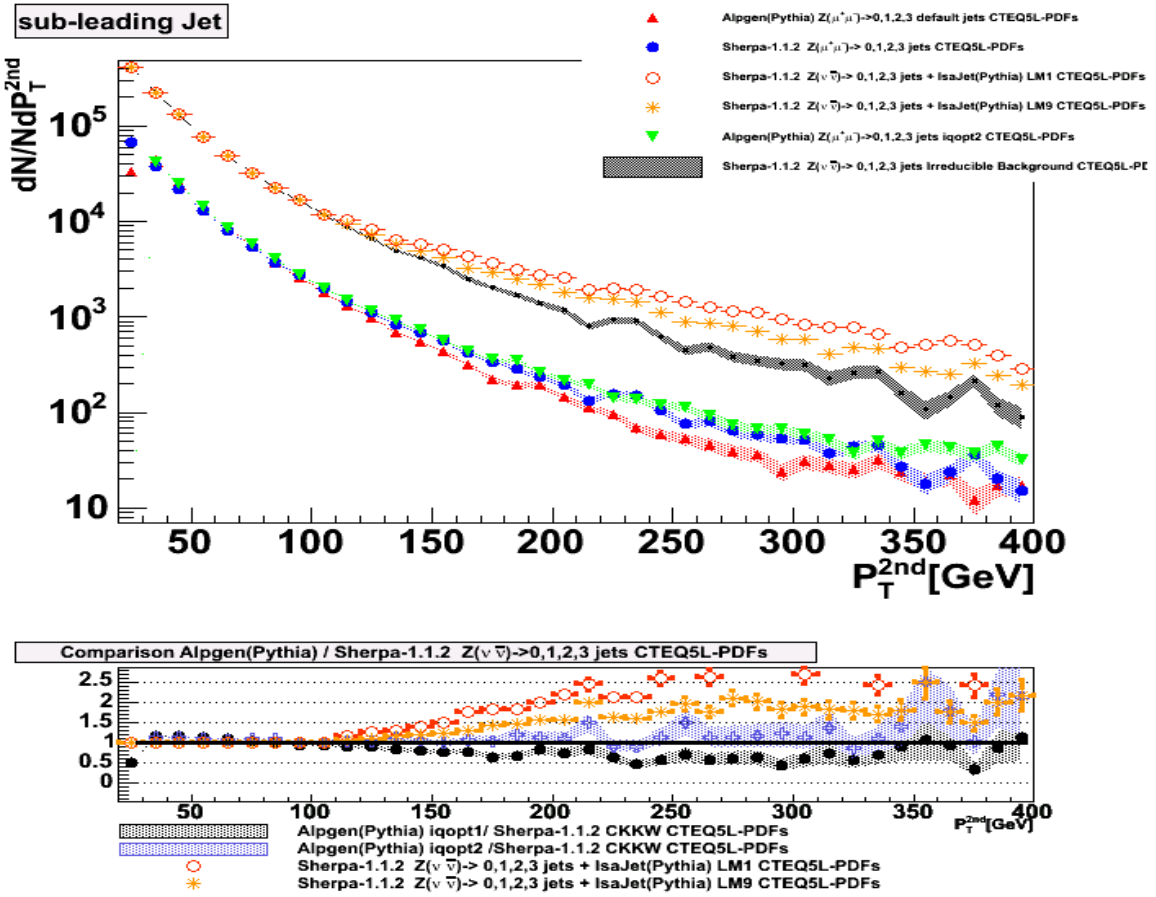
Alpgen 2.13+PYTHIA6.4 CTEQ5L
Etj>20 GeV eta<5
dRjj>0.7

Sherpa 1.1+PS as in PYTHIA6.3 CTEQ5L
Etj>20 GeV eta<5

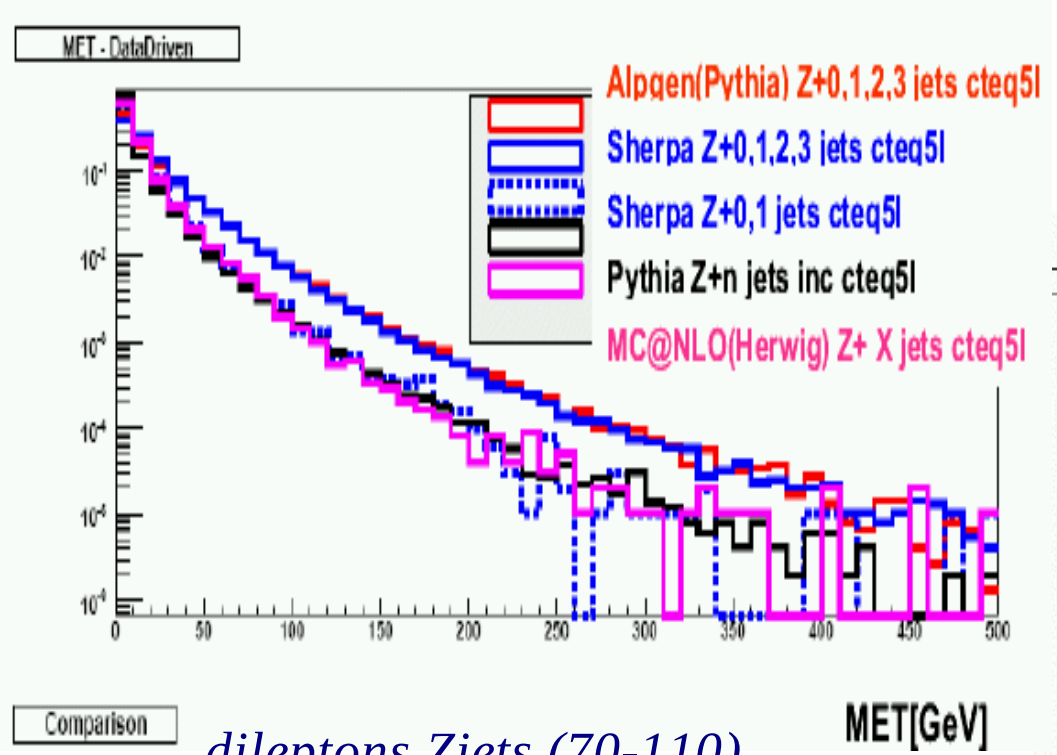
Zjets Njets ET>60 GeV



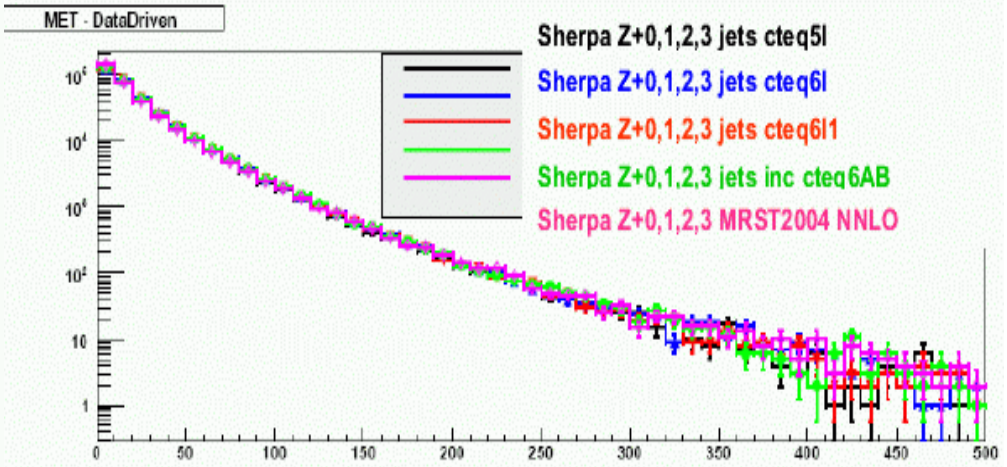
Zjets ET second jet



MET Z+jets : Alpgen, Sherpa, MCNLO



MET(MC) Zjets different PDF



Comparison

dileptons Zjets (70-110)