Photon production at hadronic colliders

J.Ph. Guillet

LAPTH

CNRS/Université de Savoie

France

Outline

- Inclusive photon production

Outline

- Inclusive photon production
  - Theoretical frame

Outline

- Inclusive photon production
  - Theoretical frame
  - Comparison with fixed target data

Outline

- Inclusive photon production
  - Theoretical frame
  - Comparison with fixed target data
- Two photon production

Outline

- Inclusive photon production
  - Theoretical frame
  - Comparison with fixed target data
- Two photon production
  - Existing codes

Outline

- Inclusive photon production
  - Theoretical frame
  - Comparison with fixed target data
- Two photon production
  - Existing codes
  - Comparison with new CDF data

Outline

- Inclusive photon production
  - Theoretical frame
  - Comparison with fixed target data
- Two photon production
  - Existing codes
  - Comparison with new CDF data
- Conclusion.

Inclusive photon production

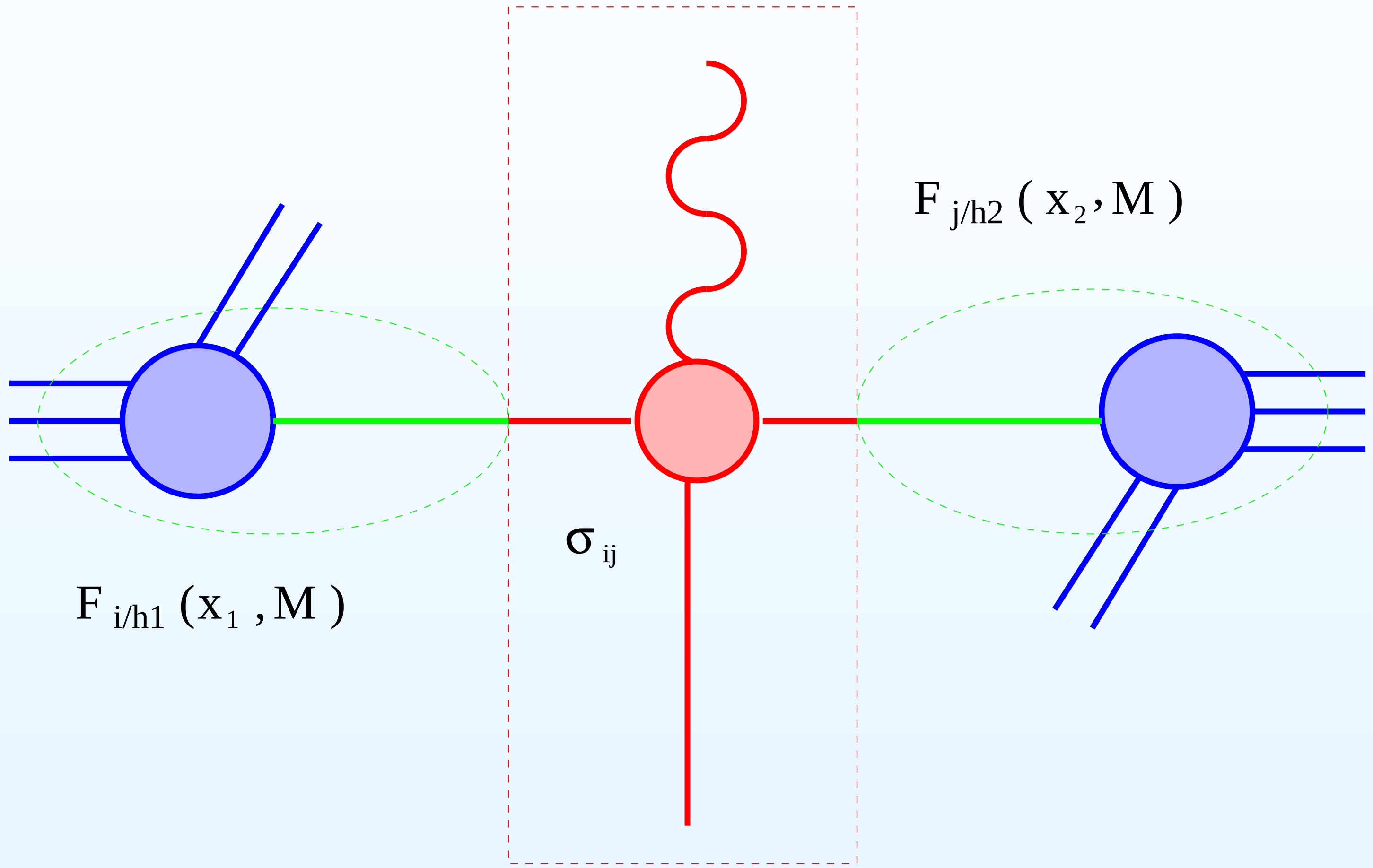
Large domain of energies experimentally studied, a wide variety of observables has been measured (it was thought that photon production gave a clean probe of parton dynamics!!!!!)

Inclusive photon production

Large domain of energies experimentally studied, a wide variety of observables has been measured (it was thought that photon production gave a clean probe of parton dynamics!!!!!)

Theoretical frame: QCD improved parton model: “Fixed order”

Direct



Direct in equation

$$\frac{d\,\sigma^D}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma} = \sum_{i,j=q,g} \int d\,x_1\,d\,x_2\;F_{i/h_1}(x_1, M)\;F_{j/h_2}(x_2, M) \times \frac{\alpha_s(\mu)}{2\,\pi}\;\frac{d\,\hat{\sigma}_{ij}(\mu, M)}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma}$$

$$\frac{\partial\,F_{i/h}(x, M)}{\partial\ln(M)} = \sum_j \frac{\alpha_s(M)}{2\,\pi} F_{j/h}(M) \otimes P_{ij}(\alpha_s(M))$$

Direct in equation

LO (Leading Order)

$$\frac{d\,\sigma^{D}}{d\,\vec{P}_{T\,\gamma}\;d\,y_{\gamma}} = \sum_{i,j=q,g} \int d\,x_1\,d\,x_2\;F_{i/h_1}(x_1, M)\;F_{j/h_2}(x_2, M) \times \frac{\alpha_s(\mu)}{2\,\pi}\;\frac{d\,\hat{\sigma}^{0}_{ij}}{d\,\vec{P}_{T\,\gamma}\;d\,y_{\gamma}}$$

$$\frac{\partial\,F_{i/h}(x, M)}{\partial\,\ln(M)} = \sum_{j} \frac{\alpha_s(M)}{2\,\pi} F_{j/h}(M) \otimes P^{0}_{ij}$$

Direct in equation

NLO (Next-to-Leading Order)

$$\frac{d\,\sigma^D}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma} = \sum_{i,j=q,g} \int d\,x_1\,d\,x_2\;F_{i/h_1}(x_1, M)\;F_{j/h_2}(x_2, M)$$

$$\times\;\frac{\alpha_s(\mu)}{2\,\pi}\left[\frac{d\,\hat{\sigma}^0_{ij}}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma} + \frac{\alpha_s(\mu)}{2\,\pi}\;\frac{d\,\hat{\sigma}^1_{ij}(\mu, M)}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma}\right]$$

$$\frac{\partial\,F_{i/h}(x, M)}{\partial\ln(M)} = \sum_j \frac{\alpha_s(M)}{2\,\pi} F_{j/h}(M) \otimes \left[P^0_{ij} + \frac{\alpha_s(M)}{2\,\pi}\,P^1_{ij}\right]$$

Direct in equation

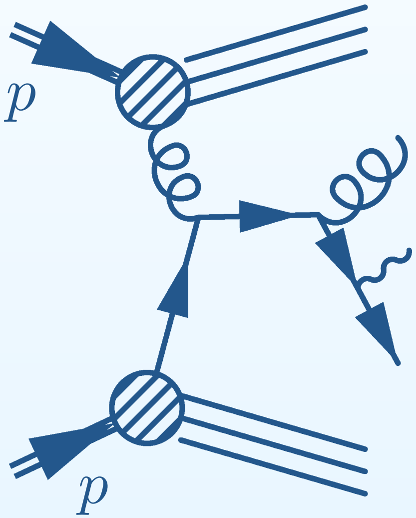
$$\frac{d\,\sigma^D}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma} = \sum_{i,j=q,g} \int d\,x_1\,d\,x_2\;F_{i/h_1}(x_1, M)\;F_{j/h_2}(x_2, M)$$

$$\times\;\frac{\alpha_s(\mu)}{2\,\pi}\;\frac{d\,\hat{\sigma}_{ij}(\mu, M)}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma}$$

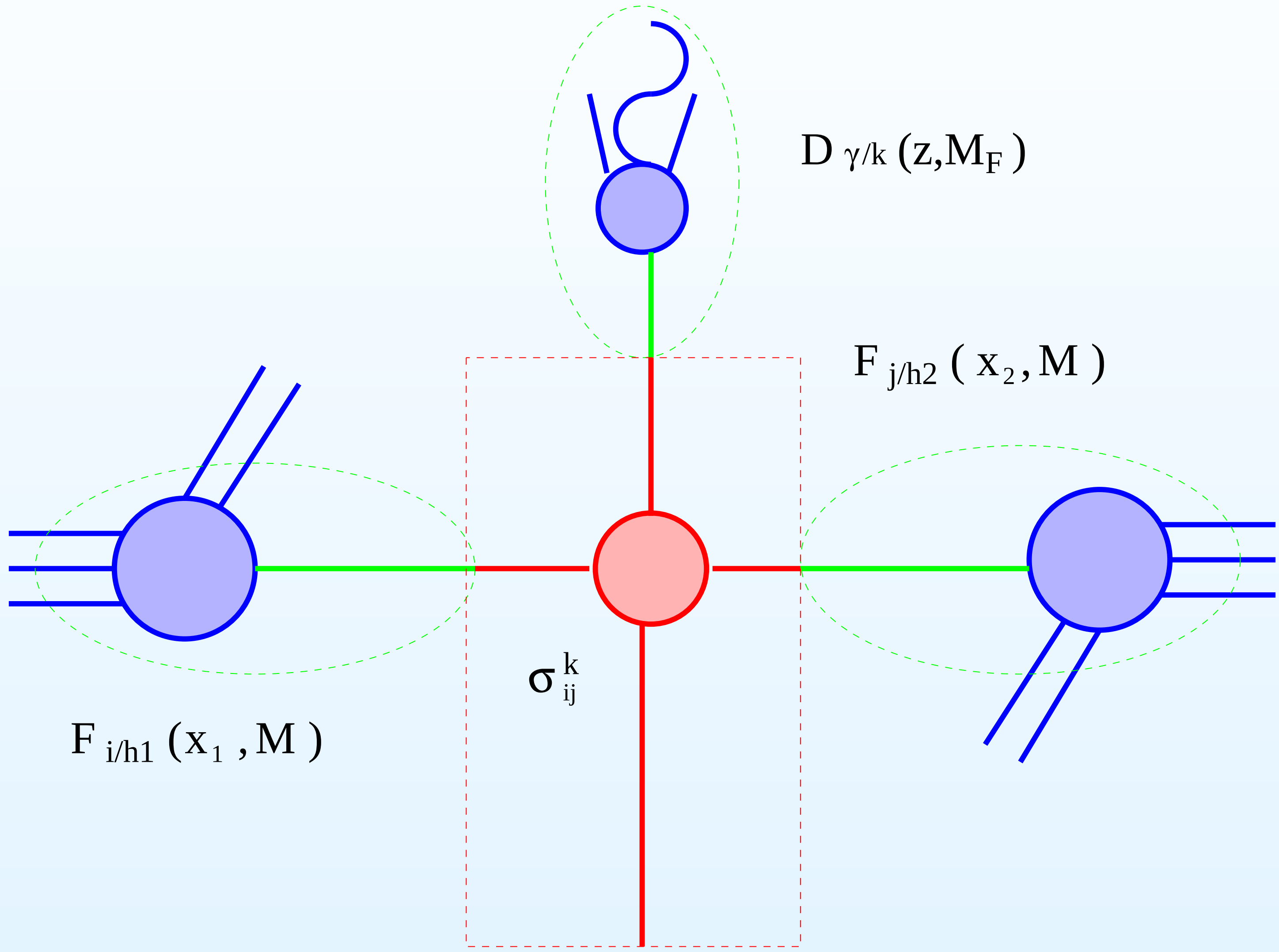
$$\mu\,,\;M \simeq O(P_{T\,\gamma})$$

Additional component for photon production

$O(\alpha_s)$:



Fragmentation



Fragmentation in equation

$$\frac{d\,\sigma^F}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma} = \sum_{i,j,k=q,g} \int d\,x_1\,d\,x_2\,\frac{d\,z}{z} D_{\gamma/k}(z,M_F)\,F_{i/h_1}(x_1,M)$$
$$\times\,F_{j/h_2}(x_2,M)\,\left(\frac{\alpha_s(\mu)}{2\,\pi}\right)^2\,\frac{d\,\hat{\sigma}^k_{ij}(\mu,M,M_F)}{d\,\vec{P}_{T\,k}\;d\,y_k}$$

$$\frac{\partial\,D_{\gamma/k}(z,M_F)}{\partial\ln(M_F)} = P_{\gamma\,k}(\alpha_s(M_F))$$
$$+\sum_j \frac{\alpha_s(M)}{2\,\pi} P_{jk}(\alpha_s(M_F)) \otimes D_{\gamma/j}(M_F)$$

Fragmentation in equation

$$\frac{d\,\sigma^F}{d\,\vec{P}_{T\,\gamma}\,d\,y_\gamma} = \sum_{i,j,k=q,g} \int d\,x_1\,d\,x_2\,\frac{d\,z}{z} D_{\gamma/k}(z, M_F)\,F_{i/h_1}(x_1, M)$$

$$\times\,F_{j/h_2}(x_2, M)\,\left(\frac{\alpha_s(\mu)}{2\,\pi}\right)^2 \frac{d\,\hat{\sigma}^k_{ij}(\mu, M, M_F)}{d\,\vec{P}_{T\,k}\,d\,y_k}$$

$M_F \simeq O(P_{T\,\gamma})$ $\qquad$ $y_k = y_\gamma$

Remarks

- Only the sum $\sigma^D + \sigma^F$ is a physical observable

Remarks

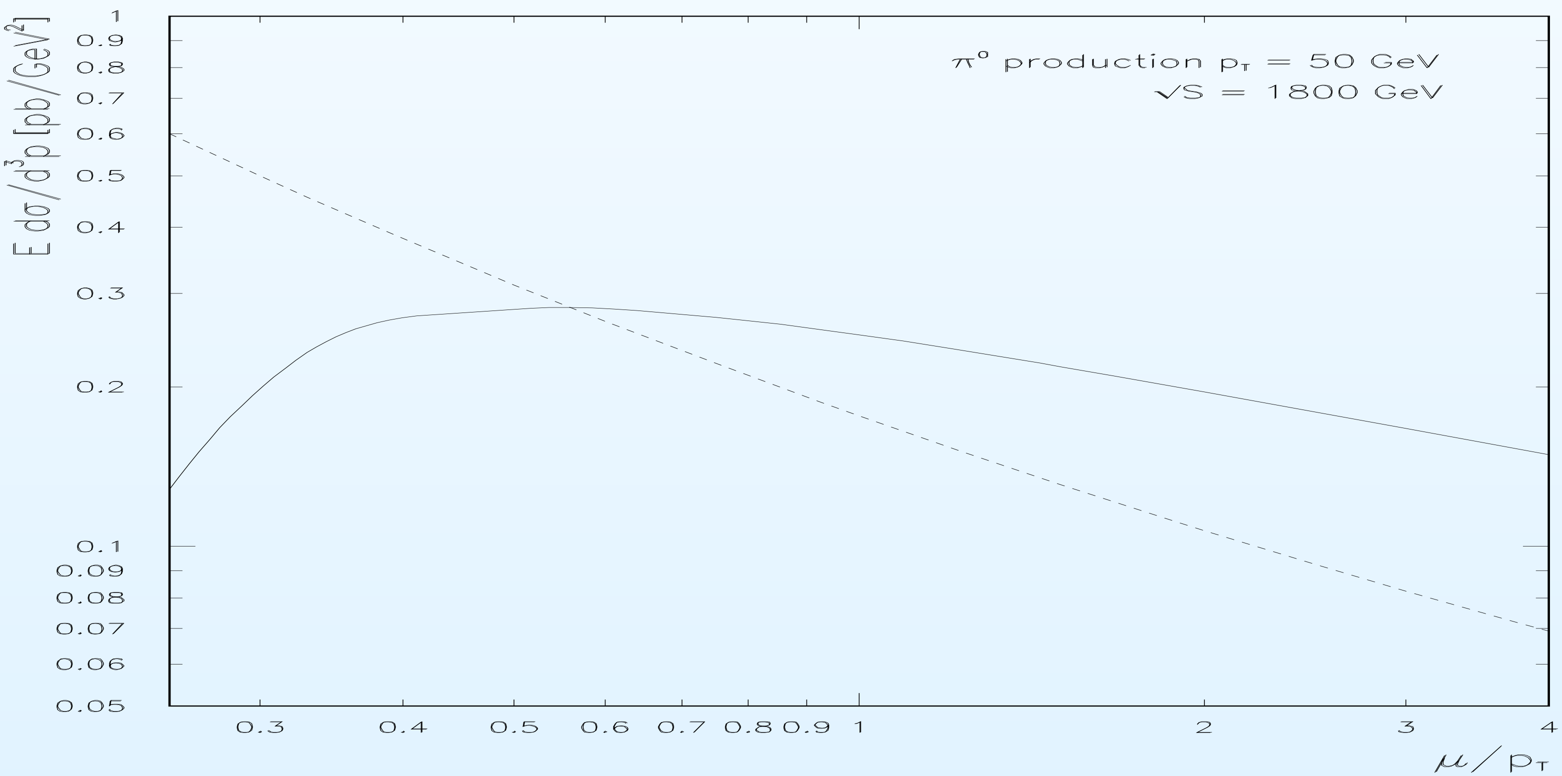
- Only the sum $\sigma^D + \sigma^F$ is a physical observable
- When $M_F \gg$ hadronic scale $D_{\gamma/k}(z, M_F)$ behave like $\alpha/\alpha_s(M_F)$

Remarks

- Only the sum $\sigma^D + \sigma^F$ is a physical observable
- When $M_F \gg$ hadronic scale $D_{\gamma/k}(z, M_F)$ behave like $\alpha/\alpha_s(M_F)$
- Thanks to factorization property, $d\,\sigma^F/(d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma)$ can be used to compute inclusive hadron production by changing $D_{\gamma/k}(z, M_F)$ in $D_{h/k}(z, M_F)$

Why NLO?

$$\frac{\partial}{\partial \ln(M)} \left(\frac{d\,\sigma}{d\,\vec{P}_{T\,\gamma}\;d\,y_\gamma} \right) = O(\alpha_s^{n+1})$$



Validity of this type of calculation

- $\hat{\sigma}_{ij}^{(1)}$ contains other logarithmic terms such as $\ln(x_T)$, $\ln(1 - x_T)$, ... where $x_T = 2\,P_{T\,\gamma}/\sqrt{S}$.

Validity of this type of calculation

- $\hat{\sigma}_{ij}^{(1)}$ contains other logarithmic terms such as $\ln(x_T)$, $\ln(1 - x_T)$, ... where $x_T = 2\,P_{T\,\gamma}/\sqrt{S}$.
  - when $P_{T\,\gamma}$ is close to $\sqrt{S}/2$, the extra gluons are forced to be soft $\longrightarrow$ large logarithms of infra-red origin

Validity of this type of calculation

- $\hat{\sigma}_{ij}^{(1)}$ contains other logarithmic terms such as $\ln(x_T)$, $\ln(1 - x_T)$, ... where $x_T = 2\, P_{T\,\gamma}/\sqrt{S}$.
  - when $P_{T\,\gamma}$ is close to $\sqrt{S}/2$, the extra gluons are forced to be soft $\rightarrow$ large logarithms of infra-red origin
  - when $P_{T\,\gamma} \ll \sqrt{S}$, two scale problem, in this regime, the assumptions of the QCD improved parton model are not valid $\rightarrow$ The Altarelli-Parisi evolution is not correct.

Validity of this type of calculation

- $\hat{\sigma}_{ij}^{(1)}$ contains other logarithmic terms such as $\ln(x_T)$, $\ln(1 - x_T)$, ... where $x_T = 2\, P_{T\,\gamma}/\sqrt{S}$.
  - when $P_{T\,\gamma}$ is close to $\sqrt{S}/2$, the extra gluons are forced to be soft $\longrightarrow$ large logarithms of infra-red origin
  - when $P_{T\,\gamma} \ll \sqrt{S}$, two scale problem, in this regime, the assumptions of the QCD improved parton model are not valid $\longrightarrow$ The Altarelli-Parisi evolution is not correct.
- assumption that the γ produced is collinear to the parent parton $\longrightarrow$ inter jet activity cannot be described by this type of calculation

Validity of this type of calculation

- $\hat{\sigma}_{ij}^{(1)}$ contains other logarithmic terms such as $\ln(x_T)$, $\ln(1 - x_T)$, ... where $x_T = 2\, P_{T\,\gamma}/\sqrt{S}$.
  - when $P_{T\,\gamma}$ is close to $\sqrt{S}/2$, the extra gluons are forced to be soft $\longrightarrow$ large logarithms of infra-red origin
  - when $P_{T\,\gamma} \ll \sqrt{S}$, two scale problem, in this regime, the assumptions of the QCD improved parton model are not valid $\longrightarrow$ The Altarelli-Parisi evolution is not correct.
- assumption that the γ produced is collinear to the parent parton $\longrightarrow$ inter jet activity cannot be described by this type of calculation
- the fragmentation functions are extracted from $e^+\, e^-$ data in a range $.1 < z < .8$. What are the errors due to FF on a γ of 5 GeV?

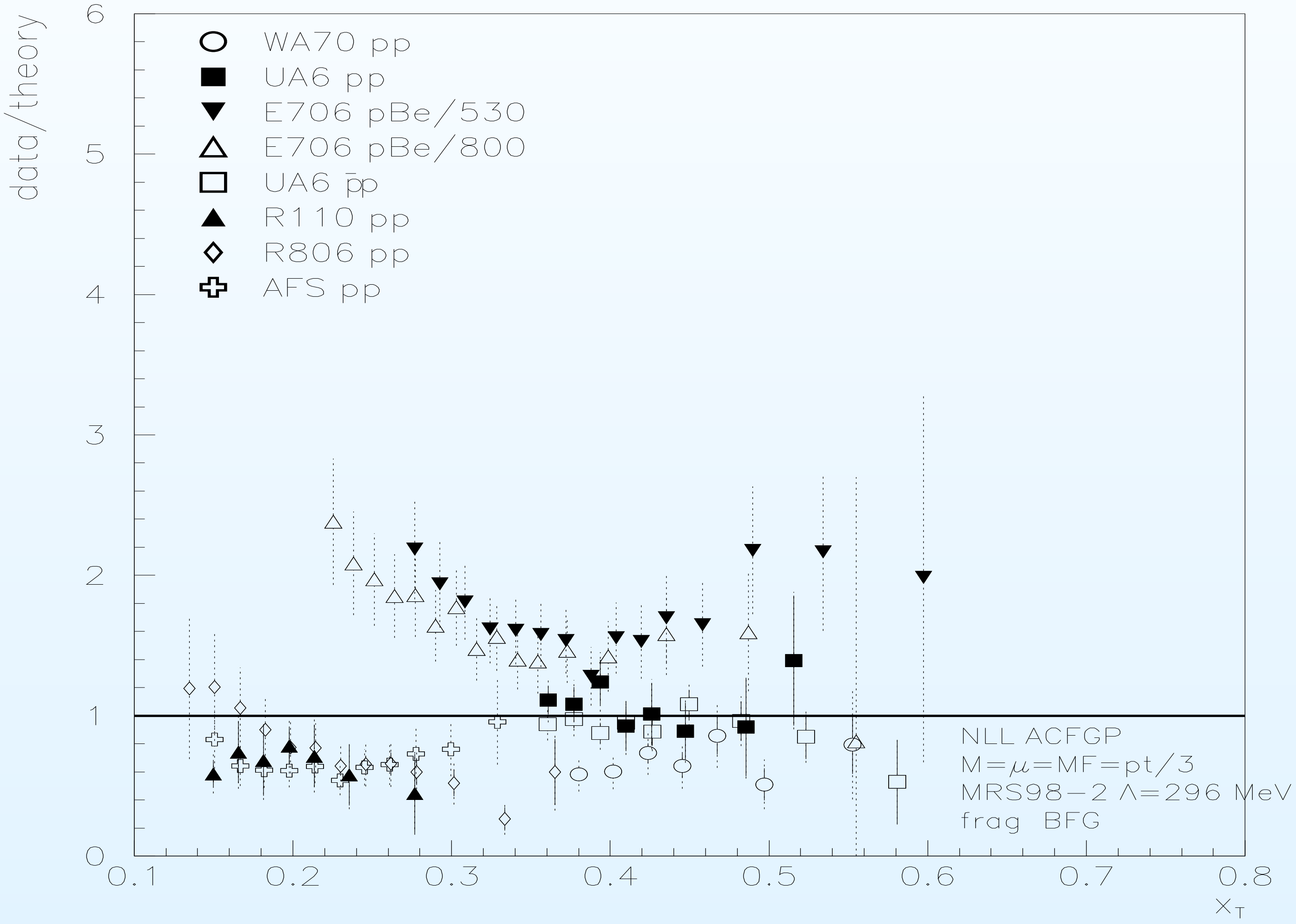
Validity of this type of calculation

- $\hat{\sigma}_{ij}^{(1)}$ contains other logarithmic terms such as $\ln(x_T)$, $\ln(1 - x_T)$, ... where $x_T = 2\, P_{T\,\gamma}/\sqrt{S}$.
  - when $P_{T\,\gamma}$ is close to $\sqrt{S}/2$, the extra gluons are forced to be soft $\longrightarrow$ large logarithms of infra-red origin
  - when $P_{T\,\gamma} \ll \sqrt{S}$, two scale problem, in this regime, the assumptions of the QCD improved parton model are not valid $\longrightarrow$ The Altarelli-Parisi evolution is not correct.
- assumption that the γ produced is collinear to the parent parton $\longrightarrow$ inter jet activity cannot be described by this type of calculation
- the fragmentation functions are extracted from $e^+\, e^-$ data in a range $.1 < z < .8$. What are the errors due to FF on a γ of 5 GeV?
- what about underlying events?

Comparison with fi xed target data

Disagreement between data and theory

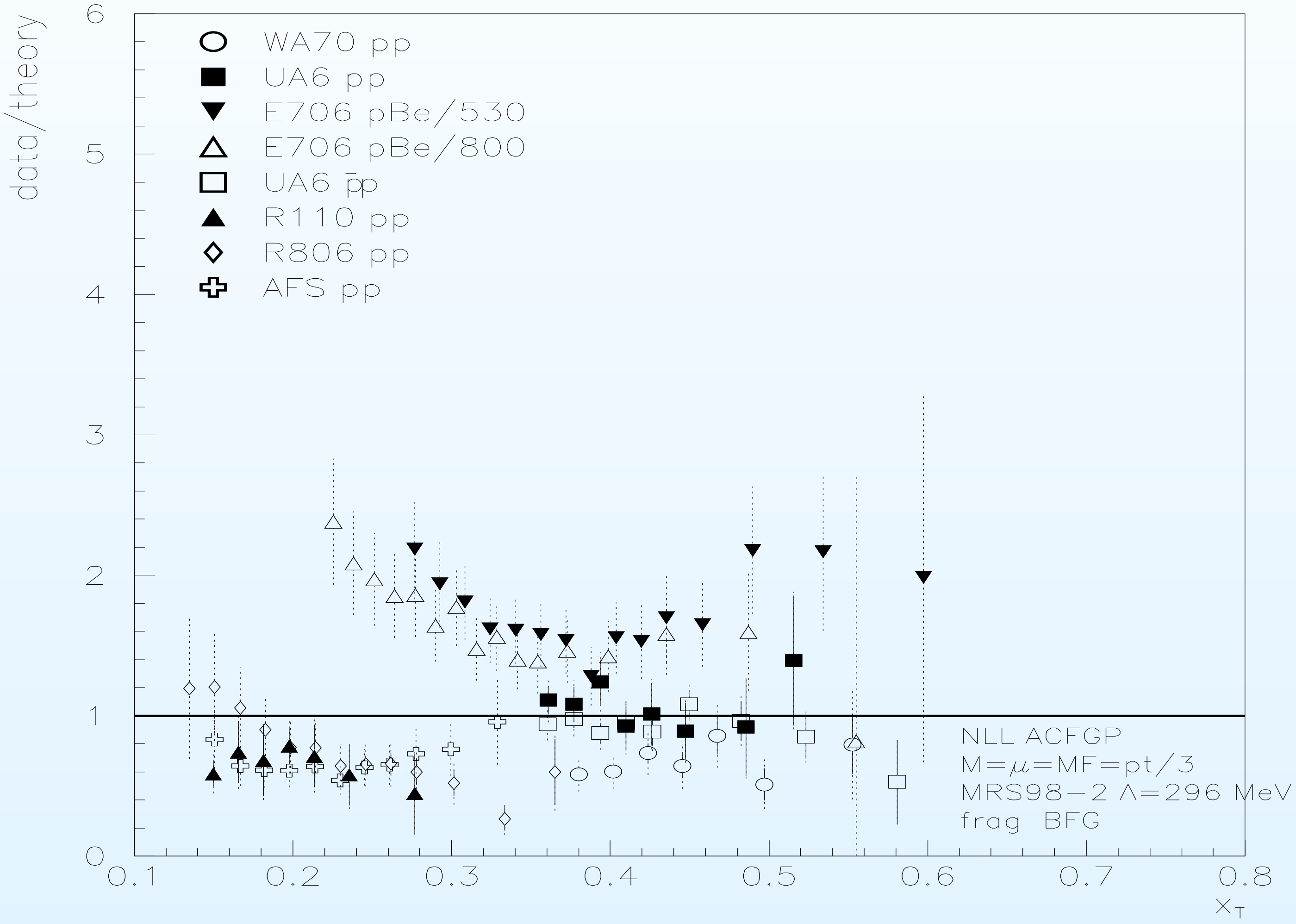
$23 \leq \sqrt{S} \leq 63$ GeV: fi xed target + ISR data



Comparison with fi xed target data

Disagreement between data and theory or disagreement among experimental data???

$23 \leq \sqrt{S} \leq 63$ GeV: fi xed target + ISR data



NLO codes

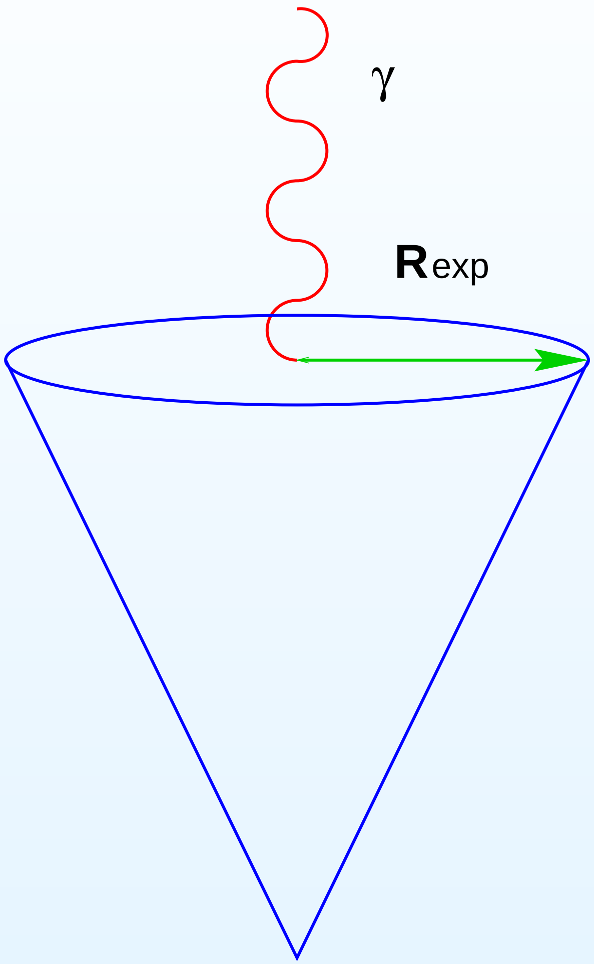
	type of code	Direct	Fragmentation
INCNLO (*)	I/FO	NLO	NLO
Vogelsang, Gordon (*)	I/FO	NLO	NLO
Owens et al. (*)	G/FO	NLO	LO
Frixione, Vogelsang	G/FO	NLO	LO
JETPHOX (*)	G/FO	NLO	NLO

I : Inclusive
G : Generator
FO : Fixed Order

(*) http://wwwlapp.in2p3.fr/lapth/PHOX_FAMILY/main.html

Threshold resummation: (*) Catani et al.
(*) Kidonakis, Owens

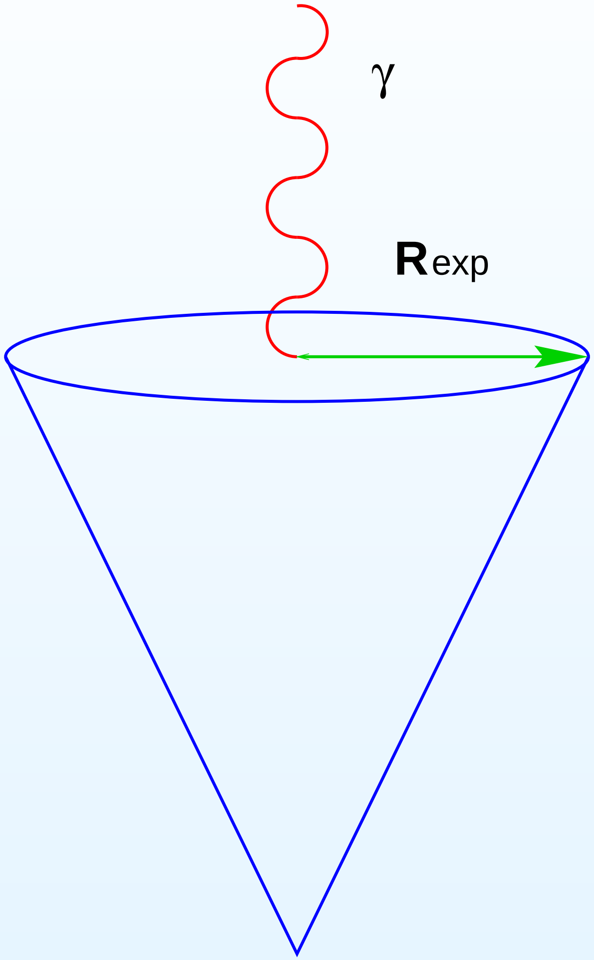
Isolation criterion



$E_T^{had} \leq E_{T\,max}$ inside

$(y - y_\gamma)^2 + (\phi - \phi_\gamma)^2 \leq R_{exp}^2$

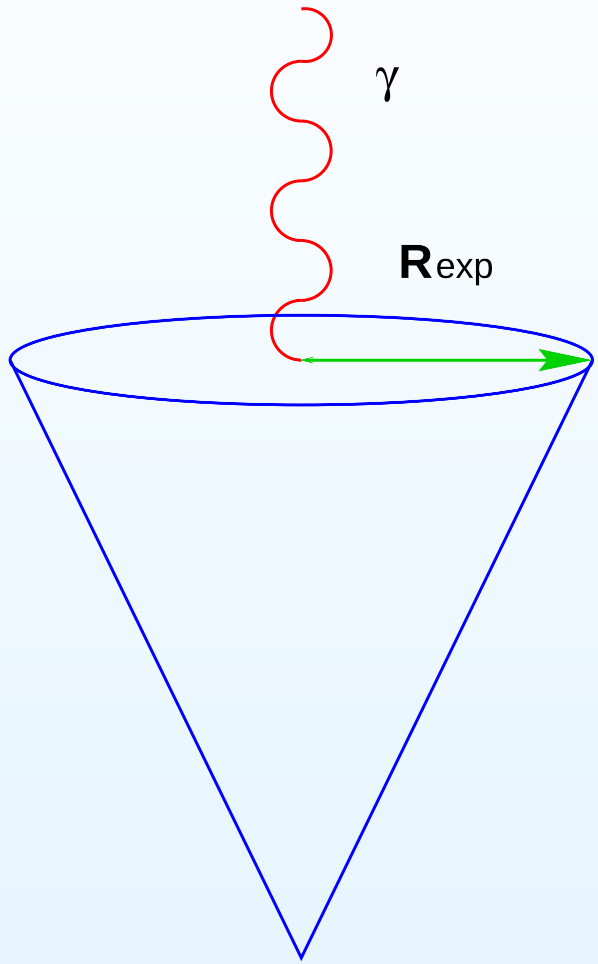
Isolation criterion



$E_T^{had} \le E_{T\,max}$ inside
$(y - y_\gamma)^2 + (\phi - \phi_\gamma)^2 \le R_{exp}^2$

Large Log. when $R_{exp} \to 0$ and $E_{T\,max} \to 0$

Isolation criterion



$E_T^{had} \leq E_{T\,max}$ inside $(y - y_\gamma)^2 + (\phi - \phi_\gamma)^2 \leq R_{exp}^2$

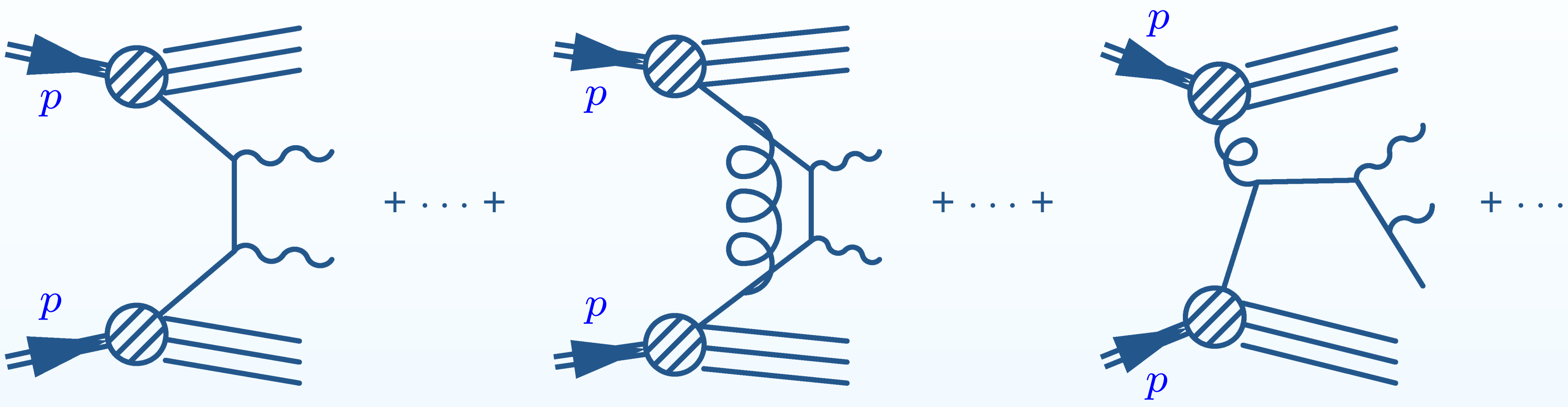
Large Log. when $R_{exp} \rightarrow 0$ and $E_{T\,max} \rightarrow 0$

Other isolation criterion (S. Frixione) where $E_{T\,max} = F(r)$

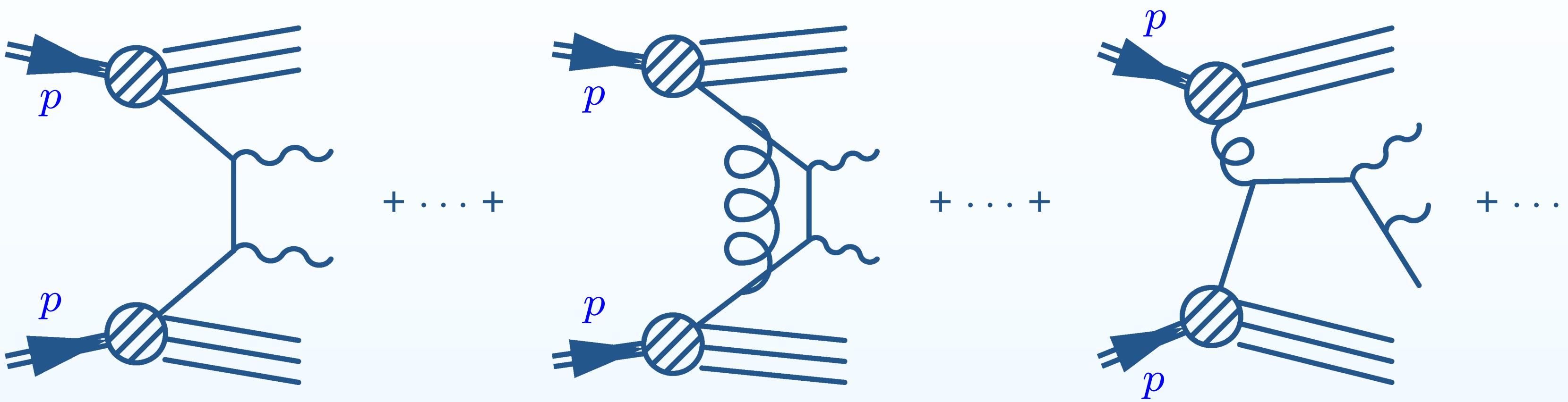
Double photon production

Higgs search at LHC ($M_{Higgs} \leq 140$ GeV)

Direct

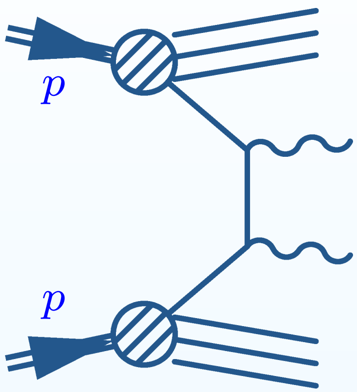


Direct

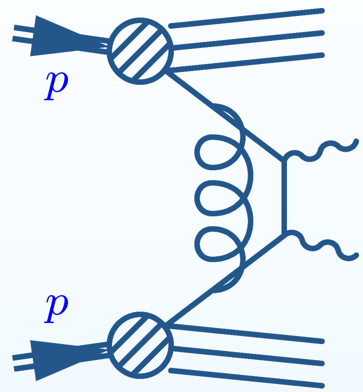


$O(\alpha^2) + O(\alpha^2\ \alpha_s)$

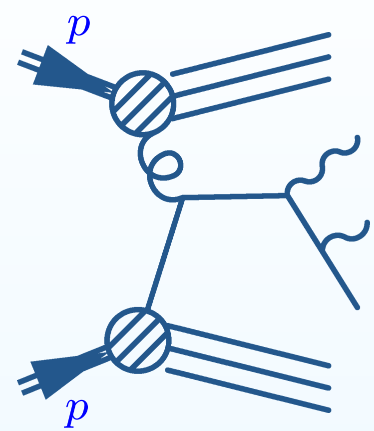
Direct



$+ \cdots +$

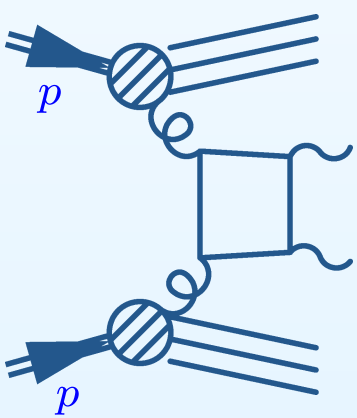


$+ \cdots +$



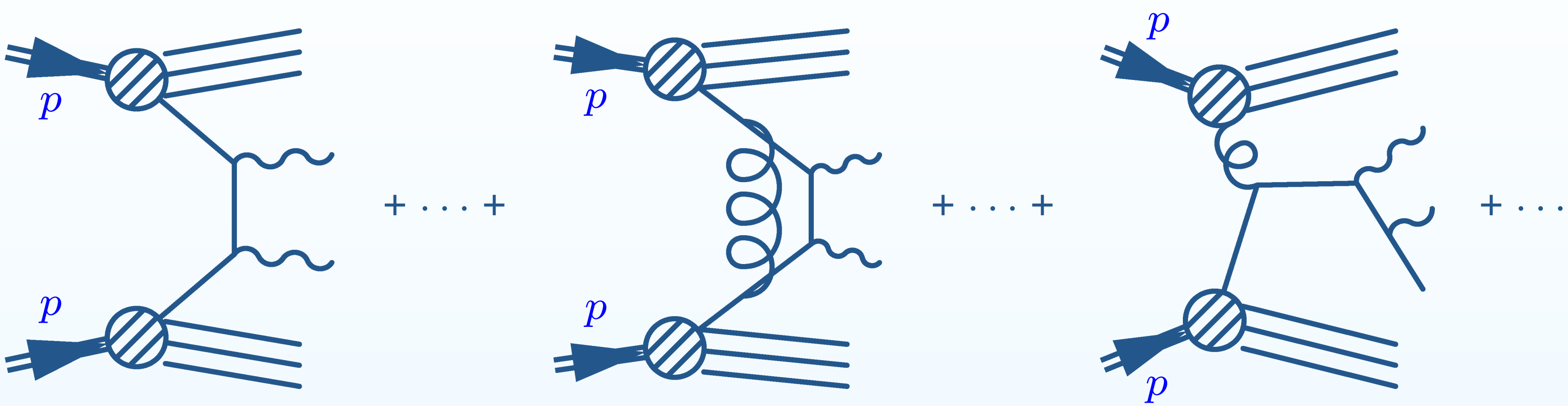
$+ \cdots$

$O(\alpha^2) + O(\alpha^2\ \alpha_s)$

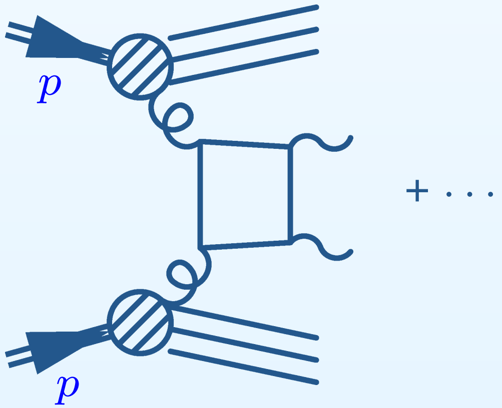


$+ \cdots$

Direct

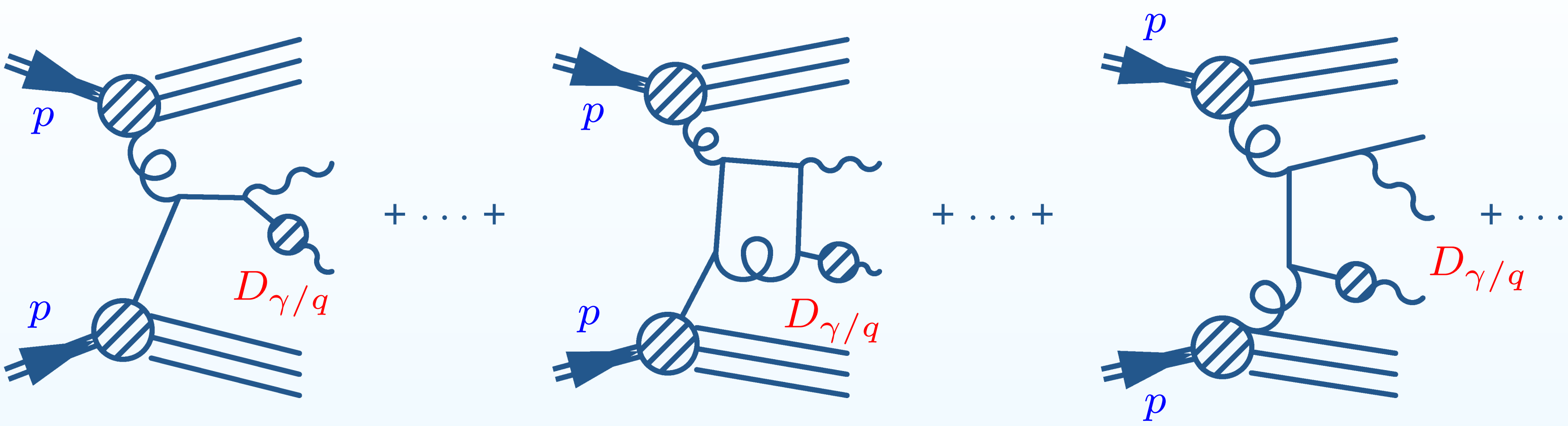


$O(\alpha^2) + O(\alpha^2\ \alpha_s)$

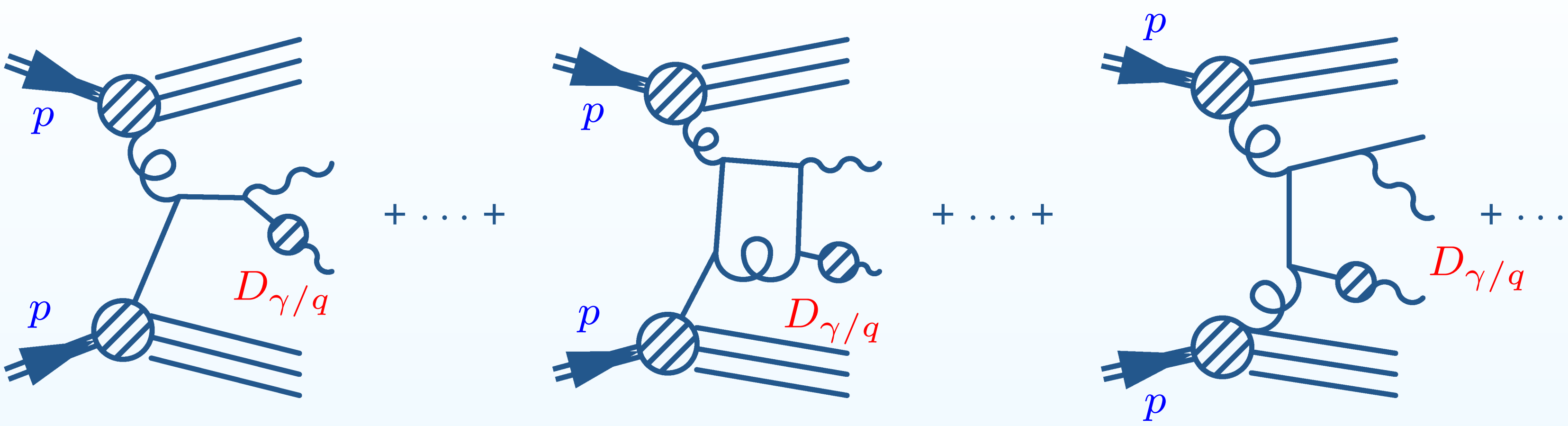


$O(\alpha^2\ \alpha_s^2)$

One Fragmentation

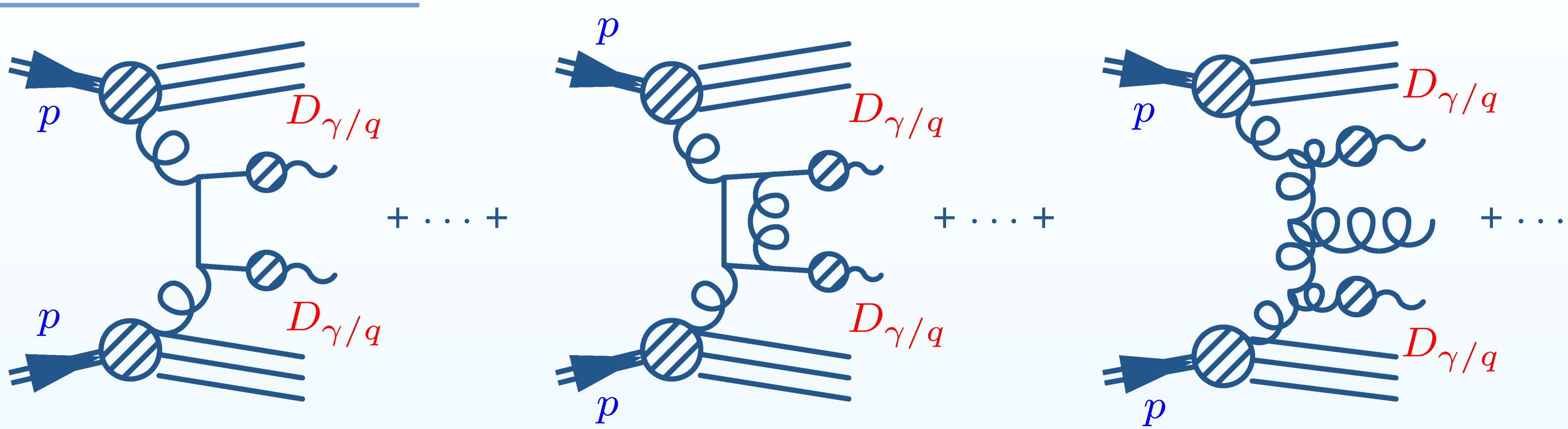


One Fragmentation

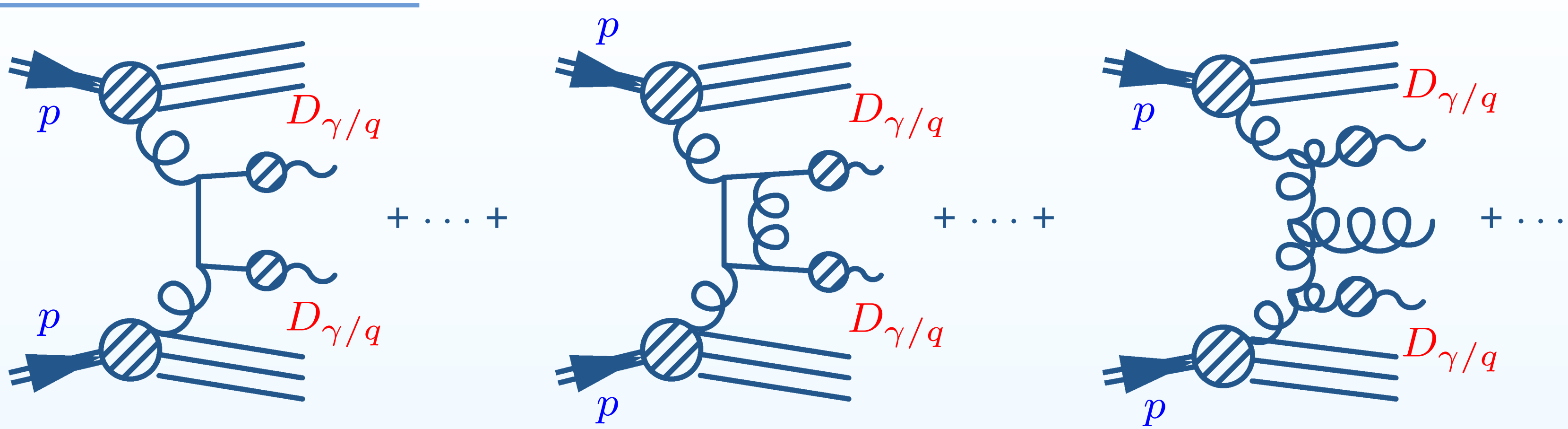


$O(\alpha^2\ \alpha_s)$ + $O(\alpha^2\ \alpha_s^2)$ but $D_{\gamma/q}(z, M_f^2) \simeq 1/\alpha_s(M_f^2)$

Two Fragmentation



Two Fragmentation



$O(\alpha^2\ \alpha_s^2) + O(\alpha^2\ \alpha_s^3)$

NLO codes

	type of code	Direct	One Frag.	Two Frag.
Aurenche et al.	I/FO	NLO	LO	none
Owens et al.	G/FO	NLO	LO	none
DIPHOX (*)	G/FO	NLO	NLO	NLO
RESBOS	G/SGS	NLO	LO	none

I : Inclusive
G : Generator
FO : Fixed Order
SGS: Soft Gluon Summation

(*) http://wwwlapp.in2p3.fr/lapth/PHOX_FAMILY/main.html

Comparison with existing data

Preliminary CDF runII data (Y. Liu)

$P_{T\gamma_1} > 14$ GeV, $P_{T\gamma_2} > 13$ GeV, $|y_{\gamma_{1,2}}| < 0.9$

Photon isolation:

$E_T^{had} \leq 4$ GeV in a cone of $R_{exp} = 0.4$

Acollinearity cut between the photons:

$R_{min} \; : \; \sqrt{(y_{\gamma_1} - y_{\gamma_2})^2 - (\Phi_{\gamma_1} - \Phi_{\gamma_2})^2} > 0.3$

Scale choice:

μ = M = M$_f$ = $M_{\gamma\,\gamma}$/2

also Data points D0 (RunI never published!!) (Wei Chen Ph.D.Thesis)

$P_{T\gamma_1} > 14.9$ GeV, $P_{T\gamma_2} > 13.85$ GeV, $|y_{\gamma_{1,2}}| < 1$

Photon isolation:

$E_T^{had} \leq 2$ GeV in a cone of $R_{exp} = 0.4$

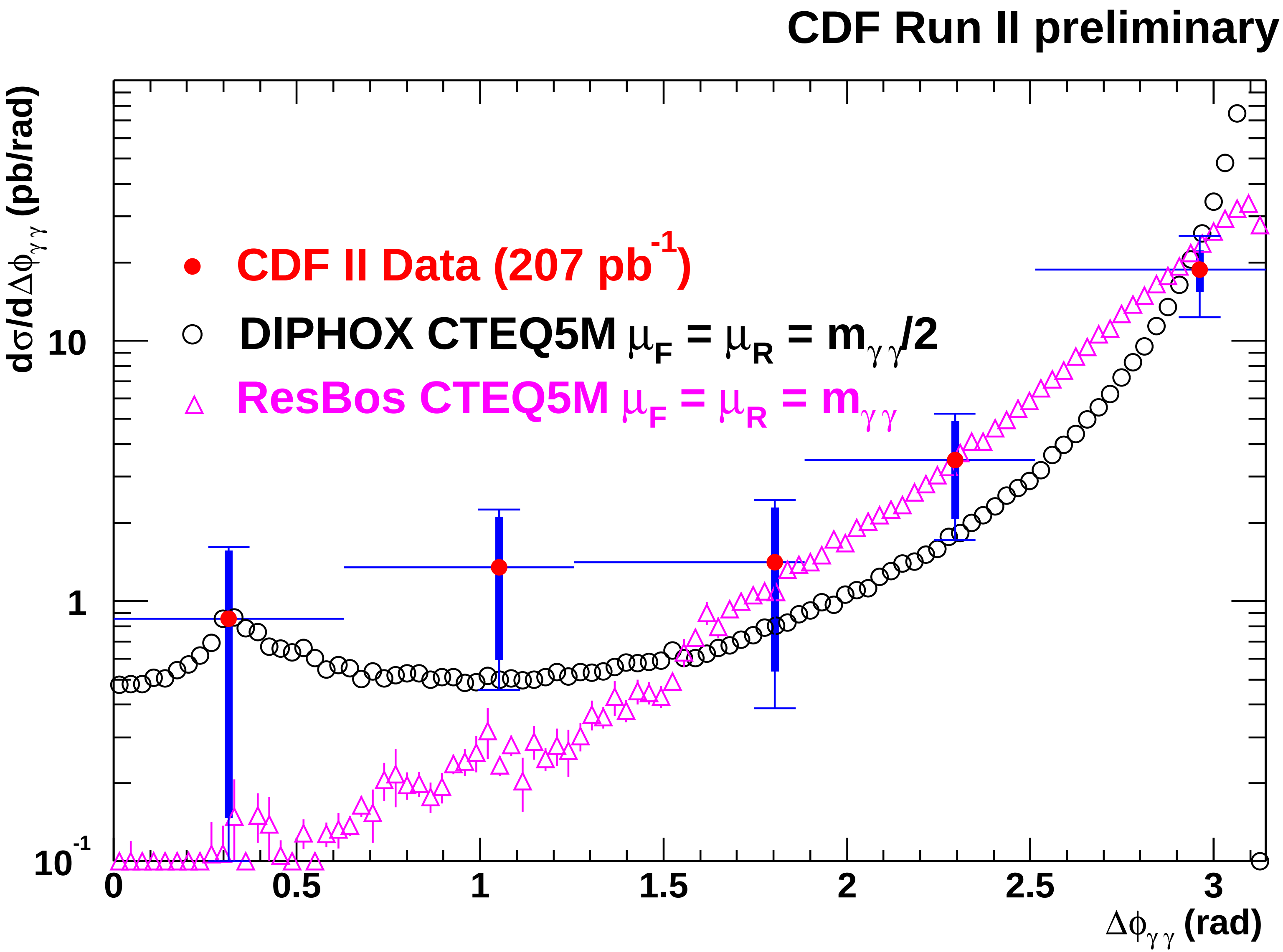
Acollinearity cut between the photons:

$R_{min} \; : \; \sqrt{(y_{\gamma_1} - y_{\gamma_2})^2 - (\Phi_{\gamma_1} - \Phi_{\gamma_2})^2} > 0.3$

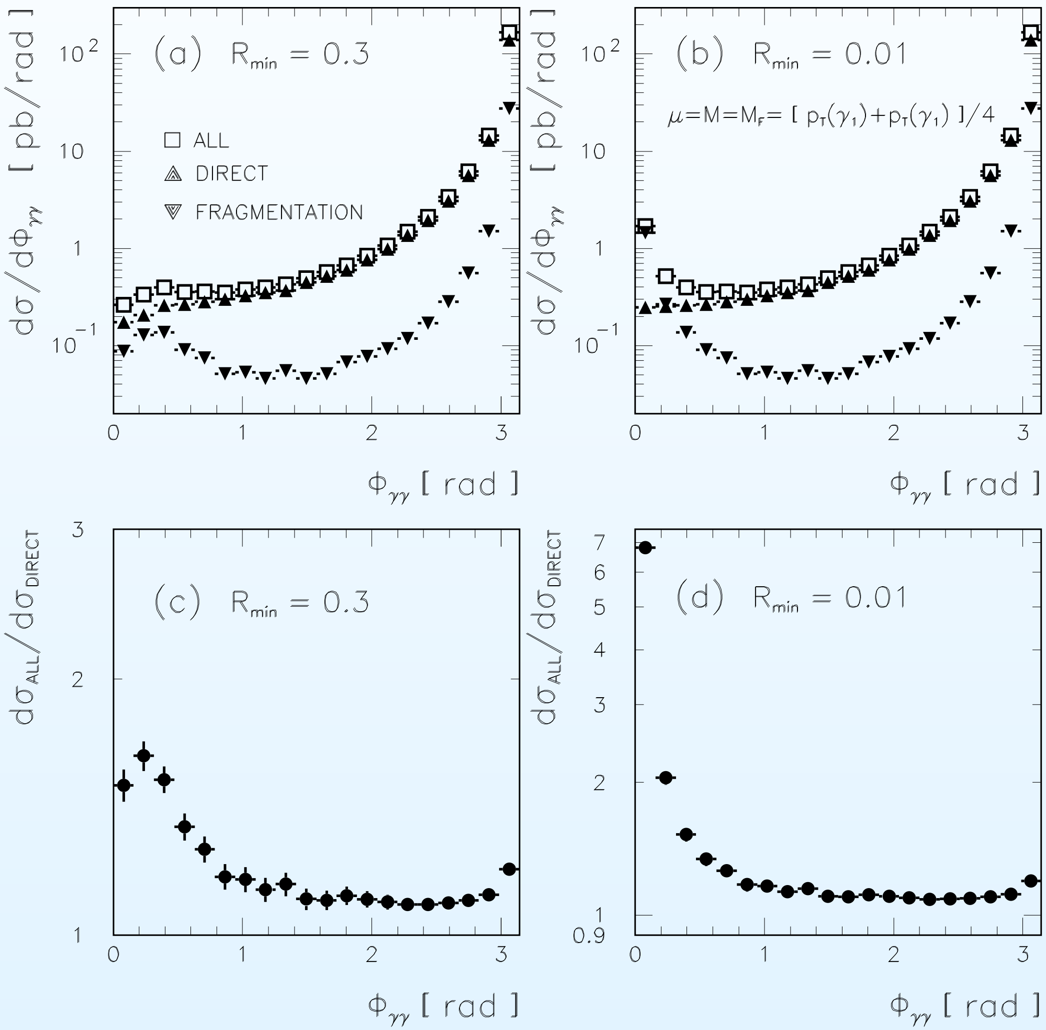
Scale choice:

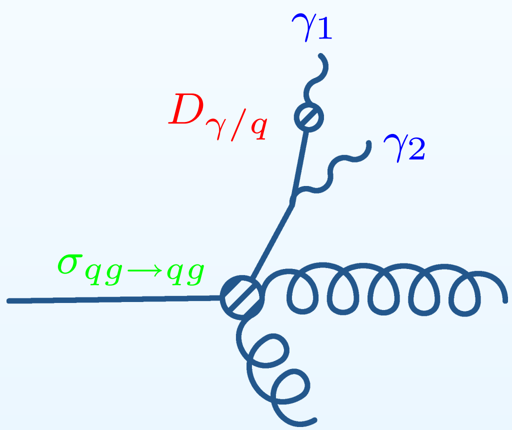
μ = M = M$_f$ = $(P_{T\gamma_1} + P_{T\gamma_2})$/4

Azymuthal angle distribution

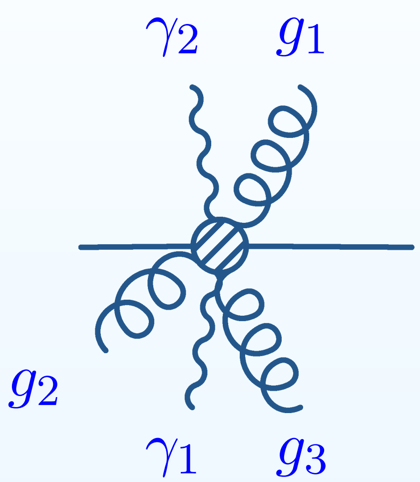


Enhancement at $\phi_{\gamma\gamma} = 0$



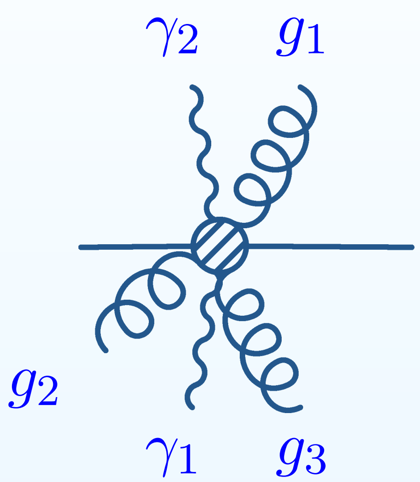


Divergence of IR origin at the end of phase space



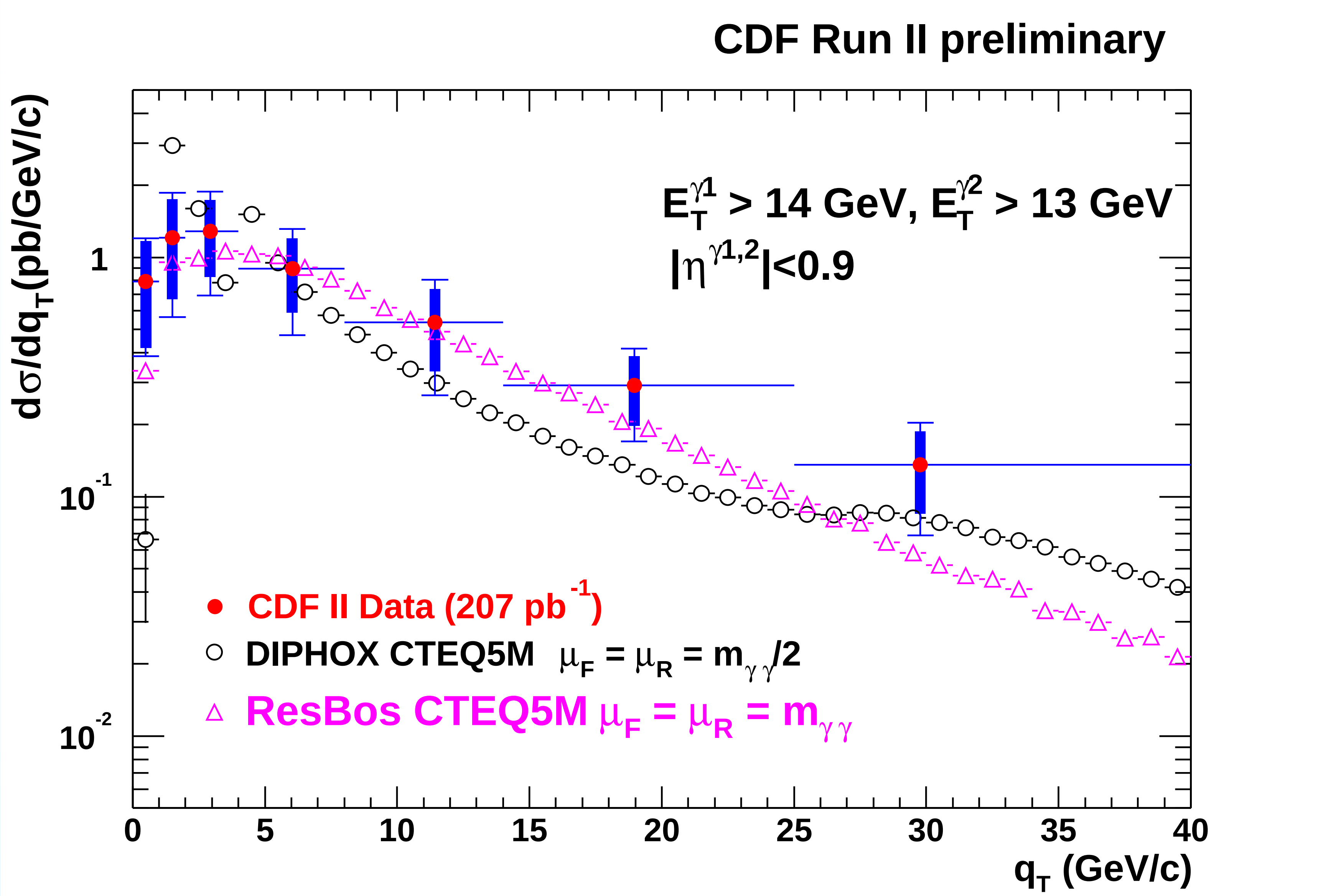
- $\phi_{\gamma\gamma} \simeq \pi$ dominated by config. where the extra gluons are forced to be either soft or collinear to the initial or final state $\rightarrow$ large logarithms of infra-red origin

Divergence of IR origin at the end of phase space

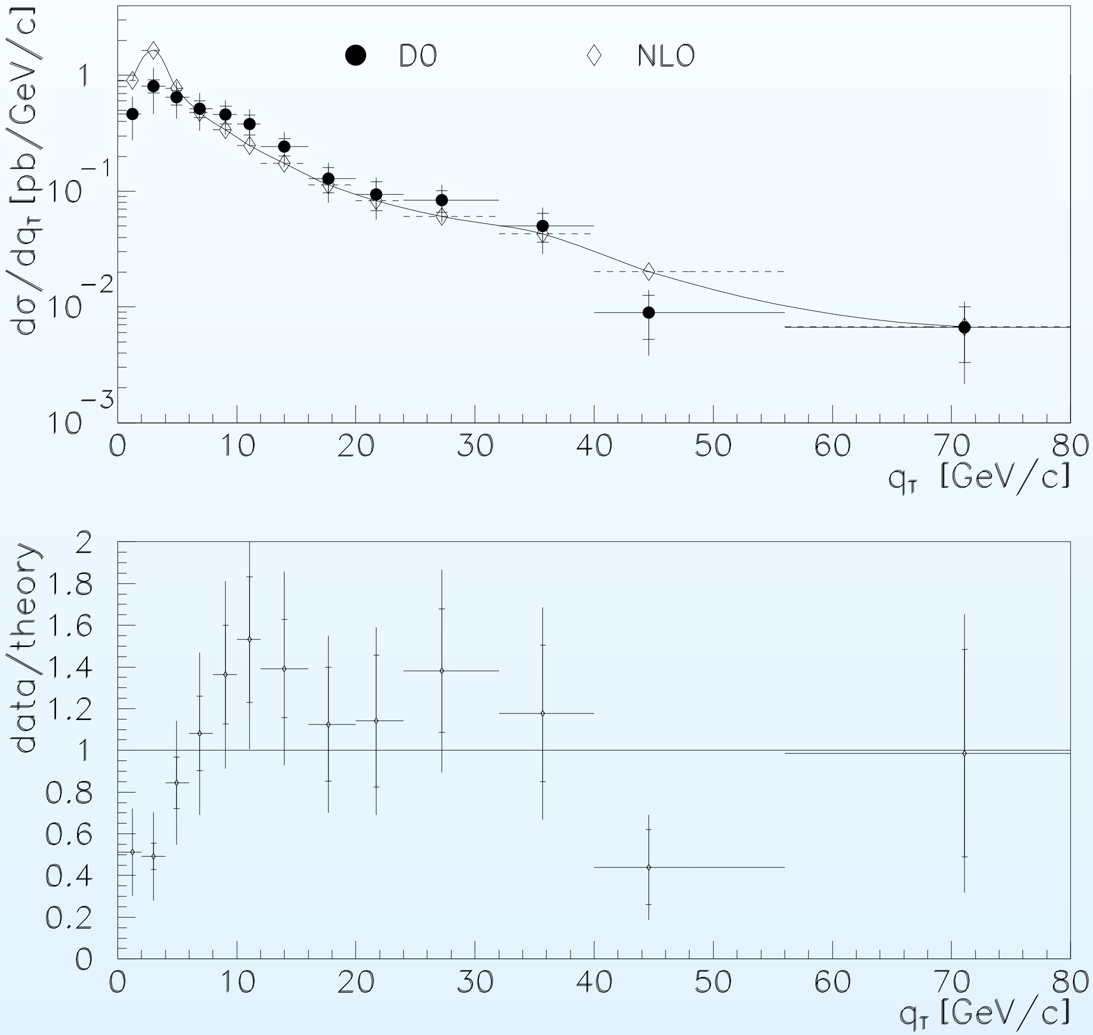


- $\phi_{\gamma\,\gamma} \simeq \pi$ dominated by config. where the extra gluons are forced to be either soft or collinear to the initial or final state $\longrightarrow$ large logarithms of infra-red origin
- $q_T \simeq 0$ dominated by config where the extra gluons are forced to be either soft or collinear to the initial state $\longrightarrow$ large logarithms of infra-red origin

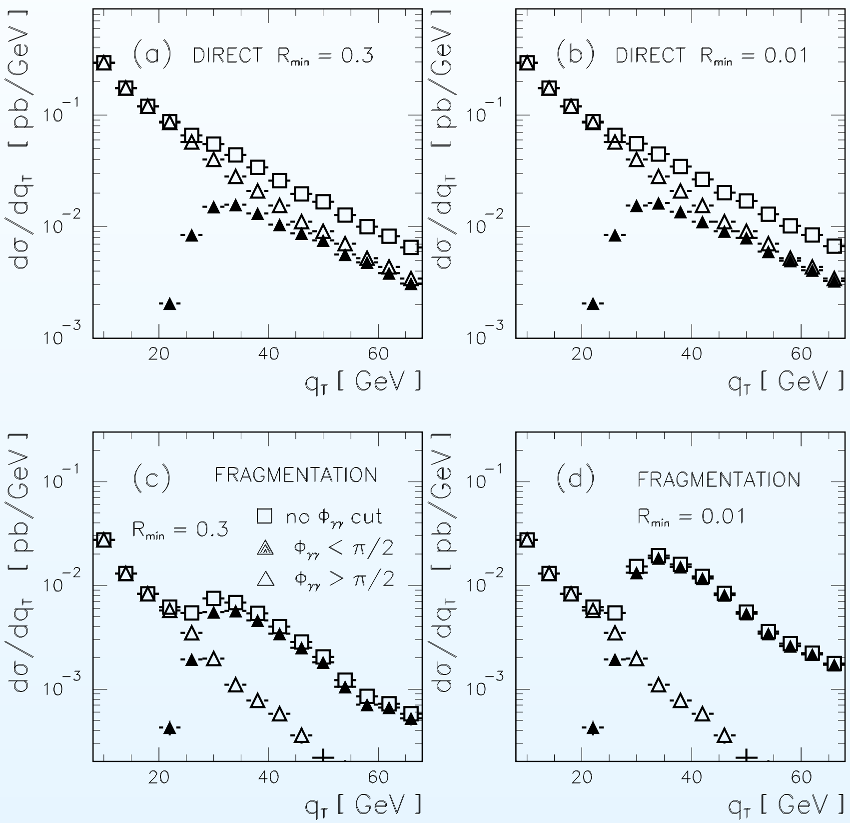
q_T of the pair distribution



q_T of the pair distribution: D0



q_T shoulder

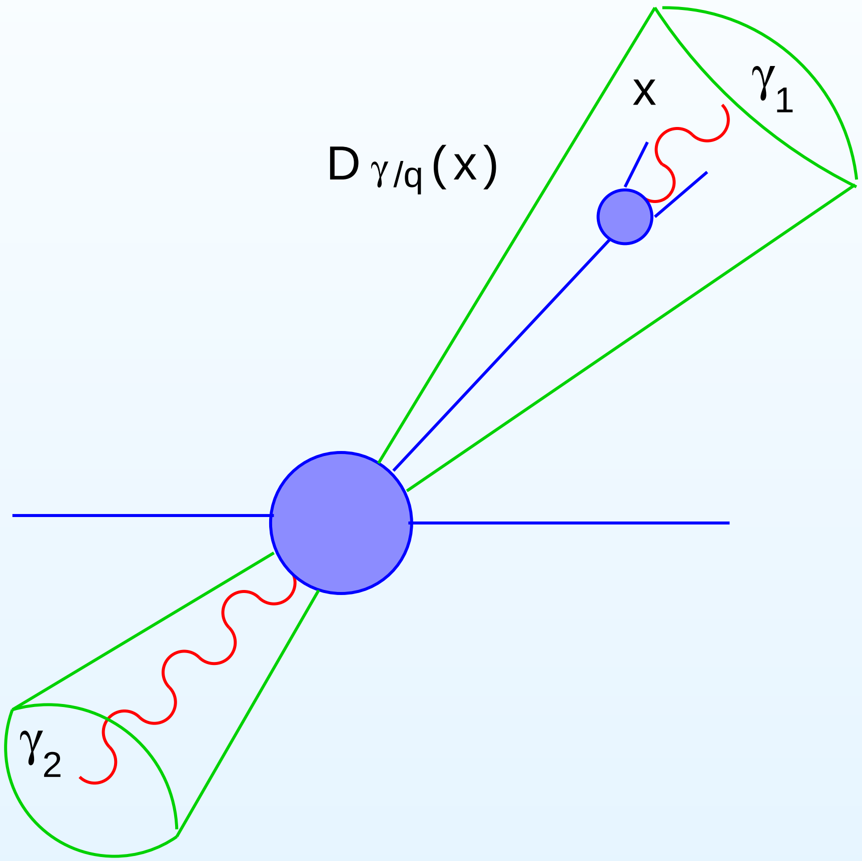


$$q_T^2 = |\vec{P}_{T\,\gamma_1} + \vec{P}_{T\,\gamma_2}|^2$$
$$= P_{T\,\gamma_1}^2 + P_{T\,\gamma_2}^2$$
$$+ 2\,P_{T\,\gamma_1}\,P_{T\,\gamma_2}\,\cos\Phi_{\gamma\gamma}$$

$$q_{T\,min} = \sqrt{P_{T\,\gamma_1\,min}^2 + P_{T\,\gamma_2\,min}^2} \simeq 20.34\ \text{GeV}$$

$$q_{T\,lim} = P_{T\,\gamma_1\,min} + P_{T\,\gamma_2\,min} \simeq 28.75\ \text{GeV}$$

Divergence of IR origin inside spectrum



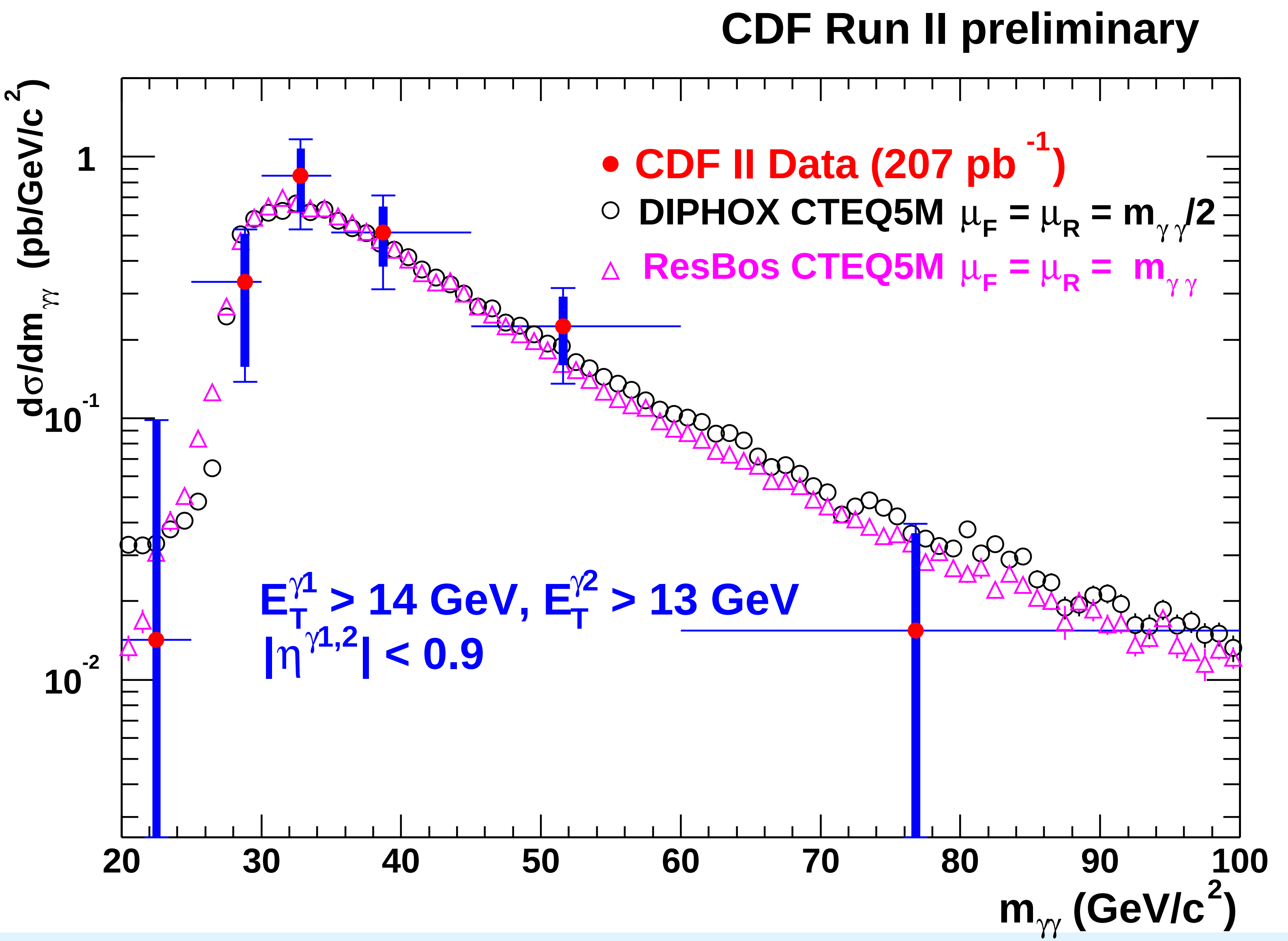
For one fragmentation, at LO:

$$
\begin{aligned}
q_T &= |\vec{P}_{T\gamma_1} + \vec{P}_{T\gamma_2}| \\
&= (1-x)\, P_{T\gamma_2} \\
&= E_T^{had}
\end{aligned}
$$

Because of isolation criterion:

$$\frac{d\sigma^{LO}}{dq_T} \simeq \Theta(E_{T\,max} - q_T)\,\sigma$$

Invariant mass distribution



Conclusion

- Needs for new data on inclusive photon production (RHIC, RUNII)

Conclusion

- Needs for new data on inclusive photon production (RHIC, RUNII)
- Two photon production at Tevatron is understood, waiting for LHC