Search for non Standard Model Higgs boson decays in events with boosted dimuons

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Overview

- Motivation
- Beyond the standard model scenarios: dark SUSY & NMSSM
- The CMS detector at the LHC
- Datasets
- Event selection
- Standard model backgrounds
- Model independent results
  - Interpretation in benchmark scenarios: dark SUSY & NMSSM
- Conclusions & outlook

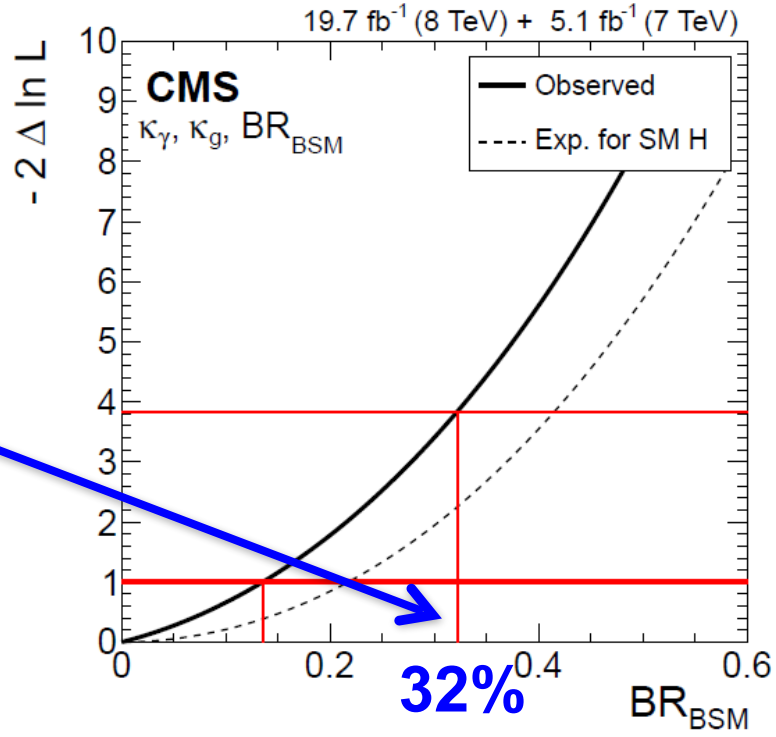
Motivation

2012 – Milestone in particle physics! Discovery of a scalar boson!

Is it the SM Brout-Englert-Higgs boson?

- Precision measurements of its SM branching ratios:
  - Might require several hundreds of fb^{-1}
  - Current 95% CL limit: $B_{BSM} \leq 32\%$

- Direct searches for non-SM Higgs boson decays:
  - In case of observation: evidence for non-SM Higgs!
  - In case of no observation: restrict a wide range of scenarios beyond the SM



CMS-HIG-14-009
http://arxiv.org/abs/1412.8662

Motivation

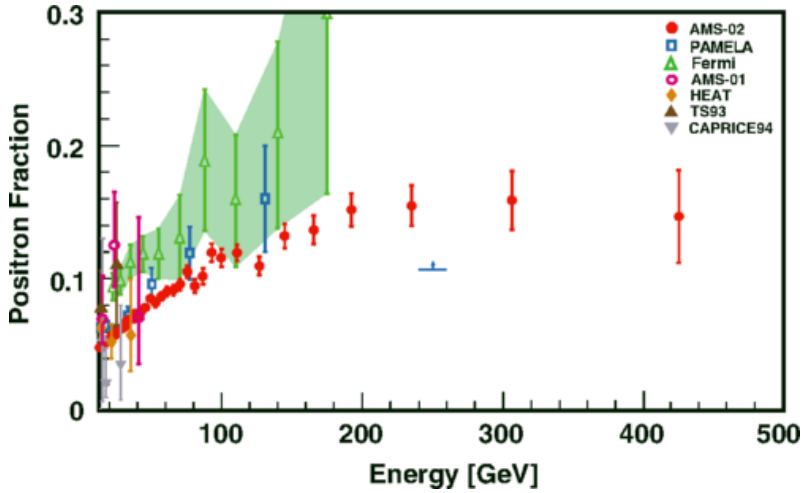
- Search for non-SM Higgs boson which decays to new light bosons
  - $h \rightarrow 2a + X \rightarrow 4\mu + X$
  - With m_a between $2m_\mu$ and $2m_T$
- Design the analysis such that results are model independent
  - Can be used for a wide range of BSM scenarios for new light bosons, with boosted dimuons in event topology
- We consider two BSM scenarios:
  - SUSY + dark sector (dark SUSY)
  - Next-to-minimal supersymmetric standard model (NMSSM)

BSM scenario: Dark SUSY

Observation of rising positron fraction up to 200 GeV by satellite experiments (AMS-02)

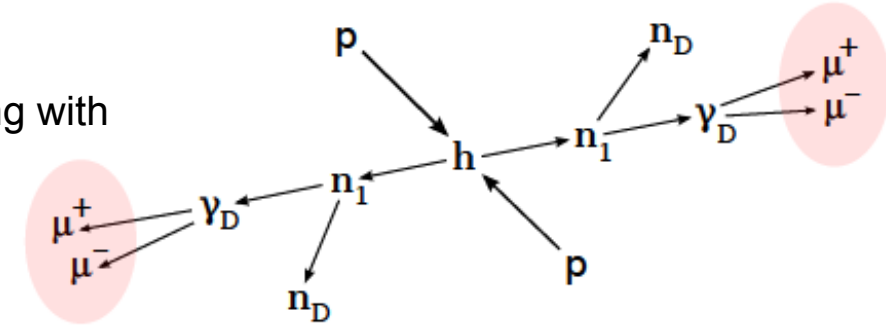
Can it be due to dark matter particles annihilating?

New light bosons mediate attractive potential between slow-moving WIMPs



- Model a simplified dark sector $U(1)_D$ in SUSY
- Higgs decays to SUSY neutralinos n_1
- n_1 decays to dark neutralino n_D (new LSP) + dark photon γ_D
- mass $\gamma_D < 2$ GeV
  - no anti-proton excess in cosmic ray spectrum
- Dark photon weakly couples to SM via kinetic mixing with photon

Phys. Rev. Lett. 113, 121101

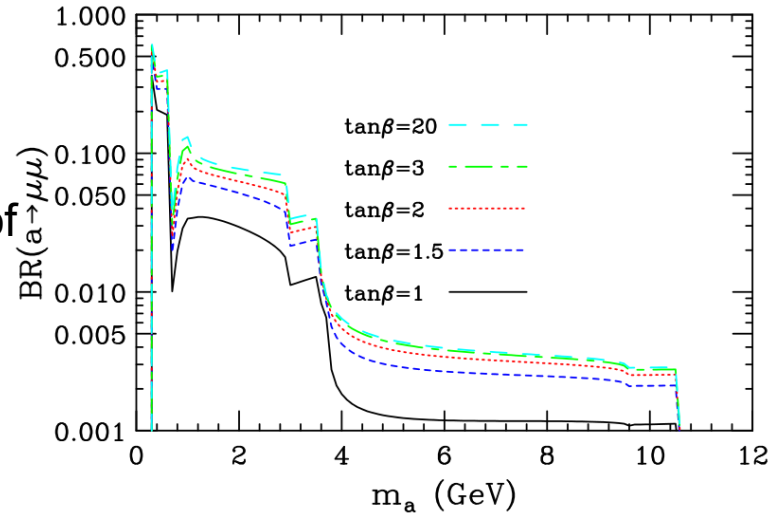


BSM scenario: NMSSM

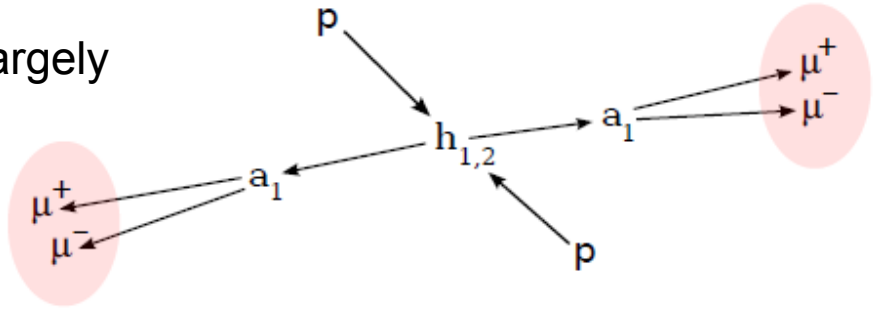
NMSSM: extend minimal SUSY with singlet field "S"

$$W_{\mathrm{NMSSM}} = W_{\mathrm{Yuk}} + \lambda S H_u H_d + \frac{\kappa}{3} S^3$$

- Requires less fine-tuning + dynamical generation of μ-term (solves μ-problem)
- Extended Higgs sector
  - 3 CP-even states ($h_{1,2,3}$)
  - 2 CP-odd states ($a_{1,2}$)
  - 2 charged Higgs states $H^{\pm}$
- Higgs-like scalar boson can be the lightest or the 2nd-lightest CP-even scalar (h_1 or h_2)
- $h_{1,2}$ can decay to a new light boson a_1
- a_1 couples weakly to SM particles due to its largely singlet nature
  - In particular a_1 can decay to μμ with dimuon branching ratio when $2m_\mu < m_{a1} < 2m_T$

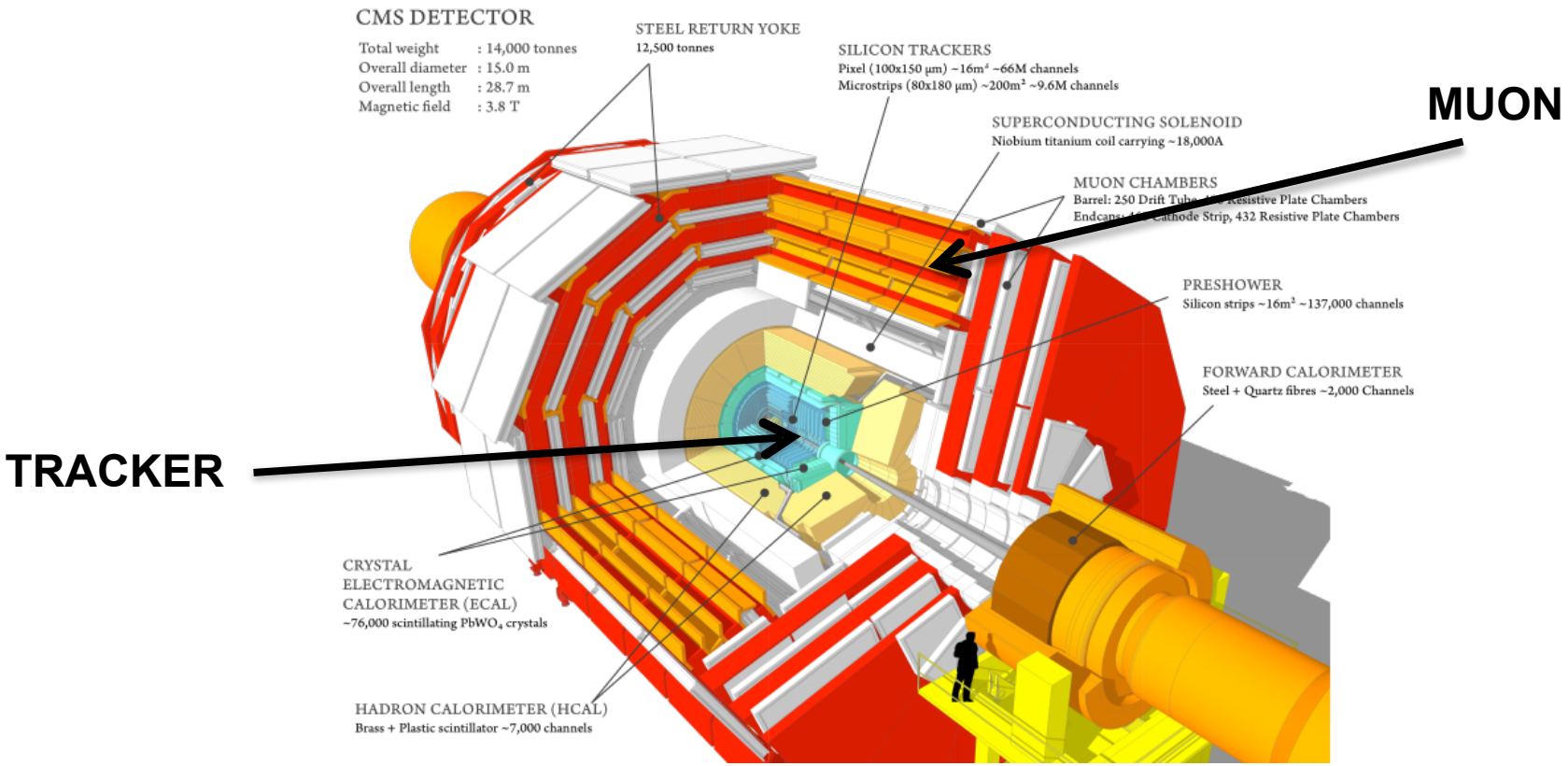


Phys. Rev. D 81, 075003



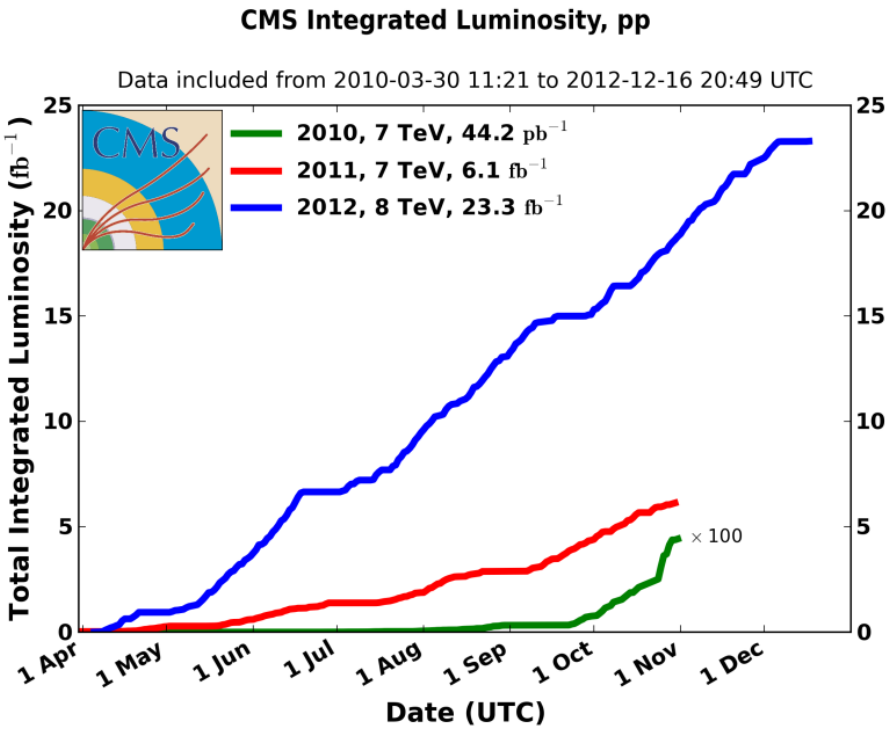
The CMS detector at the LHC

- Multi-purpose detector at LHC
- Excellent muon detection and reconstruction abilities
- This analysis uses information from tracker + muon system



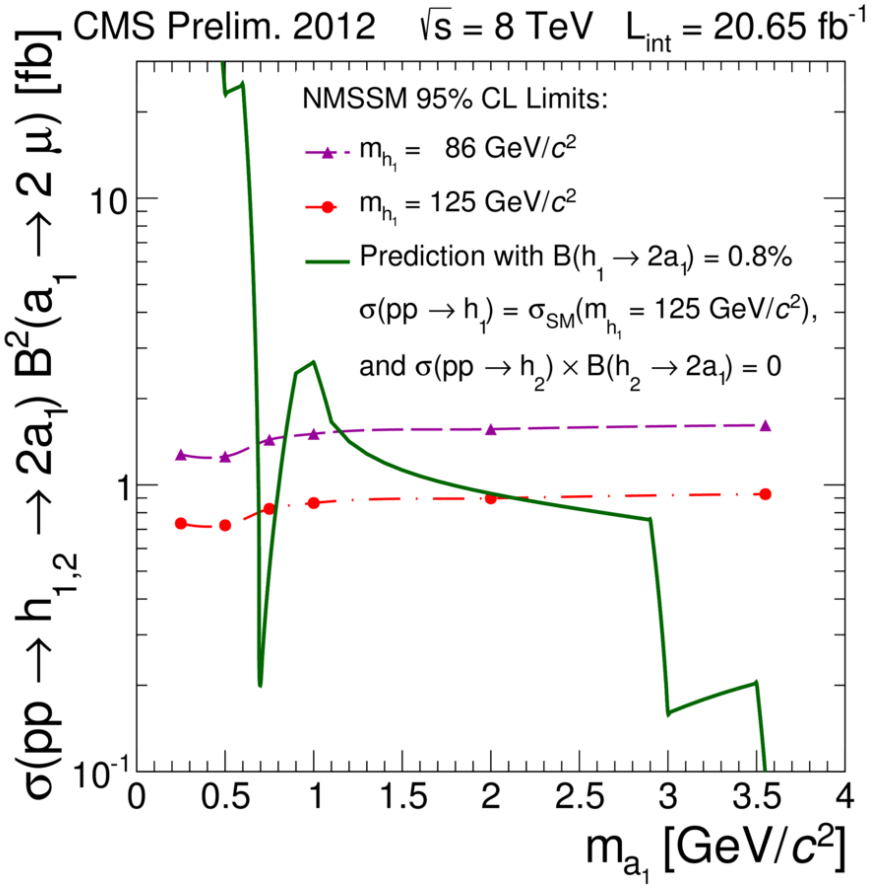
Datasets

- 2010: 35 pb^{-1} @ 7TeV 10.1007/JHEP07(2011)098
- 2011: 5.3 fb^{-1} @ 7TeV 10.1016/j.physletb.2013.09.009
- **2012: 20.7 fb^{-1} @ 8TeV (Paper will be sent to PRL soon) - - This talk**
- 2015: analysis on 13TeV started



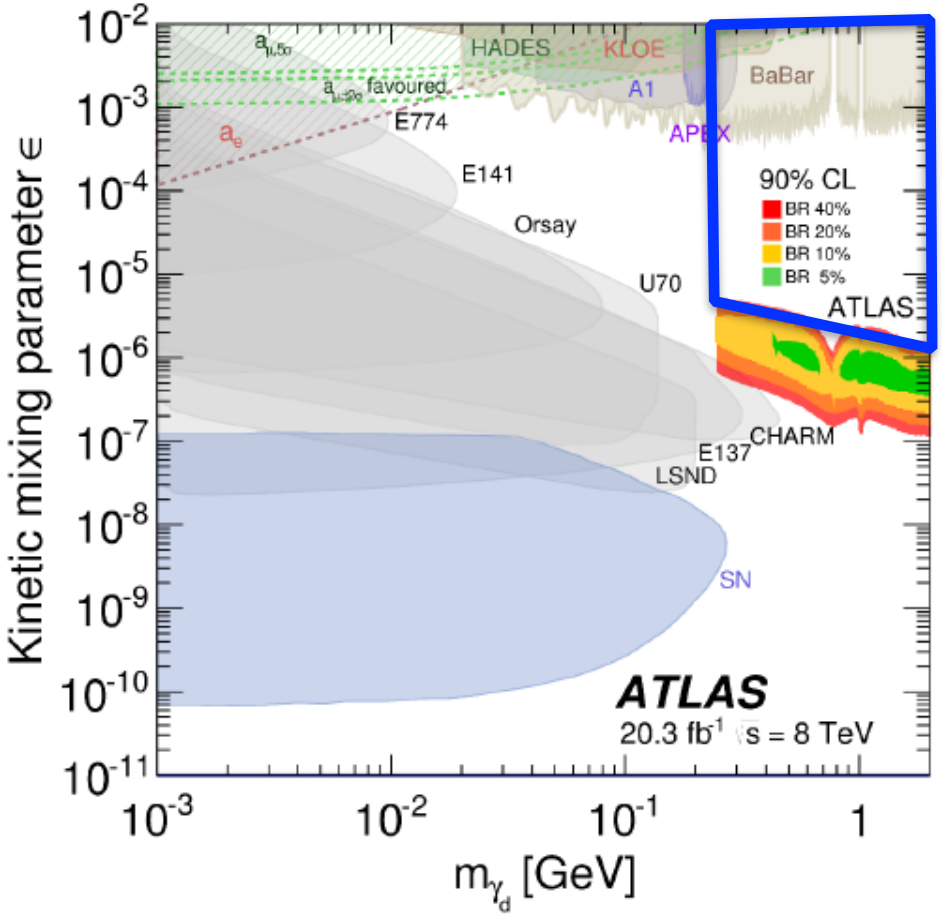
Results from previous analysis

- Search for new light bosons with **prompt** dimuons
- 95% CL limit on $\sigma(pp \to h_{1/2} \to 2a_1) \times B^2(a_1 \to 2\mu)$ w.r.t. m_{a1}



New in this analysis

- Extend search with **displaced** dimuons
  - Dark photon cτ between 0 and 5 mm
- Set 2D limit in (dark photon cτ is related to kinetic mixing)

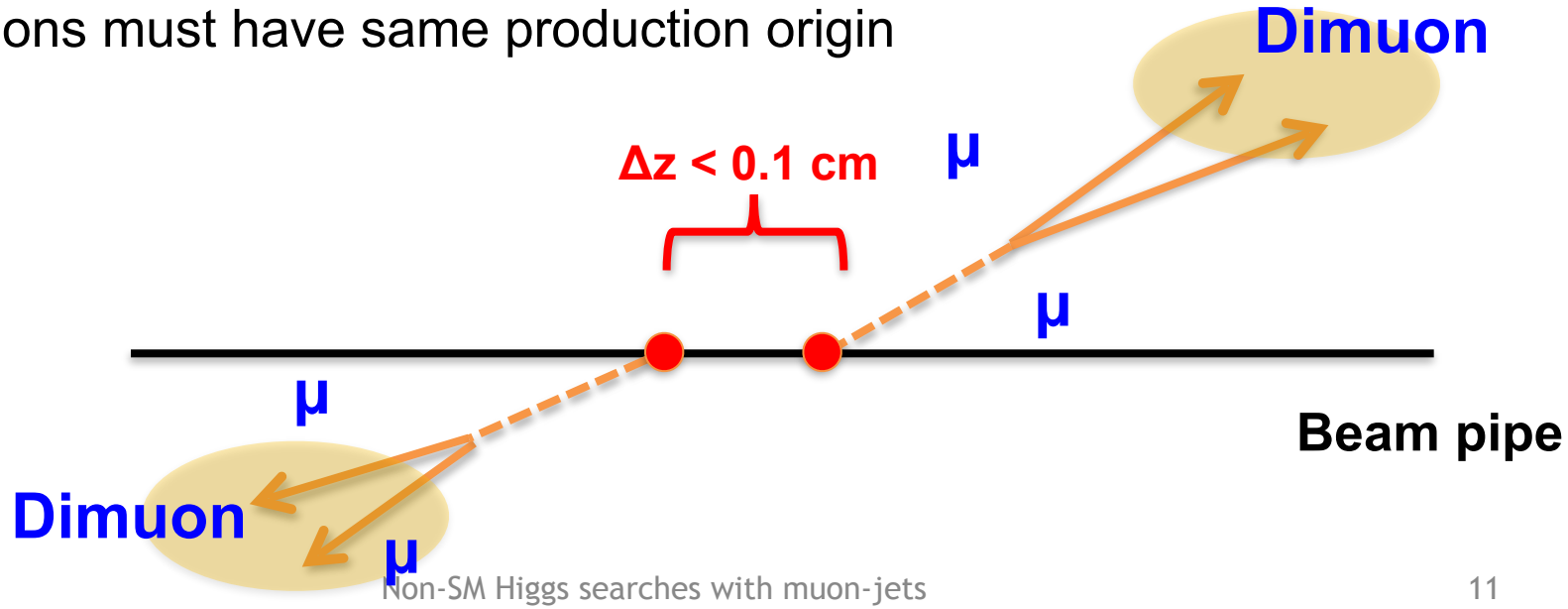


CMS region of sensitivity

10.1007/JHEP11(2014)088

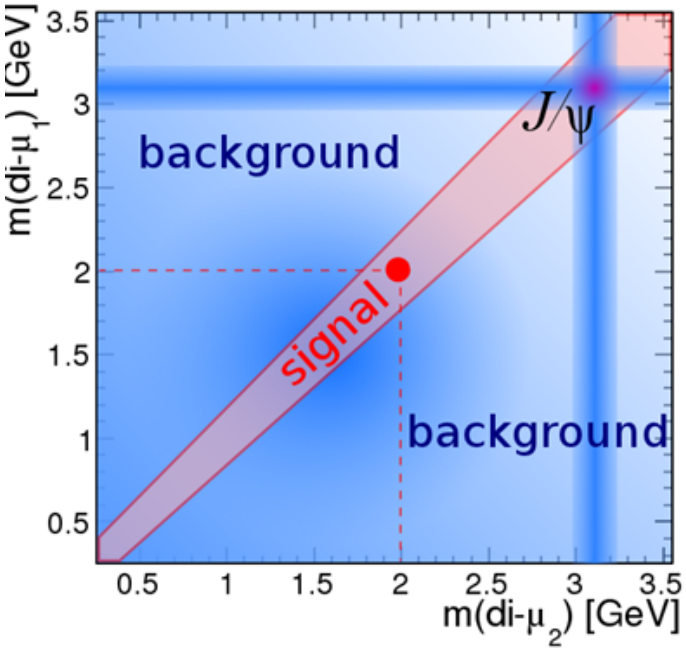
Event selection

- At least 4 muons
  - Dimuon trigger with p_T = 17 GeV and 8 GeV (online)
  - 4 muons with 8 GeV in $|\eta| < 2.4$, 1 muon with 17 GeV in $|\eta| < 0.9$ (offline)
- Nearby muons are clustered into pairs of dimuons
  - Based on vertex probability and invariant mass
- Require events with exactly 2 dimuons
  - No limit on number of unpaired muons
- Dimuons must have same production origin



Dimuon mass constraint

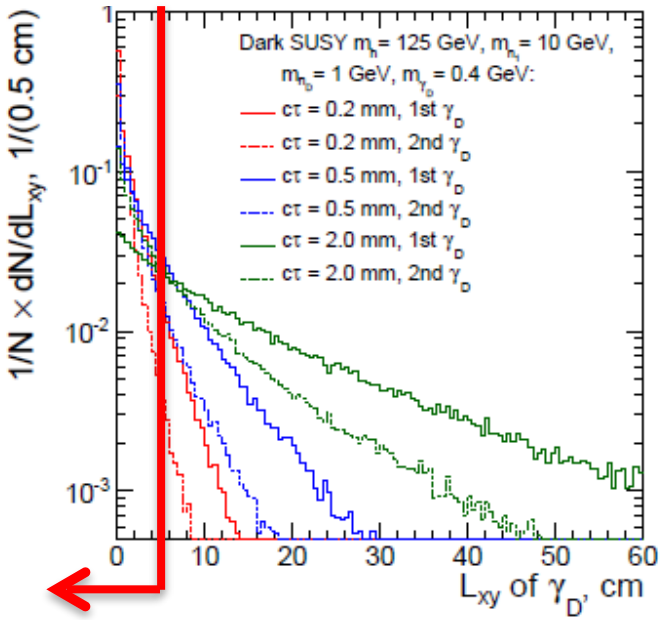
- Dimuons are produced in decay of same type of new light bosons
- Dimuon masses must be compatible
  - Diagonal mass corridor
    - $|m_{\mu\mu 1} - m_{\mu\mu 2}| < 5 \times$ mass resolution
  - Use light SM resonances (ρ, ω, ϕ, J/ψ) to study mass resolution



Fiduciality of dimuons

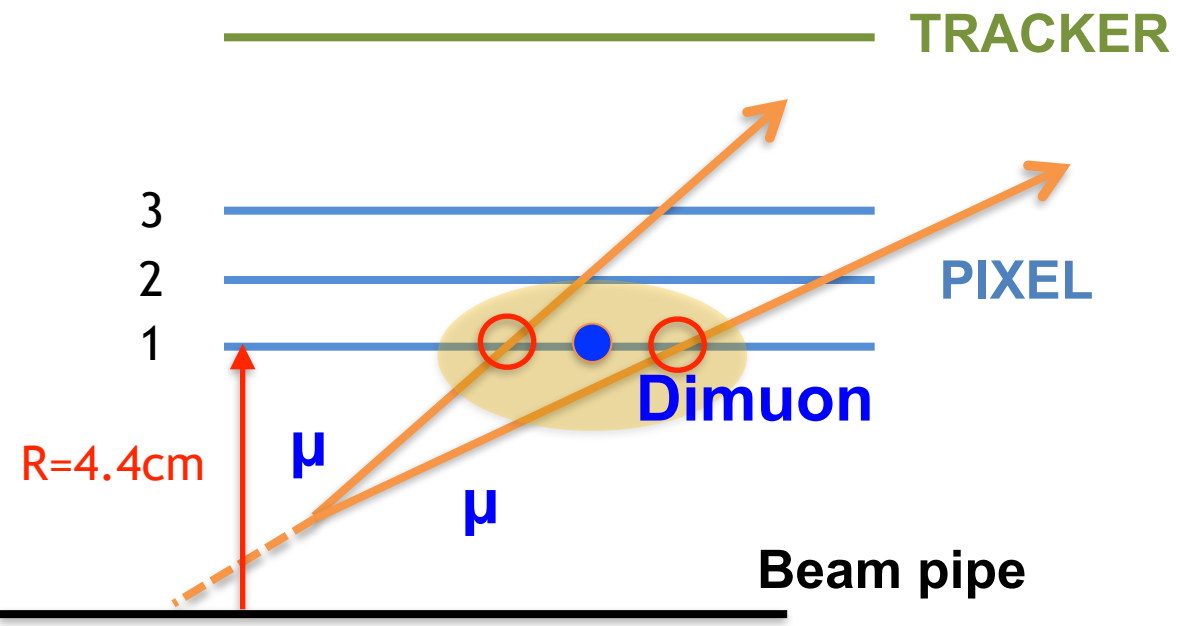
- New in this analysis: **displaced dimuons**!
- Trigger **efficiency falls** rapidly with larger **displacement**
- We don't want any effects due to losses in trigger or tracker
- Construct a fiducial region: at least 1 hit in the first pixel layer
  - **L_{xy} < 4.4 cm** – distance perpendicular to the beam pipe
- Ensure model independent interpretation
- Sensitive to signal even with L_{xy} cut

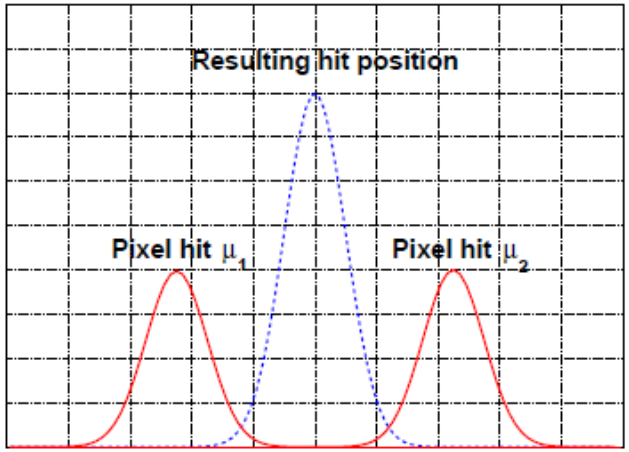
Displaced muon trigger for 2015 analysis to increase fiducial region



Clustered hit issue

- Displaced muons from very light dark $m_{\gamma_D} = 2m_\mu$ are highly parallel and spatially close to one another in tracker
- Dimuon hits in the 1st pixel layer can end up being clustered into a single hit, not assigned to either muon: event fails selection

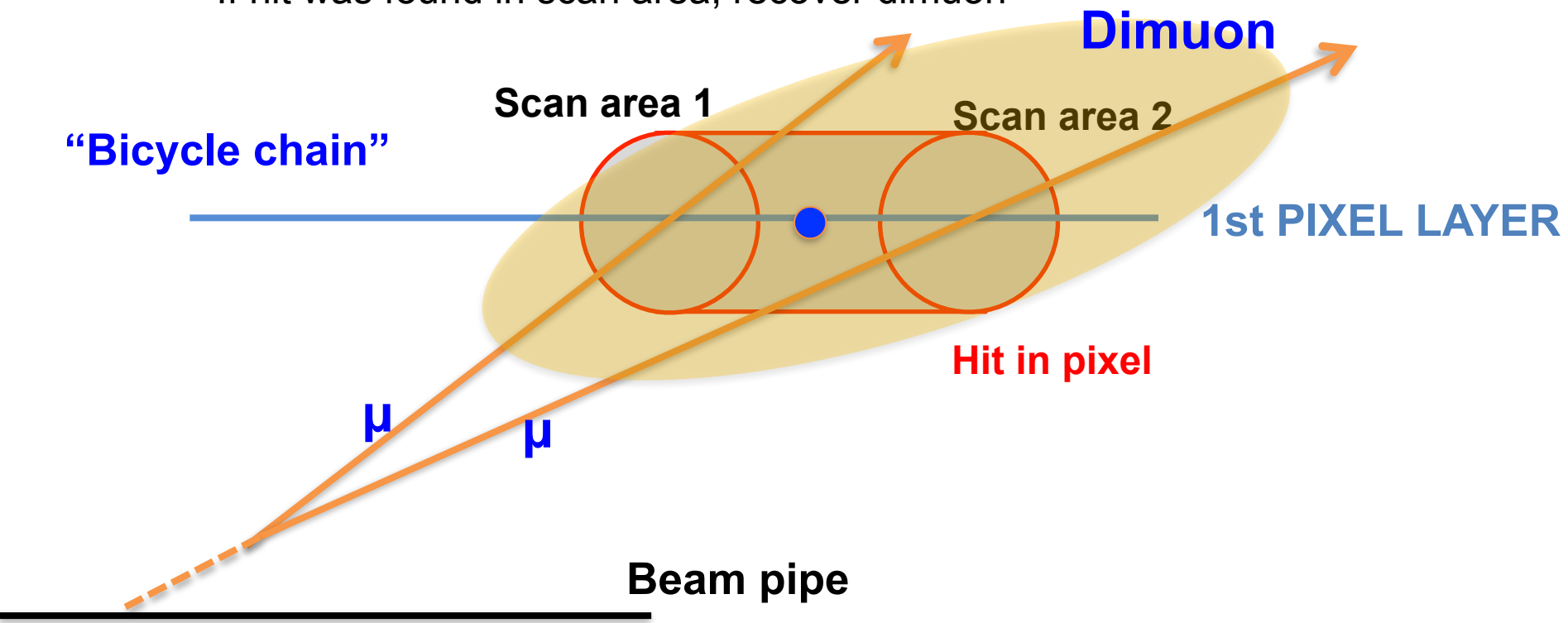




Two hits are reconstructed as one single hit

Clustered hit recovery technique

- A hit recovery technique was developed for this analysis
  - Extrapolate muon trajectories to 1st layer of the pixel detector
  - Collect all nearby pixel hits in scan areas 1 and 2 and in between
  - If hit was found in scan area, recover dimuon

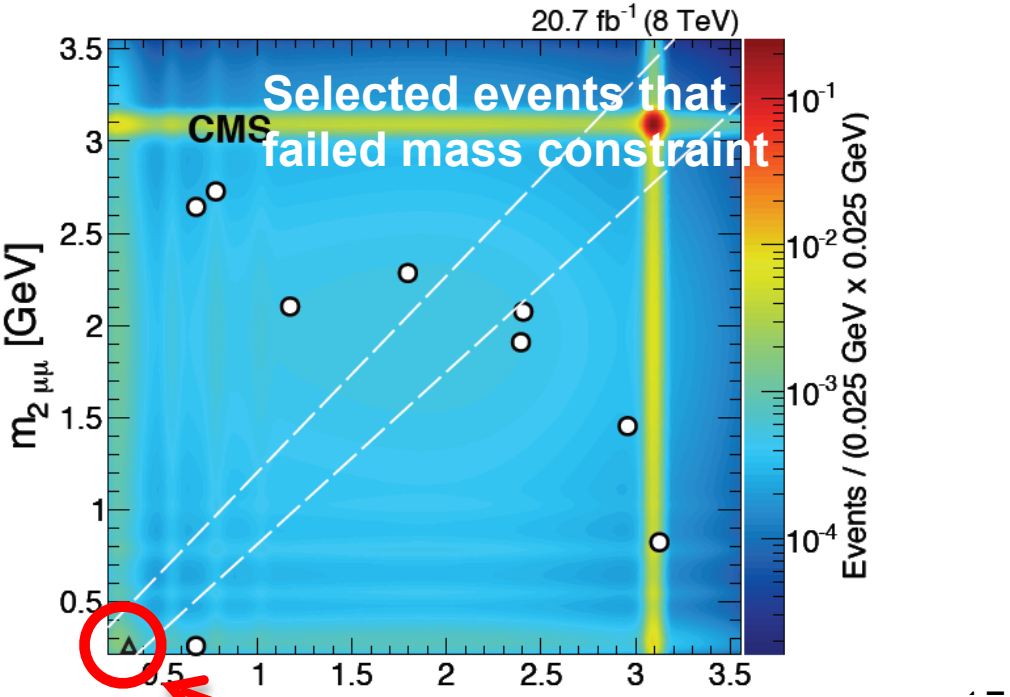


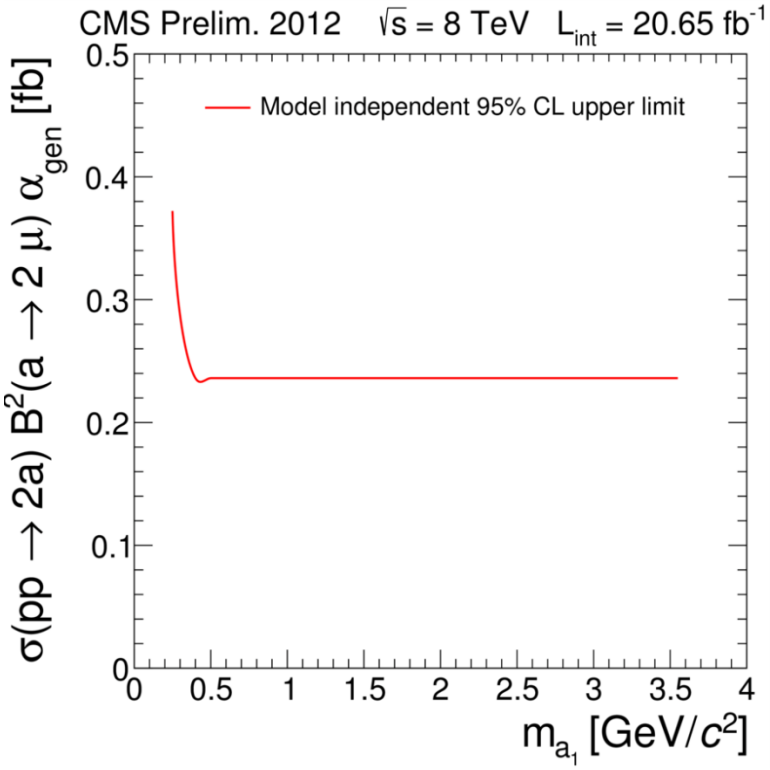
Standard model backgrounds

- B-Bbar: 2.0 ± 0.7
  - Both b quarks decay into a pair of muons, via semileptonic decay of b-quark and daughter c-quark, or via resonances (ρ, ω, ϕ, J/ψ)
- Prompt double J/ψ production: 0.05 ± 0.03
- Electroweak production of dimuons: 0.15 ± 0.03
  - $pp \rightarrow Z/\gamma^{*} \rightarrow 4\mu$
- Total SM background: 2.2 ± 0.7

Results

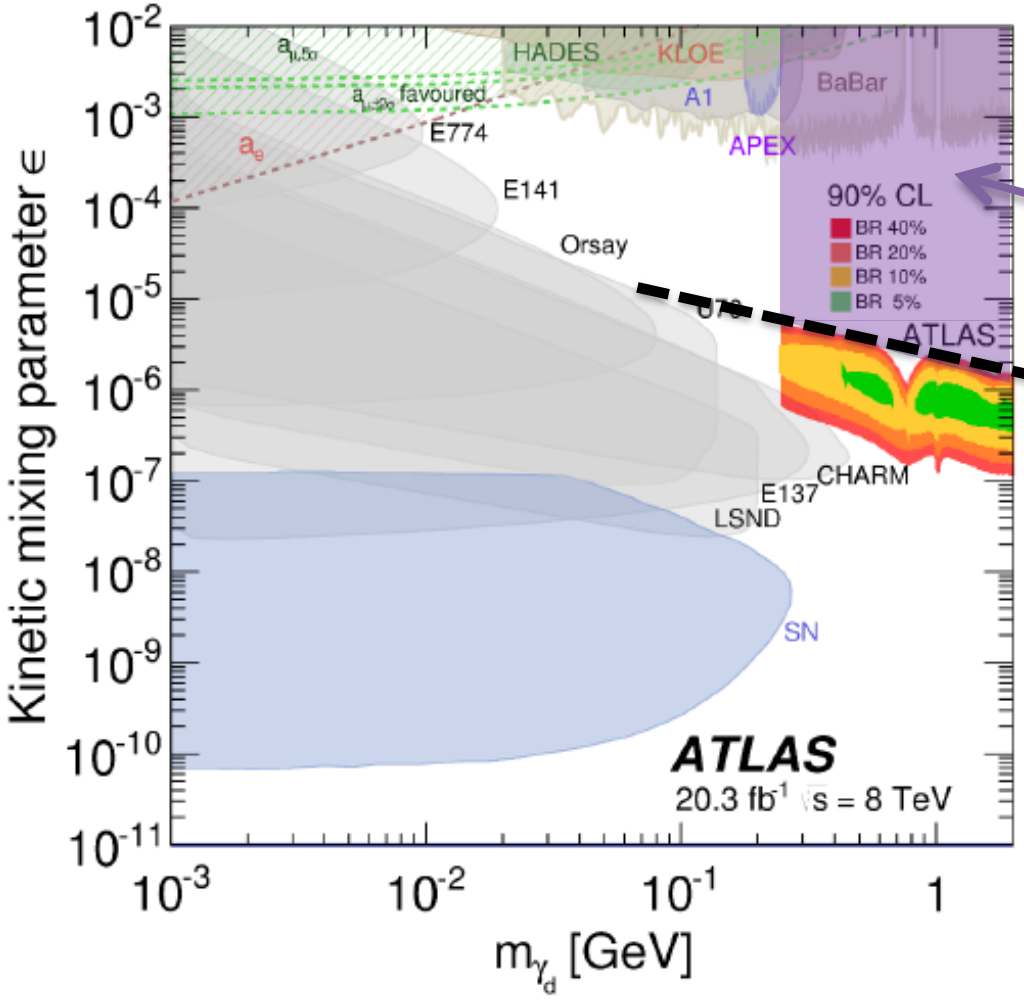
- After full event selection only one event survives in data (20.7 fb^{-1})
- Consistent with SM expectation (2.2 ± 0.7 events)
- Model independent limit on cross section x (branching ratio)^2





Benchmark scenario: dark SUSY

NOT THE ACTUAL RESULT!!! EXCLUSION RANGE WAS DRAWN BY HAND



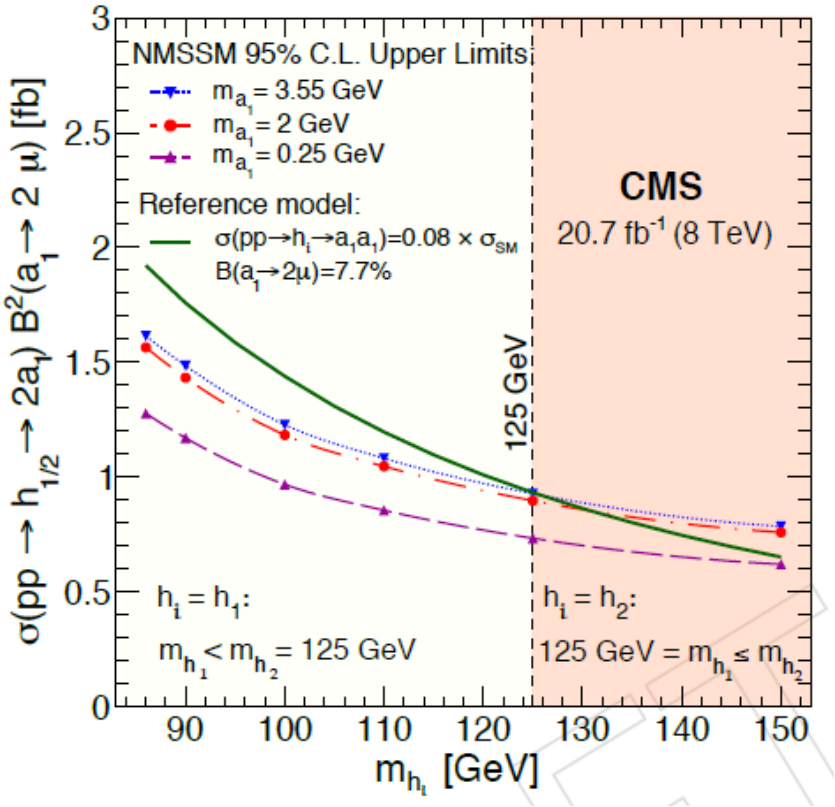
Paper is going through collaboration review. Results will be public soon.

Excluded by this analysis

10.1007/JHEP11(2014)088

Benchmark scenario: NMSSM

- **95% CL upper limits as function of m_h on $\sigma(pp \to h_{1/2} \to 2a_1) \times B^2(a_1 \to 2\mu)$**
- Assume one of the two CP-even higgs is LHC higgs boson, then the other one is lighter or heavier.
- Invisible BSM fraction (0.08) was tuned such that model cross section intersects with blue line at 125 GeV (<<32% Exp.)
- $B(a_1 \to 2\mu)$ = 7.7% from theory
- Limit at each mass point is calculated as if **only source of signal events is CP-even higgs** boson with corresponding mass



Conclusions & outlook

- A search for new light bosons was presented
  - Decaying to prompt or displaced dimuons
- 1 event observed in 20.7 fb^{-1} of data consistent with SM expectation
- 95% CL model independent limit is set
- Results are applicable to a whole range of non-SM scenarios
- Interpreted in 2 benchmark scenarios:
  - dark SUSY and NMSSM
- Analysis will be continued in Run-II with improved trigger

STAY TUNED!!!

Backup slides

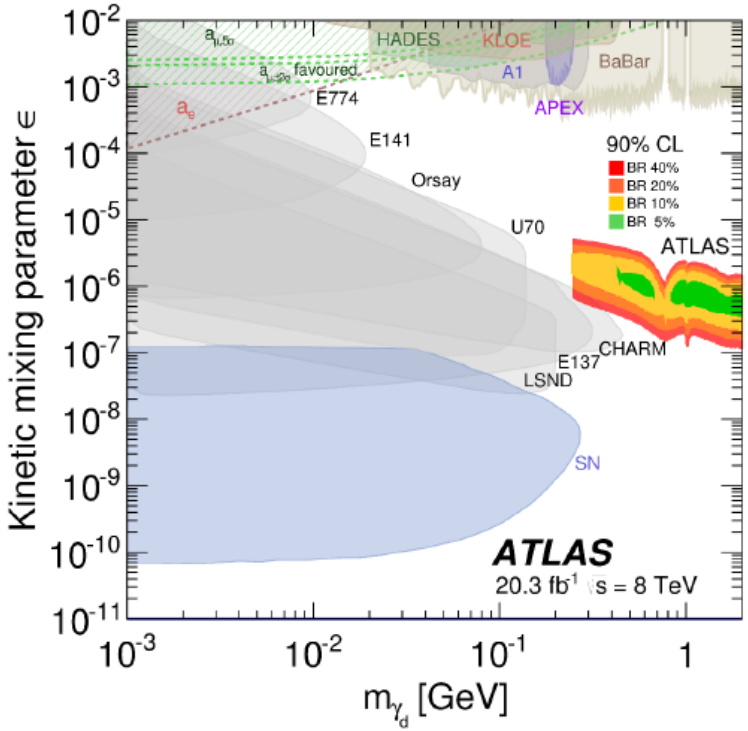
Kinetic mixing parameter

- Ctau is related to kinetic mixing parameter in following way:

$$c\tau_{\gamma_D}(\epsilon, m_{\gamma_D})[mm] = \frac{1.97 \cdot 10^{-13}[GeV \cdot mm]}{\epsilon^2} \times f(m_{\gamma_D})[GeV^{-1}],$$

Monte Carlo event simulation

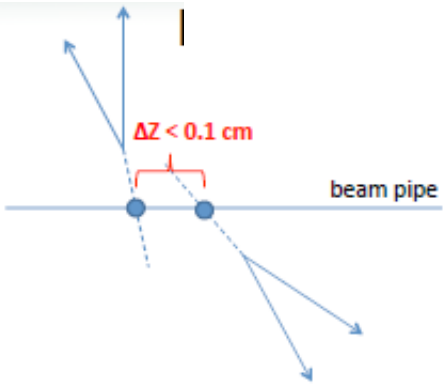
- NMSSM
  - Higgs production via gg-fusion with Pythia
    Decay to $2A_{NMSSM}$
  - Higgs masses between 90 and 150 GeV
  - Mass A_{NMSSM} between 0.25 and 3.55 GeV
- Dark SUSY
  - Higgs production via gg-fusion with MadGraph
  - Bridge program to force Higgs to decay via
  - $H \rightarrow 2n_1$, $n_1 \rightarrow n_D + \gamma_D$, $\gamma_D \rightarrow 2\mu$
  - $m(n_1) = 10GeV$, $m(n_D) = 1GeV$, $m(\gamma_D)$ between 0.25 and 2 GeV
  - Decay length between 0 and 5 mm

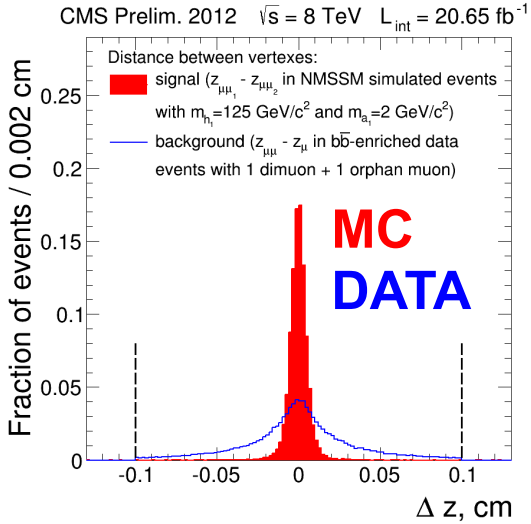


- Events are processed through detailed simulation of CMS based on GEANT4

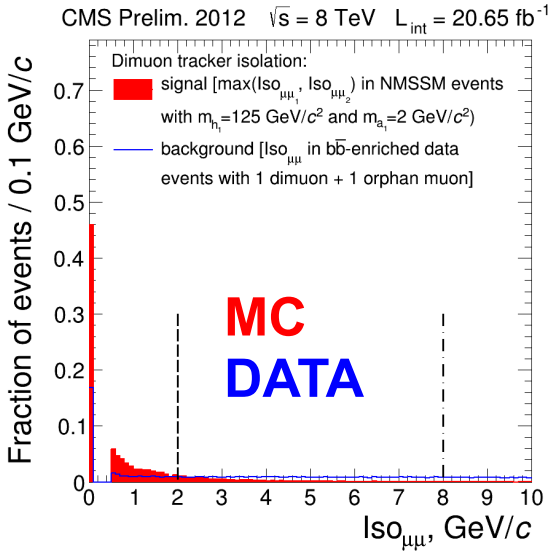
Additional requirements for dimuons

- Dimuon originating from same light boson must h same production origin
  - Require Δz < 0.1 cm





- Require low activity around dimuons
  - Select tracks with pT > 0.5GeV
  - Require total isolation < 2GeV



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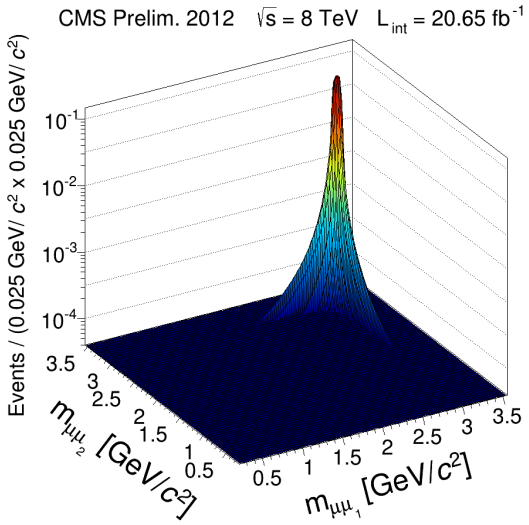
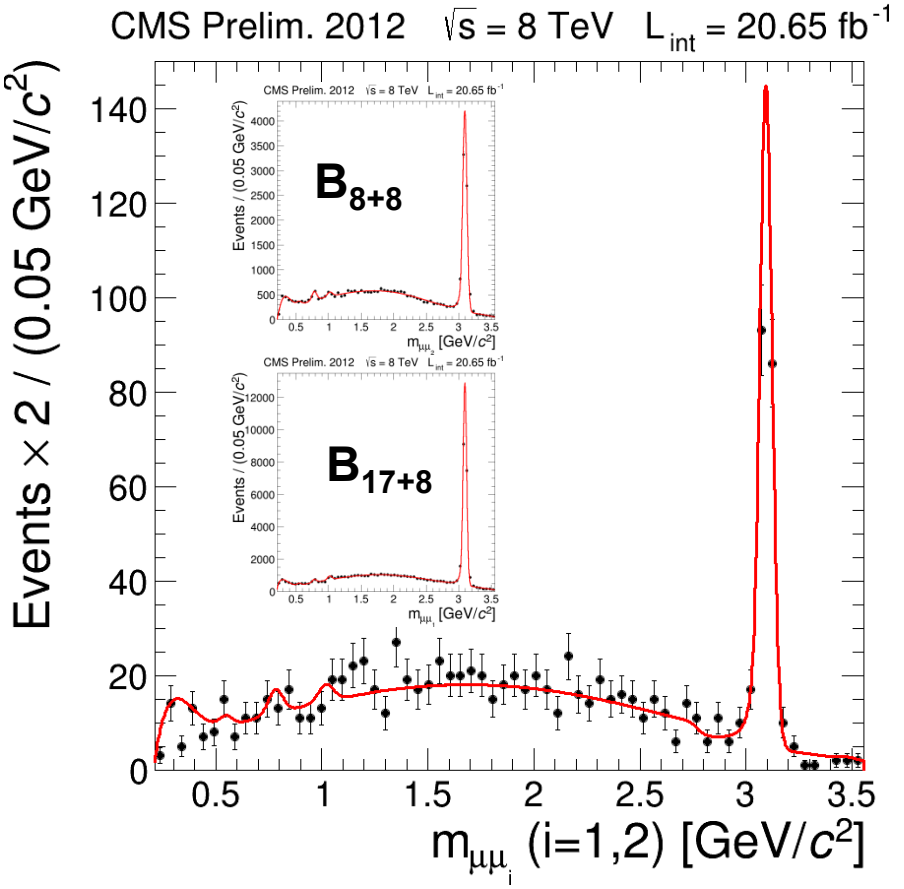
Standard model backgrounds

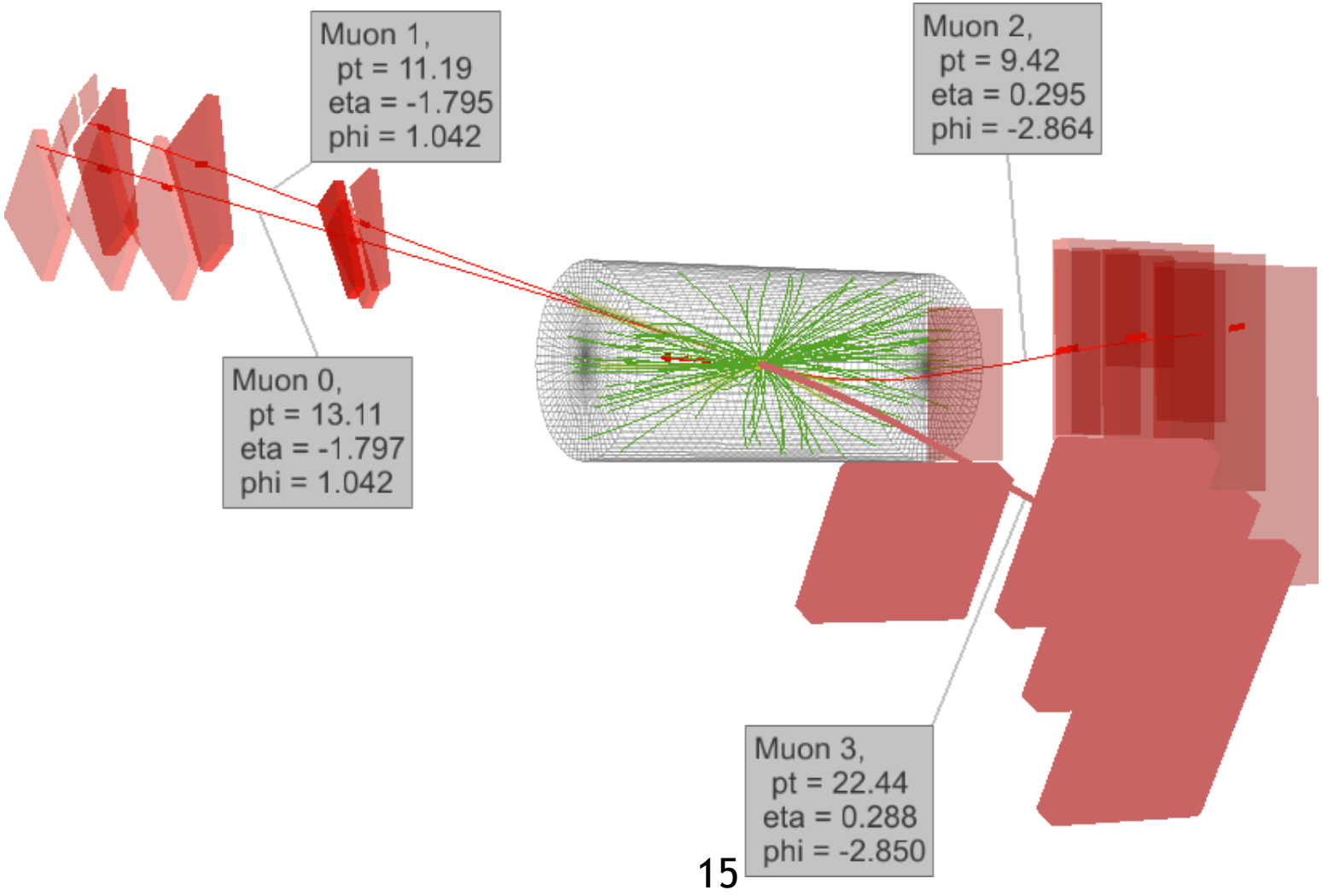
- BBbar
  - Both B-quarks decay to dimuons + X via double semileptonic decays + resonances (ρ, ϕ, J/ψ)
  - 1 background templates (B_{17+8} and B_{8+8}) from BB enriched data with 3 muons, no isolation requirement and normalized to data





- Direct double J/ψ production:
  - 2D Crystal Ball template normalized to data

Event display



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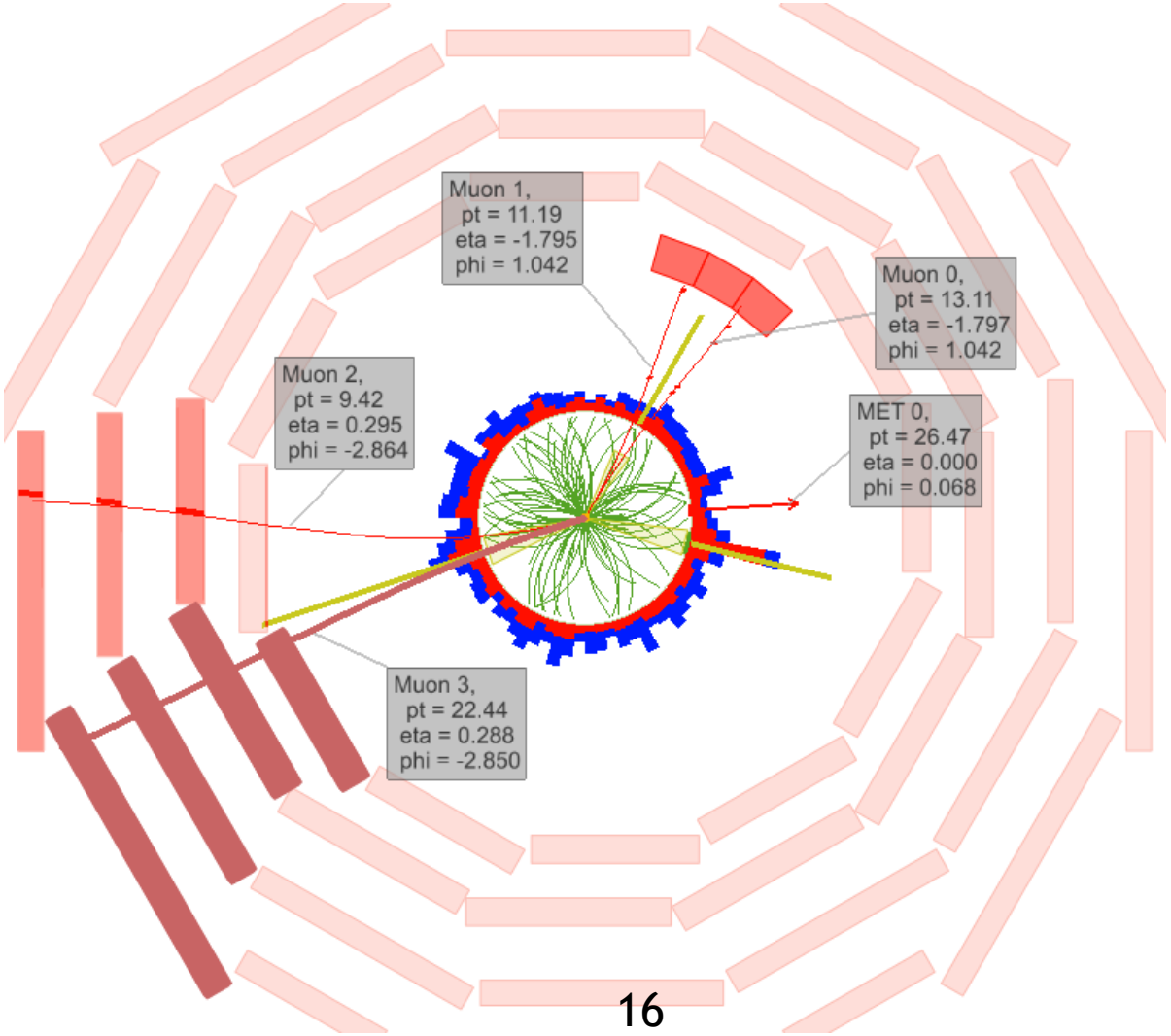
Event display



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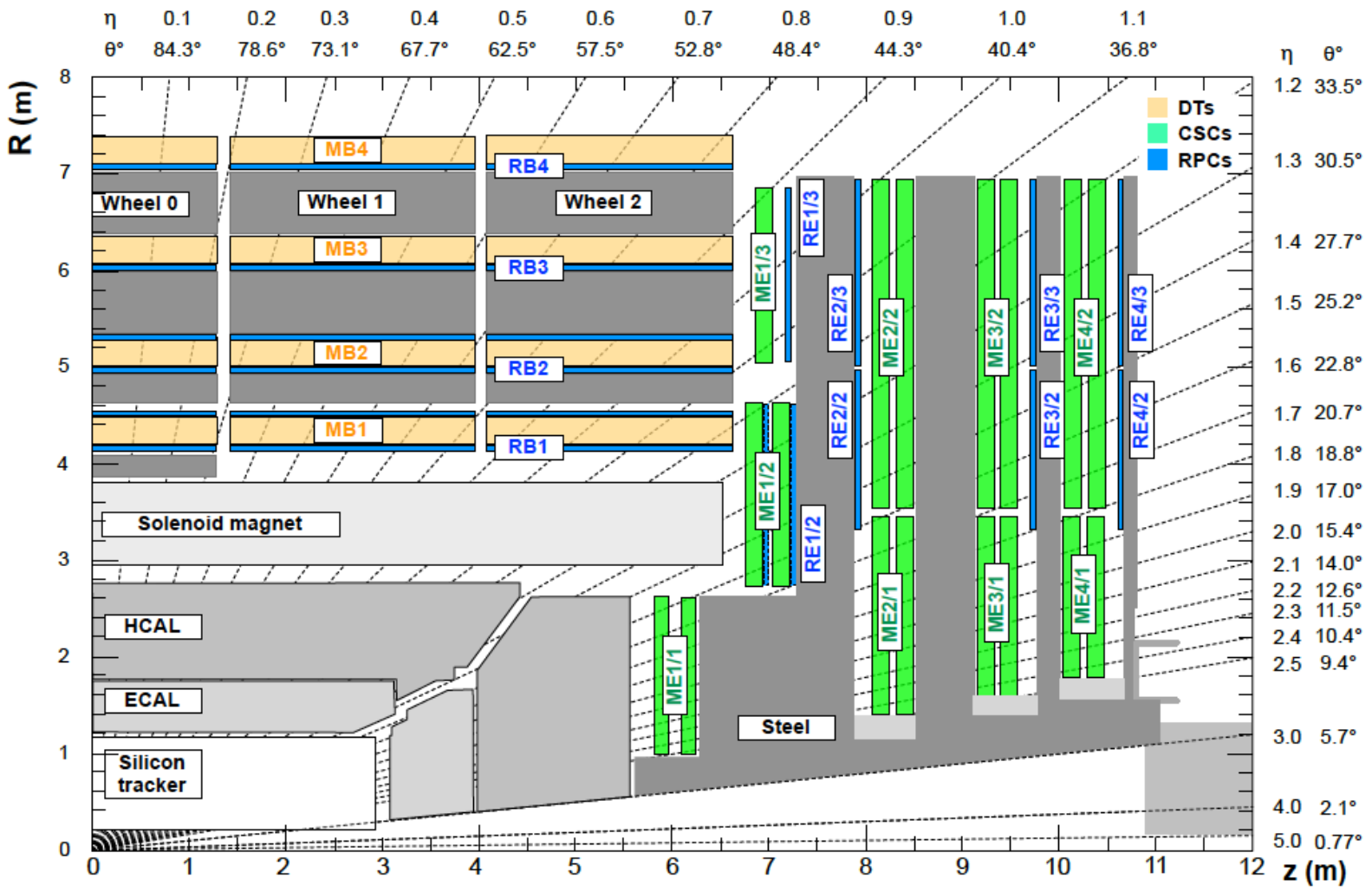
Outlook

- Paper with 2012 results will be submitted to PRL soon
- This analysis will be continued on 13TeV collision data
- We developed a high level trigger algorithm dedicated for displaced muons studies
- Monte Carlo production ongoing

Systematic uncertainties

Source of uncertainties	Error, %
Integrated luminosity	2.6%
Muon HLT	1.5%
Muon ID	$4 \times 1\%$
Muon tracking	$4 \times 0.2\%$
Overlapping in Tracker	$2 \times 1.2\%$
Overlapping in Muon System	$2 \times 1.3\%$
Dimuons mass consistency	1.5%
NNLO Higgs p_T re-weighting	2.0%
PDF+α_s	3.0%
Total	7.3%

CMS in Run-2


η 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
θ° 84.3° 78.6° 73.1° 67.7° 62.5° 57.5° 52.8° 48.4° 44.3° 40.4° 36.8°
η θ°
1.2 33.5°
1.3 30.5°
1.4 27.7°
1.5 25.2°
1.6 22.8°
1.7 20.7°
1.8 18.8°
1.9 17.0°
2.0 15.4°
2.1 14.0°
2.2 12.6°
2.3 11.5°
2.4 10.4°
2.5 9.4°
3.0 5.7°
4.0 2.1°
5.0 0.77°
R (m)
z (m)
DTs
CSCs
RPCs
Wheel 0
Wheel 1
Wheel 2
MB4
MB3
MB2
MB1
RB4
RB3
RB2
RB1
Solenoid magnet
HCAL
ECAL
Silicon tracker
Steel
ME1/3
ME1/2
ME1/1
RE1/3
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