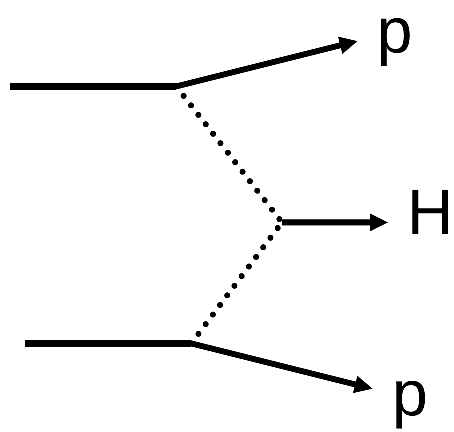
Diffractive Higgs production at the LHC



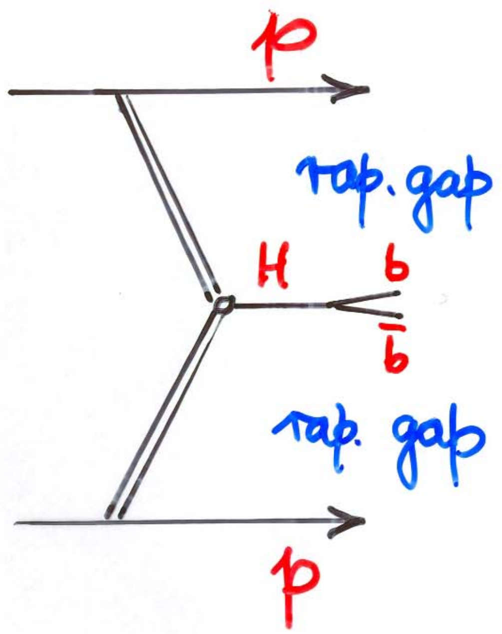
Alan Martin (Durham)

October 2007

Exclusive Higgs production at the LHC

Khoze, Martin, Ryskin

$pp \to p + H + p$



O(1 GeV) ?

<u>advantages</u>:

- $M_H = \begin{cases} M(b\bar{b}) \\ M_{missing} \end{cases}$ if protons tagged far from IP
- LO $gg \to b\bar{b}$ background v. suppressed by $J_z = 0$ selection rule ($= 0$ for $m_b = 0$ and forward protons)
- unique LHC signal if $M_H \lesssim 130$ GeV ($S/B \sim 1$)
- for SUSY Higgs, S/B $\tan\beta$ enhanced

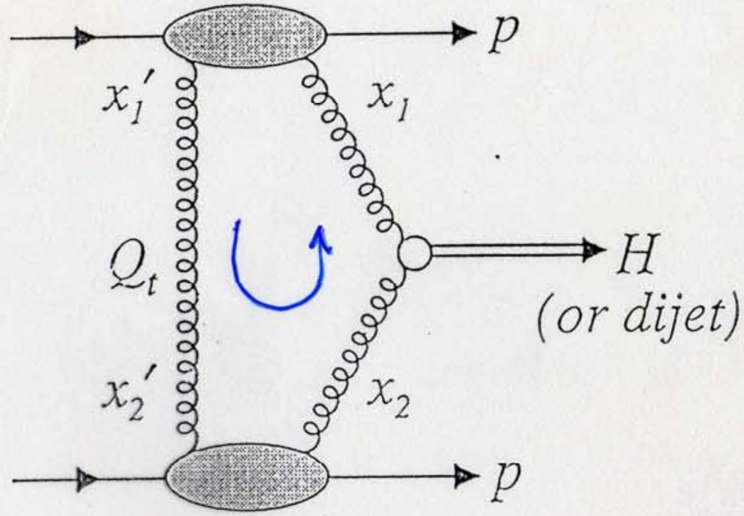
The price for rapidity gaps ? →

$pp \to p + H + p$

Survival prob. of rap. gaps

$$W = S^2 \, T^2$$

price for: no soft rescatt. (S^2); no g rad^n in $gg \to H$ (T^2)



$$\Lambda^2_{QCD} \ll Q_t^2 \ll M_H^2 \quad \to \text{pQCD}$$

$$\left(x' \sim \frac{Q_t}{\sqrt{s}}\right) \ll \left(x \sim \frac{M_H}{\sqrt{s}}\right) \ll 1$$

need uninteg. skewed gluons

$pp \to p + H + p$

Survival prob. of rap. gaps

$$W = S^2 \, T^2$$

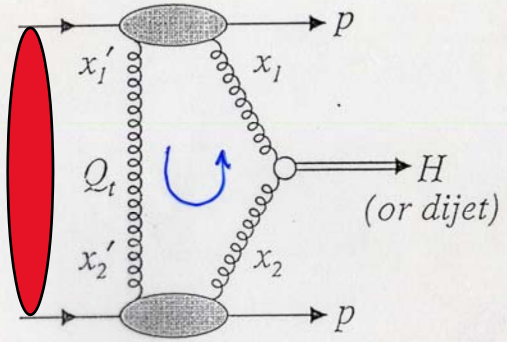
price for [no soft rescatt.] → S^2

[no g rad^n in $gg \to H$] → T^2

calculated from multi-Pomeron multi-channel eikonal analysis of soft pp data

$S^2 = 0.02$ at LHC

$S^2 = 0.05$ at Tevatron



$$\Lambda^2_{QCD} \ll Q_t^2 \ll M_H^2 \quad \to \text{pQCD}$$

$$\left(x' \sim \frac{Q_t}{\sqrt{s}}\right) \ll \left(x \sim \frac{M_H}{\sqrt{s}}\right) \ll 1$$

need uninteg. skewed gluons

$$\mathcal{M} = \frac{A}{M_H^2} \int \vec{Q}_{1t} \cdot \vec{Q}_{2t} \, \frac{d^2 Q_t}{Q_t^6} \, f\left(x_1, x_1', Q_t^2, \frac{M_H^2}{4}\right) f\left(x_2, x_2', Q_t^2, \frac{M_H^2}{4}\right)$$

where $f(x, x', Q_t^2, \mu^2) \approx R \dfrac{\partial}{\partial \ln Q_t^2} \left[\sqrt{T(Q_t, \mu)} \, x g(x, Q_t^2) \right]$

R is calculable skewed effect (R=1.2 at LHC)

$$T(Q_t, \mu) = \exp\left(- \int_{Q_t^2}^{\mu^2} \frac{dk_t^2}{k_t^2} \frac{\alpha_s}{2\pi} \int_0^{1-k_t/\mu} dz \, z P_{gg} \ldots \right)$$

strongly suppresses Q_t infrared region

no emission when $(\lambda \sim 1/k_t) > (d \sim 1/Q_t)$

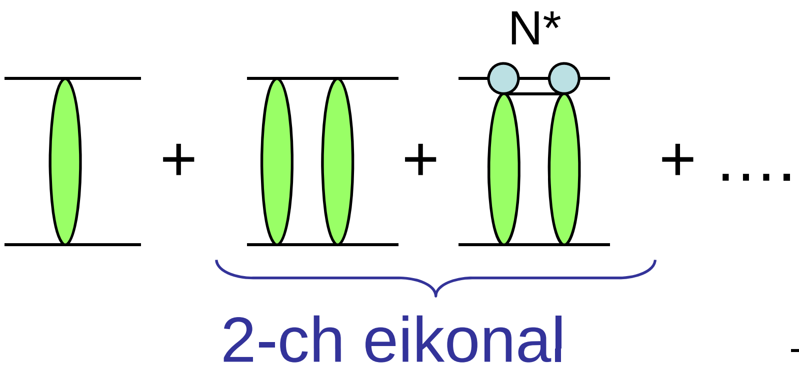
i.e. only emission with $k_t > Q_t$

Description of ‘soft’ high energy pp interactions

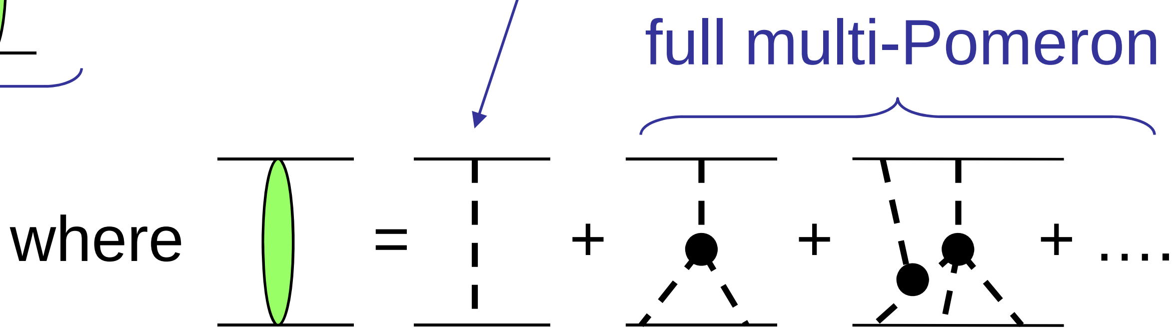
DL: $\alpha_{eff} = 1.08 + 0.25t$ ---but nothing about inelastic int^{n}

Inclusion of multi-P effects essential: new analysis

KMR 2007



$\alpha_{bare} \sim 1.5 + 0t$



$\sigma_{total}(LHC) \sim 90$ mb

$S^2_{Higgs}(LHC) \sim 0.02$

Suppression factor / survival prob. of rap. gap

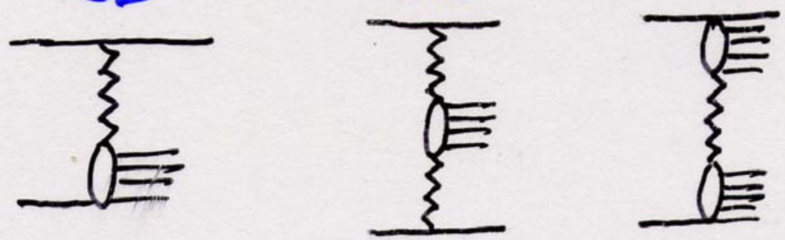
prob. of p to be in diff. estate ϕ_n

prob. of producing heavy system from ϕ_n

prob. to have no inel. reaction

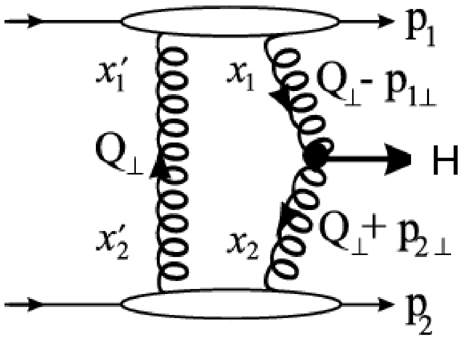
$$S^2 = \frac{\sum_n \int d^2b \, |a_{pn}|^2 \, |\mathcal{M}_n|^2 \, e^{-\Omega_n}}{\sum_n \int d^2b \, |a_{pn}|^2 \, |\mathcal{M}_n|^2}$$

Values of S^2



	SD	CD	DD
Tevatron	0·10	0·05	0·15
LHC	0·06	0·02	0·10

Prediction of $\sigma(pp \to p + H + p)$



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

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

$$f_g(x, x', Q_t^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_t^2} \left[\sqrt{T_g(Q_t, \mu)}\, xg(x, Q_t^2) \right]$$

S^2 is the prob. that the rapidity gaps survive population by secondary hadrons → soft physics → S^2=0.02 (LHC)

S^2=0.05 (Tevatron)

$\sigma(pp \to p + H + p)$ ~ 3 fb at LHC for SM 120 GeV Higgs

~0.2 fb at Tevatron

$\sigma(pp \rightarrow p+H+p) \sim 3$ fb at LHC for 120 GeV Higgs

if $\mathcal{L} = 60\ fb^{-1}$, then 180 events

⇓ efficiency of p taggers

54

⇓ $BR(H \rightarrow b\bar{b})$

36

⇓ $b,\bar{b}$ tag efficiency

18

⇓ polar angle cut

9

⇓ mass window

6 events

Background to $pp \to p + (H \to b\bar{b}) + p$ signal

assuming $\Delta M_{miss} \sim 3\sigma_M \sim 5$ GeV

B/S

LO (=0 if m_b=0, forward protons)

$gg \to gg$ mimics $gg \to b\bar{b}$ (P(g/b)=1.3%)

after polar angle cut → **0.3**

Irreducibe $b\bar{b}$ → **0.5**

HO $(gg)_{col.sing} \to b\bar{b}$+ng

Soft emissions still suppressed by J_z=0 → **~ 0**

Hard emissions if g not seen:

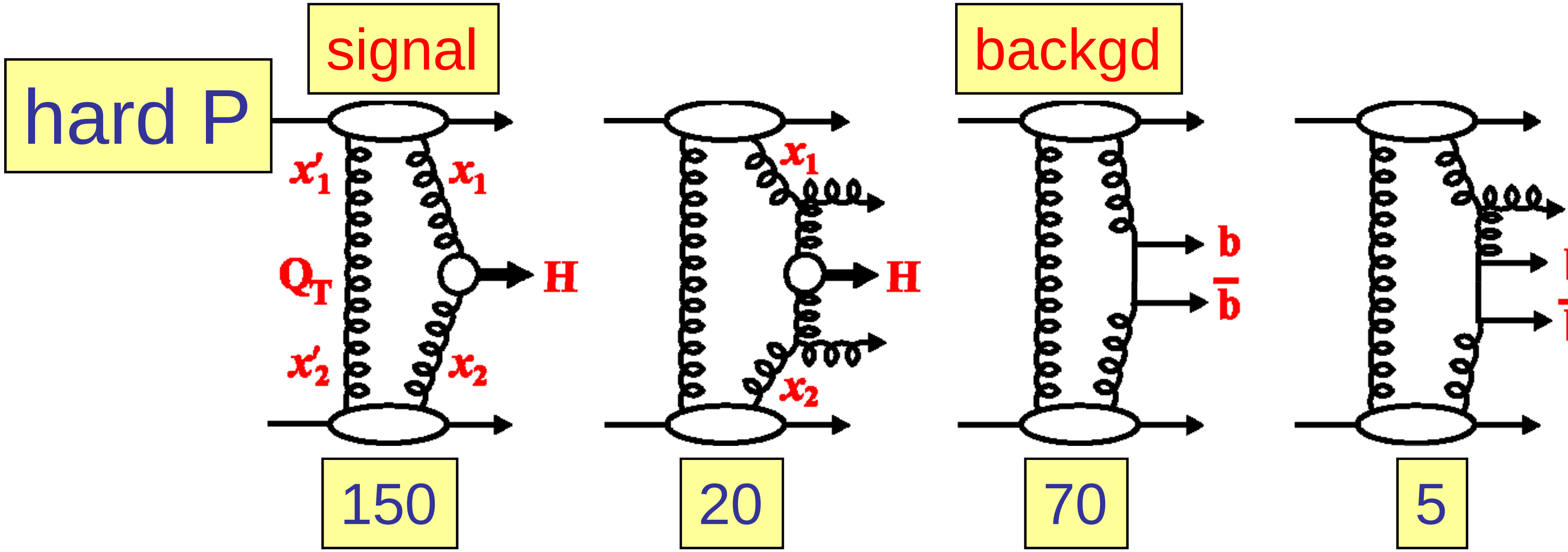
extra gluon along beam $M_{miss} > M_{bb}$ → **~ 0**

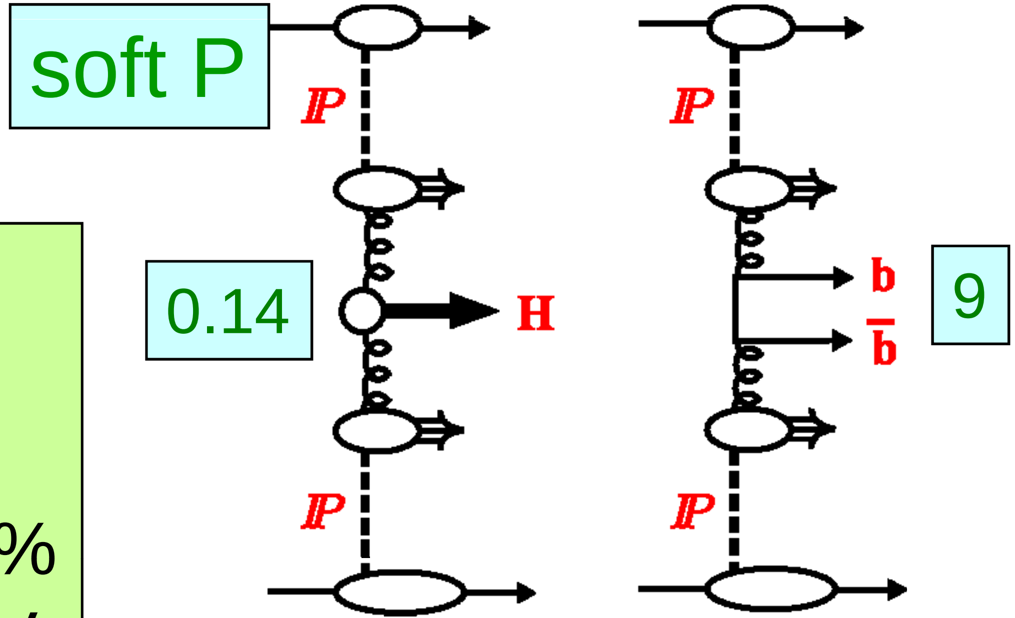
extra g from initial g along b or $\bar{b}$ → **0.2**

Pomeron-Pomeron inelastic → 0.06

for M=120 GeV → total B/S~1

S~1/M³, B~ΔM/M⁶ : triggering, tagging, ΔM better with rising M

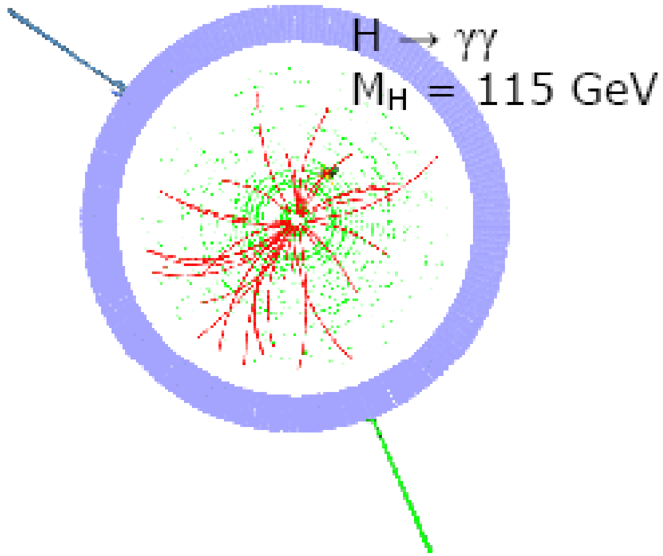


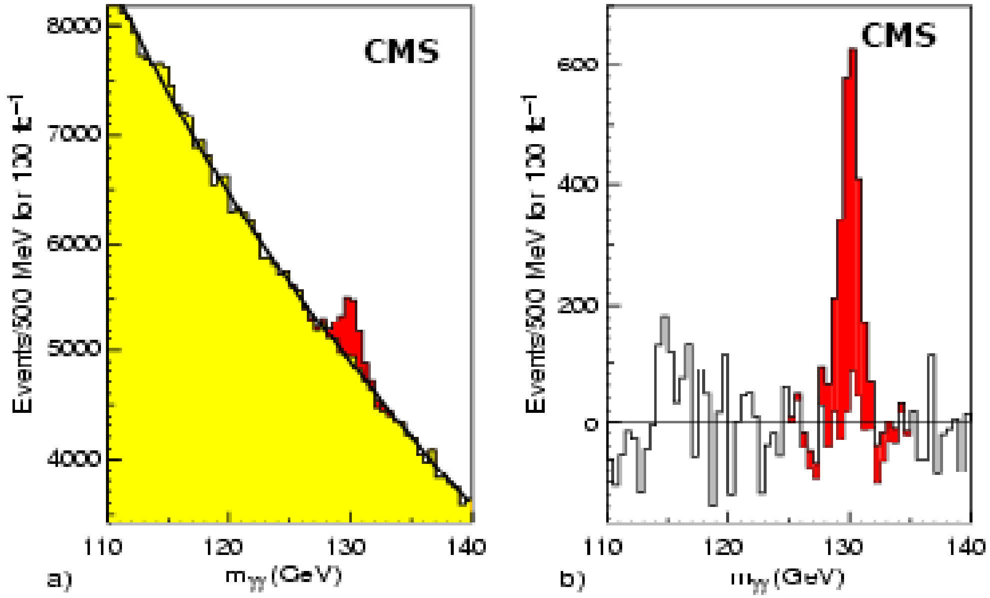


$d\sigma/dy|_{y=0}$
units 10^{-3} fb
k_T<5 GeV
$\Delta M_{dijet}/M_{bb}$=20%
$\Delta M_{missing}$=4GeV

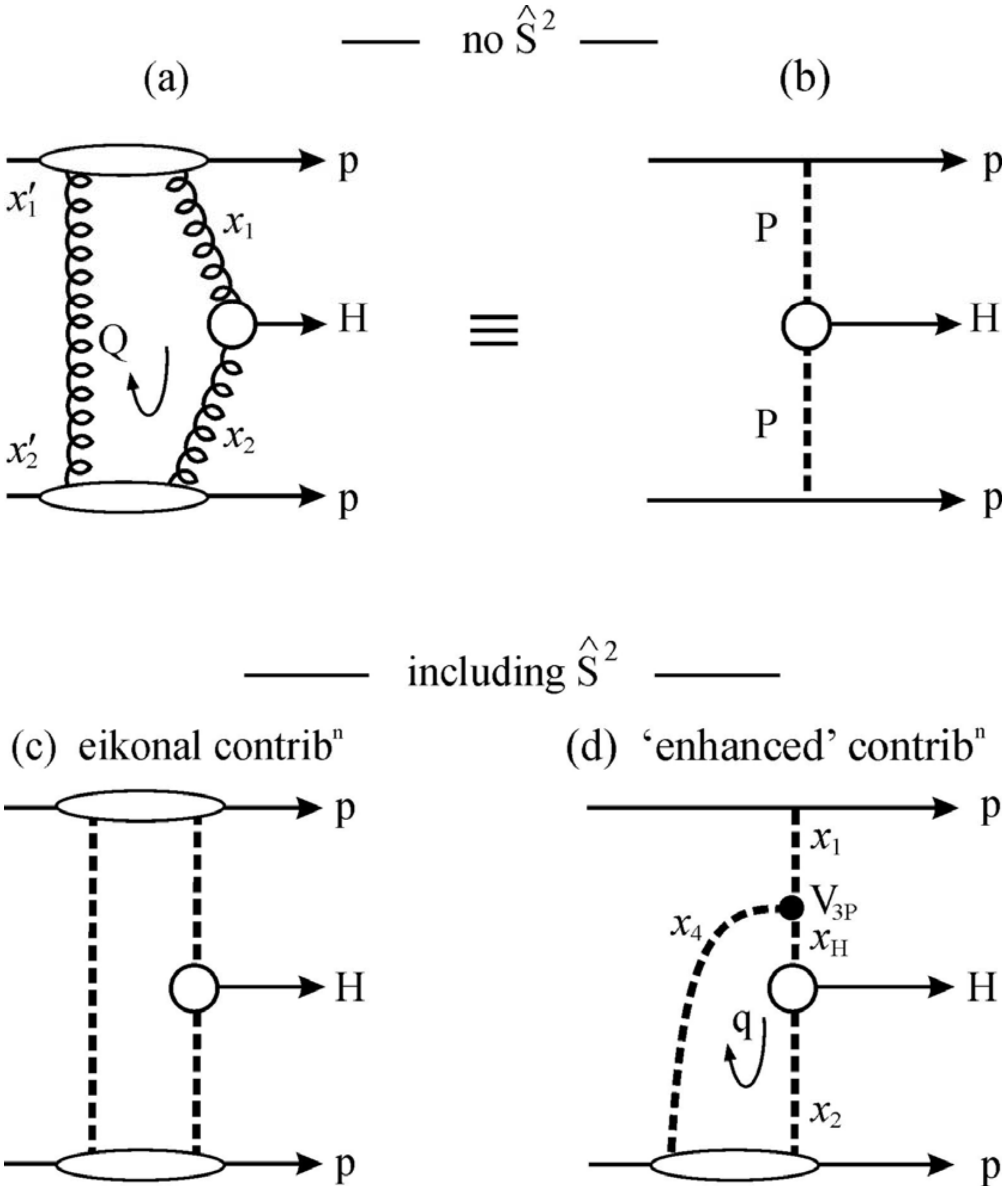
H→ γγ

- Sigma x BR ~90 fb for M_H = 110-130 GeV
- Irreducible backgrounds from gg→ γγ, qq → γγ, pp → γ jet → γγ jet
- Reducible background from fake photons from jets and isolated π^0
- Vertex estimated from the underlying event and recoiling jet
- Very good mass resolution ~1%





conventional signal for SM 110-130 GeV Higgs



eikonal

$S^2 = 0.02$

enhanced

BBKM.→ (first) corr^n could be large and -ve,

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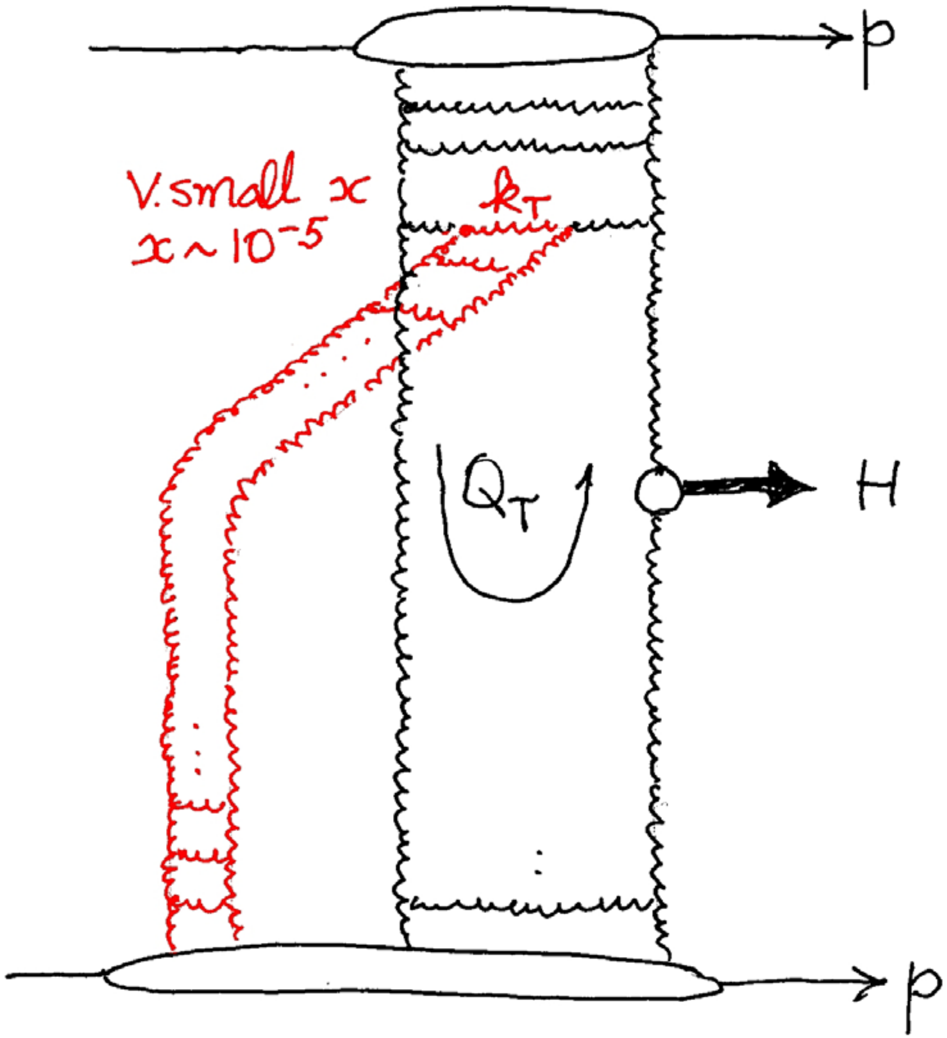
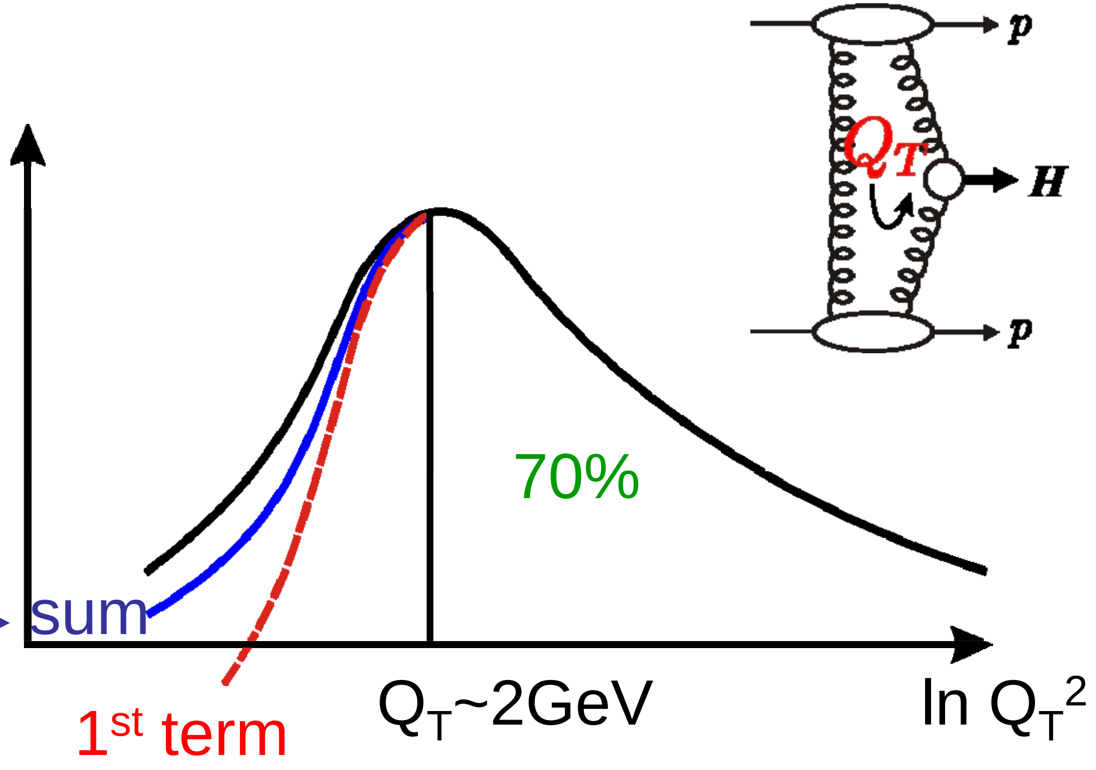


$$\int_{Q_T^2} \frac{dk_T^2}{k_T^4} \sim \frac{1}{Q_T^2}$$

$$\frac{df}{dy} = K_{BFKL}\, f - g_{3\mathbb{P}}\, f^2$$

BBKM (pQCD analysis) find first corr^n could be large and –ve.
BUT…need to sum complete set of diagrams.
terms alternate in sign



Analogous new "soft" non-perturbative analysis finds that even at low Q_T, amp. is not completely suppressed

corr^n affects mainly small Q_T (large size dipoles)

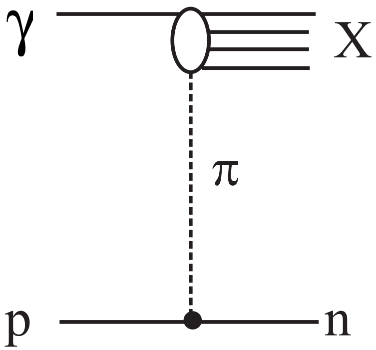
- New global fit to “soft” data

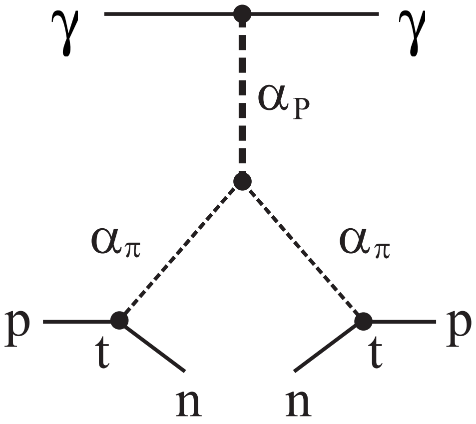
The full set of enhanced diag. are included in σ_{tot}, σ_{SD} …
in global soft fit

The fit to “soft” data including enhanced rescatt.
--redistributes abs. effects between eik. and enh.
--find total S^2 same

Analogously pred^n for σ_{tot}(LHC) has v.weak model dep.
since model fits existing soft data and there is
log s energy behaviour

σ_{SD}, sensitive to enh. effects, ~flat from 100 GeV,
so expect no extra suppression of diffraction at LHC



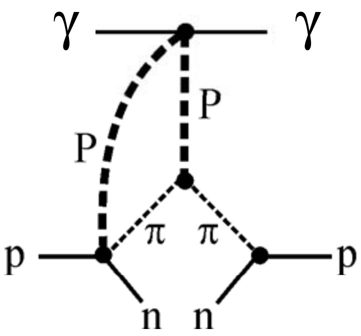


Leading neutron prod. at HERA

KKMR '06

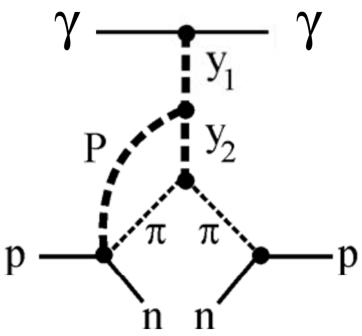
gap due to π exchange
~ exclusive Higgs

eikonal



seen

"enhanced"



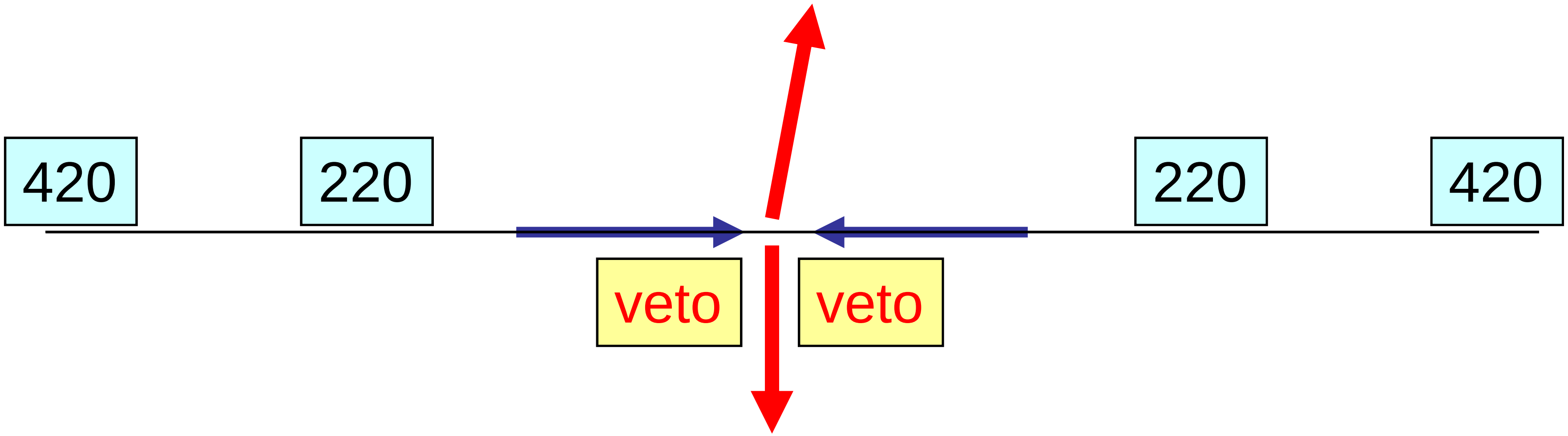
not seen

$y_i > 2 - 3$

correction prop. to rap. interval
prop. to γ energy
(negative)

Prob. to observe leading neutron must decrease with γ energy
But expt. → flat
→ small enhanced correction

Level 1 trigger



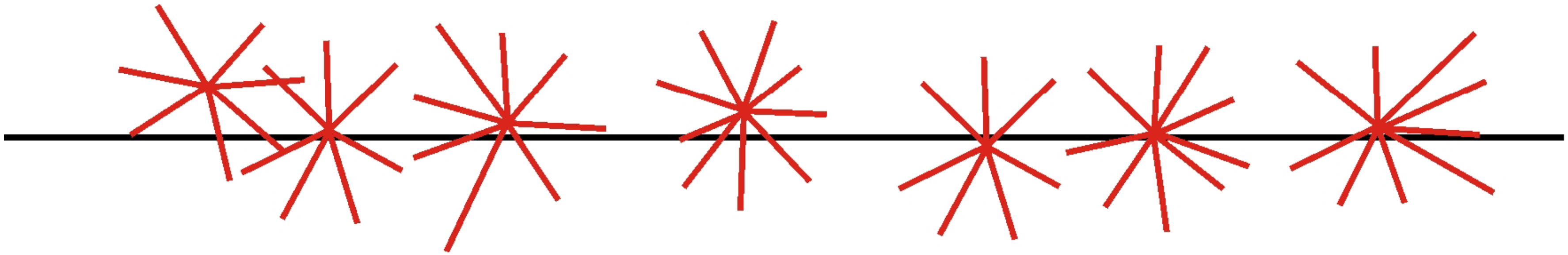
veto-trigger spoiled by pile-up
420-trigger spoiled by c ------------- buffer ?

At present, plan to use 2 high E_T jets/μ + 220 (+ 420) +…?

LHC

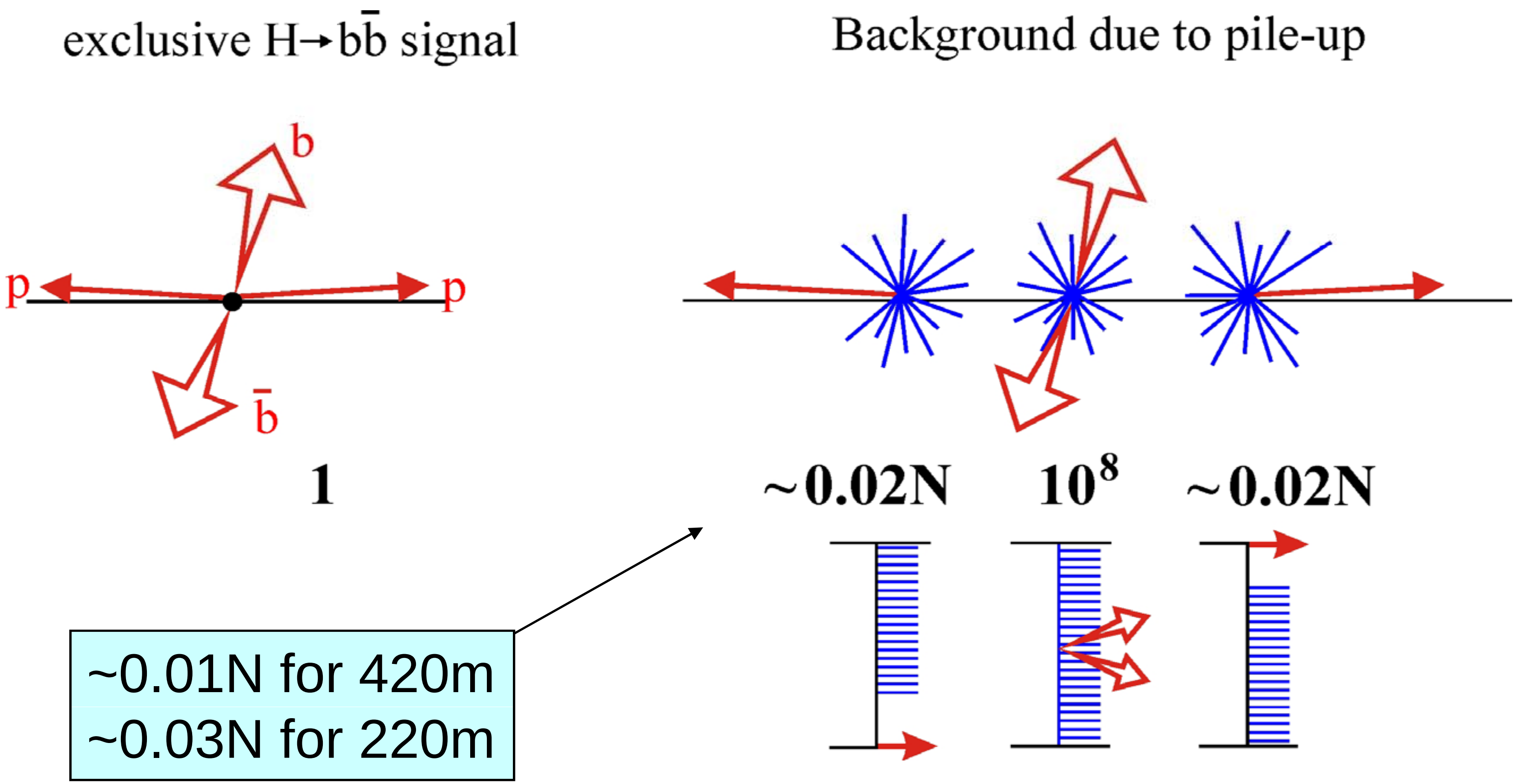
Pile-up $\mathcal{L} = 10^{33}$ cm^{-2} sec^{-1} N = 3.5

10^{34} N = 35



every bunch crossing !

Note N = 3.5 → 1.7 as above numbers include elastic
N = 35 → 17 and low mass inelastic in pile-up



Note: much recent progress (Tasevsky, Cox, Brandt,….) using timing, dijet 4-mom = missing 4-mom., checking multiplicity transverse to b jets, etc….much more optimistic

SUSY Higgs: h, H, A, (H^+, H^{--})

There are parameter regions where the

$$pp \rightarrow p + (h,H) + p$$

signals are greatly enhanced in comparison to the SM

Selection rule favours 0^{++} diffractive production

Tree-level couplings

relative to SM

$hZZ, \quad hWW, \quad ZHA, \quad WH^\pm H \quad \rightarrow \sin(\beta-\alpha)$

$HZZ, \quad HWW, \quad ZhA, \quad WH^\pm h \quad \rightarrow \cos(\beta-\alpha)$

$AZZ, \quad AWW = 0$

$(h, H, A)\, u\bar{u} \rightarrow \frac{\cos\alpha}{\sin\beta}, \quad \frac{\sin\alpha}{\sin\beta}, \quad \frac{1}{\tan\beta}$

$(h, H, A)\, d\bar{d} \text{ or } l^+l^- \rightarrow -\frac{\sin\alpha}{\cos\beta}, \quad \frac{\cos\alpha}{\cos\beta}, \quad \tan\beta$

Decoupling limit $M_A \gg M_Z$

$$\cos^2(\beta-\alpha) = \frac{M_h^2(M_Z^2 - M_h^2)}{M_A^2(M_H^2 - M_h^2)} \rightarrow 0$$

$h \rightarrow h_{SM}$ with $M_h^2 \simeq M_Z^2 \cos^2 2\beta$

$M_A \simeq M_H \simeq M_{H^\pm}$

$b\bar{b}H \simeq b\bar{b}A \sim \tan\beta$

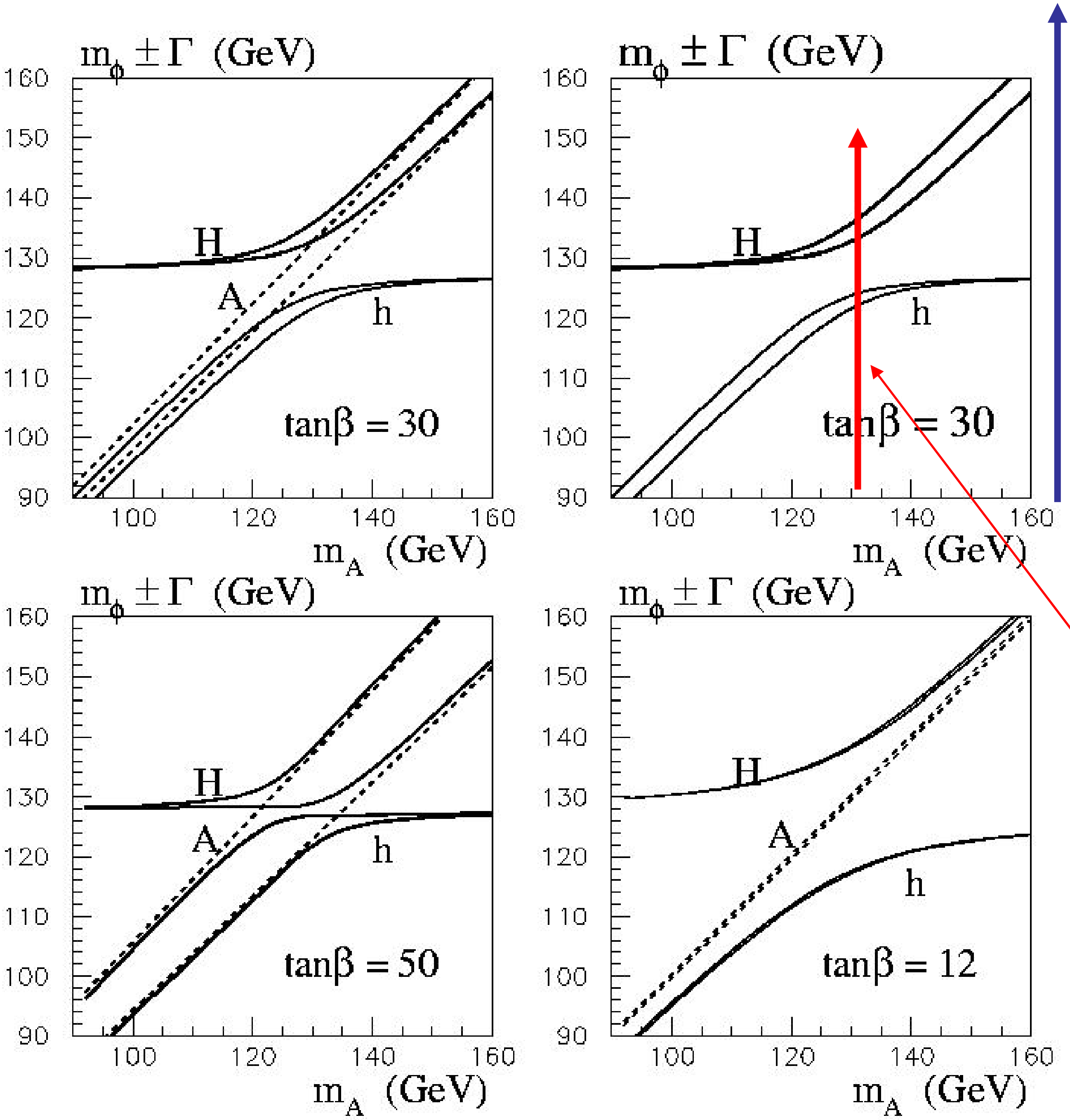
$VVH \simeq 0 \quad (VVA = 0)$

} H, A hard to detect ($\tau\tau$)

Anti-decoupling limit $M_A \lesssim M_Z$ $\quad |\cos(\beta-\alpha)| \sim 1$

$b\bar{b}h \simeq b\bar{b}A \sim \tan\beta$

$VVh \sim 0 \quad VVH \sim VVh_{SM}$



decoupling regime:

$m_A \sim m_H > 150$

h ~ SM

bbH ~ tanβ

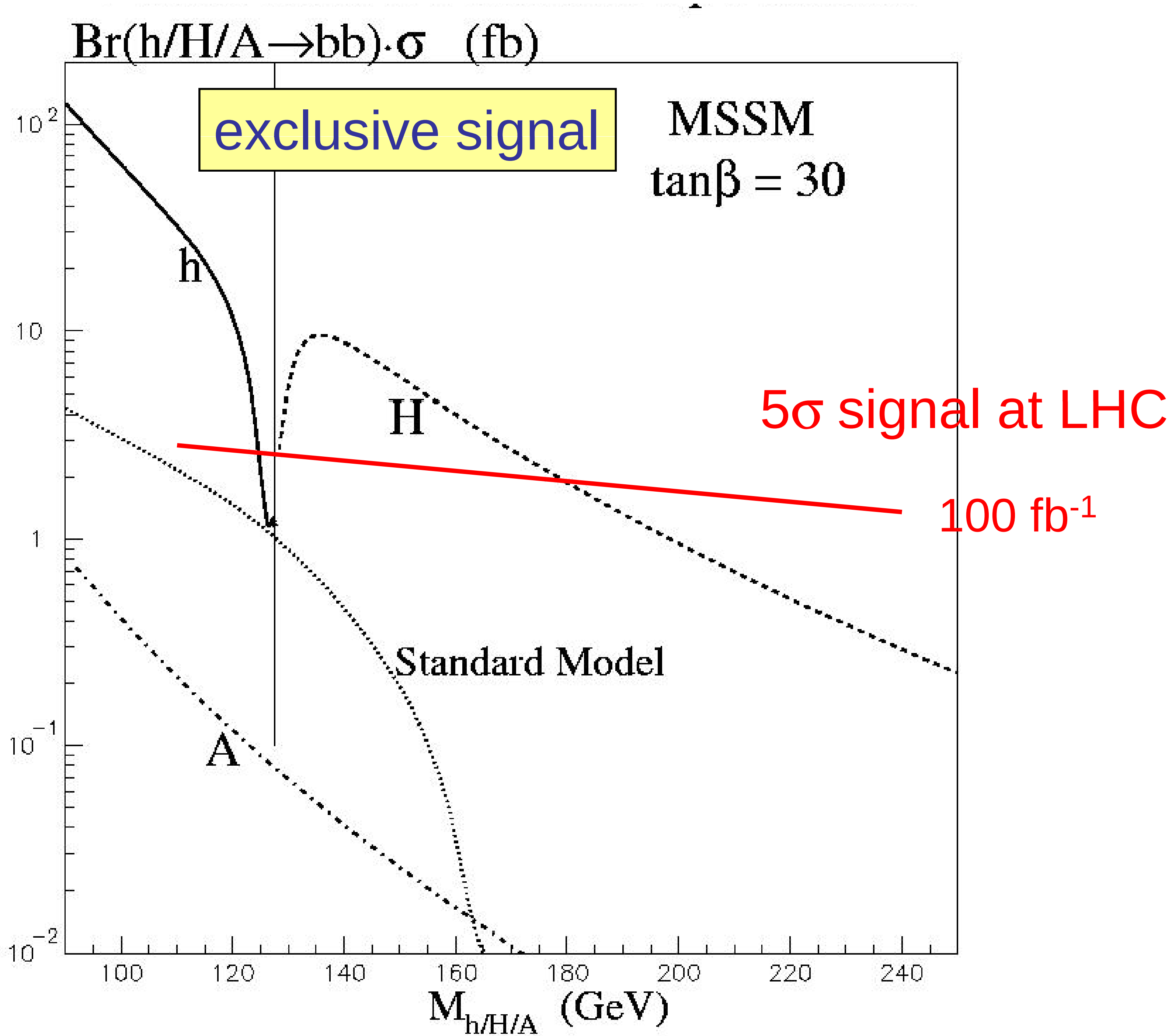
VVH ~ 0

H,A→ ττ (bb)

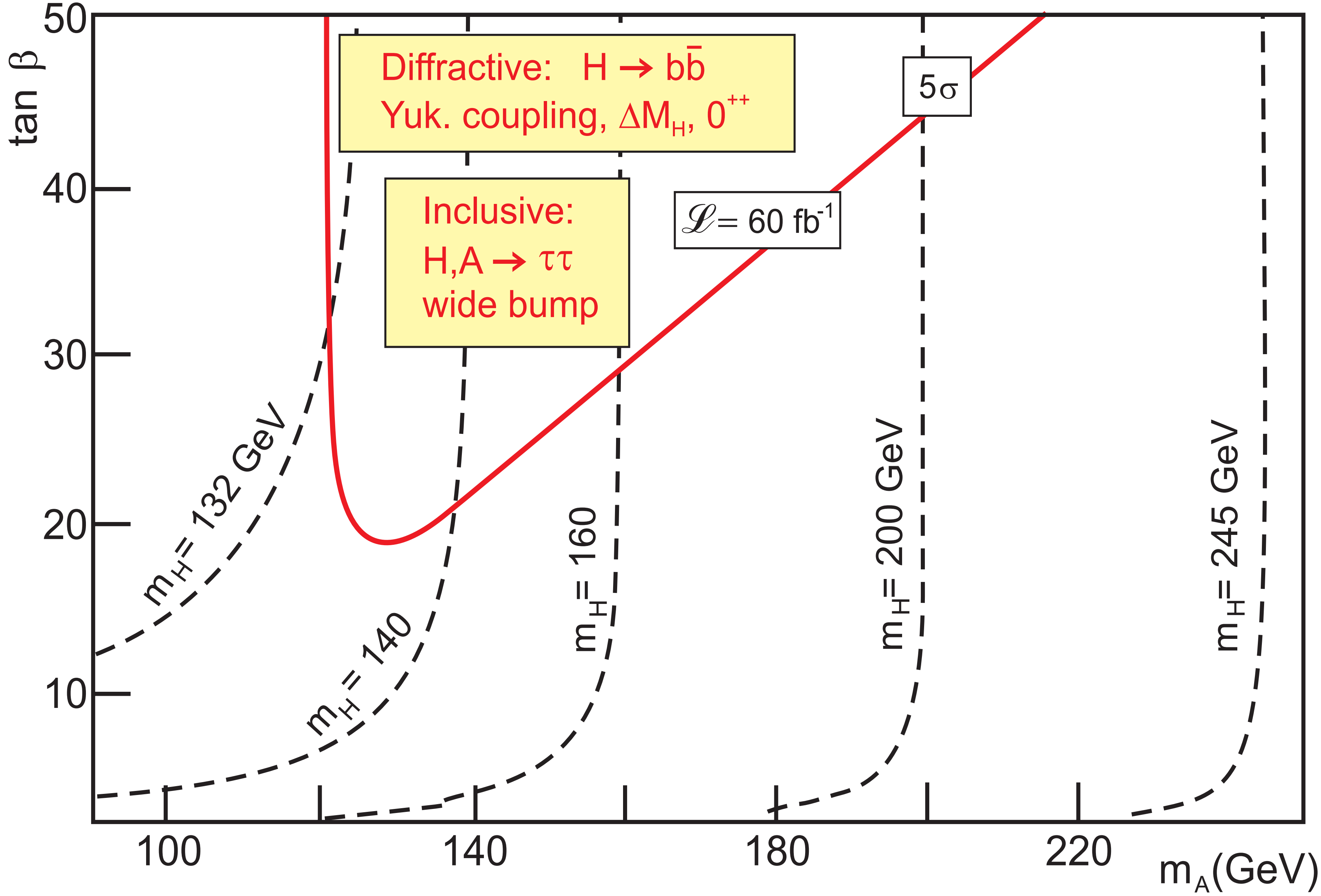
intense coup:

$m_h \sim m_A \sim m_H$

γγ,WW.. coup. suppressed

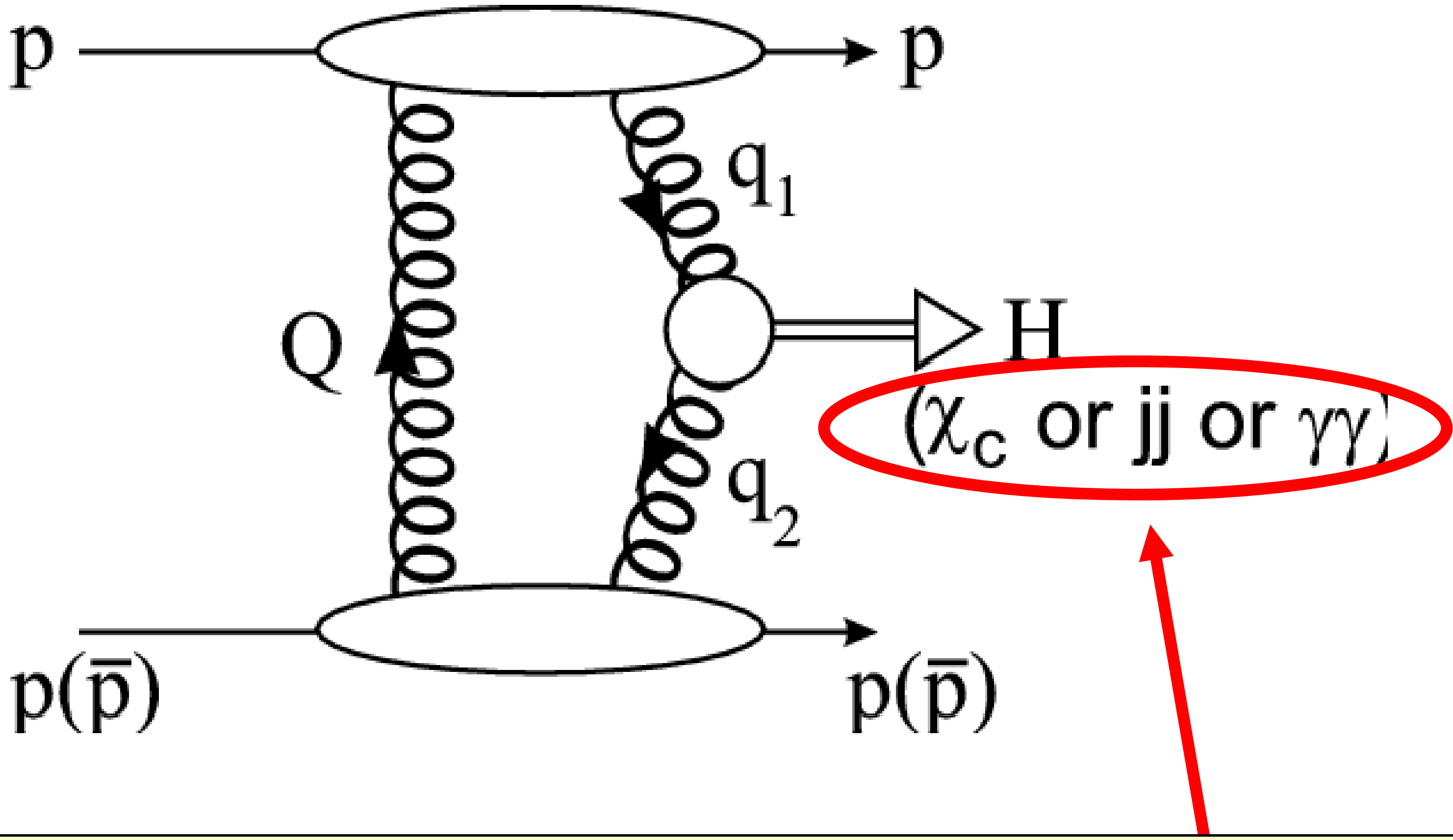


Br(h/H/A→bb)·σ (fb)
exclusive signal
MSSM
tanβ = 30
5σ signal at LHC
100 fb-1
h
H
A
Standard Model
10^2
10
1
10^-1
10^-2
100
120
140
160
180
200
220
240
M_h/H/A (GeV)



Adapted from a preliminary plot of Tasevsky et al. (HKRSTW)

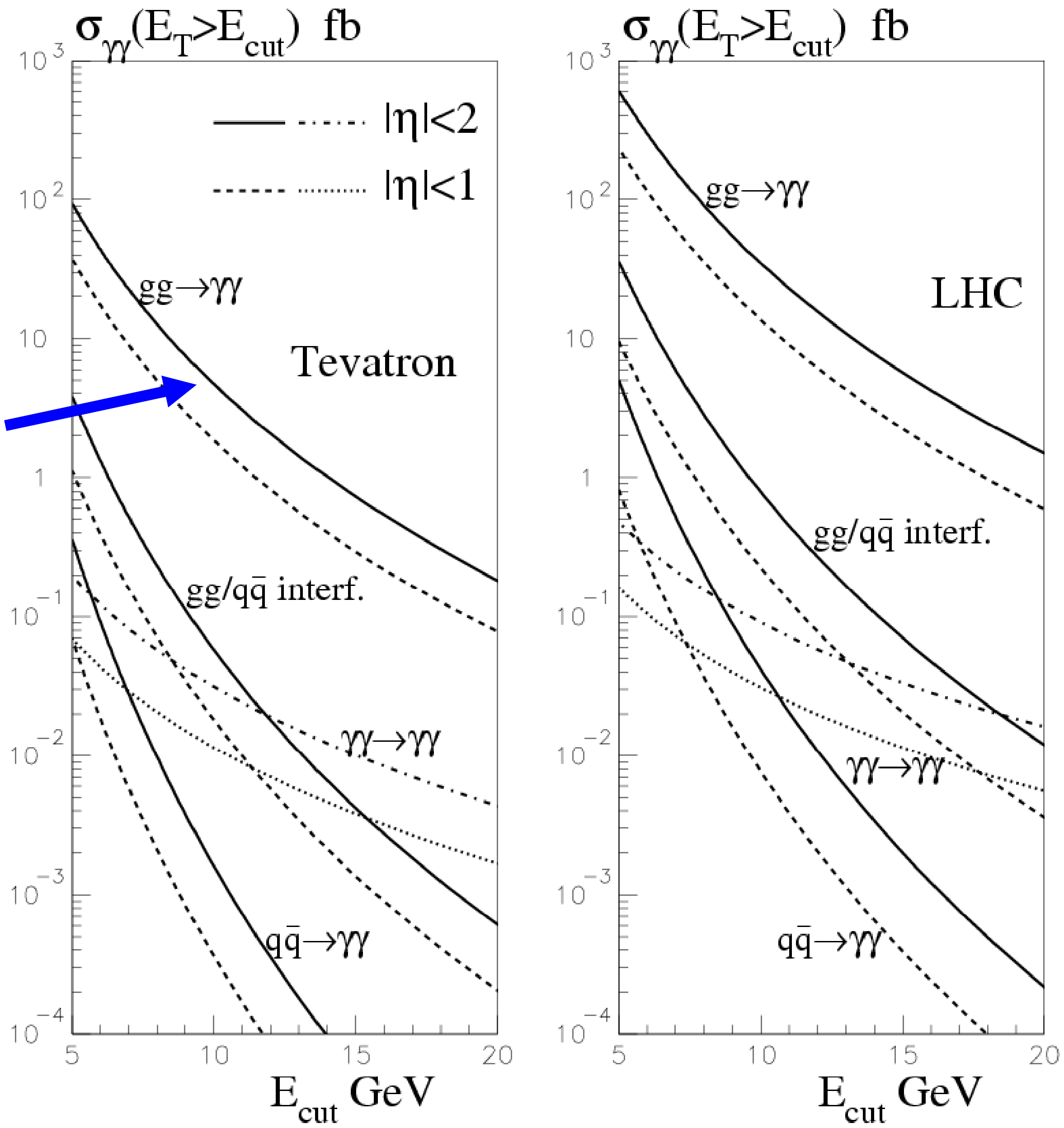
Possible checks of exclusive rates at the Tevatron



"standard candles" at Tevatron to test excl. prod. mechanism

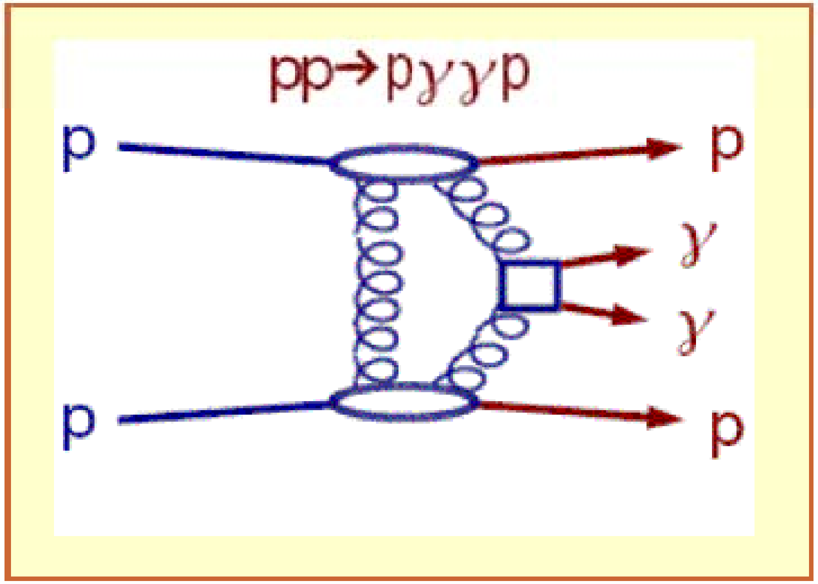
pp→p + χ + p	high rate, but only an ord.-of-mag.estimate
pp→p + jj + p	rate OK, but jet algorithm, hadronization etc
pp→p + $\gamma\gamma$ + p	low rate, but cleaner signal

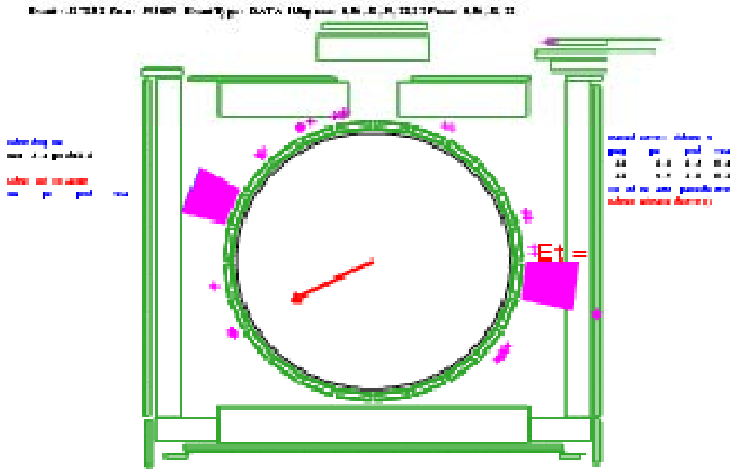
$p\bar{p} \to p + \gamma\gamma + \bar{p}$

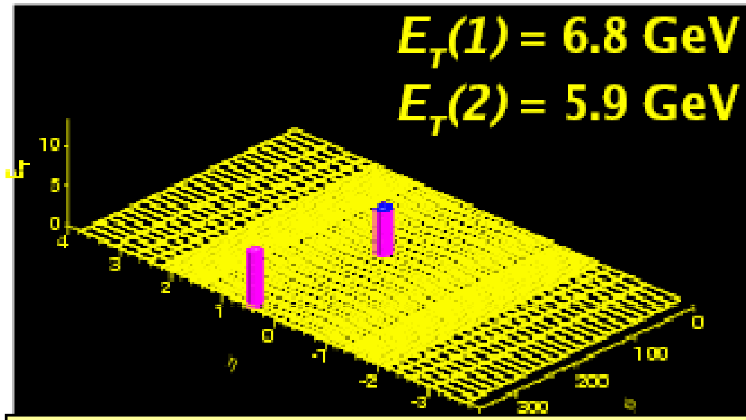


KMR+Stirling

Exclusive $\gamma\gamma$ Candidates







3 candidate events observed

no background estimate yet

1^{+3}_{-1} events predicted by ExHuME Monte Carlo

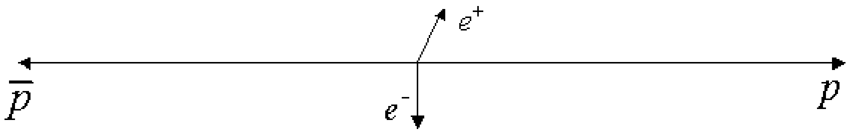
(based on Khoze, Martin, Ryskin, Ref: Eur. Phys. J. C38, 475-482, 2005)

Measurements with $M_{\gamma\gamma}$=10-20 GeV could confirm σ_H(excl) prediction at LHC to about 20% or less

CDF, Albrow et al.

one appears due to $\pi^0 \rightarrow \gamma\gamma$

Exclusive e^+e^- pairs



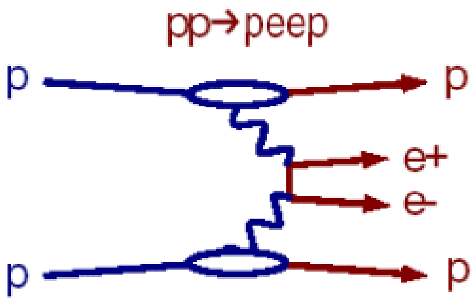
16 events observed

Estimated background = $2.1^{+0.6}_{-0.3}$

(mostly p-dissociation)

$\sigma_{MEAS.} = 1.6^{+0.5}_{-0.3}\,(stat) \pm 0.3\,(syst)$ pb

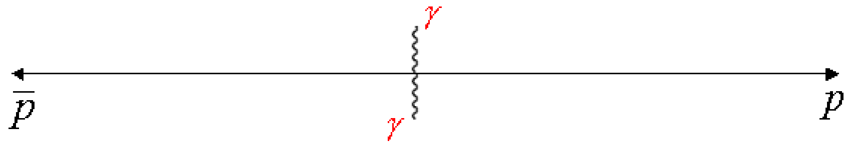
Poisson Prob. = $3\times10^{-8} \approx 5.5\sigma$



QED: LPAIR Monte Carlo

$\sigma_{QED} = (1.711 \pm 0.008)$ pb

Exclusive $\gamma\gamma$ pairs



3 events observed

Estimated background = $0.0\,^{+0.3}_{-0.0}$ events

(p-dissociation, exclusivity, fakes) ~0.09pb

$\sigma_{MEAS.} = 0.14\,^{+0.14}_{-0.04}\,(stat) \pm 0.03\,(syst)$ pb

Poisson Prob.$(0.3 \rightarrow \geq 3) = 3.6\times10^{-3}$

(conservative)

KMR (Durham) prediction = ~0.04pb pb

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

It means exclusive H must happen (if H exists) and probably σ~ 10 fb within factor ~ 2.5.
σ higher in MSSM

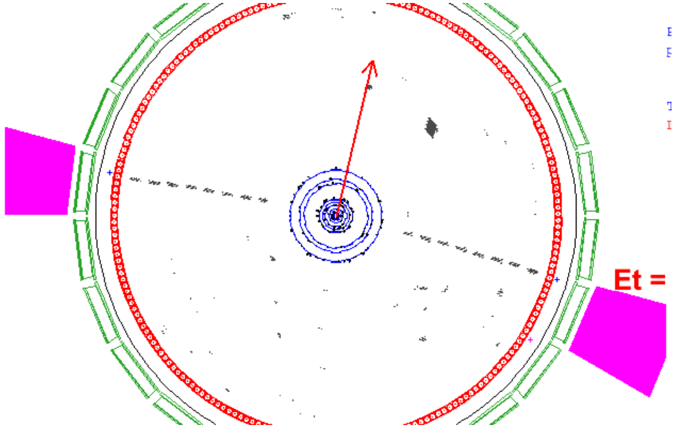
$\sigma(\gamma\gamma)$ = 10 fb for E_T^{γ}>14 GeV at LHC

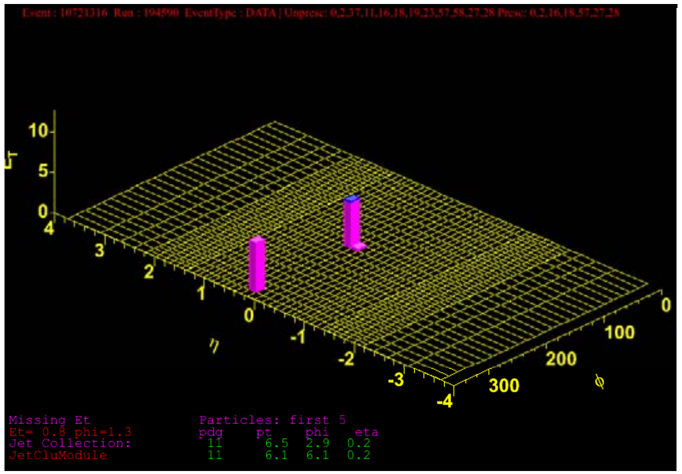
16 events were like this:

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

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

Δp_T small ($\cong$ resolution)





3 events were like this:

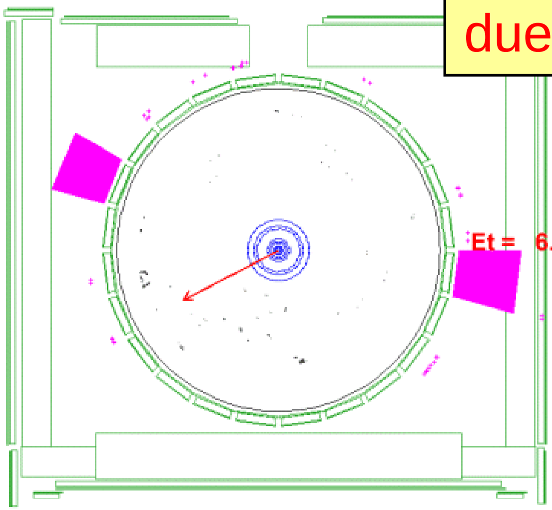
Albrow

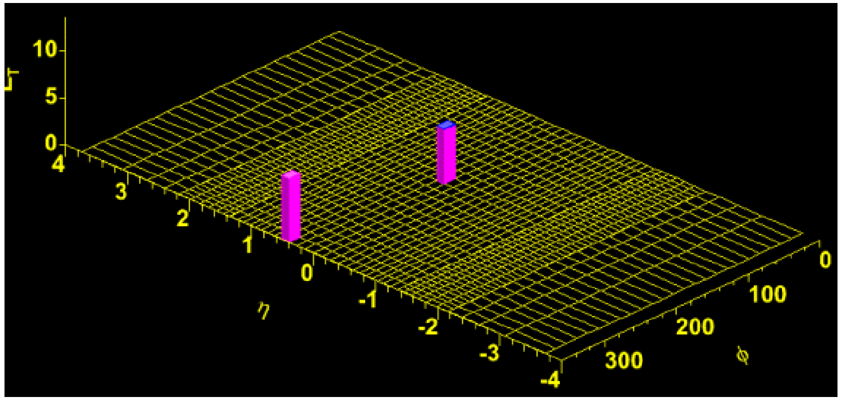
$\gamma\gamma:\quad \Delta\phi > 170^0$

$M(e^+e^-)\, 10 \rightarrow 20$ GeV

ΔE_T small

one appears due to $\pi^0 \rightarrow \gamma\gamma$

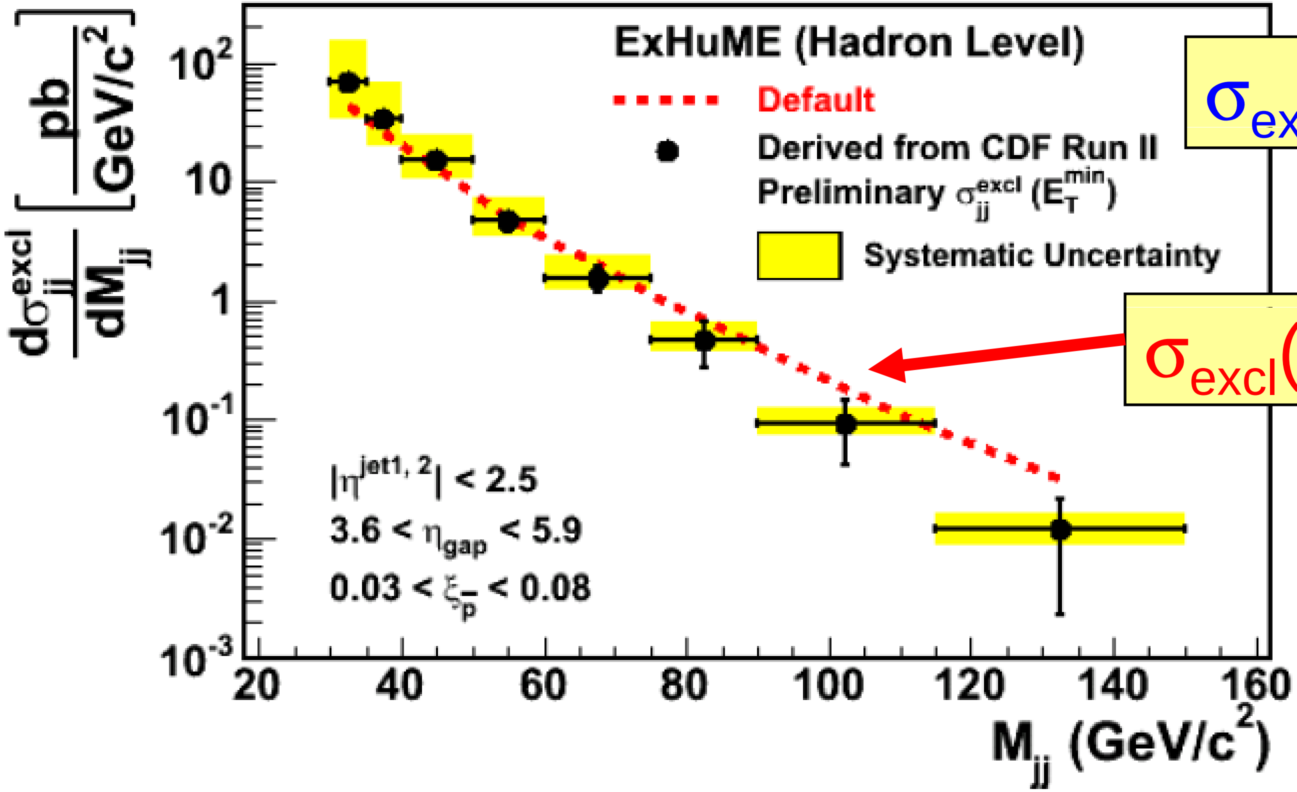




$p\bar{p} \rightarrow p + jj + \bar{p}$

Exptally more problematic due to hadronization, jet algorithms, detector resolution effects, QCD brem…

Exclusive events have $R_{jj} = M_{jj}/M_X = 1$, but above effects smear out the expected peak at $R_{jj} = 1$ (ExHuME MC)



$\sigma_{excl} \sim R_{jj} > 0.8$

$\sigma_{excl}(M > M_{jj})$

Conclusion

- The pp→p+H+p cross section prediction is robust----factor 2
  S/B~1 for SM h -----can be more for SUSY h, H.
  Checks are starting to come from Tevatron data ($\gamma\gamma$,dijet…)

- There is a strong case for installing proton taggers
  at the LHC, far from the IP ---- it is crucial to get the
  missing mass ΔM of the Higgs as small as possible.
  Need more expt^{al} and theoretical work on L1 trigger

- The diffractive Higgs signals beautifully complement the
  conventional signals. Indeed there are SUSY Higgs
  regions where the diffractive signals are advantageous
  ---determine ΔM_H, Yukawa H→bb coupling, 0^{++}
  ---searching for CP-violation in the Higgs sector