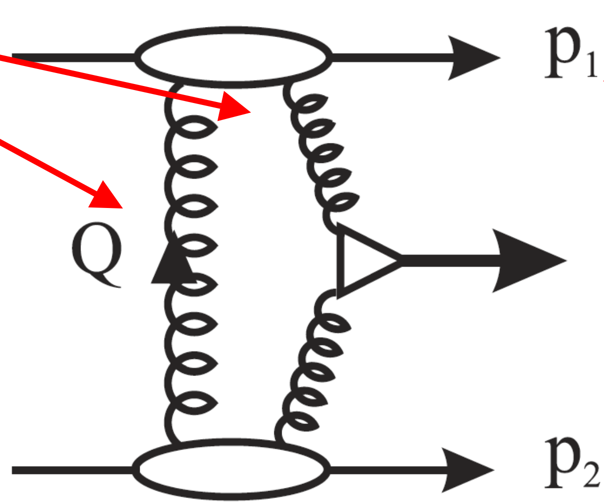
THE UNIVERSITY of MANCHESTER

Diffraction at LHC, Tevatron and HERA

Even 'normal' people are becoming interested in diffraction at the LHC …

Only 0^{++} (or 2^{++}) systems produced

$b\bar{b}$ background strongly suppressed

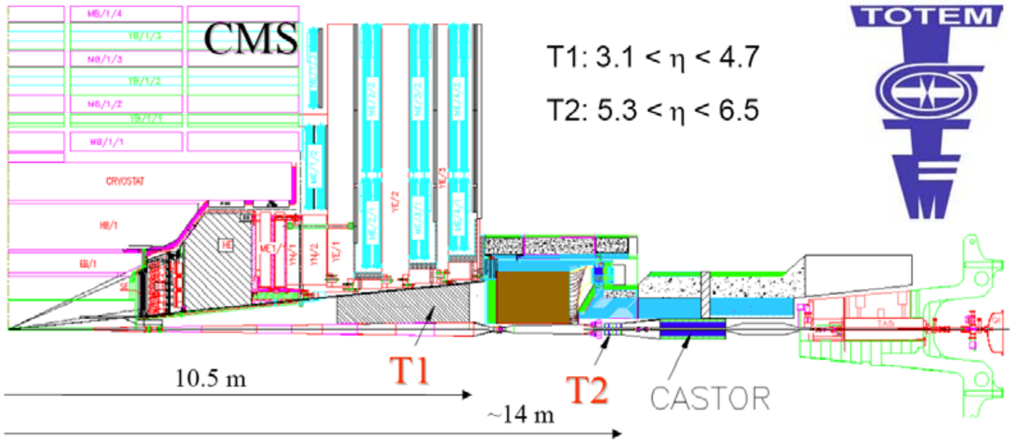


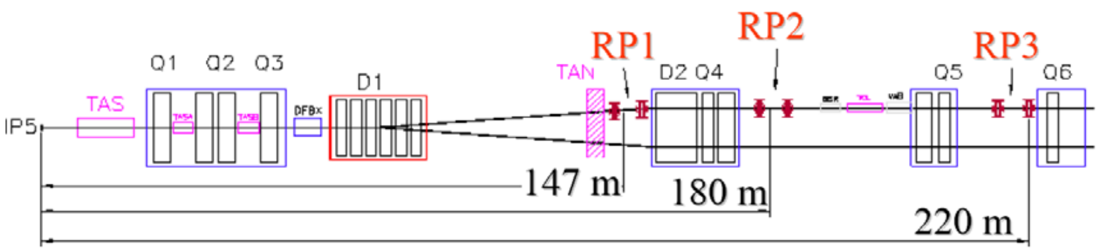
Improved mass resolution

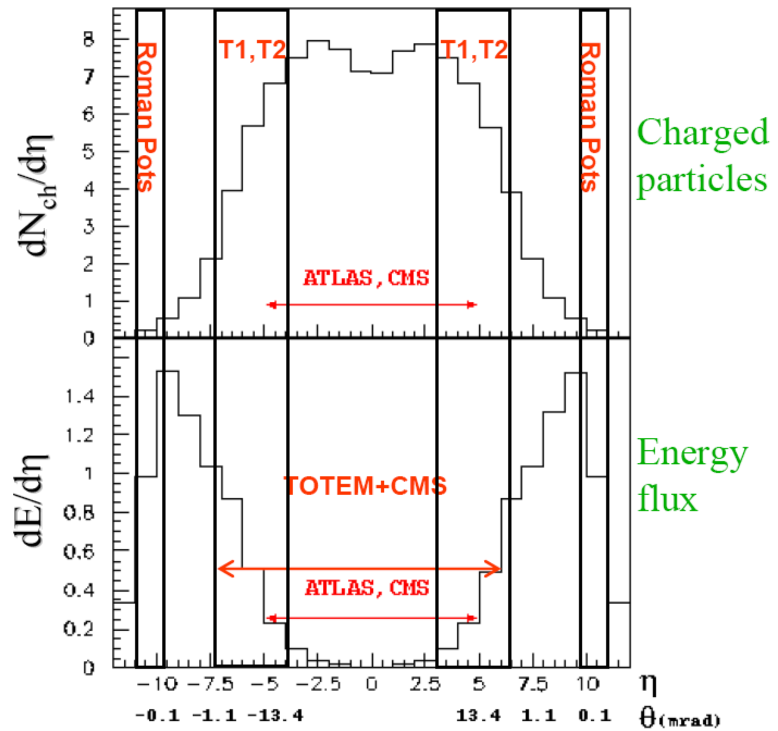
Very schematically, it's a glue-glue collider where you know the beam energy of the gluons

- Is 'Central Exclusive Double Pomeron' process a useful tool at LHC?
- Do we understand diffractive processes well enough to use them for searches?

The Diffractive Program at the LHC

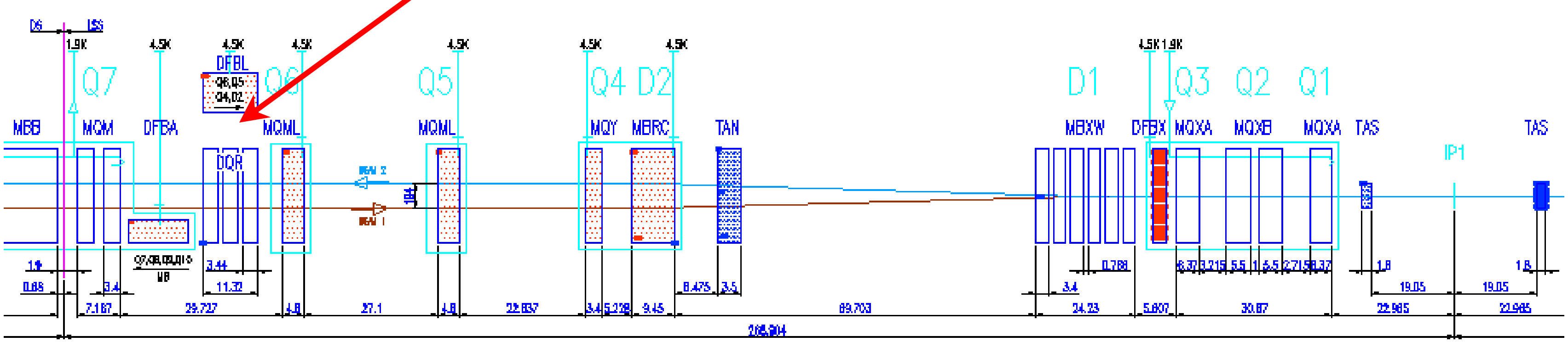






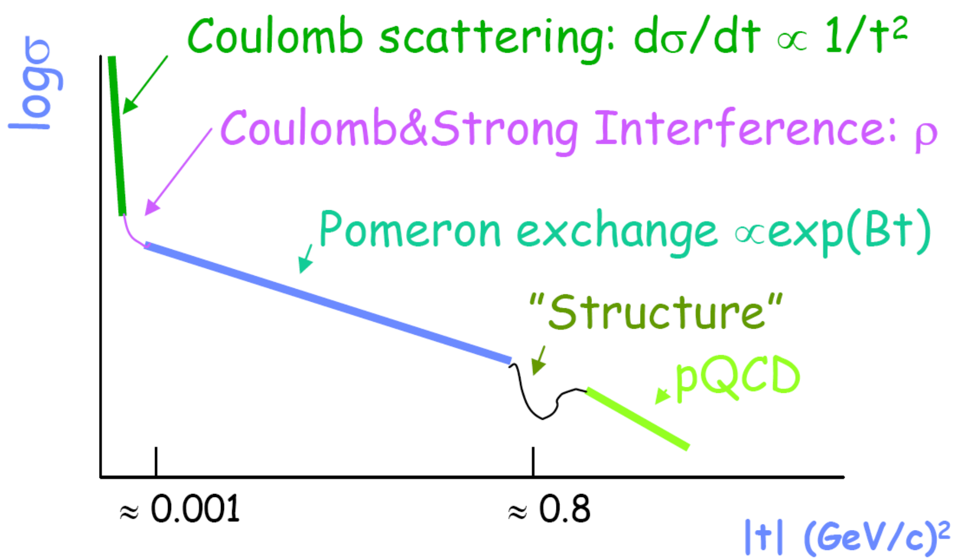
Each **RP station** consists of two **Roman Pot Units** separated by 3.4 m, centered at 240.0 m from IP1

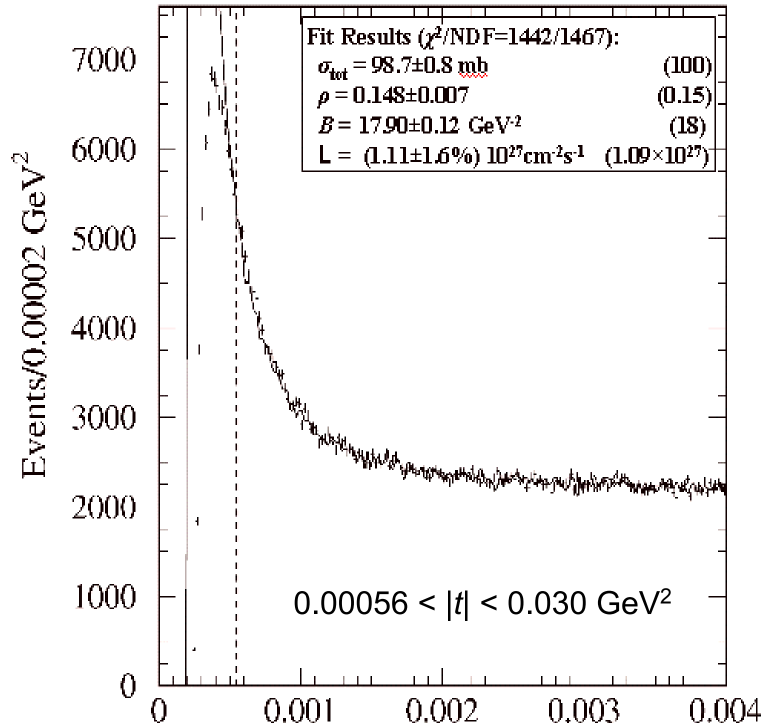
TOTEM Design!



Elastic scattering

Atlas has alternative very high β^* (2625m) optics to get to coulomb region

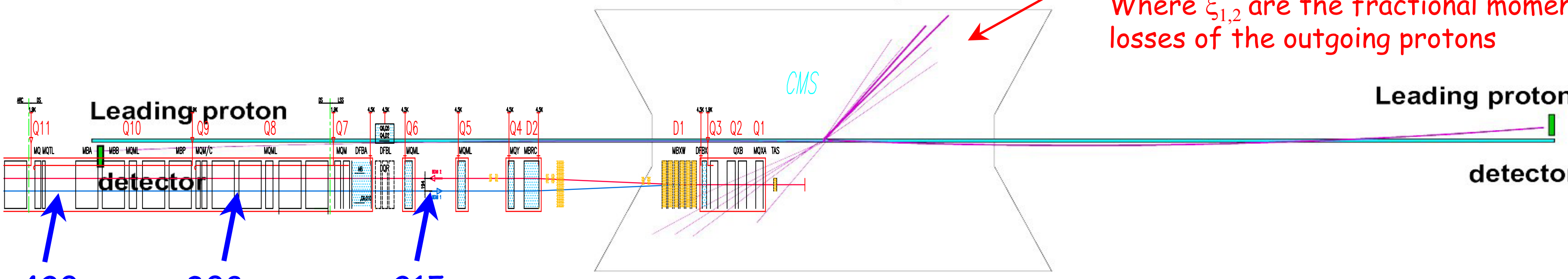




Region	$\|t\|$ $[GeV]^2$	Running Scenario
Coulomb region	$\leq 5\times10^{-4}$	[lower s, RP's closer to beam]
Interference, ρ meas.	$5\times10^{-4} \div 5\times10^{-3}$	[as above], standard β^* = 1540 m
Pomeron exchange	$5\times10^{-3} \div 0.1$	β^* = 1540 m
Diffractive structure	$0.1 \div 1$	β^* = 1540 m, 200 - 400 m (?)
Large $\|t\|$ – perturb. QCD	$1 \div 10$	β^* = 18 m

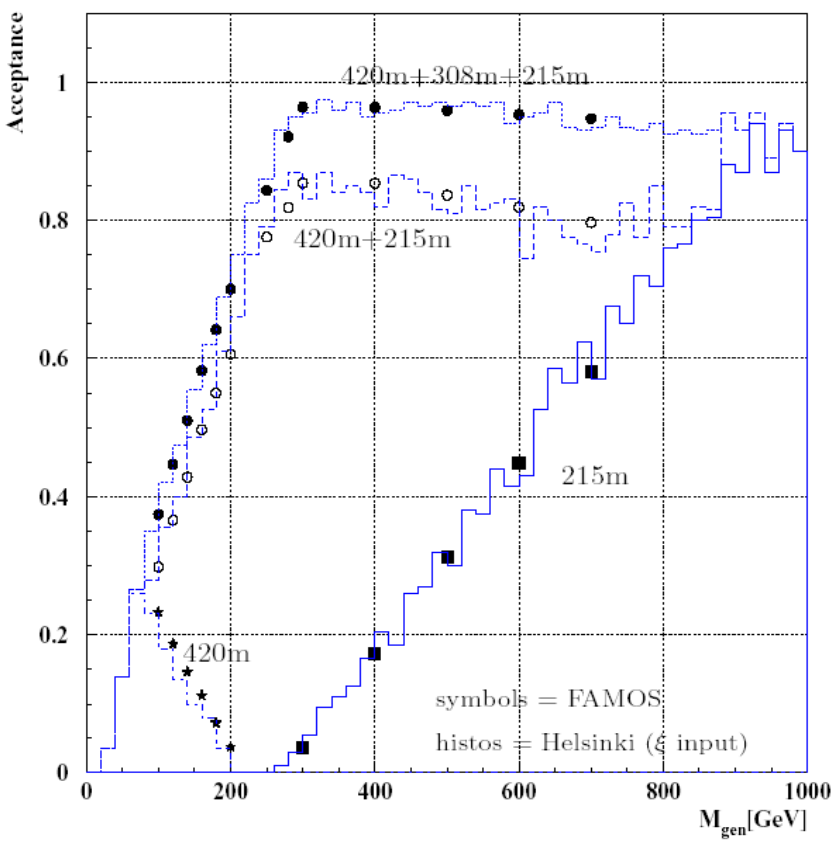
K. Österberg

The Experimental Challenges for Exclusive States

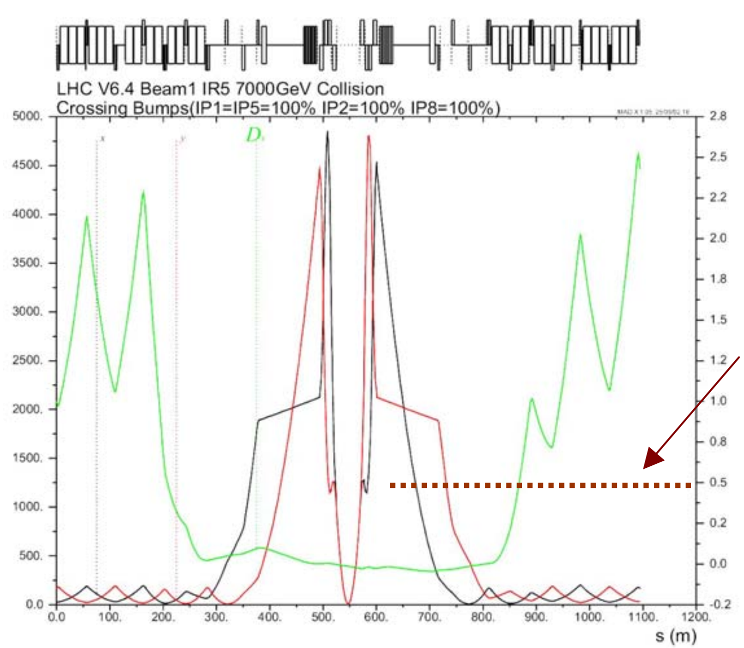


$M^2 = \xi_1 \xi_2 S$

Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons



horizontal offset $= \xi \cdot D_x$

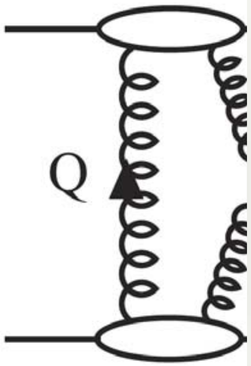


To get $\xi \sim 0.005$ proton (M ~ 70 GeV) 2.5mm from beam (10σ) pots must be > 250 m from IP

-> cold region, & level 1 trigger not possible

K. Österberg

Particularly promising scenarios for CEDP



Summary

Detection of light Higgs is challenging
($M_H \lesssim 130$ GeV)

A valuable process:

exclusive DD Higgs production

$$pp \to p + H + p$$
$$\hookrightarrow b\bar{b}$$

$$M_H = \begin{cases} M_{b\bar{b}} & \sim 10 \text{ GeV resol}^n \\ M_{miss} & \sim 1 \text{ GeV resol}^n \end{cases}$$

if p taggers installed at 420m

$\mathcal{L} = 30\ fb^{-1}$ $M_H = 120$ GeV

11 $H \to b\bar{b}$ events seen

4 $b\bar{b}$ background

bkgd suppressed

ect to

g becomes

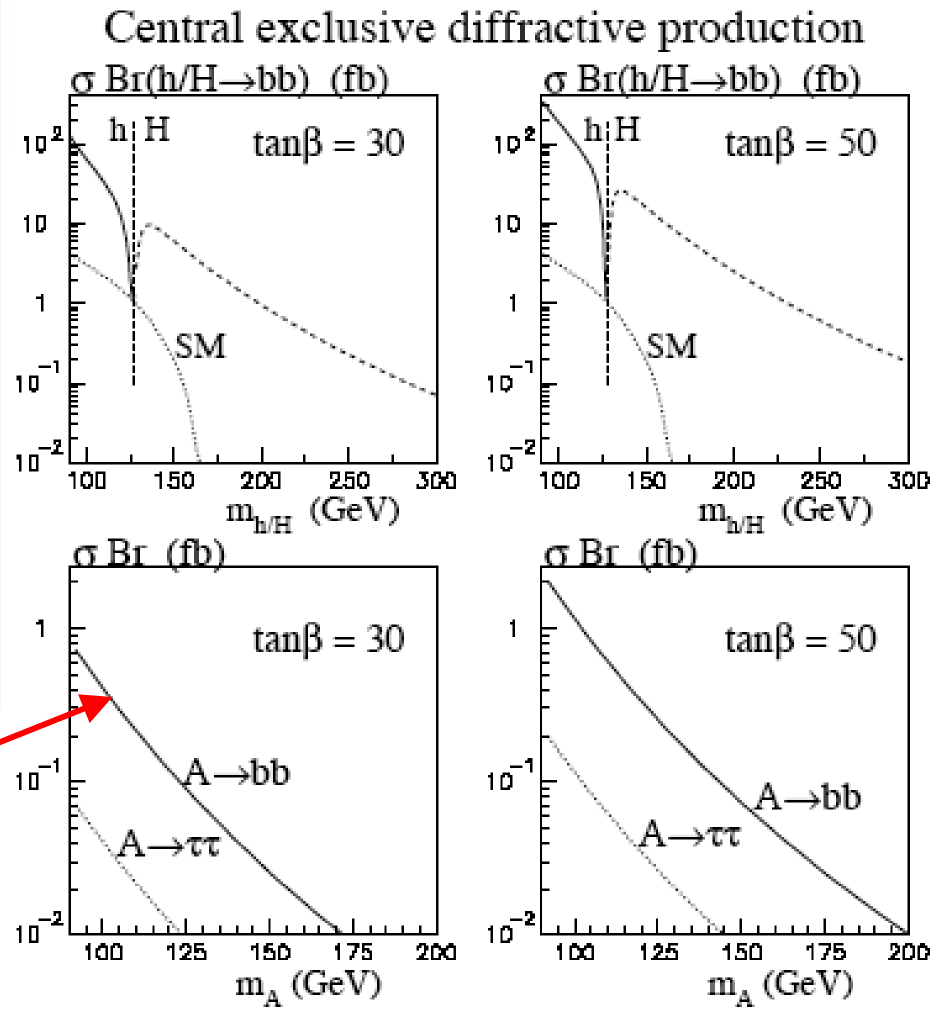
- ‘Difficul
- The MS

An example : The intense coupling regime of the MSSM

e.g. m_A = 130 GeV, tan β = 50
(difficult for conventional detection,
but exclusive diffractive favourable)
L = 30 fb^{-1}, ΔM = 1 GeV

	S	B	
m_h = 124.4 GeV	71	3	events
m_H = 135.5 GeV	124	2	
m_A = 130 GeV	1	2	

Alan Martin Manchester Dec 2003



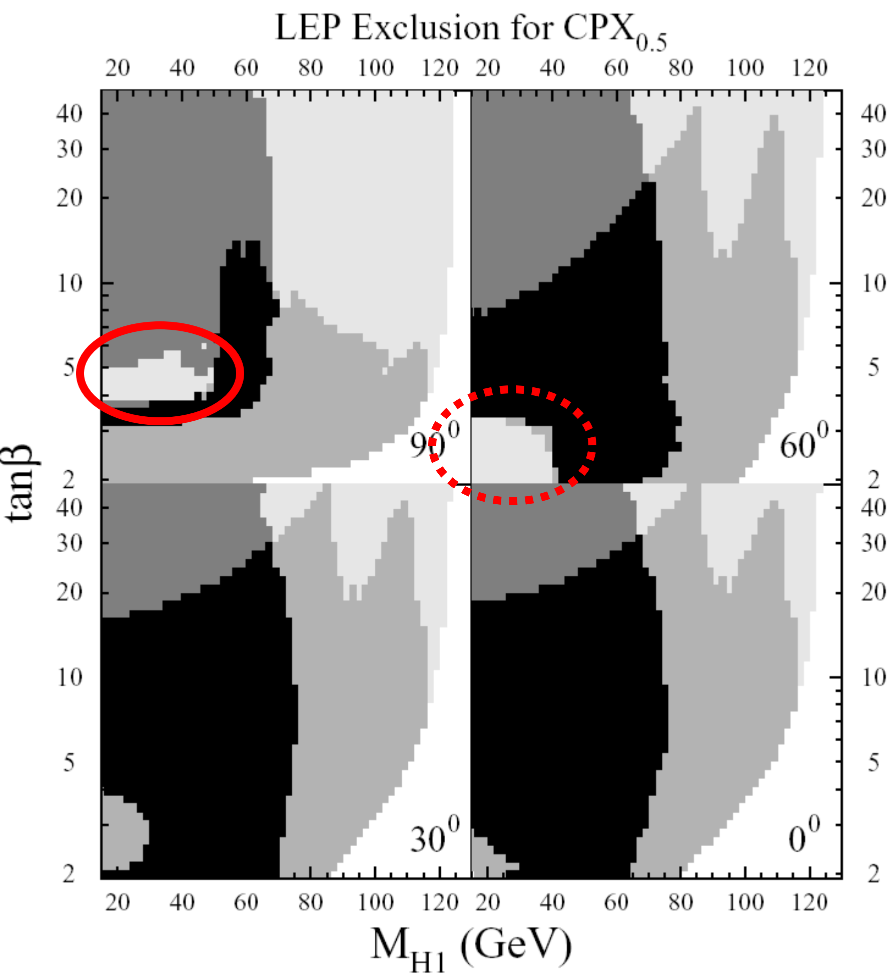
0^{++} selection rule suppresses A production:

CEDP 'filters out' pseudoscalar production,
leaving pure H sample for study

Kaidalov, Khoze, Martin, Ryskin hep-ph/0311023

The MSSM with explicit CP violation - the 'CPX' scenario

Imagine a light scalar which couples predominantly to glue, and decays to b jets … would we see it at LEP, Tevatron or LHC?



In the CPX scenario, the three neutral MSSM Higgs bosons, (CP even) h^0 and H^0, and (CP odd) *a* mix to produce 3 physical mass eigenstates H_1, H_2 and H_3 with mixed CP

Medium grey $e^+e^- \to ZH_i$

Dark grey $Z^* \to H_iH_j \to 4b$

"there are small regions of parameter space in which none of the neutral Higgs bosons can be detected at the Tevatron and the LHC"

M. Carena, J. Ellis, S. Mrenna, A. Pilaftsis and C. E. M. Wagner, Nucl. Phys B659 (2003) 145

CPX MSSM Higgs

b bbar very difficult because of large background:

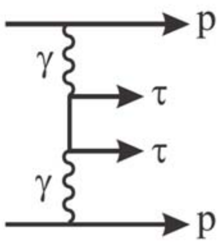
0^{++} Selection rule

QCD Background ~ $\frac{m_b^2}{E_T^2}\frac{\alpha_S^2}{M_{b\bar{b}}^2 E_T^2}$

Also, since resolution of taggers > Higgs width:

$$S/B \propto \Gamma(H \to gg)/\Delta M \propto G_F M_H^3/\Delta M$$

But ττ mode has only QED background



$$A = \frac{\sigma(\varphi < \pi) - \sigma(\varphi > \pi)}{\sigma(\varphi < \pi) + \sigma(\varphi > \pi)}$$

$M(H_1)$ GeV	cuts	30	40	50
$\sigma(H_1)\mathrm{Br}(\tau\tau)$	a, b	1.9	0.6	0.3
$\sigma^{\mathrm{QED}}(\tau\tau)$	a, b	0.2	0.1	0.04
$A_{\tau\tau}$	b	0.2	0.1	0.05

σ in fb

(b) $p_i^\perp > 300$ MeV for the forward outgoing protons

Direct evidence for CP violation in Higgs sector

$$\mathcal{M} = g_S \cdot (e_1^\perp \cdot e_2^\perp) - g_P \cdot \varepsilon^{\mu\nu\alpha\beta} e_{1\mu} e_{2\nu} p_{1\alpha} p_{2\beta}/(p_1 \cdot p_2)$$

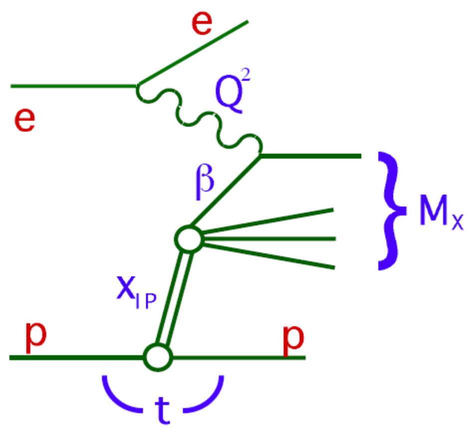
CP even

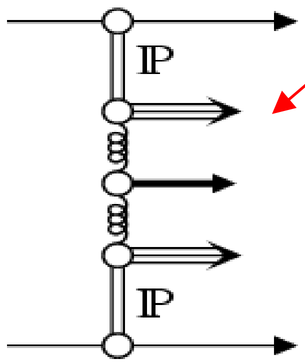
CP odd active at non-zero t

B.C., Forshaw, Lee, Monk and Pilaftsis hep-ph/0303206

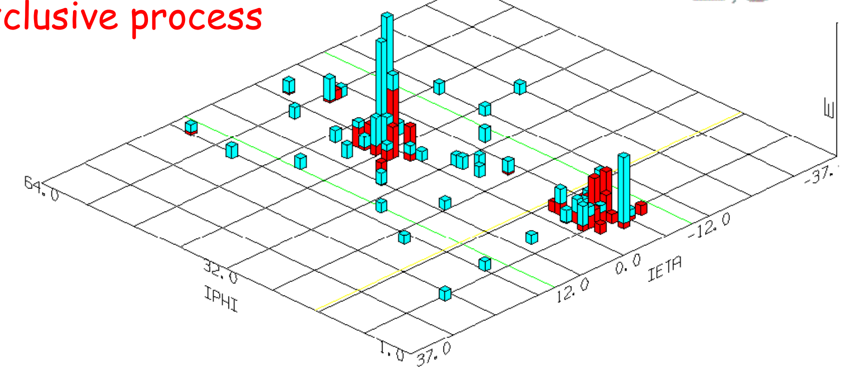
Khoze, Martin and Ryskin hep-ph/0401078

Do we understand diffraction well enough to use it as a search tool?





Important background to exclusive process

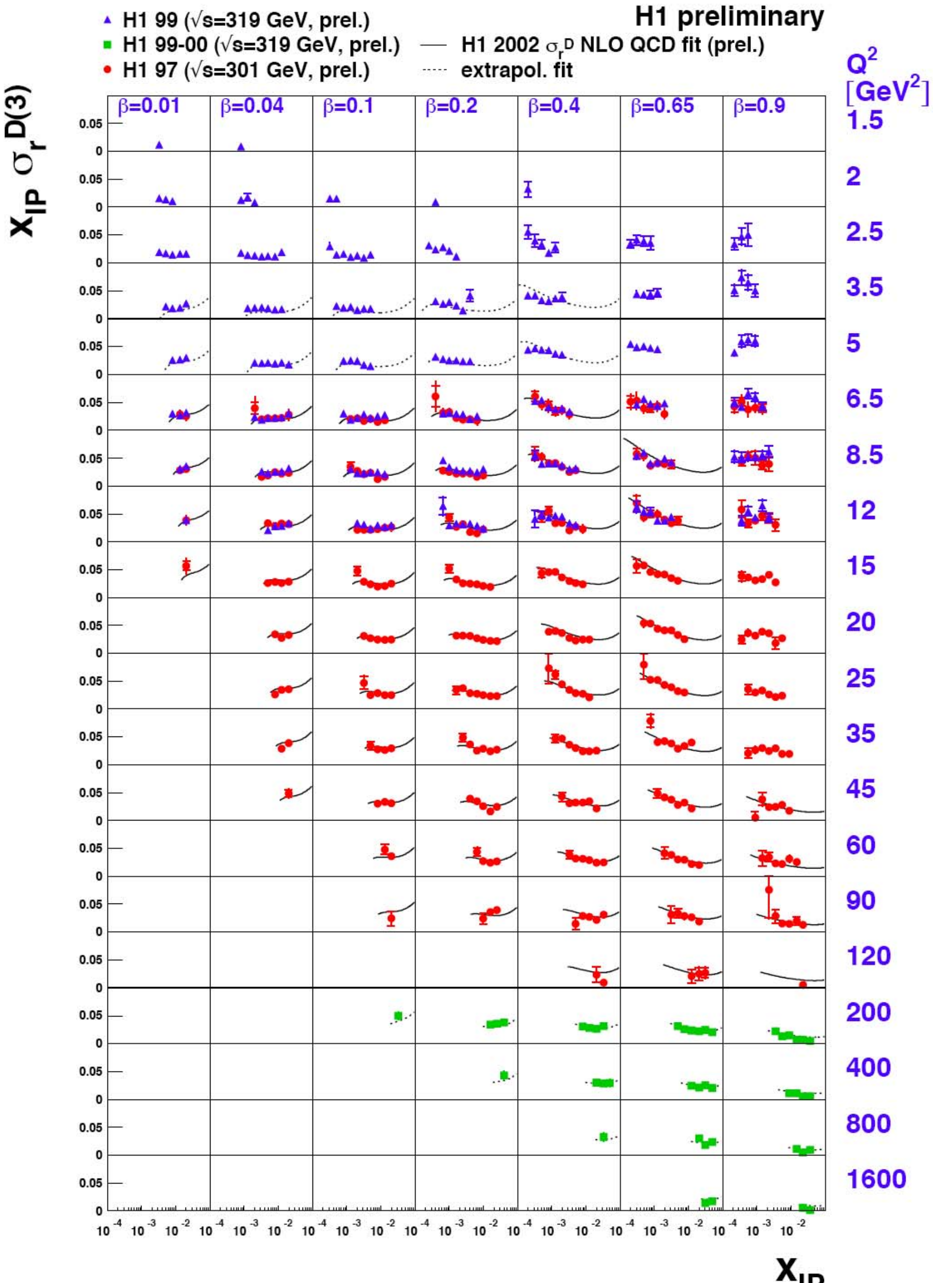


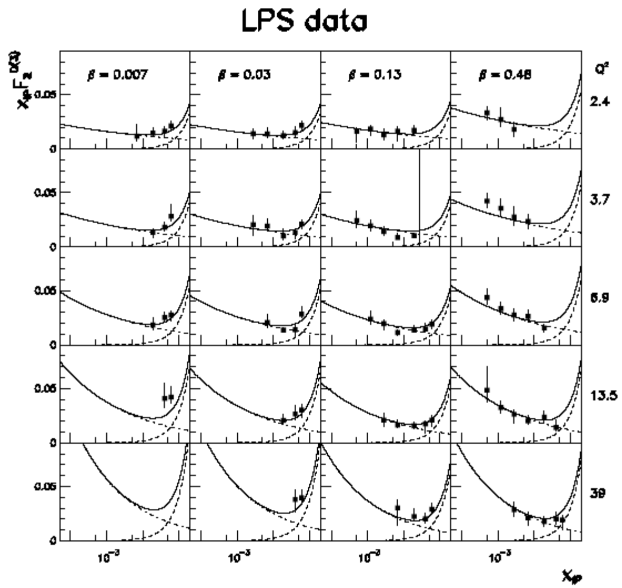
As with all processes at hadron colliders, the structure functions are of prime importance

$$\frac{d^2\sigma(x,Q^2,x_{I\!P},t)^{\gamma^* p\to p' X}}{dx_{I\!P}\, dt} = \sum_i \int_x^{x_{I\!P}} d\xi\, \hat{\sigma}^{\gamma^* i}(x,Q^2,\xi)\, p_i^D(\xi,Q^2,x_{I\!P},t)$$

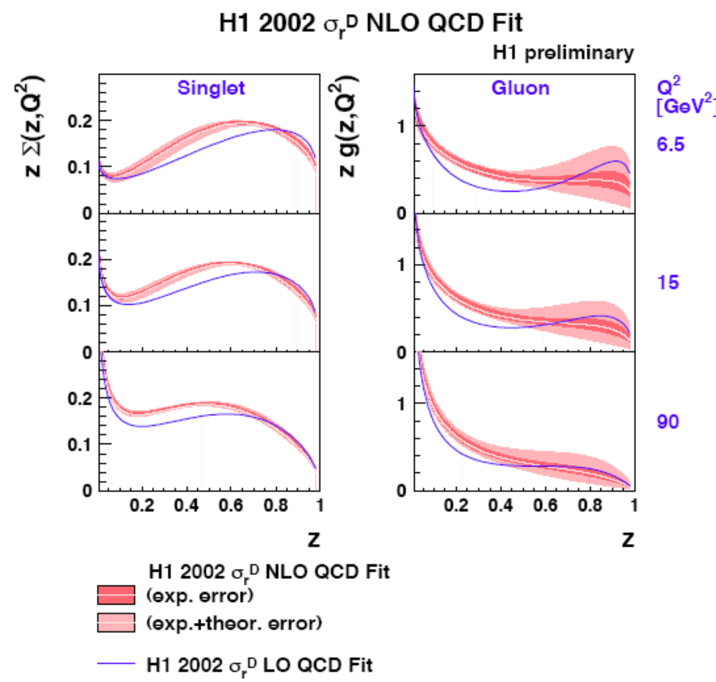
- $\hat{\sigma}^{\gamma^* i}$ hard scattering coeff. functions, as in incl. DIS
- p_i^D diffractive PDF's in proton, conditional probabilities, valid at fixed $x_{I\!P}$, t, obey (NLO) DGLAP

Diffractive Structure Functions at HERA

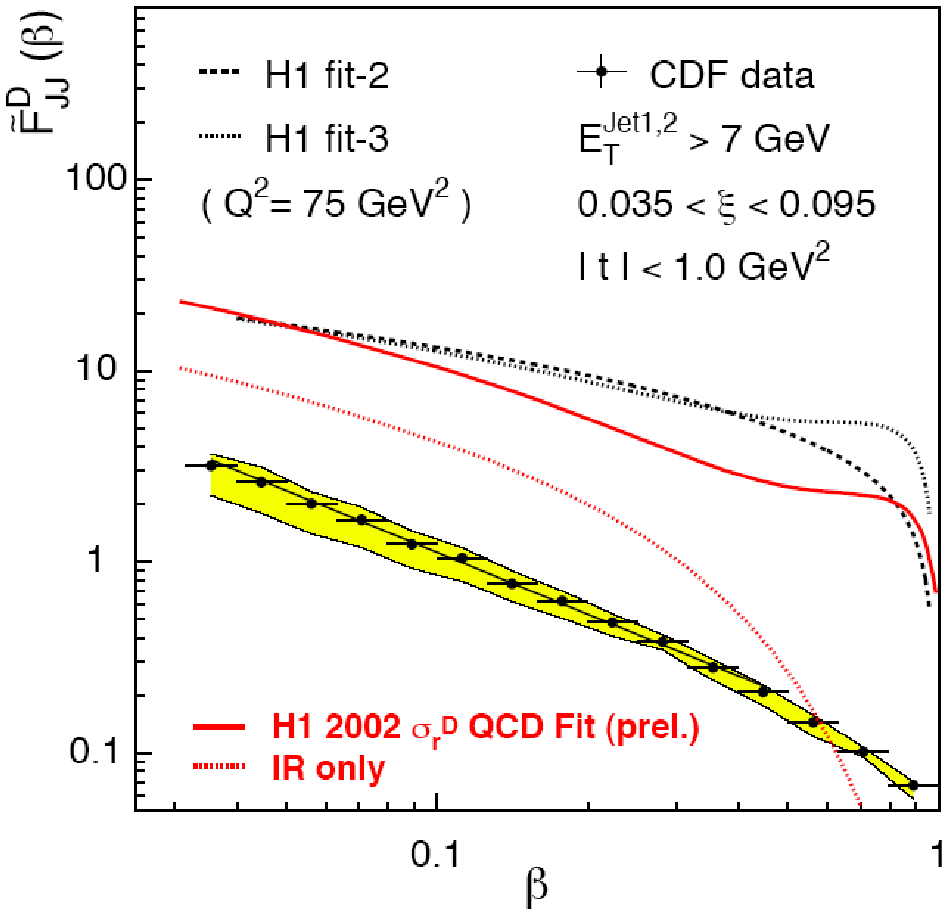


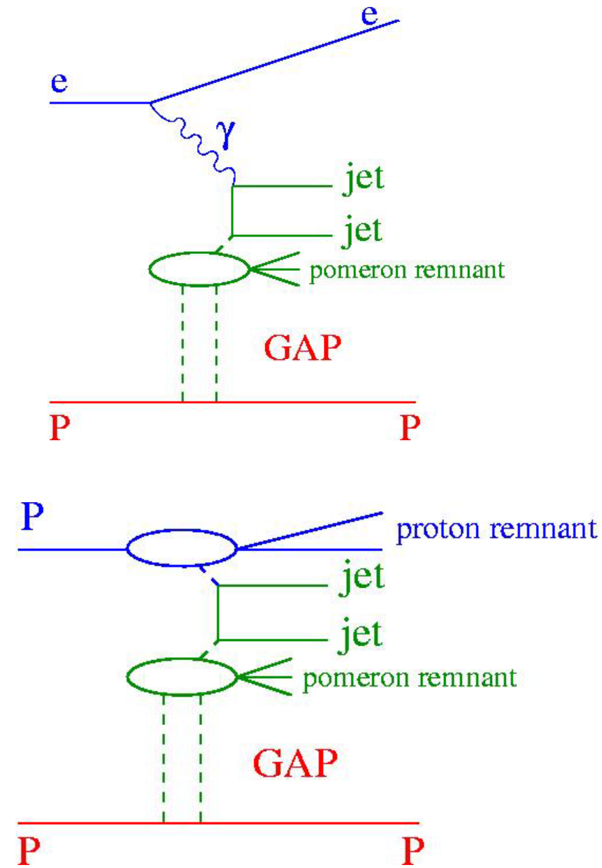


dash-dotted: pom dashed: regge solid: pom+regge



Factorisation does not hold in PP



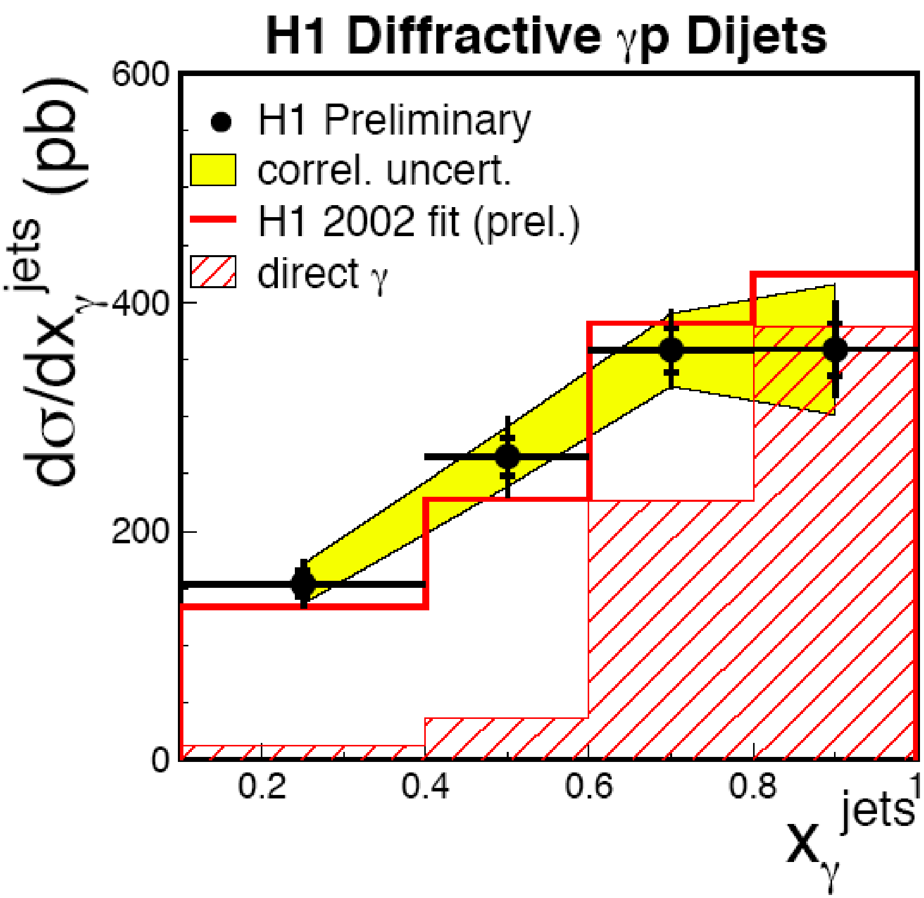


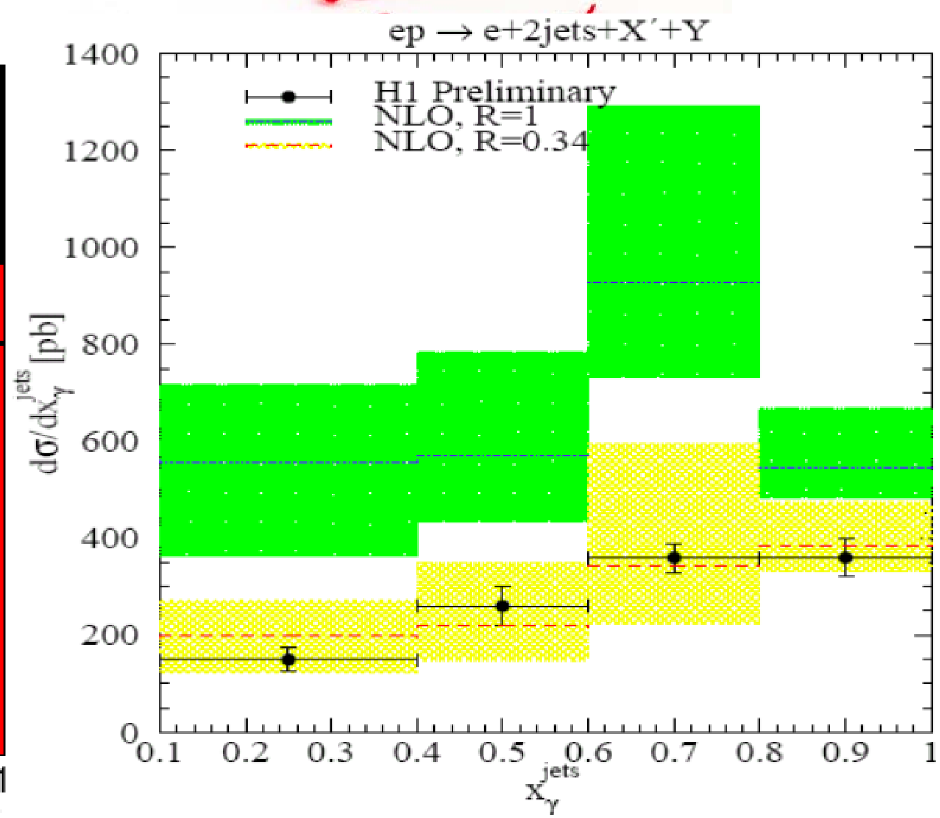
An unproved statement : If there are no multi-parton interactions, then the diffractive structure functions measured at the Tevatron are ~ the same as those at HERA

Factorisation in PP

Most (all?) eikonal models yield similar predictions for S^2 provided they are tuned to σ_{tot} & $\sigma_{elastic}$

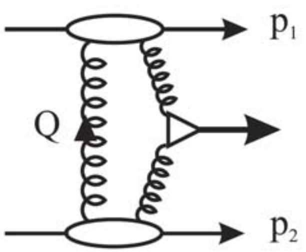
→ $\checkmark$ for central diffraction at LHC





M. Klasen HERA - LHC Workshop

How reliable are the predictions?



- The cross section ~ factorises …

Hard subprocess cross section

$$\sigma = \mathcal{L}(M^2, y)\, \hat{\sigma}(M^2)$$

Effective luminosity for production of mass M at rapidity y

… so can be checked by measuring higher rate processes at Tevatron and LHC

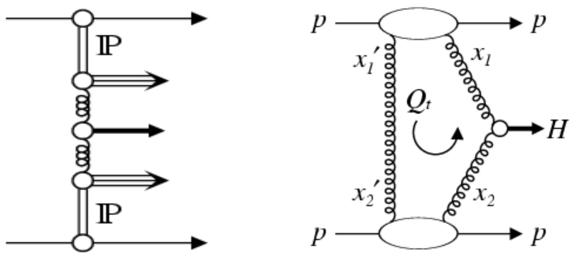
Particle	σ_{excl}	Decay channel	BR	Rate at 2.4×10^{29} cm^{-2} s^{-1} β^* = 1540 m	Rate at 10^{31} cm^{-2} s^{-1} β^* = 200-400m
				(no acceptance / analysis cuts)	
χ_{c0} (3.4 GeV)	3 μb [KMRS]	$\gamma J/\psi \to \gamma \mu^+\mu^-$ $\pi^+\pi^- K^+ K^-$	6×10^{-4} 0.018	1.5 / h 46 / h	62 / h 1900 / h
χ_{b0} (9.9 GeV)	4 nb [KMRS]	$\gamma \Upsilon \to \gamma \mu^+\mu^-$	10^{-3}?	0.08 / d	3.5 / d
H (120 GeV)	0.1 ÷ 10 fb assume 3 fb	$b\bar{b}$	0.68	0.02 / y	1 / y

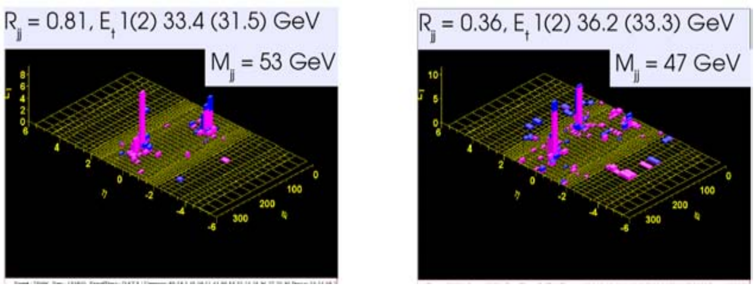
KMR Prediction → $\sigma(\bar{p}p \to \bar{p} + \chi_c^{0}(\to J/\Psi + \gamma) + p)$

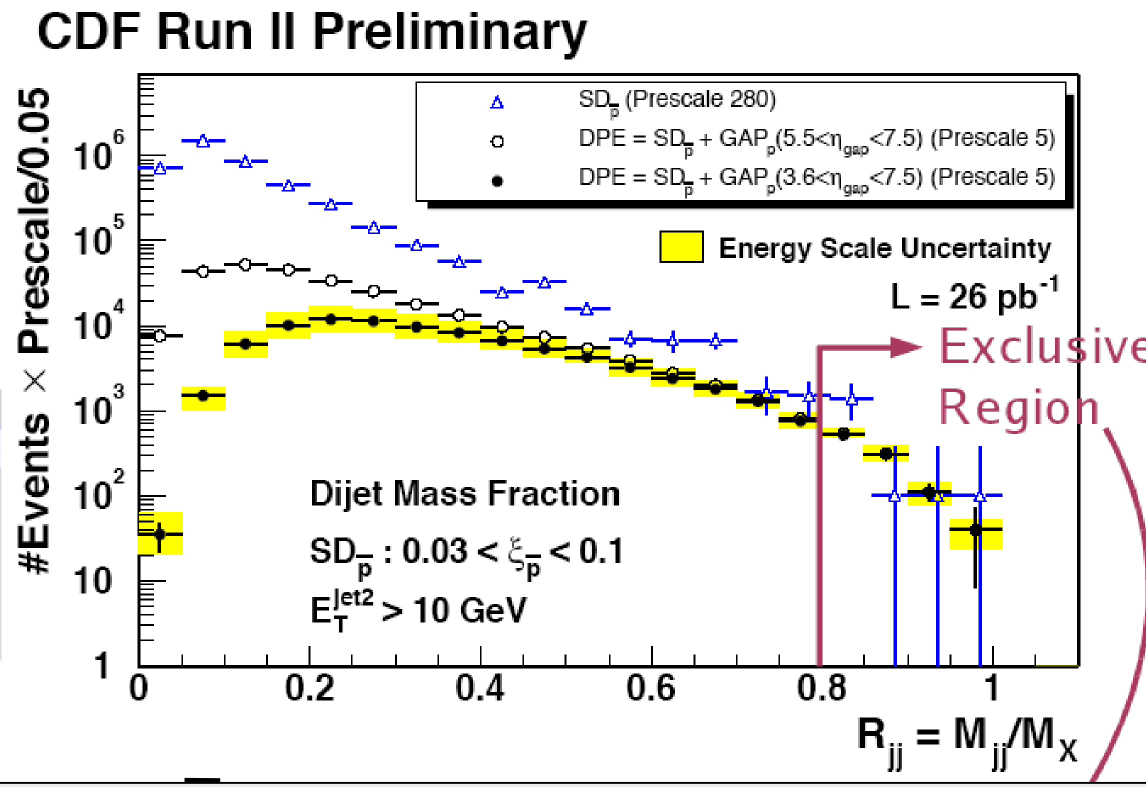
Eur. Phys. J. C19, 477 (2001)

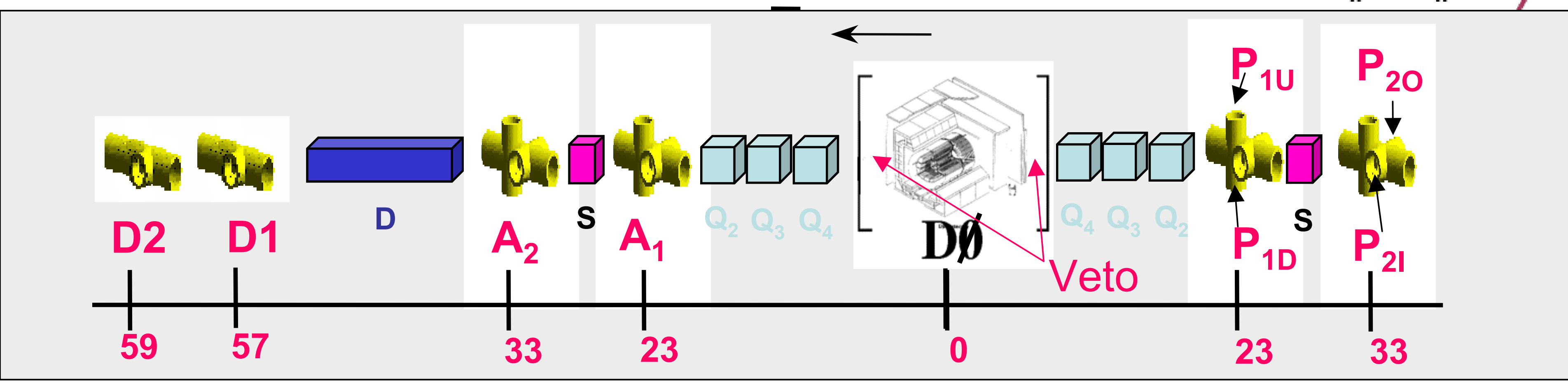
$\approx$ 70 pb at $|y^{J/\Psi}|<0.6$ (factor 2-5 uncertainty)

How reliable are the predictions?









K. Terashi (Rockefeller Univ.)

Summary and work in progress

- Real discovery potential in certain scenarios
- Possibility to measure Higgs branching ratio to e.g. b or τ - complementary information to conventional searches
- Azimuthal asymmetries allow direct measurement of CP violation in Higgs sector
- Assuming CP conservation, any object seen with 2 tagged protons has positive C parity, is (most probably) 0^+, and is a colour singlet

- Need theoretical and experimental verification of the cross section and background predictions
- If we can get the pots close enough for level 1 trigger, and increase the acceptance at 120 GeV, this project is extremely exciting - can we do it?

SUDAKOV

- So far all cross-sections are DIVERGENT

$$\int_0 \frac{dQ_T^2}{Q_T^4} \quad \left(\text{and} \int_0 \frac{dQ_T^2}{Q_T^6}\right)$$

{ not quite so bad due to anomalous dimension of gluon density $\sim (Q_T^2)^\gamma$ }

But there exist Sudakov logarithms

$P_T < Q_T$: soft gluon screens emission

Emission probability $\approx C_A \int_{Q_T^2}^{M_H^2/4} \frac{dP_T^2}{P_T^2} \frac{\alpha_s(P_T^2)}{\pi} \int_{P_T}^{\frac{1}{2}M_H} \frac{dE}{E}$

(soft & collinear approximation i.e. double log approx.)

$\left(\sim \frac{\alpha_s C_A}{\pi} \frac{1}{4} \ln^2 \frac{M_H^2}{4Q_T^2}\right)$

exponentiating generates a factor in amplitude of

$$\exp(-S) = \exp\left(-\frac{C_A}{\pi} \int_{Q_T^2}^{\frac{1}{4}M_H^2} \alpha_s \frac{dP_T^2}{P_T^2} \int_{P_T}^{M_H/2} \frac{dE}{E}\right)$$ ← double logs

$$= \exp\left(-\int_{Q_T^2}^{M_H^2/4} \frac{\alpha_s(P_T^2)}{2\pi} \frac{dP_T^2}{P_T^2} \int_0^{1-\Delta} \left\{ z P_{gg}(z) + \sum_q P_{qg}(z) \right\} dz \right)$$

← double and single logs

↓

Collinear AND soft logs if

$\Delta = \frac{P_T}{(P_T + 0.62 M_H)}$

As $Q_T \to 0$ so the screening gluon fails to screen and $P_T \approx 0$ emission is allowed. Hence e^{-S} vanishes faster than any power of Q_T.

Jeff Forshaw