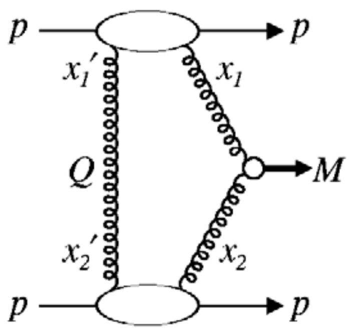
Diffractive Higgs Production

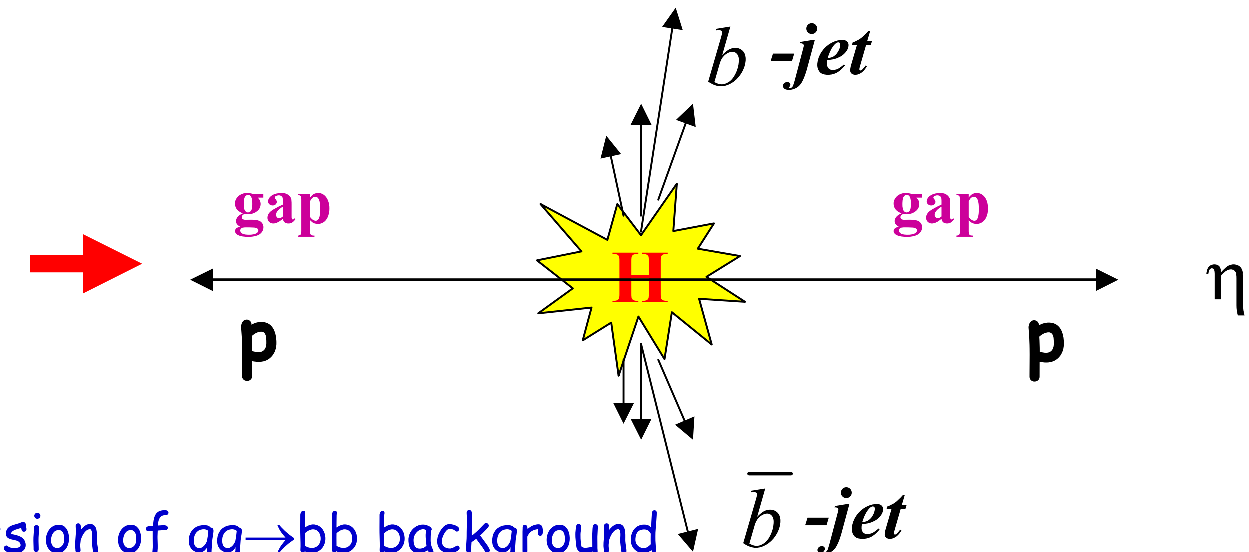
A. De Roeck/CERN

Les Houches meeting
May/June 03

Diffractive Higgs Production

Exclusive diffractive Higgs production pp→ p H p : 3-10 fb
Inclusive diffractive Higgs production pp → p+X+H+Y+p : 50-200 fb

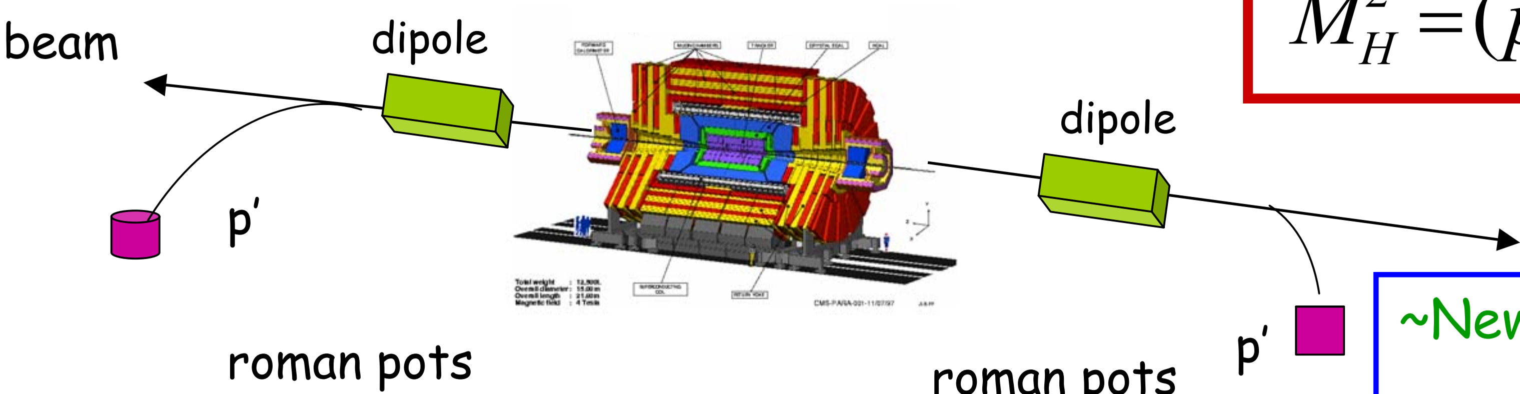




Advantages:

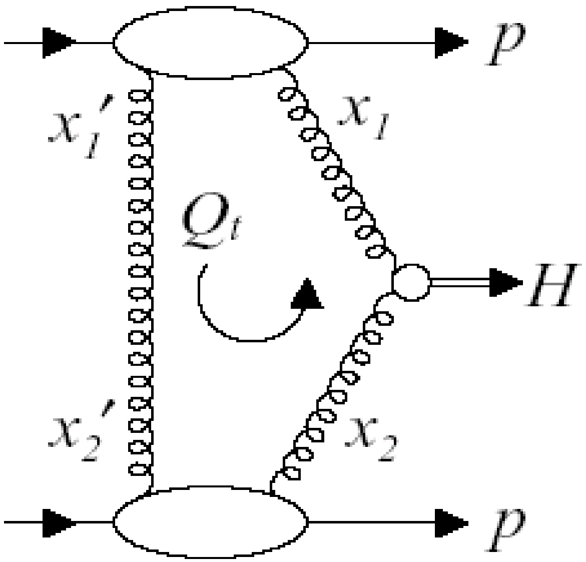
- Jz=0 suppression of gg→bb background
- Mass measurement via missing mass

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$



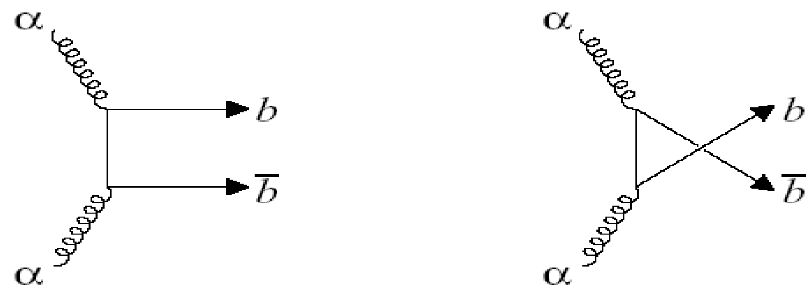
~New: Under study by many groups

Interest in Diffraction



- For light Higgs, dominant decay mode is $H \longrightarrow b\bar{b}$
- For inclusive production, the QCD $b\bar{b}$ background is overwhelming

- For double diffractive production (2 tagged protons) there is a $J_Z = 0$, parity even selection rule :



e.g. V. Khoze

cancel each other in the $m_b \longrightarrow 0$ limit

- Cross section suppressed as m_b^2 / E_T^2

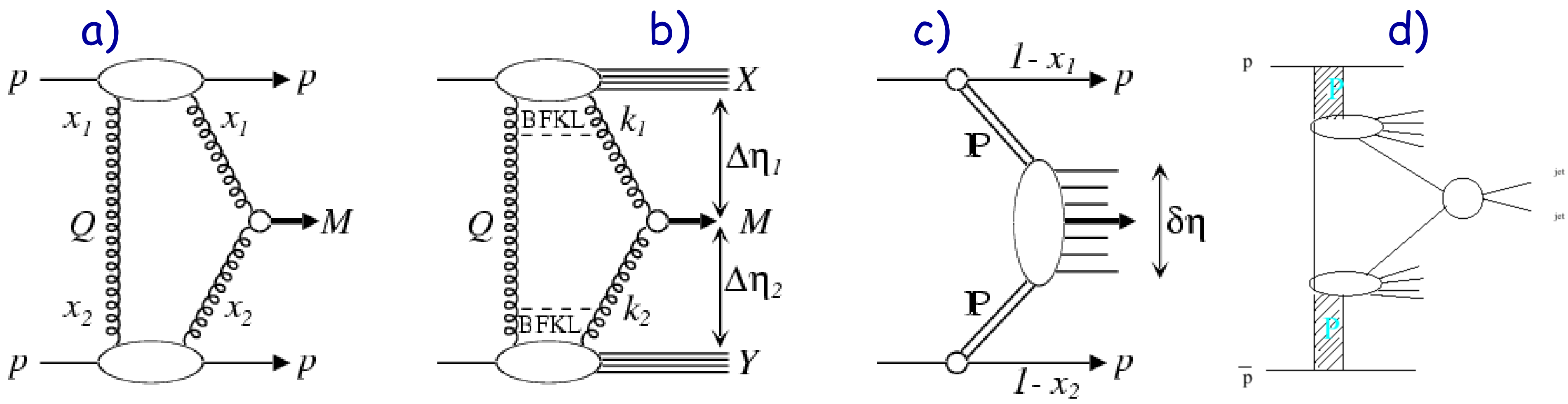
where $E_T \sim M_H/2$

Problem: diffractive production = mixture of perturb.+non-peturb. QCD

Studied Processes

Exclusive processes

Inclusive processes



a) and b) proton induced c) and d) pomeron induced

c) "factorizable" pomeron model: $\varepsilon = 0.2$ (flux factor $d\sigma(s') \sim (s')^{2\varepsilon}$)

d) "non-factorizable" pomeron model: $\varepsilon = 0.08$ (R. Peschanski)

e) SCI/GAL proton models

Khoze et al → a),b),c) Boonekamp et al → d)

Cox et al → c) Enberg at al → e) Godizov et al → a)

Cross Section Calculations

- Fold either pomeron structure functions (as measured at HERA) or proton structure functions with the cross section $gg \to H$

$$\sigma_H \approx \frac{G_F \alpha_s^2}{288\pi\sqrt{2}} \tau \int_\tau^1 \frac{dx}{x} g_1(x, m_h^2) g_2(\tau/x, m_h^2)$$

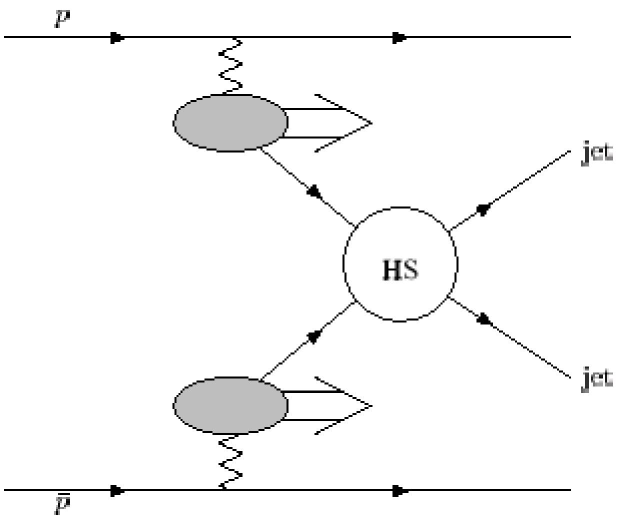
$$g_i(x, Q^2) = \int_x^{\xi_{max}} d\xi_i f_{\mathbb{P}/i}(\xi_i) g_{\mathbb{P}}(x/\xi_i, Q^2).$$

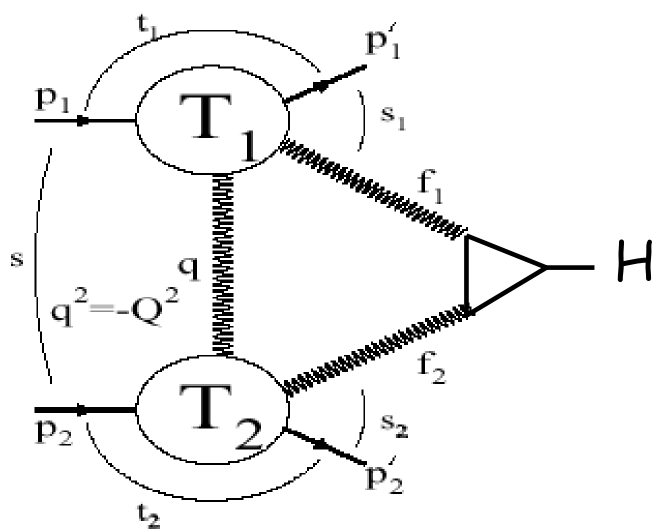
Important unknowns

- Energy dependence Pomeron flux factor $f_{\mathbb{P}/i}(\xi_i)$
- Normalization to di-jets (colour factor)
- Gap survival probability (SP) (factorization breaking)
  - Normalize at Tevatron (di-jet data)
  - Calculate (Khoze et al.: soft rescattering/QCD radiation in the gap)
  - Some group do not take such SP into acount $\Rightarrow$ High cross sections!

Reliability of the cross section calculations?

Recent Calculations





Cox, Forshaw, Heinemann (2001)
- Factorized Pomeron induced model
- gluon from H1/ε = 0.20 (flux)

Boonekamp, Peschanski, Royon, ADR (2002)
- Non-Factorized Pomeron induced model
- gluon from H1/ε = 0.08 (flux)

Khoze, Martin, Orava, Ryskin, ADR (2002)
- Exclusive channel with uncertainties, acceptance and full background estimates

Godizov, Petrov, Prokudin, Ryutin (2003)
- Exclusive, proton induced
- Regge Eikonal approach, used to describe HERA data. Uses fully non-factorized form of the amplitude
- No rapidity gap suppression

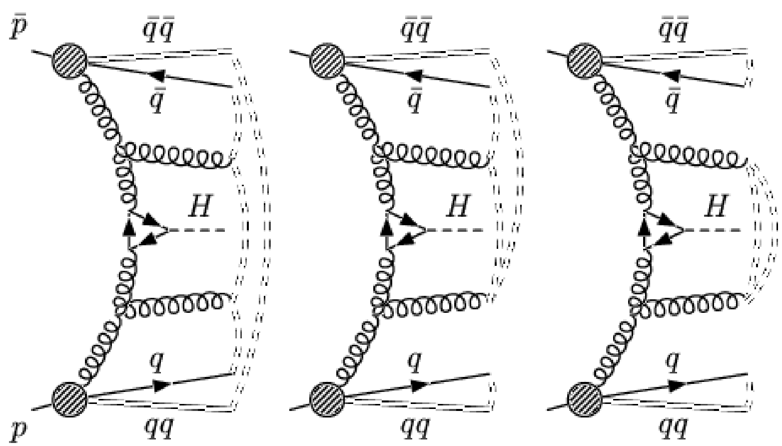
Recent Calculations

Enberg, Ingelman,Kissavos, Timneanu (2002)

- Soft color interaction model
- Generalized area law model

Claimed to describe Tevatron and HERA data

No explicit color singlet exchange

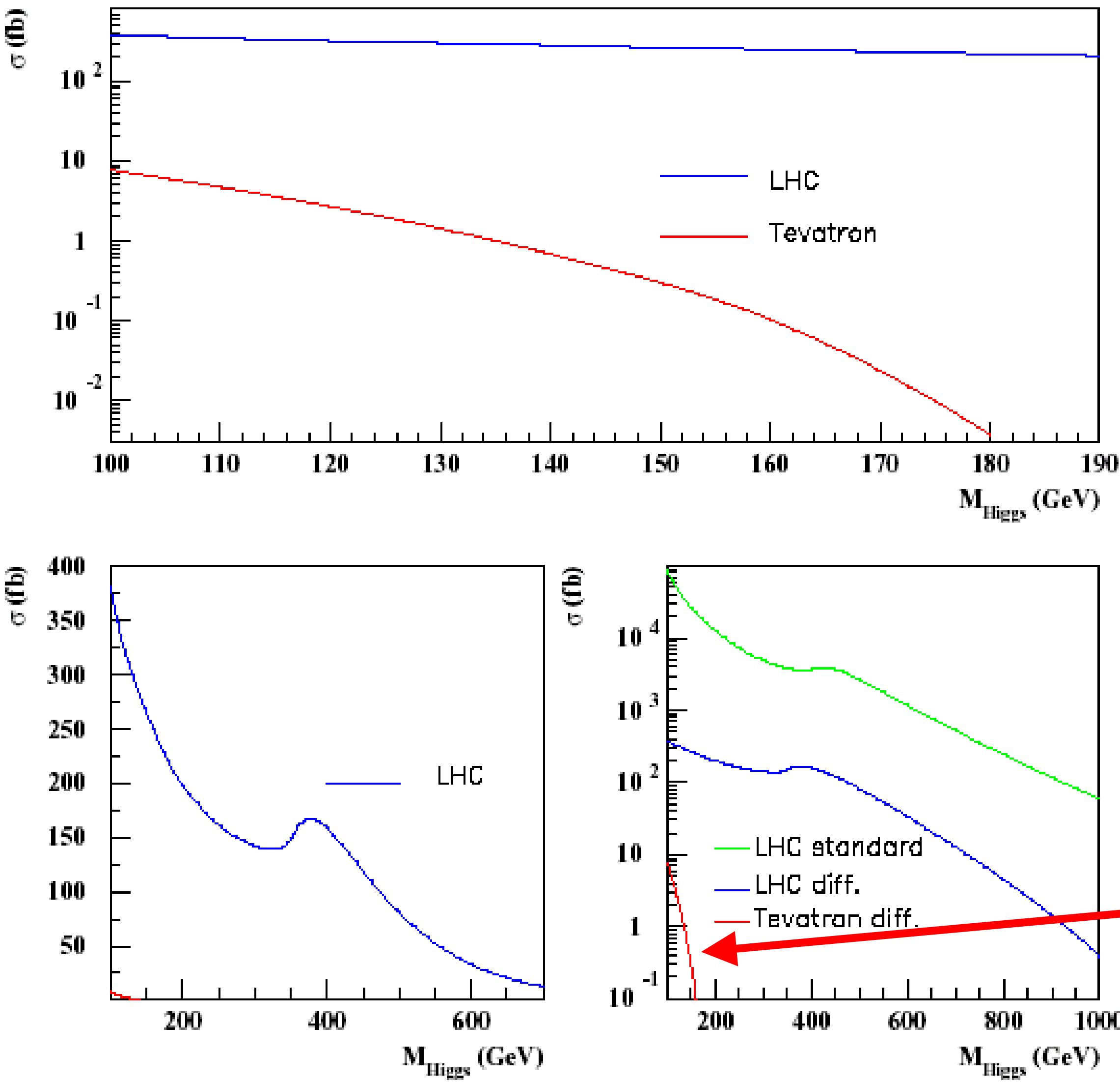


	Tevatron		LHC	
$m_H = 115$ GeV	$\sqrt{s} = 1.96$ TeV		$\sqrt{s} = 14$ TeV	
	$\mathcal{L} = 20\ \text{fb}^{-1}$		$\mathcal{L} = 30\ \text{fb}^{-1}$	
σ[fb] Higgs-total	600		27000	
	SCI	GAL	SCI	GAL
Higgs in single diffraction:				
σ [fb] leading-p	1.2	1.2	190	160
σ [fb] gap	2.4	3.6	27	27
R [%] leading-p	0.2	0.2	0.7	0.6
R [%] gap	0.4	0.6	0.1	0.1
# H + leading-p	24	24	5700	4800
$\hookrightarrow$ # H $\to \gamma\gamma$	0.024	0.024	6	5
Higgs in DPE:				
σ [fb] leading-p's	$1.2 \cdot 10^{-4}$	$2.4 \cdot 10^{-4}$	0.19	0.16
σ [fb] gaps	$2.4 \cdot 10^{-3}$	$7.2 \cdot 10^{-3}$	$2.7 \cdot 10^{-4}$	$5.4 \cdot 10^{-3}$
R [%] leading-p's	0.01	0.02	0.1	0.1
R [%] gaps	0.1	0.2	0.001	0.02
# H + leading-p's	0.0024	0.0048	6	5

No exclusive events produced in this model

Inclusive Production Cross sections

Boonekamp et al.



Inclusive Higgs production

Rather hopeless at the Tevatron

Inclusive cross sections (fb) for LHC

M_{Higgs}	(1)	(2)	(3)	(4)
100	182.3	152.1	12.4	1.5
120	158.5	114.3	9.6	18.1
140	137.7	54.3	4.6	61.6
160	122.5	6.2	0.5	109.0
180	108.9	0.8	0.1	101.4
200	98.1	0.3	0.0	72.5

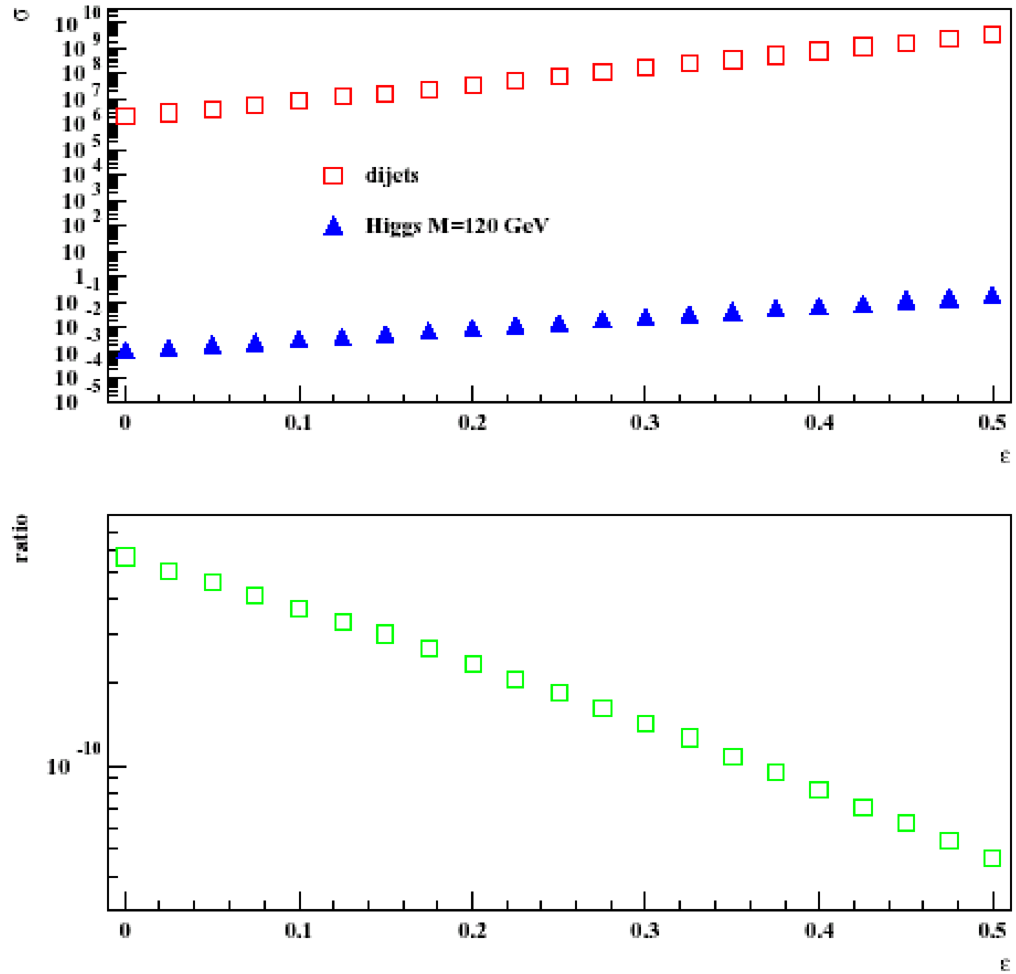
- (1): generator level
- (2): $b\bar{b}$ channel
- (3): $\tau\tau$ channel
- (4): W^+W^- channel

1. Boonekamp et al.(*)
2. Cox et al. (*) 5-20 fb (120GeV)
3. Khoze et al. 40 fb (120 GeV)

Difference in predictions about a factor 10-20.
Difference essentially due to the flux factor (and gap suppression)
Model assumptions can be tested with (Run-II) Tevatron data.

(*) both normalized to the CDF Diffractive di-jet data

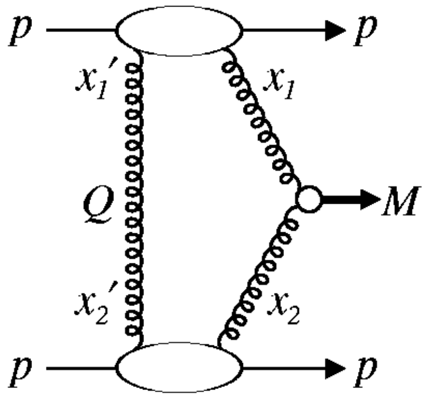
E.g. effect of the choice of ε



Exclusive Higgs production for LHC

Pre- DIS02 status

A. Sobol



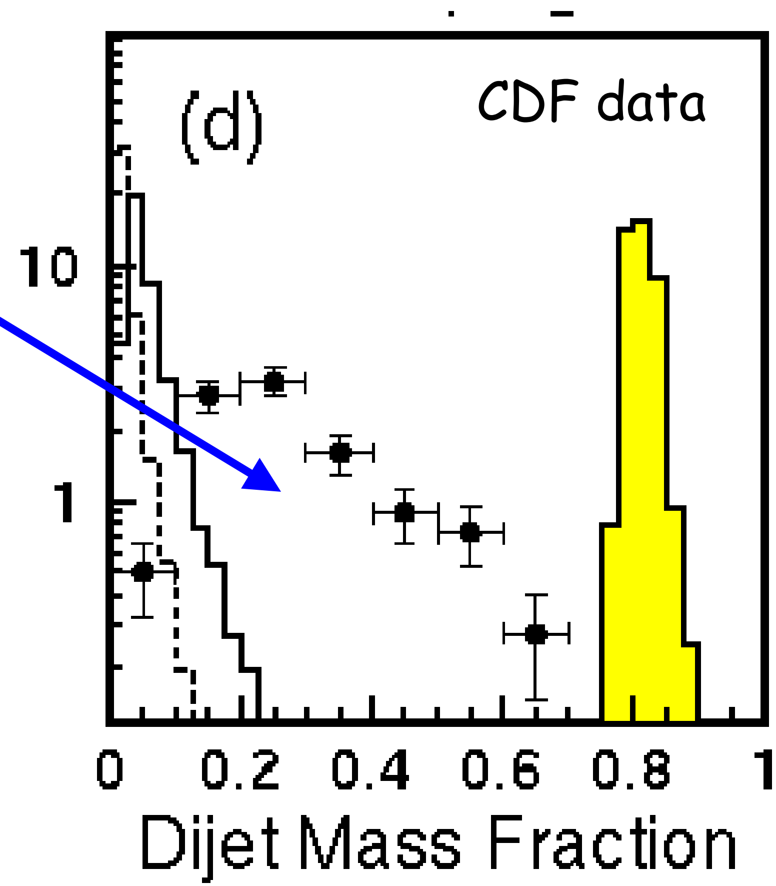
Year	Authors	M_H, GeV	σ_H, fb
1991	*Bialas Landshoff*	[100,400]	$100 \div 200$
1994	*Cudell Hernandez*	[100,400]	$200 \div 400$
2000	*Khoze Martin Ryskin*	120	≈ 2
2000	*Kharzeev Levin*	100	$10 \div 270$
2001	*Petrov Ryutin Godizov*	[100,400]	$80 \div 140$

A. Bialas: cross sections easily uncertain by a factor 10 or more
V. Khoze et al numbers are low mostly due to gap survival probability

Are high cross sections possible?

Test for Exclusive Production

There is a published measurement of double diffractive dijet production from Run I from CDF,



CDF di-jets in DPE
Upper limit 3.7 nb

Generally predictions of
>O(100) pb for the Higgs
Overshoot this predictions
By a factor 10-100

Hence → ruled out!

CDF and D0 should find &
measure a signal with run IIa

Smooth decrease of the cross section.
Can exclusive processes be seen on top of the non-exclusive background?

Comparison of models

V. Khoze et al., hep-ph/0207313

Reference	Process	Survival factor T^2	Survival factor S^2	Norm.	σ_{Higgs} (fb) Teva.	σ_{Higgs} (fb) LHC	Notes
Cudell, Hernandez [21]	excl incl	no	no	σ_{tot}	30 200	300 1200	Overshoots CDF dijets by 1000.
Levin [20]	excl incl	yes No DL	yes	σ_{tot}	20 70	–	Overshoots CDF dijets by 300.
Khoze, Martin, Ryskin [16]	excl incl C.inel	yes	yes	pdf pdf	0.2 1 ~ 0.03	3 40 50	Uses skewed gluons. CDF dijets OK.
Cox, Forshaw, Heinemann [5]	C.inel	$T \simeq 1$	norm	CDF dijet	0.02	6	No LO, only NLO, QCD i.e., no Fig.2(a), only 2(c).
Boonekamp, De Roeck, Peschanski, Royon [7]	C.inel	$T \simeq 1$	norm	CDF dijet	**1.9**	**180**	No LO, only NLO, QCD. Assume $S^2_{CDF} = S^2_{LHC}$.
Enberg, Ingelman, Kissavos, Timneanu [19]	incl C.inel	yes	yes	$F_2^{Diff.}$	< 0.01	0.2	No coherence.

Higgs signal	number of events: signal	number of events: background	S/B	significance $S/\sqrt{S+B}$
a) $H \to \gamma\gamma$ CMS	313	5007	$0.06 \left(\frac{1\text{ GeV}}{\Delta M_{\gamma\gamma}}\right)$	4.3σ
ATLAS	385	11820	$0.03 \left(\frac{2\text{ GeV}}{\Delta M_{\gamma\gamma}}\right)$	3.5σ
b) $t\bar{t}H$, $H \to b\bar{b}$	26	31	$0.8 \left(\frac{10\text{ GeV}}{\Delta M_{b\bar{b}}}\right)$	3σ
c) $gg^{PP} \to p + H + p$, $H \to b\bar{b}$	11	4	$3 \left(\frac{1\text{ GeV}}{\Delta M_{\text{missing}}}\right)$	3σ
d) $gg^{PP} \to X + H + Y$, $H \to b\bar{b}$	190	21,000	$0.009 \left(\frac{10\text{ GeV}}{\Delta M_{b\bar{b}}}\right)$	1.3σ
e) Weak Boson Fusion (WBF)				
$qWWq \to jHj \to j\gamma\gamma j$	17	9	CMS	3.3σ
	18	17	ATLAS	3σ
$\to j\tau\tau j$	25	8		4.4σ
$\to jW(l\nu)W^*(l\nu)j$	49	31		5.4σ
f) WBF with rapidity gaps	jet E_T cuts:			
$qWWq \to j + H(\text{high } q_t) + j$, $H \to b\bar{b}$	250	1800	$0.14 \left(\frac{10\text{ GeV}}{\Delta M_{b\bar{b}}}\right)$	5.5σ
	Higgs q_t cut:			
	400	3700	$0.11 \left(\frac{10\text{ GeV}}{\Delta M_{b\bar{b}}}\right)$	6.2σ
g) $gg \to ZZ^* \to 4l$	6	4	CMS	1.9σ
	3	1.5	ATLAS	1.4σ
h) $gg \to WW^* \to l\nu l\bar{\nu}$	44	272	CMS	2.5σ
i) $WH \to l\nu b\bar{b}$	161	7095	0.02	1.9σ

LHC 30 fb^{-1} for 120 GeV Higgs

Khoze, Martin, Orava, Ryskin and ADR, Eur.Phys.J. C25 (2002) 391-403

Numbers for 30 fb^{-1} and a Higgs of 120 GeV

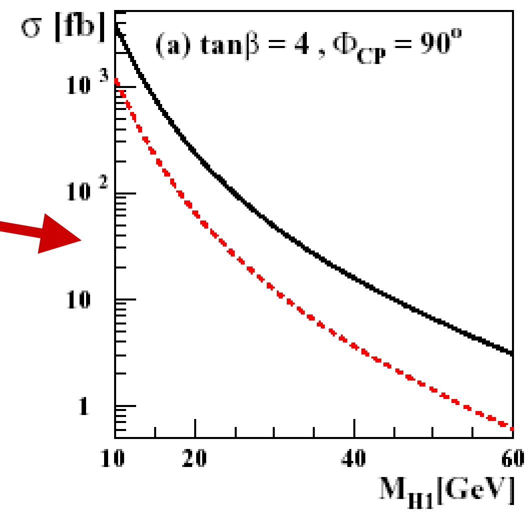
A light Higgs will be a challenge for the LHC!

Beyond Standard Model

Diffractive production of new heavy states pp→ p + M + p
Particularly if produced in gluon gluon (or γγ) fusion processes

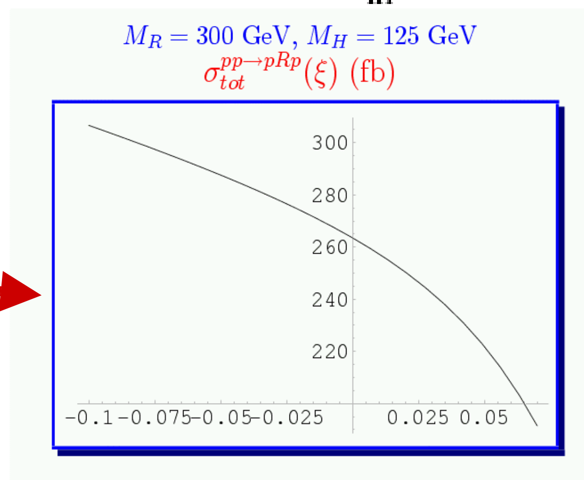
Examples:

Light CP violating Higgs Boson M_H < 70 GeV
B. Cox et al.



Light MSSM Higgs h→bb at large tan β
Light H,A (M<150 GeV) in MSSM with
large tan β (~ 30) → S/B > 10
Medium H,A (M=150-200 GeV) medium tan β?
V. Khoze et al.

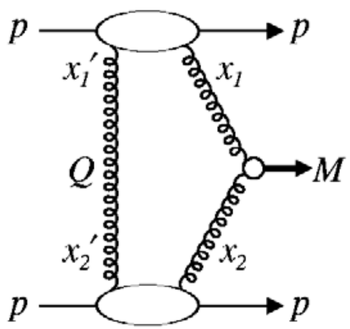
Radion production - couples strongly to gluons
Ryutin, Petrov

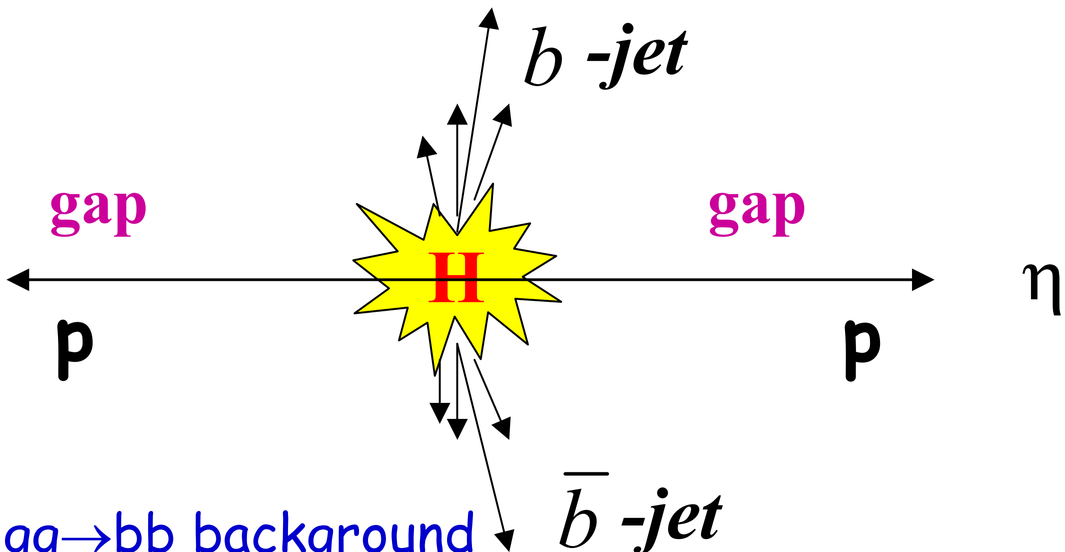


Exclusive gluino-gluino production?
Only possible if gluino is light (< 200-250 GeV)
V. Khoze et al.

Diffractive Higgs Production

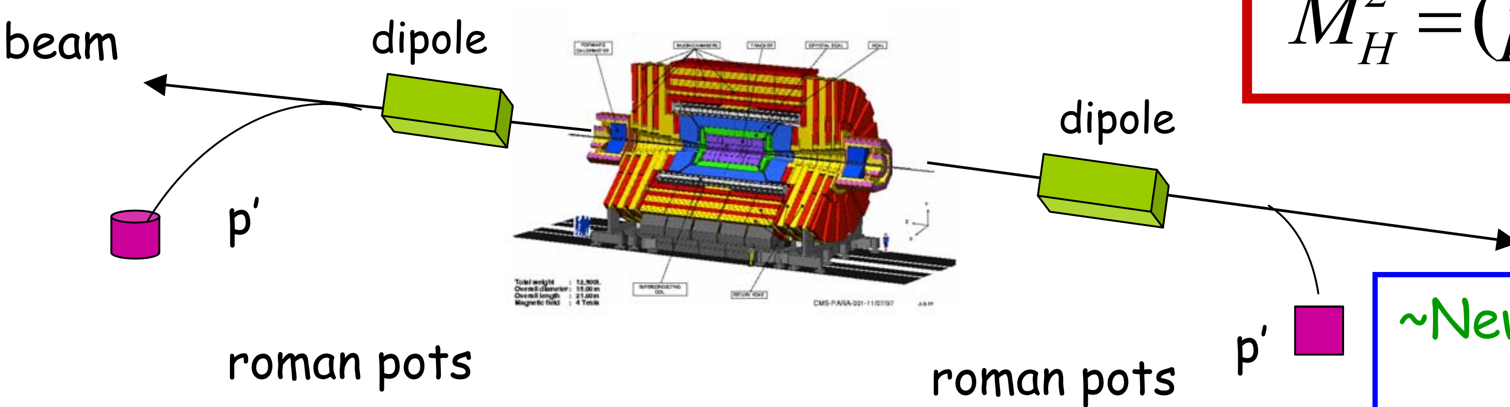
Exclusive diffractive Higgs production pp→ p H p : 3-10 fb
Inclusive diffractive Higgs production pp → p+X+H+Y+p : 50-200 fb





Advantages:
- Jz=0 suppression of gg→bb background
- Mass measurement via missing mass

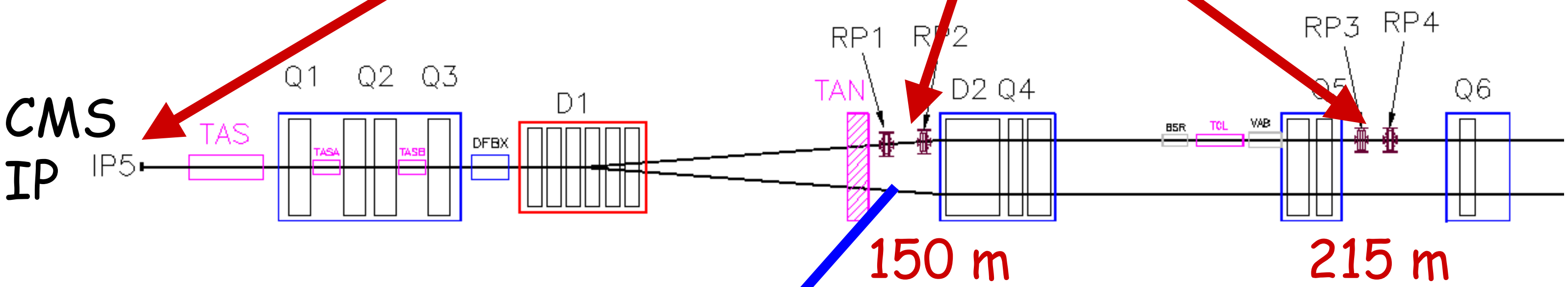
$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

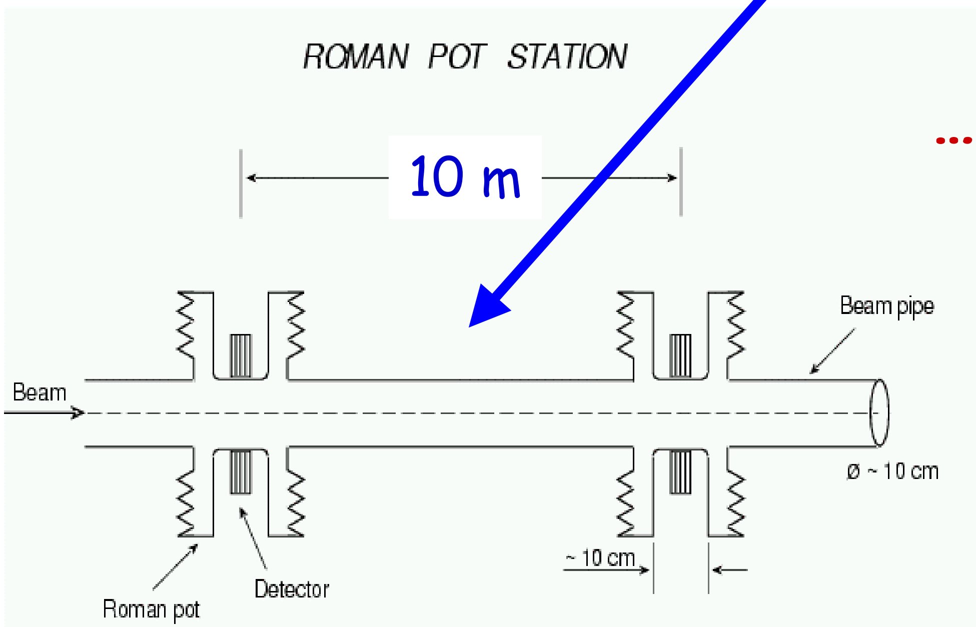


~New: Under study by many groups

The TOTEM Experiment

TOTEM physics program: total pp cross section, elastic cross section
Apparatus: Inelastic Detectors & Roman Pots (2 stations)





…and RP5 at 300-400m?

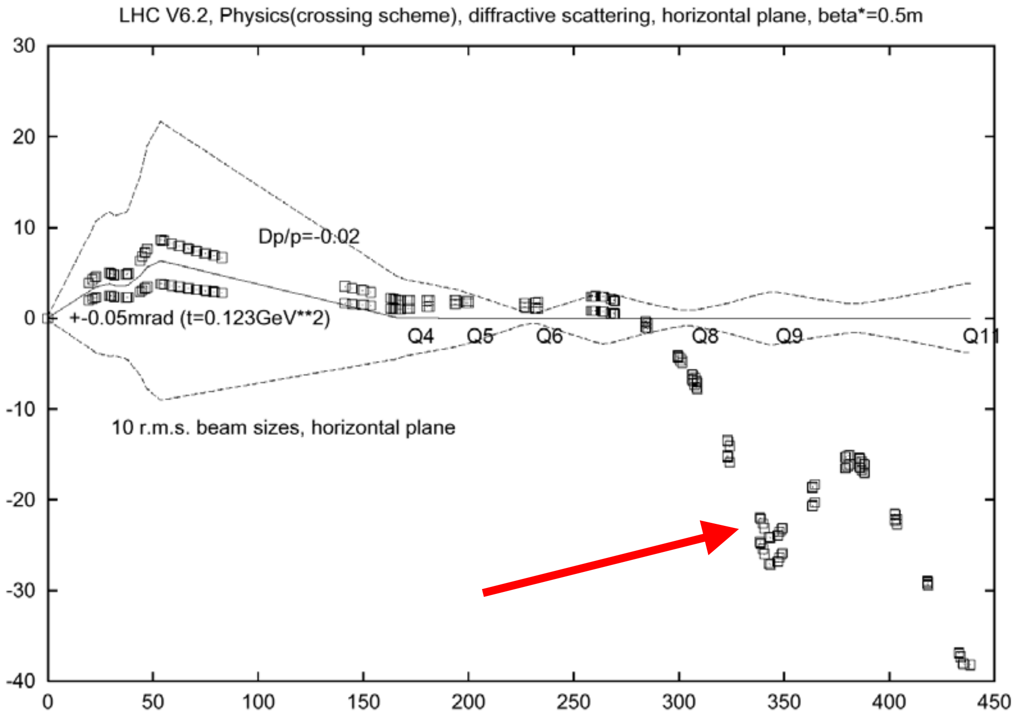
TOTEM uses the same IP as CMS

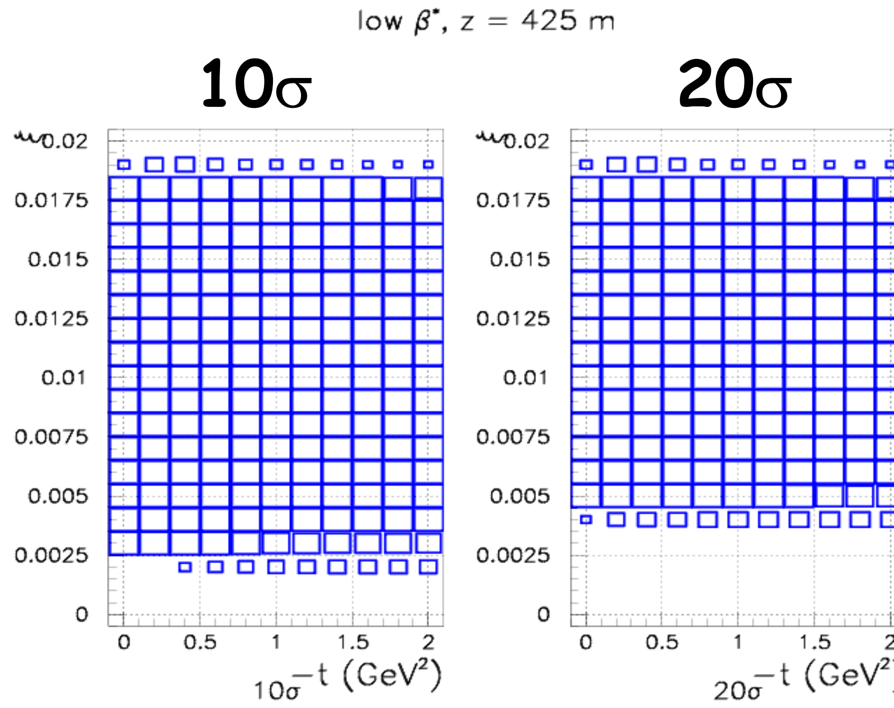
Roman pot acceptances

	$pot_{opt.}$	ξ - range	t - range	$L(cm^{-2}sec^{-1})$
$\beta^* = 0{,}5$ m	4 + 5	0.003 – 0.15	> 5 GeV^2	10^{32} - 10^{33}
= 18 m	3	0.03 – 0.15	> 0.3 GeV^2	10^{31}
= 1100 m	1 + 2	0.02 – 0.15	> $5 \cdot 10^{-3}$ GeV^2	10^{28}

MAD calculations
acceptance
0.003(2) <ξ<0.15

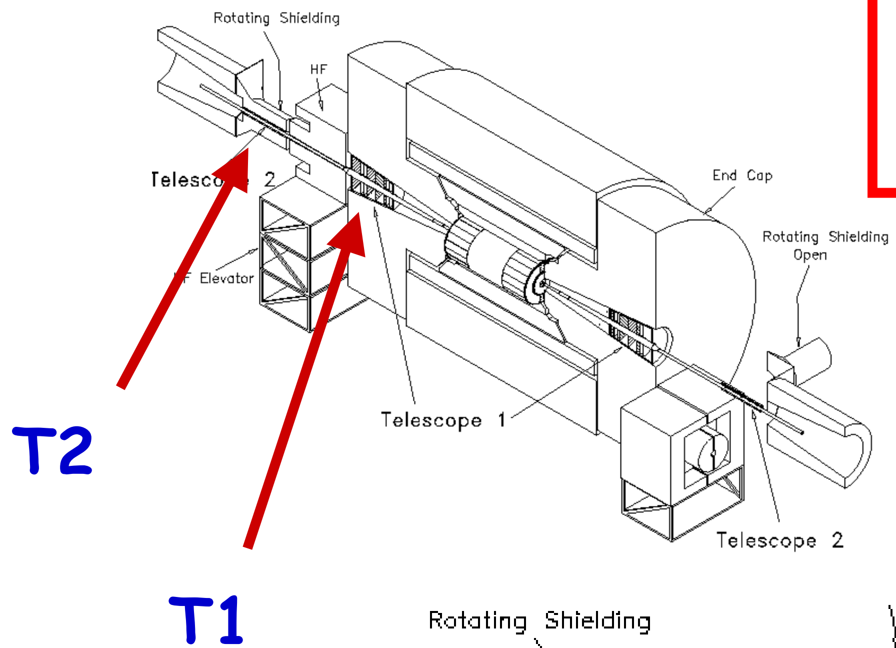
For Higgs need
acceptance ξ~ 0.01

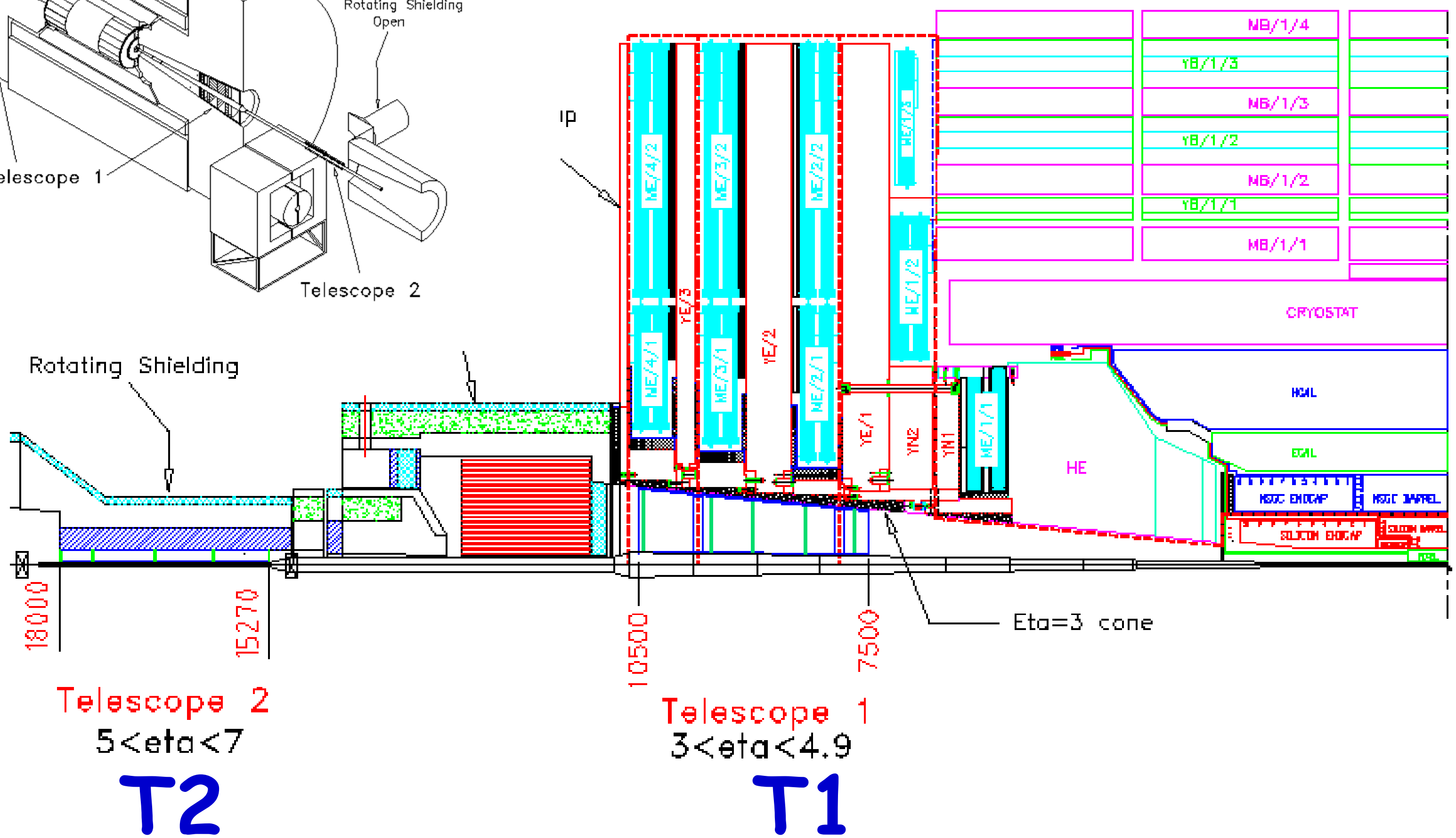




TOTEM inelastic detectors

Standard: T1/T2 Cathode Strip Chambers
Not usable at medium/high lumi (>10^{33})
Now: rethink T2 region ($5<|\eta|<7$-7.5)





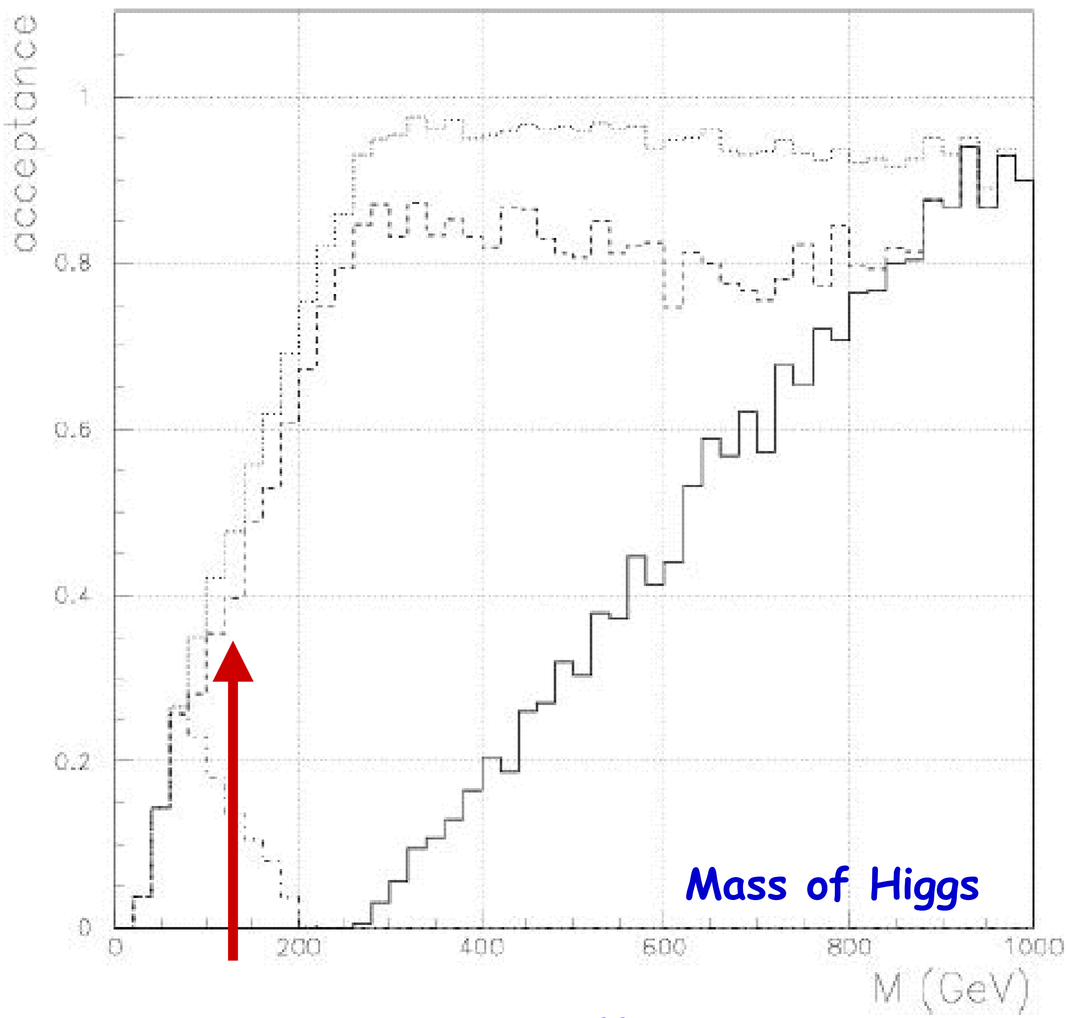
Status of the CMS/TOTEM study

- Common working group to study diffraction and forward physics at full LHC luminosity approved by CMS and TOTEM (ADR/ K. Eggert organizing)
  Use synergy for e.g. simulation, physics studies & forward detector option studies. Report back with EOI spring 2004

- Detector options being explored
  - Roman Pot/microstations for beampipe detectors at 150, 215 , add 310 & 420 m
  - Inelastic detectors
    T1 and T2 CSC trackers of TOTEM
    Replace T2 with a compact silicon tracker (~ CMS technology)
    Add EM/HAD calorimeter (CASTOR) behind T2
    Add Zero degree calorimeter (ZDC) at 140 m
- Common DAQ/Trigger for CMS & TOTEM
- Common simulation etc…

SM Higgs Studies: Exclusive Production

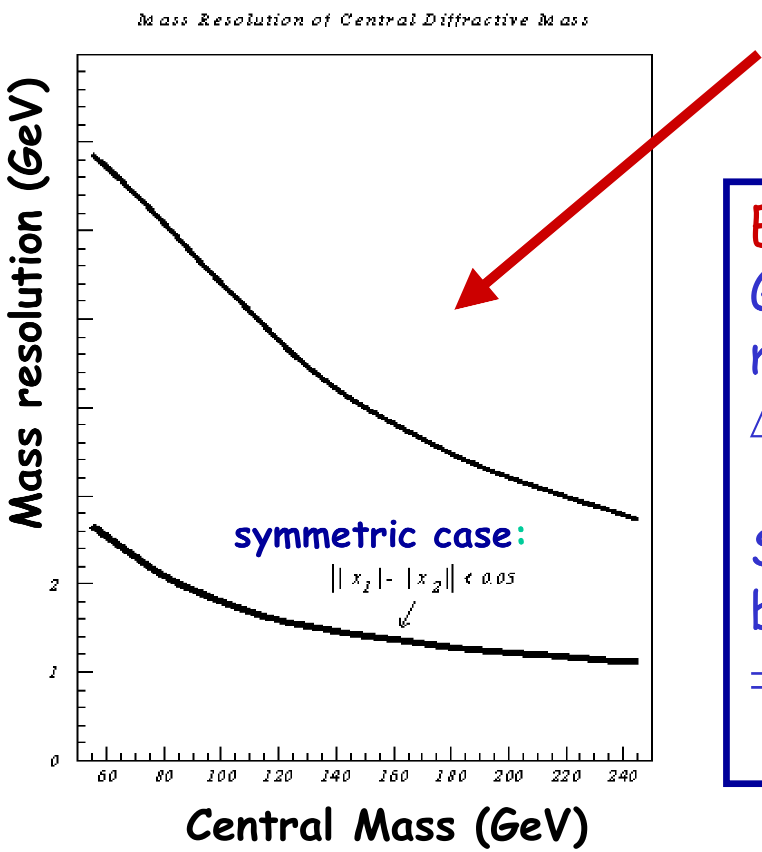
Needs Roman Pots at new positions 320 and/or 420 m
Technical challenge: "cold" region of the machine, Trigger signals…



- Combined acceptance of
  - → All detectors
    - ❍ Dotted line
  - → 420 m + 215 m
    - ❍ Dashed line
  - → 215 m alone
    - ❍ Solid line
  - → 420 m alone
    - ❍ Dash-dotted line
- without 308 / 338 m location
  - → 10-15 % loss in acceptance

R. Orava et al.

Diffractive Higgs Production



Mass resolution vs. central mass
from protons measured in roman pots
assuming $\Delta x_F/x_F = 10^{-4}$

Exclusive channel pp$\rightarrow$ p H p advantages

Good mass resolution thanks to missing mass method:

$\Delta M = O(1.0 - 2.0)$ GeV (including systematics)

Study possible in the b-quark decay mode

b-quark background suppression: (J_Z =0 states)!!

$\Rightarrow$Switch of dominant background (at LO)!

Discussion: Diffractive Higgs production

Range of predictions by different models: different approaches
$\Rightarrow$ Differences are expected.
How can we distinguish these approaches. Use Tevatron data..
Understanding gap survival probabilities? Extrapolation to LHC?

- Exclusive predictions
  - CDF dijets are a serious constraint. Excludes large Higgs cross section predictions. What is the range of predictions that is left? Only Khoze et al. I.e. 3 fb^{-1}?
  - Criticism: do pure exclusive high mass processes at such high energies exist? --aren't there always soft gluons around?
    Can we demonstrate this at the Tevatron?
    - High mass di-jets (but can one be sure about pure exclusiveness?)
    - Two photon production (too small a cross section? Trigger?)
    - low mass systems, (χ_c , χ_b)...
  - Uncertainty on the cross sections (Khoze et al: Factor 2). How to reduce that with measurements?

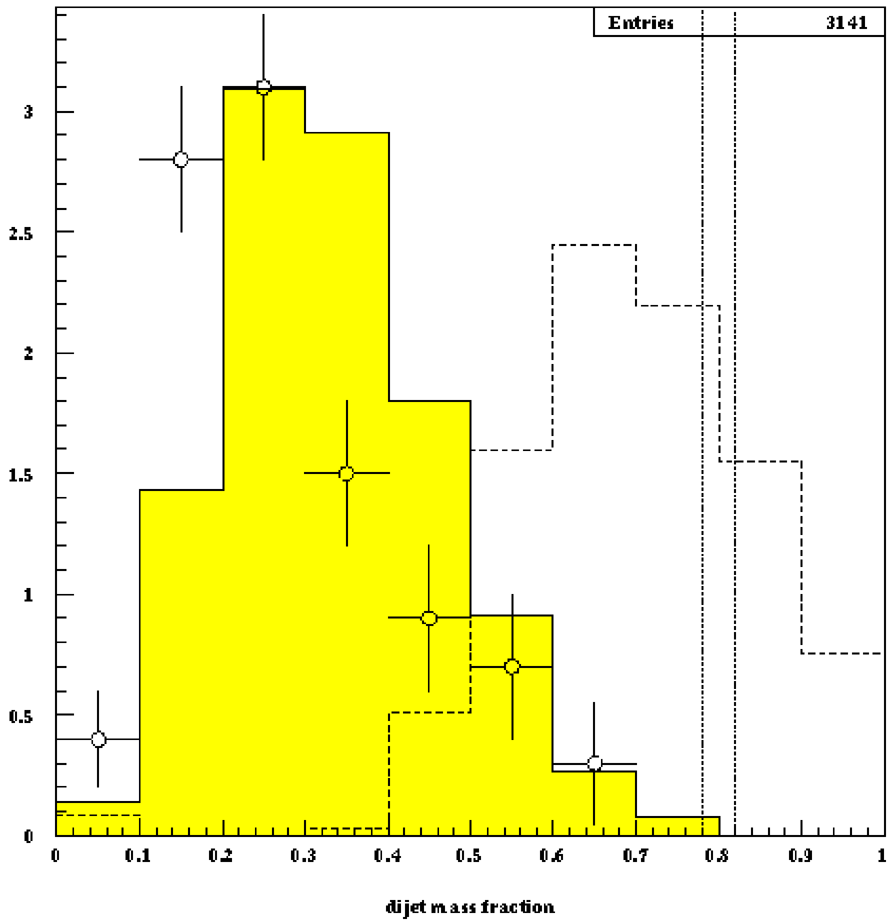
Discussion: Diffractive Higgs production

- Inclusive predictions
  - What can we believe? Pomeron intercept (hard/soft)?
  - What are the uncertainties on the individual calculations?
  - What do we gain in inclusive diffraction?

    No spin selection rule

    Better (sufficient) S/B ? Use of remnants to improve M_H resolution ?
  - Test the models with present or upcoming Tevatron/HERA to reduce the uncertainty (e.g. measure ε)
    - Diffractive dijet cross sections. Dijet mass fraction. VM at HERA?
    - 2-photon production
    - Do all models give the good description of the di-jets?

CDF diffractive dijets



Boonekamp et al.

Use same formalism to describe the diffractive di-jets

Shape well described (normalization factor 3.8 off)

Summary

- Higgs at the Tevatron: chances look rather dim
- Exclusive Higgs production at the LHC: small if gap survival probability is taken into account. Large Higgs cross sections lead to large dijet rates which can be tested/excluded by upcoming Tevatron data. Theoretical uncertainties?
- Inclusive Higgs production: larger cross sections but less clean signal and no J=0 suppression of the background.

  What do we gain in inclusive diffraction? Better M_H resolution in bb?

  Use of pomeron remnants? Other channels (e.g. τ decays?)
- Others channels: light MSSM Higgs, Radions… (theory)
- Monte Carlo generators exist for all models
- Experimental issues/studies in progress
  - Roman pot acceptances/trigger question
  - Forward tagging $|\eta| \sim 5$-7 (remant tagging)