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The 2 Higgs Doublet Model At Hera

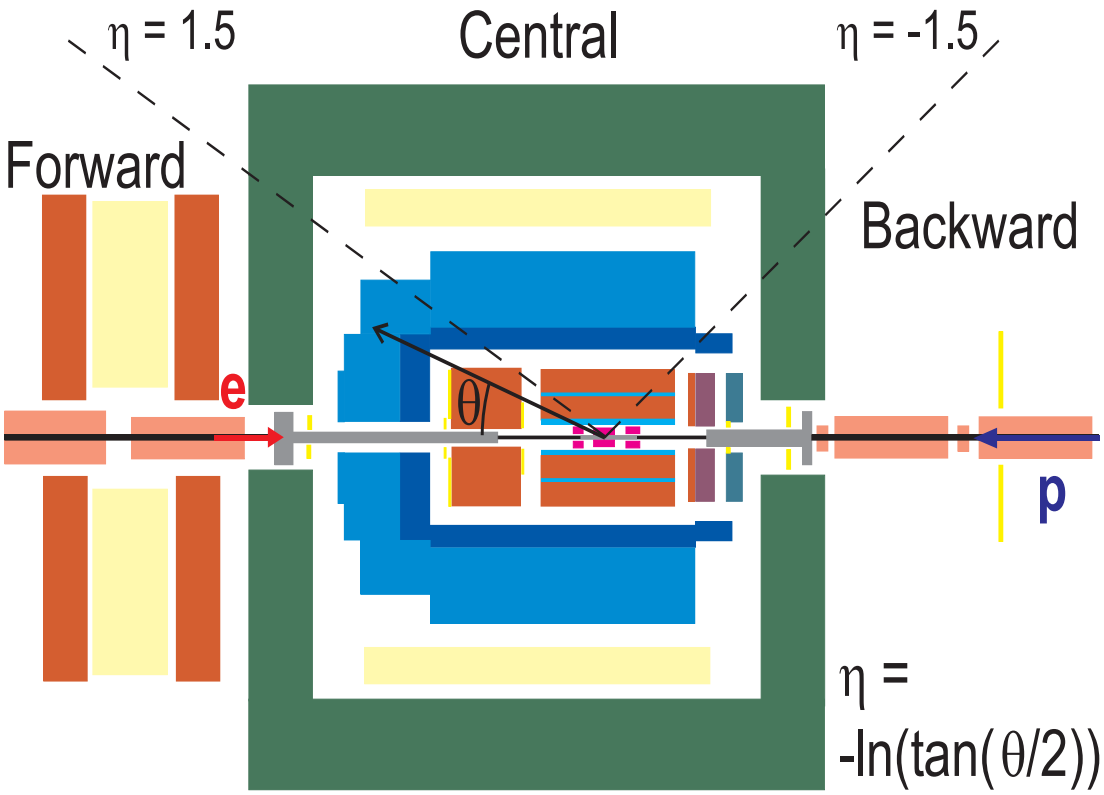
Overview

- Short Reminder: HERA, H1
- The 2 Higgs Doublet Model
- Processes at HERA
- MC study for H1
- Outlook

Reminder HERA / H1

- HERA: ep collisions at 320 GeV CM energy

- The H1 detector



- Tracking: Drift chamber ($-1.5 < \eta < 1.5$)
- Vertexing: 2 layers silicon detector
  Internal resolution $\sim 15\ \mu$m
- Calo: LAr Res: $\frac{\sigma}{\sqrt{E}} = \begin{cases} 12\% & \text{em} \\ 50\% & \text{had} \end{cases}$
- Luminosities:
  HERA I $\quad \mathcal{L} \sim 100\ pb^{-1}$
  HERA II $\quad \mathcal{L} \sim 1\ fb^{-1}$ (Design)

The 2 Higgs Doublet Model

- Introduce 2 Higgs Doublets
  $\Phi_1 = \begin{pmatrix} \Phi_1^+ \\ \Phi_1^0 \end{pmatrix} \quad \Phi_2 = \begin{pmatrix} \Phi_2^+ \\ \Phi_2^0 \end{pmatrix}$

- Ratio of vacuum expectation values:
  $tan\beta \equiv \frac{v_2}{v_1}$

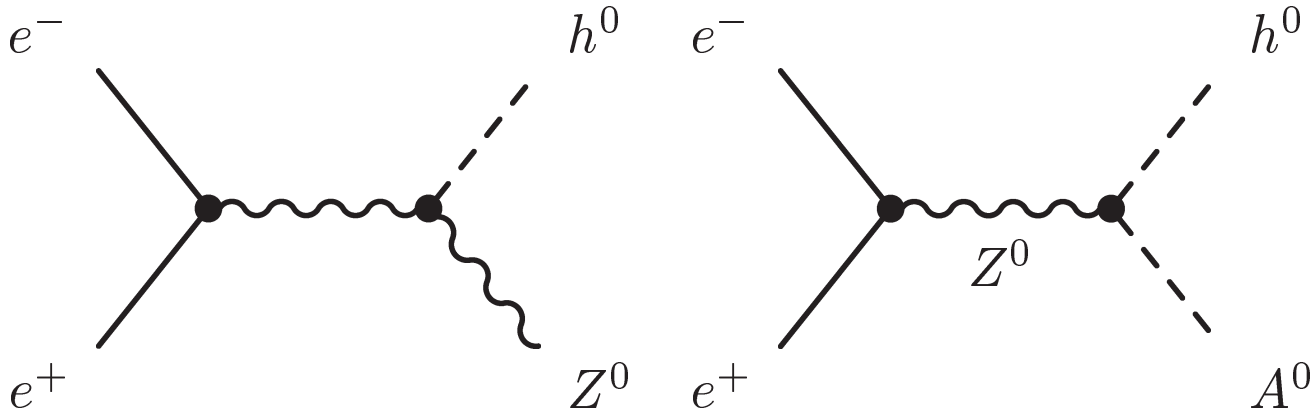
- Choose unitary gauge $\rightarrow$ 5 physical Higgs Bosons remain: $h^0, A^0, H^0, H^\pm$

- $\alpha \equiv$ mixing angle in the neutral higgs sector

- In a Type II 2HDM (as MSSM) one of the doublets couples only to uptype quarks and neutrinos, the other only downtype quarks and leptons

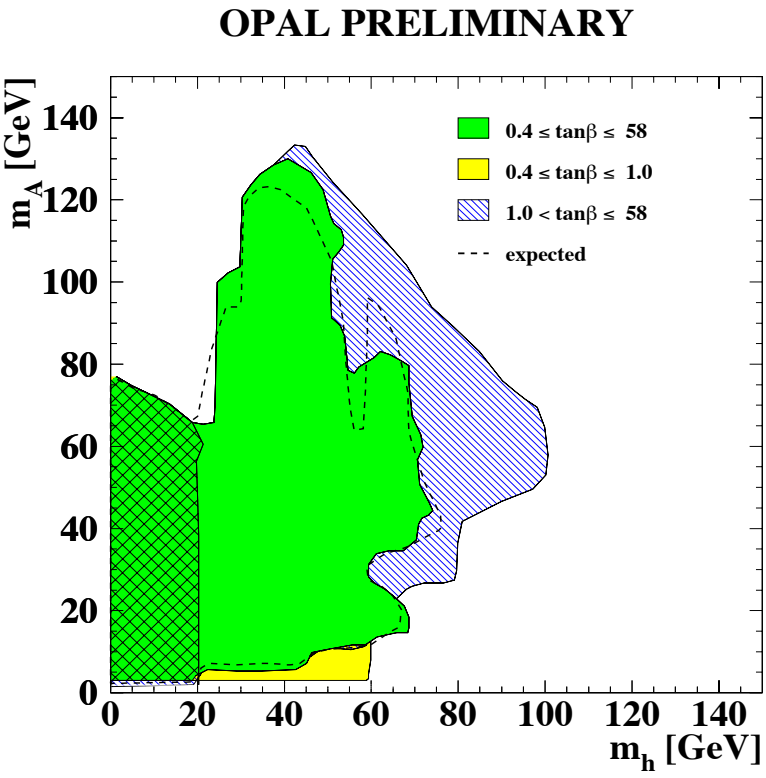
- Type II couplings w.r.t. SM:
  $hb\bar{b}$: $\frac{-sin\alpha}{cos\beta}$ $\quad$ $ht\bar{t}$: $\frac{cos\alpha}{sin\beta}$
  $Ab\bar{b}$: $tan\beta$ $\quad$ $At\bar{t}$: $ctg\beta$

2HDM at Lep



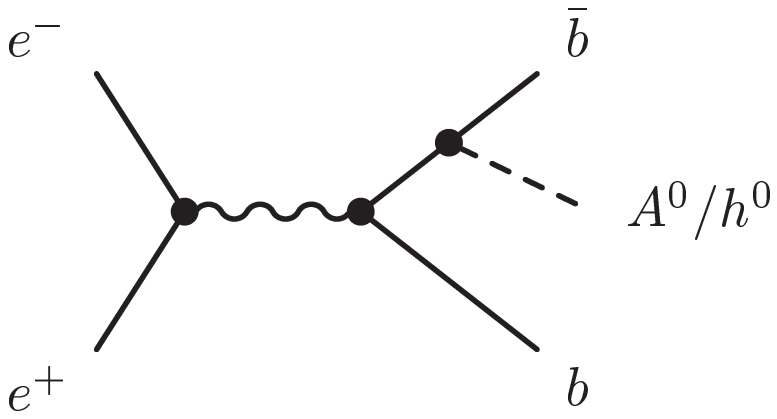
- $e^+e^- \to h^0 Z^0$: $\sim sin^2(\beta - \alpha)$
  $e^+e^- \to h^0 A^0$: $\sim cos^2(\beta - \alpha)$

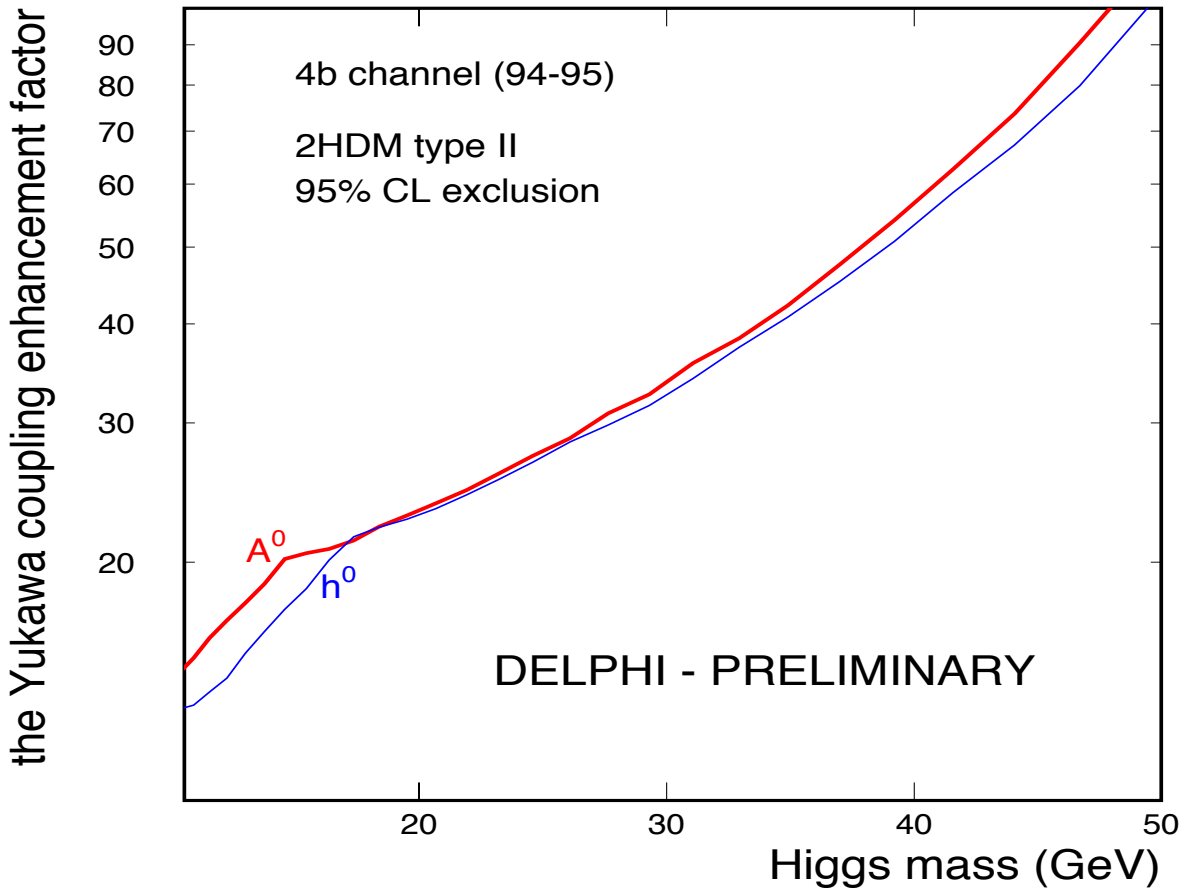
- From the first process: $sin^2(\beta - \alpha) < 0.1$ for $M_h \leq 50$ GeV



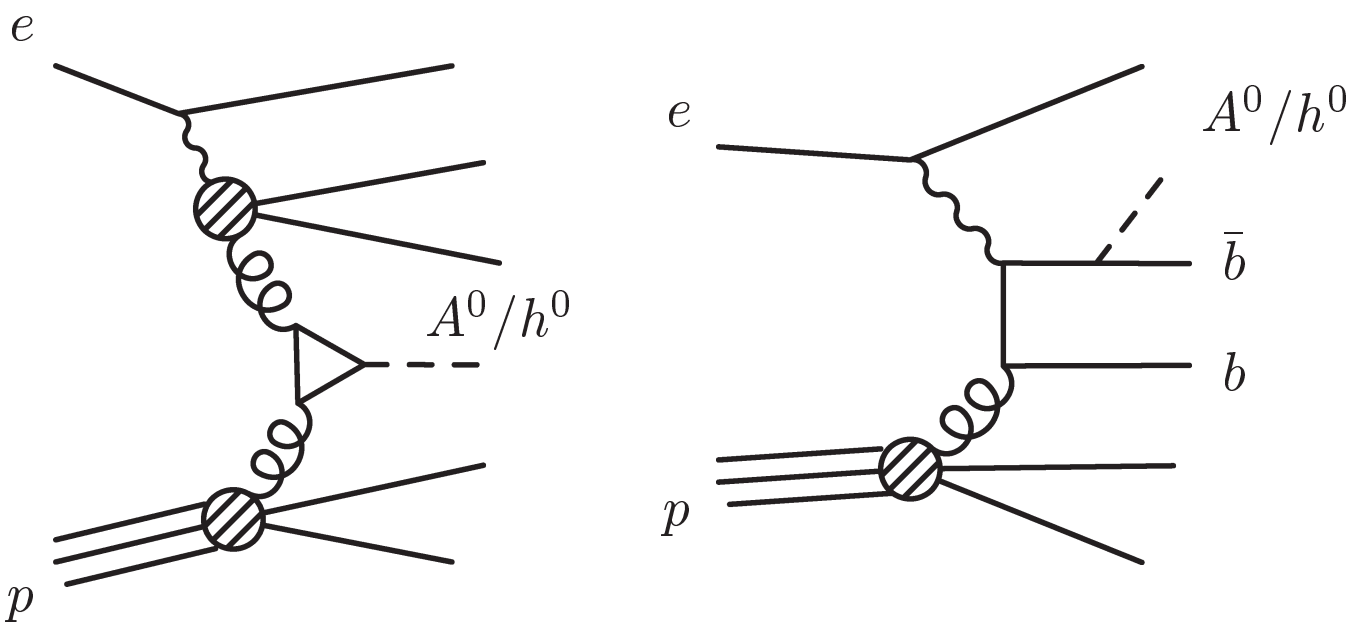
2HDM at Lep (II)

- DELPHI Yukawa process (4b)





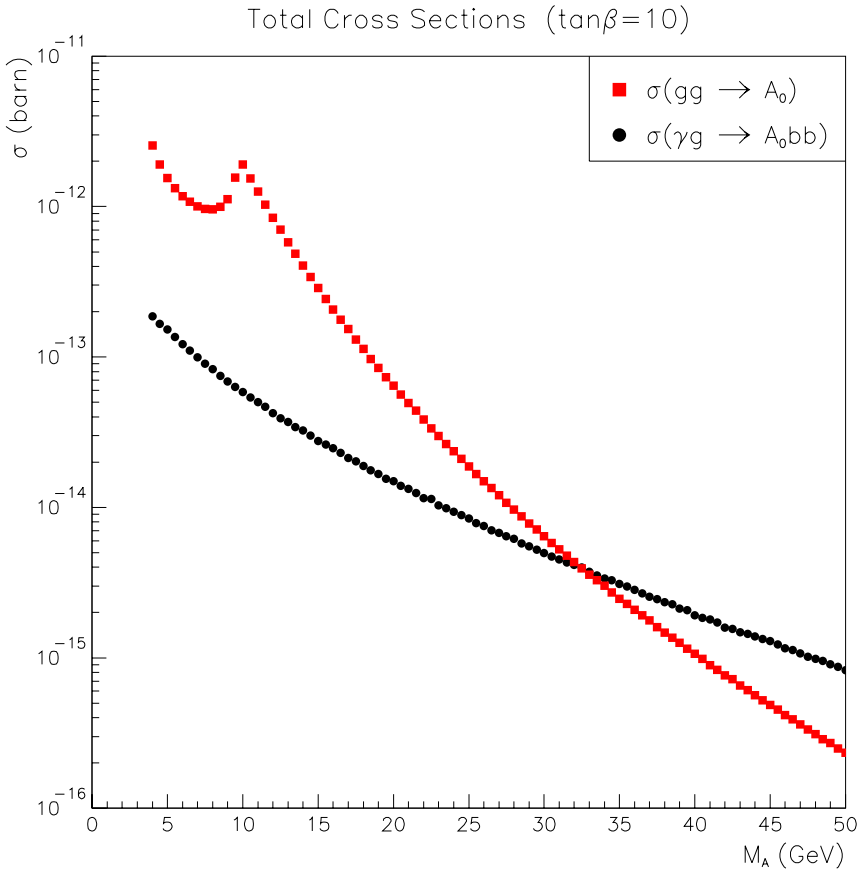
Processes At Hera



- Left: Gluon Fusion (Resolved Photoproduction)
- Right: Boson-Gluon Fusion (BGF)
- MC Generator Status:
  - gg-Fusion: Implemented in PYTHIA 6.2
  - BGF: Selfmade Generator based on code for cross section calculation by M.Krawczyk

Cross Sections

- Total cross sections for HERA (A^0, $\tan\beta = 10$)



- HERA sensitivity at low Higgs masses M $\leq$ 20 GeV

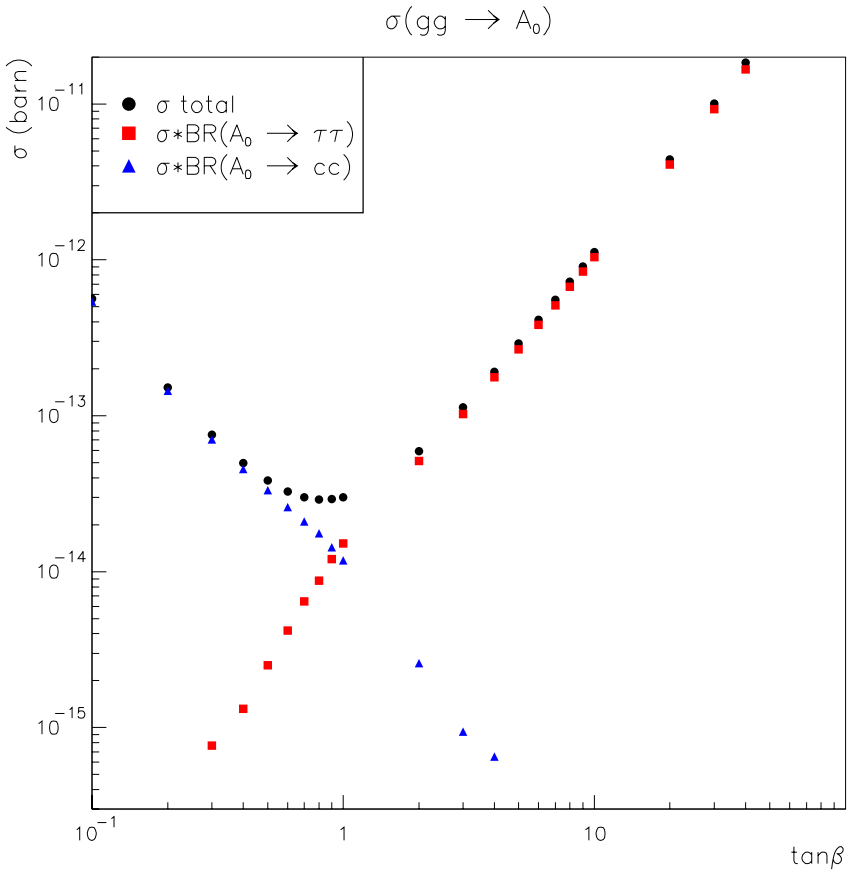
- $\sigma_{gg\to h} > \sigma_{\gamma g\to b\bar{b}h}$ (factor $\sim$ 10)

- For HERA restrict analyses to low Higgs masses M $< 2m_b$

- Depending on $\tan\beta$ restrict to gg-Fusion

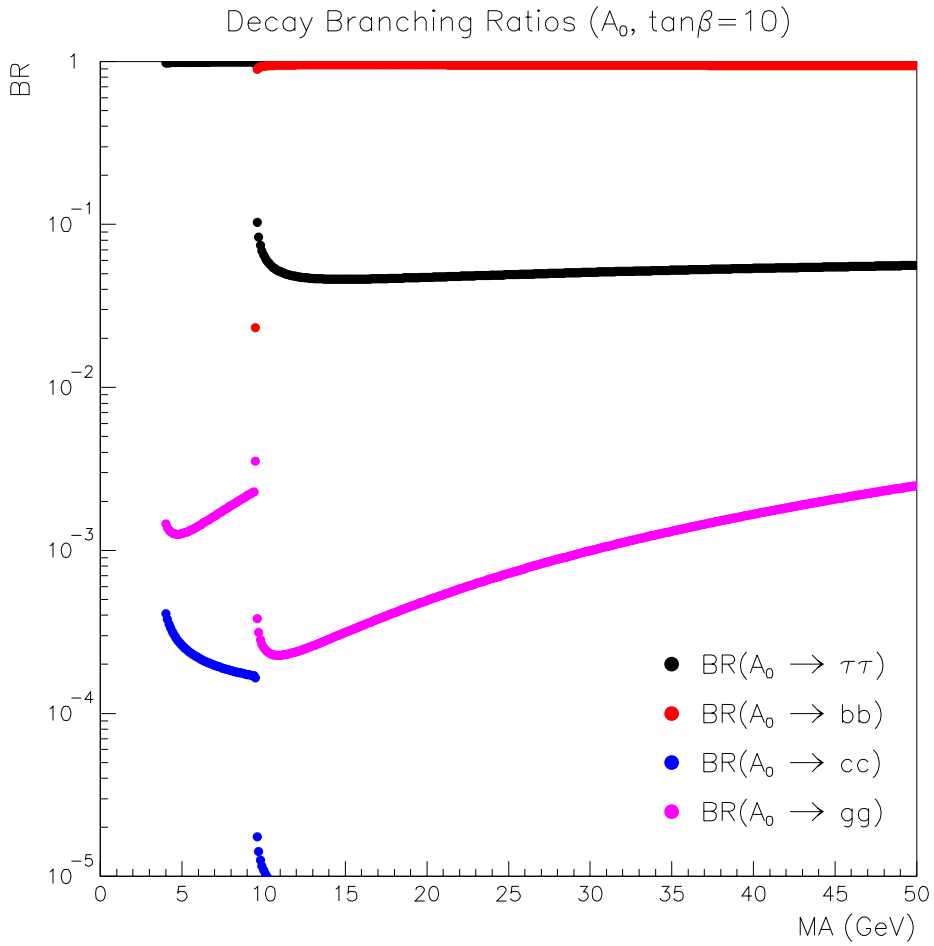
Cross Sections (II)

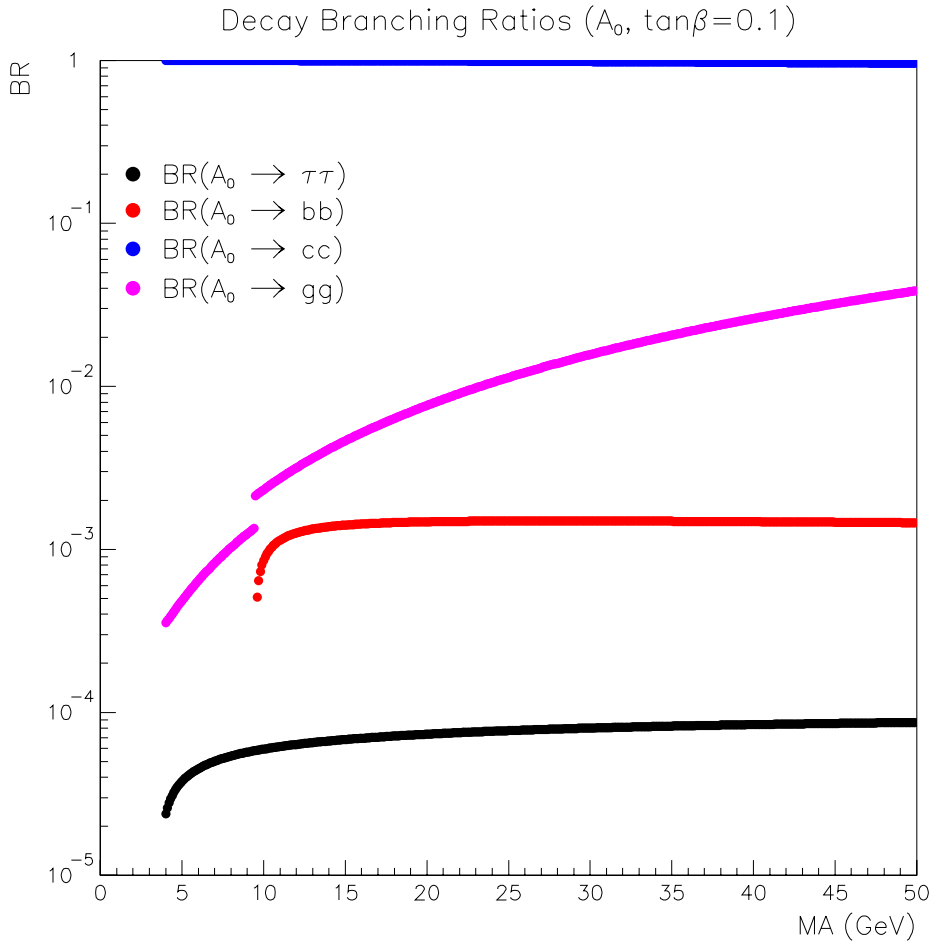
- gg-Fusion: Total cross section for HERA (A^0, $M_A = 9$ GeV)



- Higher sensitivity for either low or high tanβ

Higgs Decay Branching Ratios





MC Studies

- Goal: Show or disprove feasibility for 2HDM analysis

- Restrict to most promising channel:
  - gg-fusion process
  - Restrict to τ channel: A,h $\rightarrow \tau^+\tau^-$
  - Restrict to leptonic tau decay (BR $\sim$ 36%) but cleanest experimental signal

- Procedure:

1. Show possibility to trigger 2HDM at H1 with high efficiency and acceptable rate
   $\rightarrow$ was shown for L1
2. Get a measure for the number of expected signal events at H1
3. Get a handle to reduce the background

2HDM L1 Trigger for HERA I

- HERA bunch crossing frequency: 10 MHz
- L1 trigger decision after 2.3 μs
  based on $\sim$ 256 trigger elements (TE)
- Ratereduction by TE-coincidence
  (L2 input $\sim$ 1 kHz)

- Simple algorithm: maximize $\frac{\epsilon_{ij}^2}{R_{ij}}$
  $\epsilon_{ij} = \epsilon(TE_i \quad \&\& \quad TE_j) \rightarrow$ from MC
  $R_{ij} = P(TE_i \quad | \quad TE_j) \cdot R_j \rightarrow$ from special run

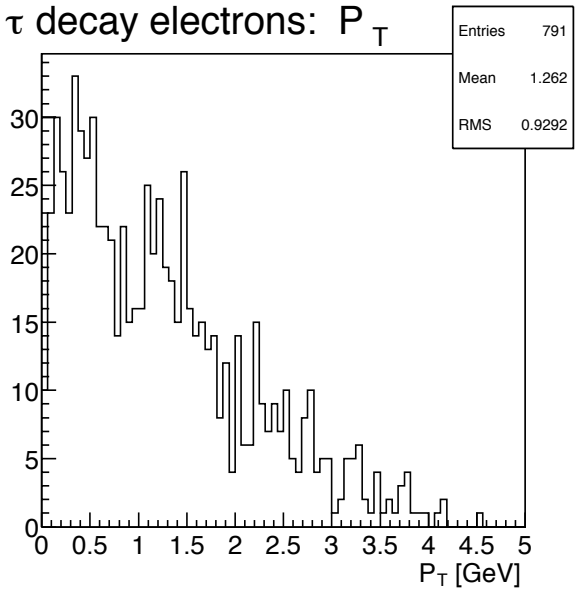
- E.g. for $m_A = 9$ GeV:

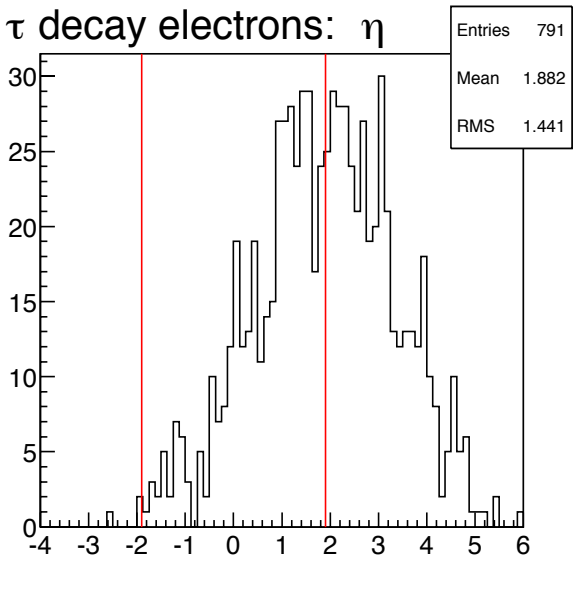
TE_i && TE_j	$\frac{\epsilon_{ij}^2}{R_{ij}}$	ϵ_{ij}	R_{ij} [Hz]
77 CIP_4 && 43 SPCLE_IET	0.070149	0.544529	4.226892
77 CIP_4 && 19 DCRPH_TC	0.014280	0.910941	58.110344
77 CIP_4 && 46 SPCLE_TOF_E_1	0.012807	0.843511	55.554848

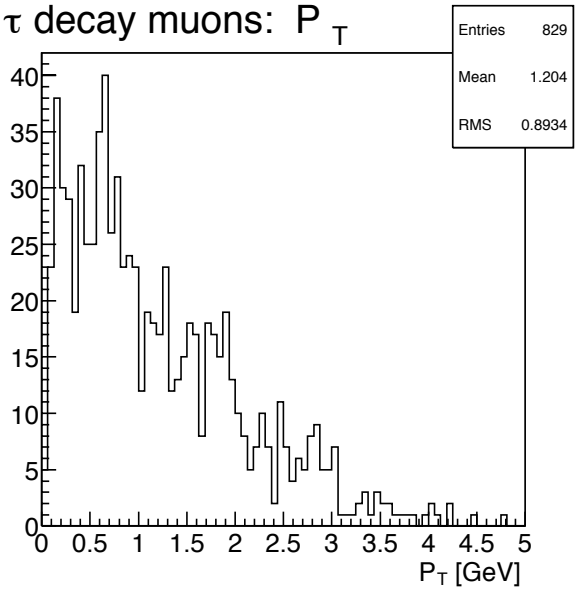
- Quintessence: 2HDM can be triggered!

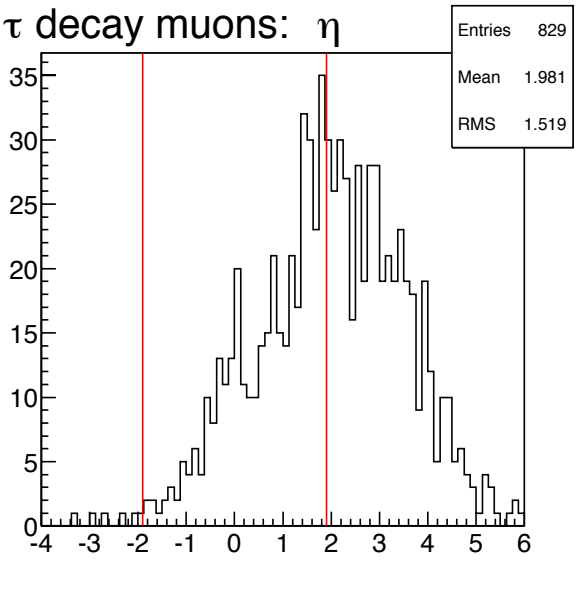
gg Fusion: Signal MC

- So far 2 MC files for A^0 available:
  $M_A = 5$ GeV, $\tan\beta = 10$ (5000 evts $\sim 2.5\ fb^{-1}$)
  $M_A = 9$ GeV, $\tan\beta = 10$ (5000 evts $\sim 5.0\ fb^{-1}$)
- τ decay lepton distributions (9 GeV)









- Require both τs in central region
  $\rightarrow$ Data reduction factor $\mathrm{CJC}_{acc} = 0.22$

Lepton Finders

- For discrimination against BG:
  Need to tag τ decay leptons

- Use standard lepton finders from H1 reconstruction software

- Determine signal efficiencies (from MC) for decay leptons in central region

Lepton	$m_A = 9$ GeV	$m_A = 5$ GeV
$\mu^{\pm}$	$(65.0 \pm 2.1)\%$	$(49.9 \pm 2.2)\%$
$e^{\pm}$	$(49.2 \pm 2.2)\%$	$(44.6 \pm 2.2)\%$

- Preliminary Signalreduction:
  $0.9_{L1} \cdot 0.22_{CJC} \cdot 0.13_{\tau BR} \cdot 0.25_{LeptonTag} = 0.006$

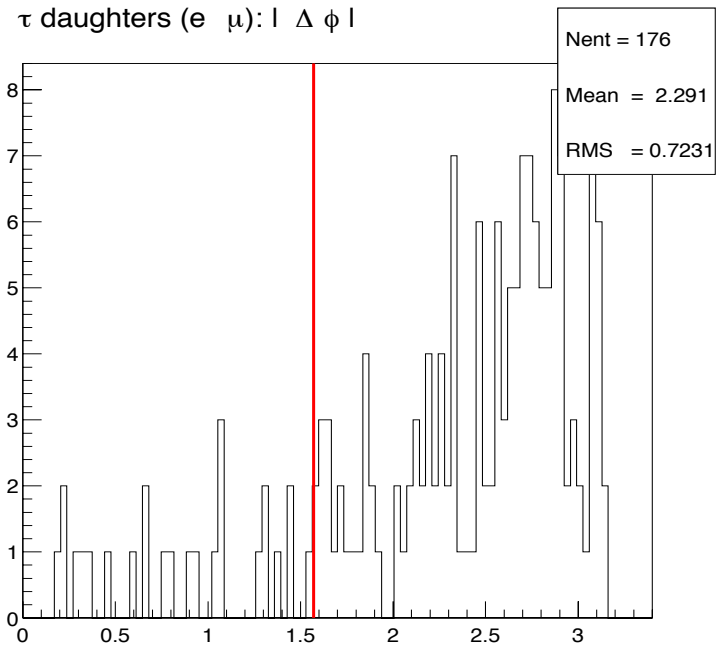
  ...still ignoring things like:
  - BR($A^0 \to \tau\tau$)
  - Trigger level 3 efficiency
  - Selection efficiency
  - ...

Background and Data Selection

- Background for gg-Fusion:
  H1 99/2000 dataset: tagged photoproduction
  ($\sim$ 5M events)

- Preliminary Data Selection:

- H1 Standard track quality cuts on τ decay lepton candidates
- Require minimum $p_T > 500$ MeV
- Require 2 tracks tagged as leptons (e,μ)
  $\rightarrow$ τ decay lepton candidates
- Require the candidates to have opposite charge
- Require the candidates to be in opposite hemispheres: $|\Delta\phi| > \frac{\pi}{2}$



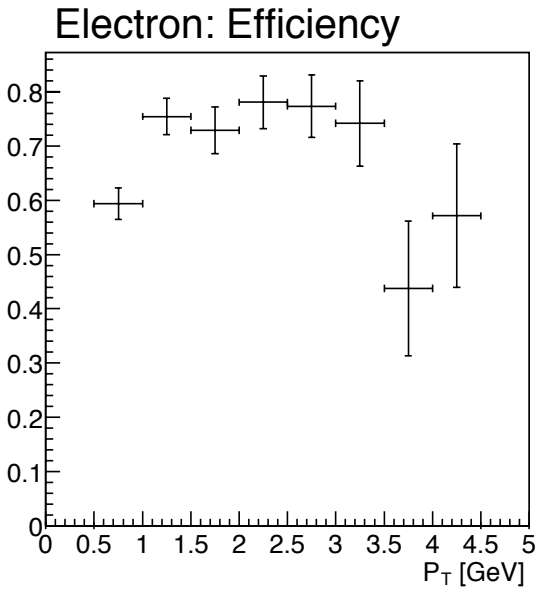
First Results

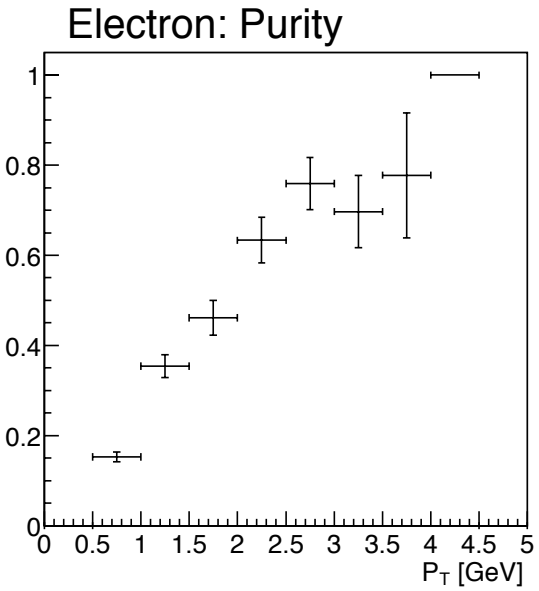
- Run this selection over signal MC and BG
- Results for $M_A = 9$ GeV

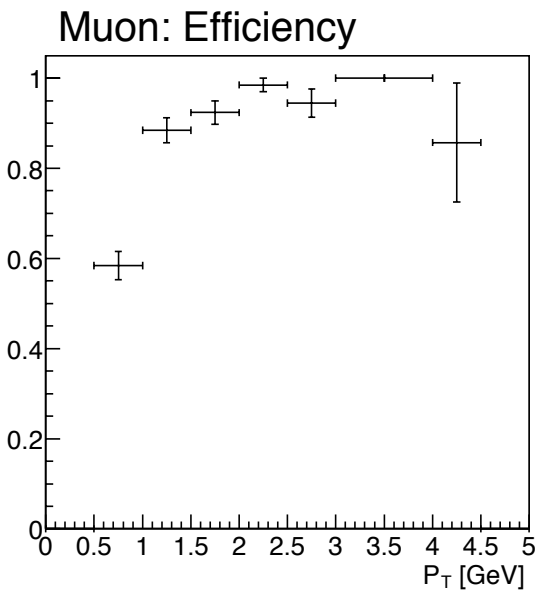
  ϵ_{tot} = Selection efficiency $\times$ P_T acceptance

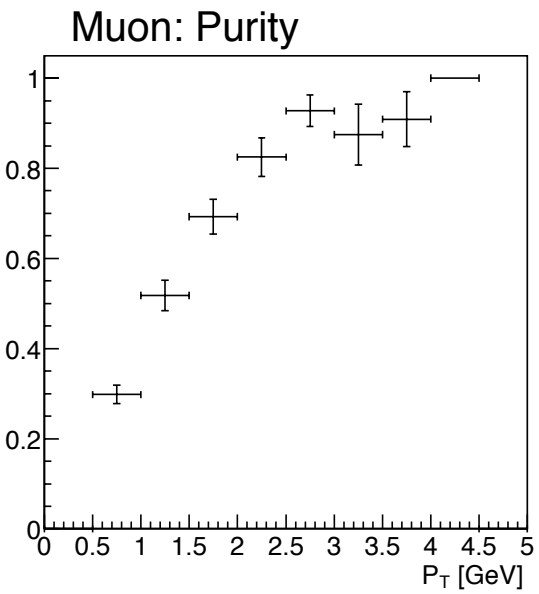
P_T^{cut}	500 MeV	750 MeV
ϵ_{tot}	$(38.6 \pm 3.7)\%$	$(30.7 \pm 3.5)\%$
S/B	1:123000	1:86000

- Reason for huge BG? $\rightarrow$ Finder Purities





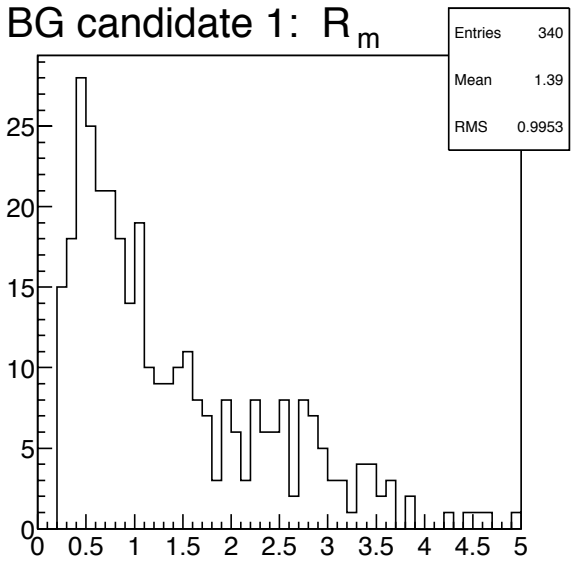


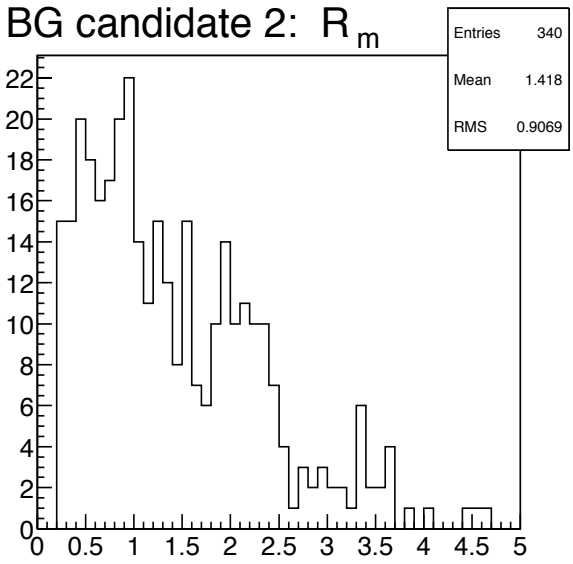


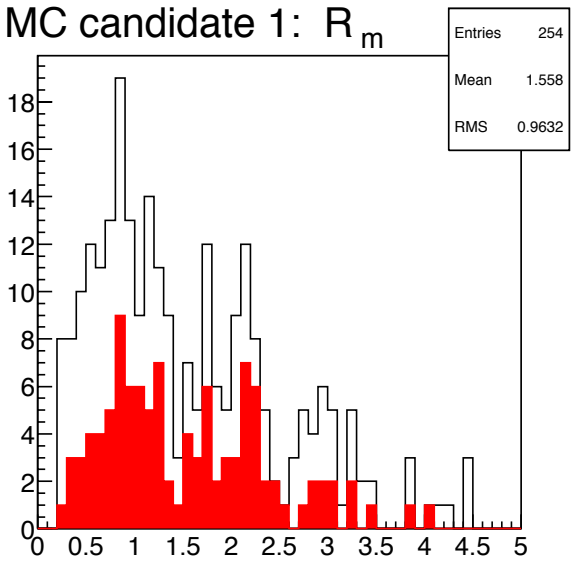
Idea: Use Track Isolation

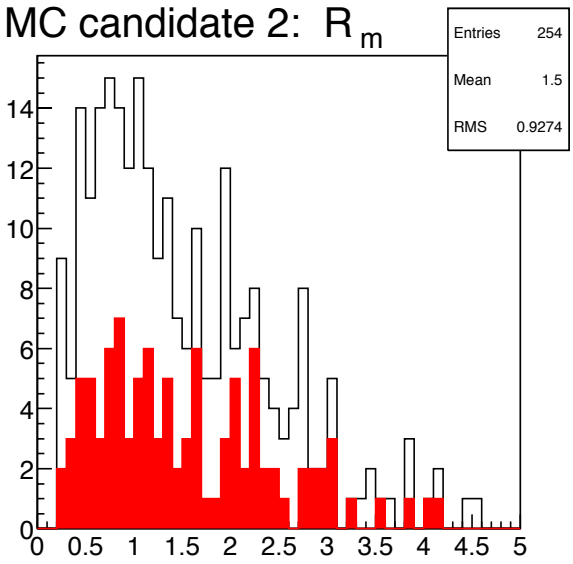
- Assume τ decay leptons independent from Hadronic Final State (HFS)

- Cut on track isolation in (η, ϕ) e.g. distance to closest track: $R_{min} \equiv min(\sqrt{\Delta\phi^2 + \Delta\eta^2})$









- No clear separation of Signal and BG with R_{min} (closest track) :-(

Summary And Outlook

- 2HDM cross sections are large enough to be observable at H1 but...
- Background is much too large (S/B $\sim$ 1:100000) for $\tan\beta = 10$
- Possible improvements:
  - Look at different track isolation criteria, e.g. energy in cone around lepton candidate
  - Tune lepton finders for low energies (especially electron finder)
  - Multivariate Analysis
- In any case: need a lot of improvement, otherwise this analysis is not possible