Perspective for rare-decay angular analysis: $K^{(*)}\mu\mu$

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Current status

$B^0 \to K^* \mu\mu$

- BPH-15-008
- PAS-PUB, soon CWR
- Alessio, SL, Mauro, Linwei ,Dayong
  - Padova, MIB, PKU
- Dataset 2012, $L = 20.5\,\text{fb}^{-1}$
- Signal/Background yield: 1400/1800
- Measured $BR(q^2)$, A_{FB} and F_L, P_1, P_5', no correlation
- no full anagular analysis yet

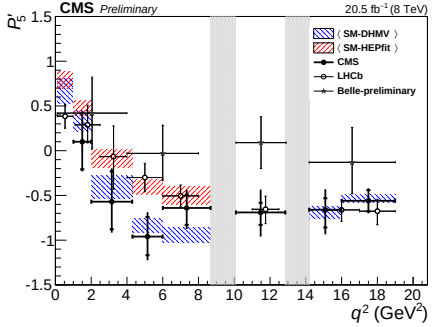
$B^+ \to K^{*+} \mu\mu$ / $B^+ \to K^+ \mu\mu$

- Many people: Geng, Niladri, Po-Hsun, Dayong, Sanjay ...
  - PKU, NTU, NISER
- Dataset 2012, $L = 20.5\,\text{fb}^{-1}$
- BPH-15-009: PreApp (24/11/2015)
  - Sgn/Bkg yield: 130/1000 events
  - Measure A_{FB} and F_L : $\text{pdf}(\cos\theta_l, \cos\theta_K)$
- BPH-15-001: PreApp (2/6/2015)
  - Sgn/Bkg yield: 780/2400 ev $q^2 < 6$
  - wSgn/Bkg yield: 2300/5000 ev full q^2
  - Measure A_{FB} and F_H: $\text{pdf}(\cos\theta_l)$

What can be useful to measure

We don't have (yet) a common measurement of all the angular parameters of a $b \to s\ell\ell$ decay (LHCb has)
$\sim 40\,\text{fb}^{-1}$ at 13 TeV, not yet looked at, plus 2017 data to collect (say other $\sim 40\,\text{fb}^{-1}$

Comparison with other exp



Yield for various experiment

- CMS: 1400 events ($25\,\text{fb}^{-1}$)
- LHCb [LHCb(2016)]: 2400 ev ($3\,\text{fb}^{-1}$) full angular analysis, correlations
- ATLAS [ATLAS(2017)]: 342 ($20\,\text{fb}^{-1}$) 4 different foldings, many angular parameters, no correlation
- Belle [Belle(2017)]: 187 μ (127 e) ($0.71\,\text{ab}^{-1}$ $7.7 \cdot 10^8$ $B\overline{B}$): 4 foldings

Events yield for $B^0 \to K^* \mu\mu$ in 2016

- Back of the envelope estimation of 2016 yield
- Inputs:
  - Signal Yield on 2012 dataset
    - ★ ($L = 20.5\,\text{fb}^{-1}$) 1400 $B^0 \to K^* \mu\mu$
  - Inclusive B^+ x-section at 13 TeV [CMS(2016)](BPH-15-004)
    - ★ in 2012 using same HLT trigger `HLT_DoubleMu4_Jpsi_Displaced`: Yield 600k events
    - ★ in 2016 (datasets B,C,D, and E $L = 17\,\text{fb}^{-1}$) `HLT_DoubleMu4_JpsiTrk_Displaced` 400k events
- Estimate for $L = 40\,\text{fb}^{-1}$ (2016)

$$Y(2016) = Y(2012) \cdot \frac{Y(2016, B^+ \to J/\psi K^+)\frac{40}{17}}{Y(2012, B^+ \to J/\psi K^+)} = 1400 \frac{400\,000 \frac{40}{17}}{600\,000} = 2200$$

Details on trigger 2012/2016/2017

Trigger: 2012

L1
- $p_T(\mu_1) > 3$ and $p_T(\mu_2) > 3$ GeV and $|\eta(\mu_1) - \eta(\mu_2)| < 2.2$

HLT
- single muon $p_T > 3.5$ GeV
- dimuon $p_T > 6.9$ GeV
- $1 < m(\mu\mu) = q < 4.8$ GeV
- $L/\sigma > 3$ w.r.t. beamspot
- Vtx $CL > 10\%$

Trigger: 2016

L1
- $p_T(\mu_1) > 11(12)$ and $pT(\mu_2) > 4(5)$ GeV

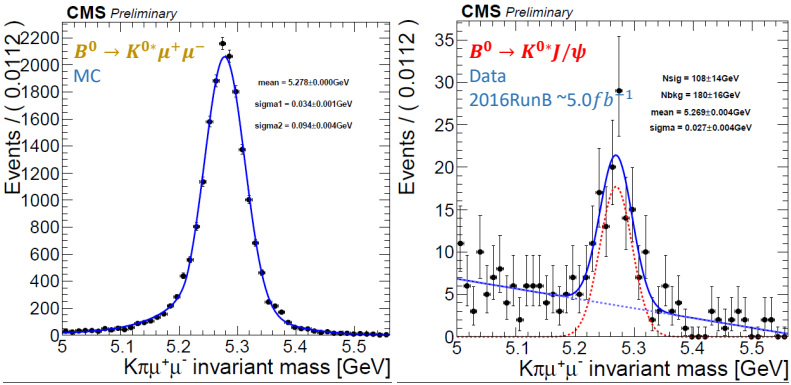
or
- $p_T(\mu_1) > 0$ and $p_T(\mu_2) > 0$ and $|\eta(\mu_1)| < 1.6(1.4)$ and $|\eta(\mu_2)| < 1.6(1.4)$ and Opposite Sign and $|\eta(\mu_1) - \eta(\mu_2)| < 1.8$

HLT
- single muon $p_T > 4$ GeV
- dimuon $pT > 6.9$ GeV
- $1 < m(\mu\mu) = q < 4.8$ GeV
- $L/\sigma > 3$ w.r.t. beamspot
- Vtx $CL > 10\%$

First Look of 2016 Data with B0ToKstMuMu

$B^0 \to K^{0*}\mu^+\mu^-$: ***HLT_DoubleMu4_LowMassNonResonantTrk_Displaced_v7***

$B^0 \to K^{0*}J/\psi$: ***HLT_DoubleMu4_JpsiTrk_Displaced_v7***



Comparison with LHCb/Belle2

- LHCb
  - Luminosity will not increase as fast as CMS: $L \sim 5\,\text{fb}^{-1}$ in Run2
  - but the trigger is way more favourable: same eff as in 2012
  - can expect to double the statistics at the end of Run2
  - Also K^*ee, $\Lambda_b \to \Lambda\mu\mu$, LFU in $K^*\ell\ell$
- Belle2
  - Very clean environment, but the number of B is "small" compared with LHC: $\sim 200\ ev/ab$
  - for charged final state, typically LHCb is competitive/dominant
  - Will reach $50\,\text{ab}^{-1}$ by ~ 2023
  - if we extrapolate from Belle: 13 000 events per ℓ channel
  - also $K^*\tau\tau$ possible
  - very interested in lepton universality test
  - also channels $B_s^0 \to \phi\ell\ell$ and $B \to X_s\ell\ell$

Charged final states: extrapolation

- Limited feedback from charged K group
- Using the ratio of B^0 to B^+ in 2012, and the expected yield for B^0, we can expect 200 events for B^+ in 2016 dataset
- Possible to redo the current analysis with 2 bins in $q^2 < m^2(J/\psi)$?
- not enought for a full angular analysis, not even with full 2017 dataset

Alternative triggers?

From [Nachman and Rubbo(2016)] reported by M. Pierini: do not use a dedicated trigger, but look for B decays in any trigger among the PU vertexes. Zero Bias Trigger

Some back-on-the envelope computation

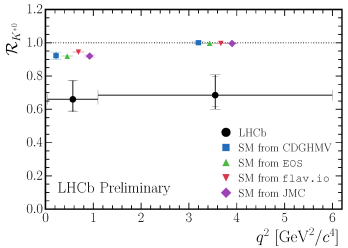
- HLT rate: 1 kHz
- LHC dutycycle: 100 days for 10^5 s/day. Total: $5 \cdot 10^{10}$ triggers
- PU average 40, total pp interaction in total $2 \cdot 10^{11}$
- $\frac{\sigma pp \to bb}{\sigma min\ bias} \sim 1\%$
- $N(bb) \sim N(\mathrm{B}^0) \sim 2 \cdot 10^9$
- $BR(\mathrm{B}^0 \to \mathrm{K}^* \mu\mu) \sim 1 \cdot 10^{-6}$
- So, we expect roughly $2 \cdot 10^3$ events, w/o considering acceptance ($\sim 10\%$) and efficiency
- expected yield $\sim \mathcal{O}(100)$ events $\times$ efficiency $(1 \cdot 10^{-3})$.
- Maybe if we could run the displaced HLT trigger on all L1 seeds (so 1 $kHz \to 100$ kHz): but can we?

Any chance for lepton universality?

Recent results from LHCb: [LHCb(2017)] ratio of $\frac{B^0 \to K^* \mu\mu}{B^0 \to K^* ee} \sim 0.67$ Lepton universality violated?

$$R_{K^{*0}} = \begin{cases} 0.660^{+0.110}_{-0.070} \pm 0.024 & \text{for } 0.045 < q^2 < 1.1\ \text{GeV}^2/c^4 \\ 0.685^{+0.113}_{-0.069} \pm 0.047 & \text{for } 1.1 < q^2 < 6.0\ \text{GeV}^2/c^4 \end{cases}$$

$N(K^* \mu\mu) = 285(353)$ Low (central) q^2
$N(K^* ee) = 89(111)$ Low (central) q^2



Can we repeat the measure?

- Short answer: no. We do not have a trigger for low pT electron
- And very little chance to develop one at L1.
  - True, but we can maybe do something at HLT also for electron, using L1-less idea;
  - prescaled Low-Pt electron trigger might be better
- Major problem would be CPU-time and data reduction, but maybe it is worth a shot.
- if we can collect $\mathcal{O}(100)$ events in electron channel by 2017, a $\sim 10\%$ measurement migh be possible...

People

B^0 SL, Alessio (Padova), Mauro, Sara, Paolo (MIB), Dayong, Linwei (PKU): all have expressed interest

- The analysis is not easy, and takes significant time and effort
- Initial workplan, ideas, preliminary work in place
- need a robust estimate of yield and balcground
- goal should be to have a full angular analysis (a al LHCb) with Run2 dataset: probably the statistics will be enough by the end of 2017.
- If we are not able to improve the efficiency (trigger, selection) the yield gap with LHCb will not be reduced

B^+ Geng to finish 8 TeV analysis, will graduate

- next year would need additional people to do for 13 TeV
- PKU will try to find someone else to work on B^+

LFU very challeging, but the interest can be very high.

ther
- $\phi\mu\mu$: some initial work shown in 2016
- Λ_b angular analysis maybe?
  - ⋆ The current trigger is not suitable, given the lifetime of Λ

Additional stuff

Additional or backup slides

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