BPH Analyses Prioritisation Proposal
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Mario & Martino

Analyses Prioritisation

- Run2 statistics offers different opportunities depending on the specific analysis (statistical/systematic errors, competitiveness wrt other collaborations results, manpower limitation)
  - Define a prioritised list of topics according to physics impact, competitor's results, time scale, trigger rate consumption
  - Exercise useful towards the definition of the future trigger paths and rate allocation:
    - Some measurements, already limited by systematic uncertainties or not sensitive to CM energy, could be abandoned to save trigger rate.
    - Other measurements could be pursued parasitically using the same trigger path developed for other ones.

Analyses Prioritisation

- Homework from the different PAGS will be presented during the October 26th plenary meeting (20+10 minutes for each PAG)
  - Select ~10/12 topics (3/4 for each BPH subgroup)
  - Preliminary material has to be sent to the PC by next thursday October 19th
- In the following slides: Proposal of a list of analyses selected based on informations included in spreadsheets available since September:

https://docs.google.com/spreadsheets/d/1UK8GnIRreeShE9ySqEyQR1_p1AIDp_9CjAPFcsibYfM/edit#gid=0

  - Some relevant informations still missing for some analyses: e.g. proposed trigger, extrapolation to the full Run2 statistics

Proposal for Critical Analyses

- Analyses to be discussed in the October 26th meeting
- Production:

  Quarkonium cross sections and ratios, polarization studies (Quarkonium, φ, Λ_b), $\chi_b \rightarrow \Upsilon(nS)\gamma$
- Spectroscopy & Properties:

  Double quarkonia (including $J/\psi\Upsilon$): cross sections and resonance searches, $\Upsilon\mu\mu$, $\Delta\Gamma_s$ & Φ_s with $B_s \rightarrow J/\psi\varphi$
- Rare Decays:

  $B \rightarrow \mu\mu$, $Z/W \rightarrow V\gamma(l^+l^-)$ (cross PAG with SMP), $\tau \rightarrow 3\mu$, $B \rightarrow K^* \mu\mu$
- Cross Subgroups:

  $B\Lambda$ resonances (Production & Spectroscopy), $B \rightarrow \tau X$ (Rare & Properties)

Proposal for Nice-to-have Analyses

- Analyses to be listed in the October 26th meeting
- Production:

  f_d, f_s fragmentation functions, B and B_c cross sections, associated production of Z(W)J/ψ(ϒ) (cross PAG with SMP)

- Spectroscopy & Properties:

  Y(4140) $\rightarrow$ J/ψφ inclusive search and in $B^+ \rightarrow$ J/ψφK, X_b, $B_s \rightarrow$ J/ψφ

  byproducts from flavor tagging studies: χ, g splitting, σ_{bb}

Production

Quarkonium cross sections and ratios:

- Propedeutic to the Polarization and Double quarkonia masurements. Main interest in high pT region: possible to manage the trigger rate. Complementary wrt LHCb due to different acceptance.
- Main systematics:
    - Possible improvements:
    - Could suffer from
- Trigger paths:
    - L1: L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4, L1_DoubleMu4p5er2p0_SQ_OS_Mass7to18, L1_DoubleMu5_SQ_OS_Mass7to18, L1_DoubleMu8_SQ. In common with Polarization, $B \rightarrow \mu\mu$, $B \rightarrow K^*\mu\mu$, $Bs \rightarrow J/\psi\varphi$, $\tau \rightarrow 3\mu$, $\chi_b \rightarrow \Upsilon\gamma$
    - HLT: HLT_Dimuon10_PsiPrime_Barrel_Seagulls, HLT_Dimuon20_Jpsi_Barrel_Seagulls, HLT_Dimuon10_Upsilon_Barrel_Seagulls, HLT_Dimuon14_Phi_Barrel_Seagulls. In common with Polarization, $\chi_b \rightarrow \Upsilon\gamma$.
    - Rate:

Quarkonium cross sections and ratios:

- Competitivity: different phase space wrt LHCb
  - Extrapolation using full Run2 statistics:
  - Assumptions:
- Manpower: Vienna, LIP, CERN, Torino, CINVESTAV

Polarization studies (Quarkonium, φ, Λ_b):

- Understand P, S wave polarization dependence with pT to investigate production processes. φ results interesting due to lighter mass wrt other states. Complementary wrt LHCb due to different acceptance.

- Main systematics: Angular distribution bias of unknown origin in 8 TeV data; φ meson: trigger, id, BKG modelling, reconstruction and fit
  - Possible improvements: new framework to cope with unknown angular distribution bias. Move from absolute to reative measurements.
  - Could suffer from

- Trigger paths:
  - L1: L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4, L1_DoubleMu4p5er2p0_SQ_OS_Mass7to18, L1_DoubleMu5_SQ_OS_Mass7to18, L1_DoubleMu8_SQ. In common with Quarkonium cross sections, B → μμ, B → K*μμ, Bs → J/ψφ, τ → 3μ, χ_b → ΄ϒγ
  - HLT: HLT_Dimuon10_PsiPrime_Barrel_Seagulls, HLT_Dimuon20_Jpsi_Barrel_Seagulls, HLT_Dimuon10_Upsilon_Barrel_Seagulls, HLT_Dimuon14_Phi_Barrel_Seagulls. In common with Quarkonium cross sections, χ_b → ΄ϒγ
  - Rate:

Polarization studies (Quarkonium, φ, Λ_b):

- Competitivity: different phase space wrt LHCb
    - Extrapolation using full Run2 statistics:
    - Assumption:
- Manpower: Vienna, LIP, CERN, Torino, CINVESTAV

$\chi_b \to \Upsilon(nS)\gamma$

- Possibility to distinguish χ_{b1} from χ_{b2} due to very good photon energy resolution from conversions (LHCb cannot do that!): https://cds.cern.ch/record/2276459/files/DP2017_029.pdf

  Analysis propedeutic to X_b searches.

- Main systematics: signal modelling, efficiency determination
  - Possible improvements: study shapes to improve signal modelling, increase MC statistics, explore higher pT regions.
  - Could suffer from
- Trigger paths:
  - L1: L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4, L1_DoubleMu4p5er2p0_SQ_OS_Mass7to18, L1_DoubleMu5_SQ_OS_Mass7to18, L1_DoubleMu8_SQ, L1_DoubleMu4_SQ_OS_dR_Max1p2. In common with Quarkonium cross sections and pol., $B \to \mu\mu$, $B \to K^*\mu\mu$, $B_s \to J/\psi\phi$, $\tau \to 3\mu$.
  - HLT: HLT_Dimuon10_Upsilon_Barrel_Seagulls, HLT_Dimuon12_Upsilon_eta1p5. In common with Quarkonium cross sections and pol.
  - Rate:

$\chi_b \rightarrow \Upsilon(nS)\gamma$

- Competitivity: very good due to the excellent mass resolution. LHCb cannot separate the different states, so they are affected by additional systematics on the assumptions.
  - Extrapolation using full Run2 statistics: reduction of statistical error by a factor ~2. Probably dominated by systematics with L~300 fb^{-1}
  - Assumptions:
- Manpower: Torino, Cinvestav

Spectroscopy & Properties

Double quarkonia (including J/ψϒ):

- Provides insight into underlying production mechanism (perturbative & nonperturbative). Investigate Double Parton Scattering interaction. Useful informations for Heavy Ion studies. 2015/16 sample could be enough to measure DPS constribution for J/ψJ/ψ. Possible resonant ϒϒ and J/ψϒ production, and ϒ(1S)ϒ(2S) (full Run2 statistics needed).
- Main systematics:
  - Possible improvements:
  - Could suffer from
- Trigger paths:
  - L1: L1_TripleMu_5_3p5_2p5_DoubleMu_5_2p5_OS_Mass_5to17, L1_TripleMu_5SQ_3SQ_0OQ_DoubleMu_5_3_SQ_OS_Mass_Max9. In common with B → K*μμ, Bs → J/ψφ, ´ϒμμ.
  - HLT: HLT_Dimuon0_Jpsi3p5_Muon2, HLT_Trimuon5_3p5_2_Upsilon_Muon. In common with ´ϒμμ, Bs → J/ψφ.
  - Rate:

Double quarkonia (including J/ψϒ):

- Competitivity: High pT reach, expertise, use of J/ψμ trigger wrt ATLAS single J/ψ one that needs prescaling.
  - Extrapolation using full Run2 statistics:
  - Assumption:
- Manpower: J/ψJ/ψ: Tennessee, IHEP; ϒϒ: Iowa, Fermilab

Υμμ:

- Very hot analysis going to be finalized on Run1 data. Theory paper on possible tetraquark discovery https://arxiv.org/abs/1709.09605. Two new trigger paths already included in HLT train n.4
- Main systematics:
  - Possible improvements: open muon trigger paths
  - Could suffer from
- Trigger paths:
  - L1: L1_TripleMu_5_3p5_2p5_DoubleMu_5_2p5_OS_Mass_5to17. In common with Double Quarkonia. L1_DoubleMu5Upsilon_OS_DoubleEG3, L1_DoubleMu3_OS_DoubleEG7p5Upsilon, L1_TripleMu_5OQ_3p5OQ_2p5OQ_DoubleMu_5_2p5_OQ_OS_Mass_8to14, L1_TripleMu_5OQ_3p5OQ_2p5OQ_DoubleMu_5_2p5_OQ_OS_Mass_5to17
  - HLT: HLT_Trimuon5_3p5_2_Upsilon_Muon, HLT_TrimuonOpen_5_3p5_2_Upsilon_Muon, HLT_DoubleMu5_Upsilon_DoubleEle3_CaloIdL_TrackId, HLT_DoubleMu3_DoubleEle7p5_CaloIdL_TrackIdL_Upsilon. In common with Double Quarkonia.
  - Rate:
- Manpower: Iowa

CPV with $B_s \to J/\psi\phi$

- Probe of possible new sources of CPV. Sensitivity improved by new flavor tagging algorithm & hopefully pixel detector
- Main systematics: model bias, K pT reweighting, angular efficiencies
  - Possible improvements: Tagging power, time resolution, pT reweighting & model bias (MC stat), angular efficiency (MC stat, new techniques), additional not displaced trigger path improves ct resolution and efficiency (main systemtic for $\Delta\Gamma_s$)
  - Could suffer from trigger efficiency reduction due to the requirement of two additional tracks at the HLT level, tighter muon pT, pixel issues inefficiencies in standard tracking sequence (2017).
- Trigger paths:
  - L1: L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4, L1_DoubleMu4_SQ_OS_dR_Max1p2, L1_TripleMu_5SQ_3SQ_0OQ_DoubleMu_5_3_SQ_OS_Mass_Max9. In common with $B \to K^* \mu\mu$, $B \to \mu\mu$, $\tau \to 3\mu$, quarkonia cross section and polarization, double J/ψ
  - HLT: HLT_DoubleMu4_JpsiTrkTrk_Displaced, HLT_Dimuon0_Jpsi3p5_Muon2. In common with Double Quarkonia.
  - Rate:

CPV with $B_s \to J/\psi\varphi$

- Competitivity wrt LHCb: $L(R2)_{LHCb}$ ~4 fb^{-1} vs $L(R2)_{CMS}$ ~150 fb^{-1}
  - Extrapolation using full Run2 statistics: $\delta\Phi_{stat}$~(17-32)±(15-20) mrad vs LHCb $\delta\Phi_{stat}$~30±6 mrad
  - Assumption: $\varepsilon_{trigger}$ (0.6/0.7)ε_{Run1} , Tag. Power: 1/1.5 wrt Run1, Time resolution: 70/45 fs
- Manpower: Pisa, Padova

Rare Decays

$B \to \mu\mu$

- Flag CMS Analysis mandatory to be pursued in Run2. Analysis dominated by statistical errors.
- Main systematics: fs/fu, displaced trigger for lifetime measurement, muon fake rate
  - Improvements: change normalization, new BDT-based μ identification, $B \to hh$ control samples, measurement of effective lifetime
  - Could suffer from yields instability due to different trigger conditions through the Run2, Data/MC discrepancy in some variables related to muon displacement BR and lifetime measurements
- Trigger paths:
  - L1: L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4. In common with $B \to K^* \mu\mu$, $B_s \to J/\psi\varphi$, $\tau \to 3\mu$, quarkonia cross section and polarization
  - HLT: HLT_DoubleMu4_3_Bs + HLT_DoubleMu4_3_Jpsi_Displaced (normalization channel).
  - Rate:
- Competitivity wrt LHCb: roughly equivalent
  - Extrapolation using full Run2 statistics: roughly equivalent to LHCb result
- Manpower: PSI, TW, Niser

$Z \rightarrow J/\psi X$

- Search for new Z decays (e.g. $J/\psi\mu\mu$ going to be finalized), synergy with Standard Model PAG
- Main systematics:
  - Possible improvements:
  - Could suffer from
- Trigger paths:
  - L1:
  - HLT:
  - Rate:
- Competitivity: roughly equivalent
  - Extrapolation using full Run2 statistics:
  - Assumption:
- Manpower:

$\tau \rightarrow 3\mu$

- Very important LFV channel. Strict time scale due to Belle II starting of data taking
- Main systematics: muon misidentification, BKG, trigger efficiency
  - Possible improvements:
  - Could suffer from
- Trigger paths:
  - L1: L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4, L1_DoubleMu4_SQ_OS_dR_Max1p2, L1_TripleMu_5SQ_3SQ_0OQ_DoubleMu_5_3_SQ_OS_Mass_Max9. In common with $B \rightarrow K^* \mu\mu$, $B \rightarrow \mu\mu$, $B_s \rightarrow J/\psi\varphi$, $\chi_b \rightarrow \Upsilon\gamma$, Quarkonium cross sections and polarization
  - HLT: HLT_DoubleMu3_Trk_Tau3mu, HLT_Tau3Mu_Mu7_Mu1_TkMu1_IsoTau15_Charge1, HLT_Tau3Mu_Mu7_Mu1_TkMu1_IsoTau15, HLT_Tau3Mu_Mu7_Mu1_TkMu1_Tau15_Charge1, HLT_Tau3Mu_Mu7_Mu1_TkMu1_Tau15
  - Rate:

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

- Flag CMS Analysis. Indirect search for NP. Limited by statistical errors. Sensitivity improved by statistics and hopefully new pixel detector performance
- Main systematics: fixed parameters from previous measurements
  - Possible improvements: global fit with all parameters free to float
  - Could suffer from trigger efficiency reduction due to the requirement of one additional track at the HLT level, tighter muon pT, pixel issues inefficiencies in standard tracking sequence (2017)
- Trigger paths:
  - L1: L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4, L1_DoubleMu4_SQ_OS_dR_Max1p2. In common with $B \to \mu\mu$, $B_s \to J/\psi\varphi$, $\tau \to 3\mu$, quarkonia cross section and polarization, BΛ resonances.
  - HLT: HLT_DoubleMu4_LowMassNonResonantTrk_Displaced + HLT_DoubleMu4_JpsiTrk_Displaced, HLT_DoubleMu4_PsiPrimeTrk_Displaced (control/normalization channels). In common with BΛ resonances.
  - Rate:

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

- Competitivity wrt LHCb: $L(R2)_{LHCb}$ ~4 fb^{-1} vs $L(R2)_{CMS}$ ~150 fb^{-1}
  - Extrapolation using full Run2 statistics: larger CMS signal yield by a factor ~2/2.3 wrt LHCb (but worse S/N ratio and no PID)
  - Assumption: $\varepsilon_{trigger}$ $(0.6/0.7)\varepsilon_{Run1}$
- Manpower: Milano, Padova

Cross Subgroups

BΛ resonances (Production & Spectroscopy)

- Search for new Xi_b^{**} states and beauty charmed baryon $Xi_{bc} \rightarrow$ BΛ. Trigger paths to be defined.
- Main systematics:
  - Possible improvements:
  - Could suffer from
- Trigger paths:
  - L1: L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4, L1_DoubleMu4_SQ_OS_dR_Max1p2. In common with $B \rightarrow \mu\mu$, $B \rightarrow K^*\mu\mu$, $B_s \rightarrow J/\psi\varphi$, $\tau \rightarrow 3\mu$, quarkonia cross section and polarization.
  - HLT: HLT_DoubleMu4_JpsiTrk_Displaced. In common with $B \rightarrow K^*\mu\mu$.
  - Rate:
- Competitivity
- Manpower: MEPhi

$B \to \tau X$ (Rare & Properties)

- B decays in tau lepton final states are important probes of New Physics (e.g. 2-Higgs Doublet Model) due to large H^+-fermion coupling. Popular channels due to some tensions wrt Standard Model expectations (e.g. $B \to D^* \tau\nu$, marginally $B \to \tau\nu$). Search for LFV decays or measurement of CKM matrix elements. Difficult analyses with uncertain outcome.

- Main systematics: BKG, normalization
  - Could suffer from difficult reconstruction of tau,
- Trigger paths:
  - L1: To be defined
  - HLT: To be defined
- Competitivity
  - Extrapolation using full Run2 statistics:
  - Assumption:
- Manpower: Milano

L1 trigger seeds

L1 menu	Unprescaled rate [1.5e34]	Post-DT rate [1.5e34]	Prescale value [column 1]	Quarkonium cross sections and polarization	Chi_b->Y(nS) gamma	Double quarkonia (including J/Psi Y)	Ymumu	CPV with Bs -> J/Psi Phi	Bmm	Z -> J/Psi X	tau->3Mu search	P5' angular analysis	B Lambda resonance search	B -> tauX
L1_DoubleMu0er1p5_SQ_OS_dR_Max1p4	3,286	3,032	1	x	x			x	x		x	x	x	
L1_DoubleMu4p5er2p0_SQ_OS_Mass7to18	1,752	1,618	1	x	x									
L1_DoubleMu5_SQ_OS_Mass7to18	1,275	1,178	1	x	x									
L1_DoubleMu8_SQ	1,080	996	1	x	x									
L1_DoubleMu4_SQ_OS_dR_Max1p2	3,506	3,237	1		x			x			x	x	x	
L1_TripleMu_5_3p5_2p5_DoubleMu_5_2p5_OS_Mass_5to17	1,313	1,213	1			x	x							
L1_TripleMu_5SQ_3SQ_0OQ_DoubleMu_5_3_SQ_OS_Mass_Max9	1,488	1,375	1			x		x			x			
L1_DoubleMu5Upsilon_OS_DoubleEG3	v4	v4					x							
L1_DoubleMu3_OS_DoubleEG7p5Upsilon	v4	v4					x							
L1_TripleMu_5OQ_3p5OQ_2p5OQ_DoubleMu_5_2p5_OQ_OS_Mass_8to14	v4	v4					x							
L1_TripleMu_5OQ_3p5OQ_2p5OQ_DoubleMu_5_2p5_OQ_OS_Mass_5to17	v4	v4					x							
SMP High pT triggers										x				

HLT trigger paths

HLT menu	Prescaled rate [@ 1.5e34]	average prescale	Quarkonium cross sections and polarization	Chi_b->Y(nS) gamma	Double quarkonia (including J/Psi Y)	Ymumu	CPV with Bs -> J/Psi Phi	Bmm	Z -> J/Psi X	tau->3Mu search	P5' angular analysis	B Lambda resonance search	B -> tauX
HLT_Dimuon10_PsiPrime_Barrel_Seagulls	4.7	1	x										
HLT_Dimuon20_Jpsi_Barrel_Seagulls	6.9	1	x										
HLT_Dimuon10_Upsilon_Barrel_Seagulls	7.3	1	x	x									
HLT_Dimuon14_Phi_Barrel_Seagulls	6.7	1	x										
HLT_Dimuon12_Upsilon_eta1p5	8.6	1		x									
HLT_Dimuon0_Jpsi3p5_Muon2	13.8	1			x		x						
HLT_Trimuon5_3p5_2_Upsilon_Muon	9.9	1			x	x							
HLT_TrimuonOpen_5_3p5_2_Upsilon_Muon	v4					x							
HLT_DoubleMu5_Upsilon_DoubleEle3_CaloIdL_TrackIdL	v4					x							
HLT_DoubleMu3_DoubleEle7p5_CaloIdL_TrackIdL_Upsilon	v4					x							
HLT_DoubleMu4_JpsiTrkTrk_Displaced	10.9	1					x						
HLT_DoubleMu4_3_Bs	9.6	1						x					
HLT_DoubleMu4_3_Jpsi_Displaced	4.9	8						x					
SMP High pT triggers									x				
HLT_DoubleMu3_Trk_Tau3mu	18.6	1								x			
HLT_Tau3Mu_Mu7_Mu1_TkMu1_IsoTau15_Charge1	4.7	1								x			
HLT_Tau3Mu_Mu7_Mu1_TkMu1_IsoTau15	4.8	1								x			
HLT_Tau3Mu_Mu7_Mu1_TkMu1_Tau15_Charge1	0.7	20								x			
HLT_Tau3Mu_Mu7_Mu1_TkMu1_Tau15	0.7	20								x			
HLT_DoubleMu4_LowMassNonResonantTrk_Displaced	22.1	1									x		
HLT_DoubleMu4_JpsiTrk_Displaced	15.1	1									x	x	
HLT_DoubleMu4_PsiPrimeTrk_Displaced	1.2	1									x		