Collider Physics: Discussion session

Keith Ellis, Fermilab

Topics

* NLO QCD: Assessment of the methods, advantages and limitations of the various methods.
* NNLO QCD: Achievements and desiderata
* Snowmass 2013. Is America asking the right questions?
* Top mass
* AOB

NLO revolution?

- Considerable progress in the last few years in calculation of one loop diagrams with N-external legs and involving R powers of the loop momenta for NLO applications
- Analytic helicity amplitude methods
  - Numerical Stability
  - Speed of evaluation
  - Utility as input to NNLO
- OPP, d-dimensional unitarity and variants
  - Scaling of numerical complexity with N
  - Poorly understood regions of numerical stability
- PV tensor reduction and modern developments
  - Well understood regions of numerical instability
  - Well developed strategies for recovery in unstable regions
  - Scaling of computer time with N and R?

NLO revolution (cont)

- Purely Numerical methods (Soper et al, Weinzierl)
  - Computation needs?
- Also developments in how the basic one-loop integrands are generated, Openloops, Recola, Berends-Giele type methods, aMC@NLO. What are the advantages and limitations?

Was the demise of the NLO wish-list premature?

* Are there processes that our BSM collegues would like to see included in the Monte Carlos?

NNLO wish list

J. Huston, Loopfest 2012

- t-tbar production, (in progress, Czakon et 1210.6832)
- W^+W^- production
- inclusive jet/dijet production (in progress Gehrmann de Ridder et 1301.7310)
- V+1 jet production
- V+gamma production
- Higgs + 1 jet production (in progress Boughezal et al 1302.6216)
- b+gamma (addition for b pdf?)
- c+gamma (addition for c pdf?)
- W+c (addition for s pdf?)
- ?????

How well do we need to know the top mass?

* 2012 values $173.18 \pm 0.56 \pm 0.75$ GeV : Tevatron

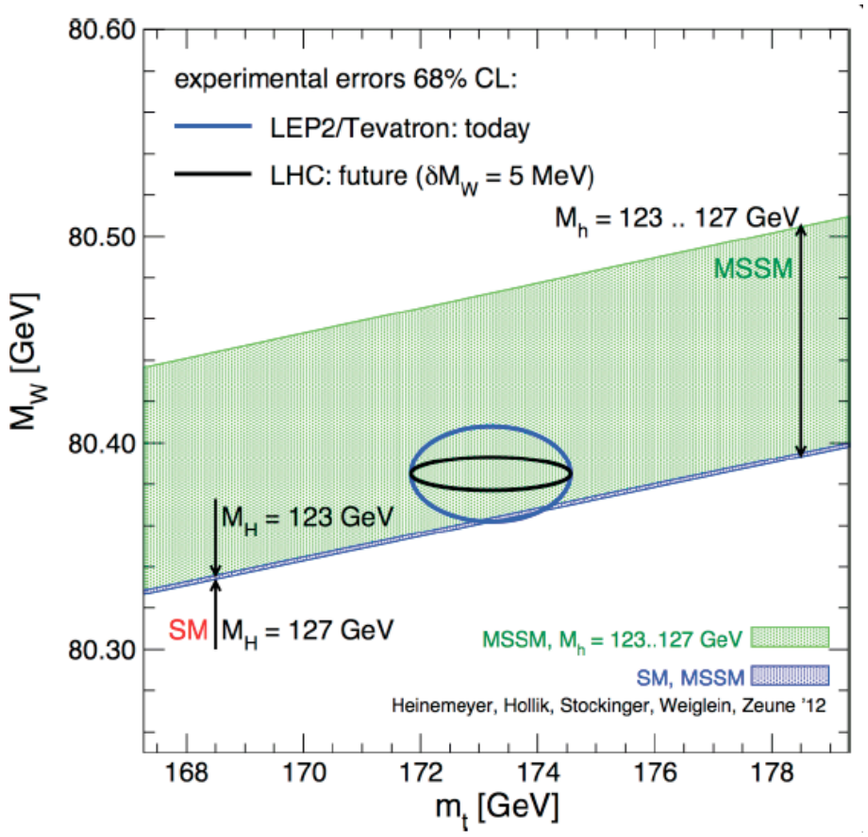
  $173.3 \pm 0.5 \pm 1.3$ GeV : LHC

* In the metric provided by the ρ-parameter, the top mass, precision required is $\Delta M_t \approx 160\, \Delta M_W$.

* In flavor physics the top mass is needed as an input to loop processes. Processes with Z-penguins depend as m_t^2.

* Higgs mass in the MSSM depends on m_t^4.

* ILC projected uncertainty, $\Delta M_t \approx$ 200-300 MeV, arXiv:0709:1893

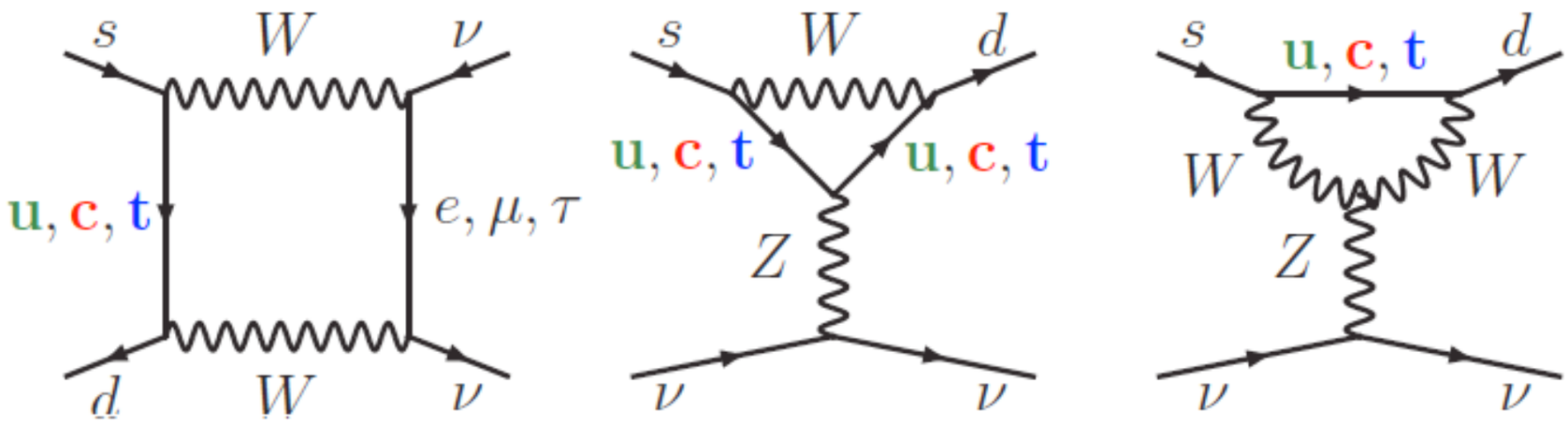


ΔM_W	ΔM_t
15 MeV	2.4 GeV
5 MeV	0.9 GeV

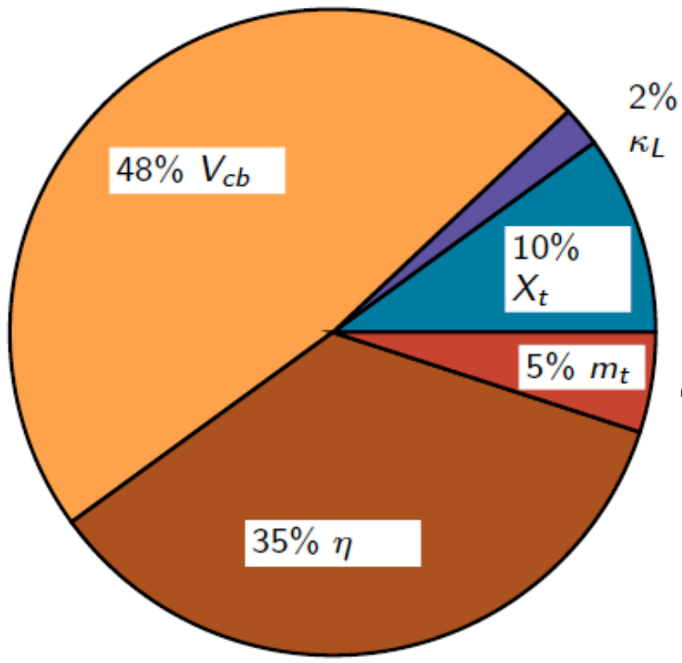
Errors on M_W and M_t required by ρ-parameter

m_t in flavor physics, eg. $K_L \to \pi^0 \nu\nu$

* Effective hamiltonian



* Error budget is completely dominated by CKM parameters V_{cb} and η.
* Even with $\Delta V_{cb}/V_{cb}$=1%, top mass error gives only 9% of total error budget.
* For currently envisaged engineering purposes $\Delta m_t \approx 1$GeV is sufficient.



Δm_t=1.4GeV

Brod and Gorbahn, arXiv:0804.4119
Brod, Project X Phyics study, FNAL,June 2012

m_t ,Higgs mass and vacuum stability.

* Higgs potential at High scale can be estimated using renormalization group arguments

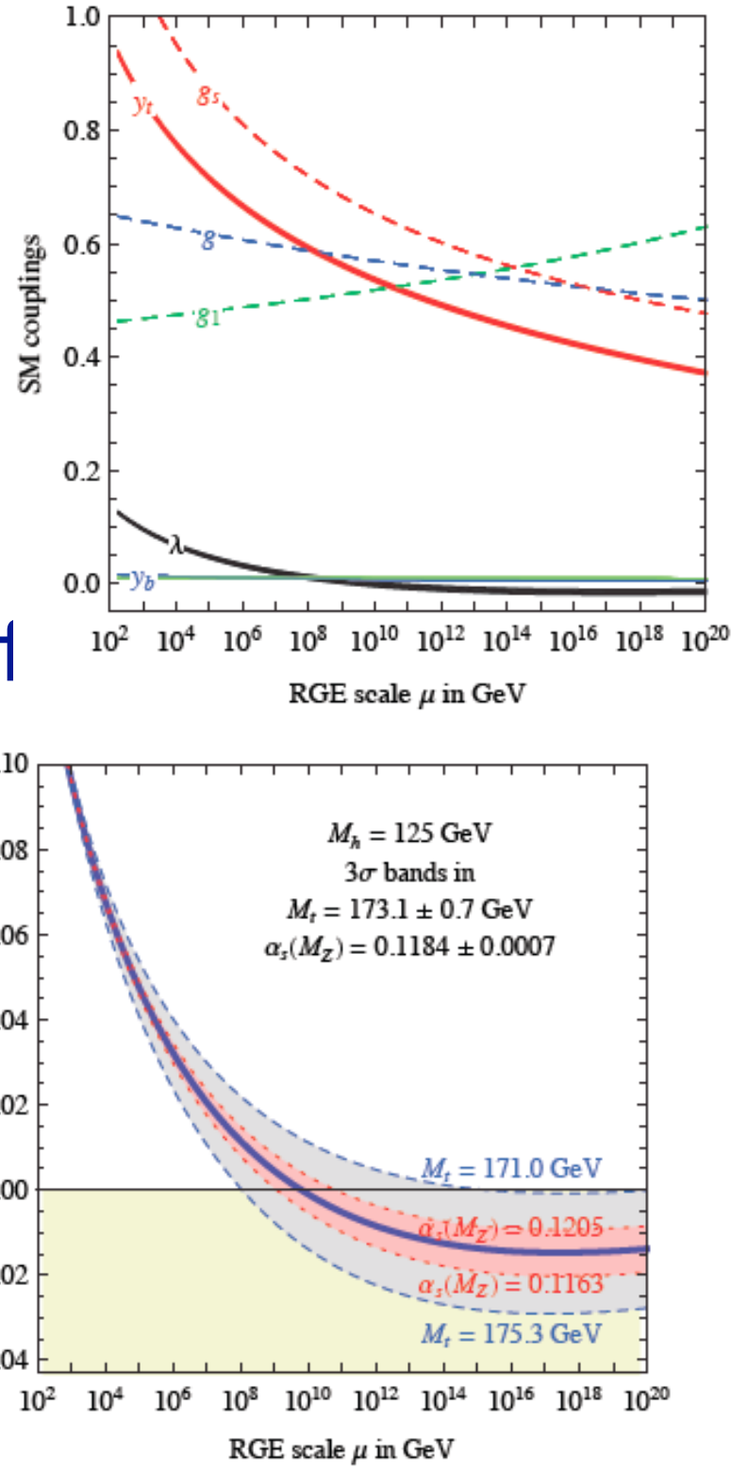
$$V(\phi) = \lambda(|\phi^2|^2 - v^2)^2 \simeq \frac{\lambda}{4}\, h^4$$

* In the quartic approximation the stability of V(ϕ) is equivalent to the positivity of λ.

$$16\pi^2 \frac{dy_t}{dt} = y_t(\frac{9}{2}y_t^2 - 8g_3^2)$$

$$16\pi^2 \frac{d\lambda}{dt} = 4\lambda^2 + 12\lambda y_t^2 - 36y_t^2 + \ldots$$

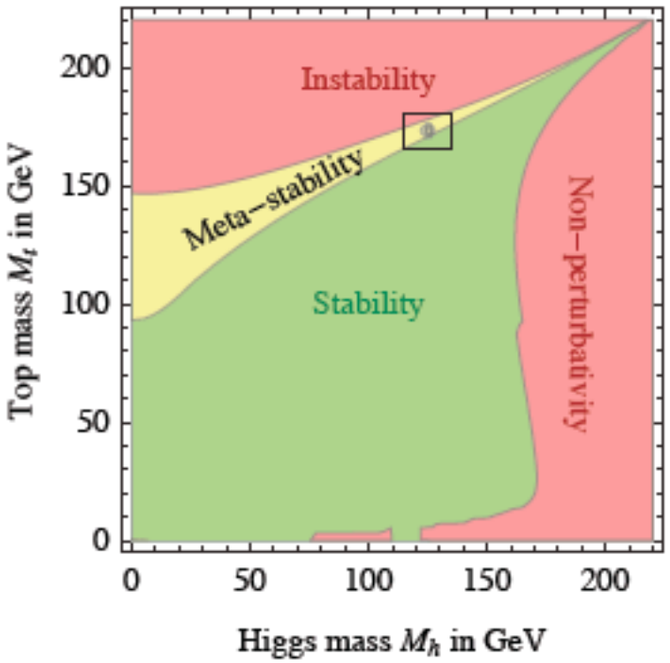
* Depends sensitively on the top mass

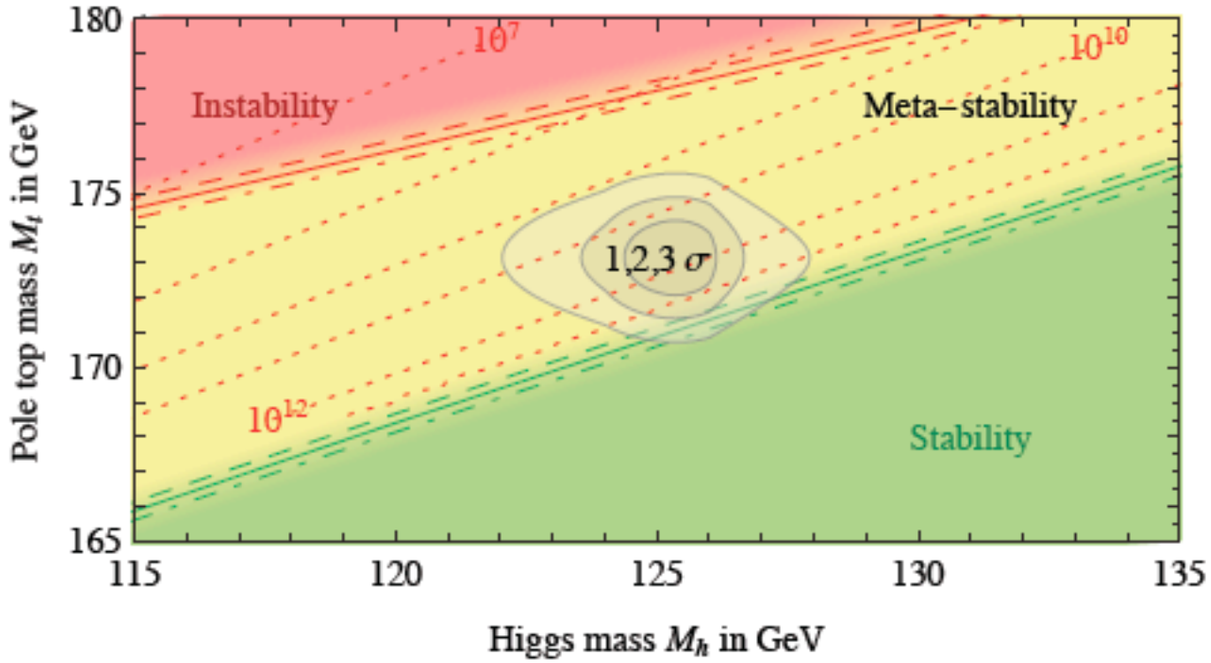


arXiv:1205.6497

Vacuum stability

* An up-to-date analysis indicates that we are in the stable/metastable region.



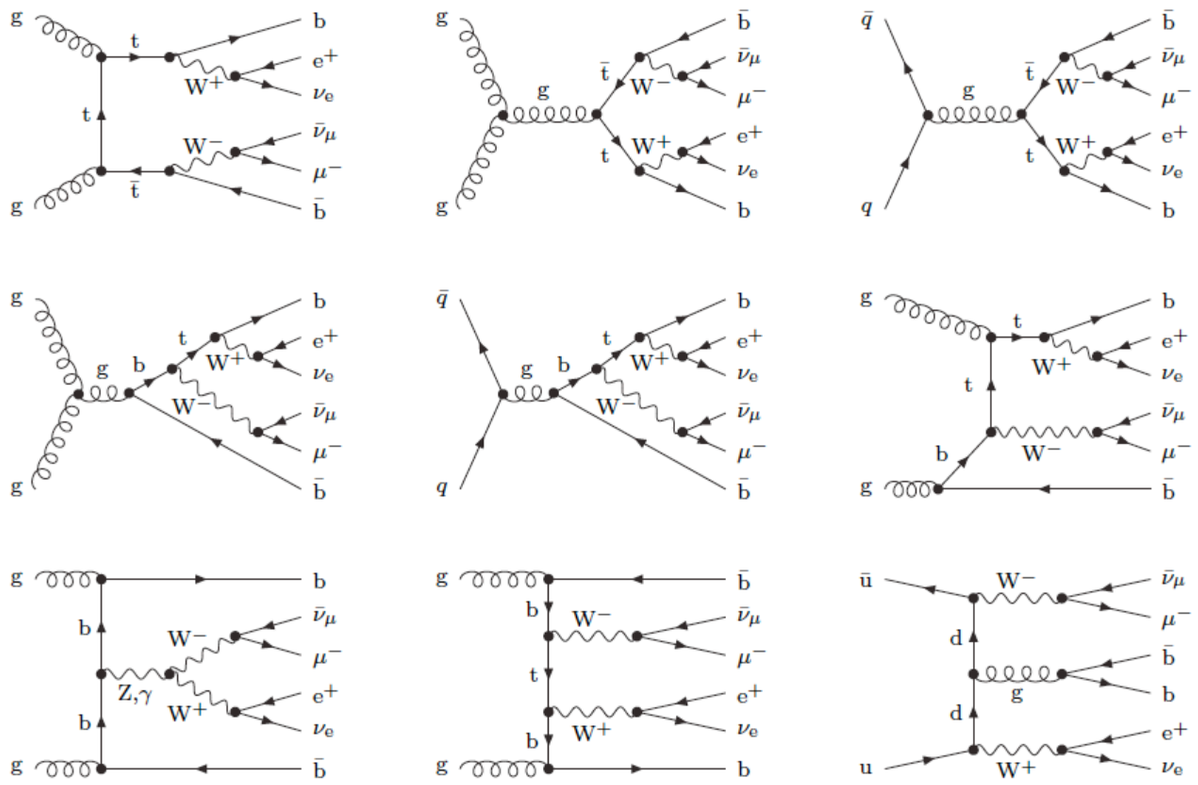


De Grassi et al, arXiv:1205.6497

Top rate predictions, (in a perfect world).

- In a perfect world we would have:-
  - Full calculations (NLO,N^{2}LO,N^{3}LO...) to every final state, say $e^-\nu b\mu^+\nu b+X$, including singly resonant and non-resonant diagrams, production-decay interference, color connection effects.
  - all matched with a parton showers.
  - all non-standard model theories included.
  - all running on your Iphone!

Worek



First steps on this road, Bevilacqua et 1012.4230
Denner et al, 1012.3975.1208.5018 and cf similar steps for single top reviewed by Falgari

NNLO prognosis for the future.

* The next major experimental break point is in March 2015 when the LHC will start running at 13 TeV.
* I invite people to make predictions about where we shall be with NNLO calculations at that date.
* What are the stumbling blocks to further progress?

A set of questions www.snowmass2013.org

John Campbell (Fermilab), **Kenichi Hatakeyama** (Baylor), **Joey Huston** (Michigan State), **Frank Petriello** (ANL/Northwestern)

* What are the prospects for future higher order calculations at NLO and matched with parton showers? What subtleties remain to be understood for precision measurements?
* What is the best way to distribute the results of complex NLO, and emerging NNLO, calculations to the experimental community?
* Survey of the importance of electroweak corrections (both those already calculated and possible impact of as-yet un-calculated contributions). Do we need a "NLO EW wish-list" similar to the now-defunct NLO QCD one, or will such calculations be automated soon as well?
* The 2->2 NNLO frontier is expected to be breached soon. On what timescale will be have (or need) such calculations available? Prime examples are vector boson + jet and diboson production.
* What are the prospects for inclusion of NNLO effects in a parton shower? To what extent are analyses limited by the choice of either NLO+PS or NNLO, e.g. for Higgs studies?
* Are measurements now constraining subtle effects in parton shower or NLO+PS calculations?

Snowmass questions (jets)

- Can jet substructure, in particular in boosted systems, be put to wider use in other physics analyses?
- Can jet substructure, in particular in boosted systems, be put to wider use in other physics analyses?
- Can particle-flow techniques be taken advantage of in future jet algorithms?
- Can event shapes such as jettiness be useful in future measurements, and should the experimental collaborations study their implementation at the LHC?

Snowmass questions (PDFs)

- What impact will LHC jet data have on PDFs?
- How much better might an e-LHC constrain PDFs? Is the improved precision necessary?
- What are the prospects for improving the theoretical description of PDFs?
- How important will knowledge of the photon PDF be for future measurements, such as in precision electroweak measurements at hadron colliders or in the study of WW scattering at high energy?

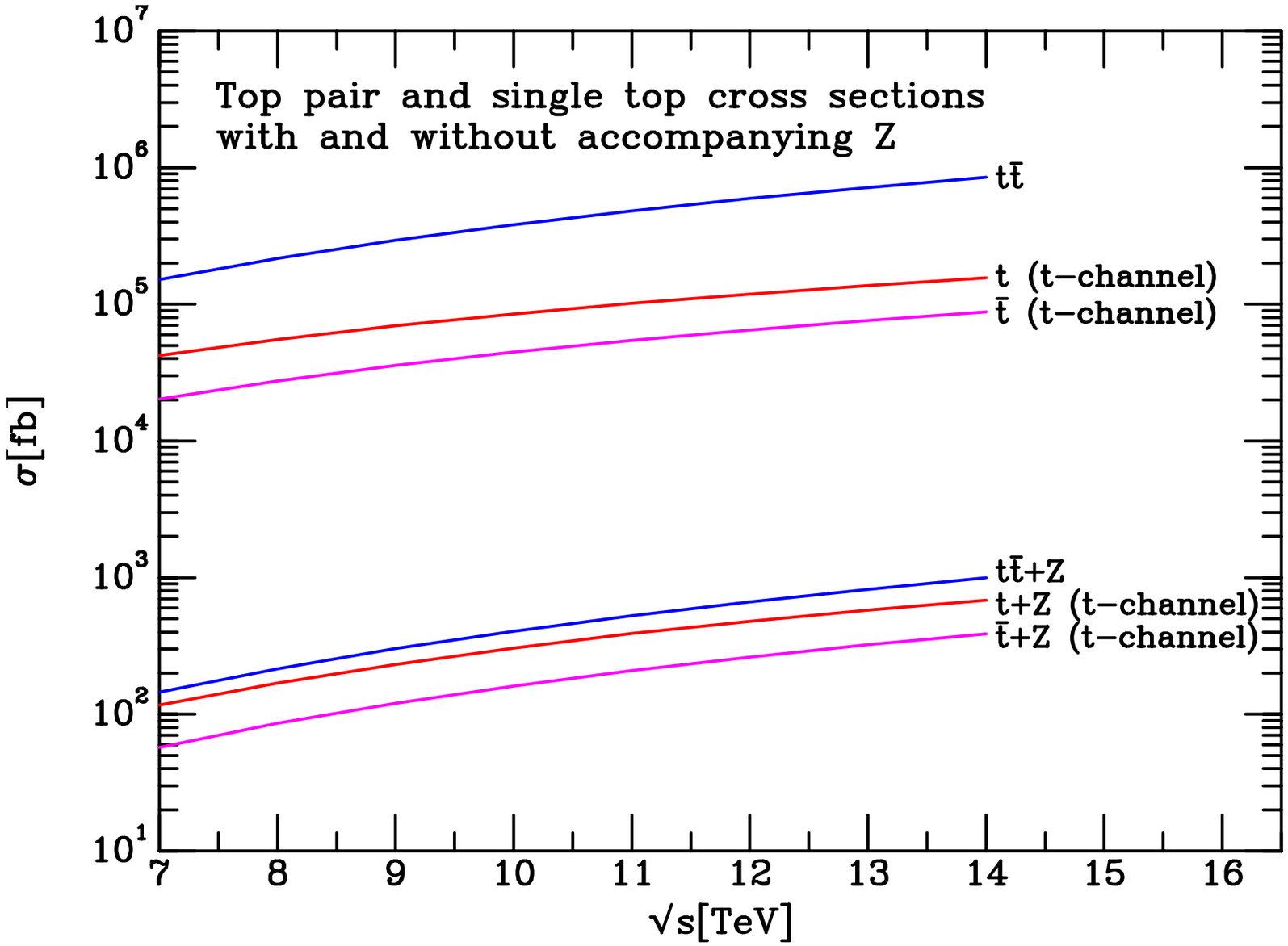
Snowmass questions (resummation and non-perturbative)

- In what situations do we need better resummation techniques? Can we envisage future experimental measurements where severe phase space restrictions will be required?
- To what extent do current formalisms to resum large logarithms in jet-binned cross sections agree? Can we envisage more flexible resummation formalisms to handle more complicated observables?
- Are there gaps in our understanding of diffractive and hard diffractive physics?
- How hampered are we by our limited understanding of non-perturbative physics?

MCFM v.6.5 (March 5th 2013)

* Available at mcfm.fnal.gov
* New features:-
  * Implementation of single top tH and tZ processes.
  * Implementation of dark matter mono-jet and mono-photon processes.
  * Inclusion of TensorReduction library for one-loop integrals.

Single top + Z



Campbell,R.K.Ellis, Rontsch
arXIv:1302.3856

* Rate for single top +Z (both charges) is the same as ttZ
* Consequences for ttZ search and unaccounted for background in search for FCNC in top decay