STAR Note SN0287
Version 1.0
May 12, 1997

Dielectron Backgrounds and Their Impact On J/ψ Physics

Thomas J. LeCompte
Argonne National Laboratory

1 Introduction

The J/ψ meson is an interesting object at STAR, for a number of reasons. One of the most discussed is that J/ψ suppression can be a signature for formation of a Quark-Gluon Plasma. The obvious question is "can STAR see the J/ψ?". In an event that contains just a J/ψ, the answer is "of course". However, there are thousands of other particles in an Au-Au collision, so the real issue is whether or not the J/ψ can be pulled out of the background.

For STAR, the golden decay mode of of the J/ψ is $J/\psi \to e^+e^-$. This is attractive because it has a large branching fraction (6%) and because the EMC can identify electrons (and reject hadrons) and pull the signal out from a hadronic background that can be hundreds of thousands of times larger.

This hinges on the ability of STAR to reject the various backgrounds. Presently, detector choices are being made (e.g. depth segmentation) that can impact electron identification. The total J/ψ yield (as will be shown) depends critically on how low in p_T one can successfully reconstruct electrons, which in turn depends on what the electron-hadron separation is as a function of $p_T(e)$; detector design choices determine this function.

2 Sources of Backgrounds

2.1 Hadrons

One source of background is "fakes", that is, hadrons that are misidentified as electrons. In general, electrons are identified by three features. The first, usually called

E/p, arises because electrons deposit all of their energy electromagnetically. The ratio of the energy E, as measured by the calorimeter, to the momentum p, as measured by the spectrometer will be close to 1 for electrons. Hadrons have a broad distribution, with a maximum well below 1. The second is the transverse shower energy profile, as measured by the energy deposition in calorimeter towers, but also (and more importantly for STAR) by the shower maximum detector. The third is longitudinal shower energy deposition, as measured by a depth segmented calorimeter, such as proposed by STAR. The second and third techniques rely on the fact that electromagnetic showers show relatively small fluctuations from shower to shower.

How then can hadrons be misidentified as electrons? Simply put, hadronic interactions can mimic electromagnetic showers. As a simple case, consider the case where a pion interacts with a nucleus in the EMC via $\pi^- + p \rightarrow \pi^0 + n$. Since the produced π^0 decays electromagnetically, the full energy of the incident pion can be deposited in the EMC: E/p will therefore be close to 1. Furthermore, since the π^0 was produced in the calorimeter where it has only a few centimeters of distance to open before the shower maximum detector (unlike a π^0 produced at the interaction point which has several meters), the shower maximum profile looks more like a single electromagnetic shower than two.

There is a continuum between the extremes of hadrons that look very unlike electrons and hadrons that perfectly mimic electrons. For a given detector, a set of selection requirements can be imposed with a particular signal efficiency and background rejection. Bill Llope has created a set of cuts that give hadron rejection factors over 100 in the Small Prototype EMC (SPEMC) for electrons with $p_T > 2$ GeV, at roughly 80% efficiency. Both values vary with p_T.

2.2 Conversions

Another serious background is from photon conversions. GSTAR studies show 5-6% of the produced photons convert to e^+e^- pairs before the TPC. These electrons are perfectly good electrons, and no calorimeter in the world will distinguish them from "real" electrons. They *are* real electrons!

Conversions can be identified in one of three ways: first, a single electron track can be determined not to point back to the vertex. Alternatively, the conversion partner can be found: a track of opposite charge and low invariant mass, possibly also with a closest point of approach ahead of the primary vertex. This technique tends to work somewhat better than the former method; however, it fails when the second track is not found. Finally, the third way to identify the conversion is to observe that the electron track did not exist before the conversion point. An example of this would be to require electrons to have three SVT hits, to insure that they were not formed by conversions in the outer SVT layers or inner TPC field cage.

In the studies that follow, electrons are produced according to a flat spectrum in $(E_+ - E_-)/(E_+ + E_-)$. In reality, electron pairs are produced with a Bethe-Heitler distribution. The flat approximation tends to overestimate the production of highly asymmetric conversions. These are the ones that cause the most difficulty: first, they produce the highest p_T electrons from a photon of a given E_T, and second, the conversion partner is difficult to detect. So in this note the conversion background is slightly overestimated.

A general feature of conversion electrons is that their spectrum is softer than the charged hadron spectrum. Isospin tells us that the spectrum of the π^0 is the same as the $\pi^\pm$. When the π^0 divides its momentum between two photons that softens the spectrum, and when the photon converts and divides its energy between two electrons that softens the spectrum further.

2.3 Dalitz Decays

A second source of real electrons is from the Dalitz decays ($\pi^0 \rightarrow \gamma e^+ e^-$) of π^0's and to a lesser extent η's. Again, because these are real electrons, it doesn't matter how good the calorimeter is - they will be identified as electrons.

Dalitz decays are suppressed relative to conversions, partly because of branching fractions (1% vs. a few percent of a radiation length), and partly because of decay kinematics. Mechanisms to reject conversions, such as detection of a low mass partner, will also reject Dalitz decays, at a somewhat lower efficiency. As with conversion electrons, the spectrum of electrons from this process is also softer than the hadron spectrum.

Here Dalitz decays are generated in the Monte Carlo (HIJING, in this case), and no attempt is made to check that this is done correctly.

3 Monte Carlo J/ψ Studies

3.1 J/ψ Yield vs. $p_T(e)$

We begin by trying to understand the yield of J/ψ's. The starting point is to understand the functional dependence of the yield on p_T. To do this, we use PYTHIA to generate 100,000 J/ψ and χ_c mesons, forcing the decay $J/\psi \to e^+e^-$. There is no explicit p_T requirement imposed on the J/ψ.

The cross sections returned by PYTHIA are shown in the following table:

Process	Cross section (nb)	Cross section for J/ψ (nb)
$pp \to J/\psi + X$	464	464
$pp \to \chi_0 + X$	3962	26
$pp \to \chi_1 + X$	1744	476
$pp \to \chi_2 + X$	4607	622
Total	10777	1588

Already, there is some reason to be suspicious. This model tells us that 70% of the J/ψ's at 200 GeV come from χ decays, when the experimental numbers are more like 30%. This is telling us that charmonium production still isn't modeled as well as it could be. Nonetheless, since we will ultimately normalize to the *total* number of J/ψ's. The main effect is in the p_T spectrum of the J/ψ, because J/ψ's from χ decays have a few hundred MeV boost added in quadrature from the recoil against the decay photons.

Minimum $p_T(e)$ (GeV)	N(events)	Mean p_T (MeV)	90% p_T (MeV)
0.5	4715	1969	700
0.6	4549	1966	690
0.7	4295	1958	690
0.8	3993	1948	680
0.9	3580	1958	640
1.0	3142	1975	600
1.1	2689	2028	600
1.2	2172	2111	600
1.3	1679	2299	600
1.4	1214	2573	840
1.5	826	2936	1210
1.6	548	3396	1850
1.7	384	3790	2300
1.8	276	4058	2550
1.9	198	4393	3000
2.0	144	4756	3340
2.1	112	4962	3500
2.2	87	5265	4000

The 90% p_T point is defined as the point where 90% of the J/ψ's have a p_T greater than the 90% p_T point.

3.2 Absolute J/ψ Yields

This is problematic. HIJING is based on PYTHIA, which is in turn based on the Lund string model of fragmentation. However, Lund fragmentation does not produce J/ψ mesons in any quantity. So PYTHIA has to be tuned to produce any J/ψ's at all. Whether or not this tuning is accurate is something that can be questioned.

The relation between the cross-sections at 1800 GeV $\overline{p}p$ to 200 GeV pp is more reliable. That depends only on the gluon densities of the proton: we know from fixed target experiments on production of charmonium from proton and antiproton beams that J/ψ's are produced in a gluon initiated process. One might worry about structure functions, and in fact the PYTHIA defaults are fairly old ones (the 1986 revision of EHLQ-1), but since the background processes, largely jets, are also dominated by gluon-gluon processes, the signal to background ratio is relatively independent of structure functions.

At 1800 GeV, PYTHIA predicts a J/ψ cross section times branching fraction, integrated over all rapidities, of 9.97 nb. CDF [1] sees 889 events in 2.6 pb^{-}1 from which they infer a cross section times branching fraction of $6.88 \pm 0.23^{+0.93}_{-1.06}$ nb for $p_T > 6$ GeV and $|\eta| < 0.5$.

The acceptance of STAR for these events (with the same kinematic cuts as CDF) is approximately 8%. CDF's acceptance is roughly 4% (it varies between 3% at the lowest p_T to 15% at the highest and is dominated by the large cross section at low p_T), but they have instrumented only about half the area that STAR has. So this is understood.

The CDF cross section includes charmonium from the decay $b \to J/\psi + X$, which may be relatively smaller at RHIC. (To be conservative, here we assume *no* contribution from b hadron decay.) That contribution has been measured by CDF using their silicon vertex detector and is around 15%, with slight variations with p_T. So the prompt J/ψ cross section is about 5.8 nb. Next, the cross section over all rapidities is roughly 6 times larger than over the single unit measured by CDF, which results in a cross section times branching fraction of roughly 35 nb. PYTHIA predicts 10, so its predictions must be increased by a factor of roughly 3.5.

This factor of 3.5 is phenomologically understood. At these energies, PYTHIA predicts that 90% of J/ψ's are χ daughters. Experimentally, that number is more like 30%, so this factor of 3.5 can be understood if:

- PYTHIA correctly predicts χ production.
- PYTHIA underestimates J/ψ production by a large factor.

When the correct ψ/χ ratio is included, the theoretical cross section agrees with experiment to within the uncertainties.

At 200 GeV, we therefore use the cross section times branching fraction of 1.59 μb (PYTHIA cross section) $\times$ 6% (branching fraction) $\times$ 3.5 (factor to bring PYTHIA in line with CDF), for a total of 333 nb. This is for pp collisions. Using the relation $\sigma_{\rm AuAu} = 3880\sigma_{pp}$, we get a cross section in gold on gold collisions of 1.3 mb. At a luminosity of 2×10^{26}cm^{-2}/s, this is an event rate of 0.26 Hz for a $J/\psi \rightarrow e^+e-$ to be made anywhere in the detector.

The Snowmass convention is that there are 10^7 seconds in a year, when one factors in detector dead time, detector down time, accelerator down time, accelerator fill time and periods of less than full luminosity. Adopting this convention, we will produce 2.6 million J/ψ events per year. The efficiency of identifying an electron was measured in the test beam, and is typically around 70-75%. Tracking efficiency is probably around 90-95% (recall these are high p_T tracks). Using the middle value of both of these numbers, the probability of identifying both electrons is taken to be 45%. That gives us annual yields of:

Minimum $p_T(e)$ (GeV)	Monte Carlo Events	Annual STAR Yields
0.5	4715	55200
0.6	4549	53200
0.7	4295	50300
0.8	3993	46700
0.9	3580	41900
1.0	3142	36800
1.1	2689	31500
1.2	2172	25400
1.3	1679	19600
1.4	1214	14200
1.5	826	9660
1.6	548	6410
1.7	384	4490
1.8	276	3230
1.9	198	2320
2.0	144	1680
2.1	112	1310
2.2	87	1020

4 Monte Carlo Background Studies

4.1 Fake Electrons

Now we turn our attention to backgrounds. We generate central ($b = 0$) Au+Au events with HIJING 1.34, with all settings at their defaults [1]. Also, not all J/ψ's are produced at very central impact parameters (although most of them are), so this is not quite a perfect model.

This version of HIJING was modified so that only particles with $p_T > 1.5$ GeV were preserved. 10,000 events were generated on a DEC Alpha processor, corresponding to an equivalent running time of 5-1/2 minutes. The number of opposite signed pairs between 3.0 and 3.2 GeV were calculated, and the results are shown before, including extrapolation to a year's running:

Minimum $p_T(e)$ (GeV)	Monte Carlo Dihadron Pairs	Annual STAR Yields
1.5	78574	2360 $\times 10^6$
1.6	35124	1050 $\times 10^6$
1.7	17392	521 $\times 10^6$
1.8	9087	273 $\times 10^6$
1.9	4902	147 $\times 10^6$
2.0	2681	80 $\times 10^6$
2.1	1562	46.9 $\times 10^6$
2.2	929	30.6 $\times 10^6$

Fortunately, we are searching for electrons, so we do not have to consider all the hadron pairs, just the ones that fake electrons. Unfortunately, the electron rejection factor is a steeply changing function between 1 and 2 GeV. Below 1 GeV, it is around 8-10 and moderately flat, and above 2 GeV it is around 80-120 and flat. Between, it is changing rapidly. Here I assume that it is changing linearly with p_T, and will call this the baseline assumption. There is no motivation for this particular choice of interpolations other than calculational simplicity. On the other hand, it would be far more valuable to gather more data in this region than to try and tune the interpolation. The hadron rejection factor used is shown below, along with surviving pairs (corrected for tracking efficiency - we can miss a fake J/ψ as easily as we can miss a real one), the expected J/ψ yields, signal to background, and significance.

[1] IHPR(2) is set to zero, to allow decays of π^0's etc.

Min. $p_T(e)$ (GeV)	Hadron Rejection	$N(h^+h^-)$	$N(e^+e^-)$ (Fake)	$N(J/\psi)$	S/B 1:	Significance (in σ)
1.5	60	2360M	468,000	9660	48	13.9
1.6	70	1050M	157,000	6410	25	15.9
1.7	80	521M	64,500	4490	14	17.1
1.8	90	273M	24,700	3230	7.6	19.3
1.9	100	147M	11,400	2320	4.9	19.8
2.0	110	80M	5660	1680	3.4	19.6
2.1	110	46.9M	3320	1310	2.5	19.3
2.2	110	30.6M	2160	1020	2.1	18.1

There is certainly a temptation to push below 1.5 GeV. Although the Monte Carlo doesn't produce tracks below 1.5 GeV, a rough estimate is that the background will be 2-3 times larger at 1.4 GeV than 1.5 GeV. Assuming that factor is 2.5, and that the hadron rejection is a factor of 50, there would be an additional 1.2 billion dihadrons, yielding another 410,000 fake pairs. We would gain about 4500 J/ψ's. This gives a signal to background of 1:63.

Now consider the case where instead of a linear rise in hadron efficiency vs. p_T, the rise is logarithmic. In this case, the table looks like this:

Min. $p_T(e)$ (GeV)	Hadron Rejection	$N(h^+h^-)$	$N(e^+e^-)$ (Fake)	$N(J/\psi)$	S/B 1:	Significance (in σ)
1.5	33	2360M	1,395,000	9660	144	8.2
1.6	42	1050M	366,000	6410	57	10.5
1.7	54	521M	109,000	4490	24	13.3
1.8	68	273M	36,500	3230	11	16.2
1.9	87	147M	13,200	2320	5.7	18.6
2.0	110	80M	5660	1680	3.4	19.6
2.1	110	46.9M	3320	1310	2.5	19.3
2.2	110	30.6M	2160	1020	2.1	18.1

Here, the significance of the points added between 1.6 and 1.5 GeV is just over 3σ. Here moving to 1.4 GeV is less tempting. The same prescription as used above adds 1.5 million fake pairs and 4500 additional J/ψ's, so the signal to background drops to around 1:200.

For a turn on that is both sharper and later than the previous two, we have:

Min. $p_T(e)$ (GeV)	Hadron Rejection	$N(h^+h^-)$	$N(e^+e^-)$ (Fake)	$N(J/\psi)$	S/B 1:	Significance (in σ)
1.5	10	2360M	11.2M	9660	1160	2.8
1.6	15	1050M	2.42M	6410	377	4.1
1.7	25	521M	410,000	4490	91	7.0
1.8	45	273M	70,600	3230	22	11.9
1.9	70	147M	17,400	2320	7.5	16.5
2.0	110	80M	5660	1680	3.4	19.6
2.1	110	46.9M	3320	1310	2.5	19.3
2.2	110	30.6M	2160	1020	2.1	18.1

In this case, in going from 1.6 to 1.5, all that has happened is that more background has entered into the sample. For this shape, somewhere around 1.65 GeV is as low as you might want to go. The point of this is that the reach in p_T depends on the hadron rejection factor between 1 and 2 GeV, and this is not known at the present time.

4.2 Conversion and Dalitz Electrons

We repeat the same study we did with hadrons with conversion electrons and Dalitz decays. Here every single photon converts to an e^+e^- pair.

4.3 One Real Electron

We start with the raw Monte Carlo yields for the various processes and a function of minimum hadron p_T, shown in the table below.

Minimum $p_T(e)$ (GeV)	Monte Carlo $e^\pm - h^\mp$ Pairs Conversions	Monte Carlo $e^\pm - h^\mp$ Pairs Dalitz
1.5	7558	37
1.6	3180	10
1.7	1522	5
1.8	783	3
1.9	416	1
2.0	229	1
2.1	112	1
2.2	74	0

Next, we correct this for the running time factor of 30,000, and the conversion probability of 5returns between 4 and 6%, depending on the exact material geometry)

Minimum $p_T(e)$ (GeV)	Monte Carlo $e^{\pm} - h^{\mp}$ Pairs Conversions	Monte Carlo $e^{\pm} - h^{\mp}$ Pairs Dalitz
1.5	11,337,000	1,100,000
1.6	4,770,000	300,000
1.7	2,283,000	150,000
1.8	1,174,500	90,000
1.9	624,000	30,000
2.0	343,500	30,000
2.1	168,000	30,000
2.2	111,000	0

These are so far just hadron-electron pairs. We next include the probability of misidentifying a hadron as an electron under the baseline assumption, and the 92.5% tracking efficiency:

Minimum $p_T(e)$ (GeV)	Fake $e^{\pm} - h^{\mp}$ Pairs (conversions)	Fake $e^{\pm} - h^{\mp}$ Pairs Dalitz
1.5	161,700	15,700
1.6	58,300	3700
1.7	24,400	1600
1.8	11,200	860
1.9	5340	260
2.0	2670	230
2.1	1300	230
2.2	860	0

Note that these are already smaller than the fake hadron background.

Next, we try and reject conversions by finding their partners. We assume that if the partner has $pT > 200$ MeV, we always find it; if it has $p_T < 100$ MeV we never find it, and if it is in-between, we have a 50-50 chance of finding it. We assume that this algorithm has no effect on Dalitz pairs, to be conservative.

Minimum $p_T(e)$ (GeV)	Conversion Pairs	Partner above 200	Partner above 100	Partner 100-200
1.5	7558	4067	2054	1437
1.6	3180	1760	831	589
1.7	1522	867	373	282
1.8	783	442	190	151
1.9	416	244	101	71
2.0	229	140	53	36
2.1	112	70	24	18
2.2	74	48	16	10

From this, we can calculate the number of surviving pairs:

Minimum $p_T(e)$	Fake $e^{\pm} - h^{\mp}$ Pairs	Fake $e^{\pm} - h^{\mp}$ Pairs
(GeV)	(conversions)	Dalitz
1.5	59,300	15,700
1.6	20,600	3700
1.7	8200	1600
1.8	3800	860
1.9	1750	260
2.0	830	230
2.1	380	230
2.2	240	0

A few comments are in order. One is that the Dalitz to conversion ratio is small, and falling with $p_T(e)$, even when one neglects the low statistics high $p_T(e)$ bins. Another is that the total background from $e-h$ pairs is about 10% of the background from $h-h$ pairs, after all cuts. Clearly the more important background is fake electrons.

4.4 Two Real Electrons

For completeness sake, we discuss the case where both electrons are real. As before, we begin with the raw Monte Carlo yields for the various processes and a function of minimum hadron p_T, shown in the table below.

Minimum $p_T(e)$ (GeV)	2 Conversions	1 Conversion	2 Dalitz
1.5	528	0	0
1.6	201	0	0
1.7	105	0	0
1.8	40	0	0
1.9	20	0	0
2.0	8	0	0
2.1	6	0	0
2.2	4	0	0

There are events with one or more Dalitz decays, but none in this sample with $m(e^+e^-) > 2$ GeV and $p_T(e) > 1.5$ GeV.

Next, we correct this for the running time factor of 30,000, the conversion probability of 5the tracking efficiency factor of 92.5% per track.

Minimum $p_T(e)$ (GeV)	e^+e^- Events
1.5	33,900
1.6	12,900
1.7	6700
1.8	2600
1.9	1280
2.0	510
2.1	390
2.2	260

This is before rejecting conversions by locating their partners. This is more complicated in this case, because we have two conversions, and we only have to find one of the two partners. We divide the events into four categories: Category A has at least one partner with $p_T > 200$ MeV. Every one of these events is identified as a conversion. Category B has both partners between 100 and 200 MeV. 75% of these events are identified as conversions and thus rejected. Category C events have one partner between 100 and 200 MeV, and the other one is below 100 MeV. 50% of these events are identified and rejected. Category D events have both partners below 100 MeV; none of these events are identified. The number of raw Monte Carlo events in the various categories is shown in the following table:

Minimum $p_T(e)$ (GeV)	Category A	Category B	Category C	Category D
1.5	167	103	24	234
1.6	65	46	8	82
1.7	31	25	5	44
1.8	14	10	0	16
1.9	8	2	0	10
2.0	5	1	0	2
2.1	4	1	0	1
2.2	2	1	0	1

This works out to an expected annual yield of fake pairs under the J/ψ peak of:

Minimum $p_T(e)$ (GeV)	e^+e^- Events
1.5	17,500
1.6	6300
1.7	3360
1.8	1200
1.9	670
2.0	140
2.1	80
2.2	65

5 Expected Signals

We can sum these sources of background up, and get an estimate for an overall signal to noise ratio and significance. Although the statistics for the smaller sources of background is relatively poor, because these are smaller sources, the overall effect of these uncertainties is minimal.

Min. $p_T(e)$ (GeV)	Hadron Rejection	N(Background)	$N(J/\psi)$	S/B 1:	Significance (in σ)
1.5	60	561,000	9660	58	12.9
1.6	70	188,000	6410	29	14.8
1.7	80	77,700	4490	17	15.7
1.8	90	30,600	3230	9.5	17.6
1.9	100	14,100	2320	6.1	18.1
2.0	110	6860	1680	4.1	18.2
2.1	110	4010	1310	3.1	18.0
2.2	110	2470	1020	2.4	17.3

The next three figures show what the dielectron spectrum might look like for a year's running at design luminosity, with the baseline assumptions. Here three different momentum cut-offs are chosen: 2.2 GeV, because it is the lowest p_T that has been shown at STAR meetings so far, 1.9 GeV which is a hair under where we have a good understanding of the hadron rejection of the EMC, and 1.5 GeV, in a region where we do not yet have this understanding.

These are not technically Monte Carlo plots. The background was generated by Monte Carlo, and fit to a seventh degree polynomial. This seventh degree polynomial was then just to generate the background shape, scaled to the appropriate level of background, with Poisson uncertainties in each bin. The signal was generated in a similar way: Monte Carlo J/ψ's were generated, fit to a Gaussian, and a properly normalized Gaussian of the same width was added to these plots. Widths are shown in the following table:

Minimum $p_T(e)$ (GeV)	$\sigma(J/\psi)$ (MeV)
1.5	18.3
1.9	21.2
2.2	22.4
3.0	42 ± 12

The J/ψ does have some non-Gaussian tails at the few percent level, due largely to electron Brehmstrahlung. These are not included here.

The next three figures "zoom in" on the J/ψ. They are the same plots as the Figures 1-3, with zero suppression and a restricted range in mass.

The significances of the signals are shown in the following table

Minimum $p_T(e)$ (GeV)	Significance
1.5	21.1σ
1.9	10.0σ
2.2	10.3σ

6 Discussion

6.1 Why Does It Look Worse?

At the EMC Technical Design Review of December, 1996, a plot of J/ψ's with substantially better signal to noise was shown. Why is this worse? What has changed?

First, the signal is a factor of about two smaller. Part of this is due to better

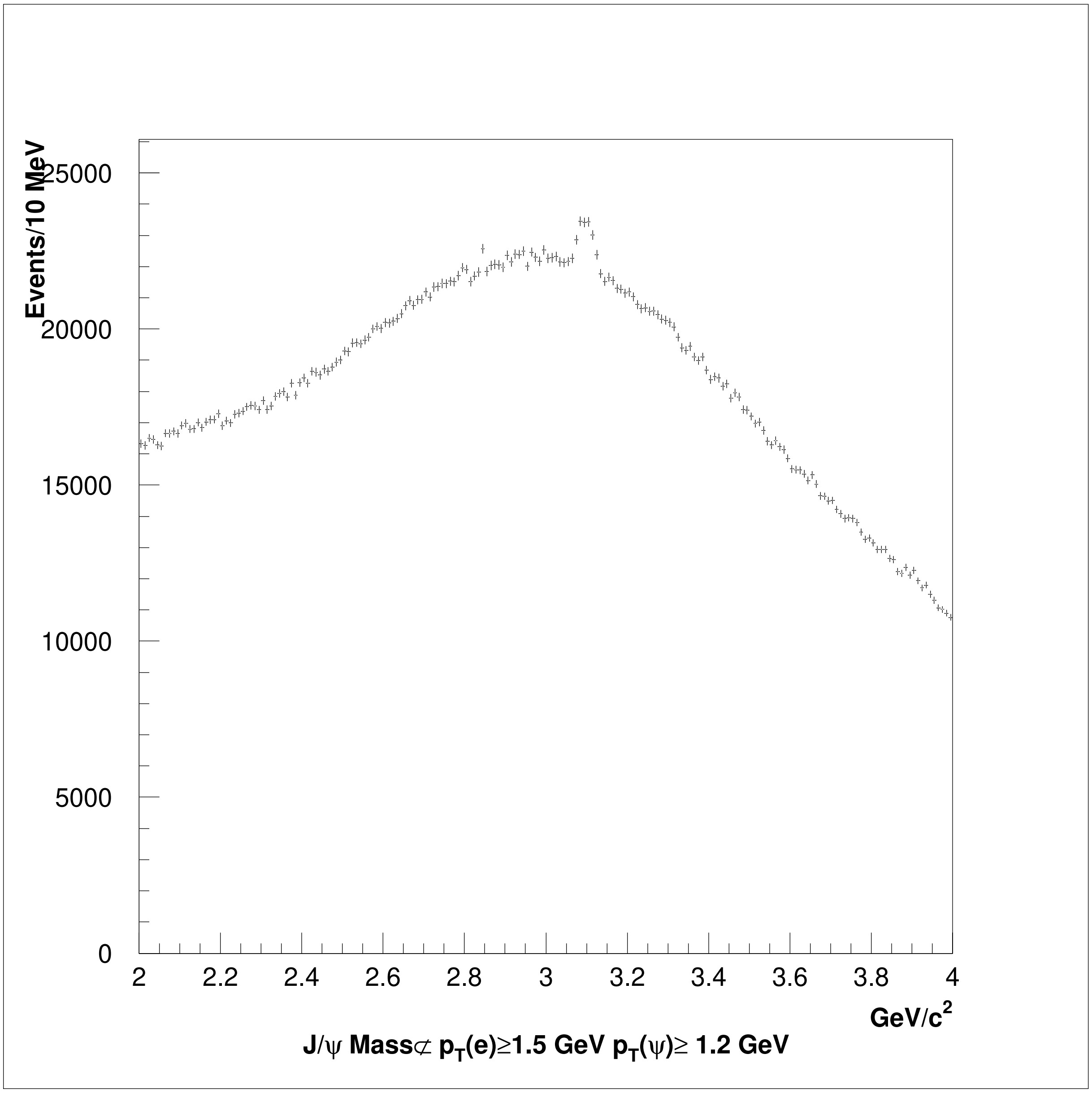

Figure 1: A dielectron mass plot for a year's running under the baseline assumptions. Here $p_T(e) \geq 1.5$ GeV and $p_T(J/\psi) \geq 1.2$ GeV.

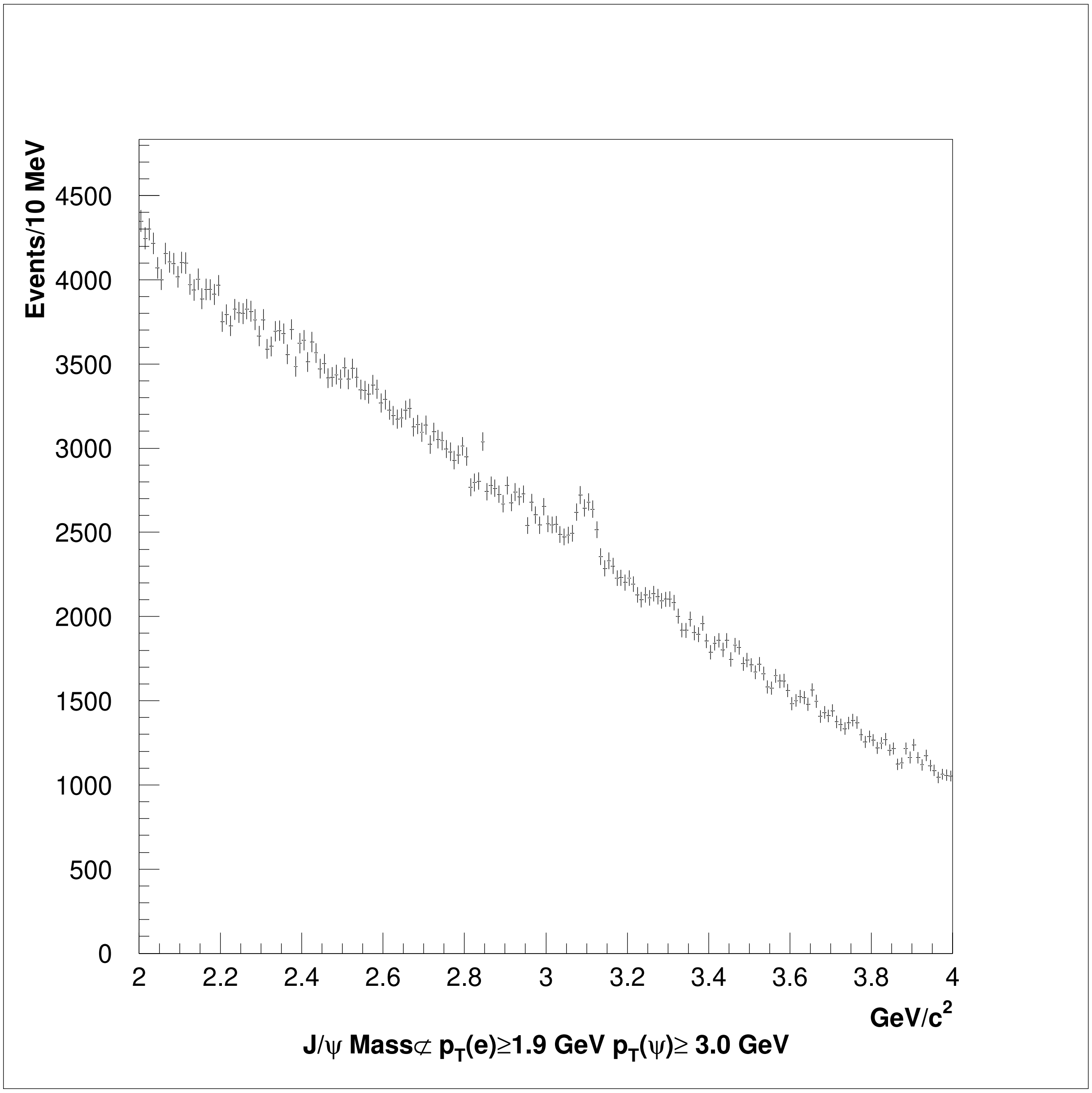

Figure 2: A dielectron mass plot for a year's running under the baseline assumptions. Here $p_T(e) \geq 1.9$ GeV and $p_T(J/\psi) \geq 3.0$ GeV.

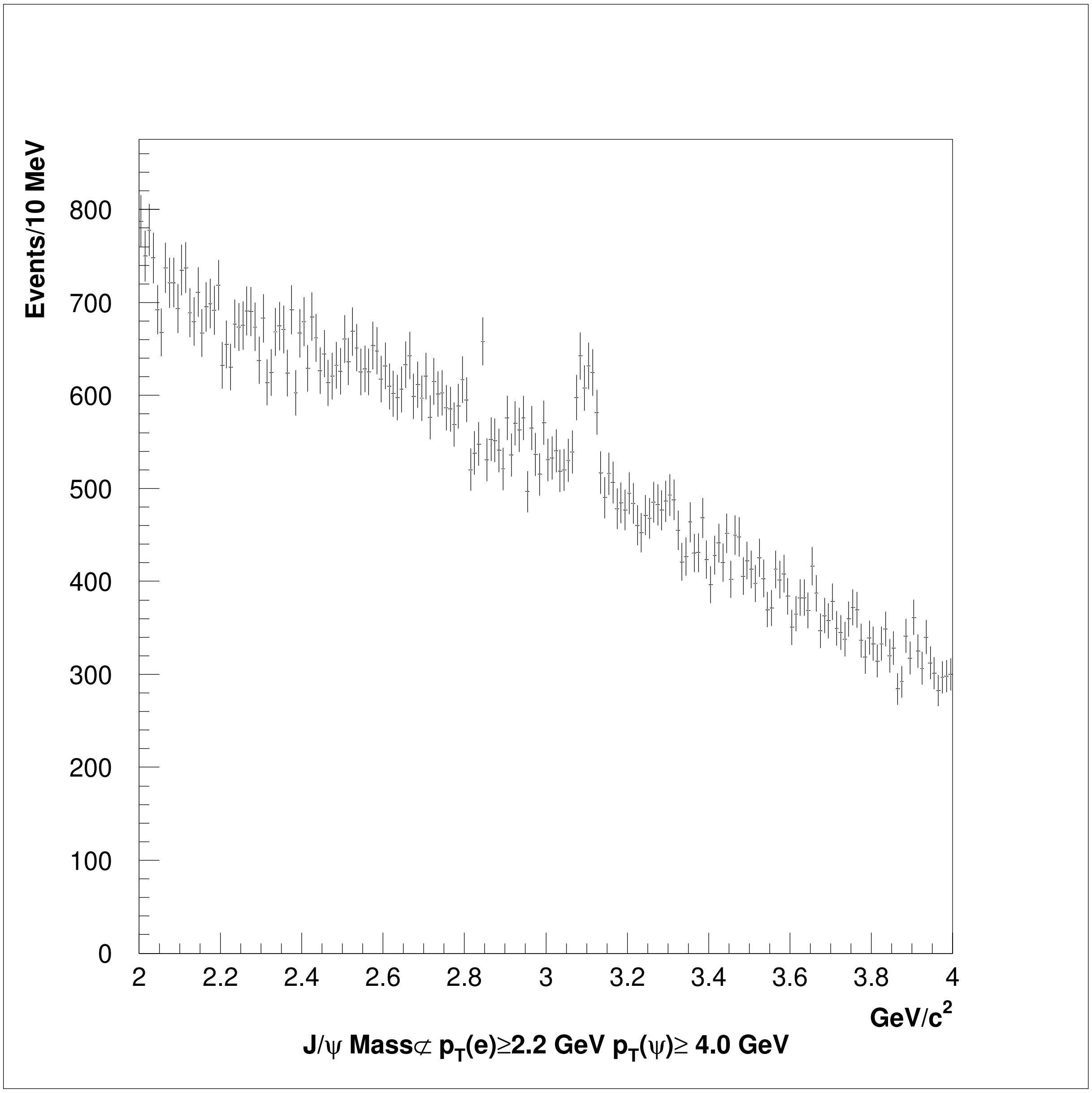

Figure 3: A dielectron mass plot for a year's running under the baseline assumptions. Here $p_T(e) \geq 2.2$ GeV and $p_T(J/\psi) > 4.0$ GeV.

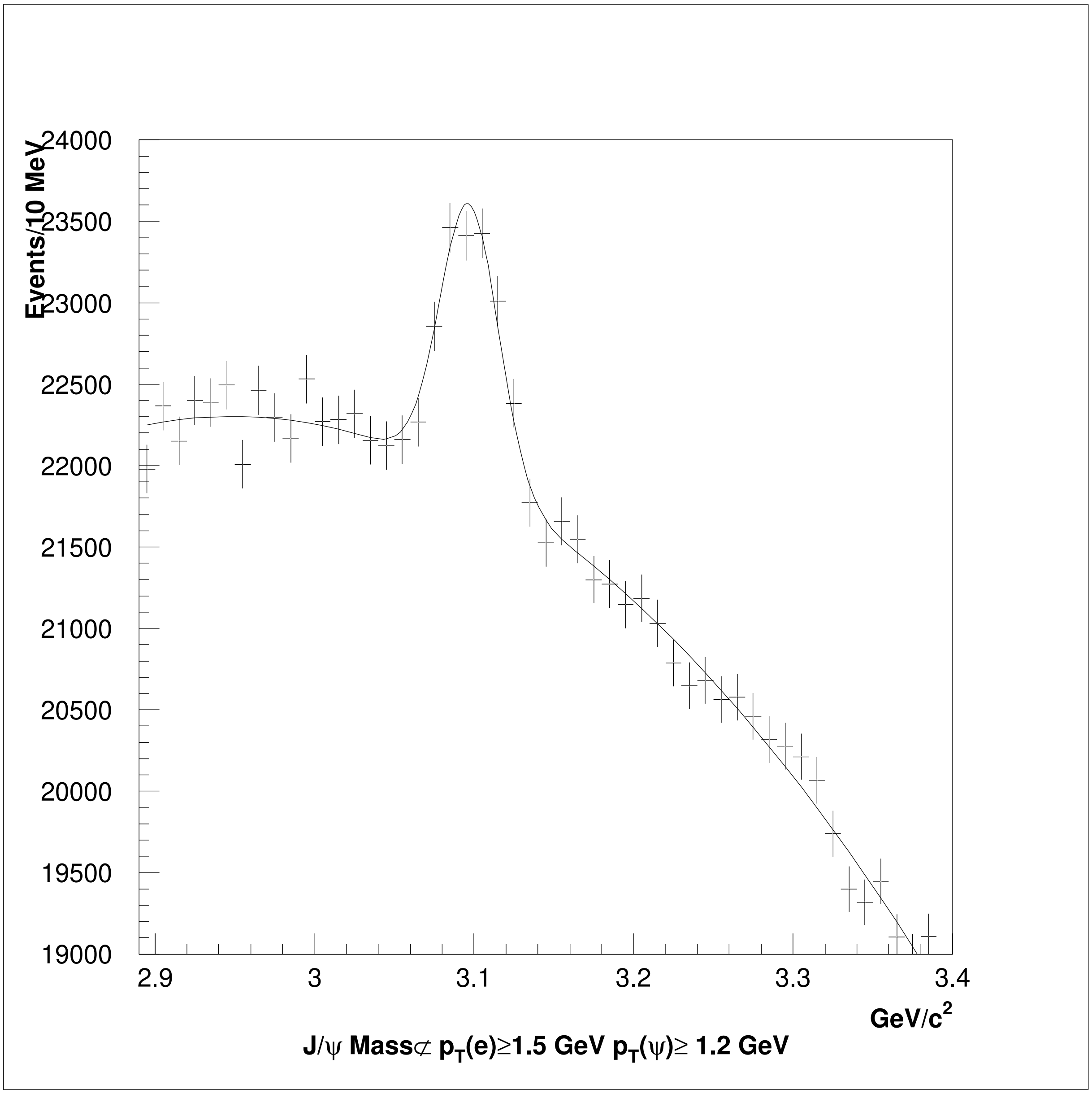

Figure 4: A dielectron mass plot for a year's running under the baseline assumptions. Here $p_T(e) \geq 1.5$ GeV and $p_T(J/\psi) \geq 1.2$ GeV. This is Figure 1, with zero suppression and a Gaussian fit on a quadratic background. The J/ψ significance is 21.1σ

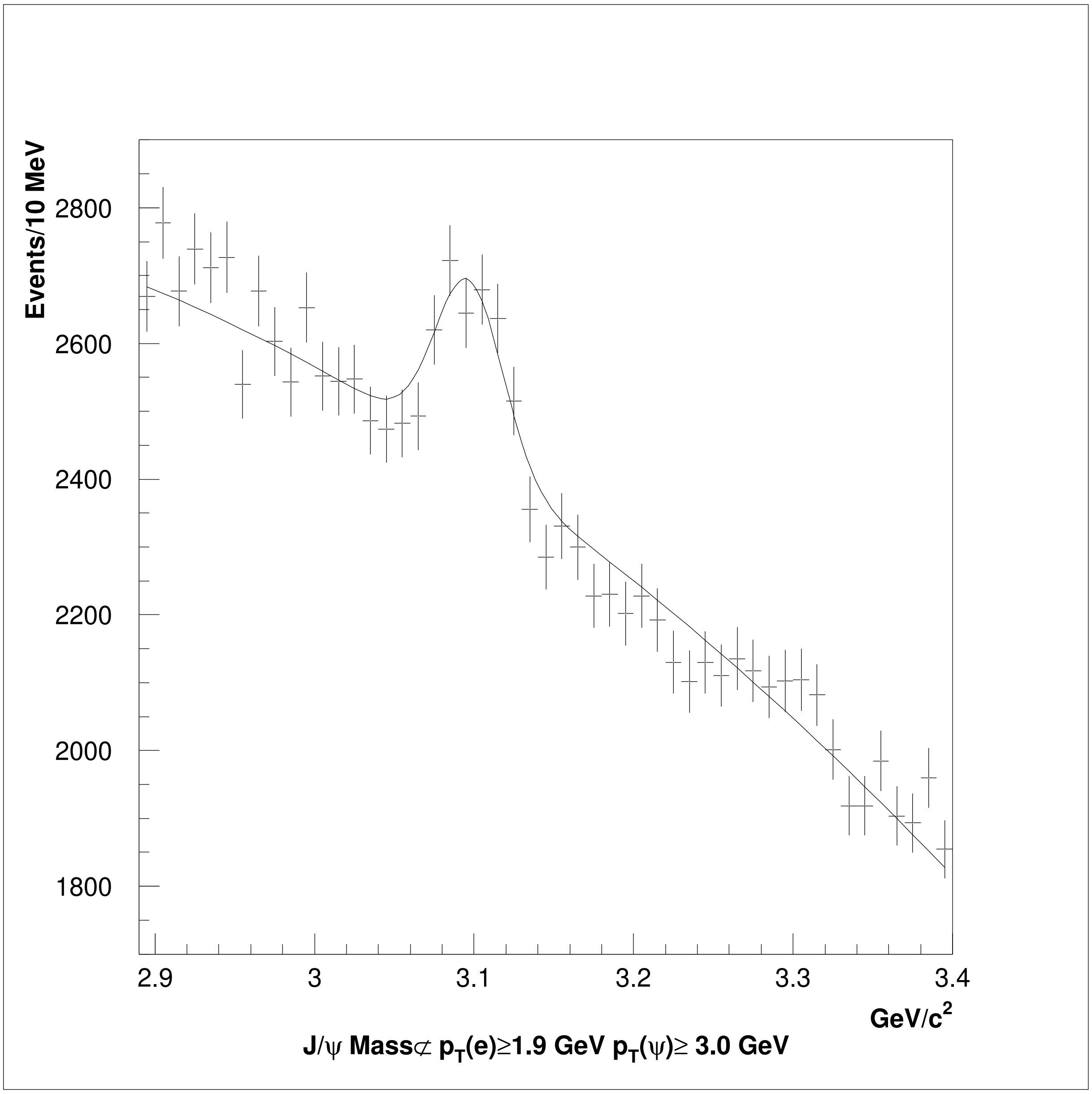

Figure 5: A dielectron mass plot for a year's running under the baseline assumptions. Here $p_T(e) \geq 1.9$ GeV and $p_T(J/\psi) \geq 3.0$ GeV. This is Figure 2, with zero suppression and a Gaussian fit on a quadratic background. The J/ψ significance is 10.0σ

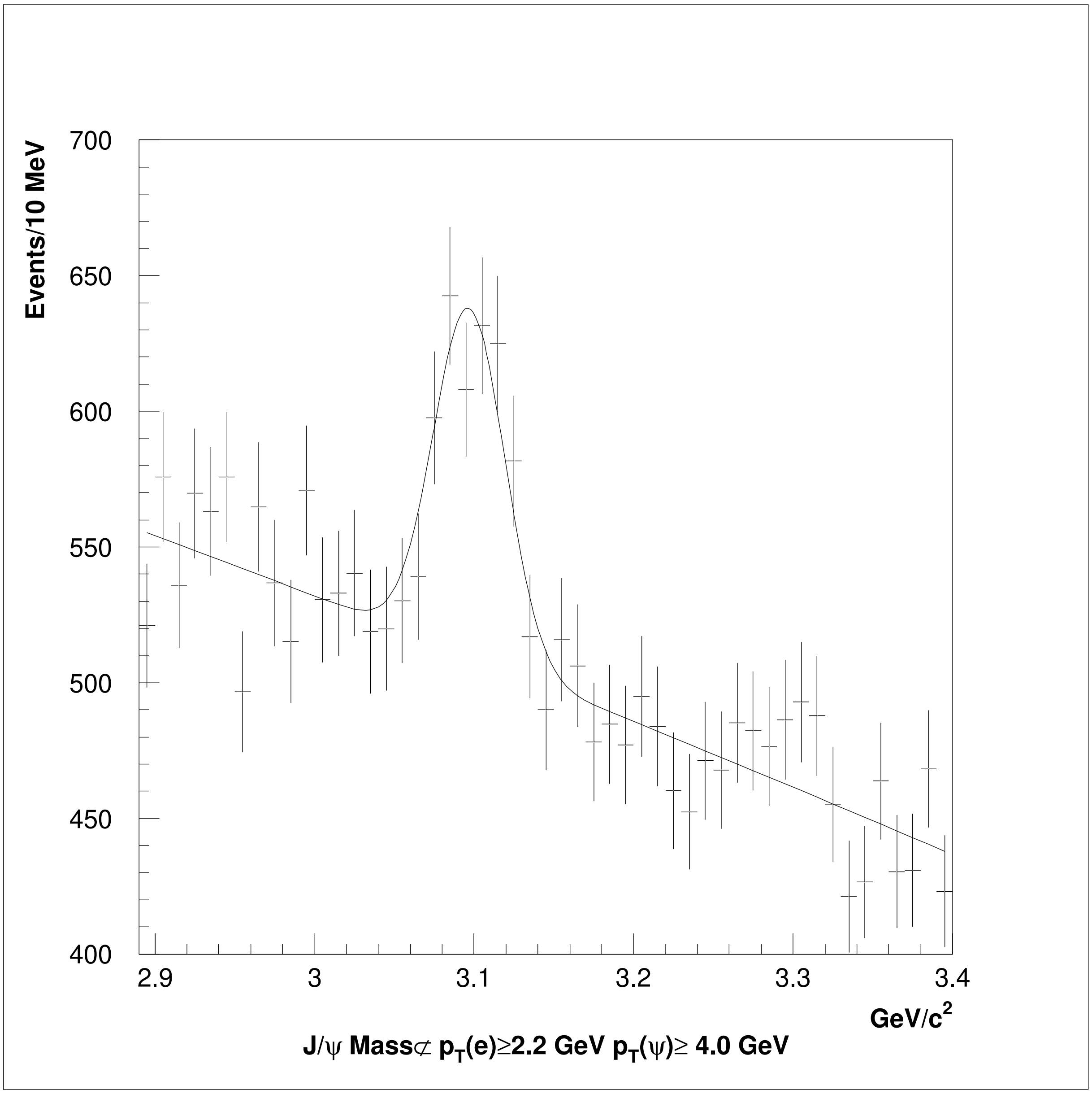

Figure 6: A dielectron mass plot for a year's running under the baseline assumptions. Here $p_T(e) \geq 2.2$ GeV and $p_T(J/\psi) \geq 4.0$ GeV. This is Figure 1, with zero suppression and a Gaussian fit on a quadratic background. The J/ψ significance is 10.3σ

knowledge of efficiencies (tracking efficiencies were not included before, and the electron efficiencies are now taken from data). Part of this is from the 15% of J/ψ's from b decays which are removed [2], and part of this is that the prediction now extrapolates via cross sections rather than yields, which should be more accurate.

In any event, I doubt that we understand the expected yield to within a factor of 2. Perturbative QCD predictions of heavy flavor production are valid where $p_T(q) >> m(q)$ [2], which is not valid for J/ψ's of a few GeV. This is on top of the difficulties in predicting how J/ψ's emerge from the fragmentation process, a topic still under considerable theoretical discussion.

The more significant change was in the background. The background, even before any electron identification, is substantially larger. The review study used the STAR version of HIJING, which is frozen at 1.14; this used the latest version of HIJING [3] which is 1.34. The change may be in HIJING proper, or it may be in a difference in settings.

One physics effect that will improve the signal to background is jet quenching. If jets undergo more quenching than HIJING predicts, the background will decrease dramatically. The fact that the signal requires two high p_T tracks instead of one means that the background will drop as the square of the size of the quenching effect and the significance will rise in proportion to this effect.

This quadratic dependence makes calculating the background difficult. A factor of two difference in dN/dy can cause a factor of four increase in background. Various models and Monte Carlos deviate by at least this much.

This analysis can therefore be said to give an idea of what sort of hadron rejection we need to do the physics, and can be used as a starting point in asking the question "if we change the parameters of the detector, how does this impact the physics." It cannot and shouldn't be used to predict the signal to background ratio that we will ultimately see, since we don't have very reliable estimates for either one.

6.2 Possible Improvements

CDF claims a hadron rejection rate of over 500:1 in identifying electrons from $t \to b \to e$ decays.[3] They cut on the following variables:

[2] These J/ψ's are born millimeters from the plasma; they cannot possibly be affected by it. In a forthcoming STAR Note I will address the possibilities and issues of studying Debye screening of $(c\bar{c})$ pairs by comparing prompt J/ψ production with J/ψ's from b decays.

[3] I am grateful to X-N. Wang for providing this.

- Shower max size, shape and position relative to the extrapolated track.
- Energy-momentum matching (E/p)
- dE/dx in the tracking chambers
- Electromagnetic to hadronic energy deposition (HAD/EM).
- Energy deposited in the preradiator.

How does STAR compare? The shower maximum detector (SMD) is likely to be a virtual clone of the CDF detector, with better granularity in the z view. E/p is dominated by energy resolution, and STAR's is of order $15 - 16\%\sqrt{E}$ as opposed to CDF's 14%.

dE/dx is something that has not been investigated at STAR and probably should be. Even a small rejection in the background could make a large difference: removing only 1/3 of the hadrons removes more than half the background. That is, multi-σ $\pi - e$ separation is not necessary. All that is necessary is that some tracks with dE/dx not consistent with electrons be removed.

HAD/EM is not possible, since we don't have a hadronic calorimeter. However, we do have depth segmentation in the present design. We need to better understand its role in $e - \pi$ separation. Similarly, we don't have a preradiator, although a 3-layer EMC design has been talked about, where the first layer acts as a preradiator. Again, this needs to be studied in more detail: the cost of a third layer is over $2M.

One difference that could be raised is that CDF has cleaner events than STAR. While this is true in general, these numbers were taken from electron identification in b-jets, with a mean E_T of around 50 GeV. The energy density in this environment is comparable to what it is in a STAR Au-Au collision.

Another difference is that STAR has smaller towers than CDF. This allows rejecting hadrons based on transverse shower shape - effectively, asking how well the shower maximum position correlates with the shower centroid, and whether the shower width in the calorimeter towers looks electromagnetic or not. The benefits of using this should be studied.

6.3 Conclusions

Physics with charmonium still looks possible, although perhaps not as simple as it first appeared. We are extremely sensitive to the level of background (and there is some evidence that the predictions are not yet entirely stable), as well as the hadron rejection near 2 GeV. Even small improvements in hadron rejection will correspond to a large improvement in signal to background.

References

[1] F. Abe *et. al*, *Phys. Rev. Lett.* **69**, p.3705 (1992)

[2] P. Nason, S. Dawson, R.K. Ellis, . *Nuclear Physics* **B327**:49 (1989).

[3] F. Abe *et. al*, *Phys. Rev.* **D50**, p.2966 (1994)