Theory of CP measurement in tau 1-prong decays

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Content

- Brief recap key results last weeks
- Data-driven calibration using $Z/\gamma \rightarrow \tau\tau$ decays: further opportunities
- Fundamental signal/background optimisation in $\pi^{+}\pi^{-}$ channel
  - i.e, emerging from **analytical** differences between scalar and vector decay
- Summary observations
- Next steps
- Discussion points for theorists

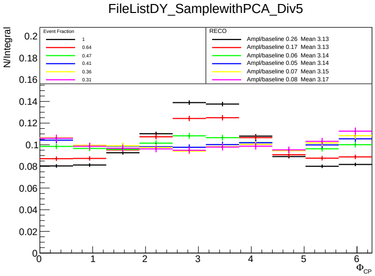
Recap last week

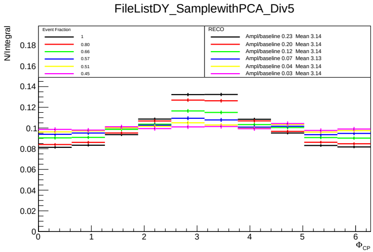
Birds eye view

- Discussed spectral functions
  - Decay to single charged pion: flat spectral function
  - Muons: pick cutoff $p_T > 20$ GeV. Imposed already by trigger requirements
  - Rho+A1 decay: spectral function has sign flip around pT=40 GeV
    - Need to apply this cut at RECO level, otherwise negative interference
- IP cutoff:
  - It diminishes effects of smearing (as expected)
  - DY: becomes flat for sufficient cutoff (re-assuring observation!)
  - From DY we learn that smearing effect is in opposite direction as expect from theory paper $\rightarrow$ Pull effect of muons? This may require further investigation
- **Normalising to a DY spectrum, results generally:**
  - Have correct phase
  - Have sensible amplitude/baseline ratio
  - $\mu + \pi$: appears rather independent of IP cutoff, slight decrease with increasing cut. A/B of 0.2 seems feasible
  - $\mu + \rho$: appears still dependent on IP cut, higher cutoff increases A/B. Statistics limiting factor. A/B of 0.2 seems feasible, perhaps larger
    $\rightarrow$ IP method seems work for rho+A1, and looking competitive w.r.t. neutral pion method!
  - May gain substantially in various channels!
  - Important: this needs to be tested on a **mixed** sample also
- For DY and particularly pseudoscalar, more statistics highly desirable
- Key results DY and normalised signals below
- Update: previous results contained small bug in calculation a/b ratio, updated results below

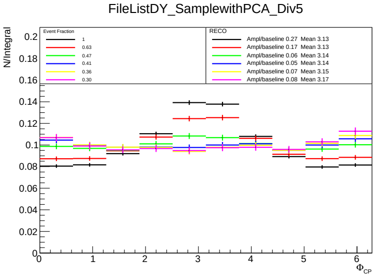
DY for mu+ pion (left) and mu+rho (right) channel, RECO

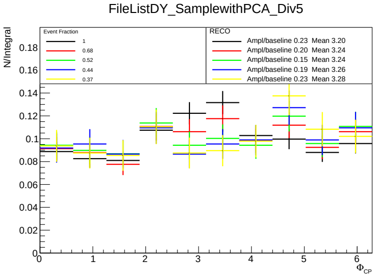
Note that we applied no pT cutoff here yet.. Note strong effect of IP cutoffs: DY becomes (nearly) flat as expected! THIS IS GOOD NEWS.. However, note that the direction of the effect is opposite of what expect from theory..





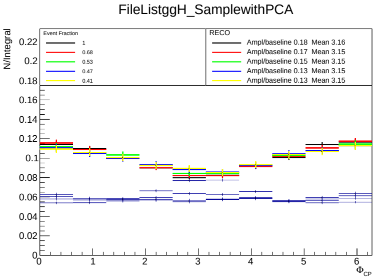
With pT cuts of 20 (lef) and 40 (right) Observe that the statistics becomes limiting for mu+rho, even for the large DY sample

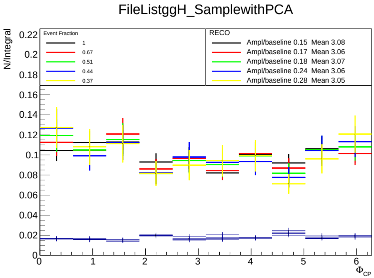




ggh Mu+pi (left) and mu+rho (right) normalised by the DY spectrum

With pT cuts of 20 (lef) and 40 (right) Mu+pion becomes approx. independent of vertex cutoff now.
Shape quite nice.
mu+rho better (no phase flip), but needs more statistics.

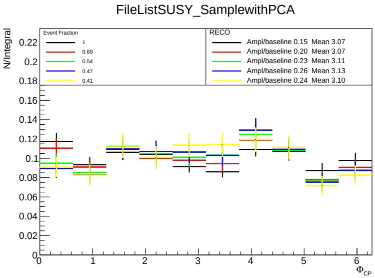


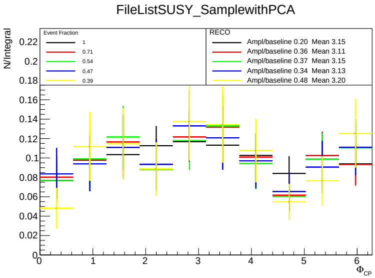


Approaching mu+rho, given correct pT cut, with impact parameter method quite interesting..
Note that mu+rho and mu+pi may get e With correct pT cutoff and a DY sample to normalise, in retrospect vertex cut may not be necessary! (perhaps good control handle).
More statistics definitely needed, plus mixed sample

SUSY mu+pi (left) and mu+rho (right) normalised by the DY spectrum

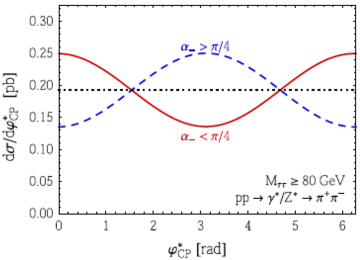
With pT cuts of 20 (lef) and 40 (right)
mu+rho looks encouraging but statistics currently bottle neck

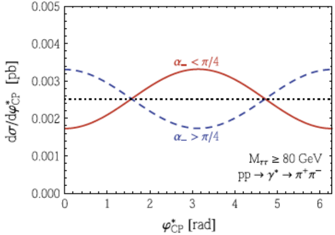




Data-driven calibration: extension

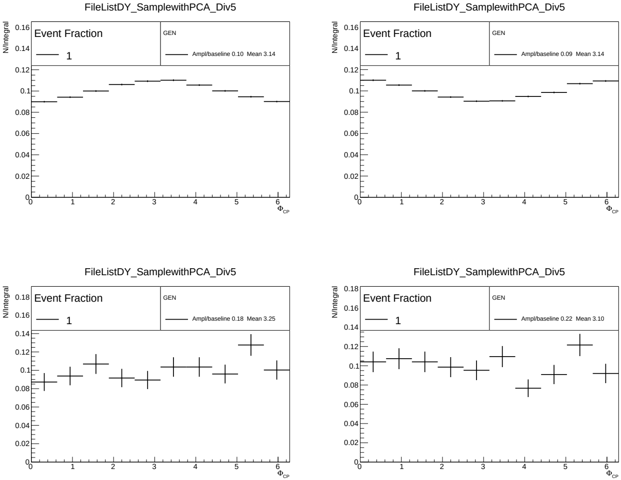
- This is worked out theoretically for $\pi + \pi$ case only..
- All *cosine*ϕ dependent terms will drop when fully integrated over
  - Resulting distribution independent from ϕ
- But what if we would NOT fully integrate over all ϕ^+ or ϕ^-?
  - for example, require π^- to be in plane $\phi^- = 0$
- Exact definition requires τ momentum. May define strongly correlated observable in lab frame observables:
- $\cos(\alpha_-) = \left| \frac{\hat{e}_z \times \hat{p}_{L-}}{|\hat{e}_z \times \hat{p}_{L-}|} \cdot \frac{\hat{n}_- \times \hat{p}_{L-}}{|\hat{n}_- \times \hat{p}_{L-}|} \right|$
- $\hat{e}_z$ is beam axis, $\hat{p}_{L-}$ and $\hat{n}_{L-}$ are IP and momentum vectors
- Decomposition $\alpha_- > \pi/4$ and $\alpha_- < \pi/4$ displayed for Z (top) and γ (bottom)
  $\rightarrow$ Potentially additional handle to "validate" observable ϕ in real data, before considering the signal region!
  - Perhaps reweigh MC to data..
- Note that here only for charged pions; easiest case since spectral function constant





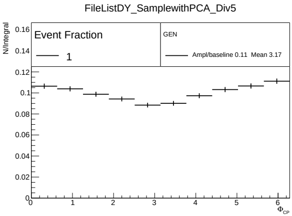
DY for genlevel pi+pi, two regions α_-

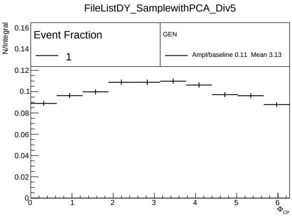
Can only assess $\pi + \pi$ at gen level..
Top: no cuts. Effect softer than expected (perhaps due to mass of Z/γ)
Bottom: pT> 40 GeV (trigger treshold). Statistics become limiting

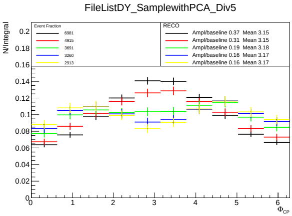


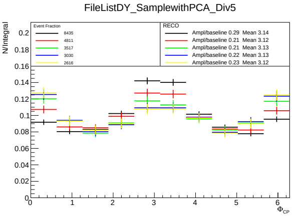
DY for mu+pi two regions α_{-}

Top: gen level, no cuts. Effect may be softer than expected (perhaps due to mass of Z/γ)
Bottom: RECO level for pT> 20 GeV (trigger treshold). Observe very distinct behaviour for sufficiently large IP cuts!
Potentially, interesting handle to further validate the DY data/MC agreement!



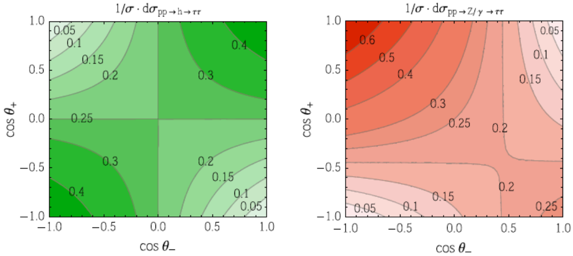






Focus again $\pi + \pi$ channel first

- Review angular dependence normalised signal and DY pion emissions
  - Signal: $d\sigma/d\cos(\theta_-)d\cos(\theta_+) \propto (1 + \cos(\theta_-)\cos(\theta_+))/4$
  - Signal: $d\sigma/d\cos(\theta_-)d\cos(\theta_+) \propto (1 - \cos(\theta_-)\cos(\theta_+))/4$ + terms linear in $\cos(\theta_-)$ and $\cos(\theta_+)$
  - Note: part cross section sensitive to CP nature has angular coefficient $\sin(\theta_-)\sin(\theta_+)$
  - Note: for pure pionic channel, spectral functions are constant!
- Altogether, potential for s/b optimisation

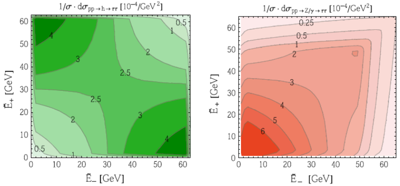


Signal/Background reduction

Focus again $\pi + \pi$ channel first

- Experimentally, may try to boost pion energy to Higgs RF, *E*
- Leading order *ggH*: *E* becomes pT in lab frame..
- Suggestive to remove events where both pion energies are small
- Keep events with pT around 30. Region most sensitive to CP effects! Theory suggests 20<pT<40.
- REGRETTABLY, for full hadronic channel usually (?) work with pT>35
- Played on gen level. Preliminary conclusion:
  - Indeed region 20<pt<40 most senitive
  - For lower cutoff 35 GeV, an upper cutoff won't increase sensitivity

  $\rightarrow$ If we could select hadronic di-taus for 20<pT<40, very interesting..
- Cutoff imposed by trigger requirements?Preliminary: if trigger induces cutoff, for this analysis may want to add an HLT path for the lower energetic pions for Run III !



Signal/Background reduction in mu+pi channel

Focus $\mu + \pi$ channel

- Here the spectral functions come into play
- Have lower cutoffs of 20 GeV already..
- First, preliminary observation: upper cutoffs cut too hard in the signal region
- Remember also, spectral functions become maximal for highest energy of prong in τ frame
- Could further pursue 2-D distributions in lab frame. Suggest to drop for now
- May want to take treshold observation along for Higgs presentation for discussion..

General conclusions

Cuts signal

- ρ and A_1 mesons: for IP method we should be able to sum them simultaneously!
- RECO first estimate: summed up already..
- ρ: Impact param method may work, provided $\pi^{\pm}$ pT cutoff!
- Going in opposite pT cut region: no phase flip but distribution becomes flat. Encouraging result..

Background

- Drell-Yan: IP cut important to obtain reasonably flat background. Confirms smearing effects for small IP
- This works reasonable for single-pion and ρ channel
- It seems that smearing moves the IP and vertices closer
  - Some pull effect?
- This would explain the phase flip when applying IP cut

General conclusions

Calibration

- Dividing signal by normalised DY has good effect on signal shape
  - mu+pi: becomes approx. independent from ip cutoff and looks promising
  - mu+rho: normalisation avoids the phase flip. More statistics needed
- Cutoff on α_- for DY: pure pion channel gen level
  - pure pion channel gen level: A/B effects of order 0.1
  - $\mu + \pi$ channel: effects similar magnitude
  - RECO level: very distinct behaviour! $\rightarrow$ may want to discuss with theorists if sensible to apply to asymmetric decays..
  - Potentially, interesting handle for data/MC validation in control regions

To do

Signal

- General: suggest to first evolve "complete" analysis on coarse lines to identify bottle necks!
- Later, may optimise bottle necks with ML techniques
- To do anyway:
  - Rerun everything with beamspot-corrected RECO vertices. Prepare plots comparable to Andrea for Higgs workshop
  - High priority: reconstruction of all backgrounds!
  - May want to derive normalisation factors for different backgrounds for data/MC in different control regions?
  - Implement cutoff also in z direction IP vectors
  - Sort issue pions at GEN level
  - Need larger SUSY, DY, and definitely a CPV sample
  - General: make sure we lodge proper MC requests to have our necessary signals taken into general MC campaigns!
  - Worth to cross check if electron channel has potential. Ongoing..

Theory

- Check with theorists if can use α_- with asymmetric decay modes
- For pure pionic decays, pT cutoffs <35 GeV could be very interesting
- Currently use ψ in calculation of ϕ. Anticipate this distribution may have moreover enhanced resolution for studying CPV

mu+rho with and without DY normalisation with neutral pion method

With pT cuts of 20

Left: DY spectrum. Right: normalised, a/b approx. 15%. Bottom: normalised SUSY

DY normalisation has very positive effect (and again: more stat needed)

Appears that IP and neutral pion method reasonably competitive

two methods for 35% decays is high gain!