Opportunities and Challenges in Jets+MET Topologies

Seema Sharma
Fermilab

(On behalf of LPC Jets+MET Topology group)

Conveners:
Anwar Bhatti bhatti@fnal.gov
Teruki Kamon kamon@physics.tamu.edu

Meetings :
Tuesday 13:00-15:00 (CST) (BiWeekly)
Round Table (WH11SE)/EVO

Outline

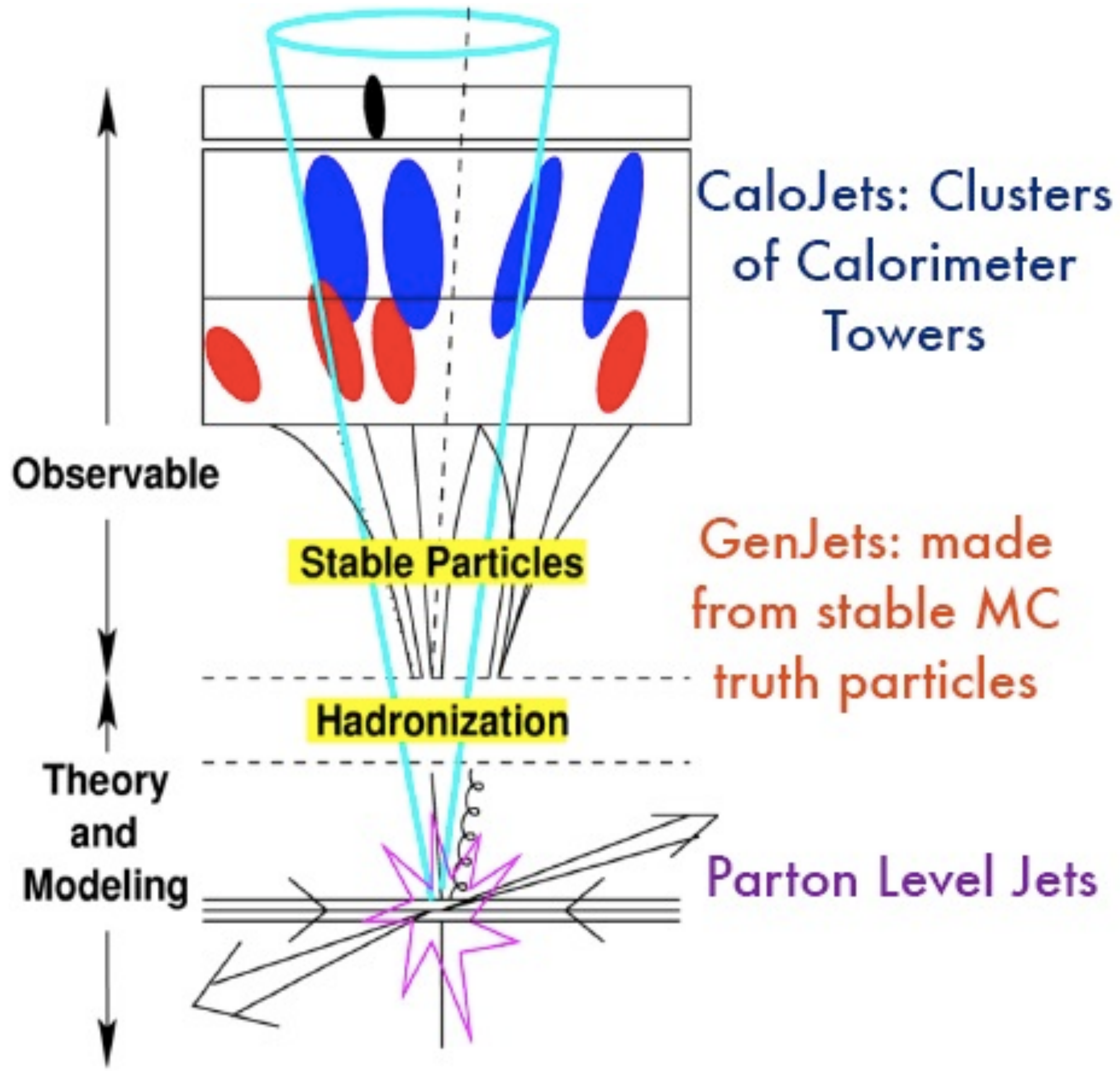
- Jets and Missing Transverse Energy
- Physics processes - SUSY, ExtraDimension, Black Holes ....
- Search Strategies : All Hadronic Analyses
- Estimation of Backgrounds
- SUSY Physics Commissioning
- Summary

Jets in High Energy pp collision

High pT partons are produced in high energy pp collisions which is essetially an interaction between the underlying partons.

A parton (quark or gluon) manifest itself as a jet which is nothing but a collimated spray of hadrons travelling closely along the direction of the parent parton.

These hadrons (charged and neutral) are usually detected using calorimeter as the clusters of energies which are gathered together by Jet Algorithms to deduce the four momenta of the parent parton.



Challenges - Response of the calorimeter to particles is not linear in momentum,
Non-uniform response in different parts of the detector,
Uncertainties in determination of Jet Energy Scale .....

Missing Transverse Energy (MET)

MET as a physics object : The weakly interacting neutral particles escape the detector without depositing any energy resulting in an imbalance in transverse energy.

MET is calculated as the vector sum of transverse momentum of all calorimeter towers

$$\vec{P}_T^P + \vec{P}_T^P = \sum_i \vec{P}_T^i = 0 \text{ sum over all outgoing particles.}$$

$$\vec{P}_T^{miss} = -\sum_i \vec{P}_T^i(\text{measured}) \neq 0 \Rightarrow$$

Some particles escaped without interacting with detector

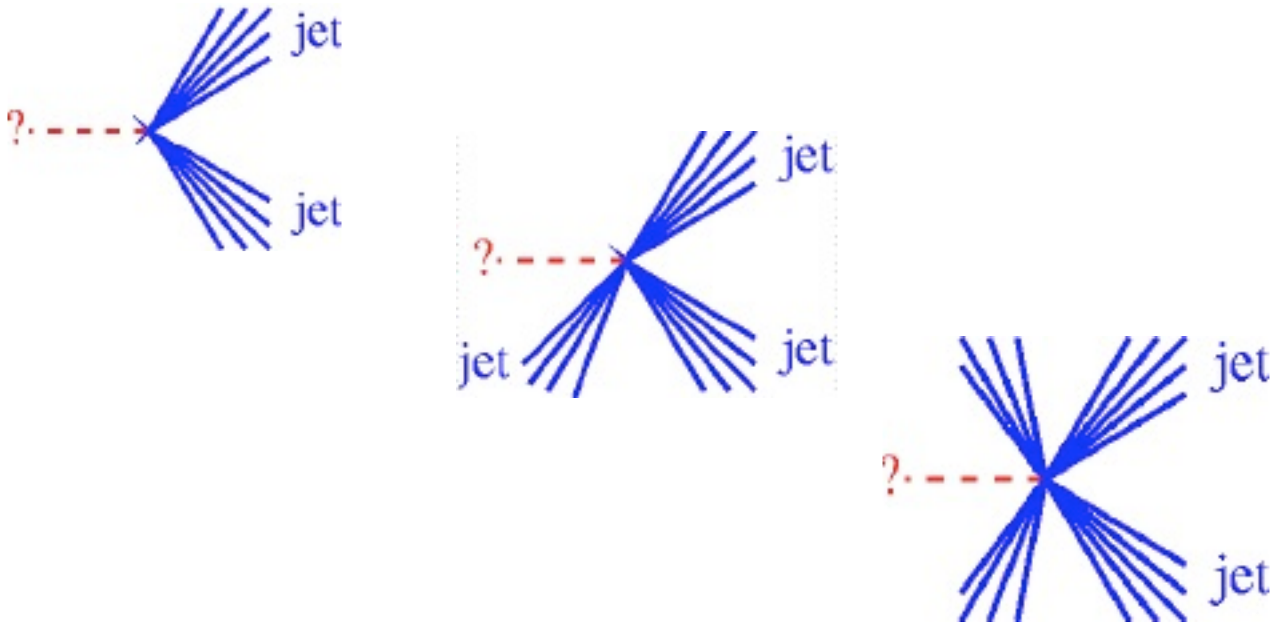
In addition, any mis-measurement may result in an imbalance in pT

- Detector Performance :
  - Response of calorimeter to various particles
  - Longitudinal leakage of energy from detector
  - Dead materials and cracks in detector
  - Electronics Noise (dead channels, hot channels ...)
- Beam halo, cosmic rays
- Need to understand the effect of pile-up/underlying effects ...

Jets + MET Topologies

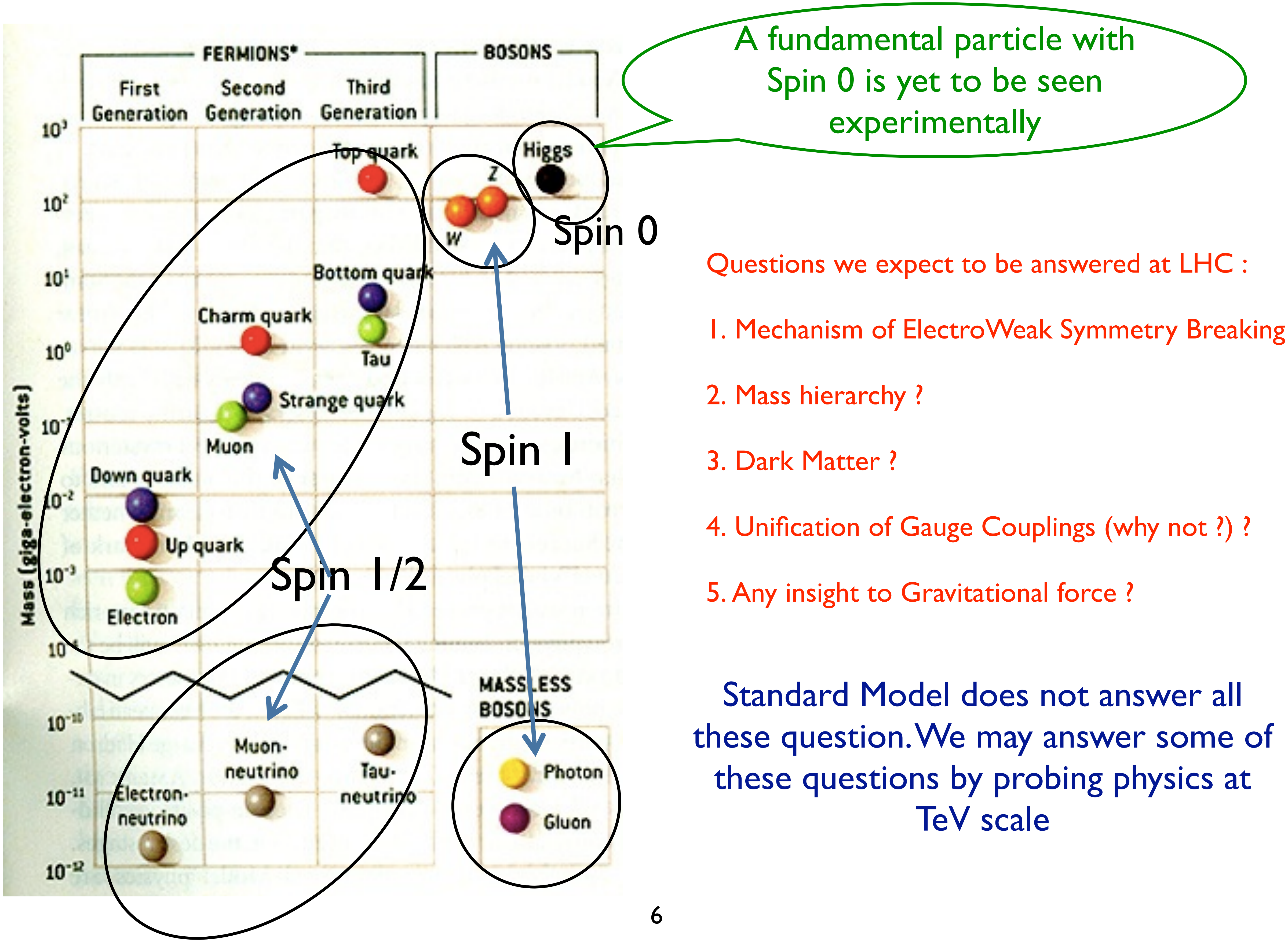
Final state : A number of Jets + MET

1 Jet + MET + X
2 Jets + MET + X
3 Jets + MET + X
.
.
.



Let's see the motivation to study these topologies and their sources

Standard Model of Particles



Questions we expect to be answered at LHC :

1. Mechanism of ElectroWeak Symmetry Breaking ?
2. Mass hierarchy ?
3. Dark Matter ?
4. Unification of Gauge Couplings (why not ?) ?
5. Any insight to Gravitational force ?

Standard Model does not answer all these question. We may answer some of these questions by probing physics at TeV scale

SuperSymmetry (SUSY)

SuperSymmetric extension of Standard Model

a SuperSymmetric partner for every SM particle differing by spin-half

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks (×3 families)	Q	$(\widetilde{u}_L \ \ \widetilde{d}_L)$	$(u_L \ \ d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons (×3 families)	L	$(\widetilde{\nu} \ \widetilde{e}_L)$	$(\nu \ \ e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	H_u	$(H^+_u \ \ H^0_u)$	$(\widetilde{H}^+_u \ \ \widetilde{H}^0_u)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	H_d	$(H^0_d \ \ H^-_d)$	$(\widetilde{H}^0_d \ \ \widetilde{H}^-_d)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

Minimal SUSY extension needs two Higgs doublets to provide massed to both left and right handed states

Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\widetilde{g}$	g	$(\mathbf{8}, \mathbf{1}, 0)$
winos, W bosons	$\widetilde{W}^\pm \ \ \widetilde{W}^0$	$W^\pm \ \ W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
bino, B boson	$\widetilde{B}^0$	B^0	$(\mathbf{1}, \mathbf{1}, 0)$

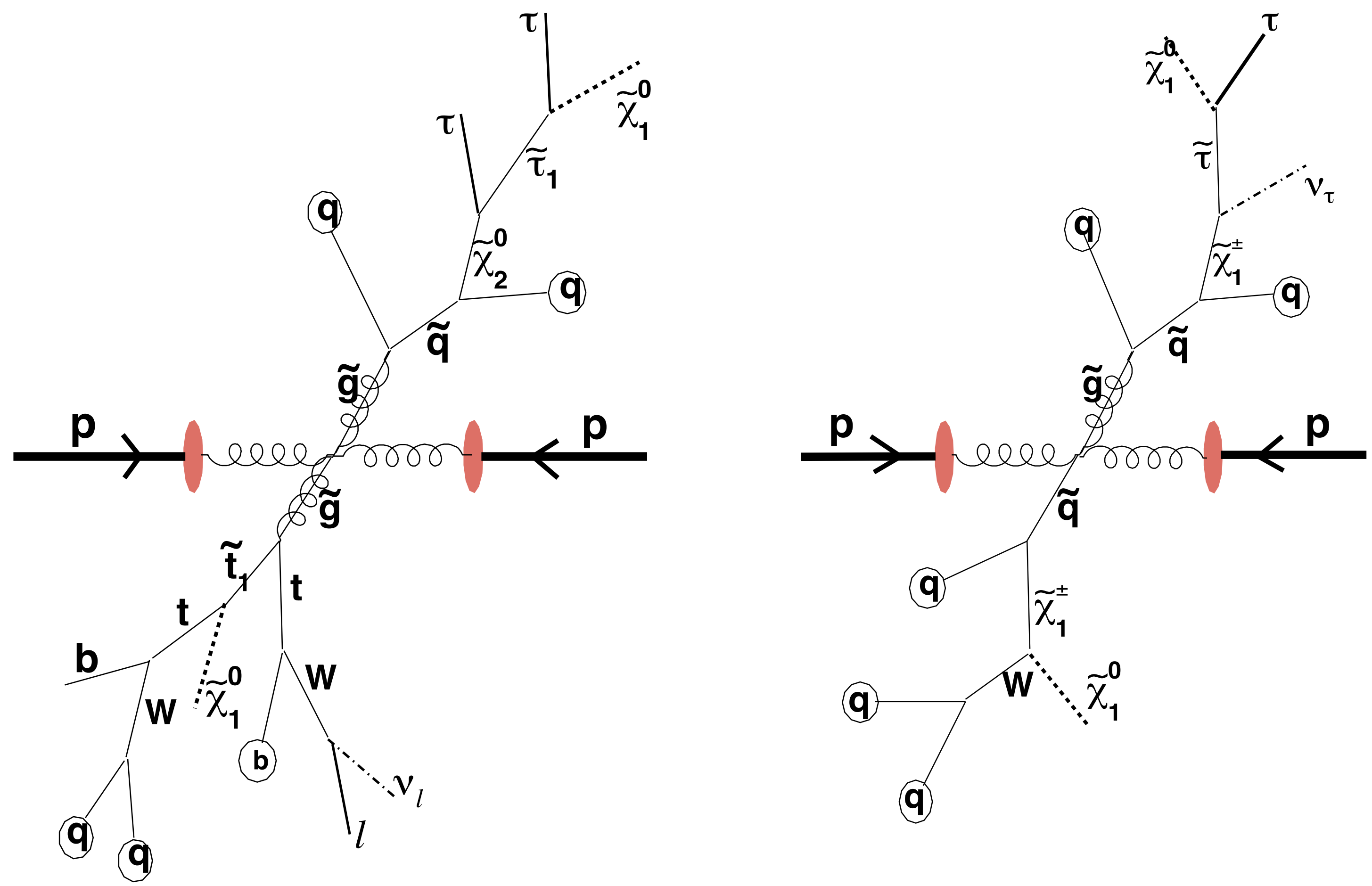
Experimental Consequences of R-parity conserving SUSY

(lepton and baryon numbers are conserved)

- EWK precision is easily satisfied
- The super partners must be produced in pair
- The Lightest Supersymmetric Particle (LSP) should be stable
- A weakly interacting neutral LSP is an obvious Dark Matter candidate

SUSY Particle Production and Decays

Squarks and gluinos decay and create a cascade of particles : a number of quarks and gluons, leptons and weakly interacting stable neutral particles Neutralino



Classical Signature

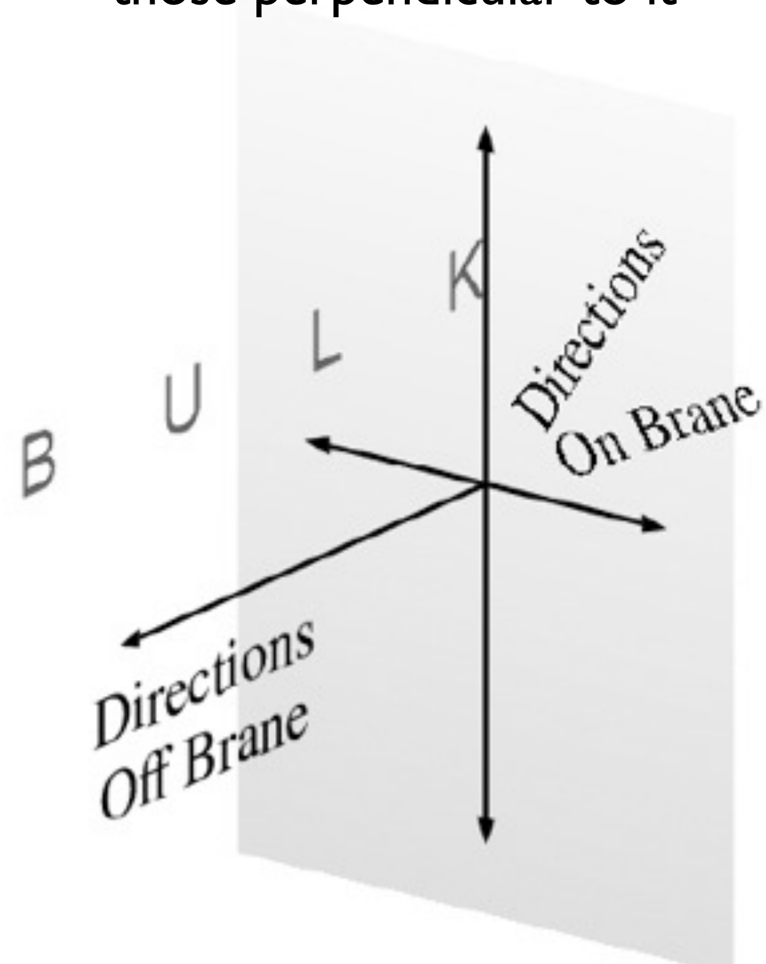
Jets + Missing ET + (Leptons)

And/or look for an access of bs, Taus, Tops, Ws, Zs ...

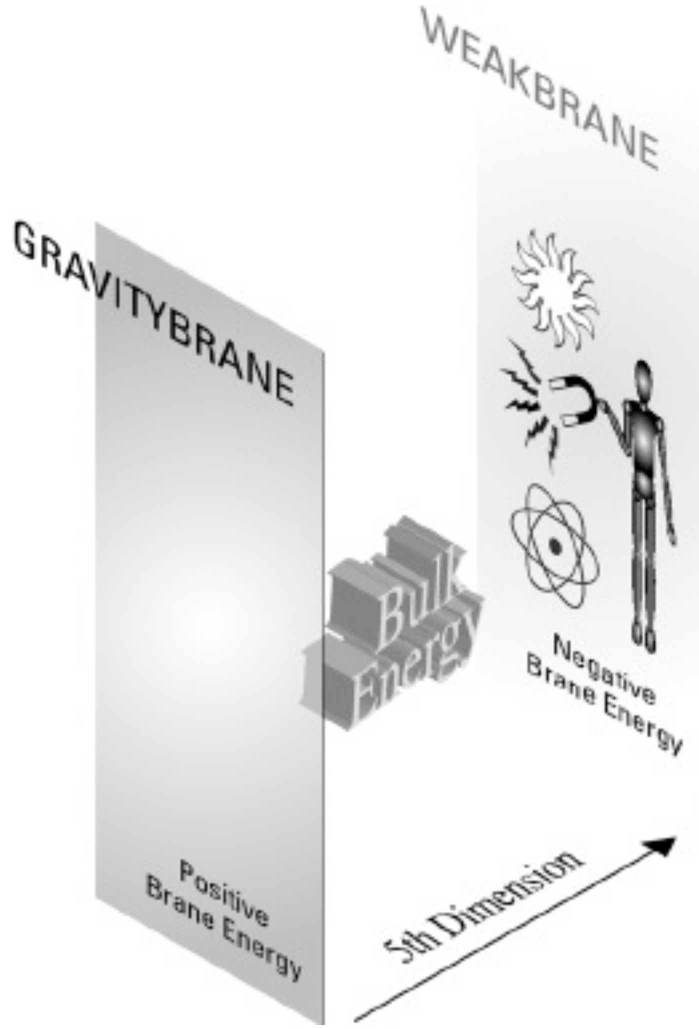
Extra Dimensions (I)

Another extension of Standard Model is using Extra Dimensions (ADD, RS ...) and it becomes crucial to understand the experimental consequences

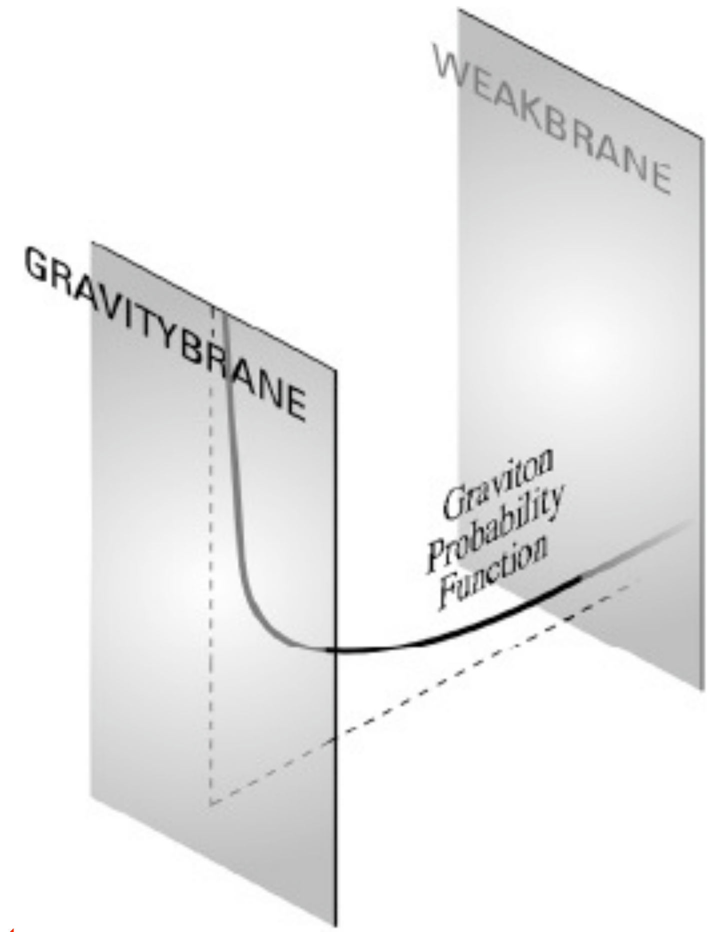
Concept of Branes : to distinguish dimensions along a brane from those perpendicular to it



Gravity is on GravityBrane and we live on WeakBrane



The probability of having graviton on weak brane is small and so the gravity seems to be weak when seen from anywhere other than GravityBrane



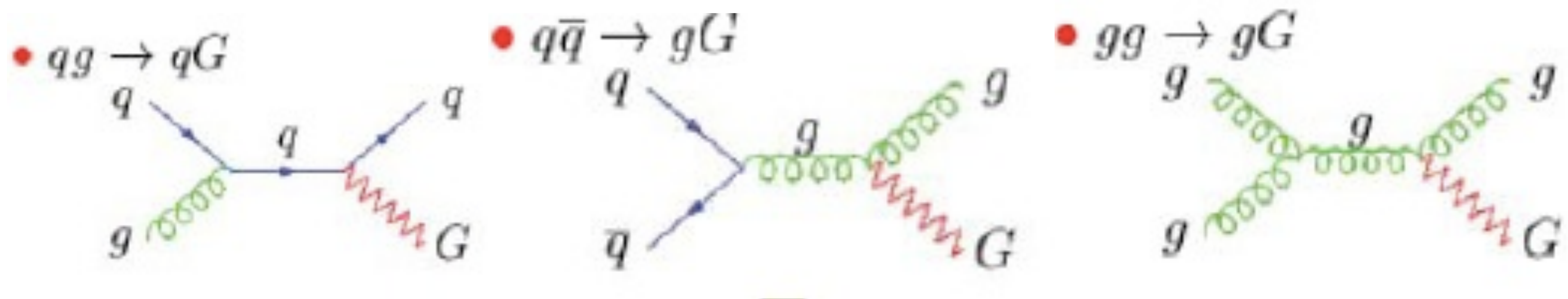
The additional dimensions can either be hidden by curling up the additional dimensions or these can bounded by branes - the basic idea is that these hidden dimensions (if exist) can be probed at LHC

Extra Dimensions

ADD model with large extra dimensions :
n extra dimensions compactified at radius R

$$M_{Pl}^2 \sim R^n M_D^{2+n}$$

Graviton Production



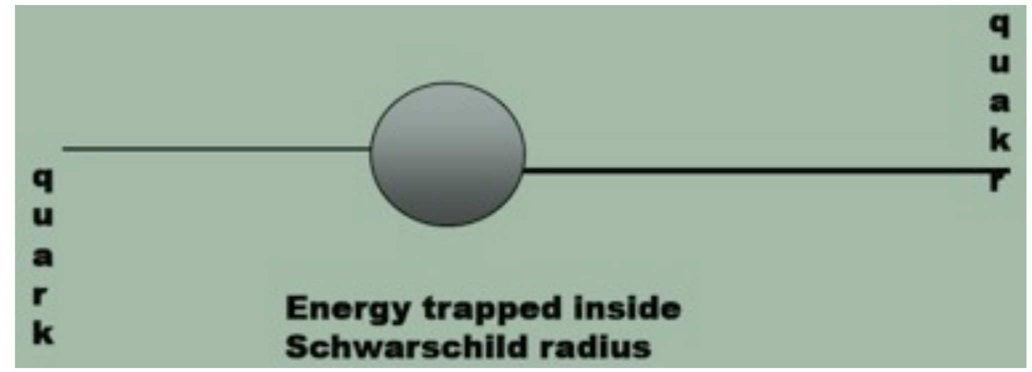
Graviton does not interact in detector and escapes without leaving a signal

Experimental Signature

MonoJet + Missing ET

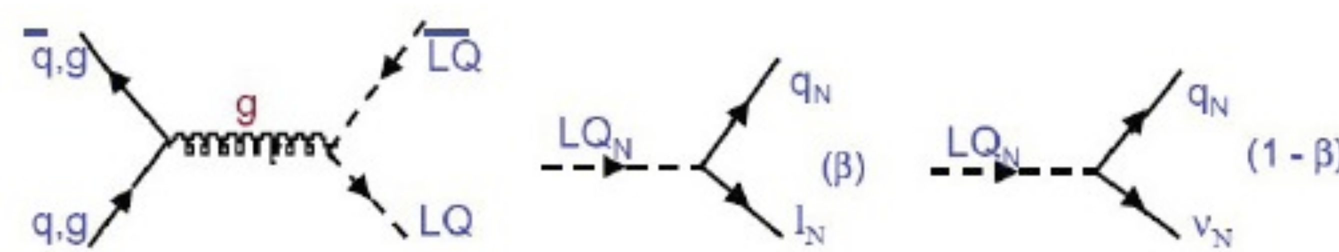
Black Holes

Two particles collide with sufficiently high energies, it gets trapped in small area forming a Black Hole which in turn decays to multiparticle final states



LeptoQuarks

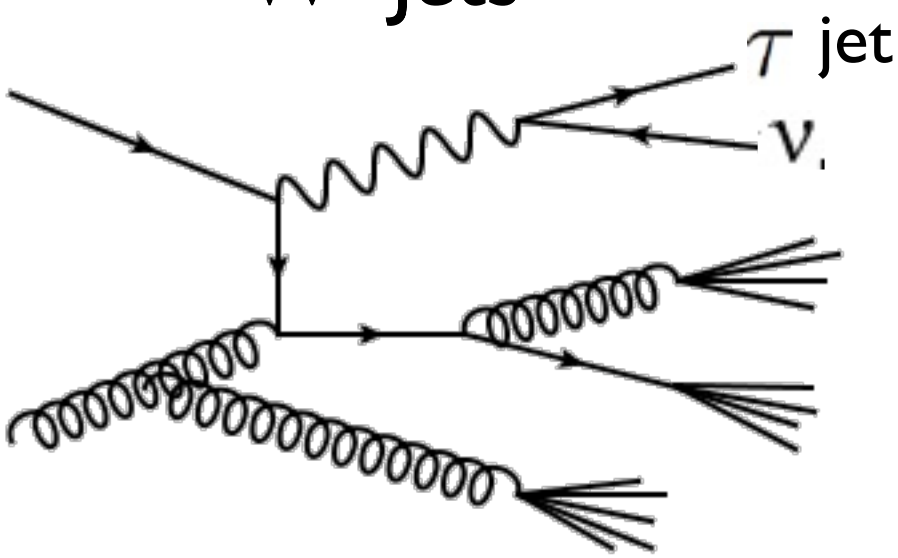
- Leptoquarks carry both Lepton and quark quantum number
- Predicted by many extensions of the SM
- Scalar and Vector LQ



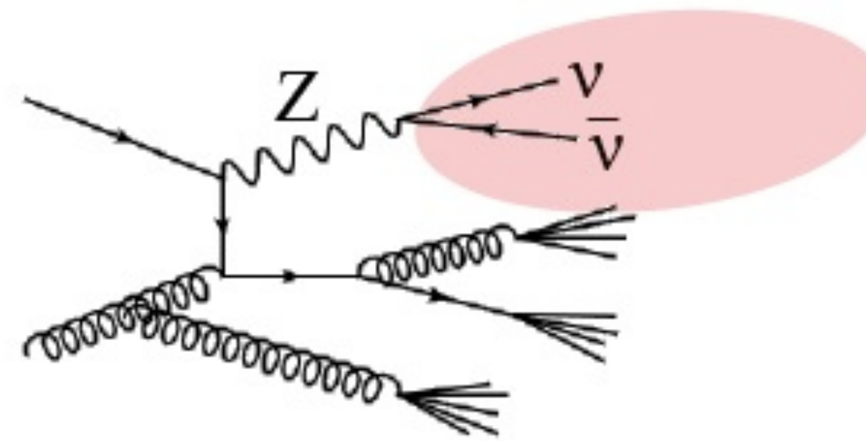
Possible signature - Jets + MET

Standard Model Processes

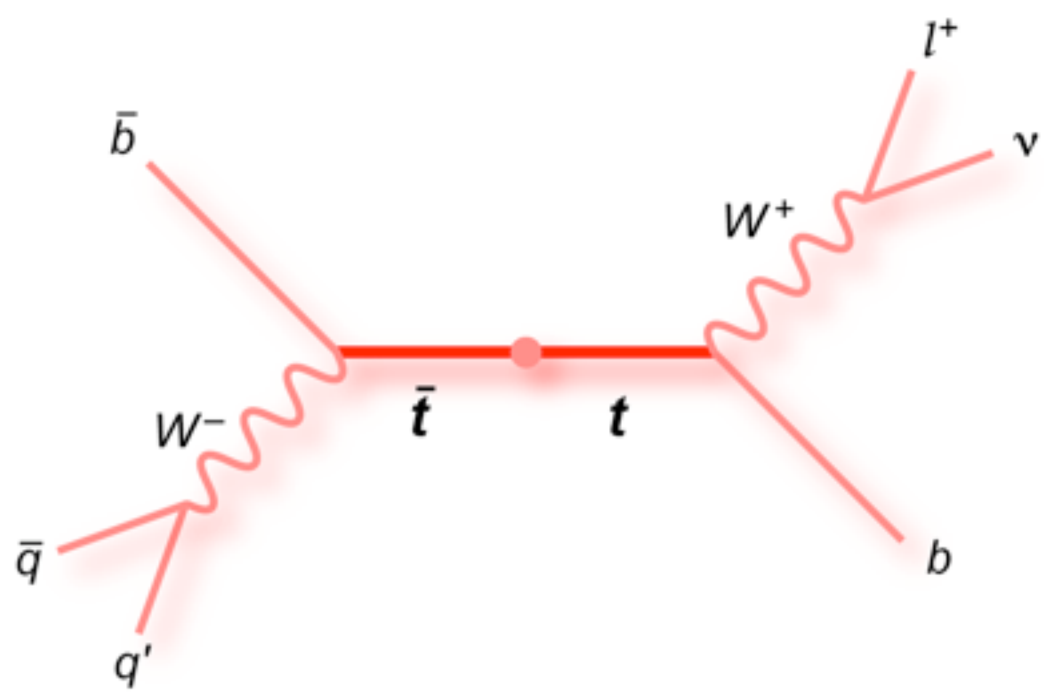
W+Jets



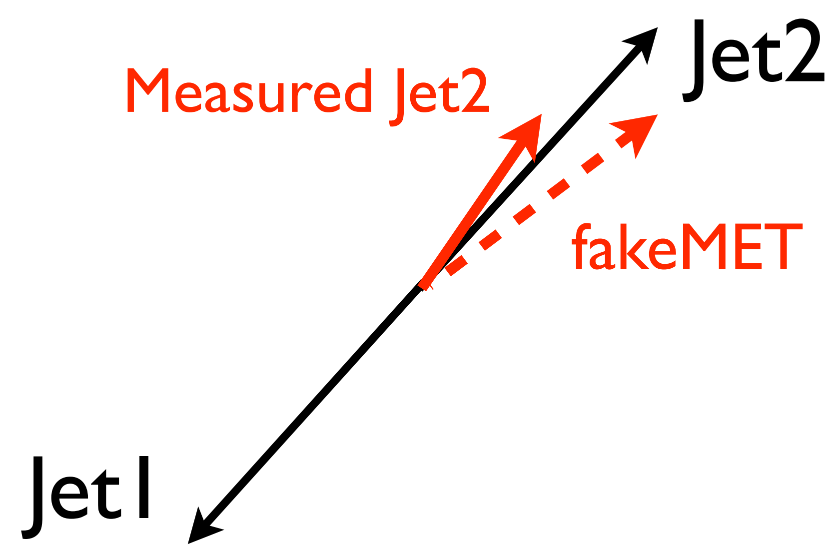
Z+Jets



ttbar+Jets



QCD : mainly jet mis-measurement



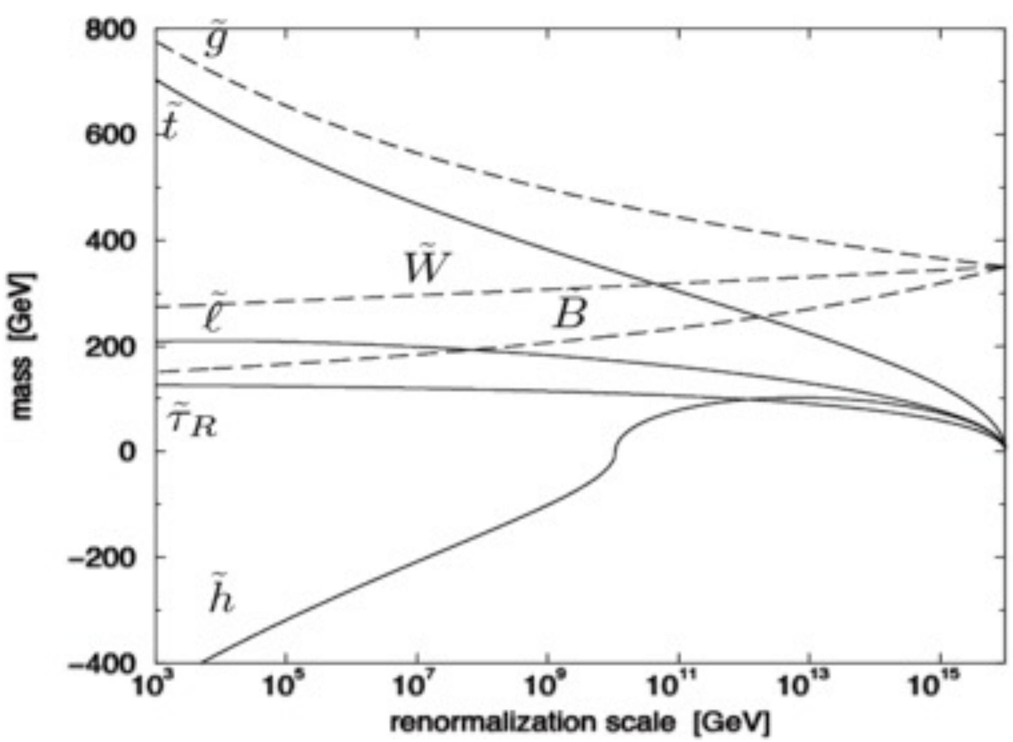
Search Strategies at CMS

SUSY @ CMS

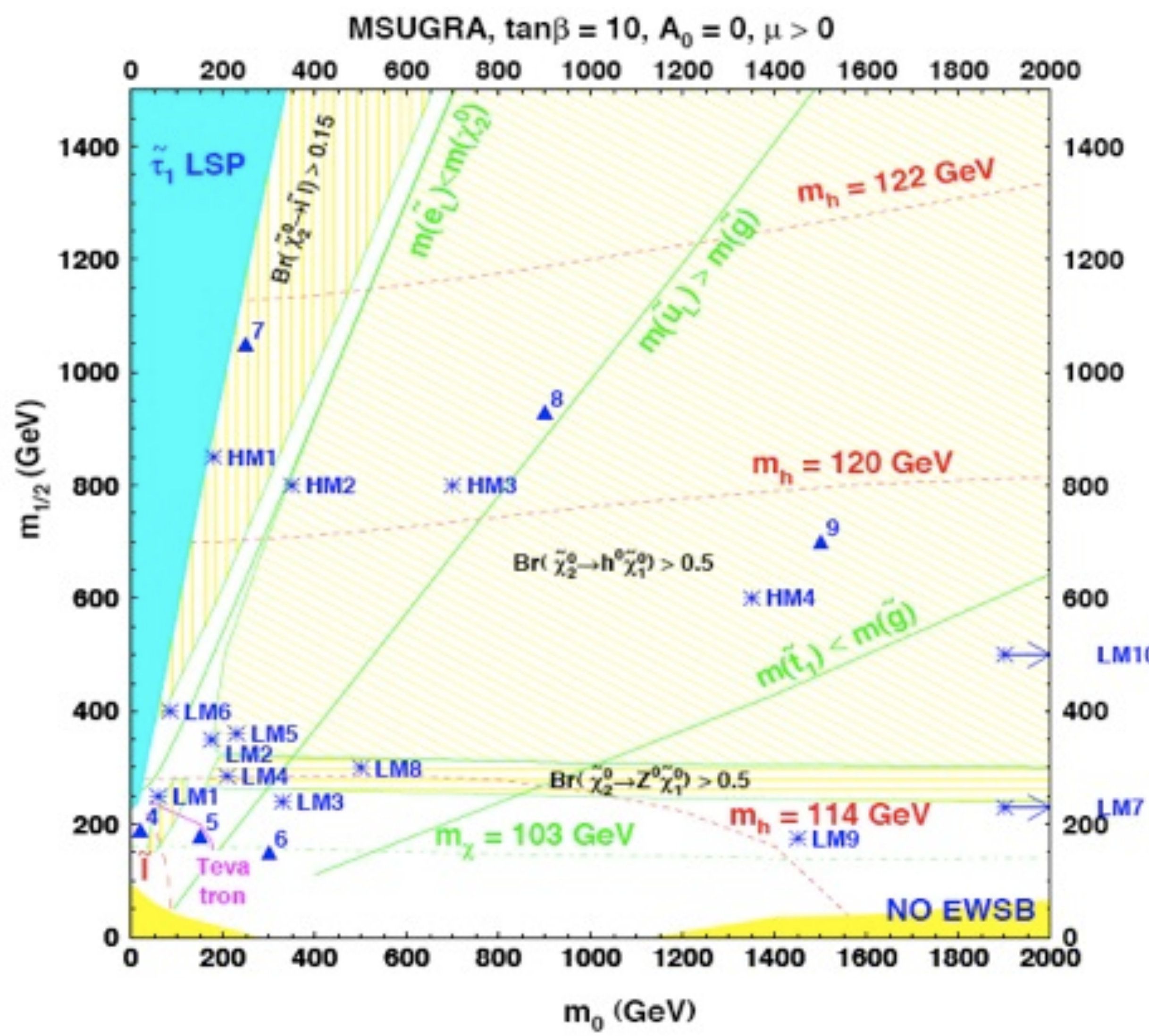
CMS test points to study SUSY are based on mSUGRA framework

4 parameters + 1 sign

$\tan\beta$	: $\langle H_u \rangle / \langle H_d \rangle$ at M_Z
$m_{1/2}$	: Common gaugino mass at M_{GUT}
m_0	: Common scalar mass at M_{GUT}
A_0	: Trilinear couping at M_{GUT}
sign(μ)	: Sign of μ in $W^{(2)} = \mu\, H_u\, H_d$

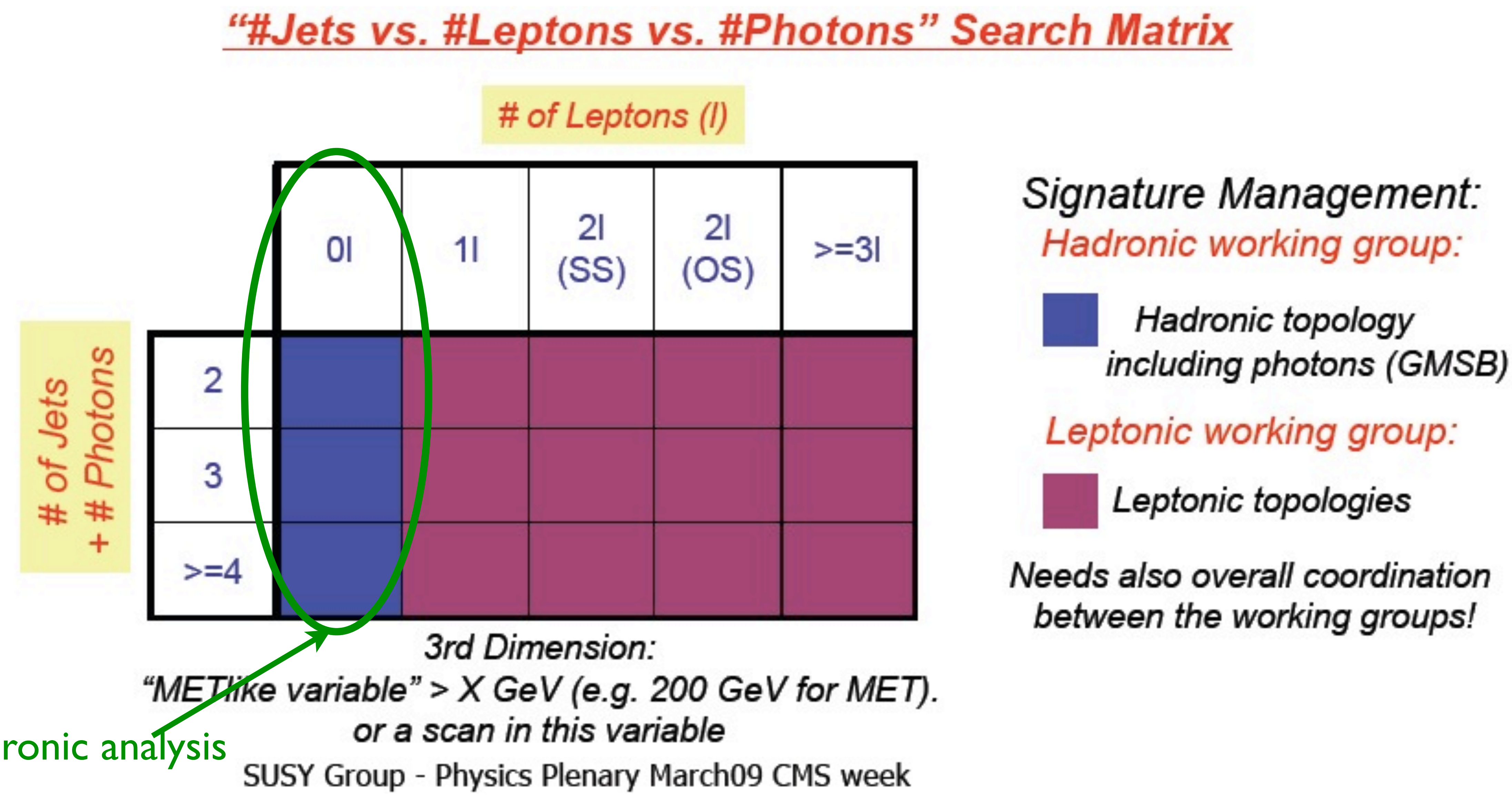


CMS Benchmark Points



Basic Signatures

SUSY a very rich spectrum of final states and we don't know what would come up :
CMS SUSY group has chosen to categorize basic signatures in terms of fundamental objects



All hadronic analysis

Exclusive Dijet Analysis

Exclusive N Jet (N>2)Analysis

Inclusive N Jet (N>2)Analysis

Exclusive N-Jets Final State (1)

DiJet Final States like $\tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^0 \; q\tilde{\chi}_1^0$

Preselection

- Trigger: jet110.
- No electron or global muon with $P_T > 10$ GeV.
- No Photons > 25 GeV.
- Jets $F_{em} < 0.9$ && $|\eta|$ jets < 3 && $P_T > 50$ GeV.
- No muon in jet with P_T muon > 0.5 P_T jet.
- Second jet $P_T > 100$ GeV.
- $|\eta|$ first jets < 2.
- HT > 350 GeV.

Kinematic Variables

$$HT = \Sigma \; p_T(jets)$$

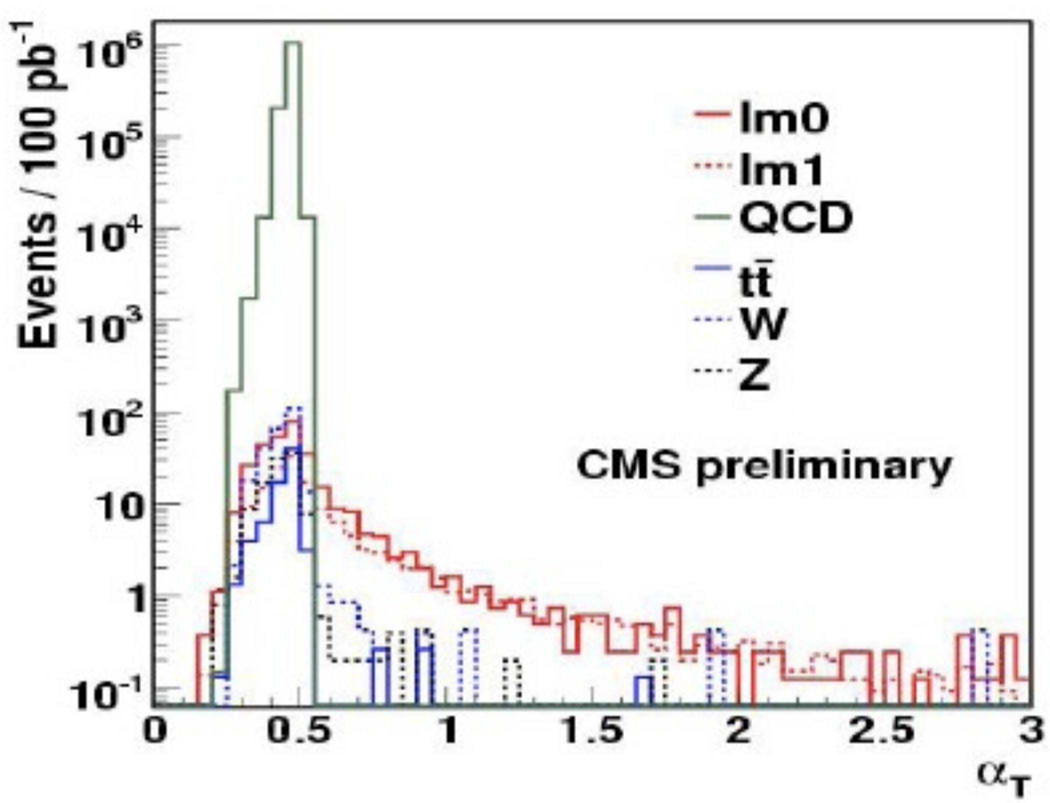
$$M\vec{H}T = -\Sigma \; \vec{p_T}(jets)$$

For N>2, construct a system of two pseudo-jets such that difference in HT of two systems is minimum.

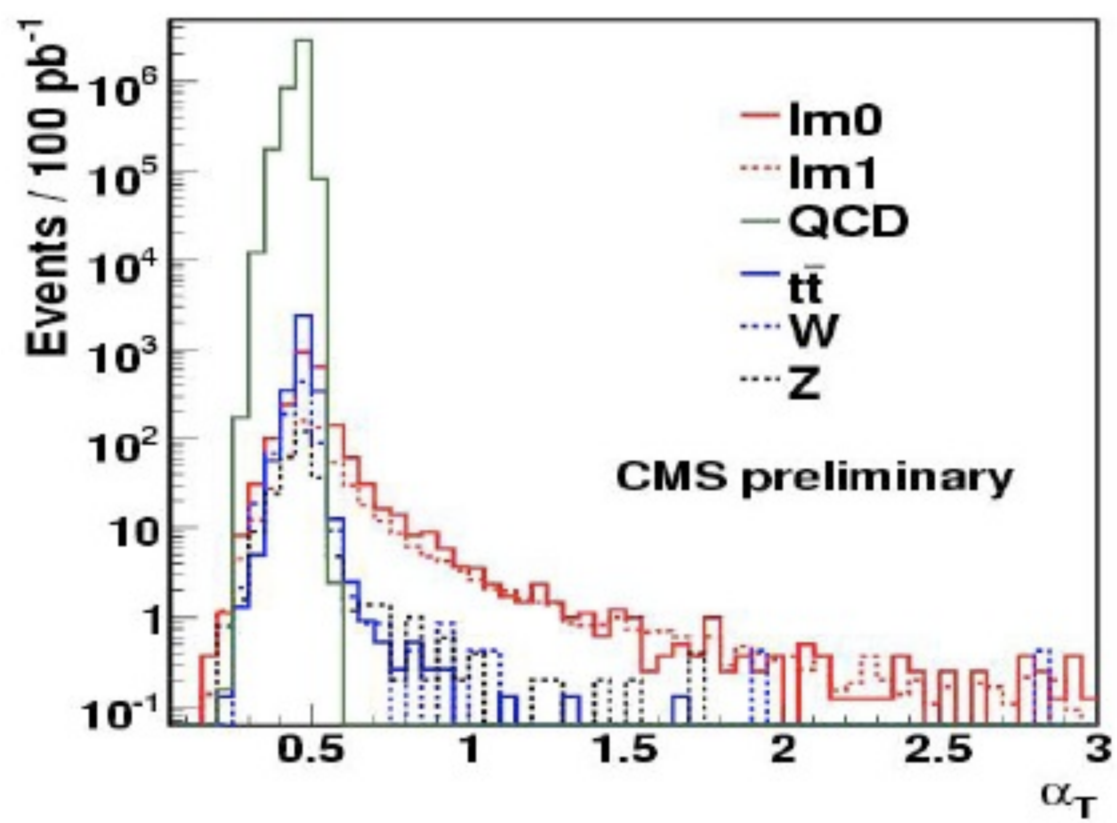
Exclusive N-Jets Final State (II)

Discriminating variable $\alpha_T = 0.5 \frac{1 - \Delta H_T / H_T}{\sqrt{1 - MHT^2 / H_T^2}}$

di-jet case



2-6 jets



Key feature - Robustness

Tylan Yetkin
Mehmat Vergili
Anwar Bhatti
Teruki Kamon

Inclusive N Jets Final State

Defining Signal : Events with atleast 3 energetic jets and high MET

- Atleast three jets with pT > 180, 150, 50 GeV

- MET > 200 GeV

- Veto on muons and electrons --> removes most of the background from W, Z, top decays where one of the decay products is a lepton

- Angular cuts : min $\Delta\varphi$ (jet 1-3, MET) > 0.3 --> angular cuts to remove QCD background where missing ET is due to mis-measurement of a jet and therefore is aligned in its direction

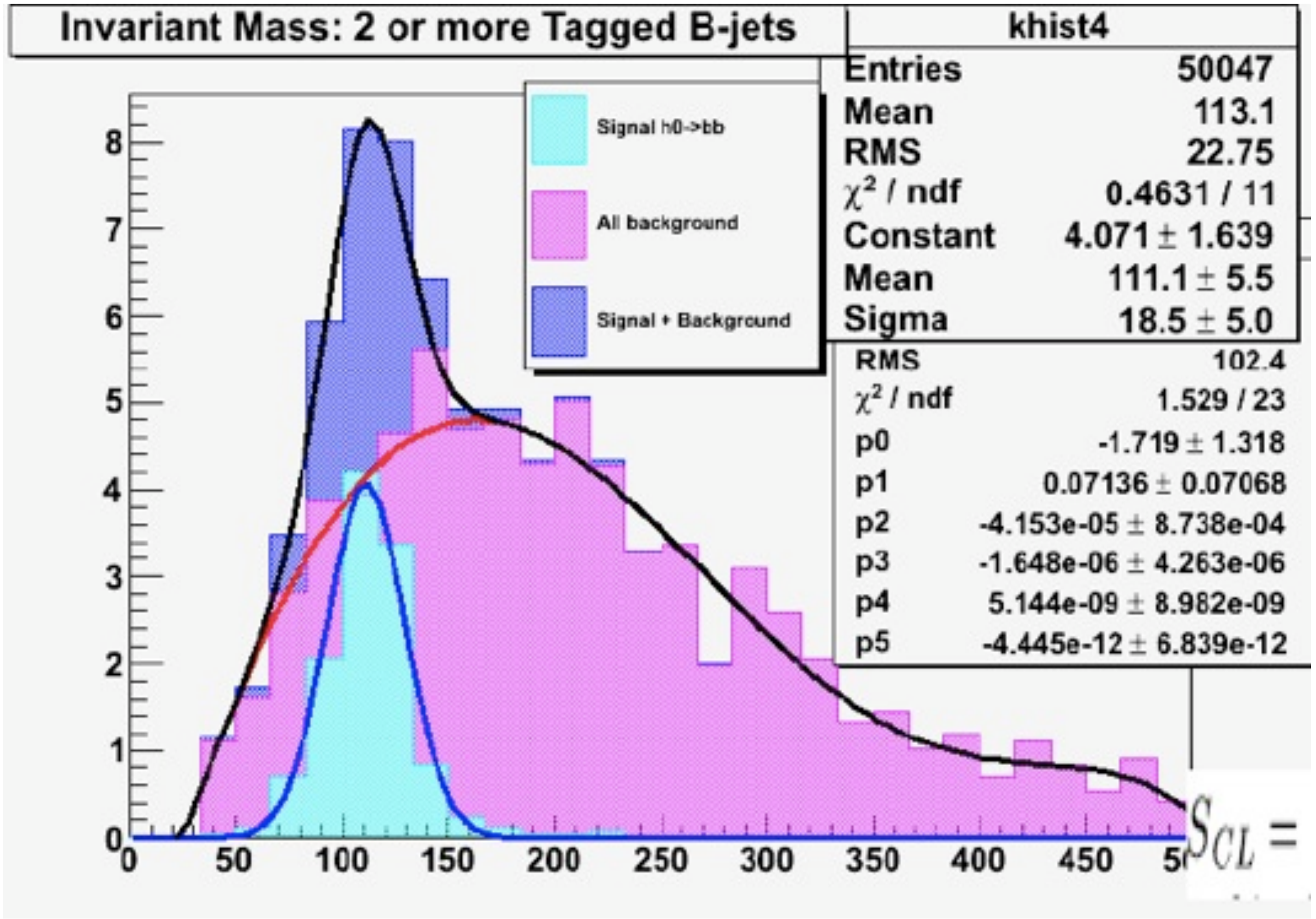
Jets + MET + b

Explore the decay chains with a Higgs in final state

LM5 : $\tilde{q} \rightarrow \tilde{\chi}_2^0 + q$ and $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + h^0 \rightarrow \tilde{\chi}_1^0 + b\bar{b}$ 21%

- Signal events contain light Higgs decaying to two b-jets that are correctly reconstructed using truth information

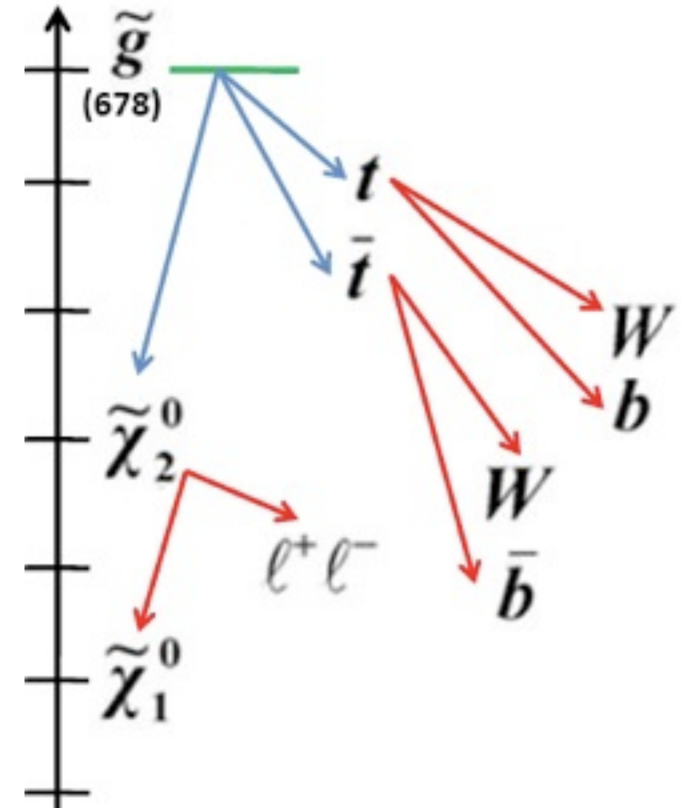
- Background events may or may not contain light higgs, with 2 b-jets that are not correctly reconstructed



Work in progress : more details in the presentation by Harold

Harold Nguyen
Bill Gary

Jets + MET + Ws

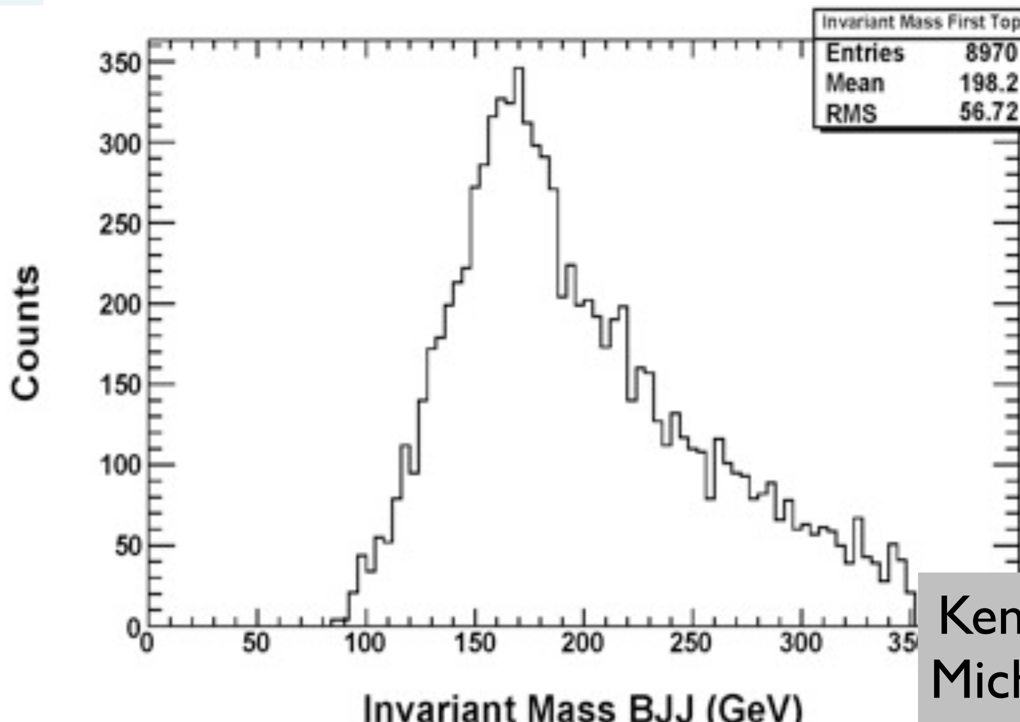


Gluino is lighter than squarks

$m_{\tilde{g}}$	$m_{\tilde{q}}$	$m_{\tilde{e}/\tilde{\mu}/\tilde{\tau}}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$
630	3000	3000	94	176

	E_T^{miss} + Dilepton + Jets
[1]	N(ℓ) ≥ 2 p_T > 10 GeV; |η| < 2.5
[2]	E_T^{miss} > 150 GeV
[3]	Selection of $W \to jj$ $p_T(j)$ > 30 GeV; 0.4 < ΔR(*j*,*j*) < 1.5 M(*jj*) < 78 ± 15 GeV
[4]	Selection of $t \to Wb$ $p_T(b)$ > 30 GeV 0.4 < ΔR(*jj*, *b*) < 2

In early stage, we want to tag "W" inclusively. The work is in progress with Full Simulation



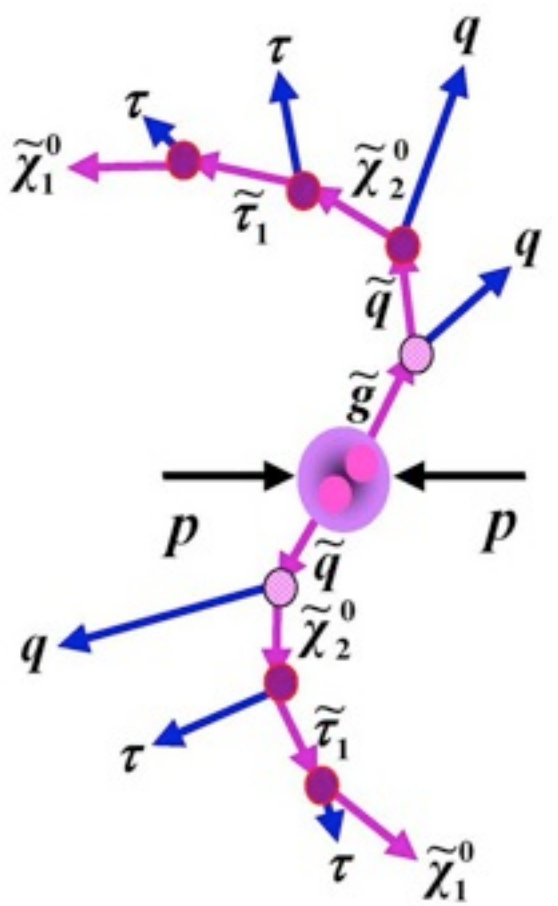
Keng Kovitanggoon
Michael Weinberger
SungWon Lee
Teruki Kamon

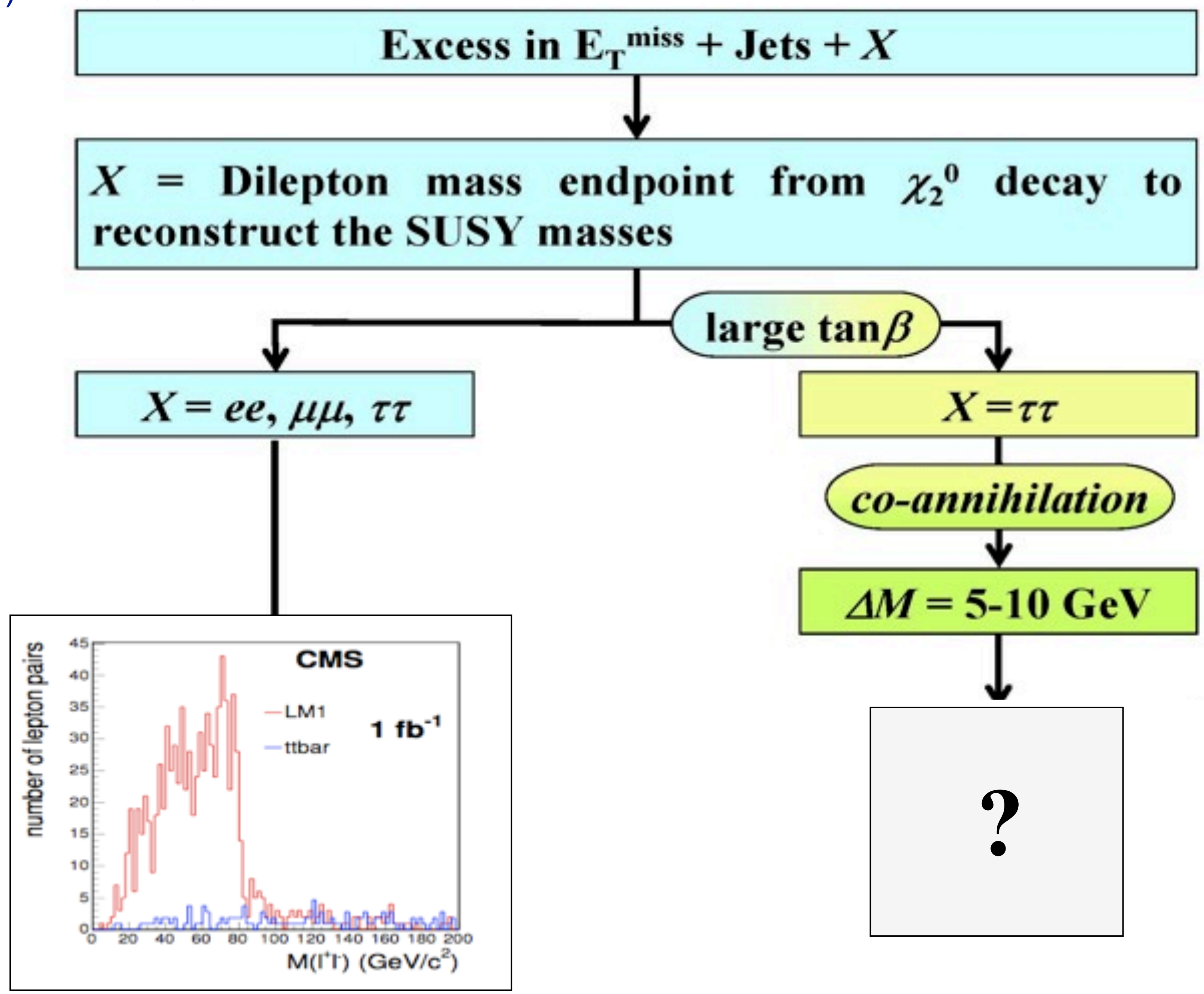
Jets + MET + Taus

Benchmark Point LM2 (7.2 pb) : m_0=185 GeV $m_{1/2}$=350 GeV tan(β)=35 A=0 sign(μ)=+ve

Lightest SUSY particle (LSP) : $M\chi_1^0$ = 141.48 GeV
Next to Lightest SUSY particle (NLSP) : M(stau) = 156.46 GeV

$BR(\chi_2^0 \to$ stau + tau) = 96%
$BR(\chi_1^+ \to$ stau + ν_τ) = 95%



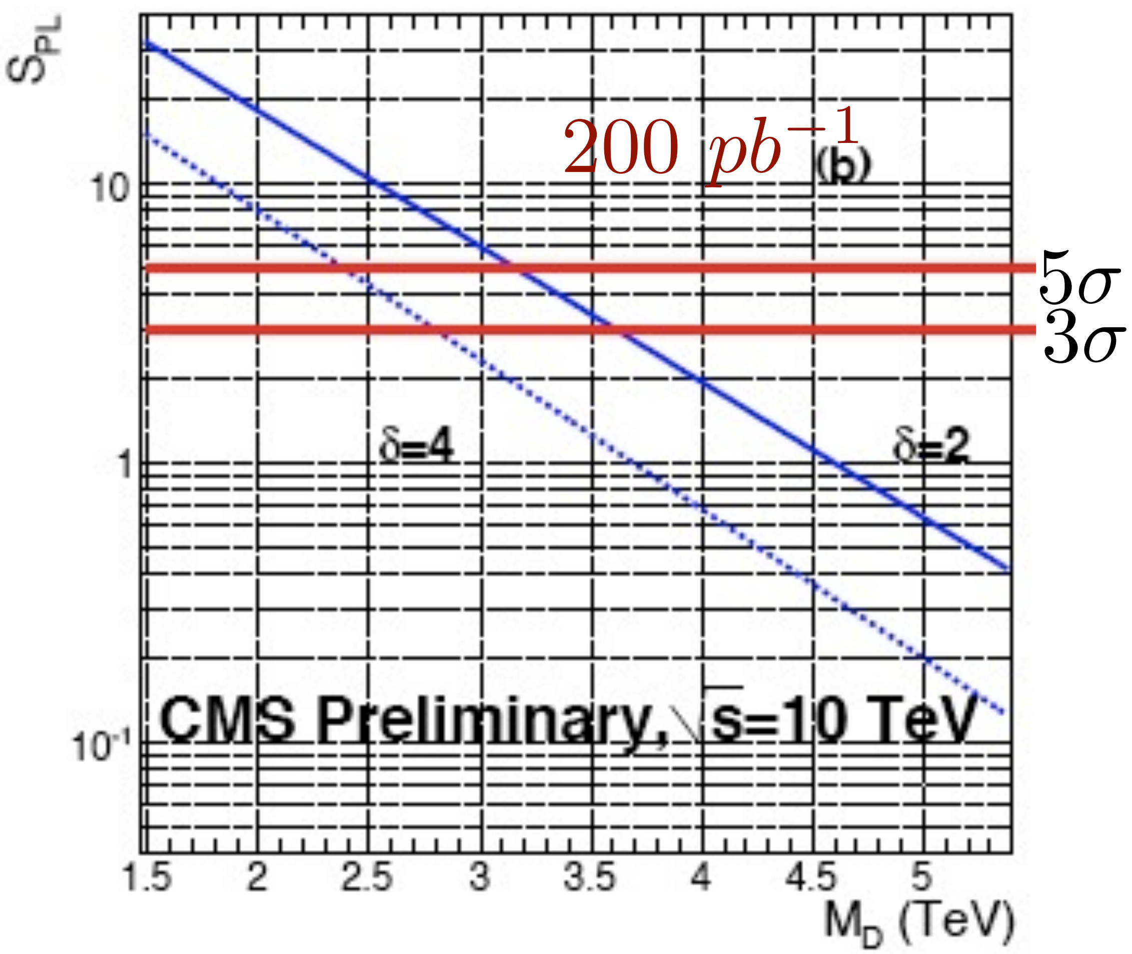


Anwar Bhatti, David Toback, Seema Sharma, Sinjini Sengupta, Teruki Kamon

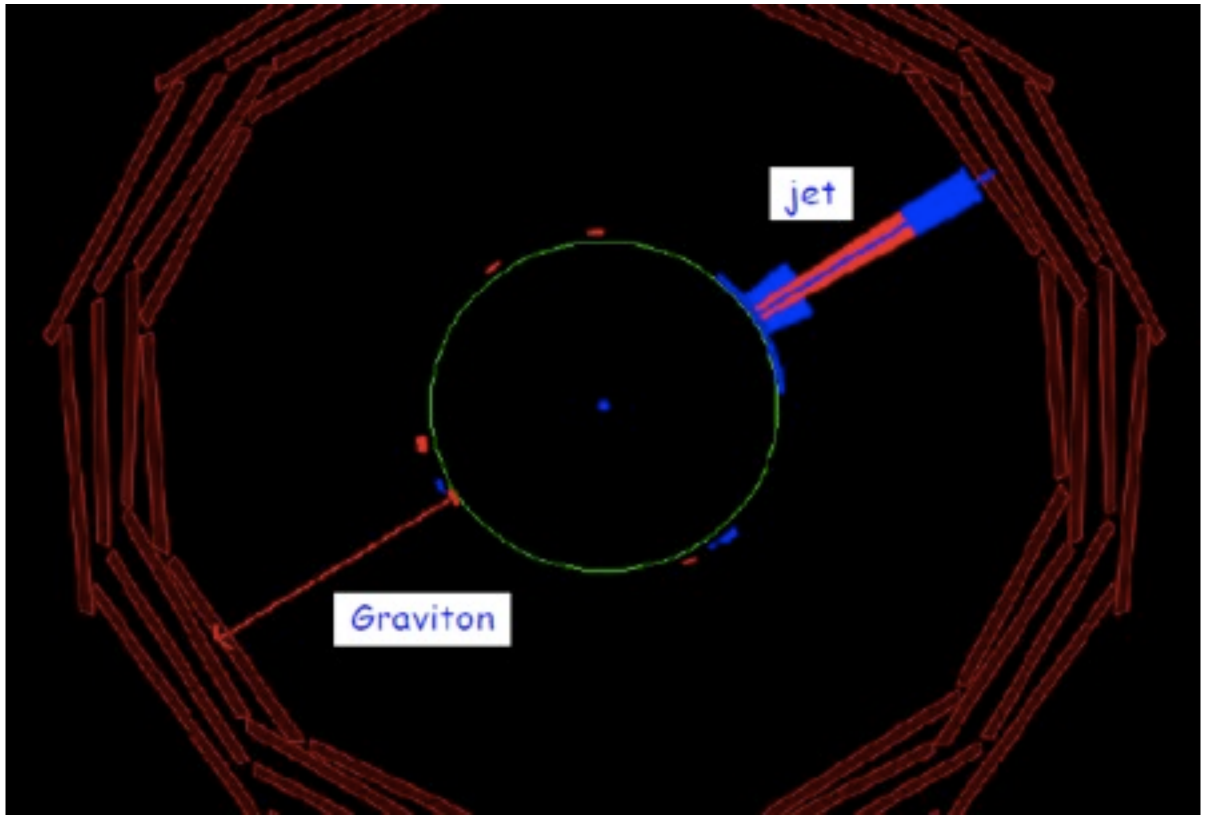
MonoJet Analysis

Summary of selection cuts:

- 1. *MHT > 200GeV (Low statistic for higher cut);*
- 2. *Preselection :* pT (jet) > 50GeV, |η(jet)| < 3;
- 3. *Indirect Lepton Veto*
- 4. *Kinematic cuts : pT (jet 1) > 150GeV, |η(jet 1)| < 1.7;*
- 5. *Jet cleaning : veto against 3 or more jets in the event;*
- 6. *Angular cuts :* $\varphi(jet\ 1, E_T^{miss}) > 2.8$, $\varphi(jet\ 2, E_T^{miss}) > 0.5$.



Signature : One jet Pt>150 GeV in |eta|<1.7



Early discoveries for $\delta = 2(4)$ scenarios are possible, if M_D is below 3.1(2.3) TeV, respectively.

Latife Vergili
Shuichi Kunori

Black Hole Physics using CATFISH

Collider gr**A**vi**T**ational **F**Ield **S**imulator for black **H**oles

Developed at the University of Mississippi by M. Cavaglià, R. Godang, L. Cremaldi, D.Summers

http://www.phy.olemiss.edu/GR/catfish

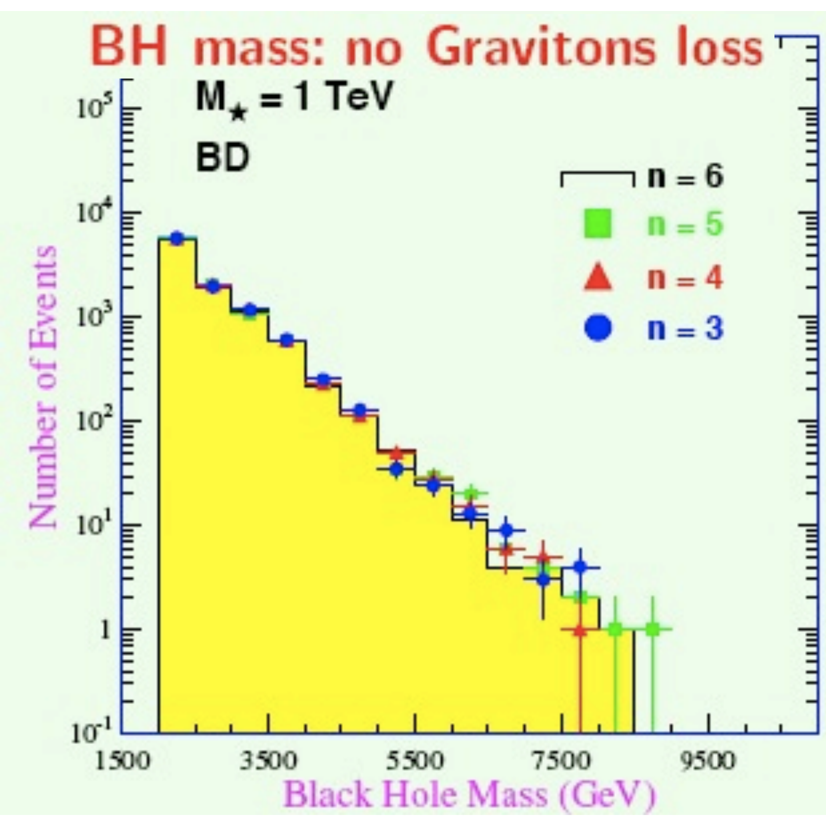
Non-spinning black holes:

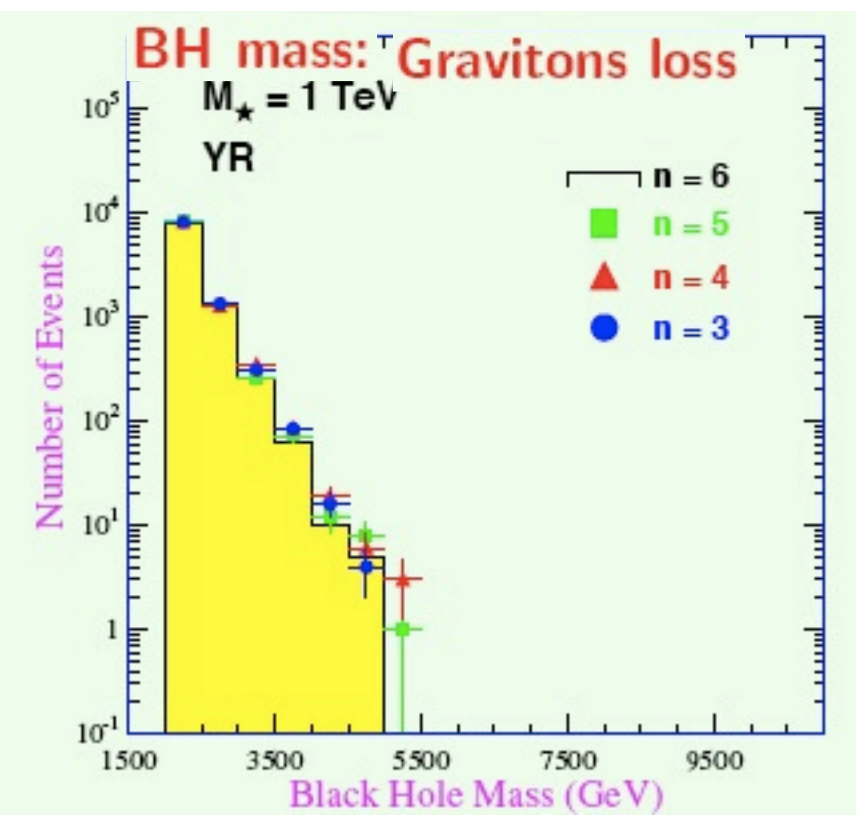
- Inelastic production
- Graviton production @ black hole formation
- Hawking radiation includes gravitons
- Black hole remnant

Uses Pythia 6: call scatter cross section, include parton distribution and hadronize.

Aim : To look for BH signatures at CMS via dilepton channel (spin correlations)

A working version is available in CMSSW_2_2_3

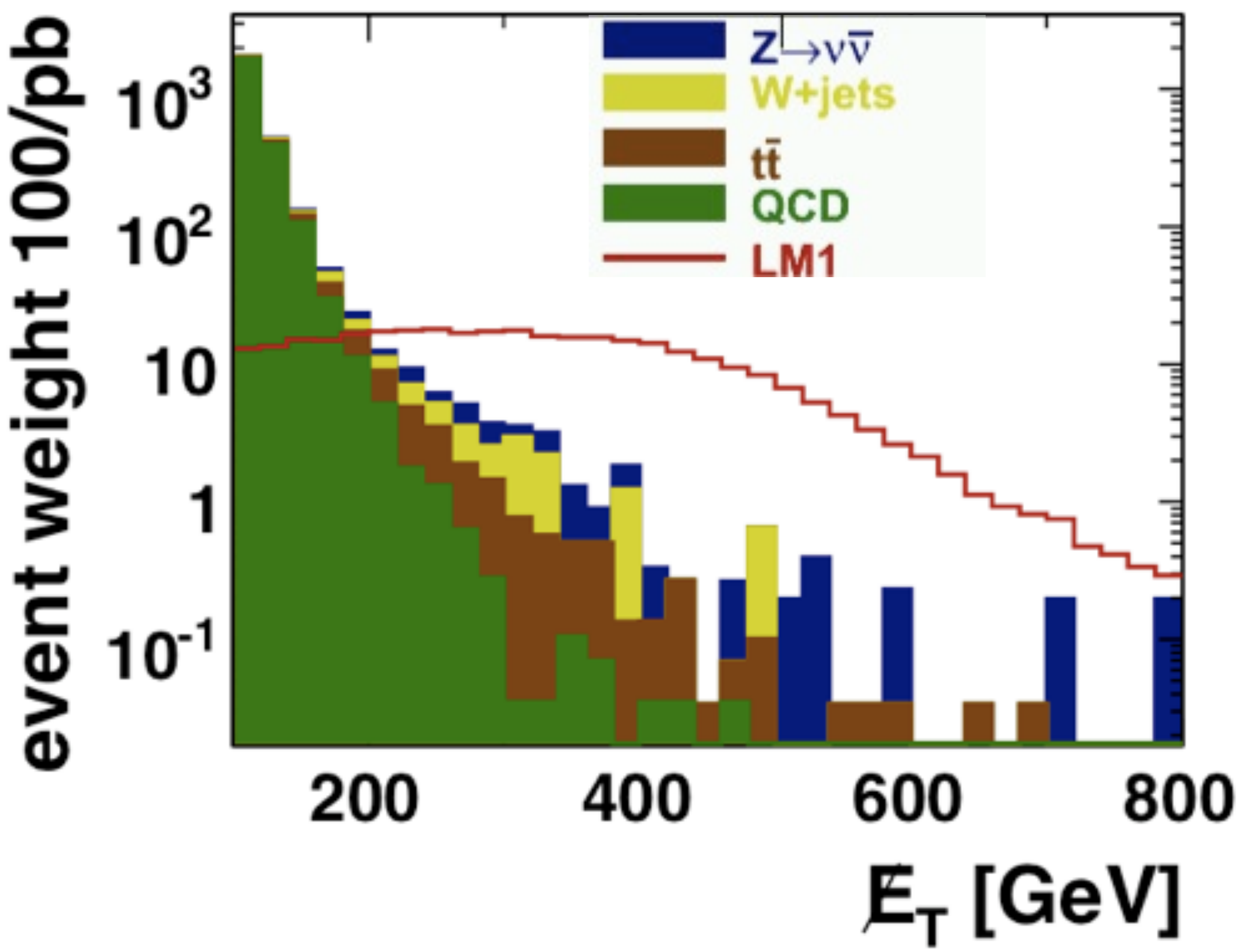




Dominant BH backgrounds: BSM including SUSY and Zprime resonance

Group: M. Cavaglia, L. Cremaldi, R. Godang, M. Jenkins, A. Roy, D. Summers

Estimation of Backgrounds



After applying the selection cuts for inclusive all hadronic analysis :

- **Atleast three energetic jets**
- **MET > 200 GeV**
- **Veto leptons**
- **Angular cuts between direction of MET and leading Jets**

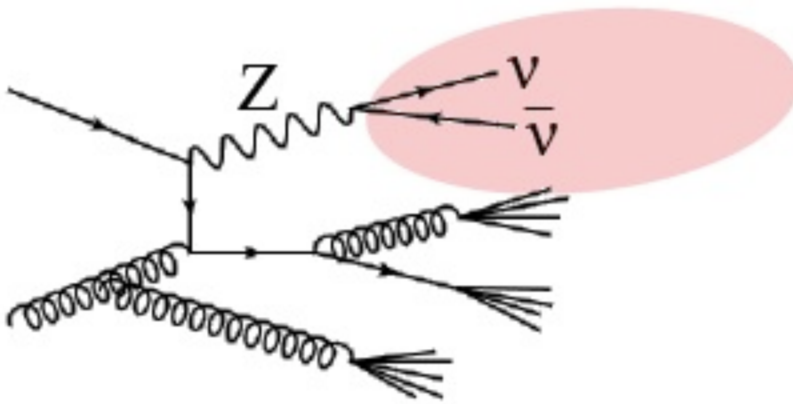
We are looking for an access in tails of MET spectrum and have to carefully measure the contribution from physics and instrumental backgrounds

Why Data Driven Methods ??

- Presently High Energy experiments extensively use Monte Carlo simulation for analysis
- The MC techniques for predicting multi-parton final states are still not very reliable - we need to tune our generators with data
- The theoretical uncertainties on V+Jets final states may be higher
- Although the detector simulation for LHC era experiments are more sophisticated but have to be validated with collider data
- Fluctuations in detector response would result in non-Gaussian high MET tails which are difficult to be simulated
- The energy and momentum calibrations have to be understood
- Contribution due to detector collision and non-collision instrumental effects needs to be properly taken into account

Estimate background contribution from data itself

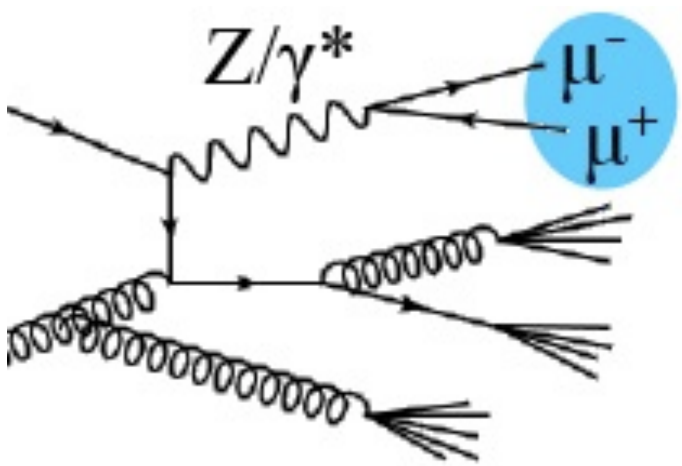
Invisible Z boson



$$p_T^Z > 200GeV => MET > 200GeV$$

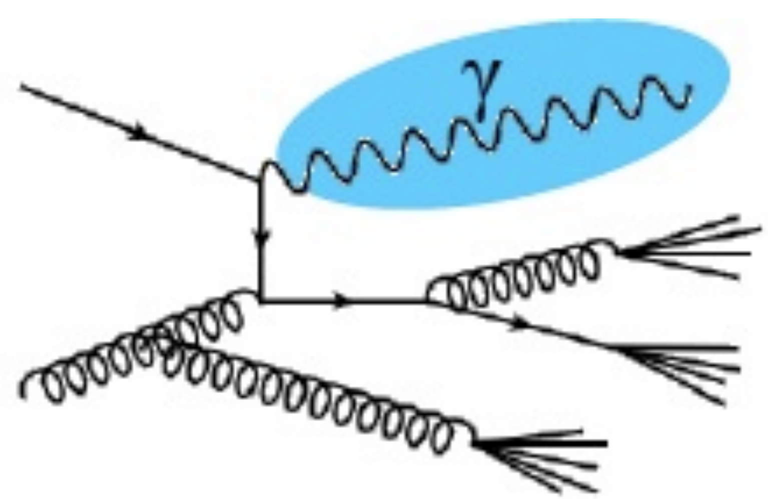
$$\sigma(Z- > \nu\nu) = 20\% \times \sigma(Z)$$

Muons are well measured and can be used to predict MET spectrum due to invisible decays of Z



Dominated by statistical uncertainty in early data

Similarly gamma + Jets events can also be used for
an estimation of invisible Z backgrounds



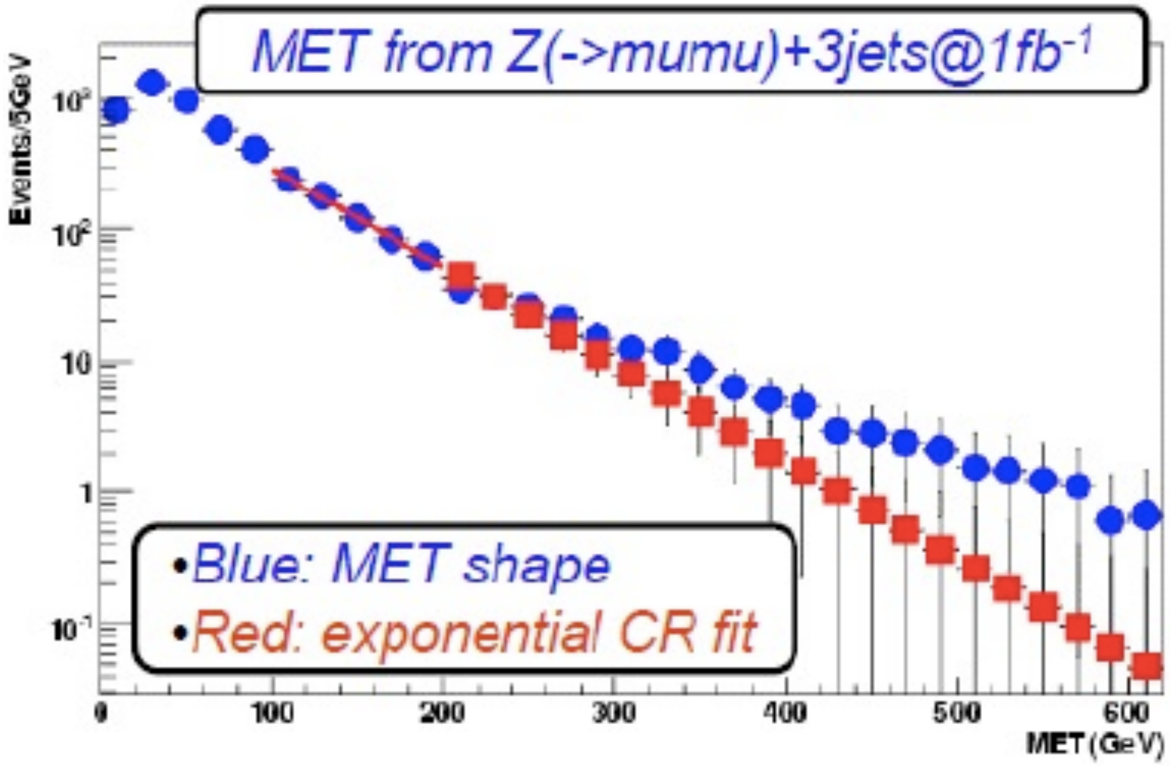
Larger statistics but also larger theoretical corrections

Jim Lungu
Anwar Bhatti

Invisible Z backgrounds using $Z->\mu\mu$

$\sigma(Z\rightarrow\mu\mu) = \sigma(Z\rightarrow\nu\nu)/6$

Signal Region(SR) : MET > 200 GeV
Control Region(CR) : MET 100-200 GeV



Fit the CR with an exponential and use the fit function extended in SR to represent real MET distribution

Events @100 pb^{-1}

- Fit 15, true 19.4

The method relies minimally on the MC and the estimation is biased by the shape of fit function

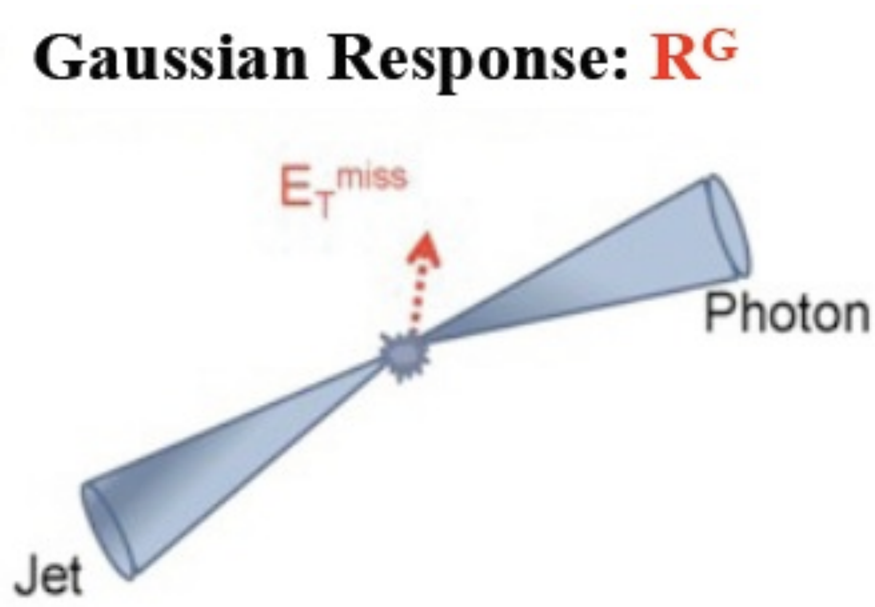
Enough statistics for direct measurement at high luminosity ($600\ pb^{-1}$) :
116 events with MET>200 GeV in $Z\rightarrow\mu\mu$+3jets

Estimation of MET in QCD Events (I)

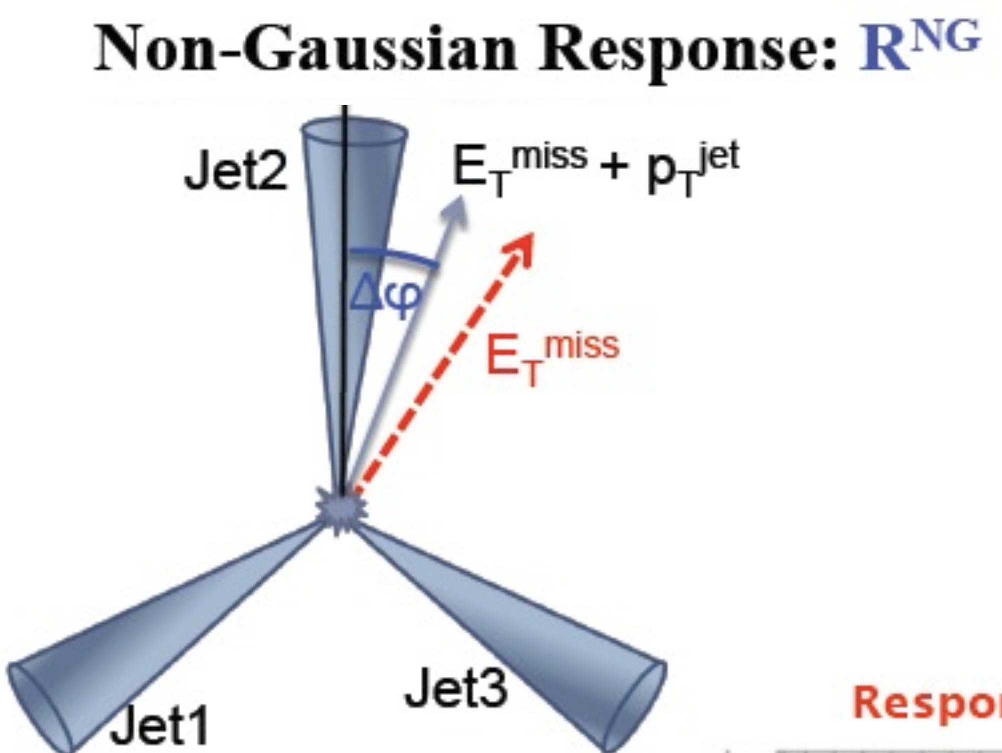
(a data driven approach)

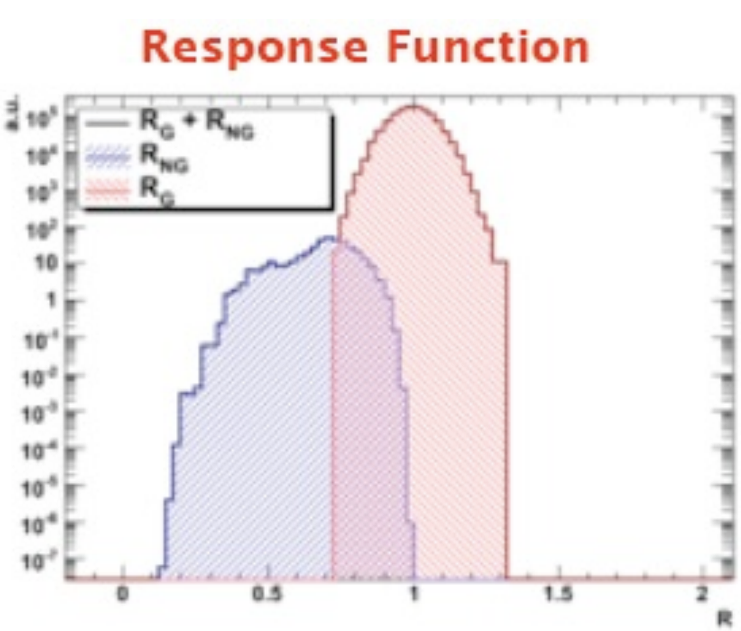
The idea is to obtain a response function using photon+Jets and QCD-MultiJet events which have small generated Missing ET

using Photon+Jets



Using QCD MultiJet

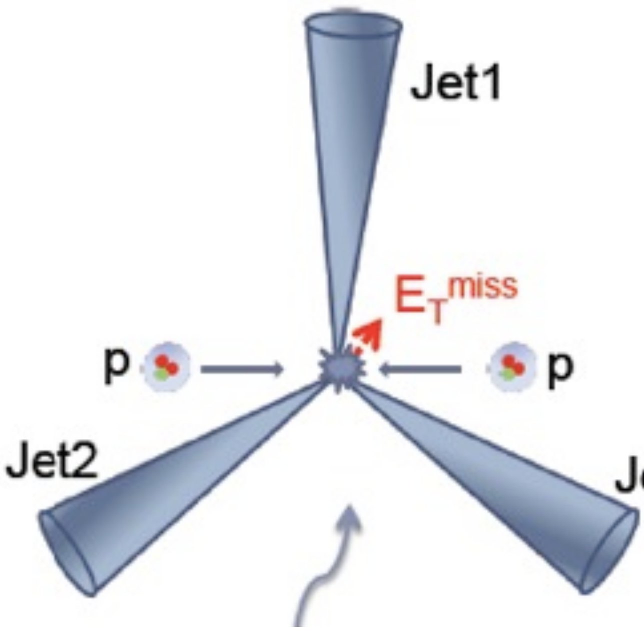




Elif Asli Albarayak

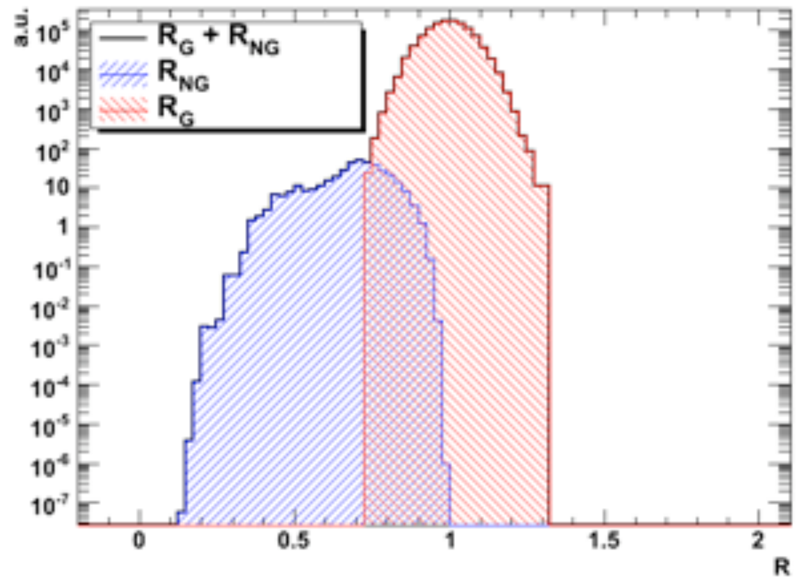
Estimation of MET in QCD Events(II)

Low E_T^{miss} Event



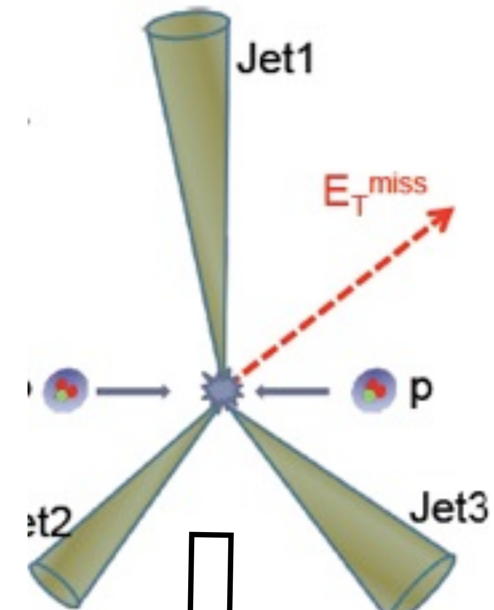
⊗

smear with response function

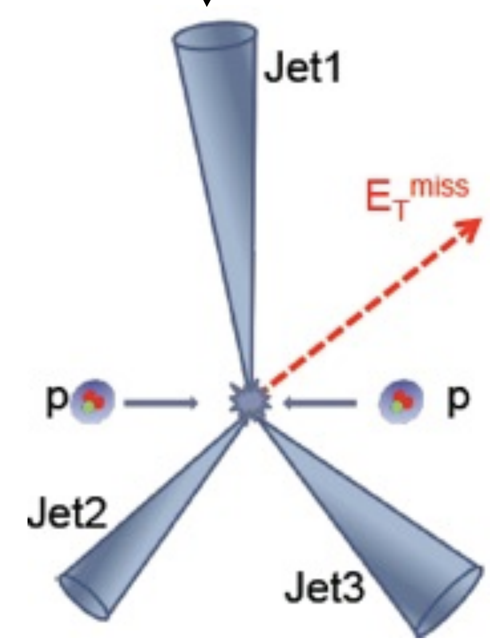


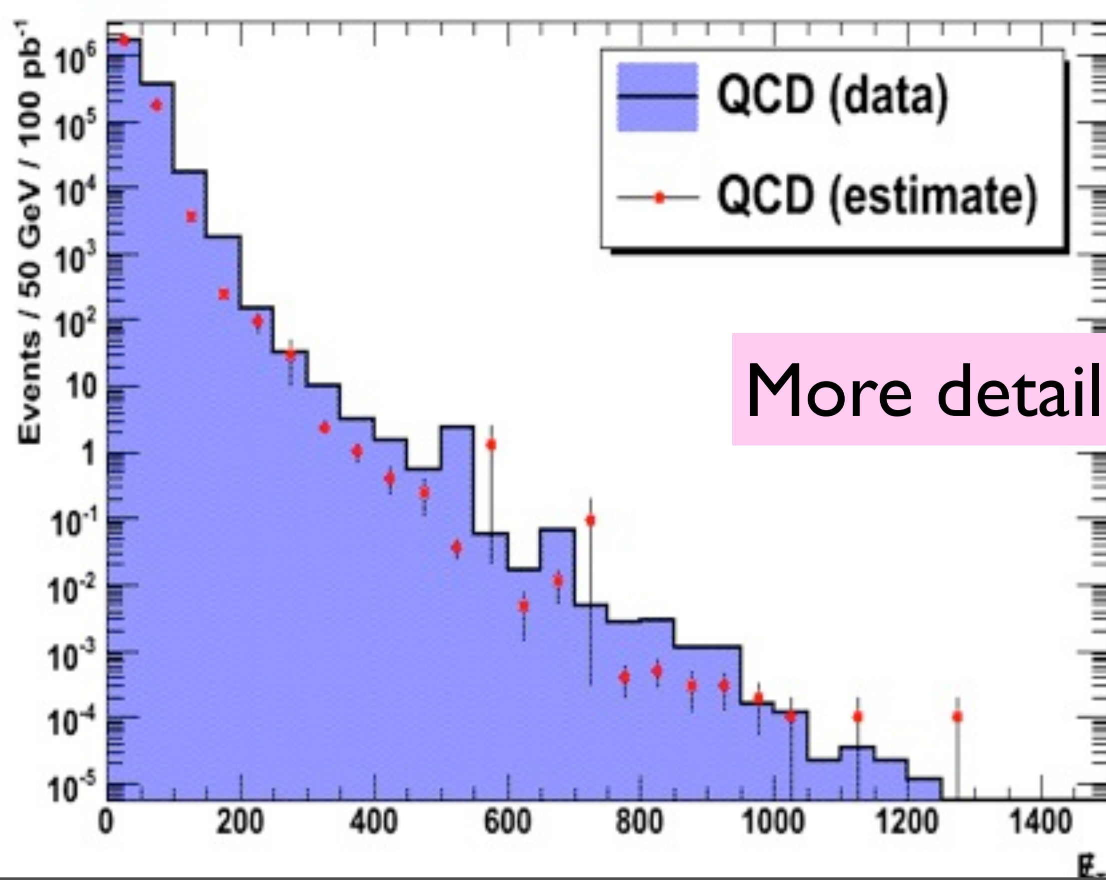
=

smeared event



equivalent to a high MET event





More details in talk by Elif

PAT Layer Production and Synchronization with central SUSY group

To keep the efforts of the groups from various institutes, CMS SUSY group has opted to have centralized PAT Layer1 production and validation

Validation

Object	Link	Contributors
Triggers	SusyTriggerThoughtsAndIssues	CarstenMagass , MassimilianoChiorboli
Jets (caloJets,pfJets,Jet+Tracks,trackJets)	SusyJetThoughtsAndIssues	SueAnnKoay, TorbenSchum, RobertBainbridge
MET (caloMet, tcMet, pfMet)	SusyMETThoughtsAndIssues	TorbenSchum, MariarosariaDalfonso, SeemaSharma, PuneethKalavase, FrankGolf
Muons	SusyMuonThoughtsAndIssues	FinnRebassoo, FedorRatnikov
Electrons	SusyElectronThoughtsAndIssues	LorenzoAgostino
Photons	SusyPhotonThoughtsAndIssues	TomWhyntie, YuriGershtein, OleksiyAtramentov, AndrewAskew, MariarosariaDalfonso
b-Tagging	SusyBTaggingThoughtsAndIssues	WolfgangAdam, HaroldNguyen
Taus	SusyTauThoughtsAndIssues	SeemaSharma, AlfredoGurrola
Particle flow	SusyPFlowThoughtsAndIssues	MichelePioppi
Tracks	SusyTracksThoughtsAndIssues	
Cross-cleaning	SusyXCleaningThoughtsAndIssues	GeorgiaKarapostoli, BenediktMura

SUSY Physics Commissioning

- Data quality has to be understood from SUSY point of view as soon as the data starts coming up
- For example : Missing ET
  - Select High MET events
  - Understand the source of noise and apply known algorithms to filter noise. Develop/test more filters
  - Analyze interesting events further, scan visually .....
- Continuous monitoring of triggers rates and efficiencies - MET and Jet triggers
- Develop techniques to identify and remove Beam Halo (using MC right now)
- "SUSY in CRAFT" projects
- Measure the efficiency and rejection power of noise filters provided by HCAL group
- Study Muon ID, selection, isolation etc ...
- Develop algorithms to identify background from Cosmic events

Summary

- A variety of interesting final states can be studied in Jets +MET topologies
- Since we do not know what kind of physics is going to be revealed at LHC and in which final states, the emphasis is to frame the analysis as generic and robust as possible rather than tuning it to a given parameter space
- Need to understand and estimate the backgrounds (with minimum dependence on simulation)
- Please contact conveners and discuss your interests with them as soon as possible

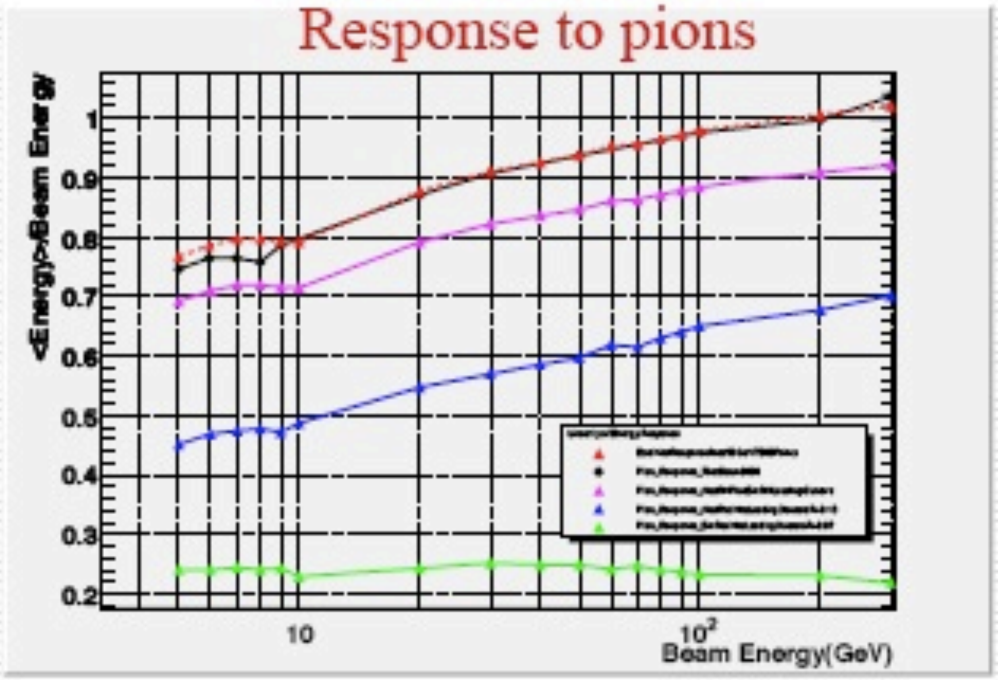
Anwar Bhatti : Co-Convener CMS SUSY Commissioning Group
Teruki Kamon : Co-Convener CMS MET Group

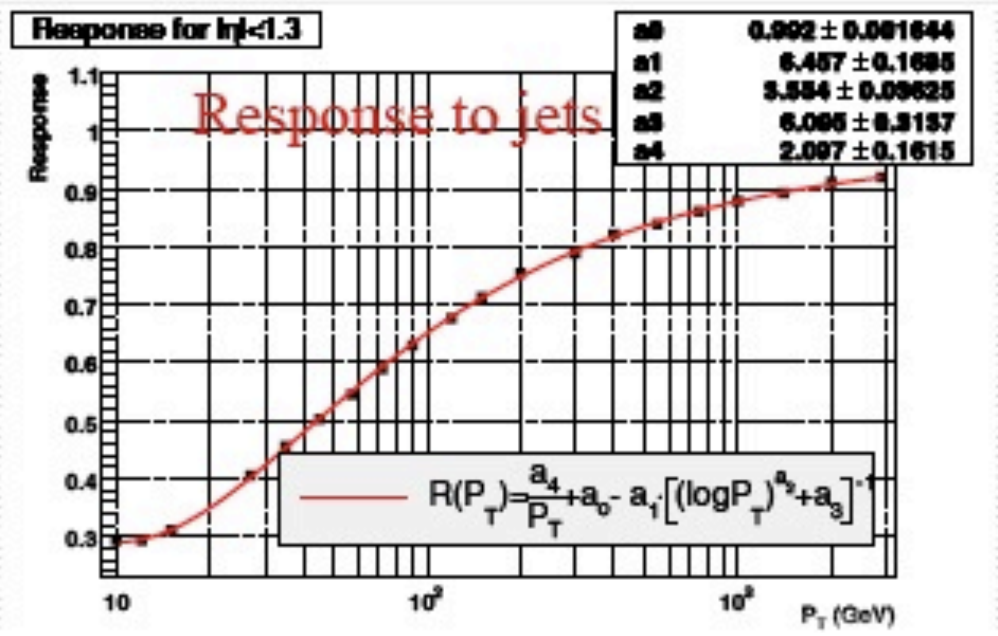
Meetings : Tuesday 13:00-15:00 (CST) (BiWeekly) in Round Table (WH11SE)/EVO

Back Up

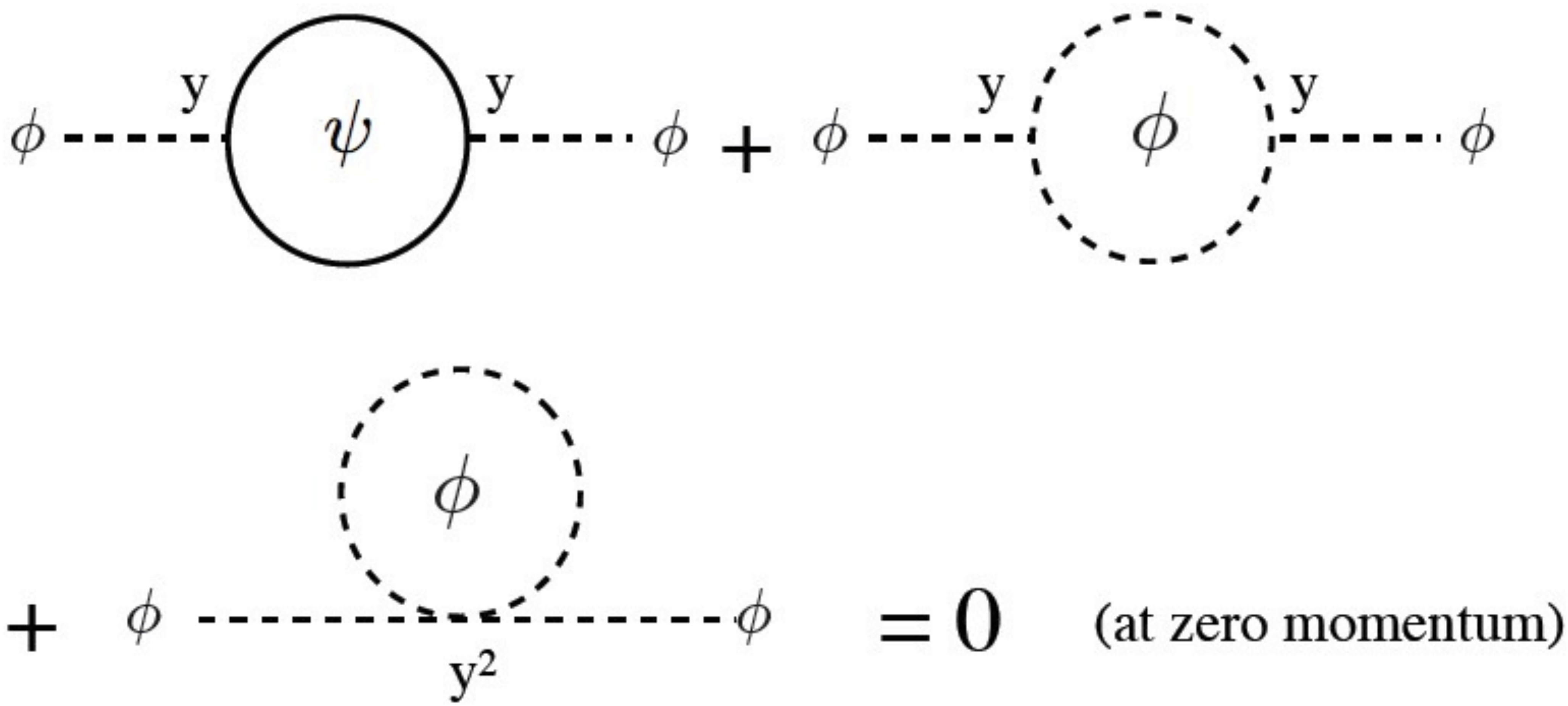
Jet Energy Corrections

- Jet is a collection of different types of particles.
- Particle Type (mean, rms)%
  - Neutral pions $\pi^0(\rightarrow\gamma\gamma)$ (~25, 16)%
  - Charged hadron (~67, 17)%
  - Neutrons/K_L (~ 8, 11)%
- Jet are normally measured by calorimeter.
- Calorimeter response to photons is linear.
- Calorimeter response to charged hadrons, neutrons, K_L is non-linear and different than the response to the photons.
- The precise jet energy scale determination is complex due to large fluctuations in the particle composition and momentum, and large fluctuations in the calorimeter response. It also depend on the jet flavor.



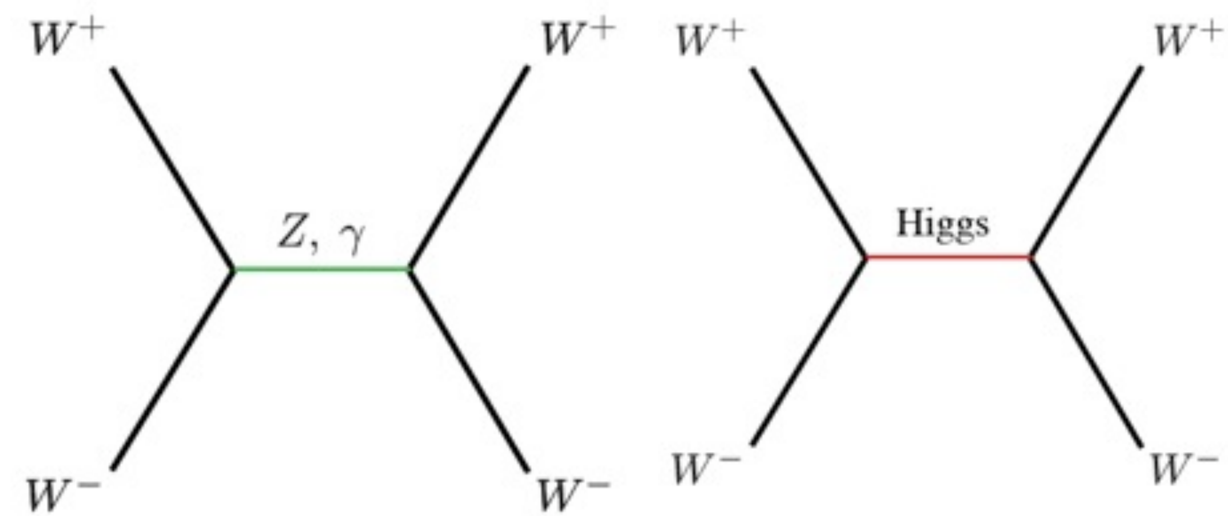


Stabilizing Higgs Mass



Physics At 1 TeV

The WW scattering probabilty is greater than unity and theory breaks down at a scale of ~ 1 TeV. However, Theory retains its predictive power with the inclusion of a fundamental spin 0 particle - Higgs Boson.

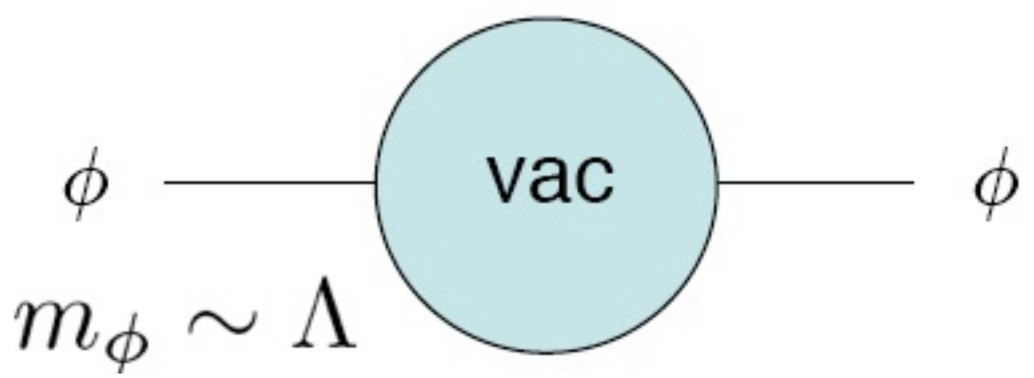


EWK Symmetry Breaking can be explained by Higgs mechanism in Standard Model

The Higgs is constrained to be ~1 TeV by :

★ The Unitarity Bound

★ Electroweak Precision measurements



In SM, the mass of a spin zero particle is not protected by any symmetry (infinitely large self-energy corrections) .

If we can produce Higgs at LHC we are already at an energy scale where we can probe the underlying theory - what it is ???

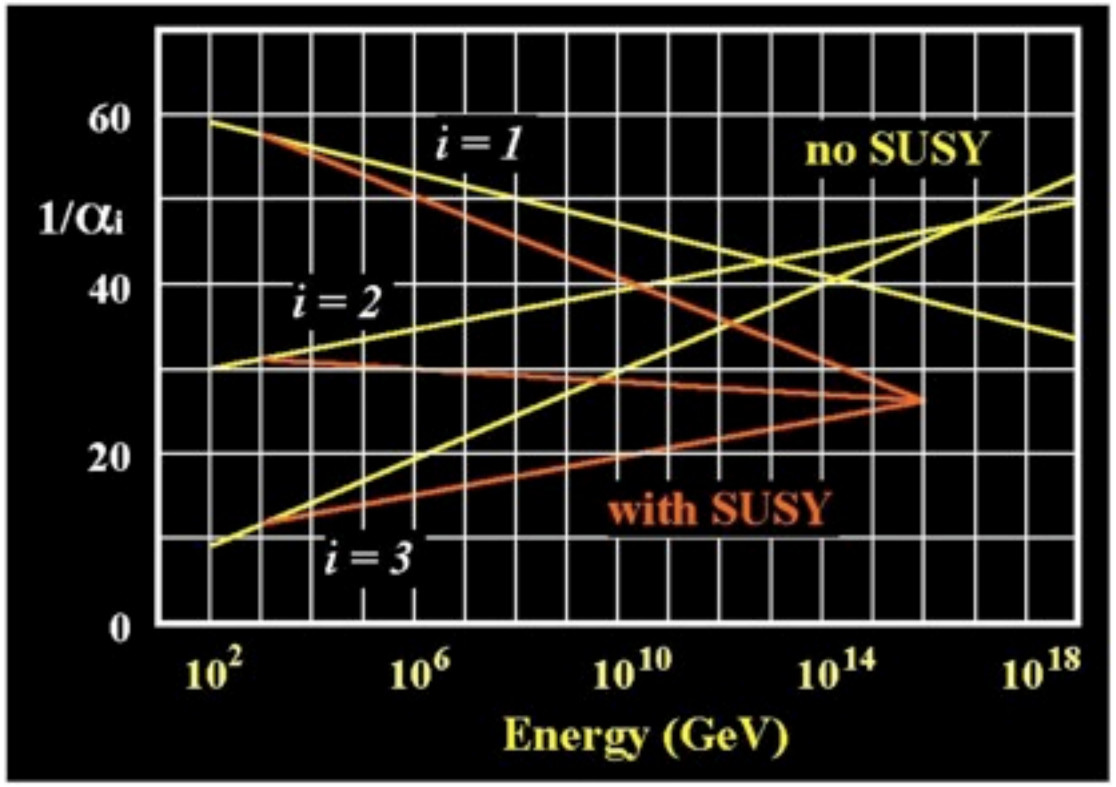
Connection to Cosmology : It is well known now that ~99% of energy in universe is dark and 96% appears to be in new forms of matter/energy and we do not have any clue what it is !!!

Consequenses of SUSY

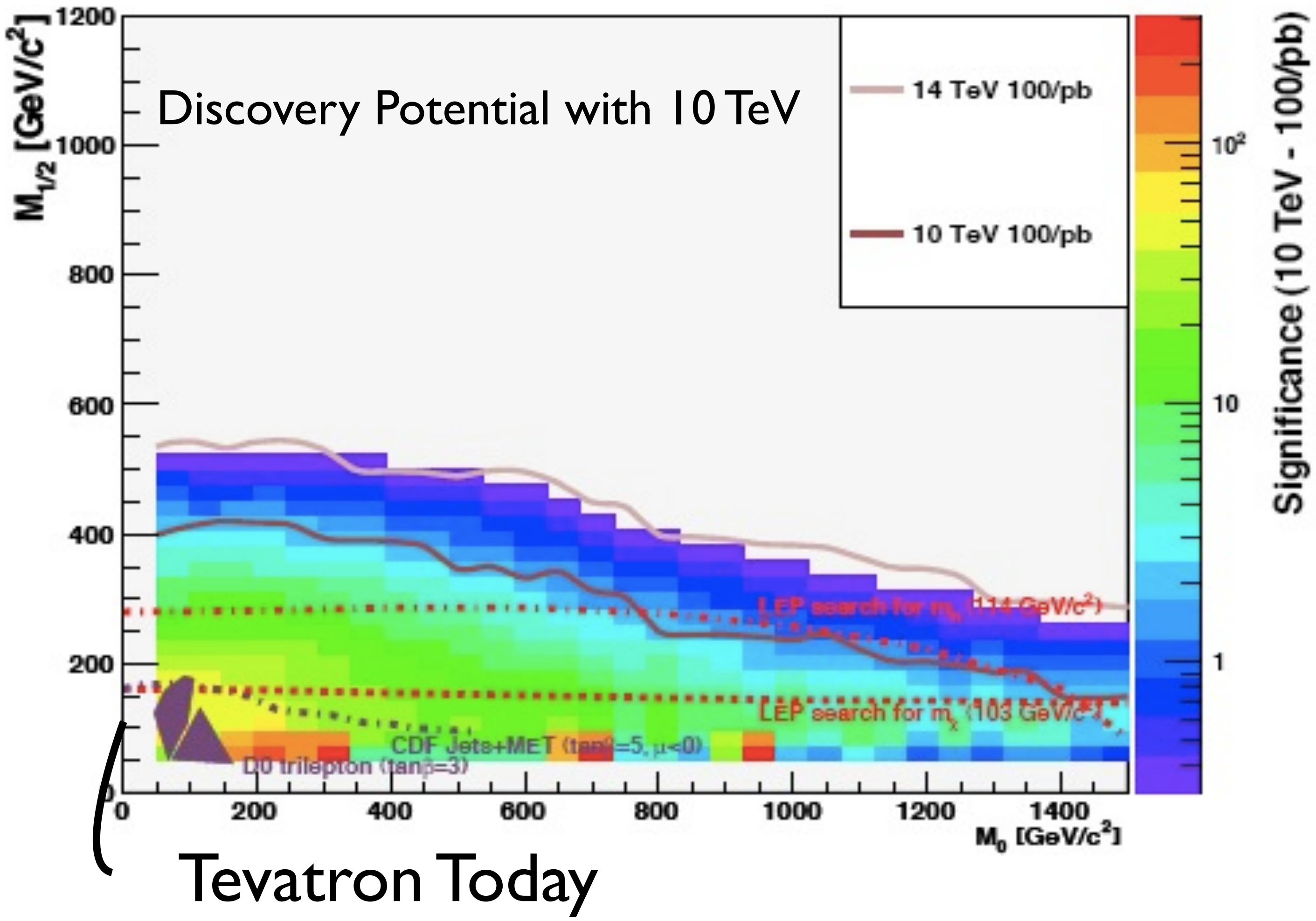
Superpartners at ~ 100 GeV?

- Electroweak symmetry breaking works
- No problems with electroweak precision
- Contains a viable dark matter WIMP (after saving the proton from decay)

Gauge Unification



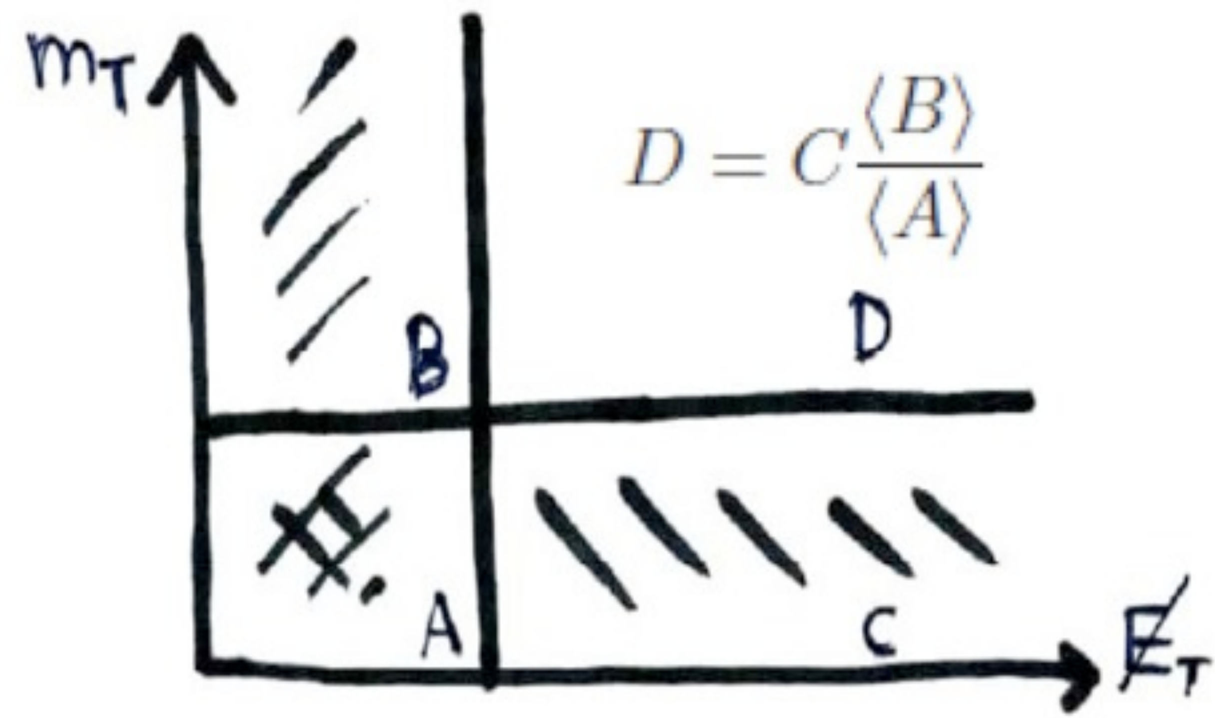
SUSY @ CMS



Wednesday, August 5, 2009

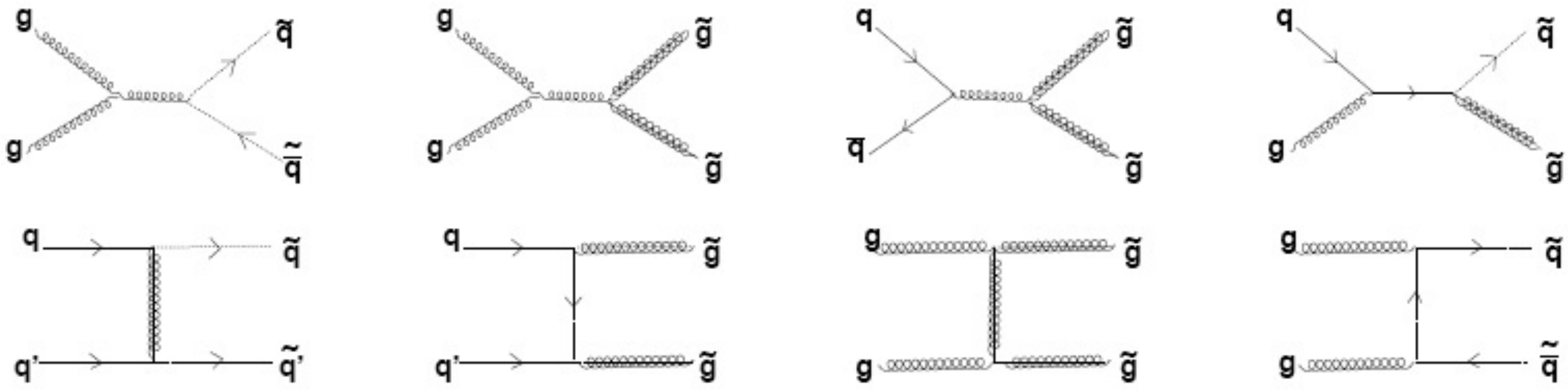
ABCD Method of Background Estimation

If we have two independent variables, e.g. MET and mT, we can model the Background in the "signal region" D, by extrapolating from the A,B, and C regions.



As the two variables we use MET, and mT. The MET variable we slice into 100 < MET < 200 (A and B regions), and 200 > MET (C and D regions).
For mT, we chose 50 < mT < 100 (A and C), and 100 < mT (B and D).

Feynman diagrams for production of SUSY particles in the lowest order



The mSUGRA parameters of the CMS test points

Point	m_0 (GeV/c^2)	$m_{1/2}$ (GeV/c^2)	$\tan\beta$	sgn(μ)	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.