Measurements of central exclusive processes at LHC

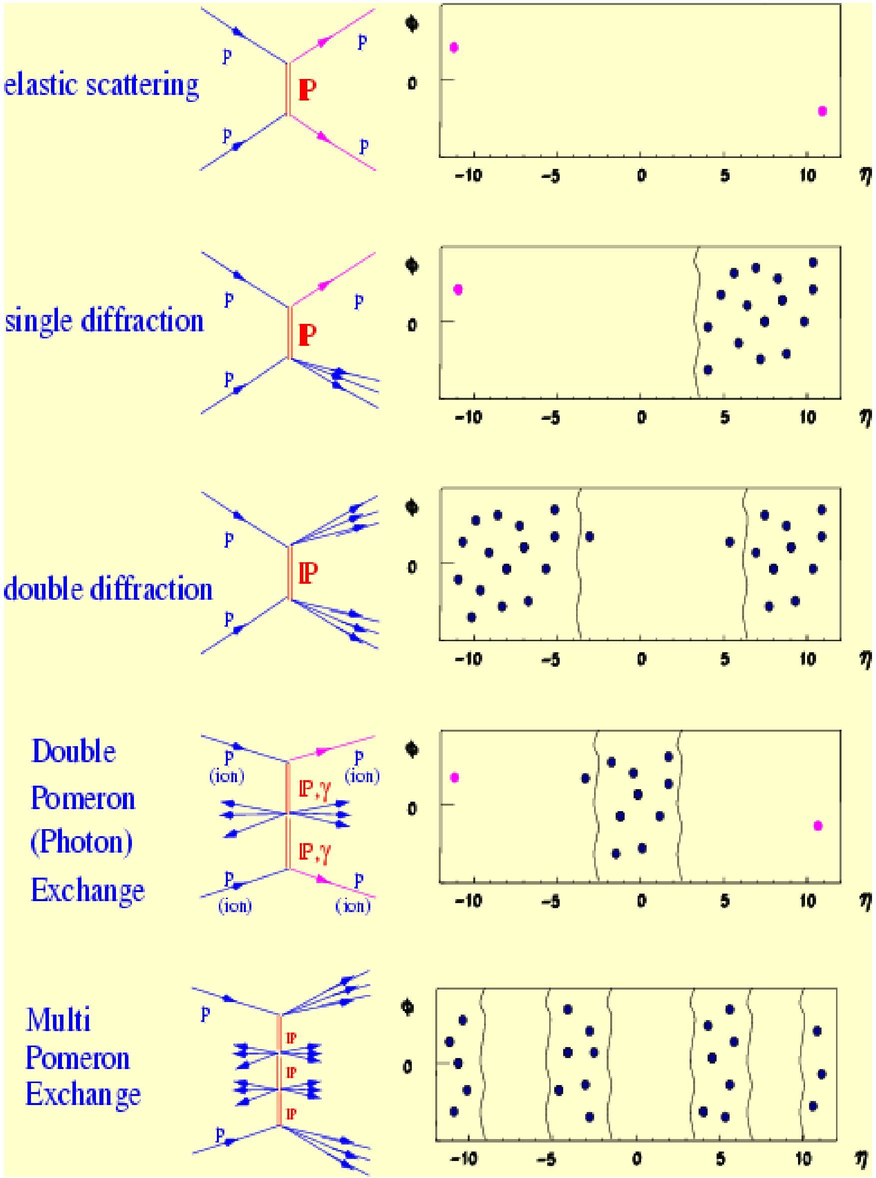
Marek Taševský

Institute of Physics, Academy of Sciences, Prague

Blois conference - 02/07 2009

1. Future LHC measurements
2. Early LHC measurements

Diffraction at LHC:



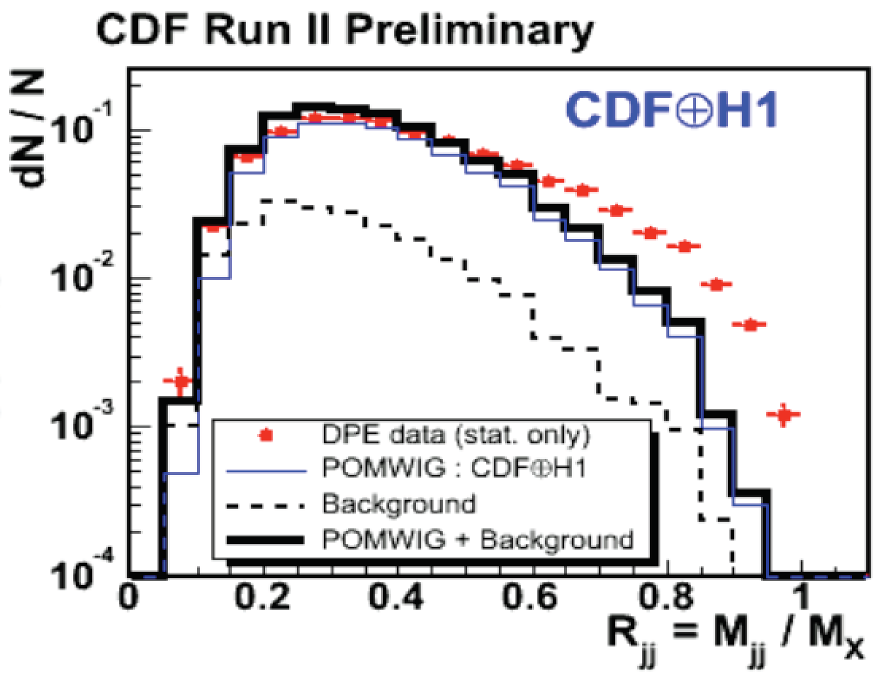
- Forward proton tagging in special runs with ALFA/TOTEM

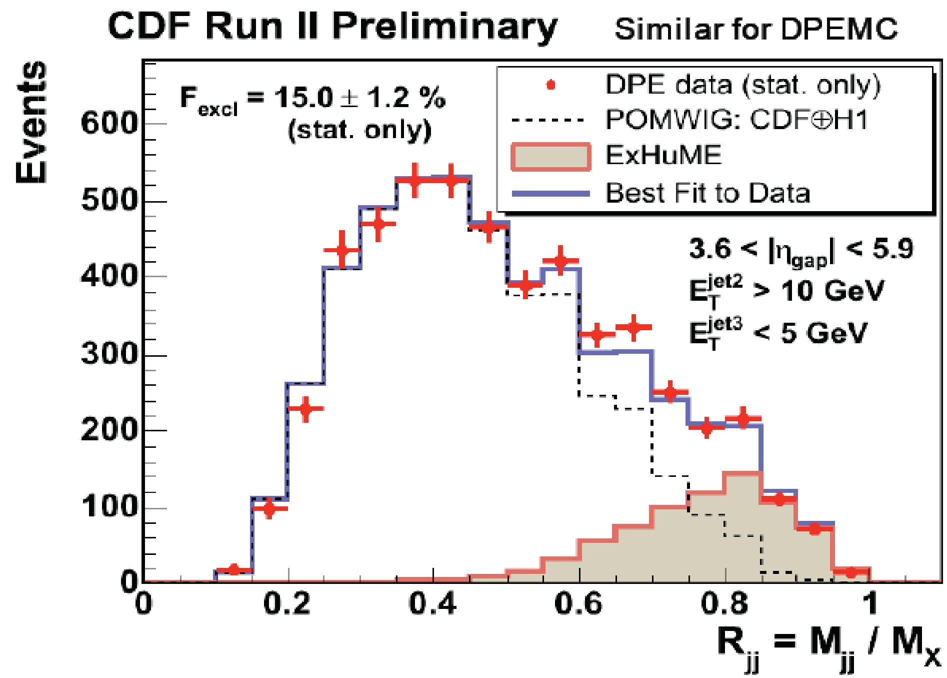
- Combined tag of proton in ALFA/TOTEM on one side and remnants of dissociated proton in LUCID/CASTOR on the other side

- Central rapidity gap in EM/HAD calorimeters (|η|<3.2) and inner detector (|η|<2.5)

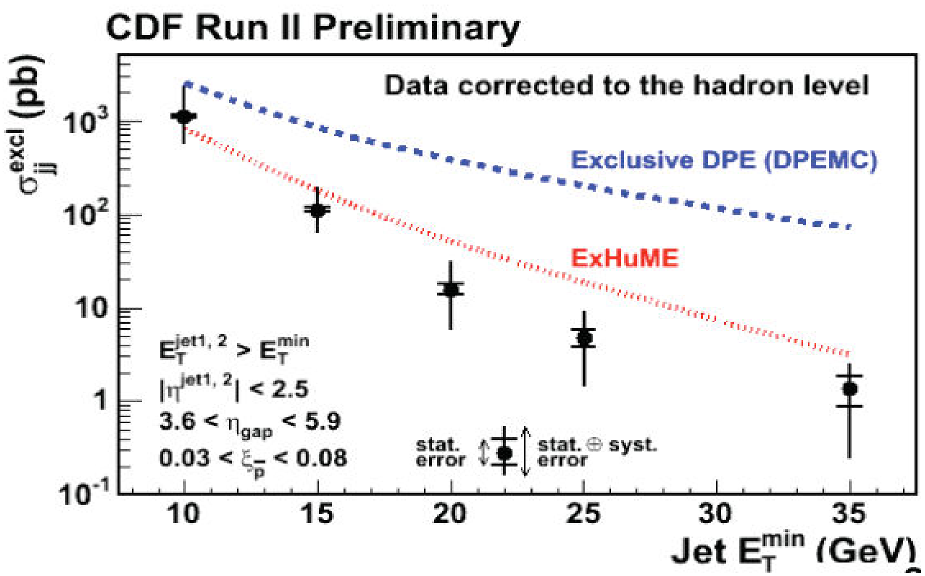
- Two rap.gaps on both sides from IP:
Inclusive Double Pomeron Exchange: parton from Pomeron brings a fraction β out of ξ into the hard subprocess → Pomeron remnants spoil the gaps
Central exclusive diffraction: β = 1 → no Pomeron remnants

CDF measurements of CEP dijets



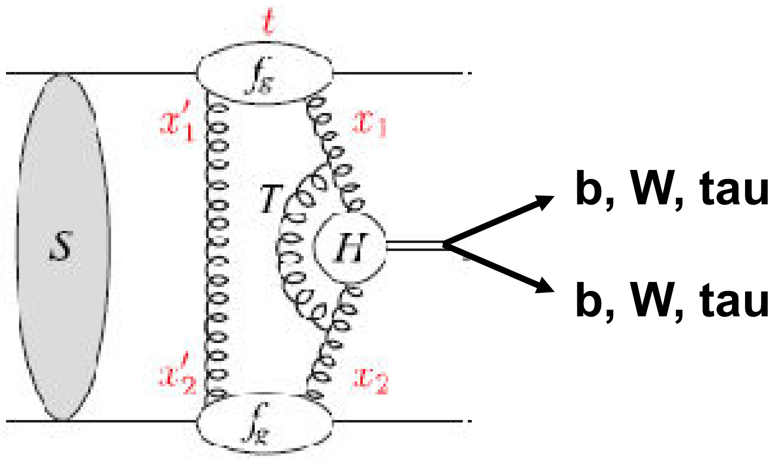


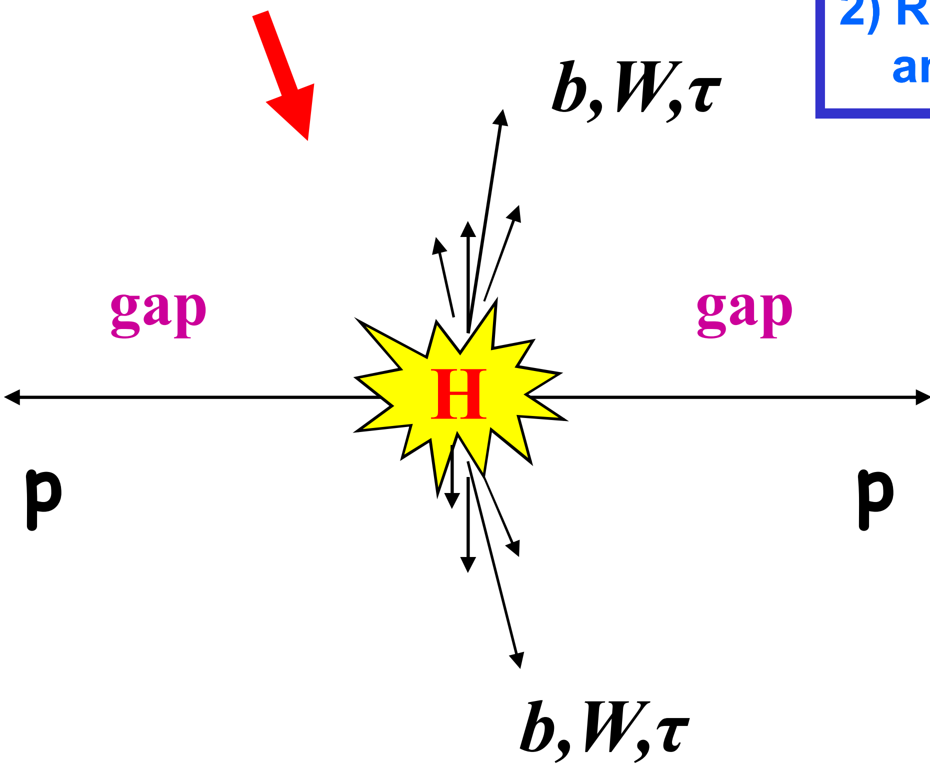
POMWIG (Cox & JRF) simulates INCLUSIVE production, i.e. p+jj+X+p, central systems and its parameters are fixed by the HERA data on diffractive deep inelastic scattering.



[CDF also sees a suppression of quark jets in the "exclusive" region in accord with the expectations of ExHuME.]

Central Exclusive Diffraction: Higgs production





This process is the core of the physics case of Forward detector upgrades (AFP in ATLAS, FP420 in CMS)

1) **Protons remain undestroyed and can be detected in forward detectors**
2) **Rapidity gaps between leading protons and Higgs decay products**

cross-sections predicted with uncertainty of 3 !! (or more?) (KMR group, Kharzeev-Levin)

bb: at 120 GeV needs a special diffractive trigger

WW: promising for M>130 GeV use leptonic triggers

ττ : interesting around 100 GeV under study

Central Exclusive Diffraction: Higgs production

Advantages:

I) Roman Pots give much better mass resolution than the central detector

II) $J_Z = 0$, CP-even selection rule:

- strong suppression of QCD bg
- produced central system is 0^{++} → **just a few events is enough to determine Higgs quantum numbers. Standard searches need high stat. (φ-angle correlation of jets in VBF of Higgs)**

III) Access to main Higgs decay modes in one (CED) process: bb, WW, tautau

↓

information about Yukawa coupling
(Hbb difficult in standard searches due to huge bg.)

IV) In MSSM, CED Higgs process give very important information on the Higgs sector, and in addition, for sufficiently high tanβ values, it allows direct measurement of the Higgs width.

Disadvantages:

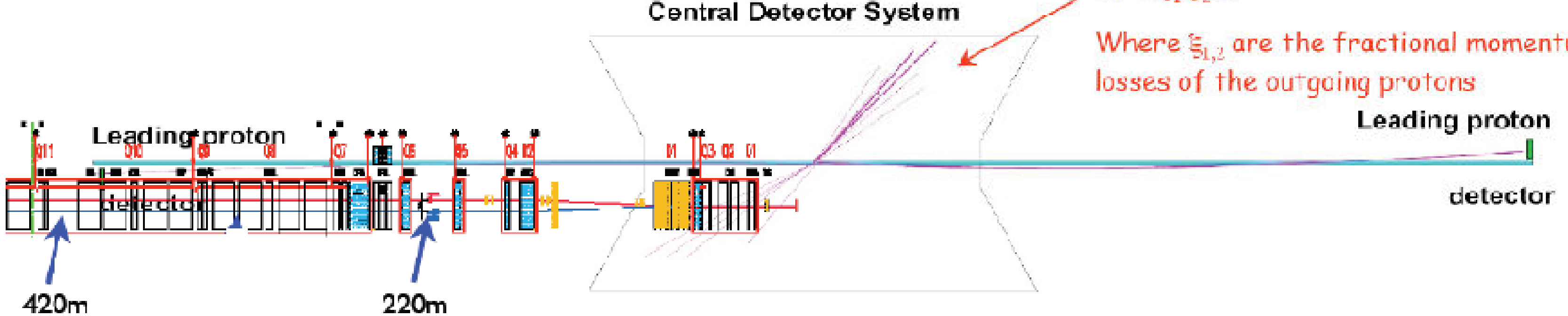
- Low signal x-section
- Large Pile-up

Forward Physics Upgrades for High Lumi

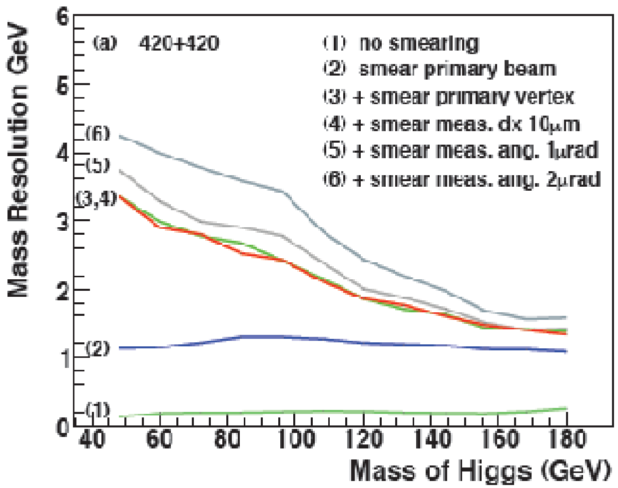
Measure forward protons from DPE/CEP.

$M^2 = \xi_1 \xi_2 S$

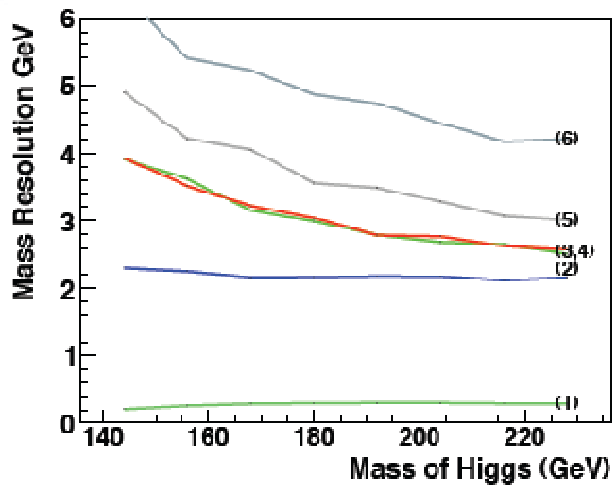
Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons



Very good mass resolution from forward protons

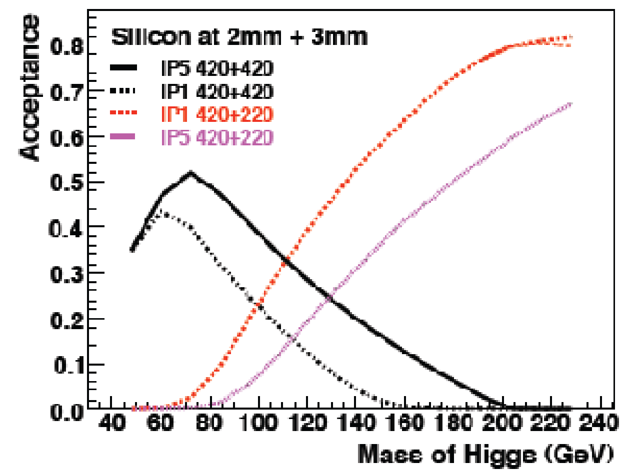


420+420



220+420

Good acceptance for combined detectors at 420m and 220m



AFP = ATLAS Forward Proton (detectors at 420m and 220m)

FP420 = Forward Proton at 420m (CMS side)

Physics with Forward Proton Tagging at High Lumi

CEP Higgs production (Higgs mass, quantum numbers, discovery in certain regions of MSSM/NMSSM):

SM $h \to WW^*$, $140 < M_h < 180$ GeV(H→bb in S.Heinemeyer's talk)

MSSM h→bb, h→tautau for $90 < M_h < 140$ GeV

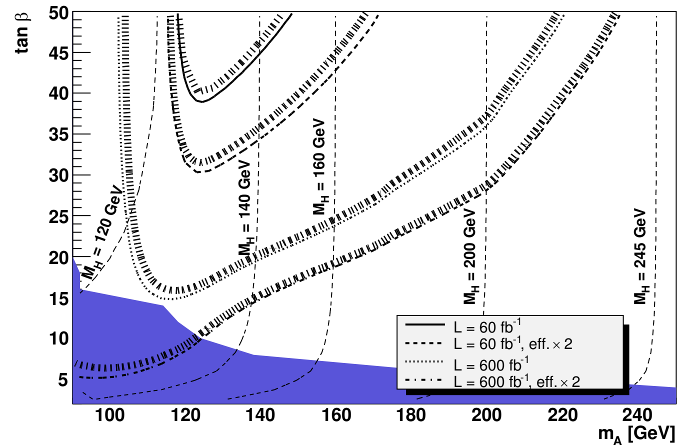
MSSM H→bb ($90 < M_h < 300$), $H \to \tau\tau$ ($90 < M_h < 160$)

NMSSM $h \to aa \to \tau\tau\tau\tau$ for $90 < M_h < 110$ GeV

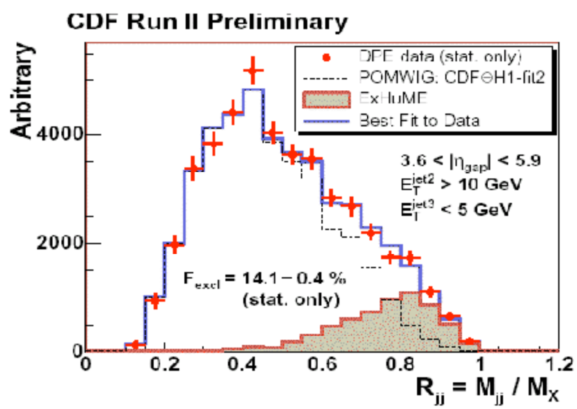
Triplet scenario(talk by K.Huitu)

CEP dijets: a la CDF

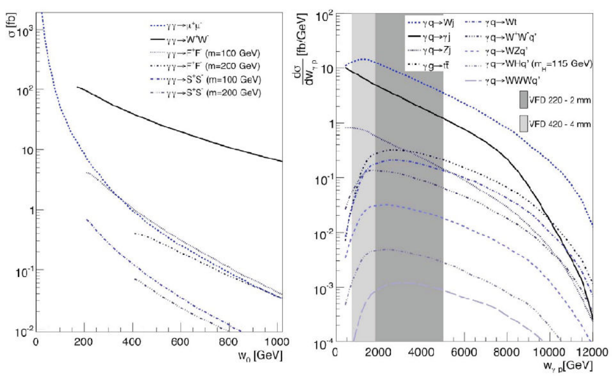
γγ and γp:



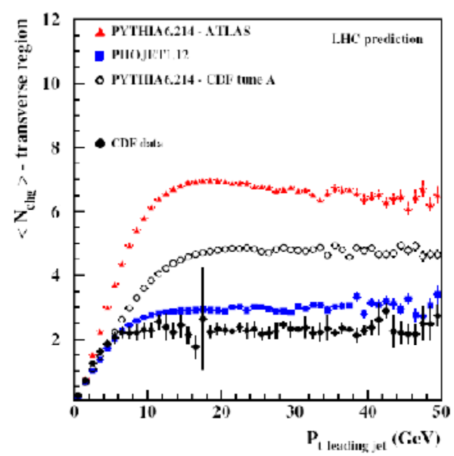
[Heinemeyer et al., EPJC 53 (2008) 231]



[CDF Coll, arXiv:0712.0604]



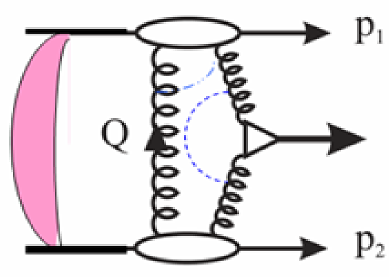
[Louvain Photon group arXiv:0807.1121]



Average mult. transv. to leading jet

[C.Buttar et al., HERA-LHC proc.]

- **Hard SD and DPE (dijets, W/Z, …)**
- **Gap survival / Underlying event**
- **Study of gluon jets**



$$\sigma_{pp}(M^2,\ldots) = L_{eff}(M^2,y) * \sigma_{hard}(M^2,\ldots)$$

$$\frac{\partial^2 L_{eff}}{\partial y \partial M^2} M^2 = S^2 * L(M^2)$$

focus on $\sigma^{bgd}{}_{hard}(M^2,\ldots)$

$L_{eff}(M^2,y)$ → the same for Signal and Bgds

$$L_{eff} \sim \frac{\hat{S}^2}{b^2} \left| N \int \frac{dQ_t^2}{Q_t^4} f_g(x_1, x_1', Q_t^2, \mu^2) f_g(x_2, x_2', Q_t^2, \mu^2) \right|^2$$

contain Sudakov factor T_g which exponentially suppresses infrared Q_t region → pQCD

$$< Q_t >_{SP} \simeq M/2 * \exp(-1/\bar{\alpha}_s) \approx 2GeV \gg \Lambda_{QCD},$$

$$\bar{\alpha}_S \simeq (N_C/\pi) * \alpha_s(M) * C_\gamma$$

T_g + anom .dim. → *IR filter*

S^2 is the prob. that the rapidity gaps survive population by secondary hadrons → soft physics

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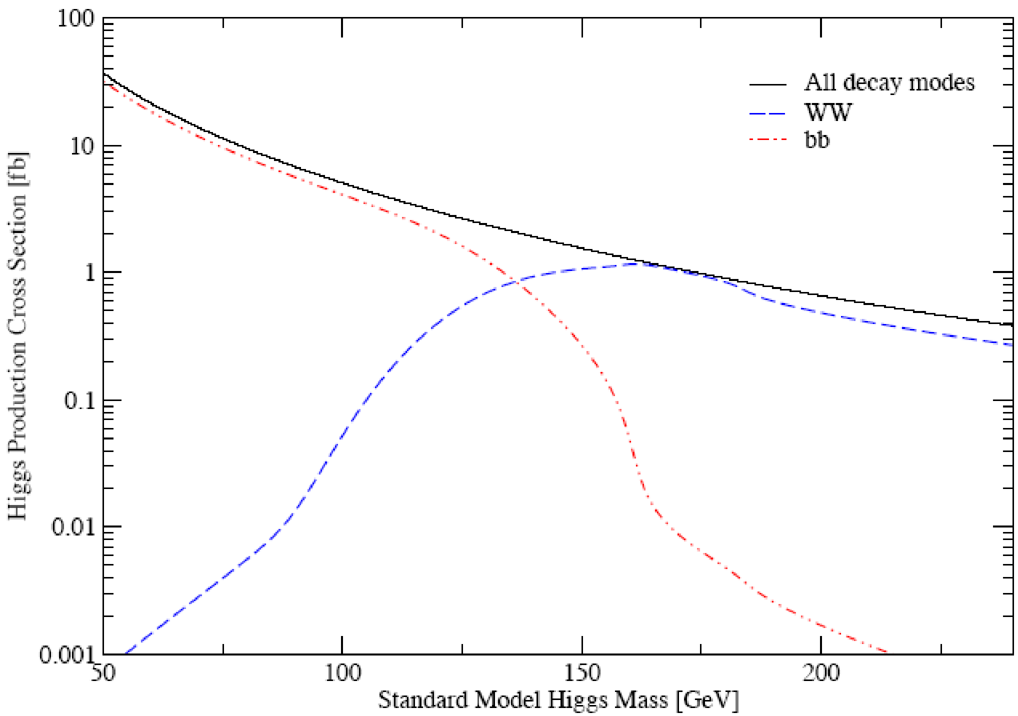
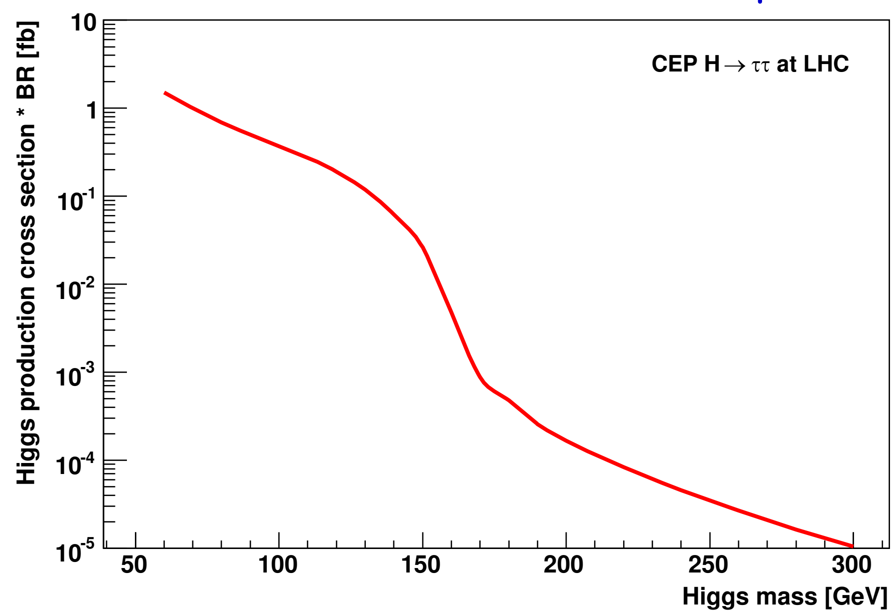
Cross sections and FD Acceptances

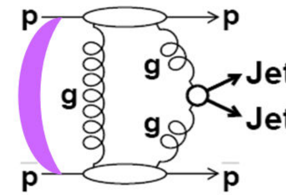
M_H [GeV]	σ ($H \to bb$) [fb]	σ ($H \to WW^*$) [fb]	Acc (420+420)	Acc(420+220)
120	1.9	0.37	0.20	0.17
130		0.70	0.15	0.24
140	0.6	0.87	0.11	0.31
160	0.045	1.10	0.04	0.43
180	0.0042	0.76	0.01	0.53



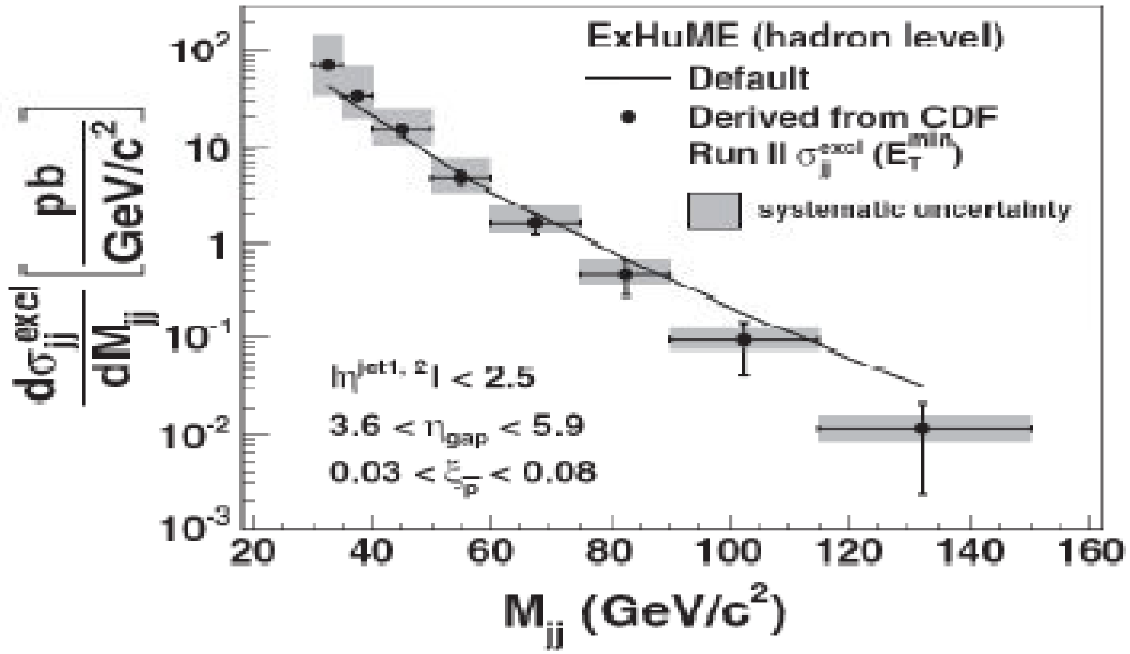
Acceptances for (220,420)=(2.5mm,4mm) from the beam with 1 mm dead space



Exclusive dijet x-section vs. M_{jj}



arXiv:0712.0604 , PRD-2008

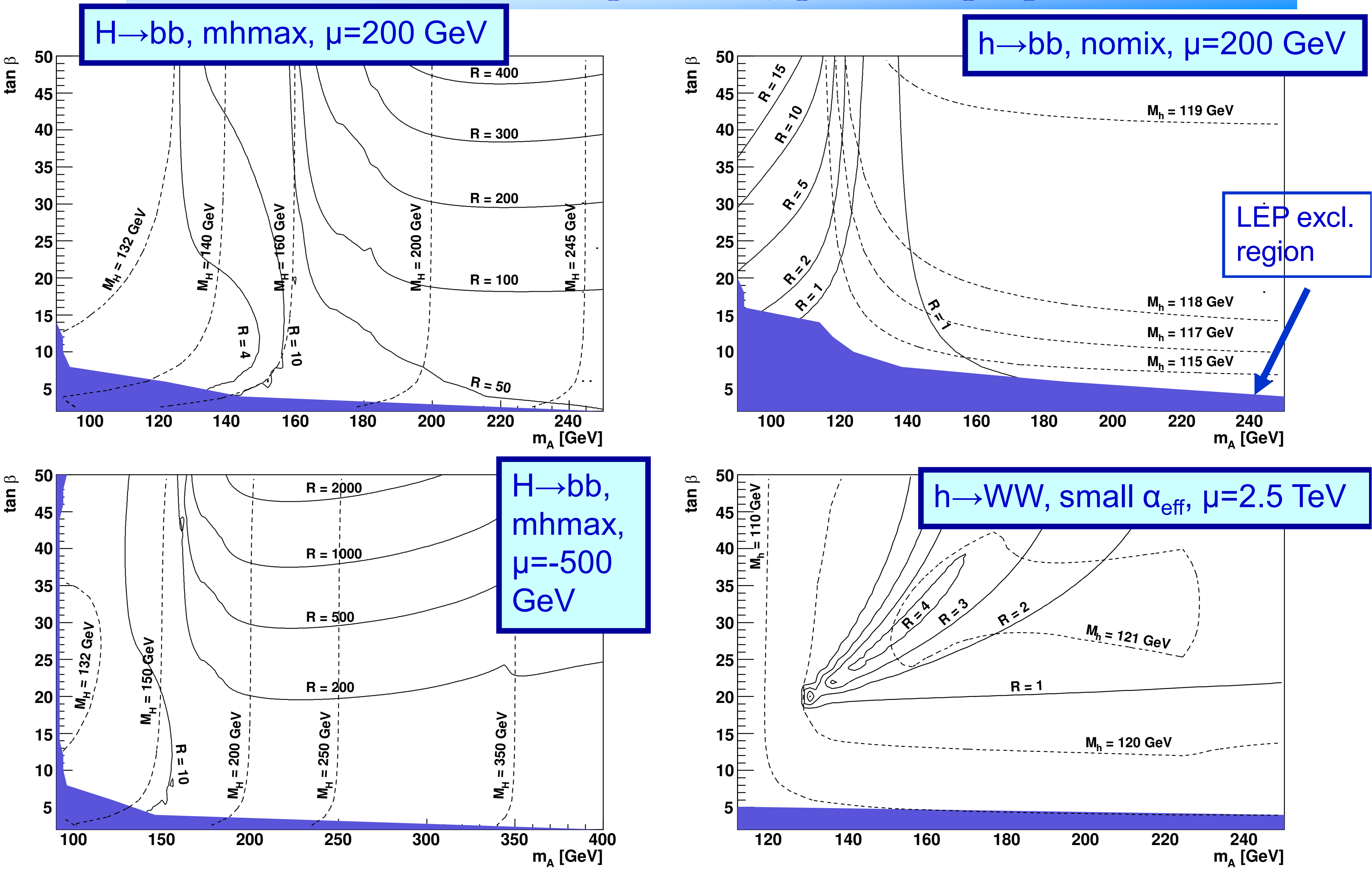


curve: ExHuME hadron-level exclusive dijet cross sections vs. dijet mass

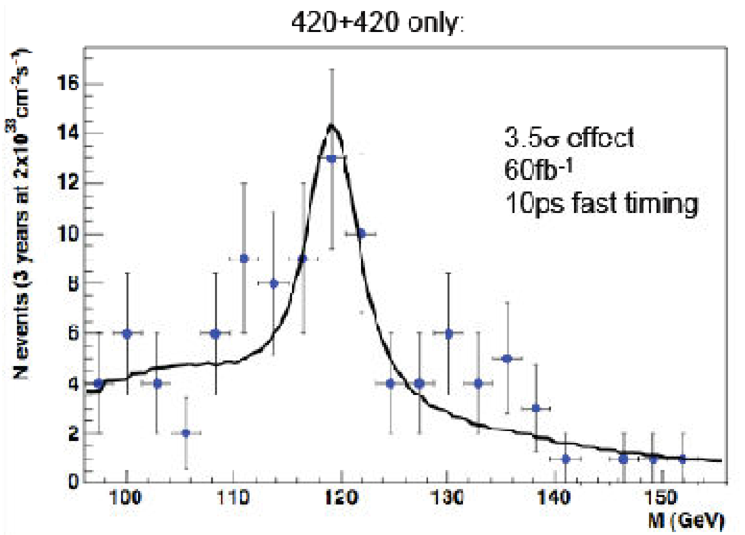
points: derived from CDF excl. dijet x-sections using ExHuME

Stat. and syst. errors are propagated from measured cross section uncertainties using M_{jj} distribution shapes of ExHuME generated data.

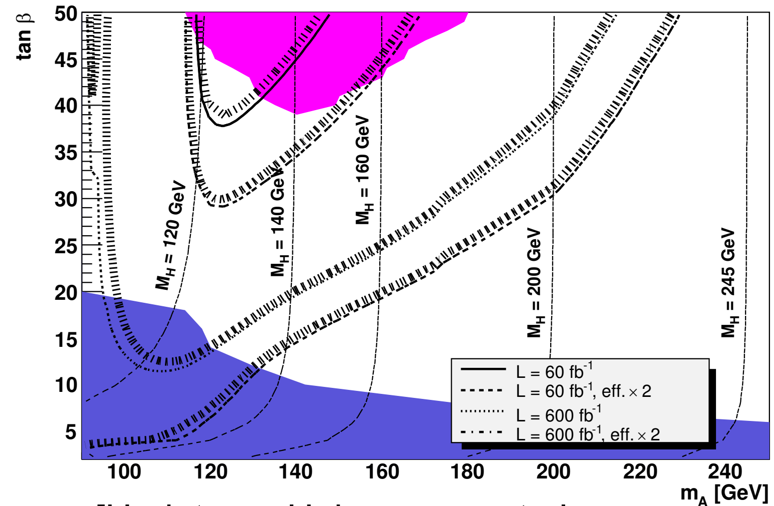
R=MSSM[M,tanβ] / SM[M]



H→bb in MSSM



[Cox et al., JHEP0710:090]



[Update on Heinemeyer et al., EPJC 53 (2008) 231]

Backgrounds intensively studied by KMR group: calculations still in progress

[DeRoeck, Orava+KMR, EPJC 25 (2002) 392, EPJC 53 (2008) 231]

1) Admixture of |Jz|=2 production

2) NLO radiative contributions (hard blob and screened gluons)

3) NNLO one-loop box diagram

4) Central inelastic backgrounds (soft and hard Pomerons)

5) b-quark mass effects in dijet process

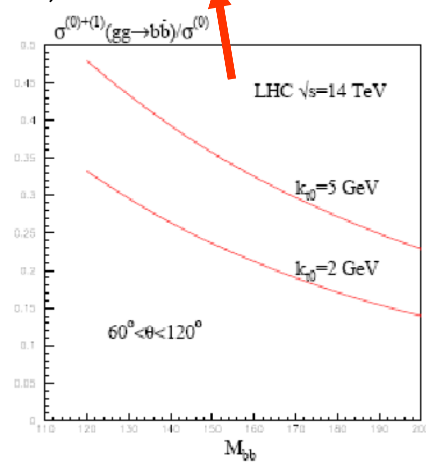
Approximate formula for the background:

$$\sigma_B \approx 2\,\text{fb}\left[0.92\frac{\Delta M}{(4\ \text{GeV})}\left(\frac{120}{M}\right)^6 + \frac{1}{2}\frac{\Delta M}{(4\ \text{GeV})}\left(\frac{120}{M}\right)^8\right]$$

ΔM = mass window over which we collect S or B

b-jet angular cut applied: 60°< θ <120° ($|\Delta\eta_{jet}|$ <1.1) P(g/b)~1.3%(ATLAS)

Four major bg sources: ~(1/4+1/4+1.3²/4 +1/4) at M_h=120 GeV, ΔM=4 GeV



The mass dependence of the ration of the NLO exclusive $b\bar{b}$ cross section to that calculated in Born approximation.

[Shuvaev et al., arXiv:0806.1447]

$H \to WW^*$ in SM and MSSM

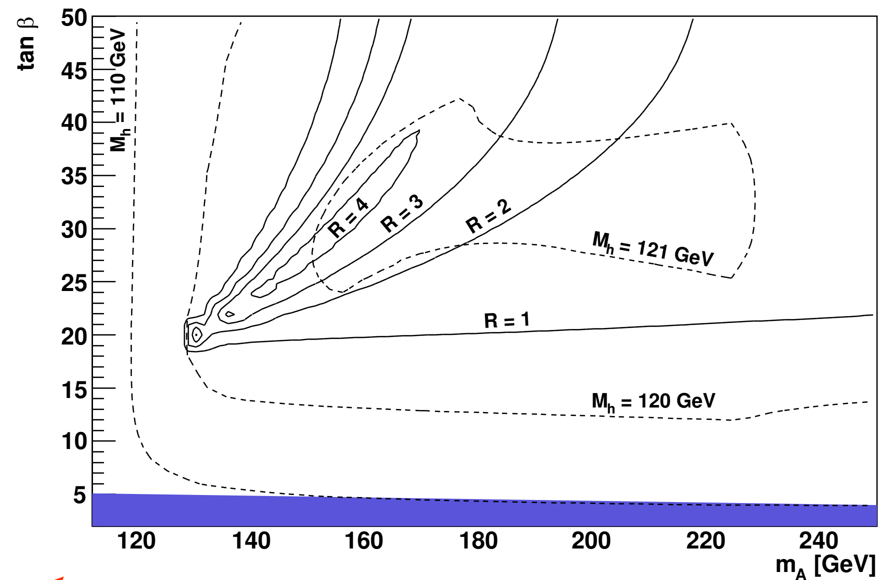
$h \to WW^*$, small α_{eff}, μ=2.5 TeV

[Cox et al., EPJC 45 (2006) 401]:
Generator level study showed that about 2 semi-leptonic and 1 fully-leptonic candidates may be collected in 30fb^{-1} using available ATLAS/CMS lepton triggers in 140 < M_h < 200 GeV

- Confirmed by ATLAS/CMS fast sim. studies at one mass point: 160 GeV

- Overlap bg suppressed
- At this mass irreducible backgrounds heavily suppressed
- Dominant bg from $\gamma\gamma \to WW^*$

In MSSM, max. enhancement of 4 in a narrow mass region of ~120 GeV



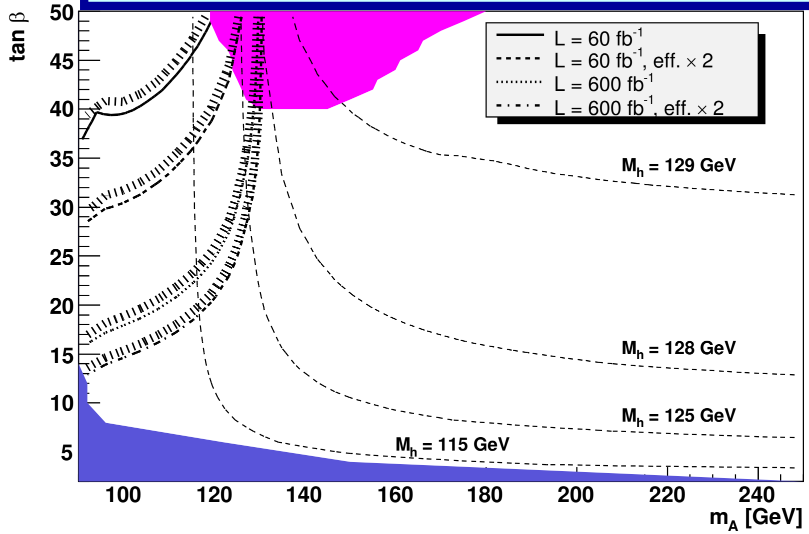
[Heinemeyer et al., EPJC 53 (2008) 231]

H → tau tau in MSSM

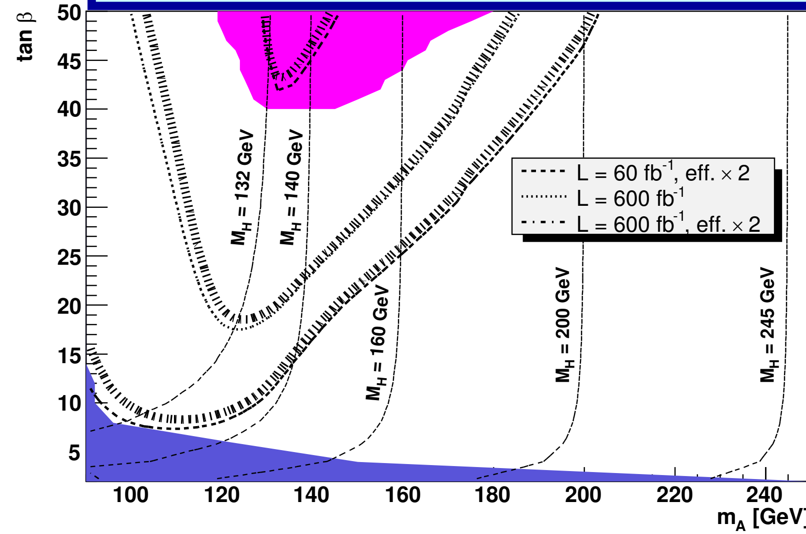
- In MSSM, BR(h,H→ττ) ~ 10%, if decays to SUSY particles not allowed
- Studied in EPJC 53 (2008) 231: the same efficiencies assumed as in the bb case
- Background: QED γγ→ττ (suppressed by $p_T^{prot} > 0.2$ GeV)

  CEP gg→gg (suppressed by $|\eta_{j1} - \eta_{j2}| < 1.1$ and P(g/τ)~1/500)

3σ: h→tautau, mhmax, μ=200 GeV



3σ: H→tautau, mhmax, μ=200 GeV



- In ATLAS the proper efficiencies now being estimated with full sim.
- All tau-decays studied.
- Backgrounds expected to be very low:

 - fully leptonic have high-pt leptons
 - fully hadronic have two tau-jets: very-few-particle jets going sharply back-to-back in φ

No problems expected with triggering

MANCHESTER 1824

The University of Manchester

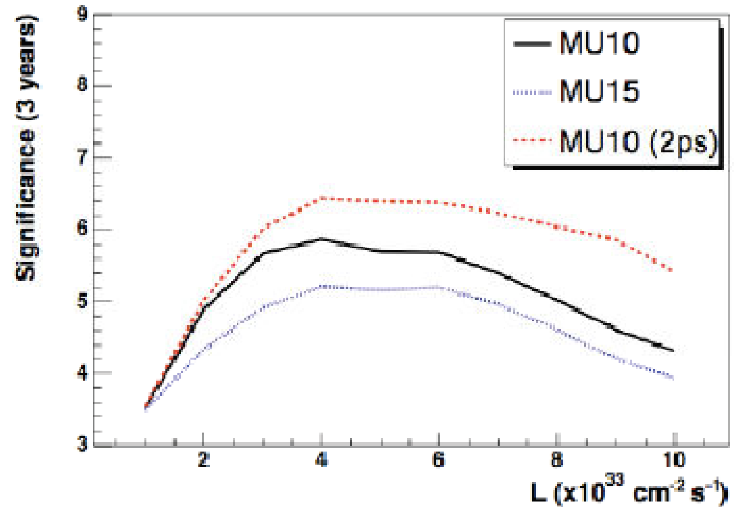
A.Pilkington, J.Forshaw, J.Gunion

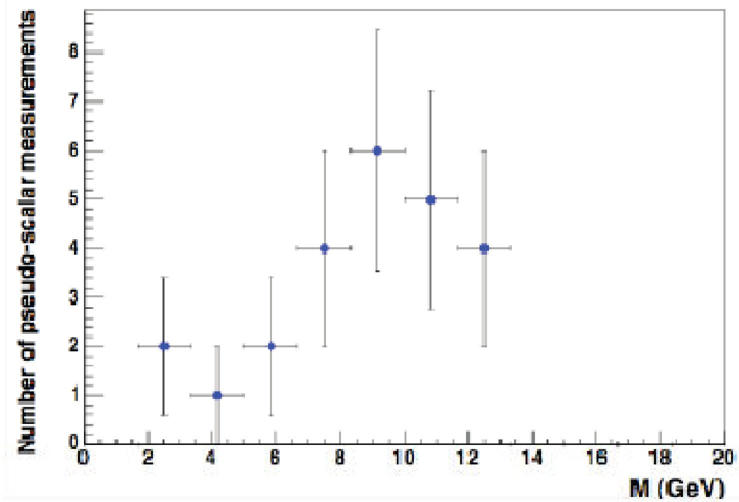
H→4τ in the NMSSM

- NMSSM Higgs sector consists of 3 neutral scalars and 2 neutral pseudo-scalars (and charged Higgs).
- Most 'natural' part of parameter space results in light scalar Higgs (~100GeV) which decays to lightest pseudo-scalar, a.
- Preferred decay of pseudo-scalar is a→ττ.

- Standard search channels at LHC may fail to discover any of Higgs bosons in NMSSM.

- Predict approx 7 CEP events after ~100fb^{-1} with no appreciable background (JHEP 0804:090,2008). Trigger on μ,e.
- Information from forward protons gives good pseudo-scalar mass measurement.





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Diffractive measurements with early data

WITHOUT PROTON TAGGING

L1 trigger: rapgap, low E_T (20-30 GeV)

Start with ratios X+gaps/X(incl.), X=W,Z,jj,μμ -> get information on S^2

pp → RG + W/Z + RG	**Info on soft survival S^2** (γ-exch. dominates for W)
pp → RG + W	**Info on soft survival S^2**
pp → RG + jj + RG	**Combined effect of all basic ingredients to CEP** (S^2, Sudakov suppr., unintegr. f_g, enhanced absorpt)
pp → RG + Y + RG	**Info on unintegrated f_g** (γ- or Odderon exchange)

Hard SD, Hard DD

WITH PROTON TAGGING

ALFA/Totem

P-tagging = info on proton p_T, i.e. dσ/dt

High rate soft diffraction:

ALFA/Totem: σ_{tot}, $d\sigma_{el}/dt$, σ_{SD}(low M), **$d^2\sigma_{SD}/dtd\xi$, $d^2\sigma_{DPE}/d\xi_1 d\xi_2$**

- tests model assumptions,
- governs rates of Pile-up bg
- Strongly restricts S^2 (info on enhanced absorption), not sensitive to higher-order (Sudakov) effects

pp → p + jj + p:

Advantages: rel. high rate
separate different effects in one process

High rate γp and γγ processes

Possible dijet study strategy

V.Khoze, DIS08

❶ Measurement of E_T dependence of inclusive dijets (NLO DGLAP calculations).
Mainly tests of efficiencies etc

❷ Ratio of $\sigma_{jj}^{SD} / \sigma_{jj}^{incl}$ (similar to the CDF studies).

With known pdfs (HERA data) we test models for/measure the survival factor S^2

❸ Ratio $\sigma_{jj}^{DPE} / \sigma_{jj}^{incl}$ with different gap sizes allows to probe Sudakov effects and the possible role of 'enhanced absorption'
Variation of the gap size and jet E_T → various quantitative tests
(e.g. absorption is higher for low-p_t particles)

❹ When/if proton tagging is operational, then the studies of proton momentum correlation should come.

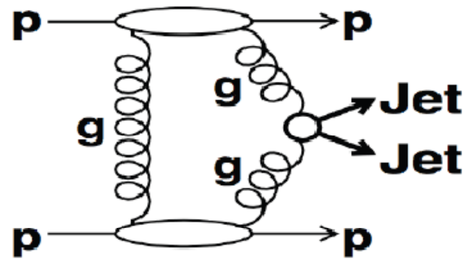
pt-spread in the beams ?

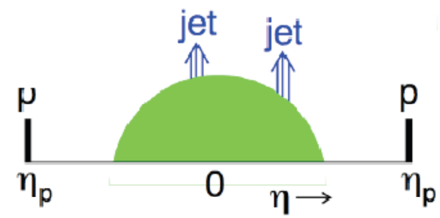
Scanning of proton opacity.
Can also pave the way to direct measurements of CP violation
In the Higgs sector.

All these measurements are interesting on their own right: diffractive (soft QCD) physics is still not fully understood !

Advantages: - comparatively high rate (3 orders higher than Higgs with the same E_T), $\sigma_{jj}^{DPE}(E_T>20)$~10nb
- possibility to separate different effects by studying one process

CEP dijets with early data





Motivation: reduce the factor three of uncertainty in calculations of production x-section at LHC (KMR)

Measure R_{jj} distribution and constrain existing models and unintegrated f_g

- Central system produced in J_z =0, C-even, P-even state → quark jets suppressed by m_q^2/m_{jj}^2

Analyses in progress at ATLAS (Andy P.) and CMS (Antonio V.P.)

Trigger: Low-Et jet .AND. Veto in FCAL (in CMS) or MBTS (in ATLAS) with $2.1 < |\eta| < 3.85$

trig.eff. ~ 65% for CEP wrt jet turn-on and efficiently reduces Incl.QCD background (by 10^4)

Expect ~ 300 events per pb^{-1} if trigger unprescaled

Backgrounds: Incl. QCD dijets, SD dijets, DPE dijets

Exclusivity cuts: Vetoing MBTS or FCAL corresponds to cutting on $\xi_{1,2} = \frac{1}{s^{\frac{1}{2}}} \sum_{clust} E_T^i e^{\pm\eta_i}$ reduces

Incl. QCD bg (has large ξ, protons broken up)

rap.gap at least on one side – all diffractive analyses working on rap.gap definition

(use rapgaps that are reproducible by theory! – talk by S.Marzani)

N_{track} (outside dijet) < X

single vertex – reduces overlap background

With proton tagging

V.Khoze, DIS08

Without proton tagging

$$\sigma(RG+W+RG) \simeq 2*(0.2-1)\,pb*S^2$$

S^2 ~0.6-0.7

$t_{\min}(\xi_p)$ - effects

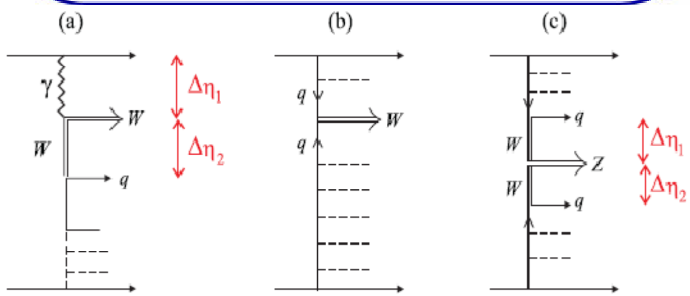
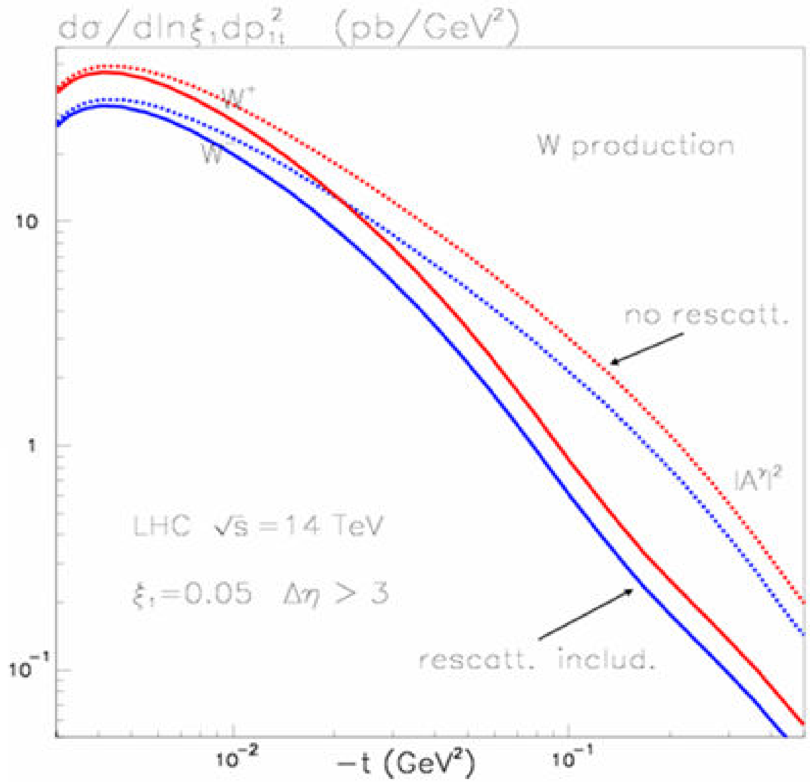
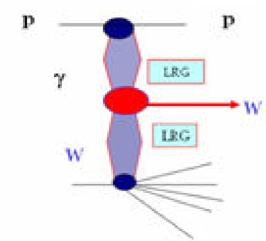
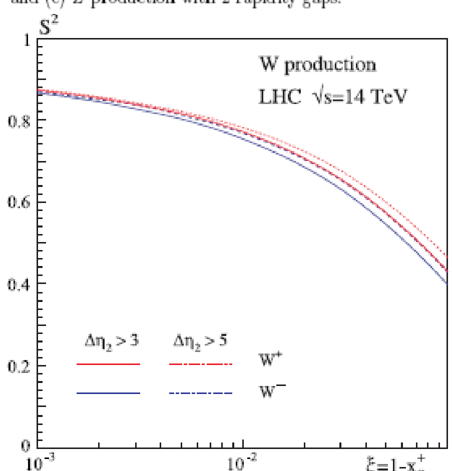


Figure 2: Diagrams for (a) W production with 2 rapidity gaps, (b) inclusive W production, and (c) Z production with 2 rapidity gaps.







The differential cross section for $pp \to p + W^{\pm} + X$ at the LHC. The dotted and ntinuous curves correspond, respectively, to the predictions without and with the rescattering ects of Figs. 8(b,c). In each case W^+ production corresponds to the upper one of the pair curves. The rapidity gap between the quark recoil jet and the W boson is taken to satisfy $\eta > 3$.

Exclusive Υ production as a probe of f_g

V.Khoze, DIS08

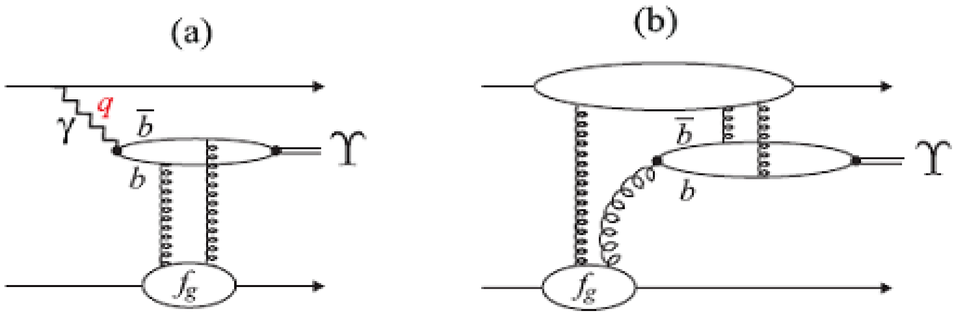


Figure 6: Exclusive Υ production via (a) photon exchange, and (b) via odderon exchange.

$$d\sigma / dy(pp \to p + \Upsilon + p) \sim 50\, pb$$

The cross section for γ +p→Y +p is given in terms of the same generalized gluon distribution fg that occurs in the CED Higgs production.

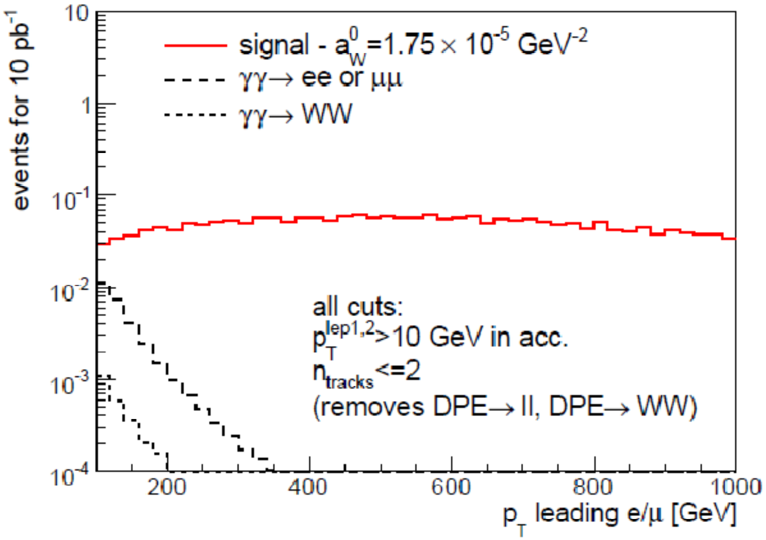
The odderon contribution (if it exists) can be separated and measured.

Tagging the lower proton will be very useful.

Quartic anomalous couplings in $\gamma\gamma$ interactions

O. Kepka, this conference

- low luminosity - 10-100 pb^{-1}
- one interaction / bunch crossing - exclusivity of two-photon events
  - two leptons and nothing else
  - true approx. up to $\sim 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ - collect $10\,\mathrm{pb}^{-1}$
  - for higher luminosity ask only one primary vertex



WW analysis

- exclusivity: small number of tracks
  - removes DPE and non-diffractive background
- $p_T^{lep1} > 160$ GeV - to select signal only
- no other cuts needed

ZZ analysis

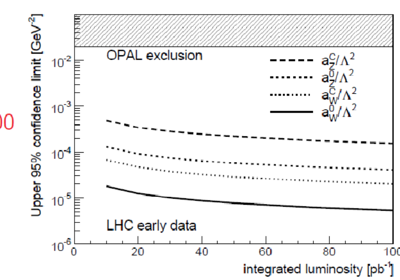
- 2 (e/μ) of the same charge or more than three leptons
- no jet above 20 GeV

Limits low luminosity

- 5σ discovery upper limits at 10 TeV, lower limits similar - negative

coupling	OPAL limits	limits $\mathcal{L}$=10 pb^{-1}	$\mathcal{L}$=100 pb^{-1}
a_0^W	0.020	2.2×10^{-5}	7.1×10^{-6}
a_C^W	0.037	8.4×10^{-5}	2.7×10^{-5}
a_0^Z	0.023	1.7×10^{-4}	5.3×10^{-5}
a_C^Z	0.029	6.3×10^{-4}	2.0×10^{-4}

Improvement of a factor up to 1000 with respect to OPAL limits



Summary

High Luminosity Upgrade:

Possible upgrade to install forward proton taggers at 220 and 420 m from IP

- Provides a good mass measurement of new physics
- Cross sections of exclusive processes (e.g. Higgs) predicted with uncertainties.
- Theory needs input from experiment (see CDF results)

Low Luminosity:

- Start with ratios X+gaps/X(incl), X=W,Z,jj,μμ …. Get S^2
- Measure exclusive Υ to probe unintegrated f_g
- Measure 2-jet and 3-jet exclusive events to probe Sudakov factor
- Measure exclusive dimuon production in γγ collisions tagged with forward rapgaps
- Photon-induced processes useful for checks of CEP predictions
- Just repeat the CDF diffractive measurements!
- Note: we start with 10 TeV collisions, but need predictions for 14 TeV