Double Pomeron Physics at the LHC

Introduction – some history, ISR discovery

DPE at SppS and Tevatron: Jets, $\chi_{c,b}$, $\gamma\gamma$?

pp → p H p @ Tev (no) @ LHC (maybe)

p X p at LHC : Jets, exotics, WW/ZZ, $t\bar{t}$

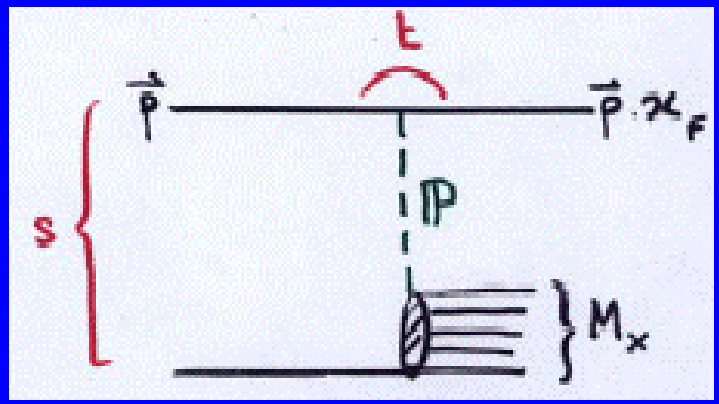
White Pomeron?

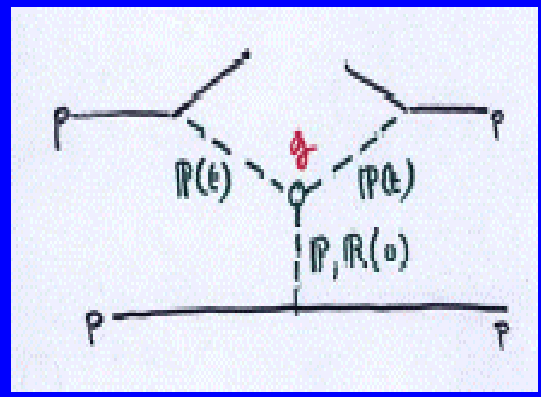
FP420 (Forward Protons at 420m) at the LHC

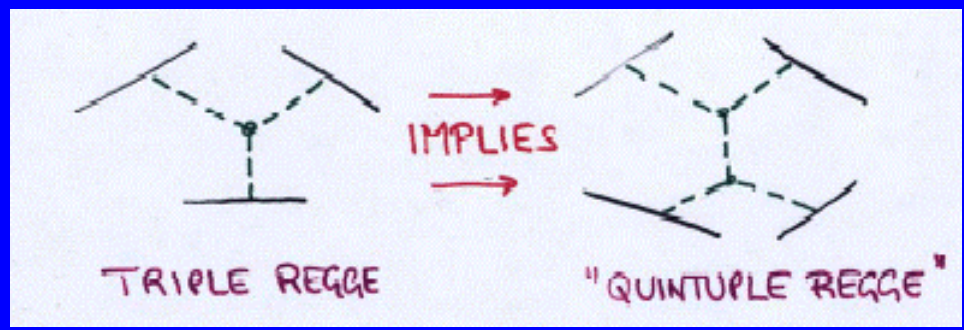
Introduction – some history, ISR discovery

1973: CHLM/ISR Discovery of "high mass" (10 GeV) diffraction.

1974: R.Schankar and D.Chew & G.Chew predicted multiple pomeron exchange in framework of Triple-Regge Theory





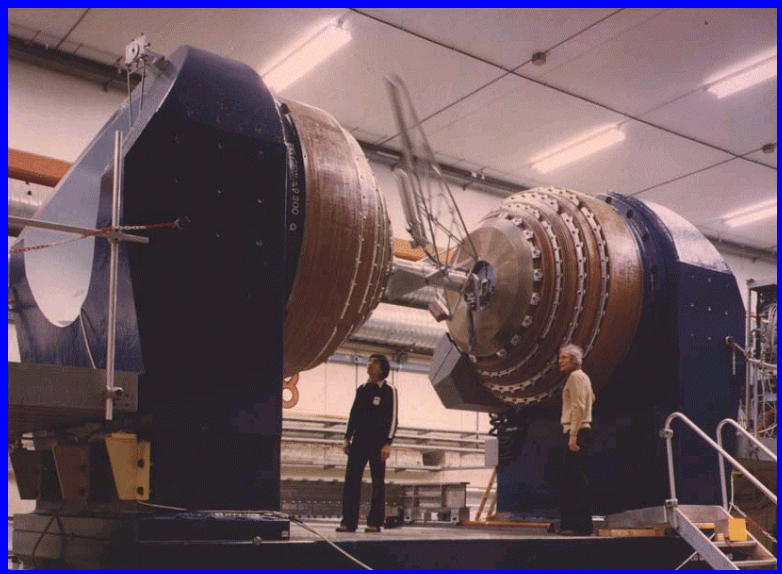


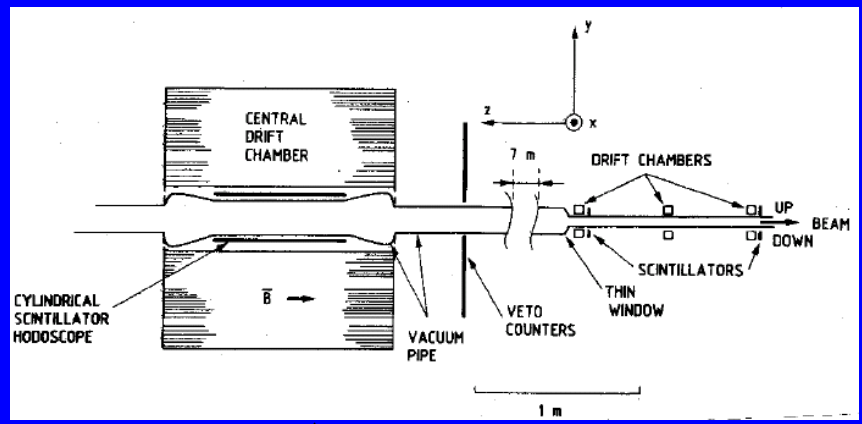
Central Exclusive Production in pp (I): ISR

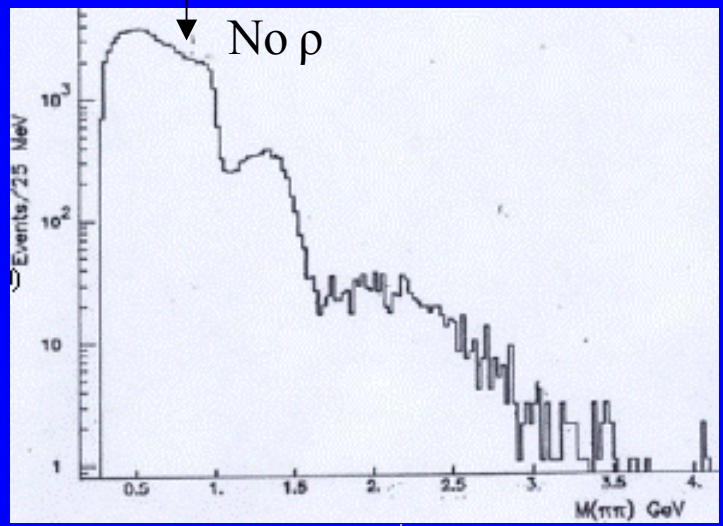
ISR : $\sqrt{s} = 63$ GeV $pp \to p \quad \pi^+\pi^- \quad p$

AFS + FWD chambers

Also K^+K^-, $p\bar{p}$, 4π







$M(\pi^+\pi^-)$

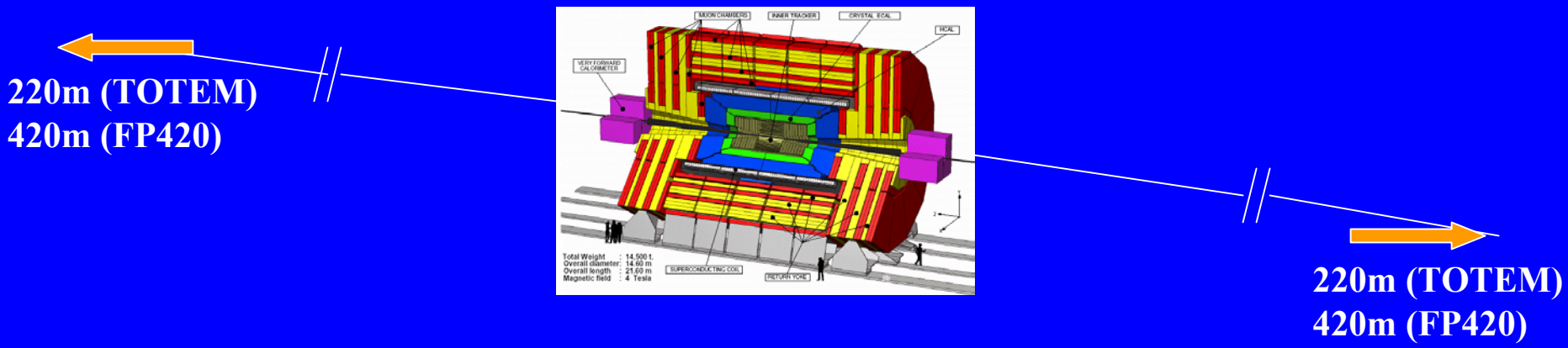
Searching for glueballs
Structures not well understood.
Not studied at higher sqrt(s)

Central Exclusive Production in pp (II): LHC

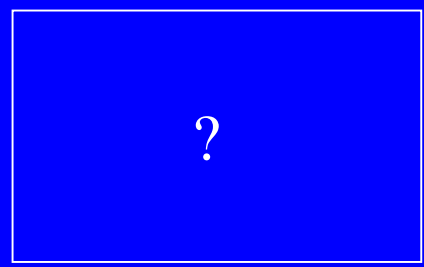
$\mathrm{LHC}: \sqrt{s} = 14{,}000\ \mathrm{GeV}$

$pp \to p\ W^+W^-\ p$

$pp \to p\ Z^oZ^o\ p$



Protons ***coherently*** scattered!
Searching for Higgs
and other structures.
Anomalous EWK-QCD couplings



Central DPE : Kinematic Limits "Rule of Thumb"

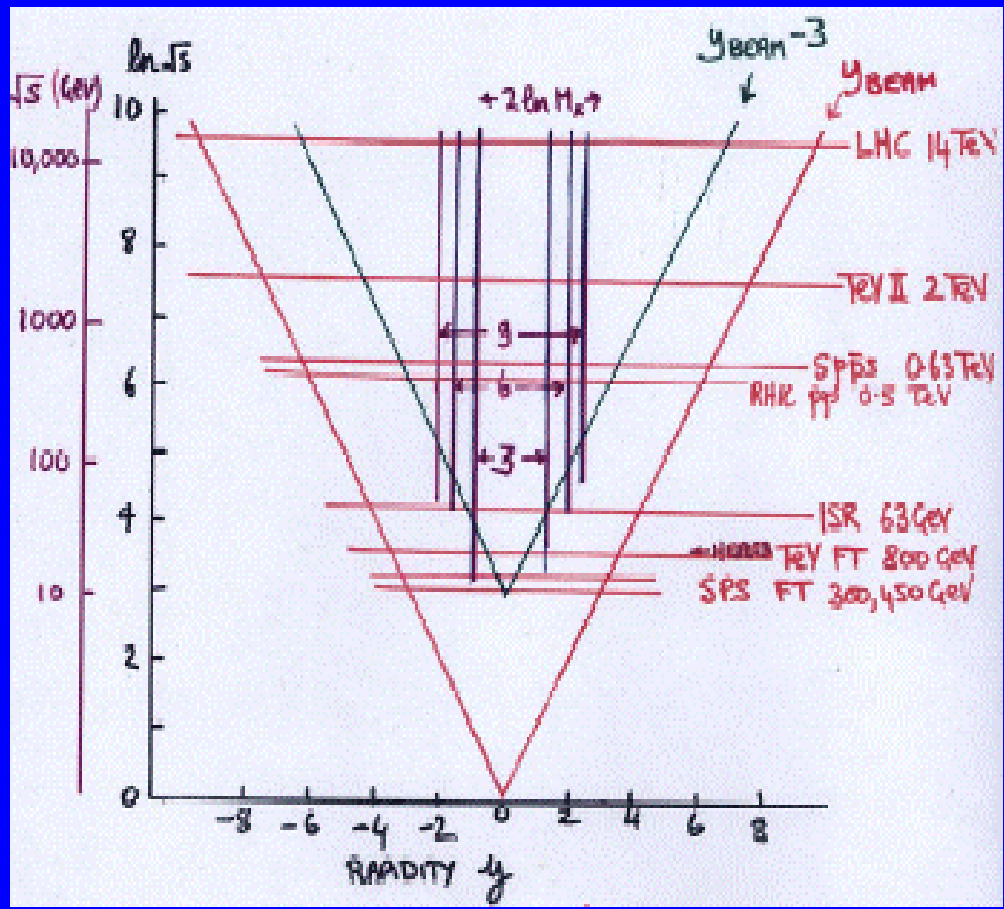
$$y_{BEAM} = \ln \frac{\sqrt{s}}{M_p} ; \; y_{CEN} \text{ spans } 2 \ln M_X \text{ ; 3 units GAP}$$

$$\text{Simply (equivalent)} : M_X(\max) \sim \frac{\sqrt{s}}{20}$$

FT Experiments marginal
ISR goes to ~ 3 GeV
TeV goes to ~ 100 GeV
LHC goes to ~ 700 GeV

Tevatron is the perfect place for low mass DPE and into jet domain.

LHC into top,W, Z, H domain



DPE at SppS and Tevatron

At SppS (630 GeV) :

UA1 : No forward proton detection.
Study with forward gaps n_{ch}, p_T, etc. to $M_{cen} \sim 60$ GeV

UA8 : UA2 + roman pots. Mostly SD, some low mass DPE

At Tevatron (1960 GeV) :

CDF : FP detection (roman pots) on one side, gap on other side.
High mass → jets out to ~ 100 GeV
Low mass exclusives with forward gaps.

D0 (Run 1) : No FP detection, high mass (& jets) study with gaps
D0 (Run 2) : FP detection both sides.
Can do low mass exclusives and high mass {p X p}

Central Exclusive Production cont.

gg fusion: main channel for H production.

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

p p → p + H + p

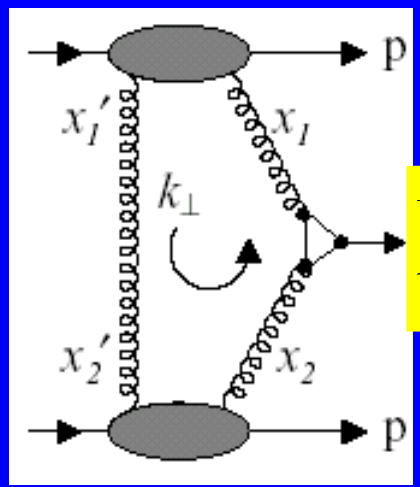
Theoretical uncertainties in cross section, involving skewed gluon distributions, gluon k_T, gluon radiation, Sudakov ff etc.

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

$$H(160) \rightarrow W^+W^- \rightarrow p\ e^+\mu^-\ \not\in_T\ p$$

$$MM^2 = (p_1 + p_2 - p_3 - p_4)^2 = M_H^2$$

Nothing else on emu vertex!



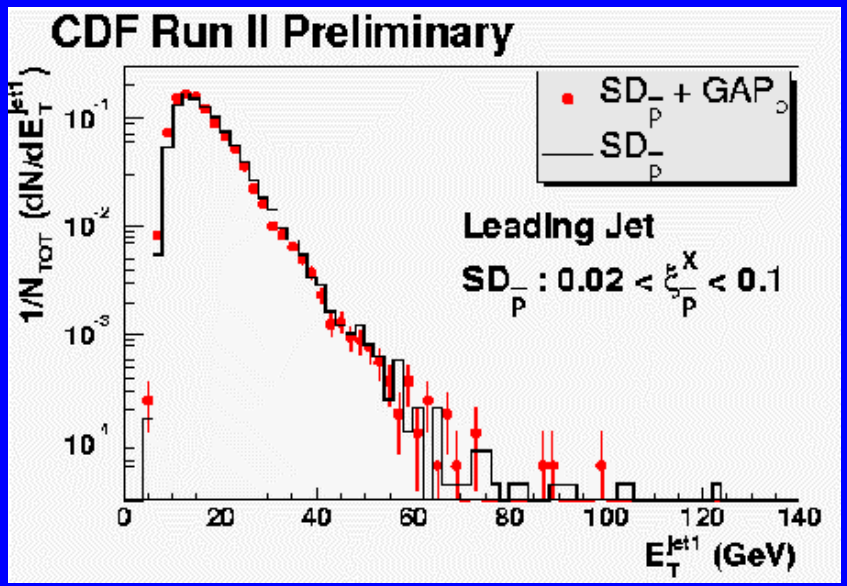
u-loop : $\gamma\gamma$ c-loop : χ_c^0

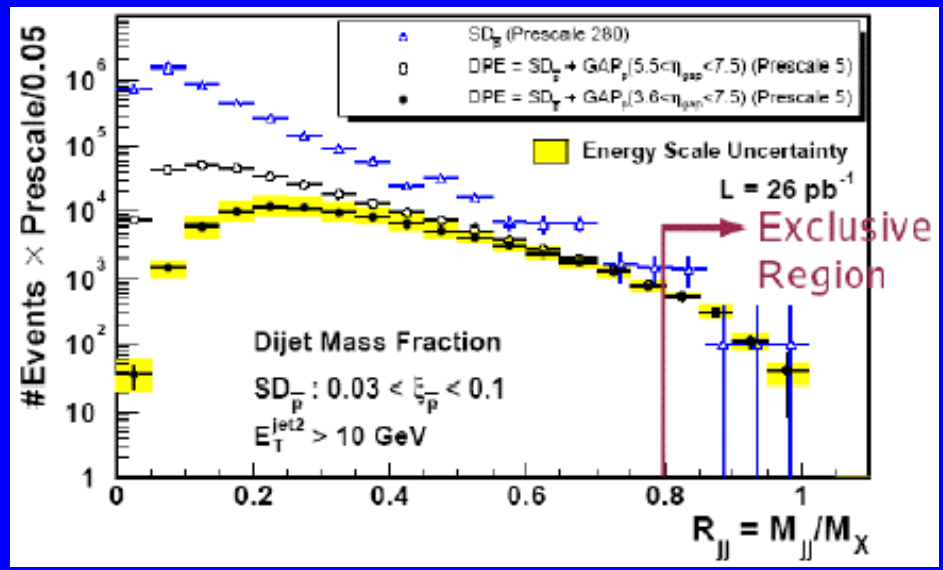
b-loop : χ_b^0 t-loop: H

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.

Exclusive Dijets?

Meaning p p → p JJ p and practically nothing else
Unlike exclusive WW (eg) this is not well defined. Arbitrariness.
Antiproton in roman pots, rapidity gap on other (p) side.





So far: upper limit ~ theoretical expectations
Expect enhancement (cf. what?) rather than peak
They should all be gluon jets !

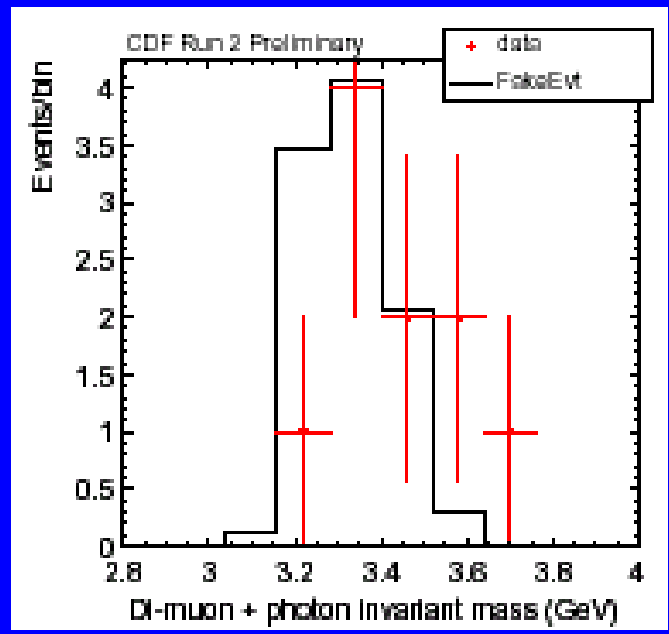
Exclusive χ_c search: $p\,\bar{p} \rightarrow p \quad \chi_c \quad \bar{p}$

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

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

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

$\Rightarrow$ few pb (1000's in 1 fb^{-1})



$\sigma(p\,p \rightarrow p \quad \chi_b \quad p) \sim 120$ pb (KMR)

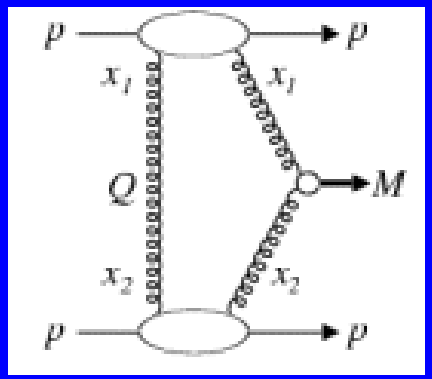
$\times(BR \rightarrow \Upsilon\gamma) \times (BR \rightarrow \mu\mu\gamma) \Rightarrow$

$> \sim 100 \times$ Acceptance / fb^{-1}

{Measuring forward p → central quantum numbers
2+ forbidden at t=0 for $q\bar{q}$ state}

$I^G J^{PC} = 0^+ 0^{++}$

Exclusive Higgs Production by Double Pomeron Exchange?



$pp \rightarrow pHp$ 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

→ Can be **inclusive** (soft central hadrons) but **exclusive** (nothing else) most interesting. Precision measurement of both p → M(central) by MM
Possible resolutions **~ 250 MeV** at Tevatron, **~ 2 GeV** at LHC.

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

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

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

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

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

$I^G J^{PC} = 0^+ 2^{++}$ next

→ Tevatron too low for SM H $\sigma_{excl} \sim$ 0.2 fb (KMR)

→ LHC possible (but difficult) $\sigma_{excl} \sim$ 3 fb (KMR)

→ Non-SM H interesting!

Diagrams for Prompt VV Pair Production in pp/ppbar

(Prompt i.e. not from top and not from Higgs)

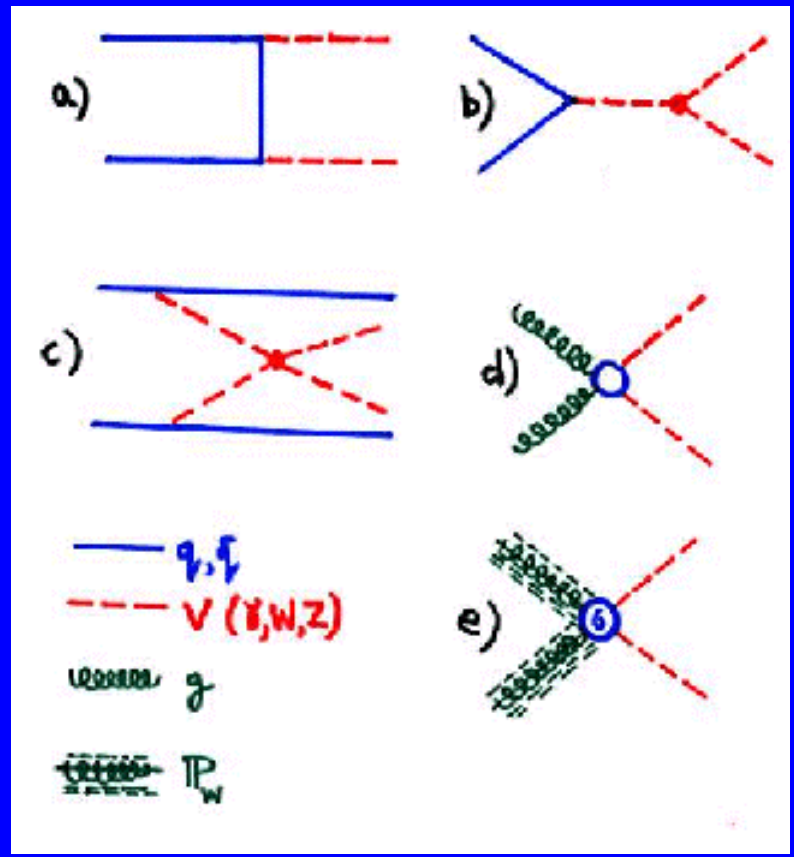
a) Any $Q = 0,1$ pair. 90% of WW at TeV, less at LHC

b) Only γW, WW, WZ

c) Any pair (even W^+W^+).
Negligible at Tevatron, larger at LHC

d) Negligible

e) Eventually dominant if White is right!



Also $\gamma\gamma \rightarrow W^+W^- \sim 100$ fb

Discriminant : t_1, t_2

Note different color flows in these diagrams → can give different hadronic activity.

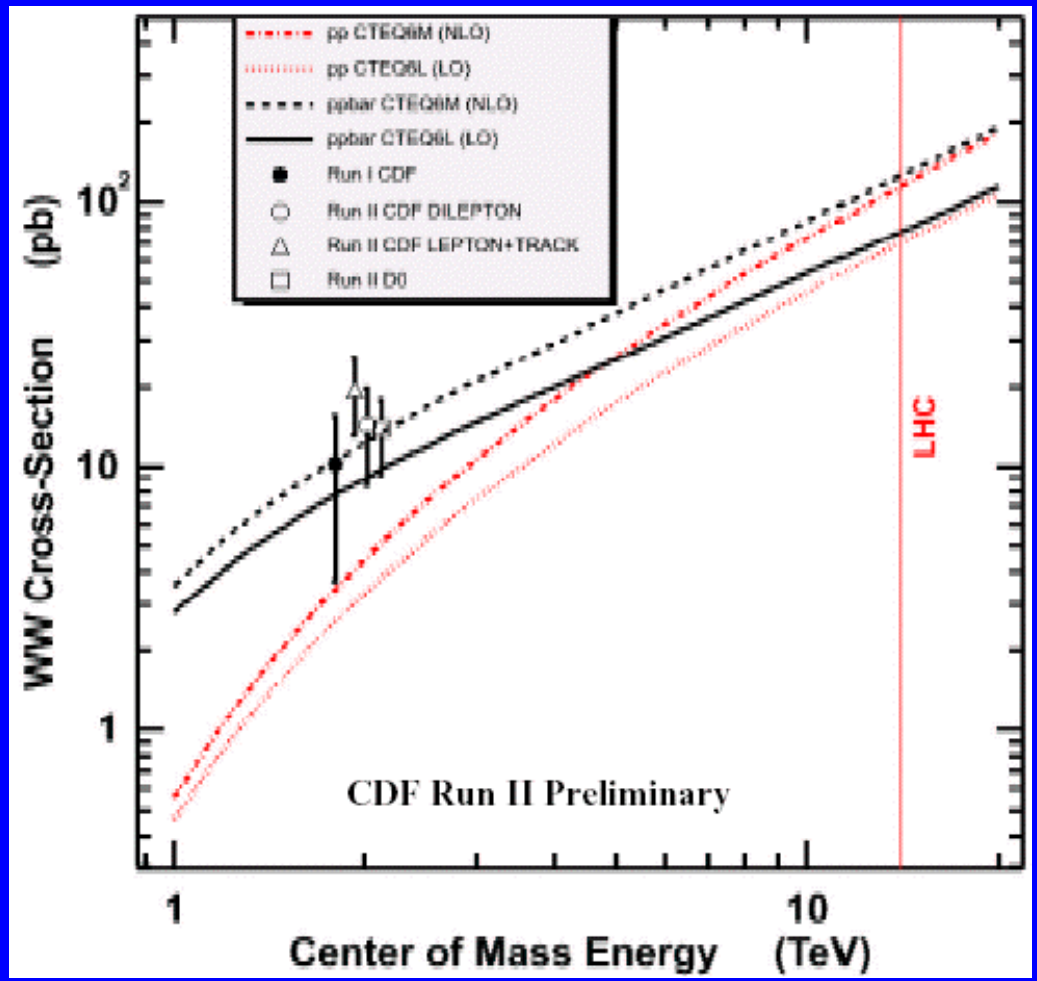
(a) and (b) have color 3 annihilation

(d) has color 8 annihilation

(c) and (e) have color singlet exchange.

(c) high pT q – forward jets; (e) low pT p's – no jets, can be exclusive

Cross section for WW Production: Energy Dependence



Tevatron cross section agrees with CTEQ NLO

Tev2 sig(ZZ) = 1.39 pb
sig (ZW) = 3.65 pb
sig WW = 12.4 pb

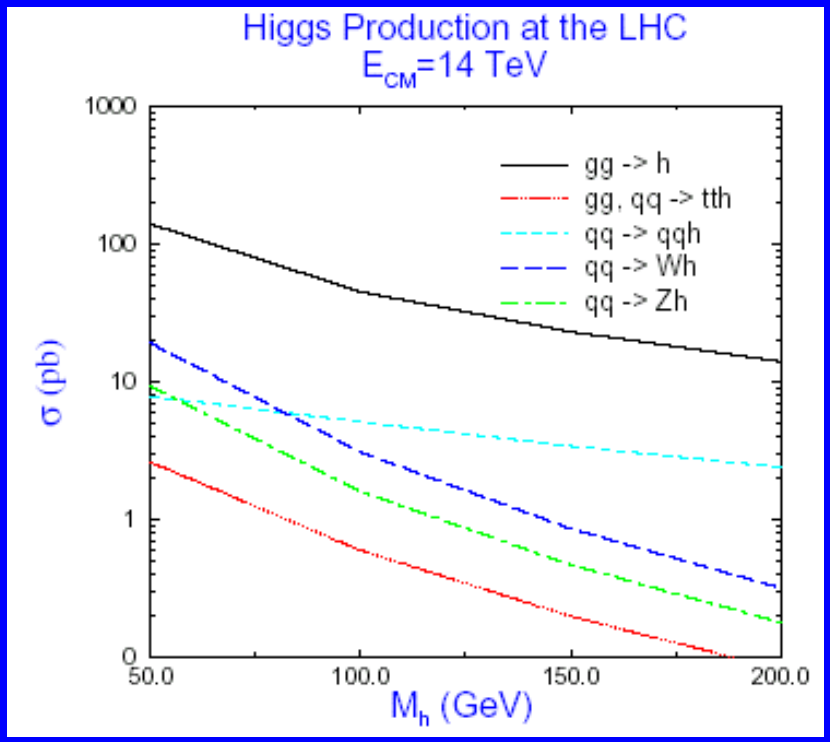
LHC ~ 10 x higher

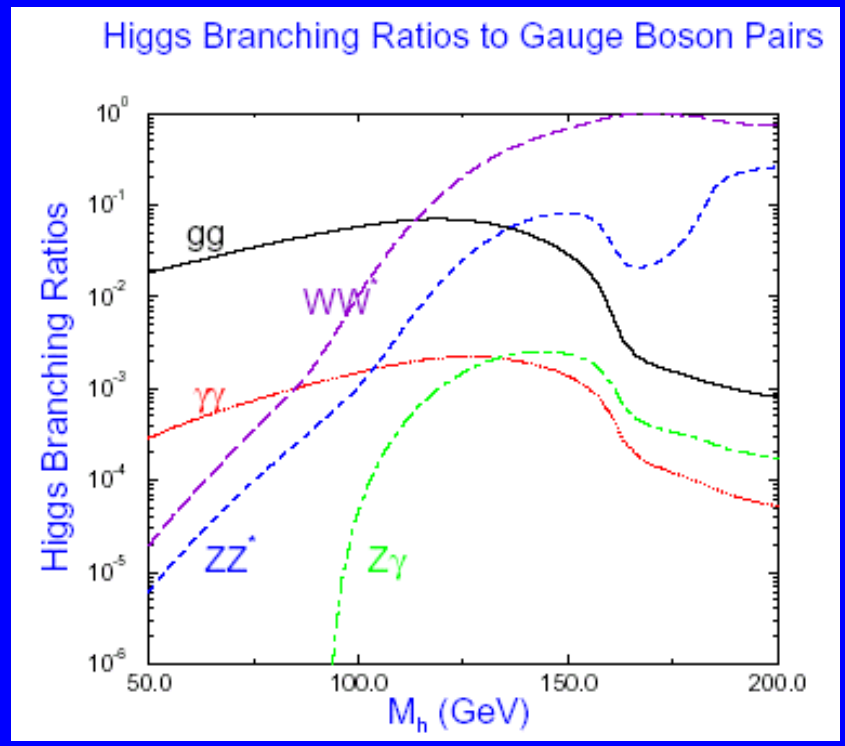
If Tevatron RoT apply,
At LHC :
SD, ~1% → ~ 100 fb
DP, ~ 10^-3 → ~ 10 fb

i.e. Guesstimate for DPE → WW (ZZ) + anything ~ 10 (1) fb

Higgs at the LHC

Just H → VV





S.Dawson

Take $M_{SM\text{-}H} = 170$ GeV

$\sigma \approx 20$ pb from gg-fusion (dominant)

$\Rightarrow$ σ(non-H: WW) $\approx$ 100 pb

$B(H \rightarrow W^+W^-) \approx 98\%$

Unfortunately $WW \rightarrow ee,e\mu,\mu\mu \sim 0.045\ (4\times0.106^2)$

~ 45 ($\times$acc$\times$eff) events / fb^{-1}

Signal "localized" but mass resolution poor

Relevant studies we are doing in CDF:

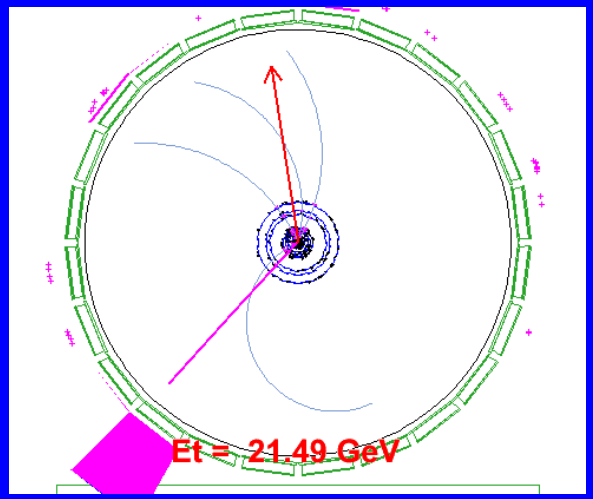
$$DPE \rightarrow JJ,\ J_bJ_b,\ \gamma\gamma,\ \chi_c,\ WW$$

(χ_b and ZZ would be great too!)

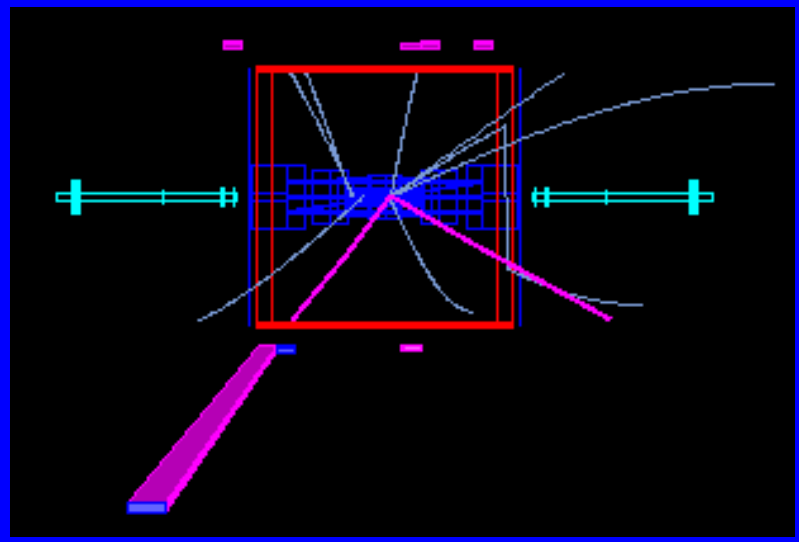
Cannot of course expect to see DPE → WW, ZZ at Tevatron, but study associated event (SDE?) and single W,Z. Zγ ?

DPE Exclusive is gold-plated
DPE Inclusive is silver-plated, also interesting.

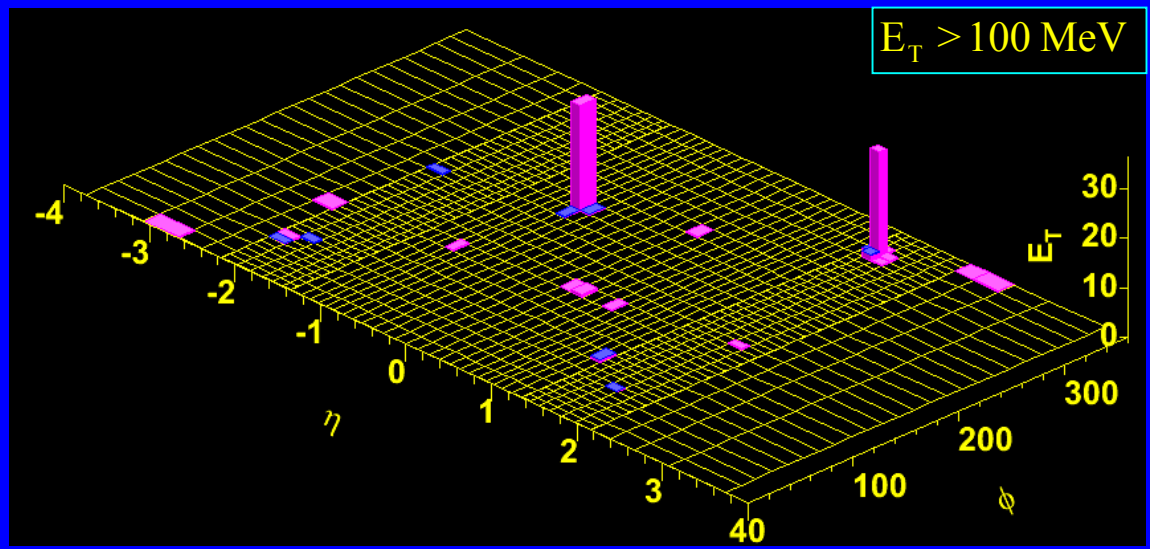
Event C: WW → ev ev Candidate



$p_T > 200$ MeV/c ; $|\eta| < 1.0$



$p_T > 200$ MeV/c



Cleanest event in sample also in E & W forward detectors.

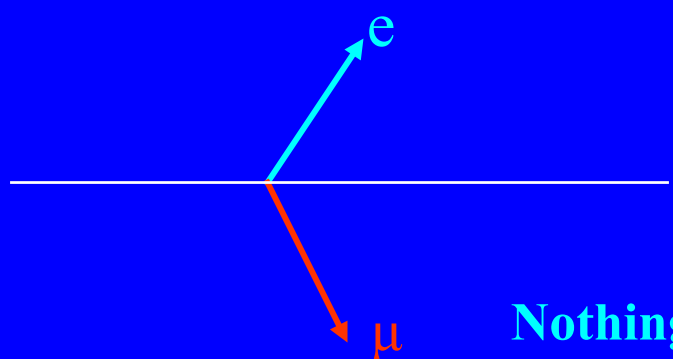
2 tracks in R-phi view dissociated -or badly measured?
Other 2 < 400 MeV/c

$p_T(W^+W^-)$ & $\sum E_T$(ass.)
also very small (of course)

Central Exclusive WW Production at LHC

$$H(160) \rightarrow W^+W^- \rightarrow p\ e^+\mu^-\ \not\in_T\ p$$

$$MM^2 = (p_1 + p_2 - p_3 - p_4)^2 = M_H^2$$



eμ

Nothing else on 2-lepton vertex!

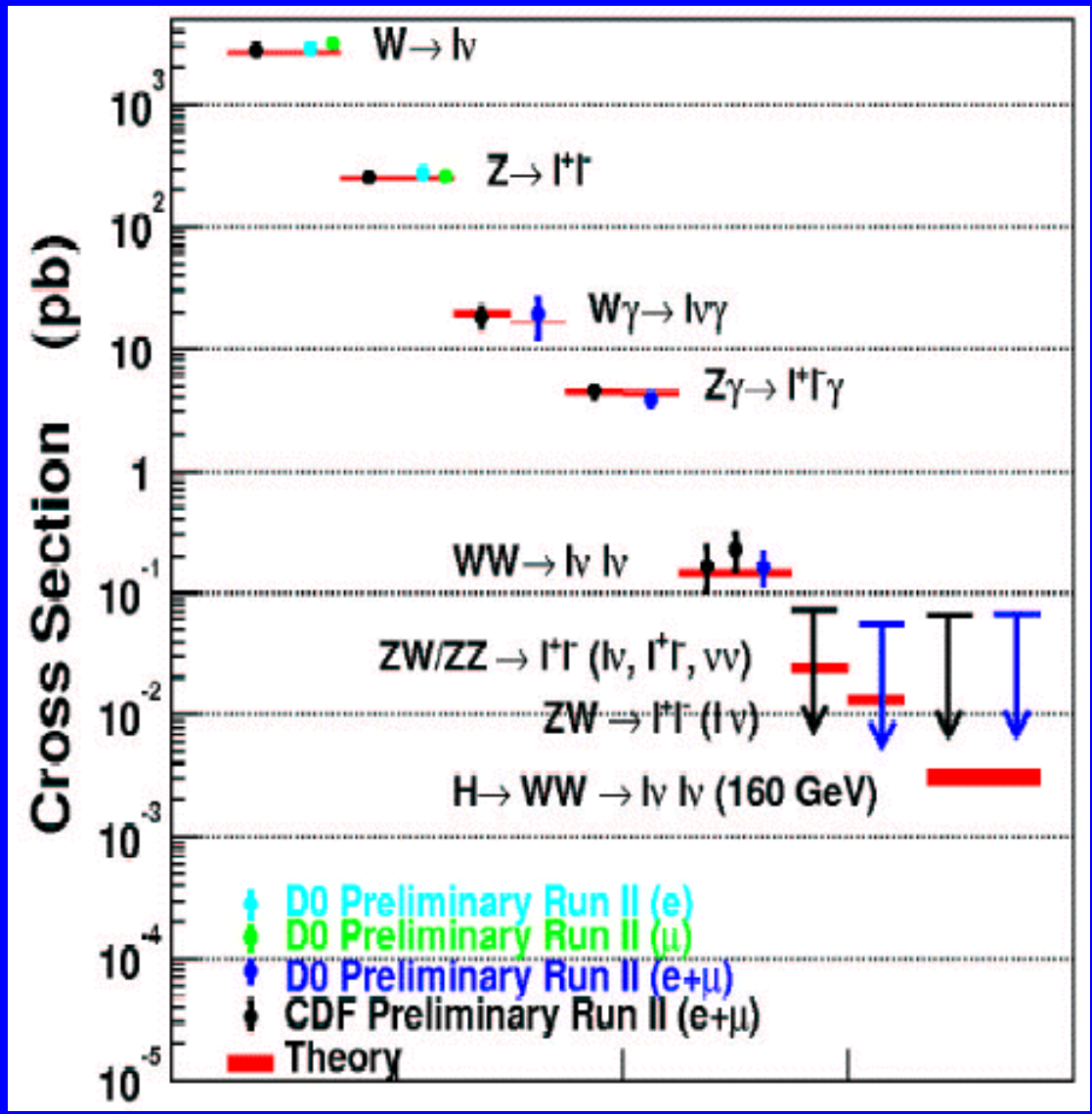
Also $pp \rightarrow p\ Z(ee,\mu\mu) + \not\in_T\ p$

MM $(1+2-3-4-\sum_{all}\ visible) \approx M_Z$

& MM $(1+2-3-4) \approx M(ZZ)$

+ White Pomeron search

Summary of Cross Sections at Tevatron Run 2



"Classical Soft" and BFKL Pomerons

0^{th} order, soft interactions (low t, Q^2) : {gg} in color singlet.
.... virtual "glueballs", summed over spins. Also {ggg}

As Q2 increases (as seen with partons) $q\bar{q}$ evolve in.

Reggeon = {$q\bar{q}$ } in color singlet, virtual mesons, summed up.

Ambitious attempt to calculate pomeron in QCD: **BFKL** pomeron
{Balitsky, Fadin, Kuraev & Lipatov}
"reggeized gluon ladder"

Alan White's Theory of Critical Pomeron

Soft pomeron **BFKL pomeron**

"White pomeron"

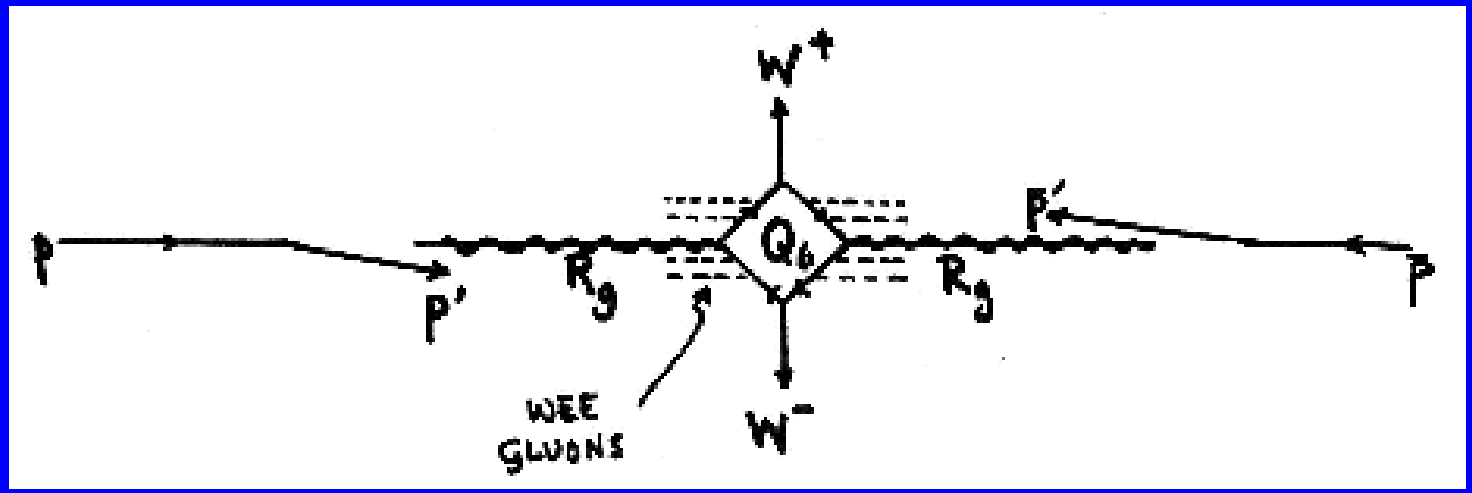
"Reggeized gluon" : single g in LO QCD is "sick": not gauge invariant.
Reggeized gluon from summing procedure → gauge invariant.

Infinite number of "wee gluons": no momentum even in infinite momentum frame.
wee gluons have properties of vacuum: in a sense they *are* the vacuum.
Rg color compensated at large distance by accompanying wg "cloud".

wg couple strongly to *color sextet Q* and to W,Z once energy ~ EW

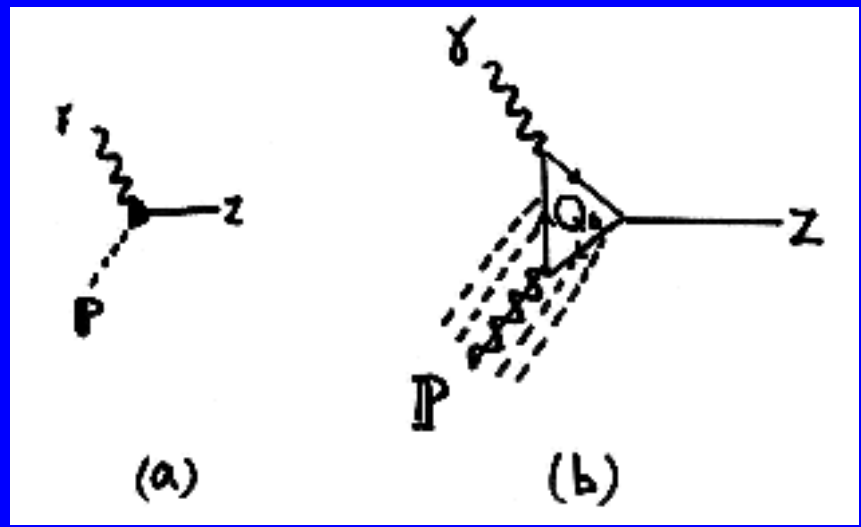
At LHC and above, diffractive W/Z production may be prolific.
Including pp → {p WW p} & {p ZZ p}

Double Pomeron → W+W- via Q6 Loop



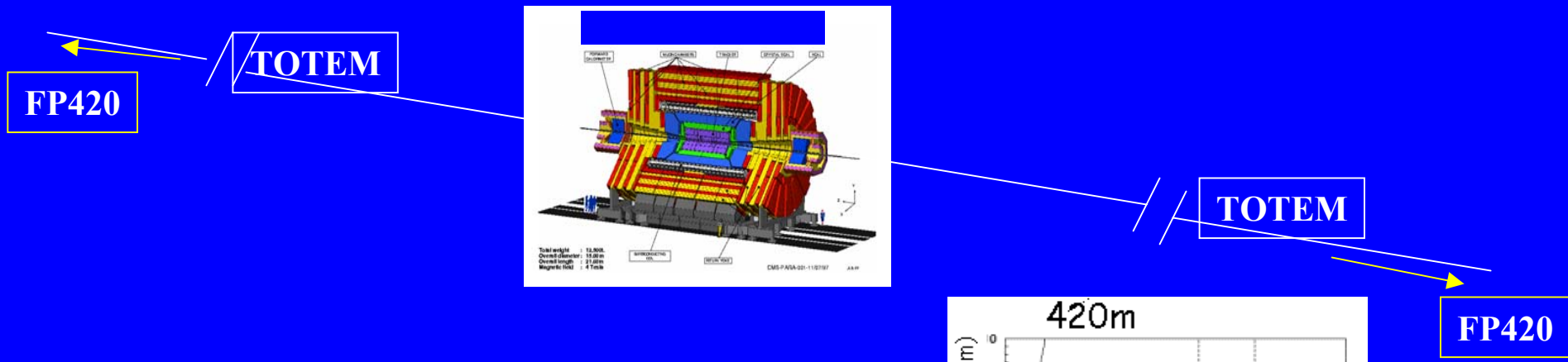
Photon-Pomeron-Z vertex via Q6 loop

Photoproduction at LHC?
pp → {p Z p}



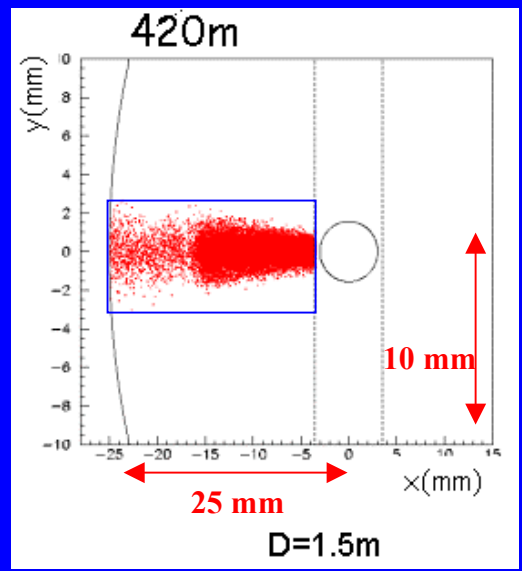
FP420 = Forward Protons at 420 m

Groups in ATLAS and CMS/TOTEM want to add
very forward proton detectors, mainly to study "DPE", central production.
Central states especially : WW, ZZ, H, $b\bar{b}$, $t\bar{t}$, jet-jet, X ...



Inelastic protons bent few mm out of beam
6mm x 24 mm detector (e.g. Si pixel)

International consortium (both expts) formed.



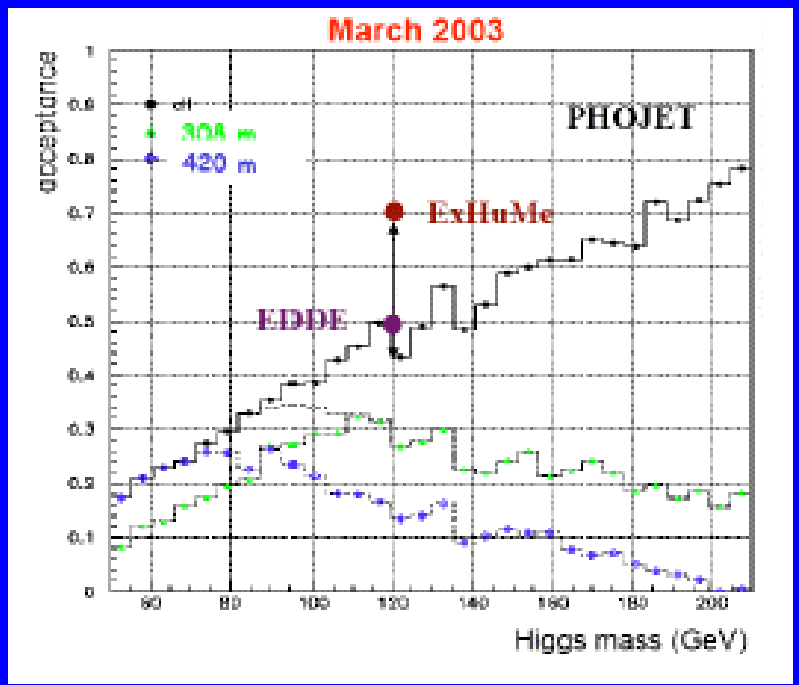
Valentina Avati

Acceptance (M)

Need both 420m and 215m (TOTEM pots)

The power of Missing Mass:

$$M^2_{\text{central}} = (p_1 + p_2 - p_3 - p_4)^2; \;\; p_i \text{ 4-vectors}$$



$$\sigma(M) \sim 2 \text{ GeV (?)}$$

(420+420)

See invisible $Z \rightarrow \nu\bar{\nu}$ e.g. in $H \rightarrow ZZ$

$$M^2_{\text{invisible}} = (p_1 + p_2 - p_3 - p_4 - \sum p_{\text{visible}})^2$$

Distinguish $ZZ \rightarrow \mu^+\mu^-\nu\bar{\nu}$

from $WW \rightarrow \mu^+\mu^-\nu\bar{\nu}$

Several more talks at this meeting about this:

Spencer Klein: Photoproduction at hadron colliders
Brian Cox: Forward proton tagging ...
Henry Kowalski: Hard and soft diffraction
Karsten Eggert: TOTEM
Krzysztof Piotrzkowski: Two photon physics
Christophe Royon: Diffractive production of massive states

This is going to be a very exciting topic at the LHC, whether or not the Higgs is in reach. If (it exists and) we see it this will be most important (mass, quantum numbers, properties ...)

$pp \rightarrow \{p \quad \pi^+\pi^- \quad p\}$ at ISR

$pp \rightarrow \{p \quad W^+W^- \quad p\}$ at LHC ?