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Jets, flow, gaps: non-global effects

Giuseppe Marchesini
Milano-Bicocca and Jussieu

Main reference: a tribute to roots

- Writing: Mesopotamia 3500-3000 BC
  Samuel N. Kramer, History begins in Sumer,
  Anchor edition, 1959

- Mathematics: Mesopotamia 3000-2500 BC
  Otto E. Neugebauer, The exact sciences in antiquity,
  Brown University Press, 1975

- 2003 AD: document destruction (National Library, Archaeological Museum)
- 1258 AD: document destruction by Mongols

QED precision test: $\frac{1}{2}(g-2)_e = 0.001159652187(4)$

Are precision tests possible in QCD? $\alpha_s(M_Z)$ with less then 5% error (hadronization, NP corrections, non convergence of PT expansion)

QCD dynamical structures are more important
Classical example are Jet shape distributions

New discovery: non-global jet shape (only part of phase space involved)
M. Dsgupta and G.Salam, JHEP 08(02) 032; JHEP 03(02) 3311
— not yet studied even at Lep
— mechanism of overall colour neutralization
— large angle soft emission (corrections to MC)

Examples:

- Sterman-Weiberg distribution (energy in a cone)
- photon isolation
- rapidity cuts in DIS and hadron-hadron
- inter jet string/drag effects
- profile of a separate jet (current hemisphere)

In this talk

1. example of global jet shape in DIS

2. example of almost global jet shape in DIS

3. general features of non-global effects

Azimuthal correlation in DIS: global jet shape

A.Banfi, G.Smye, GM, JHEP 0204:024,2002

Dijet events in Breit frame with large $P_t \sim Q$

$$H(\chi) = \sum_{hh'} \frac{p_{th}\, p_{th'}}{Q^2}\, \delta(\chi - \chi_{hh'})$$

with $\chi_{hh'}$ back-to-back azimuth angle (similar to EEC in e^+e^-)

Collinear-infrared safe $\Rightarrow$ hadrons$\sim$partons

Born process (Breit frame) $\chi = 0$

$$\gamma + P_1 \to P_2 + P_3\,, \qquad \vec{P}_{2t} = -\vec{P}_{3t} = \vec{P}_t$$

Beyond Born $\chi \neq 0$

$$\gamma + P_1 \to P_2 + P_2 + k_1 + k_2 \dots \quad \vec{P}_{2t} \neq -\vec{P}_{3t}$$

- Small $\chi \Rightarrow$ soft secondary emission $k_1, k_2, \dots$
- Momentum conservation (Breit frame)

$$P_t \chi_{23} = |\sum_i k_i^{\rm out}| \qquad \vec{P}_t \cdot \vec{k}^{\rm out} = 0$$

- At SL accuracy $H(\chi) \sim \delta\big(P_T\chi - |\sum_i k_i^{\rm out}|\big)$

Momentum conservation $\Rightarrow$ global observable

PT resummation: 3 Sudakov factors. Bremsstrahlung (independent emission) from P_1, P_2, P_3 ($q\bar{q}g,\ qg\bar{q},\ gq\bar{q}$)

Out-of-plane rad. in DIS: almost global jet shape

A.Banfi, G.Smye, GM, JHEP 0111:066,2001

Dijet events in Breit frame with large $P_t \sim Q$

$$K_{\text{out}} = {\sum_h}' |p_h^{\text{out}}|, \quad \vec{P}_t \cdot \vec{p}_h^{\,\text{out}} = 0, \quad \eta_h > \eta_0$$

Collinear-infrared safe $\Rightarrow$ hadrons$\sim$partons

Born process (Breit frame) $K_{\text{out}} = 0$

$$\gamma + P_1 \to P_2 + P_3\,, \qquad \vec{P}_{2t} = -\vec{P}_{3t} = \vec{P}_t$$

Beyond Born $K_{\text{out}} \neq 0$

$$\gamma + P_1 \to P_2 + P_2 + k_1 + k_2 \dots$$

- Small K_{out} $\Rightarrow$ soft secondary emission $k_1, k_2, \dots$
- η_0 finite $\Rightarrow$ non-global shape, but

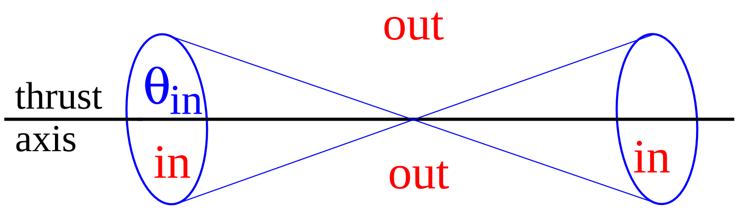
$$K_{\text{out}}^{\text{tot}} = \sum_h |p_h^{\text{out}}|, \qquad K_{\text{out}}^{\text{tot}} - K_{\text{out}} \lesssim Q e^{-\eta_0}$$

  almost global for $\eta_0 = 2-3$. SL resummation: 3 Sudakov factors
- Only NP corrections depends on η_0

General features of non-global effects

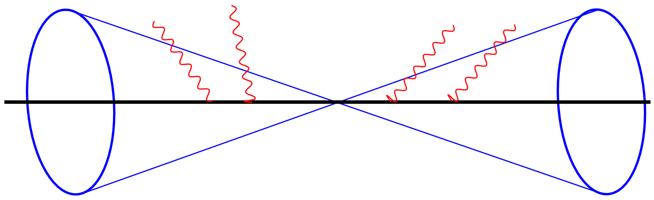
M.Dasgupta,G.Salam, PLB 512:323,2001, JHEP 0203:017,2002
C.Berger,T.Kúcs,G.Sterman,PRD 65:094031,2002
A.Banfi,G.Smye&GM,JHEP 0208:006,2002

Simplest case e^+e^-: Soft emission from $q\bar{q}$-dipole in out

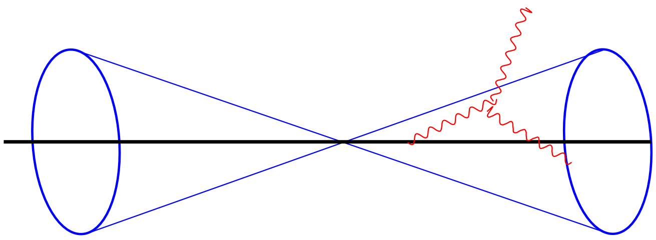


$$\Sigma(E_{\text{out}}) = \sum_n \int \frac{d\sigma_n}{\sigma_T}\, \Theta\left(E_{\text{out}} - \sum_{\text{out}} k_{ti}\right)$$

Two QCD components:



Bremsstrahlung component;
SL Sudakov factor: $S_{q\bar{q}}$
Linear evol. (DGLAP type)



Soft secondary branching;
Non linear evolution: $C_{q\bar{q}}$
(Only in large N_c limit)

$$\Sigma_{e^+e^-}(E_{\text{out}}) = S_{q\bar{q}}(\Delta) \cdot C_{q\bar{q}}(\Delta)\,,$$

$$\Delta = \int_{E_{\text{out}}}^{E} \frac{d\omega}{\omega} \frac{N_c \alpha_s(\omega)}{\pi} \simeq \frac{N_c \alpha_s}{\pi} \ln \frac{E}{E_{\text{out}}}$$

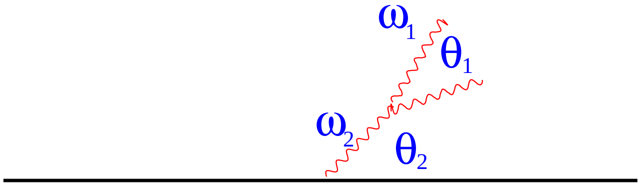
Soft secondary branching beyond SL level in global observables $(T, C, D, B \ldots)$

Why Soft secondary branching gives:

– SL for non-global observables (interjet distributions)

– beyond SL in global observables $(T, C, D \ldots)$

M.Dasgupta,G.Salam, PLB 512:323,2001



$\omega_1 \ll \omega_2$

Two-loop contribution:

$$\alpha_s^2 \int_0^E \frac{d\omega_2}{\omega_2} \int_0 \frac{d\theta_2}{\theta_2}\, u(k_2) \int_0^{\omega_2} \frac{d\omega_1}{\omega_1} \int_0 \frac{d\theta_1}{\theta_1} \theta_2 \left[1 - u(k_1)\right]$$

1) Global observable, e.g. $(1-T)$-distribution:

$$u(k_2) \Rightarrow \omega_2 < (1-T)\,E\,, \quad [1-u(k_1)] \Rightarrow \omega_1 > (1-T)\,E$$

– energy ordering conflict $\Rightarrow$ no infrared logs;

– only one collinear log $\Rightarrow$ $\alpha_s^2 \ln(1-T)$. Beyond SL

2) Non-global observable. Interjet distribution E_{out}

$$u(k_2) \Rightarrow \theta_2 < \theta_{\text{in}}\,, \quad [1-u(k_1)] \Rightarrow \omega_1 > E_{\text{out}}\,, \quad \theta_1 > \theta_{\text{in}}$$

– no energy ordering conflict $\Rightarrow$ $\alpha_s^2 \ln^2 E/E_{\text{out}}$

– interjet distribution $\Rightarrow$ no collinear log

Evolution equation for (exact) soft branching (Large N_c)
Banfi,Smye& GM JHEP 0208:006,2002

$$\Sigma_{p\bar{p}}(E_{\text{out}}) = \sum_n \int \frac{d\sigma_n}{\sigma_T}\,\Theta\left(E_{\text{out}} - \sum_{\text{out}} k_{ti}\right)\,, \quad e^+e^- \to p\bar{p}\,k_1 k_2 \ldots k_n$$

Soft gluon emission (leading order), large N_c
A.Bassetto,M.Ciafaloni&GM, Phys.Rep.100(1983)201
Y.Dokshitzer,V.Khoze,A.Mueller,S.Troian, Ed.Frontieres (1991)
M.Mangano,S.Parke, Phys.Rep.200(1991)301

$$d\sigma_n \sim \frac{(p\bar{p})}{(pk_1)(k_1k_2)\ldots(k_n\bar{p})} \qquad (k_ik_j) \equiv 1 - \cos\theta_{ij}$$

Evolution equation for Σ_{ab} (emission from the hard dipole p_a, p_b)

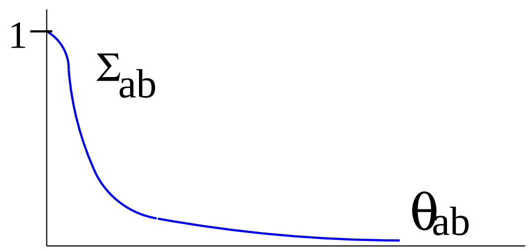
$$\partial_\Delta \Sigma_{ab} = -\partial_\Delta R_{ab}\,\Sigma_{ab} + \int_{\text{in}} \frac{d\Omega_k}{4\pi}\frac{(ab)}{(ak)(kb)}\left[\Sigma_{ak}\Sigma_{kb} - \Sigma_{ab}\right]$$

$$(ab) = 1 - \cos\theta_{ab}\,, \qquad \Delta \simeq \frac{N_c\alpha_s}{\pi}\ln\frac{E}{E_{\text{out}}}$$

SL radiator (bremsstrahlung component): $S_{ab} = e^{-R_{ab}}$

$$R_{ab} = \int_{E_{\text{out}}}^{E} \frac{d\omega}{\omega}\frac{N_c\alpha_s(\omega)}{\pi} \int_{\text{out}} \frac{d\Omega_k}{4\pi}\frac{(ab)}{(ak)(kb)} = \Delta \cdot r_{ab}$$

No dipole radiation for $p_a \to p_b \Rightarrow \Sigma_{a\to b}(\Delta) \to 1$



Structure of peak is crucial

Size of the peak at $\theta_{ab} \to 0$

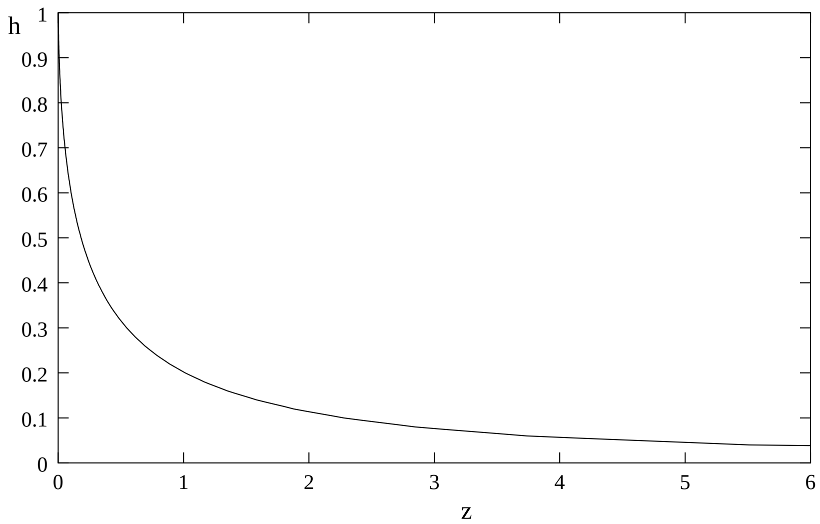
No dipole radiation for $p_a \to p_b$, $\Sigma_{ab}(\Delta) \to 1$

large Δ

$\Sigma_{ab}(\Delta) \simeq h(z)$

$$z = \frac{\theta_{ab}^2}{2\theta_{\text{crit}}^2}$$

$$\Delta \simeq \frac{N_c \alpha_s}{\pi} \ln \frac{E}{E_{\text{out}}}$$



$$\theta_{ab} \lesssim \theta_{\text{crit}} \sim \mathrm{e}^{-\frac{1}{2}c\,\Delta}, \quad c \simeq 2.5 \text{ universal}$$

— secondary branching collinear to primary partons
— large buffer for large Δ ($\theta_{\text{crit}} \ll \theta_{\text{in}}$) (Dasgupta & Salam)

General structure for ab-dipole emission

$$\Sigma_{ab} \simeq S_{ab}(\Delta) \cdot C_{ab}(\Delta)$$

SL Sudakov form factor (bremsstrahlung component)

$$S_{ab}(\Delta) = e^{-\Delta \cdot r_{ab}}, \qquad r_{ab} : \text{ geometry dependent}$$

Soft secondary branching

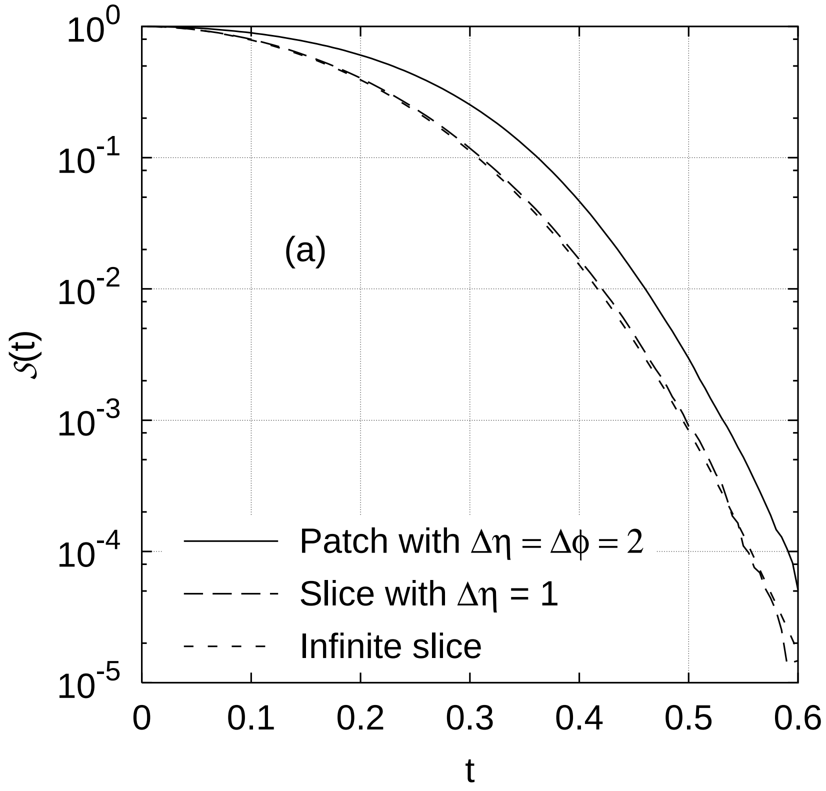
$$C_{ab}(\Delta) \simeq e^{-\frac{c}{2}\Delta^2} \qquad c \simeq 2.5 : \text{universal}$$

For large Δ secondary branching C_{ab} overcomes Sudakov S_{ab}

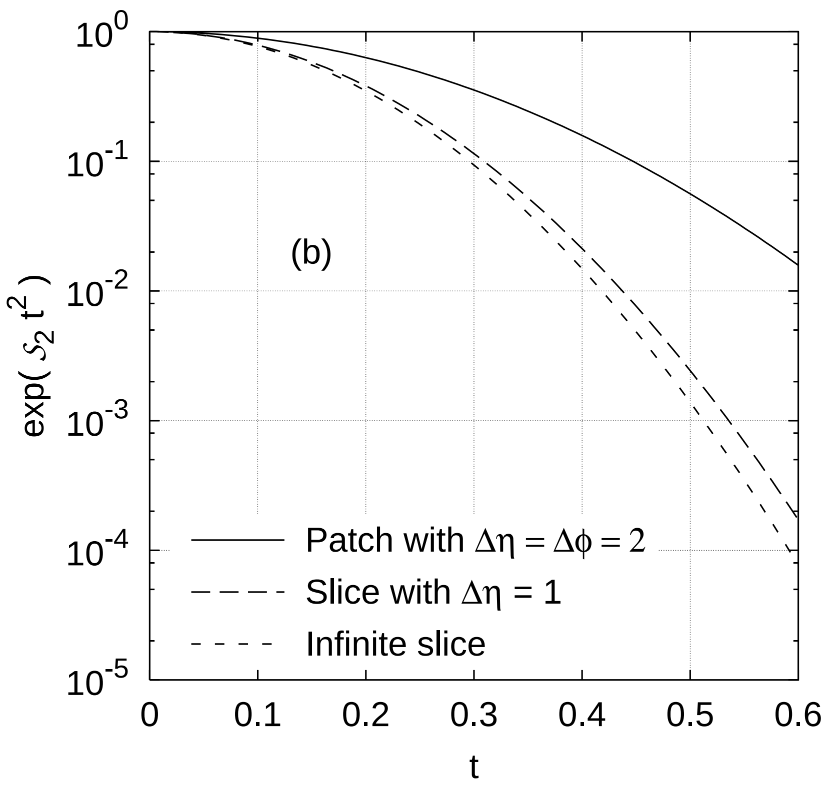
Secondary branching distribution

M.Dasgupta,G.Salam,hep-ph/0104277

$$\Sigma_{e^+e^-}(\Delta)$$
$$\Delta = 2N_c\, t$$



$$\Sigma^{(2-\text{loop})}_{e^+e^-}(\Delta)$$



Berger, Kúcs, Sterman program:
C.Berger,T.Kúcs,G.Sterman, hep-ph/0303051
Try to avoid non-global logs in non-global observables by squeezing emission in in (inhibit secondary branching emission in out)

Define flow/shape correlation (e.g. $V = 1-T$, $v(k) = \frac{k_t}{Q}\, e^{-|\eta|}$)

$$\Sigma_{fs}(Q, V, E_{\text{out}}) = \sum_n \int \frac{d\sigma_n}{\sigma_T}\, \Theta\Big(V - \sum_i v(k_i)\Big)\, \Theta\Big(E_{\text{out}} - \sum_{\text{out}} k_{ti}\Big)$$

$$\Sigma(Q, V) = \sum_n \int \frac{d\sigma_n}{\sigma_T}\, \Theta\Big(V - \sum_i v(k_i)\Big) \qquad \text{global}$$

$$\Sigma_{\text{out}}(Q, E_{\text{out}}) = \sum_n \int \frac{d\sigma_n}{\sigma_T} \Theta\Big(E_{\text{out}} - \sum_{\text{out}} k_{ti}\Big) \qquad \text{non-global}$$

For $V \ll 1$ emission in in inhibited, non non-global logs expected

$$\Sigma_{fs}(Q, V, E_{\text{out}}) \simeq \Sigma(Q, V), \quad V \sim E_{\text{out}}/Q \ll 1$$

Generalization at SL accuracy
Yuri Dokshitzer &GM, JHEP 0303:040,2003

$$\Sigma_{fs}(Q, V, E_{\text{out}}) = \Sigma(Q, V) \cdot \Sigma_{\text{out}}(VQ, E_{\text{out}})$$

Define PS^Q the real-virtual soft gluon integration region up to Q

$$\mathrm{PS}^Q_{fs}(V, E_{\text{out}}) \simeq \mathrm{PS}^Q_{\text{global}}(V) + \mathrm{PS}^{VQ}_{\text{out}}(E_{\text{out}})$$

CONCLUSIONS

Interjet/non-global observables: a new QCD avenue

Exact soft emission at large angles required

Toward understanding colour neutralization:
— geometry dependence in multi-jet events: Q_{ab}
— colour flow of hard matrix elem. dependence C_F, C_A
— presence of various hard scales: $Q, VQ, E_{\rm out}$
— constraints on NP components

Non-global observables are around:

- Sterman-Weiberg distribution (energy in a cone)
- photon isolation
- rapidity cuts in DIS and hadron-hadron
- inter jet string/drag effects
- profile of a separate jet (current hemisphere)

Overcome large N_c in secondary branching (first order)?

Improve the MC simulations?