Search for hidden-sector bosons in $B^0 \rightarrow K^{*0} \chi(\rightarrow \mu^+ \mu^-)$ decays

4th November 2015

Mitesh Patel
(Imperial College London)
On behalf of the LHCb collaboration

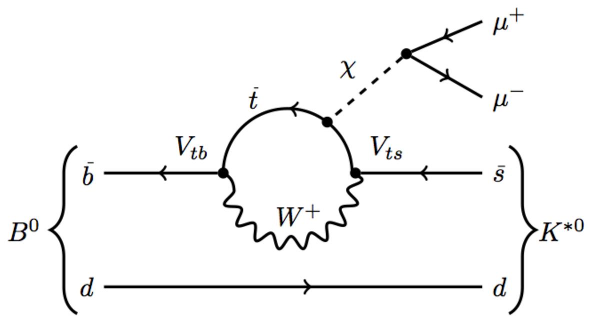
Imperial College London

Introduction

- Lack evidence for dark matter and various cosmic ray anomalies → renewed interest in "hidden sector theories"
- Hidden sector particles singlets wrt Standard Model gauge interactions → very weak interactions
  - Can still get production (and decay) of hidden-sector particle, χ, by mixing hidden sector particle with some SM "portal particle" e.g. H, Z, γ, ν
- Previous searches made at a wide range of experiments
  - Stringent constraints on hidden-sector γ and ν portals
  - Significantly weaker constraints on axial-vector and scalar portals

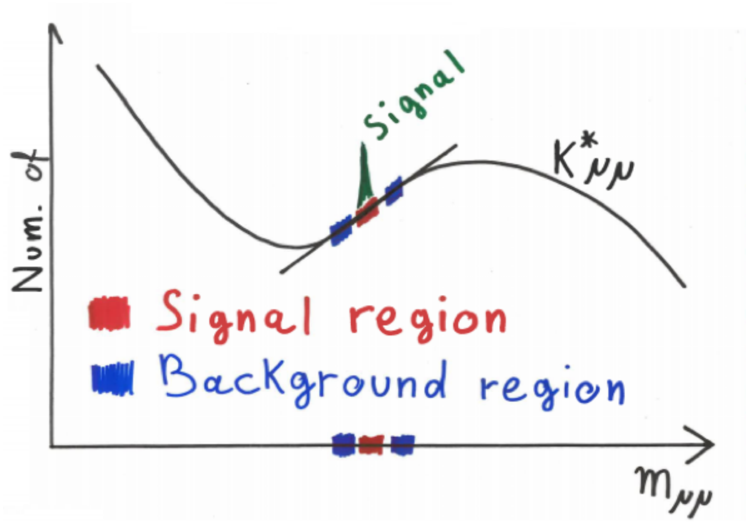
$B^0 \rightarrow K^{*0}\chi(\rightarrow\mu^+\mu^-)$ decays

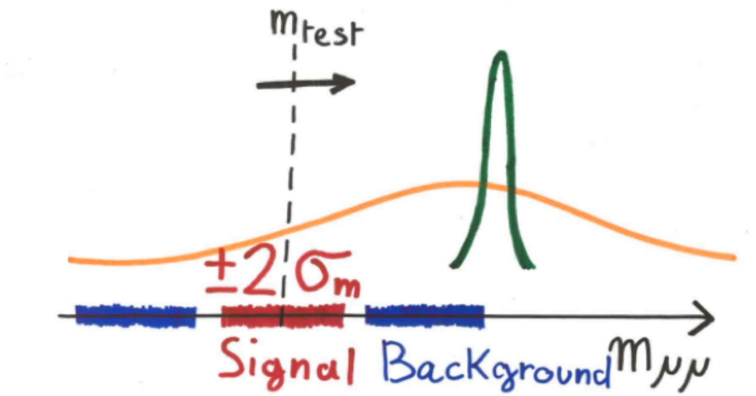
- The $B^0 \rightarrow K^{*0}\mu^+\mu^-$ final state lends itself well to searches for χ bosons with $\chi\rightarrow\mu^+\mu^-$
  - $b\rightarrow s$ transition mediated by top quark loop – enhanced sensitivity to χ with large top coupling e.g. via mixing with the Higgs sector
  - $K^{*0}\rightarrow K^+\pi^-$ gives entirely charged final state and helps with vertex reconstruction
  - Can reduce backgrounds to a low level
  - Mass range accessible $2m(\mu) < m(\chi) < m(B^0)\text{-}m(K^{*0})$
  - Can search for long-lived χ, giving displaced $\mu^+\mu^-$



Search Strategy

- Blind analysis
- Scan m_{test} in steps of ½ σ $m(\mu^+\mu^-)$
- Constrain $m(K^+\pi^-\mu^+\mu^-)$ to the known B^0 mass
  → improves $m(\mu^+\mu^-)$ resoln to 1-7 MeV
- Signal region,
  $|m(\mu^+\mu^-) - m(\chi)| < 2\sigma\ m(\mu^+\mu^-)$
- Background region > 3σ from $m(\chi)$
- Wide resonances have no impact
- Narrow resonances (ω, φ, J/ψ, $\psi(2S)$ and $\psi(3770)$) vetoed





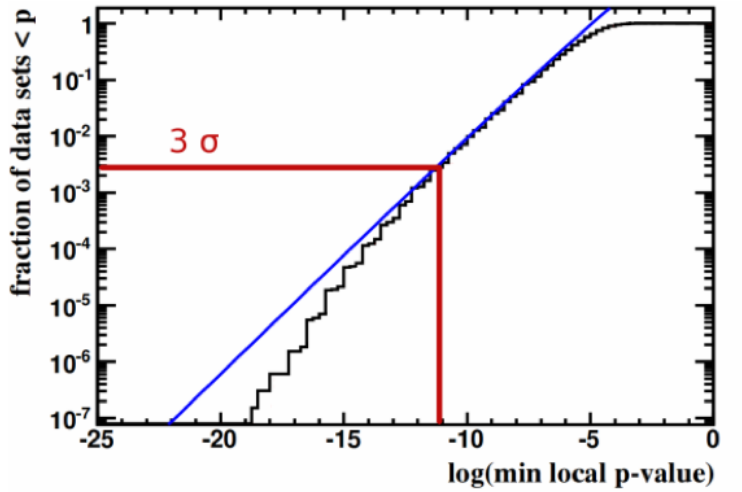
Search Strategy

- At each m_{test} form test statistic, profile likelihood ratio of hypotheses with and without a signal

- Consider two regions of dimuon lifetime, $\sigma\ \tau(m_{test})$ (0.2-1ps)
  - Prompt region : $|\tau\ (\mu^+\mu^-)| < 3\sigma\ [\tau(\mu^+\mu^-)]$
  - Displaced region : $|\tau\ (\mu^+\mu^-)| > 3\sigma\ [\tau(\mu^+\mu^-)]$

  Likelihood formed from product – no assumption made about $\tau(\chi)$

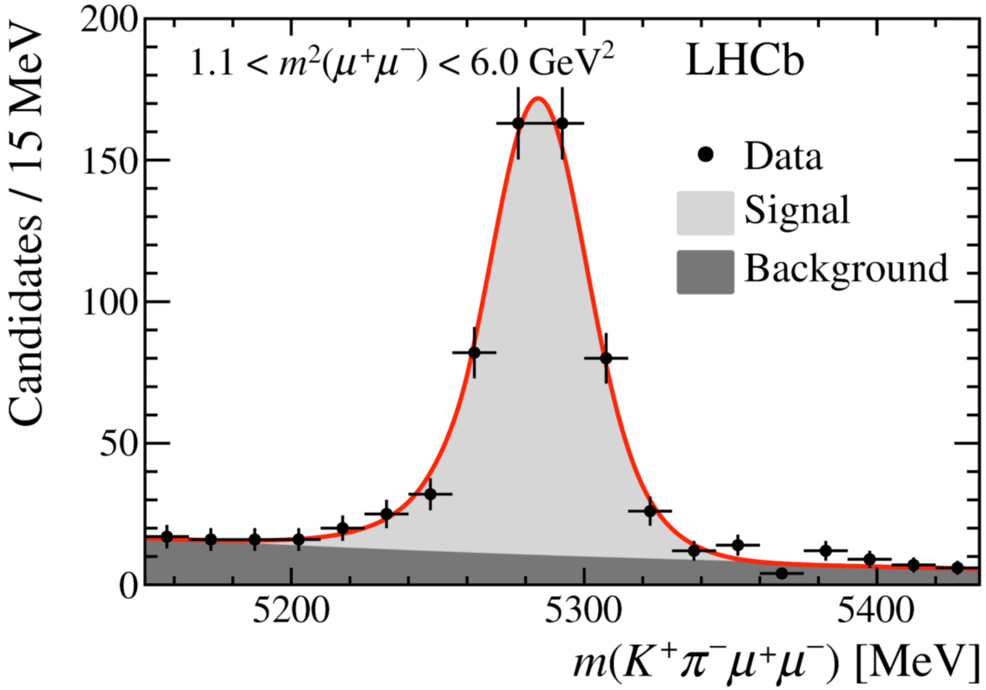
- Fraction of toys that have a minimum local p-value less than value observed in data used to compute global p-value



[JINST 10 (2015) P06002]

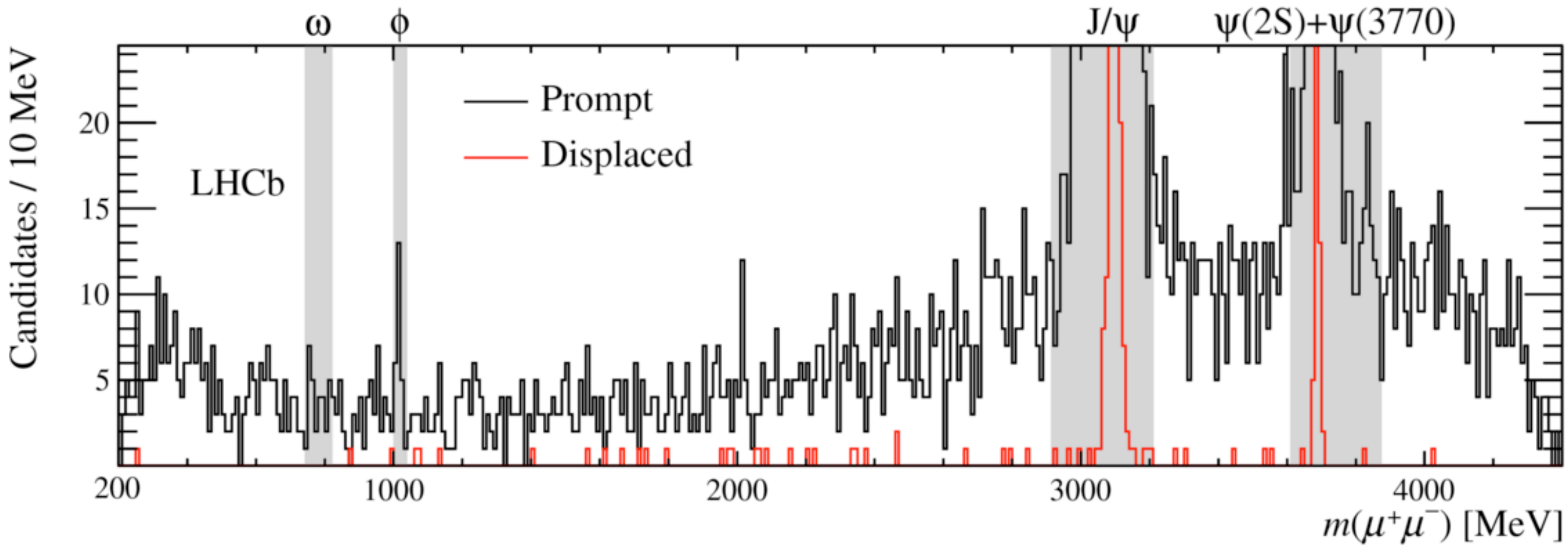
Selection and normalisation

- Use multivariate analysis to reduce backgrounds – uBoost technique gives response that is nearly independent of $\tau(\chi)$ [JINST 8 (2013) P12013]
- Measure $B(B^0 \to K^{*0}\chi(\to\mu^+\mu^-))$ relative to $B(B^0 \to K^{*0}\mu^+\mu^-)$
  - Use prompt region with $1.1 < m^2(\mu^+\mu^-) < 6.0\ \mathrm{GeV}^2$



Unblinded results

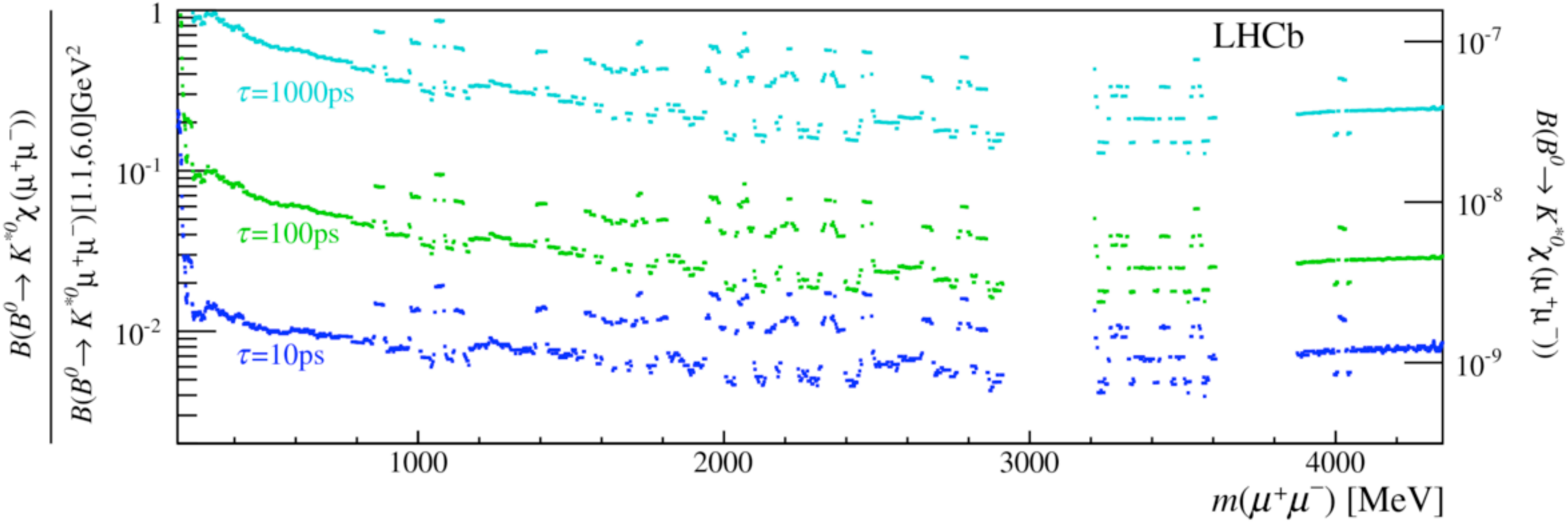
- Unblinded $m(\mu^+\mu^-)$ (for candidates in the B mass window)



  - Most significant local excess occurs for $m(\chi)$ = 253 MeV – in prompt region 11 candidates are seen with 6.2 expected
  - p-value of the no-signal hypothesis is 80% → no dark boson !

Branching fraction limits

- Spin of χ determines angular distribution and hence signal efficiency
  - Set upper limits assuming spin-zero. For $\tau(\chi)$<10ps : 0.005-0.050
  - For spin-one, limits would be 10-20% better

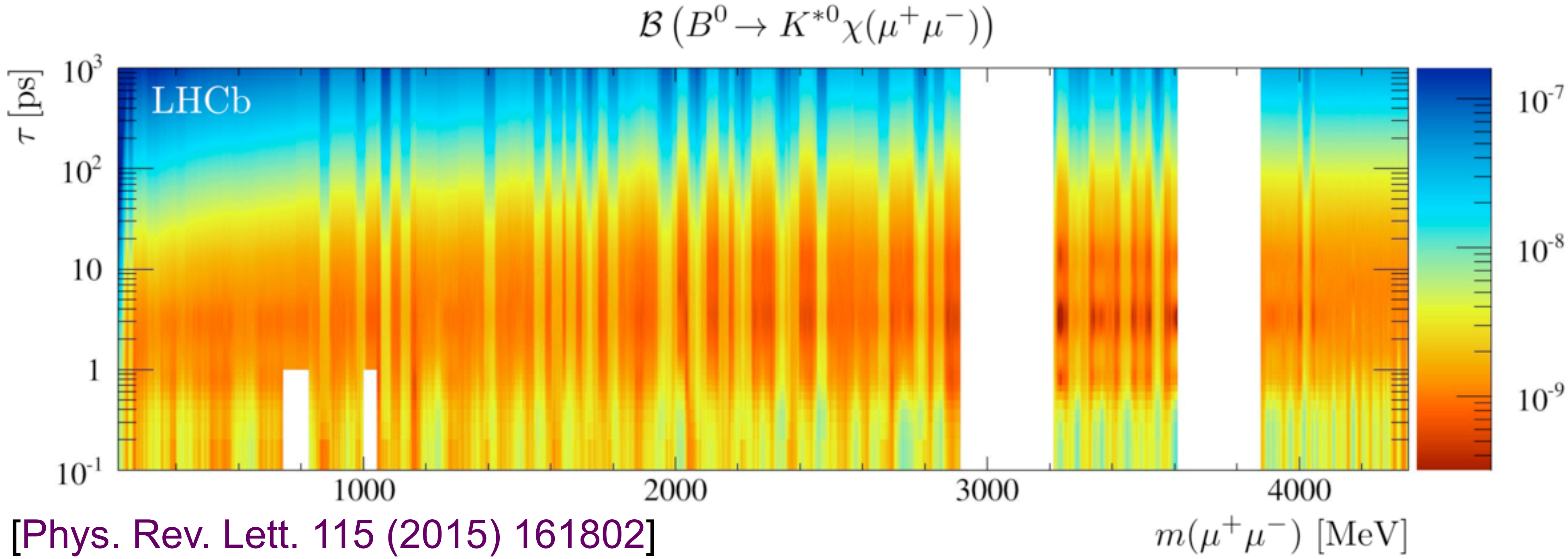


- Limits become less stringent for $\tau(\chi)$>10ps as χ would not decay in VELO

[Phys. Rev. Lett. 115 (2015) 161802]

Branching fraction limits

- Spin of χ determines angular distribution and hence signal efficiency
  - Set upper limits assuming spin-zero. For $\tau(\chi)<10$ps : 0.005-0.050
  - For spin-one, limits would be 10-20% better

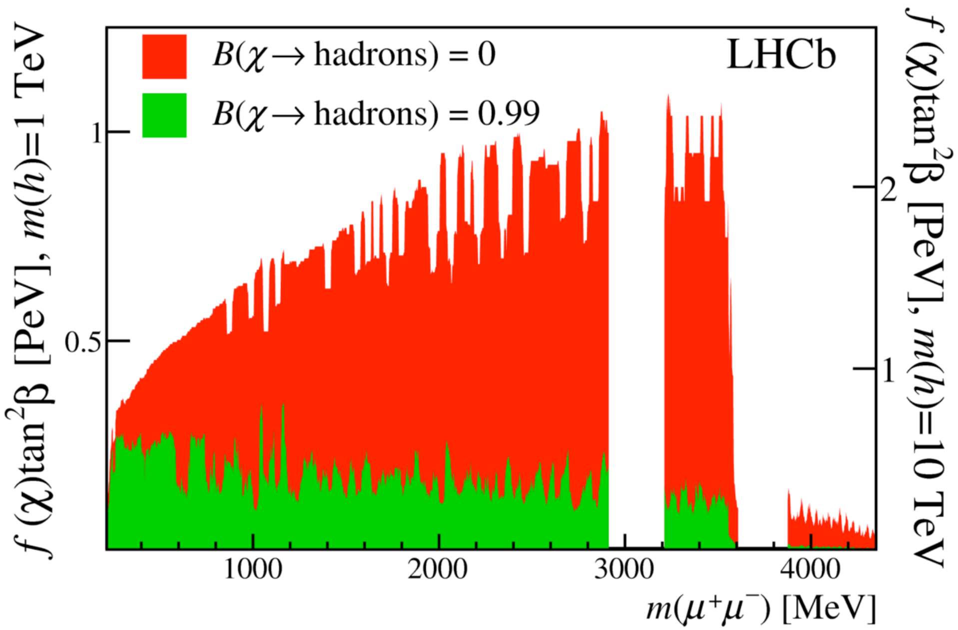


[Phys. Rev. Lett. 115 (2015) 161802]

  - Most stringent constraints to date on many theories that predict the existence of additional low-mass bosons

Constraints on models

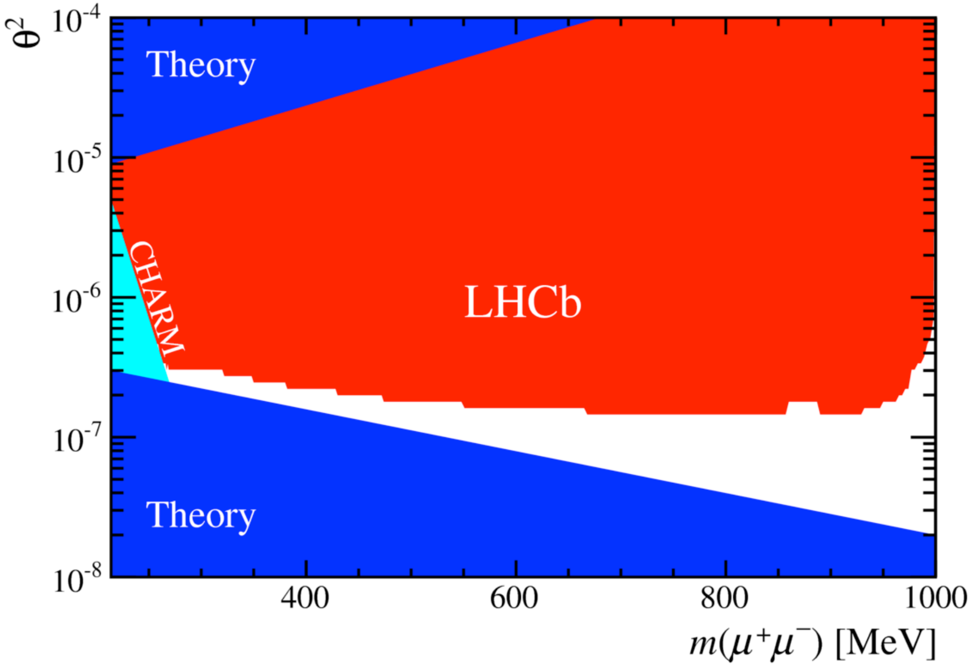
- Use limits to look at regions excluded for two example models
  - Axion model [Freytsis, Ligeti, Thaler,Phys.Rev.D81(2010)034001]
    - MSSM-like two Higgs doublet model with axion-like particles
    - Limits general but, for ease of presentation, show in limit of large ratio of Higgs-doublet vacuum expectation values, tan β>3, for charged-Higgs masses m(h) = 1 and 10 TeV



[Phys. Rev. Lett. 115 (2015) 161802]

Constraints on models

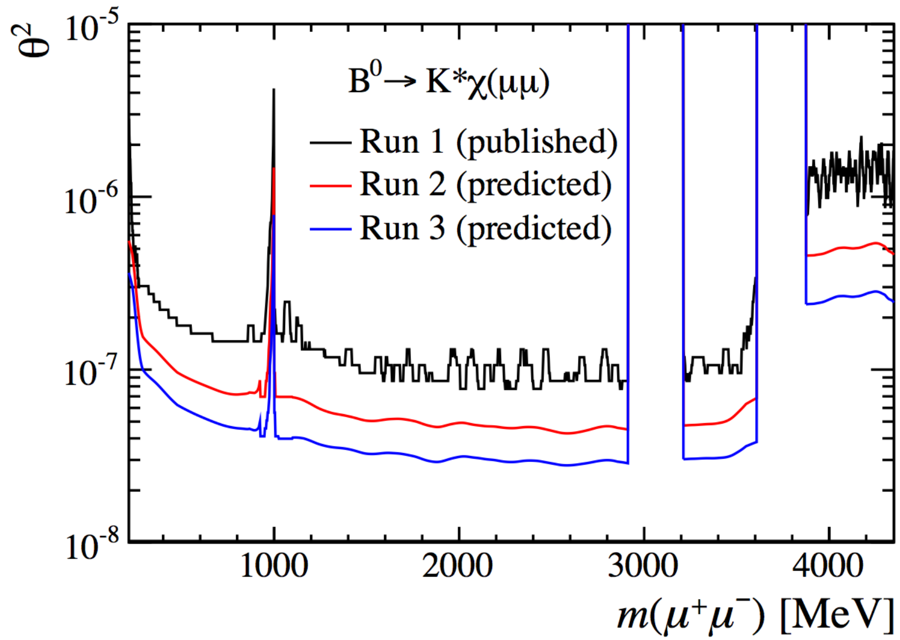
- Use limits to look at regions excluded for two example models
  - Inflaton model [Bezrukov,Gorbunov, Phys.Lett. B736 (2014) 494]
    - Hypothesizes that a scalar field χ was responsible for inflation of the early Universe and may have generated the baryon asymmetry
    - Associated "inflaton" particle expected to have mass $270 < m(\chi) < 1800$ MeV



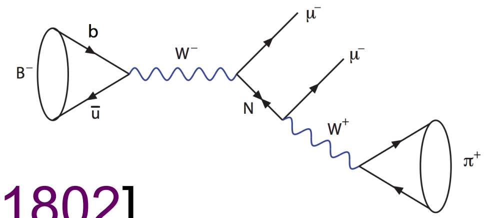
[Phys. Rev. Lett. 115 (2015) 161802]

The Future

- New data has ~double cross-section for b- and c-hadrons
- Can add "downstream" $\mu^+\mu^-$ candidates
- Hope to accumulate 5fb^{-1} during Run-II and then use upgraded detector to accumulate 15fb^{-1} during Run-III
- Extrapolate limit on scalar mixing angle

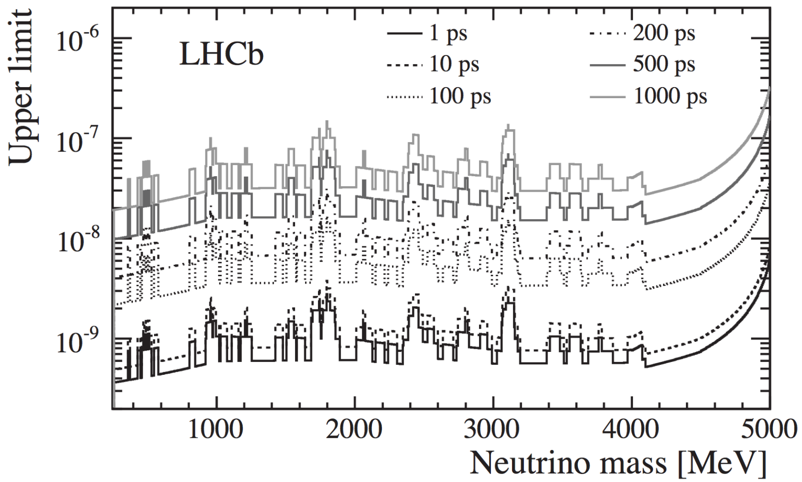


Other channels

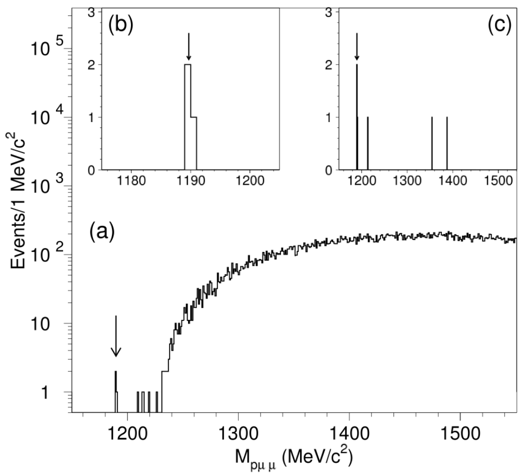


- Previous searches for Majorana neutrinos
  - $B^{-} \rightarrow \pi^{+}\mu^{-}\mu^{-}$ [Phys. Rev. Lett. 112 (2014) 131802]
  - $D^{-}_{(s)} \rightarrow \pi^{+}\mu^{-}\mu^{-}$ [Phys. Lett. B 724 (2013) 203]

  will be updated – working to improve techniques



[PRL 112 (2014) 131802]



[HyperCP, PRL 94 (2005) 021801]

- Also investigating our sensitivity to the Hyper CP anomaly: 3 muon events around 214 MeV in $\Sigma^{+} \rightarrow p\mu^{+}\mu^{-}$

Conclusions

- Search for dark bosons, χ, in $B^0 \to K^{*0}\chi(\to\mu^+\mu^-)$ decays
  - Sensitive to both prompt and displaced χ
  - No evidence for any dark boson seen
  - Set limits on $B(B^0 \to K^{*0}\chi(\to\mu^+\mu^-))$ at

    $<10^{-9}$ level for τ=0ps

    $<10^{-7}$ level for τ=1000ps

- Most stringent constraints to date on many theories that predict the existence of additional low-mass bosons

- Searches statistically limited, will improve with new data

Backup