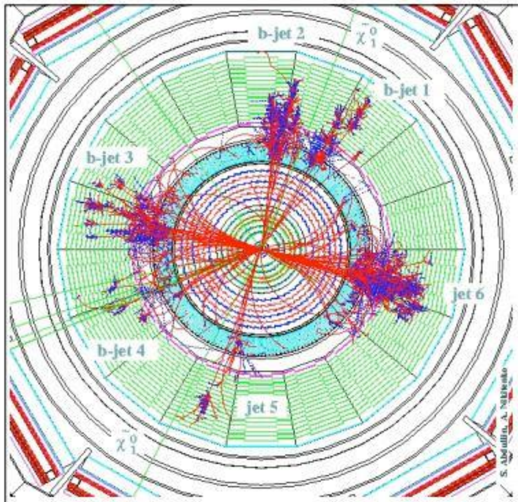


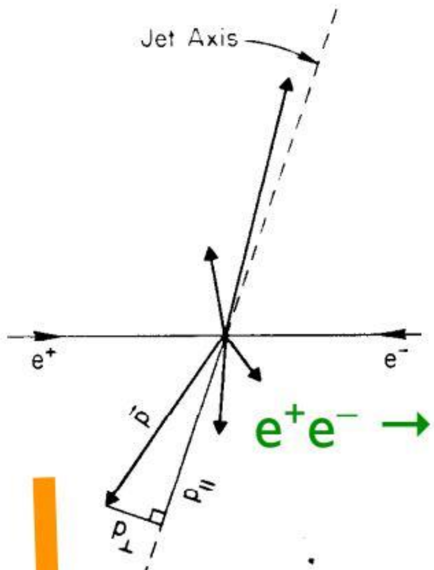
2007 Aspen Winter Conference
"New Physics at the Electroweak Scale and New Signals at Hadron Colliders"
Jan. 11, 2007

Missing E_T + Jets Signatures at the LHC

Jim Rohlf
Boston University

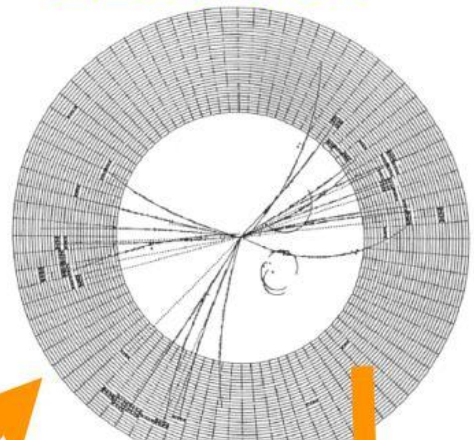
History of Jets

SPEAR 1974



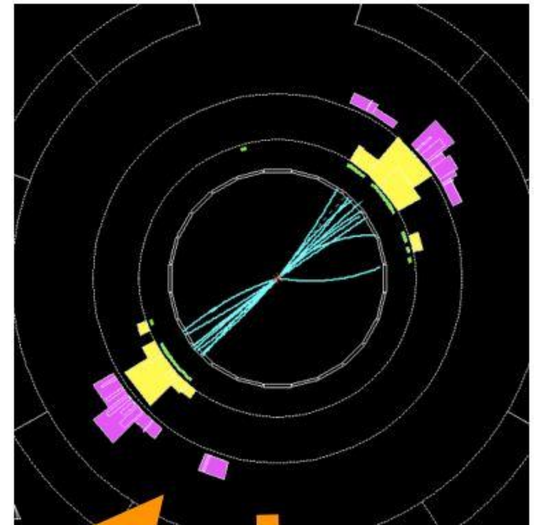
$e^+e^- \rightarrow q\bar{q}$

DESY 1979



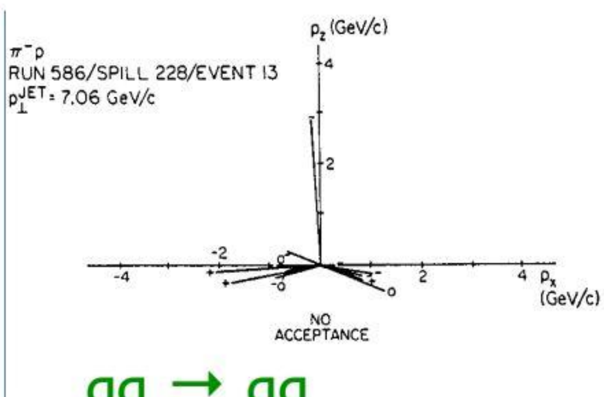
$e^+e^- \rightarrow q\bar{q}g$

CERN LEP 1989



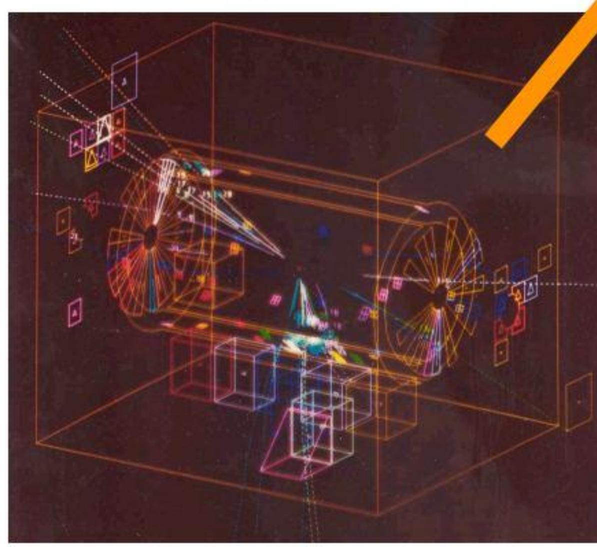
$e^+e^- \rightarrow q\bar{q}$

FNAL 1977



$qq \rightarrow qq$

CERN $p\bar{p}$ 1982



$q\bar{q} \rightarrow q\bar{q}$

LHC 2008

?

200 GeV jets in CMS (prediction)

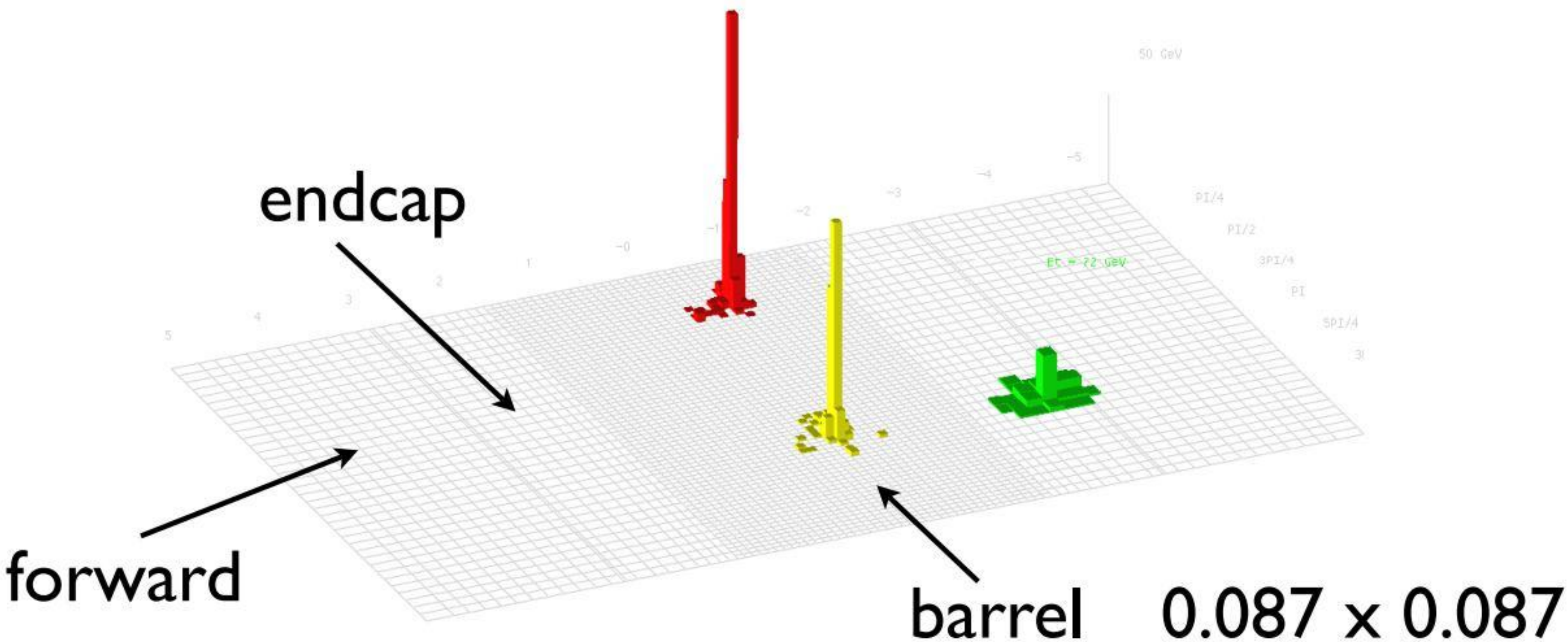
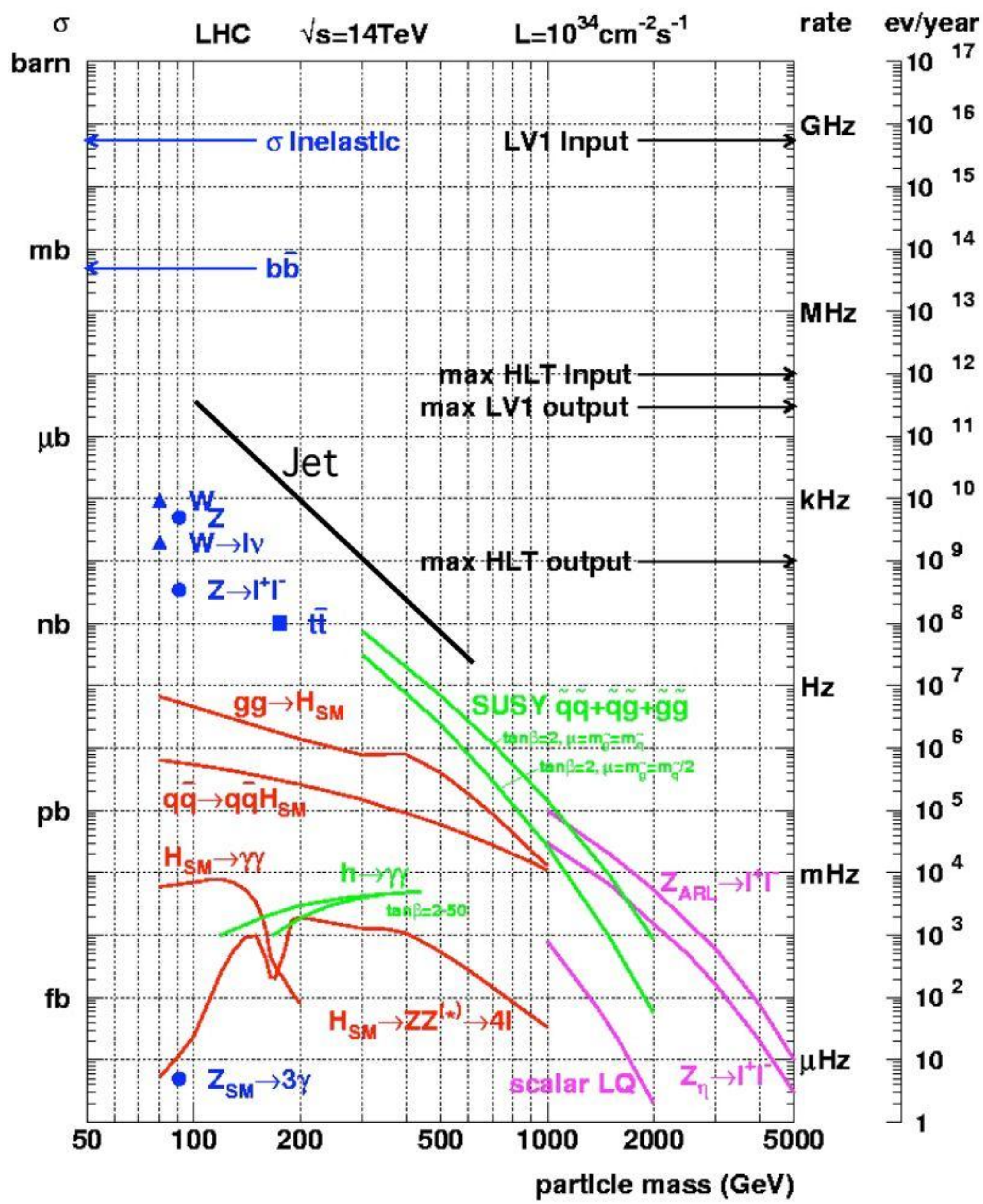
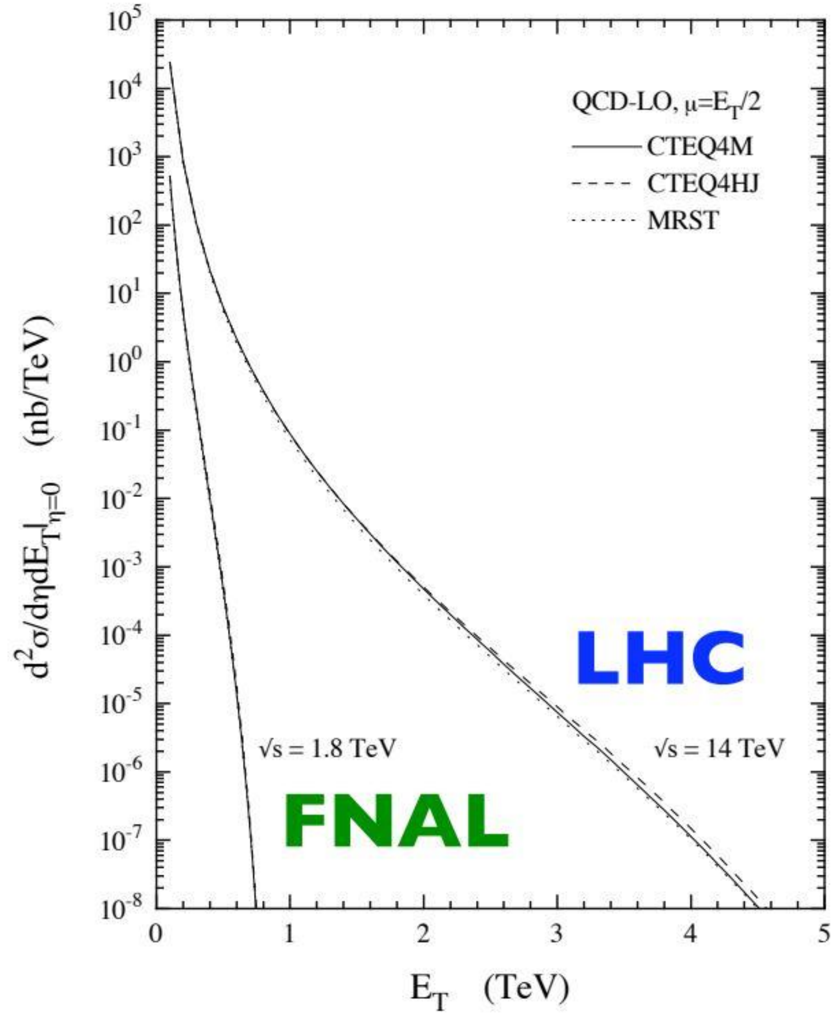


Figure 11.2: The η, ϕ segmentation of the CMS hadron calorimeter.


σ
barn
mb
μb
nb
pb
fb
LHC √s=14TeV L=10^34cm^-2s^-1
rate ev/year
σ inelastic
LV1 input
GHz
bb̄
MHz
max HLT input
max LV1 output
Jet
kHz
W
Z
W→lν
max HLT output
Z→l⁺l⁻
tt̄
Hz
gg→H_SM
SUSY q̃q̃+q̃g̃+g̃g̃
qq̄→qq̄H_SM
H_SM→γγ
h→γγ
mHz
Z_ARL→l⁺l⁻
H_SM→ZZ(*)→4l
μHz
Z_SM→3γ
scalar LQ
Z_η→l⁺l⁻
50 100 200 500 1000 2000 5000
particle mass (GeV)

Jet Cross Section



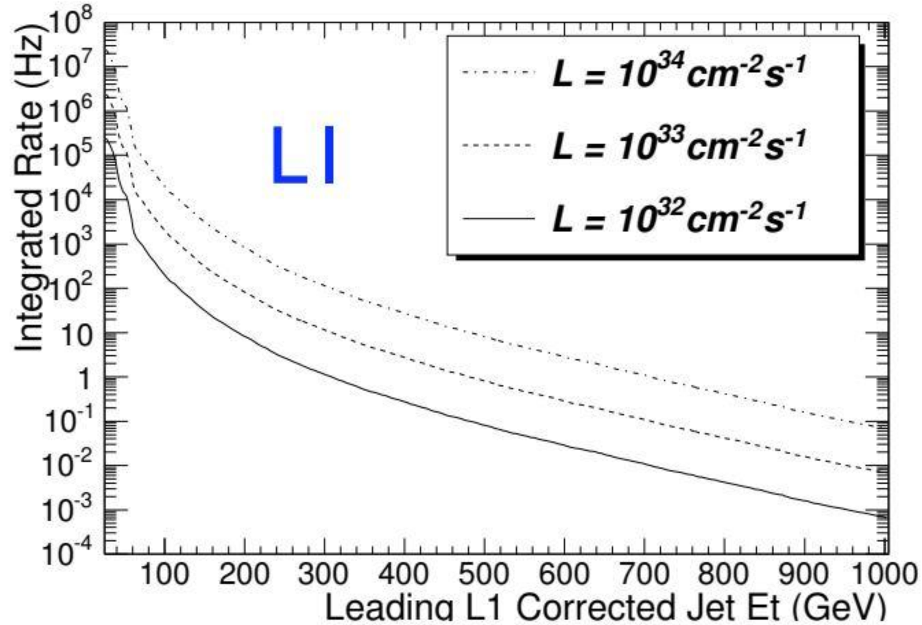
CMS Jet Rates

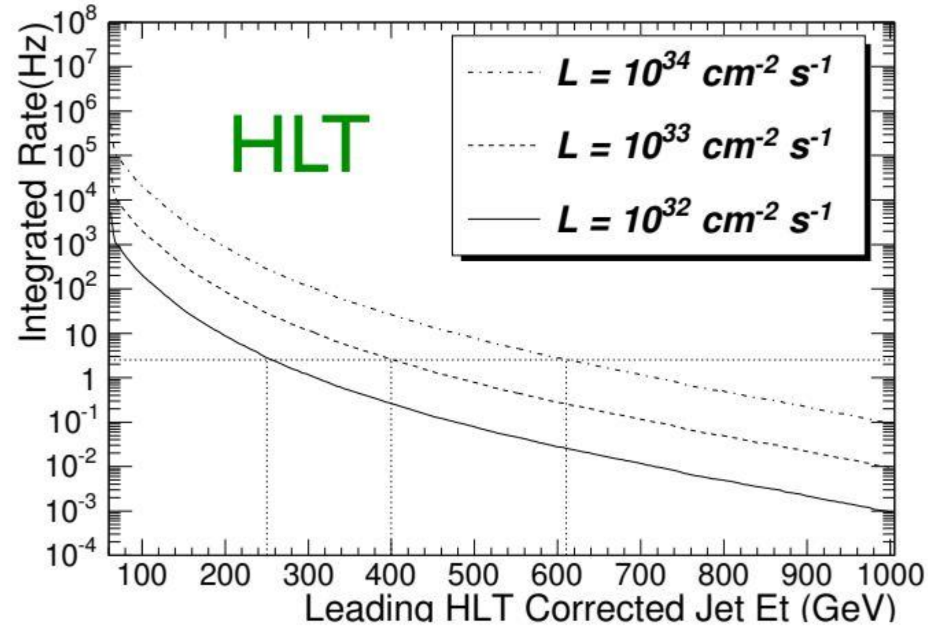
Logic: never change thresholds;
introduce new threshold and pre-scale

Path	L1				HLT	
	E_T Cut (GeV)	Unpres. Rate (KHz)	Prescale (N)	Presc. Rate (KHz)	E_T Cut GeV)	Rate (Hz)
Single Jet Triggers in Scenario 1: $\mathcal{L} = 10^{32}$ cm^{-2}s^{-1}						
High	140	0.044	1	0.044	250	2.8
Med	60	3.9	40	0.097	120	2.4
Low	25	2.9×10^2	2,000	0.146	60	2.8
Single Jet Triggers in Scenario 2: $\mathcal{L} = 10^{33}$ cm^{-2}s^{-1}						
Ultra	270	0.019	1	0.019	400	2.6
High	140	0.44	10	0.044	250	2.8
Med	60	39	400	0.097	120	2.4
Low	25	2.9×10^3	20,000	0.146	60	2.8
Single Jet Triggers in Scenario 3: $\mathcal{L} = 2 \times 10^{33}$ cm^{-2}s^{-1}						
Ultra	270	0.038	1	0.038	400	5.2
High	140	0.88	20	0.044	250	2.8
Med	60	78	800	0.097	120	2.4
Low	25	5.8×10^3	40,000	0.146	60	2.8
Single Jet Triggers in Scenario 4: $\mathcal{L} = 10^{34}$ cm^{-2}s^{-1}						
Super	450	0.014	1	0.014	600	2.8
Ultra	270	0.19	10	0.019	400	2.6
High	140	4.4	100	0.044	250	2.8
Med	60	3.9×10^2	4,000	0.097	120	2.4
Low	25	2.9×10^4	200,000	0.146	60	2.8

Low enough for ϵ_{HLT} > 95%

~10 Hz (by design)





AN 2006/09 S. Esen, R. Harris

Outline

Tools

Standard Model

Higgs

SUSY

Calorimetry

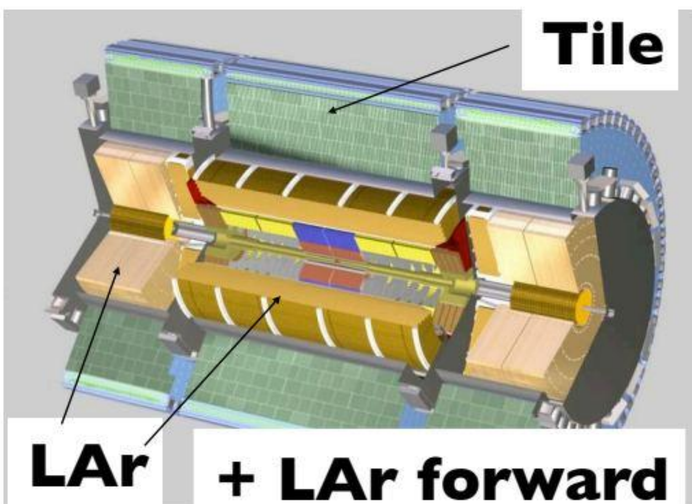
ECAL

	res. @ 50 GeV	*material in front*	*thickness*	$\Delta\eta \times \Delta\phi$
ATLAS	1.3%	2-4 χ_0	21-36 χ_0	front 0.003×0.1 middle 0.025×0.025 back 0.05×0.025
CMS	0.8%	0.4-1.3 χ_0	25-27 χ_0	0.0174×0.0174

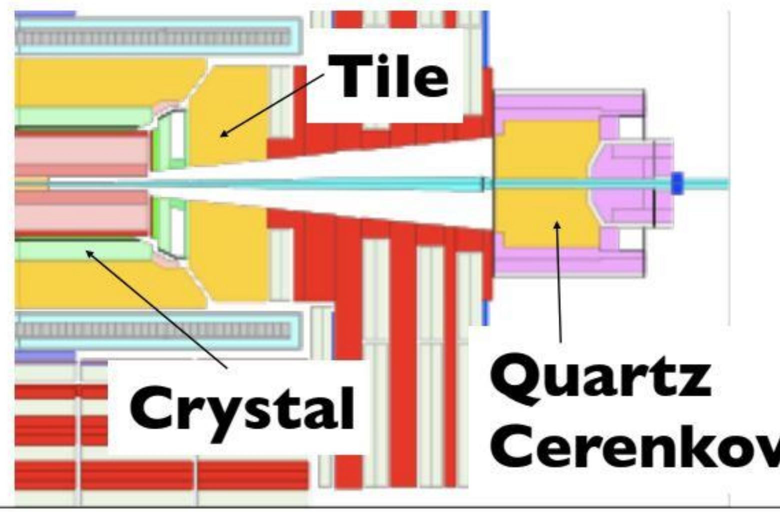
HCAL

	coverage	*res. @ 100 GeV*	*thickness*	$\Delta\eta \times \Delta\phi$
ATLAS barrel	$\lvert\eta\rvert < 1.0$	8%	8-10 λ	front 0.1×0.1
extended barrel	$0.8 < \lvert\eta\rvert < 1.7$			back 0.2×0.1
endcap	$1.5 < \lvert\eta\rvert < 3.2$			$0.1\text{-}0.2 \times 0.1$
forward	$3.1 < \lvert\eta\rvert < 4.9$			0.2×0.2
CMS barrel	$\lvert\eta\rvert < 1.4$	10%	11-15 λ	0.087×0.087
endcap	$1.4 < \lvert\eta\rvert < 3.0$			$0.087 \times 0.087\text{-}0.17$
forward	$3.0 < \lvert\eta\rvert < 5.0$	20%		0.17×0.17

ATLAS



CMS



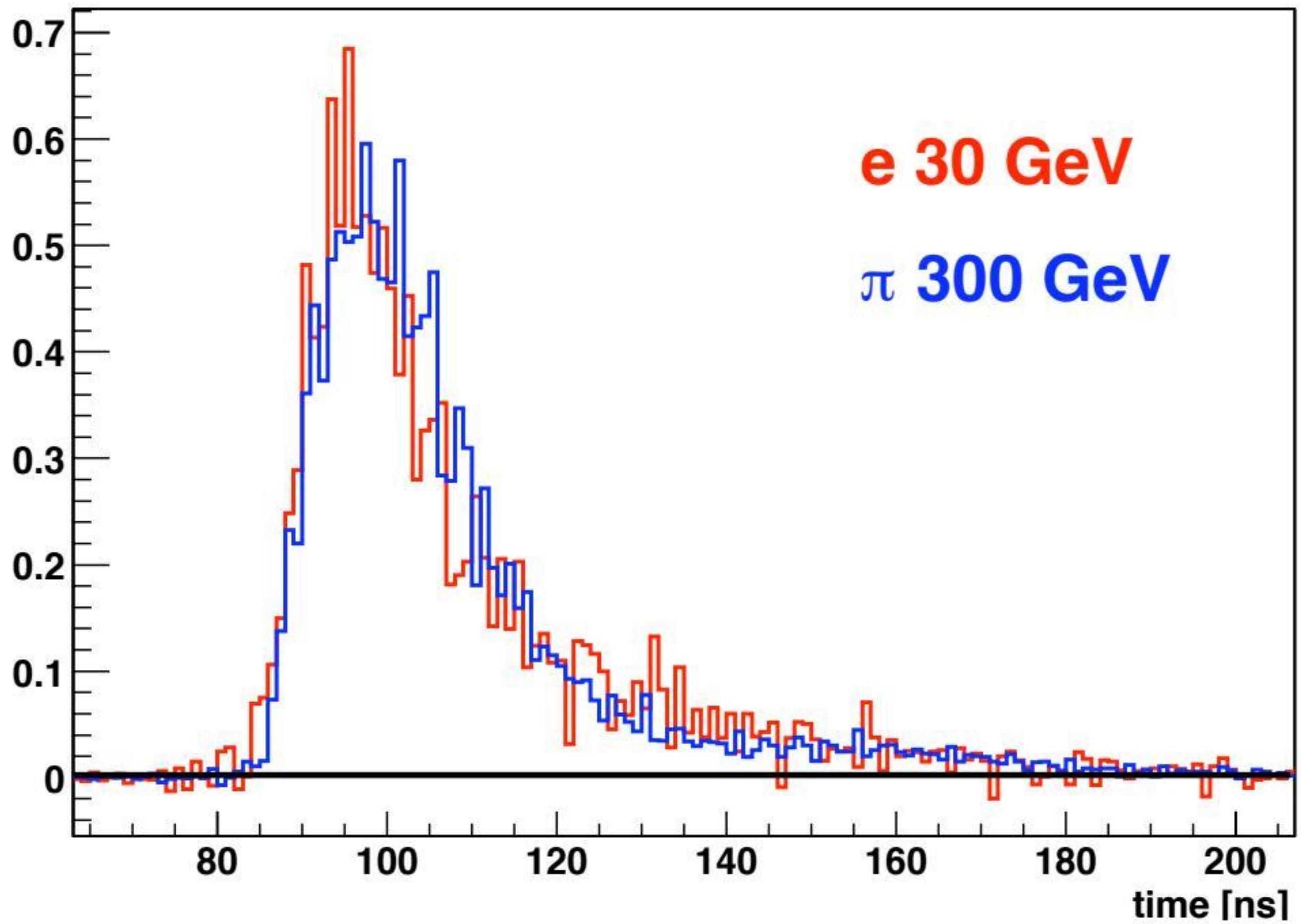


Figure 3: Pulse shape for 30 GeV electrons and 300 GeV pions.

Tiles with PMTs, 16 bit dynamic range
15 MeV to 1.5 TeV, every 25 ns

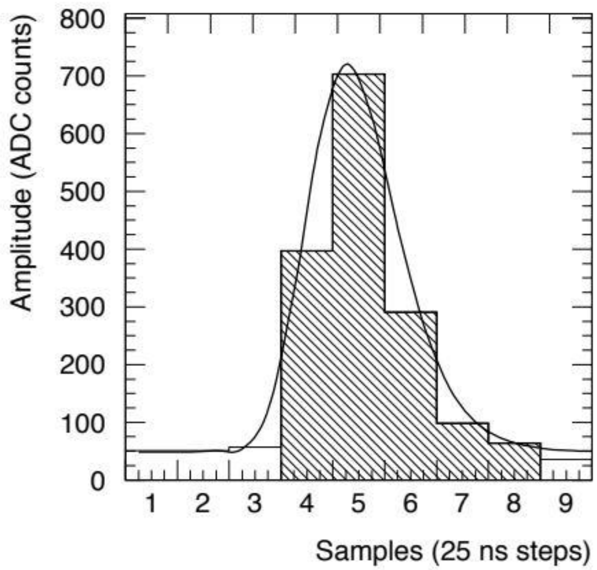


Fig. 5. Example of the 3-parameter fit method to the digitized samples of one channel. For comparison to the flat filter, the five samples with maximum amplitude are highlighted.

K. Anderson, et al., Nucl. Instr. and Meth. A 551 (2005) 469.

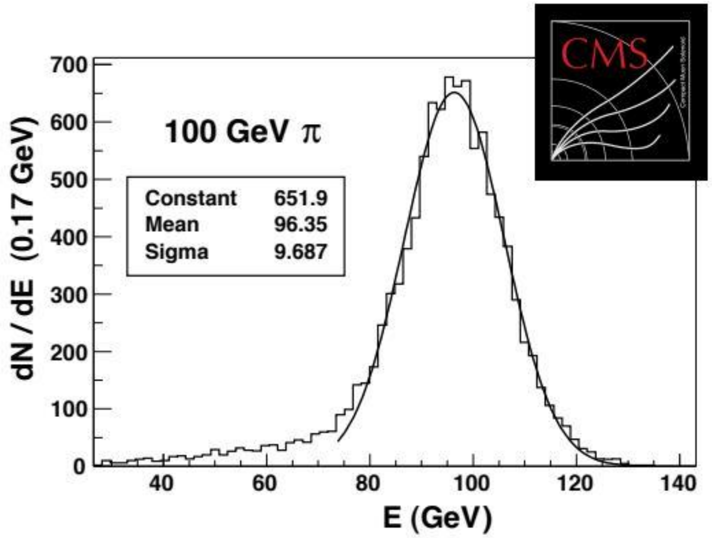
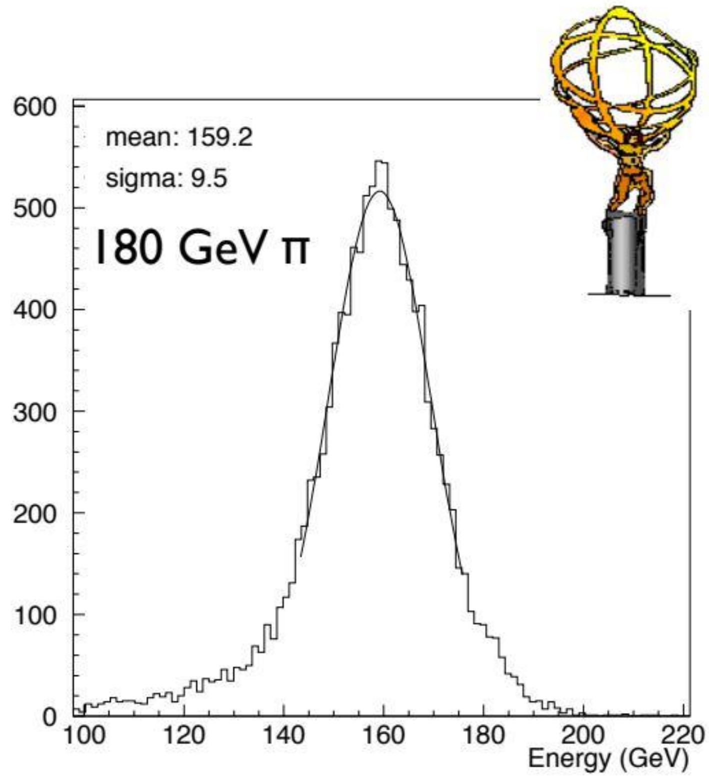
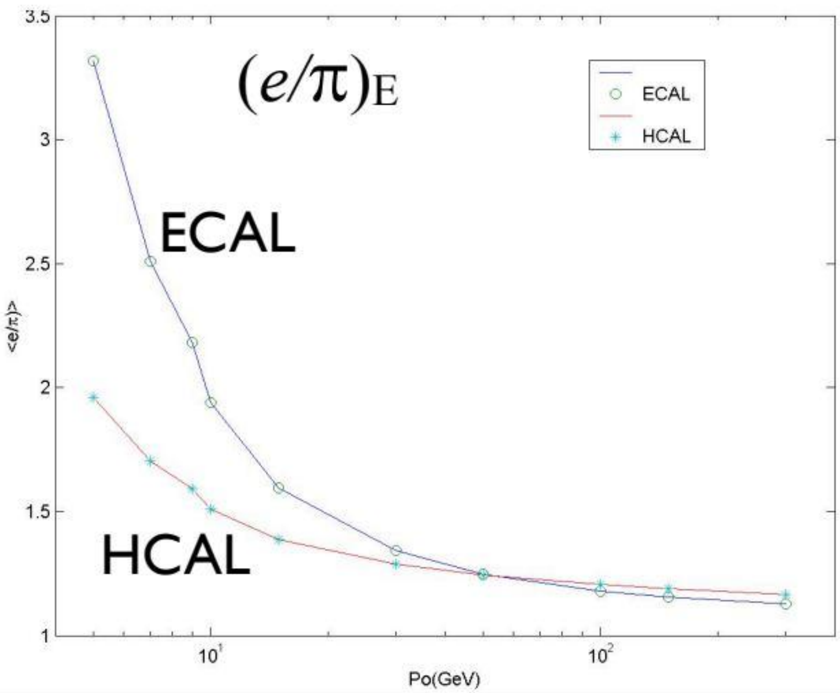


Figure 38: Energy distribution in HCAL (5 × 5 towers) for 100 GeV pions.





Jet algorithms

iterative cone:

use seed above some threshold and sum up particles in a cone of specified size, typically $R = (\Delta\Phi^2+\Delta\eta^2)^{1/2} = 0.7$

midpoint cone:

potential jets within some cone size of each other are either split or merged

inclusive k_T:

clustering algorithm, finds hits that have small momentum transverse to the reconstructed jet axis

$$\begin{aligned} d_i &= (E_{\mathrm{T},i})^2 R^2, \\ d_{ij} &= \min\{E^2_{\mathrm{T},i}\,,\, E^2_{\mathrm{T},j}\} R^2_{ij} \quad \text{with} \quad R^2_{ij} = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2, \end{aligned}$$

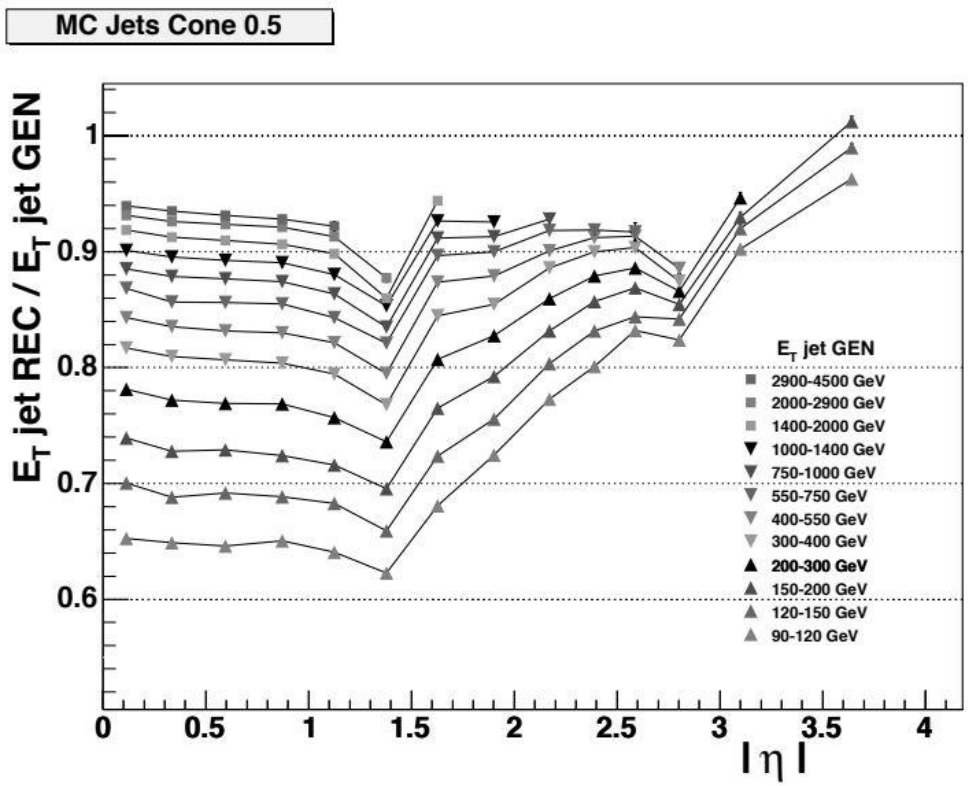
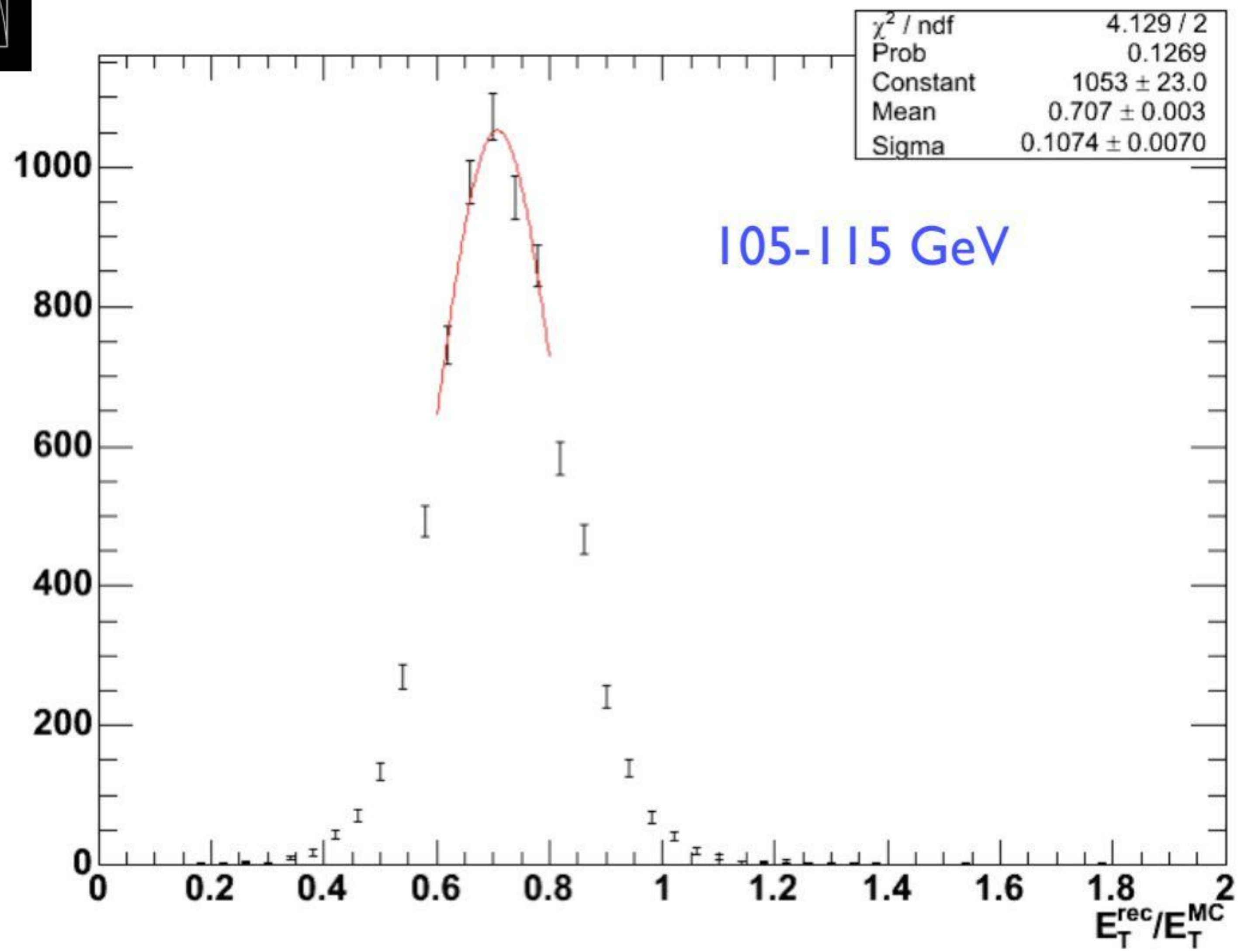


Figure 11.4: The ratio of the reconstructed jet transverse energy $E_{\mathrm{T}}^{\mathrm{rec}}$ to the generated transverse energy $E_{\mathrm{T}}^{\mathrm{MC}}$ as a function of generated jet η for jets with different $E_{\mathrm{T}}^{\mathrm{MC}}$ reconstructed by the iterative cone $R = 0.5$ algorithm before Monte Carlo corrections.

Jet Resolution Detail: Fit



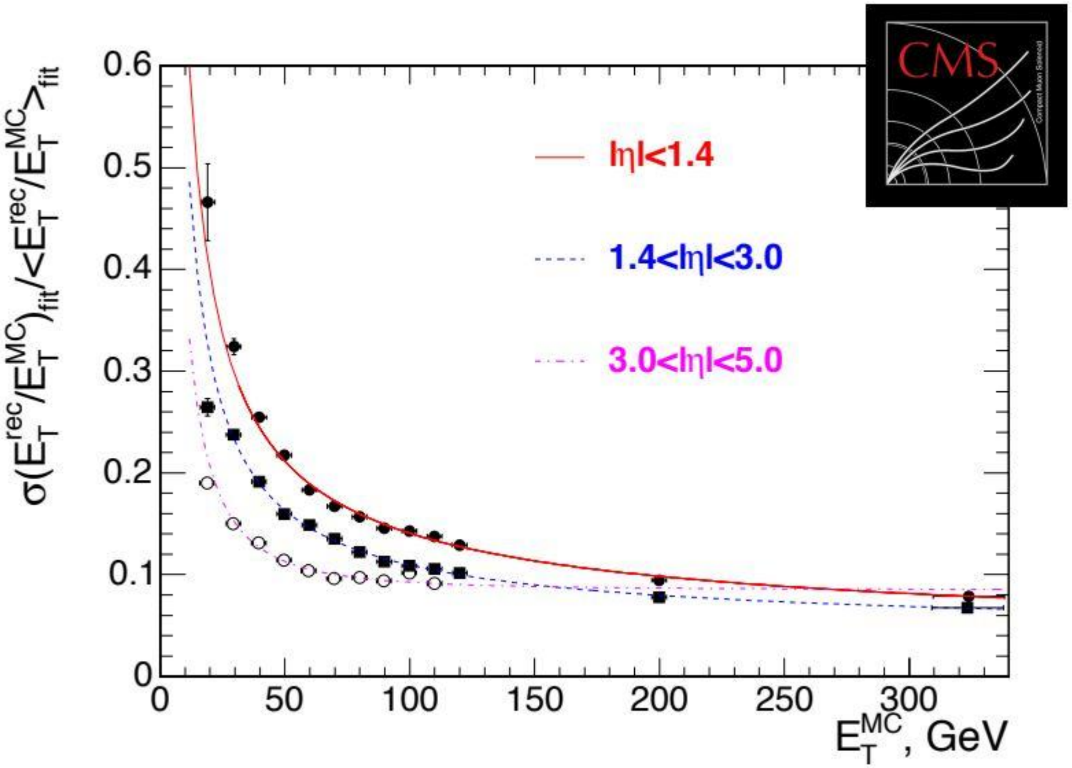
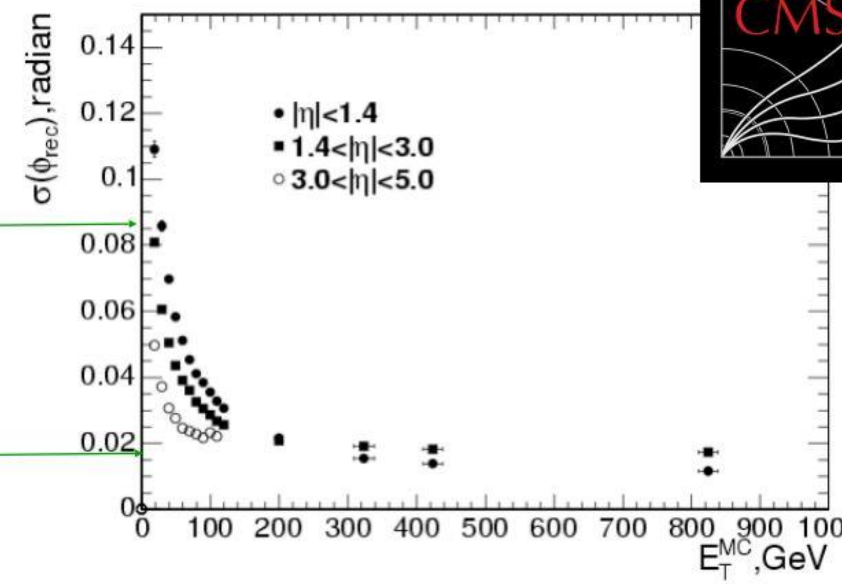


Figure 11.7: The jet transverse energy resolution as a function of the generated jet transverse energy for barrel jets ($|\eta| < 1.4$), endcap jets ($1.4 < |\eta| < 3.0$) and very forward jets ($3.0 < |\eta| < 5.0$). The jets are reconstructed with the iterative cone $R = 0.5$ algorithm. The cuts $E_\mathrm{T} > 0.5$ GeV and $E > 0.8$ GeV are used. The distance between generated and reconstructed jets is required to be $\Delta R < 0.2$. The Monte Carlo jet calibration has been applied.

Phi and Eta Resolution

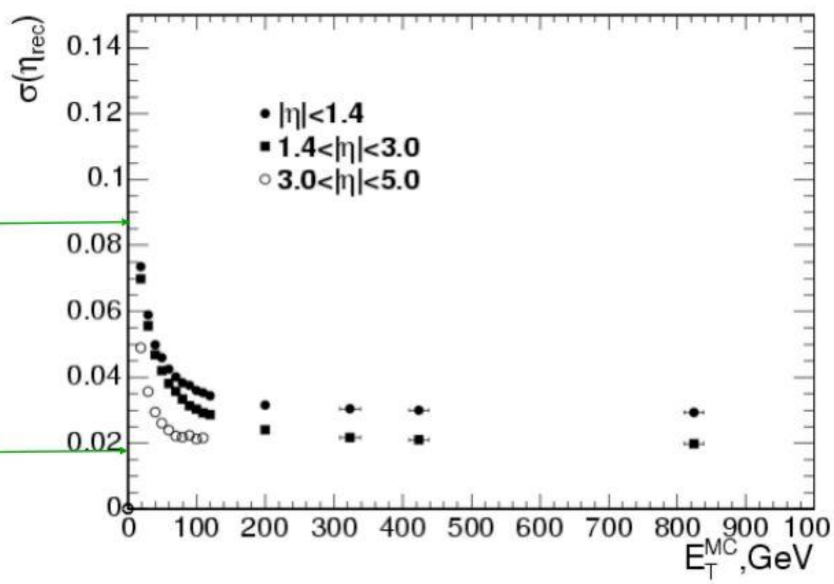
HCAL tile

crystal



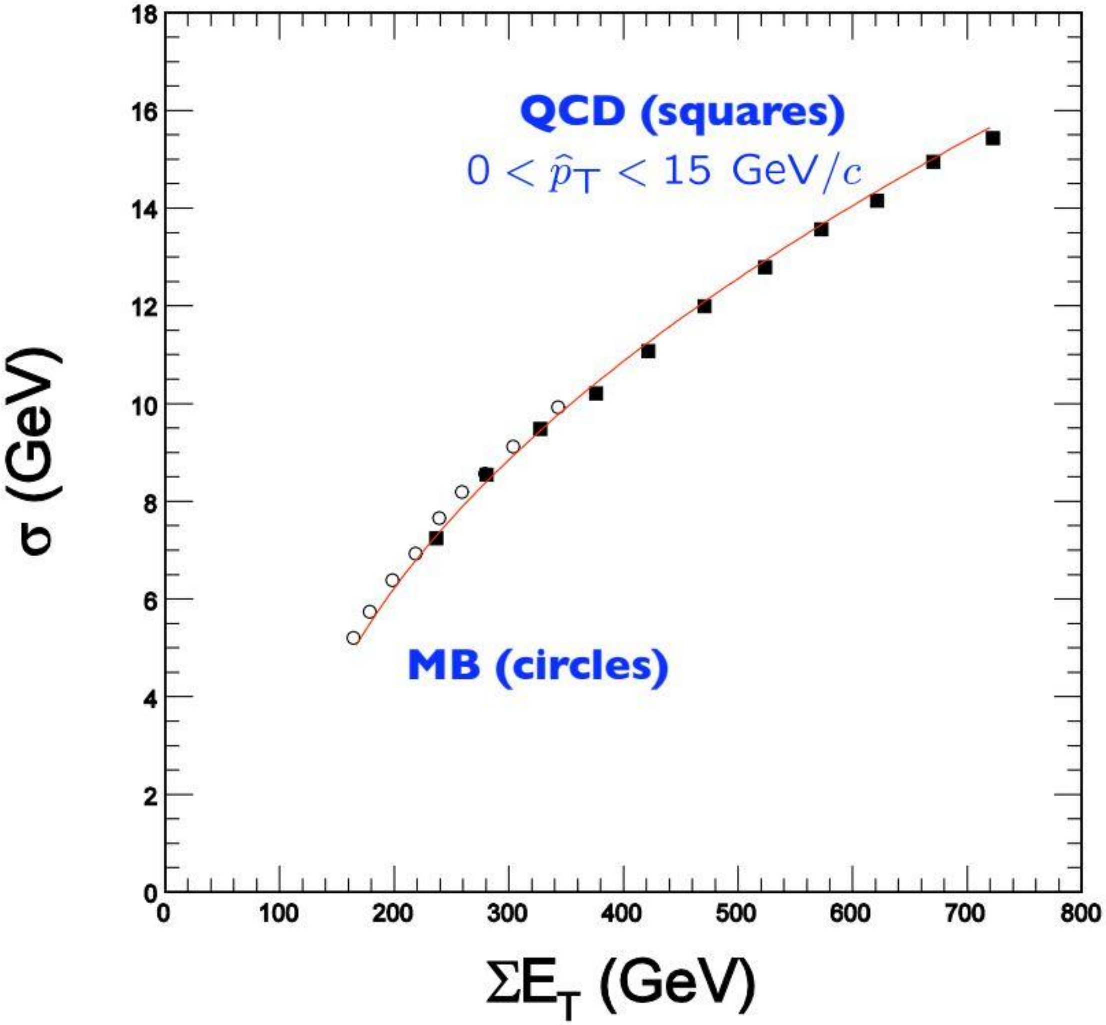
HCAL tile

crystal



E_T^{miss} resolution with pileup

$\mathcal{L} = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$



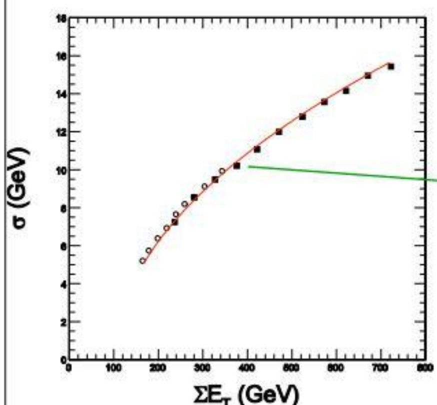
We fit same stochastic as MB no pileup (pileup just adds activity)

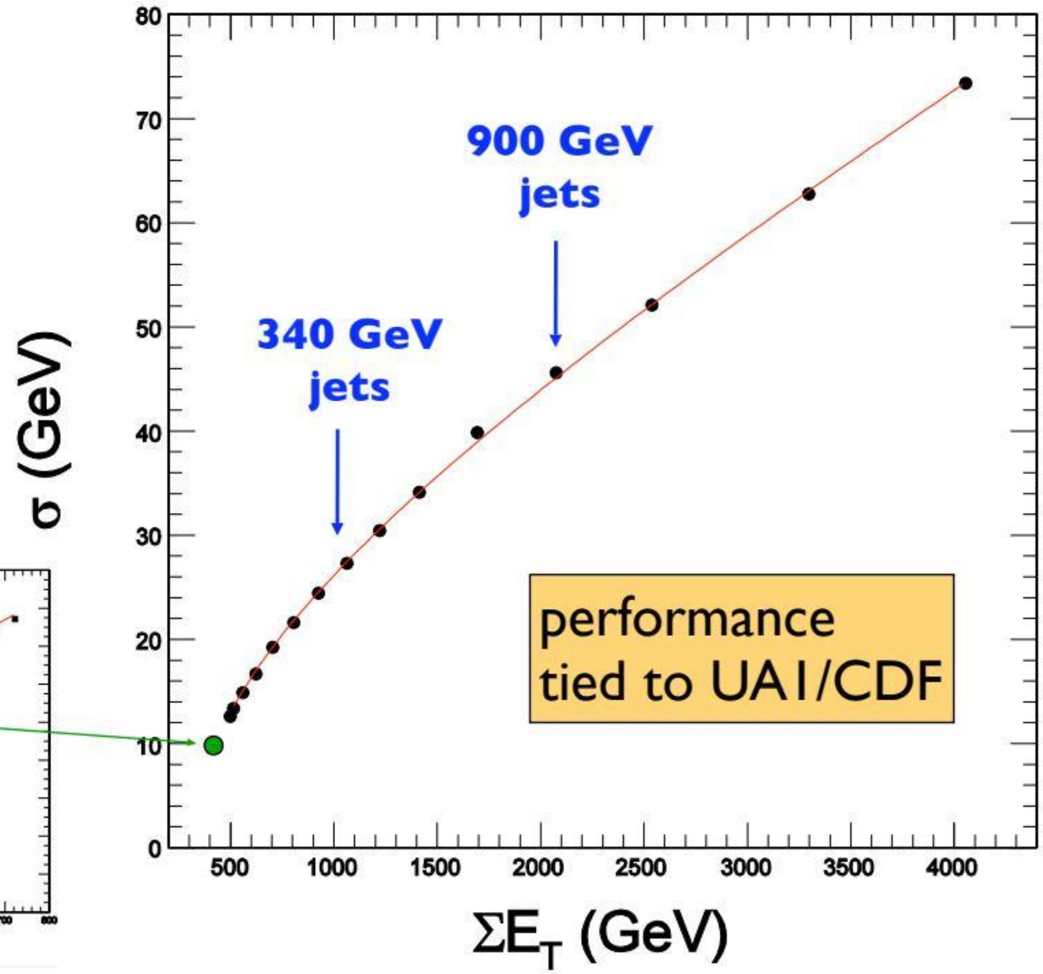
Soft QCD agrees with MB

Fit: $\sigma = [(4.0\ \text{GeV})^2 + (0.63\ \text{GeV}^{1/2}\sqrt{\Sigma E_T - 142\ \text{GeV}})^2]^{1/2}$

E_T^{miss} resolution with pileup: hard collisions

QCD, with pileup $\mathcal{L} = 2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

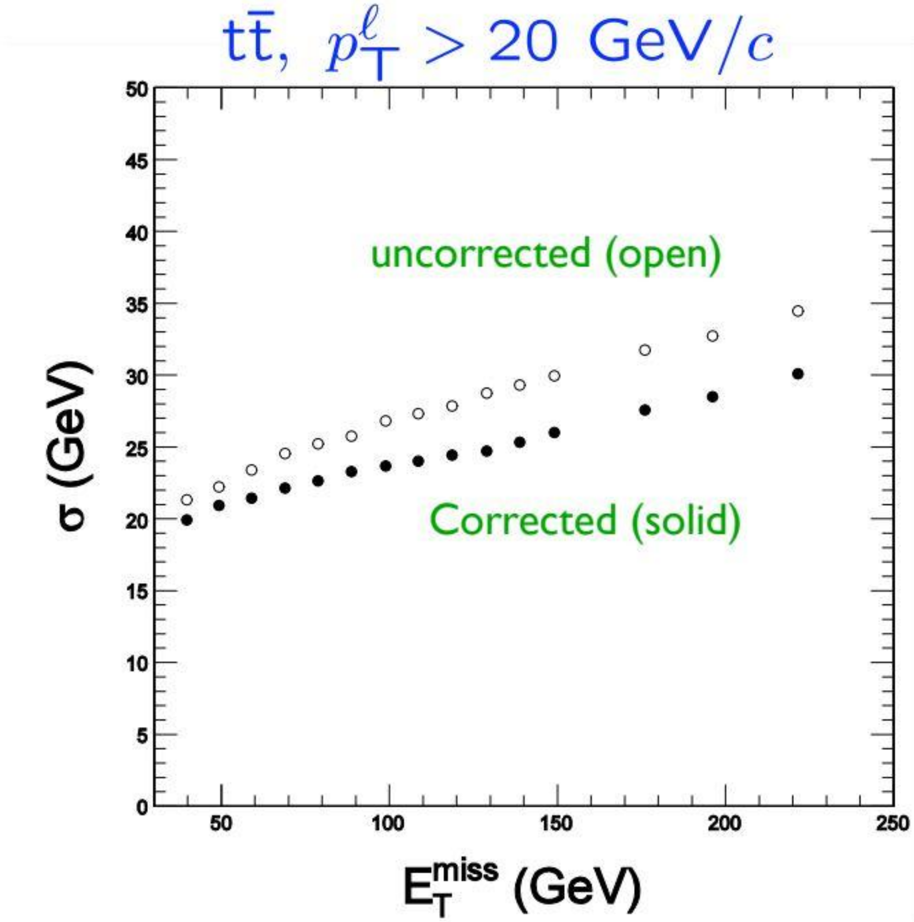




$$\sigma = [(3.8\ \mathrm{GeV})^2 + (0.97\ \mathrm{GeV}^{1/2}\sqrt{\Sigma E_T - 350\ \mathrm{GeV}})^2 + [0.012(\Sigma E_T - 350\ \mathrm{GeV})]^2]^{1/2}$$

E_T^{miss} resolution

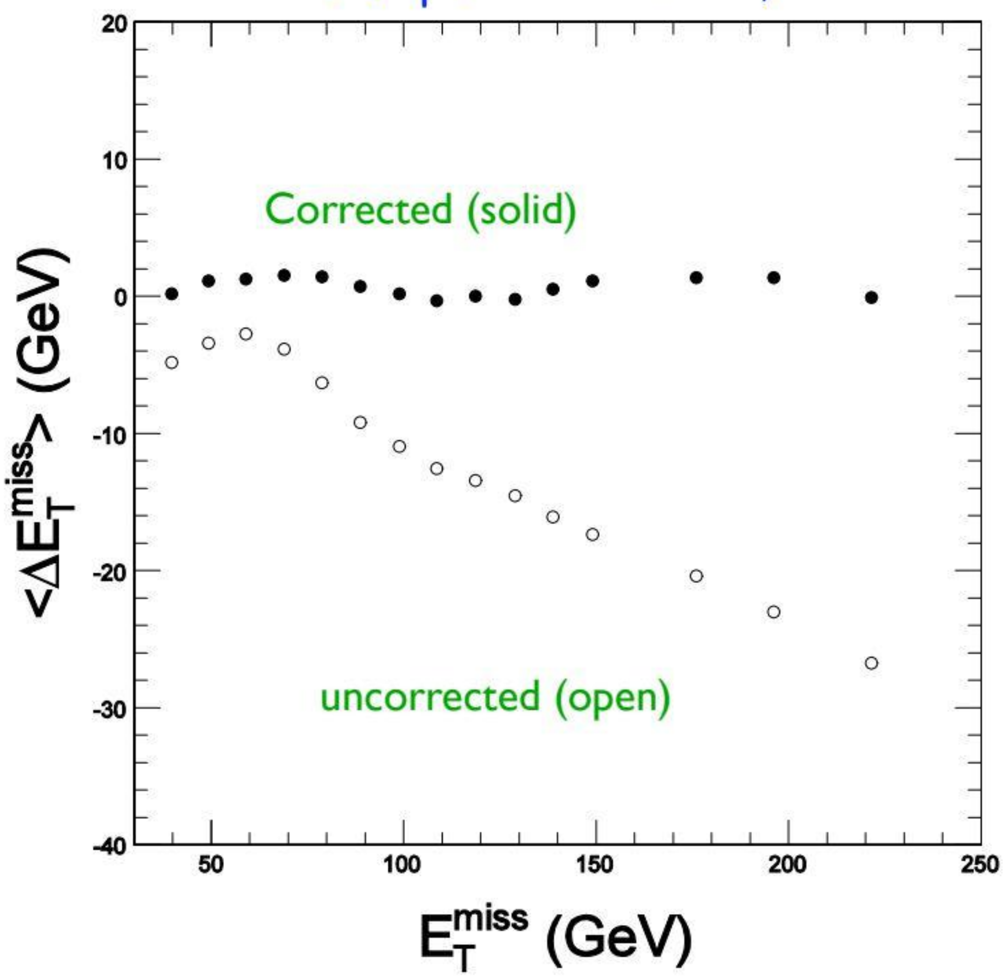
With pileup $\mathcal{L} = 2 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$



E_T^{miss} scale

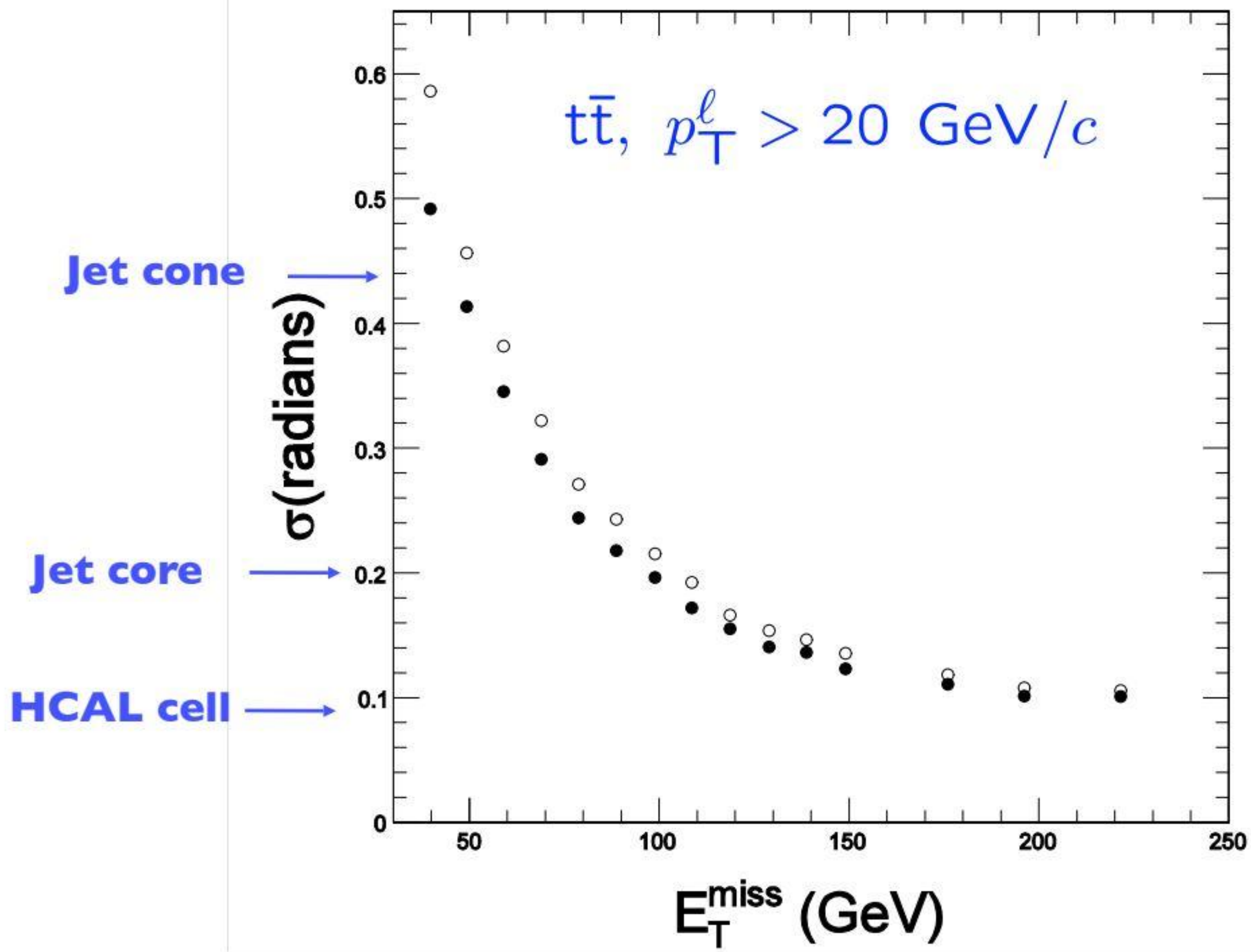
With pileup $\mathcal{L} = 2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

$\mathrm{t\bar{t}},\ p_T^{\ell} > 20\ \mathrm{GeV}/c$



E_T^{miss} Angular Resolution

With pileup $\mathcal{L} = 2 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$



Data Driven Calibration Strategy

Calorimeter tower calibration:

- Measure noise with beam-crossing triggers to check and adjust thresholds.
- Take data without zero-suppression to study the electronic noise offset.
- Check and adjust phi symmetry with minimum bias triggers.
- Use isolated muons from W decays to compare the tower-to-tower response to radioactive source source measurements and test beam muons.
- Compare isolated high p_T charged tracks with test beam data.

Jet calibration:

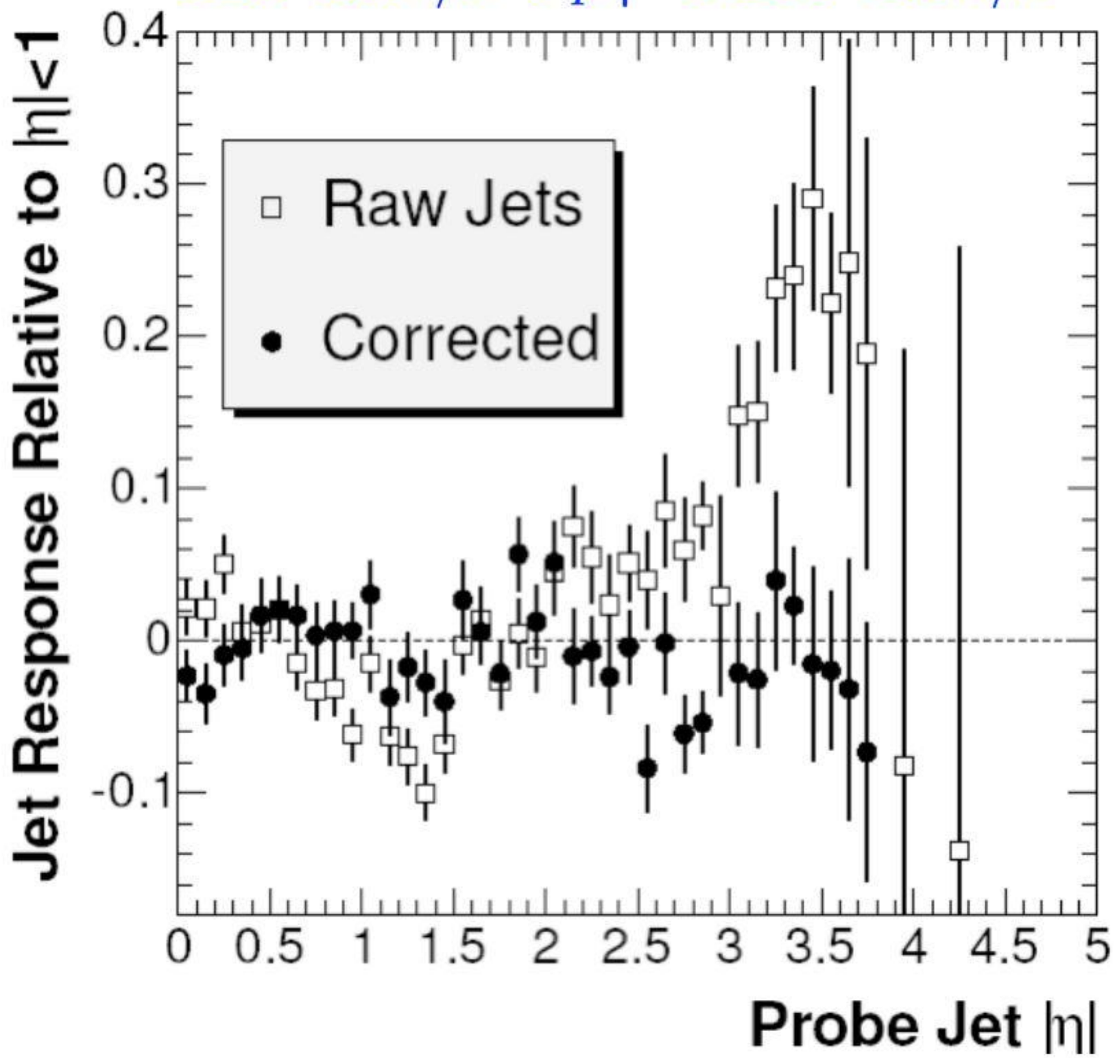
- Measure the effect of pile-up on clustering algorithms and thresholds.
- Use p_T balance in QCD dijet events to calibrate the jet energy scale vs. eta and verify the resolution.
- Use p_T balance in photon+jet events to calibrate the absolute energy scale.
- Use W mass fitting in tagged top events as to check and fine tune the jet energy scale.

Dijet Balance

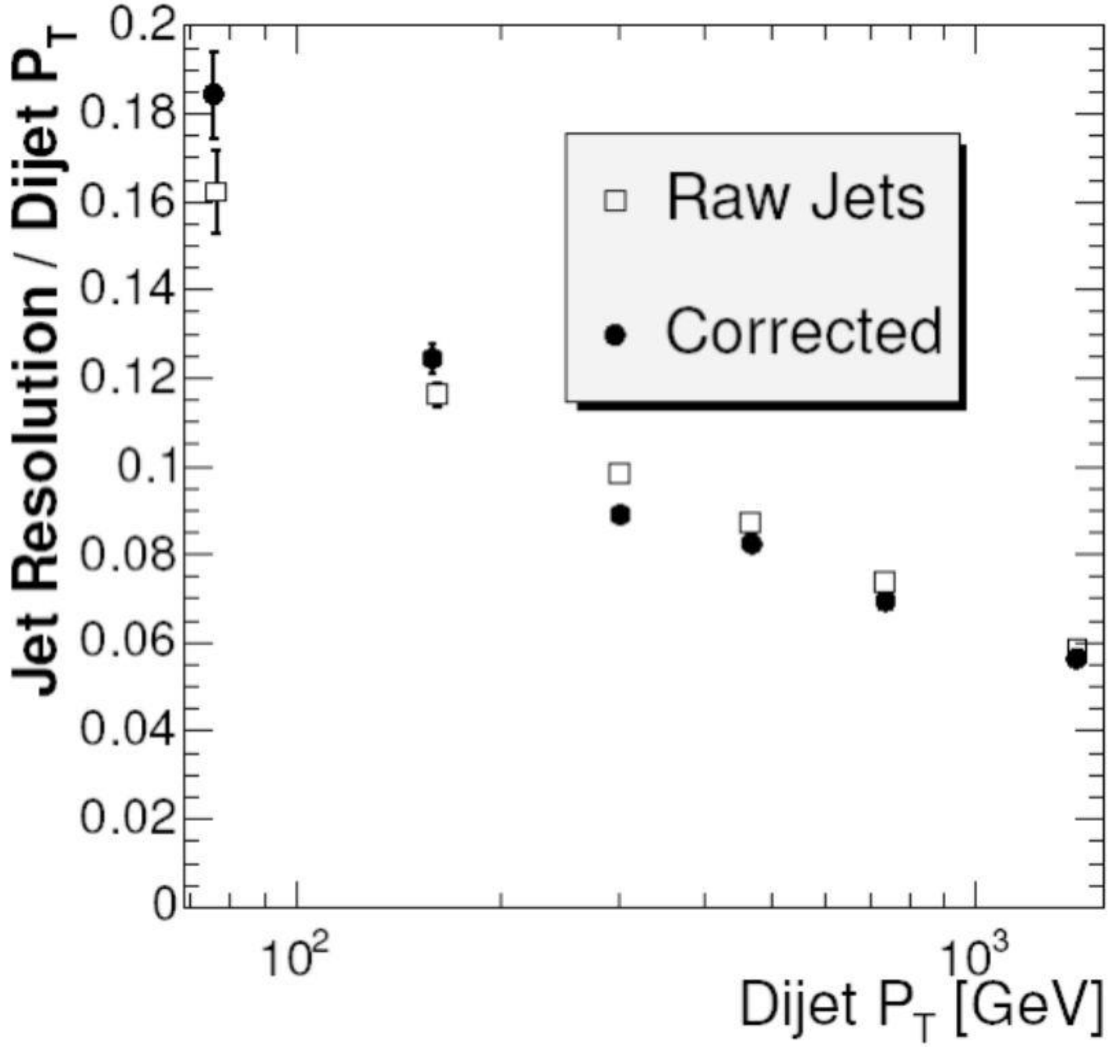
One hour of data

$\mathcal{L} = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

$120 \text{ GeV}/c < p_T < 250 \text{ GeV}/c$

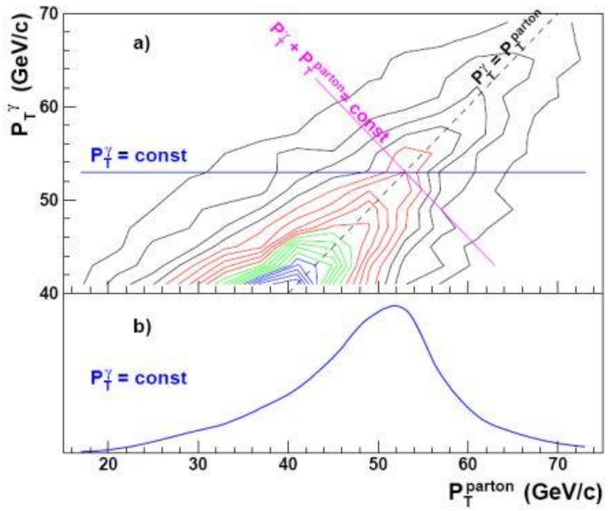


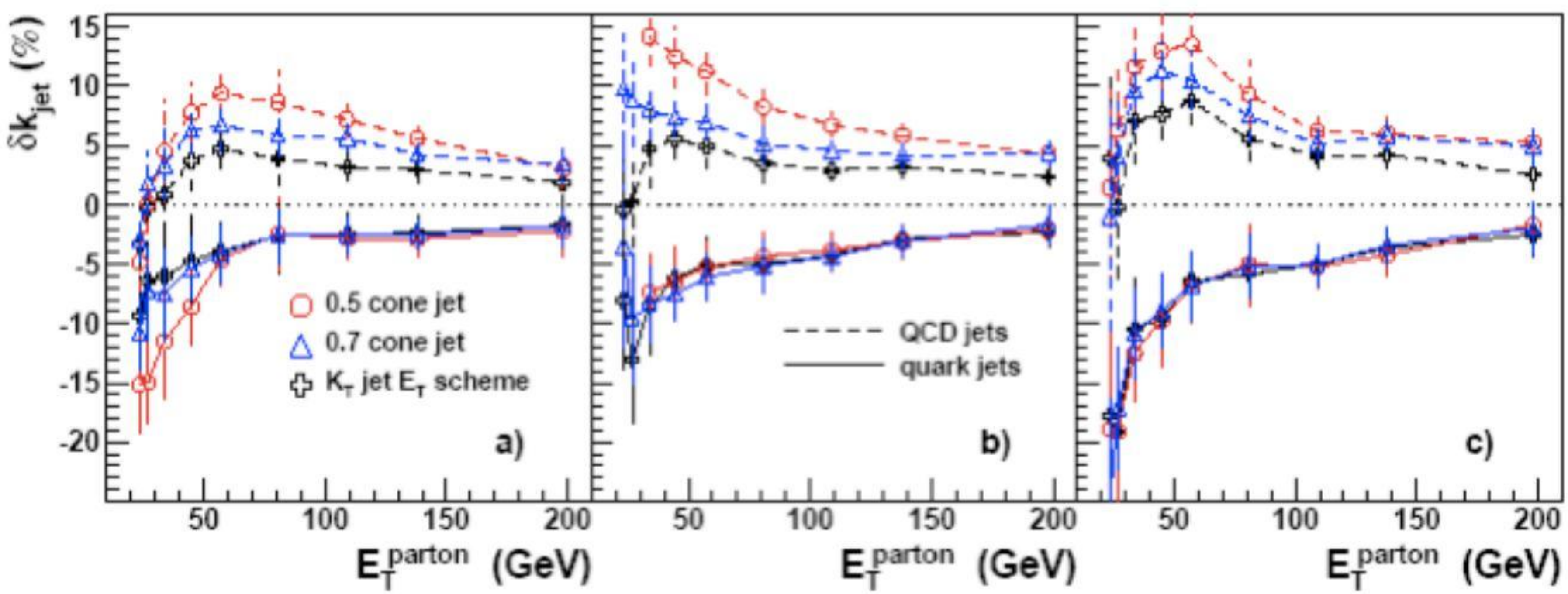
Resolution Derived from Dijets



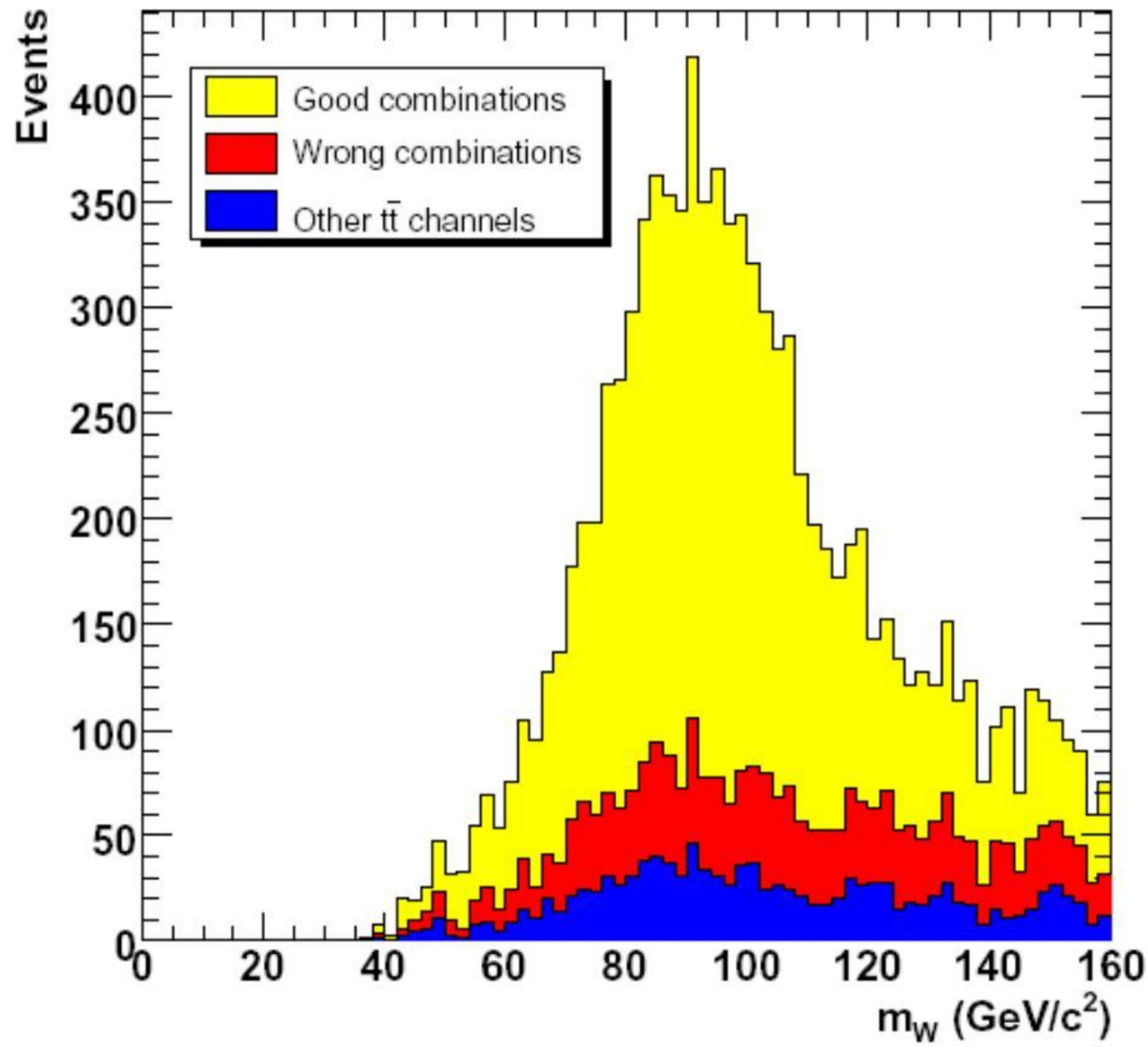
Calibration with Photon + Jet

$$k_{\text{jet}} = p_{\text{T}}^{\text{jet}} / p_{\text{T}}^{\gamma}$$

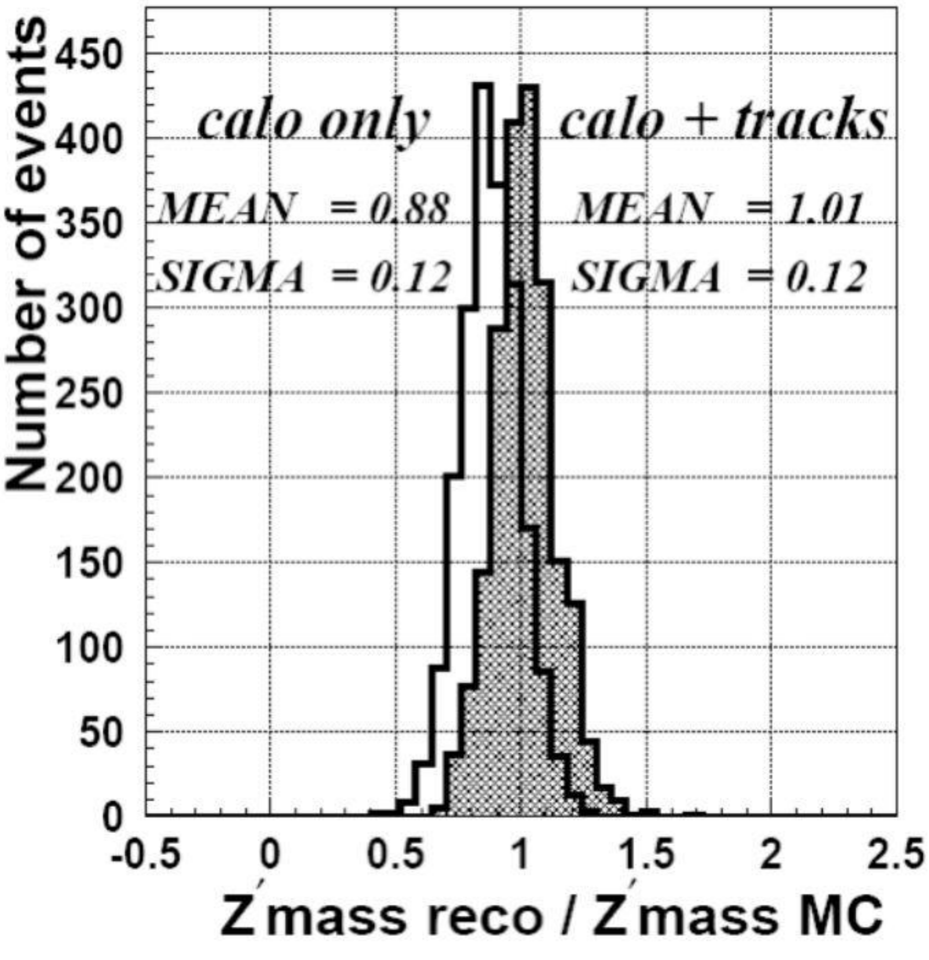


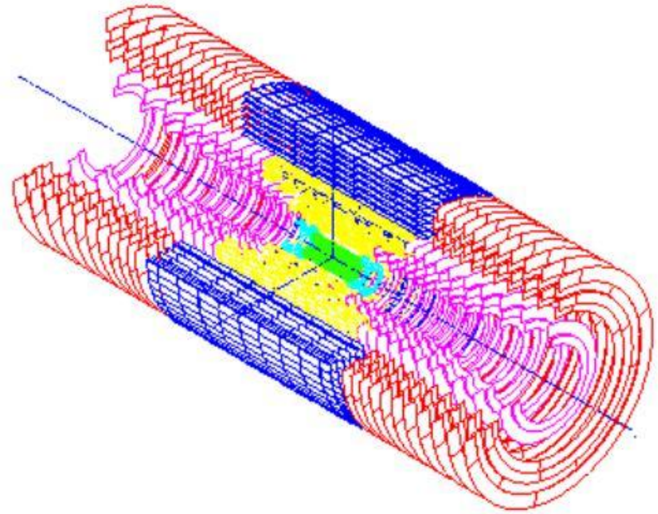


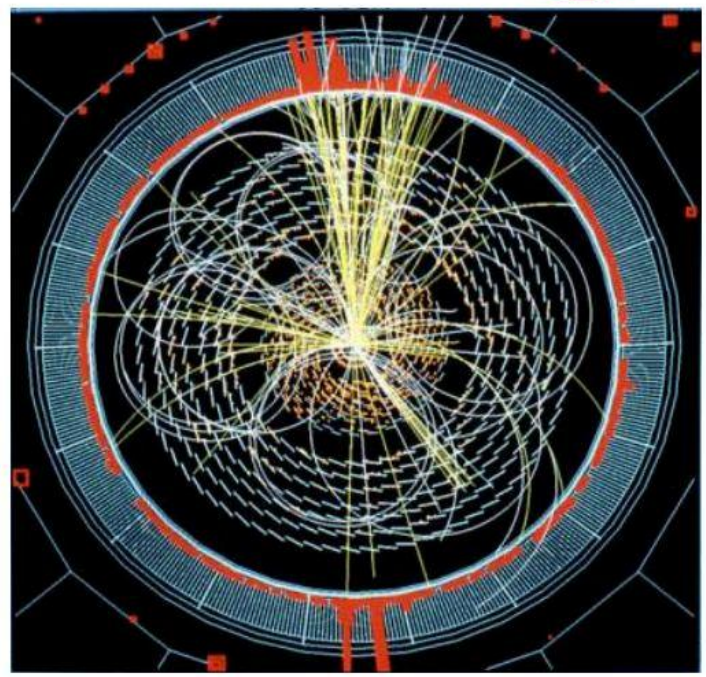
Calibration with Top → W → Jets



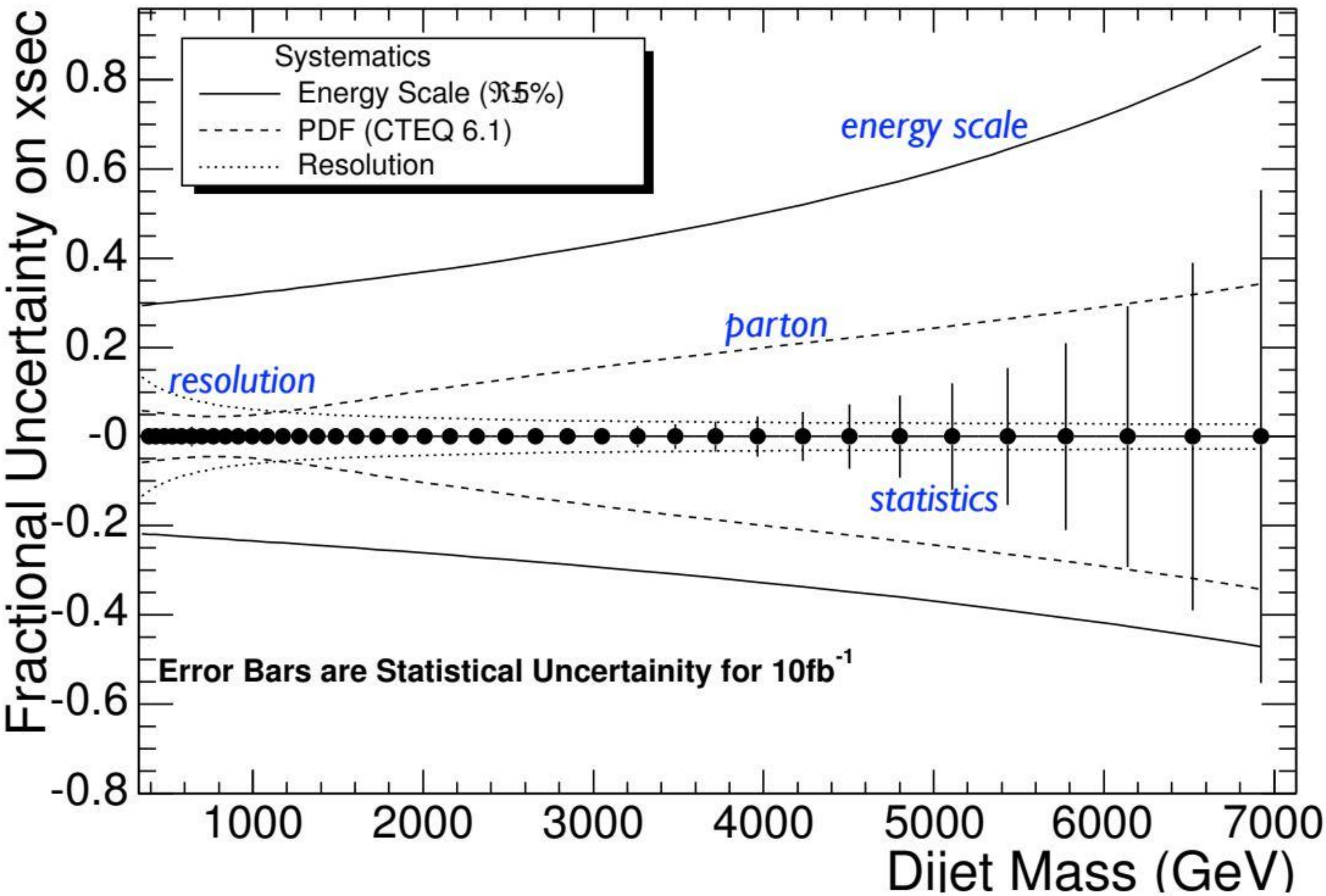
Use of Tracks to Improve Resolution







Expected error on dijet cross section*



*Does not include luminosity error.

High mass di-jet final states

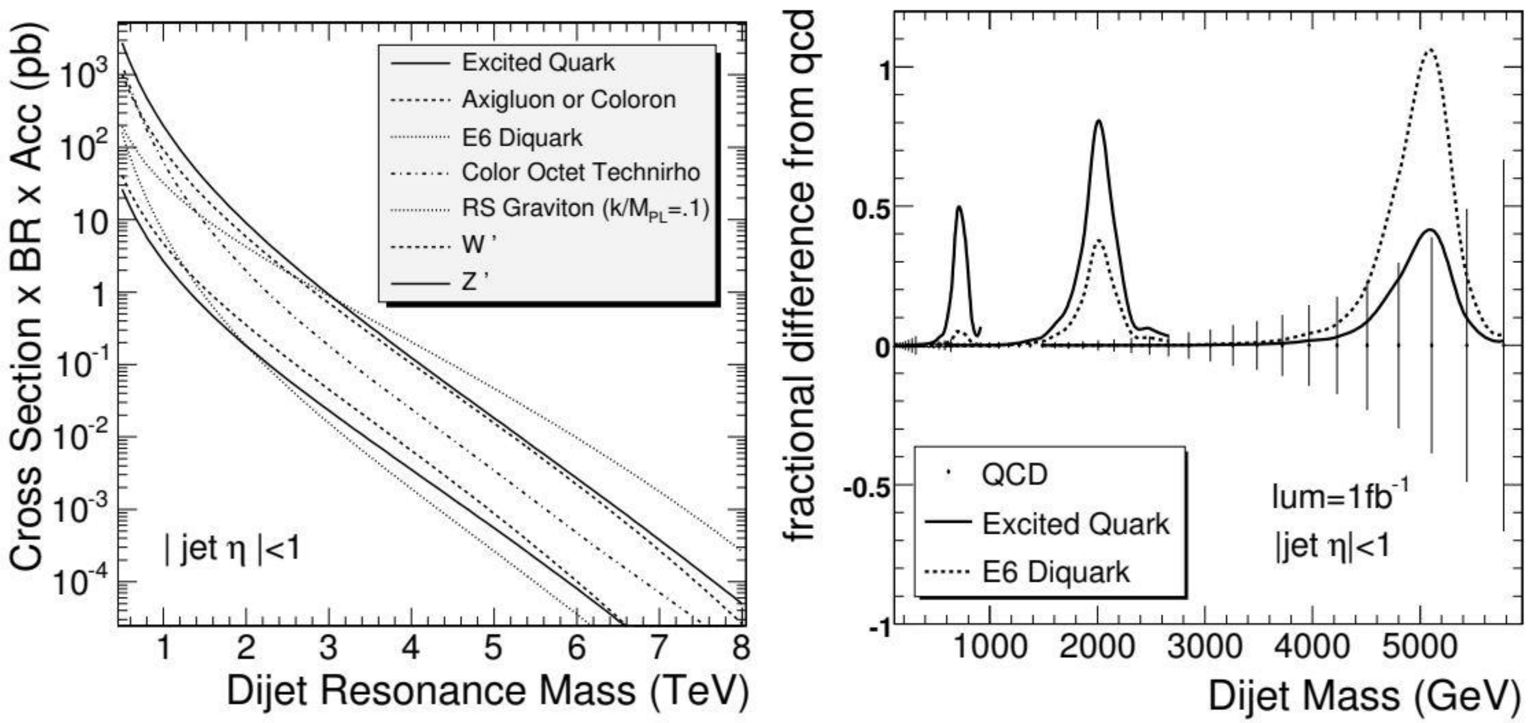
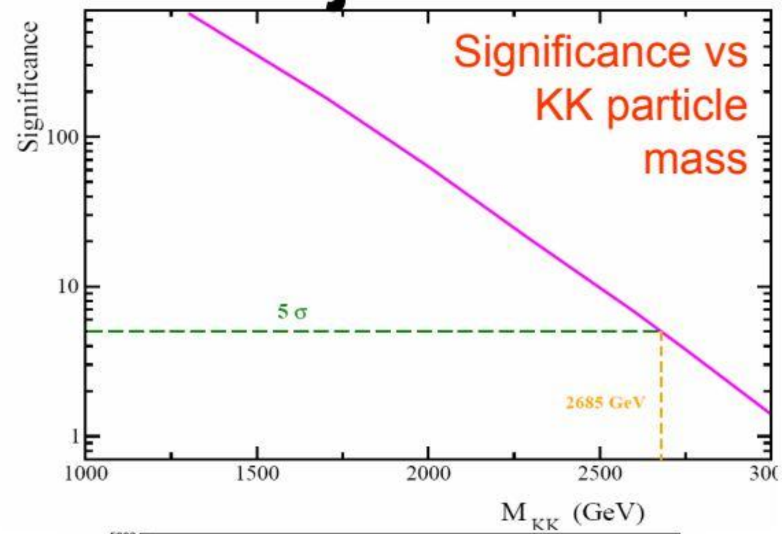


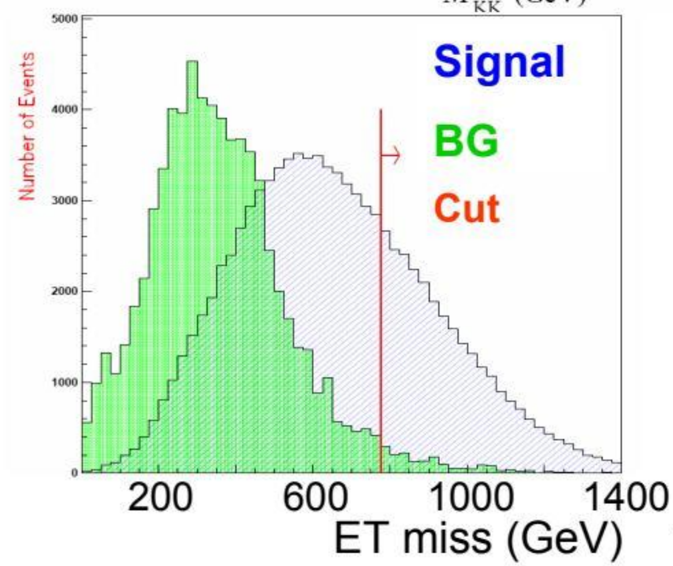
Figure 14.12: (left) The total cross section times branching ratio times acceptance for di-jet resonances from eight different models (see text). (right) For resonance masses of 0.7, 2.0, and 5.0 TeV/c^2, the fractional difference between an excited quark (solid curve) or an E6 di-quark (dashed curve) and the QCD di-jet background is compared to the QCD statistical errors (vertical lines).

UED: KK quark/gluon → di-jet

Beauchemin, Azuelos [ATL-PHYS-PUB-2005-03]

- Direct KK mode production only
- Measure excess of dijets with large missing E_T
- Assume all KK modes decay to gravitons (invisible)





Sensitivity @ 100 fb^{-1}
5σ up to 2.7 TeV

UED: KK gluons → Heavy quarks

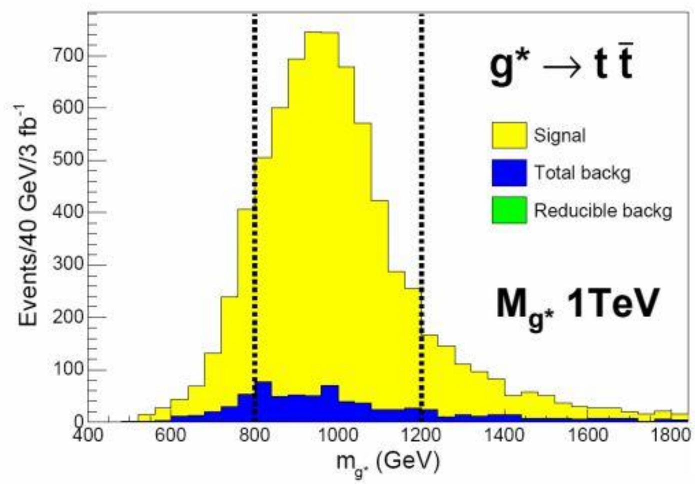
g* → bb/tt

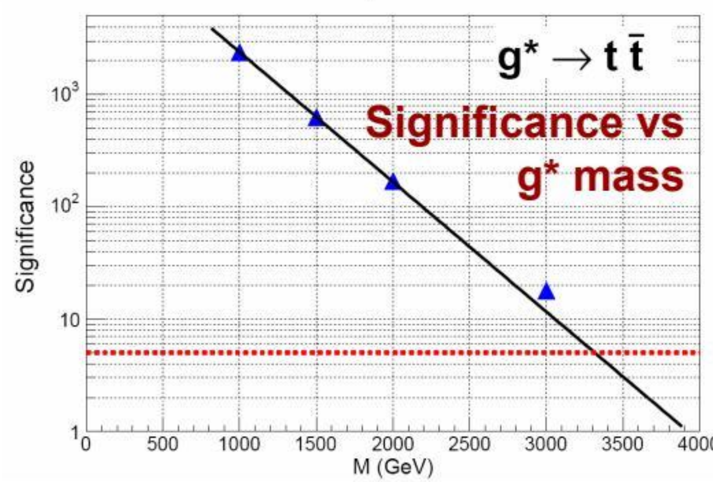
March, Ros, Salvachua

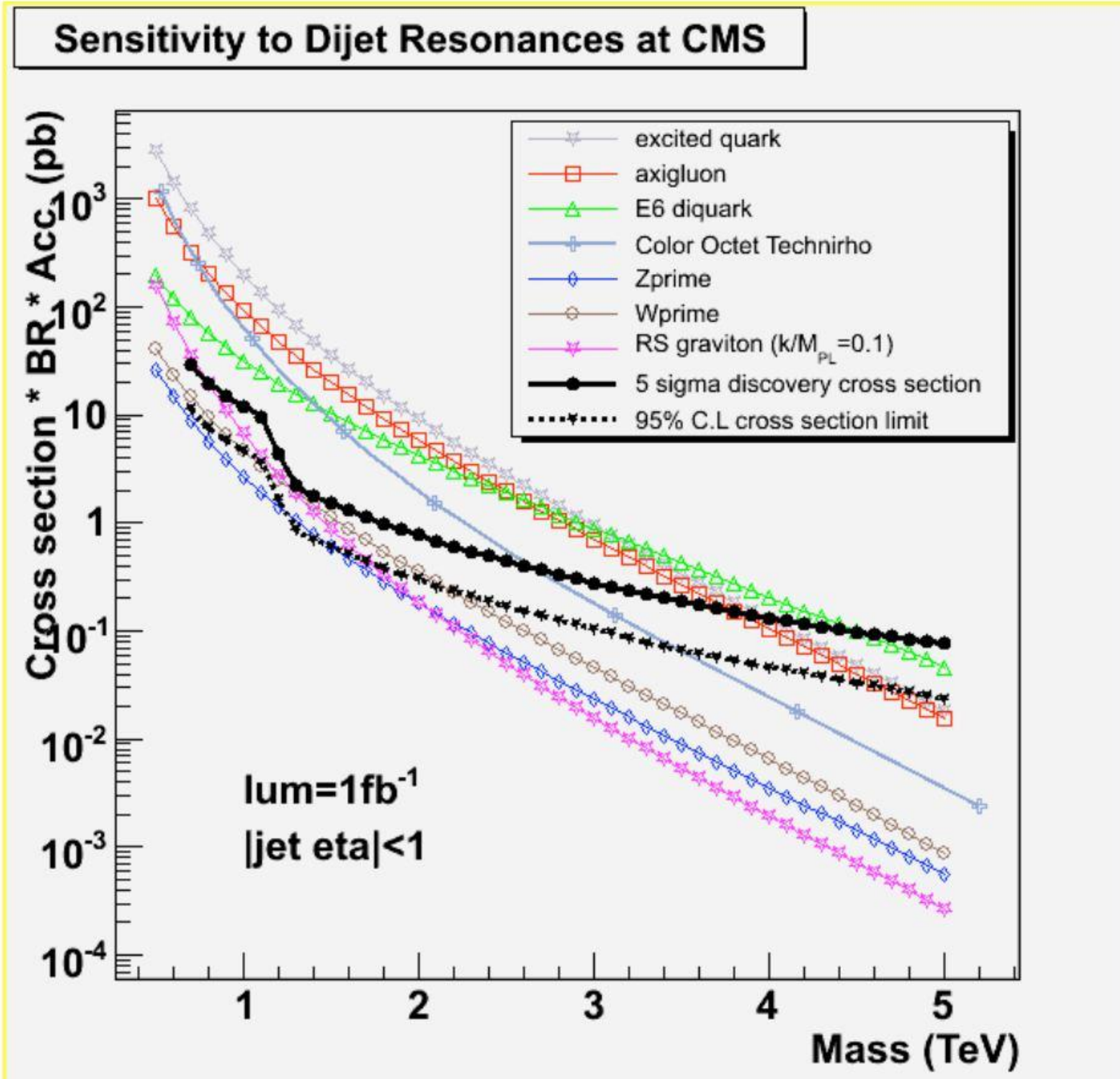
[ATL-PHYS-PUB-2006-002]

- Only produce hadronic decays
- Tag Heavy quark decays
- Excess of di-jets
- b-quark decays difficult to detect
- t-quark channel provides clearest signal

Sensitivity @ $100fb^{-1}$
5σ M_{g^*} up to 3.3TeV





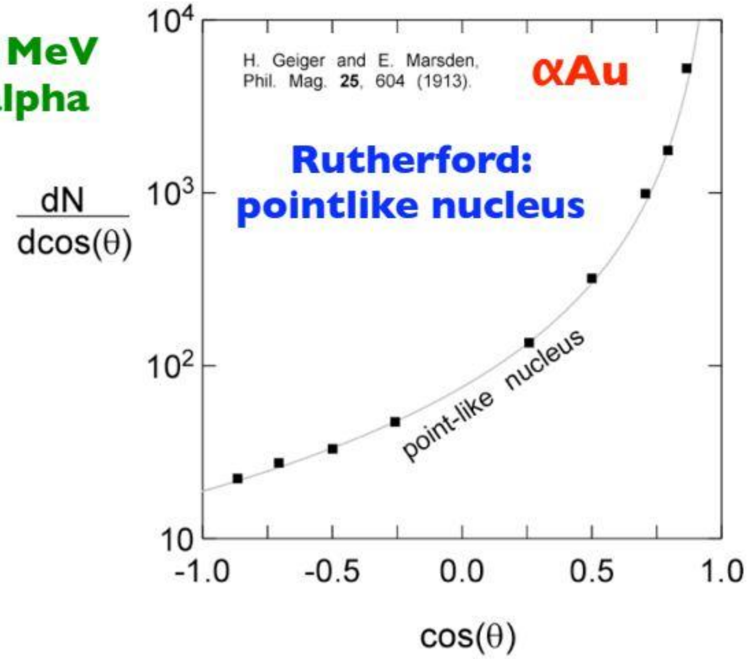


Sensitivity to Dijet Resonances at CMS
Cross section * BR * Acc. (pb)
excited quark
axigluon
E6 diquark
Color Octet Technirho
Zprime
Wprime
RS graviton (k/M_PL =0.1)
5 sigma discovery cross section
95% C.L cross section limit
lum=1fb-1
|jet eta|<1
Mass (TeV)

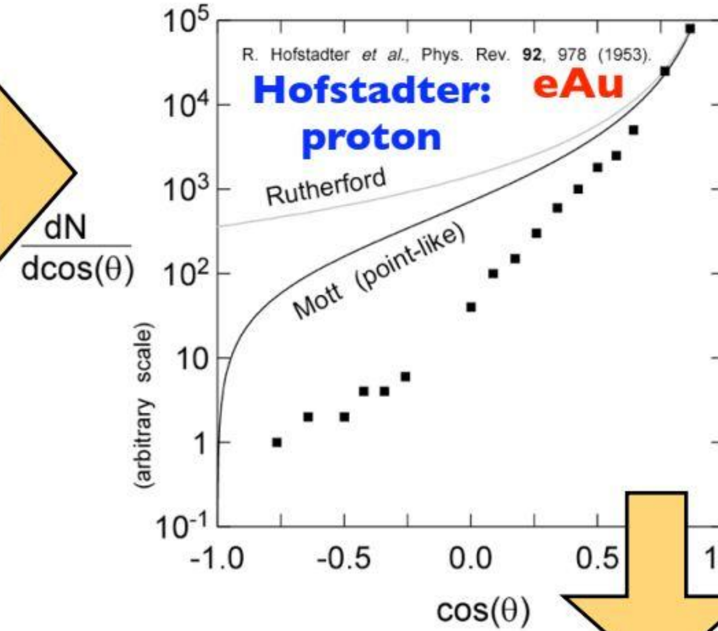
History of compositeness

J. Rohlf: Modern Physics from α to Z^0

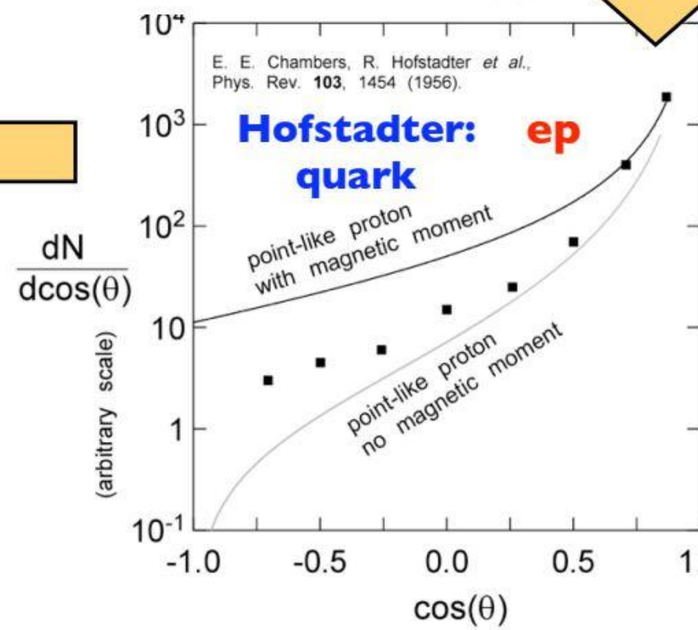
6 MeV alpha



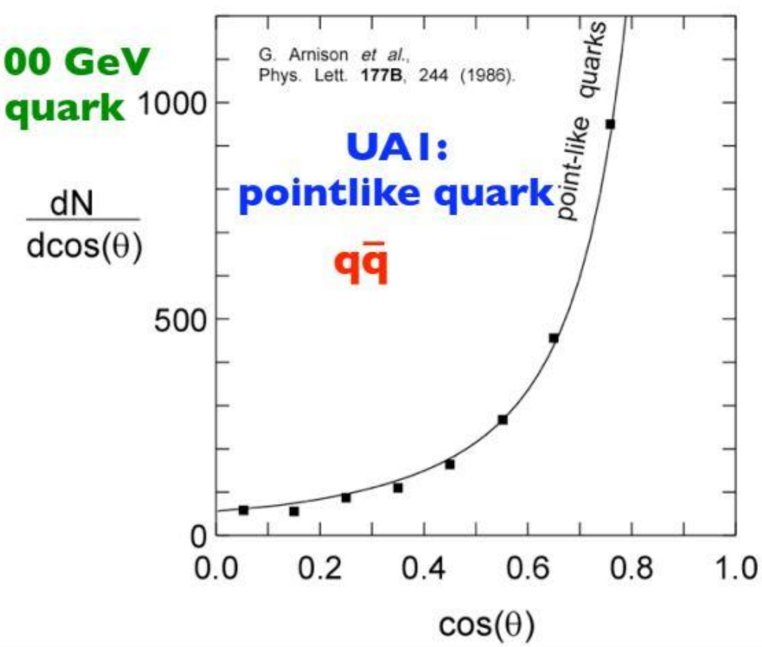
125 MeV electron

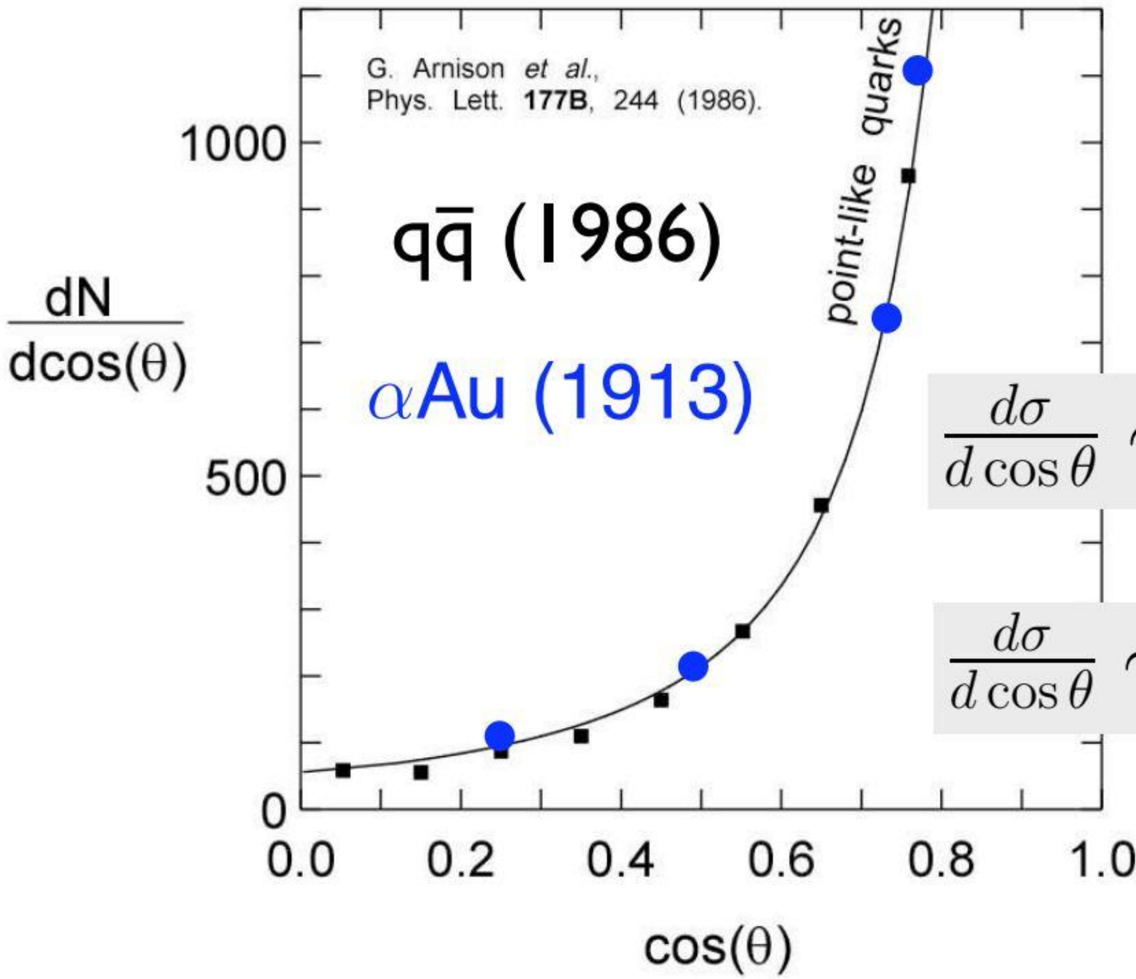


550 MeV electron



100 GeV quark





Electromagnetism

$$\frac{d\sigma}{d\cos\theta} \sim \alpha^2\left(\frac{\hbar c}{E_{\mathrm{k}}}\right)^2\frac{1}{(1-\cos\theta)^2}$$

QCD

$$\frac{d\sigma}{d\cos\theta} \sim \alpha_s^2\left(\frac{\hbar c}{E_{\mathrm{CM}}}\right)^2\frac{1}{(1-\cos\theta)^2}$$

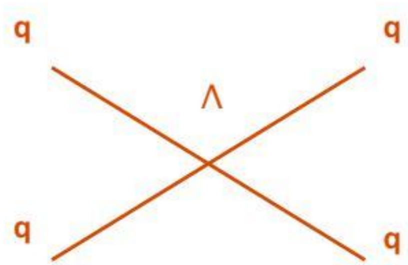
$$\frac{d\hat{\sigma}(q_i q_i \to q_i q_i)}{d\cos\theta^*} =$$

can be positive or negative

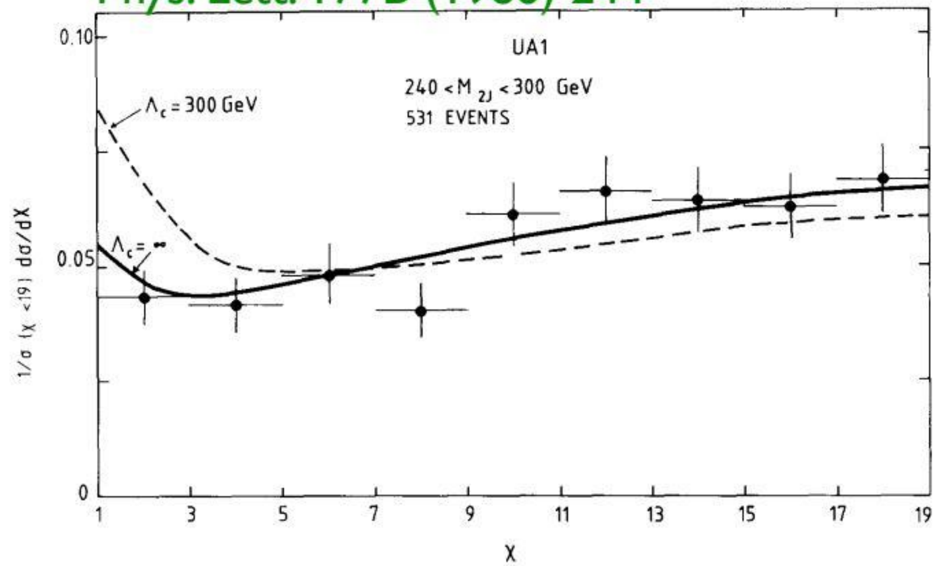
$$\frac{\pi}{2\hat{s}}\left\{\underbrace{\frac{4}{9}\alpha_S^2\left[\frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2}+\frac{\hat{t}^2+\hat{s}^2}{\hat{u}^2}-\frac{2}{3}\frac{\hat{s}^2}{\hat{t}\hat{u}}\right]}_{\text{QCD}}+\underbrace{\frac{8}{9}\alpha_S\frac{\boxed{A}}{\Lambda^2}\left[\frac{\hat{s}^2}{\hat{t}}+\frac{\hat{s}^2}{\hat{u}}\right]+\frac{8}{3}\frac{\hat{s}^2}{\Lambda^4}}_{\text{New Physics}}\right\}$$

$$\hat{t} = \hat{s}(1-\cos\theta^*)/2$$

$$\hat{u} = \hat{s}(1+\cos\theta^*)/2$$

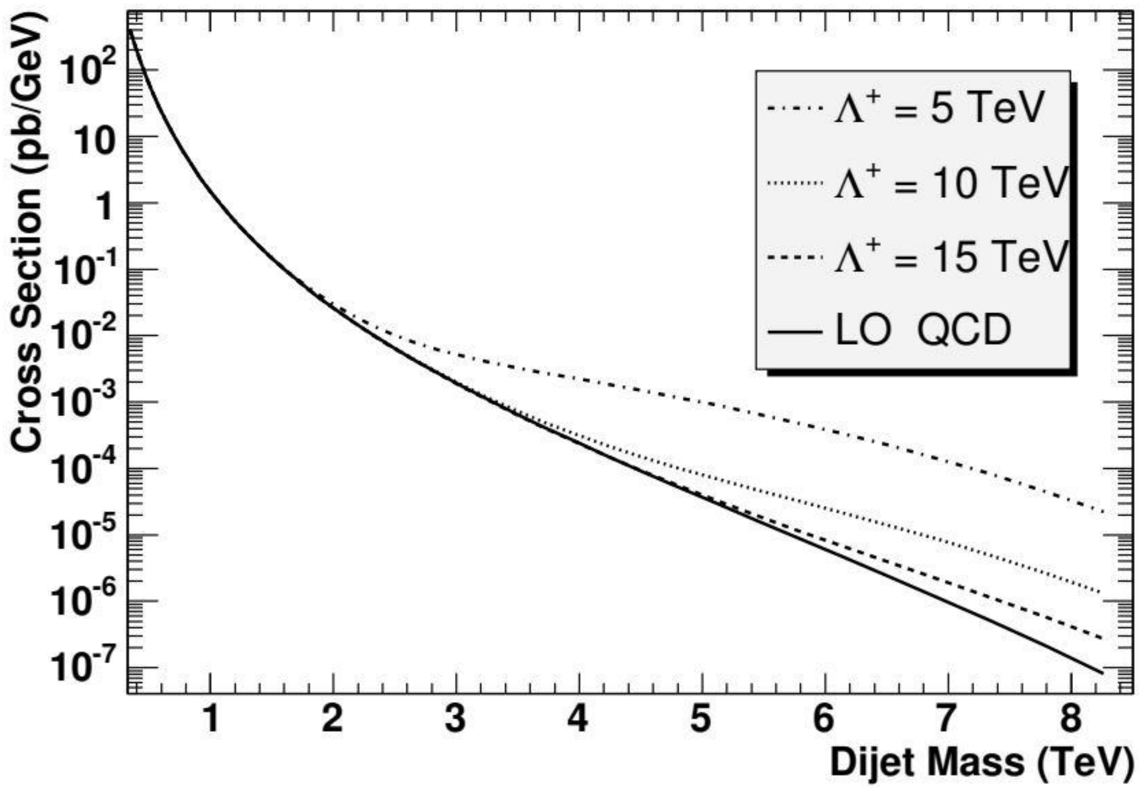


Phys. Lett. 177B (1986) 244



$$\frac{1+\cos\theta^*}{1-\cos\theta^*}$$

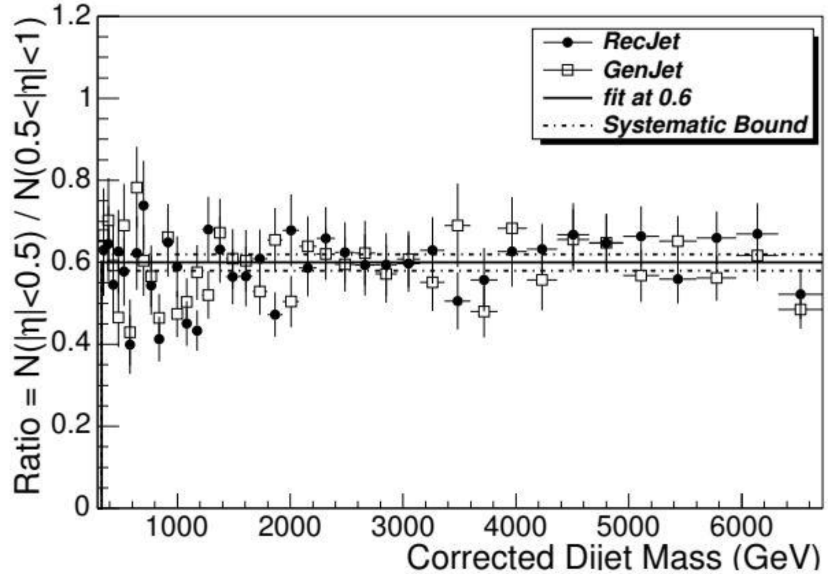
Dijet Cross Section

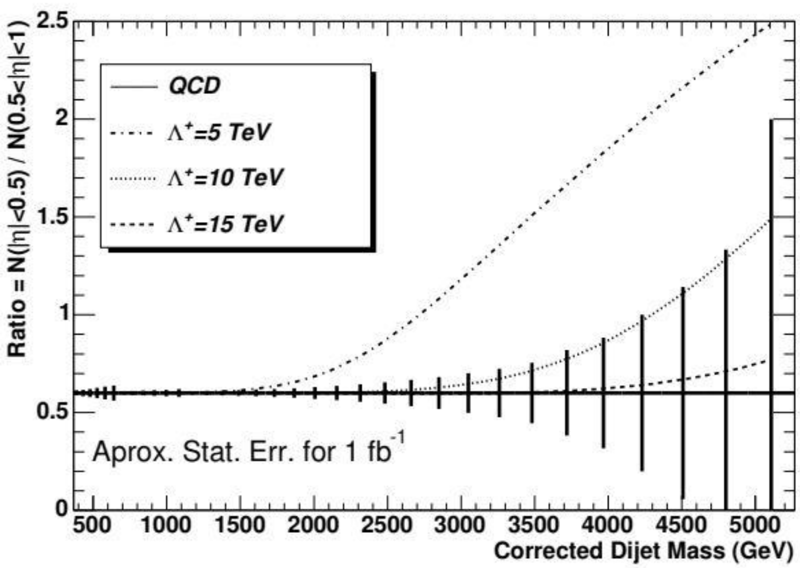


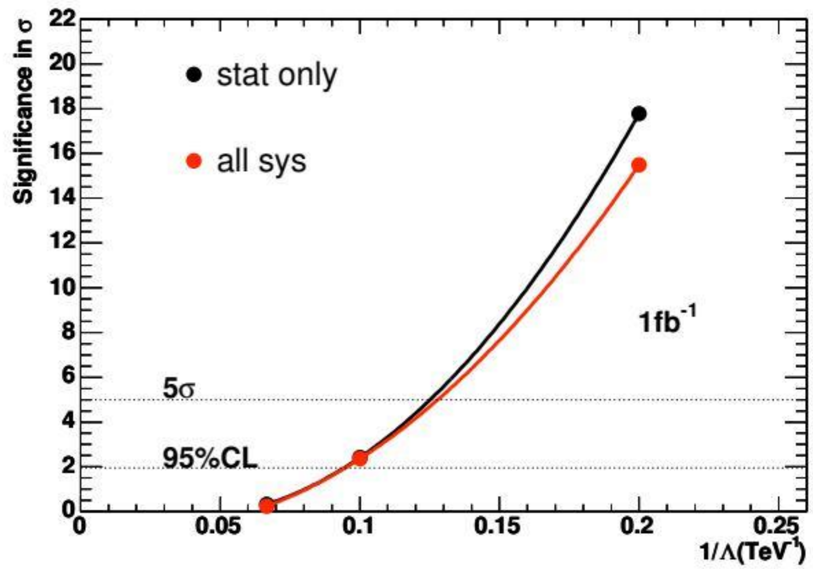
Deviations from QCD

Dijet Ratio

$N(|\eta|<0.5) / N(0.5<|\eta|<1)$

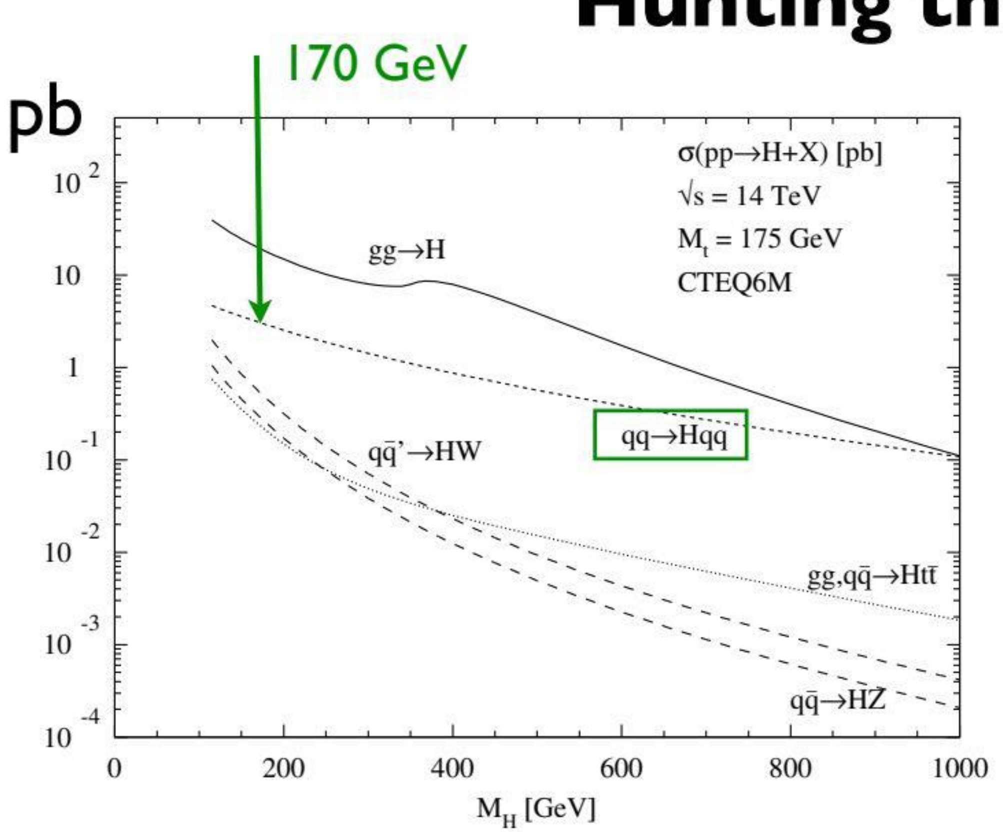


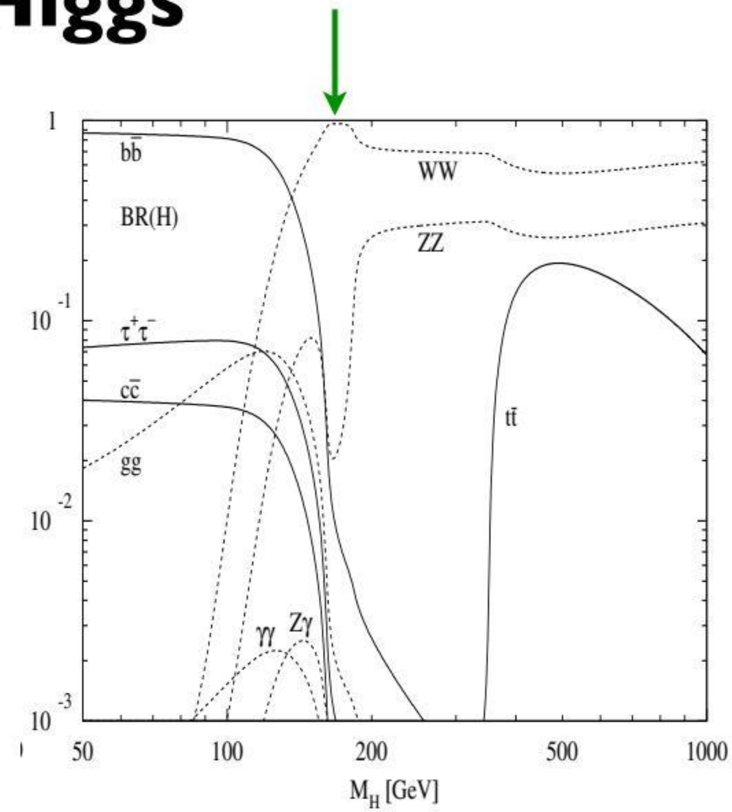


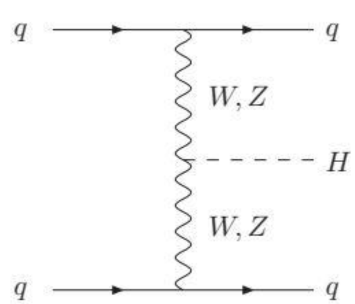


	95% CL Excluded Scale			5σ Discovered Scale		
	$100\ \mathrm{pb}^{-1}$	$1\ \mathrm{fb}^{-1}$	$10\ \mathrm{fb}^{-1}$	$100\ \mathrm{pb}^{-1}$	$1\ \mathrm{fb}^{-1}$	$10\ \mathrm{fb}^{-1}$
Λ^+(TeV)	<6.4	<10.6	<15.1	<4.7	<8.0	<12.2

Hunting the Higgs







$$\mathrm{H} \to \mathrm{WW} \to \ell^{\pm}\nu + \mathrm{q}\bar{\mathrm{q}}$$

signature:

e/μ + 4 jets (2 forward) + E_T^{miss}

Rates and Backgrounds

qqH

$l^{\pm}\nu jj$

signal

$120 < \mathrm{m_H} < 250\mathrm{GeV/c^2}$

$\mathrm{m_H}$	BR ($\mathrm{H} \to \mathrm{WW}^{(*)}$)	$\sigma(\ell\nu jj)$ (pb)	Events in 60 fb^{-1}	Generated
120	0.122	0.1789	10734	465.8 %
130	0.279	0.3623	21738	230.0 %
140	0.480	0.5520	33120	150.9 %
150	0.685	0.7037	42222	118.4 %
160	0.918	0.8530	51180	97.70 %
170	0.967	0.8489	50934	98.17 %
180	0.929	0.7639	45834	109.1 %
190	0.778	0.5995	35970	139.0 %
200	0.735	0.5287	31704	157.7 %
210	0.727	0.4895	29370	170.2 %
220	0.719	0.4539	27234	183.6 %
250	0.700	0.3701	22206	225.2 %

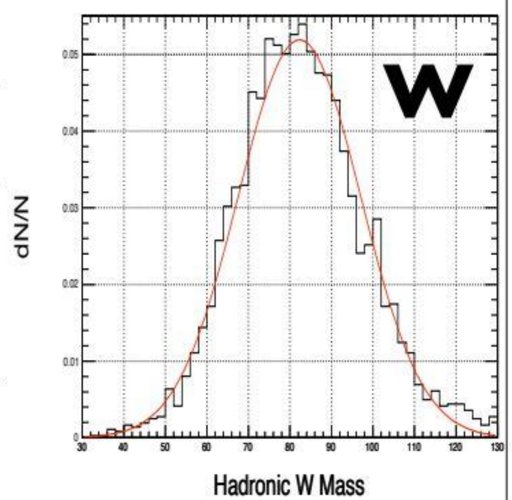
backgrounds

Channels	σ (pb)	Events in 60 fb^{-1}	Generated
$\mathrm{t\,\bar{t}}$ + jets	840	50.4 million	6.9 %
W + $\mathrm{t\,\bar{b}}$ ($\mathrm{\bar{t}b}$)	100	6.0 million	57.6 %
WW + jets (QCD)	73.1	4.39 million	3.95 %
WW + 2jets (EW)	1.26	75600	113.0 %
WZ + jets	27.2	1.63 million	15%
ZZ + jets	10.7	0.642 million	68.1 %
W + 4 jets	677.4 ($e/\mu/\tau + \nu$)	40.7 million	1.95 %
W + 3 jets	1689.7 ($e/\mu/\tau + \nu$)	101.3 million	1.04 %
Z + 4 jets	44.6 ($ee/\mu\mu$)	2.68 million	11.2 %
Z + 3 jets	112.1 ($ee/\mu\mu$)	6.73 million	8.91 %

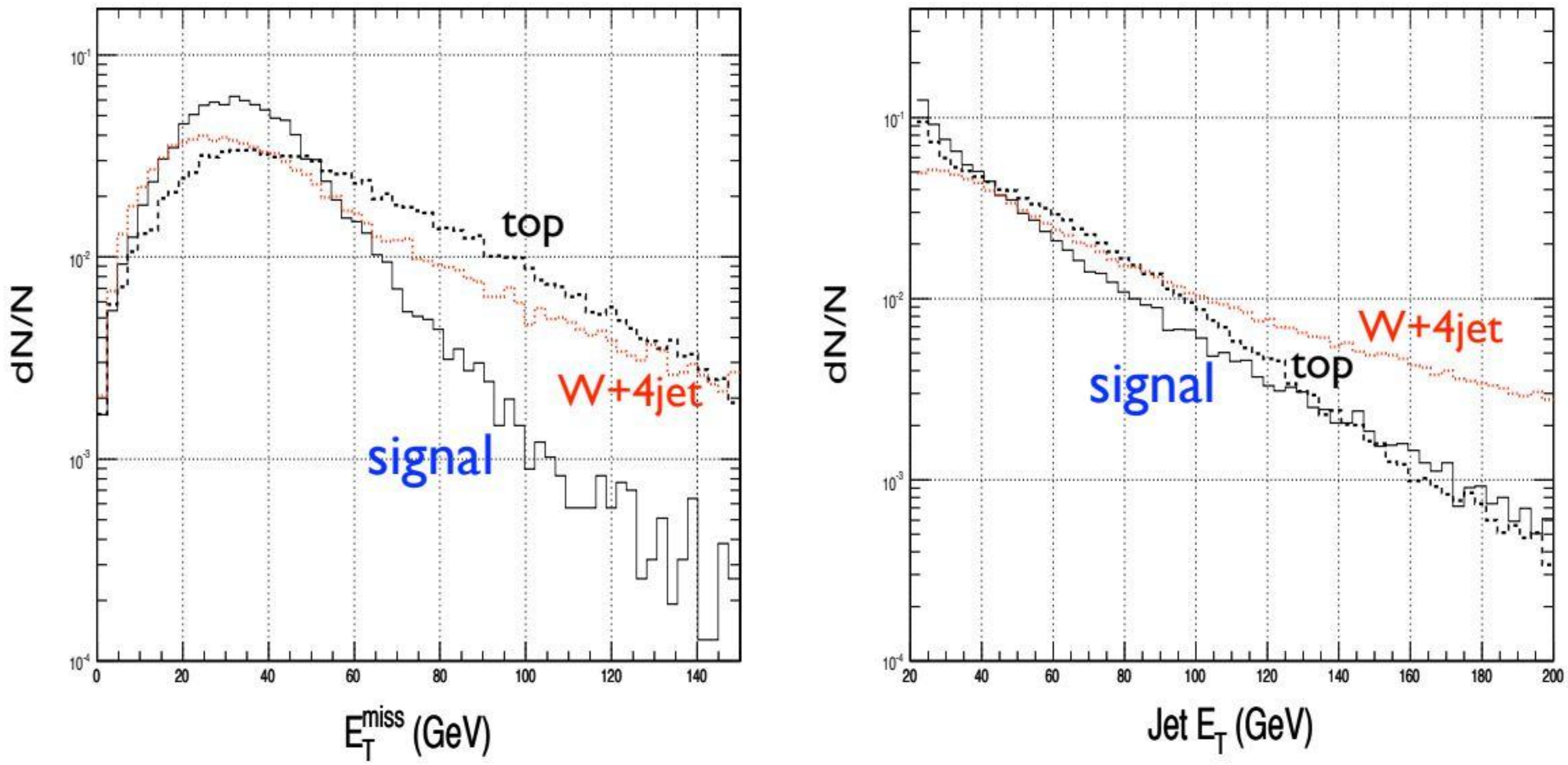
Selection Cuts (I)

Selection	Configuration
Lepton selection (L-S)	Electron: $E_T^{Hcal}/E_T^{Ecal} < 0.05$ $0.9 < E/p < 1.8$ $\lvert E_T^{0.2} - E_T^{e}\rvert < 5.0$ GeV $\lvert(E_T^{0.2} - E_T^{e})/E_T^{e}\rvert < 0.3$ $E_T^{0.2-0.4}/E_T^{e}\lvert < 0.3$ Muon : $\lvert E_T^{0.2} - p_T^{\mu}\rvert < 9.0$ GeV $\lvert(E_T^{0.2} - p_T^{e})/p_T^{\mu}\rvert < 0.3$ $E_T^{0.4}/E_T^{\mu}\lvert < 0.3$ $30 < p_T < 120$ GeV/c $\Delta R_{\ell-j} > 0.5$
Event selection (E-S)	$N_{jet} > 4$ jets with $E_T > 25$ GeV $E_T^{miss} > 30$ GeV
Forward jet tagging (FJT)	$E_T > 30$ GeV $\eta_1 \cdot \eta_2 < 0$ $\lvert\eta_1 - \eta_2\rvert > 3.8$ $m_{qq} > 800\ GeV/c^2$
Hadronic W reco (H-W)	$\Delta w_M < 25\ GeV/c^2$ ($m_H \geq 160\ GeV/c^2$) $30 < m_{jj} < 90\ GeV/c^2$ ($m_H < 160\ GeV/c^2$) select di-jet with least Δw_M for multiple ones
Leptonic W reco (L-W)	select leptonic W candidates of smaller ΔR with hadronic W

σ = 15 GeV



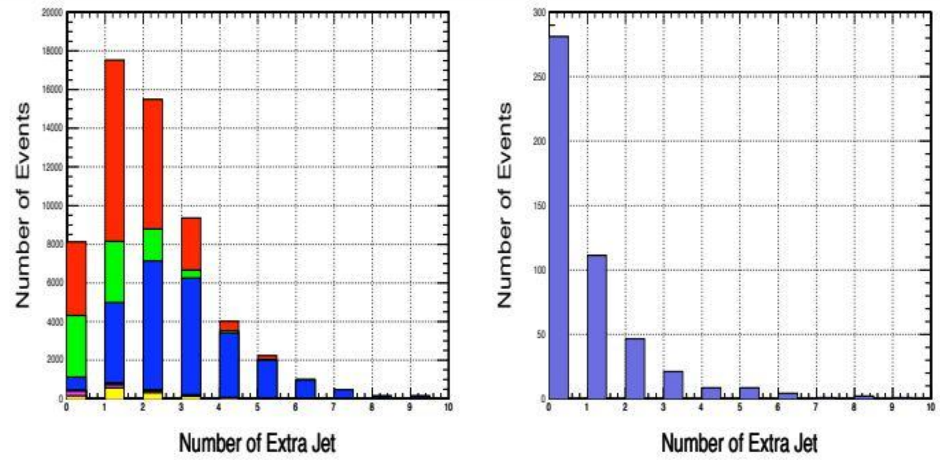
MET and Jet Distributions



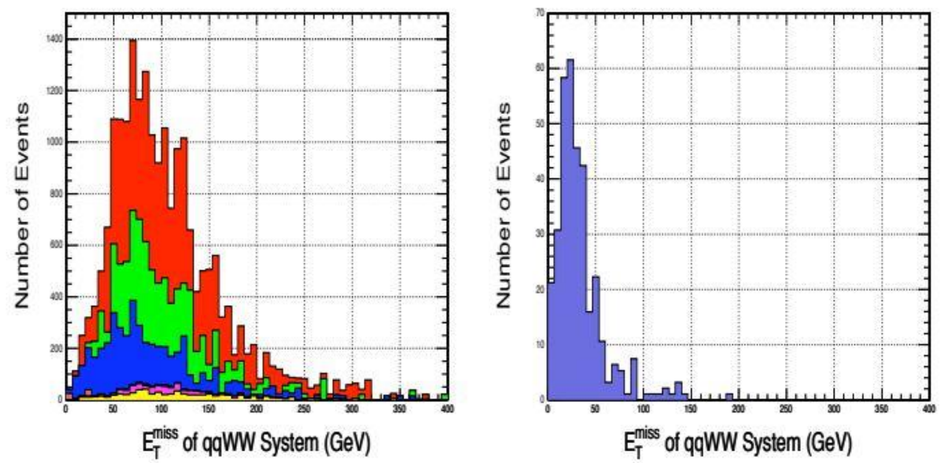
(a) (b)

Additional Cuts

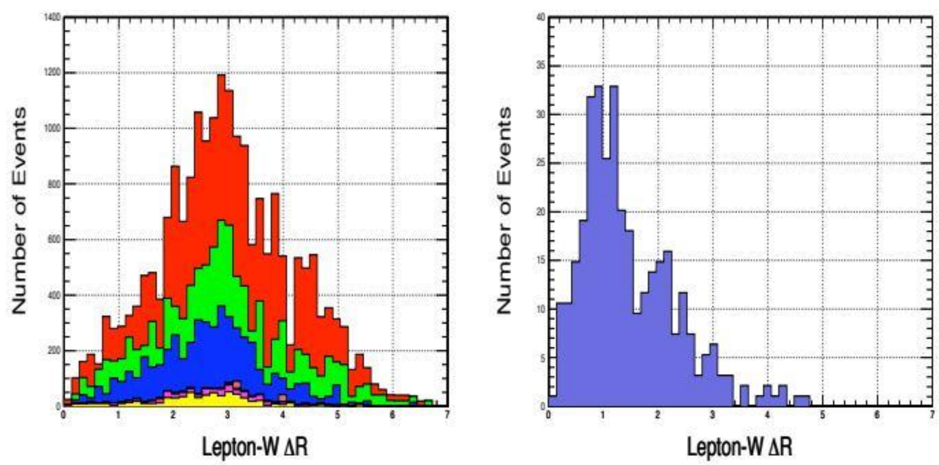
extra jets

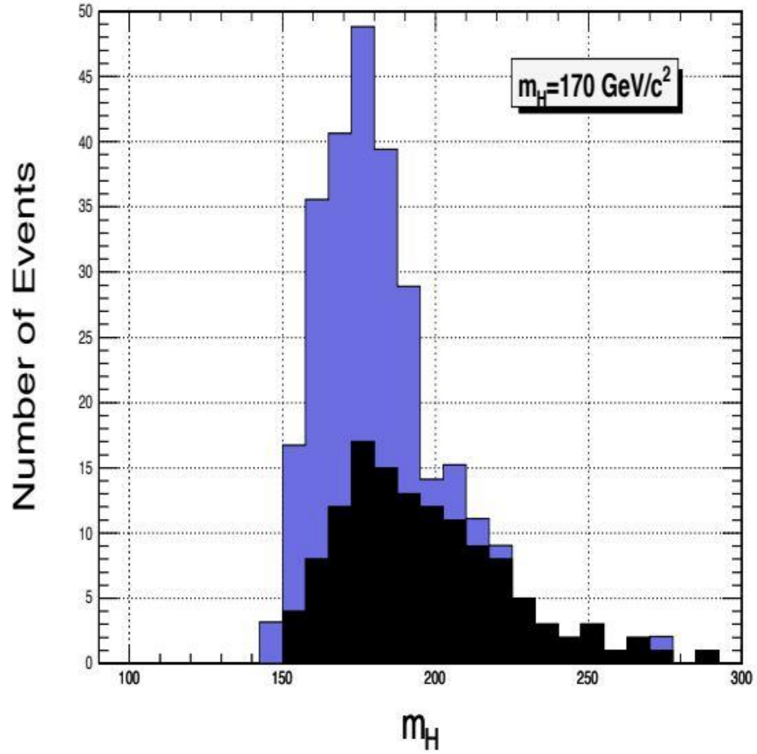


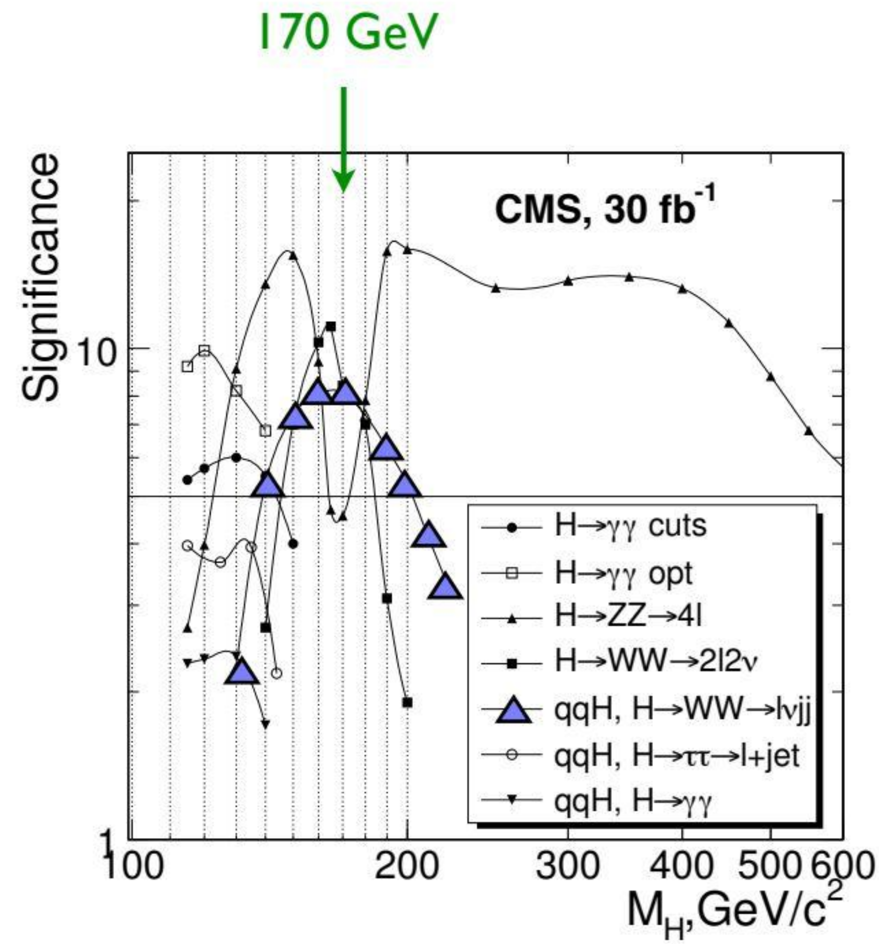
qqH E_T Balance

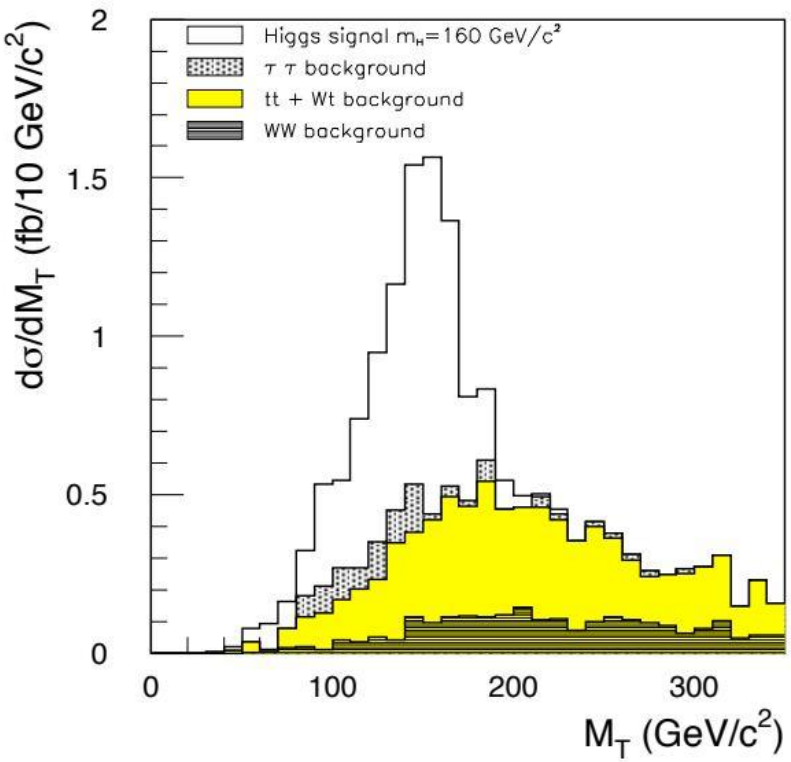


WW Separation

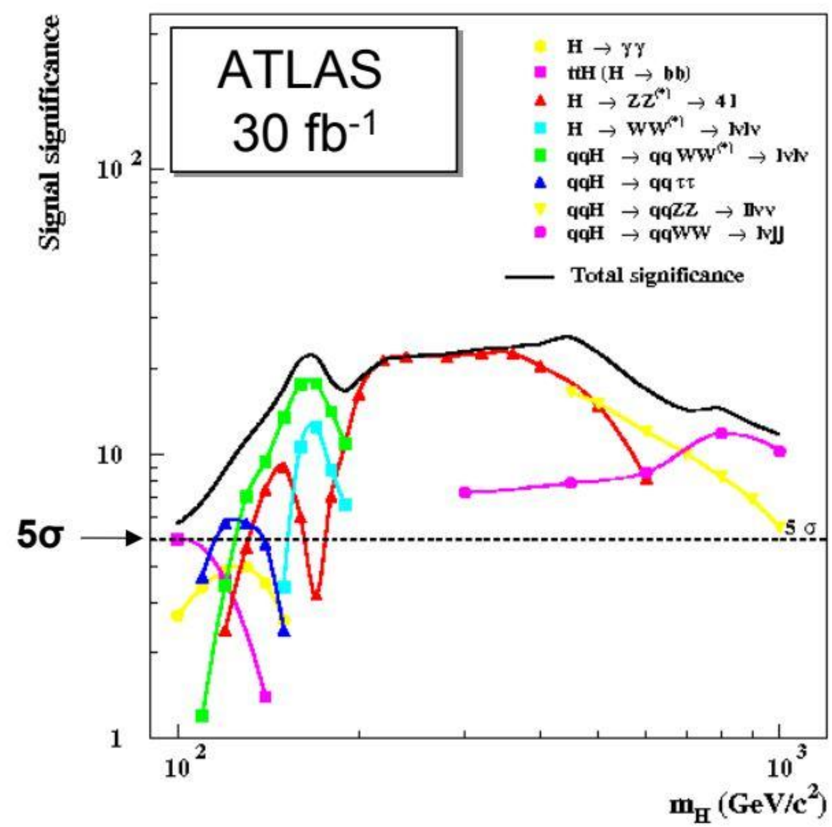



m_H=170 GeV/c^2
Number of Events
m_H


170 GeV
CMS, 30 fb^-1
Significance
H→γγ cuts
H→γγ opt
H→ZZ→4l
H→WW→2l2ν
qqH, H→WW→lνjj
qqH, H→ττ→l+jet
qqH, H→γγ
M_H,GeV/c^2


Higgs signal m_H=160 GeV/c^2
$\tau\,\tau$ background
tt + Wt background
WW background
$d\sigma/dM_T$ (fb/10 GeV/c^2)
M_T (GeV/c^2)
0
0.5
1
1.5
2
0
100
200
300

qqH, H → WW* → eνμν


ATLAS
30 fb^{-1}
$H \to \gamma\gamma$
$ttH\ (H \to bb)$
$H \to ZZ^{(*)} \to 4l$
$H \to WW^{(*)} \to l\nu l\nu$
$qqH \to qq\,WW^{(*)} \to l\nu l\nu$
$qqH \to qq\,\tau\tau$
$qqH \to qqZZ \to ll\nu\nu$
$qqH \to qqWW \to l\nu jj$
Total significance
Signal significance
m_H (GeV/c^2)
5σ
5 σ
1
10
10^2
10^3

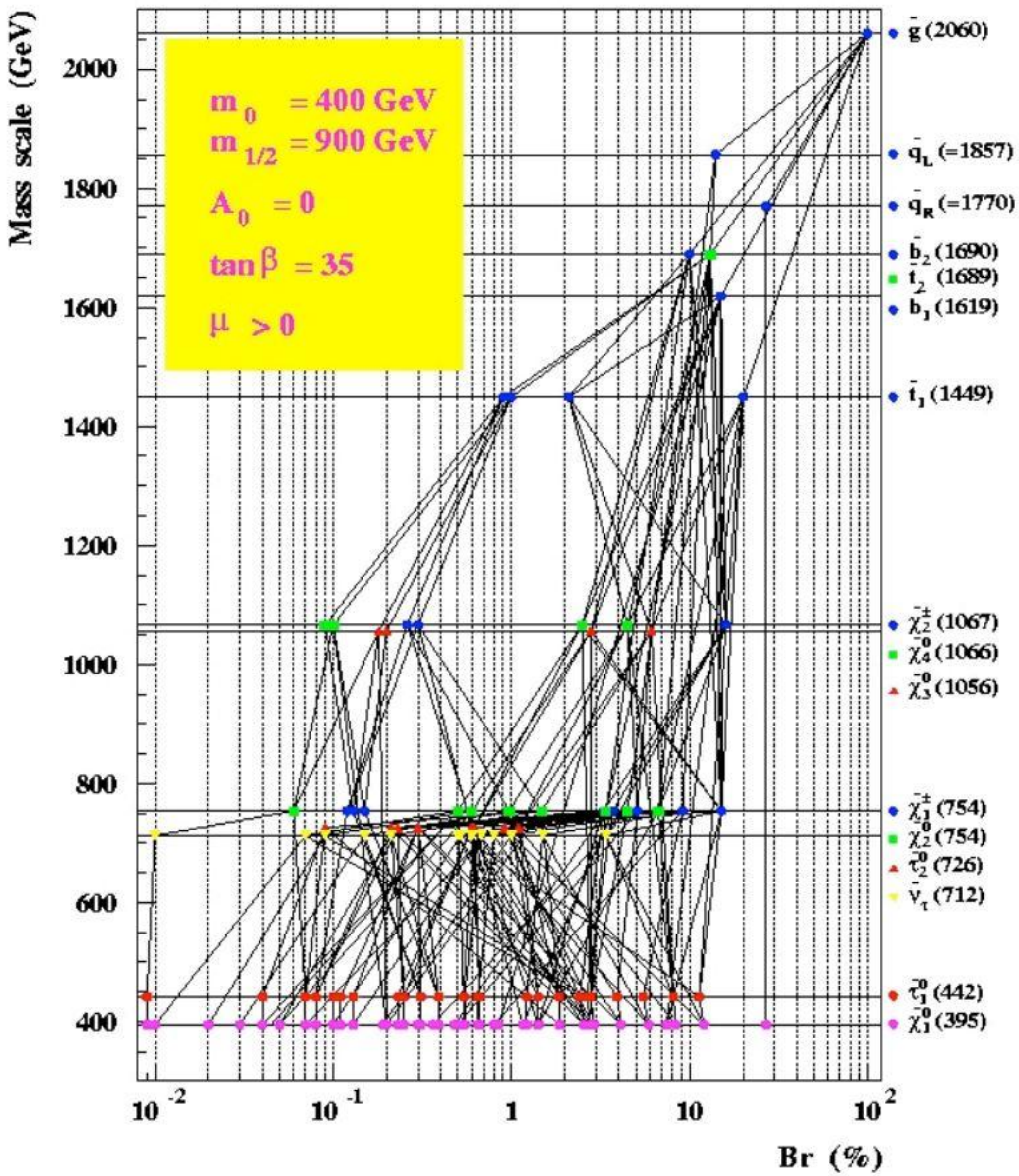
Summary of Higgs signals

jets

Production	Decay	Mass region and purpose	
Gluon Fusion	**H -> $\gamma\gamma$**	110-140GeV	Mass
	H -> ZZ-> 4 l	140-1000GeV	**Discovery**, Mass, Spin, Coupling
	H -> WW	130-170GeV	**Discovery** E_T^{miss}
Vector Boson Fusion	**H -> $\tau\tau$**	110-140GeV	**Discovery**, Mass, Coupling
	H -> WW	130-200GeV	**Discovery**, W coupling
	H -> $\gamma\gamma$	110-140GeV	**Discovery**, Mass
	H -> bb	110-140GeV	Γ_b coupling
ttH	H -> bb	110-130GeV	Γ_τ coupling
	H -> $\tau\tau$	110-130GeV	
	H -> WW	130-180GeV	
WH	H -> WW	140-170GeV	**Discovery**, W coupling

R. Mazini , Puerto Rico (2006)

SUSY Spectroscopy



Possible decays of light sparticles

$$
\begin{aligned}
\tilde{\chi}_1^\pm &\rightarrow \tilde{l}\nu, \\
\tilde{\chi}_1^\pm &\rightarrow \tilde{\nu}l, \\
\tilde{\chi}_1^\pm &\rightarrow W^\pm\tilde{\chi}_1^0, \\
\tilde{\chi}_1^\pm &\rightarrow H^\pm\tilde{\chi}_1^0, \\
\tilde{\chi}_1^\pm &\rightarrow l^\pm\nu\tilde{\chi}_1^0, \\
\tilde{\chi}_2^0 &\rightarrow \tilde{l}l, \\
\tilde{\chi}_2^0 &\rightarrow \tilde{\nu}\nu, \\
\tilde{\chi}_2^0 &\rightarrow h^0\tilde{\chi}_1^0, \\
\tilde{\chi}_2^0 &\rightarrow Z^0\tilde{\chi}_1^0, \\
\tilde{\chi}_2^0 &\rightarrow l^+l^-\tilde{\chi}_1^0
\end{aligned}
$$

stable

produces E_T^{miss}
(and jets)

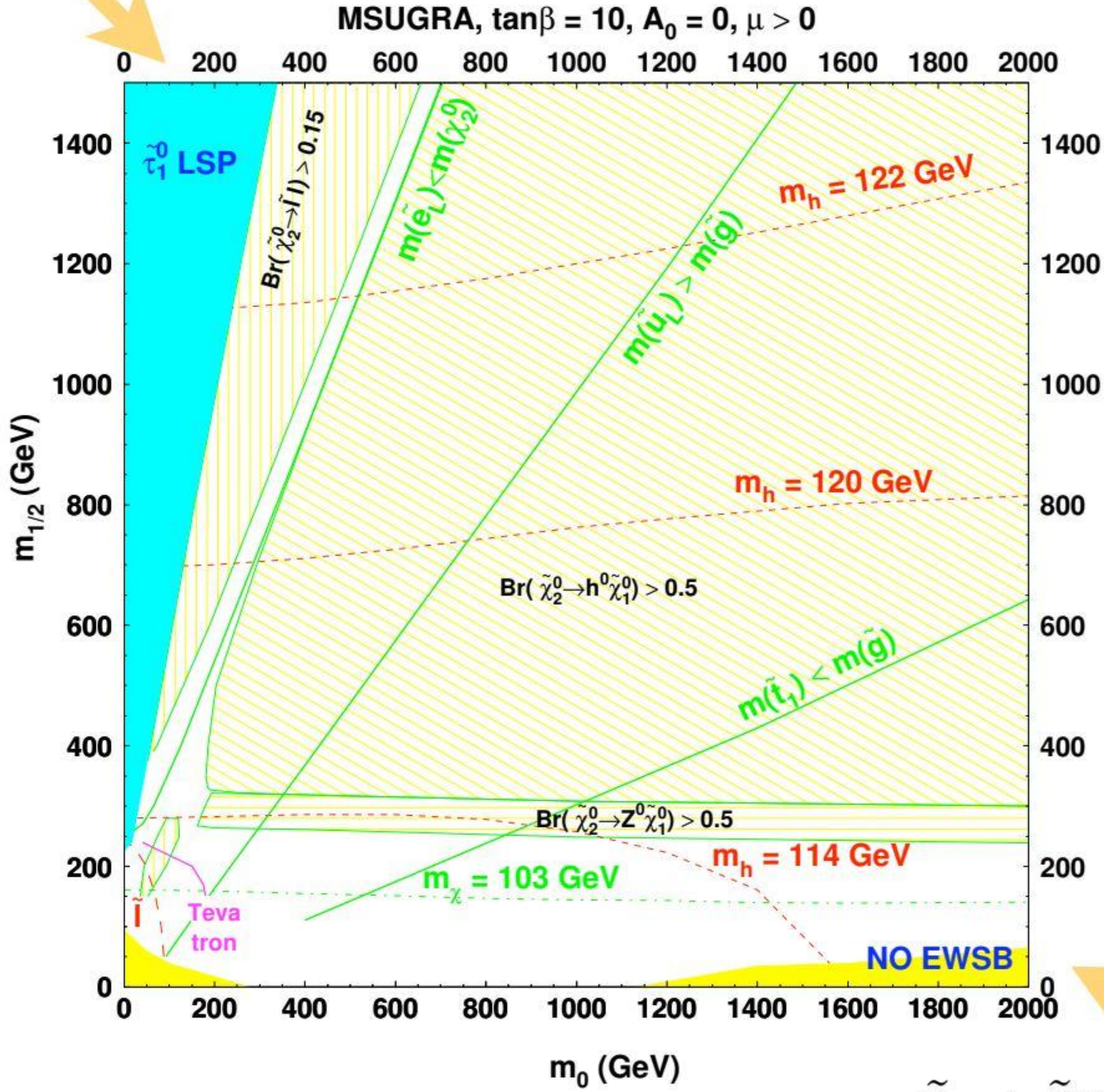
Sparticles are pair-produced with (possibly) large cross sections

Table 13.2: Cross sections for the test points in pb at NLO (LO) from PROSPINO1.

Point	$M(\tilde{q})$	$M(\tilde{g})$	$\tilde{g}\tilde{g}$	$\tilde{g}\tilde{q}$	$\tilde{q}\tilde{\bar{q}}$	$\tilde{q}\tilde{q}$	Total
LM1	558.61	611.32	10.55 (6.489)	28.56 (24.18)	8.851 (6.369)	6.901 (6.238)	54.86 (43.28)
LM2	778.86	833.87	1.443 (0.829)	4.950 (3.980)	1.405 (1.013)	1.608 (1.447)	9.41 (7.27)
LM3	625.65	602.15	12.12 (7.098)	23.99 (19.42)	4.811 (3.583)	4.554 (4.098)	45.47 (34.20)
LM4	660.54	695.05	4.756 (2.839)	13.26 (10.91)	3.631 (2.598)	3.459 (3.082)	25.11 (19.43)
LM5	809.66	858.37	1.185 (0.675)	4.089 (3.264)	1.123 (0.809)	1.352 (1.213)	7.75 (5.96)
LM6	859.93	939.79	0.629 (0.352)	2.560 (2.031)	0.768 (0.559)	0.986 (0.896)	4.94 (3.84)
LM7	3004.3	677.65	6.749 (3.796)	0.042 (0.028)	0.000 (0.000)	0.000 (0.000)	6.79 (3.82)
LM8	820.46	745.14	3.241 (1.780)	6.530 (5.021)	1.030 (0.778)	1.385 (1.230)	12.19 (8.81)
LM9	1480.6	506.92	36.97 (21.44)	2.729 (1.762)	0.018 (0.015)	0.074 (0.063)	39.79 (23.28)
LM10	3132.8	1294.8	0.071 (0.037)	0.005 (0.004)	0.000 (0.000)	0.000 (0.000)	0.076 (0.041)
HM1	1721.4	1885.9	0.002 (0.001)	0.018 (0.016)	0.005 (0.005)	0.020 (0.021)	0.045 (0.043)
HM2	1655.8	1785.4	0.003 (0.002)	0.027 (0.024)	0.008 (0.007)	0.027 (0.028)	0.065 (0.061)
HM3	1762.1	1804.4	0.003 (0.002)	0.021 (0.018)	0.005 (0.004)	0.018 (0.019)	0.047 (0.043)
HM4	1815.8	1433.9	0.026 (0.014)	0.056 (0.043)	0.003 (0.003)	0.017 (0.017)	0.102 (0.077)

heavy gluino

$\tilde{g} \to \tilde{q}\bar{q}\ ,\ \tilde{q} \to q\chi$

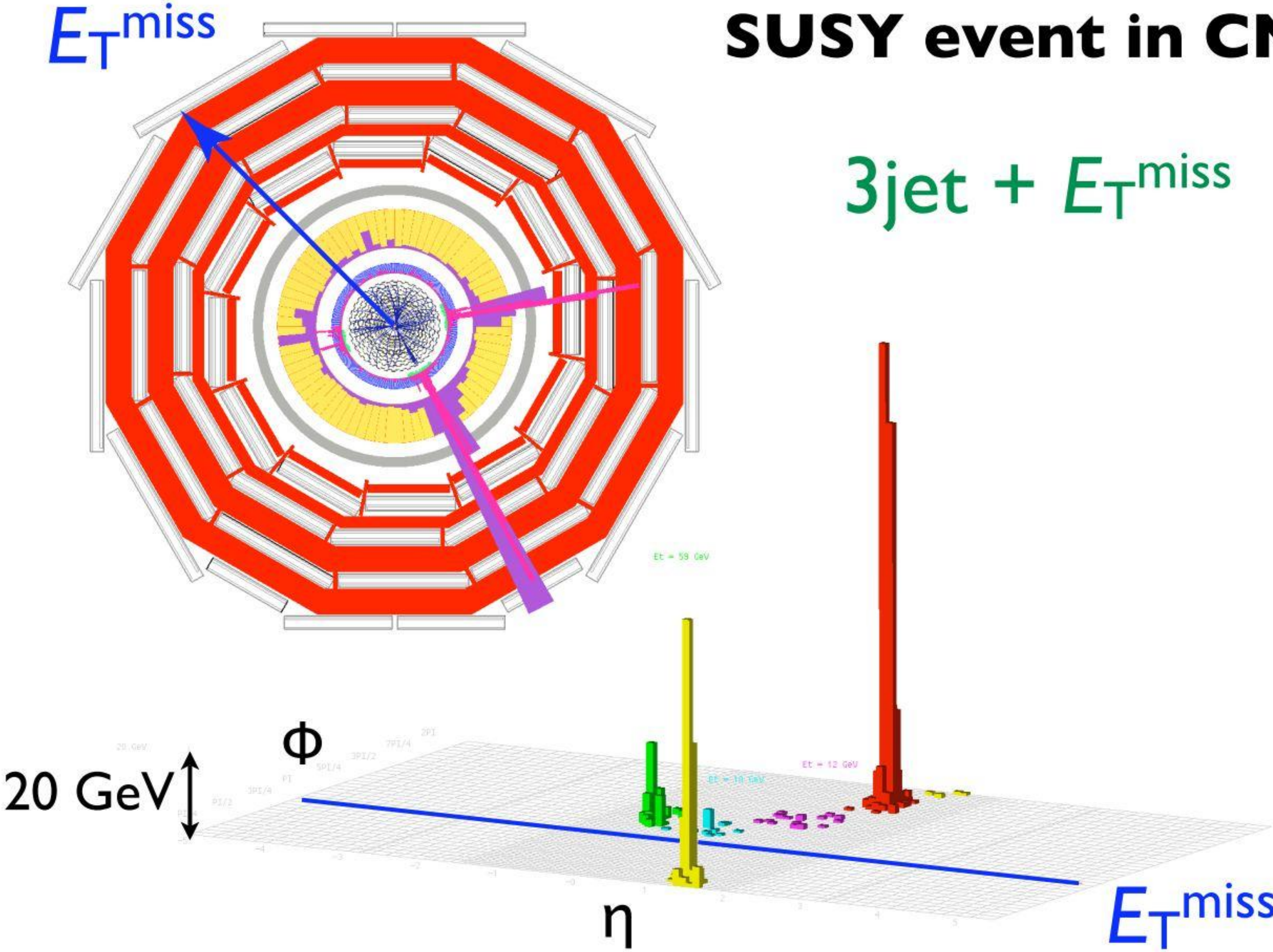


heavy squark

$\tilde{q} \to \tilde{g}q\ ,\ \tilde{g} \to q\bar{q}\chi$

SUSY event in CMS

3jet + E_T^{miss}



Inclusive analysis with missing transverse energy and jets

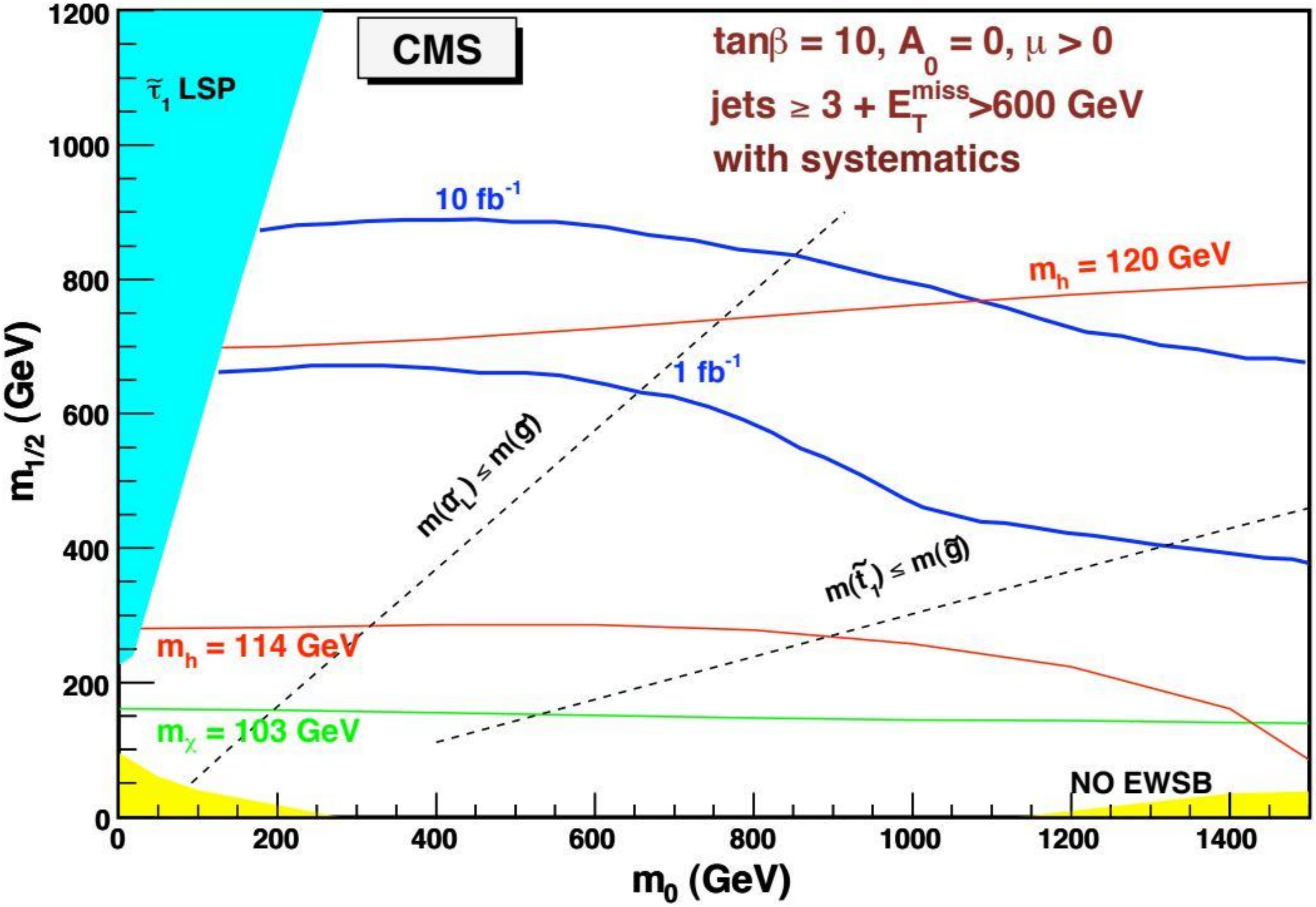
Table 13.5: The $E_{\mathrm{T}}^{\mathrm{miss}}$ + multi-jet SUSY search analysis path

Requirement	Remark
Level 1	Level-1 trigger efficiency parametrisation
$\boxed{\text{HLT, } E_T^{miss} > 200\,\text{GeV}}$	trigger/signal signature
primary vertex ≥ 1	primary cleanup
$F_{em} \geq 0.175$, $F_{ch} \geq 0.1$	primary cleanup
$\boxed{N_j \geq 3, \lvert\eta_d^{1j}\rvert < 1.7}$	signal signature
$\delta\phi_{min}(E_T^{miss} - jet) \geq 0.3$ rad, $R1, R2 > 0.5$ rad, $\delta\phi(E_T^{miss} - j(2)) > 20°$	QCD rejection
$Iso^{lead\ trk} = 0$	ILV (I) $W/Z/t\bar{t}$ rejection
$f_{em(j(1))},\ f_{em(j(2))} < 0.9$	ILV (II), $W/Z/t\bar{t}$ rejection
$E_{T,j(1)} > 180\,\text{GeV}$,$E_{T,j(2)} > 110\,\text{GeV}$	signal/background optimisation
$H_T \equiv E_{T(2)} + E_{T(3)} + E_{T(4)} + E_T^{miss} > 500\,\text{GeV}$	signal/background optimisation
SUSY LM1 signal efficiency 13%	

Table 13.6: Selected SUSY and Standard Model background events for 1 fb^{-1}

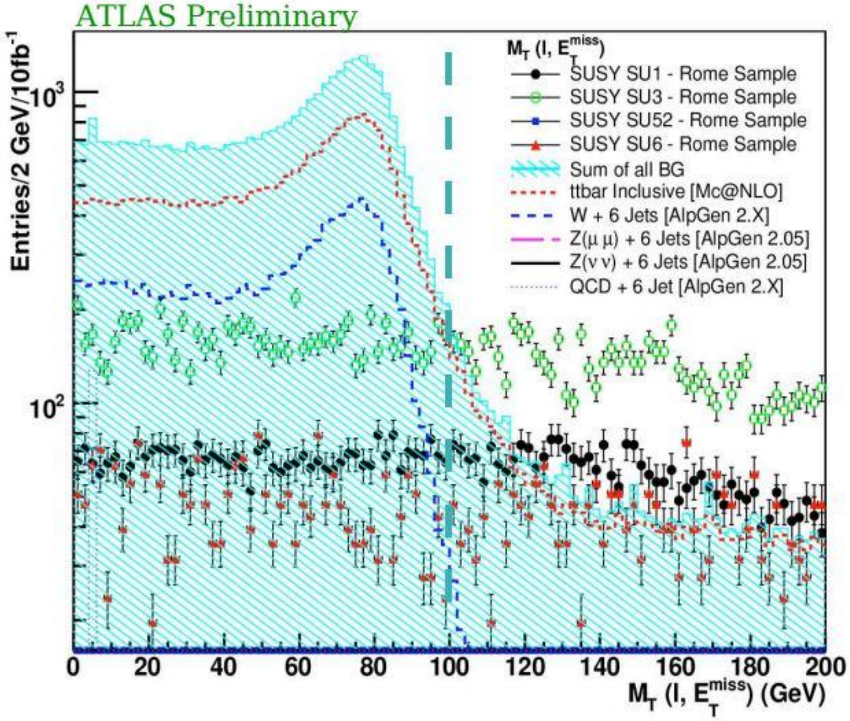
Signal	$t\bar{t}$	single t	$Z(\rightarrow \nu\bar{\nu})$+ jets	$(W/Z, WW/ZZ/ZW)$ + jets	QCD
6319	53.9	2.6	48	33	107

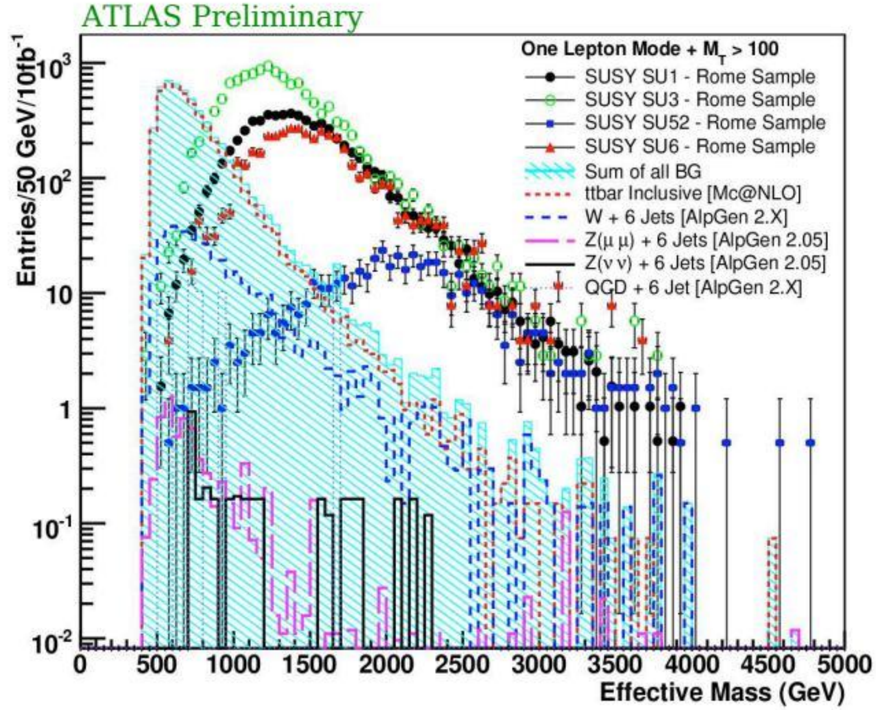
Inclusive analysis with missing transverse energy and jets



Inclusive SuperSymmetry using mSUGRA

Main final states in Cascade decays (E_T + Jets + Lepton): [One lepton Mode]





Exclude the standard Model background using the M_T cut

One Lepton Mode: Very clean discovery channel ...

S. Padhi, PASCOS 2006

Inclusive muons with jets and missing transverse energy

- **Point LM1** :
  - Same as post-WMAP benchmark point B′ and near DAQ TDR point 4.
  - $m(\tilde{g}) \geq m(\tilde{q})$, hence $\tilde{g} \to \tilde{q}q$ is dominant
  - $B(\tilde{\chi}_2^0 \to \tilde{l}_R l) = 11.2\%$, $B(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) = 46\%$, $B(\tilde{\chi}_1^\pm \to \tilde{\nu}_l l) = 36\%$

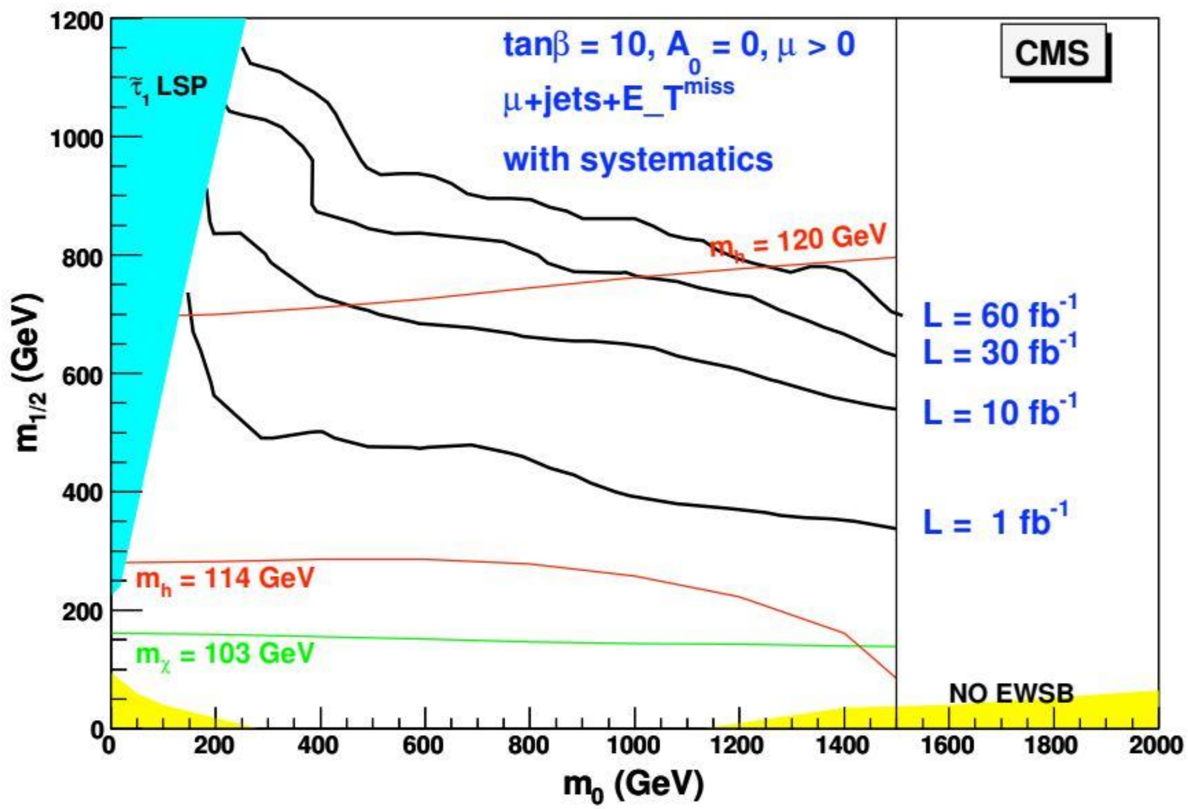


Figure 13.6: CMS discovery reach contours in the m_0–$m_{1/2}$ plane using inclusive muons with jets and missing energy for 10 fb^{-1} (lower contour), 30 fb^{-1} (middle contour), and 60 fb^{-1} (upper contour) including systematics.

Inclusive analyses with Higgs

events can be efficiently triggered using inclusive SUSY triggers such as jet+E_T^{miss}, and the dominant $h^0 \to b\bar{b}$ decay mode of the Higgs boson can be exploited

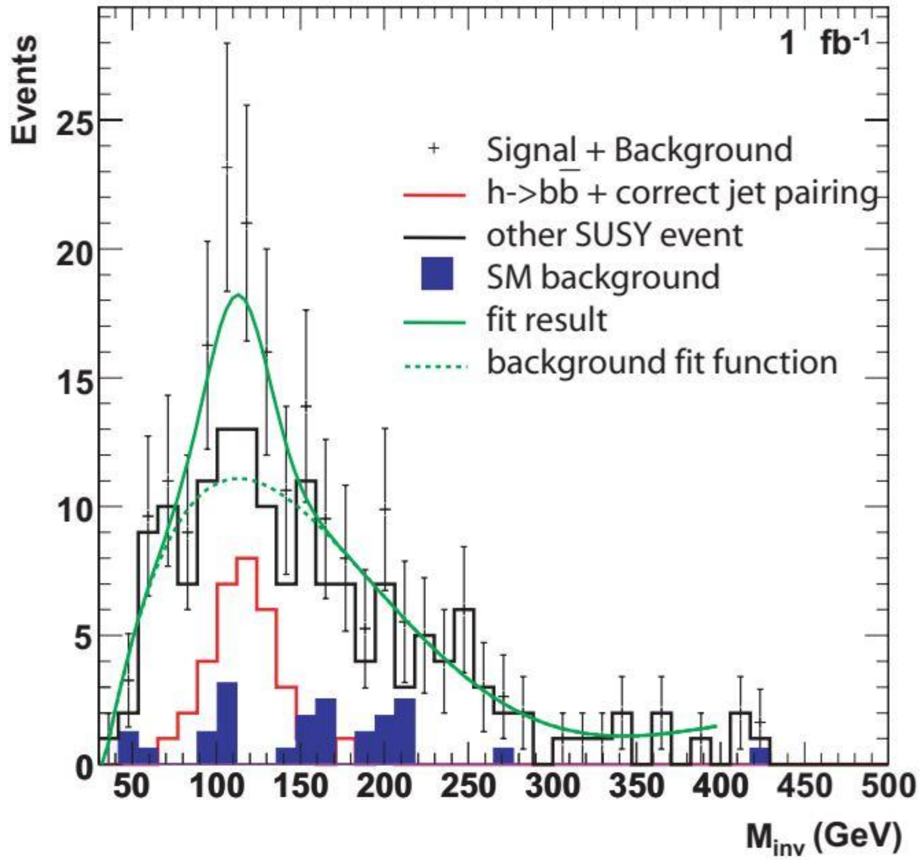


Figure 13.16: Invariant mass distribution of $b\bar{b}$ jets for the search of Higgs final states with 1 fb^{-1}.

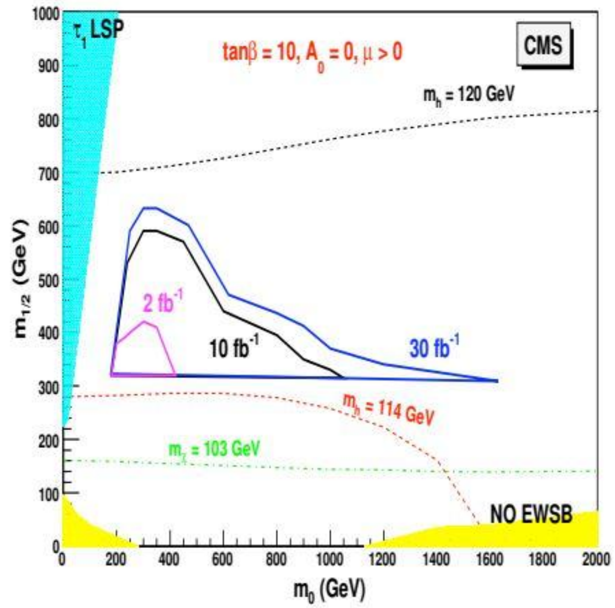
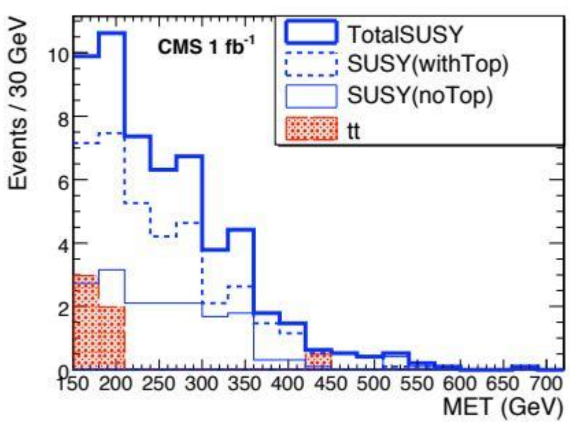


Figure 13.17: Higgs discovery reach in SUSY cascades for 2, 10 and 30 fb^{-1}.

Inclusive analyses with top

$$\tilde{t}_1 \rightarrow t\tilde{\chi}_2^0 \rightarrow tl\tilde{l}_R \rightarrow tll\tilde{\chi}_1^0$$

cut	SUSY (withTop)	SUSY (noTop)	ttInc	WW	ZW	Single t	wT/noT
x-sec(pb) NLO	52		830	269.91	51.5	250	-
No.of.used.events	494261		1674500	305000	70000	100000	-
NEve(Nor.xsec)1 fb^{-1}	8375	43625	830000	269910	51500	250000	0.19
L1T (Jet/Met)	6269	33582	75806	18498	598	10875	0.19
HLT (Jet/Met)	5070	29427	14430	4733	142	1750	0.17
MET$\geq$ 150 GeV	4183	25677	4930	2312	99	653	0.16
$n_{bj} \geq 1$	3457	14388	3718	792	32	355	0.24
$n_j^{b\ or\ light} \geq 4$	1789	4576	769	25	0	33	0.39
A convergent Fit	1335	3062	557	12	0	28	0.44
χ^2 probability >0.1	105	69	56	0	0	5	1.52
$\Delta\phi$ <2.6	79	52	12	0	0	5	1.51
$n_l > 0$	38	17	5	0	0	0	2.19



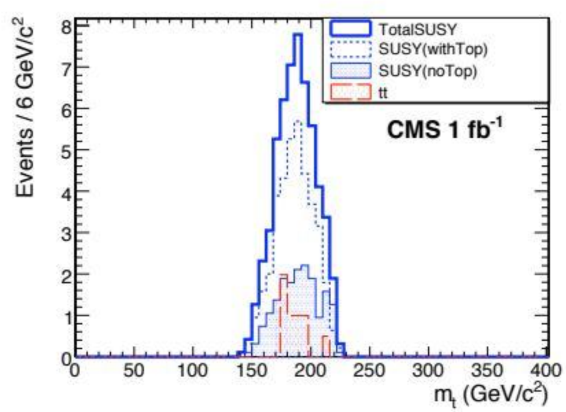


Figure 13.22: (left) Distributions of $E_{\mathrm{T}}^{\mathrm{miss}}$ and (right) fitted top mass after all selection criteria are applied

Inclusive analyses with top

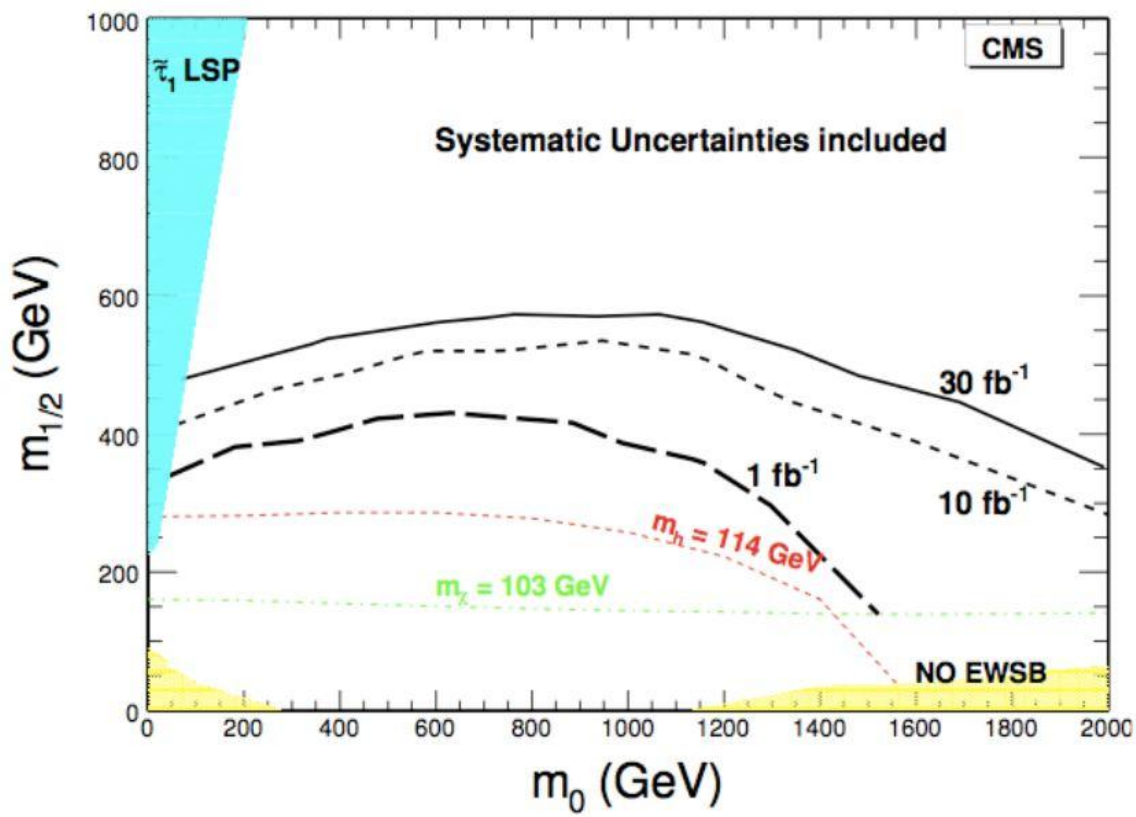
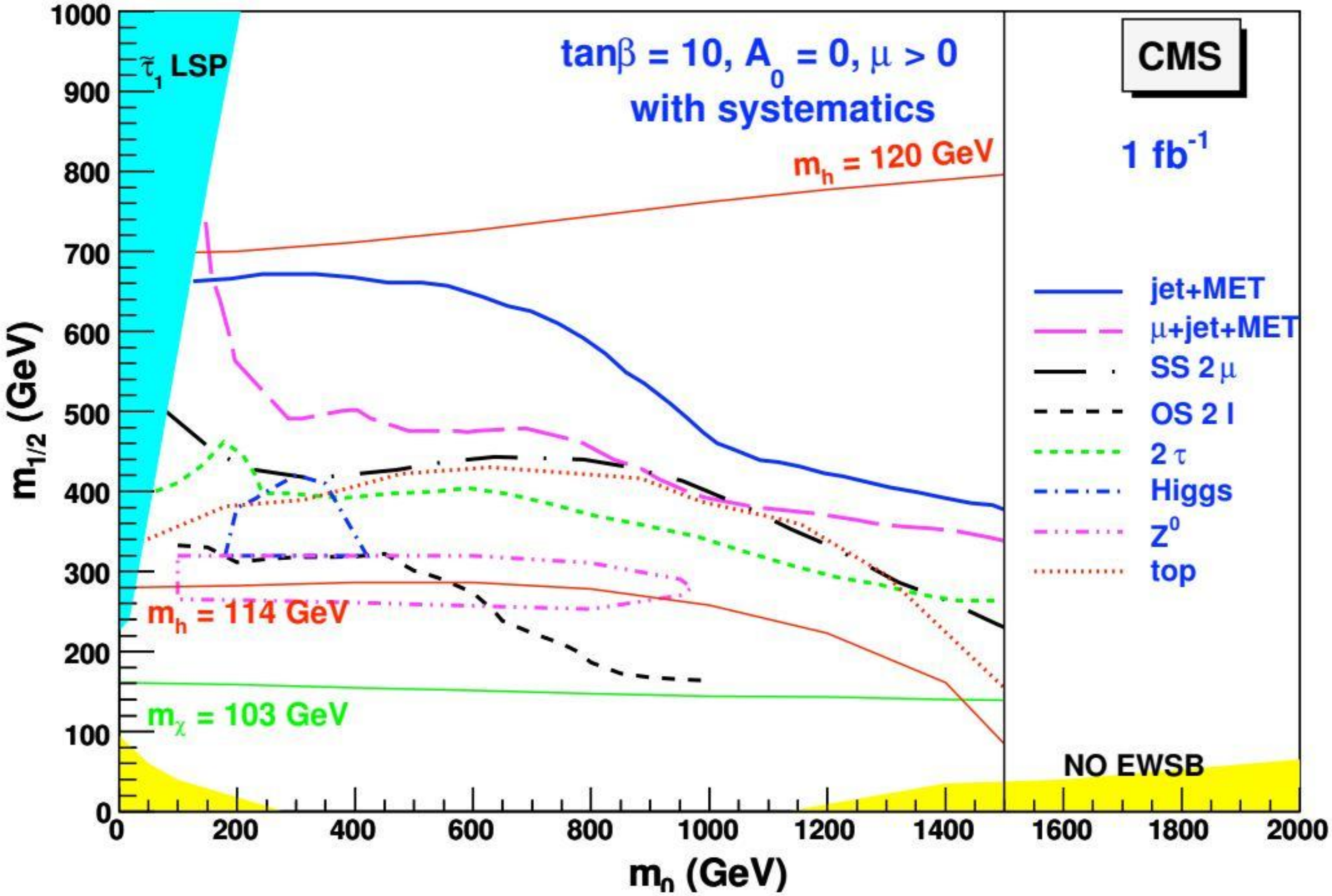


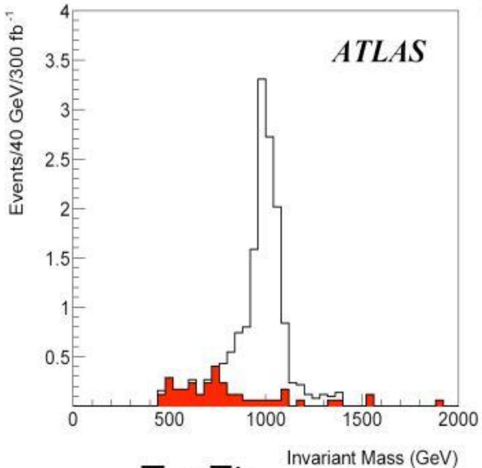
Figure 13.23: The 5σ reach in $m_0, m_{1/2}$ plane with 1, 10 and 30 fb^{-1} obtained for final states with a top quark.

SUSY Reach: Summary



Little Higgs ATLAS

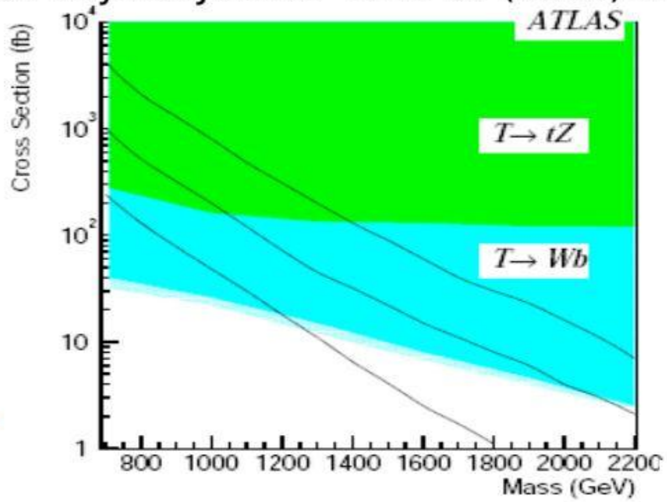
Heavy Top Searches (II)

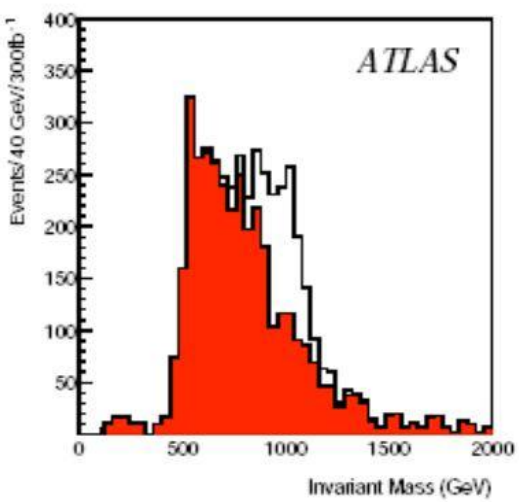


T->Zt

300 fb^{-1}

Eur. Physics Journal C 39 S2 (2005) s13-s24





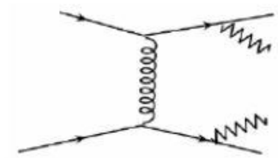
T->Wb

- Similar cuts for the tZ channel as CMS
- Wb
  - Charged lepton P_T> 100 GeV
  - 1 bjet with P_T> 200 GeV
  - No more than 2 jets with P_T> 50 GeV
  - Dijet mass > 100 GeV
  - Missing P_T> 100 GeV

K. Black, PASCOS 2006

Resonant Vector Boson Scattering

- Selection: 2 forward jets + central jets and/or leptons
  + missing E_T (for $W \rightarrow \ell \nu$)
  Require no additional central jet & b-jet veto (for jet modes)
- Bkg: gluon and γ/Z exchange with W and Z radiation
  also $t\bar{t}$ & W+4 jets (need more stats)



- Expt issues:
  - Merging of jets from high-pT W or Z decay (need cone $\Delta R = 0.2$)
  - Impact of pileup on forward jet tagging?
- Promising sensitivity for jet modes at 100 fb^{-1}
  (need 300 fb^{-1} for $WZ \rightarrow \ell\nu\,\ell\ell$)
  → study is ongoing

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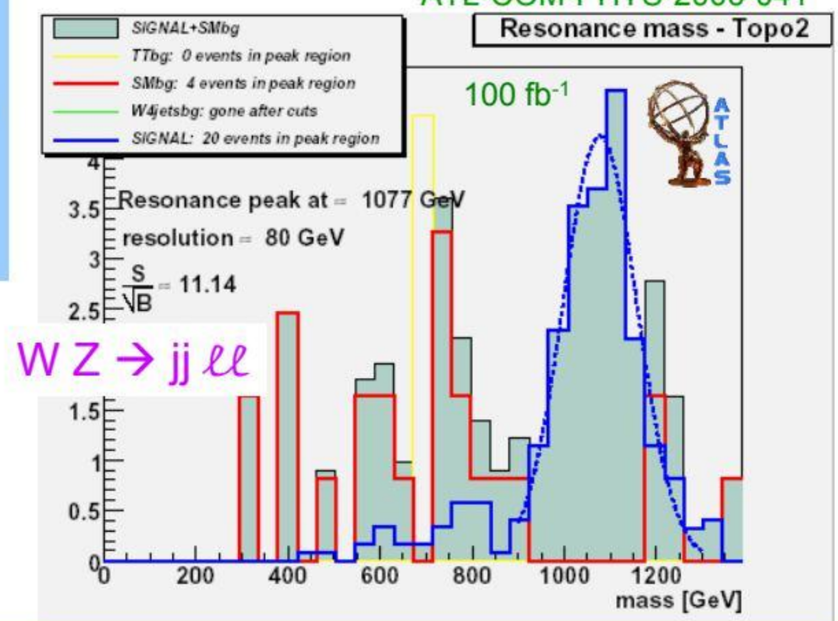
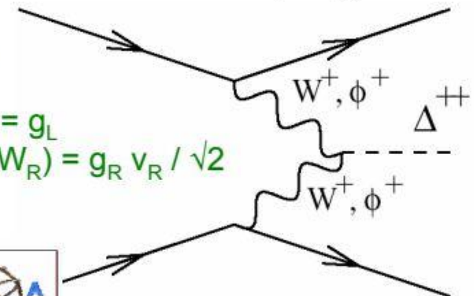


Doubly-Charged Higgs in LR Symmetric Model

- Left-Right Symmetric Model based on $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B\text{-}L}$
  - Features triplet of Higgs fields (Δ_R^0, Δ_R^+, Δ_R^{++}) + two doublets ϕ
  - Predicts new gauge bosons (W_R and Z_R) & new fermions (ν_R)
  - Addresses origin of pure left-handed charged weak interaction + origin of light neutrino masses (via see-saw mech. & heavy ν_R)
- Production: $qq \rightarrow q'q'\, W_{R,L}^+\, W_{R,L}^+ \rightarrow q'q'\, \Delta_{R,L}^{++}$

  $q\bar{q} \rightarrow \gamma^*/Z/Z_{R,L} \rightarrow \Delta_{R,L}^{++}\, \Delta_{R,L}^{--}$



$g_R = g_L$
$m(W_R) = g_R\, v_R / \sqrt{2}$

- Decay: $\Delta_{R,L}^{++} \rightarrow l^+ l^+$
- Selection (WW fusion): 2 like-sign leptons (e, μ, τ) + "forward" jets
- Bkg: $W^+ W^+ q\, q$, $W\, t\, \bar{t}$

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