Exclusive $\gamma\gamma$ and χ_Q Production

Exclusive Higgs at LHC and theoretical uncertainties

Related processes: exclusive

$\chi_c \quad J/\psi$

$\chi_b \quad \Upsilon$

$\gamma\gamma$

$e^+e^-, \mu^+\mu^-$

Studies at Tevatron

Early studies at LHC

Exclusive WW ; missing masses

2-photon processes, uses at LHC

Central Exclusive Processes: Learning at Tevatron for LHC

pp → p   X   p with nothing else.

Eventual goal: X = H (if there), WW, ZZ (especially if H not there!)

FP420 is R&D project to do this with CMS and ATLAS.

.... Albert De Roeck will talk about this.

Calculating the cross section is difficult QCD and uncertain (2-3 ??)

CDF and D0 can measure related lower mass processes and help "calibrate" the theory, testing the QCD involved.

CDF cannot see the forward (anti-)protons, relying on "X + nothing else"
D0 can now see them (Forward Proton Detectors FPD), but not efficiently (t_min)

TOTEM can also do some of this low mass physics in low luminosity running.

Central Exclusive Production

gg fusion: dominant channel for inclusive H production.

Another g-exchange can cancel color, even leave p intact.

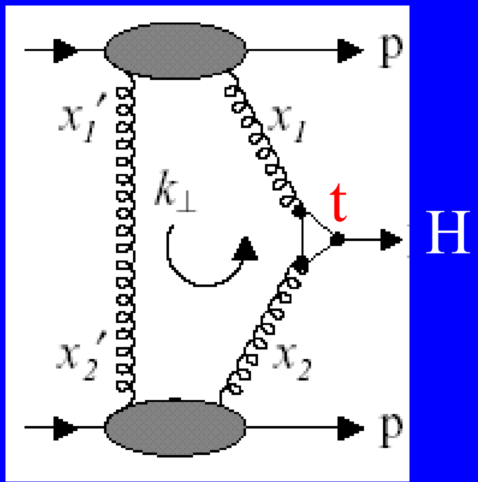
$$p\,p \rightarrow p \quad + \quad H \quad + \quad p$$

Theoretical uncertainties in cross section, involving skewed gluon distributions, gluon k_T, gluon radiation = Sudakov ff etc.

→Probably $\sigma(SMH)$ ~ 0.2 fb at Tevatron, not detectable, but should be possible at LHC (higher L and σ ~ 3 fb?)

STANDARD MODEL.

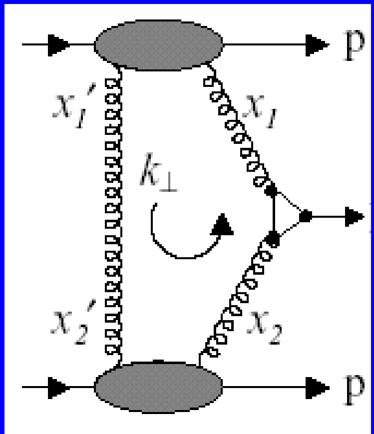
BSM can be LARGER



At Tevatron →

Theory can be tested, low x gluonic features of proton measured with exclusive $\gamma\gamma$, χ_c^0 and χ_b^0 production.

Central Exclusive Production



$pp \rightarrow pHp$ through t-loop

$pp \rightarrow p\chi_b p$ through b-loop

$pp \rightarrow p\chi_c p$ through c-loop

$pp \rightarrow p\gamma\gamma p$ through u-loop **mainly. +c etc**

→ Can be **inclusive** (soft central hadrons) but **exclusive** (nothing else) is most interesting. Precision measurement of both p → M(central) by Missing Mass. Resolution **~ 2 GeV** at LHC. $M^2_{cen} = (p_1 + p_2 - p_3 - p_4)^2 ... 4 - \text{vectors}$

→Can go for dominant H(110-130) b-bbar decay mode (trigger issue)

→Exclusive DPE → **q-qbar dijets background strongly suppressed** (Jz = 0 rule)

→For H(140+) WW and ZZ modes, using most final states (kinematic constraints)

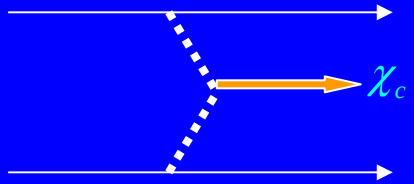
→ Selection Rule on **central Q.Nos:**

→ pp Correlations tell Q.Nos → **scalar** (need statistics!)

$$I^G J^{PC} = 0^+ 0^{++} \text{ dominant esp. as } t \rightarrow 0$$
$$I^G J^{PC} = 0^+ 2^{++} \text{ next}$$

→ Non-SM H interesting! BSM WW/ZZ interesting!

Exclusive χ_c search: $p\,\bar{p} \rightarrow p \quad \chi_c \quad \bar{p}$



Theoretical predictions:
Khoze, Martin, Ryskin: EPJ C19 (2001) 477
err: C20 (2001) 599
Khoze, Martin, Ryskin, Stirling: EPJ C35 (2004) 211
Feng Yuan, PL B510 (2001) 155
Adam Bzdak, hep-ph/0506101

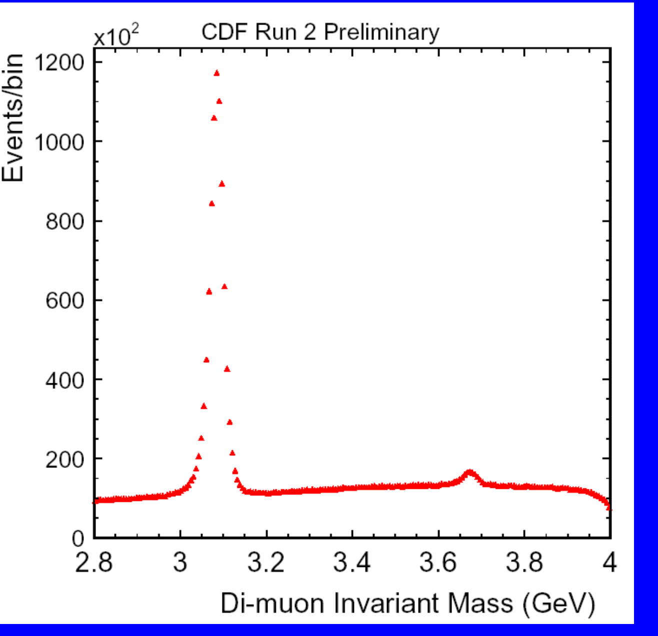
Predictions for Tevatron ~ 600 nb (~ 20 Hz!)

In reality: $BR(\chi_c^o \rightarrow J/\psi\,\gamma\ (1.2\%) \rightarrow \mu^+\mu^-\gamma\ (5.9\%))$

$\times$ no other interaction $\times$ acceptance(trig)

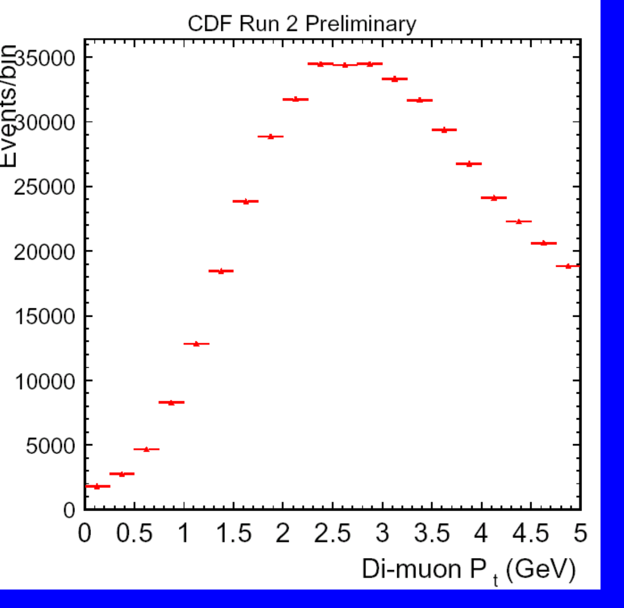
$\Rightarrow$ still 1000's in 1 fb^{-1}

Inclusive di-muon sample in
2.8 – 4.0 GeV mass region

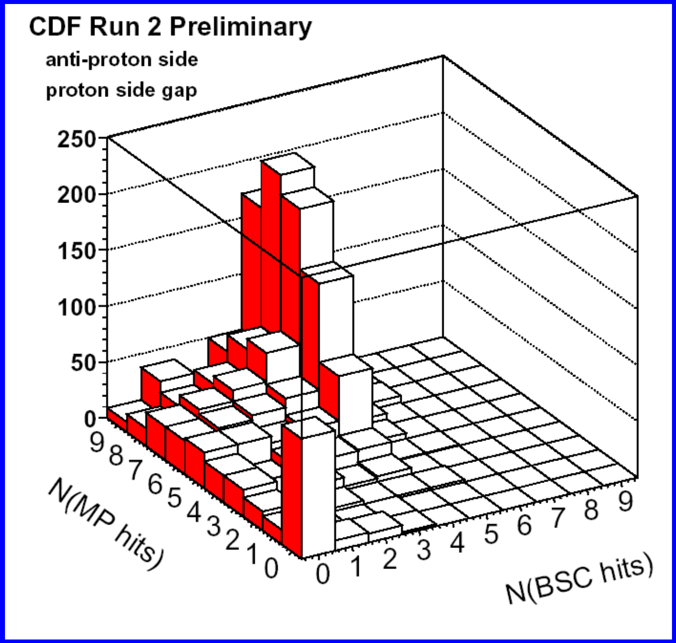


pT(di-muon) in this sample.

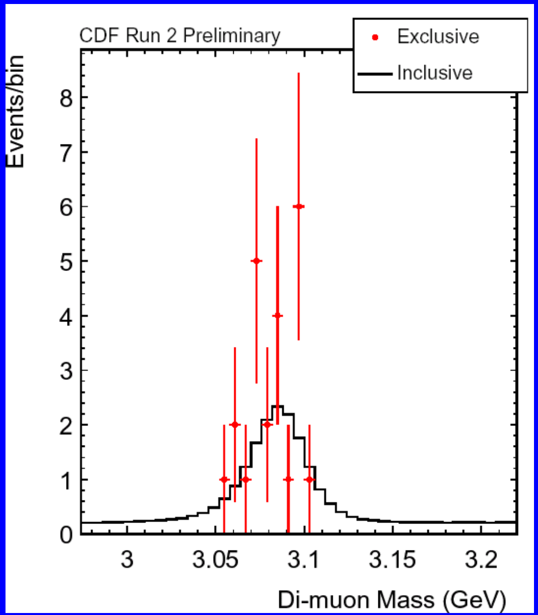
Exclusive events should have small pT (balanced by (photon) and forward diffractive protons

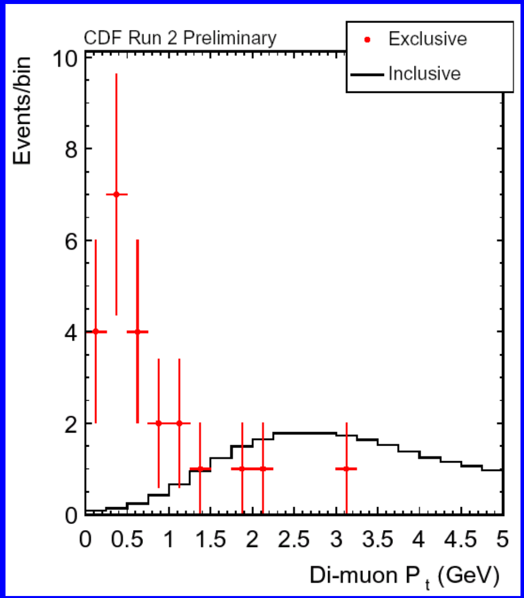


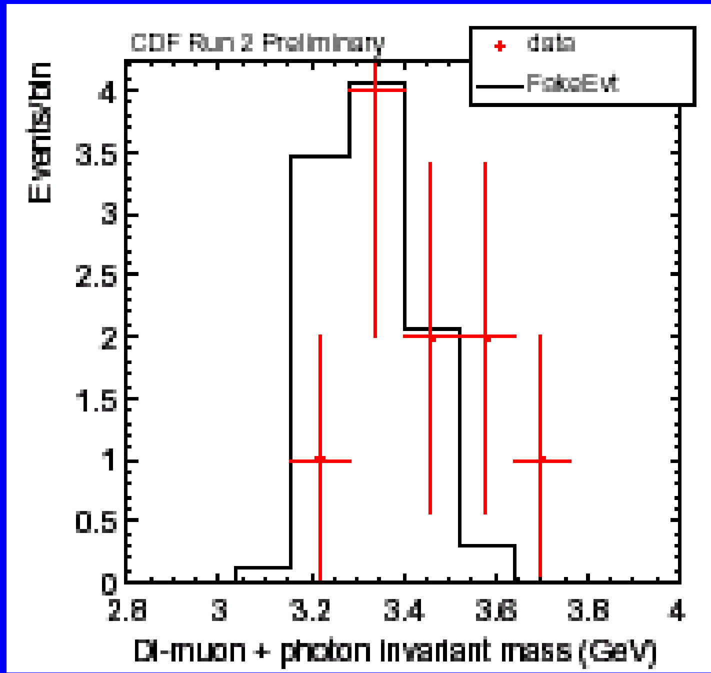
Require rapidity gap on p-side.
Look at activity on p-bar side.
See signal for 2-gap events.



Look for nothing in whole detector
except for mu-mu-(0,1 photon)
23 events = 13(0 photon) and 10(1)







$$\sigma(p\bar{p} \rightarrow p + J/\psi + \gamma + \bar{p}) = 49 \pm 18(stat) \pm 39(syst)\text{pb}, |y| < 0.6$$

Claimed as upper limit, consistent with theory

This was with generic 2-muon trigger, very small acceptance, no gaps required

Exclusive χ_c search: $p\,\bar{p} \rightarrow p \quad \chi_c \quad \bar{p}$ continued

Improved trigger: 1 muon + 1 track > 1.05 GeV + forward rap gaps.
Since June 2004 .... No blessed results yet (Angela Wyatt, post-doc, left)

However, qualitatively:
Many more (~ x 100) exclusive J/psi + (0,1 photon) candidates
Acceptance in pT(J/psi) different (pT <~ 500 MeV region)

Photon spectrum in $\chi_c \rightarrow J/\psi + \gamma$ events different $(Q \approx 320 MeV)$

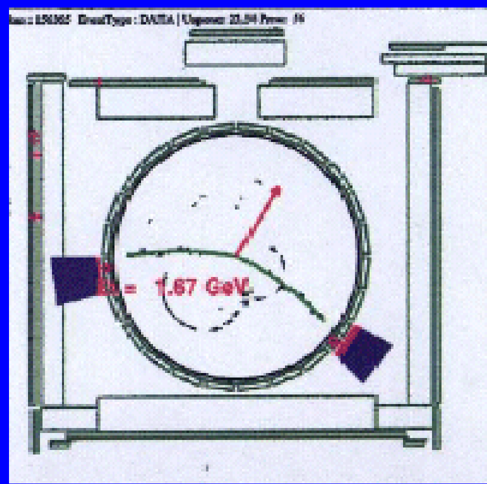
Ratio $\dfrac{J/\psi + 0\gamma}{J/\psi + 1\gamma}$ is significantly different

Efficiencies and backgrounds delicate

Thanks to higher statistics, $\gamma \rightarrow e^+e^-$ conversions detectable

Needs work to find low p_T electrons

$\Rightarrow$ Low efficiency but much better mass resolution, lower b/g



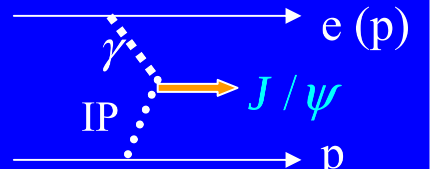
Both routes to be followed: showers and conversions

Real exclusive $J/\psi + \gamma$ expected to be all χ_c from "$IPIP$"

Mass resolution is not great (soft γ)

Real exclusive J/ψ cannot be from "$IPIP$" $(J^{PC} = 1^{--})$

Can be photoproduction as seen at HERA (ep)



Different p_T (J/ψ) spectrum

Would be new process in hadron-hadron collisions.

Numbers not crazy. Seeing pp would help a lot.

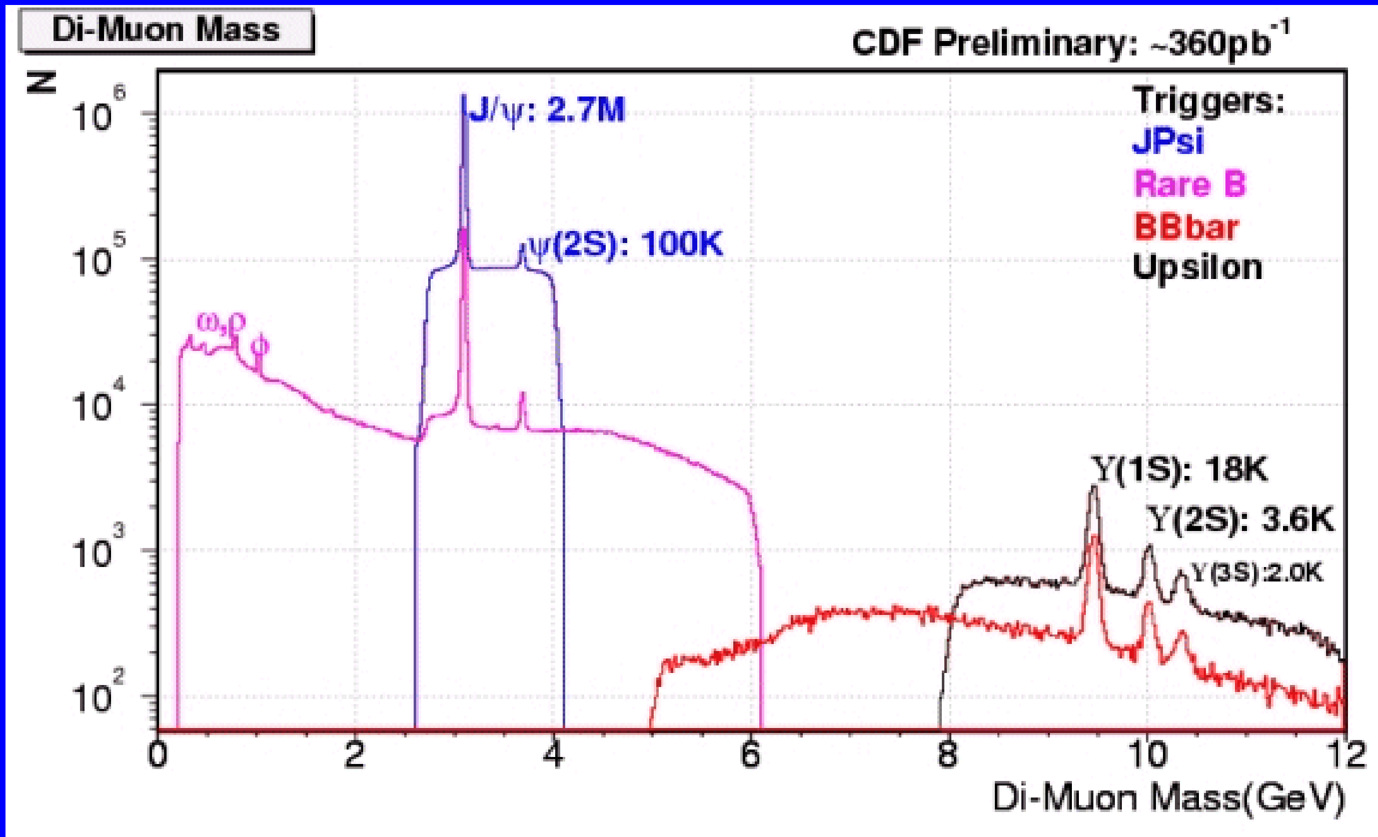
Interesting also at LHC, exclusive $\gamma IP \rightarrow \Upsilon \rightarrow e^+e^- / \mu^+\mu^-$ (CMS/TOTEM)

Future data inefficient (L high).
Now being analyzed (Alberta group)

Exclusive $p\bar{p} \rightarrow p\,\chi_b\,\bar{p}$

$\chi_b \rightarrow \Upsilon\gamma \rightarrow \mu^+\mu^-\gamma$ may be most promising channel

CDF has a beautiful dimuon mass spectrum. Now ~ 3 x this data.
(Different triggers cover different regions, cuts etc)



Exclusive $\chi_b \to \Upsilon\gamma \to e^+e^-\gamma$ would be possible with the right trigger, but we don't have it.

$$\boxed{\chi_b \to \Upsilon\gamma \to \mu^+\mu^-\gamma}$$

$$\frac{d\sigma}{dy}(pp \to p\chi_b p)_{exclusive} \approx 200 \text{ pb}$$

Khoze et al. EPJ C35 (2004) 211

(Increased from 110 pb: larger gluonic width (potential models)

$\text{BR}\{\chi_{b0}^{1P}(9860) \to \Upsilon^{1S}(9460)\} < 6\% \; (PDG)$

$\text{Probably} \approx 1\%$

$\text{BR}\{\Upsilon^{1S}(9460) \to \mu^+\mu^-\} = 0.025$

$\therefore \sigma.BR = 200 \text{ pb} \times 2 \times 0.01 \times 0.025 = 55 \text{ events}/fb^{-1} \times \text{acceptance}$

However (bad news) can only use single interactions.

There are other states which may also be visible:

$\chi_{b0}^{2P}(10232) \to \Upsilon^{2S}(10023) = (4.6 \pm 2.1)\%$

$\chi_{b2}^{1P}(9913) \to \Upsilon^{1S}(9460) = (22 \pm 4)\%$

Latter production suppressed because J=2
Don't know factor ... would be good QCD test to measure it!

In CDF we cannot measure the forward protons in these (low mass) exclusive processes.

We have to use total absence of any other activity (including VF detectors)

So we are not over-constrained and cannot measure $(t_1, t_2, \phi_1, \phi_2)$

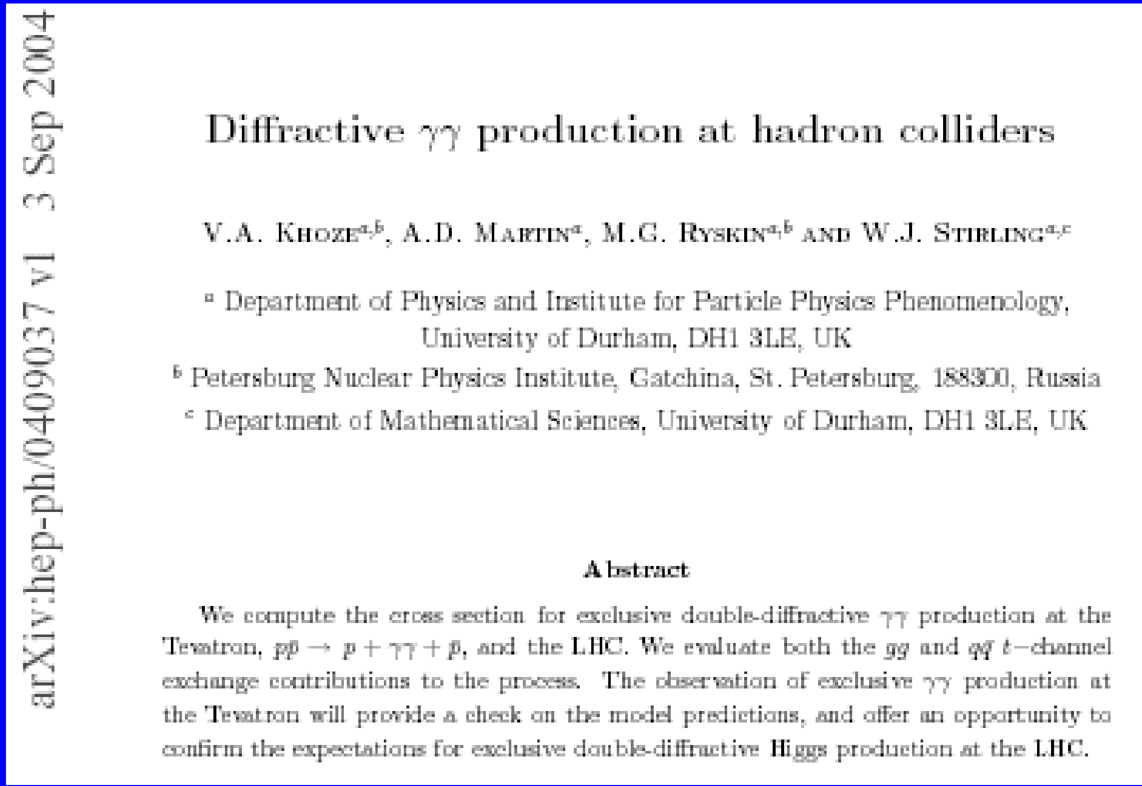
D0 now has Roman Pots both sides with tracking through quadrupoles, and can go down to these low masses with double tagging.

This could be powerful, as a constraint and can measure the central quantum numbers (e.g. J=0, 2) from azimuthal correlations.

However t(min) ~ 0.7 GeV2 which reduces rate. Possible??

TeV4LHC: We can learn from this whether $pp \rightarrow p\ \chi\ p$ is feasible at the LHC, e.g. in special TOTEM+CMS running.

Maybe best calibration of exclusive pHp calculations.



arXiv:hep-ph/0409037 v1 3 Sep 2004

Diffractive $\gamma\gamma$ production at hadron colliders

V.A. Khoze[a,b], A.D. Martin[a], M.G. Ryskin[a,b] and W.J. Stirling[a,c]

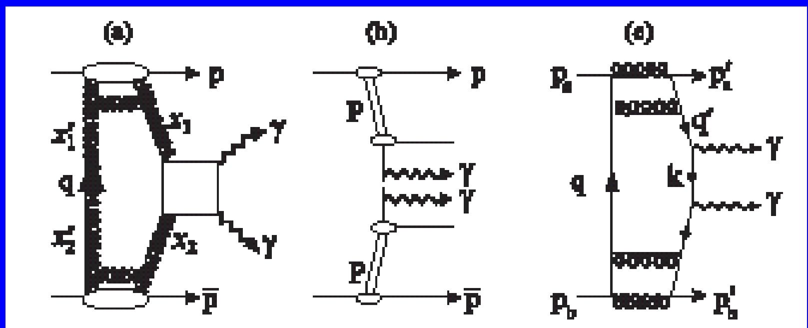
[a] Department of Physics and Institute for Particle Physics Phenomenology, University of Durham, DH1 3LE, UK

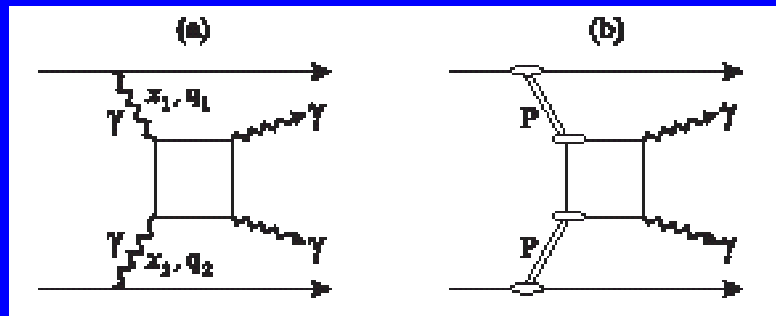
[b] Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg, 188300, Russia

[c] Department of Mathematical Sciences, University of Durham, DH1 3LE, UK

Abstract

We compute the cross section for exclusive double-diffractive $\gamma\gamma$ production at the Tevatron, $p\bar{p} \to p + \gamma\gamma + \bar{p}$, and the LHC. We evaluate both the gg and $q\bar{q}$ t-channel exchange contributions to the process. The observation of exclusive $\gamma\gamma$ production at the Tevatron will provide a check on the model predictions, and offer an opportunity to confirm the expectations for exclusive double-diffractive Higgs production at the LHC.





Not exclusive < 1%

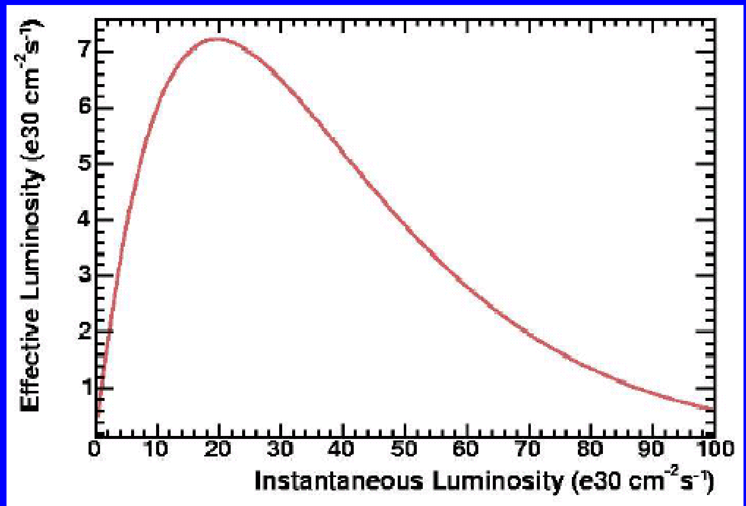
Large distance contributions small, < ~ %

This is a cleaner test of the exclusive Higgs production mechanism than “exclusive” di-jets, because it is well defined, with colorless produced state.

Advantage over exclusive chi_c because can go to higher masses, ~ 10-20 GeV, more perturbative.

Installed trigger, 2 EM showers > 4 GeV + 2 Forward gaps
Will have n00,000 triggers in “effective luminosity” ~ 100 pb^-1

Rap gap physics most efficient when <n> = 1, now unusual, becoming “impossible”



ANDREW HAMILTON

Only prediction of this process:

100 fb

KMRS hep-ph/0409037

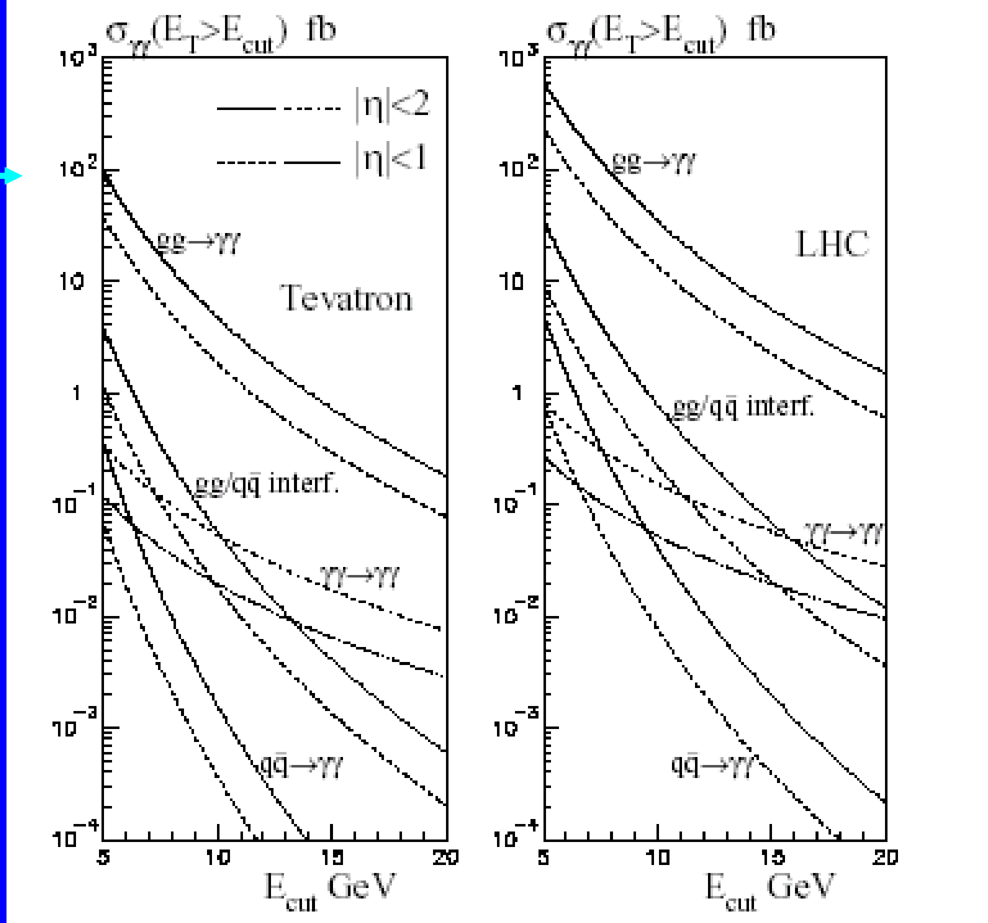


Figure 6: The contributions to the cross section for exclusive $\gamma\gamma$ production from gg and $q\bar{q}$ exchange at the Tevatron and the LHC. Also shown is the contribution from the QED subprocess $\gamma\gamma\to\gamma\gamma$. For each component we show the cross section restricting the emitted photons to have $E_T > E_{cut}$ and to lie in the centre-of-mass rapidity interval $|\eta_\gamma| < 1$ (or $|\eta_\gamma| < 2$).

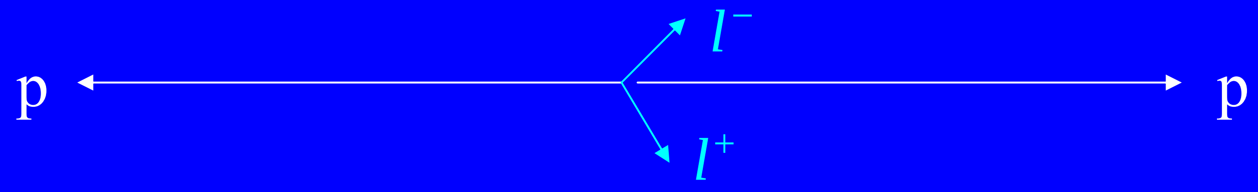
ExHume = matrix element generator for exclusive "DPE".

Needs to be interfaced with CDF Simulation.

Detailed studies of detector noise levels imperative.

Andrew Hamilton's thesis.
Selects events with 2 em showers and nothing else visible in CDF.

Central Exclusive Production of Lepton Pairs



Two photon process: cross section very well known

l^+ and l^- have $\Delta\phi = \pi$ and $p_T(l^+) = p_T(l^-)$

Exclusive $p\bar{p} \rightarrow p\gamma\gamma\bar{p}$ trigger in CDF should contain these

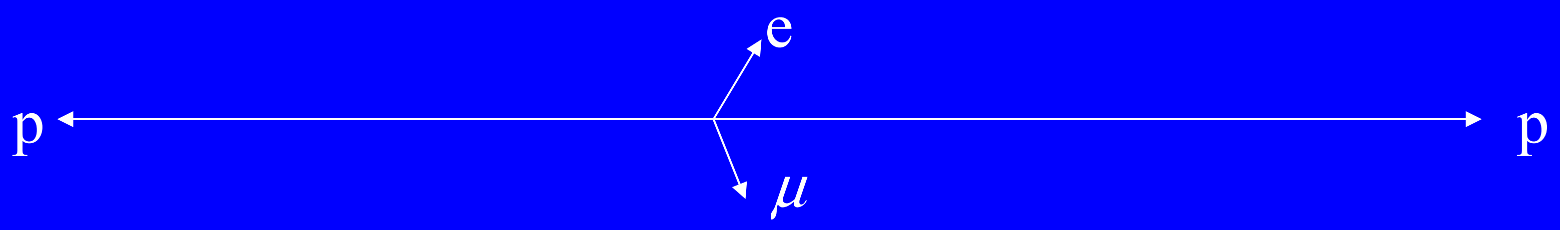
We are looking, both in **2 x EM(4 GeV) + 2 Fwd Gaps**
(no pile-up, superclean) ... high mass **>~ 10 GeV**
and in **(muon + track) + 2 Fwd Gaps** ... **M ~ 3 – 4 GeV**
Unfortunately high mass di-muon trigger excludes $\Delta\phi = 180^0$
... could look in presence of pile-up. At LHC: no need for single interaction

1) Measuring central leptons well → proton momenta
→calibrates forward proton spectrometers! ****
2) Rate calibrates luminosity monitors **

Two-photon process also important at LHC in WW regime

$$\sigma(pp \rightarrow pW^{+}W^{-}p) \approx 100\text{fb by } 2\gamma \text{ exchange}$$

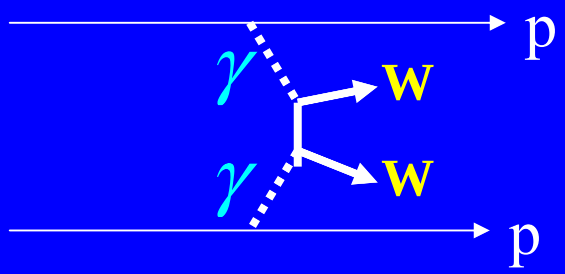
Guaranteed channel for FP420
WW final state interaction probe above LEP2 reach
Continuum background to H → WW search
Might be surprise in cross-section (BSM, e.g. White pomeron)



$$\boxed{\begin{array}{l} \mathrm{H}(160) \rightarrow \mathrm{W}^{+}\mathrm{W}^{-} \rightarrow \mathrm{p}\ \ \mathrm{e}^{+}\mu^{-} \notin_{T}\ \ \mathrm{p} \\ \mathrm{MM}^{2} = (p_1 + p_2 - p_3 - p_4)^{2} = \mathrm{M}_{\mathrm{H}}^{2} \end{array}}$$

Nothing else on emu vertex!

Exclusive WW at LHC



$\sigma \approx 100$ fb

$BR \rightarrow ee, e\mu, \mu\mu = 4.6\%$

Exclusiveness brings rewards. E.g lepton + jets mode (43%)

$MM(pp) = M(WW)\,[MM^2(pp) = \{p_1 + p_2 - p_3 - p_4\}^2]$

$M(JJ) = M(W)$

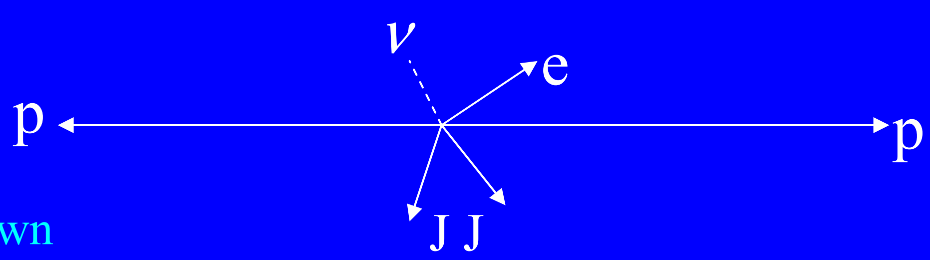
$MM(ppJJ) = M(W)$

$MM(ppJJl) = M(\nu) = 0$

$p_4(\nu) = (1+2-3-4-J-J-l)_4 \Rightarrow \nu$ known

$\Sigma \vec{p}_T(JJl\nu) \approx 0$ (p's have small, known, p_T)

$\Sigma p_L(ppJJl\nu) = 0$



$$\xi(p_{3(4)}) = \frac{1}{\sqrt{s}}\left[\sum_{i=1,4} E_{Ti} e^{-(+)\eta_i}\right]$$

Even 4-jet mode?

Hopeless in inclusive WW production

Conclusions

$\chi_c \quad J/\psi$

$\chi_b \quad \Upsilon$

$\gamma\gamma$

$e^+e^-, \mu^+\mu^-$

Searches for central exclusive (ultra-peripheral)

are all being done in CDF $(IPIP\ , IP\gamma, \gamma\gamma)$

unfortunately without p (pbar) detection.

D0 has some potential ...

but beyond 2005 luminosity will be usually too high for n = 1

→ all are important for LHC Exclusive program:

CMS/TOTEM → FP420: Higgs, WW/ZZ, BSM