Search for NMSSM $h \rightarrow aa \rightarrow 4\mu$ at the LHC

Sergey Senkin

Alexei Safonov

Jim Pivarski

Texas A&M University

Alexander Belyaev

University of Southampton

5 May, 2009

NMSSM Higgs sector

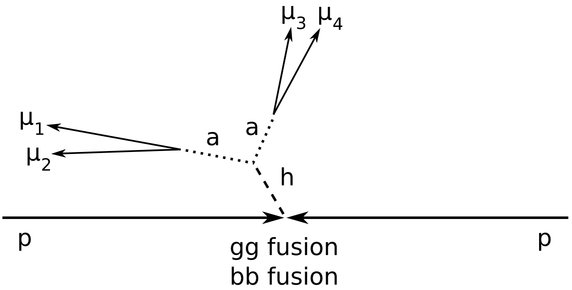
- Next-to-minimal supersymmetry (NMSSM) solves the μ coincidence problem by promoting the μ term into a new singlet superfield
- Also has a richer Higgs sector with CP-even (h_1, h_2) and CP-odd (a_1, a_2) scalars
  - more parameter space survives LEP Higgs bounds than MSSM
  - Higgs-to-Higgs decays can be significant
- Exotic case: if a_1 is light (1–10 GeV) and $\mathcal{B}(h_1 \to a_1 a_1)$ is significant, normal detector signatures ($b\bar{b}$, $W^* W$, $\tau^+\tau^-$) do not apply
- Previously studied: $h_1 \to a_1 a_1 \to 4\tau/2\tau 2\mu$ when $2m_\tau < m_{a_1} < 2m_b$
- With a very light $m_{a_1} < 2m_\tau$ and $m_{h_1} < 114$ GeV, primary decay mode would be

$$h_1 \to a_1 a_1 \to 4\mu$$

where LEP bounds do not apply to h_1 because of this exotic (but very distinct!) final state

Collider signature

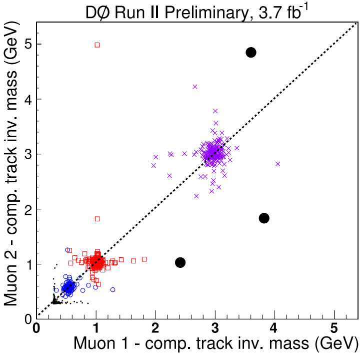
- Two tightly-collimated $\mu^+\mu^-$ pairs, labeled 1-2 and 3-4



- Leading μ $p_T > 20$ GeV: negligible background from J/ψ
- Because of low backgrounds, one does not need to resort to sub-dominant vector boson fusion production for tagging

- Released upper limit on $h \to aa \to 4\mu$: `Conference Note 5891-CONF`

  `http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H67/`

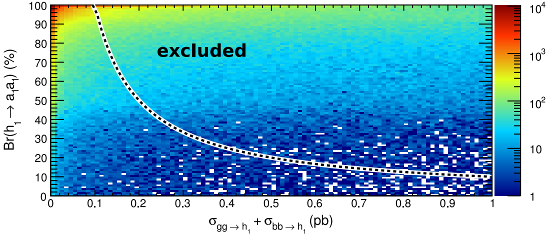


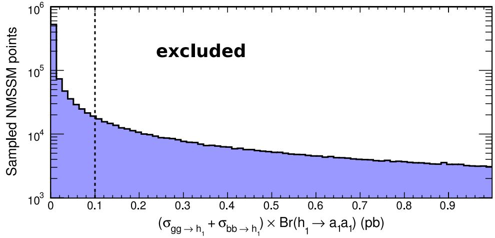
- Insufficient muon granularity to resolve two muons with a small opening angle
- Paired identified muon with "companion track" in narrow cone
- muon + track pair isolated to reduce backgrounds
- m_a = 0.5 GeV, 1 GeV, and 3 GeV simulations and 3 surviving data events shown in m_{12} vs. m_{34} plane

- Assuming an h production cross-section of 1 pb, DØ sets an upper limit on $\mathcal{B}(h \to aa)$ at 10%

4μ model is not ruled out

h_1 has a non-standard coupling to gg, $b\bar{b}$; NMSSM prefers low cross-section





NMSSMTools uniform scan over parameters:

$$0 < \kappa/\lambda < 0.8$$

$$0 < \lambda < 0.1$$

$$-0.1 < A_\kappa < 0 \text{ GeV}$$

$$0 < A_\lambda < 4 \text{ TeV}$$

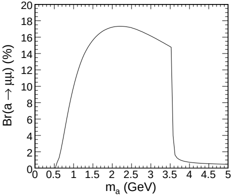
$$100 < \mu < 200 \text{ GeV}$$

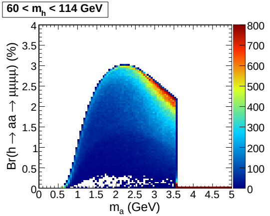
$$10 < \tan\beta < 60$$

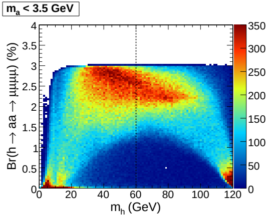
Cross-section $\ll$ limit for most parameters

(note log scales)

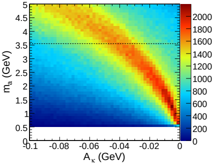
Branching fractions study

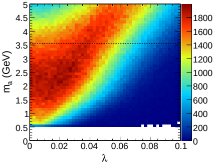




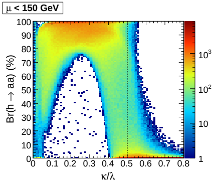


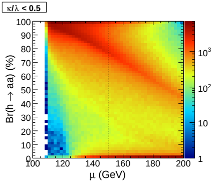
- Significant for 1 GeV $< m_a < 2m_\tau = 3.55$ GeV and $m_h < 114$ GeV





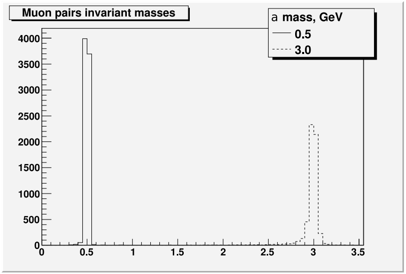
- A_κ and λ must be small for $m_a < 2m_\tau$ (linear scale)

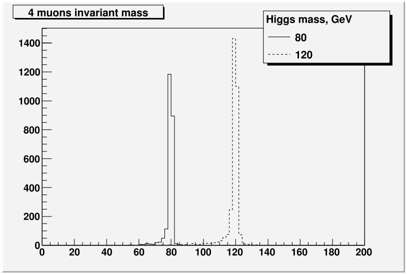




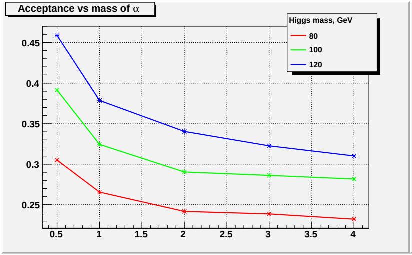
- κ/λ and μ must be small for $\mathcal{B}(h \to aa) \gtrsim 50\%$ (log scale)
- Different regions have qualitatively different behvaior

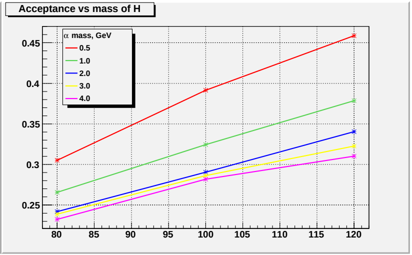
- CMS as a benchmark
- Finer granularity in muon identification than DØ: require 4 muons
  - highest $p_T > 20$ GeV, all others > 5 GeV
  - $|\eta| < 2.4$
  - minimize $\Delta R(\mu_1, \mu_2)^2 + \Delta R(\mu_3, \mu_4)^2$ to pair 1-2 and 3-4
  - simultaneously fit m_{12}, m_{34}, and m_{1234} spectra
- Simulated distributions with detector resolution (CMS TDR):





Acceptance





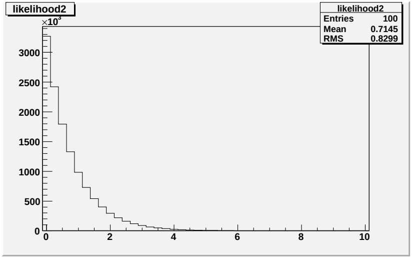
Backgrounds

	Inclusive $\mu + X$	diboson/DY	J/ψ
before cuts (100 pb^{-1})	150,000	48	120
kinematic cuts on 4μ	150	5.9	$0^{+0.07}_{-0.00}$
effective region of fit*	$0^{+2.0}_{-0.0}$	$0^{+0.005}_{-0.000}$	

*fit sensitive to m_{12}, $m_{34} < 4$ GeV, $m_{1234} > 60$ GeV, and

$$|m_{12} - m_{34}| < 0.08 \text{ GeV} + 0.005\,(m_{12} + m_{34})$$

- Example likelihood function with no signal



95% C.L. on $\sigma(pp \to h) \times \mathcal{B}(h \to aa)$ at $\mathcal{L} = 100\ \text{pb}^{-1}$

	$m_a = 1$ GeV	2 GeV	3 GeV
$m_h = 80$ GeV	10.9 pb	4.1 pb	4.6 pb
100 GeV	8.9 pb	3.4 pb	3.8 pb
120 GeV	7.7 pb	2.9 pb	3.4 pb

Conclusions

- NMSSM solves naturalness problems in them MSSM, including tension from LEP Higgs limit
- Introduces a rich Higgs sector with Higgs-to-Higgs decays
- $h \to aa \to 4\mu$ is a sensitive discovery mode when $m_a < 2m_\tau$
- D∅ search doesn't rule out the 4μ parameter space
- CMS muon spectrometer allows for identification of all four muons