Camille Bélanger-Champagne
Uppsala Universitet
with Claus Buszello,
Carlos Garcia, Tord Ekelöf
and André Sopczak

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The Matrix Element Method in charged Higgs boson searches

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The Matrix Element Method

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- A recently developped analysis method
- First use: re-measurement of the Run I top mass at DØ (2001)
- Particularity: maximal use of kinematic information content of events
- Progressively used more and recently contributed to the single top “evidence” paper.
- Becoming a staple for searches/analyses with low statistics*

Outline

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- Light charged Higgs physics
- Technical description of the Matrix Element (ME) Method
- Current results ongoing work
- Summary

Light charged Higgs

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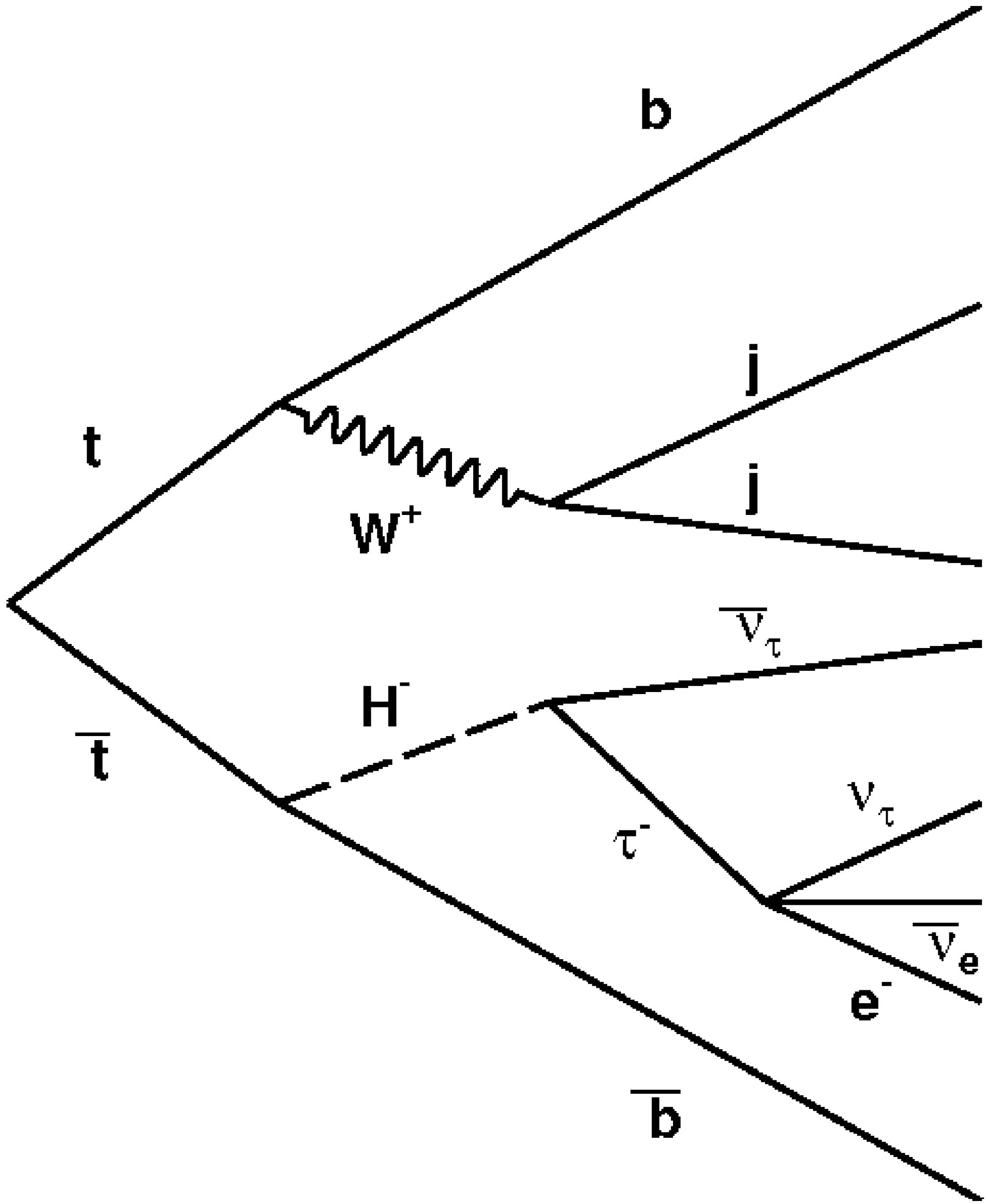
- Many Beyond the Standard Model models (including SUSY) feature an extended Higgs sector that contains at least one pair of electrically charged Higgs boson.
- Like rest of Higgs sector, couples preferentially to heaviest particles
- "Light H+":
  - H+ is heavier than W+ or they are mass degenerate
  - H+ is lighter than the top quark so it can be observed in top quark decays

Investigated process



- Produced in top pair decays
- $H^{\pm}$ decays to a tau which in turn decays into an electron
- $W^{\pm}$ decays into hadrons

Matrix Element Method

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- Goal: maximize use of all the kinematic information contained in each event analyzed
- Analysis procedure:
  - Compute the "extended likelihood" that an event is from the studied $H^{\pm}$ process
  - For each background process, compute the "extended likelihood" that an event is from that process (SM top pair production, W+jets)
  - Minimize simultaneously likelihood outputs for all processes and parameters that embody the sample composition

Extended Likelihood I

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- For measurements **x**, the probability that they correspond to signal with a parameter set α ($m_{H\pm}$, 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

Extended Likelihood II

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- 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 find, in our case, the charged Higgs mass
- Bonus: simple extraction of uncertainty from likelihood curve

ME Method: Pros and Cons

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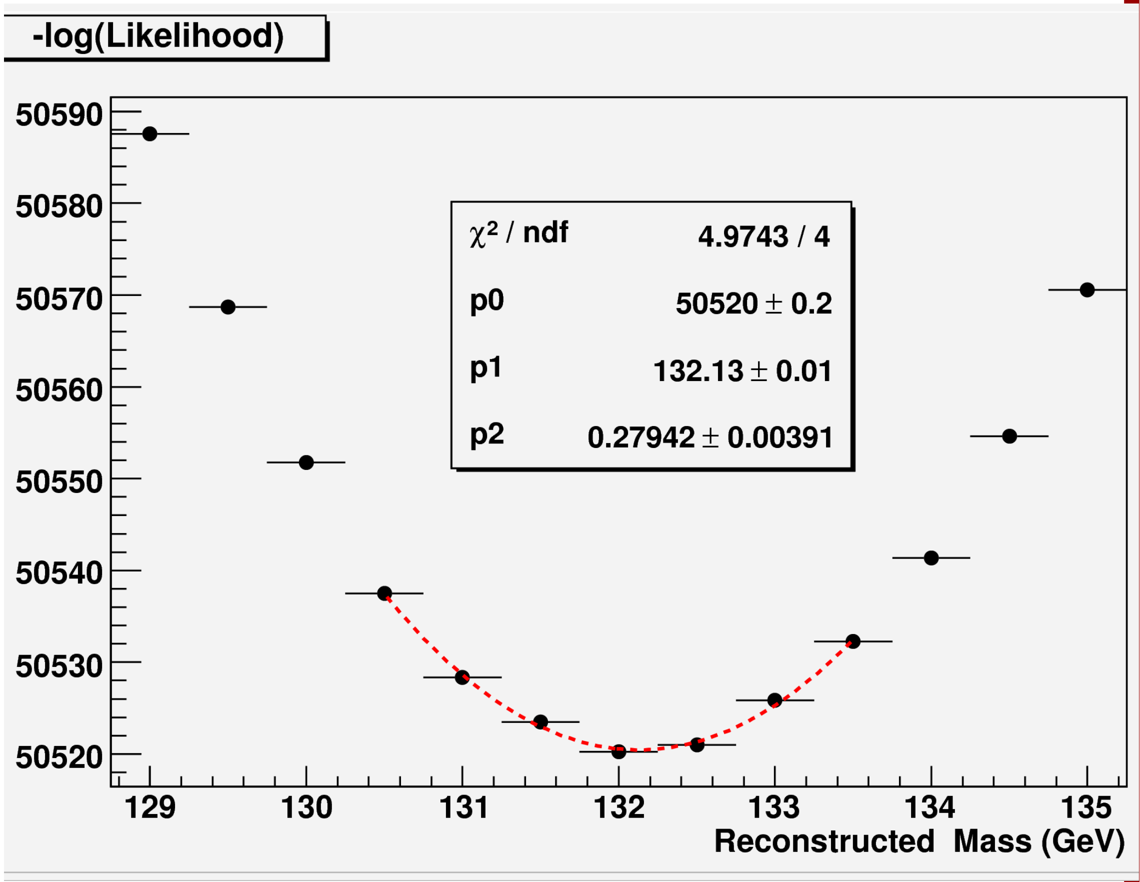
- Powerful to extract significant and varied results from few events with high statistical significance
- Does not require draconian event selection since the method is built to be tolerant, sample composition is fitted
- Numerical integration is difficult because the integrand has structure in peaks, high dimensionality: very consuming of computer ressources
- Can only be used for exclusive channels
- Cannot be practically applied to high statistics analyses
- Requires excellent understanding of detector
- Treatment of systematic errors is challenging

The first look study

- Using small private signal MC samples with generation masses of 125, 130 and 135 GeV, **parton level,** stable tau
- Using a lightly modified version of the top mass measurement analysis where the two W's are not required to be of identical mass
- Fitted mass consistent with generated mass within what is expected from method



A deeper look

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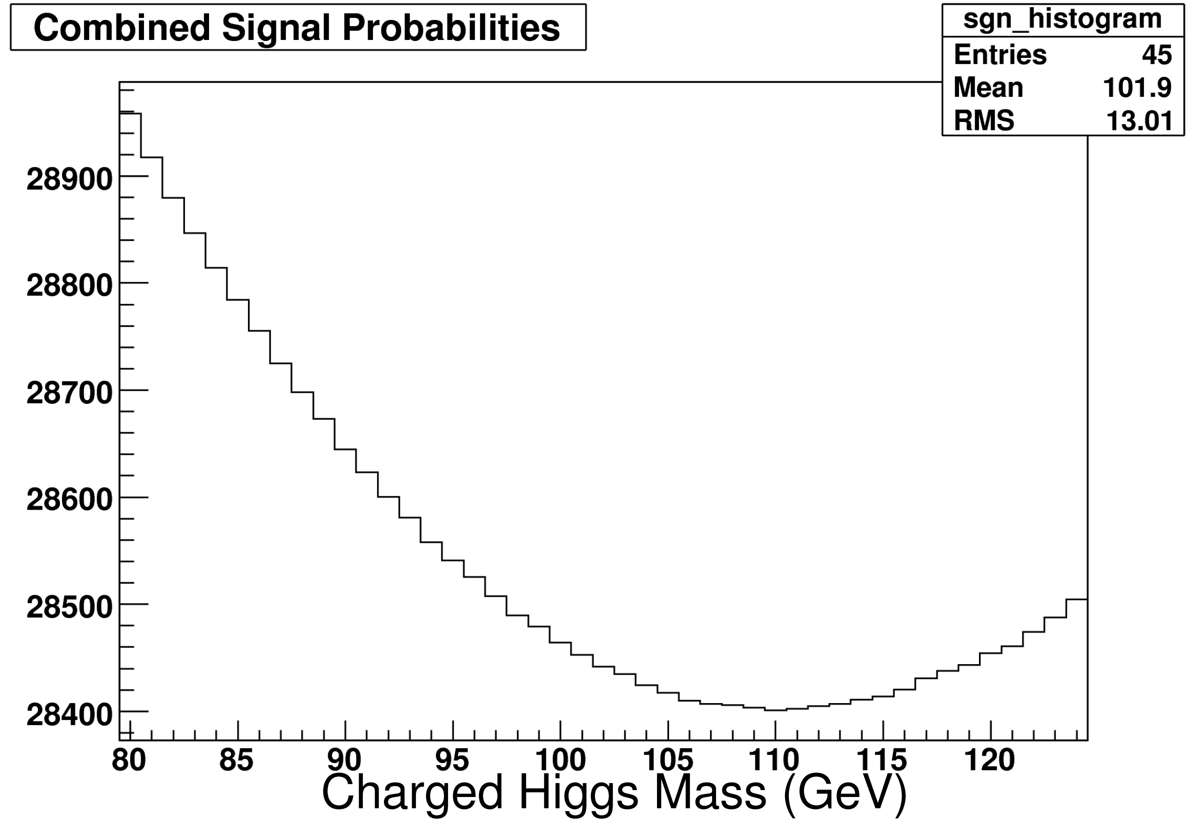
- Moved to detector level MC, from DØ central production
  - Introduction of transfer functions, detector resolution
  - 3 neutrinos in the final state instead of 1
- Larger mass range: 80, 100, 120, 130, 140, 160 GeV
- Minor modifications to matrix element used:
  - still top pair production and decay to W's of different masses
  - averaging over angular correlations (PYTHIA) and to remove effect of substituting spin-1 particle with spin-0 particle

Detector level ME

- Large departure of fitted mass from generated mass: fitted mass higher by as much as 30 GeV
- Appears mass dependant, with largest shifts at lower masses
- At 130 GeV, 4GeV shift, similar to 2GeV in first study



Under investigation

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- Go back to parton level information for the official MC samples: is the mass shift already present?
  - Must reconsider the use of the modified top mass measurement method and the assumptions it carries
  - New MadWeight infrastructure is probably the tool for the job
- If the mass shift is not observed at parton level, isolate the detector effect(s) or method differences that induce shift
- Work ongoing on multiple fronts

Summary

- The Matrix Element method is becoming an established and trusted analysis method to obtain more precise measurements of known quantities and for searches
- An investigation into using the method to search for a charged Higgs boson in top decays at DØ is under way
- After an encouraging start, discrepancies have arised when trying to use detector level simulated events
- Source of discrepancies are under investigation
- Report planned by the end of the year