AFP project and recent CED Higgs studies

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Low-x workshop, Ischia - 11/09 2009

1. AFP Project
2. CED Higgs in SM and MSSM

FP420 R&D Collaboration

R&D report
hep-ex/0806.0302,
accepted by JINST

- Spokes : Brian Cox (Manchester, ATLAS) and Albert DeRoeck (CERN,CMS)
- Technical Co-ordinator : Cinzia DaVia (Manchester)

Collaboration : FNAL, The University of Manchester, University of Eastern Piedmont, Novara and INFN-Turin, The Cockcroft Institute, University of Antwerpen, University of Texas at Arlington, The University of Glasgow, University of Calabria and INFN-Cosenza, CERN, Lawrence Livermore National Laboratory, University of Turin and INFN-Turin, University of Lund, Rutherford Appleton Laboratory, Molecular Biology Consortium, Institute for Particle Physics Phenomenology, Durham University, DESY, Helsinki Institute of Physics and University of Helsinki, UC Louvain, University of Hawaii, LAL Orsay, University of Alberta, Stony Brook University, Boston University, University of Nebraska, Institute of Physics, Academy of Sciences of the Czech Republic, Brookhaven National Laboratory, University College London, Cambridge University

AFP

Roman pot upgrade at 220m with additional horizontal pots

France : Saclay, Paris 6

Czech Republic : Prague

US : Stony Brook

Poland : Cracow

Germany : Giessen

Michigan State Univ.

Univ. of Chicago, Argonne (timing det.)

FP420 and RP220 ATLAS projects have merged into the AFP project in 2008.
Under review: all key questions have been satisfactorily answered.

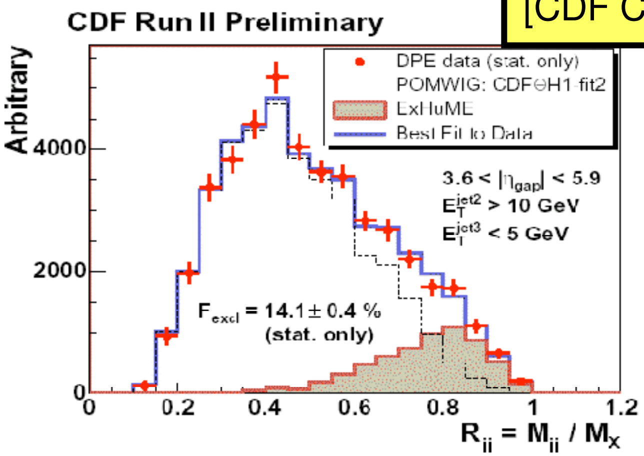
Physics with forward proton tagging at high lumi

Diffraction

Hard SD/DPE (dijets, W/Z, …)
Gap Survival / Underlying event
High precision calibration for the Jet Energy Scale

Central Exclusive Diffraction of dijets:

[CDF Coll, arXiv:0712.0604]



Evidence for CED

Central Exclusive Diffraction of Higgs

- Higgs mass, quantum numbers, discovery

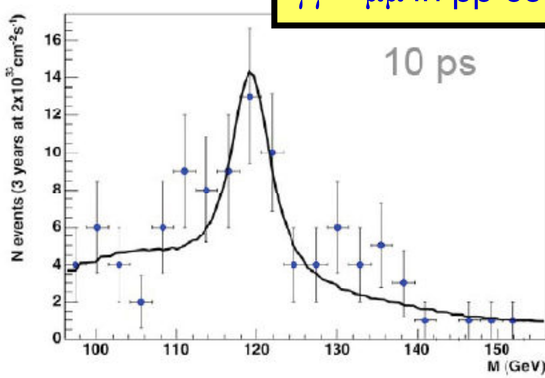
SM h→WW*, 140 < M < 180 GeV [EPJC 45 (

MSSM h→bb, h→ττ, 90 < M < 140 GeV

MSSM H→bb (90 < M < 300), H→ ττ (90 < M <160 GeV)

NMSSM h→aa→ττττ for 90 < M < 110 GeV

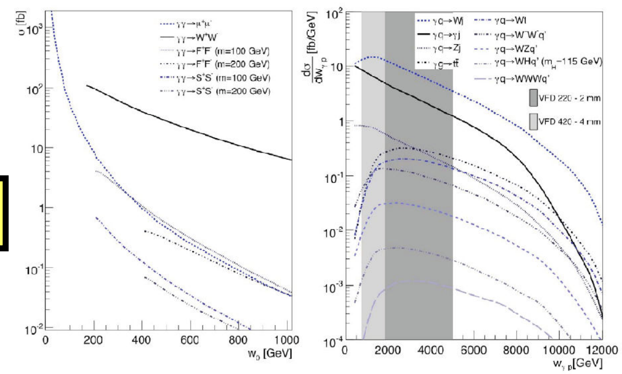
Triplet scenario [arXiv: 0901.3741]

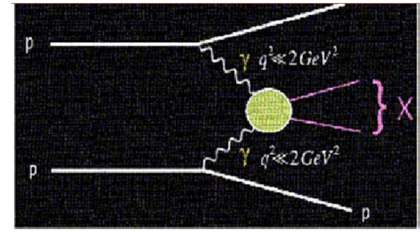


[JHEP 0710:090,2008]

Two-photon interactions

- Absolute lumi calibration, calibration of FDs
- Factorization breaking in hard diffraction

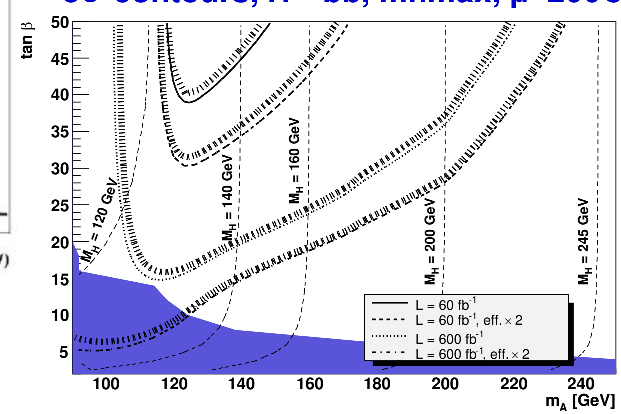




Louvain Photon Group (CMS)
arXiv:0807.1121

CDF: Observation of Exclusive Charmonium Prod. and γγ→μμ in pp collisions at 1.96 TeV [arXiv:0902.1271]

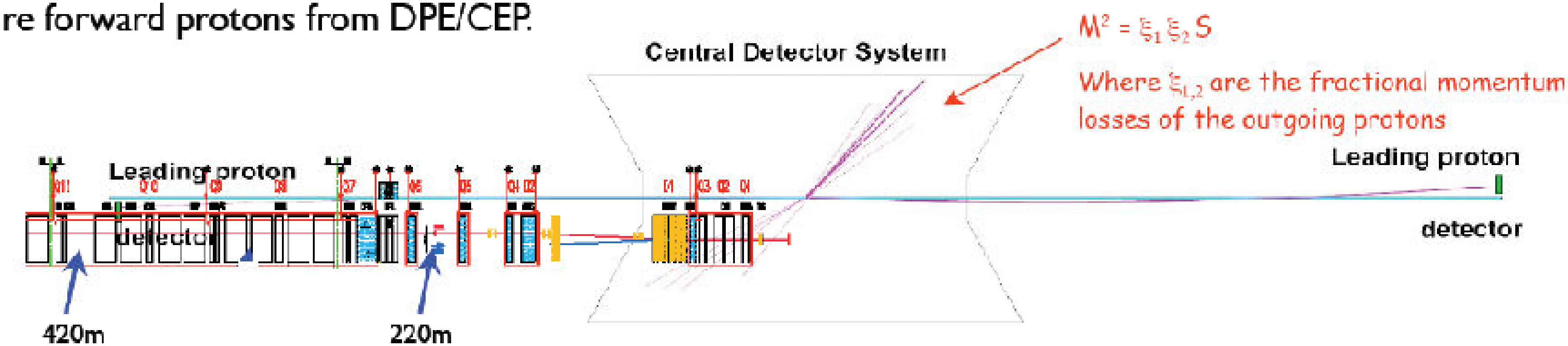
5σ-contours, H→bb, mhmax, μ=200GeV



[EPJC 53 (2008) 231]

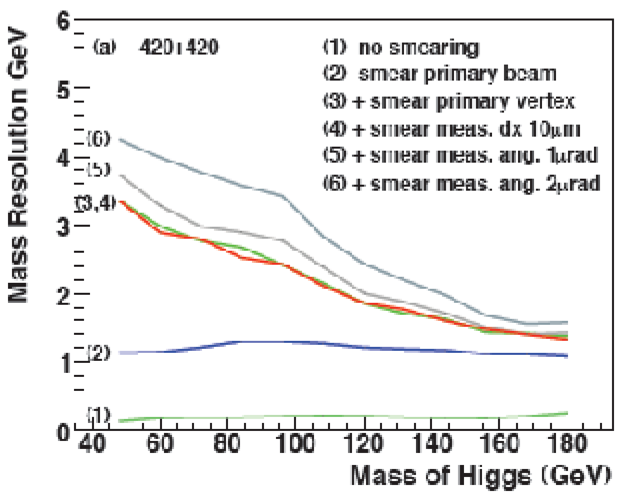
Forward Physics Upgrades for High Lumi

Measure forward protons from DPE/CEP.

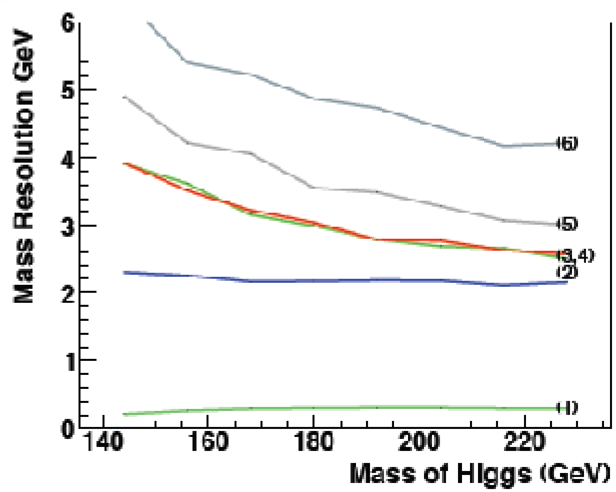


Cold section: detectors have to be integrated with cryostat → modified cryostat

Very good mass resolution from forward protons

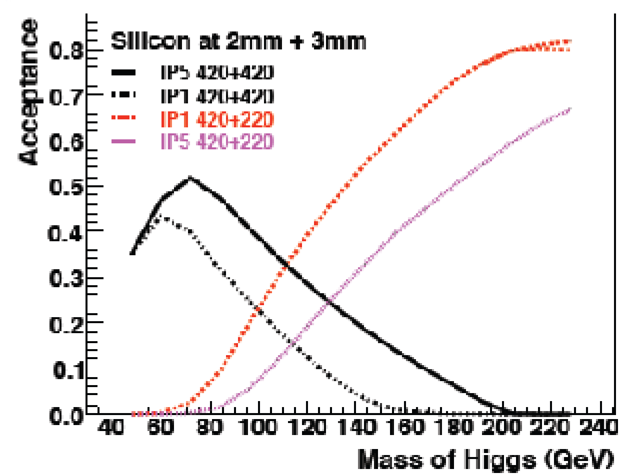


420+420



220+420

Good acceptance for combined detectors at 420m and 220m



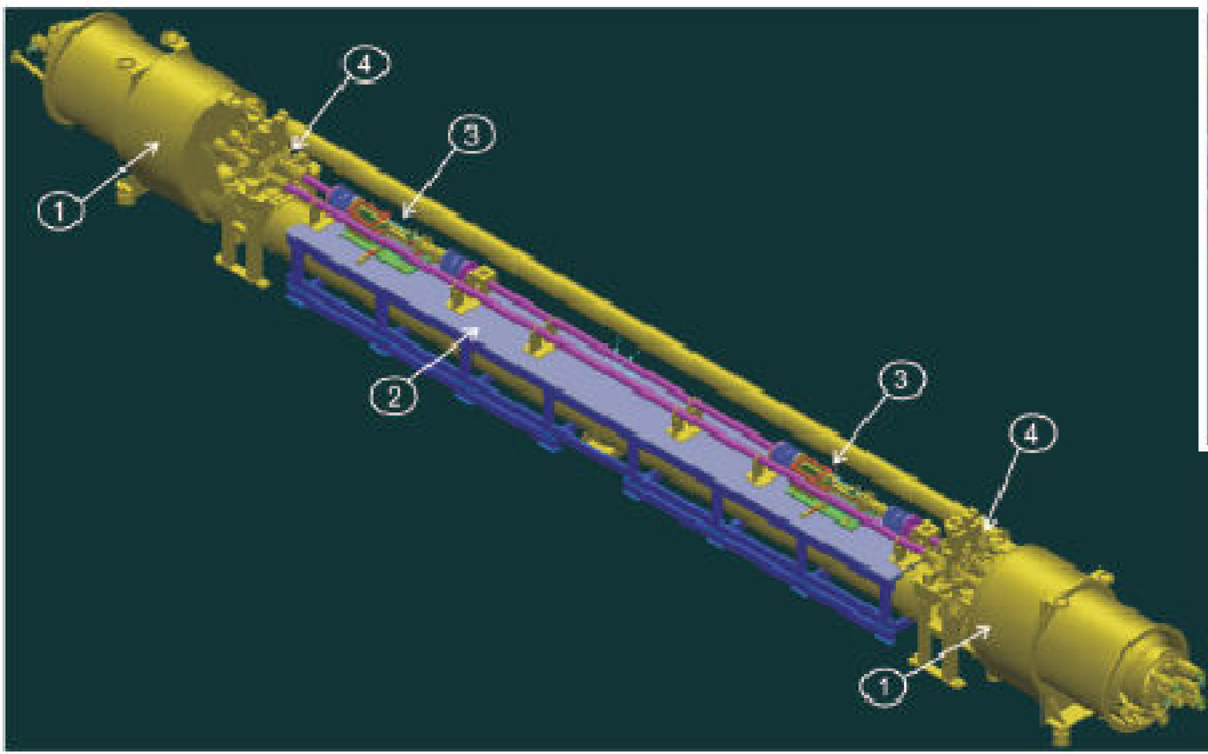
AFP = ATLAS Forward Proton (detectors at 420m and 220m)

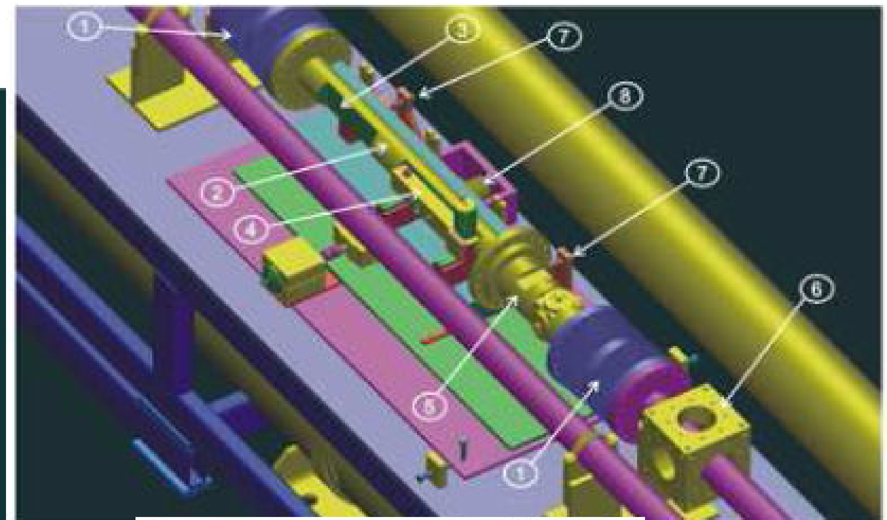
FP420 = Forward Proton at 420m (CMS side)

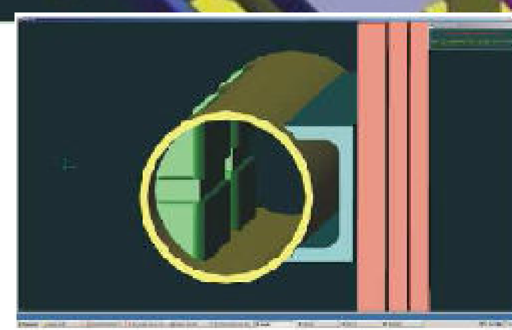
Movable beam pipes at 220 and 420 m

- Movable beam pipe (Hamburg beam pipe) technique used to move the detectors to and from the beam – in horizontal direction.
- First used at PETRA collider, then proven to be viable at ZEUS (for e-tagger)
- Takes less space than Roman Pots
- It will host position as well as timing detectors at 220 and 420 m.

Current design for the 420 m region with
New Connection Crvostat







Position detectors

The same requirements for 220 and 420 m regions:

Close to the beam => edgeless detectors

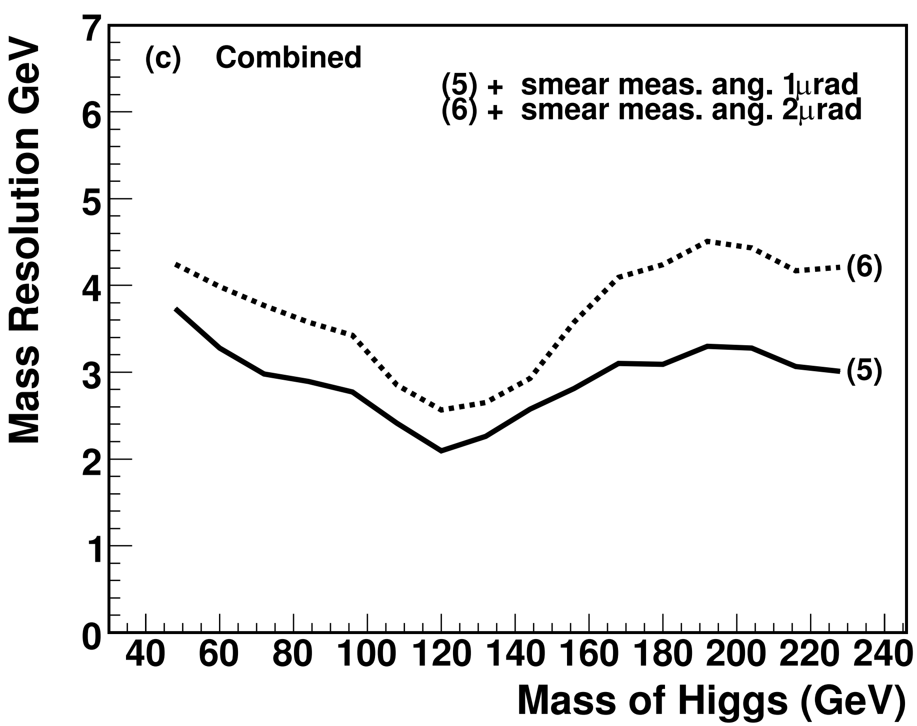
High lumi operation => very radiation hard

Mass resolution of 2-3% => 10-15 μm precision

Suppress pile-up => add fast timing det.

3D Silicon

ATLAS, 1.5 mm (220) and 5 mm (420) from beam

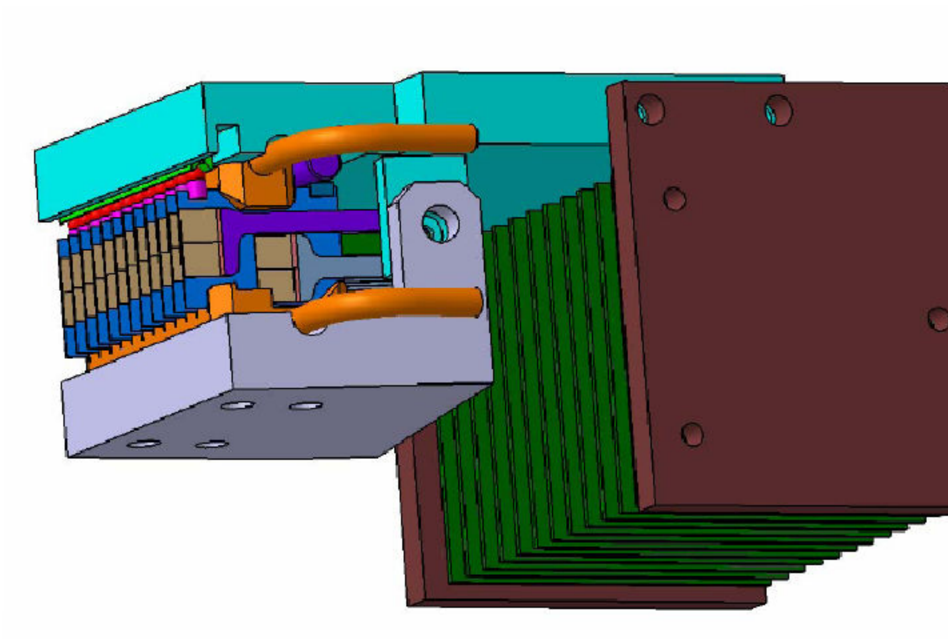


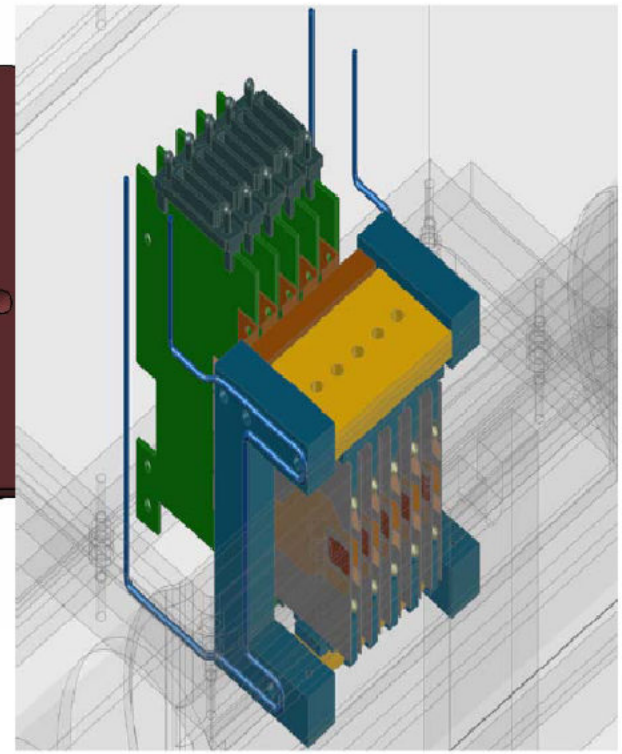
Reconstruct the central mass from the two tagged protons (from their trajectories and incorporating experim. uncertainties):

Beam en.smearing σ_E= 0.77 GeV
Beam spot smearing $\sigma_{x,y}$ = 10 μm
Detector x-position resol. σ_x = 10μm
Detector angular resolution = 1, 2 μrad

[P.Bussey, FP420 TDR]

220 m layout – note that FE-I3/sensor is around 7 x 8 mm²



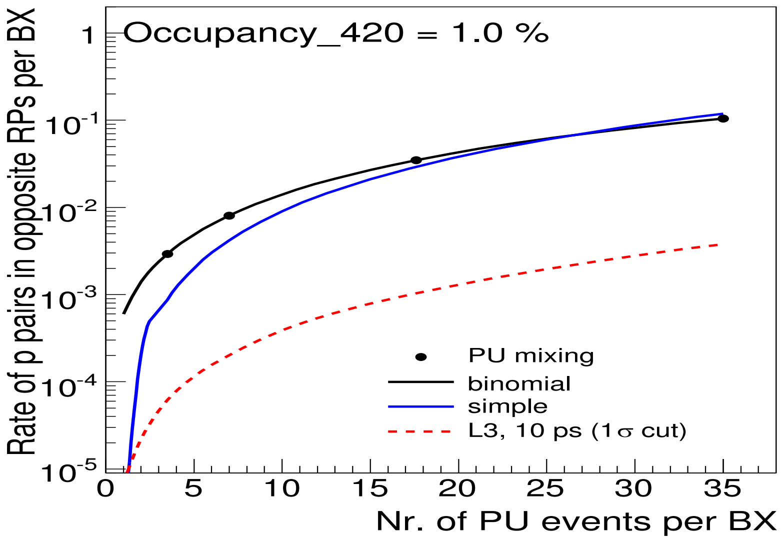


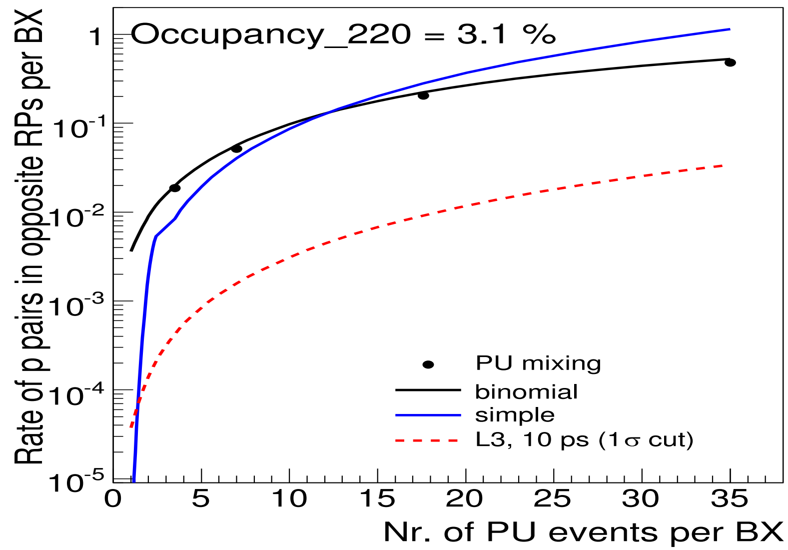
220 Design

Twice FE-I3/sensors per layer compared to 420 design

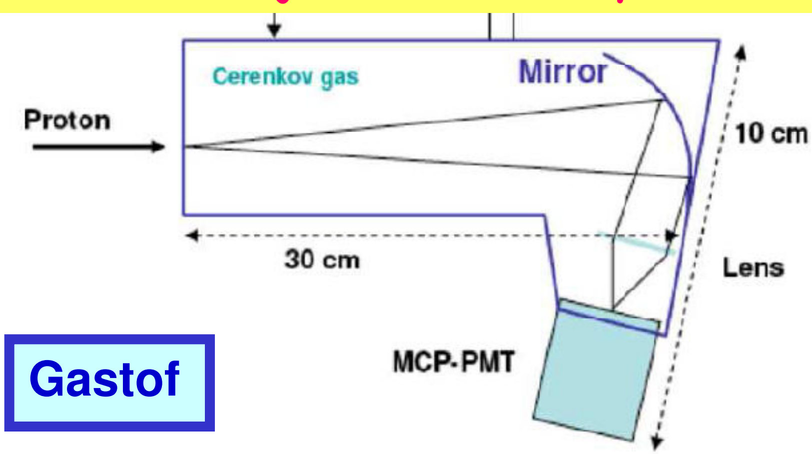
420 Design

PILE-UP (Overlap) Background and Fast Timing detectors



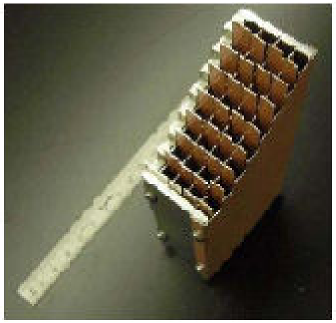


Overlap of three events (2xSD+non-diffr.dijet) in one BX can fake Higgs Signal. Fortunately there are many kinematical cuts that can be used to distinguish between exclusive signal and overlap background. Due to large cross sections for SD (~20mb) and non-diffr.dijets (~μb), additional rejection necessary: REDUCE BY FAST TIMING DET



Gastof

Quartic

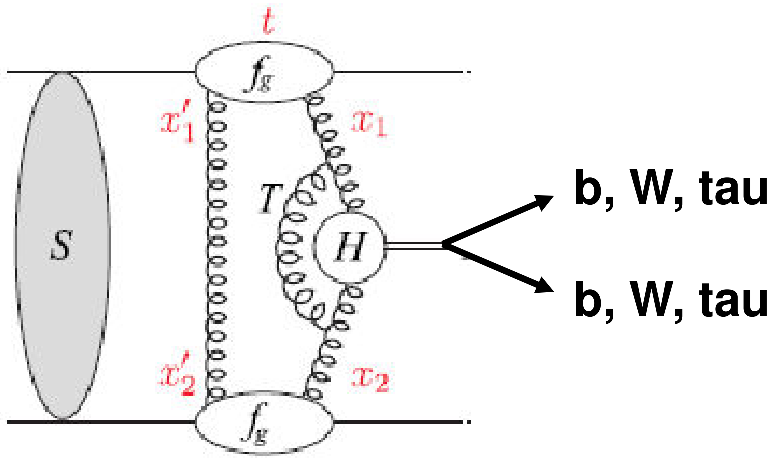


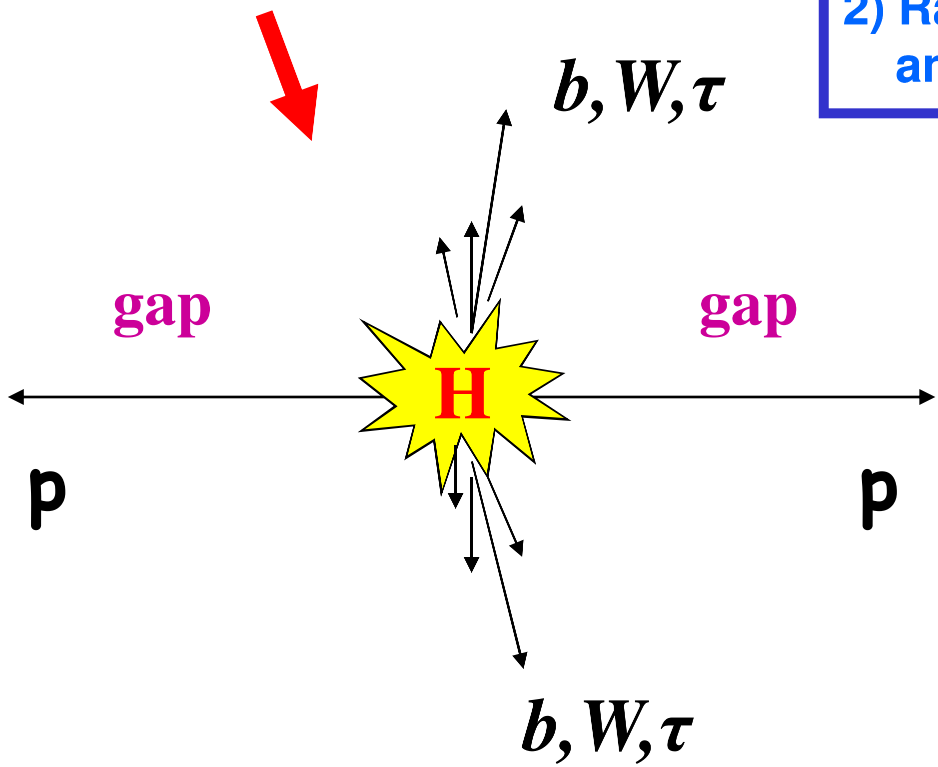
σ_t = 10 ps → σ_{zvtx} =2-3mm
Reject PU bg by factor 20

Test beams: 10ps by Gastof
10-20ps Quartic

UTA, Louvain, Fermilab, Alberta
Saclay, Stony Brook, Chicago Uni,Argonne

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, BPR)

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) Forward detectors 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

↓

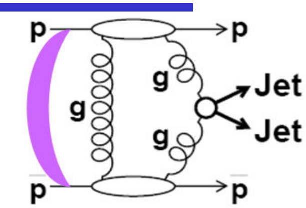
information about Yukawa coupling
(Hbb difficult in standard searches due to huge bg.)

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.

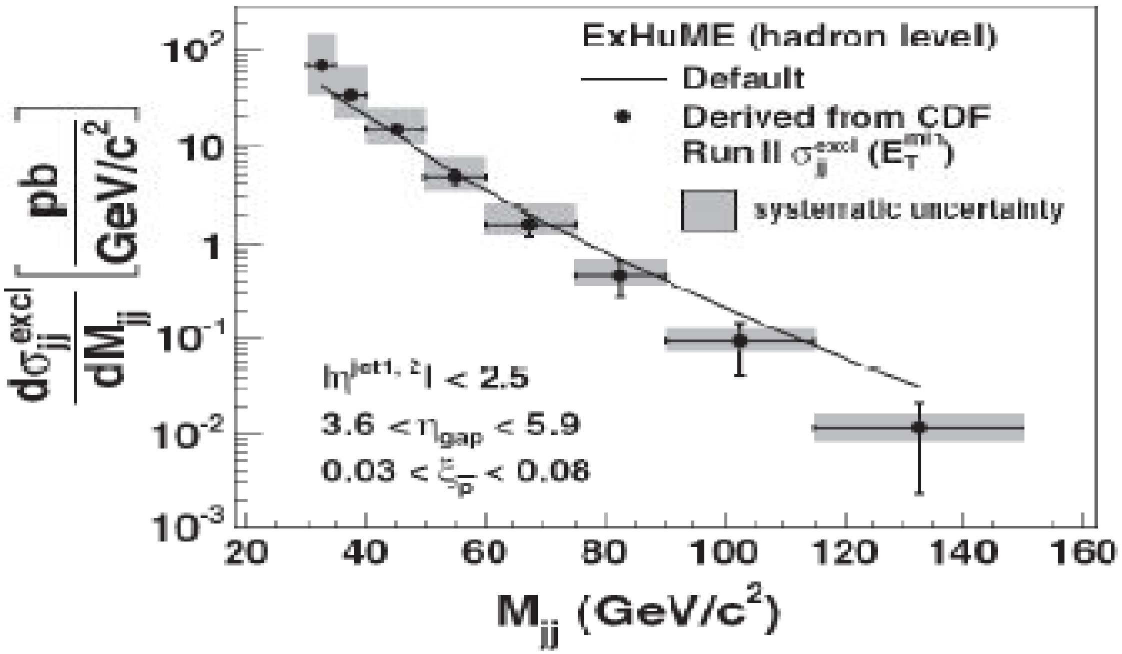
Disadvantages:

- Low signal x-section
- Large Pile-up

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

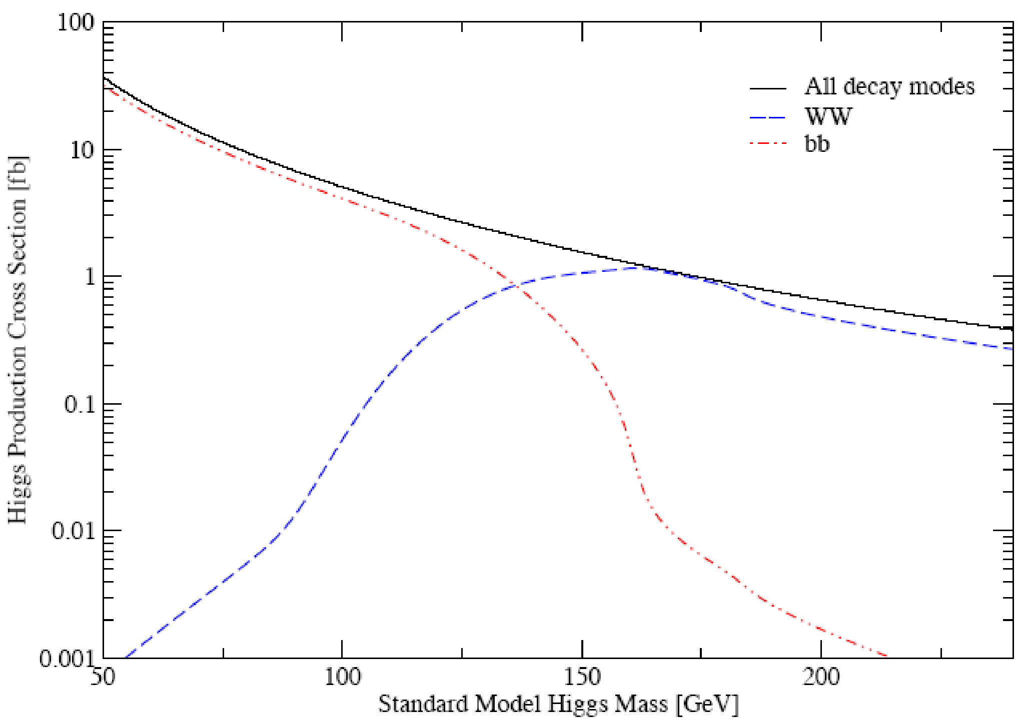
Stat. and syst. errors are propagated from measured cross section uncertainties using M_{jj} distribution shapes of ExHuME generated data.

HERA & LHC 2008 @ CERN May 26-30 Diffractive and Exclusive Dijets and W/Z at CDFD K. Goulianos 32

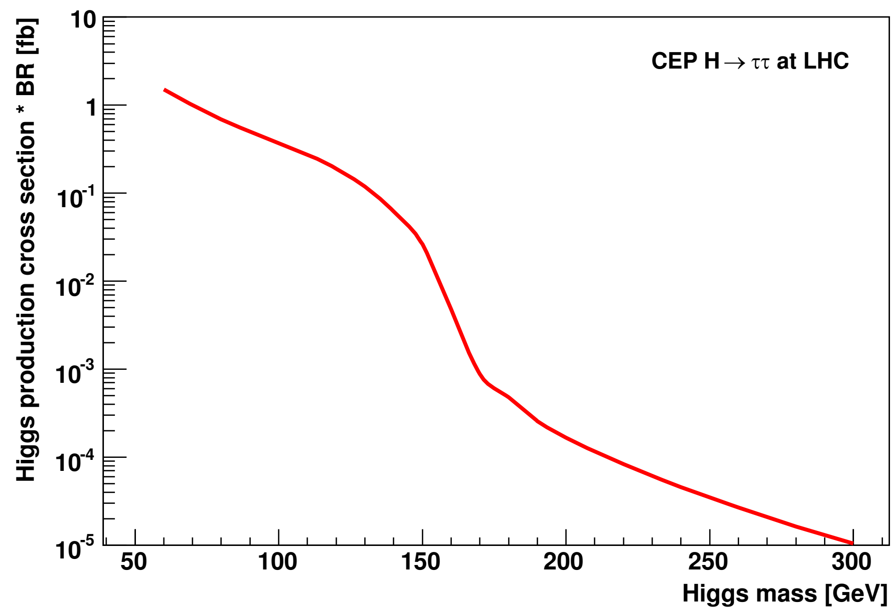
Use ExHuMe as the standard event generator

Cross sections (KMR) and FD Acceptances

M_H [GeV]	σ (bb) [fb]	σ (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 AFP detectors at (220,420) m and 2.5mm,4mm from the beam (1mm dead space)



Analyses on CED Higgs production

CMS:

H→bb: fast simulation, 100 < M_H < 300 GeV, d_{220}~1.5mm, d_{420}~4.5mm, Acc=Acc(ξ,t,φ) **Marek**

- track variables (N_C, $N_C^{\perp}$) not used →PU bg overestimated
- L1 trigger: single-sided FD220 .AND. Etjet1>40.AND. Etjet2>40. No efficiencies applied
- published in CMS-Totem document CERN/LHCC 2006-039/G-124
- signal selection efficiencies used in MSSM study (EPJC 53 (2008) 231)

ATLAS:

H→bb: 1) gen.level + smearing of basic quantities, M_H = 120 GeV **Andy**

- L1 trigger: fixed rates of dijet triggers with prescales
- one MSSM point (tanβ = 40): JHEP 0710 (2007)090

2) fast simulation, M_H = 120 GeV

- L1 trigger: significant progress documented in ATLAS Note
  Efficiencies and prescales easily applicable offline
- common ATLAS note in preparation **Vojta**

H→WW: fast + full simulation, M_H = 160 GeV

- common ATLAS note in preparation **Arnab+Andrew**

H→tautau: full simulation, 100 < M_H < 300 GeV (designed for a MSSM study) **Vlasta**

All ATLAS analyses use d_{220}~2-3mm, d_{420}~4-5mm, Acc=Acc(ξ,t)

Selection cuts for $H \rightarrow bb$ at M_H=120 GeV

1) FD acceptances: (420.and.420).or.(420.and.220).or.(220.and.420)

Acc(ξ,t): $0.002 < \xi < 0.2$, $0.0 < t < 2$ GeV2, $0 < \varphi < 2\pi$

d(420,220) = (4,2.5)mm(dead space=1mm): Acc(420+420) ~ 20%, Acc(420+220) ~ 17%

2) jets: two b-tagged jets

$E_{T1} > 45$ GeV, $E_{T2} > 30$ GeV, $|\eta_{1,2}| < 2.5$, $3.0 < |\varphi_1 - \varphi_2| < 3.3$

3) Kinematics constraints – matching criteria: $0.75 < R_j < 1.2$, $|\Delta y| < 0.1$

4) L1 triggers:

420+220: J20J40 + FD220 + $\bar{\eta} < 0.5$ + $|\Delta\eta| < 2$ + $f_T > 0.45 \rightarrow 2.9$ kHz at 10^{34}

420+420: J20J40 + $\bar{\eta} < 0.5$ + $|\Delta\eta| < 2$ + $f_T > 0.45 \rightarrow 21$ kHz at 10^{34}

5) Mass windows: $117.6 < M_{420} < 122.4$, $114.2 < M_{420+220} < 125.8$

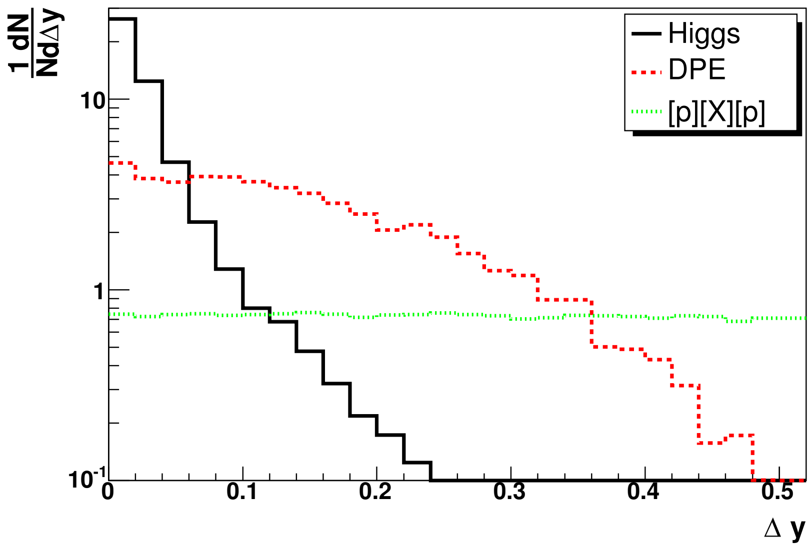
(3σ – windows)

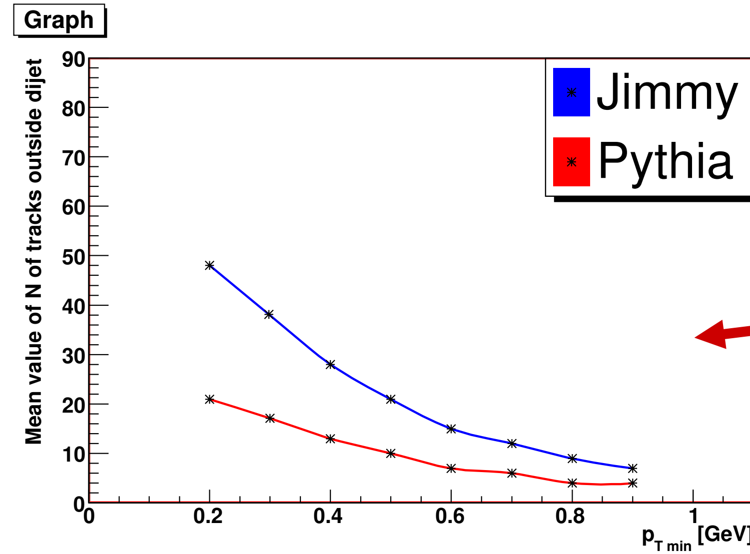
6) PU bg suppressors:

$N_C < 3$. AND. $N_C^{\perp} < 1$

- reduction factor ~20 from fast timing detector

PU background suppressors





This difference has big impact on PU-bg rejection

-

$$\Delta y = (\eta_{jet1}+\eta_{jet2})/2 - y_X$$

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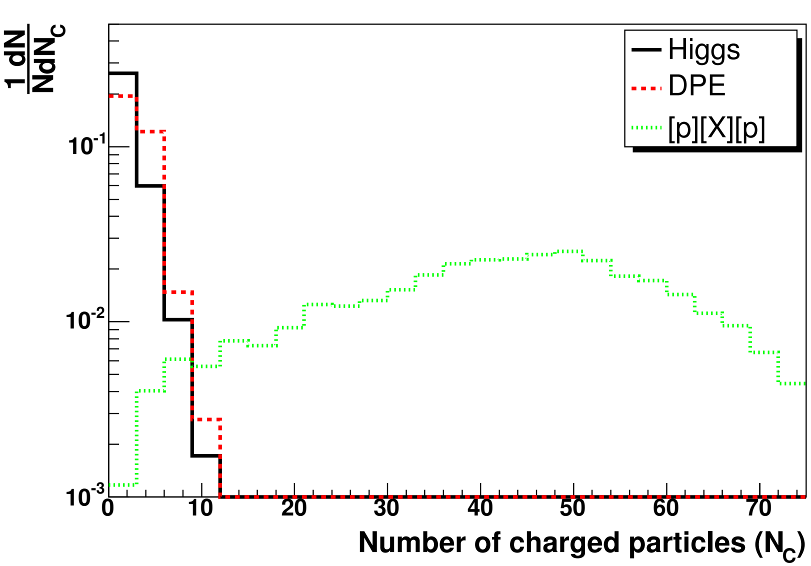
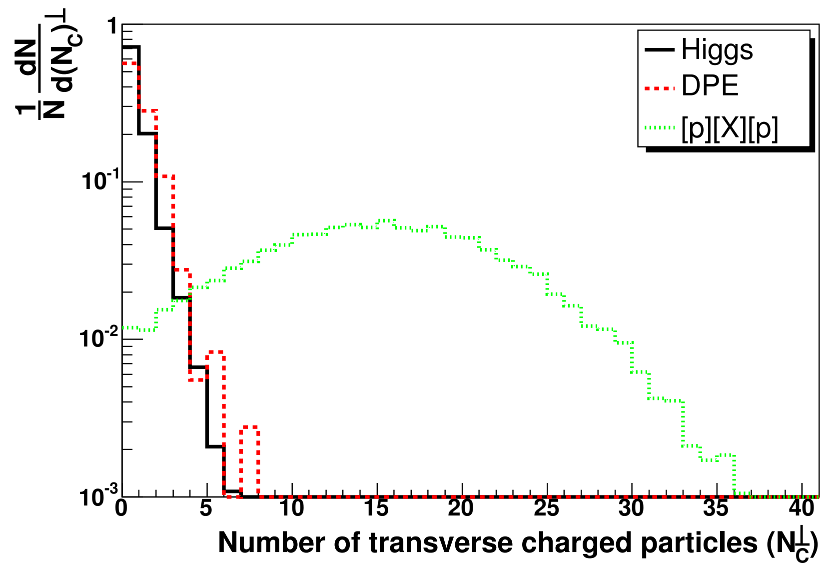
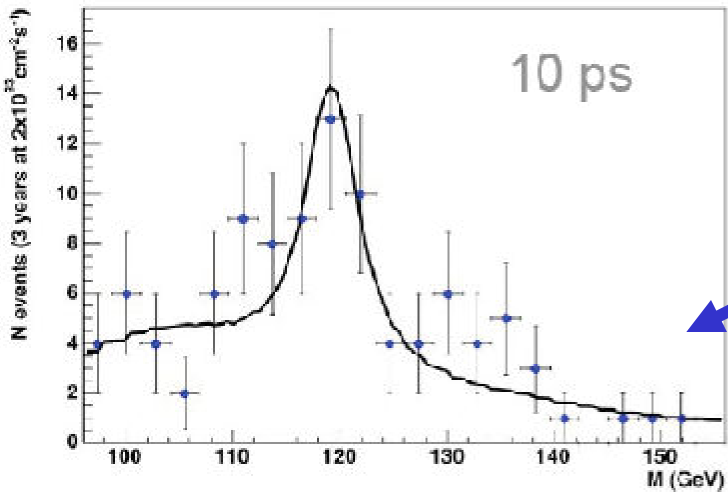




CED H→bb using Forward Proton Tagging

h→bb, mhmax scenario, standard ATLAS L1 triggers, 420m only, 5 mm from beam

Huge Pile-up bg for diffractive processes: overlap of three events (2* SD + non-diffr. Dijets). Can be reduced by Fast Timing detectors: t-resol. required: 2 ps for high lumi!

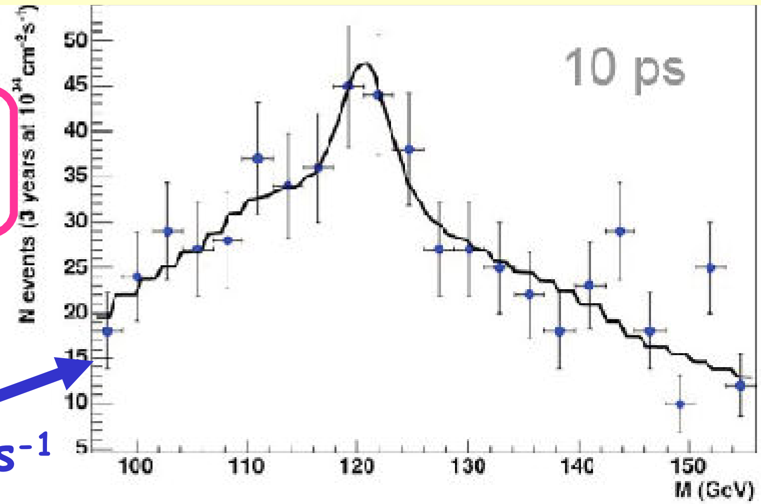


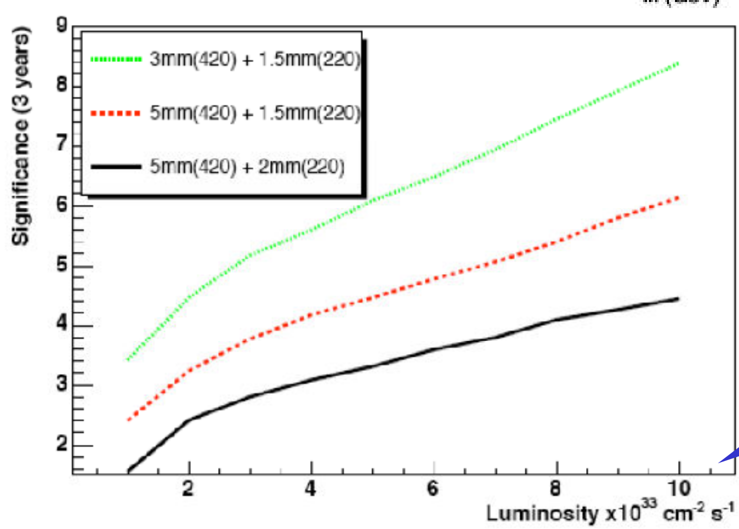
JHEP 0710:090,2007

m_A=120 GeV, tanβ=40
$\sigma_{h\to bb}$=17.9 fb

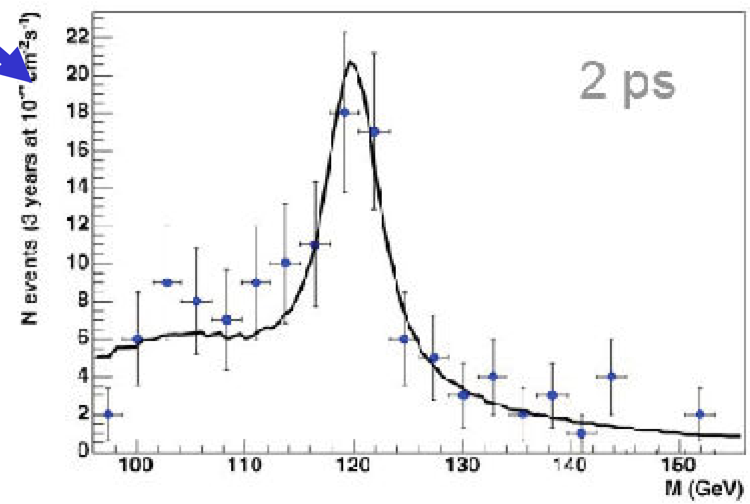
3 years at 2×10^{33}cm^{-2}s^{-1}

3 yrs at 10^{34}cm^{-2}s^{-1}





Assume 220m Pots at L1
High signific. for detectors close to beams



L1 trigger for low mass H→bb in ATLAS

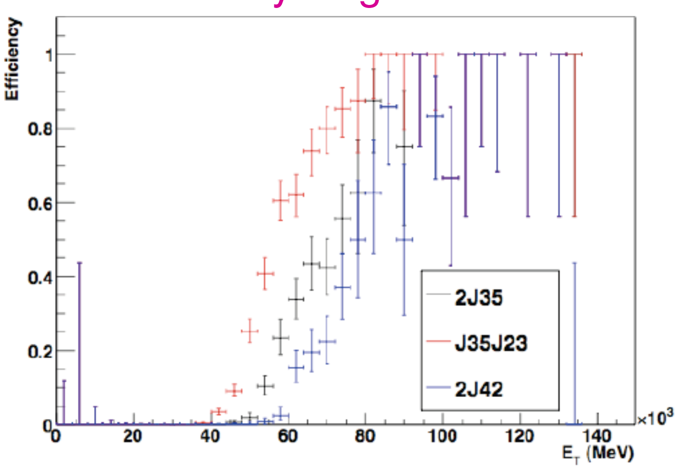
- ATLAS-COM-DAQ-2009-062: Reasonable trigger rates/efficiencies expected for low mass CED H→bb using AFP if :

1) AFP-220 trigger is capable of triggering only on hits in the inner 4.5 mm part
2) The L1-calorimeter is capable of defining new exclusivity criteria using E_T, η and φ (ask for that in the planned L1 calorimeter upgrade)

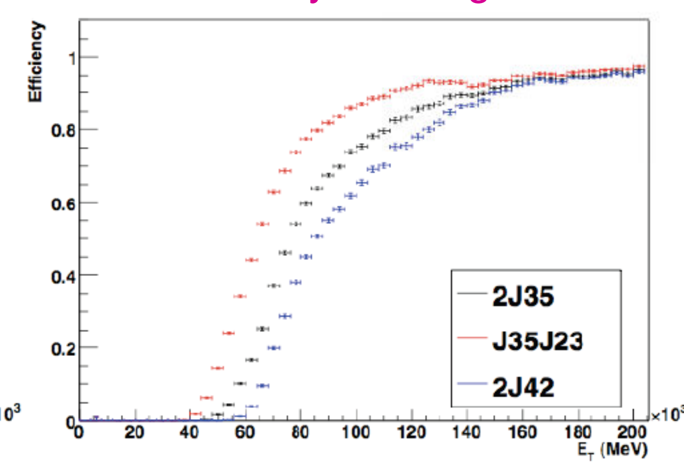
Di-jets | Proton tag | $\bar{\eta}$ | $\Delta\eta$

L1 item	Rate at 2×10^{33} (kHz)	Rate at 10^{34} (kHz)
J23+J35 + p220 + X_A=0.5 + X_D=1.5 + $\Delta\phi > 2.5$	0.61	14.8
J23+J35 + p220 + X_A=0.5 + X_D=1.5 + $f_T > 0.45$	0.12	2.9
J20+J40 + p220 + X_A=0.5 + X_D=1.5 + $\Delta\phi > 2.5$	0.51	12.2
J20+J40 + p220 + X_A=0.5 + X_D=1.5 + $f_T > 0.45$	0.12	2.9

Efficiency –signal



Efficiency – background



Possible improvements:

- calculate M_{jj} in global merger processor
- additional segmentation of L1 trig at 220 (0.5-1mm strips) allow finer cuts on average η
- external muon input to L1 calo-trig

Selection cuts for $H \rightarrow WW$ at M_H=160 GeV semi-leptonic $W \rightarrow \mu\nu jj$-decays

1) FD acceptances: (420.and.420).or.(420.and.220).or.(220.and.420)

Acc(ξ,t): $0.002 < \xi < 0.2$, $0.0 < t < 2$ GeV^2, $0 < \varphi < 2\pi$

d(420,220) = (4,2.5)mm(dead space=1mm): Acc(420+420) ~ 11%, Acc(420+220) ~ 45%

2) jets: two jets

$E_{T1,2} > 25$ GeV, $|\eta_{1,2}| < 3.2$

3) Kinematics constraints – matching criteria: $E_T^{miss} > 25$ GeV, $0.6 < r_{cm} < 1.3$, $|\Delta y| < 0.4$, $|\Delta yM| < 1.3$

$r_{cm}=m_c/M_{mm}$, $m_c=\mathrm{sqrt}(p_T^2(jjl)+m_{jjl}^2)+E_T^{miss}$

$\Delta yM = \cosh^{-1}(M_{mm}/2(p_{T,j1}+p_{T,j2})) - \Delta y$

4) L1 triggers:

Leptonic triggers

(All assuming 100%-efficient)

5) Mass windows: $157.9 < M_{420} < 162.1$, $153.2 < M_{420+220} < 166.8$

(3σ – windows)

6) PU bg suppressors:

$N_C < 4$

- reduction factor 20 from fast timing detector

Selection cuts for H→tautau at M_H=120 GeV for all tau-decays

1) FD acceptances: (420.and.420).or.(420.and.220).or.(220.and.420)

Acc(ξ,t): $0.002<\xi< 0.2$, $0.0<t<2$ GeV^2, $0<\varphi<2\pi$

d(420,220) = (4,2.5)mm(dead space=1mm): Acc(420+420) ~ 20%, Acc(420+220) ~ 17%

2) Kinematics constraints: $E_{T,jet}$ > 20 GeV, $|\eta jet| < 5.0$, $|\eta_{lepton}|<2.5$,

fully hadronic events: jets sharply back-to-back: $3.08 < |\Delta\varphi_{jet}| <3.15$

Suppress QED γγ background: p_T^{prot} > 0.2 GeV

3) Only use jets identified as tau-candidates:

Loose method for tau-finder still gives very good efficiencies and purities

4) L1 triggers:

Leptonic triggers:

2e (p_T >15) .OR. 2e (p_T^{max} >25) .OR. 2μ (p_T >10) .OR. 2μ (p_T^{max} >20) .OR.

eμ (p_T^e >15. AND. P_T^μ >10) .OR. eμ (p_T^e >25 .OR. P_T^μ >20)

(All assuming 100%-efficient)

5) PU bg suppressors: tau-jets have very few particles

S/B for SM Higgs for L=30 fb^{-1}

$M_H = 120$ GeV	**Andy** (2mm/5mm)		**Vojta** (2mm/4mm)		**Marek** (1.5mm/4.5mm)	
Process	420+420	420+220	420+420	420+220	420+420	420+220
CED $H \to b\bar{b}$	2.1	1.2	1.8	1.2	0.6	0.9
CED $b\bar{b}$	1.1	1.0	0.8	1.3	1.0	1.5
CED gg	2.5	2.7	0.8	2.5	-	-
Incl. DPE $b\bar{b}$	0.1	0.1	~ 0	0.2	~ 0	~ 0
Overlap	0.4/24.0	0.4/20.0	0.1/17.9	0.1/40.0	-	-

H → bb: S/B ~1 up to 1-2*$10^{33}cm^{-2}s^{-1}$, trigger eff.(~50%) and prescales not included

•

$M_H = 160$ GeV	**Arnab** (2.5mm/4mm(1mm))	
Process	420+420	420+220
CED $H \to WW$	0.19	0.75
Excl. $\gamma\gamma \to WW$	0.01	0.40
Overlap	0.00/0.01	0.00/0.28

H → WW: S/B ~1 up to $10^{34}cm^{-2}s^{-1}$, only semi-leptonic W→μνjj decays

Agrees with published generator-level estimates (EPJC 45 (2006) 401), fully-lept adds 1 event

$M_H = 120$ GeV	**Vlasta** (2.5mm/4mm(1mm))	
Process	420+420	420+220
CED $H \to \tau\tau$	0.15	0.1
CED gg	?	?
Excl. $\gamma\gamma \to ll$	?	?
Overlap	?/?	?/?

H → tautau:

Luminosity scenario for H→bb

Assume: Lumi store lifetime ~ 15 hours
Lumi store start at $10^{34}cm^{-2}s^{-1}$
LHC year 10^7s ~ 45 pb^{-1}
L1 trigger prescales for 420+420 and 420+220 events as obtained in Trigger Note
Integrated lumi ~ 300 fb^{-1} was collected in this manner

proposed by Andrew Brandt

Hours into store	0-1	1-3	3-7	7-11	11-15
Integrated Luminosity (fb-1)	42	73	97	55	33
Instantaneous Luminosity (10^{34})	1.0	0.88	0.67	0.39	0.23
Average Lum (10^{34})		0.78	0.54	0.32	0.2
220-420 with f_t kHz (prescale)	-	2.2 (1)	1.3(1)	0.4(1)	0.2(1)
420-420 with f_t kHz (prescale)	-	-	1.8(10)	2.8 (5)	2.4(2)
Total Rate (kHz)	0	2.2	3.1	3.2	2.6

This scenario increases the significance by a factor 2 wrt the scenario with integrated lumi of 300 fb^{-1} collected at $10^{34}cm^{-2}s^{-1}$

MSSM and CED go quite well together

The *intense coupling regime* is where the masses of the 3 neutral Higgs bosons are close to each other and tan β is large

Extended Higgs sectors: "typical" features

Search for heavy MSSM Higgs bosons ($M_A, M_H \gg M_Z$):

Decouple from gauge bosons

$\Rightarrow$ no HVV coupling

$\Rightarrow$ no Higgs production in weak boson fusion

$\Rightarrow$ no decay $H \to ZZ \to 4\mu$

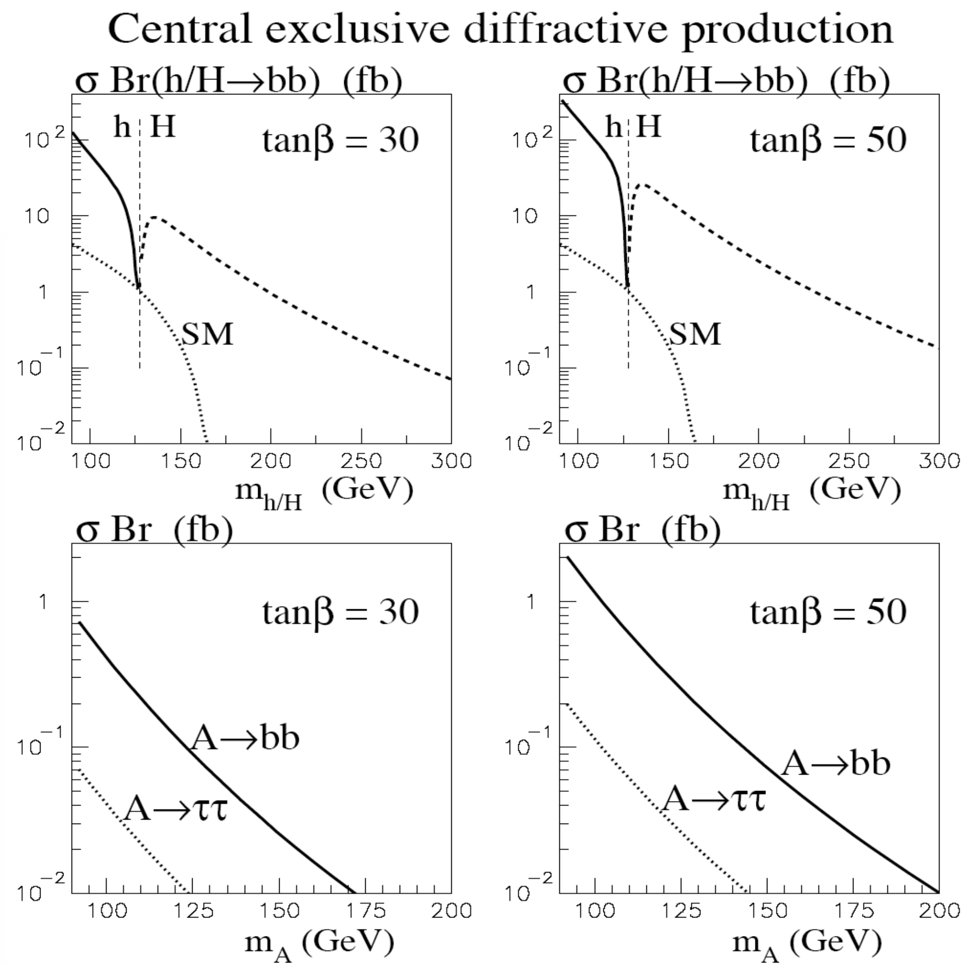
Large enhancement of coupling to $b\bar{b}$, $\tau^+\tau^-$ for high $\tan\beta$

$\Rightarrow$ Decays into $b\bar{b}$ and $\tau^+\tau^-$ play a crucial role

"Typical" features of models with an extended Higgs sector:

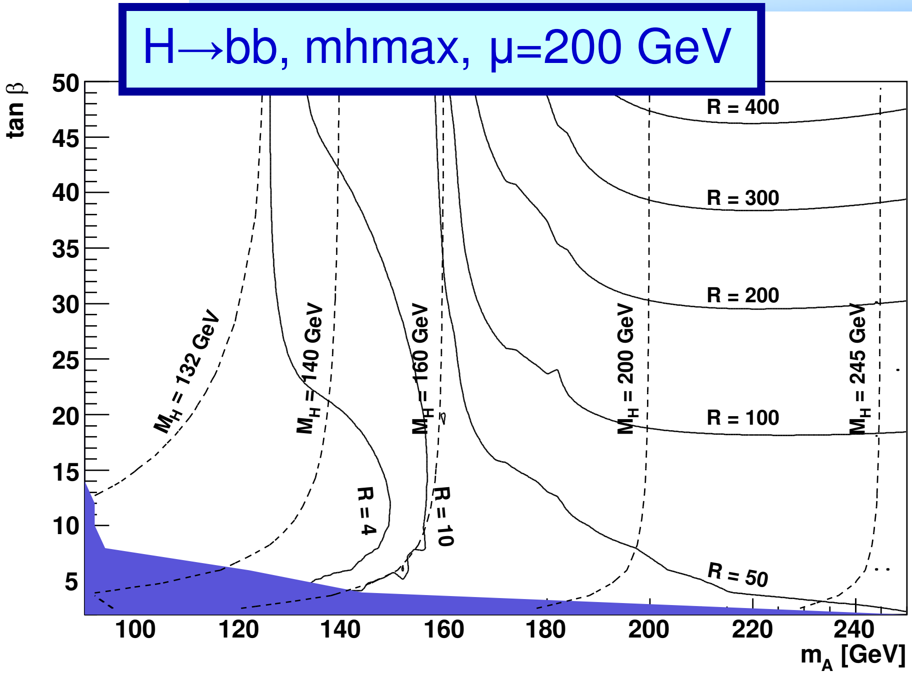
- A light Higgs with SM-like properties, couples with about SM-strength to gauge bosons
- Heavy Higgs states that decouple from the gauge bosons

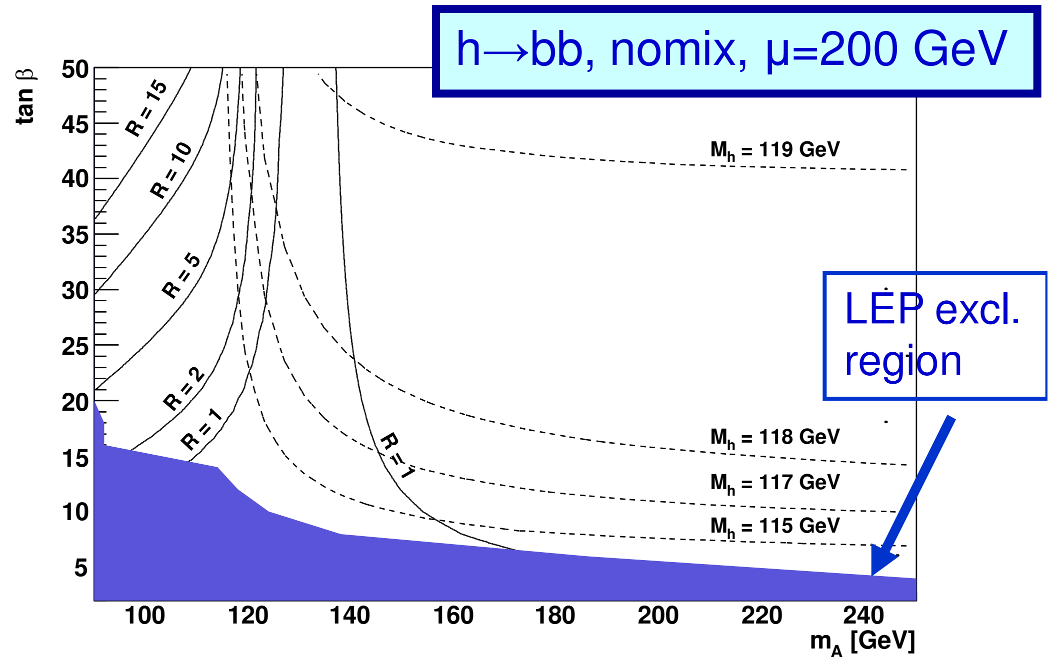
Studying the MSSM Higgs Sector by Forward Proton Tagging at the LHC, Georg Weiglein, EPS07, Manchester, 07/2007 – p.3

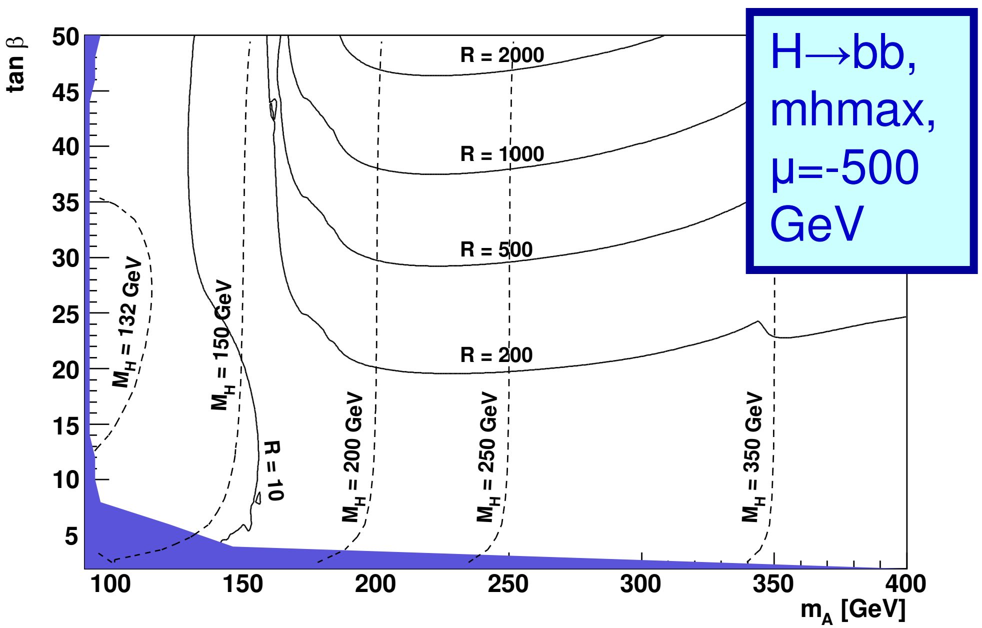


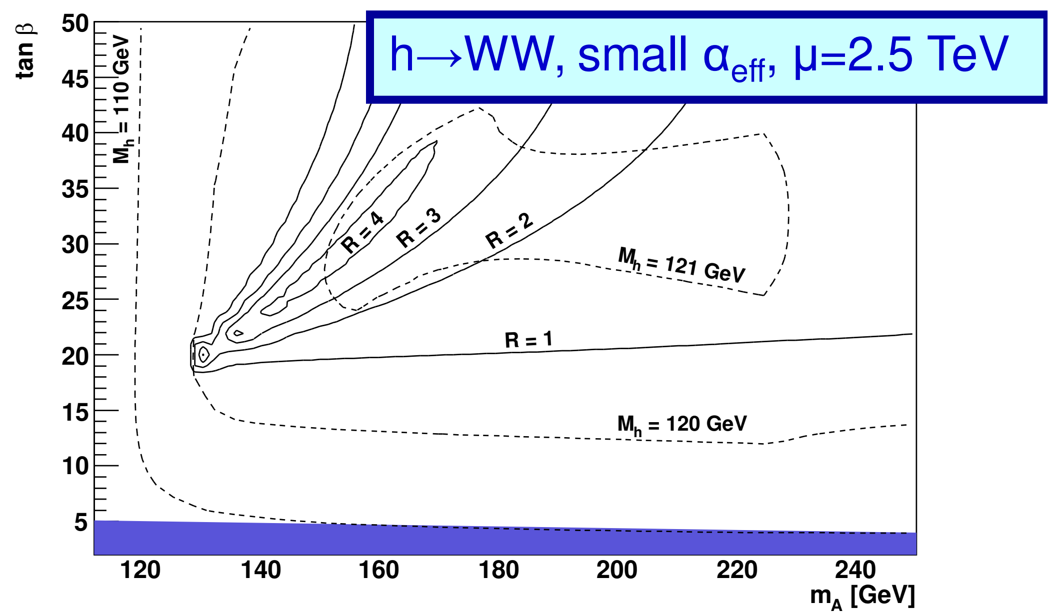
Well known difficult region for conventional channels, tagged proton channel may well be the *discovery channel* and is certainly a powerful *spin/parity filter*

R=MSSM[M,tanβ] / SM[M]

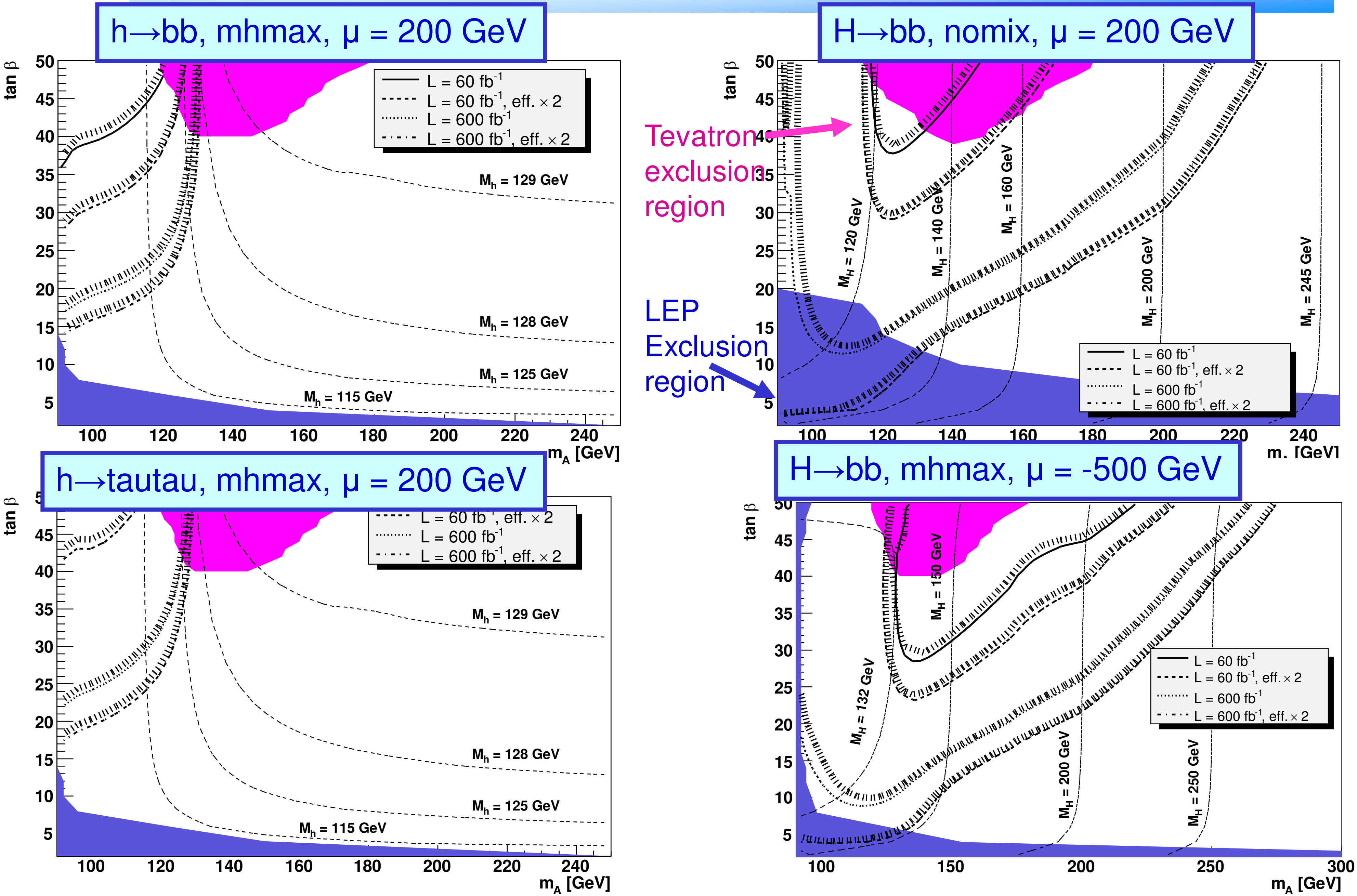








5σ-contours



h→bb, mhmax, μ = 200 GeV
H→bb, nomix, μ = 200 GeV
h→tautau, mhmax, μ = 200 GeV
H→bb, mhmax, μ = -500 GeV
Tevatron exclusion region
LEP Exclusion region
tan β
m_A [GeV]
L = 60 fb^-1
L = 60 fb^-1, eff. × 2
L = 600 fb^-1
L = 600 fb^-1, eff. × 2
M_h = 129 GeV
M_h = 128 GeV
M_h = 125 GeV
M_h = 115 GeV
M_H = 120 GeV
M_H = 140 GeV
M_H = 160 GeV
M_H = 200 GeV
M_H = 245 GeV
M_H = 132 GeV
M_H = 150 GeV
M_H = 250 GeV

Summary

- **AFP = 220 m: horizontal movable beam pipe for position and timing detectors**
  420 m: horizontal movable beam pipe for position and timing detectors
  inside a new connection cryostat
- Position detectors at 220 and 420 m: 3D Silicon
- Timing detectors: a few ps needed to reject pile-up bg at high lumi
- **Decision of the review committee to be taken in Oct. 2009**
- Developments in 3D Silicon and fast timing detectors very useful for other projects in particle physics and medical applications

220m and 420m tagging detectors have the potential to add significantly to the discovery reach of ATLAS for modest cost, particularly in certain regions of MSSM. Besides the discovery physics, there is a rich QCD and EW physics program

CED Higgs analyses:

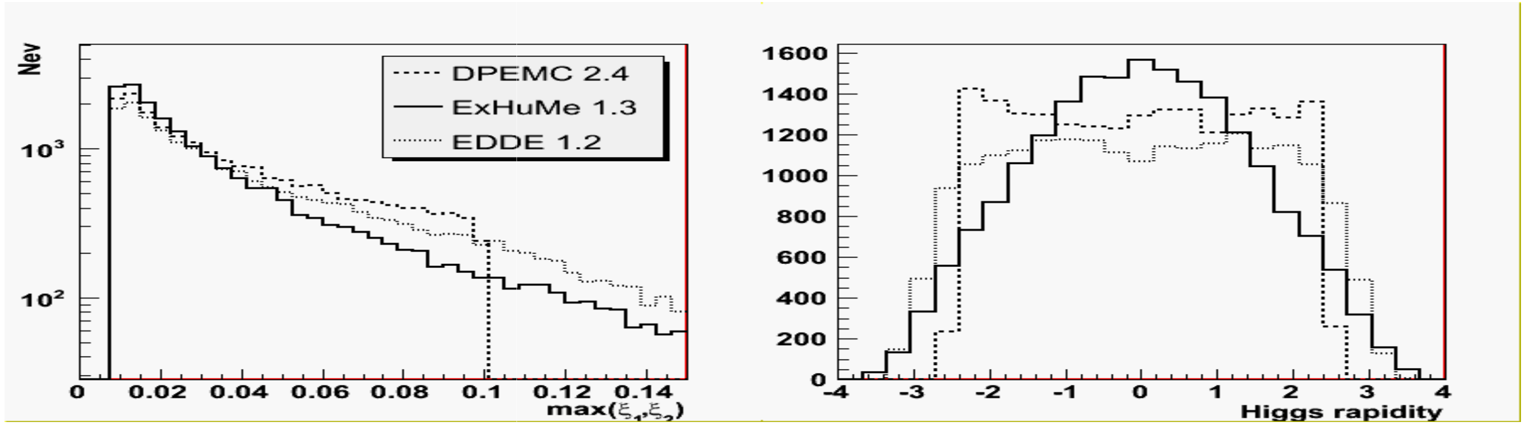
1) CED SM Higgs production provides a moderate signal yields but it is attractive because
   - a few events is enough to establish the quantum numbers of a Higgs candidate
   - gives information about Hbb Yukawa coupling – which is difficult in standard searches
   - in MSSM the signal yields are greatly enhanced
   - in MSSM it gives information about Higgs sector
   - in MSSM the Higgs width may be directly measured (for large tanβ)

2) Agreement between published generator level predictions and ATLFAST for both, $H \rightarrow bb$ and $H \rightarrow WW$. Common ATLAS note on fastsim results on bb and WW will include a possible lumi scenario for bb at 120 GeV.

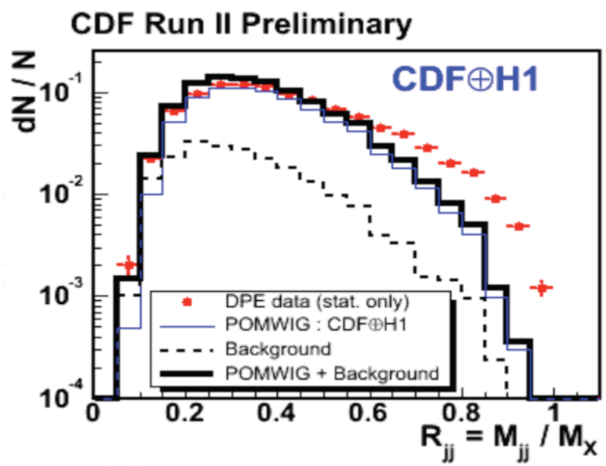
BACKUP SLIDES

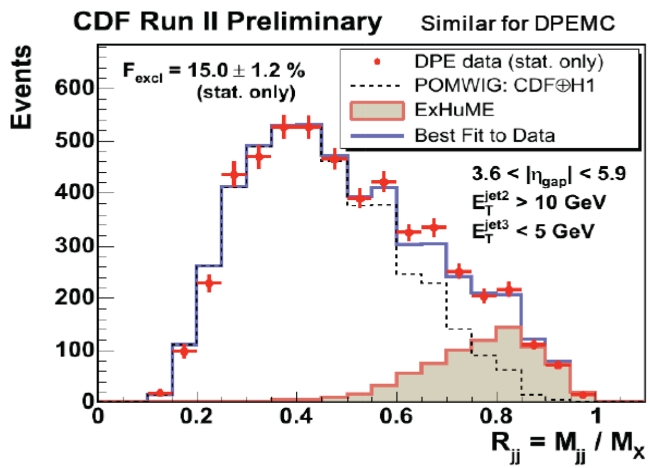
MC generators

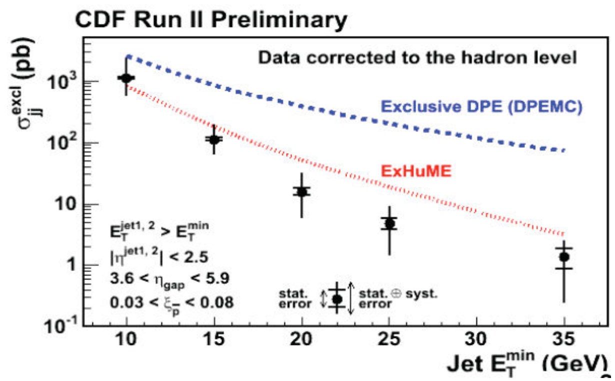
There are three generators for the signal: EDDE, DPEMC and ExHuMe.
Although all were giving similar x-sections at M_H = 120 GeV for H->bb, we observed striking differences :



So which one is best? We let the data decide:



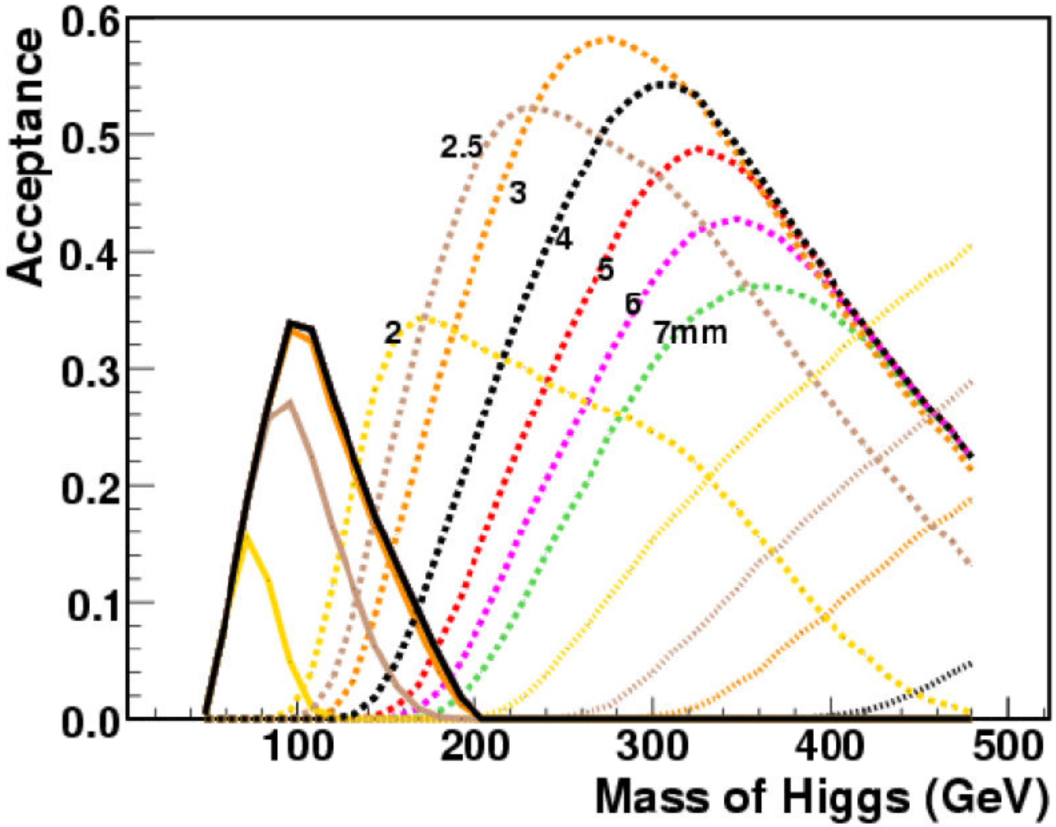




And since since 2007, all analyses use ExHuMe as the principal signal generator. DPEMC developed in FPMC, a modern model offering other interesting processes such as photon-photon, proton dissociation etc.

Acceptances

Acceptances depend heavily on the distance from the beam and dead space!
(if protons hit the dead space in 220 station, they are lost for 420 measurement)
Acceptance for 420+420, 420+220 and 220+220. Numbers mean total distances.
420 at 6 mm everywhere, 220 varying from 2mm to 7mm



Peter

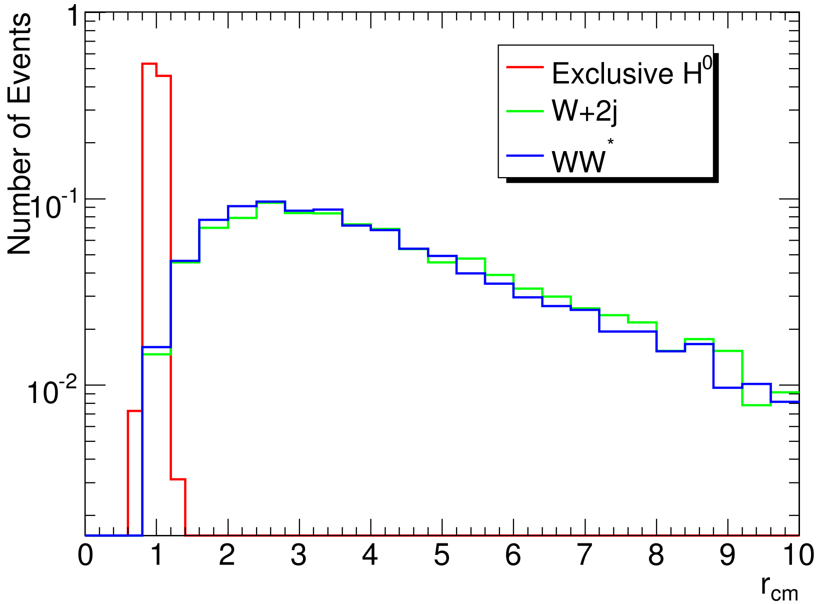
Dead space = 1.1mm

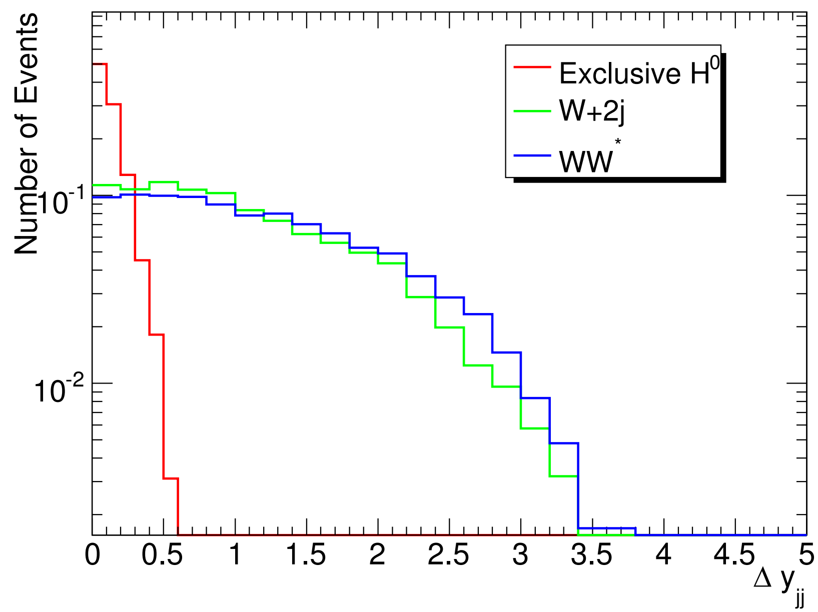
220 at 2mm obstructs the tracking at 420 !

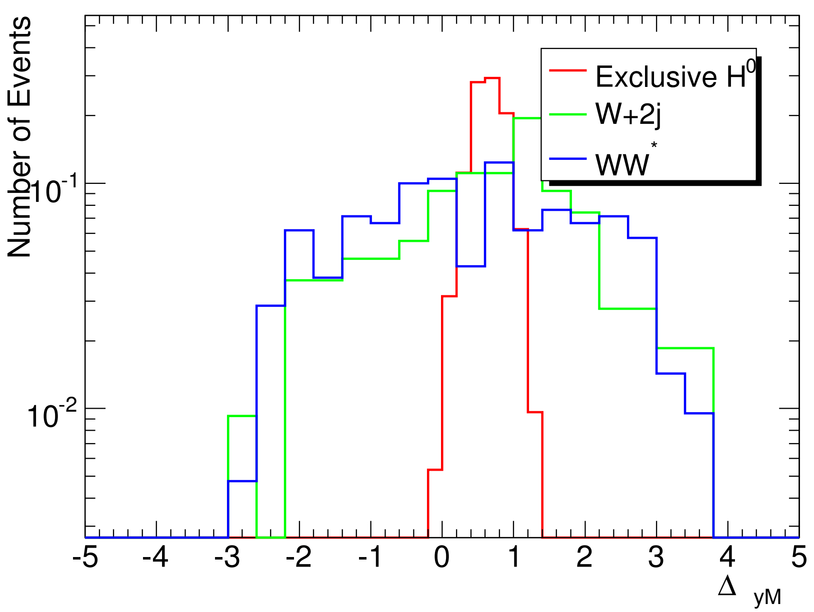
Dead space of 1.1 mm is too cautious.
Peter will make this plot for dead space of 0.5mm.
In the following analyses, dead space=0mm

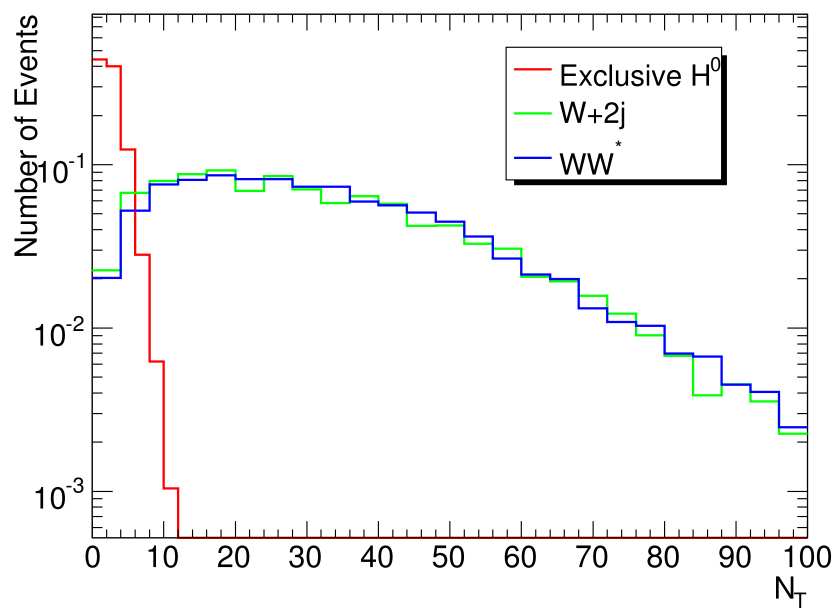
15 σ^{beam} ~ 1.5 mm
(thin window (400μm) + safety offset (300μm) + edge (5μm) + alignment) ~ 0.7 mm
Conservative guess of distance between beam center and first sensor : **2.2 mm**

Kinematics and matching for hl decays of WW





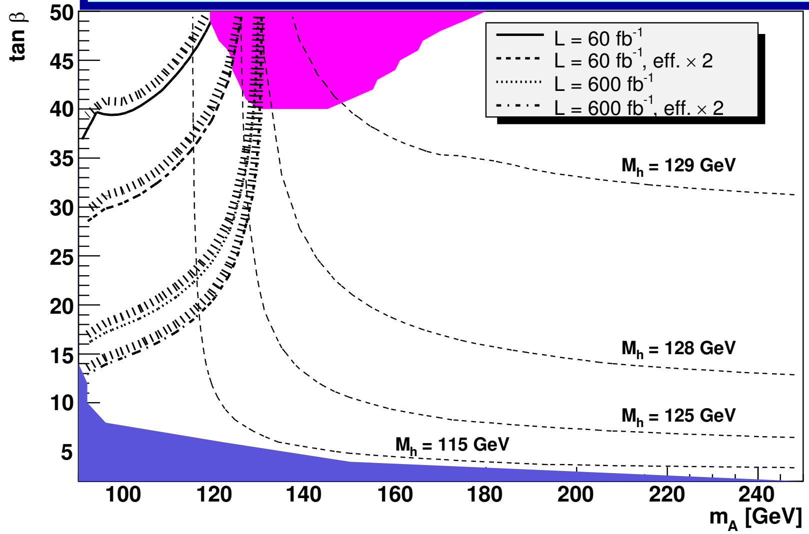




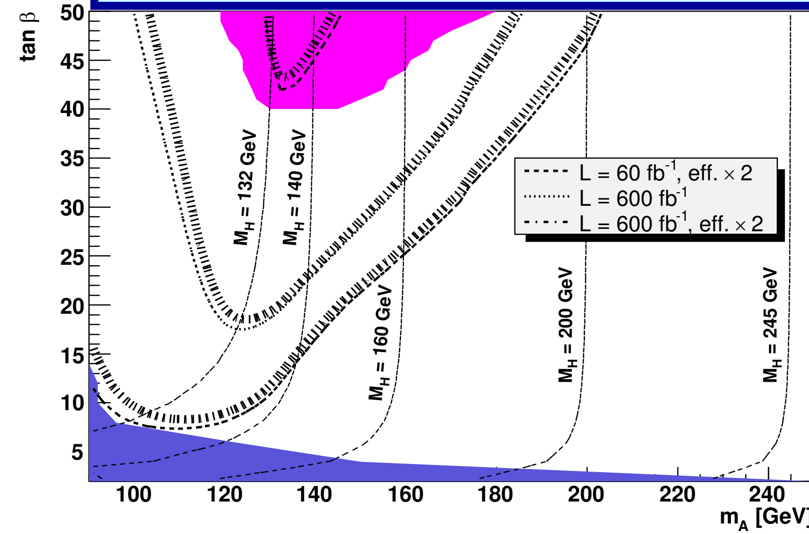
H → tau tau in MSSM

- 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→ll (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