Determination of The Top Quark Charge

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Motivation:

- CDF and D0 analyses + precision EW data do not exclude:
  Top quark seen in Fermilab is an exotic quark with $Q_t = -4/3$.
  (*D. Chang et al*, **Phys. Rev. D59, 091503**)

How to determine the top charge?

- by measuring the charges of top decay products
- via radiative $t\bar{t}$ events (sensitive to Q_{top})

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Top charge via its decay products

Event samples suitable for the analysis :

- **Dilepton decays** $t\bar{t} \rightarrow (l\nu)(l\nu)b\bar{b}$ (400 kEv./10 fb^{-1})
- **Semileptonic decays** $t\bar{t} \rightarrow (l\nu)(jj)b\bar{b}$ (2500 kEv./10 fb^{-1})

All jet modes not suitable due to huge QCD bkgd !

Determination of the b**-jet charge**:

$$q_{bjet} = \frac{\sum_i q_i |\vec{j} \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j} \cdot \vec{p}_i|^\kappa}$$

- q_i ($\vec{p}_i$) is the charge(momentum) of b-jet track
- $\vec{j}_i$ is the b-jet direction and κ is an exponent

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Selection criteria

Di-lepton	Semileptonic
2 isolated high p_T leptons (e,μ) $p_T^{(1)} > 35\ GeV$, $p_T^{(1)} > 25\ GeV$ $\|\eta\| < 2.5$	1 isolated high p_T lepton (e,μ) $p_T^{(1)} > 20\ GeV$ $\|\eta\| < 2.5$
Big $E_T^{miss} > 40\ GeV$	Big $E_T^{miss} > 20\ GeV$
At least two jets, $p_T > 25\ GeV$ 1 or 2 b-tagged, $\|\eta\| < 2.5$	At least two b-jets, $p_T > 40\ GeV$
	In total 4 jets $p_T > 40\ GeV$, $\|\eta\| < 2.5$
S/B $\approx$ 10 (Y-Book)	S/B $\approx$ 65 (P. Grenier)

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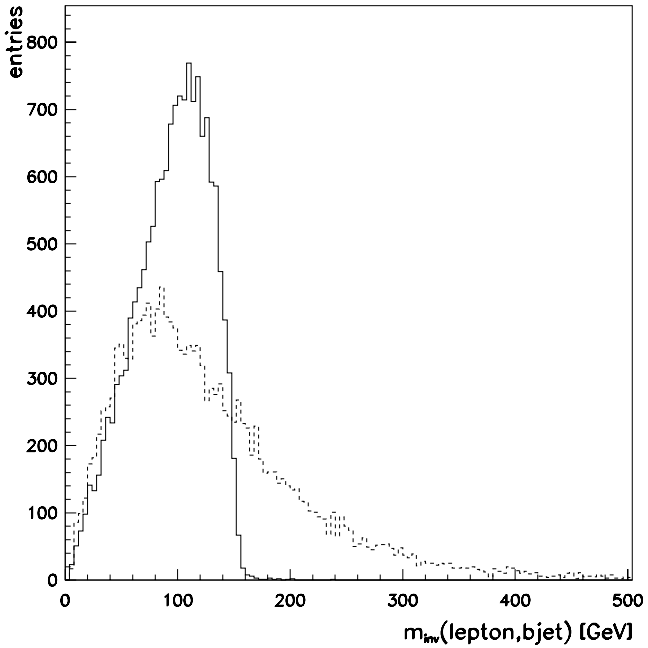
Association of lepton and b-jet



di-lepton case:

$$m(l^+, b^{(1)}_{jet}) < m_{cr} \wedge m(l^+, b^{(2)}_{jet}) > m_{cr}$$
$$m(l^-, b^{(1)}_{jet}) < m_{cr} \wedge m(l^-, b^{(2)}_{jet}) > m_{cr}$$

semileptonic case:

$$m(l, b^{(1)}_{jet}) < m_{cr} \wedge m(l, b^{(2)}_{jet}) > m_{cr}$$
$$120\,GeV < m(jjb_{jet}) < 220\,GeV$$

l − b-jet invariant mass, *solid*: l and $b-$jet from the same top, *dashed*: from different tops, $\mathbf{m_{cr} \approx 160\ GeV}$.

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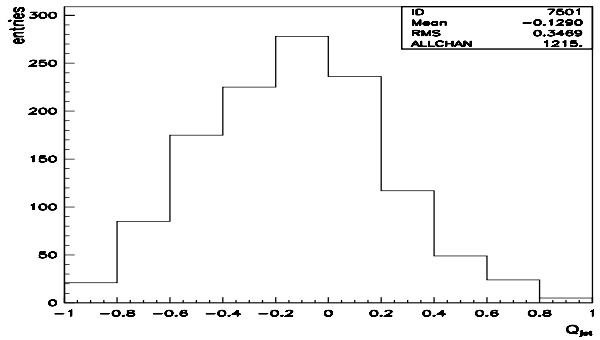
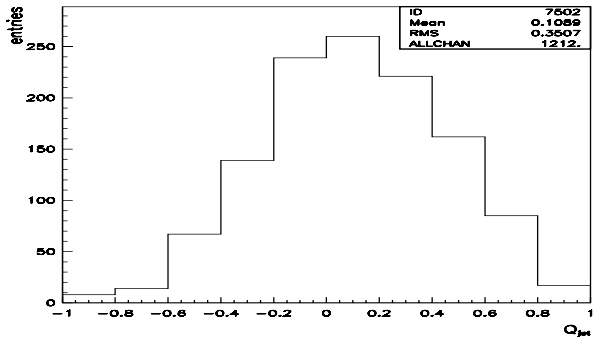
Reconstructed $b(\bar{b})$-jet charge distributions

Charge distributions of b-jets connected with l^+ (b_{jet}) and l^- ($\bar{b}_{jet}$):



b-jet charge distribution



$\bar{b}$-jet charge distribution

Mean b-jet charges :

$$q(b_{jet}) = -0.109 \pm 0.007 \quad \textbf{and} \quad q(\bar{b}_{jet}) = 0.112 \pm 0.007$$

(Independent fragment. in PYTHIA - 500k events, cone $R = 0.4$:

$$\mathbf{q(b_{jet}) = -0.113 \pm 0.007} \quad \text{and} \quad \mathbf{q(\bar{b}_{jet}) = 0.117 \pm 0.008}\ )$$

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Top charge via photon radiation in $t\bar{t}$ events

Signal processes (sensitive to Q_{top}):

- **Radiative $t\bar{t}$ production** $pp \to t\bar{t}\gamma$ (matrix el., PYTHIA)
- **Radiative top decay $t\bar{t}$, $t \to Wb\gamma$** (matrix el., PYTHIA).

Background processes (non sensitive to Q_{top}):

- Radiative W decay $t\bar{t}$, $W \to jj\gamma$ $(l\nu\gamma)$ (matrix el., PYTHIA)
- Other $t\bar{t}$ processes leading to high p_T photon (PYTHIA)
- Non$-t\bar{t}$ radiative bkgd $(W + jets + \gamma)$ (matrix el., PYTHIA)

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Radiative top production

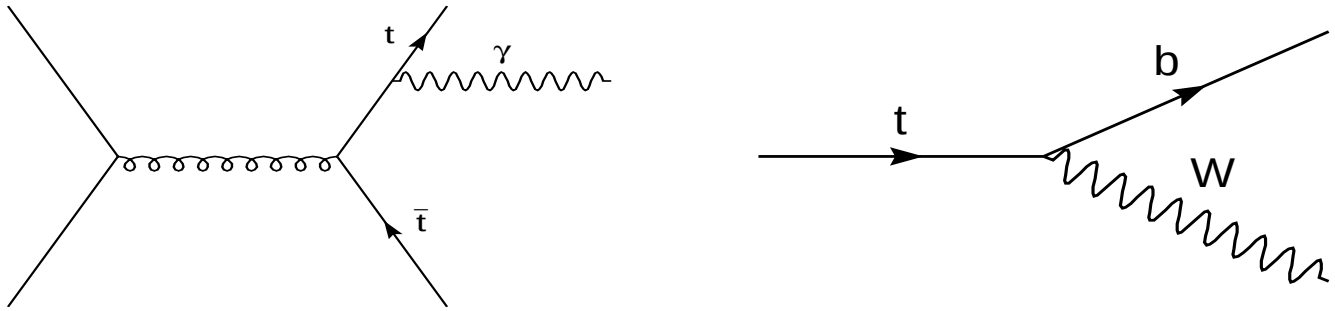

Figure 1: Radiative top production (an example) - production (matrix el.) and decay(PYTHIA), in initial state: $q\bar{q}$ and gg.

Cross section: $\sigma \sim \mathbf{Q^2_{top}}$

Important: **virtuality of radiating top is needed !**

Decay of final t-quark: $t \rightarrow Wb \rightarrow bl\nu(jj)$

Top and W decays treated in narrow width approximation.

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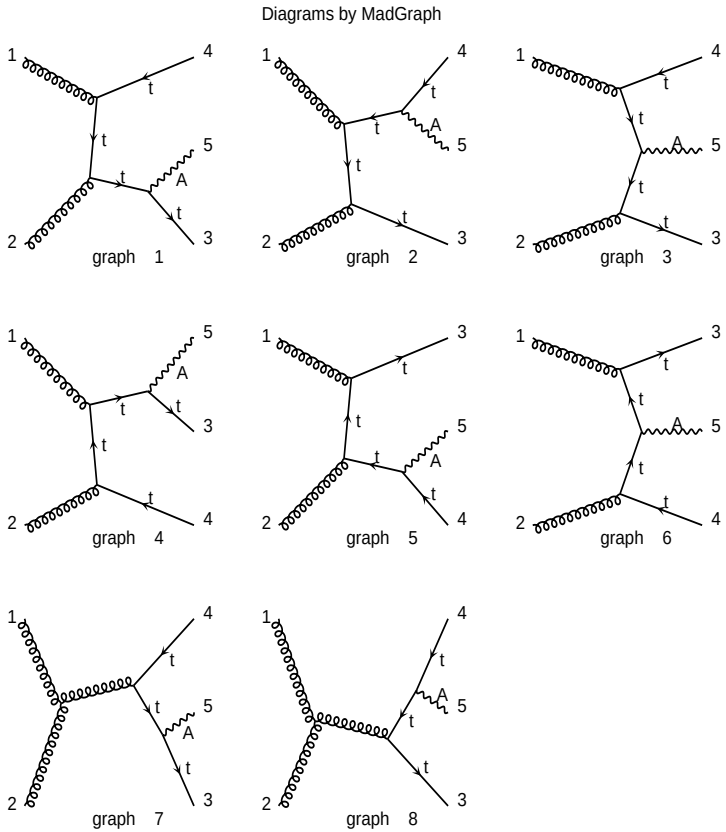
Radiative top production: $gg, u\bar{u} \to t\bar{t}\gamma$ diagrams



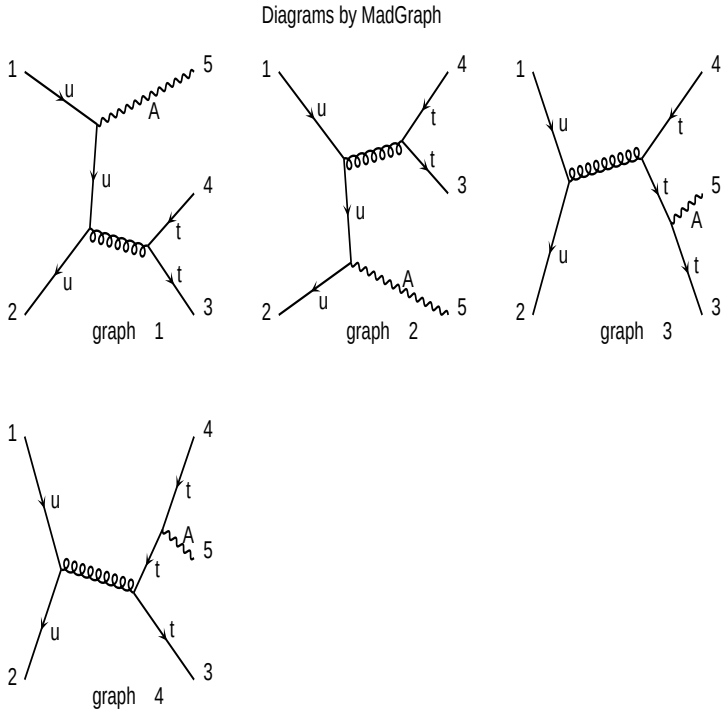


Figure 2: $pp \to t\bar{t}\gamma$, 2 gluons or $u\bar{u}$ quark pair in initial state.

Radiative top decay

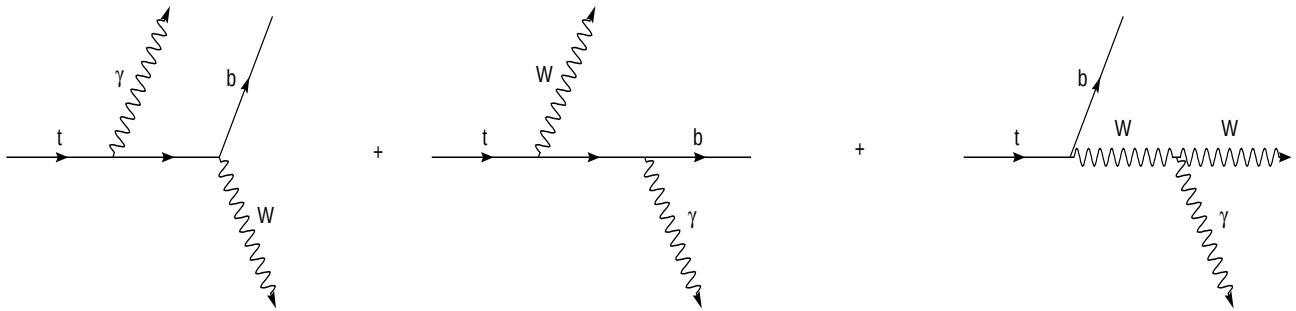


Figure 3: Radiative top decay: $pp \to t\bar{t}$ (production), $t \to Wb\gamma \ldots$

- Decaying top quark is **on mass shell**.
- Photons from the W and b lines **do not feel the top charge**!
- **Destructive interference** of the diagrams is expected: $\sigma(-4/3) < \sigma(2/3)$.

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Reconstruction by ATLFAST: sets of conditions

Selected sample: $\mathbf{t\bar{t} \rightarrow l\nu jjb\bar{b}}$ (semileptonic events)

- **General top cuts (C1)**

$njets \geq 4$	$p_T > 20\ GeV$	$\|\eta\| < 2.5$
$nbjets = 2$	$p_T > 15\ GeV$	$\|\eta\| < 2.0$
$nlep = 1$	$p_T > 20\ GeV$	$\|\eta\| < 2.5$
$nphot = 1$	$p_T > 30\ GeV$	$\|\eta\| < 2.5$
$miss$	$\not{p}_T > 20\ GeV$	

- **Top reconstructed via the $W \rightarrow jj$ decay (C2)**

$\mathbf{|m(jj) - m_W| < 20\ GeV}$ $\quad m(jj) = min\{m(j_i, j_j) - m_W\}$

$\mathbf{|m_T(l\nu) - m_W| < 20\ GeV}$

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Kinematic cuts

Radiation in top production - **top** virtuality is required

$t\bar{t}\gamma$ **cuts**: $m(b_{1,2}jj\gamma) > 190\ GeV$ and $m_T(b_{2,1}l\gamma;\not{p}_T) > 190\ GeV$

$$m_T^2(bl\gamma;\not{p}_t) = \left(\sqrt{p_T^2(bl\gamma) + m^2(bl\gamma)} + \not{p}_T\right)^2 - \left(\vec{p}_T(bl\gamma) + \vec{\not{p}}_T\right)^2$$

Radiation in top decay (on-mass-shell **top**)

Wbγ cuts:

$\mathbf{m_T(bl\gamma;\not{p}_T) < 190}$ and $\mathbf{m(bjj\gamma) > 190}$

or

$\mathbf{m_T(bl\gamma;\not{p}_T) > 190}$ and $\mathbf{160 < m(bjj\gamma) < 190}$

Selection efficiencies - $t\bar{t}\gamma$ cuts

$t\bar{t}\gamma$ cuts (radiative top production selection) applied

Selection efficiencies for different processes

Process	**$pp \to t\bar{t}\gamma$**	$t \to Wb\gamma$	$W \to l\nu\gamma$ $\to jj\gamma$	$t\bar{t}$	$W\gamma jets$
# events	**$3.5 \cdot 10^5$**	**$2 \cdot 10^5$**	$2 \cdot 10^5$	$6.9 \cdot 10^6$	$2.1 \cdot 10^6$
C1 (%)	**0.723**	**0.423**	0.148	$1.50 \cdot 10^{-3}$	$1.2 \cdot 10^{-3}$
C2 (%)	**0.423**	**0.292**	0.079	$0.76 \cdot 10^{-3}$	$6.2 \cdot 10^{-4}$
C3 (%)	**0.338**	**0.021**	0.013	$0.38 \cdot 10^{-3}$	$4.3 \cdot 10^{-4}$

Selection efficiencies $t\bar{t}\gamma$ cuts)

Radiative top production vs. Radiative to decay

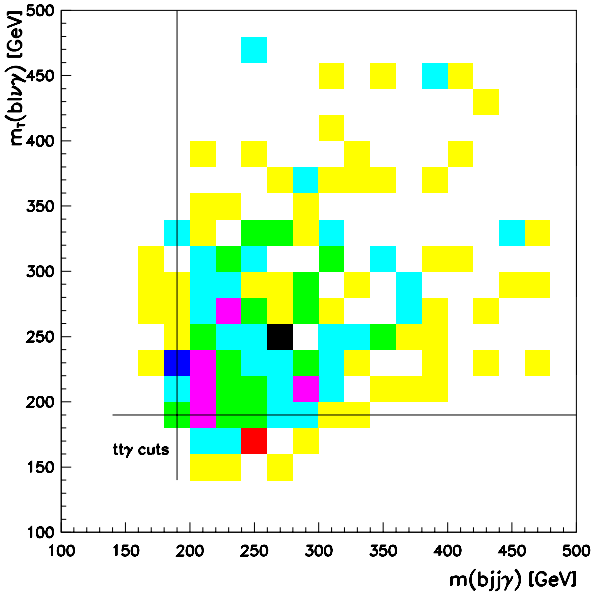

Figure 4: Criterion (C3) applied to the $tt\gamma$ spectrum

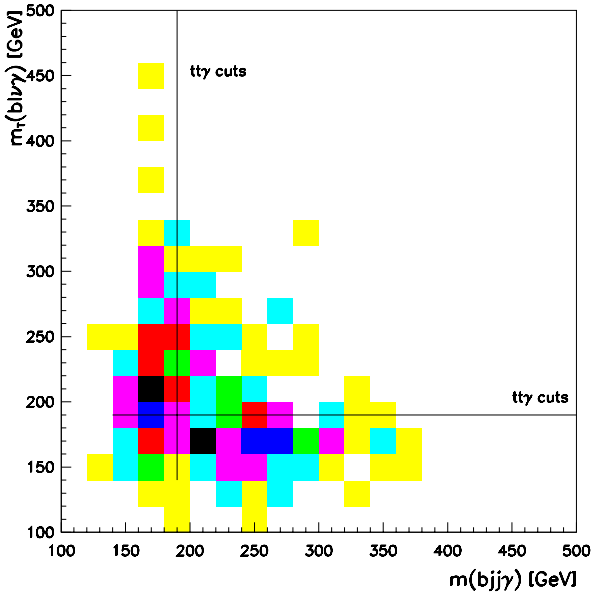

Figure 5: Criterion (C3) applied to the $t \to Wb\gamma$ spectrum

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Signal($tt\gamma$) vs. Bckg($t \to Wb\gamma$)

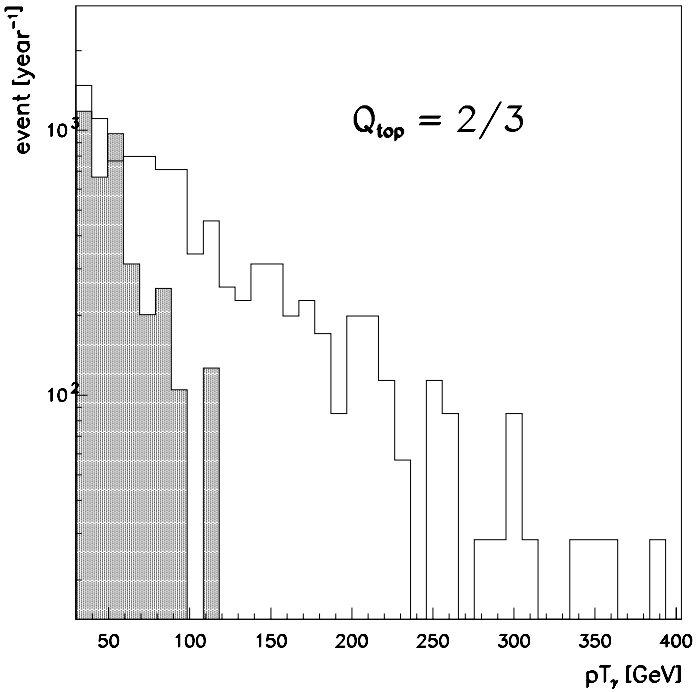

Figure 6: S vs. $p_{T\gamma}$ ($Q_t = \frac{2}{3}$)

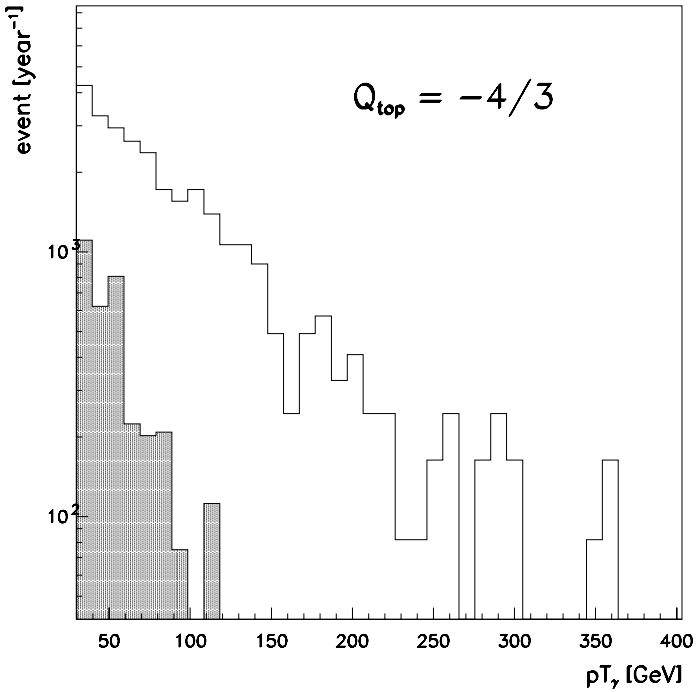

Figure 7: S vs. $p_{T\gamma}$ ($Q_t = -\frac{4}{3}$)

Cross section $Q_t = 2/3$ vs. $Q_t = -4/3$

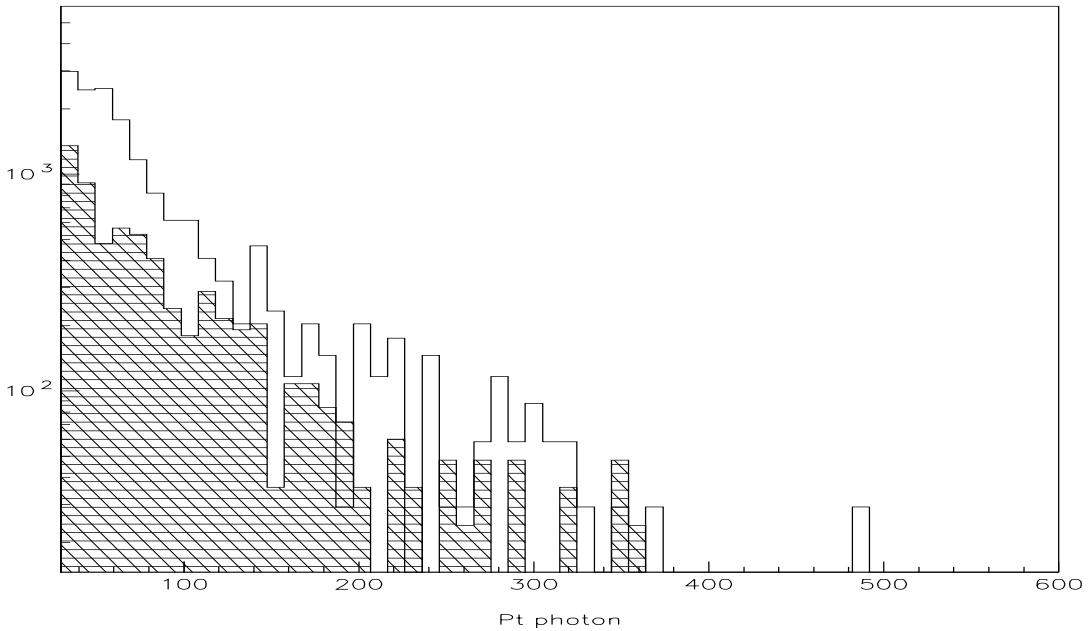

Figure 8: Comparison of S vs $p_{T\gamma}$ for $Q_t = 2/3$ and $-4/3$

Radiative top production vs Bkgd

$t\bar{t}\gamma$-cuts applied, Sample: **10 fb^{-1}**

Signal vs **Bkgd**, integrated x-sections (σ) and # events

process	$Q = 2/3$		$Q = -4/3$	
	$\sigma_{seen}[fb]$	events (1 year)	$\sigma_{seen}[fb]$	events (1 year)
$pp \to t\bar{t}\gamma$	**7.81**	**78.1**	**24.81**	**248.1**
$pp \to t\bar{t}$; $t \to Wb\gamma$	**0.62**	**6.2**	**0.244**	**2.4**
Q_{top} indep. bkgd	**6.65**	**66.5**	**6.65**	**66.5**

Background for $t\bar{t}\gamma$-cuts

Q_{top} independent Bkgd for Radiative top production, x-sections (σ) and cut and reconstr. efficiencies (ϵ):

Bkgd process	$\sigma[pb]$ ($\|y\| < 3.5$ $p_T > 10\ GeV$)	ϵ [%] $Atlfast$	events (1 year)
$pp \to t\bar{t};\ W \to p_1 p_2 \gamma$	8.25	0.013	10.7± 3.4
$pp \to t\bar{t};\ (\pi^o, \eta, ..)$	550	$3.8 * 10^{-4}$	20.7± 4.5
$pp \to W\gamma\ jets$	812	$4.3 * 10^{-4}$	35.0± 6.0
full background			**66.4**

Radiative top decay vs Bkgd

Wbγ-cuts applied, Sample: $\mathbf{10\ fb^{-1}}$

Signal vs **Bkgd**, integrated x-sections (σ) and # events:

process	$Q = 2/3$		$Q = -4/3$	
	$\sigma_{seen}[fb]$	events (1 year)	$\sigma_{seen}[fb]$	events (1 year)
$\mathbf{pp \to t\bar{t};\ t \to Wb\gamma}$	**1.036**	**10.4**	**0.406**	**4.1**
$\mathbf{pp \to t\bar{t}\gamma}$	**0.324**	**3.2**	**1.028**	**10.1**
Q_{top} **indep. bkgd**	**1.240**	**12.4**	**1.240**	**12.4**

Summary

Top charge determination studied for $ATLAS$ (LHC, 10 fb^{-1}) via

- charges of top decay products with samples of di-lepton $(pp \to (l\nu)(l\nu)b\bar{b})$ and one-lepton $(pp \to (l\nu)(jj)b\bar{b})$ $t\bar{t}$-events
- radiative $t\bar{t}$ events.

The $ATLAS$ experiment will be able (preliminary)

- to find correlations between b-quarks and W-bosons in $t(\bar{t})$decays using top decay products charges,
- to distinguish between the top charge $2/3$ and $-4/3$ by measuring the radiative $t\bar{t}$ process cross section.

Study of helicity of top decay products.

b-jet charge via leptonic b-decay

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