Benchmarks for an FCC-hh detector

FCC-hh detectors' strategy meeting

CERN, April 29 2015

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w. F.Moortgat and H.Gray

“Factorized” benchmarks:

benchmark processes and performance targets specifically addressing a given detector component (e.g. mu’s or Hcal or trkng)

“Integrated” benchmarks:

benchmark processes relying on many detector systems, whose impact on the overall physics performance is intertwined

Physics perspective on the performance priorities:

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  - jets, W/Z/H, top, b, μ, τ from decay of new heavy particles

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    ➡ *can typically use to probe performance of individual systems*
- It's likely that suitable performance in addressing the above issues will satisfy most other physics needs. E.g. signals at the O(1-10 TeV) scale, coverage of possible gaps left by HL-LHC (e.g. signals from compressed spectra, or with displaced tracks), etc.

Higgs selfcouplings: $pp \to HH$

- $gg \to HH$ (most promising?) , $qq \to HHqq$ (via VBF)
- Reference benchmark process: $HH \to bb\ \gamma\gamma$
- Goal: 5% (or better) precision for SM selfcoupling

$HH \to b\bar{b}\gamma\gamma$	Barr,Dolan,Englert,Lima, Spannowsky JHEP 1502 (2015) 016	Contino, Azatov, Panico, Son arXiv:1502.00539	He, Ren, Yao (follow-up of Snowmass study)
$FCC_{@100TeV}$ 3/ab	30~40%	30%	15%
$FCC_{@100TeV}$ 30/ab	10%	10%	5%
$S/\sqrt{B}$	8.4	15.2	16.5
Details	✓ λ_{HHH} modification only ✓ $c \to b$ & $j \to \gamma$ included ✓ Background systematics ○ $b\bar{b}\gamma\gamma$ not matched ✓ $m_{\gamma\gamma} = 125 \pm 1$ GeV	✓ Full EFT approach ○ No $c \to b$ & $j \to \gamma$ ✓ Marginalized ✓ $b\bar{b}\gamma\gamma$ matched ✓ $m_{\gamma\gamma} = 125 \pm 5$ GeV ✓ Jet $/W_{had}$ veto	✓ λ_{HHH} modification only ✓ $c \to b$ & $j \to \gamma$ included ○ No marginalization ✓ $b\bar{b}\gamma\gamma$ matched ✓ $m_{\gamma\gamma} = 125 \pm 3$ GeV

Work in progress to compare studies, harmonize performance assumptions, optimize, etc
⇒ ideal benchmarking framework

M.Son, HH summary at FCC week

Higgs selfcouplings: remarks

- Performance drivers for bbγγ:
  - b tagging, m_{bb} resolution
  - γ efficiency, jet→γ rejection, $m_{\gamma\gamma}$ resolution
  - overall geometric acceptance
- Consider additional channels (A.Papaefstathiou, H&BSM@100 TeV wshop)

$$\mathrm{BR}[(b\bar{b})(b\bar{b})] = 33.3\%$$

$$\mathrm{BR}[(b\bar{b})(WW)] = 24.8\%$$ → MET, p_T^{lept} thresholds, acceptance

$$\mathrm{BR}[(b\bar{b})(\tau\bar{\tau})] = 7.29\%$$ → τ tagging

$$\mathrm{BR}[(WW)(WW)] = 4.62\%$$

$$\mathrm{BR}[(WW)(\tau\bar{\tau})] = 2.71\%$$

$$\mathrm{BR}[(\tau\bar{\tau})(\tau\bar{\tau})] = 0.399\%$$

$$\mathrm{BR}[(b\bar{b})(ZZ)] = 3.05\%$$ → =>0.01% w. 4 lep's => ~5000 evts@30ab^{-1}

$$\mathrm{BR}[(b\bar{b})(\gamma\gamma)] = 0.263\%$$ → default mode

$$\mathrm{BR}[(b\bar{b})(Z\gamma)] = 0.178\%$$

$$\mathrm{BR}[(b\bar{b})(\mu\bar{\mu})] = 0.025\%$$

ttH/ttZ

- Potential % theory precision for ttH coupling
- Goal: % level exptl precision $\Rightarrow$ > 10 K events

ttH (pb)	ttZ (pb)	ttH/ttZ
33.9 $[^{+7.06\%}_{-8.29\%}]$Scale $[^{+0.941\%}_{-1.26\%}]$PDF	57.9 $[^{+8.93\%}_{-9.46\%}]$Scale $[^{+0.901\%}_{-1.20\%}]$PDF	0.585 $[^{+1.29\%}_{-2.02\%}]$Scale $[^{+0.0526\%}_{-0.0758\%}]$PDF

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tt + ($H\to\gamma\gamma$): b tagging, lept eff/acc, γ eff, $m_{\gamma\gamma}$, ...

$$
\begin{aligned}
p_{T,j} > 25\ \mathrm{GeV}, |\eta_j| < 2.5,\\
p_{T,b} > 25\ \mathrm{GeV}, |\eta_b| < 2.5,\\
p_{T,\gamma} > 25\ \mathrm{GeV}, |\eta_\gamma| < 2.5,\\
120\ \mathrm{GeV} < m_{\gamma\gamma} < 130\ \mathrm{GeV},\\
p_{T,\ell^\pm/\tau^\pm} > 20\ \mathrm{GeV}, |\eta_{\ell^\pm/\tau^\pm}| < 2.5,\\
E_{T,\mathrm{miss}} > 20\ \mathrm{GeV},\\
\Delta R_{jj} > 0.4, \Delta R_{bj} > 0.4, \Delta R_{bb} > 0.4.
\end{aligned}
$$

In $30\mathrm{ab}^{-1}$

~**100K** (semi-)leptonic ttH signal events

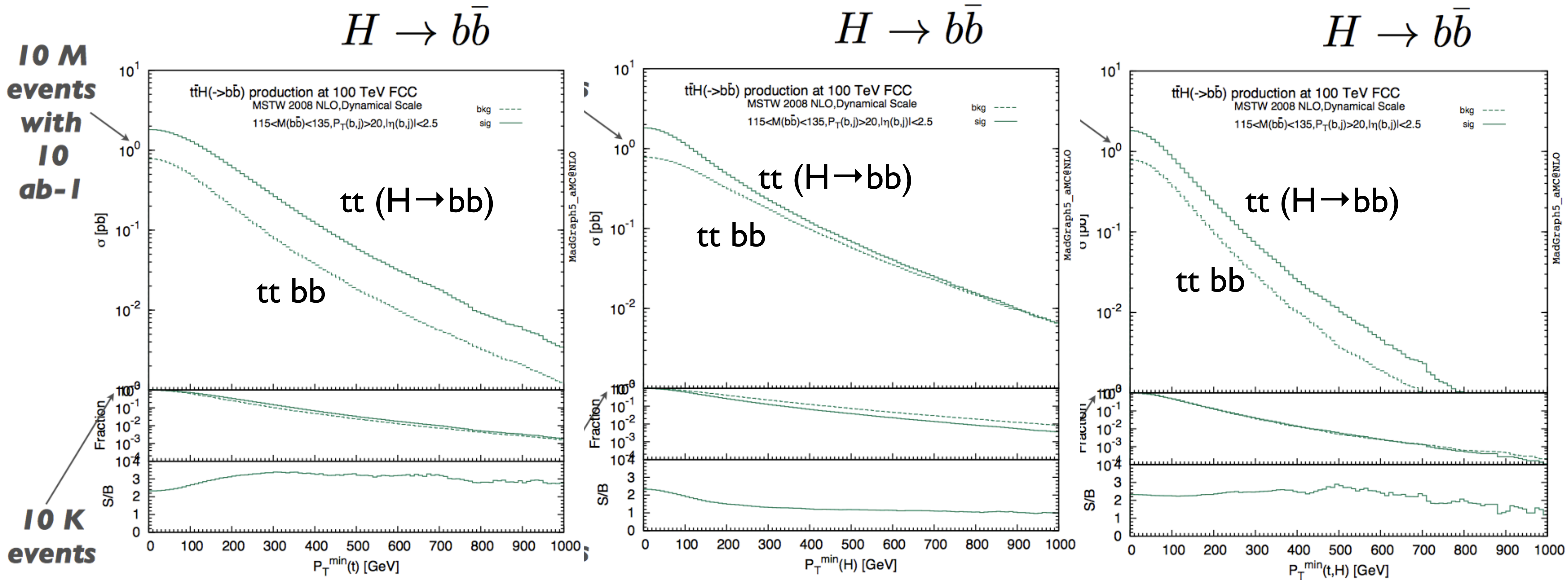
~**12K** irreducible bg (tt$\gamma\gamma$)

(H-S Shao, preliminary, H&BSM@100 TeV wshop)

ttH/ttZ

tt + (H→bb): b tagging in boosted configurations, lept eff/acc, m_{bb}, ...

115<M($b\bar{b}$)<135, P_T(b,j)>20, |η(b,j)|<2.5



$p_{T,min}$(t, tbar) $p_{T,min}$(H) $p_{T,min}$(t, tbar, H)

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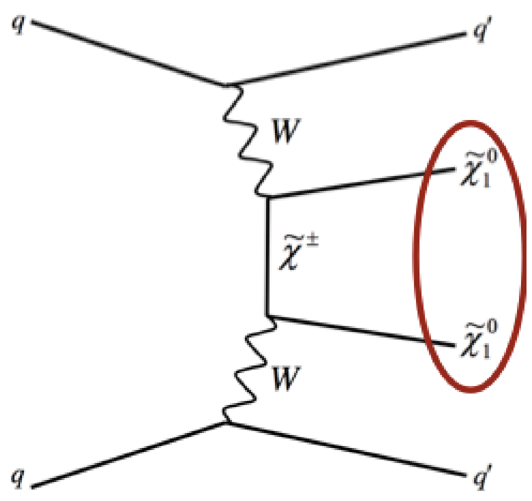
  - pileup mitigation/suppression via timing ?

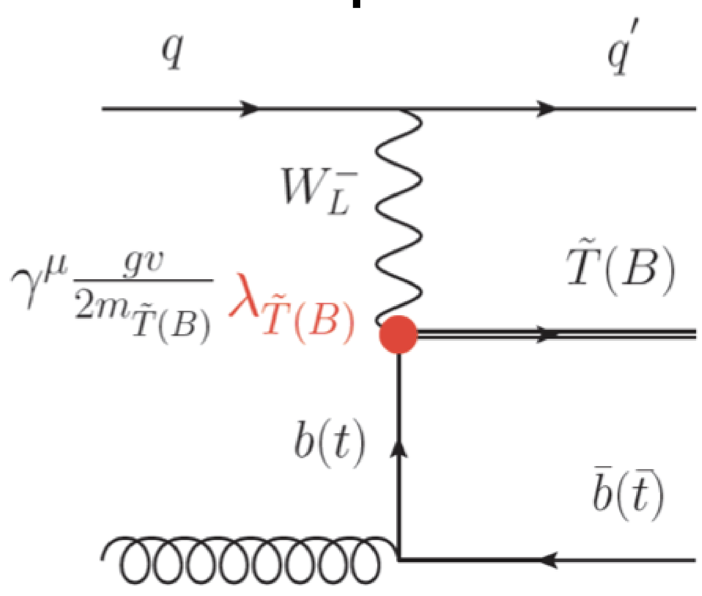
Drivers for forward-jet acceptance

Vector boson fusion and scattering:

- WW → H
- WW → WW
- WW → HH
- WW → ew-inos/DM candidates/etc



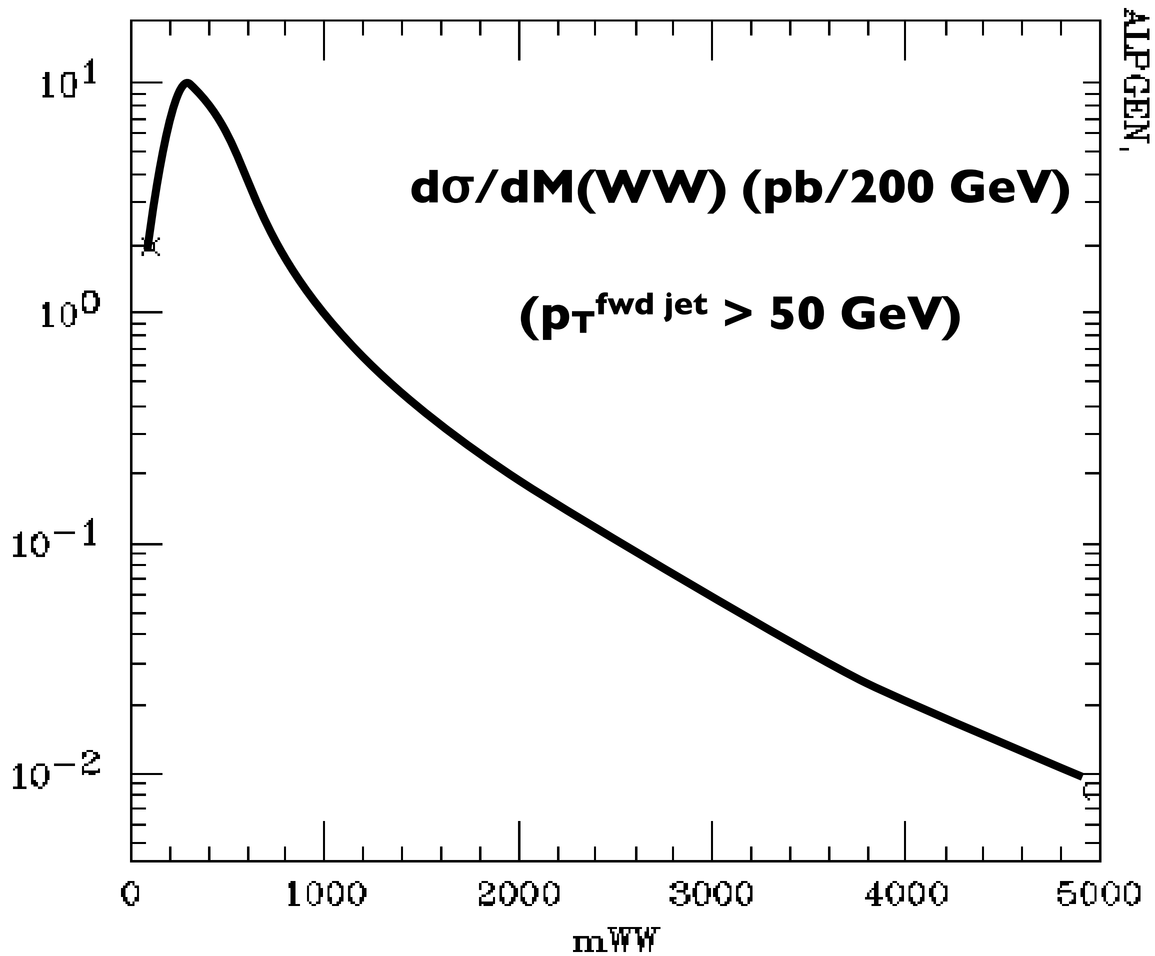
s-channel resonances in Wq fusion:

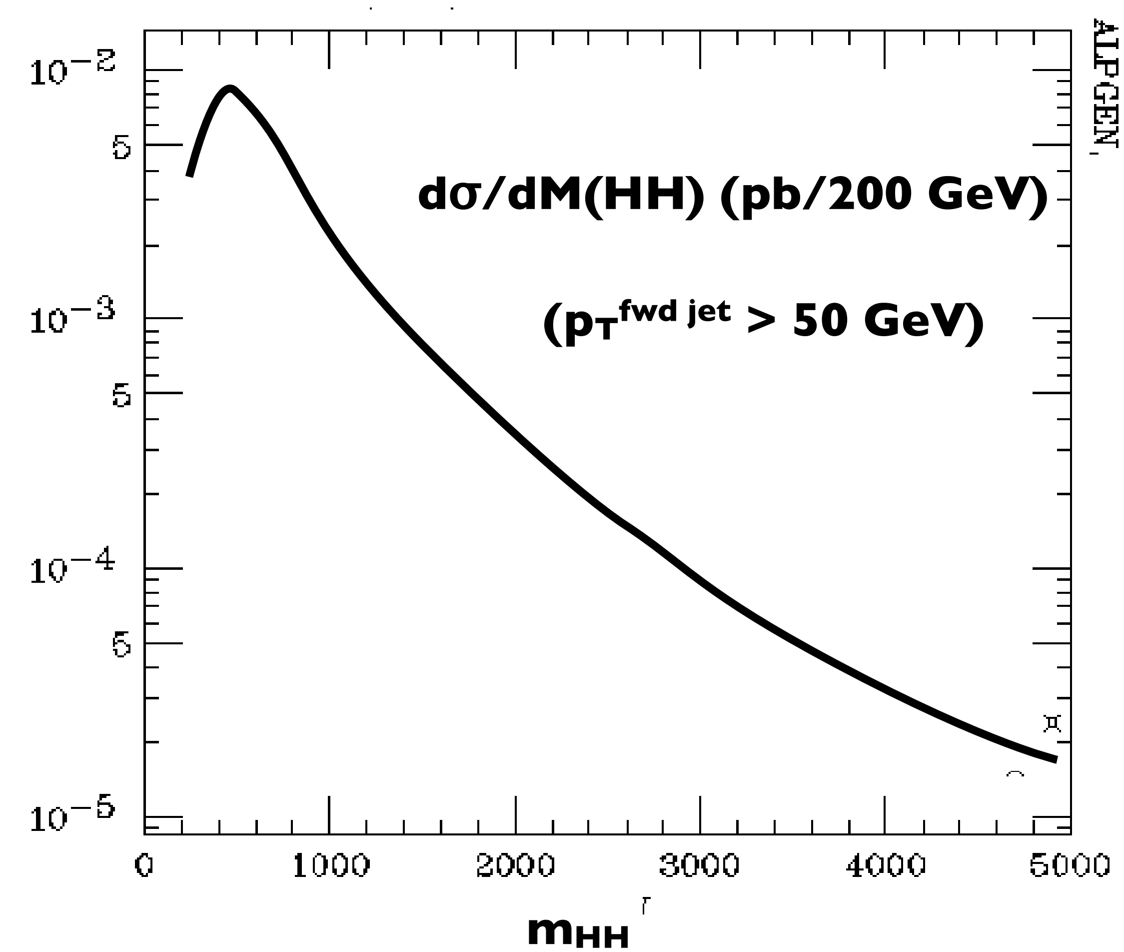


Missing-ET resolution

EWSB probes: high mass WW/HH in VBF

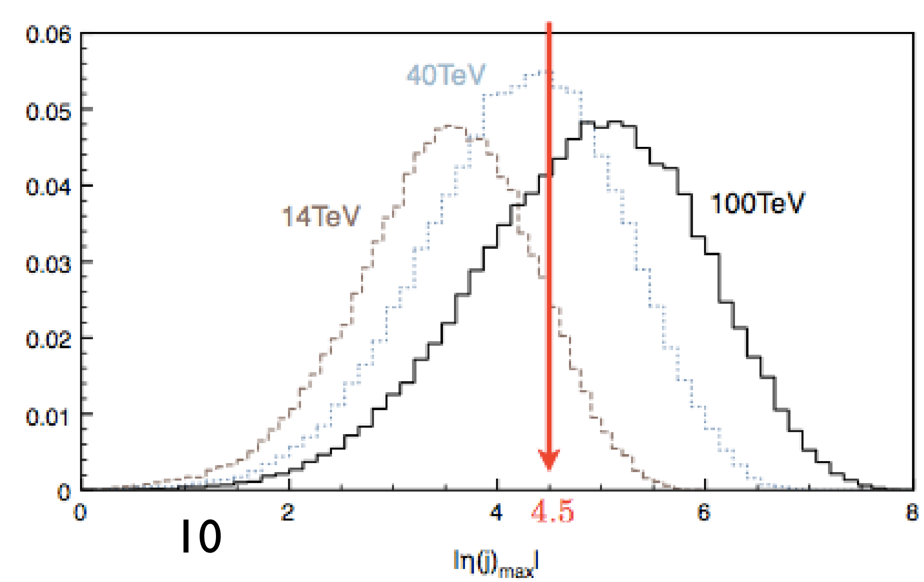
SM rates at 100 TeV





100 fb with M(WW) > ~3 TeV

1 fb with M(HH) > ~2 TeV



High mass benchmarks

- Target: tag and measure objects at the highest p_T
- Benchmarks: $X \to YY$, with m(X)=10–50 TeV, and Y=
  - light jet (light-q vs gluon separation)
  - charm, bottom jets
  - top
  - $W/Z \to$ jets, $H \to bb$
  - muons, taus

See later talks by M.Pierini, J.Santiago, S.Chekanov

See talks at H&BSM@100 TeV workshop, in particular by
- Torre and Doglioni (high mass dijet resonances)
- Salam, Selvaggi, Pierini (Multi-TeV tagging and mass resolution of jets from t, W/Z decays)

Jets at high E_T

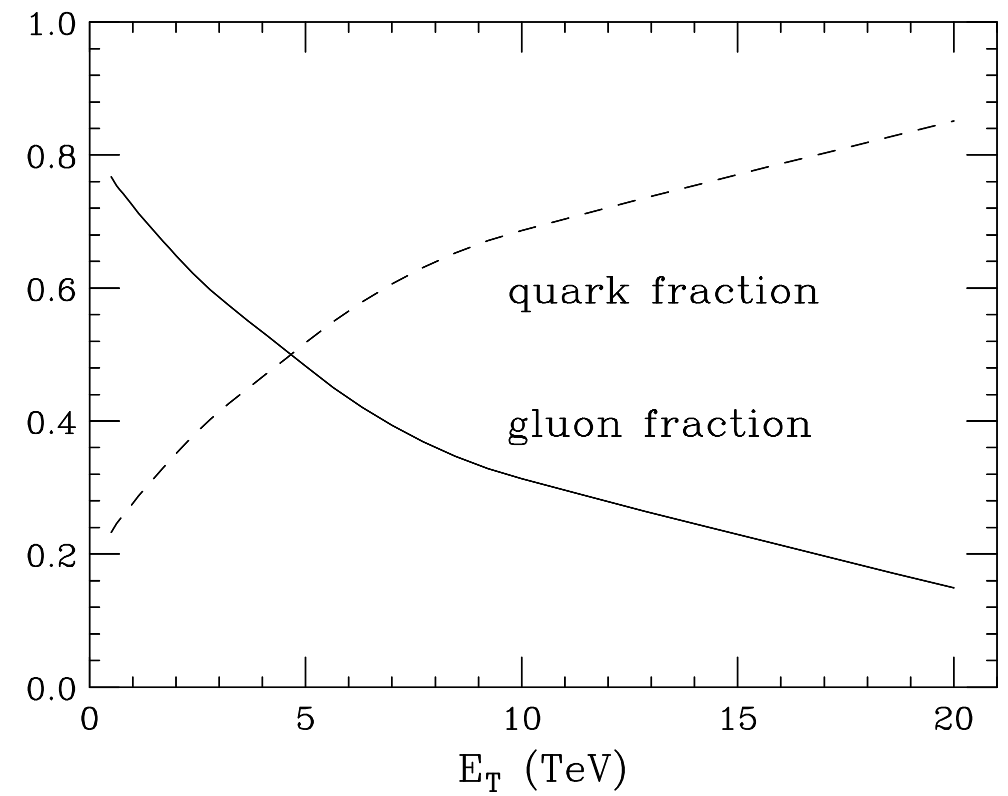
Consider some features of jet structure at high E_T. Compare jets from:

- top quark (hadronic) decay
- bottom quark
- inclusive jets
- W hadronic decay

Jets are defined by anti-k_T . Use R=1 to define jet, then look inside at smaller R. No soft UE, no pileup.

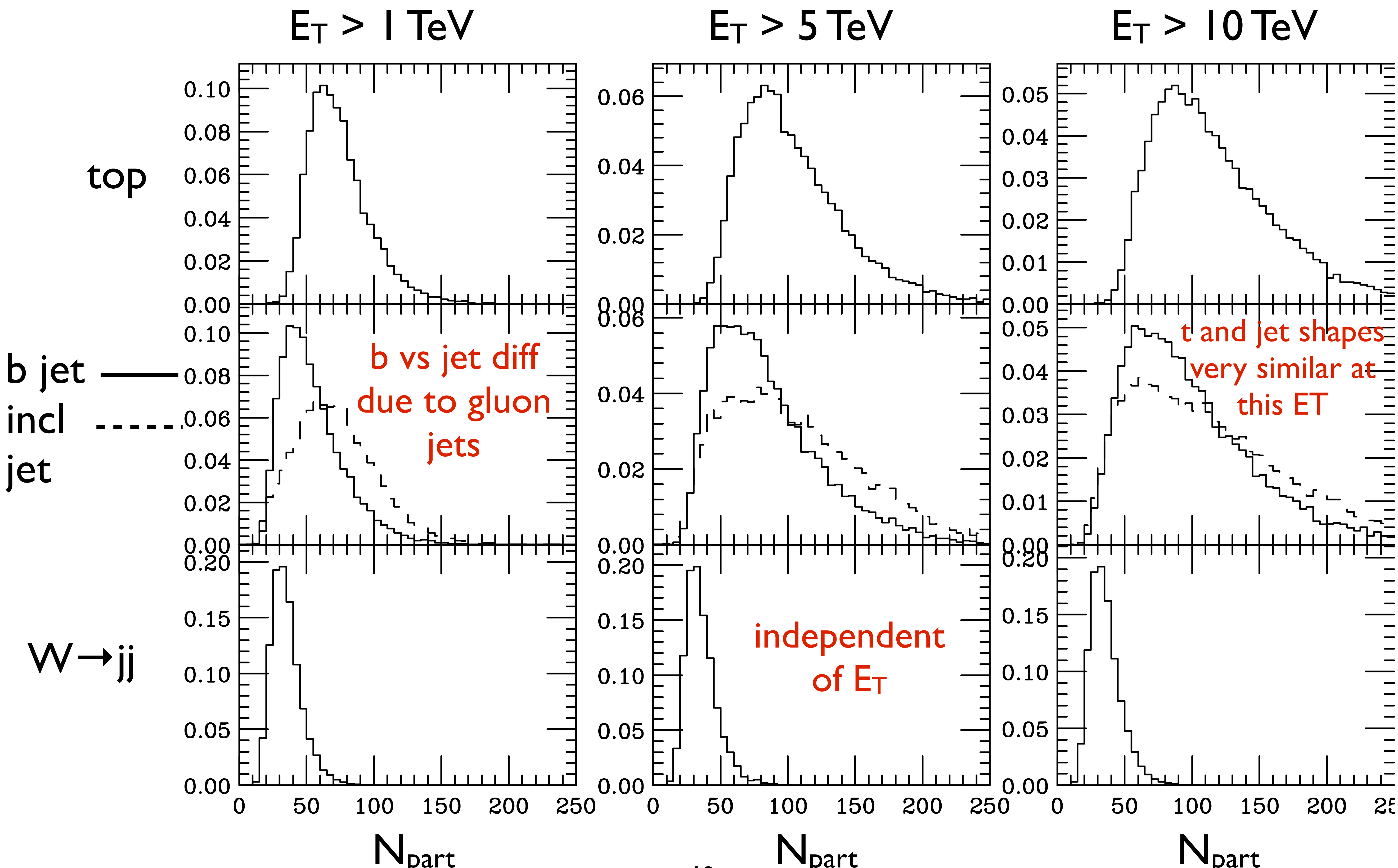
Generation: Alpgen + Herwig

NB: Inclusive jets here means jets from the QCD background. Thus they include a mixture of light quark and gluon jets, which varies vs E_T

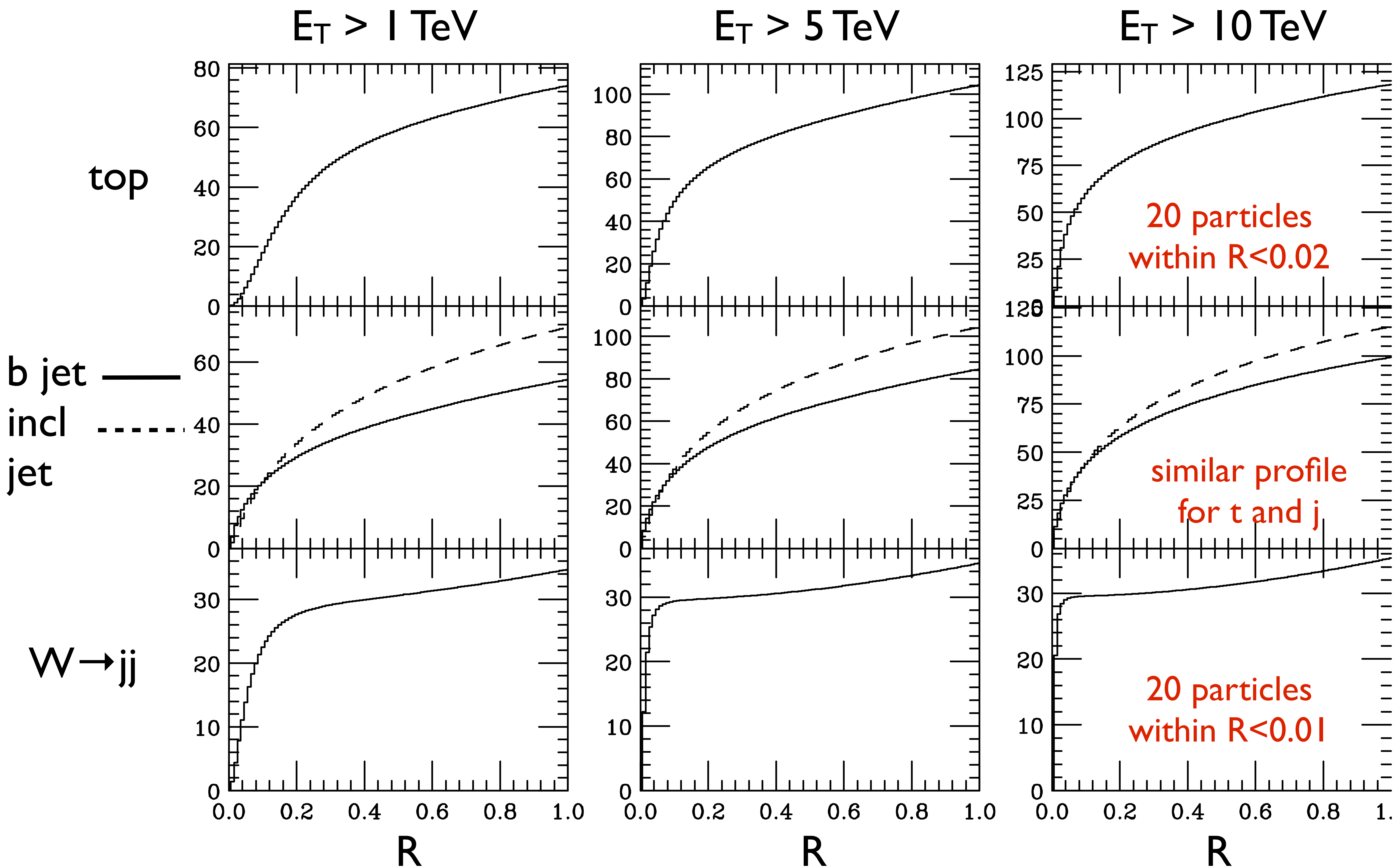


Particle multiplicity distribution: $1/\sigma \, d\sigma/dN_{part}$

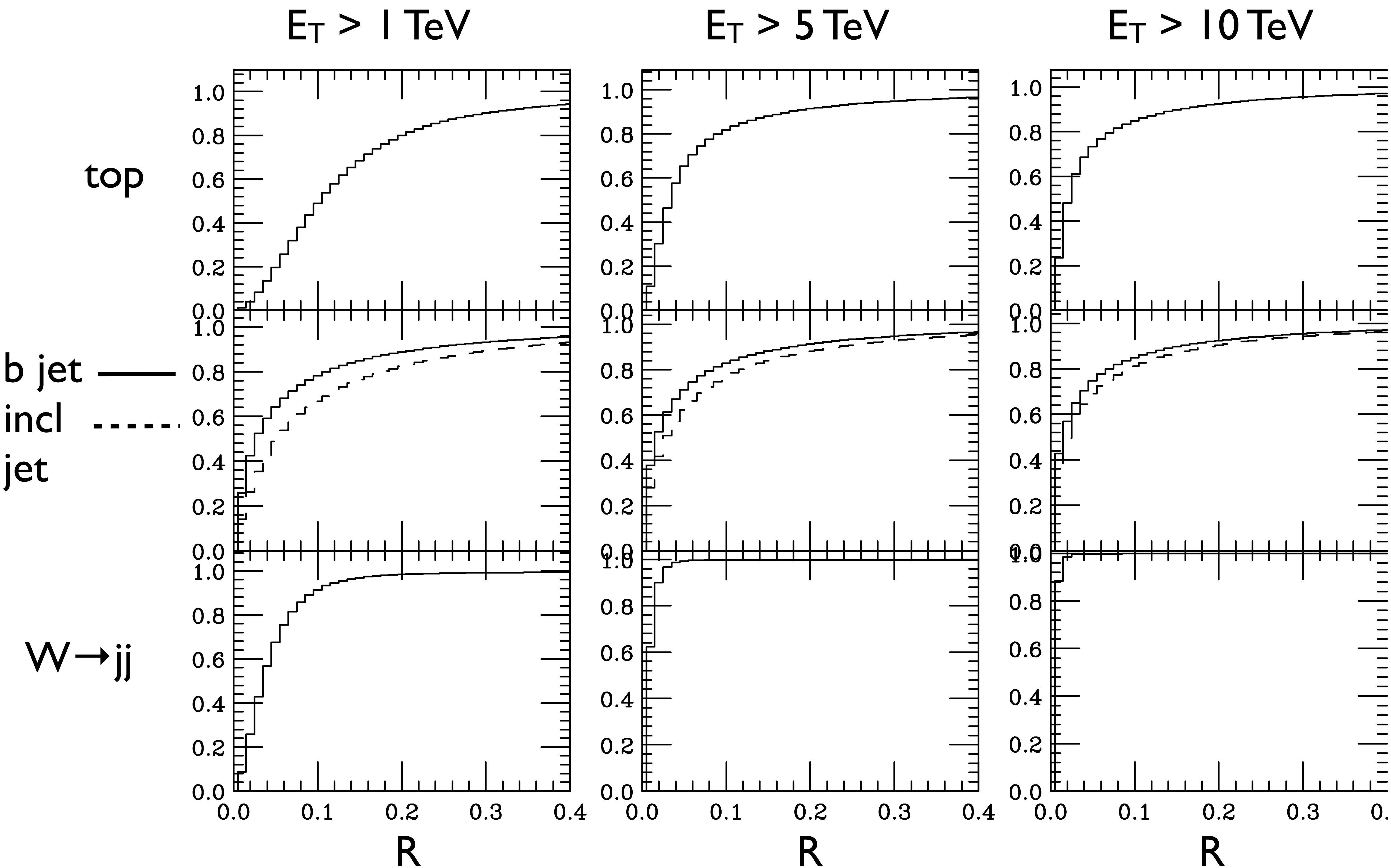
(particle: everything except neutrinos, neutral and charged, with stable π^0)



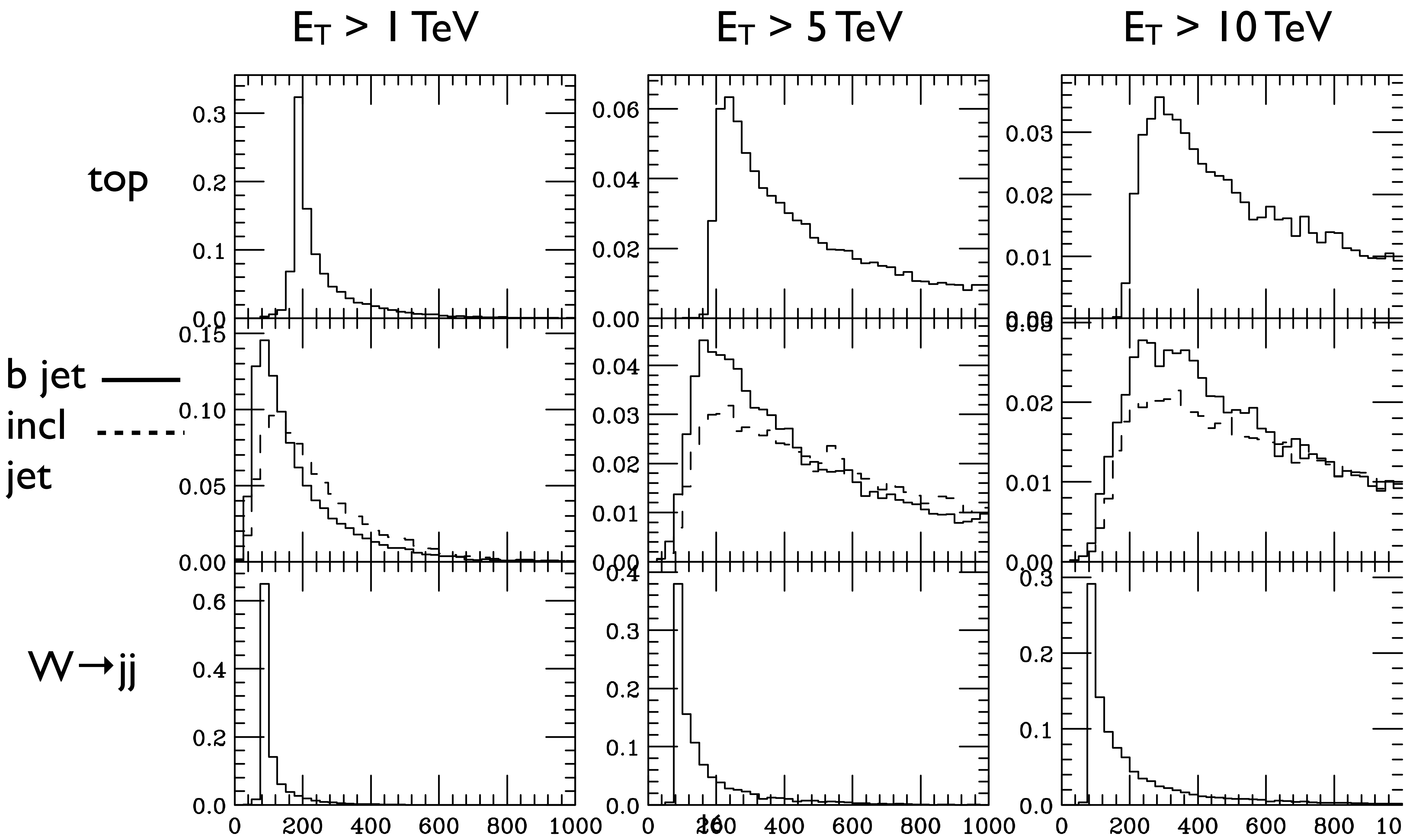
Average particle multiplicity shape: N_{part} (r<R)



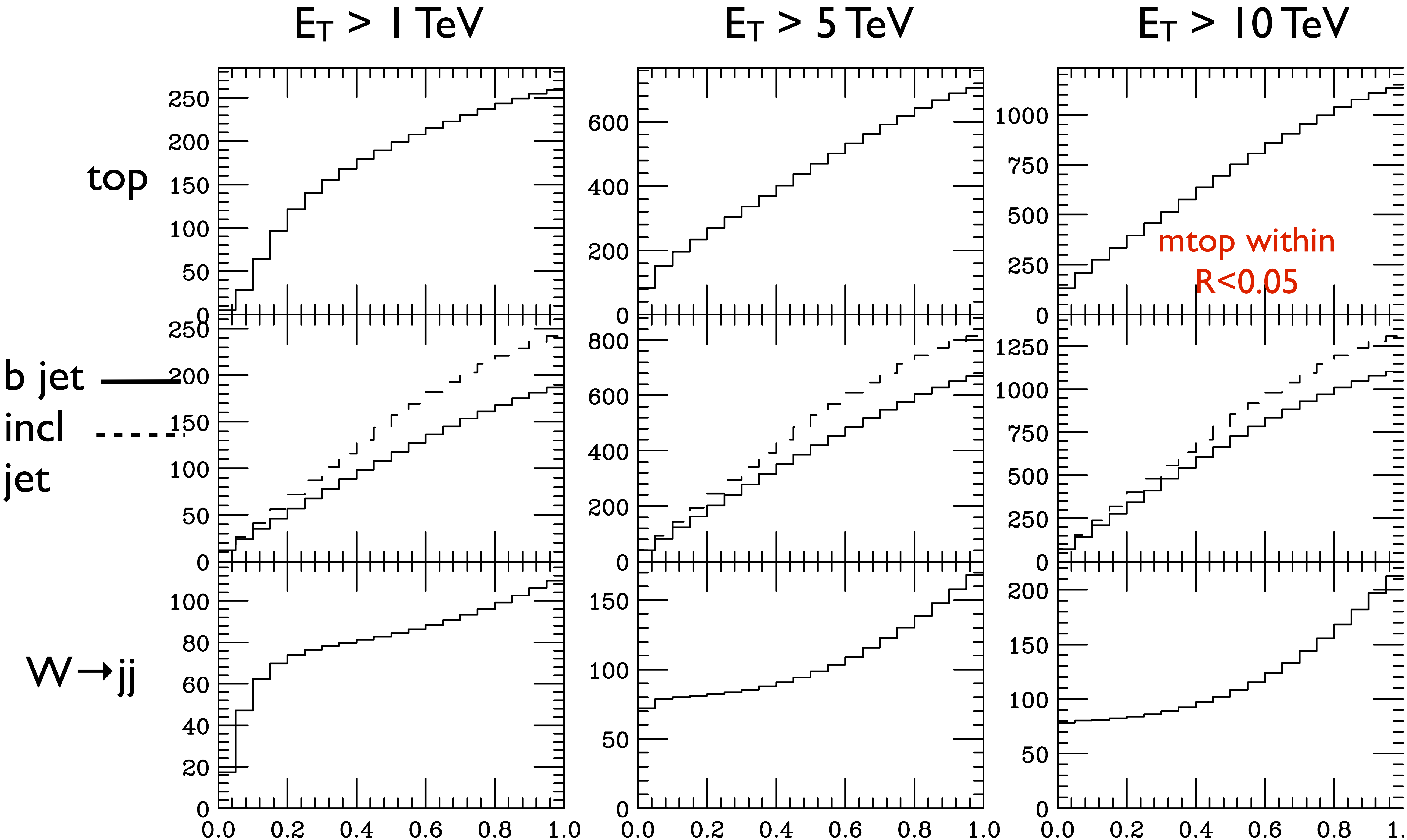
Energy shape: E(r<R) / E(r<1)



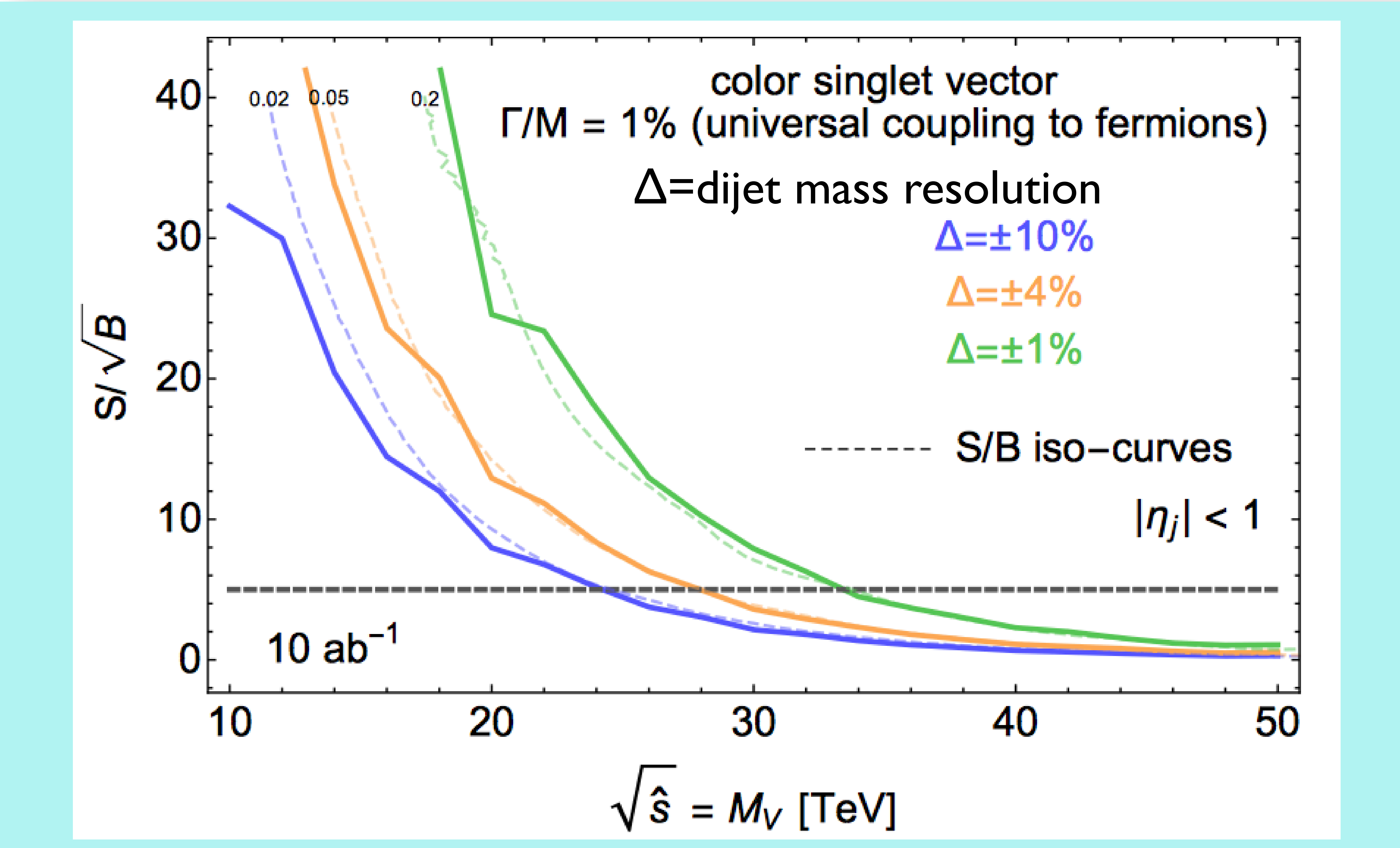
Jet mass distribution: $1/\sigma \, d\sigma/dM_{jet}$



Average jet mass: M(particles with r<R)



Discovery reach in dijet channel, weakly coupled case

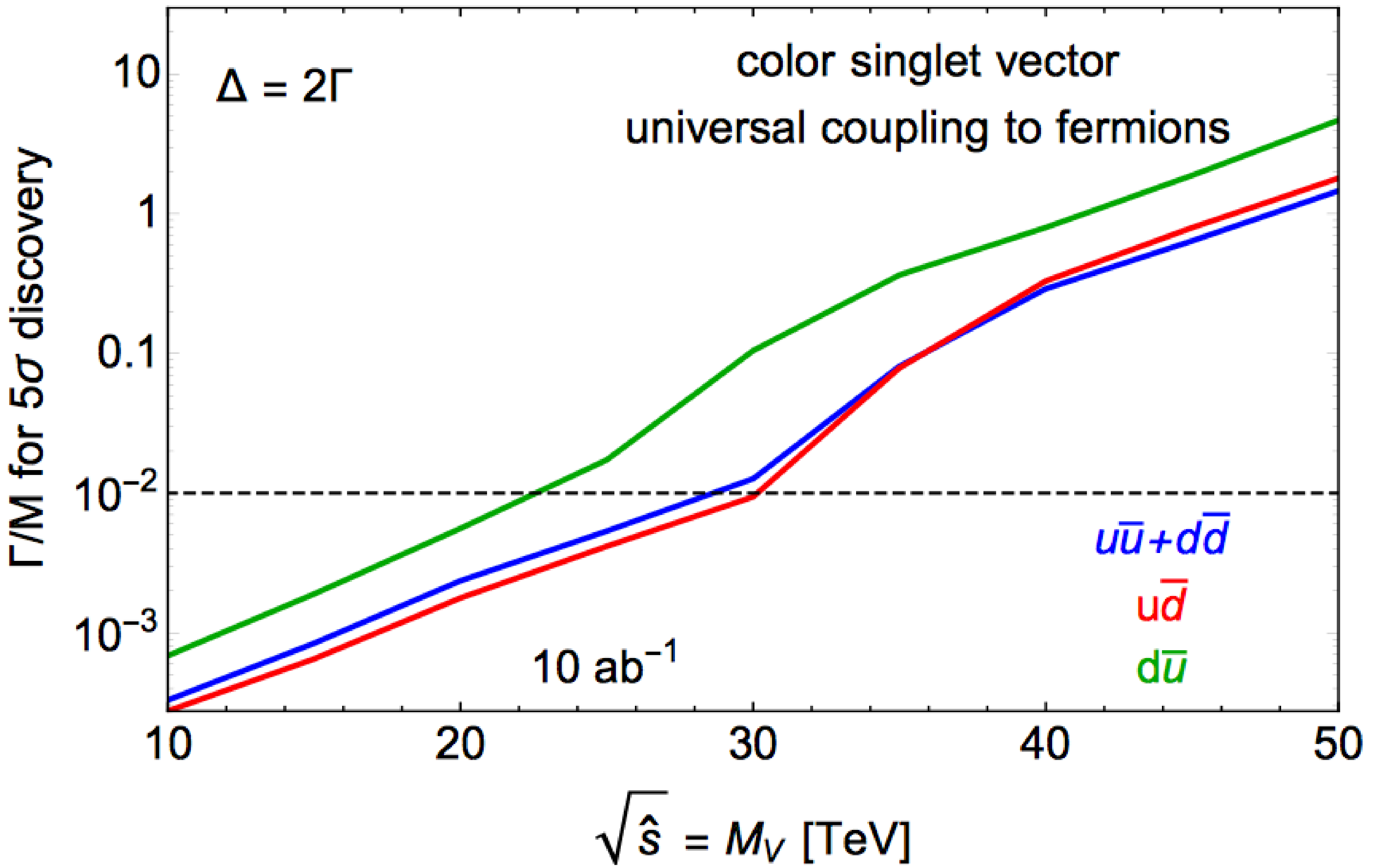


R.Torre, talk at H&BSM@100 TeV

MINIMUM WIDTH FOR DISCOVERY

The production cross section is proportional to the partial width and therefore it determines the minimum width needed for discovery

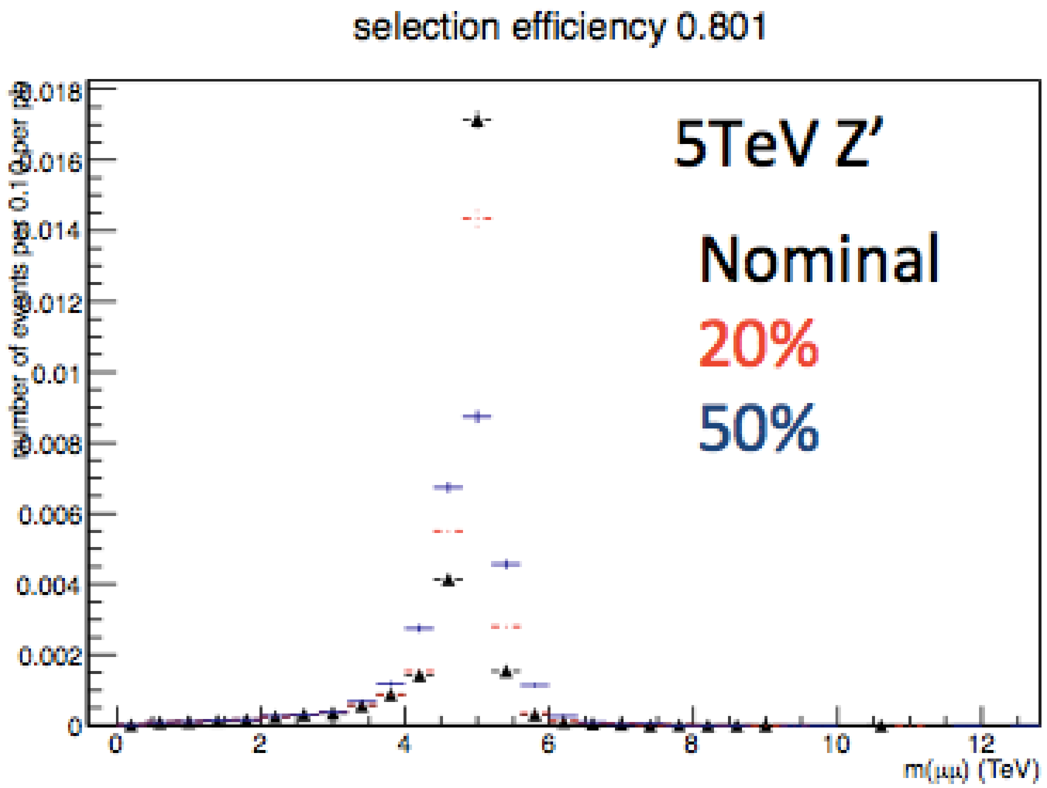
This is important to know the resolution needed to be sensitive to these resonances

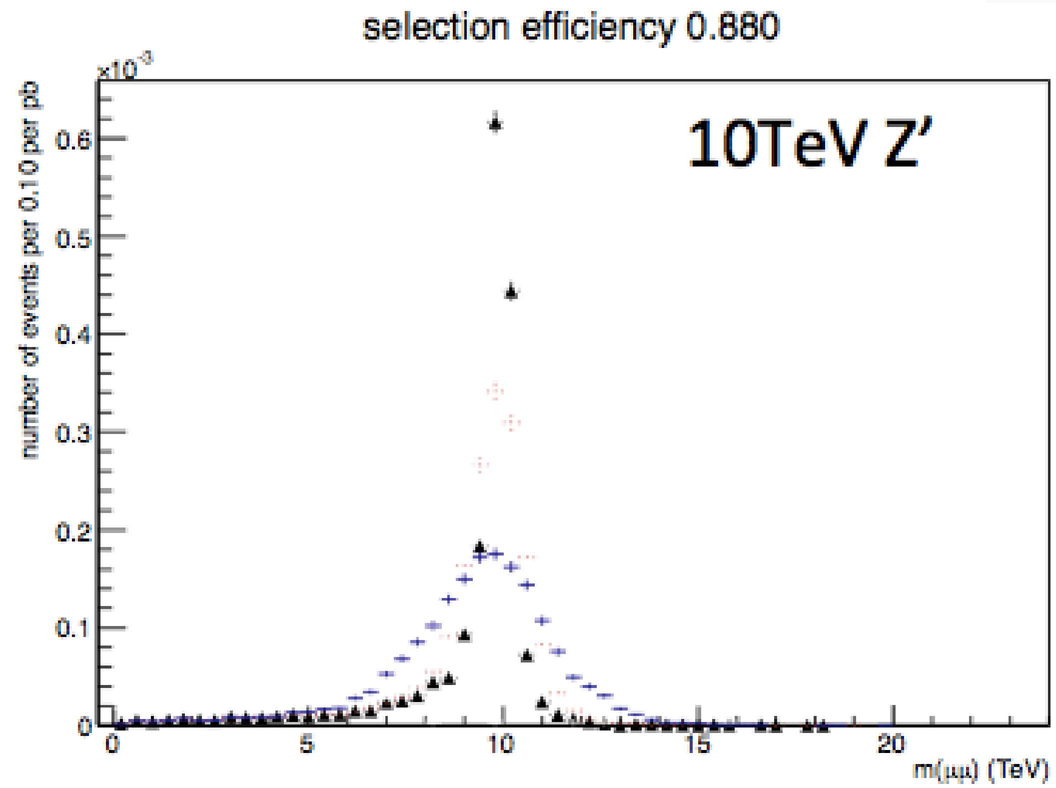


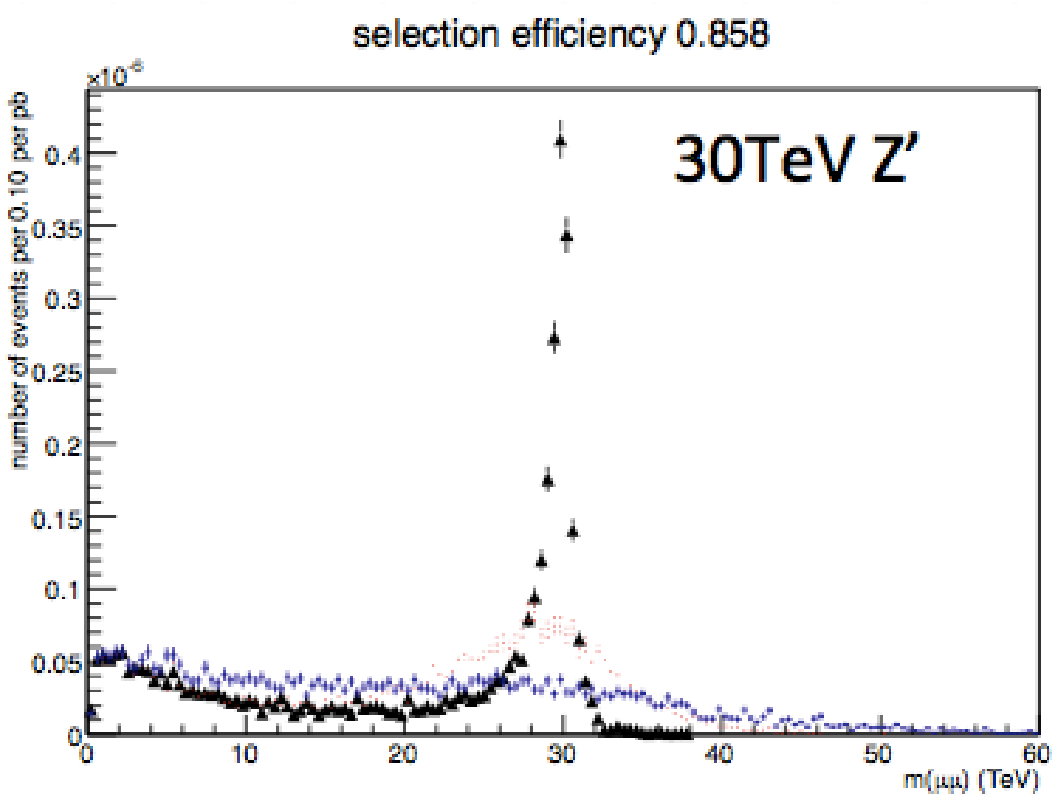
Muons

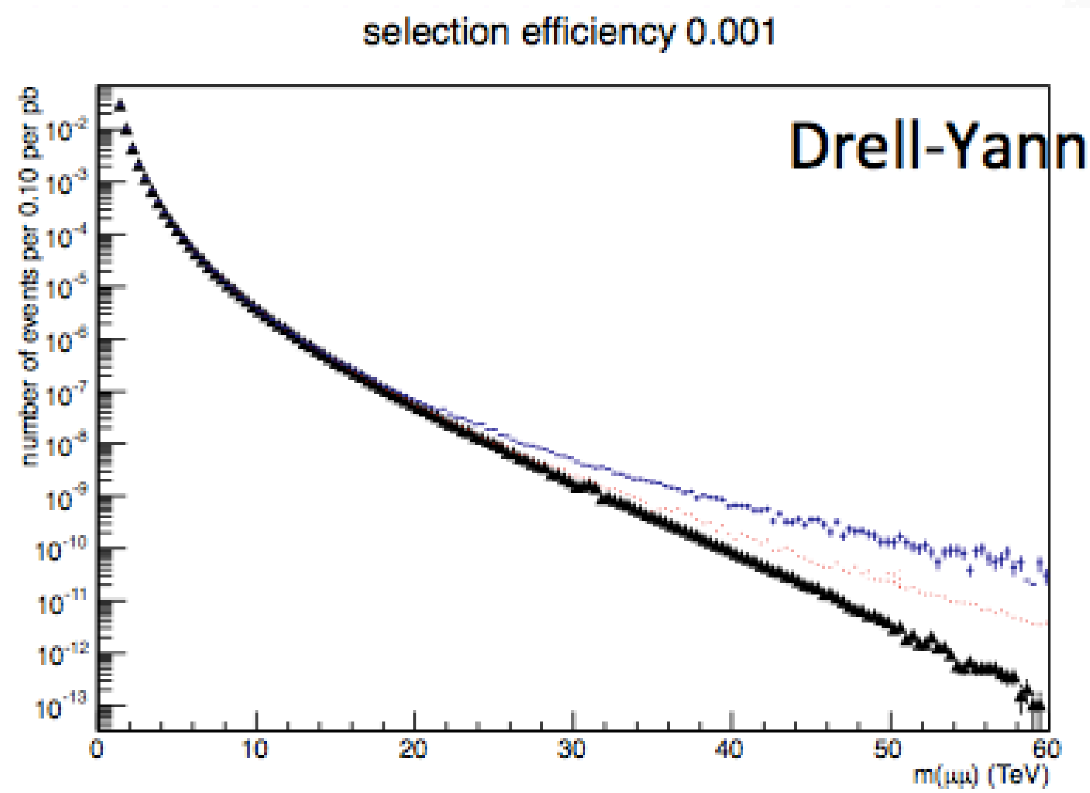
Results by Clement Helsens,
FCC mtg Febr 6 2014,
http://indico.cern.ch/event/297201/
and updates

impact of different assumptions on muon momentum resolution at 10 TeV
(nominal: natural Z' width, 3% in this case)





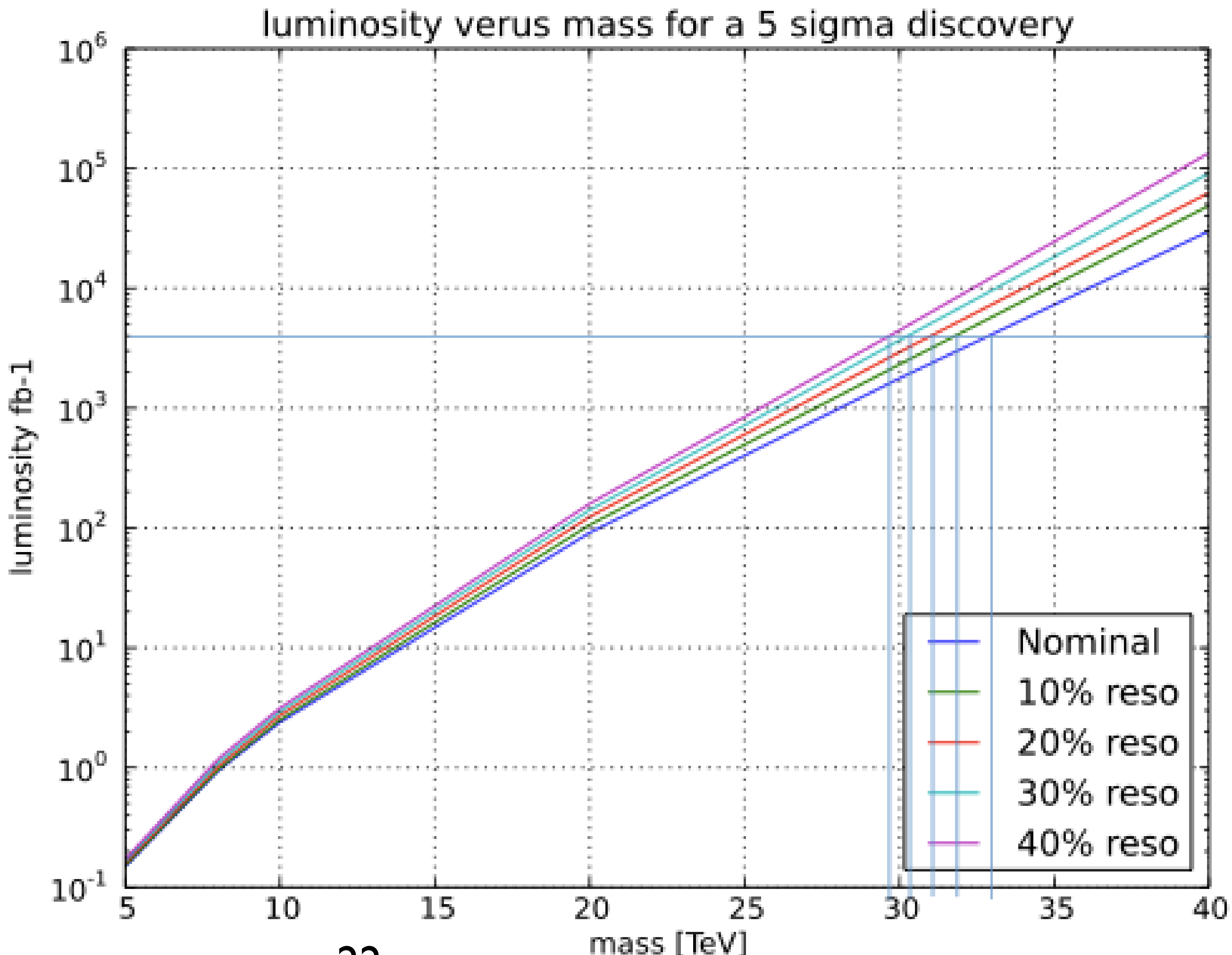




Sensitivity

Luminosity (fb^{-1}) to discover at 5sigma

	5TeV	8TeV	10TeV	20TeV	30TeV	40TeV
Nominal	0.15	0.93	2.39	91.2	1770	29983
10%	0.15	0.96	2.51	106.1	2312	48914
20%	0.16	1.02	2.72	123.9	2932	62653
30%	0.16	1.09	2.93	140.9	3674	91116
40%	0.17	1.18	3.14	159.4	4462	134534



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- soft leptons and soft photons (e.g. EW-inos, Higgsino DM, and in general leptonic and γ Higgs final states etc - see Bramante at H&BSM@100 TeV)

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- disappearing tracks (see L-T. Wang and P. Harris at FCC-week)

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  - EM granularity for jet structure vs $m_{\gamma\gamma}$ resolution

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- Useful to consider interplay/synergy/conflicts of requirements from low-pT and high-PT benchmarks. E.g.
  - ID of low-p_T muons vs thick calorimeters
  - vtx tagging for b's vs disappearing tracks
  - EM granularity for jet structure vs $m_{\gamma\gamma}$ resolution
  - ....

Benchmarks for O(TeV) scale processes

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  - ....
- Hard to set physics priorities for resolution of performance/ requirement conflicts now, it's "Higgs vs god-knows-what"