Merging QED and QCD Generator Outputs

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Outline

- Introduction
- Numerical merger
- Summary and Ongoing issues
- Question List

Introduction

- Need improved MC generation of vector bosons
- Effects to consider (in a broad sense):

  $\rightarrow$ QED (e.g. FSR)

  $\rightarrow$ QCD (e.g. resummation techniques for low p_T)
- We use **RESBOS** for the QCD physics and **WGRAD**/**ZGRAD** for the QED
- Attempt to numerically merge output of the two
- One advantage of this technique: if a better QCD/QED calculation comes along can just plug it in!
- Currently we are validating numerical merger

Numerical Merger

- Want to preserve changes in angular distribution of W decay leptons induced by gluon ISR

Recipe for numerical merger:

1. **Match** kinematics of the W bosons between **WGRAD** and **RESBOS** (use y_W and M_W) $\rightarrow$ ISR only: we plan on using 2 body W, FSR only: 3 body W

   How to handle full ISR+FSR?
   Are M_W and y_W the best kinematic matching variables?

2. **Match** a quantity sensitive to p_T dependent polarization effects (use θ^l_{CS})

   Is θ^l_{CS} adequate for capturing the polarization effects?
   What other variables could we use?

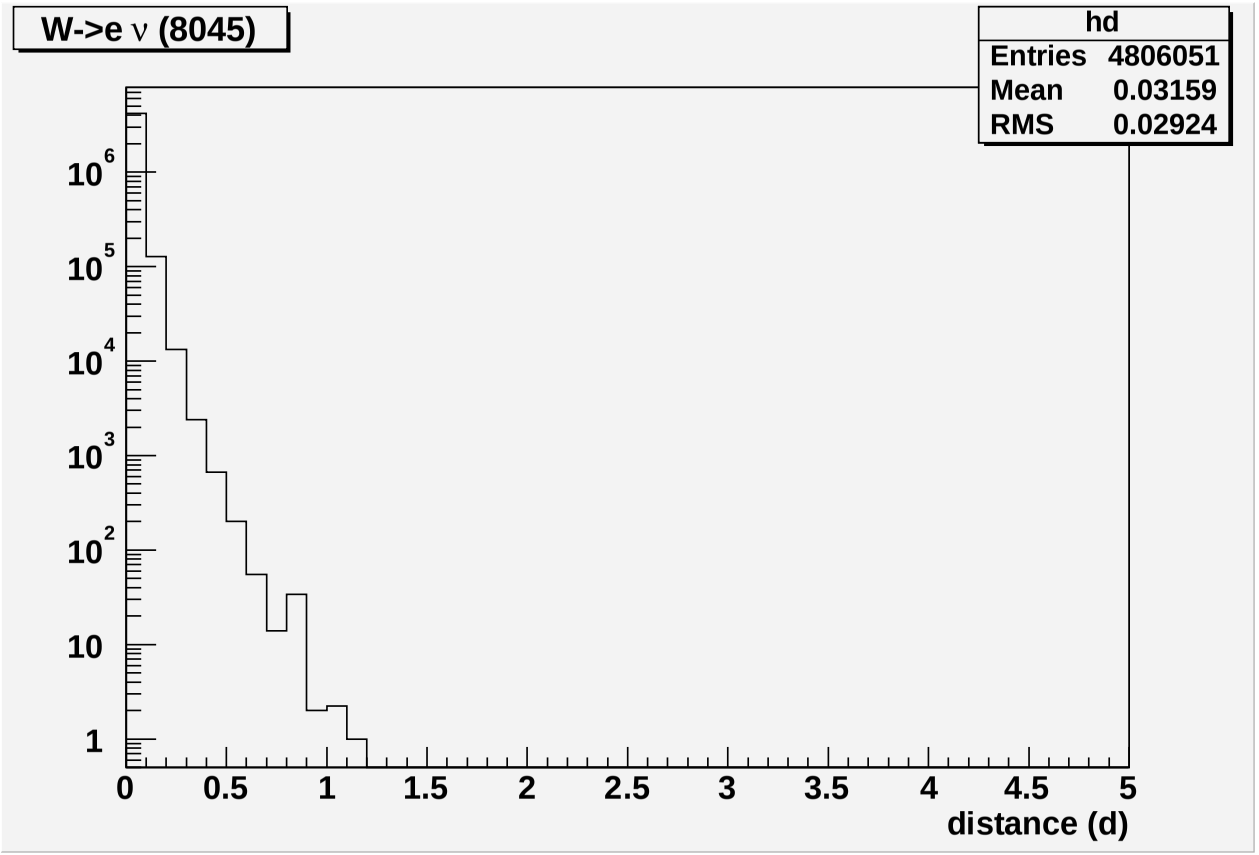
3. **Boost** **WGRAD** W (at rest) with **RESBOS** p_W (lab frame)

$\rightarrow$ Boosted **WGRAD** W is our final event

Numerical Merger (2)

- Minimize $d = \sqrt{\frac{\delta^2 M}{\sigma_M^2} + \frac{\delta^2 \theta}{\sigma_\theta^2} + \frac{\delta^2 y}{\sigma_y^2}}$ to determine best match (have been using $\sigma_M = \sigma_\theta = \sigma_y = 1$)

~ 4.8M **RESBOS** events matched using 1M **WGRAD** events:



Numerical Merger (3)

Using θ^l_{CS}:

- To get to CS frame we:
  1. Rotate coordinate system such that incoming quark is along $\hat{z}$ and p_T^W is along $\hat{x}$
  2. Apply transformations:

$$
\begin{aligned}
p_{lx}^{CS} &= \frac{1}{2}\frac{M_W}{\sqrt{M_W^2 + p_{TW}^2}}(2p_{lx} - p_{TW}) \\
p_{ly}^{CS} &= p_{ly} \\
p_{lz}^{CS} &= \pm\frac{M_W}{2}\sqrt{1 - \frac{(p_{lx}^{CS})^2 + (p_{ly}^{CS})^2}{M_W^2/4}}
\end{aligned}
$$

Reference: Mirkes, Nucl. Phys. B. **387**, 3 (1992)

How to define CS frame for WGRAD events with photons?

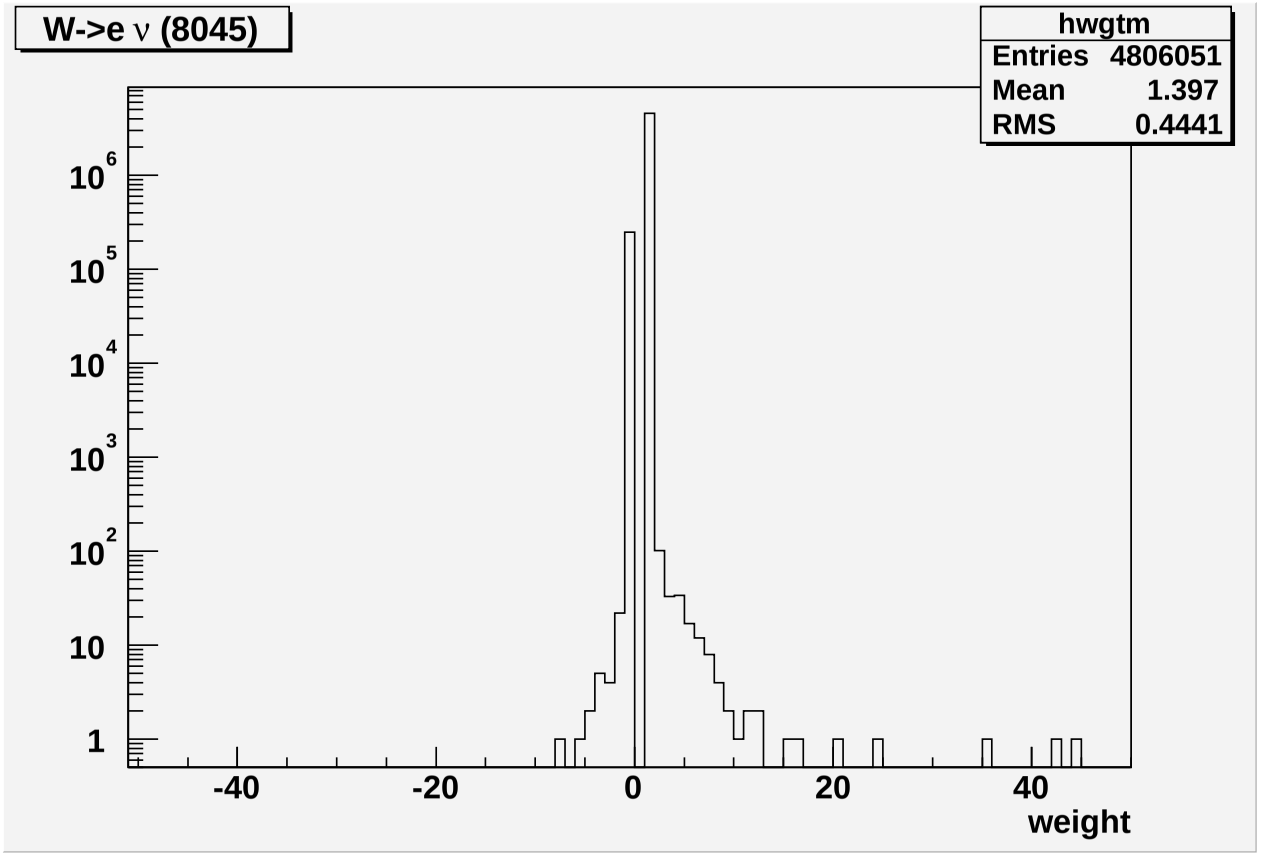
WGRAD, RESBOS, and Weights

- We use an unweighted version of **WGRAD** from Dave Waters (CDF note 5240 ... there might be a more widely distributed reference)
  - Can have event weights of ± 1 ($\sim 5\%$ negative for ISR only)
  - We have been using $E_\gamma > \delta_s \sqrt{\hat{s}}/2$ (photon energy cut) and $\cos\theta < 1 - \delta_c$ (collinear cut) with $\delta_s = 10^{-3}$ and $\delta_c = 10^{-4}$
  - These translate into $E_\gamma > 1$ GeV and $\theta > 1^\circ$
- We use a "fast" version of **RESBOS** that generates almost all events with the same weight, $\text{wgt}_{\text{resbos}}$
  - We normalize all weights: wgt_i / $\text{wgt}_{\text{resbos}}$
  - Result is all weights unity except $\sim 0.0005\%$
- Once we have a final best matched event (recall that this is a boosted **WGRAD** event) we give it the weight: $\text{wgt}_{\text{matched}} = \text{wgt}_{\text{resbos}} \times \text{wgt}_{\text{wgrad}}$

Is taking the product of the WGRAD and RESBOS weights the right thing to do?

Weights

~ 4.8M **RESBOS** events matched using 1M **WGRAD** events:

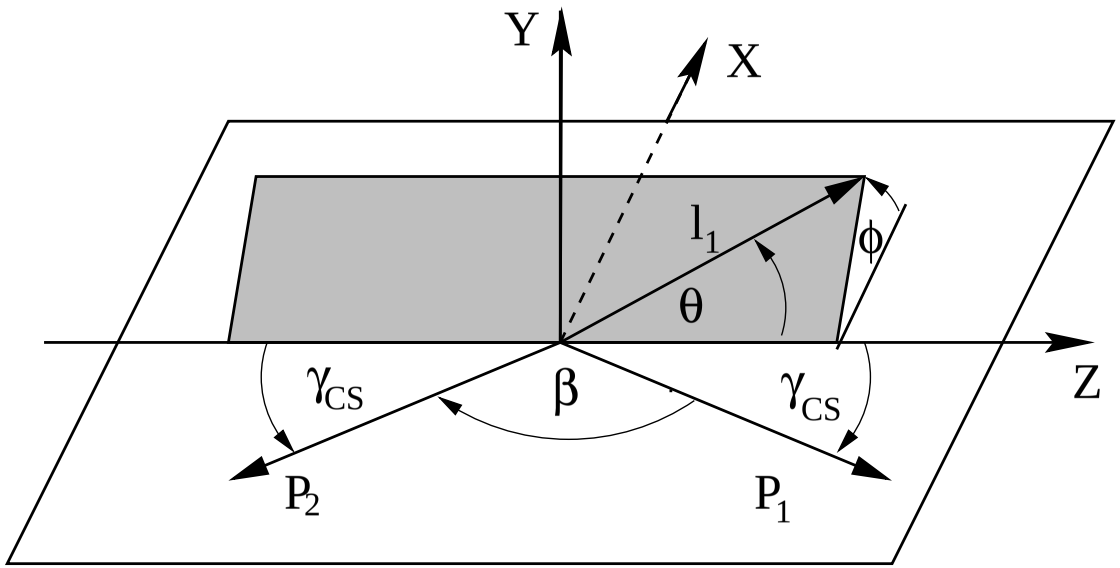


Summary and Ongoing Issues

- We have a complete framework set up for running a numerical merger between **RESBOS** and **WGRAD** (or between any **RESBOS**-like program and **WGRAD**-like program)
- Have used a fast detector simulation and fitter with our MATCHED events to try to see QED shifts in M_W – in some cases have not seen the correct size or direction of the shifts
- Also see that p_T^l, p_T^ν, M_T^W fits sometimes don't agree with each other
- Source of problem(s) traced back to merge code
  - Recently found some bugs
- Method is not completely working yet but changes/improvements can be implemented quickly
- We are making steady progress and hope to have a validated method one month from now (for a CDF W Mass Workshop in Toronto)

Question List

- Can this numerical merger (as outlined today) work?
- What coordinate system is used by **WGRAD**? by **RESBOS**?
- Is **RESBOS** adequate for modelling the Wp_T spectrum? (We have plans on investigating the effect of varying g_2)
- How to handle full ISR+FSR when matching quantities between **WGRAD** and **RESBOS**?
- Are M_W and y_W the best kinematic matching variables? What about p_Z^W or E_W instead of y_W?
- Is θ^l_{CS} adequate for capturing the polarization effects? Are there other variables we could use?
- How to define CS frame for **WGRAD** events with photons?
- Are we dealing with the weights properly by taking the product?

Bonus Slide! Collins-Soper Frame

- CS frame is a W rest frame where the $p\bar{p}$ ($P_1 P_2$) pair lies in the xz plane and the z axis is chosen to bisect the angle between the p and $\bar{p}$
- In the CS frame the p and $\bar{p}$ appear to make an angle with z axis due to transverse boost of the W (which is in the $\hat{x}$ direction)