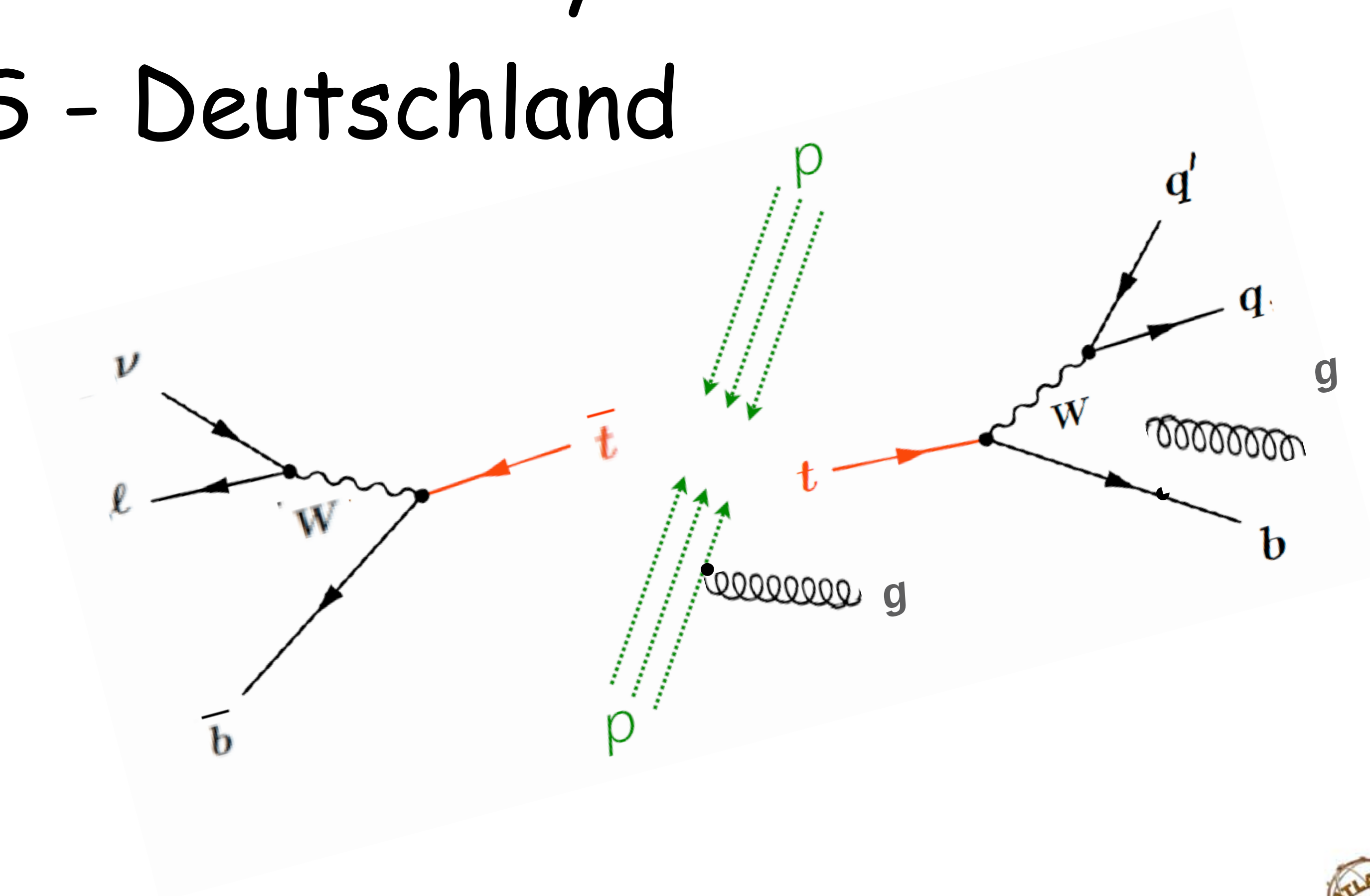
Overview
Top-quark mass analysis
ATLAS - Deutschland



Ingo Reisinger

Overview
Top-quark mass analysis
ATLAS - Deutschland

contributors

• LMU München	Full hadronic, cut based analysis
• MPI München	Semileptonic, Kt jet alogrithm
• University of Göttingen	Semileptonic, Matrix element method
• University of Bonn	Semileptonic, Decay length technique
• University of Dortmund	Semileptonic, Decay length technique

Motivation - Top-quark physics

- Precision measurements of Top-quark properties are limited on Tevatron statistics

  mass, width, el. charge, spin, isospin, BR, V-A decay, FCNC, rare decays within and beyond the bounds of the SM, …

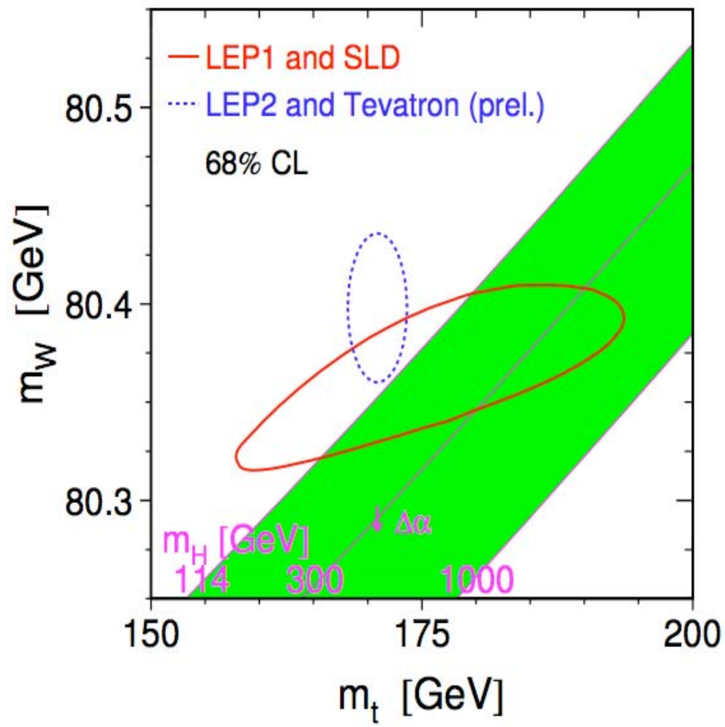
  $\Rightarrow$ Plenty of room for new physics in the top sector left!

- A tool to understand/calibrate the (sub-) detector(s)
- Special role in various SM extensions

Motivation - Top-quark mass

Top-quark mass is close to the scale of the EWSB

- ⇒ Top and W masses constrain the Higgs mass, i.e. access to the origin of mass
- ⇒ Tool to probe the SM
- ⇒ Heaviest elementary particle known with Yukawa coupling close to 1
- ⇒ Tool to probe physics beyond the SM



[CDF homepage: www-cdf.fnal.gov/]

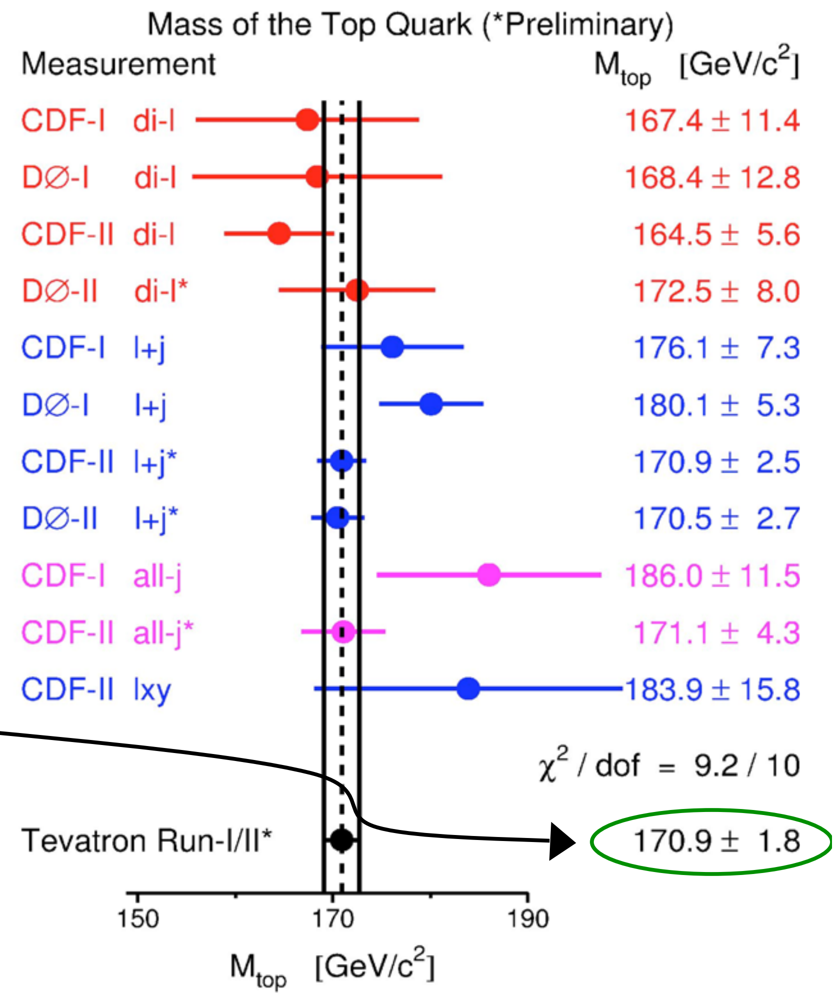
General comments - Top-quark mass analysis techniques

- many different methods used for Top-quark mass reconstruction:
  - Matrix element
  - Template
  - Matrix & Neutrino weighting
  - Ideogram
  - $b \rightarrow J/\Psi$ transition
  - Decay length
  - Lepton p_T

General comments - Tevatron results

- many different methods used for Top-quark mass reconstruction
    - Matrix element
    - Template
    - Matrix & Neutrino weighting
    - Ideogram
    - b → J/Ψ transition
    - Decay length
    - Lepton p_T
- performed by CDF & DØ resulting in an world average for the Top mass
- but limited by Tevatron statistics
- uncertainty dominated by systematics

  (JES, ISR, FSR, PDF, b-fragmentation, lifetimes and BRs of B-hadron species, …)



$$M_t = (170.9 \pm 1.1\,(stat.) \pm 1.5\,(syst.))\,GeV/c^2$$

[arXiv:hep-ex/0703034v1, April 2007]

Full hadronic channel

- ttbar decays
- Full hadronic channel

$$t\bar{t} \rightarrow W^{+}b \quad W^{-}\bar{b}$$
$$\hookrightarrow q\bar{q} \;\; \hookrightarrow q\bar{q}$$

- Reconstruction of top quark mass possible if energy / momenta of all particles known

Cut based analysis (University of München)

Rekonstruierte top Masse in einer schnittbasierten Analyse

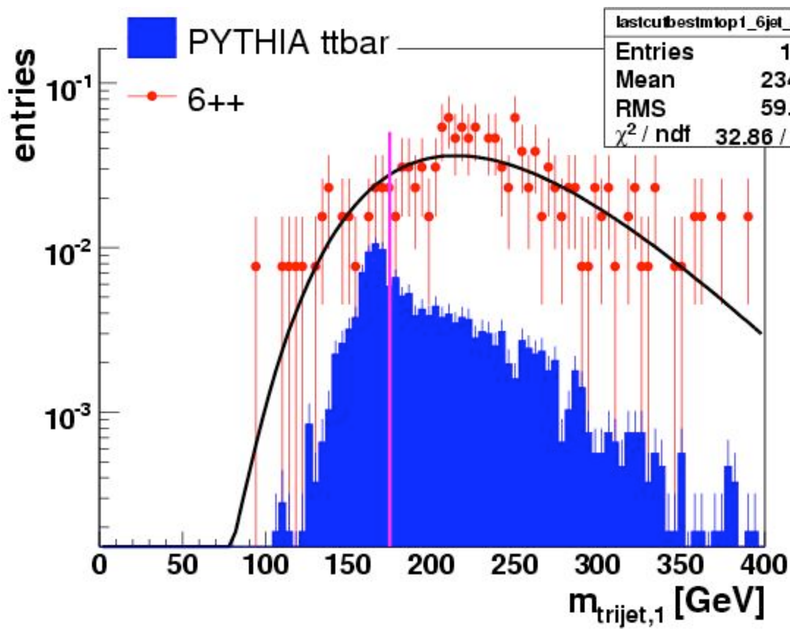
- Auswahl der sechs höchstenergetischsten Jets im Ereignis mit $|\eta_{jet}| < 3$
- Berechnung eines $\chi^2 = (m_{top1} - m_{top2})^2 + (m_{W1} - m_W)^2 + (m_{W2} - m_W)^2$ für jede Jetkombination aus sechs Jets
- Minimales χ^2 liefert beste Zuordnung der Jets zu den Mutterteilchen
- Input für die Berechnung der invarianten W und top Massen und zur Bestimmung eines Topmassen Peaks aus den hadronischen Ereignissen
- Reduktion des QCD Multijet Untergrunds durch kinematische und topologische Schnitte
- No b-tag used

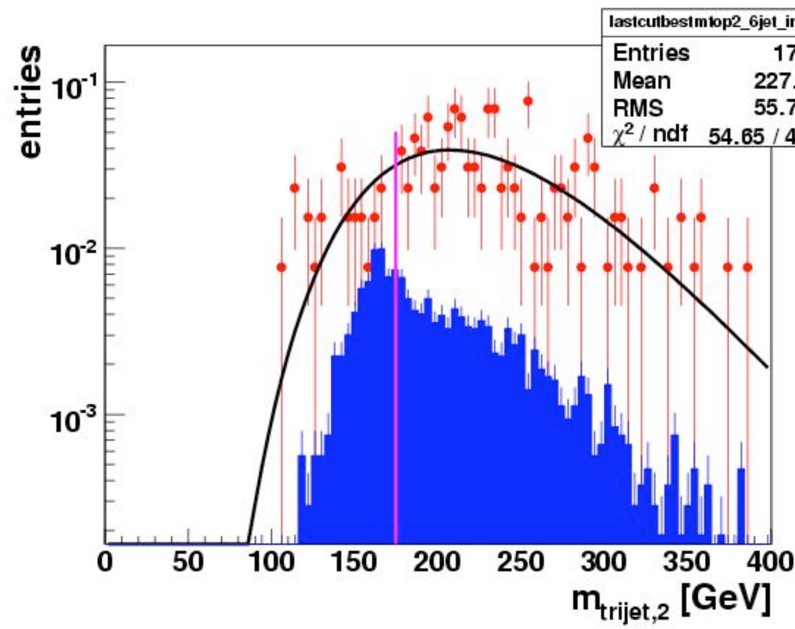
Cut based analysis (University of München)

	Angewandte Schnitte
#0	$\lvert\eta_{jet}\rvert < 3$
#1	$N_{jet} = 6$
#2	$p_{T,jet1} > 90GeV, p_{T,jet2} > 70GeV, p_{T,jet3} > 50GeV,$
#3	$p_{T,jet4} > 45GeV, p_{T,jet5} > 35GeV, p_{T,jet6} > 25GeV,$
#4	$-200GeV \le \Delta p_{z,top} \le 200GeV$
#5	$\Sigma p_{T,jets} > 120GeV$
#6	$70GeV < m_{dijet} < 90GeV$
#7	$Aplanarity > 0.5$

$$m_{trijet} < 400GeV$$

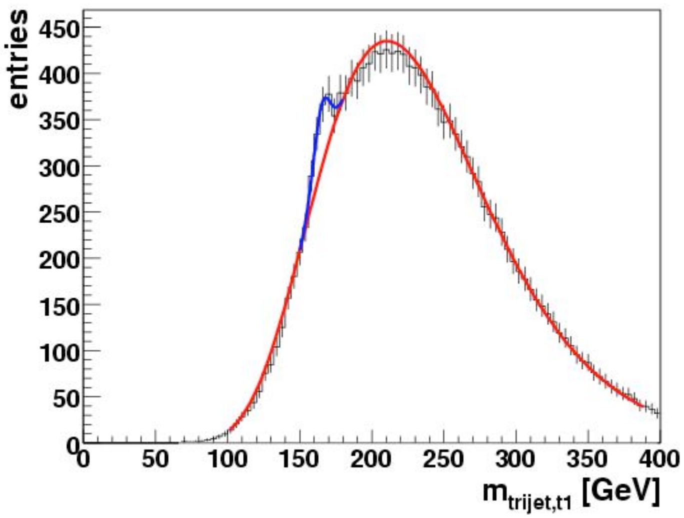
Cut based analysis (University of München)

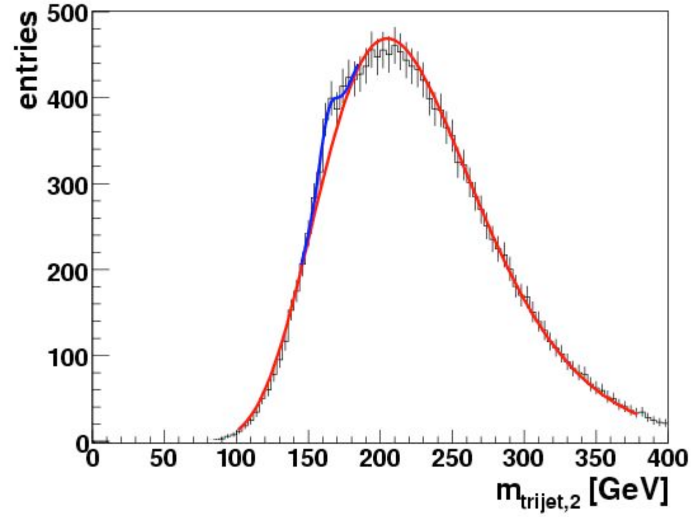




Rekonstruierte top quark Massen in rein hadronischen ttbar Ereignissen (blau) nach Anwendung aller Schnitte.
Der verbleibende QCD 6-jet Untergrund wurde mit einer Landau Funktion gefittet.

Cut based analysis (University of München)





- Signal und Untergrund Ereignisse mit Faktor ≈10000 skaliert ($\int L dt = 1560\, pb^{-1}$)
- Signal auf Untergrund addiert
- Untergrund mit Landau Funktion (gleiche Parameter -> selbe Form) nochmals gefittet
- Gauss Fit an das top Signal

⇒ Rekonstruktion eines Topmassen Peaks bei genügend grosser Statistik möglich

Lepton + jets channel

- ttbar decays
- Lepton + jets channel

$$t\bar{t} \rightarrow W^+ b \quad W^- \bar{b}$$
$$\hookrightarrow \ell^+ \nu \;\; \hookrightarrow q\bar{q}$$

- Reconstruction of top quark mass possible if energy / momenta of all particles known, neutrino reconstructed from missing p_T
- Different combinations of jets possible (depending on no/1/2 b-jet tags)

Kt Jet Algorithm (MPI München)

Currently investigating the Kt- Jet reconstruction algorithm and optimizing its parameters:

- Inclusive-Kt: Scanning for three of the recombination schemes (E, P_t, P_t^2) over the D parameter:

$$R = 0.1,...,1.2$$

- Exclusive-Kt: dCut,Recombination scheme (E, P_t, P_t^2):

$$dCut = (5GeV)^2, ..., (40GeV)^2$$

- Exclusive-Kt: Forcing the event to 4 or 5 jets.

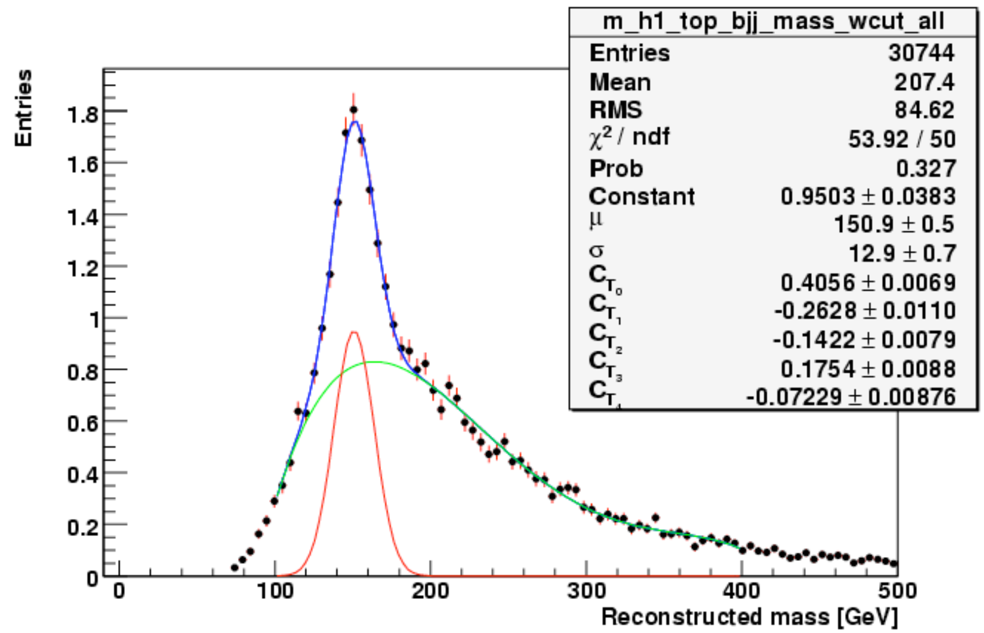
Kt Jet Algorithm (MPI München)

Analysis Selection criteria:

- At least one lepton, $P_t > 20\text{GeV}$, $|\eta| < 2.5$
- Neutrino: Missing $E_T > 20$ GeV
- At least 4 jets with $P_t > 40$ GeV, $|\eta| < 2.5$, $\Delta R(\text{Lepton, jet}) > 0.4$
- Find the three jet combination which maximizes the sum P_t
- Add the W-mass constraint $\pm$ 20 GeV

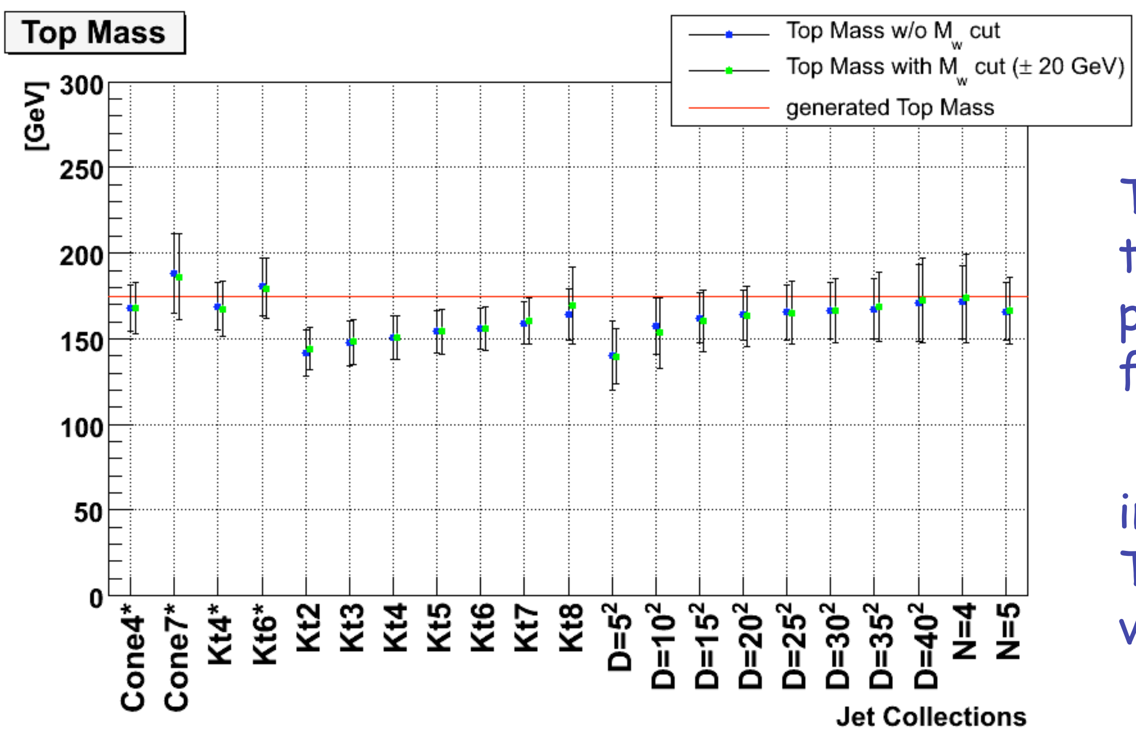
The final distribution is then adjusted with the sum of a Gauss and a Polynomial

Plot:
Reconstructed hadronic Top-quark mass for inclusive Kt with $R = 0.4$.



Kt Jet Algorithm (MPI München)

The Top-quark analysis is repeated for the various set of parameter values for the Kt jet algorithm (inclusive, exclusive).
The plot below shows the reconstructed Top-quark mass with and without the W mass constraint. The Error bars are the width of the gaussian.



The best working region in terms of Top-quark mass peak resolution, is obtained for

$$R = 0.4,\ldots,0.6$$

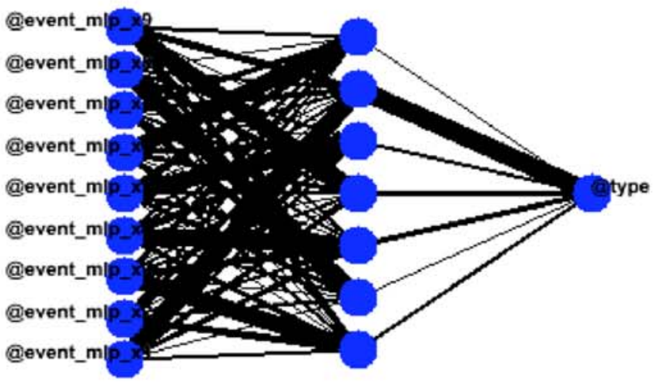
in the inclusive Kt scenario. This result holds when varying the JES by ± 10%

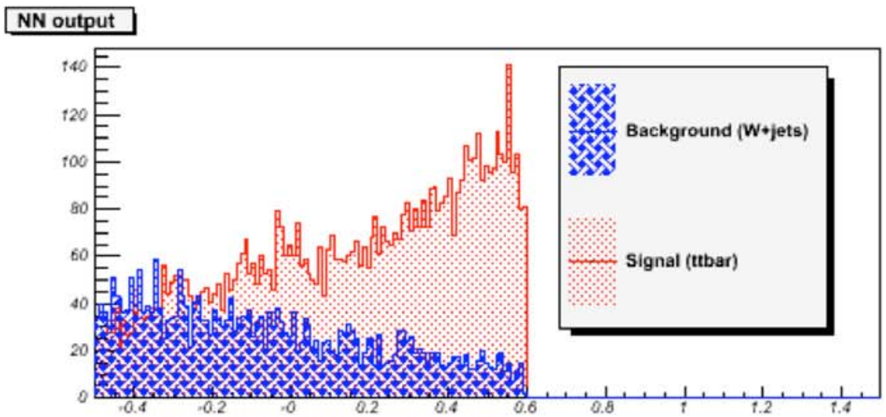
Kt Jet Algorithm (MPI München)

Further studies:

a neural network based analysis (three layer structure with 9 input discriminant variables) is currently being investigated, starting from the analysis described in:

Top quark physics at hadron colliders; A. Quadt; Springer, 2007





Very preliminary:

left plot: neural network architecture: simple feed-forward neural network

right plot: output of the neural network, when training it on semileptonic ttbar and W+jets (2,3,4,5)

Plan for the case of the top mass: Using the neural network output as a cut variable and optimizing it, by looking at the resolution of the mass distribution

Matrix Element Method

$$P(x;M_t) = f_s P_s(x;M_t) + (1-f_s) P_{bkg}(x)$$

$$P_s(x|M_t) = \frac{1}{\sigma(M_t)} \int d\Phi \;\; |M_{t\bar{t}}(q_i,p_i;M_t)|^2 \;\; W(p,x) \;\; f_{PDF}(q_1) f_{PDF}(q_2)$$

Propability to measure x

normalisation:
production croos section

phase space

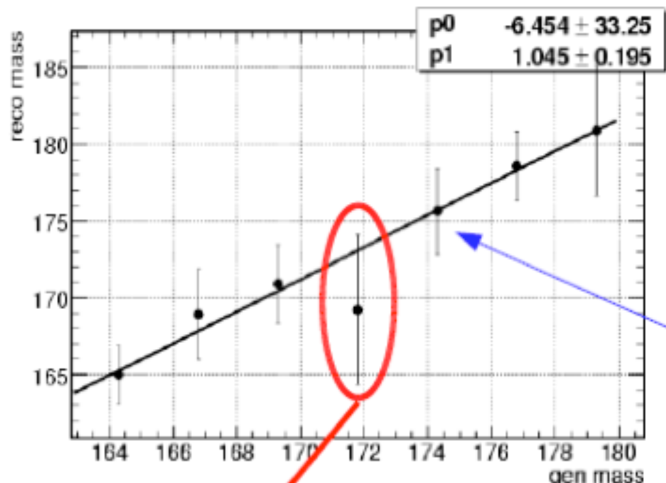
matrix element:
dynamic:
Parton/parton → ttbar

transfer function:
Maps the physical p to the detectable observable x

PDFs

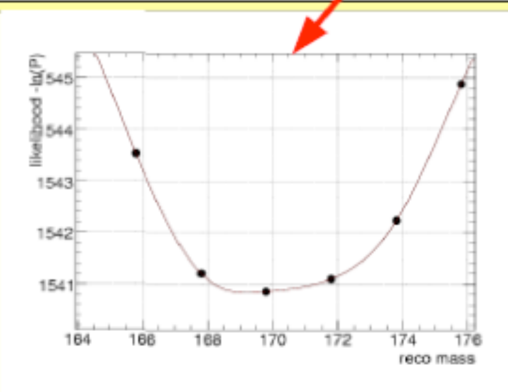
Matrix Element Method - ATLAS Top group

- First results (Top working group meeting August 2007, LPNHE)

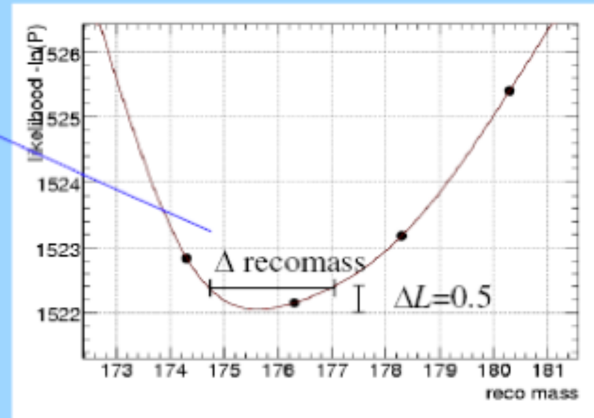


- a good linearity is observed (with the exception of point with a gen. mass of 171.8 GeV)
- the slope is 1.045 ± 0.195

  very encouraging...



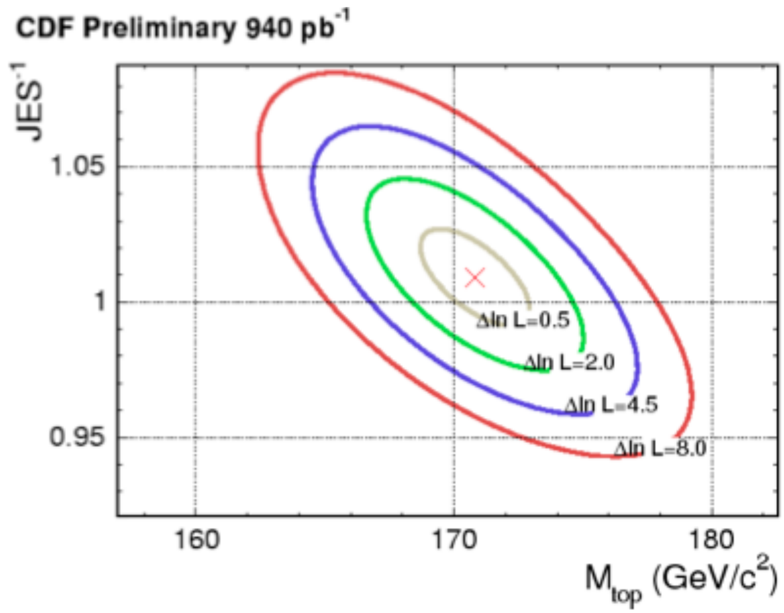
To have a more precise fit we should increase the number of the masses for which we calculate the likelihood



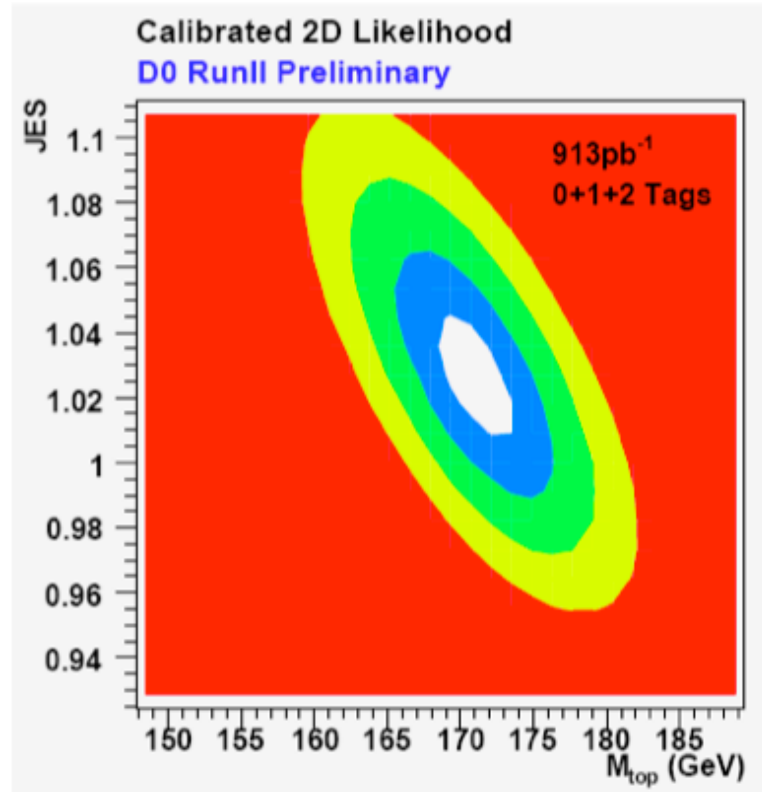
errors extracted, for the time being, from the likelihood (where it is 0.5 greater than the minimum)

28/08/07 Top WG meeting

Matrix Element Method - Tevatron



170.9 ± 2.2 (stat+JES) ± 1.4 (syst) GeV/c²



170.5 ± 2.4 (stat+JES) ± 1.2 (syst) GeV/c²

Addresses m_{Top} and Jet Energy Scale simultanously

Matrix Element Method (University of Göttingen)

Kevin Kröninger, II. Phys. Institut, Göttingen ATLAS Deutschland Zeuthen, 19.-21.09.2007

- Currently working on Top-quark physics:
  - 2 post-docs
  - 3 Diploma students
- Experience in Top-quark mass (l+jets, di-lepton) measurements from D0 → migrating experience to ATLAS
- Ongoing projects:
  - Matrix element method top mass analysis l+jets (starting)
  - Development of analysis tools (ME method and beyond)
  - χ^2 -based kinematic fitter for ttbar-events

Decay length technique - Motivation

- Tevatron:
  - World average for the Top-quark mass:

$$M_t = (170.9 \pm 1.1\,(stat.) \pm 1.5\,(syst.))\,GeV/c^2$$

  - Uncertainty systematically dominated:

    Main impact: „Jet Energy Scale"

- goal:
  - Top-quark mass reconstruction without Calorimeter input

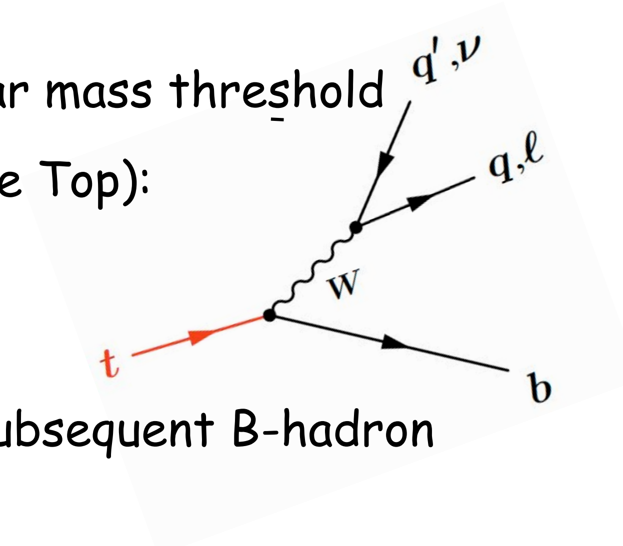
    „Decay Length Technique"

  - Complementary systematic impacts compared to other methods
  - Tevatron (CDF):

$$M_t^{L_{xy}} = (183.9 \pm 15.8)\,GeV/c^2$$

    Not competitive due to limited statistics

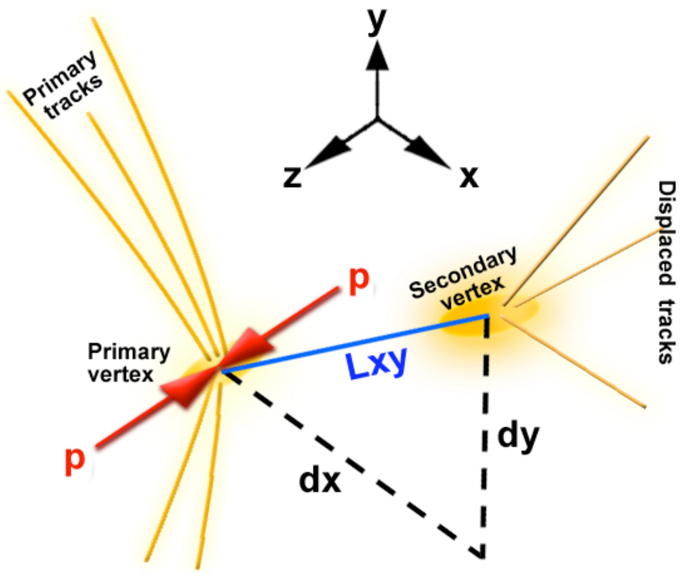
Decay length technique - Idea



- Top-quark production at LHC: *gluon-fusion near ttbar mass threshold*
- Top-quark decays into b-quark, with boost (CM of the Top):

$$\gamma_b = \frac{m_t^2+m_b^2+m_W^2}{2m_t m_b} \overset{m_t \gg m_b}{\approx} 0.4 \cdot \frac{m_t}{m_b}$$

- γ_b of the b-quark or, after hadronization, γ_B of the subsequent B-hadron directly impacts the lifetime τ_B of the B-hadron



$\Rightarrow$ m_t can statistically be inferred from τ_B , or from the easier accessible

"mean transverse decay length"

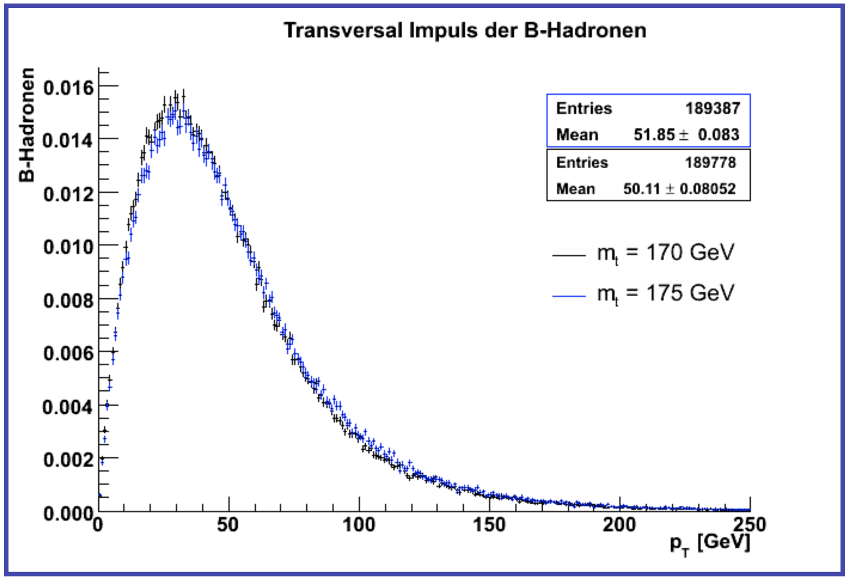
$<L_{xy}>$ of the B-hadron.

$$< L_{xy} >= c\tau_b\beta\gamma_b$$

$<L_{xy}>$ is the transverse difference between the top production and the B decay vertex

$(p_B)_T$ & L_T^{truth} resolution Bonn

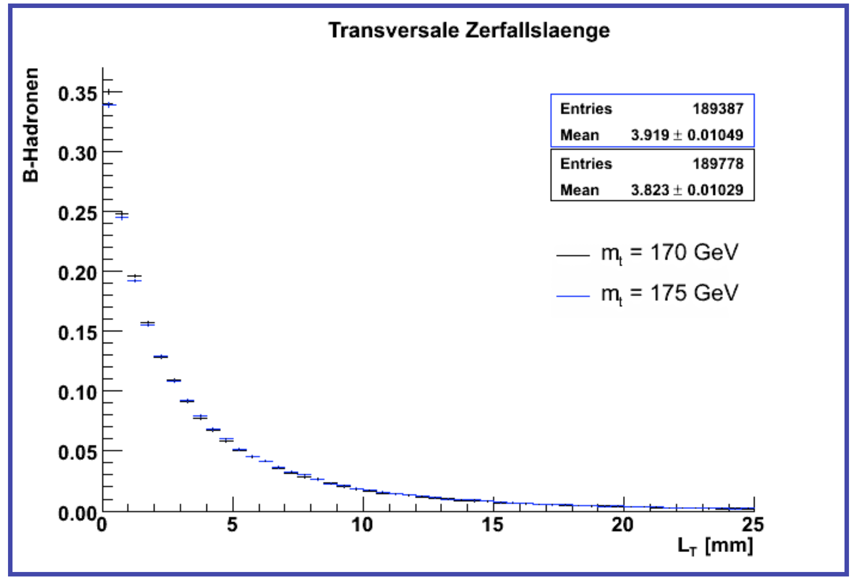
Sensitivität von $(p_B)_T$ auf m_t



$$\Rightarrow \Delta\langle p_{B,T}\rangle / \langle p_{B,T}\rangle = 3.5\,\% / 5\text{GeV}\ \Delta m_t$$

Calorimeter input nessecary
$\Rightarrow$ JES impacts

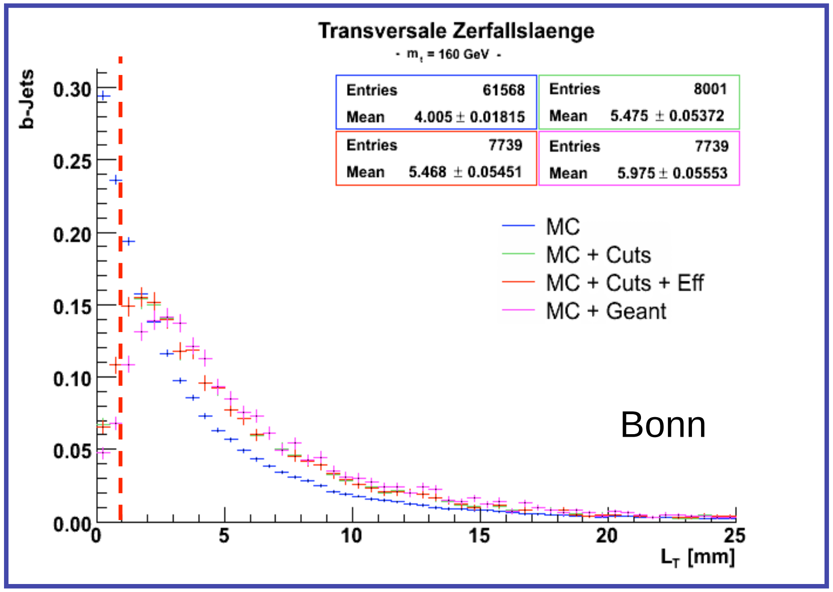
Sensitivität von L_T^{truth} auf m_t



$$\Rightarrow \Delta\langle L_T\rangle / \langle L_T\rangle = 2.6\,\% / 5\text{GeV}\ \Delta m_t$$

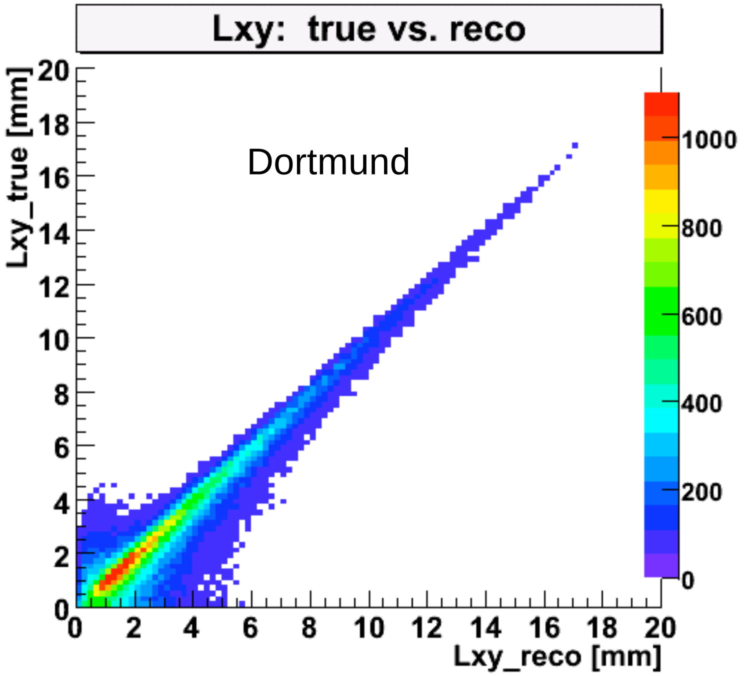
Based on track reconstruction
$\Rightarrow$ no JES impacts

Systematic studies I: Reconstruction accuracy



- Einfluss Primärvertex: Rekonstruktions Effizienz schlecht
- Beim Zerfall des B-Hadrons entstehen D-Mesonen ⇒ tertiäre Verticees

$$\Rightarrow \quad L^{reco} > L^{truth}$$



Correlation of reconstructed $<L_{xy}>$ vs. MC truth $<L_{xy}>$ of double b-tagged events estimates the accuracy of the reconstruction of $<L_{xy}>$:

⇒ Systematic overestimation of small reco $<L_{xy}>$

systematic Studies II : b-fragmentation & B-lifetime

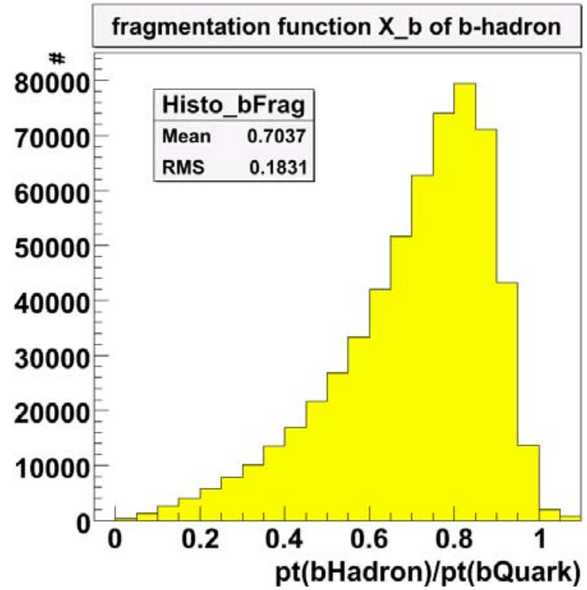
- b-fragmentation:

After hadronization the B-hadron carries away a momentum fraction X_b from the b-quark impacting the B momentum. OPAL:

$$X_B = 0.7193 \pm 0.0016\,(stat.) \begin{array}{c} +0.0038 \\ -0.0033 \end{array} (syst.)$$

Systematic uncertainty impacts a Top-quark mass with an uncertainty of:

$$\Delta m_t = 0.92\,GeV$$



Typ	BR [%]	Lifetime [ps]
B^0,$B^0$0	39.8 ± 1.0	1.527 ± 0.080
$B^\pm$	39.8 ± 1.0	1.643 ± 0.010
$B^0{}_S$,$B^0{}_{S0}$	10.4 ± 1.4	1.454 ± 0.040
B-Baryons	9.9 ± 1.7	1.242 ± 0.046

- B-meson lifetime τ_B:

The uncertainty of τ_B

$$\tau_b = (1.574 \pm 0.008) \cdot 10^{-12}\,s$$

also affects the Top-quark mass :

$$\Delta m_t = 0.89\,GeV$$

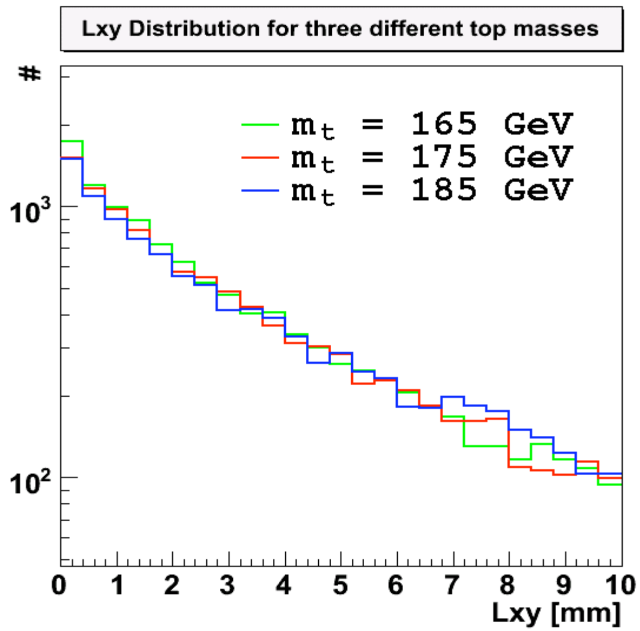
First results - Dortmund

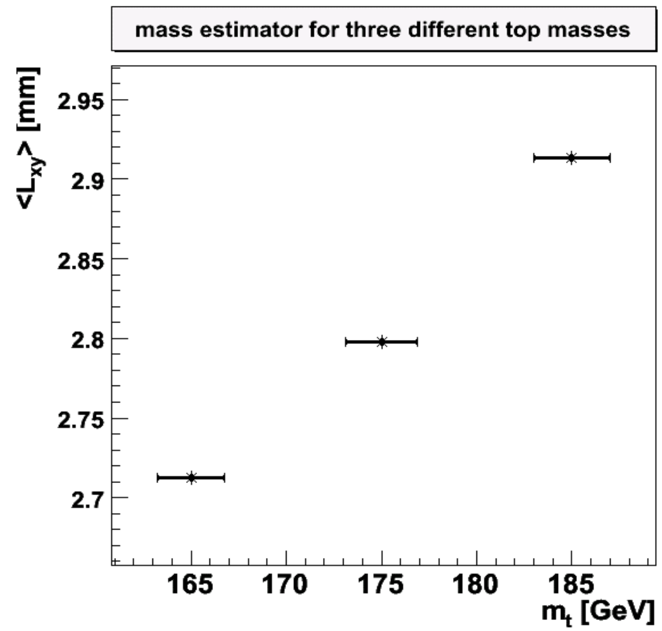
(generator level, Pythia)

- Based on $\gamma_b \approx 0.4 \cdot \frac{m_t}{m_b}$ and $< L_{xy} >= c\tau_b \beta \gamma_b$

and the systematic uncertainties:

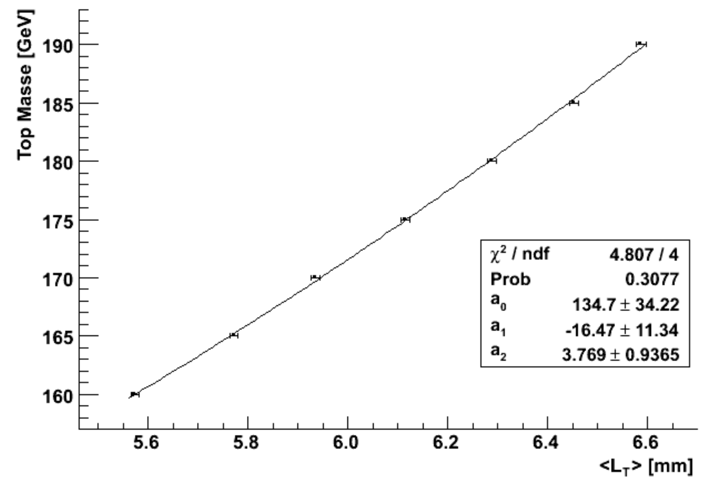
- Reconstruct $<L_{xy}>$ as a function of m_t and create the "mass estimator"





Based on private generated MC tt-samples with varying top masses, 50k events

First results - Bonn

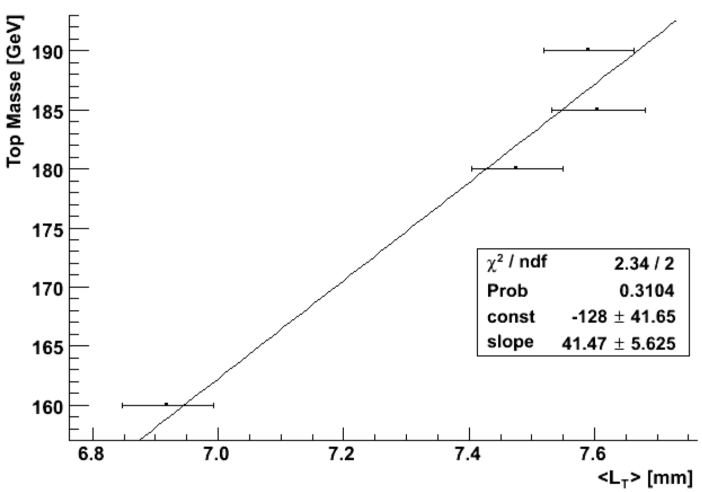


Verwendete Datensätze:

- Selbst generiert mit AcerMC 3.4 & Pythia 6.4 für

  $m_t = \{160,165,170,175,180,185,190\}$ GeV

- ~ 445k Ereignisse @ 10.9 fb-1



Verwendete Datensätze:

- csc11-evgen-Datensätze für

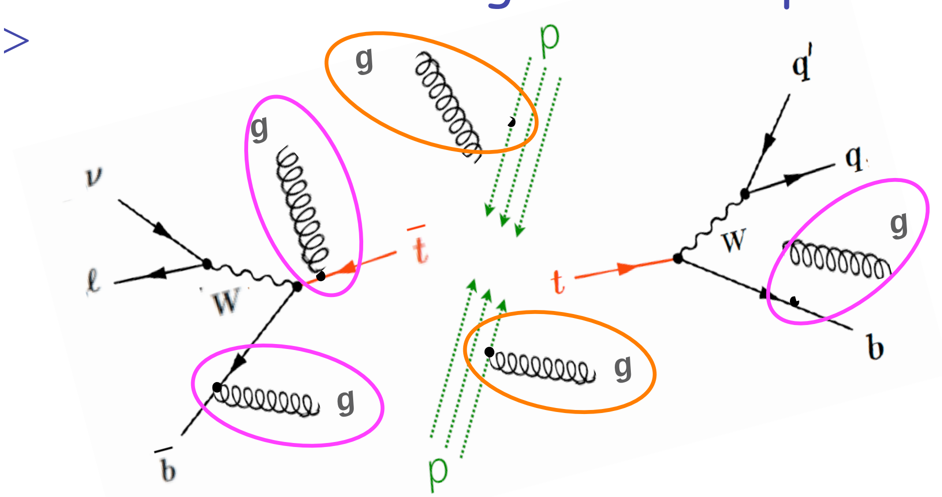
  $m_t = \{160,180,185,190\}$ GeV

- volle Simulation der Generatordaten
  ~ 36 000 Ereignisse/Masse @ 0.86 fb-1

- volle Simulation der selbst generierten Daten für 7 Top Massen läuft zur Zeit im Grid, ca. 50k Ereignisse für jede Masse schon simuliert, noch ausstehend: Rekonstruktion

Forthcoming work: ISR, FSR & PDF

- ISR affects the (transverse) momentum of the initial partons
  - ⇒ Systematic impact on $<L_{xy}>$ of the B-hadrons
- FSR affects the (transverse) momentum of the Top-quarks, the b-quarks or the subsequent B-hadrons
  - ⇒ Systematic impact on $<L_{xy}>$ of the B-hadrons
- ISR & FSR are expected to be the most significant impacts on the uncertainty of $<L_{xy}>$



- PDF affects the (transverse) momentum of the initial partons
  - ⇒ Systematic impact on $<L_{xy}>$ of the B-hadrons

Outlook - Efforts within ATLAS Top WG

- Auspicious work of german groups on Top-quark mass analysis within the ATLAS Top-quark physics working group
- ATLAS publication on Top-quark mass analysis, CSC note T9:

ATLAS NOTE

ATL-PHYS-PUB-2006-000

August 28, 2007

Top quark mass measurement with ATLAS (CSC-note T9/V0)

Thank you!

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Thank you!