

Some thoughts on possible benchmark scenarios for the NMSSM

- Define typical or challenging scenarios for Higgs boson discovery at the LHC
- Six Higgs bosons: $H_1, H_2, H_3, A_1, A_2, H^\pm$
- 6 parameters in Higgs-sector at tree-level: $\lambda, \kappa, \tan\beta, \mu_{\text{eff}}, A\lambda, A\kappa$
 - ⇒ scan parameter space over these parameters, but in which combination?

Nothing final yet, help & suggestions highly welcome !

Plots done using NMHDECAY, $m_{\text{top}}=172$ GeV, Ren. scale=1000 GeV, ...

IDEA NR. 1: a very simple scenario

$$\mu_{\text{eff}} = 250 \text{ GeV (EW-scale)}$$

$$A\lambda = A\kappa = 0$$

$$\tan\beta = 3 \text{ \& } 30$$

scan λ, κ



Do not find unexcluded region!

Vary parameters a bit:

$$\text{e.g. } \mu_{\text{eff}} = -250 \text{ GeV}$$

$$\text{e.g. } A\lambda = A\kappa = -100 \text{ GeV}$$

$$\text{e.g. } A\lambda = A\kappa = 1000 \text{ GeV}$$



Either excluded or with a light H1 ~ 120 GeV
with SM-like couplings and no decays into A1.
⇒ rather boring

Is a SM-like Higgs “frequent” in the NMSSM?
(also see this in other scenarios)

IDEA NR. 2: Maximal H1 mass

Paper from U. Ellwanger, C. Hugonie (hep-ph/0612133)

$$M_1 = 150 \text{ GeV}, M_2 = 300 \text{ GeV}, M_3 = 1 \text{ TeV}$$

$$M_{\text{Susy}} = 1 \text{ TeV}$$

$$A_t = A_b = A_\tau = 2.5 \text{ TeV}$$

$$\mu_{\text{eff}} = 620 \text{ GeV}$$

$$A\lambda = 1530 \text{ GeV}$$

$$A\kappa = 10 \text{ GeV}$$

$$\tan\beta = 2.14$$

$$\lambda = 0.678$$

$$\kappa = 0.067$$



Scan in parameter-pairs around this point:

$$\lambda, \kappa$$

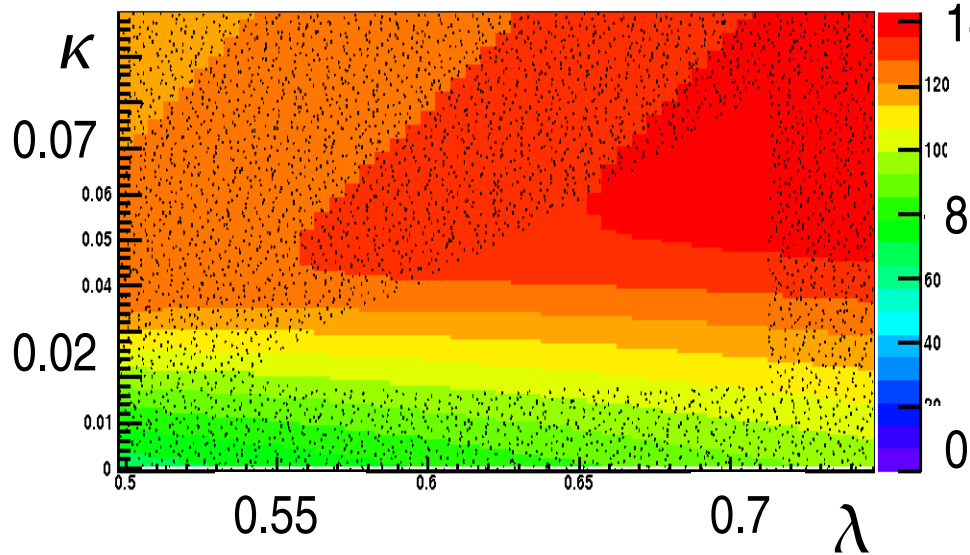
$$A\lambda, A\kappa$$

$$\mu_{\text{eff}}, \tan\beta$$

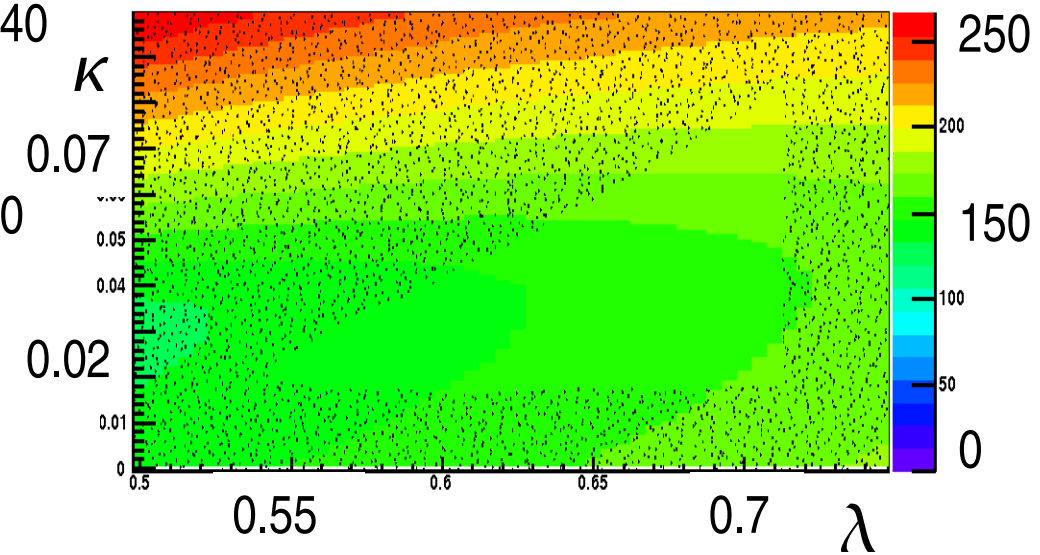
Are there better combinations for scanning?

Maximal H1 mass - λ - κ Scan

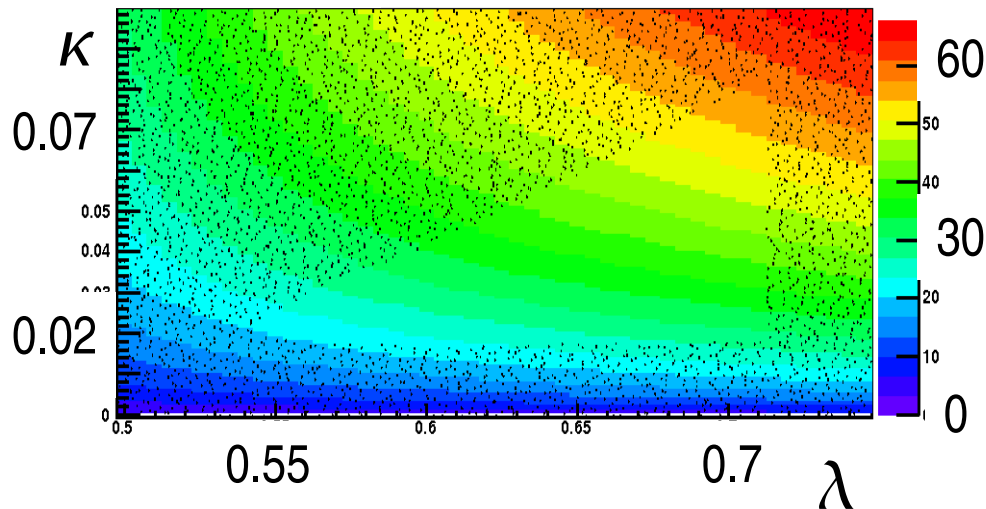
Mass of H1



Mass of H2



Mass of A1

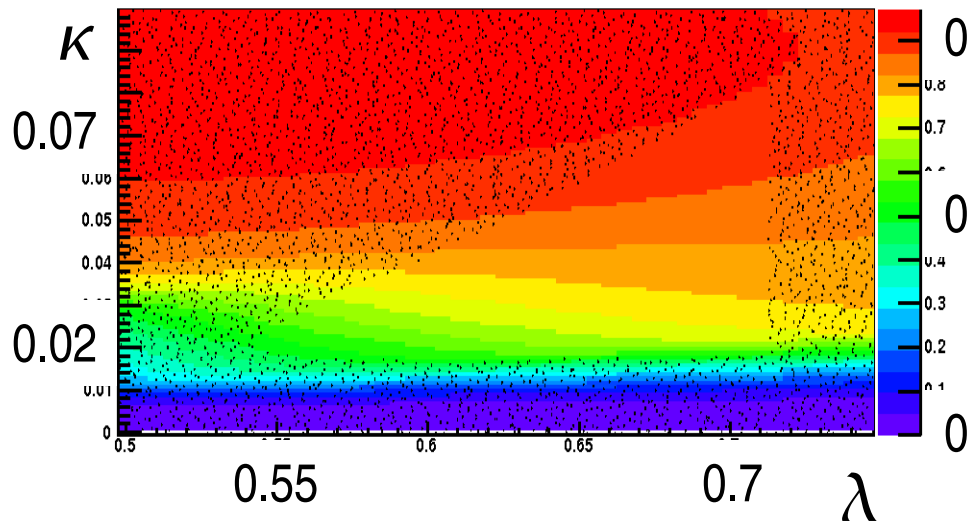


$M(H3) \sim M(A2) \sim M(H^\pm) \sim 1800$ GeV

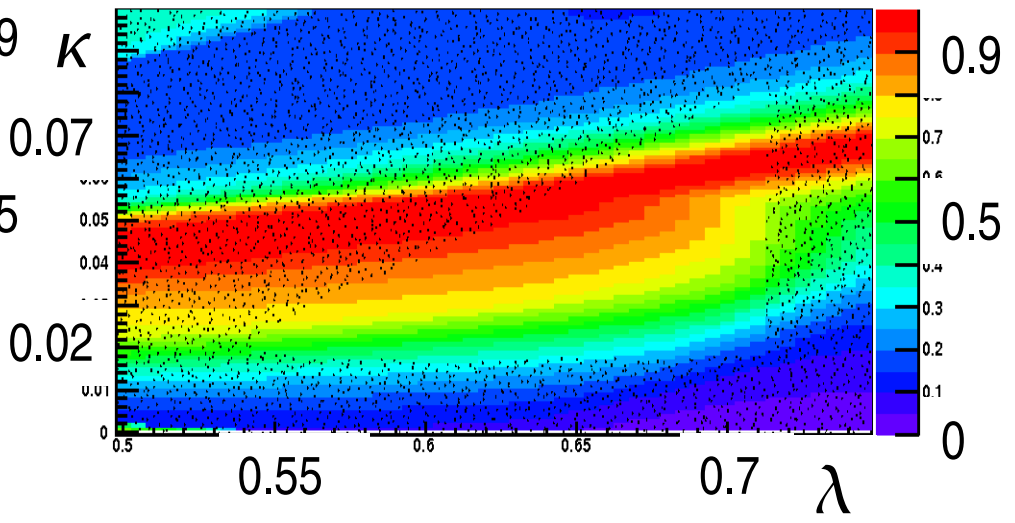
Black dots: Excluded region!

Maximal H1 mass - λ - κ Scan

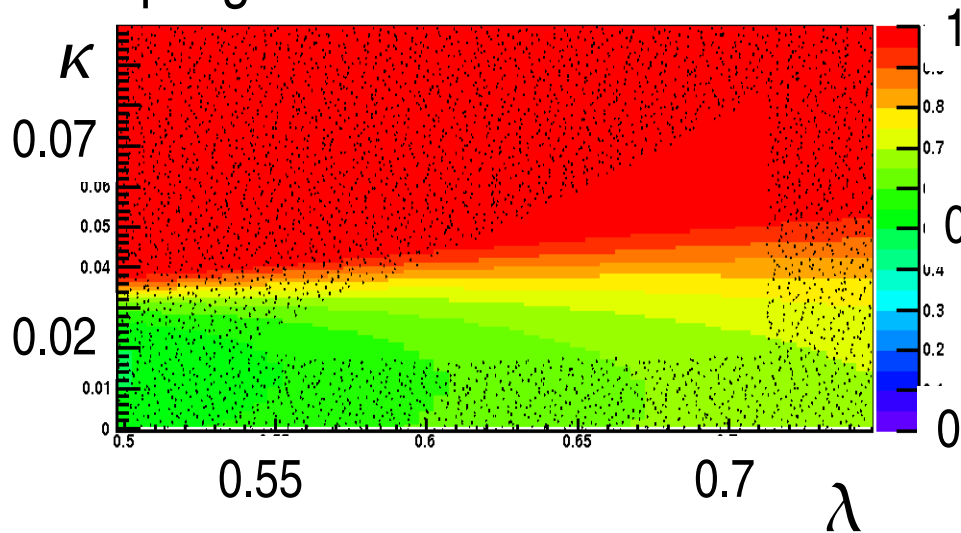
BR $H1 \rightarrow$ other Higgses



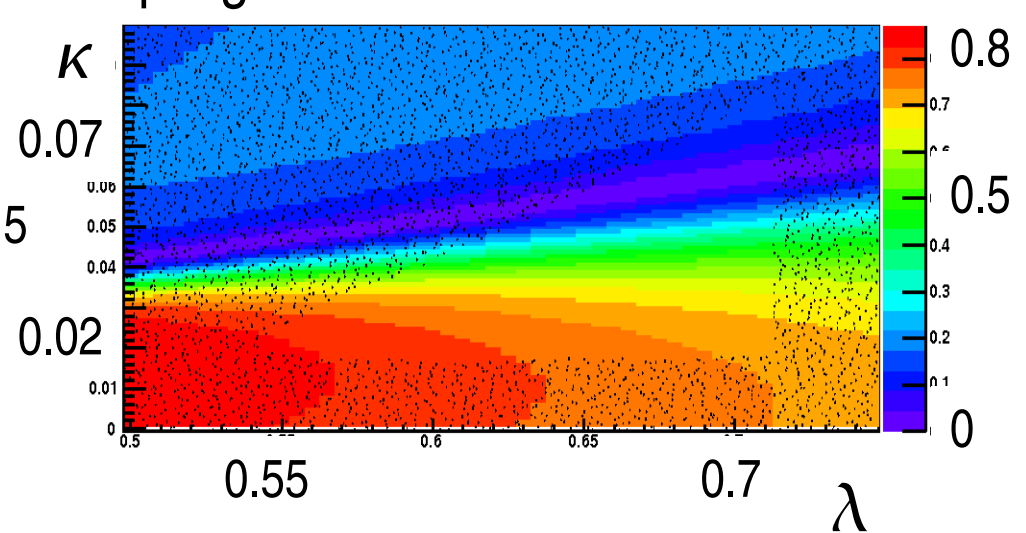
BR $H2 \rightarrow$ other Higgses



Coupling to vector bosons of H1



Coupling to vector bosons of H2



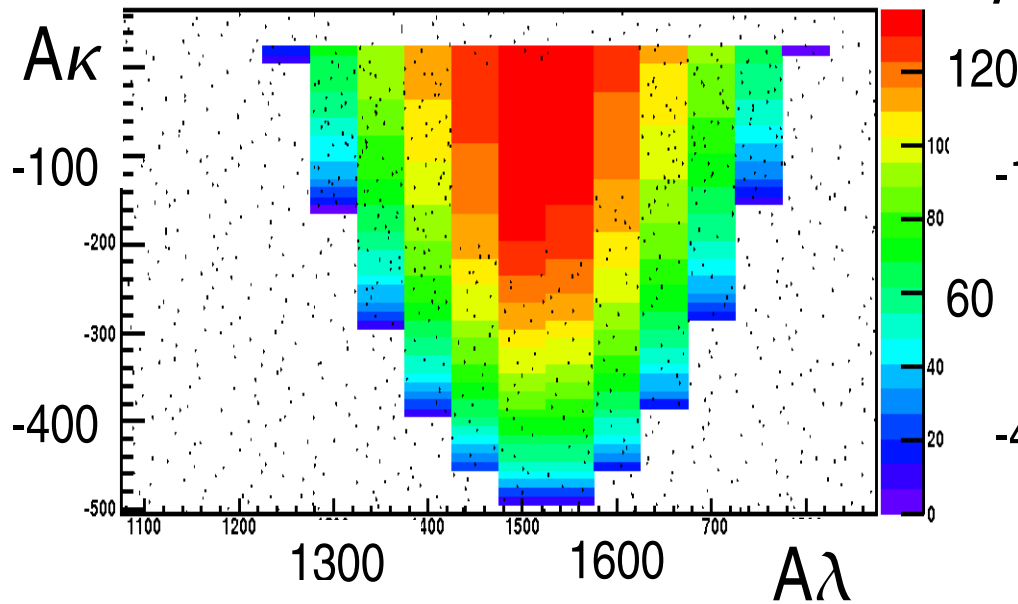
BR ($A1 \rightarrow bb$) ~ 0.9

BR ($A1 \rightarrow \tau\tau$) $\sim 0.06-0.08$

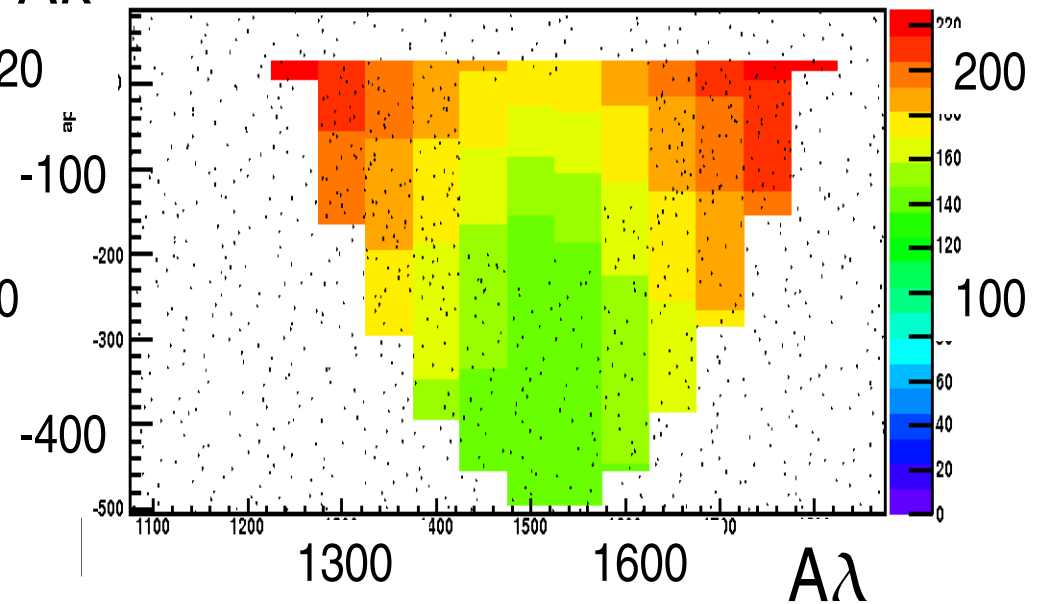
Black dots: Excluded region!

Maximal H1 mass - A_λ - A_κ Scan

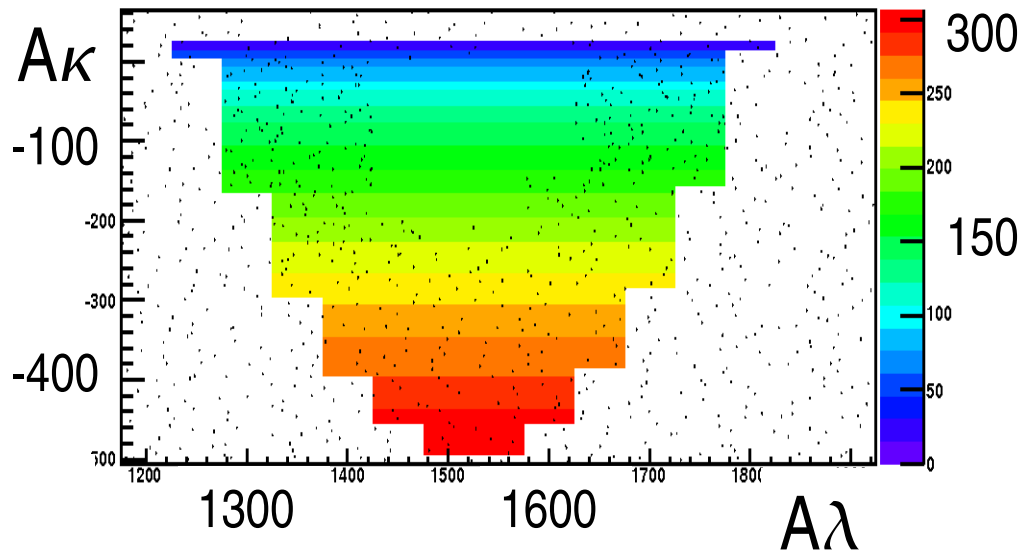
Mass of H1



A_κ Mass of H2



Mass of A1

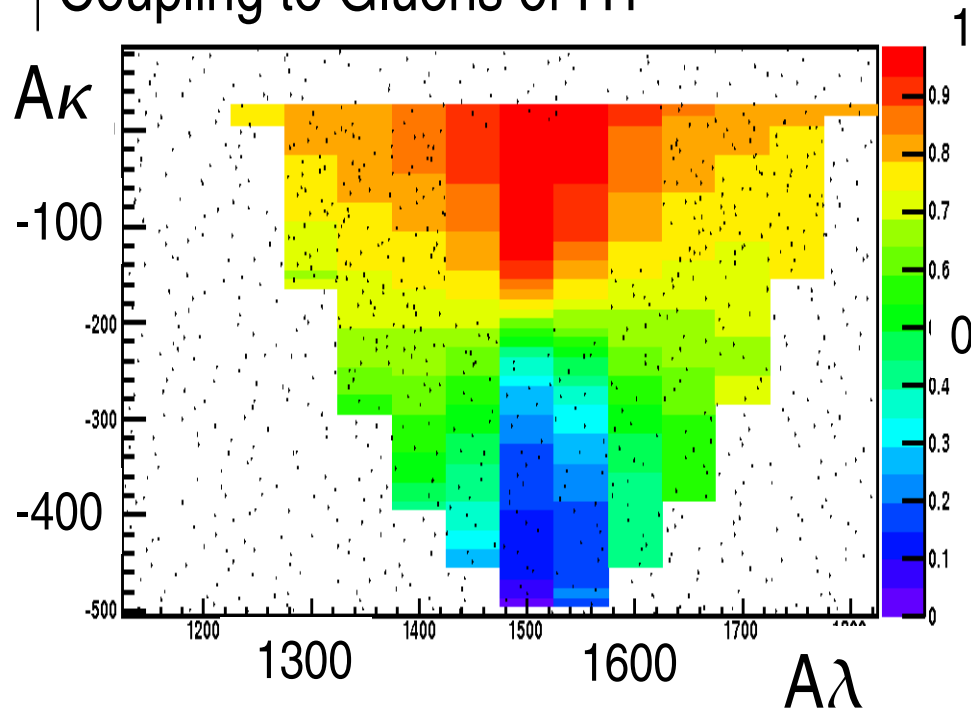


A1 gets heavy quickly \Rightarrow
H1 \rightarrow A1A1 possible only in
marginal region

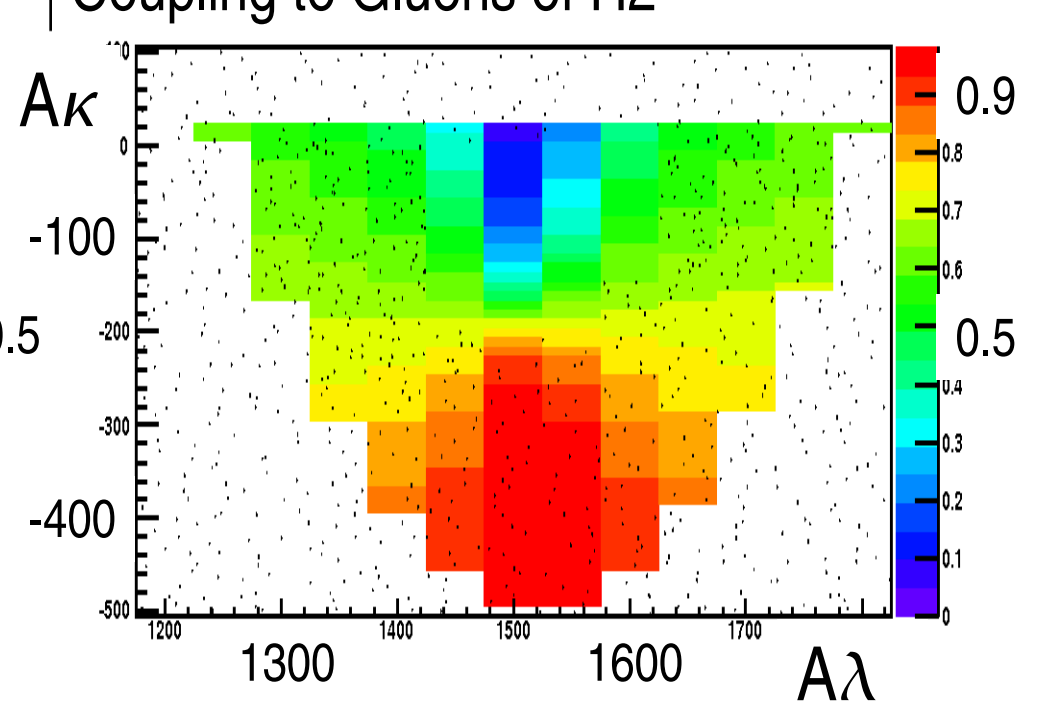
Black dots: Excluded region!

Maximal H1 mass - $A\lambda$ - $A\kappa$ Scan

Coupling to Gluons of H1



Coupling to Gluons of H2



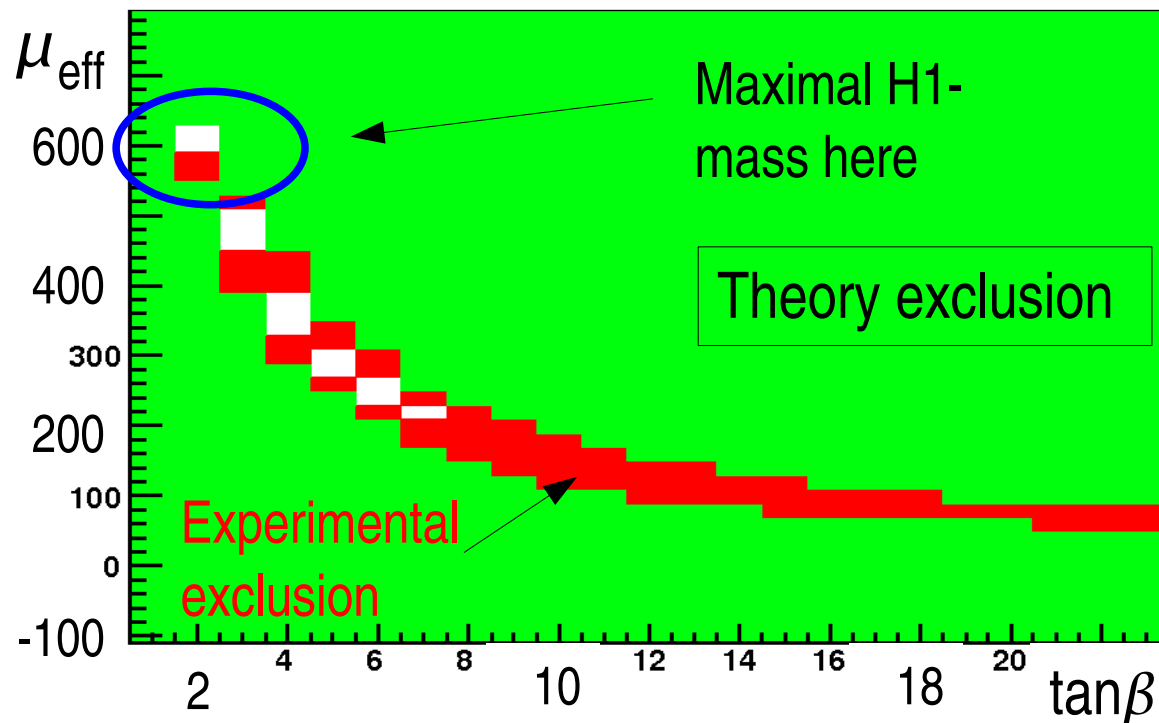
Black dots: Excluded region!

Couplings from H1 & H2 vary inversely

Maybe this scan is also interesting to see the effect of suppressed couplings?

Maximal H1 mass - μ_{eff} - $\tan\beta$ Scan

Excluded Region



Allowed region
rather small,
No big variation
seen inside

Proposal for Benchmark scan:

Keep $\tan\beta$, μ_{eff} fixed,
scan λ/κ & $A\lambda/A\kappa$

?

IDEA NR. 3: Points from Paper: Difficult Scenarios for NMSSM Higgs Discovery at the LHC by Ellwanger, Gunion, Hugonie

(hep-ph/0503203)

$$M_1 = 500 \text{ GeV}, M_2 = 1 \text{ TeV}, M_3 = 3 \text{ TeV}$$

$$M_{\text{Susy}} = 1 \text{ TeV}$$

$$A_t = A_b = A_\tau = 1.5 \text{ TeV}$$

First Point:

No $H1 \rightarrow A1A1$ decays allowed, but the lowest expected significance at LHC

$$\mu_{\text{eff}} = -284 \text{ GeV}$$

$$A\lambda = -70 \text{ GeV}$$

$$A\kappa = -54 \text{ GeV}$$

$$\tan\beta = 5.7$$

$$\lambda = 0.0163$$

$$\kappa = -0.0034$$



Scan in parameter-pairs around this point:

$$\lambda, \kappa$$

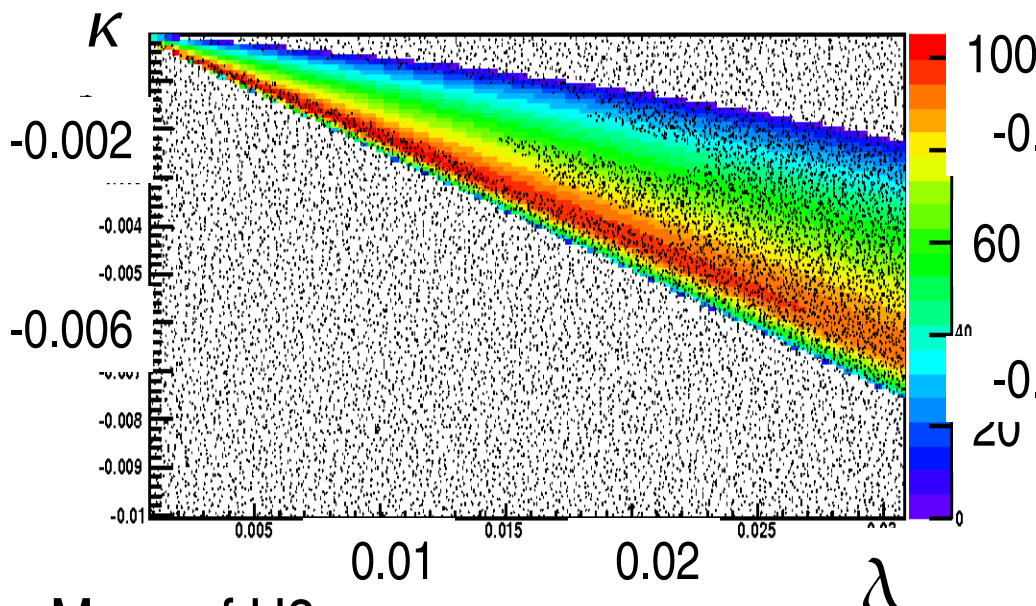
$$A\lambda, A\kappa$$

$$\mu_{\text{eff}}, \tan\beta$$

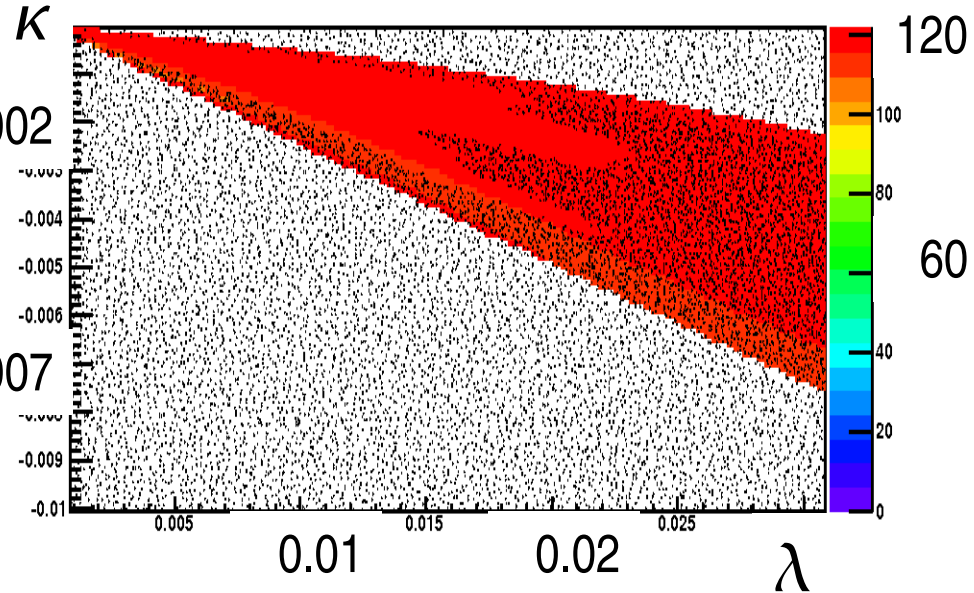
“Point 1” - λ - κ Scan

Black dots: Excluded region!
Only small region unexcluded!

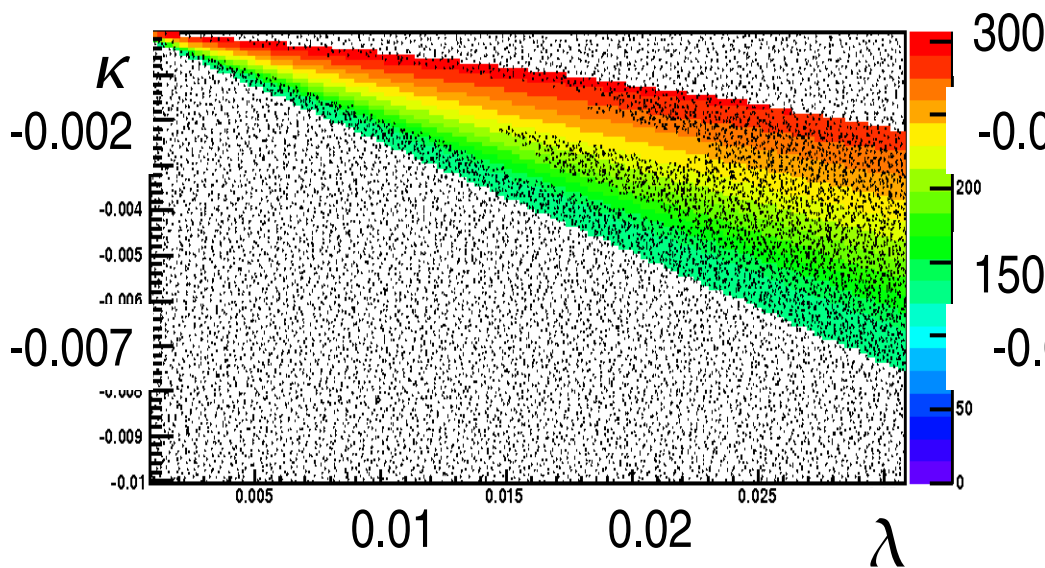
Mass of H1



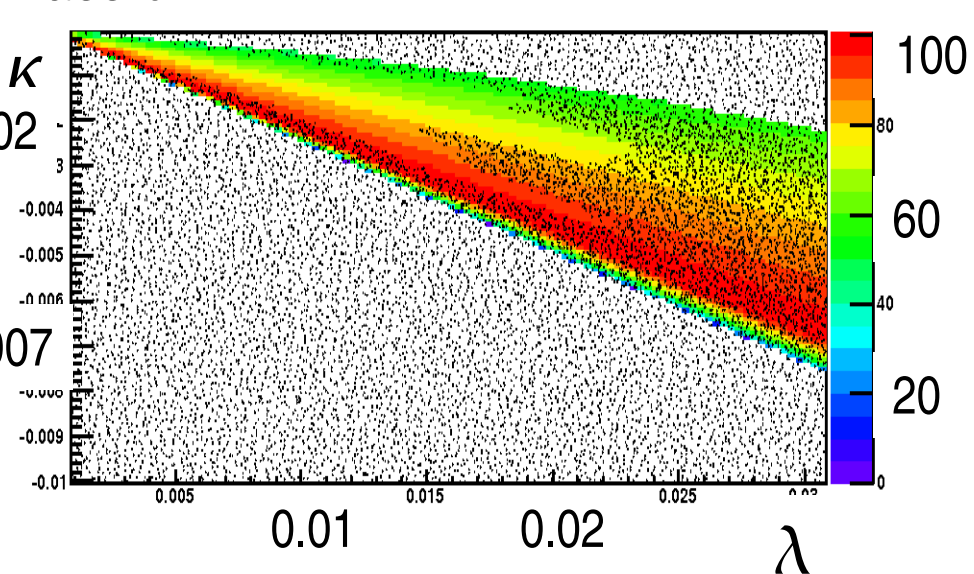
Mass of H2



Mass of H3



Mass of A1

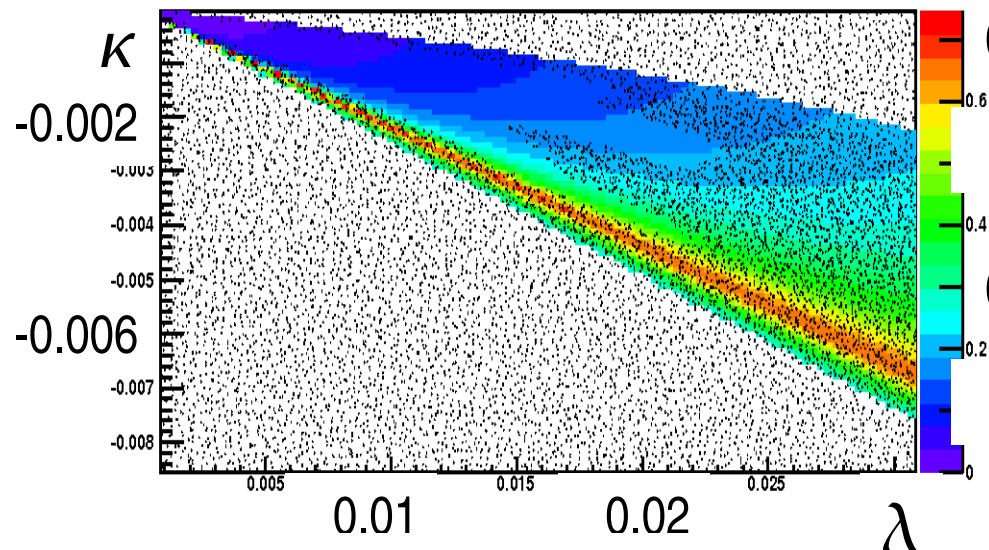


All masses relatively light!

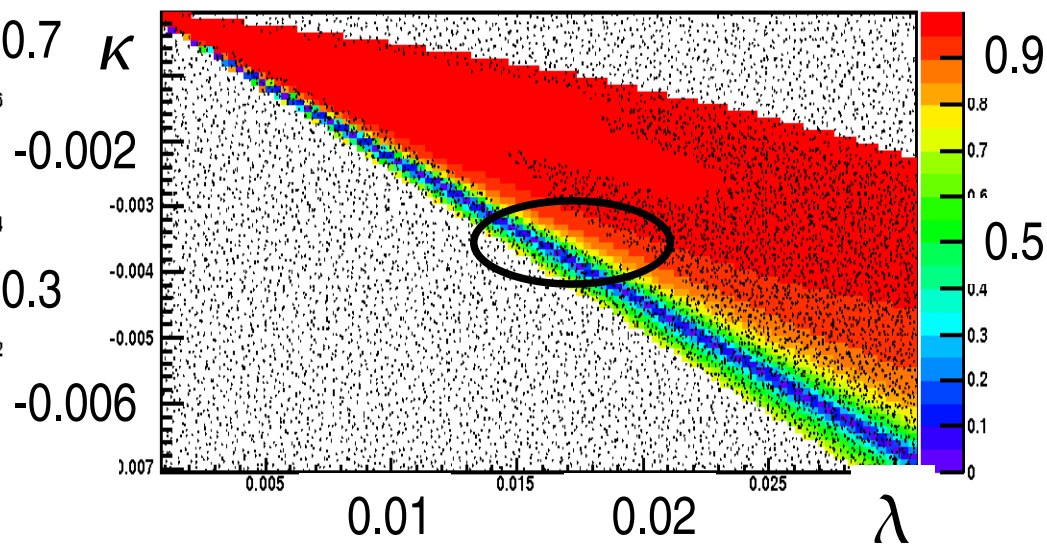
“Point 1” - λ - κ Scan

Black dots: Excluded region!

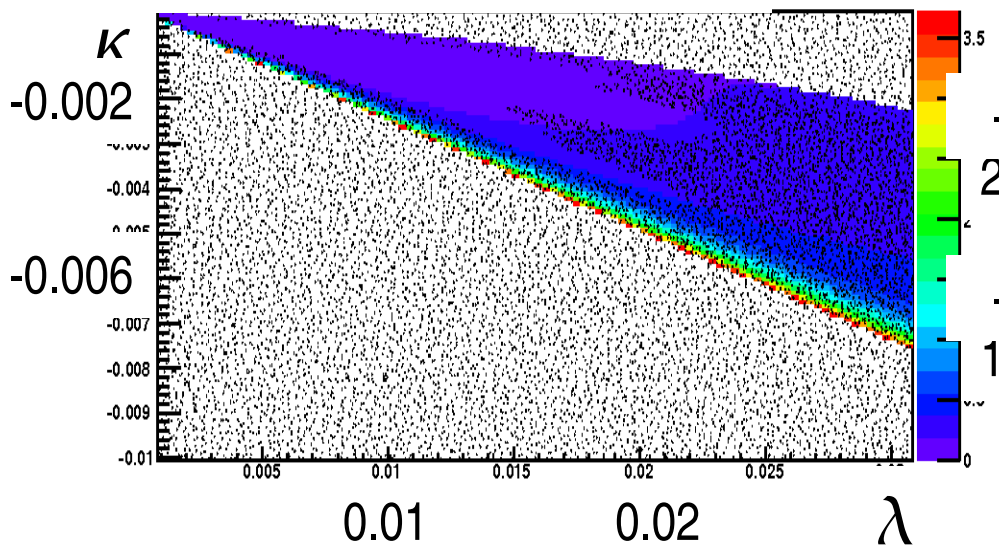
Vector boson coupling of H1



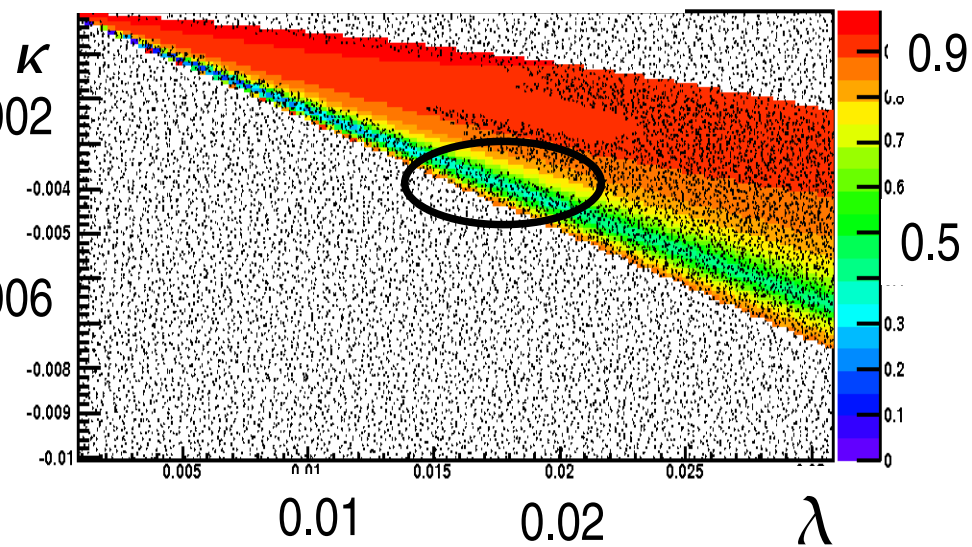
Vector boson coupling of H2



Gluon coupling of H1

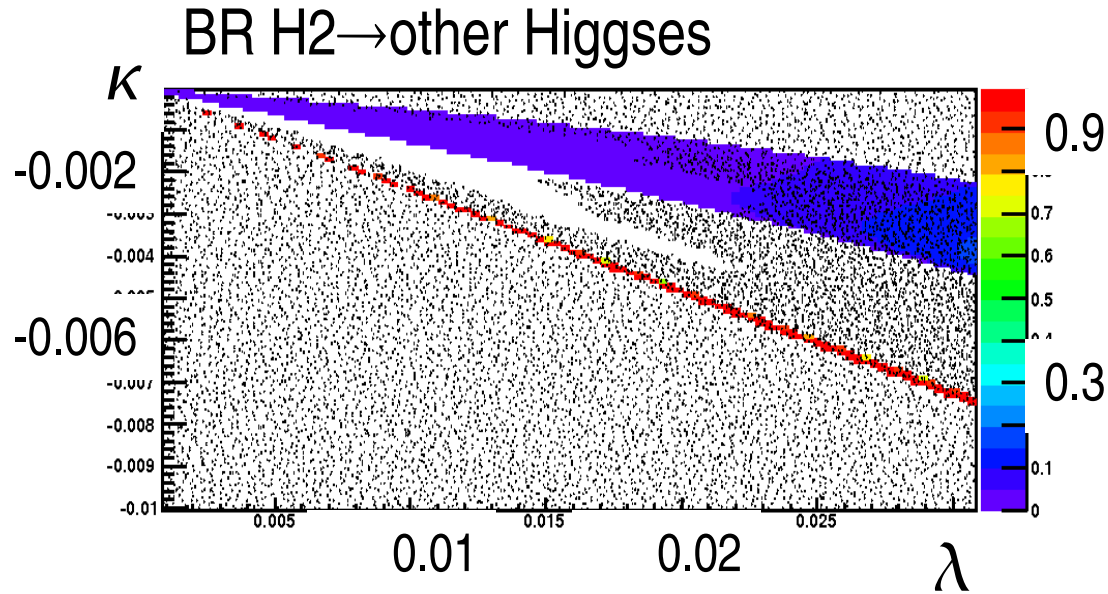


Gluon coupling of H2



Reduced couplings of H1, reduced couplings of H2 in some region around original point (black circle)

“Point 1” - λ - κ Scan



Black dots: Excluded region!

“Point 1” - $A\lambda$ - $A\kappa$ Scan

Masses of H_1 , A_1 vary with $A\kappa$ (in different direction)

Masses of H_3 , A_2 and H^\pm vary with $A\lambda$ (in same direction)

Mass of H_2 relatively stable

Also some variation of couplings & BRs

“Point 1” - μ_{eff} - $\tan\beta$ Scan

Masses of H_1 , A_1 vary with μ_{eff}

Masses of H_3 , A_2 and H^\pm vary with $\tan\beta$

Mass of H_2 relatively stable

Only small variation of couplings & BRs

Use these three

scans as a

benchmark ???

Interesting region

is quite small ?

Second Point:

$M(H1) \sim 90 \text{ GeV}$, $M(H2) \sim 480 \text{ GeV}$, $M(A1) \sim 10 \text{ GeV}$

$$\mu_{\text{eff}} = -520 \text{ GeV}$$

$$A\lambda = -580 \text{ GeV}$$

$$A\kappa = -2.8 \text{ GeV}$$

$$\tan\beta = 5.0$$

$$\lambda = 0.22$$

$$\kappa = -0.1$$

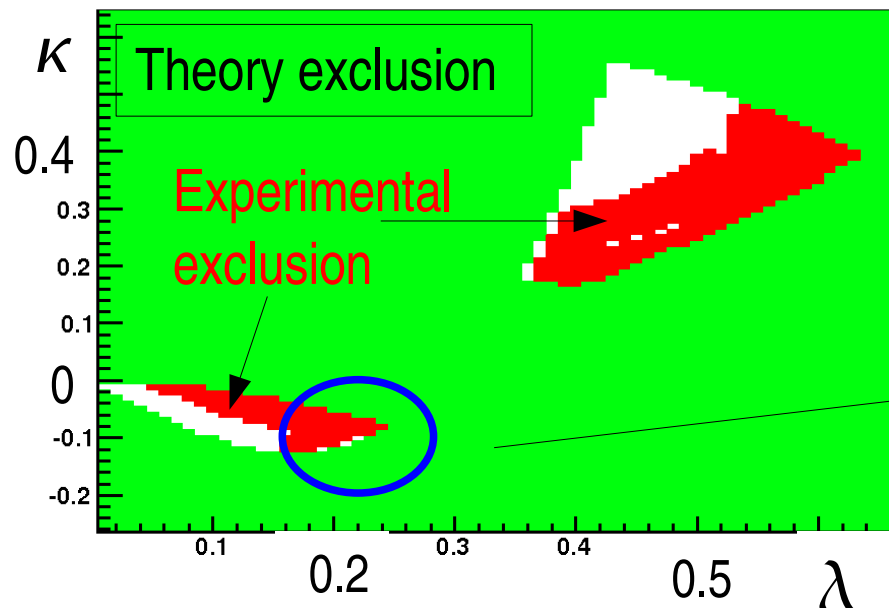
Scan in parameter-pairs around this point:

λ, κ

$A\lambda, A\kappa$

$\mu_{\text{eff}}, \tan\beta$

Excluded Regions



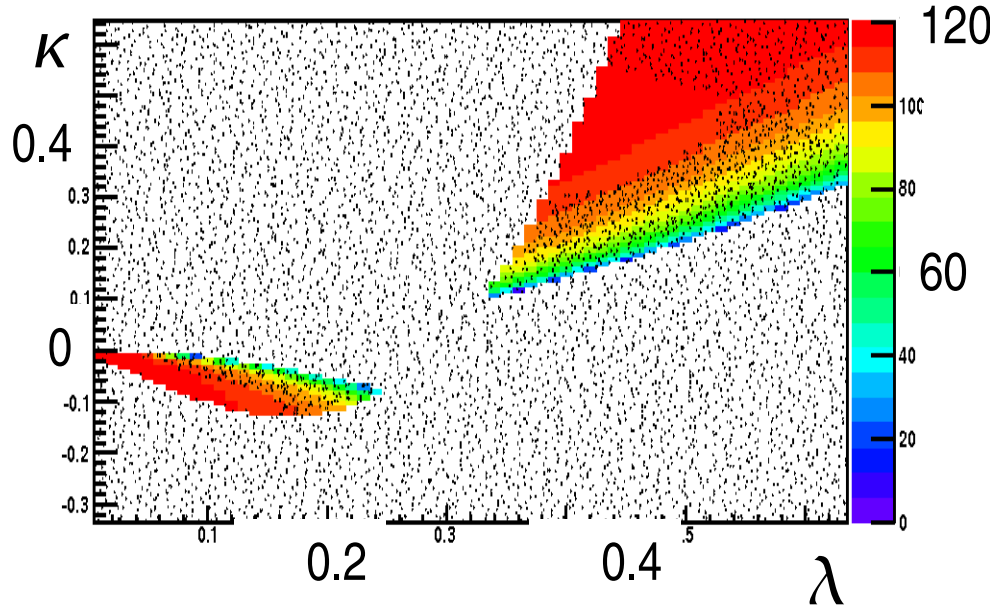
Point lies in rather small unexcluded region

⇒ look at other regions also!

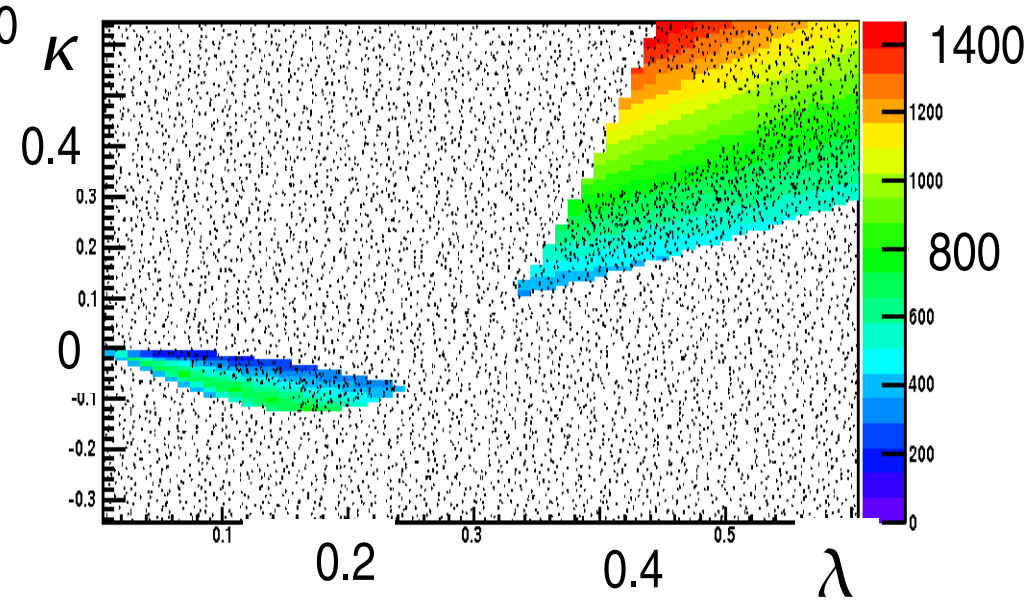
“Point 2” - λ - κ Scan

Black dots: Excluded region!

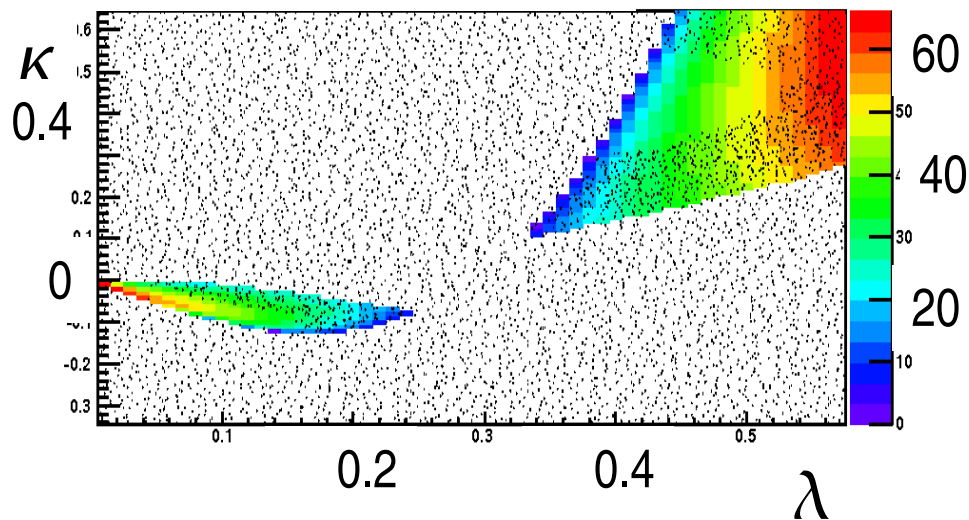
Mass of H1



Mass of H2



Mass of A1



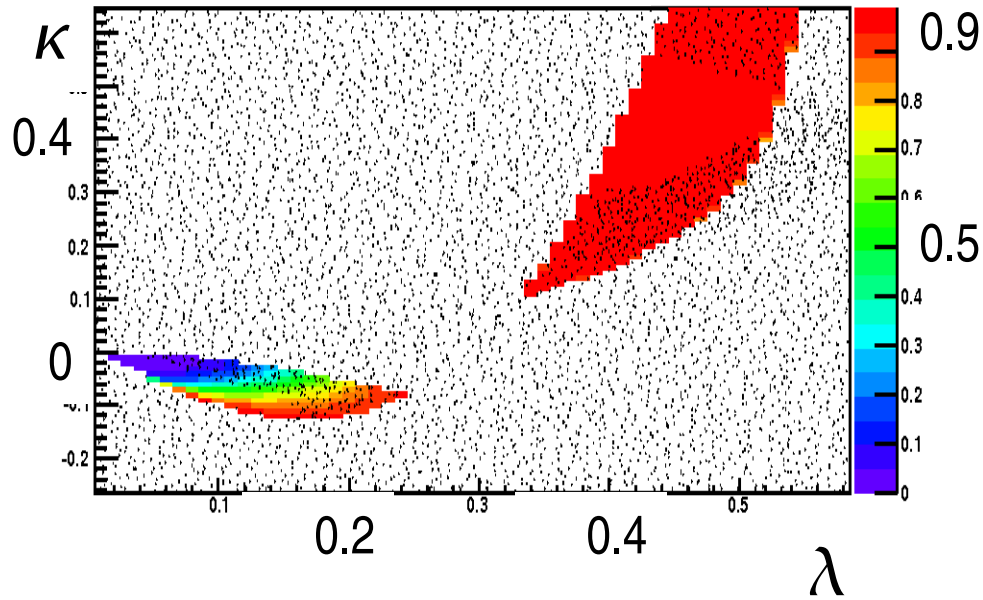
H2-mass heavier than in
“H1-max-scenario”!

H1 has SM-like couplings

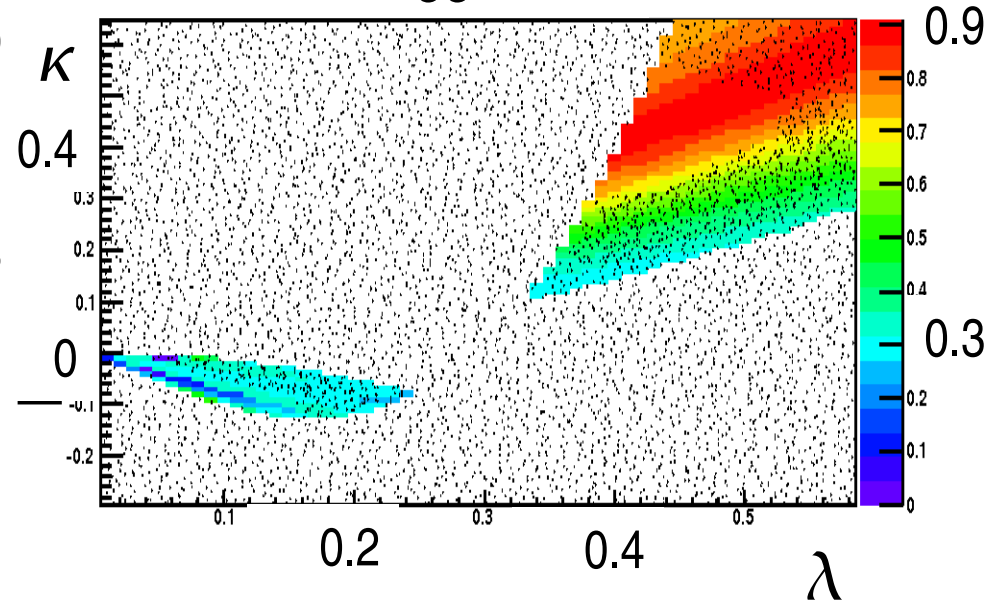
“Point 2” - λ - κ Scan

Black dots: Excluded region!

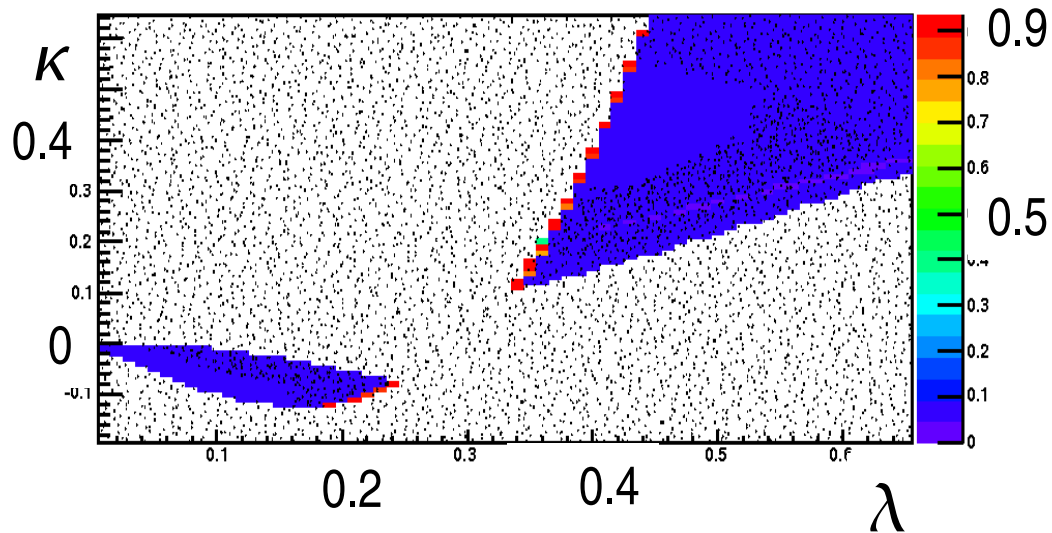
BR $H1 \rightarrow$ other Higgses



BR $H2 \rightarrow$ other Higgses



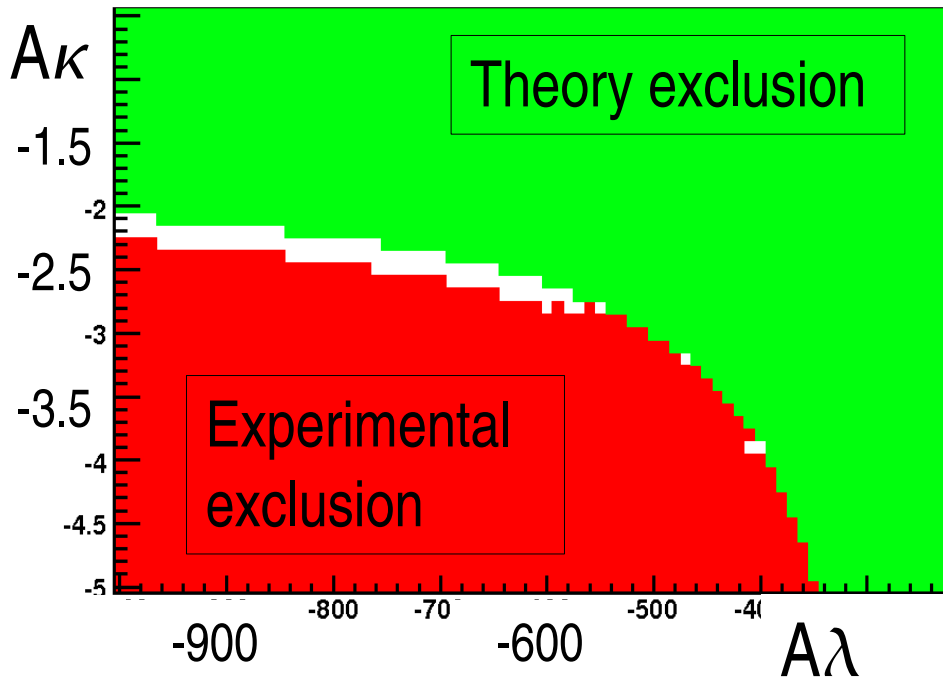
BR $A1 \rightarrow \tau\tau$



2 regions (red) with dominant $A1 \rightarrow \tau\tau$ covered by scan!

“Point 2” - $A\lambda$ - $A\kappa$ Scan

Excluded Region



Allowed region rather small,
no big variation seen inside

Maybe instead take point from
“bigger” regions as starting point?

Proposal for Benchmark scan:

Scan λ, κ around this point

For $\tan\beta/\mu_{\text{eff}}$ & $A\lambda/A\kappa$ scans: use less marginal values of λ and κ when scanning

⇒ need to check whether this give something interesting!

?

Third Point:

$M(H1) \sim 119 \text{ GeV}$, $M(H2) \sim 1431 \text{ GeV}$, $M(A1) \sim 31 \text{ GeV}$

$\mu_{\text{eff}} = 530 \text{ GeV}$

$A\lambda = -920 \text{ GeV}$

$A\kappa = -2.1 \text{ GeV}$

$\tan\beta = 7.8$

$\lambda = 0.22$

$\kappa = 0.59$



Scanning λ , κ gives only small region where $H1 \rightarrow A1A1$ is allowed, other regions “SM-like”
Phenomenology of this point ($H \rightarrow A1A1 \rightarrow bb$)
already covered by previous scans ??

Forth Point:

$M(H1) \sim 40 \text{ GeV}$, $M(H2) \sim 125 \text{ GeV}$, $M(A1) \sim 144 \text{ GeV} \Rightarrow H2 \rightarrow H1H1$

Did not look into that yet

Is phenomenology different from $H1 \rightarrow A1A1$ case ?

IDEA NR. 4: Point from Paper: An Interesting NMSSM Scenario at the LHC and LC by Miller & Moretti

Has region where $H1 \rightarrow cc$ is dominant!

Very challenging experimentally

Did not look into that yet

Other Ideas/Suggestions?

Thank you for your attention!