Outlook

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- Aims
- Parton shower issues
- Resummation issues
- Conclusions?

What are we trying to achieve?

Plausible uncertainties for IRC-safe observables:

- Fixed order: few % over understood ranges
- Resummed: few times FO over extended ranges
- Parton shower: few times RS for most IRC-safe PLUS ~10% (tunable) for many IRC-unsafe

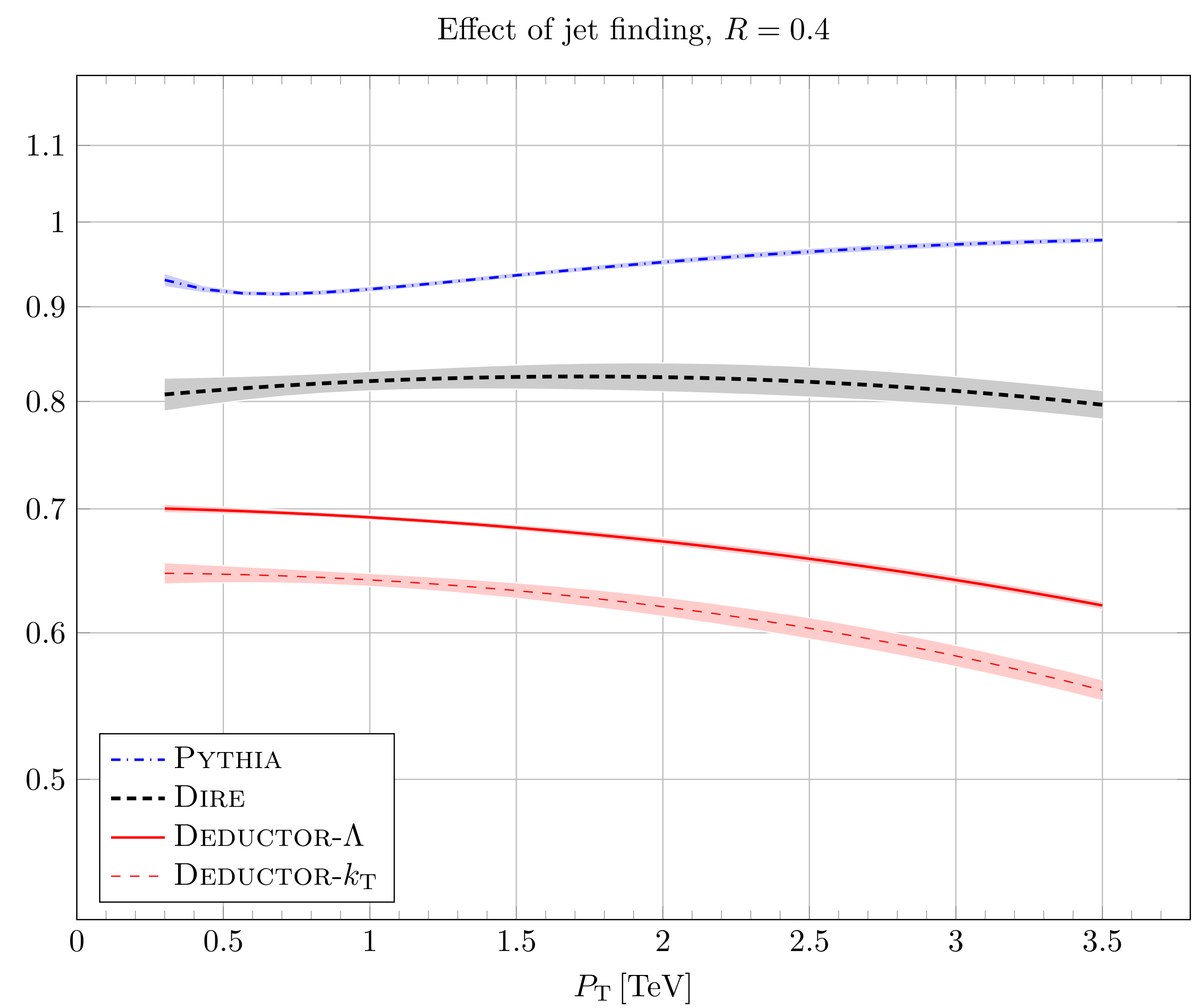
Parton Shower Issues

- Generator dependence:
    - Evolution variables: q^2, p_t, θ, “time”,…
    - Partons vs dipoles
    - Recoil schemes
- NLO splitting
- Subleading colour
- Quantum correlations (spin, EW, …)
- Hadronization

PS Generator Dependence

- Dijet pt (parton level)

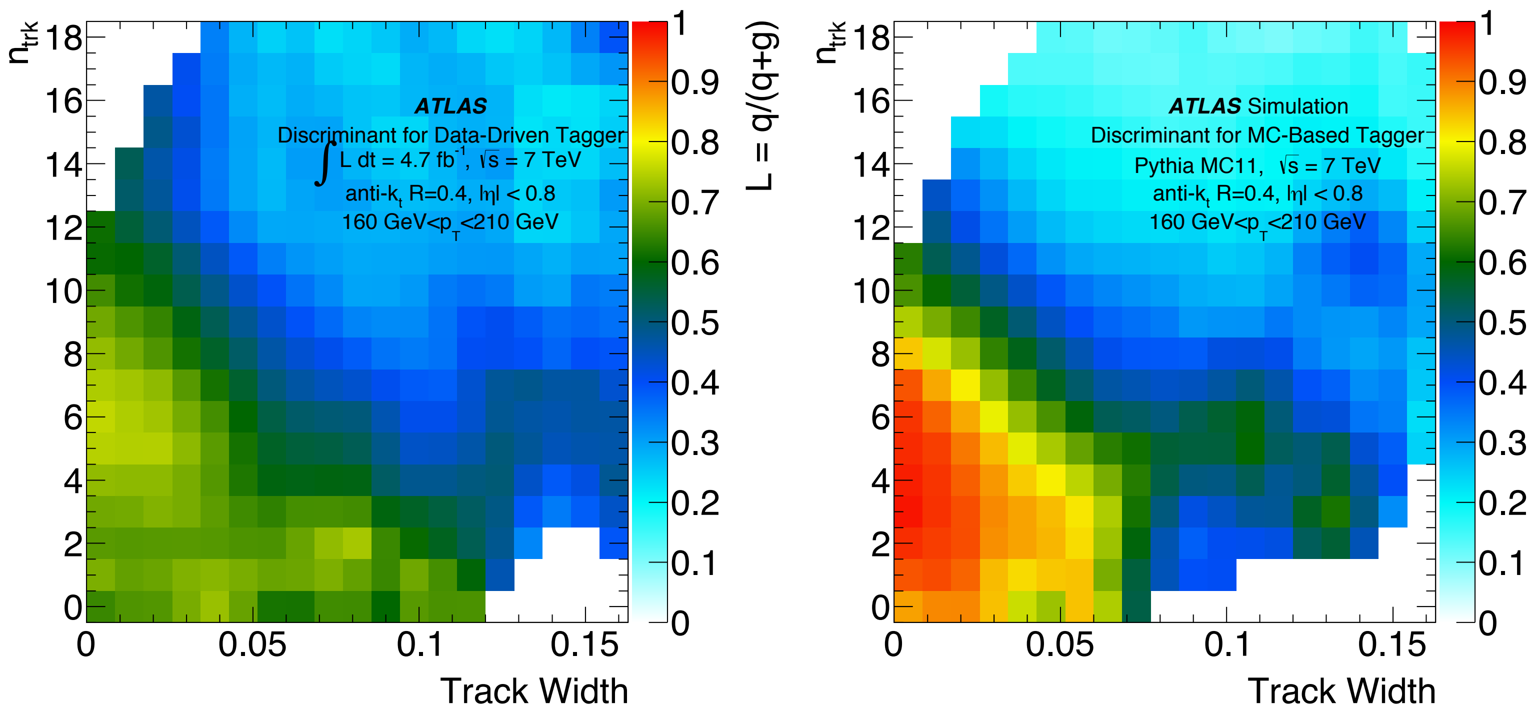
$$r(P_T) = \frac{d\sigma(\text{std.})/dP_T}{d\sigma(\text{LO})/dP_T}$$

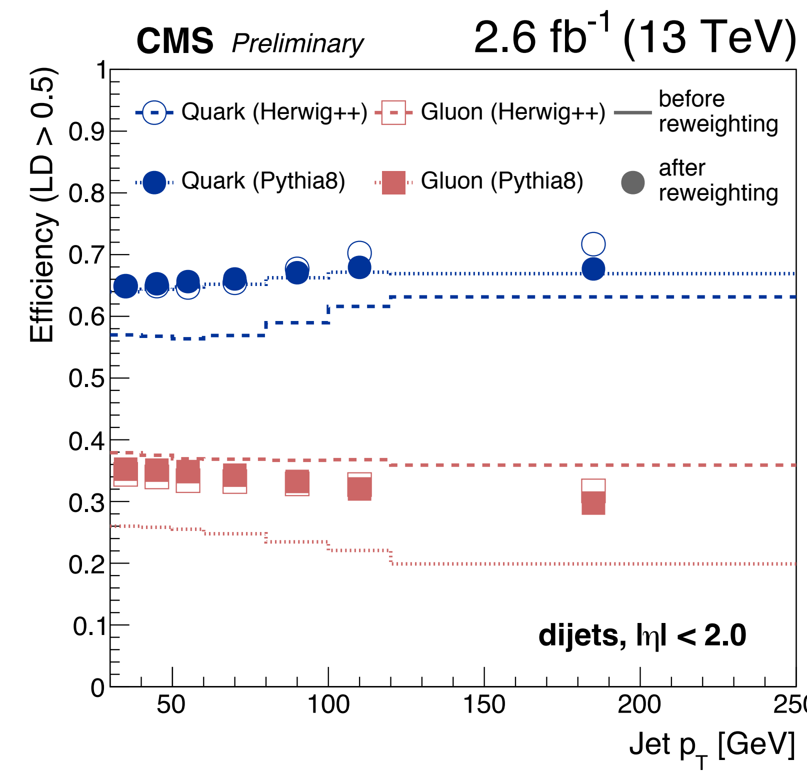


Nagy & Soper, 1711.02369

PS Generator Dependence

- Quark-gluon tagging: track width & multiplicity





ATLAS,1405.6583

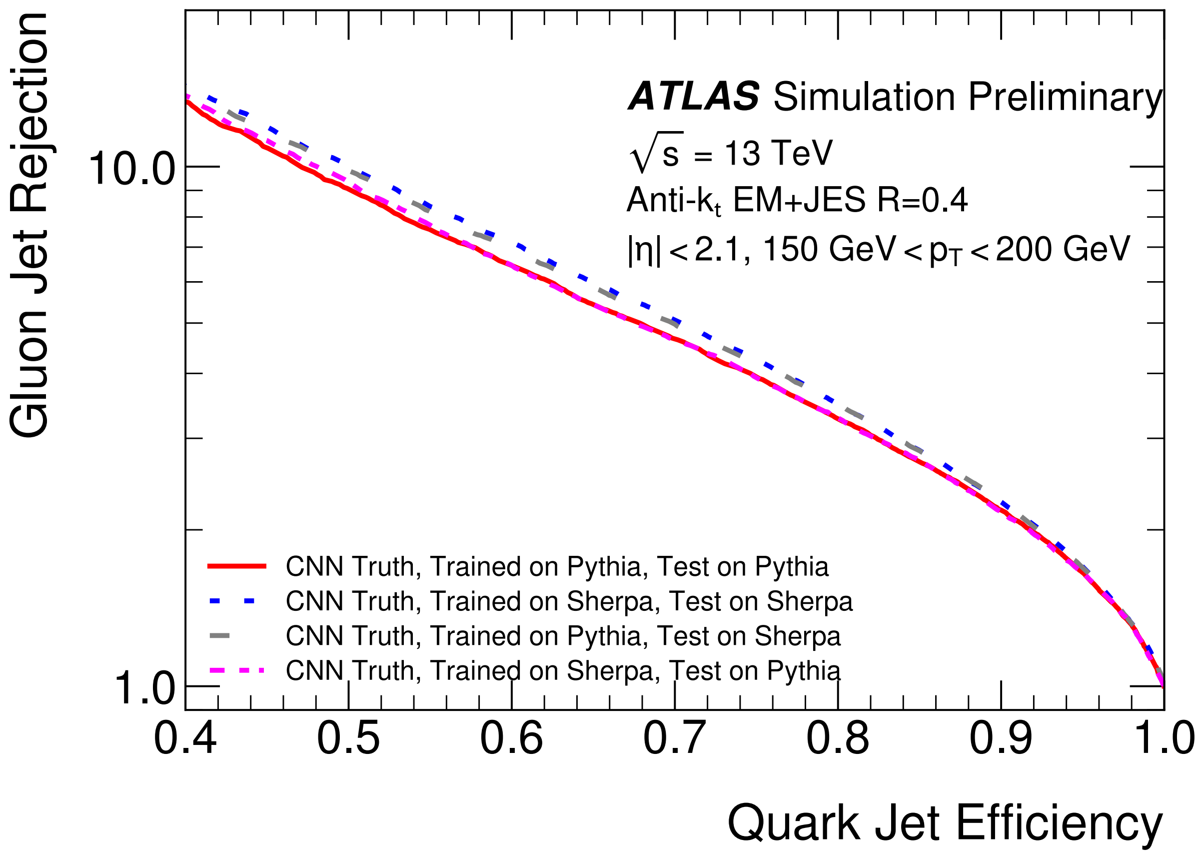
CMA-PAS-JME-16-003

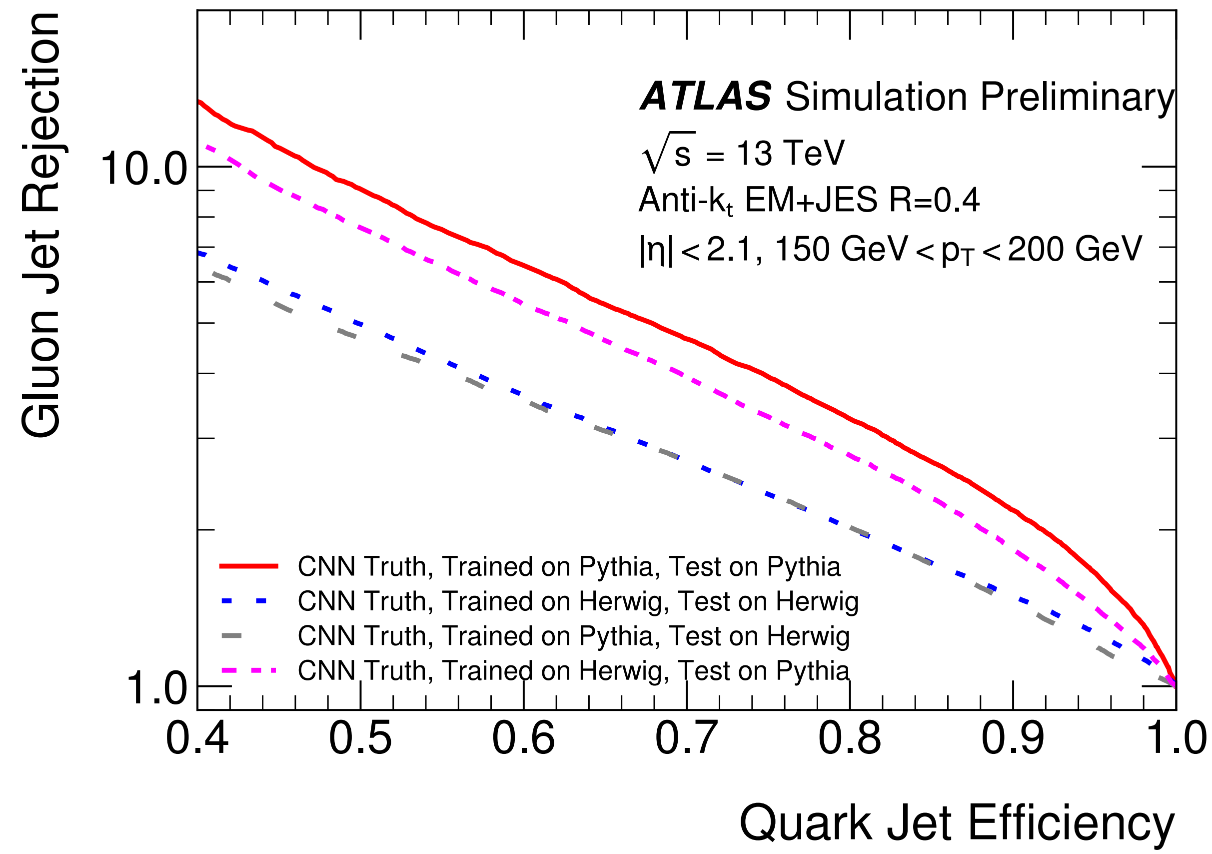
- Pythia good for quarks, not so good for gluons

- Herwig better for gluons

PS Generator Dependence

- Quark-gluon tagging: jet images

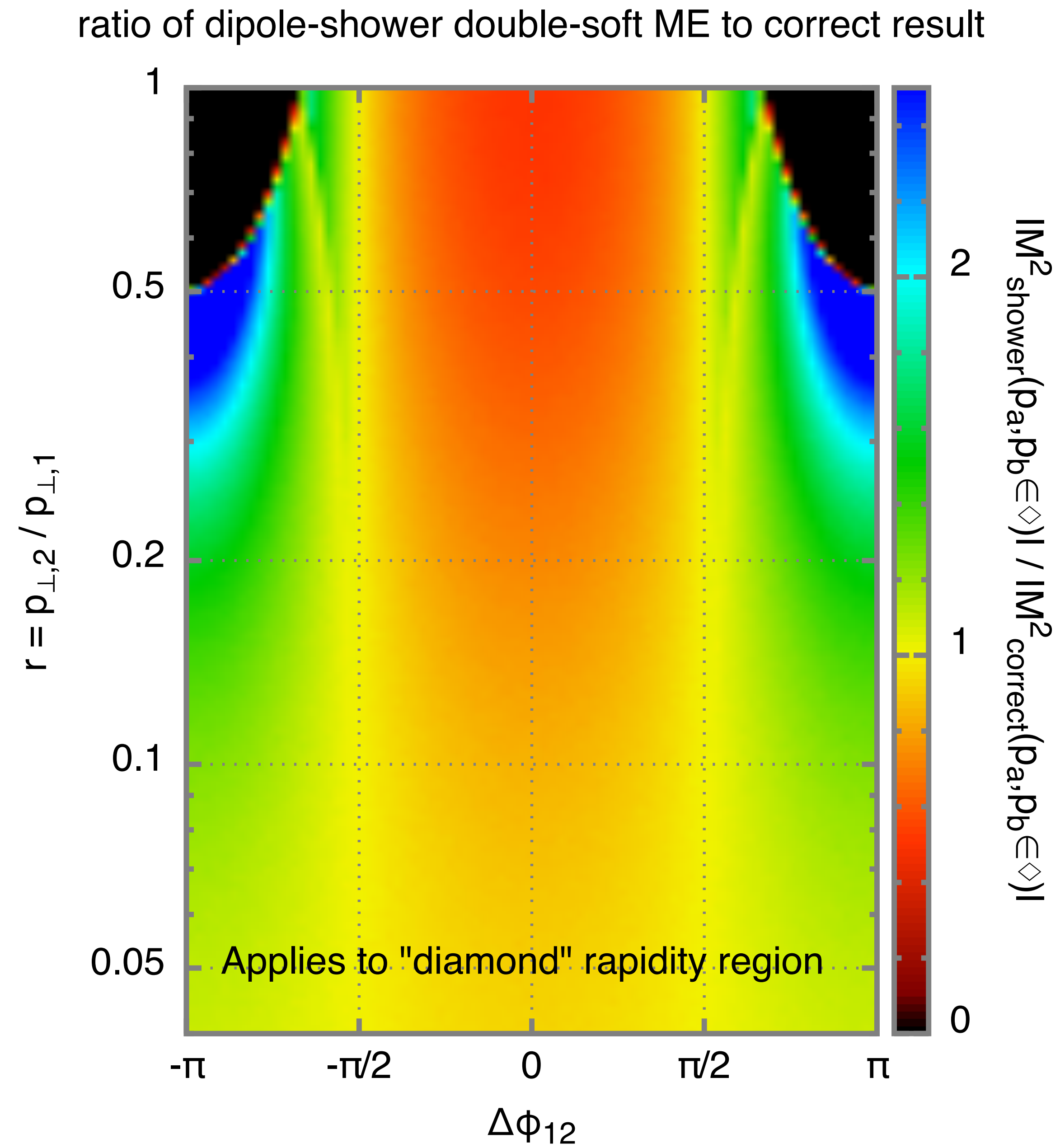




ATL-PHYS-PUB-2017-017

- Pythia, Sherpa similar, Herwig less

Dire Shower vs ME



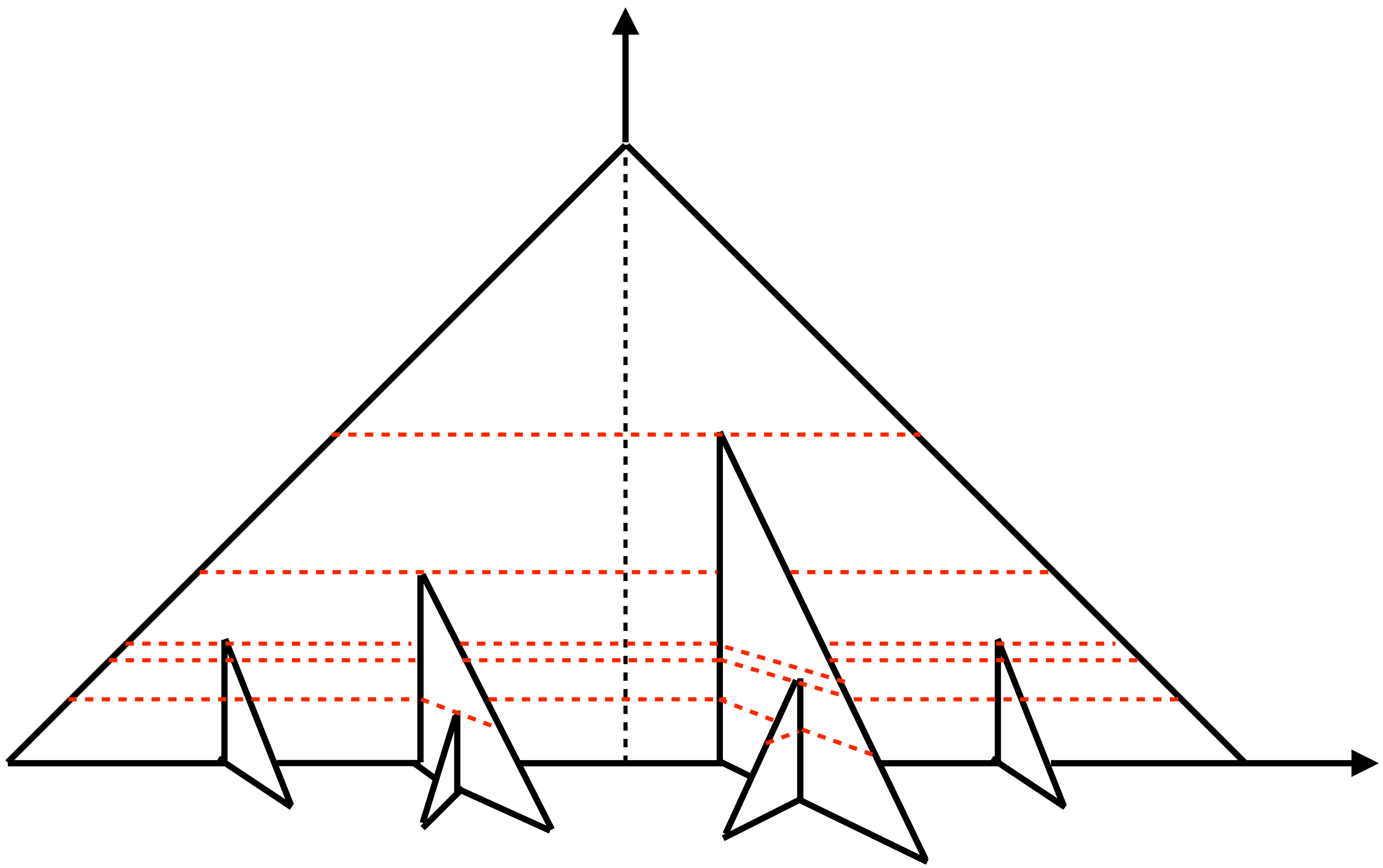
Dasgupta, Dreyer, Hamilton & Salam, 1805.09327

Dipole vs Parton Showers

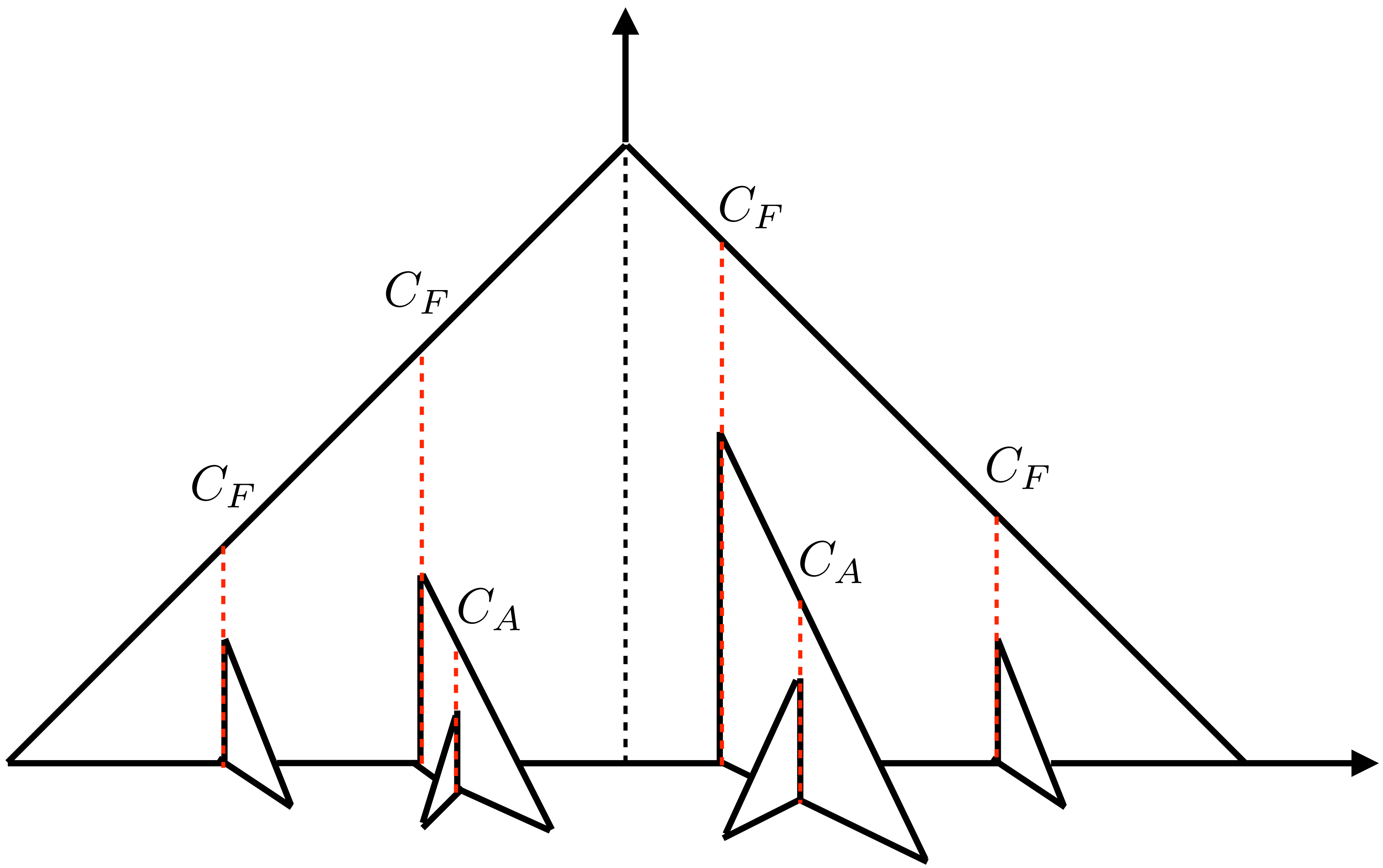
Parton vs Dipole Showers

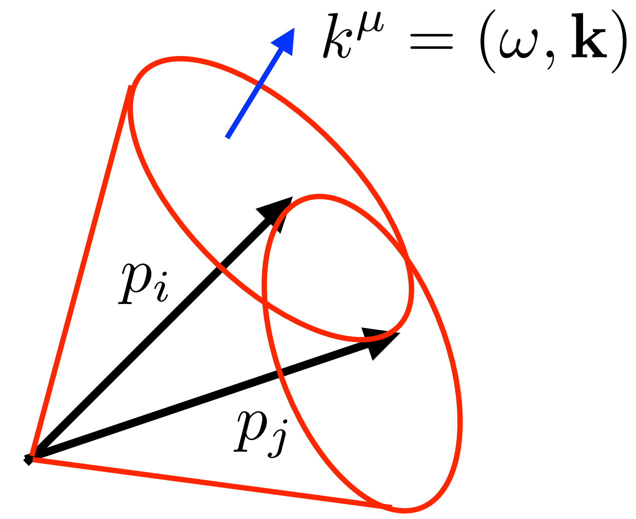
- Parton Shower
  - Simple 1-to-2 splittings: fewer recoil ambiguities
  - Colour structure simple at DL, NDL
  - Soft azimuthal correlations missing
- Dipole shower
  - 2-to-3 splittings mean more recoil ambiguities
  - Colour structure more difficult, even at DL
  - Azimuthal correlations included

k_t-ordered dipole shower

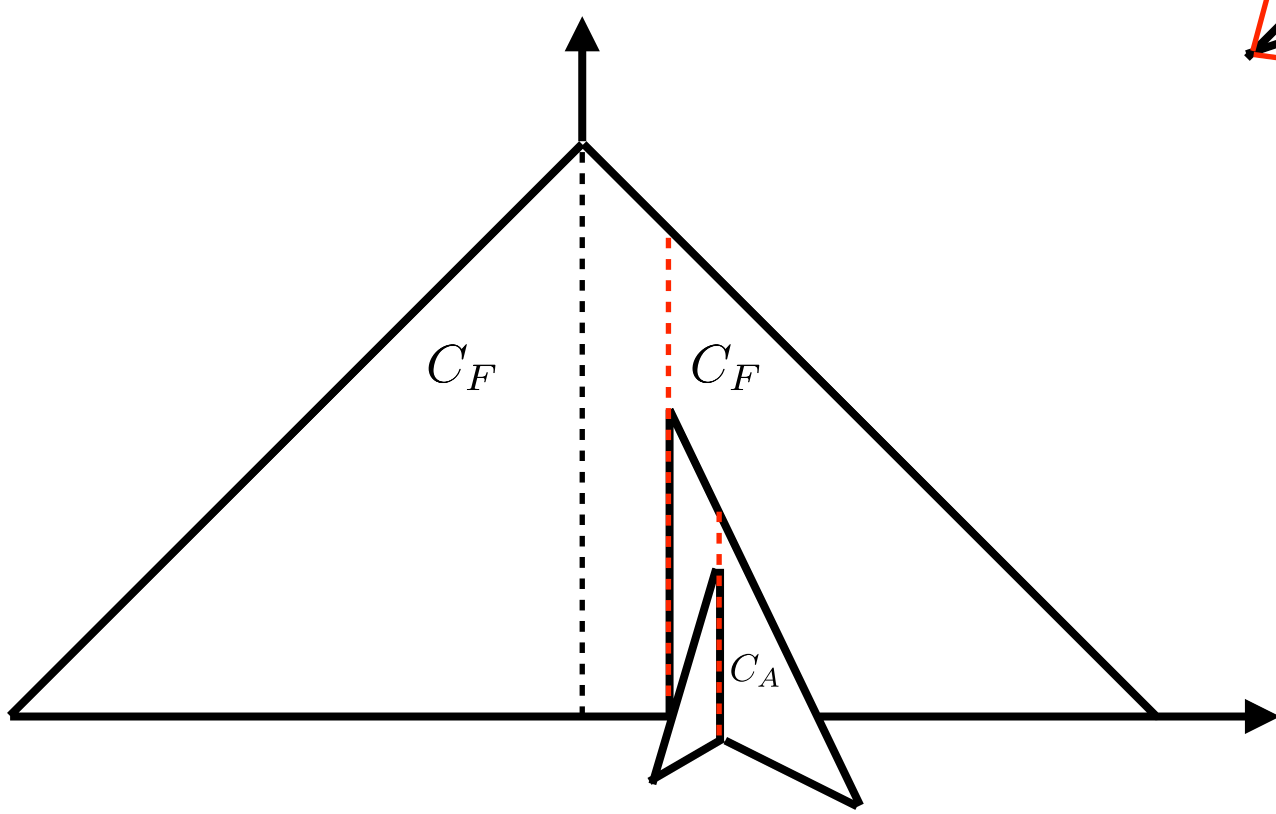


Angular-ordered parton shower



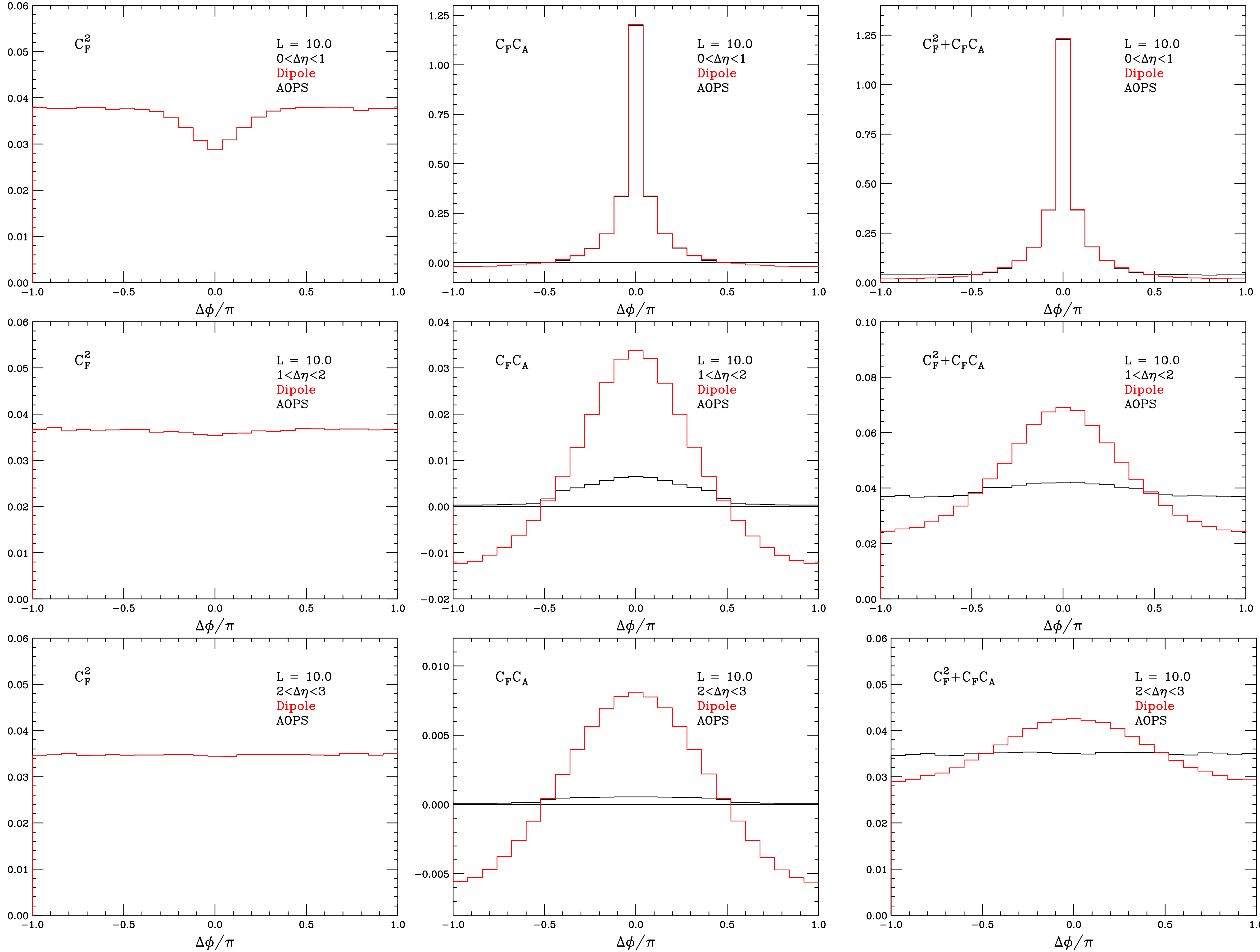


$$\int D_k^{ij} \frac{d\phi_k}{2\pi} = \frac{1}{\omega^2} \left[\frac{\Theta(\theta_{ij} > \theta_{ik})}{1 - \cos\theta_{ik}} + \frac{\Theta(\theta_{ij} > \theta_{jk})}{1 - \cos\theta_{jk}} \right]$$

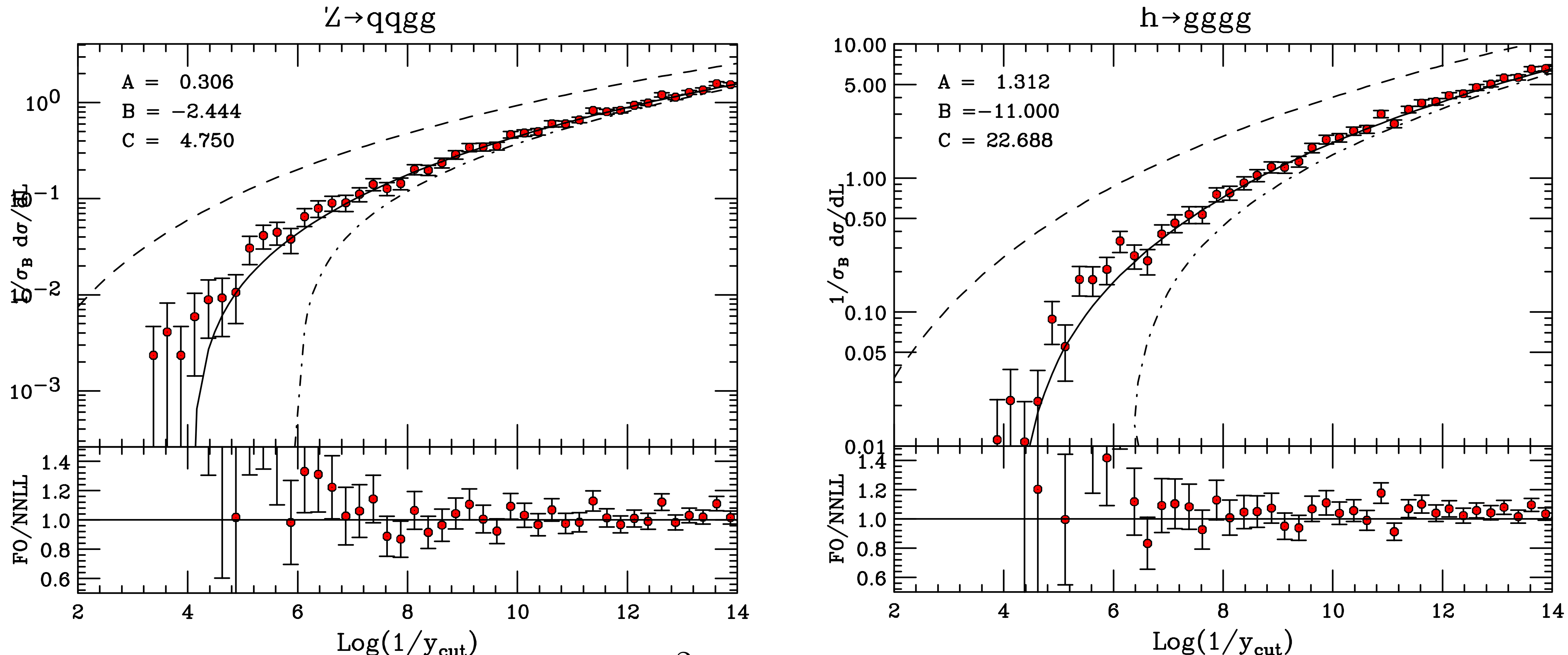


$$dP(q\bar{q}gg) \simeq C_F C_A \left(\frac{\alpha_s}{\pi} \right)^2 \frac{\Theta(\theta_{q\bar{q}} > \theta_{q1})}{1 - \cos\theta_{q1}} \frac{\Theta(\theta_{q1} > \theta_{12})}{1 - \cos\theta_{12}} \frac{d\omega_1}{\omega_1} \frac{d\omega_2}{\omega_2} d\cos\theta_1 \, d\cos\theta_2$$

- Some azimuthal correlations lost through averaging



C_F^2
$C_F C_A$
$C_F^2+C_F C_A$
L = 10.0
0<Δη<1
1<Δη<2
2<Δη<3
Dipole
AOPS
Δφ/π



$$P(q\bar{q}gg) \simeq \left(\frac{\alpha_s}{\pi}\right)^2 \left(AL^4 + BL^3 + CL^2\right)$$

$$\frac{dP}{dL} \simeq \left(\frac{\alpha_s}{\pi}\right)^2 \left(4AL^3 + 3BL^2 + 2CL\right)$$

- AOPS vs Exact LOME (Madgraph)
  - A=collinear-soft, B=collinear-nonsoft
  - C not reliable (but improves agreement)

NLO Showers

- Höche, & Prestel, 1705.00742, & Krauss1705.00982
  - Include NLO terms in 1→2 (q→q' differential)
- Dulat, Höche & Prestel, 1805.03757
  - Differential double soft vs CMW

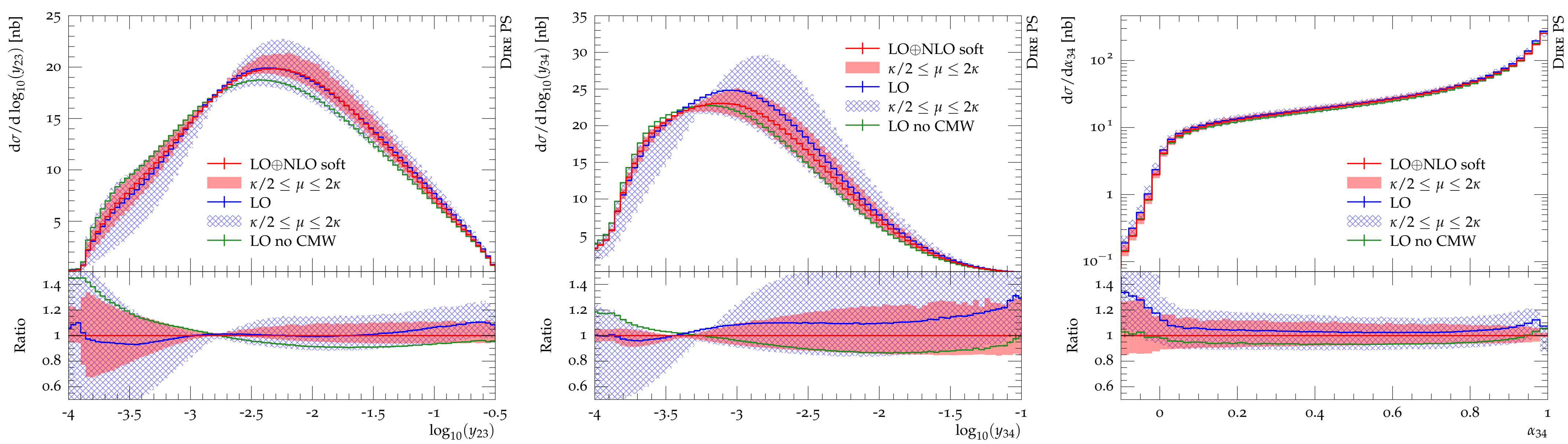
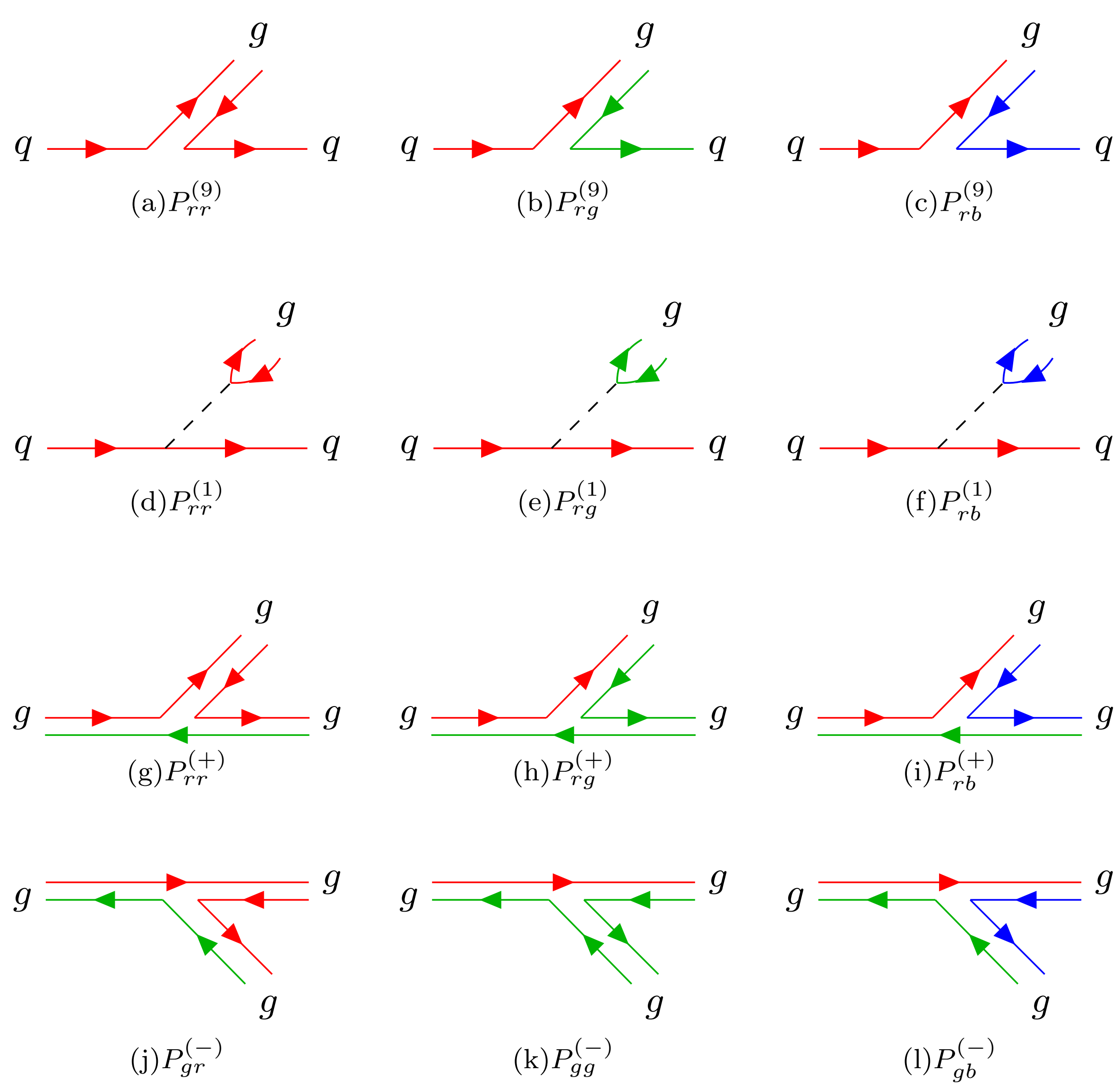


FIG. 8. Scale variations in the leading-order and next-to-leading order (soft) parton shower simulation of $e^+e^- \to$hadrons at LEP I energies at parton level. We compare to both the plain leading-order predictions (green) and the result in the CMW scheme (blue).

Subleading Colour

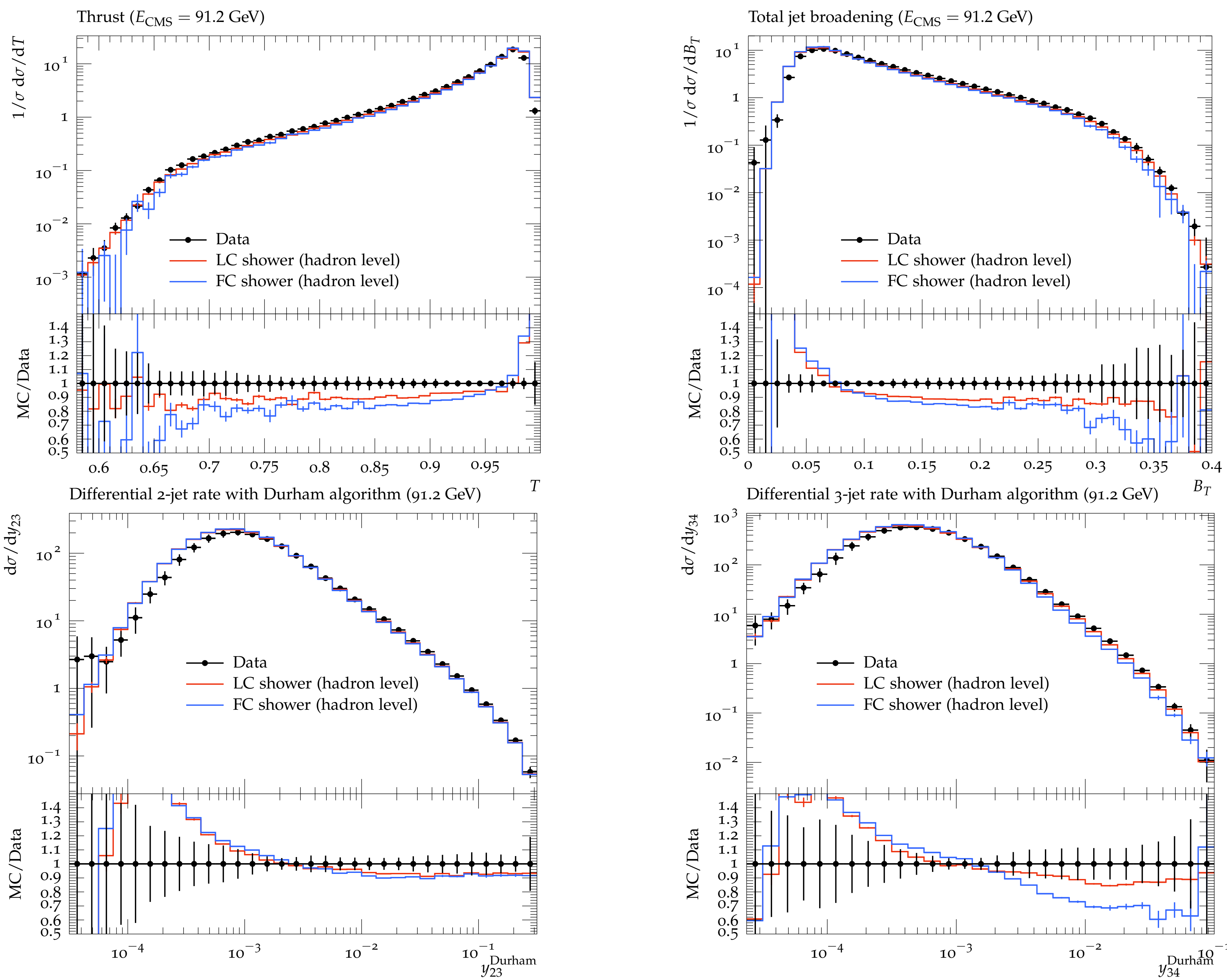
- Isaacson & Prestel, 1806.10102 use colour-flow basis



- Negative weights: MC efficiency? Looks OK …

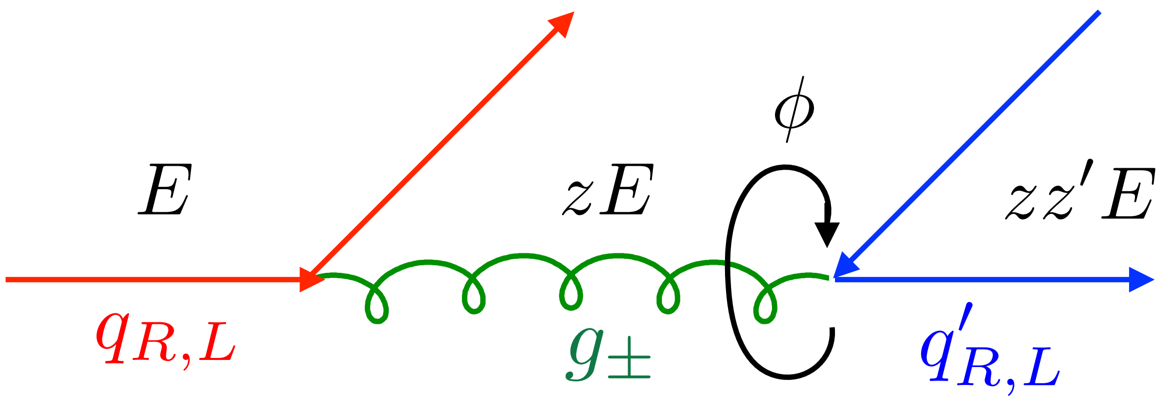
Subleading Colour

- Isaacson & Prestel, 1806.10102



Spin Effects in Showers

Azimuthal Correlations



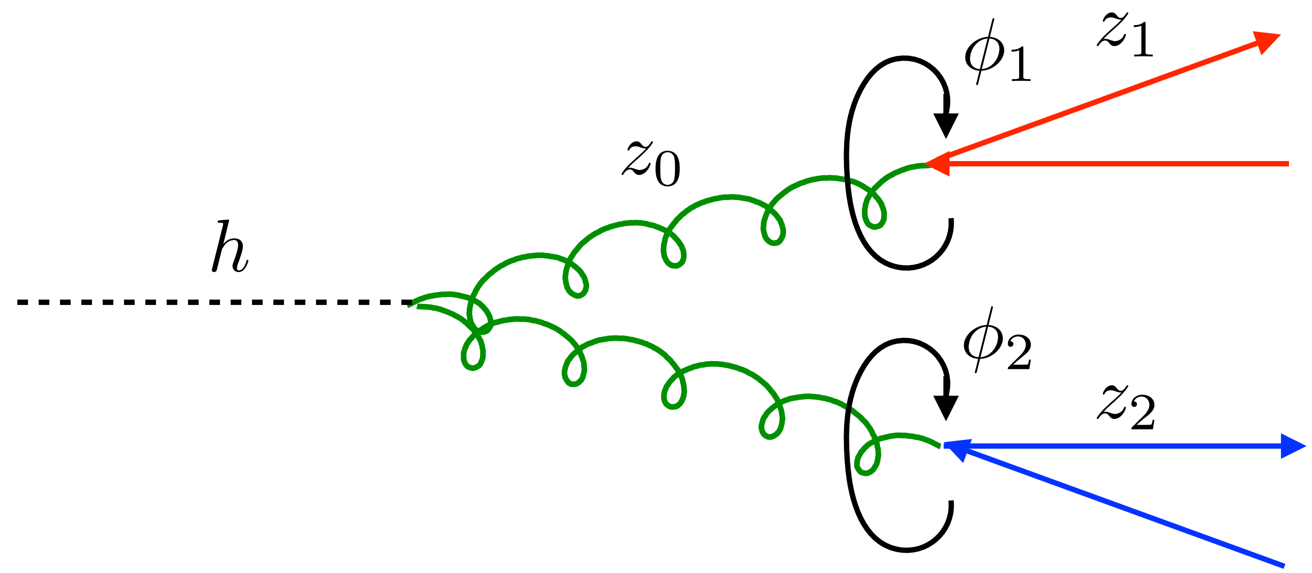
h_1	h_2	h_3	$\mathcal{M}_{h_1h_2h_3}$
R	+	R	$z^{-\frac{1}{2}}\mathrm{e}^{i\phi}z'$
R	+	L	$z^{-\frac{1}{2}}\mathrm{e}^{i\phi}(1-z')$
R	-	R	$-(1-z)z^{-\frac{1}{2}}\mathrm{e}^{-i\phi}(1-z')$
R	-	L	$-(1-z)z^{-\frac{1}{2}}\mathrm{e}^{-i\phi}z'$

$$|\mathcal{M}_{R+R}+\mathcal{M}_{R-R}|^2 = \frac{1}{z}\left[z'^2+(1-z)^2(1-z')^2 - 2(1-z)z'(1-z')\cos 2\phi\right]$$

$$|\mathcal{M}_{R+L}+\mathcal{M}_{R-L}|^2 = \frac{1}{z}\left[(1-z')^2+(1-z)^2z'^2 - 2(1-z)z'(1-z')\cos 2\phi\right]$$

$$\sum_{h_3}|\sum_{h_2}\mathcal{M}_{h_1h_2h_3}|^2 = \frac{1+(1-z)^2}{z}[z'^2+(1-z')^2] - 4\frac{(1-z)}{z}z'(1-z')\cos 2\phi$$

EPR Correlations

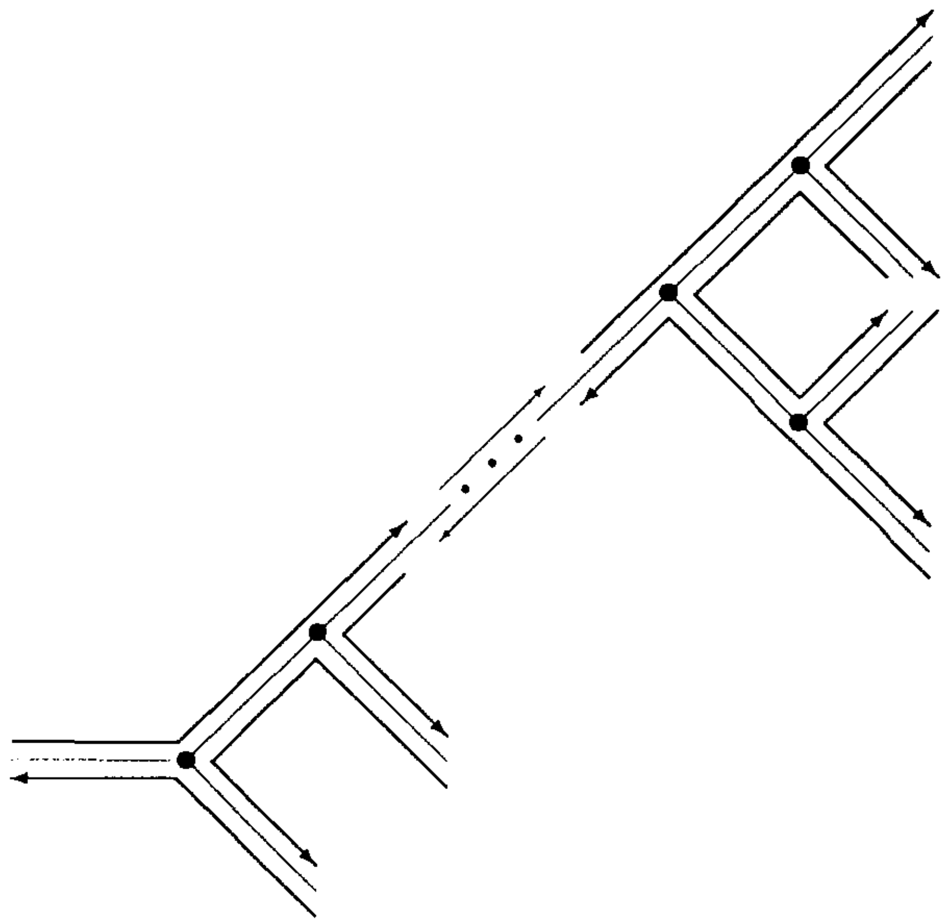


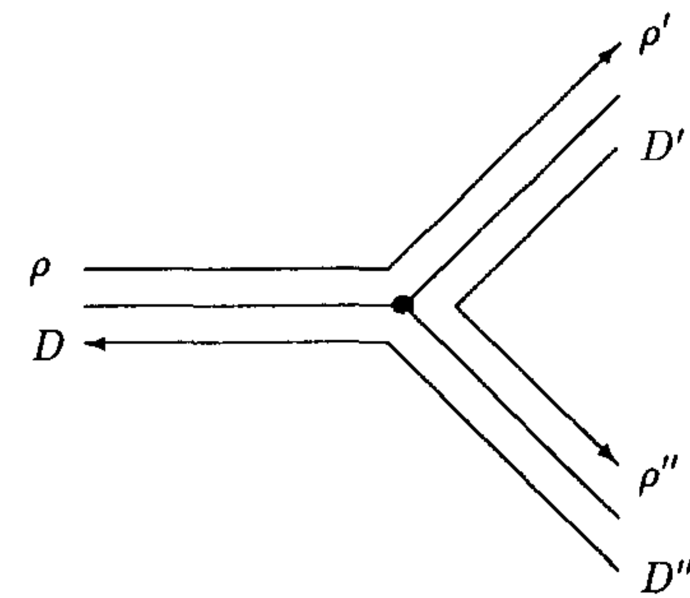
$$P(h \to q\bar{q}q\bar{q}) \propto 1 + a(z_1)a(z_2)\cos 2(\phi_1 - \phi_2)$$

- where $a(z) = \dfrac{2z(1-z)}{1-2z(1-z)}$
- Fully included in Herwig (CKR method)

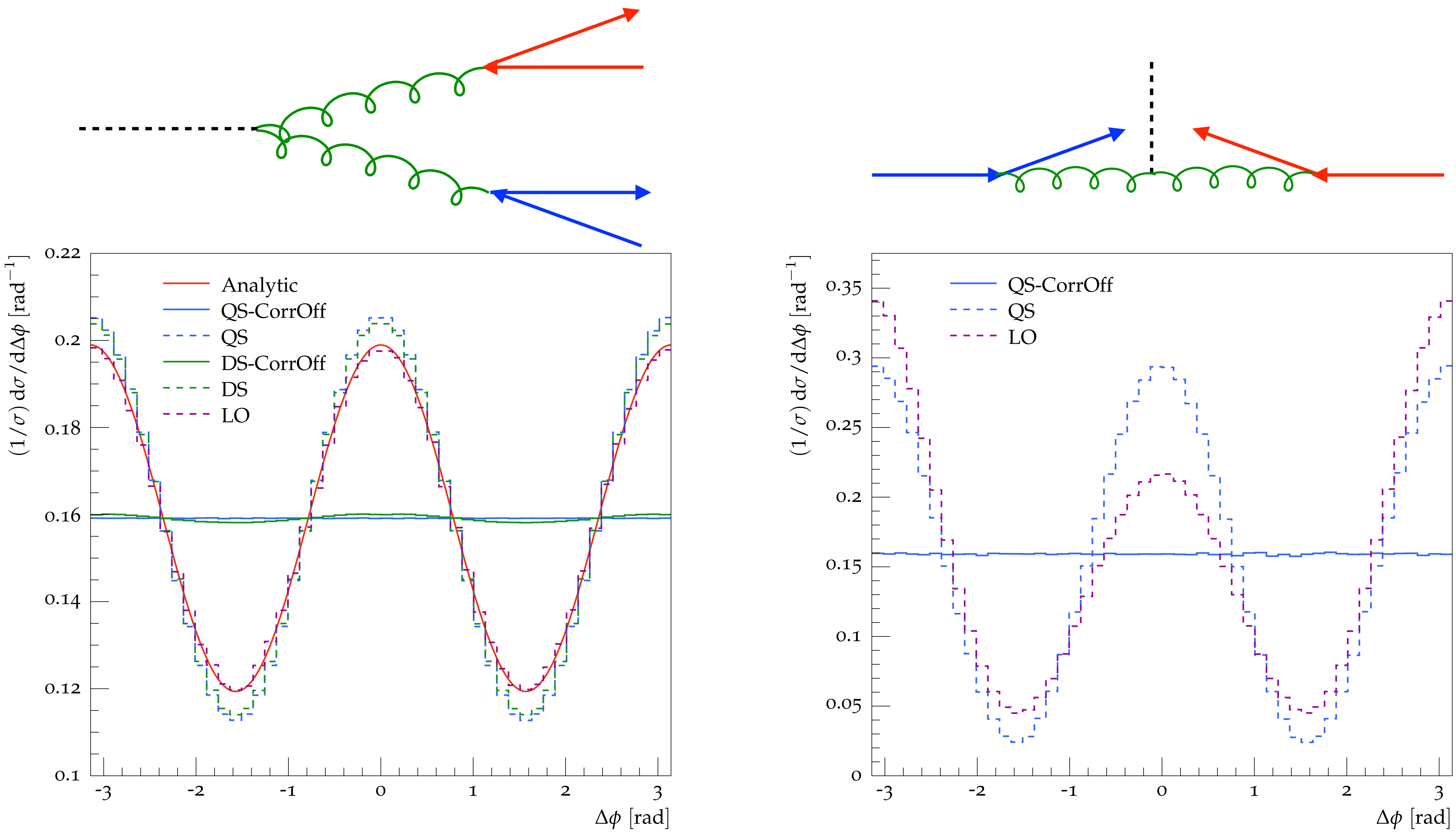
Collins, NPB304(1988)794
Knowles,CPC58(1990)271
Richardson, JHEP111(2001)029

CKR Method





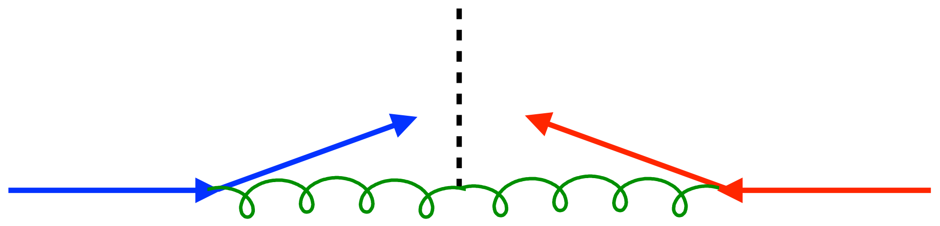
- Backtracking essential for linear algorithm

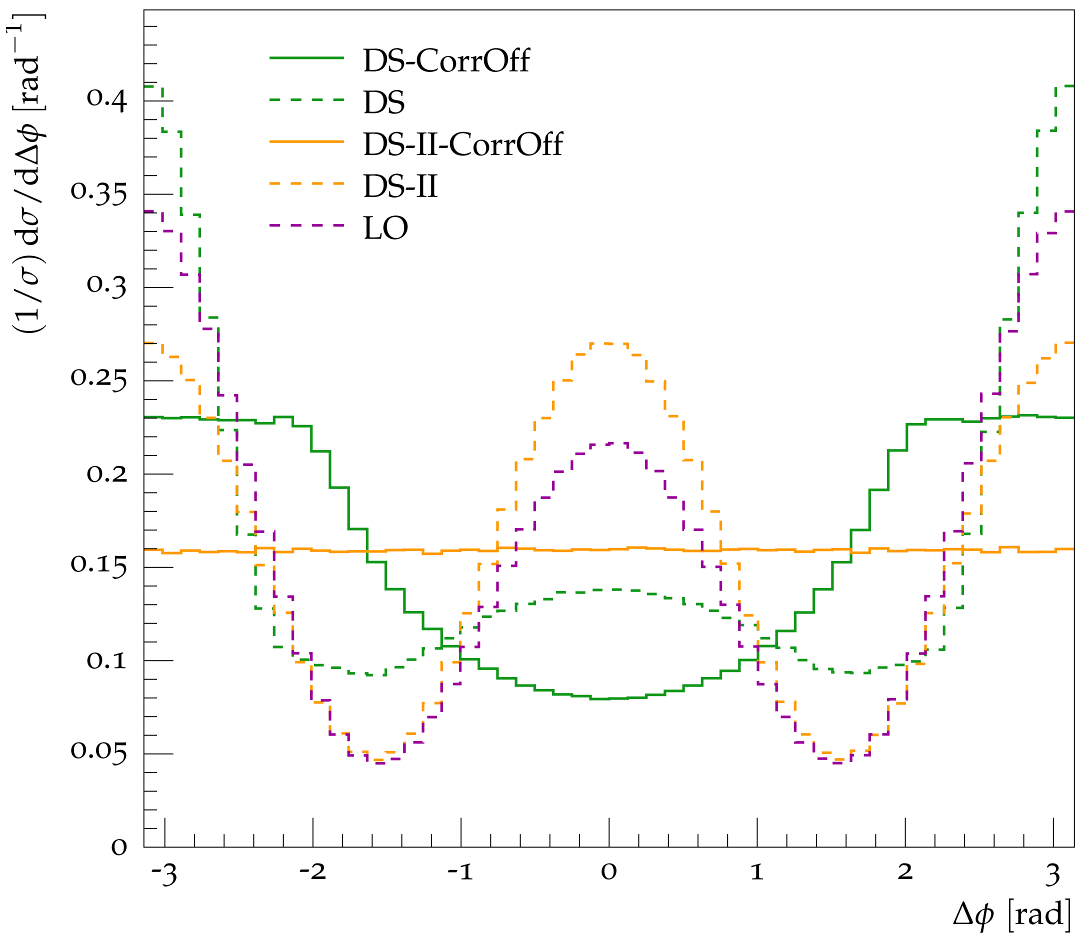


- LO=MadGraph5, QS=Herwig7AO, DS=Herwig7DS

Richardson & Webster, 1807.01955

- Different dipole options illustrate recoil ambiguity

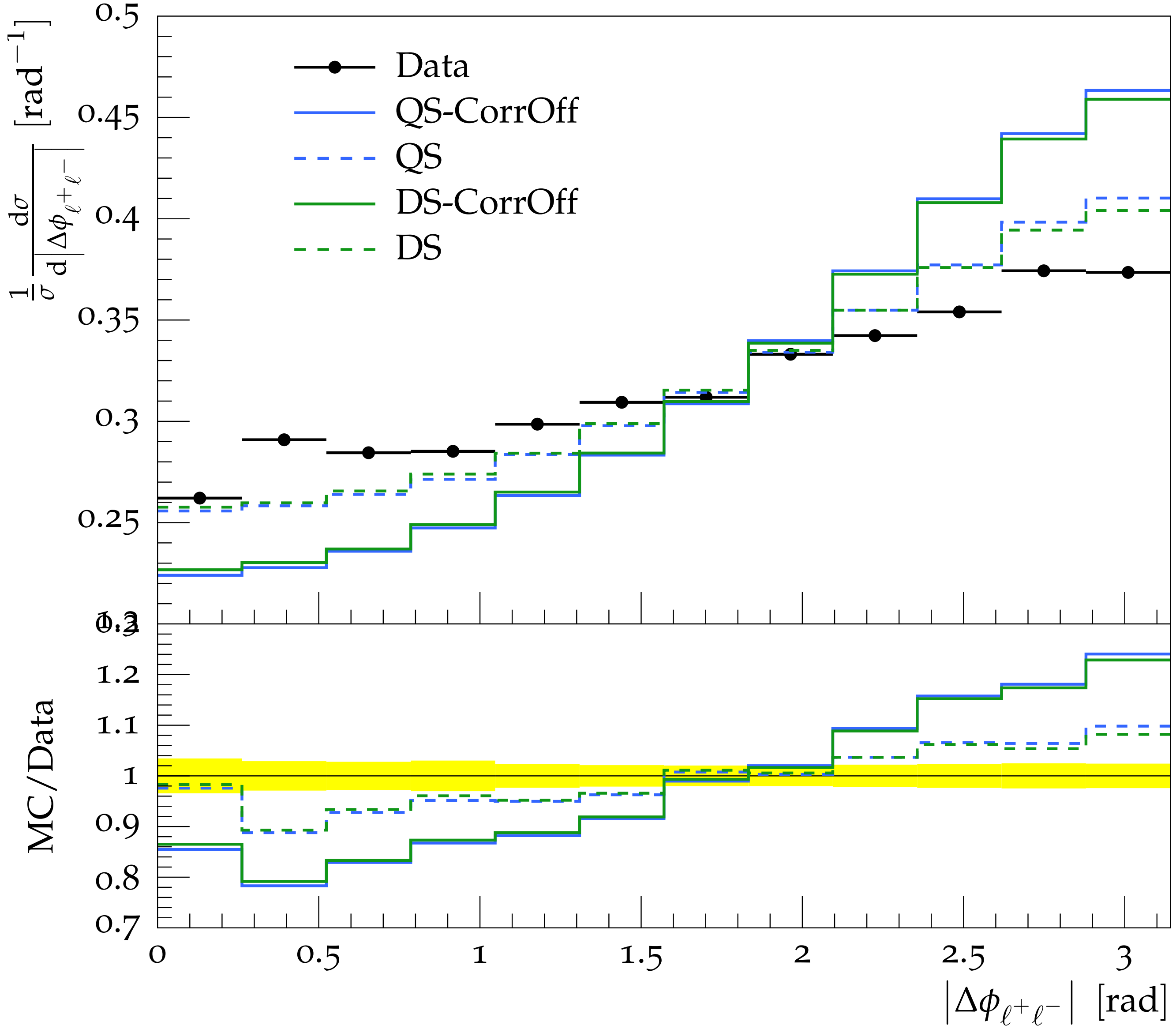




Richardson & Webster, 1807.01955

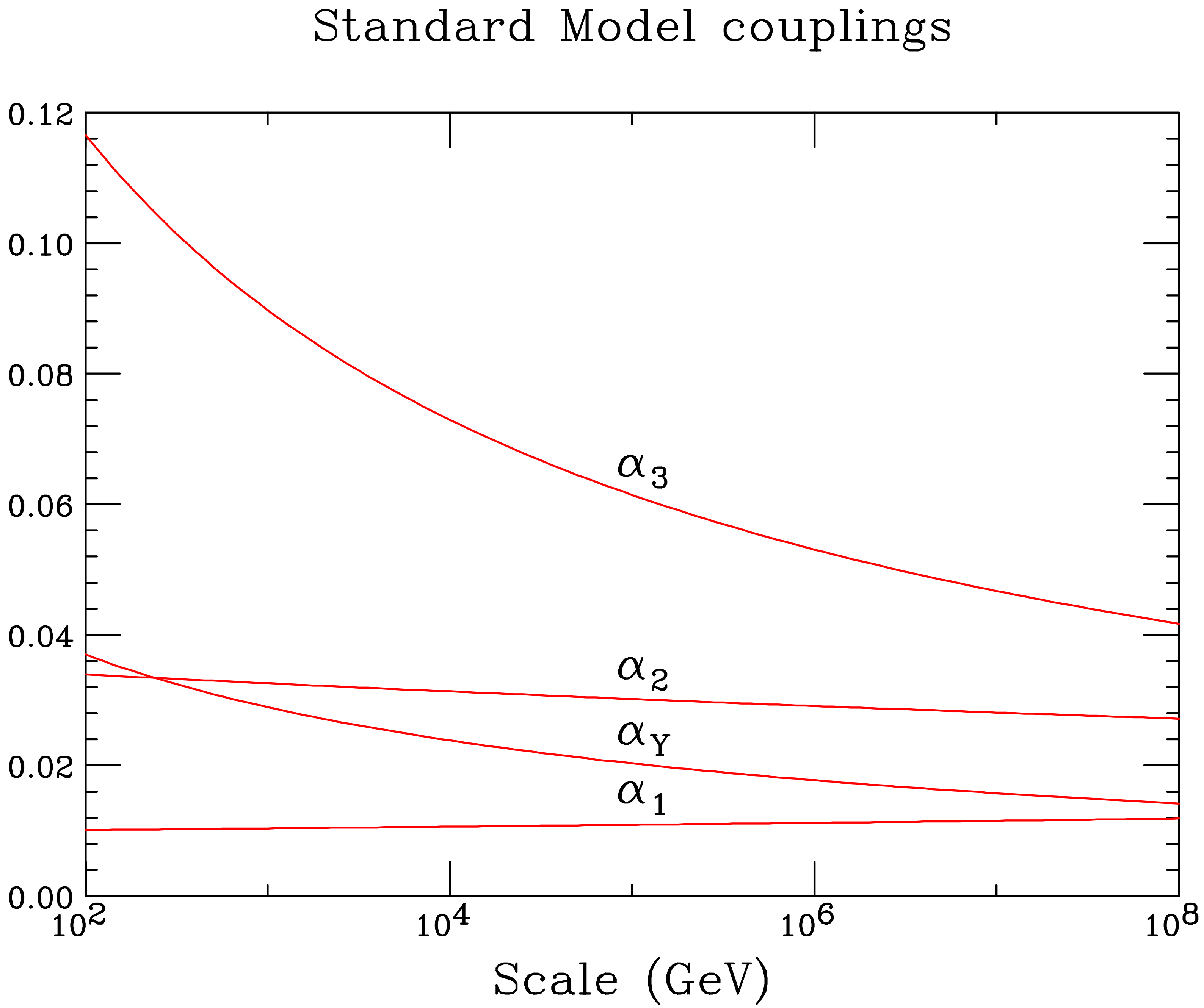
- Dilepton correlation in top decays

$$pp \to t\bar{t} \to b\bar{b}\,\ell^+\ell^-\nu_\ell\bar{\nu}_\ell$$



Richardson & Webster, 1807.01955

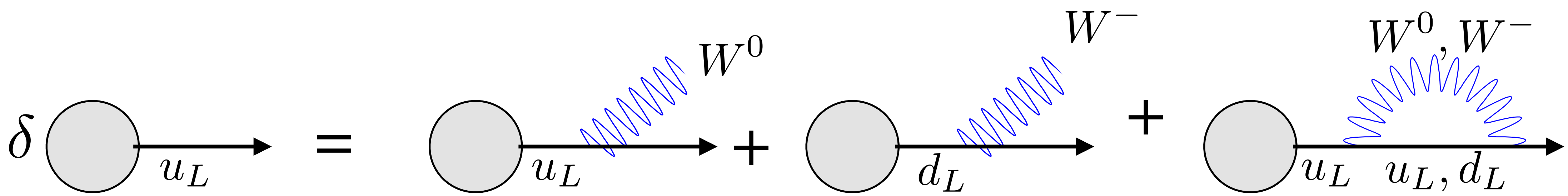
Electroweak Showering



- Far above EW scale, at $q \gg m_W$, we have approximately unbroken SU(3)xSU(2)xU(1)

- Corrections ~ m_W/q

- Real-virtual emission mismatch leads to double logarithms of q/m_W



$$q\frac{\partial}{\partial q}u_L(x,q) = \frac{\alpha_2}{\pi}C_F\int_0^{1-m_W/q}\frac{dz}{z}P_{ff}(z)\left[\frac{1}{3}u_L(x/z,q)+\frac{2}{3}d_L(x/z,q)-zu_L(x,q)\right]$$

$$q\frac{\partial}{\partial q}d_L(x,q) = \frac{\alpha_2}{\pi}C_F\int_0^{1-m_W/q}\frac{dz}{z}P_{ff}(z)\left[\frac{1}{3}d_L(x/z,q)+\frac{2}{3}u_L(x/z,q)-zd_L(x,q)\right]$$

- Define $Q^{\pm} = \frac{1}{2}(u_L \pm d_L)$

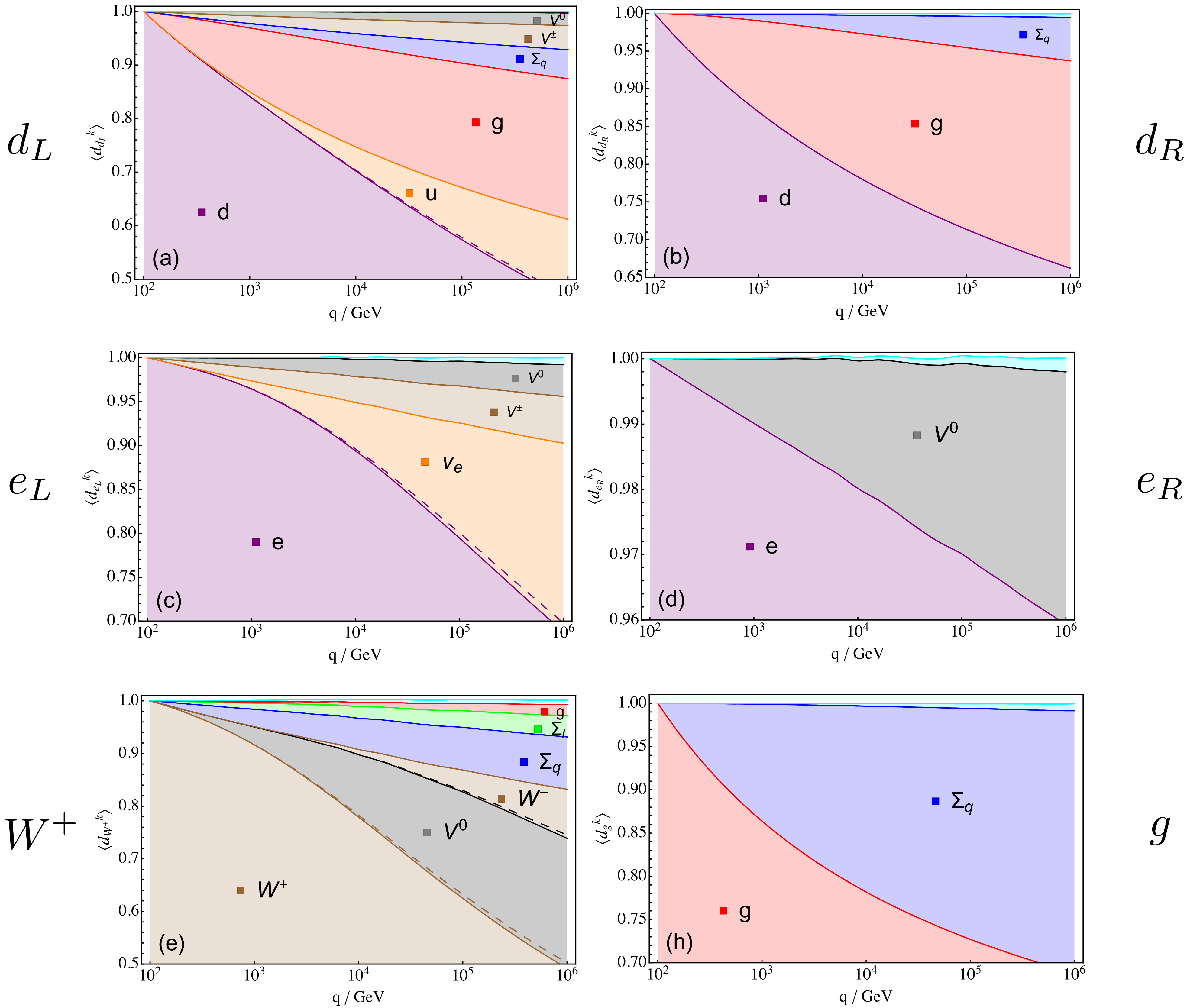
$$q\frac{\partial}{\partial q}Q^+(x,q) = \frac{\alpha_2}{\pi}C_F\int_0^{1-m_W/q}\frac{dz}{z}P_{ff}(z)\left[Q^+(x/z,q)-zQ^+(x,q)\right]$$

$$q\frac{\partial}{\partial q}Q^-(x,q) = -\frac{\alpha_2}{\pi}C_F\int_0^{1-m_W/q}\frac{dz}{z}P_{ff}(z)\left[\frac{1}{3}Q^-(x/z,q)+zQ^-(x,q)\right]$$

- Q^+ has DGLAP (single-log) evolution

- Q^- has double-log damping (asymptotic symmetry)

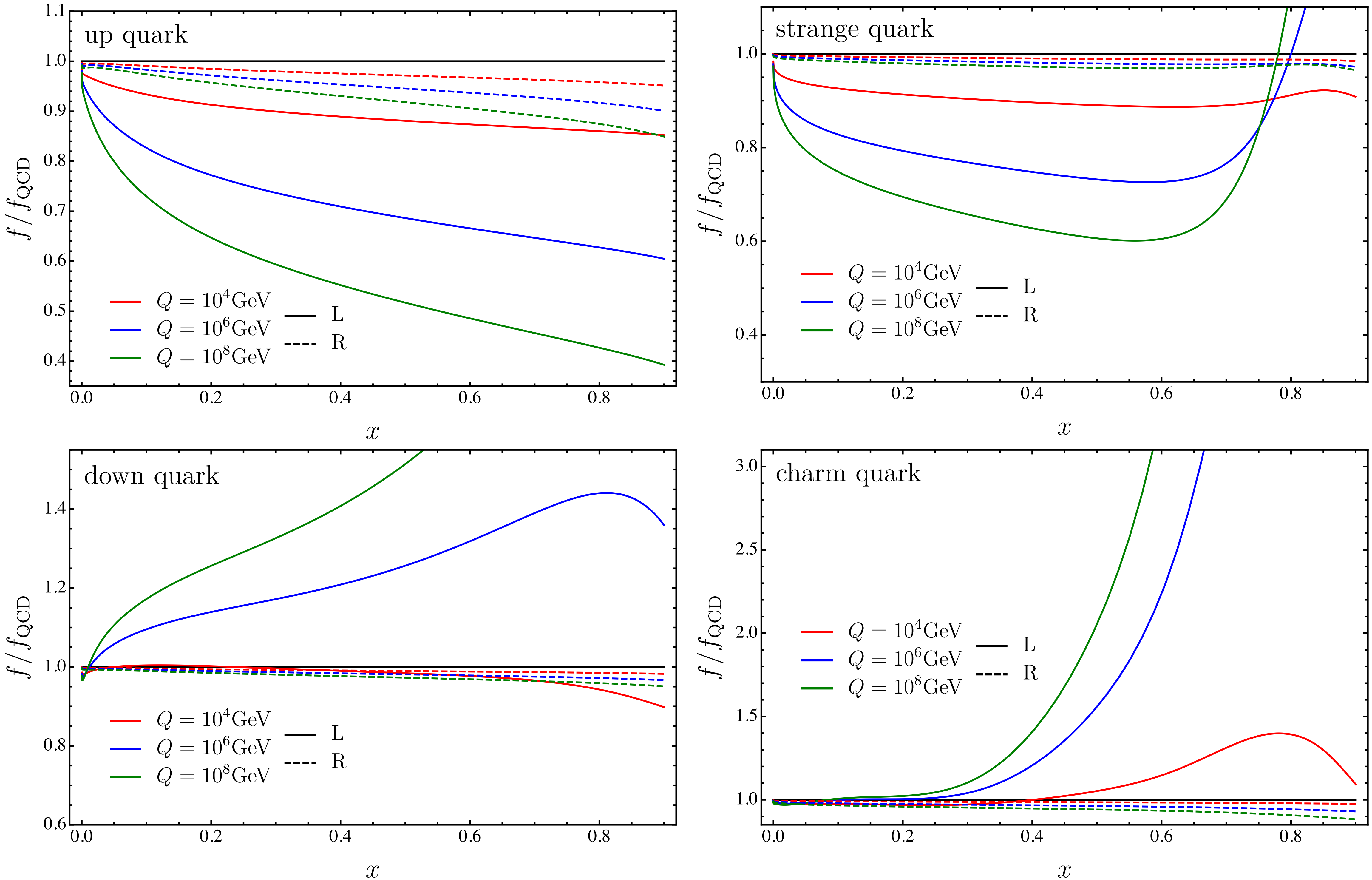
Momentum fractions in jets



Bauer, Provasoli, BW, 1808.08831

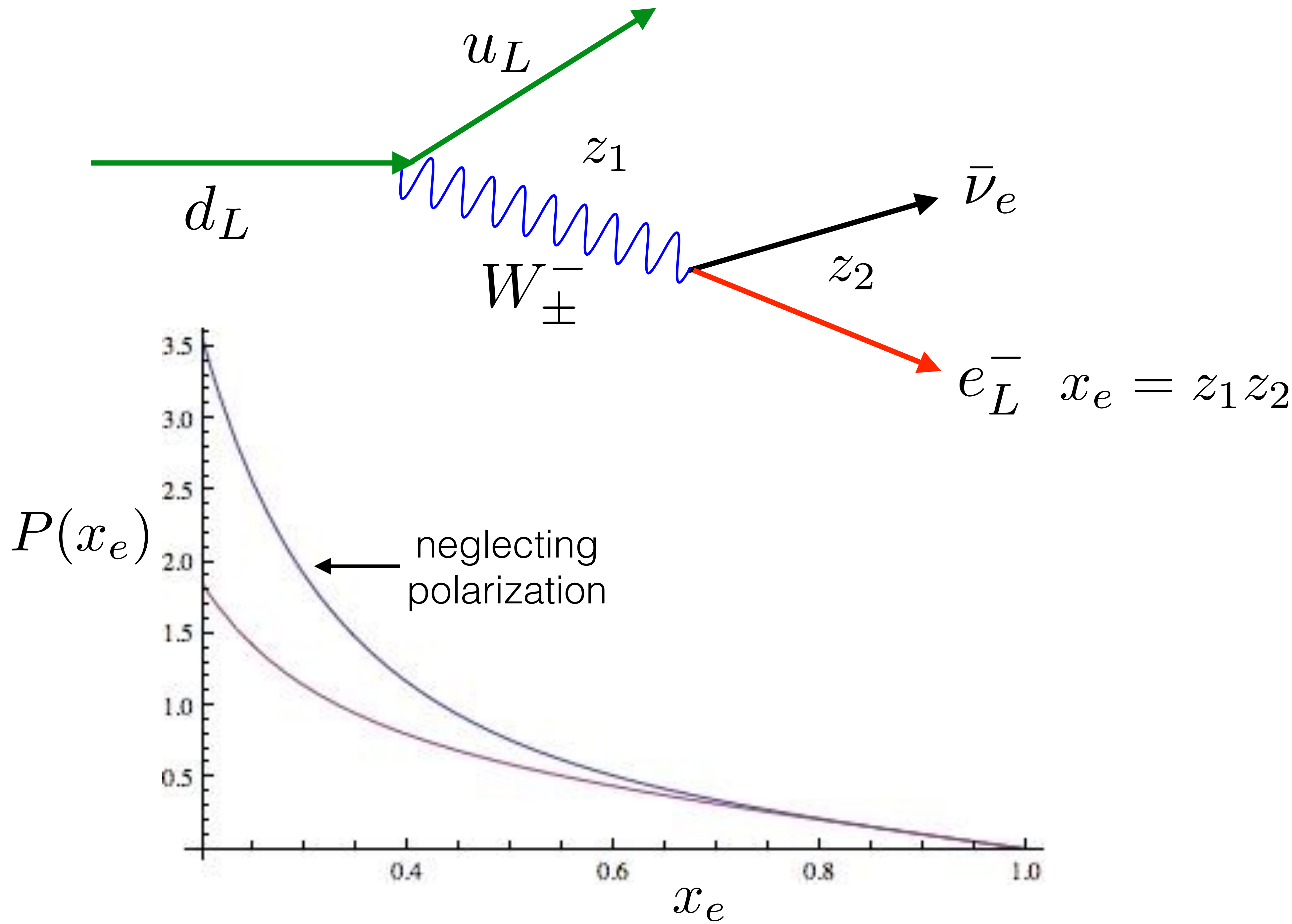
- Similarly in initial-state showering (PDF evolution)

  - u_L-d_L (& s_L-c_L) has double-log damping



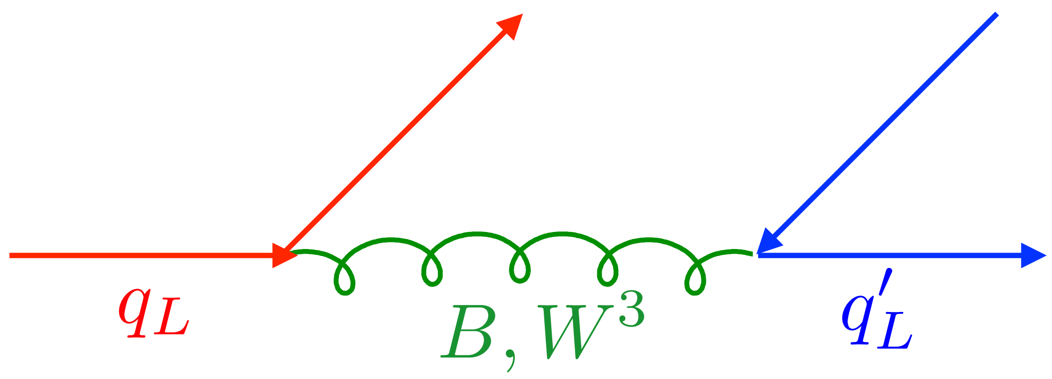
Bauer, Ferland, BW, 1703.08562

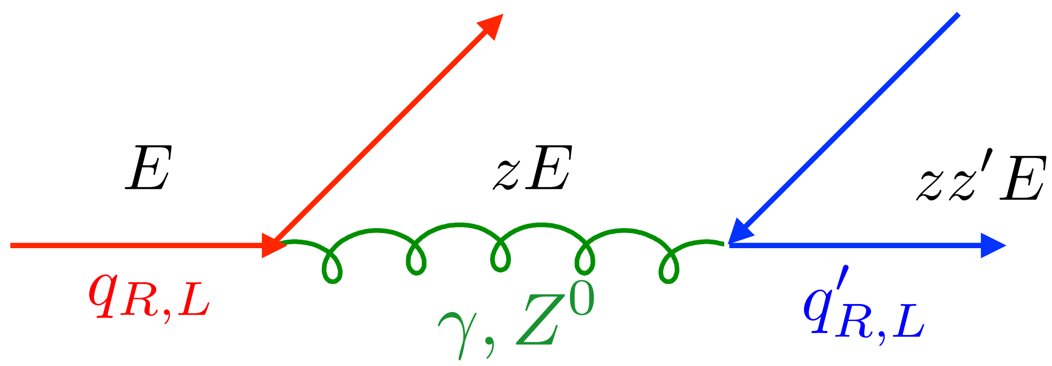
- Parity violation implies large polarisation effects
- Azimuthal integration cancels helicity interference (could be handled by CKR method)



Mixed State Showering

- Mixed states have different couplings





Unbroken phase

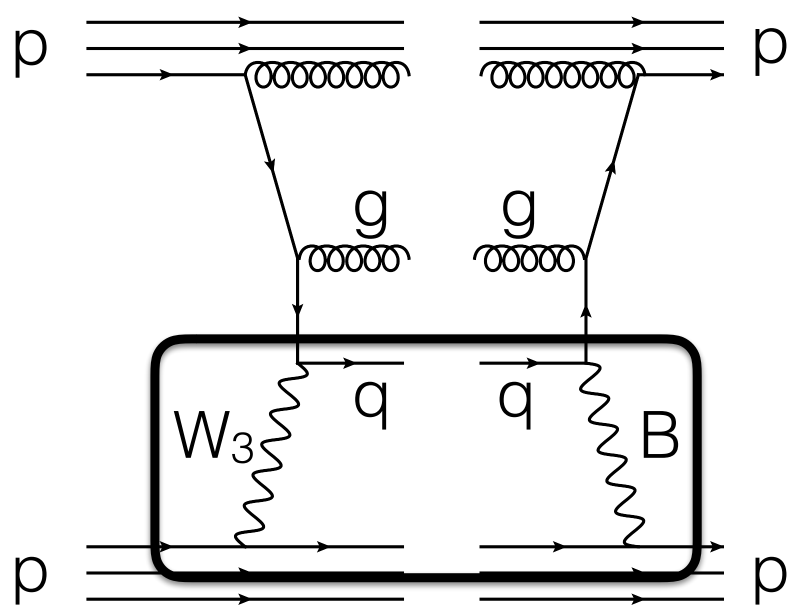
Broken phase

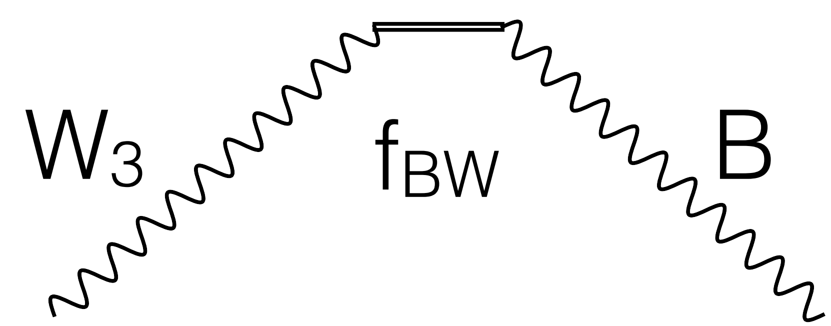
- Is there an analog of CKR?

Chen, Han, Tweedie, 1611.00788

Mixed U(1)xSU(2) PDF

$$f_{BW}(x) = \frac{2}{\bar{n}\cdot p}\int\frac{dy}{2\pi}\, e^{-i\,2x\bar{n}\cdot p\, y}\, \bar{n}^{\mu}\bar{n}_{\nu}\langle p|\, B_{\mu\lambda}(y) W_3^{\lambda\nu}(-y)|p\rangle\ +\text{h.c.}$$



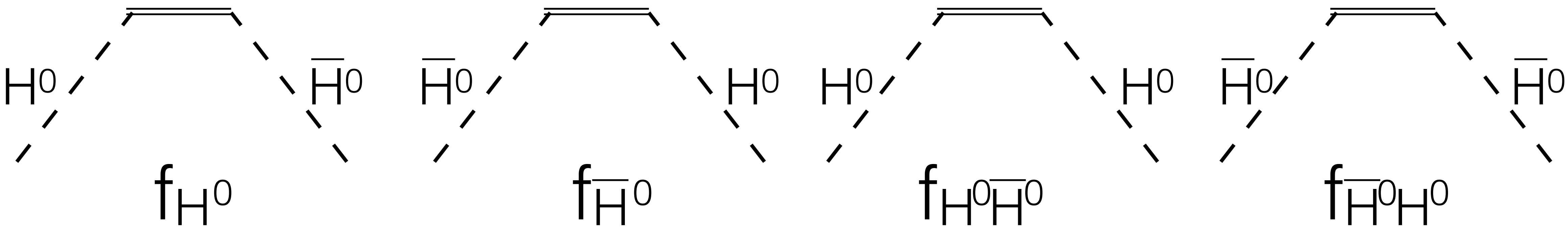


$$\alpha_M = \sqrt{\alpha_1\alpha_2}$$

- Left-handed quarks have isospin and hypercharge, so they can generate f_{BW} ($I^{CP} = 1^{+}$)

- This means in broken basis we have f_{γ}, f_Z and $f_{\gamma Z}$

Mixed Higgs PDF



$$H^0 = \frac{1}{\sqrt{2}}(h - iZ_L)\,, \quad \bar{H}^0 = \frac{1}{\sqrt{2}}(h + iZ_L)$$

$$h = \frac{1}{\sqrt{2}}\left(H^0 + \bar{H}^0\right), \quad Z_L = \frac{i}{\sqrt{2}}\left(H^0 - \bar{H}^0\right)$$

$$f_{HH}^{1\pm} = \frac{1}{2}\left(f_{H^0\bar{H}^0} \pm f_{\bar{H}^0H^0}\right)$$

- f_{HH}^{1+} distinguishes between Higgs and Z_L

$$f_{Z_L} = f_H^{0+} - f_H^{1+} - f_{HH}^{1+}\,,$$
$$f_h = f_H^{0+} - f_H^{1+} + f_{HH}^{1+}\,.$$

Amplitude-level PS

$$
\begin{aligned}
\mathbf{P}_{ij} = {} & \delta_{s_j,\frac{1}{2}}\delta_j^{\text{final}}\left(\sqrt{\frac{\mathcal{P}_{qq}}{2\mathcal{C}_{\rm F}(1+z_i^2)}}\frac{1}{\langle q_i\tilde{p}_j\rangle}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i}) + \sqrt{\frac{z_i^2\mathcal{P}_{qq}}{2\mathcal{C}_{\rm F}(1+z_i^2)}}\frac{1}{[\tilde{p}_j q_i]}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i})\right.\\
& \left. + \sqrt{\frac{\mathcal{P}_{gq}}{2\mathcal{C}_{\rm F}(2-2z_i+z_i^2)}}\frac{1}{\langle \tilde{p}_j q_i\rangle}\mathbb{W}^{ij}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i}) + \sqrt{\frac{(1-z_i)^2\mathcal{P}_{gq}}{2\mathcal{C}_{\rm F}(2-2z_i+z_i^2)}}\frac{1}{[q_i\tilde{p}_j]}\mathbb{W}^{ij}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i})\right)\\
& + \delta_{s_j,-\frac{1}{2}}\delta_j^{\text{final}}\left(\sqrt{\frac{\mathcal{P}_{qq}}{2\mathcal{C}_{\rm F}(1+z_i^2)}}\frac{1}{[\tilde{p}_j q_i]}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i}) + \sqrt{\frac{z_i^2\mathcal{P}_{qq}}{2\mathcal{C}_{\rm F}(1+z_i^2)}}\frac{1}{\langle q_i\tilde{p}_j\rangle}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i})\right.\\
& \left. + \sqrt{\frac{\mathcal{P}_{gq}}{2\mathcal{C}_{\rm F}(2-2z_i+z_i^2)}}\frac{1}{[q_i\tilde{p}_j]}\mathbb{W}^{ij}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i}) + \sqrt{\frac{(1-z_i)^2\mathcal{P}_{gq}}{2\mathcal{C}_{\rm F}(2-2z_i+z_i^2)}}\frac{1}{\langle\tilde{p}_j q_i\rangle}\mathbb{W}^{ij}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i})\right)\\
& + \delta_{s_j,1}\delta_j^{\text{final}}\left(\sqrt{\frac{(1-z_i)^2\mathcal{P}_{qg}}{2T_{\rm R}(1-2z_i(1-z_i))}}\frac{1}{[\tilde{p}_j q_i]}(\mathbb{W}^{ij}-\mathbb{1})(\mathbb{T}_j^q\otimes\mathbb{P}_j^1\mathbb{P}_j^2\mathbb{S}^{+\frac{1}{2}_i})\right.\\
& + \sqrt{\frac{z_i^2\mathcal{P}_{qg}}{2T_{\rm R}(1-2z_i(1-z_i))}}\frac{1}{[\tilde{p}_j q_i]}(\mathbb{W}^{ij}-\mathbb{1})(\mathbb{T}_j^q\otimes\mathbb{P}_j^2\mathbb{S}^{-\frac{1}{2}_i})\\
& + \sqrt{\frac{\mathcal{P}_{gg}}{2\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{\langle q_i\tilde{p}_j\rangle}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i})\\
& \left. + \sqrt{\frac{z_i^4\mathcal{P}_{gg}}{2\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{[q_i\tilde{p}_j]}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i}) + \sqrt{\frac{\mathcal{P}_{gg}(1-z_i)^4}{2\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{[\tilde{p}_j q_i]}(\mathbb{T}_j^g\otimes\mathbb{P}_j^1\mathbb{S}^{+1_i})\right)\\
& + \delta_{s_j,-1}\delta_j^{\text{final}}\left(\sqrt{\frac{(1-z_i)^2\mathcal{P}_{qg}}{2T_{\rm R}(1-2z_i(1-z_i))}}\frac{1}{\langle q_i\tilde{p}_j\rangle}(\mathbb{W}^{ij}-\mathbb{1})(\mathbb{T}_j^q\otimes\mathbb{P}_j^1\mathbb{P}_j^2\mathbb{S}^{-\frac{1}{2}_i})\right.\\
& + \sqrt{\frac{z_i^2\mathcal{P}_{qg}}{2T_{\rm R}(1-2z_i(1-z_i))}}\frac{1}{\langle q_i\tilde{p}_j\rangle}(\mathbb{W}^{ij}-\mathbb{1})(\mathbb{T}_j^q\otimes\mathbb{P}_j^2\mathbb{S}^{+\frac{1}{2}_i})\\
& + \sqrt{\frac{\mathcal{P}_{gg}}{2\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{[\tilde{p}_j q_i]}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i})\\
& \left. + \sqrt{\frac{z_i^4\mathcal{P}_{gg}}{2\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{\langle\tilde{p}_j q_i\rangle}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i}) + \sqrt{\frac{\mathcal{P}_{gg}(1-z_i)^4}{2\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{\langle q_i\tilde{p}_j\rangle}(\mathbb{T}_j^g\otimes\mathbb{P}_j^1\mathbb{S}^{-1_i})\right)\\
& + \delta_{s_j,\frac{1}{2}}\delta_j^{\text{initial}}\sqrt{\frac{1}{z_i}}\left(\sqrt{\frac{\mathcal{P}_{qq}}{\mathcal{C}_{\rm F}(1+z_i^2)}}\frac{1}{\langle q_i p_j\rangle}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i}) + \sqrt{\frac{z_i^2\mathcal{P}_{qq}}{\mathcal{C}_{\rm F}(1+z_i^2)}}\frac{1}{[p_j q_i]}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i})\right.\\
& + \sqrt{\frac{(1-z_i)^2\mathcal{P}_{qg}}{n_f\mathcal{C}_F(1-2z_i(1-z_i))}}\frac{1}{[p_j q_i]}\mathbb{W}^{ij}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i})\\
& \left. + \sqrt{\frac{z_i^2\mathcal{P}_{qg}}{n_f\mathcal{C}_F(1-2z_i(1-z_i))}}\frac{1}{\langle q_i p_j\rangle}\mathbb{W}^{ij}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i})\right)\\
& + \delta_{s_j,-\frac{1}{2}}\delta_j^{\text{initial}}\sqrt{\frac{1}{z_i}}\left(\sqrt{\frac{\mathcal{P}_{qq}}{\mathcal{C}_{\rm F}(1+z_i^2)}}\frac{1}{[p_j q_i]}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i}) + \sqrt{\frac{z_i^2\mathcal{P}_{qq}}{\mathcal{C}_{\rm F}(1+z_i^2)}}\frac{1}{\langle q_i p_j\rangle}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i})\right.\\
& + \sqrt{\frac{(1-z_i)^2\mathcal{P}_{qg}}{n_f\mathcal{C}_F(1-2z_i(1-z_i))}}\frac{1}{\langle q_i p_j\rangle}\mathbb{W}^{ij}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i})\\
& \left. + \sqrt{\frac{z_i^2\mathcal{P}_{qg}}{n_f\mathcal{C}_F(1-2z_i(1-z_i))}}\frac{1}{[p_j q_i]}\mathbb{W}^{ij}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i})\right)\\
& + \delta_{s_j,1}\delta_j^{\text{initial}}\sqrt{\frac{1}{z_i}}\left(\sqrt{\frac{2n_f\mathcal{P}_{gq}}{T_{\rm R}(2-2z_i+z_i^2)}}\frac{1}{\langle p_j q_i\rangle}(\mathbb{T}_j^q\otimes\mathbb{P}_j^2\mathbb{S}^{+\frac{1}{2}_i})\right.\\
& + \sqrt{\frac{2n_f(1-z_i)^2\mathcal{P}_{gq}}{T_{\rm R}(2-2z_i+z_i^2)}}\frac{1}{[q_i p_j]}(\mathbb{T}_j^q\otimes\mathbb{P}_j^1\mathbb{P}_j^2\mathbb{S}^{-\frac{1}{2}_i}) + \sqrt{\frac{\mathcal{P}_{gg}}{\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{\langle q_i p_j\rangle}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i})\\
& \left. + \sqrt{\frac{z_i^4\mathcal{P}_{gg}}{\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{[q_i p_j]}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i}) + \sqrt{\frac{\mathcal{P}_{gg}(1-z_i)^4}{\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{\langle q_i p_j\rangle}(\mathbb{T}_j^g\otimes\mathbb{P}_j^1\mathbb{S}^{-1_i})\right)\\
& + \delta_{s_j,-1}\delta_j^{\text{initial}}\sqrt{\frac{1}{z_i}}\left(\sqrt{\frac{2n_f\mathcal{P}_{gq}}{T_{\rm R}(2-2z_i+z_i^2)}}\frac{1}{[q_i p_j]}(\mathbb{T}_j^q\otimes\mathbb{P}_j^2\mathbb{S}^{-\frac{1}{2}_i})\right.\\
& + \sqrt{\frac{2n_f(1-z_i)^2\mathcal{P}_{gq}}{T_{\rm R}(2-2z_i+z_i^2)}}\frac{1}{\langle p_j q_i\rangle}(\mathbb{T}_j^q\otimes\mathbb{P}_j^1\mathbb{P}_j^2\mathbb{S}^{+\frac{1}{2}_i}) + \sqrt{\frac{\mathcal{P}_{gg}}{\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{[p_j q_i]}(\mathbb{T}_j^g\otimes\mathbb{S}^{-1_i})\\
& \left. + \sqrt{\frac{z_i^4\mathcal{P}_{gg}}{\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{\langle p_j q_i\rangle}(\mathbb{T}_j^g\otimes\mathbb{S}^{+1_i}) + \sqrt{\frac{\mathcal{P}_{gg}(1-z_i)^4}{\mathcal{C}_{\rm A}(1-z_i+z_i^2)^2}}\frac{1}{[p_j q_i]}(\mathbb{T}_j^g\otimes\mathbb{P}_j^1\mathbb{S}^{+1_i})\right).
\end{aligned}
\tag{A.1}
$$

Forshaw, Holguin & Plätzer, 1905.08686

Quantum MC

- Bauer, Nachman, Provasoli & de Jong, 1904.03196

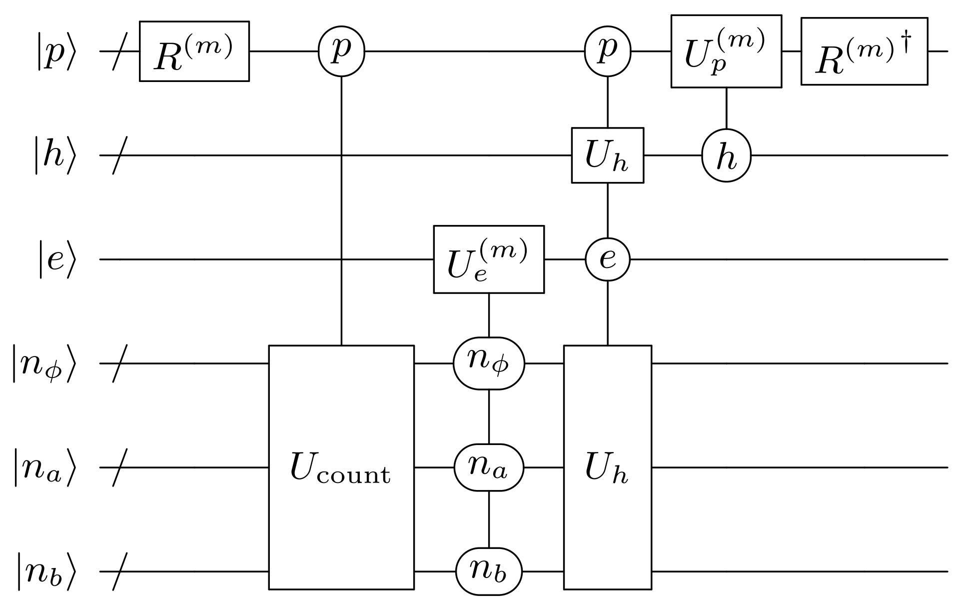


FIG. 1: Quantum circuit block for one step, to be repeated N times for the full circuit.

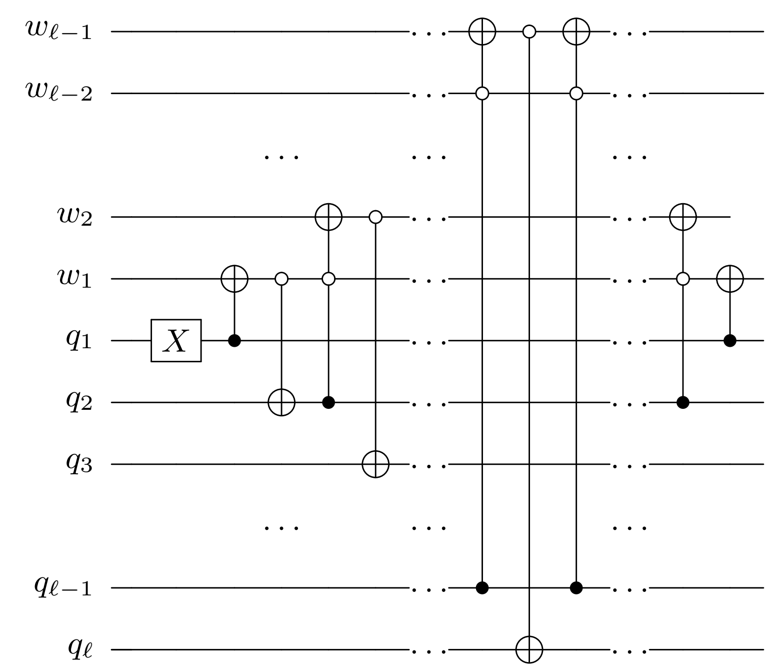
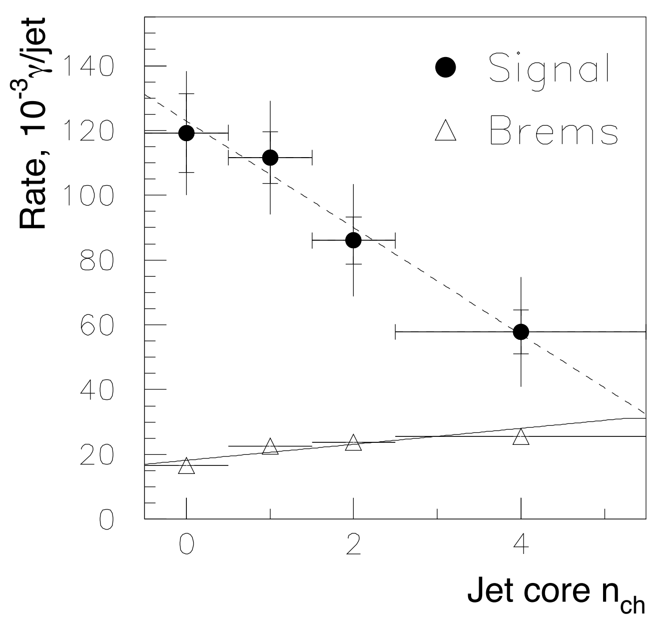


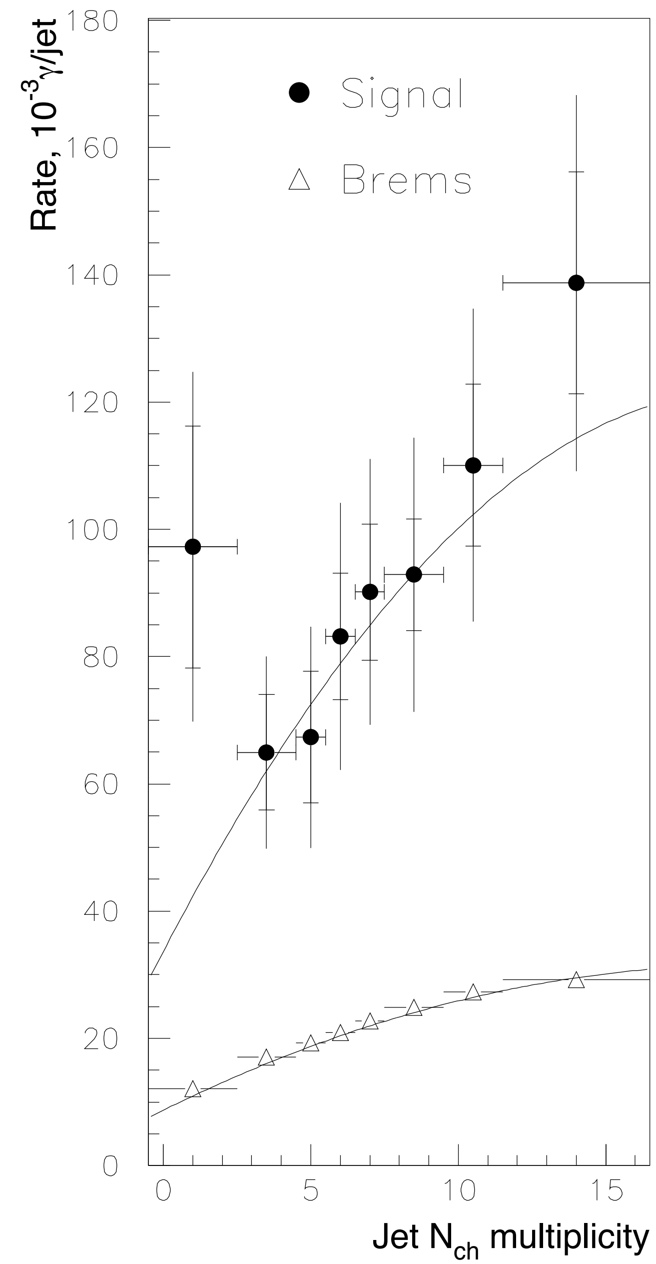
FIG. 8: Decomposition of the U_+ gate for integers as large as a, where $\ell = \lceil \log_2(a) \rceil$.

Hadronisation

- Unexplained features: e.g. soft photon excess



Core: Δθ<0.1



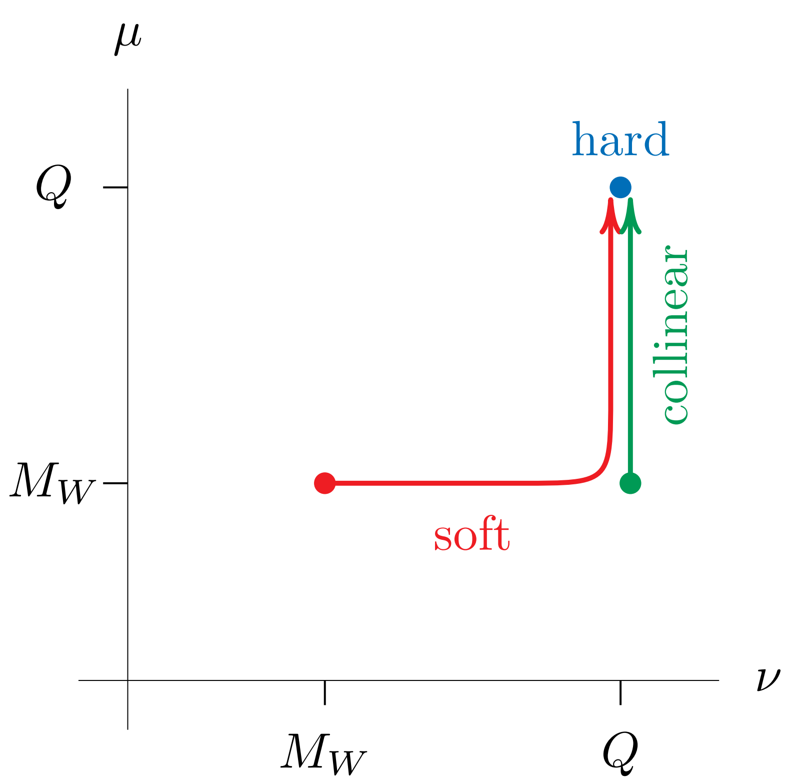
DELPHI, 1004.1587

Resummation Issues

- SCET vs “traditional”: EW Sudakov
- Coloured final states
- Factorisation

Electroweak Sudakov

- SCET approach (Manohar & Waalewijn, 1802.08687)
  - μ-anomalous dimension has ln ν terms and v.v.
  - Resum logs by double evolution:



- Equivalent to angular evolution with $\alpha_W(p_t)$ (Bauer & BW, 1808.08831) - why?

Coloured Final States

- Resumption:
    - Soft function incorporates soft wide-angle ISR and FSR and interference
- Parton Showers:
    - How well do different dipole initial scales ($p_i.p_j$) approximate this?

Factorisation

- MPI/UE leads to violation for certain observables, e.g. ET = $\Sigma|p_T|$, beam thrust, …
- Does it make sense to use these as factorisation scales?

Conclusions?

- Both PS and R are (still) very active fields
- Aiming for precision to make full use of LHC data
- PS issues: recoils, correlations, NLO, …
- R issues: SCET vs trad, coloured FS, multivariable, …
- Plenty to be done (by you!)

Thanks

Backup

$$q\frac{\partial}{\partial q}Q^-(x,q) = -\frac{\alpha_2}{\pi}C_F\int_0^{1-m_W/q}\frac{dz}{z}P_{ff}(z)\left[\frac{1}{3}Q^-(x/z,q)+zQ^-(x,q)\right]$$

- Define $F(q) = \int_0^1 dx\, x\, Q^-(x,q) = \int_0^1 dx\, x\,[u_L(x,q) - d_L(x,q)]$
  - Then $q\frac{dF}{dq} = -\frac{\alpha_2}{\pi}C_F\int_0^{1-m_W/q} dz\, P_{ff}(z)\frac{4}{3}F(q)$

    where $C_F\int_0^{1-m_W/q} dz\, P_{ff}(z) \sim \frac{3}{2}\ln\left(\frac{q}{m_W}\right)$ $[C_F = 3/4 \text{ for SU}(2)]$

- Hence

$$F(q) \sim F(m_W)\exp\left[-\frac{\alpha_2}{\pi}\ln^2\left(\frac{q}{m_W}\right)\right]$$

- For LLA resummation: $\alpha_2 \to \alpha_2(q(1-z))$

Polarised Splitting Functions

- For any gauge interaction G=SU(3), SU(2), U(1) (neglecting azimuthal correlations)

$$
\begin{aligned}
P^R_{f_L f_L,G}(z) &= P^R_{f_R f_R,G}(z) = \frac{2}{1-z} - (1+z)\,, \\
P^R_{V_+ f_L,G}(z) &= P^R_{V_- f_R,G}(z) = \frac{(1-z)^2}{z}\,, \\
P^R_{V_- f_L,G}(z) &= P^R_{V_+ f_R,G}(z) = \frac{1}{z}\,, \\
P^R_{f_L V_+,G}(z) &= P^R_{f_R V_-,G}(z) = \frac{1}{2}(1-z)^2\,, \\
P^R_{f_L V_-,G}(z) &= P^R_{f_R V_+,G}(z) = \frac{1}{2}z^2\,, \\
P^R_{V_+ V_+,G}(z) &= P^R_{V_- V_-,G}(z) = \frac{2}{1-z} + \frac{1}{z} - 1 - z(1+z)\,, \\
P^R_{V_+ V_-,G}(z) &= P^R_{V_- V_+,G}(z) = \frac{(1-z)^3}{z}\,, \\
P^R_{HH,G}(z) &= \frac{2}{1-z} - 2\,,
\end{aligned}
$$