*

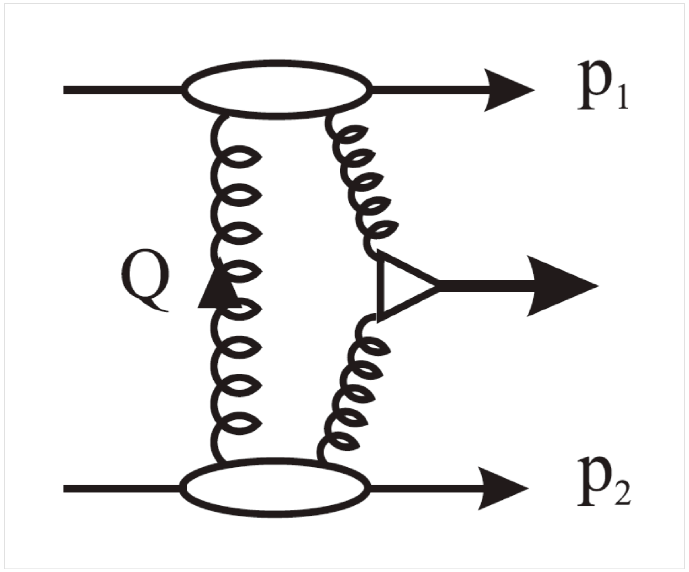
Exclusive production of a Standard Model Higgs boson – experimental prospects

Andy Pilkington and Mario Campanelli - University College London

Outline

1) A brief reminder of the exclusive process and detector needs
2) Prospects for Standard Model H->bb measurements
    - Signal extraction and exclusive/inclusive background
    - The problem with pile-up
    - How to trigger on low-p_T jets?
3) Prospects for Standard Model H->WW and H->ττ

Exclusive Higgs production



- Defined as the process pp -> p + H + p
- Protons remain intact, scatter through small angles
- All of the momentum lost by the protons during the interaction goes into the production of the central system, ϕ.
- ϕ produced in a J_z=0, C-even, P-even state

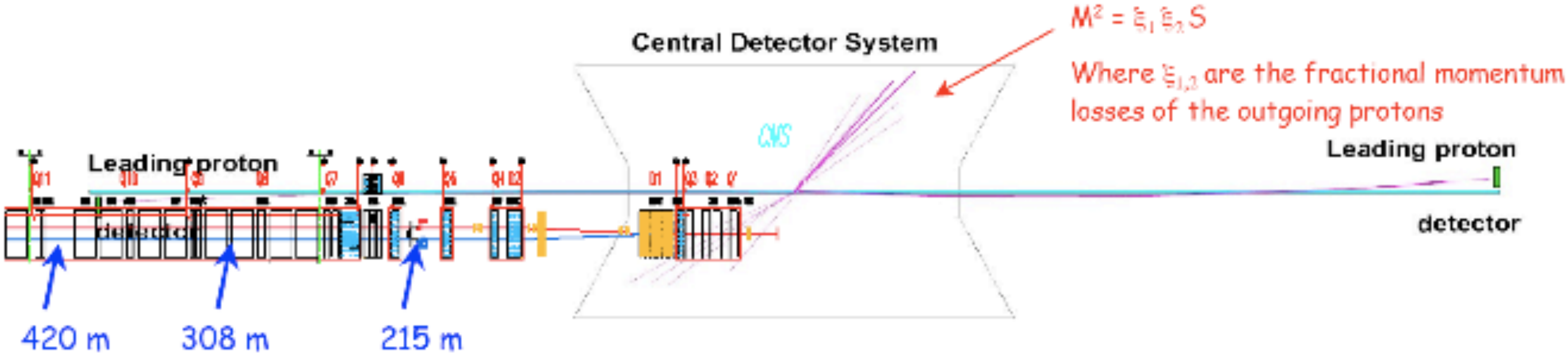
Kinematics

- Mass of the central system is given by: $\mathbf{M^2 = \xi_1 \xi_2 s}$

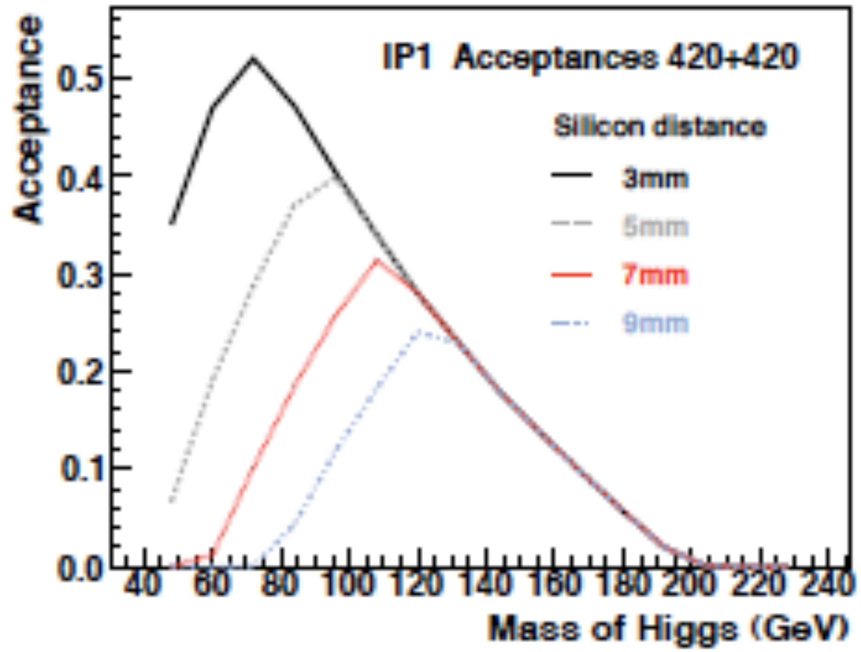
  where $\xi_{1,2}$ are the longitudinal momenta of the outgoing protons

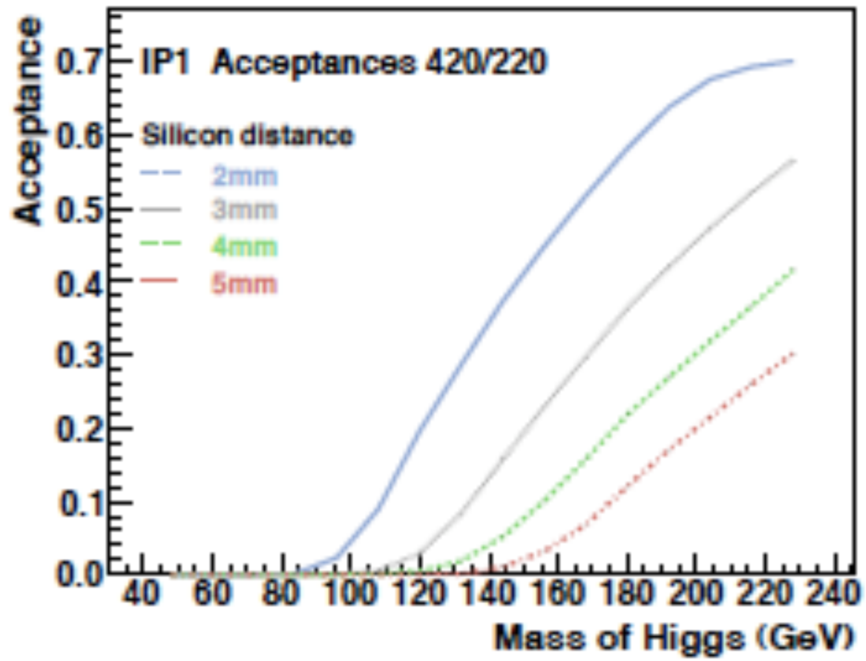
- Rapidity of the central system is similarly reconstructed by: $\mathbf{y = \frac{1}{2} Ln\left(\frac{\xi_1}{\xi_2}\right)}$

The basics of forward proton detection



JINST 4 (2009) T10001





Baseline studies

Signal cross section

- ExHuME version 1.3.4 used for signal generation.
- Cross section of $3fb^{-1}$ for a 120GeV Standard Model Higgs boson (all decay channels).

H->bb

- Studied in **JHEP 0710 (2007) 090** for a 120GeV Higgs boson (SM and MSSM)
  - Full generator-level study with all backgrounds (including pile-up).
  - Resolutions and reconstruction efficiencies accounted for in final yields
- Results consistent with MSSM studies presented in **Eur.Phys.J. C53 (2008) 231-256**
- Internal ATLAS study with full detector simulation gives very similar results.

H->WW*

- Baseline study in **Eur.Phys.J. C45 (2006) 401-407** for a range of Higgs masses
  - Full generator-level study with all non-pile-up backgrounds
- Internal ATLAS study for a 160GeV Higgs in the semi-leptonic channel gives reasonable agreement

Outlook for Standard Model H -> bb

2 b-jets plus 2 protons tagged at 420m

Kinematic matching

No extra radiation or underlying event

	Cross section (fb)						
Cut	CEP			DPE	[p][X][p]	[p][pX]	[pp][X]
	H	$b\bar{b}$	gg	$b\bar{b}$	$b\bar{b}$	$b\bar{b}$	$b\bar{b}$
E_T, ξ_1, ξ_2	0.124	1.320	2.038	0.633	[illegible]	[illegible]	[illegible]
R_j	0.119	1.182	1.905	0.218			
Δy	0.010	1.036	1.397	0.063			
$\Delta\Phi$	0.093	0.996	1.229	0.058			
N_C, $N_C^\perp$	0.084	0.923	0.932	0.044			
ΔM	0.072	0.070	0.084	0.004	[illegible]	[illegible]	[illegible]

Table 2: Cross section (fb) after applying each cut for the analysis performed using the cone algorithm with radius 0.7. The first cut is applied after requiring that both protons are tagged at 420m, the mass measured by the forward detectors is between 80 and 160 GeV and the transverse energy of the leading jet is greater than 40 GeV. The overlap backgrounds are defined at high luminosity (10^{34} cm^{-2} s^{-1}) and TOF vertexing has been used.

- 7 signal and 16 background events produced per 100fb-1 in the 420-420 configuration
- 4 to 12 signal and 16 to 50 background events per 100fb-1 in the 220-420 configuration (depends on detector distances from beam)
- **But**, this has not yet accounted for the effects of trigger and pile-up

Trigger for H->bb (I)

- The ATLAS/CMS trigger systems are based on a Level 1 decision followed by Higher Level decisions.

- The total decision time at Level 1 is 2.5μs [CMS has 4μs – thanks David d'Enterria]
  - Not enough time for signal from stations at 420m (takes about 4-5μs to arrive)
  - Event information saved based on calorimeter information and proton information from 220m.
  - Following the phase 1 upgrade, ATLAS will be able to utilise calorimeter topology information (jet angles, etc) in the L1 decision

    [CMS already has some of this capability].
  - 75-100kHz total budget at L1, so need a dedicated H->bb trigger to be O(1-2kHz).

- In the HLT, much more information available:
  - Could require 2-proton tags (including 420m information), proton-time-of-flight, Higgs-like mass, match proton-proton mass/rapidity to central dijet system, etc
  - About 400Hz total budget at HLT, need final rate of H->bb trigger to be O(10Hz).

Bottom line: The issue will be obtaining an acceptable L1 rate for retaining exclusive dijet events

Trigger for H->bb (II)

- Example L1 trigger strategy outlined in **ATL-DAQ-PUB-2009-006**:

L1 item	Rate at 2×10^{33} (kHz)	Rate at 10^{34} (kHz)
J20+J40 + p220 + X_A=0.5 + X_D=1.5 + $\Delta\phi > 2.5$	0.51	12.2
J20+J40 + p220 + X_A=0.5 + X_D=1.5 + $f_T > 0.45$	0.12	2.9

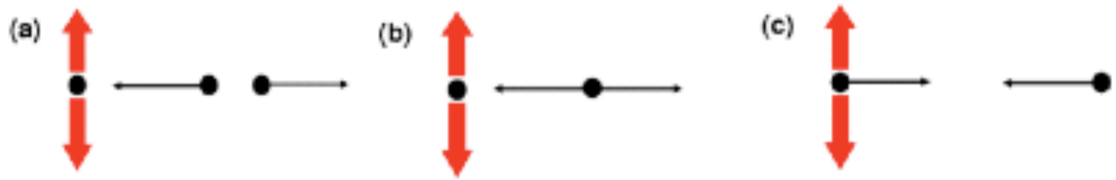
- **J20+J40** is a dijet trigger with jet thresholds of 20GeV and 40GeV
- **P220** is a proton tag at 220m
- $\mathbf{X_A}$ is a cut on the average rapidity of the two jets (assumes that a boosted dijet system exists if a Higgs candidate and one proton tagged at 220m)
- $\mathbf{X_D}$ is a cut on the rapidity separation of the two jets (Higgs decays uniformly in solid angle)
- **$\Delta\phi$** is the azimuthal angle between the jets
- $\mathbf{f_T}$ is the fraction of the transverse energy reconstructed in the dijet system (very affected by soft pile-up activity and needs to be re-studied using latest simulations)

Trigger for H->bb (III)

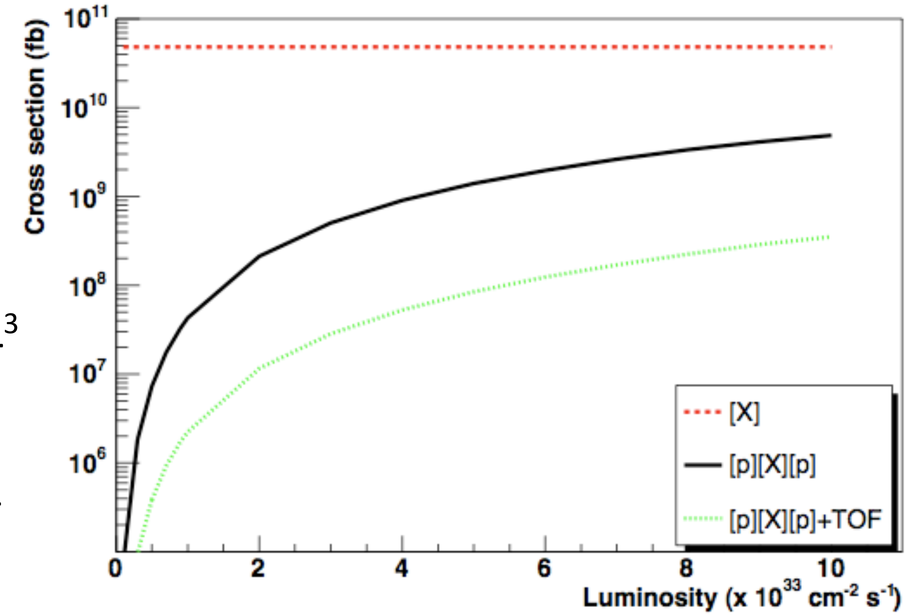
- Trigger strategy outlined on previous page offers some cause for optimism
  - Signal efficiency of O(50%) for asymmetrically measured events (220-420 tag) with an acceptable trigger rate.
  - But, no 420-only tagged events.

- Possible improvements:
  - Add dijet mass cut at L1 (we know the Higgs mass) to further reduce rate.
  - ATLAS: Upgrade trigger hardware to include a "fast-clear" system – to keep some 420-only events.
    - Allows very high rate for a specific trigger chain (e.g. dijet events) whilst waiting for the information from 420m, available at 1-2μs after the L1 decision. Events removed if the two proton tags are not available.
    - Dijet-only rate is >200kHz based on study in **ATL-DAQ-PUB-2009-006**
    - Factor of ~20 rejection from requiring two protons tagged at 420m at $L=10^{34}\ cm^{-2}\ s^{-1}$
    - By itself, this is not enough. Need much more rejection for this trigger to be feasible as the original fast-clear was envisaged to not pass events to HLT at all.
      - L1 topology cuts and 2-stage fast clear? Needs much study by experiments.
  - CMS: Allow 420m signals at L1. CMS already have 4μs latency, but need to propagate signals and make am accept decision
    - In this case, the factor 20 rejection plus some topology cuts at L1 might be enough.

The problem with pile-up (I)

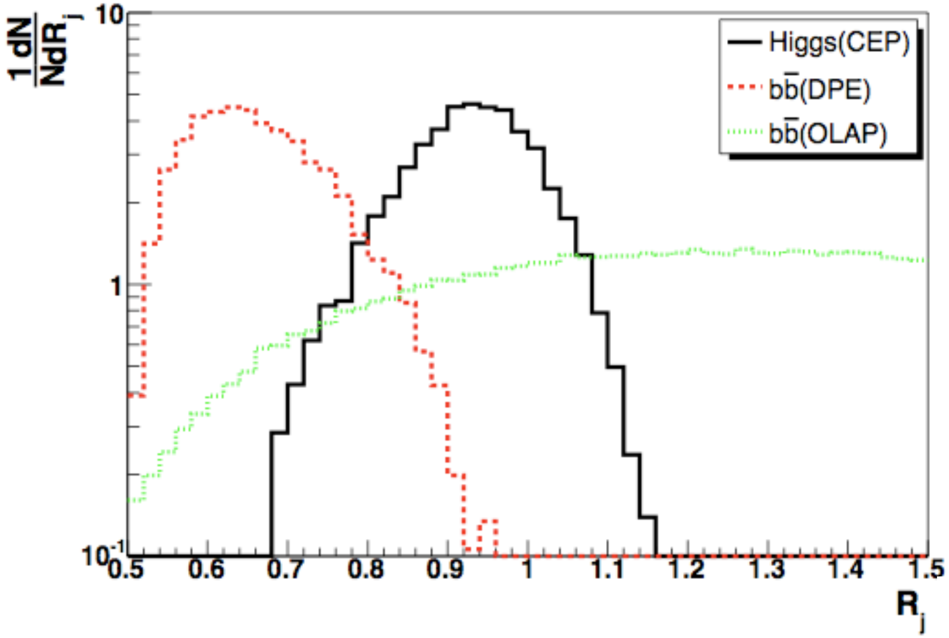


- Coincidence between one (or more) soft SD/DPE in the same bunch crossing as a dijet event.

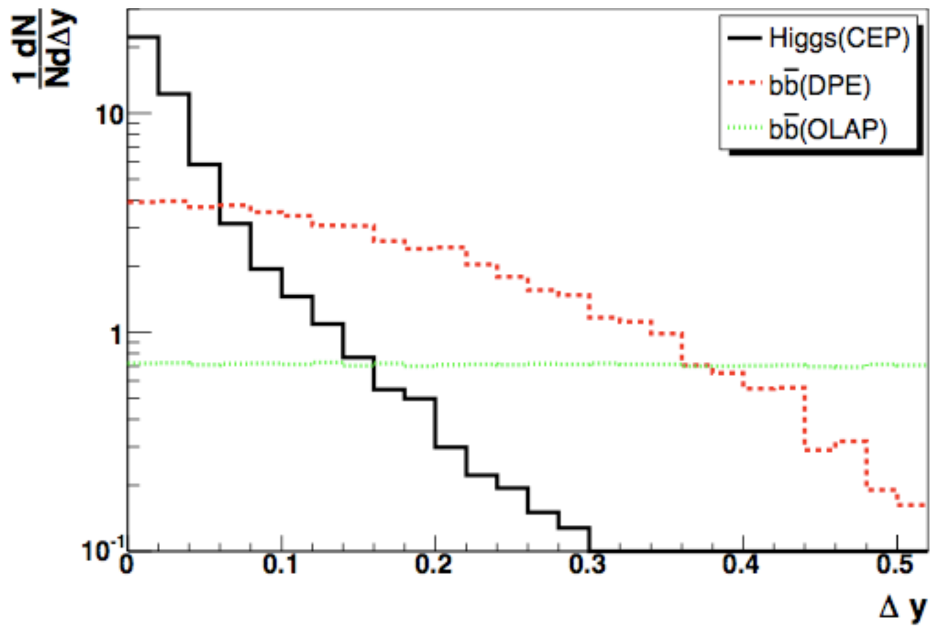


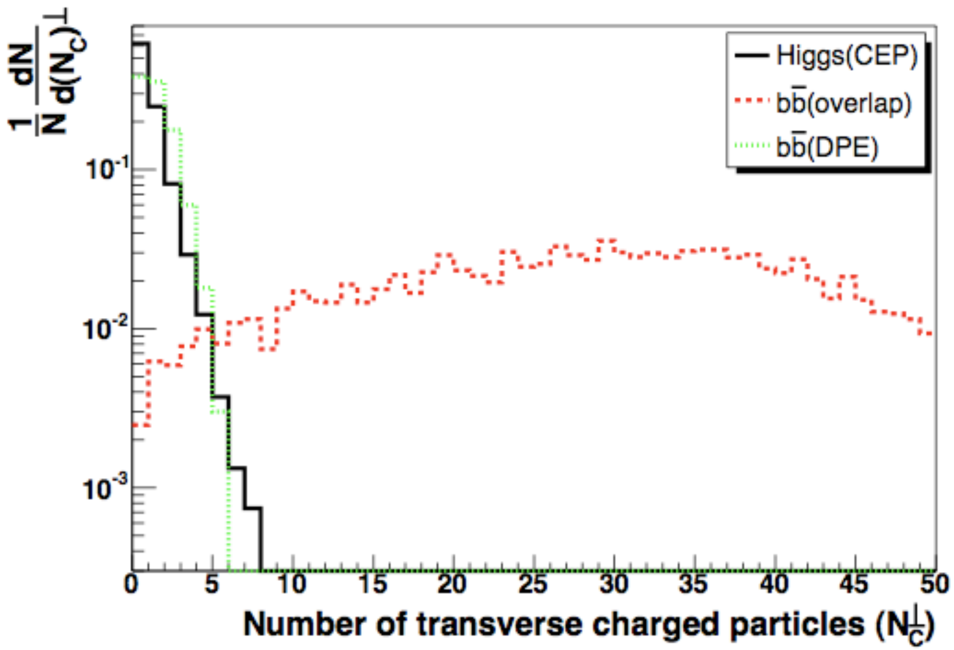
- Luminosity dependent: probability of this occurring increases with the number of interactions in the crossing.
  - [p][X][p] is dominant and the rate scales as L^3
- Initially rejected by hardware by measuring primary vertex and comparing to proton time-of-flight difference (factor 40 reduction).
- At high luminosity, these “overlap events” dominate over all other backgrounds .

The problem with pile-up (II)



- Reject pile-up using exclusivity requirements:
  - Match dijet mass and rapidity to the variables reconstructed using protons (left plots)
  - Cut on number of charged tracks in the region transverse in azimuth to the leading jet (UE cut, bottom right plot).





The problem with pile-up (III)

2 b-jets plus 2 protons → E_T, ξ_1, ξ_2

Kinematic matching → R_j, Δy

No extra radiation or underlying event → $\Delta\Phi$, $N_C, N_C^\perp$

Cut	Cross section (fb)						
	CEP			DPE	[p][X][p]	[p][pX]	[pp][X]
	H	$b\bar{b}$	gg	$b\bar{b}$	$b\bar{b}$	$b\bar{b}$	$b\bar{b}$
E_T, ξ_1, ξ_2	0.124	1.320	2.038	0.633	3.91×10^5	7.33×10^2	6.29×10^4
R_j	0.119	1.182	1.905	0.218	4.73×10^4	85.2	7.59×10^3
Δy	0.010	1.036	1.397	0.063	2.16×10^3	1.38	3.50×10^2
$\Delta\Phi$	0.093	0.996	1.229	0.058	6.66×10^2	0.77	1.07×10^2
$N_C, N_C^\perp$	0.084	0.923	0.932	0.044	6.49	0.45	1.35
ΔM	0.072	0.070	0.084	0.004	0.59	0.03	0.13

Table 2: Cross section (fb) after applying each cut for the analysis performed using the cone algorithm with radius 0.7. The first cut is applied after requiring that both protons are tagged at 420m, the mass measured by the forward detectors is between 80 and 160 GeV and the transverse energy of the leading jet is greater than 40 GeV. The overlap backgrounds are defined at high luminosity (10^{34} cm^{-2} s^{-1}) and TOF vertexing has been used.

- For 420-420 configuration, 80 extra background events per 100fb^{-1}
- For 220-420 configuration, 65 to 200 extra background events per 100fb^{-1} depending on detector positioning

This pile-up background will swamp the H->bb signal unless it is reduced.

How realistic is that [old] pile-up study?

Central dijet system

- Dijet cross section predicted by leading order generators was shown to be a factor of about 1.5 too high at sqrt(s)=7TeV (atlas jets)
  - Could use NLO k-factors to get a better estimate of event rate.
- UE tune was "Tuning A" for Herwig/Jimmy in **hep-ph/0601013.** This has more UE than the Pythia 6 tunes in that review, which affects the exclusivity cuts on charged tracks.

Forward protons

- ATLAS measurement of the inelastic cross-section vs rapidity gap size indicate that the cross section predictions in the 420 acceptance are rouhgly as predicted by the SD models.
- In the 220 acceptance, the Pythia 6 prediction (default in the old pile-up study) is favoured over the Phojet prediction. This is important as the contribution from non-diffractive protons was very different between the generators.

Future cross-checks:

- The forward proton spectrum can be measured by ALFA/TOTEM.
- The dijet pile-up cross section as a function of average interaction rate can be measured in data by correlating forward protons (in Totem/ALFA) in one bunch crossing with dijets in another bunch crossing.

Possible solutions to the pile-up issues?

- Need factor of 10-20 improvement in rejection of pile-up backgrounds at $L=10^{34}\ cm^{-2}\ s^{-1}$ if we want to study SM H->bb channel.

- Analysis based possible solutions:
  - Proton p_T and ϕ information not currently used (assumed too poor resolution in previous studies – is this still the case? – could a ϕ^* like variable be constructed?
  - Identification of SD vertices?
    - Fast timing rejection measures only the difference in the TOF of the two protons and compares this pseudo-vertex to the primary vertex.
    - The SD vertices would actually be located at equal distance either side of the primary vertex, but unlikely to overlap with the PV.

- Hardware based possible solutions:
  - Fast timing detectors offer a rejection factor of 40 for 10ps time-of-flight resolution
  - Scales linearly, so factor of 2 better resolution would give factor 2 more rejection

Outlook for Standard Model H->WW

- Originally studied in **Eur.Phys.J. C45 (2006) 401-407,** generator level study for various Higgs masses.
  - Closest point is the study of a 120GeV Higgs boson. Conclusions therefore conservative because a 125GeV Higgs will benefit from (i) increased WW branching ratio (ii) better proton acceptance and (iii) better lepton/jet acceptance from the off-shell W.

- Two analysis channels investigated for a “120GeV Higgs boson”:
  - **Fully-leptonic**. Two leptons and nothing else! Very small exclusive/inclusive background. Excellent lepton trigger prospects. Pile-up not studied, but expected to be a small effect. Yield: 1 signal event per $100fb^{-1}$ for dilepton triggers. Could double this if single lepton trigger (p_T>15GeV) plus proton tag is viable.
  - **Semi-leptonic**. Single lepton trigger. Larger background from exclusive qqW production (not yet studied at generator level). Pile-up events expected to be non-negligible. Yield: 0.3 signal event per $100fb^{-1}$

Outlook for Standard Model H->ττ

- Very little published work on this channel, especially for a SM Higgs boson
- Most illuminating study is presented in **Eur.Phys.J. C53 (2008) 231-256** for MSSM Higgs bosons
  - Assumes same signal selection efficiencies as the bb channel. This is thought to be a conservative estimate.
  - Result: slightly worse coverage of the tanβ-M_A plane (in statistical significance) than for the corresponding analyses in the bb channel.
  - Caveat: trigger possibly easier if selecting tau candidates (esp from e/μ decays).
  - Caveat: No knowledge of pile-up conditions. Likely to be problematic unless both taus decay leptonically

  - <u>This channel needs a bit more attention</u>, to quantify the expected signal and background yields. Could add a couple of signal events to final yield with only a slight background increase if jet backgrounds can be adequately rejected.

Summary

Channel and event yield summary

(1) H->bb offers the largest signal yield, but has the largest backgrounds and the most difficult trigger

(2) Other channels offers, at best, an event or two for the nominal signal. Any reduction from $3fb^{-1}$ would likely make the yields too low (*see talk by Jeff Forshaw*).

(3) All of this was for a Standard Model Higgs boson. Yields can be higher for a BSM Higgs boson. That said, the boson we have observed is seemingly SM-like in rates , at least at present.

Experimental road-map:

(4) New cuts to reject the pile-up backgrounds will be necessary in order to extract a SM Higgs boson in the H->bb channel

(5) Extensive work is needed to define the most appropriate trigger strategy for H->bb