Central Exclusive $H \to b\bar{b}$ and di-gluino production at the LHC

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Overview

- FP420 and central exclusive production
- Background processes and rejection methods
- $H \rightarrow b\bar{b}$ using FP420
- Di-gluino production using 420+220m forward detectors

Central Exclusive Production (CEP)

- Defined as the process $p\,p \to p + \phi + p$.
- The protons remain intact during the interaction and in principle can be detected.
- All of the momentum lost by the protons during the interaction goes into the production of the central system, ϕ.
- From the momentum loss of each proton, x, it is possible to reconstruct the mass of the central system, M, by

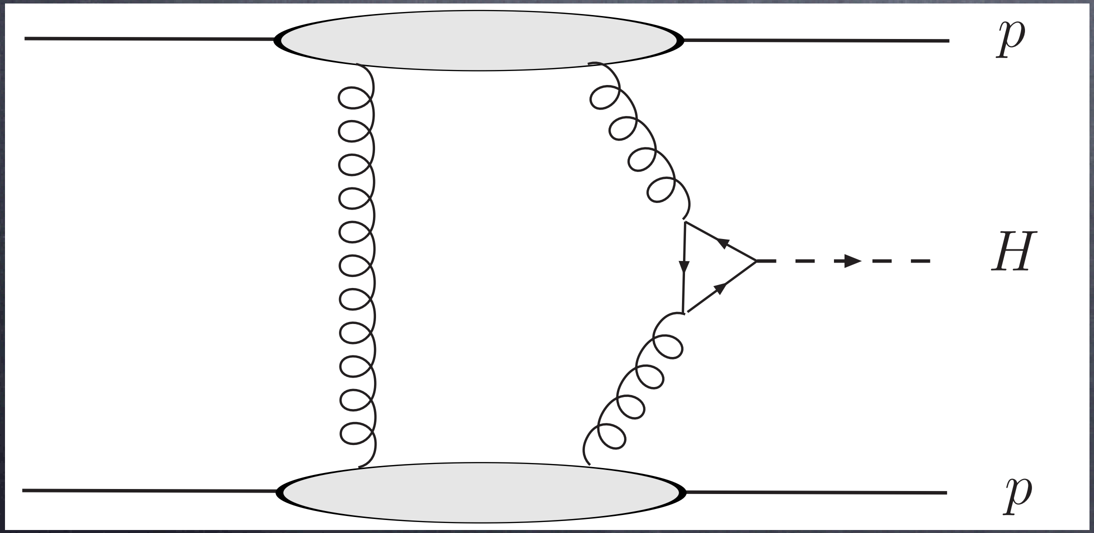
$$M^2 \simeq x_1\, x_2\, s$$

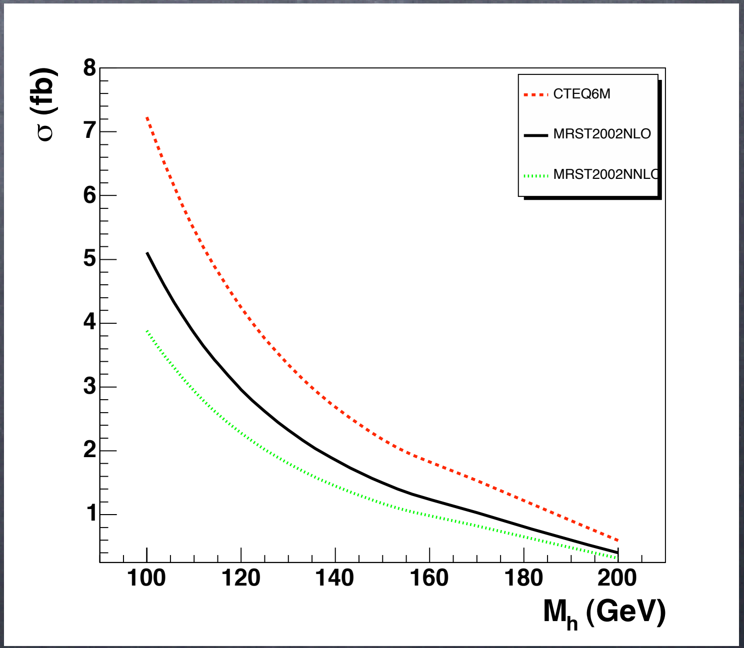
- It is also possible to reconstruct the rapidity, y, of the central system by

$$y \simeq \frac{1}{2} \ln\left(\frac{x_1}{x_2}\right) .$$

Why Higgs? Why $b\bar{b}$ channel?

- Using the protons, the mass of the resonance can be measured independent of the decay process.
- Furthermore, the resonance must be a spin-0 particle.
- However, the cross section is typically small for CEP, therefore need to study channels with large branching ratios.
- Need $b\bar{b}$ channel for 120GeV Standard Model Higgs.





The FP420 project - basics

- A system of forward proton detectors for ATLAS/CMS that are 420m from the interaction point.
- Protons from CEP have lost momentum and are bent out of the beam by the LHC magnets. It is a magnetic spectrometer.
- The distance the protons are displaced from the beam is determined by the momentum loss during the interaction.
- FP420 will measure protons that have lost between 0.2% and 2% of their momentum. For higher momentum losses, need 220m forward detectors.
- For more information , see talk by S.Watts.

FP420 specifics for this analysis

- The acceptance of FP420, found using the FPTRACK program, can be approximated by

$$
\begin{aligned}
0.0023 &\leq x_1 \leq 0.0129 \\
0.0029 &\leq x_2 \leq 0.0171
\end{aligned}
$$

- The expected resolution of the momentum loss measurement is also found using FPTRACK. From this we find, for example, that the mass resolution is approximately 1.5 - 2GeV for FP420 at ATLAS.

- Vertex measurement by FP420 (using proton time of flight) accurate to 2.1 mm.

Backgrounds I: CEP

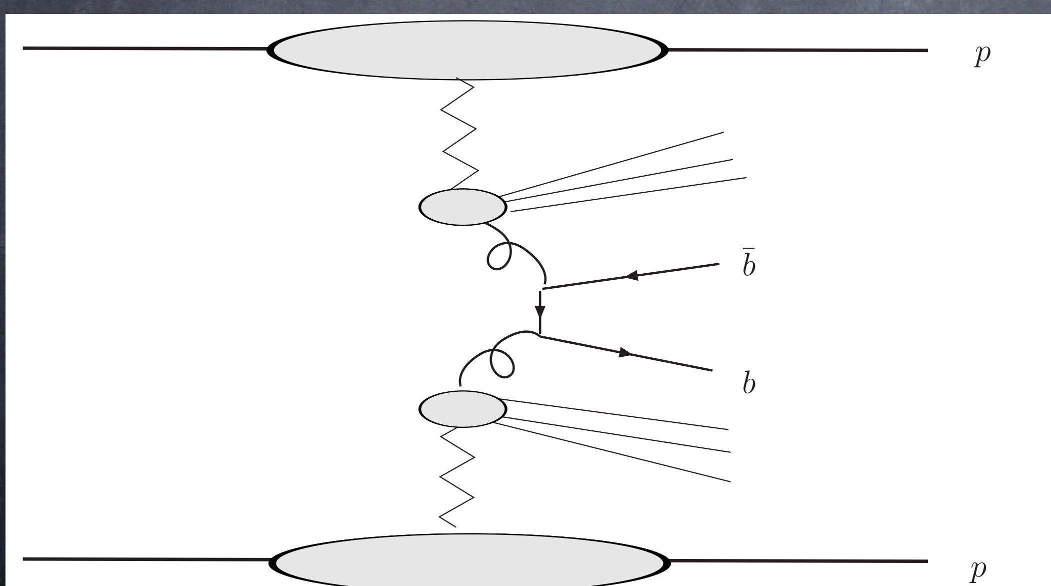
- The relevant backgrounds are $gg \to b\bar{b}$

  $gg \to gg$

- The di-quark backgrounds are suppressed, by the spin selection rule, by a factor of $\frac{m_q^2}{M^2}$.
- Both backgrounds are reduced by a jet transverse energy cut of $E_T \geq 40GeV$.
- The di-gluon background is reduced by the b-tagging algorithm at ATLAS. This is expected to have a mis-tag of 1.3% for a 60% b-jet efficiency.
- All of the central exclusive processes are produced using the ExHuME event generator.

Backgrounds II: Double Pomeron Exchange (DPE)

- Defined as the process $p\,p \rightarrow p + \phi + A + p$
- The protons remain intact, but the central system is accompanied by extra activity, A, which are the pomeron `remnants'.
- The relevant backgrounds are di-jet backgrounds, denoted as b-jet (bb) and non-b-jet (jj).



These backgrounds are produced using the POMWIG event generator with the latest H1 diffractive PDFs. We use H1 2006 Fit B in the results presented here.

Backgrounds III: Overlap

- Defined as a three-fold coincidence between two single diffractive events, each of which produces a proton hit in FP420, and a normal QCD di-jet event.
- The cross section is defined as

$$\sigma_{\rm olap} = (N-1)\,(N-2)\;P_1\,P_2\;\,Q\;\sigma$$

- N is the average number of pile-up events.
- Q is the rejection factor from matching di-jet vertex to the vertex measured by FP420 from proton TOF ($\sim$40).
- σ is the di-jet cross section.
- The P's are the probability for a single diffractive event to produce a proton with a momentum loss in the FP420 acceptance range.

- These probabilities are calculated from the single diffractive (SD) cross section (KMR: hep-ph/0609312)

$$\frac{1}{\sigma_T}\frac{d\sigma^{SD}}{dtdx_L} = \frac{g_N^2(t)g_{3\mathbb{P}}}{16\pi^2 g_{N(0)}}(1-x_L)^{\alpha_{\mathbb{P}}(0)-2\alpha_{\mathbb{P}}(t)}\, S^2_{SD}(s,t)$$

- Find that $P_1 = 0.85\%$ and $P_2 = 0.86\%$.

- The SD cross section is also used to construct the SD proton momentum on an event by event basis using standard Monte Carlo methods.

- The QCD di-jet event is constructed using HERWIG + JIMMY tuned to CDF data.

- The overlap event = QCD event + 2 SD protons.

Background Reduction I: Kinematic Matching

- The di-jet mass fraction compares the mass of the di-jets to the mass measured by FP420. It is estimated by

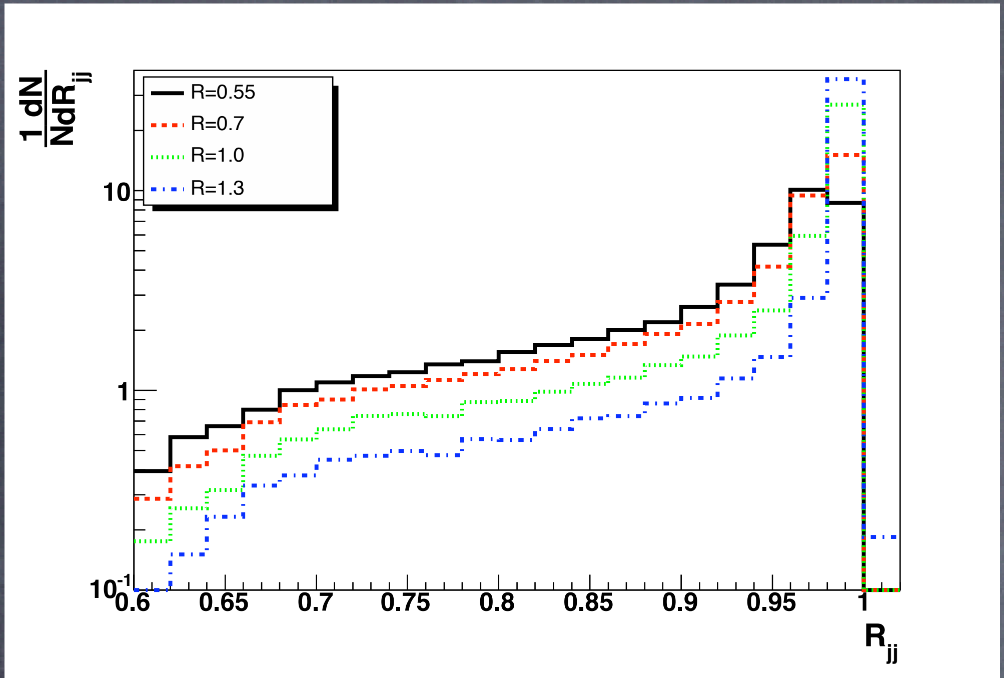
$$R_{jj} = \frac{M_{jj}}{M}$$

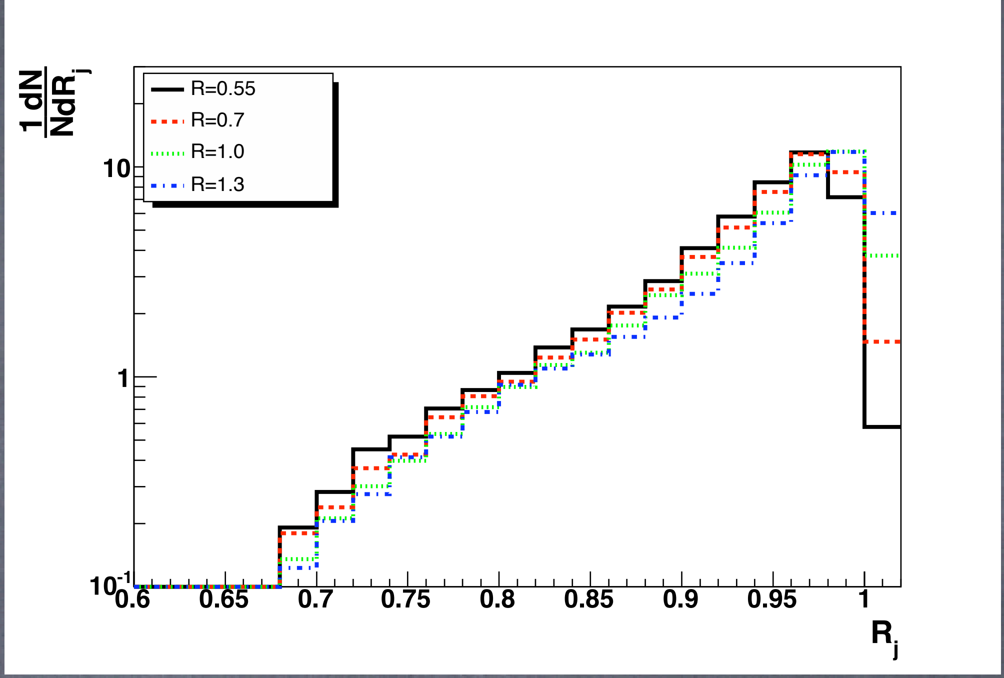
- Another measure of the mass fraction uses just the transverse energy, E_T^1, and pseudo-rapidity, η_1, of the leading jet and is given by

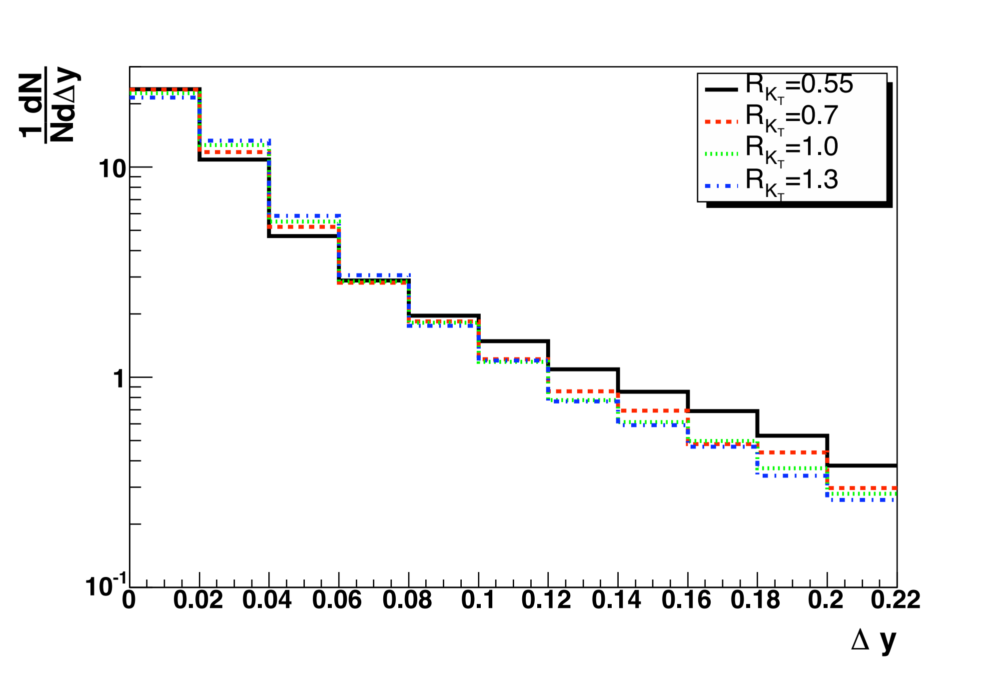
$$R_j = \frac{2E_T^1}{M} \cosh\left(\eta_1 - y\right).$$

- The difference, Δy, between the rapidity measured by FP420 and the average jet rapidity should be approximately the same

$$\Delta y = y - \left(\frac{\eta_1 + \eta_2}{2}\right).$$



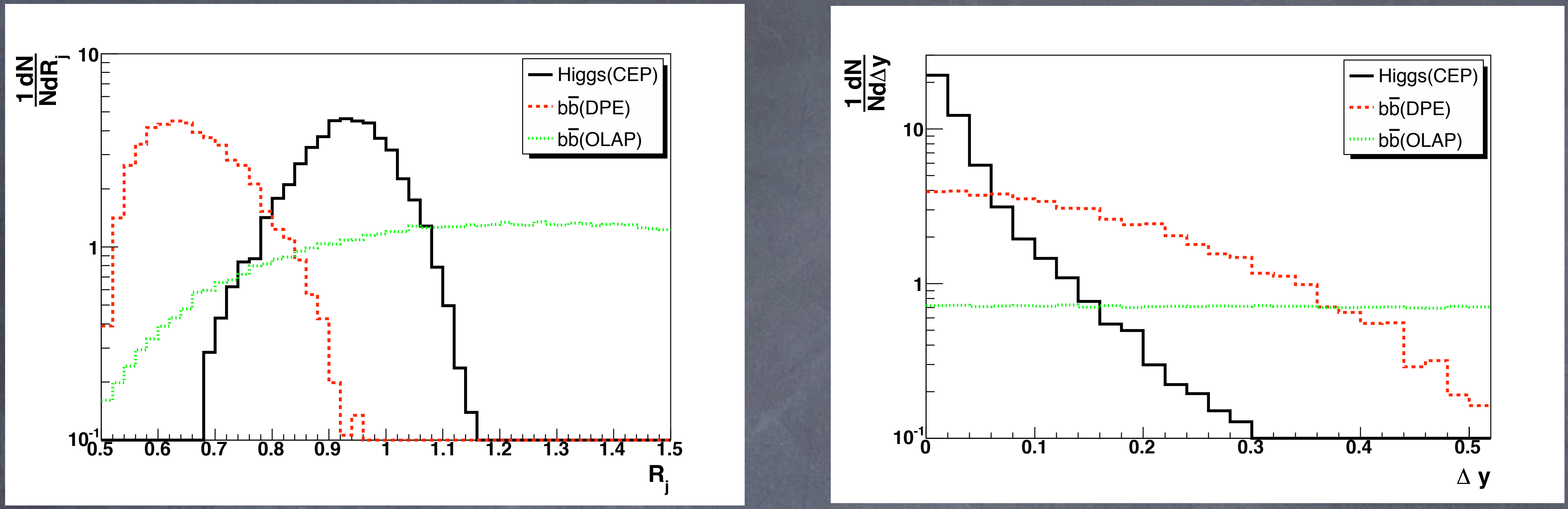




$H \rightarrow b\bar{b}$ reconstruction using the KT algorithm (hadron level).

Conclude that R_j and Δy are robust variables for CEP.

Similar results found for the cone algorithm.



- Comparison of R_j and Δy for the signal, DPE $b\bar{b}$ and overlap $b\bar{b}$ events.
- Particles smeared with intrinsic resolution of ATLAS as defined in TDR. Jets found using cone algorithm with radius of 0.4.
- Exclusive region defined by $0.8 \leq R_j \leq 1.1$

$$\Delta y \leq 0.06$$

Background Reduction II: Underlying Event

- CEP events (and DPE ones) have intact protons and therefore no underlying event associated with the interaction.

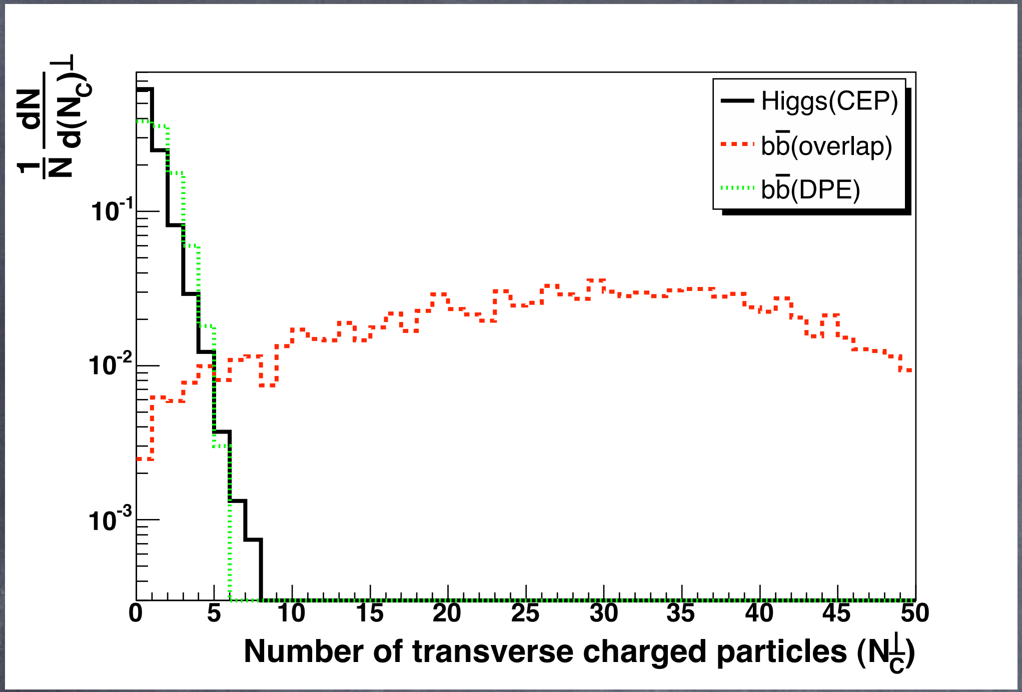
- This is not true for overlap events. The protons that produce the di-jets break up during the interaction. Therefore have protons remnants and multi-parton interactions.

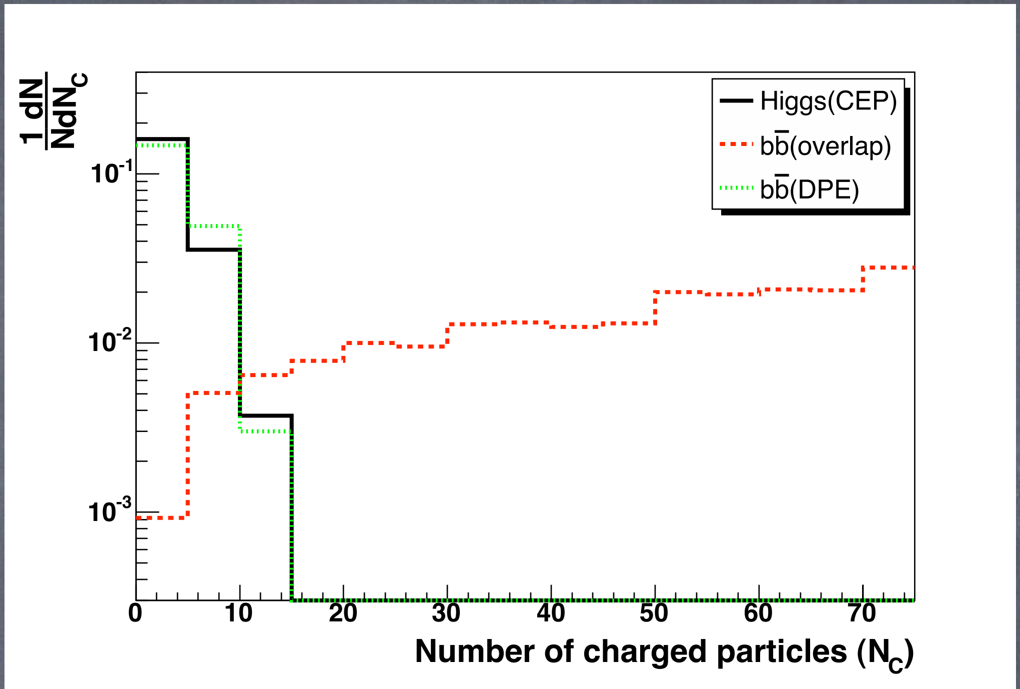
- Cut on the number of charged particles that are transverse to the leading jet, $N_C^{\perp}$. The transverse region is defined as

$$\frac{\pi}{3} < |\phi_k - \phi_j| < \frac{2\pi}{3} \quad \text{and} \quad \frac{4\pi}{3} < |\phi_k - \phi_j| < \frac{5\pi}{3}$$

- Could also cut on the total number of charged particles outside of the dijet system, N_C .

- The particles are restricted to ATLAS inner detector acceptance, i.e $p_T \geq 0.5\text{GeV}$ and $\eta \leq 2.5$.





- Find that the overlap events have a much more charged particles. The CEP and DPE events are well described (i.e we retain more than 80% of the events) by

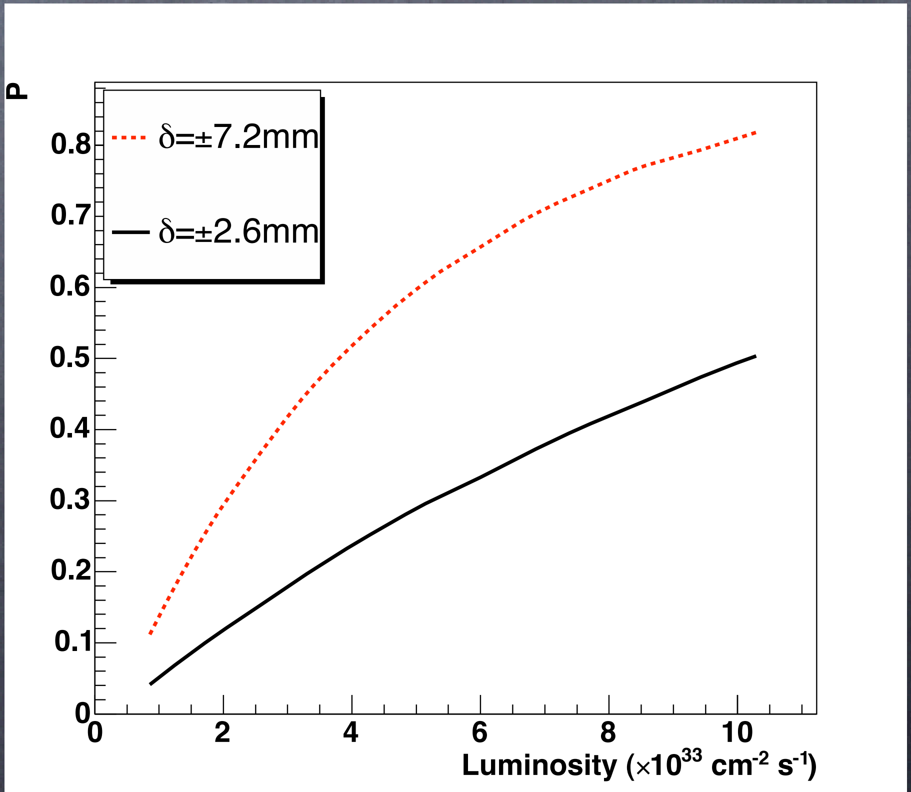
$$N_C \leq 7 \quad \text{and} \quad N_C^\perp \leq 1$$

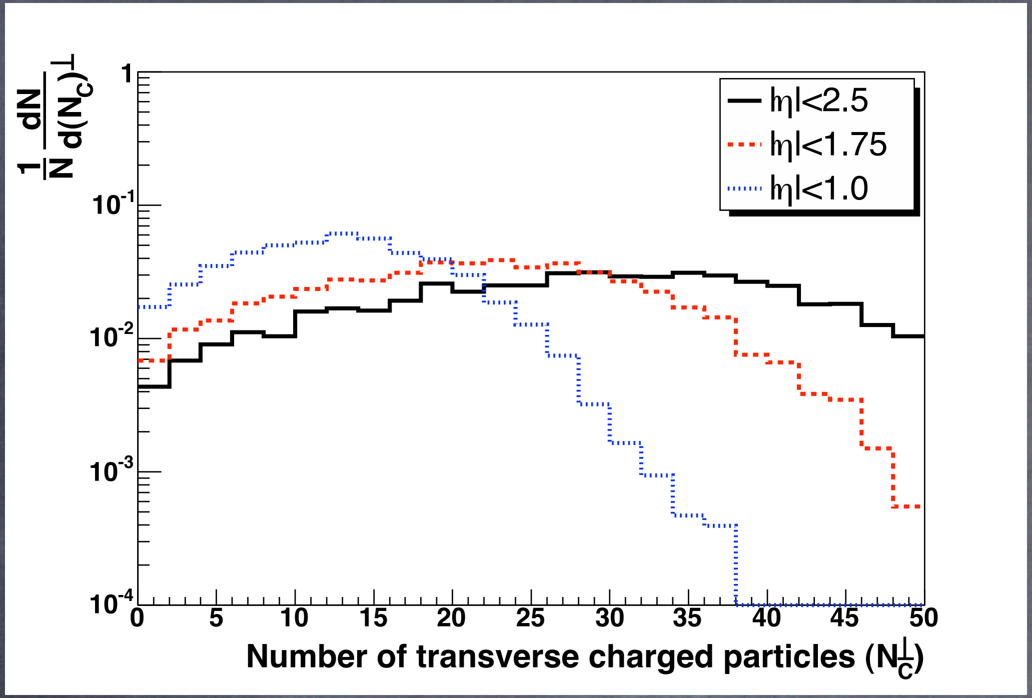
- This could be affected by charged tracks from pile-up, so we need to estimate (check) whether our results will be robust.

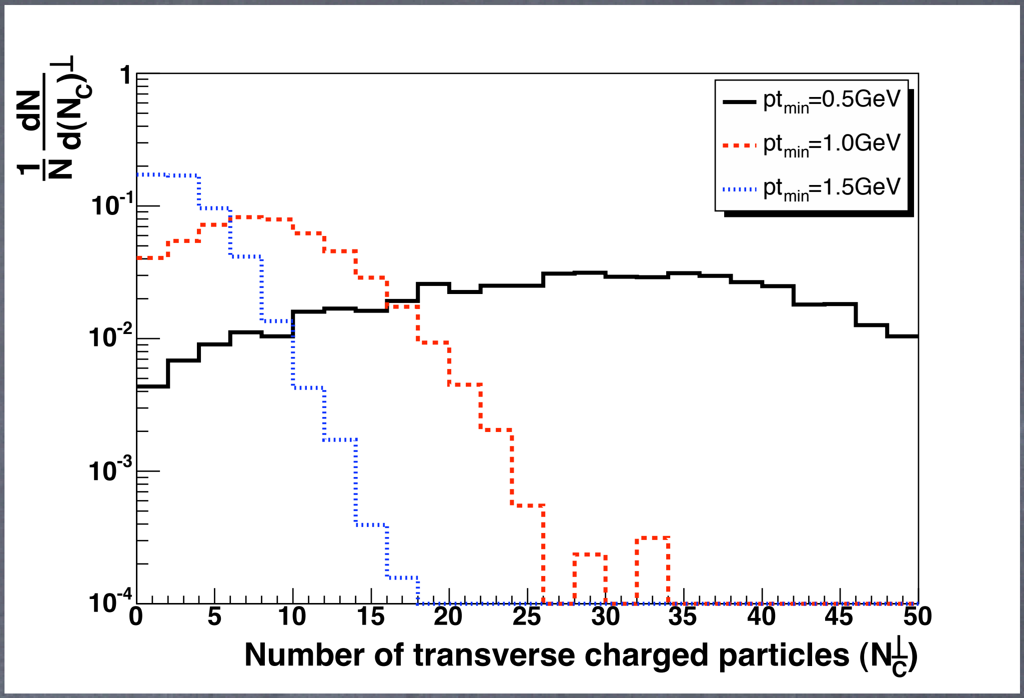
- In order to minimise the effect of pile-up tracks, impose a vertex window around primary vertex. Vertex window needs to be $\delta = \pm 2\sigma_z$, where δ is the vertex resolution of a charged track using the ATLAS inner detector.

- The resolution becomes worse at low transverse momentum and high pseudo-rapidity.

1) The plot shows the probability of a inelastic pile-up event being within the vertex window.
2) $\delta = 7.2$ corresponds to the vertex window for a particle with $p_T = 0.5\mathrm{GeV}$ and $\eta = 2.5$.
3) $\delta = 2.6$ corresponds to $p_T = 0.5\mathrm{GeV}$ and $\eta = 1.75$.







- Need to be able to use low transverse momentum particles.
- Not that important to use high pseudo-rapidity particles. If we restrict our particles to $|\eta| \leq 1.75$ then we increase this background by a factor of 1.5.
- Define the pseudo-rapidity range to be $|\eta| \leq 1.75$

Extra requirements

- Mass window (we are looking for a resonance) is

$$118 \leq M \leq 122 \quad \mathrm{GeV}$$

- Azimuthal angle between the two jets satisfies

$$|\Delta\phi - \pi| \leq 0.2$$

- The azimuthal angle cut is essentially an ISR cut.

Results - CEP cross section

- The $H \rightarrow b\bar{b}$ cross section after all cuts is 0.055fb
- This is small - where has the signal gone?
  - Total (original) cross section for Higgs is 3.0fb. The $b\bar{b}$ branching ratio is about 67%.
  - Acceptance of FP420 is 28%.
  - Higgs decays uniformly in solid angle. Therefore 75% of events will have a b-quark with transverse energy greater than 40GeV. For jets, less pass due to parton showering.
  - b-tagging efficiency for two jets is 36%.
  - Max cross section before analysis cuts = 3.0*0.67*0.28*0.75*0.36 = 0.15fb.
  - Experimental cuts remove just under two-thirds of the signal.

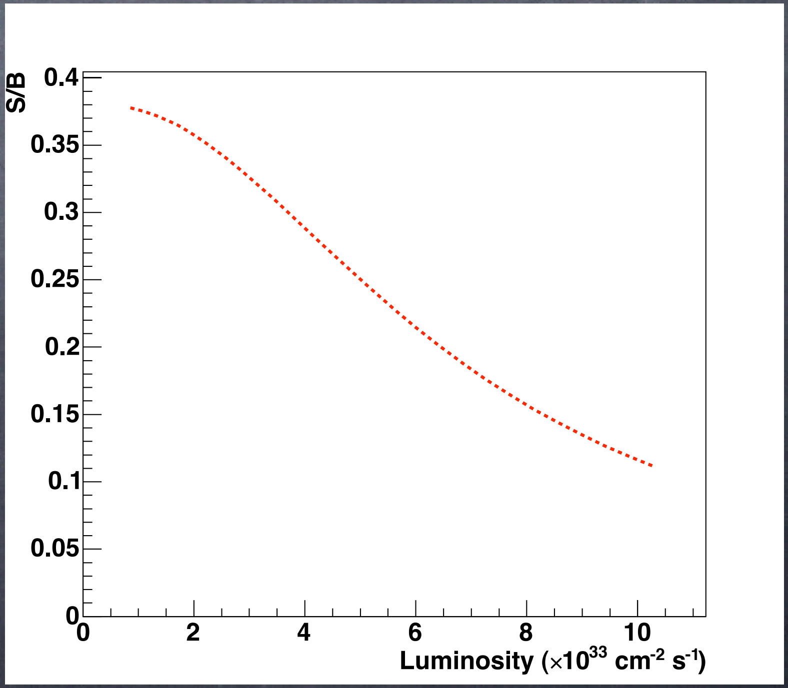
Results - Signal to Background ratio

Generator	Process	Cross section (fb)
ExHuME	$H \to b\bar{b}$	0.055
	$b\bar{b}$	0.05
	gg	0.086
POMWIG	$b\bar{b}$	0.0008
	jj	$\ll 0.0001$
HERWIG + 2×SD	$b\bar{b}$	0.007
	jj	< 0.001

Notes:

Overlap background defined at $L = 2 \times 10^{33}\text{cm}^{-2}\ \text{s}^{-1}$.

DPE background approximately 100 times smaller with new dPDFs. Now negligible. Confirmation of KMR result (hep-ph/0702213).



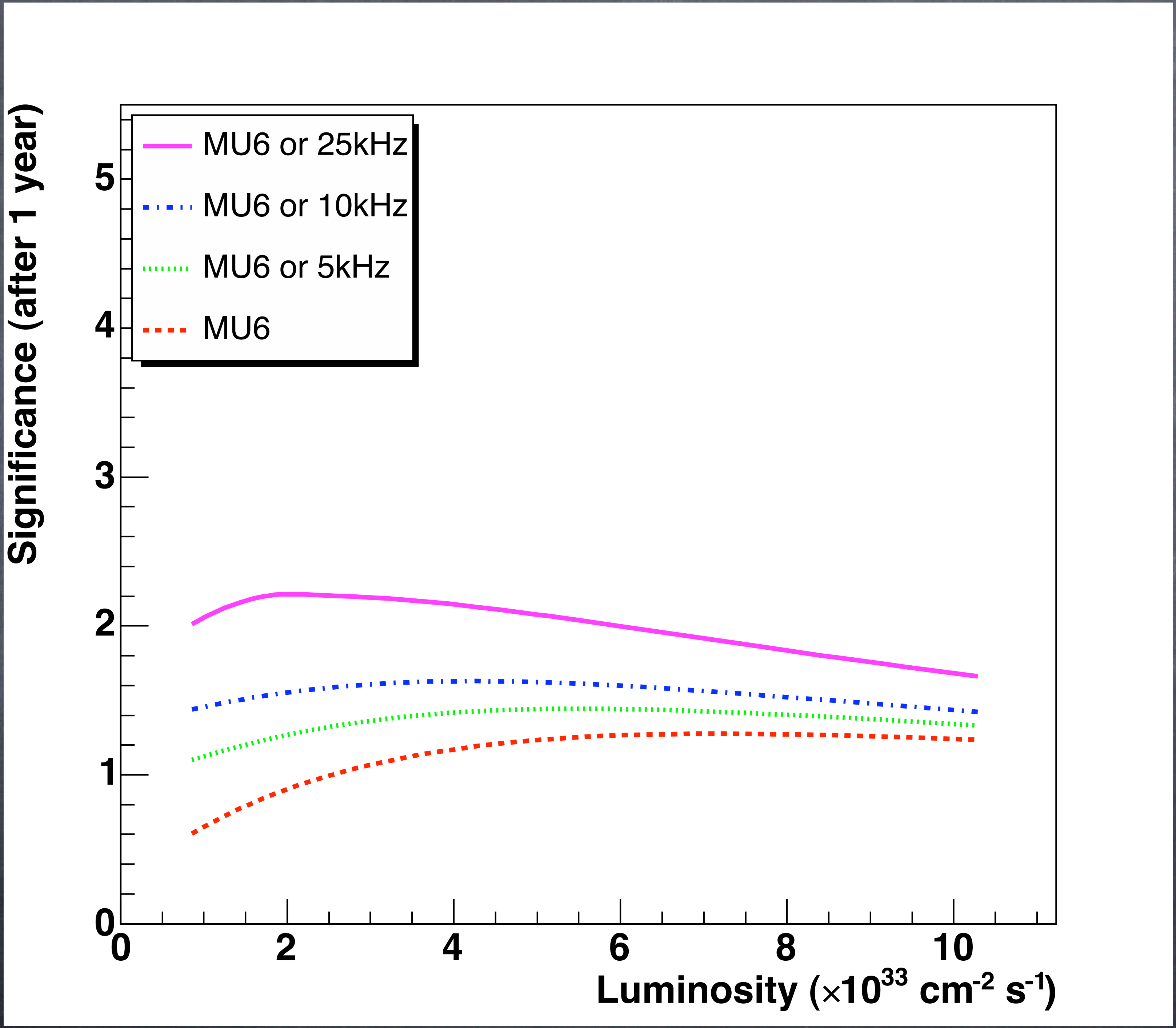
Trigger Possibilities

- Low transverse momentum muon, $p_T \geq 6\text{GeV}$.
- Rapidity gap. Possible only at low luminosity, due to increased pile-up wrecking the rapidity gap at higher luminosities. From poisson statistics, estimate that approximately 13% of events at low luminosity have no pile-up events overlaid. Ignore this one today.
- Pre-scaled low transverse energy jet trigger. Idea: ask collaboration for a fixed rate at level 1. Reduce at level 2 by requiring two proton hits and vertex matching from proton time-of-flight.

Luminosity ($\times 10^{33}$)	Non-diffractive reduction by FP420 without QUARTIC	with QUARTIC
1	2.7×10^{-4}	6.8×10^{-6}
3	5.8×10^{-3}	1.5×10^{-4}
5	1.8×10^{-2}	4.6×10^{-4}
10	8.1×10^{-2}	2×10^{-3}

MSSM $H \longrightarrow bb$

- Not a scan and not exhaustive - see talk by M. Tasevsky.
- Idea: pick a point in parameter space, with an enhanced cross section, that the results presented previously can be applied to. Use $m_A = 120\mathrm{GeV}$ and $\tan\beta = 40$. Cross section increases w.r.t SM by factor of approximately 8.
- Get light Higgs boson with $m_h = 119.5\mathrm{GeV}$ and $\Gamma_h = 3.2\mathrm{GeV}$
- Need a bigger mass window: $114.5 \leq M \leq 119.5 \quad \mathrm{GeV}$
- Now apply the triggers and see what happens.



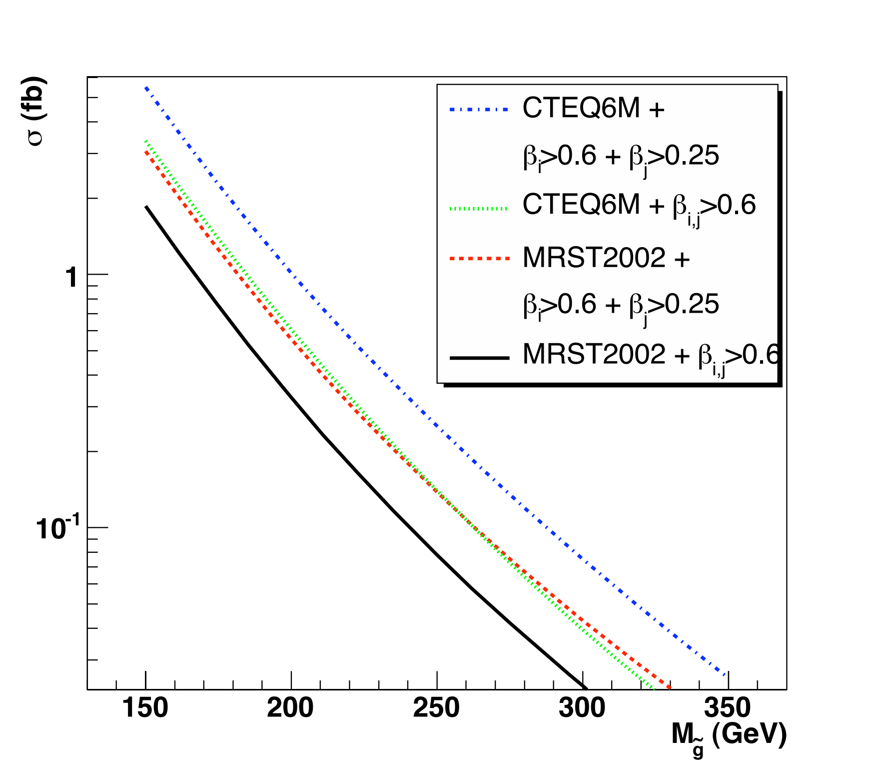
MU6 or 25kHz
MU6 or 10kHz
MU6 or 5kHz
MU6
Significance (after 1 year)
0
1
2
3
4
5
0
2
4
6
8
10
Luminosity (×10^33 cm^-2 s^-1)

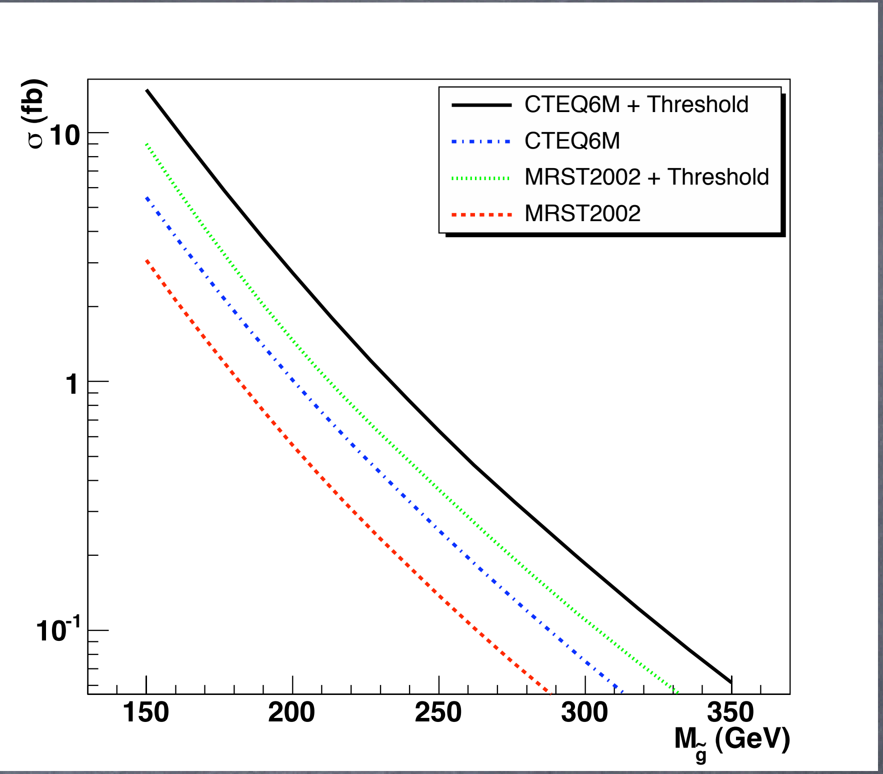
Di-gluino production

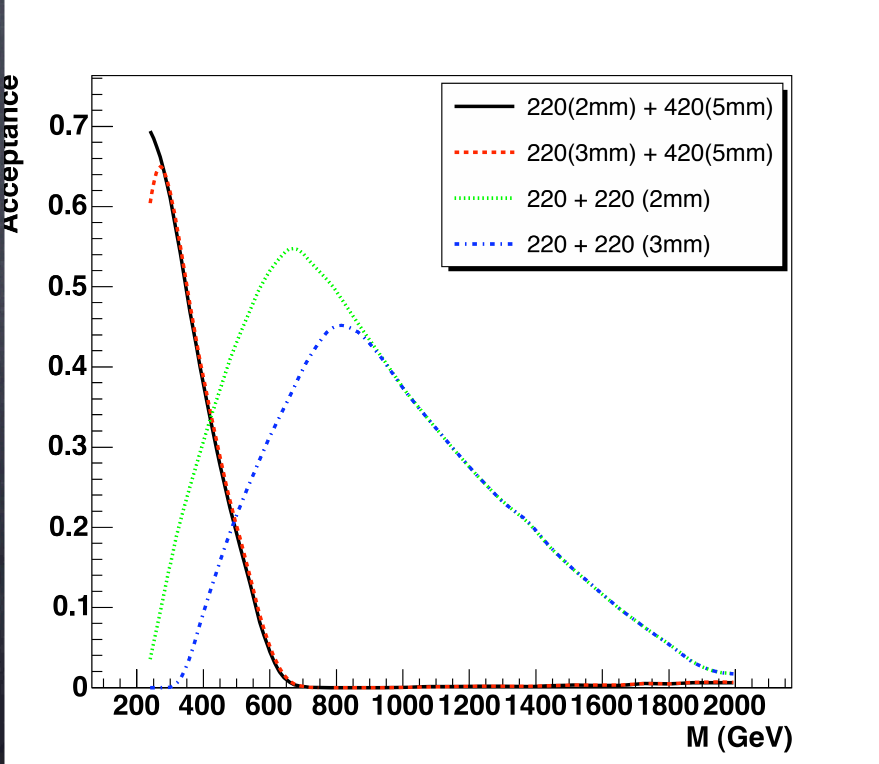
- Wanting to see $pp \to p + \tilde{g}\tilde{g} + p$ in the case where the gluino is long lived.
- This can happen in split-susy models, where the sfermions have masses far above the TeV scale. The gluino is lighter and therefore long lived.
- Gluino's form neutral and charged R-hadrons which decay on large times scales.
- Tevatron limits at present are that, in this scenario, $m_{\tilde{g}} \geq 170\mathrm{GeV}$
- See JHEP 0611:027,2006 for more details.

Trigger and Acceptance

- Charged R-hadrons will look like high transverse momentum muons. Therefore the strategy is to trigger on these particles.
- Roughly 3/4 of the R-hadrons are charged after passing through the calorimeters.
- Need velocity of one R-hadron to satisfy $\beta \geq 0.6$ so that it reaches the trigger chambers in time to trigger the event in the correct bunch crossing.
- Second R-hadron must satisfy $\beta \geq 0.25$ for the event information to be available for the analysis.
- Trigger efficiency is 60% for this strategy. Lower than normal because R-hadron is more likely to interact with the muon spectrometer.







Monte Carlo events produced by ExHuME v1.3.2 with different PDF's.

Acceptance of FP420 and FP220 calculated for 3mm and 5mm configuration

- The gluino mass can be obtained by just measuring the pseudo-rapidity of the outgoing R-hadrons.
- After applying the trigger and forward detector acceptance, we find for high luminosity statistics ($300 fb^{-1}$):

$m_{\tilde{g}}$ (GeV)	$\sigma_{m_{\tilde{g}}}$ (GeV)	$\frac{\sigma_{m_{\tilde{g}}}}{\sqrt{N-1}}$ (GeV)	N
200	2.31	0.19	145
250	2.97	0.50	35.0
300	3.50	1.10	10.2
320	3.61	1.54	6.5
350	3.87	2.45	3.5

- It is possible to measure the gluino mass to approximately 1% using forward detectors up to $m_{\tilde{g}} \sim 350\text{GeV}$.

Summary

- Non-exclusive backgrounds can be reduced by a series of exclusivity cuts using the forward detectors and the central calorimeters.
- The SM Higgs, in the bb channel, will be difficult due to low cross section after cuts.
- MSSM scenarios possible but the trigger strategy will be crucial.
- Forward detectors at 220m and 420m can make an excellent mass measurement of long-lived gluino's.