SM physics at 100 TeV

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    - higher sensitivity to BSM deviations

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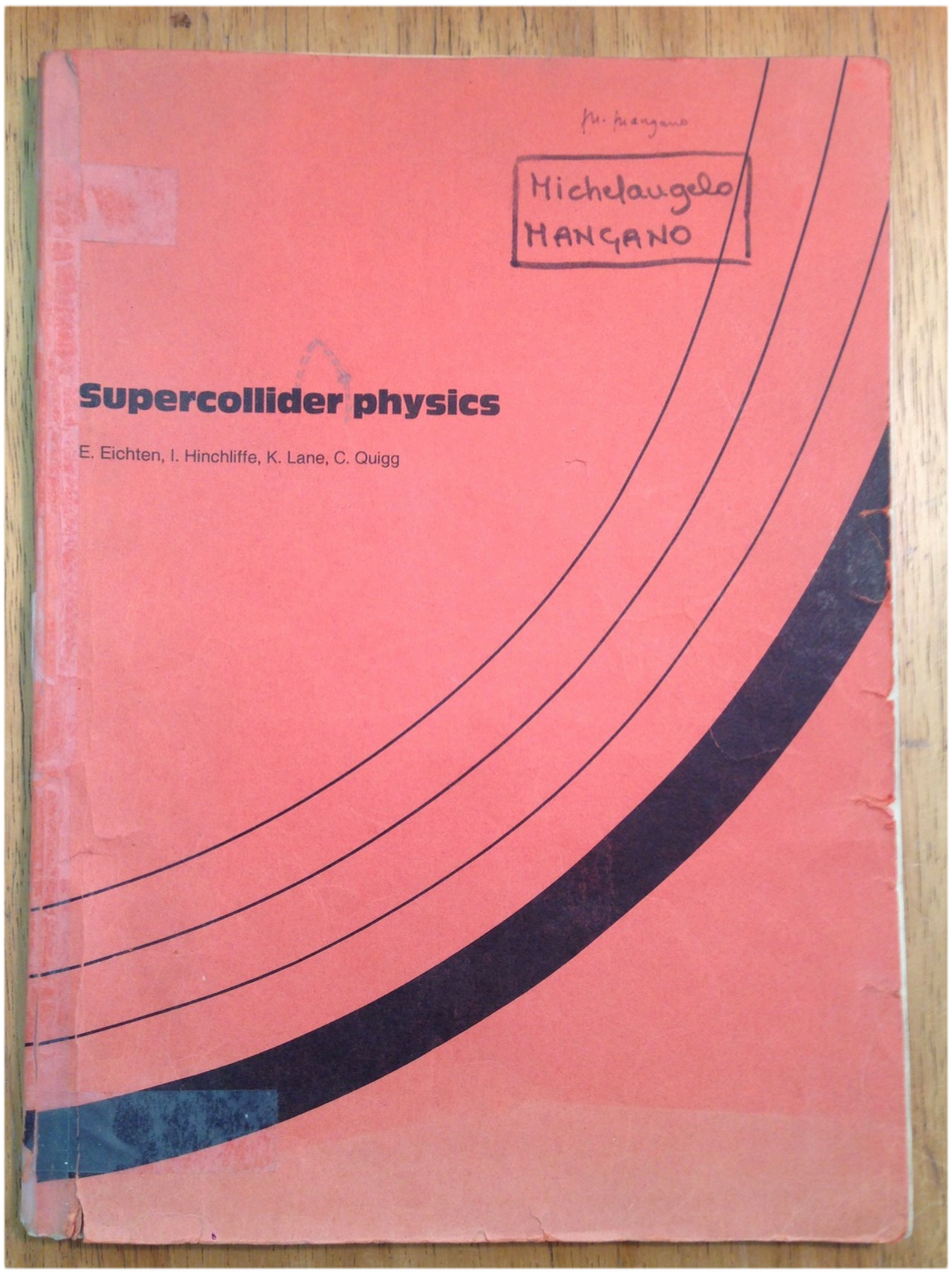
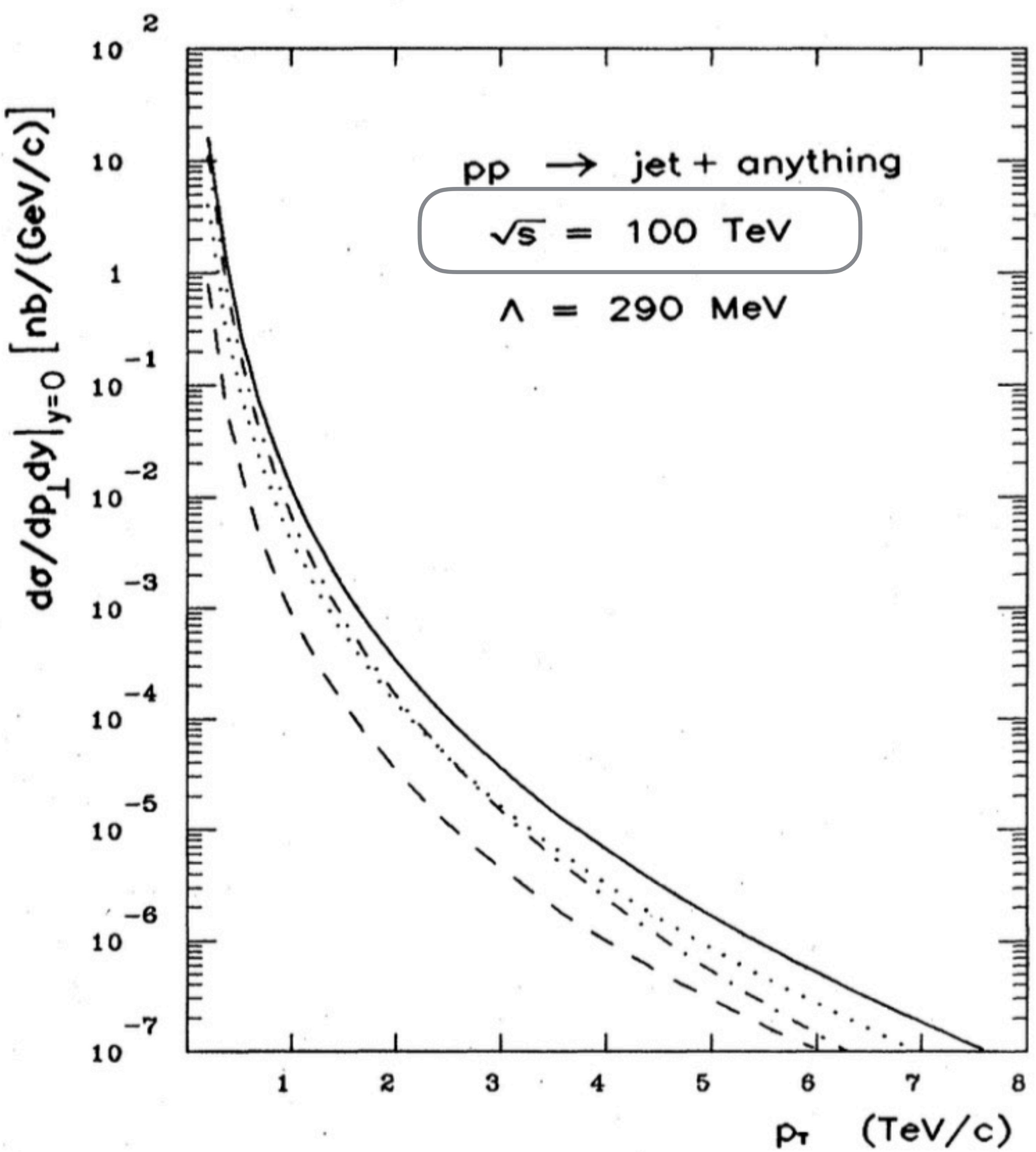
- There is still room to improve SM measurements. 100 TeV implies larger statistics, and extreme kinematical reach, leading to:
  - better precision for parameters
  - higher sensitivity to BSM deviations
- The study of SM processes/bgs at colliders is typically much more complex than that of BSM signatures (requires higher precision, larger final state multiplicities, etc), and in the yrs it's been the main driver of fundamental theoretical progress

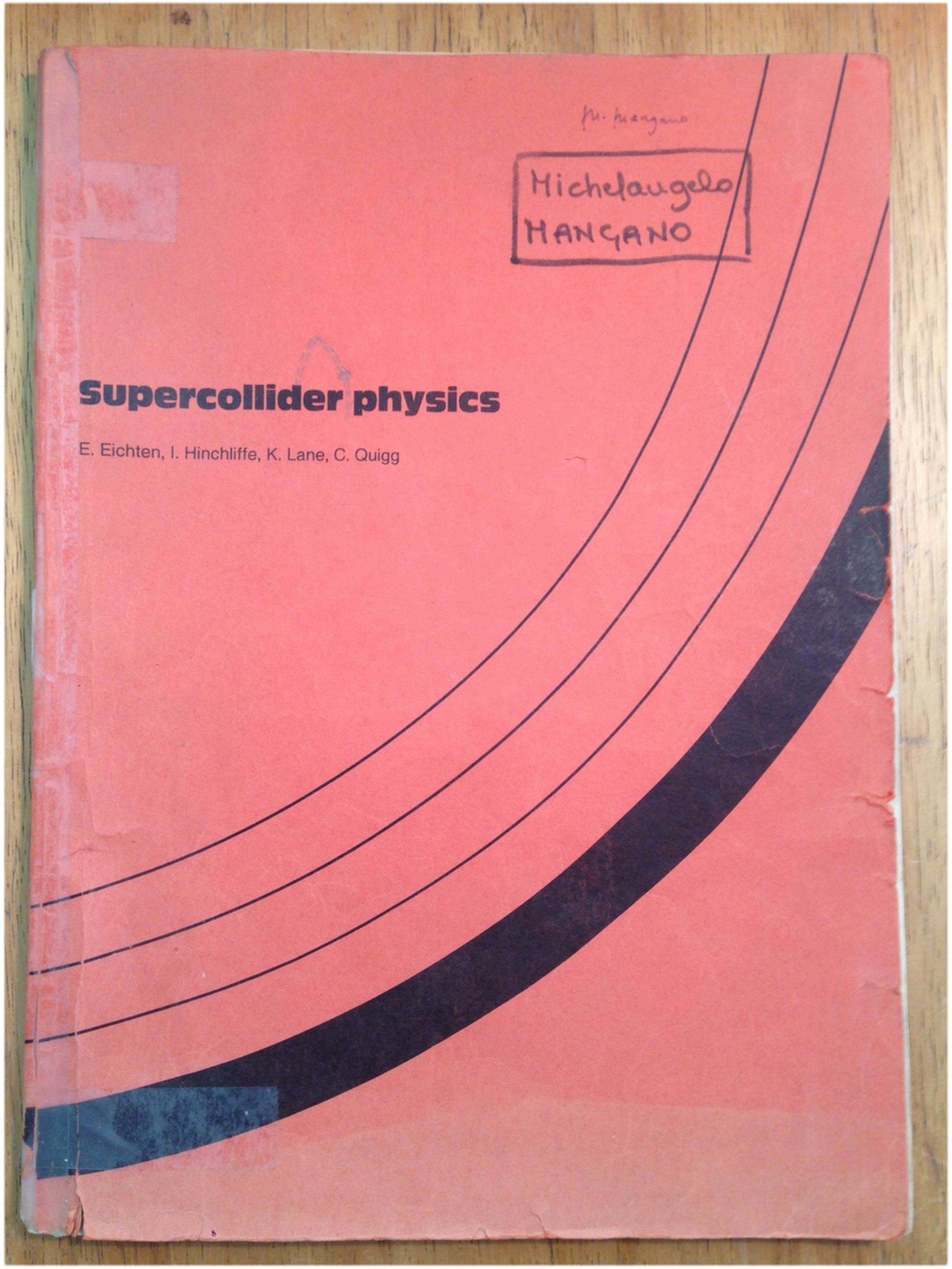
Reviews of Modern Physics, Vol. 56, No. 4, October 1984





EHLQ: Eichten, Hinchliffe, Lane, Quigg

Reviews of Modern Physics, Vol. 56, No. 4, October 1984



For multijet events containing more than three jets, the theoretical situation is considerably more primitive. A specific question of interest concerns the QCD four-jet background to the detection of W^+W^- pairs in their nonleptonic decays. The cross sections for the elementary two$\to$four processes have not been calculated, and their complexity is such that they may not be evaluated in the foreseeable future. It is worthwhile to seek estimates of the four-jet cross sections, even if these are only reliable in restricted regions of phase space.

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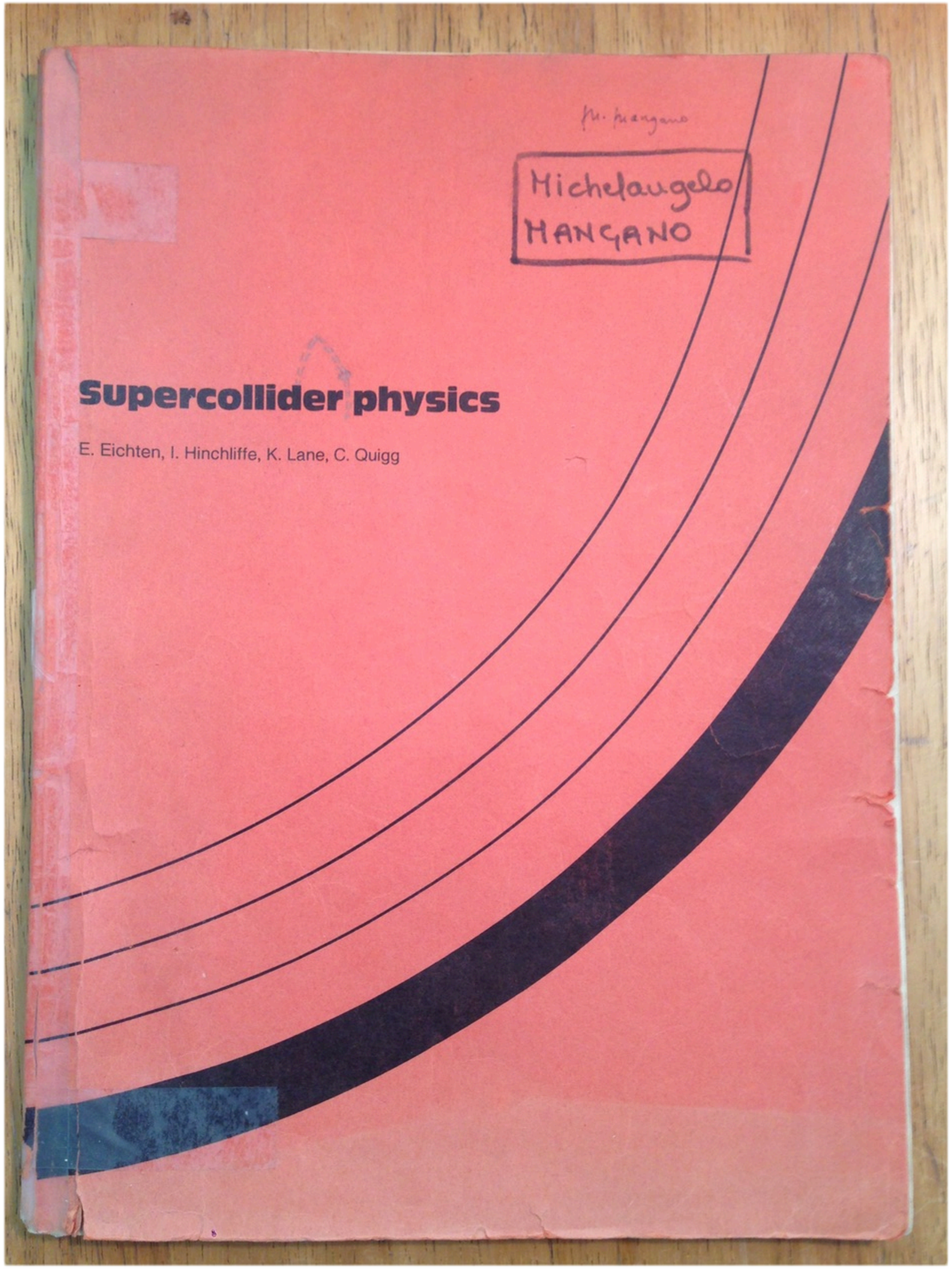

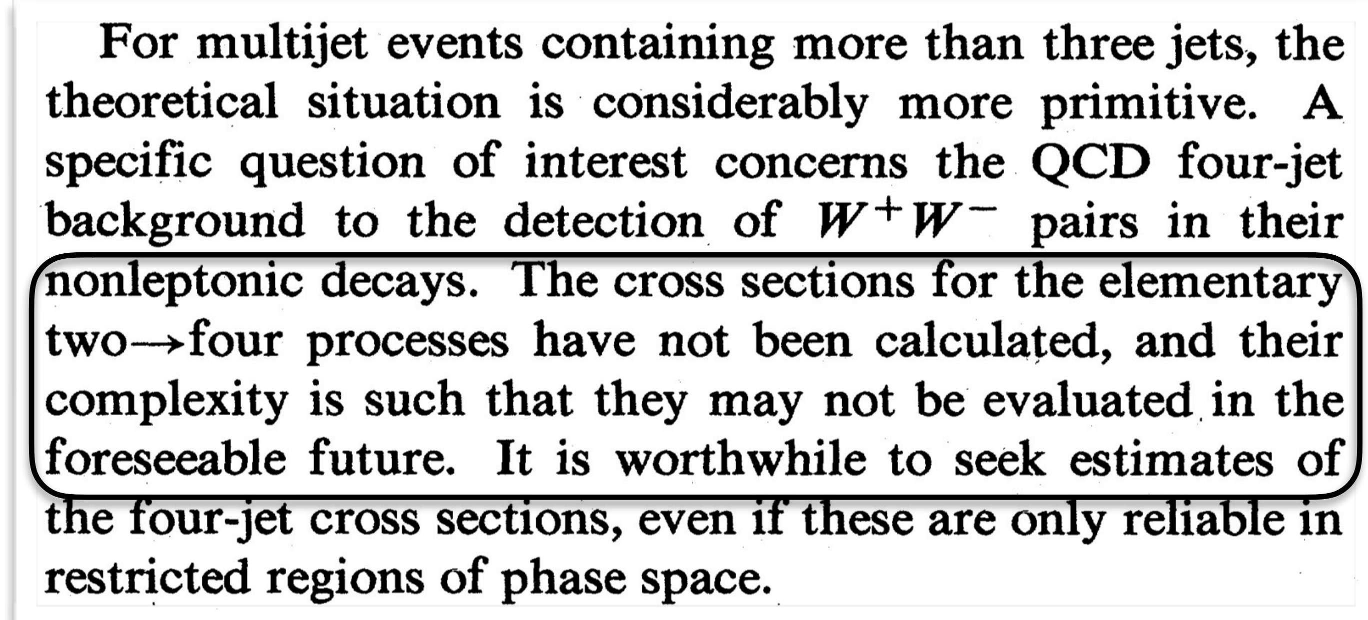

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Those calculations actually became available in the following 12 months, thanks to new ideas (e.g. SUSY relations), which surpassed the potential improvements due to the availability of more powerful computers.

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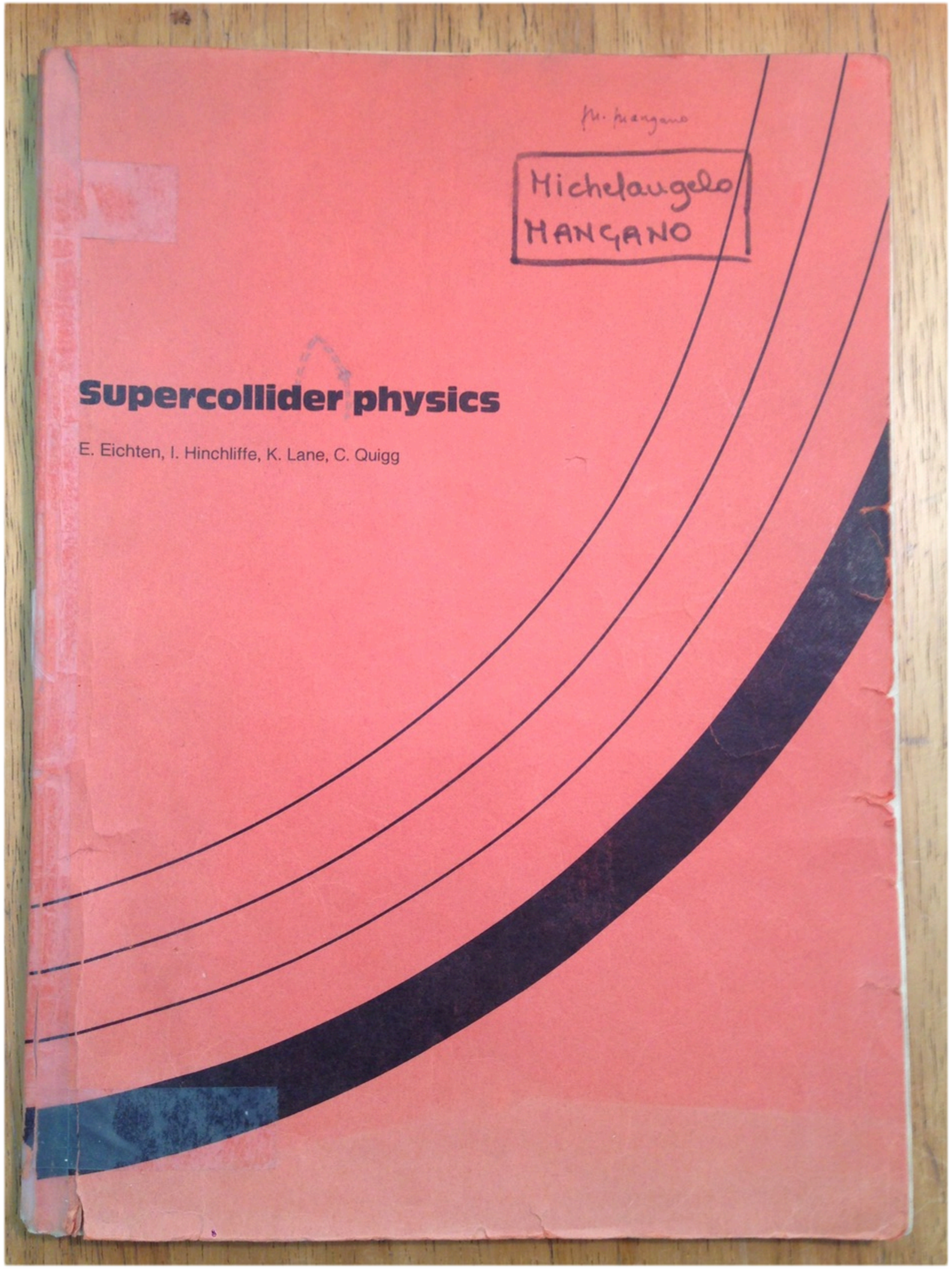

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Those calculations actually became available in the following 12 months, thanks to new ideas (e.g. SUSY relations), which surpassed the potential improvements due to the availability of more powerful computers.

Soon after, came Parke&Taylor relations for MHV amps, the explosion of multi-parton amplitude technology at LO, then NLO, eventually twistors and all that …

Physics at the FCC-hh

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/FutureHadroncollider

- **Volume 1: SM processes** (238 pages)
- **Volume 2: Higgs and EW symmetry breaking studies** (175 pages)
- **Volume 3: beyond the Standard Model phenomena** (189 pages)
- **Volume 4: physics with heavy ions** (56 pages)
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- *

input to forthcoming simulations and studies of detector design and performance assessment

** Flavour physics at FCC-hh will be the subject of a future dedicated study and report*

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Volumes 1–3: to appear on arXiv (next week)

Volume 4: arXiv:1605.01389

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SM chapter of FCC physics report

CERN-TH-2016-112

Physics at a 100 TeV *pp* collider: Standard Model processes

M.L. Mangano[a1], *G. Zanderighi*[a1] *(conveners)*, *J.A. Aguilar Saavedra*[a37], *S. Alekhin*[a30,a38], *S. Badger*[a35], *C.W. Bauer*[a3], *T. Becher*[a4], *V. Bertone*[a2], *M. Bonvini*[a2], *S. Boselli*[a5], *E. Bothmann*[a36], *R. Boughezal*[a32], *M. Cacciari*[a6,a7], *C.M. Carloni Calame*[a10], *F. Caola*[a1], *J. M. Campbell*[a9], *S. Carrazza*[a1], *M. Chiesa*[a10], *L. Cieri*[a28], *F. Cimaglia*[a27], *F. Febres Cordero*[a11], *P. Ferrarese*[a36], *D. D'Enterria*[a70], *G. Ferrera*[a27], *X. Garcia i Tormo*[a4], *M. V. Garzelli*[a30], *E. Germann*[a12], *V. Hirschi*[a13], *T. Han*[a14], *H. Ita*[a11], *B. Jäger*[a15], *S. Kallweit*[a33], *A. Karlberg*[a2], *S. Kuttimalai*[a17], *F. Krauss*[a17], *A. J. Larkoski*[a16], *J. Lindert*[a28], *G. Luisoni*[a1], *P. Maierhöfer*[a34], *O. Mattelaer*[a17], *H. Martinez*[a5], *S. Moch*[a30], *G. Montagna*[a5], *M. Moretti*[a29], *P. Nason*[a18], *O. Nicrosini*[a10], *C. Oleari*[a18], *D. Pagani*[a19], *A. Papaefstathiou*[a1], *F. Petriello*[a31], *F. Piccinini*[a10], *M. Pierini*[a70], *T. Pierog*[a20], *S. Pozzorini*[a28], *E. Re*[a21], *T. Robens*[a22], *J. Rojo*[a2], *R. Ruiz*[a17], *K. Sakurai*[a17], *G. P. Salam*[a1], *L. Salfelder*[a15], *M. Schönherr*[28], *M. Schulze*[a1], *S. Schumann*[a36], *M. Selvaggi*[a19], *A. Shivaji*[a10], *A. Siodmok*[a1,a26], *P. Skands*[a12], *P. Torrielli*[a23], *F. Tramontano*[a24], *I. Tsinikos*[a19], *B. Tweedie*[a14], *A. Vicini*[a27], *S. Westhoff*[a25], *M. Zaro*[a7], *D. Zeppenfeld*[a20]

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Higgs chapter of FCC physics report

CERN-TH-2016-113

Physics at a 100 TeV pp collider: Higgs and EW symmetry breaking studies

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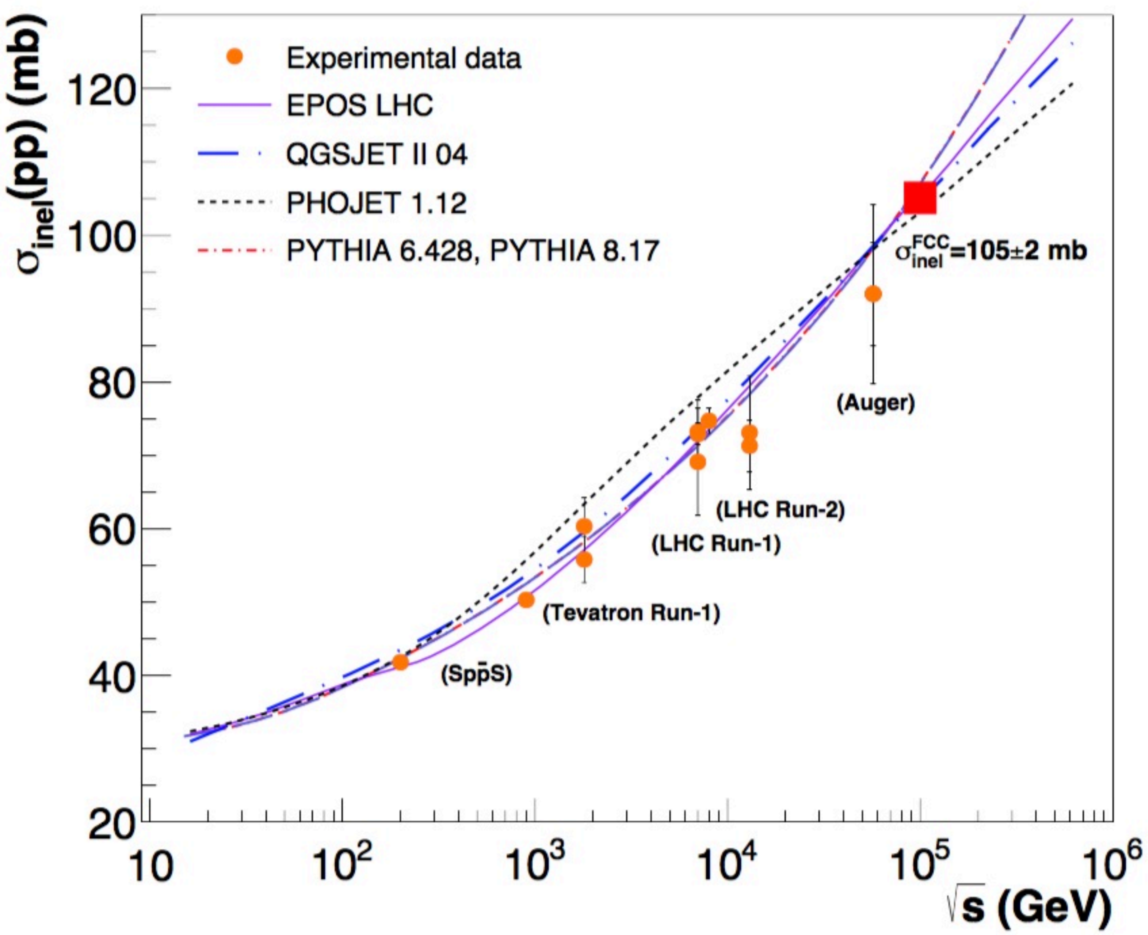
SM

Contents

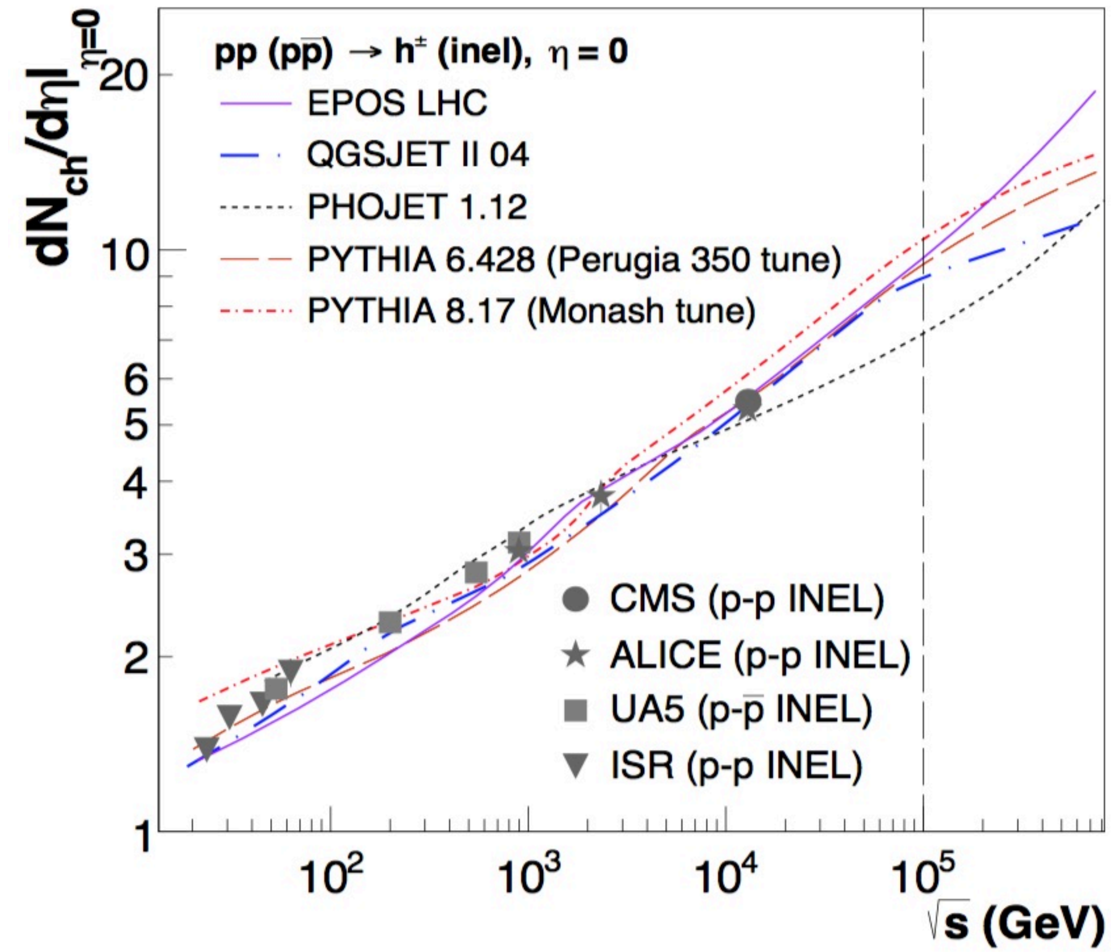
all material for this talk is
taken from the above docs,
which contain more details,
and all proper ref’s

Global event properties

Total inelastic σ ~ 1.4 x LHC



track density @ 90° ~ 1.6 x LHC



=> the overall environment (e.g. pileup) is not much worse than at 14 TeV

	PYTHIA 6	PYTHIA 8	EPOS-LHC	QGSJET-II	PHOJET	Average*
$\sigma_{\rm inel}$ (mb)	106.9	107.1	105.4	104.8	103.1	105.1 ± 2.0
N_{ch} (N_{ch}^{NSD})	131 (150)	160 (170)	161 (184)	152 (172)	101 (121)	150 (170) ± 20
$dN_{ch}/d\eta\|_{\eta=0}$	9.20 ± 0.01	10.10 ± 0.06	9.70 ± 0.16	9.10 ± 0.15	6.90 ± 0.13	9.6 ± 0.2
$dN_{ch}^{NSD}/d\eta\|_{\eta=0}$	10.70 ± 0.06	10.90 ± 0.06	11.10 ± 0.18	10.30 ± 0.17	7.50 ± 0.15	10.8 ± 0.3
$dE/d\eta\|_{\eta=0}$ (GeV)	12.65 ± 0.07	15.65 ± 0.02	13.70 ± 0.02	12.2 ± 0.02	9.9 ± 0.01	13.6 ± 1.5
$dE/d\eta\|_{\eta=5}$ (GeV)	525 ± 4	760 ± 1	700 ± 1	670 ± 1	410 ± 1	670 ± 70
$P(N_{ch} < 5)$	0.28	0.22	0.35	0.36	0.25	–
$P(N_{ch} > 100)$	$3.3 \cdot 10^{-3}$	0.011	0.025	0.018	10^{-5}	–
$\langle p_T \rangle$ (GeV/c)	0.80 ± 0.02	0.84 ± 0.02	0.71 ± 0.02	0.67 ± 0.02	0.73 ± 0.02	0.76 ± 0.07

Uncertainty of individual MCs is from MC statistics

* PHOJET no included in avg

EW gauge bosons

Inclusive rates: 6-7 times larger w.r.t. LHC

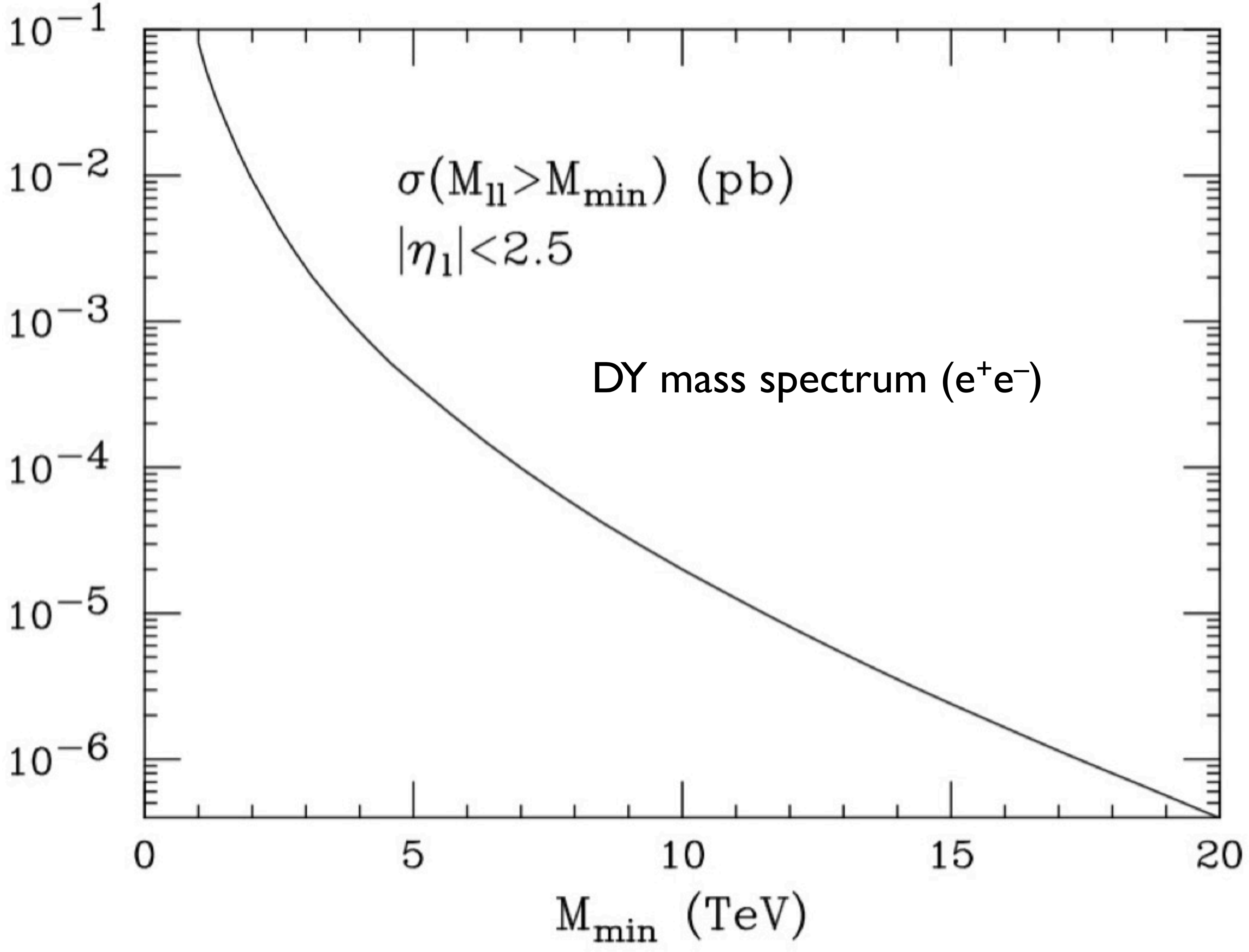
For Lum$_{100\,\text{TeV}}$ ~ 20ab^{-1} => samples ~ 50 x LHC

NNPDF3.0 NNLO					
$\sigma(pp \to V \to l_1 l_2)$ [nb] $(\pm\delta_{\text{pdf}}\sigma)$	14 TeV		100 TeV		
	No cuts	*LHC* cuts	No cuts	*LHC* cuts	*FCC* cuts
W^+	12.2 (2.2%)	6.5 (2.2%)	77.3 (13.1%)	28.3 (3.3%)	54.3 (6.5%)
W^-	9.2 (2.3%)	4.9 (2.3%)	64.3 (8.9%)	27.2 (3.3%)	45.5 (4.0%)
Z	2.1 (2.1%)	1.5 (2.1%)	14.5 (7.7%)	8.3 (3.3%)	12.8 (5.0%)

LHC cuts: p_T^ℓ > 20 GeV, $|\eta_\ell|$<2.5
FCC cuts: p_T^ℓ > 20 GeV, $|\eta_\ell|$<5

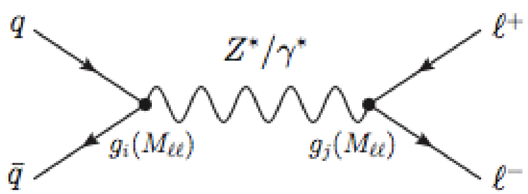
significant deterioration of PDF uncertainty for the total rate, dominated by the systematics at small/large x (large rapidity)

DY mass reach

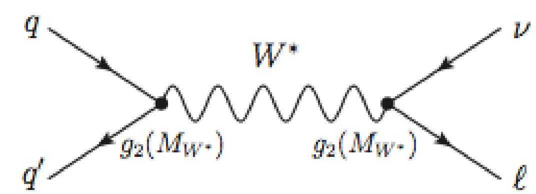


Running Electroweak Couplings at 100 TeV, as a Probe of New Physics

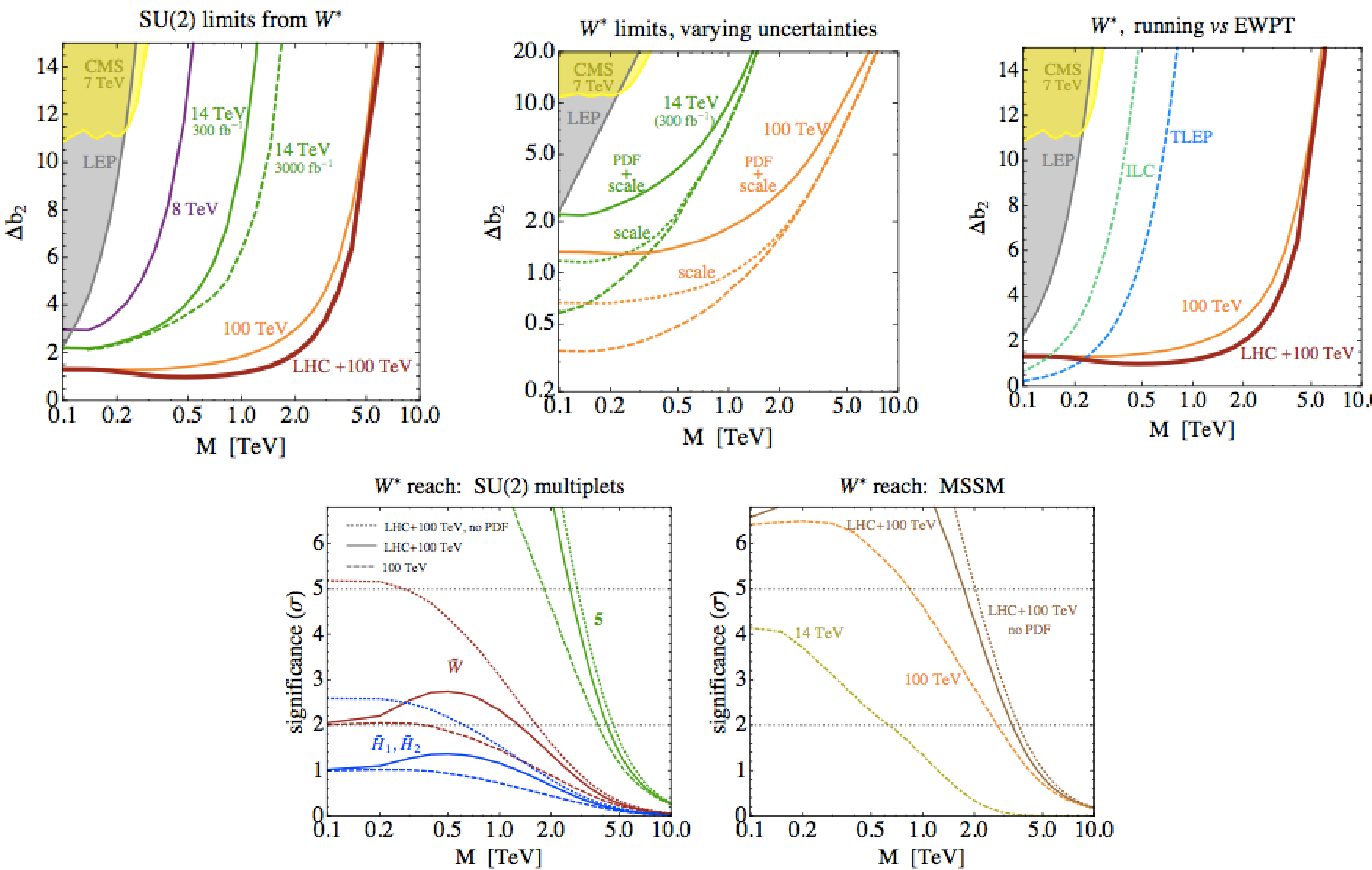
D.Alves, J. Galloway, J.Ruderman, J.Walsh *arXiv:1410.6810*



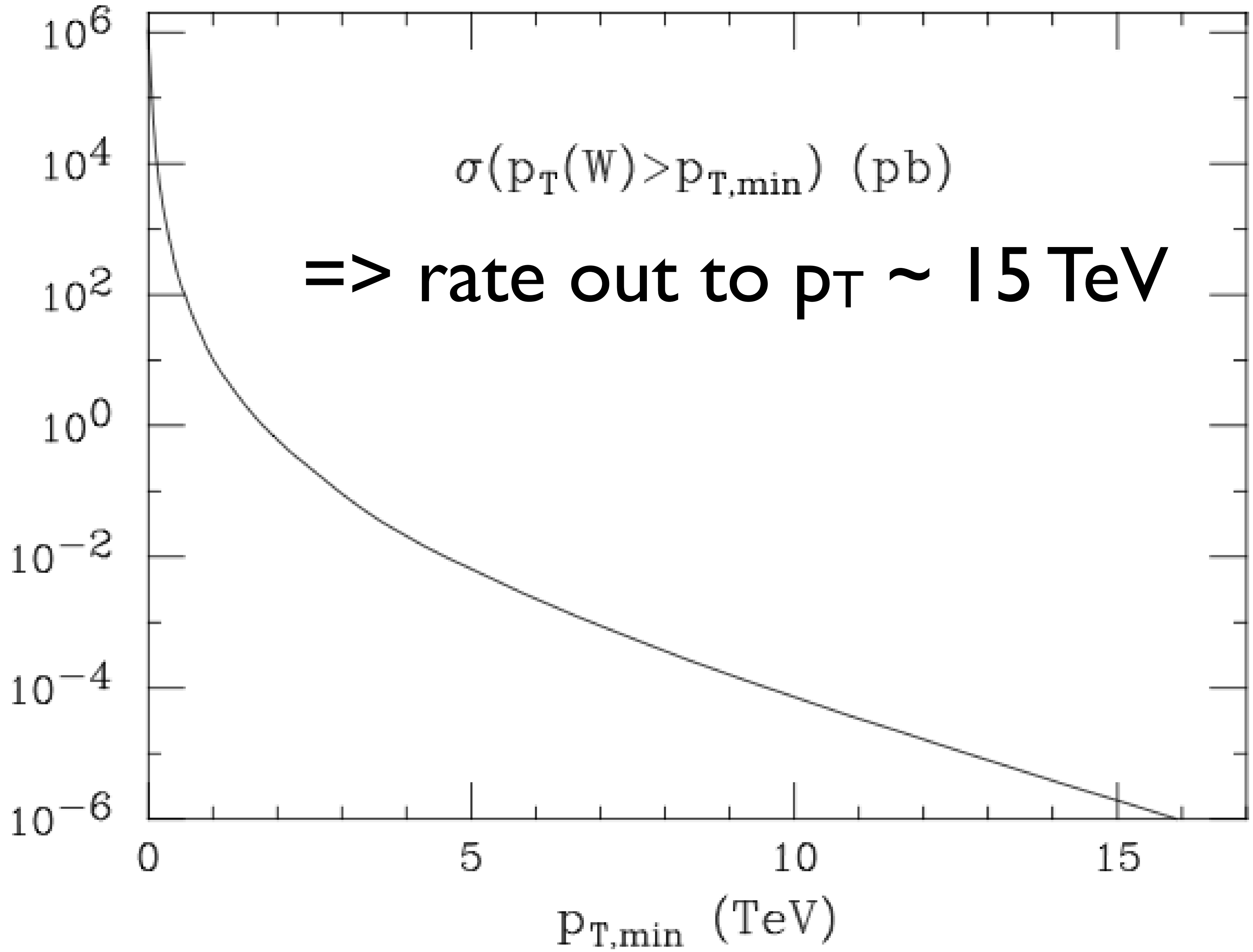
$$\frac{d\sigma}{dm_{ll}} \Rightarrow \alpha_{1,2}(q)$$



$$\frac{d\sigma}{dM_T} \Rightarrow \alpha_2(q)$$

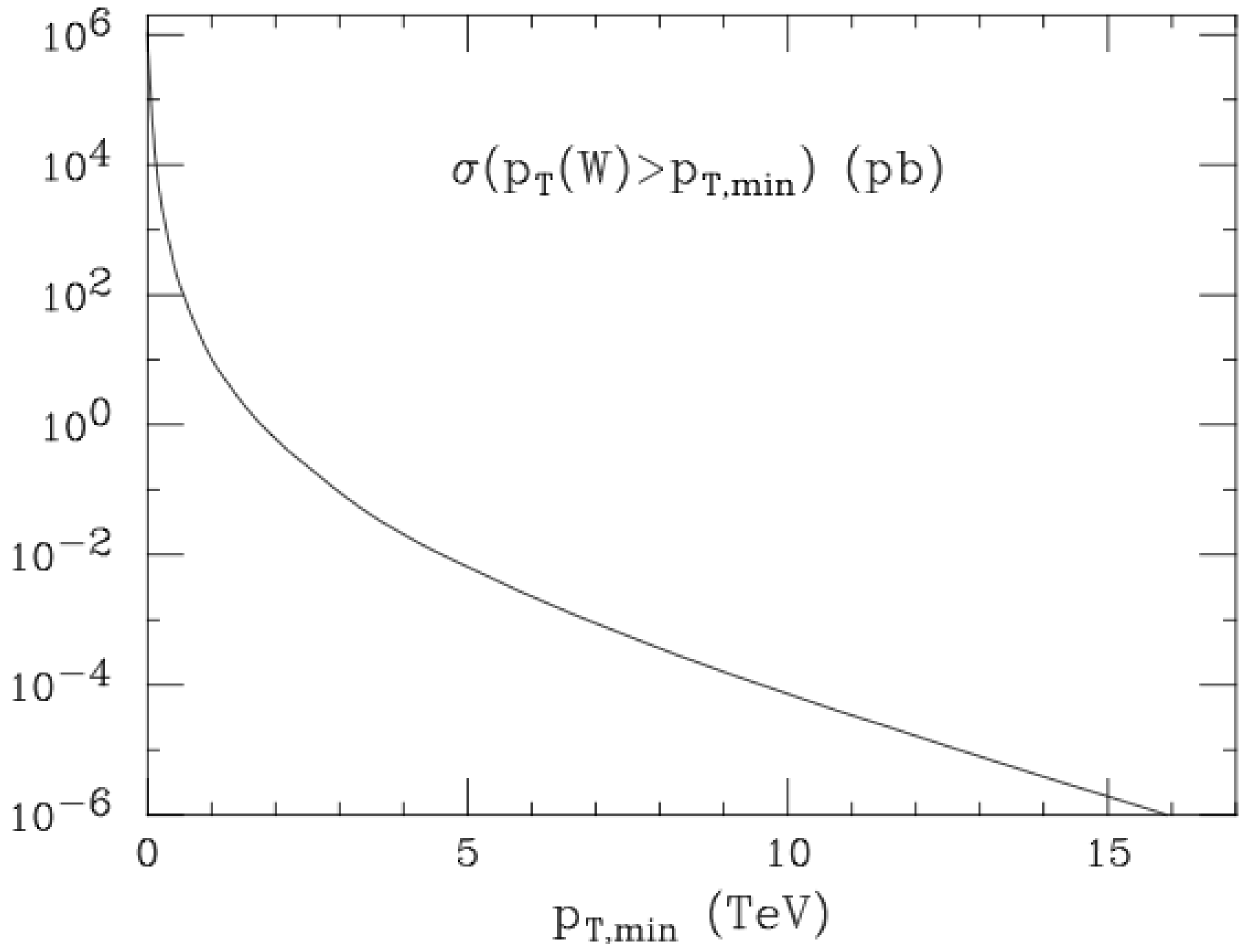


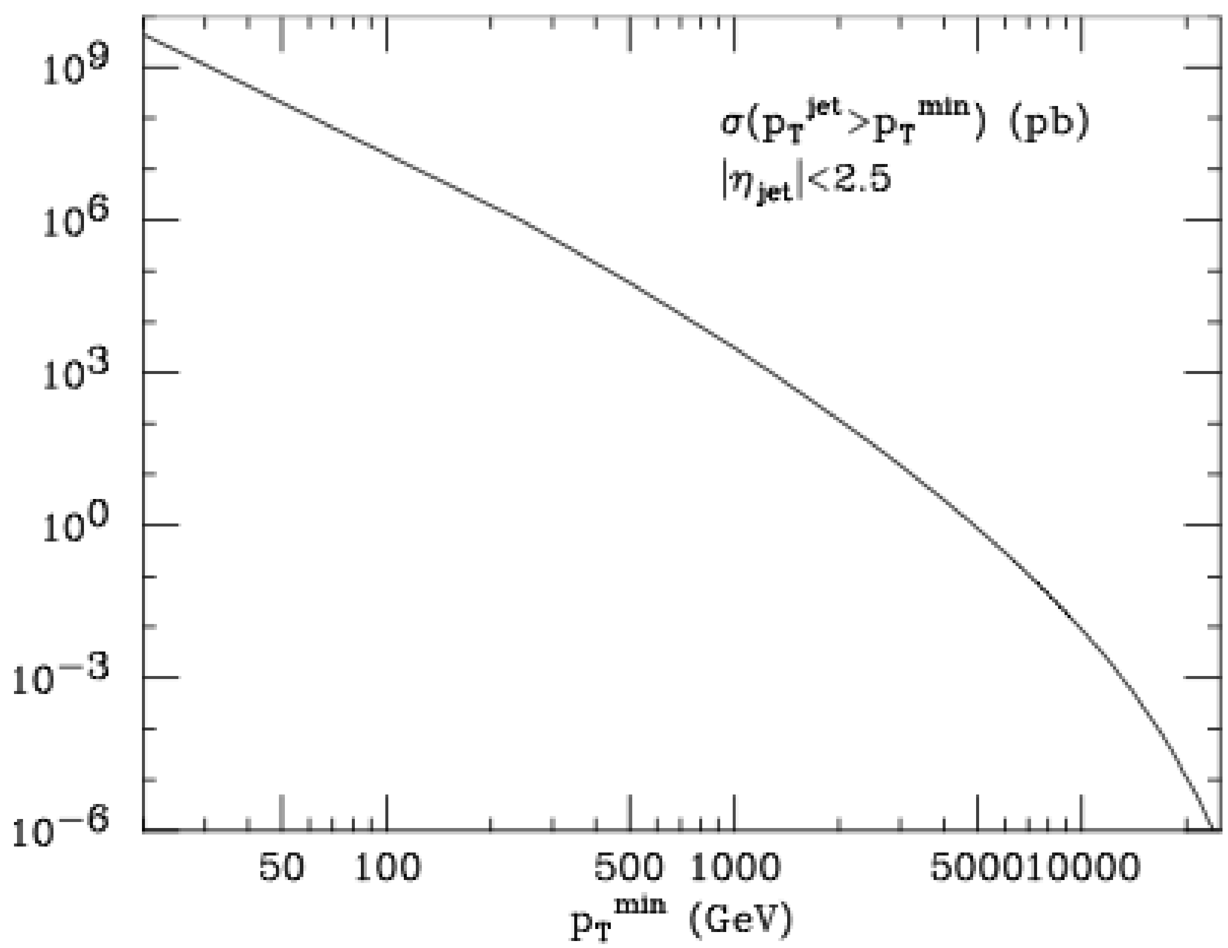
W production at large pt



Possible implications:

- $W \to \ell\nu$ source of MET in the multi-TeV region
- Can use hadronic W and/or Z decays to control MET systematics? (larger statistics than leptonic channels at high MET)





to which extend will it be possible to use systematically hadronic W/Z decays?

Jet structure at multi-TeV energies

Jets' energy shape: $E(r<R) / E_{jet}$
($\Rightarrow$ calorimeter granularity, tracker)

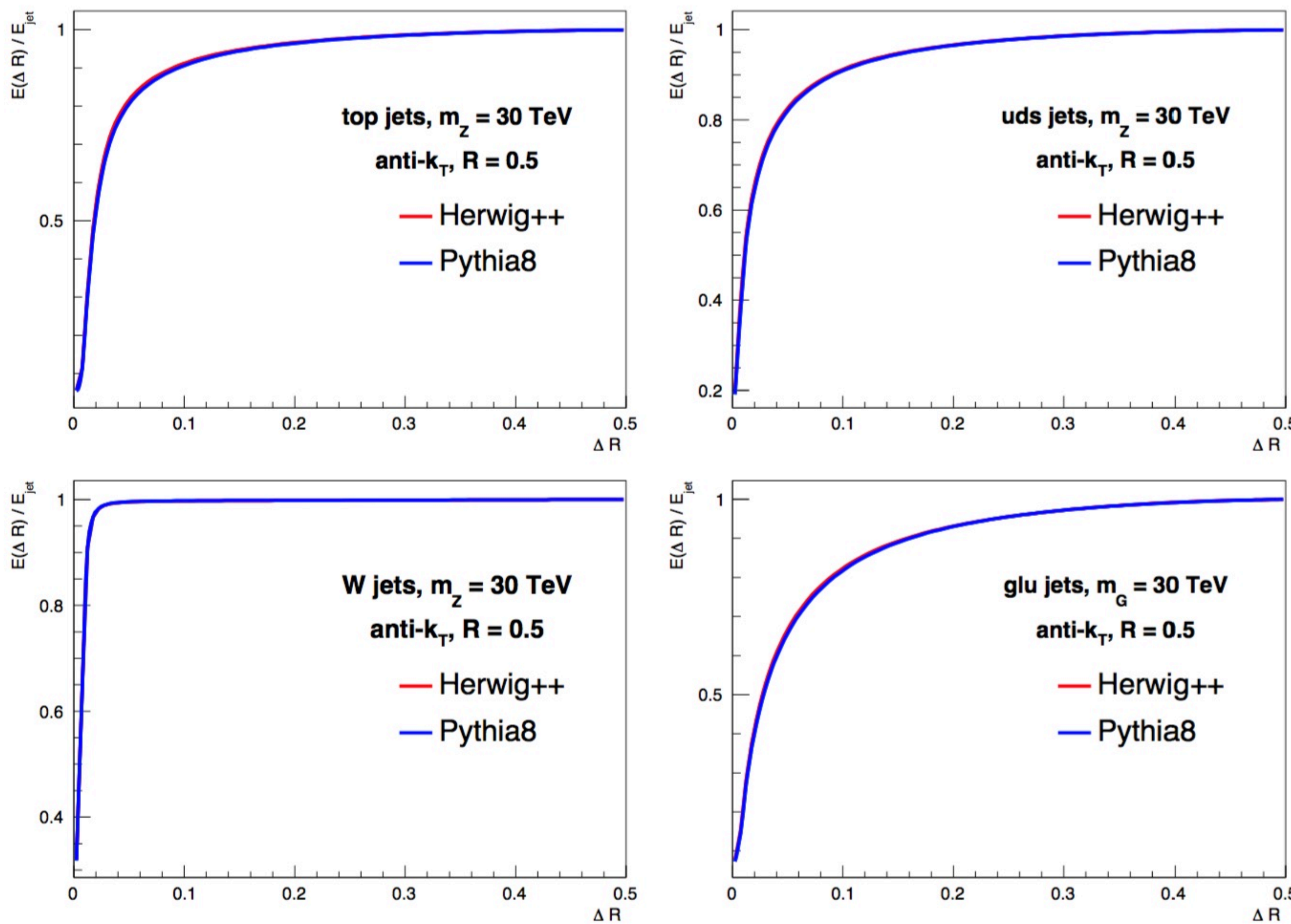
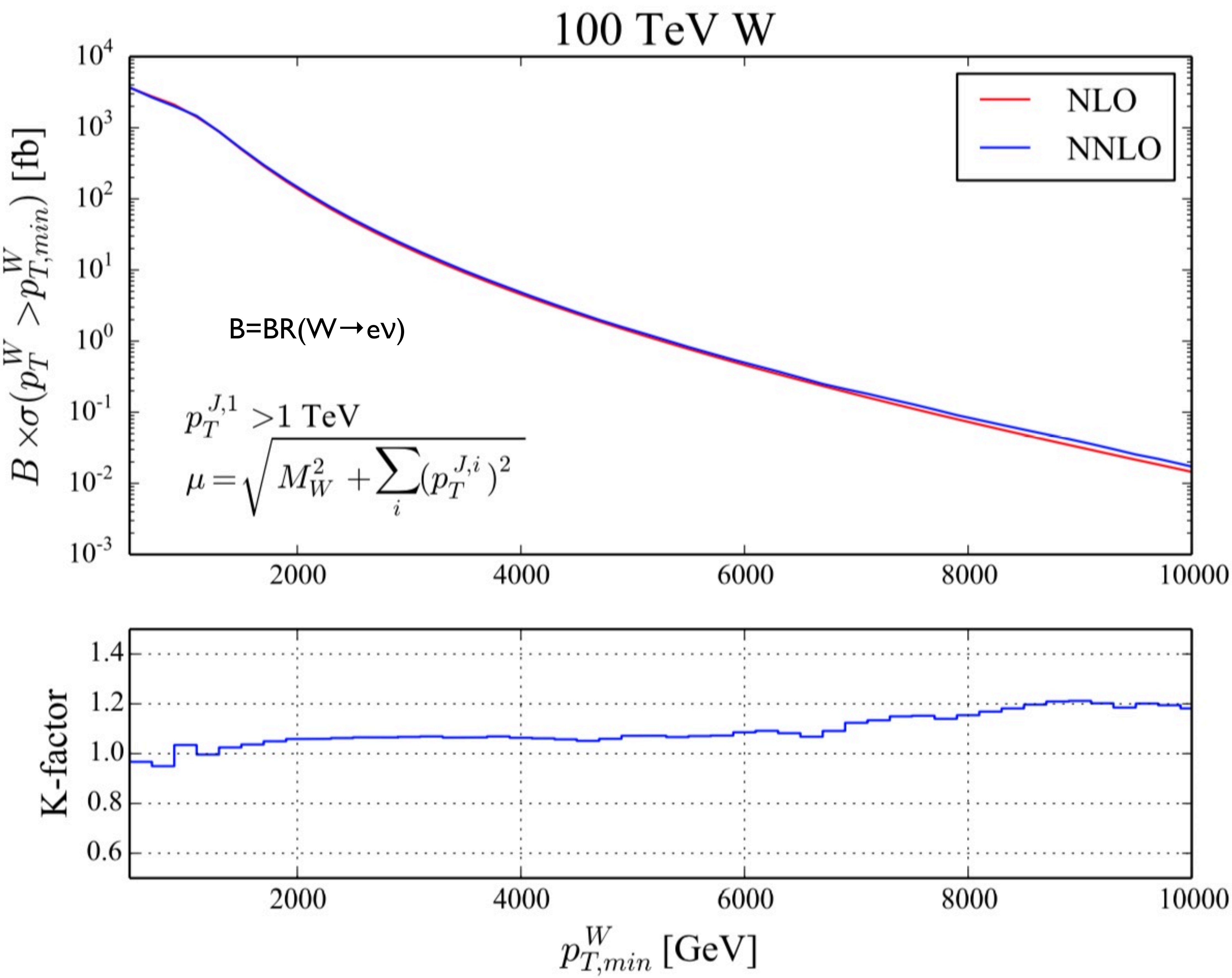
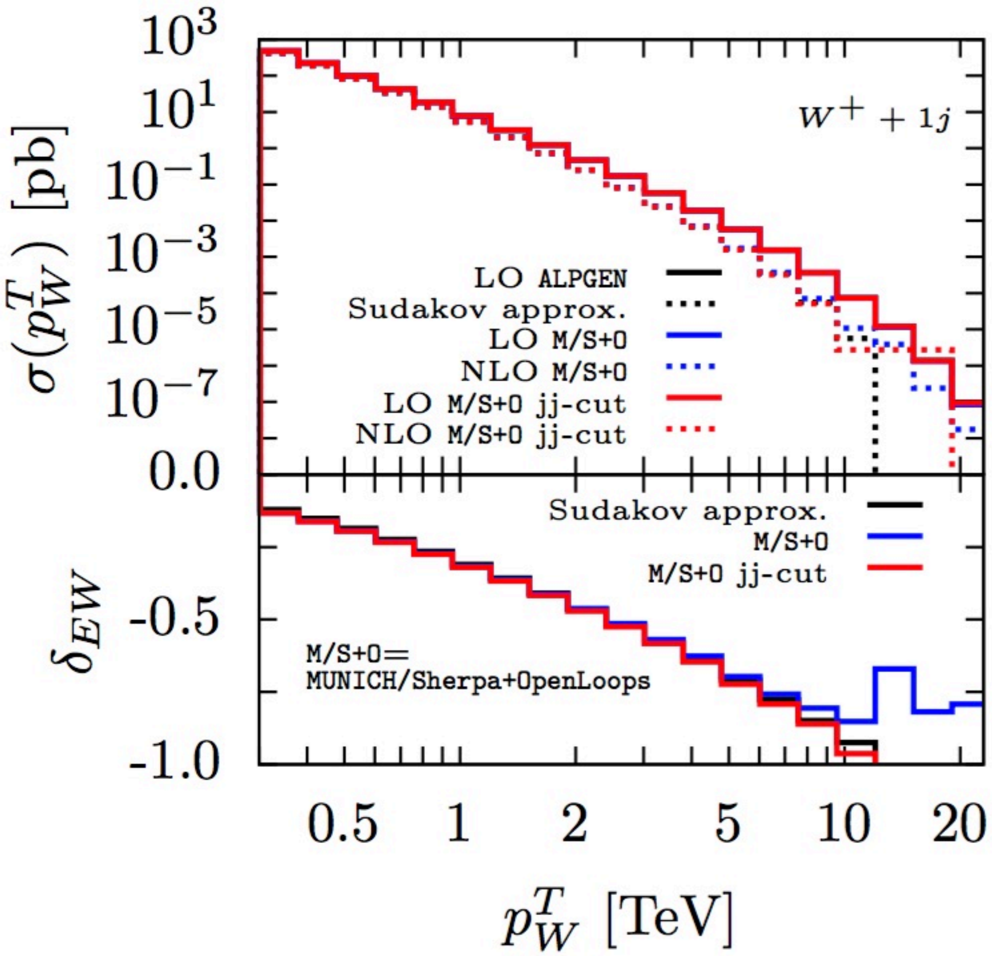


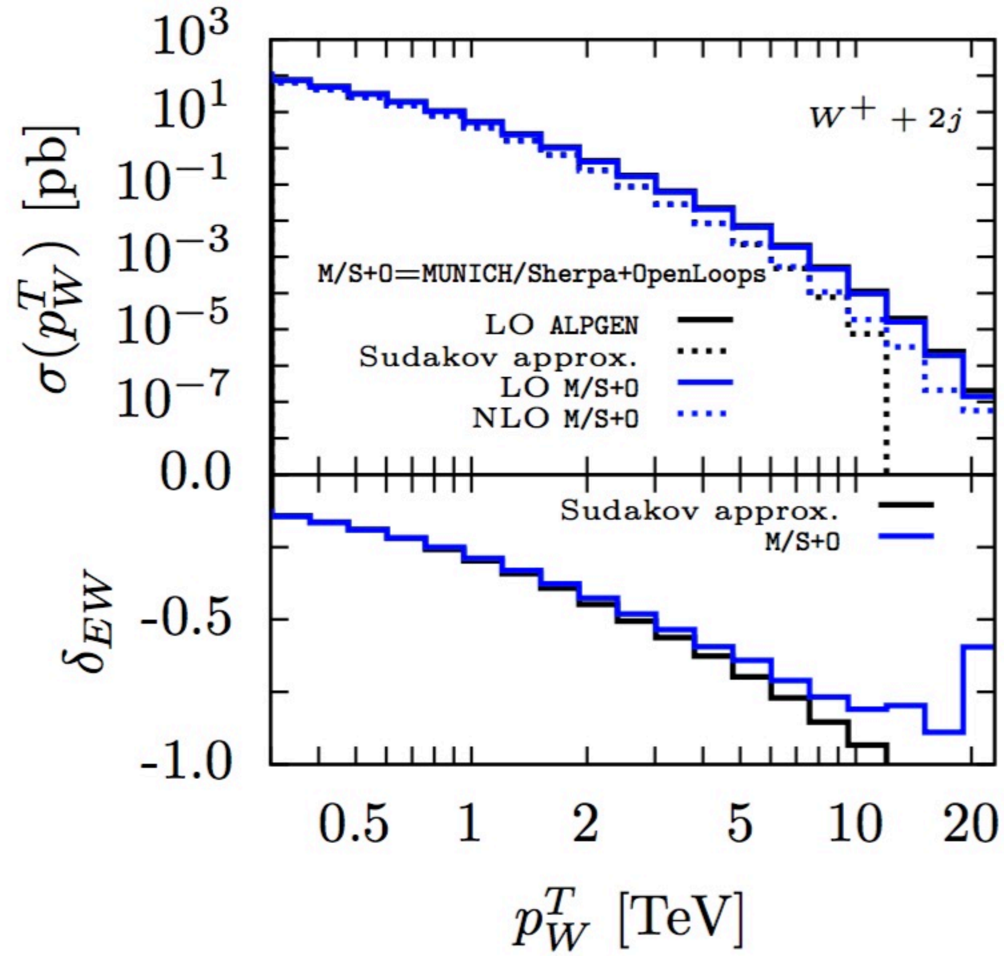
Fig. 116: Average energy fraction contained within and angular scale ΔR of jets produced from 30 TeV resonance decays to tops, light QCD quarks, Ws, and gluons.

precision: status

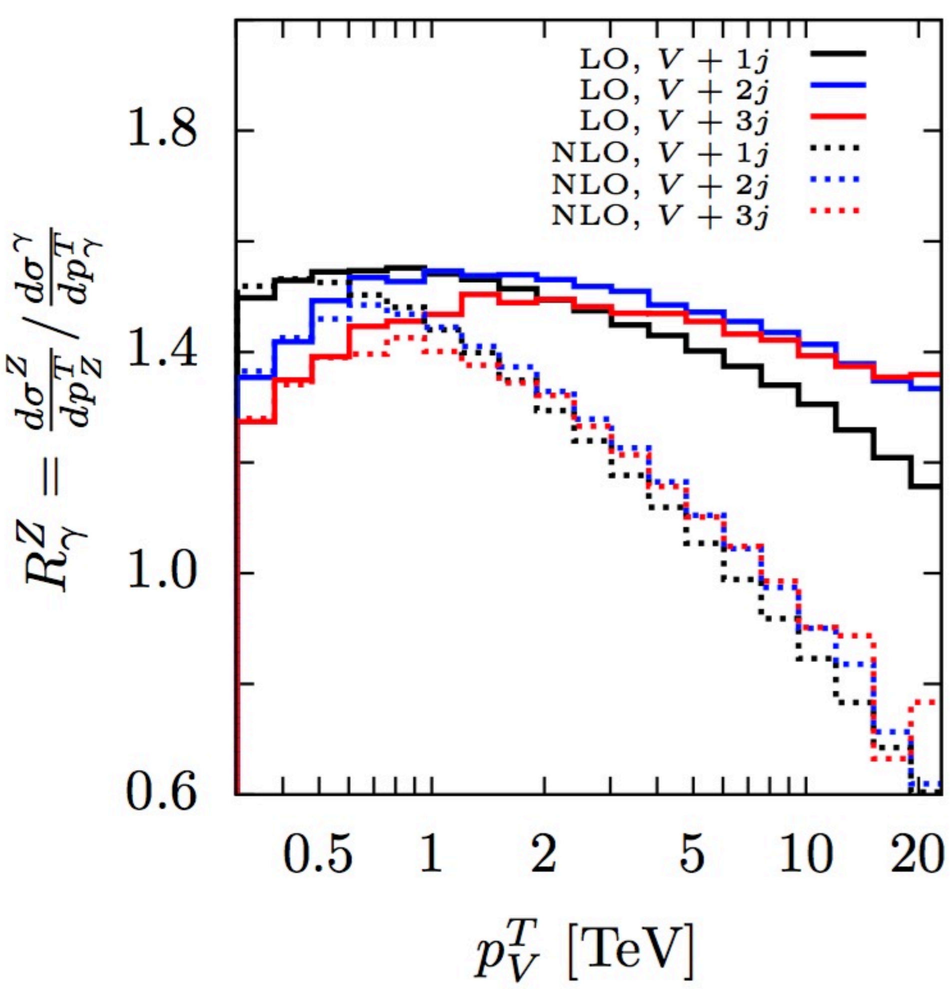


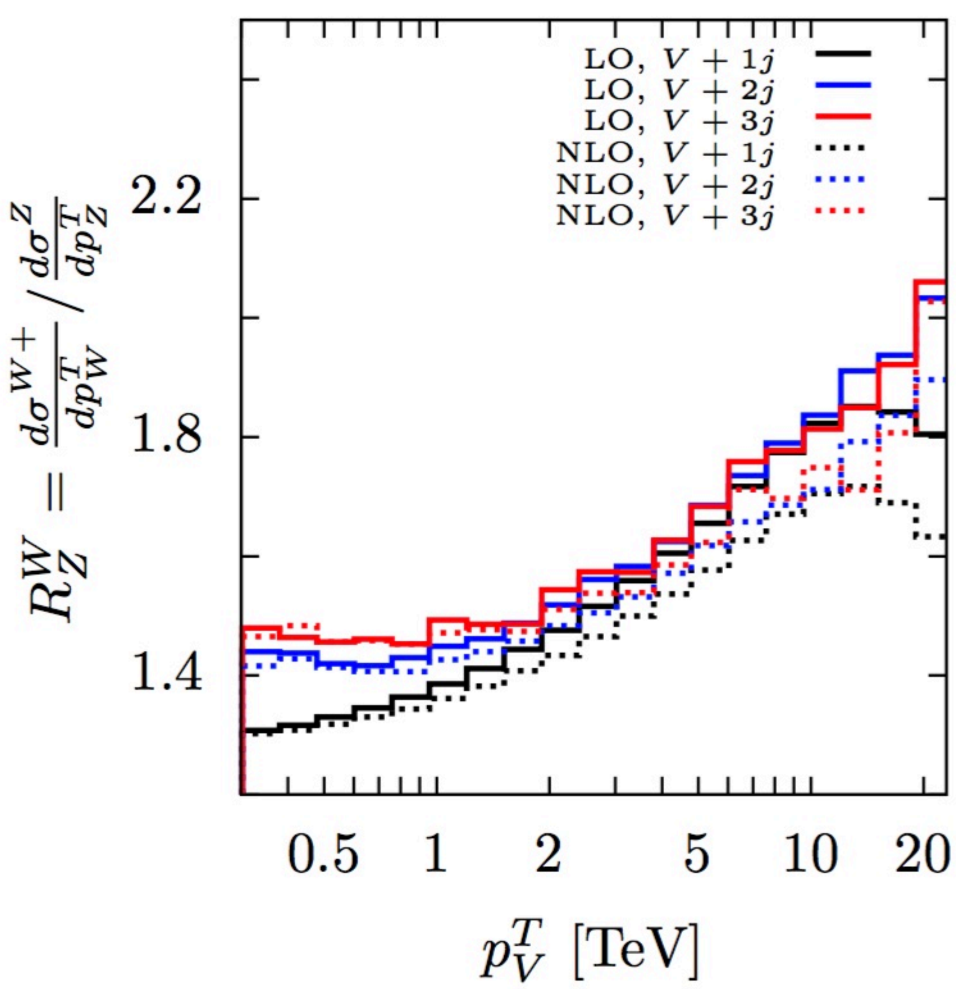
Precision will require improved control over higher-order EW corrections





N.B.
W/Z/γ receive very different EW corrections at large p_T





Multiple gauge boson production

EW procs (NLO rates)

Process	σ_{NLO}(8 TeV) [fb]	σ_{NLO}(100 TeV) [fb]	ρ
$pp \to W^+W^-W^\pm$ (4FS)	$8.73 \cdot 10^{1}\ ^{+6\%}_{-4\%}\ ^{+2\%}_{-2\%}$	$4.25 \cdot 10^{3}\ ^{+9\%}_{-9\%}\ ^{+1\%}_{-1\%}$	49
$pp \to W^+W^-Z$ (4FS)	$6.41 \cdot 10^{1}\ ^{+7\%}_{-5\%}\ ^{+2\%}_{-2\%}$	$4.01 \cdot 10^{3}\ ^{+9\%}_{-9\%}\ ^{+1\%}_{-1\%}$	63
$pp \to W^\pm ZZ$	$2.16 \cdot 10^{1}\ ^{+7\%}_{-6\%}\ ^{+2\%}_{-2\%}$	$1.36 \cdot 10^{3}\ ^{+10\%}_{-10\%}\ ^{+1\%}_{-1\%}$	63
$pp \to ZZZ$	$5.97 \cdot 10^{0}\ ^{+3\%}_{-3\%}\ ^{+2\%}_{-2\%}$	$2.55 \cdot 10^{2}\ ^{+5\%}_{-7\%}\ ^{+2\%}_{-1\%}$	43
$pp \to W^+W^-W^\pm Z$ (4FS)	$3.48 \cdot 10^{-1}\ ^{+8\%}_{-7\%}\ ^{+2\%}_{-2\%}$	$5.95 \cdot 10^{1}\ ^{+7\%}_{-7\%}\ ^{+1\%}_{-1\%}$	171
$pp \to W^+W^-W^+W^-$ (4FS)	$3.01 \cdot 10^{-1}\ ^{+7\%}_{-6\%}\ ^{+2\%}_{-2\%}$	$4.11 \cdot 10^{1}\ ^{+7\%}_{-6\%}\ ^{+1\%}_{-1\%}$	137
$pp \to W^+W^-ZZ$ (4FS)	$2.01 \cdot 10^{-1}\ ^{+7\%}_{-6\%}\ ^{+2\%}_{-2\%}$	$3.34 \cdot 10^{1}\ ^{+6\%}_{-6\%}\ ^{+1\%}_{-1\%}$	166
$pp \to W^\pm ZZZ$	$3.40 \cdot 10^{-2}\ ^{+10\%}_{-8\%}\ ^{+2\%}_{-2\%}$	$7.06 \cdot 10^{0}\ ^{+8\%}_{-7\%}\ ^{+1\%}_{-1\%}$	208
$pp \to ZZZZ$	$8.72 \cdot 10^{-3}\ ^{+4\%}_{-4\%}\ ^{+3\%}_{-2\%}$	$8.05 \cdot 10^{-1}\ ^{+4\%}_{-4\%}\ ^{+2\%}_{-1\%}$	92
$pp \to ZZZZZ$	$1.07 \cdot 10^{-5}\ ^{+5\%}_{-4\%}\ ^{+3\%}_{-2\%}$	$2.04 \cdot 10^{-3}\ ^{+3\%}_{-3\%}\ ^{+2\%}_{-1\%}$	191

tt+X procs (NLO rates)

Process	σ_{NLO}(8 TeV) [fb]	σ_{NLO}(100 TeV) [fb]	ρ
$pp \to t\bar{t}t\bar{t}$	$1.71 \cdot 10^{0}\ ^{+25\%}_{-26\%}\ ^{+8\%}_{-8\%}$	$4.93 \cdot 10^{3}\ ^{+25\%}_{-21\%}\ ^{+2\%}_{-2\%}$	2883
$pp \to t\bar{t}Z$	$1.99 \cdot 10^{2}\ ^{+10\%}_{-12\%}\ ^{+3\%}_{-3\%}$	$5.63 \cdot 10^{4}\ ^{+9\%}_{-10\%}\ ^{+1\%}_{-1\%}$	282
$pp \to t\bar{t}W^\pm$	$2.05 \cdot 10^{2}\ ^{+9\%}_{-10\%}\ ^{+2\%}_{-2\%}$	$1.68 \cdot 10^{4}\ ^{+18\%}_{-16\%}\ ^{+1\%}_{-1\%}$	82
$pp \to t\bar{t}W^+W^-$ (4FS)	$2.27 \cdot 10^{0}\ ^{+11\%}_{-13\%}\ ^{+3\%}_{-3\%}$	$1.10 \cdot 10^{3}\ ^{+9\%}_{-9\%}\ ^{+1\%}_{-1\%}$	486
$pp \to t\bar{t}W^\pm Z$	$9.71 \cdot 10^{-1}\ ^{+10\%}_{-11\%}\ ^{+3\%}_{-2\%}$	$1.68 \cdot 10^{2}\ ^{+16\%}_{-13\%}\ ^{+1\%}_{-1\%}$	173
$pp \to t\bar{t}ZZ$	$4.47 \cdot 10^{-1}\ ^{+8\%}_{-10\%}\ ^{+3\%}_{-2\%}$	$1.58 \cdot 10^{2}\ ^{+15\%}_{-12\%}\ ^{+1\%}_{-1\%}$	353

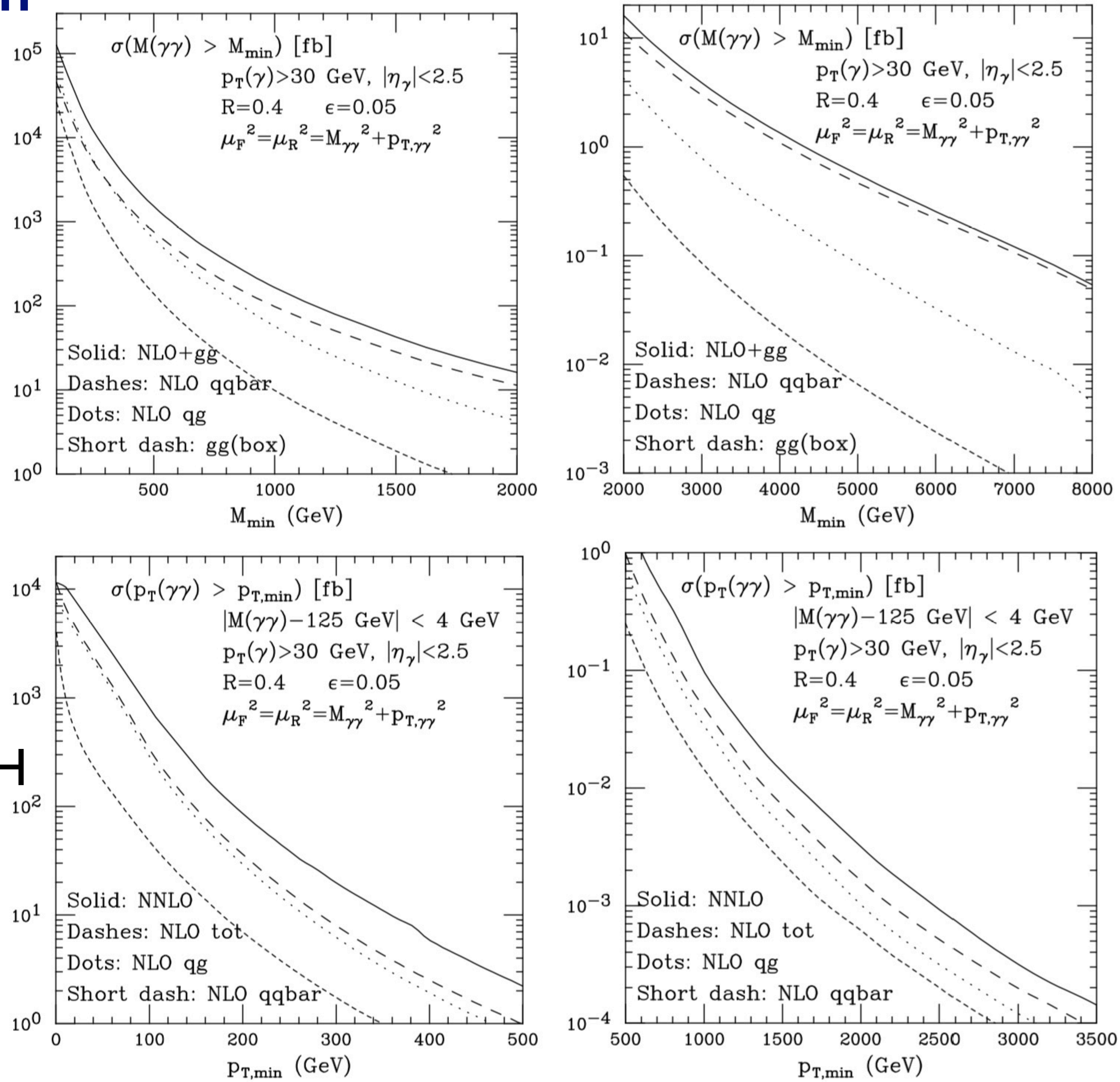
tops are the dominant source of multi-W's

	EW	tt+X
WW	1.1 nb	35 nb
WWW	4.3 pb	17 pb
WWZ	4 pb	56 pb
WWWW	0.04 pb	6 pb
WWWZ	60 fb	170 fb
WWZZ	33 fb	160 fb

γγ production

high $M_{\gamma\gamma}$

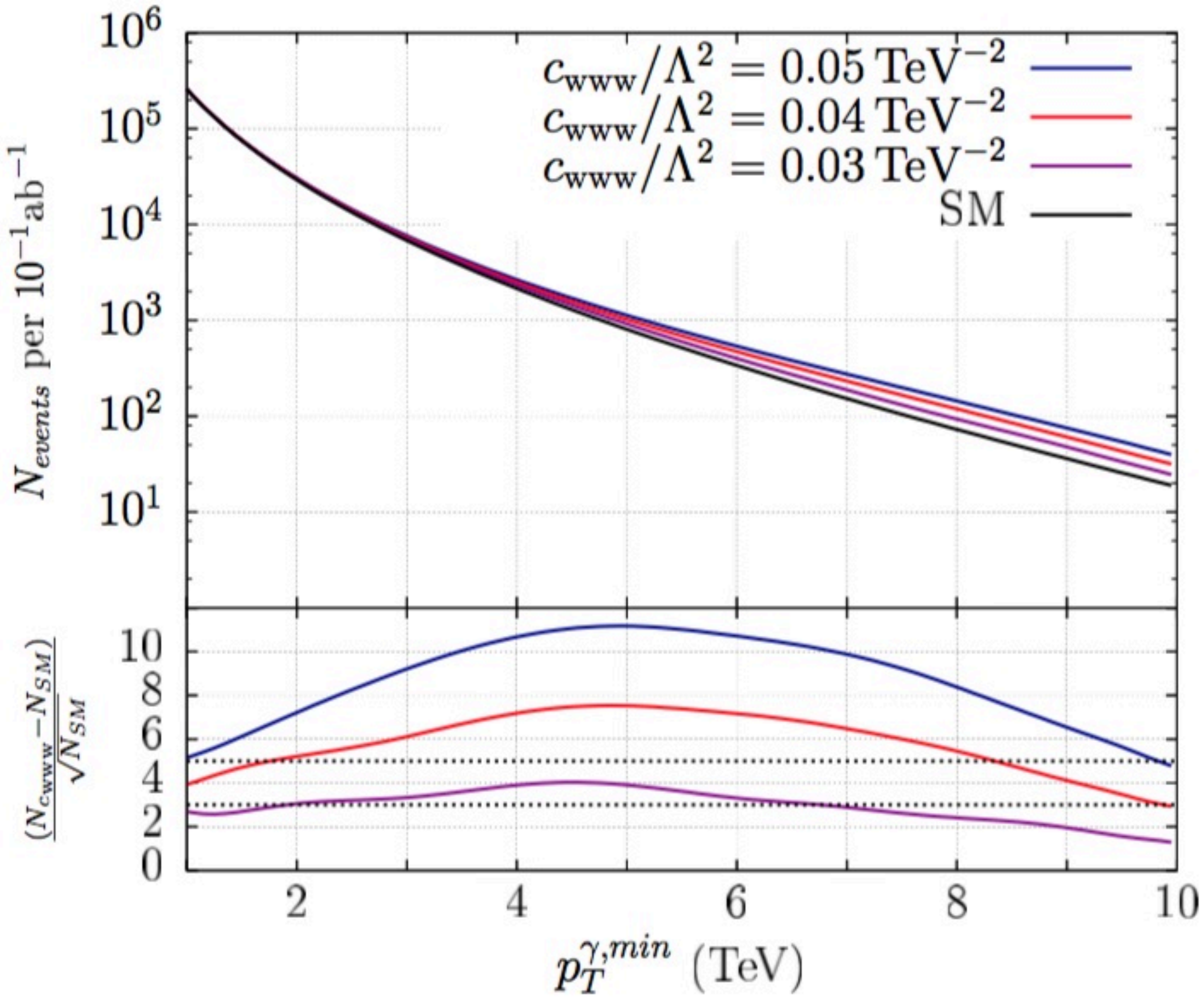
high $p_{T,\gamma\gamma}$ in the H mass window

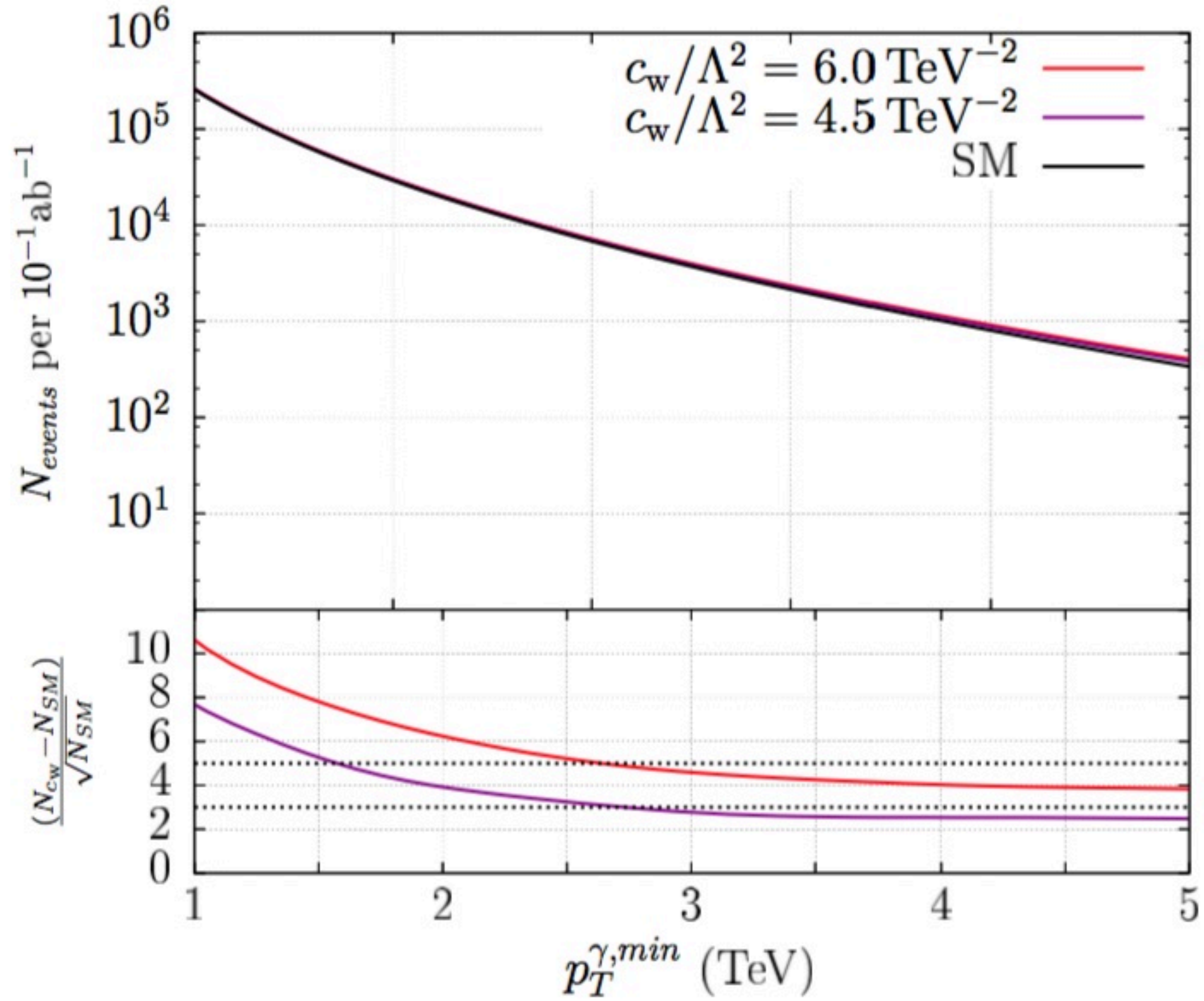


Sensitivity to anomalous gauge couplings from Wγ production

$$\mathcal{L}_{TGC} = ig_{WWV}\left(g_1^V(W^+_{\mu\nu}W^{-\nu} - W^{+\mu}W^-_{\mu\nu})V_\nu + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W_\mu^{+\nu} W_\nu^{-\rho} V_\rho^\mu\right),$$

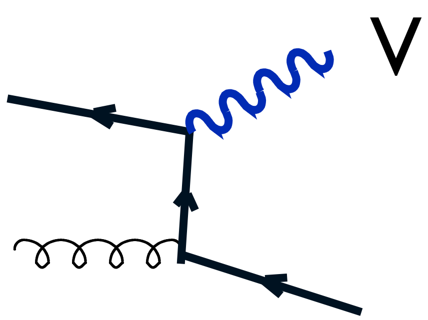
$$g_1^Z = 1 + c_{\rm w}\frac{m_Z^2}{2\Lambda^2},$$
$$\kappa_\gamma = 1 + (c_{\rm w} + c_{\rm b})\frac{m_W^2}{2\Lambda^2},$$
$$\kappa_Z = 1 + (c_{\rm w} - c_{\rm b}\tan^2\theta_W)\frac{m_W^2}{2\Lambda^2},$$
$$\lambda_\gamma = \lambda_Z = c_{\rm www}\frac{3g^2 m_W^2}{2\Lambda^2}.$$



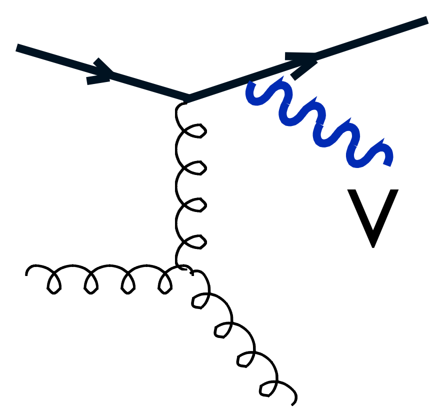


Production of gauge bosons in high-energy final states ($\sqrt{s} \gg M_V$)

$O(\alpha_S)$



$\Rightarrow \sqrt{s} \approx p_T^V \gg M_V$



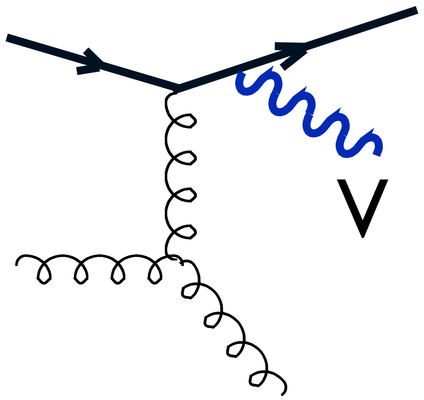
$O(\alpha_S^2)$, but enhanced by t-channel g exchange, and by $\log(p_T^{jet}/M_W)$

$\Rightarrow$ could be larger than $O(\alpha_S)$
$\Rightarrow$ no strong ordering between p_T^V and M_V

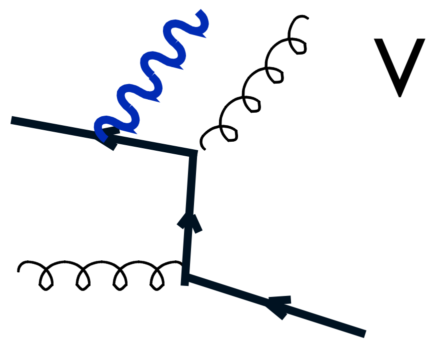
- Need to include $O(\alpha_S^2)$ in order to capture all sources of V production.
- This requires, in principle, the complete $O(\alpha_S^2)$ calculation, inclusive of virtual corrections to $O(\alpha_S)$.
- But the contribution from the soft-jet region to the enhanced EW logs is marginal, so one can define observables which are insensitive to the jet Sudakov region

In practice, I will consider p_T>30 GeV for both jets, and explore the TeV region for E_T(leading jet)

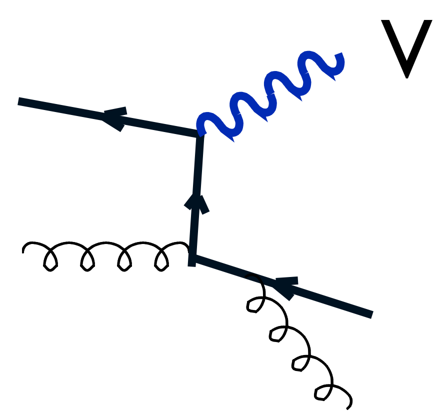
Study V emission rate in dijet events at very large $E_T^{(\text{leading jet})}$



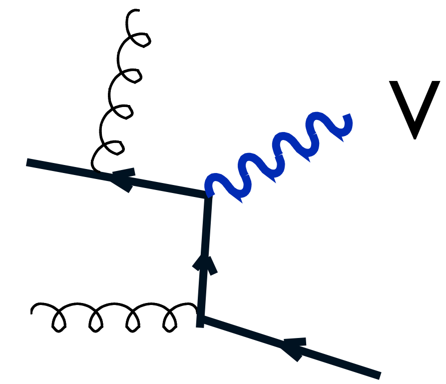
Large EW logs,
V correlated to jet



Large EW logs,
V not correlated
to jet



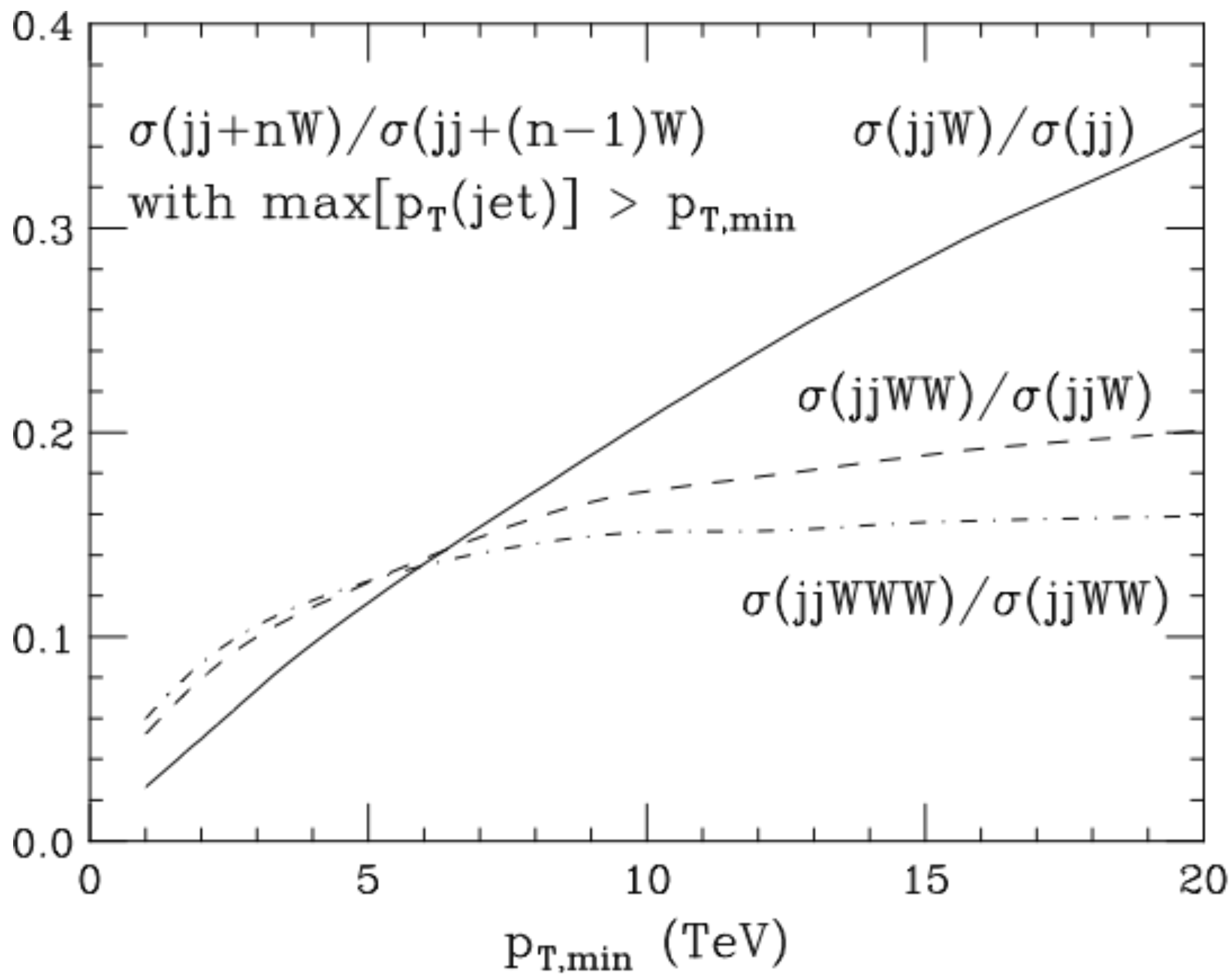
Radiative
correction to V+jet,
no EW log



Radiative
correction to V+jet,
no EW log

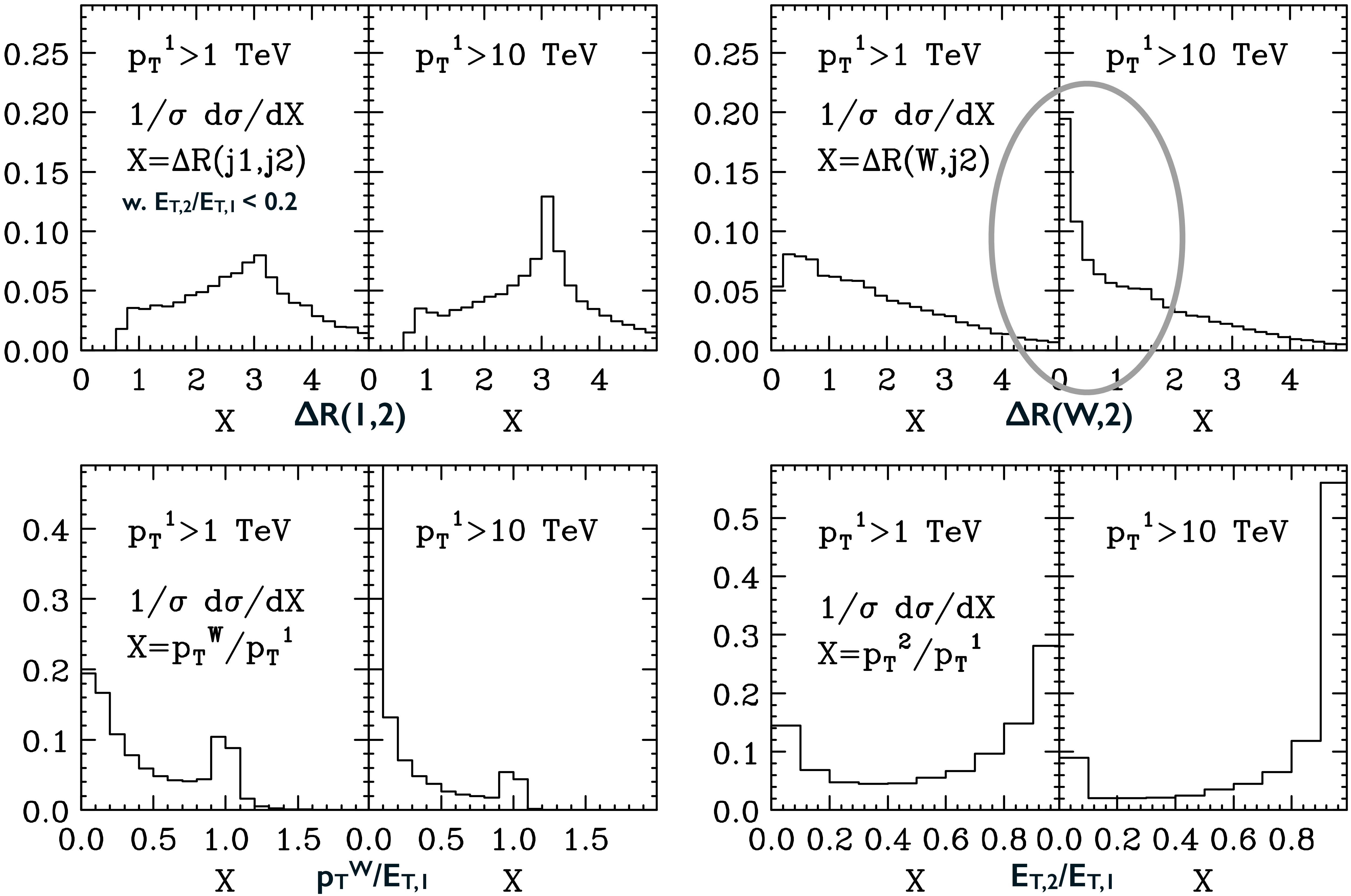
Study σ(jet jet + V) / σ(jet jet) vs $E_T^{(\text{leading jet})}$

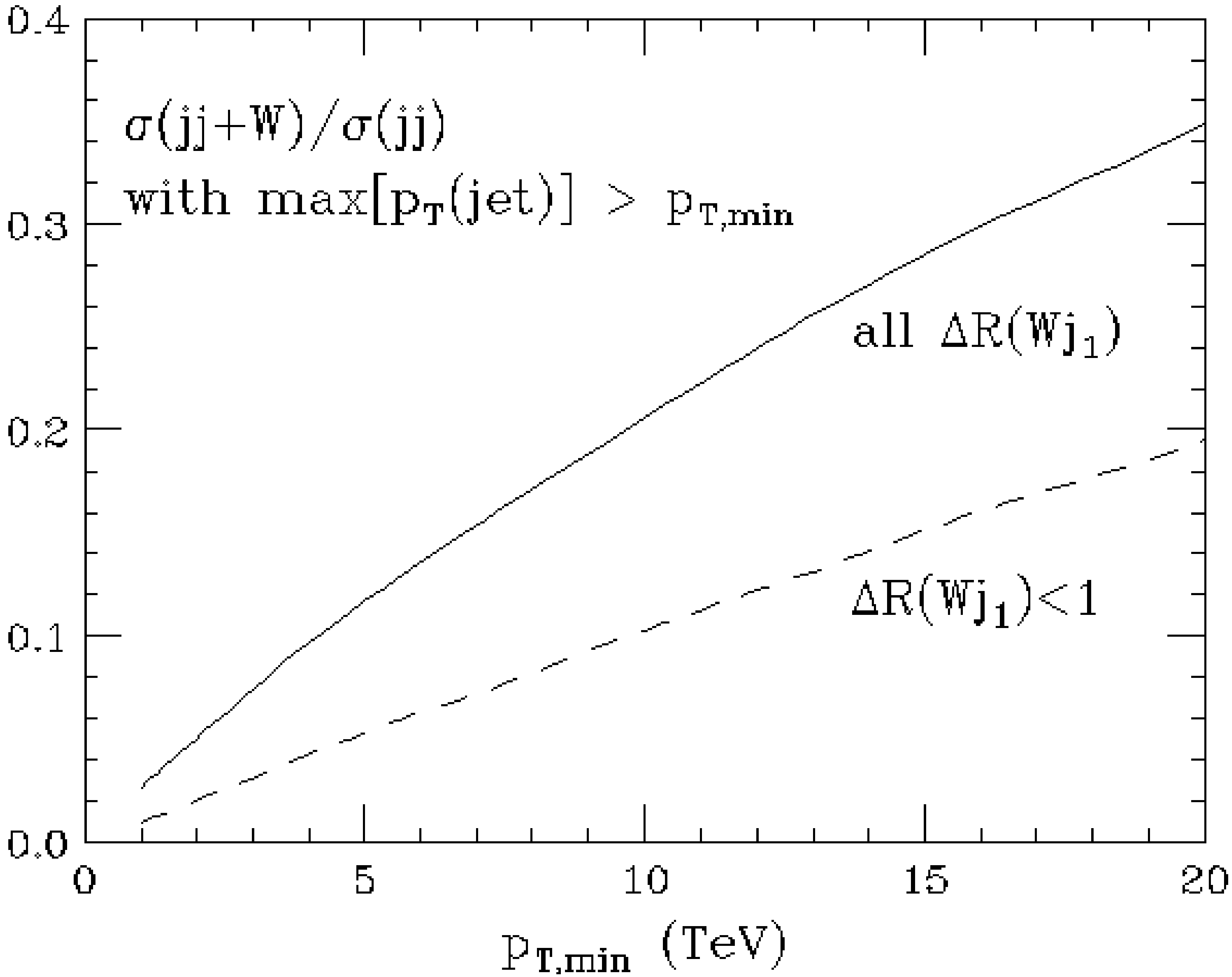
W emission rates from jets



W emission distributions

which fraction of Ws can be associated to radiation off the jet, vs ISR or ISR/FSR interference?

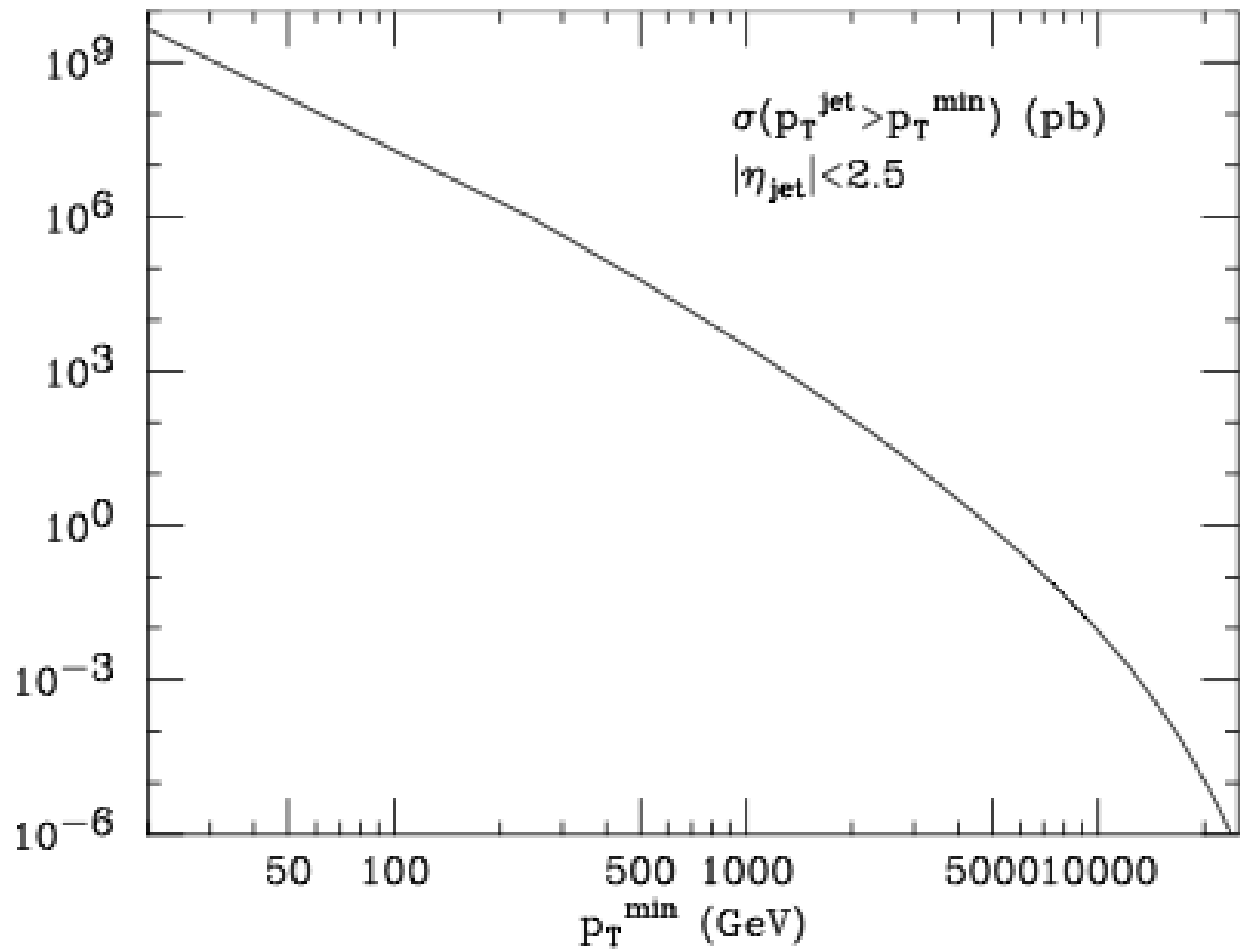




Possible implications:

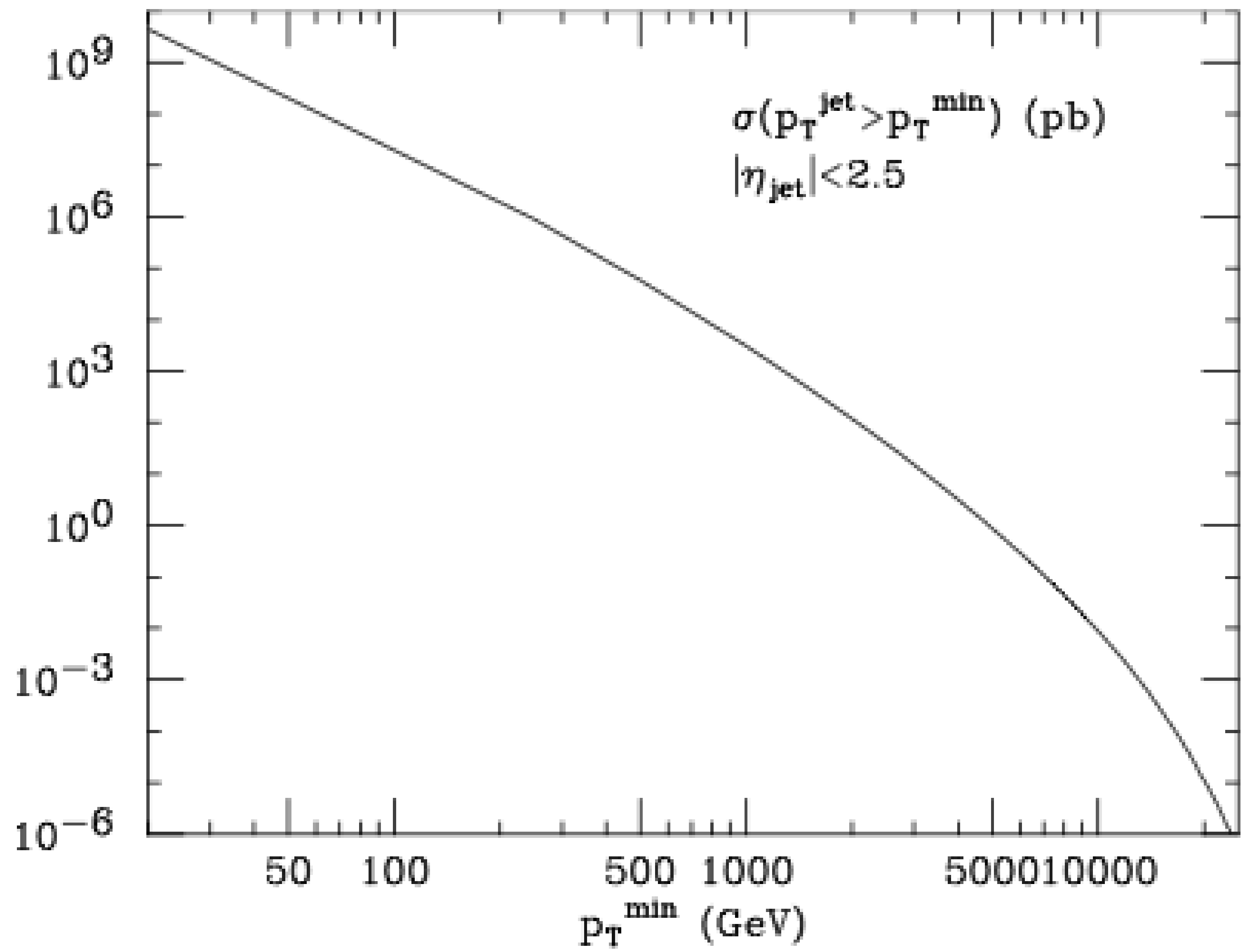
- 10-20% probability of $q \rightarrow qW$ ⇒ may need b-tagging to separate top jet above 1- TeV from ordinary light-q jet?

Jet pT spectrum



=> statistics out to p_T > 20 TeV !!

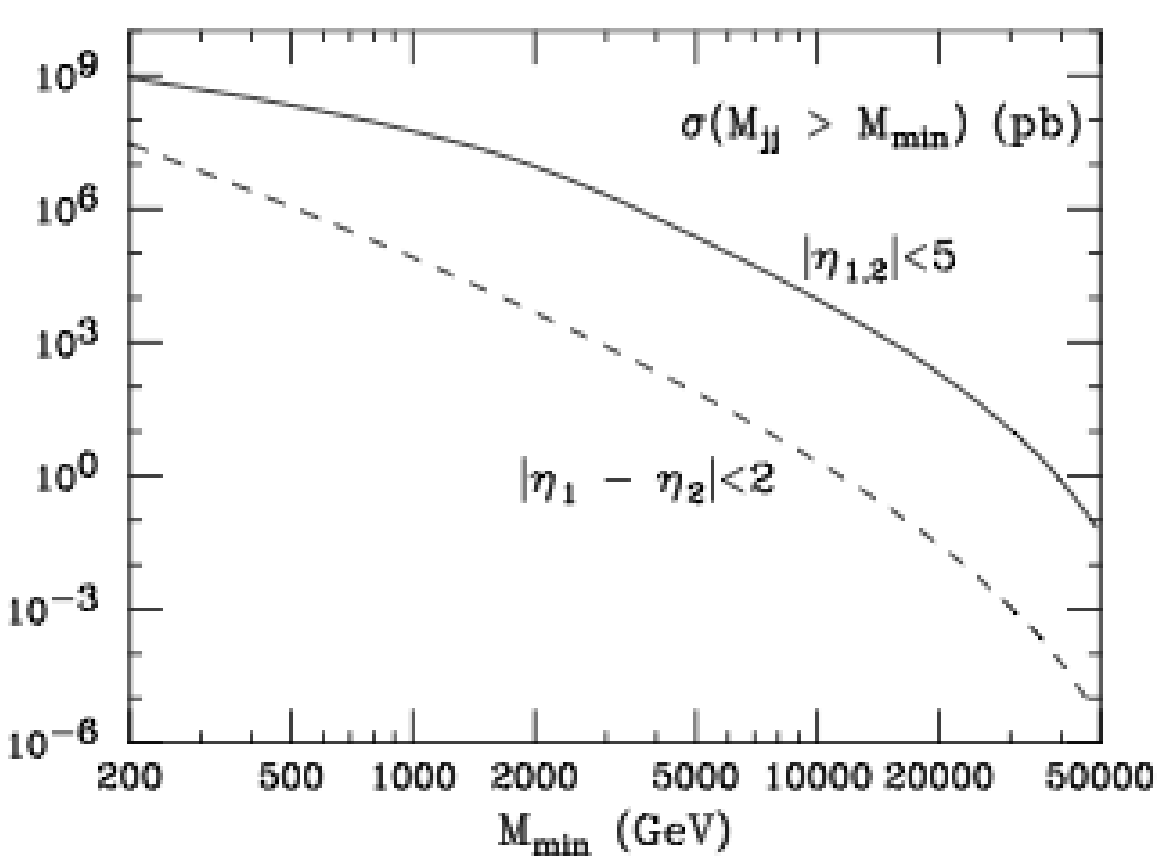
Jet pT spectrum

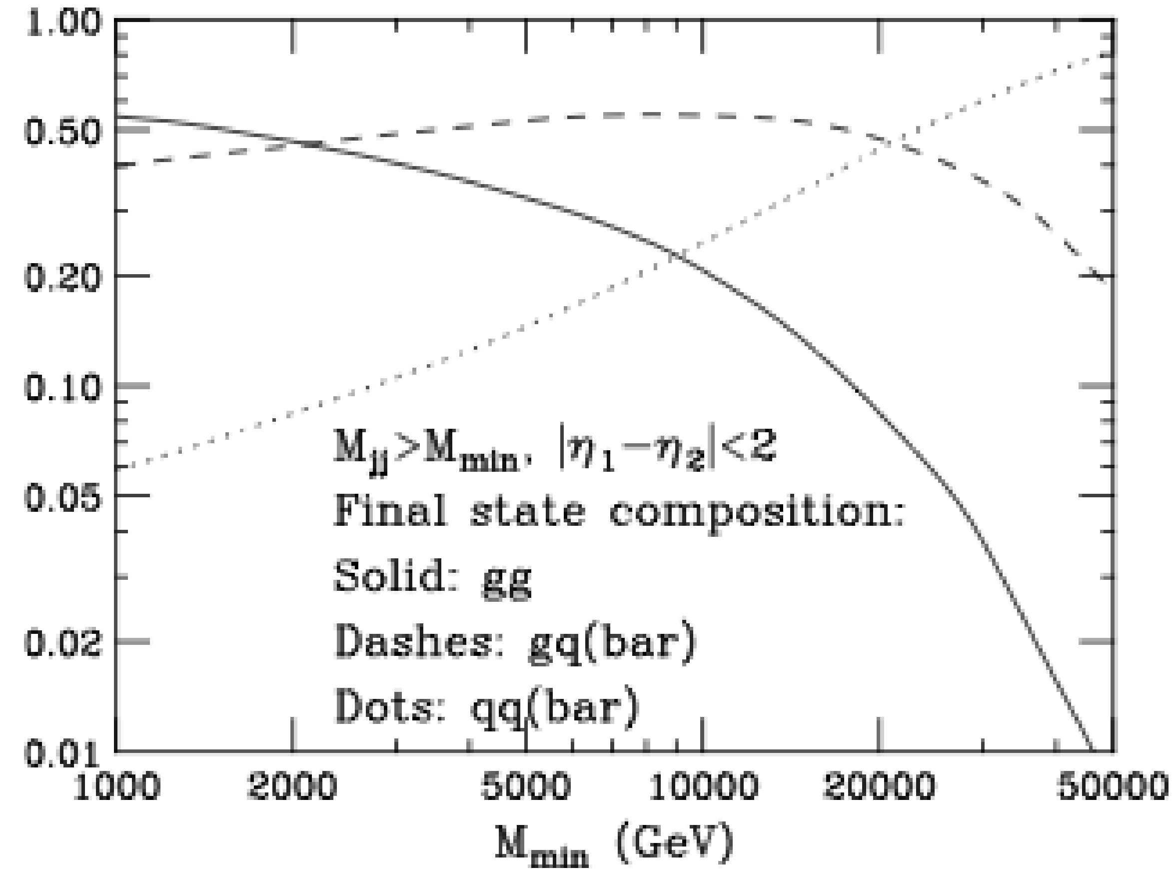


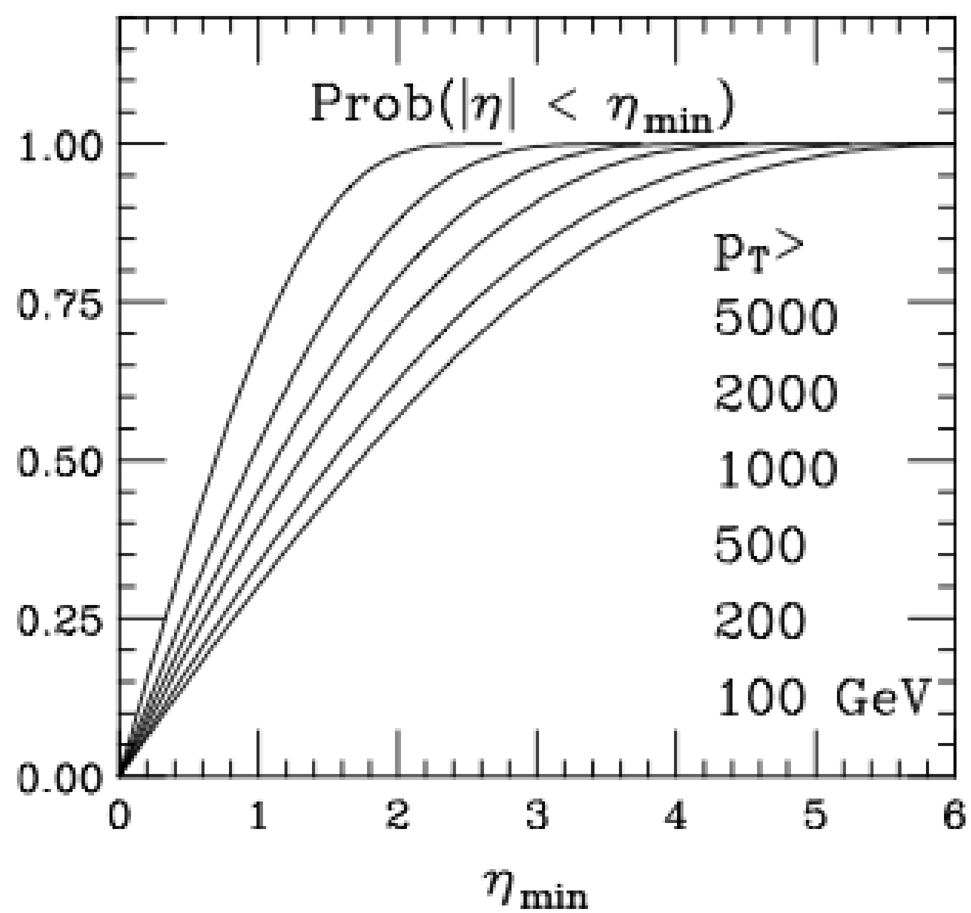
=> statistics out to p_T > 20 TeV !!

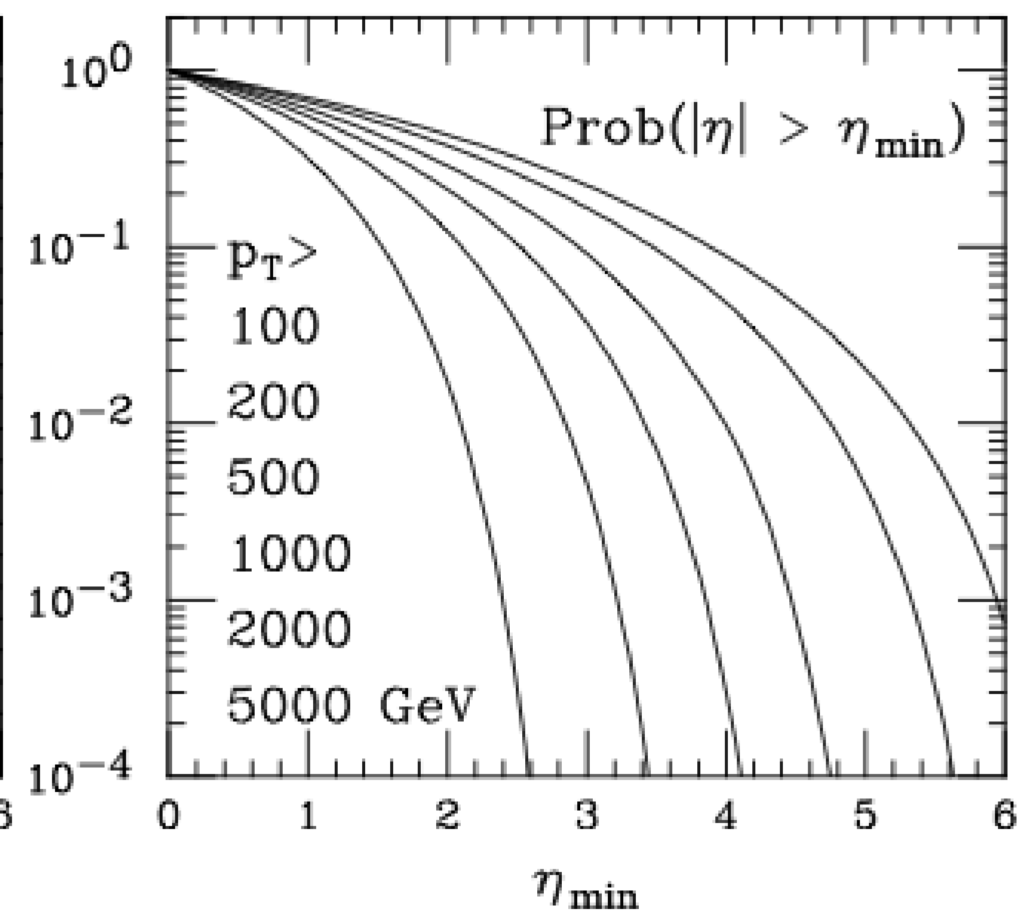
... no study as yet of how to use this for measurements of PDFs, or α_S running and sensitivity to massive colored states

Jet distributions and composition

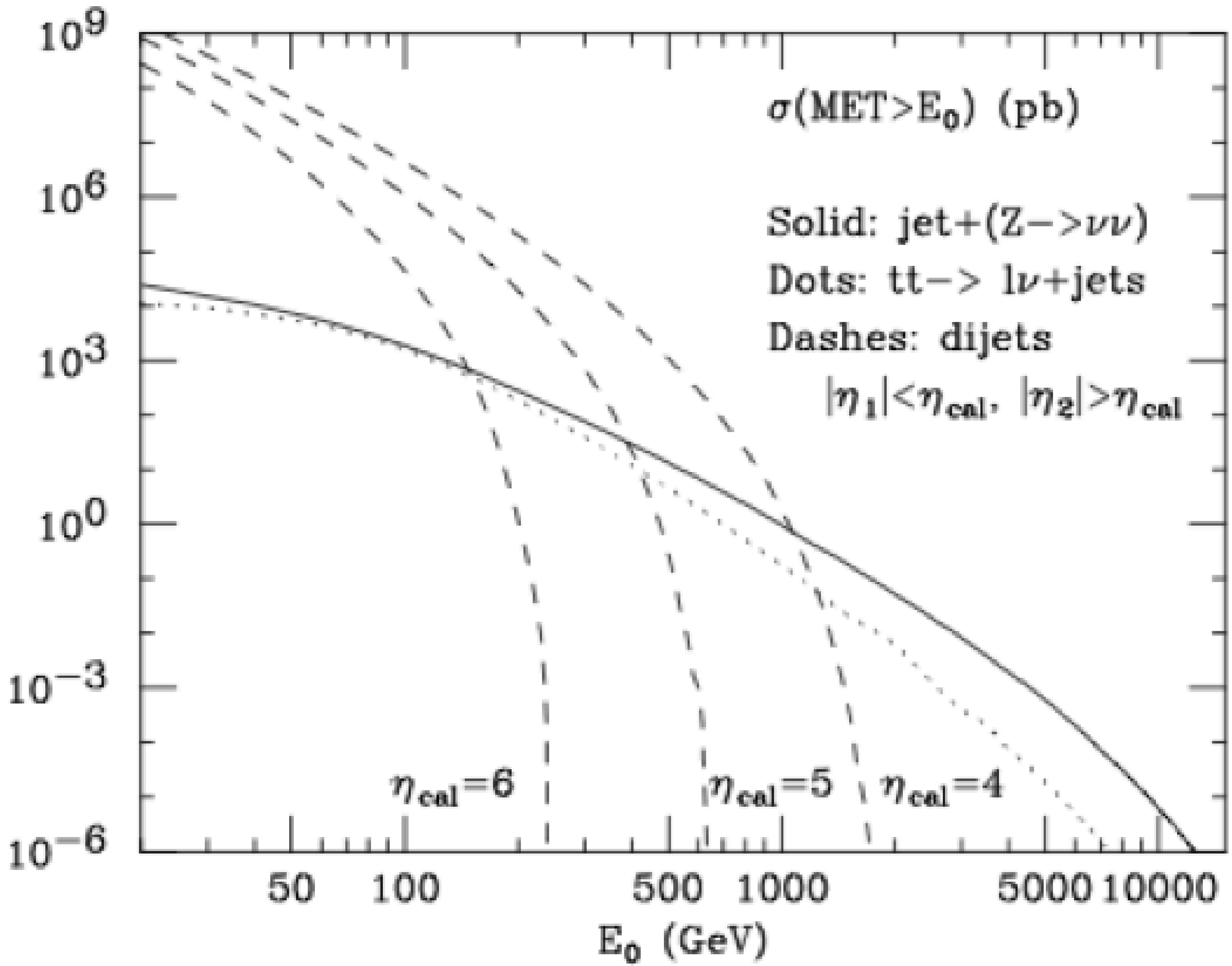








Implications for missing E_T



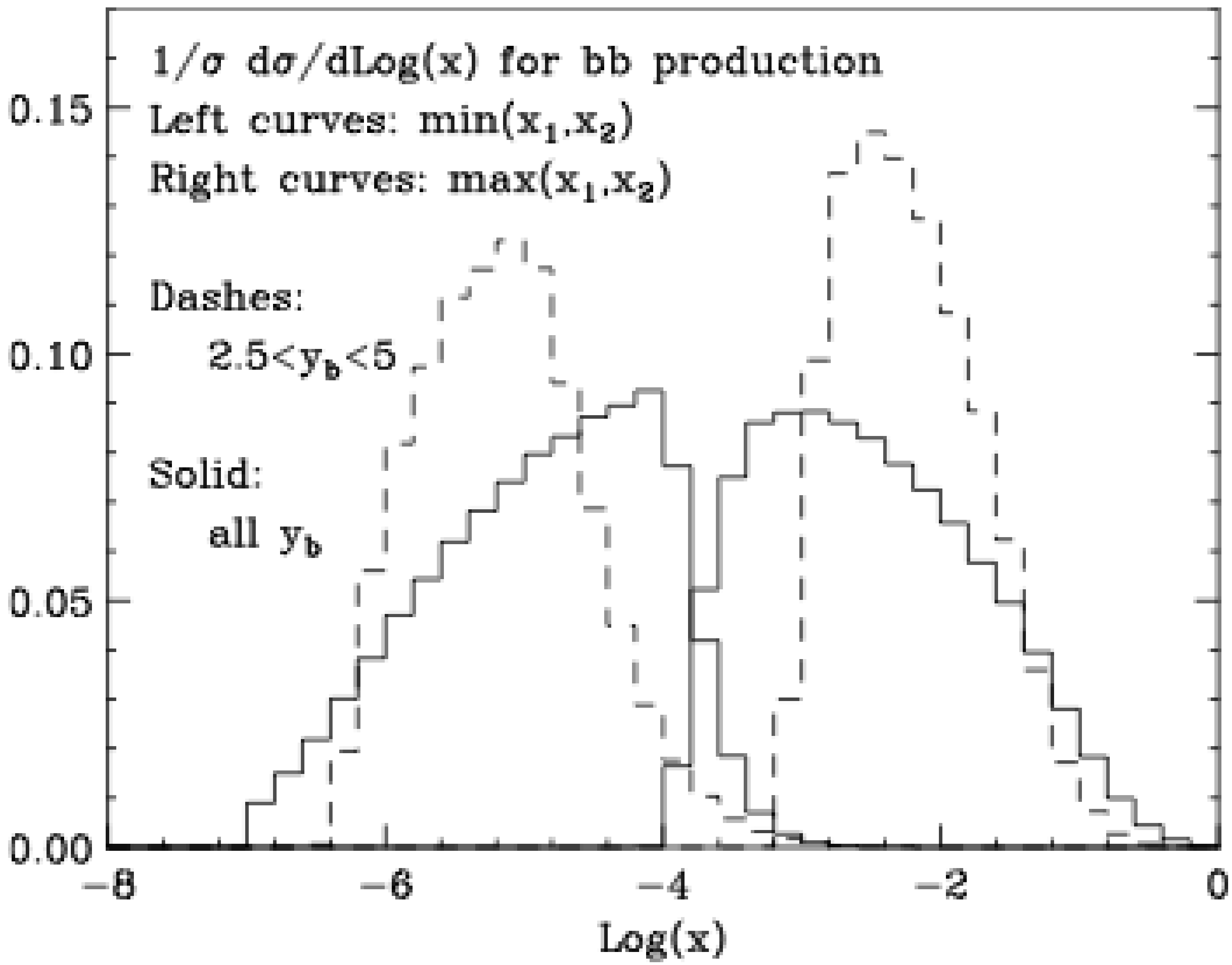
Heavy quark production: c & b

PDF sets	$\sigma(c\bar{c})^{\rm NLO}$ [mb]	$\sigma(c\bar{c})^{\rm NNLO}$ [mb]	$\sigma(b\bar{b})^{\rm NLO}$ [mb]	$\sigma(b\bar{b})^{\rm NNLO}$ [mb]
ABM11 [396]	29.5 ± 2.7	36.6 ± 2.6 (54.9 ± 3.8) *	3.57 ± 0.13	3.06 ± 0.11 (4.52 ± 0.18)
ABM12 [20] [46]	17.3 ± 2.0	33.2 ± 2.6	2.36 ± 0.10	2.97 ± 0.12
CJ15 [22] [47]	$18.4\,^{+5.3}_{-2.5}$	– $(40.3\,^{+10.3}_{-4.6})$	$2.67\,^{+0.55}_{-0.26}$	– $(3.42\,^{+0.69}_{-0.31})$
CT14 [18] [48]	$24.7\,^{+1315.5}_{-3.1}$	$31.8\,^{+624.3}_{-3.0}$ $(47.9\,^{+1981.2}_{-5.2})$	$3.06\,^{+5.35}_{-0.25}$	$3.12\,^{+3.39}_{-0.21}$ $(3.91\,^{+6.91}_{-0.30})$
HERAPDF2.0 [21] [49]	$19.0\,^{+3.8}_{-4.4}$	$3.2\,^{+10.1}_{-18.2}$ $(41.5\,^{+5.2}_{-5.9})$	$3.14\,^{+0.10}_{-0.13}$	$2.70\,^{+0.21}_{-0.22}$ $(4.01\,^{+0.13}_{-0.16})$
JR14 (dyn) [23]	33.6 ± 0.5	32.7 ± 0.5 (58.1 ± 1.0)	3.17 ± 0.04	3.08 ± 0.04 (3.98 ± 0.06)
MMHT14 [19] [50]	$140.0\,^{+187.0}_{-104.2}$	– $\sigma<0$ $(213.9\,^{+271.9}_{-149.4})$	$4.11\,^{+1.39}_{-0.90}$	$2.37\,^{+0.98}_{-0.90}$ $(5.28\,^{+1.77}_{-1.14})$
NNPDF3.0 [17]	40.5 ± 62.2	190.3 ± 547.7 (67.9 ± 84.3)	2.99 ± 0.99	4.46 ± 4.87 (3.82 ± 1.23)

* #s in () are NNLO w. NLO PDF

underscores issues with PDF parameterizations and small-x extrapolations

Bottom quark production: small-x reach



PDF luminosity uncertainties

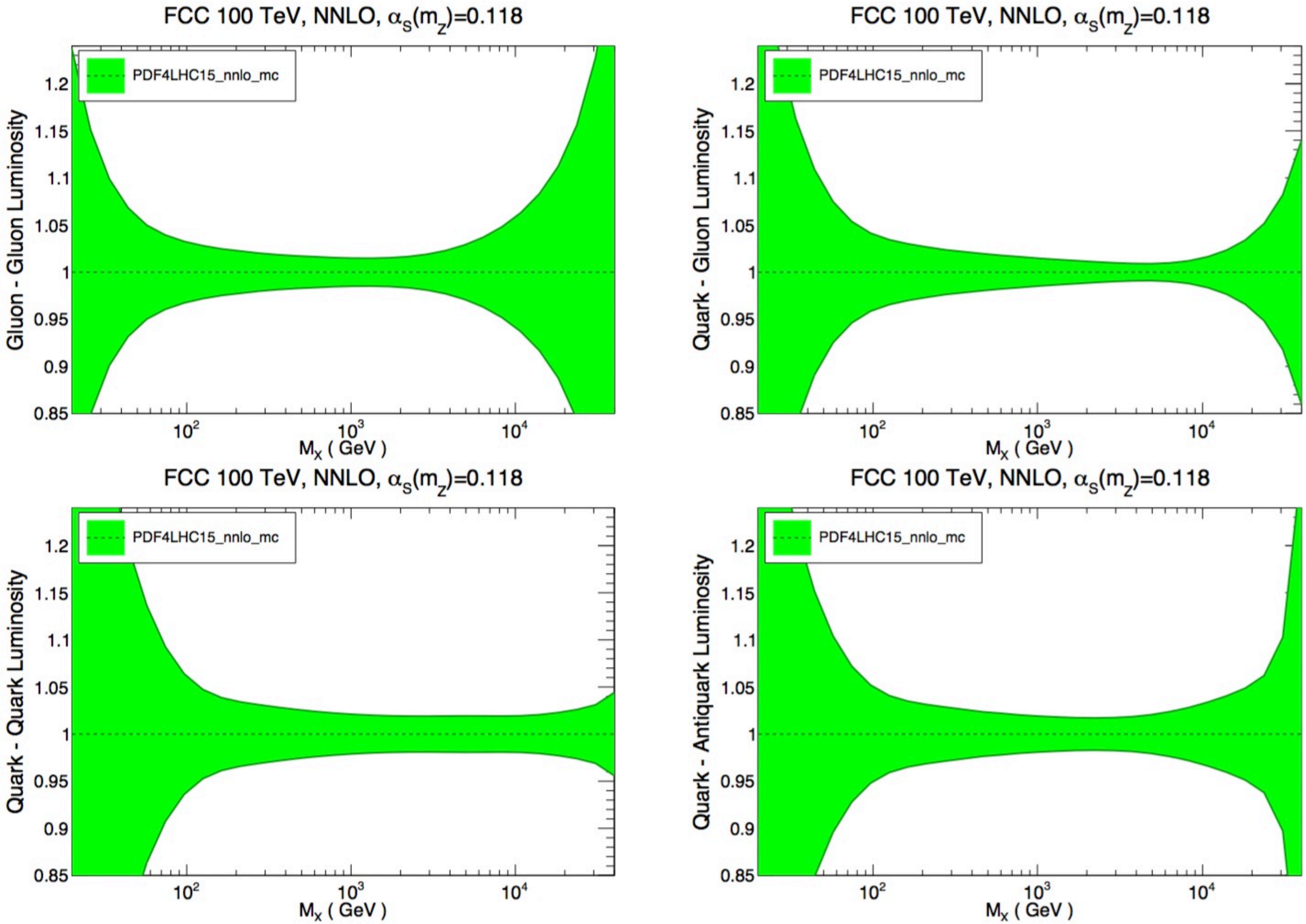


Fig. 8: The relative uncertainties in the rapidity-integrated PDF luminosity at the FCC with $\sqrt{s} = 100$ TeV computed with the `PDF4LHC15_nnlo_mc` set, as a function of the final state invariant mass M_X. From left to right and from top to bottom we show the gluon-gluon, quark-gluon, quark-quark and quark-antiquark luminosities.

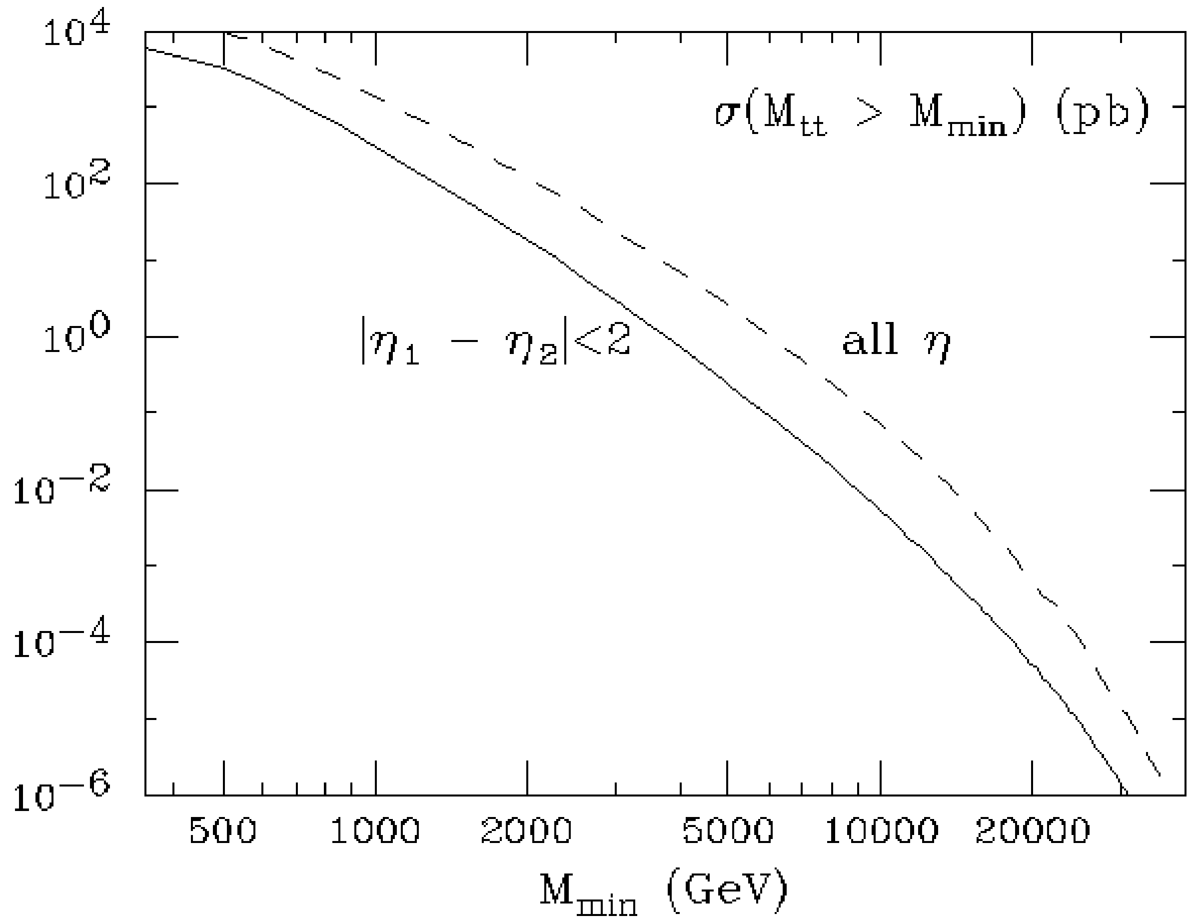
Top quark production

PDF	σ(nb)	δ_{scale}(nb)	(%)	δ_{PDF}(nb)	(%)
CT14	34.692	$+1.000$ -1.649	$(+2.9\%)$ (-4.7%)	$+0.660$ -0.650	$(+1.9\%)$ (-1.9%)
NNPDF3.0	34.810	$+1.002$ -1.653	$(+2.9\%)$ (-4.7%)	$+1.092$ -1.311	$(+3.1\%)$ (-3.8%)
PDF4LHC15	34.733	$+1.001$ -1.650	$(+2.9\%)$ (-4.7%)	± 0.590	$(\pm 1.7\%)$

$\sigma_{tot}(100\ \text{TeV}) \sim 35 \times \sigma_{tot}(14\ \text{TeV})$

- ⇒ about 10^{12} top quarks produced in 20 ab^{-1}
  - rare and forbidden top decays
  - 10^{12} fully inclusive W decays, triggerable by "the other W"
    - rare and forbidden W decays
    - 3 10^{11} W→charm decays
    - 10^{11} W→tau decays
  - 10^{12} fully charge-tagged b hadrons

Inclusive top quark production



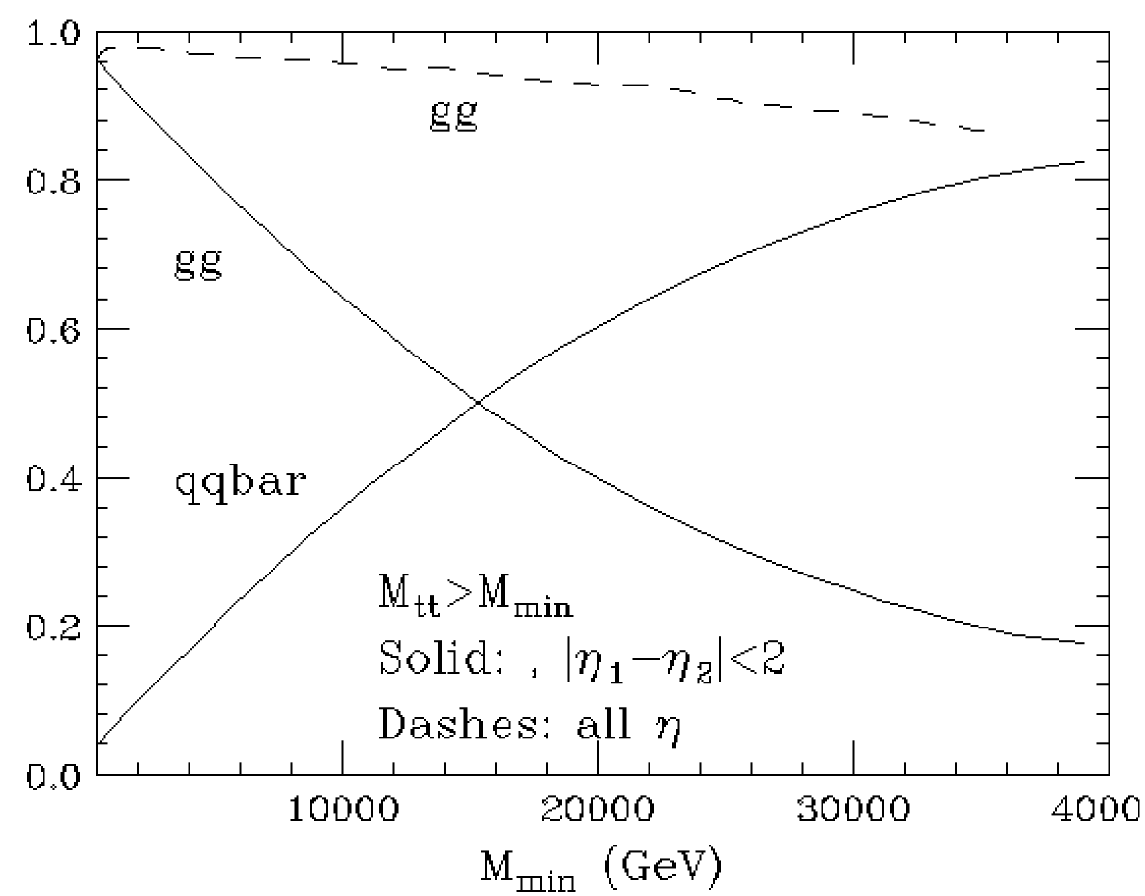
<u>Ex: integrated rates as a function of t-tbar invariant mass for centrally (inclusive) produced tops</u>

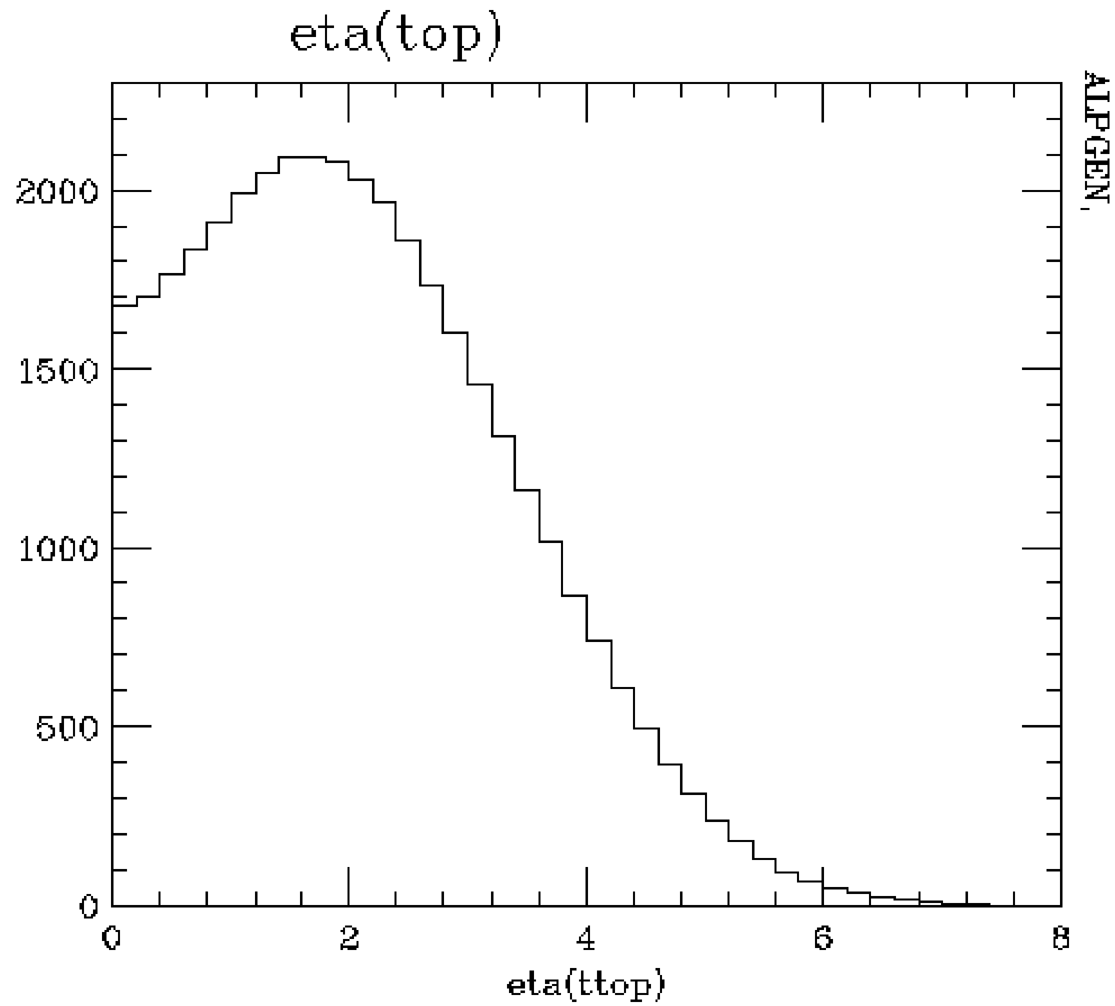
Statistics out to over 30 TeV with 10ab^{-1}
Inclusive rate ~ 10 times larger at highest mass

<u>Ex: gg initial state content for central (vs inclusive) t-tbar pairs, vs M(tt)</u>

In central production, dominated by gg up to ~ 15 TeV. Still 20% gg at the kinematic edge of ~ 30 TeV

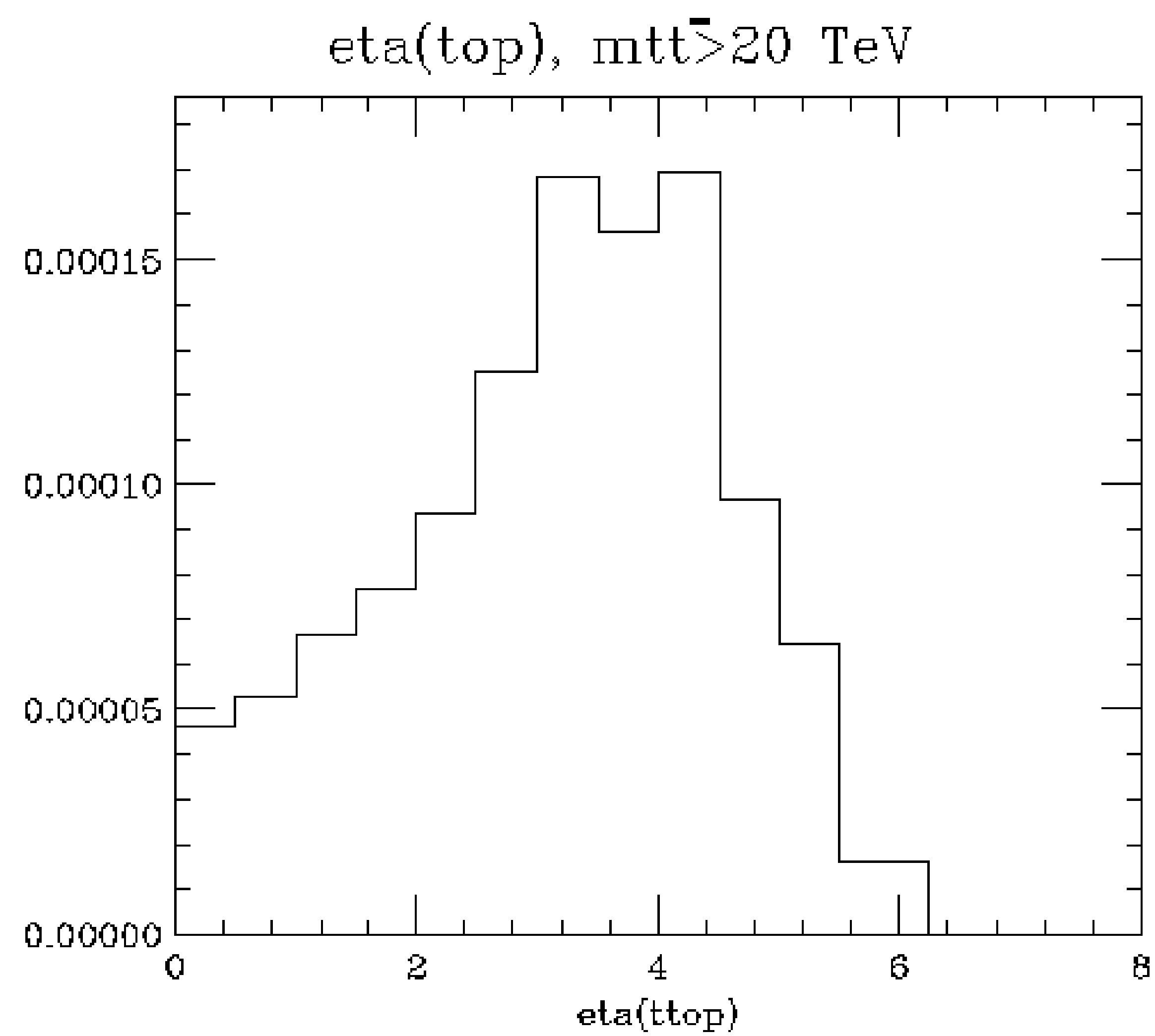
For inclusive prodution, >90% gg!



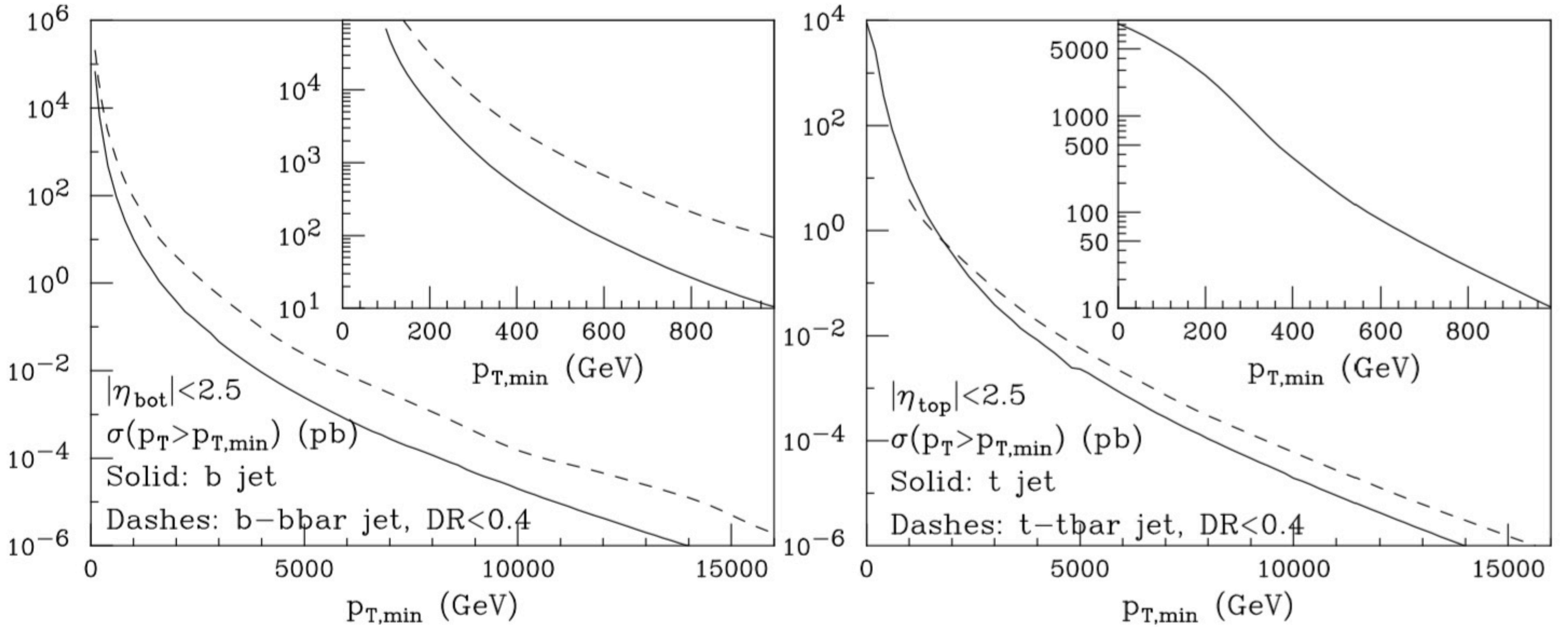


Ex: eta spectrum for m(tt)>350 GeV

Ex: eta spectrum for m(tt)>20 TeV

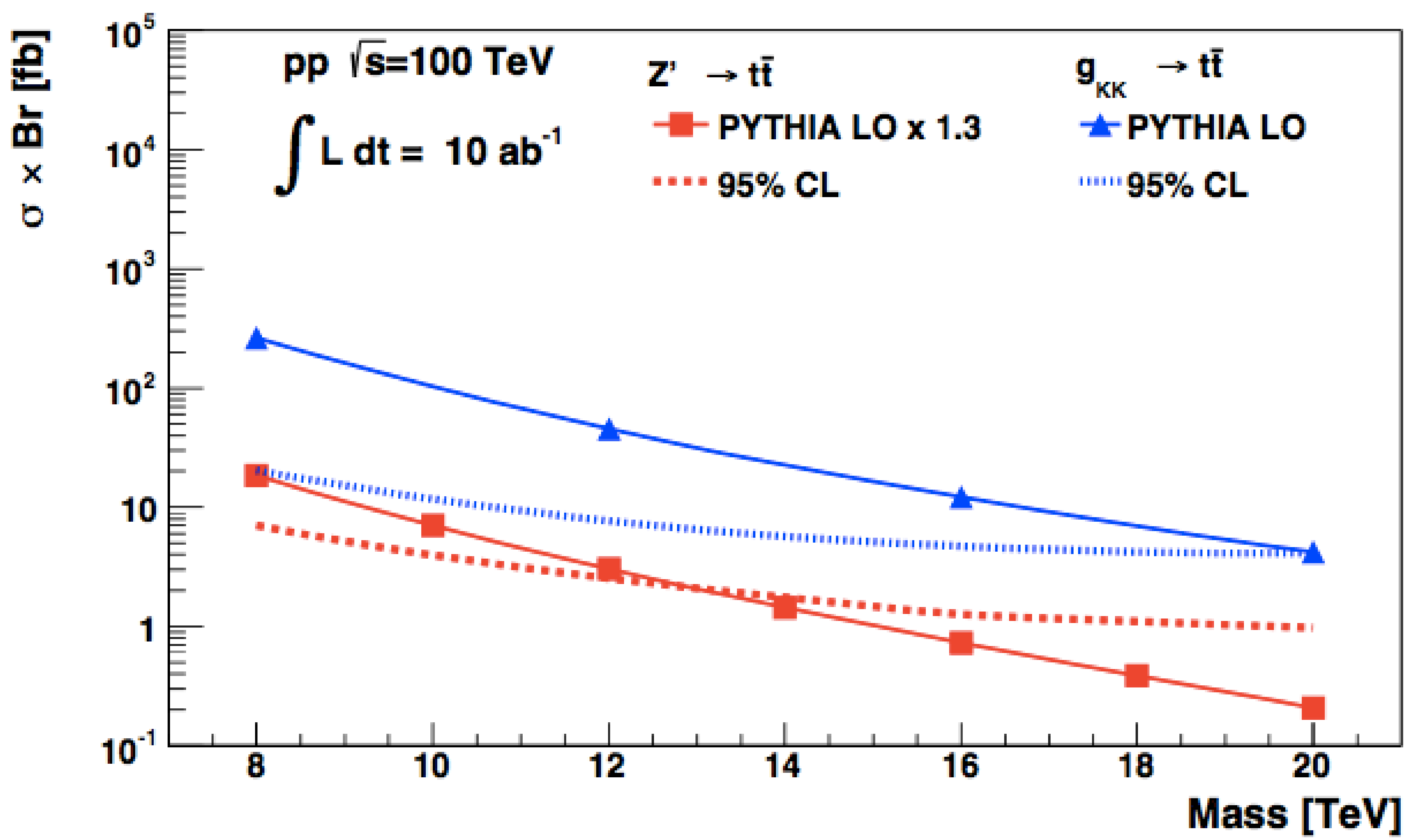


hvq and hvq jets at large p_T



Sensitivity to ttbar resonances

Auerbach, Chekanov, Proudfoot, Kotwal, arXiv:1412.5951



Top anomalous chromomagnetic moments

$$\mathcal{L}_{\rm tg} = -g_s \bar{t}\gamma^\mu \frac{\lambda_a}{2} t\, G^a_\mu + \frac{g_s}{m_t}\bar{t}\sigma^{\mu\nu}(d_V + i d_A \gamma_5)\frac{\lambda_a}{2} t\, G^a_{\mu\nu}$$

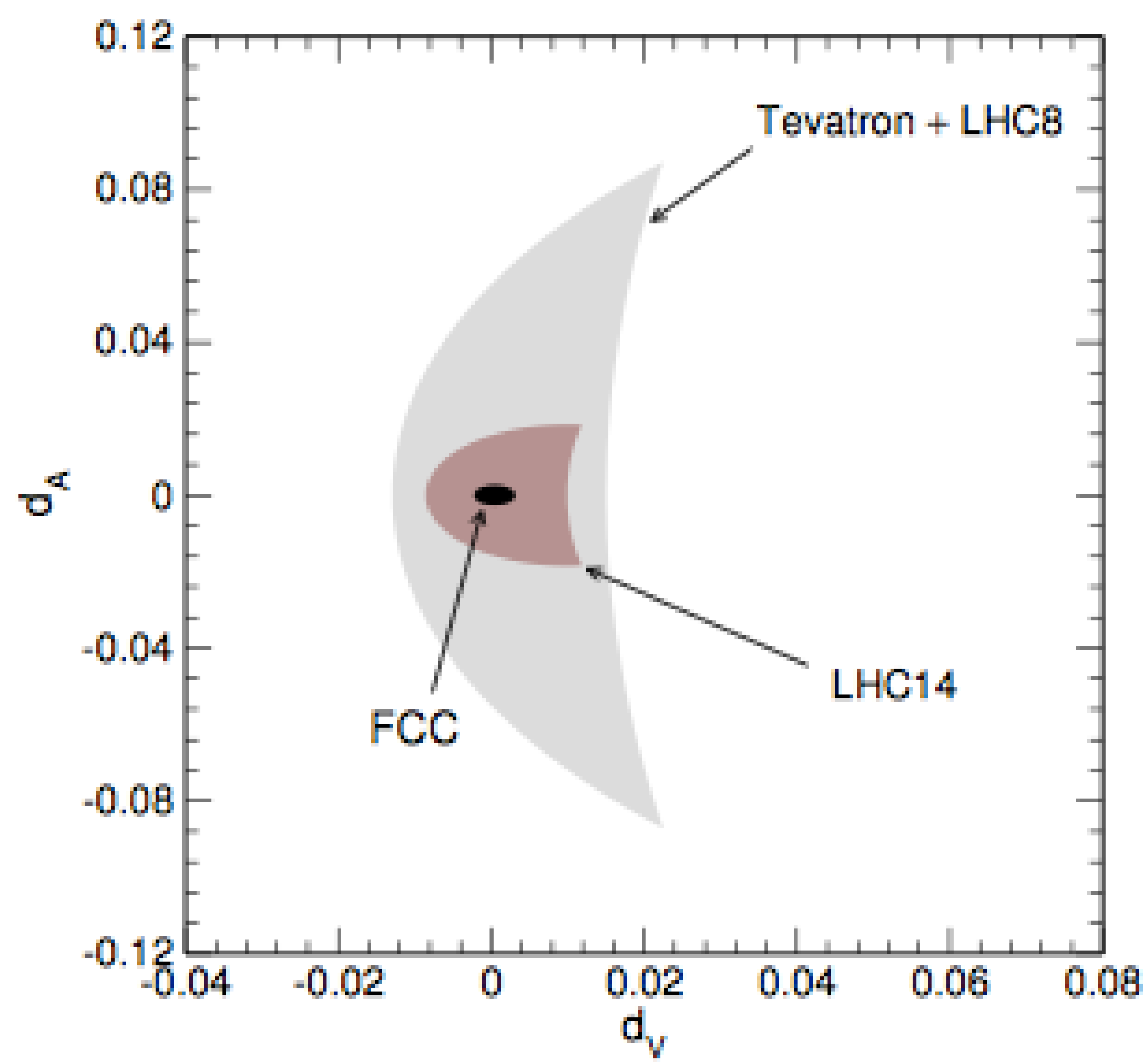
$$O^{33}_{uG\phi} = (\bar{q}_{L3}\lambda_a\sigma^{\mu\nu}t_R)\tilde{\phi}\, G^a_{\mu\nu} \quad \Rightarrow \quad d_V = \frac{\sqrt{2}vm_t}{g_s\Lambda^2}\mathrm{Re}\, C^{33}_{uG\phi}, \quad d_A = \frac{\sqrt{2}vm_t}{g_s\Lambda^2}\mathrm{Im}\, C^{33}_{uG\phi}$$

At 100 TeV, constraints from event rate at $M_{tt} > 10$ TeV:

$-0.0022 \leq d_V \leq 0.0031$

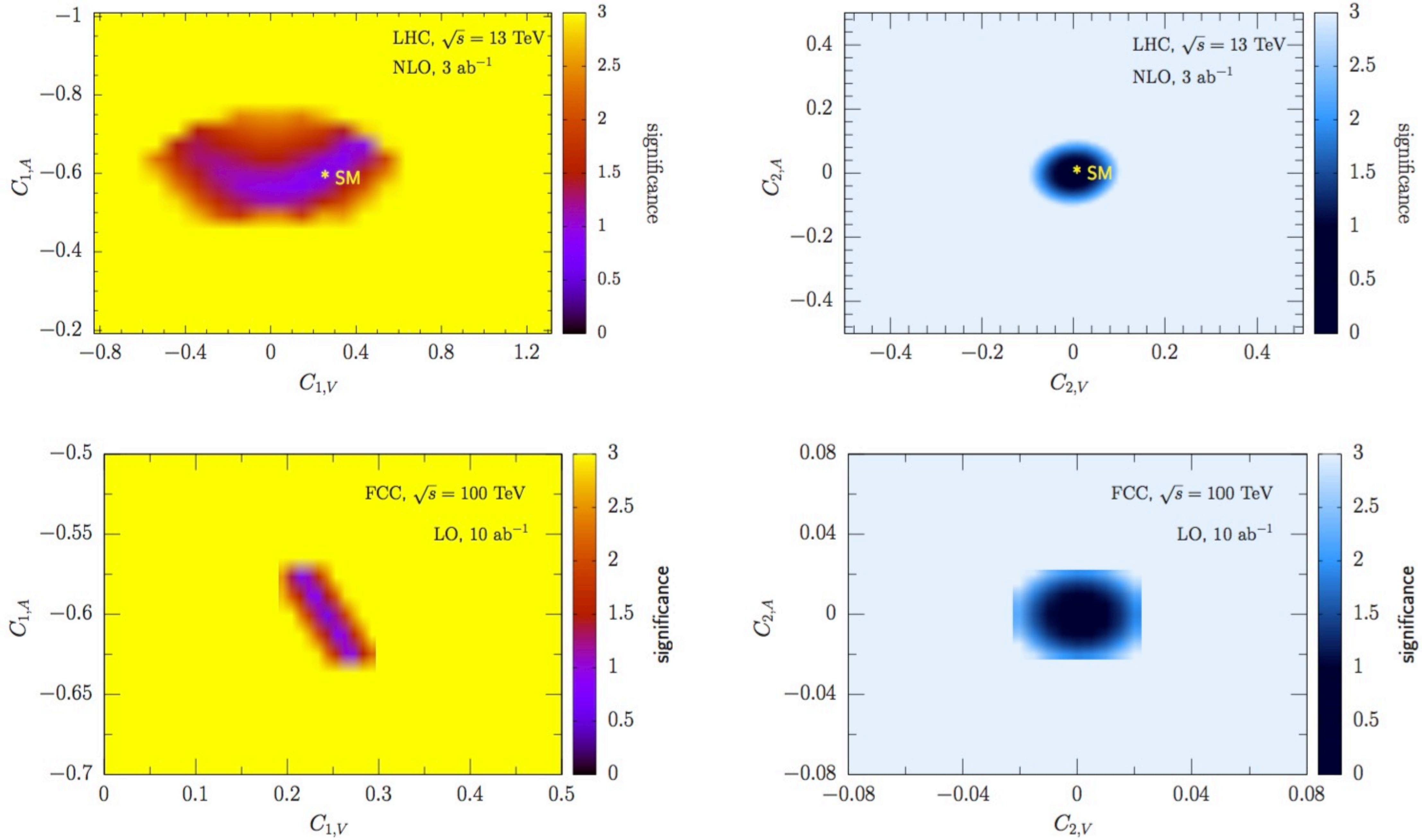
$|d_A| \leq 0.0026$

$\Rightarrow \Lambda \gtrsim 17$ TeV



Top anomalous EW couplings from ttZ

$$\mathcal{L}_{t\bar{t}Z} = e\bar{\psi}_t\left[\gamma^\mu(C_{1,V}+\gamma_5 C_{1,A}) + \frac{i\sigma^{\mu\nu}q_\nu}{M_Z}(C_{2,V}+i\gamma_5 C_{2,A})\right]\psi_t Z_\mu,$$



	$C_{1,V}$	$C_{1,A}$	$C_{2,V}$	$C_{2,A}$
SM value	0.24	−0.60	< 0.001	$\ll 0.001$
13 TeV, 3 ab^{-1}	[−0.4, +0.5]	[−0.5, −0.7]	[−0.08, +0.08]	[−0.08, +0.08]
100 TeV, 10 ab^{-1}	[+0.2, +0.28]	[−0.63, −0.57]	[−0.02, +0.02]	[−0.02, +0.02]

SM Higgs at 100 TeV

just few glimpses here, for a more complete discussion see the Higgs session at the "Future accelerators" KITP programme next week ….

	N_{100}	N_{100}/N_8	N_{100}/N_{14}
$gg \to H$	16×10^9	4×10^4	110
VBF	1.6×10^9	5×10^4	120
WH	3.2×10^8	2×10^4	65
ZH	2.2×10^8	3×10^4	85
$t\bar{t}H$	7.6×10^8	3×10^5	420

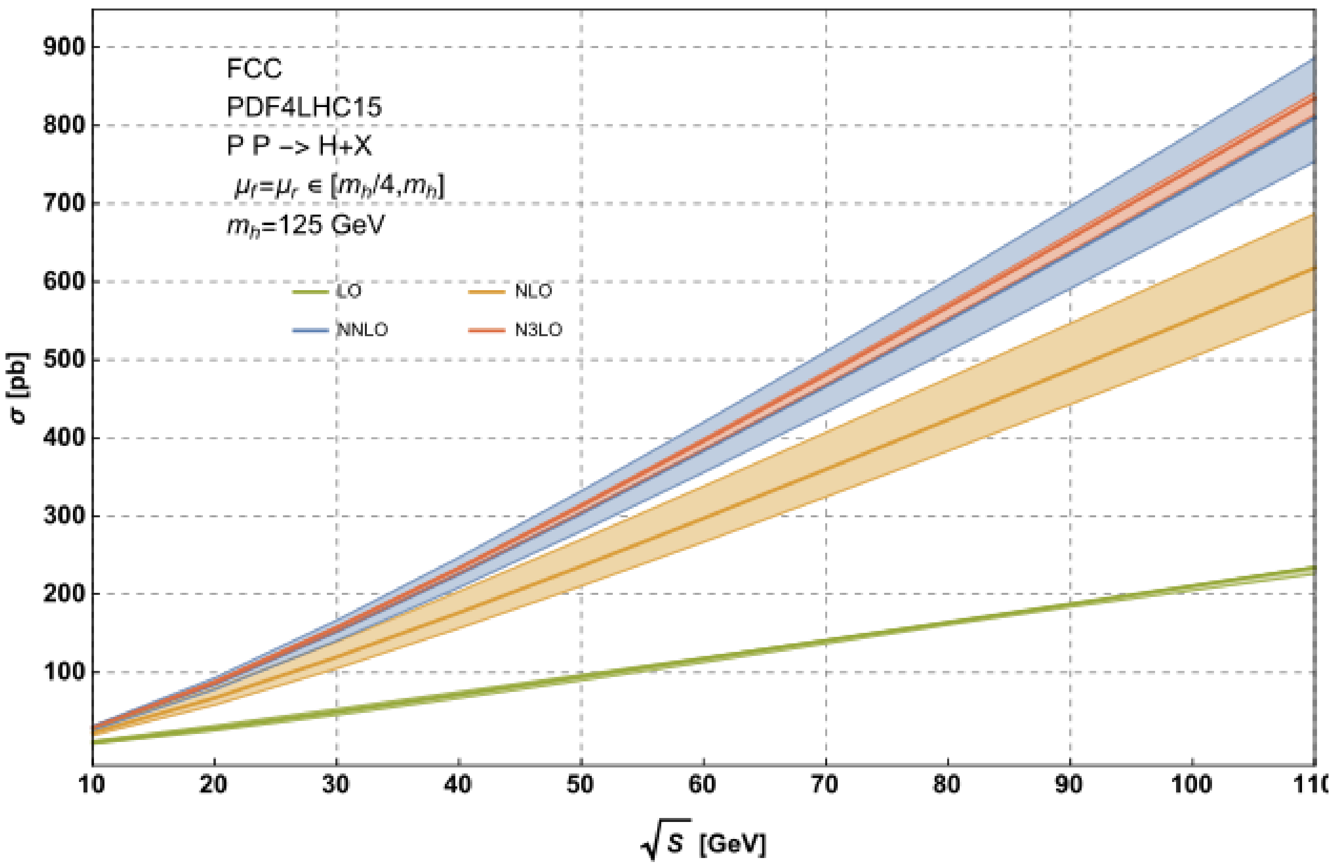
$N_{100} = \sigma_{100\,\mathrm{TeV}} \times 20\ \mathrm{ab}^{-1}$

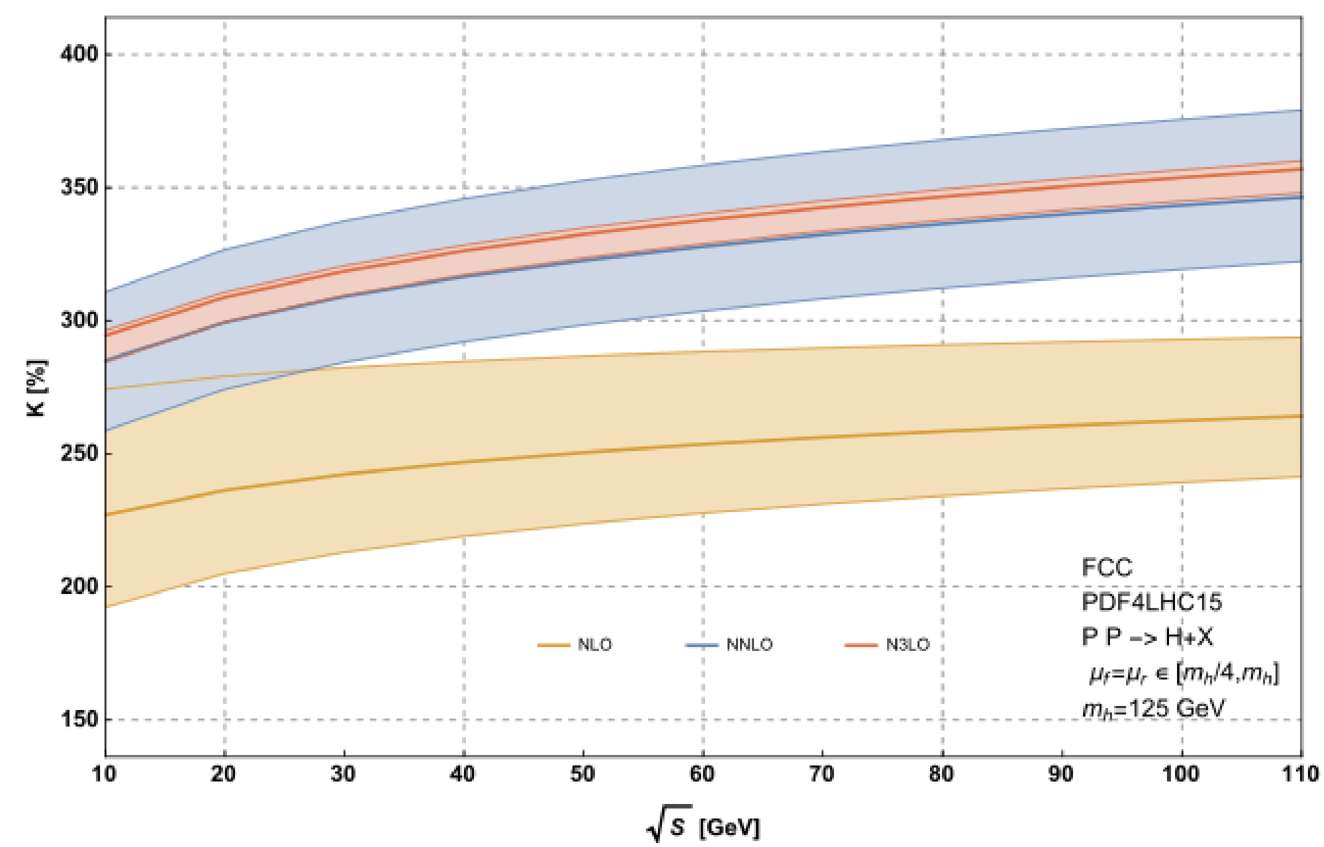
$N_8 = \sigma_{8\,\mathrm{TeV}} \times 20\ \mathrm{fb}^{-1}$

$N_{14} = \sigma_{14\,\mathrm{TeV}} \times 3\ \mathrm{ab}^{-1}$

- Huge production rates imply:
  - can afford reducing statistics, with tighter kinematical cuts that reduce backgrounds and systematics
  - can explore new dynamical regimes, where new tests of the SM and EWSB can be done

TH progress, an example





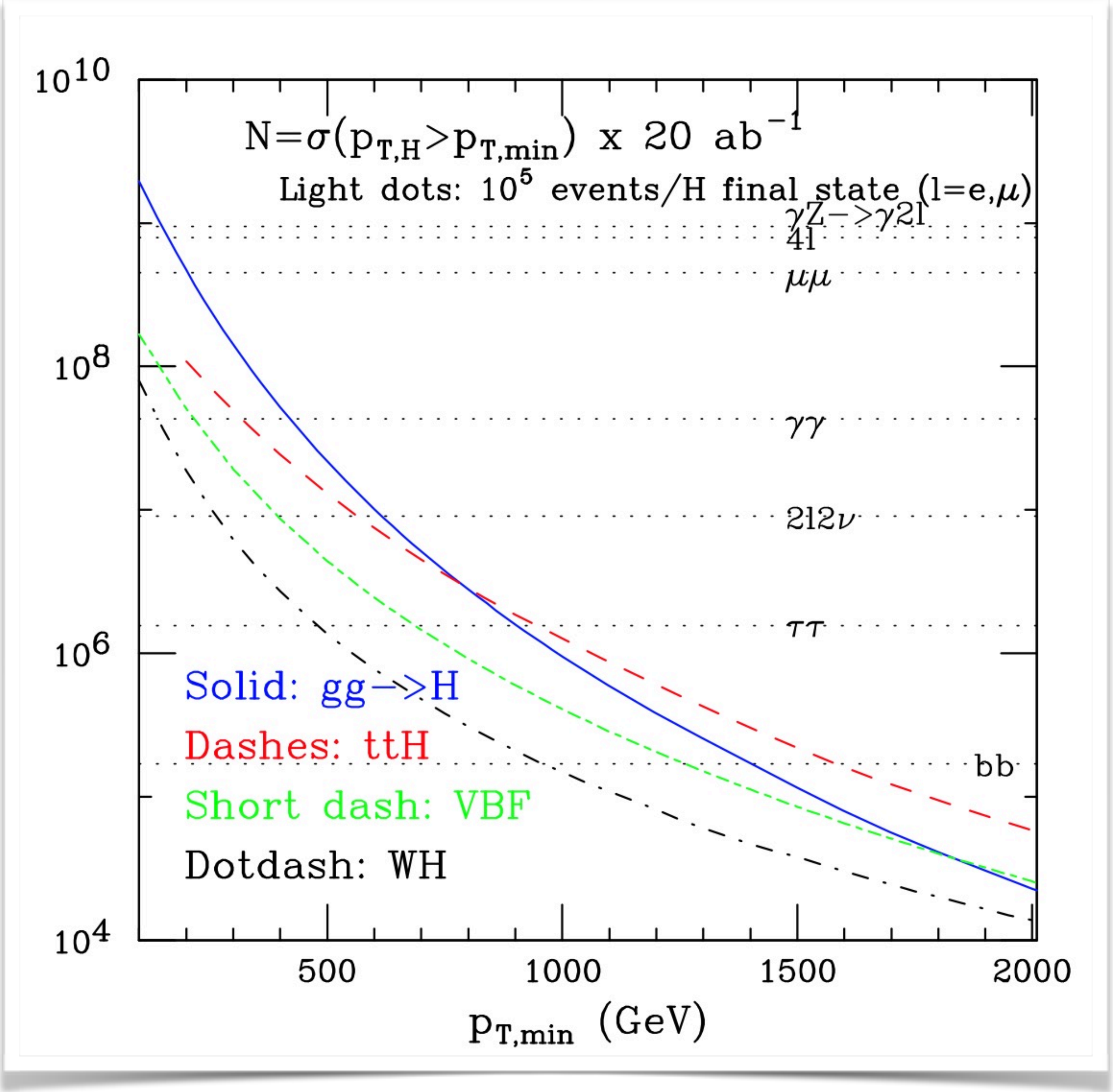
δ_{PDF}	δ_{α_S}	δ_{scale}	$\delta_{\text{PDF-theo}}$	δ_{EW}	δ_{tbc}	$\delta_{\frac{1}{m_t}}$
$\pm 2.5\%$	$\pm 2.9\%$	$^{+0.8\%}_{-1.9\%}$	$\pm 2.5\%$	$\pm 1\%$	$\pm 0.8\%$	$\pm 1\%$

Table 3: Various sources of uncertainties of the inclusive gluon fusion Higgs production cross section at a 100 TeV proton-proton collider.

linear sum of all but PDF and α_S

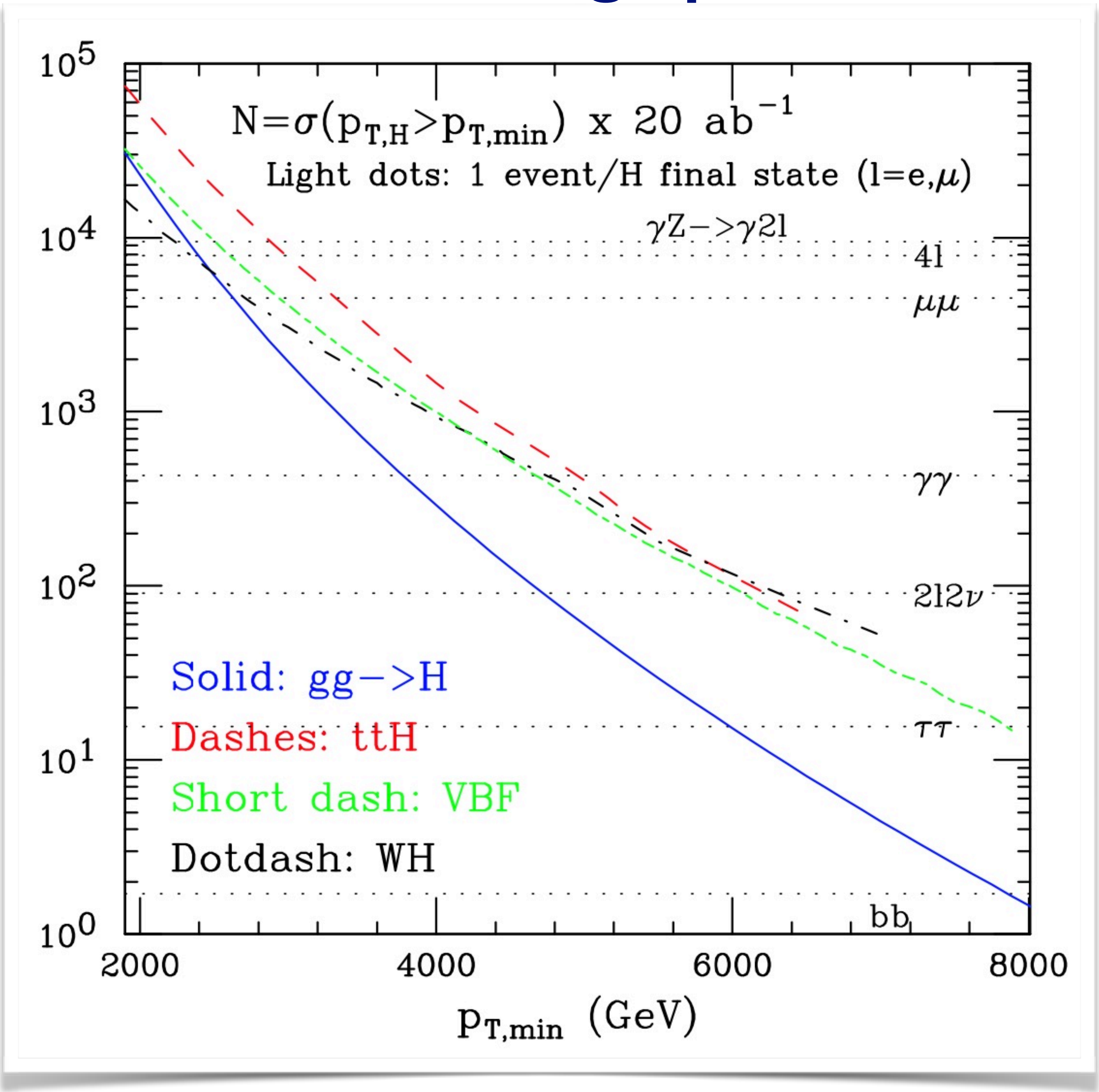
$$\sigma = 802\ \text{pb}\ {}^{+6.1\%}_{-7.2\%}(\delta_{\text{theo}})\,{}^{+2.5\%}_{-2.5\%}(\delta_{\text{PDF}})\,{}^{+2.9\%}_{-2.9\%}(\delta_{\alpha_s})$$

H at large p_T



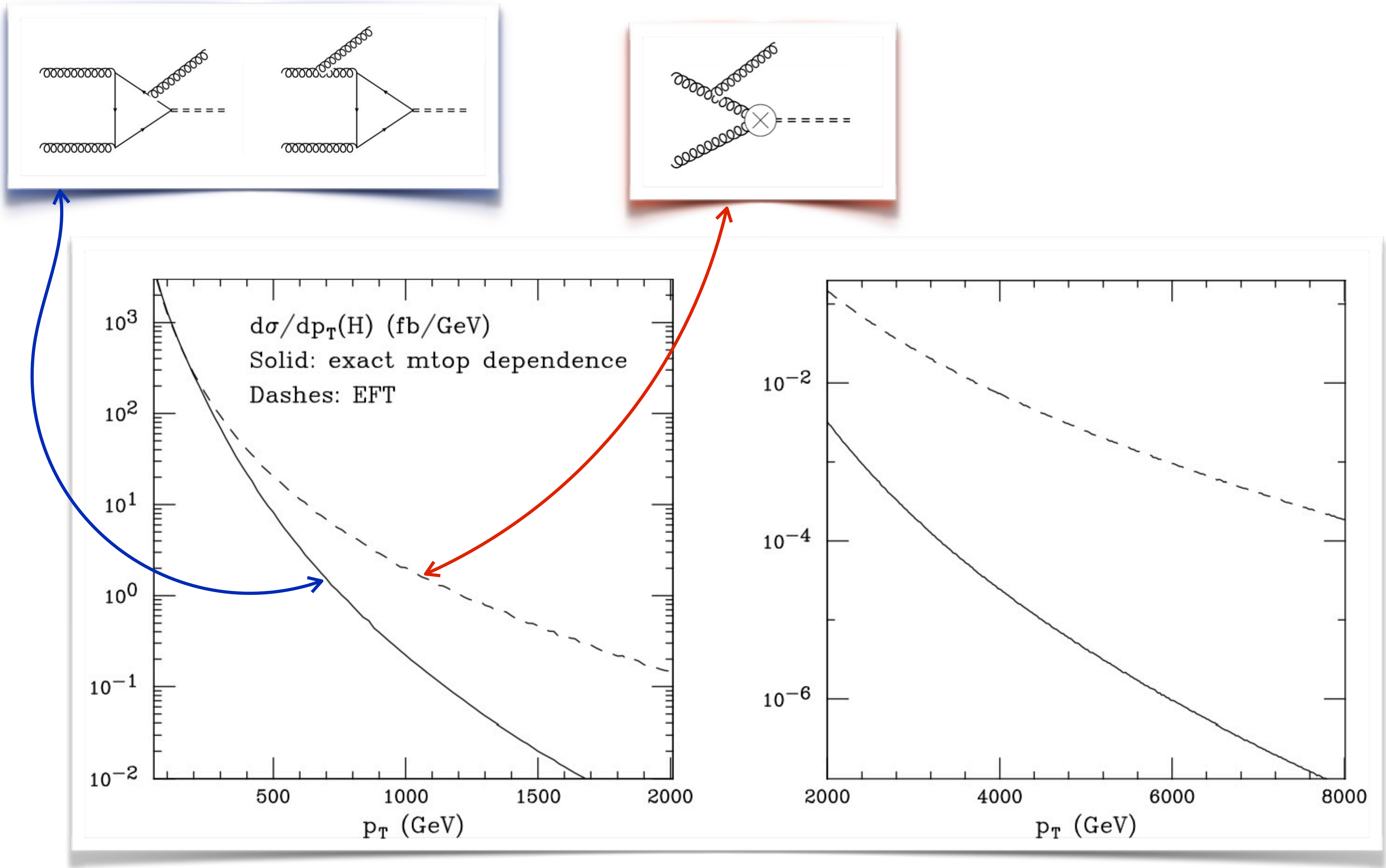
- Hierarchy of production channels changes at large $p_T(H)$:
  - $\sigma(ttH) > \sigma(gg\to H)$ above 800 GeV
  - $\sigma(VBF) > \sigma(gg\to H)$ above 1800 GeV

H at large p_T



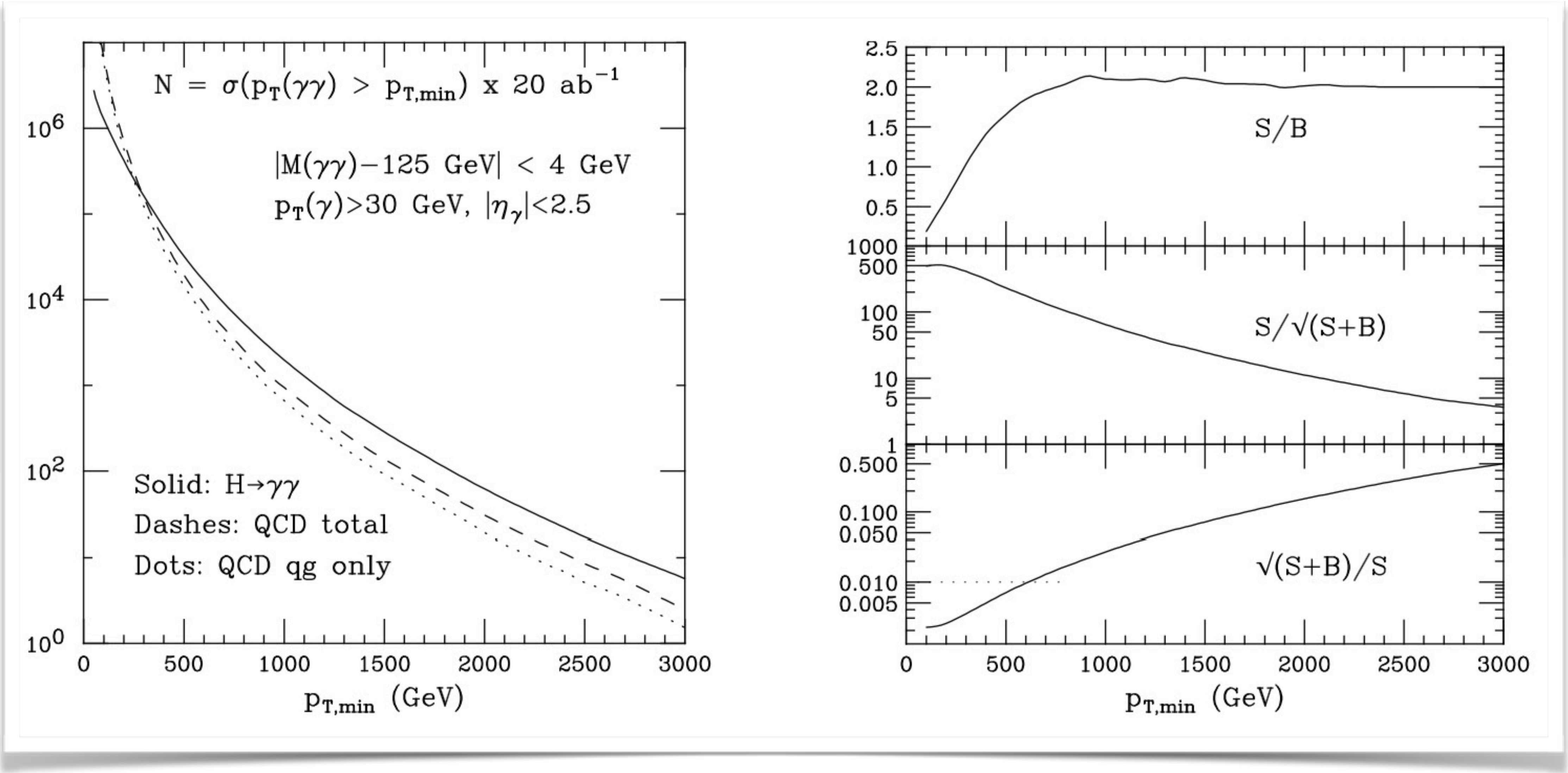
- Statistics in potentially visible final states out to several TeV

H at large p_T



- At LHC, can measure only up to $p_T \sim$ few hundred GeV ⇒ reduced sensitivity to the inner guts of the ggH coupling
- At FCC, orders of magnitude difference between EFT and exact m_{top}

H at large p_T



- At LHC, S/B in the $H \to \gamma\gamma$ channel is O(few %)
- At FCC, for $p_T(H)>300$ GeV, S/B~1

Final remarks

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- SM physics provides nevertheless an excellent training ground to exercise the design of detectors and of new analyses strategies
- Even before the 100 TeV becomes a reality, ideas emerged from its study can open new opportunities for theoretical progress, and for exploitation at the HL-LHC
- …. go read the report, and be insipired !!