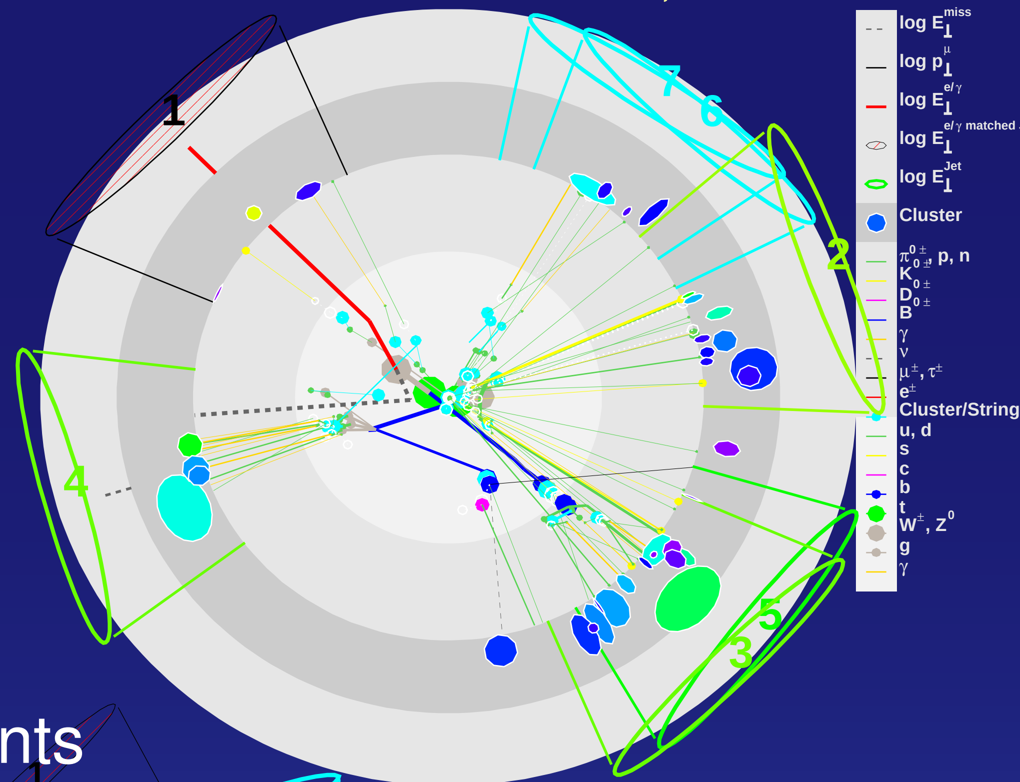
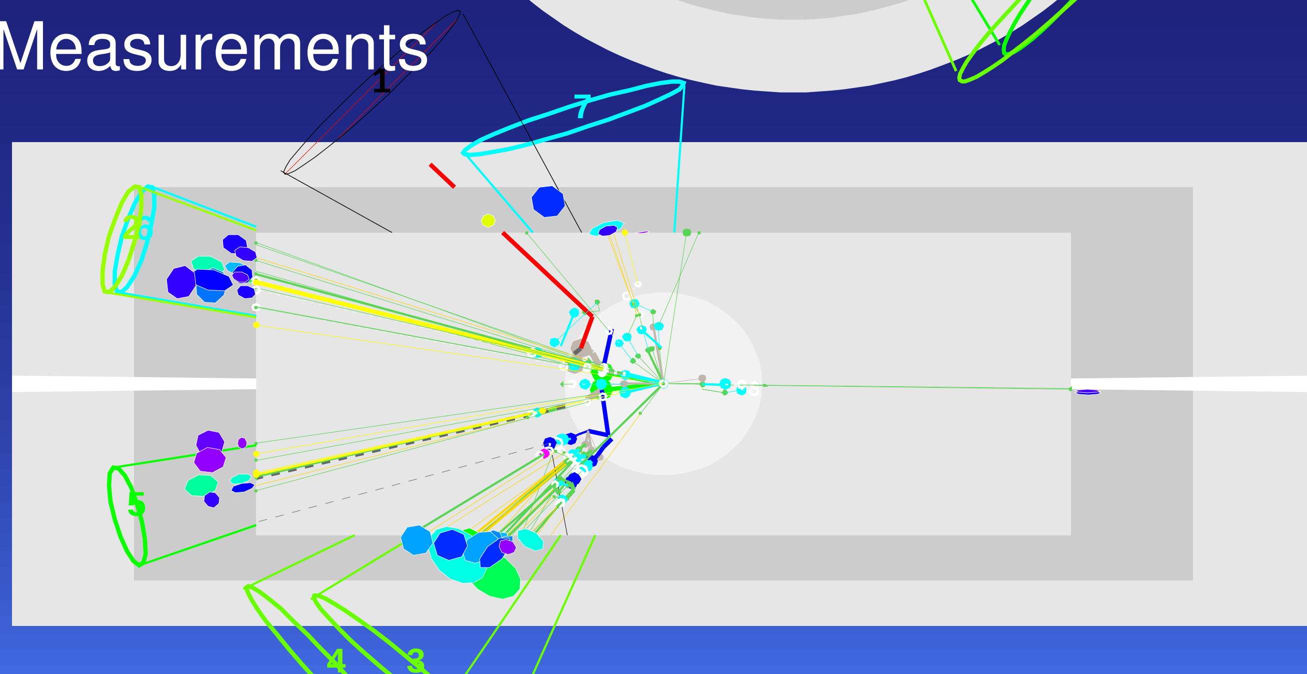
Top Group Activities

Atlas Meeting Sven Menke, MPI München 10. Mar 2008, MPI München



- ► Introduction
  - $t\bar{t}$ events @ 14 TeV
- ► top pair reconstruction
  - b-tagging
  - jet reconstruction
- ► Top-Mass Measurements
  - semi-leptonic channel
  - all hadronic channel
  - jet energy scale
- ► $t\bar{t}$ Cross section Measurements
  - semi-leptonic channel
- ► Conclusions



t production at hadron colliders

- with a mass of $(170.9 \pm 1.1_{\mathrm{stat}} \pm 1.5_{\mathrm{syst}})$ GeV [arXiv:hep-ex/0703034v1] the t-quark is the heaviest known elementary particle.

- its weight is closest to Tungsten (171.3 GeV) – not quite Gold, but . . .

	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	1 II
Sc um 910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zi 65
Y um 585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybd. 95.94	43 Tc Technet. (97.907216)	44 Ru Ruthen. 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cadı 112
1 a- s	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tu…en 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Mer 20(
03 des	104 Rf Rutherford. (261.10877)	105 Db Dubnium (262.1141)	106 Sg Seaborg. (263.1221)	107 Bh Bohrium (262.1246)	108 Hs Hassium (277.1498)	109 Mt Meitner. (268.1387)	110 Ds Darmstadt. [269,271]	111 [272]	

- can be produced currently only at the Tevatron
  $p\bar{p}$: $\sqrt{s} = 1.8\,\mathrm{TeV}_{\mathrm{RunI}}, 1.96\,\mathrm{TeV}_{\mathrm{RunII}}$

- and in the future at the LHC
  pp: $\sqrt{s} = 14\,\mathrm{TeV}$

- most processes at hadron colliders are described by a factorization ansatz:

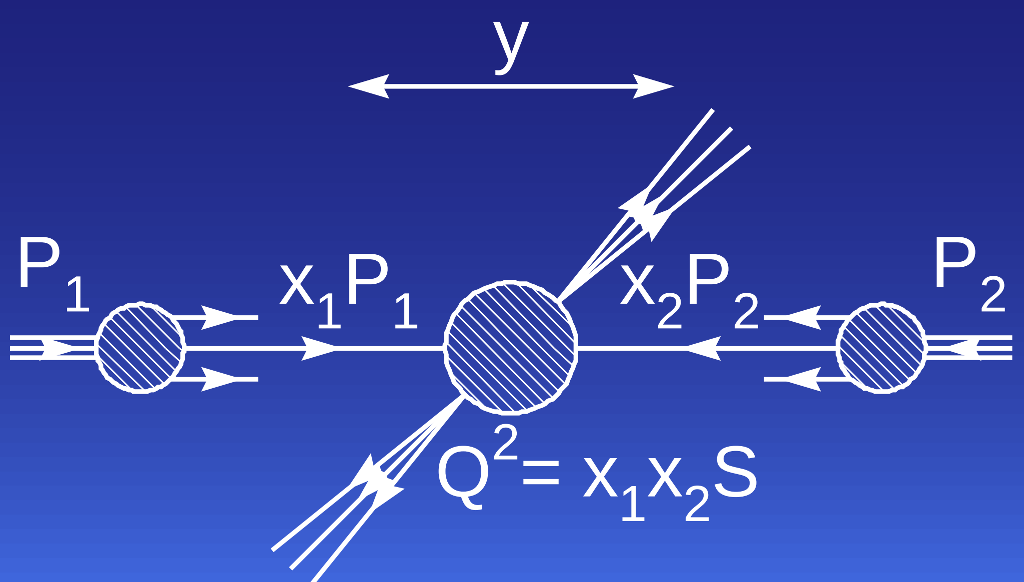
$$\sigma_{\mathrm{pp}(\bar{\mathrm{p}})\to X} = \sum_{i,j} \int \mathrm{d}x_i \mathrm{d}x_j f_i(x_i) f_j(x_j) \sigma_{ij\to X}$$

  - the total cross section σ to produce X in hadron collisions is given by the convolution of the parton distribution functions (PDF) $f_i(x_i)$ with the parton cross section σ_{ij}
  - the PDF $f_i(x_i)$ describe the probability to find parton i with a fraction x_i of the proton momentum
  - to produce the final state X the center of mass frame of the two partons is relevant:

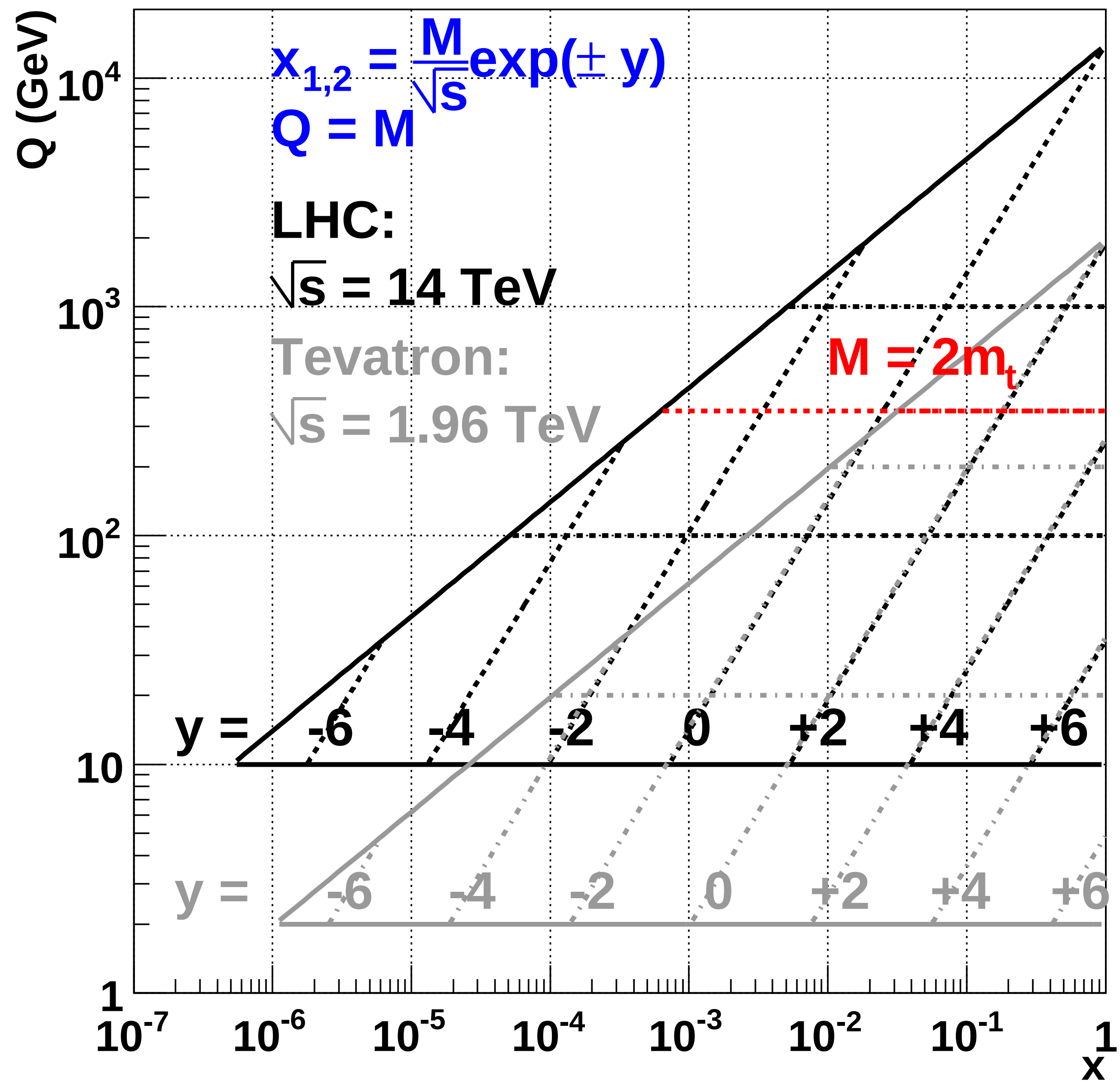
$$Q^2 = x_1 x_2 S$$

  - the final state X moves with the rapidity y:

$$y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z} \right)$$



- Q vs. $x_{1,2}$ for Tevatron and LHC
- red curve shows top-pair production

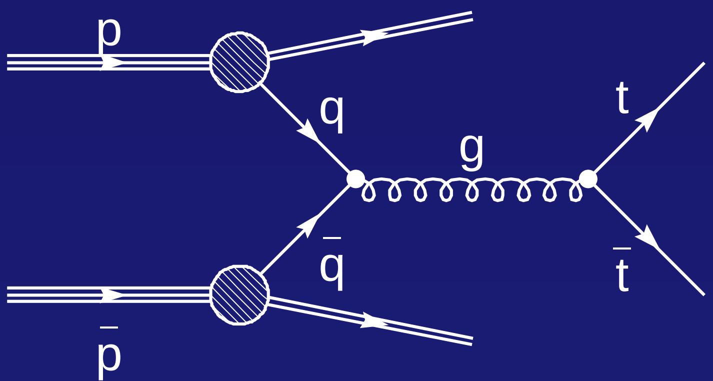


t-production at hadron colliders ► $t\bar{t}$ production

- The LO processes for $t\bar{t}$ production in $p\bar{p}$ collisions (for pp just exchange the $\bar{p}$ with a p)

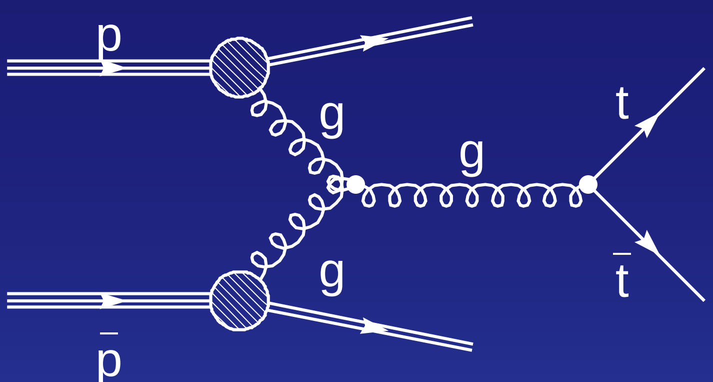
- $q\bar{q}$ annihilation

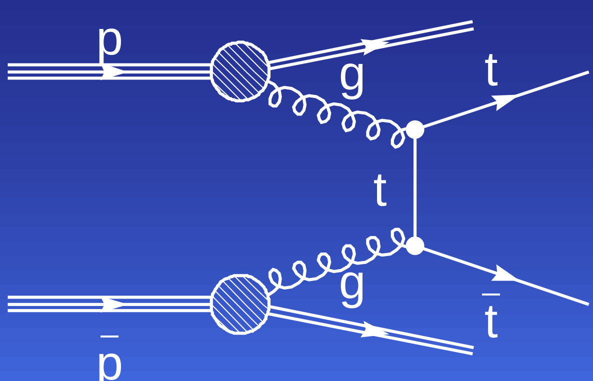
$\sqrt{s}$	$\sigma_{q\bar{q}\to t\bar{t}}/\sigma_{t\bar{t}}$
1.8 TeV	90 %
1.96 TeV	85 %
14 TeV	5 %

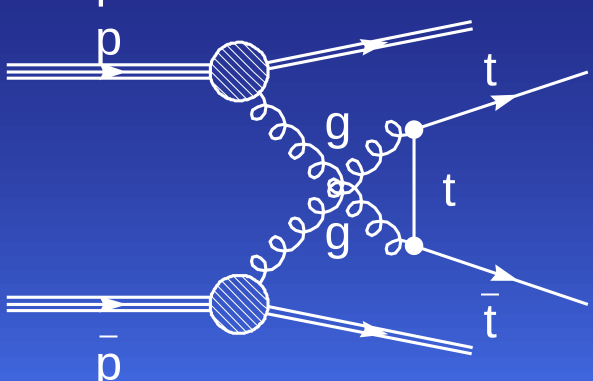


- gluon fusion

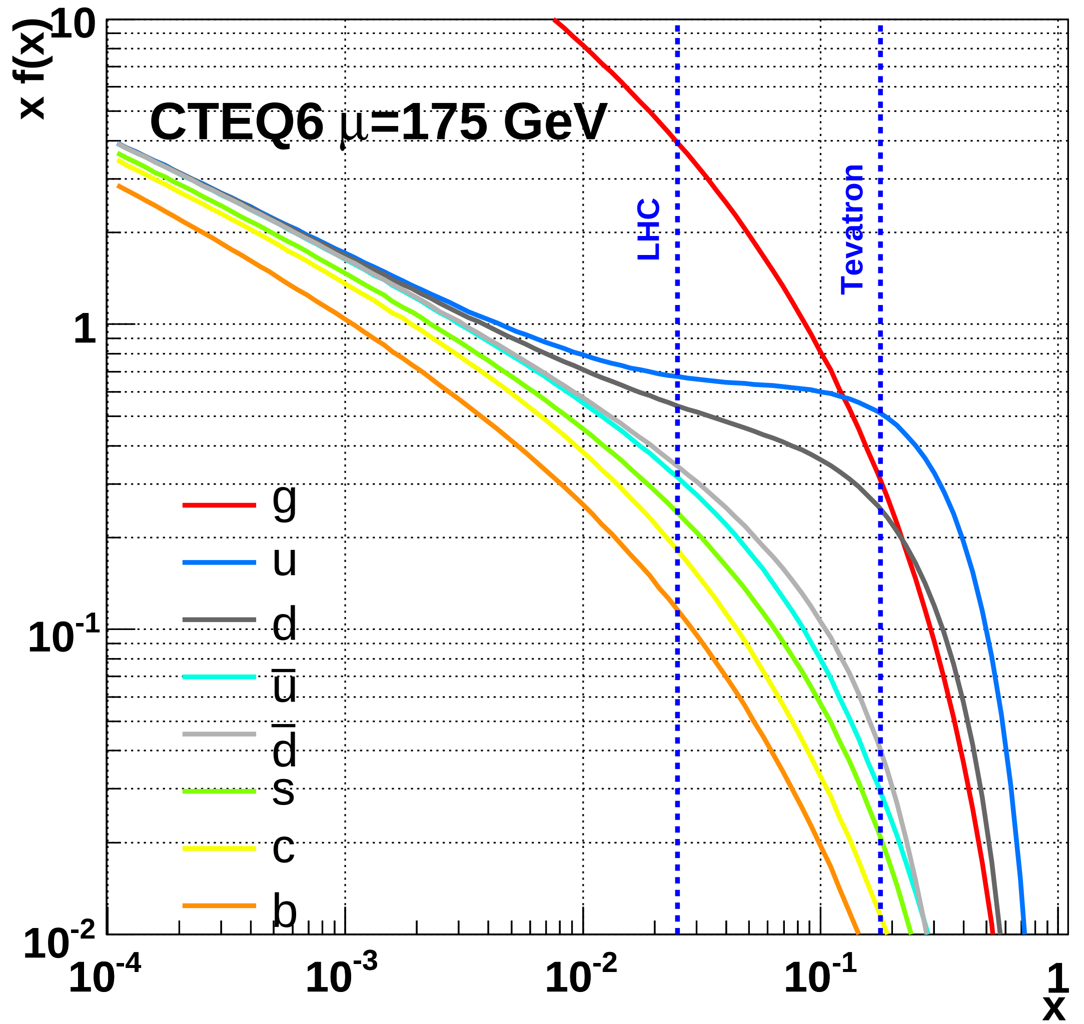
$\sqrt{s}$	$\sigma_{gg\to t\bar{t}}/\sigma_{t\bar{t}}$
1.8 TeV	10 %
1.96 TeV	15 %
14 TeV	95 %



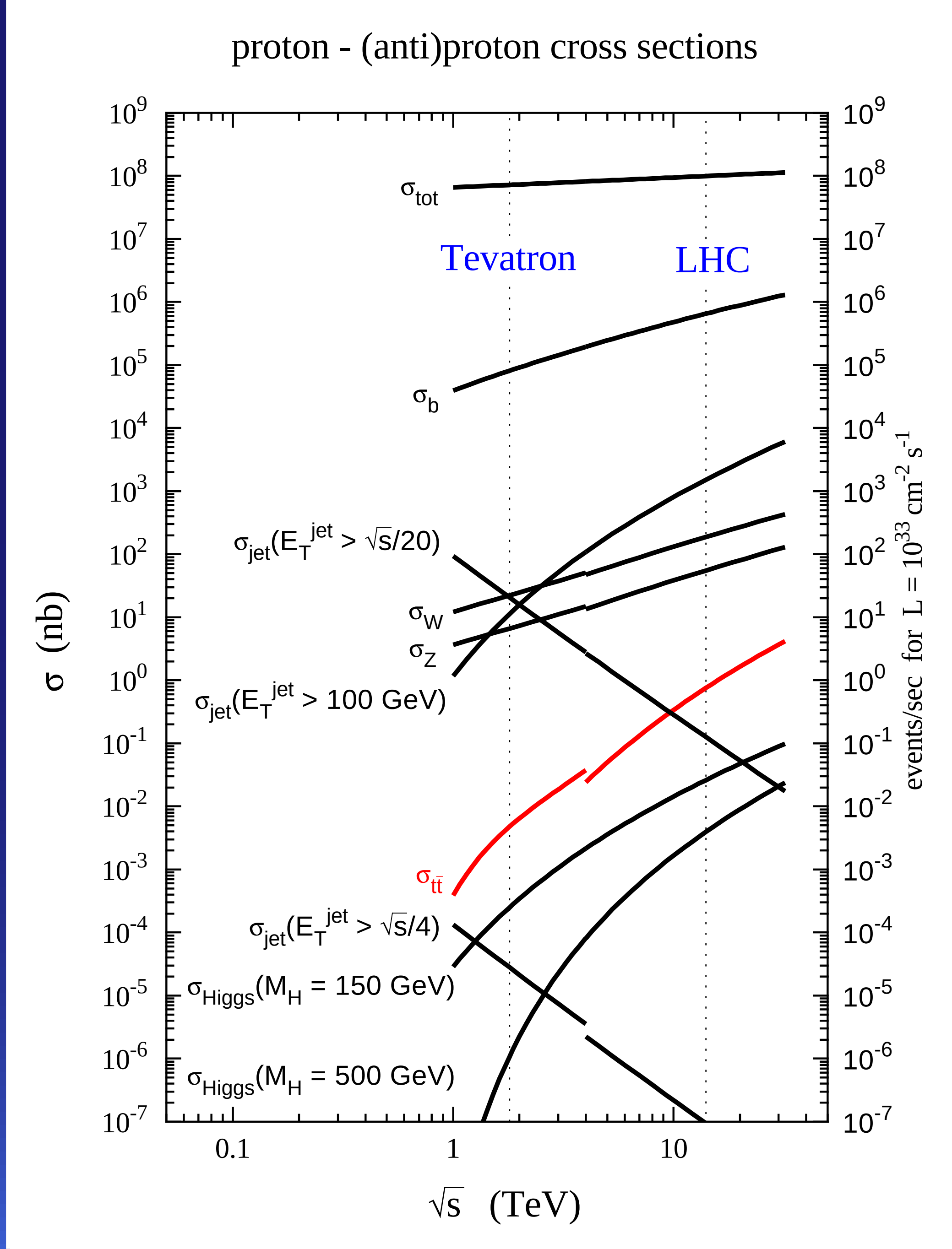




- $\sqrt{x_1 x_2 S} = 2m_t$
- assume
  $$x_1 \simeq x_2 = x = \frac{2m_t}{\sqrt{S}}$$
- $x_{\text{Tevatron}} = 0.18$
- $x_{\text{LHC}} = 0.025$
- you need antiprotons for antiquarks at large x at Tevatron (dominant production through $q\bar{q}$)
- protons are just fine for plenty of gluons at small x at LHC (dominant production through gg)



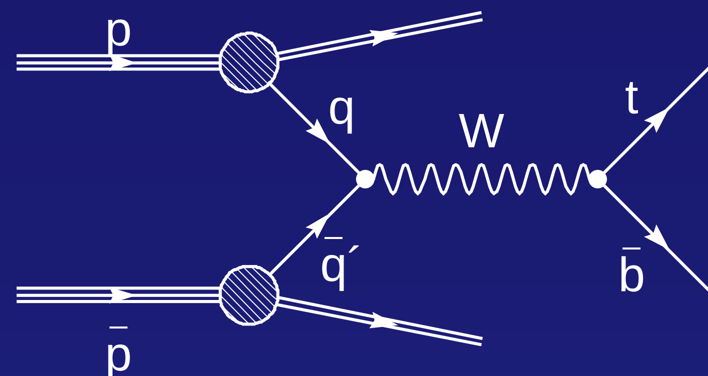
- parton level cross sections have similar magnitude for Tevatron and LHC
- $x\,f(x)$ is about a factor of 10 larger for $t\bar{t}$-production at the LHC
- total cross section for $t\bar{t}$-production is about a factor of 100 larger at LHC
- $\sigma_{t\bar{t}}(1.80\,\text{TeV}) = 5\,\text{pb}$
- $\sigma_{t\bar{t}}(1.96\,\text{TeV}) = 7\,\text{pb}$
- $\sigma_{t\bar{t}}(14.0\,\text{TeV}) = 800\,\text{pb}$



W.J. Stirling, 1998

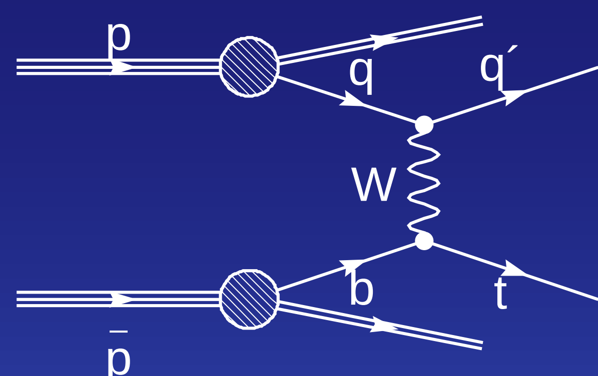
- The LO processes for e.w. single t production in $p\bar{p}$ and pp collisions (2 upper graphs)
- Total cross section for single top production surprisingly large ($\simeq 40\,\%$ of $\sigma_{t\bar{t}}$)
- s-channel

$\sqrt{s}$	$\sigma_{\mathrm{EWs}}/\sigma_{\mathrm{single\ t}}$
1.8 TeV	35 %
1.96 TeV	30 %
14 TeV	3 %



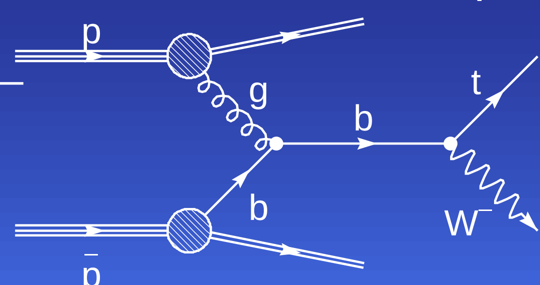
- t-channel

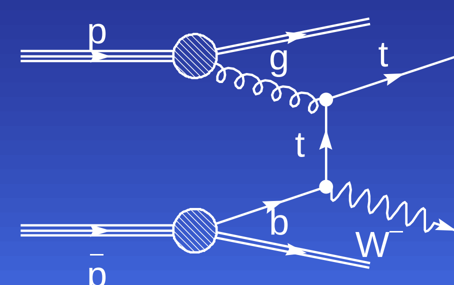
$\sqrt{s}$	$\sigma_{\mathrm{EWt}}/\sigma_{\mathrm{single\ t}}$
1.8 TeV	60 %
1.96 TeV	65 %
14 TeV	77 %



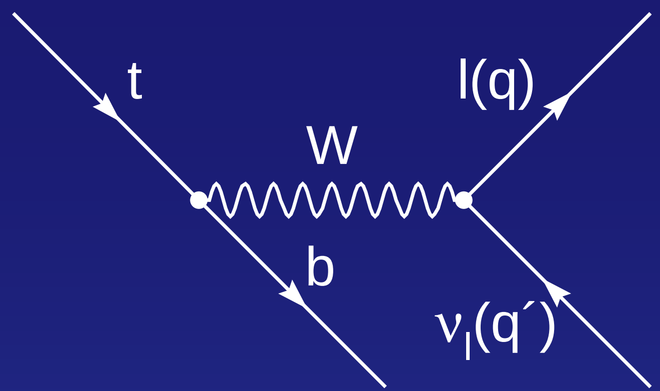
- Wt prod.

$\sqrt{s}$	$\sigma_{\mathrm{Wt}}/\sigma_{\mathrm{single\ t}}$
1.8 TeV	5 %
1.96 TeV	5 %
14 TeV	20 %





- $\Gamma_{\mathrm{t}} \simeq 1.4\,\mathrm{GeV} > \Lambda_{\mathrm{QCD}}$
  - $\tau_{\mathrm{t}} \simeq 0.46\,10^{-24}\,\mathrm{s}$
  - the top decays before it can interact via QCD
  - no top-mesons
- $m_{\mathrm{t}} > m_{\mathrm{W}} + m_{\mathrm{b}}$
  - only 2-body decays into real W and quark



- $0.9990 < V_{\mathrm{tb}} < 0.9993$
  - $> 99.8\,\%$ of top decays are $\mathrm{t} \rightarrow \mathrm{Wb}$
- W decays characterize the experimental channel:
  - $\mathrm{t} \rightarrow \mathrm{bW} \rightarrow \mathrm{bqq}'$: ‘jets‘ (2/3 of all decays)
  - $\mathrm{t} \rightarrow \mathrm{bW} \rightarrow \mathrm{b}\ell\nu_{\ell}$: ‘lepton+jets‘ (2/9 of all decays for $\ell = \mathrm{e}, \mu$; 1/9 decay to $\mathrm{b}\tau\nu_{\tau}$)

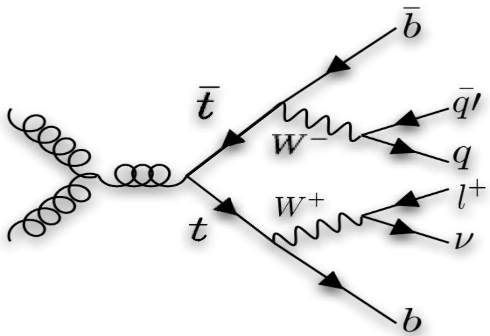
t-analyses @ MPI

- SCT and HEC groups joined for top analyses
- PhD students analyses:
- $t\bar{t}$ cross section measurement
  - Andrea Bangert (semi-leptonic channel, trigger studies)
  - Sophie Pataraia (semi-leptonic channel, b-tagging studies)
- t-mass measurement
  - Roland Härtel (semi-leptonic channel, jet algo studies)
  - Andreas Jantsch (semi-leptonic channel, jet energy calibration refinement)
  - Paola Giovannini (all-hadronic channel, jet energy calibration refinement)
  - Tobias Göttfert (semi-leptonic channel, jet algo studies)
  - Emanuel Rauter (semi-leptonic channel, calorimeter comissioning)
- PostDocs and staff working on top:
- $t\bar{t}$ cross section measurement
  - Anna Macchiolo (semi-leptonic channel, trigger studies)
- t-mass
  - Teresa Barillari (semi-leptonic channel, in-situ corrections)
- support, guidance, occasional work on top
  - Stefan Kluth
  - Sven Menke
  - Richard Nisius
  - Horst Oberlack
  - Peter Schacht
  - Jochen Schieck
- of course this is all part of the ATLAS top group

- Event Selection
- Semileptonic Channel
  - exactly one isolated electron or muon with
    - $p_\perp > 20$ GeV, $|\eta| < 2.5$, $E_{\Delta R=0.2} < 6$ GeV
    - muons are reconstructed with `Staco`; electrons with `eGamma` and `isEM == 0`
    - exclude crack region $1.375 < |\eta| < 1.52$
  - At least 4 high energetic jets with
    - $|\eta| < 2.5$
    - $\Delta R(\text{jet, electron}) > 0.4$
    - $p_\perp > 40$ GeV for first three jets
    - $p_\perp > 20$ GeV for fourth jet
    - b-tags under study but not required for selection
  - $\not{E}_\perp > 20$ GeV
- All-Hadronic Channel
  - no isolated electron or muon with
    - $p_\perp > 20$ GeV, $|\eta| < 2.5$, $E_{\Delta R=0.2} < 6$ GeV
  - At least 6 high energetic jets with
    - $|\eta| < 2.5$
    - $\Delta R(\text{jet, loose electron}) > 0.2 \vee E_{\text{jet}} > 2E_{\text{electron}}$
  - $\not{E}_\perp < 20$ GeV

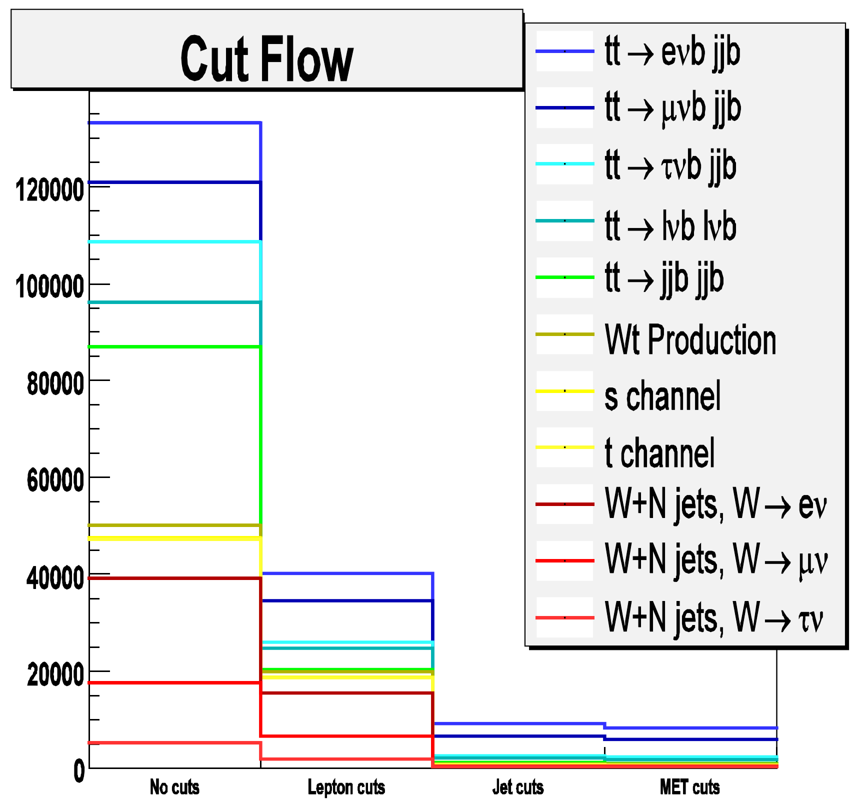
Cut Flow Semileptonic Channel

A. Bangert



Event Selection

- Commissioning Analysis Cuts.
  - **Exactly one e or μ.**
    - Central
    - Isolated
    - Highly energetic.
  - **At least four jets.**
    - Central
    - Highly energetic.
  - No b-tagging.
  - **MET > 20 GeV.**
- **Before cuts S/B = 0.16**
- **After cuts S/B = 1.56**



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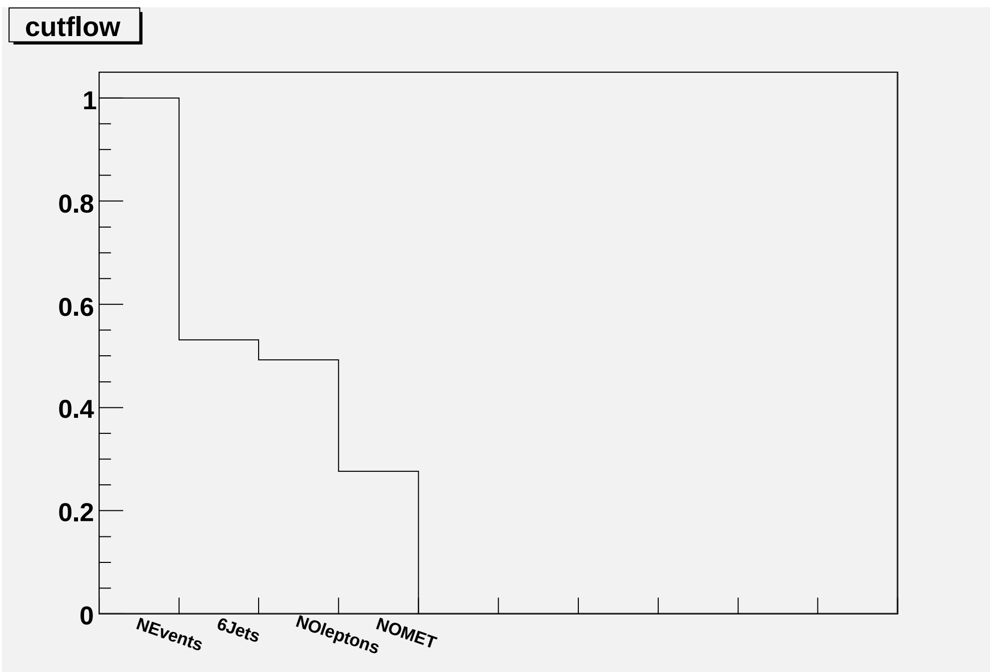
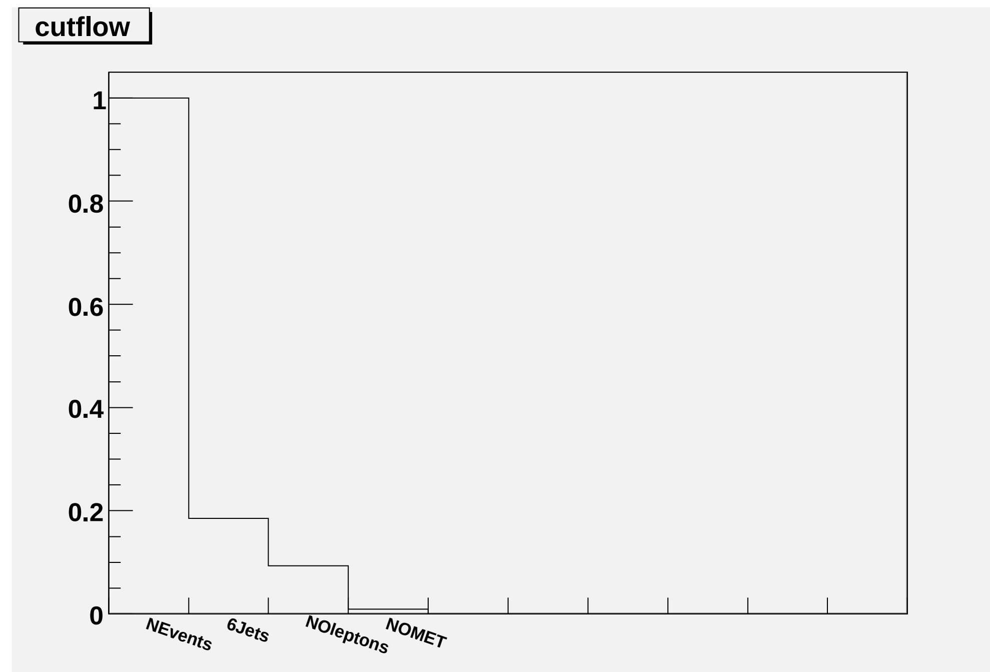
Cut Flow All-Hadronic Channel

P. Giovannini

all-hadronic signal events (5204)

semileptonic background events (5200)





Combination of hadronic jets

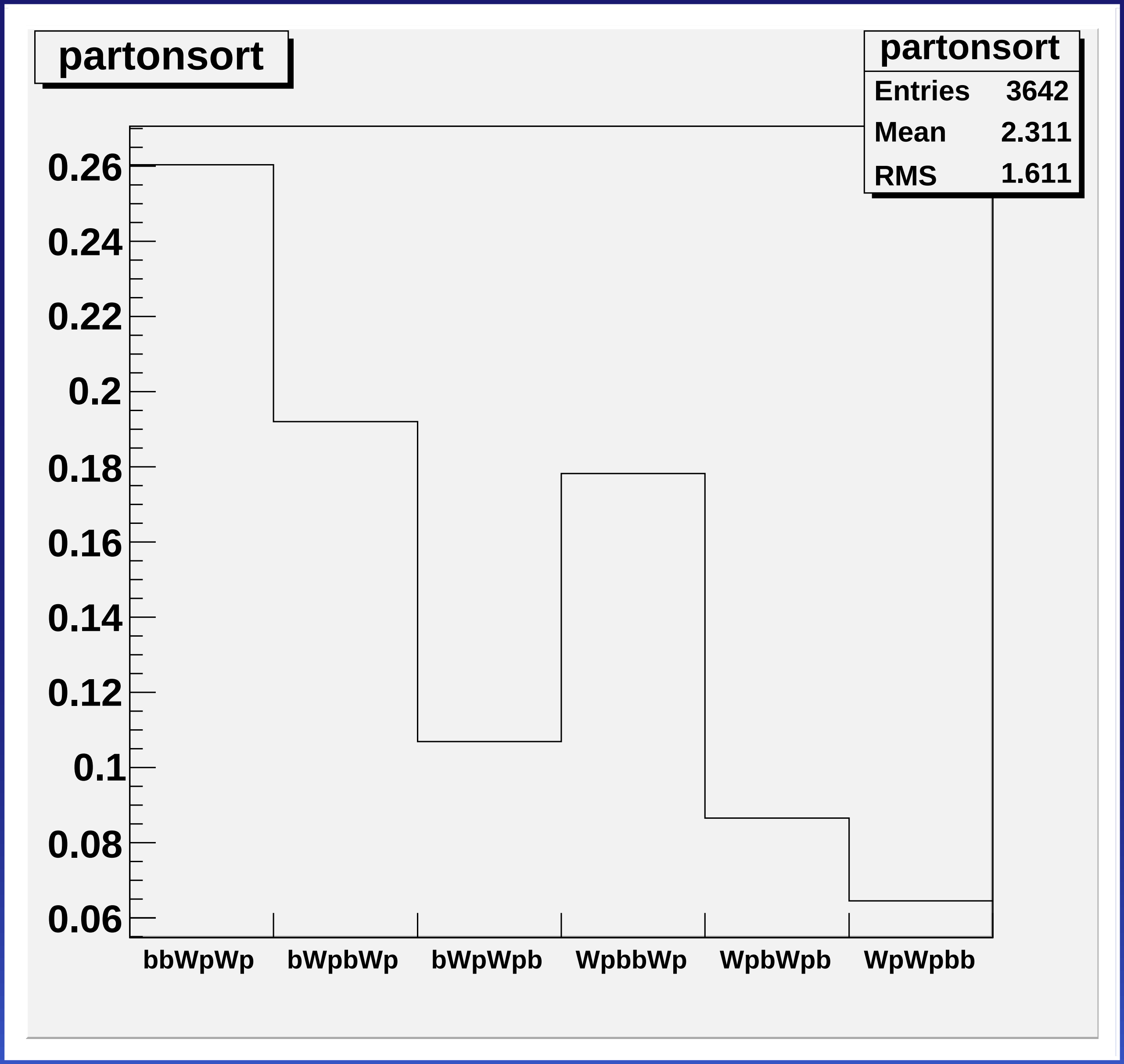
- in early data the most robust selection schemes are those without b-tagging
- try to use topological motivated combinations of jets
- Semi-leptonic channel:
- With 4 jets there are 4 ways to select the hadronic t and 12 to select hadronic W and t
- maximum $p_{\perp}$
  - call the three jets which form the largest $p_{\perp}$ for the composite object the top
    ► motivated by the fact that both tops are roughly back-to-back in the transverse plane and the leading daughter jet is the b-jet
- $p_{\perp}$-balance
  - select the three jets which lead to the smallest $\Delta|p_{\perp}|$ between the leptonic and hadronic top as hadronic top
    ► motivated by the fact that to leading order the $p_{\perp}$ of the $t\bar{t}$-system is 0.

Combination of hadronic jets

- W constituents
  - select the jet-pair closest in ΔR as W and apply one of the above methods to select the b
    - motivated by relatively low mass of the W and 2-body decay of the top
- W-mass constraint
  - select the jet-pair giving the closest mass to the PDG mass value of the W
    - should not be used as the jet energy scale uncertainty is too large in early data; unfortunately this method is very popular in other top groups ...
- $p_\perp$ ordering
  - call the 2 leading jets in $p_\perp$ the b-jets and assign the next two according to $p_\perp$-balance or maximum method
    - again motivated from the 2-body decay nature of the top
- All-hadronic channel:
- With 6 jets there are 20 ways to select 2 tops with 3 jets and 180 to select both tops and identify 2 W's
- strategy is similar to semileptonic channel but more challenging due to larger combinatorics

$p_\perp$ ordering of partons in the semi-leptonic channel

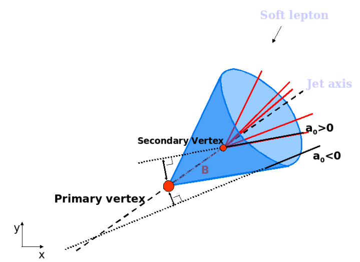
E. Rauter



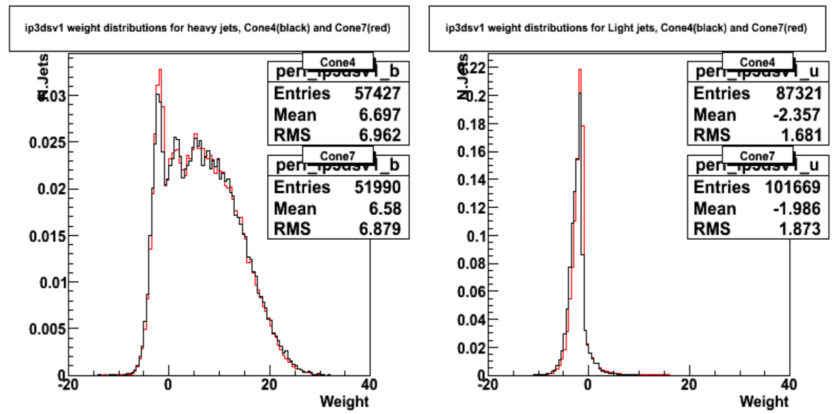
b Tagging studies

S. Pataraia

Heavy flavour tagging



Lifetime of B hadrons: $c\tau \sim 470 - 390\mu m$,
Flight length $\sim$ 5mm, for $E \sim$ 50 GeV.
Pixels and mostly b-layer are crucial.



IP3D+SV1 recommended b-tagger.

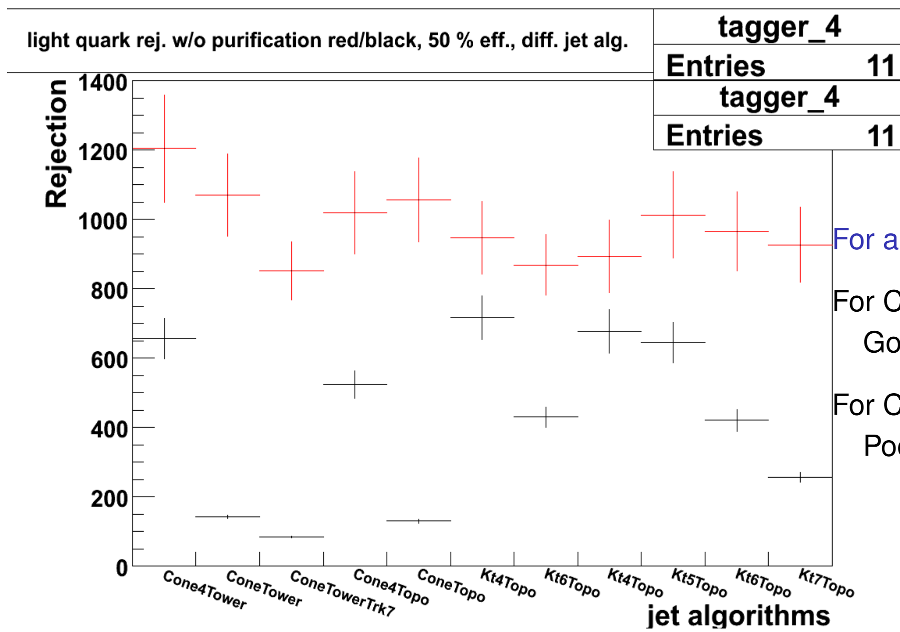
Combines in likelihood:

secondary vertex information,

distributions of track impact parameters.

Weight distributions for heavy and light flavour jets, reconstructed with Cone4(black) and Cone7(red) algorithms.

Performance studies



For all jet collections $\varepsilon_b = 50\%$;

For Cone4 and k_T, $D = 0.4$ jets,
Good performance (R_light $\sim$ 650);

For Cone7 and k_T, $D = 0.7$ jets,
Poor performance (R_light $\sim$ 200.)

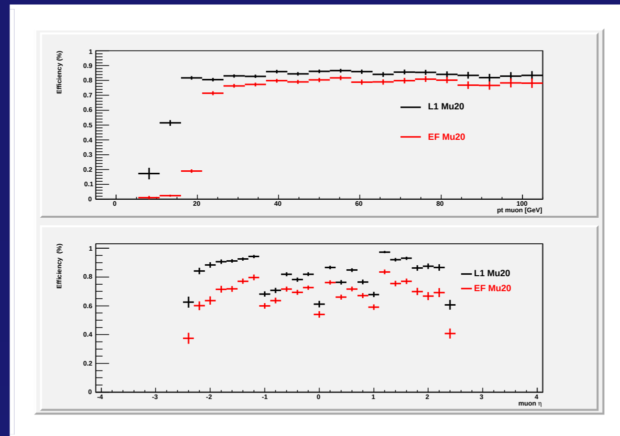
- red with light jet purification (removal of jets close to heavy jets), black without
- b-tagging is tuned for narrow jets ($\triangle R = 0.4$)
- bad performance of large jets stems mainly from low energetic jets

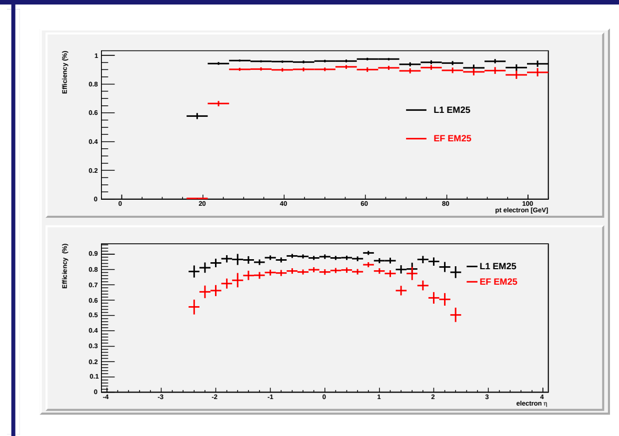
We tried to tune the track to jet association cone size. Third bin shows results for Cone7Tower jets when the track to jet association cone size was increased from default cone4 to cone7.

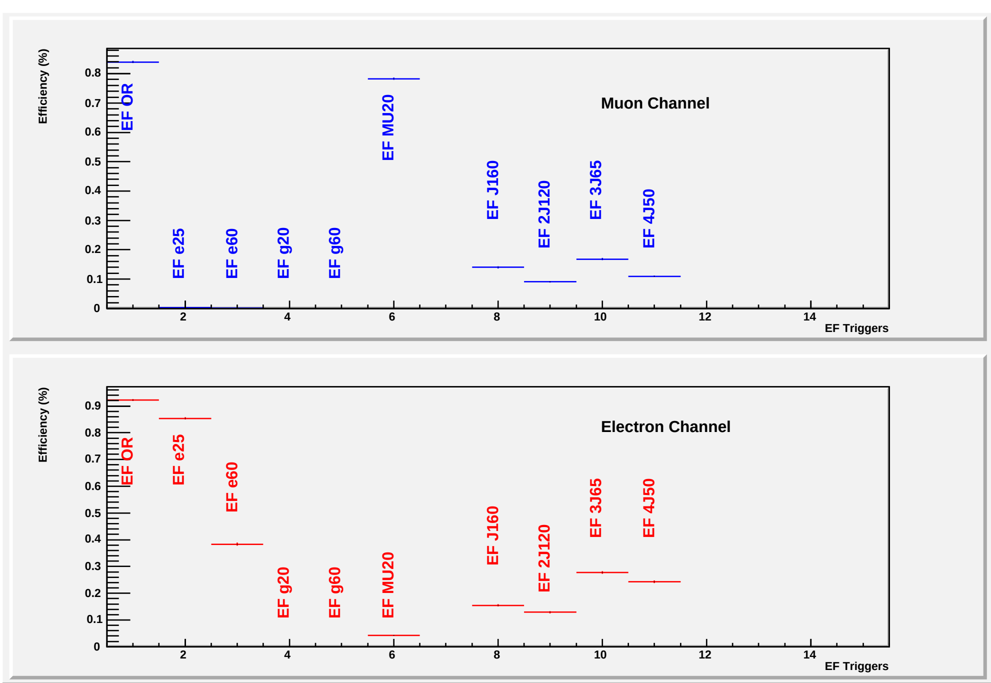
Trigger Efficiency studies

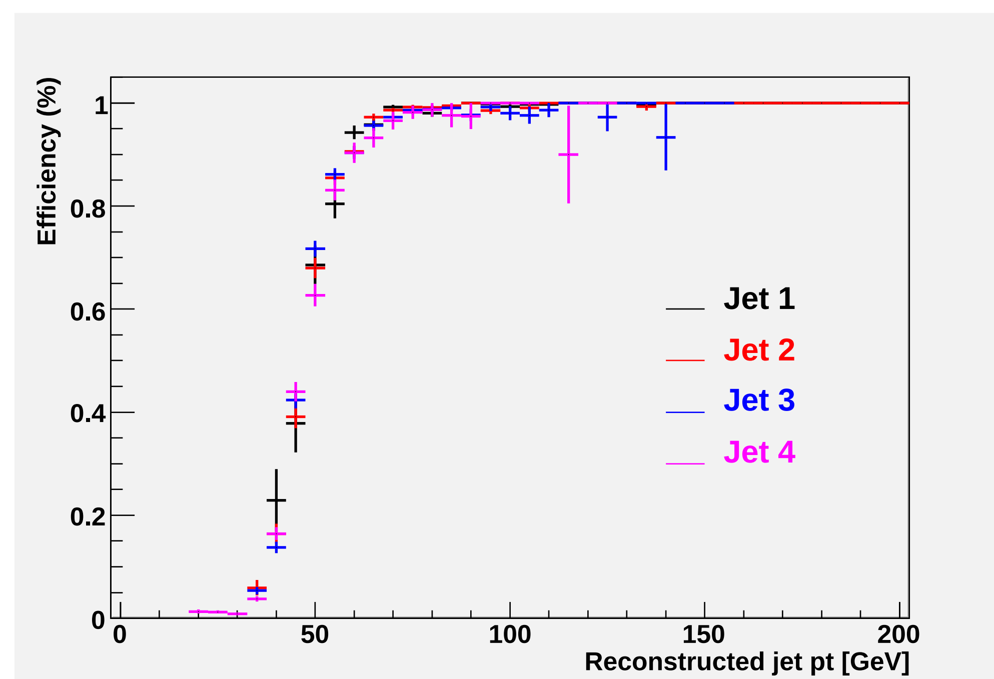
A. Macchiolo

- all plots are made on semileptonic $t\bar{t}$ events
- μ-trigger efficiency has deep dips in cracks and central barrel
- electron trigger more smooth
- both fall of towards the endcap region and show lower response compared to L1 accept rate (why?)
- some events can be recovered by the jet trigger
  - but with higher combined systematic error





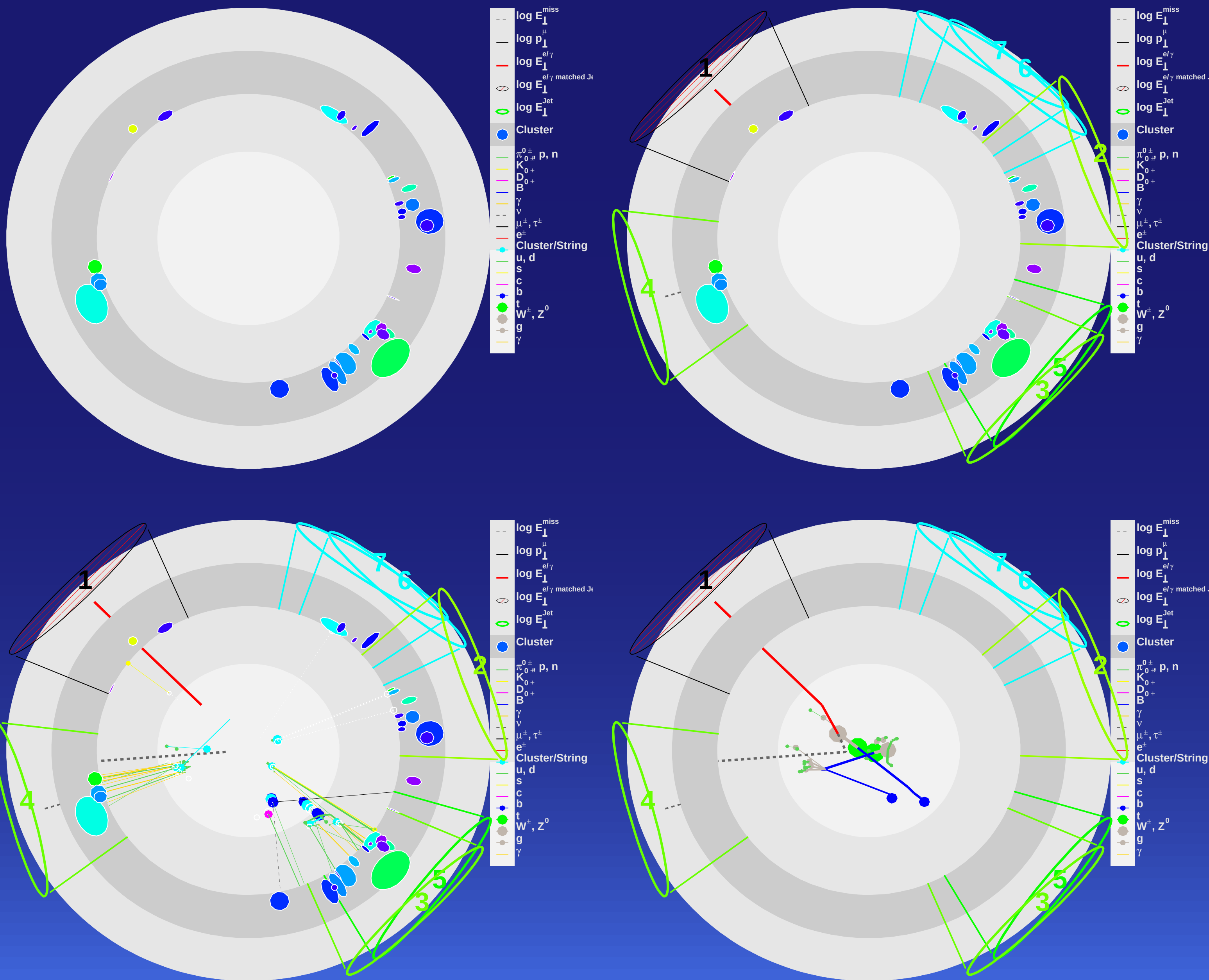




Jet Energy Scale

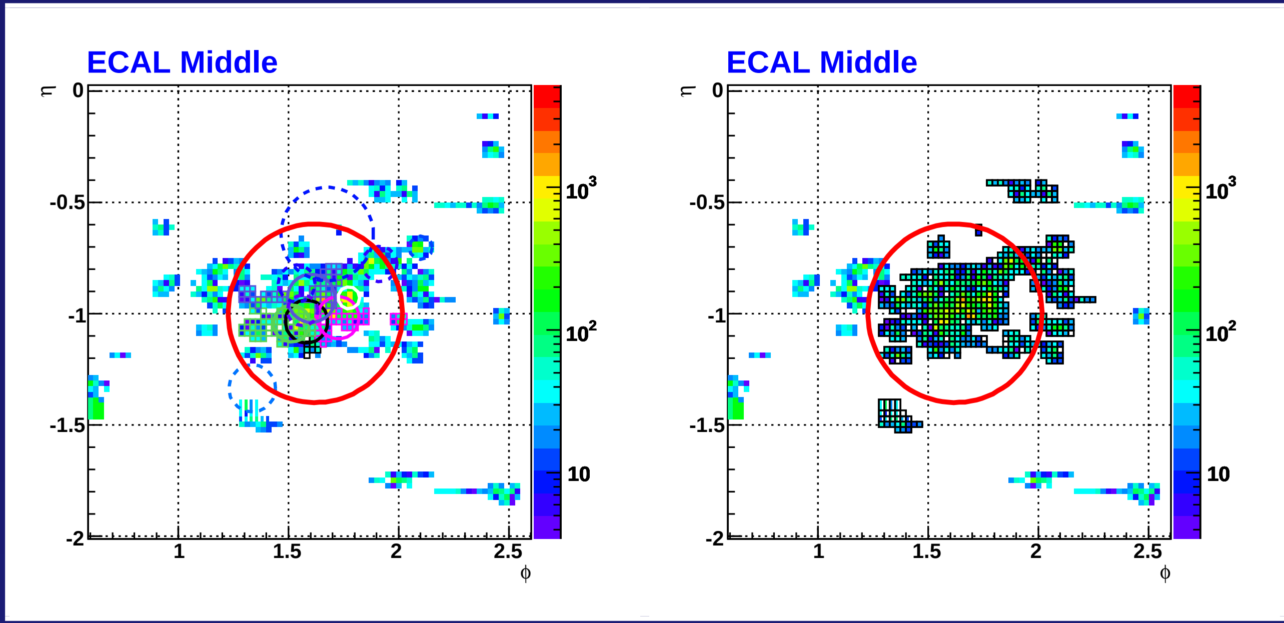
- Jet energy calibration can be divided in 4 steps

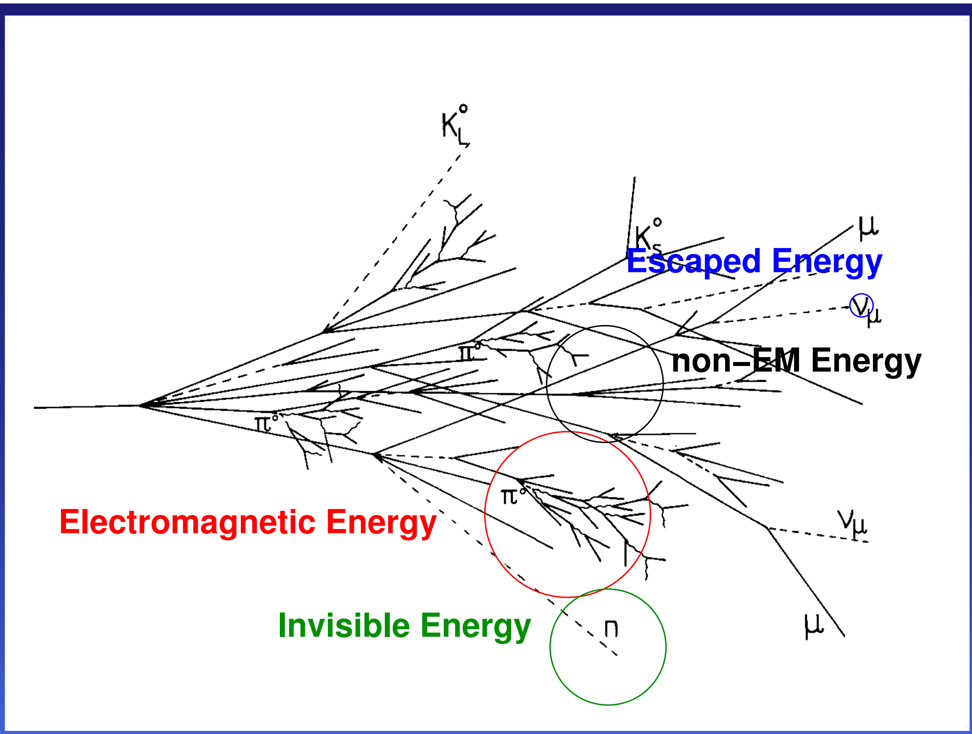
1. calorimeter tower/cluster reconstruction
2. jet making
3. jet calibration from calorimeter to particle scale
4. jet calibration from particle scale to the parton scale



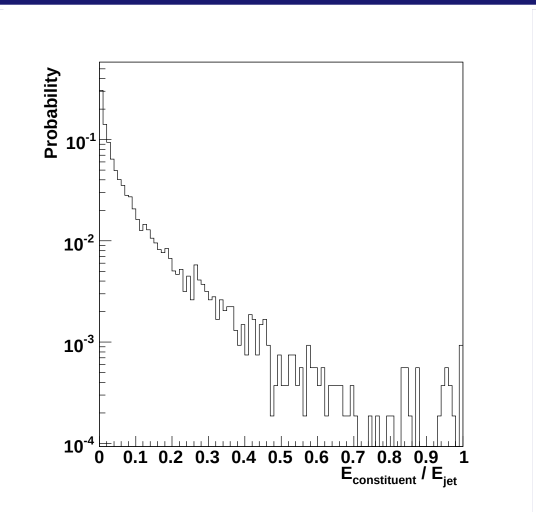
Jet Energy Scale

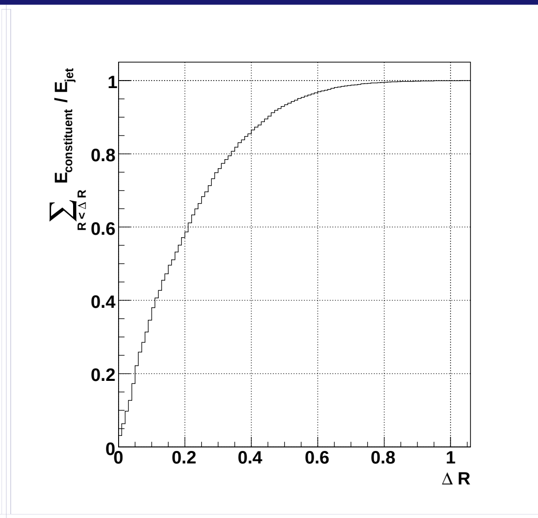
- **Calorimeter Cluster Reconstruction**
  - shower containment
  - particle separation and identification
  - electronics noise
  - pile-up
- **Jet Making**
  - choice of algorithm (cone, $K_{\perp}$, ...)
  - jet size
  - overlap with electrons
- **Jet Calibration to Particle Level**
  - e/h compensation
  - dead material corrections
  - out-of-cluster corrections
  - out-of-jet corrections
- **Jet Calibration to Parton Level**
  - match to parton jet
  - differences for light-quark, b-quark, gluon-jets
  - MC dependencies

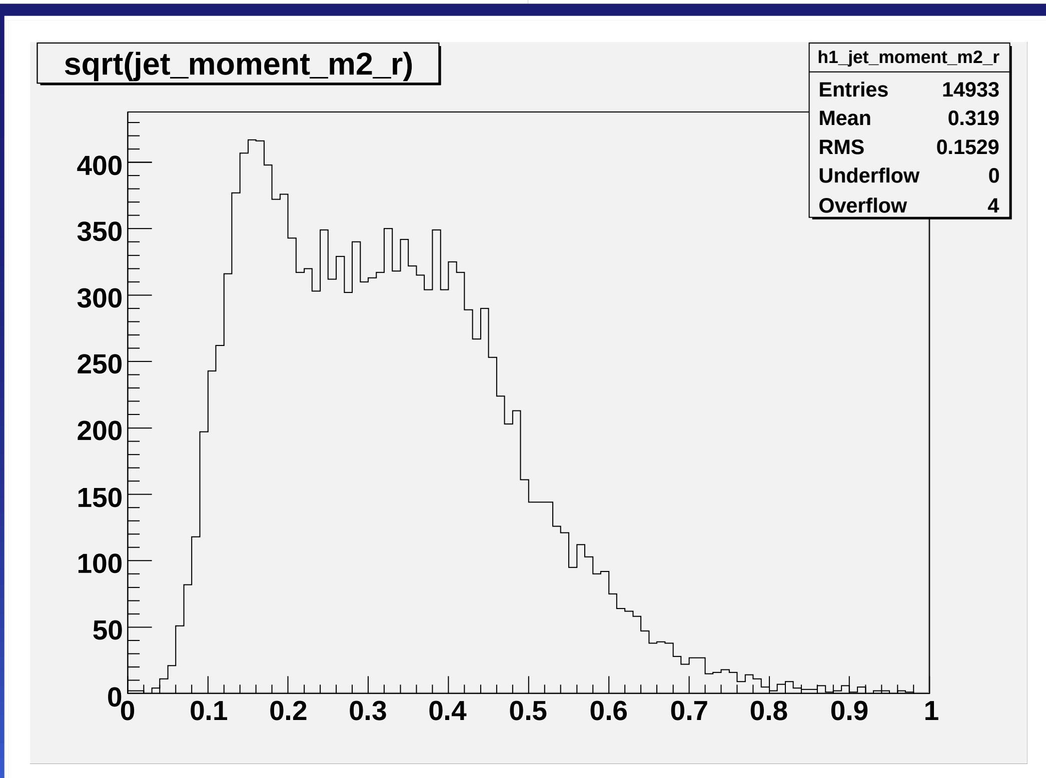




jet energy scale refinement with jet constituents







A. Jantsch, S.M.

- use jet-constituents to calculate jet-shape variables
- for example

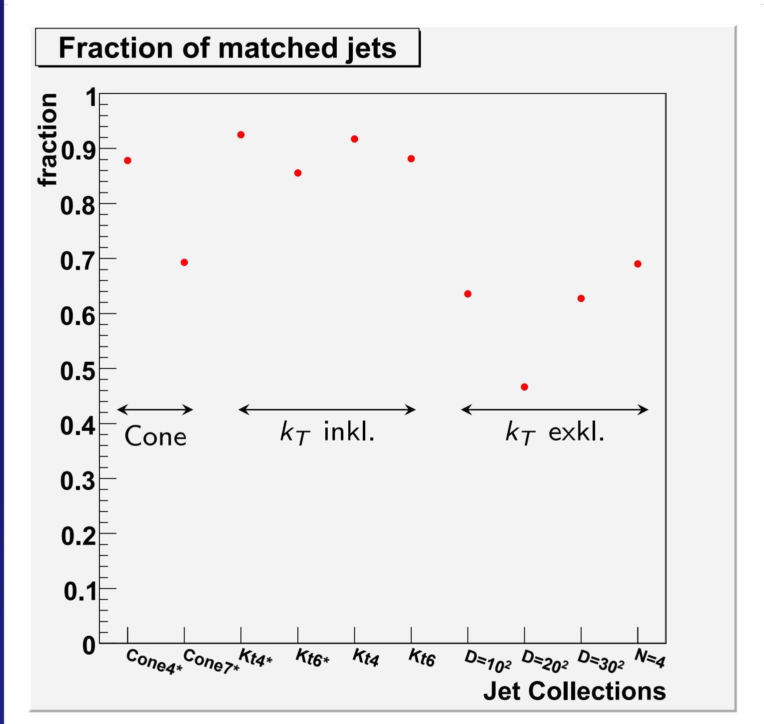
$$\langle r^2\rangle = \frac{1}{E_{\text{jet}}}\sum_{\text{cluster}} E_{\text{cluster}}\left(\left(\eta_{\text{cluster}}-\eta_{\text{jet}}\right)^2 + \left(\phi_{\text{cluster}}-\phi_{\text{jet}}\right)^2\right)$$

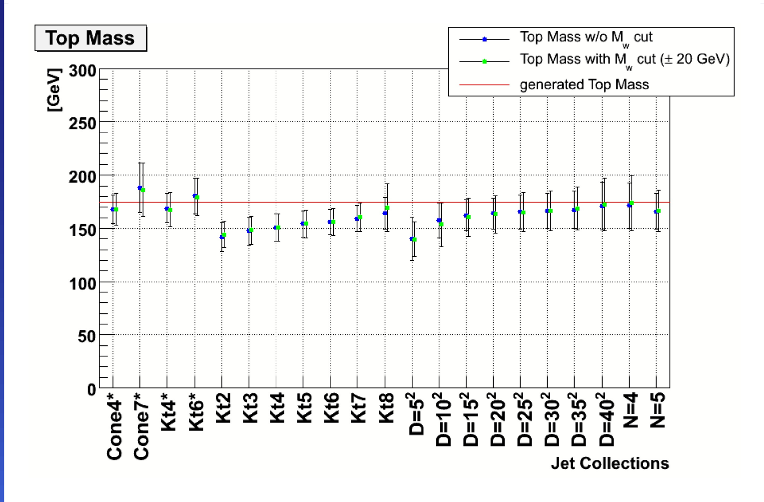
  - small $\sqrt{\langle r^2\rangle}$ values correspond to mostly electromagnetic jets
  - large $\sqrt{\langle r^2\rangle}$ values correspond to mostly hadronic jets
- look at energy flow around jet-axis
  - comparison with truth jets allows to derive out-of-jet corrections

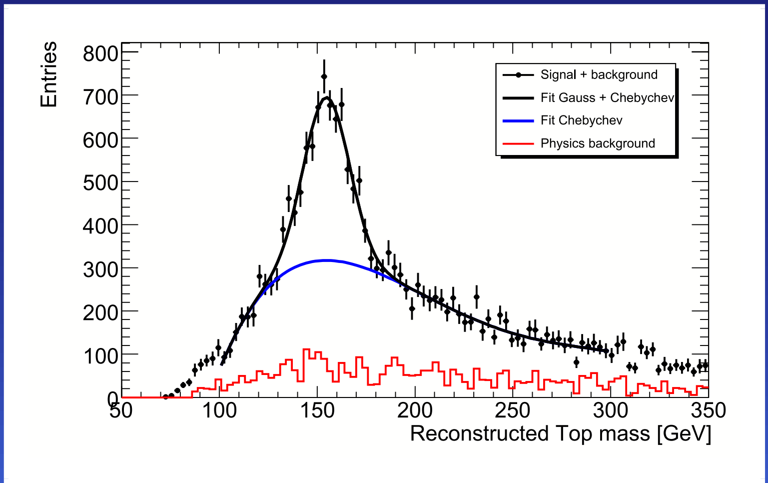
Jet Algorithm studies

T. Göttfert, R. Härtel

- matching of reconstructed with truth particle jets depends on the jet algorithm
- a good reconstructed jet has $\Delta R(\text{reco jet, truth jet}) < 0.15$ and no other truth jet has this reco jet as closest match
- mass and mass-resolution for the hadronic top depend on the jet algorithm
  - inclusive Kt algo's better than exclusive
    - probably due to $R = 1$ in exclusive mode
  - optimal size around $0.4 < R < 0.6$





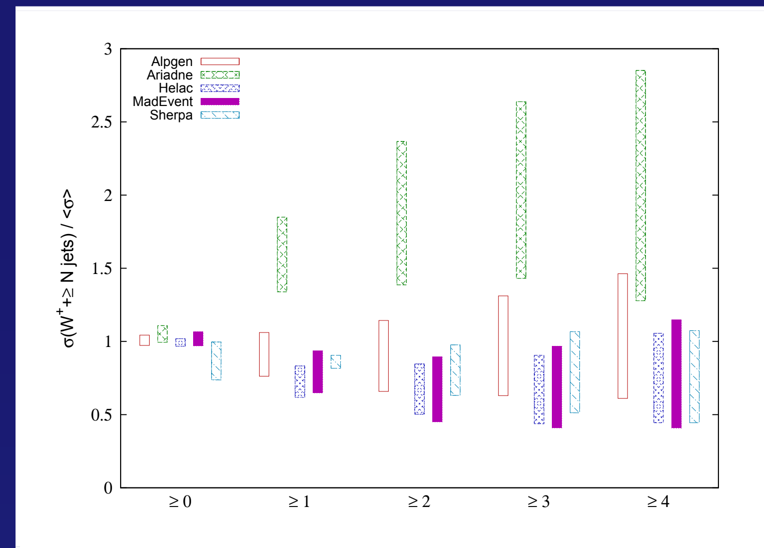


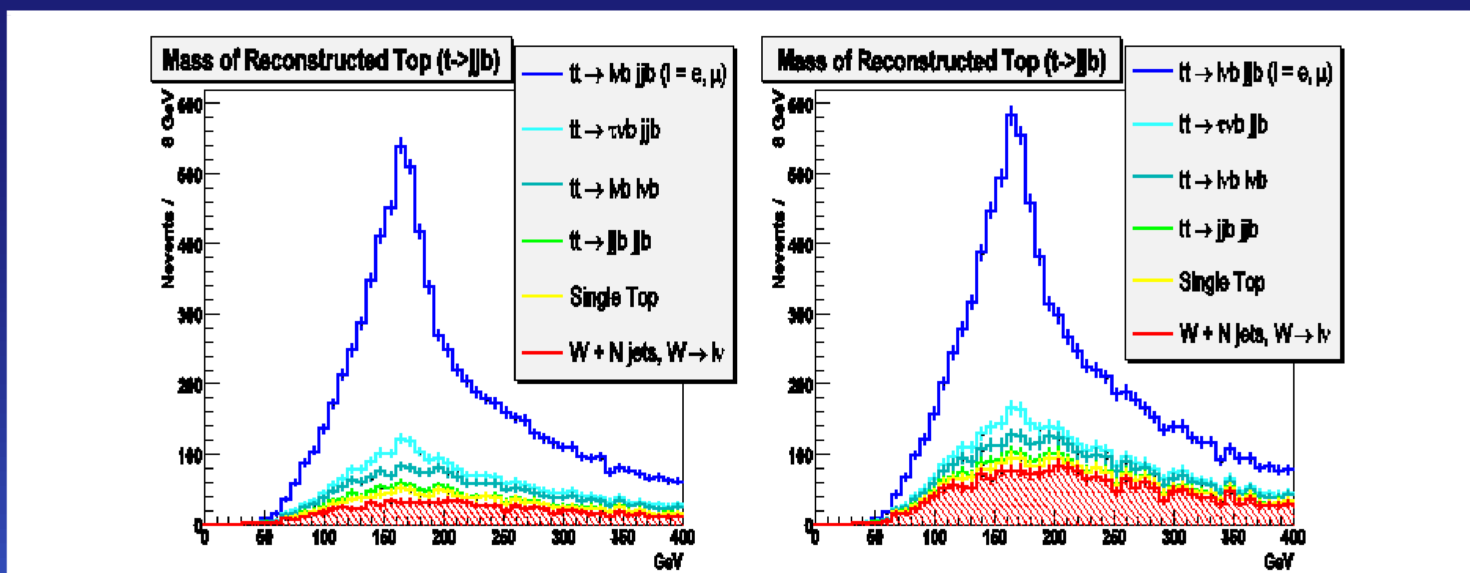
top-pair cross section measurements

A. Bangert

- $\sigma = \dfrac{N_{\mathrm{data}} - N_{\mathrm{background}}}{\epsilon_{t\bar{t}} \int \mathcal{L}\,\mathrm{d}t}$
- W + N jets most dangerous background
- systematic error on $\sigma_{W+N\,\mathrm{jets}}$ is high
- QCD multijet background will be estimated from data

J. Alwall et al., arxiv:0706.2569

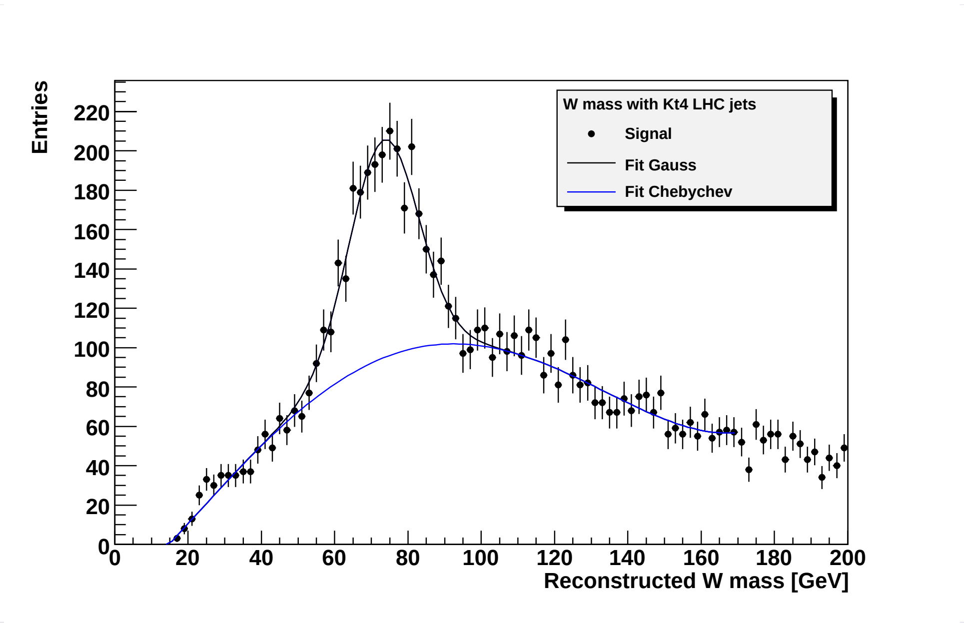


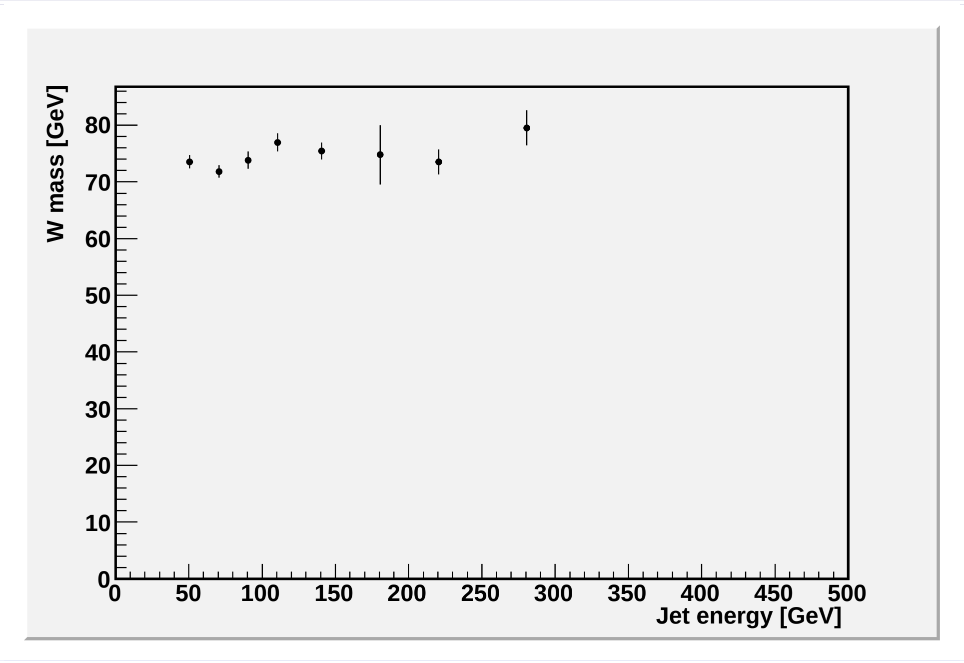


Low and high estimates of W+N jets contribution in ∫L dt = 100 pb⁻¹.

top mass measurements

T. Barillari





- W-mass can help for in-situ calibration (or in-situ check) of jet energy scale
- extract m_{jj} from di-jet combinations and histogram ratio $\alpha = m_{\mathrm{W}}^{\mathrm{PDG}} / m_{jj}$ in bins of jet-energy (jet-η)
- correct jet energies in bin i with α_i
- iterate
- need to study applicability to b-jets

Conclusions

- top is ideal to commission the subsystems we are working on
  - Calorimeters: jet energy scale and electron identification
  - Muon Chambers: muon identification
  - Inner Detector: b-tagging
- cross section measurement of top-pair production
  - only $\sim 50\%$ of the cross section are predicted in leading order
  - important number for many Higgs and BSM searches
  - $\mathrm{W} + N$ jets and multijet QCD background are a challenge
  - hope is to achieve $20 - 30\%$ uncertainty with the first $100\,\mathrm{pb}^{-1}$
- studies for top-mass measurements
  - in both the semi-leptonic and the all-hadronic channel
  - jet algorithms, jet energy scale, and topological top-reconstruction are the focus
  - will take some time to beat the 1% error from the Tevatron
  - beyond that the real fun starts:
    - what exactly do you measure when you say you measure the top-quark mass?