Status report on parity violation in the $\Delta(1232)$ resonance

Luigi Capozza

A4 Collaboration
Institut für Kernphysik
Johannes Gutenberg Universität Mainz

Institutsseminar - 6.2.2006

Outline

Theory

Measurement principle

Physical processes

Detector response

Some results

Outline

Theory

Measurement principle

Physical processes

Detector response

Some results

Theory

Parity violation asymmetry in $ep \to eN\pi$:

$$A_{RL} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \frac{G_F\, Q^2}{2\sqrt{2}\pi\alpha} \frac{W^{PV}}{W^{EM}}$$

At Tree level:

- W^{EM}: unpolarised electromagnetic
- W^{PV}: helicity dependent interference of EM and NC transition amplitudes

Flavor-SU(3) and isospin:

$$\begin{aligned} J_\mu^{EM} &= J_\mu^{EM}(T=1) + J_\mu^{EM}(T=0) \\ J_\mu^{NC} &= \xi_V^{T=1} J_\mu^{EM}(T=1) + \xi_V^{T=0} J_\mu^{EM}(T=0) + \xi_V^{(0)} V_\mu^{(s)} \\ J_{5\mu}^{NC} &= \xi_A^{T=1} A_\mu^{(3)} + \xi_A^{T=0} A_\mu^{(8)} + \xi_A^{(0)} A_\mu^{(s)} \end{aligned}$$

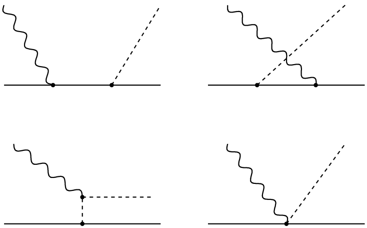
Theory

$N \to \Delta$ transition: only isovector

$$A_{RL} = A_{RL}^{\text{res}} + A_{RL}^{\text{non-res}}$$

Non resonant asymmetry $A_{RL}^{\text{non-res}}$: model dependent

- phenomenological effective interaction lagrangians:



Theory

$$J_\mu^{EM} = J_\mu^{EM}(T=1) + J_\mu^{EM}(T=0)$$

$$J_\mu^{NC} = \xi_V^{T=1} J_\mu^{EM}(T=1) + \xi_V^{T=0} J_\mu^{EM}(T=0) + \xi_V^{(0)} V_\mu^{(s)}$$

$$J_{5\mu}^{NC} = \xi_A^{T=1} A_\mu^{(3)} + \xi_A^{T=0} A_\mu^{(8)} + \xi_A^{(0)} A_\mu^{(s)}$$

Resonant asymmetry:

$$A_{RL}^{\text{res}} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha} \left[g_A^e \xi_V^{T=1} + g_V^e \xi_A^{T=1} F(Q^2, s) \right]$$

Theory

Resonant amplitudes:

$$\langle \Delta(p') | J^{EM}_\mu | N(p) \rangle = \bar{u}^\lambda(p') \left[\left(\frac{C_3^\gamma}{M}\gamma^\nu + \frac{C_4^\gamma}{M^2}p'^\nu + \frac{C_5^\gamma}{M^2}p^\nu \right) (g_{\lambda\mu}g_{\rho\nu} - g_{\lambda\rho}g_{\mu\nu})q^\rho \gamma_5 \right] u(p)$$

$$\left\langle \Delta(p') \left| J^{NC}_\mu + J^{NC}_{5\mu} \right| N(p) \right\rangle =$$

$$\bar{u}^\lambda(p') \left[\left(\frac{C^Z_{3V}}{M}\gamma^\nu + \frac{C^Z_{4V}}{M^2}p'^\nu + \frac{C^Z_{5V}}{M^2}p^\nu \right) (g_{\lambda\mu}g_{\rho\nu} - g_{\lambda\rho}g_{\mu\nu})q^\rho \gamma_5 + C^Z_{6V} g_{\lambda\mu}\gamma_5 \right.$$

$$\left. \left(\frac{C^Z_{3A}}{M}\gamma^\nu + \frac{C^Z_{4A}}{M^2}p'^\nu \right) (g_{\lambda\mu}g_{\rho\nu} - g_{\lambda\rho}g_{\mu\nu})q^\rho + C^Z_{5A} g_{\lambda\mu} + C^Z_{6A} p_\lambda q_\mu \right] u(p)$$

Considering:

- isospin symmetry
- conservation of vector current
- spin and parity of the $\Delta(1232)$ ($J^\pi = 3/2^+$)
- dominance of magnetic dipole amplitude

Theory

Resonant asymmetry:

$$A_{RL}^{\text{res}} = -\frac{G_F\, Q^2}{4\sqrt{2}\pi\alpha} \left[g_A^e \xi_V^{T=1} + g_V^e \xi_A^{T=1} F(Q^2, s) \right]$$

Axial response function of $p \longrightarrow \Delta$ transition:

$$F(Q^2, s) = \mathcal{P} \frac{C_5^A}{C_3^V} \left[1 + \frac{W^2 - Q^2 - M^2}{2M^2} \frac{C_4^A}{C_5^A} \right]$$

Outline

Theory

Measurement principle

- The A4 experiment
- Energy spectrum
- Problem: Handling the background

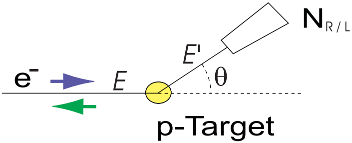
Physical processes

Detector response

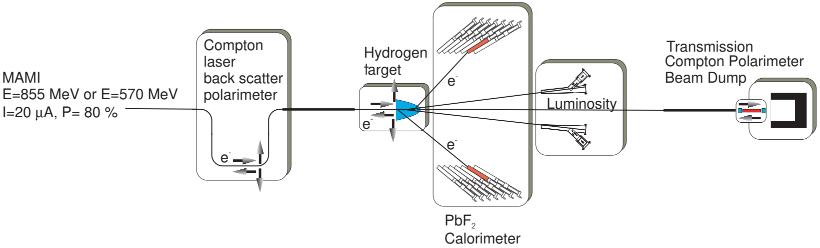
Some results

The A4 experiment

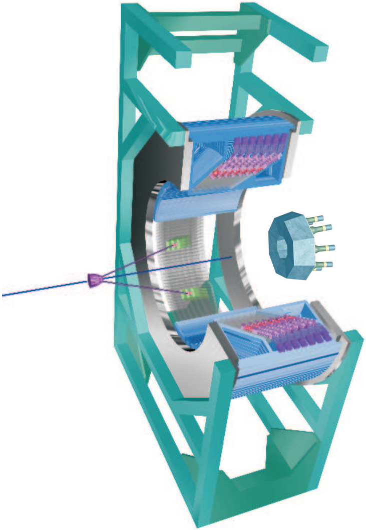
- longitudinally polarised electron beam
- unpolarised ℓ-H_2 target
- counting of scattered particles
- measurement of scattered particle energy



A4 experimental setup



A4 experimental setup



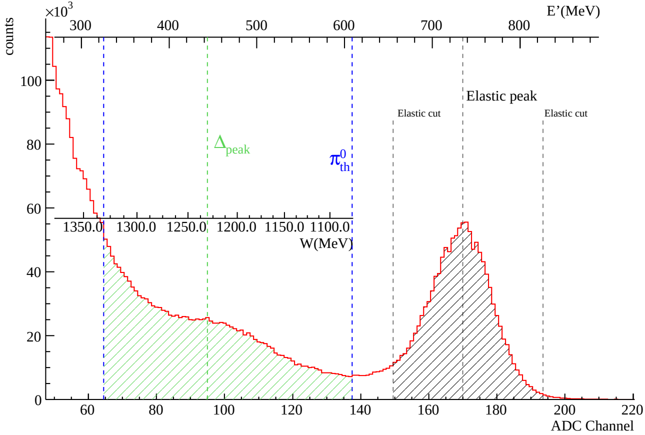
Lead fluoride Cherenkov calorimeter:

- 1022 crystals
- 7 rings
- 146 frames
- $\theta \in (30^\circ, 40^\circ)$, $\varphi \in (0, 2\pi)$

Readout electronics:

- sum of 9 neighbouring crystals

Energy spectrum



Extraction of the physical asymmetry

$$A_{exp} = \frac{\frac{N^+}{\rho^+} - \frac{N^-}{\rho^-}}{\frac{N^+}{\rho^+} + \frac{N^-}{\rho^-}} = P \cdot A_{phys} + A_{inst}$$

- extraction of counts $\surd$
- normalisation on target density $\surd$
- correction of helicity correlated instrumental effects $\surd$

Problem: Handling the background

First step:

- Identification of the contributing physical processes
- Estimation of their contribution to the spectrum

Second step:

- Estimation of their asymmetry
- Calculation of a dilution factor

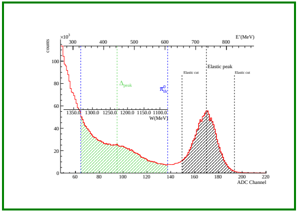
Knowledge of the background

physical processes inside the target

+

response of the apparatus

⇒



Monte Carlo simulations

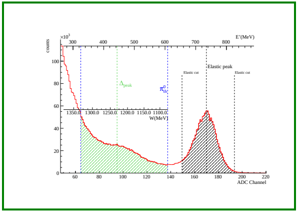
Knowledge of the background

physical processes inside the target

+

response of the apparatus

⇒



Monte Carlo simulations

Event generator

GEANT4 simulations

Outline

Theory

Measurement principle

Physical processes
- Elastic e-p scattering
- Energy straggling in the target
- Inelastic e-p scattering

Detector response

Some results

Event generator

Variables to be generated:

- x : position of the scattering
- θ : polar scattering angle
- E': final electron energy

Needed:

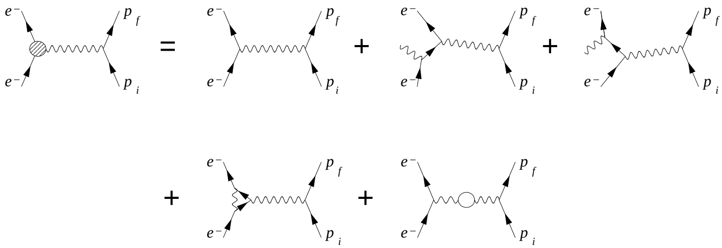
- ranges: (x_{min}, x_{max}), $\Delta\Omega$, (E'_{min}, E'_{max})
- differential cross sections: $d\sigma(x, \theta, E')$

Elastic e-p scattering

- Rosenbluth cross section:

$$\left.\frac{d^2\sigma}{d\Omega}\right|_{Ros}(E,\theta) \qquad \text{(dipole fit for } G_E \text{ and } G_M\text{)}$$

- Radiative corrections to the elastic scattering:



Radiative corrections to the elastic scattering

- Two kinematical regions:
  - radiative tail from the elastic peak ($E' < E'_{el} - \Delta E_r$)

$$\left.\frac{d^3\sigma}{d\Omega dE'}\right|_{tail}(E, E', \theta)$$

  - elastic peak ($E' > E'_{el} - \Delta E_r$)

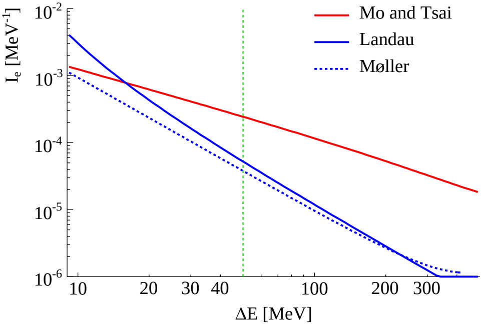
$$\left.\frac{d^2\sigma}{d\Omega}\right|_{peak}(E, \theta) = (1 + \delta(\Delta E_r, E, \theta)) \left.\frac{d^2\sigma}{d\Omega}\right|_{Ros}(E, \theta)$$

- Peaking approximation $\Rightarrow$ Mo and Tsai's formulae for δ and $\frac{d^3\sigma}{d\Omega dE'}$

Energy straggling in the target

Energy losses given by:

- Radiation
- Collisions



Large energy losses mainly due to Bremsstrahlung

Straggling function

Formula of Mo and Tsai:

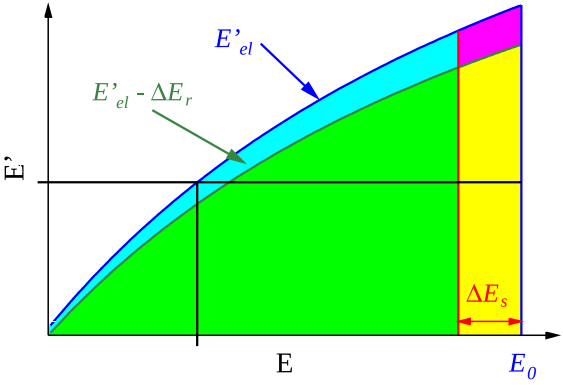
$$I_e(E_0, E, t) = \frac{bt}{E_0 - E}\left[\frac{E}{E_0} + \frac{3}{4}\left(\frac{E_0 - E}{E_0}\right)^2\right]\left(\ln\frac{E_0}{E}\right)^{bt}$$

- for Bremsstrahlung
- using peaking approximation
- valid up to a cut $E < E_0 - \Delta E_s$
- for $E > E_0 - \Delta E_s$

$$J_e^{\Delta E_s}(E_0, t) = 1 - \int_0^{E_0 - \Delta E_s} dE \cdot I_e(E_0, E, t)$$

Generation of ep→ep(γ) events

Energy straggling + radiative corrections ⇒ 4 kinematical regions



Generation of ep→ep(γ) events

Region	Cross section
I	$\left.\frac{d^2\sigma}{d\Omega}\right\|_I = J_e \left.\frac{d^2\sigma}{d\Omega}\right\|_{peak}(E_0)$
II	$\left.\frac{d^3\sigma}{d\Omega dE'}\right\|_{II} = I_e(E_0, E)\frac{dE}{dE'} \left.\frac{d^2\sigma}{d\Omega}\right\|_{peak}(E)$
III	$\left.\frac{d^3\sigma}{d\Omega dE'}\right\|_{III} = J_e \left.\frac{d^3\sigma}{d\Omega dE'}\right\|_{tail}(E_0)$
IV	$\left.\frac{d^3\sigma}{d\Omega dE'}\right\|_{IV} = \int_{E_{min}}^{E_{max}} dE\; I_e(E_0, E) \left.\frac{d^3\sigma}{d\Omega dE'}\right\|_{tail}(E)$

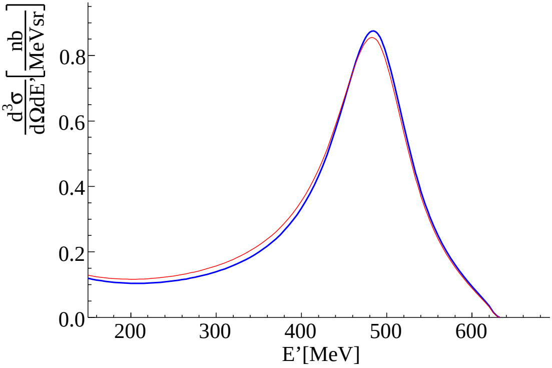
Inelastic e-p scattering

Processes:

- $e + p \to e + p + \pi^0$
- $e + p \to e + n + \pi^+$

Inclusive cross section:

$$\frac{d^3\sigma}{d\Omega_e dE'} = \int d\Omega_\pi \frac{d^5\sigma}{d\Omega_e dE' d\Omega_\pi}$$



Outline

Theory

Measurement principle

Physical processes

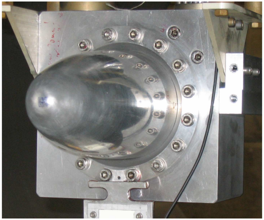
Detector response
- Simulation of the A4 detector
- Particle tracking with GEANT4
- Production and detection of Cherenkov light
- Parameterisation of the photoelectron emission

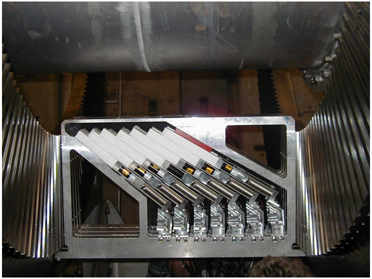
Some results

The A4 detector

PbF$_2$ Cherenkov calorimeter

ℓ-H$_2$ target



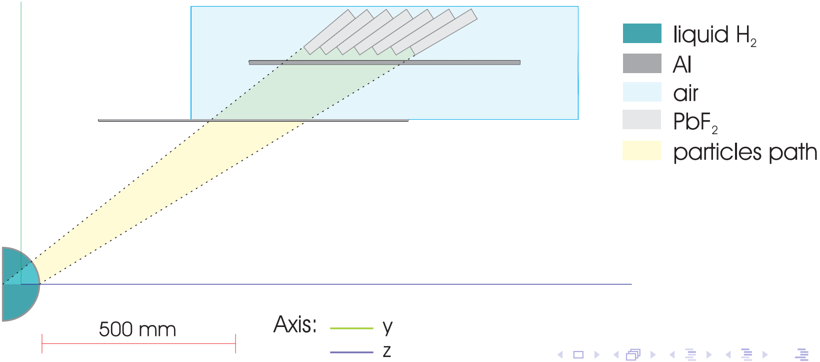


1022 crystals ordered in 7 rings

The response of the A4 detector

What happens between scattering and the energy spectrum?

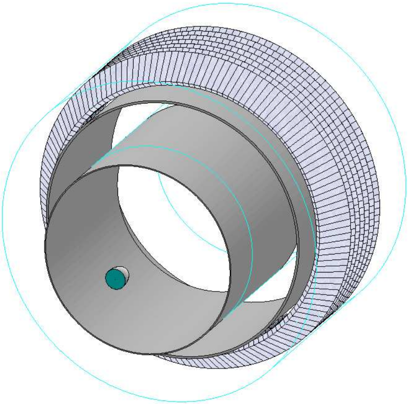
- Passage through material layers
- Physics of the detector { Electromagnetic shower / Cherenkov effect }



Simulation of the A4 detector

Definition of the detector geometry:

- Volumes (shape, dimentions, position)
- Materials (composition, ρ, Z, A)

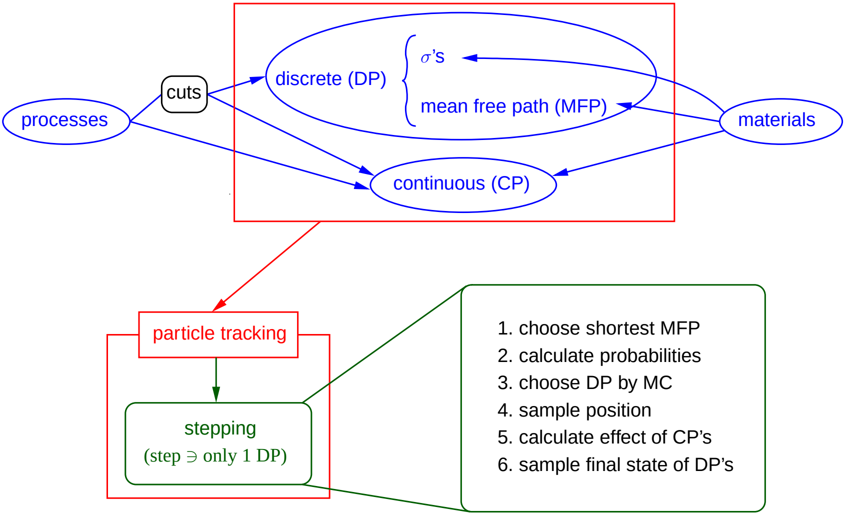


Simulation of the A4 detector

Definition of particles and processes

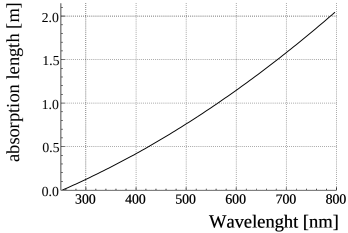
- γ:
  - Compton scattering
  - pair production
  - photoelectric effect
- e^- and e^+:
  - ionisation
  - Bremsstrahlung
  - multiple scattering
- only for e^+:
  - annihilation

Particle tracking with GEANT4

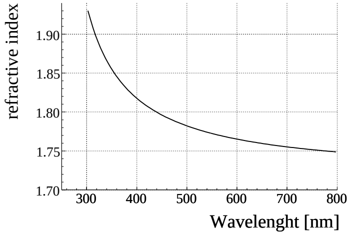


Production and detection of Cherenkov light

- More geometry and material properties:
  - refractive indexes
  - absorption lengths
  - optical surfaces



- More particles and processes:
  - optical photons
  - Cherenkov effect
  - absorption
  - boundary process

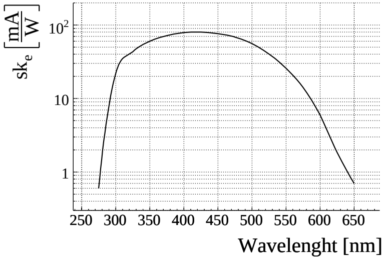


$\Rightarrow$ tracking of optical photons

Production and detection of Cherenkov light

Spectral sensitivity characteristic:

- input window
- photocathode sensitivity



Quantum efficiency:

$$QE(\lambda) \simeq \left(\frac{124\text{ nm}}{\lambda} \cdot sk_e(\lambda)\frac{\text{W}}{\text{mA}}\right)\%$$

Parameterisation of the photoelectron emission

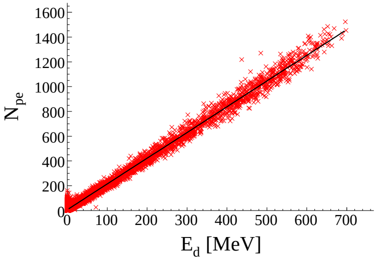
- Simulating the whole electromagnetic shower is possible
- Tracking all Cherenkov photons takes too long

Parameterisation needed:

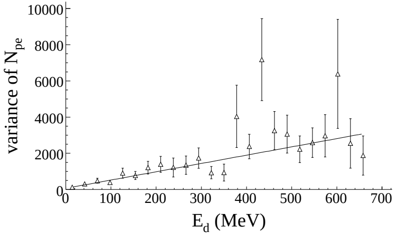
deposited energy in one crystal $\Rightarrow$ Photoelectrons in the respective PMT

Parameterisation of the photoelectron emission

Ansatz: gaussian fluctuations of N_{pe}



- strong linear correlation $r = 0.997$
- mean N_{pe} linear dependent on E_d



- $\sigma^2_{N_{pe}}$ also linear in E_d

Outline

Theory

Measurement principle

Physical processes

Detector response

Some results

Comparison with the experimental spectrum

1. "Calibration": $N_{pe} \quad \longrightarrow \quad$ ADC channel
   - knowledge of offset and peak position
   - linearity

2. Scaling factor ξ

$$\xi = \frac{\mathcal{L}\,\sigma \cdot \Delta t}{N_{evt}}$$

$\mathcal{L}$: luminosity ($\rho\ I\ \ell$)

σ : total cross section

Δt : run duration

N_{evt} : simulated events

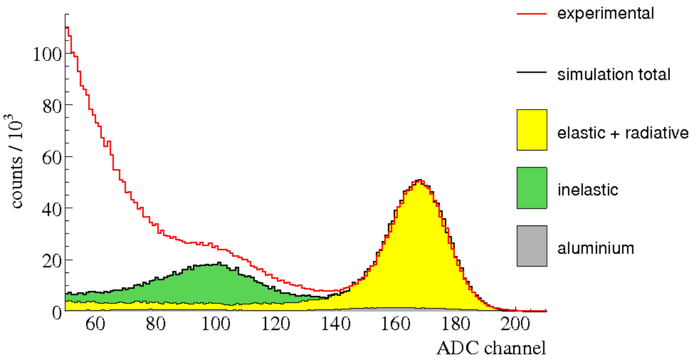
Result for electrons

Input information:

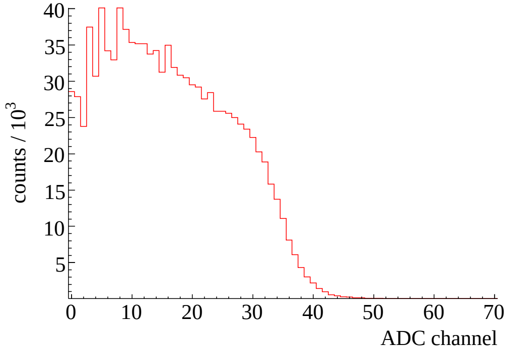
- scattering processes
- detector physics

from the spectrum itself:

- position of the peak

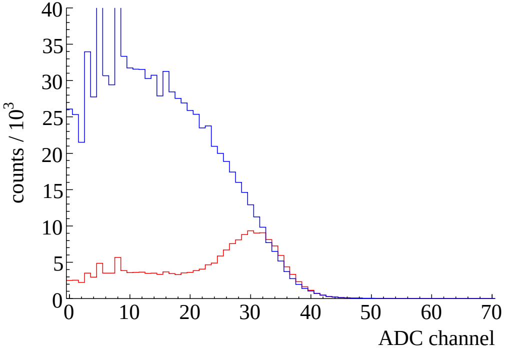


Result for backward scattering



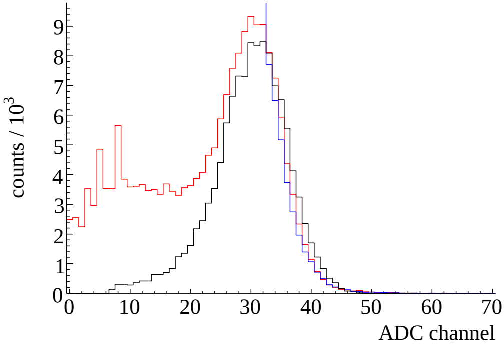
- background is dominant

Result for backward scattering



- background is dominant
- it is neutral particles $\Rightarrow \gamma$'s

Result for backward scattering



- background is dominant
- it is neutral particles $\Rightarrow \gamma$'s
- coincidence spectrum reproduced by simulation

Work in progress

Contribution of γ's?
(at backward angle important!)

- Processes

$$\begin{aligned} e+p &\rightarrow e+p+\pi^0 \rightarrow (e+p)+\gamma+\gamma \\ e+p &\rightarrow (e+p)+\gamma \end{aligned}$$

- Detector response very similar to e^-
  - conversion (dominant)
  - Compton

Summary

- Parity violation in the $\Delta(1232)$ interesting for hadron structure
- Possibility of measuring the PV asymmetry within the A4 experiment
- Large background: understanding of energy spectrum needed
- Study of
  - scattering processes
  - detector response
- Detector response under control
- Electron contribution well understood
- Working on contribution of γ's