Top-antitop Threshold Production at Electron-Positron Colliders

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Topics discussed

- *Why top threshold?*
- *Status of theoretical analysis*
- *Review of experimental simulations*
- *Open questions*

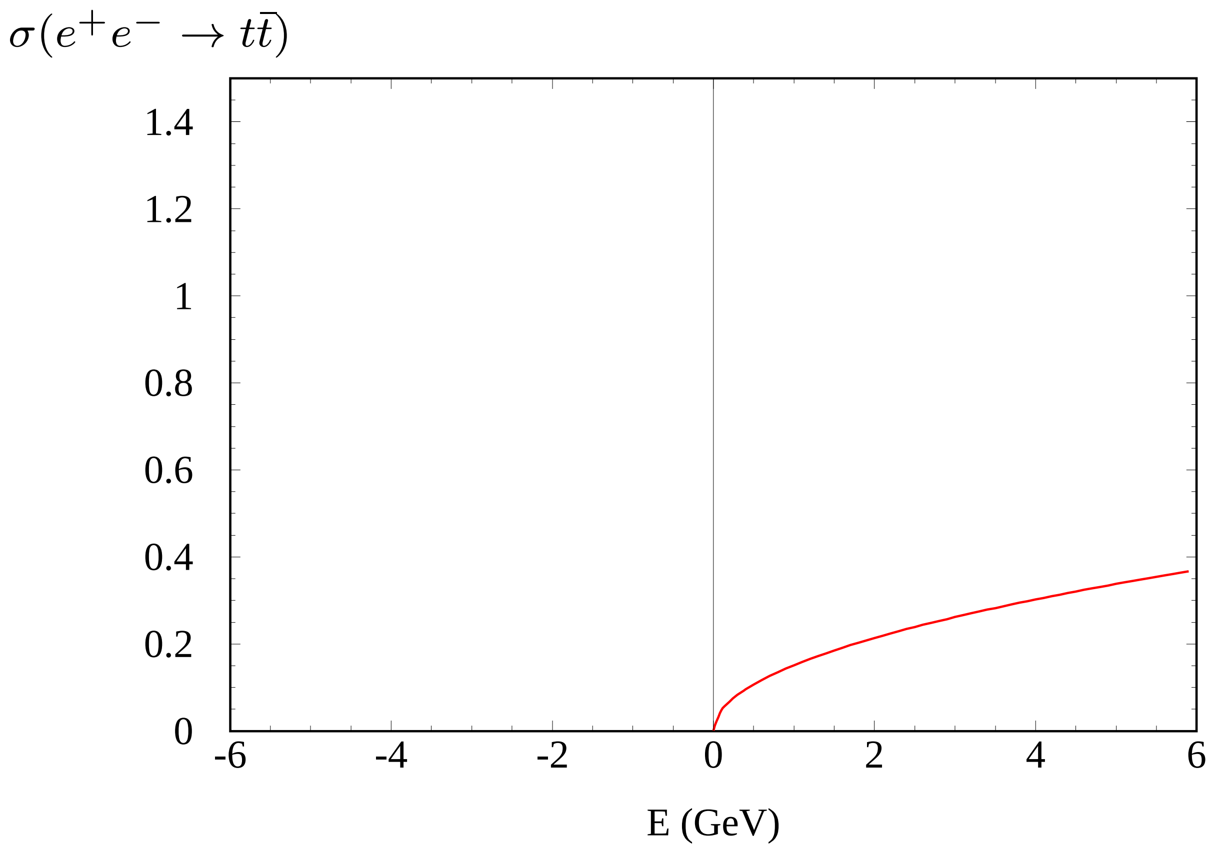
prepared in collaboration with Aurelio Juste *(Universitat Autonòma de Barcelona)*

Why threshold scan at LC?

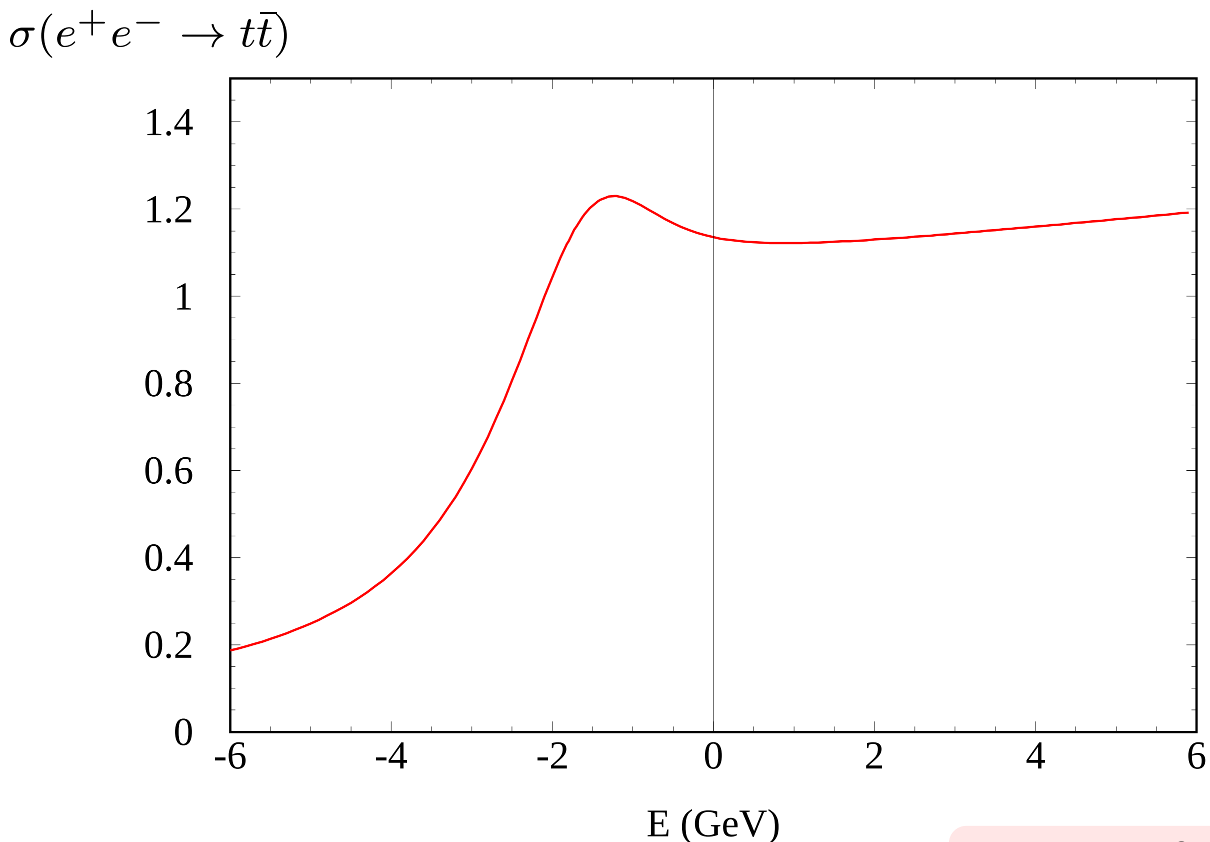
- Theory
  - *top quark width is a natural infrared cutoff*
  - ➥ *first principle QCD predictions*
- Experiment
  - *as clean as possible for a strongly interacting particle*
- Phenomenology
  - *most precise determination of top quark properties such as*

    mass, width, vector couplings

Born cross section



Coulomb and finite width effects



$$\sigma_{\rm res} \sim \frac{\alpha_s^3}{m_t\Gamma_t}, \quad E_{\rm res} - 2m_t \sim \alpha_s^2 m_t$$

Perturbation theory

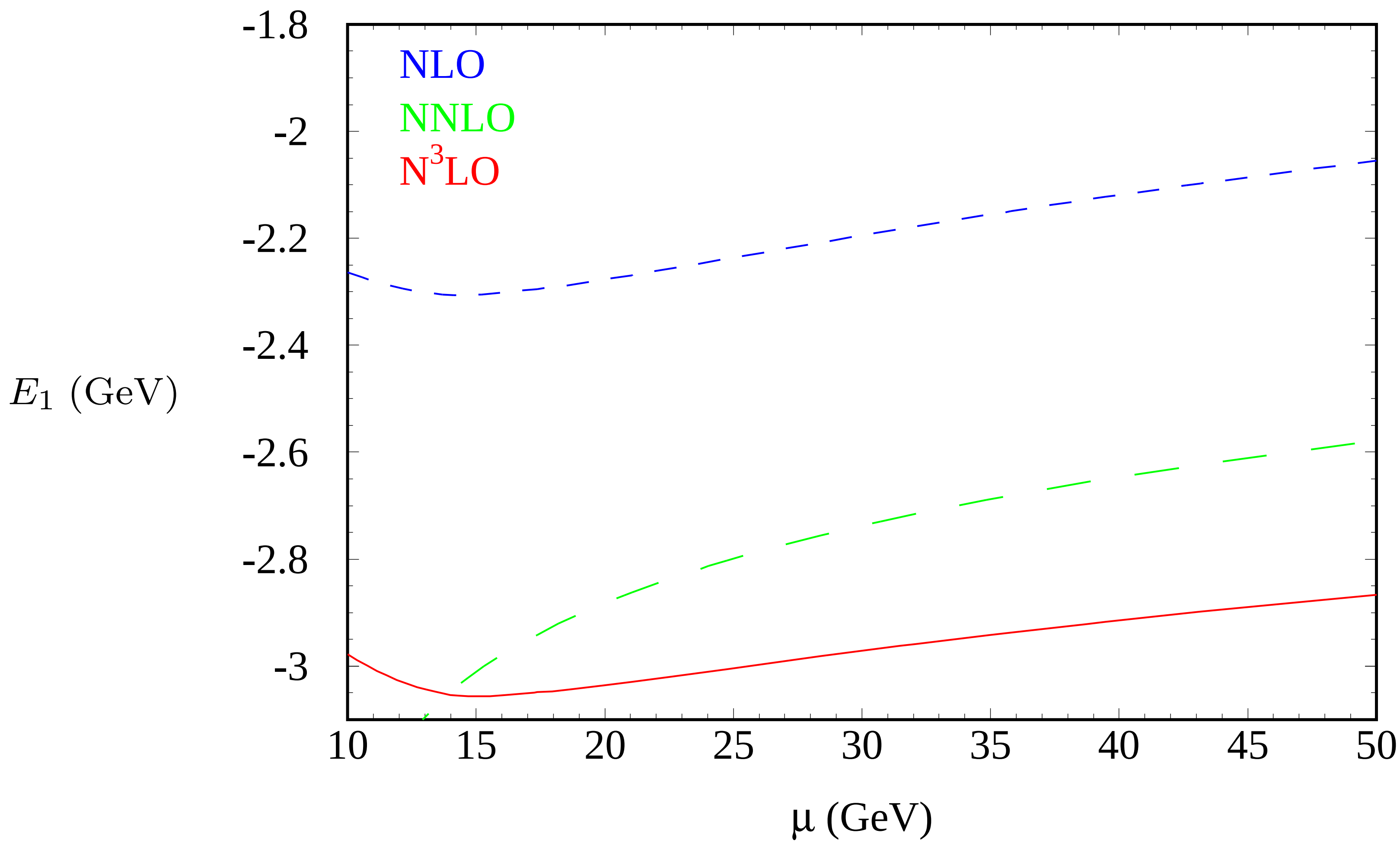
- NNLO (end of last century)
  - *Apparent slow convergence*

- Possible reasons:
  - *Renormalons* $n!(\beta_0\alpha_s)^n$
  - *Threshold logs* $\alpha_s^n \ln^m \alpha_s$

↪ *Full N^{3}LO analysis is mandatory*

N^3LO resonance energy

A. Penin, M. Steinhauser Phys.Lett. B538 (2002) 335



Top mass at N^{3}LO

A. Penin, M. Steinhauser Phys.Lett. B538 (2002) 335

Toponium resonance energy: $E_{\rm res} = 2m_t + E_1^{N^3LO} + \delta^{\Gamma_t} E_{\rm res}$

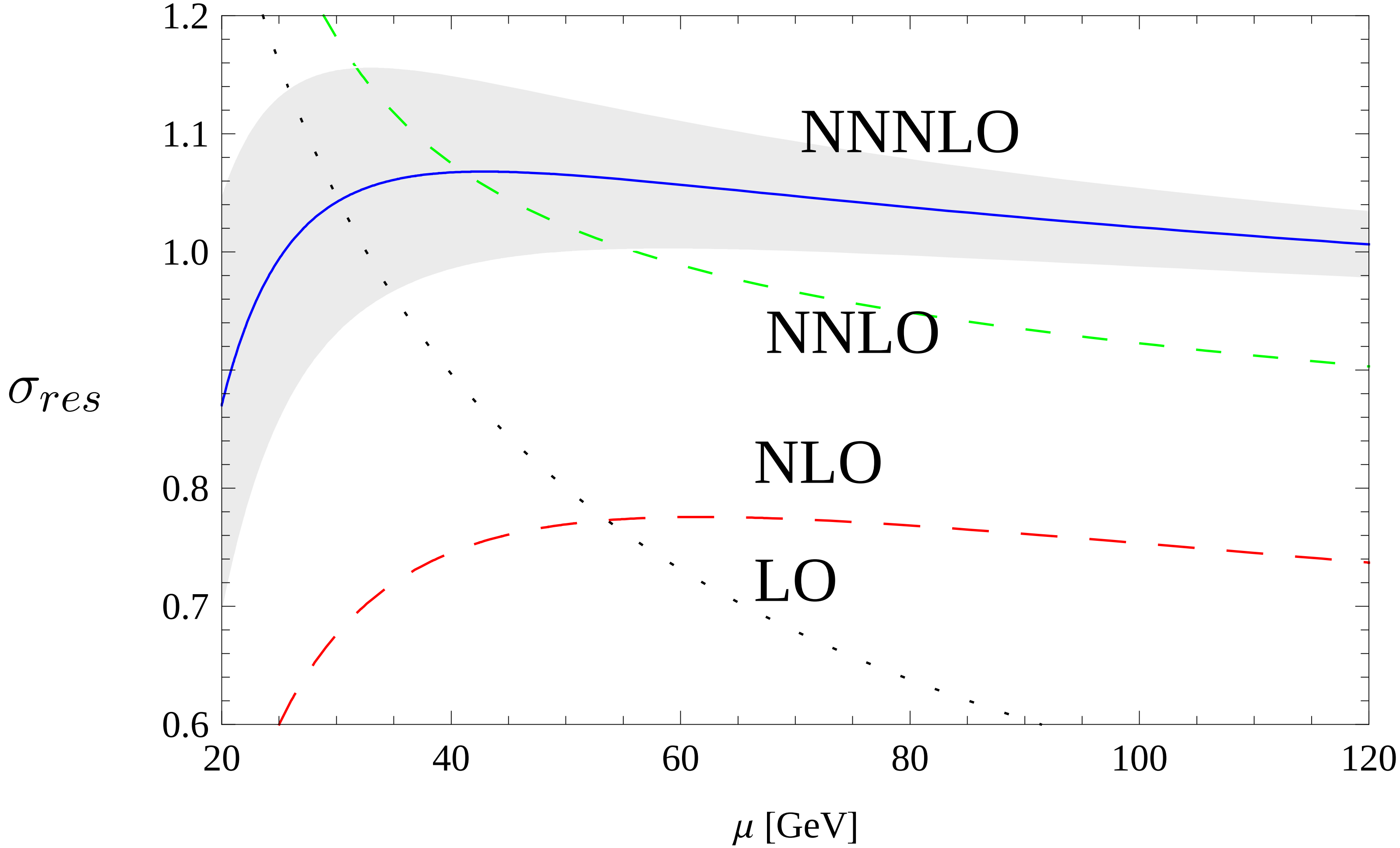
$$E_{\rm res} = \left(1.9833 + 0.007 \, \frac{m_t - 174.3 \text{ GeV}}{174.3 \text{ GeV}} \pm 0.0009 \right) \times m_t$$

- *Top quark mass m_t with 80 MeV accuracy (renormalons?)*
- *Short distance mass $\bar{m}_t(\bar{m}_t)$ with 50 MeV accuracy* *

Y. Kiyo, Y. Sumino, Phys. Rev. D **67** (2003) 071501

N^{3}LO resonance cross section

M. Beneke Y. Kiyo, A. Penin, K. Schuller, arXiv:0710.4236 [hep-ph]



Finite width effect

- Resonant approximation V.Fadin, V.Khoze, JETP Lett. 46 (1987) 525

$$\delta(\boldsymbol{p}^2 - m_t E) \to \frac{1}{\pi} \frac{\Gamma_t}{(\boldsymbol{p}^2/m_t - E)^2 + \Gamma_t^2} ,$$

not consistent in pNRQCD beyond LO!

- Nonresonant contribution *(up to 10%)*
  - *NLO*

    M. Beneke, B. Jantzen, P. Ruiz-Femenía, Nucl. Phys. B840 (2010) 186
  - *NNLO*

    A. Penin, J. Piclum, JHEP 1201 (2012) 034

Theory summary

- Top mass
  - *NNNLO QCD*

  ↪ 80 MeV (50 MeV)*accuracy*

- Total cross section
  - *NNNLO QCD (coming soon)*
  - *NNLO finite width*

  ↪ 3% *accuracy*

- Differential observables
  - *momentum distribution, forward-backward assymetry*

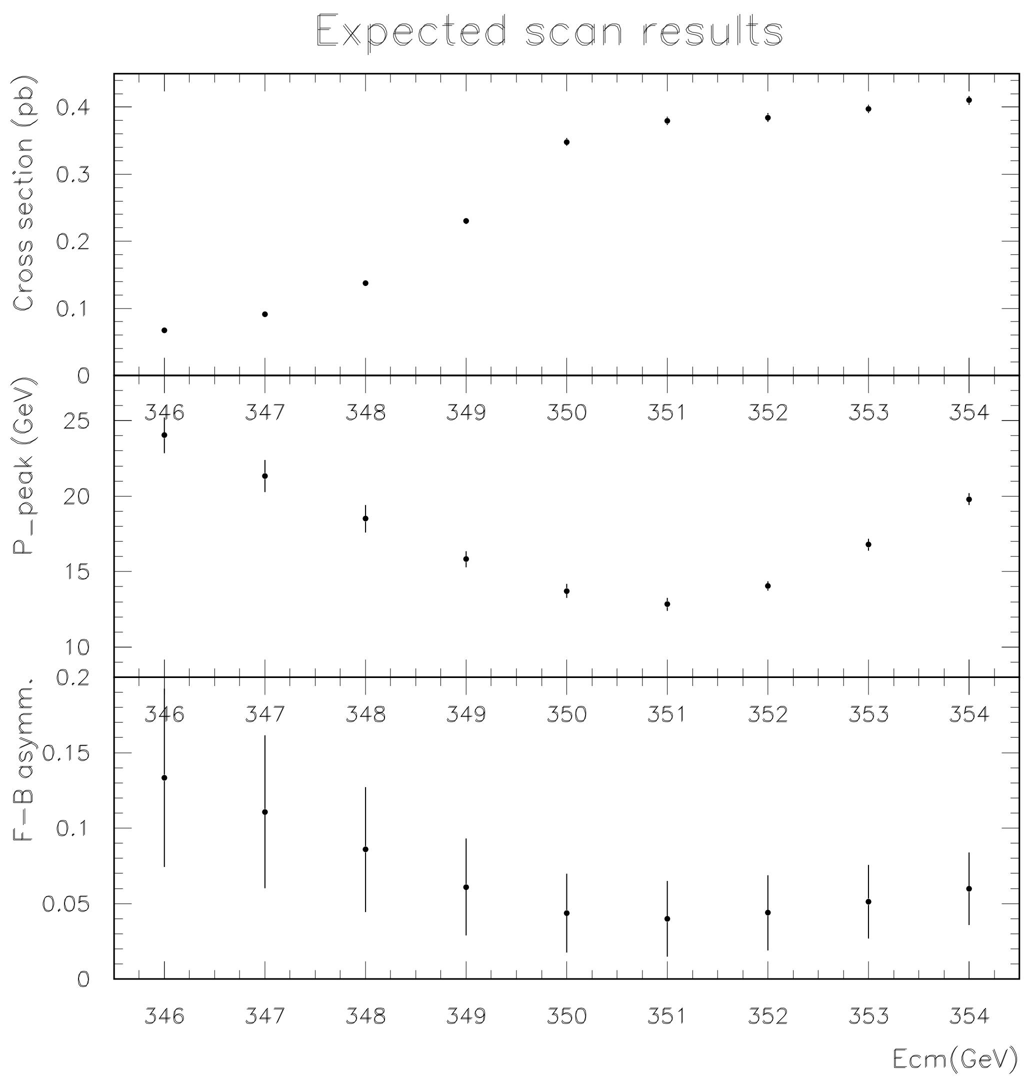
A. H. Hoang, T. Teubner, Phys. Rev. D **60** (1999) 114027;

T. Nagano, A. Ota, Y. Sumino, Phys. Rev. D **60** (1999) 114014

  - *NNLO QCD, LO finite width,* $> 10\%$ *uncertainty*

Simulations

M. Martinez, R. Miquel, Eur. Phys. J. C **27** (2003) 49



Estimated experimental accuracy

- Detectors, event selection efficiency, statistics (300 fb^{-1})

  M. Martinez, R. Miquel, Eur. Phys. J. C **27** (2003) 49; F. Simon (LCD-Note-2013-013)

  - *total cross section* 3%
  - *differential observables significantly worse*
  - *resonance energy* 31 *MeV*

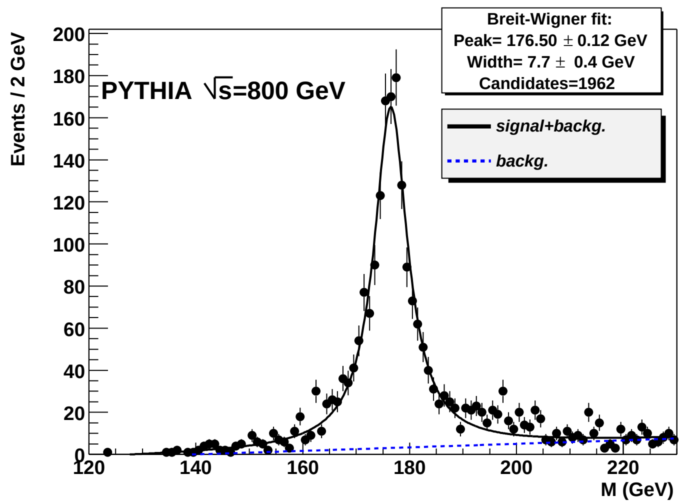
- Beam effects in resonanse energy determination

  F. Gournaris (PhD thesis 2009)

  - *nominal beam energy induced uncertaity* 35 *MeV*
  - *luminosity spectrum induced uncertainty* 50 *MeV*

Direct reconstruction of top quark mass

S.V. Chekanov, Eur. Phys. J. C **26** (2002) 13; F. Simon (LCD-Note-2013-013)



- Experimental errors in hadronic (semileptonic) channels
  - *statistical 100 fb^{-1}:* 100 MeV (140 MeV)
  - *systematical (hadronization model):* 400 MeV (250 MeV)

Top precision measurements from threshold scan

✔ Top quark mass

total uncertainty ~ 100 *MeV* ➪ *beats direct reconstruction*

✔ Top quark width

total uncertainty ~ 34 *MeV*

✔ Top quark vector couplings

total uncertainty $\sim 3\%$

✘ Top quark Higgs coupling (from Yukawa potential)

factor 2 uncertainty ➪ *cannot compete with Higgs production*

Problems to solve

- Theory
  - *Renormalization group improved NNNLO analysis*
  - *Four-loop relation between pole and* $\overline{MS}$ *mass*
- Experiment
  - *Systematic uncertainty budget for direct top mass reconstruction*