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PERFORMANCE-BASED TOLERANCES FOR MUON SUPERMODULE ALIGNMENT

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Abstract

In this note we describe a method for deriving tolerances for Muon Supermodule alignment, based on the effects of misalignment on the trigger and the offline analysis. Placement tolerances come from a Monte Carlo study of Level 1 and Level 2 trigger resolution. Knowledge tolerances arise from analytic estimates of full offline muon resolution and from the resolution of the high-luminosity "standalone" configuration. Our method can also be used in a backwards sense, to evaluate the iompact on resolution of proposed scenarios for the alignment system.

1 Introduction

The momentum resolution for muons in the SDC detector is dependent upon our understanding of the actual spatial locations of the measuring elements. The accuracy requirements imposed on the muon sub-system can be divided into two tolerances: 1) chamber "placement", which effects the resolution of the muon triggers, and 2) chamber "knowledge" which impacts the offline momentum measurements. The placement tolerances give the accuracy with which the supermodules must be *positioned*: small misplacements can be corrected in the offline analysis, but the trigger assumes that all modules are correctly positioned on the detector. Knowledge of the actual wire locations affects the momentum measurement and resolution of the muons in the offline data analysis.

Given an understanding of the nominal resolutions of the trigger and offline systems, and their dependences on the measurements made by each muon Supermodule, tolerances on translational and rotational misalignments can be extracted module-by-module. In this note, tolerances have been defined as those which, when applied to a single relevant Supermodule, would produce a 10% worsening of resultion, compared to the nominal (fully aligned) resolution. This definition must also include a choice of transverse momentum scale: for the triggers, we have evaluated tolerances at 20 (Level 1) and 100 (Level 2) GeV, while the offline tolerances are at 2 TeV, which reflects a rough upper bound from the accessible physics processes.

For the following discussions, we define the z-axis along the beam-line, the y-axis vertical, and the x-axis horizontal; generic supermodules are considered to be in "top-octant" ("12 o'clock") position. These definitions pertain to all Supermodules. Placement and knowledge errors are described in terms of three shifts (δ_x, δ_y, δ_z) and three angles (pitch, in y-z; yaw, in x-z; and roll, in x-y);

angular motions are defined about the center of the supermodule. These definitions are illustrated in Fig. 1. Given a specified level of resolution degradation, tolerances are evaluated using muons projected to each of the four corners of the Supermodule and to its center; the overall tolerance on a particular shift or translation is defined as the most restrictive tolerance from the five sets.

The tolerances presented in this note are definitional. A "tight" definition of only 10% degradation of resolution was chosen, in part, because our study assesses the effect of a single displaced Supermodule. This is of course an unrealistic scenario! In future, we will interface this work with the alignment system engineers, and will develope a system to evaluate the effect on resolution of various proposed tolerance scenarios.

2 Supermodule Placement Tolerances

2.1 Description of Monte Carlo Trigger Simulation

A simple detector simulation package (BOSSIM) was developed for the testing of trigger-related issues. Physics input to this package came from ISAJET V6.20; heavy Top events (m_t = 125 GeV), Higgs decay to 4 μ's (m_{Higgs} = 800 GeV), and minimum bias events were generated. BOSSIM propogates prompt ISAJET muons through the April '92 SDC Detector (SSC Drawing sdd81.007) to the Muon Supermodules, and includes the following effects:
(1) beam-spot size in z (σ_z=6cm),
(2) bending in the solenoid, calorimeter (flux return), and toroidal B-fields,
(3) azimuthal dependence of muon bend through toroid,
(4) multiple scattering in solenoid, calorimeter, and toroid,
(5) single-wire resolution in the muon chambers (200μm),
(6) random wire placement error in the muon chambers (100μm), and
(7) wire sagitta (1mm at center of 9m wire).
Hits are generated in the Muon Supermodules; the structure of each Supermodule is simplified to two layers of θ-measuring chambers, separated by 20cm. The Barrel (Forward) maximum drift distance is 4 (2) cm. Although the single-wire drift error assumed when the Monte Carlo was run (200μm) is somewhat smaller than the current goal (250μm), our results for L1 placement are still valid, being driven by other contributions to momentum resolution; our L2 placement results are more dependent on single-wire drift error, but should still be good to 10-15%.

2.2 Level 1 Trigger

The local (intra-supermodule) Level 1 trigger is modelled as a difference between unsigned drift-times in the two layers. Momentum at trigger-level is defined for the Barrel in the standard way as $P_t = 0.3B_{tor}T_{tor}/\Delta$, where $\Delta = (|d_1 - d_2|)\sin(\theta_{tow})/(20cm)$ and d_i is the unsigned drift-time for the ith layer. For the Intermediate and Forward, the momentum calculation is given

by $P_t = 0.3B_{tor}T_{tor}\tan(\theta)/\Delta$, where $\Delta = (|d_1 - d_2|)\cos(\theta_{tow})/(20cm)$. No attempt was made to simulate possible imprecision in the $\sin(\theta_{tow})$ or $\cos(\theta_{tow})$ factors, and only muons with both hits in the same projective tower were considered as candidate triggers. Note that this definition of transverse momentum implicitly assumes that the pre-bend muon was headed for the center of the trigger tower (see discussion of "trigger-tower smearing", below). For the results that follow, μBW2 has been taken as the trigger module in the Barrel, μIW2 in the Intermediate, and μFW4 in the Forward.

Higgs decay to 4 μ's were used to study various contributions to trigger resolution. Results are averaged over the Barrel and Intermediate/Forward separately. Figure 2 (3) shows a set of four curves of Barrel (Forward) L1 trigger resolution, dP_t/P_t (RMS, no fit performed) vs. true P_t. The upper curve is the total resolution; the lower three show separately the effects of the largest sources of error: multiple scattering, the beam-spot size in Z, and "trigger-tower smearing" (TTS). The smaller effects of chamber resolution and single-wire placement error are included in the total resolution curve, but for clarity are not shown (see discussion of "global" trigger below). The resolution overall is of order dP_t/P_t=100%P_t.

The two largest contributions to trigger resolution at Level 1, beam-spot size and TTS, arise out of the Level 1 calculation of transverse momentum: both effects violate the assumption that the pre-toroid muon was pointing directly at the trigger tower ($\theta_\mu^{pre} = \theta_{tow}$). To see how resolution depends on this assumption, first consider the effect of the beam spot. We imagine holding the post-bend muon "in place", and allow the muon production point to move around in Z due to the beam-spot. Each shift in Z necessitates a different toroidal bend in order to match-up with the post-bend muon stub, meaning that a range of true P_t's will all yield the same trigger P_t. Now consider TTS, and assume a point beam-spot. A muon ends up in tower i, and is measured to have a relative angle Δ w.r.t. θ_{tow}. The extracted trigger P_t is independent of where the muon is in tower i, so long as it makes the same angle Δ. Thus a range of combinations of initial θ and location within the tower are allowed, again meaning a range of true P_t for the same trigger P_t.

More rigorously, the trigger assumes that Δ, which is equal to $\theta_\mu^{post} - \theta_{tow}$, is also equal to $\theta_\mu^{post} - \theta_\mu^{pre}$; an uncertainty in trigger P_t is introduced by the distribution of $\theta_\mu^{pre} - \theta_{tow}$, given fixed Δ. For Barrel muons, the beam spot produces an RMS in this quantity of $\sigma_z \sin^2(\theta_{mu}^{pre})/R_{tor}$, or roughly 5mrad, which means a contribution to resolution of dP_t/P_t=0.6%P_t. This is about what's seen in Fig. 2. Assessing the contribution of TTS from first principles is somewhat more difficult, but should be driven by the RMS of $\theta_\mu^{pre} - \theta_{tow}$ assuming a flat probability distribution for this quantity. If w_{cell} is the max drift distance for the cell, the RMS is $w_{cell}\sin(\theta_{mu}^{pre})/(\sqrt{3}R_{tor})$, or again about 3mrad and dP_t/P_t=0.3%P_t. The actual simulation shows a somewhat larger error due to TTS than this prediction. The smaller cell sizes reduce the effect of TTS for the Forward system, and the smearing of the interaction vertex is also a smaller effect at these lower angles.

2.3 Level 2 Theta-Trigger

BOSSIM studies of a hypothetical "before-after" theta trigger were performed, involving μBW1 and μBW2 in the Barrel, and μFW2 and μFW4 in the Forward. Results are shown in Figs. 4&5. Δ measurements are made in both Supermodules within a pair; the difference $\Delta_1 - \Delta_2$ is taken, and used to calculate P_t. (NB: This difference can only be correctly calculated if the sign of the Δ's are known. How this would be accomplished at trigger time is not clear; if the sign is not known, perhaps the smaller of the two possible solutions for P_t could be chosen for the threshold comparison.) This hypothetical trigger is insensitive to the beam-spot and size of the towers. The primary contributions to resolution are multiple scattering, single-wire resolution (200μm in the simulation) , and single-wire placement error (random 100μm shifts).

Different Level 2 trigger definitions are currently under study.

2.4 Results for Placement Tolerances

The results shown in Figures 2-5 were used to provide goals for Supermodule placement tolerances. Level 1 (2) resolution for muons at 20 (100) GeV P_t was read off the Figures, and worsened by 10%. This is equivalent to an error in the measurement of the muon's θ angle within each Supermodule. Supermodules were then iteratively translated and rotated until the intra-Supermodule angular measurement worsens by 10%, which defined the tolerances on translation and rotation. These tolerances are given in Table 1. Note that Supermodule "roll" and "yaw" introduce momentum error because the two Barrel (Intermediate/Forward) θ-layers are not at the same radius (Z). We also note that there is no tolerance on the X position: this corresponds to the direction along the theta wires, where there is no sensitivity. Note, too, that the tolerances listed in Table 1 are exclusive in nature – they assume that placement knowledge is perfect except for the single displacement in question.

3 Supermodule Knowledge Tolerances

The requirements placed on Supermodule knowledge tolerances by more sophisticated measurements of muon momentum have been studied. Two different scenarios were used to derive these tolerances on translations and rotations: first, using the estimated resolution of the full "Offline" reconstruction, and second, using a "standalone" ("redundant") measurement in the θ layers (plus knowledge of the event vertex in z). In both cases, tolerances per Supermodule were defined by demanding that misalignment contributes less than a 10% worsening of momentum resolution at 2 TeV.

3.1 Full Offline Tolerances

Offline measurement of muon P_t can be shown to consist, to a good approximation, of three independent measurements: (a) CTD tracking, (b) bend in the toroids as seen by the θ-chambers, and (c) matching in ϕ of the muon stub with the exit-point of the muon in the CTD. An analytic expression for the offline resolution vs. P_t was derived as the weighted average of individual analytic expressions for these three techniques. This estimate of the offline resolution includes the effects of multiple scattering in the calorimeter and toroids. Since the resolution estimate is a closed-form expression, with the roles of individual Supermodules explicit, misalignments can be introduced which worsen the overall resolution to the requested level. Tolerances are derived in this fashion.

We use the TDR parametrization for CTD resolution. The equations for the Muon θ and Muon ϕ contributions to resolution are

$$
\begin{aligned}
dP_t/P_t|_\theta &= \frac{P_t \sin(\theta)}{0.3BT_{tor}}\sqrt{\frac{\sigma_0^2+\sigma_{BW1}^2}{R_{BW1}^2}+\frac{\sigma_{BW2}^2+\sigma_{BW3}^2}{(R_{BW3}-R_{BW2})^2}+(\frac{\delta\theta_{m.s.}^{tor}}{\sin(\theta)})^2} \qquad \text{(Barrel)} \\
&= \frac{P_t}{0.3BT_{tor}\tan(\theta)}\left(\frac{\sigma_0^{-2}+\sigma_{FW1}^{-2}+\sigma_{FW2}^{-2}}{(\sigma_0^{-2}+\sigma_{FW1}^{-2}+\sigma_{FW2}^{-2})(\frac{Z_{FW1}^2}{\sigma_{FW1}^2}+\frac{Z_{FW2}^2}{\sigma_{FW2}^2})-(\frac{Z_{FW1}}{\sigma_{FW1}^2}+\frac{Z_{FW2}}{\sigma_{FW2}^2})^2}\right. \\
&+ \left.\frac{\sigma_{IW2}^2+\sigma_{IW3}^2}{(Z_{IW3}-Z_{IW2})^2}+(\frac{\delta\theta_{m.s.}^{tor}}{\cos(\theta)})^2\right)^{\frac{1}{2}} \qquad \text{(Intermediate)} \\
&= \frac{P_t\cos(\theta)}{0.3BT_{tor}\tan(\theta)}\left(\frac{\sigma_0^{-2}+\sigma_{FW1}^{-2}+\sigma_{FW2}^{-2}}{(\sigma_0^{-2}+\sigma_{FW1}^{-2}+\sigma_{FW2}^{-2})(\frac{Z_{FW1}^2}{\sigma_{FW1}^2}+\frac{Z_{FW2}^2}{\sigma_{FW2}^2})-(\frac{Z_{FW1}}{\sigma_{FW1}^2}+\frac{Z_{FW2}}{\sigma_{FW2}^2})^2}\right. \\
&+ \left.\frac{\sigma_{FW4}^2+\sigma_{FW5}^2}{(Z_{FW5}-Z_{FW4})^2}+(\frac{\delta\theta_{m.s.}^{tor}}{\cos(\theta)})^2\right)^{\frac{1}{2}} \qquad \text{(Forward)}
\end{aligned}
$$

The ϕ-based measurement in the Barrel can be expressed as

$$
dP_t/P_t|_\phi = \frac{P_t}{0.48}\sqrt{\delta_{CTD}^2+\frac{R_{CTD}^2}{(\delta\phi_1)^{-2}+(\delta\phi_3)^{-2}}}
$$

where

$$
\delta\phi_1 = \frac{1}{R_{BW1}}\sqrt{\sigma_{BW1}^2+\left[(R_{BW1}-R_{cal})^2+\frac{T_{cal}^2}{3}+(R_{BW1}-R_{cal})T_{cal}\right](\frac{\delta\phi_{m.s.}^{cal}}{\sin(\theta)})^2}
$$

and

$$
\delta\phi_3 = \frac{1}{R_{BW3}}\left(\sigma_{BW3}^2+\left[(R_{tor}-R_{cal})^2+\frac{T_{cal}^2}{3}+(R_{tor}-R_{cal})T_{cal}\right](\frac{\delta\phi_{m.s.}^{cal}}{\sin(\theta)})^2\right.
$$

$$+ \quad \left[(R_{BW3} - R_{tor})^2 + \frac{T_{tor}^2}{3} + (R_{BW3} - R_{tor})T_{tor}\right] (\frac{\delta\phi_{m.s.}^{tor}}{\sin(\theta)})^2\Big)^{\frac{1}{2}}$$

Finally for the Intermediate,

$$\begin{aligned} dP_t/P_t|_\phi &= \frac{P_t}{0.48}\Big(\delta_{CTD}^2 + (\frac{R_{CTD}}{Z_{IW3}\tan(\theta)})^2 \Big[\sigma_{IW3}^2 \\ &+ ((Z_{tor} - Z_{cal})^2 + \frac{T_{cal}^2}{3} + (Z_{tor} - Z_{cal})T_{cal})(\frac{\delta\phi_{m.s.}^{cal}}{\cos(\theta)})^2 \\ &+ ((Z_{IW3} - Z_{tor})^2 + \frac{T_{tor}^2}{3} + (Z_{IW3} - Z_{tor})T_{tor})(\frac{\delta\phi_{m.s.}^{tor}}{\cos(\theta)})^2\Big]\Big)^{\frac{1}{2}} \end{aligned}$$

with B the toroid magnetic field, T_{tor} the thickness of the Barrel/Forward toroid in R/Z (1.5m/3m; for the intermediate the direct-line thickness is taken to be 2.9m); δ_{CTD} the error on the exit-point of the CTD track in (R, ϕ), assumed to be 30μm; $\delta\phi_{m.s.}^j$ and $\delta\theta_{m.s.}^j$ are angular multiple scatterings in material j; σ_i is the *station* error for measurements in the relevant layers (θ or ϕ) of Supermodule i; and σ_0 is the contribution to the error on the Z vertex from calorimeter multiple scattering (including both angular and translational scattering).

The σ_i are set equal to $\sqrt{((\sigma_i^{nom})^2 + D^2)}$, where σ_i^{nom} is the nominal station resolution, taken to be 135μm ($=\sqrt{250^2 + 100^2}/\sqrt{4}$, namely 250$\mu$m drift error plus 100$\mu$m wire-positioning error), and D is the drift-distance error introduced by misalignment. The geometry used in the analytic expression for overall offline resolution was that of Revision E of the TDR. The nominal resolution (i.e. $D = 0$), dP_t/P_t vs. P_t at η=0, is shown in Fig. 6. Nominal resolution at 3 TeV is shown vs. η in Fig. 7. The individual resolutions of the three contributions to Offline momentum measurement are also shown.

To define the misalignment tolerances for each Supermodule, we derived the value of D which would degrade the resolution to the requested level for each of the five "muons" propogated to the Supermodule; the Supermodule was then rotated and translated to achieve this drift-distance error D. The tolerances we obtain are given in Table 2. Please take note of the fact that each tolerance listed in the table – i.e., a misalignment of one parameter of one supermodule – would *alone* lead to a 10% worsening of resolution. Thus these tables are strictly illustrative.

We also note that in two cases we have modified the way in which the tolerances were derived. For Barrel ϕ measurements, the ϕ-layers in μBW1 and μBW3 are redundant; for Forward θ measurements, μFW1 and μFW2 are redundant (when taken with a Z-vertex measurement). In both cases we found that 10% tolerances could only be derived if one of the two redundant Supermodules was removed from the calculation; e.g., to estimate knowledge tolerances on μBW3, μBW1 was removed from the ϕ measurement calculation. In future, when assessing the impact of alignment scenarios on resolution, these artifical deletions will not take place.

For the following set of plots only, the LOI geometry of the SDC Detector was used in the analytic expression for resolution, and a Barrel (Int./Forward) single-wire resolution of 320 (311) μm was

assumed. This was done to faciliate the comparison of these plots of resolution with corresponding plots from Jim Wiss' SDC note 92-215 (same scales used), which were derived from elaborate Monte Carlo simulations. Figure 8 compares our analytic estimate of offline resolution, dP_t/P_t vs. P_t, at η=0. Resolution at 3 TeV is plotted vs. η in Fig. 9. Agreement with Wiss' work is worst for the complicated Intermediate region, but otherwise tracks Wiss' results to better than 20% of the claimed resolution.

3.2 Standalone Tolerances

The standalone measurement uses two line segments, one formed from the vertex and the pre-toroid position(s) and a second formed from the two post-toroid positions, to measure the theta bend as the muon traverses the toroid. Standalone is equivalent to the θ-based measurement detailed above. Figure 10 compares the the analytic result for standalone dP_t/P_t vs. η at P_t=3 TeV for LOI geometry against Jim Wiss' results. The knowledge tolerances from standalone (for TDR Revision E geometry) are also given in Table 2. Note that the tolerances are generally tighter than the full Offline tolerances, since in the standalone case the momentum measurement results from a single system, the Muon θ layers.

TABLE 1:
"SINGLE MOTION" PLACEMENT TOLERANCES

NOTES:

Level 1 trigger tolerances are defined as SINGLE misalignments that worsen L1 resolution by 10% at 20 GeV Pt.

Level 2 (theta) trigger tolerances are defined as SINGLE misalignments that worsen L2 resolution by 10% at 100 GeV Pt.

Supermodule dimensions/locations are taken from Revision E of the TDR.

MBW13

	x	y	z	pitch	yaw	roll	
Level1	--	--	--	--	--	--	mm
				--	--	--	mrad
Level2	--	14.906	6.863	4.795	20.150	13.957	mm
				1.085	3.953	5.491	mrad

MBW14

	x	y	z	pitch	yaw	roll	
Level1	--	--	--	--	--	--	mm
				--	--	--	mrad
Level2	--	14.169	9.902	3.671	17.170	13.923	mm
				1.048	3.968	5.477	mrad

MBW23

	x	y	z	pitch	yaw	roll	
Level1	--	126.327	48.527	24.234	93.672	112.616	mm
				5.484	16.436	31.293	mrad
Level2	--	25.265	9.705	4.839	18.916	23.383	mm
				1.095	3.319	6.496	mrad

MBW24

	x	y	z	pitch	yaw	roll	
Level1	--	97.475	59.272	18.564	82.664	92.373	mm
				5.301	16.462	25.667	mrad
Level2	--	19.495	11.854	3.706	16.709	18.990	mm
				1.058	3.327	5.276	mrad

MBW25

	x	y	z	pitch	yaw	roll	
Level1	--	98.902	120.177	7.761	128.290	92.358	mm
				5.257	32.982	25.663	mrad
Level2	--	19.780	24.035	1.551	26.845	18.968	mm
				1.050	6.900	5.270	mrad

MBW33

	x	y	z	pitch	yaw	roll	
Level1	--	170.917	58.039	24.325	95.705	150.865	mm
				5.505	15.510	35.036	mrad
Level2	--	34.183	11.608	4.844	19.260	31.481	mm
				1.096	3.121	7.310	mrad

MBW34

	x	y	z	pitch	yaw	roll	
Level1	--	116.089	67.022	18.709	86.212	107.707	mm
				5.342	15.532	25.011	mrad
Level2	--	23.218	13.404	3.753	17.343	22.103	mm
				1.072	3.124	5.132	mrad

MBW35

	x	y	z	pitch	yaw	roll	
Level1	--	116.092	117.947	17.496	148.723	107.805	mm
				5.253	27.320	25.034	mrad
Level2	--	23.218	23.589	3.492	30.749	22.190	mm
				1.048	5.648	5.152	mrad

MIW2

	x	y	z	pitch	yaw	roll	
Level1	--	79.390	159.435	5.050	50.708	88.148	mm
				4.383	44.030	26.931	mrad
Level2	--	19.406	38.973	1.233	13.263	22.071	mm
				1.070	11.513	6.742	mrad

MIW3

	x	y	z	pitch	yaw	roll	
Level1	--	77.673	176.101	6.183	70.237	91.054	mm
				3.958	44.980	26.446	mrad
Level2	--	18.987	43.047	1.512	18.369	22.876	mm
				0.968	11.760	6.643	mrad

MFW1

	x	y	z	pitch	yaw	roll	
Level1	--	--	--	--	--	--	mm
				--	--	--	mrad
Level2	--	3.531	20.752	0.738	25.604	8.178	mm
				0.443	15.373	6.904	mrad

MFW2

	x	y	z	pitch	yaw	roll	
Level1	--	--	--	--	--	--	mm
				--	--	--	mrad
Level2	--	4.092	25.652	0.894	32.960	10.141	mm
				0.414	15.270	6.894	mrad

MFW4

	x	y	z	pitch	yaw	roll	
Level1	--	23.088	137.740	3.218	118.261	42.832	mm
				1.497	55.039	23.226	mrad
Level2	--	6.734	40.174	0.937	38.075	12.768	mm
				0.436	17.712	6.923	mrad

MFW5

	x	y	z	pitch	yaw	roll	
Level1	--	29.845	177.478	4.178	153.061	55.512	mm
				1.500	54.965	23.229	mrad
Level2	--	8.705	51.764	1.217	49.296	16.511	mm
				0.437	17.695	6.909	mrad

TABLE 2:
"SINGLE MOTION" KNOWLEDGE TOLERANCES

NOTES:

Offline tolerances are defined as SINGLE misalignments that worsen offline resolution by 10% at 2 TeV Pt. Offline resolution is modelled as a weighted average of Tracker, Mu-theta, and Mu-Phi measurements.

Standalone (theta) tolerances are defined as SINGLE misalignments that worsen Standalone resolution by 10% at 2 TeV Pt. The event vertex location in z is assumed known.

Supermodule dimensions/locations are taken from Revision E of the TDR.

MBW13

	x	y	z	pitch	yaw	roll	
Offline	0.781	1.711	1.227	1.710	1.428	1.703	mm
				0.387	0.280	0.670	mrad
Standalone	--	0.730	0.414	0.730	1.045	0.727	mm
				0.165	0.205	0.286	mrad

MBW14

	x	y	z	pitch	yaw	roll	
Offline	1.244	0.815	1.227	0.816	1.537	0.813	mm
				0.233	0.355	0.320	mrad
Standalone	--	0.532	0.524	0.533	0.889	0.531	mm
				0.152	0.205	0.209	mrad

MBW23

	x	y	z	pitch	yaw	roll	
Offline	--	0.673	0.341	0.672	0.539	0.671	mm
				0.152	0.094	0.186	mrad
Standalone	--	0.261	0.116	0.261	0.208	0.260	mm
				0.059	0.037	0.072	mrad

MBW24

	x	y	z	pitch	yaw	roll	
Offline	--	0.276	0.330	0.276	0.474	0.275	mm
				0.079	0.094	0.076	mrad
Standalone	--	0.157	0.132	0.157	0.184	0.157	mm
				0.045	0.037	0.044	mrad

MBW25

	x	y	z	pitch	yaw	roll	
Offline	--	0.241	0.362	0.240	0.391	0.239	mm
				0.162	0.100	0.066	mrad
Standalone	--	0.151	0.207	0.150	0.222	0.150	mm
				0.102	0.057	0.042	mrad

MBW33

	x	y	z	pitch	yaw	roll	
Offline	0.912	0.810	0.343	0.809	0.490	0.808	mm
				0.183	0.079	0.188	mrad
Standalone	--	0.301	0.116	0.300	0.182	0.300	mm
				0.068	0.029	0.070	mrad

MBW34

	x	y	z	pitch	yaw	roll	
Offline	1.085	0.321	0.332	0.322	0.441	0.321	mm
				0.092	0.079	0.074	mrad
Standalone	--	0.165	0.125	0.175	0.164	0.166	mm
				0.050	0.029	0.038	mrad

MBW35

	x	y	z	pitch	yaw	roll	
Offline	2.427	0.232	0.352	0.232	0.445	0.231	mm
				0.070	0.082	0.054	mrad
Standalone	--	0.150	0.182	0.150	0.230	0.149	mm
				0.045	0.042	0.035	mrad

MIW2

	x	y	z	pitch	yaw	roll	
Offline	--	0.214	0.346	0.346	0.106	0.186	mm
				0.300	0.092	0.057	mrad
Standalone	--	0.113	0.215	0.215	0.066	0.116	mm
				0.187	0.057	0.035	mrad

MIW3

	x	y	z	pitch	yaw	roll	
Offline	1.018	0.213	0.358	0.358	0.136	0.179	mm
				0.229	0.087	0.052	mrad
Standalone	--	0.108	0.219	0.218	0.083	0.109	mm
				0.140	0.053	0.032	mrad

MFW1

	x	y	z	pitch	yaw	roll	
Offline	--	0.192	0.826	0.825	0.729	0.304	mm
				0.495	0.438	0.257	mrad
Standalone	--	0.189	0.703	0.707	0.624	0.260	mm
				0.424	0.375	0.220	mrad

MFW2

	x	y	z	pitch	yaw	roll	
Offline	--	0.227	0.976	0.976	0.887	0.360	mm
				0.452	0.411	0.245	mrad
Standalone	--	0.225	0.832	0.832	0.756	0.307	mm
				0.385	0.350	0.209	mrad

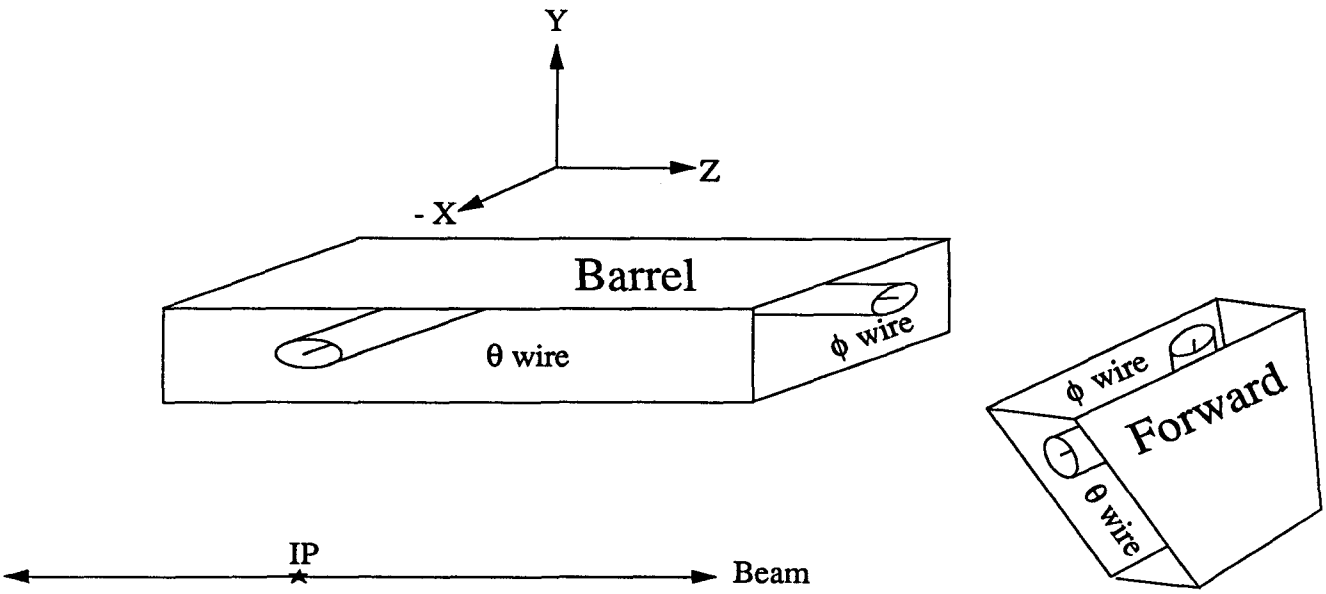
MFW4

	x	y	z	pitch	yaw	roll	
Offline	--	0.102	0.458	0.457	0.358	0.136	mm
				0.213	0.167	0.073	mrad
Standalone	--	0.101	0.380	0.379	0.297	0.112	mm
				0.176	0.138	0.061	mrad

MFW5

	x	y	z	pitch	yaw	roll	
Offline	--	0.102	0.458	0.457	0.362	0.136	mm
				0.164	0.130	0.057	mrad
Standalone	--	0.101	0.380	0.379	0.296	0.108	mm
				0.136	0.106	0.045	mrad

Coordinate System for Supermodule Alignment



Parameters to define for each supermodule.

- Translation about X, Y, and Z.
  δx , δy , and δz

- Rotations about X, Y, and Z.

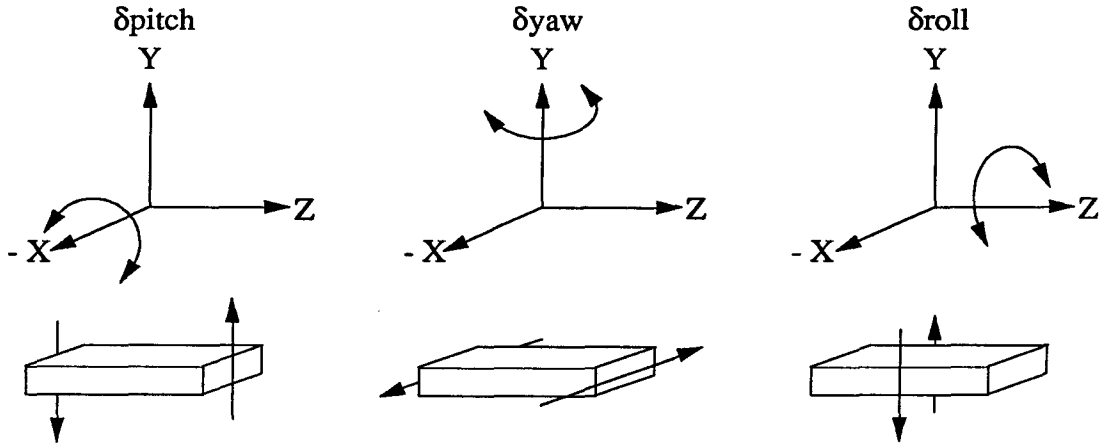


FIG. 1

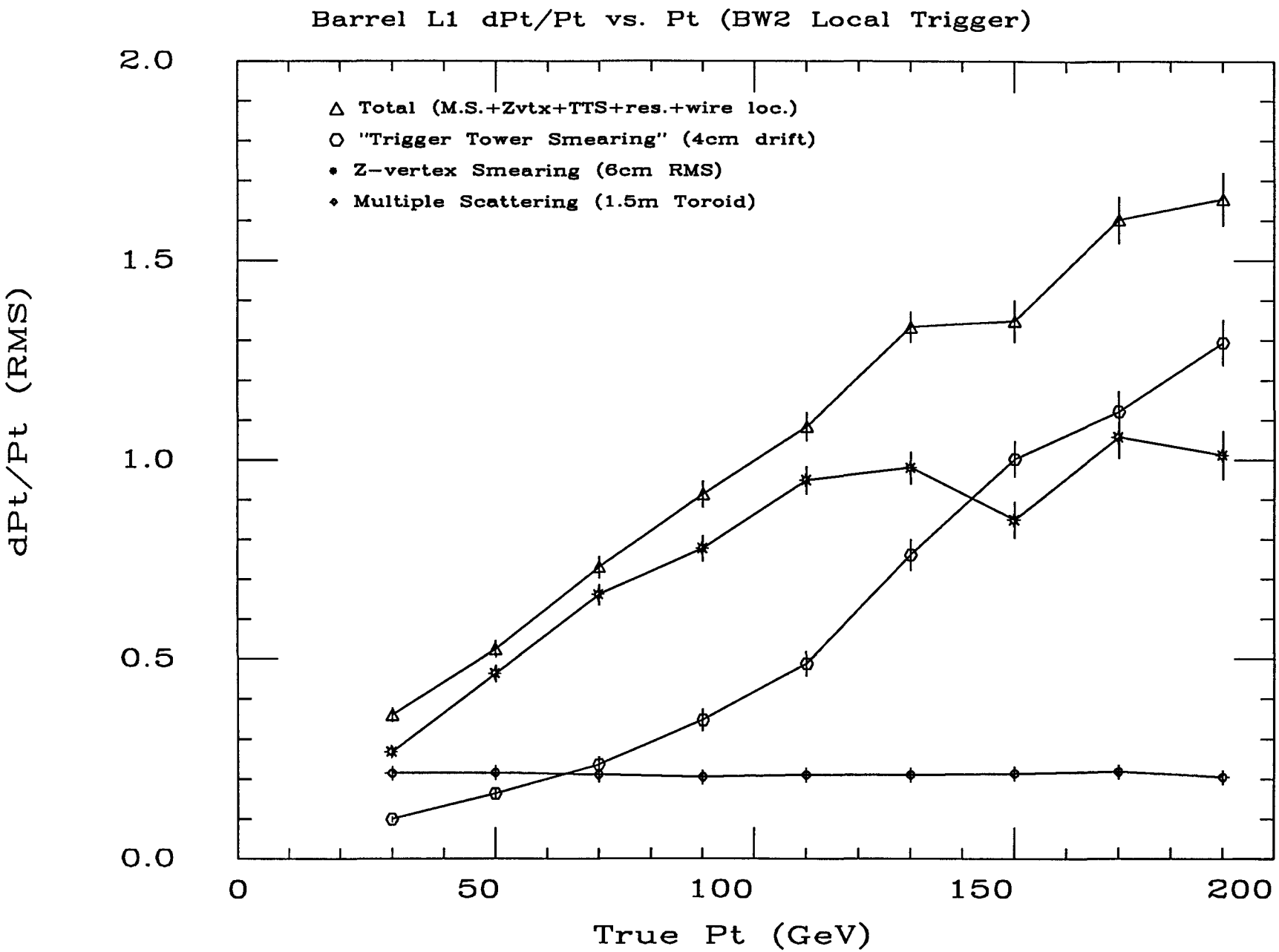

Barrel L1 dPt/Pt vs. Pt (BW2 Local Trigger)
Total (M.S.+Zvtx+TTS+res.+wire loc.)
"Trigger Tower Smearing" (4cm drift)
Z-vertex Smearing (6cm RMS)
Multiple Scattering (1.5m Toroid)
dPt/Pt (RMS)
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
True Pt (GeV)

FIGURE 2

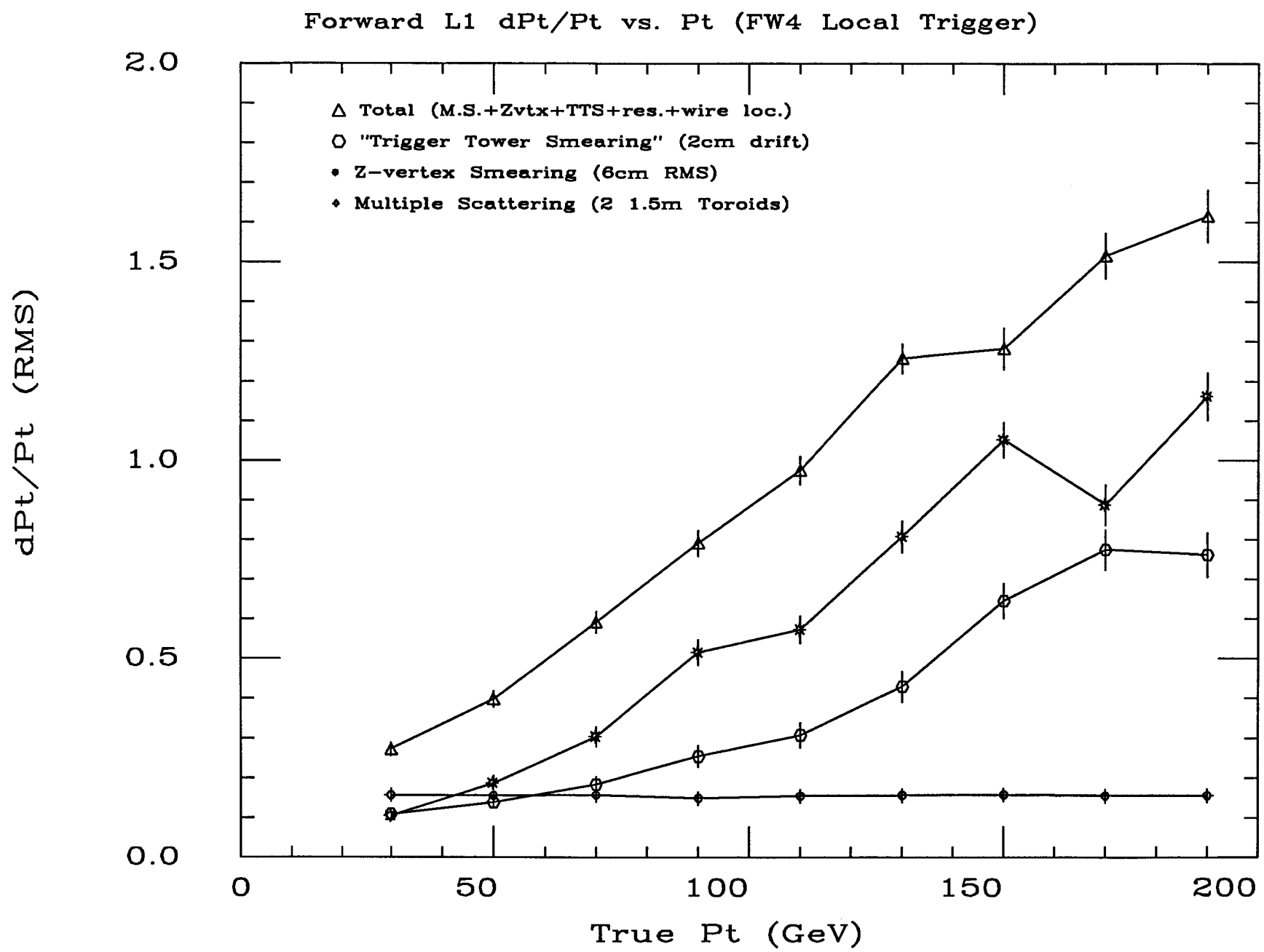

Forward L1 dPt/Pt vs. Pt (FW4 Local Trigger)
Total (M.S.+Zvtx+TTS+res.+wire loc.)
"Trigger Tower Smearing" (2cm drift)
Z-vertex Smearing (6cm RMS)
Multiple Scattering (2 1.5m Toroids)
dPt/Pt (RMS)
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
True Pt (GeV)

FIGURE 3

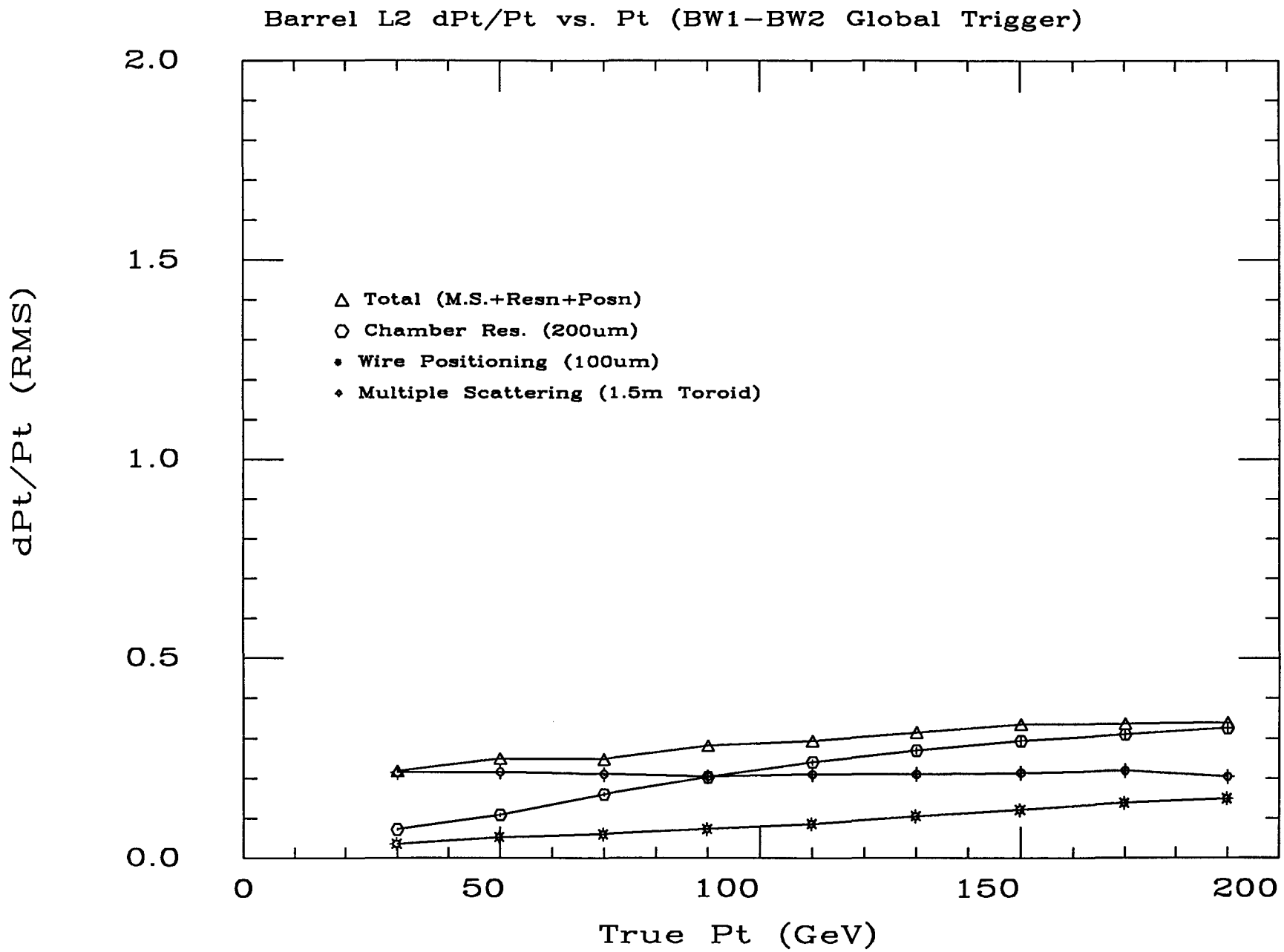

Barrel L2 dPt/Pt vs. Pt (BW1−BW2 Global Trigger)
2.0
1.5
1.0
0.5
0.0
dPt/Pt (RMS)
Total (M.S.+Resn+Posn)
Chamber Res. (200um)
Wire Positioning (100um)
Multiple Scattering (1.5m Toroid)
0
50
100
150
200
True Pt (GeV)

FIGURE 4

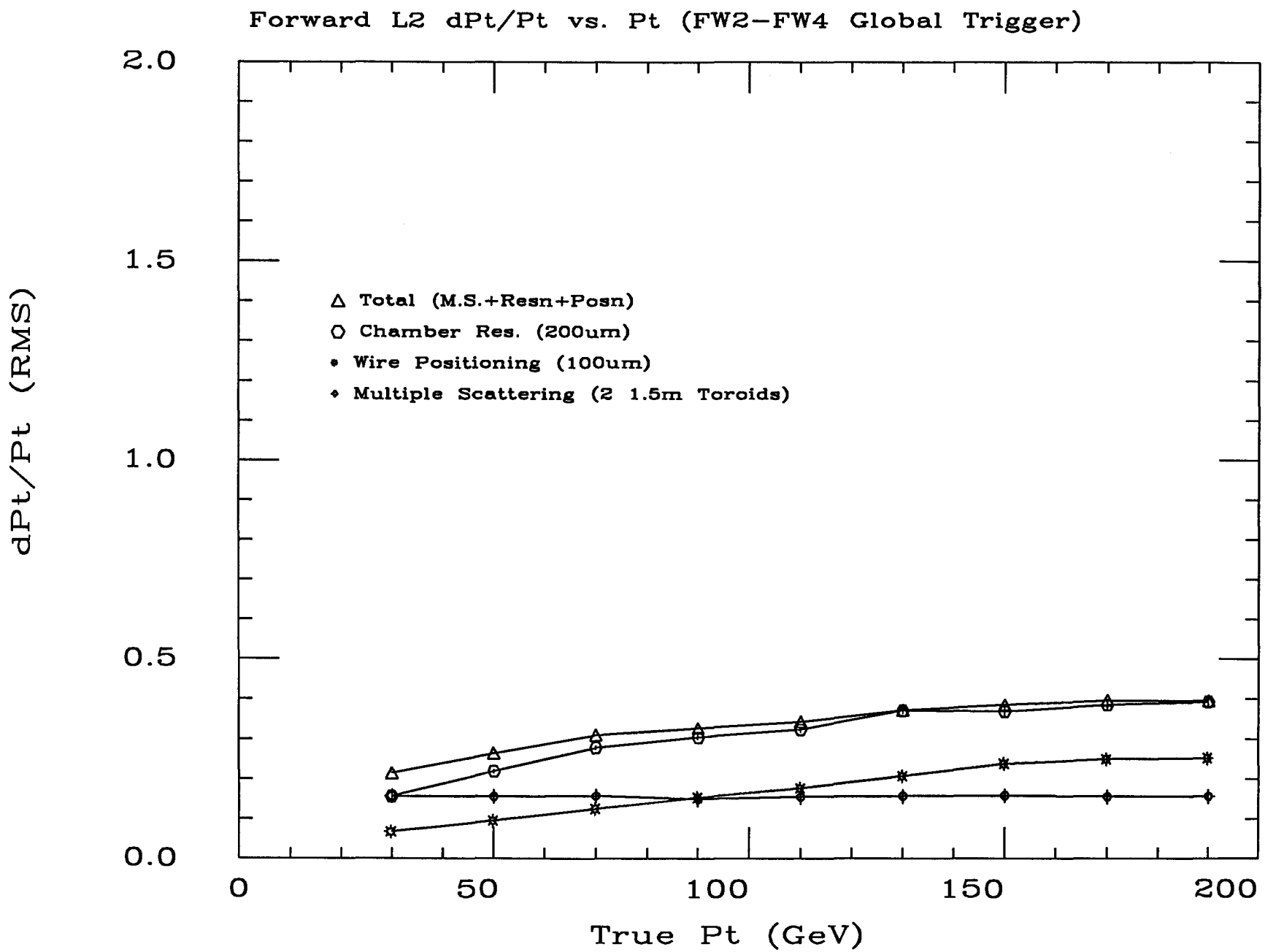

Forward L2 dPt/Pt vs. Pt (FW2–FW4 Global Trigger)
2.0
1.5
1.0
0.5
0.0
dPt/Pt (RMS)
Total (M.S.+Resn+Posn)
Chamber Res. (200um)
Wire Positioning (100um)
Multiple Scattering (2 1.5m Toroids)
0
50
100
150
200
True Pt (GeV)

FIGURE 5

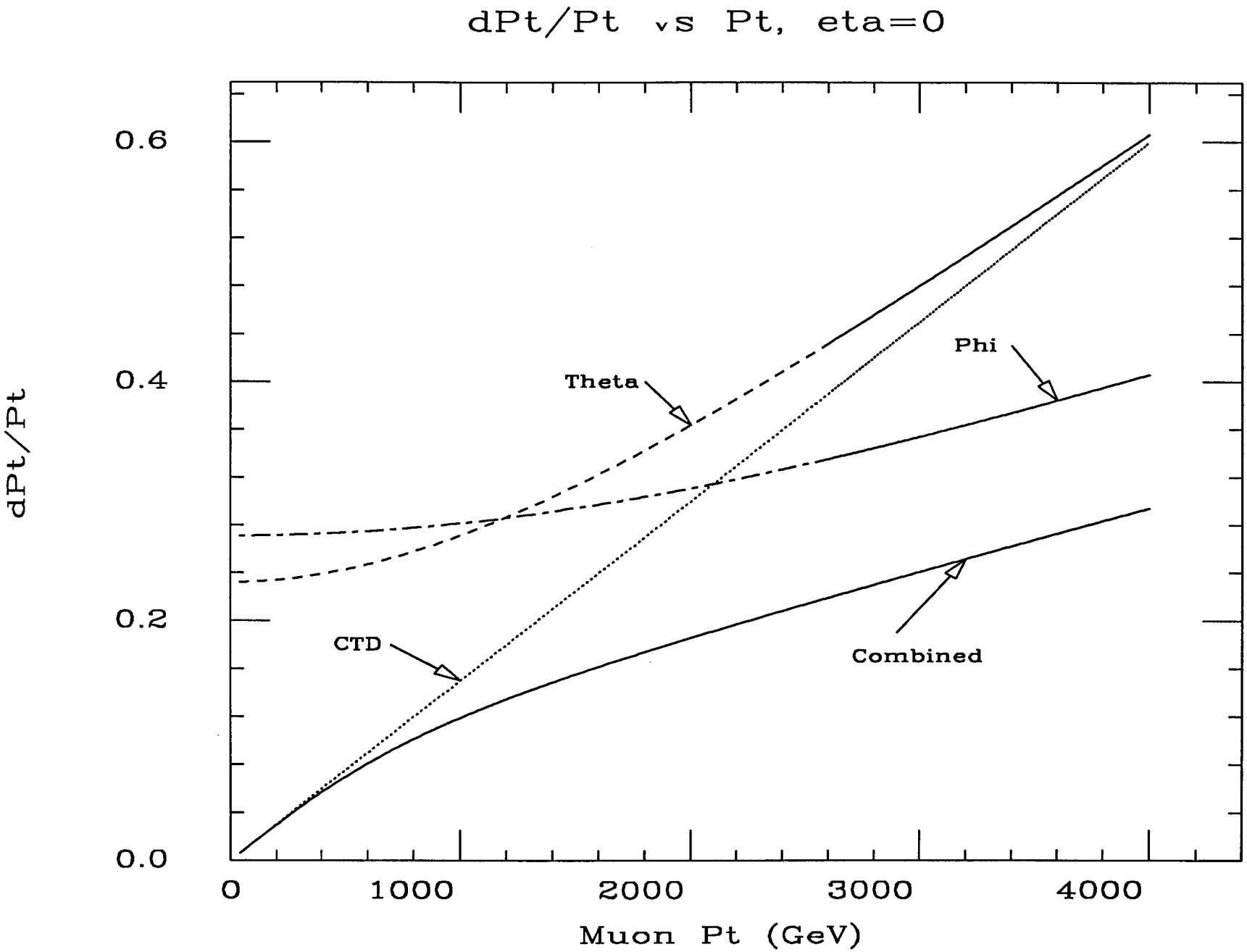

dPt/Pt vs Pt, eta=0
0.6
0.4
0.2
0.0
dPt/Pt
0
1000
2000
3000
4000
Muon Pt (GeV)
Theta
Phi
CTD
Combined

FIGURE 6

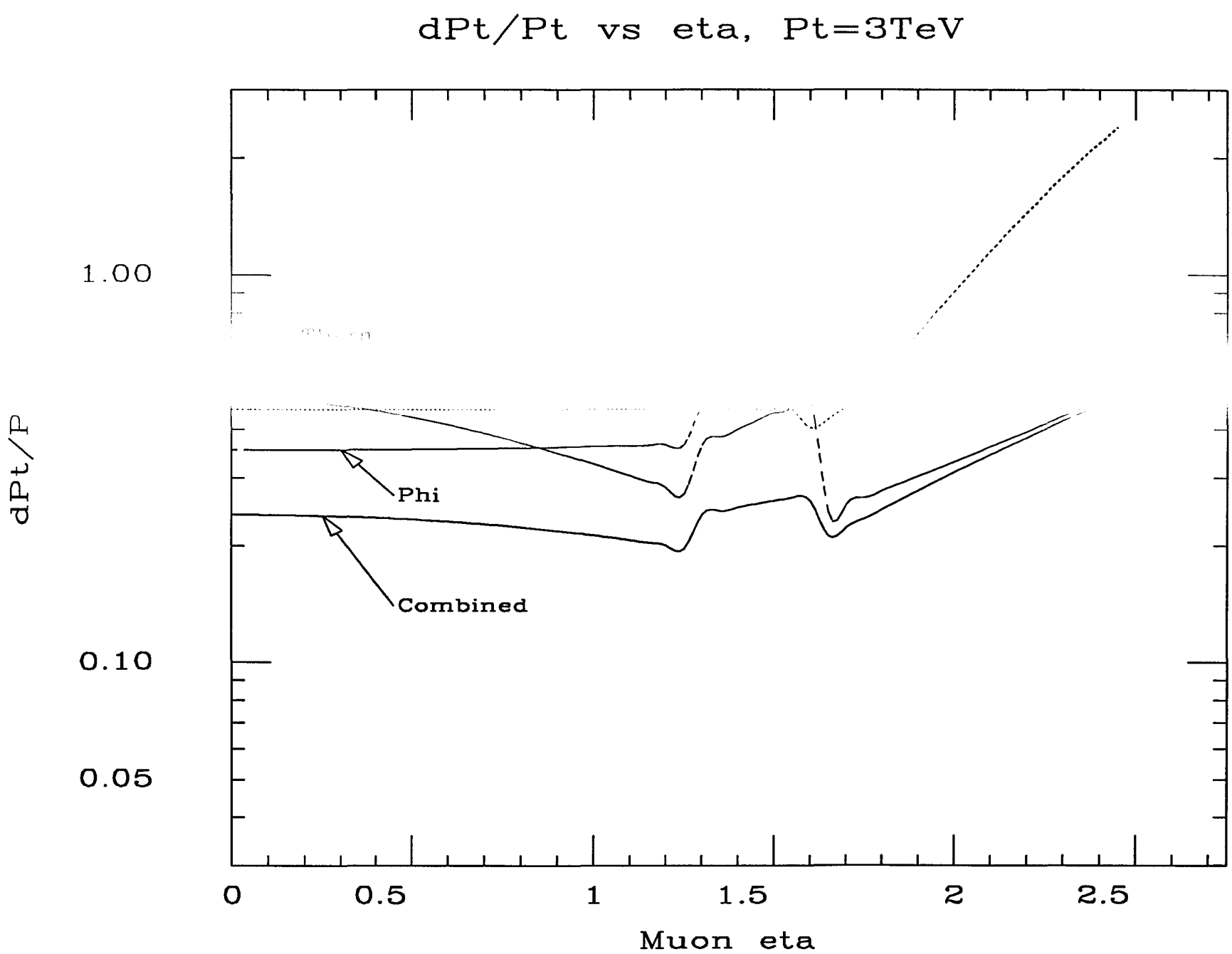

dPt/Pt vs eta, Pt=3TeV
1.00
0.10
0.05
dPt/P
Phi
Combined
0
0.5
1
1.5
2
2.5
Muon eta

FIGURE 7

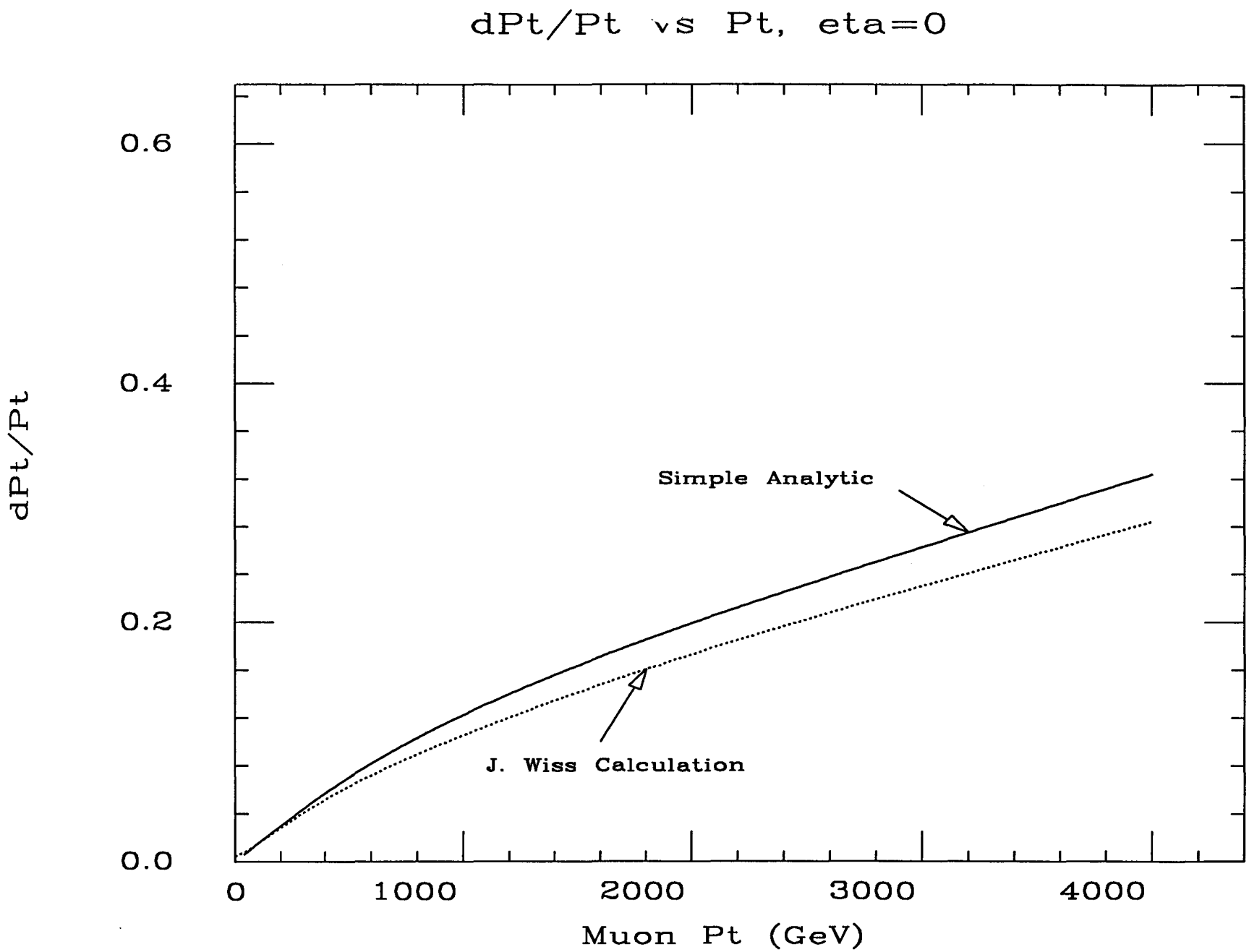

dPt/Pt vs Pt, eta=0
0.6
0.4
0.2
0.0
dPt/Pt
Simple Analytic
J. Wiss Calculation
0
1000
2000
3000
4000
Muon Pt (GeV)

FIGURE 8

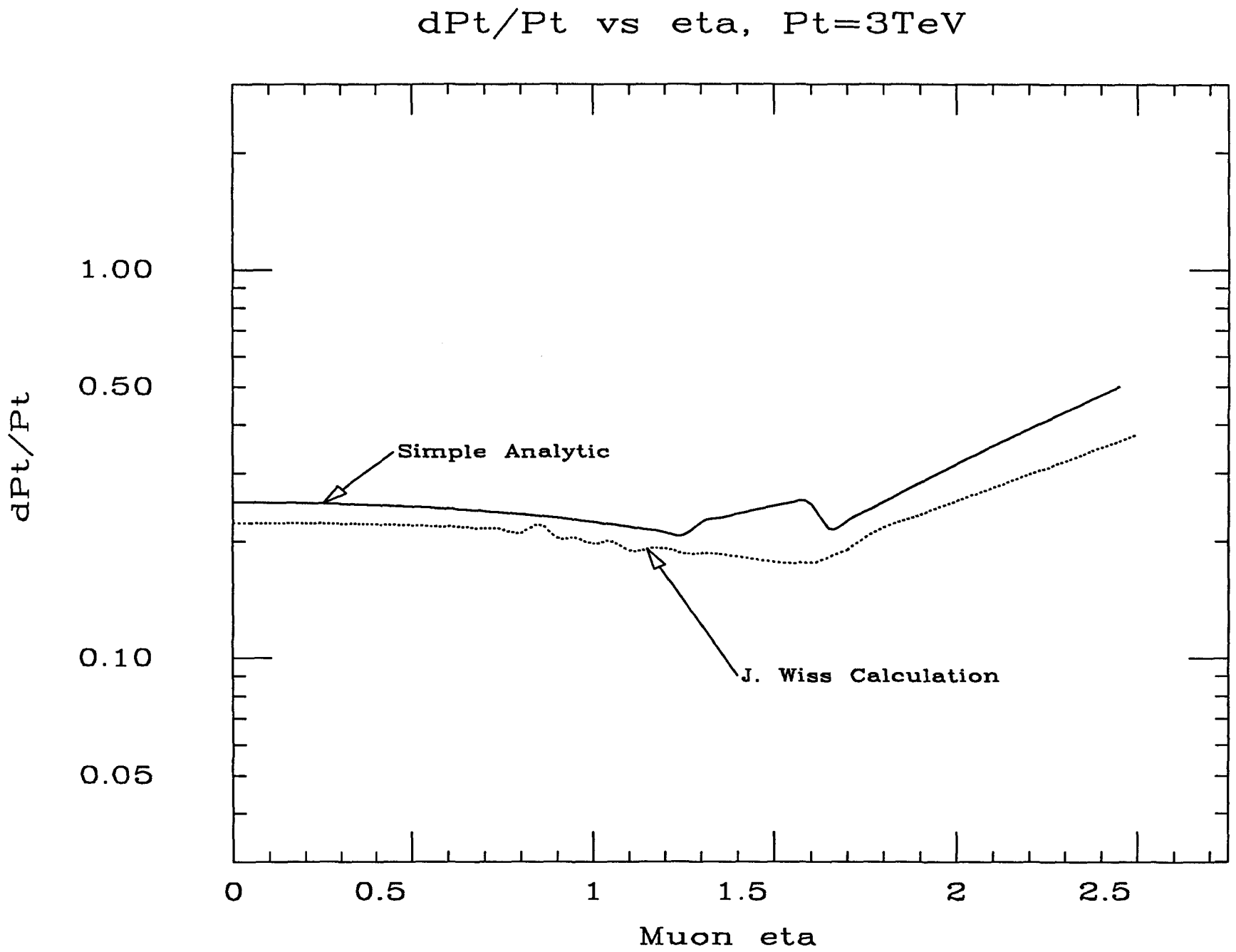

dPt/Pt vs eta, Pt=3TeV
1.00
0.50
0.10
0.05
dPt/Pt
Simple Analytic
J. Wiss Calculation
0
0.5
1
1.5
2
2.5
Muon eta

FIGURE 9

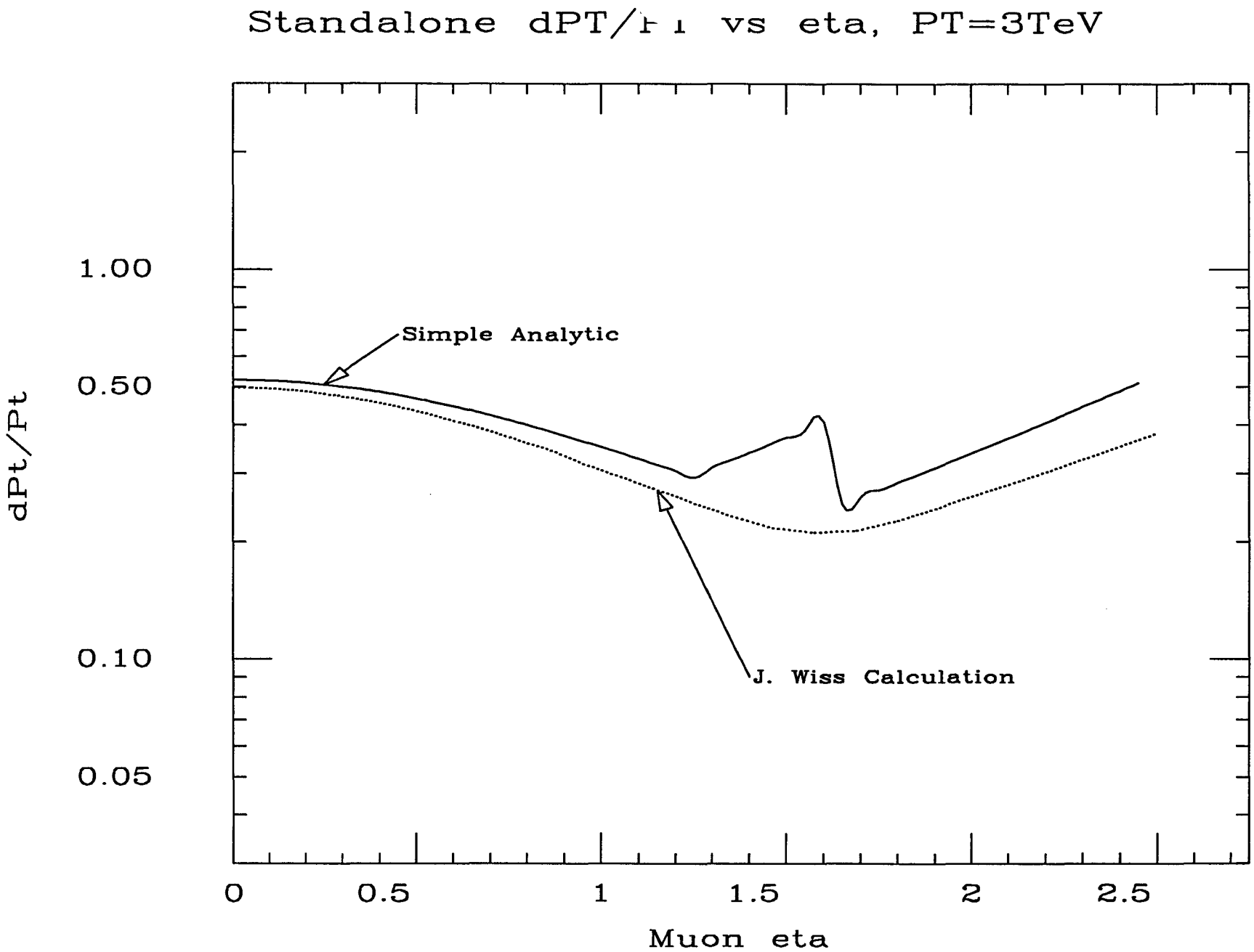

Standalone dPT/PT vs eta, PT=3TeV
1.00
0.50
0.10
0.05
dPt/Pt
Simple Analytic
J. Wiss Calculation
0
0.5
1
1.5
2
2.5
Muon eta

FIGURE 10