On the possibility of measuring the gluon distribution using "$\gamma/Z^0 + jet$" events at Tevatron Run II and LHC

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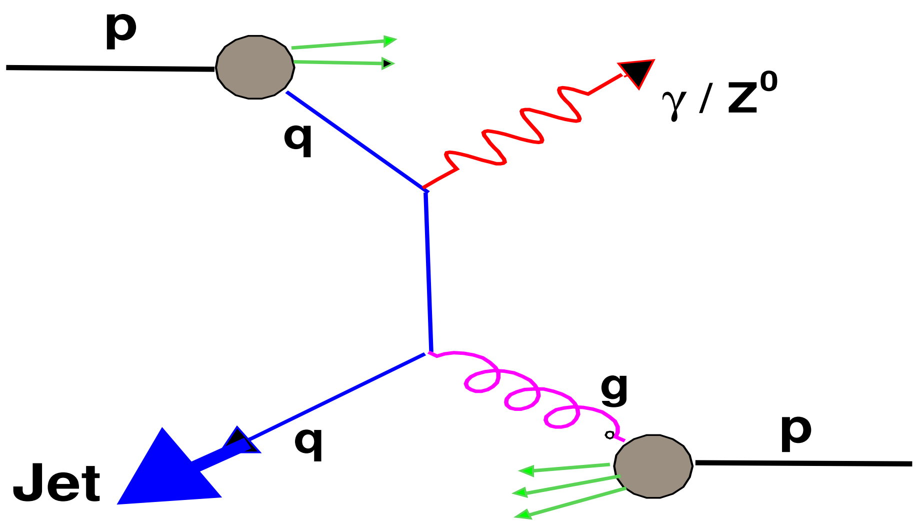


- "$\gamma+jet$" events: D0 Note 3948, 2002, hep-ex/0203003;
- "$Z^0 + jet$" events: hep-ex/0209039.

Physical goals

— **absolute jet energy scale (JES) determination**

(“raw *in situ*” sample)

$\rightarrow$ **reduction of** ΔM_{top}

— **determination of gluon distribution (“bkgd suppr.” sample)**

$\rightarrow$ $G^p(x,Q^2)$ **in new** $x - Q^2$ **region:**

$$1.6 \cdot 10^3 < Q^2 < 2 \cdot 10^4 \; GeV^2$$

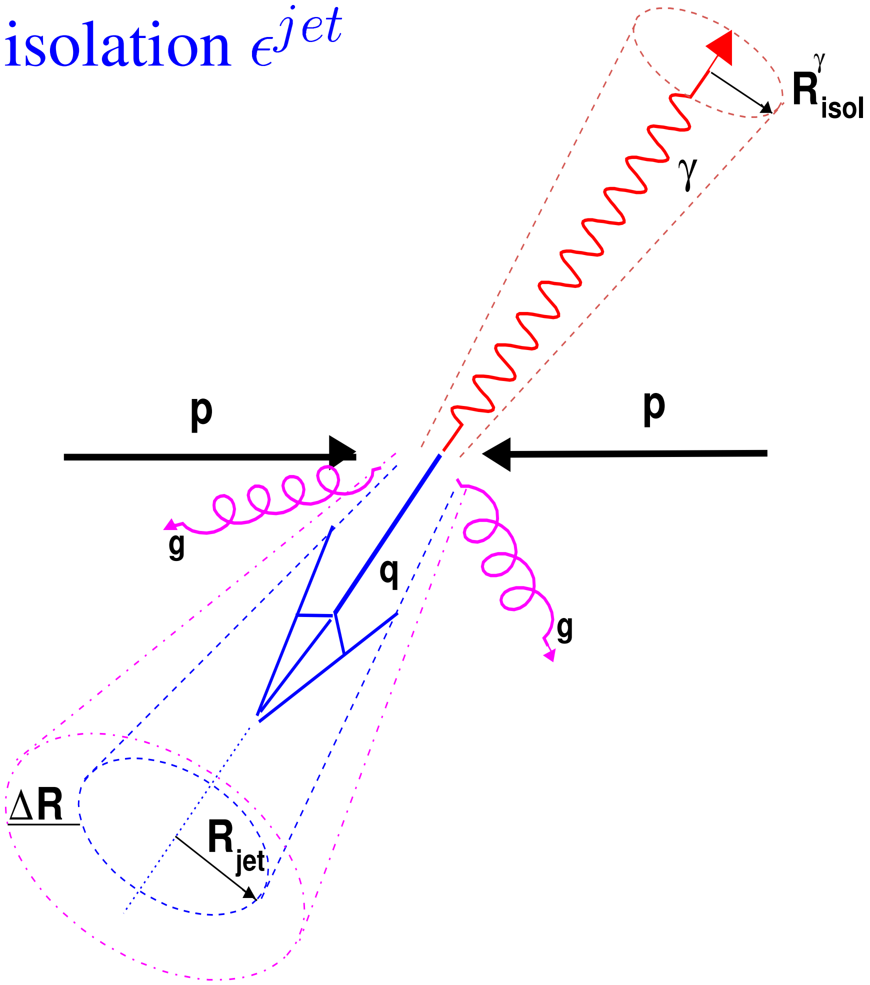
$$2 \cdot 10^{-3} < x < 1.0 \quad \textbf{(Tevatron Run II)}$$

$$1.6 \cdot 10^3 < Q^2 < 8 \cdot 10^4 \; GeV^2$$

$$2 \cdot 10^{-4} < x < 1.0 \quad \textbf{(LHC)}$$

- **D.V. Bandurin, N.B. Skachkov, “$\gamma + jet$” events at Tevatron, D0 Note 3948, 2002, hep-ex/0203003;**
- **D.V. Bandurin, V.F. Konoplyanikov, N.B. Skachkov. “$\gamma + jet$” events at LHC, hep-ex/0207028.**

- ISR clusters P_t;
- P_t^{out};
- jet isolation ϵ^{jet}



... and cuts on them to select "$\gamma/Z + jet$" events (used to suppress ISR/FSR/fragmentation effects):

- $P_t^{clust} < P_{tCUT}^{clust}$ $\;(= 5-15\; GeV/c)$;
- $P_t^{out} \equiv \left| \sum\limits_{i \notin jet, \gamma-dir} \vec{P}_t^{\,i} \right| \leq P_{tCUT}^{out}$ $\;(= 5-15\; GeV/c)$, $\;|\eta^i| \leq \eta_{max}$;
- $\epsilon^{jet} \equiv P_t^{ring}/P_t^{jet} \leq \epsilon_0^{jet}$, $\;(\epsilon_0^{jet} = .03 - .05)$,

  where $P_t^{ring} = \sum\limits_{i \in 0.7 \leq R \leq 1.0} |\vec{P}_t^{\,i}|$.

Background suppression

List of the applied cuts for selection of "$\gamma + jet$" events.

0. No cuts;

1. $a)$ $P_t^{\tilde\gamma} \geq 40\ GeV/c$, $b)$ $|\eta^{\tilde\gamma}| \leq 2.61$, $c)$ $P_t^{jet} \geq 30\ GeV/c$, $d) P_t^{hadr} < 10\ GeV/c^*$;

2. $\epsilon^{\tilde\gamma} \leq 15\%$;

3. $P_t^{\tilde\gamma} \geq \hat{p}_\perp^{\,min}$;

4. $\epsilon^{\tilde\gamma} \leq 5\%$;

5. $P_t^{isol} \leq 2\ GeV/c$;

6. $Njet = 1$;

7. $\Delta\phi < 15°$;

8. $P_t^{miss} \leq 10\ GeV/c$;

9. $P_t^{clust} < 20\ GeV/c$;

10. $P_t^{clust} < 15\ GeV/c$;

11. $P_t^{clust} < 10\ GeV/c$;

12. $P_t^{out} < 20\ GeV/c$;

13. $P_t^{out} < 15\ GeV/c$;

14. $P_t^{out} < 10\ GeV/c$;

15. $\epsilon^{jet} \leq 5\%$.

$*$ P_t of a hadron in the 5x5 ECAL cell window containing the γ^{dir}-candidate in the center.

S/B and efficiencies for $\hat{p}_\perp^{\,min}$=100 GeV/c (LHC)

Cut	S	B^*	$Eff_S(\%)$	$Eff_{B^*}(\%)$	S/B^*	$e^\pm$
0	19420	5356.E+6			0.00	3.9E+6
1	19359	1151425	100.00 $\pm$ 0.00	100.000 $\pm$ 0.000	0.02	47061
2	18236	65839	94.20 $\pm$ 0.97	5.718 $\pm$ 0.023	0.28	8809
3	15197	22437	78.50 $\pm$ 0.85	1.949 $\pm$ 0.013	0.71	2507
4	14140	9433	73.04 $\pm$ 0.81	0.819 $\pm$ 0.008	1.50	2210
5	8787	4549	45.39 $\pm$ 0.59	0.395 $\pm$ 0.006	1.93	1306
6	4844	813	25.02 $\pm$ 0.40	0.071$\pm$ 0.002	5.96	505
7	4634	709	23.94 $\pm$ 0.39	0.062 $\pm$ 0.002	6.54	406
8	4244	650	21.92 $\pm$ 0.37	0.056 $\pm$ 0.002	6.53	87
9	3261	345	16.84 $\pm$ 0.32	0.030 $\pm$ 0.002	9.45	53
10	2558	194	13.21 $\pm$ 0.28	0.017 $\pm$ 0.001	13.19	41
11	1605	91	8.29 $\pm$ 0.22	0.008 $\pm$ 0.001	17.64	26
12	1568	86	8.10 $\pm$ 0.21	0.007 $\pm$ 0.001	18.23	26
13	1477	77	7.63 $\pm$ 0.21	0.007 $\pm$ 0.001	19.18	25
14	1164	52	6.01 $\pm$ 0.18	0.005 $\pm$ 0.001	22.38	22
15	1112	46	5.74 $\pm$ 0.18	0.004 $\pm$ 0.001	24.17	21

$*$ The background B^* is considered here with no account of contribution from the "$e^\pm$ events" in which $e^\pm$'s appear as γ^{dir}-candidates, separated into the column "$e^\pm$".

- γ/mes discriminations: hep-ex/0108050, hep-ex/0108051
- $q\ jet/g\ jet$ separation: hep-ex/0109001.

Background composition, S/B

Number of signal and background events remained after cuts (LHC).

$\hat{p}_{\perp}^{min}$ (GeV/c)	Cuts	γ direct	γ brem	photons from the mesons π^0	η	ω	K_S^0	$e^{\pm}$
40	Preselection (1)	7795	12951	104919	41845	10984	15058	4204
	Photonic cuts (1-5)	4525	3179	470	158	6	26	476
	All cuts (1-14)	1052	137	86	31	0	6	6
100	Preselection (1)	19359	90022	658981	247644	69210	85568	47061
	Photonic cuts (1-5)	8787	4346	104	67	16	16	1306
	All cuts (1-14)	1164	34	13	4	1	0	22
200	Preselection (1)	32629	207370	780190	288772	82477	98015	89714
	Photonic cuts (1-5)	12888	4784	40	21	5	5	1629
	All cuts (1-14)	1080	16	2	5	0	0	9

S/B^* and efficiencies values in events without jet isolation cut (LHC).

$\hat{p}_{\perp}^{min}$ (GeV/c)	S	B^*	$Eff_S(\%)$	$Eff_B^*(\%)$	S/B^*	$S/\sqrt{B^*}$
40	1052	260	13.50 ± 0.44	0.140 ± 0.009	4.1	65.2
100	1164	52	6.01 ± 0.18	0.005 ± 0.001	22.4	161.4
200	1080	23	3.31 ± 0.10	0.002 ± 0.000	47.0	225.0

(Tevatron).

$\hat{p}_{\perp}^{min}$ (GeV/c)	S	B^*	$Eff_S(\%)$	$Eff_B^*(\%)$	S/B^*	$S/\sqrt{B^*}$
40	6238	2122	34.55±0.51	0.831±0.018	2.9	135.4
70	8608	984	21.88 ± 0.26	0.079 ± 0.003	8.8	274.4
100	11452	544	20.17 ± 0.21	0.033 ± 0.001	21.1	491.0

Selection cuts and the numbers of events (Tevatron)

(1) $\mathbf{P_t}^{\gamma} \geq \mathbf{40\ GeV}, \quad |\eta^{\gamma}| \leq \mathbf{2.5}$;

(2) $\mathbf{P_t}^{\gamma}_{\mathbf{isol}} \leq \mathbf{4\ GeV/c}, \quad \epsilon^{\gamma}_{\mathbf{isol}} \leq \mathbf{7\%} \quad (\mathbf{\Delta R}^{\gamma}_{\mathbf{isol}} = \mathbf{0.7})$;

(3) **No charged tracks inside** $\Delta R = 0.4$**;**

(4) $\mathbf{P_t}^{\mathbf{jet}} \geq \mathbf{30\ GeV/c}$; (5) $\phi_{(\gamma,\ \mathbf{jet})} = \mathbf{180}^{\circ} \pm \mathbf{15}^{\circ}$;

(6) $\mathbf{P_t}^{\mathbf{miss}} \leq \mathbf{10\ GeV/c}$, (7) $\mathbf{P_t}^{\mathbf{clust}} \leq \mathbf{10\ GeV/c}$.

Number of $g\,q \to \gamma^{dir} + q$ events (divided by 10^3) at different Q^2 and x intervals for $L_{int} = 3\ fb^{-1}$ (Tevatron).

Q^2 $(GeV/c)^2$	x values of a parton						All x
	.001–.005	.005–.01	.01–.05	.05–.1	.1–.5	.5–1.	.001–1.0
1600-2500	8.6	56.3	245.2	115.9	203.0	3.6	632.6
2500-4900	0.4	13.5	119.3	64.4	119.8	3.2	320.7
4900-8100	0	0.2	17.9	13.5	26.4	1.1	59.0
8100-19600	0	0.0	3.8	5.6	11.5	0.5	21.5
							1 034

Number of $g\,c \to \gamma^{dir} + c$ events (divided by 10^3) at different Q^2 and x intervals for $L_{int} = 3\ fb^{-1}$ (Tevatron).

Q^2 $(GeV/c)^2$	x values of a parton						All x
	.001–.005	.005–.01	.01–.05	.05–.1	.1–.5	.5–1.	.001–1.0
1600-2500	0.3	2.3	21.2	11.8	14.2	0.06	49.8
2500-4900	0.01	0.3	9.5	6.2	7.8	0.04	23.9
4900-8100	0.0	0.0	0.9	1.1	1.6	0.02	3.6
8100-19600	0.0	0.0	0.1	0.3	0.6	0.01	1.1
							78.4

Selection cuts and the numbers of events (LHC)

... the same for the case of LHC.

Number of $g\,q \to \gamma^{dir} + q$ events (divided by 10^3) at different Q^2 and x values for $L_{int} = 20\ fb^{-1}$ (LHC).

Q^2 $(GeV/c)^2$	x intervals				all x	P_t^{γ}
	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}– 10^{-1}	10^{-1}–10^{0}	10^{-4}–10^{0}	(GeV/c)
1600-2500	735.7	2319.2	2229.0	236.9	5521.0	40–50
2500-5000	301.6	1323.3	1402.7	207.4	3235.1	50–71
5000-10000	33.7	361.3	401.0	97.7	893.8	71–100
10000-20000	1.5	80.8	99.4	38.0	219.9	100–141
20000-40000	0	15.6	24.4	12.4	52.5	141–200
40000-80000	0	2.1	4.2	2.5	8.8	200–283
					9 931	

Number of $g\,c \to \gamma^{dir} + c$ events (divided by 10^3) at different Q^2 and x values for $L_{int} = 20\ fb^{-1}$ (LHC).

Q^2 $(GeV/c)^2$	x values for c-quark				All x	P_t^{γ}
	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}– 10^{-1}	10^{-1}–10^{0}	10^{-4}–10^{0}	(GeV/c)
1600-2500	109.4	360.5	329.6	34.7	834.4	40–50
2500-5000	35.1	189.7	202.7	25.4	453.2	50–71
5000-10000	3.9	51.5	58.6	12.1	126.3	71–100
10000-20000	0.1	9.0	12.4	3.4	25.0	100–141
20000-40000	0	1.4	3.2	1.0	5.6	141–200
40000-80000	0	0.1	0.4	0.1	0.7	200–283
					1 440	

Event composition in $x - Q^2$ intervals

"$qg \to q + \gamma$" events.

Q^2 $(GeV/c)^2$	x values of a parton				All x
	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}– 10^{-1}	10^{-1}–10^{0}	10^{-4}–10^{0}
1600-2500	945.0	2387.4	2608.6	246.7	6187.8
2500-5000	410.5	1723.1	1865.0	253.0	4251.7
5000-10000	41.3	443.2	475.5	134.6	1094.6
10000-20000	2.6	105.0	114.5	58.7	281.0
20000-40000	0	20.9	25.9	17.3	64.2
40000-80000	0	4.0	6.3	5.3	15.7

"$q\bar{q} \to \gamma + g$" events.

Q^2 $(GeV/c)^2$	x values of a parton				All x
	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}– 10^{-1}	10^{-1}–10^{0}	10^{-4}–10^{0}
1600-2500	109.5	142.9	192.6	45107	490201
2500-5000	39.2	185.1	196.8	29737	450958
5000-10000	7.0	48.7	54.1	17897	127788
10000-20000	0.6	13.8	12.1	8778	35363
20000-40000	0	3.5	3.2	3518	10225
40000-80000	0	0.7	1.3	1143	3216

"$\gamma - brem$" events.

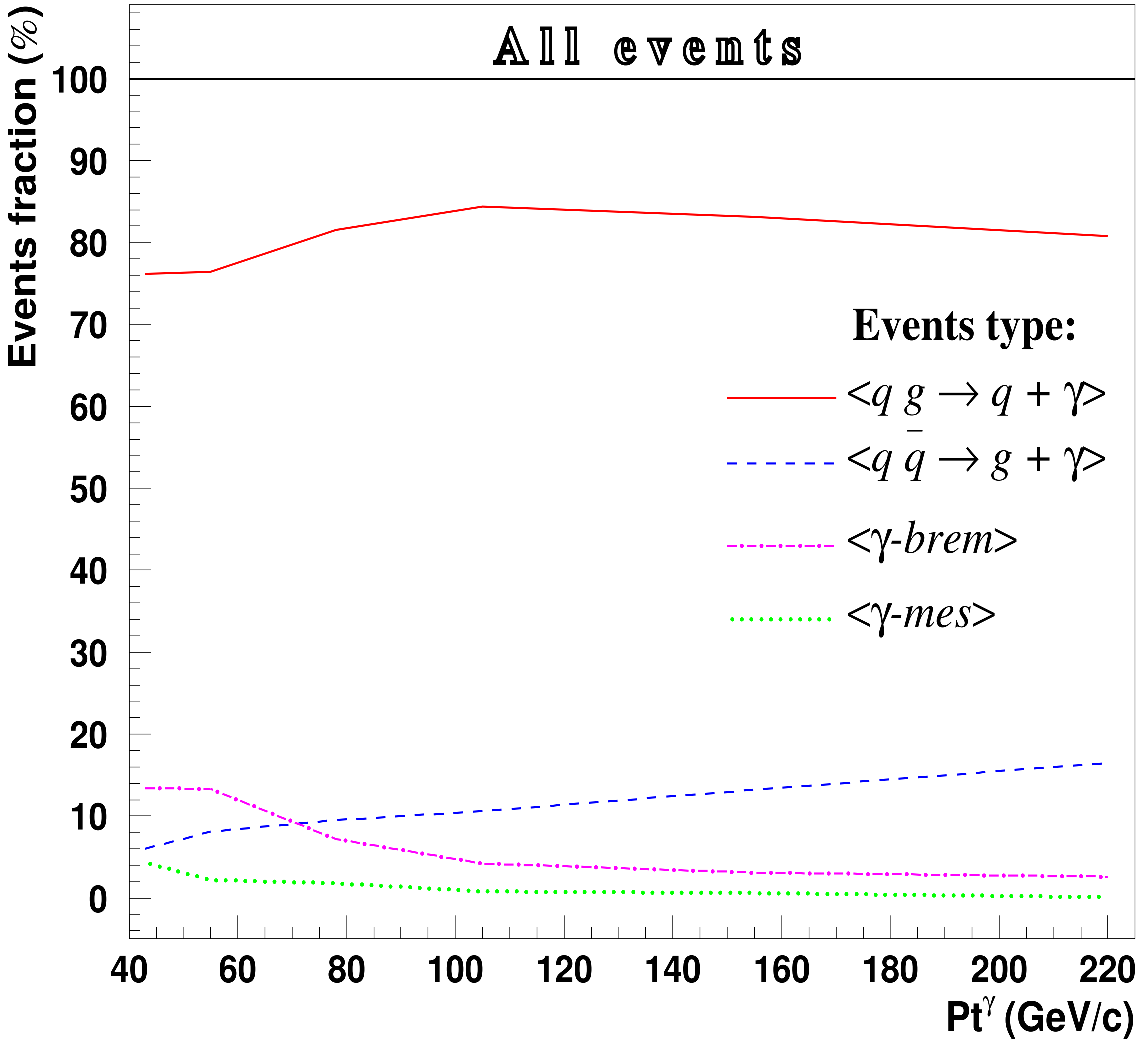
Q^2 $(GeV/c)^2$	x values of a parton				All x
	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}– 10^{-1}	10^{-1}–10^{0}	10^{-4}–10^{0}
1600-2500	129.9	394.3	476.6	87.2	1088.0
2500-5000	46.7	258.5	359.8	74.8	739.8
5000-10000	3.9	34.0	47.1	11.7	96.6
10000-20000	0	4.4	7.1	2.4	13.9
20000-40000	0	0.8	0.7	0.9	2.4
40000-80000	0	0.1	0.3	0.2	0.6

"$\gamma - mes$" events.

Q^2 $(GeV/c)^2$	x values of a parton				All x
	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}– 10^{-1}	10^{-1}–10^{0}	10^{-4}–10^{0}
1600-2500	30.2	148.5	155.2	15.4	349.4
2500-5000	6.4	53.9	56.6	6.4	123.3
5000-10000	1.9	6.9	11.2	4.6	24.6
10000-20000	0	1.1	0.9	0.8	2.8
20000-40000	0	0.1	0.3	0.1	0.5
40000-80000	0	0	0.01	0.01	0.02

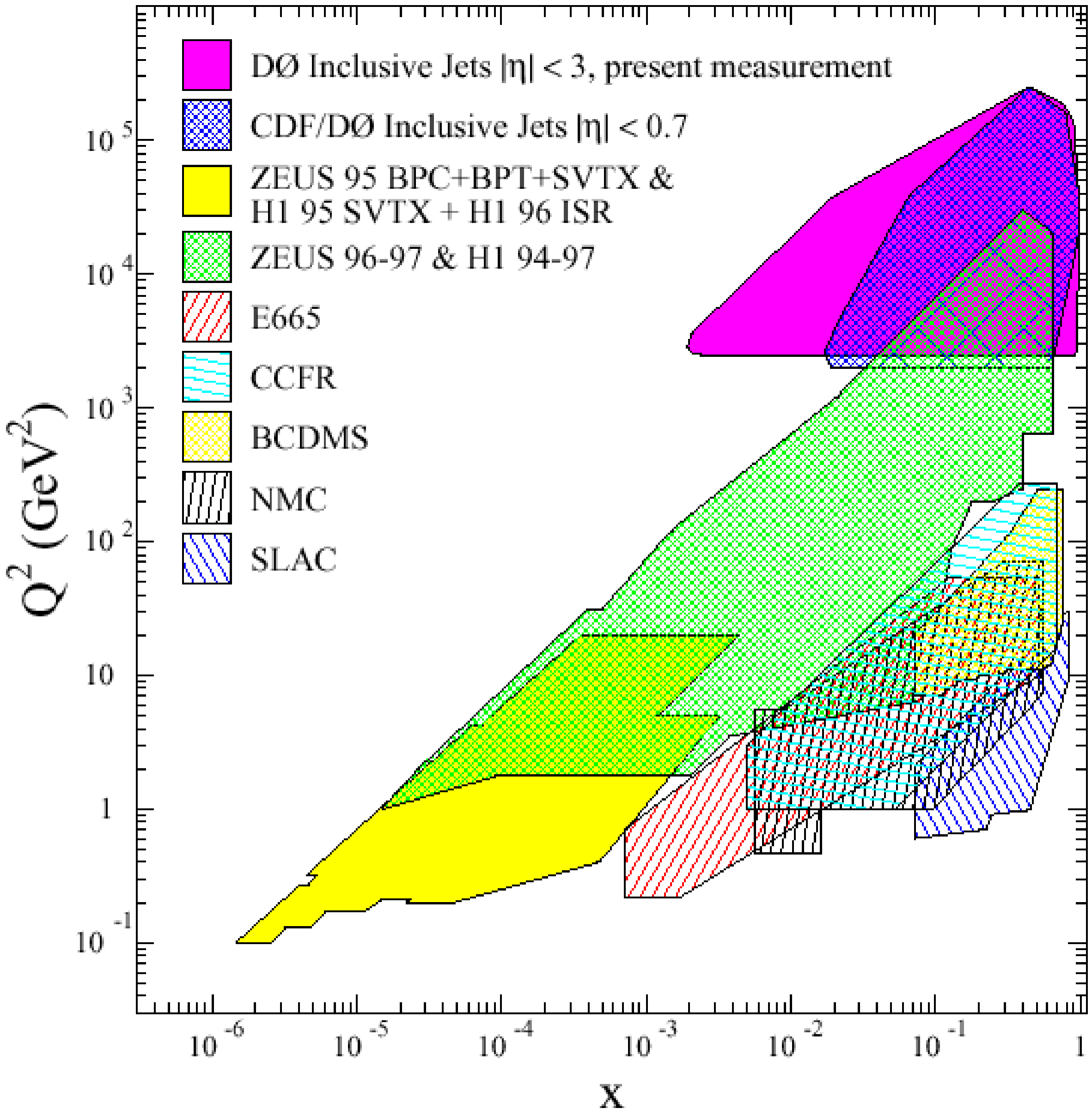
- γ/mes efficiencies are taken into account;
- integrated luminosity is $L_{int} = 10\ fb^{-1}$.

Event fractions in Q^2 intervals

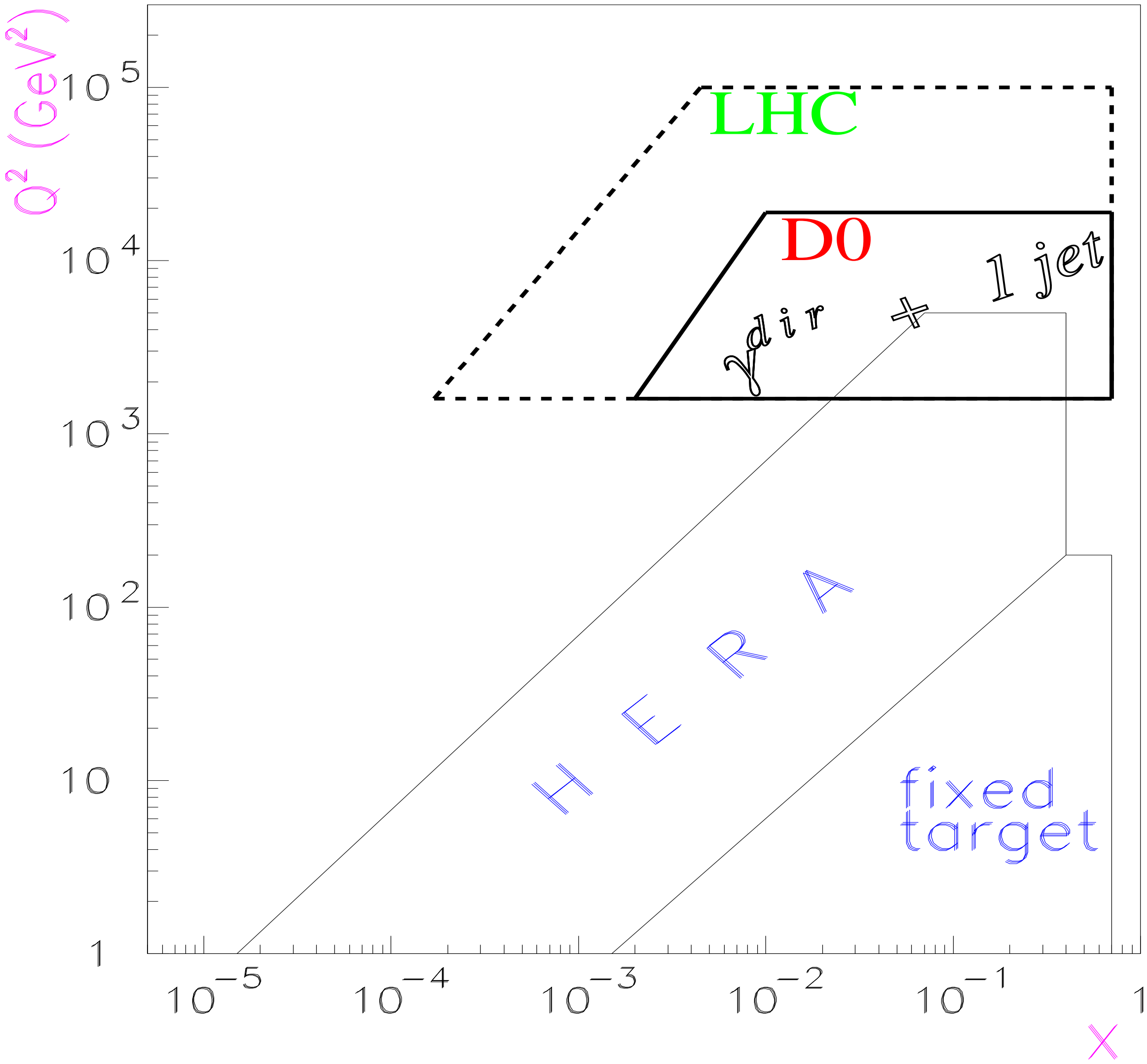


- γ/mes efficiencies are taken into account (hep-ex/0210004);

$x - Q^2$ kinematical region reached in experiments



Kinematical region for process $\overset{(-)}{p p} \to \gamma + jet$ at Tevatron and LHC



Event rates and background estimations:

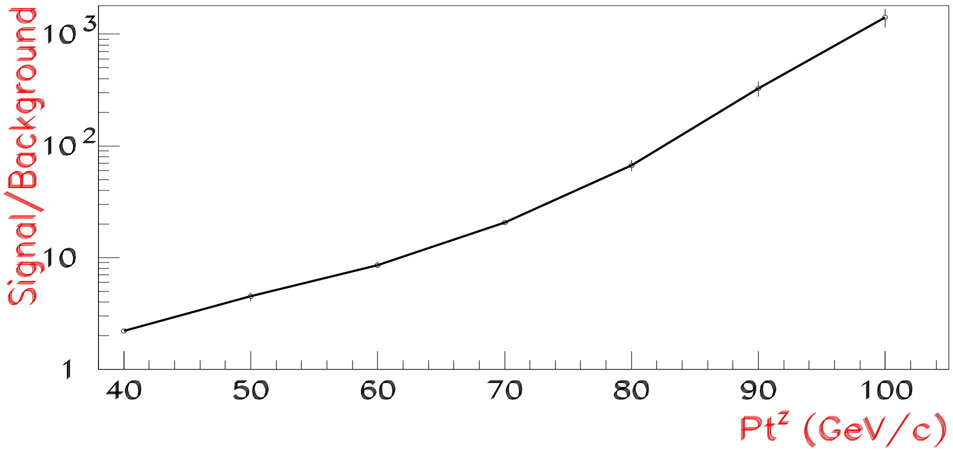
- at Tevatron: D0 Note 3948, 2002, hep-ex/0203003.
- at LHC: Part.Nucl.Lett.103:34-43,2000. hep-ex/0011015.
- at LHC: hep-ex/0210004.

“$Z^0 + jet$” events at LHC

List of the applied cuts for selection of “$Z^0 + jet$” events.

1. $(a)\ P_t^{\mu} > 10\ GeV/c$; $(b)\ |\eta^{\mu}| < 2.4$;
2. $(a)\ |M_{\mathbf{Z}} - M_{inv}^{ll}| < 5\ GeV/c^2$;
3. $P_{t\ isol}^{\mu}(\Delta R = 0.3) < 2\ GeV/c$;
4. $P_{t\ max}^{\mu} > P_{tCUT}^{\mu}\ (= 40,\ 50,\ 60\ GeV/c)$;
5. 1 jet events selected;
6. $\Delta\phi < 15°$;
7. $P_{tCUT}^{clust} = 10\ GeV/c$;

Signal/Background (DY+combinatoric) ratio via P_t^Z after cuts 1-7.



Number of $g\,q \to Z^0 + q\ \ (Z^0 \to \mu^+\mu^-)$ events at different Q^2 and x intervals for $L_{int} = 20\ fb^{-1}$ (divided by 10^3).

Q^2 $(GeV/c)^2$	x values of a parton				All x	P_t^Z (GeV/c)
	10^{-4}–10^{-3}	10^{-3}–10^{-2}	10^{-2}– 10^{-1}	10^{-1}–10^{0}	10^{-4}–10^{0}	
1600-2500	12.2	42.8	49.5	4.2	108.7	40–50
2500-5000	7.4	46.4	55.7	5.7	115.2	50–71
5000-10000	0.6	14.8	20.2	2.4	38.0	71–100
10000-20000	0.01	5.5	9.7	1.7	16.9	100–141
20000-40000	0.0	1.4	3.5	0.9	5.8	141–200
					285	

- “$Z^0 + jet$” **events at LHC: hep-ex/0209039**.

$$\frac{d^2\sigma}{d\eta dP_t}(AB \to \gamma + X) =$$

$$\sum_{ab} \int_0^1 dx_a dx_b f_{a/A}(x_a) f_{b/B}(x_b) \frac{\hat{s}}{\pi} \frac{d\sigma}{d\hat{t}}(ab \to \gamma + X) \delta(\hat{s} + \hat{u} + \hat{t})$$

$$\frac{d^3\sigma}{d\eta_1 d\eta_2 dp_T^2}(AB \to \gamma + jet + X) =$$

$$\sum_{ab} x_a x_b f_{a/A}(x_a) f_{b/B}(x_b) \frac{d\sigma}{d\hat{t}}(ab \to 12)$$

$$x_a = \frac{p_T}{\sqrt{s}}(e^{\eta_1} + e^{\eta_2}), \quad x_b = \frac{p_T}{\sqrt{s}}(e^{-\eta_1} + e^{-\eta_2}).$$

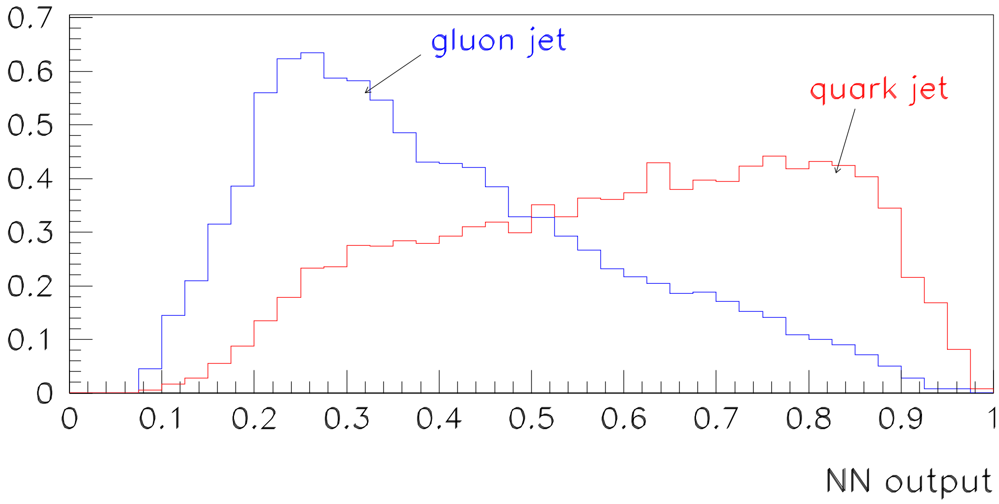
$$\eta_1 = \eta^\gamma, \eta_2 = \eta^{jet}; \;\; a, b = q, \bar{q}, g; \;\; 1, 2 = q, \bar{q}, g, \gamma$$

Discrimination between quark and gluon jets (1).

Jet information used for the discrimination:

⋆ Et, η, ϕ of the first 15 calorimeter cells ordered by Et;

⋆ number of tracks with $Et > 1\ GeV$.



Signal(quark jet)/ Background (gluon jet).

P_t^{jet} (GeV/c)	Region	NN output cut 0.3	0.4	0.5	0.6	0.7
40 – 50	HB	1.45	1.91	2.40	3.11	4.19
	HE+HF	1.41	1.81	2.38	3.10	4.04
100 – 120	HB	1.72	2.63	3.26	4.04	4.59
	HE+HF	1.75	2.19	2.95	3.61	4.21
200 – 240	HB	1.76	2.37	3.35	4.26	5.56
	HE+HF	1.64	2.40	3.17	4.16	5.39

∗ Full simulation using CMSJET

Discrimination between quark and gluon jets (2).

Signal/Background VS. quark jet efficiency