$$A_{jk}^{0\text{-MHV}} = A_n^0(1^{(+)}, 2^{(+)}, \ldots, j^{(-)}, j+1^{(+)}, \ldots, k^{(-)}, \ldots, n^{(+)})$$

$$= i \frac{\langle jk\rangle^4}{\langle 12\rangle\langle 23\rangle \cdots\cdots \langle n1\rangle}$$

$$A_4^0(1^{(-)}, 2^{(+)}, 3^{(-)}, 4^{(+)}) = i\frac{\langle 34\rangle^4}{\langle 12\rangle\langle 23\rangle\langle 34\rangle\langle 41\rangle}$$

$$A_4^0(1^+, 2^{(-)}, 3^+, 4^{(-)}) = i\frac{\langle 24\rangle^4}{\langle 12\rangle\langle 23\rangle\langle 34\rangle\langle 41\rangle}$$

$$A_4^0(1^{(+)}, 2^{(+)}, 3^{(+)}, 4^{(+)}) = A_4^0(1^{(+)}, 2^{(+)}, 3^{(+)}, 4^{(-)}) = 0$$

$$\left|A_4^0(1,2,3,4)\right|^2 = \frac{s_{34}^4 + s_{12}^4 + s_{14}^4}{s_{12}\, s_{23}\, s_{34}\, s_{41}}$$

+	+	−	−
−	−	+	+
+	−	+	−
−	+	−	+
+	−	−	+
−	+	+	−

6 MHV

2) IR Singularity in NLO Real part.

Tree QCD amplitude IR. divergence :

$g \to 0$ soft limit

$g \parallel g \quad q \parallel g, \quad q \parallel \bar{q}$ collinear limit

$$|A_4^0|^2 \xrightarrow[p_2 \to 0]{2 \to 0} \frac{0}{s_{12}^4 + s_{13}^4 + s_{14}^4 + s_{23}^4 + s_{24}^4 + s_{34}^4}{s_{12} s_{23} s_{34} s_{41}}$$

$$s_{2i} = (p_2 + p_i)^2 = p_2^2 + p_i^2 + 2 p_2 \cdot p_i = 0$$

$$= \frac{s_{13}}{s_{12} s_{23}} \times \frac{s_{13}^4 + s_{14}^4 + s_{24}^4}{s_{13} s_{34} s_{41}}$$

$$= \frac{s_{13}}{s_{12}\, s_{23}} \left| A_3^0 \right|^2$$

$$|A_4^0|^2 \xrightarrow{2 \to 0} = \frac{S_{123}}{2} \left| A_3^0 \right|^2$$

$$S_{123} = \frac{2 s_{13}}{s_{12}\, s_{23}} \quad \text{Eikonal factor} \sim \frac{1}{\delta^2}$$

$$|A_4^0|^2(1,2,3,4) \xrightarrow{l \to 0} \underline{\underline{S_{iLk}}}\ \underline{\underline{|A_3^0|^2(i,j,k)}}$$

$$S_{123}\ ,\ S_{234}\ ,\ S_{412}$$

$$\left[\left|A_4^0(1,2,3,4)\right|^2 + \left|A_4^0(1,4,3,2)\right|^2\right]$$

$$\xrightarrow{2\to 0} \frac{2\,S_{13}}{S_{12}S_{23}} \left|A_3^0(1,3,4)\right|^2$$

Single collinear limit. $P_1 /\!/ P_2$

$$P_1 + P_2 = P$$

$$\begin{cases} P_1 = zP \\ P_2 = (1-z)P \end{cases}$$

$$\frac{\sum \left|A_4^0(1,2,3,4)\right|^2}{\text{helicity}} \quad 1/\!/2$$

$S_{12} \Rightarrow 0$ $\qquad S_{24} \to (1-z)S_{P4}$

$S_{13} \Rightarrow z S_{P3}$

$$= \frac{[z^4 + (1-z)^4](s_{p3}^4 + s_{p4}^4) + s_{34}^4}{z(1-z)\, s_{12}\, s_{p3}\, s_{34}\, s_{p4}}$$

$$= \left(\frac{P^0_{gg\to g}(z)}{s_{12}} \right) |A_5^0(p,3,4)|^2$$

$+$ Angular term.

$$P^0_{gg\to g}(z) = 2\left(\frac{z}{1-z} + \frac{1-z}{z} + z(1-z) \right) = \frac{1+z^4+(1-z)^4}{z(1-z)}$$

$$\left| \frac{\langle ij\rangle^4}{\langle 12\rangle \cdots \langle a-1, a\rangle \langle ab\rangle \langle b, b+1\rangle \cdots \langle n1\rangle} \right|^2 \quad a^{(+)} / b^{(+)} \to$$

$$\underbrace{\frac{1}{\sqrt{(1-z)z}\,\langle ab\rangle}}\times\frac{\langle ij\rangle^4}{\langle 12\rangle\cdots\langle a-1,P\rangle\langle P,b+1\rangle\cdots\langle n1\rangle}$$

$$\mathrm{Split}_-(a^+,b^+)=\frac{1}{\sqrt{z(1-z)}\,\langle ab\rangle}$$

$$\mathrm{Split}_+(a^-,b^+)=\frac{z^2}{\sqrt{z(1-z)}\,\langle ab\rangle}$$

$$\mathrm{Split}_+(a^+,b^-)=\frac{(1-z)^2}{\sqrt{z(1-z)}\,\langle ab\rangle}$$

$$|\mathrm{Split}_-(a^+,b^+)|^2+|\mathrm{Split}_+(a^-,b^+)|^2+|\mathrm{Split}_+(a^+,b^-)|^2$$

$$\approx \frac{1}{s_{ab}} \left[\frac{1}{z(1-z)} + \frac{z^4}{z(1-z)} + \frac{(1-z)^4}{z(1-z)} \right]$$

$$n = (1, 0, 0, -1)$$

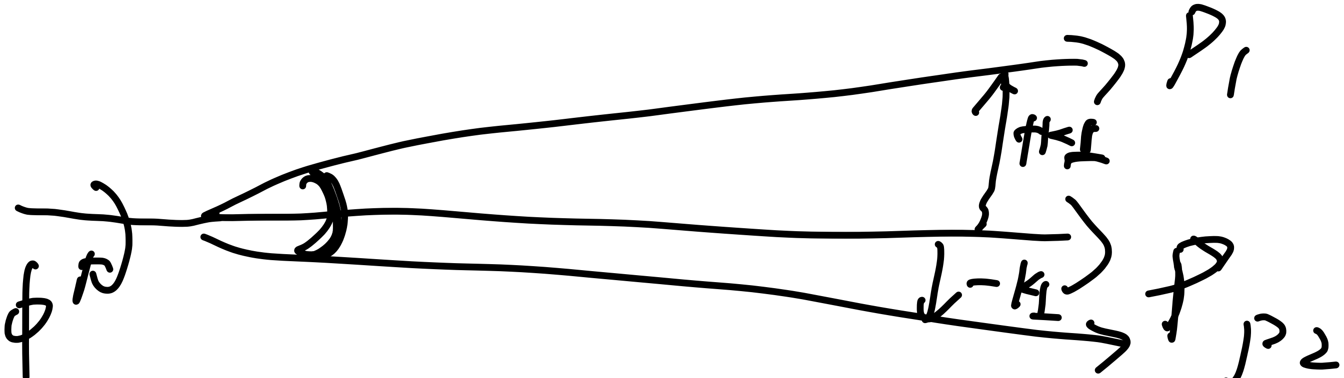
$$p_1 = \underline{z p} + \underline{k_\perp} - \frac{k_\perp^2}{z} \frac{n}{2 p \cdot n}$$

$$p_2 = \underline{(1-z)} p \underline{- k_\perp} - \frac{k_\perp^2}{\underline{1-z}} \frac{n}{2 \underline{p \cdot n}}$$

$$k_\perp = (0, \varepsilon, \varepsilon, 0)$$

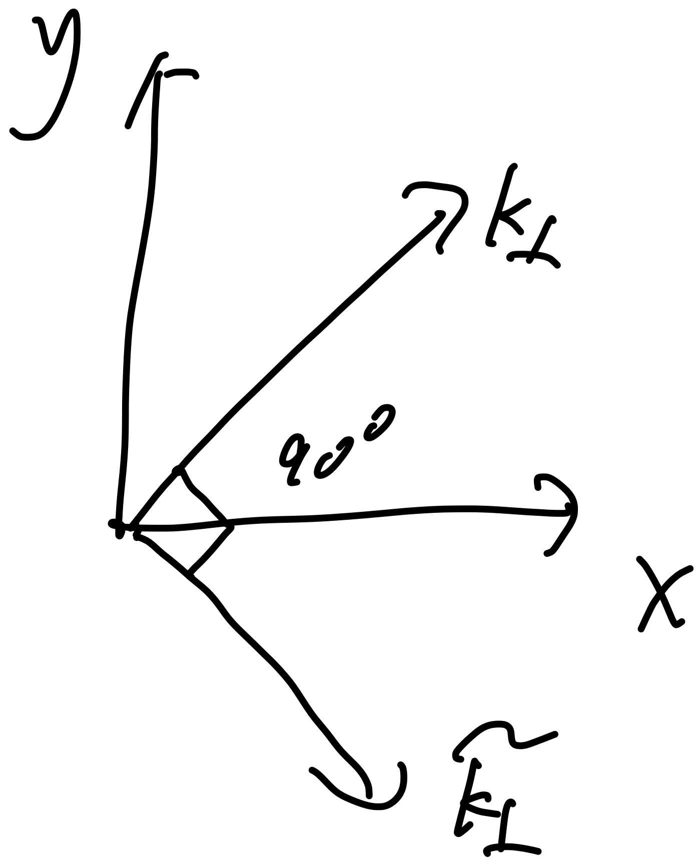
$$p_1 + p_2 \approx p \qquad p_1^2 = p_2^2 = p^2 = 0$$

$$p_1^2 = p_2^2 = 0$$



$$\begin{cases} P_1(p, k_\perp, z) \\ P_2(p, k_\perp, 1-z) \end{cases} \qquad \begin{cases} \tilde{P}_1(p, \tilde{k}_\perp, z) \\ \tilde{P}_2(p, \tilde{k}_\perp, 1-z) \end{cases}$$

$$\tilde{k}_\perp \to k_\perp$$



$$|A_4^0(1,2,3,4)^2|^2$$

$$+\ |A_4^0(\tilde{1}, \tilde{2}, 3, 4)$$

$$1 \| 2 \longrightarrow \frac{2\, P^0_{gg\to g}(z)}{s_{12}} \times |A_3^0(P, 3, 4)|^2$$

$$\left| A_4^0(\underline{\underline{1,2,3,4}}) \right|^2$$

$2 \to 0$

$2 // 1$ IR

$2 // 3$ divergene

$3 \to 0$ IR

$2 // 3$ $3 // 4$

$1 \to 0 \sim \frac{1}{0^2}$

$2 \to 0 \sim \frac{1}{0^2}$

$1 // 2 \to \frac{1}{0} \underline{\underline{P^0_{gg \to g}(z)}}$

$2 // 4 \to 1$

$1 // 3 \to 1$

$3 // 4 \to \frac{1}{0} P^0_{gg \to g}(z)$

$$P^0_{qg\to q}(z) = \frac{1+(1-z)^2}{z}$$

$$S_{ijk} = \frac{2S_{ik}}{S_{ij}S_{jk}} \sim \frac{1}{\epsilon^2}$$

$$P^0_{q\bar{q}\to g}(z) = z^2+(1-z)^2$$

$$\frac{P^0_{gg\to G}(z)}{S_{ij}} \sim \frac{1}{\epsilon} \text{ in } \overbrace{z}^{55\%} \sim \overbrace{1-z}^{45\%}$$

$$\sim \frac{1}{\epsilon^2} \text{ in } \underline{z\to 0} \quad 1-z\to 1$$

$$\underline{P_1 = zP \Rightarrow 0}$$

$$\prod_j \frac{d^3 p_j}{(2\pi)^3\, 2E_j} (2\pi)^4 \delta\left(p_1 + p_2 - \sum_j p_j\right) \delta\left(p_j^2 - m_j^2\right)$$

$$\frac{d^3 p_j}{2E_j} S_{ik} = \frac{\cancel{2} E_j^{\cancel{2}}\, dE_j\, d\cos\theta_j\, d\phi\, S_{ik}}{\cancel{2E_j}\; E_i \cancel{E_j} (1-\cos\theta_{ij}) E_j E_k (1-\cos\theta_{jk})}$$

2π

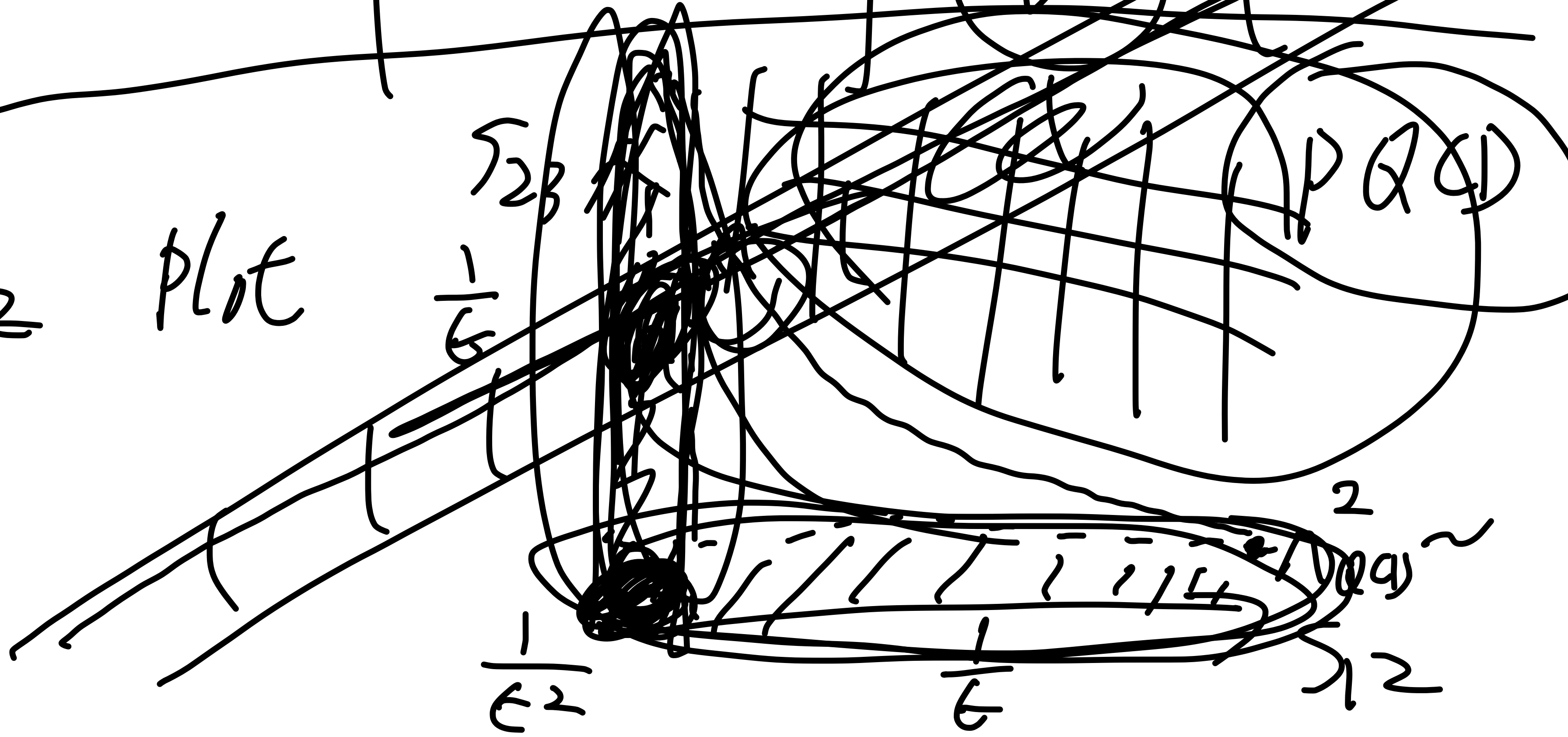
$p_j \to 0$

$$= \frac{2\pi S_{ik}\, dE_j\, d\cos\theta_j}{E_i E_k E_j (1-\cos\theta_{ij})(1-\cos\theta_{jk})} \sim$$

$\to 0$

$\frac{1}{\epsilon}$	$F_j \to 0$	$\theta_{ij}, \theta_{jk} \sim 1$
$\frac{1}{\epsilon^2}$	$F_j \to 0$	$\theta_{ij} \sim 0$, or $\theta_{jk} \sim O(1)$

Dalitz plot



3) IR Singularity @ NLO Virtual.

$$A_n = A_n^0 + g A_{n+1}^0 + g^2 A_n^1 + g^3 A_{n+1}^1 + g^4 A_n^2 \cdots\cdots$$

$$|A_n|^2 = |A_n^0|^2 \sim \text{LO / Born}$$

Real

Virtual

NLO $\quad + g^2 \left\{ |A_{n+1}^0|^2 + \left[A_n^0 A_n^{1\dagger} + A_n^{1\dagger} A_n^0 \right] \right\}$

NNLO $\quad + g^4 \left\{ |A_{n+2}^0|^2 + |A_n^1|^2 + \cdots \right\}$

$\left(N^3LO\right.$ $+$

$\vdots$ $\vdots$

Real + Virtual = finite

KLN theorem

$$\text{pole}\Big\{\underbrace{A_4^{0}(\overset{1234}{gggg})A_4^{1\dagger}(\overset{1234}{gggg}) + A_4^{0\dagger}(\overset{1234}{gggg})A_4^{1}(\overset{1234}{gggg})}_{\text{Virtual}}\Big\}$$

$$= \left[2 I_{gg}^{(1)}(\varepsilon, \underline{\underline{s_{12}}}) + 2 I_{gg}^{(1)}(\varepsilon, \underline{\underline{s_{23}}})\right.$$

$$+ 2 I^{(1)}_{gg}(\varepsilon, s_{34}) + 2 I^{(1)}_{gg}(\varepsilon, s_{41}) \Big] \times$$

$$\left| A_4^0(1234)(gggg) \right|^2$$

$$I^{(1)}_{gg}(\varepsilon, s_{ij}) = -\boxed{\frac{e^{\varepsilon \gamma_E}}{2\Gamma(1-\varepsilon)}} \left[\frac{1}{\varepsilon^2} + \frac{11}{6\varepsilon} \right] \boxed{\mathrm{Re}(-s_{ij})^{-\varepsilon}}$$

$I^{(1)}_{qg}$, $I^{(1)}_{q\bar{q}}$ ...

Lecture 2 NLO Subtraction Method and application

1) structure of NLO subtraction :

Parton Model :

$$d\sigma(P_{H_1}, P_{H_2}) = \sum_{ij} \int \frac{d\xi_1}{\xi_1} \frac{d\xi_2}{\xi_2} \underline{\underline{f_i^0(\xi_1)}} \underline{\underline{f_j^0(\xi_2)}}$$

$$\underline{\underline{d\sigma_{ij}}} \left(\xi_1 P_{H_1}, \xi_2 P_{H_2} \right)$$

$$f_i^{0}(z) = \int dx\, dy\, \delta(z - x\underline{\underline{y}})\, f_{\hat{j}}(x, \underline{\mu_F})\, \Gamma_{\hat{j}i}(y, \mu_F)$$

$$f^0 = f \otimes \Gamma^{+}$$

$$\Gamma^{+}_{ij}(x, \mu_F) = \delta_{ij}\,\delta(1-x) - \frac{\alpha_s(\mu_F^2)}{2\pi}\Gamma^1_{ij}(x) + \frac{\alpha_s^2(\mu_F^2)}{(2\pi)^2}\Gamma^2_{ij}(x)$$

$$\Gamma^1_{ij}(x) = -\frac{1}{\epsilon} P^0_{ij}(x)$$

$\rightarrow$ DGLAP splitting functions

$$d\Gamma(P_{H_1}, P_{H_2}) = f^0 \, d\sigma \, f^{0'}$$

QCD improved Parton model

$$d\hat{\sigma}(p_{H_1}, p_{H_2}) = f \otimes \underbrace{\Gamma^{-1} \cdot d\sigma \cdot \Gamma^{-1}} \otimes f'$$

$$= f \otimes d\hat{\sigma} \otimes f'$$

$$d\hat{\sigma}^{LO}_{ij} = d\sigma^{LO}_{ij}$$

$$d\hat{\sigma}^{NLO}_{ij} = d\sigma^{NLO}_{ij} + d\hat{\sigma}^{MF,LO}_{ij}$$

$$
= d\sigma^{R}_{i\bar{j}} + d\sigma^{V}_{i\bar{j}}
$$

$$
M^{MF,LO}_{\hat{i}\hat{j}} \left\{ + \int \Gamma'_{ki}(x_1)\, d\sigma^{LO}_{kj}\, \delta(1-x_2) \frac{dx_1}{x_1}\frac{dx_2}{x_2} \right.
$$

$$
\left. + \int \Gamma'_{lj}(x_2)\, d\sigma^{LO}_{il}\, \delta(1-x_1) \frac{dx_1}{x_1}\frac{dx_2}{x_2} \right.
$$

7.19 $\left|B_5^0(\hat{1}_q, 3_g, 4_g, 5_g, \hat{2}_{\bar{q}})\right|^2 J_2^{(3)}(3_g, 4_g, 5_g)$

$- d_3^0(\hat{1}_q, 3_g, 4_g) \times \left|B_4^0([\hat{1}]_q, [34]_g, 5_g, \hat{2}_{\bar{q}})\right|^2 \times J_2^{2}([34]_g, 5_g)$

$- f_3^0(3_g, 4_g, 5_g) \times \left|B_4^0(\hat{1}_q, [34]_g, [45]_g, \hat{2}_{\bar{q}})\right|^2 \times J_2^{2}([34]_g, [45]_g)$

$- d_3^0(\hat{2}_{\bar{q}}, 5_g, 4_g) \times \left|B_4^0(\hat{1}_q, 3_g, [45]_g, [\hat{2}]_{\bar{q}})\right|^2 \times J_2^{(2)}(3_g, [45]_g)$

$1, 3, 4 \longrightarrow [\hat{1}], [34]$

$3 \to 0 \longrightarrow [\hat{1}] = 1 \quad [34] = 4$

$$\int_{P.S.} \left[d\sigma^{R}_{m+1} - \underline{d\sigma^{S}_{m+1}} \right]$$

IR finite

$$\underbrace{\int_{P.S} \left[d\sigma^{V}_{m} + d\sigma^{MF,NLO}_{m} + \underline{\int_{1} d\sigma^{S}_{m+1}} \right]}_{\text{IR finite}}$$

$$\int_1 d\sigma^S_{ij} = \int_1 \frac{1}{2s} \left[A_3^0(3_q, 4_g, 5_{\bar q}) \times \left[B_4^0([34]_q, 1_g, 2_g, [45]_{\bar q}) \right]^2 \times d\Phi_2(p_3, p_4, p_5; p_1+p_2) \, J_2^{(2)}([34]_q, [45]_{\bar q}) \right]$$

$$d\Phi_{m+1}(p_3, \cdots p_{m+3}; p_1, p_2) = (2\pi)^d \, \delta\left(p_1+p_2 - \sum_{l=3}^{m+3} p_l\right) \times \prod_{l=3}^{m+3} [d\phi_l]$$

$$d = 4 - 2\epsilon$$

$$[dp] = d^d p \, \delta(p^2) / (2\pi)^{d-1}$$

$$d\Phi_{3}(p_3, p_4, p_5; p_1+p_2) = d\Phi_2([34]_q, [45]_\tau; p_1+p_2)$$

$$\times \, d\Phi_{345}$$

$$d\Phi_{345}(p_3, p_4, p_5; p_{[34]_q + [45]_\tau}) = \frac{d\Phi_3(p_3, p_4, p_5, p_{\cdots})}{d\Phi_2(p_{[34]}, p_{[45]}; p_{\cdots})}$$

$$\int_1 d\sigma^S_{\bar{i}j} = \frac{1}{2S} \boxed{\int_{3,4,5} A_3^0(3_q, 4_g, 5_{\bar{q}})\, d\Phi_{3,4,5}}$$

$$\times \int \left| \mathcal{B}_4^0([34]_q, 1_g, 2_g, [45]_{\bar{q}}) \right|^2 d\Phi_2([34]_q, [45]_{\bar{q}}; p_1+p_2)$$

$$\times J_2^{(2)}([34]_q, [45]_{\bar{q}})$$

$$\int_1 H(\text{sub}) \times LO$$

$$\int \frac{\dfrac{A_3^0(i,j,k)}{d\Phi_2}}{\dfrac{d\Phi_3(p_i,p_j,p_k;p_1+p_K)}{}}$$

$$d\Phi_3(p_i,p_j,p_k;p_1+p_K) = (2\pi)^{3-2d}\, d^d p_i\, d^d p_j\, d^d p_k$$

$$\delta(p_i^2)\,\delta(p_j^2)\,\delta(p_k^2)\,\delta^d(p_1+p_K-p_i-p_j-p_k)$$

$$= \frac{(2\pi)^{3-2d}}{32(s_{ij}+s_{ik}+s_{jk})}\, ds_{ik}\, ds_{jK}\, d\Omega_i^{(d-1)}\, d\Omega_j^{(d-2)}$$

$$\times \left[\frac{(s_{ik}+s_{ij}+s_{kj}-s_{ik}-s_{jk})\,s_{ik}\,s_{jk}}{s_{ij}+s_{ik}+s_{kj}}\right]^{\frac{d-4}{2}}$$

$$\int d\Omega^{(d)} = \frac{2\pi^{\frac{d}{2}}}{\Gamma\left(\frac{d}{2}\right)}$$

$$\underline{\underline{d\Phi_3}} = \frac{2^{1-2d} \times \pi^{1-d}}{\Gamma(d-2)} \left(s_{ij}+s_{jk}+s_{ik}\right)^{1-\frac{d}{2}} \, \underline{ds_{ik}} \, \underline{ds_{jk}}$$

$$\times \left[s_{ij} \, s_{ik} \, s_{jk} \right]^{\frac{d-4}{2}}$$

$$s_{ijk} = (p_j + p_k)^2$$

$s_{ik} > 0$ $\quad s_{ij} > 0$

$s_{jk} > 0$

$$S_{ijk} - S_{ik} - S_{jk} > 0$$

$$A_3^0 = (4\pi)^{-d-\epsilon} \times \frac{S_{ijk}^{-1+2\epsilon}}{\Gamma(1-\epsilon)} \int_0^{S_{ijk}} dS_{jk} \int_0^{S_{ijk}-S_{ik}} dS_{jk}$$

$$[S_{ij} S_{ik} S_{jk}]^{-\epsilon} A_3^0(i,j,k)$$

$$A_2^0(i,j,k) = \frac{1}{S_{ijk}} \left[\frac{S_{ik}}{S_{jk}} + \frac{S_{jk}}{S_{ik}} + \frac{2(S_{ijk} - S_{ik} - S_{jk}) S_{ijk}}{S_{ik} S_{jk}} \right]$$

$$-\frac{\varepsilon}{s_{ijk}} \times \left[\frac{s_{ik}}{s_{jk}} + \frac{s_{jk}}{s_{ik}} + 2 \right]$$

$$A_3^0 = \frac{(4\pi)^\varepsilon}{8\pi^2 e^{\varepsilon\gamma_E} s_{ijk}^\varepsilon} \left[\frac{1}{\varepsilon^2} + \frac{3}{2\varepsilon} + \frac{19}{4} - \frac{7}{12}\pi^2 + \varepsilon\left(\frac{109}{8} - \frac{7}{8}\pi^2 - \frac{25}{3}\zeta(3)\right) + O(\varepsilon^2) \right]$$

$$\mathrm{Pole}\left\{ A^0_{3\,qg\bar{q}}(s_{ijk}, \varepsilon) \right\} = -2\, I^{(1)}_{q\bar{q}}(s_{ijk}, \varepsilon)$$

$$\text{pole}\left\{ D_3^0(s_{ijk}) \right\} = -4\, I_{qg}^{(1)}(s_{ijk}, \varepsilon)$$

$q\,g\,g$

$$\text{pole}\left\{ F_3^0(s_{ijk}) \right\} = -6\, I_{gg}^{(1)}(s_{ijk}, \varepsilon)$$

$g\,g\,g$

$$A_3^0(\bar{q}g\bar{q}) = -2\, I_{q\bar{q}}^{(1)}(s_{ijk}, \varepsilon)\,\delta(1-x) + (s_{ijk})^{-\varepsilon} \times \left[-\frac{1}{2\epsilon} P_{q\bar{q}}^{(0)}(x) \right]$$

$d\Gamma^{MF,NLO}_{ij}$

DGLAP

$$\text{Pole}\left[\int_1 d\sigma^S_{\tilde{ij}} + d\sigma^V_{\tilde{ij}} + d\sigma^{\text{MF, NLO}}_{\tilde{ij}}\right] = 0$$

$$-2 I^{(1)}_{1K}(s_{\tilde{ij}k}, \epsilon) - \frac{1}{\epsilon} P^{(0)}_{\tilde{ij}}(x) \qquad +2 I^{(1)}_{2K}(s_{\tilde{ij}k}, \epsilon) \qquad + \frac{1}{\epsilon} P^{(0)}_{\tilde{ij}}(x)$$

Lecture 3 IR safe observable

3.1) jet algorithm. PP collider

$$P_1, P_2 \rightarrow \{P_i\} \text{ for } i \text{ in final state}$$

$$P_i^T = \sqrt{{P_i^x}^2 + {P_i^y}^2}$$

i) Define distance measure:

$$d_{ij} = \min\left\{ (P_i^T)^{2p}, (P_j^T)^{2p} \right\} \frac{\Delta_{ij}^2}{R^2}$$

C/A $\leftarrow d_{ij}$: $\frac{\Delta_{ij}^2}{R^2}$

$$d_{iB} = (P_i^T)^{2p} \Rightarrow \text{C/A } 1$$

$$\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

$$y_i = \frac{1}{2}\ln\left(\frac{E_i - p_i^z}{E_i + p_i^z}\right)$$

$$p = \begin{cases} 1 & k_T\text{-jet} \\ 0 & \text{Cambirdge/Aachen-jet} \\ -1 & \text{anti-}k_T\text{ jet} \end{cases}$$

ii) Find the minimum of $\{d_{ij}\ d_{iB}\}$

If d_{iB} is minimum $P_i \rightarrow$ i-jet

If d_{ij} is minimum $P_I = P_i + P_j$

iii) Calculate, d_{iB}, d_{ij}

except i-jet, but P_I

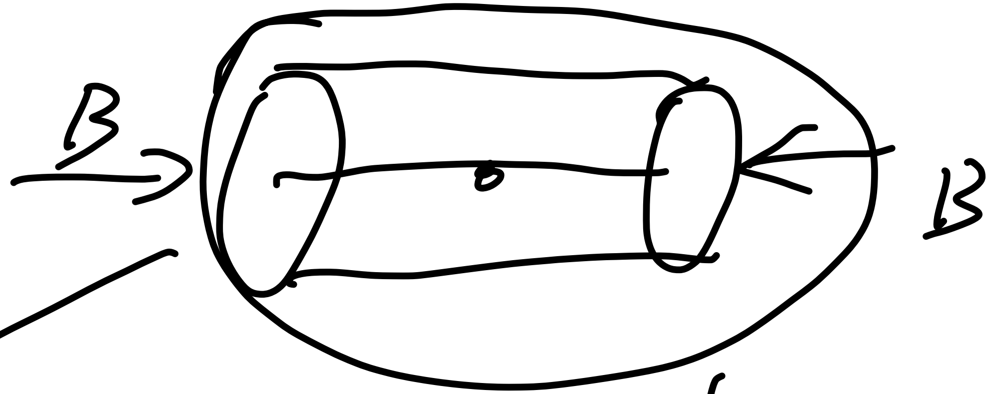
$d_{iB} \to 0$

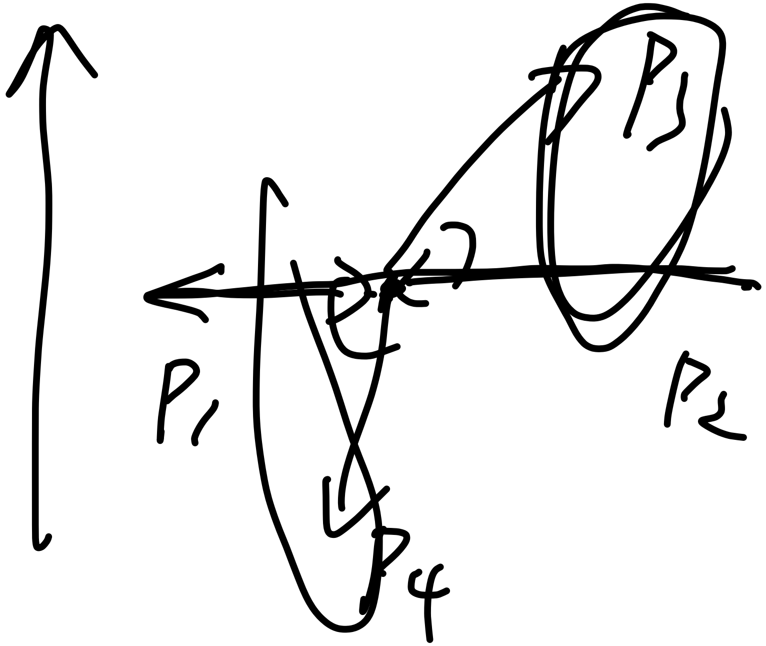
define $p_{T,cut}^{jets} > 30\ \text{GeV}$ $\sim$ 4.5 $\sim$ $0.0001\ \text{MeV}$

$|y|_{jets}^{cut} < 4.4 \to \underline{\underline{99^{100}}}$

$R = \underline{\underline{0.3 \sim 0.5}}$ $\sim$ $(0.1)^{100}$

At LO **di-jet**

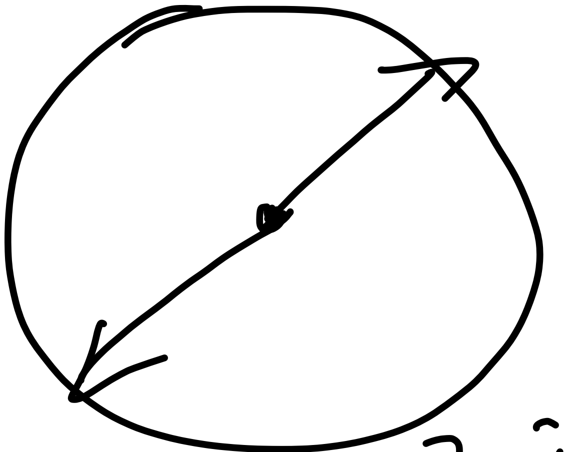




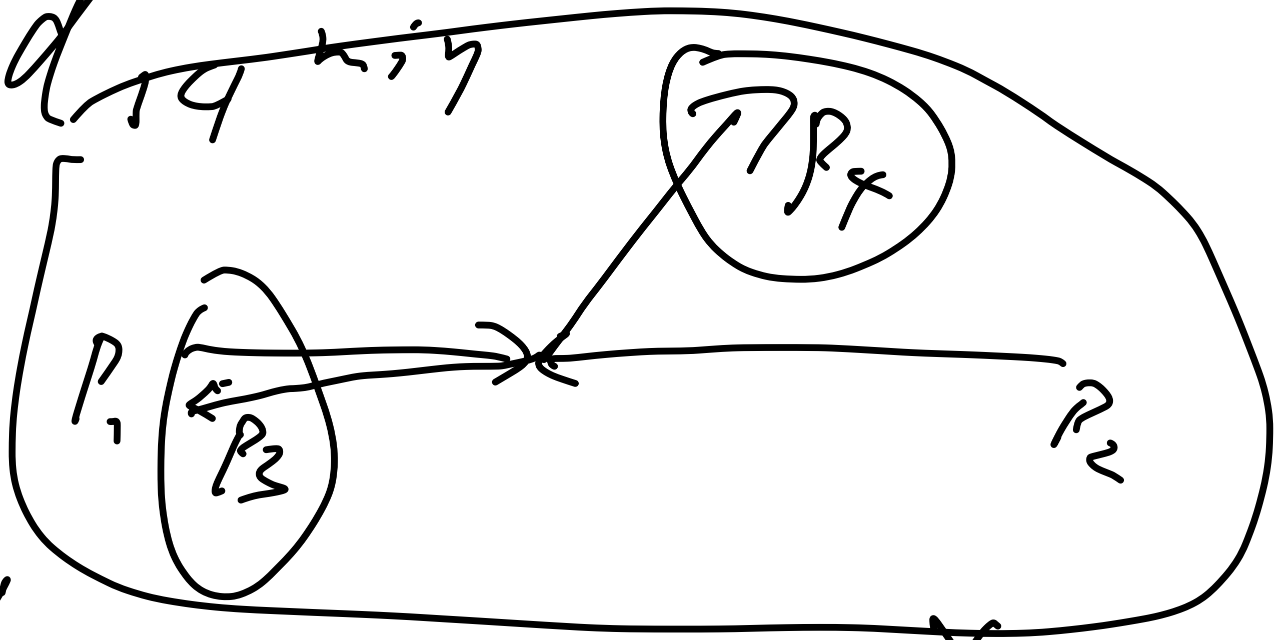
d_{32} min

$$\left|M_4^0(1,2,3,4)\right|^2$$

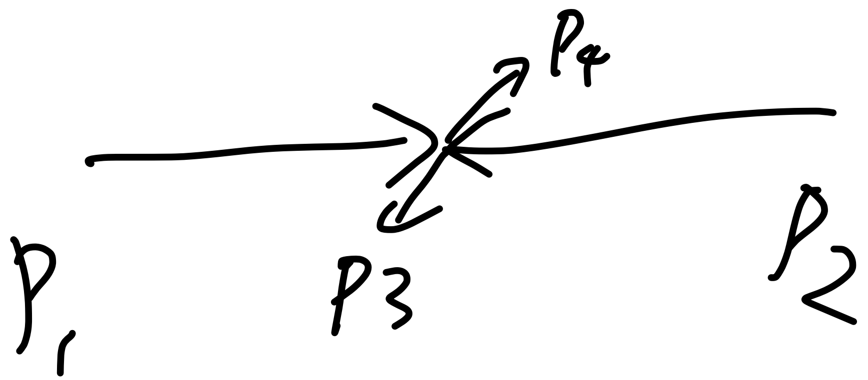
d_{14} min



2-jet event ✓



1-jet event ✗



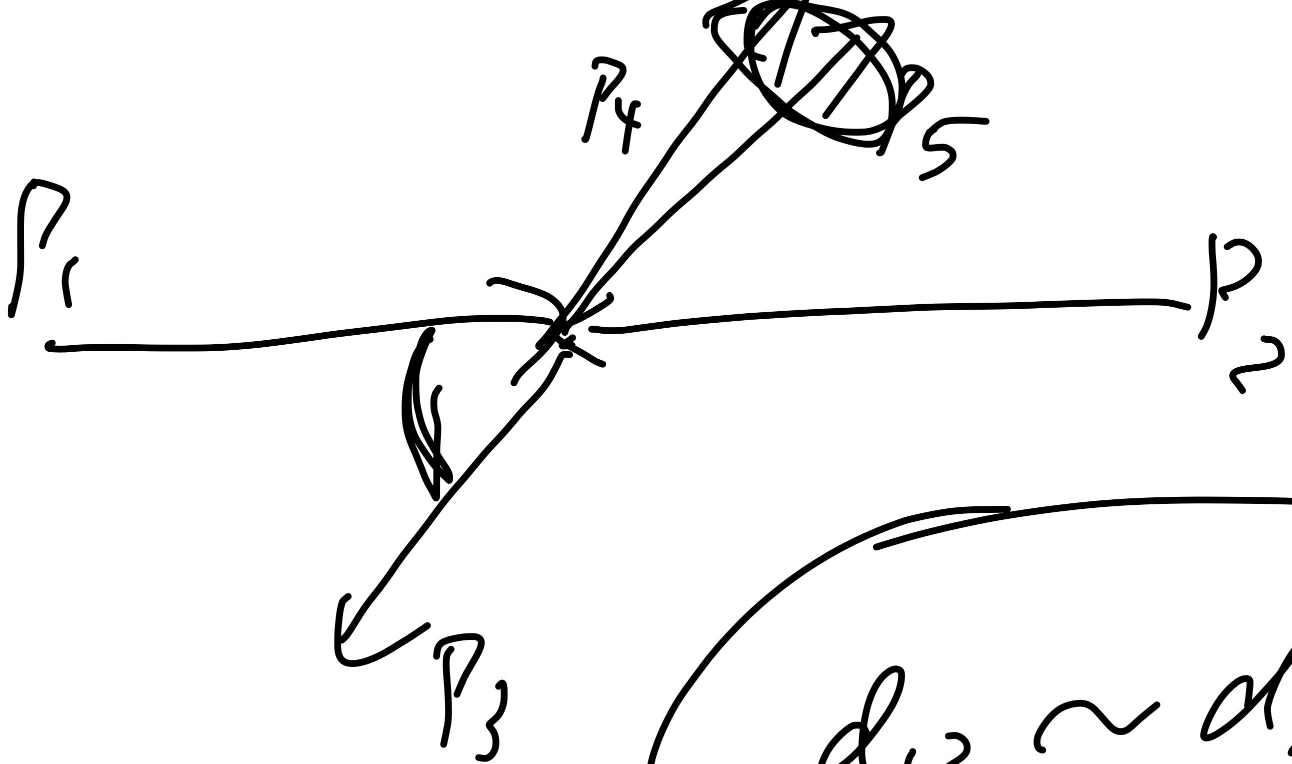
$\Rightarrow$ 0-jet event

At NLO,

LO, $|M_4^0(1,2,3,4)|^2$

NLO, $|M_5^0(1,2,3,4,5)|^2 + |M_4^1(1,2,3,4)|$

$- \times 2 \, |M_4^0|^2 \quad + S_1 \times 2$

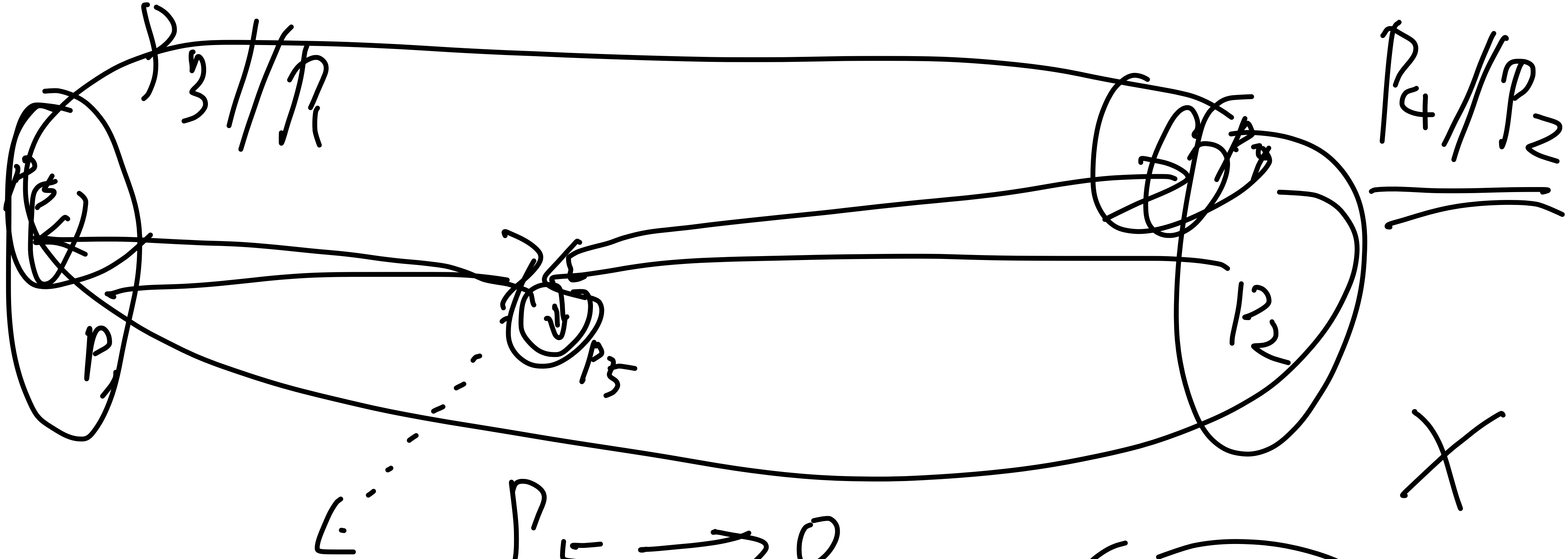


2-jet event

$$d_{13} \sim d_{32} \sim d_{14} \sim d_{52} \sim O(1)$$

$$d_{45} \sim \frac{\Delta_{ij}^2}{R^2} \sim O(0)$$

$$p_4 + p_5 \sim p_{(\widetilde{45})} \rightarrow \begin{matrix} d_{1(\widetilde{45})} \\ d_{2(\widetilde{45})} \end{matrix}$$



$p_5 \to 0$

H

$\sim d\sigma_H^{NNLO}$

0-jet

$(H+3p)^0_{RRR}$ $(H+p)^2_{VVR}$

$(H+2p)^1_{VRR}$ $(H)^3_{VVV}$