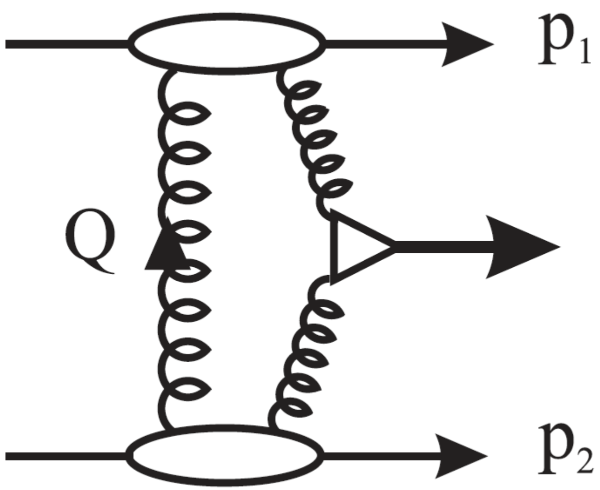
Brian Cox

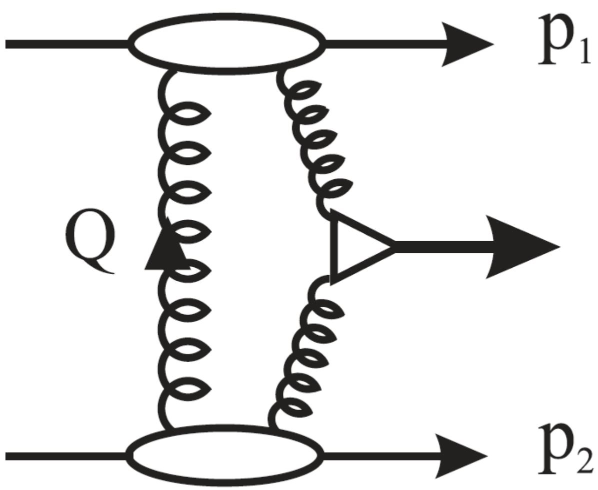
Forward Physics at the LHC



- Selection rules mean that central system is (to a good approx) 0^{++}
- If you see a new particle produced exclusively with proton tags you know its quantum numbers
- CP violation in the Higgs sector shows up directly as azimuthal asymmetries
- Proton tagging may be the discovery channel in certain regions of the MSSM
- Tagging the protons means excellent mass resolution (~ GeV) irrespective of the decay products of the central system
- Unique access to a host of interesting QCD

Very schematically it's a glue – glue collider where you know the beam energy of the gluons - source of pure gluon jets - and central production of any 0^{++} state which couples strongly to glue is a possibility …

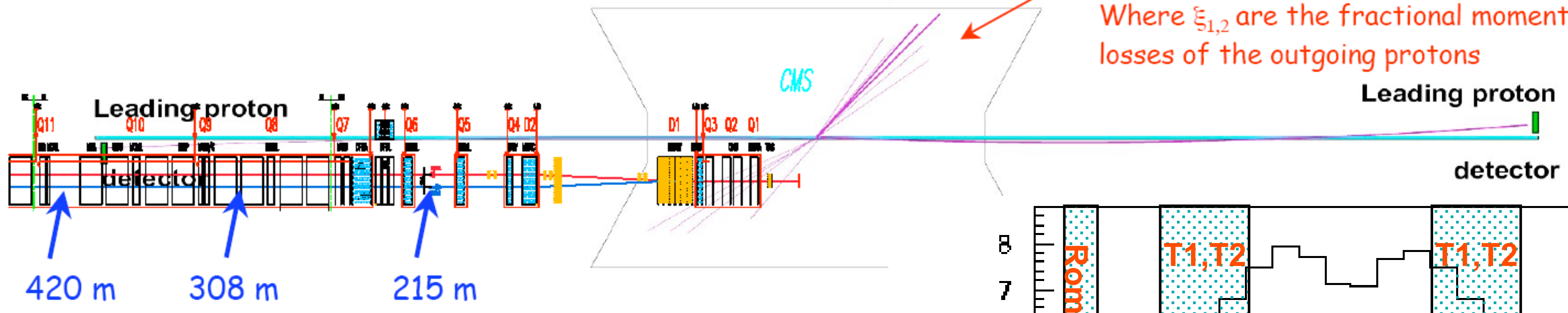
Forward Physics at the LHC

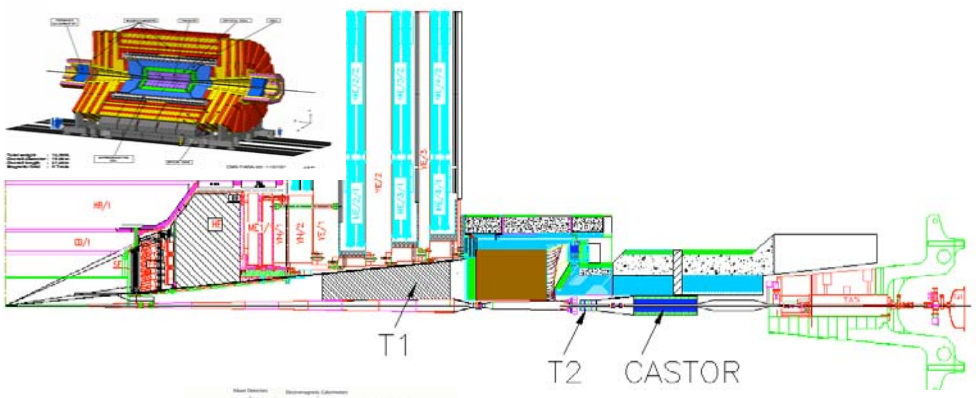


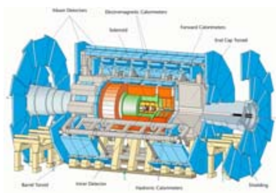
Very schematically it's a glue – glue collider where you know the beam energy of the gluons - source of pure gluon jets - and central production of any 0^{++} state which couples strongly to glue is a possibility …

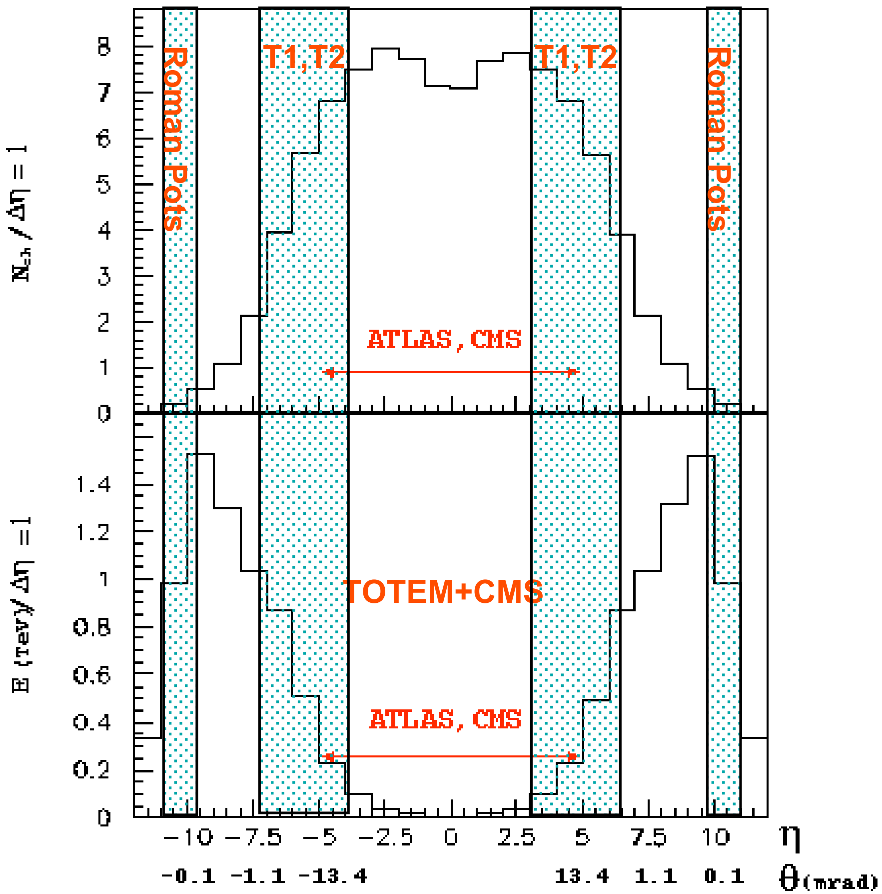
$M^2 = \xi_1 \xi_2 S$

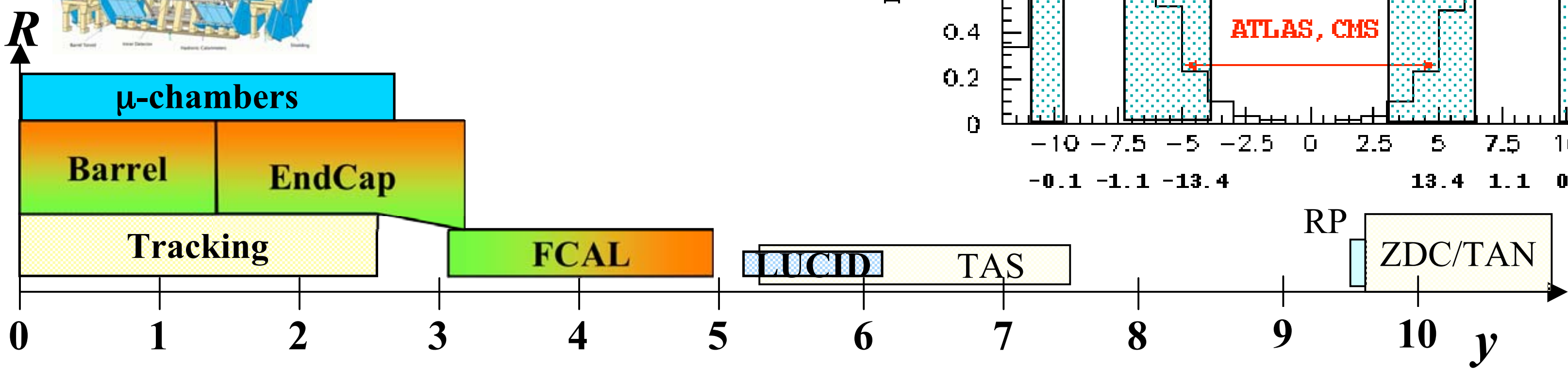
Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons



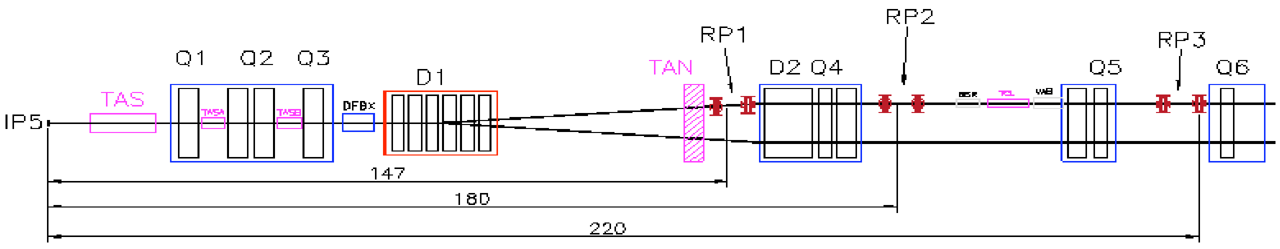


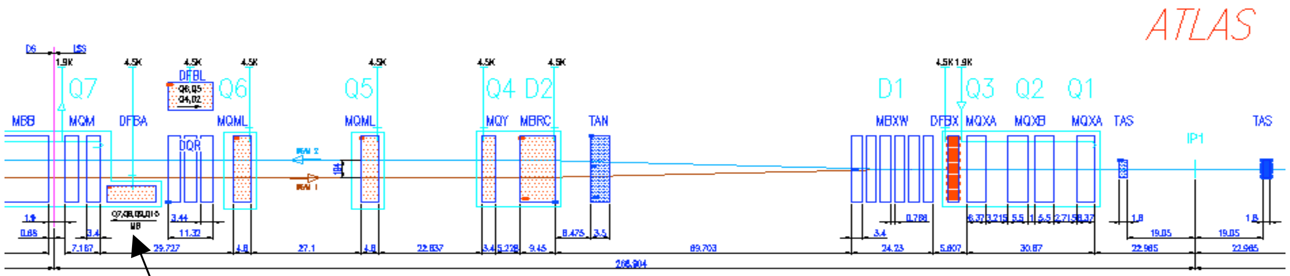




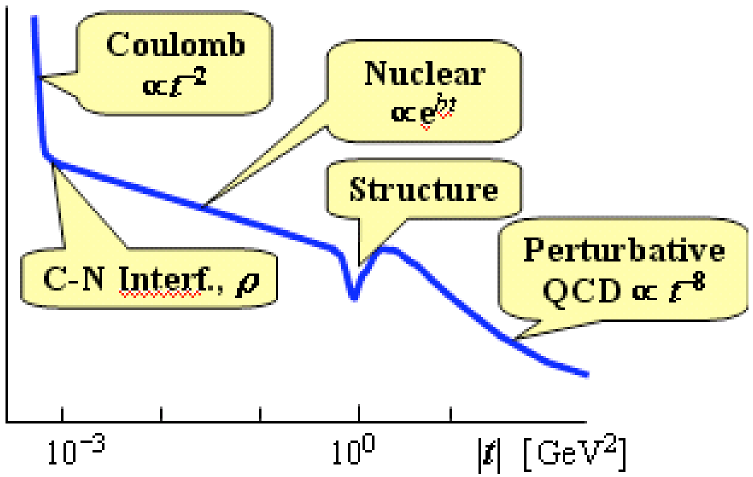


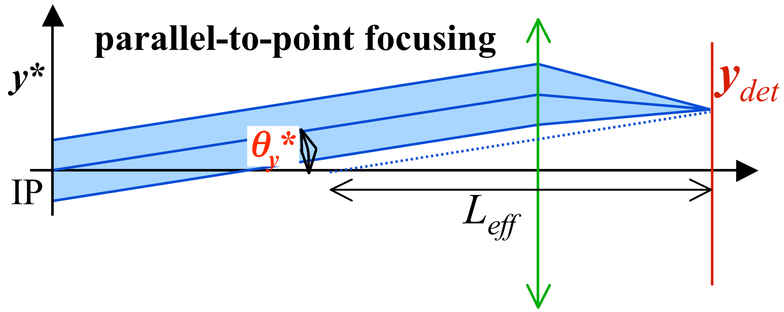
Elastic Scattering and Total Cross Section at LHC





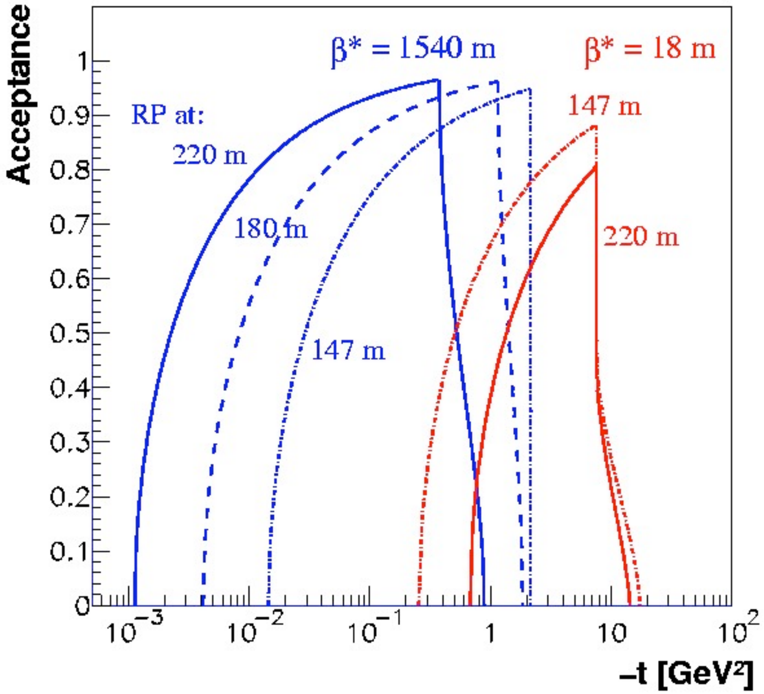
RP (2 stations 3.4m apart at 240m)

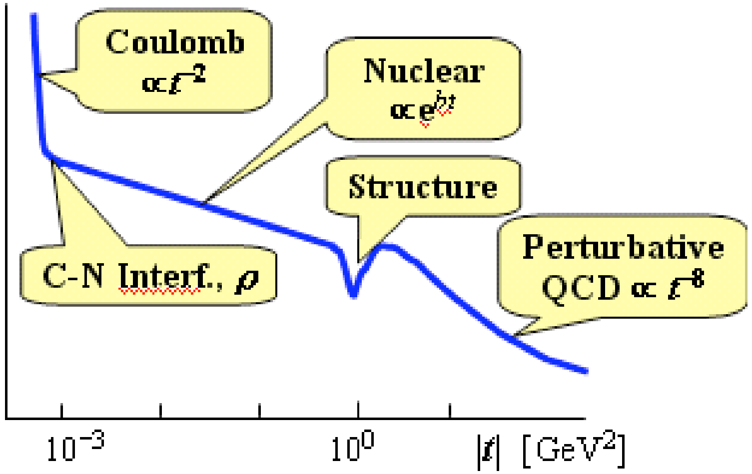




Special runs at high β* to access low t elastics

Elastic Scattering and Total Cross Section at LHC





ATLAS : Very high β^* (2625 m) optics

Detector at 1.5 mm or 12σ : t_{min} =0.0004 GeV²

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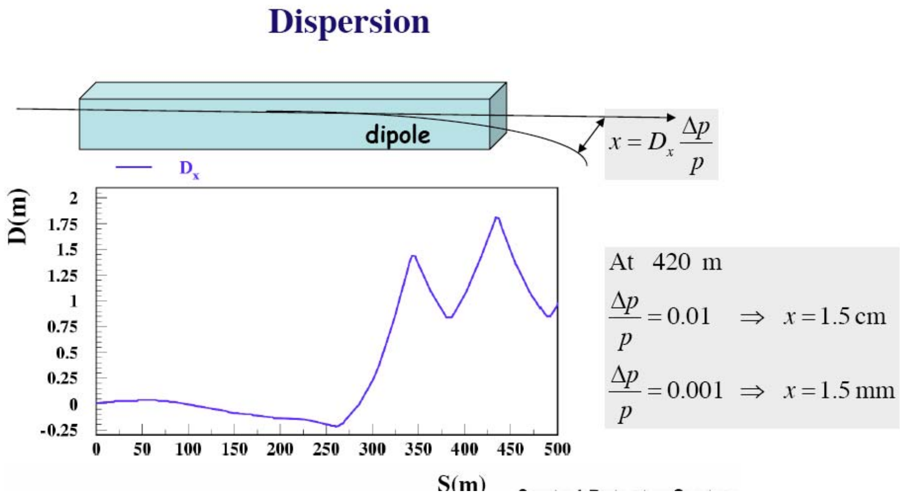
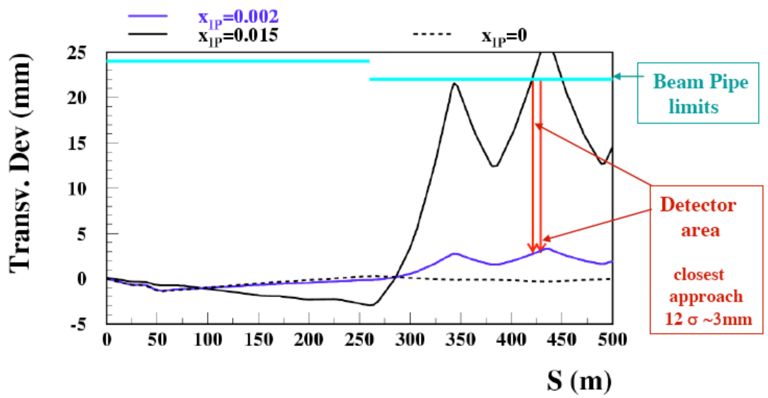
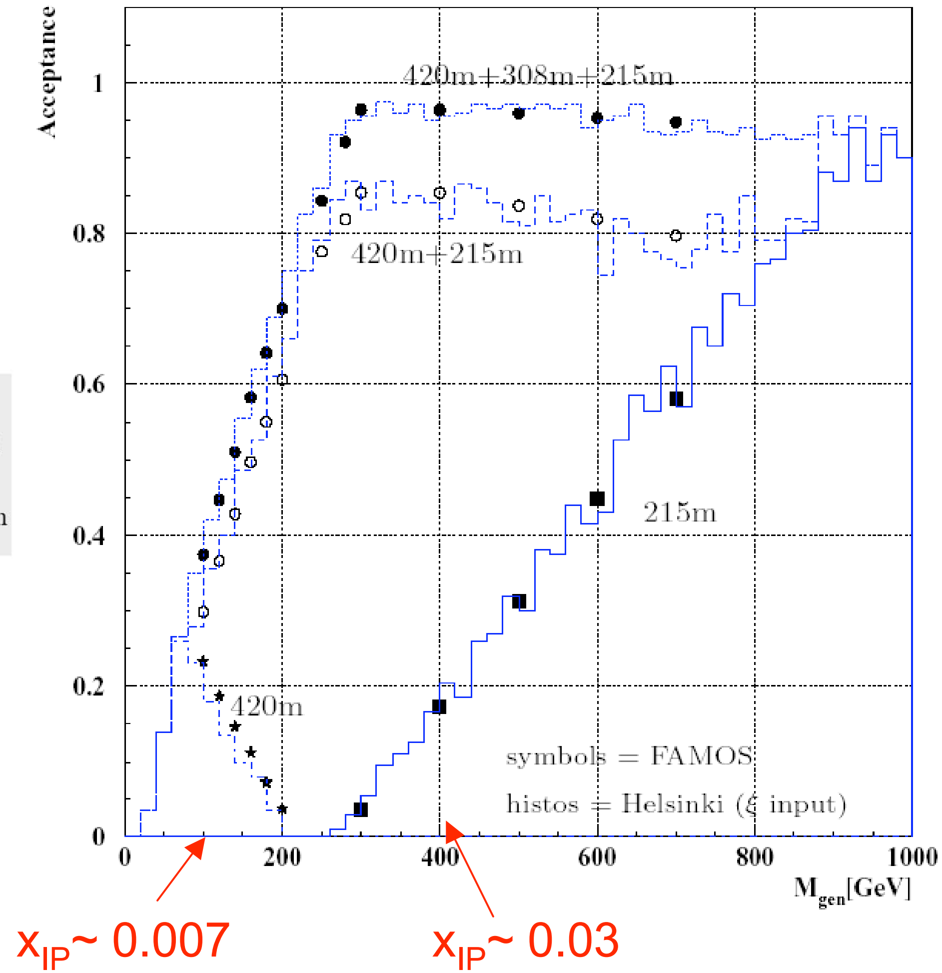
Central Production at LHC







Plots from Henri Kowalski, Ken Osterberg, this workshop

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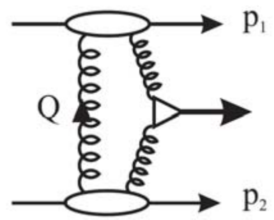
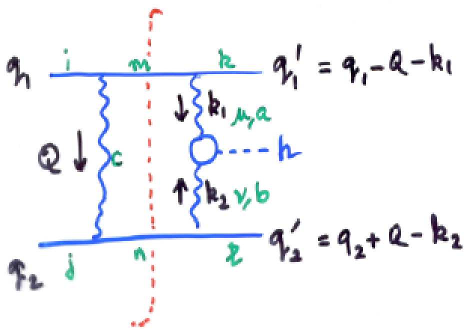
The KMR Calculation of the Exclusive Process



$qq \to q + H + q$



q -> Proton

$$\frac{d\sigma}{dy_H} \simeq \frac{1}{256\pi b^2} \frac{\alpha_s^2 G_F \sqrt{2}}{9} \left[\int \frac{d^2Q_\perp}{Q_\perp^4} f(x_1, Q_\perp^2) f(x_2, Q_\perp^2) \right]^2$$

$$f(x_i, Q_\perp^2) = \frac{\partial G(x_i, Q_\perp^2)}{\partial Q_\perp^2} \quad (x_i = \alpha_i)$$

Dominant uncertainty: KMR estimate factor of 2-3. Independent estimate by Lund group "definitely less than 10".

assuming

$f \sim (Q^2)^\gamma$

$$Q \sim \frac{M_H}{2} \exp\left(-\frac{2\pi}{N_c \alpha_s} \frac{\left[\frac{n}{2} - 1 - 2\gamma\right]}{2}\right)$$

$\alpha_s = 0.2$, $M_H = 100$ GeV, $n = 4$, $\gamma = 0.2$

$\rightarrow$ 2 GeV

Divergent: controlled by Sudakov

exponentiating generates a factor in amplitude of

$$\exp(-S) = \exp\left(-\frac{C_A}{\pi} \int_{Q_T^2}^{M_H^2} \frac{dp_T^2}{p_T^2} \int_{p_T}^{M_H/2} \frac{dE}{E}\right) \leftarrow \text{double logs}$$

Jeff Forshaw, this workshop

Exclusive production at Tevatron

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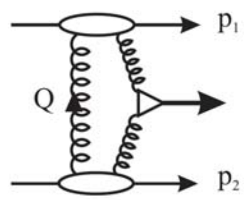
- The cross section ~ factorises …

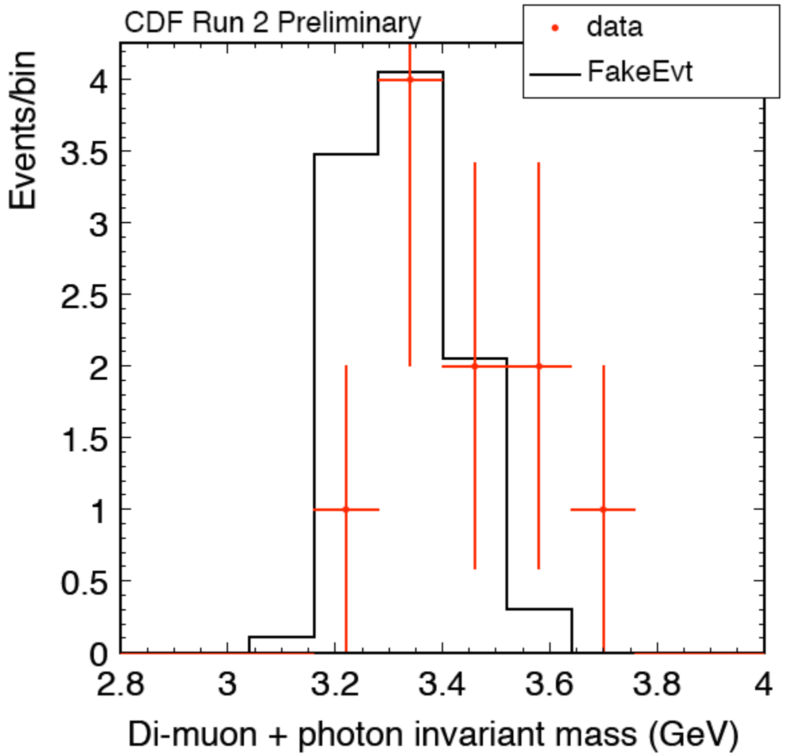
$$\sigma = \mathcal{L}(M^2, y)\, \hat{\sigma}(M^2)$$

Hard subprocess cross section



Effective luminosity for production of mass M at rapidity y

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



$\bar{p} + p \rightarrow \bar{p} + \chi_c^{\,0} (\rightarrow J/\Psi + \gamma) + p$

10 events:

Exclusive $\chi_c^{\,0}(\rightarrow J/\Psi + \gamma)$ candidates

Assume 10 events are all $J/\Psi + \gamma$

$|y^{J/\Psi}|<0.6$, $p_T^{J/\Psi}>2$ GeV

$\sigma(\bar{p}p \rightarrow \bar{p} + J/\Psi + \gamma + p) = 49 \pm 18(\text{stat}) \pm 39(\text{syst})$ pb

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

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

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

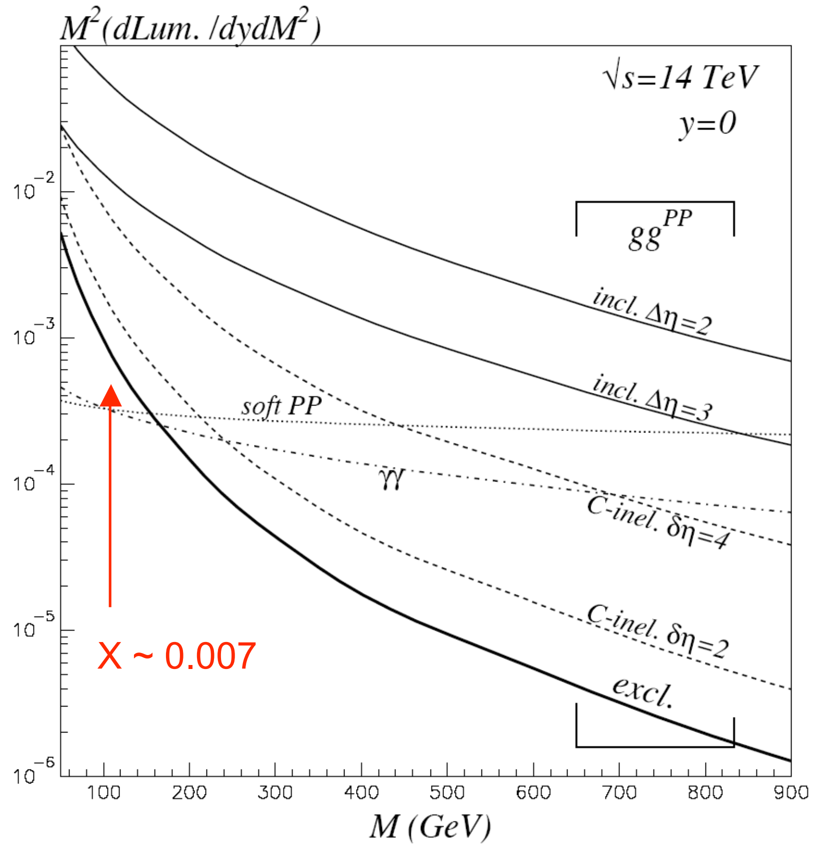
K. Terashi (Rockefeller Univ.)

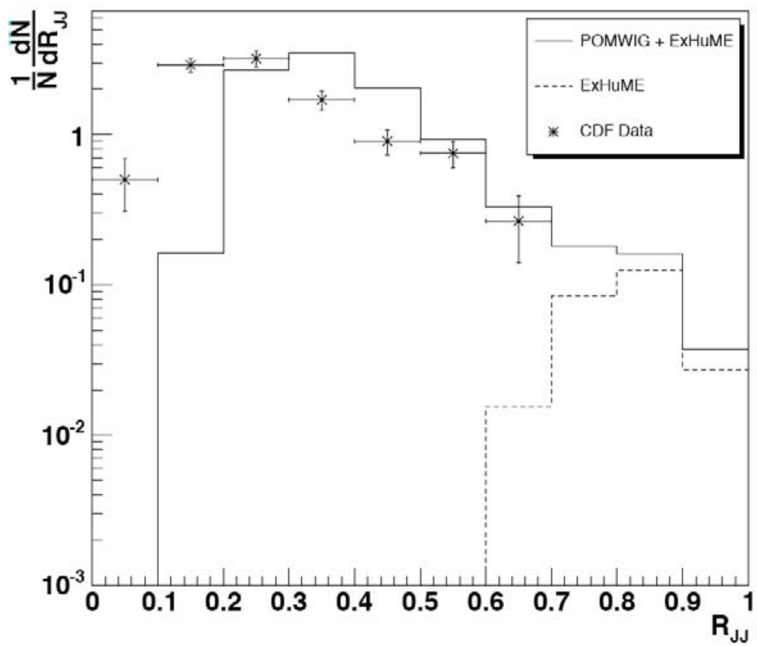
Exclusive dijets

ExHuME Monte Carlo - direct implementation of KMR

www.exhume-me.com

J. Monk and A. Pilkington, hep-ph/0502077





$pp \Rightarrow pp + g_{JET}\, g_{JET}$ $\sigma \sim$ 1 nb for $E_T > 20$ GeV , M(jj) ~ 50 GeV

$\sigma \sim 0.5$ pb for $E_T > 60$ GeV , M(jj) ~ 200 GeV

$|\eta_{JET}| < 2$

Khoze, Martin and Ryskin, Eur.Phys.J.C23:311-327,2002

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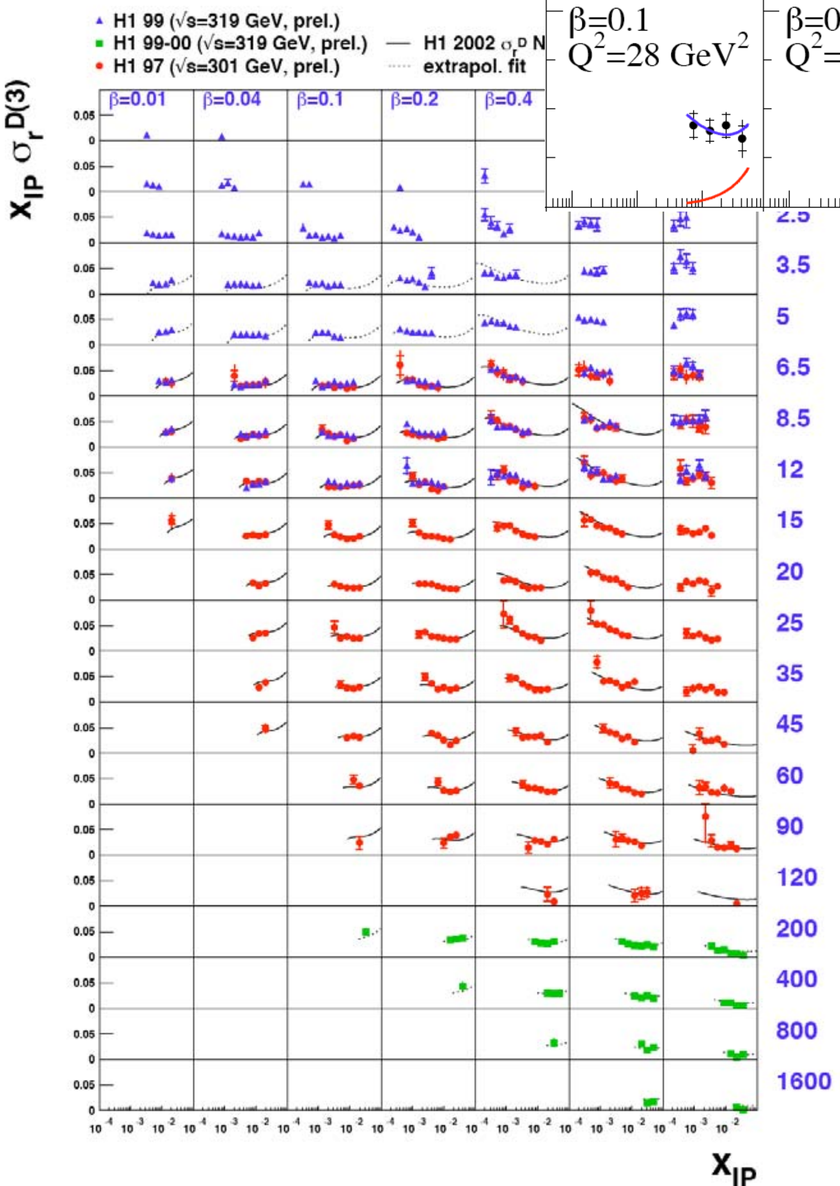
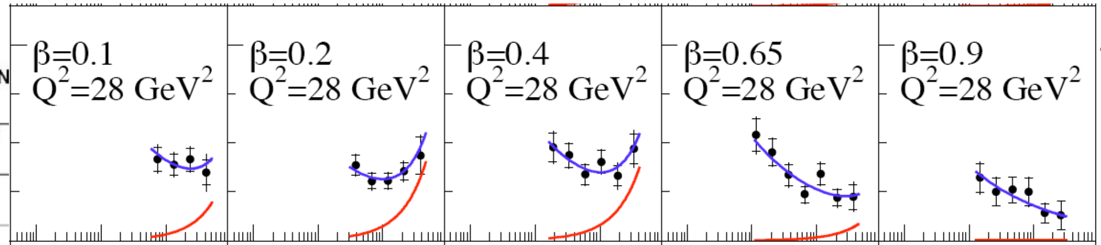
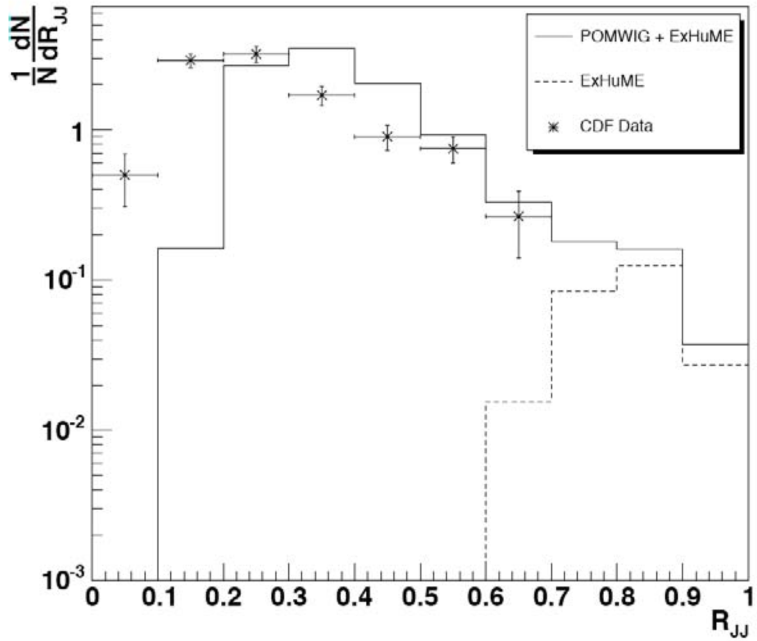
Exclusive dijets







$_T > 20$ GeV , M(jj) ~ 50 GeV

$_T > 60$ GeV , M(jj) ~ 200 GeV

Khoze, Martin and Ryskin, Eur.Phys.J.C23:311-327,2002

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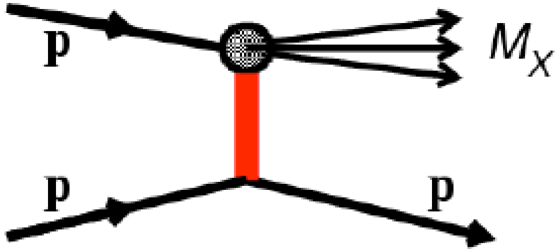
Overlap Backgrounds at 420m

- Single diffraction



At 10^{34} s^{-1} cm^2 : 1 proton / bunch crossing into 420m detectors

Note - at high x_{IP} this is the main background source for the machine - 10^8 protons / sec - above magnet quench limit

Killed by requiring at least 1 rapidity gaps (M_x ~ 1 TeV)

- Beam Halo overlap with non-diffractive dijet event

Probability to have 1 beam halo overlap ~ 1/80 at worst

Henri Kowalski, this workshop

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Effective single interaction luminosities

The no pileup situation allows to apply rapidity gap, primary single vertex and energy matching requirements to select diffractive events.

inclusive and single diffractive events with $\sigma = 70$ mb produce,
at $L = 10^{34}\ s^{-1}\ cm^{-2}$ => ~ 20 events per bunch crossing

$L = 10^{33}$ => ~ 2 events per bunch
probability to have only one vertex is ~ 30%
effective $L \sim 3*10^{32}$ or $0.3\ nb^{-1}\ s^{-1}$

$L = 2*10^{33}$ => ~ 4 events per bunch
probability to have only one vertex is ~ 7%
effective $L \sim 1.4*10^{32}$

$L = 4*10^{33}$ => ~ 8 events per bunch
probability to have only one vertex is ~ 0.25%
effective $L \sim 1*10^{31}$

Exclusive dijet cross sections ~ few hundred pb -> O (10^7) exclusive events with no pileup

Henri Kowalski, this workshop

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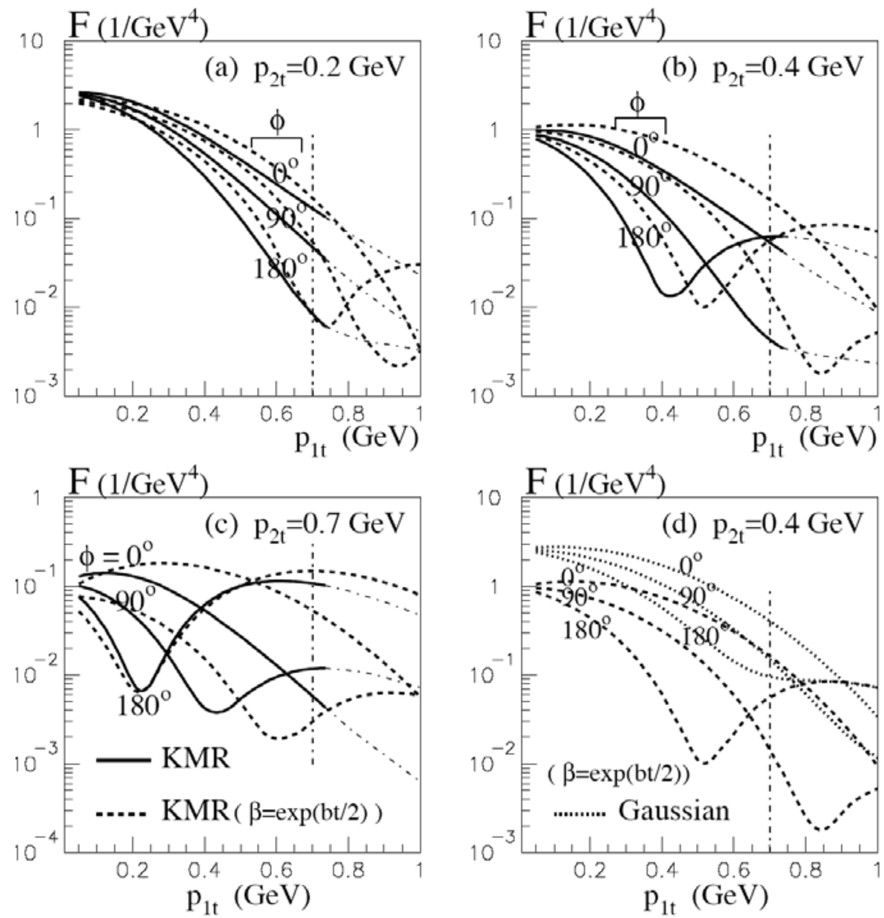
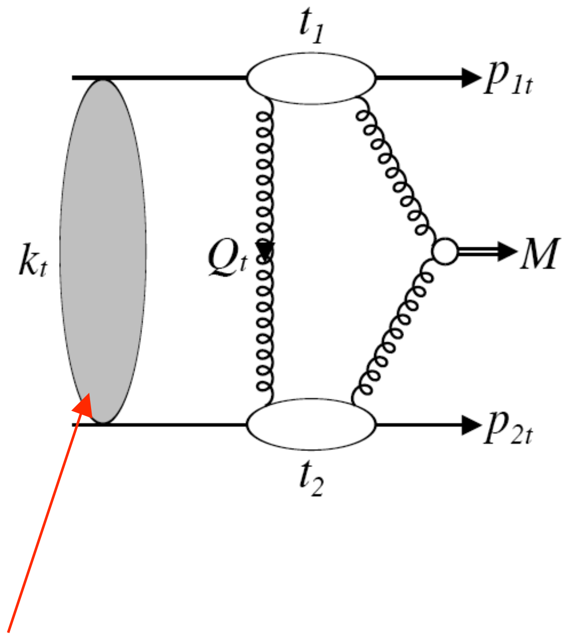
Experimental sensitivity to soft rescattering corrections

p_{1t}, p_{2t} - dependence of the diffractive cross section



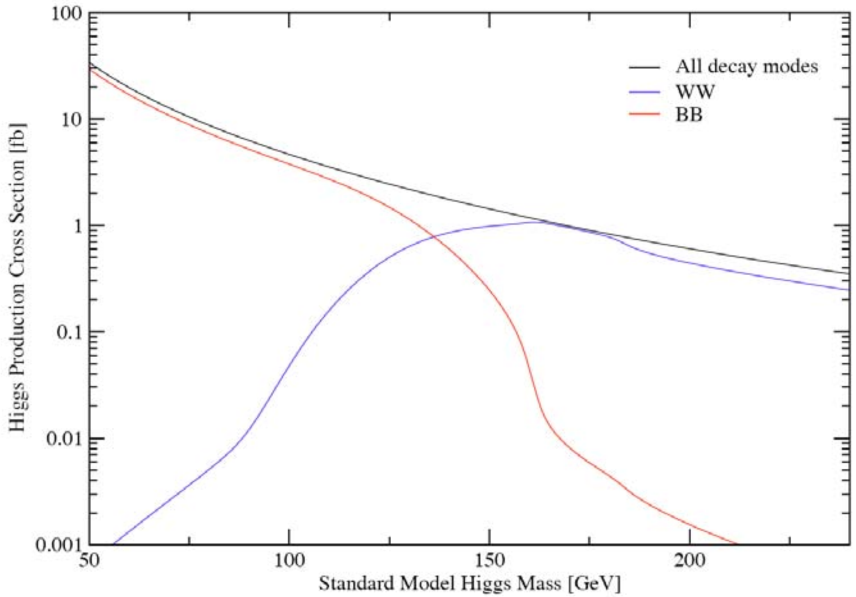


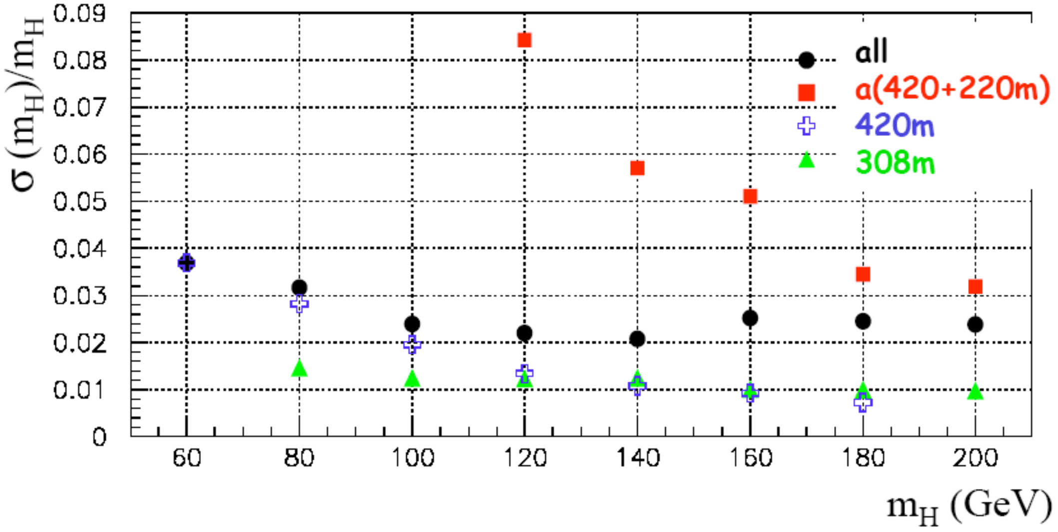
$$\hat{S}^2 = \frac{\int \sum_i |\mathcal{M}_i(s,b_t^2)|^2 \exp\left(-\Omega_i(s,b_t^2)\right) d^2b_t}{\int \sum_i |\mathcal{M}_i(s,b_t^2)|^2 d^2b_t}$$

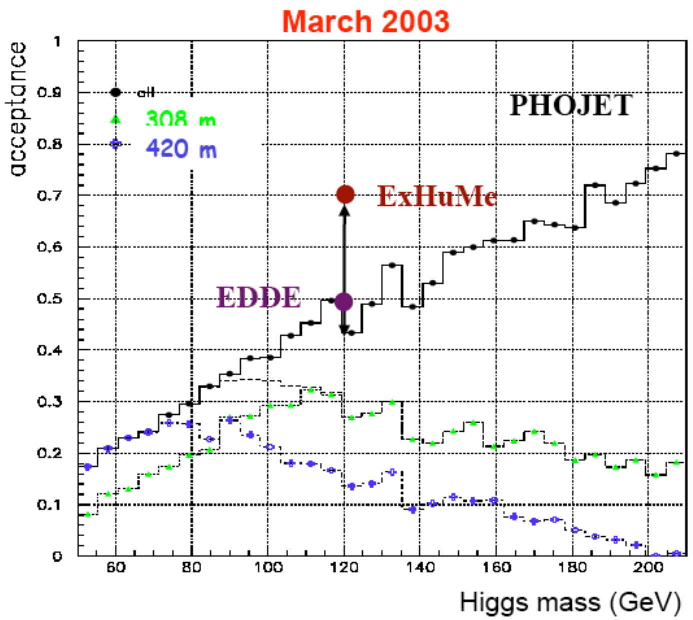
~ 0.02 at LHC

Khoze, Martin and Ryskin, Eur.Phys.J.C24:581-587,2002

Searching for New Physics using the Exclusive Process







Plots from K. Osterberg, this workshop

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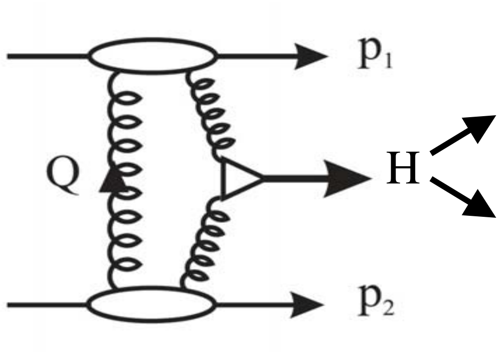
The benchmark : Standard Model Higgs Production

Standard Model Higgs



b jets : M_H = 120 GeV σ = 2 fb (uncertainty factor ~ 2.5)

M_H = 140 GeV σ = 0.7 fb

M_H = 120 GeV : 11 signal, S/B ~ 1 in 30 fb^{-1}

WW* : M_H = 120 GeV σ = 0.4 fb

M_H = 140 GeV σ = 1 fb

M_H = 140 GeV : 8 signal / 1? background in 30 fb^{-1}

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:

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

- The b jet channel is possible, with a good understanding of detectors and clever level 1 trigger
- The WW* (ZZ*) channel is extremely promising : no trigger problems, better mass resolution at higher masses (even in leptonic / semi-leptonic channel)
- If we see Higgs + tags - the quantum numbers are 0^{++}

De Roeck, Khoze, Martin, Orava and Ryskin, Eur. Phys. J. C 25 (2002)391

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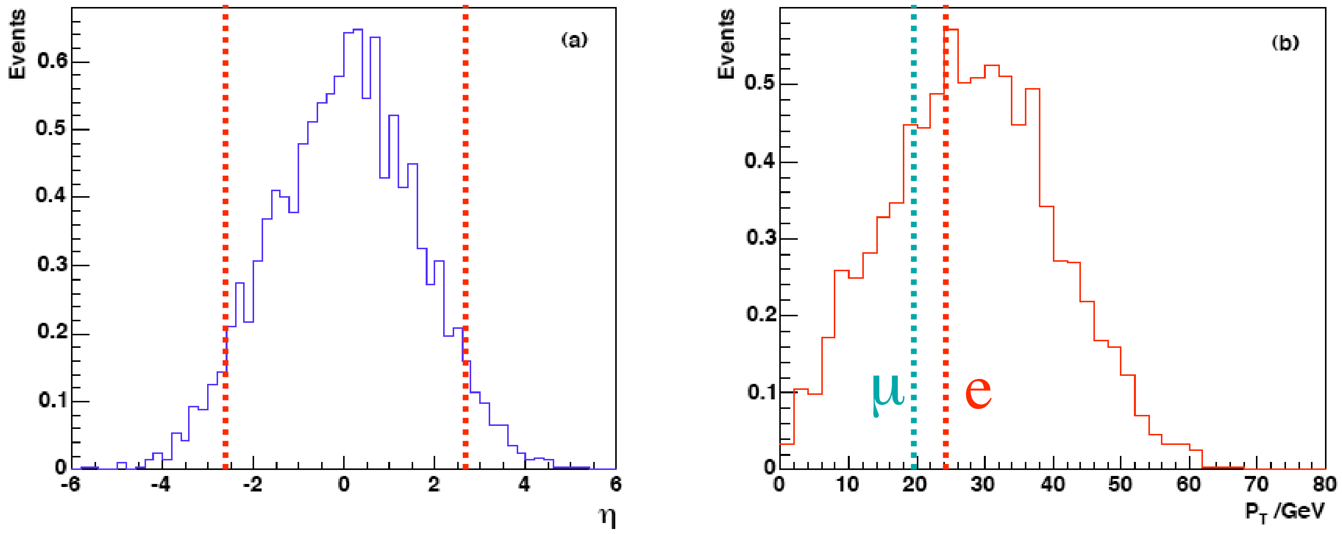
Standard Model Higgs -> $WW^{(*)}$

- Level 1 trigger from 420m is difficult, therefore may require central system trigger with pots at level 2



- Semi-leptonic W decays + current L1 trigger thresholds ->

12 H -> WW^* events at M_H=140 GeV pass L1 trigger in $30fb^{-1}$

- Very little background, excellent mass resolution at higher masses irrespective of decay channel

B.C., DeRoeck, Khoze et. al. in preparation

The MSSM can be very proton-tagging friendly

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The intense coupling regime is where the masses of the 3 neutral Higgs bosons are close to each other and tan β is large

$\gamma\gamma, WW^\star, ZZ^\star$ suppressed

$gg \rightarrow \phi$ enhanced

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

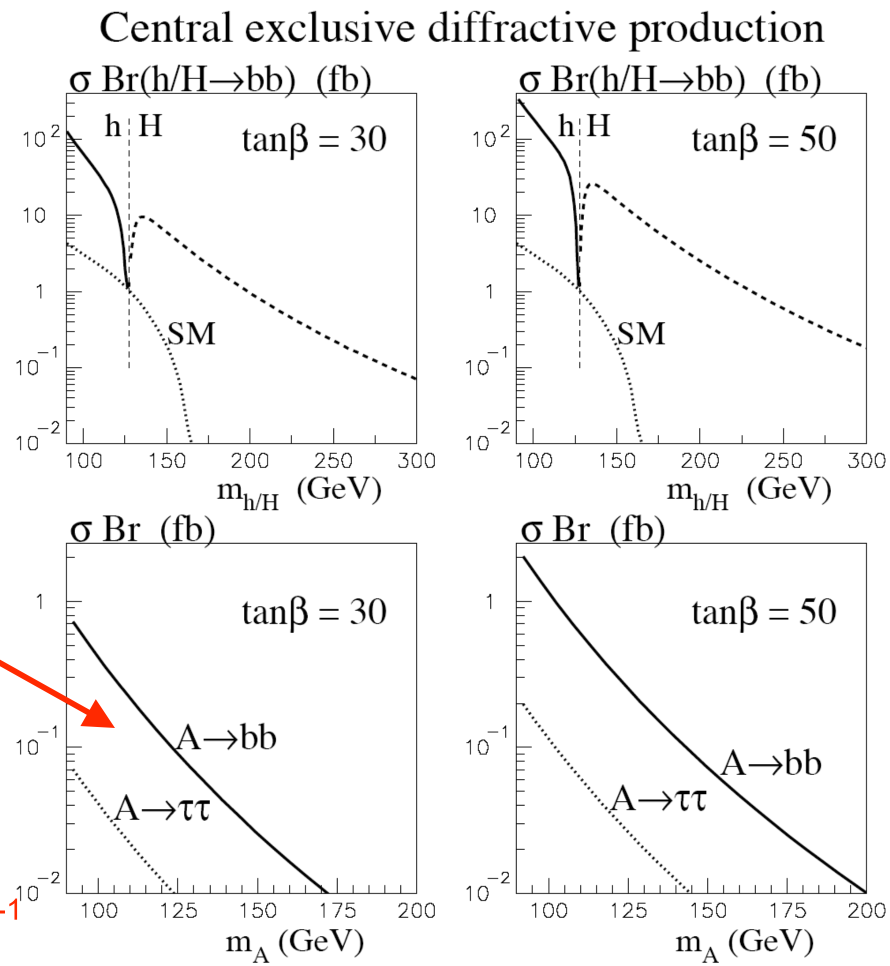
CEDP 'filters out' pseudoscalar production, leaving pure H sample for study

M_A = 130 GeV, tan β = 50

M_h = 124 GeV : 71 signal / 3 background in 30 fb^{-1}

M_H = 135 GeV : 124 signal / 2 background in 30 fb^{-1}

M_A = 130 GeV : 3 signal / 2 background in 30 fb^{-1}



Well known difficult region for conventional channels, tagged channel may well be the discovery channel, and is certainly a powerful spin/parity filter

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Probing CP violation in the Higgs Sector

Azimuthal asymmetry in tagged protons provides direct evidence for CP violation in Higgs sector

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

$M(H_1)$ 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

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

'CPX' scenario

σ in fb

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

CP even

CP odd active at non-zero t

Ongoing work - are there regions of MSSM parameter space where there are large CP violating couplings AND enhanced gluon couplings?

B.C., Forshaw, Lee, Monk and Pilaftsis Phys. Rev. D. 68 (2003) 075004

Khoze, Martin and Ryskin Eur. Phys. J. C 24 (2004) 327

CP violation in the Higgs Sector

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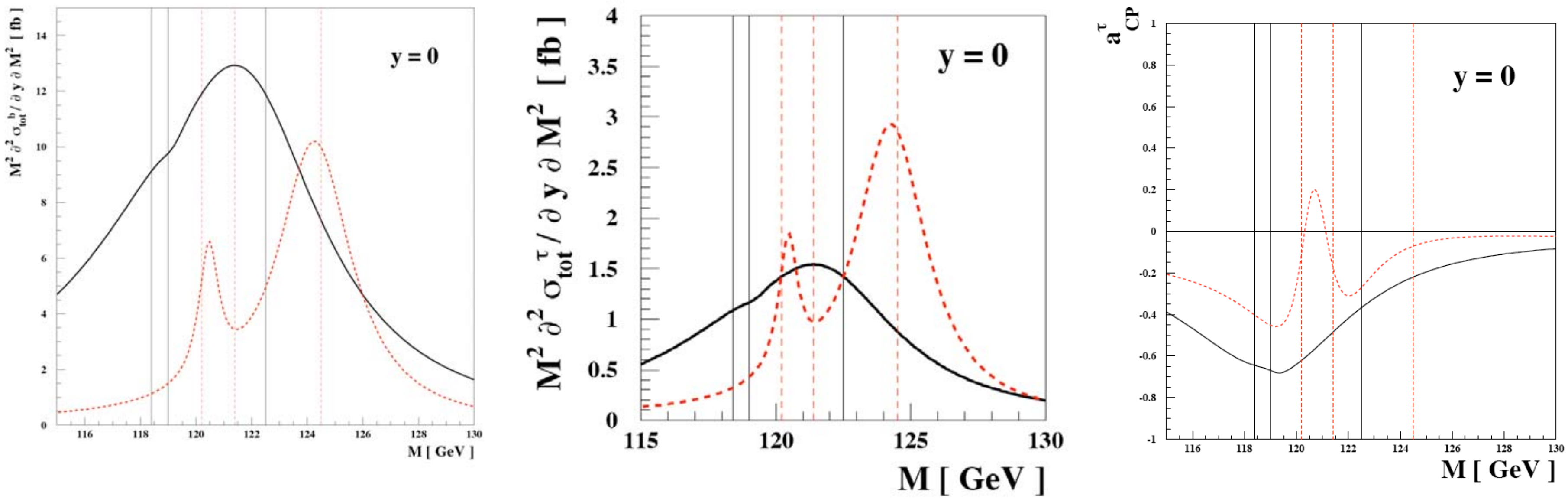
bb decay | ττ decay | ττ decay



This example shows that exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production. In particular, we have shown that exclusive double diffraction constitutes an efficient CP and lineshape analyzer of the resonant Higgs-boson dynamics in multi-Higgs models. In the specific case of CP-violating MSSM Higgs physics discussed here, which is potentially of great importance for electroweak baryogenesis, diffractive production may be the most promising probe at the LHC.

J. Ellis et. al. hep-ph/0502251

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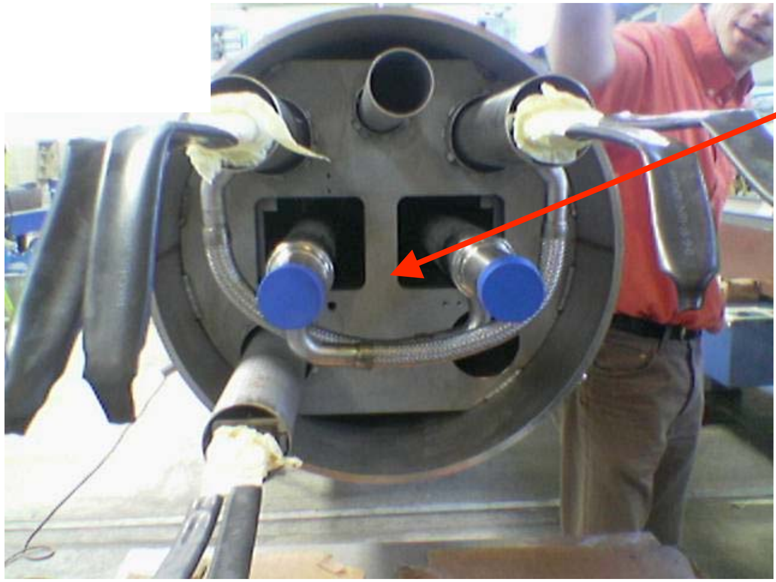
Instrumenting the 420m region



Diffracted protons emerge between beam pipes

- Most likely scenario : Cryogenic bypass, warm beam pipes
- First opportunity to replace 420m cryostat is in planned long shutdown after first physics runs of LHC (autumn 2008?)

- UK FP420 is funded for R&D (including 3D silicon detector research)
- Negotiations in progress to hire cryogenic engineer to design prototype cryostat (in collaboration with AT-CRI group at CERN)
- Meeting at FNAL April 26th of UK, US, Belgium, CERN groups (and anybody else who wants to come along) to coordinate international effort and form R&D collaboration
- Aim for SOI to LHCC this summer

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The case for FP420

- If you have a sample of Higgs candidates, triggered by any means, accompanied by proton tags, it is a 0^{++} state.

- Standard model Higgs will be seen in WW / WW* modes. b decay mode opens up if mass resolution and trigger acceptable, with S/B > 1

- In certain regions of MSSM parameter space, S/B > 20, and double tagging is THE discovery channel

- In other regions of MSSM parameter space, explicit CP violation in the Higgs sector shows up as e.g. azimuthal asymmetry in the tagged protons -> direct probe of CP structure of Higgs sector at LHC

- "Exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production" J. Ellis et. al.

- The commissioning phase will produce a wealth of interesting physics, including detailed probe of gap survival / underlying event

For a review and references, see hep-ph/0409144