



CALOR 2006, Chicago

June 5-9, 2006

Electromagnetic and Hadron Calorimeters in the MIPP Experiment

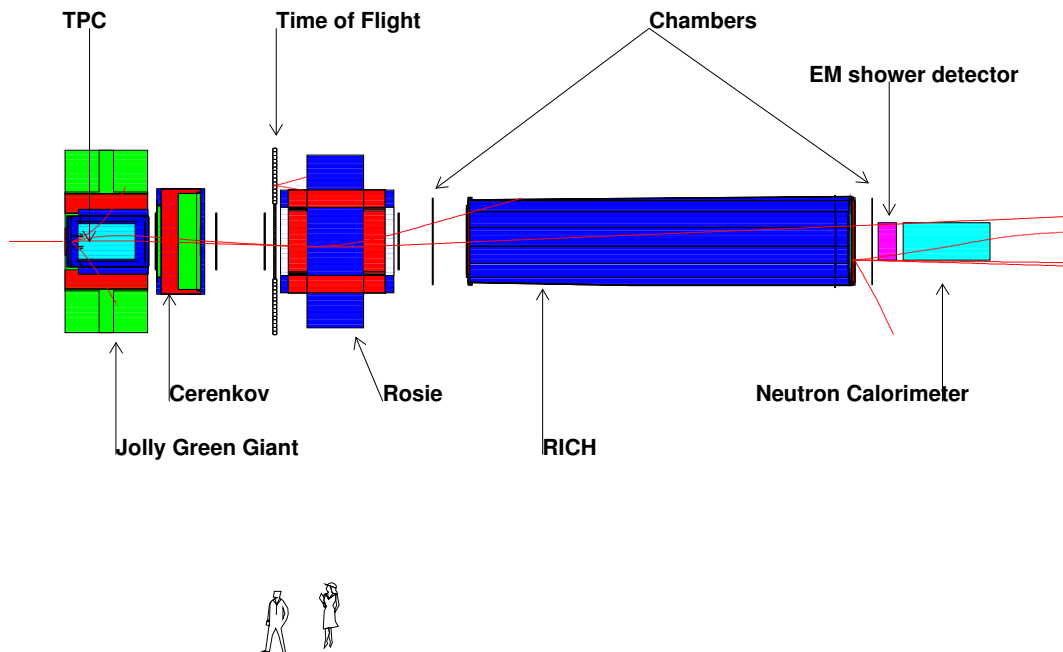
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On Behalf of the MIPP Collaboration

MIPP

Main Injector Particle Production Experiment (FNAL-E907)

Horizontal cut plane



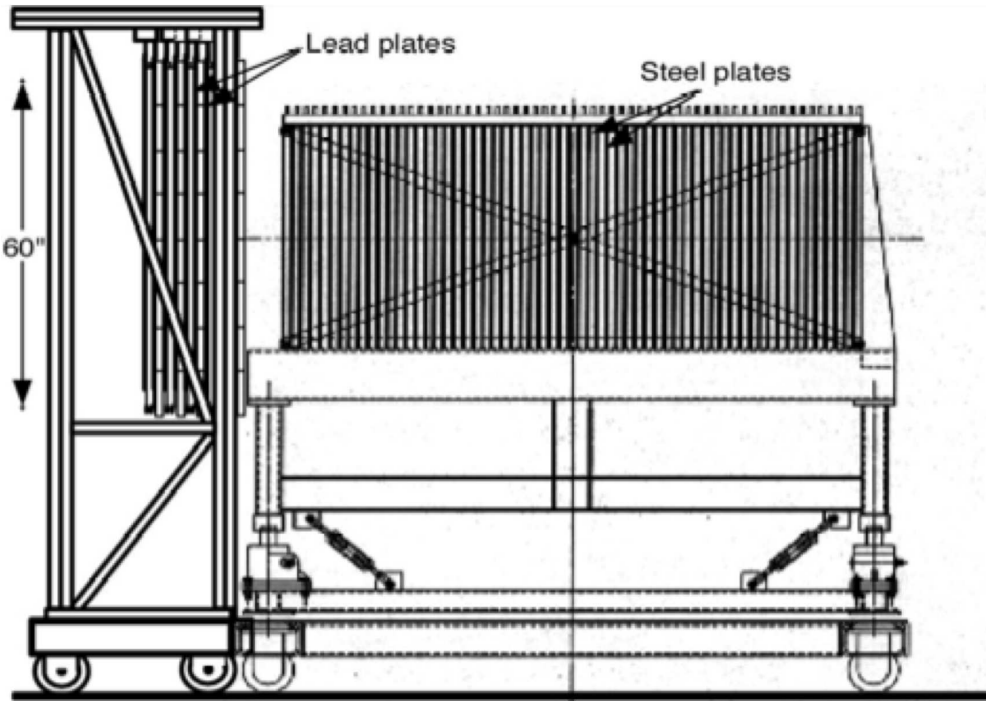
MIPP main goals:

- Hadronic Fragmentation Scaling Law Test
- NuMI Target Study for the MINOS Experiment
- Proton Radiography
- Anti-proton Physics (upgrade)
- ILC Calorimeter studies (upgrade)

data sample

Target	Momentum(GeV)	Events $\times 10^6$		Target	Momentum(GeV)	Events $\times 10^6$
LH2	5	0.21		2%Carbon	120	0.47
LH2	20	1.94		NuMI	120	1.78
LH2	60	1.98		Aluminum	35	0.10
LH2	85	1.73		Bismuth	35	0.52
Beryllium	35	0.10		Bismuth	60	1.26
Beryllium	60	0.56		Bismuth	120	1.05
Beryllium	120	1.08		Uranium	60	1.18
Carbon	60	0.21		<i>K</i> mass	40	5.98
2%Carbon	20	0.39		<i>K</i> mass	60	8.35
2%Carbon	60	0.26		<i>Total</i>		31.38

calorimeters view



EMCAL and HCAL schematics

Main calorimeter goals:

- photon and neutron production studies
- studies for proton radiography
- inclusive π^0 production

Calorimeters specifications

EMCAL (built for MIPP):

- 10 layers of Pb and PWC's
- $1.6(x) \times 1.5(y) \times 0.3(z) \text{ m}^3$
- 10 radiation lengths
- P10+CF4 gas mix in PWC's
- 640 ADC channels

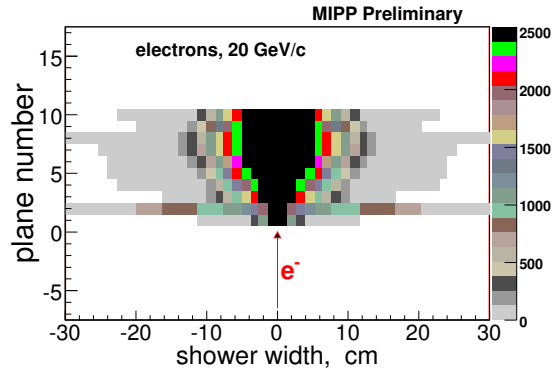
HCAL (reused from E871 HyperCP):

- 64 layers of Fe and PS scintillator
- $1.0(x) \times 1.0(y) \times 2.4(z) \text{ m}^3$
- 9.6 interaction lengths
- 8 ADC channels

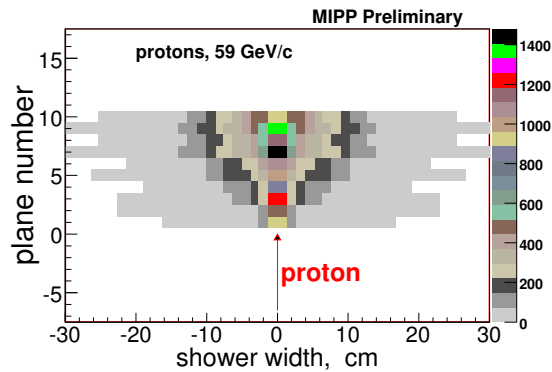


EMCAL and HCAL looking upstream

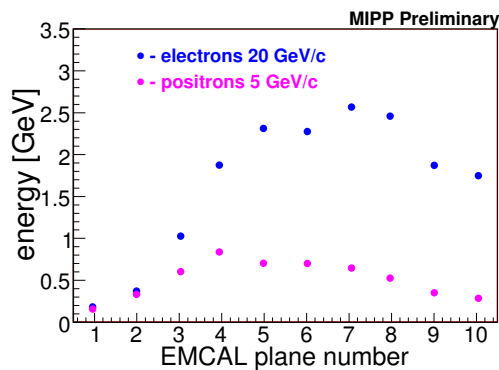
cascade slices



Top graph: transverse slice of the electromagnetic cascade from 20 GeV/c electrons on lead

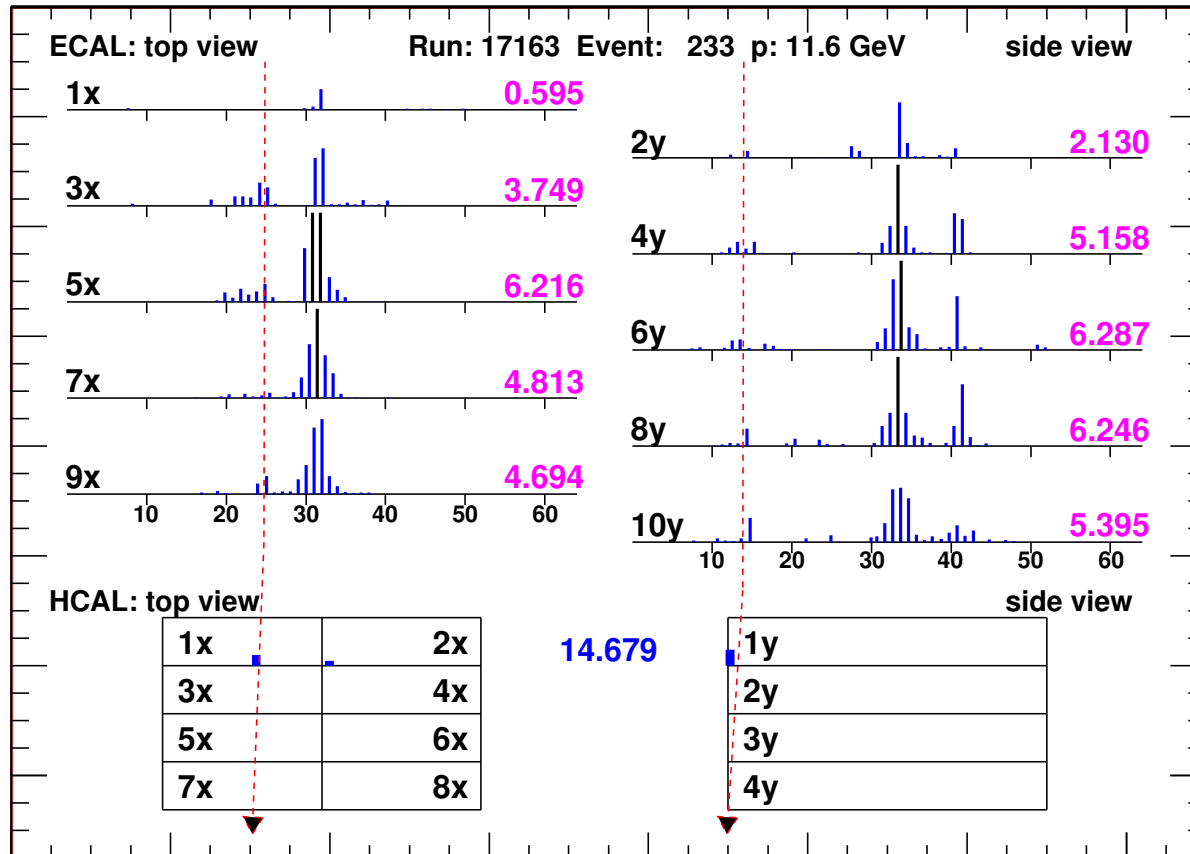


Middle graph: transverse slice of energy deposition of 59 GeV/c protons on lead



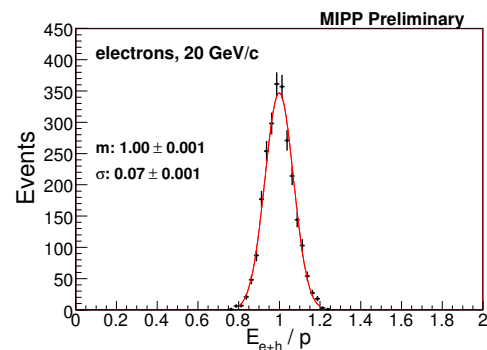
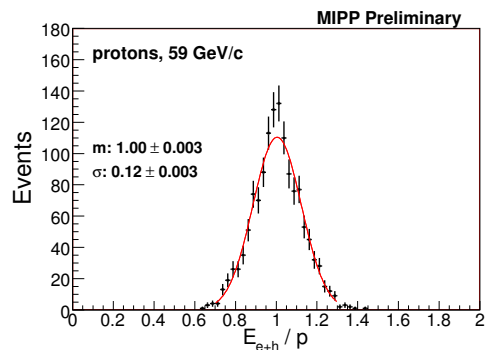
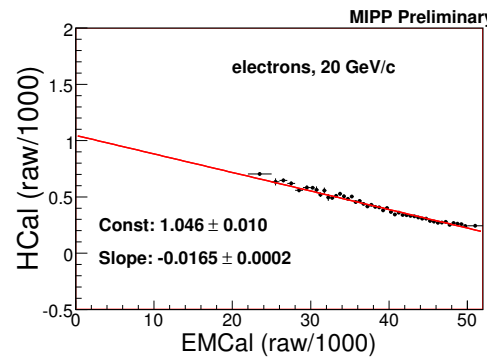
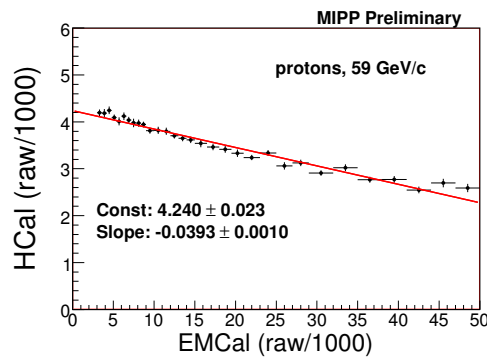
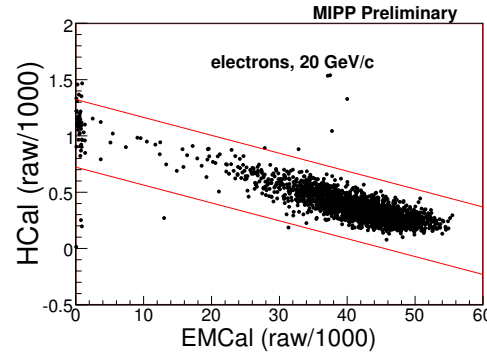
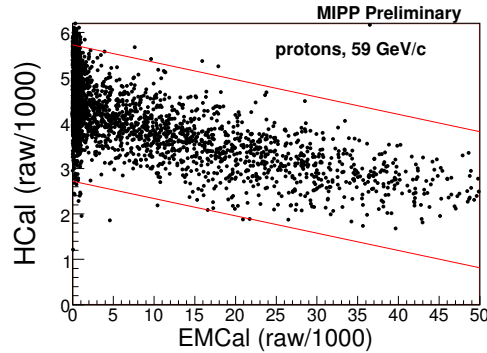
Bottom graph: longitudinal energy deposition profiles of 20 GeV/c electrons and 5 GeV/c positrons on lead

calorimeters display



EMCal and HCal event display. HCal is not in scale in Z direction. Graph shows the charged track with two gammas (π^0 candidate?) produced with 59 GeV/c pion on Uranium target.

energy calibration : method 1



Energy calibration. Method 1:

$$E_o = C_E \times \Sigma EMCAL + C_H \times \Sigma HCAL$$

Top graphs: HCal vs EMCAL dependences for protons (on left) and electrons (on right).

Middle graphs: Least square fit of above data.

Bottom graphs: Ratios of the energy deposited in the calorimeters to the particle's momentum.

calibration method 1, results

MIPP Preliminary

	p (GeV/c)	C_{EMCAL} (MeV)	C_{HCAL} (MeV)
π^+	59	0.52 ± 0.01	13.2 ± 0.1
p	59	0.57 ± 0.01	13.9 ± 0.1
K^+	59	0.57 ± 0.02	13.2 ± 0.1

	p (GeV/c)	C_{EMCAL} (MeV)	C_{HCAL} (MeV)
e^+	≈ 5	0.43 ± 0.02	12.8 ± 0.3
e^+	≈ 10	0.41 ± 0.02	12.8 ± 0.2
e^-	20	0.31 ± 0.02	13.3 ± 0.2

EMCAL and HCAL energy scale factors for hadrons (on top) and for e^-/e^+ (on bottom).

method 1 results, cont.

MIPP Preliminary

	p (GeV/c)	$e/\pi(EMCAL)$	$e/\pi(HCAL)$
e^+	≈ 5	0.83 ± 0.05	0.97 ± 0.02
e^+	≈ 10	0.79 ± 0.05	0.97 ± 0.02
e^-	20	0.60 ± 0.07	1.01 ± 0.02

Comparison of e and π results: e/π ratios.

MIPP Preliminary

	p (GeV/c)	$\sigma/p, \%$
e^-	20	7 ± 0.1
π^+	59	11 ± 0.3
p	59	12 ± 0.3
p	70	9 (HyperCP)

Measured energy resolution of calorimeters

With thin active layer in EMCAL, gas PWC, the e/π ratio appears to be less than 1 (see top table). But the energy resolution appears to be quite good (see bottom table). This suggests that one can use a lead calorimeter (for photons) with the right ratio of active to passive layer thickness and get good energy resolution.

Our findings: sampling calorimeter is good for hadrons and also for photons!

energy calibration : method 2

Calibration method 2

Energy deposited in Layer E_j is given by

$$E_j = \sum_{k=1}^{k=N} \lambda_{jk} L_k$$

where L_k is the live energy observed in layer.

Total energy in calorimeter is given by

$$E_{tot} = \sum_{j=1}^{j=N} \sum_{k=1}^{k=N} \lambda_{jk} L_k = \sum_{k=1}^{k=N} \omega_k L_k$$

where the weights $\omega_k = \sum_{j=1}^{j=N} \lambda_{jk}$

Minimizing the sum of squares

$$S^2 \equiv \sum_{l=1}^{l=M} (E_{tot}^l - \sum_k \omega_k L_k^l)^2$$

over M events with respect to ω_k leads to

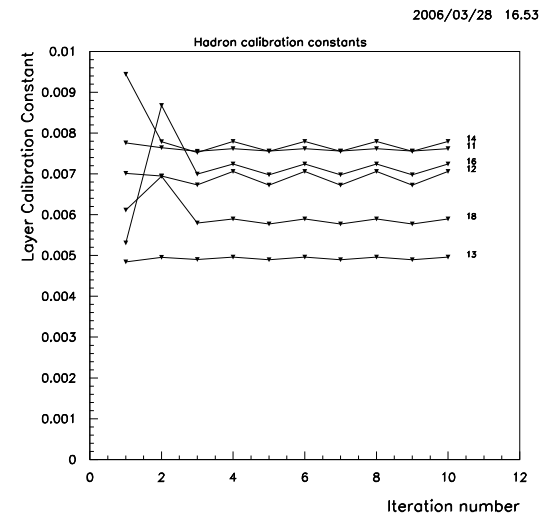
$$\sum_{k=1}^{k=N} \langle L_j L_k \rangle \omega_k = \langle E_{tot} L_j \rangle$$

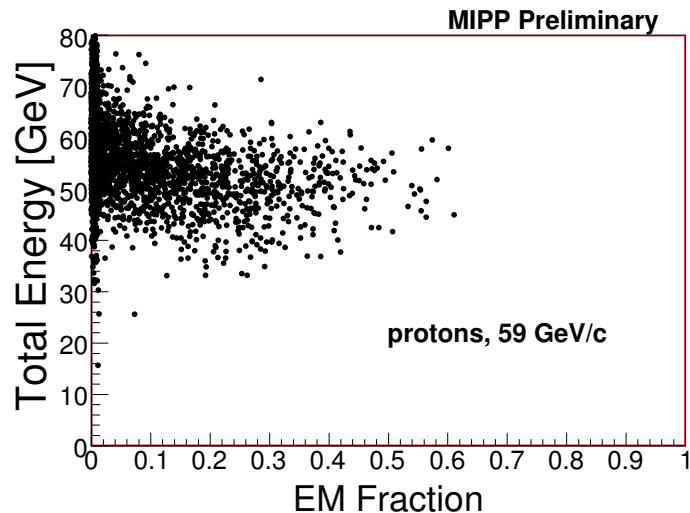
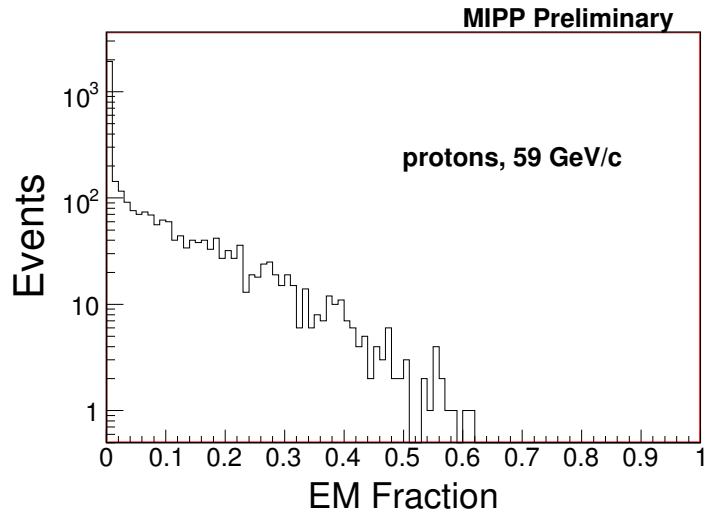
where $\langle \rangle$ implies average over events.

This lead to the matrix inversion solution $\omega_k = \sum_{j=1}^{j=N} M_{jk} d_j$ where M is the inverse of the matrix $\langle L_j L_k \rangle$ and d_j is the vector $\langle E_{tot} L_j \rangle$

The process needs to be iterated to obtain stable weights.

The results converge after several iterations shown in the graph below (preliminary).



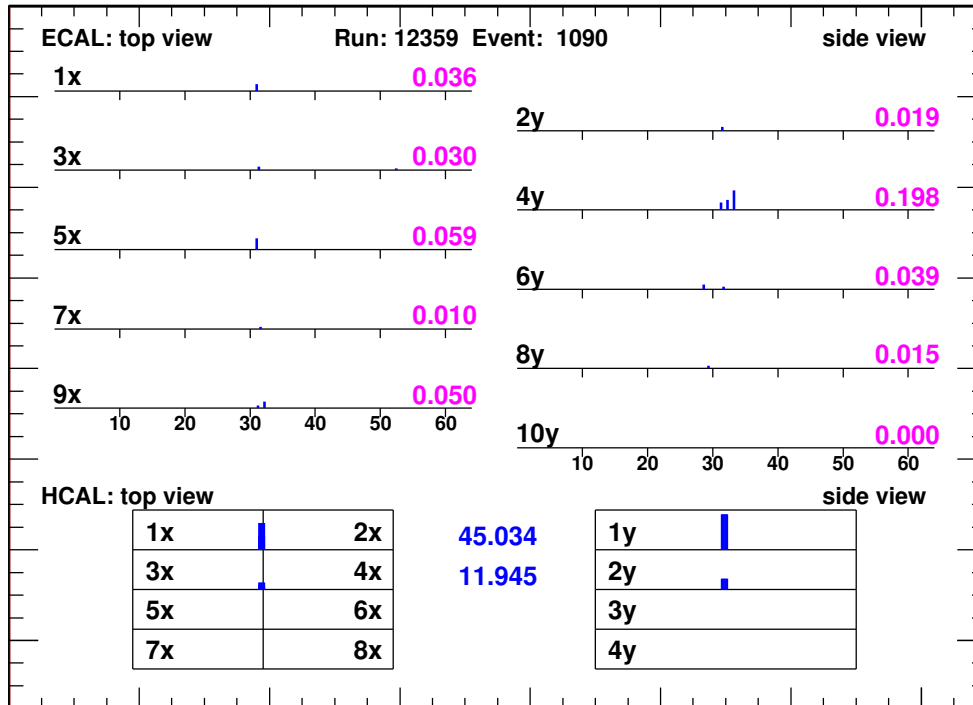


MIPP is investigating the use of hadrons for EMCAL calibration. EMCAL and HCAL calibration are fit simultaneously. Hadrons will leave some fraction of their energy in EMCAL for example via producing π^0 which decays into two gammas.

Top graph on left shows the fraction of energy deposited into EMCAL. Bottom - EM fraction vs total energy. Most of the time the protons make small contribution. In some events it contribute high fraction of energy - up to 60%. This fraction might be higher for π^- particles due to possible $\pi^- + p \rightarrow \pi^0 + n$ process.

The EMCAL weights as a function of fraction f_{EM} can be extrapolated to $f_{EM}=1$ to yield the EMCAL calibration.

neutrons

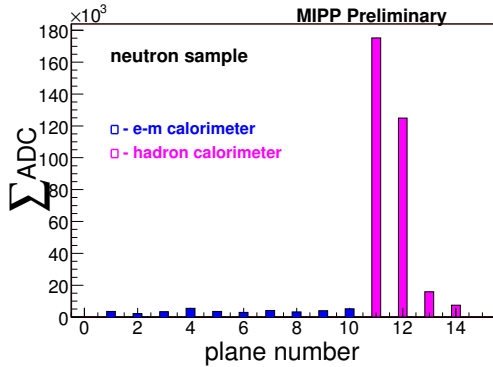


Search for Neutrons from the elastic proton to neutron charge exchange reaction ($E_n \approx P_o$).

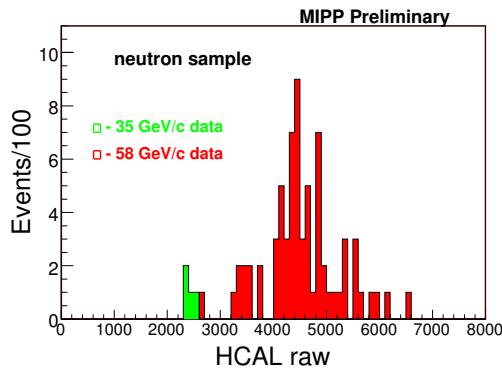
- beam - 35 and 59 GeV/c protons
- target - LH2, Carbon, and Beryllium
- veto on events with forward-going charged tracks based on the downstream wire chambers
- veto on events with TPC tracks matched to the incident beam tracks

Proton \rightarrow neutron elastic charge exchange candidate event. Incident beam momentum: 59 GeV/c on Carbon target. Deposited energy into EMCAL - 0.5 GeV, into HCAL - 57.0 GeV.

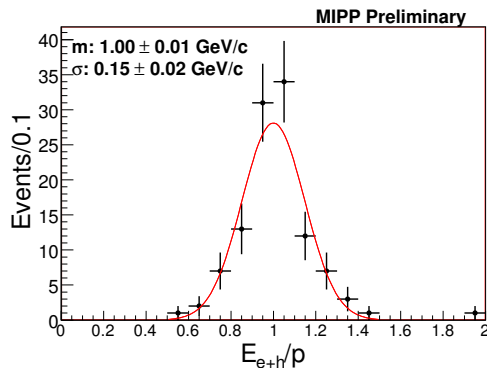
neutrons, cont.



Top graph: EMCAL and HCAL plane ADC sums for the neutron sample.



Middle graph: HCAL ADC sum for the neutron sample. Green colored events - 35 GeV/c and red - 59 GeV/c data.



The ratio of calorimeters energy to proton beam momentum for the neutron sample.

summary, plans

- MIPP collected 31M events with different incident particles and targets.
- EMCAL and HCAL were energy calibrated with $e^- (e^+)$ and hadrons.
- More calibration studies are in progress.
- Will test EMCAL performance by reconstructing $\pi^0 \rightarrow \gamma\gamma$ and HCAL with neutron data.