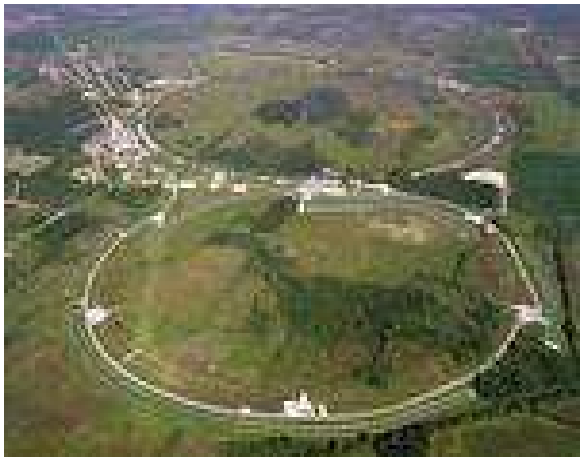
W Mass Theory Workshop

Fermilab, November 6, 2003



Introduction and Overview

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Workshop Goals

- Theoretical inputs are an important aspect of the *W* boson mass measurement at the Tevatron.
- CDF and D0 have published *W* mass measurements from Run 1 data, ~100 pb^{-1} each, with a combined uncertainty of 59 MeV.
- Generator-level inputs contributed ~25 MeV uncertainty
  - Boson p_T 15-20 MeV
  - QED radiative corrections 12 MeV
  - PDFs 8-15 MeV
- Experience shows that experimental uncertainties can be constrained with collider data and have reduced as $1/\sqrt{N}$
- Generator-level inputs would limit improvements in precision beyond 400 pb^{-1} (have ~200 pb^{-1} already)
- LEP *W* mass uncertainty ~ 40 MeV

Workshop Goals

- Start thinking about improved generator-level tools for Run 2:
  - How should we compute PDF uncertainty?
  - How should we incorporate all the available information on boson p_T (experimental, theoretical) into the W mass fit? What are the degrees of freedom in the p_T spectrum?
  - How can we incorporate QED radiative corrections into our detector simulation and mass-fitting programs?

Review of Run 1 Techniques

- 3-momenta of charged lepton and radiative photon and hadronic recoil $\vec{p}_T$ (= -$\vec{p}_T$(boson)) represents generator-level event in simulation.
- Fast detector simulation processes ~10M events/day
- High-statistics histograms (smooth templates) of detector-level kinematics such as W transverse mass (m_T) , $p_T(l)$, $p_T(\nu)$, m_{ll} are generated for a range of finely-spaced values of true M_W or M_Z
- "Measured" M_W , M_Z correspond to the template chosen by mixiumum likelihood fit to data distribution.

Run 1 Generators

- No complete (l, ν, γ) final state generator available!
- QCD and QED/EWK physics of W and Z boson production patched together into homebrew generators by CDF and D0.
  - Triple differential boson cross section factorized into mass lineshape function and double-differential (y,p_T) distributions
  - D0 used Ladinsky-Balazs-Yuan code for making (y,p_T) grid, CDF used homebrew $p_T(W,Z)$ parametrization
  - p_T-dependent W polarization due to QCD ISR taken from Mirkes' calculation, tacked on.
  - Photon FSR tacked on according to Berends-Kleiss (D0) or PHOTOS (CDF), checked by fitting against Baur *et al.* calculation.

Run 2 Technique (CDF)

- Separate generation and detector simulation programs
- Use generator level programs to write files containing 3-momenta of l, ν, γ .
- Read events from vector files into detector simulation program to generate templates.

Generators @ CDF for Run 2

- Using RESBOS for full boson triple-differential cross section $\sigma(Q, y, p_T)$
  - Contains tunable parameters for p_T spectrum
  - Can set W mass and width independently (new from Csaba)
  - Contains p_T-dependent W polarization effects from QCD (affects decay angular distribution a la Mirkes: 40 MeV effect on W mass)
  - Would like photon propagator contribution added for $Z \rightarrow ll$
- RESBOS does not generate QED-radiative photons

Generators @ CDF for Run 2

- WGRAD/ZGRAD is current choice for generating radiated photons, ISR and FSR
- Photon needed in generated final state to simulate biases in lepton selection and kinematics
- But all QCD effects missing
- Need some way to incorporate both QED and QCD physics (with good accuracy) into a usable event-generation scheme
  - Hopefully better than Run 1 solutions

Proposals to combine QCD+QED

- Ideally: merge RESBOS and WGRAD into a single generator
  - Very worthwhile long-term investment: perhaps the only reliable solution for 20 MeV measurement of *W* mass (with 2 fb^{-1})
- Experimentalists' approaches:
  - Run WGRAD through parton showering MC's like PYTHIA, HERWIG, but
    - not easily tunable
    - missing depolarization a la Mirkes
  - Add Run 1 – style parametrization of QCD effects on WGRAD output, but
    - no theory control on the QCD physics

CDF Method of Merging RESBOS, WGRAD

(see Ian's talk)

- Create RESBOS and WGRAD event vector files
- For each RESBOS event
  - use WGRAD file as lookup table
  - find best-matching WGRAD event in production and decay kinematics
  - impart 3-momentum of W_{RESBOS} to W_{WGRAD}
  - Final event contains (?) the physics of both programs
- Can be adapted to new input programs, e.g. 2γ calculation.

PDFs and Boson p_T

- Run 1 (notorious) method for PDF error estimation: pick ~5 PDFs and compare M_W
  - CDF and D0 used different sets of 5 PDFs
  - CDF did further internal tuning based on W charge asymmetry measurement
  - Run 2: would like a more defensible, public method to estimate PDF uncertainty on M_W
- Boson p_T error: $p_T(Z)$ parameters are fit to $Z \rightarrow ll$ data, parameter errors propagated to $p_T(W)$
  - does p_T(boson) model of RESBOS address all the degrees of freedom?
  - is there any additional uncertainty in predicting $p_T(W)$?

Workshop Agenda

- Discussion of WGRAD, RESBOS and unified generator (Doreen, Csaba, Pavel)
- WGRAD+RESBOS outputs merging scheme (Ian)
- New developments in Electroweak calculations (Ulrich)
- PDF errors: CTEQ scheme and resulting δM_W (Joey, Oliver)
- Boson p_T and other observables (Pavel)
- General discussion and summary