The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization
IAEA
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Signaling the Arrival of the LHC Era

8 - 13 December 2008

ttbar Cross Section: prospects at LHC

Marina Cobal
INFN Udine and University of Udine
Italy

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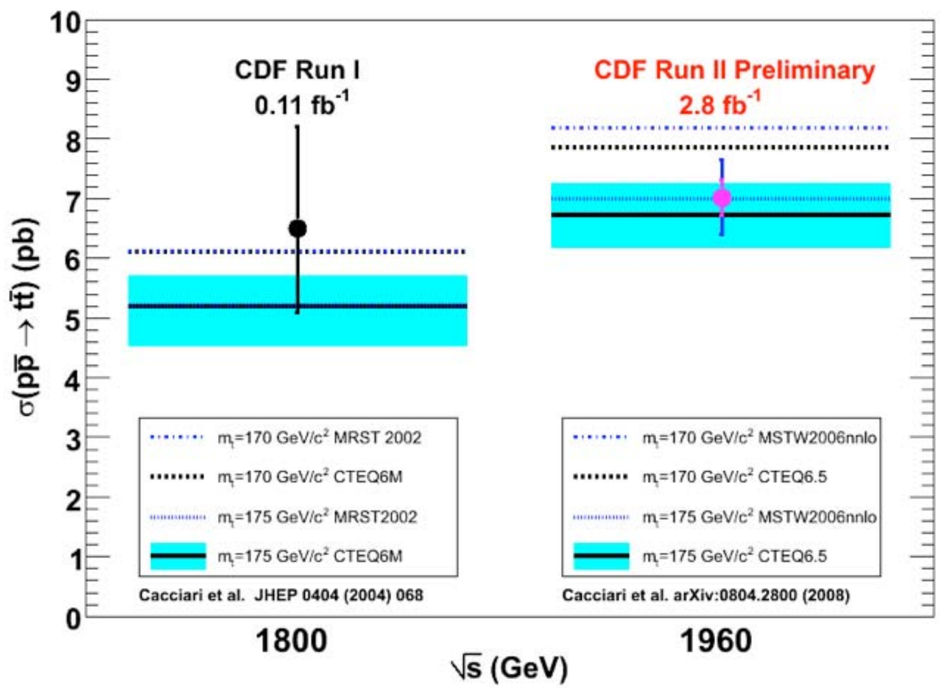
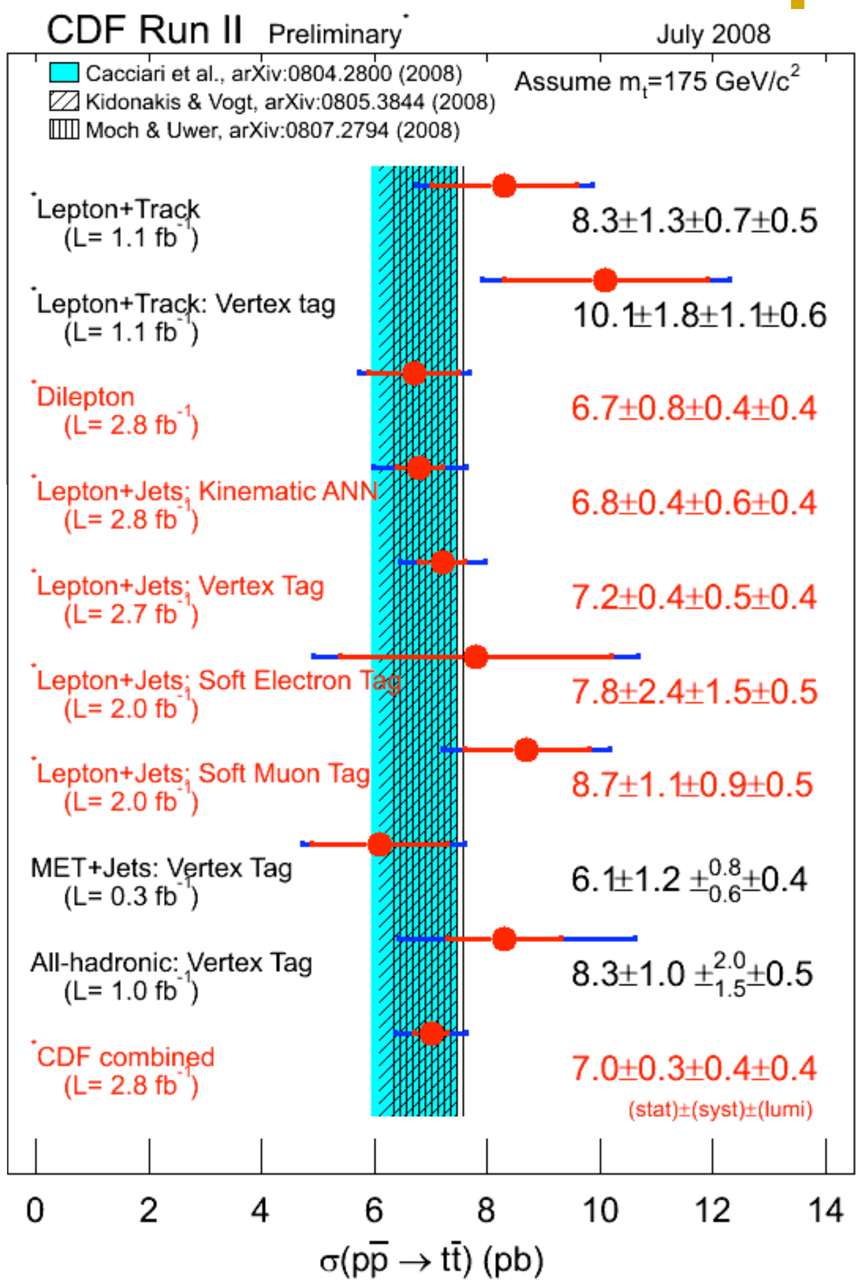
INFN Gruppo Collegato di Udine and University of Udine

SIGNALING THE ARRIVAL OF THE LHC ERA
ICTP, Miramare, Trieste, December 2008

x-sec at Tevatron

- CDF results as example
- Many channels exploited
- Combined precision 9 !





Tevatron to LHC

Process	Tevatron ~2 TeV	LHC 14Tev	
$\sigma_{NLO}(t\bar{t})$	6.7 pb	833 pb	x100
$q\bar{q} \to t\bar{t}$	85%	10%	
$gg \to t\bar{t}$	15%	90%	
σ_{NLO}(single t)			
t-channel	2 pb	240 pb	x100
s-channel	1 pb	11 pb	x10
Wt	0.1 pb	66 pb	x70
W+jets	~2nb	~20nb	x10

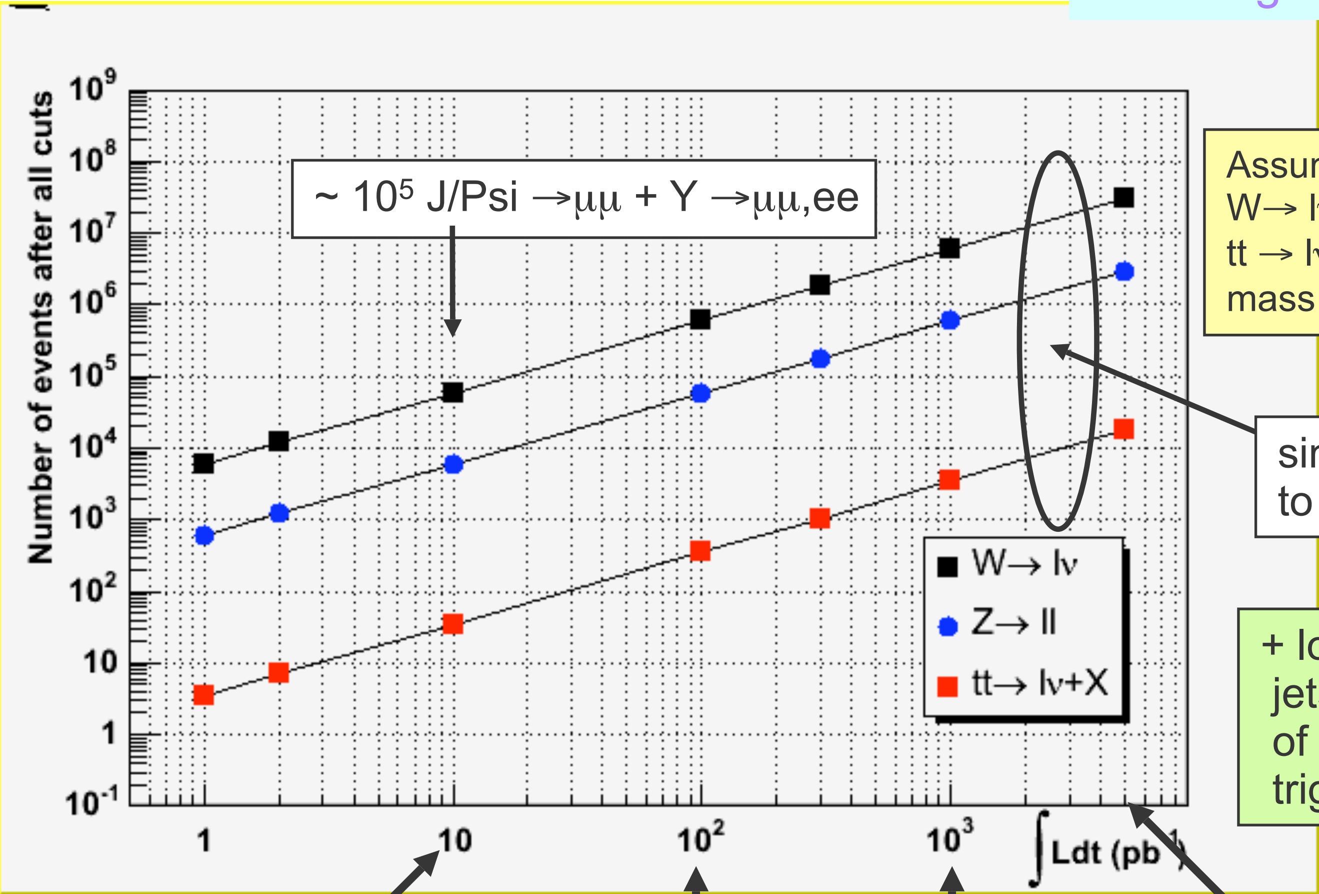
A lot to learn from Tevatron, similarities but also differences

Tevatron to LHC (II)

- Large statistics:~1 Hz $t\bar{t}$ @ $L=10^{33}cm^{-2}s^{-1}$
  $100pb^{-1}$ (3 days @ $10^{33}cm^{-2}s^{-1}$), 10% acceptance, 3000 semi-leptonic (e,μ) top pair events
- Relative cross-section:
  - ratio $t\bar{t}$ / W+jets ~ 10 x larger (jet multiplicity dependent!)
  - single top (t-channel) / $t\bar{t}$ unchanged
  - $gg \rightarrow t\bar{t}$ dominates over $q\bar{q} \rightarrow t\bar{t}$
- Possible "contamination" from new physics
- New "phenomenology": high p_T boosted top decays
- Pile-up

How many events at the beginning ?

Including selection efficiencies!



l ≡ e or μ

Assumed selection efficiency:
W→ lν, Z→ ll : 20%
tt → lν+X : 1.5% (no b-tag, inside mass bin)

similar statistics to CDF, D0 today

+ lots of minimum-bias and jets (10^7 events in 2 weeks of data taking if 20% of trigger bandwidth allocated)

10 pb^{-1} ≡ 1 month at 10^{30} and < 2 weeks at 10^{31}, ε=50%

100 pb^{-1} ≡ few days at 10^{32}, ε=50%

1 fb^{-1} ≡ 6 month at 10^{32}, ε=50%

5 fb^{-1} ≡ 3 month at 10^{32} and 3 month at 10^{33}, ε=50%

From early data → large statistics

- Early data:
  - emphasis on data-driven methods
  - robust observables not relying on ultimate performance (ex. no b-tagging, tight isolation criteria lepton ID, etc.)
  - cut and count
- Progressively:
  - more demanding S/B separation: needs b-tagging, performing MET, tighter lepton ID
  - more powerful statistical methods likelihood, BDT
  - methods based on templates, Matrix Elements, etc.

need validated MC physics processes and detector performance description to provide signal efficiencies, transfer function, templates, background shapes, etc... with their associated systematic uncertainties

Rough Top Physics Timeline

Physics measurements | **Top as calibration tool**

10 pb-1

establish $t\bar{t}$ signal

σ_{tt}- semi-leptonic, ll channel

100 pb-1

stat (~5%)-syst(~15-5%)-lumi (3%)

light jet JES ~2%

b-tagging efficiency 3%

1 fb-1

m_{top} to 1-3.5 GeV (1-5% b-JES)

single top t-channel @ 5σ

top charge 5σ, W polarization 5-10%,
constrain anomalous coupling ~.15,
rare decays BR~10^{-3} , $m_{Z'}$~700 GeV

light jet JES ~1%

b-tagging efficiency

with pT dependence

10 fb-1

single top Wt-channel@ 5σ

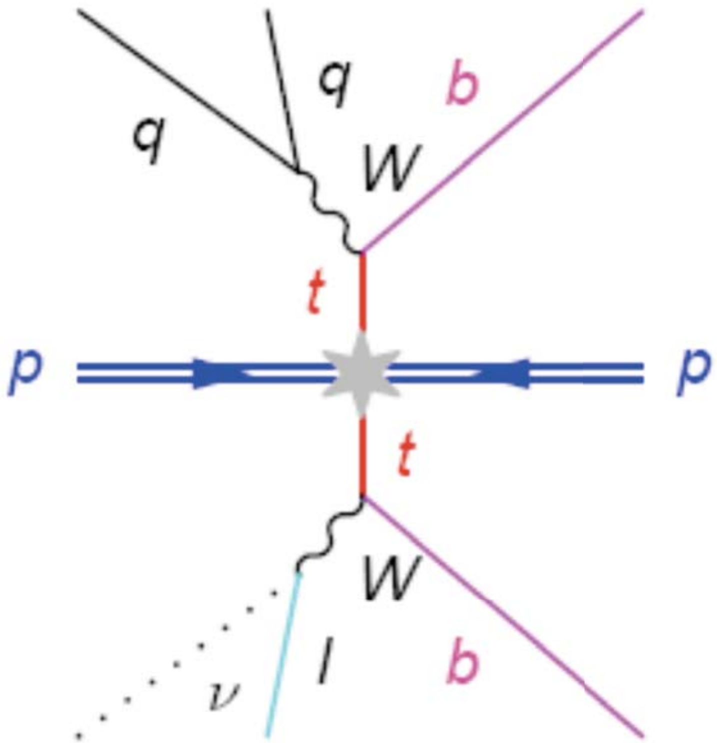
$t \rightarrow H+ \rightarrow \tau$

100 fb-1

single top s-channel@ 5σ

ttH (bb-,WW)?

The experimental problem



Final state:

- many jets with a wide spectrum of pt
- b-jets
- Lepton(s)
- Missing *ET*

Complete detector capability at play

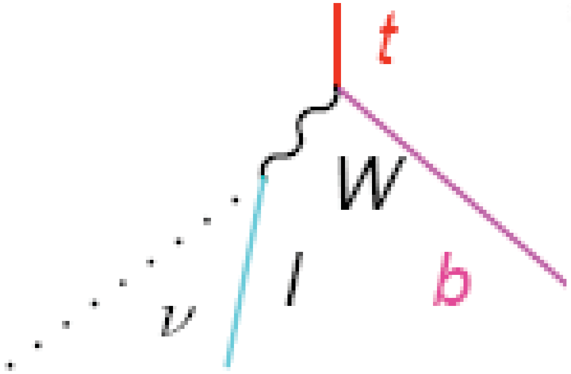
Detector performance on day one ?

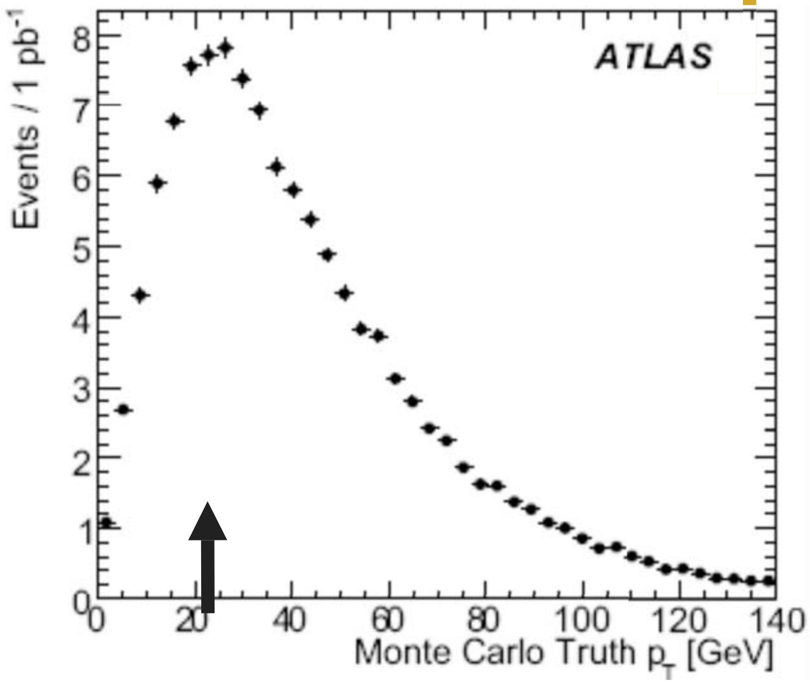
Based on detector construction quality, test-beam results, cosmics, simulation

	Expected performance day 1	Physics samples to improve
ECAL uniformity	~ 1%	Minimum-bias, Z→ ee
e/γ scale	~ 2 %	Z → ee
HCAL uniformity	~ 3 %	Single pions, QCD jets
Jet scale	< 10%	Z (→ ll) +1j, **W → jj in tt** events
Tracking alignment	20(100)-200 μm in Rφ?	Generic tracks, isolated μ , Z →μm

Ultimate statistical precision achievable after few weeks of operation.
Then face systematics….
E.g. : tracker alignment :
100 μμ (1 month) → 20μμ (4 months) → 5 μμ (1 year) ?

Leptons





- Efficient ID
- Low level of fakes
  use isolation
- Trigger
  - single lepton **(20-25 GeV)**
  - dilepton triggers **(6-15GeV)**

  well matched to need

But effect of high jet multiplicity environment has to be well understood !

Fake rate

Isolation criteria

Overlap removal

Study in QCD, W/Z+jets

Transfer to Top environment

Jets

- The 1rst jet is hard
- The ≥ 4th jet is soft

Need to understand with enough precision JES in full range

Expecially difficult

Low Pt jet response,

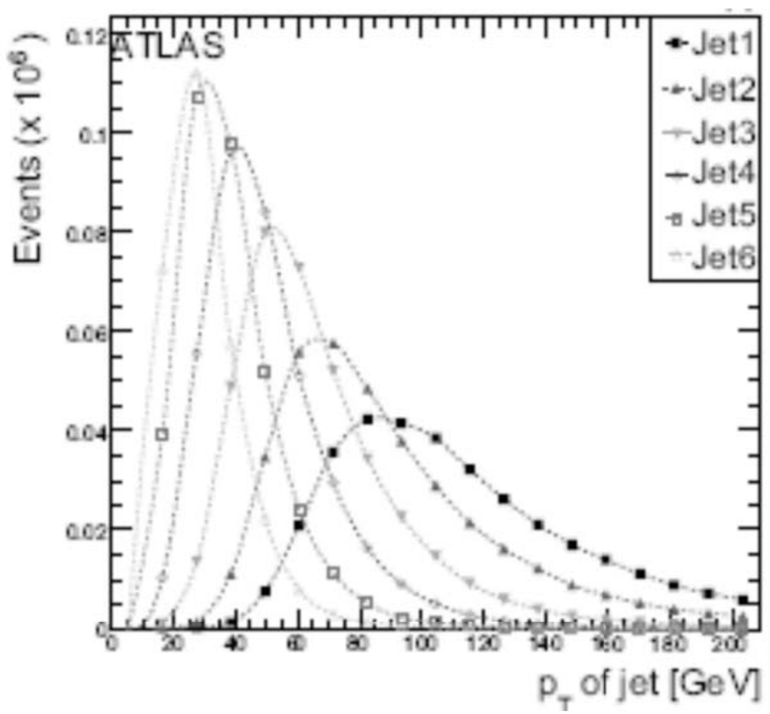
UE and pile-up

Resolution

Combine jet calibration strategy in ATLAS+ in-situ calibration from W→jj in $t\bar{t}$ events

Need also to translate to b-jets

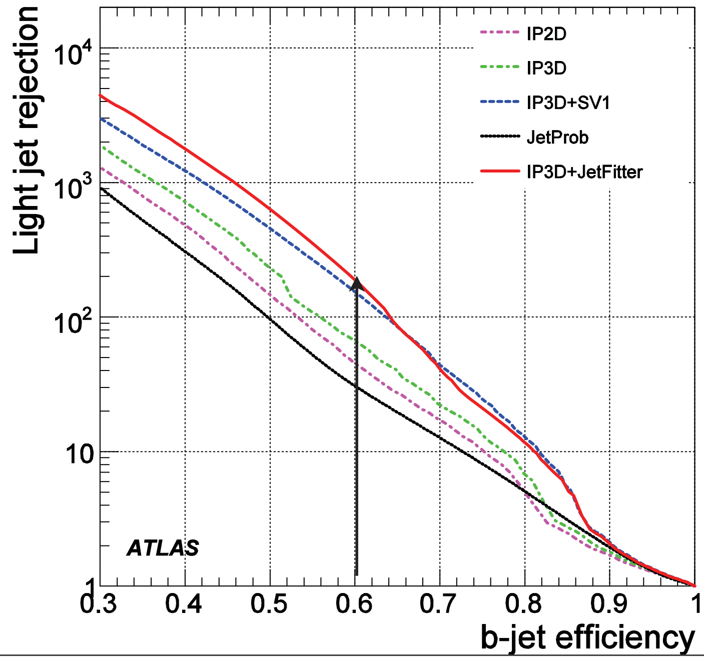
Trigger: multijet for fully hadronic $t\bar{t}$ or semi-leptonic t→W→τ→had



Jet pT distribution in fully hadronic $t\bar{t}$ events

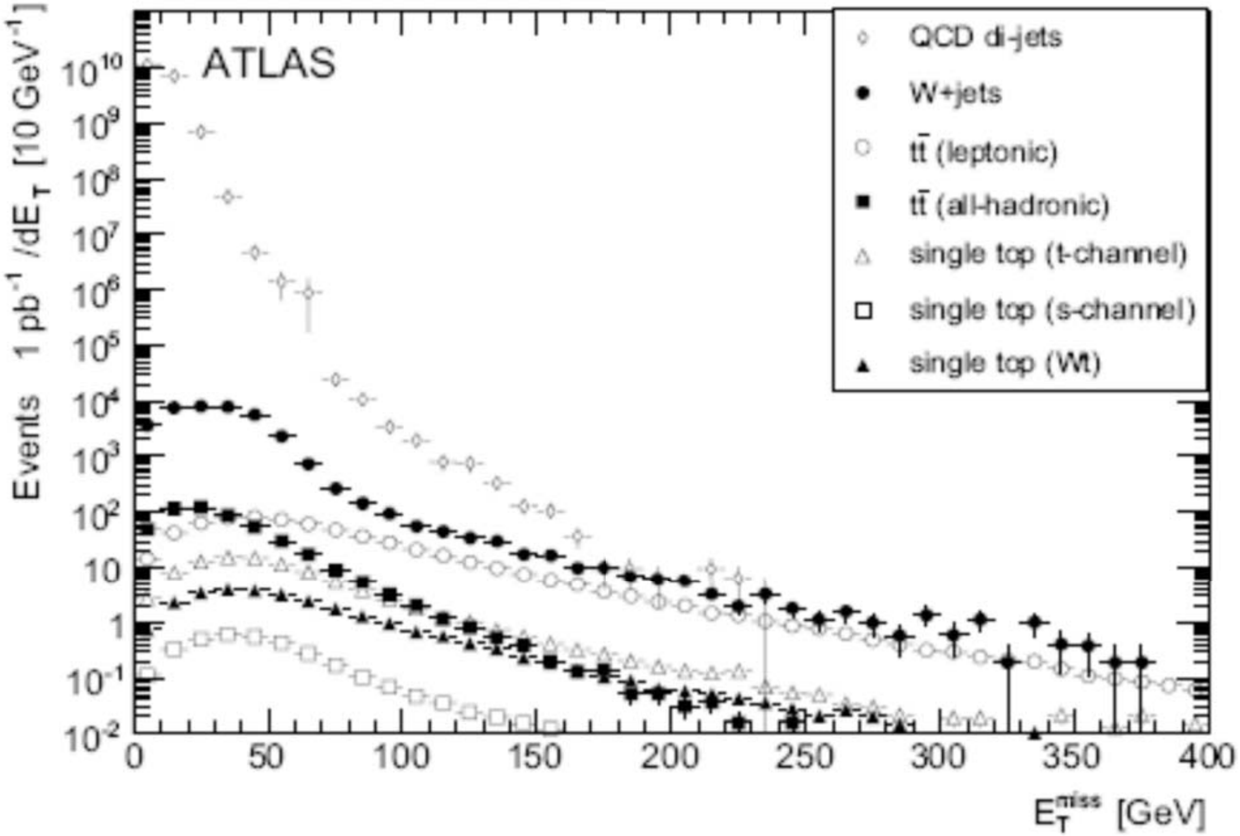
b-jet

- b-tagging is excellent to reduce background and internal combinatoric
  - in some analysis indispensable!
  - need to understand efficiency - purity
  - algorithms used and conditions will evolve with time
- b-jet scale (important impact on mass measurement)
- b-jet trigger?



Missing ET

- Excellent against QCD, but tails?
- Trigger: jet+MET, τ+MET semi-leptonic $t \rightarrow W \rightarrow \tau \rightarrow$ had



Generating top events

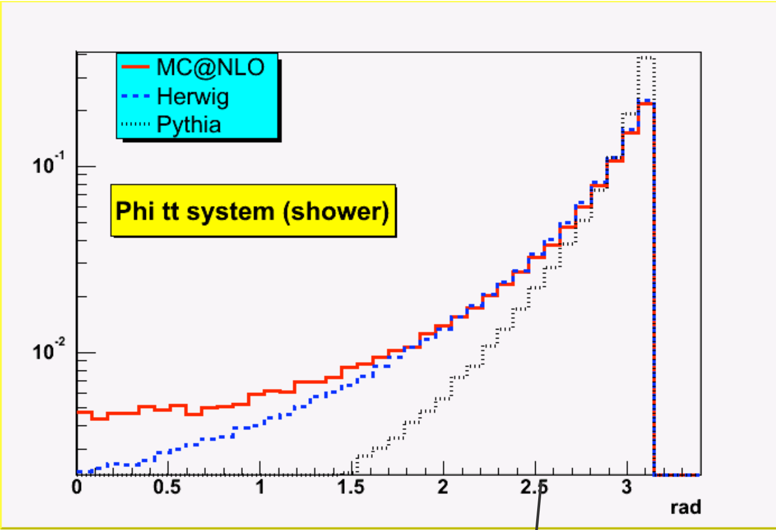
- Leading Order MC:
  - Pythia & Herwig : full standalone MC
  - AcerMC (include spin effects – interfaced to Pythia)
  - AlpGen (include additional hard jets)

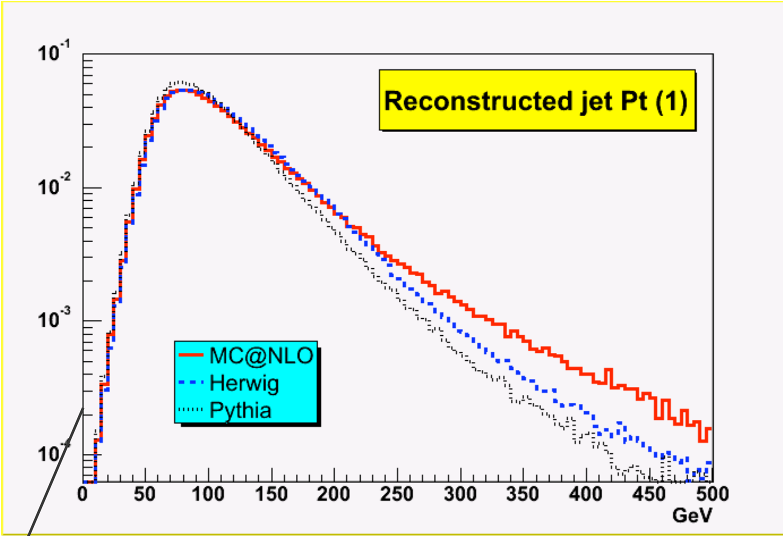
- NLO QCD calculations implemented in MC
  - MC@NLO – interfaced to Herwig shower and fragmentation
  - ttbar process (among others) available
  - single top processes included (s- and t-channel)

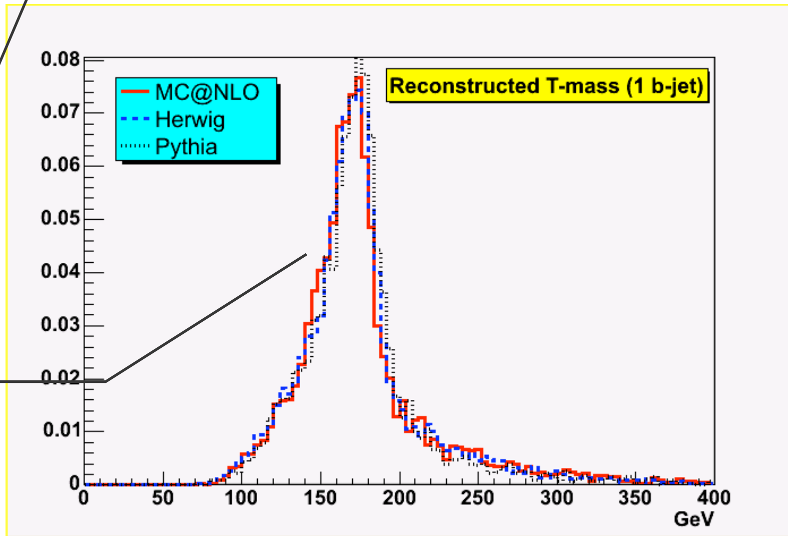
  - Validation done for MC@NLO

Generators: MC@NLO, Herwig, Pythia

Examples of MC validation







Azimuthal opening angle top-anti-top
Deviations from 'back-to-back' production most pronounced in NLO predictions

PT of jet with highest PT
Influences selection and jet qualities

Top mass
Standard reconstruction using 1 b-tagged jet
Variation of 2-3 GeV

Early measurements

- Both experiments concentrated on studies at very low $\mathcal{L}$
  - Top "rediscovery" with O(10 pb^{-1})
  - Detector simulation according to expected startup conditions
    - **CMS, ee, eμ, $\mu\mu$ dilepton channels**
    - **CMS μ single lepton channel**
    - **ATLAS e, μ single lepton channel**
    - **ATLAS ee,$\mu\mu$,eμ dilepton channel**
  - Top cross section: 100 pb^{-1}, even no b-tag
  - Detector simulation according to expected conditions at **100pb^{-1}**
    - **ATLAS e, μ single lepton channel**
    - **ATLAS, CMS ee, eμ, $\mu\mu$ dilepton channel**
    - **CMS eτ, $\mu\tau$**
- For ttbar ATLAS uses MC@NLO and CMS uses ALPGEN

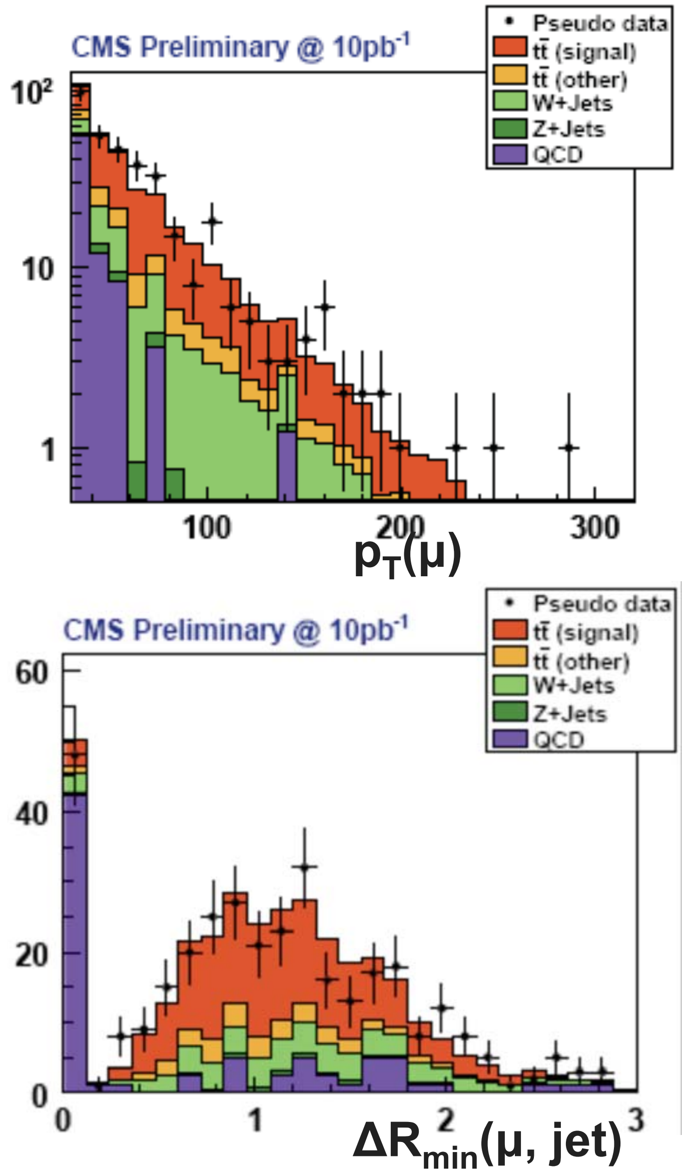
Single lepton: $10pb^{-1}$ rediscovery

- HLT
  - non-isolated single μ
- Exactly one μ
  - $p_T(\mu) > 30$ GeV
  - $|\eta(\mu)| < 2.1$
  - $p_{T,\,iso}^{Trk}(\mu)<3$GeV,
- Jet cuts

N jets ≥ 4 with $p_T^{jet} > 40$ GeV

N jets ($p_T^{jet}>65$) ≥1

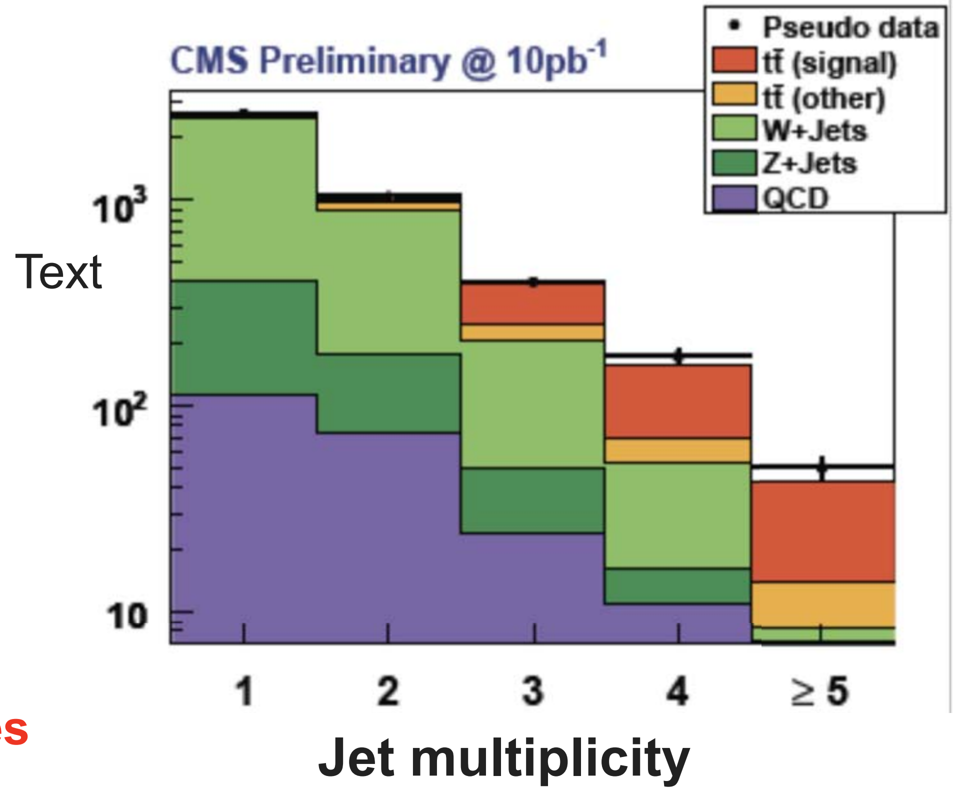
- $E_{T,iso}^{Ecal}(\mu)<1$GeV
- $\Delta R_{min}(\mu,jet) > 0.3$



Single lepton: 10pb^{-1} rediscovery

ttbar (signal)	128
ttbar (other)	25
W + jets	45
Z + jets	7
QCD*	11
S/B	1.5
Signal efficiency	10.3%

(All cuts but $N_j \geq 4$)



*** pp→μX sample, not including fakes and μ from in-flight decays**

No single top background added

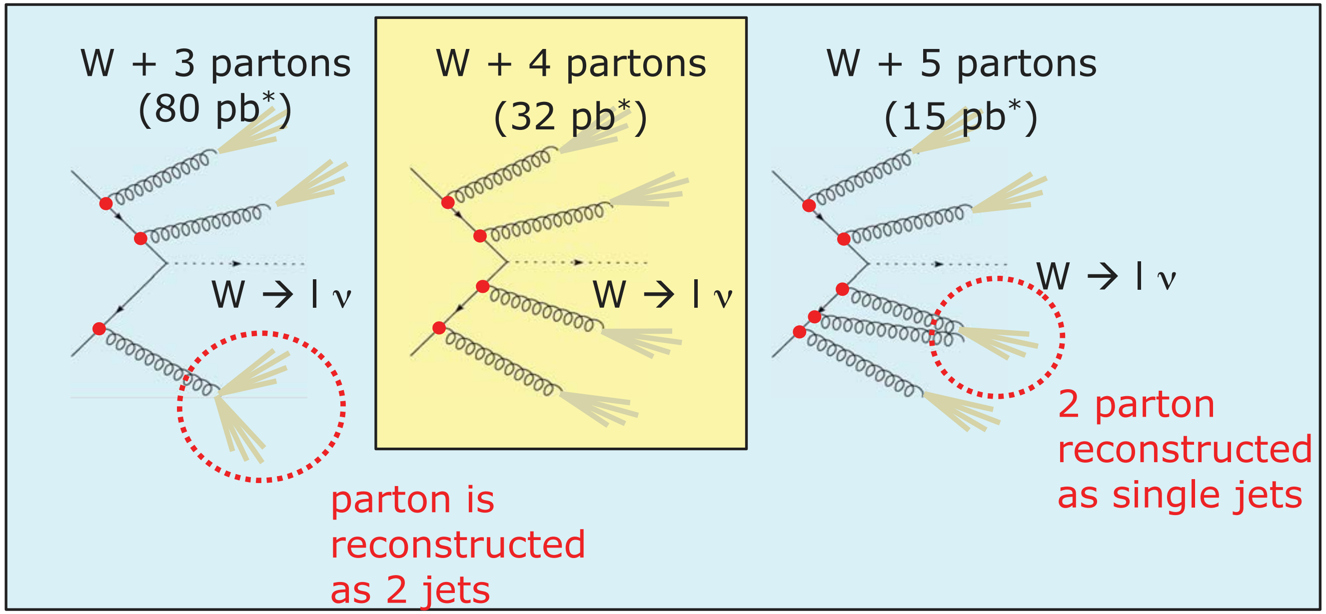
Background

- W/Z+jets
- Single top
- Diboson (WW,ZZ)
- QCD background
  - Huge cross sections and tiny efficiencies.
  - In order to naively extract the efficiency one would need a huge amount of MC with perfect "tails"…
  - In order to avoid underestimating the efficiency for multi-jet topologies, ME+PS generators like Alpgen should be used.
  - To estimate the small efficiencies, different methods are:
    - from MC: cut factorization
    - from Data: "matrix" method
  - At Tevatron the QCD background was kept under control, so there are good hopes that this will happen also at LHC.

W+jets background

This background cannot be simulated by Pythia or Herwig shower process. Dedicated generator needed: e.g. AlpGen. Large uncertainties in normalization

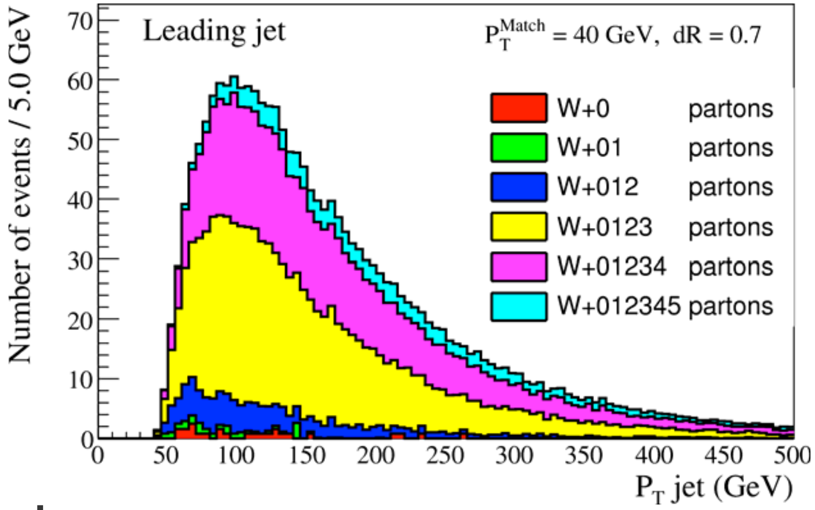
- Sources of physics background
  - W+njet production
    - Not only W + 4 *partons*, since W + 3,5 *partons* may also result in W + 4 *jet* final state due to splitting/merging
    - MLM matching prescription to explicit elimination of double counting.
  - W+bbar, W+ccbar

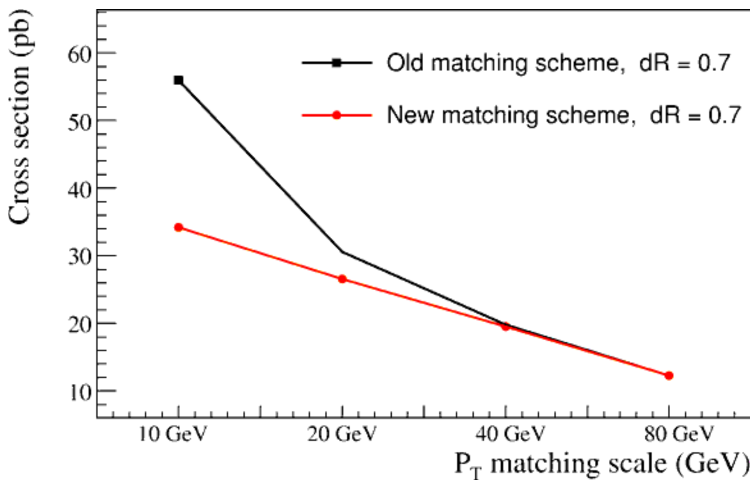


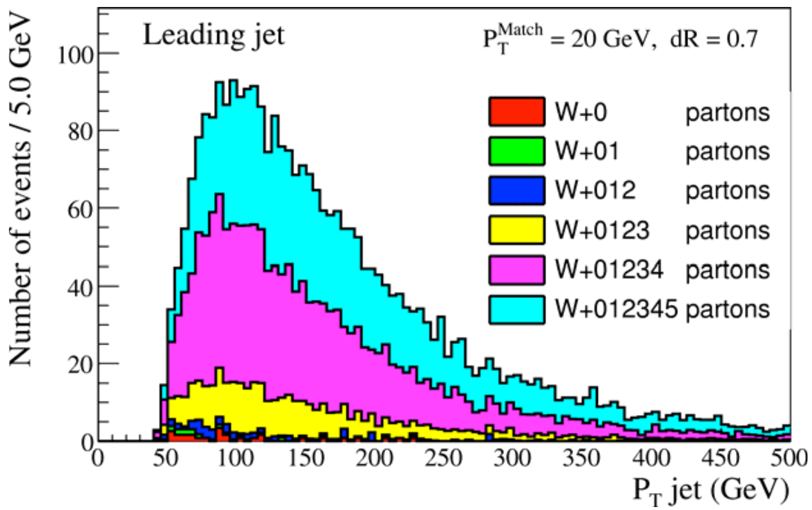
* These are the cross sections with the analysis cuts on lepton and jet pT applied at the truth level

W+jets background

- 'Freedom' in the matching
  - Between matrix element calculations and parton shower
    - Results should be independent
    - Typically inspect effects on the parton PT scale and the jet cone sizes
  - Effect on cross section non negligible!
    - Uncertainty ~factor 2



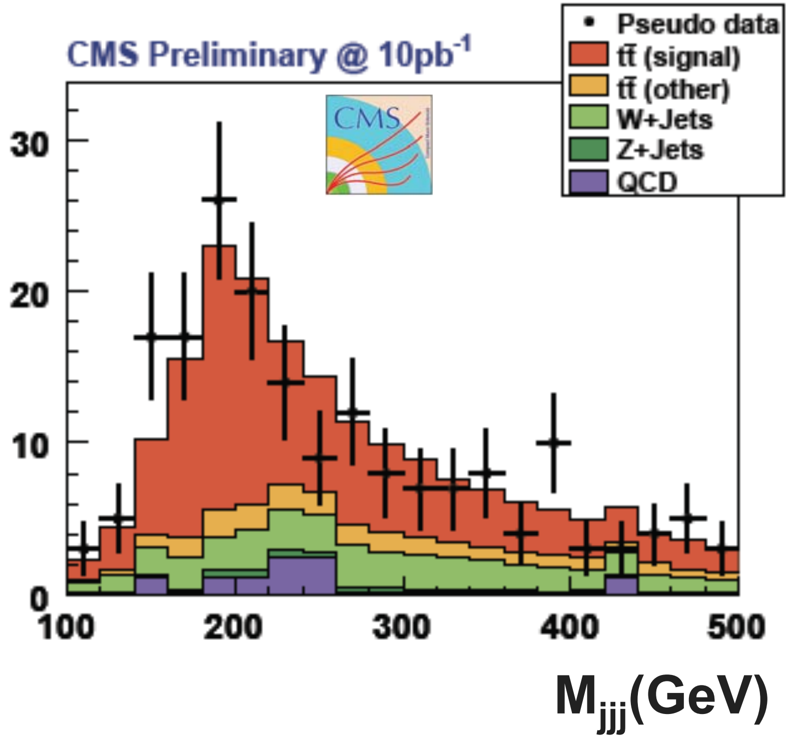


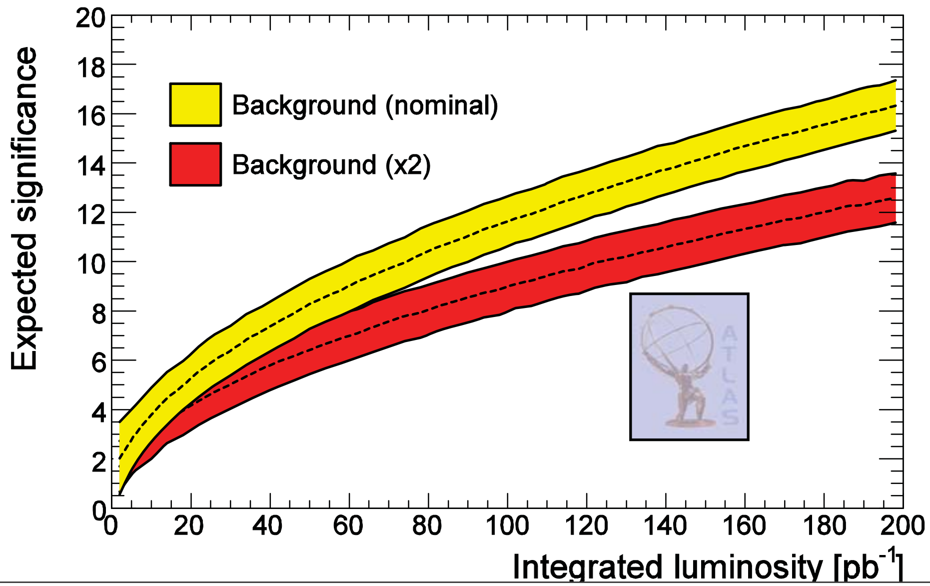


Single lepton: 10pb^{-1} top rediscovery

- Select the three jets that maximize

$$(\sum_{i=1}^{3} \vec{p}_{J,i})_T$$





The significance curve

Single lepton: x-sec with 100 pb^{-1}

Electron

Sample	default	W const.
$t\bar{t}$	2555	1262
hadronic $t\bar{t}$	11	4
W+jets	761	241
single top	183	67
$Z\to ll$ +jets	107	33
$W\ b\bar{b}$	17	6
$W\ c\bar{c}$	19	6
WW	4	2
WZ	2	1
ZZ	0.3	0.1
Signal	2555	1262
Background	1104	360
S/B	2.3	3.5

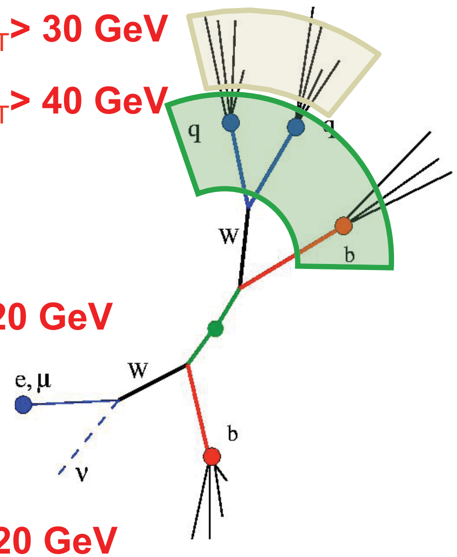
ε_{ttbar} =18.2%

4 jets p_T> 30 GeV

3 jets p_T> 40 GeV

P_T^{lep} > 20 GeV

E_T^{miss} > 20 GeV



No b-tagging

100 pb^{-1}

Muon

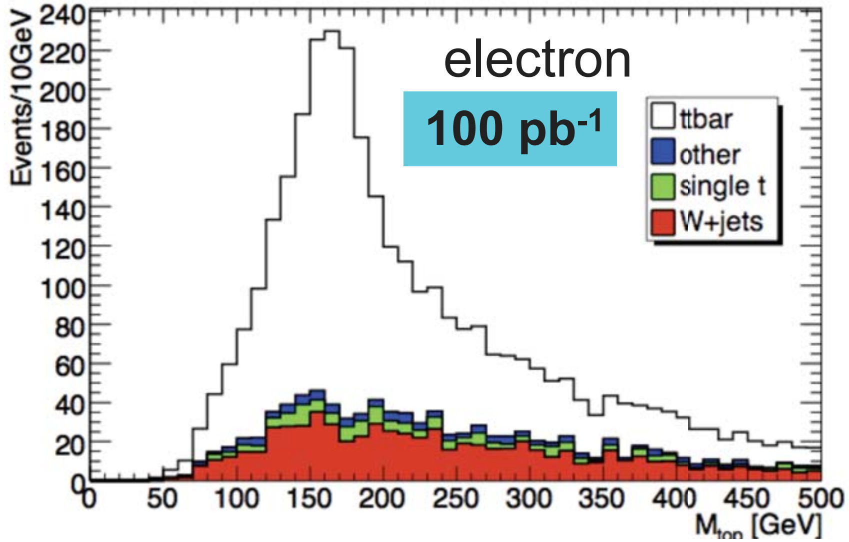
Sample	default	W const.
$t\bar{t}$	3274	1606
hadronic $t\bar{t}$	35	17
W+jets	1052	319
single top	227	99
$Z\to ll$ +jets	78	22
$W\ b\bar{b}$	25	7
$W\ c\bar{c}$	26	9
$W\ W$	4	2
$W\ Z$	3	1
$Z\ Z$	0.4	0.2
Signal	3274	1606
Background	1446	479
S/B	2.3	3.4

ε_{ttbar} 23.6%

Detector simulation according to expected conditions

QCD fakes expected to be smaller than W+jets bkg

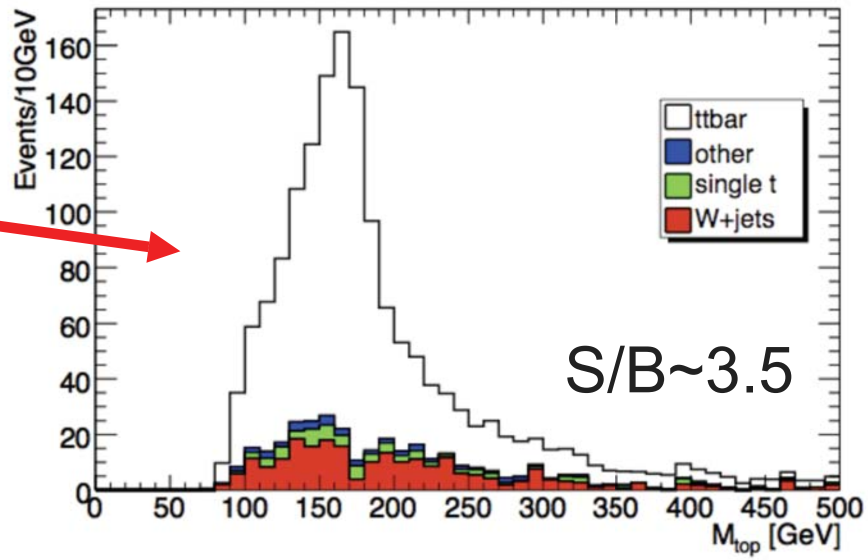
Single lepton x-sec with 100 pb^{-1}



Top quark candidate: 3-jet combination with highest P_T

Purer samples adding:

M_W constraint: at least one of three di-jet sys in top candidate has $|M_{jj}-M_W|<10$ GeV



and/or

Centrality : require $|\eta_{jet}|<1$ for 3 highest P_T jets

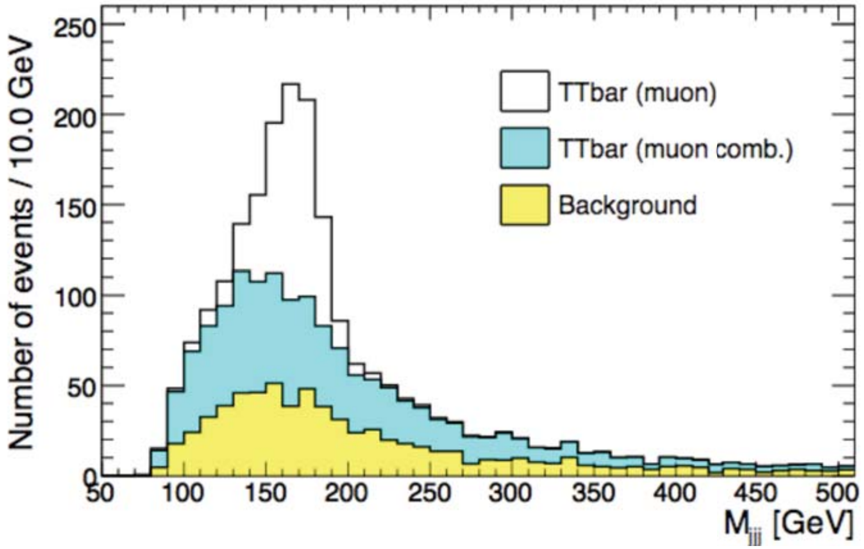
S/B~5

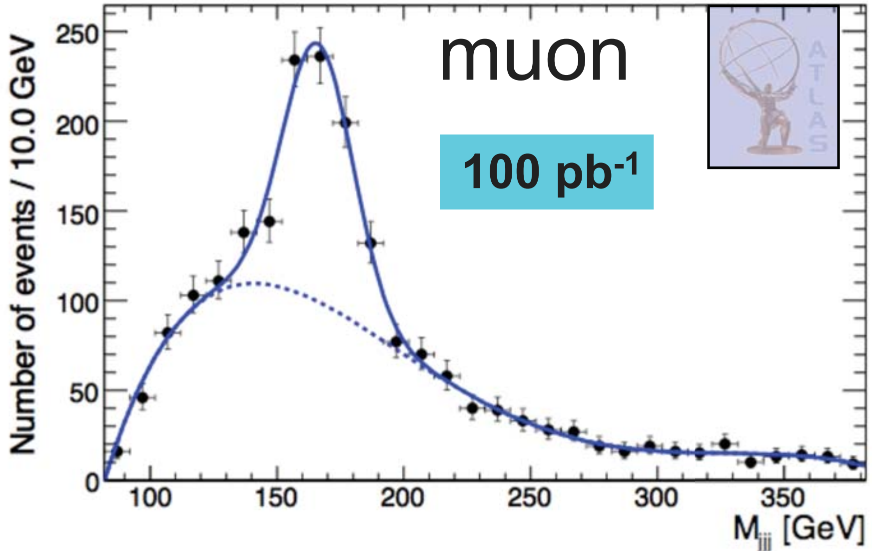
Single lepton: x-sec extraction

Likelihood fit method

- Assume 3-jet mass dist using Gaussian signal +Chebychev pol bkg
- Likelihood as a function of N_{sig} and N_{bkg}
- Gaussian fit to extract N_{sig}
- Extract x-sec by scaling with event selection, combinatorics and reconstruction eff

Sensitive to mass shape reco





Single lepton: Cross Section Extraction

Counting method

Simply counting events passing selection and calculate

$$\sigma = \frac{N_{\text{sig}}}{\mathscr{L} \times \varepsilon} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\mathscr{L} \times \varepsilon}$$

where

N_{obs} number of observed selected events

N_{bkg} number of estimated bkg events from MC and/or data

$\mathscr{L}$ integrated luminosity

ε total efficiency (geometrical, trigger,event selection)

Monte Carlo samples broken in 2 stat indep parts:
to have pseudo data and simulation

sensitive to bkg normalization, less to shape

Single Lepton: Results

in % of cross section

	Likelihood fit		Counting method (elec)	
Source	**Electron**	**Muon**	**Default**	***W* const.**
Statistical	10.5	8.0	2.7	3.5
Lepton ID efficiency	1.0	1.0	1.0	1.0
Lepton trigger efficiency	1.0	1.0	1.0	1.0
50% more W+jets	1.0	0.6	14.7	9.5
20% more W+jets	0.3	0.3	5.9	3.8
Jet Energy Scale (5%)	2.3	0.9	13.3	9.7
PDFs	2.5	2.2	2.3	2.5
ISR/FSR	8.9	8.9	10.6	8.9
Shape of fit function	14.0	10.4	-	-

Expect reduction from in-situ calibration with increasing luminosity

Likelihood method: $\Delta\sigma/\sigma = (7(\mathrm{stat}) \pm 15(\mathrm{syst}) \pm 3(\mathrm{pdf}) \pm 5(\mathrm{lumi}))\%$

Counting method: $\Delta\sigma/\sigma = (3(\mathrm{stat}) \pm 16(\mathrm{syst}) \pm 3(\mathrm{pdf}) \pm 5(\mathrm{lumi}))\%$

ISR/FSR uncertainty

Problem:

MC Generator ISR/FSR description: model + parameters.
LHC: at 14TeV you have no data[1] $\Rightarrow$ you don't know:
- which model to choose,
- to which values to set parameters values.

Therefore: for ISR/FSR sensitive observables your prediction has a modeling uncertainty. Since there is no data (and MC hopefully describes the data): systematics uncertainty $\sim$ modeling uncertainty (reco. and analysis effects included).

Evaluation procedure:

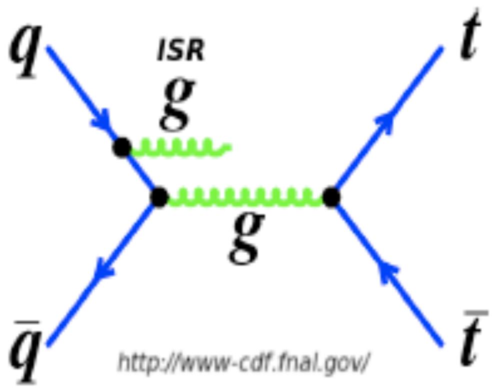
1. compare different ISR/FSR models (used by different MC generators),
2. for the different models vary ISR/FSR parameters,
3. The biggest difference for an observable = MC uncertainty.

If ISR/FSR is your dominant source of uncertainty in this way you estimate the range of possible observable values MC Generators can describe.

1. We compared Herwig + MCNLO, Pythia + AcerMC and Herwig + AcerMC.
2. We identified the most important ISR/FSR tunable parameters (Pythia has plenty, Herwig not so many).
3. MC uncertainty was determined from Pythia ISR/FSR parameters variation.

ISR/FSR uncertainty

Monte Carlo ISR/FSR modeling is complicated, but for the top mass and x-sect. main effects are:



- hard ISR can add extra hard (pt>40 GeV) jets to ttbar event,
- soft ISR adds particles (energy) to final state jets,
- FSR from the jets from ttbar takes particles (energy) from the jets.

For the top-mass and sel. efficiency and a typical ttbar analysis:
more energetic jets will result in higher reco. t-mass,
more high-pt jets will increase selection efficiency for ttbar events.

Most important[2] Pythia tunable parameters:
- ISR and FSR Λ_{QCD}: determine running of α_{strong} for ISR and FSR,
- ISR and FSR cutoffs - parameterize minimal *pt* value of the ISR and FSR.

We defined 2 samples, Max. and Min. mass sample:
parameters are tuned simultaneously to increase or decrease the reconstructed top mass value (for typical mass reco. procedure).
Not optimized but reasonably good also for x-section uncertainty estimation.

Absolute Luminosity Measurements

$L = \frac{N}{\sigma}$

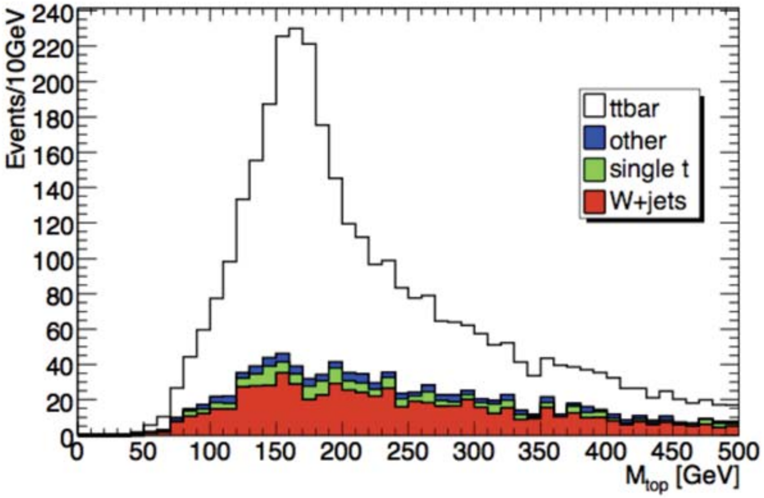
Goal: Measure L with ≲ 3% accuracy (long term goal)

How? Three major approaches

- LHC Machine parameters
- Rates of well-calculable processes:
  e.g. QED (like LEP), EW and QCD
- Elastic scattering
  - Optical theorem: forward elastic rate + total inelastic rate:
  - Luminosity from Coulomb Scattering
  - Hybrids
    - Use σ_{tot} measured by others
    - Combine machine luminosity with optical theor

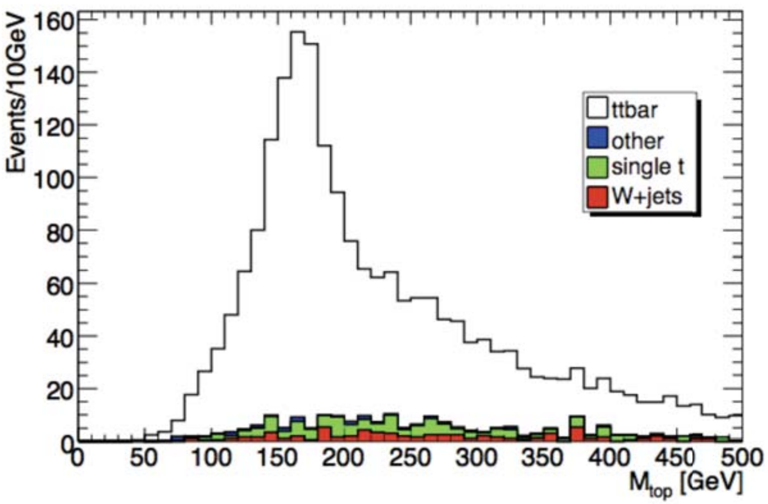
We better pursue all options

Single Lepton: adding the b-tagging

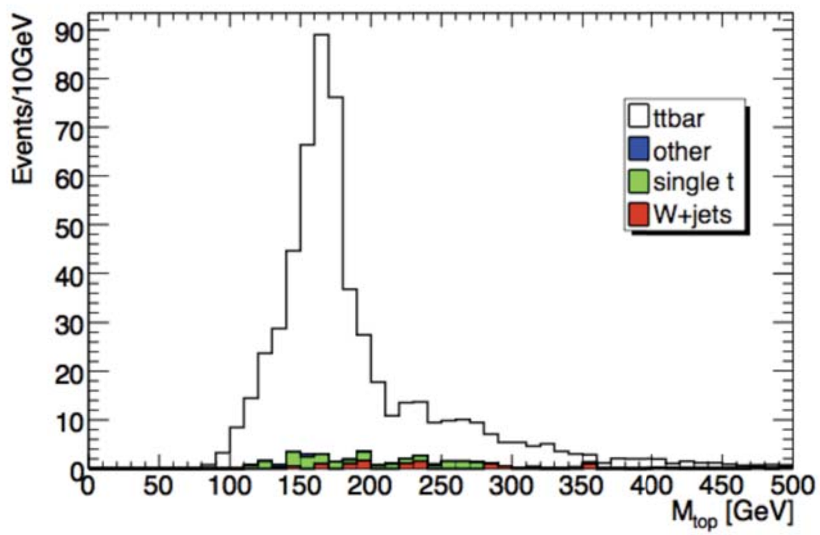


no btag, no Mw constraint

- More than one option: only 1 tag, only 2 tag only, 1 or 2 tagged jets
- Use default electron selection + btag=1 or 2 tags
- Purity: improved by ~4
  ε_{sig} : reduced by ~2



b-tag, no M_W constraint

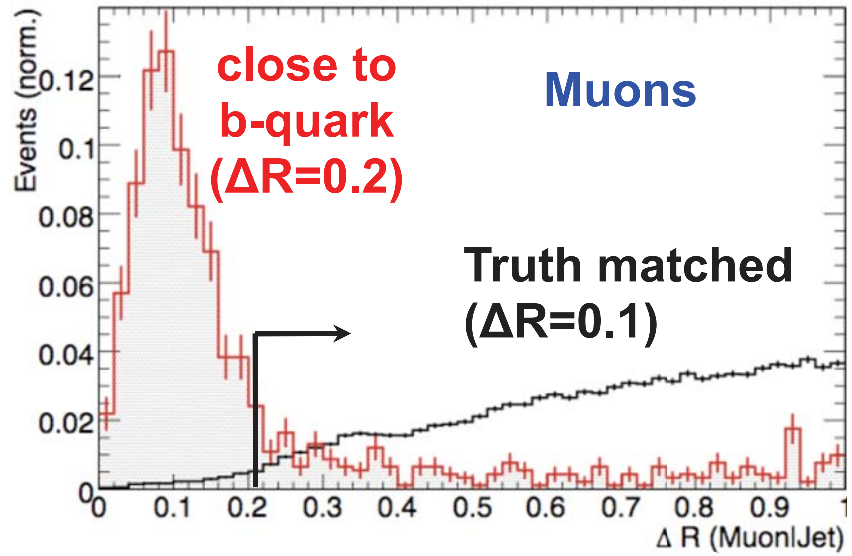


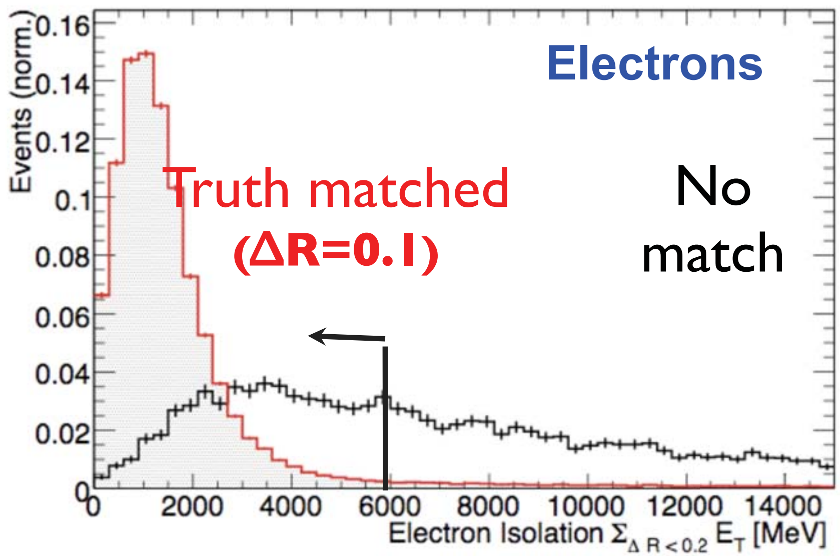
b-tag+M_W constraint

x-sec with 100 pb^{-1}: dileptonic

2 OS leptons (ee,eμ,μμ)
P_T(lep) >20 GeV
2 jets with P_T > 20 GeV
No b-tagging
high quality isolated leptons
Fakes from single lep events

Sample	$e\mu$	ee	$\mu\mu$
$t\bar{t}$ (signal)	699	312	381
$t\bar{t}$ (bkg)	31	20	8
$Z \to e^+e^-$	5	37418	0
$Z \to \mu^+\mu^-$	153	0	51139
$Z \to \tau^+\tau^-$	249	101	159
$W \to e\nu$	42	69	0
$W \to \mu\nu$	152	0	40
WW	76	32	44
WZ	6	41	52
ZZ	1	25	31
single top	5	3	2

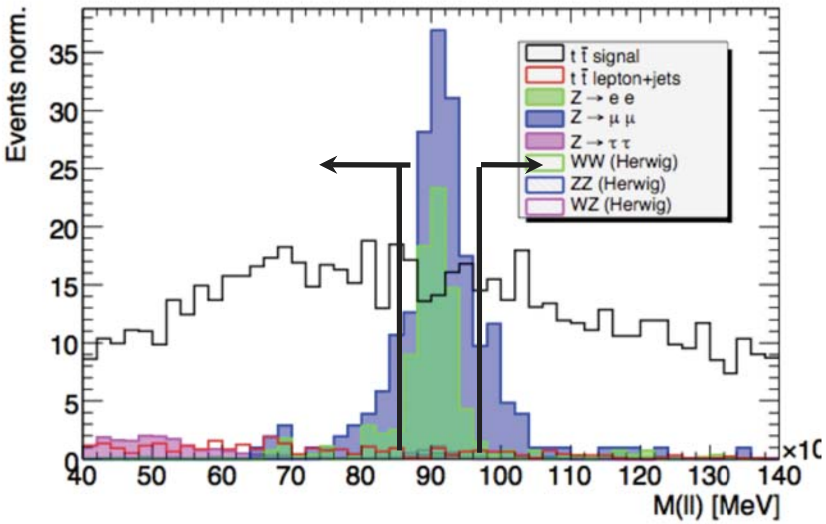




reduce signal by ~4%, single-lep bkg by 2

x-sec with 100 pb^{-1}: dileptonic

Cut and count method

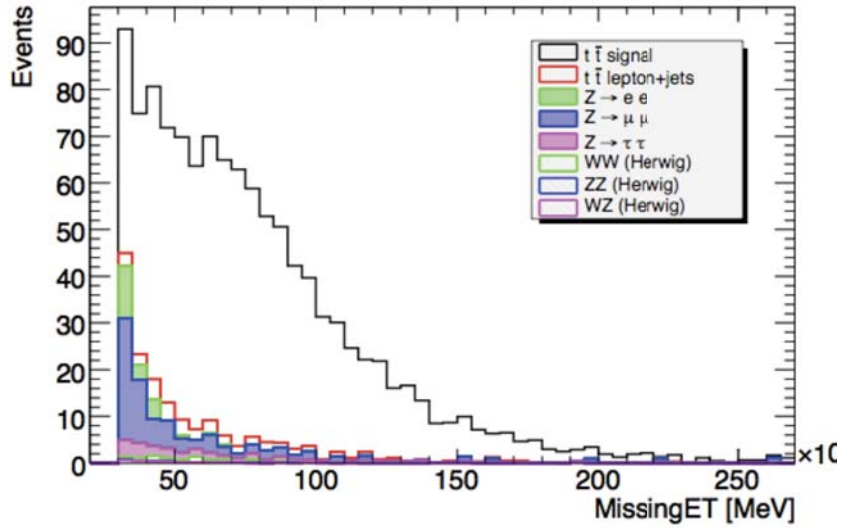


Scan lepton, jet P_T and E_T^{miss} cuts to maximise $\varepsilon \times p \propto \frac{S}{\sqrt{S+B}} = s$

E_T^{miss} > 30 GeV (flavour blind)
>25 GeV for eμ
>35 GeV for ee,μμ

Selection

Only 2 leptons, Njets≥2
Z veto: $85<M_{ll}<95$ GeV



dataset	$e\mu$	ee	$\mu\mu$	all channels
$t\bar{t}$ (signal)	555	202	253	987
ε [%]	**20.2**	**14.7**	**18.3**	**17.9**
Total bkg.	86	36	73	228
S/B	6.3	5.6	3.4	4.3

Di-lepton: Results

in % of cross section

	cut and count method			
$\Delta\sigma/\sigma$ [%]	$e\mu$	ee	$\mu\mu$	all
CTEQ6.1L set	2.4	2.9	2.0	2.4
MRST2001L set	0.9	1.1	0.7	0.9
JES-5%	-2.0	0.0	-3.1	-2.1
JES+5%	2.4	4.1	4.7	4.6
FSR	2.0	2.0	4.0	2.0
ISR	1.1	1.1	1.2	1.1
parameters-1σ				
paramterrs+1σ				

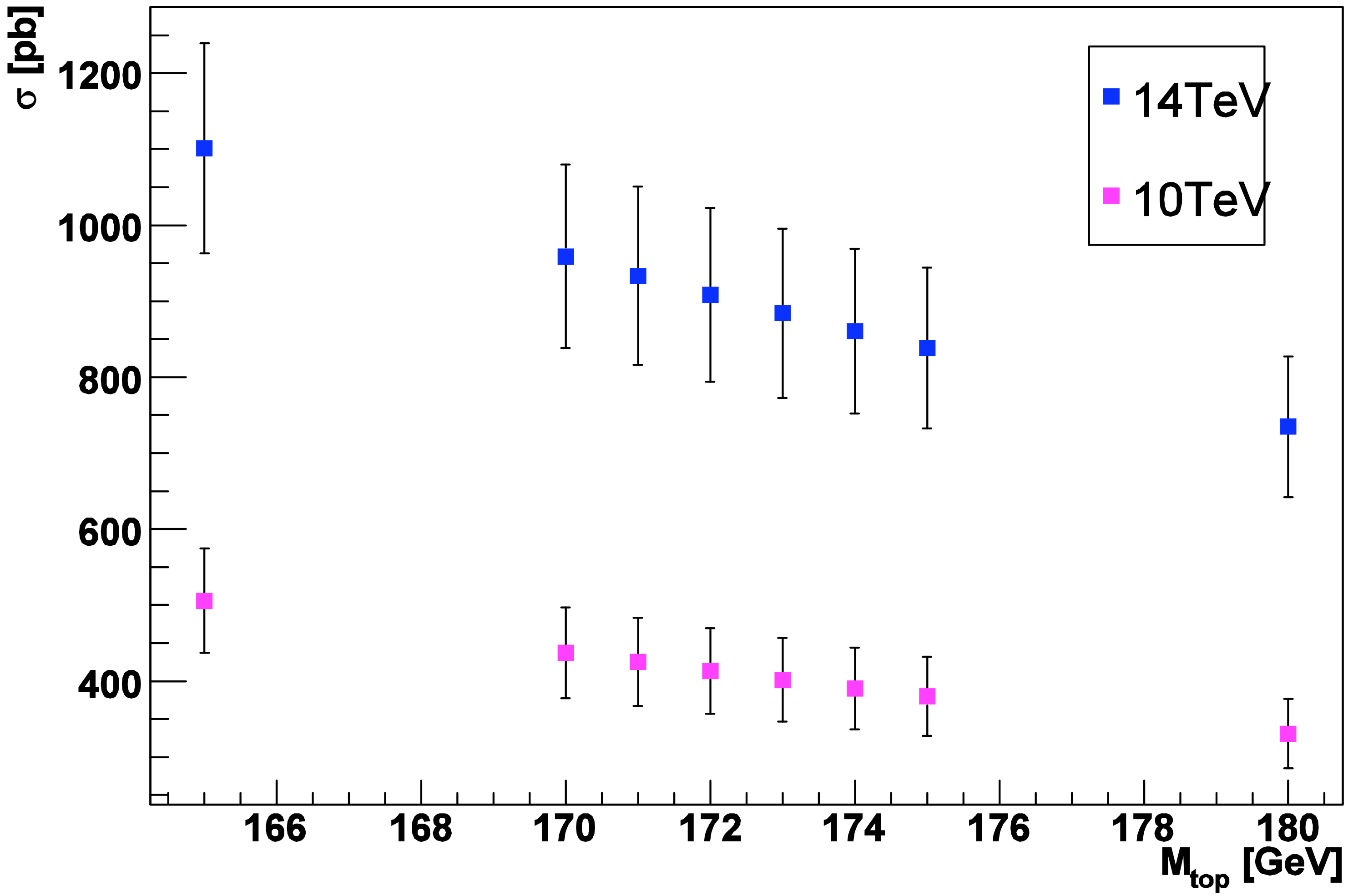
Expect lep-ID and lepton trigger to be derived in situ using Z events

Cut and Count method: $\Delta\sigma/\sigma = \quad (4(\mathrm{stat})^{+5}_{-2}(\mathrm{syst}) \pm 2(\mathrm{pdf}) \pm 5(\mathrm{lumi}))\%$

Conclusions

- A top signal can be extracted already with the first 10 pb^{-1} of data.
- The expected uncertainty on ttbar cross section is determined in both semi-leptonic and dileptonic events for L =100 pb^{-1} at $\sqrt{s}$ = 14 TeV
- Overall uncertainties are of the order of 5 to 10% and dominated by systematics
- Consistency between methods and channels can place constraint on new physics
- For the luminosity we expect to have a 5-10% additional uncertainty

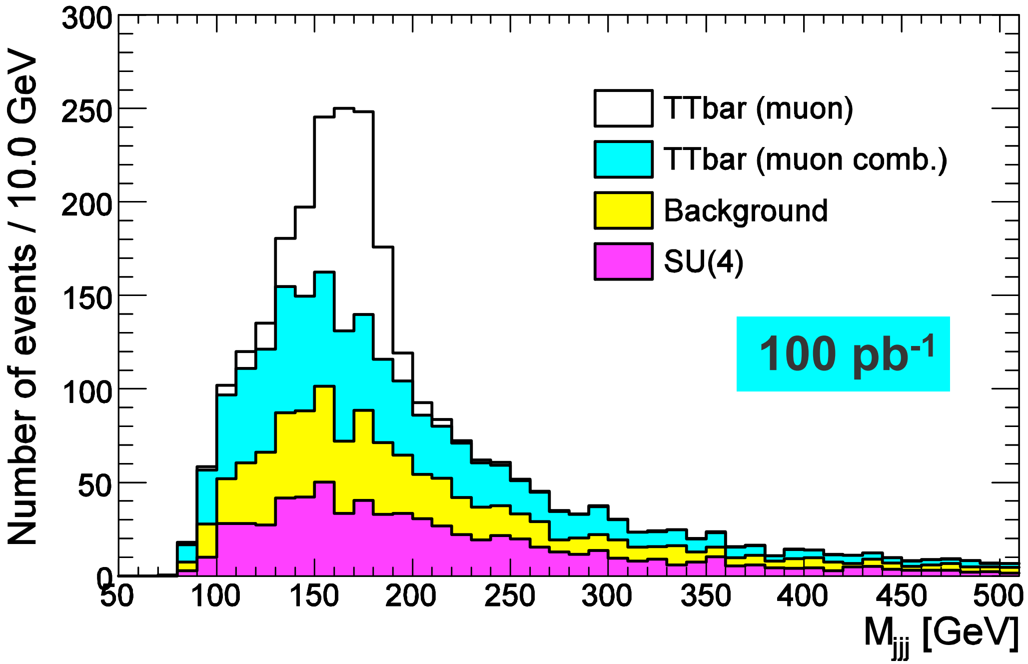
10 TeV: x-sec theoretical prediction



BACkup

Single Lepton: new contributions?

New phys at TeV scale has cross sections ~ a few pb.
Expected efficiencies for V→ttbar are ~1%:
small impact on total cross section



Contribution of the SU4 SUGRA point

Summary – Machine parameters

- The special calibration run will improve the precision in the determination of the overlap integral . In addition it is also possible to improve on the measurement of N (number of particles per bunch). Parasitic particles in between bunches complicate accurate measurements. Calibration runs with large gaps will allow to kick out parasitic particles.

- Calibration run with special care and controlled condition has a good potential for accurate luminosity determination. About 1 % was achieved at the ISR.

- Less than ~5 % might be in reach at the LHC (will take som time !)

Summary – optical theorem

Measurements of the total rate in combination with the t-dependence of the elastic cross section is a well established and potentially powerful method for Luminosity calibration.

Error contribution from extrapolation to t=0 < 1 % (theoretical and experimental)

Error contribution from total rate ~ 0.8 % → 1.6 % in luminosity

Ultimate goal stated by TOTEM:

Error from ρ ~ 0 .5 %

"Measurement of L and σ_{tot} with Optical Theorem at the 1 % level. "

⇨ Luminosity determination of 2-3 % might be in reach

Luminosity from Machine parameters

- Luminosity depends exclusively on beam parameters:

$$\mathcal{L} = \frac{N^2 f_{\mathrm{rev}} n_b}{4\pi\sigma^{*2}}$$

Depends on f_{rev} revolution frequency

n_b number of bunches

N number of particles/bunch

σ^* beam size or rather overlap integral at IP

$$\sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

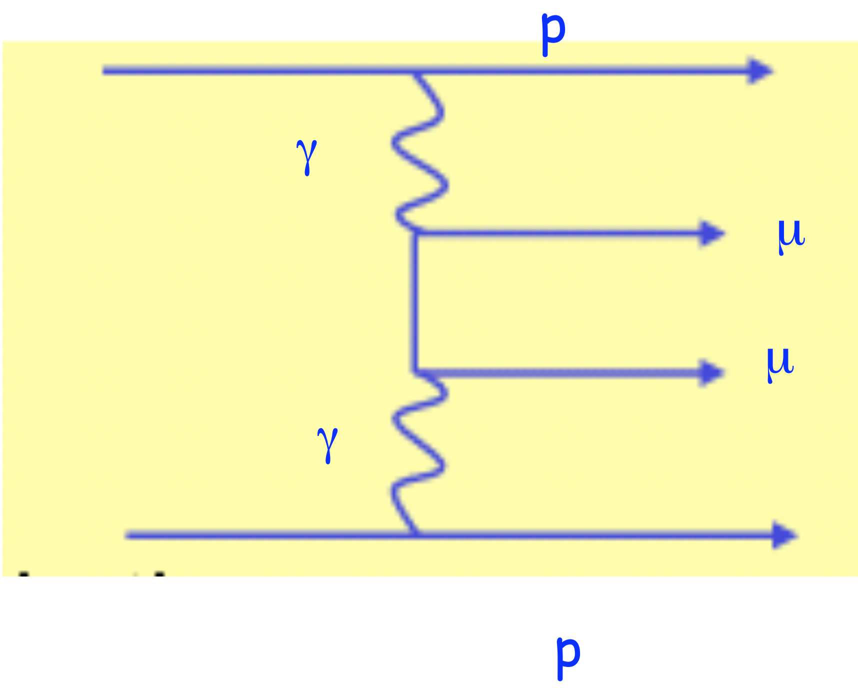
The luminosity is reduced if there is a crossing angle (300 μrad)

1 % for β^* = 11 m and 20% for β^* = 0.5 m

- Luminosity accuracy limited by
  - extrapolation of σ_x, σ_y (or ε, β_x^*, β_y^*) from measurements of beam profiles elsewhere to IP; knowledge of optics, …
  - Precision in the measurement of the the bunch current
  - beam-beam effects at IP, effect of crossing angle at IP, …

We expect to be able to predict absolute luminosities for head-on collisions based on beam intensities and dimensions, to maybe 20-30 % and potentially much better if a special effort is made.

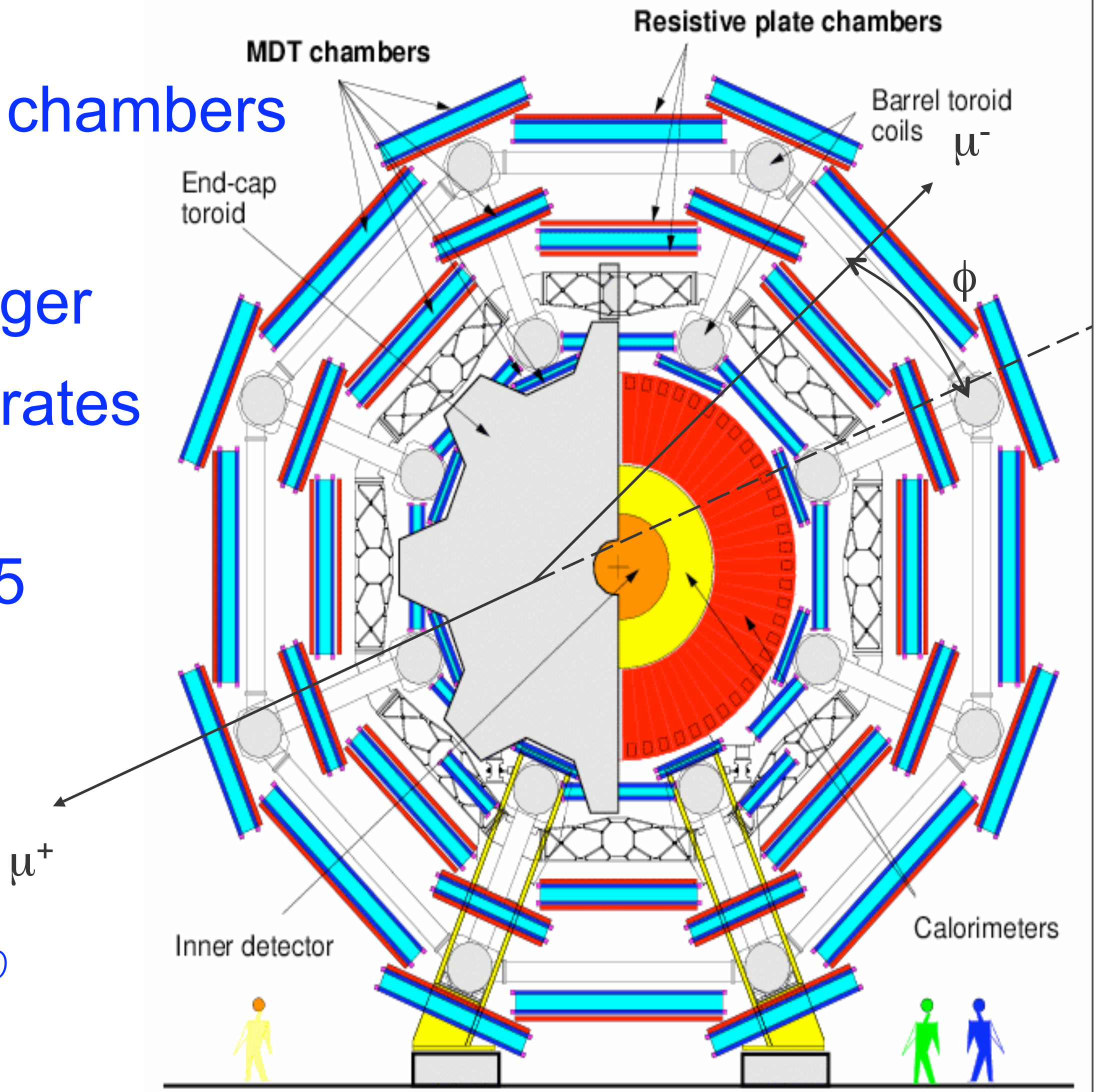
Two γ production of muon pairs-QED



- Pure QED
- Theoretically well understood
- No strong interaction involving the muons
- Proton-proton re-scattering can be controlled
- Cross section known to better than 1 %

Two photon production of muon pairs

- P_t >3 GeV to reach muon chambers
- P_t >6 GeV to maintain trigger efficiency and reasonable rates
- Centrally produced η < 2.5
- $P_t(\mu\mu) \sim$ 10-50 MeV
- Close to back to back in φ (background suppression)



What are the difficulties ?

- The rate

  The kinematical constraints ⇨ $\sigma \sim 1$ pb

  A typical $10^{33}/cm^2/sec$ year ~ 6 fb $^{-1}$ and ~ 150 fills

  ⇨ 40 events fill ⇨ Luminosity MONITORING excluded

  What about LUMINOSITY calibration?

  1 % statistical error ⇨ more than a year of running

- Efficiencies

  Both trigger efficiency and detector efficiency must be known very precisely. Non trivial.

- Pile-up

  Running at $10^{34}/cm^2/sec$ ⇨ “vertex cut” and “no other charged track cut”

  will eliminate many good events

- CDF result

  First exclusive two-photon observed in e^+e^-. …. but….

  16 events for 530 pb^{-1} for a σ of 1.7 pb ⇨ overall efficiency 1.6 %

W and Z counting

- Constantly increasing precision of QCD calculations makes counting of leptonic decays of W and Z bosons a possible way of measuring luminosity. In addition there is a very clean experimental signature through the leptonic decay channel.
- Use W in this discussion. σ (W) x BR(W $\rightarrow$ lν) has more favourable rate. The rate is 10 x σ (Z) x BR(Z $\rightarrow$ ll).

$$L = (N - BG) / (\varepsilon \times A_W \times \sigma_{th})$$

L is the integrated luminosity

N is the number of W candidates

BG is the number of back ground events

ε is the efficiency for detecting W decay products

A_W is the acceptance

σ_{th} is the theoretical inclusive cross section

W and Z counting

- W/Z production -> high cross section and clean experimental signature.

- The biggest uncertainties in the W/Z cross section comes from the PDF's. Sometimes quoted as big as 8 % taking into account different PDF's sets. Adding experimental uncertainties we end up in the 10 % range.

- The precision might improve considerable if data themselves can help the understanding of the differences between different parameterizations ….. (A_w might be powerful in this context!)

- The PDF's will hopefully get more constrained from early data. Aiming at 3-5 % error on the Luminosity from W/Z cross section after some time after the start up

Single Lepton: di-top mass spectrum

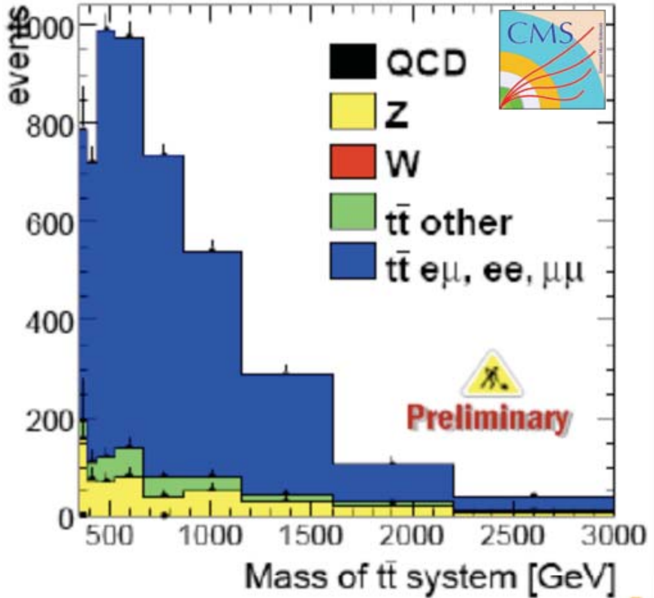
- Use Default selection.
- Kinematic fit imposes M_W and M_{top} + min X^2 used to choose jet assignment → improves reco

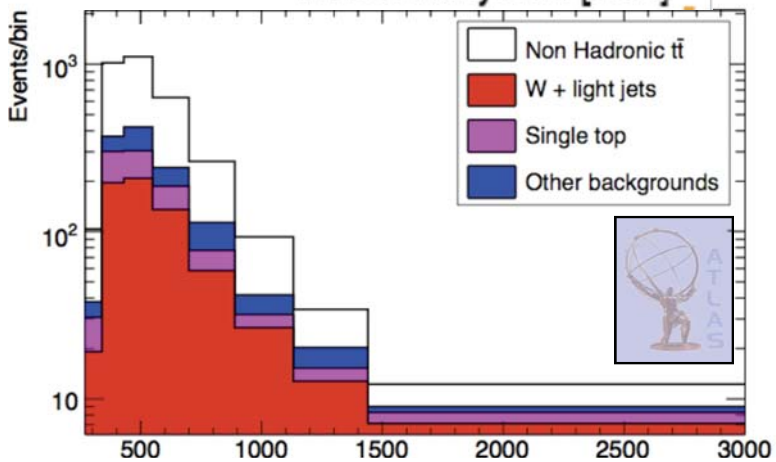
Resolution: critical.
$RMS(M_{tt}^{true} - M_{tt}^{reco})/M_{tt}^{true}$ ~5% to 9% in 200 to 850 GeV range

Variable bin size (2•8% M_{tt}) to reduce bin-to-bin migrations

Expected stat uncertainty on M_{tt} bins: from ~3% to ~25% (8% on av)

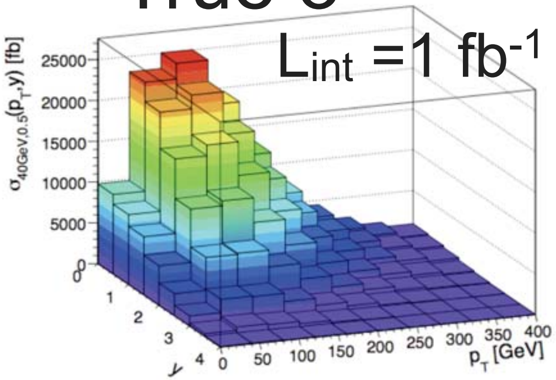
Consistency check of SM and openly sensitive to new physics





Single Lepton: $d\sigma/dydp_T$

True σ



Standard sel + only 2 b-tags (high purity)

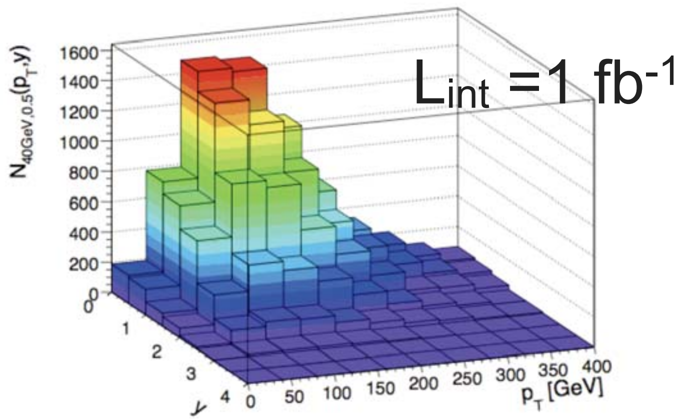
Small bkg contr included in plots

Reconstructed σ

- Get W candidates: all di-jet comb with 60 GeV<M(jj)<100 GeV
- Couple each W candidate with nearest b-tagged jet
- Top is highest P_T comb

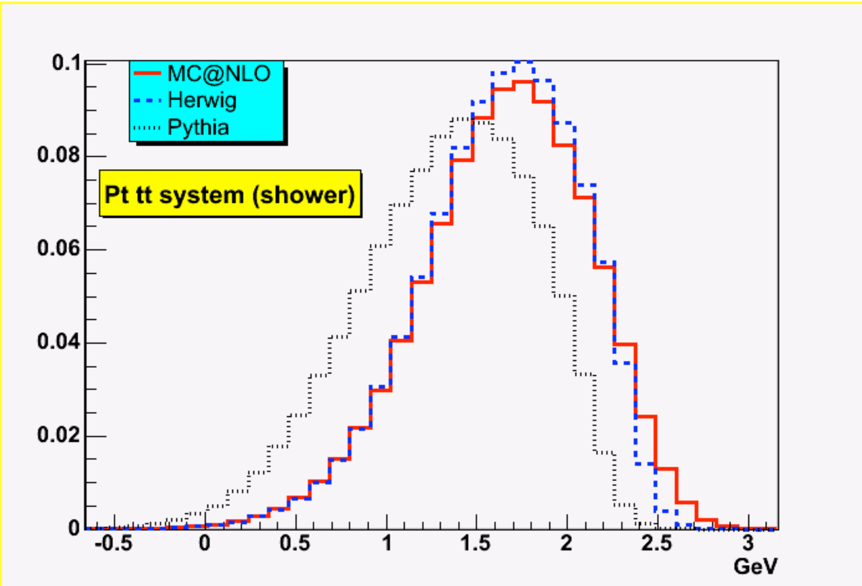
45% purity

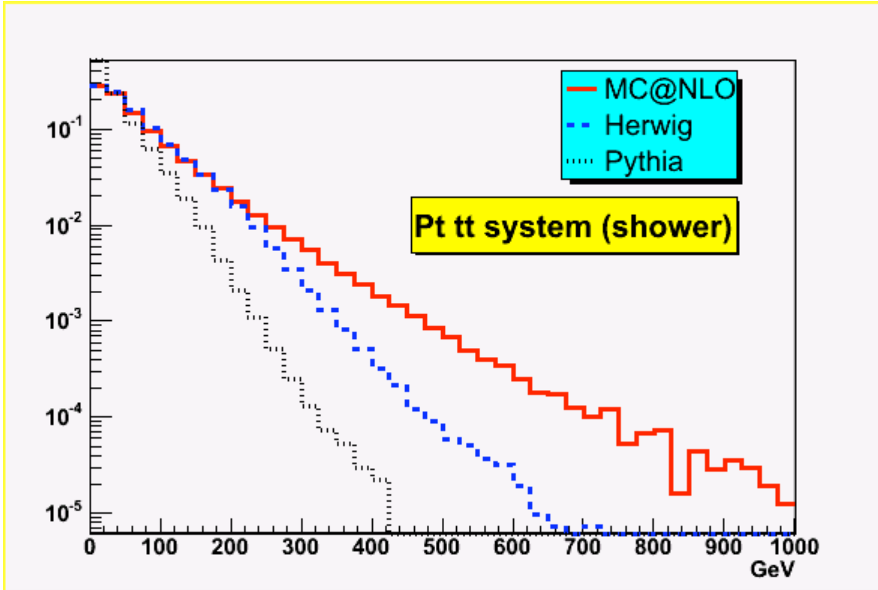
Interesting region: |y|<2 ,
50 GeV<P_T <280 GeV



Stat uncertainty on edge bins: 10% for L_{int} = $1fb^{-1}$ and 30% for L_{int} = 100 pb^{-1}

Comparison to LO generators





Log(Pt)

- Pt(tt system)
  - Pt balanced by ISR & FSR
  - Herwig & MCatNLO agree in soft region at low Pt,
  - At large Pt NLO effects visible
  - PYTHIA completely off

Same distribution on linear scale

All distributions normalised to 1

Top quarks and search for new physics

First year at the LHC:

A new detector **AND** *a new energy regime*

1. Understand ATLAS using *cosmics*
2. Understand SM+ATLAS in *simple topologies*
3. Understand SM+ATLAS in *complex topologies*
4. Look for *new physics* in ATLAS at 14 TeV

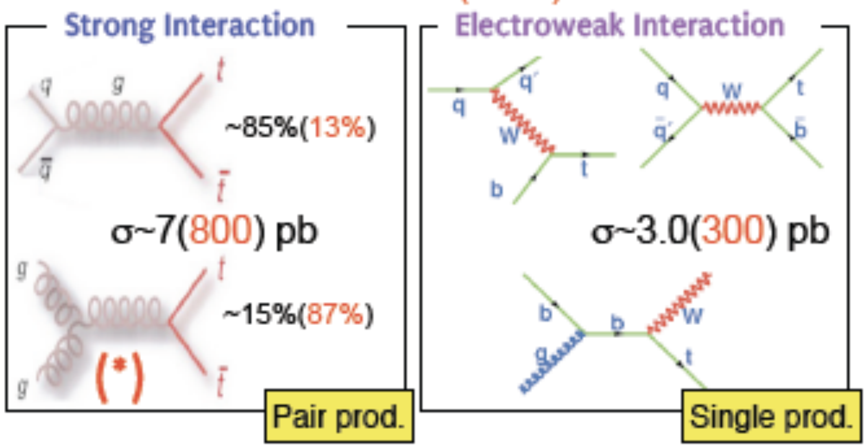
Process	#events 10 fb^{-1}
$b\bar{b}$	10^{12}
W ® eí (2)	10^{8}
Z ® $e^{+}e^{-}$/ì$^{+}$ì$^{-}$	10^{7}
$t\bar{t}$ (3)	10^{7}
$Min.\,bias$	10^{7}
$QCD\ jets\ P_T > 150\,GeV$	10^{7}
$h\ (m_h = 130\,GeV)$	10^{5}
$\tilde{g}\tilde{g}\ (m_{\tilde{g}} = 1\,TeV)$ (4)	10^{4}

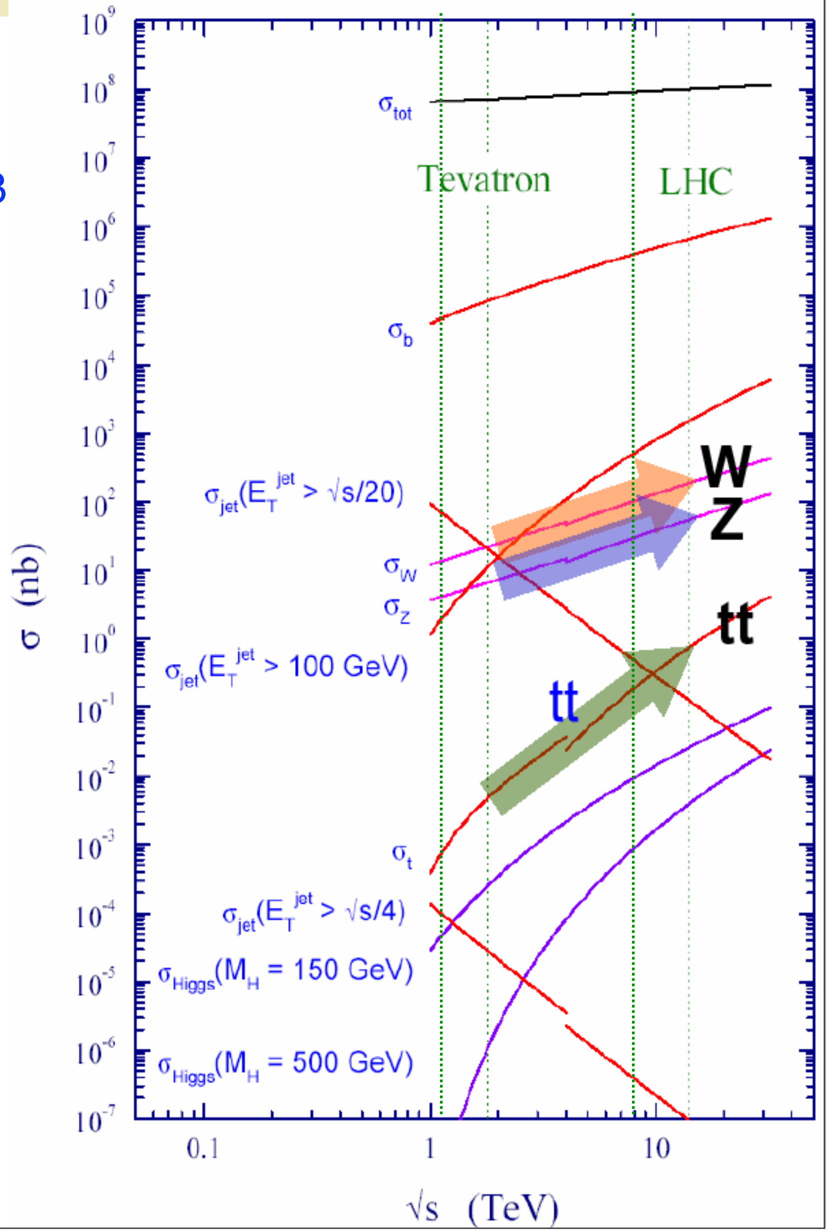
ttbar production

- LHC: A real **top “factory”**:
  $8 \cdot 10^6$ tt /experiment/year at L=10^{33}
  - Factor 10 increase later on
- Parton kinematic region (low-x) is gluon dominated:

$$x_1 x_2 = \frac{\hat{s}}{S} \geq \frac{4m_t^2}{S} \simeq 6 \cdot 10^{-4}$$

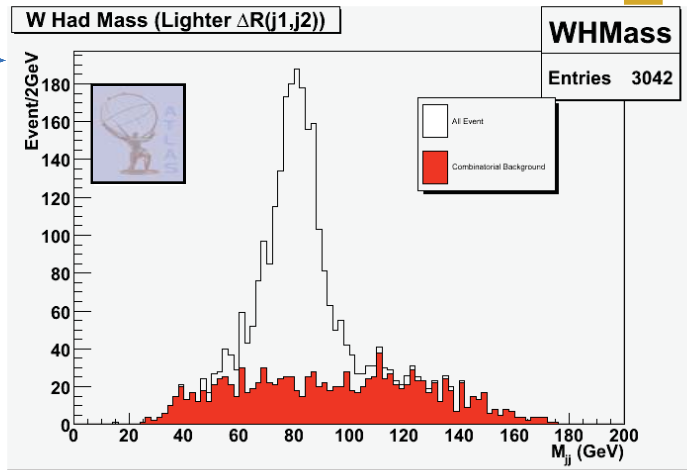
Tevatron (LHC)



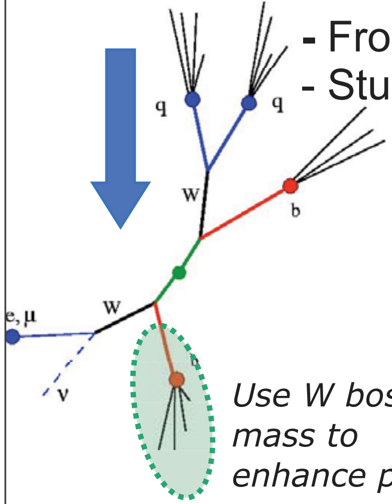


What can you do with early tops?

- **Calibrate light jet energy scale**
  - impose PDG value of the W mass (precision < 1%)



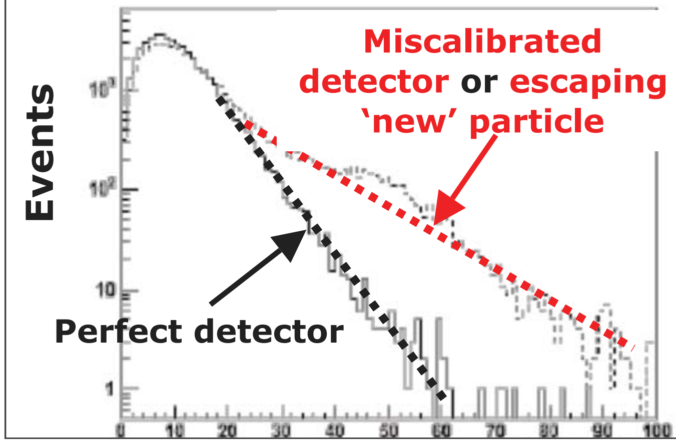
- **Estimate/calibration b-tagging ε**
  - From data (precision ~ 5%)
  - Study b-tag (performance) in complex events



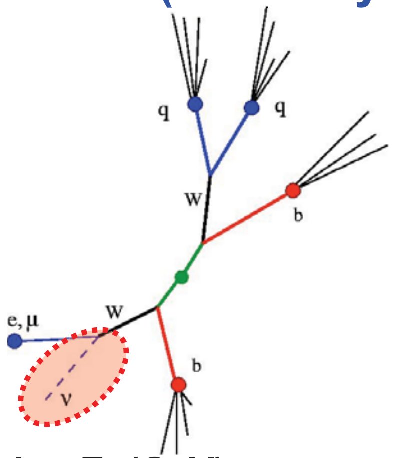
Use W boson mass to enhance purity

- **Study lepton trigger**

- **Calibrate missing transverse energy**
  - use W mass constraint in the event
  - range 50 GeV < p_T < 200 GeV



- **Estimate (accuracy ≤20%) of m_t and σ_{tt}.**

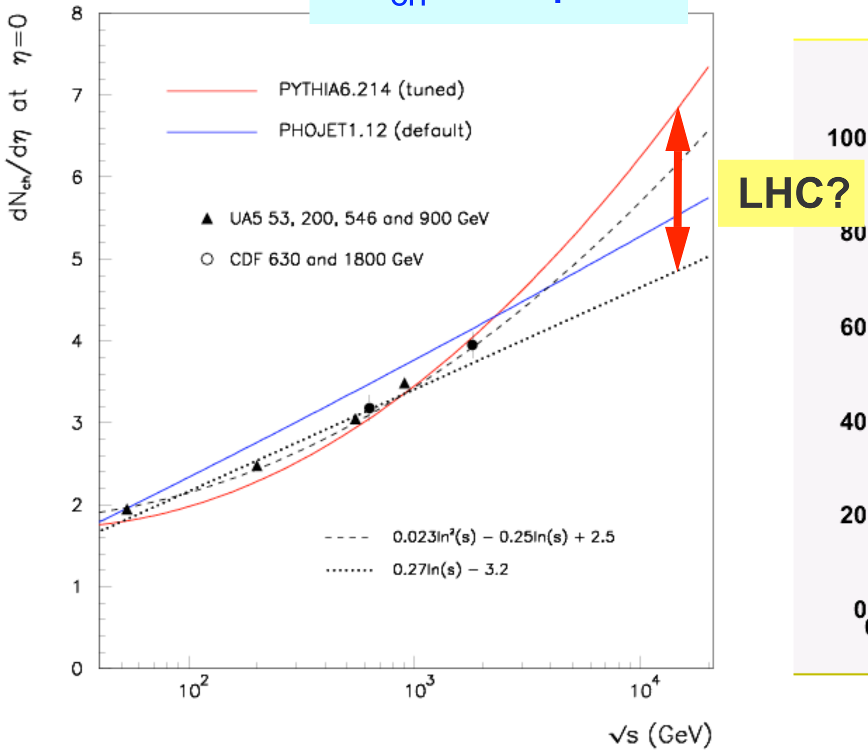


Missing E_T (GeV)

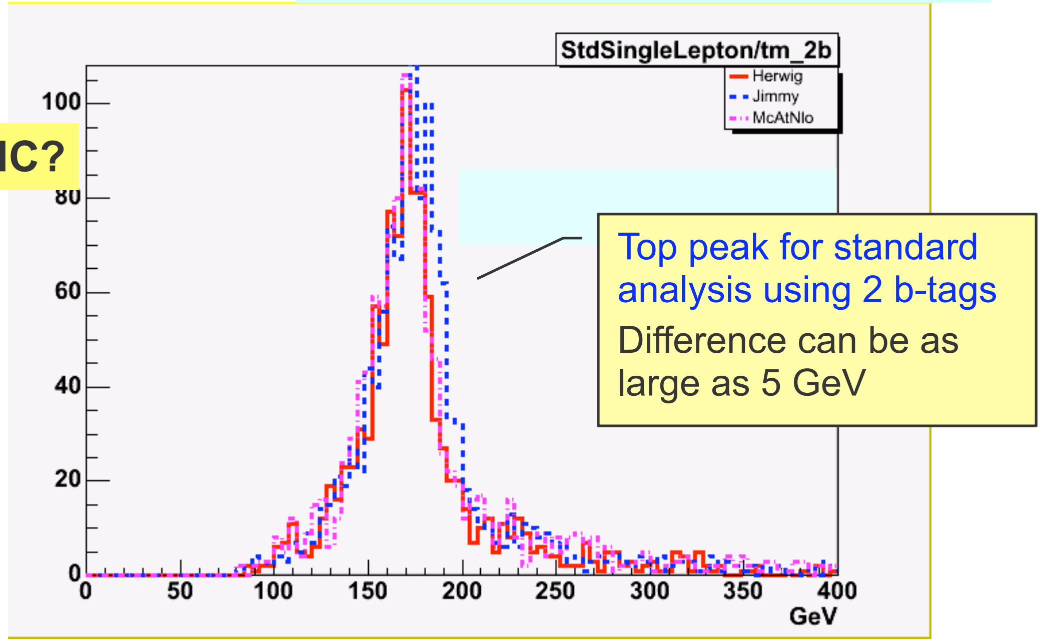
For calibration tools look at Petra's talk

UE / min-bias determination

$\langle n_{ch} \rangle$ at $\eta = 0$



M_{top} for various UE models



- Extremely difficult to predict the magnitude of the UE at LHC
  - Will have to learn much more from Tevatron before startup
  - Energy dependence of dN/dh ?

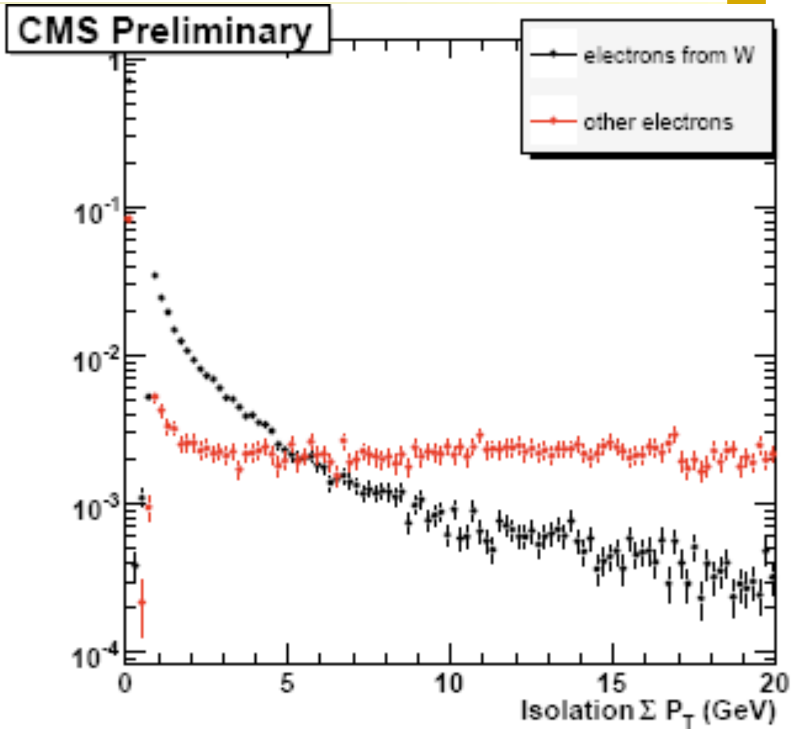
High precision top mass only after well understood detector & underlying physics

Trigger

- Single, dilepton triggers
  - understand efficiency curves in full pT range
  - isolation criteria for different topologies, luminosity in boosted tops, etc.
- Multijet trigger
  - for fully hadronic $t\bar{t}$ or semi-leptonic $t\bar{t}$ with $t \rightarrow W \rightarrow \tau \rightarrow$ had
  - add b-jet trigger?
- jet+MET
  - for semileptonic and dilepton decays including $\tau \rightarrow$ had
- τ+MET

Many triggers still to be understood and studied from the beginning

100pb^{-1}, ee,eμ,μμ: Event Selection



- HLT

ee :
-Single e or
-Double e trigger
eμ,μμ :
-Single μ (no iso, p_T>16GeV) or
-Double μ (no iso, p_T>3GeV) or
-Double mixed
(iso e, E_T>10GeV && no iso μ, P_T>10GeV)

- 2 OS leptons (ee,eμ,μμ)

P_T >20 GeV
H/E(lep) < 0.05
$0.8 \le E_{Ecal}/E_{Trk} \le 3.0$
e and μ: $\sum_{\Delta R \le 0.3} p_T^{Trk} < 3$
μ: $\sum_{\Delta R \le 0.3} E_T^{Tower} < 1$, e: $\sum_{\Delta R \le 0.3} E_T^{Tower} < 6$

- 2 jets

P_T > 30 GeV
ΔR(j, e with isoTrack > 2) > 0.3

100pb^{-1}, ee,eμ,μμ: x-section

$$\sigma \times BR = \frac{N_{sel} - N_{bkg}}{\varepsilon_{t\bar{t}} \times \int \mathcal{L}}$$

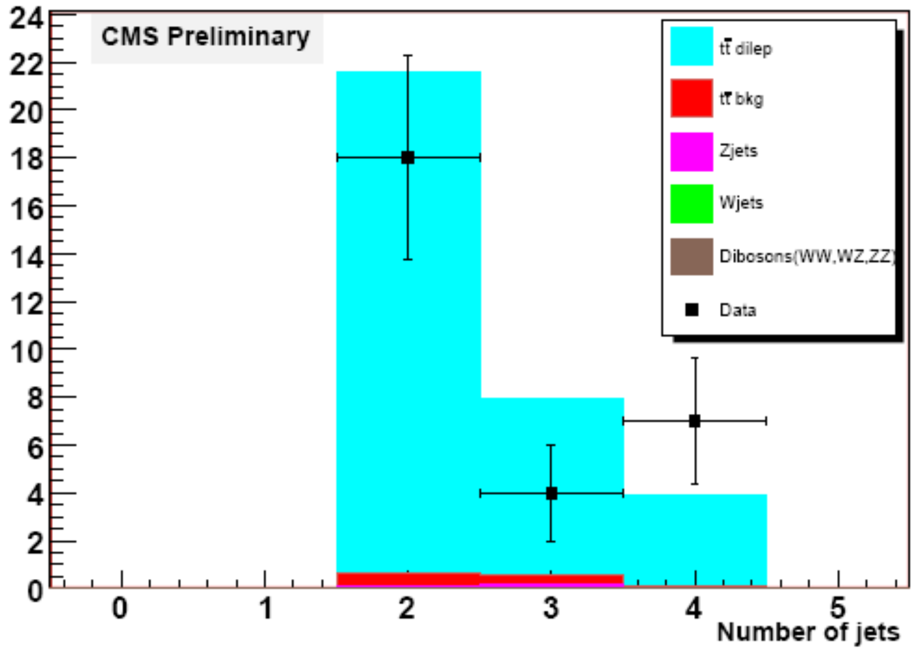
$$\varepsilon_{t\bar{t}} = \varepsilon_{t\bar{t}}^{HLT} \times \varepsilon_{t\bar{t}}^{MC} \times \varepsilon_{t\bar{t}}^{reco/sel}$$

$\varepsilon_{t\bar{t}}^{HLT}$ = HLT efficiency (from data)

$\varepsilon_{t\bar{t}}^{MC}$ = Selection efficiency (from MC)

$\varepsilon_{t\bar{t}}^{reco/sel}$ = MC/data correction factor (=1)

ee jet multiplicity

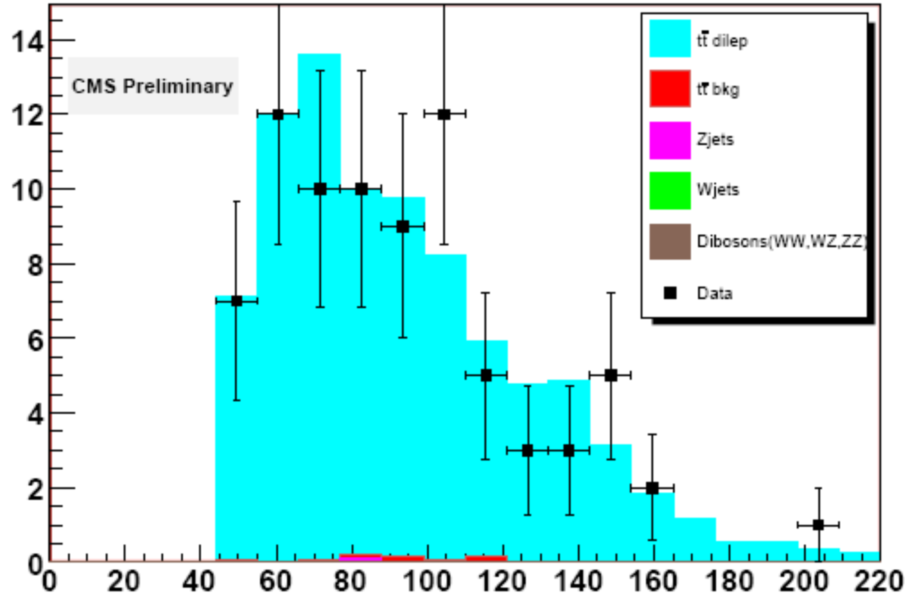


	ε_{tt}	S/B	$(\Delta\sigma/\sigma)_{stat}$
ee	2.3%	4	15%
μμ	3.5%	6	18%
eμ	3.2%	20	11%

All channels $(\Delta\sigma/\sigma)_{stat} = 8\%$

100pb^{-1}, ee,eμ,μμ: Event Selection

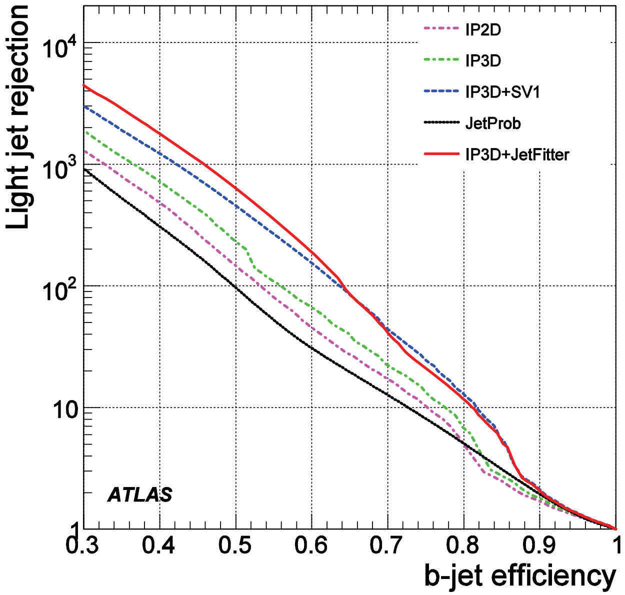
- E_T^{miss} > 50 GeV
  To suppress DY & QCD
- Require b-tagged jets
  Track counting algorithm
  "loose" requirements
  ε = 65%, mistag rate = 13%
- $|M(ll) - M_Z|$ > 15 GeV
  ee and μμ events only!
  To reject Z+jets events

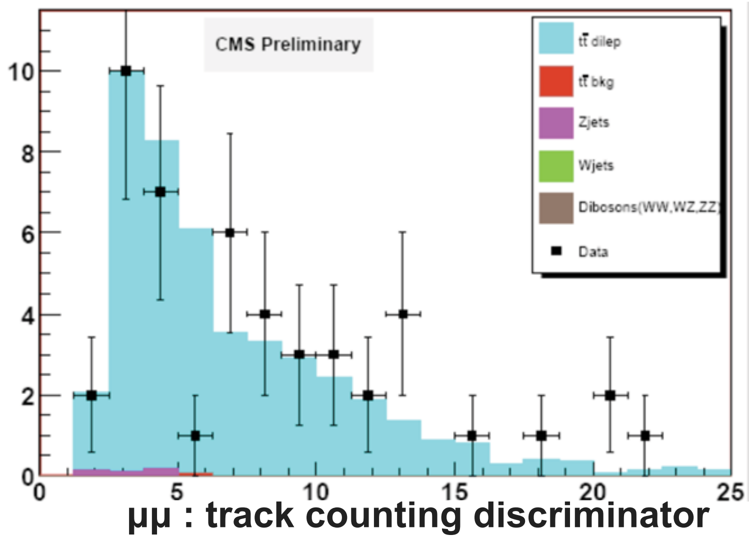


eμ : E_T^{miss}(GeV)

Single Lepton: adding the b-tagging

- ATLAS: likelihood algorithm weight *w* constructed from the results of the IP3D impact parameter and SV1 secondary vertex-based tagger.
  - *w* is large for b-jets and low for light jets: a cut *w*>6 results in an overall efficiency ε_b~63% R_u~250
- CMS uses mainly “track counting” and “track probability” methods involving IP and SV for tracks inside the jet
  - Typical efficiency for standard level is ε_b~50% R_{udsg}~100





Motivations for top quark physics

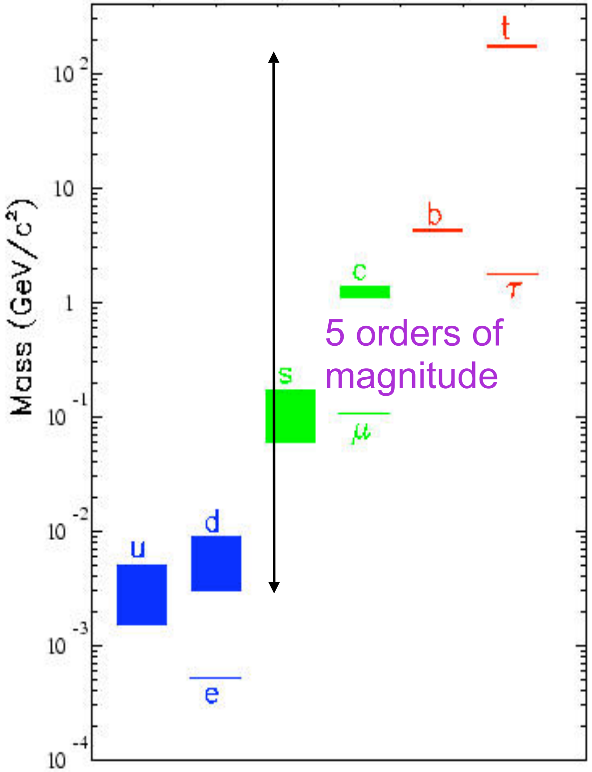
- Special in the EW role sector and in QCD
  - Heaviest elementary particle known → Yukawa coupling close to 1.0
  - Top and W masses constrain the Higgs mass

A tool to probe symmetry breaking in SM

- Special role in various SM extensions
  - New physics often preferentially coupled to tc
  - New particles can produce / decay to tops

A sensitive probe to new physics

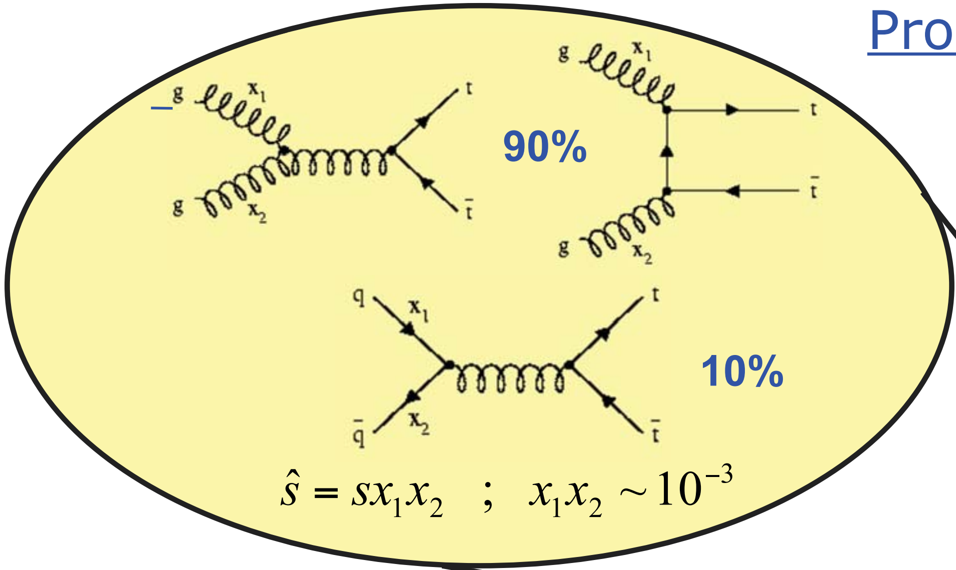
- Special interest even if it is just «normal»



A major source of background for many searches

A tool to understand/calibrate the detector, all sub-detectors involved

Top quark production at the LHC



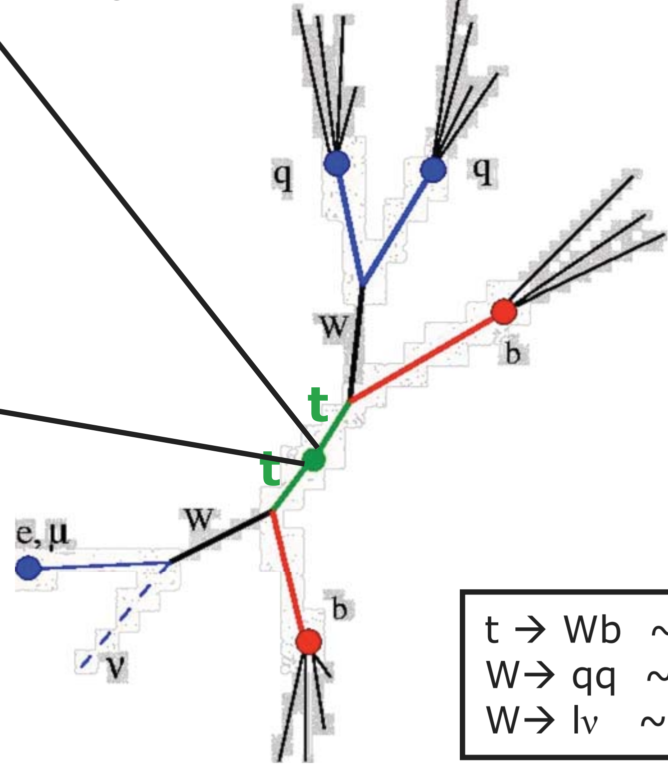
$$\hat{s} = s x_1 x_2 \quad ; \quad x_1 x_2 \sim 10^{-3}$$

Production: σ_{tt}(LHC) ~ 830 ± 100 pb

→ *1 tt-event per second*

Cross section LHC = 100 x Tevatron

Background LHC = 10 x Tevatron



Final states:

1) Full hadronic (4/9): 6 jets
2) Semi-leptonic (4/9): 1l + 1ν + 4 jets
3) Full leptonic (1/9): 2l + 2ν + 2 jets

t → Wb ~ 1
W→ qq ~ 2/3
W→ lν ~ 1/3

→ *Golden channel* (l=e,μ)→ 2.5 million events@10 fb^{-1}

10 pb^{-1} Rediscovery: dileptonic

HLT:

- Single μ (p_T > 16 GeV) or
- Single e (p_T > 17GeV), loose isolation cuts

2 opposite-charge leptons:

- Track-based isolation for e
- Track-&Calo-based isolation for μ
- $p_T \geq 20$ GeV

eμ:

- $E_T^{miss} > 20$ GeV

ee and μμ:

- $|M(ll) - M(Z)| > 15$ GeV
- $E_T^{miss} > 30$
- $E_T^{miss} > 0.6\, p_T^{ll}$

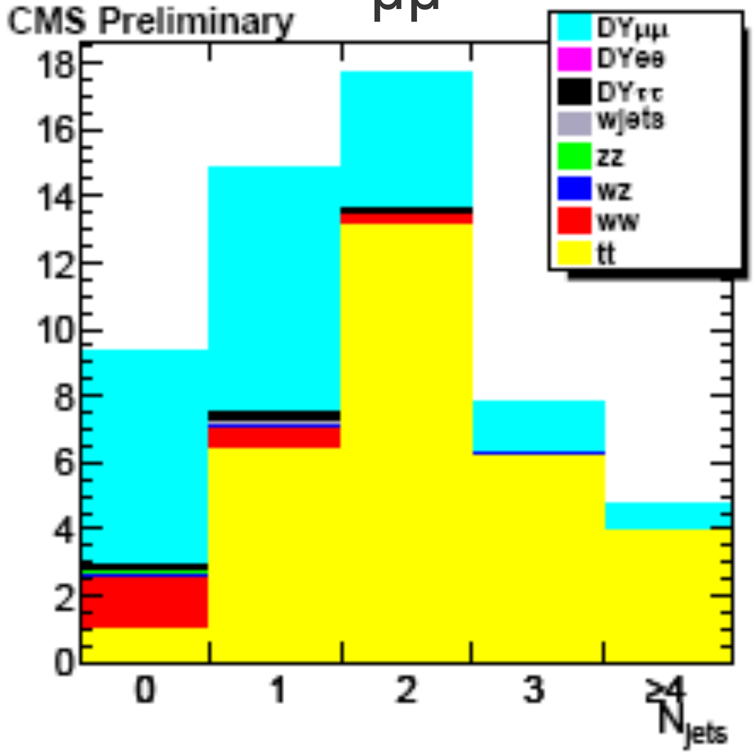
OR angle($\mathbf{p_T^{ll}}$, $\mathbf{E_T}$)>0.25

$10pb^{-1}$ Rediscovery: dileptonic

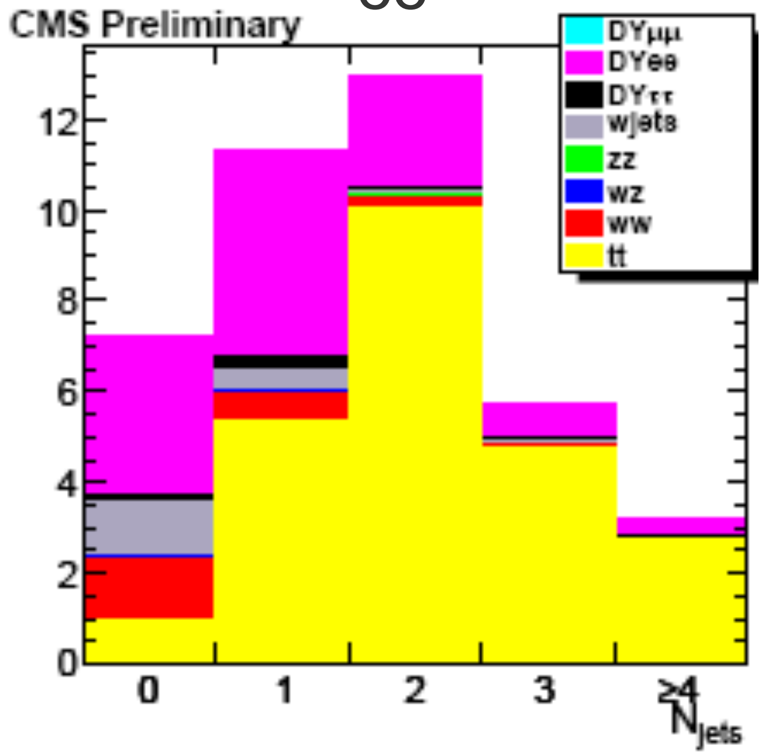
Count jets with p_T>30 GeV

Test background prediction with N_j=0,1, extract signal from N_j≥2

μμ



ee

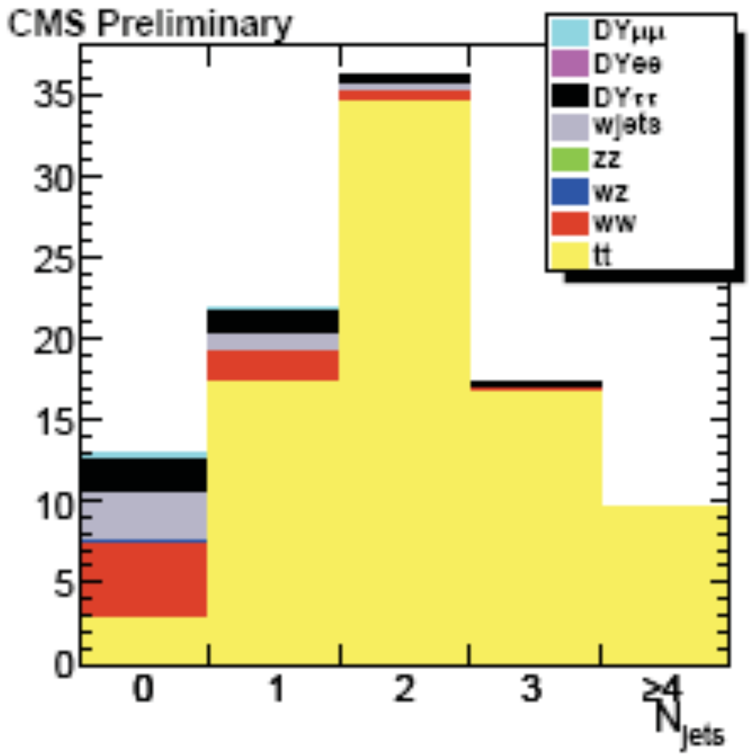


Main Background: DY+jets

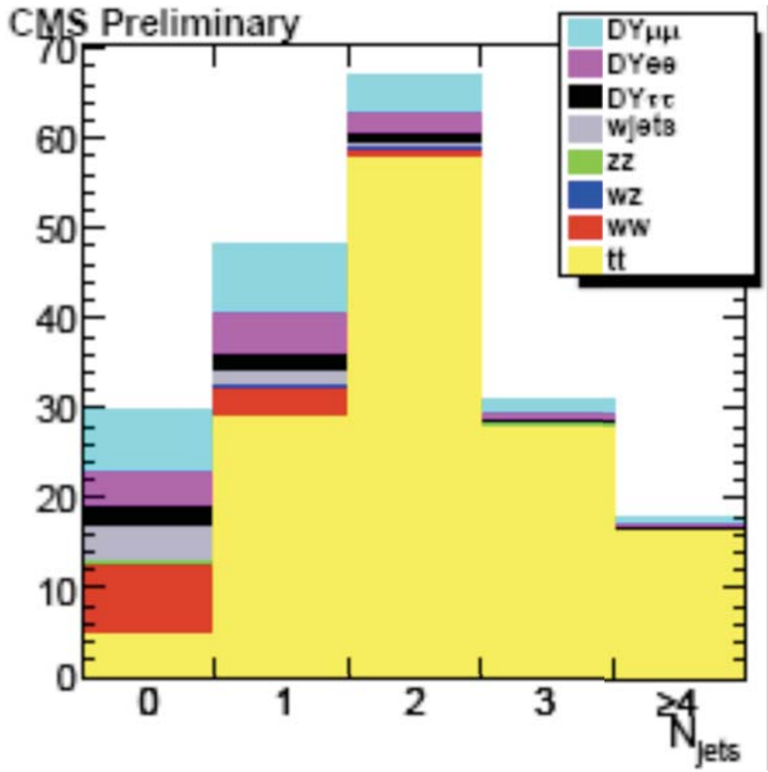
Dependent on our understanding of E_T^{miss}

10 pb^{-1} Rediscovery: dileptonic

eμ



Total



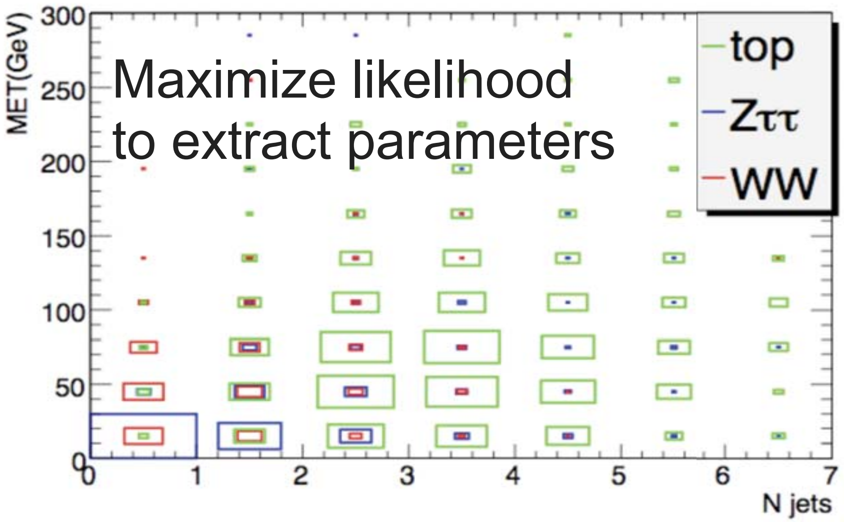
Statistical uncertainty ~ 9%

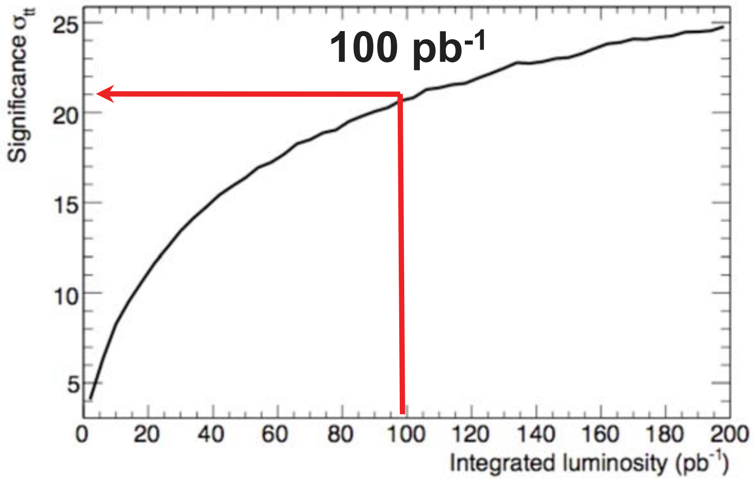
…or by limiting ourselves to the eμ channel ~13%

Systematic uncertainties expected to be in the same order

x-sec with 100 pb^{-1}: dileptonic

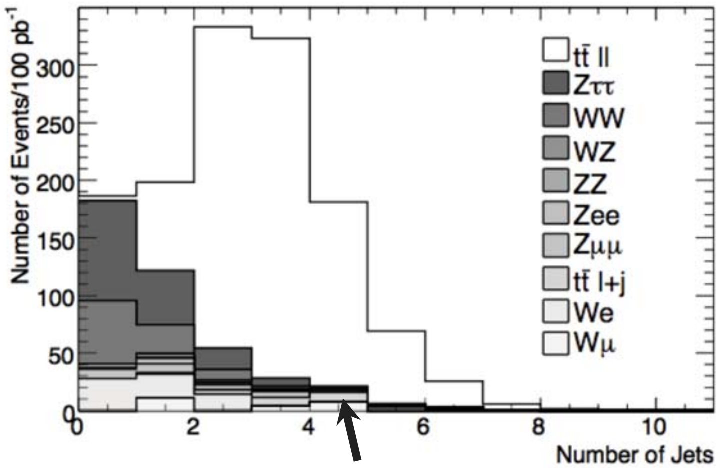
Inclusive template method





Build 2D distrib (E_T^{miss}, N_{jets}) for signals and bkgs

Derive binned likelihood for data as a function of x-sec, acceptance, bkg norm



Fit (eμ) then impose Z veto and Et>35 GeV on (ee, μμ)

Syst on acceptance and template shapes are taken into account

100pb^{-1}, $e\tau,\mu\tau$: Selection

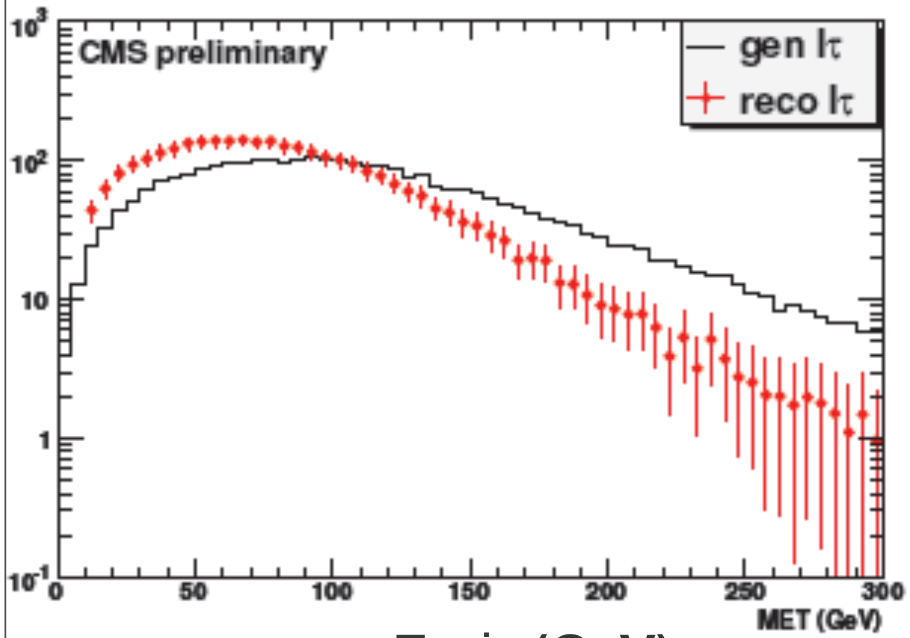
- HLT

Same triggers as ee, eμ, μμ channels

- At least one e/μ

P_T >30 GeV, $|\eta|$ < 2.4

Isolation



E_T^{miss}(GeV)

	1-prong	3-prong
$e\tau$	32.1	6.4
$\mu\tau$	41.2	6.5
Other ttbar	105.1	55.6
W+jets	56.1	32.9
Z+jets	23.2	4.2
S/B	0.397	0.139
$\varepsilon(e\tau)$	2.1%	0.42%
$\varepsilon(\mu\tau)$	2.7%	0.43%

- One τ candidate (OS)

$P_T^{leadTrk}$ > 20GeV, $|\eta|$ < 2.4

- E_T^{miss} > 60 GeV
- Objects separated by ΔR > 0.3
- b-tagging could double S/B

x-sec with 100 pb^{-1}: dileptonic

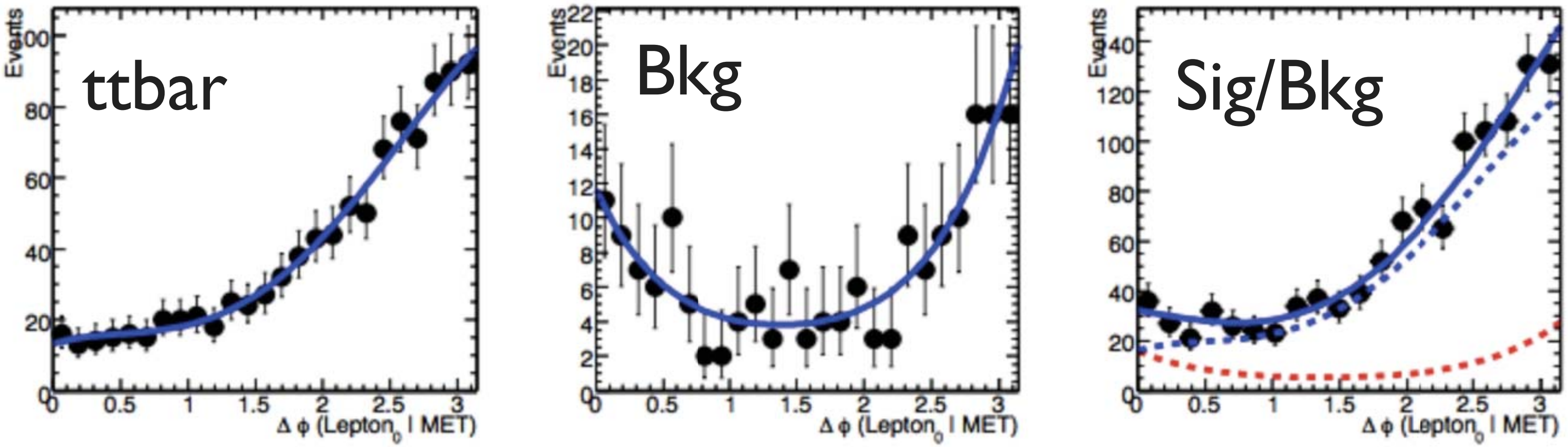
Likelihood method

Build unbinned likelihood

$$L = -\sum_{i=1}^{N_{tot}} \ln(G[x_i|N_{sig}, N_{bkg}]) + N_{tot}$$ with $$G(x) = N_{sig} \times S(x) + N_{bkg} \times B(x)$$

where $S(x)$ and $B(x)$ are signal and background distributions

for $x = \Delta\phi$ (highest pt lepton/ E_T^{miss}) or $\Delta\phi$ (highest pt jet/E_T^{miss})
derived by fitting Chebychev polynomial to MC samples



Maximize L to extract N_{sig} and N_{bkg}

x-sec with 100 pb^{-1}: dileptonic

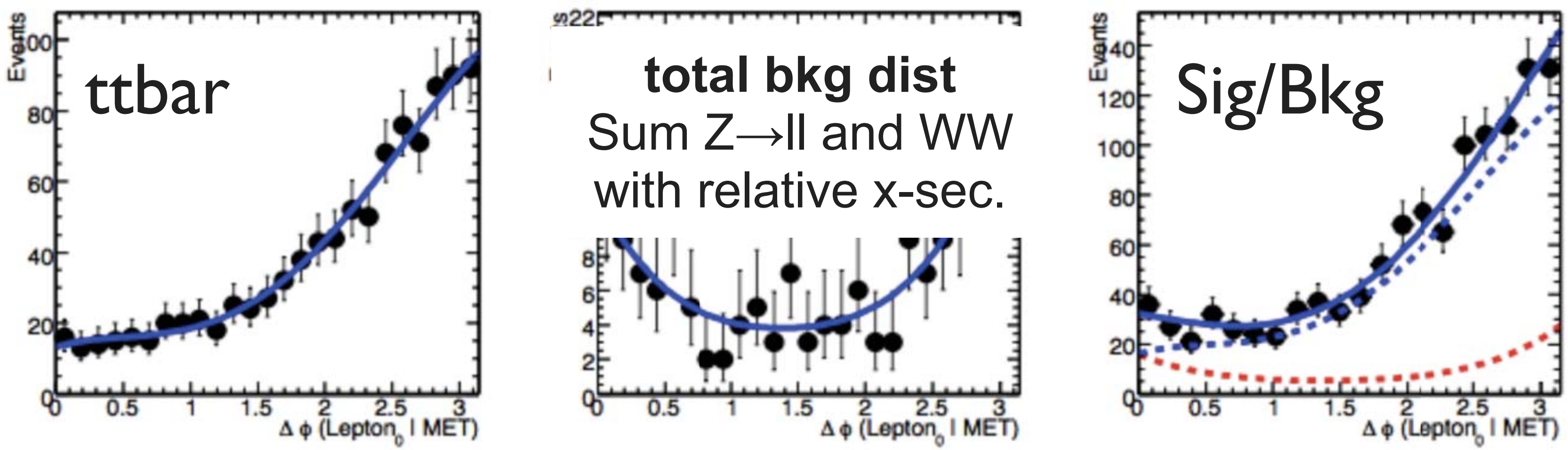
Likelihood method

Build unbinned likelihood

$$L = -\sum_{i=1}^{N_{tot}} \ln(G[x_i|N_{sig}, N_{bkg}]) + N_{tot} \quad \text{with} \quad G(x) = N_{sig} \times S(x) + N_{bkg} \times B(x)$$

where $S(x)$ and $B(x)$ are signal and background distributions

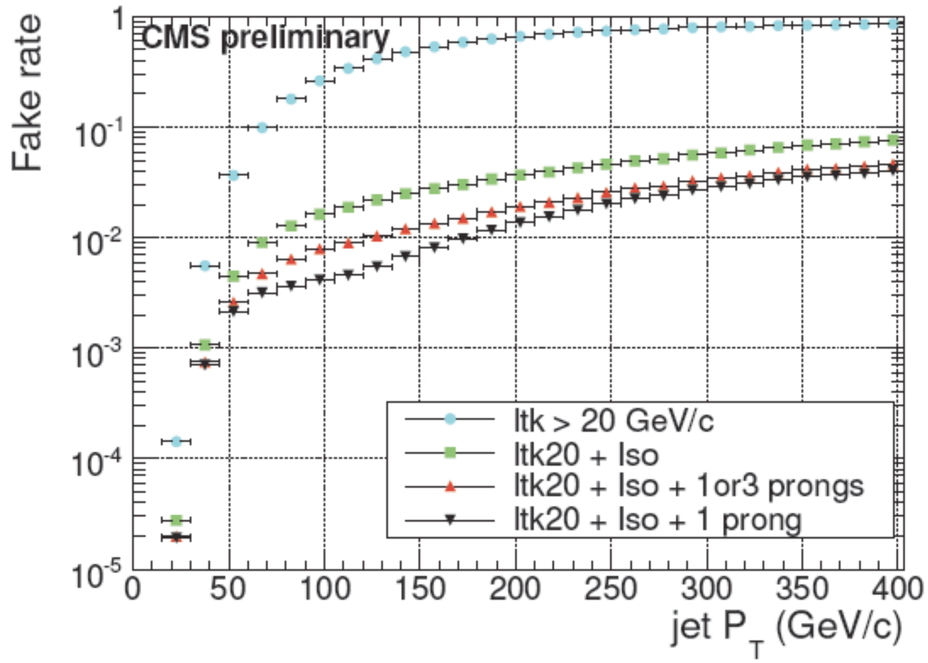
for $x=\Delta\phi$ (highest pt lepton/ E_T^{miss}) or $\Delta\phi$ (highest pt jet/E_T^{miss}) derived by fitting Chebychev polynomial to MC samples



Maximize L to extract N_{sig} and N_{bkg}

$100pb^{-1}$, eτ,μτ: BG estimation

- Large W+fake τ background
  - QCD W+jets
  - Semileptonic ttbar
- Multi-jet sample
  - find probability that a jet fakes a τ
  - parametrise it by P_T
- Jets passing the selection
  - apply fake rate on P_T spectrum
- Results on fake rate on multijet compared with results obtained in subsamples and γ+jets sample
  - after averaging, results are 27-30% from expectation from multi-jets

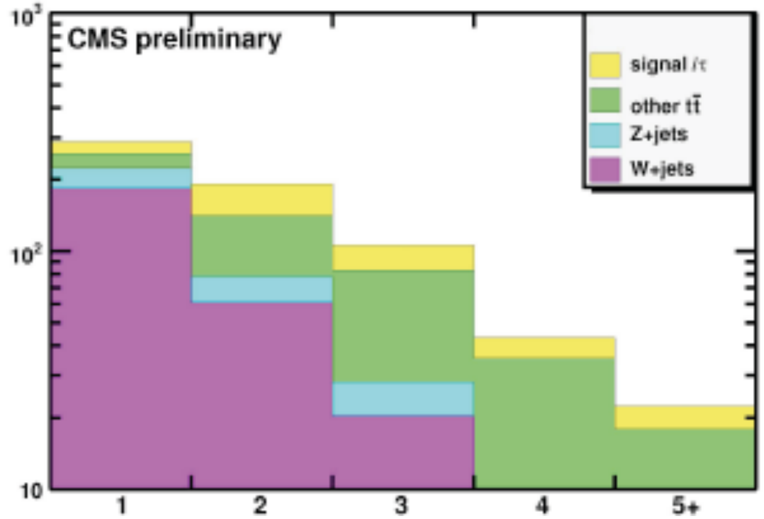


100pb^{-1}, eτ,$\mu\tau$: x-section

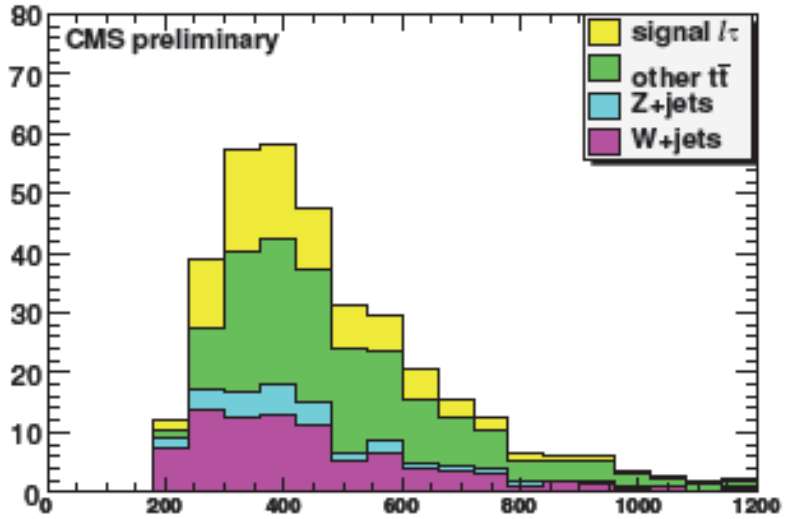
- The cross section can be extracted by an event count
- Main idea of this analysis: measure the ratio:

$$R = \frac{\sigma[t\bar{t} \rightarrow (l\nu)(\tau\nu_\tau)b\bar{b}]}{\sigma[t\bar{t} \rightarrow (l\nu)(l\nu)b\bar{b}]}$$

  - sensitive to deviations from the SM (eg by τ excess)
  - for which a lot of systematic uncertainties cancel out



No jets



HT(GeV)

How to evaluate ISR/FSR systematics uncertainty for top@LHC?

Problem:
MC Generator ISR/FSR description: model + parameters.
LHC: at 14TeV you have no data[1] $\Rightarrow$ you don't know:
- which model to choose,
- to which values to set parameters values.

Therefore: for ISR/FSR sensitive observables your prediction has a modeling uncertainty. Since there is no data (and MC hopefully describes the data): systematics uncertainty $\sim$ modeling uncertainty (reco. and analysis effects included).

Evaluation procedure:
1. compare different ISR/FSR models (used by different MC generators),
2. for the different models vary ISR/FSR parameters,
3. The biggest difference for an observable = MC uncertainty.

If ISR/FSR is your dominant source of uncertainty in this way you estimate the range of possible observable values MC Generators can describe.

For top (ttbar) mass and sel. efficiency at ATLAS evaluation looked like this:
1. We compared Herwig + MCNLO, Pythia + AcerMC and Herwig + AcerMC.
2. We identified the most important ISR/FSR tunable parameters (Pythia has plenty, Herwig not so many).
3. MC uncertainty was determined from Pythia ISR/FSR parameters variation.

Results and details of the evaluation at ATLAS are shown in the next 2 slides.

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[1] Tevatron data has been used to choose (more) appropriate ISR/FSR models and ranges of parameters values, but for many ISR/FSR sensitive observables predictions for the LHC have large uncertainties.