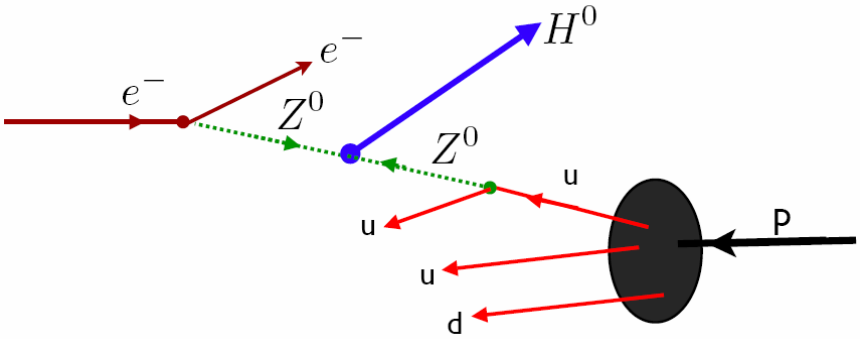
Higgs → $b\bar{b}$
Prospects at the LHC

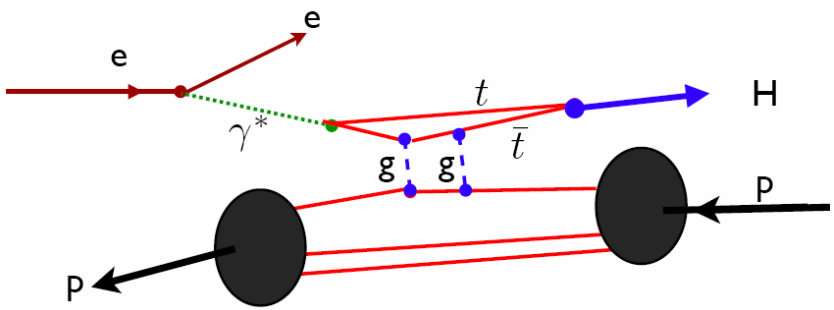
Sue Ann Koay [UCSB], 2nd September 2008
Material from *CMS NOTE-2006/119*, *FP420 Design Report* (and elsewhere)

SB's non intrinsic wishlist for the LHeC

Inclusive Higgs

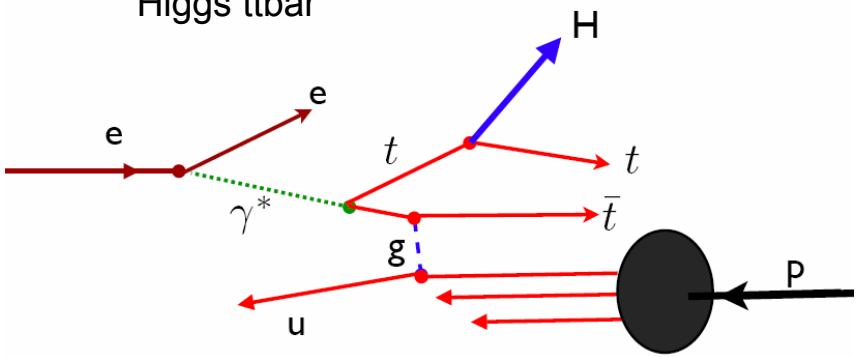


Diffractive Higgs



Kopeliovich, Schmidt, sjb

Higgs ttbar



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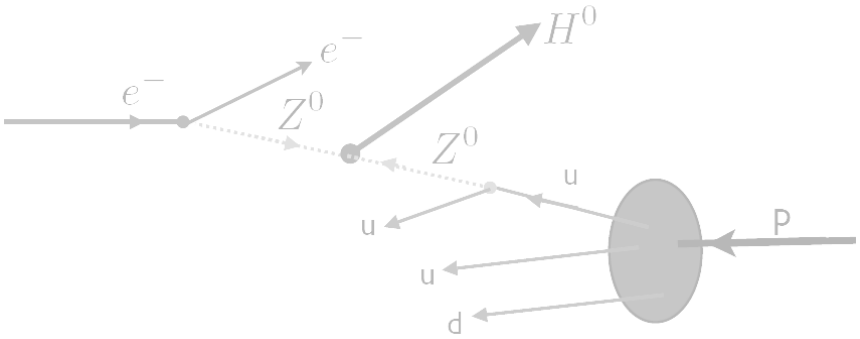

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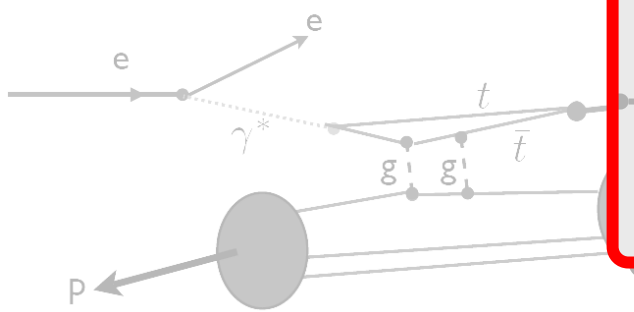
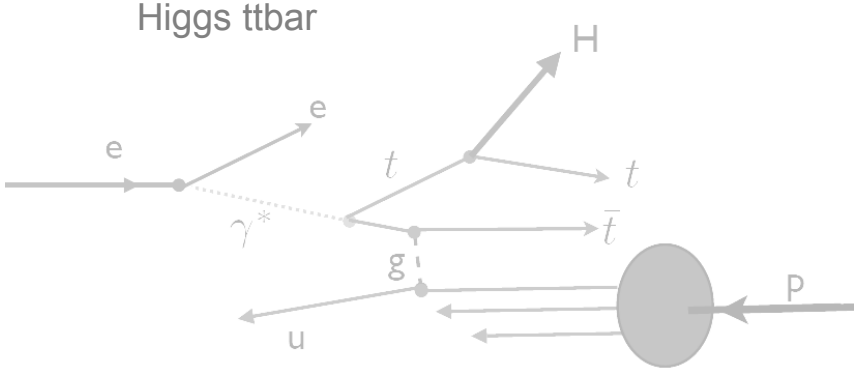


Higgs ttbar

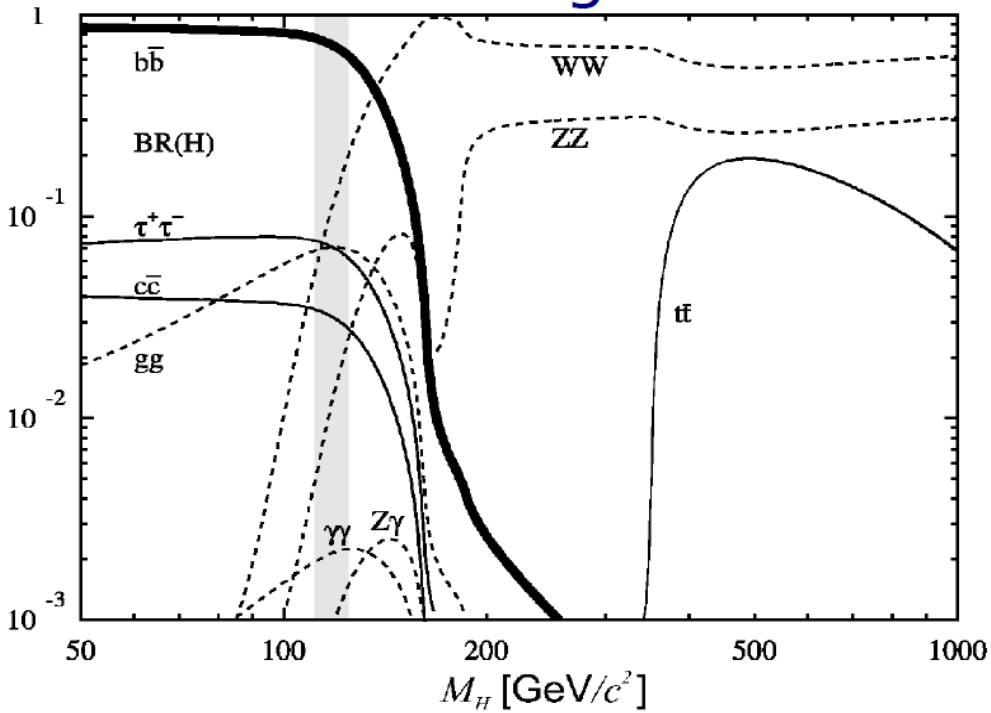


- H→bb̄ Prospects
  - **SM**
  - **MSSM**
- ttH @ CMS
  - **All hadronic**
  - **Semi-leptonic**
  - **Di-leptonic**
- FP420
  - **Overview**
  - **CEP of H→bb**

Kopeliovich, Schmidt, sjb

Swapan Chattopadhyay

Branching Ratio



- $b\bar{b}$ is dominant decay mode for low-mass Higgs
- $H \rightarrow b\bar{b}$ impossible to see above QCD background
- Associated production (e.g. ttH) cross-section O(1 pb) are possibilities
- Still a difficult (a.k.a. long term) channel!

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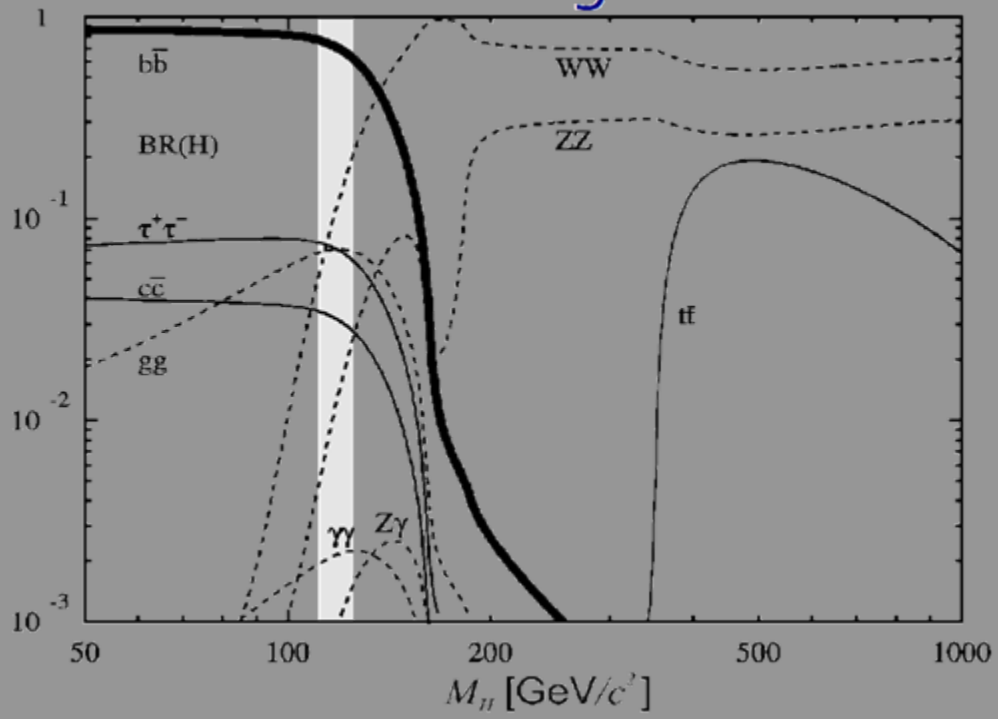
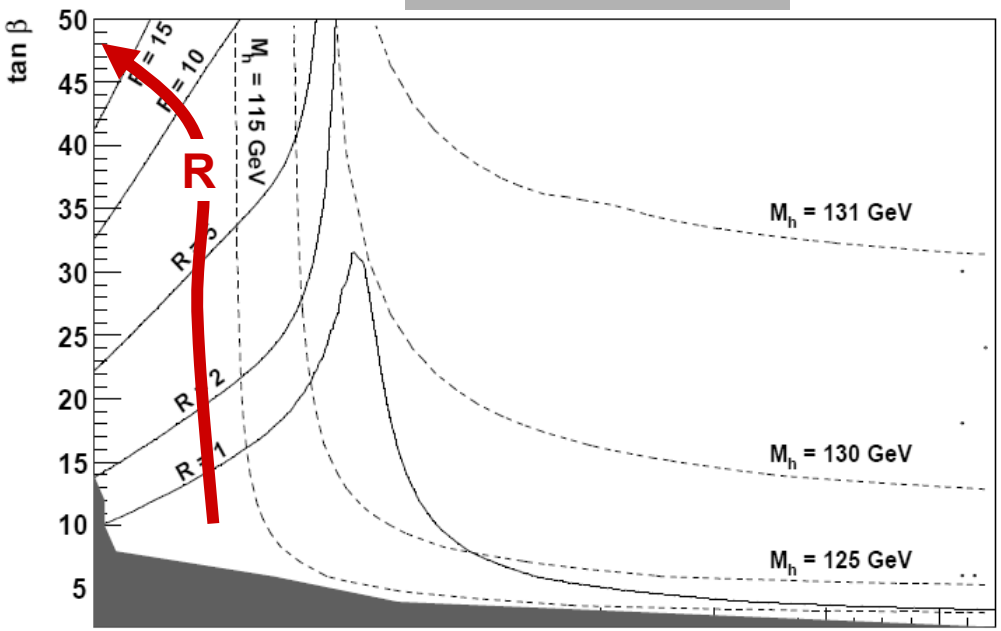


- bb̄ is dominant decay mode for low-mass Higgs
- H→bb̄ impossible to see above QCD background
- Associated production (e.g. ttH) cross-section O(1 pb) are possibilities
- Still a difficult (a.k.a. long term) channel!

- MSSM Higgs tends to be "SM-like" for large M(A)
- H→bb enhanced [and other modes suppressed] for large tan β and small M(A)

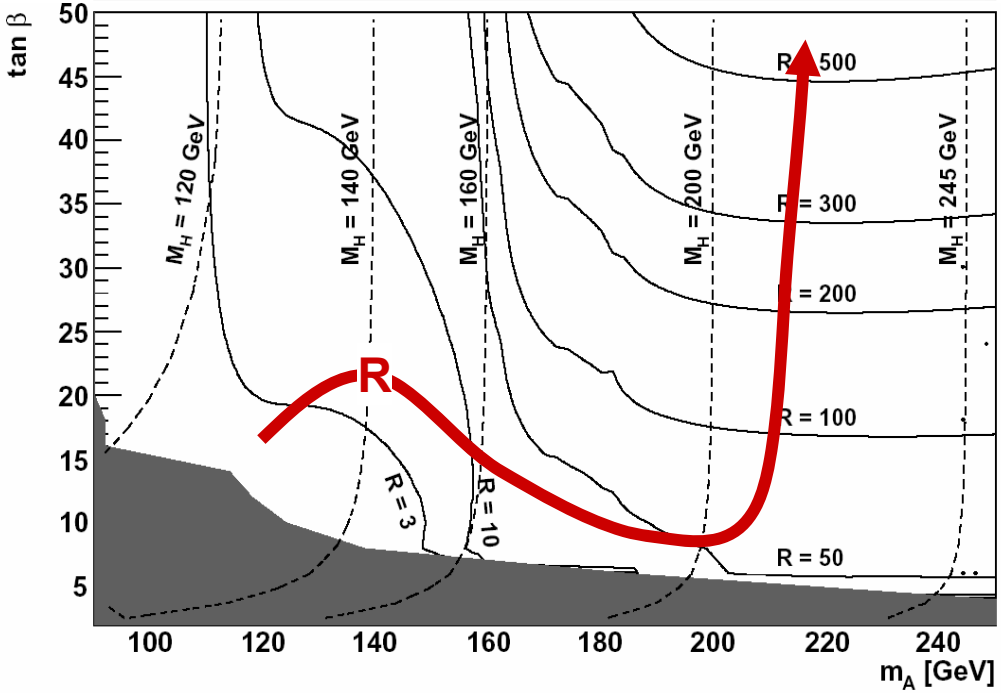
M_h^{max} scenario



Lightest parity even, neutral Higgs

R ≡ enhancement factor of MSSM Higgs over SM Higgs production

R ~ O(10) seems necessary for H→bb to be a feasible channel



Heavy parity even, neutral Higgs

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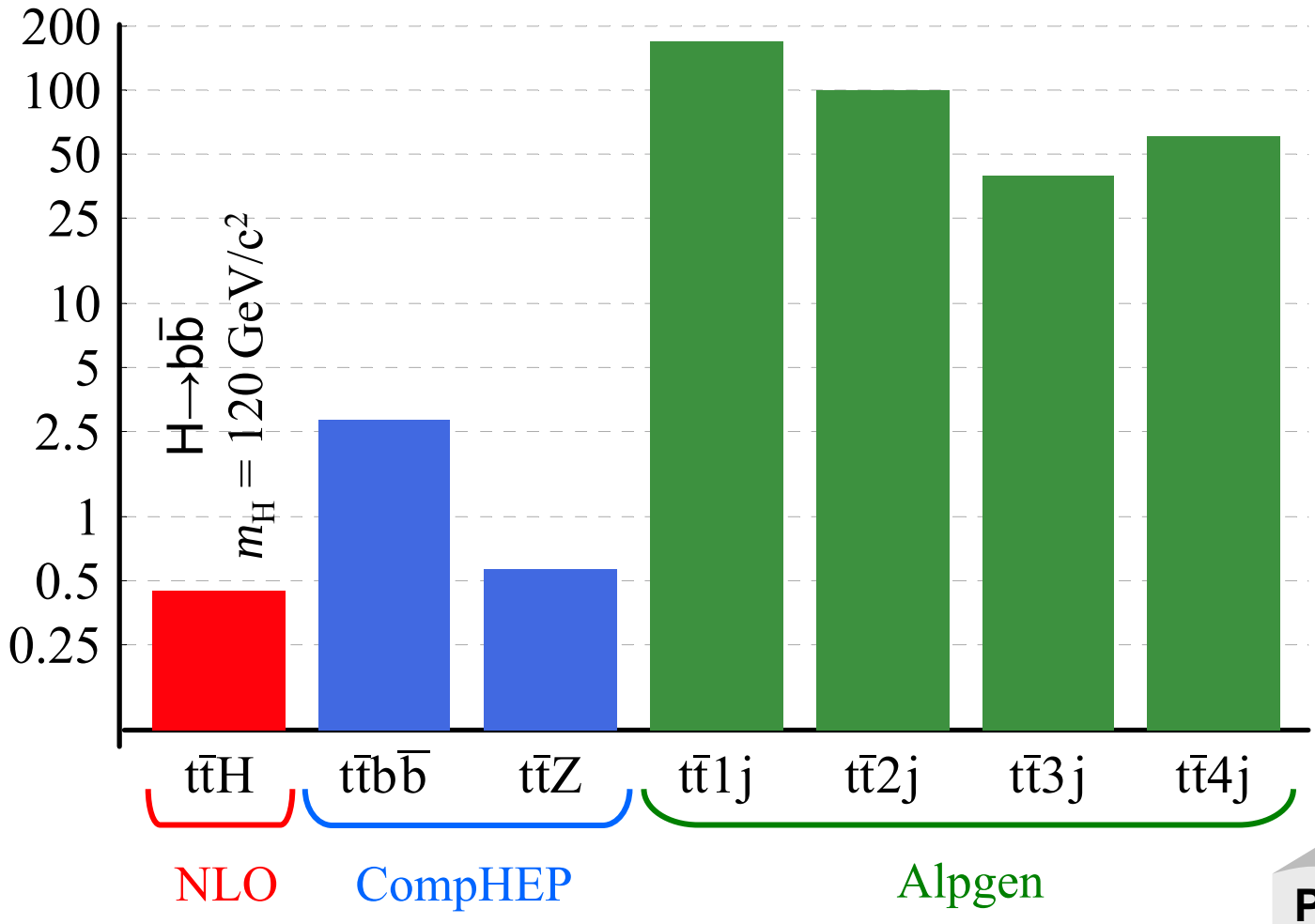
PROGRAM :
strategies for each tt decay channel (*exclusive* analyses)

Cross-sections (picobarns) at the LHC

[× branching ratio where applicable]



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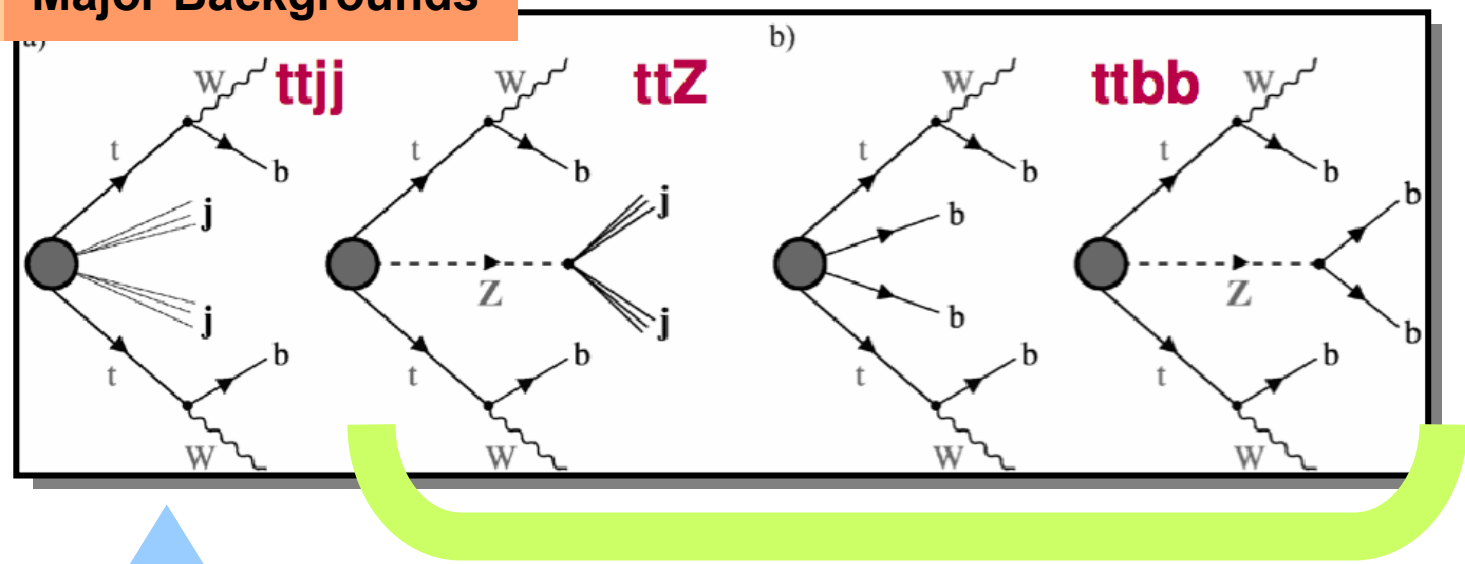
Major Backgrounds



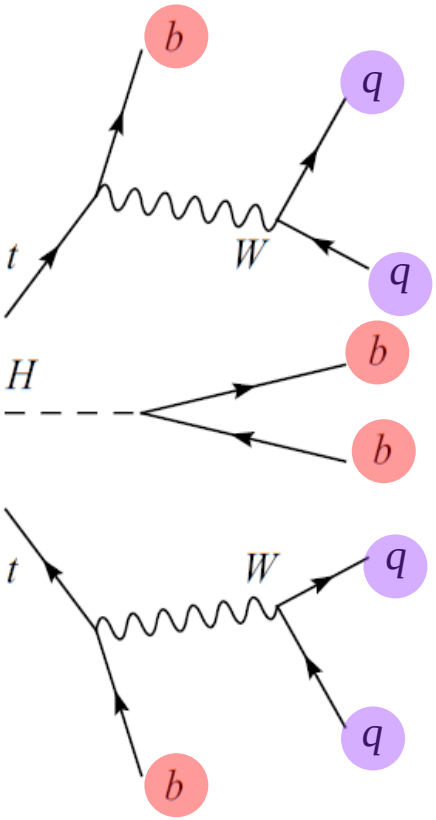
Irreducible backgrounds:

- The “other” b’s (not from top) are kinematically indistinguishable from H→b$\bar{\text{b}}$
- Combinatorial difficulties in matching b’s to parent particles

Requires mis-tagging two jets, but:

- Cross-section O(10^3) × signal
- W→cs decays inflate mis-tagging rate (charm tagging efficiency ~ 10%)
- g→b$\bar{\text{b}}$ (c$\bar{\text{c}}$) at significant rates

PROGRAM :
strategies for each tt decay channel (*exclusive* analyses)



Signature:

- 4 b-jets
- 4 light-flavor jets (some charm)

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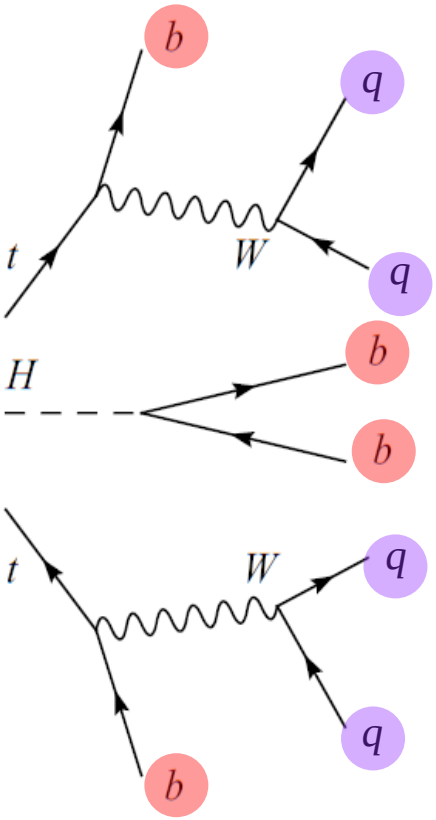
4 + 4 = a lot of jets! (really)



- 1,3,4 jet triggers ~ 25% efficient on signal
- Overlap is a problem — cone size of $\Delta R < 0.4$ optimal
- Assigment of jets to partons by minimizing "distance" of invariant masses from nominal values:

$$\chi^2_{mass} = \left(\frac{m_{W^+} - m_{jj}}{\sigma(m_W)}\right)^2 + \left(\frac{m_{W^-} - m_{jj}}{\sigma(m_W)}\right)^2 + \left(\frac{m_t - m_{jjj}}{\sigma(m_t)}\right)^2 + \left(\frac{m_{\bar{t}} - m_{jjj}}{\sigma(m_t)}\right)^2 \Bigg\} < 3$$

- Require all 4 jets assigned to b-partons to be b-tagged
- Lepton (e, μ) veto — to be exclusive w.r.t. leptonic channels
- Event centrality cuts

Signature:

- 4 b-jets
- 4 light-flavor jets (some charm)

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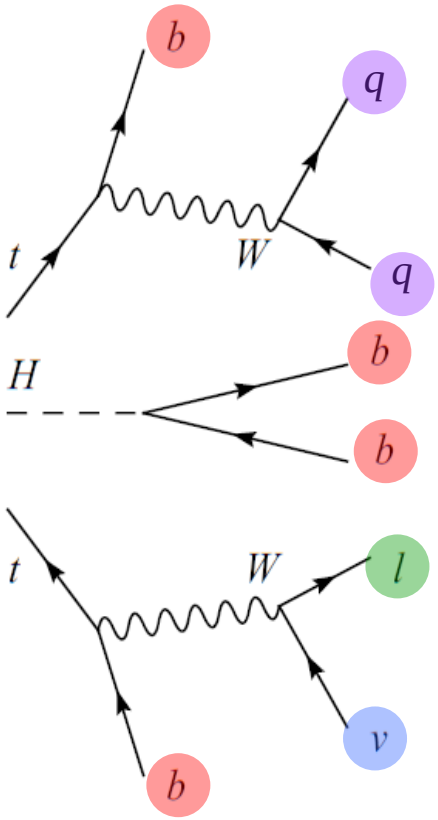
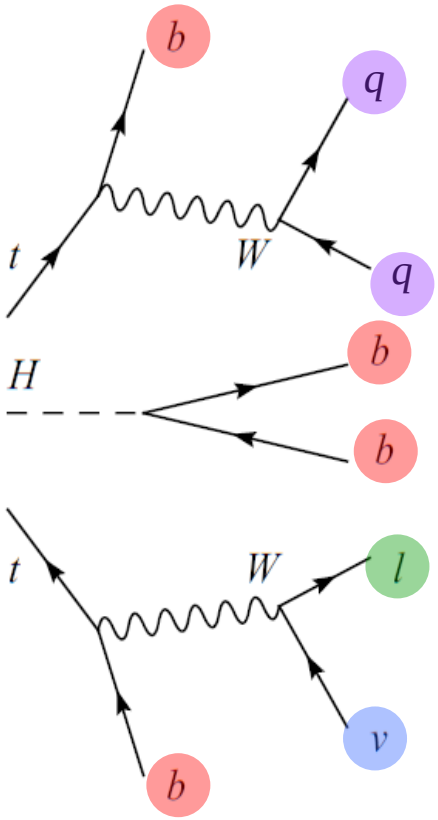


Signature:

- 4 b-jets
- 2 non-b jets
- 1 lepton (e,μ)
- $\not{E}_T$ (MET)

Most performant channel:

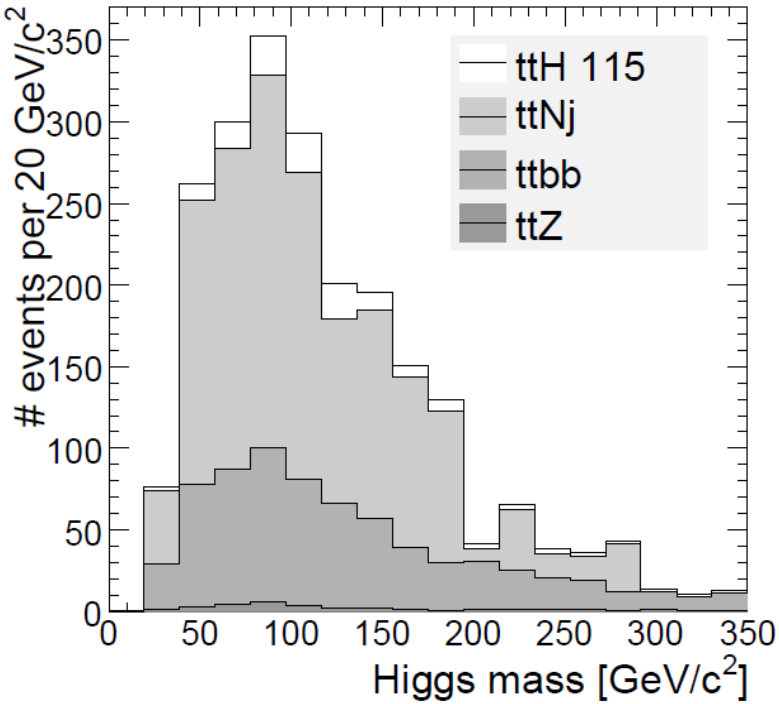


- Single-lepton triggers ~ 60% efficient
- Assigment of jets to partons via kinematic / likelihood fits
  - — use MET to partially resolve p(ν)
  - — correct 30% of the time
- 6 or 7 jets — a maximum helps!
- Cut on b-tagging likelihood for best 4 jets — significant improvement (8%) w.r.t. straight cut on b-tag discriminators
- Single lepton passing quality cuts — likelihood method trained on MC
- Di-lepton (e, μ) veto — to be exclusive w.r.t. di-leptonic channel
- **MET** > 20 GeV

Includes jet and muon corrections

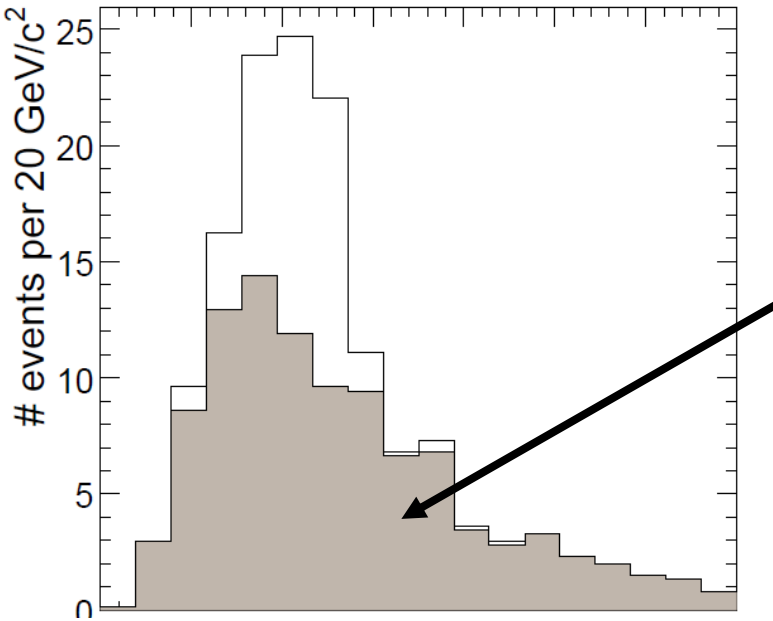
Signature:

- 4 b-jets
- 2 non-b jets
- 1 lepton (e,μ)
- $\not{E}_T$ (MET)

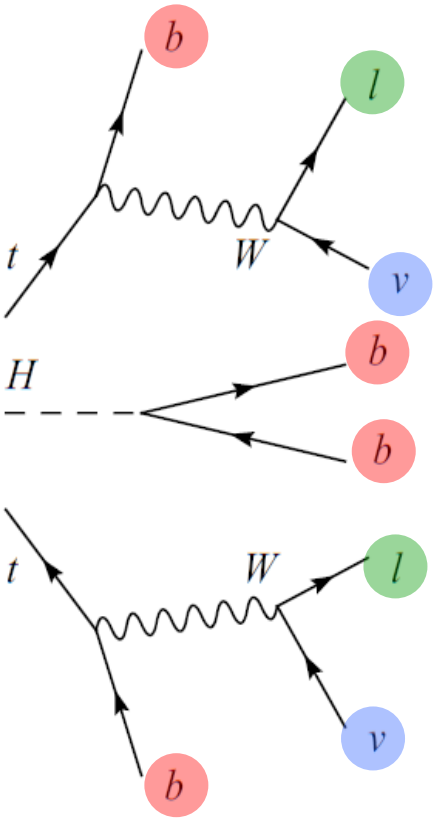


S/√B ~ 2.5 (S/B ~ 10%)

… but mass peak is **not resolvable**



Combinatorial background (70% wrong assignments of jets to partons) already causes a large spread in reconstructed invariant mass



Signature:

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- 2 leptons (e,μ)
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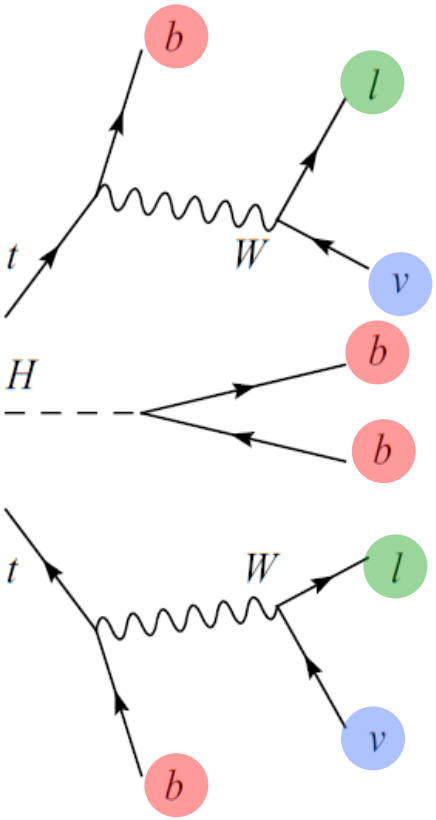

Counting experiment:

- OR of all single-lepton triggers ~ 77% efficient
- 4 to 7 jets with E_T > 20 GeV
- ≥ 3 b-tagged jets
- Two oppositely charged leptons passing quality cuts
- MET > 40 GeV

Signature:

- 4 b-jets
- 2 leptons (e,μ)
- $\not{E}_T$ (MET)

The Verdict in 60 fb^{-1}

	m_H (GeV/c^2)	S	S/B (%)	S/$\sqrt{B}$
All-Hadron	115	350	2.0	2.6
	120	310	1.8	2.4
	130	210	1.2	1.6
Semi-lepton	115	147	7.0	3.1
	120	118	5.3	2.5
	130	80	3.6	1.7
Di-lepton	115	170	1.8	1.8
	120	130	1.5	1.4
	130	82	0.9	0.9

The Verdict in 60 fb^{-1}

Standard uncertainties:
JES, jet resolution, b-tagging

	m_H (GeV/c^2)	S	S/B (%)	S/$\sqrt{B}$	S/$\sqrt{(B+dB^2)}$
All-Hadron	115	350	2.0	2.6	0.07
	120	310	1.8	2.4	0.07
	130	210	1.2	1.6	0.05
Semi-lepton	115	147	7.0	3.1	0.20
	120	118	5.3	2.5	0.16
	130	80	3.6	1.7	0.11
Di-lepton	115	170	1.8	1.8	0.10
	120	130	1.5	1.4	0.08
	130	82	0.9	0.9	0.05

Reality happened : systematics ~ 18% – 34%

Insufficient suppression of tt+jets background via b-tagging:

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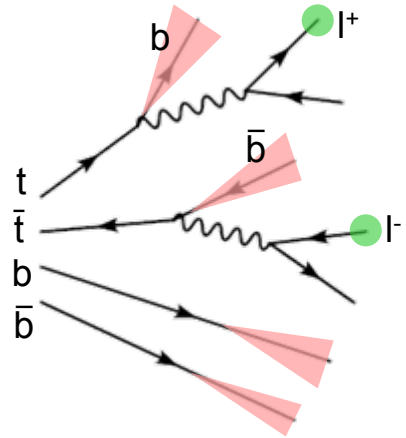
In practice, we get **14**

$$\frac{\varepsilon_{ttbb}}{\varepsilon_{ttjj}} \sim \frac{\varepsilon_b^4}{\varepsilon_b^2\,\varepsilon_{uds}^2} \sim \frac{60^2}{2^2} = 900$$

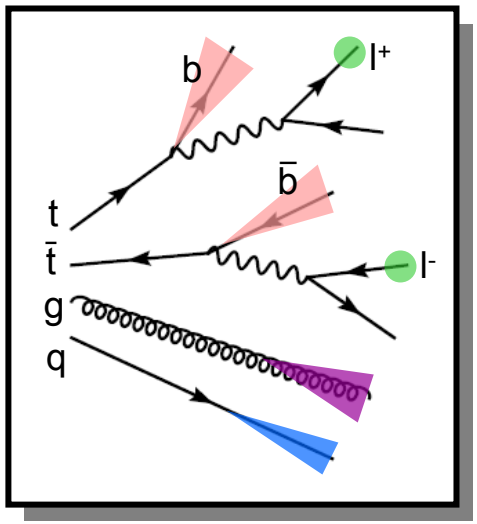
Reality happened

Insufficient suppression of tt+jets background via b-tagging:



e.g. di-lepton channel

$$\frac{\varepsilon_{ttbb}}{\varepsilon_{ttjj}} \sim \approx 1070$$



g→cc̄ ~ 8%
g→bb̄ ~ 4%

Reality happened

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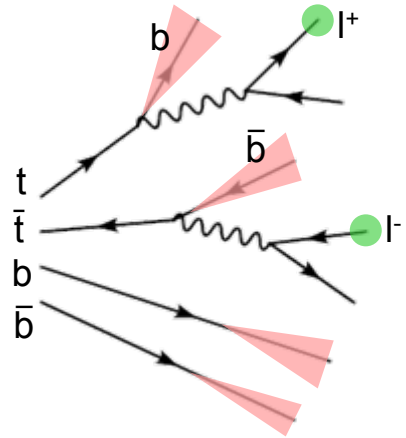
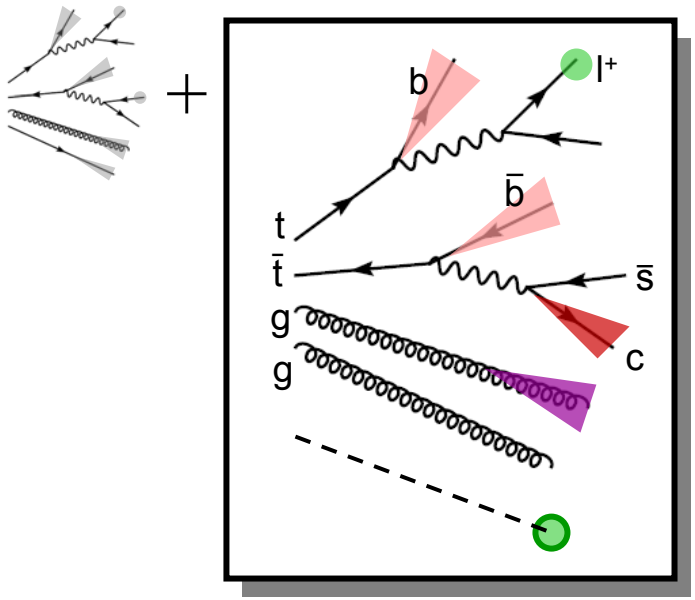


$$\frac{\varepsilon_{ttbb}}{\varepsilon_{ttjj}} \sim \frac{}{} \approx 512$$



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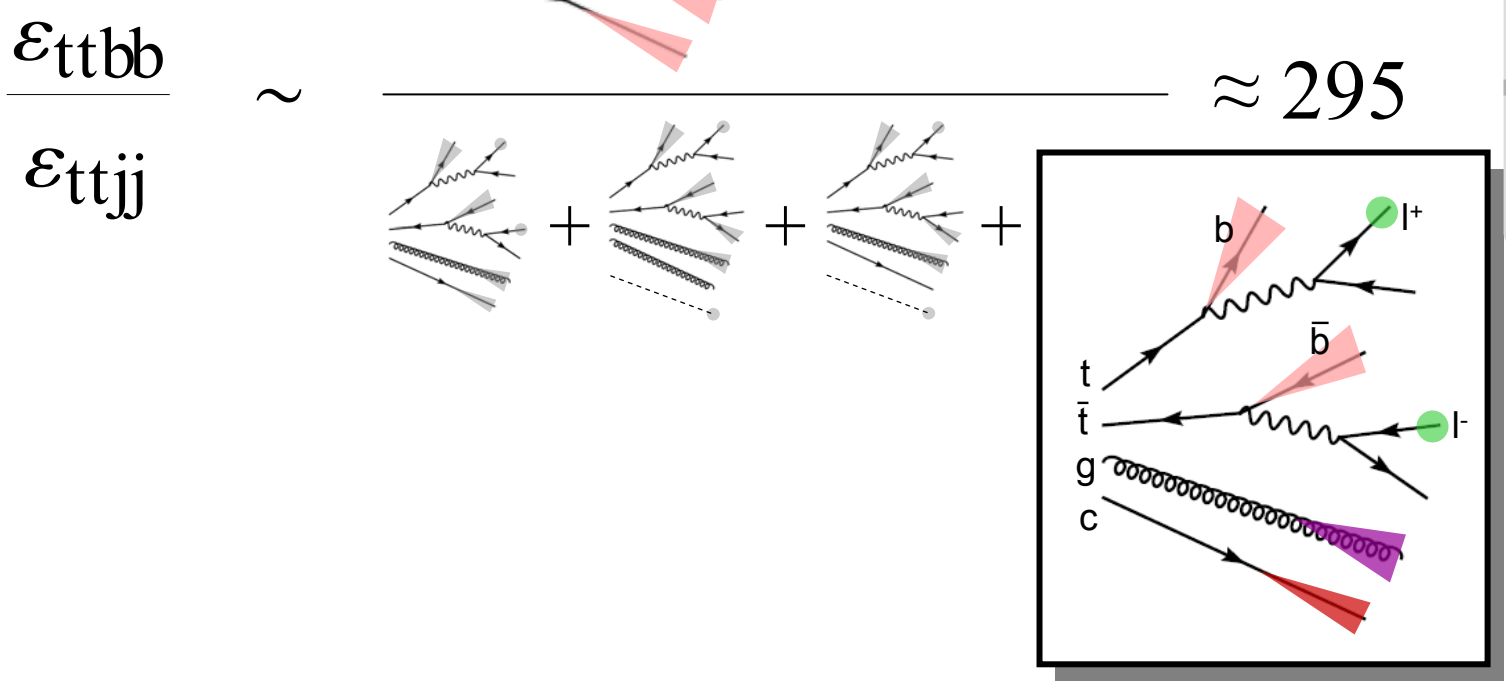

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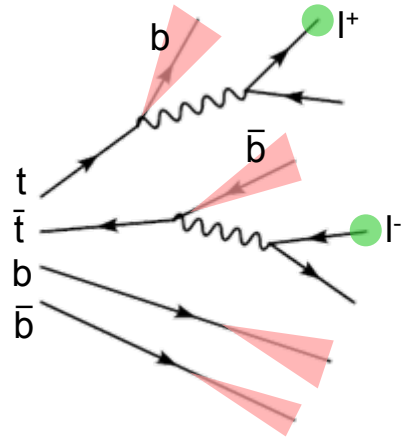
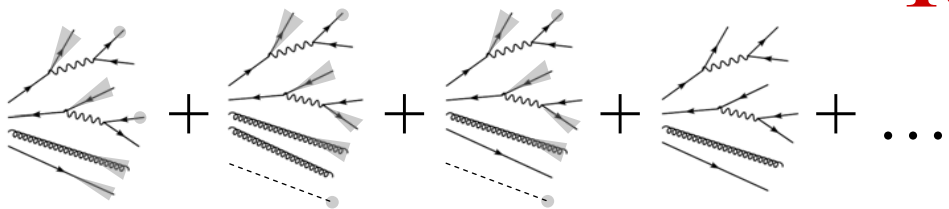


$$\frac{\varepsilon_{ttbb}}{\varepsilon_{ttjj}} \sim \frac{\quad}{\quad} \approx 18.1$$



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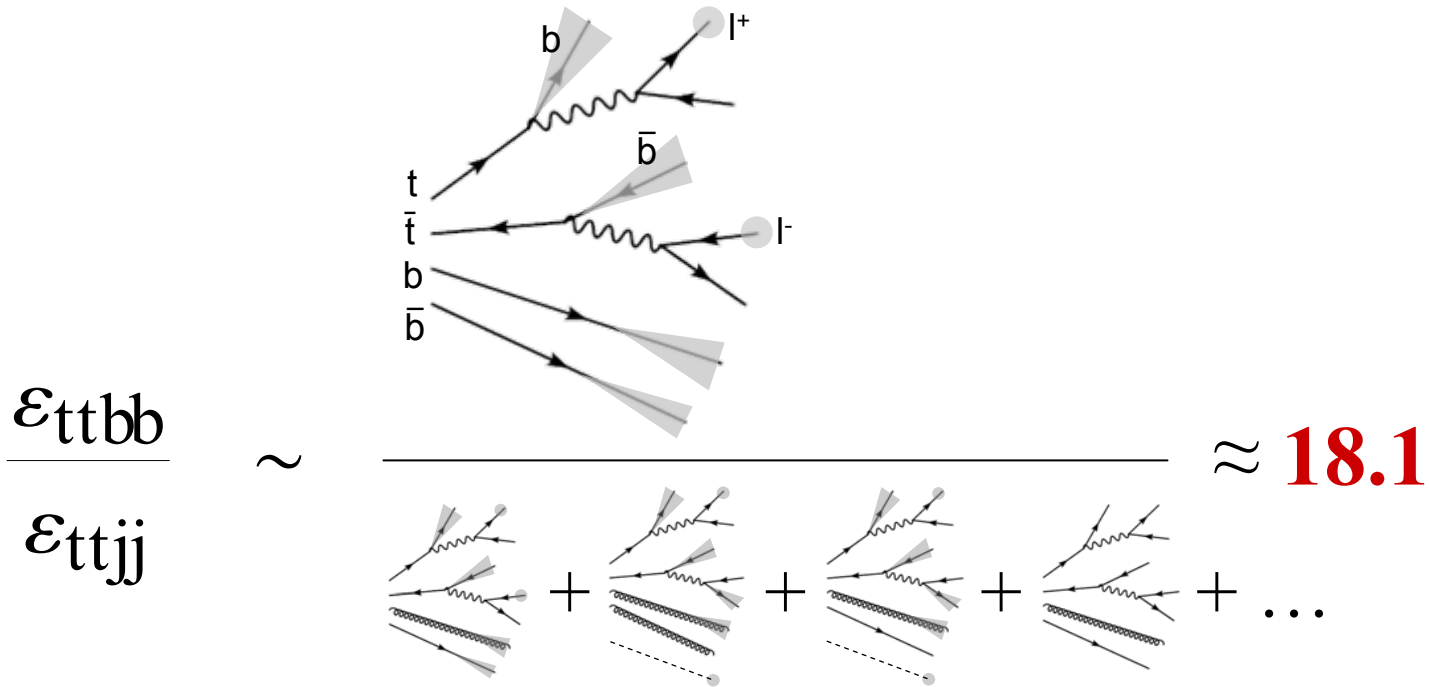

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Large number of jet-type objects induces large systematic uncertainties

	JES	Jet res.	b,c-tag	uds-tag	Stat.	Sys.
uncertainty	13%	3.7%	9.3%	6.6%	2.5%	18%

Di-leptonic channel, background

Reality happened

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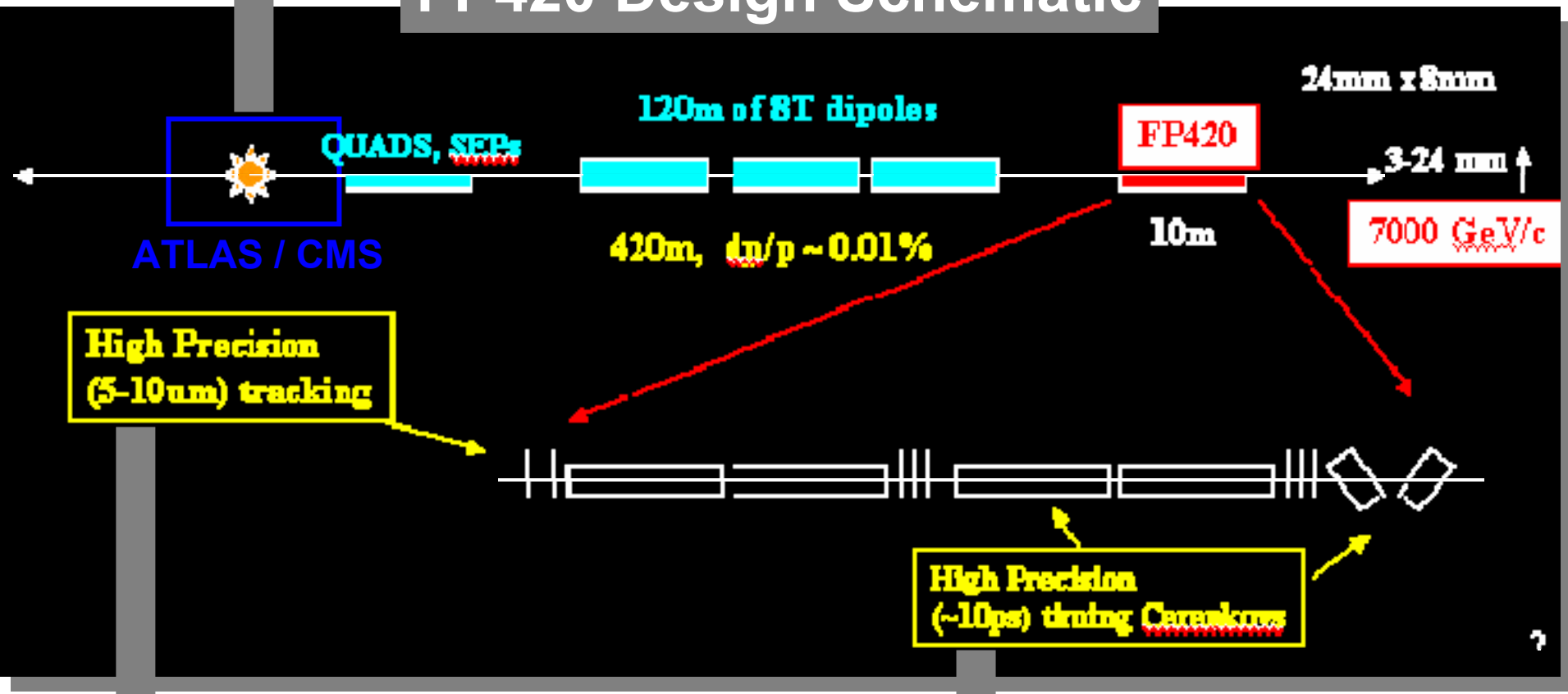
A diffractive physics detector

L1 triggering at CMS / ATLAS — FP420 is too far away

$L \geq 10^{33} cm^{-1} s^{-1}$

FP420 Design Schematic



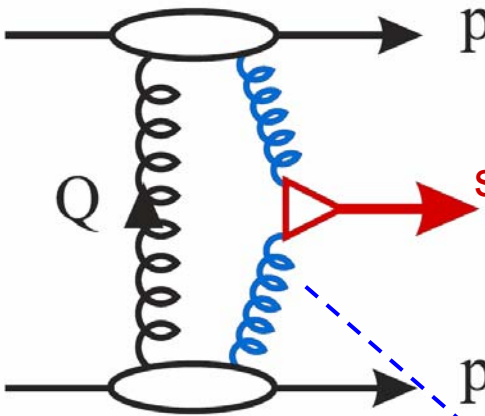
Tags and measures outgoing momenta of protons → can resolve mass of (single) produced particle to 2-3 GeV/c^2

Difference in arrival times of the 2 protons → can resolve primary vertex position to 2.1mm

Central Exclusive Production

$p\ p \rightarrow p + \varphi + p$

- Predominantly $J_Z = 0$, C-even, P-even
- No color flow into final states
  → no extra hadronic activity
  → large rapidity gap
- Incoming / outgoing momenta known
  + single-object (φ) production
  → mass of object can be resolved

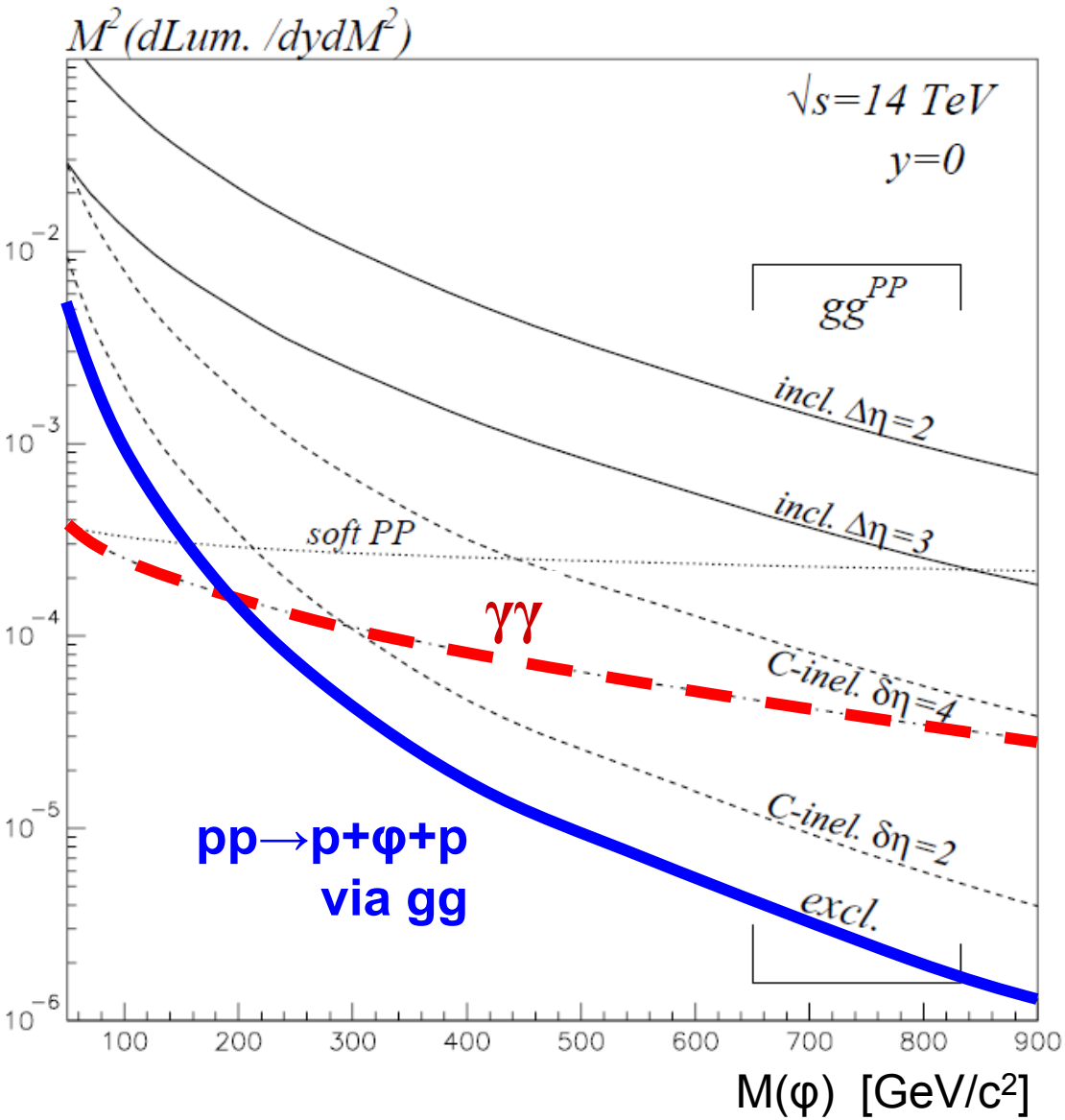


single object production { quantum numbers: **0^{++} or 2^{++}**; strong gluon / photon coupling

gluon production suppressed

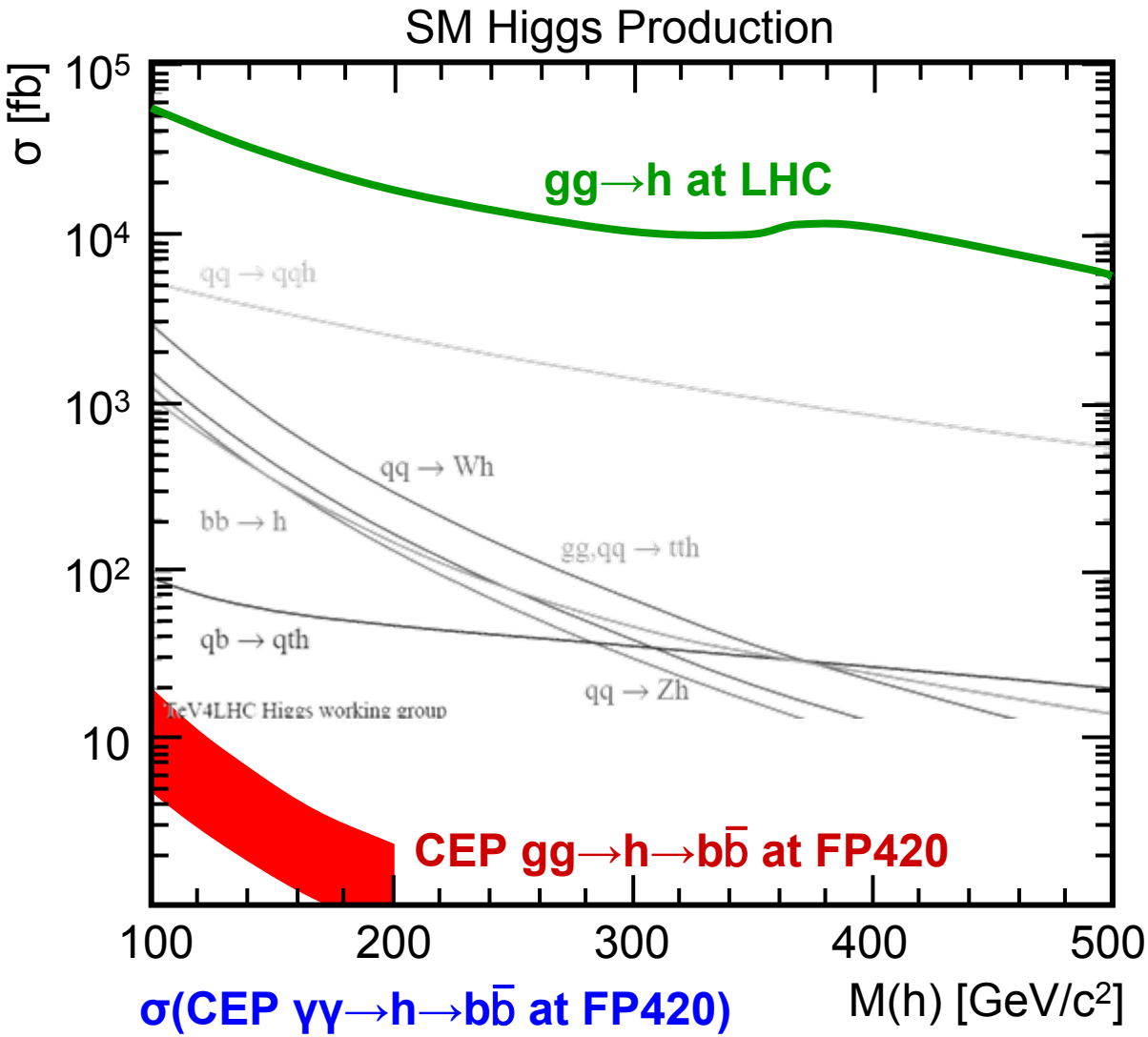
incoming states { gluon-gluon; photon-proton; photon-photon

Number of effective collisions per *pp* interaction



γp interactions : "energy reach and effective luminosities are much higher than for the $\gamma\gamma$"

[The FP420 R&D Project: Higgs and New Physics with forward protons at the LHC]



σ(CEP γγ→h→bb̄ at FP420) = 0.15 fb

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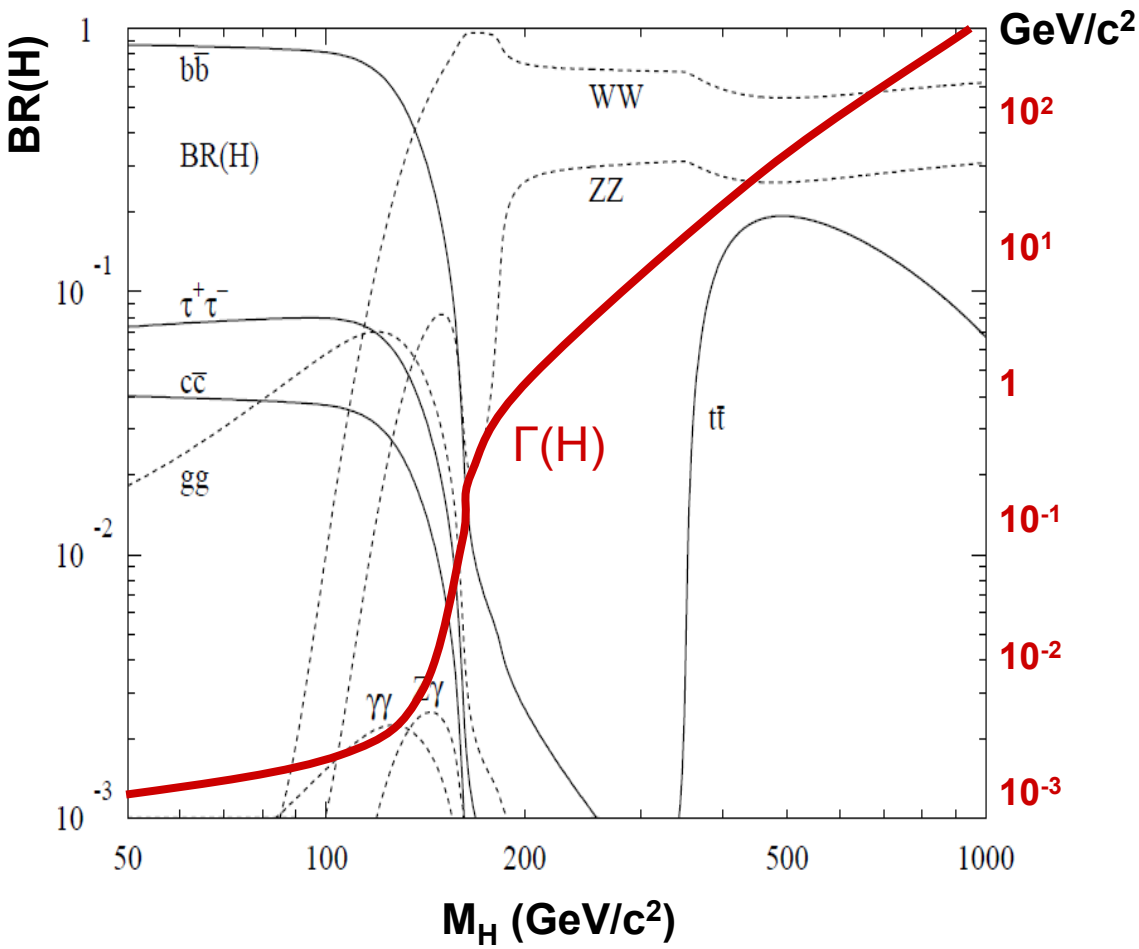

- Mass resolution ~ 2 GeV/c^2 from momentum conservation — regardless of final states!
- Natural widths of a few GeV/c^2 can be directly measured

Double Pomeron Exchange

Combinatorial backgrounds (3.5 – 35 overlap interactions)

Cut	Cross section (fb)						
	CEP			DPE	[p][X][p]	[p][pX]	[pp][X]
	$h \to b\bar{b}$	$b\bar{b}$	gg	bb	bb	bb	bb
E_T, ξ_1, ξ_2, M	1.011	1.390	2.145	0.666	5.42×10^{6}	8.98×10^{3}	1.16×10^{6}
TOF (2σ,10 ps)	0.960	1.320	2.038	0.633	3.91×10^{5}	7.33×10^{2}	6.29×10^{4}
R_j	0.919	1.182	1.905	0.218	4.73×10^{4}	85.2	7.59×10^{3}
Δy	0.774	1.036	1.397	0.063	2.16×10^{3}	1.38	3.50×10^{2}
$\Delta\Phi$	0.724	0.996	1.229	0.058	6.66×10^{2}	0.77	1.07×10^{2}
$N_C, N_C^{\perp}$	0.652	0.923	0.932	0.044	6.49	0.45	1.35
ΔM	0.539	0.152	0.191	0.009	1.28	0.06	0.28

MSSM (M_h^{max})
Neutral CP even
Higgs of mass
120 GeV/c

H→bb̄ Prospects
SM
MSSM
ttH @ CMS
All hadronic
Semi-leptonic
Di-leptonic
FP420
Overview
CEP of H→bb

Strategies

The "right" momentum

- Produced mass ↔ mass of central dijets
- Rapidity à la FP420 ↔ rapidity of dijets
- Jets back-to-back in φ
- Low extra activity (number of tracks, …)

"Quiet" events

Double Pomeron Exchange

Combinatorial backgrounds (3.5 – 35 overlap interactions)

Cut	Cross section (fb)						
	CEP			DPE	[p][X][p]	[p][pX]	[pp][X]
	$h \to b\bar{b}$	$b\bar{b}$	gg	bb	bb	bb	bb
E_T, ξ_1, ξ_2, M	1.011	1.390	2.145	0.666	5.42×10^{6}	8.98×10^{3}	1.16×10^{6}
TOF (2σ,10 ps)	0.960	1.320	2.038	0.633	3.91×10^{5}	7.33×10^{2}	6.29×10^{4}
R_j	0.919	1.182	1.905	0.218	4.73×10^{4}	85.2	7.59×10^{3}
Δy	0.774	1.036	1.397	0.063	2.16×10^{3}	1.38	3.50×10^{2}
$\Delta\Phi$	0.724	0.996	1.229	0.058	6.66×10^{2}	0.77	1.07×10^{2}
$N_C, N_C^{\perp}$	0.652	0.923	0.932	0.044	6.49	0.45	1.35
ΔM	0.539	0.152	0.191	0.009	1.28	0.06	0.28

MSSM (M_h^{max})
Neutral CP even
Higgs of mass
120 GeV/c

Other Requirements

Lower bound of detectable mass limited by radial distance to beam line [O(5mm) design]

	Signal Eff.
Acceptance (pp tagging)	28%
Trigger	60% — 20%
b-tagging	36% (2 jets)

- μ + jet (~ 10% eff.)
- rapidity gap + jet ← not very useful for $L \geq 2\times10^{34}cm^{-2}s^{-1}$
- L1 jet + L2@FP420

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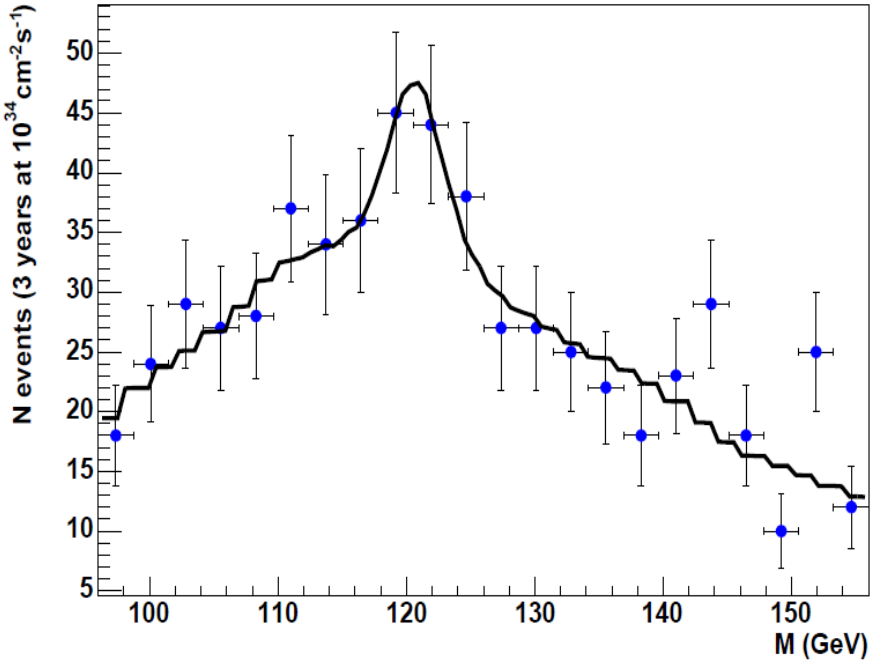
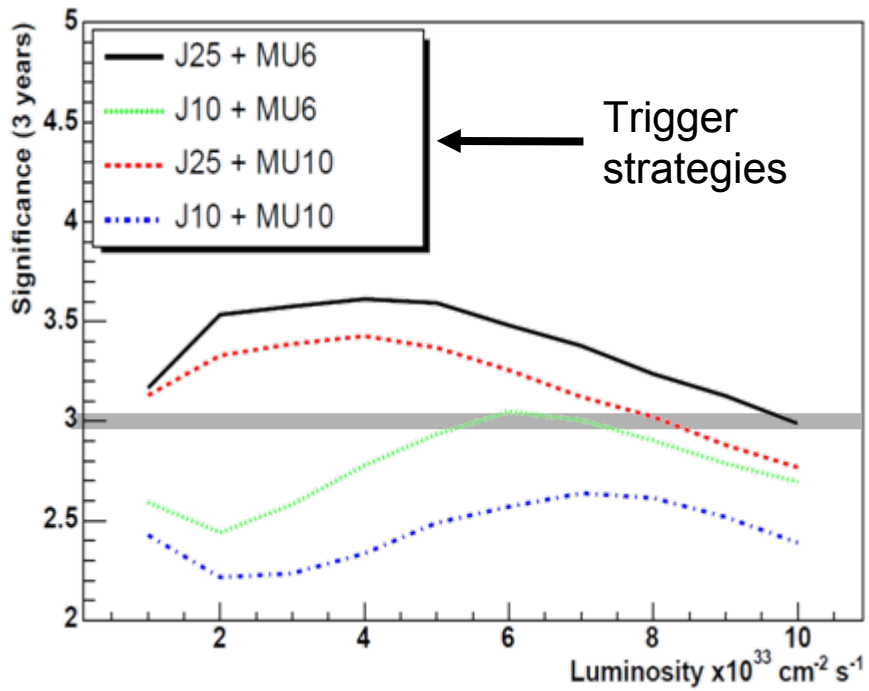


Fit mass distribution (FP420 measurement) for Signal + Background

→ count events within ΔM ~ 2.4 GeV/c window around mass peak



Better significances at high luminosities possible with improved overlap background removal (e.g. better timing info)

MSSM (M_h^{max}) Neutral CP even Higgs of mass 120 GeV/c

Advantages (versus CMS central)

- QCD background suppression (diffractive physics)
- Momentum measurement for outgoing protons
  - Decay-independent mass measurement for **singly produced** object
  - Mass peak reconstruction → mass window cut

no combinatorial ambiguities

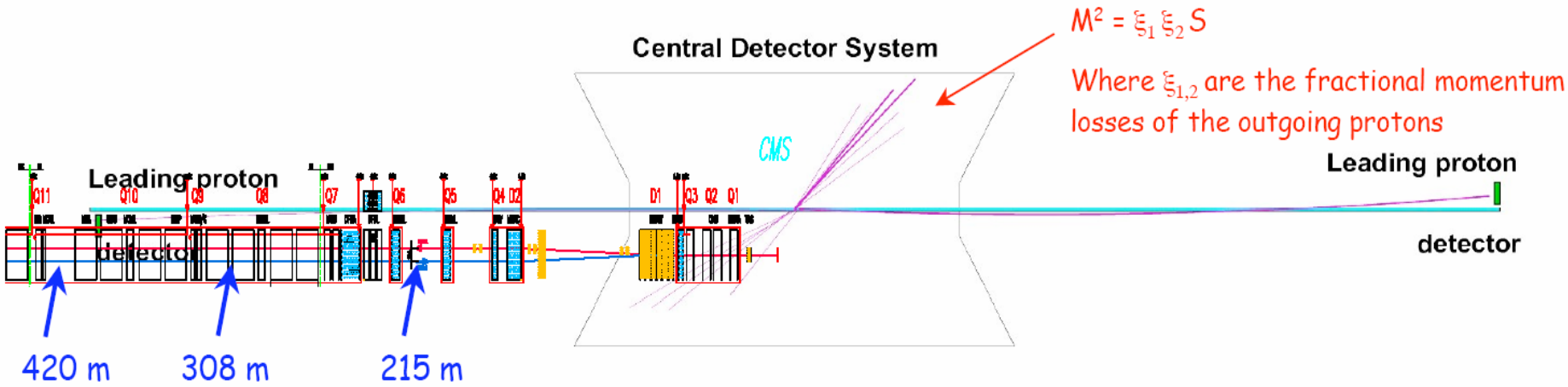
Challenges

- Cross-sections intrinsically 4 – 5 orders of magnitude less
- Triggering
  - Standard CMS triggers → low efficiency for diffractive physics
  - Rapidity gap triggers not very useful at high luminosities (18% eff. at $10^{33}cm^{-2}s^{-1}$ … 2% eff. at $2\times10^{33}cm^{-2}s^{-1}$)

Open Issues

- Systematic uncertainties
- Associated production channels possible?

Backup



FP420

TOTEM (ATLAS/RP220)

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E_{T1}, E_{T2}, M, acc, 2 b-tag	0.124	1.320	2.038	0.633	3.91×10^{5}	7.33×10^{2}	6.29×10^{4}
R_j	0.119	1.182	1.905	0.218	4.73×10^{4}	85.2	7.59×10^{3}
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