A_{LR} analysis with muon pairs

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Introduction

- Goal is to develop the muon pair analysis to a level suitable for the polarization white paper.
  - Selection, but not necessarily optimized.
  - Discussion of systematic uncertainties.

Data / MC / software

- Data: experiment 14 run 2112, processed with release-05-01-12.
  - special processing for trigger studies.
  - 3199 seconds, 31,116 nb^{-1} (online luminosity).
- MC: mc13b (run-dependent) for experiment 10.
  - generated using unpolarized KKMC .
- Generator-only studies: KKMC (left and right handed), BabayagaNLO (unpolarized).
- Release-05-01-12.

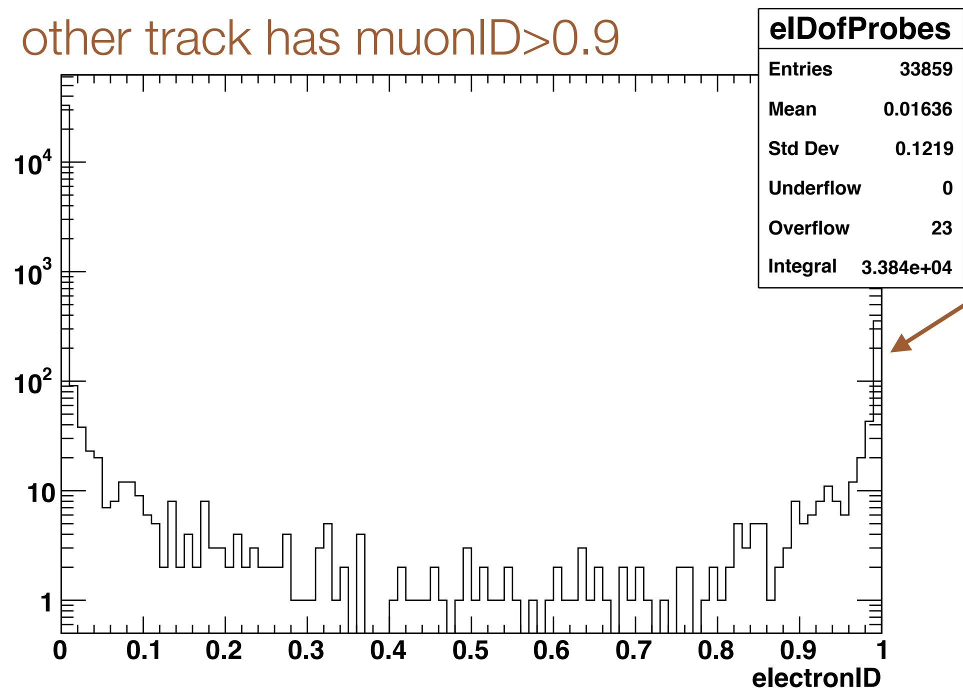
Basic selection

- Events stored in ntuple must satisfy:
  - Exactly two good tracks with p_{cms}>3.5 GeV/c.
    - good: |d0|<0.5 cm, |z0|<4 cm, CDC and VXD.
  - Back-to-back in ϕ_{cms} to within 5°.
  - Sum of θ_{cms} between 175° and 185°.
  - Invariant mass between 8 GeV/c^2 and 11 GeV/c^2.
    - sort of motivated by PRD 101, 053003 (2020)

Rejecting Bhabhas

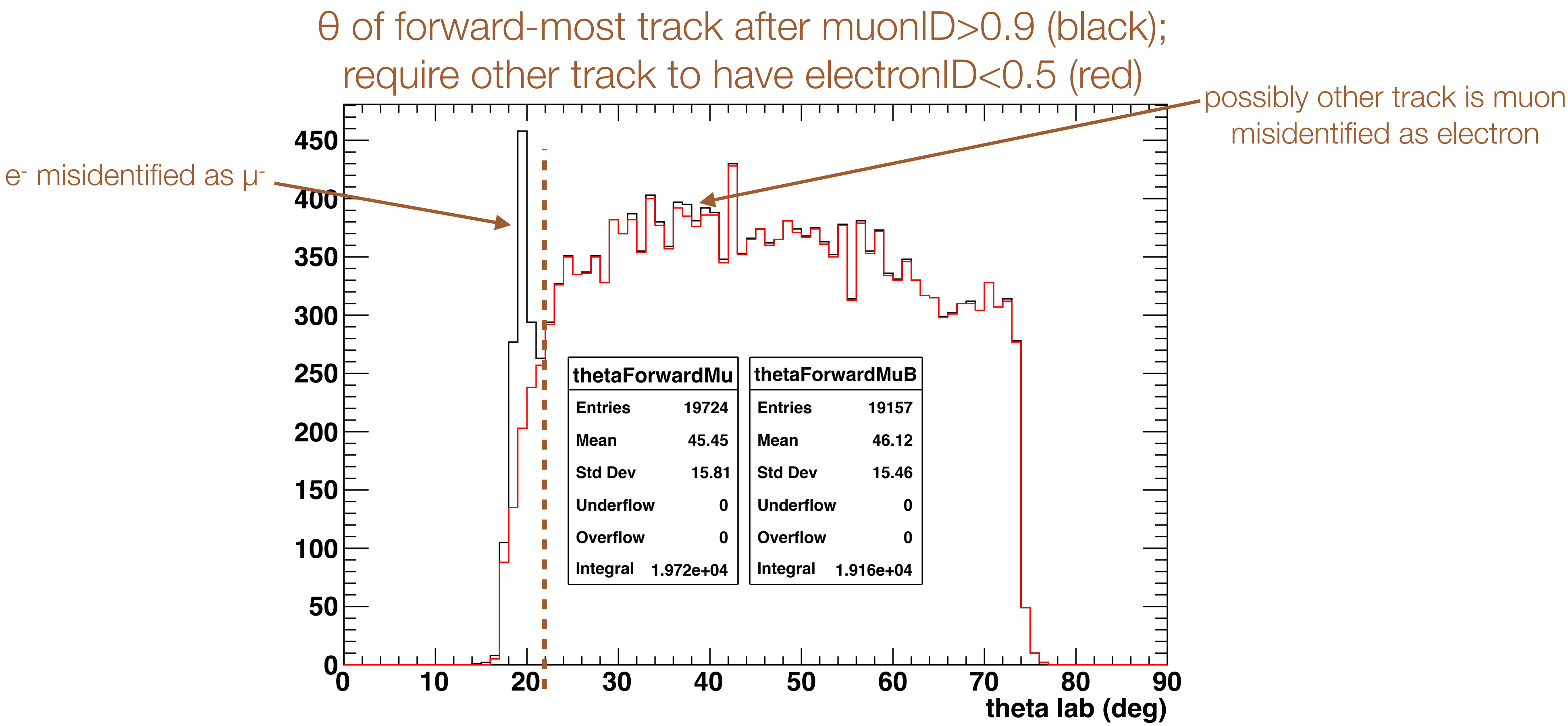
- Most of these events are Bhabhas: require at least one track has muonID > 0.9
  - muonID = muon likelihood /(sum of 5 likelihoods).

electronID of one track when other track has muonID>0.9



events with 1 “muon” and 1 “electron”

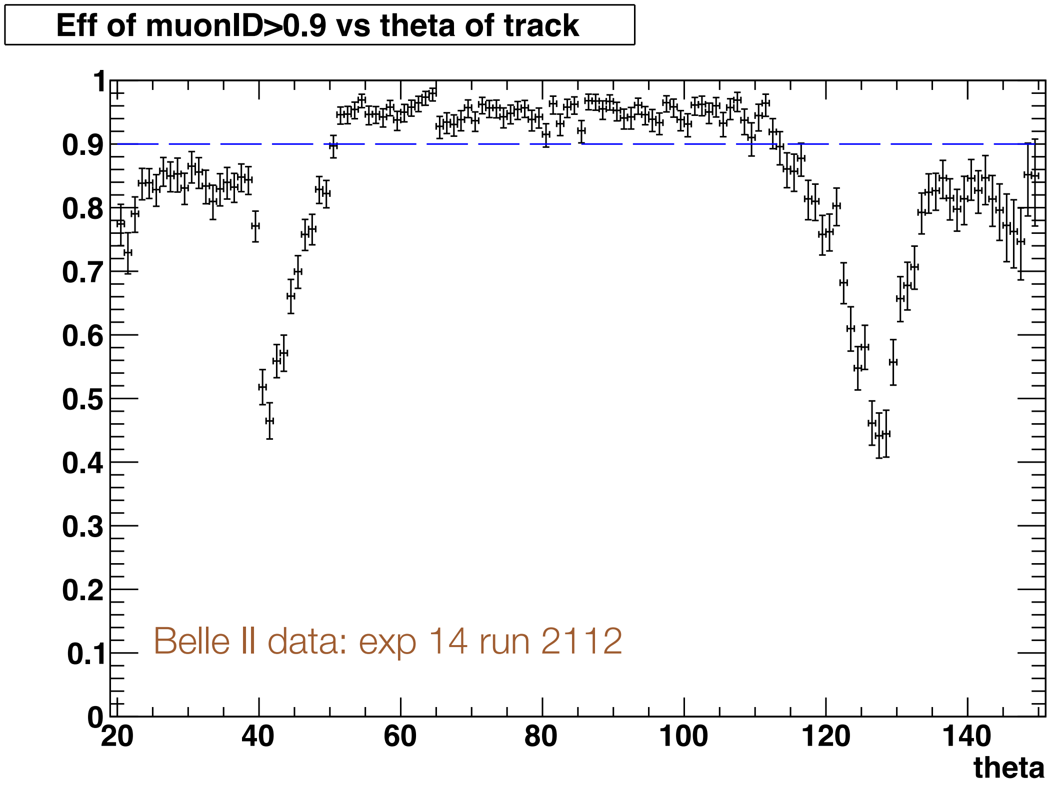
- Also require no tracks with electronID>0.5.



- Require forward-most track >22°.
  - 0.5% of events above 22° are rejected by electronID cut.

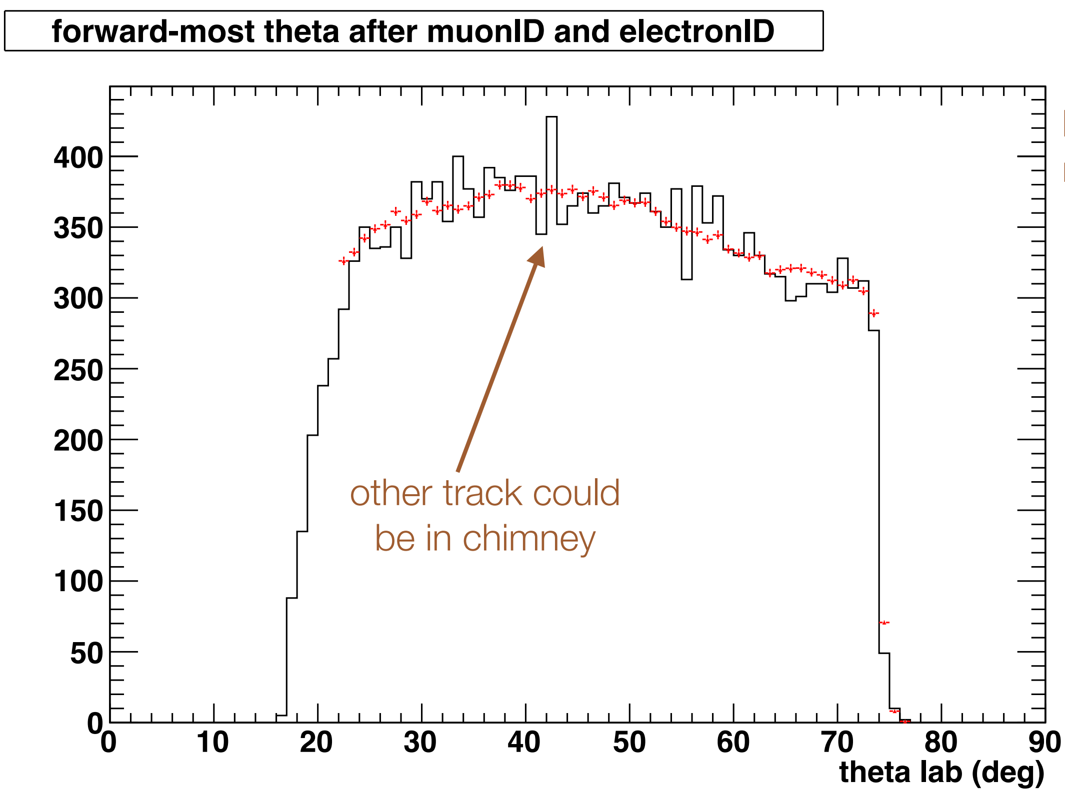
Efficiency of muon identification requirement vs θ

- For each track with muonID>0.9, look at fraction of other tracks that have muonID>0.9 as a function of theta.



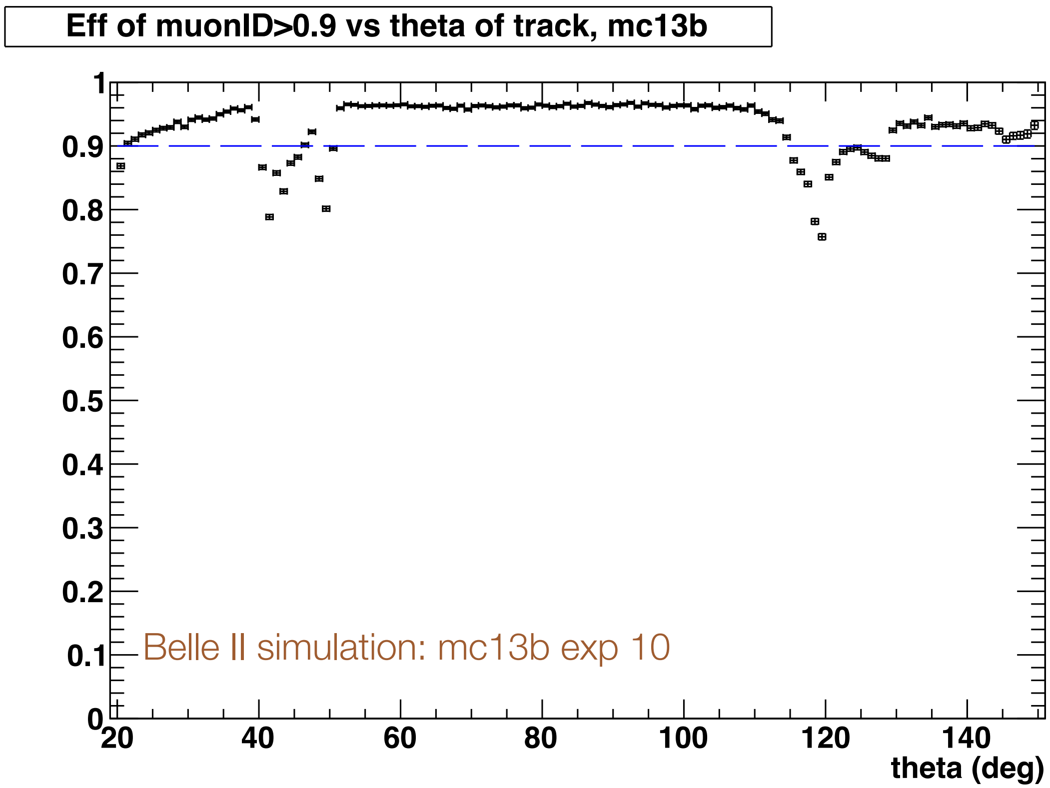
Overall efficiency of muonID requirement

- Convolve generator-level muon theta (after selection) with efficiency of muonID vs θ. Overall efficiency = 97.7%.



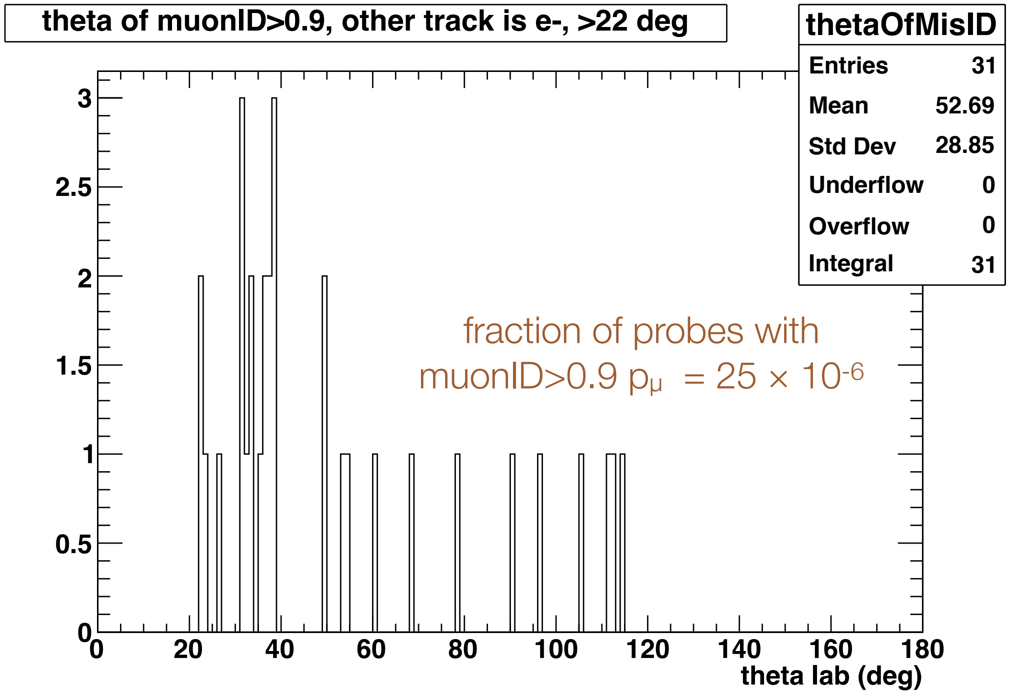
black = data after particle ID, before 22° cut
red = Babayaga generator weighed by muonID efficiency

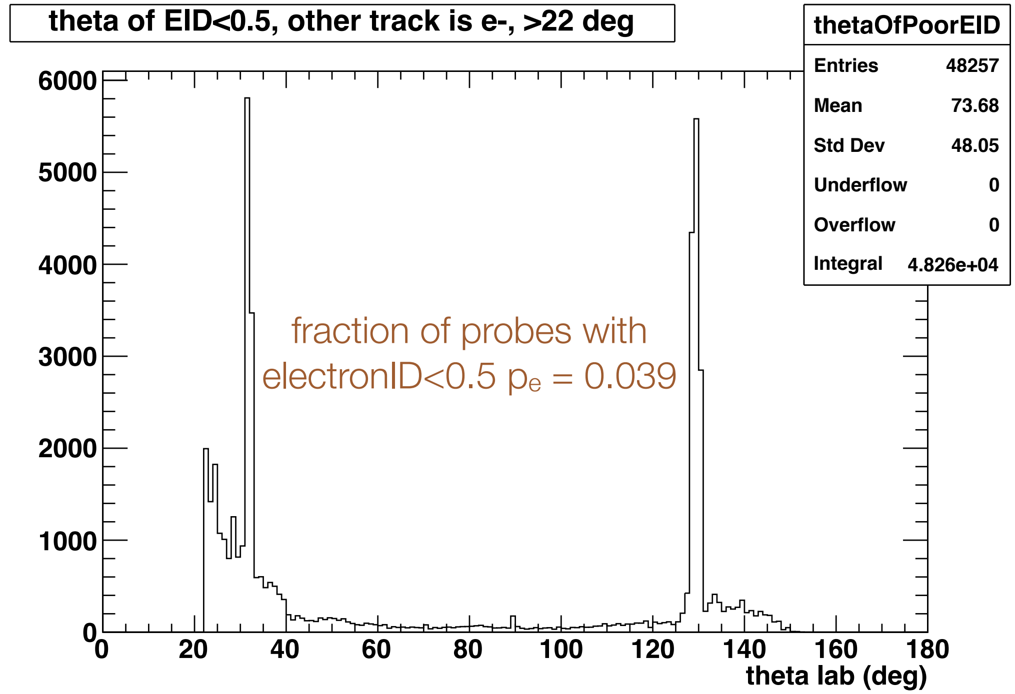
- Muon ID works much better in simulation:



Bhabha contamination

- Estimate Bhabha contamination using events with forward track > 22°, containing at least one track with electronID>0.9 and 0.6 < E/p < 1.4.
  - N_{ee} = 670,472 events in exp 14 run 2112.
- For tracks satisfying the electron identification check for other track to have muonID>0.9, or electronID<0.5.



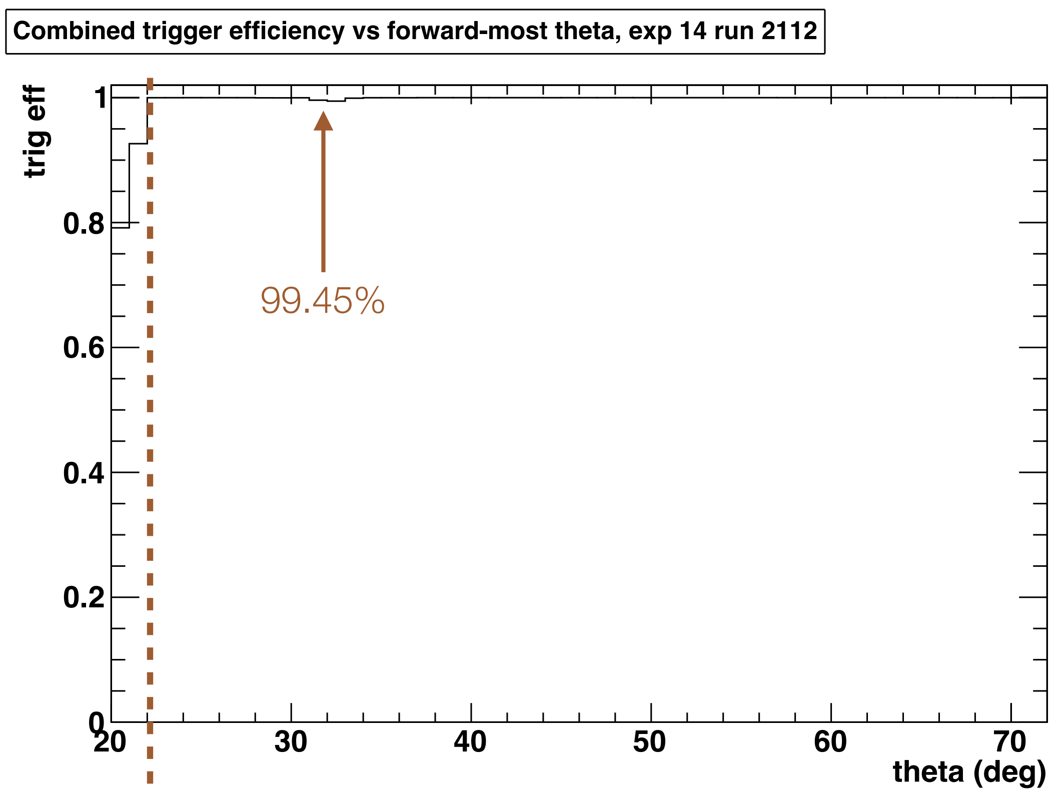


- Simple estimate of the number of mis-identified Bhabhas = $2 \times N_{ee} \times p_{\mu} \times p_e$ = 0.7 in exp 14 run 2112 - in 18,231 selected events. Fraction = 37×10^{-6}.
- With more stats, convolute histograms with MC generated distributions to include correlations.

- Alternatively, four tracks in the selected muon pair sample (out of 36,462) have $0.8 < E/p < 1.2$.
- In mc13b muon pairs: 0 out of 1,165,580.
- 4 events = 0.02% may be a better estimate.

Level 1 trigger efficiency

- Combination of CDC, ECL, and KLM triggers at level 1, plus pair-wise combinations. Details in backup slides.
  - convolve with generator distribution: overall efficiency = 99.98%



HLT trigger efficiency

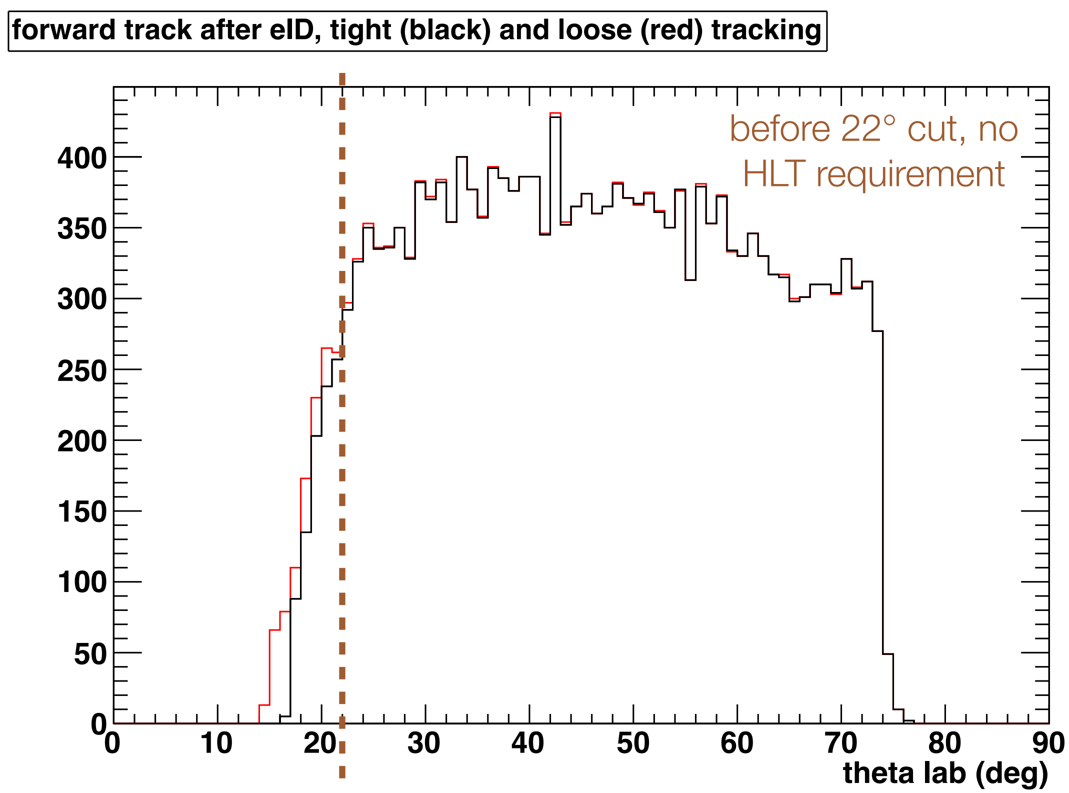
- HLT efficiency = 99.6%.
  - 99.5% for selectmumu

- Monitoring mode for exp 14.

Note on track requirements

- I require tracks to have both CDC and VXD information, which is unusually strict.
- HLT trigger selectmumu requires tracks to have CDC information.
- Bhabha contamination varies strongly with θ at low angles. I am not confident about the CDC-only measurement of θ at low angles.

- If I remove the requirement on CDC and SVD hits, number of selected events in data increases by only 0.11% after requiring selectmumu trigger.
  - extra events are at low angles.



Predicted cross sections and A_{LR}

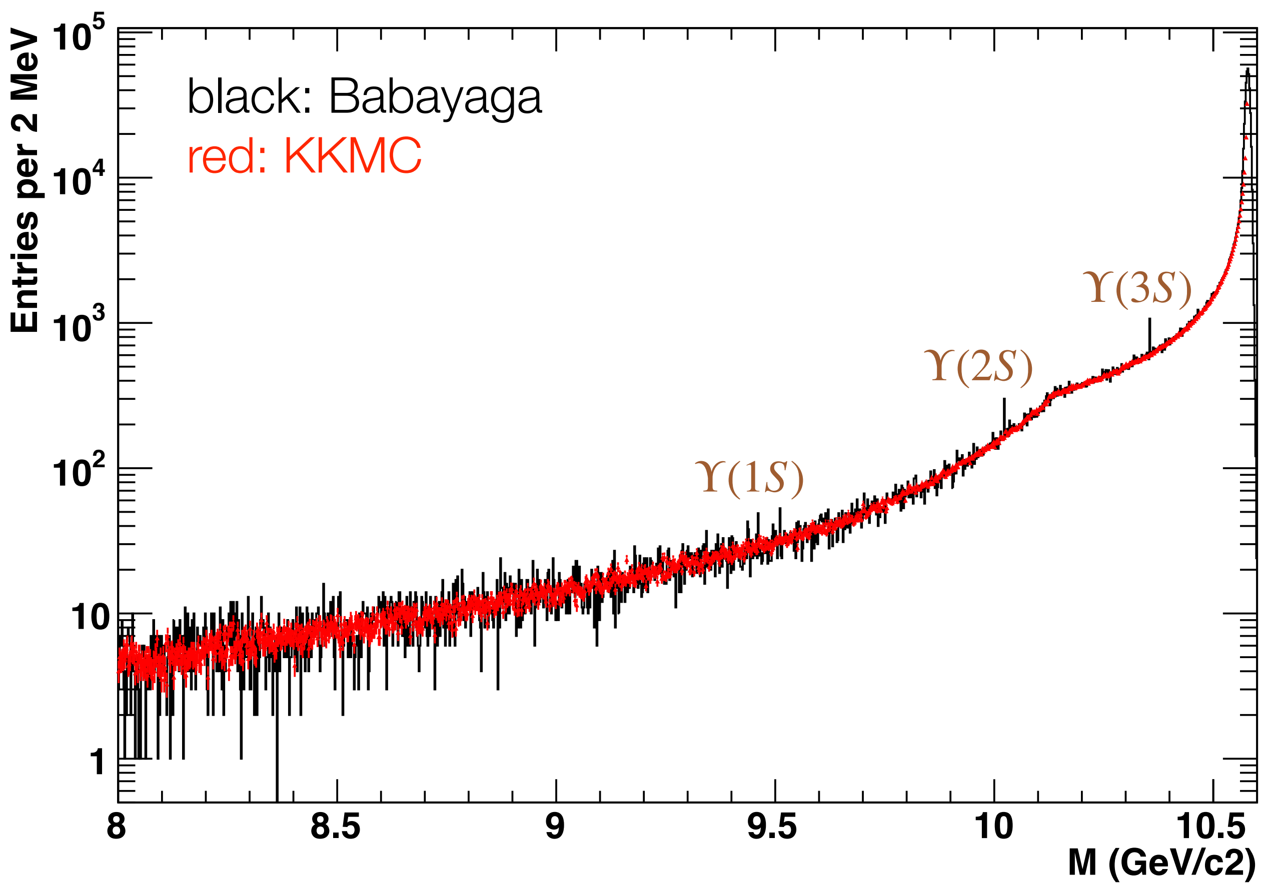
- KKMC, generator only (no detector simulation).
- 10M events each with 100% L or R polarization.
  - 8.8 fb^{-1} per polarization.
- Apply kinematic event selection (no muon or electron ID).
  - L: σ = 587.90 ± 0.19 pb
  - R: σ = 588.88 ± 0.19 pb

  ⇒ ALR = -0.00083 ± 0.00023 (for 100% polarization)

- In data (exp 14 run 2112):
  - 18,231 events / 0.977 / 0.9998 = 18,664 events after muonID and trigger corrections
  - 31,116 nb^{-1} online luminosity ⇒ 0.60 nb

Comparison with Babayaga

- Babayaga does not handle polarization, but it does have other features, including resonant production:



Upsilon contamination

- Babayaga indicates that 0.09% of the selected events are from Upsilon decay.
- From Mike's FPCP talk, A_{LR} for $b\bar{b}$ events = -0.021 (26× larger than for muon pairs).
  ⇒ shifts observed value of A_{LR} by 2.3%.

Summary

- I am about ready to start writing a Belle II note on the analysis.
- Are these calculations of Bhabha and Upsilon contaminations adequate for a white paper?
  - i.e., do they point the direction towards final analyses?
- Any other systematics on A_{LR}?

Appendix — level 1 trigger efficiency for muon pairs using exp 14 run 2112

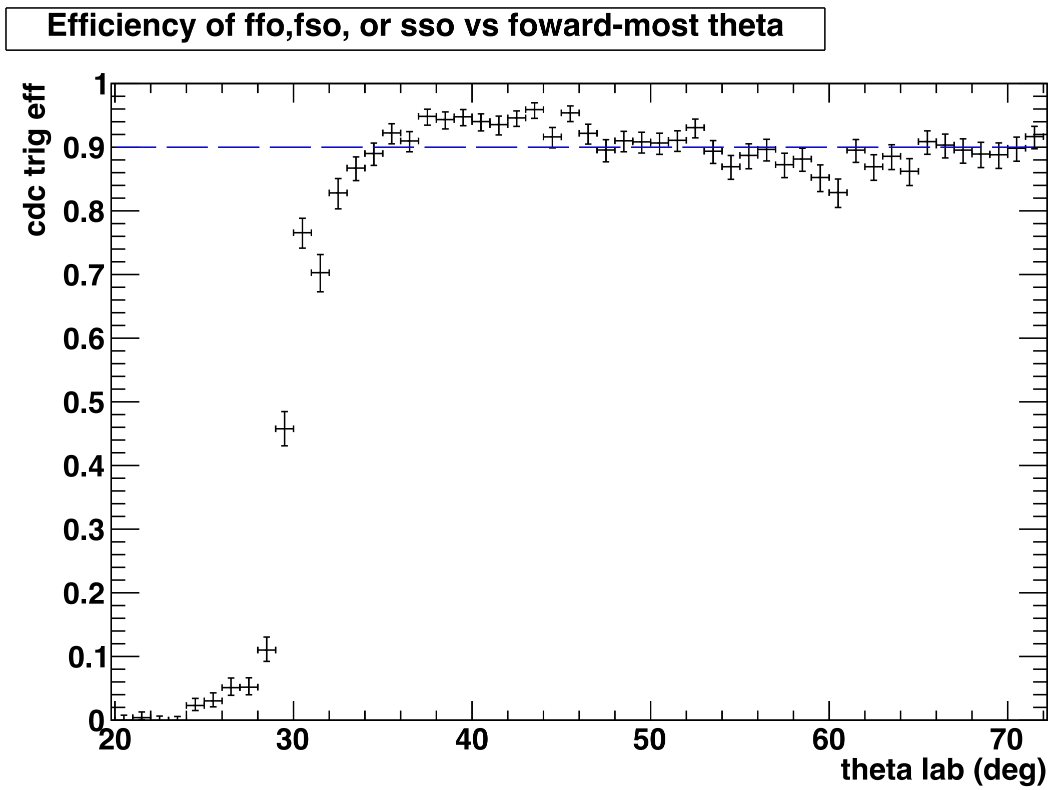
L1 lines used in the study

```
# ---------------------------------------------
# ..Level 1 variables
variables.addAlias('ffo', 'L1PSNMBit(17)')
variables.addAlias('fso', 'L1PSNMBit(18)')
variables.addAlias('sso', 'L1PSNMBit(19)')
variables.addAlias('eclmumu', 'L1PSNMBit(53)')
variables.addAlias('mu_b2b', 'L1PSNMBit(73)')
variables.addAlias('mu_eb2b', 'L1PSNMBit(76)')
variables.addAlias('eklmhit', 'L1PSNMBit(77)')
variables.addAlias('cdcklm1', 'L1PSNMBit(105)')
variables.addAlias('cdcklm2', 'L1PSNMBit(106)')
variables.addAlias('seklm1', 'L1PSNMBit(107)')
variables.addAlias('seklm2', 'L1PSNMBit(108)')
variables.addAlias('lml10', 'L1PSNMBit(132)')
variables.addAlias('ecleklm', 'L1PSNMBit(154)')
variables.addAlias('fwd_seklm', 'L1PSNMBit(165)')
variables.addAlias('bwd_seklm', 'L1PSNMBit(166)')
variables.addAlias('eklm2', 'L1PSNMBit(168)')
variables.addAlias('beklm', 'L1PSNMBit(169)')
variables.addAlias('ieklm1', 'L1PSNMBit(175)')
```

Efficiency of CDC triggers vs θ of forward-most track (ffo, fso, or sso)

- Require an ECL, KLM, or ECL and KLM trigger.

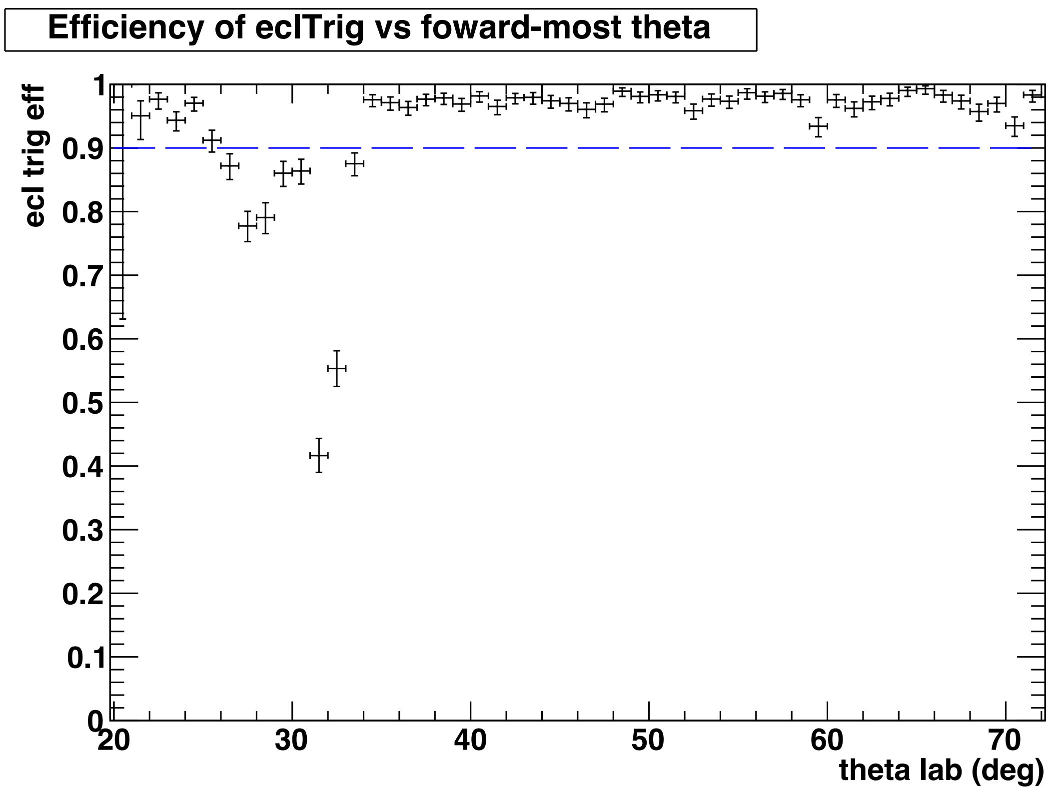
```
bool eclTrig = (lml10 + eclmumu)>0.5;
bool klmTrig = (mu_b2b + mu_eb2b + eklmhit + eklm2 + beklm)>0.5;
bool klmAndEclTrig = ecleklm>0.5;
```



Efficiency of ECL triggers vs θ of forward-most track (lml10 or eclmumu)

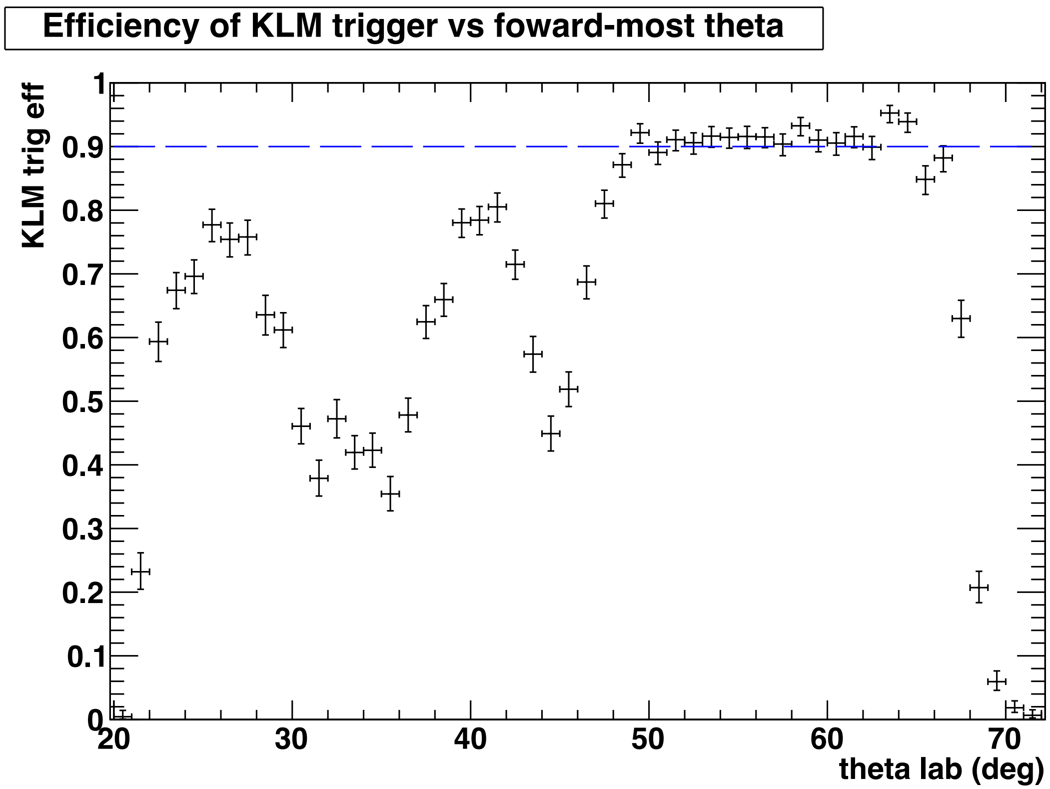
- Require CDC, KLM, or CDC and KLM trigger.

```
bool cdcTrig = (ffo + fso + sso)>0.5;
bool cdcAndKlmTrig = (cdcklm1 + cdcklm2 + seklm1 + seklm2 + fwd_seklm + bwd_seklm +
    ieklm1) > 0.5;
bool klmTrig = (mu_b2b + mu_eb2b + eklmhit + eklm2 + beklm)>0.5;
```



Efficiency of KLM-only triggers vs θ of forward-most track (mu_b2b, mu_eb2b, eklmhit, eklm2, beklm)

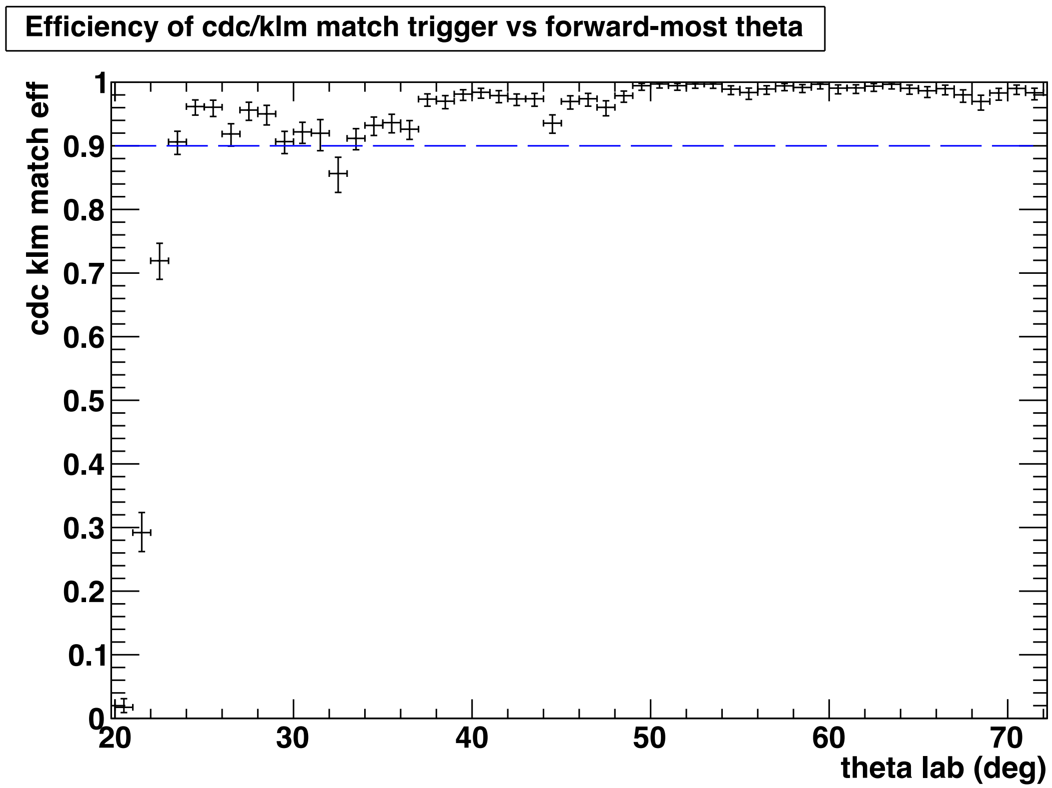
- Require CDC or ECL trigger.



Why this drop? Both tracks near θ = 70°

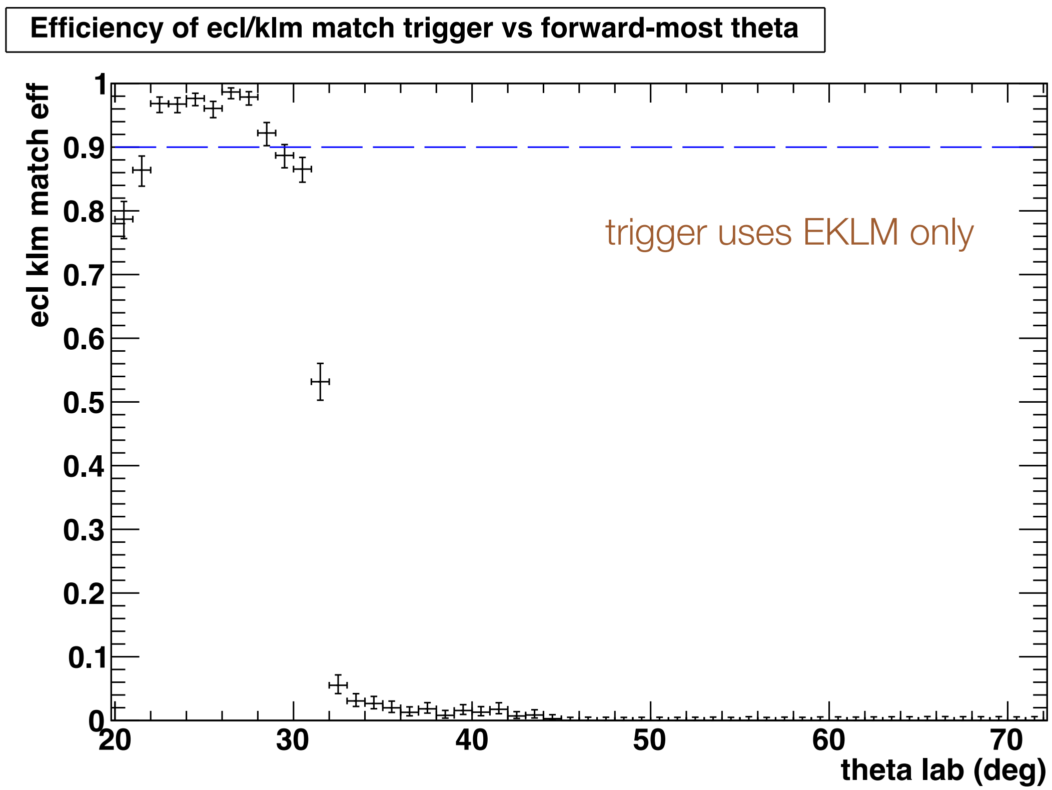
Efficiency of CDC-KLM triggers vs θ of forward-most track (cdcklm1, cdcklm2, seklm1, seklm2, fwd_seklm, bwd_seklm, ieklm1)

- Require ECL trigger (lml10 or eclmumu)



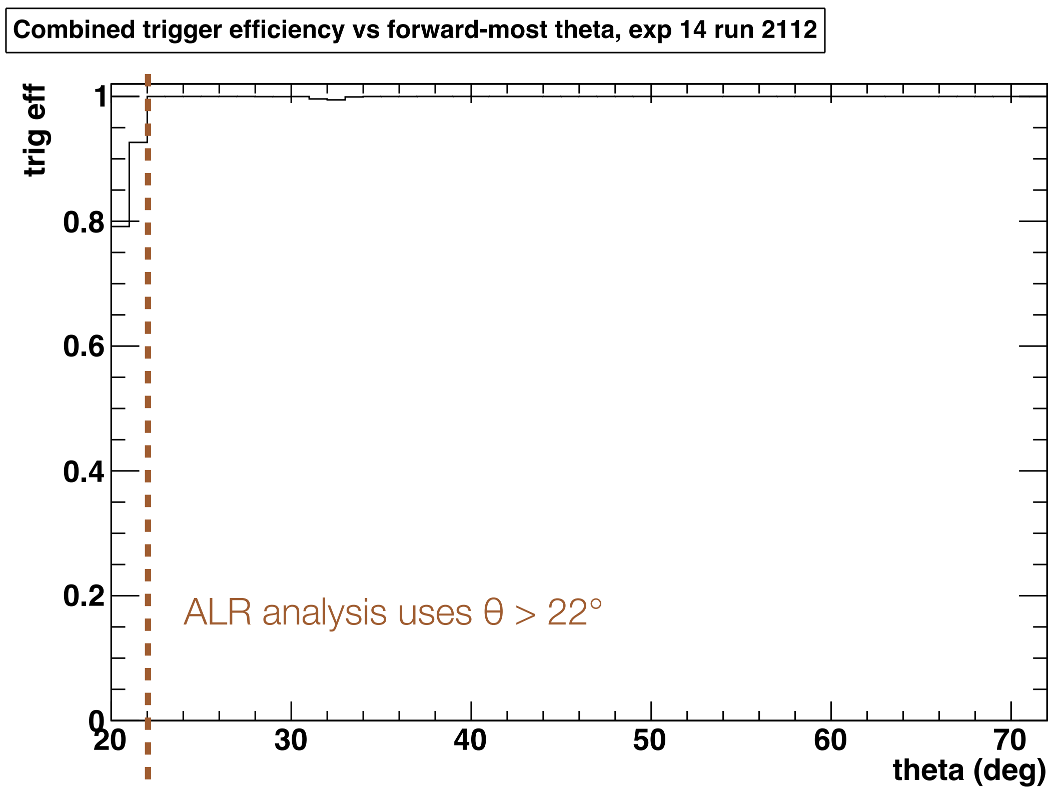
Efficiency of ECL-KLM trigger vs θ of forward-most track (ecleklm)

- Require CDC or ECL trigger (so not truly independent).



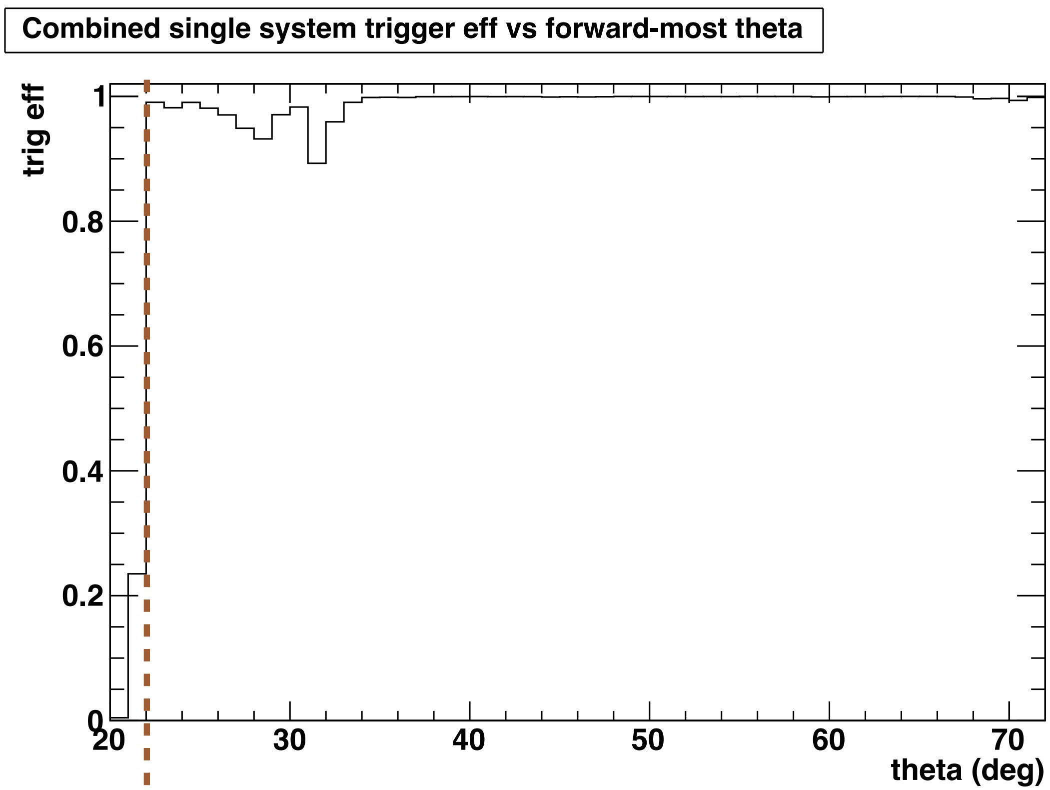
Overall trigger efficiency vs θ of forward-most track

- Derived from efficiency curves on preceding five slides.



Trigger efficiency without CDC-KLM or ECL-KLM triggers (i.e. single subsystem only)

- Derived from 3 earlier plots.



Summary of L1 trigger study

- Overall trigger efficiency is good, but relies on many lines.
- Triggers that combine KLM with CDC or ECL are important, particularly if we prescale eclmumu and lml10.
- It is hard to measure the combined ECL-EKLM trigger efficiency, because the CDC triggers have little efficiency at those angles.
- Big drop in KLM-only trigger efficiency at wide angles. Is this understood?

Backup

- Efficiency plots requiring layer 1 or 2 are similar.