QWG3 CsI-3

• Why CsI?
• Care & Feeding
• Get Ready for Physics
Get Ready for Physics

Outline

- SCal: Shower level Energy Scale
- RCal: Run (time) dependence
- Shower Shape & Track-Shower Matching
- Lepton ID
- Luminosity
- $\pi^0/\eta \rightarrow \gamma \gamma$
- Conclusions
SCal

$E_{sh} = f(E_N) \times E_N$, is a run-time correction

Highest-N is biased toward taking upward noise fluctuations – important at low E

Convention is that isolated single $\gamma$’s should peak at the correct energy, despite the asymmetric line shape

Data & MC may (do!) behave differently

MC calibration is easy – correct to $E_{gen}$

Test any procedure for the data on MC
Crucial Convention

Which do you want?
- $\gamma$ energy peaks at right place
- $\pi^0$ mass peaks at right place

You can’t have both, because
- Line shape has low-side tail (leakage!)

W/correct $\gamma$ energy, $\gamma\gamma$ mass peaks LOWER than $M(\pi^0)$

CLEO chose $\gamma$ energy to be accurate, allowing $\pi^0$ constrained fit to fix the bias (more on that later)

BaBar chose differently
Calibration Procedure

- Use MC truth to calibrate MC
- In $E_{HI}$ vs $E_{LO}$ bins, fit for $\pi^0$ ($\eta$) mass peak in each bin, $M_{ij}$ (132.7-134.2 MeV)
- Use $10^6$ MC events & $2 \times 10^6$ data events
- Determine corrections $f_j$ in each energy bin $i$ by correcting the data to match the MC as closely as possible:

$$\chi^2 = \frac{\sum_{ij} \left\{ \sqrt{f_i} \sqrt{f_j} (M_{ij}(\text{data}) - M_{ij}(\text{MC}) \right\}^2}{\sigma_{ij}^2(\text{data}) + \sigma_{ij}^2(\text{MC})}$$
MC Shower Energy Scale

After fitting MC corrections which are determined bin-by-bin, how accurate is it?

Energy Dependence after New Calibration for CLEOIII MC

- Good Barrel
- Good Endcap
Shower Energy Scale

Features:
- Compensates for noise at low energy
- Data ≠ MC
- MC cross check confirms method !!

Energy-dependent Correction for the Barrel

$E_{\text{true}} / E_{\text{measured}}$

Data: $\gamma\gamma$
Data: $\pi^0$
MC (pi0 cal.)
MC (single photon cal.)
Overall Scale Cal

More features:
- Endcap $\neq$ Barrel
- CLEO2 $\neq$ CLEO3 (slightly diff algor.)
- Only $\sim$3% correc. for $E>100$ MeV
Unfortunately:
- $\pi^0 \neq \eta$
- 0.5% offset
- Not understood
- $\pi^0 = \eta$ in MC
- Split the diff.
- Need tie-breaker

What else can we do?
More SCal Methods

\[ e^+e^- \rightarrow \mu^+\mu^- \gamma \]

- With 3 directions ONLY, 0C fit
- For each \( \gamma \), have a measured energy & an expected energy

\[ \psi(2S) \rightarrow \gamma \chi_{cJ} : \text{monochromatic} \gamma \]

\[ \chi_{cJ} \rightarrow \gamma J/\psi : \text{monochromatic} \gamma, \text{Doppler shifted} \]
$\psi(2S)$ Inclusive $\gamma$ Spectrum

Bottomonium

Charmonium

Diagram showing various states of charmonium and bottomonium transitions.

Graph showing the inclusive $\gamma$ spectrum with peaks at different energy levels.
Run (or time) dependence

Need a metric that allows transference of overall scale calibration from one dataset to the next

Something w/high statistics

CLEO uses
- Mean Bhabha energy (high end)
- Mean $M_{\gamma\gamma}$ for soft $\pi^0$’s (low end)

Can avoid redoing SCal too often
Shower Shape

- \( \gamma \) showers well-collimated; transverse spreading limited
- Hadronic split-off showers are broader & less regular
- “Photon-like” shower shape cut is powerful non-\( \gamma \) suppression tool; ALSO AN ISOLATION CUT!
- CLEO std: “E9/E25”

- CTR

\[ E9 = \text{Energy sum of 3x3} \]
\[ E25 = \text{Energy sum of 5x5} \]
\[ E9/E25 \leq 1 \text{ always} \]
- Photons: \( E9/E25 > 0.8 \text{-} 0.9 \)
- Splitoffs: \( E9/E25 < 0.8 \)

Other shape variables: tend to be highly correlated w/\( E9/E25 \)
“Unfolded” Shape

1. Suppose 2 photons overlap
2. Define “Unfolded” E9/E25 as the same ratio AFTER removing crystal energy assigned to the OTHER shower
3. Has higher efficiency, but results in a slightly dirtier sample of photon candidates (because energy sharing is not exact).
4. Removes “isolation” effect.
Track-Shower Matching

- Task: Identify showers caused by charged particles
- More subtle than you think!
- Because nuclear int’ns not localized like e-m ones... neutrons travel!

Trade off

- Chgd particle showers correctly tagged
- Photon showers incorrectly tagged
Types of matching

- **Standard**
  - Track projects <8 cm of any crystal in a shower
  - Track can match nothing or several showers

- **Simple**
  - Track is matched only to closest shower to projection point in calorimeter if <20° apart
  - At most, & usually, one shower matched per trk

- **CR**
  - Shower is matched if any in “connected region” have std match - most matches per track

- **CR50**
  - Like CR but left unmatched if $E_{\text{matched shwr}} > 50\%$
Matching Example

Track enters at $\times$.

- **Std:** A & B are matched
- **Simple:** Only B is matched
- **CR:** A, B, C, & D are matched
- **CR50:** A, B, & C are matched
What is your metric?

Showers from Photons - Simple TM Best

Showers from non-Photons - Simple TM Worst
Track-Matching Conclusions

- Several algorithms - there are others
- Optimal one depends on what you want
- “Std” method is a reasonable intermediate choice, if you want to choose just one (default CLEO)
- Shower shape & isolation (E9/E25) cuts reduce the importance of track-shower matching: split-off showers are not photon-like, & tend to fail such requirements
Physics: Lepton ID

- $e^\pm$ deposits ~all energy, in contrast w/ $\mu^\pm$, $\pi^\pm$, $K^\pm$, p
- $\mu^\pm$ deposits ~220 MeV (min. i.) with Landau tail, ~independent of momentum
- Form “E/p” variable: shower energy/momentum
  - Peak near ~1 for $e^\pm$
  - Only small tail from $\pi^\pm$ at high E/p
  - $\mu^\pm$ peak near small E/p
Lepton efficiencies

\( e^\pm \): E/p > 0.85 is \( \sim 98\% \) efficient

- Usually combined with dE/dx to achieve \( \pi^\pm \) suppression of \( \sim 1000:1 \)

\( \mu^\pm \): E < 400 MeV is \( \sim 95\% \) efficient

- Suppresses \( \pi^\pm \) by \( \sim \)half
Lepton ID Example

Consider $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow e^+e^-$ or $\mu^+\mu^-$

Very clean signal, so the easiest case for id

Only very small contributions from $J/\psi \rightarrow \pi^+\pi^-$, $K^+K^-$, $\rho\pi$
Lepton ID Example

- Notice log scale!
- Excellent MC/data agreement
- Cuts are:
  - One E/p > 0.85, other E/p > 0.5
  - One E/p < 0.25, other E/p < 0.5
- Very loose, eff.
- Easiest case!
Physics: Luminosity

Tag $e^+e^-$ & $\gamma\gamma$ final states with calorimeter only

- CLEO uses this online for lumi: fast, no tracking info needed
- Simple cuts: two showers with ~beam energy in both
- $e^+e^-$ has showers not back-to-back in $\phi$ due to magnetic bending
- $\gamma\gamma$ exactly back to back in $\phi$
Luminosity

- Energy response of MC not perfect, but cut loosely
- Angular MC modeling is excellent
- $\gamma\gamma$ more useful when running on $\psi(2S)$- no bgd from direct decays to dileptons
Physics: $\pi^0/\eta \rightarrow \gamma\gamma$

Finding/fitting/usage

Finding

- Loop over pairs of showers
- Restrict $M_{\gamma\gamma}$? Sidebands useful!
- Unmatched to a track?
- Include regions of poorer resolution? (CLEO: $1\gamma$ in endcaps)
\( \pi^0/\eta \rightarrow \gamma\gamma \) Fitting

**Input:** \( E_1, \theta_1, \phi_1, E_2, \theta_2, \phi_2 \)

& their errors

**Constrain:** \( m(\gamma\gamma) = M(\pi^0/\eta) \)

\[ m(\gamma\gamma) = 2 E_1 E_2 \sin^2(\alpha/2) \] where \( \alpha \) = opening angle between showers

\[ \text{Minimize } \chi^2: \text{ non-linear problem} \]

\[ \text{Iterate with method of Lagrange multipliers} \]

\[ \text{Converges in 2-3 iterations} \]
Key points

- Uncertainties from “lookup table”, unlike, e.g. tracking errors
- Must compute error matrix for input to later kinematic fits
- Fit “wiggles” input values commensurate with uncertainties to get mass to match
- Exercise: for CLEO energy & angle resolutions, prove that for $E(\pi^0) \sim < 1$ GeV, that energy resolution dominates the $m(\gamma\gamma)$ resolution (hint: take case of $E_1=E_2$ as limit for which angular resolution should matter most)
\[ \pi^0 / \eta \rightarrow \gamma \gamma \] Usage

- Need to access
  - Fitted momentum
  - \( M(\gamma \gamma) \) “pull” = \( \#_\sigma \) from \( M(\pi^0) \)
  - \( \chi^2 \)
  - Unconstrained mass
  - \( \cos \theta^* \) = decay angle in c.m. w.r.t. momentum direction... flat in this variable

- Fakes accumulates near \( |\cos \theta^*| = 1 \)
Example: $\psi(2S)\rightarrow\pi^0\pi^0, J/\psi, J/\psi\rightarrow l^+l^-$

Very clean, well-modeled
Example: $\psi(2S) \rightarrow \eta \ J/\psi$, $\eta \rightarrow \gamma\gamma$

Very clean, well-modeled

$\psi(2S) \rightarrow \gamma \chi_{c0}$, $\chi_{c0} \rightarrow \gamma J/\psi$
QWG3 CsI: Conclusions

- W/careful design, a CsI(Tl) EMCal offers excellent resolution in energy (1.5-8%) & angle (3-15mr) for E=0.05-5 GeV
- Long term stability demonstrated (glue joints!)
- ECal, XCal straightforward: can be ~stable
- Preserve energy resolution w/careful summing; angular resolution w/MC corrections to c.o.g.
- SCal a challenge, but can achieve <0.5% accuracy above 50 MeV with some work
- Shower shape, track-shower matching both useful for isolation & splitoff rejection