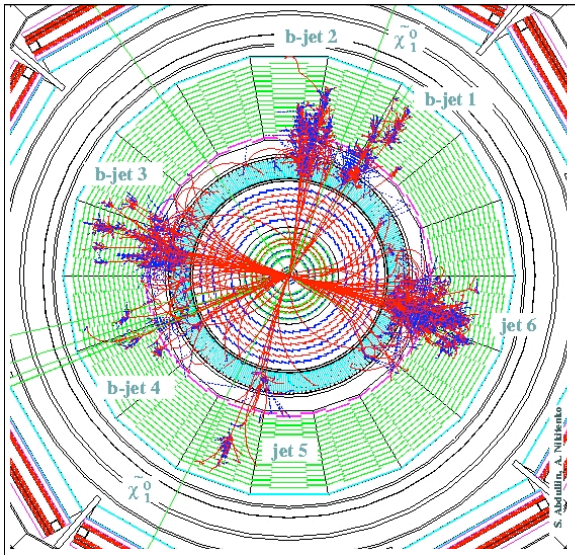


2007 Aspen Winter Conference
"New Physics at the Electroweak Scale and New Signals at Hadron Colliders"
Jan. 11, 2007

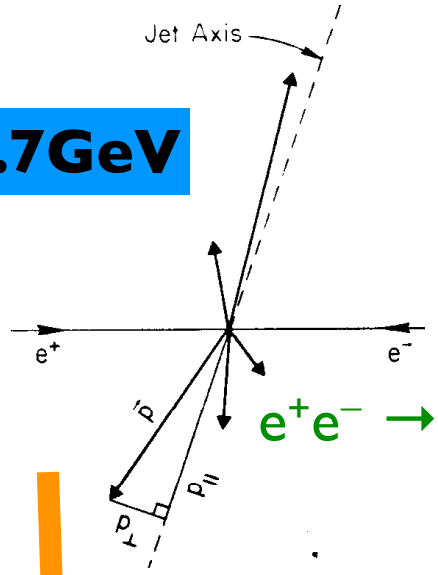
Missing E_T + Jets Signatures at the LHC

Jim Rohlf
Boston University

History of Jets

SPEAR 1974

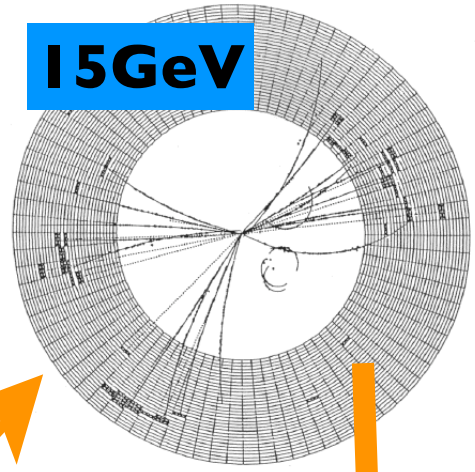
3.7GeV



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

DESY 1979

15GeV



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

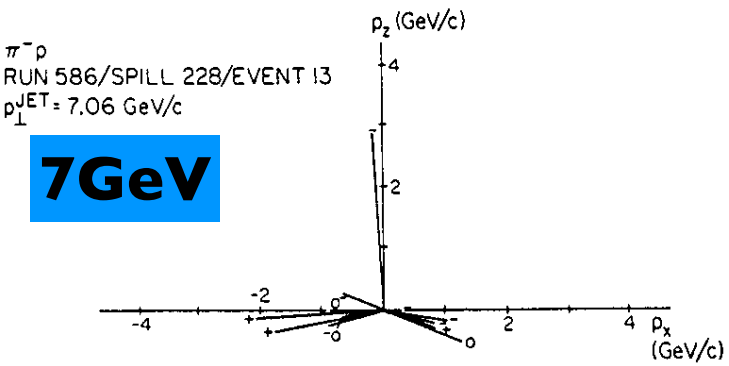
CERN LEP 1989

flavor tagging

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

FNAL 1977

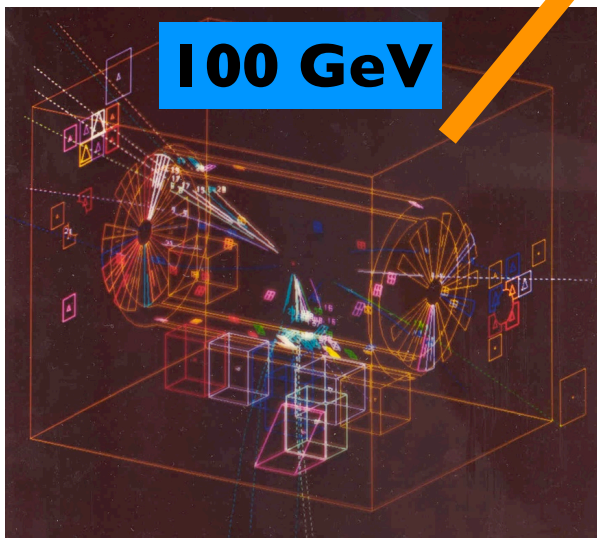
7GeV



$qq \to qq$

CERN $p\bar{p}$ 1982

100 GeV

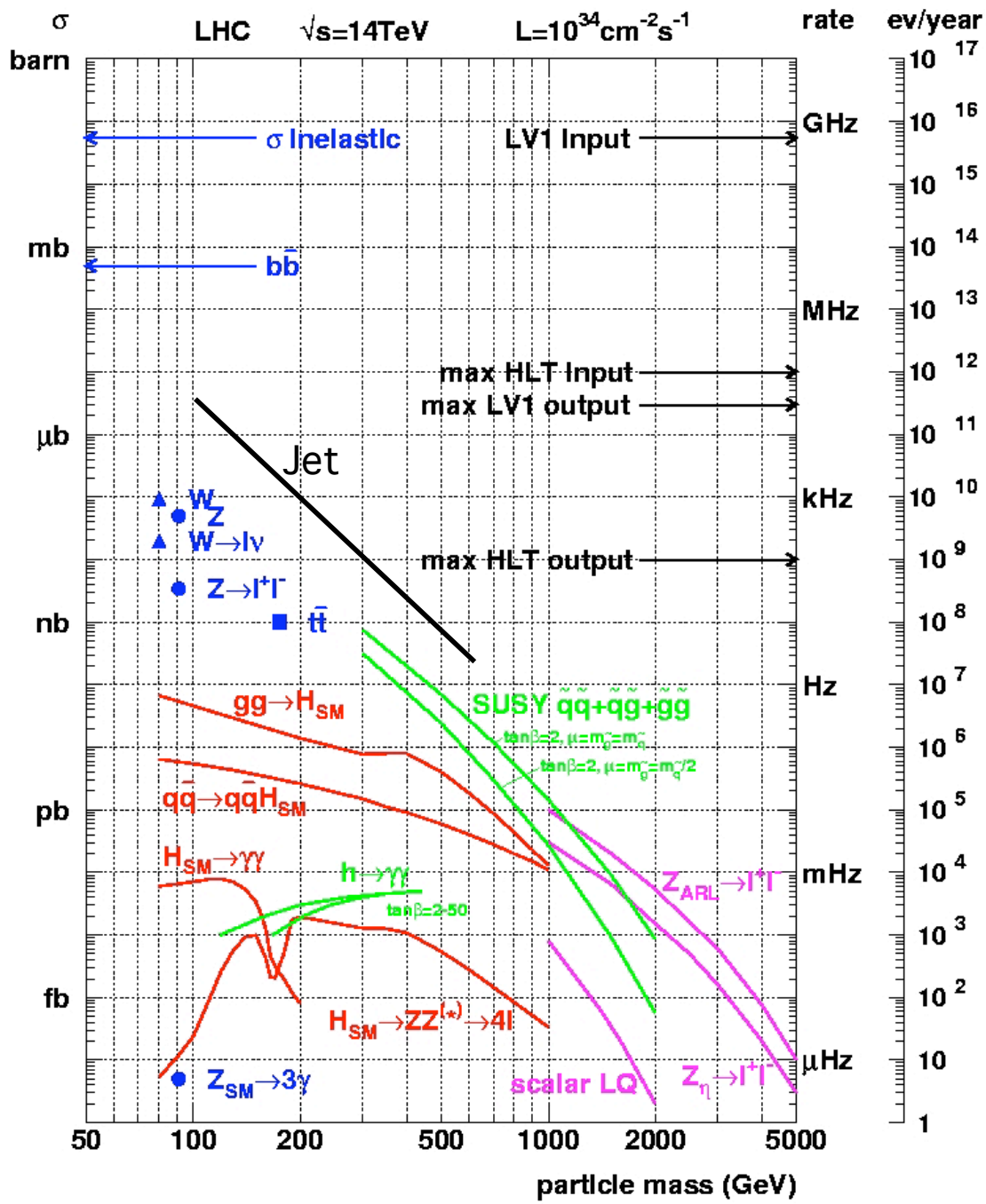


$q\bar{q} \to q\bar{q}$

LHC 2008

?

multi-TeV



at design luminosity

100 GeV jet	1 μb ~ 10 / ms
TeV jet	1 nb ~ 10 / s
Higgs	1 pb ~ 1 per min.
exotic	1 fb ~ 1 per day

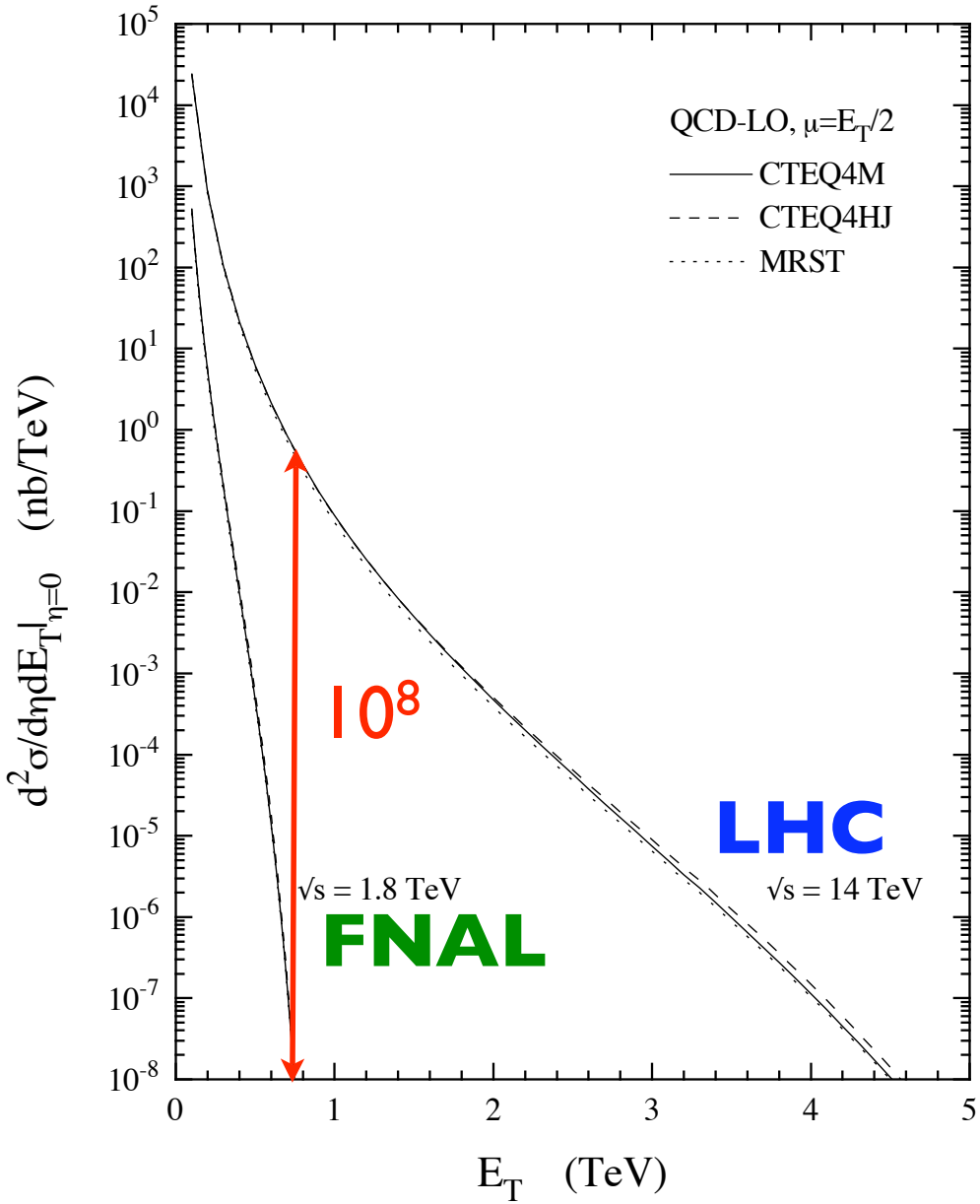
$\sigma_{jet} / \sigma_{SUSY} \sim 10\text{-}20$

$\sigma_{jet} / \sigma_{W} \sim 10^2$

$\sigma_{jet} / \sigma_{top} \sim 10^2$

$\sigma_{jet} / \sigma_{Higgs} \sim 10^3\text{-}10^4$

Jet Cross Section



Outline

Tools

Standard Model

Higgs

SUSY

Calorimetry

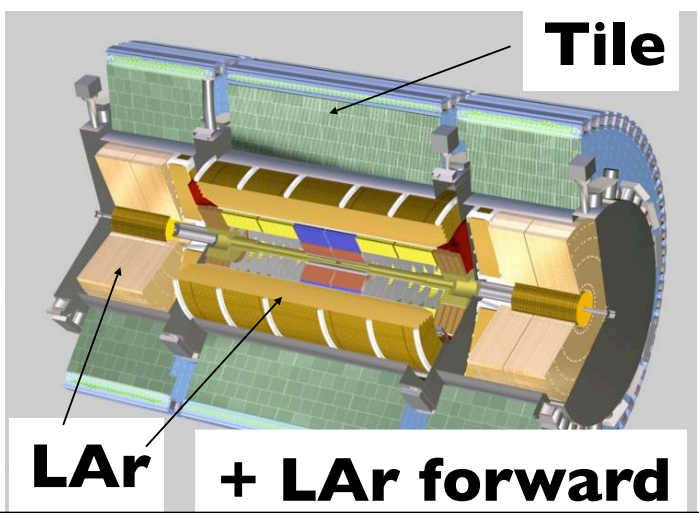
ECAL

	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

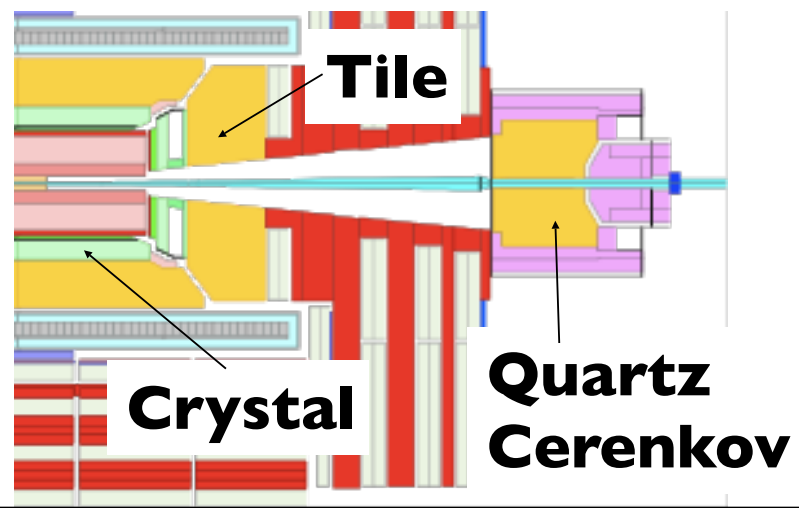
HCAL

	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

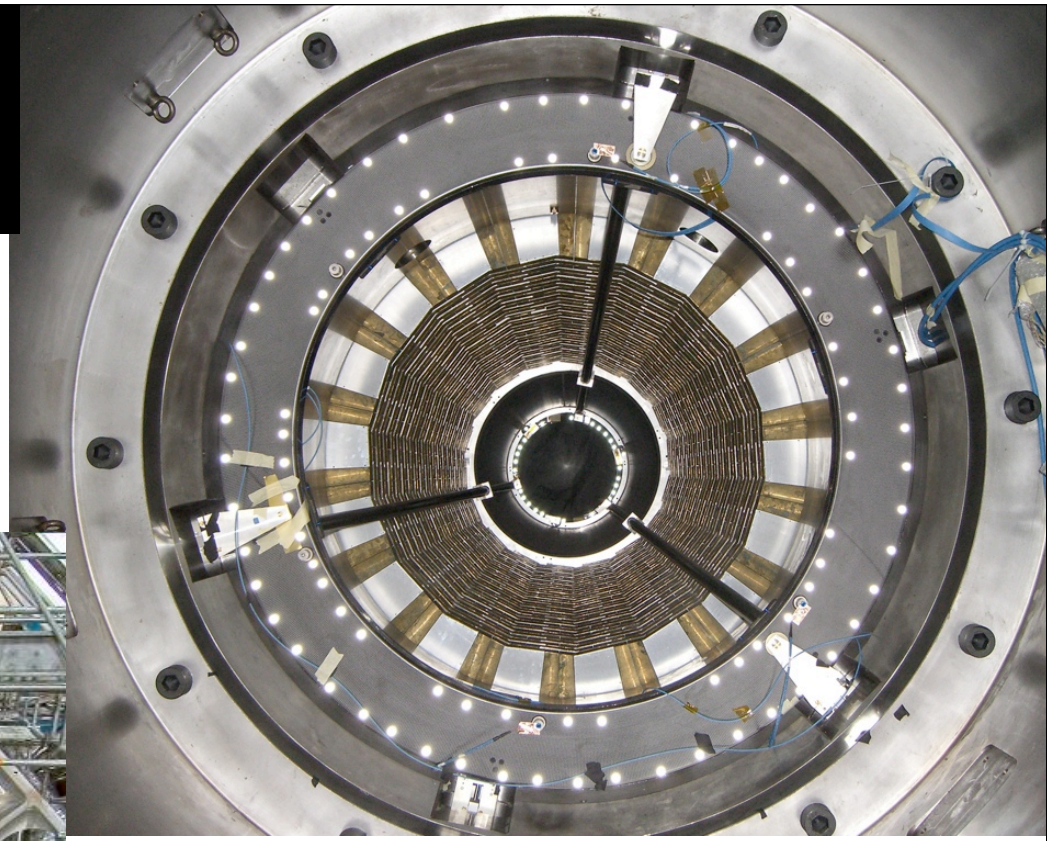
ATLAS

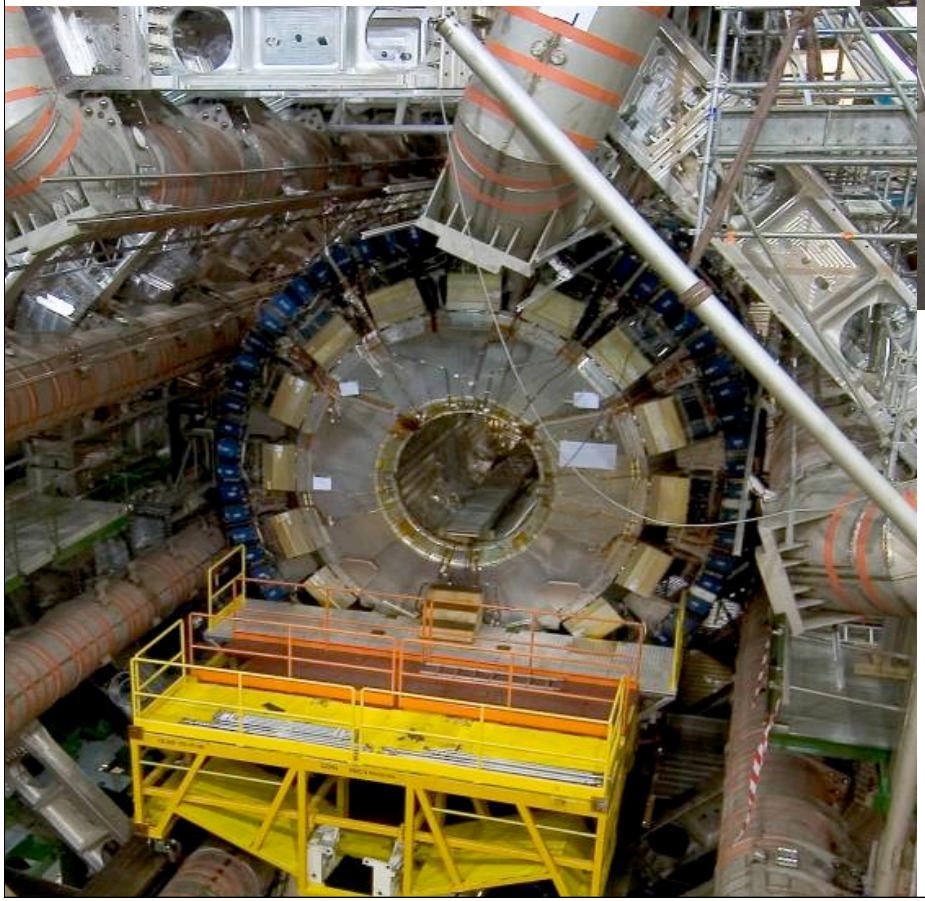


CMS



View inside the coils





Calorimeter Performance Studied Extensively in Test Beams

G. Baiatian *et al.*
CMS NOTE 139/2006

EPJ in press

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

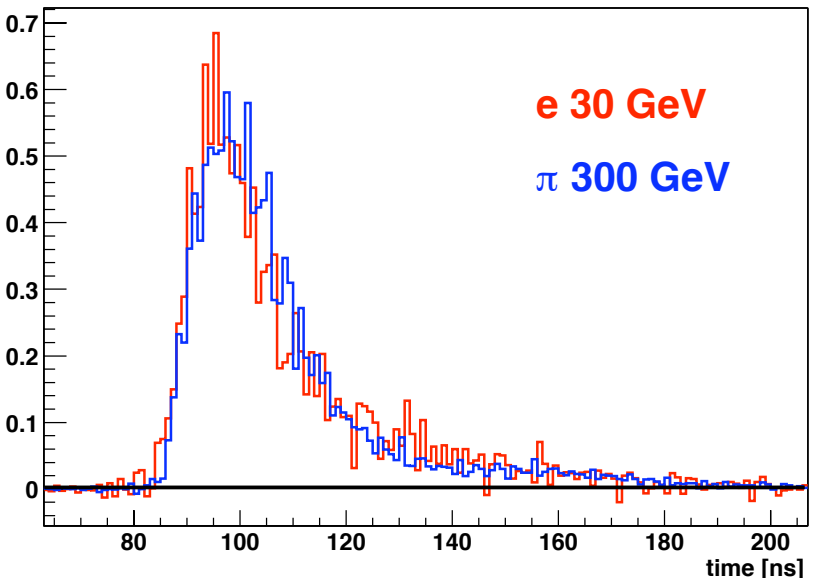
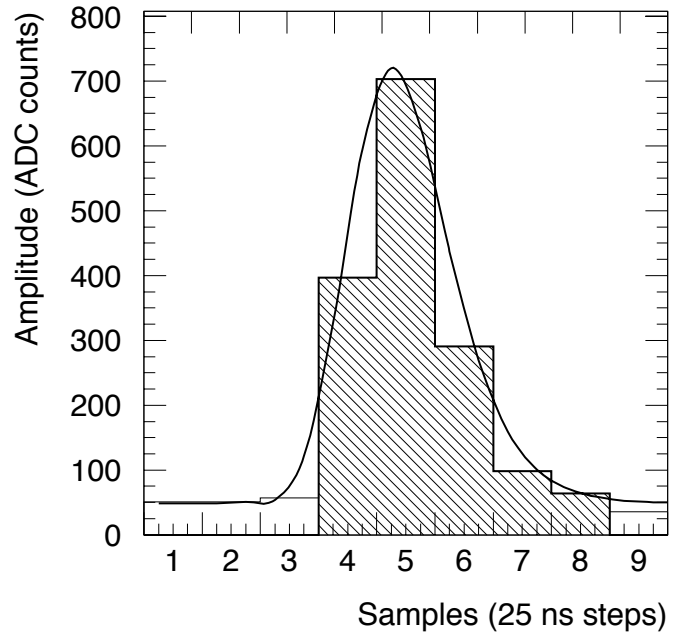


Figure 3: Pulse shape for 30 GeV electrons and 300 GeV pions.



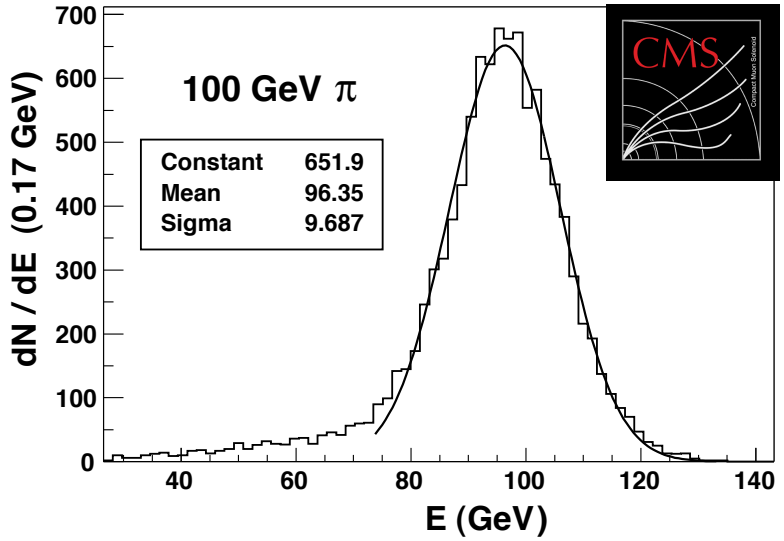
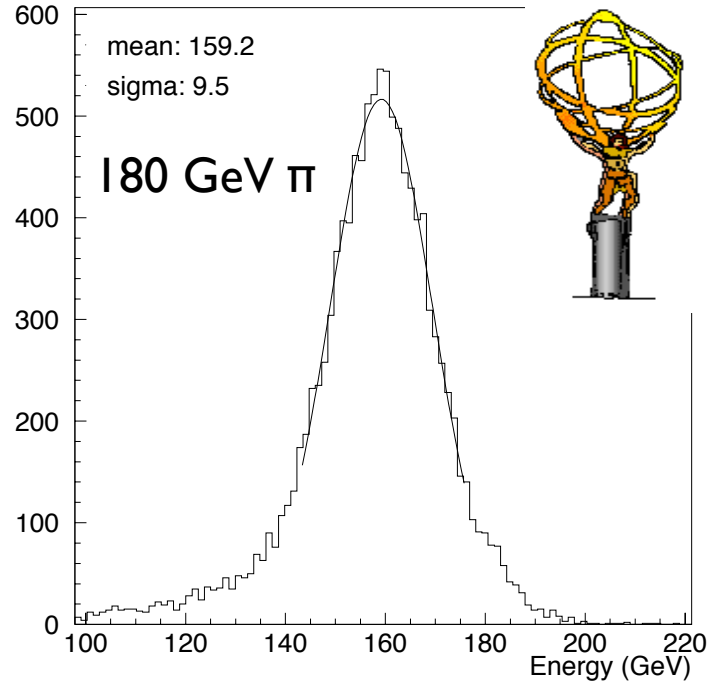
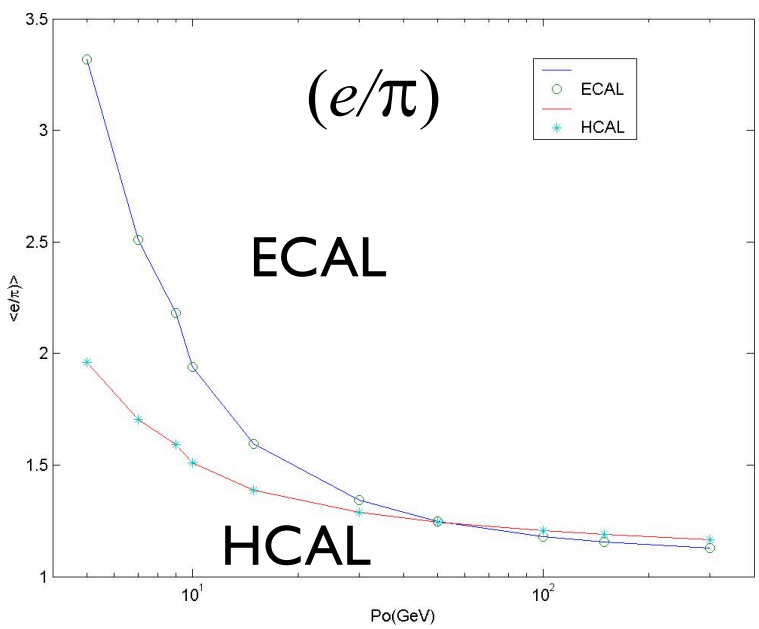
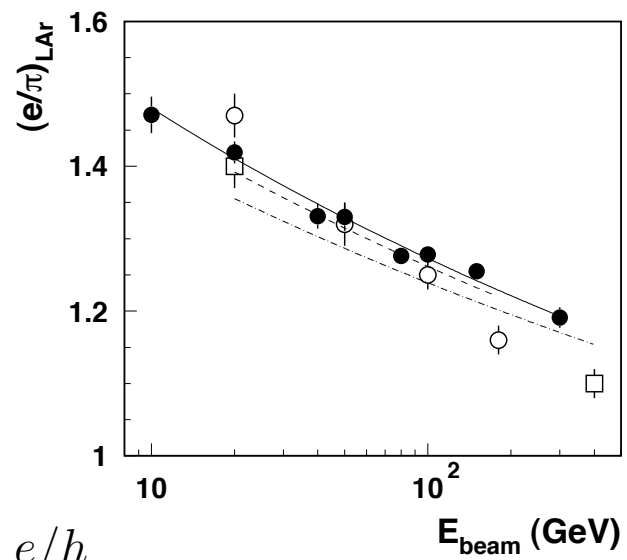


Figure 38: Energy distribution in HCAL (5×5 towers) for 100 GeV pions.







$$\left(\frac{e}{\pi}\right) = \frac{e/h}{1 + (e/h - 1) \cdot f_{\pi^0}}$$

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:

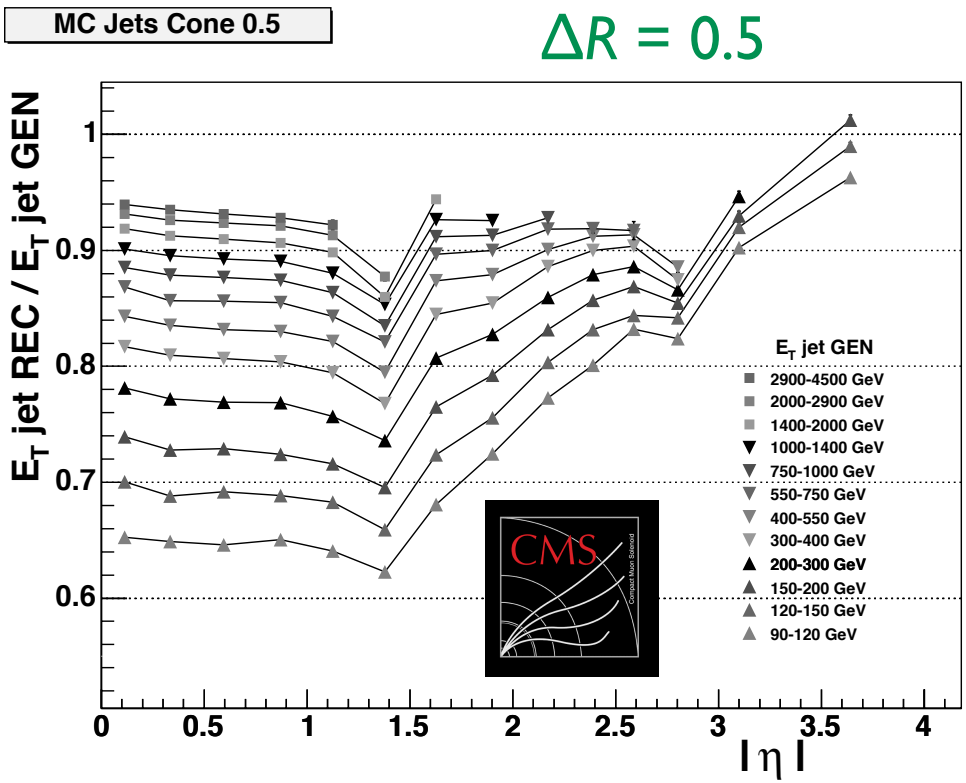
potential jets within some cone size of each other are either split or merged

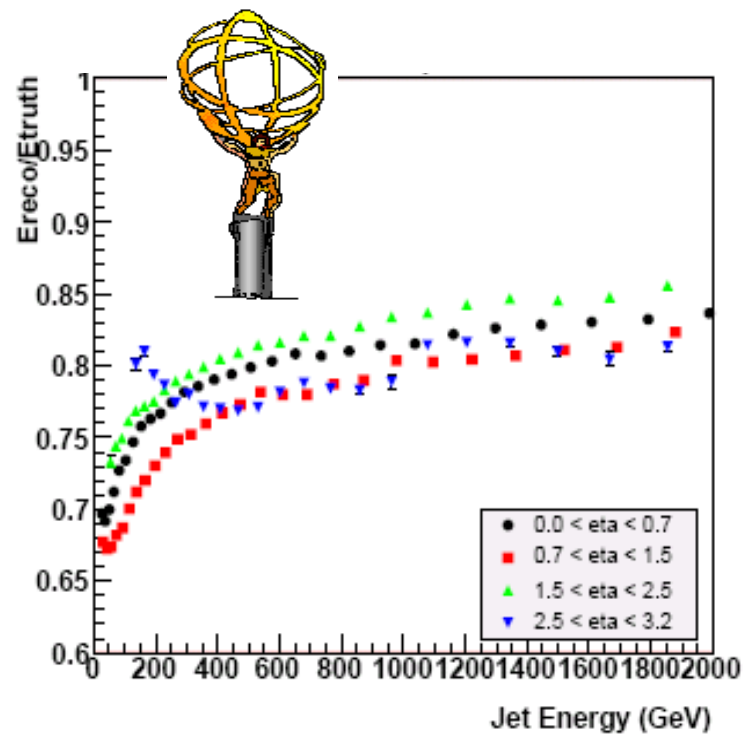
inclusive k_T: now available as "fast k_T" $N^3 \rightarrow N\ln N$

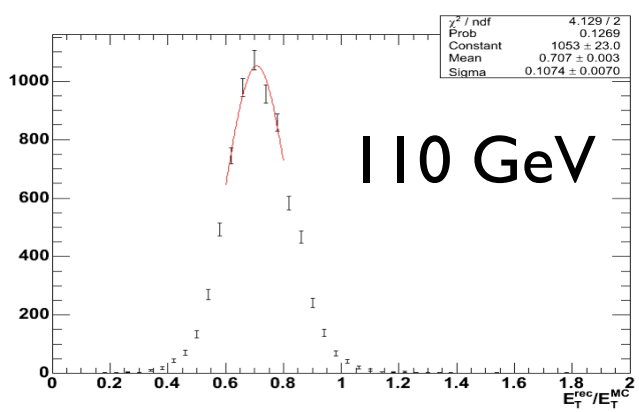
clustering algorithm, finds hits that have small momentum transverse to the reconstructed jet axis

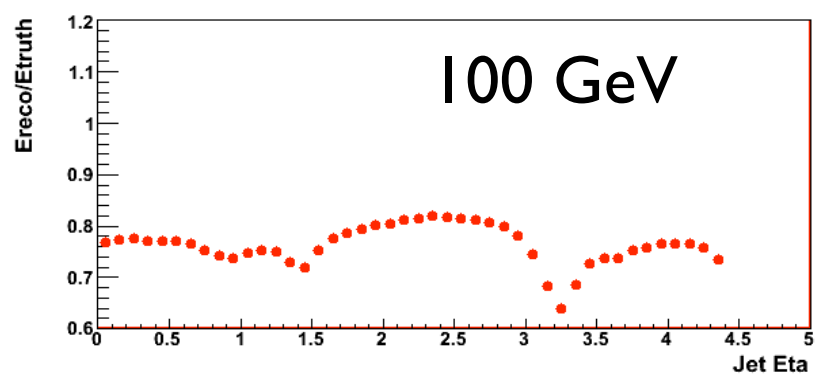
$$
\begin{aligned}
d_i &= (E_{\mathrm{T},i})^2 R^2, \\
d_{ij} &= \min\{E^2_{\mathrm{T},i}\,,\, E^2_{\mathrm{T},j}\} R^2_{ij} \quad \text{with} \quad R^2_{ij} = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2,
\end{aligned}
$$

Reconstructing the Jet Energy

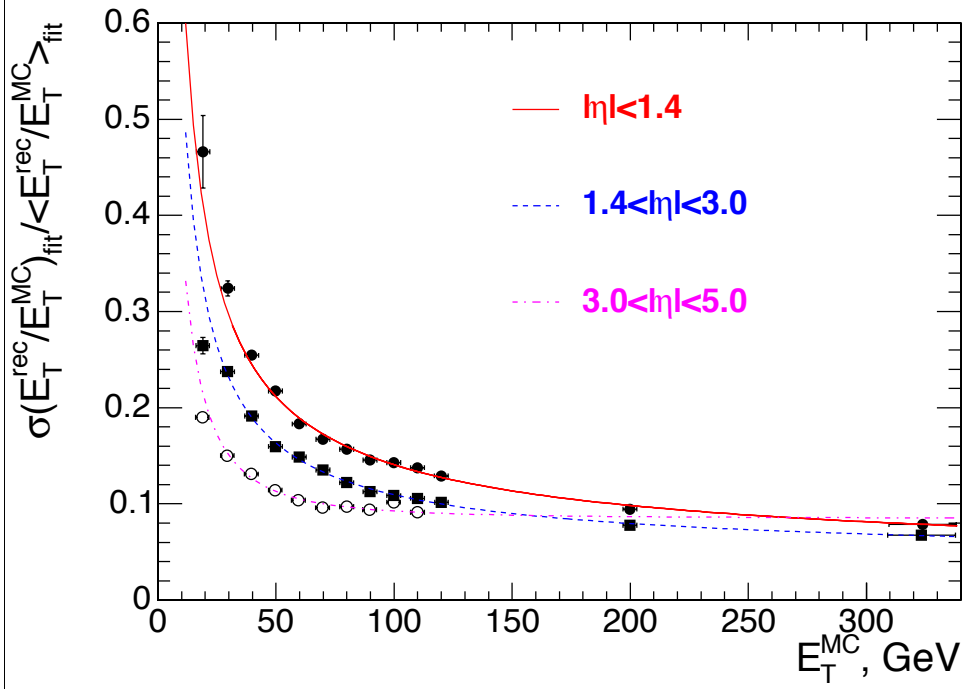


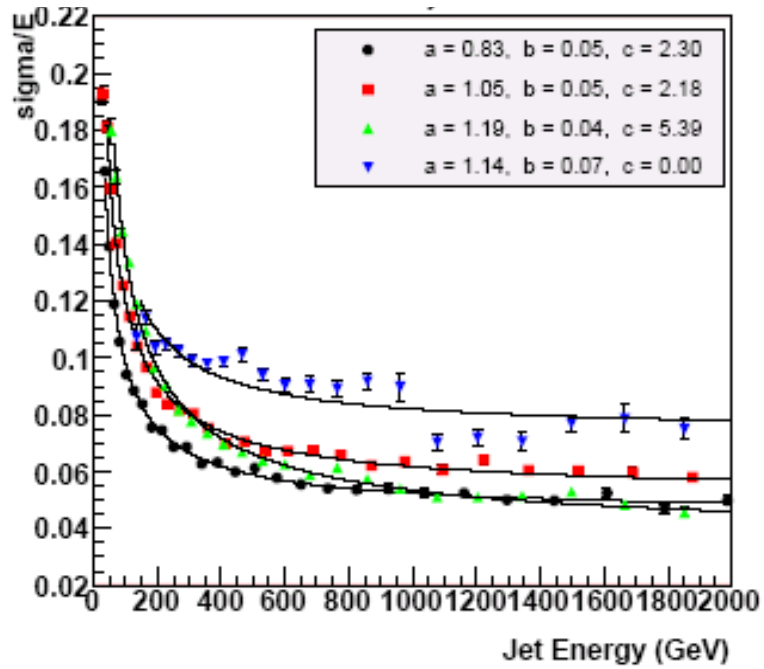






Jet Energy Resolution



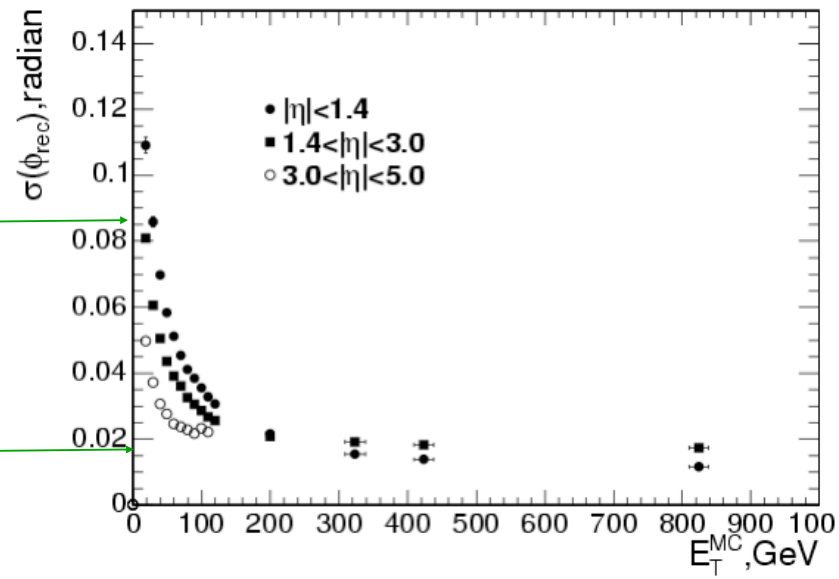


Can be improved with e/π response calibration.

Phi and Eta Resolution

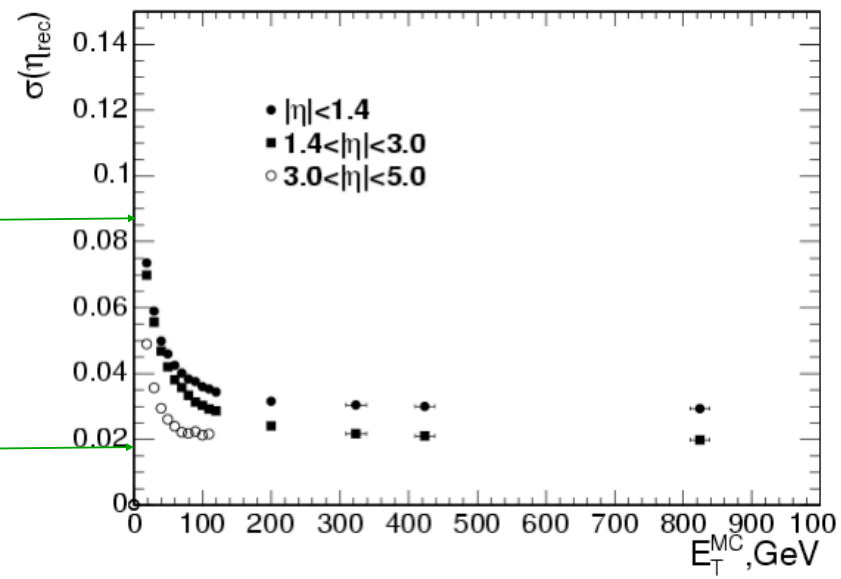
HCAL tile

crystal

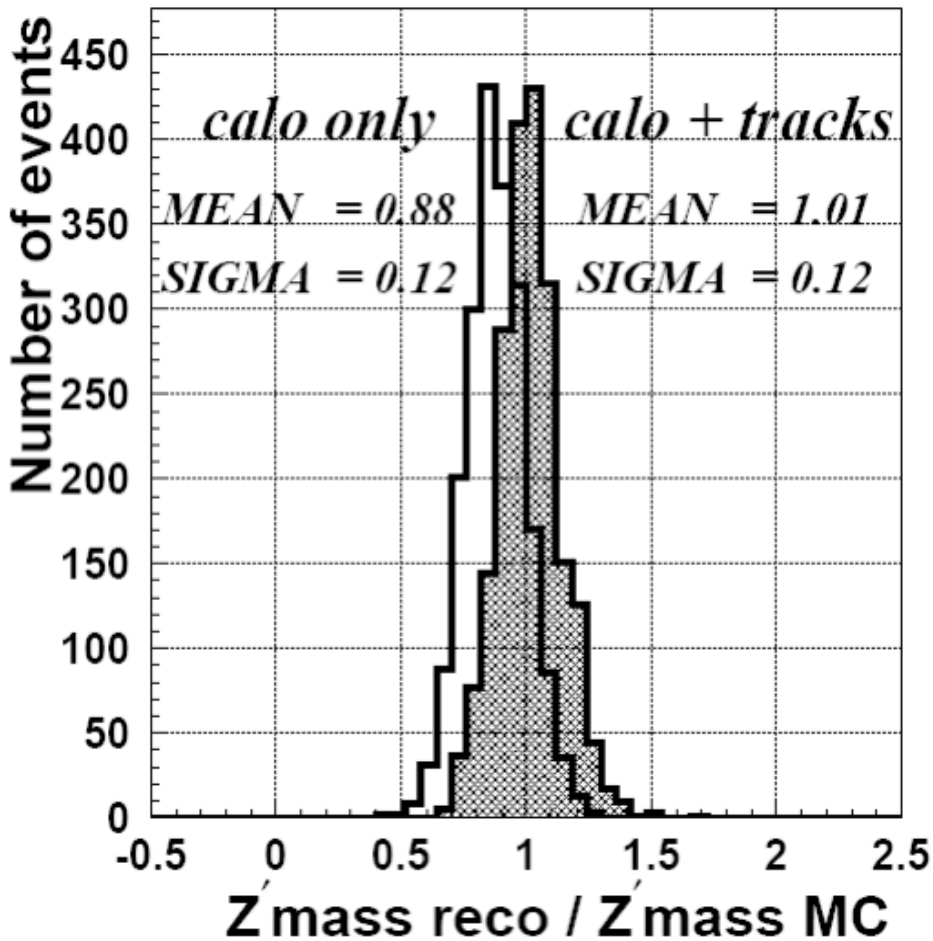


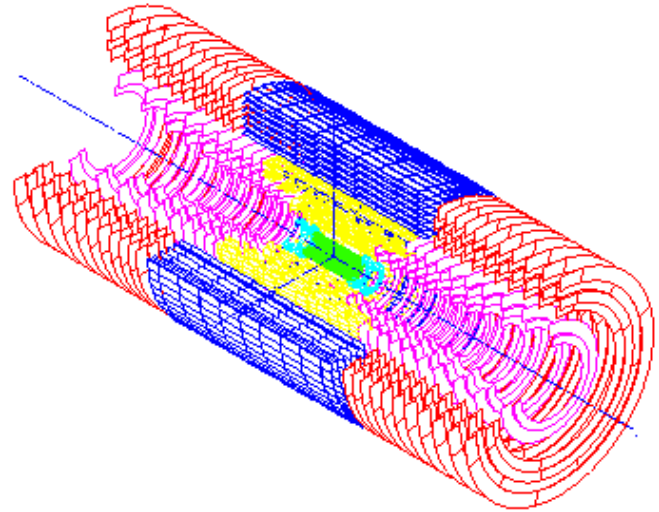
HCAL tile

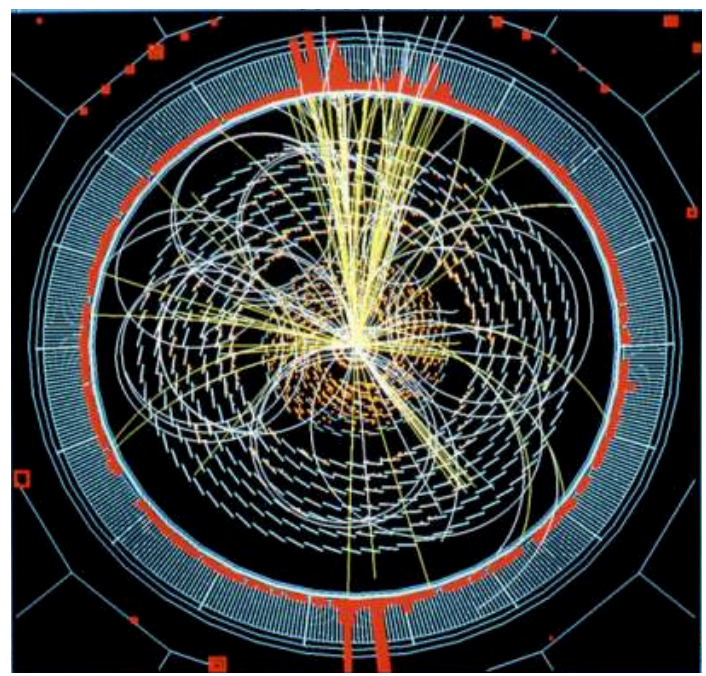
crystal



Use of Tracks to Improve Resolution







E_T^{miss} Performance

EXPERIMENTAL OBSERVATION OF ISOLATED LARGE TRANSVERSE ENERGY ELECTRONS WITH ASSOCIATED MISSING ENERGY AT $\sqrt{s}$ = 540 GeV

UA1 Collaboration, CERN, Geneva, Switzerland

Volume 122B, number 1 PHYSICS LETTERS 24 February 1983

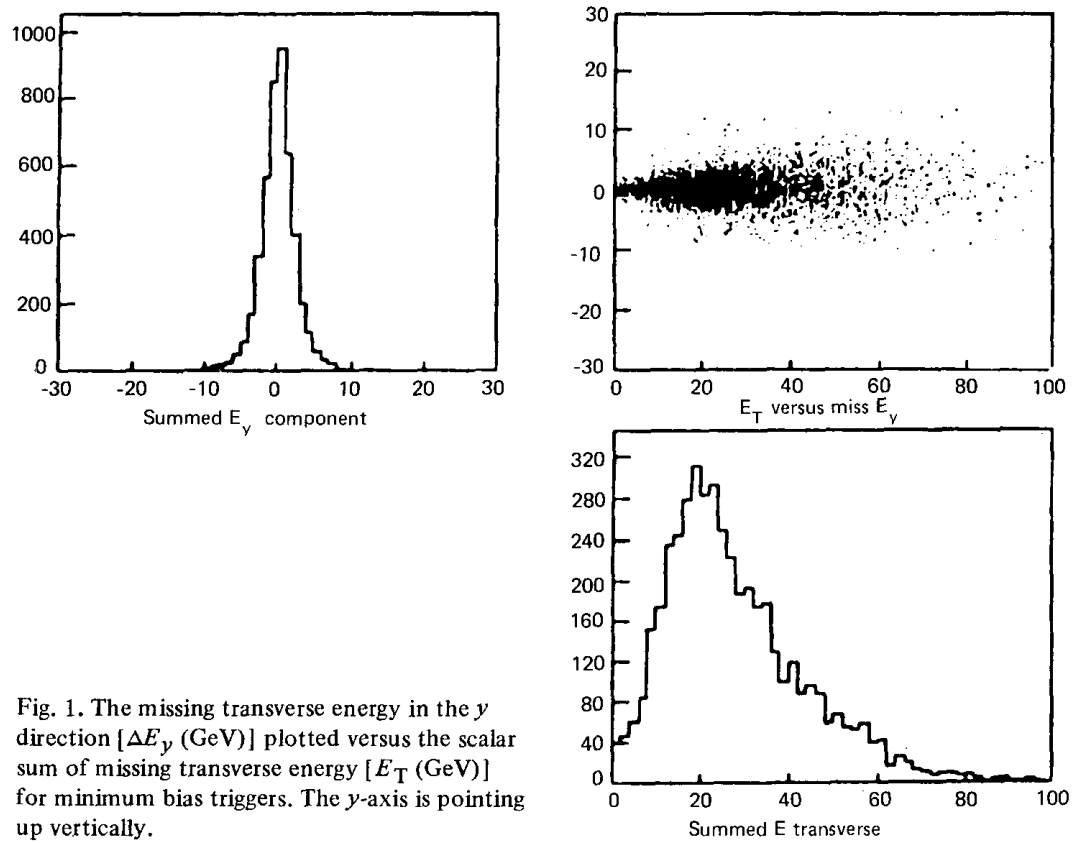
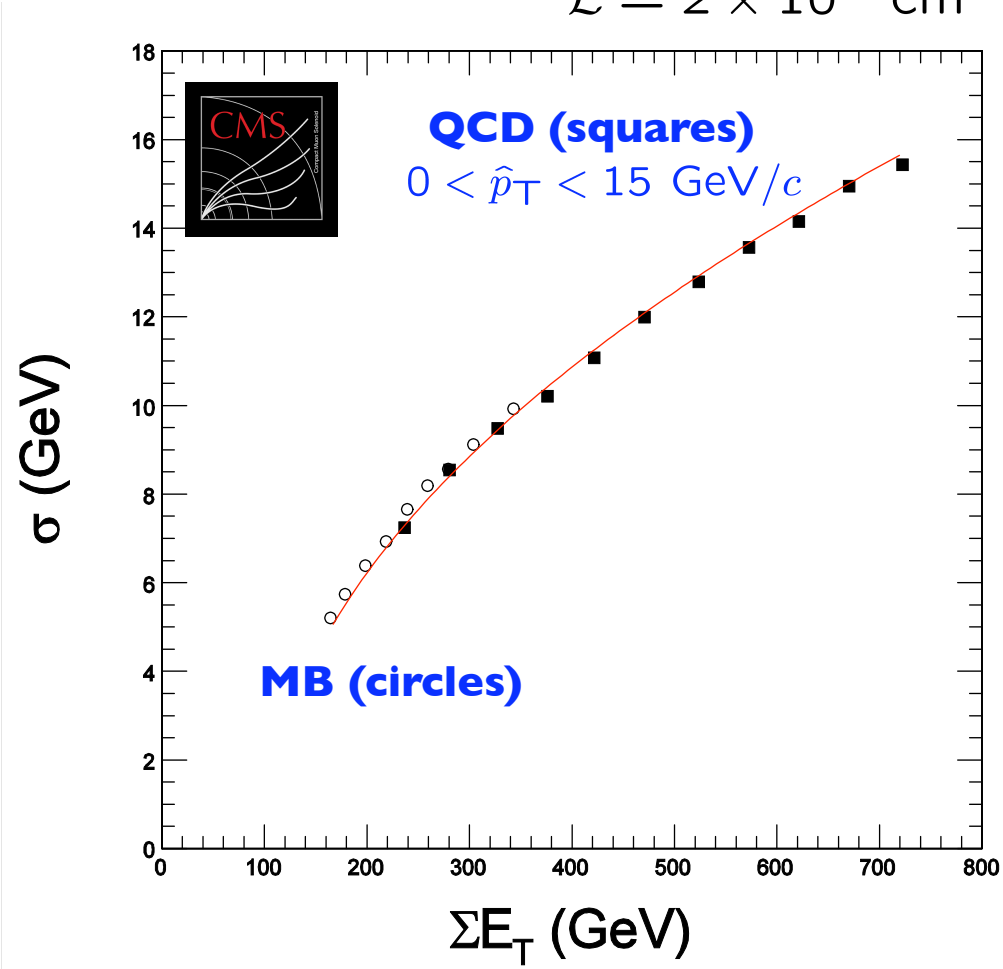


Fig. 1. The missing transverse energy in the y direction [ΔE_y (GeV)] plotted versus the scalar sum of missing transverse energy [E_T (GeV)] for minimum bias triggers. The y-axis is pointing up vertically.

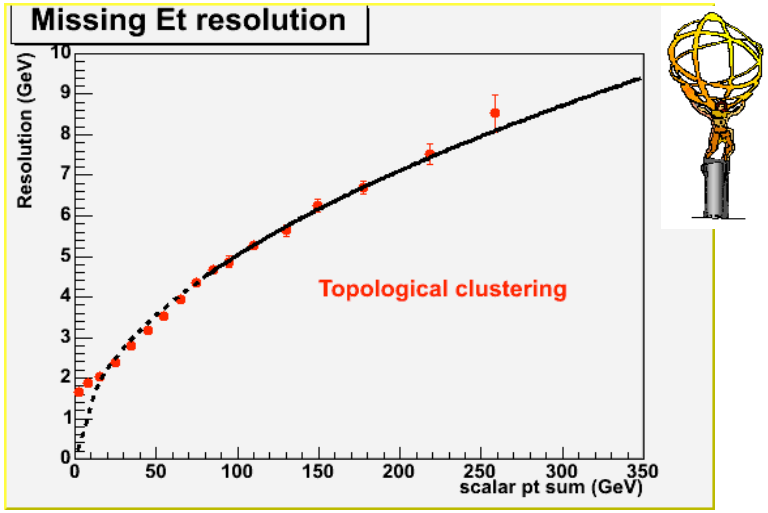
E_T^{miss} resolution with pileup

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



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

Soft QCD agrees with MB



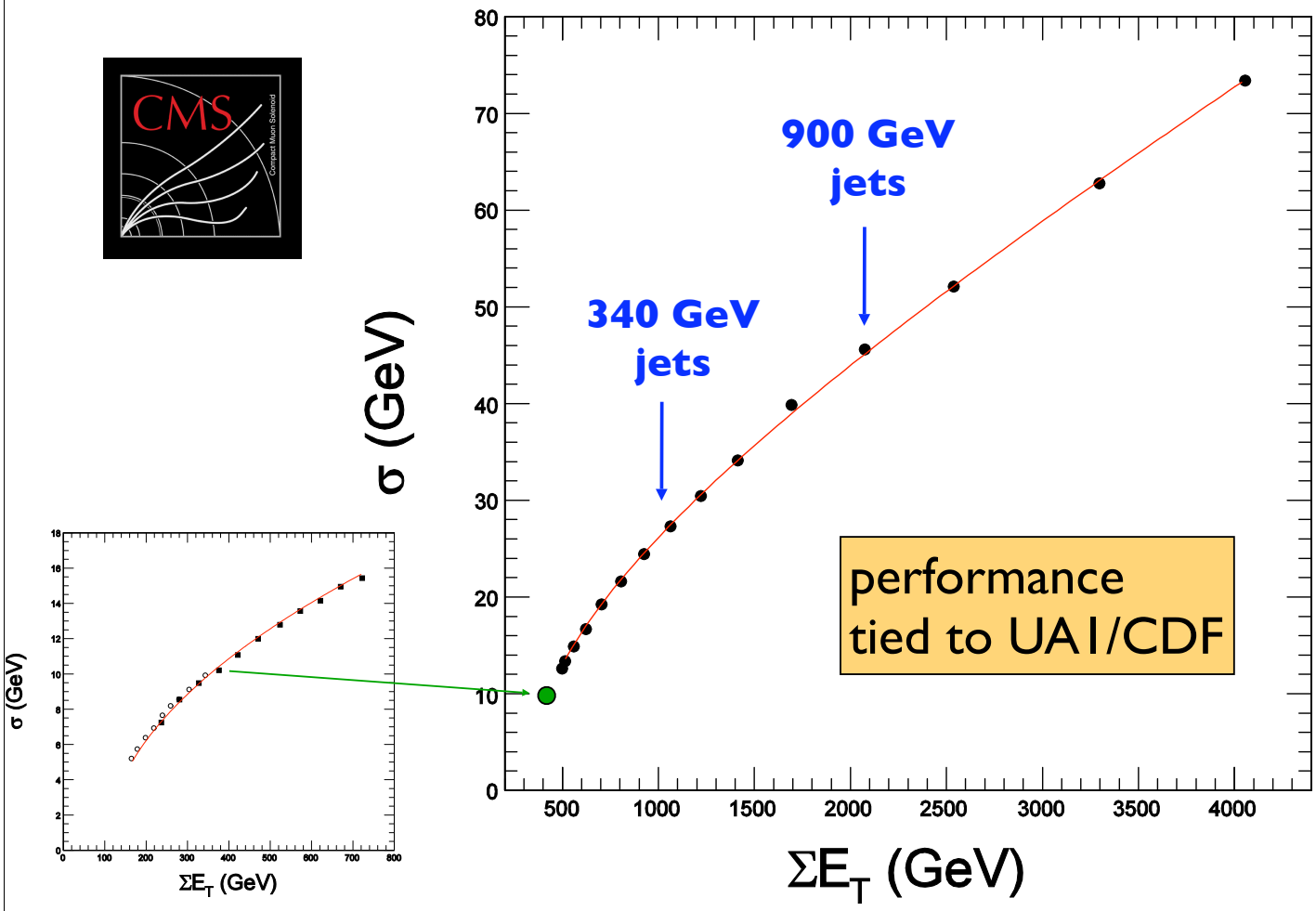
F. Gianotti, ICHEP Moscow (2006)

CMS 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

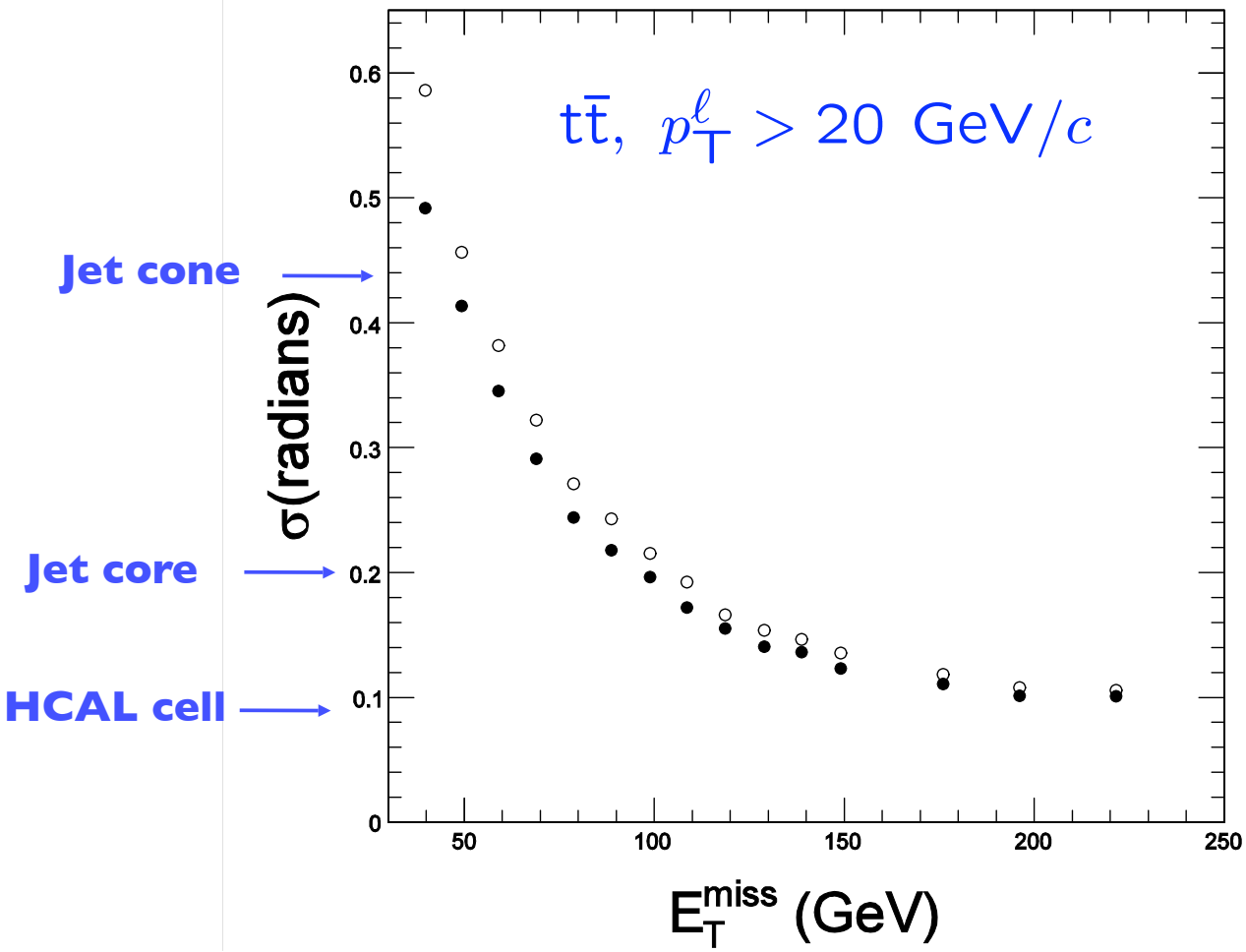
QCD, with pileup $\mathcal{L} = 2 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$



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

E_T^{miss} 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:

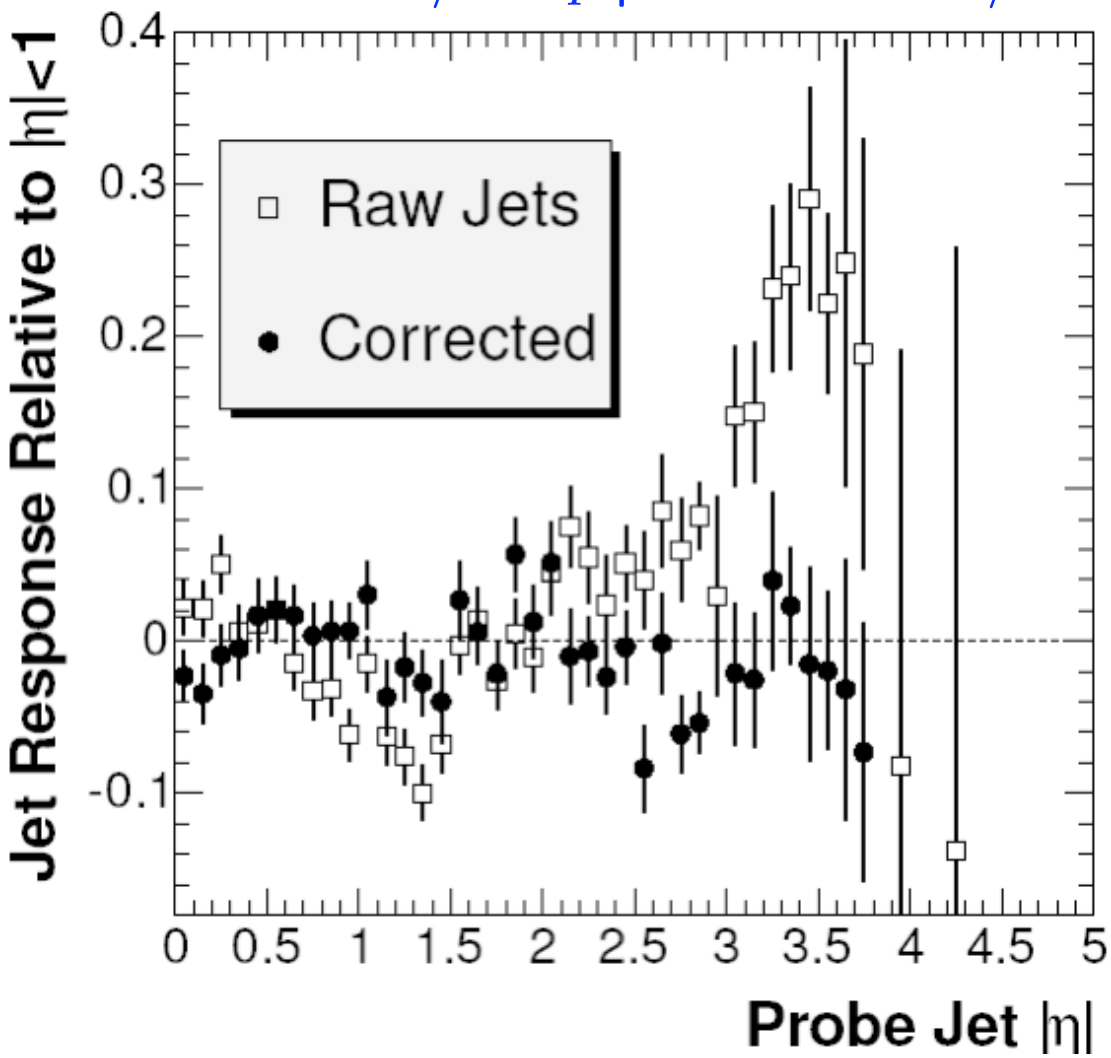
- Measure the effect of pile-up on clustering algorithms and thresholds.
- Use p_T balance in QCD dijet events to calibrate the jet energy scale vs. eta and verify the resolution.
- Use p_T balance in photon+jet events to calibrate the absolute energy scale.
- Use W mass fitting in tagged top events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

Dijet Balance

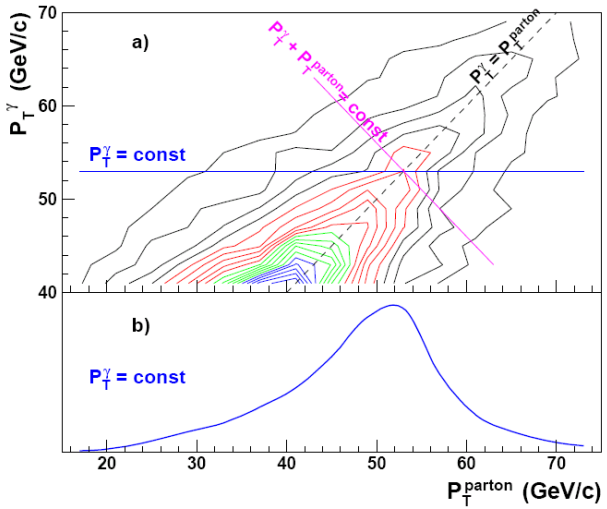
One hour of data

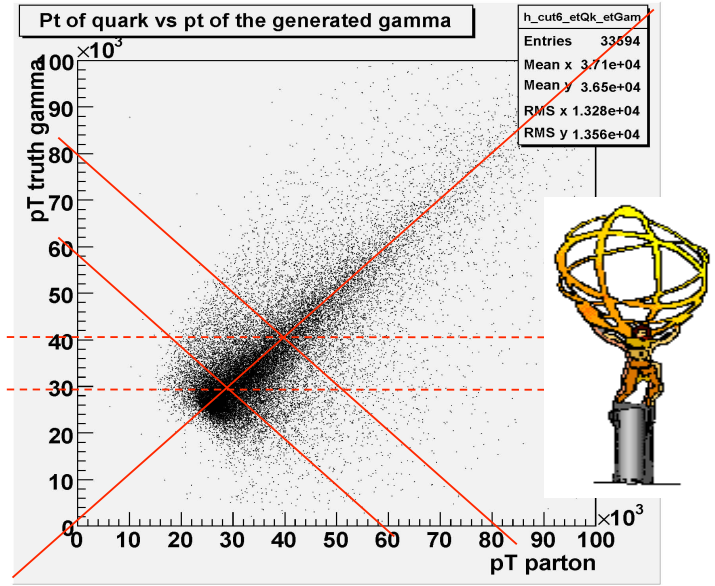
$\mathcal{L} = 2 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

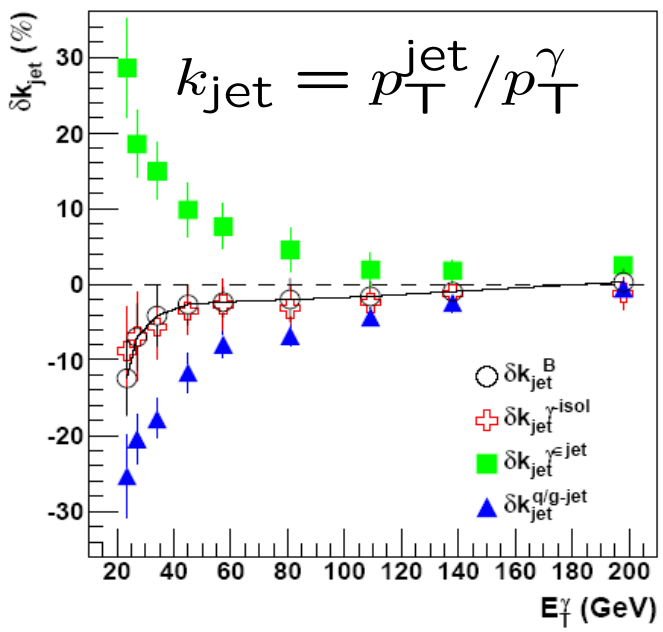
$120\ \mathrm{GeV}/c < p_{\mathrm{T}} < 250\ \mathrm{GeV}/c$

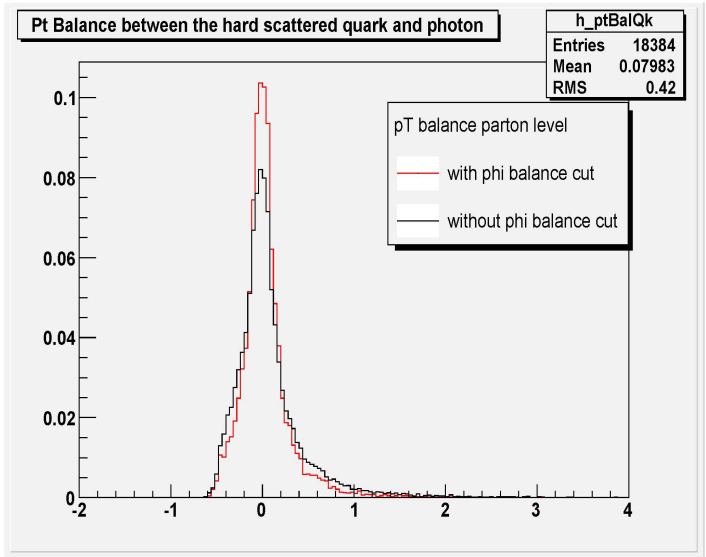


Calibration with Photon + Jet



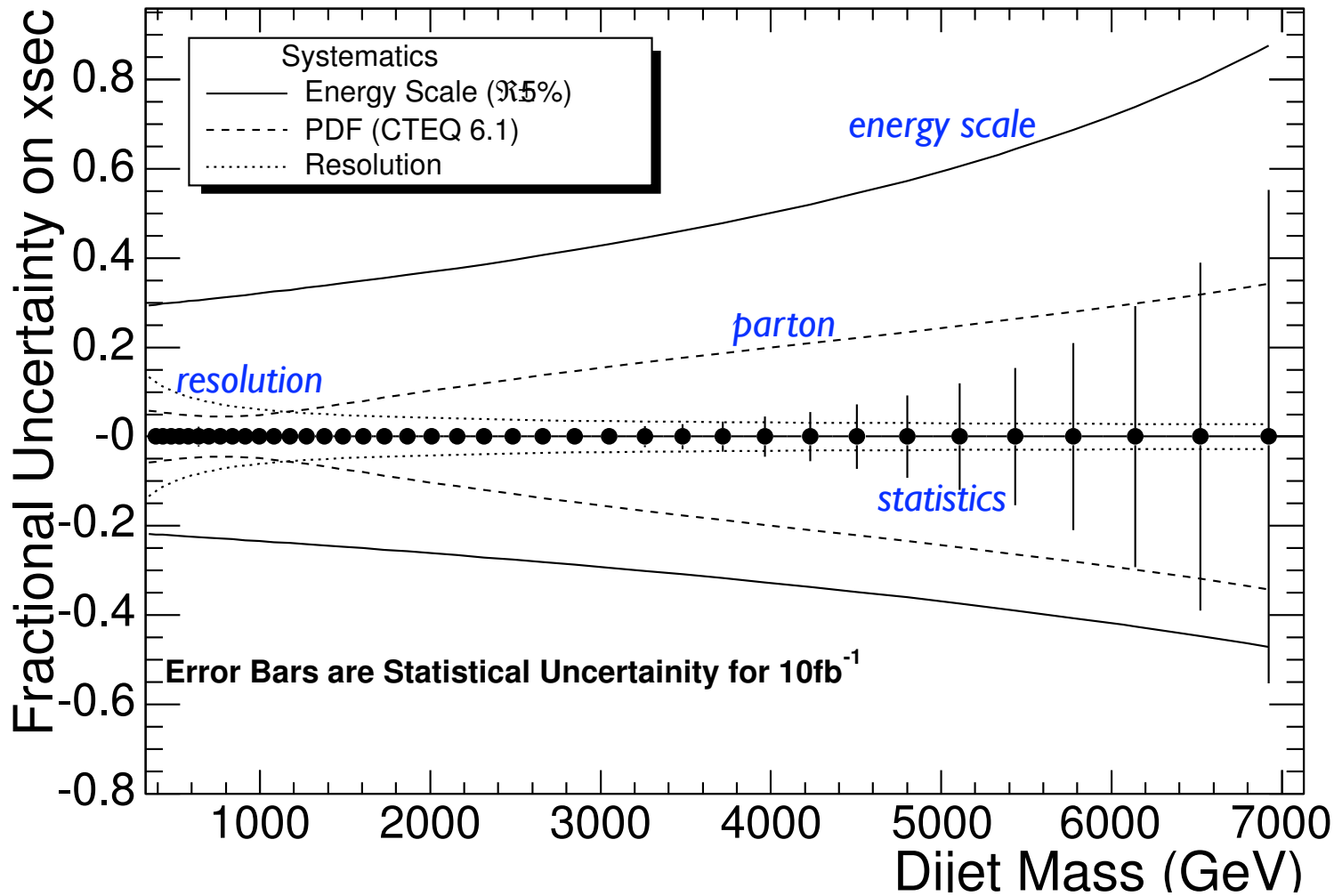




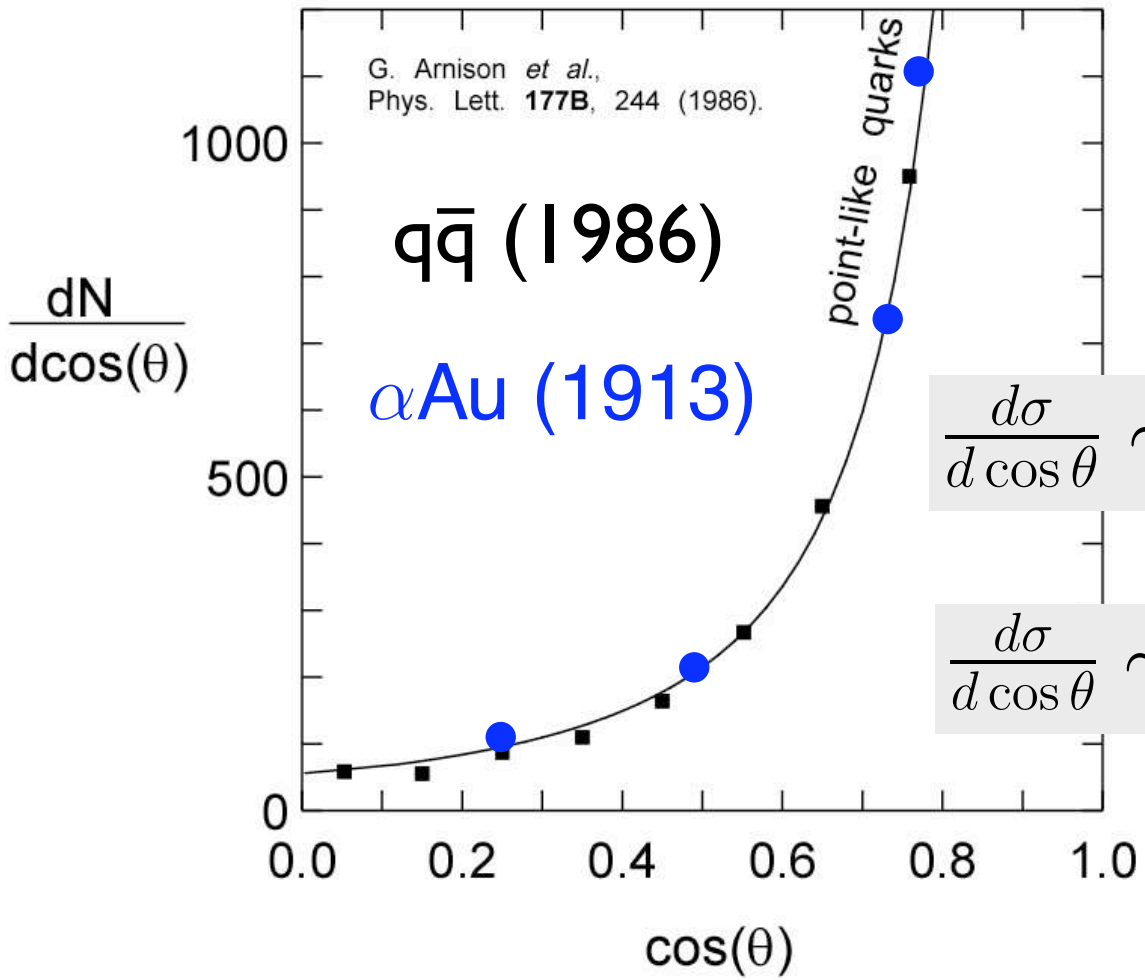


pT balance =
(pT jet – pT photon)/ pT photon
Fit peak region iterating a gaussian fit

Expected error on dijet cross section*



*Does not include luminosity error.



Electromagnetism

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

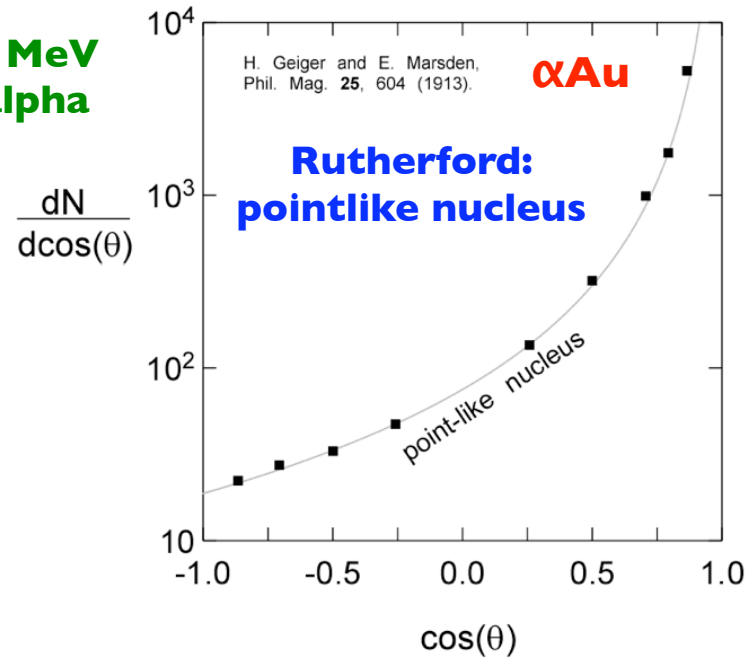
QCD

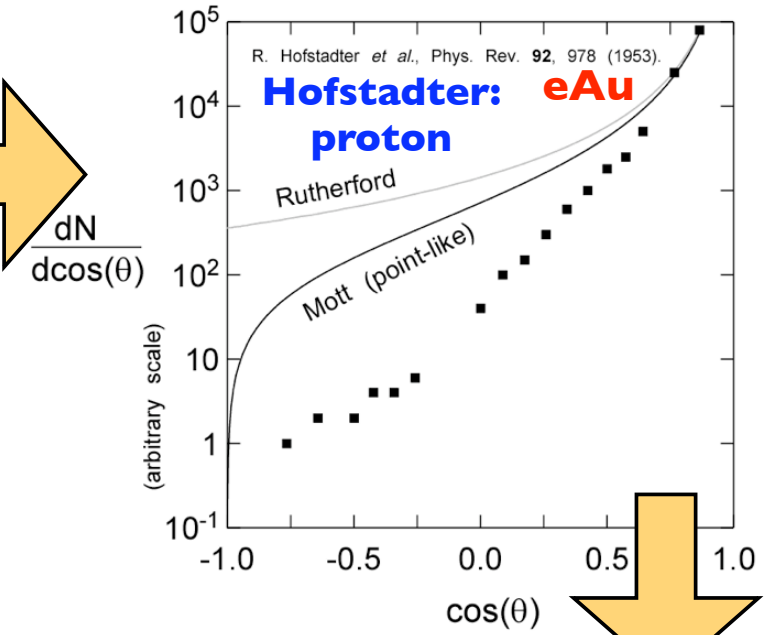
$$\frac{d\sigma}{d\cos\theta} \sim \alpha_s^2 \left(\frac{\hbar c}{E_{\rm CM}}\right)^2 \frac{1}{(1-\cos\theta)^2}$$

History of compositeness

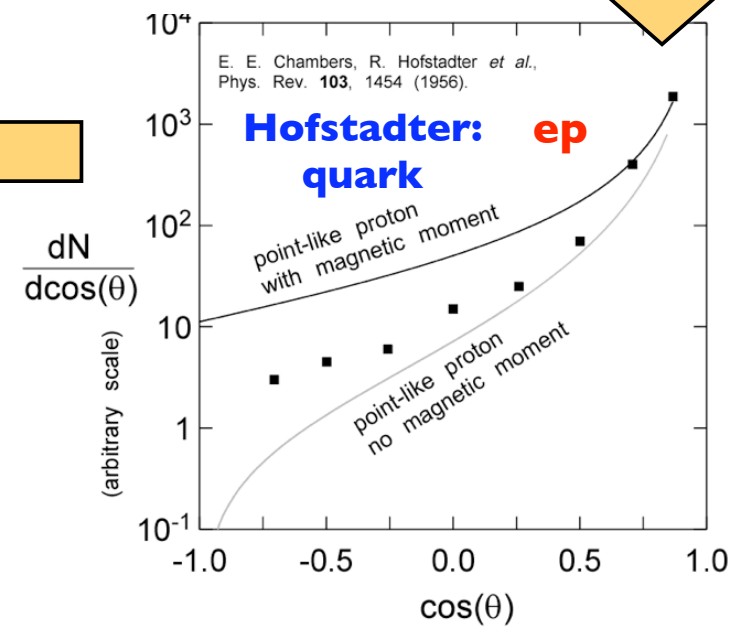
J. Rohlf: Modern Physics from α to Z^0

6 MeV alpha



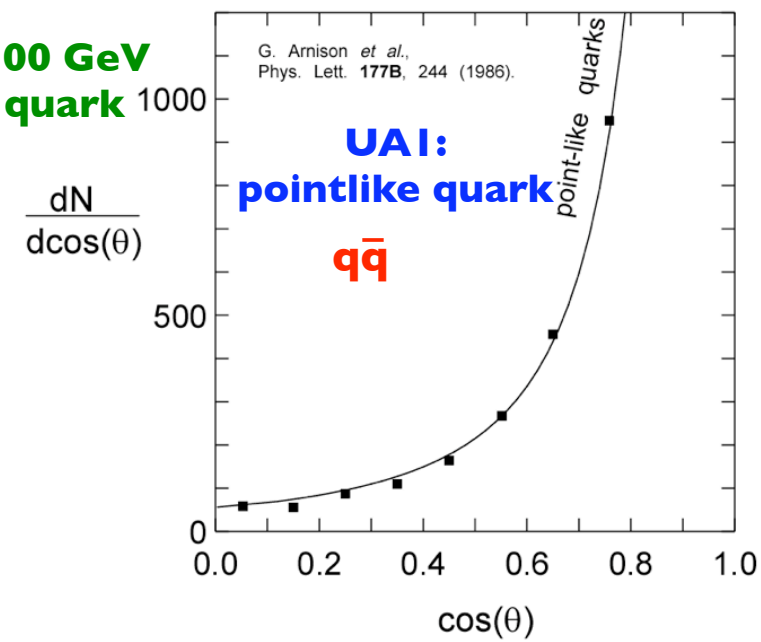


125 MeV electron



550 MeV electron

100 GeV quark

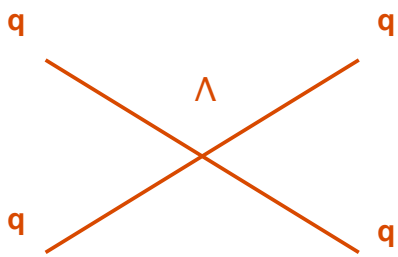


can be positive or negative

$$\frac{d\hat{\sigma}(q_i q_i \to q_i q_i)}{d\cos\theta^*} = \frac{\pi}{2\hat{s}}\left\{\frac{4}{9}\alpha_S^2\left[\frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2}+\frac{\hat{t}^2+\hat{s}^2}{\hat{u}^2}-\frac{2}{3}\frac{\hat{s}^2}{\hat{t}\hat{u}}\right]+\frac{8}{9}\alpha_S\frac{A}{\Lambda^2}\left[\frac{\hat{s}^2}{\hat{t}}+\frac{\hat{s}^2}{\hat{u}}\right]+\frac{8}{3}\frac{\hat{s}^2}{\Lambda^4}\right\}$$

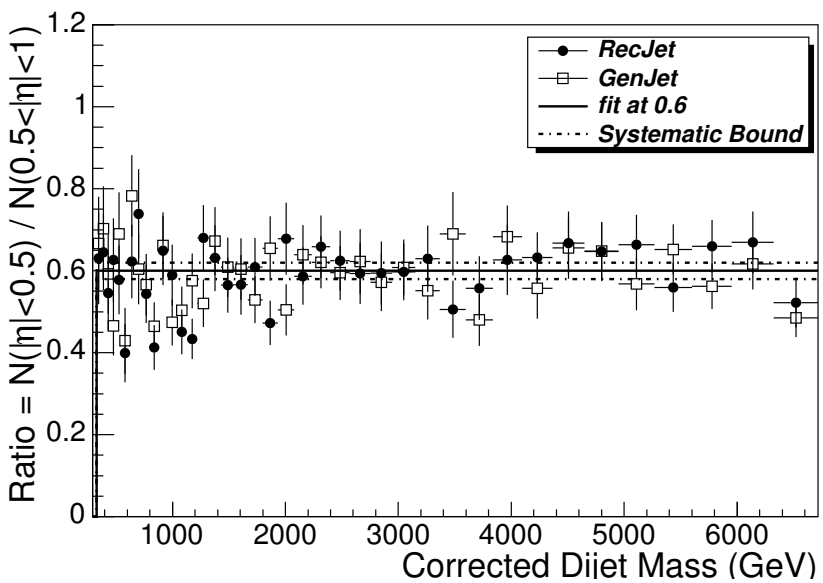
QCD

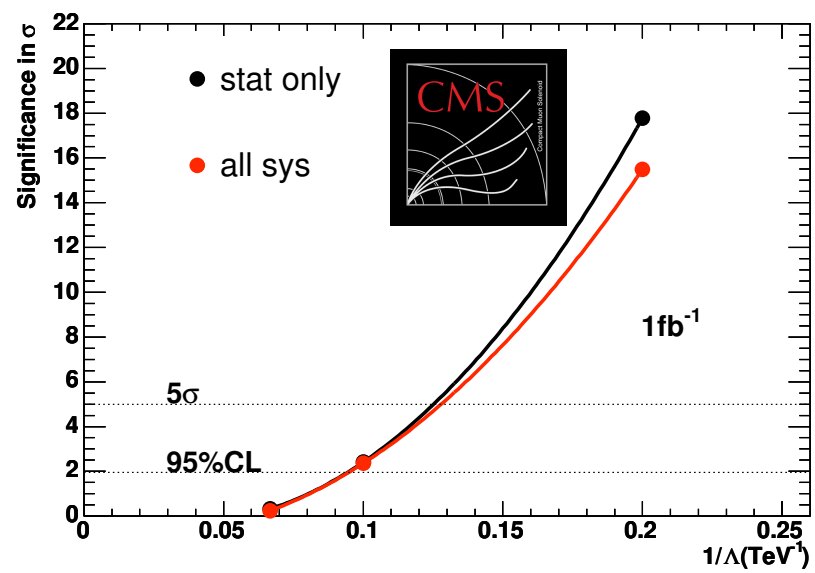
New Physics



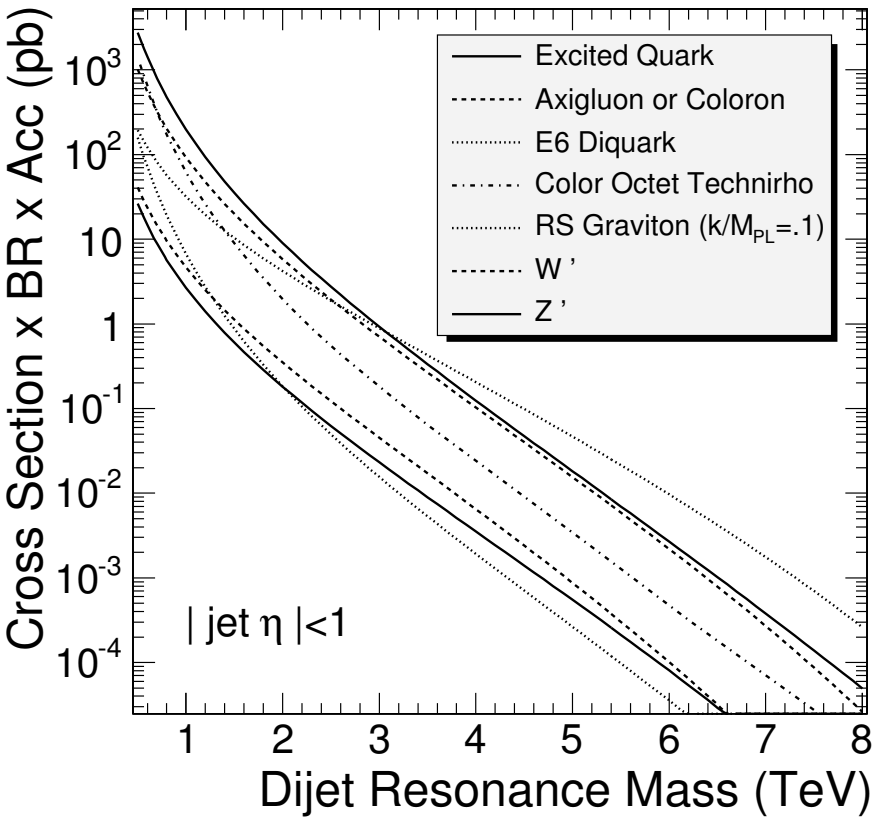
$$\hat{t} = \hat{s}(1-\cos\theta^*)/2 \qquad \hat{u} = \hat{s}(1+\cos\theta^*)/2$$

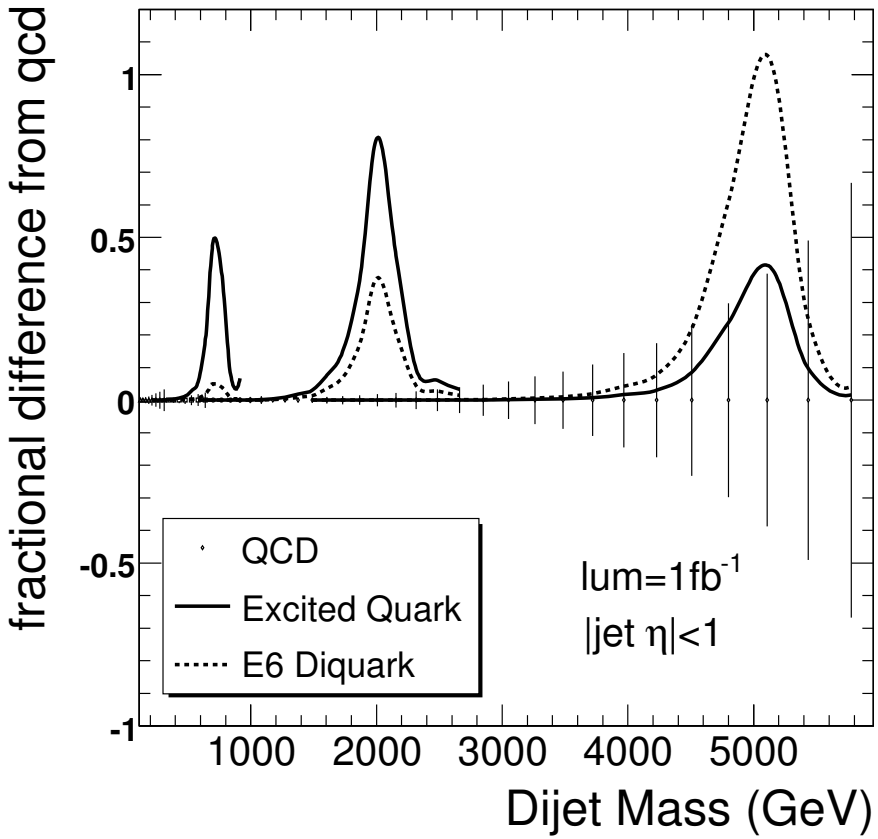
Easy way: look at ratio of dijet rate in two η regions





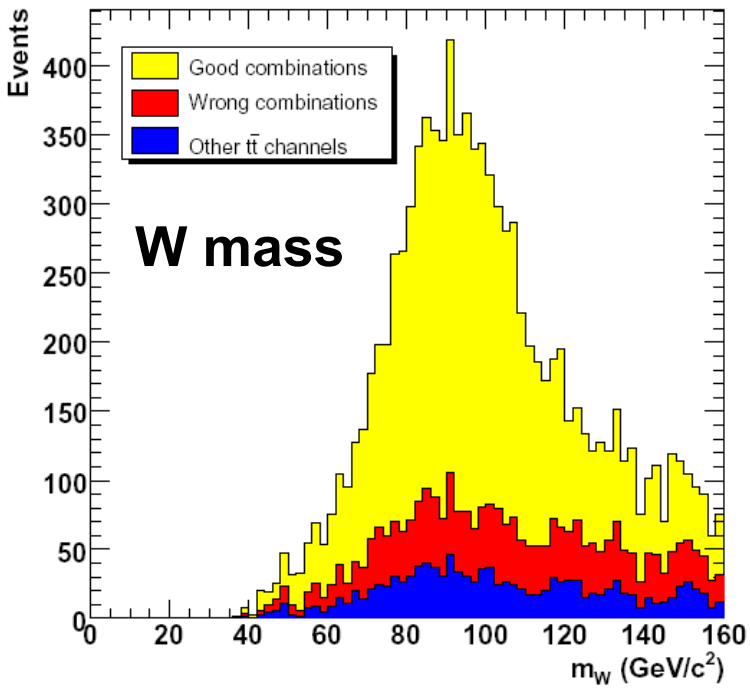
High mass di-jet final states





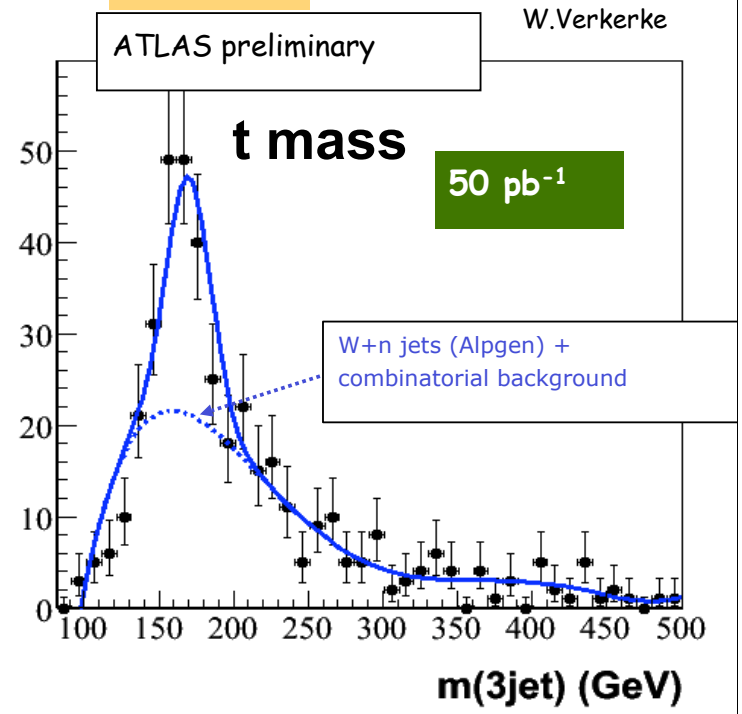
Calibration with Top

$$t\bar{t} \rightarrow W\bar{b} + Wb \rightarrow b\ell\nu + bjj$$



No b tag (250 pb with br)

W.Verkerke



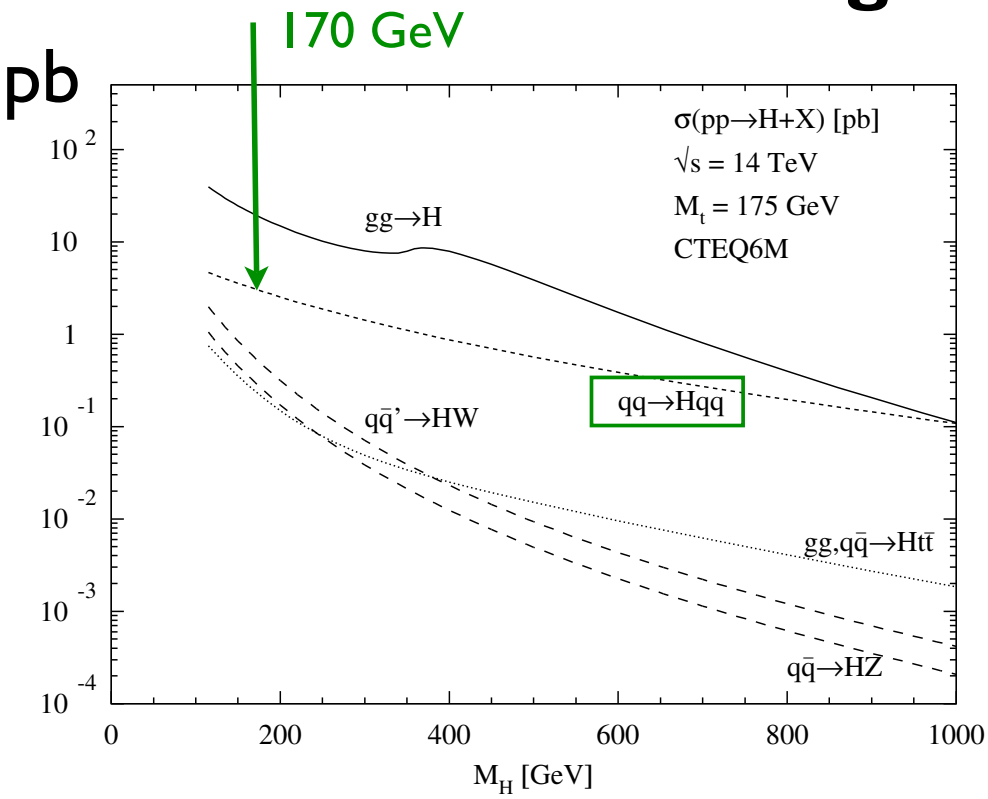
isolated lepton p_T > 20 GeV

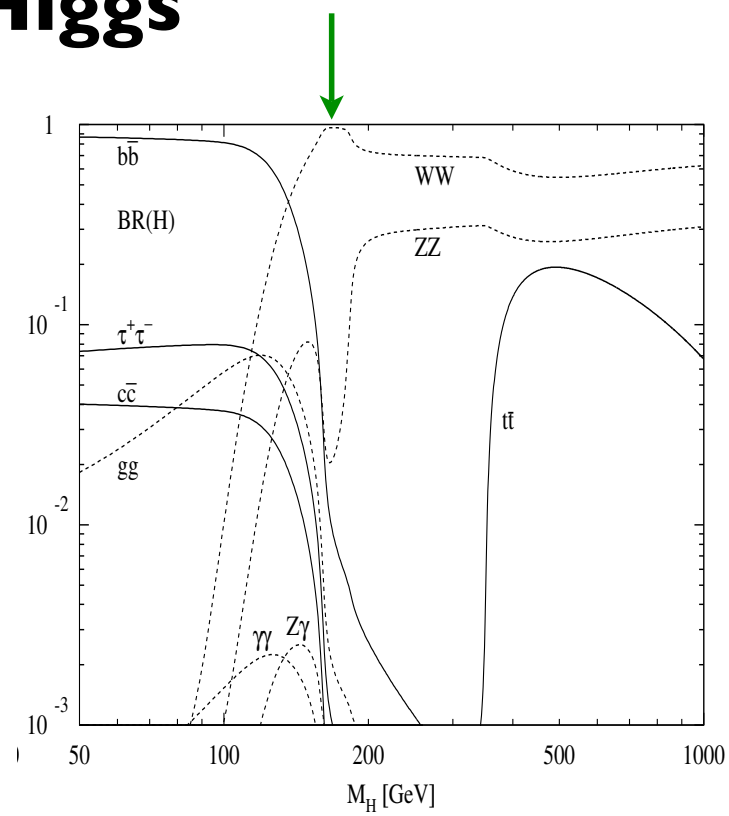
4 jets p_T > 40 GeV

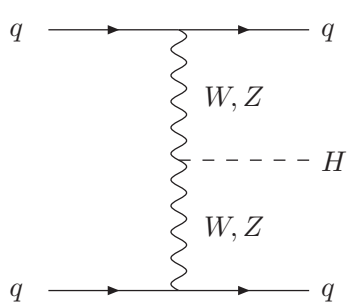
$m_{jj} = m_W$

E_T^{miss} > 20 GeV

Hunting the Higgs







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

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 ($\mathrm{H} \to \mathrm{WW}^{(*)}$)	$\sigma(\ell\nu\mathrm{jj})$ (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 %

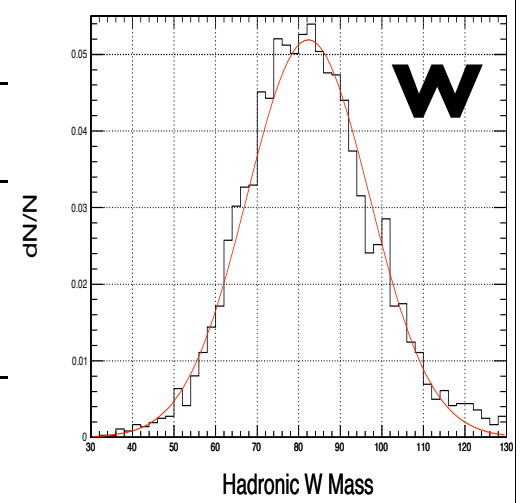
backgrounds

Channels	σ (pb)	Events in 60 fb^{-1}	Generated
$\mathrm{t\,\bar{t}}$ + jets	840	50.4 million	6.9 %
W + $\mathrm{t\,\bar{b}}$ ($\bar{\mathrm{t}}$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 %

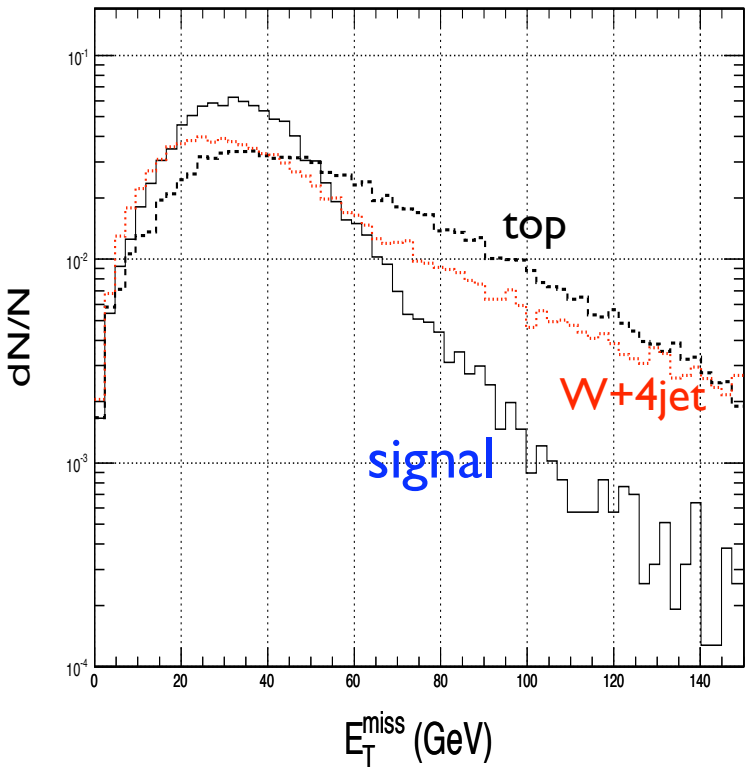
Selection Cuts (I)

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 $\lvert (E_T^{0.2} - E_T^{e})/E_T^{e}\rvert < 0.3$ $E_T^{0.2-0.4}/E_T^{e}\rvert < 0.3$ Muon : $\lvert E_T^{0.2} - p_T^{\mu}\rvert < 9.0$ GeV $\lvert (E_T^{0.2} - p_T^{e})/p_T^{\mu}\rvert < 0.3$ $E_T^{0.4}/E_T^{\mu}\rvert < 0.3$ $30 < p_T < 120$ 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 $\eta_1 \cdot \eta_2 < 0$ $\lvert \eta_1 - \eta_2 \rvert > 3.8$ $m_{qq} > 800\ \mathrm{GeV}/c^2$
Hadronic W reco (H-W)	$\Delta w_M < 25\ \mathrm{GeV}/c^2$ ($m_H \geq 160\ \mathrm{GeV}/c^2$) $30 < m_{jj} < 90\ \mathrm{GeV}/c^2$ ($m_H < 160\ \mathrm{GeV}/c^2$) 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

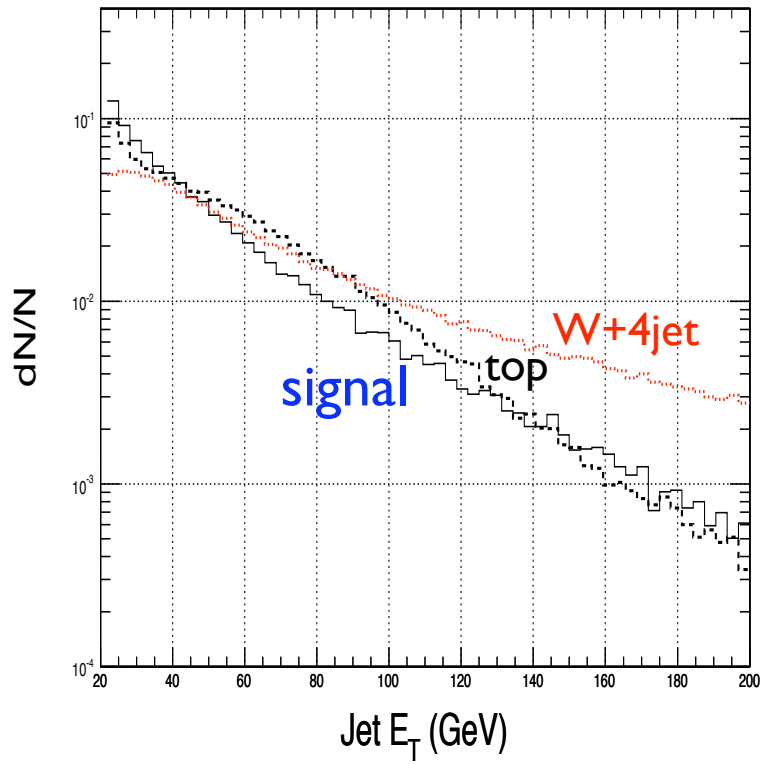
σ = 15 GeV



MET and Jet Distributions



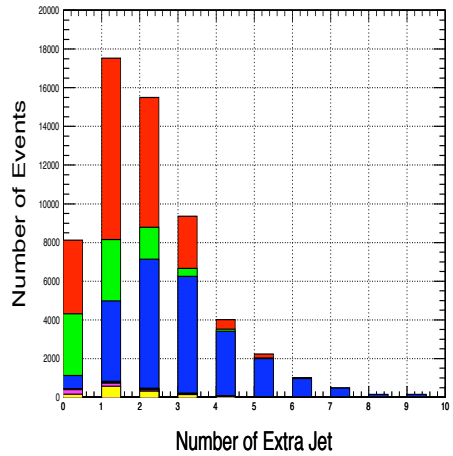
(a)

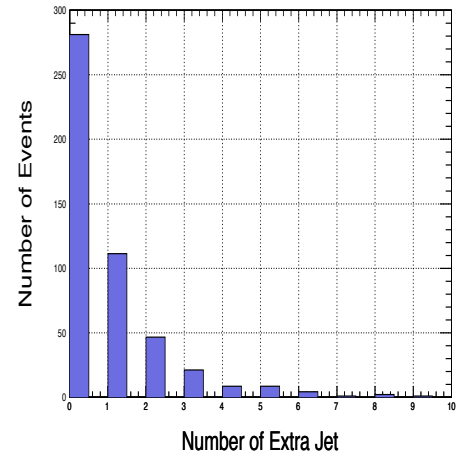


(b)

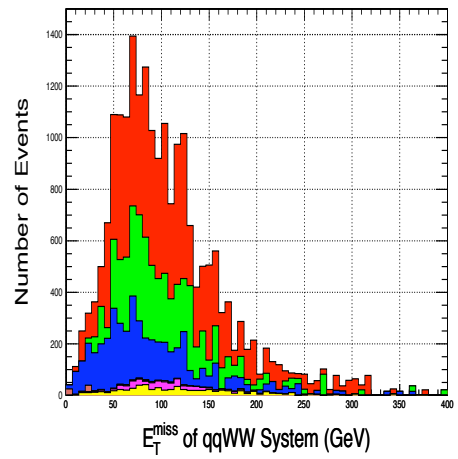
Additional Cuts

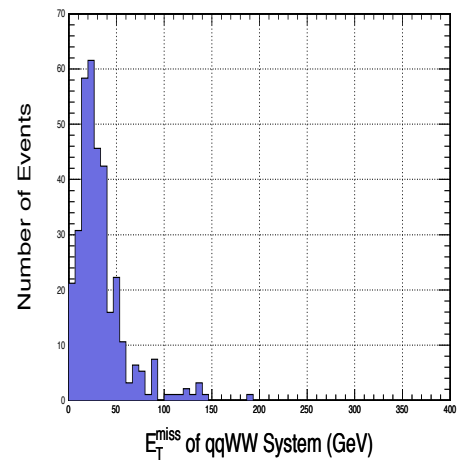
extra jets



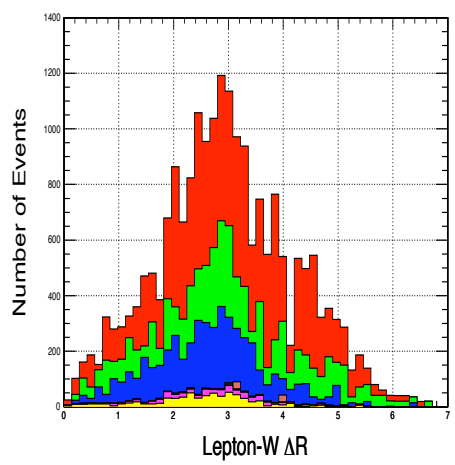


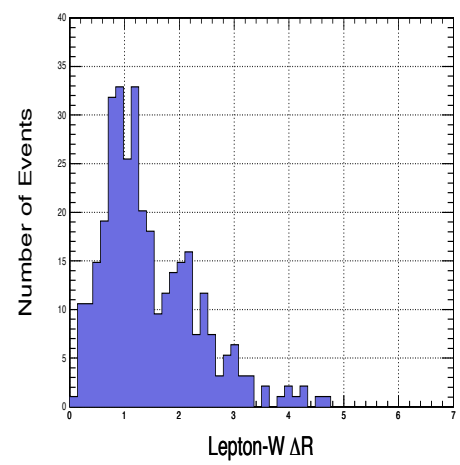
qqH E_T Balance

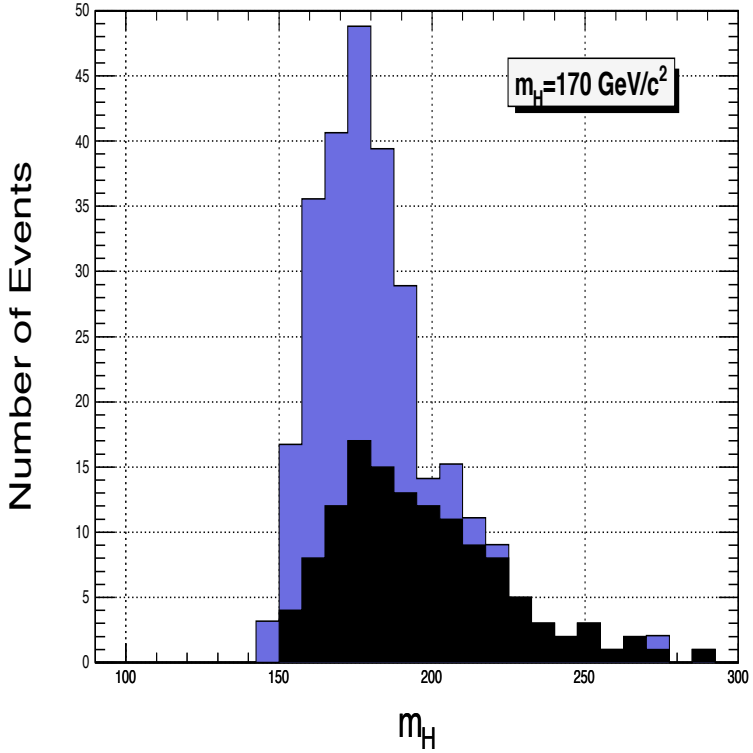


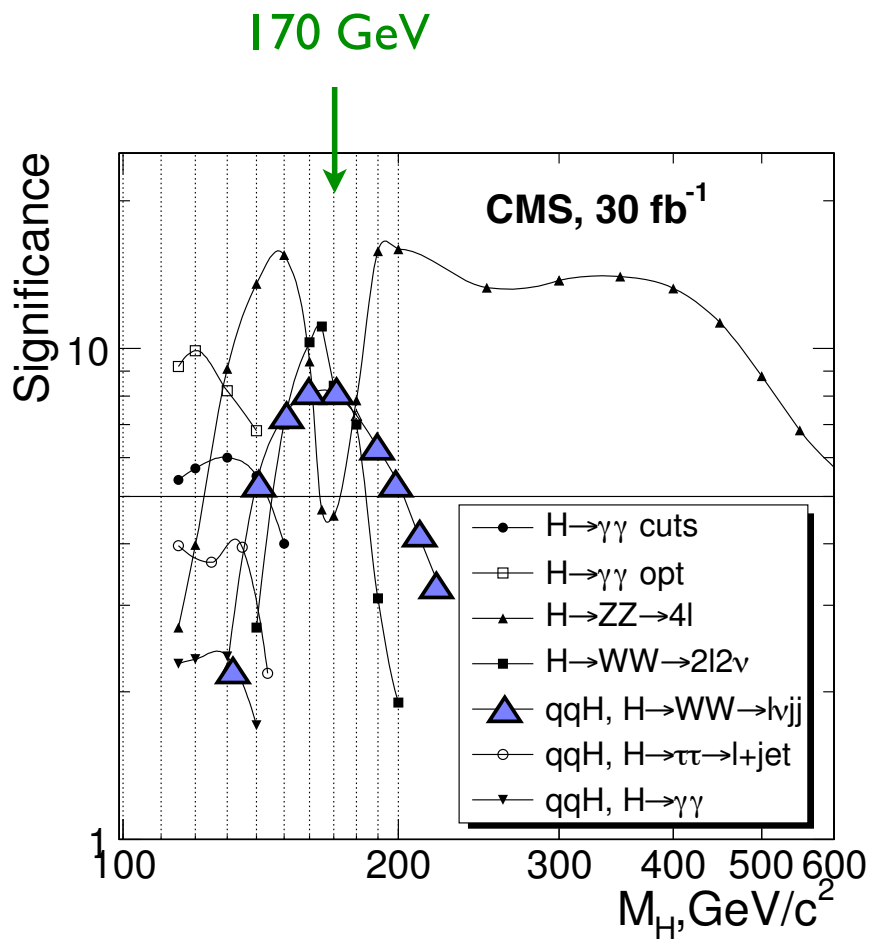


WW Separation

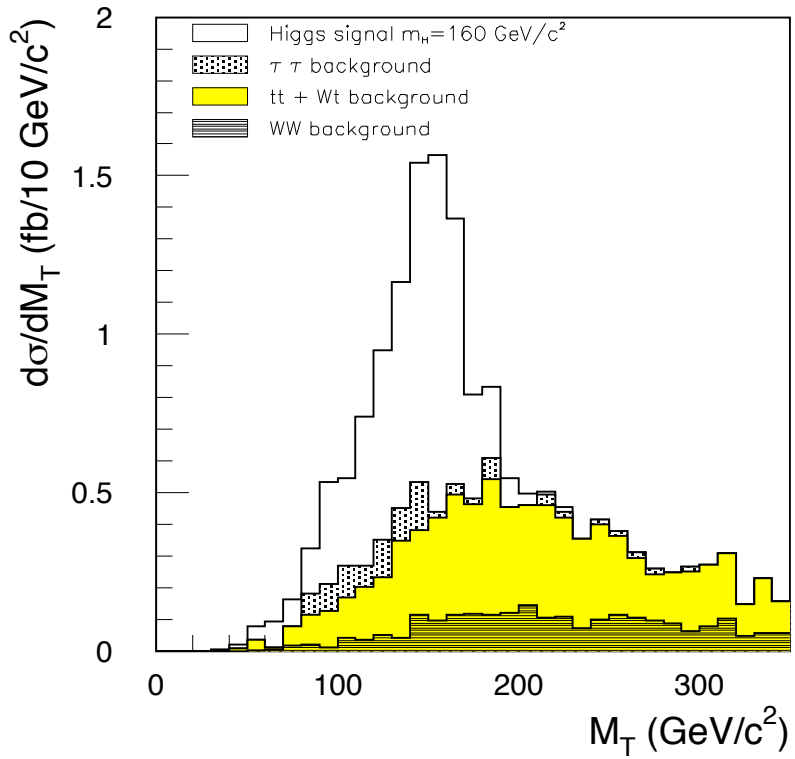


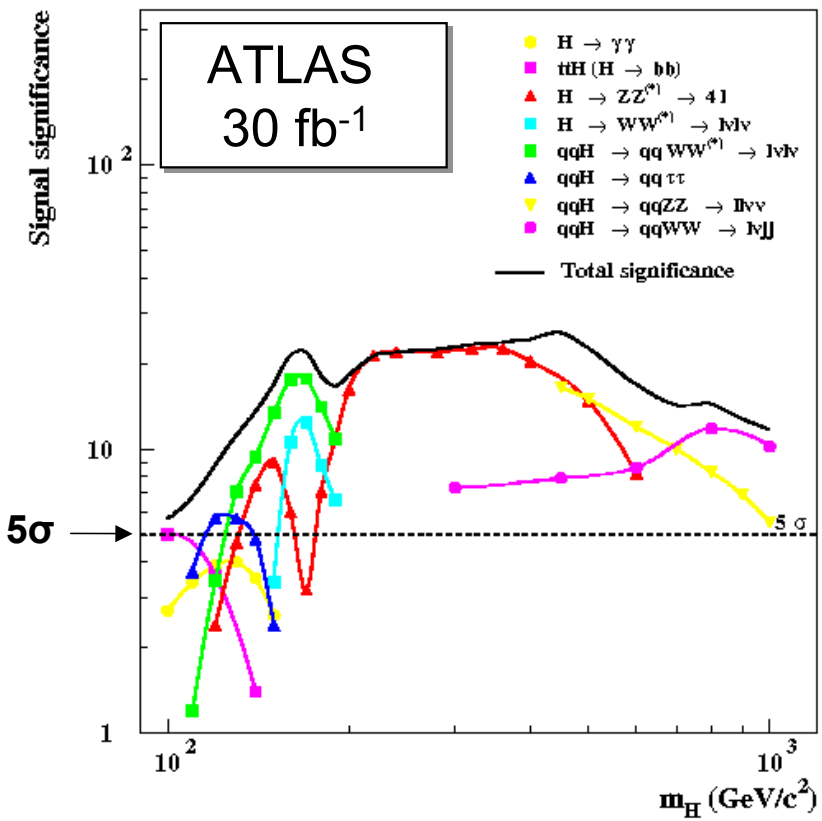



m_H=170 GeV/c^2
Number of Events
m_H


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

qqH, H → WW* → eνμν


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


ATLAS
30 fb^{-1}
H → γγ
ttH (H → bb)
H → ZZ$^{(*)}$ → 4l
H → WW$^{(*)}$ → lνlν
qqH → qq WW$^{(*)}$ → lνlν
qqH → qq ττ
qqH → qqZZ → llνν
qqH → qqWW → lνjj
Total significance
Signal significance
5σ
5 σ
10^2
10
1
10^2
10^3
m_H (GeV/c^2)

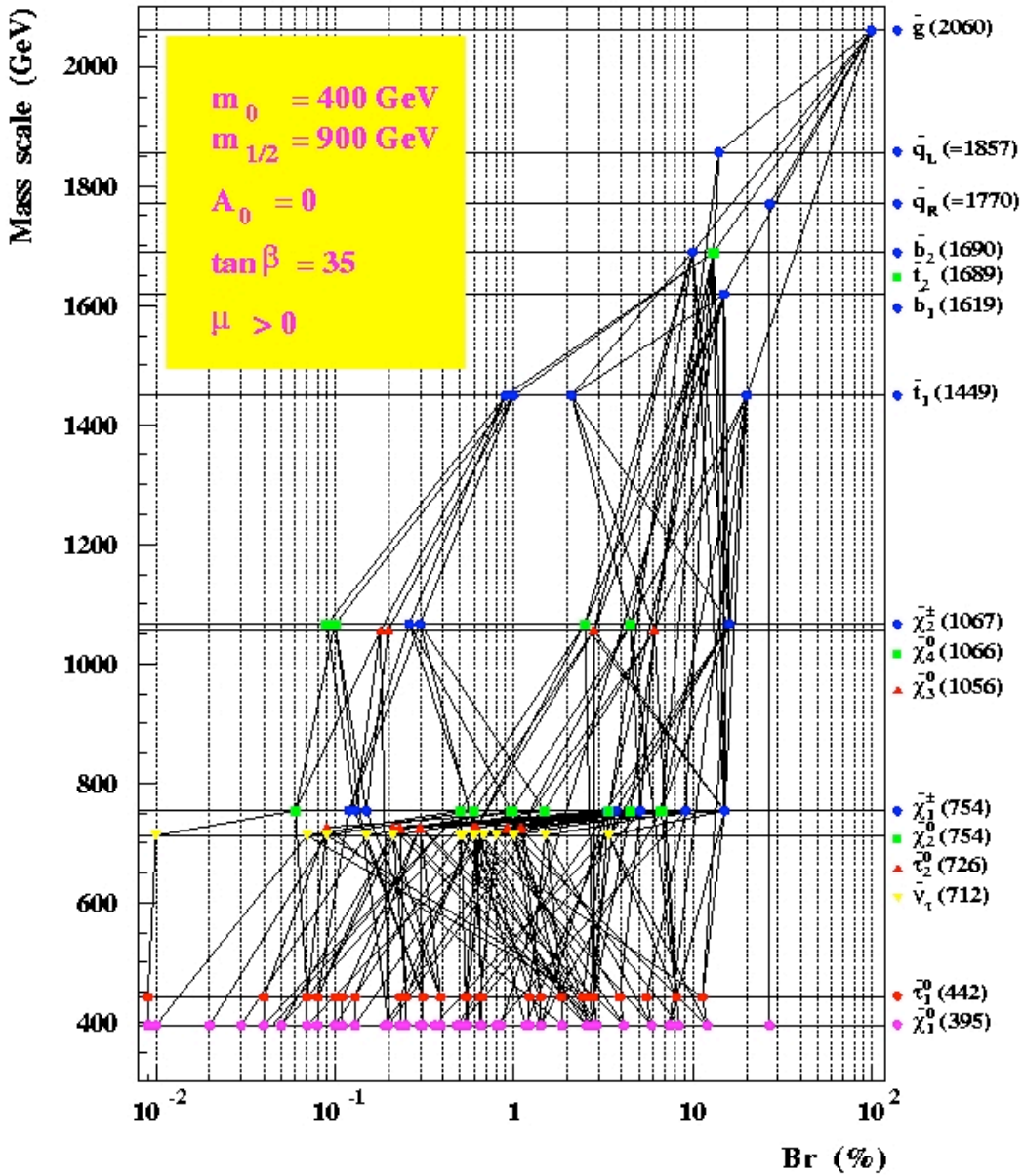
Summary of Higgs signals

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

$$\tilde{\chi}_1^\pm \rightarrow \tilde{l}\nu,$$
$$\tilde{\chi}_1^\pm \rightarrow \tilde{\nu}l,$$
$$\tilde{\chi}_1^\pm \rightarrow W^\pm\tilde{\chi}_1^0,$$
$$\tilde{\chi}_1^\pm \rightarrow H^\pm\tilde{\chi}_1^0,$$
$$\tilde{\chi}_1^\pm \rightarrow l^\pm\nu\tilde{\chi}_1^0,$$

$$\tilde{\chi}_2^0 \rightarrow \tilde{l}l,$$
$$\tilde{\chi}_2^0 \rightarrow \tilde{\nu}\nu,$$
$$\tilde{\chi}_2^0 \rightarrow h^0\tilde{\chi}_1^0,$$
$$\tilde{\chi}_2^0 \rightarrow Z^0\tilde{\chi}_1^0,$$
$$\tilde{\chi}_2^0 \rightarrow l^+l^-\tilde{\chi}_1^0$$

stable

⇨ **produces E_T^{miss}**
(and jets)

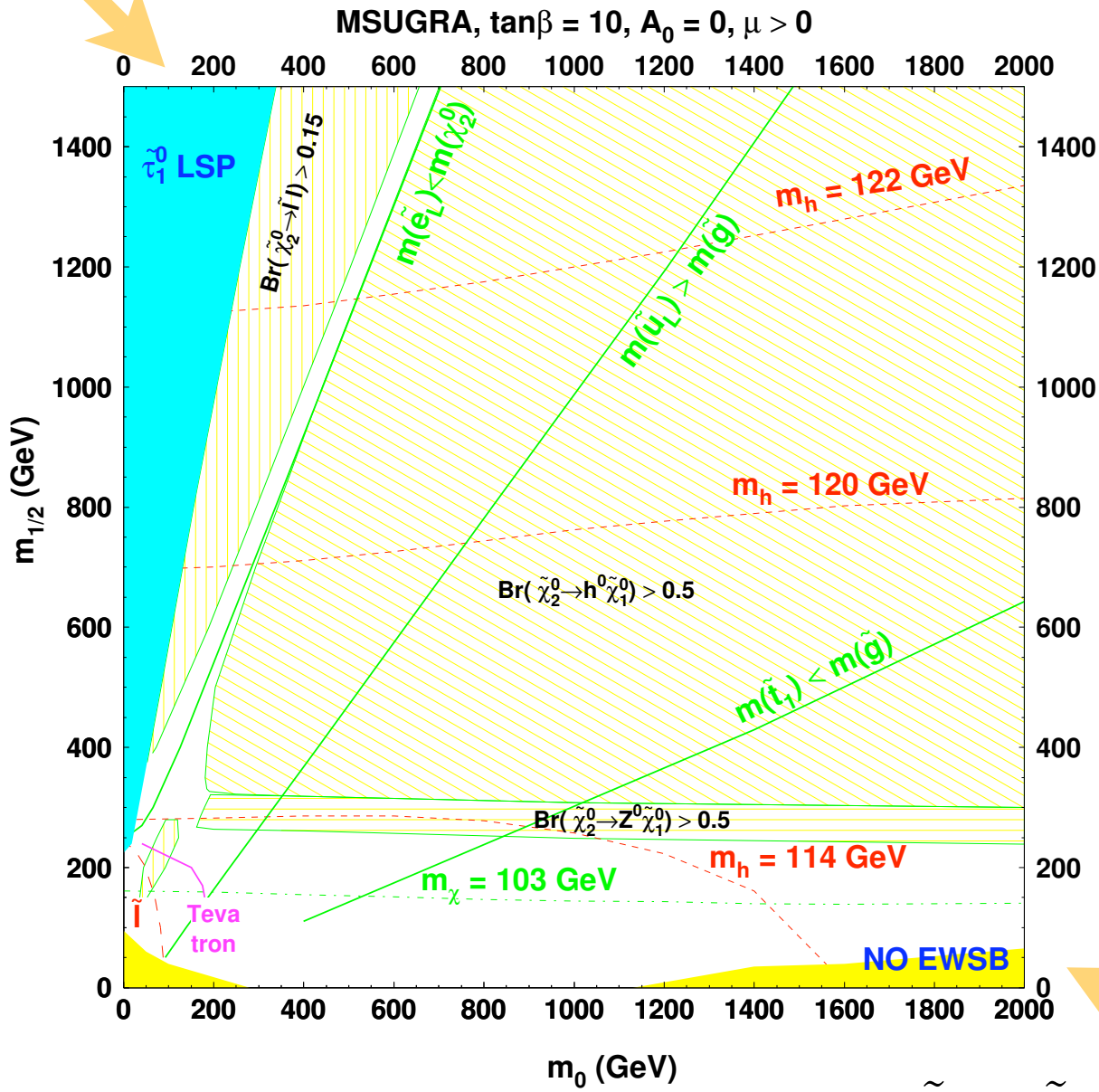
Sparticles are pair-produced with (possibly) large cross sections

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

Point	$M(\tilde{q})$	$M(\tilde{g})$	$\tilde{g}\tilde{g}$	$\tilde{g}\tilde{q}$	$\tilde{q}\bar{\tilde{q}}$	$\tilde{q}\tilde{q}$	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

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

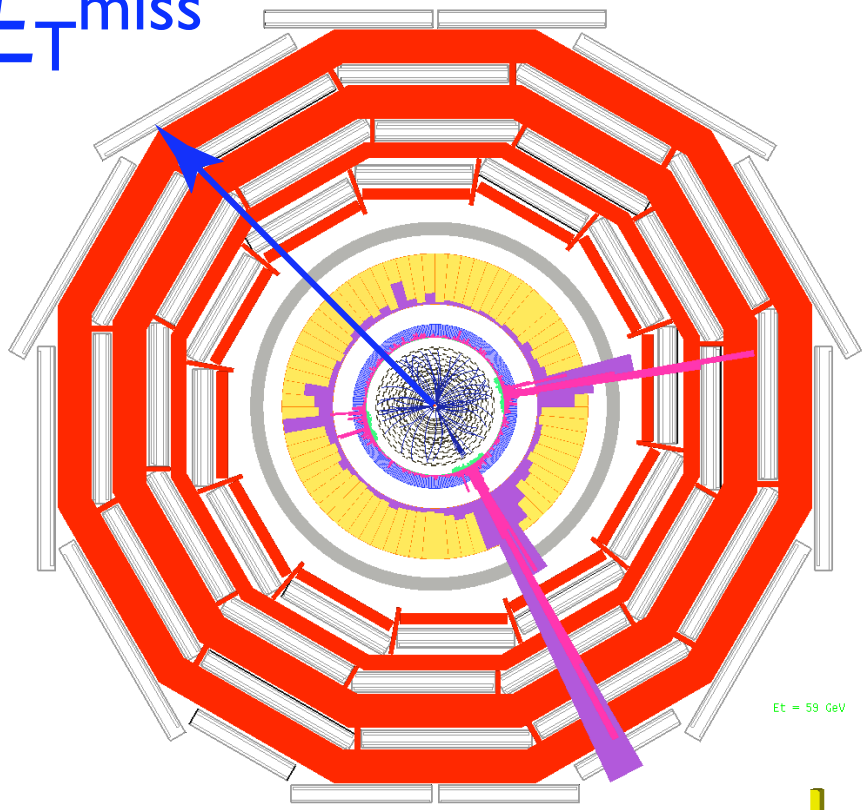


heavy squark

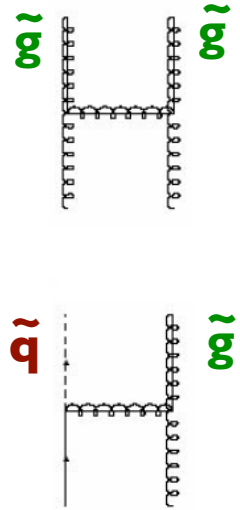
$\tilde{q} \to \tilde{g}q\ ,\ \tilde{g} \to q\bar{q}\chi$

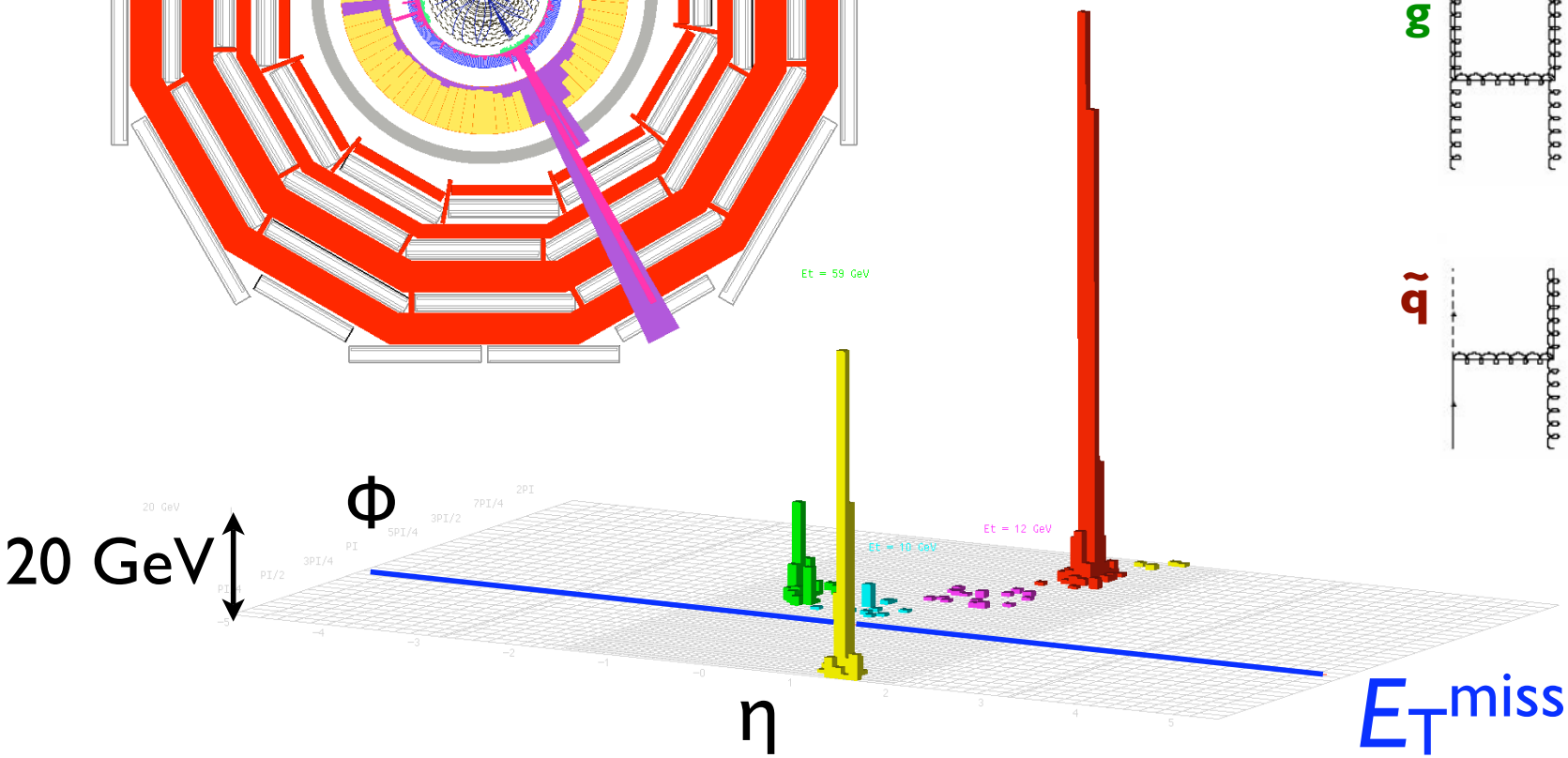
SUSY event in CMS

E_T^{miss}



3jet + E_T^{miss}



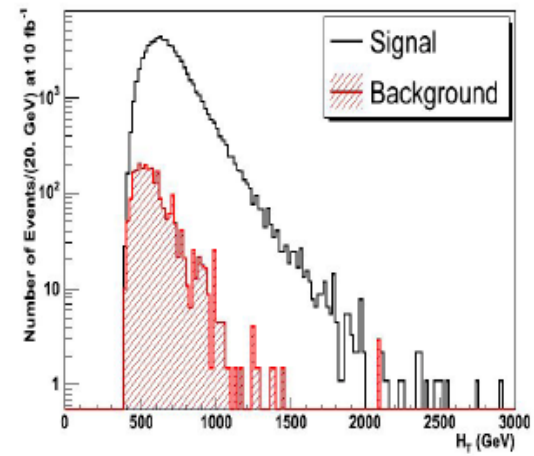


E_T^{miss}

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 effi
HLT, $E_T^{miss} > 200\,\mathrm{GeV}$	trigger/signal sig
primary vertex ≥ 1	primary cleanup
$F_{em} \geq 0.175$, $F_{ch} \geq 0.1$	primary cleanup
$N_j \geq 3, \lvert\eta_d^{1j}\rvert < 1.7$	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) $W/Z/t\bar{t}$ reje
$f_{em(j(1))},\ f_{em(j(2))} < 0.9$	ILV (II), $W/Z/t\bar{t}$ re
$E_{T,j(1)} > 180\,\mathrm{GeV}$, $E_{T,j(2)} > 110\,\mathrm{GeV}$	signal/backgroun
$H_T \equiv E_{T(2)} + E_{T(3)} + E_{T(4)} + E_T^{miss} > 500\,\mathrm{GeV}$	signal/backgroun
SUSY LM1 signal efficiency 13%	

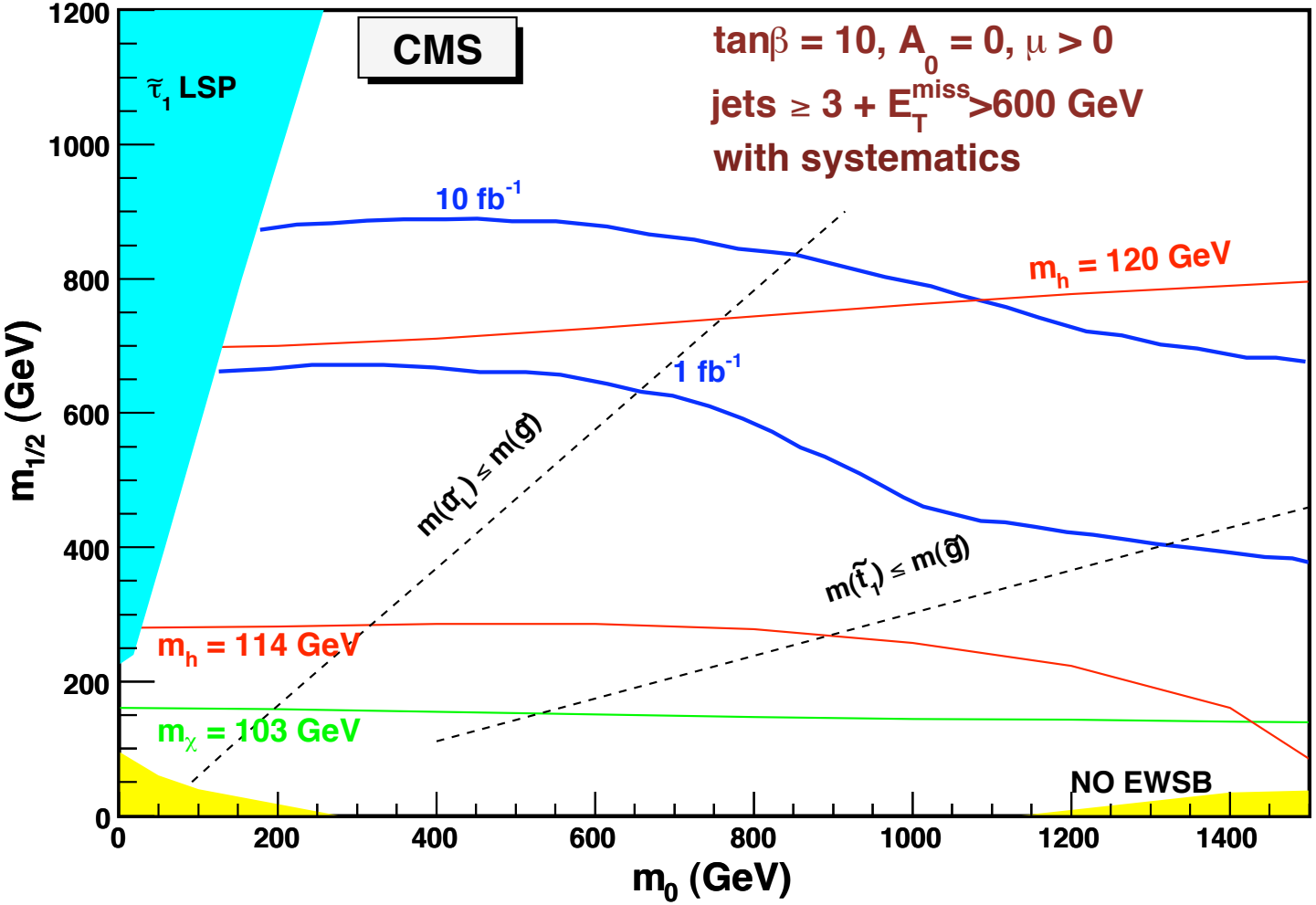


H_T

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

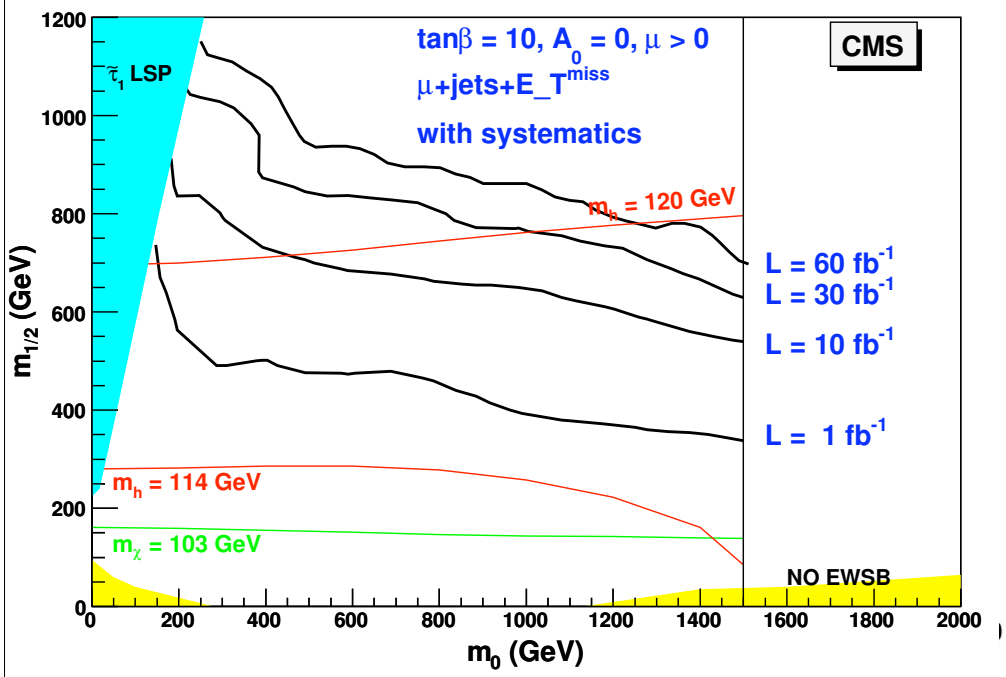
Signal	$t\bar{t}$	single t	$Z(\rightarrow \nu\bar{\nu})$+ jets	$(W/Z, WW/ZZ/ZW)$ + jets	QCD
6319	53.9	2.6	48	33	107

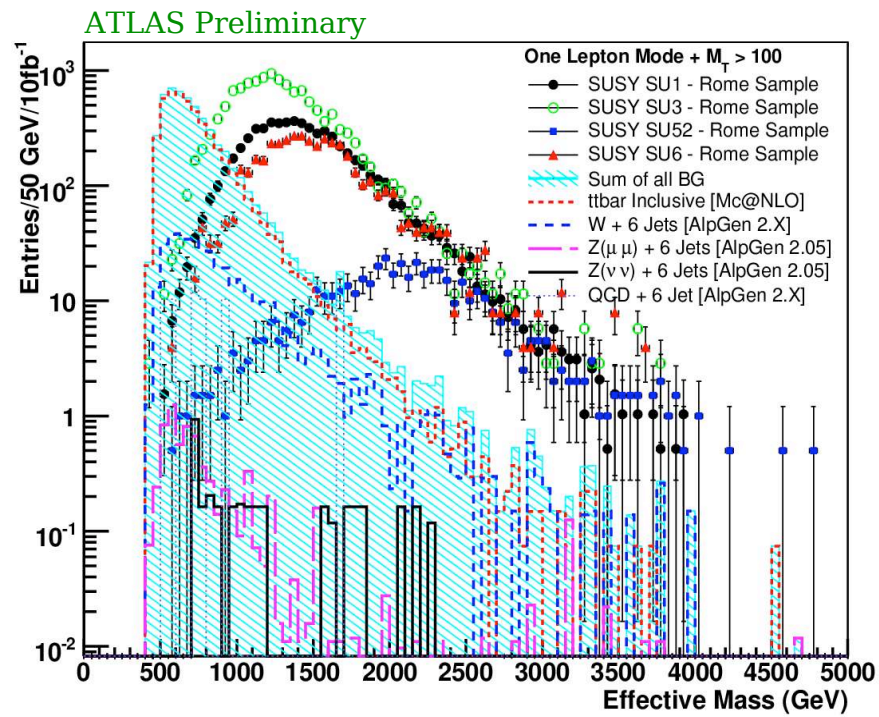
Inclusive analysis with missing transverse energy and jets



Not easy!

Lepton + jets + E_T^{miss}





$$M_3 \equiv M_{\tilde{g}} \quad \simeq \quad 2.7 m_{1/2}$$

S. Padhi, PASCOS 2006

Also not easy!

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

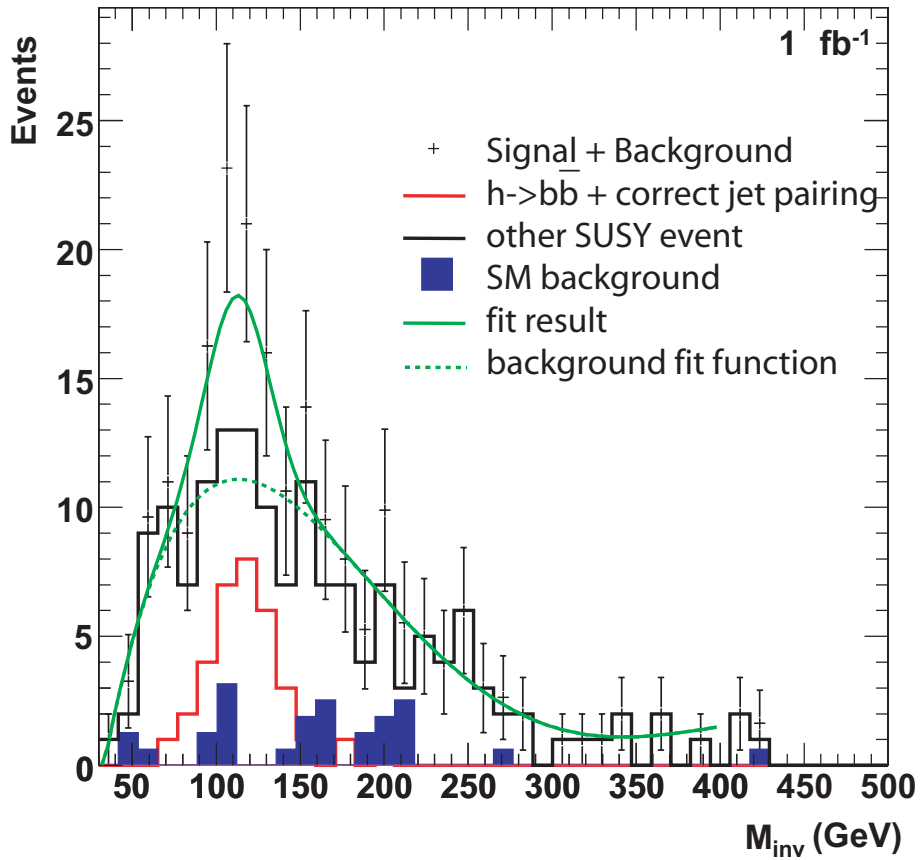


Figure 13.16: Invariant mass distribution of $b\bar{b}$ jets for the search of Higgs final states with 1 fb^{-1}.

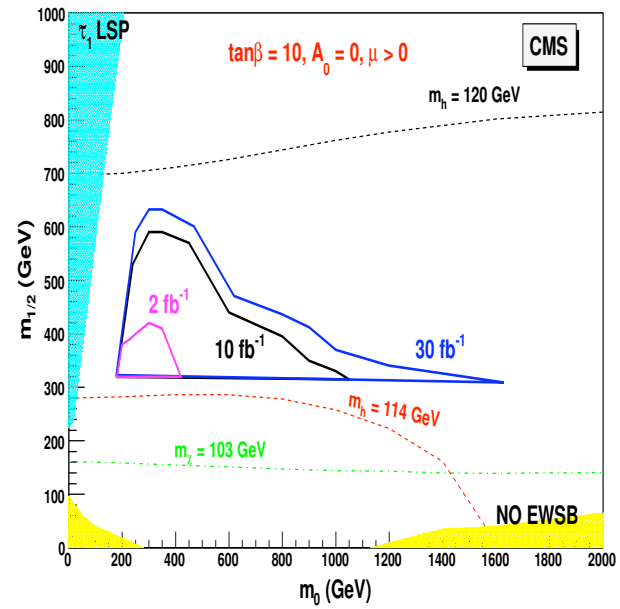


Figure 13.17: Higgs discovery reach in SUSY cascades for 2, 10 and 30 fb^{-1}.

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

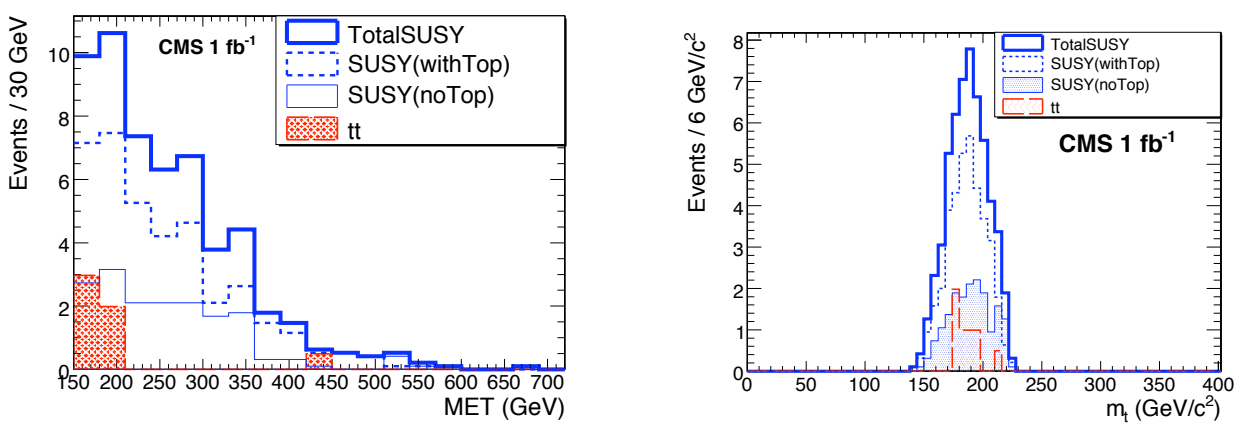


Figure 13.22: (left) Distributions of $E_{\mathrm{T}}^{\mathrm{miss}}$ and (right) fitted top mass after all selection criteria are applied

Inclusive analyses with top

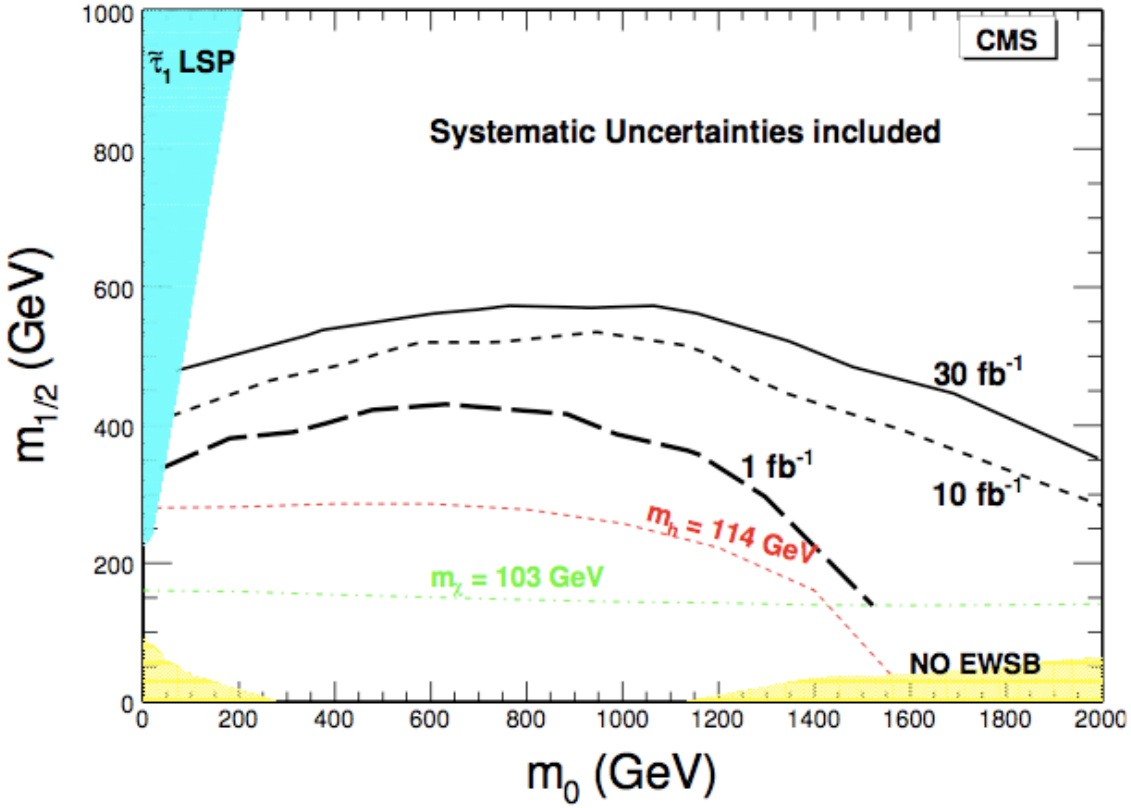
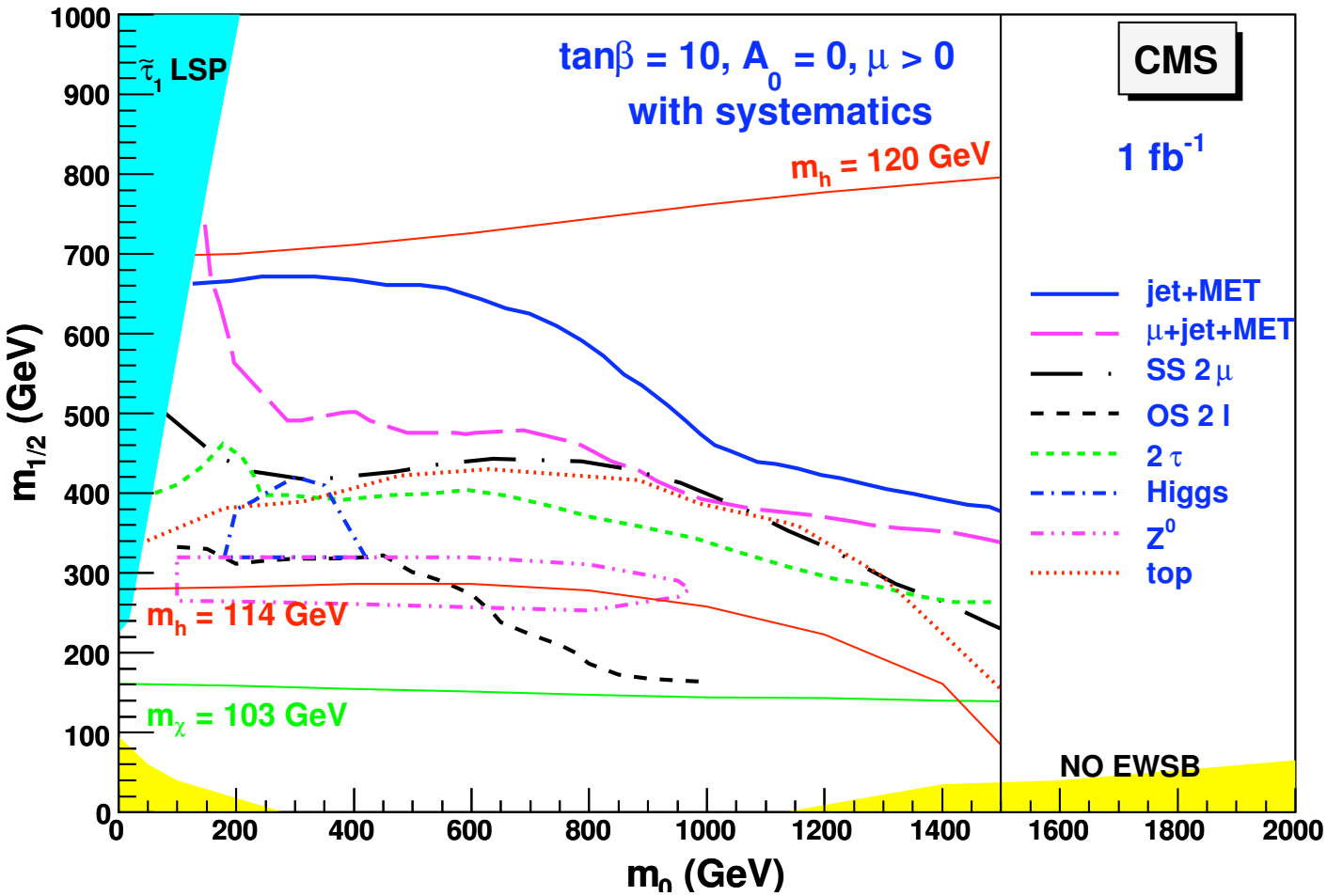


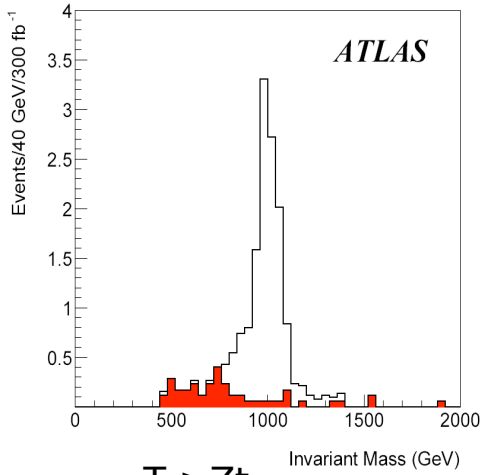
Figure 13.23: The 5σ reach in $m_0, m_{1/2}$ plane with 1, 10 and 30 fb^{-1} obtained for final states with a top quark.

SUSY Reach: Summary



Little Higgs ATLAS

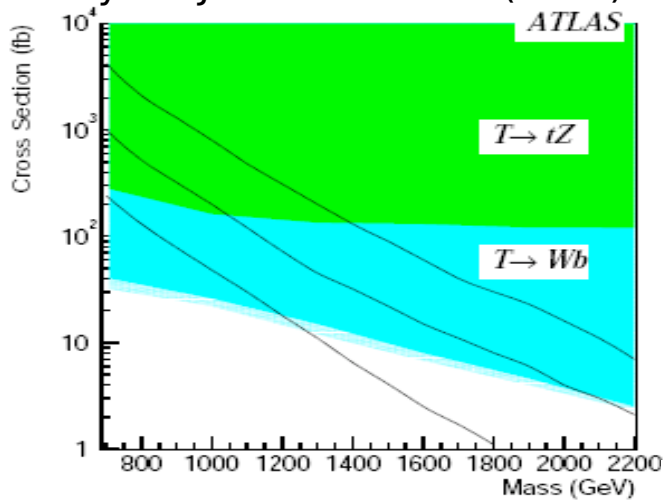
Heavy Top Searches (II)

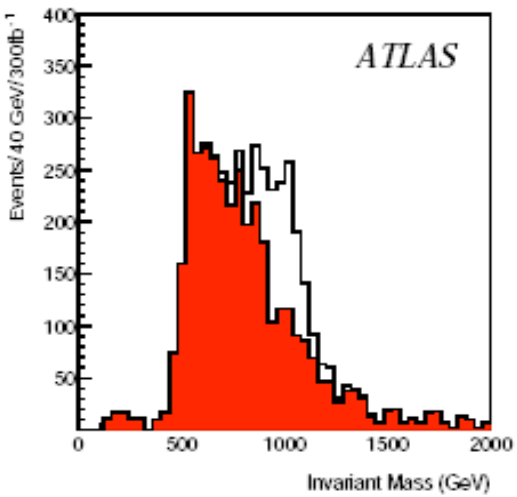


T->Zt

300 fb^{-1}

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





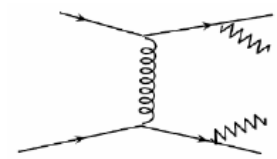
T->Wb

- 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)



- Exp^t 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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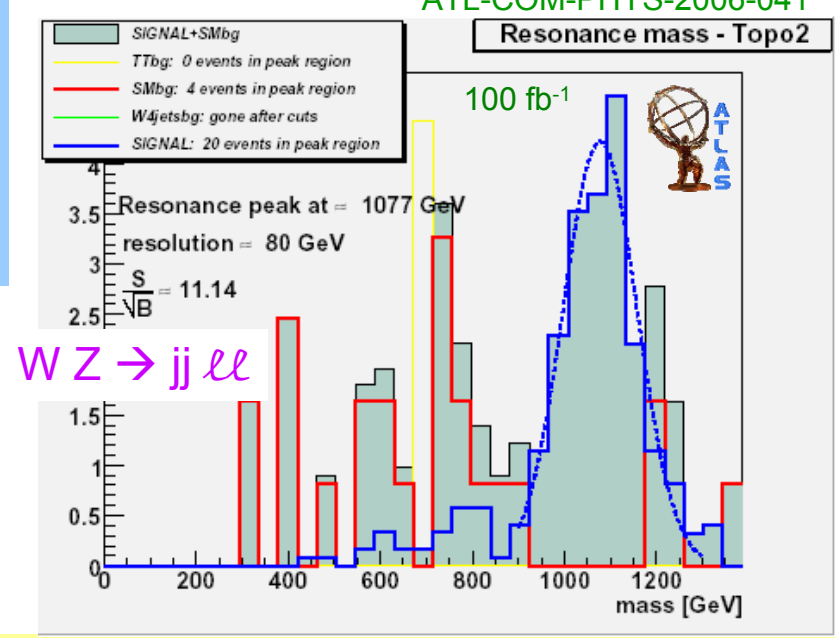


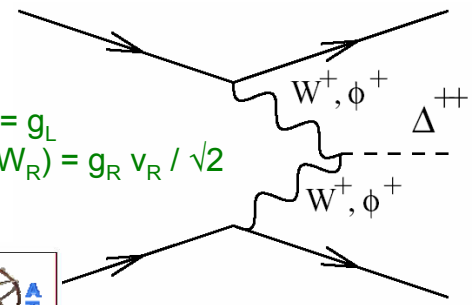
Doubly-Charged Higgs in LR Symmetric Model

- Left-Right Symmetric Model based on $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$
  - 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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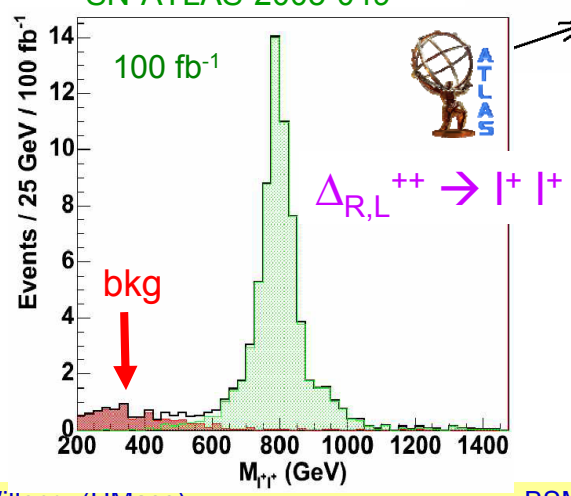

Summary

Response of ATLAS and CMS calorimeters to single particles is well understood from years of test beam work

Expected Jet and E_T^{miss} performance is well studied by MC (and tied to TB work) E_T^{miss} will be a tremendous challenge at startup

Measurement QCD jet rates will be a prerequiste for verifying detector functionality and will provide the first glimpse of the new energy frontier

Jets and E_T^{miss} will play a major role, especially in combination with a lepton trigger, in the search for Higgs and Supersymmetry