QCD corrections to top-pair production near threshold

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AEC
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FOR FUNDAMENTAL PHYSICS

based on

M. Beneke, Y. Kiyo, P. Marquard, A. Penin, JP, M. Steinhauser,
PRL 115 (2015) 192001, arXiv:1506.06864

Top Mass Determinations

direct reconstruction: [ATLAS, CDF, CMS, D0 2014]

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$$\text{ABM12: } m_t = 171.2 \pm 2.4 \text{ GeV}$$

extract pole mass from flavour physics and electroweak data:
[Giudice, Paradisi, Strumia 2015]

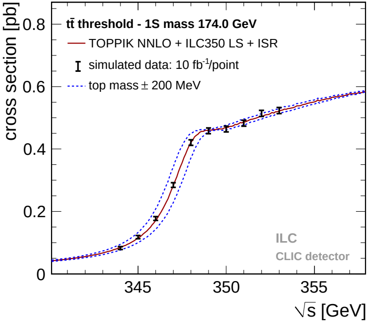
$$m_{t,\text{flavour}} = 175.1 \pm 8.0 \text{ GeV}$$

$$m_{t,\text{EW}} = 177.0 \pm 2.6 \text{ GeV}$$

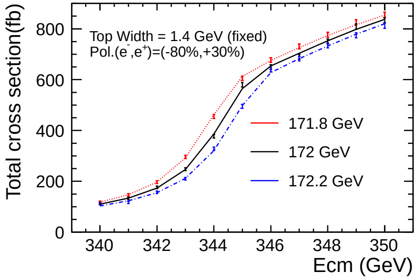
Top Mass at ILC I

perform threshold scan

⇝ comparison with theoretical prediction in well-defined mass scheme (e.g. PS or 1S)



[Seidel, Simon, Tesař, Poss 2013]



[Horiguchi et al. 2013]

Top Mass at ILC II

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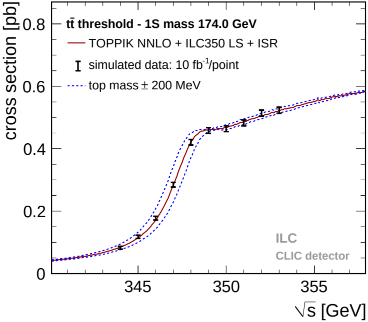

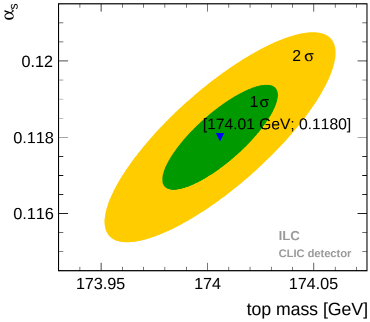

for 10 fb^{-1} per point:

	δm_t	$\delta \alpha_s$
stat. error	27 MeV	0.0008
theory (3%)	9 MeV	0.0022

see also Frank Simon's LCWS talk for update with NNNLO result

Threshold Production

relative velocity of quark-antiquark pair is small:

$$\sqrt{s} = E + 2m_Q \approx 2m_Q \quad \Rightarrow \quad v = \sqrt{\frac{E}{m_Q}} \ll 1\,; \quad v \sim \alpha_s(m_Q v)$$

- multi-scale problem: mass m_Q, momentum $m_Q v$, energy $m_Q v^2$
- perturbation theory breaks down due to terms proportional to $\frac{\alpha_s}{v}$
  $\rightsquigarrow$ Coulomb resummation
- formation of bound states below threshold

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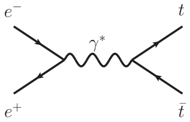

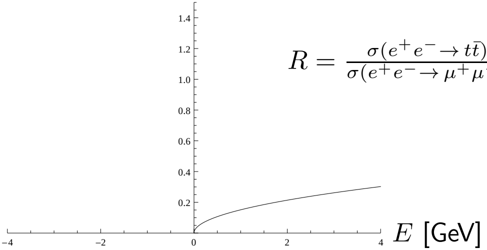

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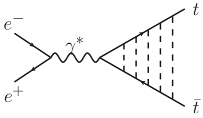

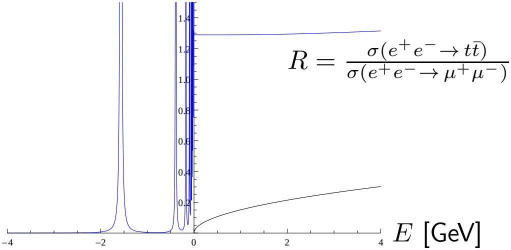

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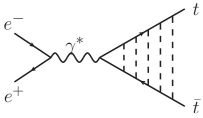
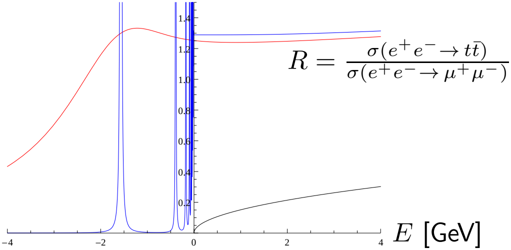
- $t\bar{t}$: large width prevents existence of bound states





Effective Theory Setup

[Thacker, Lepage; Lepage, Magnea, Nakhleh, Magnea, Hornbostel; Bodwin, Braaten, Lepage]
[Pineda, Soto; Beneke, Signer, Smirnov; Brambilla, Pineda, Soto, Vairo]

scale hierarchy: $m_t \gg m_t v \gg m_t v^2 \gg \Lambda_{\mathrm{QCD}}$

QCD full theory

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integrate out hard modes: $k^0 \sim k^i \sim m_t$
hard subgraphs become point-like vertices
$\rightsquigarrow$ hard matching coefficients

NRQCD

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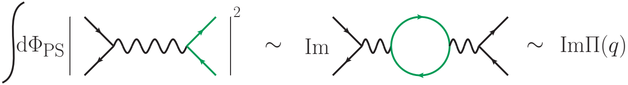
NRQCD

↓ integrate out soft modes: $k^0 \sim k^i \sim m_t v$
soft subgraphs become instantaneous, non-local vertices
$\rightsquigarrow$ potentials

pNRQCD — contains potential quarks and ultrasoft gluons

Calculating the Cross Section

use optical theorem:



compute polarisation function in pNRQCD: $\Pi(q) \sim c_v^2\, G(\vec{0}, \vec{0}; E)$

- compute hard matching coefficients
- compute potential
- solve Schrödinger equation
- compute ultrasoft corrections

power counting:

$$\sum_n \left(\frac{\alpha_s}{v}\right)^n \times \left\{1;\ \underbrace{\alpha_s, v}_{\text{NLO}};\ \underbrace{\alpha_s^2, \alpha_s v, v^2}_{\text{NNLO}};\ \underbrace{\alpha_s^3, \alpha_s^2 v, \alpha_s v^2, v^3}_{\text{NNNLO}};\ \ldots\right\}$$

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- finite-width effects [Fadin, Khoze; Hoang, Reißer, Ruiz-Femenía; Beneke, Jantzen, Ruiz-Femenía; Penin, JP]
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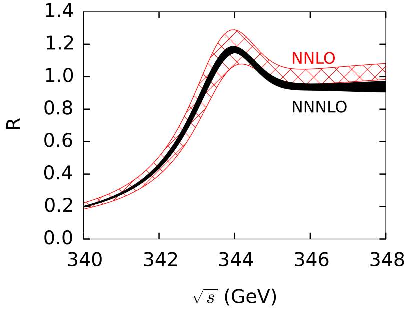
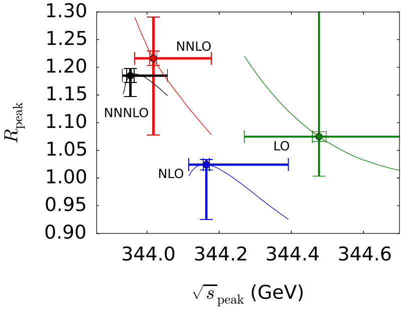
→ following talk by Thomas Rauh

Scale Dependence





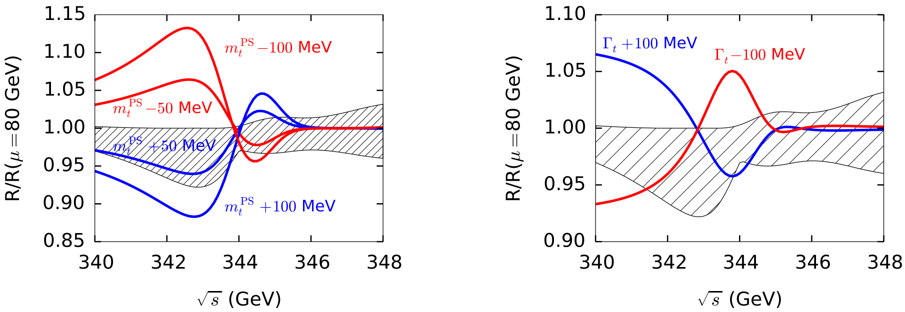
PS scheme: $m_t^{\mathrm{PS}}(\mu_f = 20\,\mathrm{GeV}) = 171.5$ GeV

$\Gamma_t = 1.33$ GeV

$\alpha_s(M_Z) = 0.1185 \pm 0.0006$

$\mu = 50 - 350$ GeV

Parameter Dependence



(see Frank Simon's LCWS talk for more detailed analysis of mass determination)

Summary

- threshold production allows for very precise and theoretically clean determination of top-quark mass
- very high theoretical precision is required
- NNNLO QCD corrections are done
- scale uncertainty $\pm 3\%$
- ± 50 MeV uncertainty in top mass seems feasible

lots of work still to be done, e.g.:

- electroweak/finite-width corrections $\rightarrow$ see next talk
- combination of fixed-order and resummed calculations