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Transfer function treatment of leptonic tau decays in the Matrix Element Method

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Matrix Element Method (MEM)

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- Powerful to extract significant and varied results from few events with high statistical significance
  - Maximize use of all the kinematic information contained in each event analyzed
- Does not require draconian event selection
  - Sample composition is fitted
- Numerical integration is difficult because the integrand has structure in peaks, high dimensionality: very consuming of computer ressources
- Method of interest for H^+ searches and properties measurement

Mathematical Description I

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- For measurements **x**, the probability that they correspond to signal with a parameter set α (m, jet assignement, etc) is

$$P(\boldsymbol{x},\alpha) = N \int d\phi(\boldsymbol{y}) dz_1 dz_2 f(z_1) f(z_2) |M_\alpha|^2(\boldsymbol{y}) R(\boldsymbol{x} \rightarrow \boldsymbol{y})$$

$R(\boldsymbol{x}\rightarrow\boldsymbol{y})$ is the resolution function relating the measured **x**'s to the partonic quantities **y**, obtained experimentally

$d\varphi(\boldsymbol{y})$ is the partonic phase-space measure for the integral

$|M_\alpha|^2(\boldsymbol{y})$ is the matrix element squared evaluated at **y**

$f(z_1)f(z_2)$ are the parton distribution functions

N is a normalization factor

Mathematical Description II

- These probabilities from *N* events are combined into the extended likelihood *L*:

$$L(\alpha) = e^{\int d\boldsymbol{x}\, P(\boldsymbol{x}, \alpha)} \prod_{i=0}^{N} P(\boldsymbol{x}_i, \alpha)$$

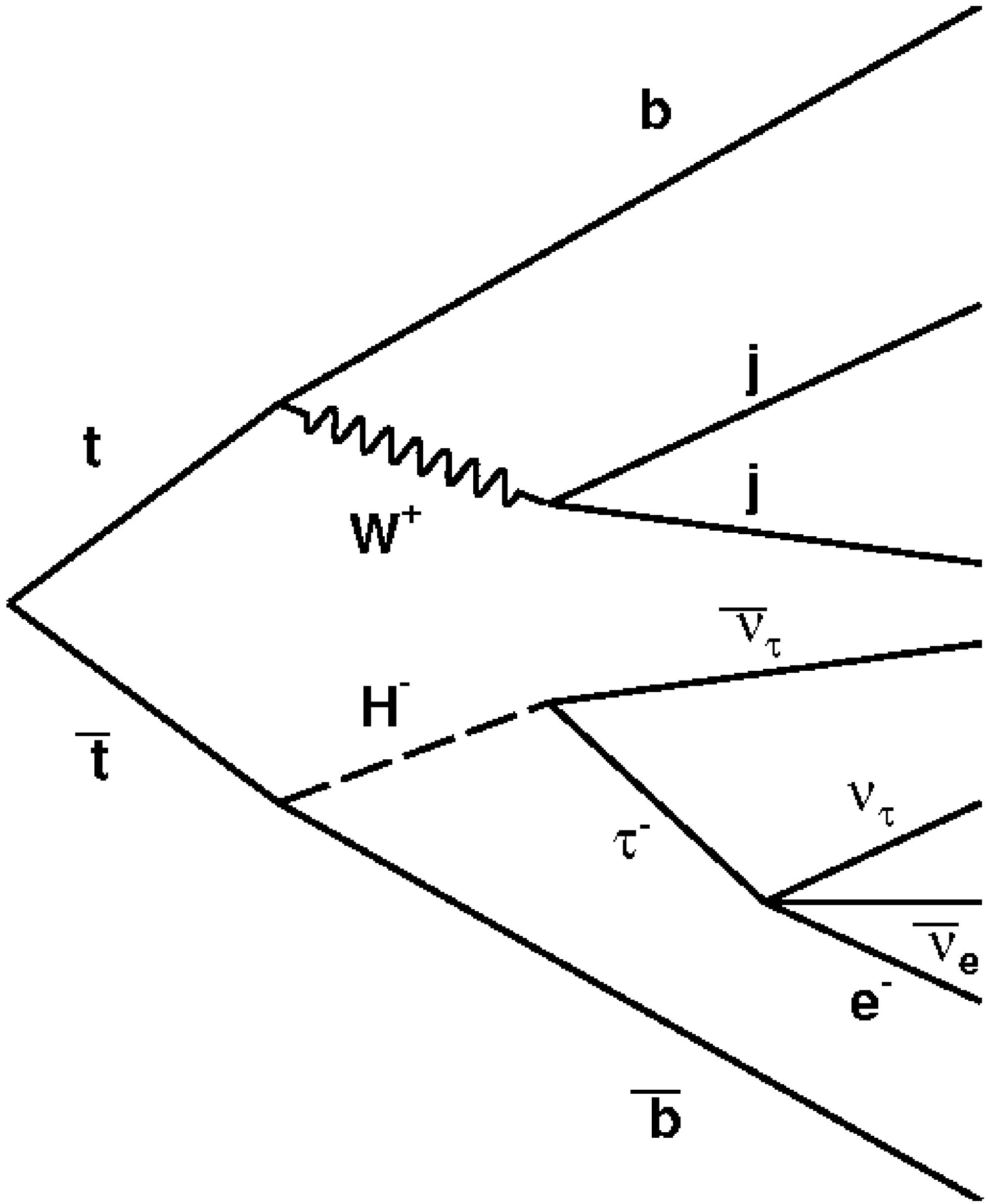
- For pratical purposes, use -ln(*L*)
- Combine likelihoods of all processes and insert sample composition parameters
- Minize the resulting function relative to α to measure quantity of interest
- Bonus: simple extraction of uncertainty from likelihood curve

MadWeight

- Tool by the authors of MadGraph/MadEvent
- Phase-space generator for computation of probability weights in MEM
- Powerful tool to streamline use of MEM
  - Generate MEs for process in MadGraph
  - Compute weights in MadWeight
    - Detector resolution effects treated with transfer functions

MAD WEIGHT

A process of interest



- $H^\pm$ produced in top pair decays
- $H^\pm$ decays to a τ which in turn decays into an electron
- $W^\pm$ decays into hadrons

MadWeight cannot treat this full 2→8 process: too many internal propagators!

Simulated event studies

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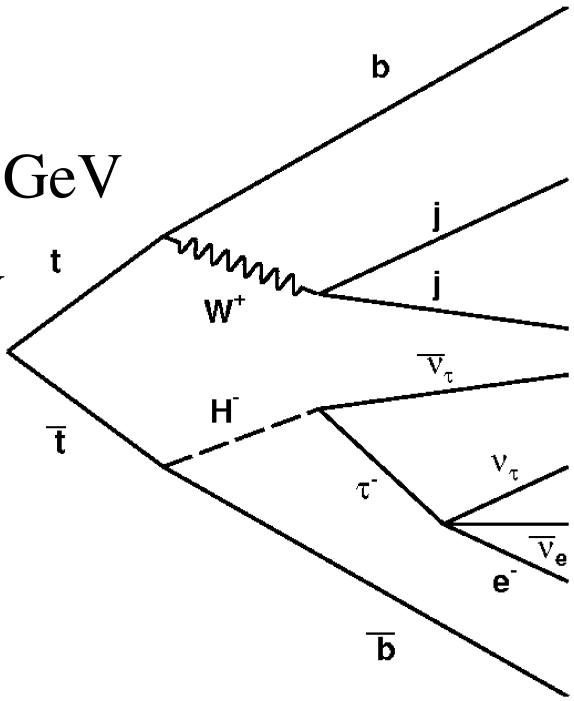
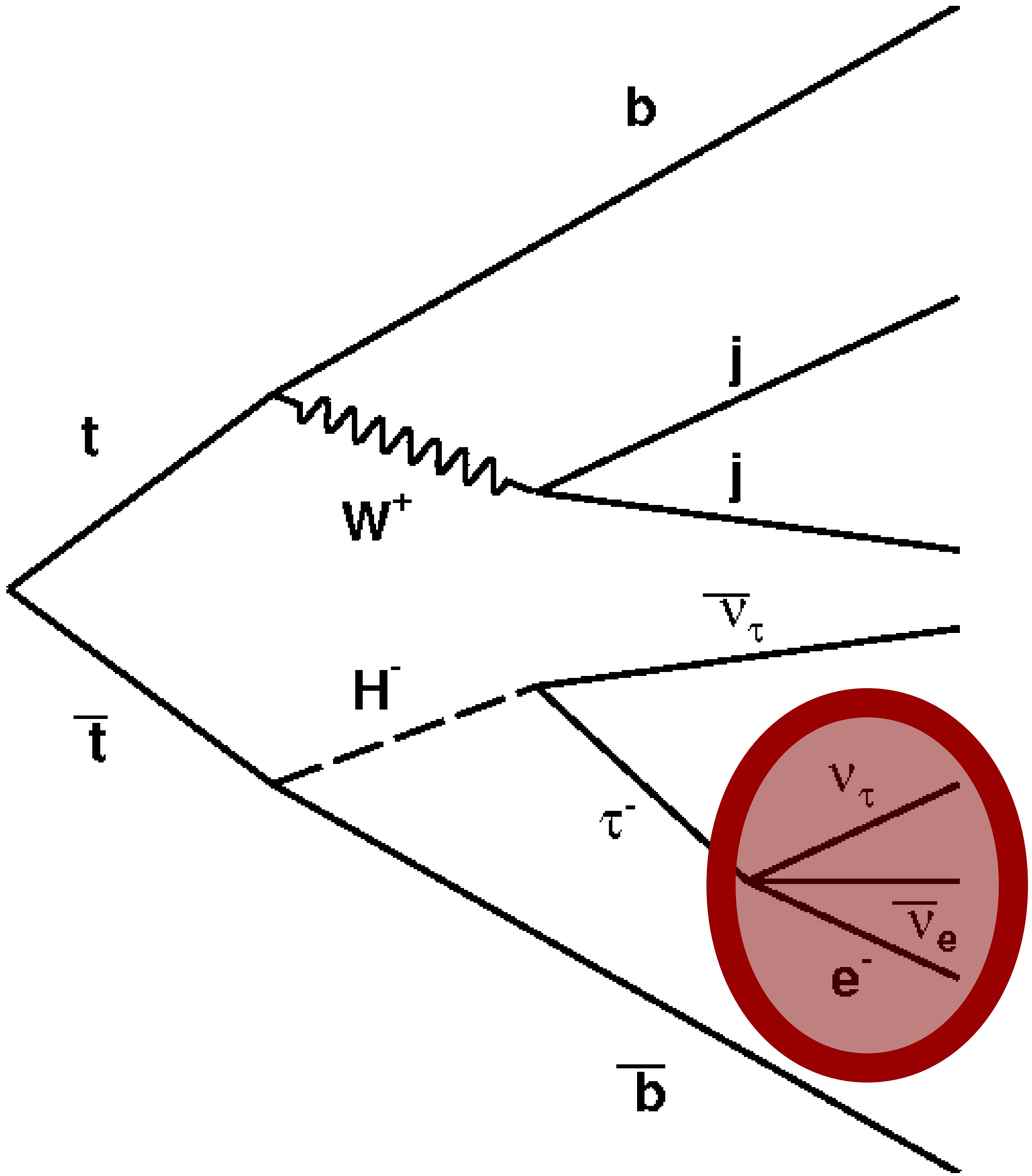
- Official D0 MC events (PYTHIA) with full detector reconstructions
  - Signal events only, 200 000 events per simulated mass point
- Simulated H masses: 80, 100, 120, 140 GeV
- Select events with
  - Exactly 1 reconstructed electron with p_T>10 GeV
  - Exactly 4 reconstructed jets with p_T>15 GeV
  - No isolated muons
  - Successful truth matching
- Signal election efficiency: ~0.7%



Parton level: stable τ

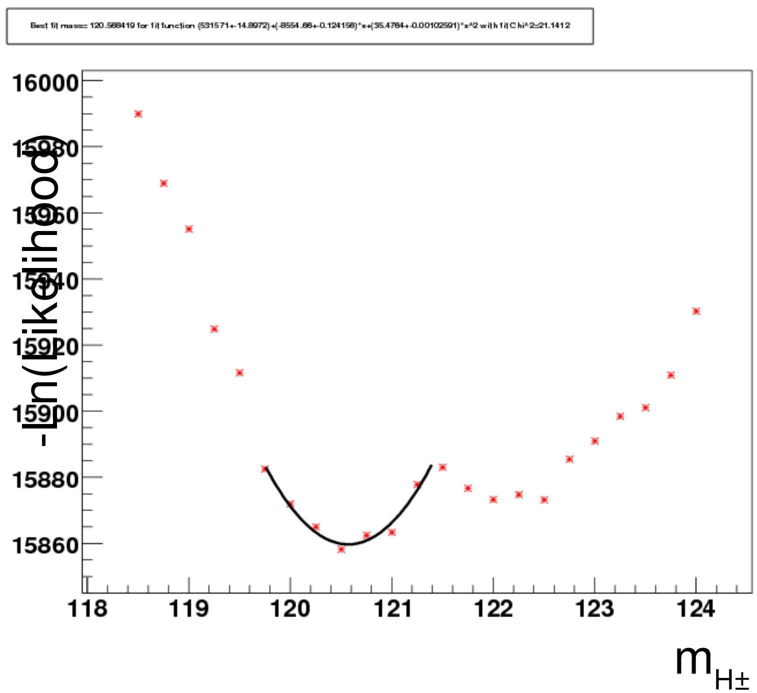


- Quark information used for jets
- Stable τ

MadWeight cannot treat this full 2→8 process: too many internal propagators!

Result at parton level

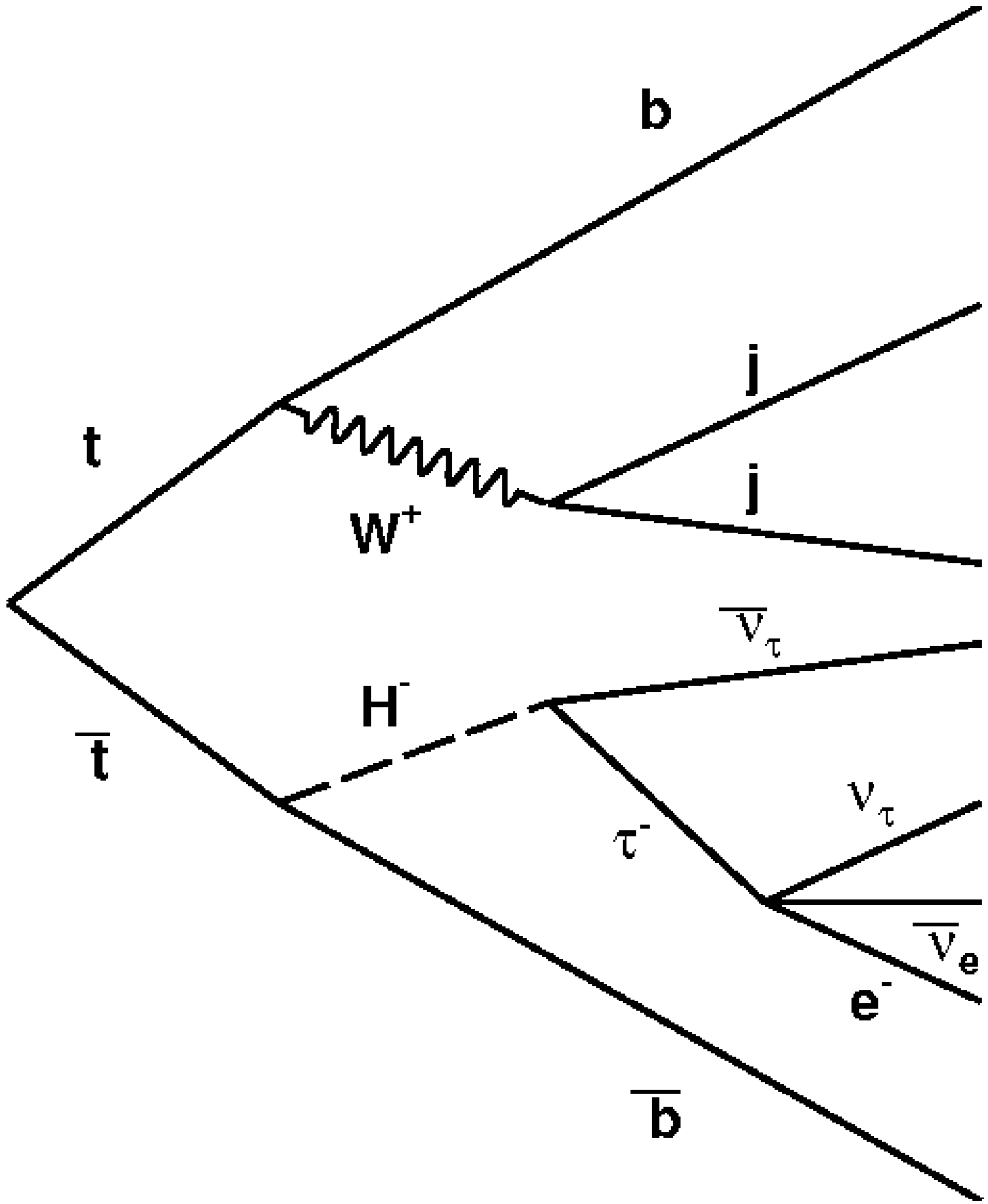
- Fitting likelihood with 2nd-order polynomial to fit minimum: most likely $m_{H\pm}$



Input Mass (GeV)	Most likely mass (parton)
80	84.2
100	101.7
120	120.5
140	139.7

- Mass measurement result within method tolerance

Hybrid level: leptonic τ decay



- Quark information used for jets
- Decay of τ into electron, reconstructed at detector-level

Transfer function

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- Upon observing the shape of the distribution of "energy difference" between the tau and electron, tried to fit a Landau distribution
- Good fit (as determined by chi square) but Landau distribution does not have a closed analytical form
- Choose to use the Moyal approximation of the Landau distribution:

$$TF_{\tau}(D, p_{0,} p_{1,} p_2) = p_0 \sqrt{\frac{e^{-(X+e^{-X})}}{2\pi}}$$

$$where\ X = p_2(D - p_1)$$

The parameters are:

p_0: parameter related to amplitude

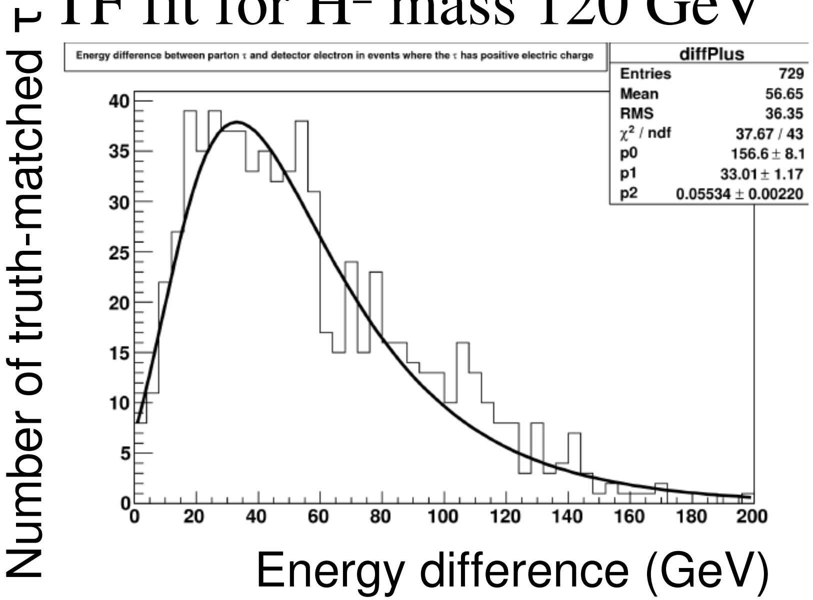
p_1: most probable value

p_2: parameter related to width

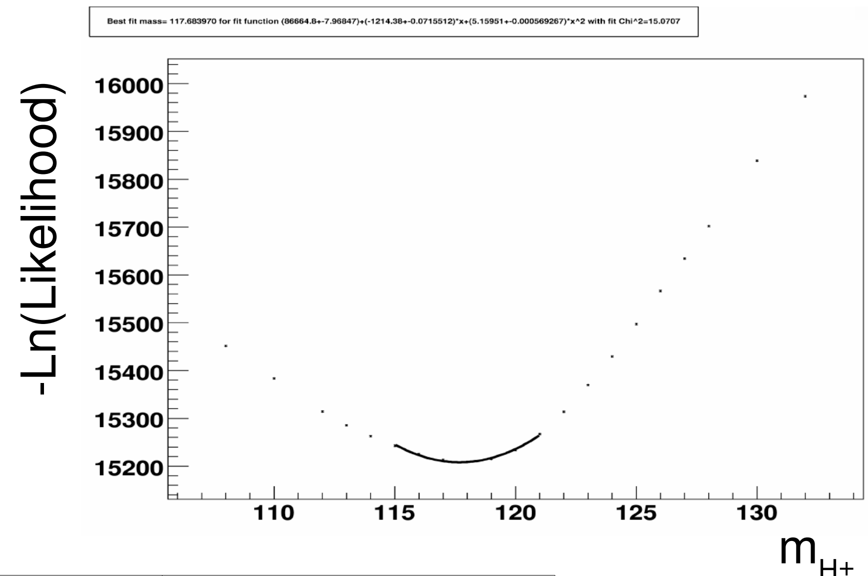
D: energy difference

TF and result with hybrid events

TF fit for $H^{\pm}$ mass 120 GeV



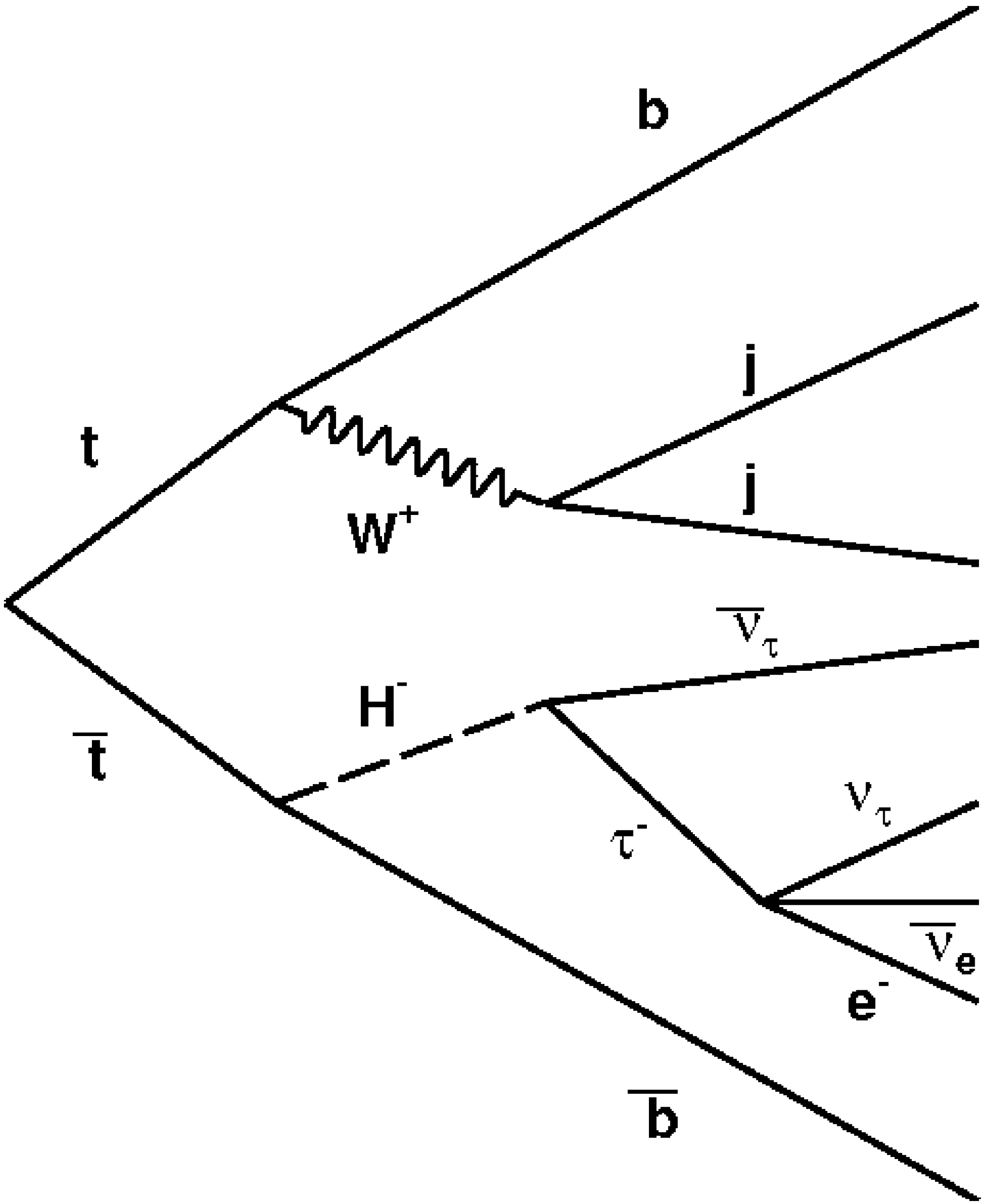
Likelihood fit result



Input Mass (GeV)	Most likely mass (parton)	Most likely mass (detector electron)
80	84.2	78.1
100	101.7	97.4
120	120.5	117.7
140	139.7	137.8

Mass well measured also for these hybrid events, within method tolerance

Fully simulated events



- Reconstructed detector-level jets
- Decay of τ into electron, reconstructed at detector-level

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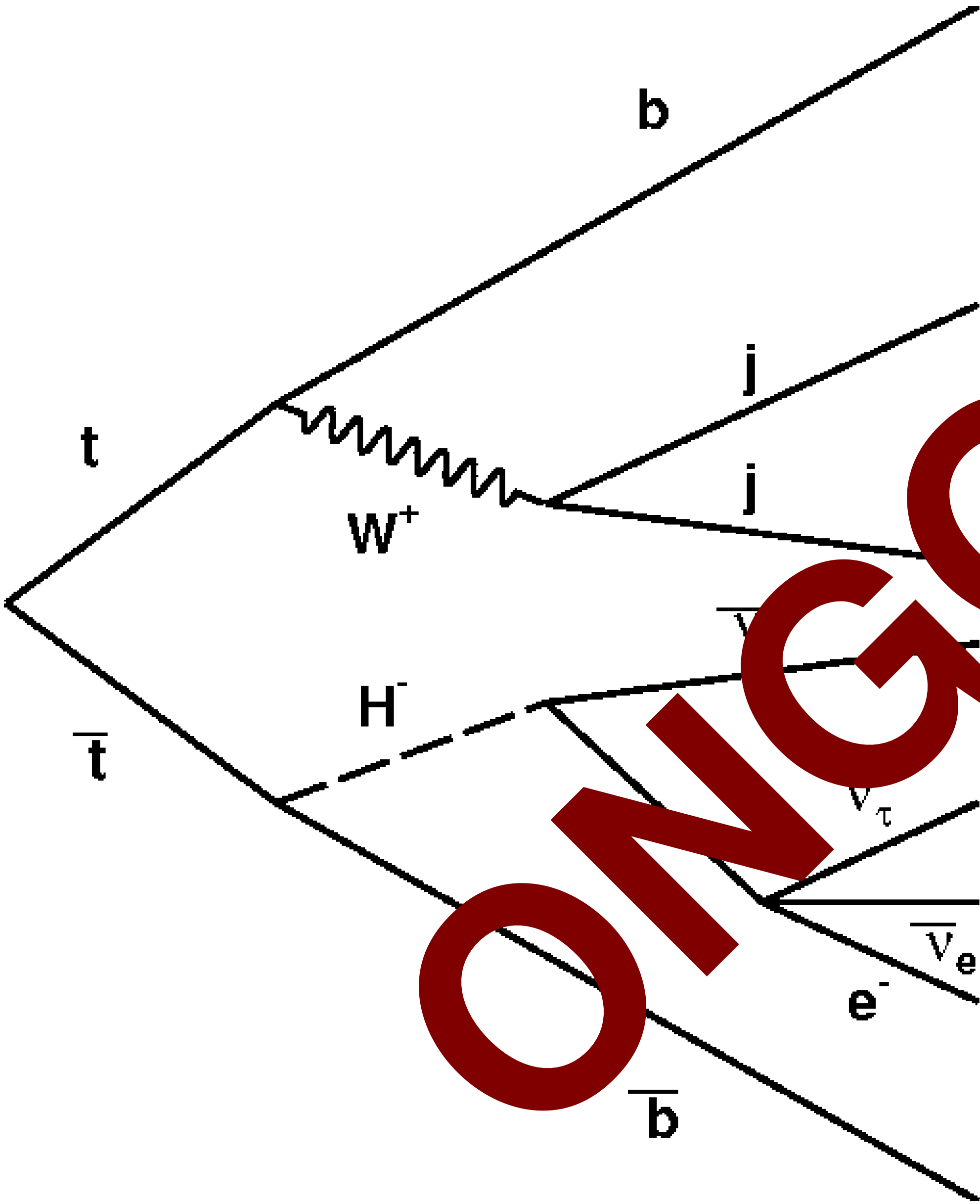
Fully simulated events



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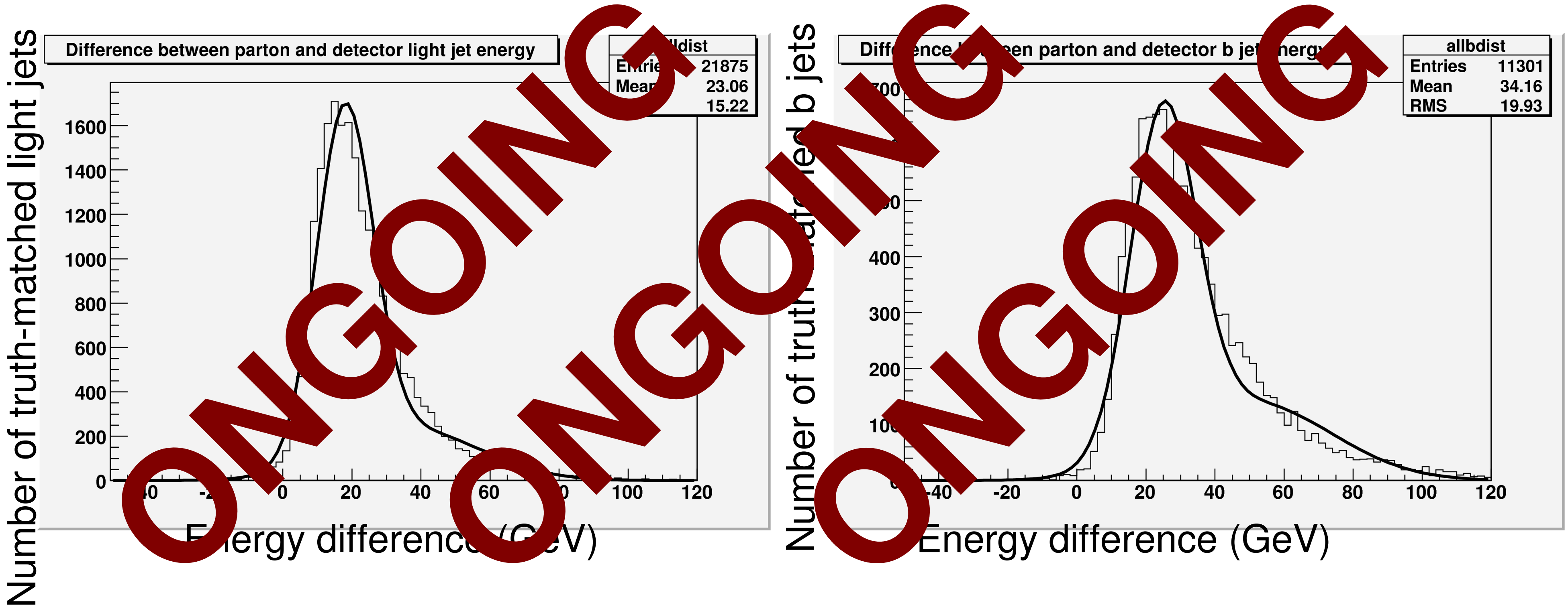
ONGOING

Jet transfer functions

- Jet transfer functions: separately for light and b-jets
- Fitted with a double gaussian distribution



Summary

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- MEM is a powerful method to extract results of maximum significance from a limited sample
- MadWeight is a component to the MadGraph family that computes MEM probabilities, making the method more accessible than ever
  - ME cannot have too many internal propagators
- In cases, such as the $H^{\pm}$ example presented, which contain leptonic τ decays
  - Can treat τ decay in a transfer function in hybrid events
  - Use more typical transfer functions for jets to complete demonstration is **ongoing**