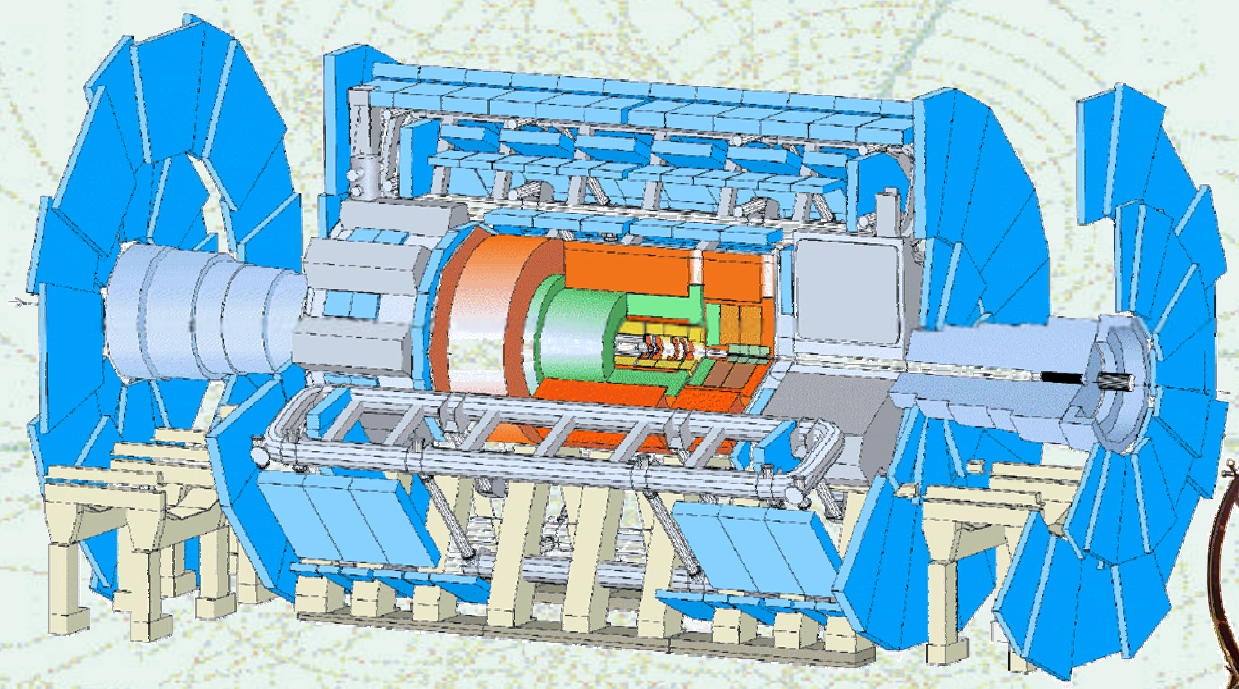
Physics studies for ATLAS



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PPAP visit – 24 March 2004
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LHC:

Design luminosity: $10^{34}cm^{-2}s^{-1}$

Integrated luminosity:

10 fb-1/year (low-lumi)

100 fb-1/year (high lumi)

Beam energy: 7 TeV

Bunch crossings:

every 25 ns

~23 pp events/crossing

Cosmic-ray data: summer 2006

First beams: summer 2007

Who we are

Elena Brambilla (until June '03)

Teh Lee Cheng (TLC)

Antonella De Santo (ADS)

Glen Cowan (GC)

Ricardo Gonçalo (RG)

Graham Hollyman (GH)

Graham Kilvington (GK)

Scott McGarvie (SM)

Clare Quarman (CQ)

Pedro Teixeira-Dias (PTD)

Outline

- Overview
- Analysis environment
- CP-parity of a light Higgs from tth production
- Light Higgs in the Wh→lnbb channel
- Invisible Higgs in tth production
- Bayesian analysis of parton distributions
- Summary and outlook

Overview

The LHC will be at the highest energy frontier that has ever been reached in accelerator physics. ATLAS will be collecting data in 2007.

- Prepare for data in challenging LHC environment
- Develop analysis competence - techniques, tools, physics

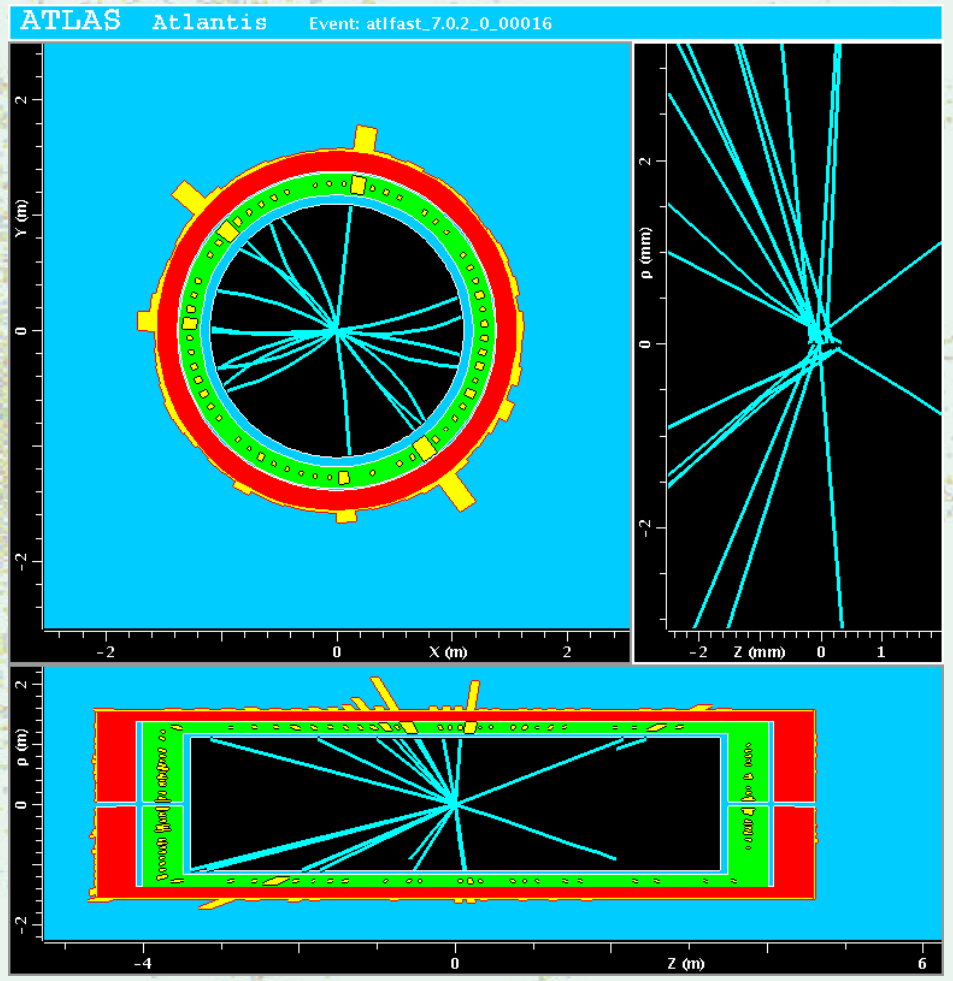
Physics program at RHUL:

- **Higgs studies** in both the **Standard Model (SM)** and **Supersymmetry (SUSY)**
- **Bayesian analysis of Parton Density Functions (PDFs)**

Analysis environment at RHUL

Local, complete and up-to-date

- CMT: environment configuration
- ATHENA: software framework
- ATLFAST: fast detector simulation –using latest production release (7.0.2) installed locally with official distribution kit (pacman, see Simon's talk)
- ATLANTIS: event display
- Linking C++ user code to Athena
- PYTHIA and HERWIG Monte Carlo generators (standalone/wrapped)
- ROOT/PAW
- …



$gg \to q\bar{q}H,\ H \to Z^0Z^0 \to l^+l^-l^+l^-$

Higgs studies

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CP-parity of a light Higgs from $t\bar{t}h$ production

- Once one or more Higgs bosons have been discovered, its properties must be determined.
- The MSSM predicts ***h*** (**CP even**) and ***A*** (**CP odd**)
- CP-violating SUSY Models allow for Higgs particles with **mixed CP parity**: $h_1 = a\,h + (1-a)\,A$

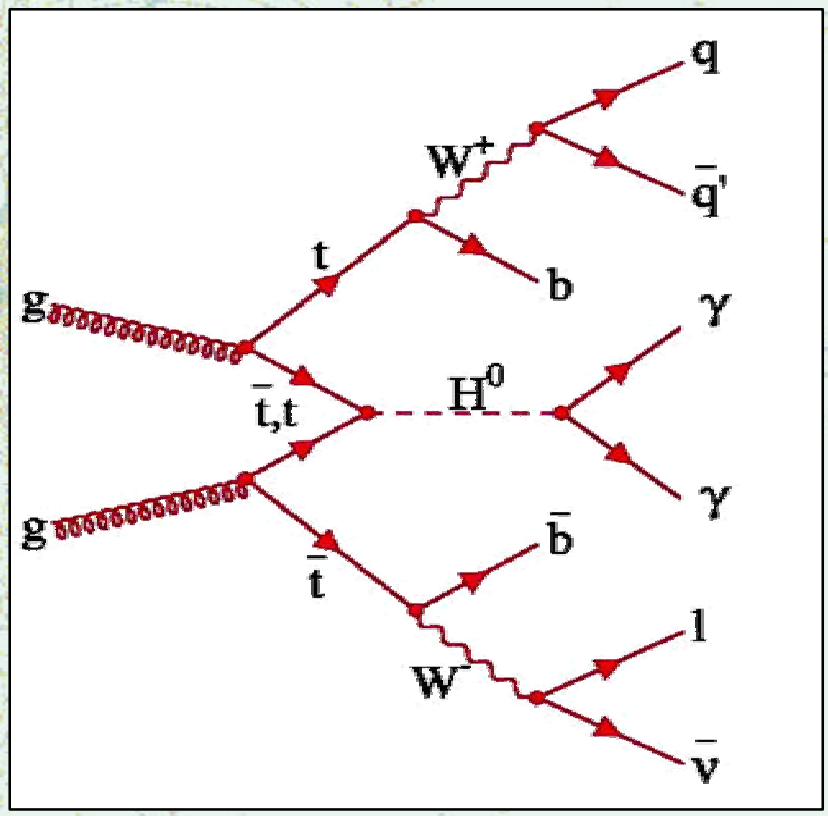
For a light Higgs ($m_h<2m_Z$), tth production can be used to find the CP parity (*Gunion and He. PRL 76, '96*).

- The momenta of the top quarks must be completely reconstructed.
- The $H \to gg$ decay channel was chosen (m_H = 130 GeV):

+ Clean signal

+ Low backgrounds

- Small branching fraction (BF~10^{-3}).



Set of variables sensitive to the CP parity of the Higgs:

$$a_1 = \frac{(\vec{p}_t \times \hat{n}) \cdot (\vec{p}_{\bar{t}} \times \hat{n})}{|(\vec{p}_t \times \hat{n}) \cdot (\vec{p}_{\bar{t}} \times \hat{n})|}$$

$$a_2 = \frac{p_t^x p_{\bar{t}}^x}{|p_t^x p_{\bar{t}}^x|}$$

$$b_1 = \frac{(\vec{p}_t \times \hat{n}) \cdot (\vec{p}_{\bar{t}} \times \hat{n})}{p_t^T p_{\bar{t}}^T}$$

$$b_3 = \frac{p_t^x p_{\bar{t}}^x}{p_t^T p_{\bar{t}}^T}$$

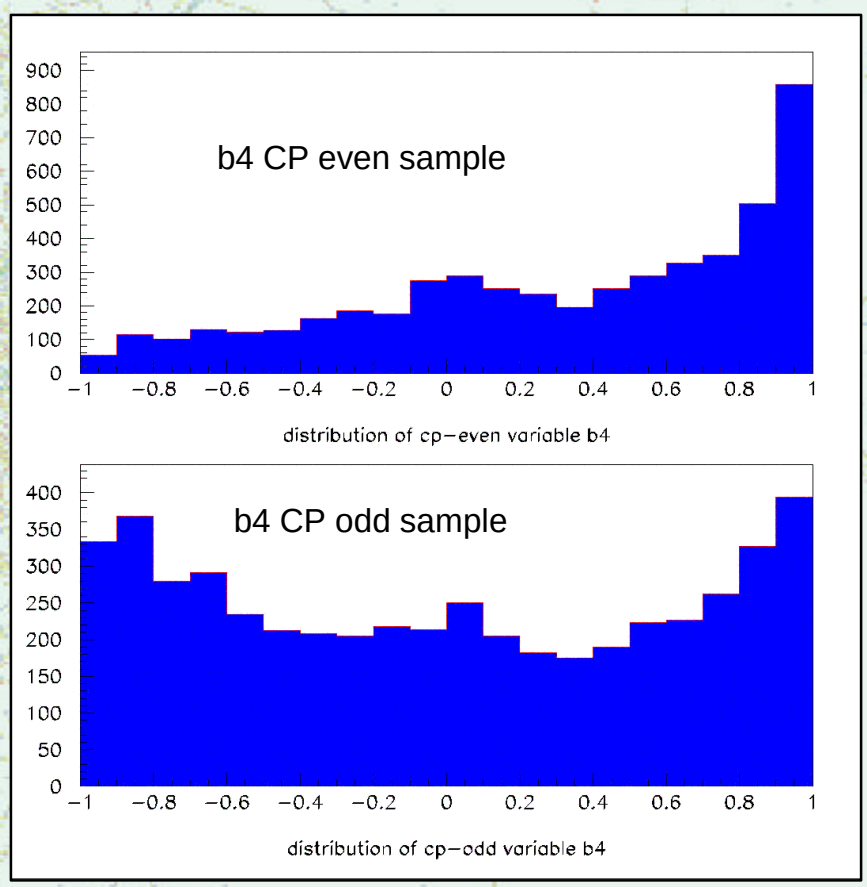
$$b_2 = \frac{(\vec{p}_t \times \hat{n}) \cdot (\vec{p}_{\bar{t}} \times \hat{n})}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$

$$b_4 = \frac{p_t^z p_{\bar{t}}^z}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$

***p*$_t$** : 3-momentum of the top or anti-top;

z ,***n***: beam direction;

x : any direction perpendicular to the beam axis.



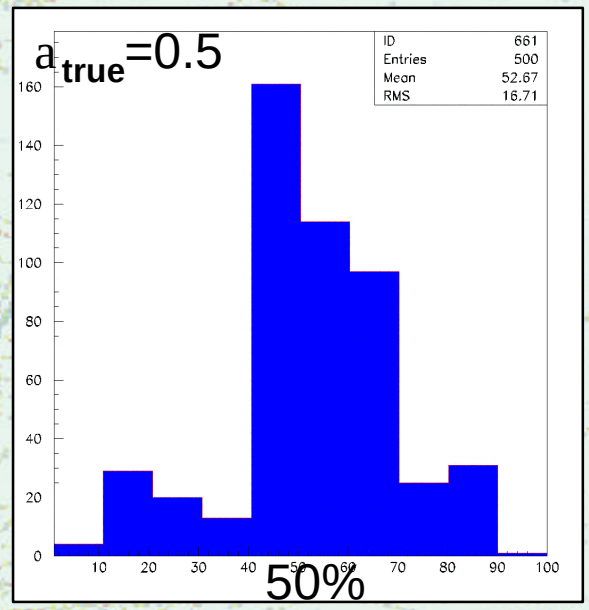
Gunion and He. Phys.Rev.Letters 76, 24, 4468 (1996)

[SM,PTD]

- Parton level analysis (Herwig)
- Multivariate method used to extract information from CP-sensitive variables
- Maximize likelihood to extract mixing parameter a

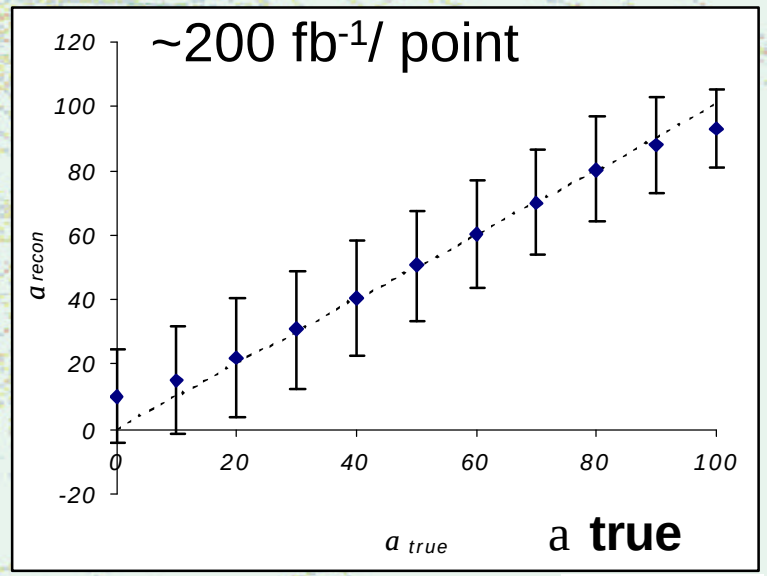
$$\mathcal{L}(\alpha) = \prod_{i=1}^{i=n} f(x;\alpha)$$

$$f(x;\alpha) = \alpha f(x)_{\mathrm{CP-even}} + (1-\alpha) f(x)_{\mathrm{CP-odd}}$$



Results:

Tested method with mixed CP parity samples to obtain bias (small!) and resolution (~0.2)



Plans:

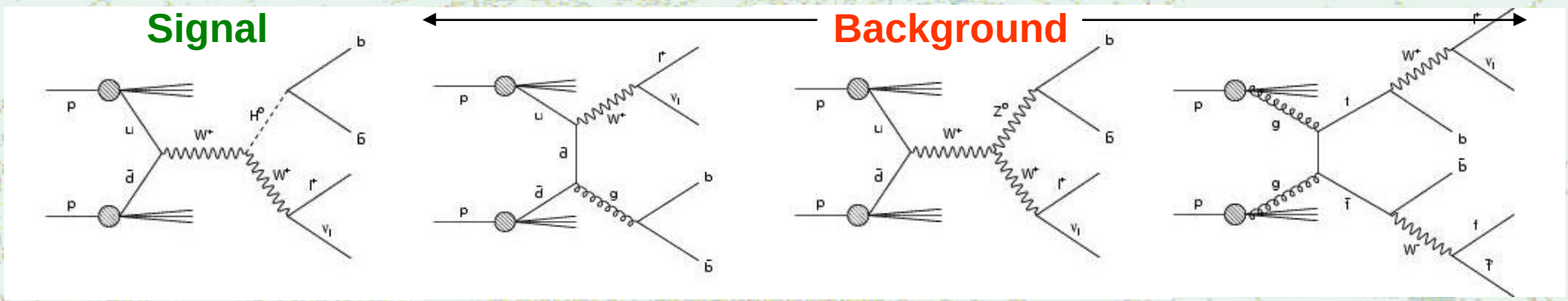
- Simulate detector response
- Use different hadronisation model: Pythia

[GH,PTD]

Light Higgs in the $Wh \to l\nu b\bar{b}$ channel

Very challenging channel: $q\bar{q}' \to Wh$: low production cross section

$h \to b\bar{b}$: very high QCD background



m_H = 100 – 150 GeV

Standard selection (ATLAS TDR):

- 1 e or 1 m
- 2 b-tagged jets
- Veto on additional jets or leptons

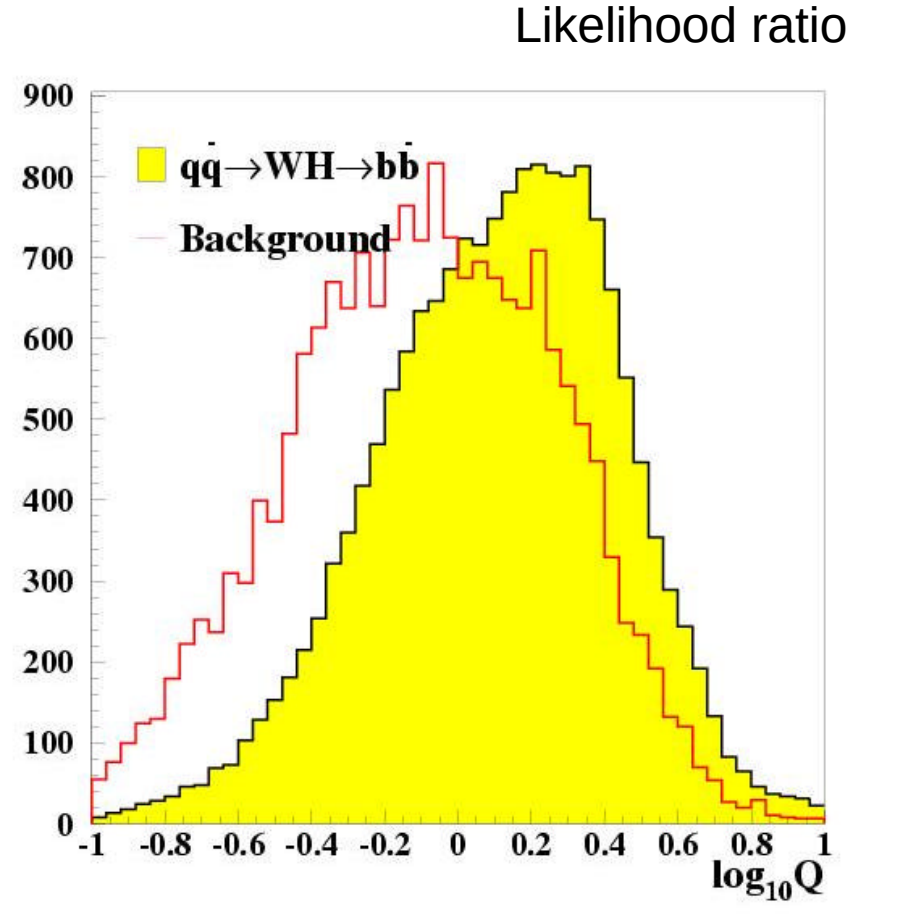
$30fb^{-1}$	Nr. Events	ε
Signal	232	3.9%
Backgr	9600	$2x10^{-4}$

Aim to improve basic event selection by using a likelihood incorporating additional kinematical information:

$$\left(\Delta h_{hl}, \Delta f_{hl}, \Delta h_{b\bar{b}}, \not{E}_T, g_h\right)$$

30fb^{-1}	Nr. Events	ε
Signal	189	3.2%
Backgr.	5900	1.2×10^{-4}

Obtained moderate improvement (~5%) in significance



Invisible Higgs in $t\bar{t}h$ production

Several models of new physics predict a light Higgs boson ($m_h < 150$ GeV) decaying to **invisible particles** with a high branching ratio:

- light neutralinos in R-parity conserving Supersymmetry (SUSY)
- right-handed neutrinos in extra dimensions opening at the TeV scale
- Majorana particles at a mass scale ~TeV
- …

(S.P.Martin and J.D.Wells, Phys.Rev. D, 60,035006; R.M.Godbole et al., hep-ph/0304137)

Analysis done for $t\bar{t}h$ production with Higgs decaying to light, stable neutralinos

One SUSY point chosen, but conclusions easily extendable for other models

m_H = 121 GeV

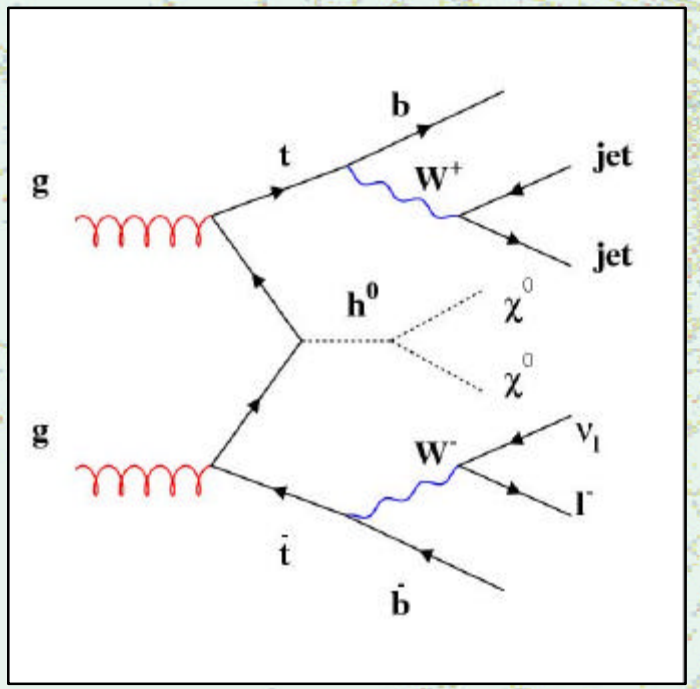
m_c = 35.5 GeV

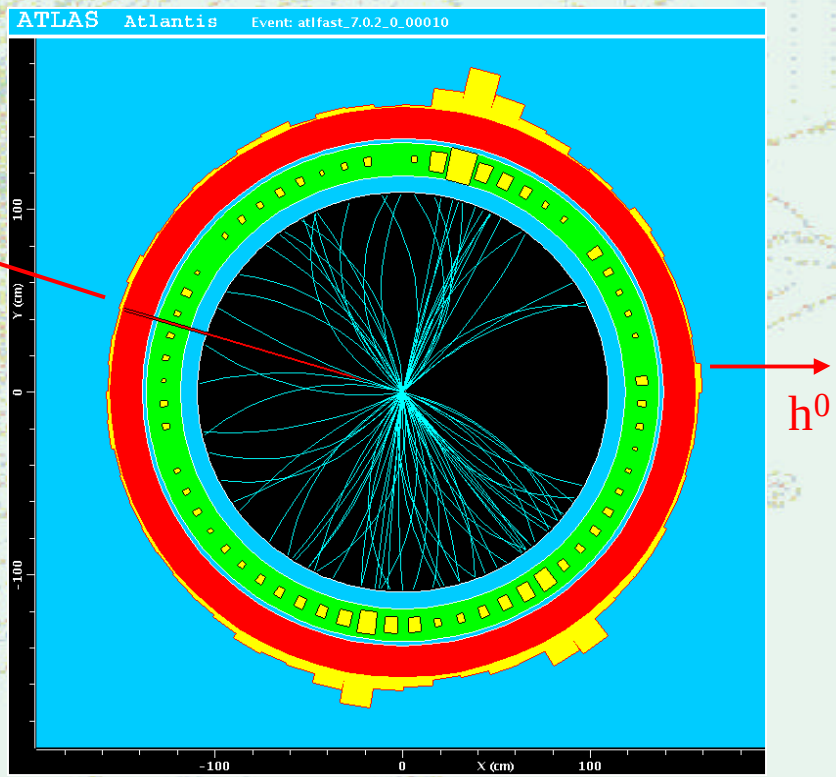
Branching fraction = 1

- Large backgrounds
- Studied $t\bar{t}$ background so far
- Events not easy to reconstruct due to 2 components of missing p_T:

$$\vec{p}_T^{\,total} = \vec{p}_T^{\,Higgs} + \vec{p}_T^{\,n}$$

Process	σ×BR
tth	330 fb
tt	490 000 fb
bbW, W → lν	73 000 fb
bbZ, Z → l^+l^-	61 400 fb
ttW, W → lν	420 fb
ttZ, Z → ν	190 fb

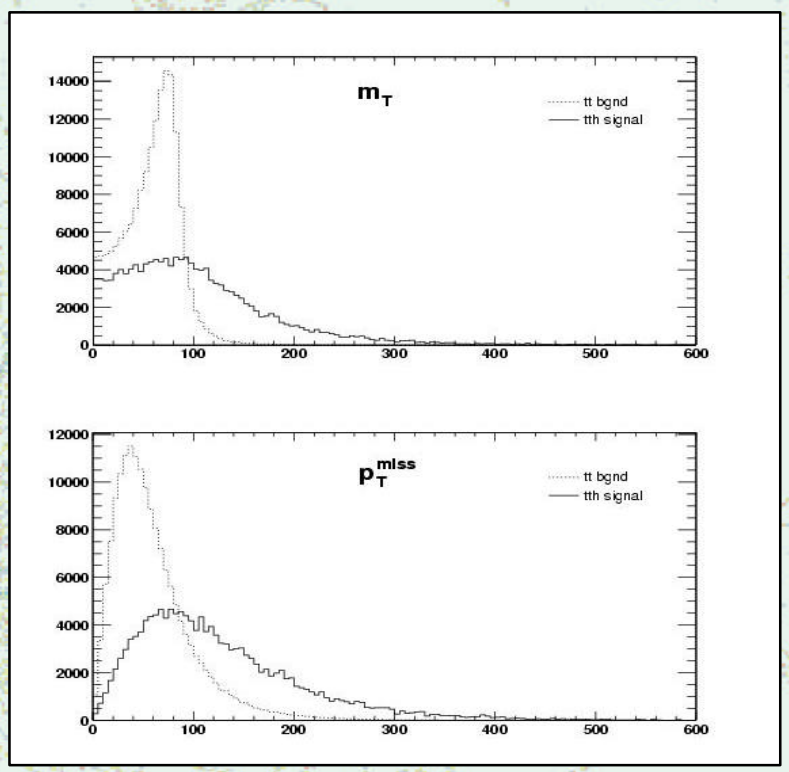




Standard event selection:

- 1 e / 1 m
- 2 b-tagged jets
- 2 or more light jets
- veto on additional leptons (e/m)
- t→bjj fully reconstructed

$$m_T = \sqrt{\left(E_T^{miss} + E_T^{lepton}\right)^2 + \left(\vec{p}_T^{\,miss} + \vec{p}_T^{\,lepton}\right)^2}$$



Further cuts on missing p_T and m_T give encouraging results

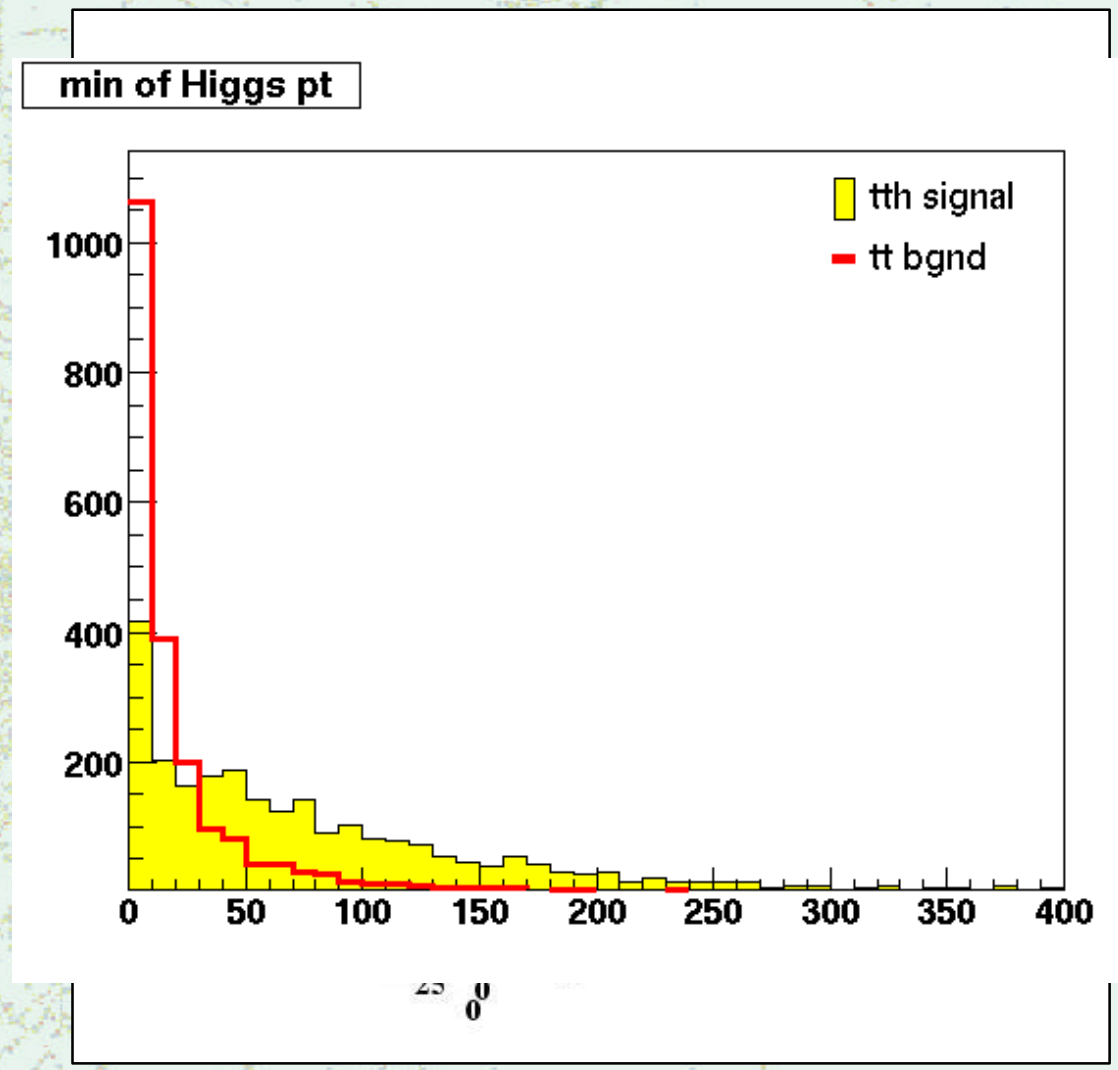
100 fb^{-1}	N_{signal}	$N_{background}$	signal/vback
t→bjj reconstr.	621±4	(810±2)x10^3	0.689
m_T>100 GeV	270±3	34010±410	1.46
p_T^{miss}>150 GeV	118±2	1107±74	3.36

Kinematic fit to $t \to bl\nu$:

Attempting to improve on standard analysis results by fully reconstructing the neutrino with kinematic fit

- Assuming p_T of neutrino and Df_{In}, get p_Z from m_W constraint
- Combine with b jet and compare resulting mass to $m_t \rightarrow$ obtain c^2
- Obtain p_T of Higgs from missing p_T and p_T^n

(take point with smallest c^2 or minimum p_T^n)

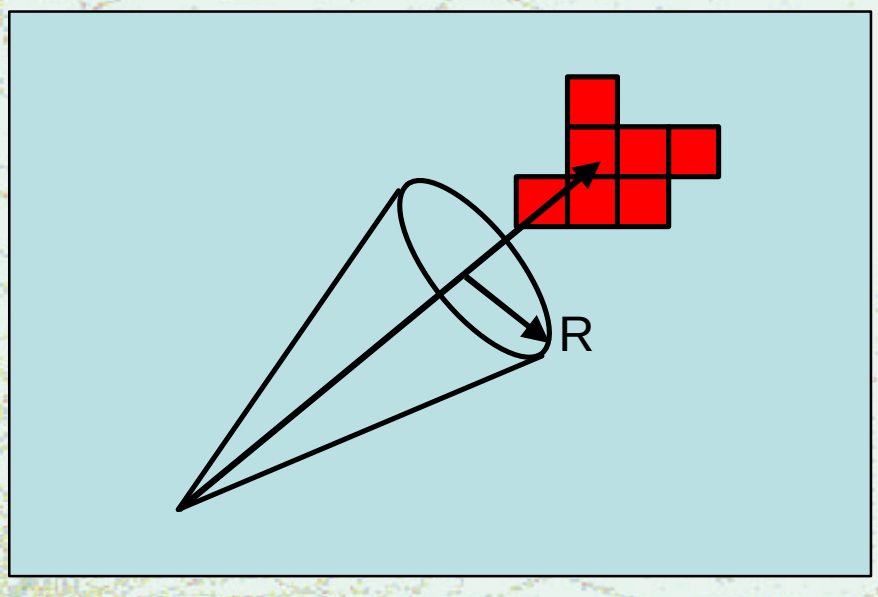


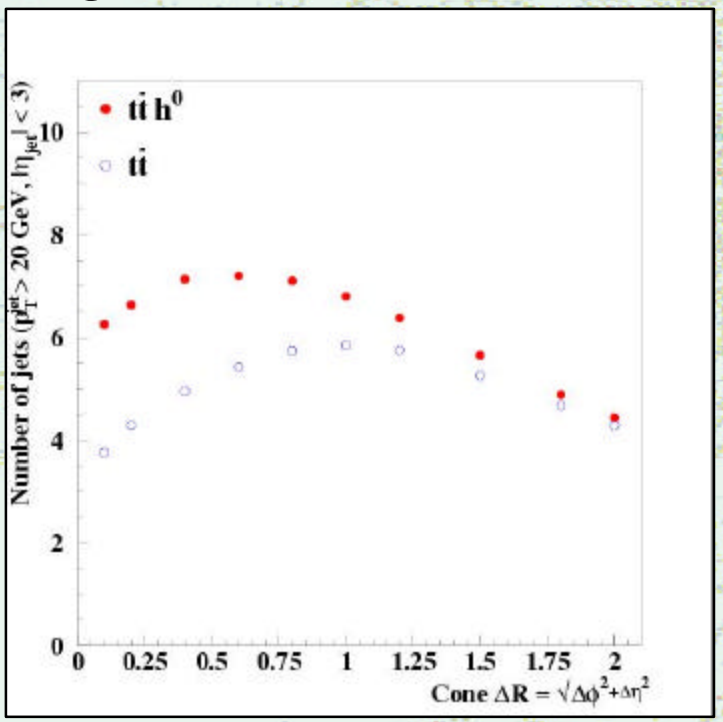
[GK,RG,ADS]

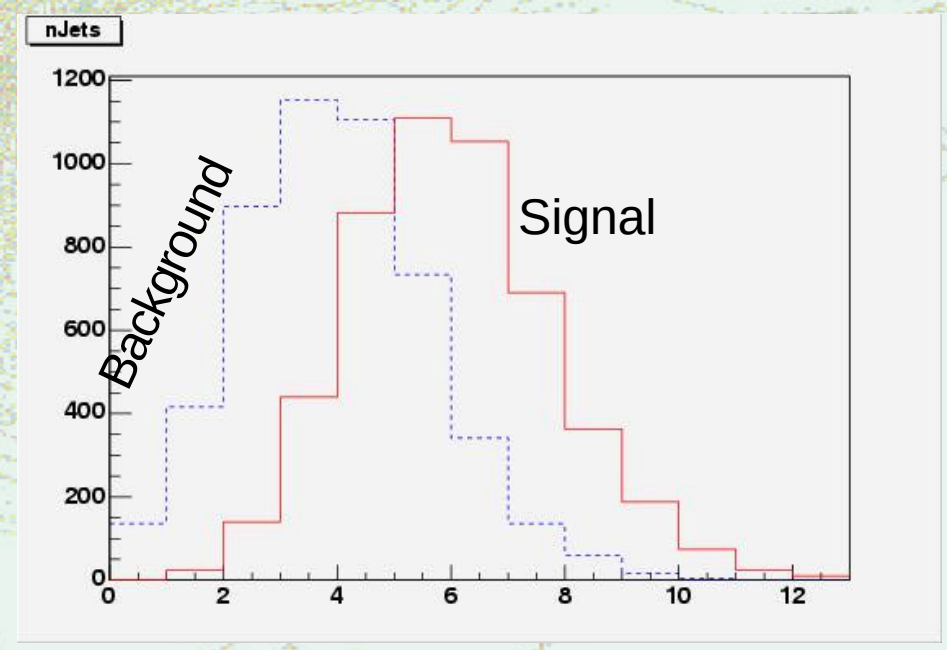
Jet studies :

Understanding the jet finding is crucial to most analyses at the LHC

The cone jet algorithm is being studied







Bayesian analysis of parton density functions

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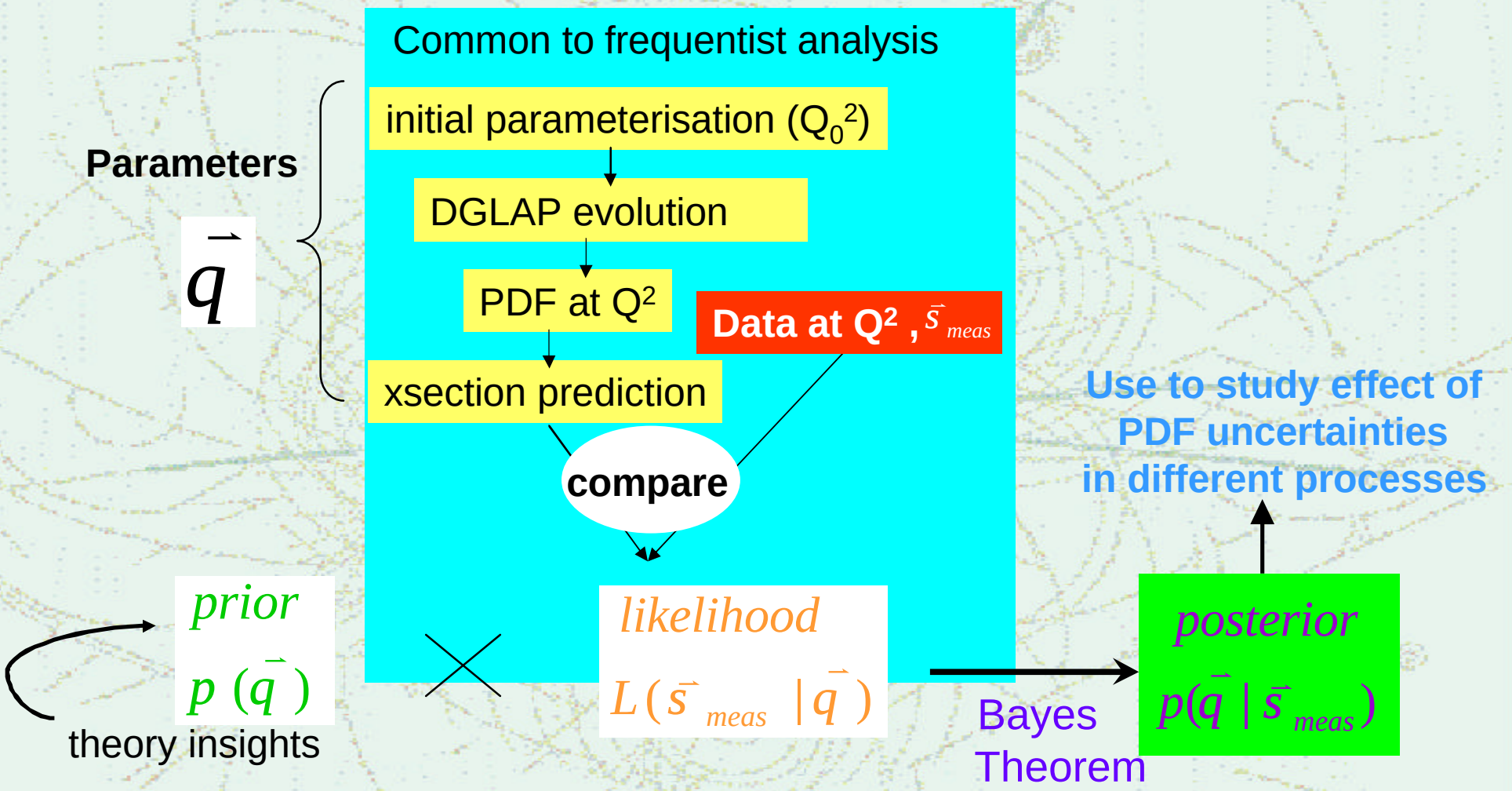
Parton distribution (PDF) uncertainties will be an important **source of error** in LHC measurements.

- The data sets used in recent PDF fits are increasingly precise. **Systematic uncertainties** play an important role
- Some data sets seem **incompatible**
- **Theoretical errors** also become more evident, higher orders, higher twist corrections, heavy target corrections, input parametrisations, etc...
- Global **frequentist** fits are forced to vary χ^2 by "**arbitrary**" amounts to obtain meaningful uncertainties (MRST $\Delta\chi^2=50$, CTEQ $\Delta\chi^2=100$)

A Bayesian analysis may provide a more suitable framework to treat systematic and theoretical errors.

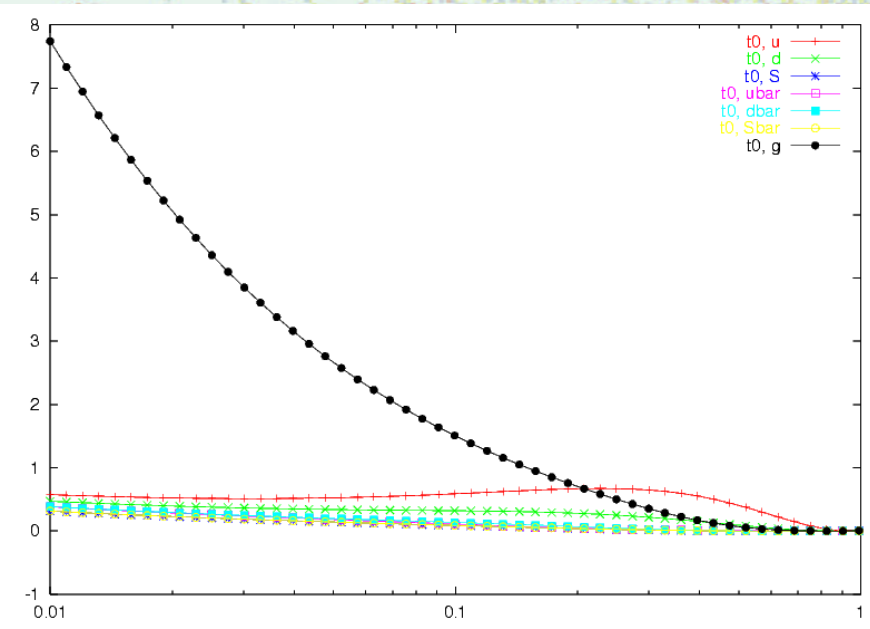
Ingredients :

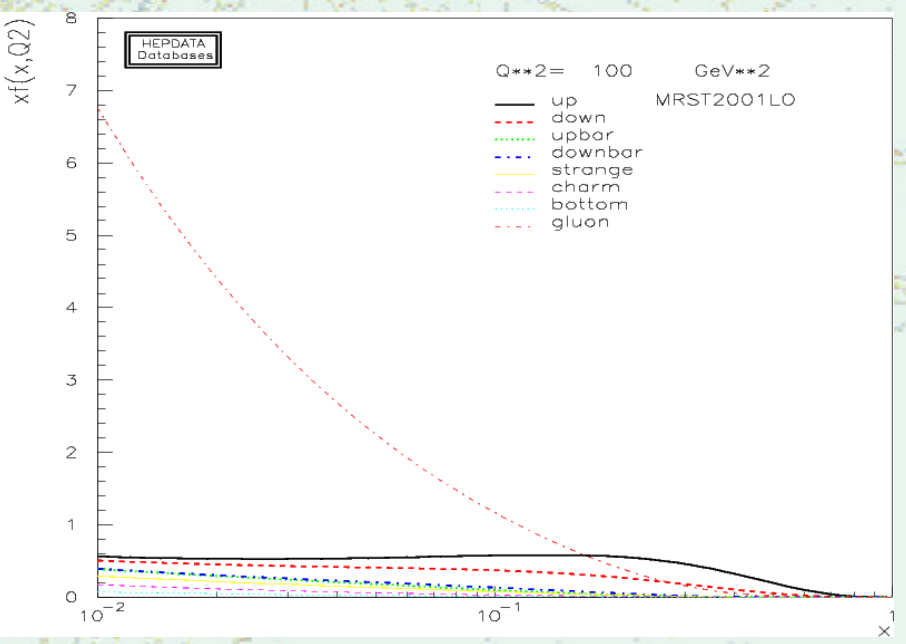


[CQ,GC]

Under development :

- **PDF evolution at NLO** (QCDNUM C++ wrapper)
- **Markov-chain Monte Carlo** (high-dimensional generating/sampling)
- **Goodness-of-fit** measure
- Methods for treating **incompatible data sets**





Fruitful contacts established with J.Stirling (MRST, IPPP), Amanda Cooper-Sarkar (Oxford, ATLAS), M.Goldstein (Bayesian statistician)

Summary and outlook

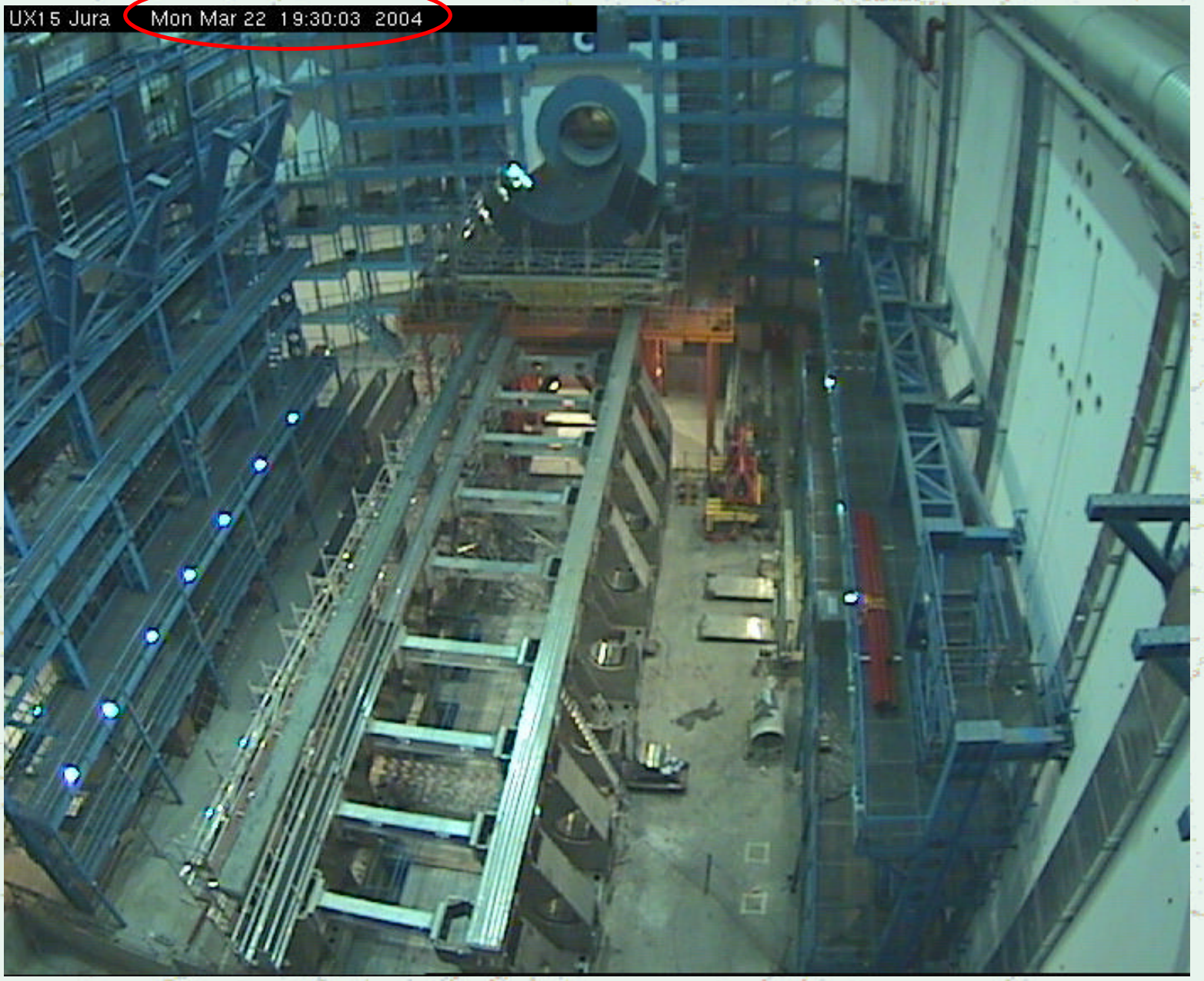
Current physics programme focuses on:

- **Higgs physics**
- **Bayesian analysis of parton density functions**

Future plans:

- Include **full simulation** studies (e.g. for ATLAS Data Challenge 2)
- Include **SUSY searches** in our programme

We are exercising analysis tools & techniques to be ready to exploit the full physics potential of ATLAS and the LHC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