Working group summary

Loopverein, Top and QCD

Thomas Becher, Fermilab

LCWS08,
UIC, Nov. 15-20, 2008

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LCWS08,
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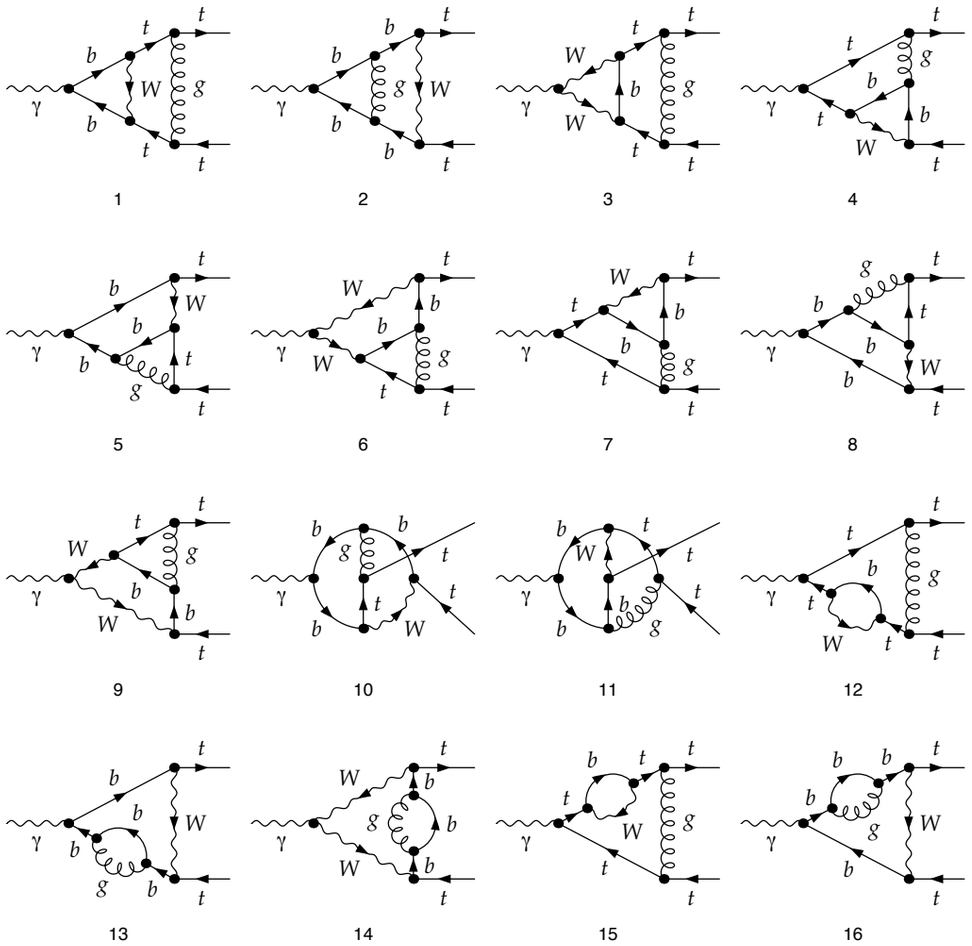
PREDICTIONS FOR THE ILC

- Precise predictions are crucial for the physics program at the ILC.
  - QCD effects present the main challenge:
    - rich phenomenology, produces backgrounds to many new physics signals,
    - large coupling constant, leading order perturbation theory is often not sufficient,
    - need to control non-perturbative effects (hadronisation, ...).
  - ILC: higher energy and luminosity → higher precision and higher multiplicity final states.

Challenges

- Many loops
  - NNLO corrections to Bhabha scattering
  - NNLO corrections to $e^+e^- \to 3\,\text{jets}$
- Many legs
  - Unitarity methods, recursion relations
- Many scales
  - Effective theory calculations and resummation
- More realism
  - Detailed simulations and exp. studies

17 talks in our WG



from Dirk Seidel's talk

MANY LOOPS

Bhabha Scattering @NNLO

[A. Ferroglia]

- Bhabha scattering is used for the luminosity measurement at lepton colliders

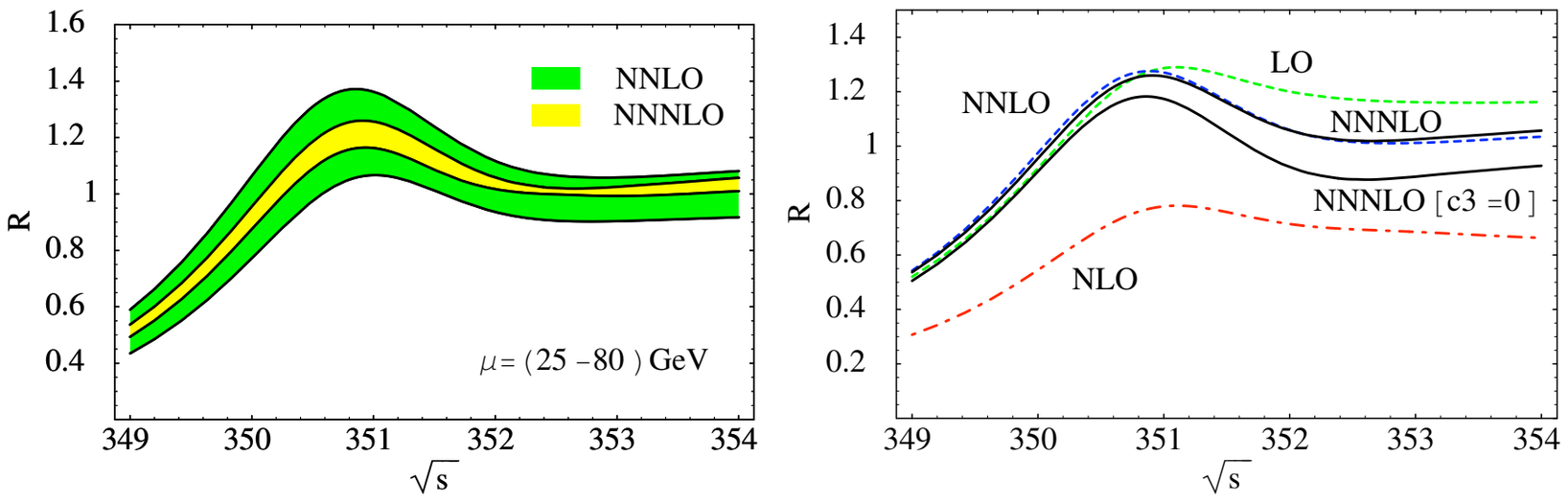
$$\mathcal{L} = \frac{\frac{dN}{dt\,d\Omega}\Big|_{\text{measured}}}{\frac{d\sigma}{d\Omega}\Big|_{\text{theory}}}$$

← precise prediction crucial

- After a large effort by many people, we now have all relevant 2-loop QED corrections, including
  - heavy flavor corrections
  - hadronic corrections
- Corrections still need to be implemented into MC event generator.

$\sigma(e^+e^- \to t\bar{t})$ NEAR THRESHOLD

[D. Seidel]

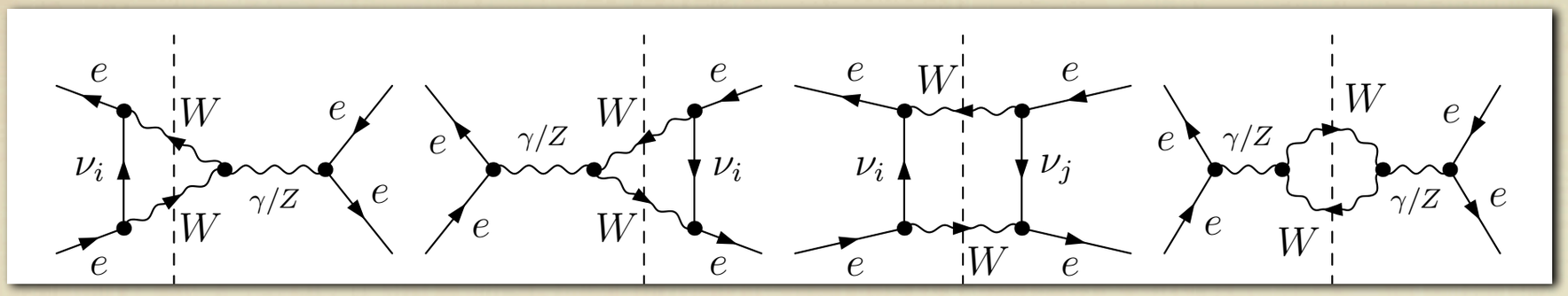


Plots from [Beneke, Kiyo, Schuller '08]

- NNNLO nearly complete. Needed for <3% accuracy on cross section. $\delta m_t < 100\mathrm{MeV}$
  - hard matching calculation incomplete, ongoing work.
- Part of the $\mathcal{O}(\alpha\alpha_s)$ corrections were calculated and found to be very small ~ 0.1%. Presumably, the entire correction is negligible. Kiyo, Seidel and Steinhauser '08

W^+W^- NEAR THRESHOLD

[S. Actis]

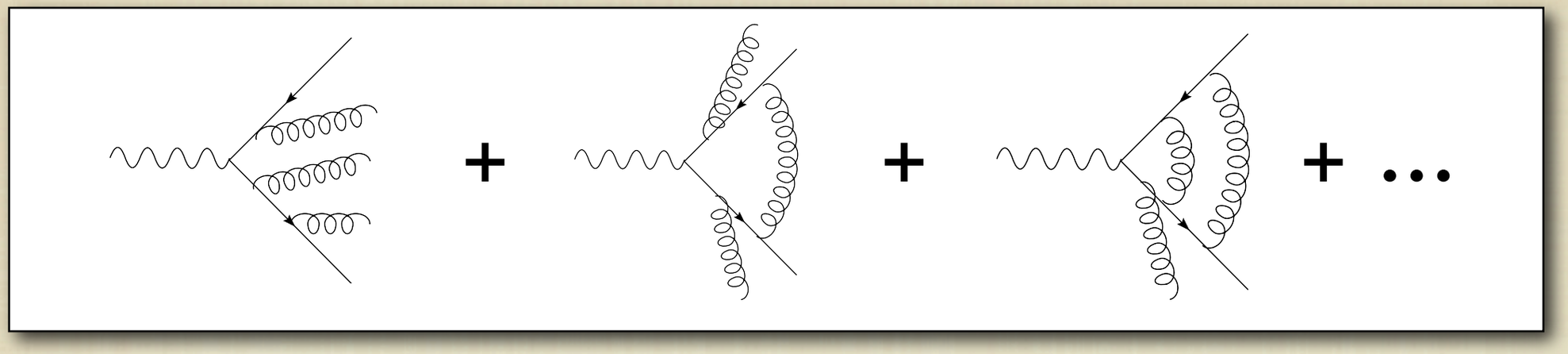


- Precision determination of m_W. 6 MeV accuracy?
- NLO corrections where the W width is consistently included by two groups:
  - using complex mass scheme Denner et al. '05
    - exclusive: arbitrary cuts
  - using EFT for unstable particles Beneke at al.'07
    - works only in the threshold region but can include dominant NNLO effects.

$e^+e^- \to 3$ JETS @ NNLO

A. Gehrmann-De Ridder, T. Gehrmann, E.W.N. Glover, G. Heinrich '07 Weinzierl '08

[Gionata Luisoni]



- Implemented in fixed order event generator. Can be used for NNLO evaluation of event shapes.
- Used to determine α_s from LEP data:

$$\alpha_s(M_Z^2) = 0.1240 \pm 0.0008\,(\text{stat}) \pm 0.0010\,(\text{exp}) \pm 0.0011\,(\text{had}) \pm 0.0029\,(\text{theo})$$

- Even at NNLO perturbative uncertainty dominates.
  - Resum logarithmically enhanced contributions.

$e^+e^- \longrightarrow 3$ JETS @ NNLO

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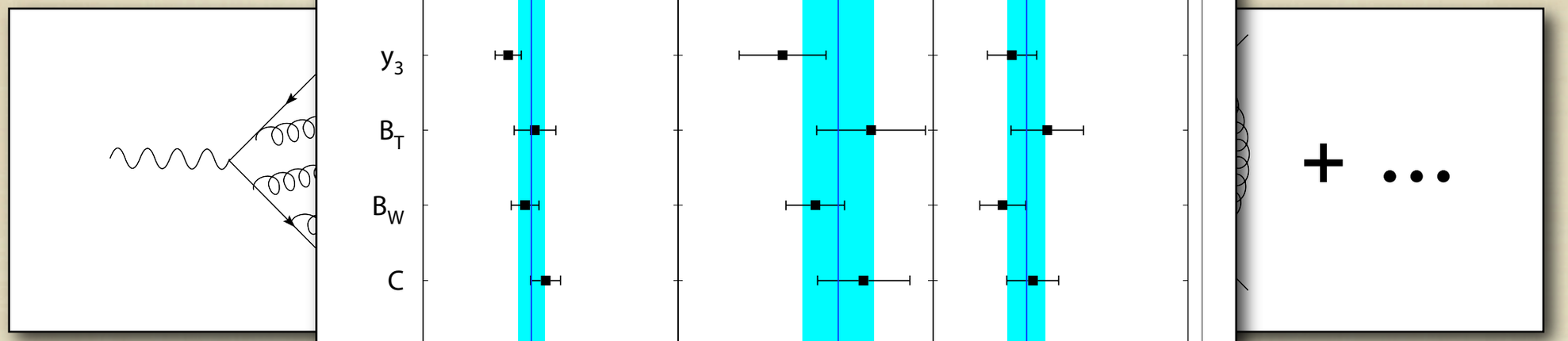

- Impleme rator. Can be used for apes.
- Used to determine α_s from LEP data:

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MANY LEGS

MANY LEGS

- As the number of external legs grows, the standard Feynman diagram approach to perturbative calculations becomes impractical:

  1. Number of diagrams grows factorially with the number of external legs.

  2. Passarino-Veltman reduction to scalar integrals produces large number of terms and is numerically unstable when external momenta are linearly dependent.

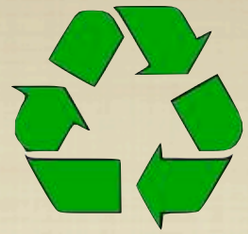
- Solution to 1.) at tree level: Berends-Giele ‘88 recursion relations

  - Polynomial-complexity algorithm for calculating high-multiplicity tree-level amplitudes in QCD.

Many Legs @ NLO

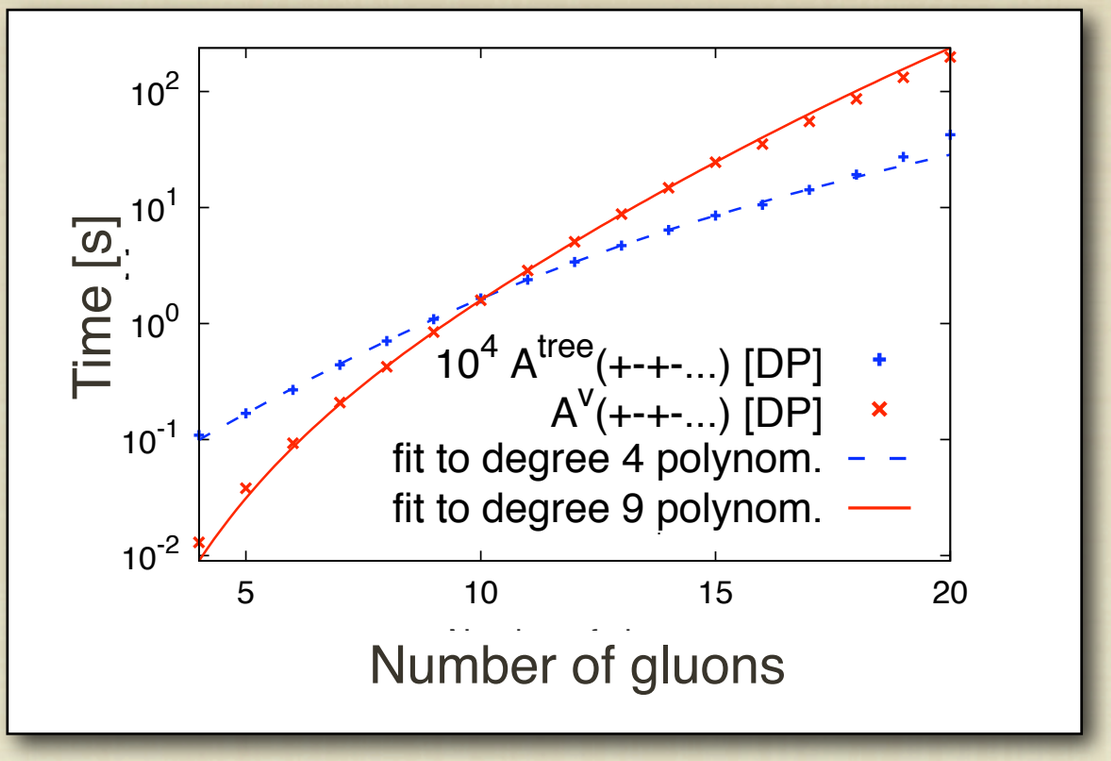
- A pressing problem in pQCD are NLO calculations of processes with many legs
  - $pp \to \geq 3$ jets, $e^+e^- \to \geq 4$ jets
  - $pp \to (W, Z) + \geq 2$ jets, $pp \to (W\,W, W\,Z, WW) + \geq 2$ jets, ...
- Most of this work is done in preparation of the LHC, but the same methods will be used to calculate ILC processes.
- Talks on
  - $pp \to t\bar{t}Z$ T. McElmurry
  - Tensor reduction of pentagon and hexagon int's Th. Diakonidis

Recycling of Trees



- Lots of recent work and many interesting new ideas over the last few years, e.g.
  - New tree-level recursion relations: based on MHV amplitudes Cachazo, Svrcek and Witten, between on-shell amplitudes Britto, Cachazo, Feng and Witten.
    - implemented in new matched MC code [M. Peskin]
  - Generalized unitarity. Bern et al., Britto, Cachazo and Feng. Simple numerical implementation: Ossola, Padadapoulos and Pittau.
    - Recycles trees into loops!

Yes, we can: 20 gluon one loop amplitudes

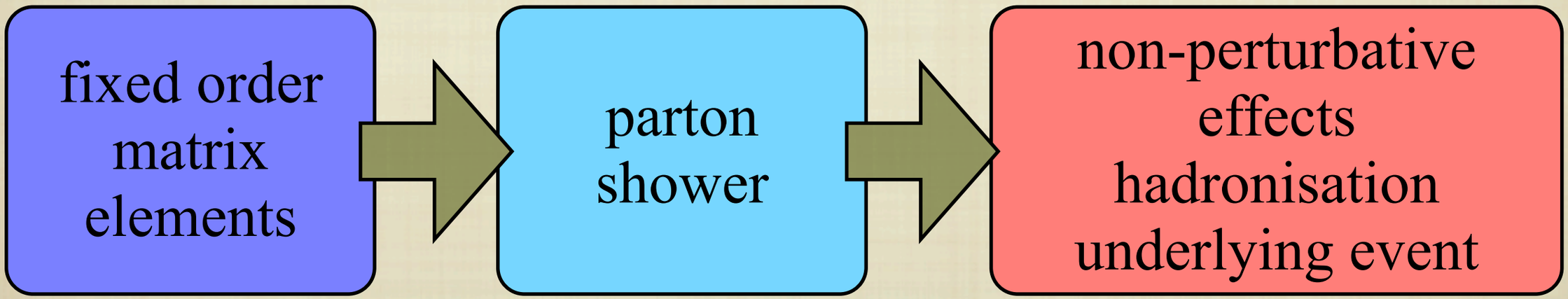


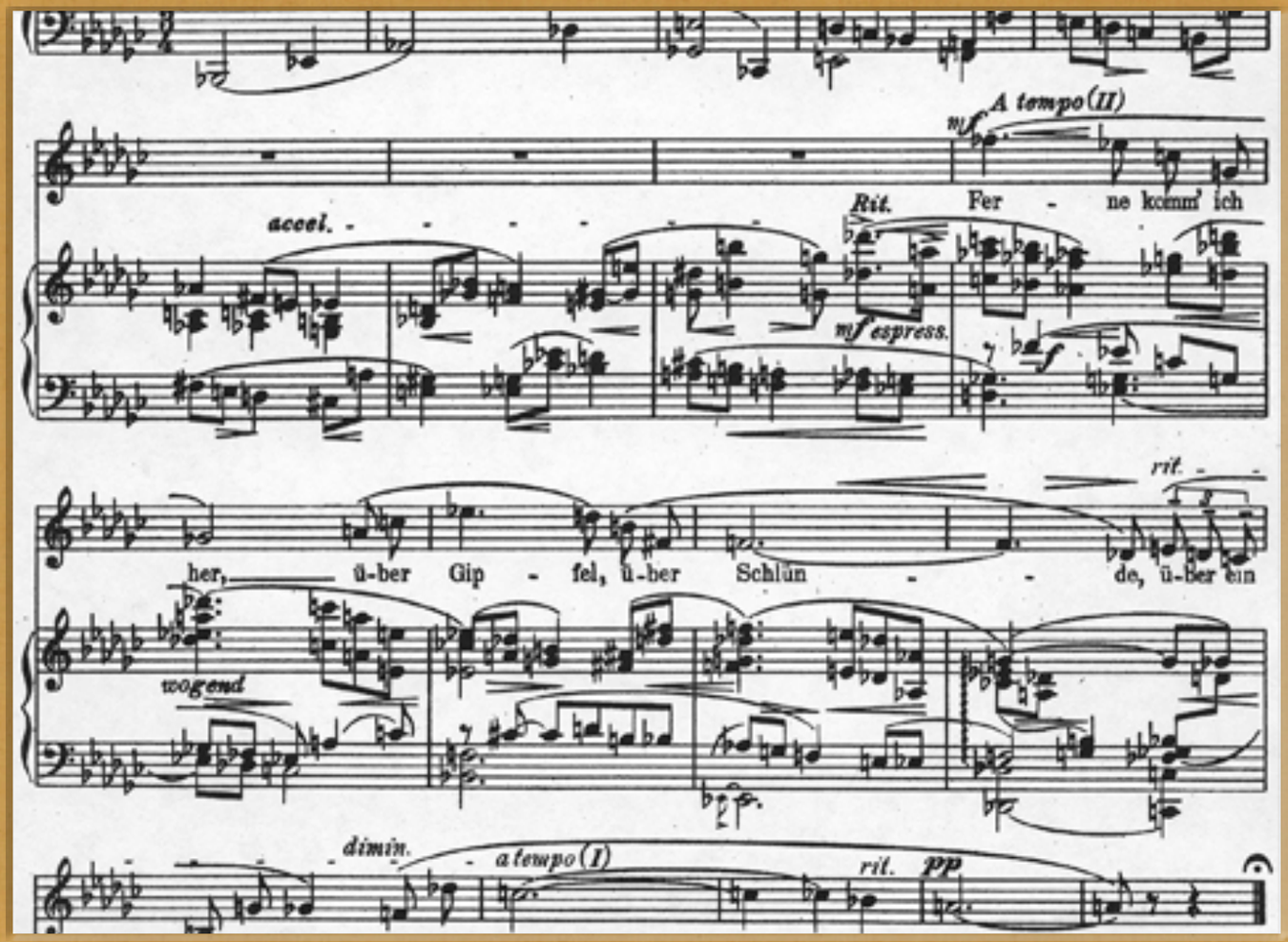
[J. Winter]

- Code for the purely gluonic case has been written and validated. Uses Berends-Giele recursion for tree amplitudes. Giele and Zanderighi arXiv:0805.2152
  - High precision, polynomial computing time!
- New, independent C++ implementation by J. Winter

Outlook

- Virtual corrections for $pp \to W, Z$ +3 jets based on unitarity and recursion relations are now available
  - Berger, Bern, Dixon, Febres Cordero, Forde, Ita, Kosover, Maitre arXiv: 0808.0941
  - Ellis, Giele, Kunszt, Melnikov and Zanderighi arXiv:0810.2762
- Next steps: add real emission. Phase-space integration.
- Future: implement results into MC generator




A tempo (II)
mf
accel.
Rit.
Fer - ne komm' ich
mf espress.
rit.
her, ü-ber Gip - fel, ü-ber Schlün - - de, ü-ber ein
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a tempo (I)
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pp

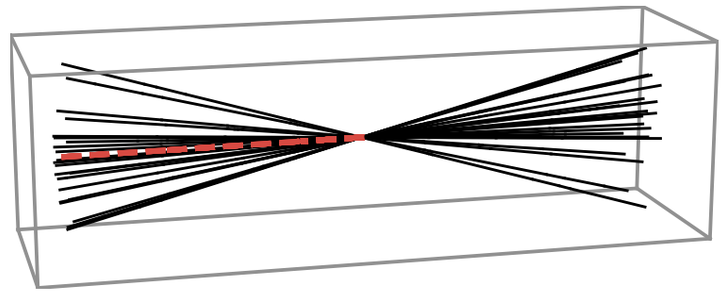
Many scales

Effective Field Theory

- Fixed order calculations become unreliable in situations where several disparate scales are relevant. Higher order corrections enhanced by large logarithms of scale ratios.
- Effective field theories can be used to simplify such problems, and to resum the enhanced higher-order corrections.
- Many examples
  - Top production near threshold: NRQCD
  - WW production near threshold: unstable particle EFT
  - Production of energetic jets with small invariant masses: Soft-Collinear Effective Theory

Resummation for Thrust [TB]

$$T = \max_{\mathbf{n}} \frac{\sum_i |\mathbf{p}_i \cdot \mathbf{n}|}{\sum_i |\mathbf{p}_i|}$$



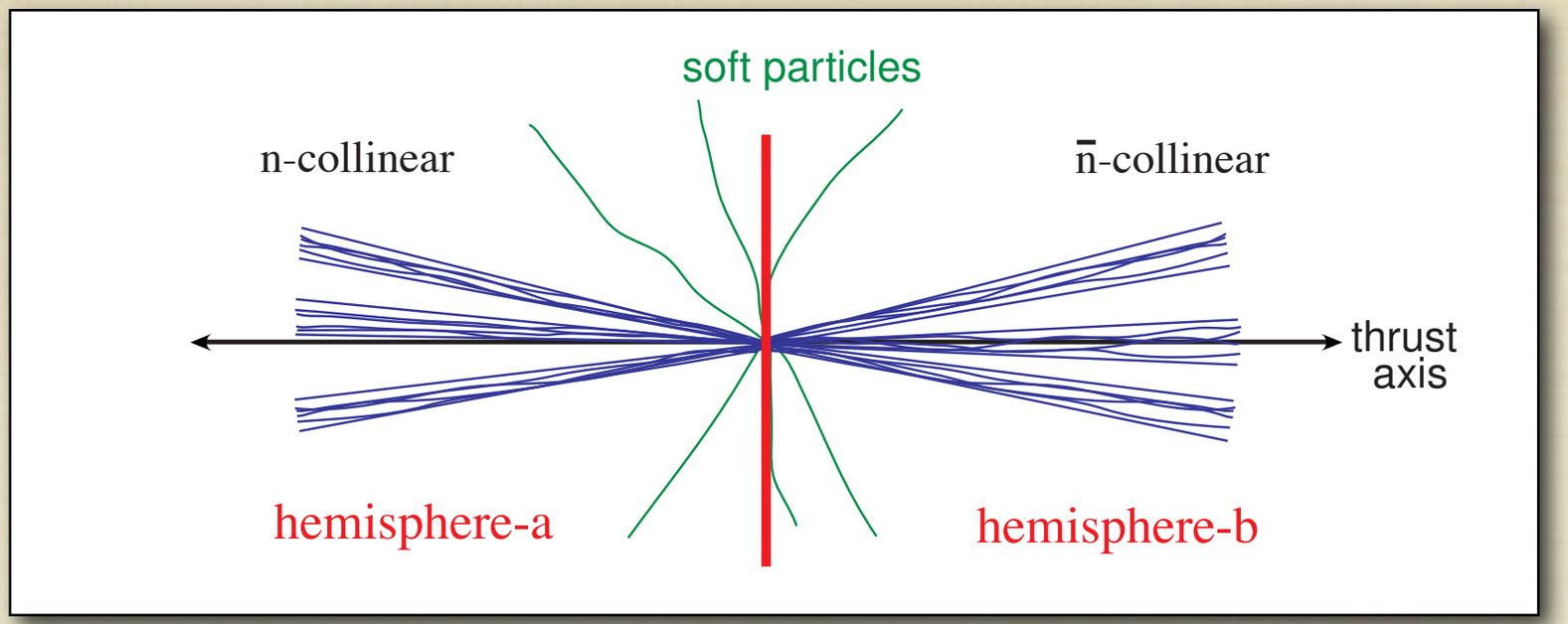
$$1 - T \approx \frac{M_1^2 + M_2^2}{Q^2}$$

- Prediction for event-shape variables dominated by perturbative uncertainty even at NNLO Gehrmann et al. '07.
  - Traditional methods allowed resummation to NLL Catani et al. '93 but not beyond.
- Using RG evolution in SCET we were able to derive NNNLL resummed distribution matched to NNLO TB and Schwartz, JHEP 0807:034, 2008. Fit to LEP data gives

$$\begin{aligned} \alpha_s(m_Z) &= 0.1172 \pm 0.0010(\text{stat}) \pm 0.0008(\text{sys}) \pm 0.0012(\text{had}) \pm 0.0012(\text{pert}) \\ &= 0.1172 \pm 0.0022\,. \end{aligned}$$

most precise α_s at high energy. theory unc. no longer dominant

Top mass from jet shapes [S. Mantry]

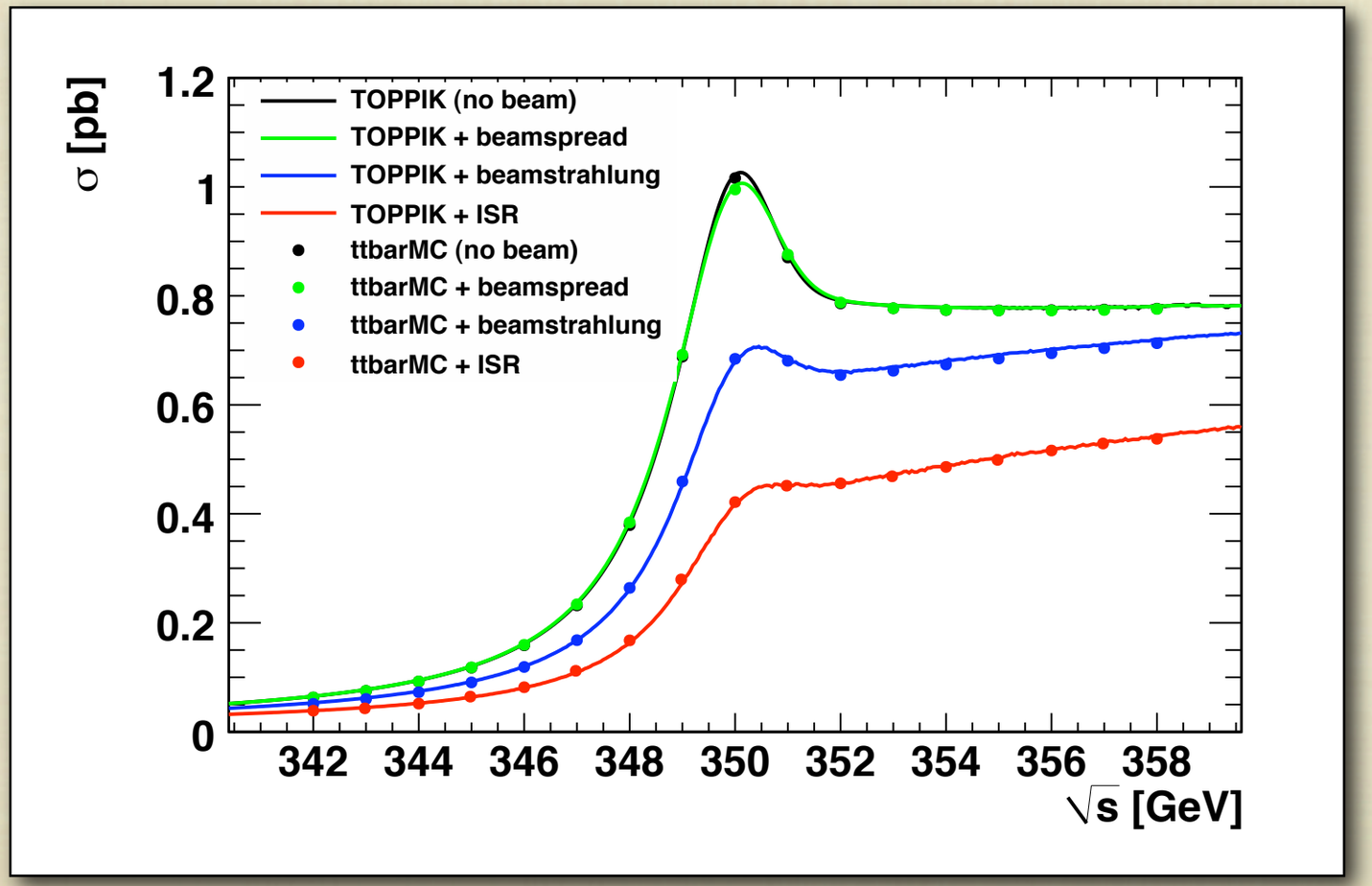


- Consider energetic top jets: $Q^2 \gg M_{\rm jet}^2 \approx m_t^2 \gg m_t \Gamma_t$
- Factorization theorem based on sequence of effective theories QCD → SCET → HQET
  - resum log's using RG evolution
- Measurement of the jet-mass distribution gives precise top mass determination with controlled systematics.

MORE REALISM

Simulation

- Important to confront these theoretical calculations with experimental reality.
- Example: effects of beamspread, beamstrahlung and ISR on $t\bar{t}$ cross section near threshold [Boogert & Gournaris]



TOP PRODUCTION

- Several talks on MC simulation of top production
  - One-loop matched shower for production and decay of top quarks [S. Latunde-Dada]
  - $t\bar{t}$ analysis at SiD [E. Devetak]
  - Simulation study of top-antitop event reconstruction [K. Ikematsu]
- and on various aspects top physics
  - theory review [Z. Sullivan]
  - new physics studies with top [M. Vos]
  - at the Tevatron [C. Gerber]

Thank you!