Exclusive Diffraction: Tevatron ➔ LHC

ECT* Workshop on Photoproduction :: Trento, Italy

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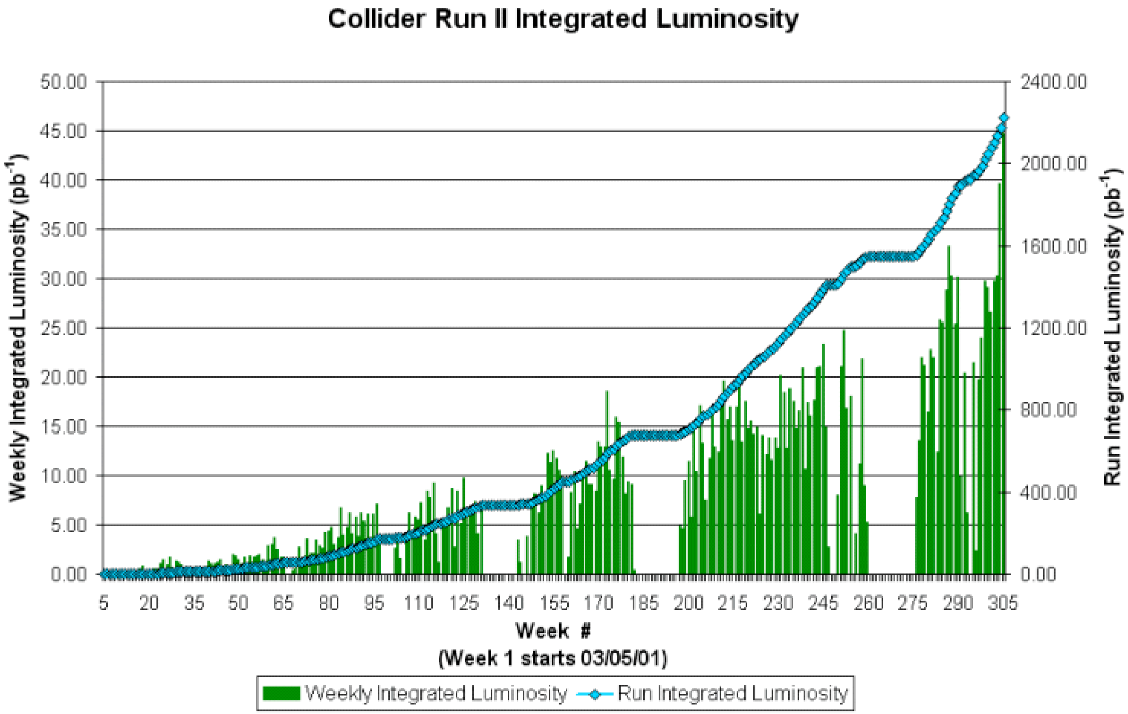
Tevatron :: Introduction

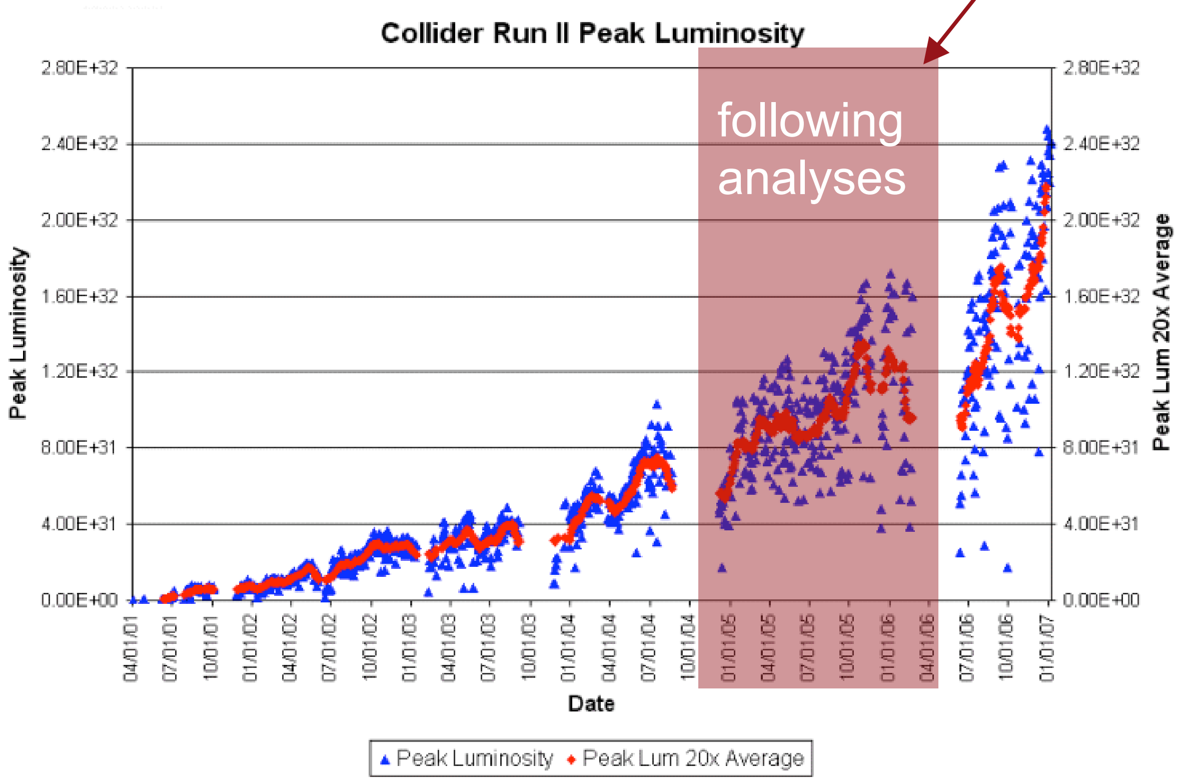
- $p\bar{p}$ collider
- $\sqrt{s} = 1.96$ TeV
- ~2.2 fb^{-1} delivered



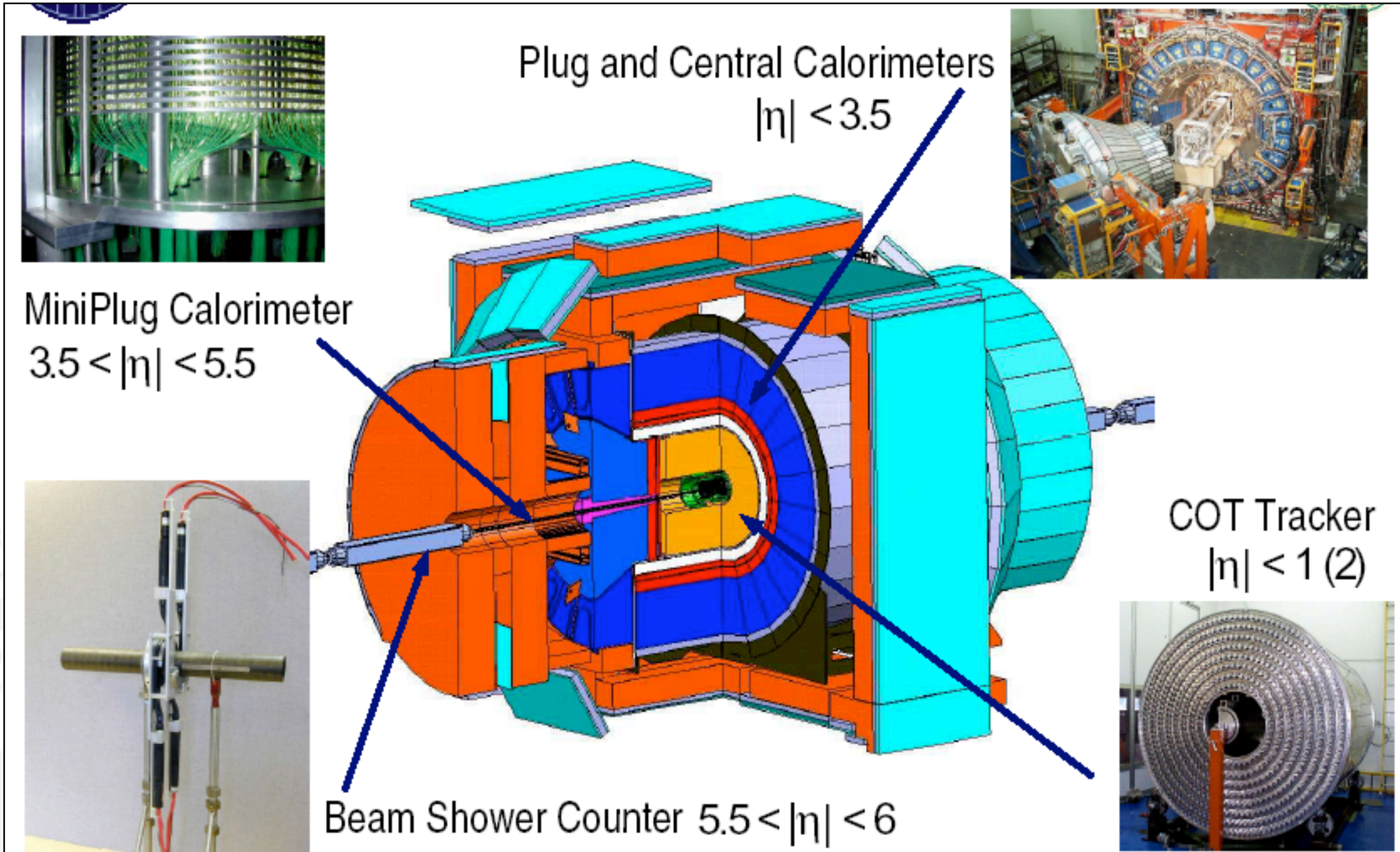
Tevatron :: Performance

- Tevatron performing very well
- Record breaking $\mathcal{L}_{inst}$

~ 1 - 6 interactions per beam crossing



CDF :: Introduction

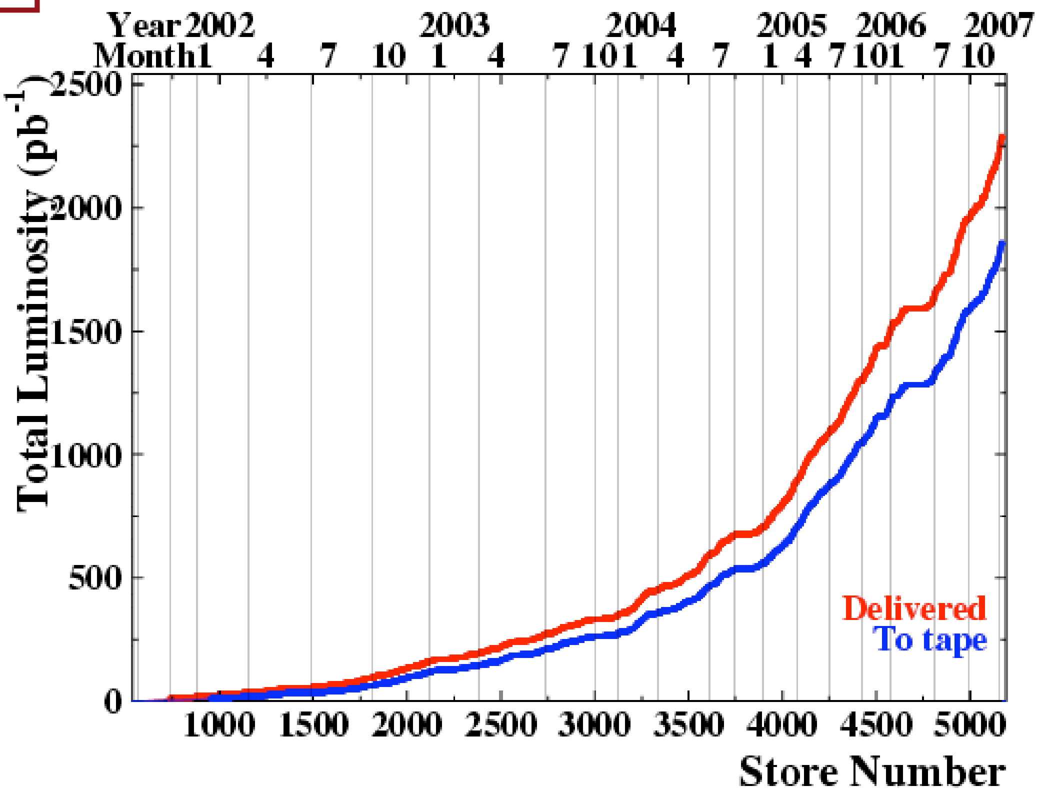


CDF :: Performance

Recently made the World's best W mass measurement:

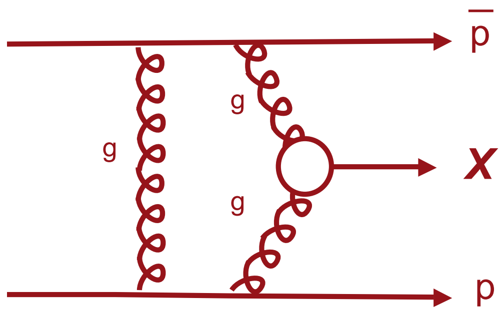
$M_W = 80,413 \pm 48$ MeV/c^2

- Well understood and
- performing very well
- almost 2 fb^{-1} written to tape



Motivation :: Introduction

Exclusive Diffraction:



where ***X*** has $J^{PC} = 0^{++}$

Two significant advantages over inclusive case:

- mass of ***X*** can be determined from outgoing protons
- 'measures' the quantum numbers of ***X***

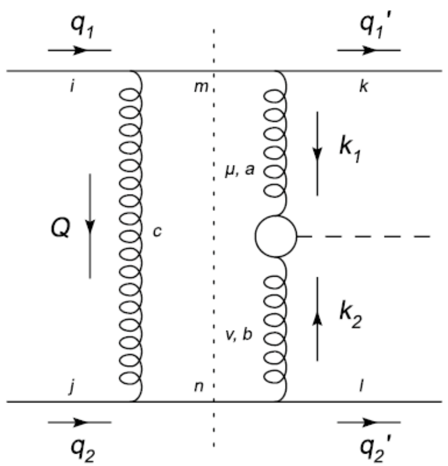
Models Include:

- "*Durham*" model, implemented in ExHume MC
- "*Saclay*" model, implemented in DPEMC

Motivation :: Durham Model

V.A. Khoze, A.D. Martin and M.G. Ryskin, Phys. Lett. B401, 330 (1997). hep-ph/9701419
V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. C14, 525 (2000). hep-ph/0002072
V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. C23, 311 (2002). hep-ph/0111078

Start at parton level:



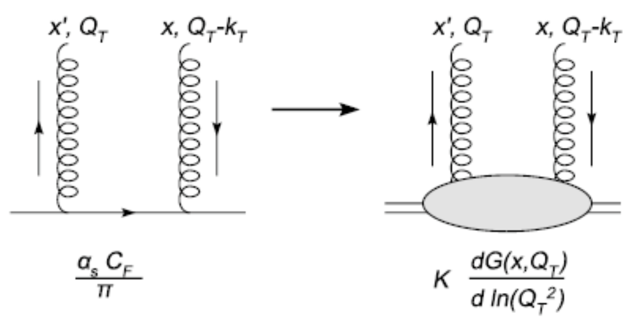
$$\frac{d\sigma}{d^2\mathbf{q_{1T}}'d^2\mathbf{q_{2T}}'dy} \approx \left(\frac{N_c^2-1}{N_c^2}\right)^2 \frac{\alpha_s^6}{(2\pi)^5}\frac{G_F}{\sqrt{2}}\left[\int \frac{d^2\mathbf{Q_T}}{2\pi}\frac{\mathbf{k_{1T}}\cdot\mathbf{k_{2T}}}{\mathbf{Q_T}^2\mathbf{k_{1T}}^2\mathbf{k_{2T}}^2}\frac{2}{3}\right]^2$$

$$q_1^\mu V^{ab}_{\mu\nu} q_2^\nu \approx \frac{k_{1T}^\mu}{x_1}\frac{k_{2T}^\nu}{x_2}V^{ab}_{\mu\nu} \approx \frac{s}{m_H^2}k_{1T}^\mu k_{2T}^\nu V^{ab}_{\mu\nu} \quad \begin{cases} Q_T \approx -k_{1T} \approx k_{2T} \\ \epsilon_i \sim k_{iT}. \end{cases}$$

$$k_i = x_i q_i + k_{iT}$$

colliding gluons must have equal helicity ➔ ***J^{PC} = 0^{++} central state***

Replace quarks with protons:

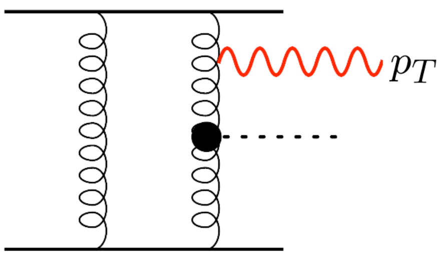


$$K \approx e^{-bk_T^2/2}\frac{2^{2\lambda+3}}{\sqrt{\pi}}\frac{\Gamma(\lambda+5/2)}{\Gamma(\lambda+4)}$$

Off-diagonal gluon correction, K, estimated from HERA J/ψ data giving *b = 4 GeV^{-2}.*

Motivation :: Durham Model

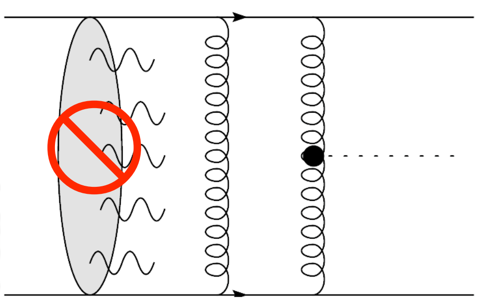
Require fusing gluons not radiate (*Sudakov suppression*):



$$\int \frac{dQ_T^2}{Q_T^4} f(x_1, Q_T) f(x_2, Q_T)\, e^{-S}$$

$$e^{-S} = \exp\left(-\frac{C_A \alpha_s}{\pi} \int_{Q_T^2}^{m_H^2/4} \frac{dp_T^2}{p_T^2} \int_{p_T}^{m_H/2} \frac{dE}{E}\right)$$

Require no other soft interaction between protons (*gap survival*):



$$d\sigma(p+H+p|\text{no soft emission}) = d\sigma(p+H+p) \times S^2$$

S^2 is difficult to estimate. Assume it's Poissonian and extract $\chi(r)$ from elastic scatter and total cross section data

$$S^2 = \frac{\int dr\ \ d\sigma(r)\ \ \exp(-\chi(r))}{\int dr\ \ d\sigma(r)}$$

➔ $S^2 \sim 0.1$ at Tevatron
0.03 at LHC

Durham Model is implemented in ExHume MC.

Motivation :: Saclay Model

M. Boonekamp, R. Peschanski and C. Royon, Nucl. Phys. B669, 277 (2003). Erratum-ibid. B676, 493 (2004). E-Print archive: hep-ph/0301244.

Start with the same quark level calculation as Durham:

$$\frac{d\sigma}{d^2\mathbf{q_{1T}}'d^2\mathbf{q_{2T}}'dy} \approx \left(\frac{N_c^2-1}{N_c^2}\right)^2 \frac{\alpha_s^6}{(2\pi)^5}\frac{G_F}{\sqrt{2}}\left[\int \frac{d^2\mathbf{Q_T}}{2\pi}\frac{\mathbf{k_{1T}}\cdot\mathbf{k_{2T}}}{\mathbf{Q_T}^2\mathbf{k_{1T}}^2\mathbf{k_{2T}}^2}\frac{2}{3}\right]^2$$

Change quark coupling to proton using Bialas-Landshoff approach:

A. Bialas and P.V. Landshoff, Phys. Lett. B256, 540 (1991).

- multiply by a factor 9 for three quarks in proton
- multiply by suppression factor $\exp(-bq_{iT}'^2)$ with b = 4 GeV^{-2}

Do 'Sudakov suppression' using Landshoff-Nachtmann approach:

P.V. Landshoff and O. Nachtmann, Z. Phys. C35, 405 (1987).

- Replace perturbative gluon with non-perbative gluon: $\frac{g^2}{k^2} \rightarrow A\exp(-k^2/\mu^2).$
- A and μ are determined from *pp* eleastic scattering data with a 'Reggeization' factor $s^{\alpha(t)-1}$

  where: $\alpha(t) = 1+\epsilon+\alpha'\,t$ and the fit to data leads to: $\alpha' = 0.25\ \mathrm{GeV}^{-2}$. $\epsilon = 0.08$

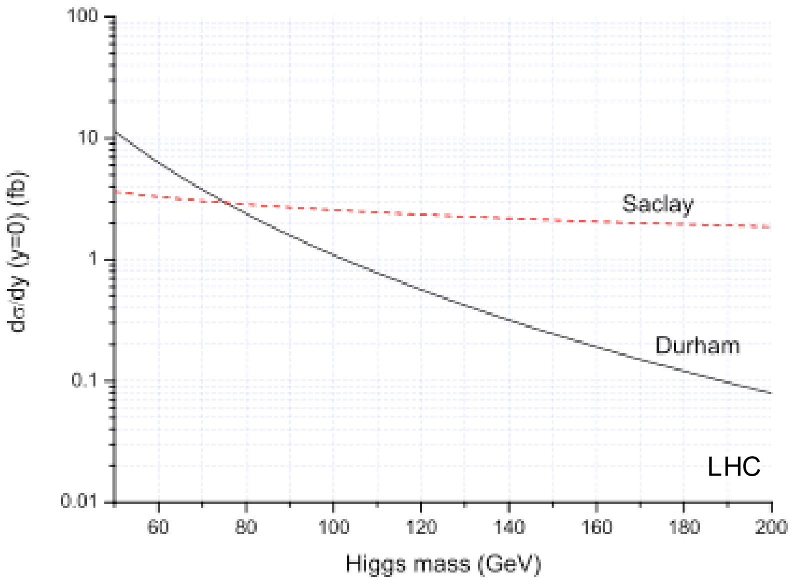
  gives: $A \approx 30\,\mathrm{GeV}^{-2}$ $\mu \approx 1\,\mathrm{GeV}$

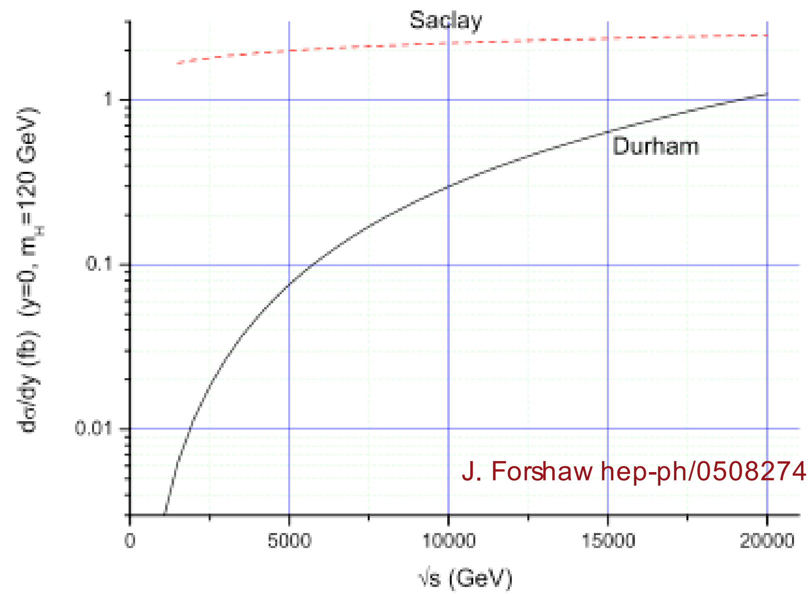
Require same *gap survival* factor as Durham.

Saclay Model is implemented in the DPEMC Monte Carlo.

Motivation :: Model Comparison

Saclay predicts higher cross sections than Durham:

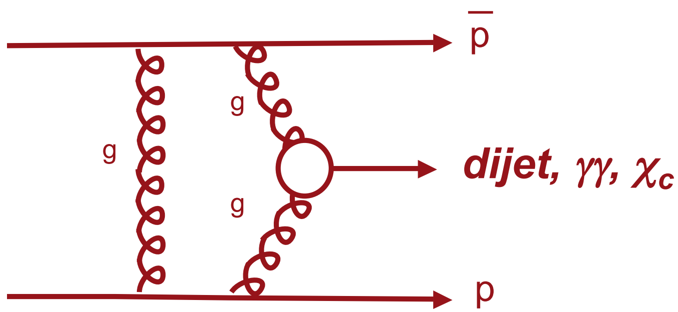




Need some *pp* collider data to check models!

Motivation :: What to do at CDF

Exclusive Diffraction at CDF:



Exclusive channels we are looking at include:

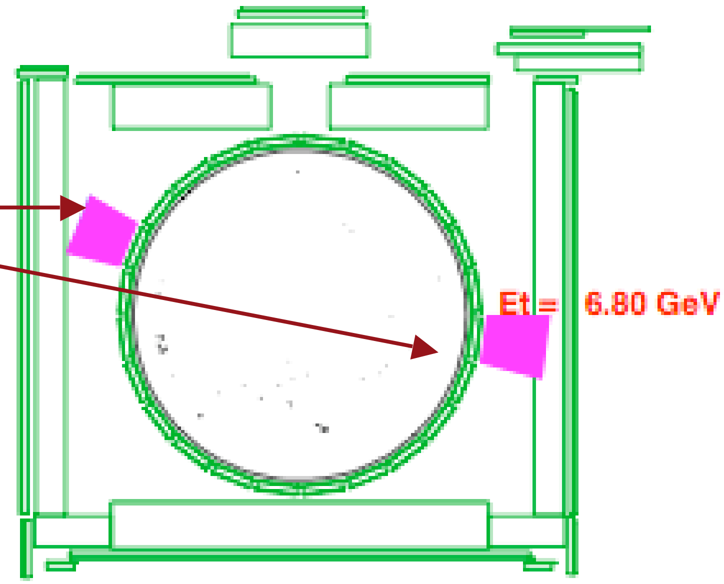
- $\gamma\gamma$ - very 'clean' signature, but low cross section
- ***Dijet*** - high cross section, but definition of exclusive is subtle
- χ_c - high cross section, but soft photon difficult to measure

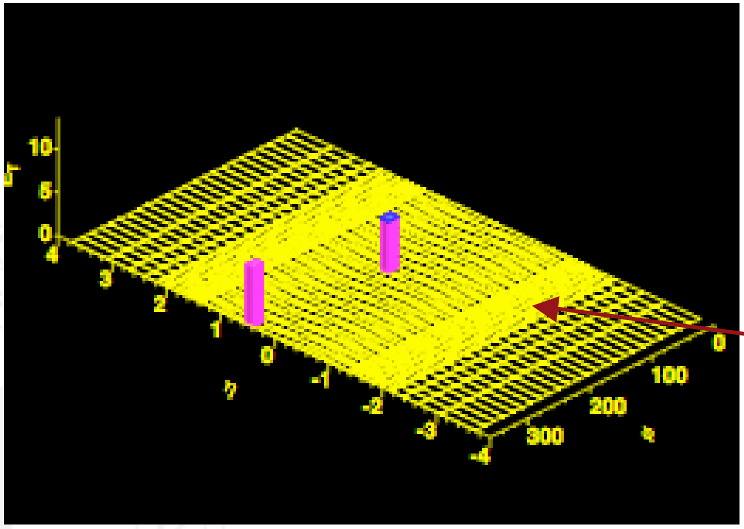
Exclusive $\gamma\gamma$ :: Introduction

Events selected with:

(same trigger as e^+e^-)

$\gamma\gamma$ pair: $E_T > 5$ GeV/c, $|\eta|<1.0$





No other calorimeter activity: $|\eta|<7.4$

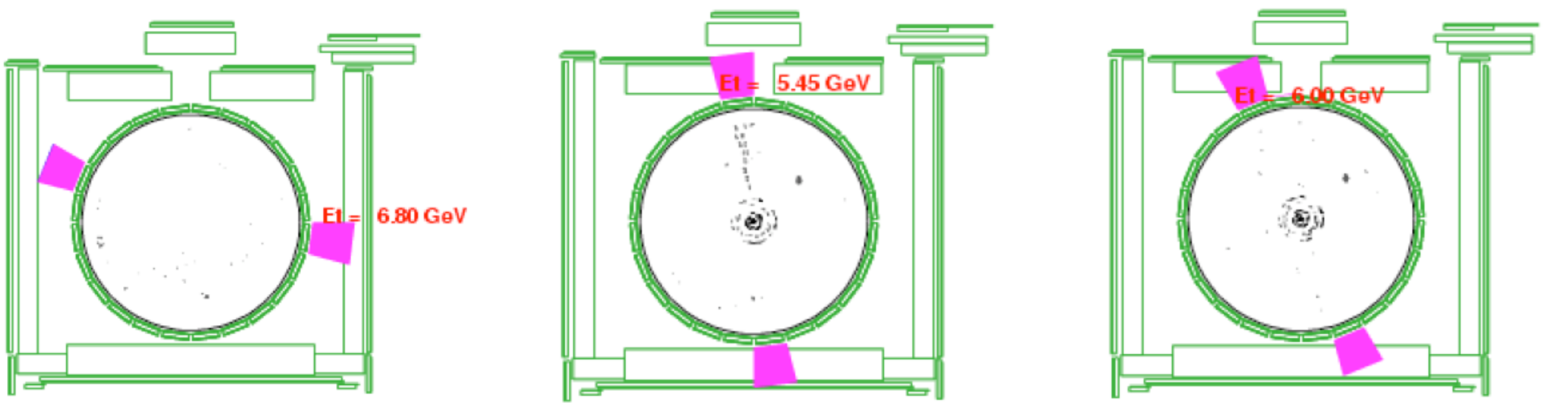
(this eliminates "pile-up" events!)

pile-up ≡ bunch crossing with more than one pp interaction

Exclusive $\gamma\gamma$ :: Candidate Sample

3 candidate events are found.

- selected in the same way as $\gamma\gamma \rightarrow e^+e^-$ (except tracks)
- agreement of $\gamma\gamma \rightarrow e^+e^-$ cross section gives confidence in analysis methodology
- 1^{+3}_{-1} events predicted from ExHuME MC
- No predictions from DPEMC are available
- Background estimate not yet complete ($\pi^o\pi^o$)
- Result expected soon…



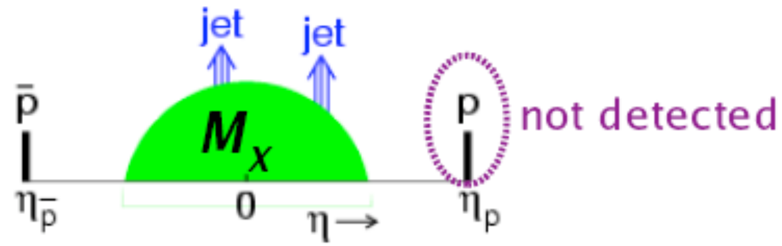
Exclusive Dijets :: Introduction

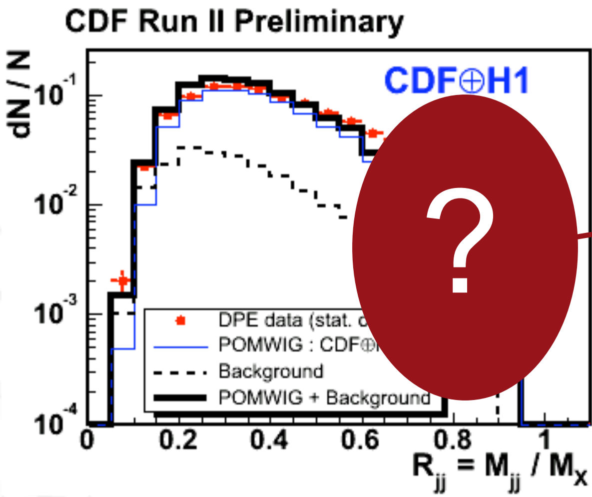
DPE = Double Pomeron Exchange

Event selection:

- DPE dijets: $\bar{p} + p \rightarrow \bar{p} + X$ *(≥2jets+…) + gap*
- examine the *dijet mass fraction* R_{jj}

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





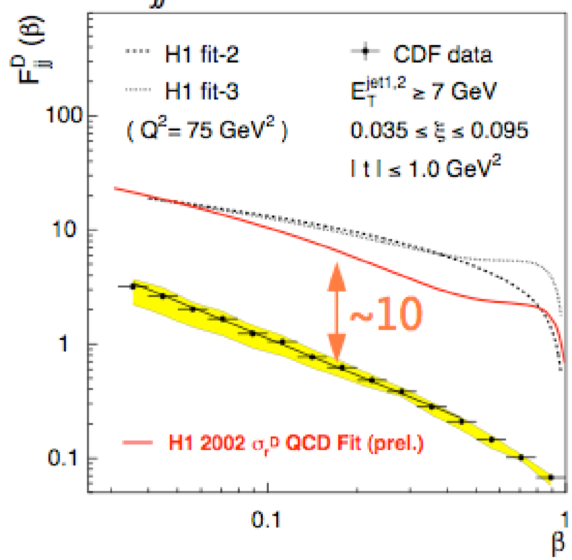
Excess at high R_{jj} compared to *inclusive DPE* dijets is expected if there is an exclusive component

Exclusive Dijets :: POMWIG MC

POMWIG with CDF⊕H1 structure functions is used to simulate *inclusive Double Pomeron Exchange* dijets

(Cox and Forshaw, CPC 144 (2002), 104)

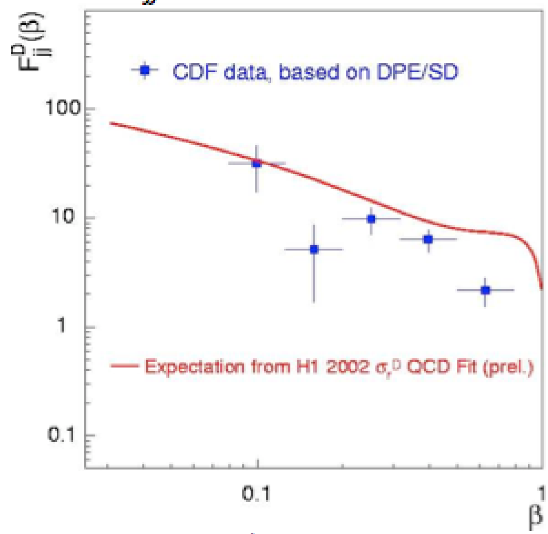
F_{jj}^{D} from SD Dijets



$$F_{jj}^{D}(\beta, \xi) = C \cdot \beta^{-n} \cdot \xi^{-m}$$

$$n = 1.0 \pm 0.1$$

F_{jj}^{D} from DPE Dijets



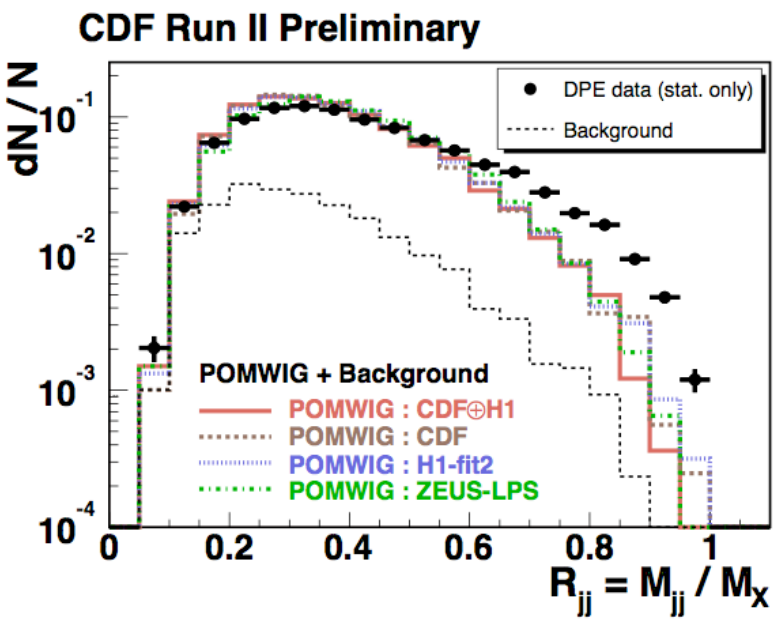
Formation of 2nd gap less suppressed

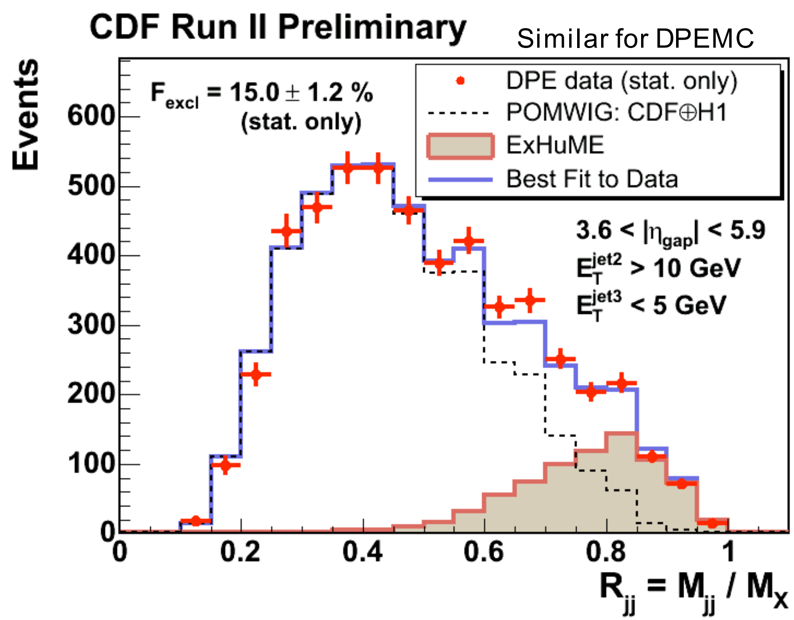
DPE: $IP_1 + IP_2 \rightarrow X$

	IP_1	IP_2
CDF	β^{-1}	β^{-1}
CDF⊕H1	β^{-1}	H1-fit2

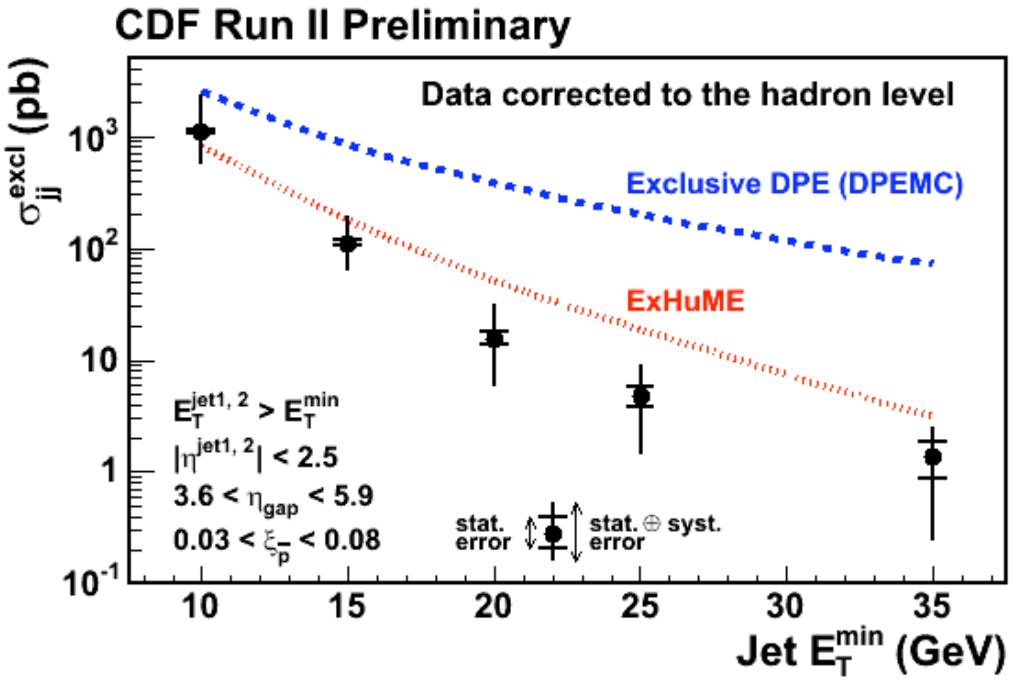
Exclusive Dijets :: High R_{jj} Excess

An excess at $R_{jj}>0.6$ in data compared to POMWIG



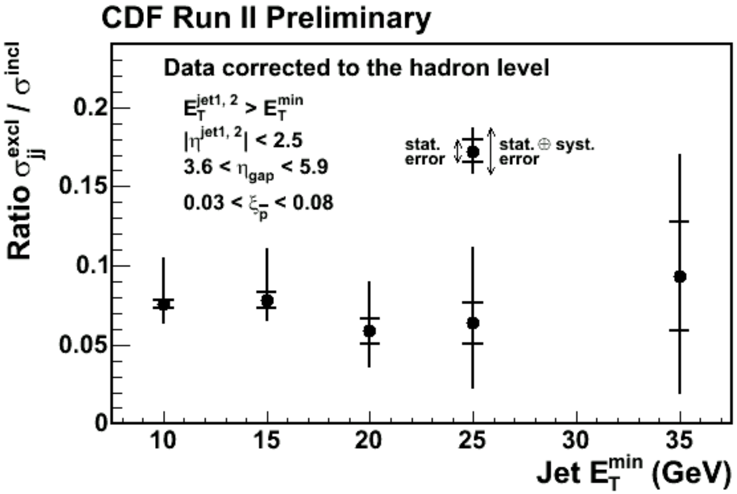


Exclusive Dijets :: Cross Section



The data favors ExHuME MC

Ratio of exclusive to inclusive DPE cross sections is flat.

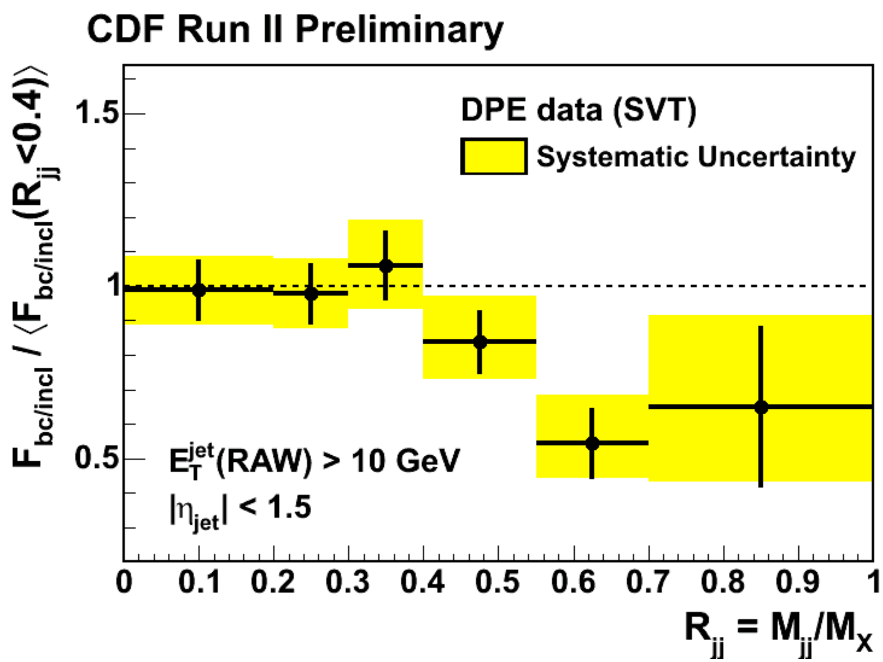


Exclusive Dijets :: $J^{PC}=0^{++}$

Can we see the $J^{PC}=0^{++}$ selection?

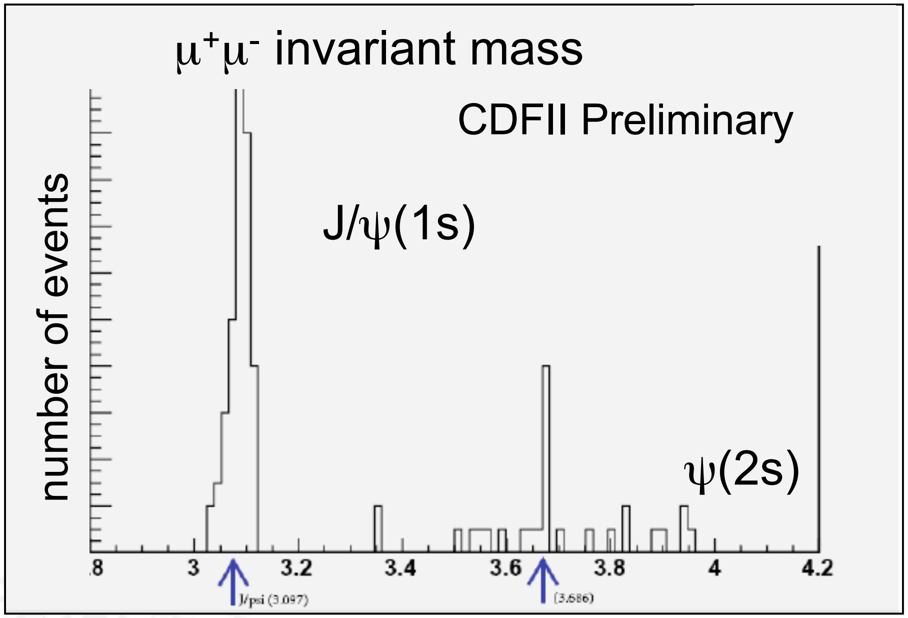
- 'dijets' are either *qq* or *gg*
- exclusive *gg* → *qq* is suppressed by $J^{PC}=0^{++}$ selection
- exploit this by looking at ***fraction of heavy flavor (b/c) jets*** in dijet data as a function of R_{jj}

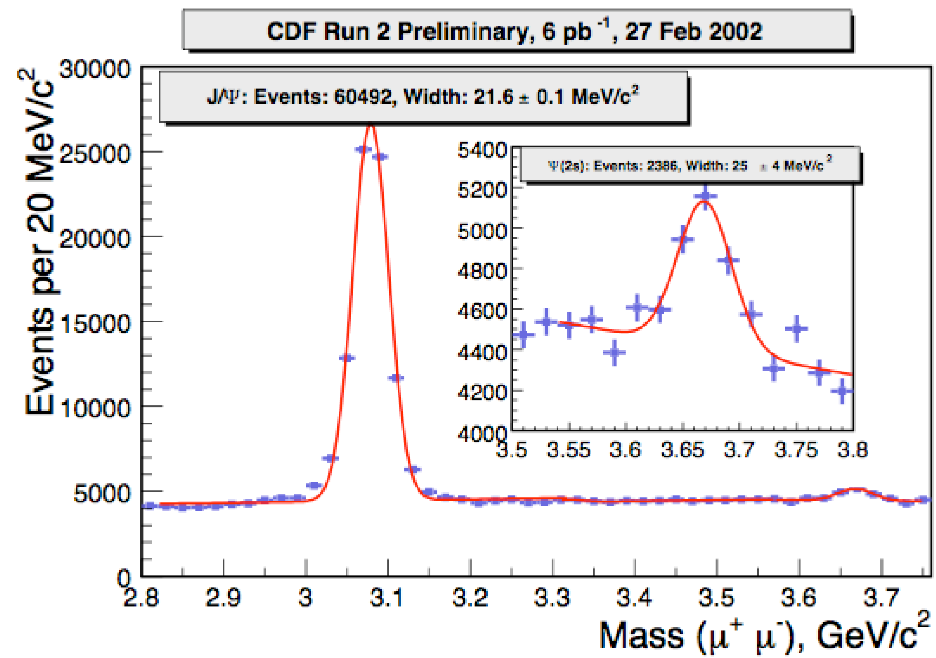
b/c jets are suppressed at high R_{jj} → shows $J^{PC}=0^{++}$ *selection*

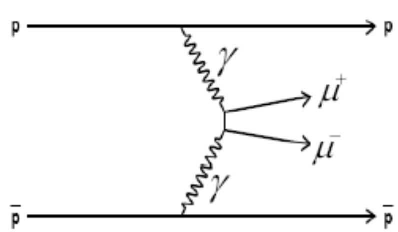


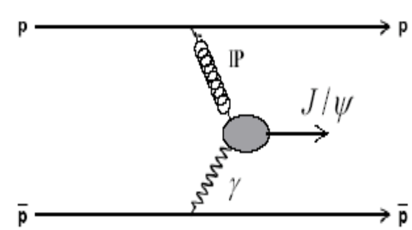
Exclusive χ_c :: Introduction

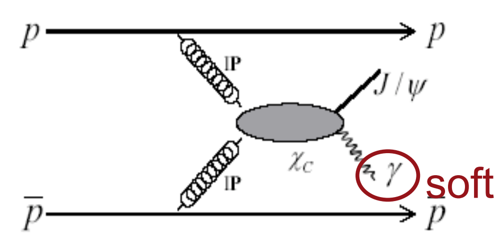
How many of the exclusive $\mu^+ \mu^-$ pairs are actually χ_c?





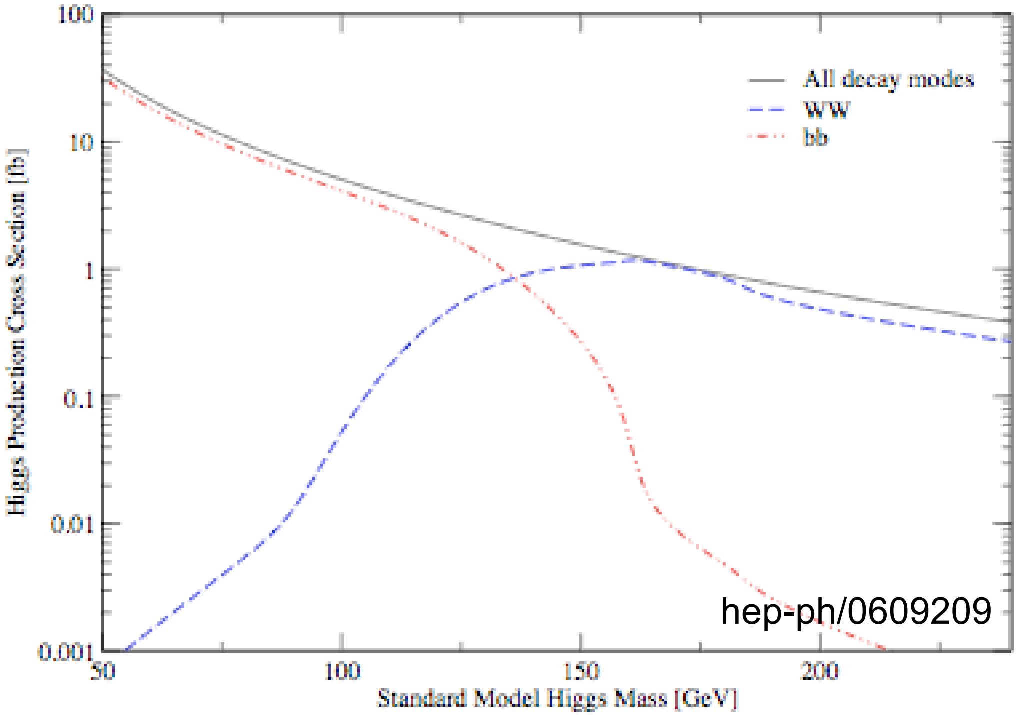






LHC :: Exclusive Higgs

SM Higgs has $J^{PC}=0^{++}$ ➞ it should be produced exclusively.



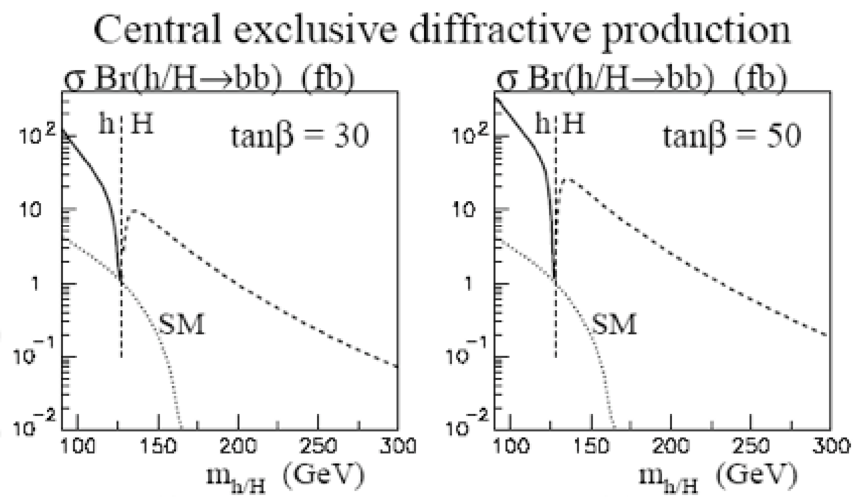
Advantages:

- QCD-b background is suppressed (by $J^{PC}=0^{++}$)
- another handle on the mass (from proton tagging)
- measurement of Higgs quantum numbers
- S:B ~

$\gamma\gamma$ production are the primary backgrounds

LHC :: Exclusive BSM

MSSM Intense Coupling Region:



- three Higgses similar masses, large tan β
- coupling to b-bar enhanced
- very challenging via conventional modes
- …. big exclusive cross-section!
- S:B from ~2 to ~75!

Stable gluinos:

- Stable gluinos, (e.g. as in split SUSY)
- May bind into gluinonium or decay into distinctive final state (R-hadrons).
- R-hadrons look like slow muons
- Can reconstruct mass of R-hadrons event-by-event with the outgoing proton information

Gluino mass (GeV)	No. of events (300/fb)	Error on mass (GeV)
200	145	0.2
250	35	1.1
300	10	1.5
350	4	2.5

Conclusions

- CDF has demonstrated that exclusive diffraction can be predicted by the Durham model in ~TeV collisions
- If suitable forward proton taggers are installed at LHC (*www.fp420.com*), the physics reach of both ATLAS and CMS can be considerably extended.