Exclusive Central Production in Proton-Proton Collisions: from Glueballs to Higgs Bosons

Mike Albrow (Fermilab)

1) Background: elastic and hard diffractive scattering

2) Single Diffractive Excitation of High Masses (Jets,W,Z) – CDF/D0

3) Central Exclusive Production:

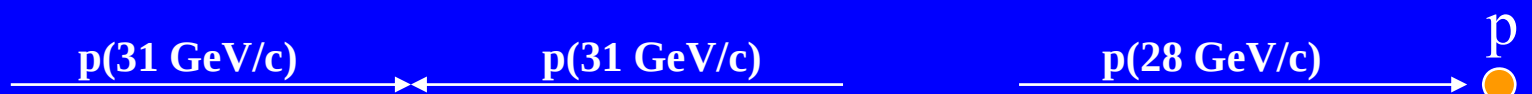
$$\text{Higgs},\ \gamma\gamma,\ e^+e^-,\ \mu^+\mu^-,\ \chi_c(\chi_b),\ Jet+Jet$$

4) LHC: Study of Higgs *(iff)* through p+H+p, WW and ZZ.

5) FP420: R&D project to make this happen.

Compare & Contrast ISR & LHC

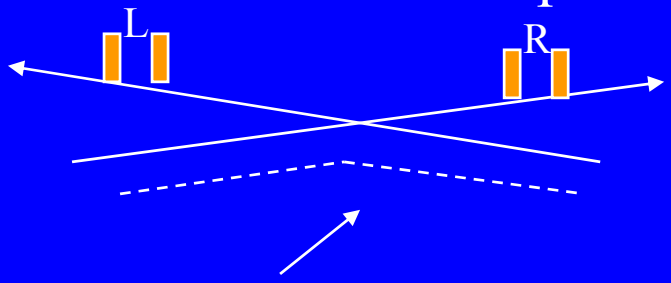
ISR = Intersecting Storage Rings started 1971
First colliding proton beams.

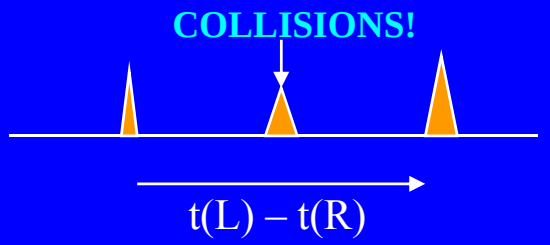


Centre of Mass Energy = 63 GeV **Centre of Mass Energy = 7.4 GeV**

Equivalent to beam of 2110 GeV + fixed p target
"Into the realm of cosmic rays!"

First collisions ... no detectors installed! ... put in 4 counters!





Experiment 101

Emulsions on a toy train set!

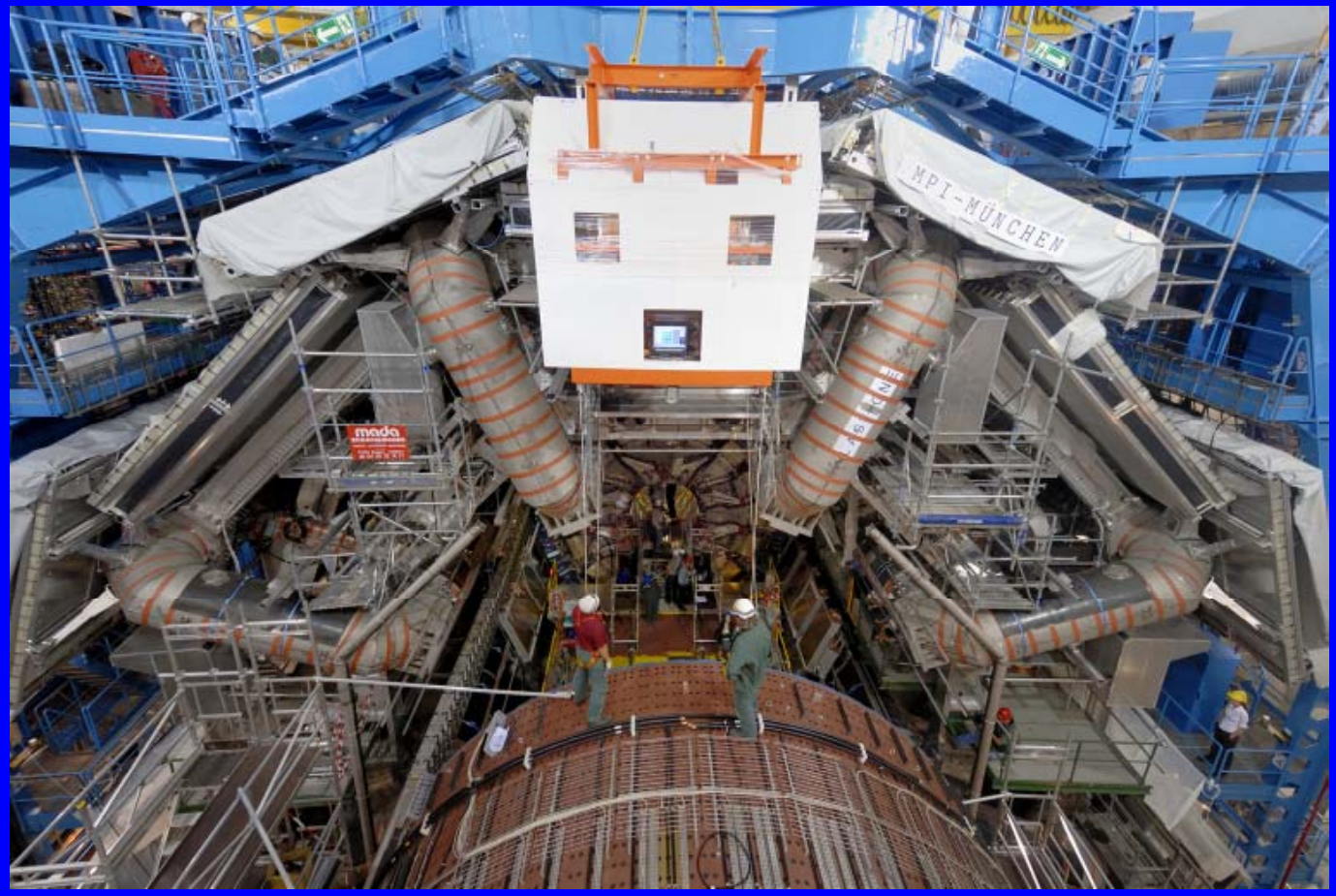
2006: LHC = Large Hadron Collider

7 TeV = 7000 GeV

7 TeV = 7000 GeV

$\equiv 10^8$ GeV$=10^{17}$ eV

cf. cosmic cut off $\approx 10^{20}$ eV

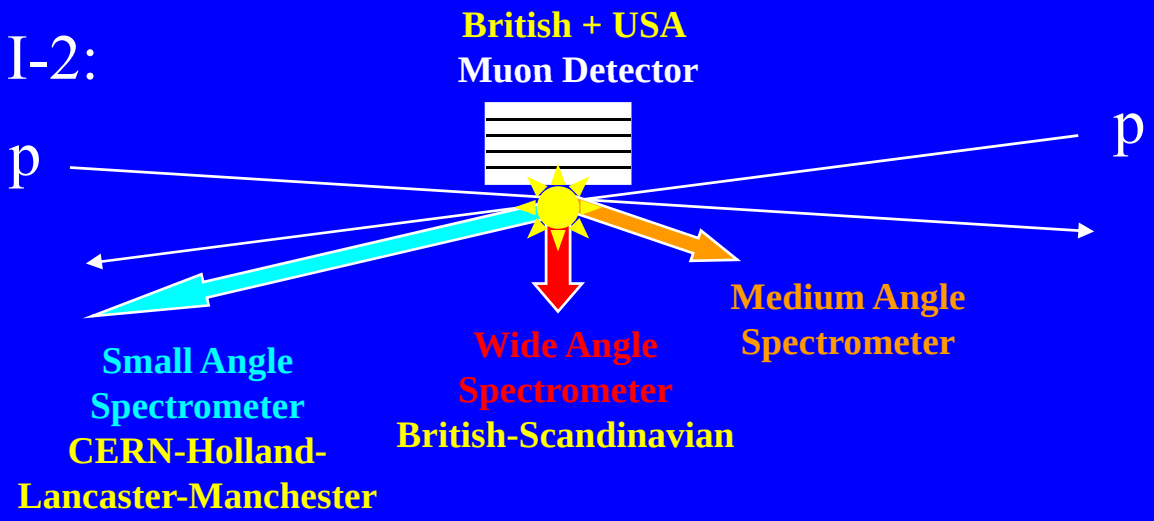


ATLAS being installed. ~ 2000 physicists!

One of four experiments.

Meanwhile, back at the ISR in 1972 ...

Intersection I-2:



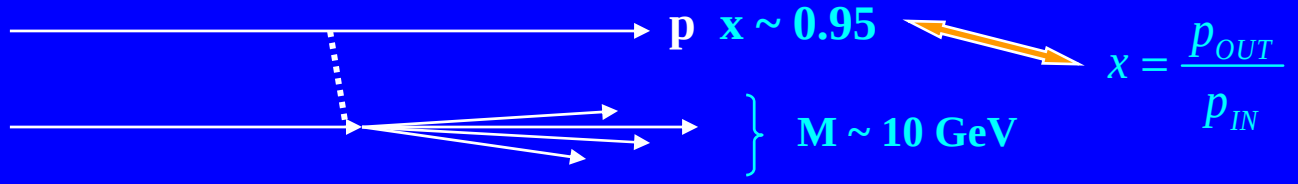
Nobody knew what to do with complete multi-particle (~ 10+) final states.

Study "inclusive" particle production: pp → e, μ, π, K, p ... + "anything".

Muon Detector: Looking for W(~3-4 GeV!) ... missed J/ψ

Wide Angle Spectrometer: co-discovered high p_T (quark scattering)

Small Angle Spectrometer: discovered high mass (10 GeV) diffraction



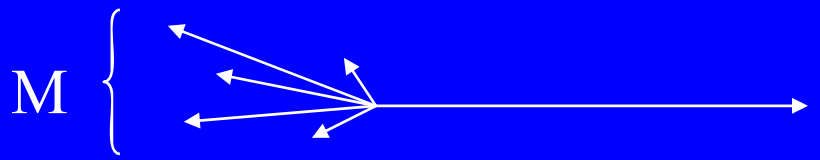
Small Angle Spectrometer: Forward proton spectra

$$x_{Feynman} = \frac{p_L}{p_{beam}}$$

Feynman scaling:

$$E\frac{d^3\sigma}{dp^3} = f(x_F, p_T) \text{ not } \sqrt{s}$$

Discovery of high-x, scaling peak

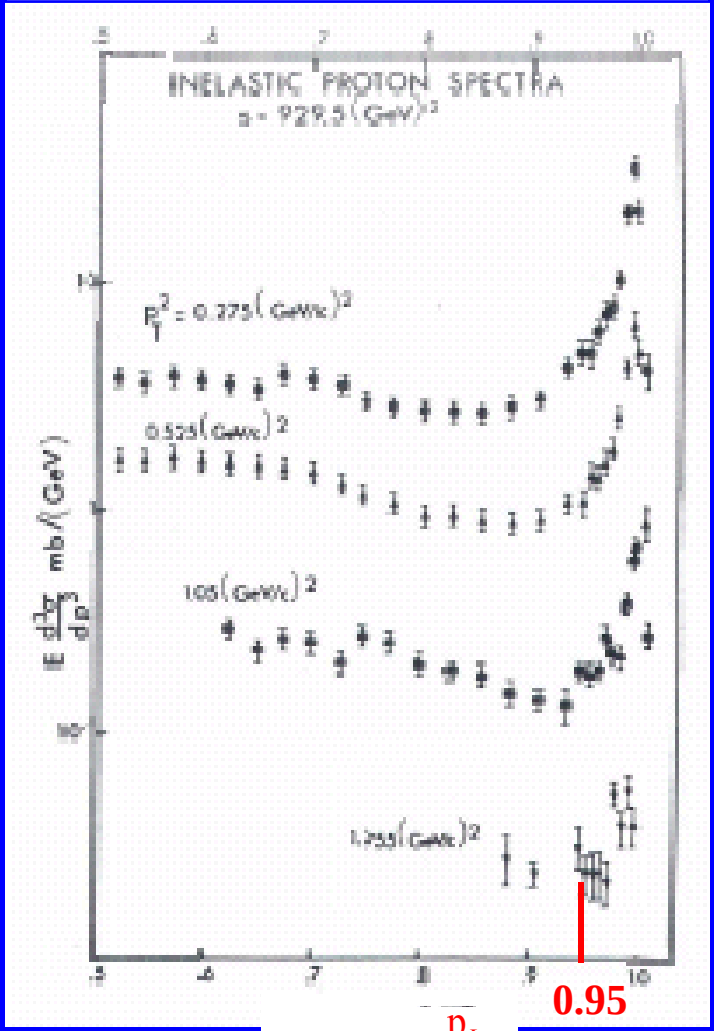


$M < \sqrt{0.05}\sqrt{s} = 0.22\sqrt{s}$

x > 0.95

M up to about 14 GeV at ISR
440 GeV at Tevatron
3100 GeV at LHC

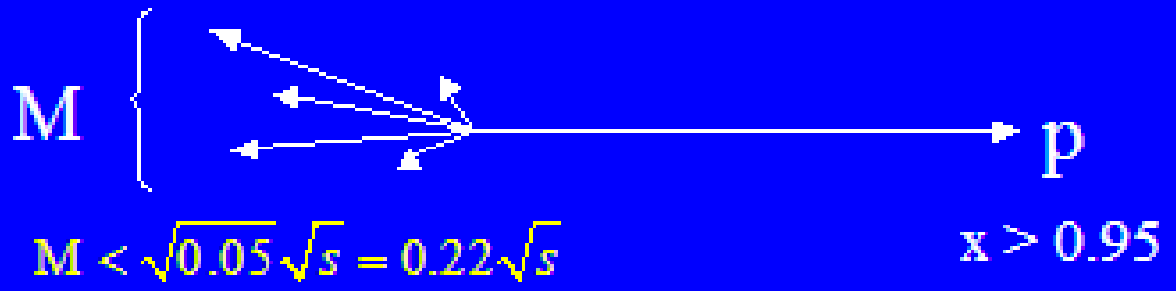
MGA et al., NP**B54** (1973) p.6



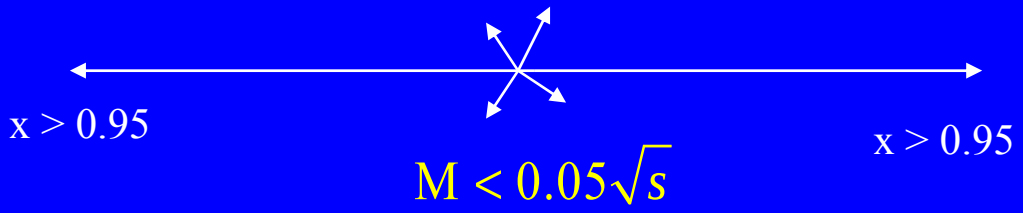
$$x_{Feynman} = \frac{p_L}{p_{beam}}$$

Central Diffractive Excitation

Theoretically, if:

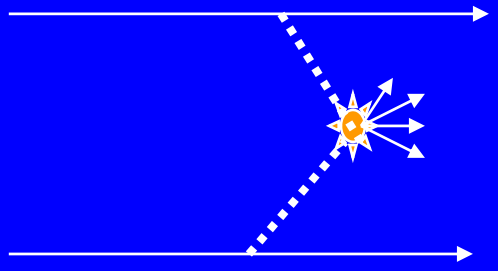


happens, so should:



… both protons coherently scattered

H,WW → **M up to about 3 GeV at ISR**
100 GeV at Tevatron
700 GeV at LHC



"Vacuum Excitation"

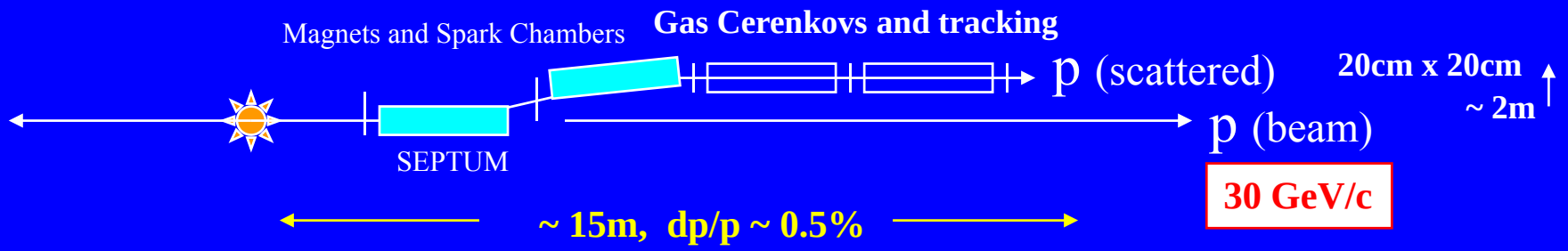
Exchanged 4-momentum must
have no electromagnetic charge
or strong charge (colour), spin >=1

γ or g ($+g$, gg)

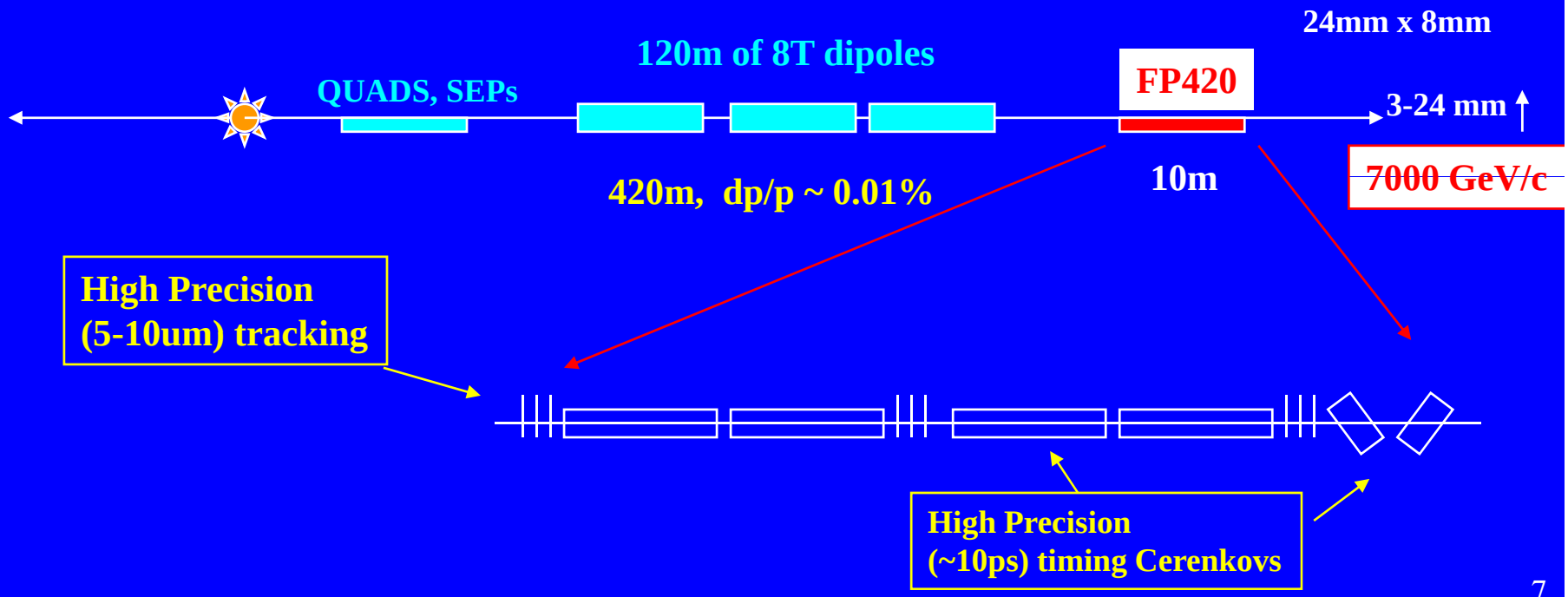
Central state Quantum Numbers restricted

Forward Proton Spectrometers: ISR → LHC

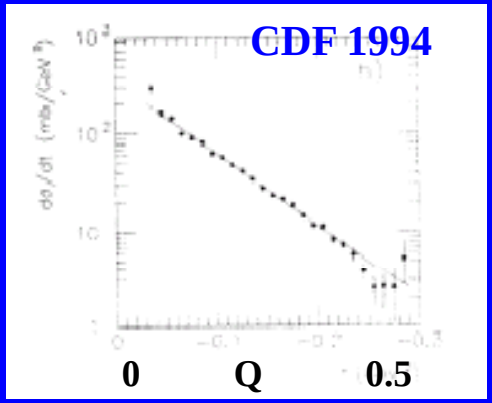
ISR (1971)

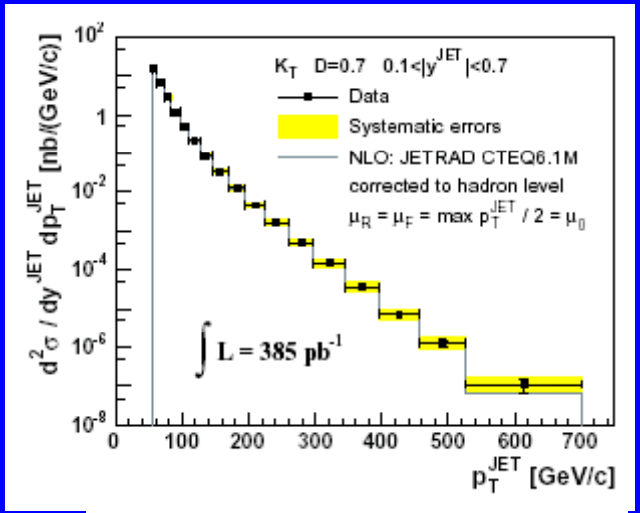


LHC (2009?)

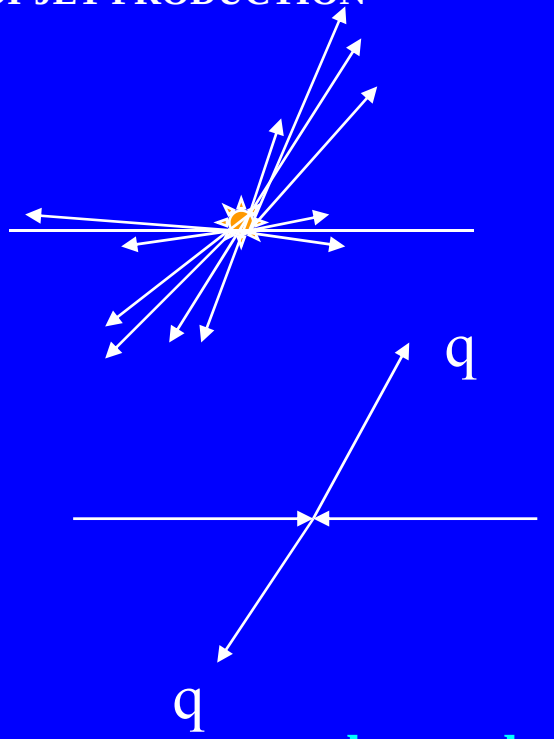


ELASTIC SCATTERING





DI-JET PRODUCTION



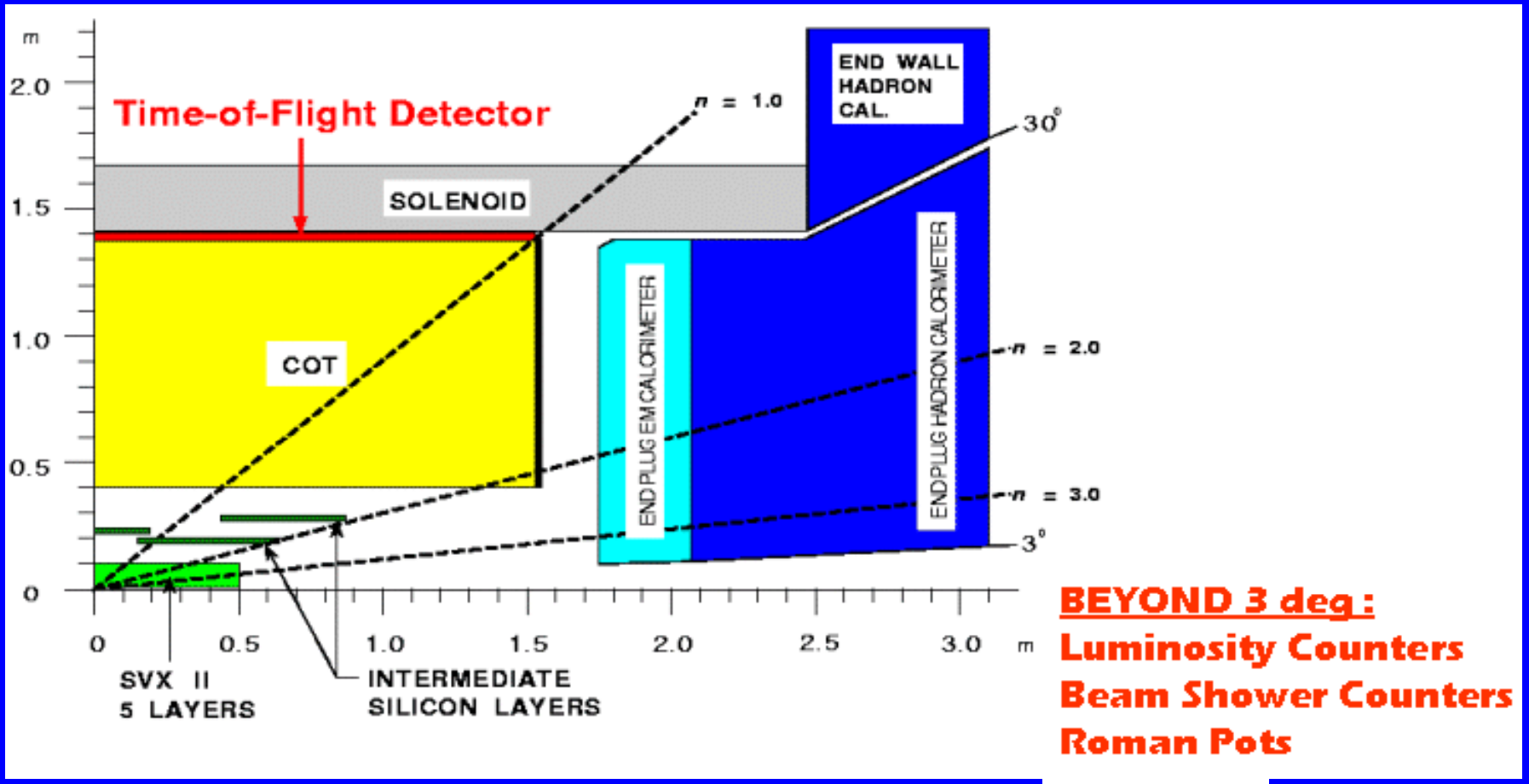
quark-quark scattering

Q = 4-momentum transferred

Jets, W or Z produced but proton stays intact!!

High Q^2 and low Q^2 together

CDF Detector at Fermilab Tevatron



BEYOND 3 deg :

Luminosity Counters

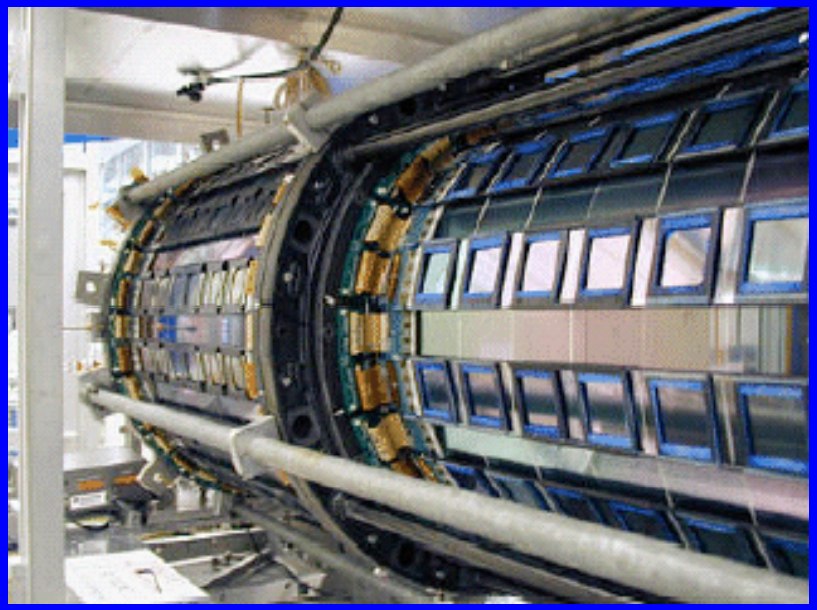
Beam Shower Counters

Roman Pots

MiniPlugs

980 GeV pbar → ← **980 GeV p**

Central tracking: Silicon strips & Drift Chamber



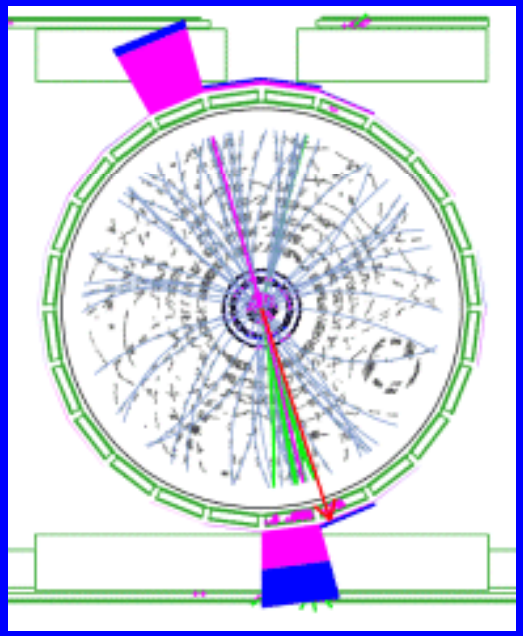
~ 720,000 strips,
25um with 50um readout

Drift chamber
96 layers → 30,240 s.wires
40 um gold-plated tungsten
ADC and TDC each end
Resolution ~ 150 um/wire

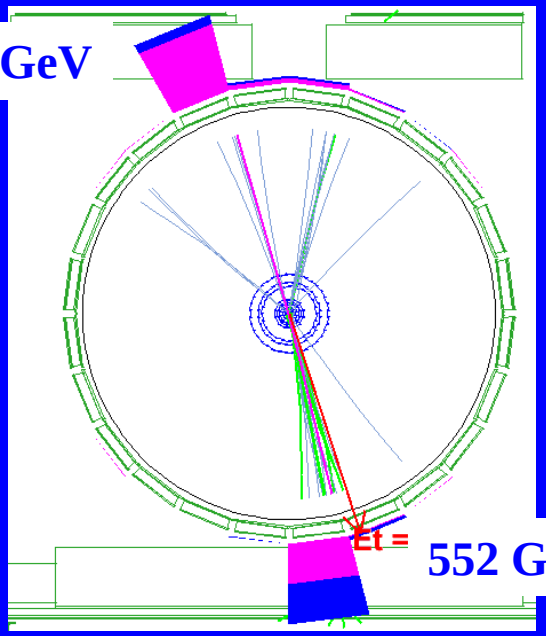
Surrounded by lead/iron scintillator sandwich calorimeter for energy measurement

Highest Energy Jets probe smallest distances

All hits/tracks

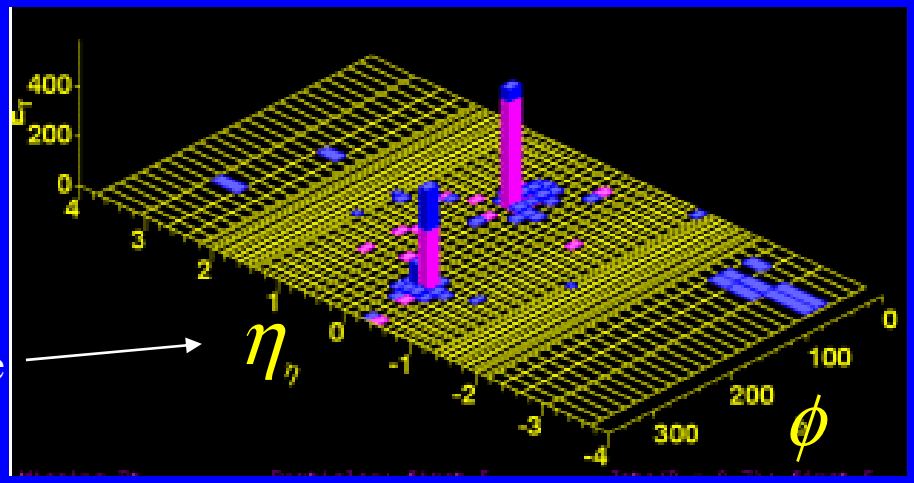


tracks pT > 2 GeV/c



$$\eta = -\ln\tan\left(\frac{\theta}{2}\right)$$

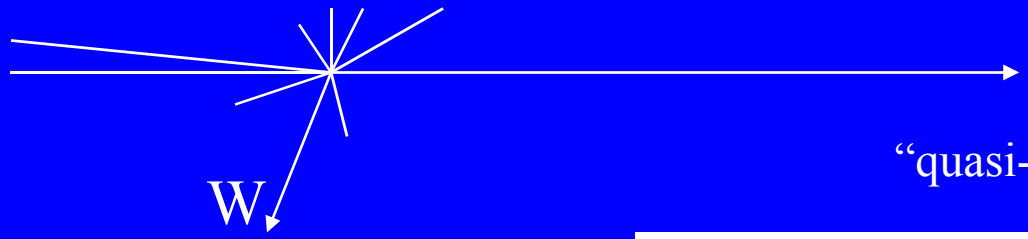
~log polar angle



~ 3×10^{-4} × proton size

(quarks "point-like")

Diffractive W and Z Production



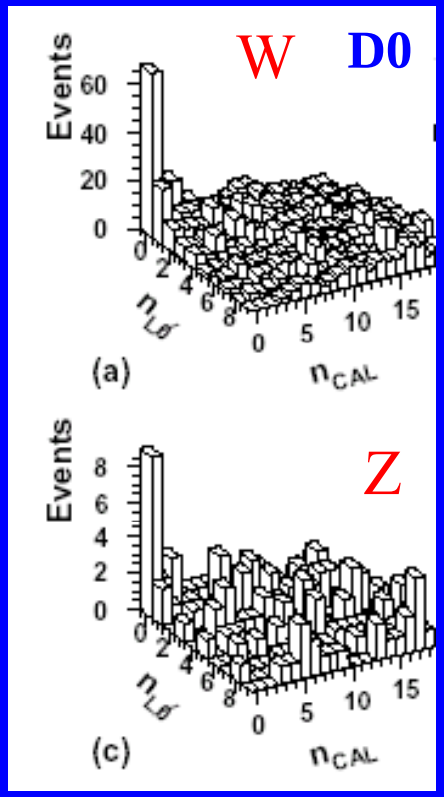
"quasi-elastic"

W produced but p "stays intact"

CDF:

$$\frac{\text{Diff. W}}{\text{Non-Diff W}} = (1.15 \pm 0.55)\%$$

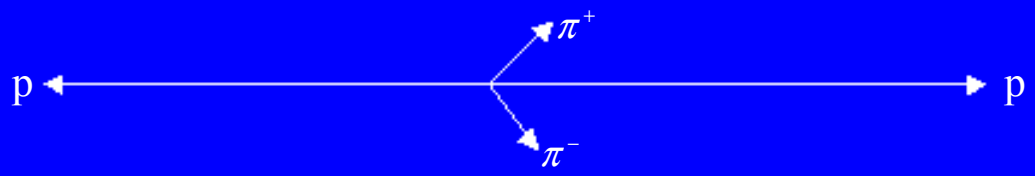
D0 sees diffractive W and Z
all consistent with 1% diff./ND



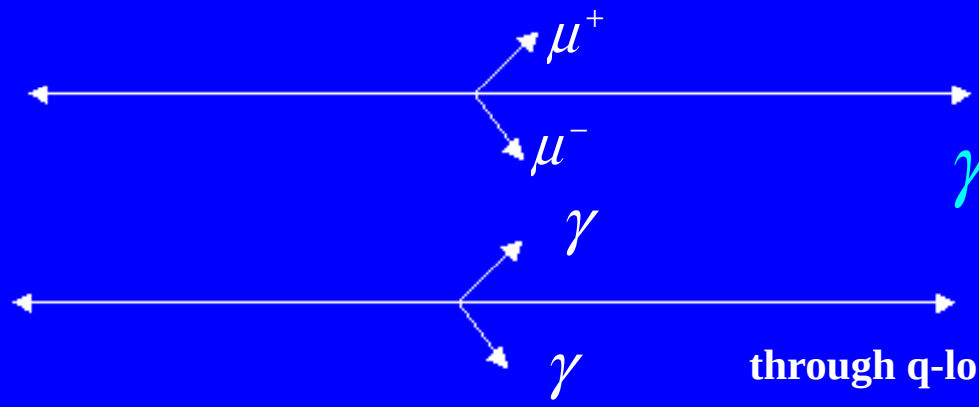
$$\eta(LO) = 2.3 - 4.3$$
$$\eta(CAL) = 3.0 - 5.2$$

Central Exclusive Production

pp → p X p where X is *a simple system completely measured*



At CERN ISR
Glueball Search

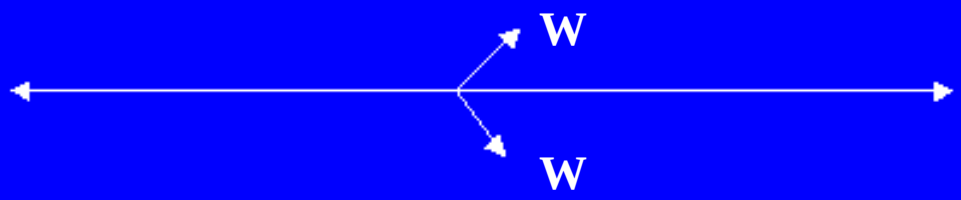


At Tevatron & LHC

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

$gg \to \gamma\gamma$

through q-loops (box) + color bleaching (g)



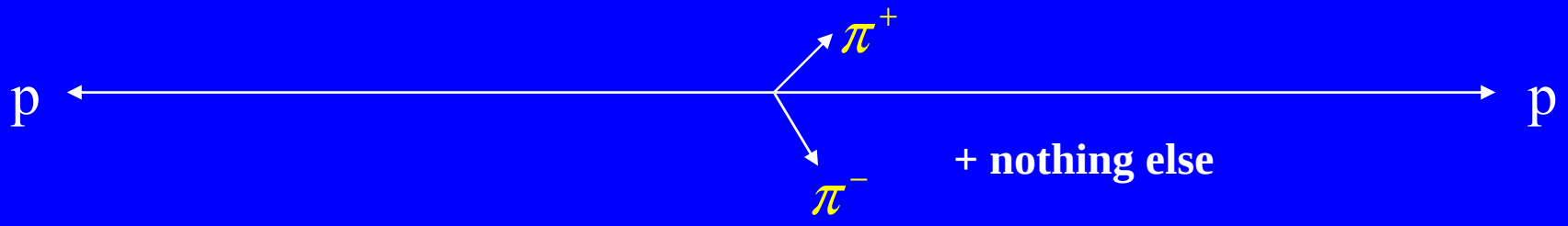
$\gamma\gamma \to WW; H \to WW, H \to ZZ$

$H \to b\bar{b}; BSM \to WW, SUSY\ etc$

Low Mass Central Exclusive Production

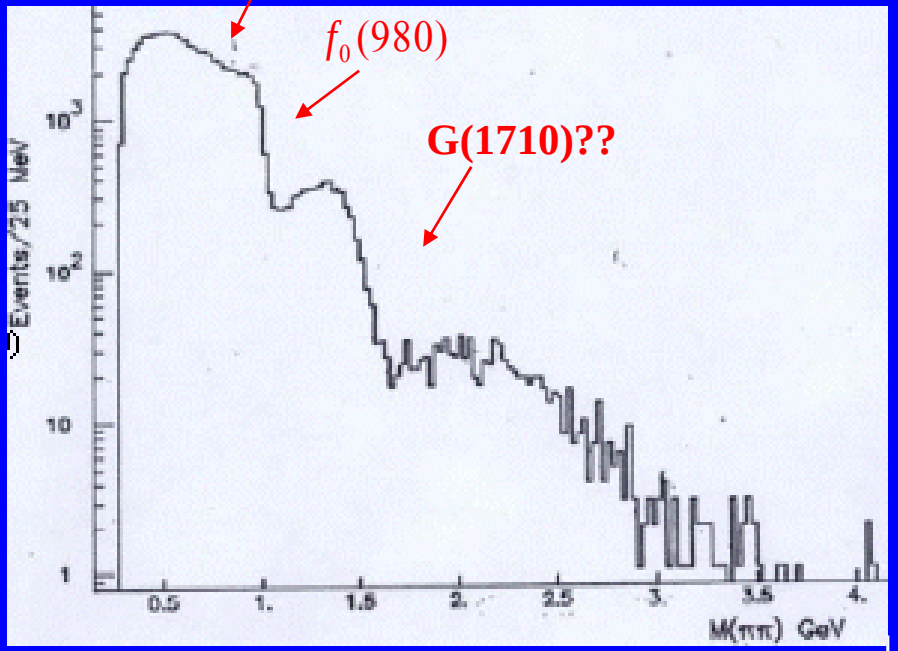
pp → p X p
X fully measured

ISR $\sqrt{s}$ **= 63 GeV**



Search for "Glueballs"
$\{gg\}$ as distinct from $\{q\bar{q}\}$

No ρ, broad $\sigma(600)$?



Structures not well understood beyond f(980).
Not studied at higher $\sqrt{s}$

… and

$\alpha\alpha \to \alpha + \pi^+\pi^- + \alpha$

coherence!

Central Exclusive Production of Higgs Bosons

Gluon-gluon fusion: main channel for H production.

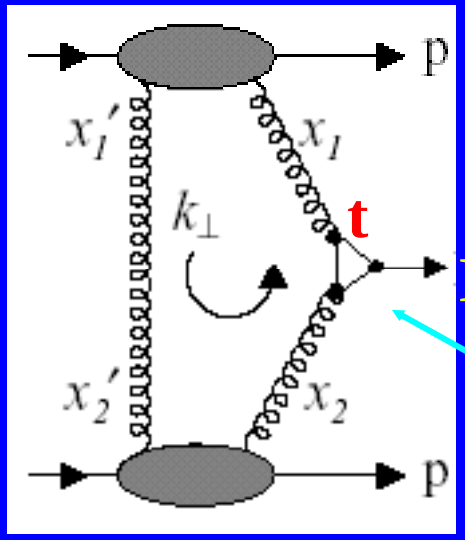
Another gluon-exchange can cancel color, even leave p intact.

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

Theoretical uncertainties in cross section.

→Probably $\sigma(SMH) < 0.1$ fb at Tevatron, not detectable, but may be possible at LHC (higher L and σ= 1-10 fb?)

LHC (2-3 years) ~ 30/fb



u-loop : $\gamma\gamma$	c-loop : χ_c^0
b-loop : χ_b^0	t-loop: H

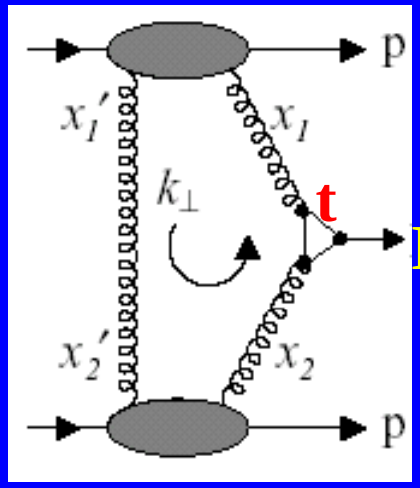
Theory can be tested, low x gluonic features of proton measured with exclusive $\gamma\gamma$, χ_c^0 and χ_b^0 production.

Hadrons with same quantum numbers as Higgs.

Central Exclusive Production of Higgs

Higgs has vacuum quantum numbers, vacuum has Higgs field.
So pp → p+H+p is possible ***in principle***.
Allowed states: $I\,J^{PC} = 0\ \text{even}^{++}$

J >= 2 strongly suppressed at small p angle (t)



If measure p's:

4-vectors

$$M_{CEN} = \sqrt{(p_1 + p_2 - p_3 - p_4)^2} \longrightarrow \sigma(M_H) \approx 2\ \text{GeV per event}$$

Even for $H \to W^+W^- \to l^{\pm}\nu JJ$!

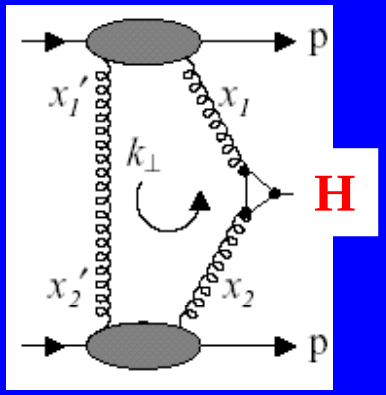
MGA+Rostovtsev: hep-ph/0009336

Aim: be limited by incoming beam momentum spread
{& can even that be reduced?}

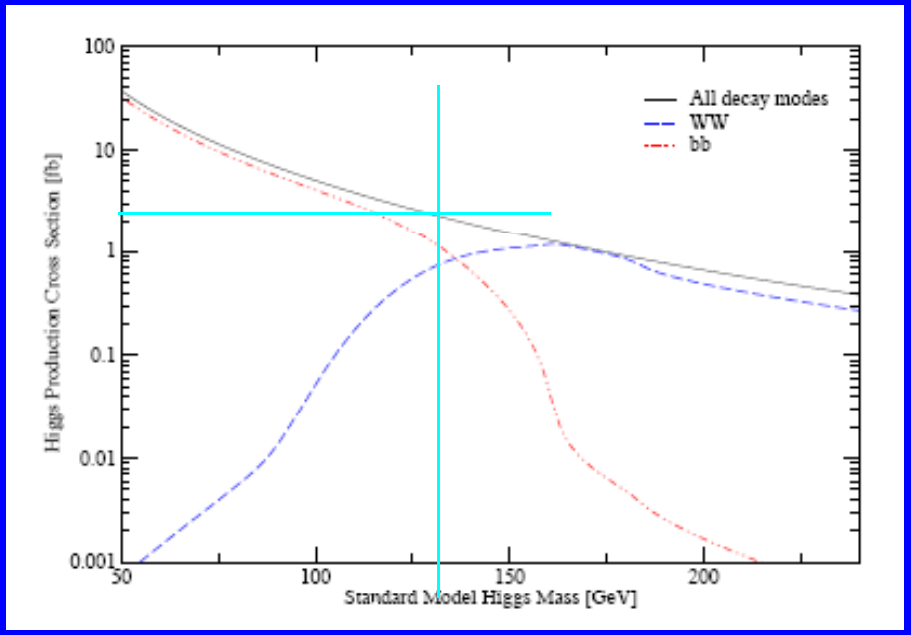
$$\frac{\sigma_p}{p} \approx 10^{-4} = 0.7\ \text{GeV}$$

What is exclusive H cross section?

$$\sigma[pp \rightarrow p + H + p](M_H), \sqrt{s} = 14\ \text{TeV}$$



Calculation involves:
gg → H (perturbative, standard, NLO)
Unintegrated gluon densities $g(x_i).g(x_i')$
Prob.(no other parton interaction) ("Gap survival")
Proton form factor
Prob.(no gluon radiation → no hadrons) ***Sudakov Suppression***



Durham Gp: Khoze, Martin, Ryskin, Stirling
hep-ph/0505240 ++

σ ~ 3 fb (M(H)=130 GeV)
"factor ~ 3 uncertainty"

➡ 33 fb^-1 → 100 Ae events
(Ae = acceptance, efficiency)

But other estimates differ by "large" amounts!
Need to calibrate theory!

Exclusive Theory Calibration: Exclusive 2-Photon

MGA et al. (2001) hep-ex/0511057

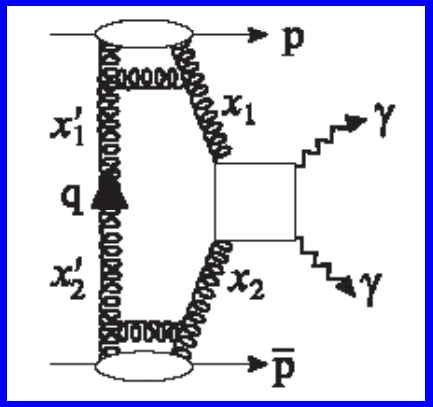
Khoze, Martin and Ryskin, hep-ph/0111078, Eur.Phys.J. C23: 311 (2002)
KMR+Stirling hep-ph/0409037

QCD diagram identical to pHp

$M(\gamma\gamma) \sim 10 - 20$ GeV

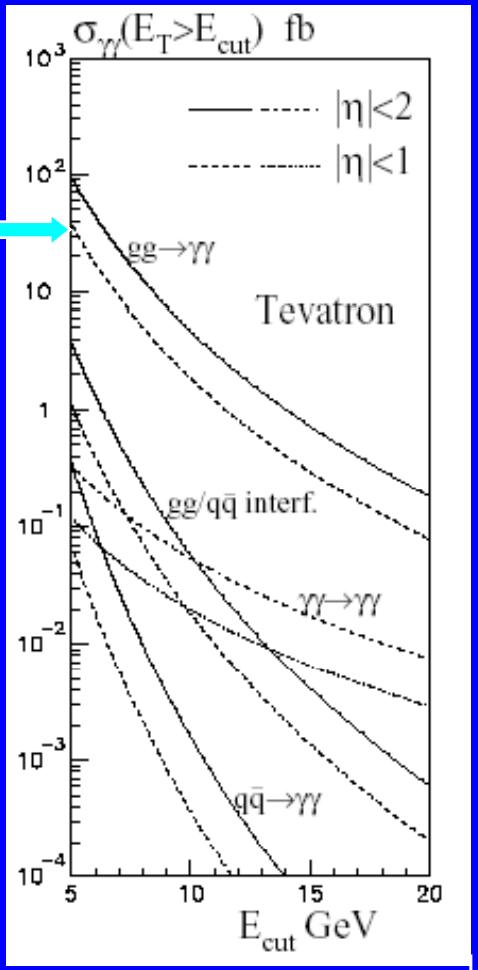
x_1, x_2 similar, Q^2 lower

top $\rightarrow$ u,c (mainly)



Tevatron

38 fb



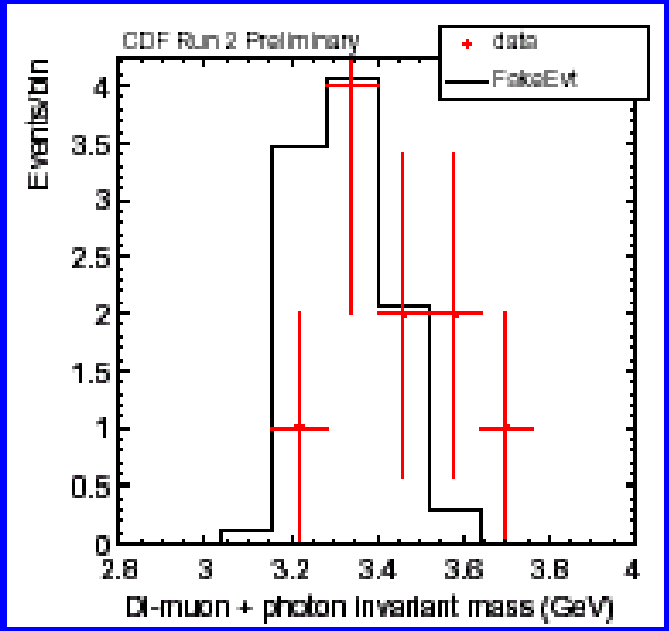
~ 40 events per fb^{-1} with $p_T(\gamma) > 5$ GeV/c & $|\eta| < 1.0$

Claim factor ~ 4 uncertainty ; Correlated to p+H+p

$\gamma\gamma \rightarrow \gamma\gamma$ & $q\bar{q} \rightarrow \gamma\gamma$ much smaller

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

Predictions for Tevatron ~ 600 nb (~ 20 Hz!)
Angela Wyatt study (but she left!)



Candidate events

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

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

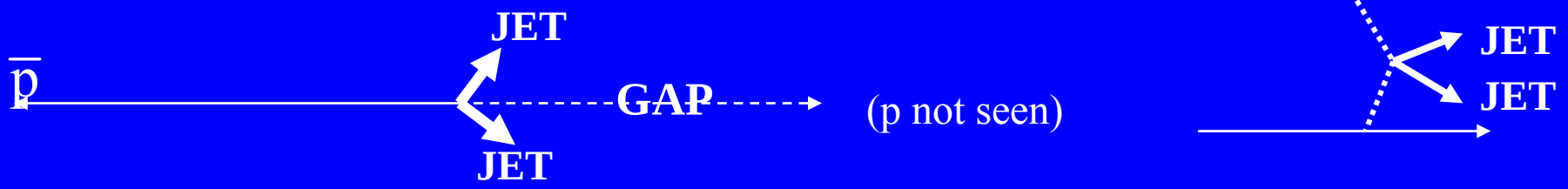
$\Rightarrow$ few pb (1000's in 1 fb^{-1})

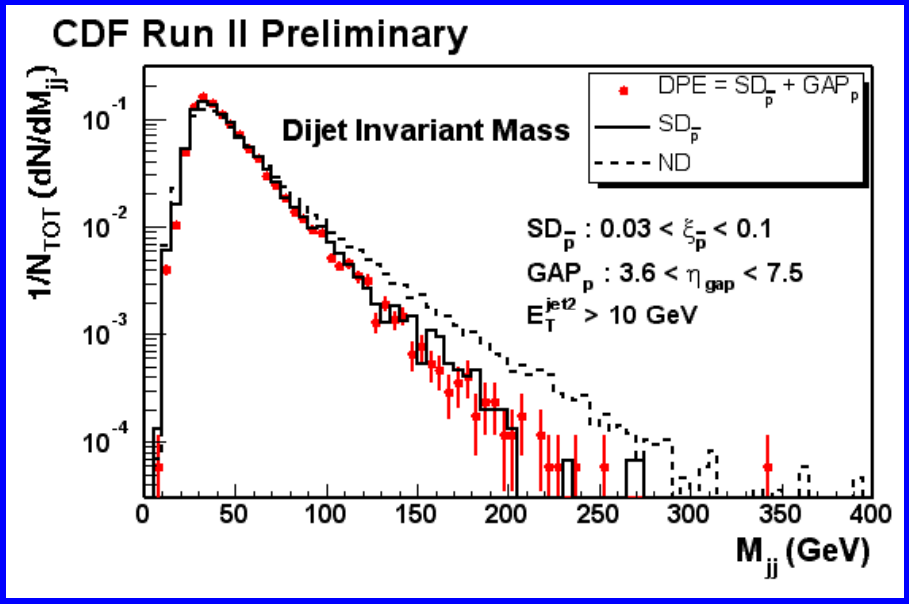
Difficulty is soft photons, and "background"
From photoproduction: $\gamma + IP \rightarrow J/\psi$

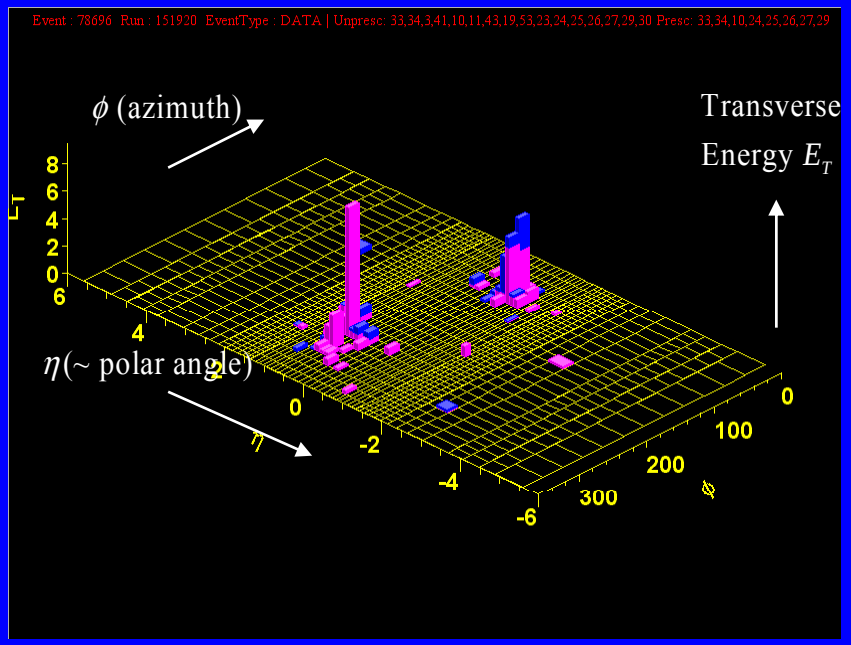
{Measuring forward p → central quantum numbers
2+ forbidden at t=0 for $q\bar{q}$ state}

$I^G J^P = 0^+ 0^+$ ← Isotopic spin, spin, G-parity, parity same as Higgs boson

Double Diffractive Di-Jets in CDF







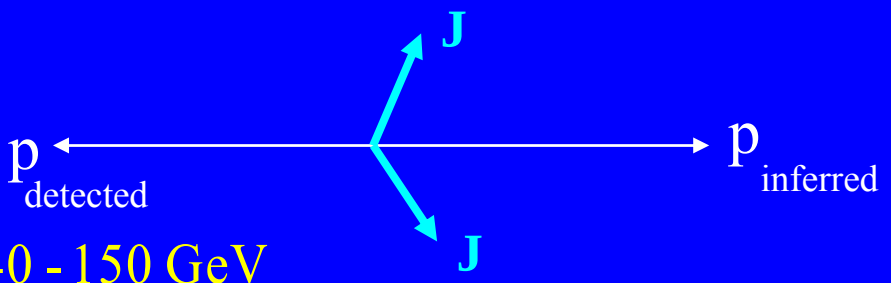
"Almost" exclusive di-jet,
Two jets and nothing else

$$\frac{M_{JJ}}{M_{CEN}} > 0.8$$

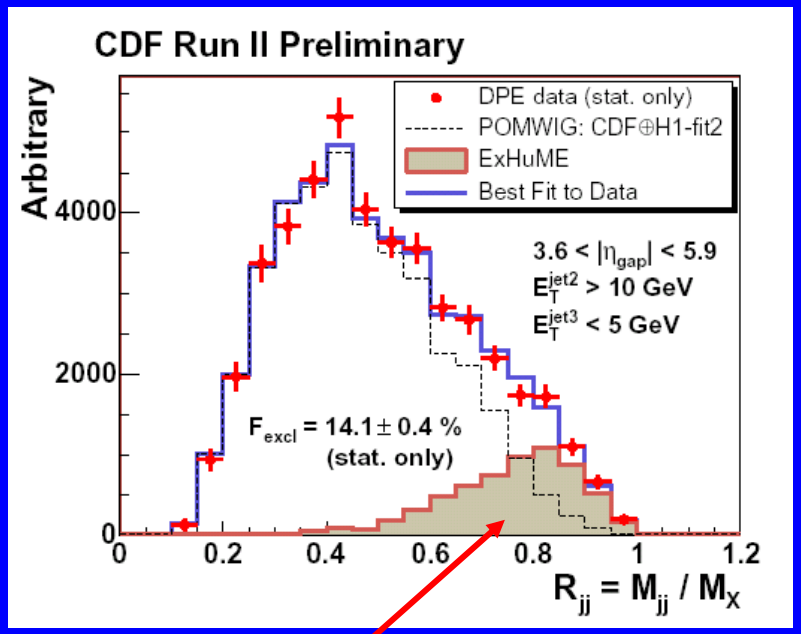
Jet <ET> spectra ~ same in SD and DPE

CDF Search for Exclusive Dijets (2 central jets + "nothing")

$$R_{JJ} = \frac{M_{JJ}}{M_X} \approx 1.0$$

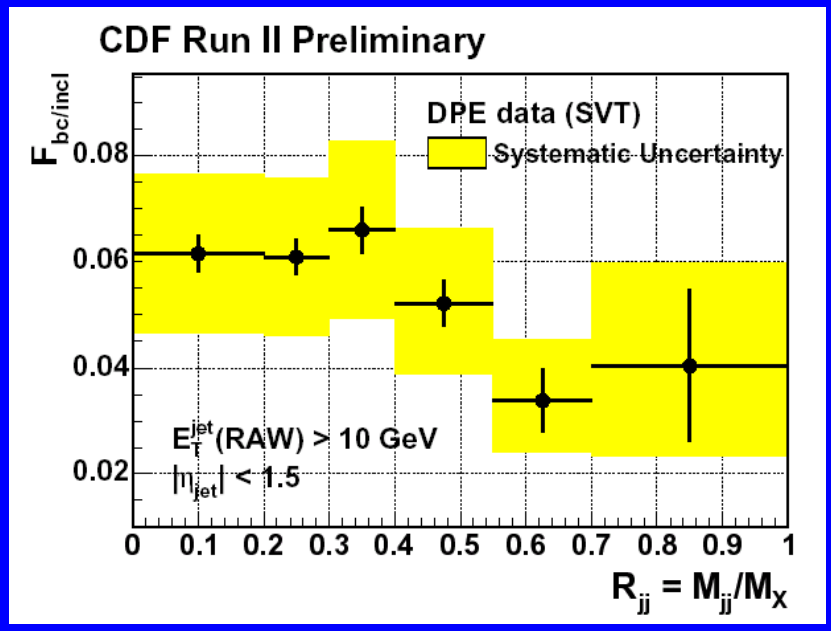


M_X = total central mass $M_{JJ} \approx 40 - 150$ GeV



ExHuME: MC with exclusive di-jets.

Cross section comparison not yet done



Apparent b-jet suppression as they become exclusive ?
(Theoretically → 0 as Rjj → 1, Jz=0 rule)
Greatly reduces QCD background

Exclusive 2-photon Search in CDF

$$p\bar{p} \rightarrow p + \gamma\gamma + \bar{p}$$

Cannot detect protons. Need to look for $\gamma\gamma$ + nothing.
Trigger on 2 EM4 showers + forward BSC1veto. $(5.4 < |\eta| < 5.9)$
Require all calorimetry and Beam Shower Counters $(-7.4 < \eta < +7.4)$
in pedestals except 2 EM showers > 5 GeV. (1.2 mrad)

Can only use events with no other collisions in bunch crossing.
→ "exclusive efficiency" = 0.086

~ 2.10^6 triggers in 532 pb^{-1} delivered, $L_{effective(si)} = 46\ pb^{-1}$

19 events have 2 EM showers with
E_T > 5 GeV and $|\eta| < 2.0$ + nothing else

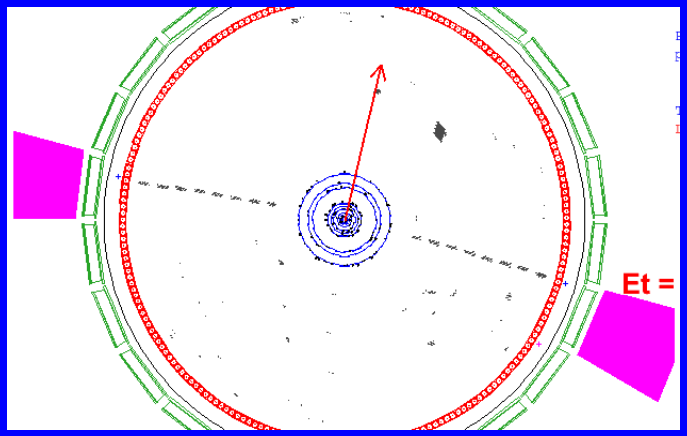
No track requirements yet ...

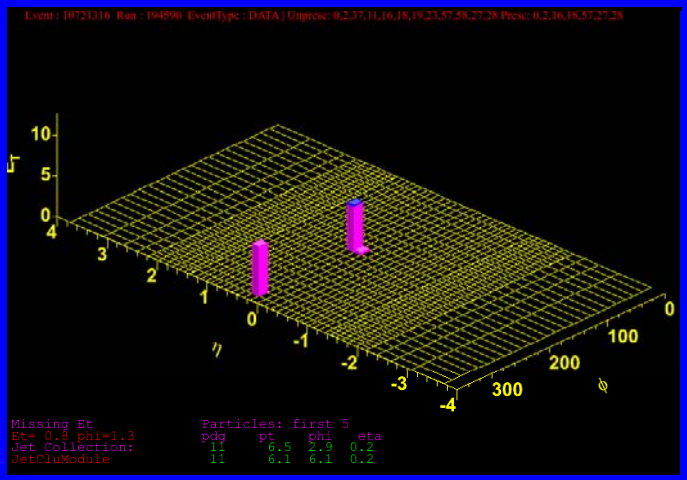
16 events were like this:

e^+e^- : $\Delta\phi = 180^0 \pm 2^0$

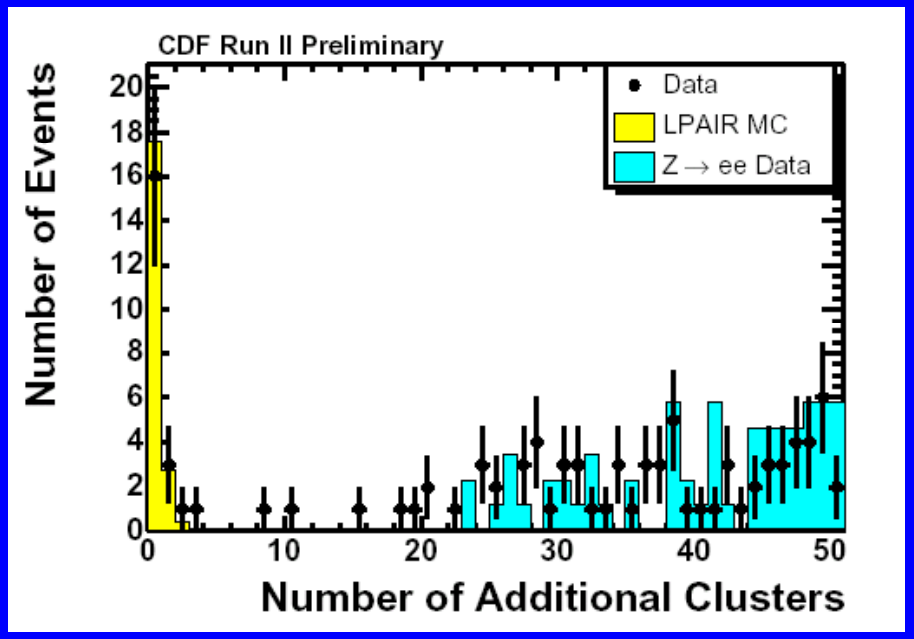
$M(e^+e^-)\,10 \rightarrow 38$ GeV

Δp_T small ($\cong$ resolution)

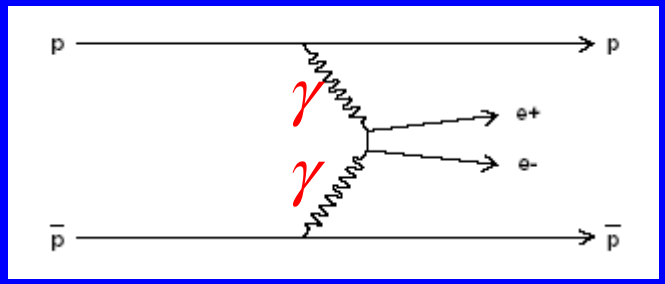




Different fits → "exclusivity background" under 0 peak 0.3 ± 0.1



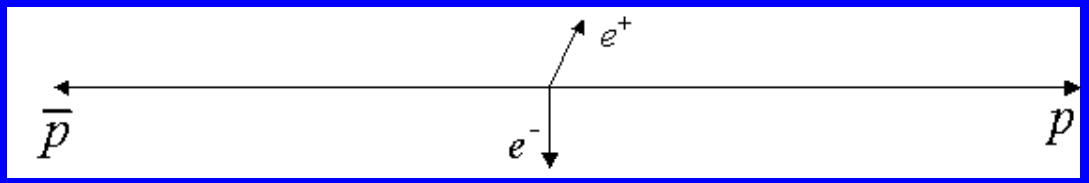
QED process : $\gamma\gamma$ collisions!



Monte Carlos : LPAIR, GRAPE

Observation of Exclusive Electron-Positron Production in Hadron-Hadron Collisions

PRL 98, 112001 (2007)
hep-ex/0611040



16 events observed $E_T(e^{\pm}) > 5\ \mathrm{GeV};\ |\eta(e^{\pm})| < 2.0$

Estimated background $= 1.9 \pm 0.3$

(mostly p-dissociation) $\Leftarrow$ all products $|\eta| > 7.4$

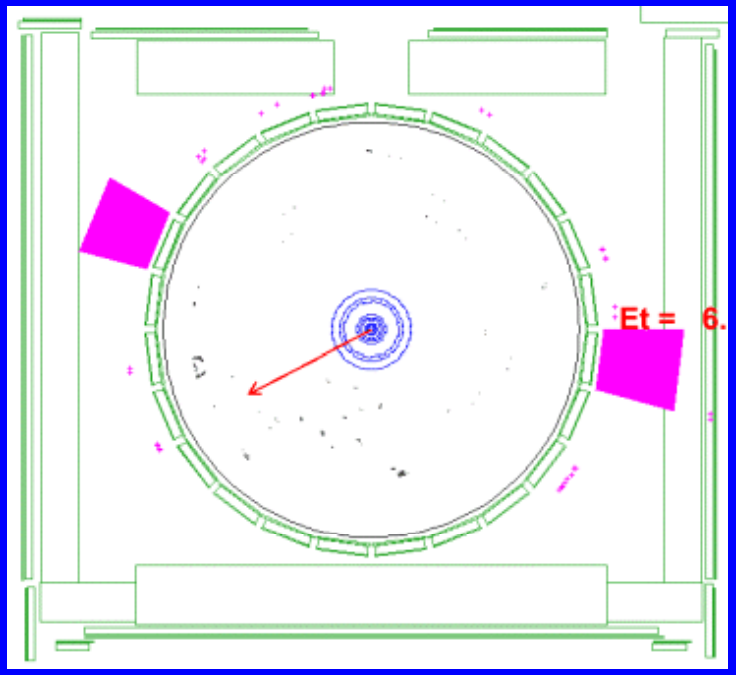
$\sigma_{MEAS.} = 1.6\ ^{+0.5}_{-0.3}\ (\mathrm{stat}) \pm 0.3\ (\mathrm{syst})\ \mathrm{pb}$ $\quad y_{beam} = 7.65$

p-value $= 1.3 \times 10^{-9} (\equiv 5.5\sigma)$

QED: LPAIR Monte Carlo: $\sigma_{\mathrm{QED}} = (1.711 \pm 0.008)\ \mathrm{pb}$

(Excellent agreement gives confidence in technique)

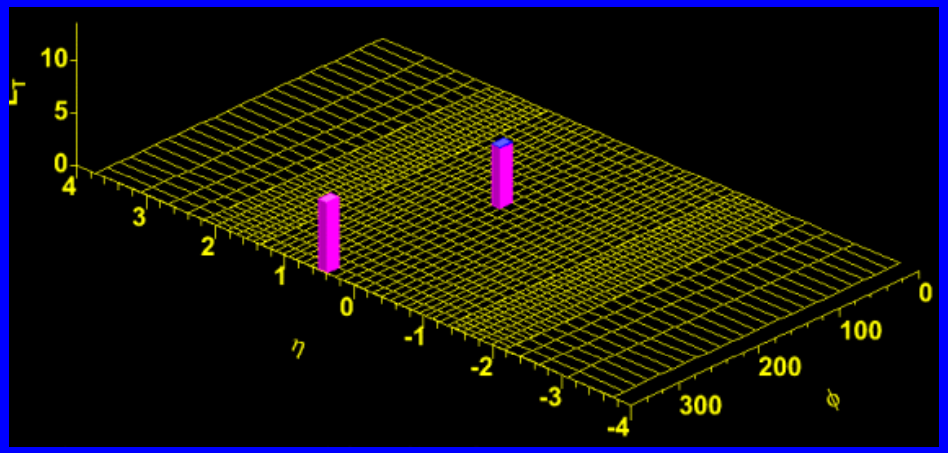
3 events were like this:



$\gamma\gamma / \pi^o\pi^o$: $\Delta\phi > 175^0$

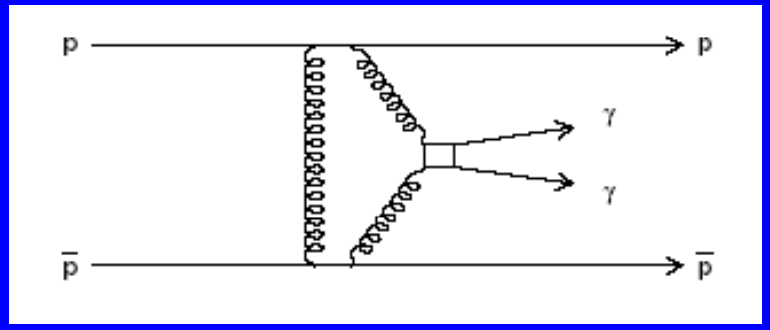
$M(\gamma\gamma / \pi^o\pi^o)\,10 \rightarrow 12$ GeV

ΔE_T small



QCD +QED process

$gg \rightarrow \gamma\gamma$



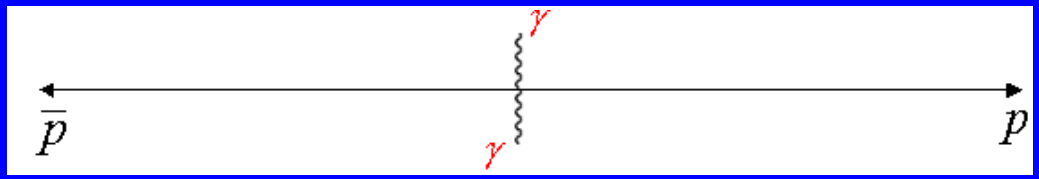
ExHuME Monte Carlo

James Monk &

Andy Pilkington (MCR)

Exclusive $\gamma\gamma$ Production in Hadron-Hadron Collisions

Draft with CDF



Exclusive $\gamma\gamma$ pairs

3 candidates observed $E_T(\gamma) > 5$ GeV; $|\eta(\gamma)| < 1.0$

Actually 2 events are good $\gamma\gamma$ candidates

and 1 is a good $\pi^0\pi^0$ candidate.

(Remember $\pi^+\pi^-$ at ISR)

Results just "blessed" by CDF

Can the 3 candidates be exclusive $\pi^0\pi^0$ or $\eta\eta$ rather than $\gamma\gamma$?

$\gamma\pi, \gamma\eta$ are forbidden by C-parity

$\pi\eta$ is forbidden by isospin

Theory (Durham): $\pi^0\pi^0 / \gamma\gamma \approx 0.25$ and $\eta^0\eta^0 / \gamma\gamma \approx 1$

We will give an upper limit on the $\gamma\gamma$ cross section, which is valid independent of the $\pi^0\pi^0$ and $\eta\eta$ background in the 3 candidates.

Note : $\sigma_{MEAS} \approx 2\times10^{-12}\sigma_{INEL}$!

Conclusion: We have observed:

3 candidates for exclusive $(\gamma\gamma + \pi^0\pi^0 + \eta\eta)$ production

May be mixture

$\mathrm{B/G} = 0.09 \pm 0.04;\ \mathrm{P}(\geq 3) = 1.7 \times 10^{-4} \equiv 3.7\sigma$

$\sigma(\gamma\gamma) < 410$ fb (95% c.l.)

A, B favor $\gamma\gamma$ and C favors $\pi^0\pi^0$

If we assume that 2 of the 3 candidates are gamma-gamma events we obtain a cross section: $\sigma(2 \text{ events}) = (90^{+120}_{-30} \pm 16)$ fb

cf **Durham Group Khoze, Martin, Ryskin & Stirling hep-ph/0507040 Eur.Phys.J C38 (2005) 475 : 40 fb with factor 3 uncertainty**

Existence of exclusive $\gamma\gamma$ implies that exclusive H must exist (if H exists)

Agreement with Durham group suggests H cross section at LHC in reach

Central Exclusive $\mu^+\mu^-$ Production

Why interesting?

Among other things:

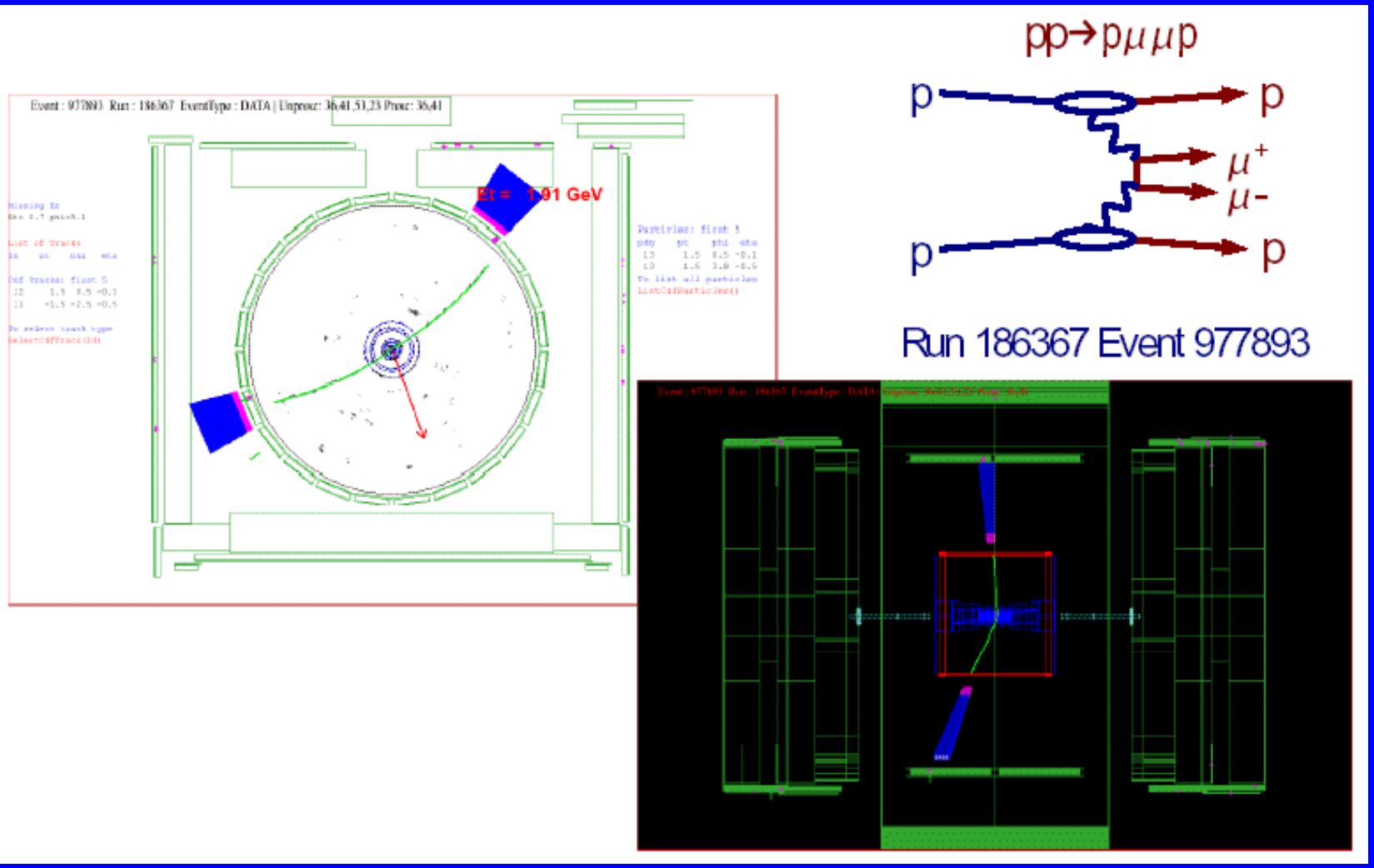
Two-photon production: $\gamma\gamma \to \mu^+\mu^-$ continuum.

Cross section very well known (QED) so can calibrate LHC luminosity, if can do with pile-up.

Forward proton momenta precisely known: calibrate momentum scale of forward spectrometers.

We installed a trigger: μ + track + forward gaps (BSC1)

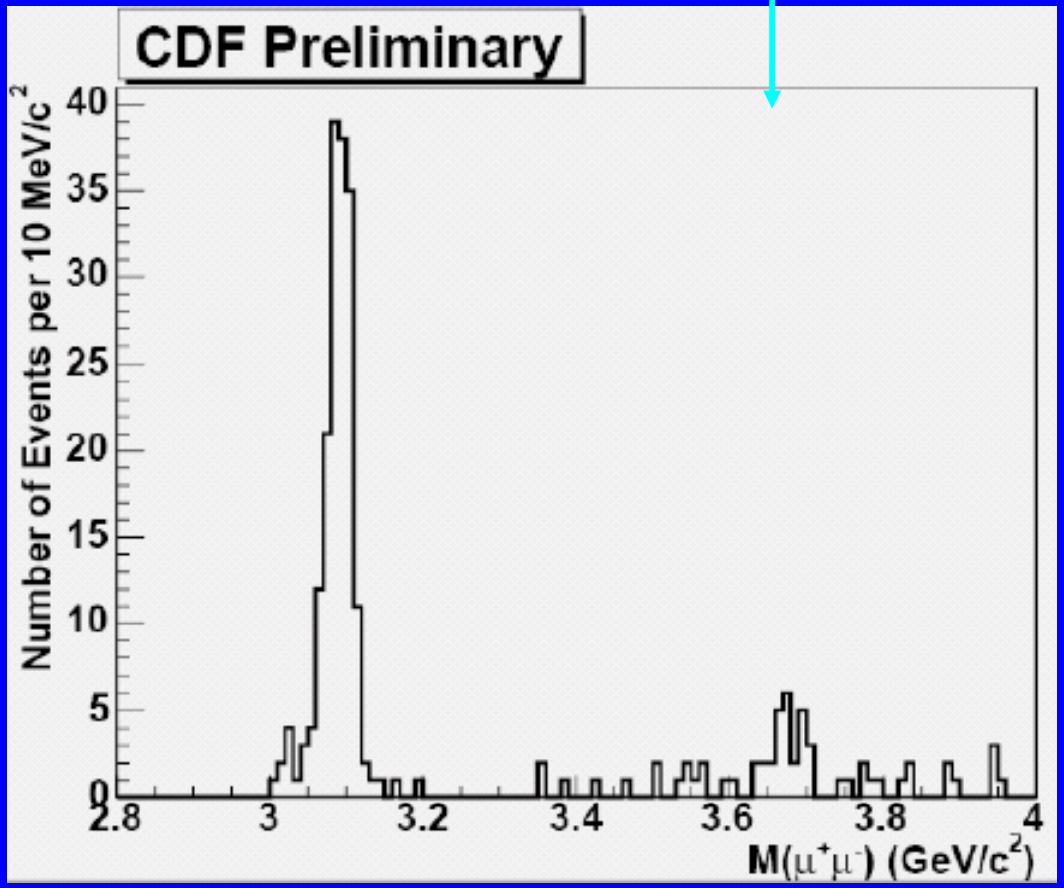
Being studied. Have candidates:



Preliminary spectrum: Exclusive di-muon candidates

J/psi : photoproduction
(1st time in hadron-hadron)

psi(2S)(3686)



Continuum (2-photon)

Acceptance rising strongly through M-range

Search for exclusive $\mu^+\mu^-$ in presence of pile-up.

Potential use as luminosity calibrator. (But can be done with lowish luminosity.)

Inclusive di-muon trigger (no gap requirement, no pre-scales)

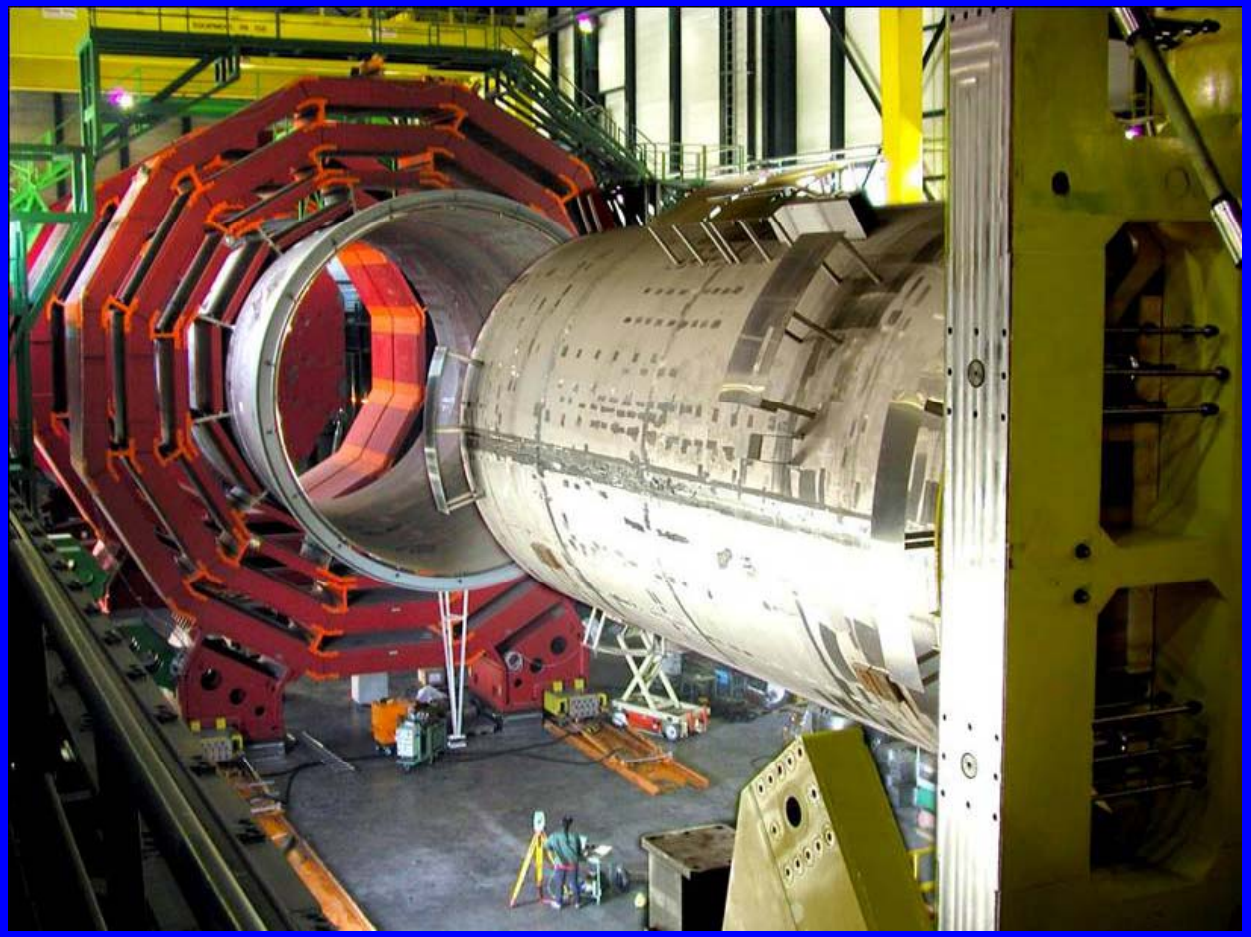
$$p_T(\mu^+) = p_T(\mu^-)$$
$$\Delta\phi(\mu^+\mu^-) = 180^0$$
$$n_{associated}(tracks) = 0$$

(because in 2-photon (Coulomb) process, p's have very small pT)

If see associated p (at LHC), know its momentum to < 10^-4
Calibrate forward proton spectrometers

FP420 : Forward Protons 420m downstream of CMS & ATLAS

Hopefully both

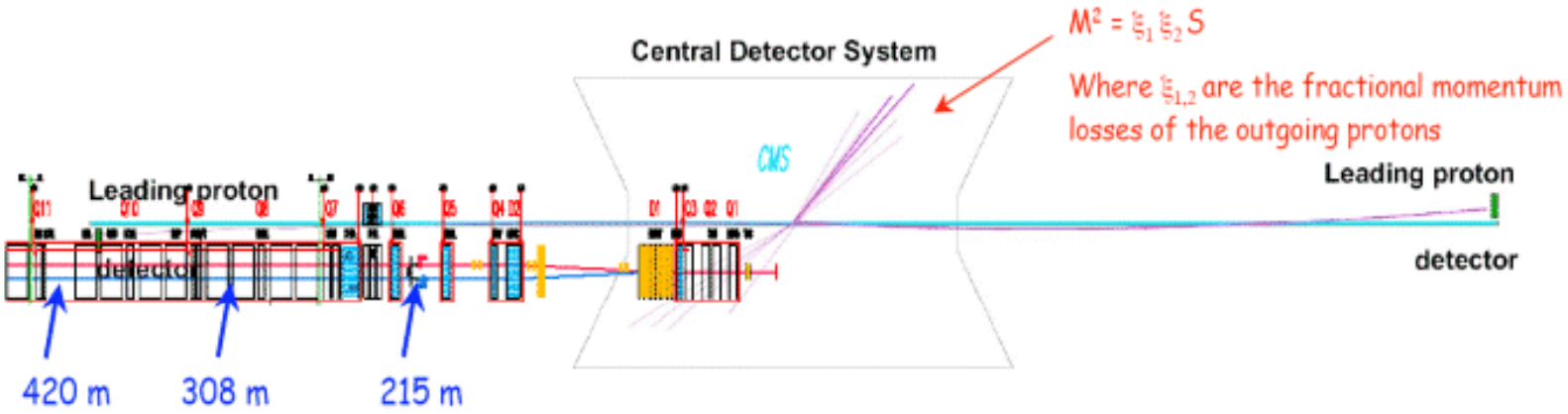


CMS: Inner Vacuum Tank insertion

Very Forward Proton Detectors (& Momentum Measurement)

& FP420

Roman pot acceptances



Straight Section

Low β*: (0.5m): Lumi 10^{33}-10^{34} $cm^{-2}s^{-1}$

220m: $0.02 < \xi < 0.2$

300/400m: $0.002 < \xi < 0.2$

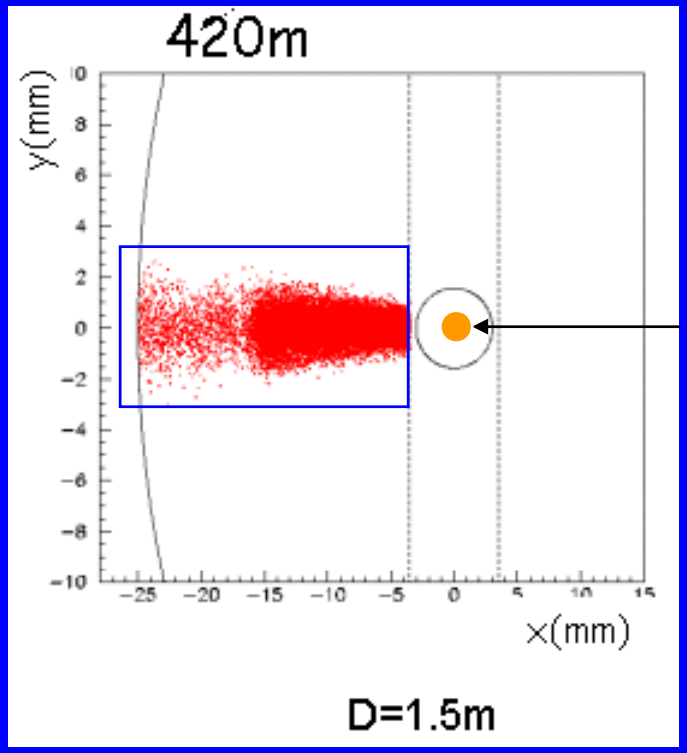
~~(RPs in the cold region/ under discussion in CMS/ATLAS)~~

Measure distance of track from beam (5-10 um) and slope (~5-10 um over 10 m) → fractional momentum loss ξ

Protons, in x and y at detector

Generated flat in $\ln \xi, \ln x$

Normal Low-β operation

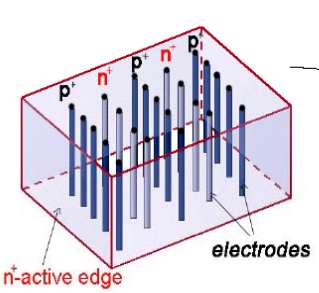


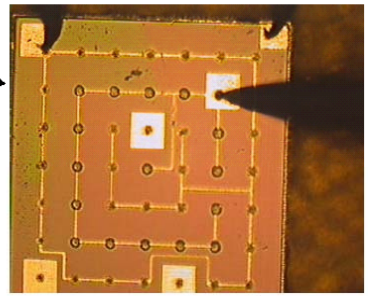
Note: A detector 6mm(y) x 24mm (x) covers distribution.

3D Si Tracking, Cerenkov Fast Timing

Resolution
Rad hardness
Edgelessness
Speed, S/N
Availability
Enthusiasts!

3D DETECTORS AND ACTIVE EDGES Brunel, Hawaii, Stanford



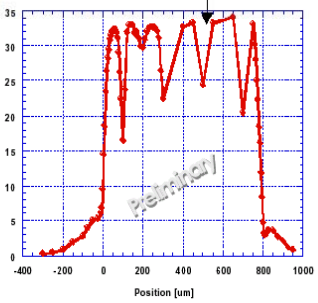


❖EDGE SENSITIVITY	<10 μm
❖COLLECTION PATHS	~50 μm
❖SPATIAL RESOLUTION	10-15 μm
❖DEPLETION VOLTAGES	< 10 V
❖DEPLETION VOLTAGES at 10^{15}n/cm²	~105 V
❖SPEED AT RT	3.5 ns
❖AREA COVERAGE	3X3 cm²
❖SIGNAL AMPLITUDE before Irradiation	24 000 e
❖SIGNAL AMPLITUDE at 10^{15}n/cm²	15 000 e⁻

❖15 μm InfraRed beam spot
❖FWHM = 772 μm
❖Edge Al strip width = 16 μm

INSENSITIVE EDGE (INCLUDING 16 μm Al STRIP):

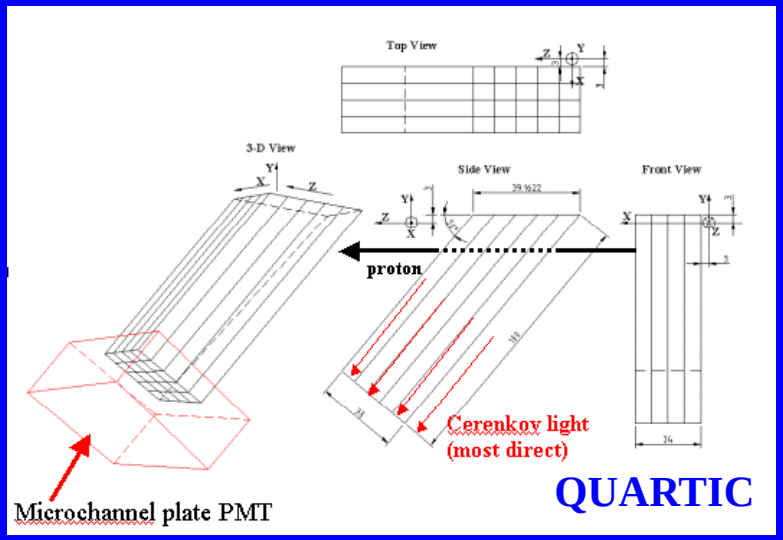
(813 - 772) / 2 = 21 μm



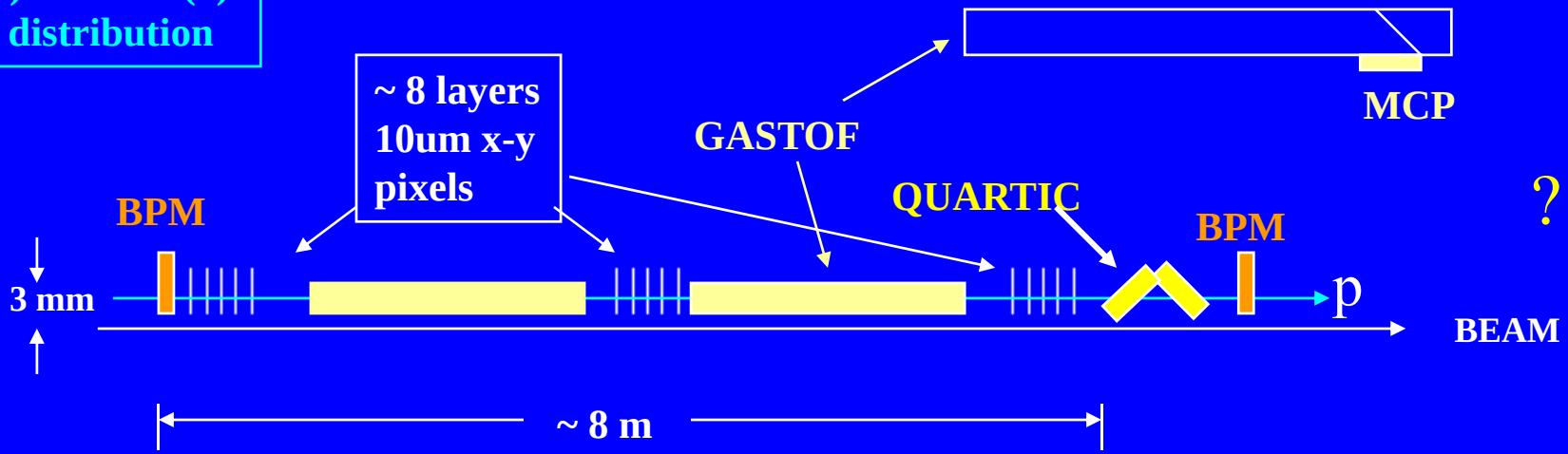
❖CERN Courier, Vol 43, Number 1, Jan 2003

$\sigma_{TOF}(z) \approx 4.2 \rightarrow 2.1$ mm

cf σ_Z(interactions) ≈ 52 mm



6mm(y) x 24mm (x) covers distribution



Fast Timing Counters: GASTOFs and QUARTICs

Pile-Up background: p's, JJ or WW from different collisions

Counters with ~ 10 ps timing resolution behind tracking

10 ps = 3 mm $\qquad \frac{3mm}{\sqrt{2}} = 2.1mm$

1) Check both p's from same collision (reduce background)
2) Get z(vertex) to match with central track vertex
3) Tell what part of bunches interacting protons were (F-M-B)

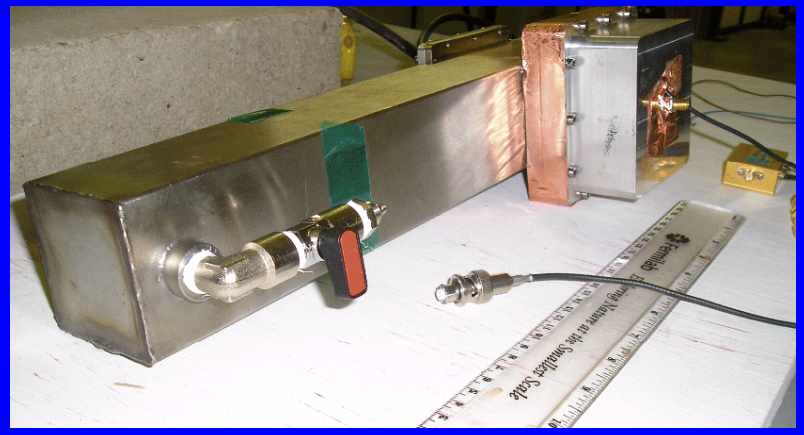
Likely solution:
Cerenkov light in gas or quartz (fused silica) bars →
MCP-PMT (Micro-Channel Plate PMT) (or Si-PMT?)
Also possible (?): 3D-silicon optimised for timing

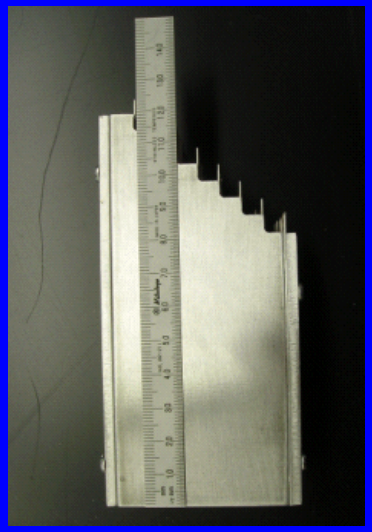
Precision Timing: Testing GASTOF and QUARTIC Prototypes

Had 1st round test beam studies at Fermilab. 2nd round Feb-March

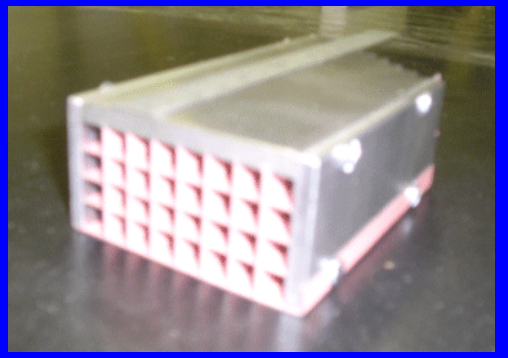
Results not yet final… need good tracking for x,y corrections (2mm = 10um)

GASTOF (U.Louvain) … real is smaller

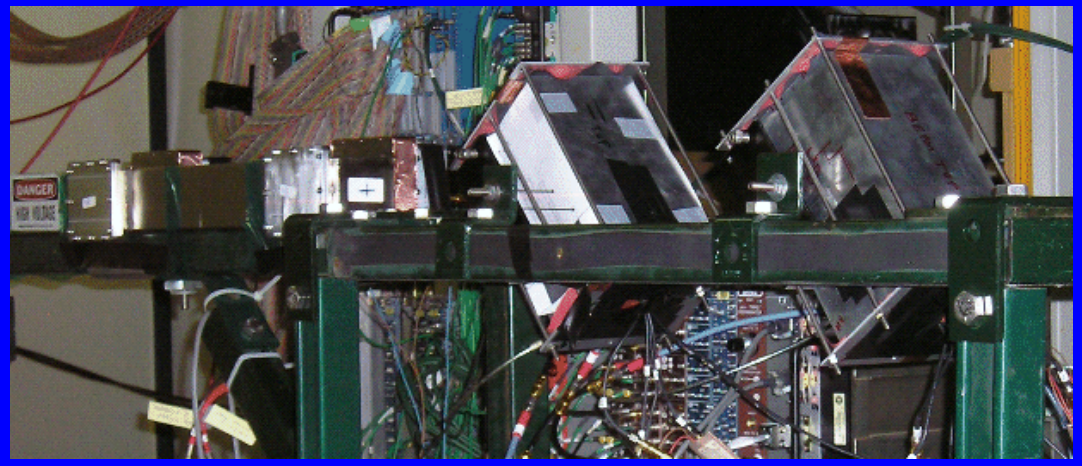




QUARTIC2



Test beam setup



Exclusiveness brings many rewards. H → Jet Jet case

$$M_{CEN} = \sqrt{(p_1 + p_2 - p_3 - p_4)^2}$$

Two jets' E_T are the same to ~ 1 GeV, $\Delta\phi = 180^0$

and, knowing that and η_1, η_2 and $\xi_1(220)$

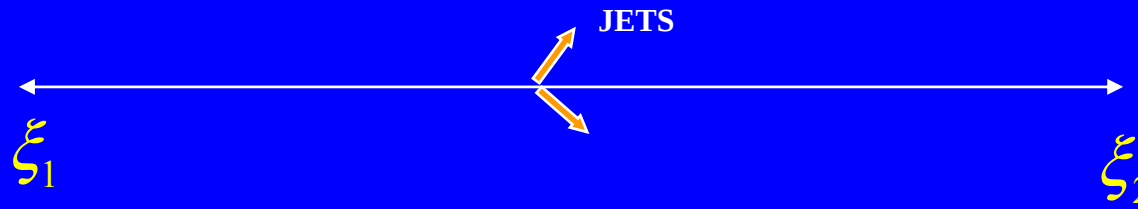
in L1 trigger (fast look-up) can use correlation

to reduce L1 trigger rate.

$$\xi = 1 - \frac{p_z(out)}{p_z(beam)}$$

(fractional momentum loss)

$$\xi_{1(2)} = \frac{1}{\sqrt{s}} \sum_{jets} E_{Ti} e^{+(-)\eta_i}$$



420m just too far for L1 trigger. 420 + 220 + Jet info.

What is H Signal:Background? (not pile-up)

$H(120-135\ \mathrm{GeV}) \to b\bar{b}$

$H \to b\bar{b},\ W^+W^-,\ ZZ$

Inclusively, $gg \to b\bar{b}$ background overwhelming

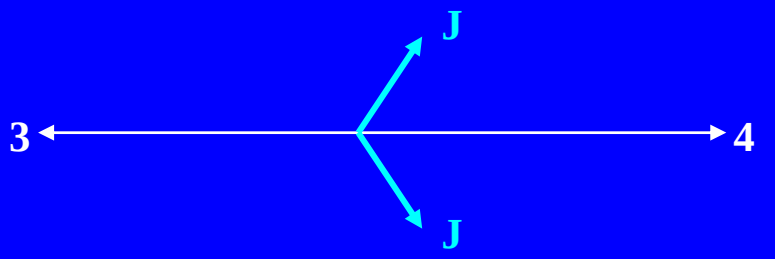
Exclusively, $pp \to p + qq + p$ (q = quark jet)

strongly suppressed at LO $\left(\sim \frac{M_q^2}{M_H^2}\right)$ by

spin selection rule $J_z = 0$.

Most "exclusive dijets" are gg

Need b-tagging, then $\frac{S}{B}(SMH) \sim 3 \times \frac{1\ \mathrm{GeV}}{\sigma(M)}$



$q\bar{q}$ dijets strongly suppressed

J = 1 forbidden, J=0 strongly favored

J = 0,2 discrimination possible

Kinematic constraints:

$E_{T,1} \approx E_{T,2};\ \phi_1 = -\phi_2$

$\xi_{3(4)} = \frac{1}{\sqrt{s}} \sum_{1,2} E_T e^{-(+)\eta}$

Trigger is issue:
Probably need asymmetric
220m + 420m and:
Eventual trigger upgrade??

$\left(\xi = 1 - \frac{p_{out}}{p_{beam}}\right)$

What is Signal:Background? H(135-200) (not pile-up)

$H(135-200\ \mathrm{GeV}) \rightarrow W^+W^-$

$\sigma_{\mathrm{incl}}(W^+W^-\ \text{non-H}) \sim 100\ \mathrm{pb}; \sigma(H) \sim 20\ \mathrm{pb}$

& M(WW) resolution v.poor ($\nu(s)$ and/or jets)

Exclusive B/G is $\gamma\gamma \rightarrow W^+W^-, \sigma \sim 50\ \mathrm{fb}$, continuum

Mass resolution $\sigma_M(WW^{(*)}) \sim 2\ \mathrm{GeV}$ *any decay*

Exclusive $H \rightarrow ZZ$, negligible B/G

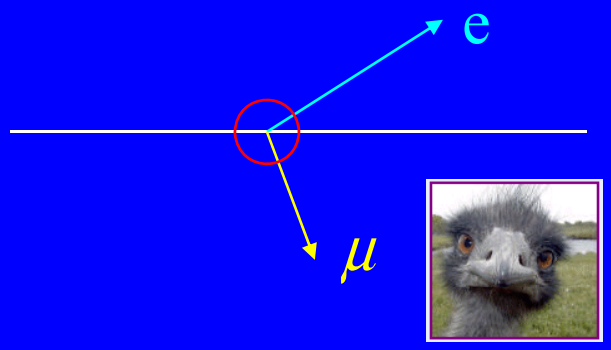
Examples: $WW \rightarrow l\nu l\nu, l = e, \mu$

NO OTHER TRACKS ON VERTEX!

(But only 4.6% of WW)

$H(160) \rightarrow W^+W^- \rightarrow p\ e^+\mu^-\not{E}_T\ p$

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

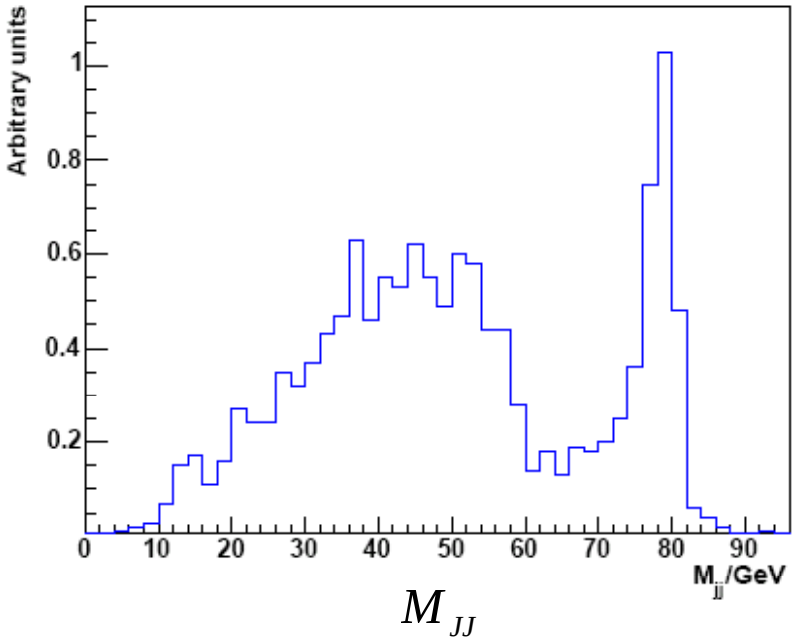


Always : $\sigma(M_{WW} \approx 2\ \mathrm{GeV})$!

What is Signal:Background? H(135-200) → WW(*)

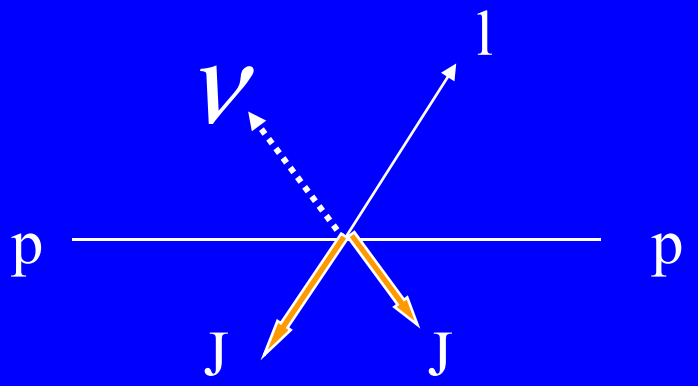
$$WW \rightarrow l\nu JJ\,,\ l = e, \mu, \tau$$

Durham Gp: Khoze, Martin, Ryskin, Stirling hep-ph/0505240



M_{JJ}

Fig. 6: The di-jet invariant mass distribution dN/dM_{jj} in the semi-leptonic decay channel $H \rightarrow WW^* \rightarrow l\nu jj$ for M_H = 140 GeV.



$MM\,(12-34JJl) \approx 0(M_\nu)$

$MM\,(12-34JJ) = M_W^{(*)}$ (even for $\tau\nu$)

$M\,(JJ) = M_W^{(*)}$

Can use ~ 50% of WW (all but JJJJ)

$$\mathrm{H}(180) \rightarrow \mathrm{ZZ} \rightarrow l^+l^-\nu\bar{\nu}\ (\mathrm{BR} \sim 10 \times l^+l^-l^+l^-)$$

$$MM\,(12-34l^+l^-) = M\,(Z_{\nu\bar{\nu}}),\ \sigma_M \sim 2\ \mathrm{GeV}!$$

!! **Unfortunately very few events (SM)**

In WW/ZZ case, central trigger effective (420+420 OK)

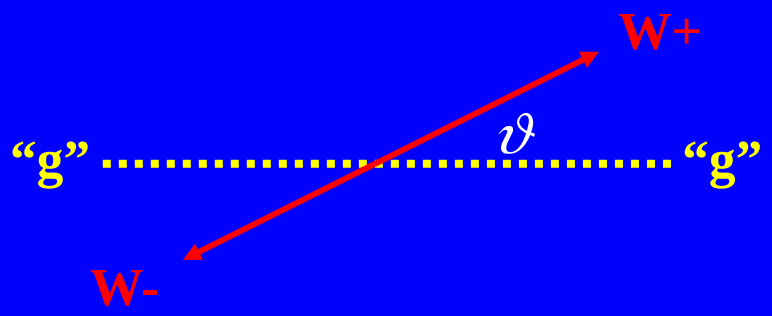
Determining Quantum Numbers of Central State (H?)

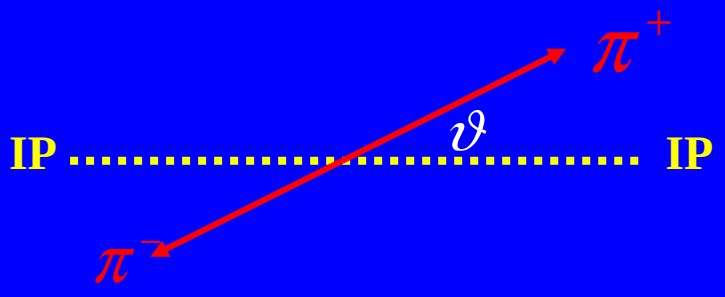
Is it J = 0, CP = ++?

In gg → X only **CP = ++** is allowed.
(a CP –ve A (MSSM) is highly suppressed)

gg → vector (J = 1) forbidden, Yang's theorem.

J = 0, 2 can be distinguished by angular distributions
→ partial wave analysis. Can even see states hidden in overall M distribution!





Moments H(LM) of the cos(ϑ) distributions → M(J=0), M(J=2).

e.g. ISR/R807 glueball search in $pp \to p + \pi^+\pi^- + p$ **NPB264 (1986) 154**

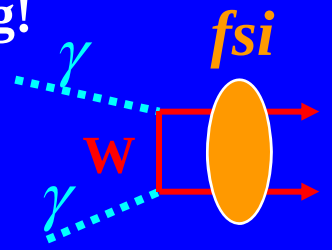
Non-SM cases : no Higgs? MSSM Higgses?

1) **No SMH?** Can we exclude? Suppose measure 100 exclusive $\gamma\gamma$ in CMS. (~ 0.1 fb^-1 effective S.I.Lum) → predict p+SMH+p to ~ 20%
Expect (say) 100 pHp events in 30 fb^-1, see < 50. Conclusion?

2) No SMH or MSSM-Hs? WW physics becomes very interesting!

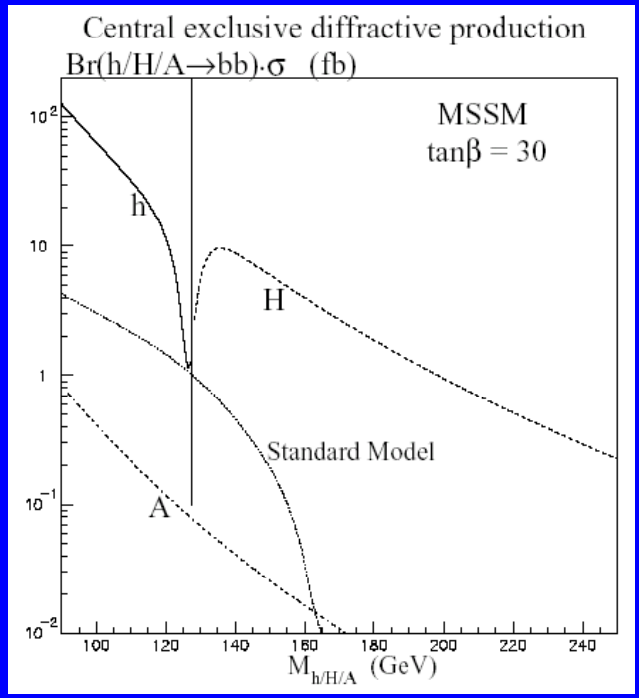
$pp \to p + W^+W^- + p$ via $\gamma\gamma \to W^+W^-$ $\quad \sigma \approx 50$fb (precisely known in SM)

W^+W^- Final State Interactions distort $\dfrac{d\sigma}{dM_{WW}}$, visibly? New physics?



Preview of ILC physics!

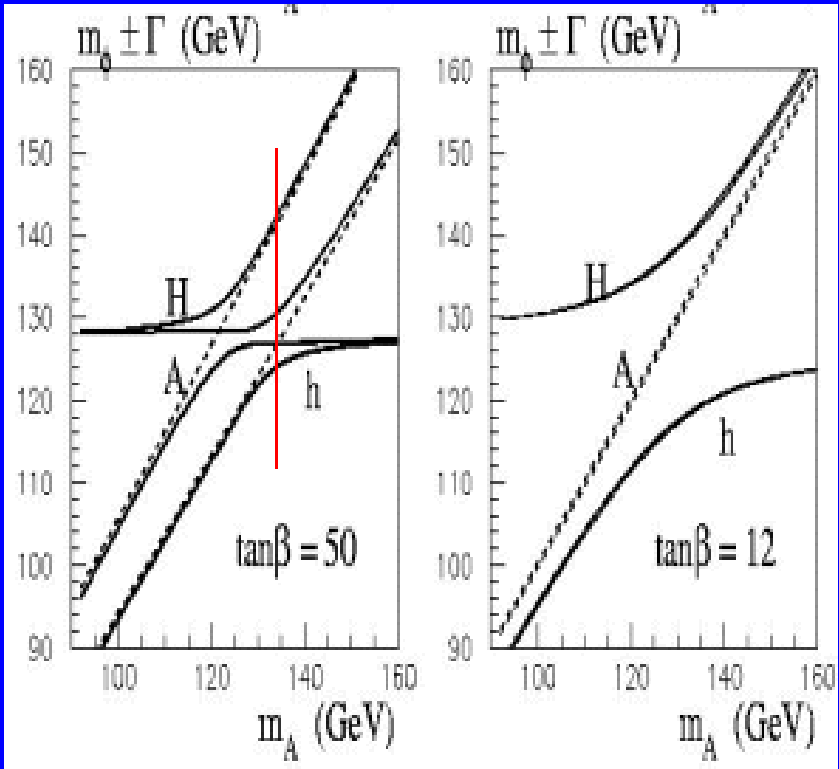
3) In case of SUSY, Forward p-tagging can be crucial! Cross section can be ***much*** higher than SMH. Decays to $b\bar{b}$ enhanced.
A(CP –ve) highly suppressed.



Kaidalov Khoze Martin Ryskin
hep-ph/0307064

MSSM

Can have {h, A, H} close together in mass (few GeV)
Hard to resolve by inclusive production.
Exclusive advantages: higher production than SM, A highly suppressed
Excellent mass resolution could separate h and H (unique)
Excellent mass resolution might even measure H widths (if ~ few GeV)



Durham Group (KMRS)

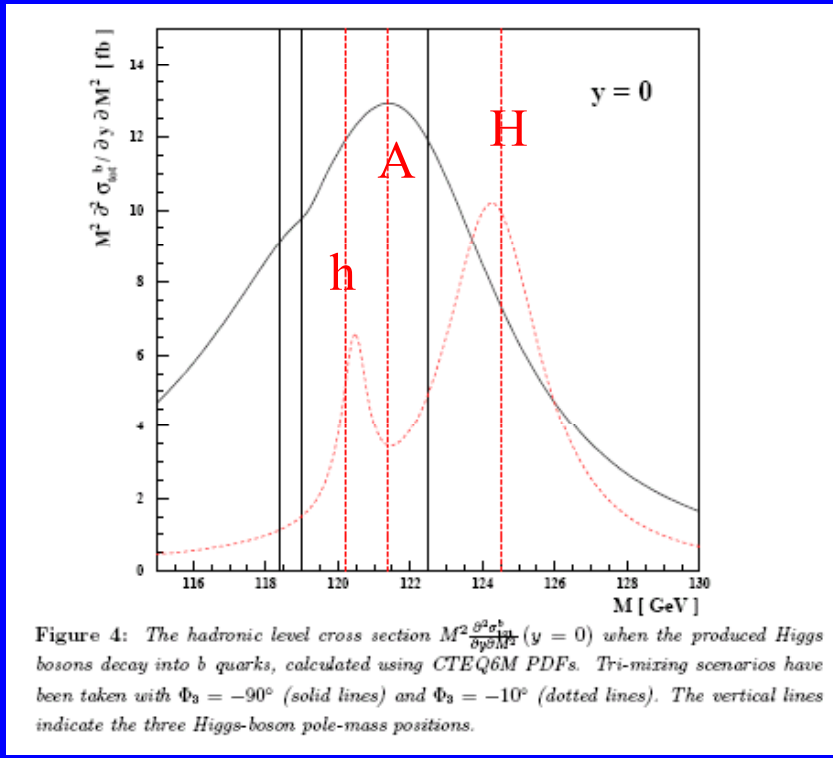


Figure 4: *The hadronic level cross section $M^2 \frac{\partial^2 \sigma^h_{tot}}{\partial y \partial M^2}(y = 0)$ when the produced Higgs bosons decay into b quarks, calculated using CTEQ6M PDFs. Tri-mixing scenarios have been taken with $\Phi_3 = -90°$ (solid lines) and $\Phi_3 = -10°$ (dotted lines). The vertical lines indicate the three Higgs-boson pole-mass positions.*

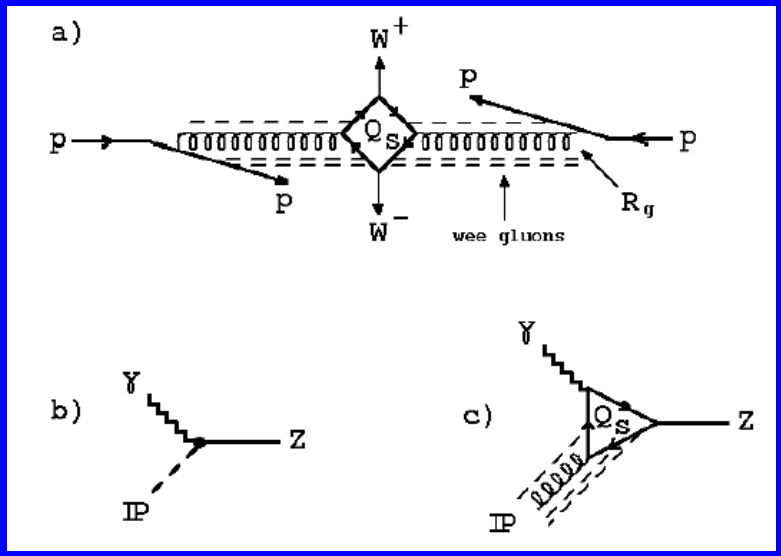
J.Ellis, J.S.Lee and A.Pilaftsis, PRD71:075007, hep-ph/0502251

BSM: The White Pomeron

Alan White (ANL)

BFKL Pomeron = 2 reggeized gluons / ladder
White Pomeron = 1 reggeized gluon + sea wee g's

Asymptotic freedom → 16 color triplet q's
Only 6 known (d u s c b t)
But (!) 1 color sextet Q counts 5 times, so
{ud}+{cs}+{tb} + {UD} works!



$\Pi = U\bar{D}$ etc, η_6 ....EWSB, role of Higgs *"composite higgs"*

Can be dark matter (N = DDU ~ TeV)

Pomeron couples strongly to WW through U,D loops

→Anomalous (quasi-diffractive) production of WW, ZZ (not WZ) production at LHC **(M(DPE@LHC) <~ 700 GeV).**
Also Z photo-production possible at LHC

Dramatic effects at LHC, especially in pp → p + WW/ZZ + p

Status of FP420 R&D Project

LOI to LHCC July 2006
Plan on TDR → LHCC,CMS,ATLAS
~ May 2007. Install in 2009-2010.

http://www.fp420.com/

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New collaborators welcome!

Detectors: timing, tracking, BPMs, DAQ, Triggering. Simulations, pre-analysis…

Summary

Any states with vacuum quantum numbers and strong or electromagnetic couplings can be produced at LHC by

Central Exclusive Production

This includes *Higgs boson(s), W-pairs*, lepton and photon pairs.
Cross section pp → p+SMH+p known to factor ~ 3 (~ 3 fb) (?)
If protons well measured, can get mass of central state to ~ 2 GeV per event, Quantum numbers (J, CP) and couplings to gg.
S:B can be good – excellent in BSM scenarios.
For good acceptance/resolution need both 220m and 420m detectors.

R&D on FP420: tiny but v.high precision tracking, timing, BPM
Best particle spectrometer ever, using part of LHC
We aim to propose this as upgrade to CMS (and ATLAS) in 2007 for installation in 2009-2010

PS →