Exclusive γγ Production at LHC
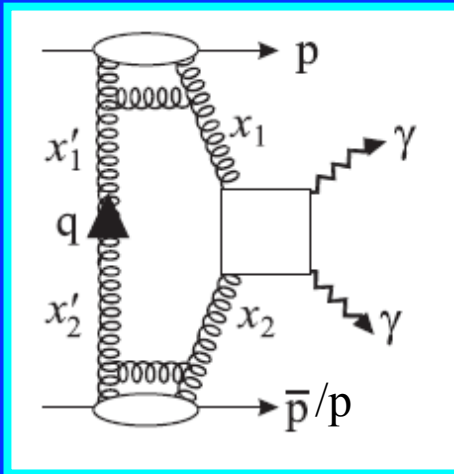
Michael Albrow (Fermilab): on behalf of the CMS Collaboration

$$p + p \;\rightarrow\; p + \gamma\gamma + p$$

with two high p_T central photons and <u>no</u> produced hadrons

Ingredients for calculation:

Khoze, Martin, Ryskin & Stirling
Eur.Phys. J.C38 (2005) p.475

σ(g + g → γ + γ)
Unintegrated g(x,x') σ ~ g⁴
Loop integral over quarks
No gluon/hadron radiation (Sudakov)
No other parton-parton interaction
(Gap survival factor)

Interesting QCD physics
Understanding pomeron {gg}
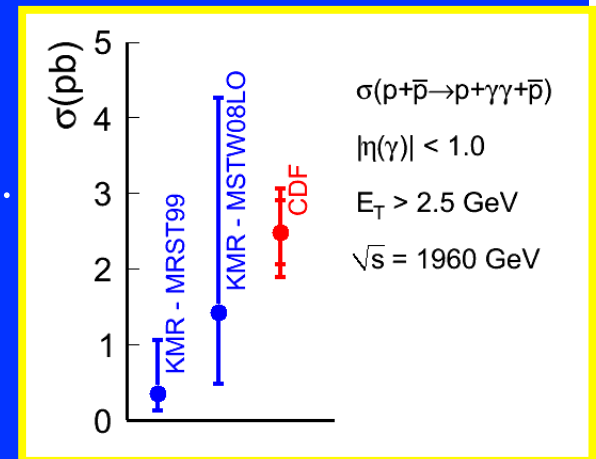from perturbative direction

Quark loops (box/triangle), mostly u and c

ALSO: c-loop → χ_c, b-loop → χ_b, t-loop → Higgs!

γγ is cleanest, like the H (no strong interactions in final state).
Observed at Tevatron (CDF) : PRL 99 (2007) 242002 (search: 3 candidates)
PRL 108 (2012) 081801 (observation, 43 events)

Could not detect protons, but rap gaps to |η| = 7.4
Beams had y = 7.64.

σ(pb)

KMR - MRST99
KMR - MSTW08LO
CDF

σ(p+p̄→p+γγ+p̄)
|η(γ)| < 1.0
E_T > 2.5 GeV
√s = 1960 GeV

When p's not detected, diffraction dissociation allowed:

$$p + p \rightarrow p(*) + \gamma\gamma + p(*)$$

Exclusive γγ , ππ , ηη , η'η' at LHC (CMS & ...)

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36 pb^{-1}, ε(exclusive) = 0.145, L(eff, 1) ~ 5 pb^{-1}

No candidates, upper limit. →

$E_T(\gamma) > 5.5$ GeV
$|\eta(\gamma)| < 2.5$

σ [pb]

MRST01-NLO   MSTW08-NLO   MRST01-LO   MSTW08-LO   CMS:upper limit

What _could_ we do? Goal: 5% stat.error
KMRS (Durham): Eur.Phys.J C38 (2005) 475
Lines: |η(γ)| < 2 and 1

Suppose:
250 hours (can do in 2 weeks)
PU (μ) = 1/crossing (max # single ints./hour)
2800 bunches → L(eff,1) ~ **200 pb^{-1}**

0.8 pb^{-1}/hour
Trigger = 2 EM > 2 GeV (cut offline at 3 GeV)
in |η| < 3 (EE+EB)
Veto on HB + HE + HF, CASTOR, ZDC?
Off-line: < = 2 tracks (want e+e- also)
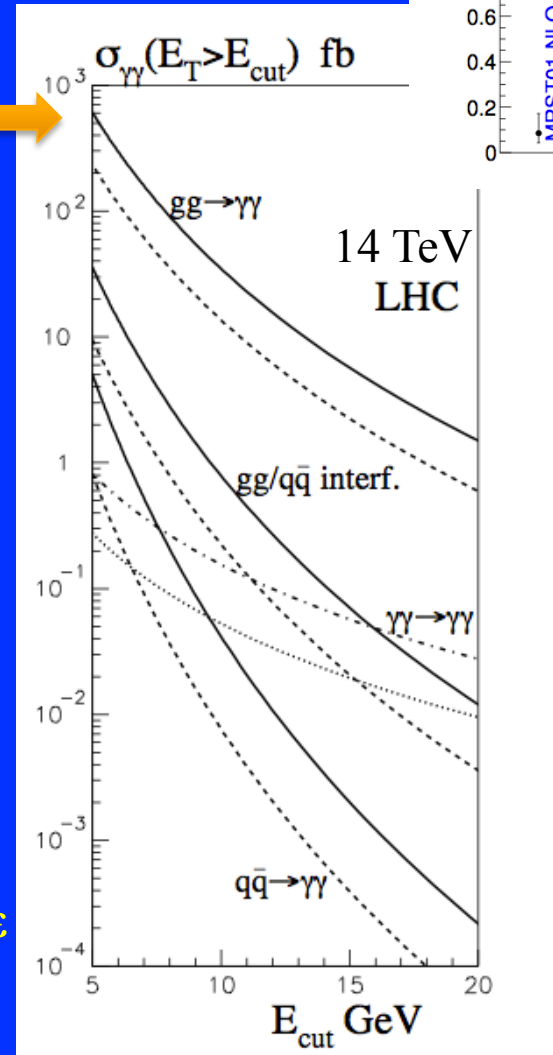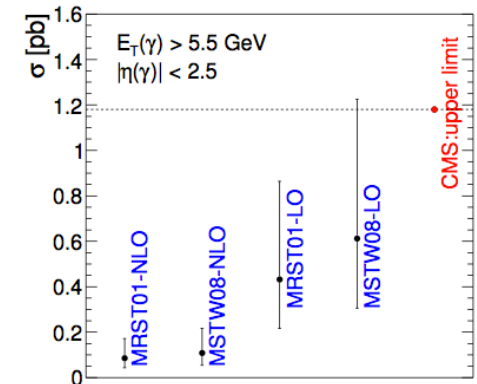σ(>5 GeV, |η| < 2) = 0.6 pb
→ σ(>5 GeV, |η| < 3) ~ **1.8 pb** (extrapolated)
FSC in/out of trigger? Measure Diff.Diss & ε
If 60% efficiency: 200x1.8x0.6 = **180 events**

7% statistical error

$\sigma_{\gamma\gamma}(E_T>E_{cut})$ fb

gg→γγ

14 TeV
LHC

gg/q$\bar{q}$ interf.

γγ→γγ

q$\bar{q}$→γγ

E_{cut} GeV

Backgrounds
small:
Δφ ~ π
$p_{T1} \sim p_{T2}$

$\pi^0\pi^0$ & e$^+$e$^-$
can be
measured

Exclusive γγ , ππ , ηη , η'η' at LHC (CMS & ...)   Mike Albrow

Notes:
This is for "elastic" case. Dissociation increases cross sections (~ x 2?)
Cannot detect protons in Roman Pots at Low-β (Min. Mass > 200 GeV)
Reduce (and measure) dissociation with FSC (upgraded), ZDC (if in) veto.
For high-β running with TOTEM may accept protons, but 2800 bunches, μ = 1 ?

Cross section uncertainties from $g(x)^4$ and Rap gap survival ... we constrain these.

Always allow 2 tracks → exclusive [γγ → e+e-] comes at same time, ideal control.

Allow also 4 γ with 0, 2, 4 tracks: Exclusive $\pi^0\pi^0$, ηη, η(548)η'(958), η'η' come too.
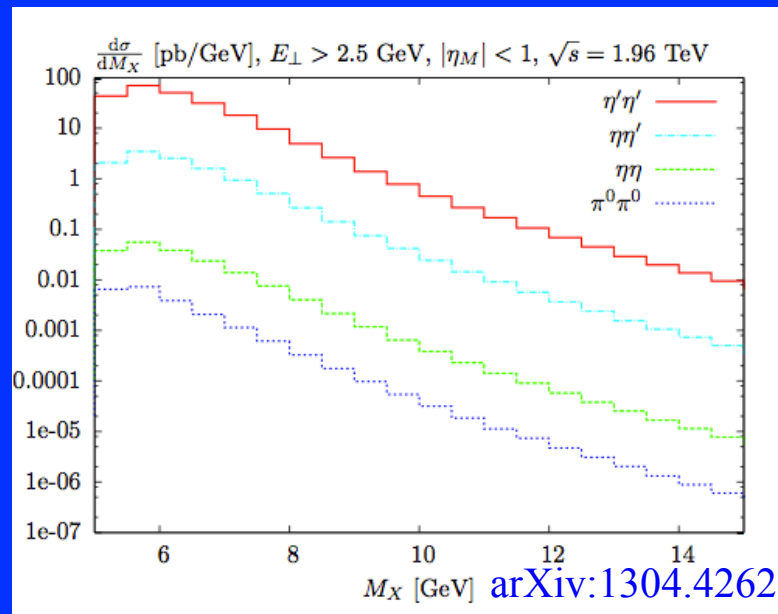Durham prediction:
For Tevatron, 1.96 TeV

η'η' ~ 1000 x $\pi^0\pi^0$!!

Surprise! Why:
η' is isoscalar (π is not)
η' has high glue component

Great test of QCD theory

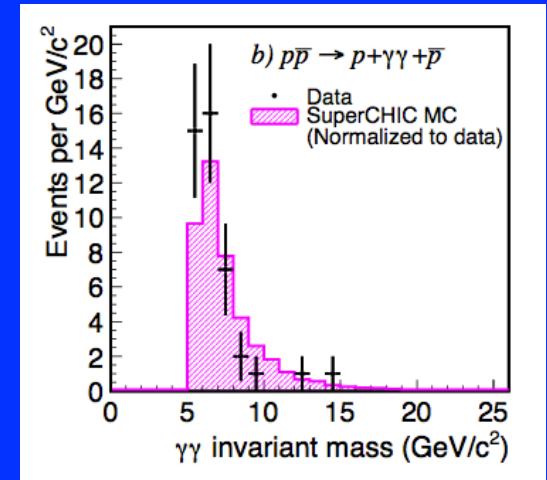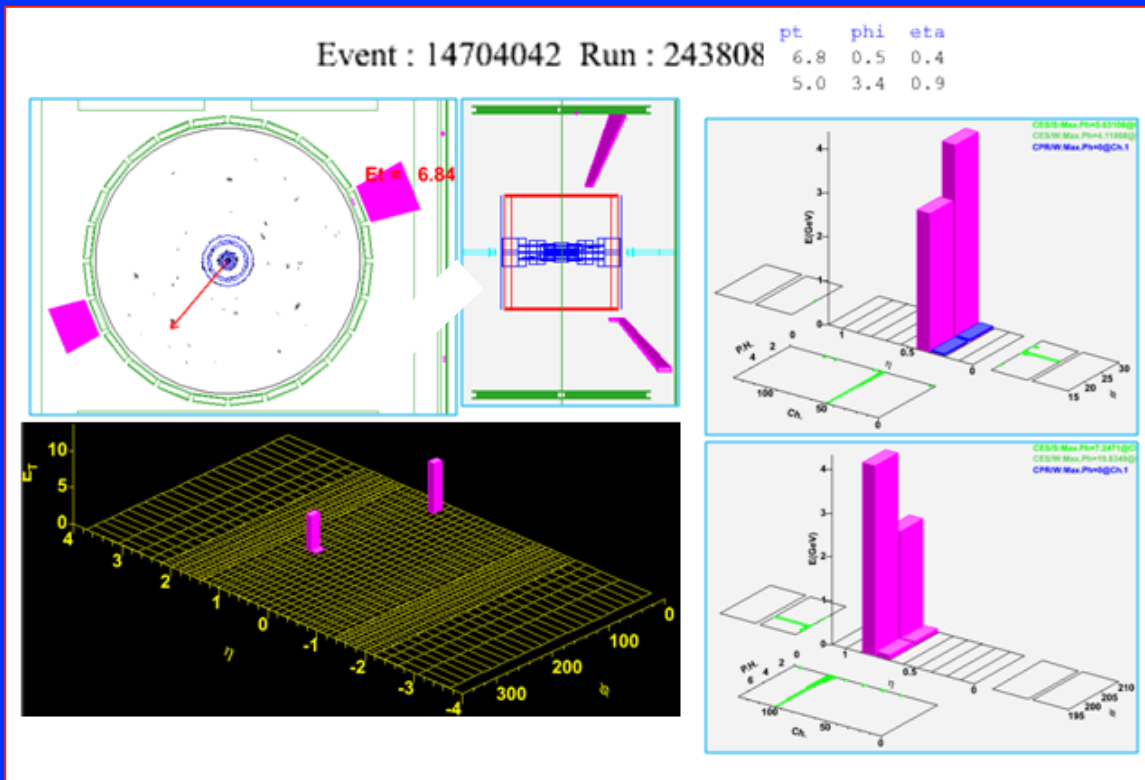$\frac{d\sigma}{dM_X}$ [pb/GeV], $E_\perp > 2.5$ GeV, $|\eta_M| < 1$, $\sqrt{s} = 1.96$ TeV

η'η'
ηη'
ηη
$\pi^0\pi^0$

M_X [GeV] arXiv:1304.4262

10% of η'η' →
π+π-γ & π+π-γ

200 pb⁻¹ →
~200 events/GeV
at M(η'η') ~ 7 GeV

(and ~0 $\pi^0\pi^0$!)

Exclusive γγ , ππ , ηη , η'η' at LHC (CMS & ...)   Mike Albrow

Example of exclusive γγ event in CDF

+ Gaps in forward detectors to $\eta = +/- 7.4$ ($y_{BEAM} = 7.65$) ~ no diff.diss.
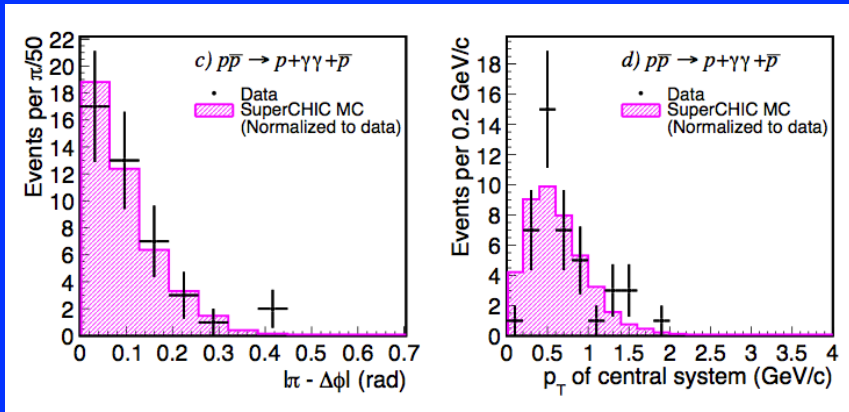
With 43 γγ candidates, had
34 e+e- events as QED expects:
important check.
Ratio γγ:ee decreases with M

Exclusive γγ , ππ , ηη , η'η' at LHC (CMS & ...)   Mike Albrow

Remarks (my opinions):

Although ~ 2 weeks of low pile-up running at 13 TeV will provide many good physics results in publications, just 3 or 4 high profile measurements should make the case.
One of these is certainly $\sigma(p + p \rightarrow p + \gamma\gamma + p)$ [& e+e- comes "for free"]
It must have a restrictive L1 trigger, vetoing most inelastic collisions.
HF veto (conservative), HE and
Forward Shower Counters (FSC in CMS)
Optimal is (Poisson) $\mu = 1.0$ ... if $\mu = 0.3$ or $\mu = 2.4$, $\varepsilon = 60\%$ ... not good
Optimise vetoing for $|\eta| > 3$ both sides. 37% of bunch crossings empty
Must require >= 2 EM showers as low as possible ... 2 or 3 GeV (TBD ... L1 rate)

Another may be (also comes "for free") : $\sigma(\eta'\eta' : \eta'\eta : \eta\eta : \pi^0\pi^0)$ for M >~ 5 GeV.

I.M.O.
We should make strongest case for 2 weeks of 13 TeV, 2800 bunches, $\mu = 1$ with optimised forward detectors (FSC etc) and priority triggers for a few QCD, exclusive and diffractive channels. $p + \gamma\gamma + p$ is clearly one.

Not γγ, but:

Another strongly motivated exclusive channel is p + JJ + p & p + JJJ + p
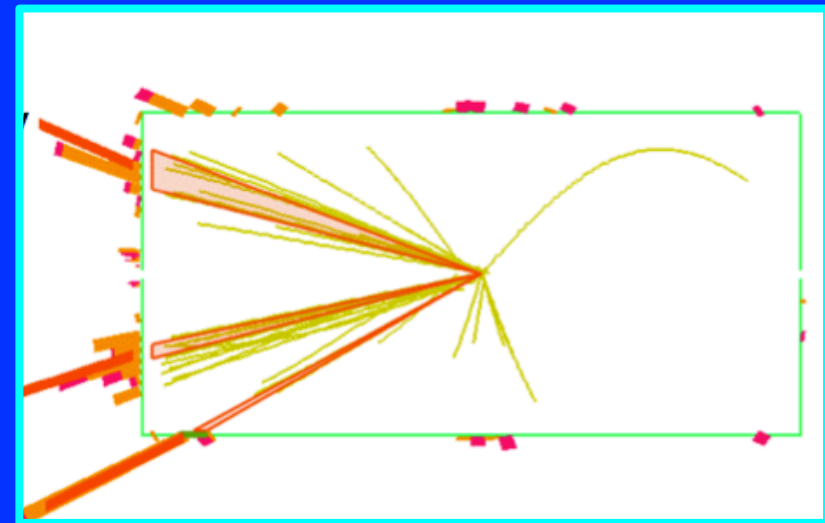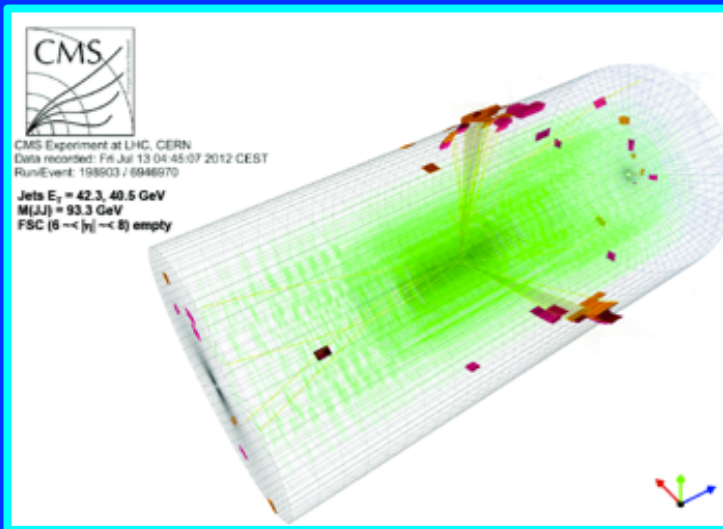at high M(JJ/JJJ) with flavour tagging (especially b's)

Ideally with two modes:
High-β with TOTEM RPs for M(X) < 200 GeV
Low-β with or without RPs for M(X) > 200 GeV.

Estimate numbers in 200 pb^{-1}

Never saw cleaner jet events at
a hadron collider!

3-jet events too!

g + g or (small fraction) b + bbar

ggg (~ Y) or qqg (u = d = s = c = b)