Explore Matrix Element Method for new physics

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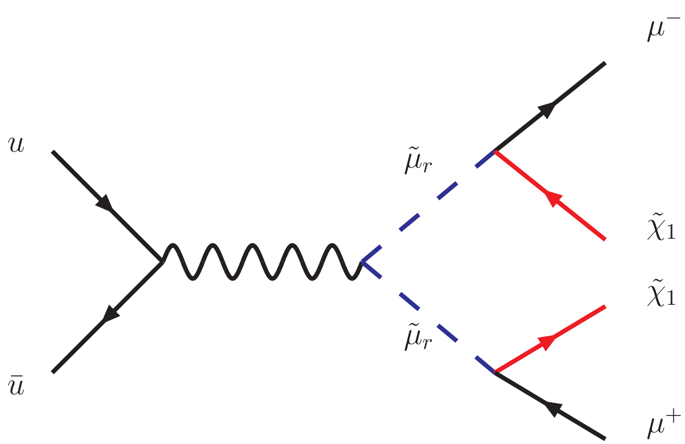
Motivation

- Study of resonances at hadron colliders in decay chains with invisible particles

Example : slepon production



- How to identify this signature ?
- How to measure the properties of (new) particles in the decay chain ?

- Method to maximize the information that you can extract from a sample of events

Motivation

Outline :

- Matrix Element Method : procedure to discriminate between two theoretical assumptions using the maximum amount of information
- Search for New Physics : Application of the method for new physics

Matrix Element Method

- given a theoretical assumption α, attach a **weight** $P(\boldsymbol{x}, \alpha)$ to each experimental event $\boldsymbol{x}$ quantifying the validity of the theoretical assumption α for this event.

$$P(\boldsymbol{x}, \alpha) = \qquad |M_\alpha|^2(\boldsymbol{x})$$

where

- $|M_\alpha|^2$ is the squared matrix element

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  - $d\phi(\boldsymbol{y})$ is the parton-level phase-space measure

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The value of the weight $P(\boldsymbol{x},\alpha)$ is the probability to observe the experimental event $\boldsymbol{x}$ in the theoretical frame α.

Weighting experimental events

- combine the weights into a likelihood

$$L(\alpha) = \prod_{i=1}^{N} P(\boldsymbol{x}_i; \alpha)$$

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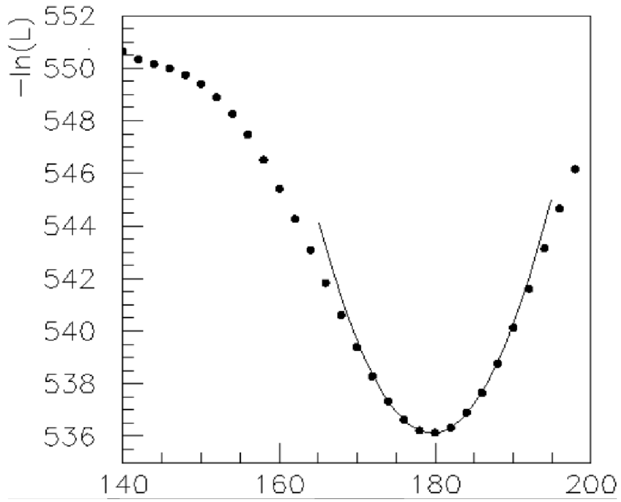
example : top-quark mass measurement from $t\bar{t} \to l^+ X$ sample at DØ



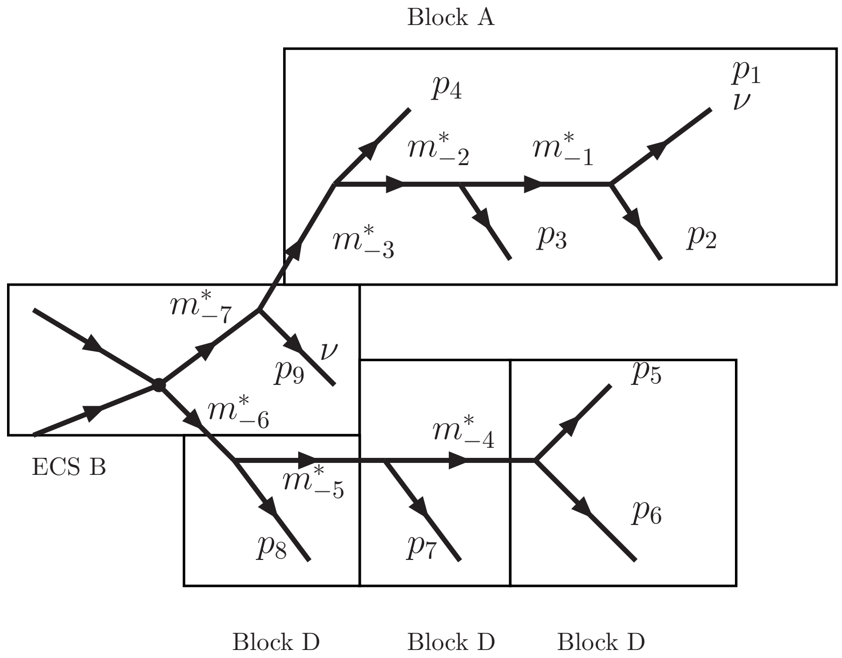
- 72 events
- $M_{top} = 180.1 \pm 3.6_{stat} \pm 4.0_{sys}$ GeV
- J. Estrada : Phd dissertation, University of Rochester (2001)

The Matrix Element Method

- advantages :
  - it is conceptually simple
  - the maximum amount of experimental information can be used to discriminate different theoretical hypothesis
  - the events are weighted with the squared matrix element $\longrightarrow$ refined analysis of the decay chain (spin, coupling types, masses, . . .)
- drawbacks :
  - difficult to estimate the systematic errors
    in particular : parametrization of the transfer functions ?
  - the evaluation of the weight is time-consuming : one phase-space integration per event and per theoretical assumption.

Decay chain example

- MadWeight : Resolution of the kinematics by applying a suite of local change of variable



P. Artoisenet, V. Lemaître, F. Maltoni, OM (in preparation)

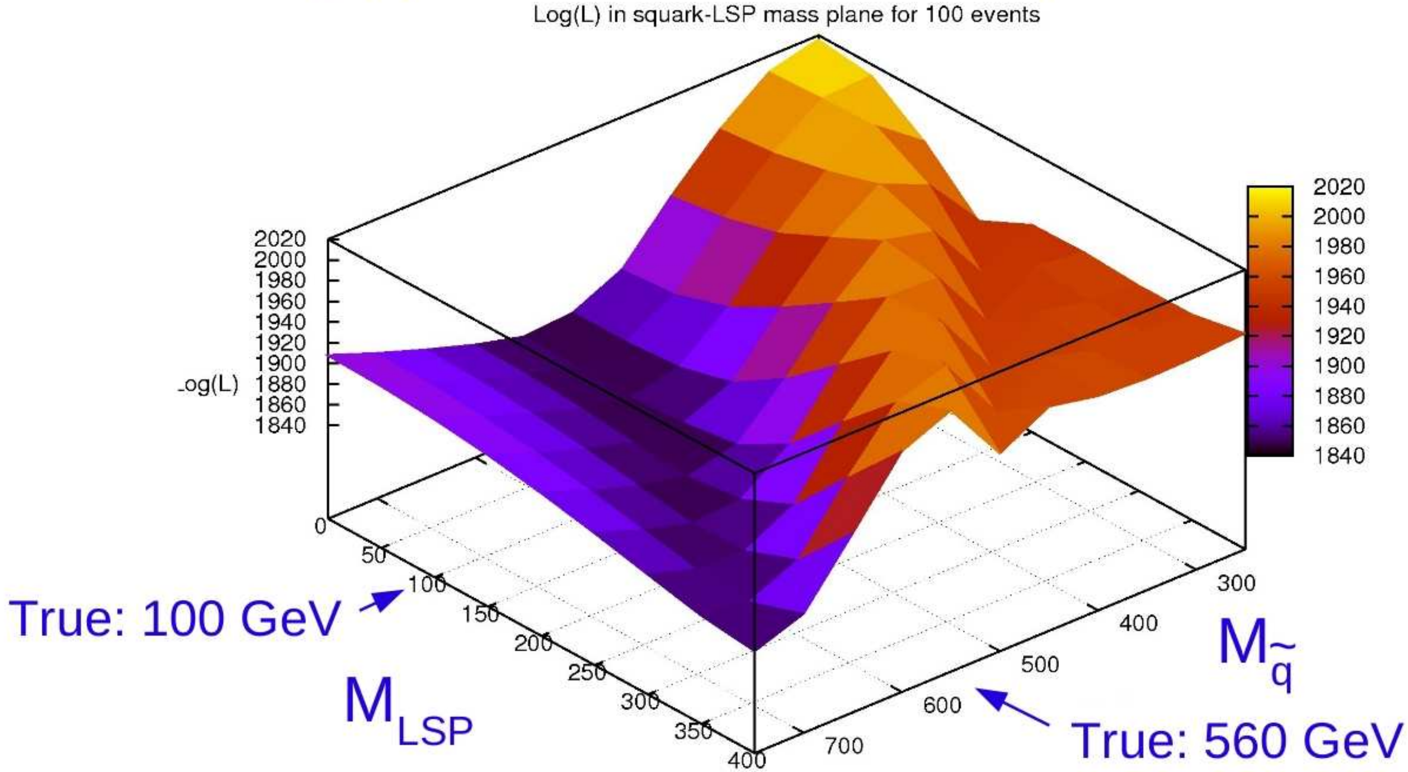
Search for New physics

Search for New Physics

- Imagine (crazy ?) scenary with only 2 jet+MET events visible in early data
- Compatible with squarks pair production (decaying in dark matter)
- How to measure simultaneously squark and LSP mass ?
- Matrix Element extract maximum information

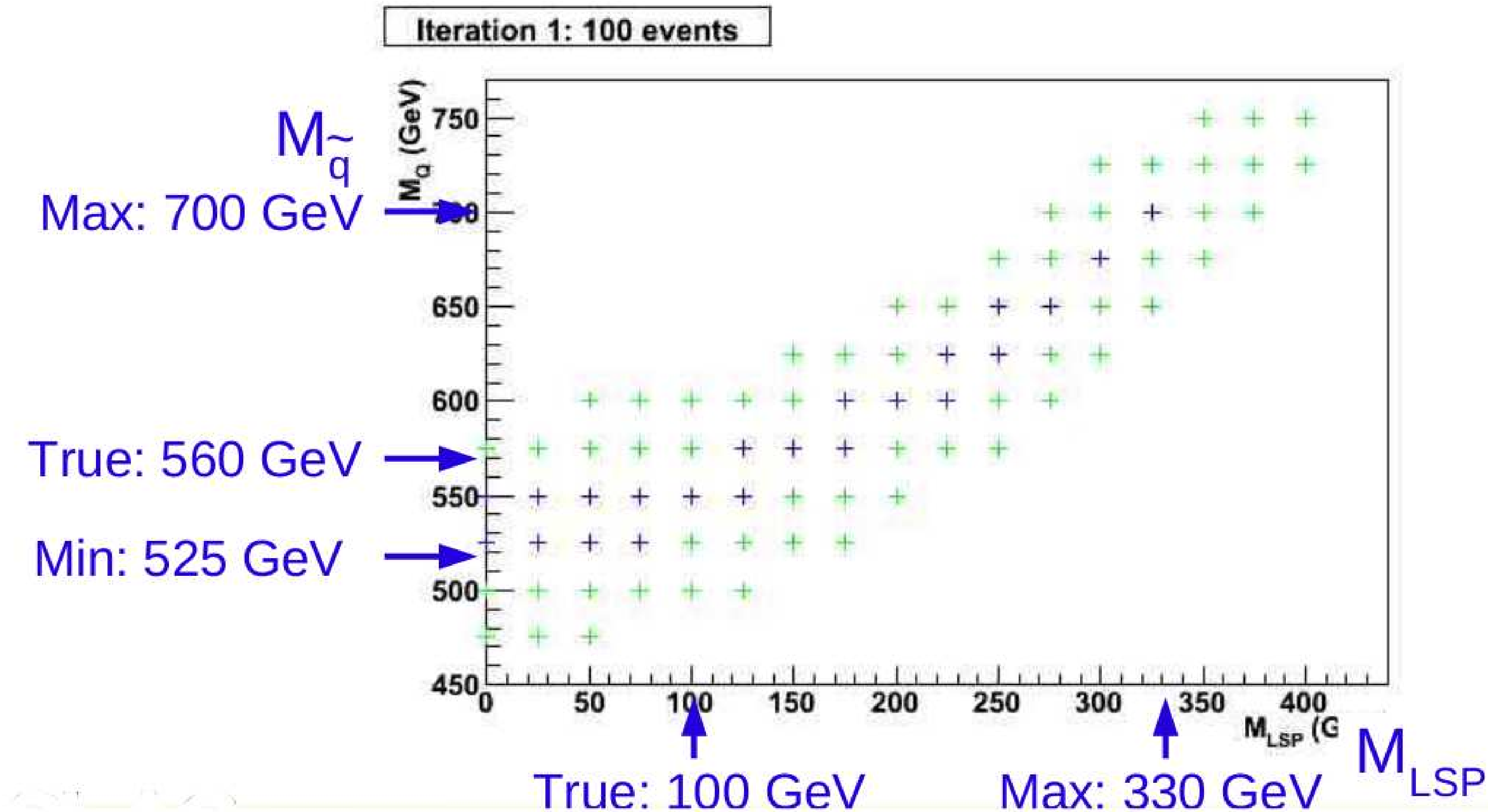
Search for New Physics

-Log(L) for 100 events – still parton level



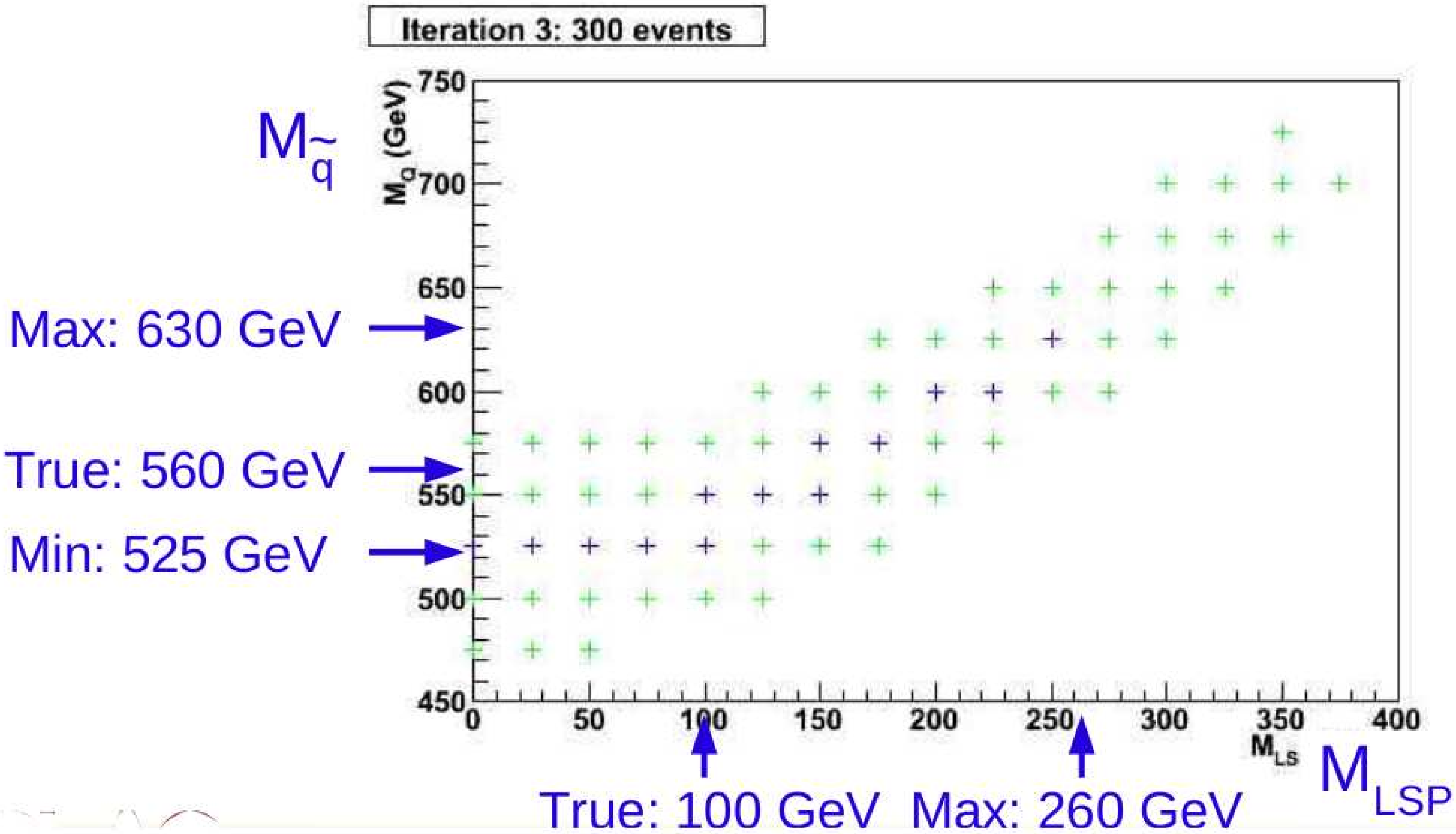
Search for New Physics

-Log(L) for 100 events – blue below min+4



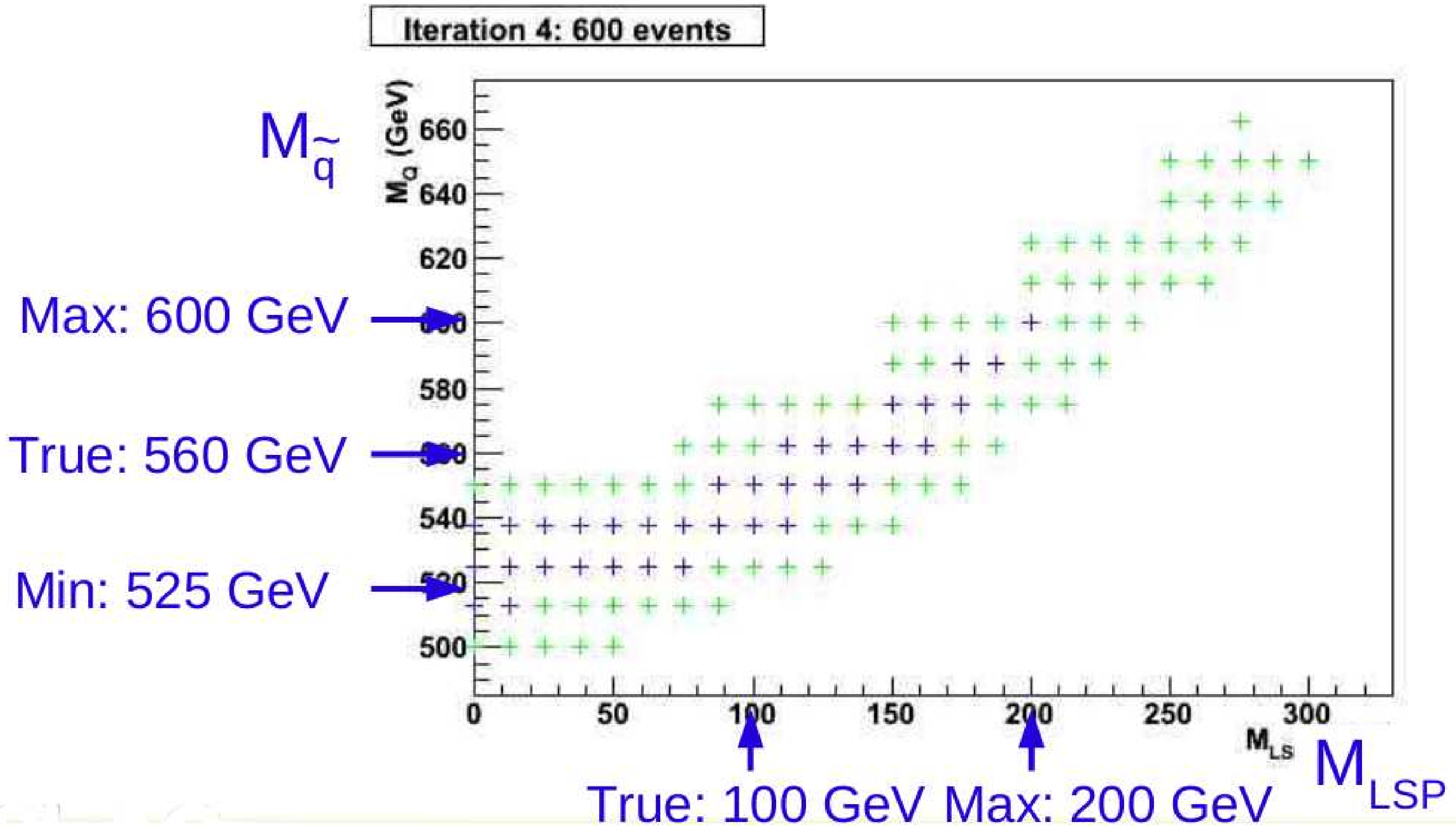
Search for New Physics

-Log(L) for 300 events – blue below min+4



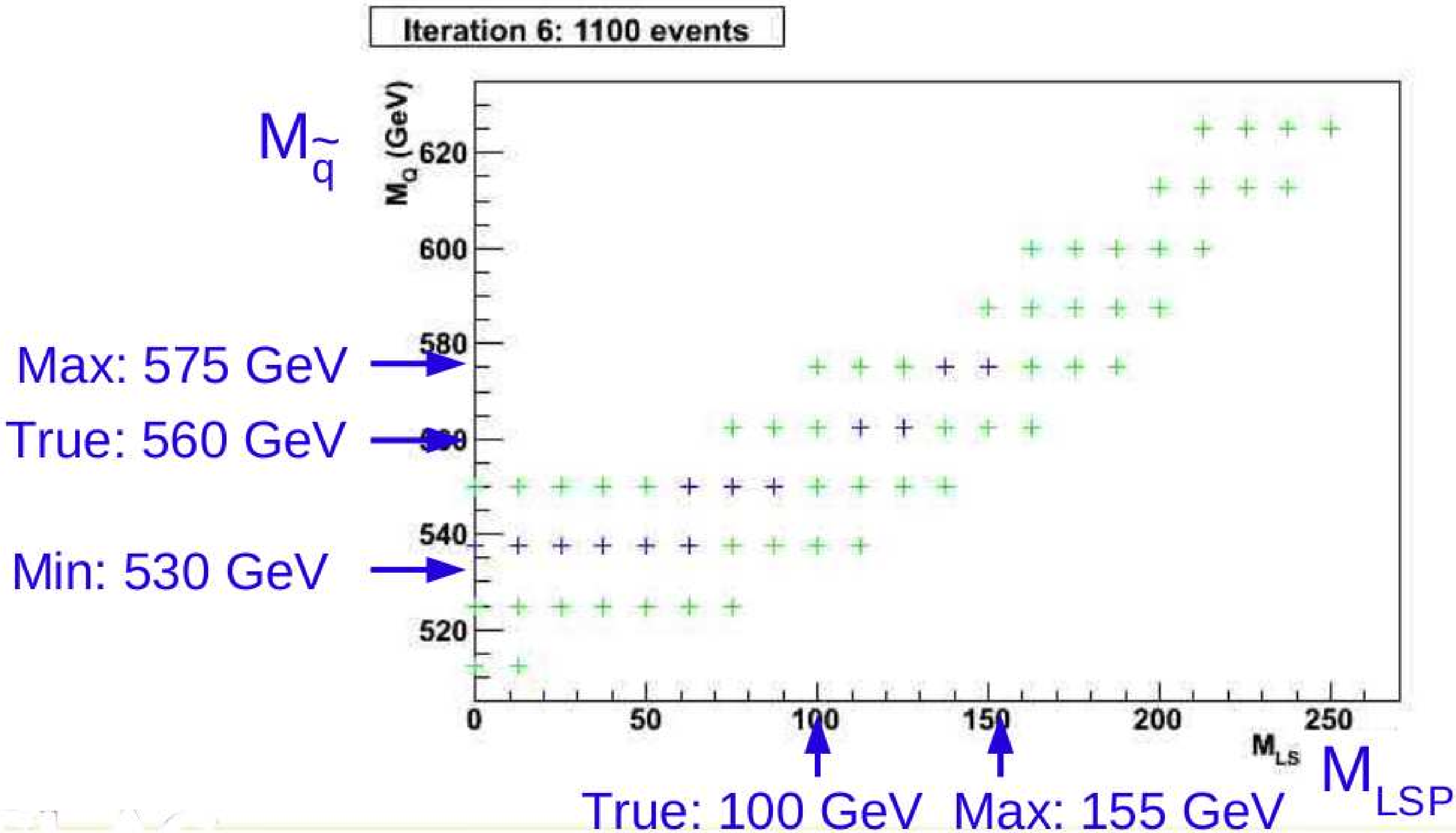
Search for New Physics

-Log(L) for 600 events – blue below min+4



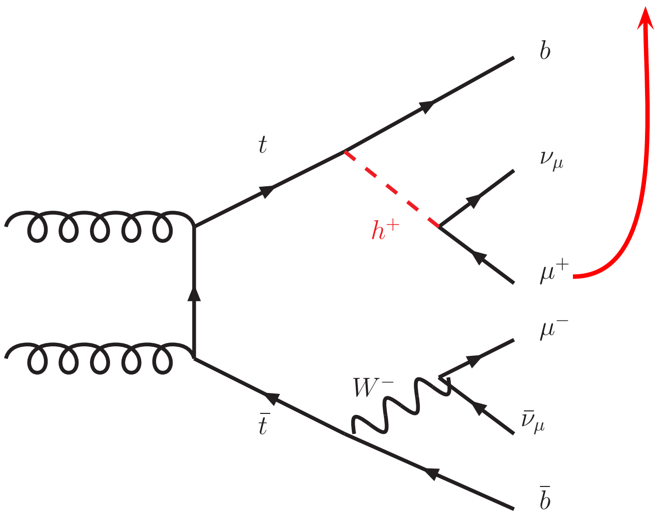
Search for New Physics

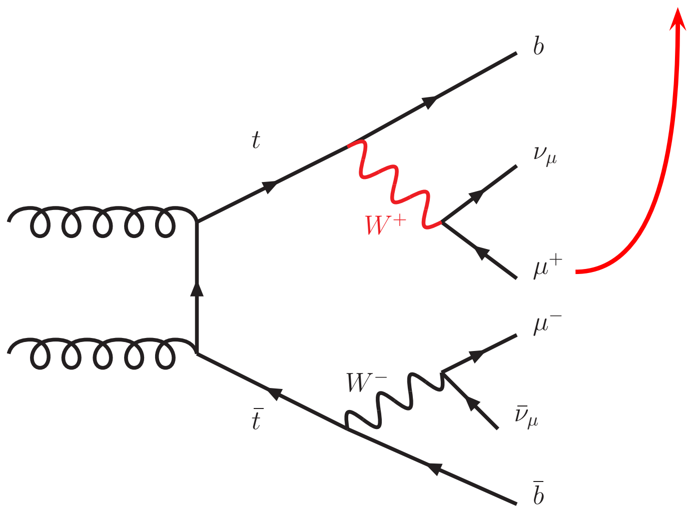
-Log(L) for 1100 events – blue below min+4



Charged Higgs

- Example 2 :
  separate the signal $t \to H^+ b$ from the background $t \to W^+ b$





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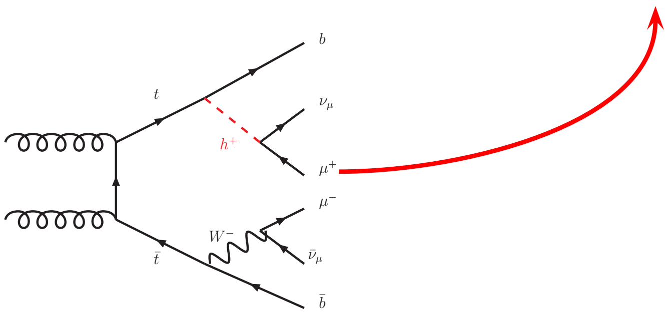

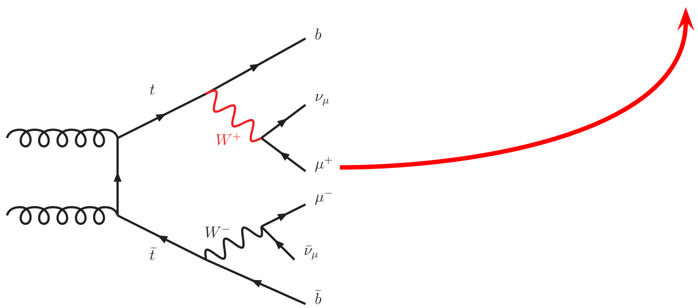

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  - $M_{H^+} = 100GeV$

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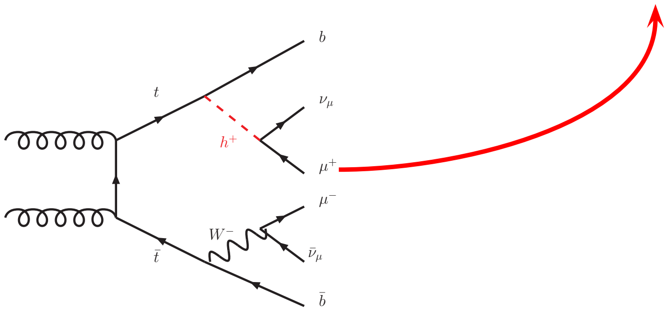

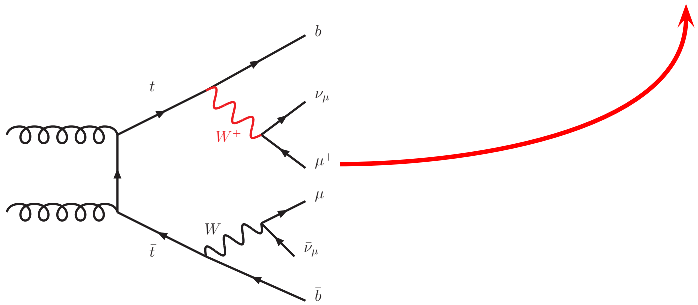

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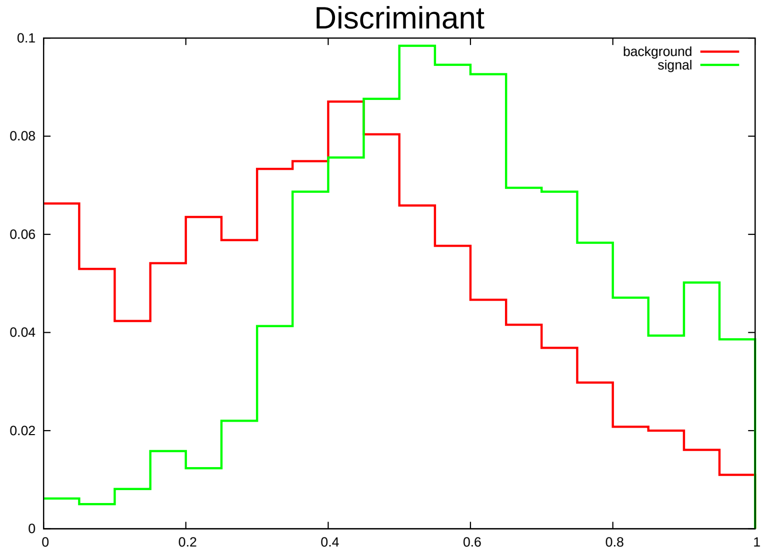
- define the discriminator

$$d = \frac{P_S}{P_S + P_B}$$



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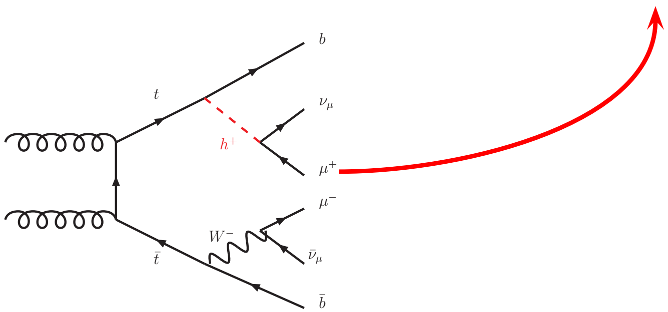

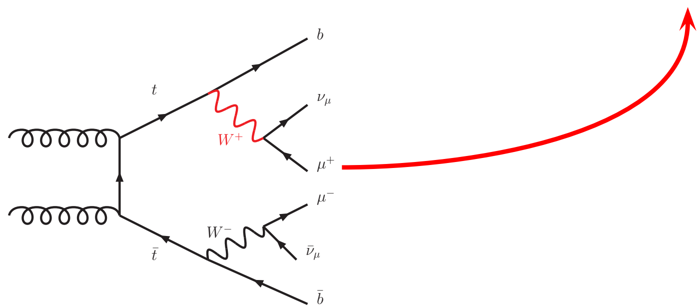

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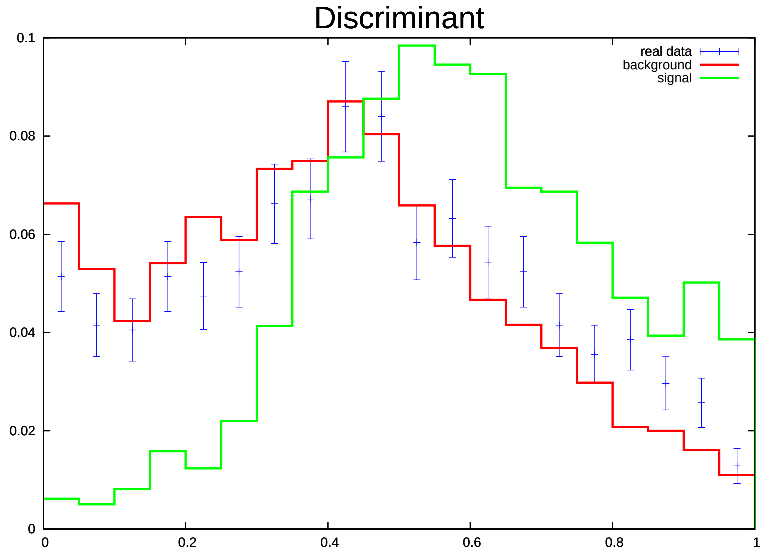
  $$d = \frac{P_S}{P_S + P_B}$$

- 750 background events
- 262 signal events
- $r = 25.9\%$



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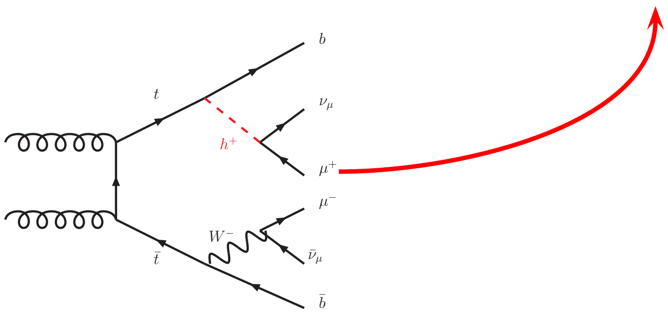

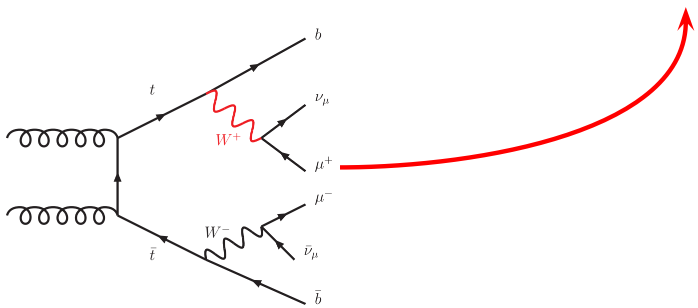

- define the discriminator
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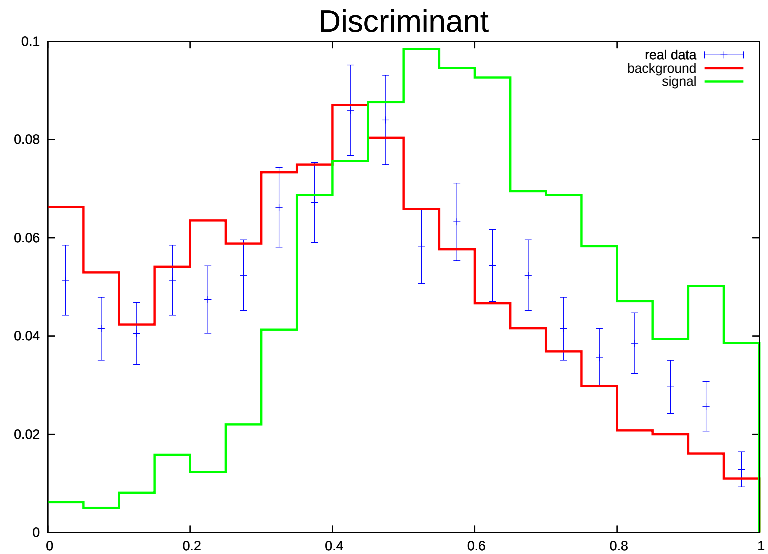
- $r = 25.9\%$
- $r_{mes} = 21 \pm 4\%$



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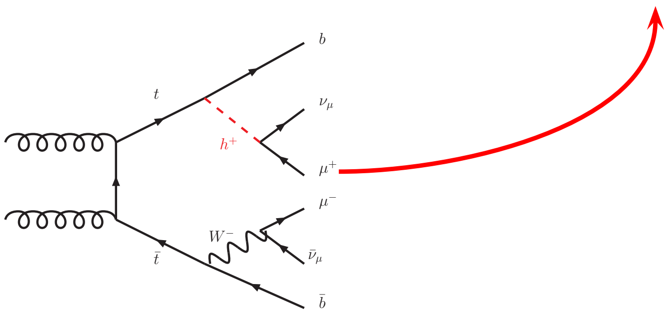
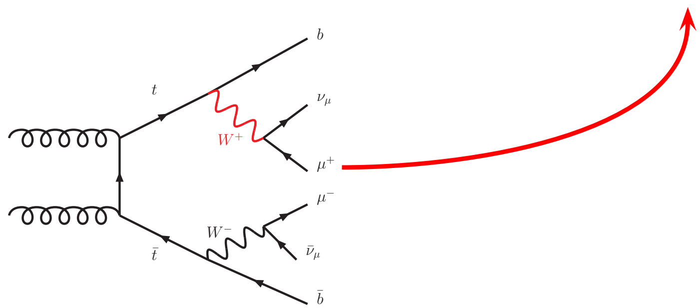
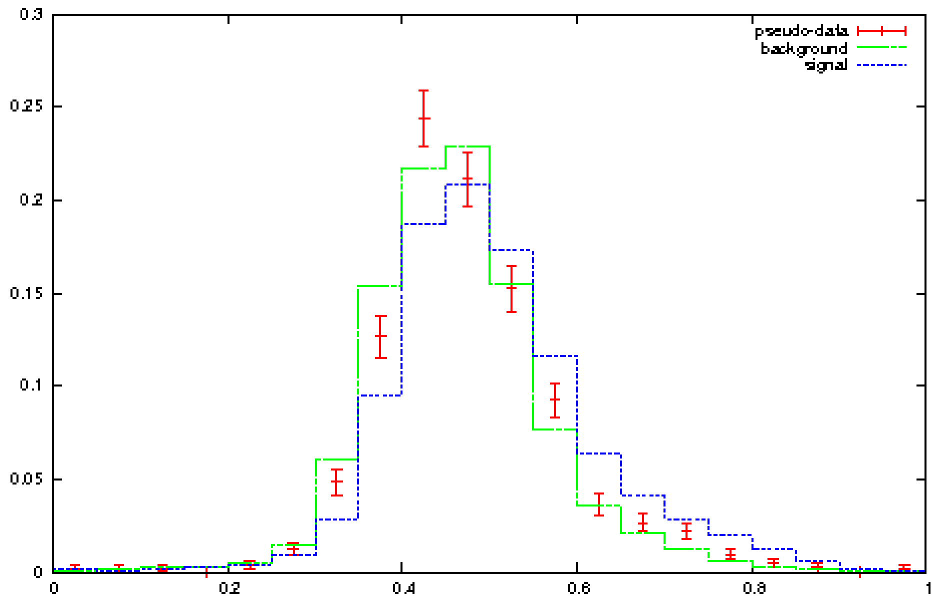




- $M_{H^+} = M_{W^+}$
- $\sigma = 1.632pb$
- $L = 8.5fb^{-1}$
- $\sigma_{mes} = 1.7 \pm 0.4pb$

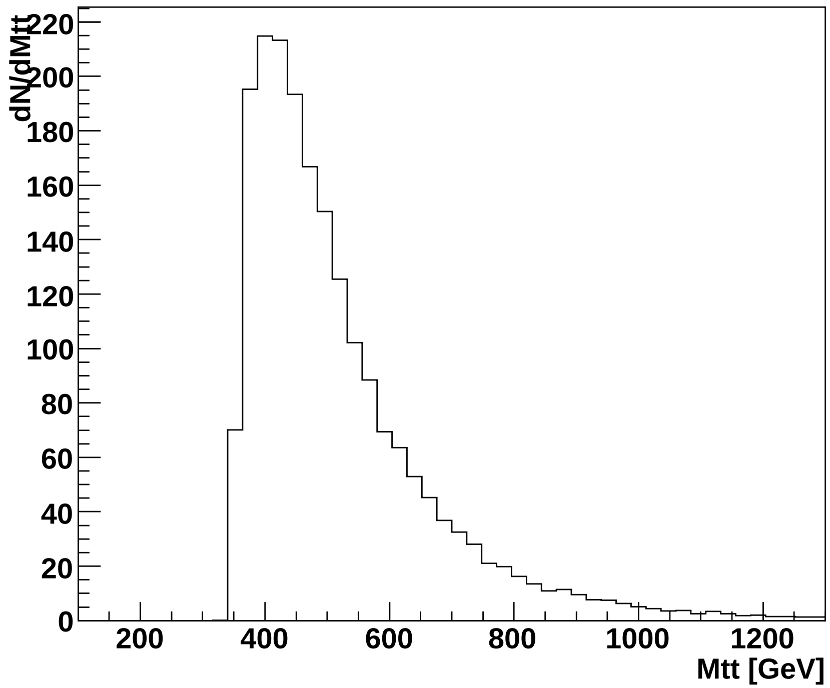


Search of New Resonances

- Use the Matrix Element Method for estimate differential cross-section.
- $$\frac{1}{P}\frac{dP}{dm}(m_0) = \frac{1}{P}\frac{1}{\sigma}\int d\phi(\boldsymbol{y})|M|^2(\boldsymbol{y})W(\boldsymbol{x},\boldsymbol{y})\delta(M_{rec} - m_0)$$
- Each event gives a curve with unitary weight
- Sum All those curves, provides a differential cross-section estimator.
- In general, and strictly speaking the sum of those curves is not the differential cross-section. (due to neutrino integration)

Search of New Resonances

- $t\bar{t}$ invariant mass. ($t\bar{t}$ decay in fully leptonicaly)



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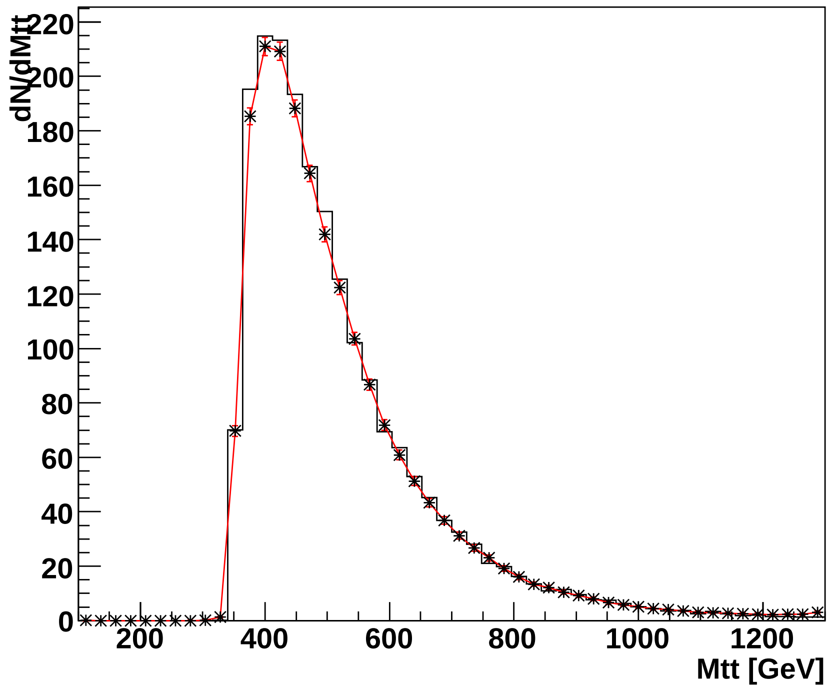

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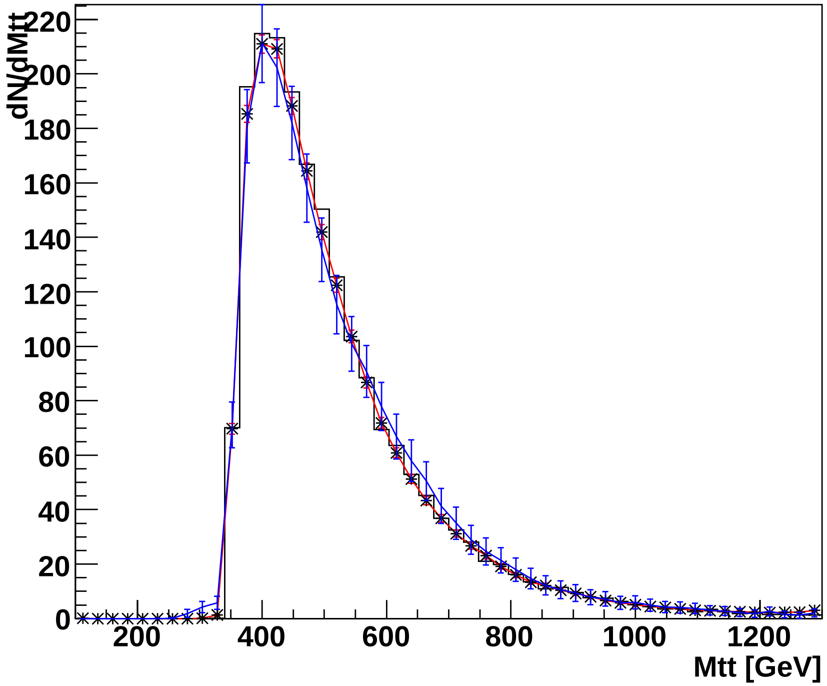

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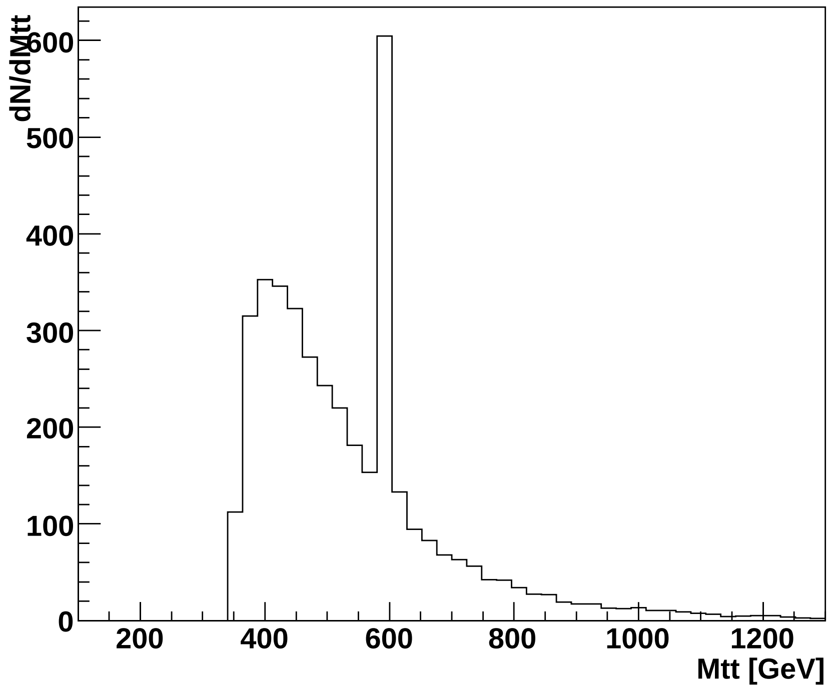
- What happens if a BSM resonances creates some $t\bar{t}$ events.



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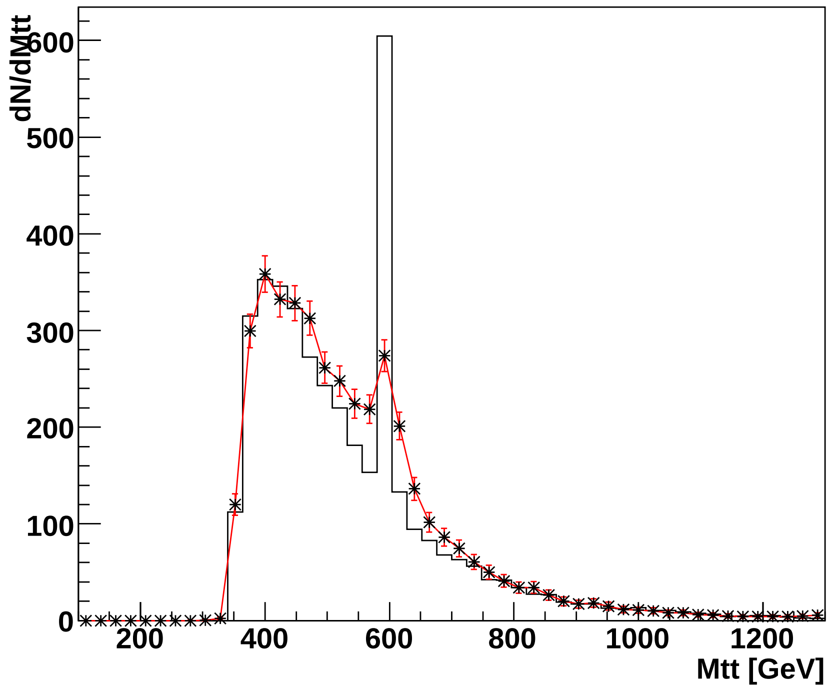

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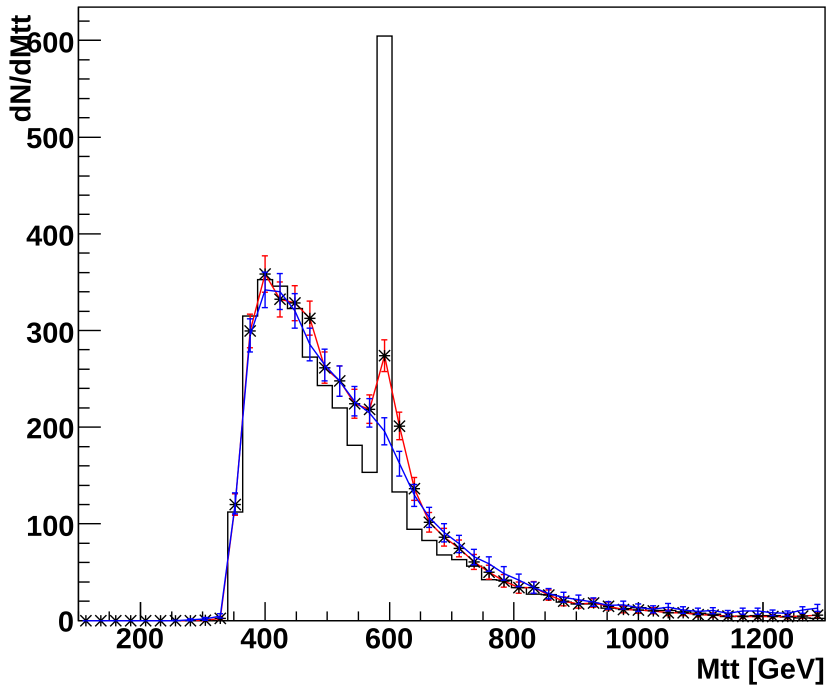

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Conclusion

- the Matrix Element method provides the best discriminator on an event-by-event basis
- both theoretical ($|M|^2$) and experimental ($\boldsymbol{x}$, $W(\boldsymbol{x}, \boldsymbol{y})$) information is used
- the computation of the weights requires a specific phase space generator : MadWeight
- Matrix Element Method can be used for difficult observables
- Not only for precise measurement.

backup slides

Search for New Physics

- Energy of the quark in squark rest frame : $E_q = \frac{M_{\tilde{q}}^2 - M_{LSP}^2}{2M_{\tilde{q}}}$
- Maximum p_T at threshold