Light gluino effects in thrust at NNLL order

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DPG Frühjahrstagung

28. März - 01. April 2011

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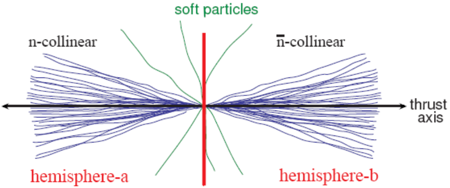
Outline

1. Thrust and Factorization
2. Modifications of Matrix elements and Running
3. Preliminary numbers
4. Conclusions

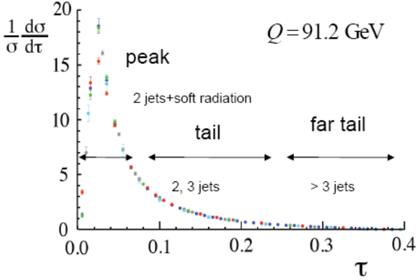
$$T = \max_{\hat{t}} \frac{\sum_i |\hat{t}\cdot\vec{p}_i|}{\sum_i |\vec{p}_i|}$$

Thrust

$$\tau \equiv 1 - T$$



differential cross section $\frac{d\sigma}{d\tau} \propto \delta(\tau)$ at tree level



measurements for 14GeV$\leq Q \leq$207GeV (LEP, TASSO, JADE)

peak region	$\tau \sim 2\Lambda_{QCD}/Q$
tail region	$2\Lambda_{QCD}/Q \ll \tau \lesssim 1/3$
far-tail region	$1/3 \lesssim \tau \leq 1/2$

Three different scales (Q e^+e^- c.m. energy):

pure	QCD	peak region
hard	$\mu_H \simeq Q$	Q
jet	$\mu_J \simeq Q\sqrt{\tau}$	$\sqrt{Q\Lambda_{QCD}}$
soft	$\mu_S \simeq Q\tau$	Λ_{QCD}

		peak region	tail	far-tail
hard	$\mu_H \simeq Q$	Q	$\star$	
jet	$\mu_J \simeq Q\sqrt{\tau}$	$\sqrt{Q\Lambda_{QCD}}$	$\star$	$\mu_H \simeq \mu_J \simeq \mu_S$
soft	$\mu_S \simeq Q\tau$	Λ_{QCD}	$\mu_S \gg \Lambda_{QCD}$	$\gg \Lambda_{QCD}$

$\mu_{\tilde{g}} \simeq M_{\tilde{g}}$

soft radiation described by a non-perturbative function, dependence on α_s

OPE for soft radiation, depends on α_s & Ω_1: first moment of a non-perturbative soft function

- SCET provides the suitable theoretical framework
- we include light Gluino effects $\leftarrow$ additional colored Majorana
- this introduces gluino matching scale $\mu_{\tilde{g}}$
- Modifications of running and matrix elements depend on the relative position of the scales $\mu_H \geq \mu_J \geq \mu_S$ with respect to $\mu_{\tilde{g}}$

FACTORIZATION of THRUST

[R.Abbate, M.Fickinger, A.H.Hoang, V.Mateu, I.W.Stewart, 10']

non-perturbative soft function from $S_\tau = S_\tau^{part} \otimes S_\tau^{mod}$, 1st moment Ω_1

$$\frac{d\sigma}{d\tau} = \int dk \left(\frac{d\hat{\sigma}_s}{d\tau} + \frac{d\hat{\sigma}_{ns}}{d\tau} \right) \left(\tau - \frac{k}{Q} \right) \otimes S_\tau^{mod} (k - 2\bar{\Delta}) + \mathcal{O}\left(\sigma_0 \frac{\alpha_s \Lambda_{QCD}}{Q} \right)$$

$$\frac{d\hat{\sigma}_s}{d\tau} = \sum_j \alpha_s^j \delta(\tau) + \sum_{k,j} \alpha_s^j [\ln^k(\tau)/\tau]_+$$

$$= H(\mu_H) \times J(\mu_J) \otimes S(\mu_S)$$

Singular partonic contribution
for massless quarks
matrix elements + summation

power correction

$$\frac{d\hat{\sigma}_{ns}}{d\tau} = \sum_{j,k} \alpha_s^j \ln^k(\tau) + \sum_j \alpha_s^j f_j(\tau)$$

Nonsinglular partonic contrib.
= (thrust in fixed-order) − (singular)

$$\ln\left[\frac{d\tilde{\sigma}_s}{dy}\right] \sim \left[L \sum_{k=1}^{\infty} (\alpha_s L)^k \right]_{LL} + \left[\sum_{k=1}^{\infty} (\alpha_s L)^k \right]_{NLL} + \left[\alpha_s \sum_{k=0}^{\infty} (\alpha_s L)^k \right]_{NNLL} + \left[\alpha_s^2 \sum_{k=0}^{\infty} (\alpha_s L)^k \right]_{N^3LL}$$

$L = \ln(\imath y)$, Fourier transformed

Factorization formula for singular partonic

$$\frac{d\hat\sigma_s}{d\tau}(\tau) = Q\sum_I \sigma_0^I H_Q^I(Q,\mu_H)U_H(Q,\mu_H,\mu_J)\int ds\; J_\tau(s,\mu_J)\int dk'\; U_S^\tau(k',\mu_J,\mu_S)$$

$$\times\; e^{-2\frac{\delta(R,\mu_S)}{Q}\frac{\partial}{\partial\tau}} S_\tau^{part}\left(Q\tau - \frac{s}{Q} - k', \mu_S\right)$$

(massless QCD) [Abbate et al., 10']

- ▶ hard function H_Q
- ▶ jet function J_τ , SCET jet fct.:

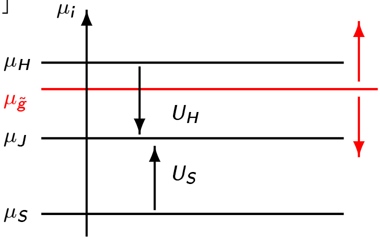
$$J(Qr^+,\mu) = \frac{-1}{4\pi N_c Q}\Im\left[\imath\int d^4x\; e^{\imath r\cdot x}\langle 0|\mathrm{T}\{\bar\chi_n(0)\bar{n}\!\!\!/\chi_n(x)\}|0\rangle\right]$$

- ▶ partonic soft function S_τ^{part} , SCET soft fct.:

$$S_\tau(k,\mu) = \frac{1}{N_c}\langle 0|tr_c[\bar Y_{\bar n}^T Y_n\delta(k-\imath\hat\partial)Y_n^\dagger \bar Y_{\bar n}^\star]|0\rangle$$

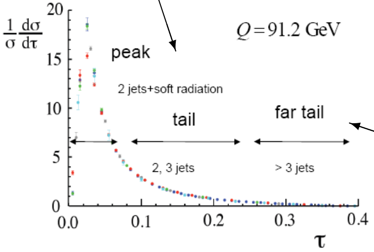
▶ series $\delta(R,\mu_S)$ for renormalon subtraction

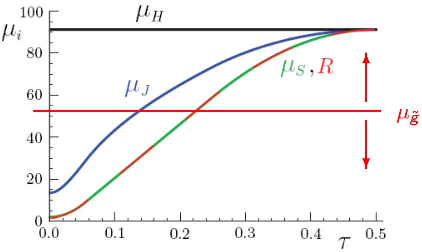
- ▶ RG-evolution factors U_H, U_S



Profile functions

summation of $\ln(\tau)$
$(\mu_H \gg \mu_J \gg \mu_S)$





multijet threshold @ $\tau = 0.5$
$\Rightarrow$ no log summation
$(\mu_H = \mu_J = \mu_S \sim Q)$

- hierarchy of involved scales μ_H, μ_J, μ_S
- location of gluino matching scale

} τ-dependent

$\mu > \mu_{\tilde{g}}$	Gluino included
$\mu \leq \mu_{\tilde{g}}$	Gluino integrated out

- e.g. $\alpha_s(\mu)$

$$\mu > \mu_{\tilde{g}} \quad \beta_0 = 11 - \frac{2}{3}(n_f + 3)$$

$$\mu \leq \mu_{\tilde{g}} \quad \beta_0 = 11 - \frac{2}{3} n_f$$

for β_1, β_2 exact dependence on #gluinos known [Clavelli et al., 96'.], [Harlander, Mihaila, Steinhauser., 09'],

and use matching relation at $\mu = \mu_{\tilde{g}}$

$$\alpha_s^{n_f}(\mu_{\tilde{g}}) = \alpha_s^{n_f+\tilde{g}}(\mu_{\tilde{g}}) \left[1 - \frac{\alpha_s^{n_f+\tilde{g}}(\mu_{\tilde{g}})}{\pi} \frac{1}{2} \ln \left(\frac{\mu_{\tilde{g}}^2}{M_{\tilde{g}}^2} \right) \right]$$

- e.g. $U_i(\mu_0, \mu, \mu_{\tilde{g}})$ $(i = H, J, S)$

$$U_i(\mu_0, \mu_1) = \begin{cases} U_i^{n_f}(\mu_0, \mu_1) & \mu_{\tilde{g}} > \mu_0,\ \mu_1 \\ U_i^{n_f+\tilde{g}}(\mu_0, \mu_{\tilde{g}}) U_i^{n_f}(\mu_{\tilde{g}}, \mu_1) & \mu_0 > \mu_{\tilde{g}} > \mu_1 \\ U_i^{n_f+\tilde{g}}(\mu_0, \mu_1) & \mu_0,\ \mu_1 > \mu_{\tilde{g}} \end{cases}$$

$$\frac{d}{d \ln \mu} \ln U_C(Q, \mu, \mu_0) = 2\Gamma_V[\alpha_s] \ln \frac{\mu}{Q} + \gamma_V[\alpha_s]$$

$$\Gamma_V[\alpha_s] = \left(\frac{\alpha_s}{4\pi} \right) \Gamma_0^V + \left(\frac{\alpha_s}{4\pi} \right)^2 \Gamma_2^V + \dots$$

$\mu > \mu_{\tilde{g}}$	Gluino included
$\mu \leq \mu_{\tilde{g}}$	Gluino integrated out

- e.g. $J(s, \mu_J^2)$

$$\mu < \mu_{\tilde{g}} : \quad \delta J_{n_f}^{\mathcal{O}(\alpha_s^2)} = \left(\frac{\alpha_s}{4\pi}\right)^2 C_F T_f n_f \left[\frac{8}{3}\left(\frac{\ln^2 \tilde{s}}{\tilde{s}}\right)_+ - \frac{116}{9}\left(\frac{\ln \tilde{s}}{\tilde{s}}\right)_+ + \left(\frac{494}{27} - \frac{8\pi^2}{9}\right)\left(\frac{1}{\tilde{s}}\right)_+ + \left(-\frac{4057}{162} + \frac{68}{27}\pi^2 + \frac{16}{9}\zeta_3\right)\delta(\tilde{s})\right]$$

$(M_{\tilde{g}} = \infty)$

$$\mu > \mu_{\tilde{g}} : \quad \delta J_{n_f}^{\mathcal{O}(\alpha_s^2)} = \left(\frac{\alpha_s}{4\pi}\right)^2 C_F T_f (n_f + 3) \left[\frac{8}{3}\left(\frac{\ln^2 \tilde{s}}{\tilde{s}}\right)_+ - \frac{116}{9}\left(\frac{\ln \tilde{s}}{\tilde{s}}\right)_+ + \left(\frac{494}{27} - \frac{8\pi^2}{9}\right)\left(\frac{1}{\tilde{s}}\right)_+ + \left(-\frac{4057}{162} + \frac{68}{27}\pi^2 + \frac{16}{9}\zeta_3\right)\delta(\tilde{s})\right]$$

$(M_{\tilde{g}} = 0)$

there is no computation of exact $M_{\tilde{g}}$-dependence within SCET @ moment

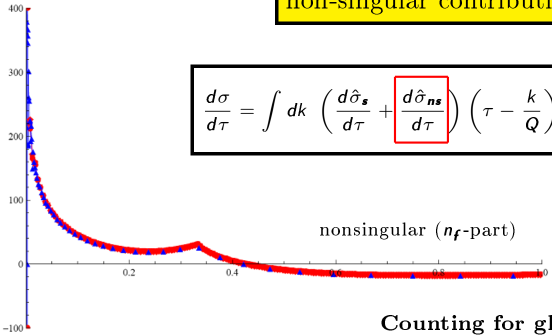
and similar for hard and soft fct.

$$\Gamma_1^{J,n_f} = -\frac{80}{9} C_F T_F n_f \longrightarrow -\frac{80}{9} C_F T_F (n_f + 3) \qquad \text{cusp}$$

$$\gamma_1^{J,n_f} = C_F T_F n_f \left(-\frac{484}{27} - \frac{8}{9}\pi^2\right) \longrightarrow C_F T_F (n_f + 3)\left(-\frac{484}{27} - \frac{8}{9}\pi^2\right) \qquad \text{non cusp}$$

non-singular contributions

$$\frac{d\sigma}{d\tau} = \int dk \left(\frac{d\hat{\sigma}_s}{d\tau} + \frac{d\hat{\sigma}_{ns}}{d\tau} \right) \left(\tau - \frac{k}{Q} \right) \otimes S_\tau^{mod} \, (k - 2\bar{\Delta}) + p.c.$$



- thrust in fixed order minus fixed ord. expansion of singular part.
- extract the n_f-part at $\mathcal{O}(\alpha_s^2)$ (fixed order) from EVENT2
- multiply by $8/5$ to account for gluinos

Counting for gluino effects:

	LL′	NLL′	NNLL′
α_s	β_0 ✓	β_1 ✓	β_2 ✓
Γ	Γ_0 ✓	Γ_1 ✓	Γ_2 [$n_f \to n_f + 3$]
γ	-	γ_0 ✓	γ_1 ✓
Matrix elements	tree ✓	$\mathcal{O}(\alpha_s)$ ✓	$\mathcal{O}(\alpha_s)^2$ (✓)
non-singular	tree ✓	$\mathcal{O}(\alpha_s)$ ✓	$\mathcal{O}(\alpha_s)^2$ (✓)

expansion in $\frac{\mu_i}{M_{\tilde g}}$ vs. exact dependence on $\frac{\mu_i}{M_{\tilde g}}$

▶ Normalization of the cross section: had. R-Ratio at $\mu^2 = s$ additional massive species

[Hoang et al.,95']
[Kniehl,90´]

$\mu < \mu_{\tilde g}$:

$$R^{n_f}(s) = 1 + \frac{\alpha_s^{n_f}(s)}{\pi} + \left(\frac{\alpha_s^{n_f}(s)}{\pi}\right)^2 \left[\mathcal{R}_1 + \mathcal{R}_2^{n_f}\right] + \left(\frac{\alpha_s^{n_f}(s)}{\pi}\right)^2 2(\rho^R + \rho^V)(M_{\tilde g}^2, s)$$

n_f massless quark flavours

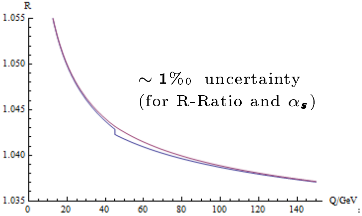
▶ scheme change for α_s to avoid large logs in the small $M_{\tilde g}$-limit

$\mu > \mu_{\tilde g}$:

$$R^{n_f}(s) = 1 + \frac{\alpha_s^{n_f+\tilde g}(s)}{\pi} + \left(\frac{\alpha_s^{n_f+\tilde g}(s)}{\pi}\right)^2 \left[\mathcal{R}_1 + \mathcal{R}_2^{n_f}\right] + \left(\frac{\alpha_s^{n_f+\tilde g}(s)}{\pi}\right)^2 2\left[(\rho^R + \rho^V)(M_{\tilde g}^2, s) - \frac{1}{4}\ln\left(\frac{s}{M_{\tilde g}^2}\right)\right]$$

Compared to expansion in $\mu/M_{\tilde g}$:

$$M_{\tilde g} = \begin{cases} 0 & \mu > \mu_{\tilde g} \\ \infty & \mu \le \mu_{\tilde g} \end{cases}$$

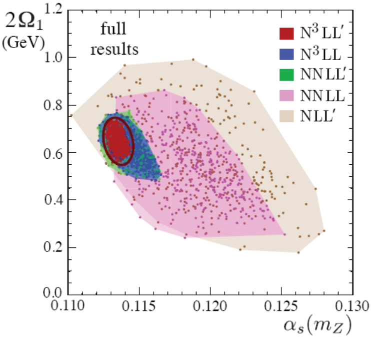


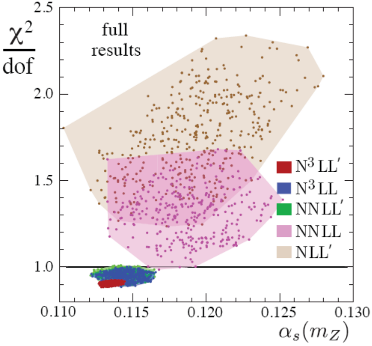
Preliminary numbers

[Abbate et al., 10']
$\alpha_s(M_Z) = 0.1135$
$\pm 0.002_{exp} \pm 0.005_{had}$
$\pm 0.009_{pert}$

- ~ 500 random points in 12-dimensional parameter space
  (μ-variation, theory uncertainties in fixed order numerical results
  4-loop cusp, constant contributions in 3-loop jet and soft)
- no sensitivity for $M_{\tilde{g}} \gtrsim 207$GeV

$$\Omega_1 \equiv \bar{\Delta} + \frac{1}{2N_c} \langle 0 | tr_c \{ \bar{Y}_{\bar{n}}^T(0) Y_n(0) \imath\hat{\partial} Y_n^\dagger(0) \bar{Y}_{\bar{n}}^\star(0) \} | 0 \rangle$$





Conclusions

1. Factorization theorem of thrust within SCET
2. New scale $\mu_{\tilde{g}} \simeq M_{\tilde{g}}$
3. Modifications: $\leftrightarrow$ extreme approach $\mu \lesseqgtr \mu_{\tilde{g}}$ **vs.** exact $M_{\tilde{g}}$-dependence
4. Nonsingular contribution included
5. Numerics is on the way, preliminary numbers available at the DPG next week.