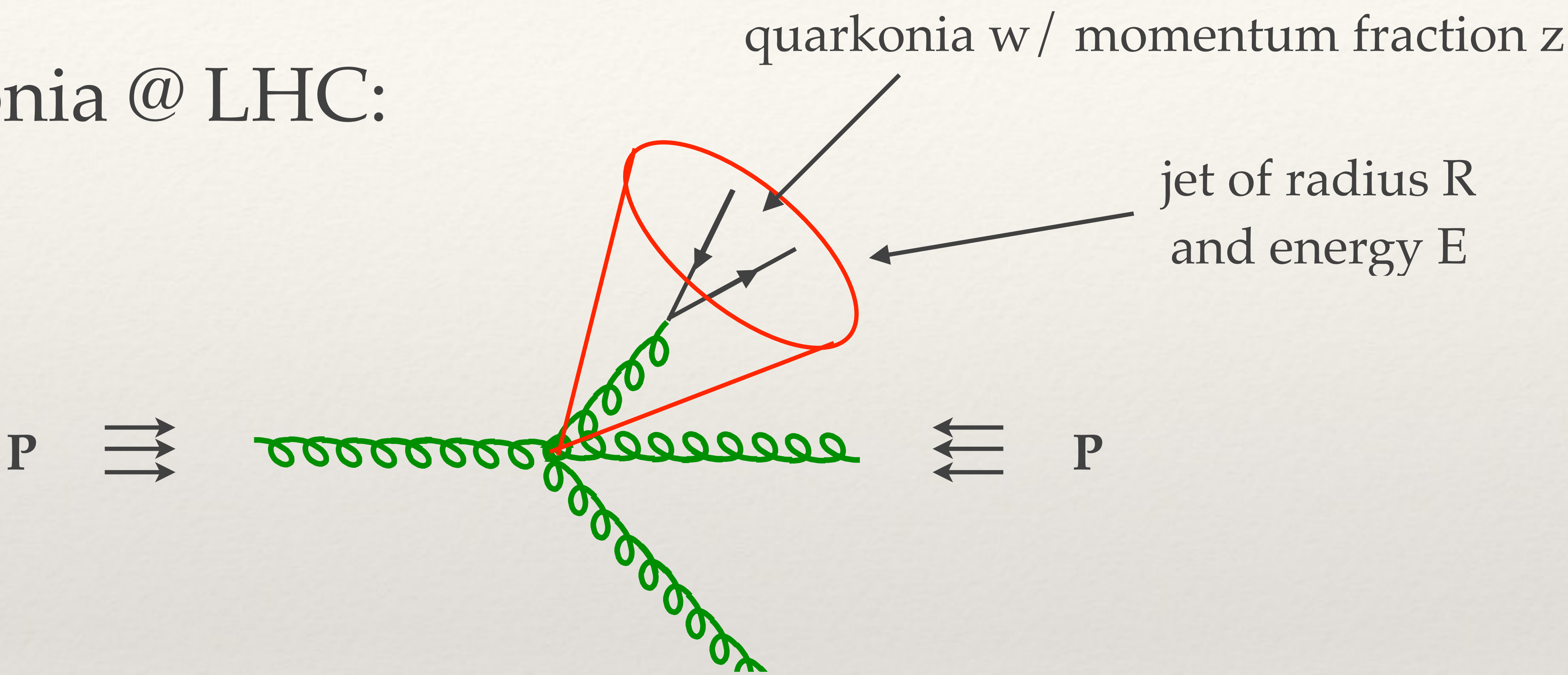
LHC Jet Shapes in Dijet Events

Andrew Hornig
LANL
March 27, 2015

In collaboration with Yiannis Makris, Thomas Mehen

Motivation

- quarkonia @ LHC:



- "unmeasured jets" : tagged with algorithm but unproved
- "measured jets" : probed with mass, angularity, etc

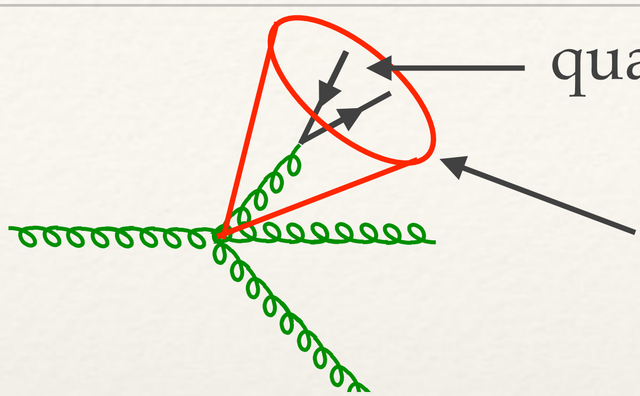
"jet shapes" (not *the* jet shape $\Psi(r/R)$)

Ellis, Kunszt, Soper '91, '92

see also: Yang-Ting Chien's talk

Motivation

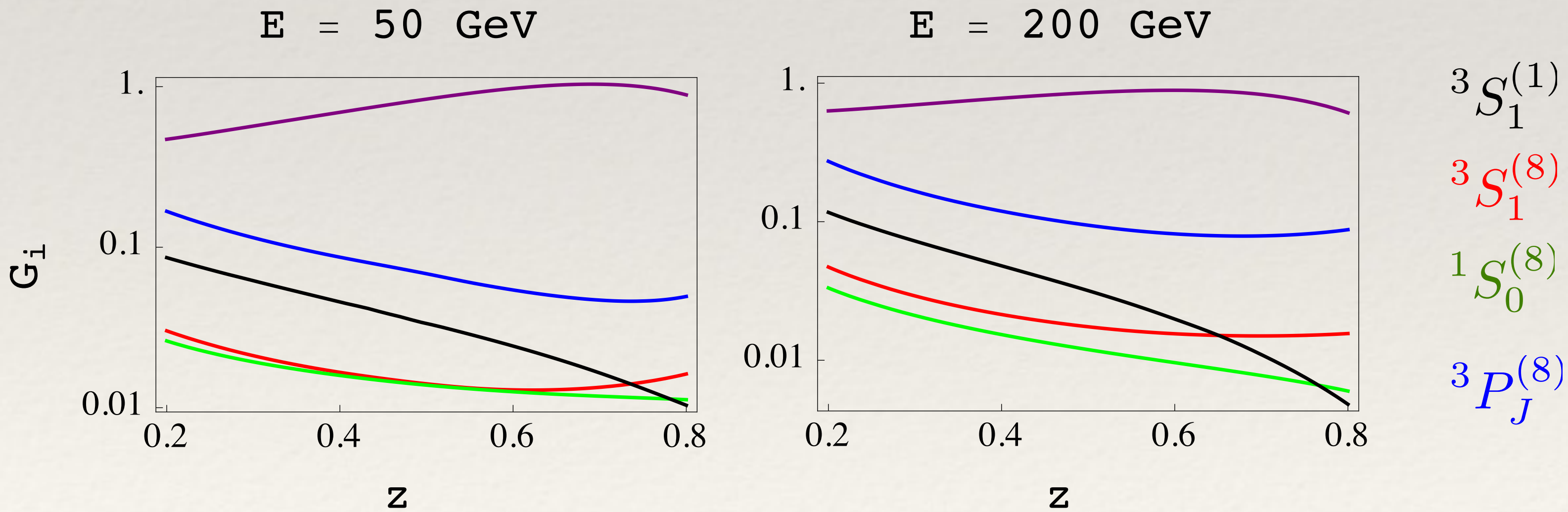
- quarkonia @ LHC:



- for "unmeasured jet" (tagged but inclusive in mass, etc)

$$\sigma_\psi(z) \propto \mathcal{G}_g^\psi(E, R, z, \mu = 2E \tan\frac{R}{2})$$

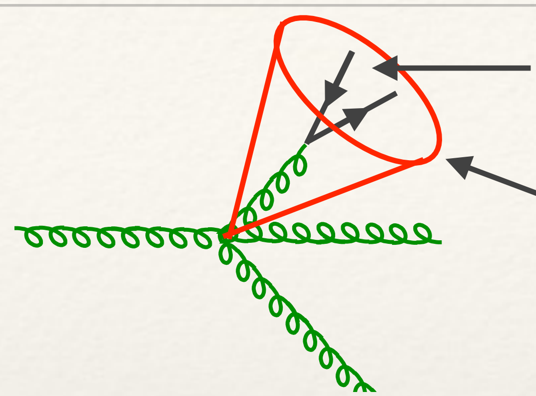
("unmeasured" fragmenting jet function)
Procura, Waalewijn 1110.0839



Baumgart, Leibovich, Mehen, Rothstein 1406.2295

Motivation

- quarkonia @ LHC:



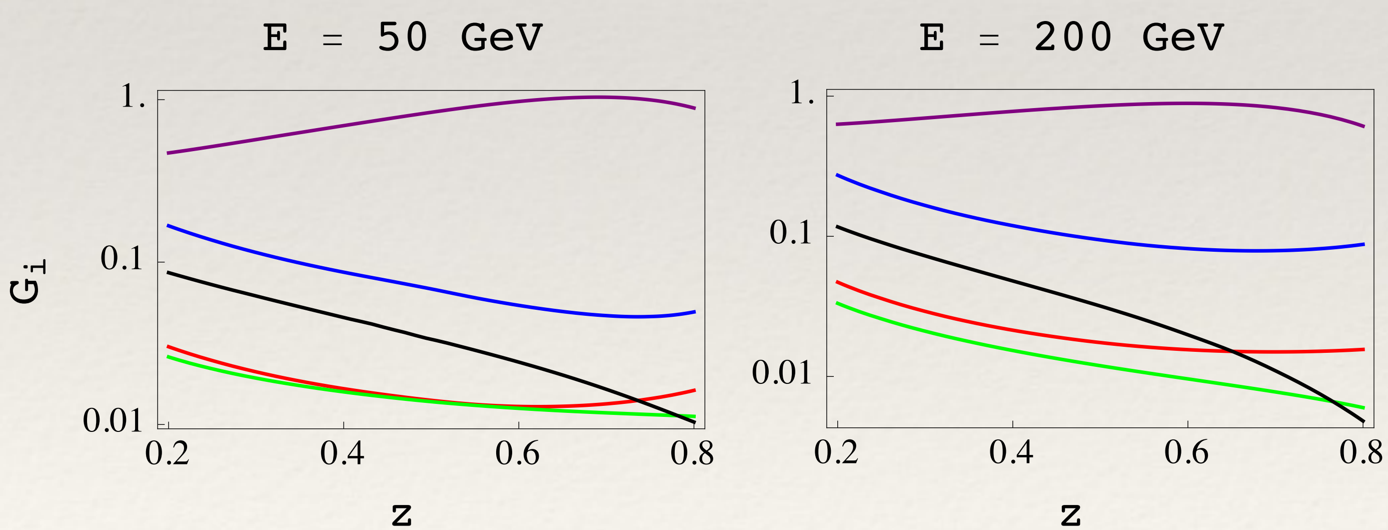
quarkonia w/ momentum fraction z

jet of radius R
and energy E

- for “unmeasured jet” (tagged but inclusive in mass, etc)

$$\sigma_\psi(z) \propto \mathcal{G}_g^\psi(E, R, z, \mu = 2E\tan\frac{R}{2})$$

(“unmeasured” fragmenting jet function)
Procura, Waalewijn 1110.0839



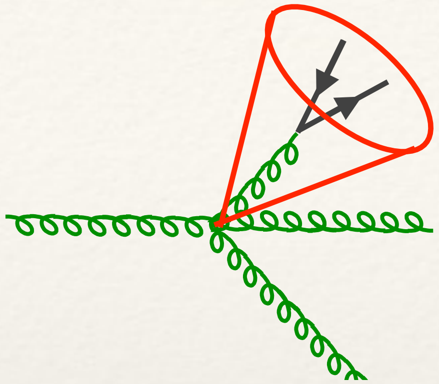
Baumgart, Leibovich, Mehen, Rothstein 1406.2295

${}^3S_1^{(1)}$
${}^3S_1^{(8)}$
${}^1S_0^{(8)}$
${}^3P_J^{(8)}$

→ high p_T and global fit tensions

Motivation

- quarkonia @ LHC:



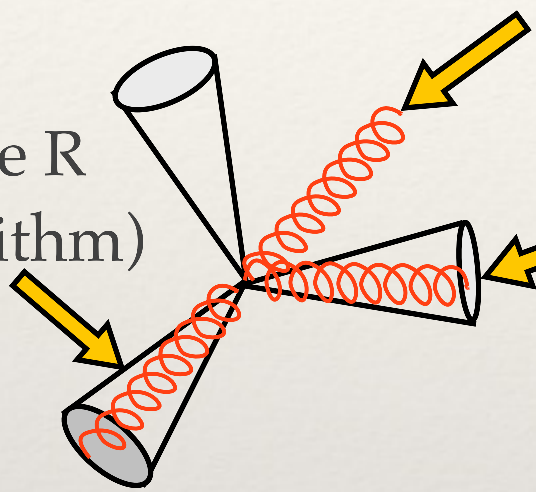
- one step further:
    - more info if "measured" jets?
    - unmeasured factorization not as well understood
    - Pythia/Madonia not great for LHC J/Ψ

➔ setup σ for measured case

(bye quarkonia, for now)

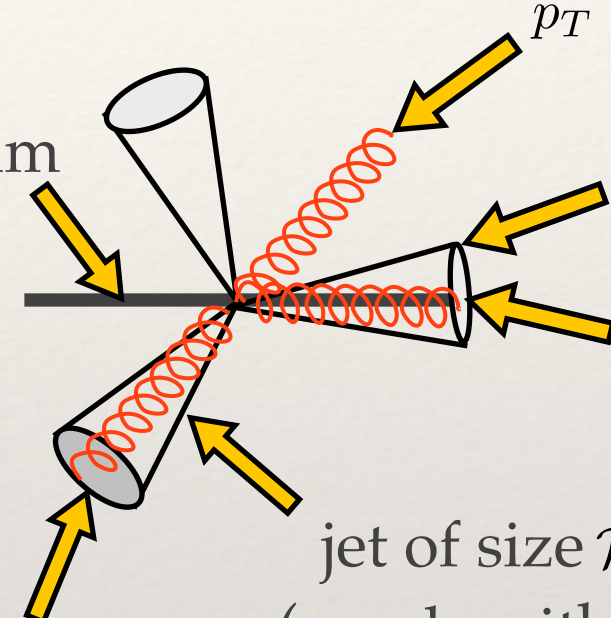
Setup

- e$^+$e$^-$ jet shape setup:



Ellis, AH, Lee, Vermilion, Walsh 1001.0014

- pp jet shape setup:



- changes:

(1) $R \to \mathcal{R}$ (3) $\Lambda \to p_T^{\rm cut}$

(2) $\tau_a^{e^+e^-} \to \tau_a^{pp}$ (4) + (unmeasured) beam functions/PDFs

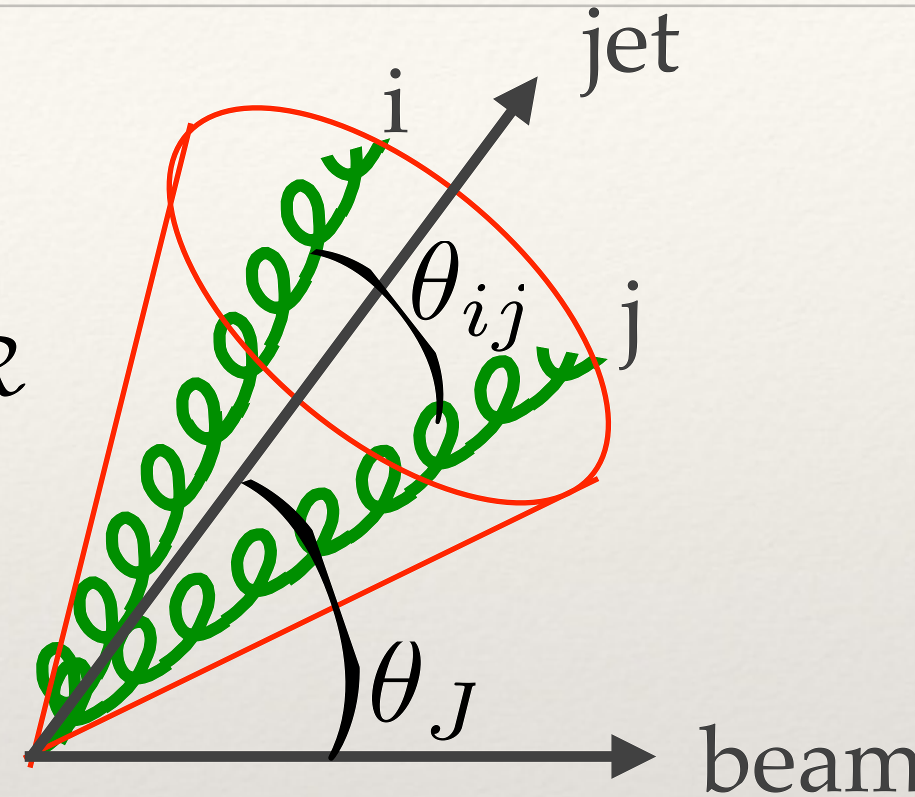
- fragmentation: "just" change $J(\tau) \to J(\tau, z)$

Jet Algorithms

- combine particles i,j if

$$\Delta\mathcal{R}_{ij} \equiv \sqrt{(\Delta y_{ij})^2 + (\Delta\phi_{ij})^2} < \mathcal{R}$$

$$= \frac{\theta_{ij}}{\sin\theta_J} + \mathcal{O}(\theta_{ij}^2)$$



- same for all k_T-type (k_T, C/A, anti-k_T) to $\mathcal{O}(\alpha_s)$
- simple replacement

$$R \to \mathcal{R}\sin\theta_J = \frac{\mathcal{R}}{\cosh y_J} \qquad \left(\text{and } \; 2E\tan\frac{R}{2} \to p_T\mathcal{R}\right)$$

Hadron Angularities

- e^+e^- definition:

$$\tau_a^{e^+e^-} = \frac{1}{2E_J}\sum_i |p_T^{iJ}| e^{-(1-a)|y_{iJ}|}$$

original *event* shape: Berger, Kucs, Sterman hep-ph/0303051

this def'n *for jets*: Ellis, AH, Lee, Vermilion, Walsh 1001.0014

$$= (2E_J)^{-(2-a)} (p_T)^{1-a} \sum_i |p_T^i| \left(\frac{\theta_{iJ}}{\sin\theta_J}\right)^{2-a} \left(1 + \mathcal{O}(\theta_{iJ}^2)\right)$$

boost inv. offender (overall factor!)

- another simple rescaling:

cancels offender (and dimensionless)

$$\tau_a^{pp} \equiv \frac{1}{p_T}\sum_i |p_T^i| (\Delta\mathcal{R}_{iJ})^{2-a} = \left(\frac{2E_J}{p_T}\right)^{2-a} \tau_a^{e^+e^-} + \mathcal{O}(\tau_a^2)$$

Scale Hierarchies

- for unmeasured jets & beams, need

$$\mathcal{R}^2 \ll 1$$

$$e^{-y_{\rm cut}} \ll 1$$

- for measured jets, could get full R-dep numerically

Bauer, Dunn, AH 1102.4899

see also: Jim Talbert's talk

- to avoid non-global and kinematic logs

see also: Shireen Gangal's talk;
Gangal, Stahlhofen, Tackmann 1412.4792

see also: David Farhi's talk from `14

soft scales: $p_T^{\rm cut}/p_T^J \sim \tau_a^1 \sim \tau_a^2$

see also: Duff Neill's talk; Larkoski, Moult, Neill 1501.04596

(within $10^{\pm 1}$)

hard scales: $p_T^J \sim \hat{s} \sim \hat{t} \sim \hat{u}$

see also: Bauer, Tackmann, Walsh, Zuberi ("Ninja") 1106.6047

see also: Piotr Pietrulewicz's talk

Factorized Cross-Section

- born:

$$\frac{d\sigma_{\rm born}}{dy_1 dy_2 dp_T} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4} \frac{1}{N} f_1(x_1;\mu) f_2(x_2;\mu)\, {\rm Tr}\{\mathbf{H}_0 \mathbf{S}_0\}$$

- unmeasured jets:

$$\frac{d\sigma}{dy_1 dy_2 dp_T} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4} \frac{1}{N} B(x_1;\mu) \bar{B}(x_2;\mu)\, {\rm Tr}\{\mathbf{H}(\mu) \mathbf{S}^{\rm unmeas}(\mu)\} [J_1(\mu) J_2(\mu)]$$

unmeas./measured jet functions (different)

- measured jets:

$$\frac{d\sigma}{dy_1 dy_2 dp_T d\tau_a^1 d\tau_a^2} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4} \frac{1}{N} B(x_1;\mu) \bar{B}(x_2;\mu)\, {\rm Tr}\{\mathbf{H}(\mu) \mathbf{S}(\tau_a^1, \tau_a^2;\mu)\} \otimes [J_1(\tau_a^1;\mu) J_2(\tau_a^2;\mu)]$$

Unmeasured Beam Functions

- "unmeasured" fragmenting jet function:

$$\mathcal{G}(E,R,z;\mu) = \sum_i \int \frac{dz}{z} \mathcal{J}_{ij}(E,R,z';\mu) D_j^h(z/z';\mu) + \mathcal{O}(\Lambda_{\rm QCD}^2/E^2)$$

Procura, Waalewijn 1110.0839

$$\mathcal{J}_{ij}(E,R,z',\mu) \equiv \mathcal{J}_{ij}(2E\tan\frac{R}{2},z',\mu)$$

- simple replacement: $2E\tan\frac{R}{2} \to E_{\rm cm}e^{-y_{\rm cut}}$

- unmeasured beam function:

same as D at $\mathcal{O}(\alpha_s)$ (different at $\mathcal{O}(\alpha_s^2)$)

$$B_i(\mathrm{E}_{\rm cm}, y_{\rm cut}, x_i;\mu) = \sum_j \int \frac{dz}{z} \mathcal{J}_{ij}(\mathrm{E}_{\rm cm}e^{-y_{\rm cut}}, z', \mu) f_j(z/z',\mu) + \mathcal{O}(\Lambda_{\rm QCD}^2/E^2)$$

evolves like unmeas. jet

Procura, Stewart 0911.4980

same as above to $\mathcal{O}(\alpha_s)$

Jet Functions

- unmeasured:

$$J_i \xrightarrow{E\tan\frac{R}{2}\to p_T\mathcal{R}} 1+\frac{\alpha_s}{2\pi}\left[\left(\frac{C_i}{\epsilon^2}+\frac{\gamma_i}{\epsilon}\right)\underbrace{\left(\frac{\mu}{p_T\mathcal{R}}\right)}^{2\epsilon}+d_J^{i,\mathrm{alg}}\right]$$

now boost invariant!

- measured: definition of J(τ) and $\delta(\tau - A\hat{\tau}) = A^{-1}\delta(A^{-1}\tau - \hat{\tau})$

$$J_i(\tau_a) = \left(\frac{p_T}{2E_J}\right)^{2-a} J_i^{e^+e^-}\left(\left(\frac{p_T}{2E_J}\right)^{2-a}\tau_a\right)$$

$$= \delta(\tau_a) - \frac{\alpha_s}{2\pi}\left[\underbrace{\left(\frac{\mu}{p_T}\right)^{2\epsilon}\left(\frac{1}{\tau_a}\right)^{1+\frac{2\epsilon}{2-a}}}\left(\frac{1}{\epsilon}\frac{2C_i}{1-a}+\frac{\gamma_i}{1-a/2}\right)+\delta(\tau_a)f_i(a)\right]$$

now boost invariant!

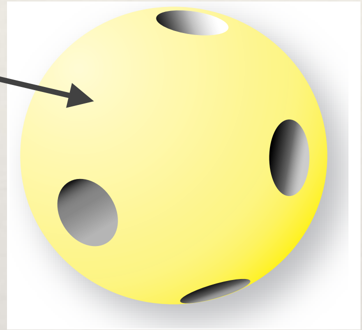
Soft Function(s)

$$\mathbf{S}(\tau_a^1, \tau_a^2) = \mathbf{S}^{\rm unmeas}\delta(\tau_a^1)\delta(\tau_a^2) + [\mathbf{S}_0 S^{\rm meas}(\tau_a^1)\delta(\tau_a^2) + (1 \leftrightarrow 2)] + \mathcal{O}(\alpha_s^2)$$

always present

add for each meas jet
(can sub in favorite jet shape)

$p_T < p_T^{\rm cut}$



Soft Function(s)

$$\mathbf{S}(\tau_a^1, \tau_a^2) = \mathbf{S}^{\text{unmeas}} \delta(\tau_a^1)\delta(\tau_a^2) + [\mathbf{S}_0 S^{\text{meas}}(\tau_a^1)\delta(\tau_a^2) + (1 \leftrightarrow 2)] + \mathcal{O}(\alpha_s^2)$$

always present

add for each meas jet
(can sub in favorite jet shape)

Soft Function(s)

$$\mathbf{S}(\tau_a^1, \tau_a^2) = \mathbf{S}^{\text{unmeas}} \delta(\tau_a^1)\delta(\tau_a^2) + [\mathbf{S}_0 S^{\text{meas}}(\tau_a^1)\delta(\tau_a^2) + (1 \leftrightarrow 2)] + \mathcal{O}(\alpha_s^2)$$

always present

add for each meas jet
(can sub in favorite jet shape)

rescaling $\tau_a^{e^+e^-} \to \tau_a^{pp}$

$$S^{\text{meas}}(\tau_a^i) = \sum_{\langle i \neq j \rangle} \left(\frac{p_T}{2E_J}\right)^{2-a} S_{ij}^{\text{meas}}\left(\left(\frac{p_T}{2E_J}\right)^{2-a} \tau_a^i\right)$$

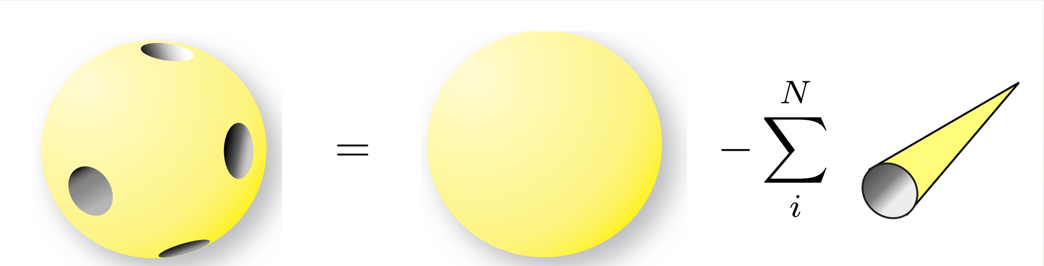
$$= \frac{1}{\epsilon} \frac{\alpha_s C_i}{\pi} \frac{e^{\gamma_E \epsilon}}{\Gamma(1-\epsilon)} \frac{1}{1-a} \left(\frac{1}{\tau_a^i}\right)^{1+2\epsilon} \left(\frac{\mu}{p_T}\right)^{2\epsilon} \mathcal{R}^{2\epsilon(1-a)}$$

boost invariant

Soft Function(s)

$$\mathbf{S}(\tau_a^1,\tau_a^2) = \mathbf{S}^{\rm unmeas}\delta(\tau_a^1)\delta(\tau_a^2) + [\mathbf{S}_0 S^{\rm meas}(\tau_a^1)\delta(\tau_a^2) + (1\leftrightarrow 2)] + \mathcal{O}(\alpha_s^2)$$

$$\mathbf{S}^{\rm unmeas} = \mathbf{S}_0 + \left[\frac{\mathbf{S}_0}{2}\sum_{\langle i\neq j\rangle}\mathbf{T}_i\cdot\mathbf{T}_j\Big(S_{ij}^{\rm incl} + \sum_{k=1}^{N} S_{ij}^k\Big) + \text{h.c.}\right]$$



$$S_{ij}^{\rm incl} \equiv \frac{1}{\epsilon}\frac{\alpha_s}{2\pi}\left(\frac{\mu}{p_T^{\rm cut}}\right)^{2\epsilon}\mathcal{I}_{ij}^{\rm incl} = -g^2\mu^{2\epsilon}\int\frac{d^dk}{(2\pi)^{d-1}}\frac{n_i\cdot n_j}{(n_i\cdot k)(n_j\cdot k)}\delta(k^2)\Theta(k^0)\Theta_{p_T}$$

p_T veto!

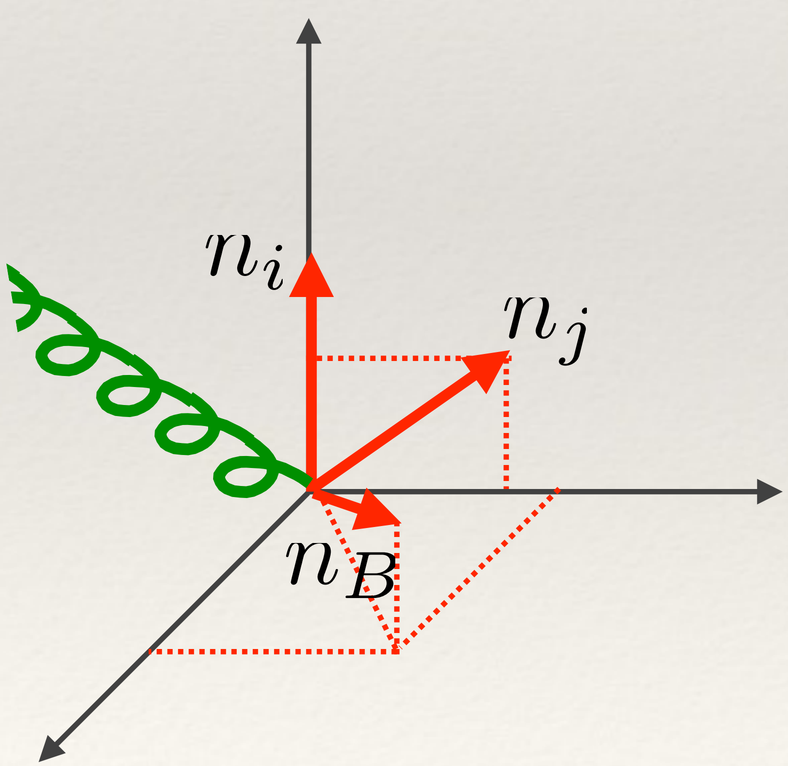
$$S_{ij}^{k} \equiv \frac{1}{\epsilon}\frac{\alpha_s}{2\pi}\left(\frac{\mu}{p_T^{\rm cut}}\right)^{2\epsilon}\mathcal{I}_{ij}^{k} = g^2\mu^{2\epsilon}\int\frac{d^dk}{(2\pi)^{d-1}}\frac{n_i\cdot n_j}{(n_i\cdot k)(n_j\cdot k)}\delta(k^2)\Theta(k^0)\,\Theta_{p_T}\Theta_{\mathcal{R}}^k$$

- not simply related to anything calculated…

Soft Function(s)

$$S^{\rm incl}_{ij} \equiv \frac{1}{\epsilon}\frac{\alpha_s}{2\pi}\left(\frac{\mu}{p_T^{\rm cut}}\right)^{2\epsilon}\mathcal{I}^{\rm incl}_{ij} = -g^2\mu^{2\epsilon}\int\frac{d^dk}{(2\pi)^{d-1}}\frac{n_i\cdot n_j}{(n_i\cdot k)(n_j\cdot k)}\delta(k^2)\Theta(k^0)\Theta_{p_T}$$

$$\mathcal{I}^{\rm incl}_{ij} = \frac{(1-c_{ij})e^{\gamma_E\epsilon}}{2\sqrt{\pi}\Gamma(1/2-\epsilon)}\int_0^\pi d\theta_1\,\sin^{1-2\epsilon}\theta_1\int_0^\pi d\theta_2\,\sin^{-2\epsilon}\theta_2\frac{1}{1-c_1}\frac{1}{1-c_{ij}c_1-s_{ij}s_1c_2}$$
$$\times\left[\frac{\Gamma(1/2-\epsilon)}{\sqrt{\pi}\Gamma(-\epsilon)}\int_0^\pi d\theta_3\,\sin^{-1-2\epsilon}\theta_3\big(1-(n_{B1}c_1+n_{B3}s_1c_2+n_{B3}s_1s_2c_3)^2\big)^\epsilon\right].$$



$$\vec{n}_i\cdot k = c_1$$
$$\vec{n}_j\cdot k = c_{ij}c_1 + s_{ij}s_1c_2$$
$$\vec{n}_B\cdot k = n_{B1}c_1 + n_{B2}s_1c_2 + n_{B3}s_1s_2c_3$$

Soft Function(s)

$$\mathcal{I}_{ij}^{\rm incl} = \frac{(1-c_{ij})e^{\gamma_E\epsilon}}{2\sqrt{\pi}\Gamma(1/2-\epsilon)}\int_0^\pi d\theta_1\,\sin^{1-2\epsilon}\theta_1\int_0^\pi d\theta_2\,\sin^{-2\epsilon}\theta_2\frac{1}{1-c_1}\frac{1}{1-c_{ij}c_1-s_{ij}s_1c_2}$$
$$\times\left[\frac{\Gamma(1/2-\epsilon)}{\sqrt{\pi}\Gamma(-\epsilon)}\int_0^\pi d\theta_3\,\sin^{-1-2\epsilon}\theta_3\big(1-(n_{B1}c_1+n_{B3}s_1c_2+n_{B3}s_1s_2c_3)^2\big)^\epsilon\right].$$

$$\Big[\cdots\Big]\xrightarrow{\text{planar}}\big(1-(n_{B1}c_1+n_{B2}s_1c_2)^2\big)^\epsilon$$

➔ can boost for back-to-back jets!

$$\Big[\cdots\Big]\xrightarrow{n_i=n_B}\sin^{2\epsilon}\theta_1$$

➔ rapidity divergences…

$$\underbrace{\mathcal{I}_{B\bar B}^{\rm incl}+\mathcal{I}_{B\bar B}^{B}+\mathcal{I}_{B\bar B}^{\bar B}}$$

sum is IR finite

$$\overbrace{\mathcal{I}_{BJ}^{\rm incl}+\mathcal{I}_{BJ}^{B}}+\mathcal{I}_{BJ}^{J}$$

(different coordinates)

alternative: rapidity regulate $\mathcal{I}_{B\bar B}^{\rm incl}$ & $\mathcal{I}_{BJ}^{\rm incl}$ with $\mathrm{SCET_{II}}$ (measured) beam functions for p_T resummation

Soft Function(s)

$$\mathbf{S}(\tau_a^1, \tau_a^2) = \mathbf{S}^{\text{unmeas}} \delta(\tau_a^1)\delta(\tau_a^2) + [\mathbf{S}_0 S^{\text{meas}}(\tau_a^1)\delta(\tau_a^2) + (1 \leftrightarrow 2)] + \mathcal{O}(\alpha_s^2)$$

$$\mathbf{S}^{\text{unmeas}} = \mathbf{S}_0 + \left\{ \frac{\mathbf{S}_0}{2} \left[\left(\frac{1}{\epsilon} + 2 \ln \frac{\mu}{p_T^{\text{cut}}} \right) \mathbf{S}^{\text{div}} - \frac{\alpha_s}{\pi} (C_1 + C_2) \ln^2 \mathcal{R} \right. \right.$$
$$\left. \left. - \frac{2\alpha_s}{\pi} \underbrace{\mathbf{T}_1 \cdot \mathbf{T}_2}_{\text{only one (new) matrix}} \ln\left(1 + e^{\Delta y}\right) \ln\left(1 + e^{-\Delta y}\right) \right] + \text{h.c.} \right\}$$

Soft Function(s)

$$\mathbf{S}(\tau_a^1, \tau_a^2) = \mathbf{S}^{\rm unmeas}\delta(\tau_a^1)\delta(\tau_a^2) + [\mathbf{S}_0 S^{\rm meas}(\tau_a^1)\delta(\tau_a^2) + (1 \leftrightarrow 2)] + \mathcal{O}(\alpha_s^2)$$

$$\mathbf{S}^{\rm unmeas} = \mathbf{S}_0 + \left\{ \frac{\mathbf{S}_0}{2}\left[\left(\frac{1}{\epsilon} + 2\ln\frac{\mu}{p_T^{\rm cut}}\right)\mathbf{S}^{\rm div} - \frac{\alpha_s}{\pi}(C_1 + C_2)\ln^2\mathcal{R} - \frac{2\alpha_s}{\pi}\mathbf{T}_1\cdot\mathbf{T}_2 \ln\left(1+e^{\Delta y}\right)\ln\left(1+e^{-\Delta y}\right)\right] + \text{h.c.}\right\}$$

only one (new) matrix

$$\mathbf{S}^{\rm div} = \Gamma(\alpha_s)\left(\frac{1}{2}\sum_{\langle i\neq j\rangle}\mathbf{T}_i\cdot\mathbf{T}_j \ln\frac{n_i\cdot n_j}{2} - y_{\rm cut}(C_B + C_{\bar B}) + C_1\ln\frac{\mathcal{R}}{2\cosh y_1} + C_2\ln\frac{\mathcal{R}}{2\cosh y_2}\right)$$

NLL' Cross-Section

- unmeasured result:

$$\frac{d\sigma}{dy_1 dy_2 dp_T} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4} \frac{1}{N} B(x_1;\mu_B)\bar{B}(x_2;\mu_B) J_1(\mu_J) J_2(\mu_J)\, \Pi^{\rm unmeas}(\bar{\mu}_S, \bar{\mu}_J, \mu_B, \mu_H)$$
$$\times \,\mathrm{Tr}\{\mathbf{H}(\mu_H)\mathbf{U}^\dagger(\mu,\bar{\mu}_S,\mu_H)\mathbf{S}^{\rm unmeas}(\mu_S)\mathbf{U}(\mu,\bar{\mu}_S,\mu_H)\}$$

- measured result:

$$\frac{d\sigma}{dy_1 dy_2 dp_T d\tau_a^1 d\tau_a^2} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4} \frac{1}{N} B(x_1;\mu_B)\bar{B}(x_2;\mu_B) \Big[\Pi^{\rm meas}(\tau_a^1,\tau_a^2;\mu_S,\bar{\mu}_S,\mu_J,\mu_B,\mu_H)\ \mathrm{Tr}\Big\{\mathbf{H}(\mu_H)\mathbf{U}^\dagger(\mu,\mu_S,\mu_H)\Big[\mathbf{S}^{\rm unmeas}(\mu_S)$$
$$+\,\mathbf{S}_0\big(f_S^1(\tau_a^1;\omega_S^1,\mu_S) + f_J^1(\tau_a^1;\omega_S^1,\mu_J) + (1\leftrightarrow 2)\big)\Big]\mathbf{U}(\mu,\mu_S,\mu_H)\Big\}\Big]_+$$

NLL' Cross-Section

- unmeasured result:

$$\frac{d\sigma}{dy_1 dy_2 dp_T} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4}\frac{1}{N} B(x_1;\mu_B)\bar{B}(x_2;\mu_B) J_1(\mu_J) J_2(\mu_J)\, \Pi^{\rm unmeas}(\bar{\mu}_S, \bar{\mu}_J, \mu_B, \mu_H)$$
$$\times\, {\rm Tr}\{\mathbf{H}(\mu_H)\mathbf{U}^\dagger(\mu, \bar{\mu}_S, \mu_H)\mathbf{S}^{\rm unmeas}(\mu_S)\mathbf{U}(\mu, \bar{\mu}_S, \mu_H)\}$$

- measured result:

$$\frac{d\sigma}{dy_1 dy_2 dp_T d\tau_a^1 d\tau_a^2} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4}\frac{1}{N} B(x_1;\mu_B)\bar{B}(x_2;\mu_B) \Big[\Pi^{\rm meas}(\tau_a^1, \tau_a^2; \mu_S, \bar{\mu}_S, \mu_J, \mu_B, \mu_H)\ {\rm Tr}\Big\{\mathbf{H}(\mu_H)\mathbf{U}^\dagger(\mu, \mu_S, \mu_H)\Big[\mathbf{S}^{\rm unmeas}(\mu_S)$$
$$+\,\mathbf{S}_0\big(f_S^1(\tau_a^1;\omega_S^1,\mu_S) + f_J^1(\tau_a^1;\omega_S^1,\mu_J) + (1\leftrightarrow 2)\big)\Big]\mathbf{U}(\mu,\mu_S,\mu_H)\Big\}\Big]_+$$

- fragmentation: $f_S + f_J \to \sum_j \int_z^1 \frac{dx}{x} D_i(x)\Big[\delta_{ij}\delta(1-z/x) f_S + f_J^{ij}(z/x)\Big]$

$$f_J^{ij}(z;\tau_a,\Omega,\mu) = \delta_{ij}\delta(1-z) f_J(\tau_a,\Omega,\mu) + \bar{P}_{ji}(z) g_a^{ij}(z;\tau_a,\Omega,\mu) + c^{ij}(z)$$

(reduces to convolving measured fragmenting jet function for a=0)

Jain, Procura, Waalewijn 1101.4953

NLL' Cross-Section

- unmeasured result:

$$\frac{d\sigma}{dy_1 dy_2 dp_T} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4}\frac{1}{N} B(x_1;\mu_B)\bar{B}(x_2;\mu_B) J_1(\mu_J) J_2(\mu_J)\, \Pi^{\rm unmeas}(\bar\mu_S,\bar\mu_J,\mu_B,\mu_H)$$
$$\times\, {\rm Tr}\{\mathbf{H}(\mu_H)\mathbf{U}^\dagger(\mu,\bar\mu_S,\mu_H)\mathbf{S}^{\rm unmeas}(\mu_S)\mathbf{U}(\mu,\bar\mu_S,\mu_H)\}$$

- measured result:

$$\frac{d\sigma}{dy_1 dy_2 dp_T d\tau_a^1 d\tau_a^2} = \frac{p_T x_1 x_2}{8\pi E_{\rm cm}^4}\frac{1}{N} B(x_1;\mu_B)\bar{B}(x_2;\mu_B)\Big[\Pi^{\rm meas}(\tau_a^1,\tau_a^2;\mu_S,\bar\mu_S,\mu_J,\mu_B,\mu_H)\ {\rm Tr}\Big\{\mathbf{H}(\mu_H)\mathbf{U}^\dagger(\mu,\mu_S,\mu_H)\Big[\mathbf{S}^{\rm unmeas}(\mu_S)$$
$$+\,\mathbf{S}_0\big(f_S^1(\tau_a^1;\omega_S^1,\mu_S)+f_J^1(\tau_a^1;\omega_S^1,\mu_J)+(1\leftrightarrow 2)\big)\Big]\mathbf{U}(\mu,\mu_S,\mu_H)\Big\}\Big]_+$$

- fragmentation: $f_S + f_J \rightarrow \sum_j \int_z^1 \frac{dx}{x} D_i(x)\Big[\delta_{ij}\delta(1-z/x)f_S + f_J^{ij}(z/x)\Big]$

numerically small!
σ ∝ D(z, μ = $\tau^{1/(2\text{-}a)}$)
(PRELIMINARY)

$$f_J^{ij}(z;\tau_a,\Omega,\mu) = \delta_{ij}\delta(1-z)f_J(\tau_a,\Omega,\mu) + \bar{P}_{ji}(z)g_a^{ij}(z;\tau_a,\Omega,\mu) + c^{ij}(z)$$

(reduces to convolving measured fragmenting jet function for a=0)

Jain, Procura, Waalewijn 1101.4953

Summary & Outlook

- most pp results can be obtained directly from e^+e^-
- new soft function for out-of-jet/beam radiation
- NLL′ resummation of (boost inv.) jet angularity
- future:
  - comparisons to Pythia, etc
  - quarkonia pheno…
  - interplay between unmeas/meas beam approaches