Before we start

- ✓ Warm thanks to the Organizers
- ✓ Non-Higgs Physics at LHC is wide
  - Special thanks to the Organizers
  - Warmest thanks to lots of people for valuable discussion & inputs
    - F. Gianotti, M. Cobal, S. Tapprogge, A. Moraes, E. Chierici, T. Lagouri, F. Charles, P. Traczyk, S. Shmatov, P. Eerola, …
- ✓ Try to be exhaustive
- ✓ Hope not to be exhausting

Non-Higgs Physics

L. Poggioli, LAPP

1. **Standard Model physics**

   W mass, TGC, TGC, QCD

2. **Supersymmetry**

   Inclusive, exclusive, Models

3. **Beyond Standard Model**

   Technicolor, Extra-dimensions, New particles

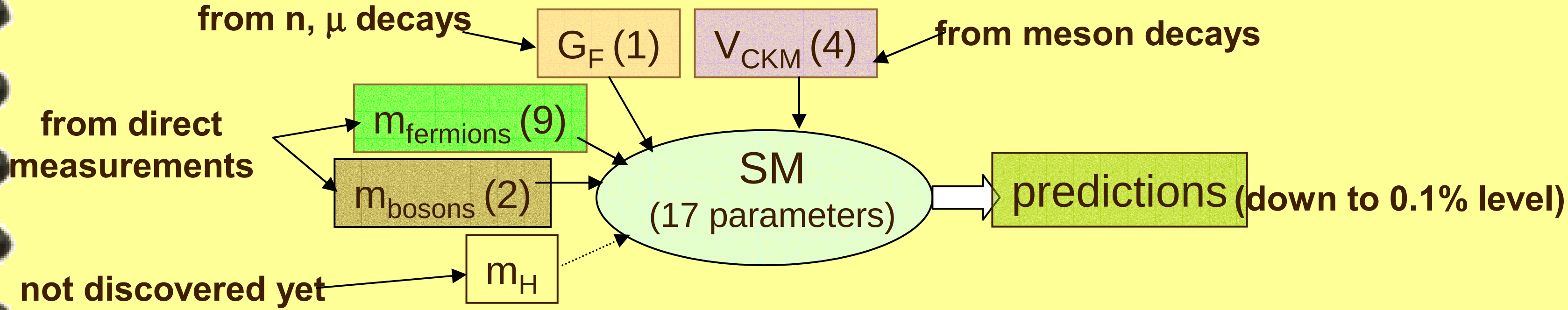
Standard Model

L. Poggioli, LAPP

- Introduction
- W mass
- Triple Gauge Boson Couplings
- Top physics
- QCD
- Prospects

Introduction

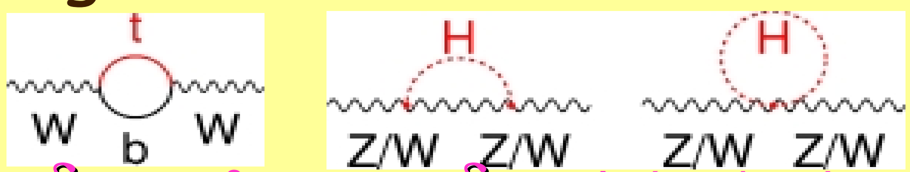
What we know



- ✓ No observable directly related to m_H: dependence through radiative corrections

Example:

$m_W = m_W(m_t^2, \log(m_H))$



$\delta t \propto m_t^2$ $\delta H \propto \ln(m_H/m_W)$

- ✓ By making precision measurements
  - Get information on the missing parameter m_H
  - Test the validity of the Standard Model

Where we are

✓ δm_t, δm_W dominates in the EW fit

$m_H < 211$ GeV @ 95% CL

✓ Perspectives at Tevatron run II

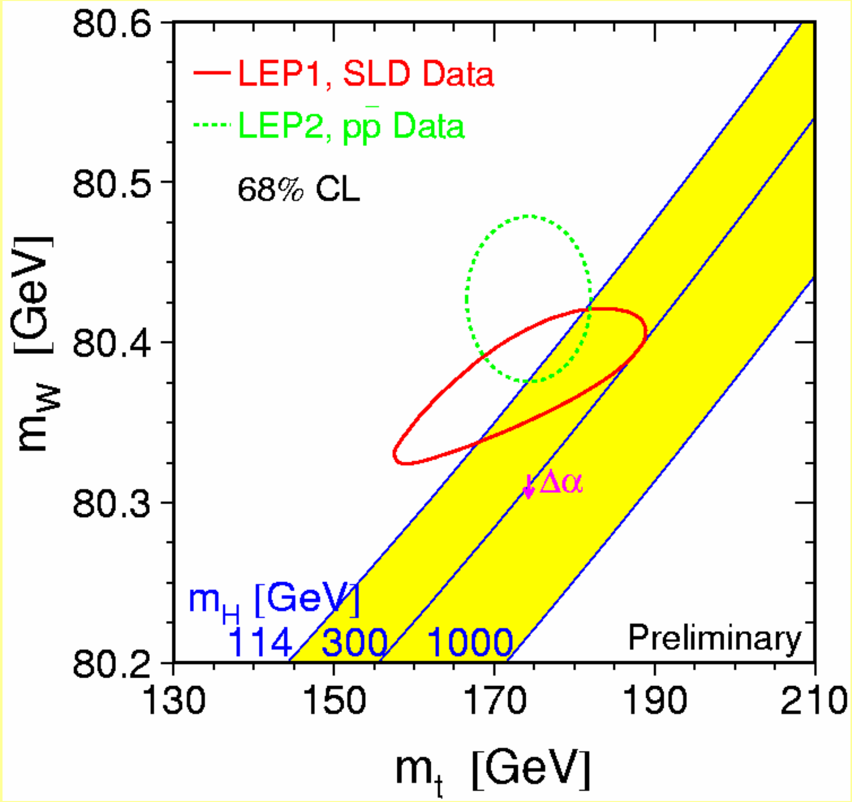
$\delta m_t \leq 2.5$ GeV ; $\delta m_W \leq 25$ MeV

$\Rightarrow \delta m_H/m_H \leq 35\%$

✓ Today

m_t=174.3 ±5.1(exp) GeV

m_W=80.426 ±0.035(exp) GeV



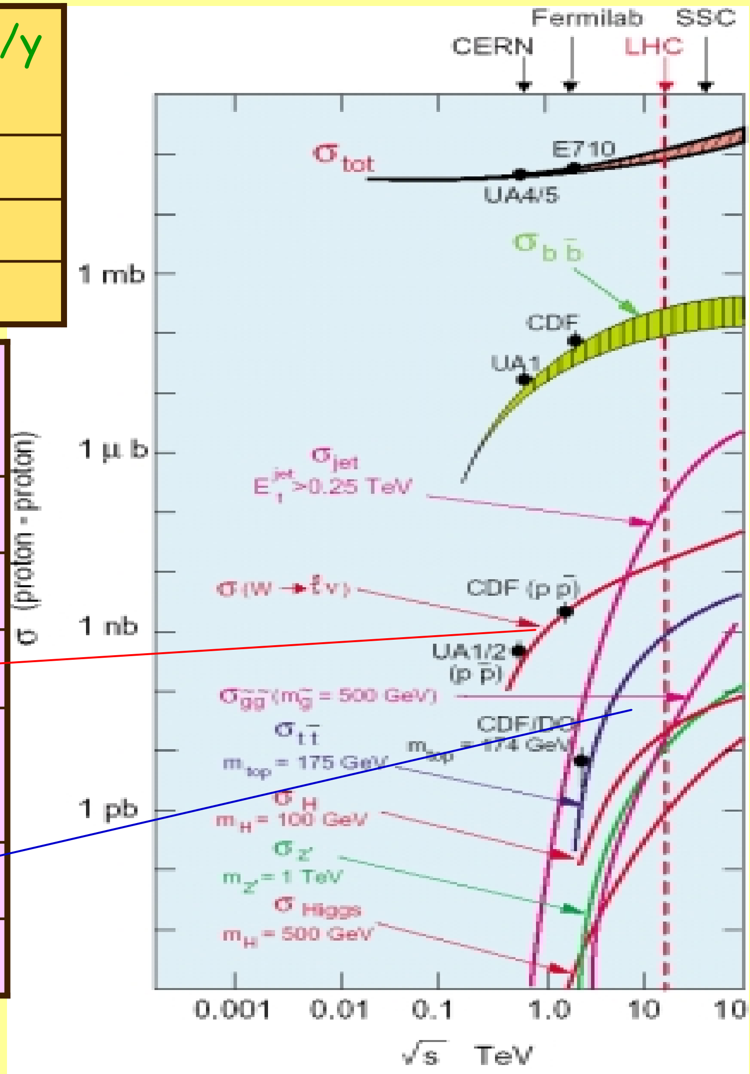
✓ At LHC ?

– Importance of SM precision physics

Expectation : SM processes

	E_{CM} TeV	Lumi $cm^{-2}s^{-1}$	Int. Lumi/y fb^{-1}
TeVatron	**2**	**$<10^{32}$**	**0.3**
LHC(low lumi)	**14**	**$2x10^{33}$**	**10**
LHC(high lumi)	**14**	**10^{34}**	**100**

Process	σ(pb)	Evts/s	Evts /y
bb	**5×10^{8}**	**10^{6}**	**10^{12}**
Z→ee	**1.5×10^{3}**	**~3**	**10^{7}**
W→eν	**1.5×10^{4}**	**~30**	**10^{8}**
WW→eνX	**6**	**10^{-2}**	**6×10^{3}**
tt	**830**	**~2**	**10^{7}**
H(700 GeV)	**1**	**2×10^{-3}**	**10^{4}**



W mass

Method

Systematics

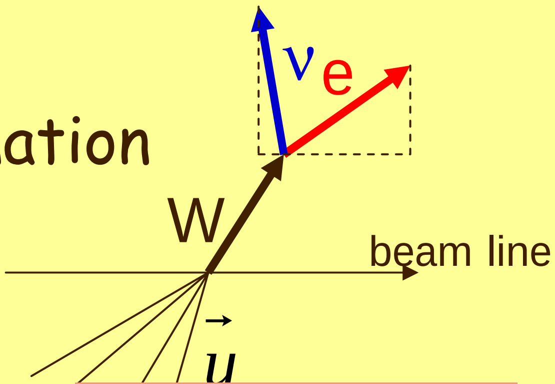
Reach

Basics

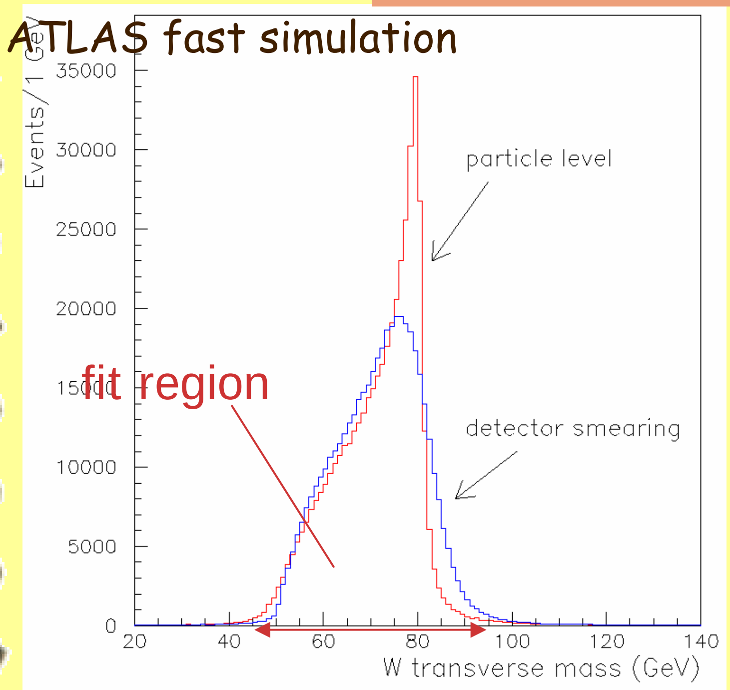
✓Determination

- W-pair cross-section is too low
- Single W: no direct m_W determination (neutrino) but huge statistics

$$m_W^T = \sqrt{2 p_l^T p_\nu^T (1 - \cos\Delta\phi)}$$



$$\vec{p}_\nu^{\,T} = -\left(\vec{p}_l^{\,T} + \vec{u}\right)$$



Selection efficiency: ~25% with
- p_T>25 GeV
- E_T^{miss}>30 GeV
- No jets with p_T>30 GeV
- Recoil |u|<20 GeV

still 60 millions W/y-e after selection
(50 times Tevatron)

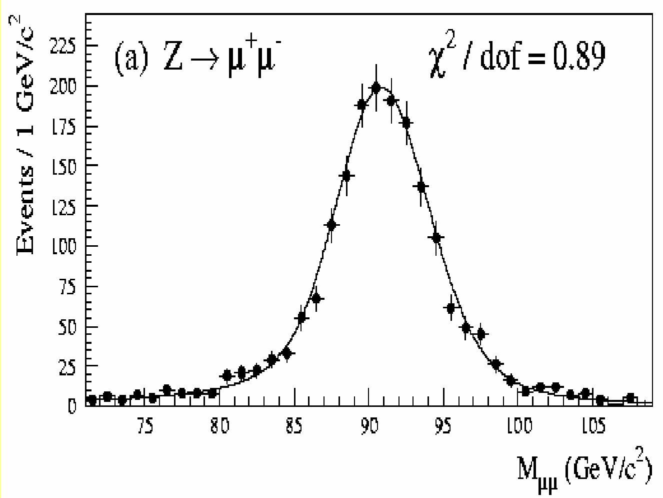
-> <2MeV/y as a statistical uncertainty

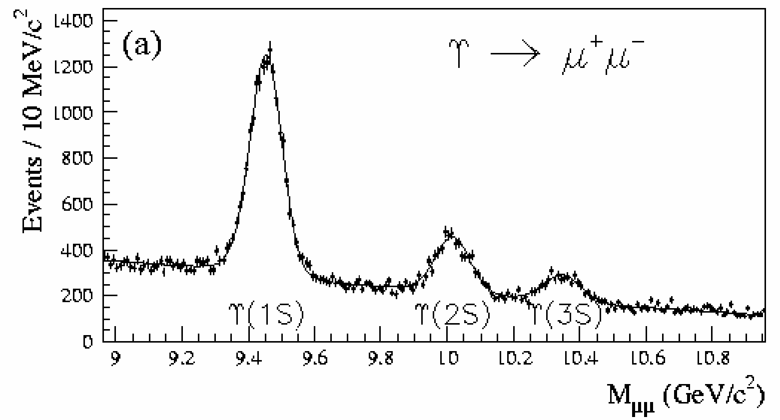
At LHC

- ✓ Issue is turning down Systematics
  - **Physics**: W width and angular distribution, structure functions
  - **Detector**: lepton momentum, E resolution, recoil spectrum
- ✓ Learn from Tevatron
  - Systematics from detector simulation -> Use data sample for in-situ calibrations
- ✓ Advantages of LHC
  - Huge statistics from control samples (Z -> ll)
  - Better detectors (acceptance, resolution)

Detector systematics

- ✓ Lepton E/P scale
  - 0.02% needed
  - Use Z->ee, μμ or Y->μμ
- ✓ Lepton E,p resolution
  - 1-2% needed
  - Use test beam & Z width reconstruction
- ✓ Recoil modelling
  - UE + detector
  - From Z->ll data





Physics systematics

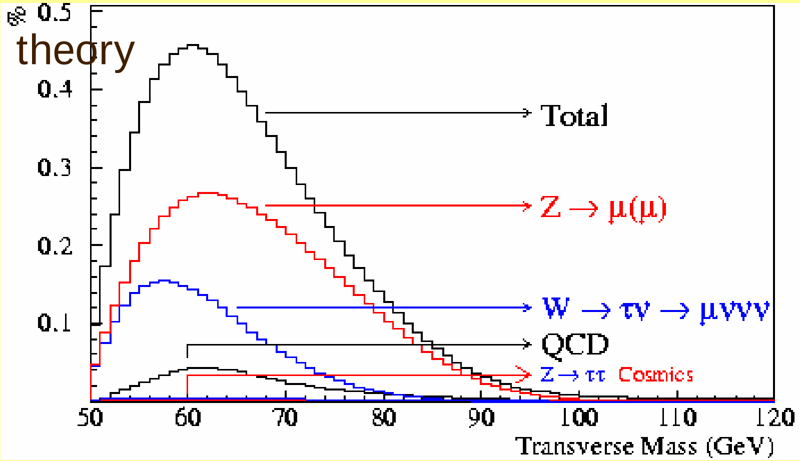
- $P_T(W)$
  - $P_T(Z)/p_T(W)$ to model Monte Carlo
  - Use P_T (Z) from Z->ll
- Uncertainties on parton density funcs
  - Compare models, constrain from Z,W data
- W width
  - Use $R = \frac{\sigma_W}{\sigma_Z} \times \frac{BR(W \to \ell\nu)}{BR(Z \to \ell\ell)}$

Implicit SM assumption to determine Γ_W from LEP

From LEP

From theory

- Radiative decays
  - From W->l $\nu\gamma$
- Backgrounds
  - Checks on Z & W->$\tau\nu$



After 1 year of LHC

Run IA

Source	Δm_W (CDF)	Δm_W (ATLAS)
Statistics	145 MeV	< 2 MeV
E-p scale	120 MeV	15 MeV
Energy resolution	80 MeV	5 MeV
Lepton identificatior	25 MeV	5 MeV
Recoil model	60 MeV	5 MeV
W width	20 MeV	7 MeV
Parton distribution functions	50 MeV	10 MeV
Radiative decays	20 MeV	< 10 MeV
p_T^W	45 MeV	5 MeV
Background	10 MeV	5 MeV
TOTAL	230 MeV	25 MeV

Uncertainties per experiment /year /lepton

The real improvement

Internal calibration from Z data mainly.
Need excellent control of energy flow+ momentum scale

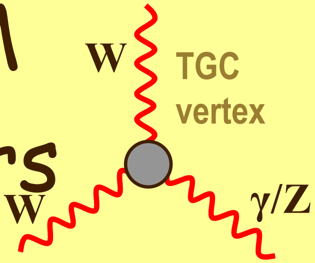
15 MeV LHC combined can then be reached… still very challenging

Triple Gauge Boson Couplings

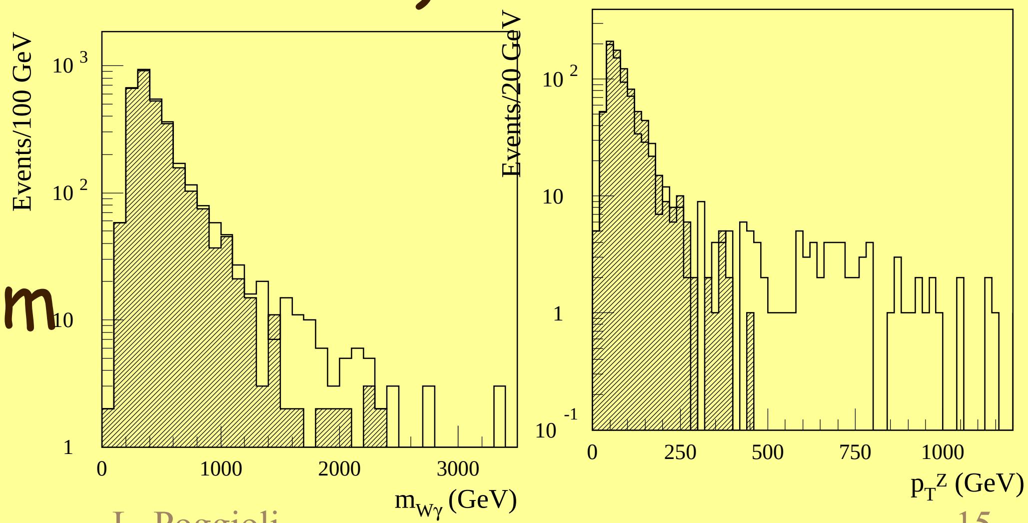
- Signal
- Reach

TGC : Basics

- TGC $WW\gamma$, WWZ are direct test of non-Abelian structure of SM



- SM description via 5 parameters
  - g^1_Z, κ_γ, κ_Z, λ_γ, λ_Z
  - At tree level $g^1_Z = \kappa_\gamma = \kappa_Z = 1$ $\lambda_\gamma = \lambda_Z = 0$ (from Gauge and C, P invariance)
- Anomalous contribution
  - Deviation from SM values



TGC : Reach

- Variables used
  - **Wγ** $(m_{W\gamma}, |\eta_\gamma^*|)$ & (p_T^γ, θ^*)
  - **WZ** $(m_{WZ}, |\eta_Z^*|)$ & (p_T^Z, θ^*)
- Results
  - Using max-Likelihood fit to $m_{WV} \otimes |\eta_V^*|$
- Systematics
  - Small from low p_T bckground (physics at high p_T)
  - Arises from pdf & higher order corrections

Parameters	Statistical (at 95% C.L.)	Systematic (at 95% C.L.)
Δg_1^Z	- 0.0064 + 0.010	±0.0058
$\Delta\kappa_Z$	- 0.10 + 0.12	±0.024
λ_Z	- 0.0065 + 0.0066	- 0.0032 + 0.0031
$\Delta\kappa_\gamma$	- 0.073 + 0.076	- 0.015 + 0.0076
Λ_γ	±0.0033	±0.0012

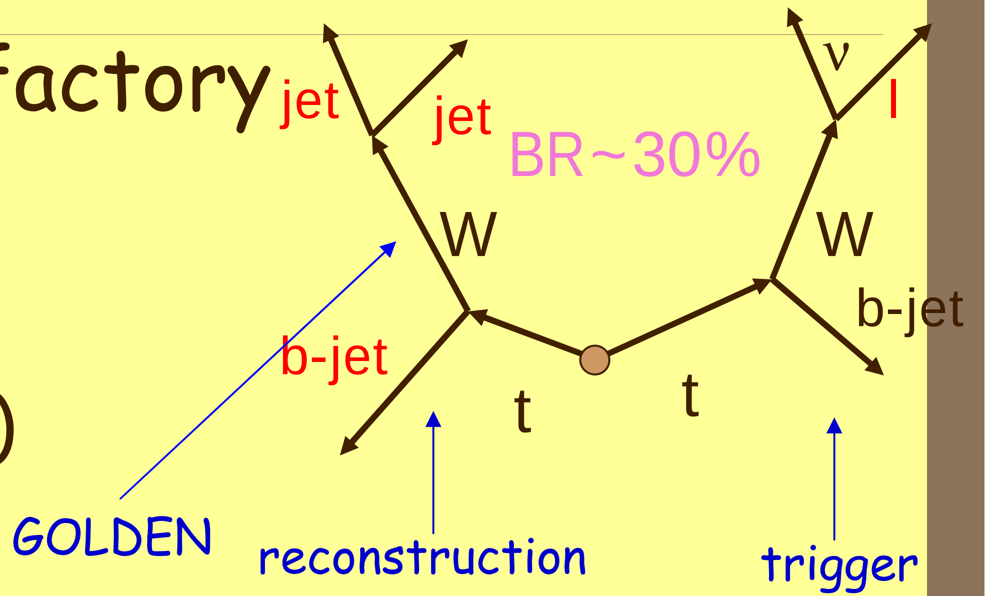
$L = 30\ fb^{-1}$

Top

- Production
- Mass measurement
- Couplings
- Single top production
- Commissioning

Basics

- LHC will be a top factory
  - $O(10^7)$ t-pair/y
- Pair production
  - t -> Wb (99.9% BR)
  - Final state qqbblν
  - 10^5 evts/y
- Reconstruction
  - Starts with W
  - Issue is b-jet tag
    - Reduces background
    - $\varepsilon_b \approx 40\%$ for $r_{u,d} \approx 10^{-3}, r_c \approx 10^{-2}$



Selection efficiency: ~5-10%

- p_T>20 GeV
- E_T^{miss}>20 GeV
- 4 jets with p_T>40 GeV
- >1 b-tagged jet

Background: <2%

W/Z+jets, WW/ZZ/WZ

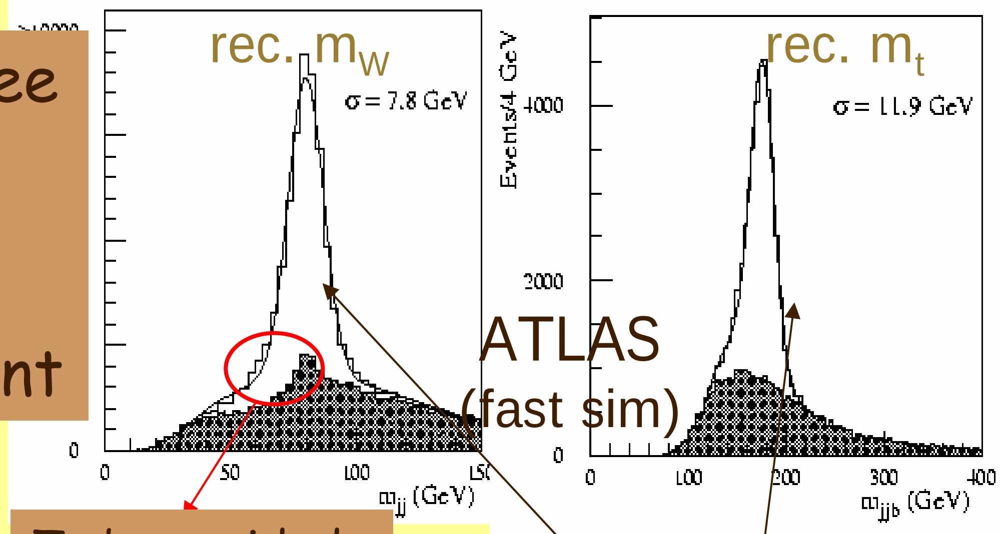
Top mass reconstruction

Fast and full sim. ~agree

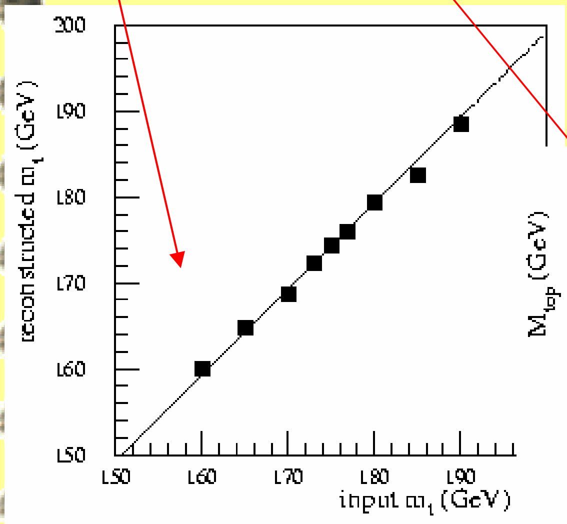
$\sigma_{fullsim}$=13.4 GeV (fast: 11.9)

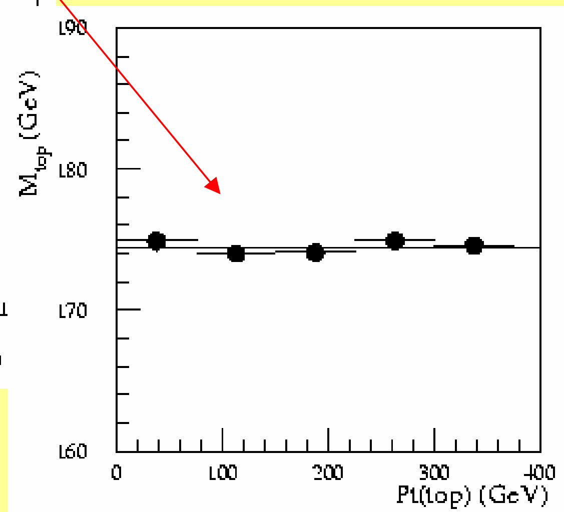
Reco. method linear in

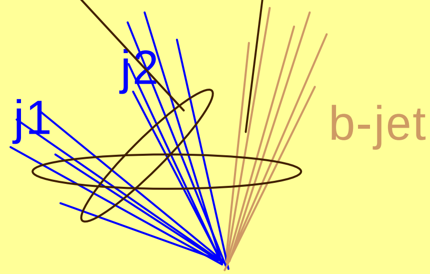
m_t & p_T(top) independent



To be avoided…







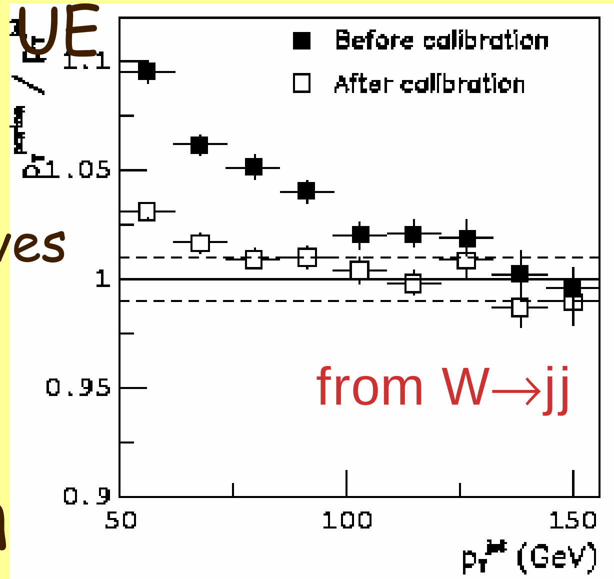
Early stage of analyses, improvements and refinements will come with final tools.

Systematics

✓Light-jet and b-jet energy scale

- Fragmentation, non-linearities, UE
- Jet energy calibration
  - W mass in the same events (top)
  - (for b also) $Z \rightarrow \ell\ell$ +1 jet (ISR gives problem) or γ+1 jet

1% uncertainty translates into <500 MeV systematic on the mass



✓b fragmentation function

- Check by varying fragmentation parameter
- May depend on reconstruction method

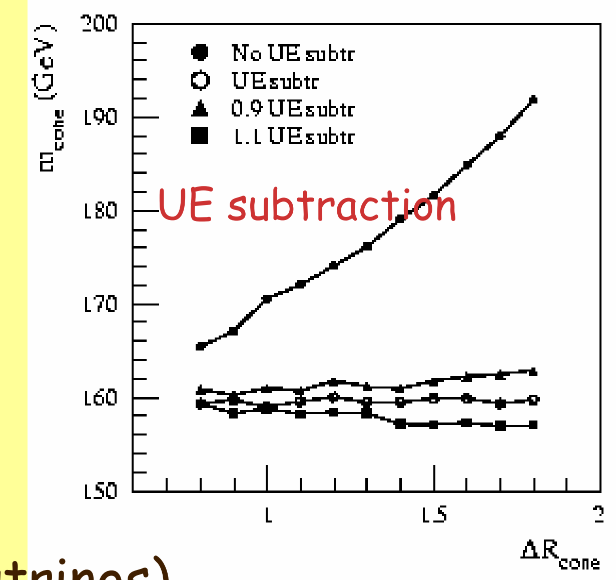
✓ISR and FSR

- FSR give large variations in mass (2-10 GeV on/off)
- Trade statistics to be less sensitive to radiation?

Alternative ways to get m_t

✓High P_T tt events (dedicated analysis)

- Hemisphere separation (background reduction, less combinatorial)
- Jets overlapping issue
  - Dedicated algos to be used
- Less prone to QCD, FSR, calib.
- Stat. & syst. under control



✓Leptonic channel

- Both W decay leptonically
  - Cleaner signature but less info. (neutrinos)
  - Determine m_t from $m_{\ell\ell}$ or $m_{\ell b}$
  - Rely upon correct MC description
    - Main systematics become b frag. and radiation description
- More sophisticated procedure for fitting whole event

✓Others (σ_{tt} & exclusive b-> J/Ψ)

m_t error breakdown

Errors per expts (in GeV)

10 fb^{-1}, low lumi — 100 fb^{-1}, high lumi

	qqbblν	qqbblν (high p_T)	bblνlν	σ_{tt}	qqbblν (+J/ψ)
statistical	0.10	0.25	0.90?	<0.05	<1.0
light jet E scale	0.20	1.2?	-	-	-
b-jet E scale	0.60	0.60	0.60	-	-
ISR/FSR	1.5?	0.2?	1.0	?	0.30?
b-fragmentation	0.25	0.10	0.70	-	0.60
background	0.15	0.10	0.10?	negl.	0.20
pdfs uncertainty	negl.	negl.	negl.	4.0	0.20
Total	<2.0?	<2.0?	<2.0?	<4.0?	<1.3?

- Most systematics are unfortunately ATLAS/CMS correlated
- Also different analyses have very similar correlations…

1 GeV error should anyway be achievable

Consequences from m_t & m_W

- ✓Repeat the EW fit
  - δm_W=15 MeV; δm_t=1GeV
  - Current central values assumed
- ✓SM constraints on m_H
  - With experiment driven $\Delta\alpha_{had}$

$$\Rightarrow m_H = 63^{+22}_{-18}$$

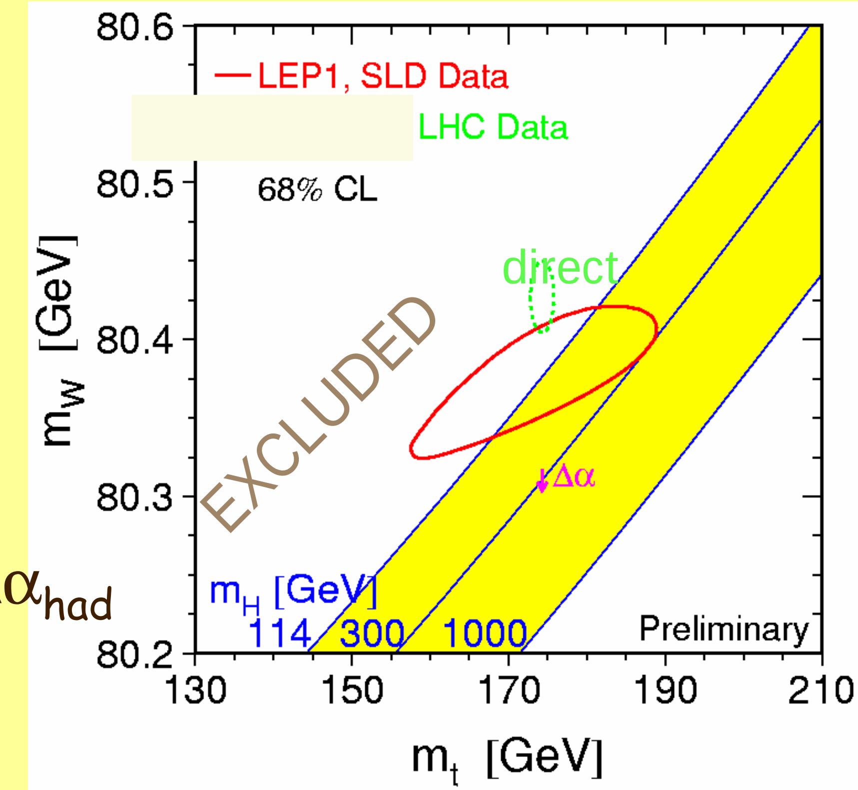
($\delta m_H/m_H \approx$ 32%)

  - Using also $\Delta\alpha_{had}$=0.00012

$$\Rightarrow m_H = 73^{+20}_{-16}$$

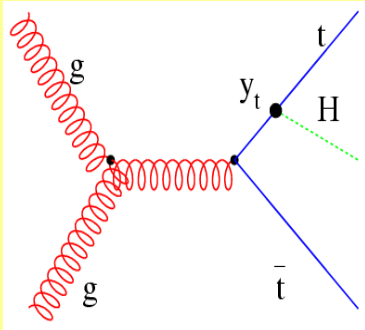
Chances of ruling out the SM !

($\delta m_H/m_H \approx$ 25%)



Couplings and decays

- ✓ Top behavior as expected in SM?
  - Yukawa coupling measured at <20% from ttH evts



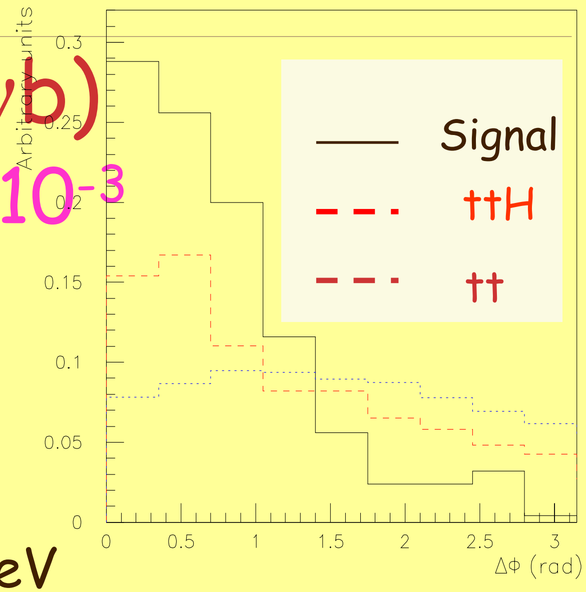
- ✓ According to SM
  - $Br(t \to Wb) \approx 99.9\%$, $Br(t \to Ws) \approx 0.1\%$
  - $Br(t \to Wd) \approx 0.01\%$ (difficult to measure)
- ✓ Many decays outside SM implies anomalous couplings
  - Many channels (ex. FCNC) have clear experimental signatures
  - t->Zq, γq sensitivity $O(10^{-4})$

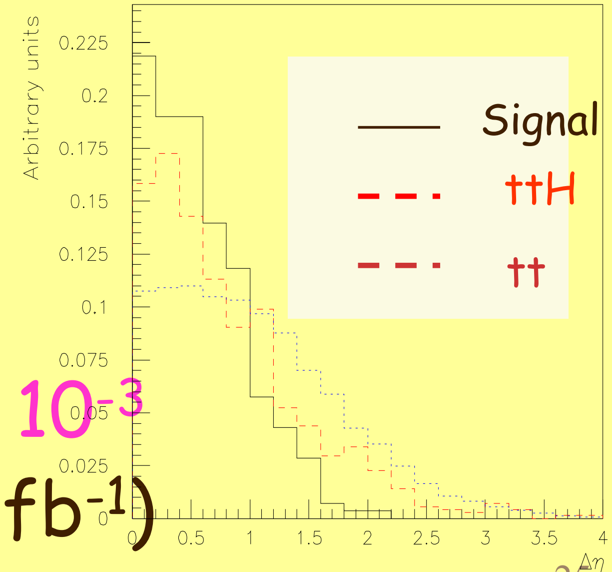
$t \to Hq$

- ✓ Old: $tt \to Hq\ Wb \to (bb)j(l\nu b)$
  - Reach $Br(t \to Hq) = 4.5 \times 10^{-3}$

    For $m(H)$=115 GeV (100 fb^{-1})
- ✓ New: $t\ t \to Hq\ Wb \to$ $WW^{*}q\ Wb \to (l\nu\ l\nu j)\ (l\nu b)$
  - $\geq$ 3 isolated lepton with p_T > 30 GeV
  - p_T^{miss} > 45 GeV
  - $\geq$ 2 jets with $p_T(j)$ > 30 GeV, incl. $\geq$ 1 b-tag jet
  - Kinematical cuts making use of angular correlations
  - Reach $Br(t \to Hq) = 2.4 \times 10^{-3}$

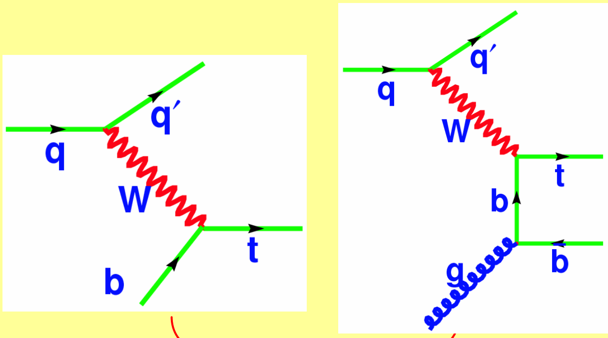
    for $m(H)$ = 160 GeV (100 fb^{-1})





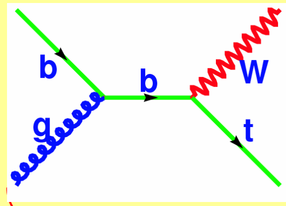
EW single t quark production

(not yet observed!)



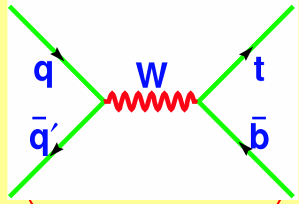
Wg fusion

σ_{Wg}~ 250 pb



Wt process

σ_{Wt}~ 60 pb



W* process

σ_{W*}~ 10 pb

For each process: $\sigma \propto |V_{tb}|^2$

✓Features

- Probe the t-W-b vertex
- Direct measurement (only) of CKM matrix element V_{tb} at ATLAS
- New physics: heavy W′
- Source of high polarized t
- Background: tt, Wbb, Wjj

Process	S/B	S/√B	$\Delta V_{tb}/V_{tb}$ – statistical	$\Delta V_{tb}/V_{tb}$ – theory
W-gluon	4.9	239	0.51%	7.5%
Wt	0.24	25	2.2%	9.5%
*W**	0.55	22	2.8%	3.8%

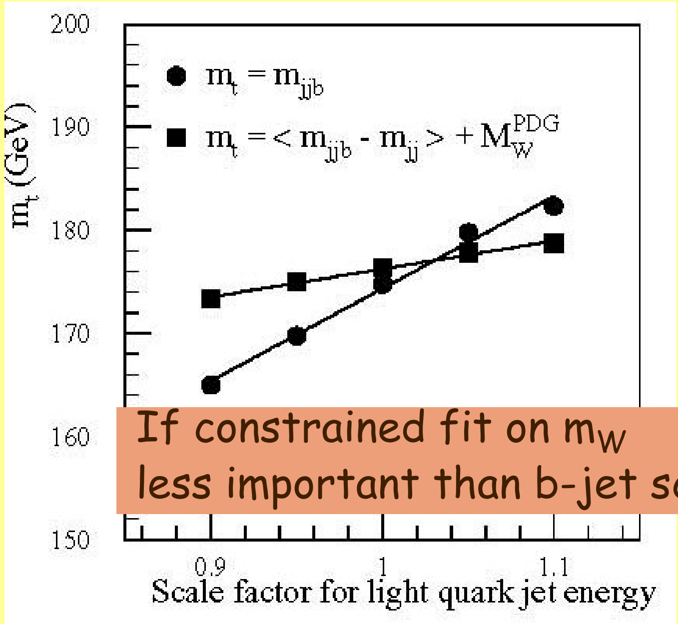
L = 30 fb^{-1}

Systematic errors: b-tagging, luminosity (ΔL ~ 5 - 10%), theoretical (dominate V_{tb} meas.)

Commissioning studies

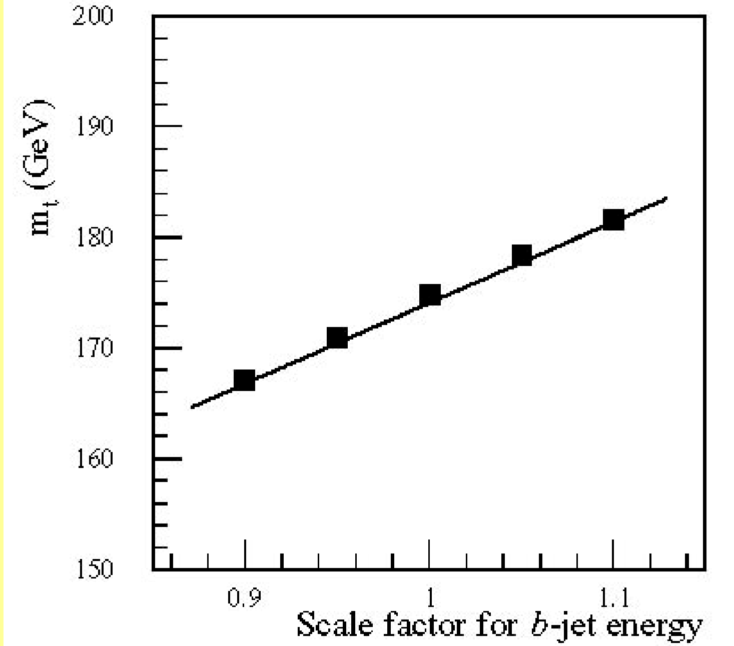
- ✓ At LHC startup
  - Detectors not complete, crude calibration & alignment
- ✓ Why top is important at LHC startup
  - Large statistical sample available
  - Allows to tackle fundamental issues from physics & detector
    - Study of isolated, high p_T electrons and muons
    - Jet calibration & energy scale with $W \rightarrow jj$
    - b-tagging and efficiency studies
  - Major background for most Higgs searches

Jet energy scale



If constrained fit on m_W
less important than b-jet scale.

Light-jet scale



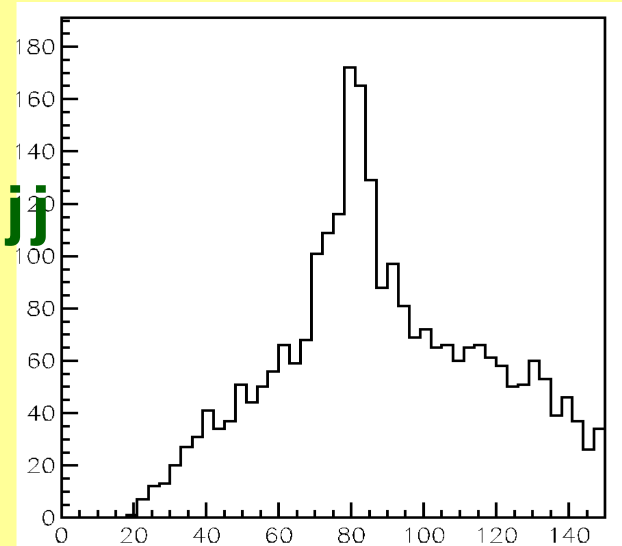
b-jet scale

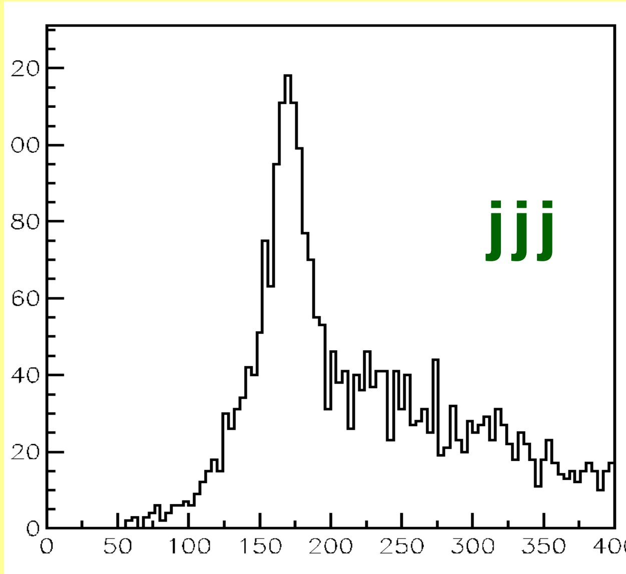
- 1500 $t\bar{t} \rightarrow bW(l\nu)bW(jj)$ requiring 4 jets above 40 GeV/day at low *L*
- Allows makings bins in P_T and rapidity for jets
- Accuracy on light jet scale ~ 10% (δM_t < 3 GeV), and b-jet scale ~10% (δM_t < 7 GeV)

If no b-tagging at startup (1)

✓ If no b-tagging available at startup

- Alignment problem, 2 pixel layers/3
- Increase of W+jets bckground (x50), signal (x4)
- Strict selection of evts
  - Lepton+4jets exactly (ΔR=0.4)



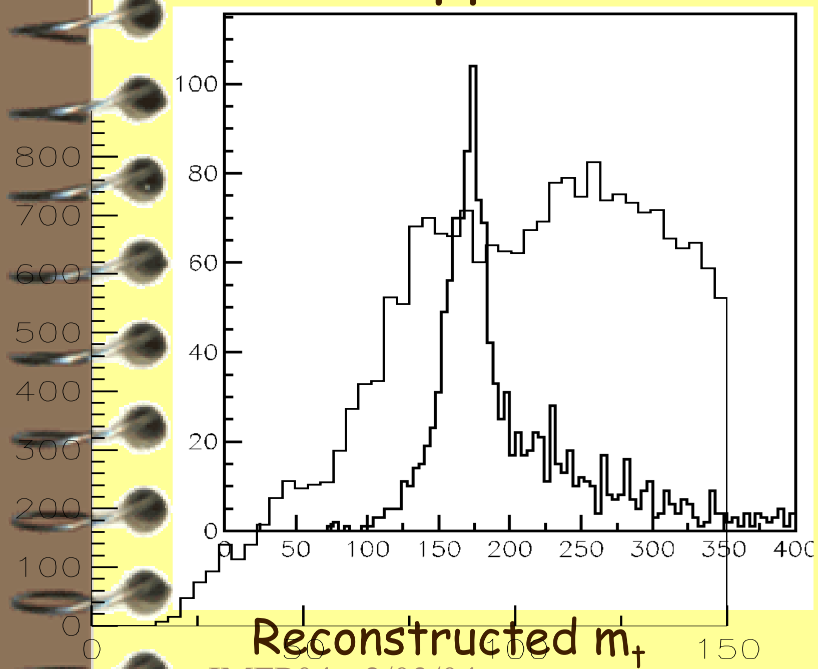


2 jets selected with maximal $\vec{P}_{T} = \sum_{i=1}^{2} \vec{P}_{T\,i}$ 3 jets selected with maximal $\vec{P}_{T} = \sum_{i=1}^{3} \vec{P}_{T\,i}$

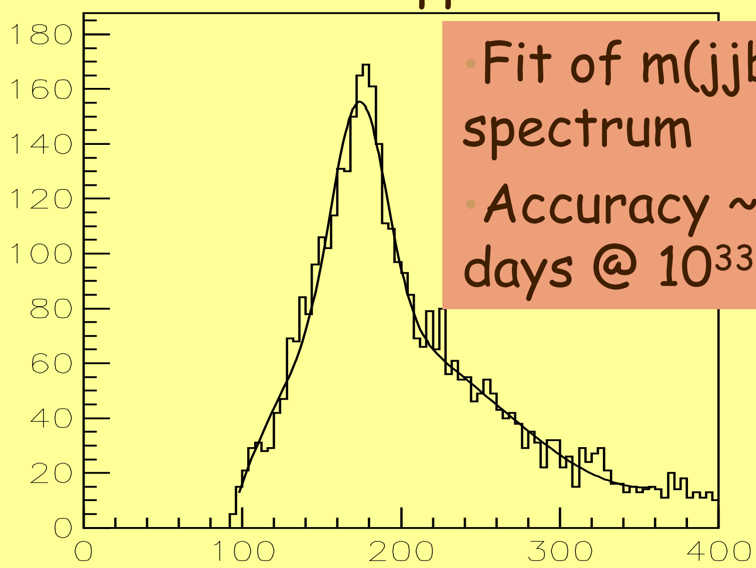
If no b-tagging at startup (2)

✓ Top mass measurement

- 3 possible jet assignments for W(jj)b
- A kinematical constraint fit can be used: $M_{W_1}=M_{W_2}$ and $M_{t_1}=M_{t_2}$.
- Approximate calibration obtained with W peak



✓ σ_{tt} measurement



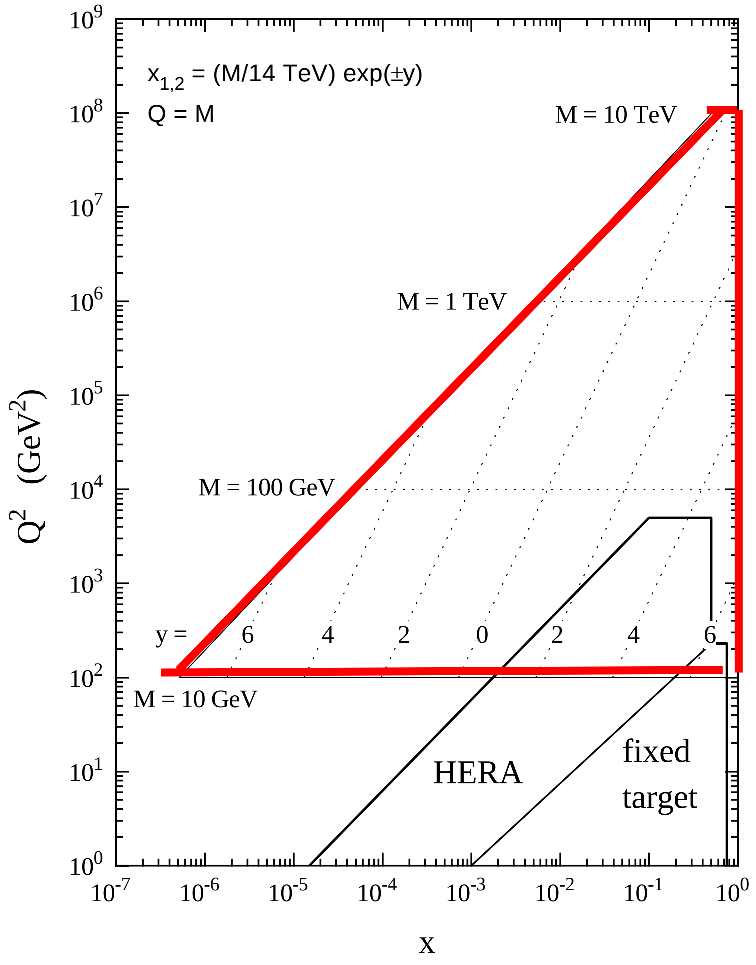
- Fit of m(jjb) spectrum
- Accuracy ~10% in 2 days @ 10^{33}

QCD

- Parton kinematics
- Jet physics
- Photon physics
- Drell-Yan, W/Z production
- Heavy flavour production
- Multiple interaction

LHC Parton Kine

- Physics at LHC
  - Connected to q & g interactions (small & large transferred momentum)
  - -> Good understanding of QCD
- SM cross-sections
  - Accurate measurements
  - Will further constrain the pdf's.
- (x,Q^2) range
  - Wide
  - Thanks also to large acceptance of LHC detectors ($|\eta| < 5$)



Parton luminosities and p.d.f.'s

$$N_{events}(pp \to X) = L_{p-p} \times pdf(x_1, x_2, Q^2) \times \sigma_{theory}(q, \bar{q}, g \to X)$$

- Uncertainties in p-p luminosity (±5%) and pdf (±5%) -> ±5% uncertainty
- Using only relative x-section measurements -> ±1% accuracy feasible

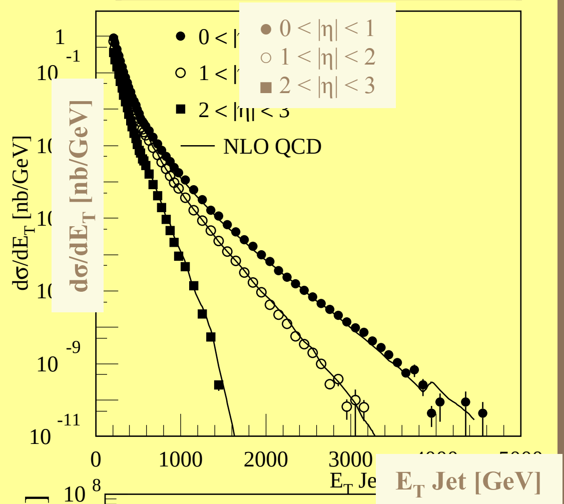
qq(ud) high-mass DY lepton pairs & other processes dominated by qq	W± & Z leptonic decays ±1%	✓ precise measurements of mass &couplings ✓ huge cross-sections (~nb); ✓ small background. ✓ x-range: 0.0003 – 0.1
g high-Q^2 reactions involving gluons	γ-jet, Z-jet, W±-jet ±1%	✓ γ-jet studies: γ p_T > 40 GeV ✓ x-range: 0.0005 – 0.2 ✓ γ-jet events: γ p_T ~ 10-20 GeV ✓ low-x: ~ 0.0001
s,c,b	γc, γb, sg→Wc 5-10% uncertainty for 0.0005 <x< 0.2	✓ quark flavour tagged γ-jet final states; ✓ use inclusive high-p_T μ and b-jet identification (lifetime tagging) for c and b; ✓ use μ to tag c-jets;

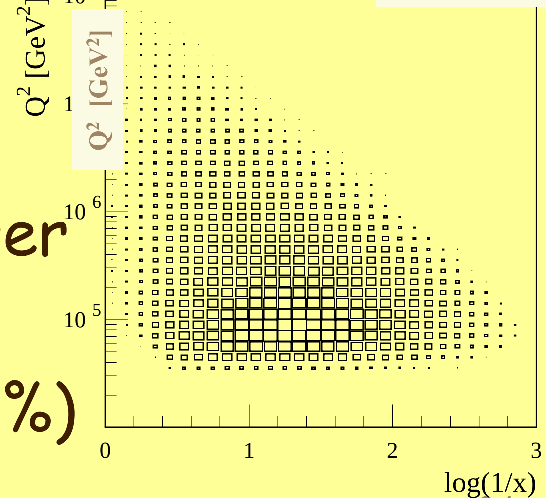
Jet physics

L = 30 fb^{-1}

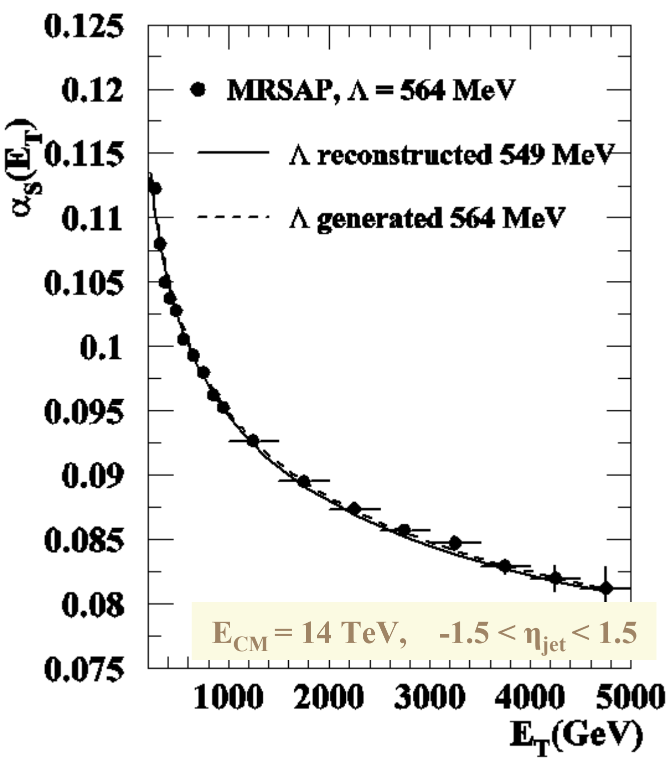
Jet E_T	N_{events}
> 1 TeV	4×10^5
> 2 TeV	3×10^3
> 3 TeV	40

- Basics (pQCD in new regime)
  - Di-jets properties (E_T and $\eta_{1,2}$)
    -> constrain p.d.f.'s
  - Inclusive jet cross section
    -> $\alpha_S(M_Z)$ with 10% accuracy
- Multi-jet production
  - tt, ttH, bbH production
  - R-parity violating SUSY
- Systematics
  - Jet algorithm, energy scale, trigger efficiciency, underlying evt
  - Luminosity (Dominant: error 5-10%)





α_s Determination



✓ Basics

- QCD check @ smallest range
  - α_S= 0.118(0.082) @ 0.1(4) TeV
- Can't compete with precision measurements from e^+e^- & DIS (gluon distribution)

✓ Measurement

$$\frac{d\sigma}{dE_T} \sim \alpha_S{}^2(\mu_R)A(E_T) + \alpha_S{}^3(\mu_R)B(E_T)$$ NLO

- A and B calculated at NLO with input p.d.f.'s.
- Fit to measured inclusive cross-section gives $\alpha_S(E_T)$for each E_T bin

- Systematics
  - pdf set (±3%),
  - A and B parameters
  - Renormalization & factorization scale (±7%)

Direct photon production

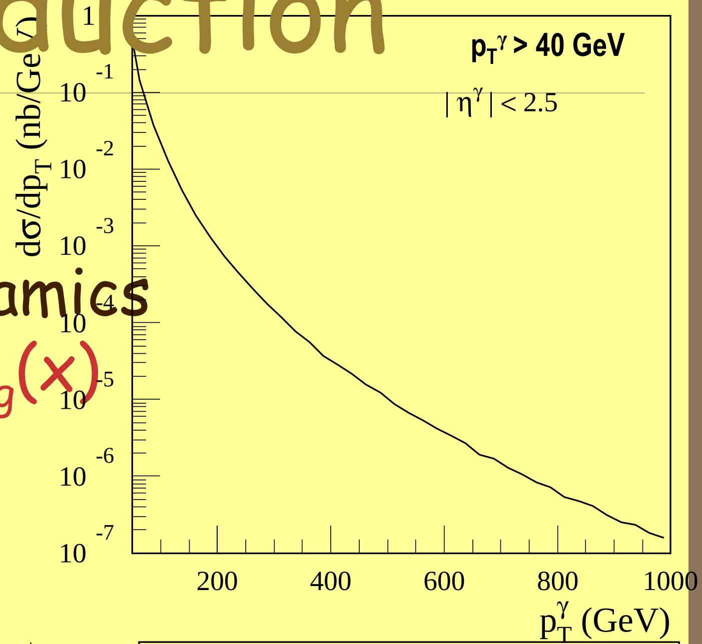
- **Basics**
  - $H\rightarrow\gamma\gamma$ signal & backgrounds
  - Study underlying parton dynamics
  - gluon density in the proton $f_g(x)$

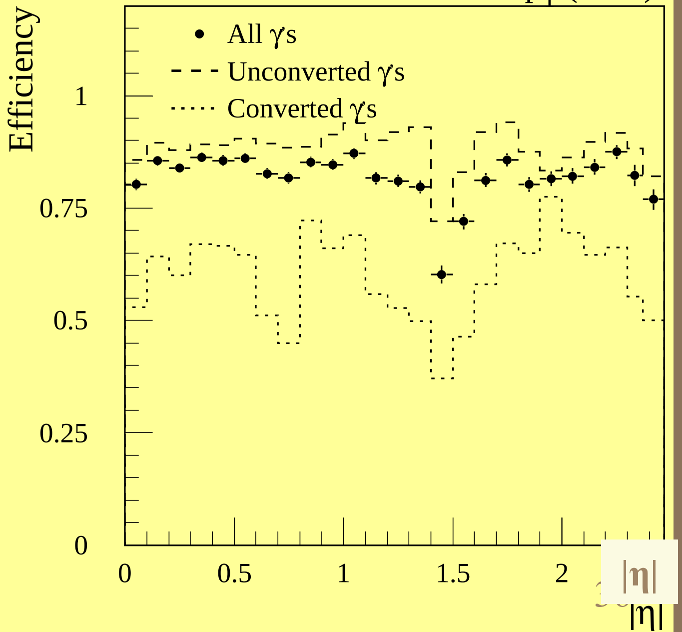
  (good knowledge of α_s needed)
- **Production**

  $qg\rightarrow\gamma q$ Compton, dominant

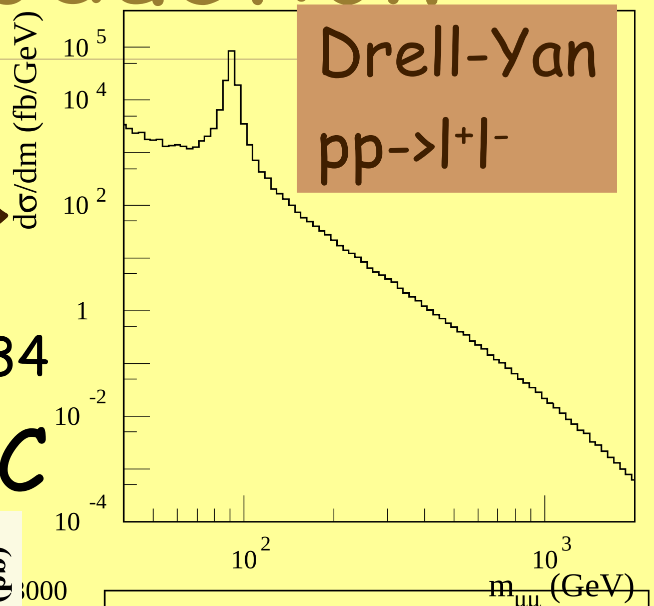
  $q\bar{q}\rightarrow\gamma g$
- **Background ($\pi^0 \rightarrow\gamma\gamma$)**
  - Fragmentation effect (non-perturbative QCD)
  - From calorimeter + Tracker

  ε = 80%, R_{jet} = 10^5 for H (120 GeV)$\rightarrow\gamma\gamma$

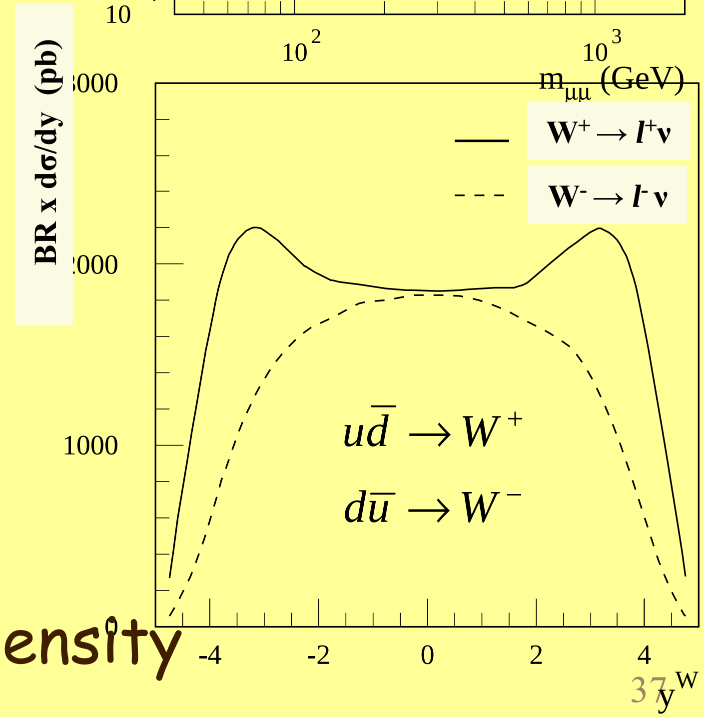




Drell-Yan, W/Z production



- DY production of l^+l^-
  - 10^4 events for $L = 30fb^{-1}$ ($m_{\mu\mu}$ > 400 GeV)
    - $Q^2 > 1.6\ 10^5\ GeV^2$ $2.3\ 10^{-3} < x < 0.34$
- W & Z production at LHC
  - Huge & clean samples
    - ~10^5 events with W (p_T^W > 400 GeV) for $L = 30fb^{-1}$
    - $Q^2 \sim 6(8)\ 10^3 GeV^2$ $3\ 10^{-4} < x < 0.1$
- W^+ & W^- production
  - Difference in y^W
  - -> constraint on proton q, $\bar{q}$ density



Heavy flavour production

✓Production & Reach

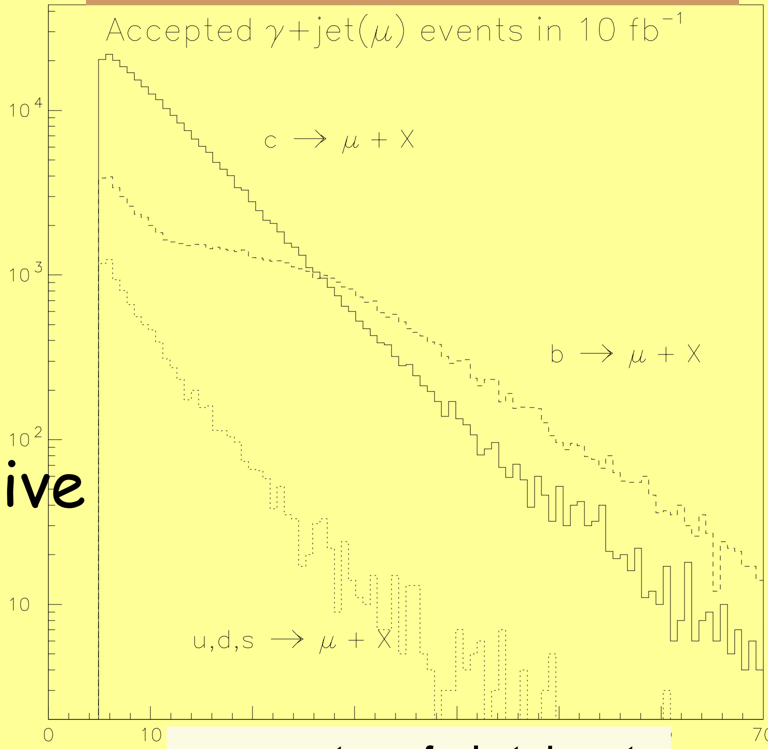
- Dominant production mechanism for heavy quarks (b and t) is g-g interaction -> constraints on g density

Process	σ (nb)	Events/year (L = 10 fb^{-1})
bb	5 x 10^5	~ 10^{12}
tt	0.8	~ 10^7

LHC: Heavy quarks factory!

✓c and b quarks

- c(b) g → c(b) γ
- From photon-jet samples
- Jet flavour by using inclusive high-p_T muons & b tagging

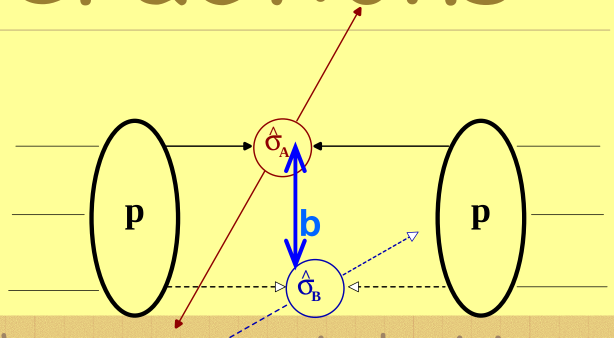


muon spectrum of selected events

Multiple parton interactions

✓ Basics

- UA2 &CDF have measured **double parton** interactions

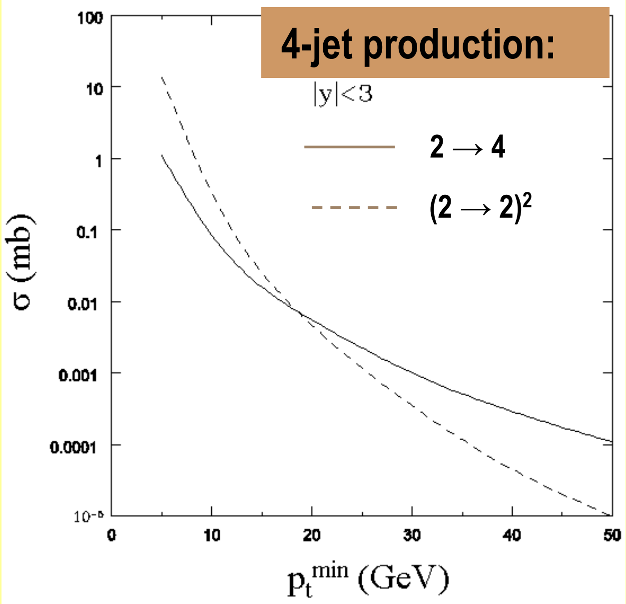


$$\sigma_D\left(p_T^{cut}\right) = m\frac{\sigma_A\sigma_B}{2\sigma_{eff}}$$

$\sigma_{eff} = 14.5 \pm 1.7$ mb

- σ_{eff} has a geometrical origin
- parton correlation in transverse space
- Energy and cut-off independent

- σ_D increases faster with **s** as compared to σ_S
- -> MPI enhanced at LHC



✓ Source of background

- WH+X→ (lν) bb+X
- W + jets
- final states with many jets

$p_T^{min} \sim 20 - 30$ GeV

B-physics

B physics at LHC (1)

- ✓ Precision measurements of B-hadrons
  - CP-violation parameters
  - B-hadron parameters: Masses, lifetimes, widths, oscillation parameters, couplings, b-production, etc.
  - Search for New Physics effects: very rare decay modes, forbidden decays/couplings, etc.
- ✓ LHC: B-factory with $\sigma(bb)=500\ \mu b$
  - "Old" B-trigger, single 6-GeV muon
  - Event rate is 4 kHz at $2\times10^{33}\ cm^{-2}s^{-1}$
  - LVL1 trigger-muon also provides a clean flavour tag

B physics at LHC (2)

- ✓ Downscoping of LVL1 trigger rate
  - Not enough processing power @ startup
  - Rate limited to 25 kHz
  - -> Increase single-muon threshold
- ✓ -> Strong & Negative impact on B-physics @ startup in ATLAS & CMS
- ✓ Consequences (at least for startup)
  - ATLAS & CMS will concentrate on high-P_T physics
  - LHCb will cover extensively B-physics

Conclusion

- ✓ LHC will probe unexplored kinematic regions & with huge stat. (W, t, jets)
- ✓ W mass can be measured to ± 15 MeV
- ✓ Top
  - Mass can be measured to ± 1 GeV
  - Access to couplings
  - Single top -> access to V_{tb}
- ✓ Anomalous TGC sensitivity
- ✓ Systematics
  - Detector & Physics
  - Being studied with extreme care