Diphoton Analysis: RS graviton search

** Blessing **

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Outline of RS model diphoton search

(pre-blessing in Exotics meeting June 10th 03)

- To bring $\gamma\gamma$ up-to-date with ee and $\mu\mu$ channels
  - Data used is from dev_240
    code version 4.10.4 + patches equivalent to 4.11.1
  - Acceptance is calculated using MC generated 4.9.1, as used for blessed ee and $\mu\mu$ searches
  - Efficiencies calculated with MC and compared/corrected for with data/MC, conversions and underlying event effects
  - Signal Region taken as a $\pm 3\sigma$ window around the signal mass, in analogy to the ee search, which has a similar signal invariant mass resolution
  - Background is assumed to be zero, all events taken as signal
  - Systematic uncertainties are included in the limit
  - Limits are obtained using Bayes program, as used for blessed ee and $\mu\mu$ searches

Dataset and Trigger

cph108 and cph109 data sets used
From run 138425 (Feb 4th 2002) (108) to 163527 (May 27th 03) (109)
Luminosity: 82 pb^{-1} + 52pb^{-1} = 134 pb^{-1}

The trigger required was PHOTON 70 ($Ultra$) which has no ISO or had/em and Trigger PHOTON 50 ($Super$) which has no ISO cut

PHOTON_50

- Level 1: L1 : One EM tower, with Energy > 8 GeV
- had/em<0.125 unless Et>14
- Level 2 : L2 :
  - Requires an EM cluster, with EM E_T > 40 GeV
  - had/em<0.125
  - No isolation cuts.
- Level 3 : L3 :
  - Require photon to have E_T > 50 GeV
  - HAD/EM<0.125, off at 200 GeV
  - No isolation cuts.

PHOTON_70

- Level 1: L1 : One EM tower, with EM+HAD Et > 10 GeV
- No had/em cut.
- Level 2 : L2 :
  - Requires an EM cluster, with EM E_T > 70 GeV
  - No had/em or isolation cuts.
- Level 3 : L3 :
  - Require photon to have E_T > 70 GeV
  - HAD/EM<0.2 +0.001*E
  - No isolation cuts.

Signal Sample Selection Criteria

Good runs requirements: bit called 'good run core components' set by shift crew, CAL offline and COT offline

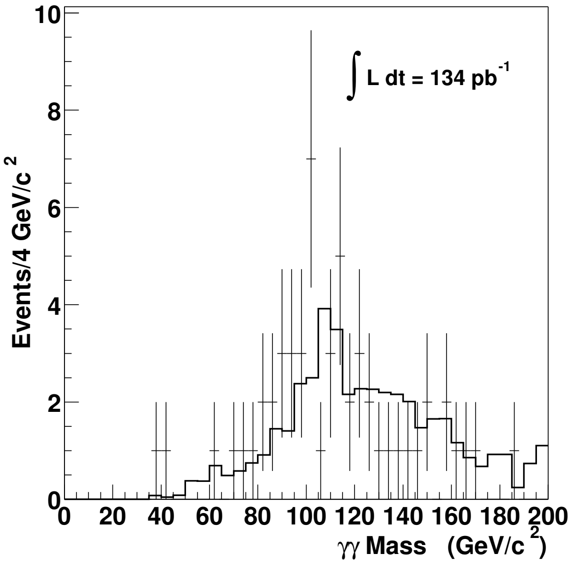
The events were reconstructed using production off-line version 4.10.4
+ patches equivalent to 4.11.1
and ntuplised using the stnuple version dev_240.

Event Cuts
trigger path ZVertex exists, $\|z\| < 60$ cm GOODRUN, CAL_OFFLINE, COT_OFFLINE bits Photon Cuts
Central CES strip and wire clusters present CES $\|x\| < 21.0$ cm CES $9.0 < \|z\| < 230.0$ cm
Had/EM$< 0.055 + 0.00045 * E$ CalIso(cone 0.4) $< 2.0 + 0.02 * (Et - 20$ GeV$)$ or $< 0.1Et$ if $Et < 20.0$ avg, scaled CES $\chi^2 < 20$ N3D$= 0$ || N3D$= 1$ and Pt$< 1.0 + 0.005 * Et$ SumPt (cone 0.4) $< 2.0 + 0.005Et$ Second CES cluster $E < 2.4 + 0.01 * Et$ or $E < 0.14 * Et$ if $Et < 18.0$

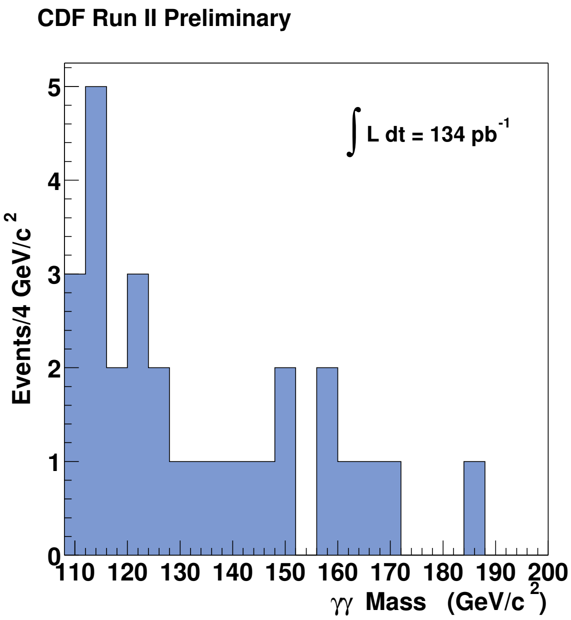
Additional Cuts: require $E_T > 25$ GeV for both central photons
and $M_{\gamma\gamma} > 25$ GeV

Data Sample

After application of selection cuts: 55 events
spectrum is consistent with the diphoton MC, after trigger sculpting:



For Blessing:



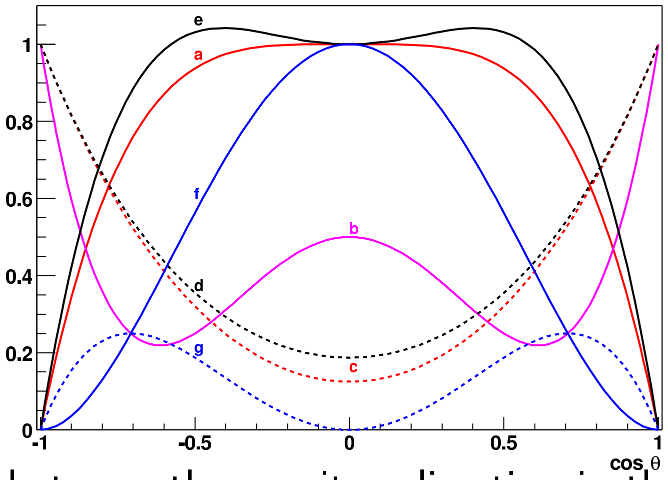
Highest invariant mass event at 185 GeV/c^2

Monte Carlo

The RS MC used was Pythia 6.203
2000 events were generated at each M_G with pdf CTEQ5L
using cdfSim and reconstructed with ProductionExe code version 4.9.1

Pythia assumes that the γs decay isotropically in the graviton rest frame
So events were weighted to account for the angular decay distributions

Angular distribution of graviton decay products

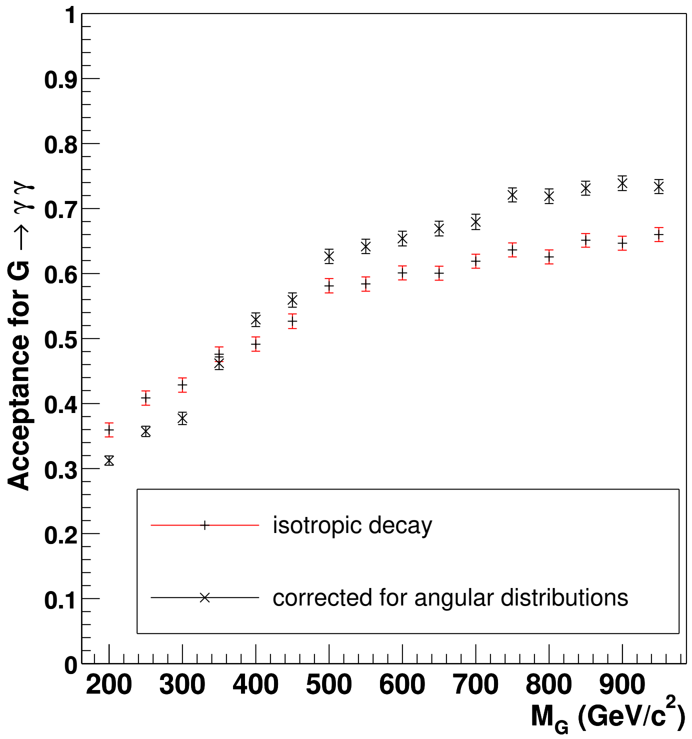


cosθ^* is the angle between the graviton direction in the lab frame and one of the photons in the graviton rest frame (Reference: hep-ph 0211205)

Process	Distribution	Plot
Assumed decays	1	*("flat")*
$gg \rightarrow G \rightarrow \gamma\gamma$	$1 + 6\cos^2\theta^* + \cos^4\theta^*$	c *("u shaped")*
$q\,\bar{q} \rightarrow G \rightarrow \gamma\gamma$	$1 - \cos^4\theta^*$	a *("n shaped")*

Acceptance per event

$$\text{acceptance} = \frac{\sum weigthed\_events\_with\_2\_central\_\gamma s\_with\_E_T > 25GeV\_and M_{\gamma\gamma} > 25GeV}{\sum \_weighted^{generated}_{events}}$$



- Larger for large M_G ($>$ 400 GeV), where gg intiated fraction is small
- Here the $f\bar{f}$ fraction is dominant and this decays mostly centrally
- Smaller for lower M_G ($<$ 350 GeV), where gg intiated fraction is large
- Here the gg fraction is dominant and the photons (in the graviton rest frame) are predominantly emitted in the direction the graviton (anti-) direction is travelling

Systematic uncertainty on the acceptance

1) E_T scale dependence: the acceptance was calculated, changing the 25 GeV E_T threshold by $\pm$ 1 % (from the difference of Z mass from MC and data).

M_G (GeV)	Acceptance (%) E_t>25	E_t>24.75	E_t> 27.50	Systematic uncertainty (%)
200	31.24	31.24	31.19	0.17
250	35.72	35.86	35.66	0.16
300	37.73	37.84	37.73	0.00
350	46.20	46.27	46.12	0.17
400	52.91	53.00	52.82	0.17
450	55.92	56.14	55.87	0.08
500	62.65	62.70	62.59	0.08
550	64.17	64.23	64.17	0.00
600	65.38	65.44	65.28	0.16
650	66.93	66.93	66.93	0.00
700	67.94	67.94	67.88	0.09
750	72.10	72.10	72.10	0.00
800	71.88	71.88	71.88	0.00
850	73.13	73.13	73.13	0.00
900	73.89	73.89	73.89	0.00
950	73.39	73.39	73.39	0.00

The systematic uncertainty conservatively taken as 0.2 %
The systematic uncertainty is assumed to be independent of M_G

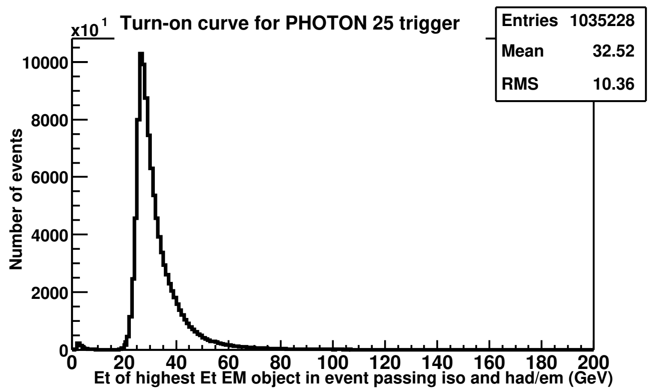
2) For M_G generate 2000 events with different pdf's

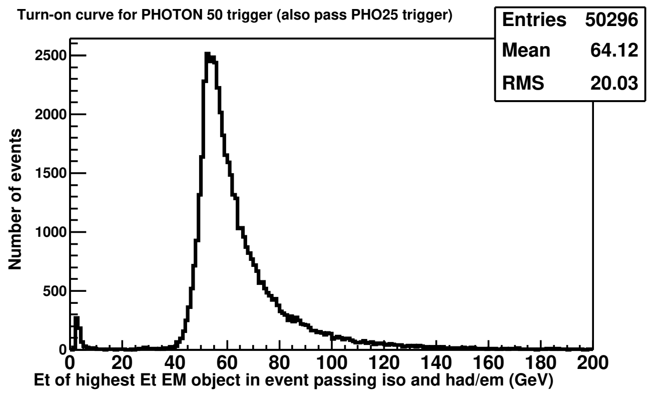
PDF	Acceptance M_G=600 GeV (%)	Relative systematic uncertainty (%)
CTEQ5L (LO)	65.4 $\pm$ 1.1	-
GRV 94L (LO)	65.1 $\pm$ 1.1	-0.43
CTEQ5M (NLO in the MS-bar scheme)	65.1 $\pm$ 1.1	-0.508
GRV 94D (NLO in DIS scheme)	64.2 $\pm$ 1.1	-1.82

Over estimate the systematic uncertainty on the acceptance as 3 %
(The same as the ee channel)

The turn-on and trigger efficiency for PHOTON 50

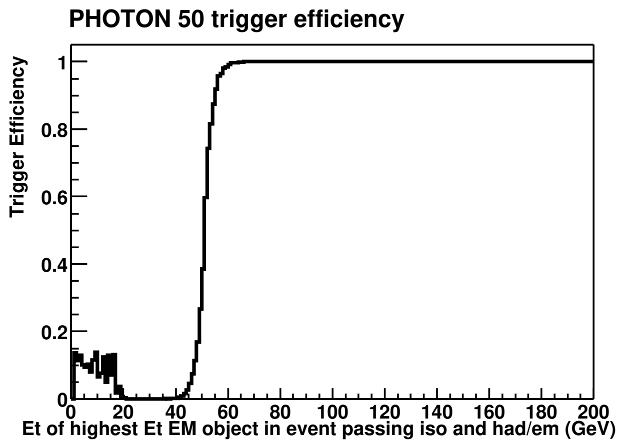
Determined using the PHOTON 25 trigger for cp108 and cph109 samples
Et of the highest Et emobject which passed the iso and had/em cuts:
for events which passed the PHOTON 25 trigger (left) and both PHOTON 25 and 50 trigger (right).
Iso and had/em cuts are to reduce the fake photon background





The small peak near zero is could be from events which pass the trigger due to another emobject in the event, which has larger Et, but which does not pass the iso and the had/em cut

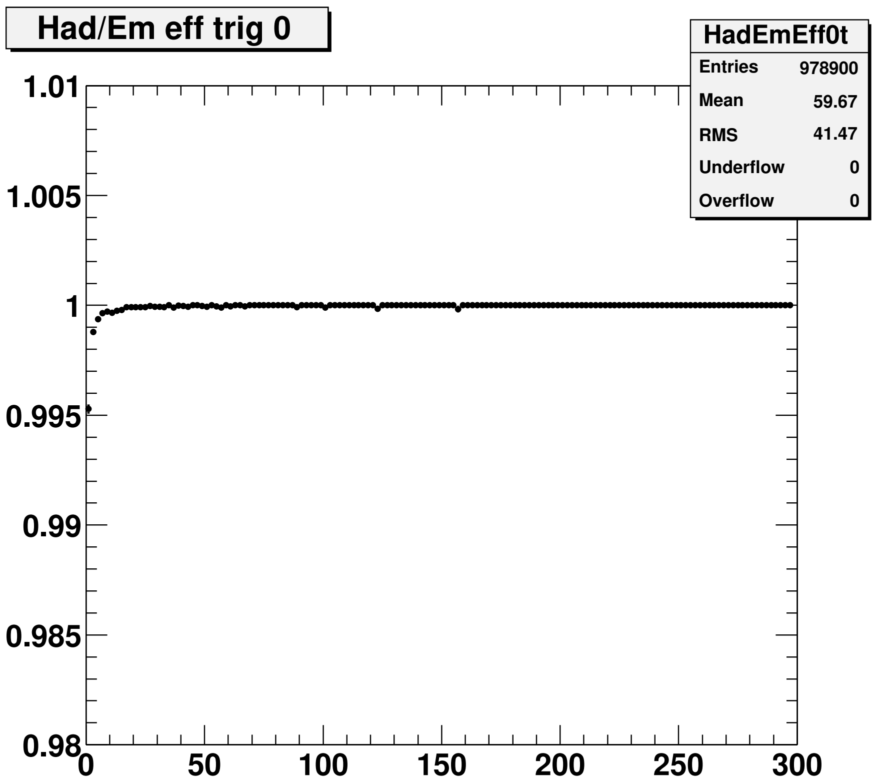
The trigger efficiency is obtained by dividing the above two histograms. PHOTON 50 trigger efficiency is $100^{+0}_{-0.01}$ % for 2γ above 55 GeV.



Turn-on and trigger efficiency for PHOTON 50

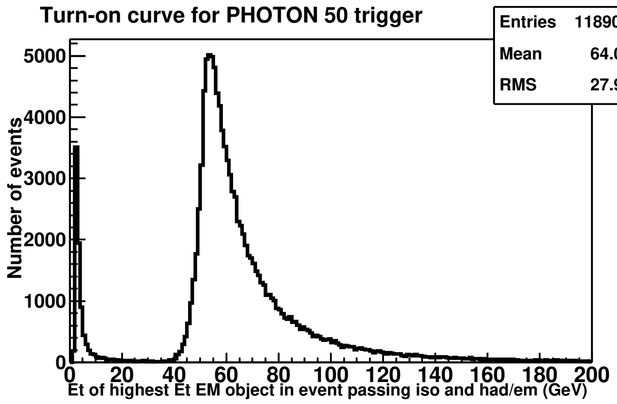
PHOTON50 trigger has HadEM at Level 1 and 2: had/em$<$0.125 (PHOTON70 does not)
The efficiency of the had/em Level 2 trigger is determined from jet data, looking at the underlying events, and estimated leakage

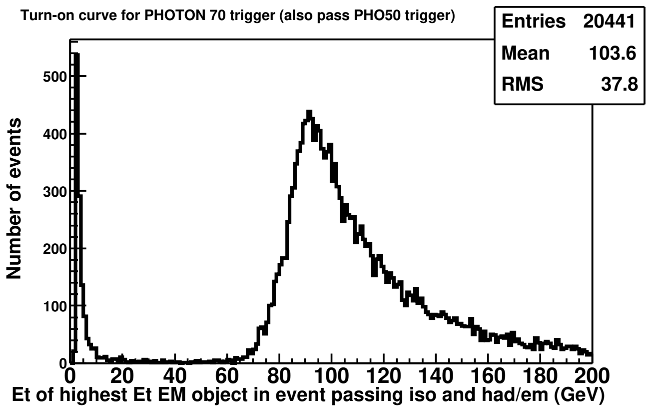
Efficiency for the L2 50 Gev trigger had/EM$<$0.125



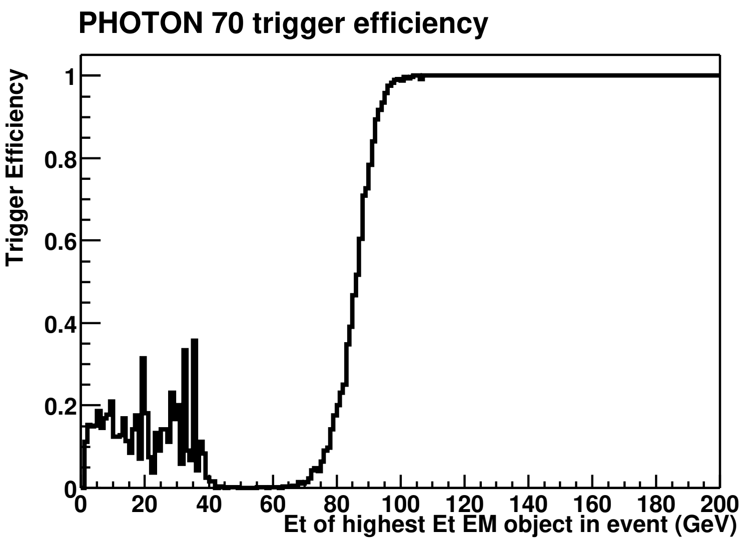
Turn-on and trigger efficiency for PHOTON 70

Et of the highest Et emobject, which passed the iso and had/em cuts in events which passed the PHOTON 50 trigger (left) and PHOTON 50 and 70 triggers (right).



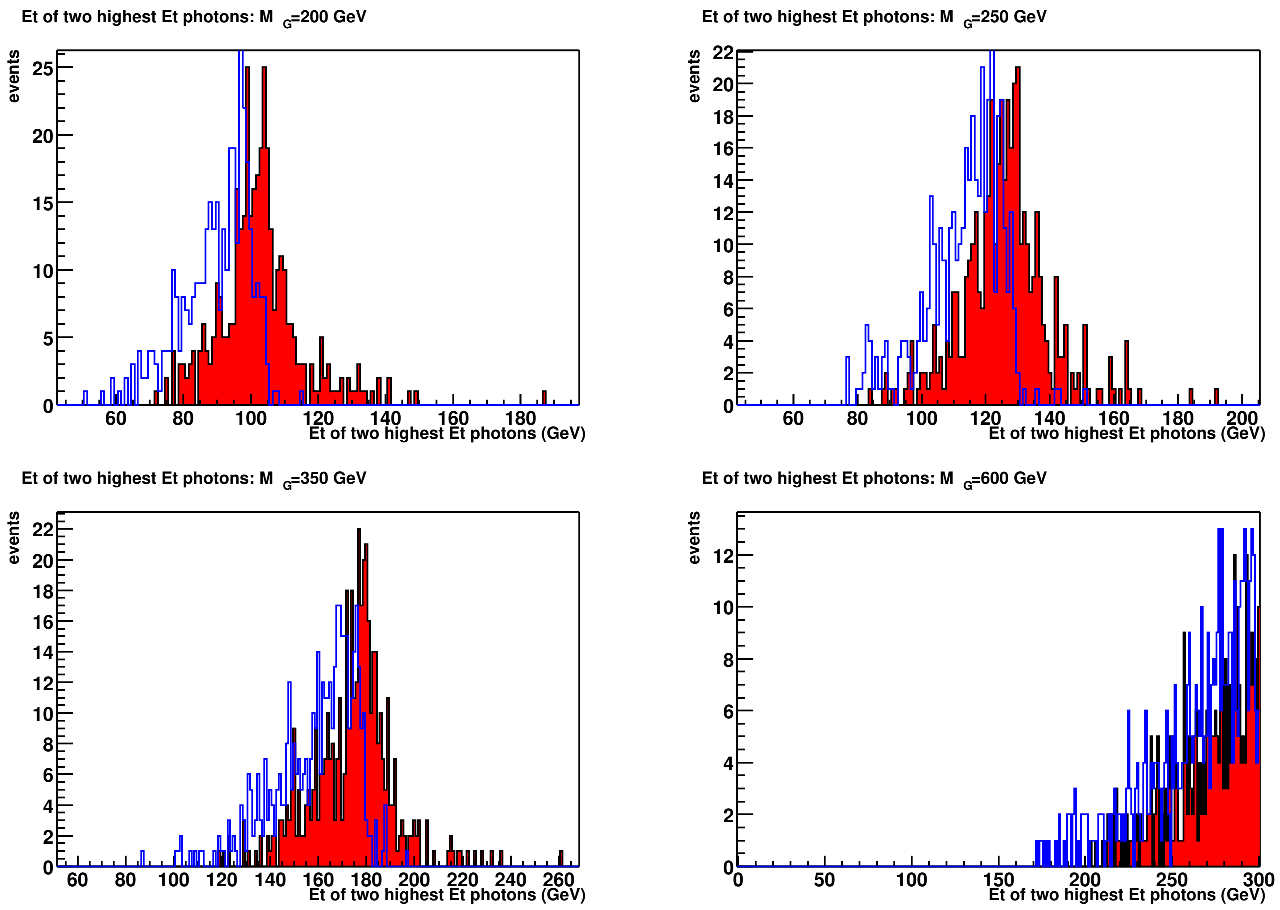


PHOTON 70 trigger efficiency is 100 % for 2γ above 95 GeV.



Trigger Efficiency Summary

PHOTON 50 trigger is 100 % efficient for two photons above 55 GeV.
PHOTON 70 trigger is 100 % efficient for two photons above 95 GeV.
The signal photons lie above 55 GeV, shown below:
highest Et signal γ 2nd highest Et signal γ
The trigger efficiency is 100 %



Efficiency for individual selction criteria

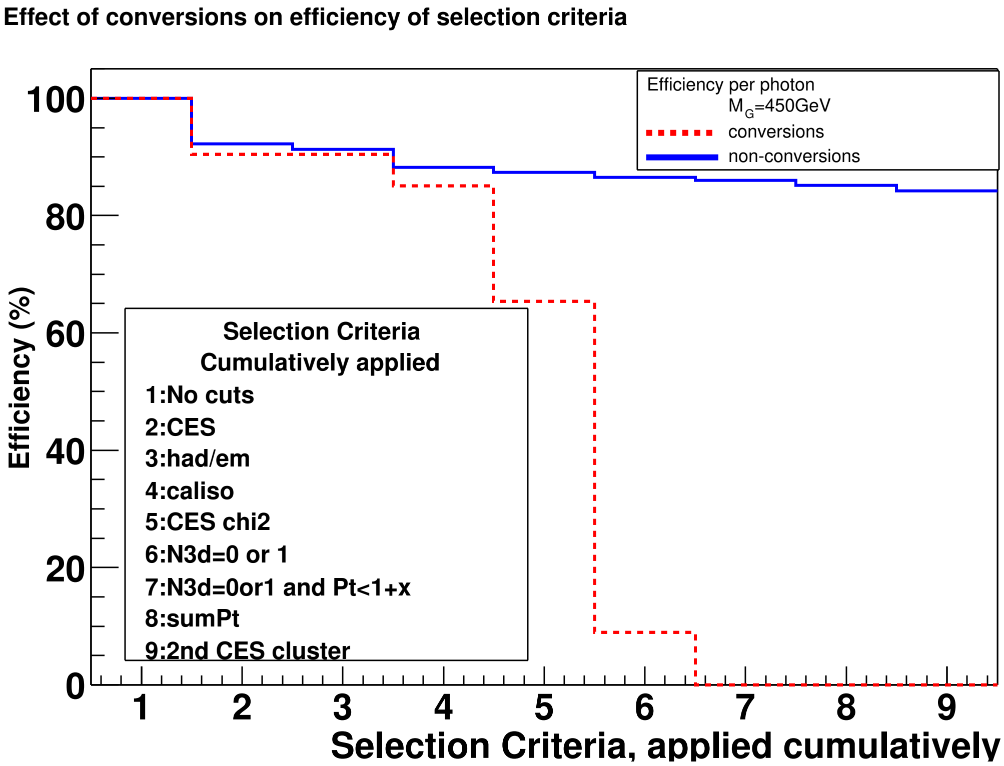
Determined from the RS graviton MC
Corrected using results and systematics obtained from 3 studies:

- Conversions
- Underlying events
- Comparisons of MC to data

Sequential efficiencies of the individual selection criteria for converted and non-converted photons

Conversions studied using RS signal MC generated as described.

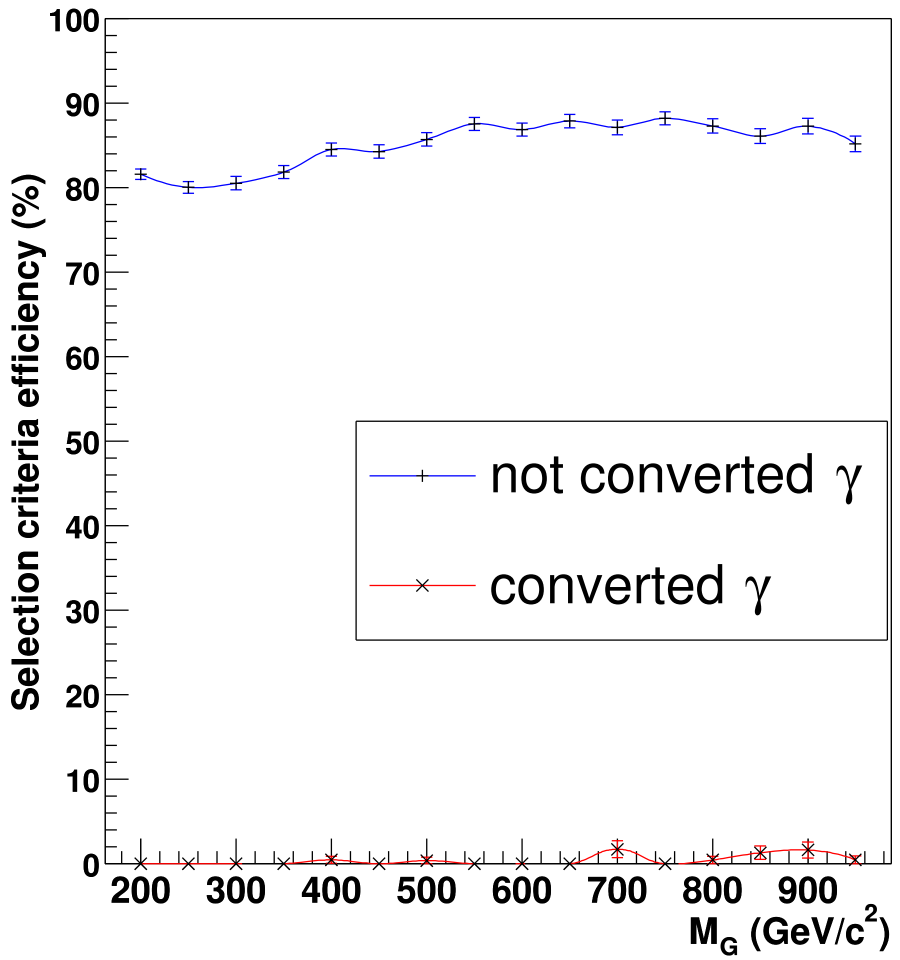
$$\text{Sequential efficiency} = \frac{N_\gamma\_passing\_cut\_and\_all\_previously\_applied\_cuts}{N_\gamma\_passing\_acceptance\_cuts}$$



The track cuts remove almost all of the conversion photons, due to the presence of the electron tracks ($\gamma \rightarrow e^+e^-$) (as expected)

Efficiency for all cuts for one photon for a (from the M_G=450 GeV sample): conversion is 0 %, non-conversion is 84.3 $\pm$ 0.8 %

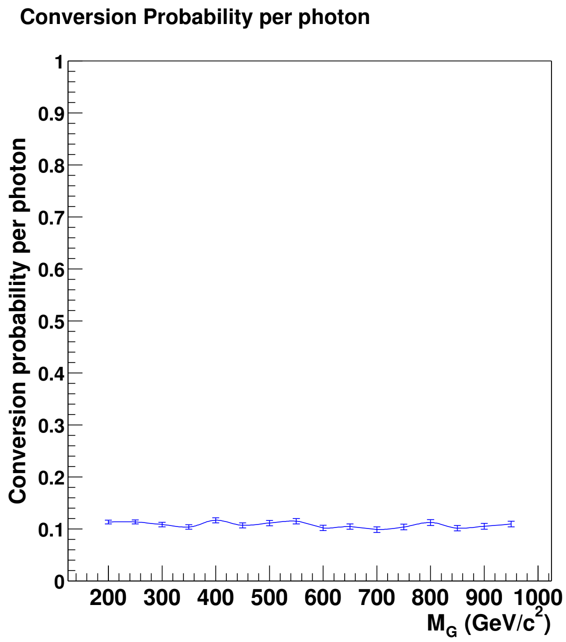
Effect of Conversions on efficiency as a function of M_G



The track cuts are not 100 % efficient at rejecting all conversion events
In some cases one of the converted electrons then emits a hard bremsstrahlung photon, and in these cases the converted events can pass the cuts

Conversion probability per photon

The conversion probability per photon is found to be independent is M_G
i.e. it is independent of the Et of the photon, as expected

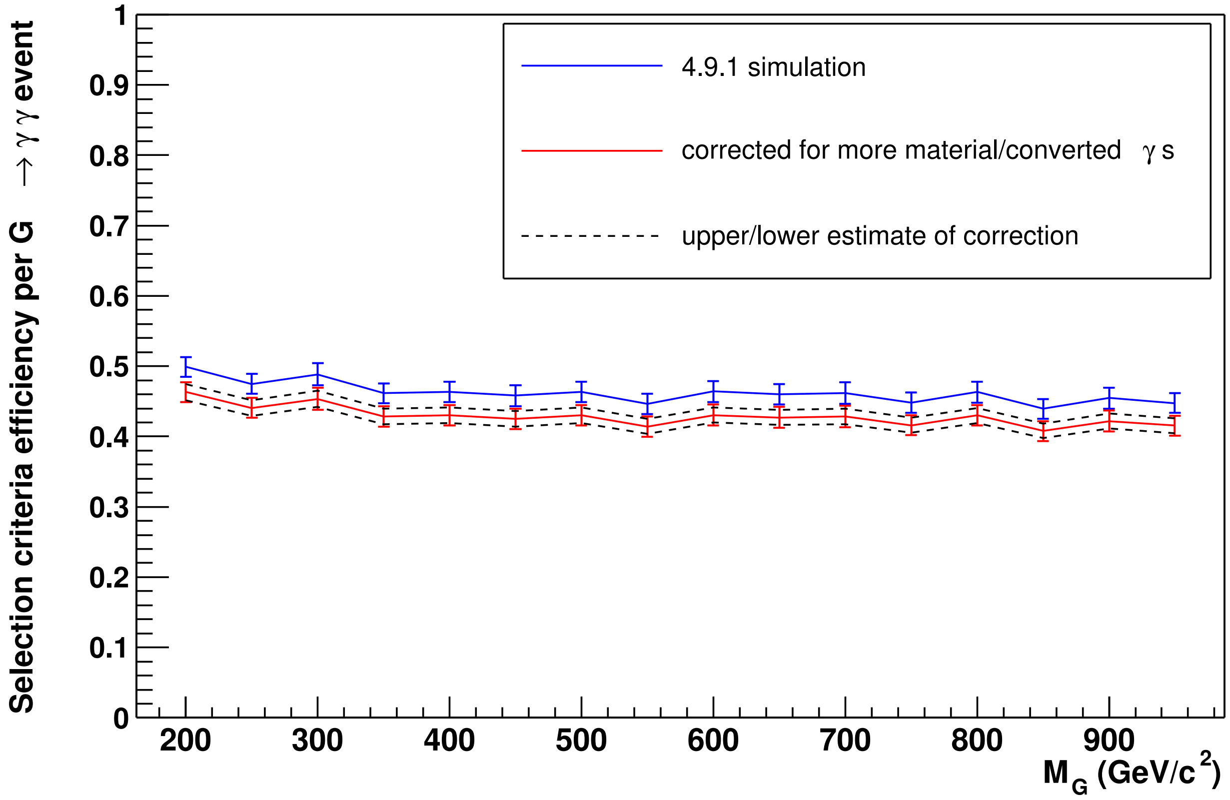


Conversion probability per photon is 10.9 $\pm$ 0.1 % in version 4.9.1 of simulation
This depends on the amount of material in the detector
which is underestimated in the 4.9.1 simulation by 30 $\pm$ 10 %

Correction to the efficiency due to conversions, and the extra material:

To the efficiency per photon of -3.7 %
and a systemtatic uncertainty of 1.2 % from the amount of material added

Efficiency per event corrected for material increase in simulation



Systematic error shown is from the 10 % uncertainty on the amount of material

Underlying Event

Ray has done a study to understand how the underlying event affects the efficiency of the cuts
This could contribute to a systematic uncertainty to the efficiency of the photon cuts

This affects certain photon variables

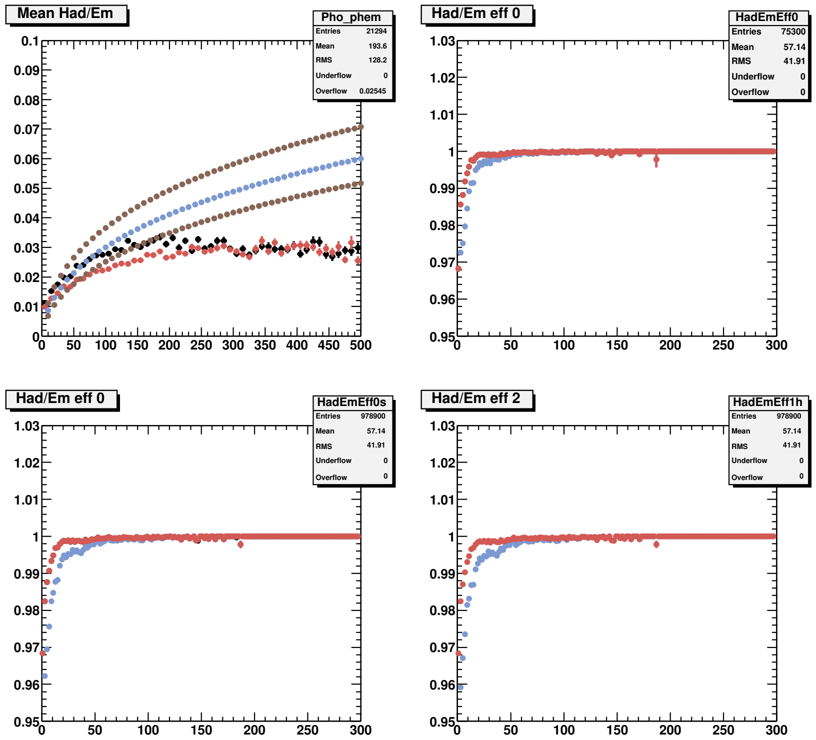
- Had/em
- Track cuts
- Calorimeter isolation
- 2nd CES

Study performed comparing dijet data to Monte Carlo
Data: sampling 1% of data of from different Et cut samples: 20,50,70,100
MC from dijet sample made for QCD winter group

Method:

Look for a jet
Define jet axis, and a 90^0 region perpdendicular to this axis
Look in cones, one from each wedge this 90^0 region
Ask in random cone:
how often does the quantity pass or fail the photon cuts?

Underlying Event: had/em



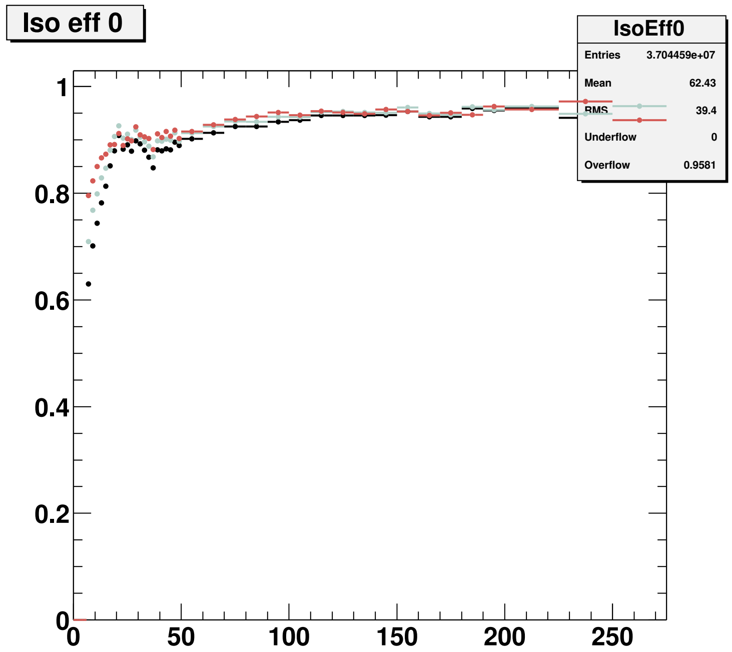
top left: black: mean had/em for fake event photons vs Et
red: mean had/em for fake event electrons vs Et
blue: predicted had/em from PDG EM shower model
brown: same as blue, but parameters adjusted to give a nominal variation for the purposes of a systematic error

upper right: $\frac{had}{em} = \frac{had\_energy\_in\_2\_or\_3\_towers\_in\_the\_random\_cone\_(UE\_energy)}{em\_Et\_energy\_of\_leading\_jet\_in\_event\_(jet\_Et)}$
efficiency: of had/em<sliding cut and had/em<0.125 or had/em<sliding cut
lower left: $\frac{had}{em} = \frac{UE\_energy\_+\_mean\_modelled\_photon\_energy\_(upper\_right)}{jet\_Et}$
lower right: $\frac{had}{em} = \frac{UE\_energy\_+\_systematic\_of\_modelled\_photon\_energy\_(brown\_upper\_right)}{jet\_Et}$

conclude: at large Et: the eff of the had/em cut is 100%, the sys uncertainty is negligible

Underlying Event: calorimeter isolation

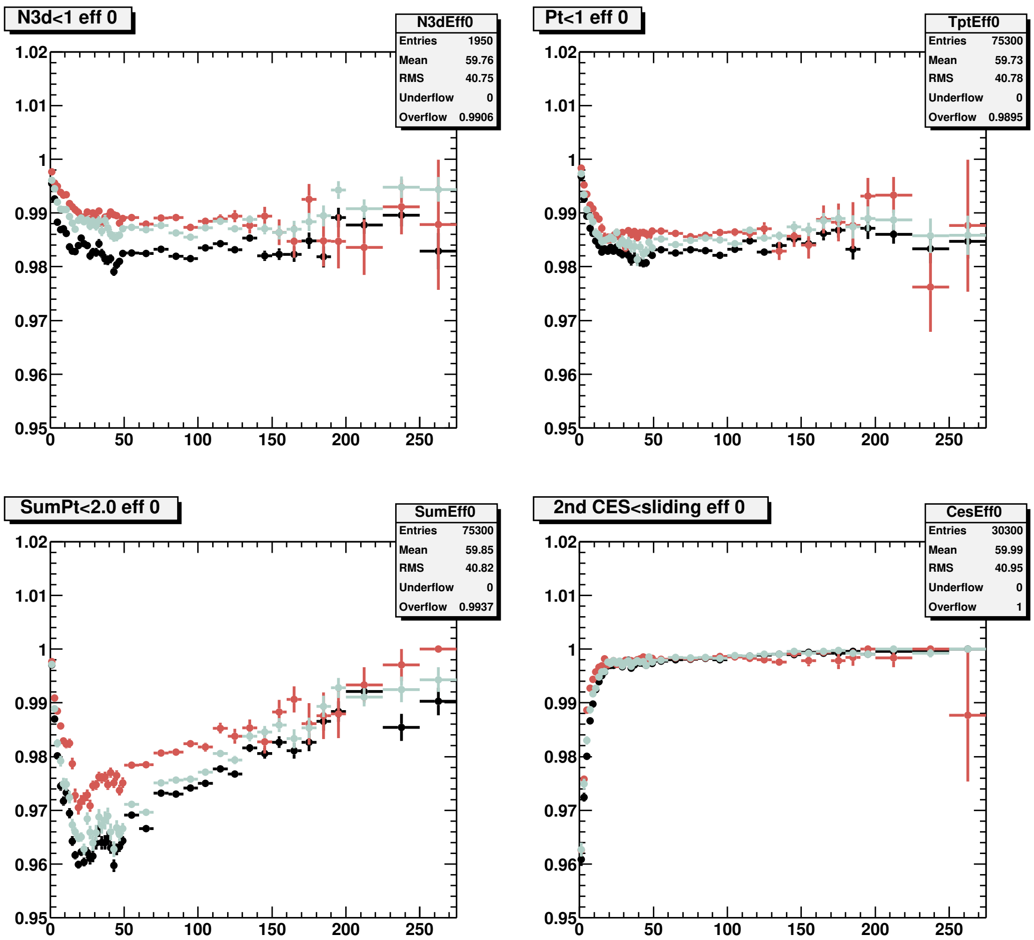
Predicted efficiencies of the isolation cut, in the cut order.
They are a combination of the expected underlying event from the jet data study, and the leakage from the EM cluster itself, taken from a fake-event photon sample.



The UE dominates.
black = based on jet data
green = based on jet data, exactly one vertex required
red = based on MC jet data

Underlying Event: Track cuts

To study how underlying events affect the track cuts:
n3d, pt of leading track, sum pt is sum pt of tracks of cone of radius 0.4



black: data eff from underlying event in jet data, off axis
green: the same as black, but for events with exactly one vertex
red: same for jet MC

Relative systematic uncertainties from comparison of Zee MC to data

Method

In electron trigger, find the cluster that passes all offline cuts
If there are two clusters which pass cuts, select one at random,
If there is one, then look for a second cluster which passes Et>20 and 0.9<E/p<1.1 (tight E/p is to reject events which brem.)
Use the second cluster to find efficiencies.
Fit Zee peaks to gaussian and linear background

Finds the effs including the probability that the EM cluster has CES clusters in both views, and the prob that the CES clusters pass fiducial.
This number is really the ratio of the prob to pass CES cluster present (or fiducial) to the prob for making an EM cluster.

	MC		data	
	cuml. eff	rel. eff	cuml. eff	rel. eff
Below denominator is cluster with $E_t > 20$, $0.9 < E/p < 1.1$				
Ces clus	97.0 ± 0.1	97.0 ± 0.1	98.8 ± 0.4	98.8 ± 0.4
cesfid	90.2 ± 0.3	93.0 ± 0.2	94.4 ± 0.8	95.5 ± 0.7
Below denominator is $E_t > 20$, $0.9 < E/p < 1.1$, "Ces cl", and "cesfid"				
HadEm	98.1 ± 0.1	98.1 ± 0.1	100.0 ± 0.3	100.0 ± 0.3
Cal Iso	92.9 ± 0.2	94.7 ± 0.2	97.2 ± 0.6	95.5 ± 0.7
Ces Chi	92.7 ± 0.2	99.7 ± 0.0	93.4 ± 0.9	96.2 ± 0.7
N3D	91.8 ± 0.3	99.0 ± 0.1	92.3 ± 1.0	98.8 ± 0.4
Pt	89.3 ± 0.3	97.3 ± 0.1	88.6 ± 1.2	96.0 ± 0.7
SumPt	86.4 ± 0.3	96.7 ± 0.2	84.0 ± 1.5	94.7 ± 0.8
Ces 2	84.0 ± 0.4	97.2 ± 0.2	81.5 ± 1.6	97.1 ± 0.6

Relative systematic uncertainty on efficiencies summary

Variable	Correction to MC	Rel.Syst.Unc.
	(%)	(%)
Had/Em	+2	1.0
Cal iso	-2	5.0
Chi2 (Strips+Wires)/2.0	-3	2.0
N track (N3D)	-1	0.5
Track Pt	-1	1.0
Cone 0.4 Track Iso	-2	1.0
2nd CES cluster (strip and wire)	-	-
Fiducial	-	3.0
Conversions	-3.7	1.2
Trigger Efficiency	-	-
Total per photon	-10.7	6.2
Total per diphoton event	-21.4	8.8

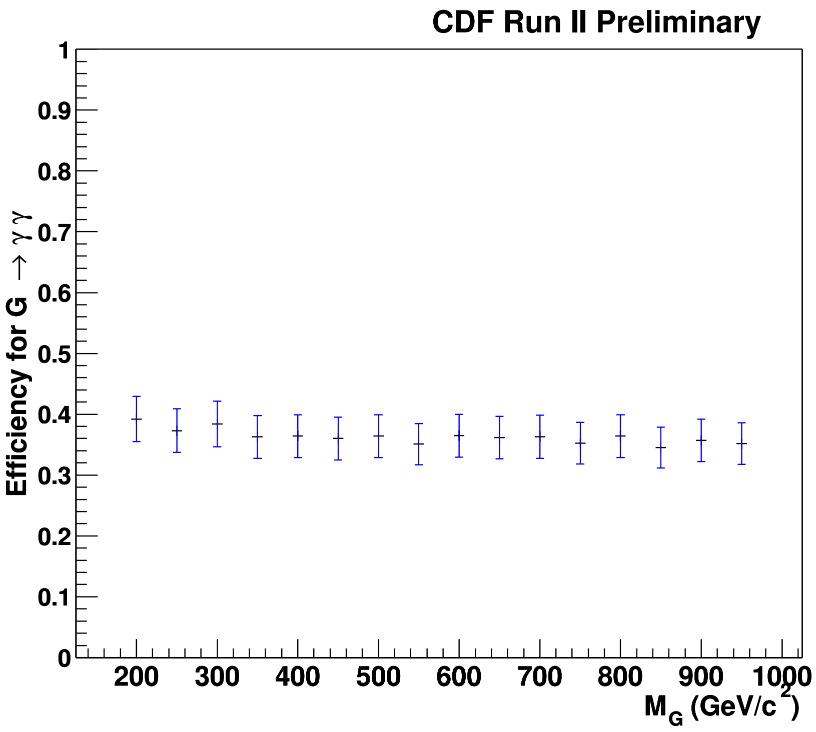
Corrections added linearly

Add systematics in quadrature:

Systematic uncertainty on efficiencies are assumed to be independent of energy

Efficiency

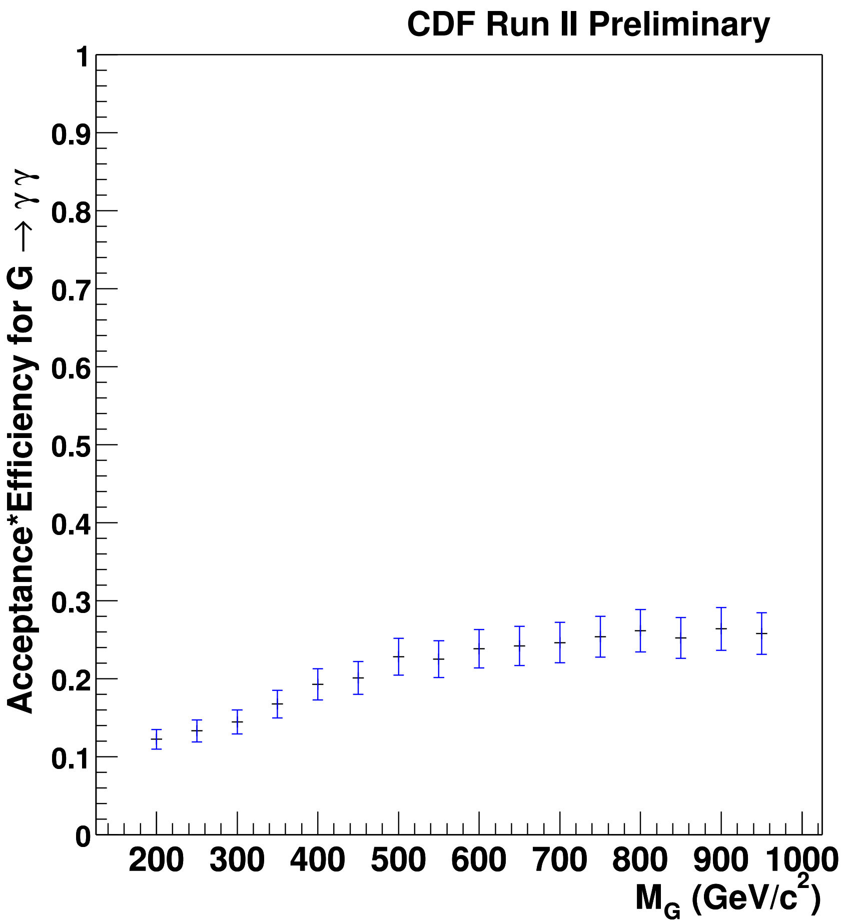
weighted for MC angular distribution
corrected for conversions, underlying events and MC/data discrepancies



Errors shown are statistical and systematic

Acceptance*Efficiency

weighted for MC angular distribution
corrected for conversions, underlying events and MC/data discrepancies



Errors shown are statistical and systematic

Systematic Uncertainties

Systematic uncertainties considered

- Acceptance
  - E_T scale
  - PDFs
- Efficiency
  - underlying events
  - comparison of MC to data
  - conversions
- Luminosity

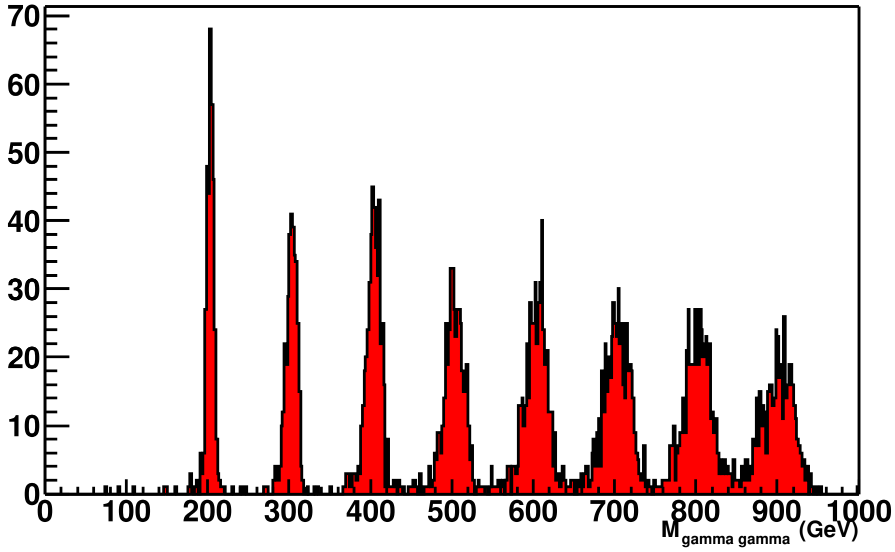
CDF Run II Preliminary (134 pb^{-1})

	Relative systematic uncertainties (%)			Statistical(%)	Combined
M_G	Efficiency	Acceptance	Luminosity	Eff*Acc	(%)
200	8.8	3.0	6.0	3.6	12.
250	8.8	3.0	6.0	3.7	12.
300	8.8	3.0	6.0	4.1	12.
350	8.8	3.0	6.0	3.8	12.
400	8.8	3.0	6.0	3.7	12.
450	8.8	3.0	6.0	3.8	12.
500	8.8	3.0	6.0	3.6	12.
550	8.8	3.0	6.0	3.7	12.
600	8.8	3.0	6.0	3.6	12.
650	8.8	3.0	6.0	3.6	12.
700	8.8	3.0	6.0	3.8	12.
750	8.8	3.0	6.0	3.5	12.
800	8.8	3.0	6.0	3.5	12.
850	8.8	3.0	6.0	3.6	12.
900	8.8	3.0	6.0	3.7	12.
950	8.8	3.0	6.0	3.5	12.

Signal Regions

Taking 3 σ around the reconstructed invariant mass for each M_G

Widths increase with M_G due to the EM energy resolution decreasing at large mass



M_G	Mean	Sigma (σ_M)	$3{\times}\sigma_M$
200	203	4.2	12.5
250	253	5.3	15.8
300	303	6.3	19.0
350	353	7.7	23.0
400	403	7.3	21.7
450	452	10.5	31.4
500	503	12.0	36.1
550	552	12.9	38.8
600	603	13.3	40.0
650	652	15.1	45.2
700	703	15.4	46.2
750	751	16.0	48.0
800	800	16.9	50.7
850	846	20.0	60.0
900	896	22.6	67.7
950	943	22.3	66.8

Background

Two major backgrounds

Unlike the ee and $\mu\mu$ channel there is no Drell-Yan background

(1) SM diphoton production In Run I:

above 200 GeV/c^2: 1.7 $\pm$ 0.3 SM diphotons predicted in $\mathcal{L}$= 100 pb^{-1}.

Scale to Run II: $\mathcal{L}$= 134 pb^{-1} and $\sigma_{1.96TeV}$= 1.3$\times\sigma_{1.8TeV}$

3.0 SM diphotons predicted, assuming same cuts

In Run II Winter diphoton analysis :

above 200 GeV/c^2 0.8 SM diphotons predicted in $\mathcal{L}$= 84 pb^{-1}

$\rightarrow$ 1.3 SM diphotons predicted in $\mathcal{L}$= 134 pb^{-1}

Taking signal region $\pm 3\sigma$ windows (c.f. ee), (e.g. 80 for M_G=600 GeV/c^2)
rather than one large mass window above X GeV/c^2 (c.f. $\mu\mu$),

so expect fraction of predicted events in this window

(2) Jets faking photons

Almost negligible for very high invariant mass.

The probability of a jet faking a photon is 10^{-4} above E_t>100 GeV/c^2

(Run I (cdf5560) Fake rate production for 156-191 GeV/c^2 $<$ 0.04)

0 is a resonable background estimate for the high invariant mass region

0 expected background gives a conservative limit is obtain

Future

Include background fits, to enable potential discovery

Summary Limits Table

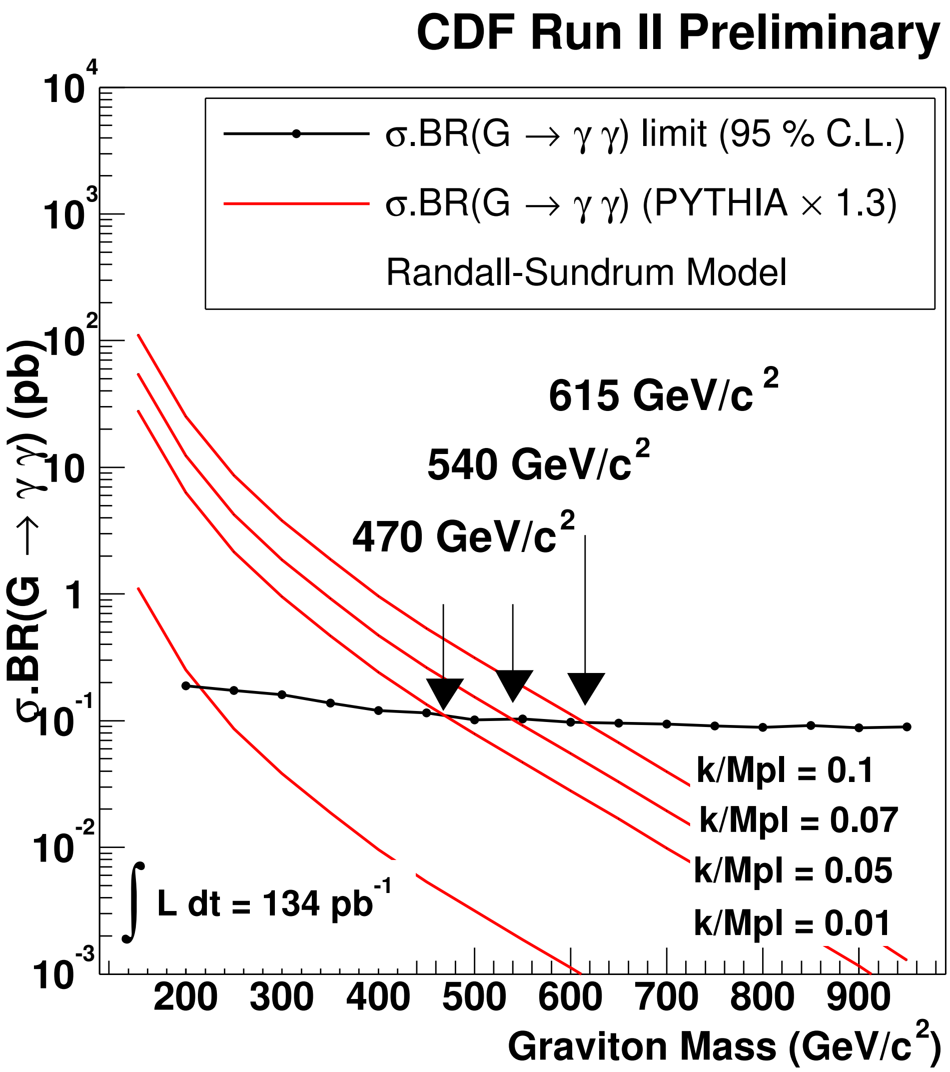
Use Bayes limit program to obtain upper limit $N_{95\%}$

$$\sigma_{95\%} \cdot B(G \to \gamma\gamma) = \frac{N_{95\%}}{\mathcal{L} \times \epsilon \times A(M)} \tag{1}$$

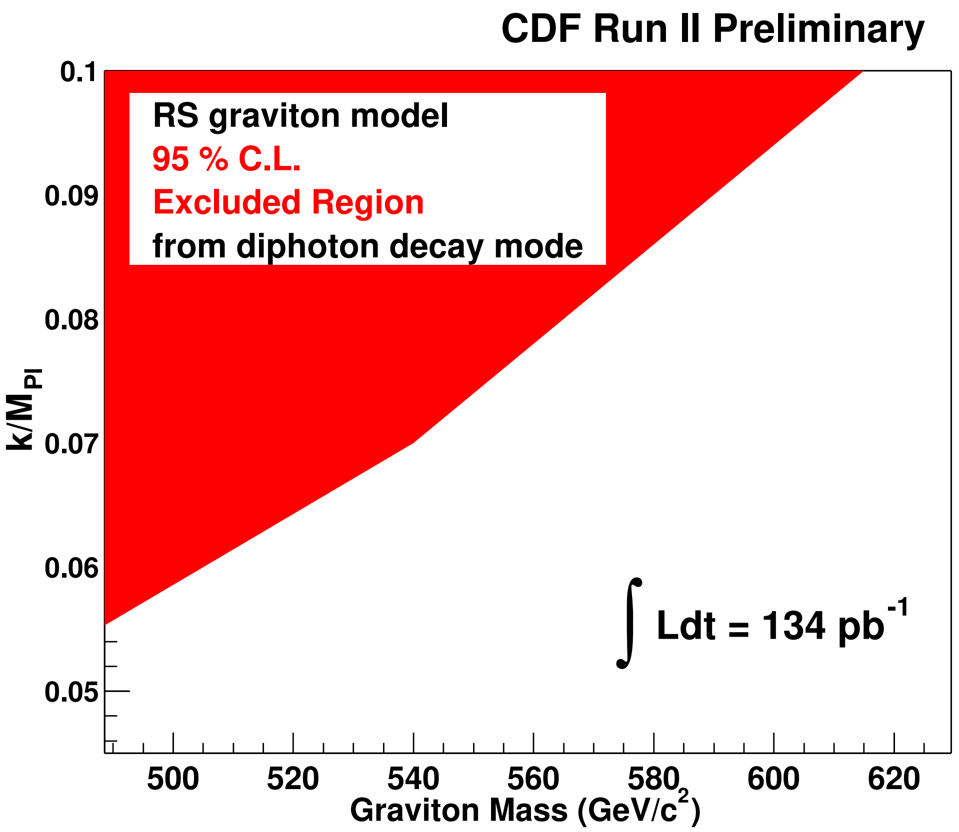
CDF Run II Preliminary (134 pb^{-1})

M_G	$3\times\sigma_{M_G}$	N_{signal}	N_{bKgd}	N_{data}	$N_{95\%}$	A*ϵ	$\sigma_{95\%}$
(GeV/c^2)	(GeV/c^2)					%	(pb)
200	12.5	4.1 ± 0.5	0	0	3.1	0.1	0.19
250	16	1.5 ± 0.2	0	0	3.1	0.1	0.17
300	19	0.74 ± 0.09	0	0	3.1	0.1	0.16
350	23	0.42 ± 0.05	0	0	3.1	0.2	0.14
400	22	0.25 ± 0.03	0	0	3.1	0.2	0.12
450	31	0.14 ± 0.02	0	0	3.1	0.2	0.11
500	36	0.096 ± 0.01	0	0	3.1	0.2	0.10
550	39	0.056 ± 0.007	0	0	3.1	0.2	0.10
600	40	0.036 ± 0.004	0	0	3.1	0.2	0.10
650	45	0.022 ± 0.003	0	0	3.1	0.2	0.10
700	46	0.013 ± 0.002	0	0	3.1	0.2	0.09
750	48	0.008 ± 0.001	0	0	3.1	0.3	0.09
800	51	0.005 ± 0.0006	0	0	3.1	0.3	0.09
850	60	0.0026 ± 0.0003	0	0	3.1	0.3	0.09
900	68	0.0016 ± 0.0002	0	0	3.1	0.3	0.09
950	67	0.00091 ± 0.0001	0	0	3.1	0.3	0.09

95 % cross-section limit



Exclusion Plane



Combining

Combine results with other RS model search channels:

only need eff, bg, uncertainties

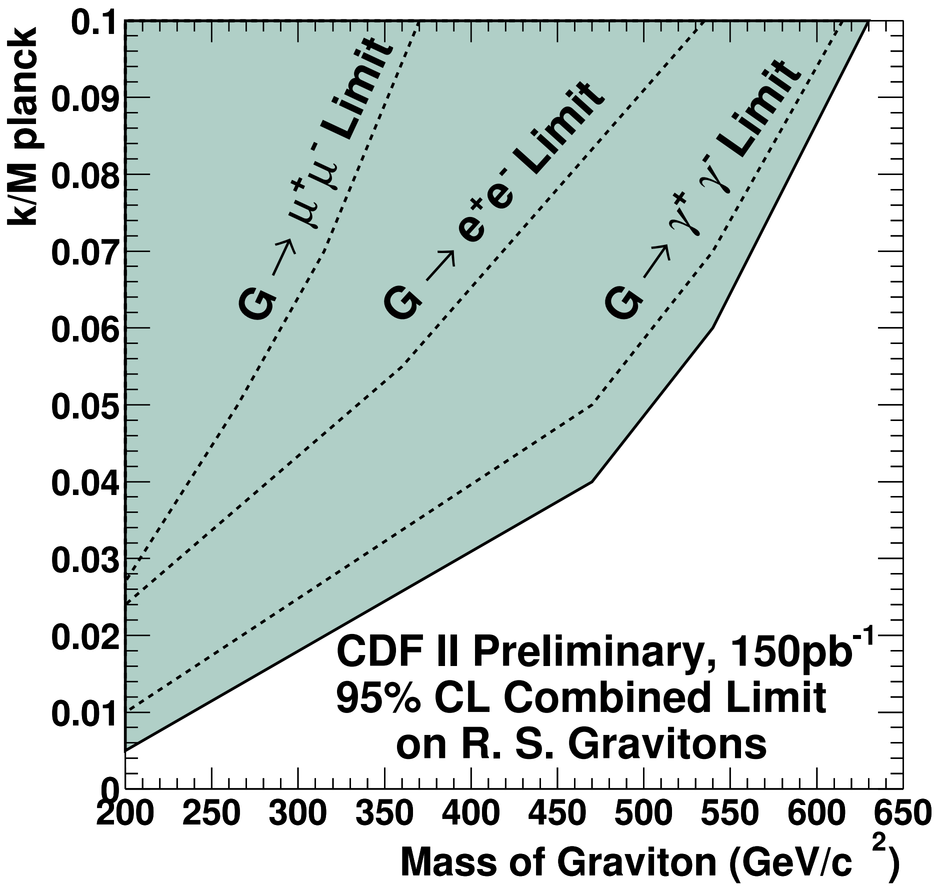
Possible scenario, need to have final discussion:

Factor	Relative Error						Relation
	Signal			BG			
	e	μ	γ	e	μ	γ	
PDF	0.027	0.042	0.03	0.027	0.042	-	Fully Corr.
material	0.026	-	0.015	0.026	-	-	Corr e/γ
vertex	0.005	0.005	0.005	0.005	0.005	-	Fully Corr.
Energy scale	f(M)	-	0.001	f(M)	-	-	UnCorr.
QCD BG	f(M)	-	-	f(M)	-	-	UnCorr.
Track resol	-	0.001		-	0.001	-	UnCorr.
μ geometry	-	0.014		-	0.014	-	UnCorr.
Efficiency	0.08	0.06	0.04	0.08	0.06	-	Corr e/γ
Luminosity	0.06	0.06	0.06	-	-	-	Fully Corr.

- Awaiting final numbers from ee and $\mu\mu$ - Awaiting John Conway's program, needs John, some mods

Combining

Artist's Conception!!



- Tried to increase limit range to jet region and allow that to also be displayed, combined - still needs work

- Possible to bless the combination next meeting?

Extra plots:

Efficiency for a single photon from MC

The cuts were then placed sequentially, in the order shown below.

Sequential efficiency $= \frac{N_\gamma\_passing\_cut\_and\_all\_previously\_applied\_cuts}{N_\gamma\_passing\_acceptance\_cuts}$

Sequential efficiency for applying the selection criteria per photon (includes conversions and non-conversions)								
M_G	CES X,Z	Had/em	CalIso	CES χ^2	N3D	Pt<1	Sum Pt	2nd CES
200	88.8±0.5	87.5±0.5	83.1±0.5	78.5±0.6	73.7±0.6	72.1±0.7	71.1±0.7	70.3±0.7
250	88.7±0.5	85.8±0.5	82.0±0.6	77.2±0.7	72.0±0.7	70.7±0.7	68.8±0.7	68.1±0.7
300	86.7±0.6	83.9±0.6	80.0±0.7	76.4±0.7	72.0±0.8	70.4±0.8	69.2±0.8	68.6±0.8
350	85.6±0.6	82.2±0.7	78.9±0.7	74.9±0.7	69.9±0.8	68.9±0.8	67.4±0.8	66.5±0.8
400	85.1±0.6	83.0±0.7	79.6±0.7	77.1±0.7	70.3±0.8	68.8±0.8	68.5±0.8	68.0±0.8
450	83.6±0.7	81.3±0.7	77.5±0.8	75.3±0.8	69.3±0.8	67.7±0.9	66.9±0.9	66.2±0.9
500	83.7±0.7	81.2±0.7	78.6±0.8	75.9±0.8	68.9±0.9	67.2±0.9	66.1±0.9	65.6±0.9
550	81.8±0.7	79.5±0.8	77.0±0.8	74.7±0.8	68.0±0.9	66.4±0.9	65.7±0.9	65.1±0.9
600	84.2±0.7	81.9±0.7	79.0±0.8	76.0±0.8	68.9±0.9	67.6±0.9	66.9±0.9	66.5±0.9
650	83.4±0.7	81.1±0.7	78.5±0.8	75.8±0.8	68.3±0.9	66.9±0.9	66.3±0.9	65.7±0.9
700	81.2±0.8	79.6±0.8	76.0±0.9	73.4±0.9	66.9±0.9	65.2±1.0	65.0±1.0	64.3±1.0
750	81.6±0.7	79.8±0.8	76.9±0.8	74.0±0.8	67.7±0.9	65.5±0.9	65.0±0.9	64.5±0.9
800	81.6±0.7	80.2±0.8	77.3±0.8	74.3±0.8	67.5±0.9	65.1±0.9	64.6±0.9	64.2±0.9
850	81.5±0.7	80.1±0.8	77.4±0.8	73.2±0.8	67.1±0.9	65.0±0.9	64.5±0.9	63.7±0.9
900	82.2±0.8	80.4±0.8	77.1±0.8	73.1±0.9	66.5±0.9	64.3±1.0	63.8±1.0	63.3±1.0
950	80.0±0.7	78.4±0.8	76.1±0.8	71.5±0.8	65.5±0.9	62.8±0.9	62.3±0.9	61.9±0.9

It is interesting to consider the photons into those that do/ do not convert.

Efficiency for individual selction criteria

The efficiency of applying each selection criterion to a single photon was determined at each graviton mass using the RS model Monte Carlo.
For each Monte Carlo sample the events were looped over to find photons which passed the acceptance cuts (central EM objects with E_T>25 GeV).
The cuts were then placed sequentially, in the order shown below.
Efficiency of cut given photon passes previous cuts =
$$\frac{N_\gamma\_passing\_cut\_and\_all\_previously\_applied\_cuts}{N_\gamma\_passing\_all\_previous\_cuts}$$

Sequential efficiency for applying the selection criteria

M_G	CES X,Z	Had/em	CalIso	CES χ^2	N3D	Pt<1	Sum Pt	2nd CES
200	88.8±0.5	98.5±0.2	95.0±0.3	94.4±0.4	94.0±0.4	97.8±0.2	98.5±0.2	98.9±0.2
250	88.7±0.5	96.7±0.3	95.6±0.3	94.1±0.4	93.3±0.4	98.2±0.2	97.3±0.3	99.0±0.2
300	86.7±0.6	96.7±0.3	95.4±0.4	95.5±0.4	94.2±0.5	97.8±0.3	98.3±0.3	99.1±0.2
350	85.6±0.6	96.1±0.4	96.0±0.4	94.9±0.4	93.3±0.5	98.6±0.2	97.9±0.3	98.7±0.2
400	85.1±0.6	97.5±0.3	96.0±0.4	96.8±0.3	91.1±0.6	98.0±0.3	99.5±0.1	99.2±0.2
450	83.6±0.7	97.3±0.3	95.4±0.4	97.1±0.3	92.0±0.6	97.6±0.3	98.9±0.2	98.9±0.2
500	83.7±0.7	97.0±0.3	96.9±0.4	96.5±0.4	90.8±0.6	97.6±0.3	98.3±0.3	99.2±0.2
550	81.8±0.7	97.2±0.3	96.9±0.4	97.1±0.4	90.9±0.6	97.7±0.3	98.9±0.2	99.2±0.2
600	84.2±0.7	97.4±0.3	96.4±0.4	96.3±0.4	90.6±0.6	98.1±0.3	99.0±0.2	99.4±0.2
650	83.4±0.7	97.2±0.3	96.9±0.4	96.6±0.4	90.0±0.7	98.0±0.3	99.1±0.2	99.2±0.2
700	81.2±0.8	98.0±0.3	95.5±0.5	96.5±0.4	91.2±0.7	97.4±0.4	99.6±0.2	98.9±0.3
750	81.6±0.7	97.8±0.3	96.4±0.4	96.2±0.4	91.6±0.6	96.7±0.4	99.2±0.2	99.1±0.2
800	81.6±0.7	98.2±0.3	96.4±0.4	96.1±0.4	90.8±0.6	96.4±0.4	99.2±0.2	99.4±0.2
850	81.5±0.7	98.2±0.3	96.6±0.4	94.6±0.5	91.7±0.6	96.9±0.4	99.2±0.2	98.8±0.3
900	82.2±0.8	97.8±0.3	95.9±0.4	94.8±0.5	91.0±0.7	96.6±0.4	99.3±0.2	99.1±0.2
950	80.0±0.7	98.0±0.3	97.1±0.4	94.0±0.5	91.5±0.6	96.0±0.5	99.1±0.2	99.3±0.2

Interesting to split efficiency per photon into those that convert and those that do not.

Efficiency for individual selction criteria- for conversions

The efficiency of applying each selection criterion to a single photon which converted was determined at each graviton mass using the RS model Monte Carlo.
For each Monte Carlo sample the events were looped over to find photons which passed the acceptance cuts (central EM objects with E_T>25 GeV).
The cuts were then placed sequentially, in the order shown below.
Efficiency of cut given photon passes previous cuts = $\frac{N_{\gamma}\_passing\_cut\_and\_all\_previously\_applied\_cuts}{N_{\gamma}\_passing\_all\_previous\_cuts}$

Sequential efficiency for applying the selection criteria to converted photons								
M_G	CES X,Z	Had/em	CalIso	CES χ^2	N3D	Pt<1	Sum Pt	2nd CES
200	92.8 ± 1.	100. ± 0.	91.4 ± 1.	51.8 ± 3.	21.3 ± 3.	0.00 ± 0.	-	-
250	96.5 ± 0.9	100. ± 0.	93.2 ± 1.	53.9 ± 3.	14.2 ± 3.	0.00 ± 0.	-	-
300	91.5 ± 2.	99.7 ± 0.3	93.0 ± 2.	55.4 ± 4.	17.2 ± 4.	0.00 ± 0.	-	-
350	95.9 ± 1.	100. ± 0.	94.2 ± 1.	54.5 ± 3.	10.7 ± 3.	0.00 ± 0.	-	-
400	92.9 ± 2.	100. ± 0.	99.0 ± 0.6	76.5 ± 3.	11.1 ± 2.	5.98 ± 5.	100. ± 0.	100. ± 0.
450	90.4 ± 2.	100. ± 0.	94.1 ± 2.	76.9 ± 3.	13.6 ± 3.	0.00 ± 0.	-	-
500	96.0 ± 1.	100. ± 0.	98.0 ± 0.9	76.9 ± 3.	11.0 ± 2.	4.68 ± 5.	100. ± 0.	100. ± 0.
550	91.3 ± 2.	100. ± 0.	98.3 ± 0.9	84.7 ± 3.	13.6 ± 3.	0.00 ± 0.	-	-
600	94.5 ± 2.	100. ± 0.	97.1 ± 1.	81.1 ± 3.	10.9 ± 2.	0.00 ± 0.	-	-
650	97.1 ± 1.	100. ± 0.	95.7 ± 1.	88.3 ± 2.	9.60 ± 2.	0.00 ± 0.	-	-
700	93.1 ± 2.	100. ± 0.	97.1 ± 1.	90.3 ± 2.	12.6 ± 3.	16.7 ± 9.	100. ± 0.	100. ± 0.
750	93.0 ± 2.	100. ± 0.	96.1 ± 1.	89.7 ± 2.	16.2 ± 3.	0.00 ± 0.	-	-
800	94.2 ± 2.	100. ± 0.	99.1 ± 0.6	92.1 ± 2.	16.7 ± 3.	3.14 ± 3.	100. ± 0.	100. ± 0.
850	97.1 ± 1.	100. ± 0.	98.1 ± 1.0	90.7 ± 2.	19.0 ± 3.	7.91 ± 5.	100. ± 0.	100. ± 0.
900	95.6 ± 2.	100. ± 0.	99.3 ± 0.6	93.1 ± 2.	19.7 ± 3.	9.36 ± 5.	100. ± 0.	100. ± 0.
950	96.5 ± 1.	100. ± 0.	98.9 ± 0.7	94.0 ± 2.	22.6 ± 3.	2.28 ± 2.	100. ± 0.	100. ± 0.

Efficiency for individual selction criteria- for non-conversions

The efficiency of applying each selection criterion to a single photon which did not convert was determined at each graviton mass using the RS model Monte Carlo.

For each Monte Carlo sample the events were looped over to find photons which passed the acceptance cuts (central EM objects with E_T>25 GeV).

The cuts were then placed sequentially, in the order shown below.

Efficiency of cut given photon passes previous cuts = $\frac{N_\gamma\_passing\_cut\_and\_all\_previously\_applied\_cuts}{N_\gamma\_passing\_all\_previous\_cuts}$

Sequential efficiency for applying the selection criteria to non-converted photons

M_G	CES X,Z	Had/em	CalIso	CES χ^2	N3D	Pt<1	Sum Pt	2nd CES
200	89.7±0.5	98.6±0.2	96.4±0.3	99.5±0.1	99.5±0.1	99.3±0.2	98.4±0.2	98.9±0.2
250	90.7±0.5	97.4±0.3	96.0±0.4	99.2±0.2	99.1±0.2	99.6±0.1	97.4±0.3	99.0±0.2
300	89.9±0.6	97.1±0.4	96.9±0.4	0.0477±0.05	0.00±0.	divide 0	98.1±0.3	99.2±0.2
350	91.6±0.6	96.9±0.4	97.1±0.4	99.5±0.2	99.1±0.2	99.8±0.09	97.8±0.3	98.7±0.2
400	92.0±0.6	98.7±0.2	96.5±0.4	99.1±0.2	99.0±0.2	99.6±0.2	99.5±0.2	99.2±0.2
450	92.2±0.6	99.0±0.2	96.6±0.4	99.1±0.2	99.0±0.2	99.4±0.2	99.0±0.2	99.0±0.2
500	92.4±0.6	99.6±0.1	97.7±0.4	99.0±0.2	99.4±0.2	99.5±0.2	98.0±0.3	99.3±0.2
550	93.4±0.6	99.7±0.1	98.3±0.3	98.7±0.3	99.3±0.2	99.8±0.1	98.7±0.3	99.1±0.2
600	94.0±0.6	99.9±0.07	97.7±0.4	98.0±0.3	98.7±0.3	99.8±0.1	98.9±0.3	99.3±0.2
650	94.0±0.6	99.9±0.08	98.4±0.3	97.4±0.4	99.8±0.1	99.8±0.1	99.0±0.3	99.2±0.2
700	93.8±0.6	99.9±0.07	98.0±0.4	97.0±0.5	99.3±0.2	99.9±0.07	99.5±0.2	99.0±0.3
750	94.6±0.5	100.±0.	98.3±0.3	97.1±0.4	99.3±0.2	99.9±0.09	99.2±0.2	99.3±0.2
800	93.9±0.6	100.±0.	98.4±0.3	96.6±0.5	99.3±0.2	99.9±0.09	99.1±0.3	99.5±0.2
850	94.2±0.6	100.±0.	98.5±0.3	95.0±0.6	99.6±0.2	100.±0.	98.9±0.3	99.0±0.3
900	96.1±0.5	100.±0.	98.5±0.3	94.8±0.6	98.8±0.3	99.9±0.1	99.2±0.3	99.2±0.3
950	94.6±0.6	99.4±0.2	99.0±0.3	93.8±0.7	99.5±0.2	99.8±0.1	98.9±0.3	99.2±0.2

Photon 50 Trigger Efficiency for diphoton events

For cph108 and cpho109 samples

PHOTON 50 Trigger Efficiency above bin minimum				
minimum Bin			Efficiency (%)	
Et (GeV)	$N_{pass25trig}$	$N_{pass25and50trig}$	$(\epsilon^{\gamma}_{trig})$	$(\epsilon^{\gamma\gamma}_{trig} = \epsilon^{\gamma}_{trig} \times (2 - \epsilon^{\gamma}_{trig}))$
50	65819	79783	82.2 ± 0.2	$96.8\ ^{+0.1}_{-0.1}$
55	51584	52815	97.8 ± 0.08	$99.9\ ^{+0.003}_{-0.004}$
60	36006	36140	99.8 ± 0.03	$100\ ^{+0}_{-0.0001}$
65	25531	25586	100 ± 0.01	$100\ ^{+0}_{-4e-06}$
70	18707	18748	100 ± 0.008	$100\ ^{+0}_{-2e-06}$
75	13909	13939	100 ± 0.01	$100\ ^{+0}_{-3e-06}$
80	10484	10506	100 ± 0.01	$100\ ^{+0}_{-5e-06}$
85	8185	8200	100 ± 0.02	$100\ ^{+0}_{-9e-06}$
90	6360	6372	100 ± 0.02	$100\ ^{+0}_{-1e-05}$
95	5020	5029	100 ± 0.03	$100\ ^{+0}_{-2e-05}$
100	4016	4023	100 ± 0.03	$100\ ^{+0}_{-3e-05}$
105	3243	3250	100 ± 0.04	$100\ ^{+0}_{-5e-05}$
110	2632	2637	99.9 ± 0.05	$100\ ^{+0}_{-8e-05}$
115	2197	2201	99.9 ± 0.06	$100\ ^{+0}_{-0.0001}$
120	1794	1796	99.9 ± 0.07	$100\ ^{+0}_{-0.0002}$
125	1465	1467	99.9 ± 0.09	$100\ ^{+0}_{-0.0002}$
130	1236	1238	99.9 ± 0.1	$100\ ^{+0}_{-0.0003}$
135	1026	1028	99.9 ± 0.1	$100\ ^{+0}_{-0.0005}$
140	865	866	99.9 ± 0.1	$100\ ^{+0}_{-0.0006}$
145	733	734	99.8 ± 0.2	$100\ ^{+0}_{-0.0009}$
150	635	636	99.8 ± 0.2	$100\ ^{+0}_{-0.001}$
155	530	531	99.8 ± 0.2	$100\ ^{+0}_{-0.002}$
160	461	462	99.7 ± 0.3	$100\ ^{+0}_{-0.002}$
165	412	413	99.7 ± 0.3	$100\ ^{+0}_{-0.002}$
170	358	359	99.7 ± 0.3	$100\ ^{+0}_{-0.003}$
175	306	307	99.6 ± 0.4	$100\ ^{+0}_{-0.004}$
180	275	276	99.6 ± 0.4	$100\ ^{+0}_{-0.005}$
185	239	240	99.5 ± 0.5	$100\ ^{+0}_{-0.007}$
190	209	210	99.4 ± 0.6	$100\ ^{+0}_{-0.009}$
195	189	190	99.4 ± 0.6	$100\ ^{+0}_{-0.01}$
200	169	170	99.3 ± 0.7	$100\ ^{+0}_{-0.01}$

PHOTON 50 trigger efficiency is $100^{+0}_{-0.01}$ % for 2γ above 55 GeV.
(largest error taken, from above 200 GeV)

Photon 70 Trigger Efficiency (from cph108)

Photon 70 trigger efficiency for above bin minimum				
minimum Bin	Number of events		Efficiency (%)	
Et (GeV)	$N^{IsoHadEm}_{pass50}$	$N^{IsoHadEm}_{pass50a70}$	$(\epsilon^{\gamma}_{trig})$	$(\epsilon^{\gamma\gamma}_{trig} = \epsilon^{\gamma}_{trig} \times (2 - \epsilon^{\gamma}_{trig}))$
70	60120	97055	52.1 $\pm$ 0.3	77.1 $^{+0.3}_{-0.3}$
75	55324	72524	65 $\pm$ 0.3	87.7 $^{+0.2}_{-0.2}$
80	48230	55405	78.3 $\pm$ 0.3	95.3 $^{+0.1}_{-0.1}$
85	40825	43382	89.5 $\pm$ 0.2	98.9 $^{+0.05}_{-0.05}$
90	33951	34560	96.8 $\pm$ 0.1	99.9 $^{+0.0087}_{-0.009}$
95	27711	27812	99.4 $\pm$ 0.06	100 $^{+0.0007}_{-0.0008}$
100	22818	22836	99.9 $\pm$ 0.03	100 $^{+5.9e-05}_{-7.8e-05}$
105	18974	18977	100 $\pm$ 0.01	100 $^{+3.6e-06}_{-7.6e-06}$
110	16022	16022	100 $\pm$ 0	100 $^{+0}_{0}$
115	13560	13560	100 $\pm$ 0	100 $^{+0}_{0}$
120	11634	11634	100 $\pm$ 0	100 $^{+0}_{0}$
125	10018	10018	100 $\pm$ 0	100 $^{+0}_{0}$
130	8689	8689	100 $\pm$ 0	100 $^{+0}_{0}$
135	7596	7596	100 $\pm$ 0	100 $^{+0}_{0}$
140	6689	6689	100 $\pm$ 0	100 $^{+0}_{0}$
145	5930	5930	100 $\pm$ 0	100 $^{+0}_{0}$
150	5305	5305	100 $\pm$ 0	100 $^{+0}_{0}$
155	4748	4748	100 $\pm$ 0	100 $^{+0}_{0}$
160	4280	4280	100 $\pm$ 0	100 $^{+0}_{0}$
165	3921	3921	100 $\pm$ 0	100 $^{+0}_{0}$
170	3595	3595	100 $\pm$ 0	100 $^{+0}_{0}$
175	3297	3297	100 $\pm$ 0	100 $^{+0}_{0}$
180	3054	3054	100 $\pm$ 0	100 $^{+0}_{0}$
185	2812	2812	100 $\pm$ 0	100 $^{+0}_{0}$
190	2586	2586	100 $\pm$ 0	100 $^{+0}_{0}$
195	2394	2394	100 $\pm$ 0	100 $^{+0}_{0}$
200	2238	2238	100 $\pm$ 0	100 $^{+0}_{0}$

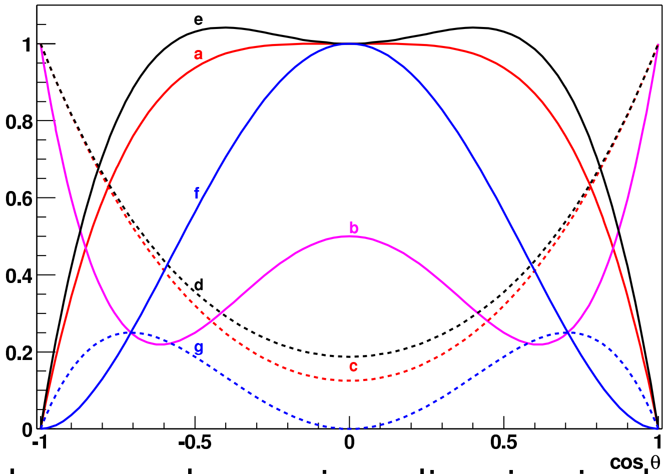
PHOTON 70 trigger efficiency is 100 % for 2γ above 95 GeV.

Monte Carlo

The RS MC used was Pythia 6.203
2000 events were generated at each M_G with pdf CTEQ5L
using cdfSim and reconstructed with ProductionExe code version 4.9.1

Pythia assumes that the diphotons decay isotropically in the graviton rest frame

Angular distribution of graviton decay products



cosθ^* is the angle between the graviton direction in the lab frame and one of the photons in the graviton rest frame (Reference: hep-ph 0211205)

Process	Distribution	Plot
Assumed decays	1	*("flat")*
gg $\rightarrow$ G $\rightarrow \gamma\gamma$	$1 + 6\cos^2\theta^* + \cos^4\theta^*$	c *("u shaped")*
$q\ \bar{q} \rightarrow$ G $\rightarrow \gamma\gamma$	$1 - \cos^4\theta^*$	a *("n shaped")*

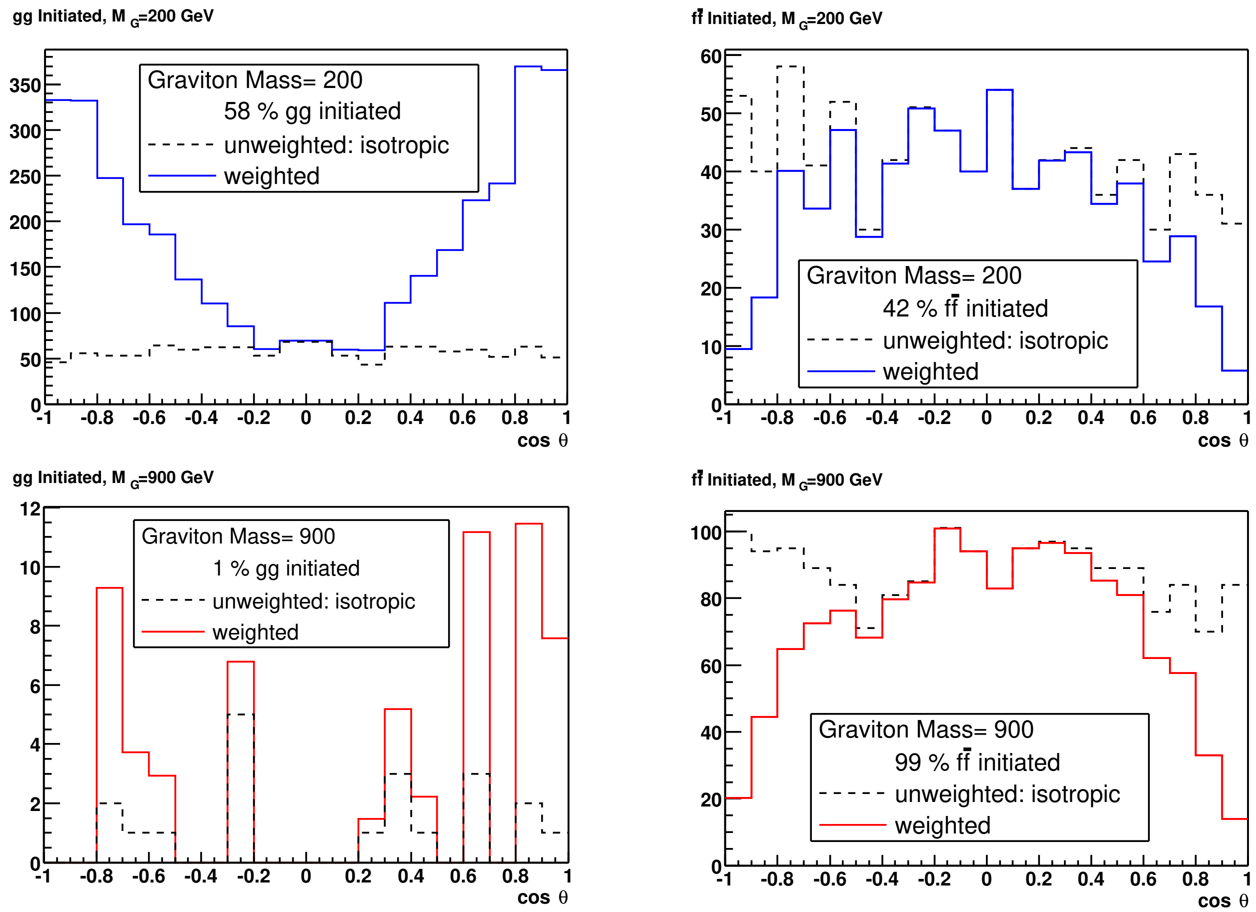
Therefore the events were weighted to give the correct angular distributions

Event weighting

To correct for the isotropic assumption:
Events are weighted according to their correct angular distributions

gg $\rightarrow$ G $q\ \bar{q} \rightarrow$ G

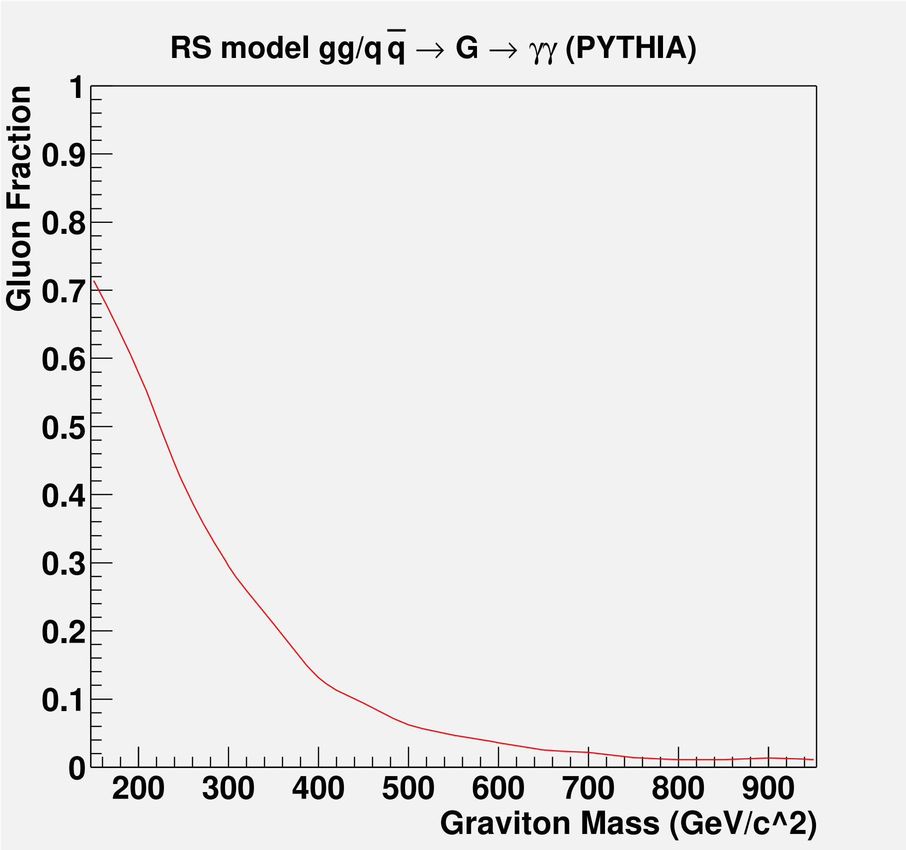
flat $\rightarrow$ *"u-shaped"*   *flat* $\rightarrow$ *"n-shaped"*



What effect will correct angular distribution have on the $\gamma\gamma$ acceptance ?
Assuming that the graviton decays at rest:
1) gg $\rightarrow$ G $\rightarrow \gamma\gamma$ will have a smaller acceptance (fewer central decays)
2) $q\ \bar{q} \rightarrow$ G $\rightarrow \gamma\gamma$ will have a larger acceptance (more central decays)

Acceptance Correction for angular distribution

Fraction of events graviton events which are gg $\rightarrow$ G $\rightarrow \gamma\gamma$



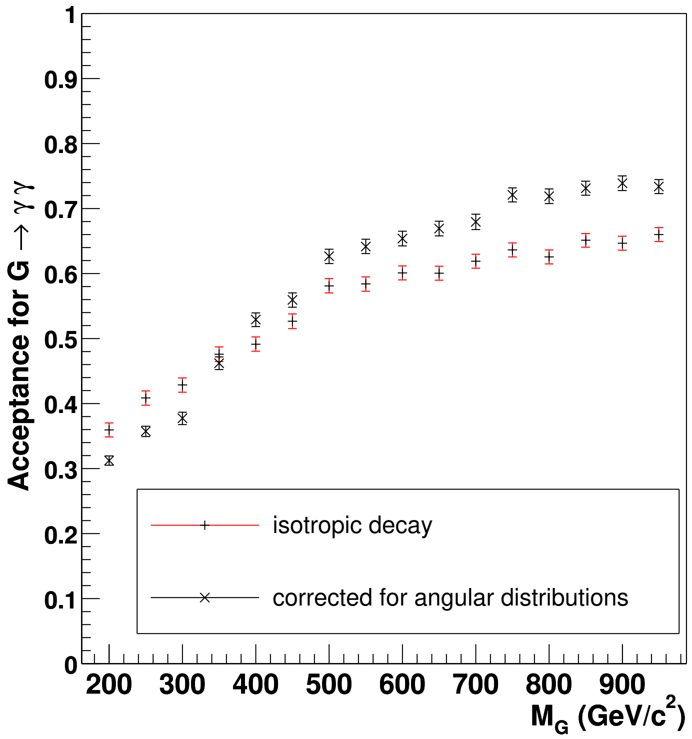
Smaller gg fraction as graviton mass increases.

So assuming that the graviton decays at rest
expect that the acceptance is increased slightly for M_G>400 GeV/c^2

So I had assumed that the acceptance with isotropic decays is a conservative estimate. Now confirmed ...

Acceptance per event

$$\text{acceptance} = \frac{\sum weigthed\_events\_with\_2\_central\_\gamma s\_with\_E_T > 25GeV\_and M_{\gamma\gamma} > 25GeV}{\sum \_weighted^{generated}_{events}}$$



Predictions confirmed:

- Larger for large M_G ($>$ 400 GeV), where gg intiated fraction is small
- Here the $f\bar{f}$ fraction is dominant and this decays mostly centrally
- Smaller for lower M_G ($<$ 350 GeV), where gg intiated fraction is large
- Here the gg fraction is dominant and the photons (in the graviton rest frame) are predominantly emitted in the direction the graviton (anti-) direction is travelling

Correction to the efficiency due to conversions

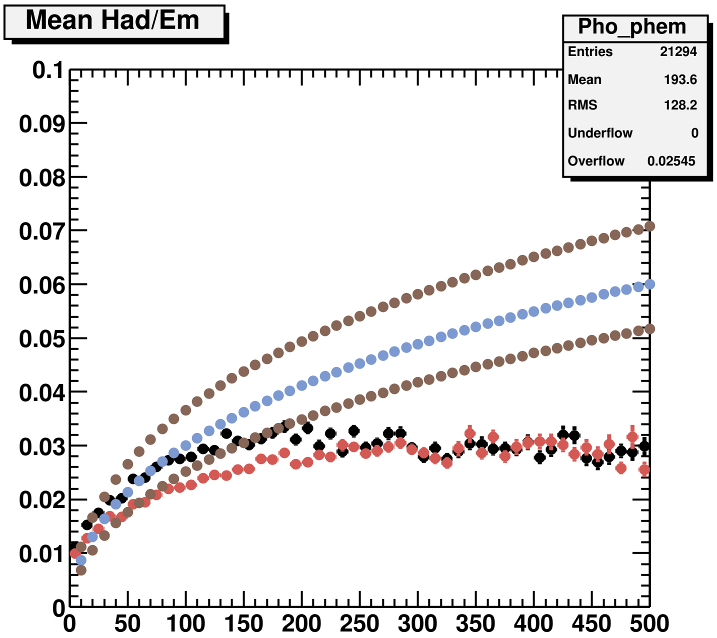
The efficiency per event depends on the conversion probability
This depends on the amount of material in the detector
which is underestimated in the 4.9.1 simulation by 30 $\pm$ 10 %
(Greg Veramendi's estimated the amount of material needed
in the tracking volume from the E/P spectrum:
4.9.1 simulation needs about 4.5 $\pm$ 1.5 % X_o of Copper on average.)
This uncertainty is probably an overestimate, and should come down in the coming months.

The efficiency per event is corrected for this:

- Assume that the number of conversions is directly proportional to the amount of material
- Increase the fraction of conversions (f_C^γ) by the increase in amount of material (30 %)
- Assume that the conversion of the two gammas are independent
- The efficiency per event is determined from Monte Carlo
  $\epsilon^{\gamma\gamma} = \frac{N_{\gamma\gamma}\_passing\_all\_cuts}{N_{\gamma\gamma}\_passing\_acceptance\_cuts}$
- The efficiency per event ($\varepsilon^{\gamma\gamma}$) depends on f_C^γ
  neither converts, 1st or 2nd photon converts, or both convert
  $\varepsilon^{\gamma\gamma}$=(1-$f_C^\gamma$)*(1-$f_C^\gamma$)*$\varepsilon_{NC}$*$\varepsilon_{NC}$+2*(1-$f_C^\gamma$)*$f_C^\gamma$*$\varepsilon_{NC}$*$\varepsilon_C$+$f_C^\gamma$*$f_C^\gamma$*$\varepsilon_C$*$\varepsilon_C$
  Conservatively assume that converted photons fail the cuts (ε_C=0)
  Therefore: $\varepsilon^{\gamma\gamma}$ = (1-f_C^γ)*(1-f_C^γ)*ε_{NC}*ε_{NC}
  More material changes f_C : so material corrected efficiency
  $\varepsilon_{cor}^{\gamma\gamma} = \frac{(1-f_{Ccor}^\gamma)*(1-f_{Ccor}^\gamma)}{(1-f_C^\gamma)*(1-f_C^\gamma)}$*$\varepsilon^{\gamma\gamma}$: correction of -7.2 %

Underlying Event: had/em

What do you expect a had/em for a photon (e) to look like?



black: mean had/em for fake event photons vs Et

red: mean had/em for fake event electrons vs Et

blue: predicted had/em from PDG EM shower model

brown: same as blue, but parameters adjusted to give a nominal variation for the purposes of a systematic error

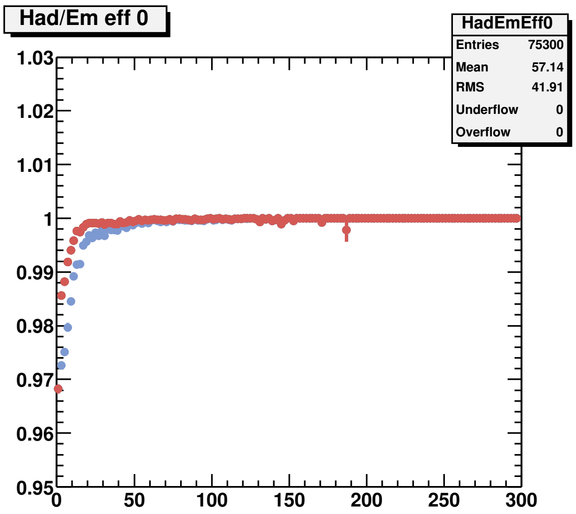
Note: MC underestimates the had/em

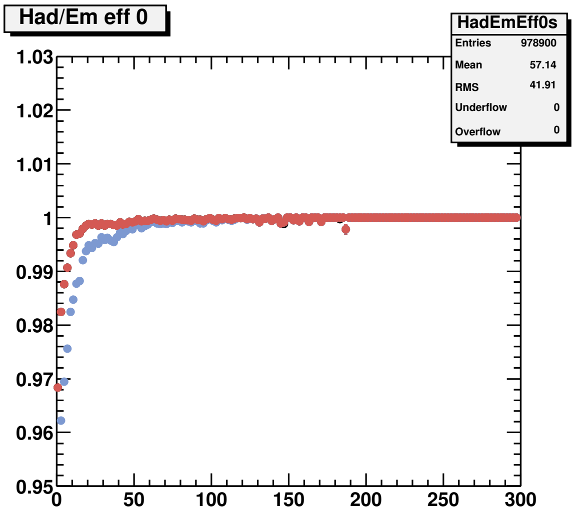
Underlying Event: had/em

Take had/em in 2 or 3 towers in the random cone
Leading jet in event defines em Et energy
Plot had/em vs Et of leading jet

ask how often this passes the cut?

Left: had/em efficiency based on simply the underlying event energy





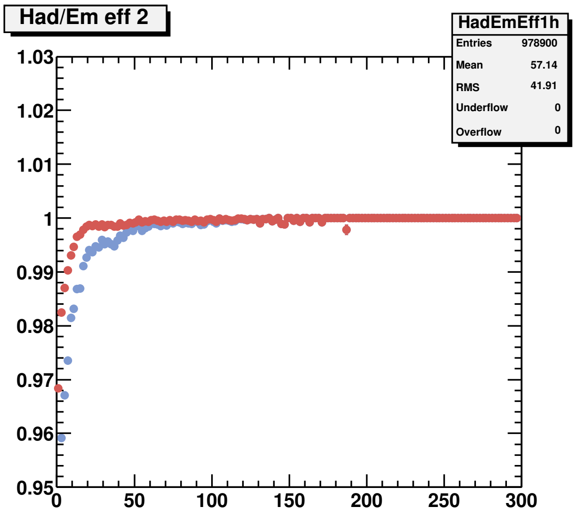
efficiency of had/em<sliding cut
had/em<0.125 or had/em<sliding cut

To find efficiency of had/em
Right: same, but now the predicted photon energy has been added to the underlying event energy.
This is the current best guess of a data-based efficiency.
The eff is slightly lower than upper right.

Underlying event systematic uncertainty: had/em

To estimate a systematic uncertainty
plot had/em vs leading jet E_T again
but now the hadronic energy predicted for the photon has been increased to the upper brown line in the first plot

i.e. it has been increased by an arbitrary amount to help set a systematic uncertainty.



Conclude: at large Et ($>$ 40 GeV):

- there is no inefficiency of the had/em cut due to the underlying event
- the eff of the had/em cut is 100%
- and the systematic uncertainty is negligible