New Physics at the Measurement of Particle Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

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Abstract

This is an attempt of figuring out the possible New physics at [1]. The three approach I use is: 1)Pedestrianly analyze the uncertainties of the experiment, 2)Try to explain to add a term to the fit, and 3)Look for hints at the subsequent papers of the group. In the end I compared everything in a table.

1 Hypothesis

1.1 Uncertainties in the Cross Section

1. The way the correct factor (page 8) is calculated is not proved to be linear when extended to high p_T, and it might have different behavior at the TeV scale. They don't show explicitly how to get the flat correction (the Monte Carlo generator tuning, MC) and there're still possibility of contamination of secondary particles.

2. Systematic uncertainties in the cross section range from 10 to 15%, dominated by the purity determination at low p_T and by the uncertainty in the photon energy scale at high p_T . Even If this value was correctly calculated, it's far from the 10^{-3} magnitude off, but **it gives some hint that the problem might be on an extra non identified excess production of photon**.

3. To avoid biases due to an incorrect multiplicity distribution in the MC generator, the correction factor was evaluated, as a function of p_T, in ten different ranges, and the fraction of secondary and misidentied tracks ranges between 1 and 3% over the whole spectrum. It's not clear where these secondary tracks are exactly in the spectrum, but it's know [17] that, for example for Z decay at 45 MeV (first part of the range), we might have many pair productions with this percentage of production, and **my first guess would be that it could reflect a same behavior for a more massive new boson**.

4. In analyzing the energy, the largest uncertainty is due to the simulation of neutral particles, and the observed difference in neutral fraction corresponds to a variation in the calorimeter response by 2%. However, the technique is new and this value could had been underestimated. Consequently, the linear extension for the TeV values is not confirmed, which gives a hint that **the TeV discrepancy might have a excess of energy from neutral particles**.

1.2 Analyzing the high p_T discrepancy

1. The new measurement (former from 1988) shows a cross section about 4% higher than the previous one. It's clammed that at least part of this difference could be explained by the increased center-of-mass energy of the collisions (from 1800 to 1960 GeV). However, **the quotient of this two energies is about 1.1, and even squared do not reproduce yet 4%**.

2. The equation for Run I was given by

$$f = A(\frac{p_0}{p_T + p_0})^n. \tag{1}$$

The new equation for fitting Run II is given by

$$f = A(\frac{p_0}{p_T + p_0})^n + B(\frac{1}{p_T})^s \tag{2}$$

This equations already include all kind of possible polynomial contributions but it still does not fit the data in the range for high p_T. Therefore, in thinking about a new term on this function, I believe that one could include a gaussian-like exponential of the kind

$$C.e^{(\frac{p_T - p_1}{D})^2} \tag{3}$$

Where C, D and p_1 are parameters to fit and to shift the curve to the range we want. I could not come with physical explanation of a inclusion of term of statistical origin in the function.

3. In [18], it's claimed that the observed difference in the shape could be due to an underestimation of the g $\rightarrow \bar{Q}Q$ splitting in the theory, which becomes dominant high p_T^γ.

4. The understand of the multiple-parton interaction could help to solve this puzzle: it provides a mechanism for producing large multiplicities that are harder than the beam-beam remnants, but not as hard as the primary 2-to-2 hard scattering [16].

1.3 Facts thought the subsequent Papers

1. **05/09 - Search for a Fermiophobic Higgs Boson Decaying into Diphotons [2].** The resulting limits exclude $m_H < 106$ GeV.

2. **06/09 - Production of $\psi(2S)$ Mesons (heavy vector mesons) [3]**. The J/ψ production cross sections were one to two orders of magnitude larger than expected from the leading order and the increase in the inclusive cross section at the higher energy of Run II compared to Run I **agrees** with expectations based on the increase in parton energy distribution.

3. **06/09 - Search for a Higgs Boson from $b\bar{b}$ channel [4]**. Observed a 95% confidence level upper limit of 5.6 (4.8) times the theoretically expected production cross section for a m_H >115 GeV.

4. **07/09 - Search for Higgs on all Hadronic Channel [5]**. Observed a 95% confidence level upper limit on the VH production cross section (V is W or Z), with V ($\rightarrow \bar{q}q/qq'$) and H($\rightarrow \bar{b}b$) decay for m_H of 100-150 GeV .

5. **09/09 - Measurement of the b-jet Cross Section with a W [6]**. The W + b-jets process poses a background in measurements

of top quark and searches for the Higgs boson. This measurement **do not agreed** with available theoretical predictions.

6. **10/09 - Measurement of the Photon Cross Section[7]**. The sample of photons is almost a factor of seven larger than former results, the result **agrees** with next-to-leading order perturbative QCD calculations.

7. **11/09 - Search for New Color-Octet Vector (massive gluon) Decaying to $t\bar{t}$ [8]**. Setting limits on the massive gluon coupling strength for masses between 400 and 800 GeV and width-to-mass ratios between 0.05 and 0.50, the coupling strength of this hypothetical massive gluon to quarks is **zero** within the explored parameter space.

8. **12/09 - Search for Technicolor Particles Produced in Association with a W Boson[9]**. It's excluded a region at 95% confidence level in the $p_T - \pi_T$ mass plane so $m(p_T) = 180 - 250$ GeV and $m(\pi_T) = 95 - 145$ GeV/c is ruled out.

9. **12/09 - Measurement of the W^+W^- Cross Section and Search for Anomalous $WW\gamma$ and WWZ Couplings[10]**. The measured total cross section had a **good agreement** with the standard model prediction.

10. **12/09 - Search for New Physics with a Dijet plus Missing Transverse Energy[11]**. It was observer **no significant event excess** with respect to the standard model prediction and extract a 95% confidence level. Based on this, the mass of a potential first or second generation scalar leptoquark is constrained to be above 187 GeV.

11. **01/10 - Search for Higgs in the WW Decay Channel [12]**. Found **no evidence** for Higgs boson production and placed upper limits at the 95% confidence level on the cross section values of the m_H in the range from 110 to 200 GeV.

12. **01/10 - Search for single top quark production [13]**. It was measured an excess of signal-like events **in agreement with** the standard model prediction, but **inconsistent with** a model without single top quark production.

13. **02/10 - Measurement of $t\bar{t}$ Cross Section [14], [15]**. The results assumes a top quark mass of M = 175 GeV, and it claims that this measurement provides an experimental basis for investigating other high-p_T physics measurements with the *soft electron tagging technique.*

2 Conclusions

Table 1 assembles all questions raised in this paper for the observed anomaly on high p_T on comparing the Run I and Run II.

Table 1: Hypotheses for the high p_T.

HYPOTHESIS	RULED OUT?
Extra γ production	X
New massive gluon	X
New technicolor particle	X
Only increasing of the center-of-mass energy	X
Anomalies on WWγ, WWZ	X
Fermiophobic Higgs	X
Higgs from $b\bar{b}$	X
Higgs from WW	X
Scalar leptoquark	X
Non-identified neutral particles	?
New term on the fitting equation	?
Underestimation of $g \to \bar{Q}Q$	?
Single top quark production	?
New particles decaying to $\bar{t}$	?
Jets from b with a W $t \to Wb$)	?

I need to understand better QCD and the Higgs mechanism to formulate more advanced hypothesis.

3 Appendix

3.1 Basics of perturbative QCD [20]

3.1.1 The transverse momentum p_T

The cross section is measured as a function of the photon transverse momentum for two different kinematical regions. For this, we work on Null Plane Coordinates:

$$p^\mu = (p^+, p^-, p^1, p^2) \tag{4}$$

$$\text{Where } p^\pm = \frac{(p^0 \pm p^3)}{\sqrt{2}} \tag{5}$$

$$p^2 = 2p^+p^- = p_T^2 \tag{6}$$

For a particle with large momentum in the $+z$ direction and limited transverse momentum, p^+ is large and p^- is small. We can choose the $+$-axis and the particle of interest will have large p^+, and small p_- and p_T.

3.1.2 Partons

A hadron is composed of point-like constituents called *partons*. A *parton distribution function* (PDF) is the probability density for finding a particle with a certain p_T at a momentum transfer Q^2, and it cannot be obtained by perturbative QCD. For this reason, the known parton distribution functions are obtained by using experimental data.

The isolation of hadron structure in parton distribution functions is a feature of QCD and the parton distributions appear in the QCD formula for any process with two hadrons in the initial state. The standard way of analyzing experiments is fitting the parton distributions and the evolution is predicted.

The parton decay function is given by:

$$\frac{d\sigma}{dE} = \int_0^1 \frac{dz}{z} \sum_a \frac{d\sigma}{dE'} d_{\pi/a}(z, \mu), \tag{7}$$

where $\frac{d\sigma}{dE'} d_{\pi/a}(z, \mu)$ is determined by the experiment. It's possible to use this parton decay functions to find photons in the final state (signal of new physics), pions in the final state, and high p_T hadrons on collider (as a signal for a jet).

3.1.3 Rapidity and Pseudo-rapidity

Rapidity is defined by:

$$y = \frac{1}{2} log(\frac{q^+}{q^-}). \tag{8}$$

For massless particles, it is defined by (where θ is the angle with the line of the jet):

$$y = -log(tan(\frac{\theta}{2})). \tag{9}$$

The pseudo-rapidity is given by this equation if the particle is not quite massless.

3.1.4 Jet

A jet is defined by its cross section by:

$$\frac{d\sigma}{dE_T d\eta} \tag{10}$$

Where η is rapidity and E_T the transverse energy.

3.1.5 Hard and MB Interactions

In hadron collisions, hard interactions are collisions of two incoming partons along with softer interactions from the remaining partons, it's treated with pertubative QCD.

The minimum-bias (MB) interactions is defined thought the triggers of the collection of the data. Such a trigger collects events from all possible inelastic interactions and it consists of the softer inelastic interactions on the Tetravon. Roughly speaking, it's a mixture of hard processes and soft processes (non-perturbative QCD) and it's very hard for simulating.

3.2 The Search for New Physics

3.2.1 Excess of γ production

A photon is a parton (point-like particle $(\gamma, g, u, \bar{u}, d, ...)$) and a hadron (it has a parton distribution function to tell its structure $f_{a/\gamma}(x, \mu)$). Because of being parton, it can directly participate in hard interactions. Because of being a hadron, its constituents can participate in hard interactions [20].

The measurement of photon production constitutes a test of perturbative QCD to constrain parton distribution functions, avoiding the complications of jet identification and energy measurements. The photon cross section is also sensitive to the presence of new physics at large E_T^{γ}.

In high-energy $\bar{p}p$ collisions, photons are mostly produced via **quark-gluon Compton scattering** or **quark-anti-quark annihilation**. In addition to them, photons can also be produced through **the fragmentation of outgoing partons**, (this contribution is reduced when the photon is required to be isolated from other particles in the final state).

3.2.2 New particles Decaying to $\bar{t}t$ pairs

The top quark is the heaviest known elementary particle, with a mass very close to the electroweak symmetry-breaking scale. As such, the top could be sensitive to physics beyond the standard model: new particles decaying to $\bar{t}t$ pairs can be scalar or vector, color-singlet or color-octet; a scalar resonance is predicted in two-Higgs-doublets models; vector particles appear as massive Z-like bosons in extended gauge theories, or as Kaluza-Klein states of the gluon and Z boson or as colorons.
A hypothetical massive gluon could be characterized by its mass, decay width, and the strength of its coupling to quarks. These parameters are determined according to the observed invariant mass distribution of top quark pairs.

3.2.3 Two Jets and missing Transverse Energy

Events with two energetic jets and significant missing transverse energy are a potential signature for new physics, such as supersymmetry, extra dimensions, and leptoquark production. Any model predicting pair production of unstable particles whose decay products are a single parton and a non-interacting particle could be observable as these event excess.

3.2.4 Single Top Production

Single top quarks can be produced through electroweak processes. The production cross section is directly proportional to the square of the magnitude of the $|V_{tb}|$ element of the *Cabibbo-Kobayashi-Maskawa matrix* and a measurement of the single top quark cross section constrains this value. If smaller than unity, it could indicate the presence of a fourth family of quarks. If a value signicantly greater, it could indicate to the existence of a heavy W-like boson enhancing the cross section [19].

3.2.5 The Higgs Search

The standard model of elementary particle physics includes a scalar Higgs boson to explain the origins of electroweak-symmetry breaking. Direct searches at the LEP collider have constrained the $m_H > 114.4\ GeV$ at 95% confidence level.

Of all possible Higgs production mechanism, three are more plausible:

- Emission by the Z gauge boson.
- gluon-gluon fusion.
- $W^+W^- fusion.$

For $m_H < 135\ GeV$, the dominant decay mode is H $\rightarrow \bar{b}b$. While the dominant production modes are direct $gg \rightarrow H$ and $\bar{q}q \rightarrow H$. However, the $\bar{b}b$ signature in this channel is overwhelmed by background. Therefore, searches for events where the Higgs boson is produced in association with a vector boson (V = W or Z) are more promising. The VH associated production cross section is smaller by an order of magnitude than for direct production, but identication of the vector boson reduces the QCD background, making searches for VH the most sensitive ones at low Higgs-boson mass.

The measurement of associated production of a W and jets from b-quarks (W+ b-jet production) provides a test of QCD. Theoretical predictions for vector boson production with associated b-jets have a large uncertainty. The systematic uncertainty, given by imprecise knowledge in the fraction of jets from b production, is approximately $30 - 40\%$, very large compared to the small expected cross sections.

3.2.6 Technicolor Particles

The mechanism of electroweak symmetry breaking in nature is still unknown. The standard model assumes the Higgs mechanism but provides no explanation as to why there should be a fundamental scalar Higgs eld with a non-zero vacuum expectation value.

An alternative is the technicolor approach, which seeks a dynamical mechanism for the symmetry breaking and proposes a new strong interaction, modeled on QCD, which spontaneously breaks electroweak symmetry. The strong technicolor interaction between the new *technifermions* results in a vacuum technifermion condensate which can break electroweak symmetry and give mass to $W_{\pm}$ and Z gauge bosons. As in QCD, the technicolor interaction should give rise to *technimesons*.

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