Pattern Recognition and Particle Identification of COMPASS RICH software

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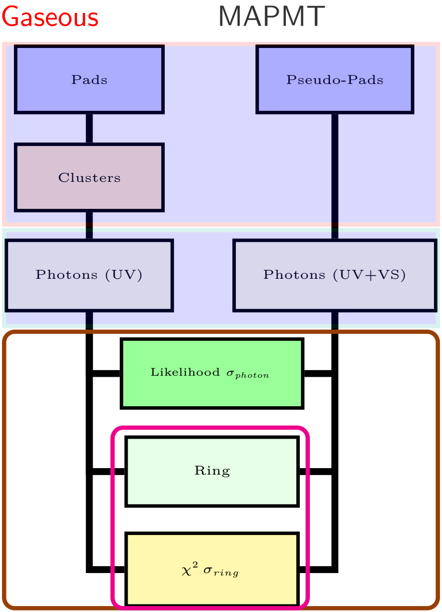
Outline

Introduction

- COMPASS reconstruction software (CORAL) takes care of the RICH pattern recognition and PID performance. The package is called RICHONE.
- RICHONE is a modular software, for each step a member class is called within the main class.
- RICHONE does not take multi-threading into account.
- Independent methods for pattern recognition and particle identifications.

RICHONE scheme



- COMPASS RICH-1 encompasses 2 essentially different wavelength regions.
- We can roughly think three major blocks of tasks:
  1. Treatment of Hit level information
  2. Photon Reconstruction level (IRT Y-S method)
  3. Pattern Recognition and PID. (**Today's topic of discussion**).

N.B. COMPASS RICH-1 operated with unique detector technology up to 2006.

Pattern Recognition in COMPASS RICH-1

1. The PID by extended likelihood method (LH) is essentially independent from pattern recognition. LH is computed for pion,kaon, proton, muon and electron hypotheses and a background hypothesis.
2. The pattern recognition (PR) serves two purposes: Detector characterization and crude particle identification. PR requires reconstructed photons within a feducial regions and tracking and reconstructs a ring. The central block to characterize and cross-check the consistency of the fine-tuned PID method, viz. LH.
3. LH algorithm requires reconstructed photon, track momentum, refractive index and background mapping. Difficult to cross-check detector alignments and figure of merits.
4. The LH method needs number of expected photons at saturation, PR provides this information.
5. Ring theta information, refractive index and track momentum provides χ^2. First level comparative PID $\rightarrow$ Can be used to cross-check LH method and tuning.

RICHONE-Ring Reconstruction

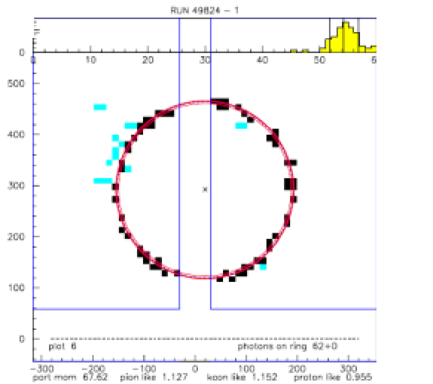
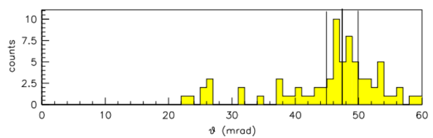


Figure: Distribution of single photon Cherenkov angles (Yellow) and a hits to reconstruct the ring (in MAPMT)

N.B. All photon (MAPMT or CsI) angles are in UV!



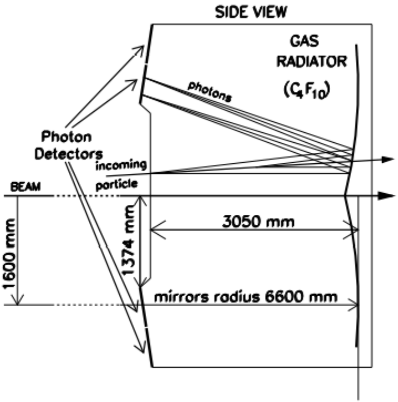
Method:

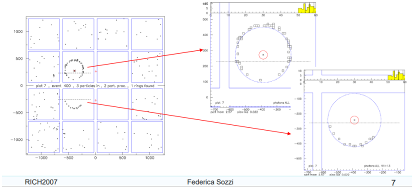
- All reconstructed photon angles within 70 *mrad* (wrt track position) is booked in a histogram.
- A peak in the θ_{photon} distribution is searched for through a scan with a fixed size window of $\pm 3\sigma_{ph}$.
- A ring is the window with largest number of photons and the average angle is the ring angle.

Comments on the Ring Reconstruction method I

Due to the RICH-1 detector architecture, photons emitted by particles scattered at small vertical angles, illuminate both mirror surfaces, and are then reflected partially onto the upper and partially onto the lower photon detector set, forming a full ring image in a detector set and a partial ring in the other one.

Comments on the Ring Reconstruction method II





Advantages:

- ✓ Extremely simple method.
- ✓ Automatic handling of split rings.
- ✓ Extract parameters to perform detector characterisation analysis.

Comments on the Ring Reconstruction method III

Caveat:

1. Low number of photons and substantial background blurs the reconstruction. For high purity rings N_{ph} should be high.
2. Systematic studies are required to set the lower limit on the N_{ph} for different RICHes using this algorithm.

RICHONE-Ring reconstruction code snip I

```
 double thePhotPk = 0.;
    {...
      float totCntPk = 0.;
      for( ih=lPhotons.begin(); ih!=lPhotons.end(); ih++ ) {
        if( !(*ih)->flag() ) continue;
        double thew = (*ih)->the();
          if( (*ih)->isPMT() ) PHw = 1.;
//        -----------------------------
          thePhotPk += thew * PHw;
          totCntPk += PHw;
        }
      }
      if( totCntPk > 0. ) thePhotPk /= totCntPk;
//    sort ring clusters inside window (+/- nMore) around average :
//    ------------------------------------------------------------
      float hWind = float( mcan + 2*nMore )* binScan /2.;
      //CC: mcan = 5 [if doclustering = 1, nmore = 3 ,binscan =1]
      // hWind = 5.5 mrad which is 3*sigma_ph
      theMN = thePhotPk - hWind;
      theMX = thePhotPk + hWind;
      //cout << theMN << "  " << theMX << endl;
```

RICHONE-Ring reconstruction code snip II

```
      nPhotPMT_ = 0;
      for( ih=lPhotons.begin(); ih!=lPhotons.end(); ih++ ) {
        if( !(*ih)->flag() ) continue;
        double thew = (*ih)->the();
        if( thew >= theMN  &&  thew <= theMX) {
          lPhotons_.push_back( (*ih) );
//        ---------------------------
          if( (*ih)->isPMT() ) nPhotPMT_++;
        }...
```

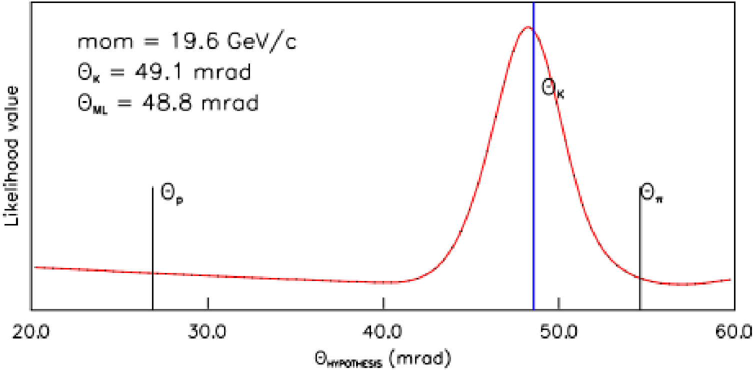
N.B The code also has the option to use a different Pattern Recognition algorithm. The "$\theta_{Likelihood}$" method. The window in that case is open around the most likely theta for certain mass hypothesis and the similar bin-content counting is performed.

```
RICHONE PeakSearchMode  COUNT
// peak search mode, string COUNT, [MASS, CHI, LIKE] (def.=COUNT)
```

RICHONE-Ring reconstruction code snip III

This alternative method is high in resource consumption. A LH value is computed for all possible $\theta_{hypothesis}$. This theta value is different than expected θ of the particle.

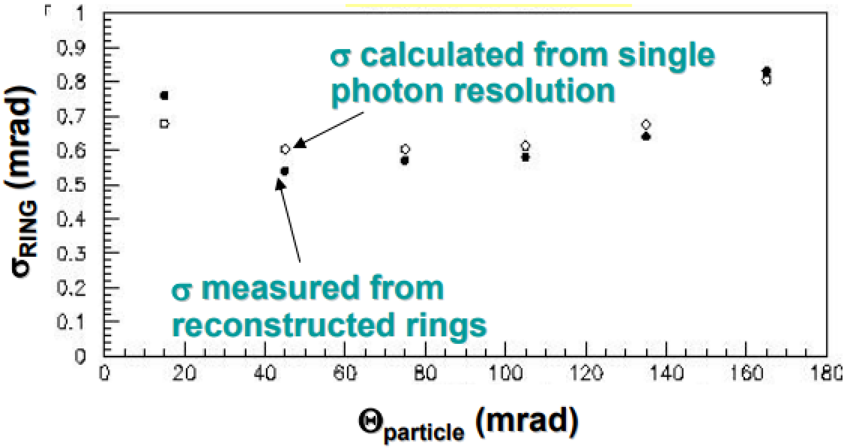
P. Abbon et al. / Nuclear Instruments and Methods in Physics Research A 631 (2011) 26–39



Ring level and photon level compatibility I

1. The refractive index from ring angle can be compared to the refractive index extracted from the reconstructed photon. The reconstructed photon angle is independent of any pattern recognition recipe.
2. Similarly, the photon angle resolution can be used to extract the ring angle resolution. This value can be compared with the directly measured ring angle resolution from the recognised ring for a given hypothesis.

Ring level and photon level compatibility II



Ring level and photon level compatibility III

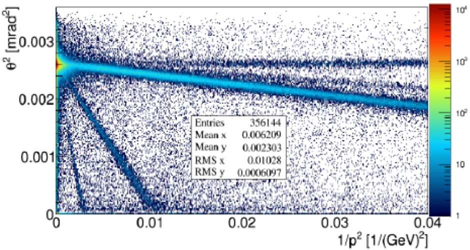
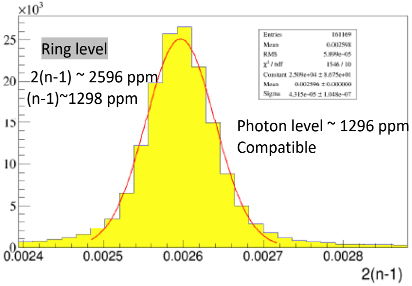


FIGURE 6.46: The 2D histogram of square of the Cherenkov angle versus the inverse square of the momentum.



$$\theta^2 = 2(n-1) - \frac{m^2}{p^2}(2-n) \quad (1)$$

Maximum Extended Likelihood I

The particle identification (independent of ring recognition) is performed by an extended likelihood method (Extension due to non-conserved number of photons for track by track).
For each photon over the feducial region (70 mrad) a signal term is computed.

$$s_m(\theta_{ph,j}, \phi_{ph,j}) = \frac{S_0}{\sqrt{2\pi\sigma_{ph}}} e^{\frac{-0.5(\theta_{ph} - \theta m)^2}{\sigma_{ph}^2}} \epsilon(\theta_{ph,j}, \phi_{ph,j}) \quad (2)$$

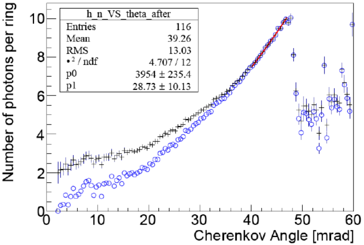
s_m is the signal strength of j^{th} photon, θ_{ph} is the reconstructed single photon angle; θ_m is the expected angle for given momentum and refractive index for particle with mass m, σ_{ph} is the single photon resolution. The ϵ term determines the photon detection efficiency based on dead areas.

Maximum Extended Likelihood II

S_0 is the expected number of photons from F-T relation.

$$S_0 = N_0 L sin^2\theta \tag{3}$$

The PR is used to extract the number of signal photons per ring at saturation (N_0). PR is therefore injects crucial input for LH. Independently for gaseous detector and PMTs N_0 are computed.



Fit formula:

$$f(\theta) = p_0 sin^2\theta + p_1\theta \tag{4}$$

A corresponding background component $b(\theta_{ph,j}, \phi_{ph,j})$ is computed from

Maximum Extended Likelihood III

the "background-map" (treatment of real data). The background is same for all the mass hypos.
The Likelihood then reads:

$$L_m = \frac{(S_M + B)^N}{N!} e^{-(S_M+B)} \prod_{j=1}^{N} \frac{(s_m(\theta_{ph,j}, \phi_{ph,j}) + b(\theta_{ph,j}, \phi_{ph,j}))}{S_M + B} \tag{5}$$

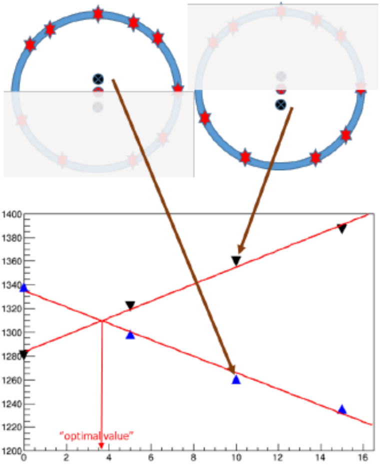
The LH does not store any monitoring level information. The inclusion of the background makes it powerful but difficult to debuging. PR serves this purpose along with complete characterization and comparative PID.

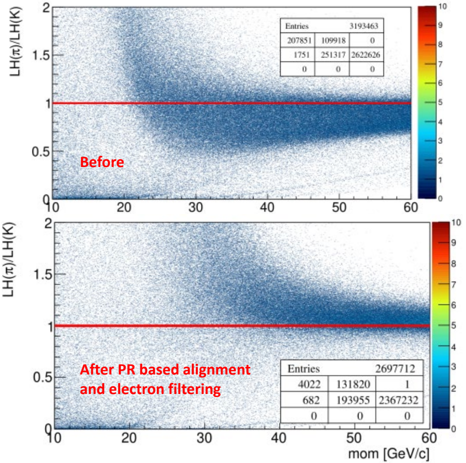
PR to tune the PID performance: example of 2016 COMPASS data I

COMPASS final states are pion dominated. We found in 2016 data taking the kaons are favored over pions. After detailed study we found that mirrors are required to be aligned. Thanks to the PR, we made a data-driven alignment.

1. The reflected track position (stored in RICH information), gives the centre of the ring. The photons above the track centre and below the track centre must provide similar θ, $(n-1)$.
2. The mirror Z coordinates were adjusted in order to obtain the similar θ, $(n-1)$ distribution.

PR to tune the PID performance: example of 2016 COMPASS data II





Summarizing...

1. COMPASS RICHONE software has implemented pattern recognition and sophisticated particle identification algorithm based on maximisation of extended likelihood.
2. Both methods require: reconstructed Cherenkov angle of single photons (Y-S IRT method), tracking and refractive index. But the treatments are essentially different and independent.
3. THE PR is relatively simple, provides powerful handle for through detector characterization, comparative PID.
4. LH method is sophisticated and delicate. Monitoring (low level) information are not easily accessible (if at all).
5. COMPASS RICH uses PR to thoroughly characterize and get a comparative flavour and to fine tune the LH for efficient PID.

References

Links:

1. Fedrica Sozzi's presentation in RICH 2007.(Global Overview)
2. Pattern recognition and PID for COMPASS RICH-1.(Global Overview)
3. Particle identification with COMPASS RICH-1.(Global Overview, detailed performance discussion and methodologies)
4. Performance study of the RICH at COMPASS experiment for hadron identification in SIDIS physics.(Global Overview,Important classes, tuning of LH with PR method)
5. RICHONE Development notes.(Enriched in ideas and historical developments)