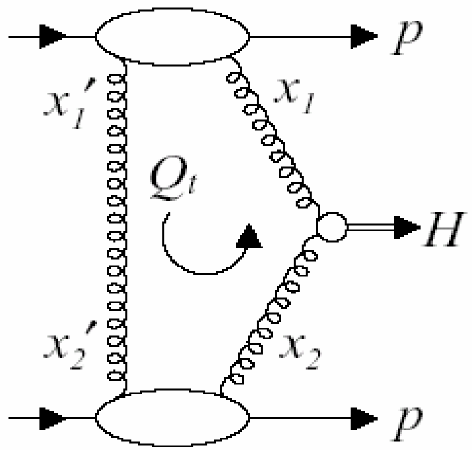
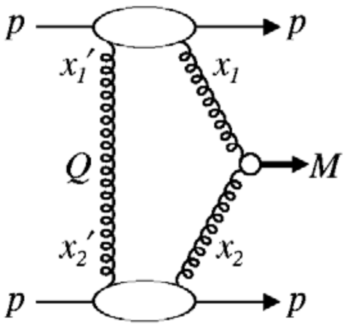
Higgs and BSM Production in DPE

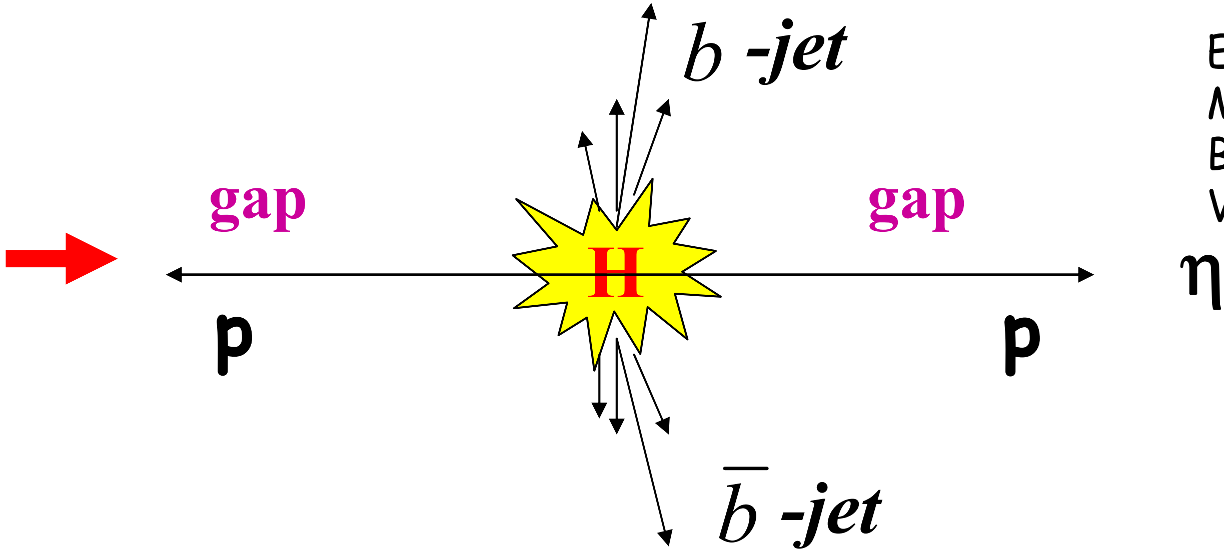
Albert De Roeck (CERN)



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

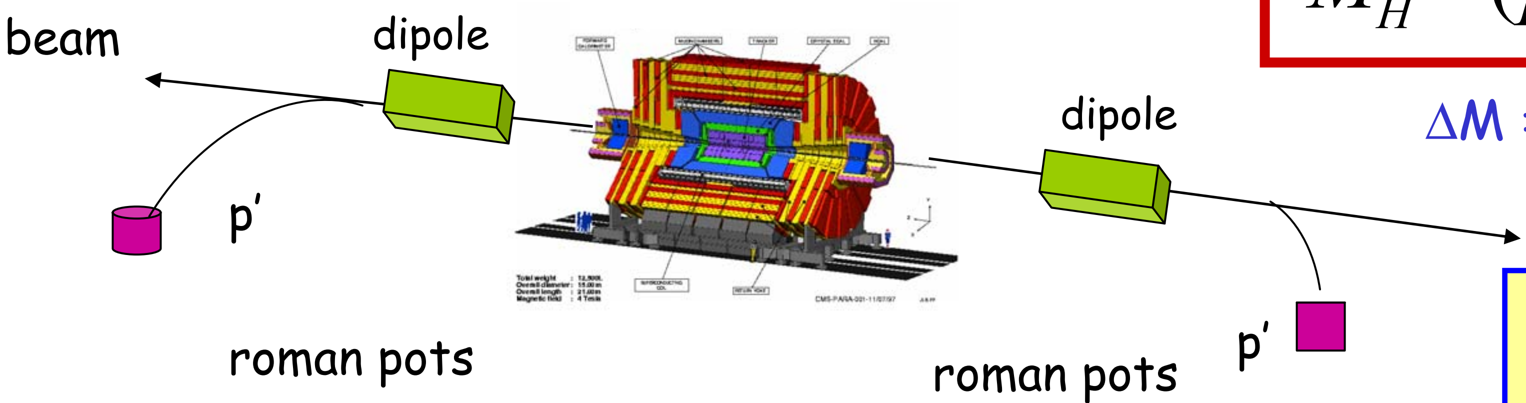




E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al.
V. Petrov et al…

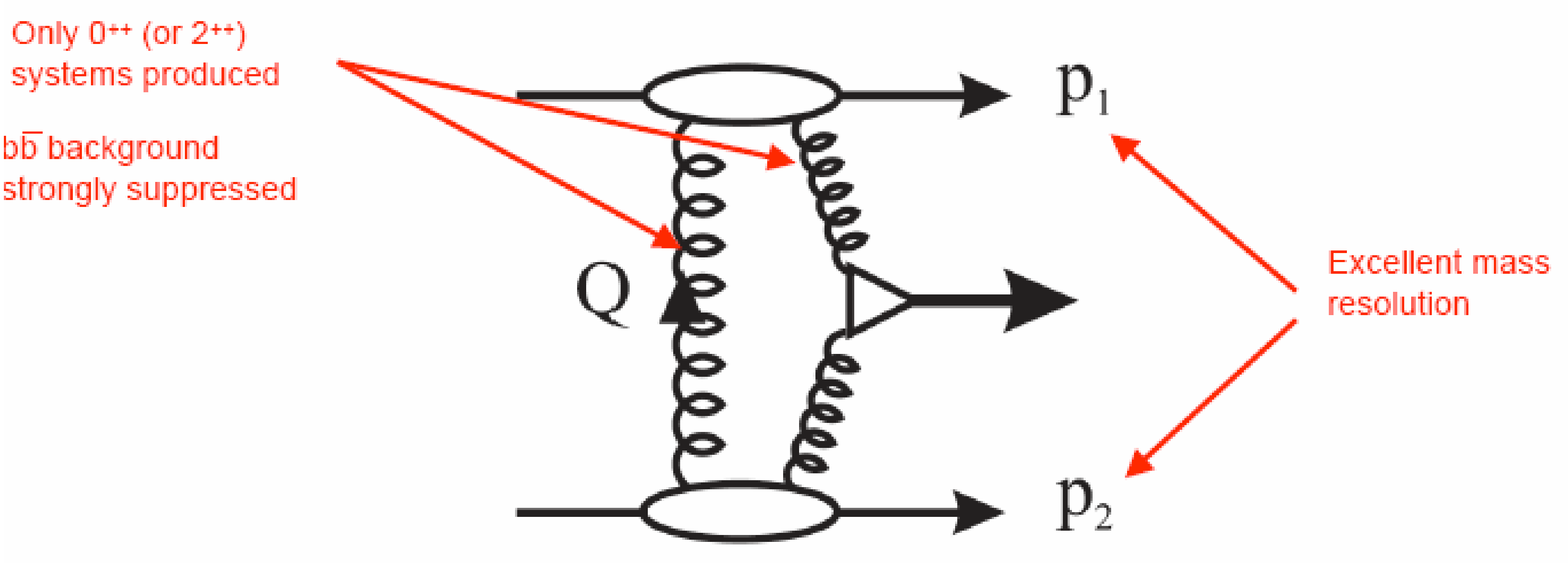
$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV



P. Landshoff not convinced that the cross sec. is small

Benefits from DPE Higgs



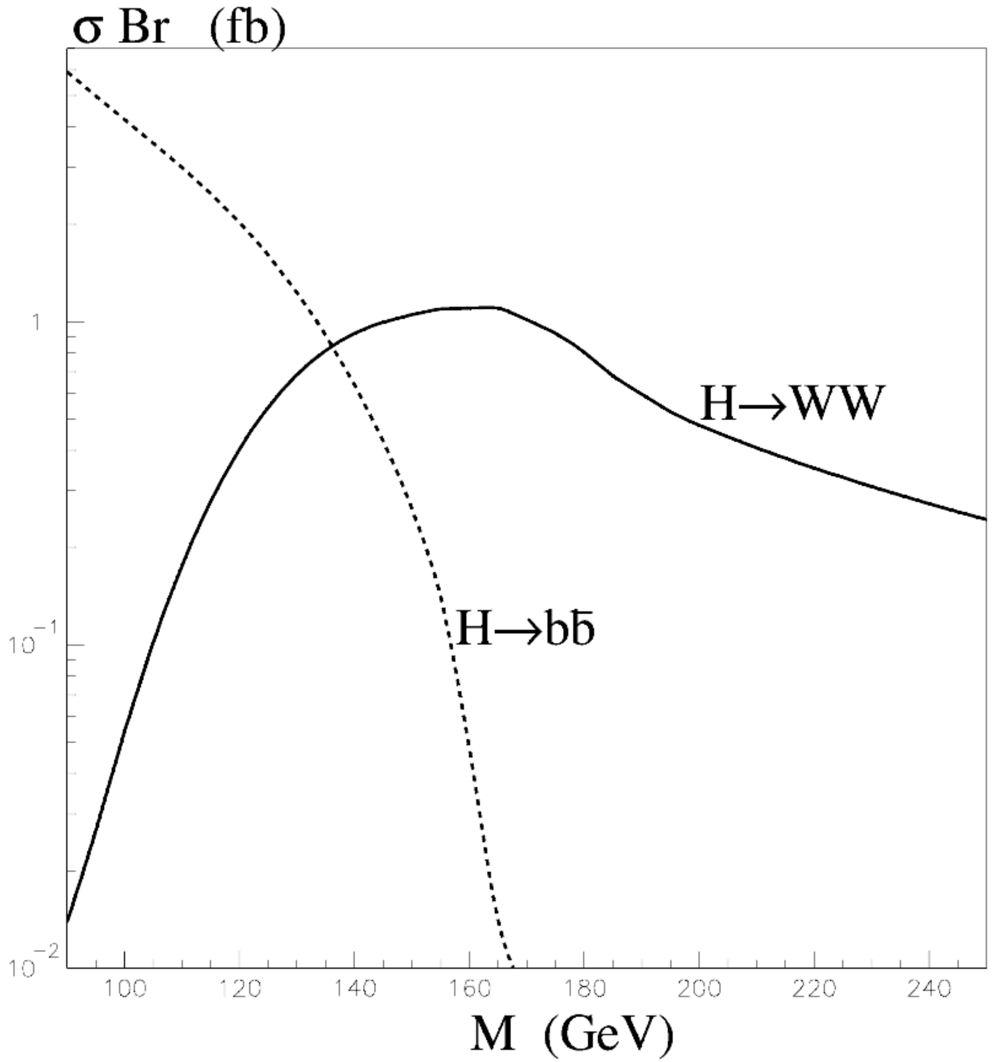
Drawback: cross section is in fb region

Exclusive Higgs production

- Advantages
  - Measure the Higgs mass via the missing mass technique
    Mass measurements do not involve Higgs decay products
  - Suppression of LO QCD backgrounds via spin selection rules
    E.g. can see in principle $H \rightarrow bb$
  - Spin parity info 0++ (2++) state
- Challenges
  - Tagging the protons
  - Selection of exclusive events/backgrounds
  - Triggering at L1 in the LHC experiments
  - Model dependent predictions: resolve some of the issues at the Tevatron?

There is a lot to learn from present and future Tevatron diffractive data

Higgs Cross Section * BR



- Cross sections ~ fb

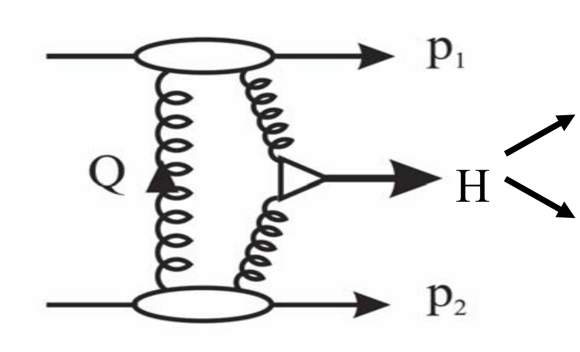
- Diffractive Higgs mainly studied for H→bb
Khoze et al.,
ADR et al.,
Boonekamp et al.,
Petrov et al…

- Recently study extended for the decay into WW can reach higher masses
Cox, Khoze, ADR, to appear

Note H→bb (120 GeV) at Tevatron ⇒ 0.13 fb

Exclusive Higgs production

Standard Model Higgs



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

M_H = 140 GeV s = 0.7 fb

M_H = 120 GeV : 11 signal / O(10) background in 30 fb^{-1} with detector cuts

WW* : M_H = 120 GeV s = 0.4 fb

M_H = 140 GeV s = 1 fb

M_H = 140 GeV : 8 signal / O(3) background in 30 fb^{-1} with detector cuts

- The b jet channel is possible, with a good understanding of detectors and clever level 1 trigger (need trigger from the central detector at Level-1)
- 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 SM Higgs + tags - the quantum numbers are 0^{++}

Phenomenology moving on fast

See e.g. J. Forshaw HERA/LHC workshop

The MSSM can be very proton tagging friendly

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

$gg \longrightarrow \phi$ enhanced

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

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

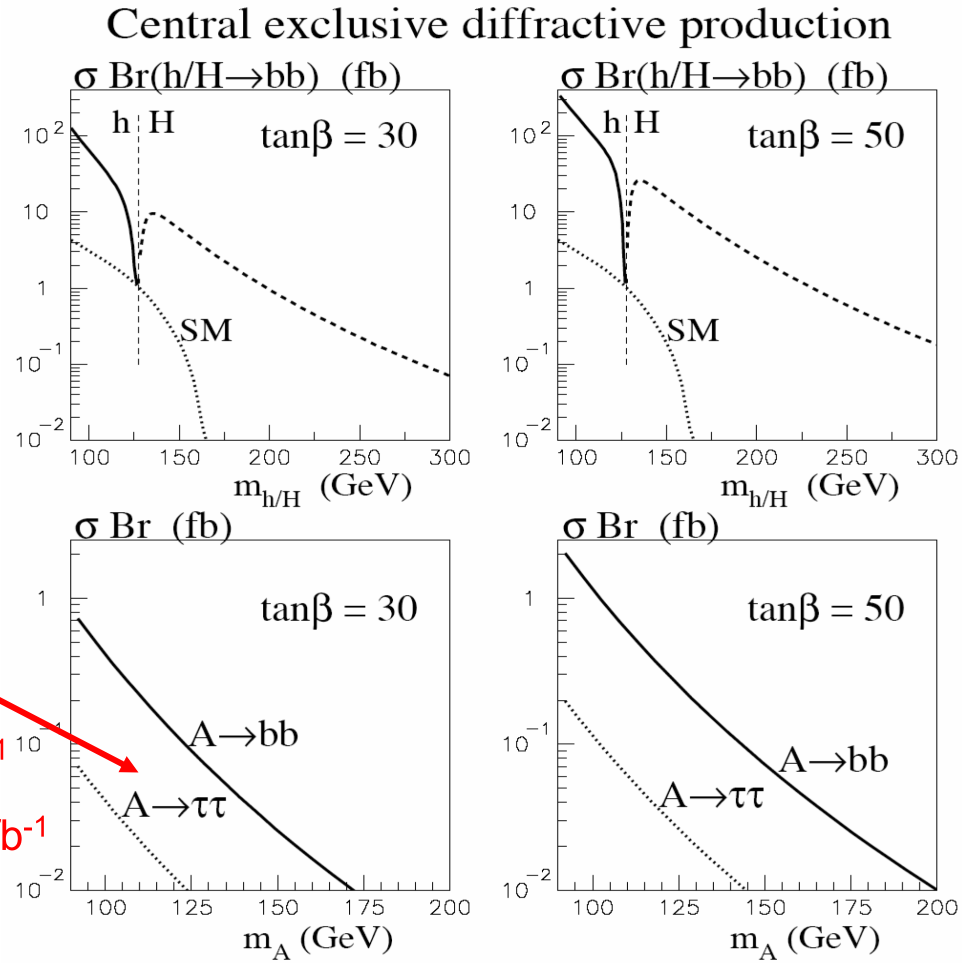
M_A = 130 GeV, tan β = 50

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

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

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

Signal in ~ 5 GeV bins



σ×BR(bb) > 0.7fb (2.7fb) for 300 (30fb^{-1})

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

Probing the CP Violating Sector of the Higgs

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
$\sigma(H_1)\text{Br}(\tau\tau)$	a, b	1.9	0.6	0.3
$\sigma^{\text{QED}}(\tau\tau)$	a, b	0.2	0.1	0.04
$A_{\tau\tau}$	b	0.2	0.1	0.05

'CPX' scenario
σ in fb

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

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

CP even

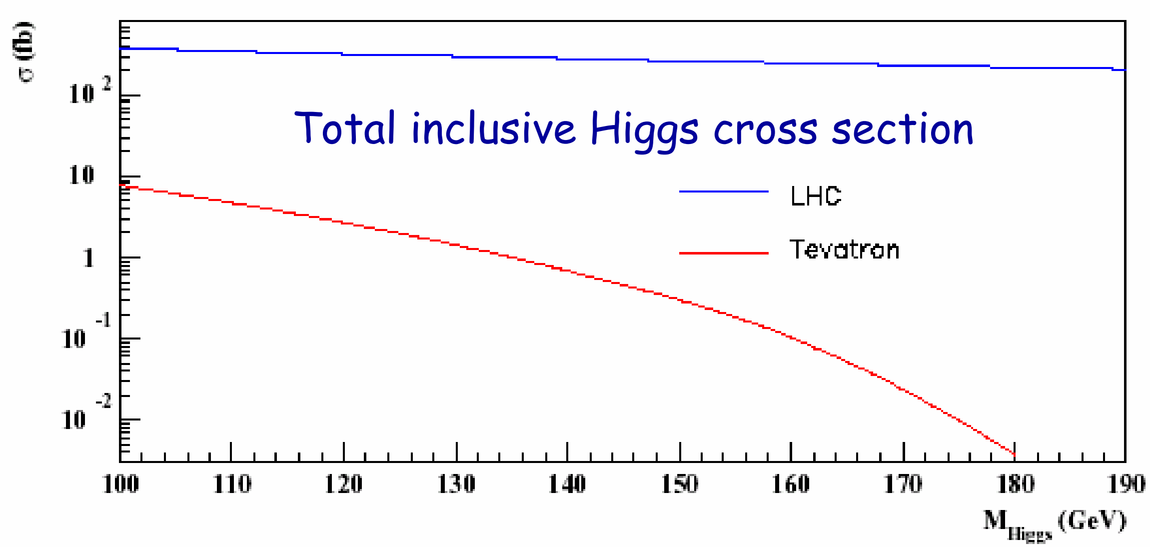
CP odd active at non-zero t

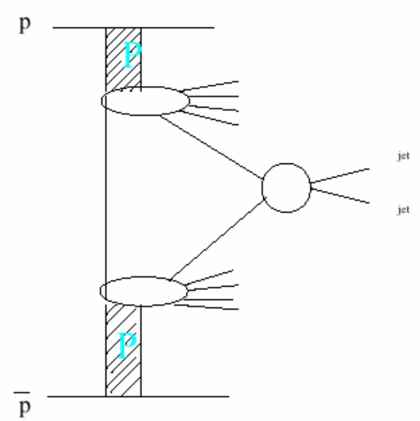
CPX: Carena, Ellis, Pilfatis, Wagner

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

Inclusive Diffractive Higgs Production

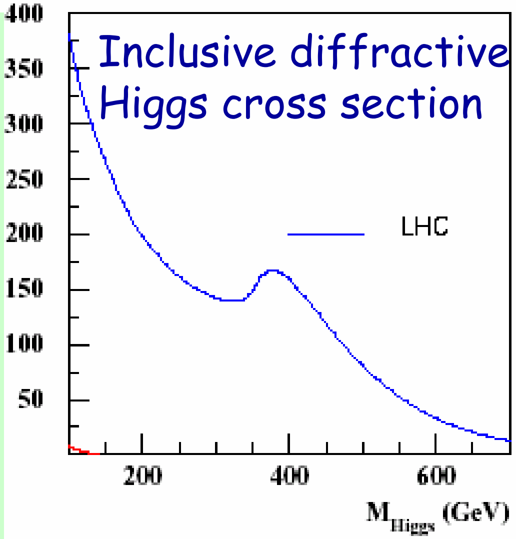
E.g. Boonekamp et al.

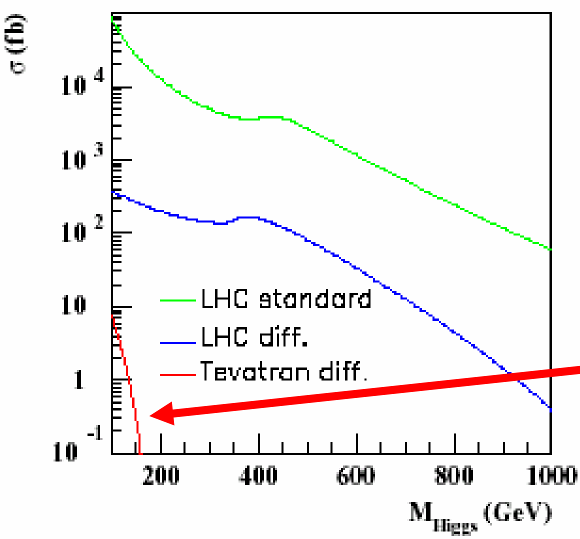




pp→p+HX+P

Cross section larger but no spin selection rules or mass reconstruction from the protons



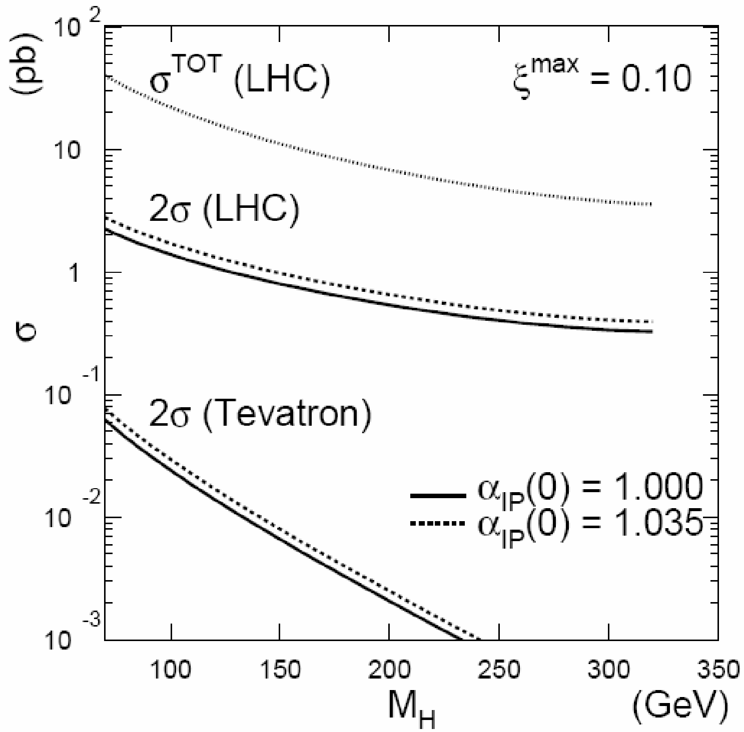


Rather hopeless at the Tevatron

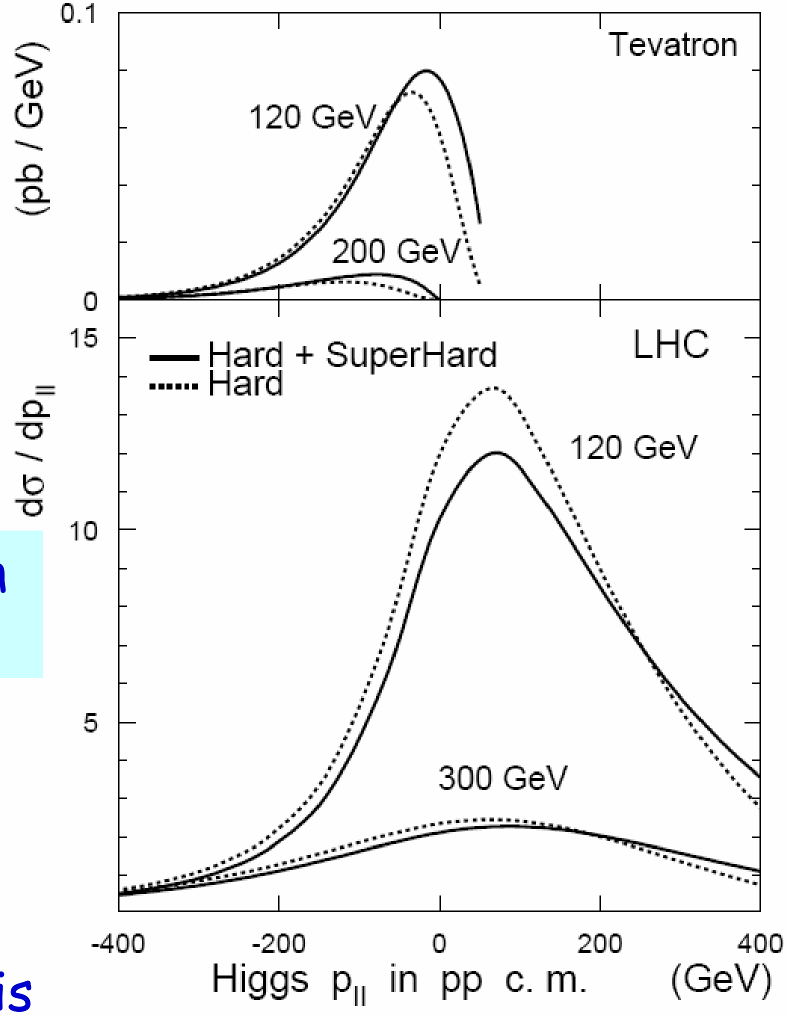
Single Pomeron Exchange

Erhan, Kim and Schlein hep-ph/0312342

SPE: ~7% of inclusive cross section



Gap suppression included?

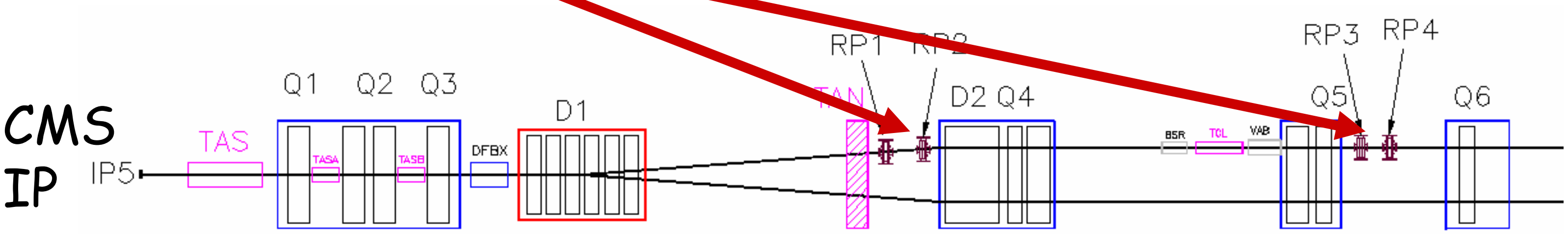


Ingelman-Schlein model implementation
⇒based on UA8 measured structure functions and Schlein et al. flux factor analysis

Gain e.g. w.r.t. total inclusive production is under study

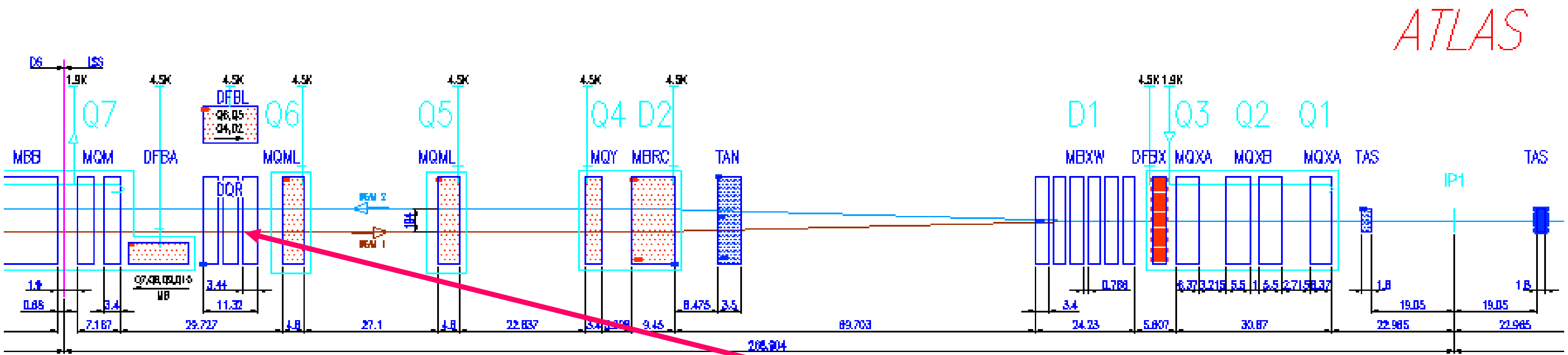
Planned Roman Pot detectors@LHC

TOTEM physics program: total pp, elastic & diffractive cross sections
CMS+TOTEM Roman pots at high lumi



150 m

215 m

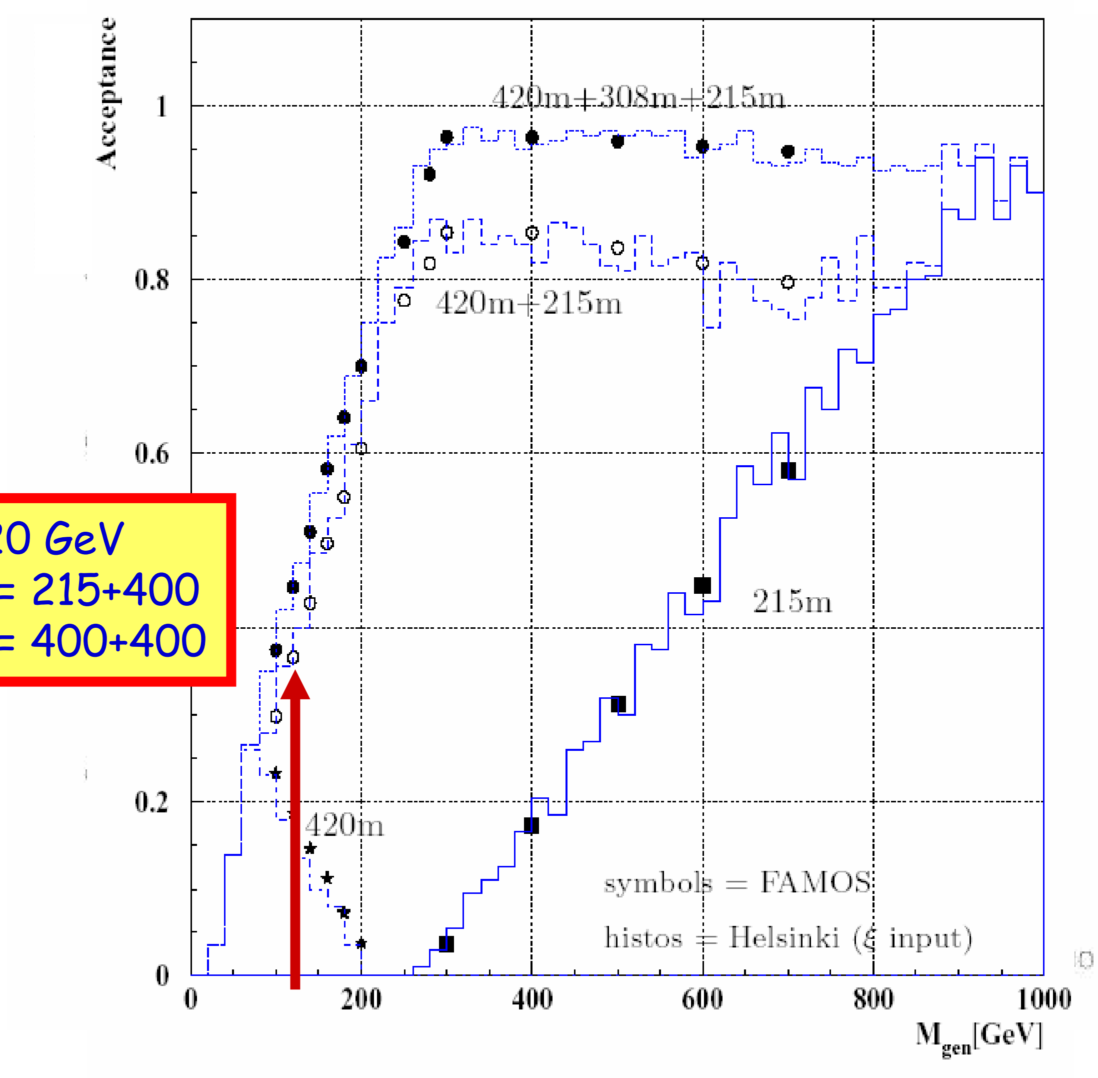


240 m
ATLAS Diffraction to be studied
Cannot use present RPs at high lumi

One **Roman Pot Station** per side
on left and right from IP1

Exclusive Diffractive Higgs Production

Acceptance of 200 m region not sufficient for Higgs detection
LHC optics: suitable positions with increased acceptance at 308/420 m



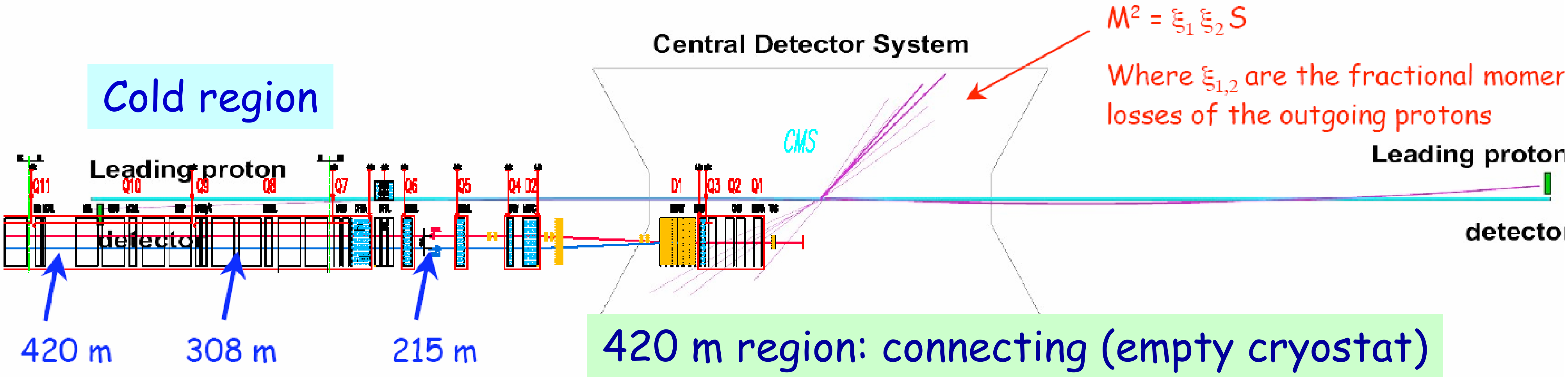
At 120 GeV
50% = 215+400
50% = 400+400

- 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

Curves: Helsinki Group

Dots CMS/FAMOS simulation

New Forward Detector Proposal (in prep.)



Proposal to study a modification of the cryostat and to operate compact detectors in the region of 400m (for ATLAS & CMS)
⇒R&D collaboration building: UK groups, Belgian & Finish institutes, CERN…

DPE Higgs event generators

1. **DPEMC 2.4** (M.Boonekamp, T.Kucs)
   - Bialas-Landshof model + rap.gap survival probability
   - Herwig for hadronization

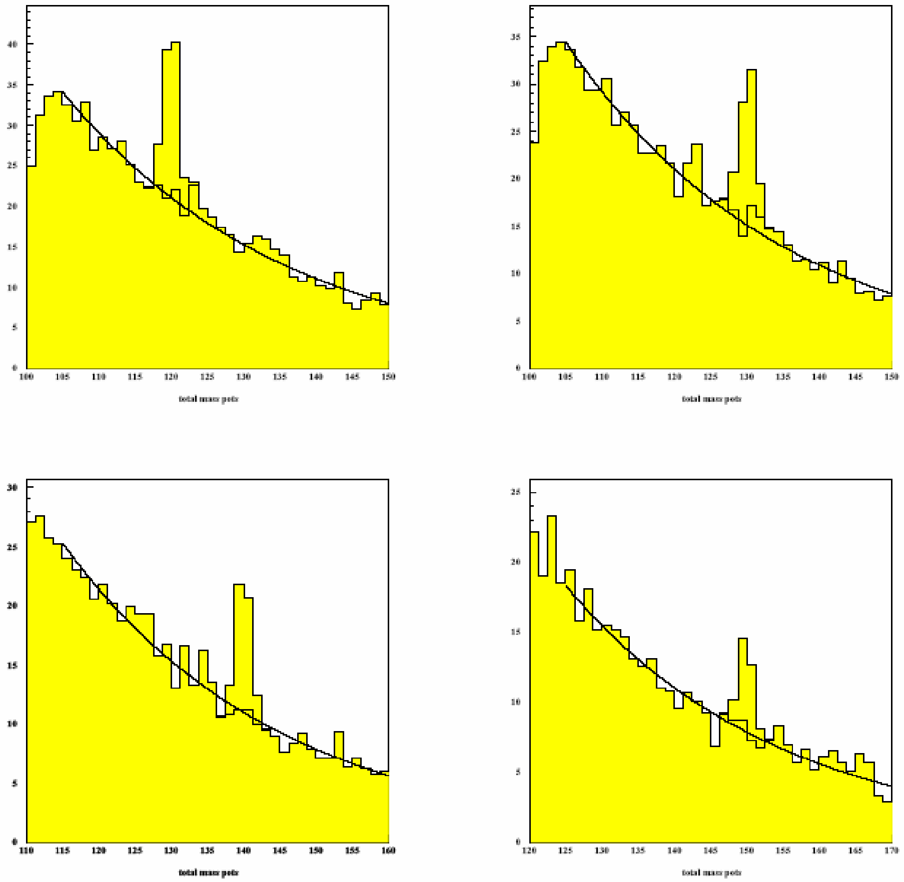
2. **EDDE 1.1** (V.Petrov, R.Ryutin)
   - Regge-eikonal approach
   - Pythia for hadronization

3. **ExHuMe β version** (J.Monk, A.Pilkington)
   - KMR model for exclusive diffraction
   - Pythia for hadronization

All three models available now in the fast CMS simulation!

Detailed Simulation Studies

Signals and background for different Higgs masses



100 fb^{-1}

Detailed studies ongoing
Fast detector simulation

Boonekamp/ATLAS
Royon/CMS

Include exclusive and inclusive bb background

Include missing mass resolution from the tagged protons

Experimental issue: L1 trigger
400m signals are too late for the L1 trigger→L1 from central detector

First look/needs to be optimized

Problems with exclusive $H \to bb$ channel

- Trigger
  - 420 m signals are too late for the L1 trigger
  - The L1 trigger threshold in CMS for the jets is ~180 GeV
    - Even with topological tricks still a factor of ~10 is missing in rate (see studies from Helsinki, Wisconsin, Bristol)
    - Not final, but certainly not going to be easy
    - Note: rate determination contains a safety factor of 3-6
  - Probably ok for asymmetric events, ie. 1 proton tagged in the 220m Roman Pot + dijet trigger: needs testing.
    - However these events have a bad mass resolution measured in the pp system (1% $\to$6%)
- Background
  - QCD process $gg \to bb(g)$, even when bb production suppressed at LO, $gg \to qq(g)$ with misidentification…
  - S/B~1 at best, likely <1 (detector simulation)
- Detection efficiency of the bb
  - Need to identify b-quarks/loose typically factor of 2

$\Rightarrow$ Investigate WW* (ZZ) channel?

Trigger Advantage for WW*

Trigger: can be done at L1 without Roman Pot info

- Full Leptonic decays (electron/ muon only so far) $WW \rightarrow ll\nu\nu$ ~4%
  - L1 lepton triggers have low thresholds ⇒ in CMS
  - Single electron 29 GeV Double electron 17 GeV
  - Single muon 14 GeV Double muon 3 GeV
- Hadronic/lepton decay $WW \rightarrow qq\, l\nu$ ~28%
  - Mostly can be triggered by single lepton trigger
  - Try to decrease the single electron/muon trigger by having a combined trigger "lepton+2 jets". So far not in the CMS trigger cocktail. Assume that we can have values like a single electron = 20 GeV and single muon = 10 GeV combined with 2 25 GeV jets
- Full hadronic decays $WW \rightarrow qqqq$ ~49%
  - Difficulty for the trigger/QCD background: 4 jet trigger at L1 is 70 GeV/jet at low luminosity
  - Charm quark tagging?
- Remaining decays include taus/ not explicitely used

Rates: detector simulation

σ (H->W+W-) = 0.34 fb (M_H = 120 GeV) / 1 fb (M_H = 135 GeV)
BR(W->e nu) = BR(W->mu nu) ~ 10.5%

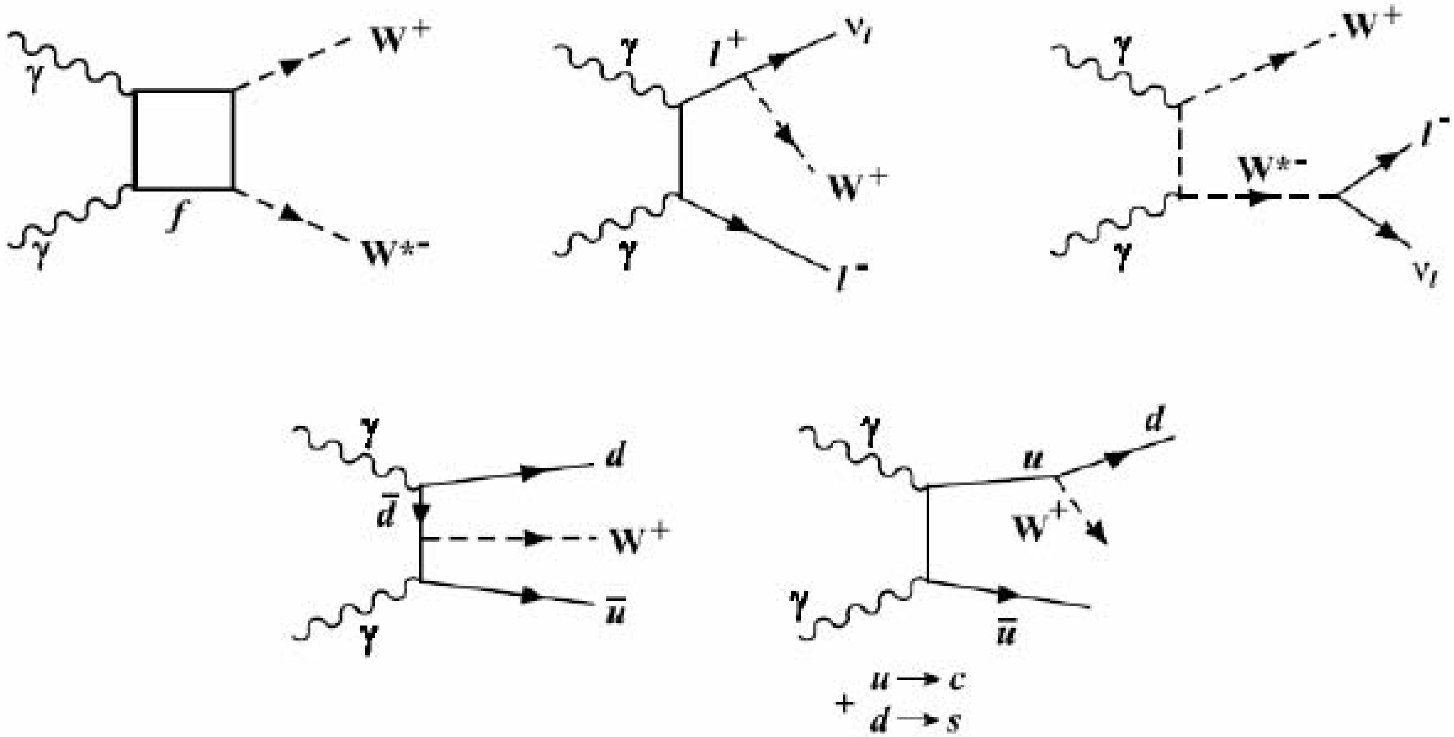
Acceptance	120 GeV / 135 GeV
• 0) Acc(RP1)>0 and Acc(RP2)>0	57.9% / 66.5%
All following are total acceptances (incl BR, RP acceptance etc.):	
• 1) single e found: pt1>29GeV, |eta1|<2.5:	3.8% / 4.9%
• 2) two e found: pt1>17GeV,pt2>17GeV, |eta1|<2.5,|eta2|<2.5:	0.2%/ 0.4%
• 3) single mu found: pt1>14GeV, |eta1|<2.1:	7.9% / 10.7%
• 4) two mu found: pt1>3GeV,pt2>3GeV, |eta1|<2.1, |eta2|<2.1:	0.6%/ 1.5%
• 5) 1 lepton + 2 quark jets > 25 GeV	2.5%/ 2.8%

Expected Number of events for 20fb^{-1} (1 'good' year of low lumi)
$\Rightarrow$ 7 (20) produced/ 1 (4) detected events at M_H =120 (140) GeV

Max possible ~ 30%

mass	120	135	140	150	160	170	180	200
Events/20 fb^{-1}	1.2	3.5	4.2	6.2	8.2	8.2	6.6	4.4

QED backgrounds to WW

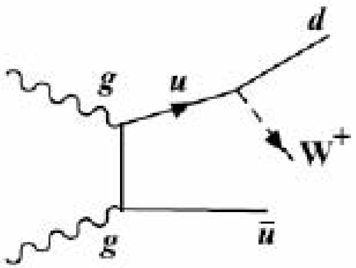


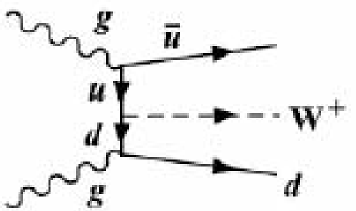
Calculated using CalcHEP

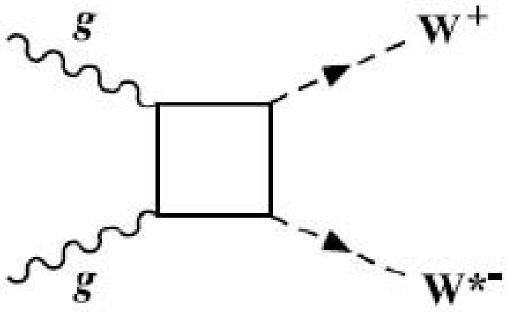
with centrality cuts ($|\eta|$ < 2.5 leptons and jets) and $\Delta M = 0.05\ M_H$

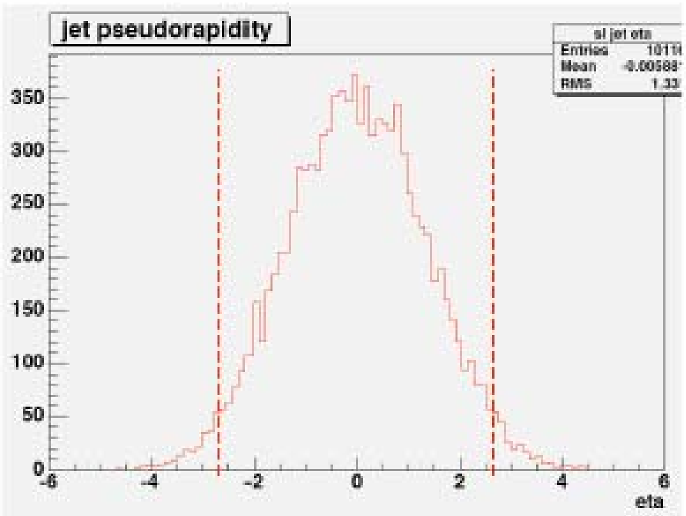
M_H = 120 GeV (140 GeV) $\sigma(WW^*)$ = 0.06 fb (0.12 fb)

QCD backgrounds to WW









QED processes
Preliminary estimates (CalcHep 2.1)
$\Rightarrow gg \rightarrow qqW$ potentially dangerous
$\Rightarrow$(V. Khoze, M. Ryskin, T Pierzchala)

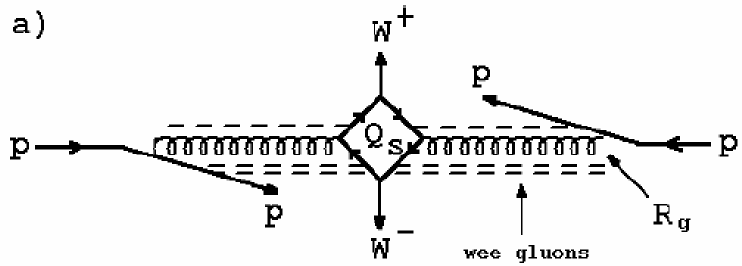
With suitable cuts on the qq system (forward rapidity, invariant mass) find conservative estimate of S/B for $H \rightarrow WW^*$ in the range of 2-4.
$\Rightarrow$Still being optimized

Anomalous WW Production

Alan White: theory of supercritical pomeron→ reggeized gluon+many (infinite) wee gluons

- color sextet quarks required by asymptotic freedom, have strong colour charge, (at least) few 100 GeV constituent mass
- Sextet mesons → EWSB
- UDD neutron dark matter candidate
- Explain high energy cosmic rays, Knee?
- Color sextet quarks couple strongly to W and Z and to the pomeron
- Phenomenology: Anomalous production of WW when above threshold ie. At the LHC (with possibly some onset already detectable at the Tevatron

color triplets	color sextets
u c t	U
d s b	D



⇒Measure exclusive WW,ZZ cross sections in DPE at the LHC
Expected Cross section orders of magnitude larger than in SM

Radions

Radions (graviscalars) RS models: quantum excitations of the brane separation

Three Fundamental Parameters :

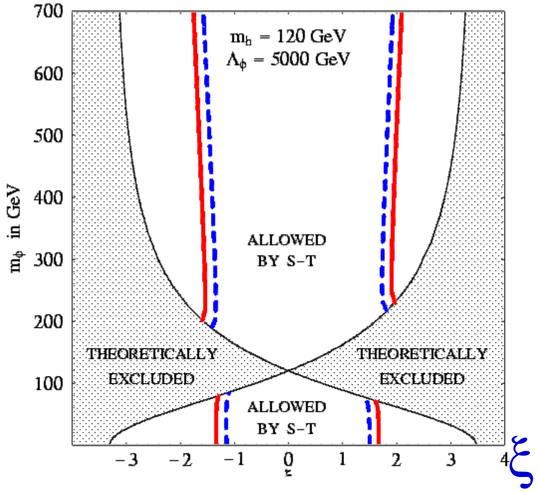
$$m_r \quad \xi \quad v/\Lambda$$

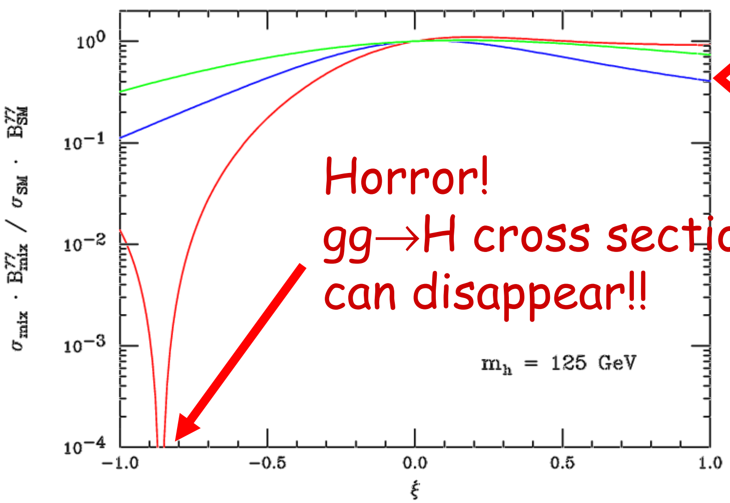
- Radion couplings to Gauge bosons and Fermions similar to SM H
- ϕ mixing to H ξ causes shift in g_{HVV} and g_{Hff} couplings

$$\frac{g'_{HVV}}{g^{SM}_{HVV}} = \frac{g'_{Hff}}{g^{SM}_{Hff}} = f_1(\xi, v/\Lambda, m_\phi) + \frac{v}{\Lambda} f_2(\xi, v/\Lambda, m_\phi)$$

Couplings to $\gamma\gamma$ and gg receive anomalous contributions

EW constraints



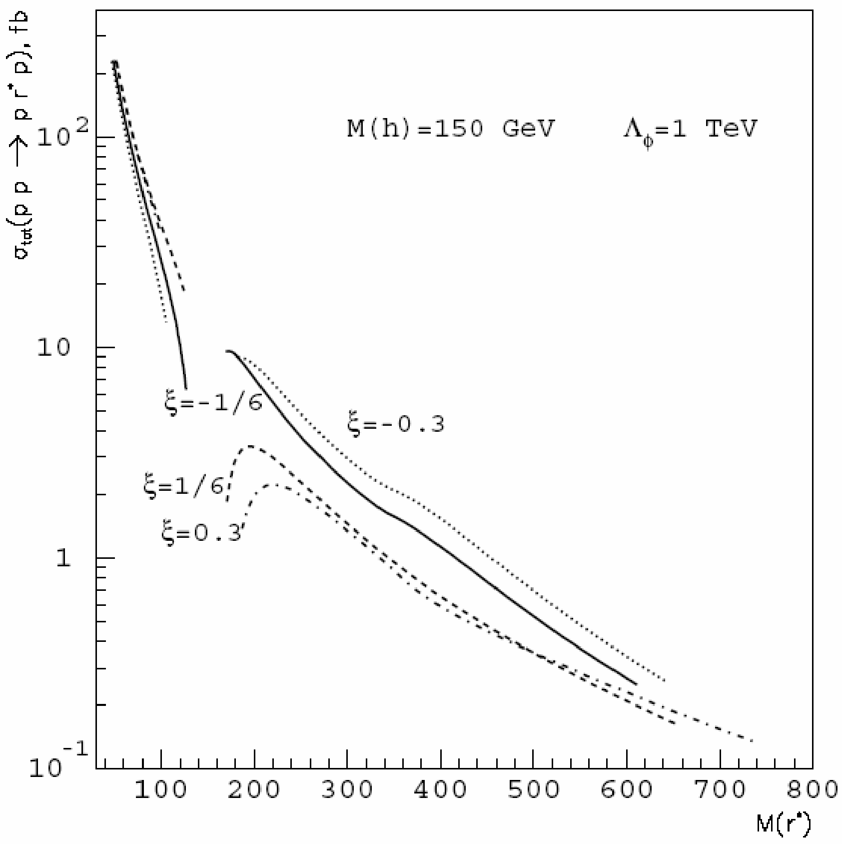


Horror!
gg→H cross section can disappear!!

Gunion, Toharia & Wells hep-ph/0311219

Radions

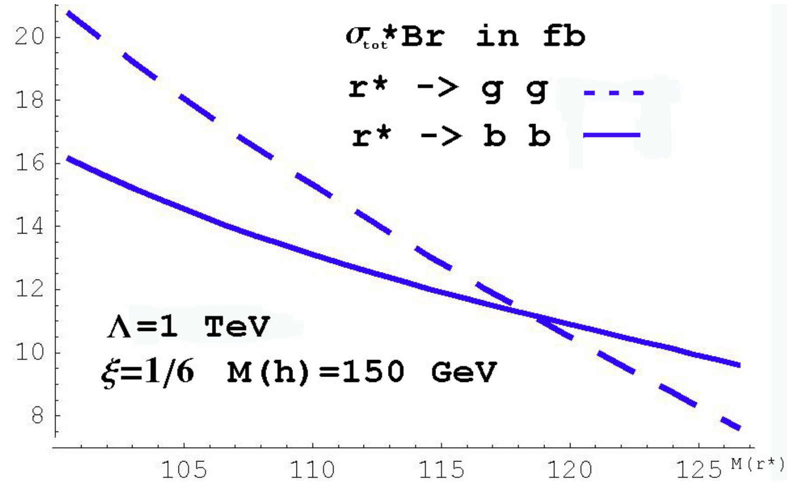
Radions like to couple to gluons
Large production rates in DPE



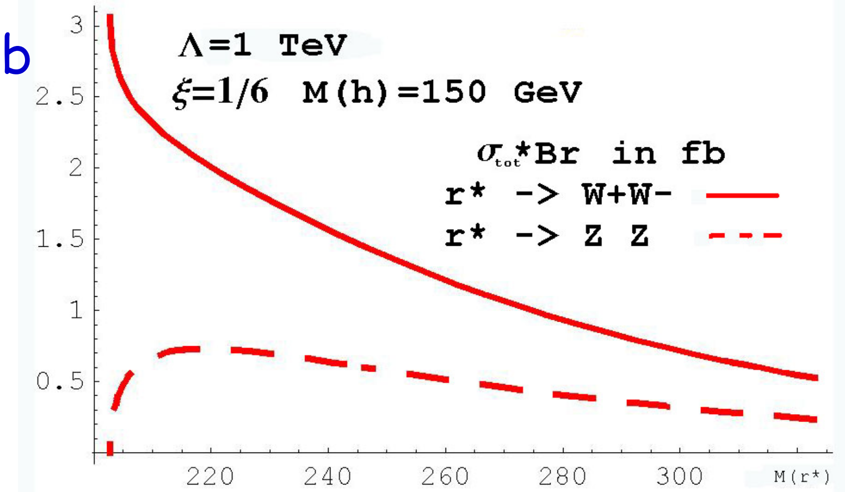
Large rate of $\phi \to bb$

Petrov
Ryutin

fb



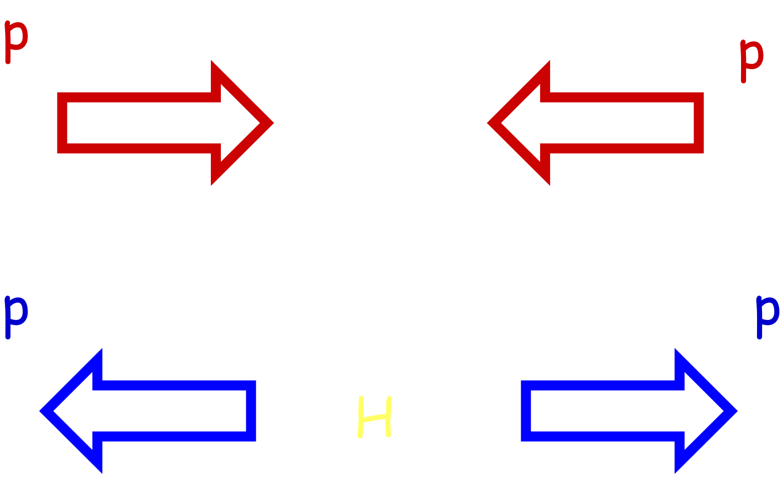
fb

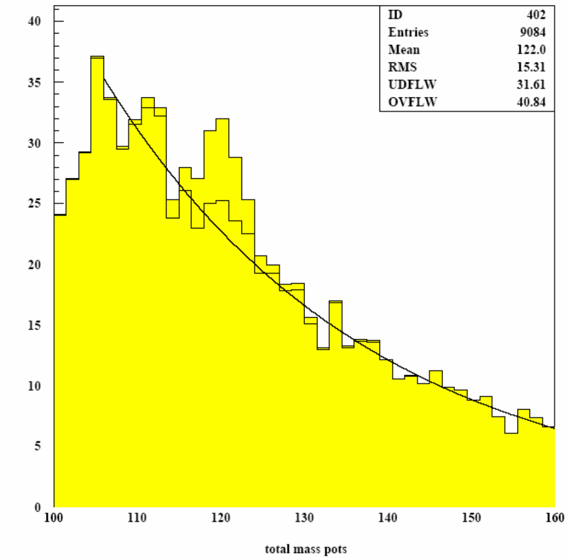


Invisible Higgs

Khoze et al.

Higgs decay into "invisible" particles, eg. neutralinos





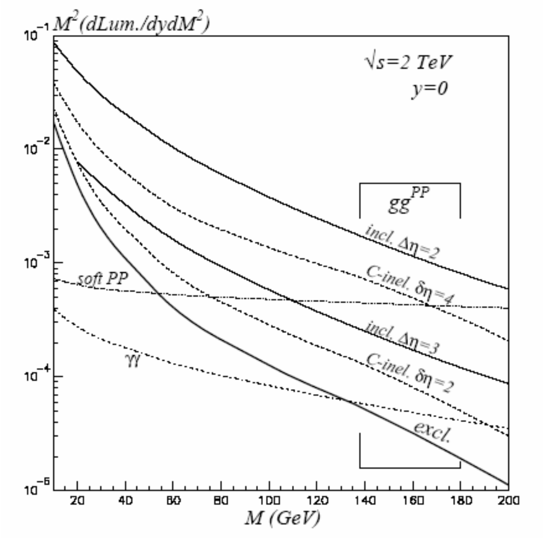
M_H (GeV)	120	150	180	210
$\Gamma(H \to gg)$ (MeV)	2.2	4.1	6.9	10.8
σ (fb)	21	11	5.9	3.6
$\mathrm{Br}(b\bar{b})$	11%	4%	0.5%	0.2%
$\sigma(b\bar{b})$ (fb)	2.3	0.4	0.03	0.007

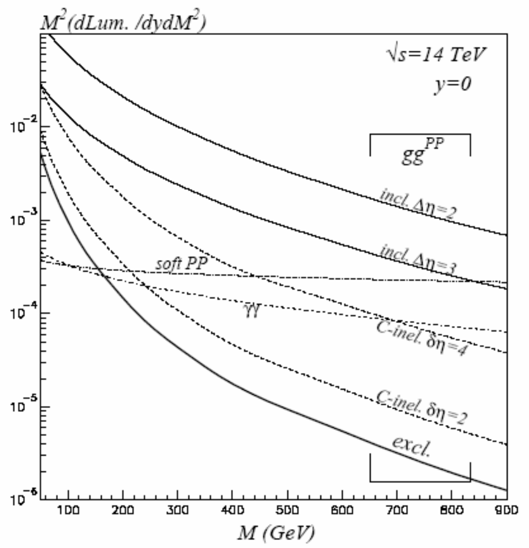
Scenario with 4^{th} generation

3 fb^{-1}/year

L1 Trigger Problem! Nothing in the central detector…
Works only at low luminosity
Effective luminosity at 10^{33} goes down to 10^{32}

Gluino production





"luminosity functions"
To be convoluted with cross sections
(Khoze et al 2001)

Exclusive diffraction

For example, if we take sparticle masses of 250 GeV and integrate from threshold (500 GeV) up to 625 GeV, then we find

$$\Delta\hat{\sigma}^{\rm excl}(\tilde{g}\tilde{g}) \simeq 6.5 \text{ pb}, \qquad \Delta\hat{\sigma}^{\rm excl}(\tilde{q}\bar{\tilde{q}}) \simeq 1.8 \text{ pb}. \qquad (78)$$

$$\Delta\sigma(pp \to p + \tilde{g}\tilde{g} + p) \simeq 0.15 \text{ fb}$$

$$\Delta\sigma(pp \to p + \tilde{q}\bar{\tilde{q}} + p) \simeq 0.04 \text{ fb}$$

Inclusive diffraction

$$\Delta\hat{\sigma}^{\rm incl}(\tilde{g}\tilde{g}) \simeq 24 \text{ pb}, \qquad \Delta\hat{\sigma}^{\rm incl}(\tilde{q}\bar{\tilde{q}}) \simeq 1 \text{ pb},$$

leading to

$$\Delta\sigma(pp \to X + \tilde{g}\tilde{g} + Y) \simeq 50 \text{ fb},$$

$$\Delta\sigma(pp \to X + \tilde{q}\bar{\tilde{q}} + Y) \simeq 2 \text{ fb}.$$

Cross sections low!

Exclusive Stop production in DPE

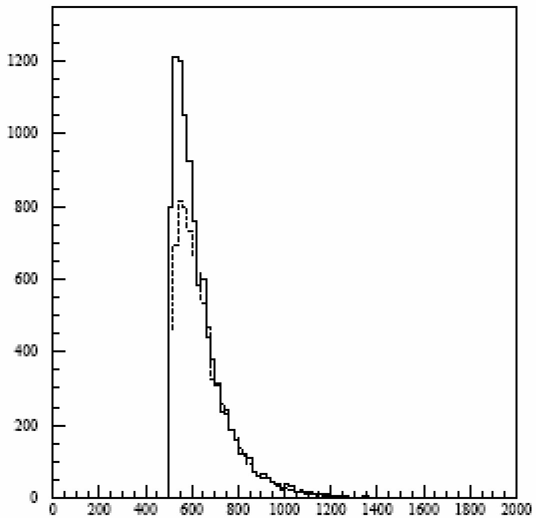
On the other hand ⇒

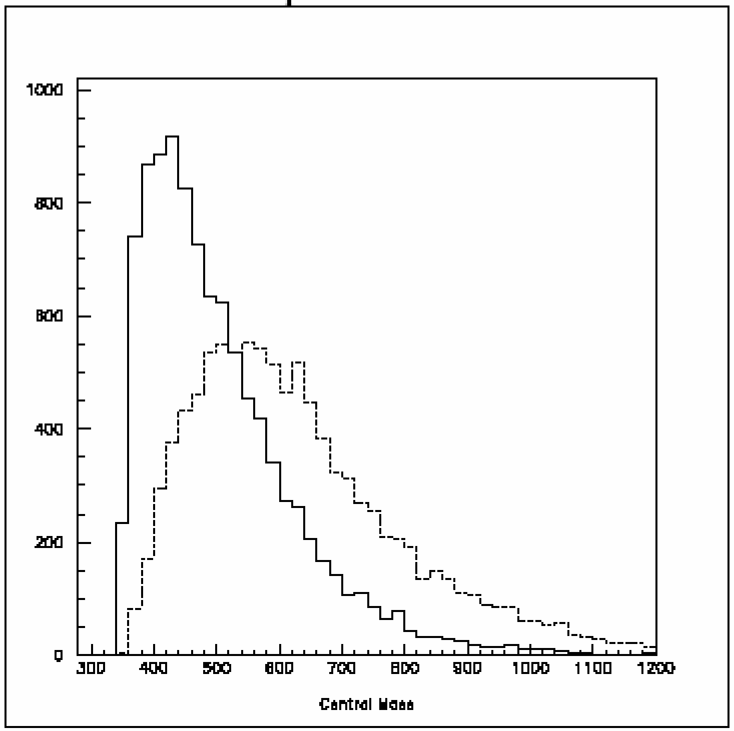
C. Royon et al. based on Bialas /Landshof model, with gap survival probability

No Sudakov suppression factors in this model

Acceptance for stop events with 200m pots

- Cross section for a stop mass of 250 GeV: $\sigma_{tot} = 8$ fb, $\sigma_{acc} = 6$ fb
- Possibility to distinguish between top and stop: using the differences in spin

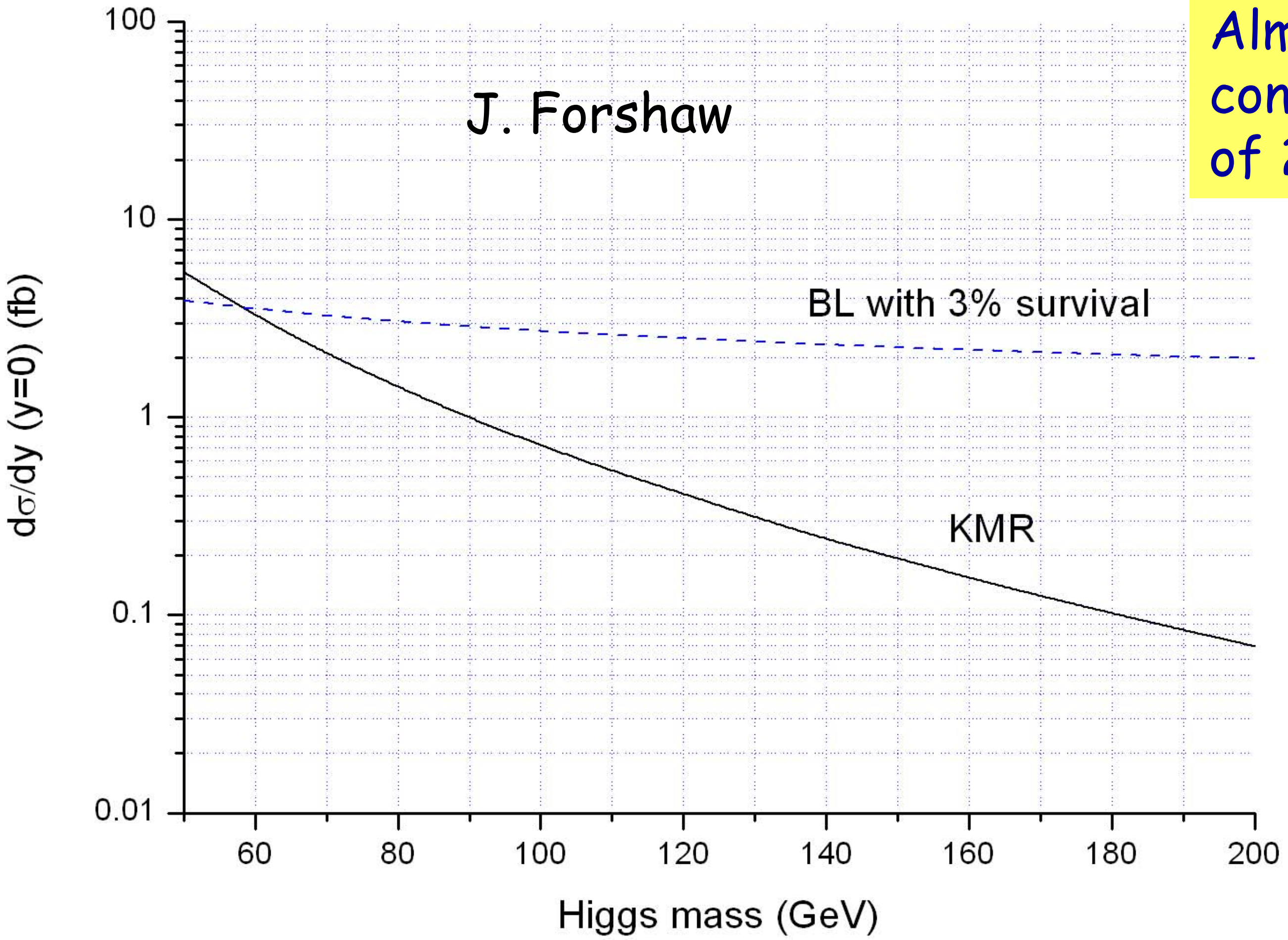




Cross section 100x larger

Models…

Different models give different predictions for
- The cross sections
- The mass/energy dependence of the cross sections



Almost all calculations now converge to a cross section of 2-10 fb for a light Higgs

BL Bialas Landshof (soft Pomeron)

KMR: Khoze Martin Ryskin

Tevatron can test these models

Test at the Tevatron

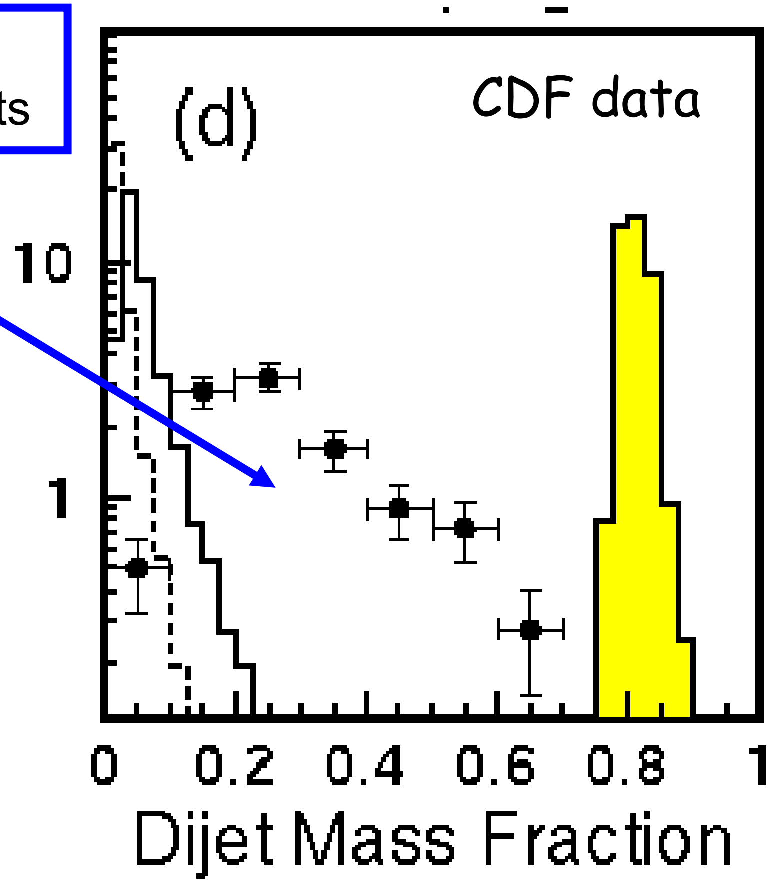
Test for exclusive production at the Tevatron
⇒Energy in the two-jets/all energy for DPE events

CDF di-jets in DPE
upper limit 3.7 nb

Generally old predictions of
>O(100) pb for the Higgs
overshoot this predictions
y a factor 10-100
Hence → ruled out!

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

Needs optimal jet finder
Cone algorithm not the best

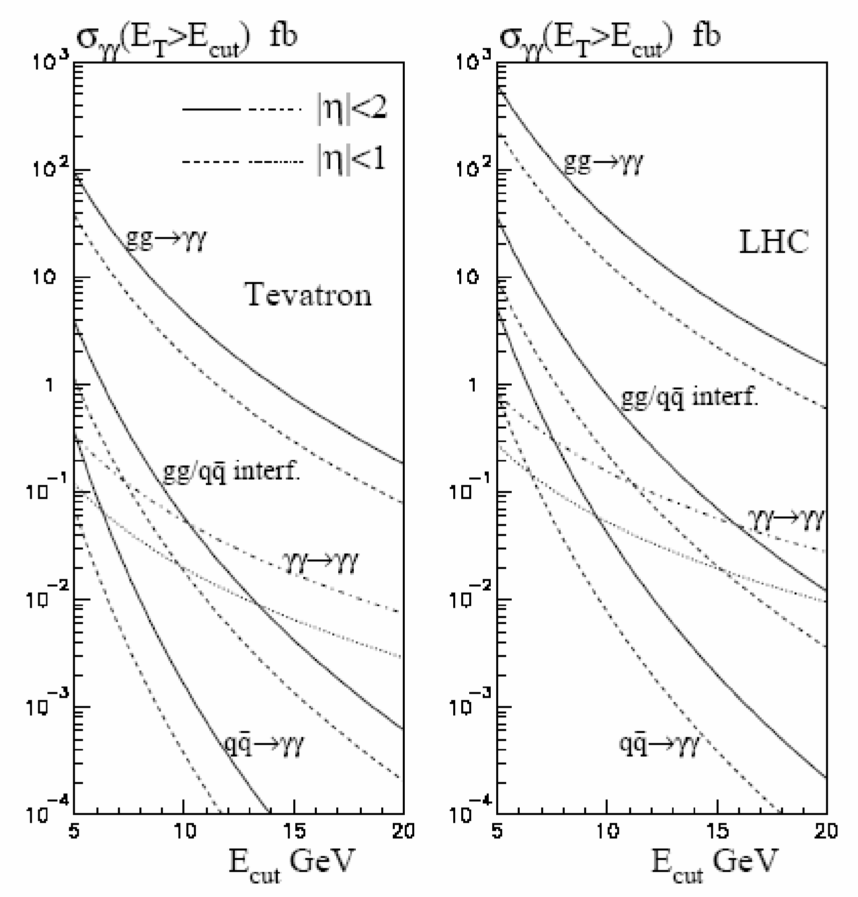


Smooth decrease of the cross section.
Can exclusive processes be seen on top of the non-exclusive background?

More Information from Tevatron!

Study of diffractive exclusive processes

V. Khoze et al., hep-ph/0409037



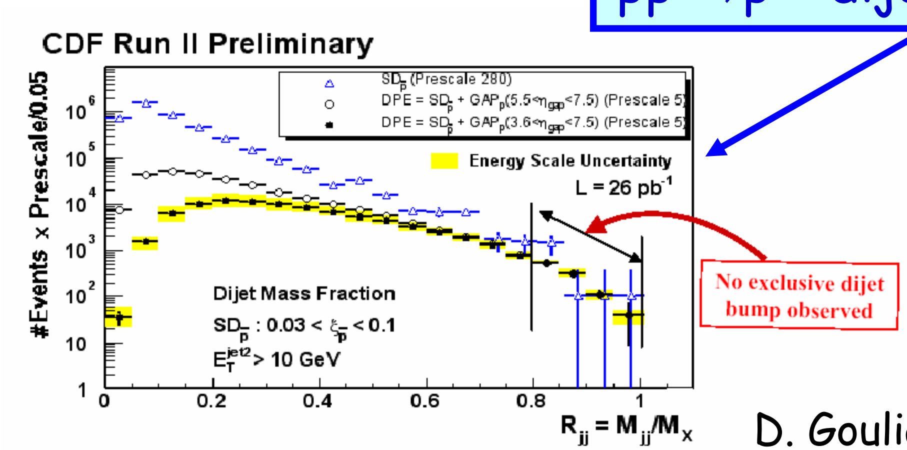
pp →p + γγ +p

V. Khoze et al., hep-ph/0403218

	Tevatron $\sqrt{s}=2$ TeV χ_c	Tevatron $\sqrt{s}=2$ TeV χ_b	LHC $\sqrt{s}=14$ TeV χ_c	LHC $\sqrt{s}=14$ TeV χ_b
$d\sigma_{excl}/dy\|_{y=0}$	130	0.2	340	0.6
σ_{excl}	650	0.5	3000	4
$d\sigma_{incl}/dy\|_{y=0}$	13	0.06	30	0.2
σ_{incl}	70	0.3	200	2

pp →p + χ_c +p

pp →p + dijets+p



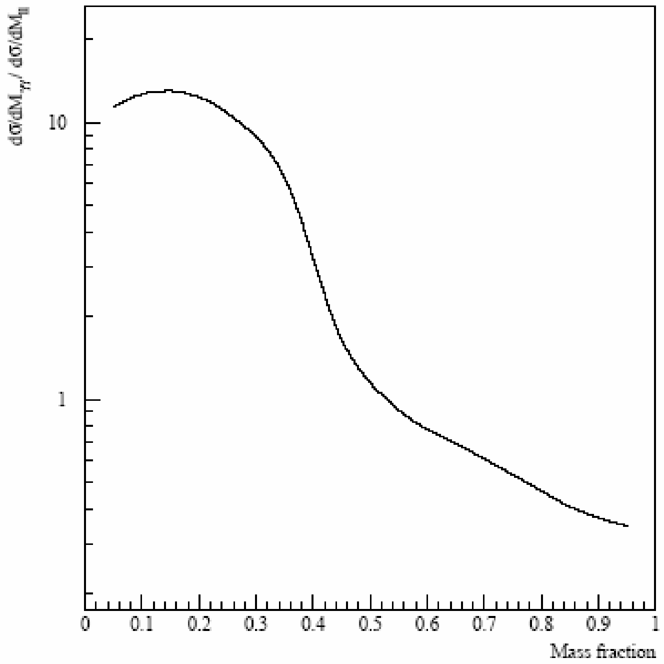
D. Goulianos

$|\eta_{jet1,2}|<2.5$, $0.03<\xi_{\bar{p}}<0.1$, $3.6<\eta_{gap}<7.5$, $R = 0.7$

Minimum E_T^{jet1}	Cross Section : $\sigma_{DPE}^{excl.\ jj}(R_{jj}>0.8)$
10 GeV	970 ± 65(stat) ± 272(syst) pb
25 GeV	34 ± 5(stat) ± 10(syst) pb

Existence of exclusive events

Test of the existence of exclusive events



C. Royon et al.

Some extra slides from Christoph on this topic included on the agenda

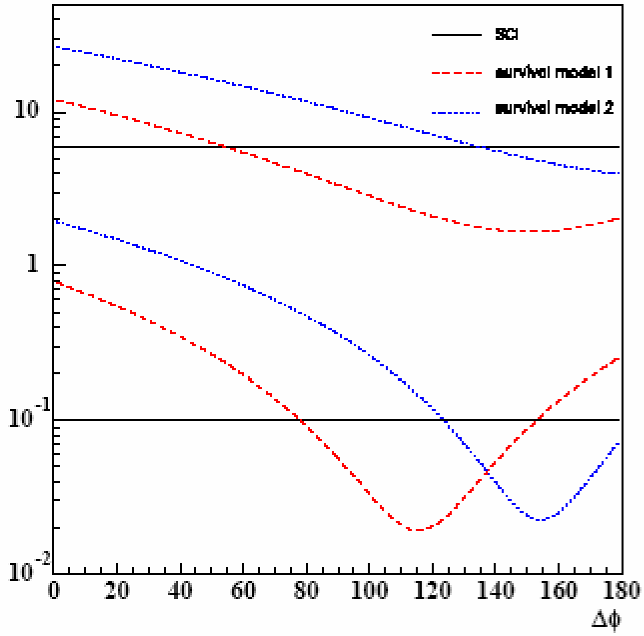
Dilepton and diphoton cross section ratio as a function of the diphoton/dilepton mass: no dilepton event for exclusive models: change of slope of ratio if exclusive events exist

Other methods: ratio b-jets / all jets, compare

More Information from Tevatron

Kupco, Peschanski, Royon

Study of the gap survival probability



- dijet production with $p_T > 5\,\text{GeV}$ at Tevatron
  - upper plots: $|t_p| > 0.6,\ |t_{\bar{p}}| > 0.1\,\text{GeV}^2$
  - lower plots: $|t_p| > 0.5,\ |t_{\bar{p}}| > 0.5\,\text{GeV}^2$
- Pomeron models
  - POMWIG interfaced with the calculation of survival probability
  - two-channel eikonal model (Model 1)
  - elastic channel model (Model 2)
- SCI model - modified version of Pythia with color string reconnection

Different azimuthal correlation between the two protons for different models for the gap survival
Important for CP studies in the Higgs sector @ LHC

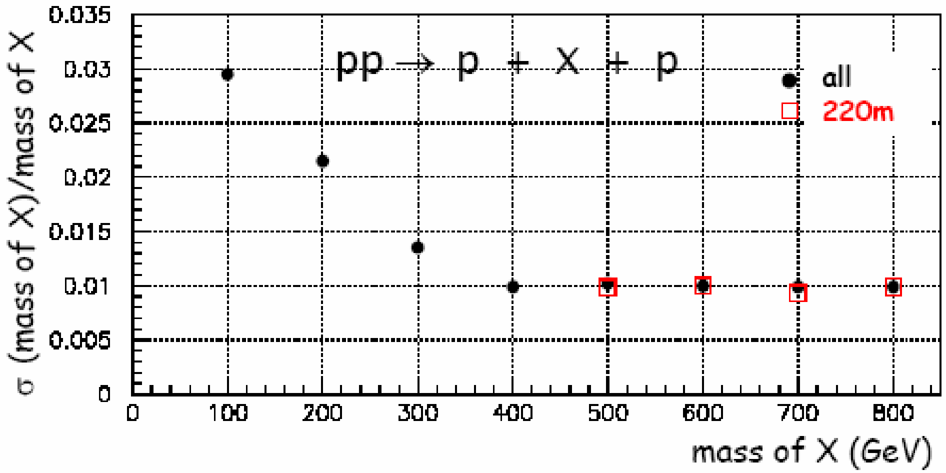
Summary

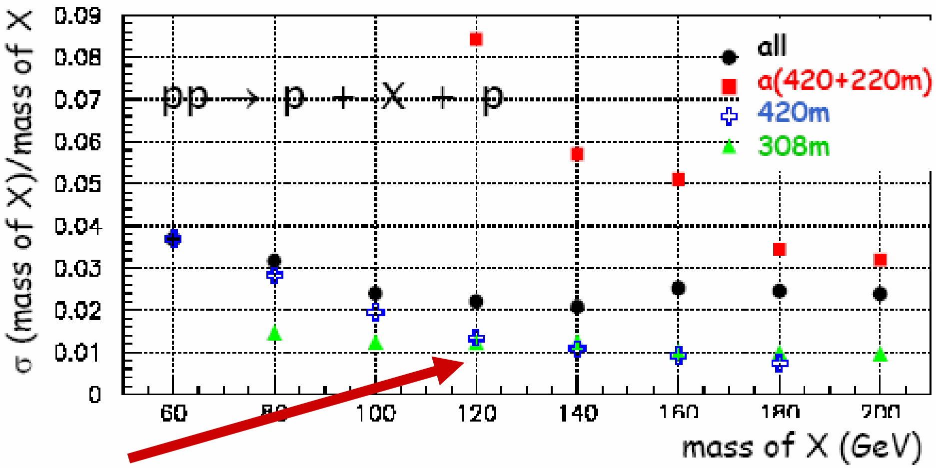
- Exclusive BSM & Higgs studies under way
  - Mostly exclusive: Higgs (SM/MSSM), Radions, Susy, anomalous WW, (ED?)
- Main issues for exclusive channels
  - Cross section ~ fb, but some die-hards believe it could be still larger
    - Higgs calculations seem to start converging, but still large differences at higher massive systems. Differnce comes from Sudakov form factors
    - Tevatron will be the referee: DPE χ_c, χ_b, $\gamma\gamma$, dijet … production rates.
      $\Rightarrow$ Observe high mass exclusive events
  - For masses < 300 GeV$\rightarrow$ New proton taggers needed at 400 m. Challenge!
    - Optimize: acceptance of the detectors, mass resolution (alignment?)
    - L1 trigger: 400m RP signals are too late for L1 (ATLAS/CMS)
  - Background from inclusive and exclusive channels. Isolate exclusive events.
  - Study of other signals for Higgs apart from bb ($\tau\tau$, WW in progress…)
- Note
  - Higgs/BSM is only part of a broad diffractive program @ LHC
  - Adding such detectors to LHC is NOT a walk in the park
  - Tevatron (HERA) RP experience at this stage of the project is vital!

Mass Resolution

Mass resolution of central system

Helsinki group





Resolutions for separate locations and all combination ("naive" combination)

- resolution ranges from ~ 4 % at low masses to ~ 1 % at high mass
- optimal resolution ~ 1 % for symmetric pairs (i.e. $\xi_1 \approx \xi_2$)

NB! a(420+215m) = $\xi_1 \gg \xi_2$ or $\xi_1 \ll \xi_2$

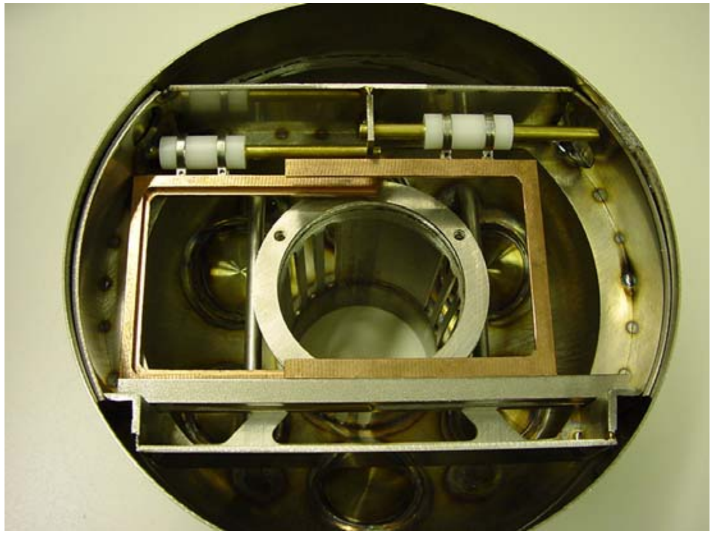
NB! Some effects are anticorrelated for ξ_1 & ξ_2 (e.g. transverse vertex position) ⇒ $\sigma(M)/M < \frac{1}{2}\sqrt{\Sigma_i \sigma(\xi_i)/\xi_i}$

Mass resolution 1-2% for symmetric events

Still being optimized

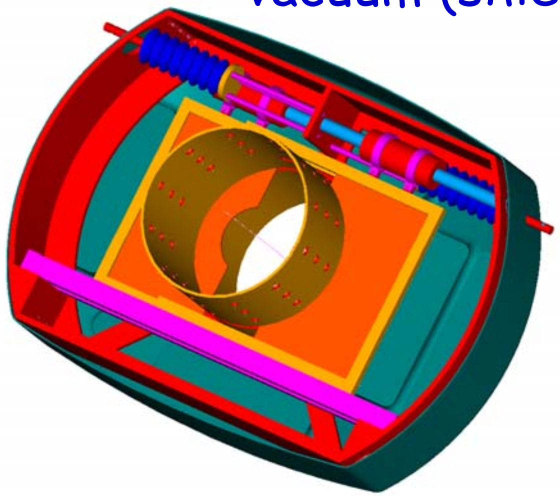
Can we improve the resolution? ⇒ would increase significance

Detectors: micro stations+3D silicon?



Very compact!

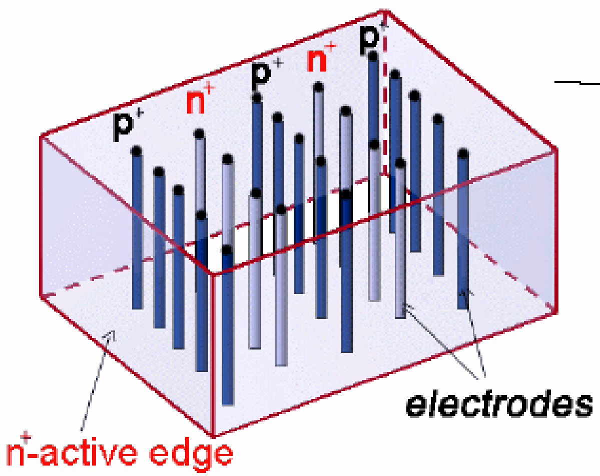
Silicon pixel or strip detectors in vacuum (shielded), 3D silicon...

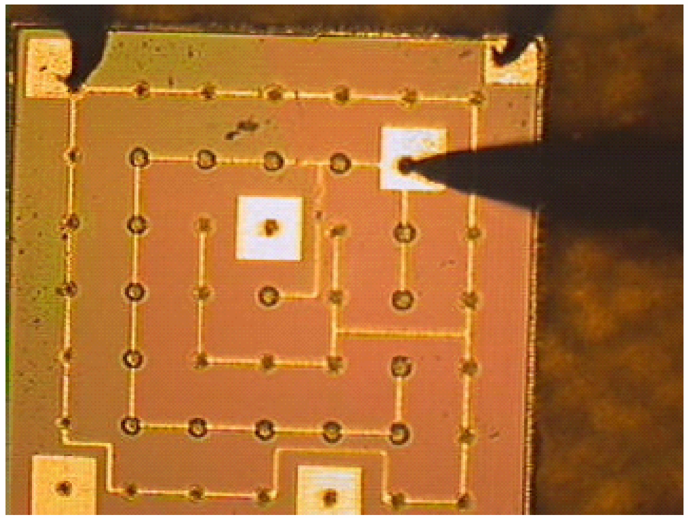


μ-station concept (Helsinki)

3D DETECTORS AND ACTIVE EDGES

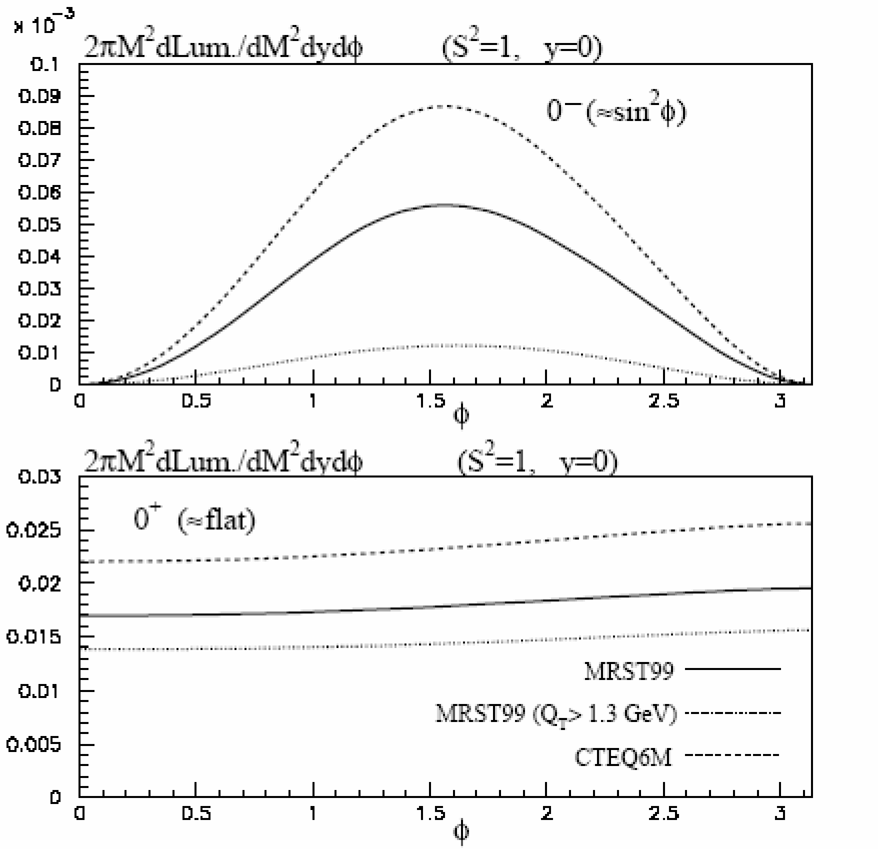
Brunel, Hawaii, Stanford

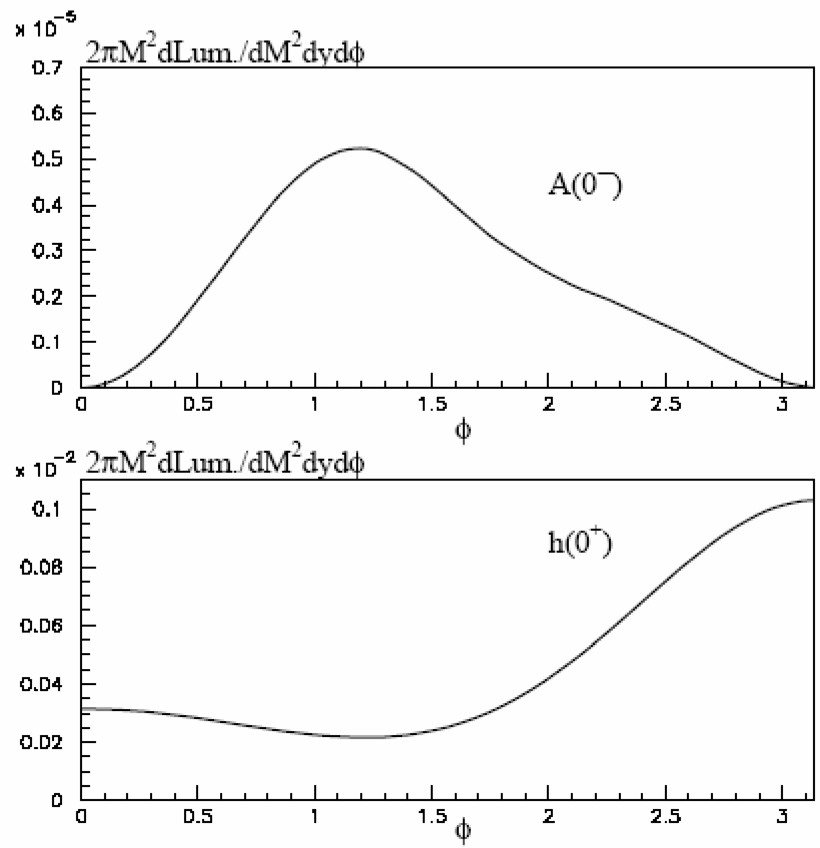




Spin Parity anaylsis

- Measure the azimuthal angle of the proton on the proton taggers
- Azimuthal angle between the protons depends on spin of H

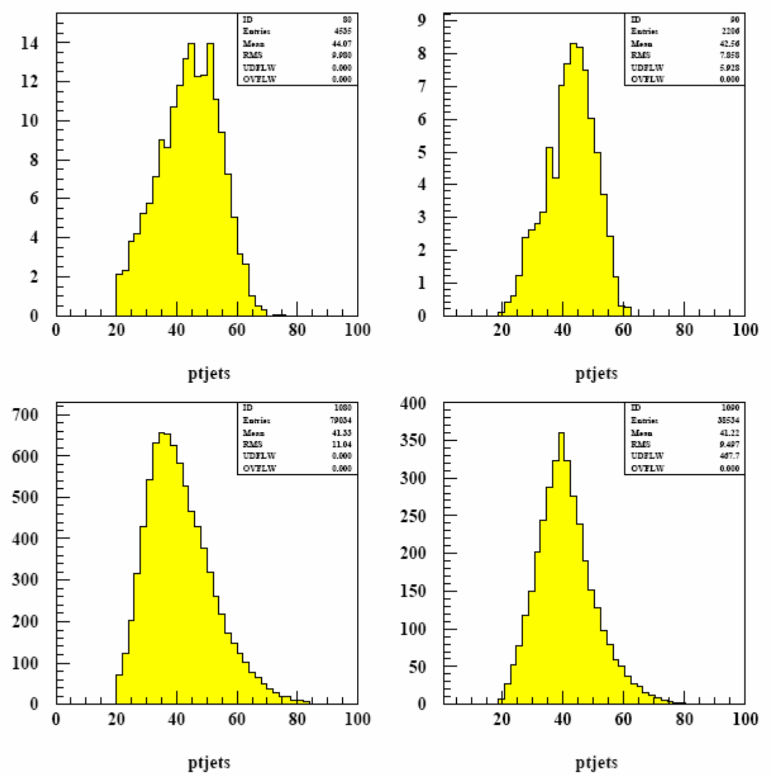




DPE Higgs Jet Characteristics

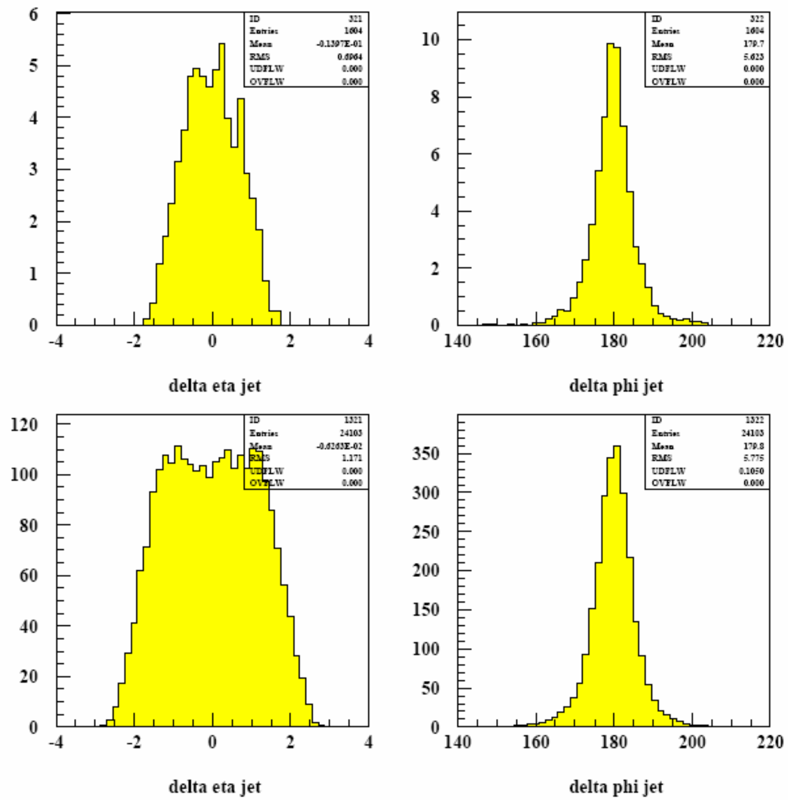
Jet p_T

2 leading jets p_T for signal and exclusive $b\bar{b}$ background



Jet $\Delta\eta$ and $\Delta\Phi$

2 leading jets $\Delta\eta$ and $\Delta\Phi$ for signal and exclusiv $b\bar{b}$ background

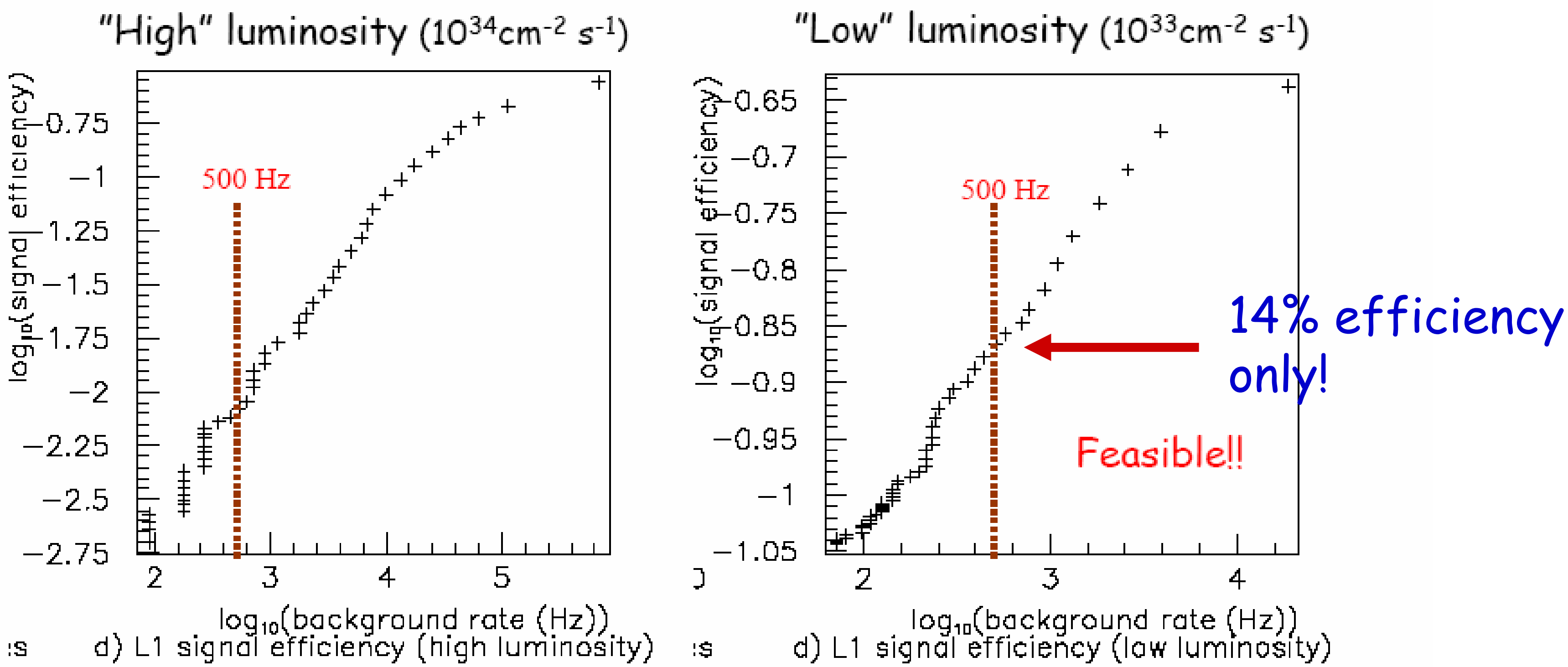


C. Royon/Detector study for CMS

Trigger Studies

Preliminary results on L1 triggering of a 120 GeV Higgs

R. Orava et al



Preliminary first study

Will be repeated with complete CMS trigger simulation !!

Improvements should be possible by using also T2 & CASTOR !!