Coherent ρ0 Measurement in Neutral Current Interaction

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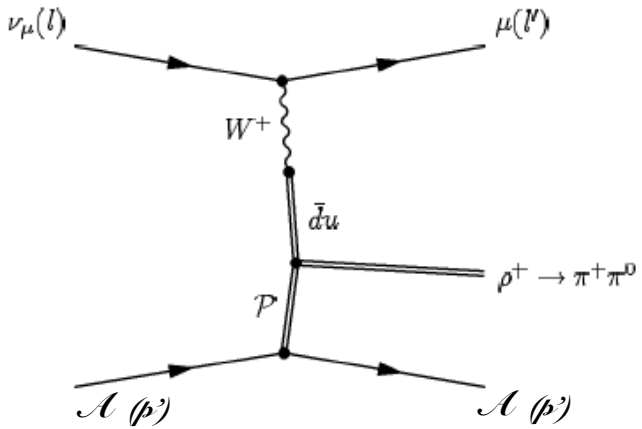
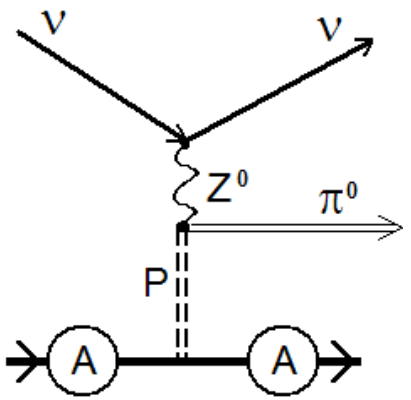
Outline

- Coherent Processes & Motivation
- Introduction to NOMAD
- Coherent ρ0 Analysis

Coherent Processes





Charged Current: π+, π-, ρ+, ρ-.

- Neutral Current: π0, ρ0

- Neutrino scatters coherently off a target nucleus.
- No quantum numbers (charge, spin, isospin) exchange.
- Small momentum transfer.
- π/ρ mesons are emitted at small angles with respect to the incident neutrino.

Motivation

- Measure Lorentz structure of weak current:
  - Coherent π:
    Partially Conserved Axial Current (PCAC) & Adler's theorem
  - Coherent ρ:
    Conserved vector current (CVC) & Vector meson dominance(VMD)
- Coh π+/π-, Coh ρ+/ρ-: identical signature => Constraint on Nu/NuBar flux.
- **γ**-induced coh ρ0 => ν induced coh ρ0 => Constraint on the neutrino flux.
- Useful channels for relative flux measurement & Eν-Scale.
- Coh-π+: Constraint on neutrino beam divergence.
- Coh-π0 like events are background to ν_e appearance.
- The ideas/tools of this analysis was developed while working on the high-resolution LBNE-ND

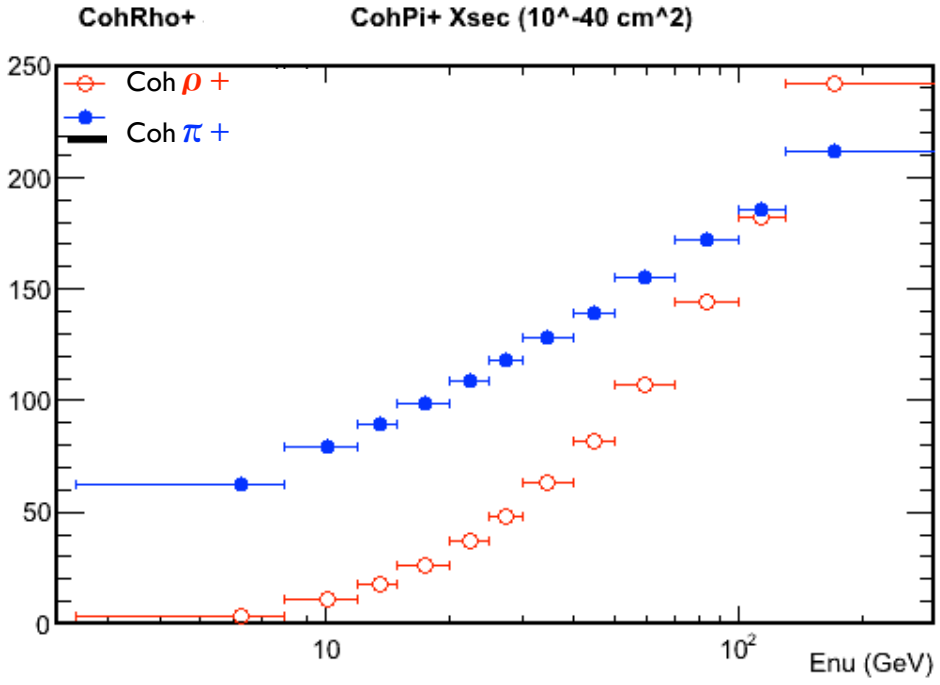
Coherent Cross-Section

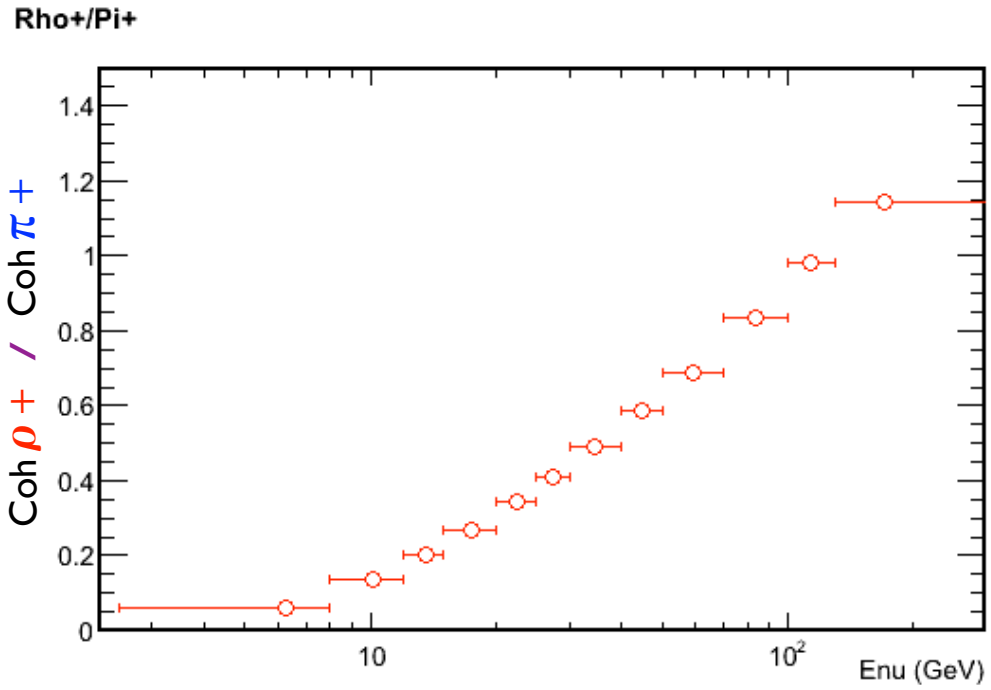
Coherent ρ+ Cross-Section:

$$\frac{d^3\sigma(\nu_\mu \mathcal{A} \to \mu^- \rho^+ \mathcal{A})}{dQ^2 d\nu dt} = \frac{G_F^2}{4\pi^2} \frac{f_\rho^2}{1-\epsilon} \frac{|q|}{E_\nu^2} \left[\frac{Q}{Q^2+m_\rho^2}\right]^2 (1+\epsilon R) \left[\frac{d\sigma^T(\rho^+ \mathcal{A} \to \rho^+ \mathcal{A})}{dt}\right]$$

$$\frac{d\sigma^T(\rho^+ \mathcal{A} \to \rho^+ \mathcal{A})}{dt} = \frac{\mathcal{A}^2}{16\pi} \sigma^2(hn) exp(-b|t|) F_{abs}$$

Rein-Segal Model





Neglib simulation of Coherent π+ and Coherent ρ+ cross-section.

Coherent Cross-Section

Simple relation between Coherent ρ+ and Coherent ρ0

$$\frac{d^3\sigma(\nu_\mu \mathcal{A} \to \nu_\mu \rho^0 \mathcal{A})}{dQ^2 d\nu dt} = \frac{1}{2}\left(1 - 2\sin^2\theta_W\right)^2 \frac{d^3\sigma(\nu_\mu \mathcal{A} \to \mu^- \rho^+ \mathcal{A})}{dQ^2 d\nu dt}$$

- σ(Coh ρ0) ≈ 0.15*σ(coh ρ+)
- Coherent ρ+ observed by E546, E632, SKAT, and BEBC
  Precision of ± 25--30%
- **Coherent ρ0 has never been reported.**

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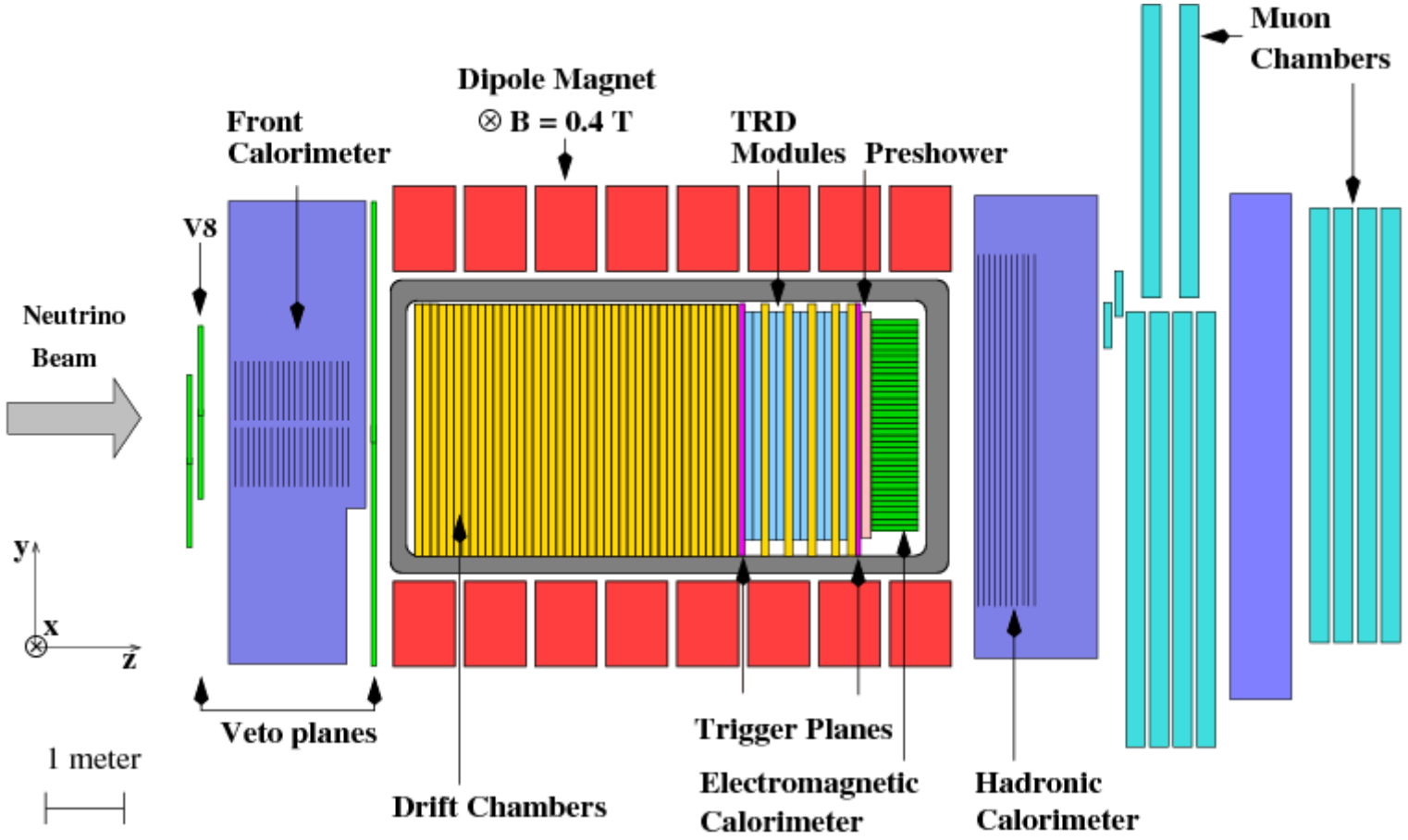
Introduction to NOMAD

- The Neutrino Oscillation MAgnetic Detector (NOMAD, WA-96) was designed to search for NuMu to NuTau appearing from oscillations in the CERN SPS wide band neutrino beam.
- NOMAD accumulated ~2 million neutrino interactions.
- In addition to oscillation search at high Δm^2, NOMAD offers the unprecedented opportunity of studying a large number of neutrino interactions with high resolution on all of the particles in the event.

Nomad Detector



- 2.7 ton, low average density (0.1 g/cm^3).
- 44 Drift Chambers (3X3 m^2).
- TRD (Transition Radiation Detector), Preshower, ECal => Electron PID.
- Dipole magnetic field B = 0.4 T
  => High precision momentum measurement of charged particles.

Signal and Background

- Signal:
  ρ0 ⇒ π+π-

- Background:

  - NC-DIS: 2-Track (+,-). The largest contribution.

  - CC-DIS: 2-Track (+,-) where "-" is μ- w/o μ ID. Small contribution.

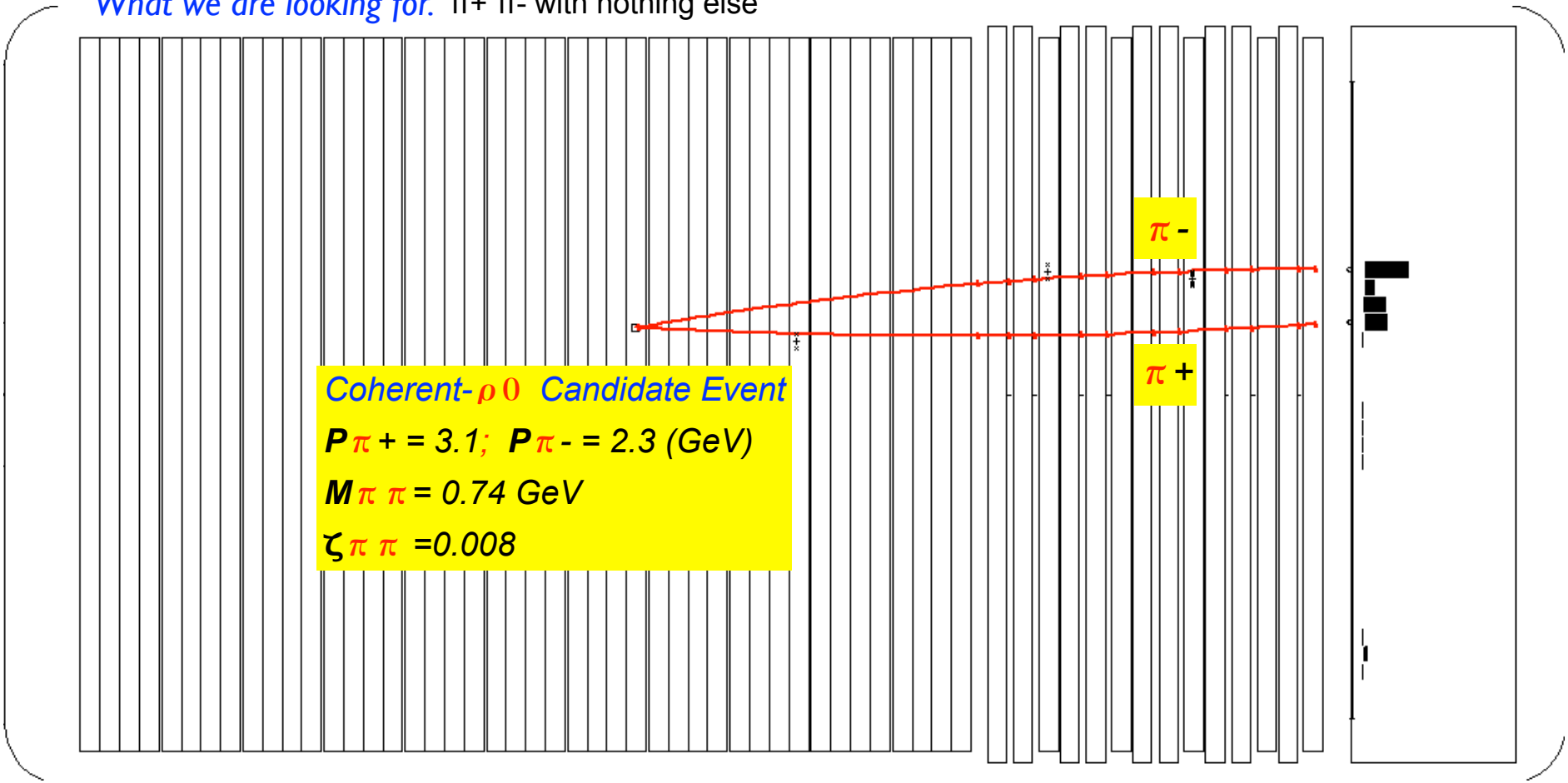
  - Outside-Background (OBG): K0s from outside-interactions. Still smaller contribution.

- Control Sample: CC Data Simulator Correction

  ν_μ-CC events where the μ- are identified and then `removed'; the remaining hadronic (+,-) tracks subjected to the analysis.

Candidate Events

What we are looking for. π+ π- with nothing else



$\zeta = E^*(1-\cos\theta)$

Candidate Events

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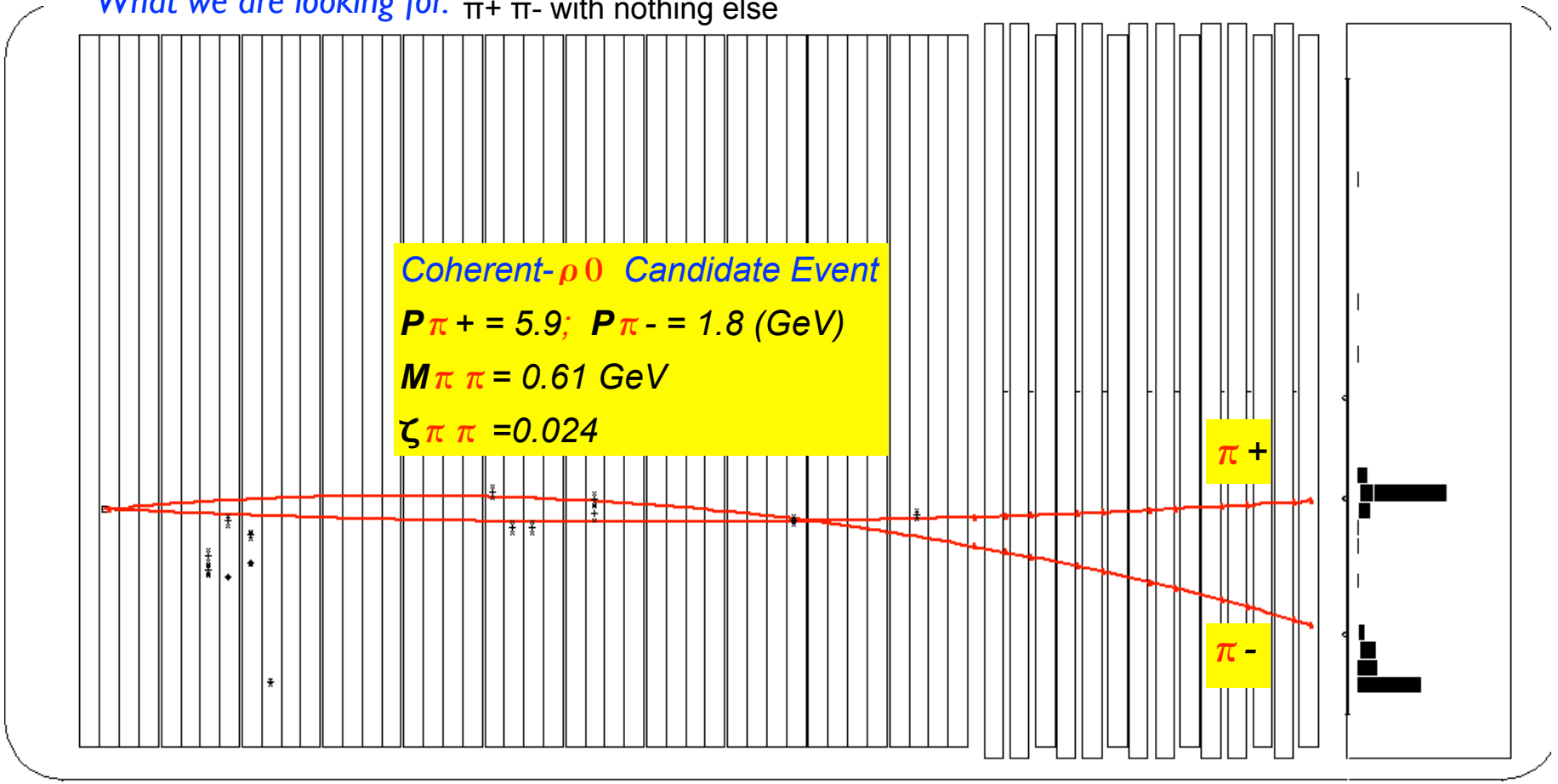

$\zeta = E^*(1-\cos\theta)$

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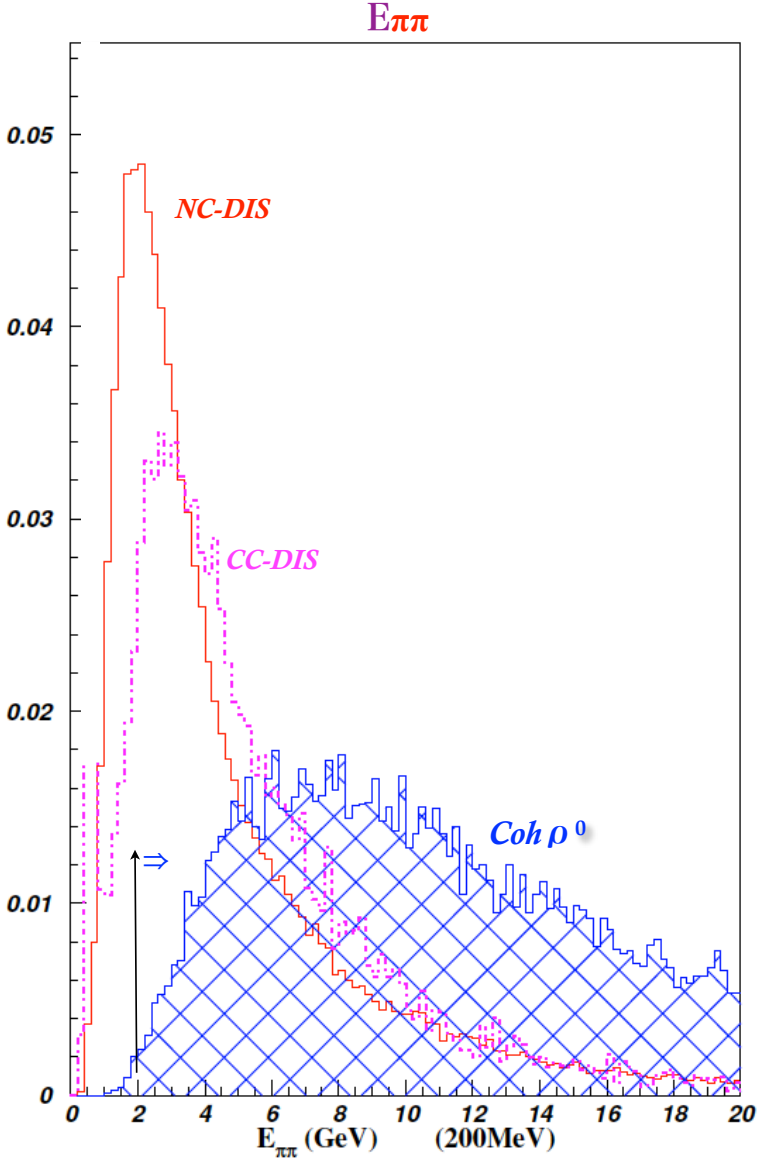
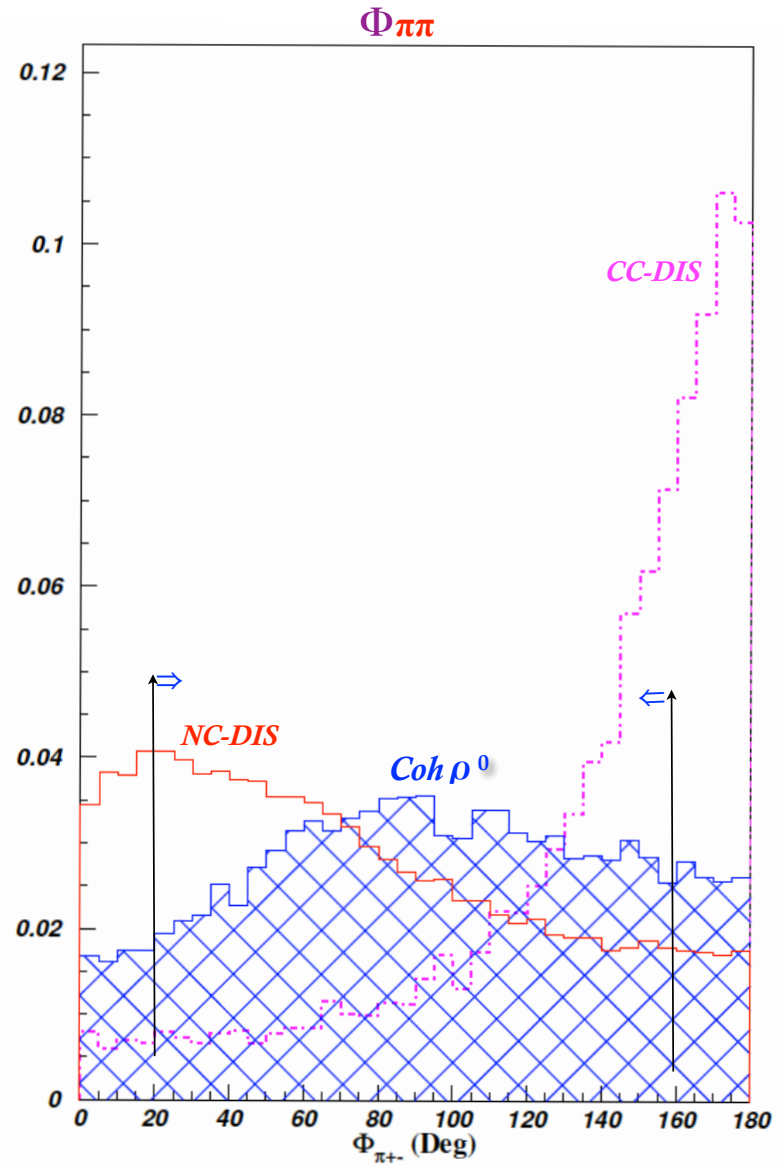
Pre-Selection Cuts (Shape Comparison)





- Shape comparison of 2-track (+-) MC events in FV with no muon ID.
- Pre-selection cuts:
  $E_{\pi\pi} > 2$ GeV, $20 \leq \Phi_{\pi\pi} \leq 160$

Pre-Selection Cuts

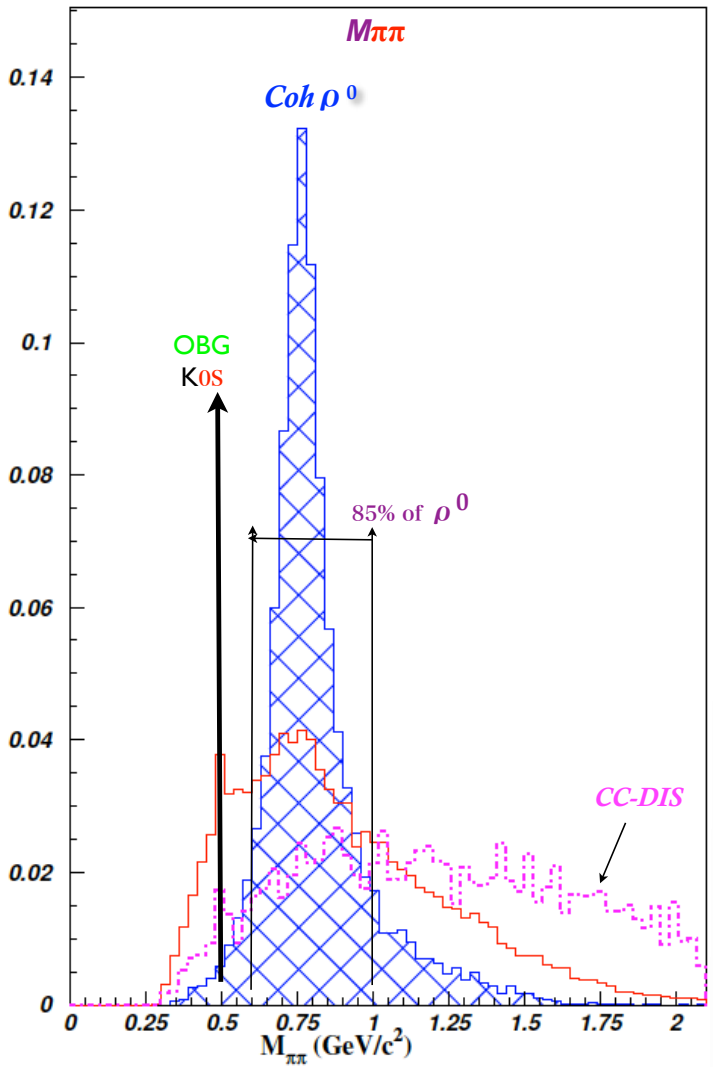
- MC:
  NC-DIS (~x4 Data) ➳ 0.44M
  CC-DIS (~x4 Data) ➳ 1.44M
  Cohπ+ ➳ 10k
  Cohρ0 ➳ 1500

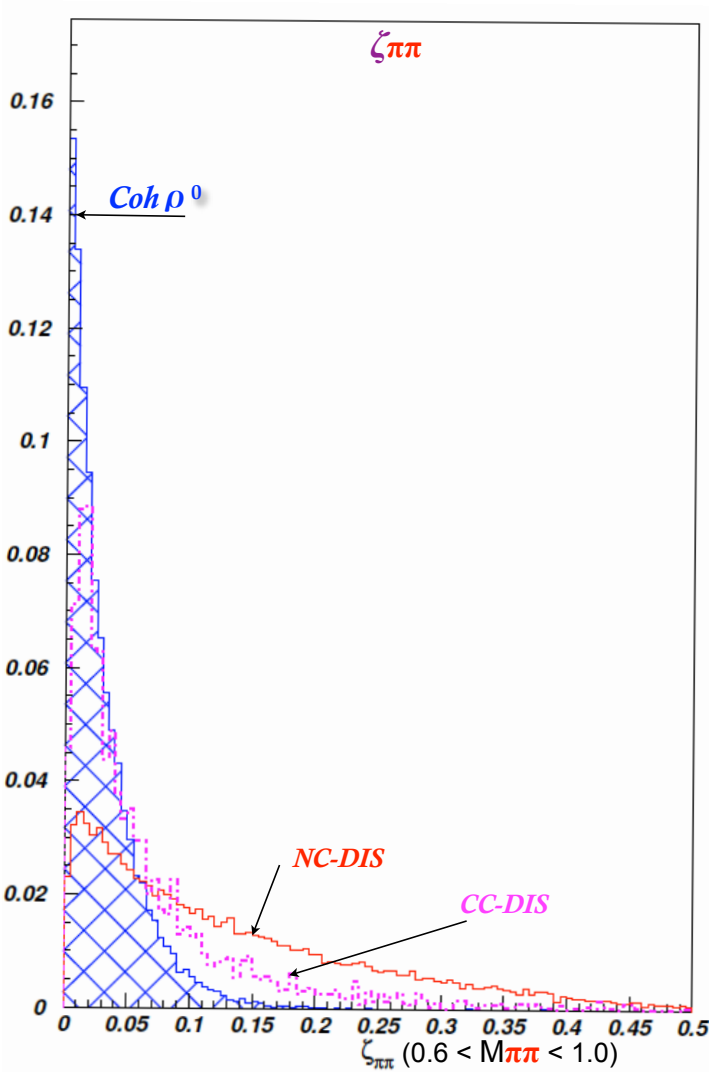
- Fiducial cut, Muon-veto, 2-tracks, $E_{\pi\pi} \geq 2$ GeV.

- Veto/UpHanger, Photon Veto, $20 \leq \Phi \leq 160$.

NC-DIS	CC-DIS	OBG	OTHER	Coh ρ0	MC	DATA
5377	833	245	88	296	6841	6852

Analysis





- Plot Mππ and ζ distribution after pre-selection cuts.
- ζ is the critical variable which distinguishes Coh ρ0 from background. Need to know the shape and normalization of NC-DIS; CC-DIS very small.

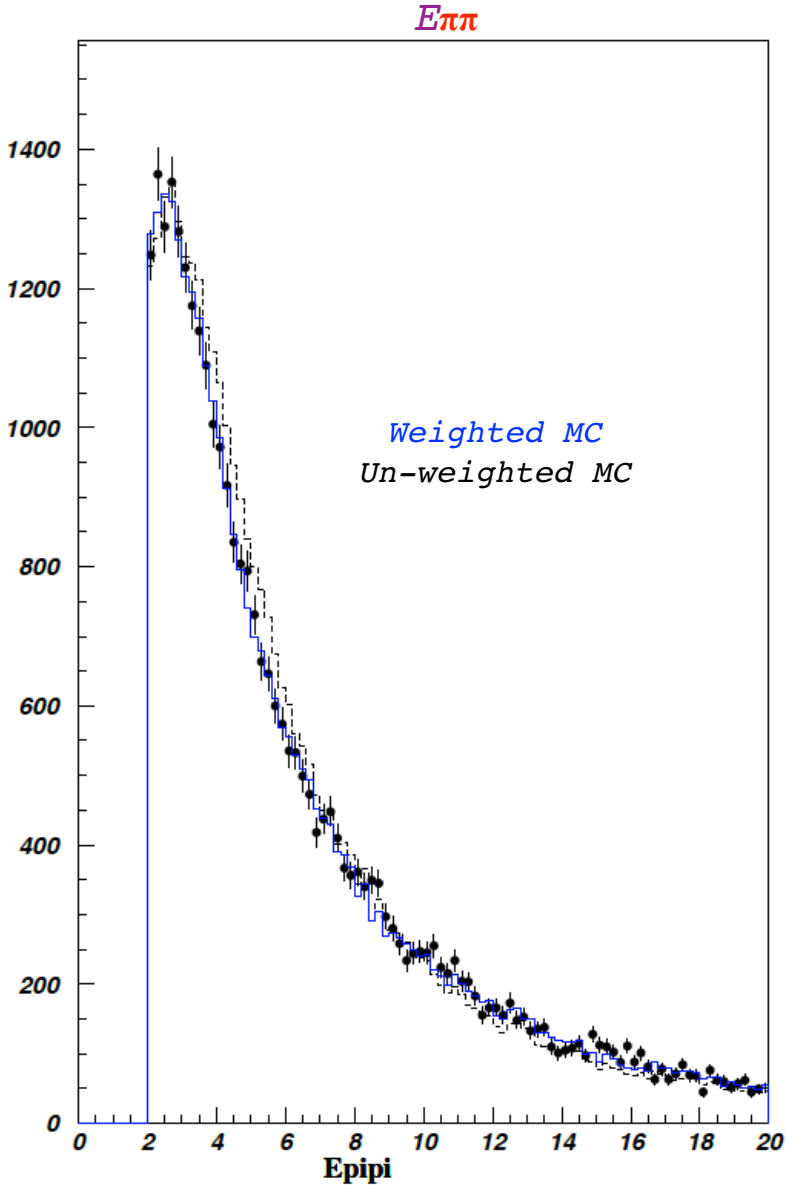
Calibration of the Background

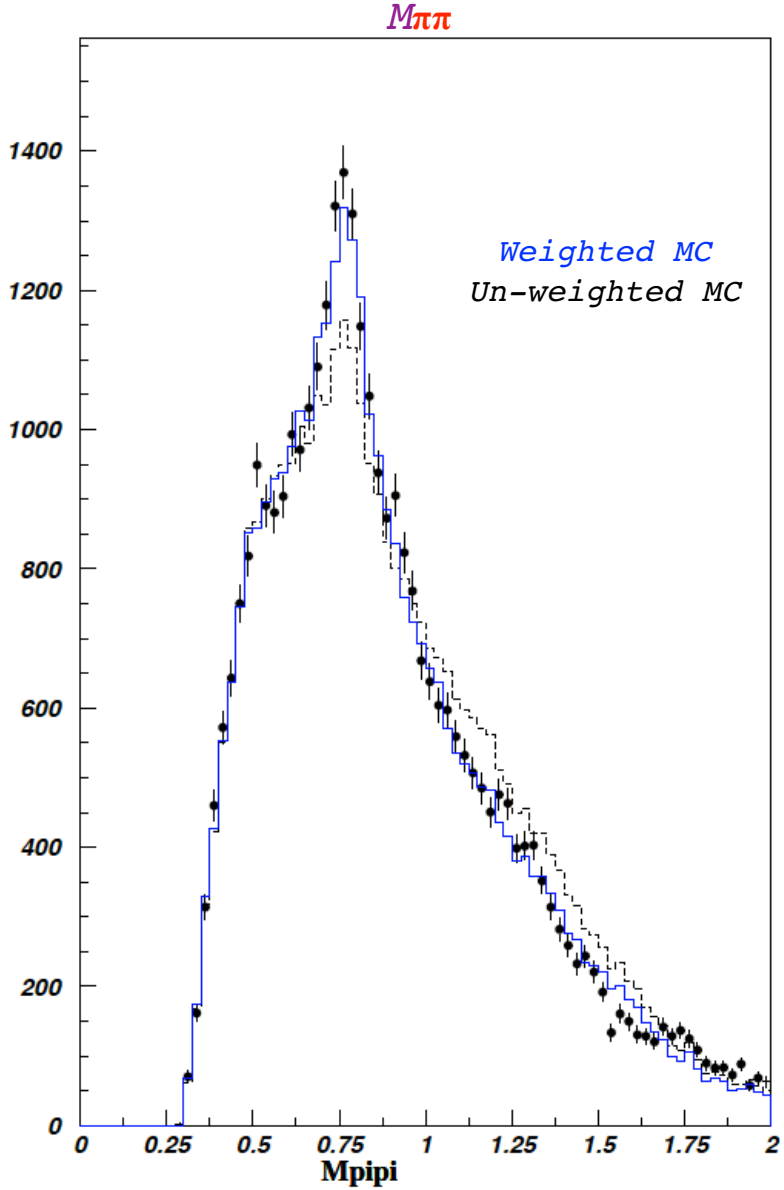
- Calibrate and normalize OBG (Outside Background):
  - Calibrate by 2-track events with primary vertex outside of detector.
  - Normalize it to the thin K0 peak in $M_{\pi\pi}$ plot (498 ± 12 MeV).
- Calibrate the shape of NC background using control sample (CC-DS).
- Normalize NC background using control sample.
- Measure Coherent ρ0 using $\zeta_{\pi\pi}$ shape.

NC Background Calibration

- We need to understand NC-DIS. The most important is the shape of $\zeta_{\pi\pi}$.
- CC Data Simulator (CC-DS):
  - Select ν_μCC events with 3, 3-&-4 Tracks, including the muon.
  - Remove the muon, put the $\pi^+\pi^-$ subjected through the standard selection.
  - Obtain a MC Re-Weight based on Data/MC [$E_{\pi\pi}$, $M_{\pi\pi}$, $\zeta_{\pi\pi}$]
- Apply the Re-Weight to calibrate the shape of $\zeta_{\pi\pi}$.
- Tried 3 track sample and 3 -&-4 track sample, 1D/2D/3D re-weighting matrix. The difference is within 10%.

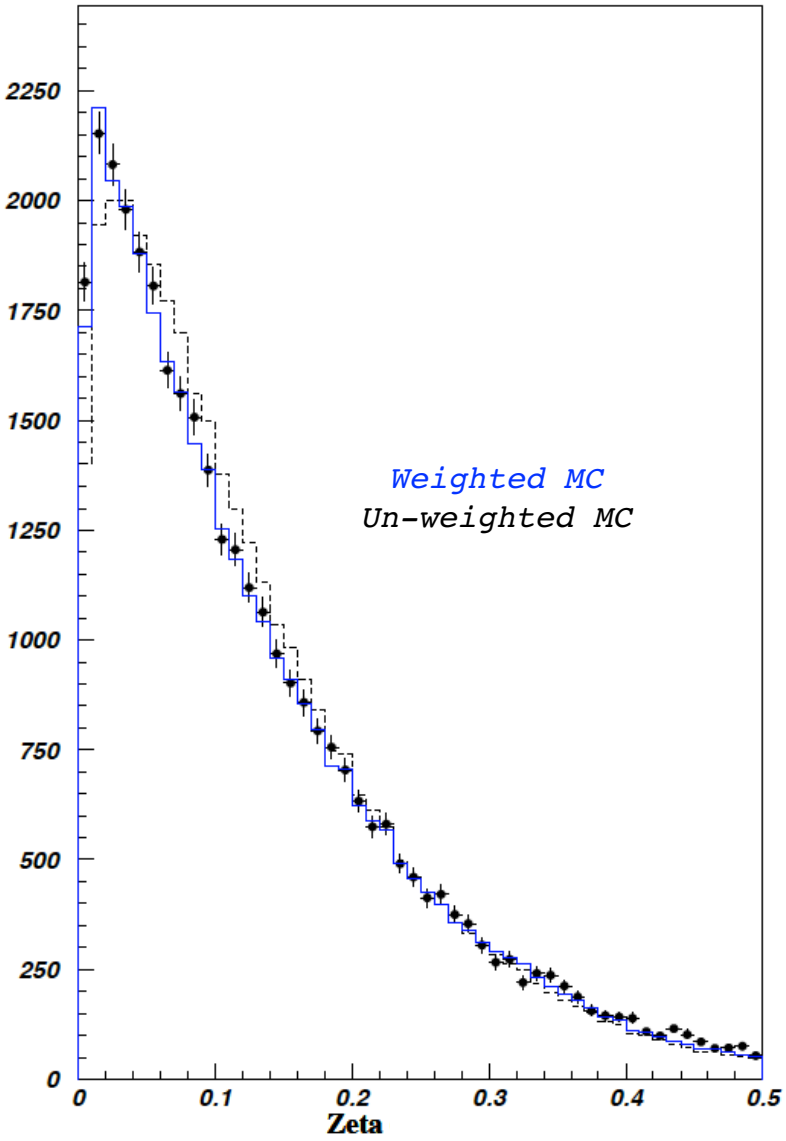
NC Background Calibration





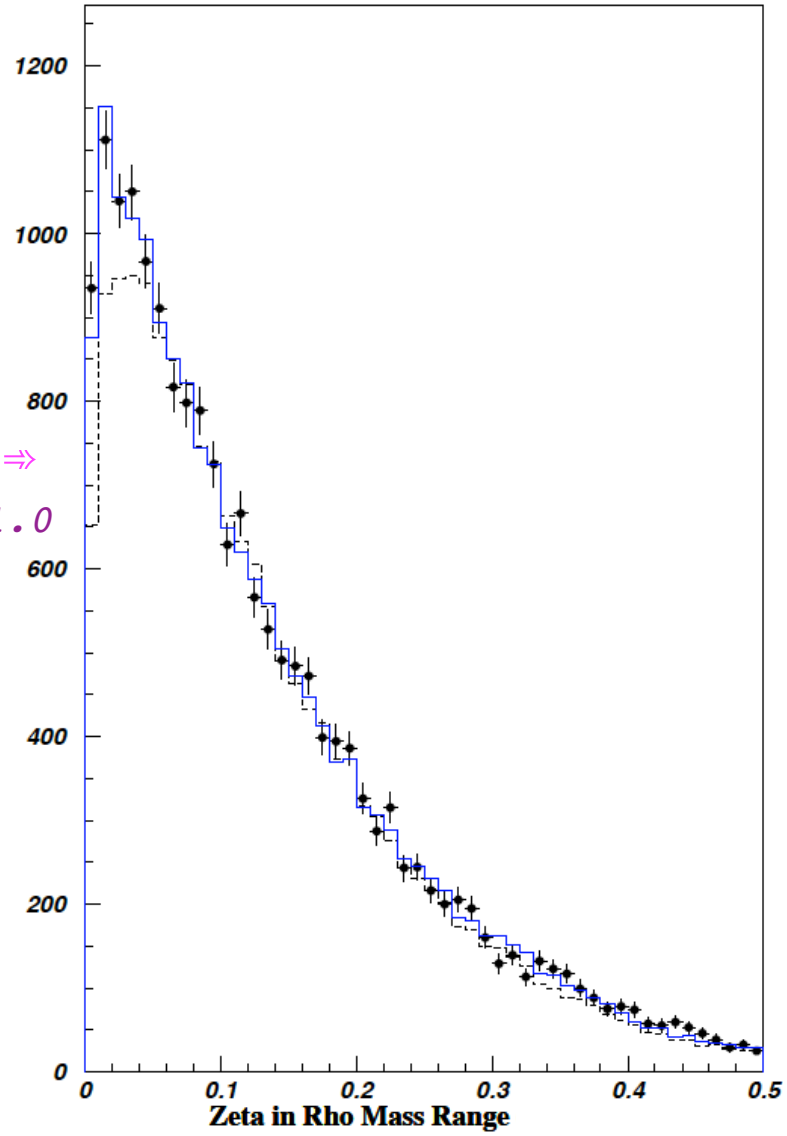
NC Background Calibration

$\zeta_{\pi\pi}$



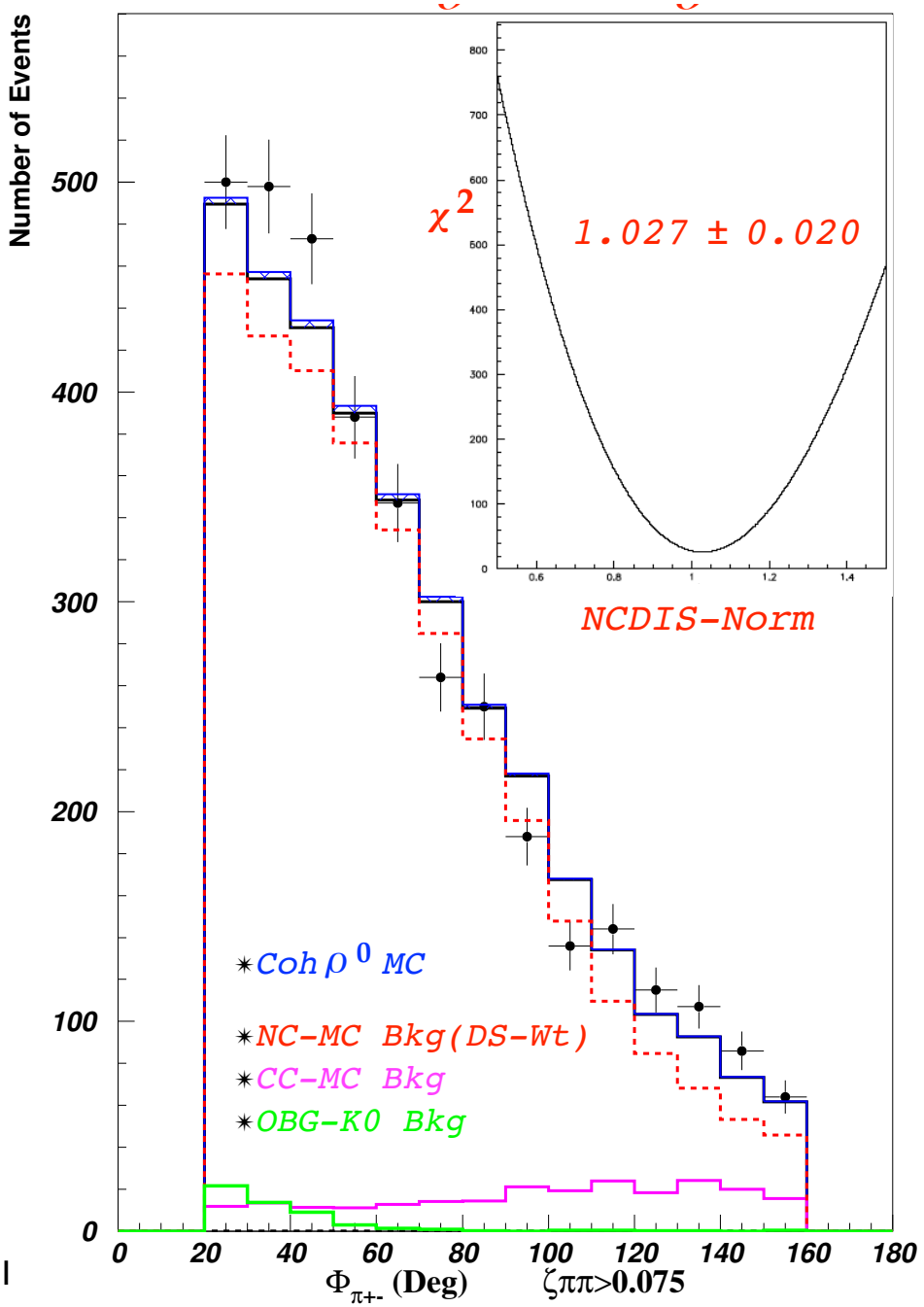
Signal ⇒

$0.6 \leq M_{\pi\pi} \leq 1.0$



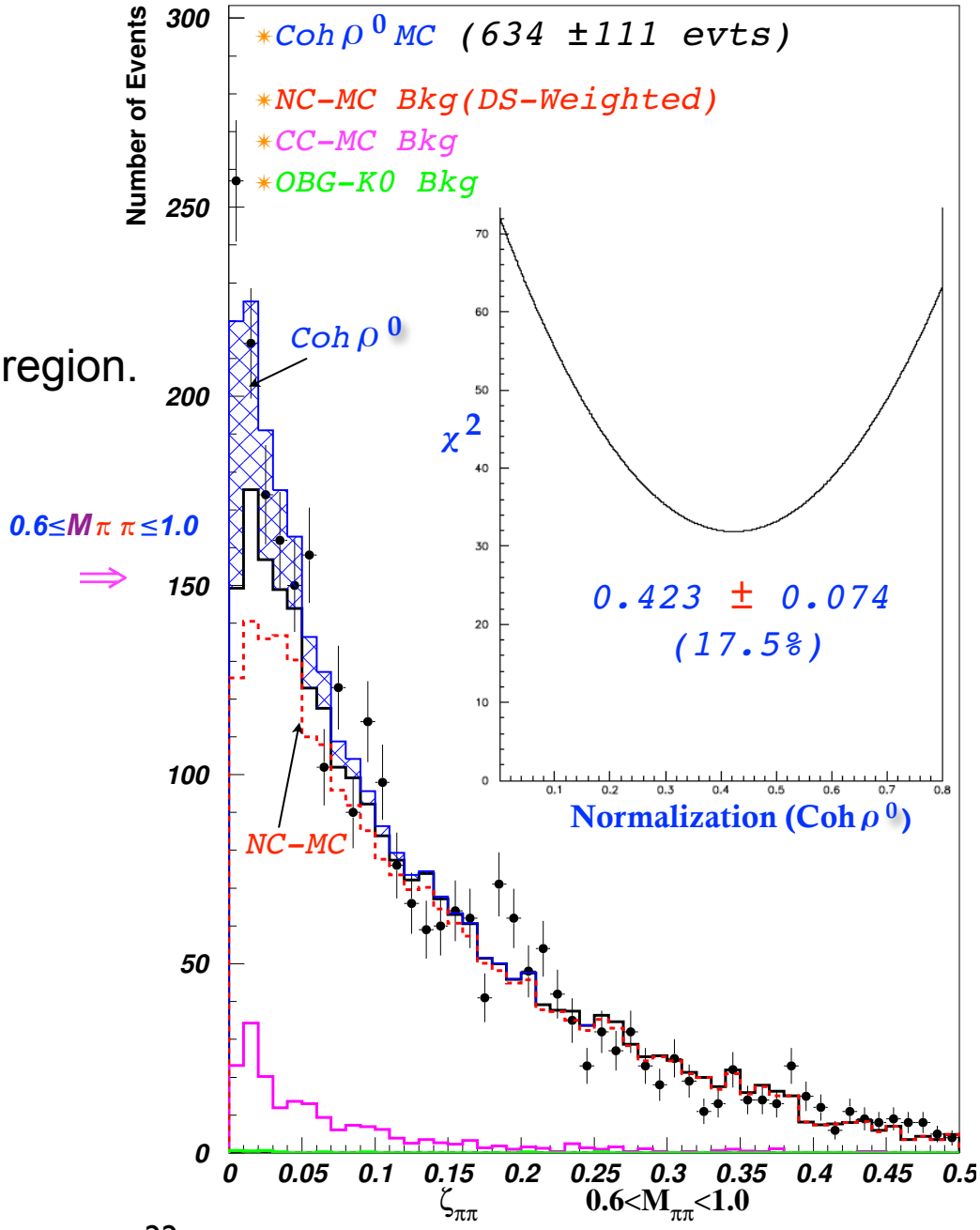
NC Background Normalization

- NC-DIS Shapes re-weighted using CC Data-Simulator
- Look at background region: $\zeta > 0.075$
- Using $\Phi_{\pi\pi}$ distribution (20 ~ 160), normalize NC-DIS mc to fit data.



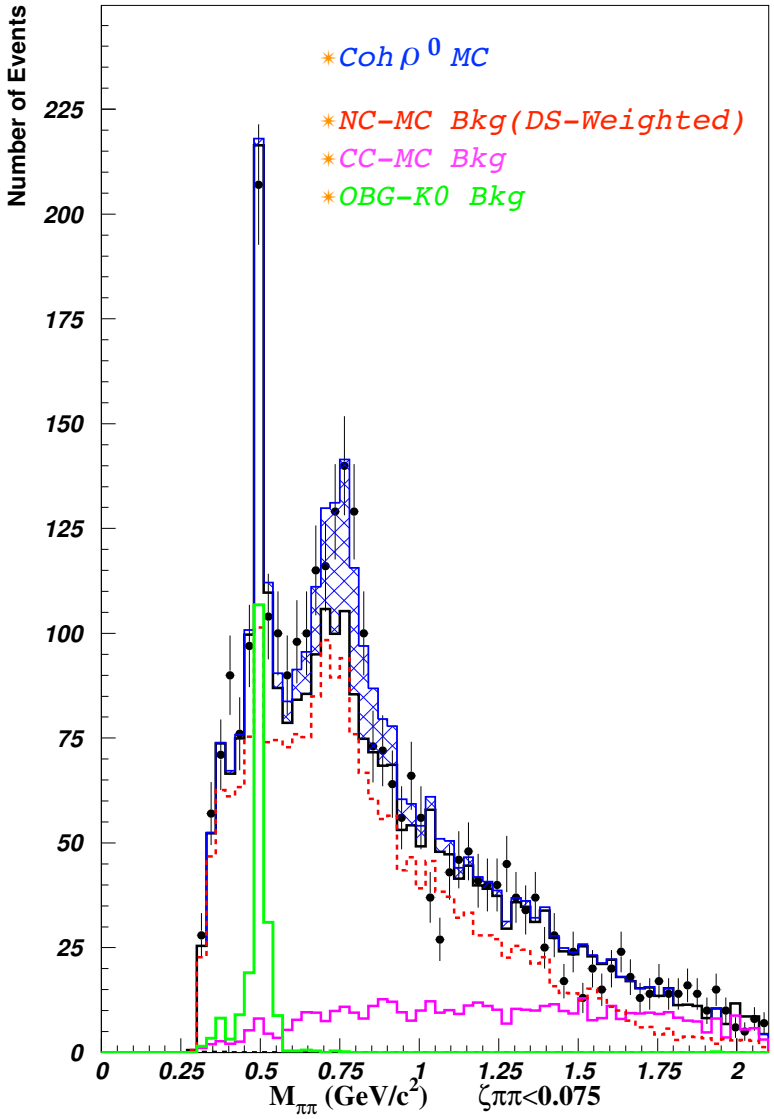
Coherent ρ0 Measurement

- Impose 0.6≤ $M_{\pi\pi}$ ≤1.0 GeV cut.
- Using $\zeta_{\pi\pi}$, fit for Coh ρ0 in ≤0.1 region.

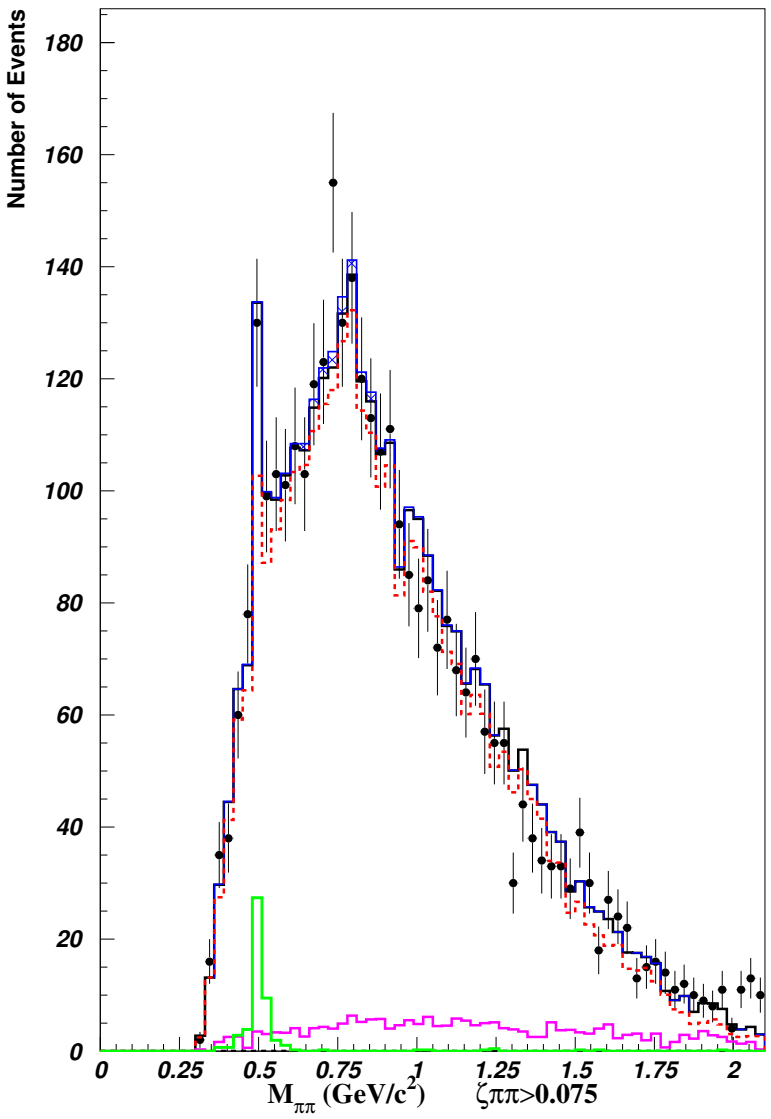


$M_{\pi\pi}$ in Coherent -vs- non-Coherent Regions

Coherent Region: $\zeta<0.075$



non-Coherent Region: $\zeta>0.075$

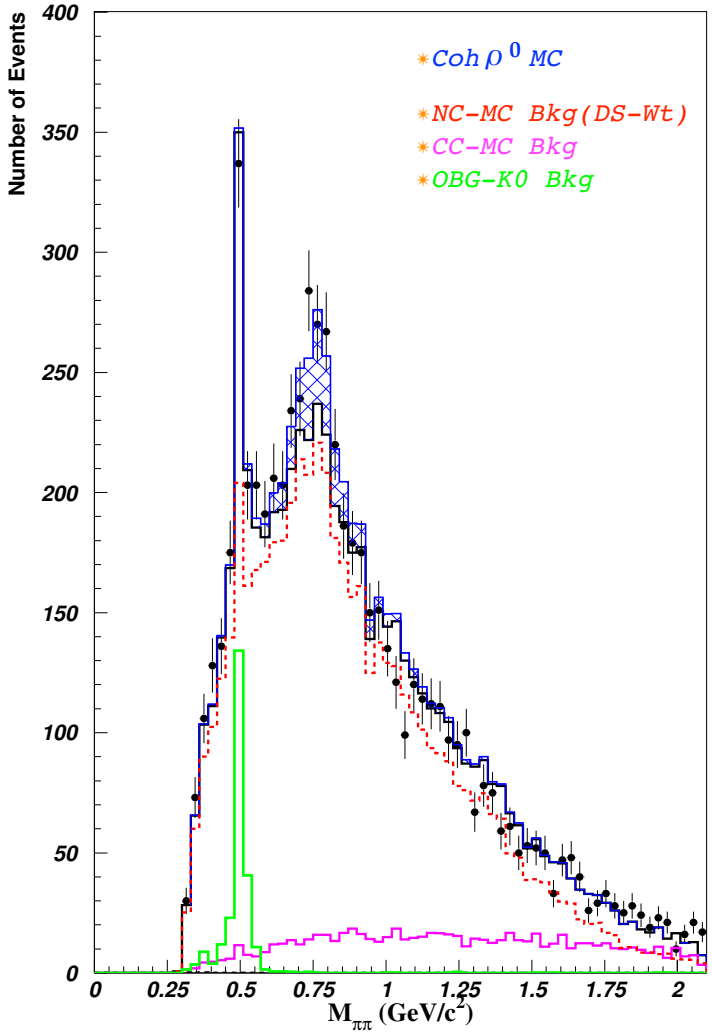


Systematic Error

- Data-Simulator: ± 0.045 (10.6%)
- NC-DIS: ± 0.040 (9.5%)
- CC-DIS: ± 0.020 (4.5%)
- OBG: ± 0.004 (1%) (negligible)
- Total systematic: ± 0.063 (15.0%)
- Total error: 0.423 ± 0.074 ± 0.063 (22.9%)

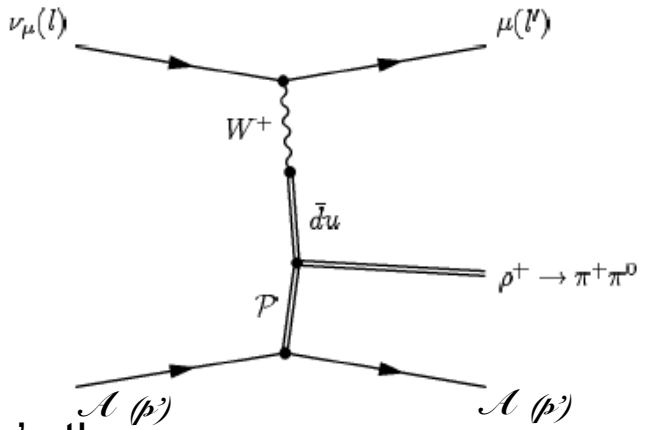
Conclusion

- We have conducted a measurement of Coherent-ρ0 production.
- The analysis is data-driven; the backgrounds are constrained using control samples.
- We observed
  634.5 ± 111.0 (Stat.) ± 95.2 (Syst.)
  fully corrected Coherent-ρ0 events. The rate with respect to CC events (1.44*10e6) is:
  (4.41 ±1.0)*10e-4.
- **This is the first observation of Coherent-ρ0.**



Backup Slides

Coherent Processes and Motivation



- Coherent π+, Coherent π-, Coherent π0,
  Coherent ρ+, Coherent ρ-, Coherent ρ0.
- Measure Lorentz structure of weak current:
  - Coherent π:
    Partially Conserved Axial Current (PCAC) & Adler's theorem
  - Coherent ρ:
    Conserved vector current (CVC) & Vector meson dominance(VMD)
- Coh π+/π-, Coh ρ+/ρ-: identical signature => Constraint on Nu/NuBar flux.
- **γ**-induced coh ρ0 => ν induced coh ρ0 => Constrained on the neutrino flux.
- Useful channels for (relative flux) measurement & Eν-Scale.
- Coh-π+: Constraint on neutrino beam divergence.
- Coh-π0 like events are background to ν_e appearance.
- The ideas/tools of this analysis was developed while working on the high-resolution LBNE-ND

Coherent Production

$$\frac{d^3\sigma(\nu_\mu \mathcal{A} \to \mu^- \rho^+ \mathcal{A})}{dQ^2 d\nu dt} = \frac{G_F^2}{4\pi^2} \frac{f_\rho^2}{1-\epsilon} \frac{|q|}{E_\nu^2} \left[\frac{Q}{Q^2+m_\rho^2}\right]^2 (1+\epsilon R) \left[\frac{d\sigma^T(\rho^+ \mathcal{A} \to \rho^+ \mathcal{A})}{dt}\right] \tag{1}$$

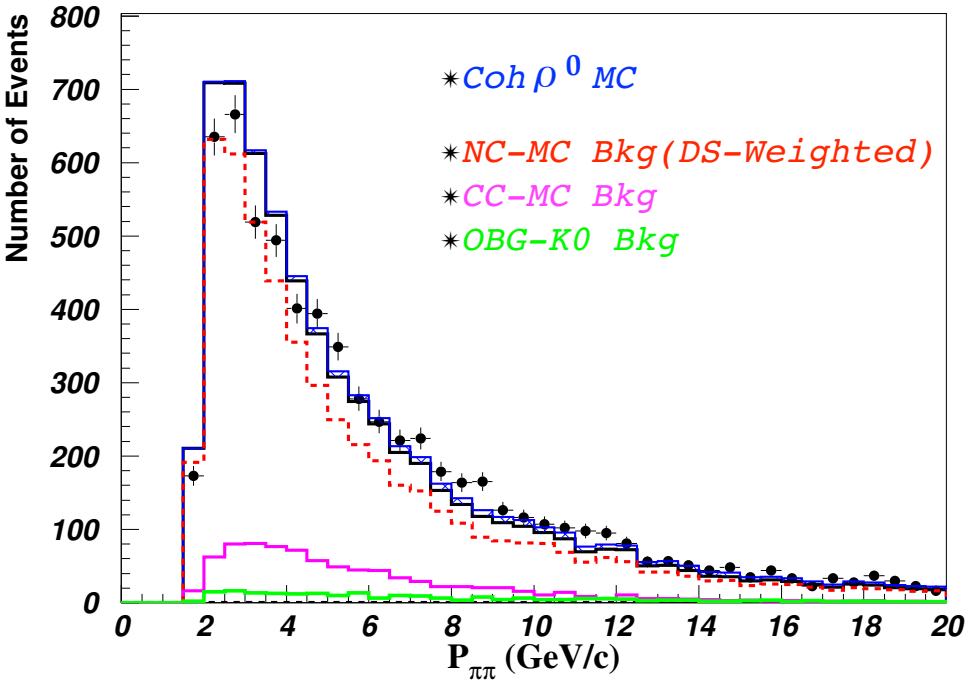
where G_F is the weak coupling constant, $Q^2 = -q^2 = -(k-k')^2$, $t = (p-p')^2$, $\nu = E_\nu - E_\mu$, $x = Q^2/(2\nu M)$, $y = \nu/E_\nu$, g_ρ is related to the ρ form-factor, the polarization parameter $\epsilon = \frac{4E_\nu E_\mu - Q^2}{4E_\nu E_\mu + Q^2 + 2\nu^2}$, and $R = \frac{d\sigma^L/dt}{d\sigma^T/dt}$ with σ^L and σ^T as the longitudinal and transverse ρ-nucleus cross sections. The ρ form factor f_ρ is related to the corresponding factor in charged-lepton scattering, $f_\rho^\pm = f_{\rho^0}^\gamma \sqrt{2} cos\theta_C$, θ_C is the Cabibbo angle and $f_\rho^\gamma = m_\rho^2/\gamma_\rho$ is the coupling of ρ^0 to photon ($\gamma_\rho^2/4\pi = 2.4 \pm 0.1$).

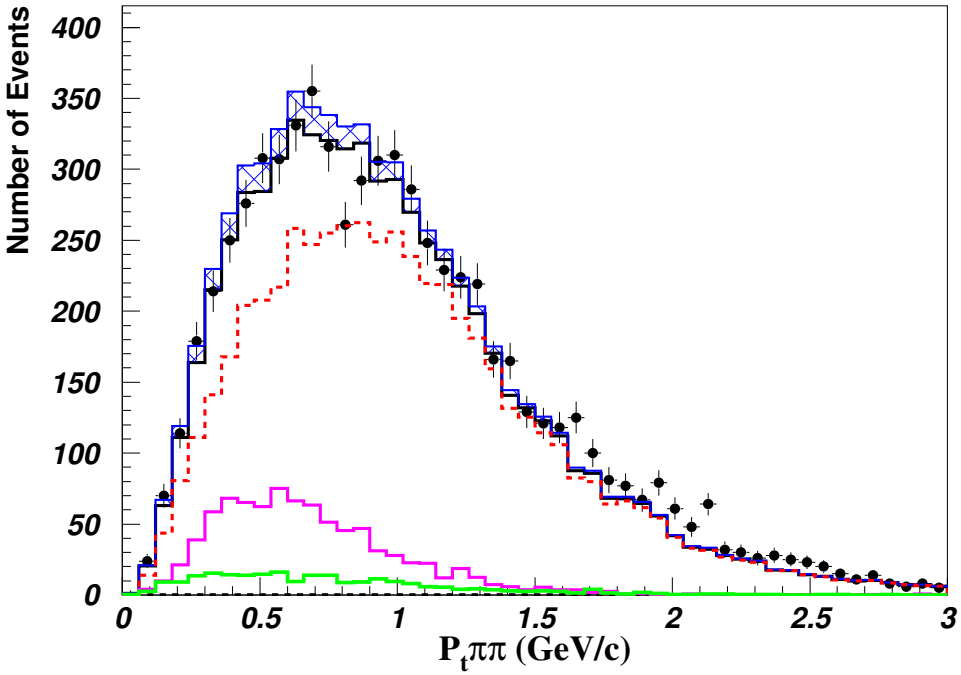
Following the Rein-Sehgal model of meson-nucleus absorption,

$$\frac{d\sigma^T(\rho^+ \mathcal{A} \to \rho^+ \mathcal{A})}{dt} = \frac{\mathcal{A}^2}{16\pi} \sigma^2(hn) exp(-b|t|) F_{abs}$$

where $\sigma(hn)$ is the 'hadron-nucleon' cross-section with the energy of the hadron $\simeq \nu$, $b = R^2/3$ such that $R = R_0 \mathcal{A}^{1/3}$, with $R_0 = 1.12 fm$ and the absorption factor $F_{abs} = 0.47 \pm 0.03$.

NC Background Calibration

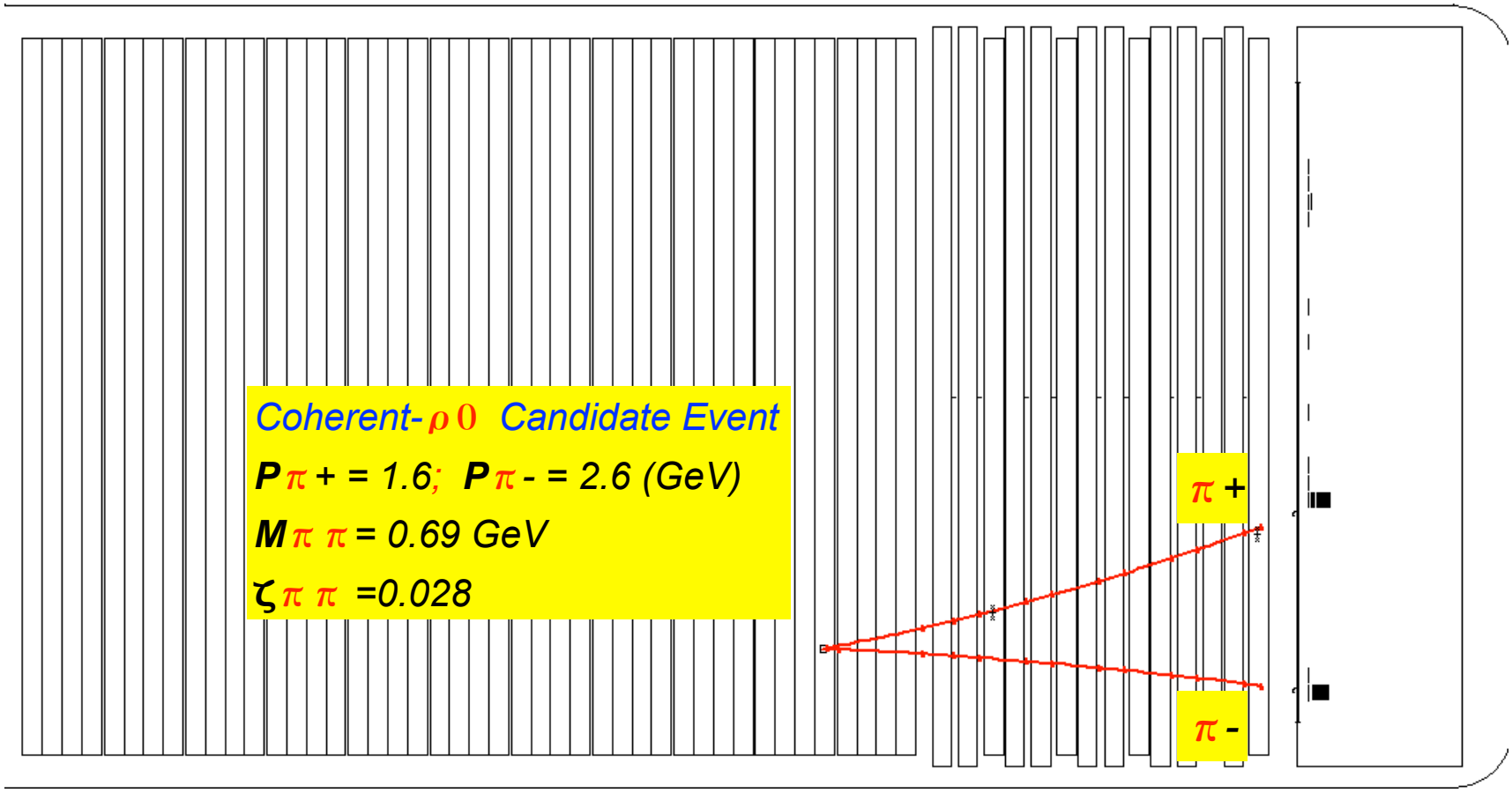




- With NC-DIS ζ-shape fixed, return to the Non-Muon 2-Track sample.
- Next we are going to obtain the NC-DIS normalization.

Candidate Events

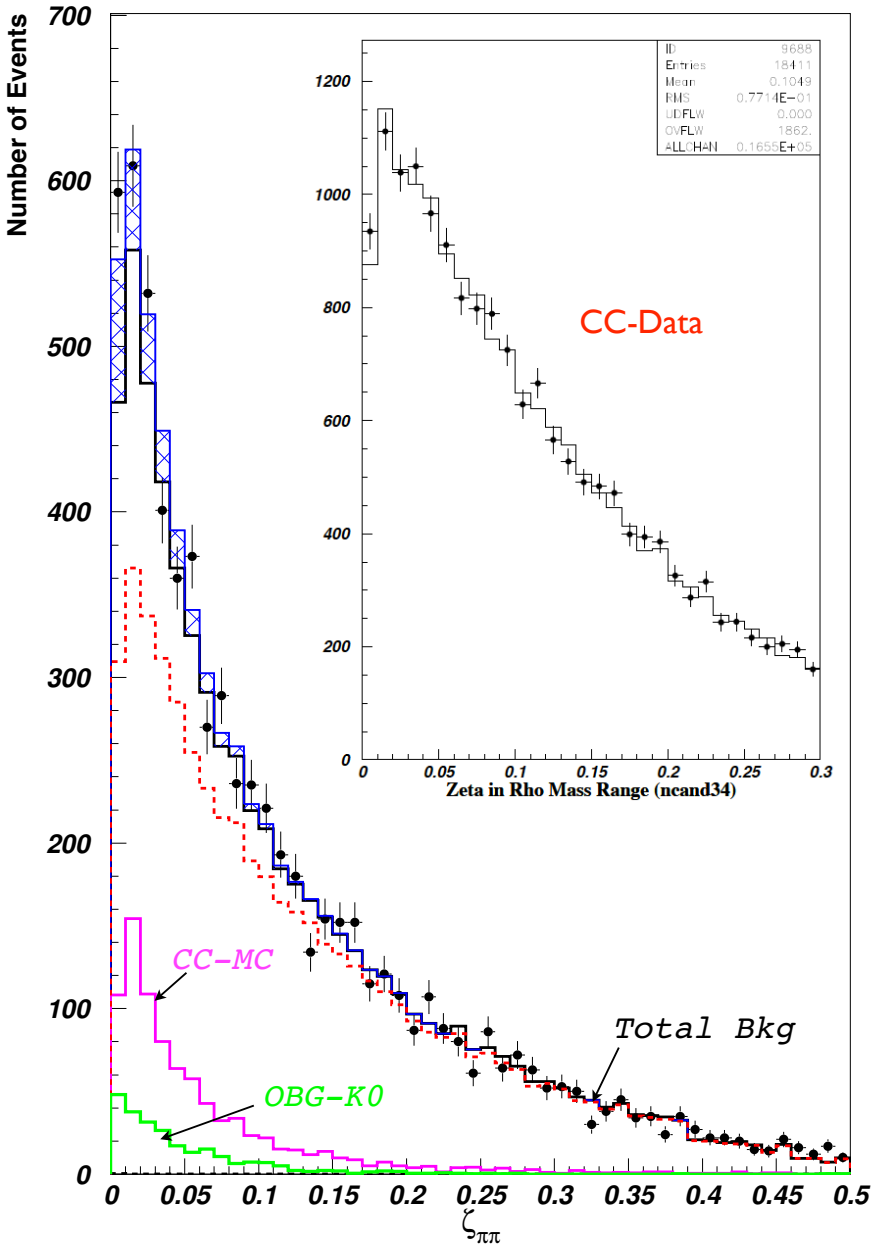
What we are looking for.



Selection Cuts

Selection	*NC-DIS* $\ast$	*CC-DIS* $\ast$	*OBG*	*Other*	*Coh* ρ^0 $\ast$	*Total*	*Data*
Veto/UpHanger	10,341	2,379	1,467	512	386	15,086	15,850
Photon Veto	6,918	1,440	347	235	359	9,300	9,490
$20 \leq \Phi \leq 160$	5,377	833	245	88	296	6,841	6,852

Signal Normalization



$0.6 \le M_{\pi\pi} \le 1.0$

$\Rightarrow$