Λ-*Based Perturbation Theory for Event Shapes in* e^+-e^- *Annihilation*

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Talk Plan

- What is Λ-Based Perturbation Theory?

  a.k.a. RESIPE (Dhar, Gupta), Method of Effective Charges (Grunberg), RGI perturbation theory...

- Event Shapes

  taking thrust as an example

- Previous Applications of Λ-Based PT to Event Shapes

  means by the DELPHI collaboration, distributions by Burby and Maxwell

- Our Analysis

  including resummation of logs and power correction fits

- Results

  fits for $\Lambda_{\overline{MS}}$ and C_1

Work done in collaboration with C. J. Maxwell

What is Λ-based Perturbation Theory?

Standard Approach to Perturbation Theory

- Consider a perturbative QCD expansion of an observable normalized as an effective charge (with $a = \alpha/\pi$):

$$R(Q) = a_S(\mu) + r_1(\mu/Q, S) * {a_S}^2(\mu) + r_2(\mu/Q, S) * {a_S}^3(\mu) + \cdots$$

- R(Q) is independent of μ and S, but only because of cancellation between different orders. So, all finite order predictions depend on μ and S.
- Normally have NLO calculation $\rightarrow$ μ dependence at $O({a_S}^3)$.
- Standard fix: choose $\mu = Q$, vary to get theoretical error.
- BUT the definition of μ depends on S! Specifically our results depend only on the ratio μ/Λ_S.

What is Λ-based Perturbation Theory?

Λ-Based Approach to Perturbation Theory

- We take the dimensional transmutation parameter Λ, defined in some scheme (e.g. $\overline{MS}$) as the fundamental parameter to fit to data.
- For each effective charge R we write

$$\frac{dR(Q)}{d\ln Q} = \rho_R(R) = -bR^2(1 + cR + \rho_2^R R^2 + \cdots)$$

where ρ is the effective charge β-function.

- Compare with

$$\frac{da_S(Q)}{d\ln Q} = \beta_S(a) = -b{a_S}^2(1 + ca_S + {c^S}_2{a_S}^2 + \cdots)$$

the β-function for the scheme S.

What is Λ-based Perturbation Theory?

Λ-Based Approach to Perturbation Theory

- Λ enters as a boundary condition. We can integrate up to find the relation

$$\Lambda_S e^{-r_1(\mu=Q,S)/b} = Q\mathcal{F}(R(Q))\mathcal{G}(R(Q))\left(\frac{2c}{b}\right)^{c/b}$$

where the LHS and RHS are scheme independent. Explicitly:

$$\mathcal{F}(R) = e^{-1/bR}(1+1/cR)^{c/b}$$

$$\mathcal{G}(R) = \exp\left[-\int_0^R dx\left(\frac{1}{\rho_R(x)} + \frac{1}{bx^2(1+cx)}\right)\right]$$

- At NLO $\rho_R(x) = -bx^2(1+cx)$ so $\mathcal{G} = 1$.

Event Shapes

- Eg. thrust

$$\tau \equiv 1 - T \equiv 1 - \max_{\vec{n}} \frac{\sum_i |\vec{p}_i . \vec{n}|}{\sum_i |\vec{p}|}$$

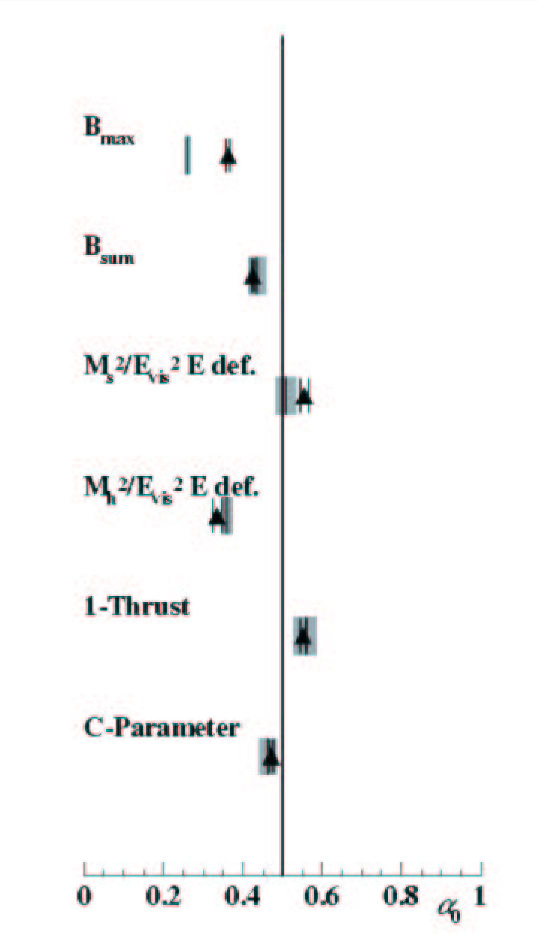
- Standard PT on its own doesn't describe <1-T> very well. Instead we fit for an additional "power correction" giving something like:

$$< \tau > = < 1 - T > = 0.335 \alpha_{\overline{MS}}(Q) + 1.02 \alpha_{\overline{MS}}{}^2(Q) + \frac{C_1}{Q}$$

  where $C_1 \sim 1 GeV$.

- More sophisticated approach: "Dokshitzer-Webber ansatz". Relate the power correcttion to a hypothetical infrared finite coupling $\rightarrow$ relate power corrections to different observables!
- Gives fairly successful description of data - "approximate universality" for new parameter $\overline{\alpha}_0$.

Λ-based PT for Event Shape Means @ DELPHI

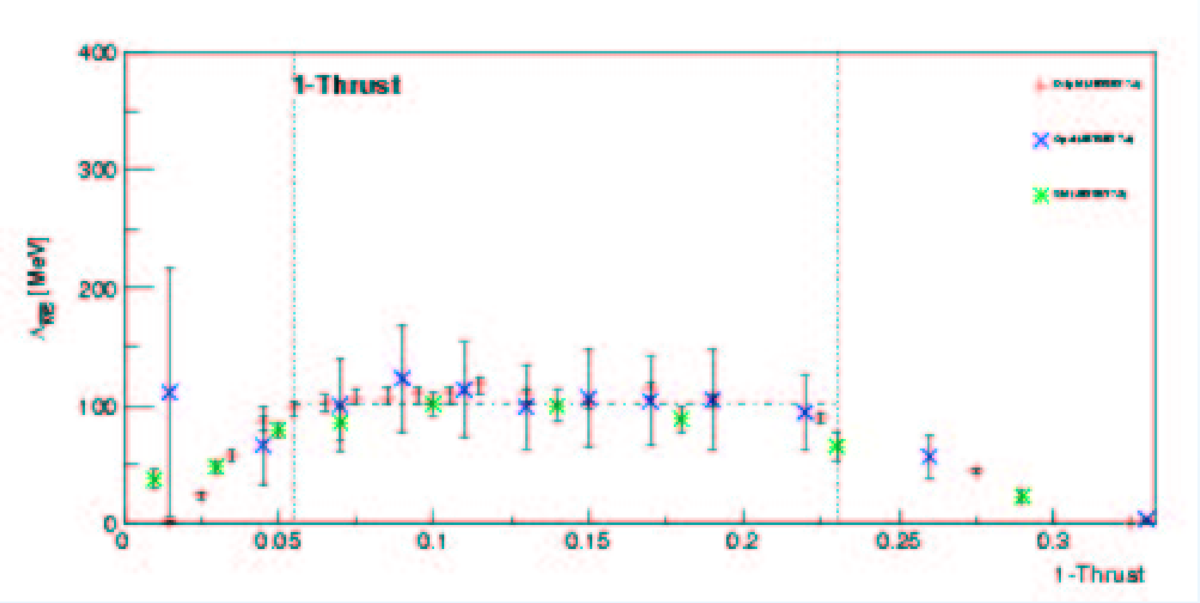


- The DELPHI collaboration have found that Λ-based PT describes the event shape means well without any power corrections.
- This plot shows the effective $\overline{\alpha}_0$ induced by converting the Λ-based results to the $\overline{MS}$ scheme.
- Remarkable agreement with experiment compared to universality hypothesis!

A study of the energy evolution of event shape distributions and their means with the DELPHI detector at LEP, DELPHI Collaboration, J. Abdallah, et al, Eur.Phys.J. C29 (2003) 285-312

Λ-based PT for Event Shape Distributions

- Also interesting to look at distributions. At NLO:



- Problems:
  - Large logs $L = \log(1/\tau)$ appear in the 2-jet region $\tau \to 0$
  - The EC description breaks down as $\tau \to 1/3$

Direct Extraction of QCD Lambda MS-bar from e+e- Jet Observables, S. J. Burby, C. J. Maxwell, Nucl.Phys. B609 (2001) 193-224

Our Analysis

We wanted to build on this analysis in 2 ways:

- Large logs in the perturbative series for the distribution give large logs in the perturbative series for $\rho \rightarrow$ need for resummation:

$$\rho(R, L) = -bR^2(\rho_{LL}(RL) + L^{-1}\rho_{NLL}(RL) + \cdots).$$

- To see if the Λ-based approach needs smaller power corrections we wanted to fit for 1/Q shifts:

$$\left.\frac{1}{\sigma}\frac{d\sigma}{d\tau}\right|_{\tau} = \left.\frac{1}{\sigma}\frac{d\sigma}{d\tau}\right|_{PT,\ \tau - C_1/Q}$$

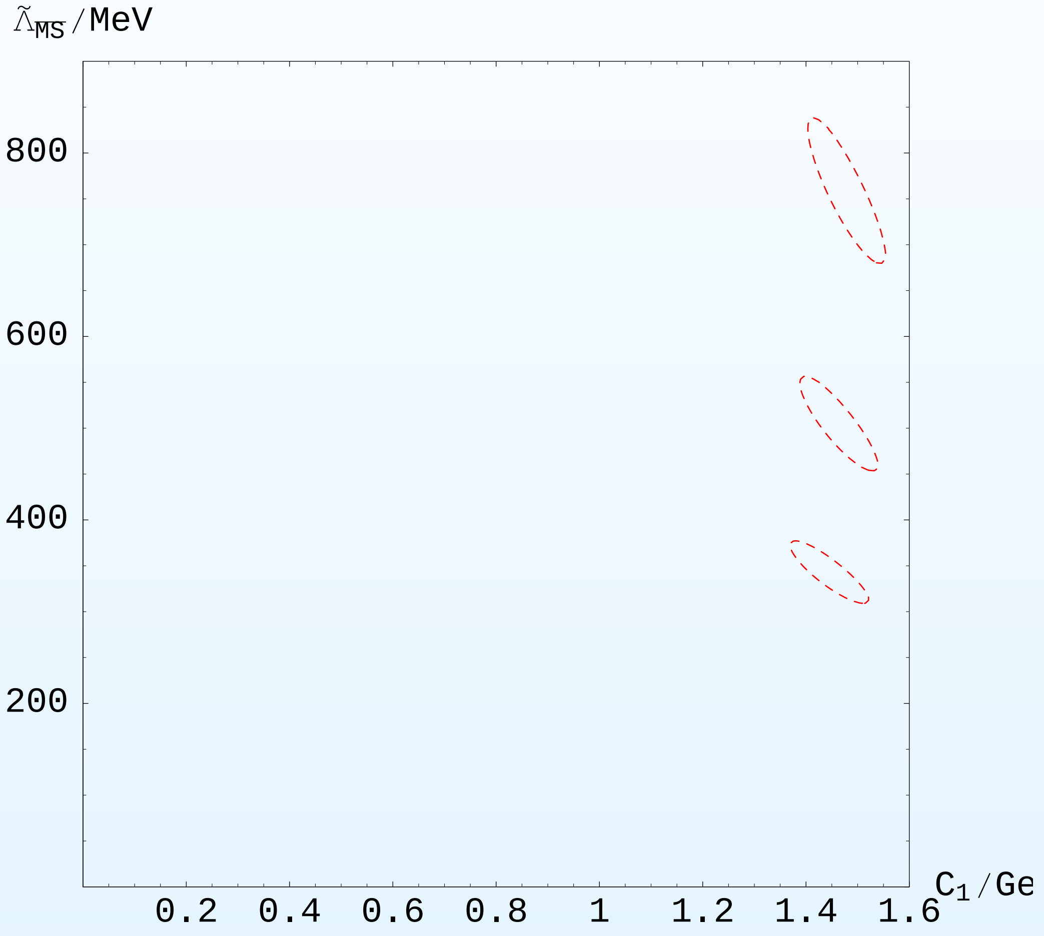
- Define an effective charge via

$$R(Q, \tau) = \ln\left(\int_0^{\tau} \frac{1}{\sigma}\frac{d\sigma}{d\tau}\right)/LO$$

Our Analysis

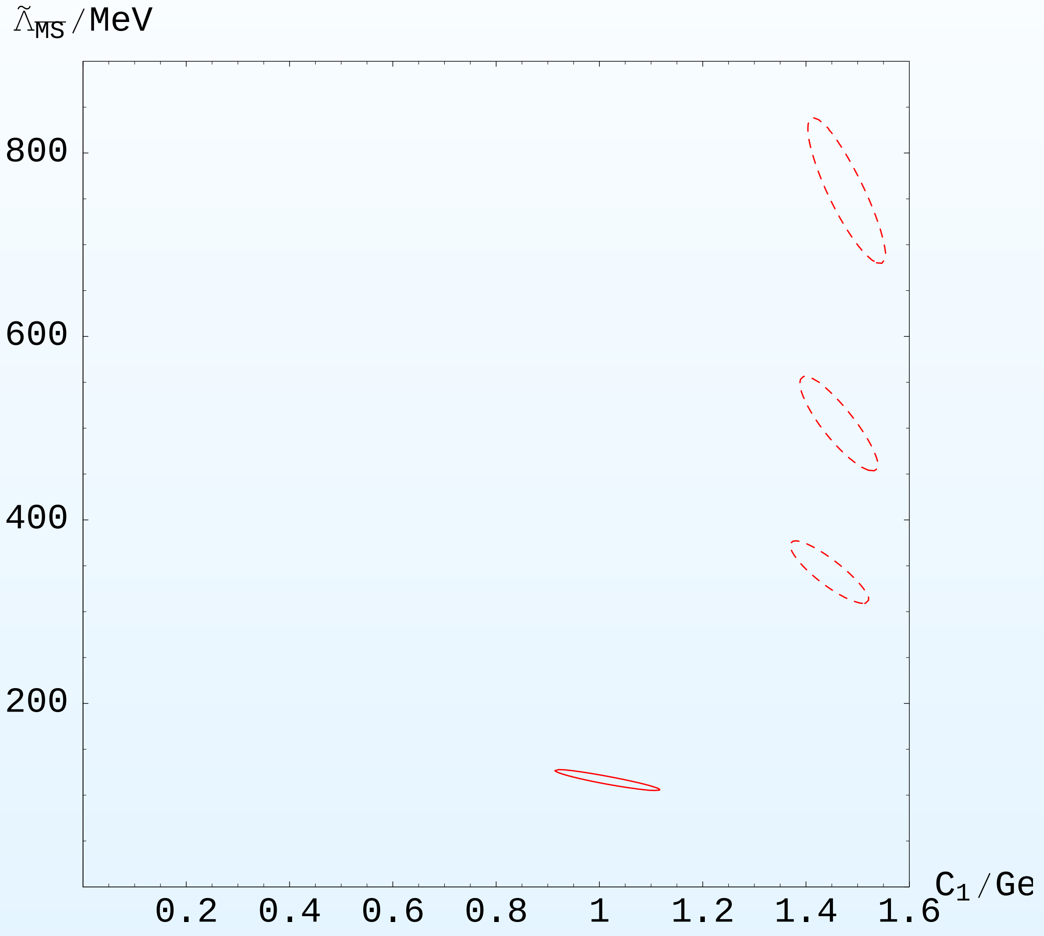
- We need to select a limited fit range to avoid problems in the extreme 2-jet region and as $\tau \to 1/3$ (made worse by exponentiating).
- Found good fit quality with $\tau = 0.04 - 0.16$ at $Q = 91.2GeV$ with the lower bound scaling $\propto 1/Q$.
- Take data from TASSO, JADE, DELPHI, L3, SLD at energies $Q = 35 - 189GeV$.
- Note that the “standard approach” in the $\overline{MS}$ scheme we can fit over a large range of τ!

Fits: Thrust



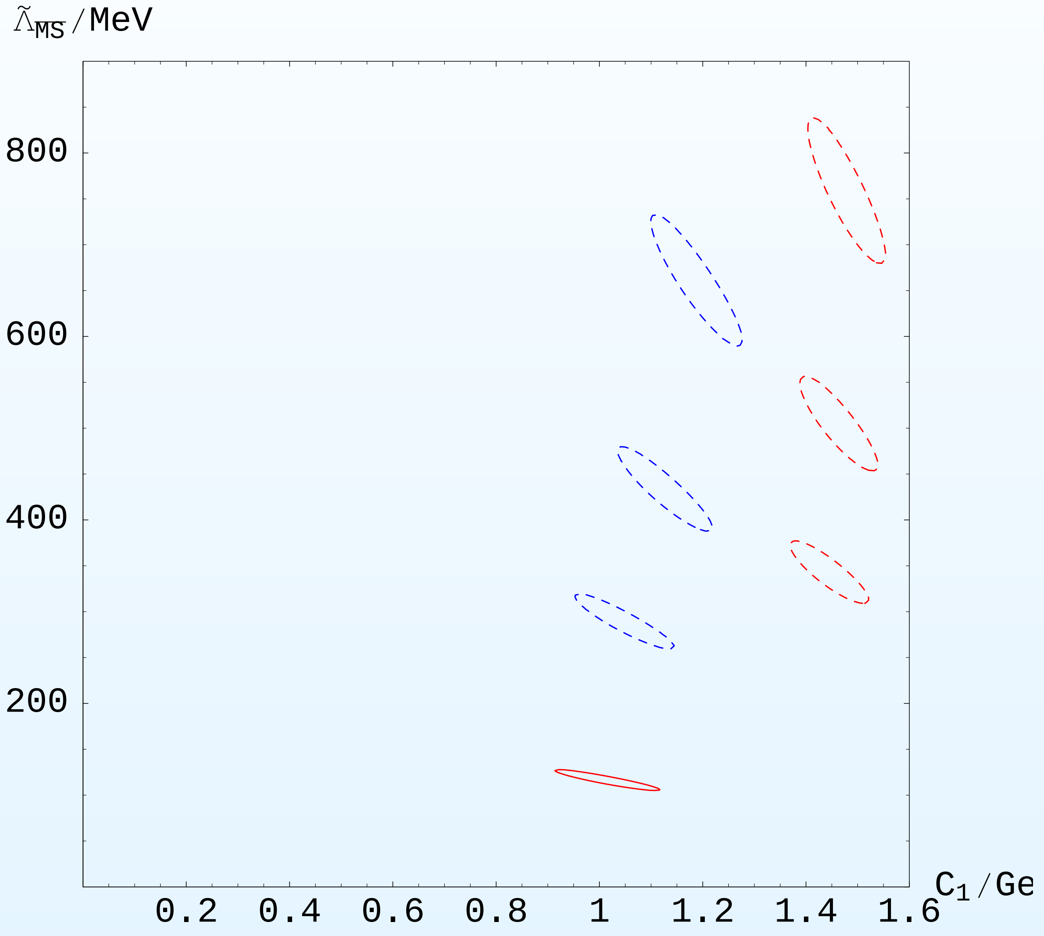
NLO

Fits: Thrust



NLO

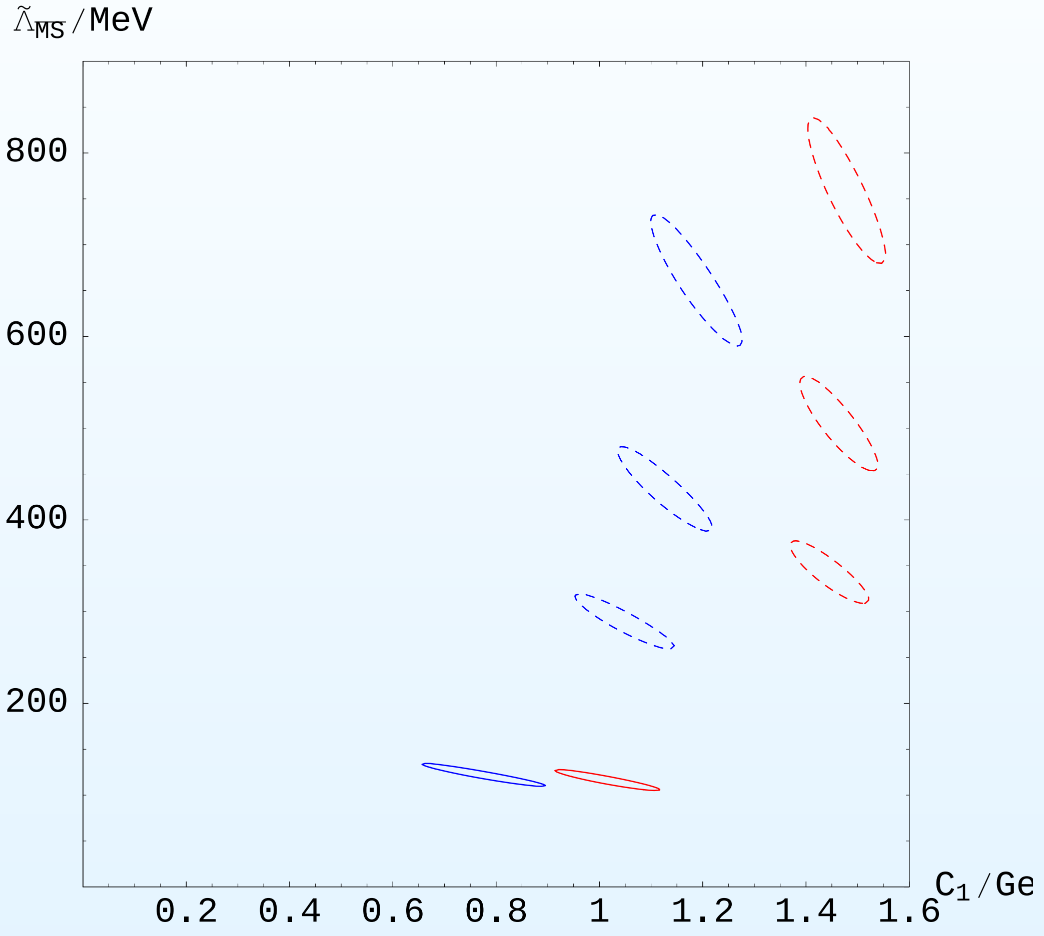
Fits: Thrust



NLO

LL

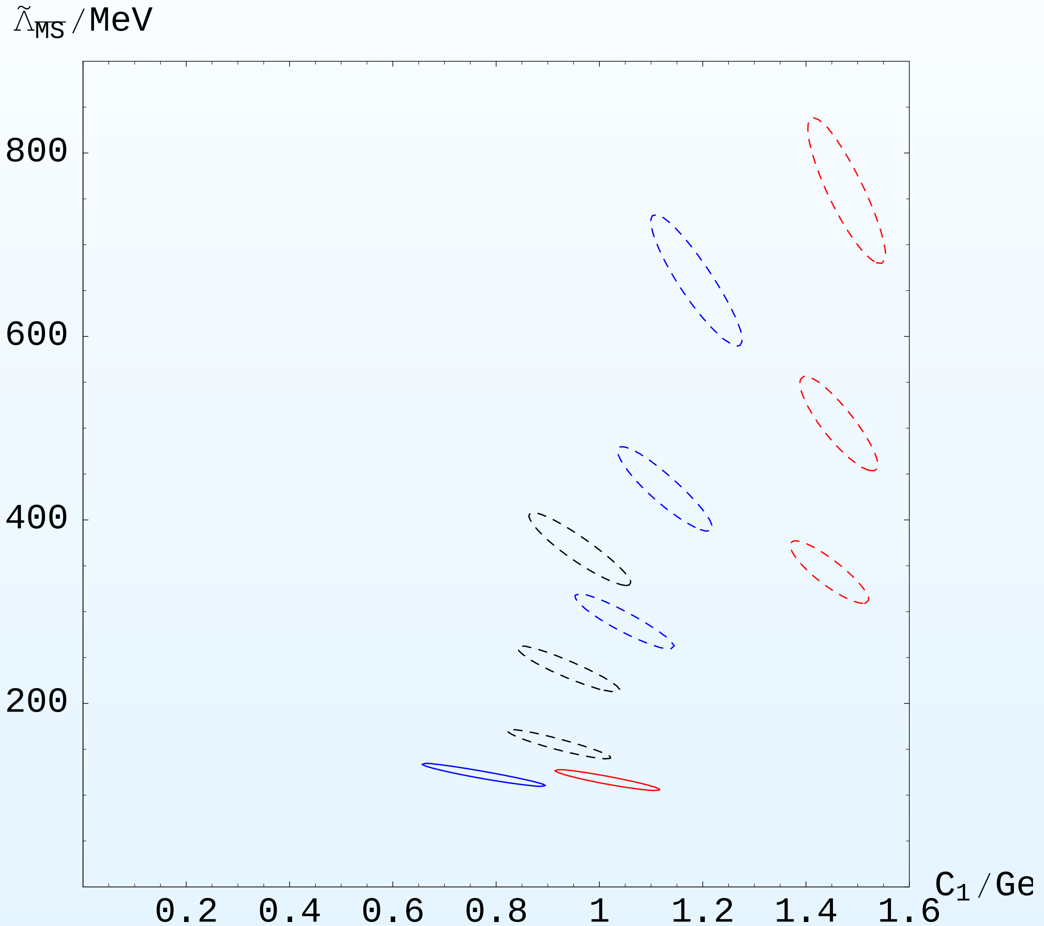
Fits: Thrust



NLO

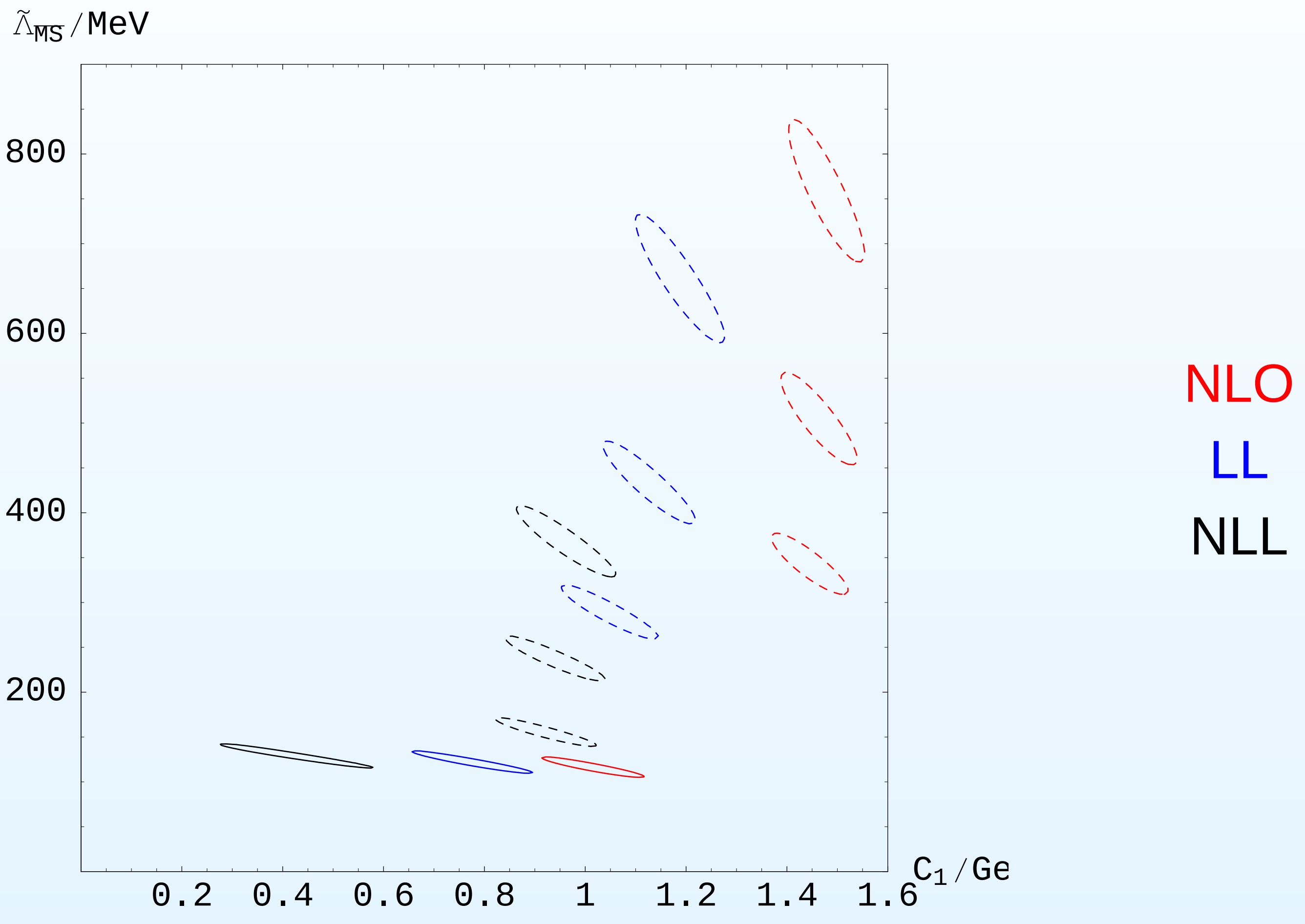
LL

Fits: Thrust



NLO
LL
NLL

Fits: Thrust



$\tilde{\Lambda}_{\overline{MS}}$ /MeV
800
600
400
200
0.2 0.4 0.6 0.8 1 1.2 1.4 1.6
C1/Ge
NLO
LL
NLL

Conclusions

- Λ-based PT provides us with a way to make perturbative predictions without needing to fix μ by some kinematical argument.
- Analysis of event shape means has suggested this may give more accurate predictions than the standard approach, with significantly reduced power corrections needed to fit the data.
- We have applied this approach to some event shape distributions, and after significantly restricting the fit range we find good agreement with reduced (though still significant) power corrections.
- Adding resummed logs further reduces the fitted power correction.