Study of the reaction $\pi^-\mathrm{Be} \longrightarrow \eta\pi^-\pi^-\pi^+\mathrm{Be}$ in the VES experiment

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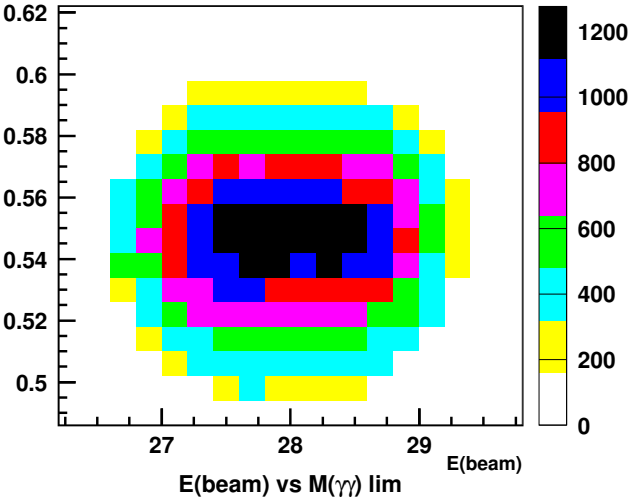
parallel talk at HADRON2011

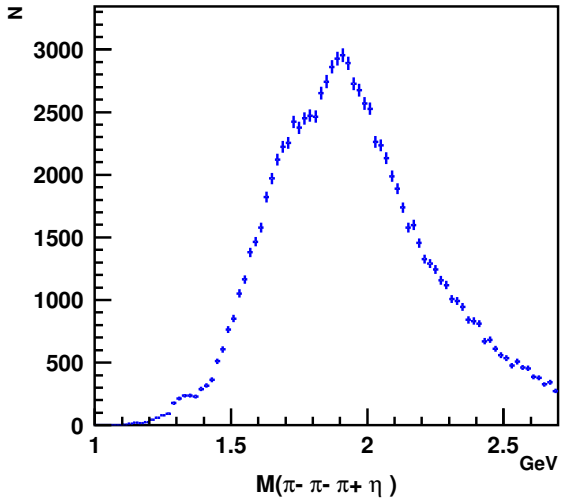
Motivation

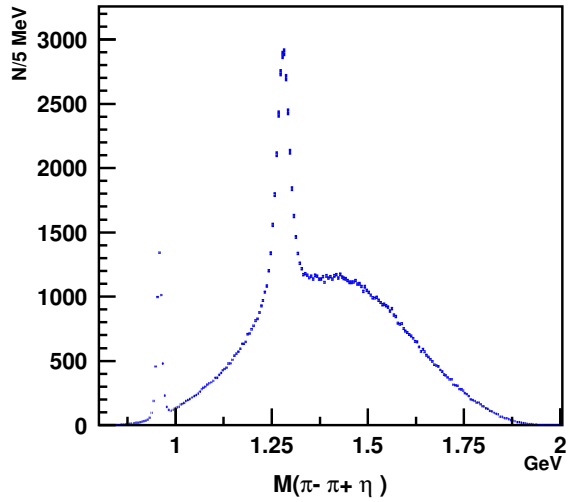
At VES beam energies ($p_{beam} = 28...36$ GeV) production of negative G-parity final states is dominated by diffraction.
The reaction $\pi^- \mathrm{Be} \to \eta\pi^-\pi^-\pi^+\mathrm{Be}$, $\eta \to 2\gamma$ is especially interesting:

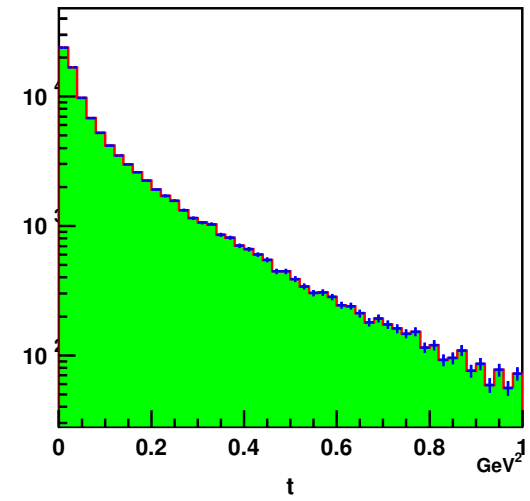
- try to study high-mass final states having $J^{PC} = 0^{-+}, 1^{++}, 2^{-+}, ...$
- try to understand nature of exotic 1^{-+} partial waves in $f_1(1285)\pi^-$ and $\eta'\pi^-$
- do we observe $\eta(1295)\pi^-$ channel ?
- known resonances: $\pi(1800)$, $\pi_2(1670)$, $a_2(1700) \to \eta 3\pi$?

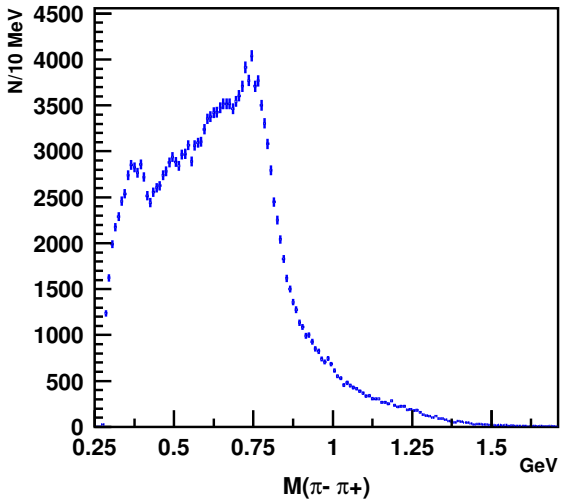
invariant mass and momentum-transfer spectrums

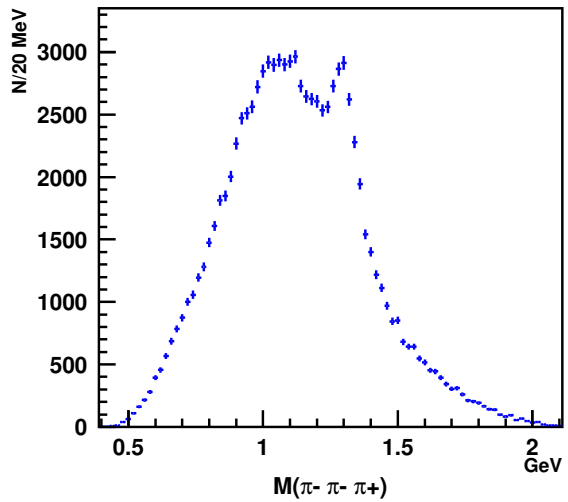






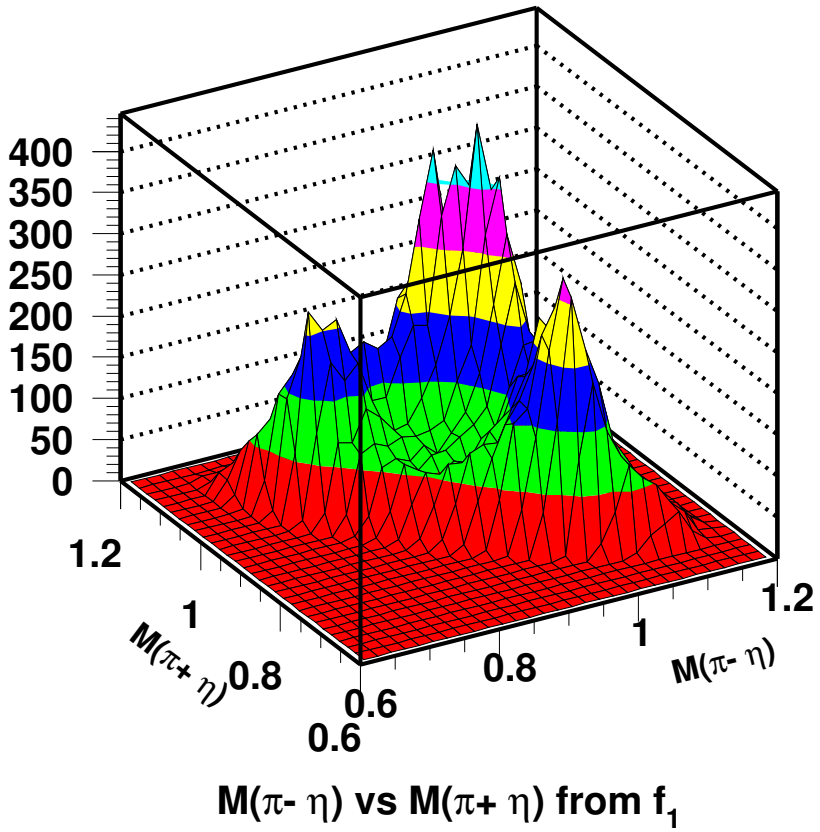






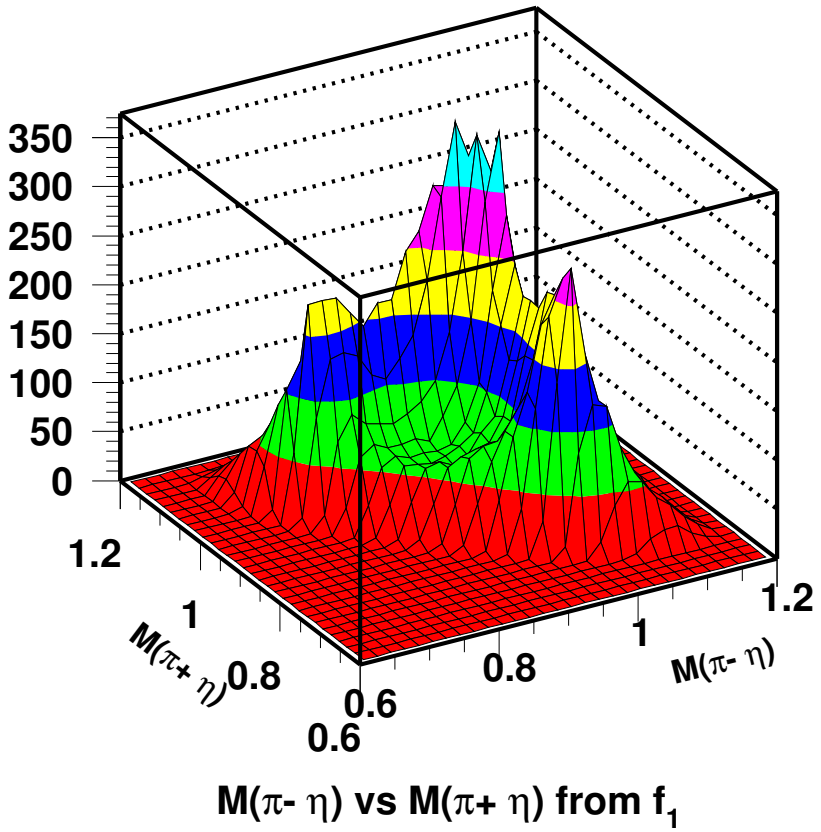
"incoherent diffraction" region: $0.06 < t' < 1.0$ GeV^2

$f_1(1285)$ decay bi-plot



M(π- η) vs M(π+ η) from f_1

DATA

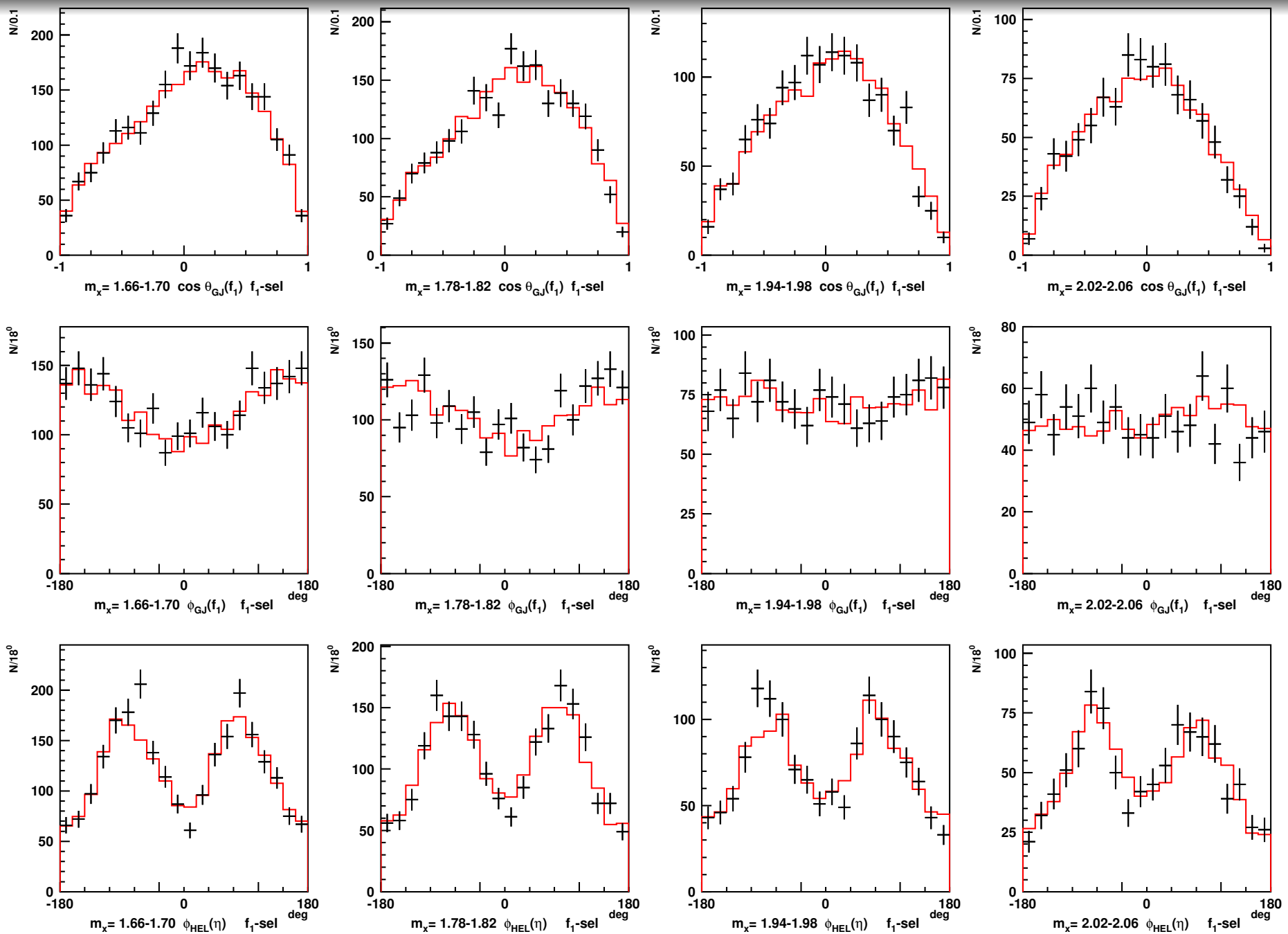


M(π- η) vs M(π+ η) from f_1

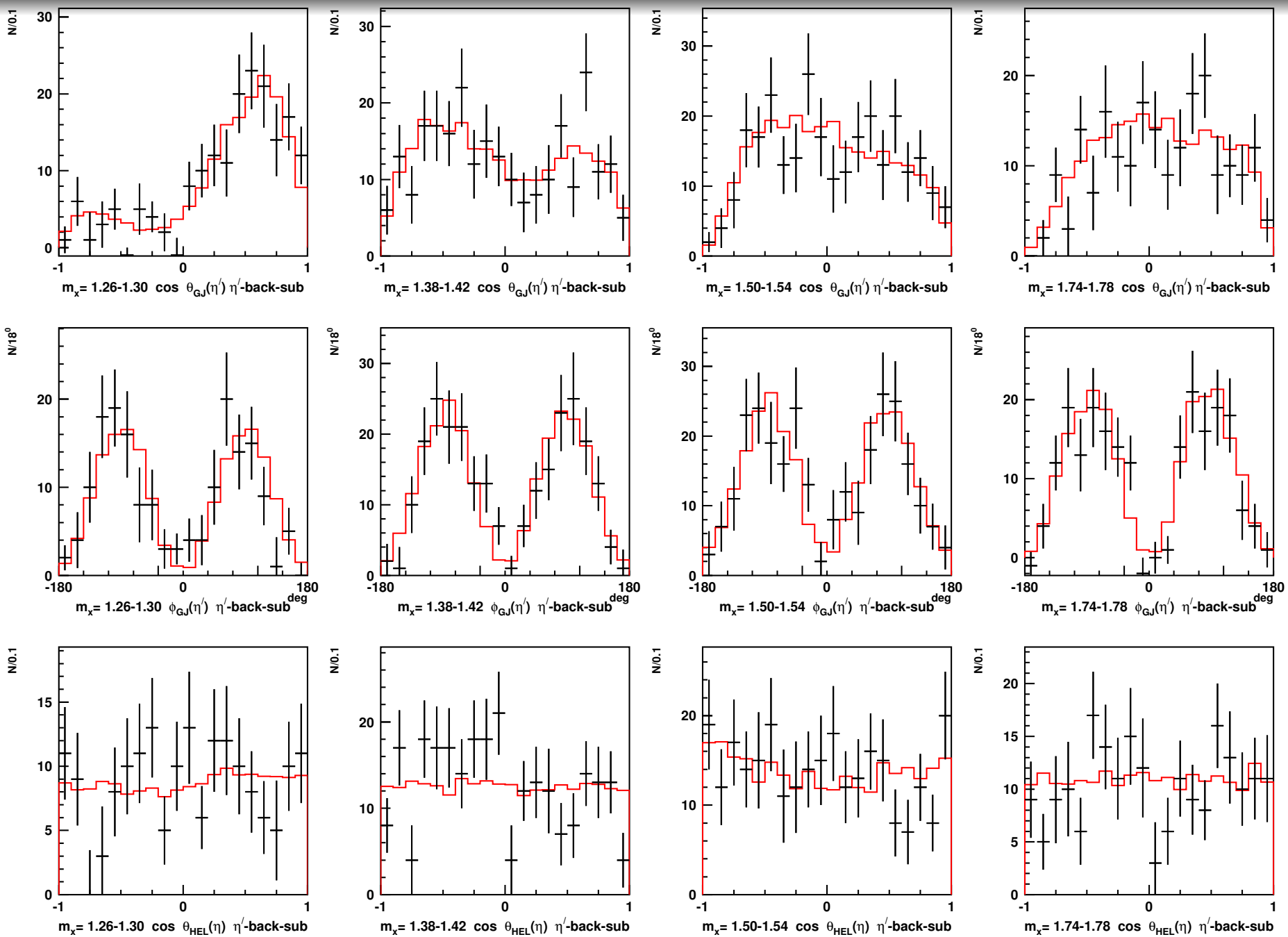
Monte-Carlo from PWA

Decay model $f_1(1285) \to a_0(980)\pi + (\pi\pi)_S\eta$ was adjusted

examples of ang. dep. in $f_1\pi^-$



examples of ang. dep. in $\eta' \pi^-$



PWA

Peripheral reaction: $\pi A \to M_1 ... M_N A'$ where π is a pion beam, $M_1 ... M_N$ is N-meson system and $A(A')$ are nuclear or nucleon target (recoil)

Reflectivity basis:

$$\psi^{\epsilon}_{JM}(\tau) = c(M)\left[\psi_{JM}(\tau) - \epsilon P(-1)^{J-M}\ \psi_{J-M}(\tau)\right], \epsilon = \pm 1, M \geq 0$$

PWA differential cross-section (for fit in mass or tprime bins):

$$\sigma_{\text{indep}}(\tau) = \sum_{\epsilon=-1}^{1}\sum_{r=1}^{N_r}\left|\sum_i T^{\epsilon}_{ir}\psi^{\epsilon}_i(\tau)\Big/\sqrt{\int|\psi^{\epsilon}_i(\tau')|^2 d\tau'}\right|^2 = \sum_{\epsilon}\sum_{i,j}\ \rho^{\epsilon}_{ij}\ \bar{\psi}^{\epsilon}_i(\tau)\ \bar{\psi}^{\epsilon}_j(\tau)^*$$

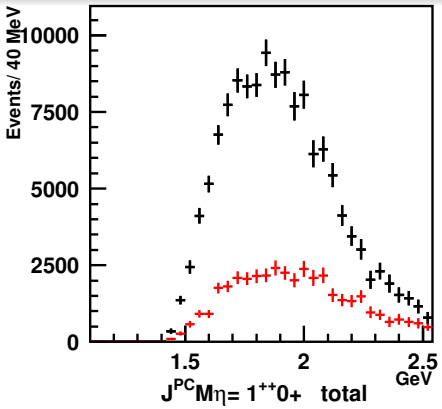
Mass-dependent χ^2-fit:

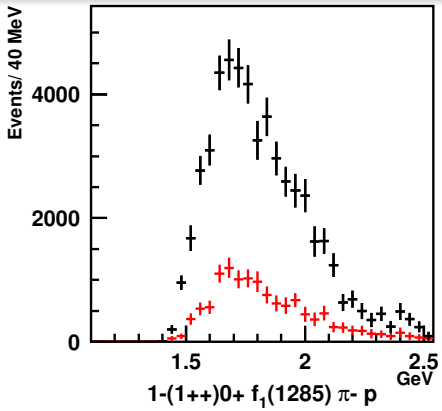
$$\rho^{\epsilon}_{ij} = \sum_{r=1}^{N_r}\left(\sum_k C^{\epsilon}_{ikr}\text{BW}_k(m)\sqrt{\int|\psi^{\epsilon}_i(\tau)|^2 d\tau}\right)\left(\sum_l C^{\epsilon}_{jlr}\text{BW}_l(m)\sqrt{\int|\psi^{\epsilon}_j(\tau)|^2 d\tau}\right)^*$$

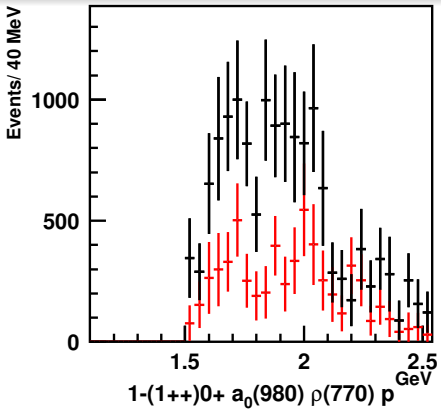
PWA specifics for $\eta\pi^-\pi^-\pi^+$ final state

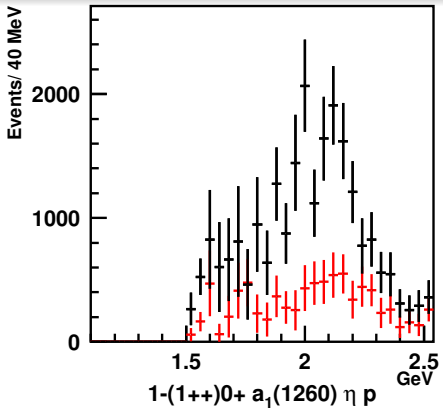
- analysis is done in full 4-body phase-space (no f_1 or η'-cuts applied).
- possible to work applying relatively wide η'-cut for $\eta'\pi^-$ results only (still combi. background and non-η' background are respected/separated).
- functional description of narrow structures includes experimental resolution (η' lineshape-sum of 2 gaussians, $f_1(1285)$-Breit-Wigner folded with resolution). This leads:
  - $\eta'\pi^-$ are added incoherently to all other $\eta 3\pi$,
    2 combinations of η'-cross-section incoherent to each-other
  - $f_1(1285)$ peak broadened, integration over wide value of t' $\Rightarrow$ rank=4 density matrix is used
- non-relativistic Zemach tensor formalism (angular part of decay amplitudes)
- various channels (seen in mass spectrums or assumed):
  $a_0(980)\rho$, $a_2(1320)\eta$, $a_1(1260)\eta$, $\rho(1450)(\to \rho\eta)\pi^-$, $a_2(1320)\rho$, ...

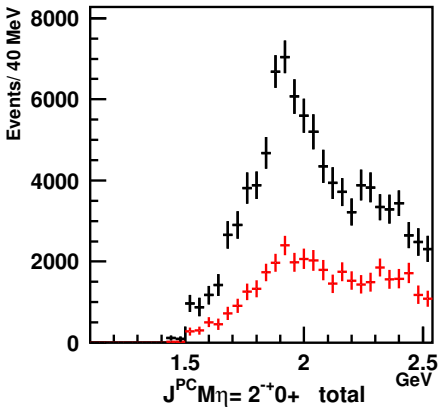
Major $J^{PC}M\epsilon$ intensities. RED: $t' > 0.06$ GeV^2

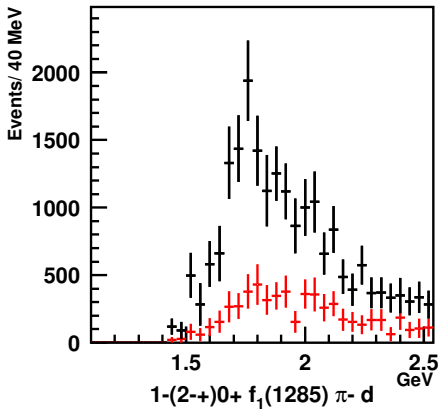


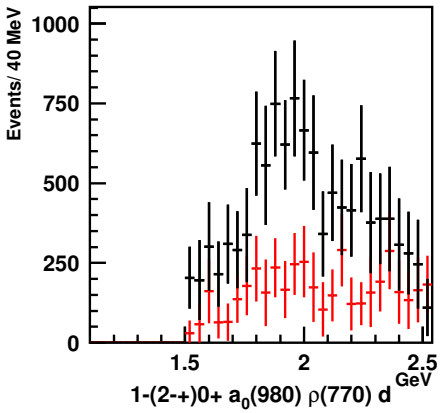


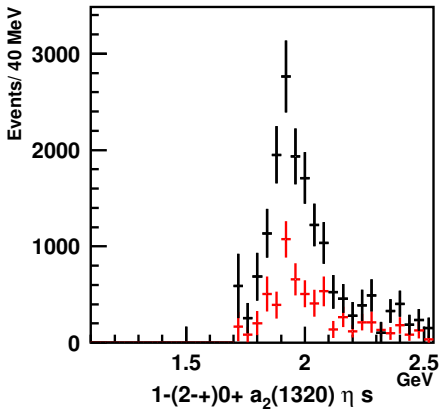


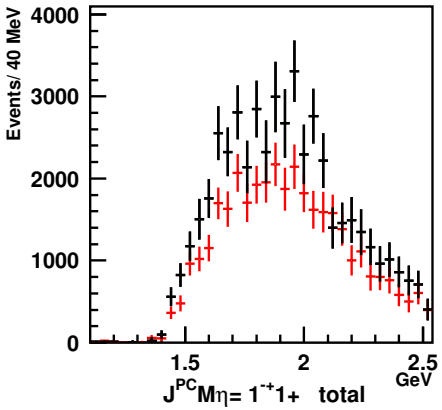


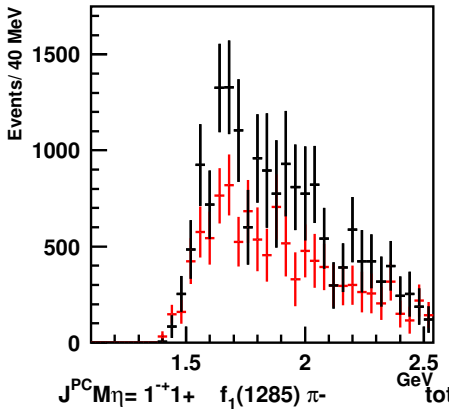


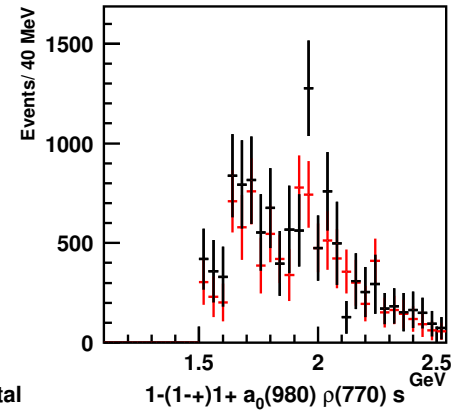


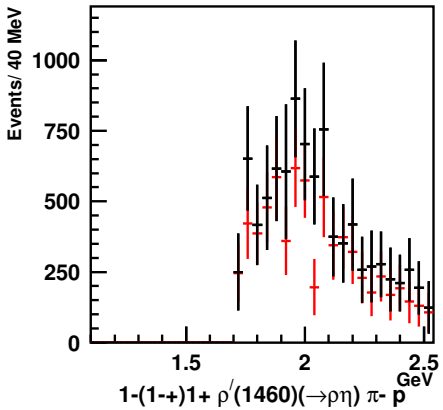




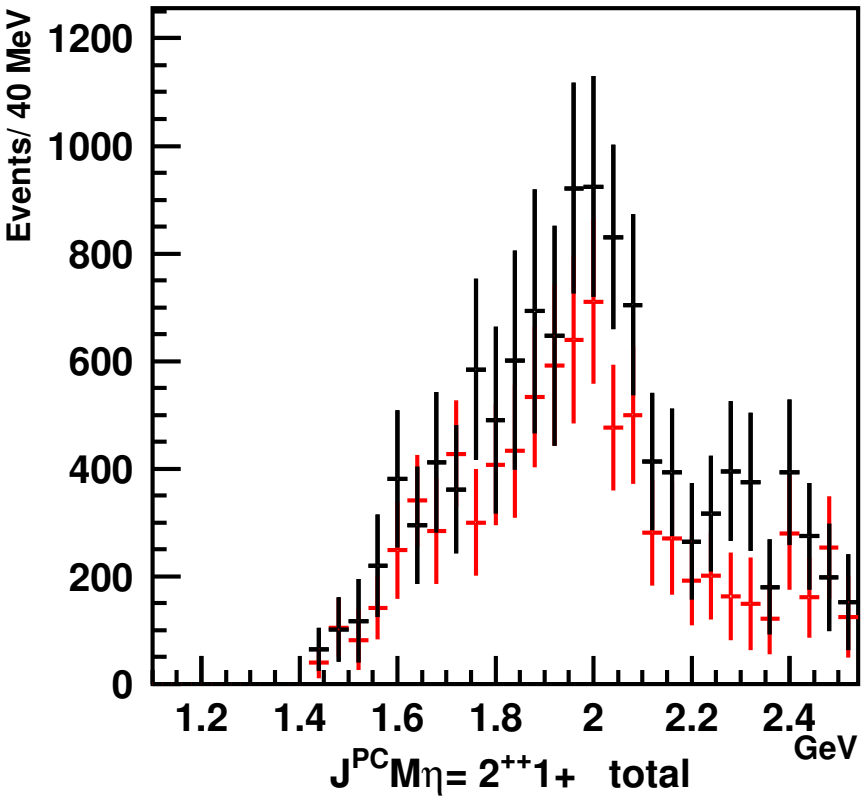


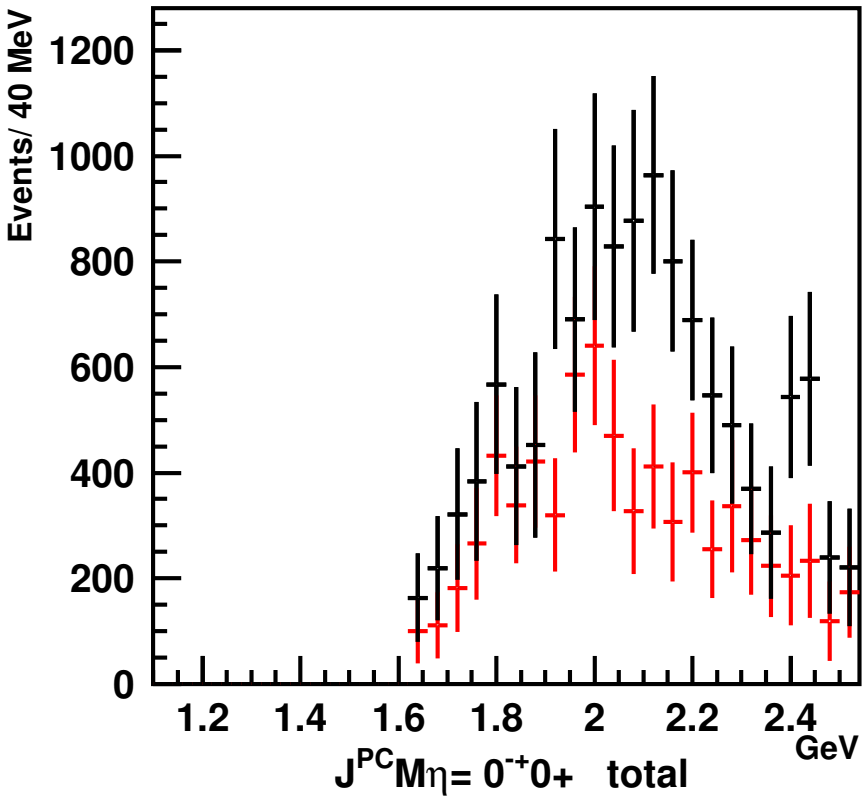






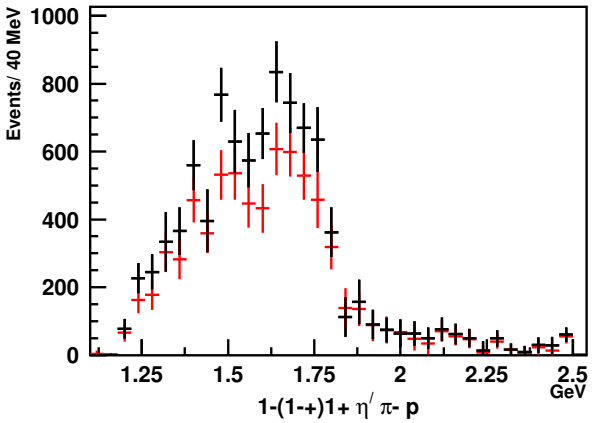
$2^{++}1^{+}$(non-$\eta'\pi$) and 0^{-+} intensities

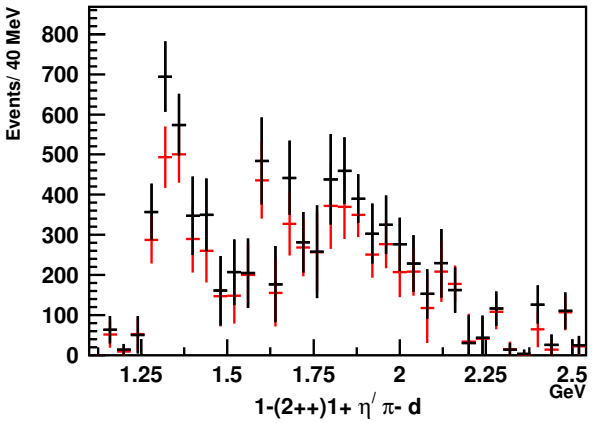


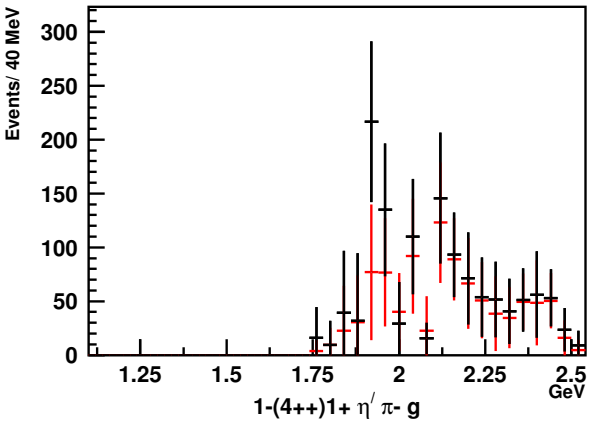


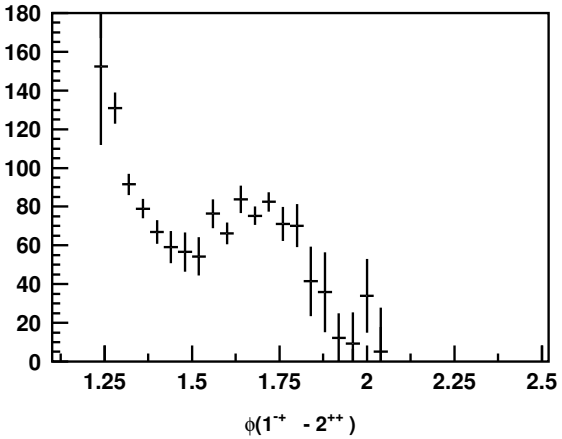
Both intensities rather small, some bump round 2 GeV. No clear phase motions.
No signal from $\pi(1800)$

$\eta'\pi^-$ results

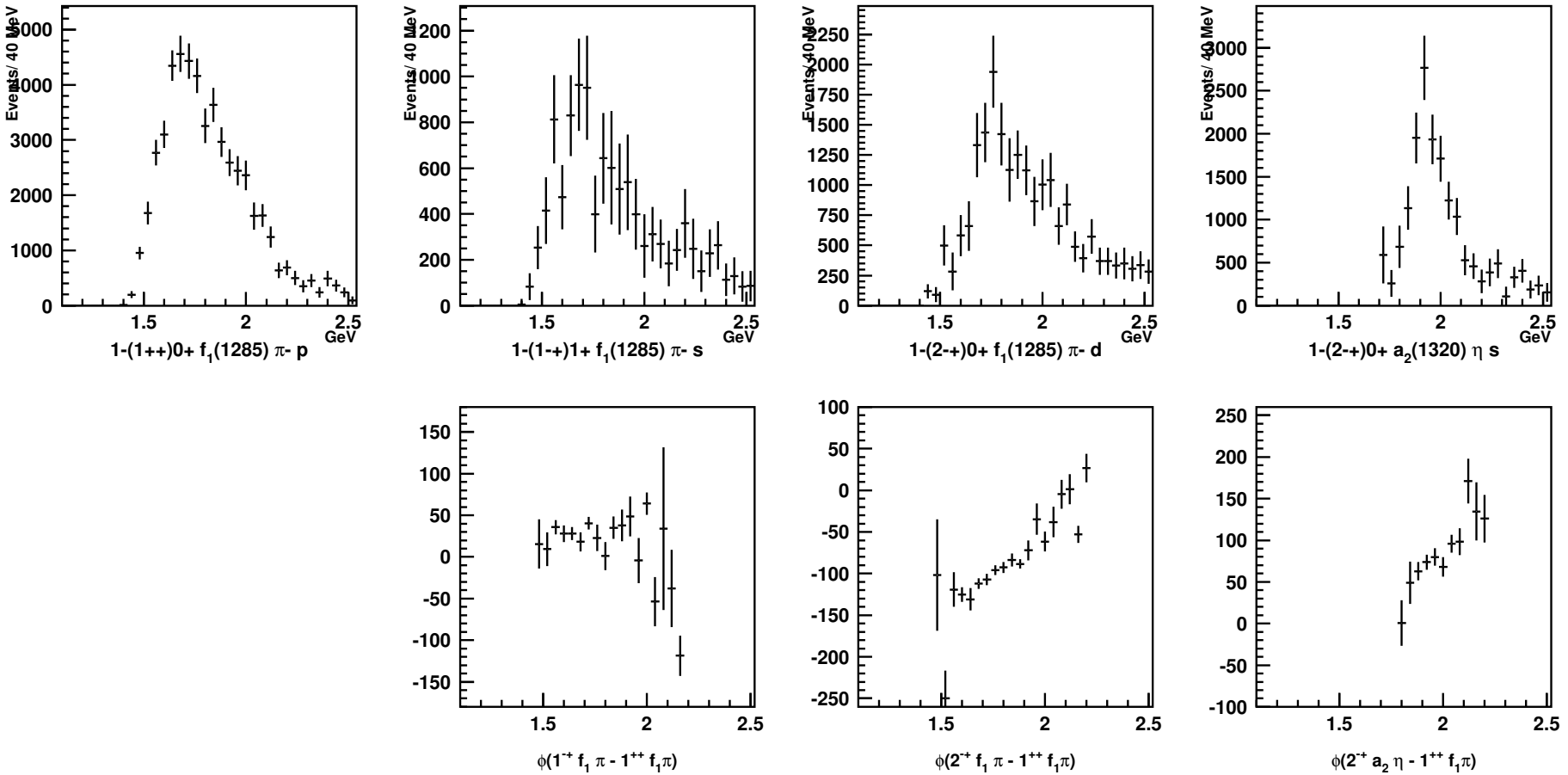






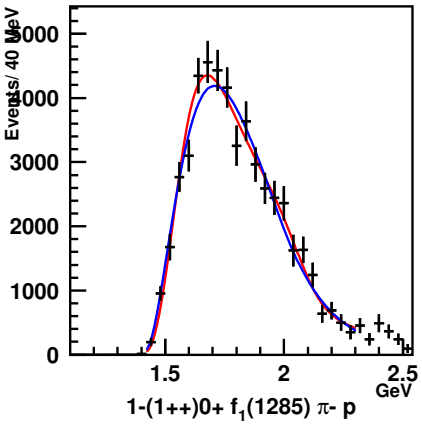


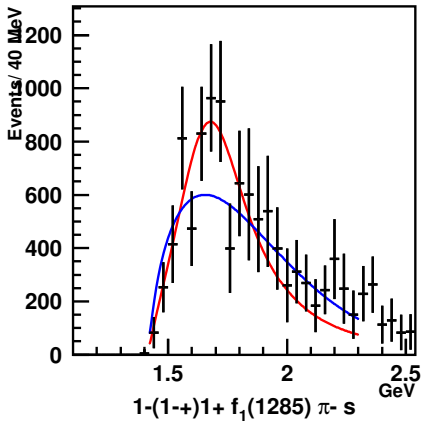
PWA in mass bins

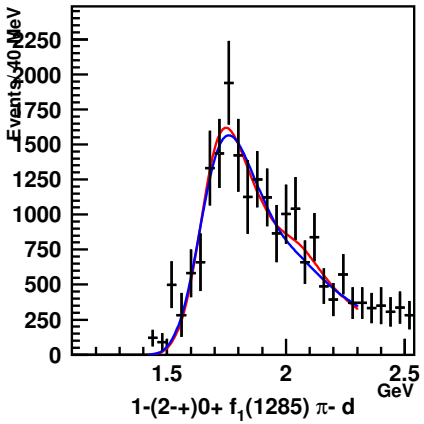


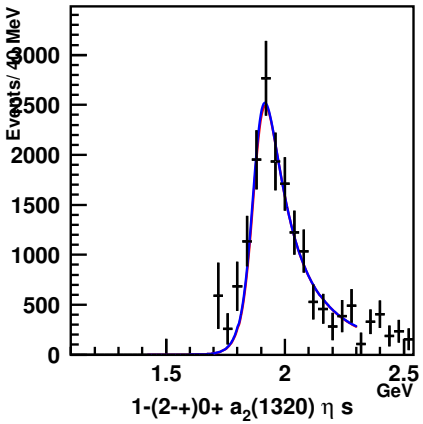
$$\sigma_{\text{indep}}(\tau) = \sum_{\epsilon=-1}^{1} \sum_{r=1}^{N_r} \left| \sum_i T^{\epsilon}_{ir} \psi^{\epsilon}_i(\tau) \Big/ \sqrt{\int |\psi^{\epsilon}_i(\tau')|^2 \mathrm{d}\tau'} \right|^2 = \sum_{\epsilon} \sum_{i,j} \rho^{\epsilon}_{ij} \; \bar{\psi}^{\epsilon}_i(\tau) \; \bar{\psi}^{\epsilon}_j(\tau)^*$$

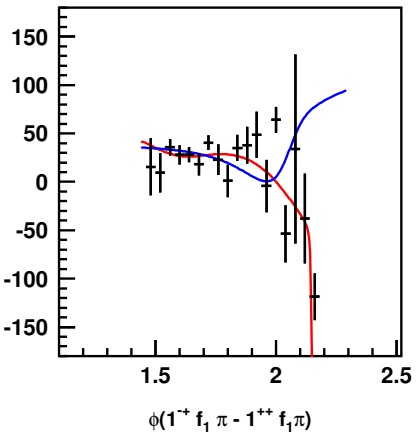
Mass-dependent fit

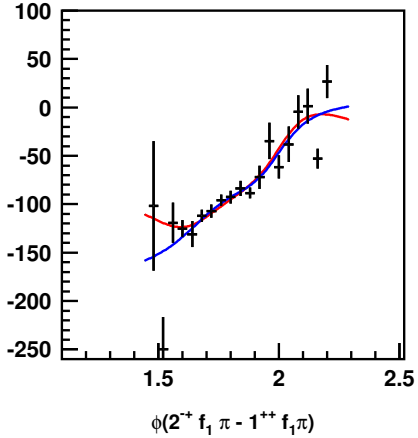


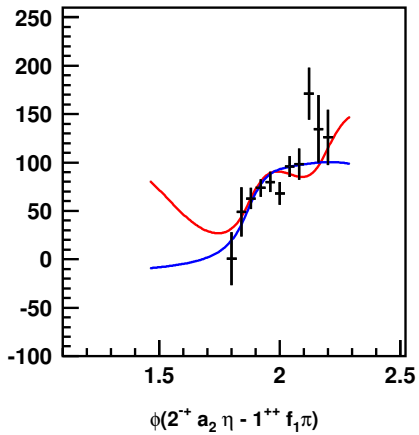












$$\rho^{\epsilon}_{ij} = \sum_{r=1}^{N_r} \left(\sum_k C^{\epsilon}_{ikr} \mathrm{BW}_k(m) \sqrt{\int |\psi^{\epsilon}_i(\tau)|^2 \mathrm{d}\tau} \right) \left(\sum_l C^{\epsilon}_{jlr} \mathrm{BW}_l(m) \sqrt{\int |\psi^{\epsilon}_j(\tau)|^2 \mathrm{d}\tau} \right)^*$$

Mass-dependent fit results

"Resonant model"

1^{-+}

M_1=1.640 ± 0.020, Γ_1=0.400± 0.050

1^{++}

M_1=1.530 ± 0.020, Γ_1=0.410± 0.040

M_2=2.050 ± 0.030, Γ_2=0.340± 0.080

2^{-+}

M_1=1.670 ± 0.024, Γ_1=0.330± 0.050

M_2=1.873 ± 0.011, Γ_2=0.167± 0.015

$a_2(1320)\eta S$

M_2=2.040 ± 0.026, Γ_2=0.290± 0.070

$f_1(1285)\pi^- D$

χ^2/NDF=300./(303-39)=1.14

"Non-Resonant model"

$A_{bg} = exp(-\alpha q^2)$

1^{-+}

$\alpha_{1^{-+}}$=-1.8±0.2

1^{++}

$\alpha_{1^{++}}$=-3.5±0.3

M_2=1.900 ± 0.100, Γ_2=0.350± 0.100

2^{-+}

M_1=1.660 ± 0.050, Γ_1=0.400± 0.110

M_2=1.872 ± 0.011, Γ_2=0.162± 0.015

$a_2(1320)\eta S$

M_2=2.000 ± 0.030, Γ_2=0.290± 0.080

$f_1(1285)\pi^- D$

χ^2/NDF=338./(303-37)=1.28

Conclusions

- PWA in mass bins of $\eta 3\pi$-system demonstrates:
  - dominance of various NPE states
  - significant $f_1(1285)\pi^-$ and many other isobaric decay chains: $a_0(980)\rho$, $a_2(1320)\eta$, $a_1(1260)\eta$, $\rho(1450)(\to \rho\eta)\pi^-$, $a_2(1320)\rho$, ...
  - no $\eta(1295)\pi^-$
  - $\eta^{'}\pi^-$ has $a_2(1320)$ + exotic wave, rather broad structure and no clear structures in high mass 2^{++}
  - very small 0^{-+}, no $\pi(1800) \to \eta 3\pi$
- Further mass-dependent analysis:
  - Can accomodate broad resonances in 1^{++} and 1^{-+} in 1.5-1.6 GeV region
  - $\pi_2(1670) \to f_1(1285)\pi^-$?? (not VERY clear yet)
  - $\pi_2(1880) \to a_2(1320)\eta$ values obtained: M_2=1.873 $\pm$ 0.011, Γ_2=0.167$\pm$ 0.015 Needed: systematic study + Branchings
  - Non-resonant model - a bit worse description. More natural to explain phase-lock between two very broad amplitudes.

Outlook

- PWA in mass bins seems to be exhausted, however
  - using "partial de-coherence method" (recently developed) $\longrightarrow$ better measure interference terms/relative phases
  - recent $f_0(600)$-parametrizations $\longrightarrow$ clarify $(\pi\pi)_S\eta$ decay mode of $f_1(1285)$
- Mass-dependent fit:
  - to combine with other reactions (but using $\pi^-\pi^-\pi^+$ was NOT a success)
  - more sofisticated Breit-Wigner terms, way of adding resonances
  - more sofisticated background parametrization

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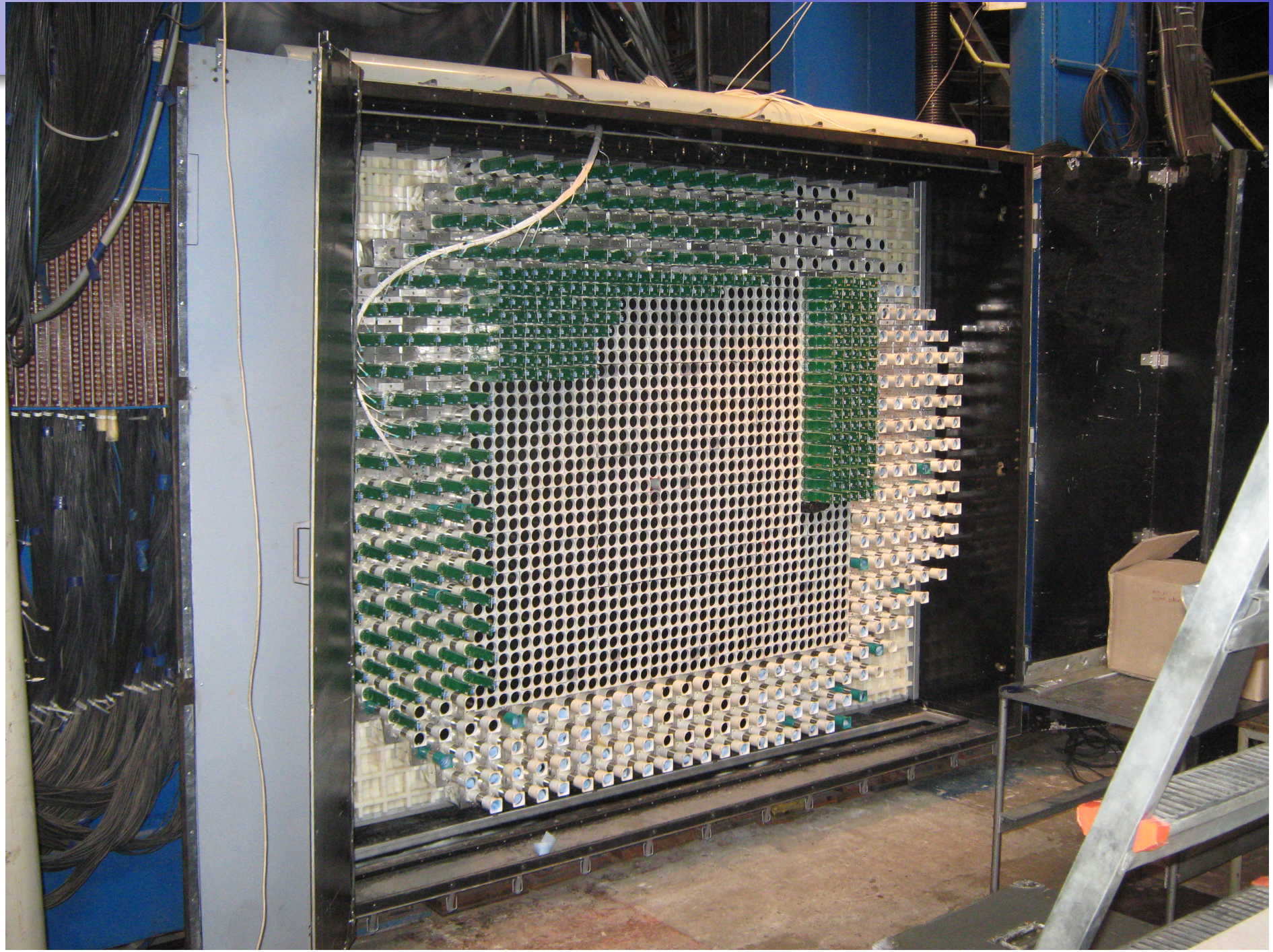
Outlook (the apparatus)

- 2009-2010-modernization of electromagnetic calorimeter.
- Replaced:
  - cells (Sci-Pb “shashlyk” against lead glass)
  - HV bases (Cocroft-Walton generators against resistive dividers)
  - PMT (partly, now unified to single type FEU-84)
  - ADC (more compact and faster)
  - 2011 2012 Large chambers of Drift Tubes to be installed to replace very old DCs.
- Nov. 2010, apr. 2011 commissioning with beam (electron beam calibration and pion beam exposure)



2 gamma spectrum