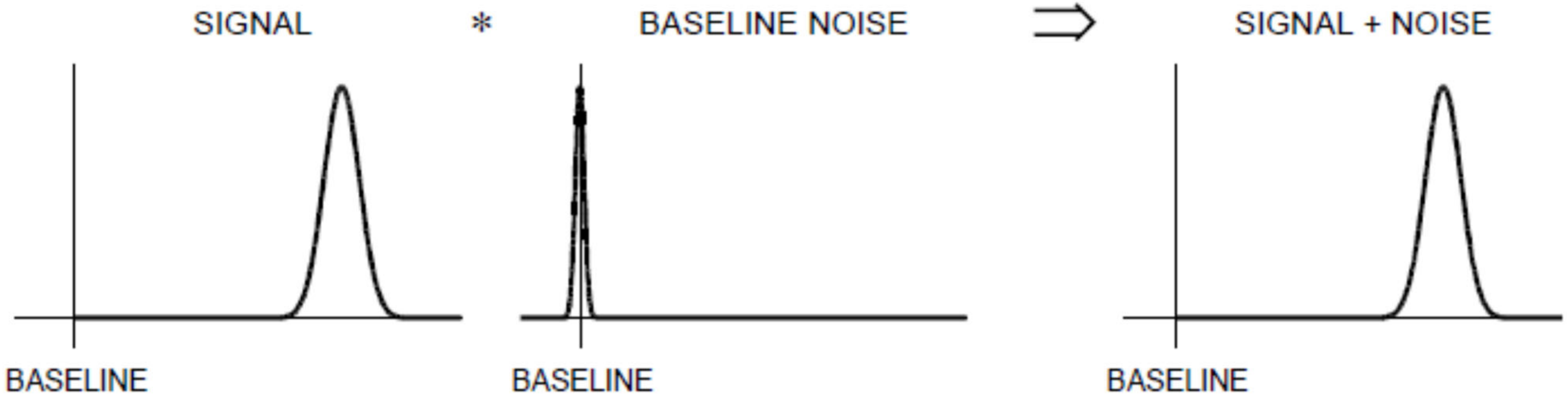
at determines Resolution?

gnal Variance >> Baseline Variance



⇒ Electronic (baseline) noise not important

Examples:
- High-gain proportional chambers
- Scintillation Counters with High-Gain PMTs

e.g. 1 MeV γ-rays absorbed by $\mathrm{NaI(Tl)}$ crystal

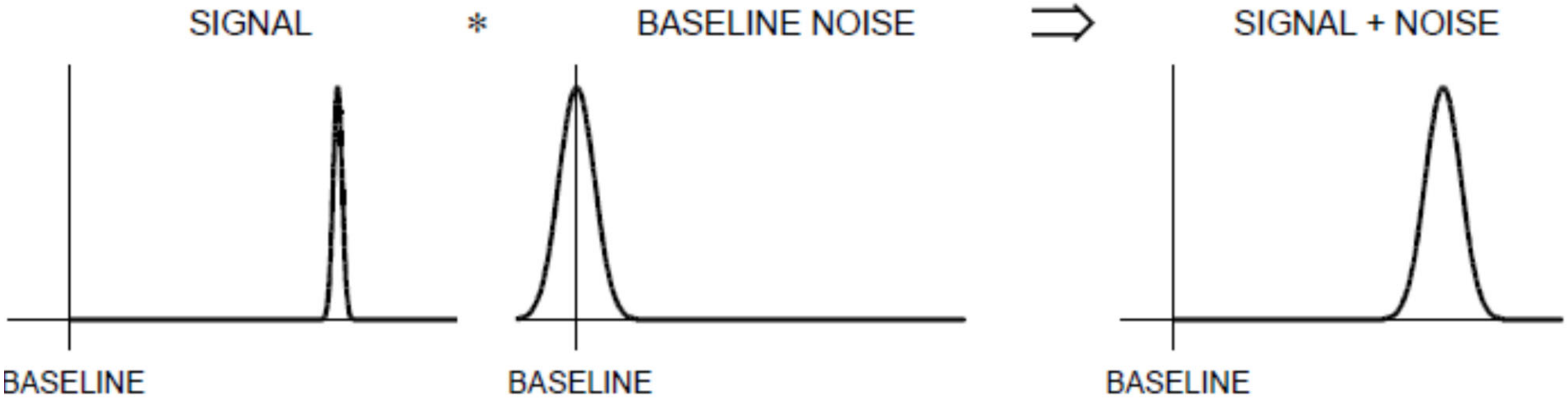
Number of photoelectrons: $N_{pe} \approx 8 \cdot 10^4$ [MeV^{-1}] $\times E_\gamma \times QE \approx 2.4 \cdot 10^4$

Variance typically: $\sigma_{pe} = N_{pe}^{1/2} \approx 160$ and $\sigma_{pe} / N_{pe} \approx 5 - 8\%$

Signal at PMT anode (assume Gain= 10^4): $Q_{sig} = G_{PMT} N_{pe} \approx 2.4 \cdot 10^8$ el anc

$\sigma_{sig} = G_{PMT}\, \sigma_{pe} \approx 1.2 \cdot 10^7$ el

whereas electronic noise easily $< 10^4$ el nal Variance << Baseline Variance



⇒ Electronic (baseline) noise critical for resolution

Examples:
- Gaseous ionization chambers (no internal gain)
- Semiconductor detectors

e.g. in Si : Number of electron-hole pairs $N_{ep} = \dfrac{E_{dep}}{3.6\text{ eV}}$

Variance $\sigma_{ep} = \sqrt{F \cdot N_{ep}}$ (where F= Fano factor ≈ 0.1)

For 50 keV photons: $\sigma_{ep} \approx 40$ el ⇒ $\sigma_{ep} / N_{ep} = 7.5 \cdot 10^{-4}$

Obtainable noise levels are 10 to 1000 el.

Baseline fluctuations can have many origins ...

- pickup of external interference
- artifacts due to imperfect electronics
- … etc.,

but the (practical) fundamental limit is electronic noise.

1.10 Detection limits and resolution

In addition to signal fluctuations originating in the sensor, the minimum detection limit and energy resolution are subject to fluctuations introduced by the electronics. The gain can be controlled very precisely, but electronic noise introduces baseline fluctuations, which are superimposed on the signal and alter the peak amplitude. Figure 1.24 (left) shows a typical noise waveform. Both the amplitude and time distributions are random.

When superimposed on a signal, the noise alters both the amplitude and time dependence. Figure 1.24 (right) shows the noise waveform superimposed on a small signal. As can be seen, the noise level determines the minimum signal whose presence can be discerned.

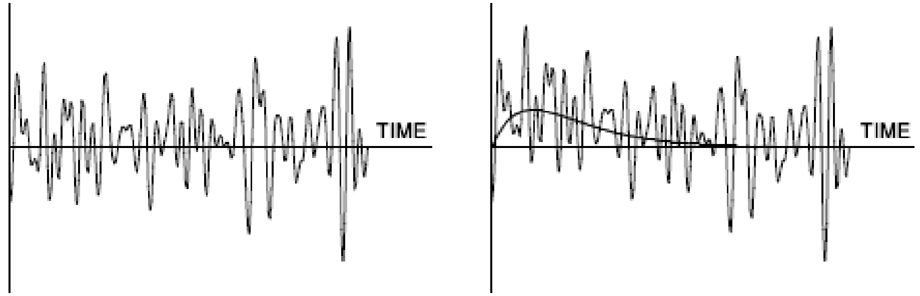
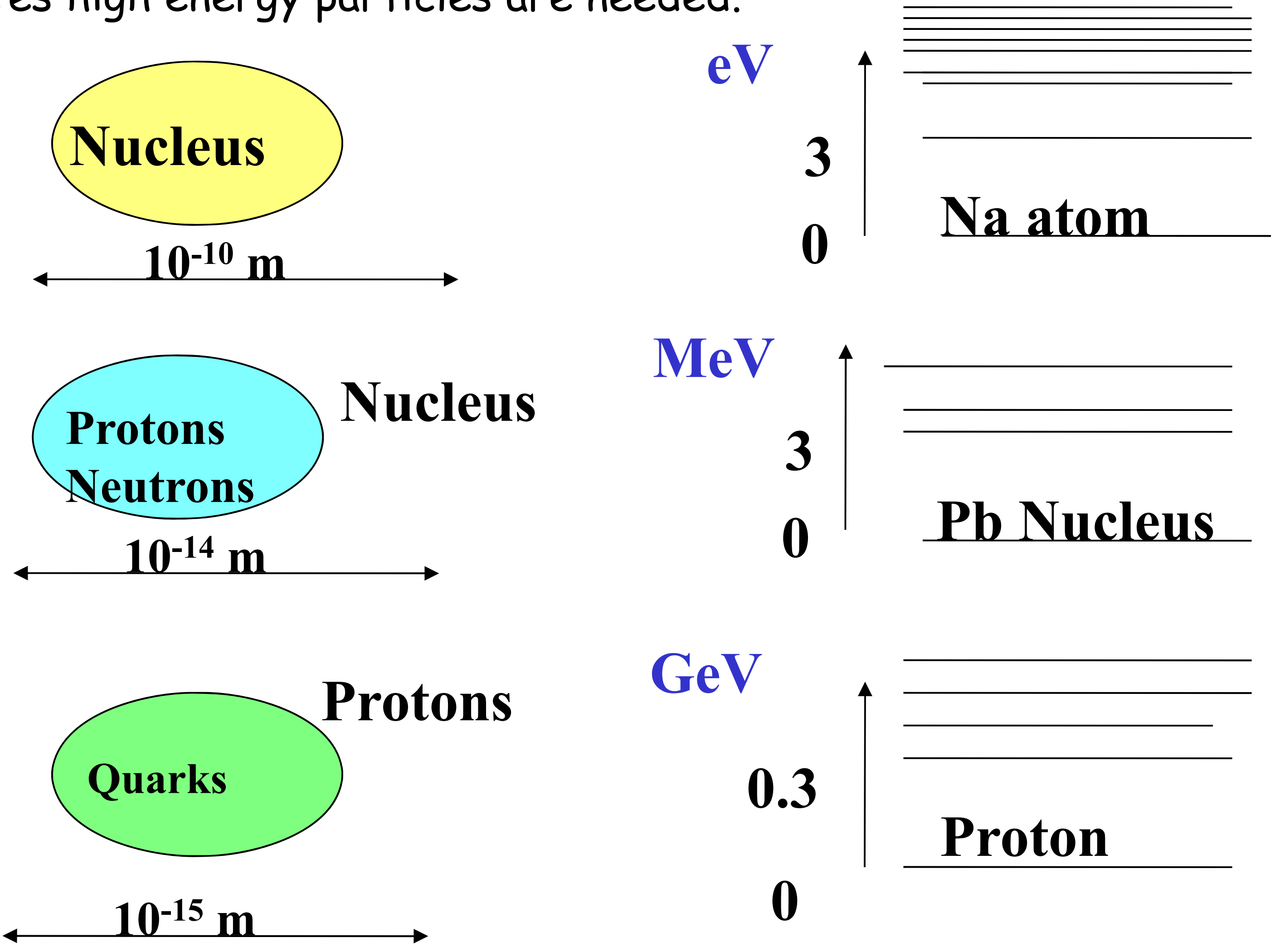


FIG. 1.24. Waveforms of random noise (left) and signal + noise (right), where the peak signal is equal to the rms noise level ($S/N = 1$). The noiseless signal is shown for comparison.

Spectroscopy:

- Experiments to determine the decay products of excited states and their interaction
- The excitation energies of a system increase as size decrease. To produce these excited states high energy particles are needed.

Absolute energies may vary a lot
But resolution usually still a critical issue



Nucleus

10^{-10} m

eV

3

0

Na atom

Protons
Neutrons

Nucleus

10^{-14} m

MeV

3

0

Pb Nucleus

Quarks

Protons

10^{-15} m

GeV

0.3

0

Proton

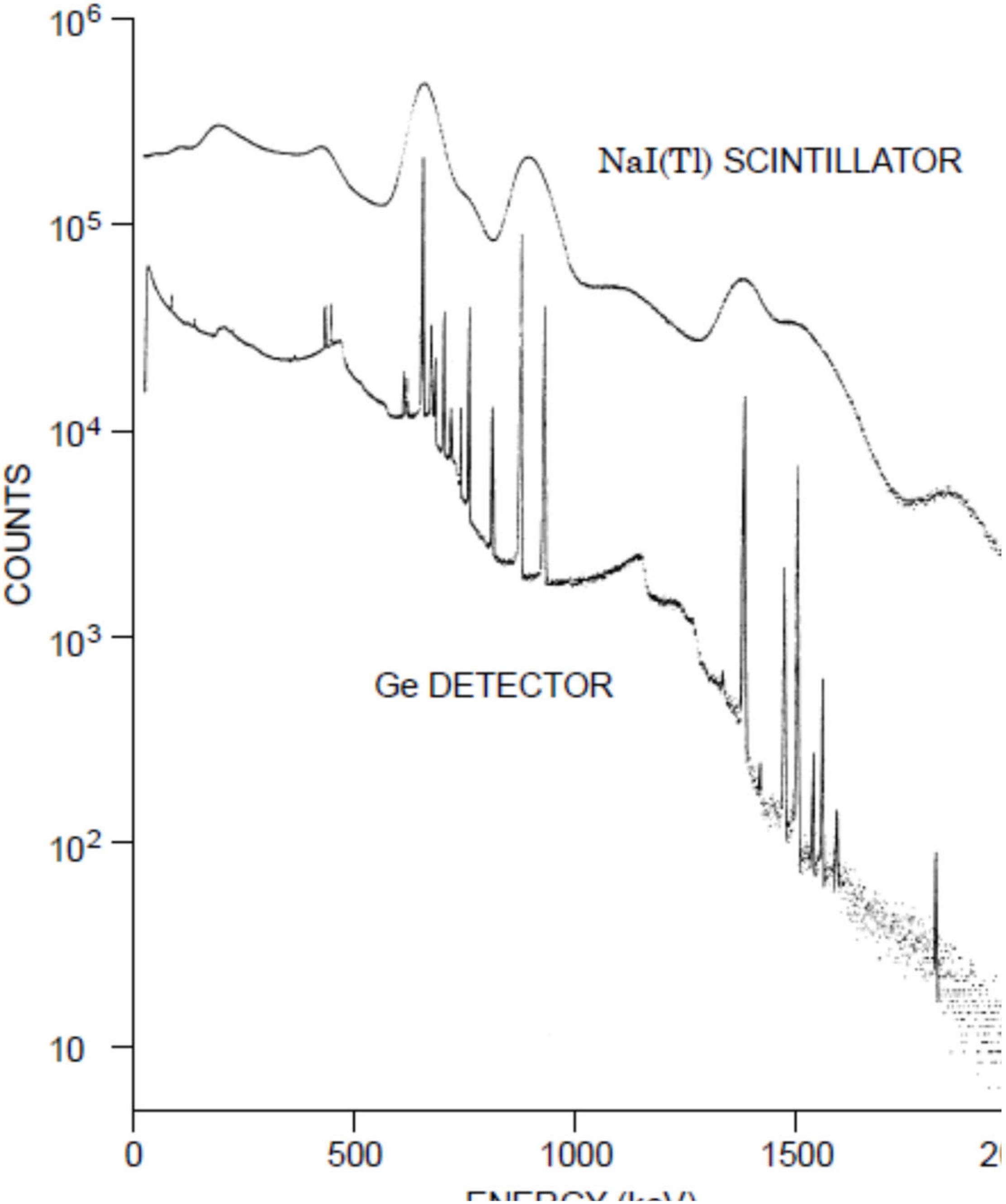
esolution and Electronic Noise

lution: the ability to
guish signal levels

hy?

ecognize structure in amplitude spectra

Comparison between NaI(Tl)
and Ge detectors

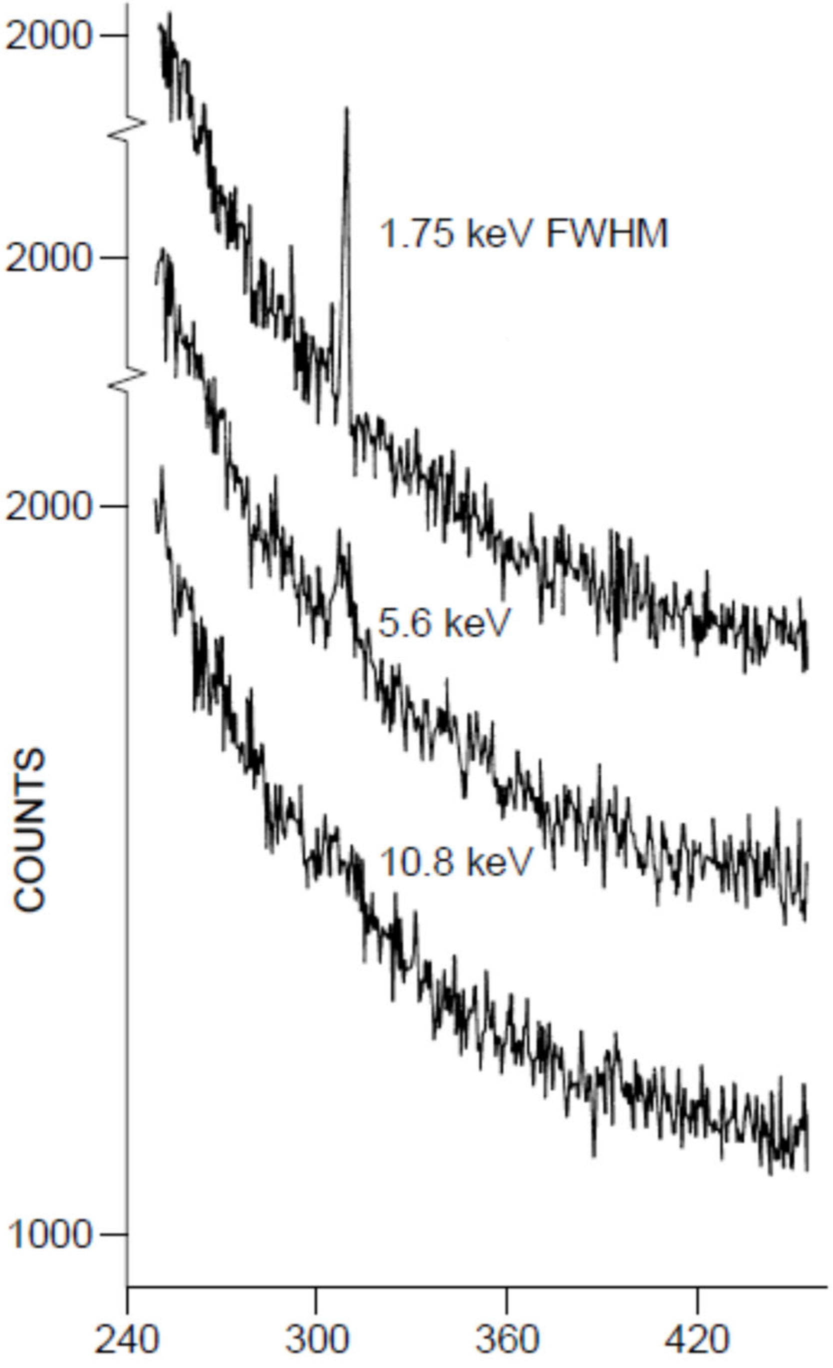


. Philippot, IEEE Trans. Nucl. Sci. **NS-17/3** (1970)
446

b) Improve sensitivity

Signal to background ratio improves with better resolution

(signal counts in fewer bins compete with fewer background counts)



G.A. Armantrout *et al.*, IEEE Trans. Nucl. Sci. **NS-19/1** (1972) 107

li di Frascati of INFN, wh
ıext year. The experiment,
ram, has some special f
ypernuclear physics experi
vill operate at a e^+e^- collide
Vhat follows will describe i

tructure of Λ–hypernu

Λ-hypernucleus $^A_\Lambda Z$ is a b
rons and a Λ hyperon. Th
ıade by the (A-1) nucleons
ıe nucleus $^{(A-1)}Z$ and the
'he Λ hyperon, carrying th
istinguishable baryon an
nposed by the Pauli princi
ım states already filled up v
hyperon, embedded in a
xplore nuclear structure.

The binding energy B_Λ of
ı its ground state is defined

$$B_\Lambda = M$$

here M_{core} is the mass (in
ıe mass of the Λ particle an
Z, experimentally measu
ope of about 1 MeV/(unit
r the heavy hypernuclei. Th
which the Λ particle is con
qual to the nuclear radius an
the 55 MeV typical value

This is consistent with a Λ-
ıcleon-nucleon one. Indee
teraction, the zero isospin [illegible]
ovector mesons like the π or the ρ with a nucleon and deter-
ines the lack of strong tensor components in the interaction.
ıe relative weakness of the Λ-nucleon interaction entails that the
ell structure is not disrupted by the insertion of the Λ in the
ıcleus and the lack of Pauli effects allows all the nuclear single
rticle states to be populated by the Λ. In Figure 2, the so called
egrè table" of the hypernuclei shows the 35 hypernuclei known
present.

Experiments of hypernucleus production by "*strangeness
change*" and "*associated production*" processes can produce
pernuclei in which the Λ populates different single particle
ıtes. The latter technique is particularly suitable for populating
v lying Λ states, thanks to the high recoil momentum trans-
rred to the Λ particle in the reaction.

A beautiful representation of this process is given in Figure 3,
ıere the excitation spectrum of $^{89}_{\Lambda}Y$, obtained by the "*associated
oduction*" reaction $^{89}Y(\pi^+, K^+)\,^{89}_{\Lambda}Y$ at the KEK laboratory in
oan, is shown. The spectrum demonstrates how, starting from
ıeutron in the $g_{9/2}$ state, it is possible to accommodate a Λ particle
the hypernuclear states f, d, p and even in the ground state s.

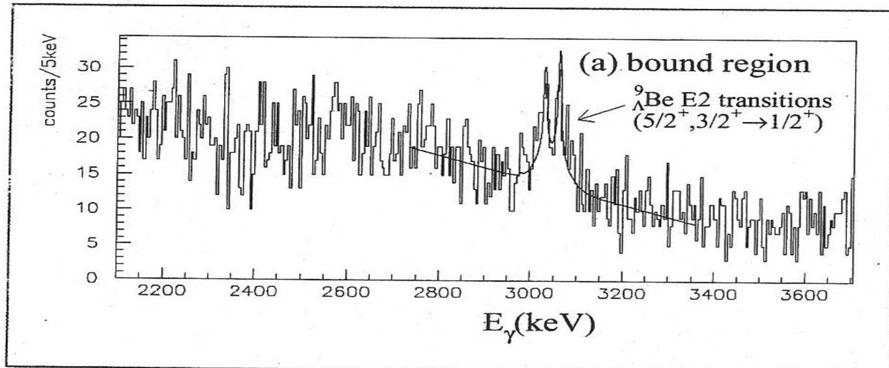
These measurements constitute the spectacular confirmation,
a textbook level, of the validity of the independent particle
odel or shell model of the nucleus. In non-strange nuclei, the
servation of single particle states is only possible for the states
the most external nucleon orbits. In fact, due to the Pauli prin-
le and pairing interactions, deeply bound nucleon single
rticle states are so fragmented as to be essentially unobservable.
e present experimental data on hypernuclear binding energies
d detailed spectroscopic features are limited in quantity and

tion of the *YN* interaction.

Figure 4 reports a recent measurement of the splitting of the $5/2^+$-$3/2^+$ doublet in $^9_\Lambda Be$ by the BNL-AGS E930 experiment [4], measuring γ rays emitted in the nuclear transitions with the new germanium detector array Hyperball. This new technique allowed the energy resolution on low lying hypernuclear levels to be improved from a few MeV to a few keV, even if the count rate resulting is still quite low, ~200 γ's per month of data taking. The spacing of the two levels was measured to be 31 ± 2 keV, incompatible with the prediction of the meson exchange models.

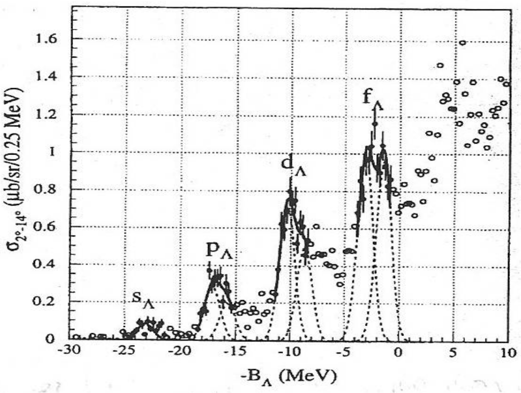
state nucleon in all but the l
mesonic decay modes of t
through the weak interac
($\Lambda + n \rightarrow n + n + 176$ MeV
process is possible only in hyp
of Λ's, stable against the mes
which is available inside a hy

The study of the non-mes
importance, since it provide
four fermion, strangeness ch

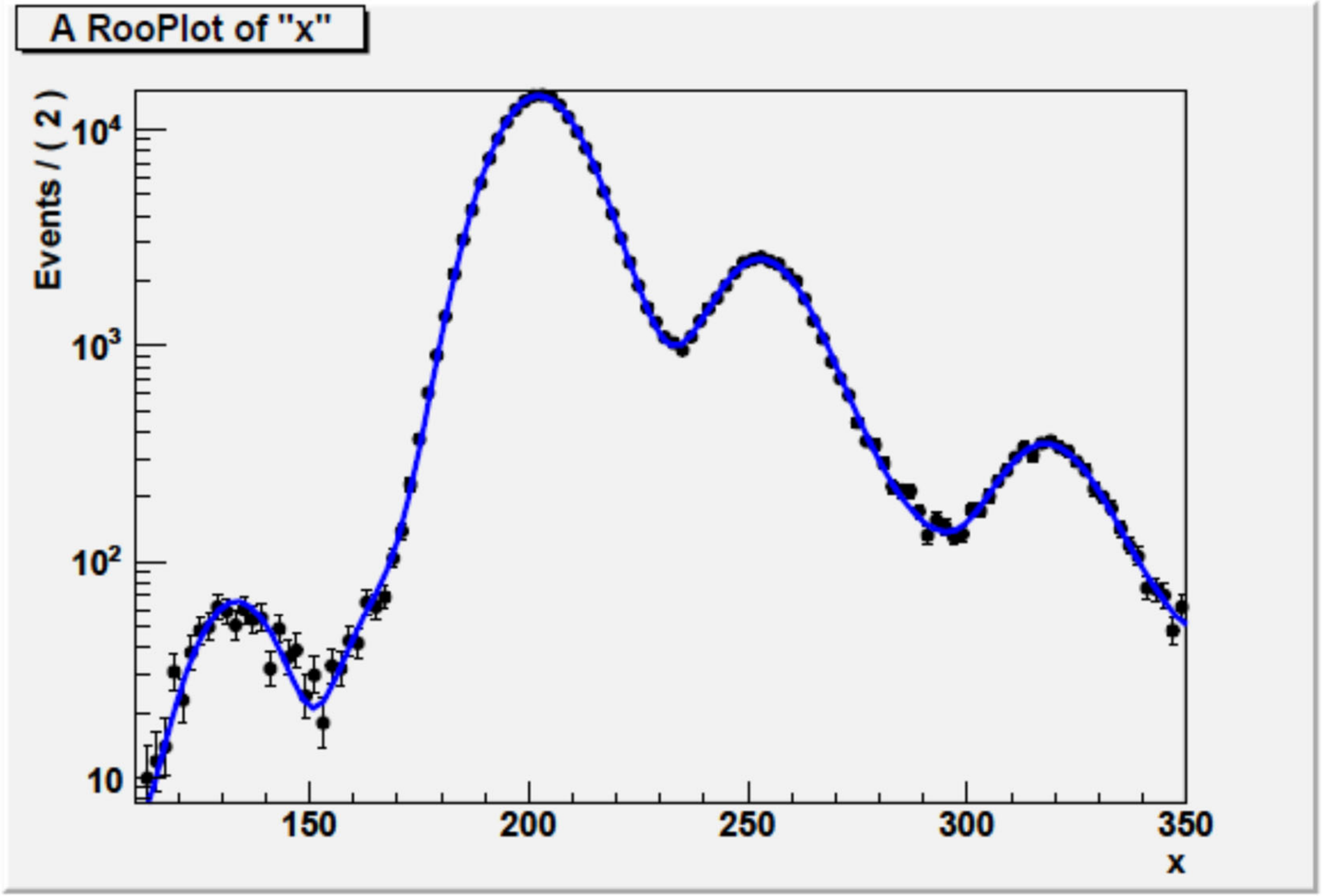


◄ **Fig.**
deexcit
obtaine
betwee
$1/2^+$) tr
strengt
The sm
31 ± 2 k
obtaine

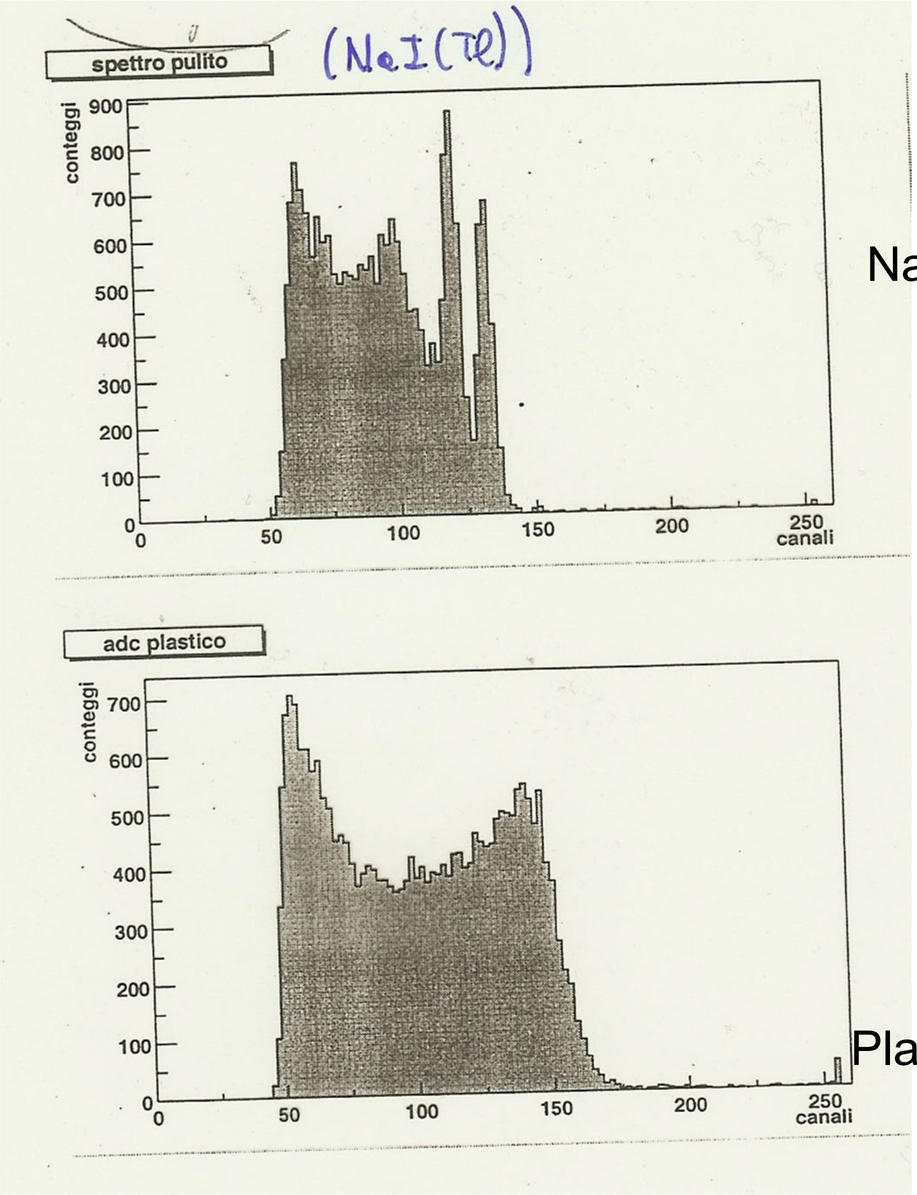
The improvement of the *YN* interaction models would need precise data on the free *YN* interaction, which are very difficult to



▲ **Fig. 3:** Hypernuclear mass spectrum of $^{89}_{\Lambda}Y$ obtained at KEK by the E369 experiment, with an energy resolution of 1.65 MeV. The bump structures correspond to the Λ major shells orbits (s, p, d, f) in the bound region. The widths of the bumps for the p-, d- and f-orbits are significantly wider than the experimental resolution and the peak for the f_Λ-orbit is split into two peaks.


A RooPlot of "x"
Events / (2)
10^4
10^3
10^2
10
150
200
250
300
350
x

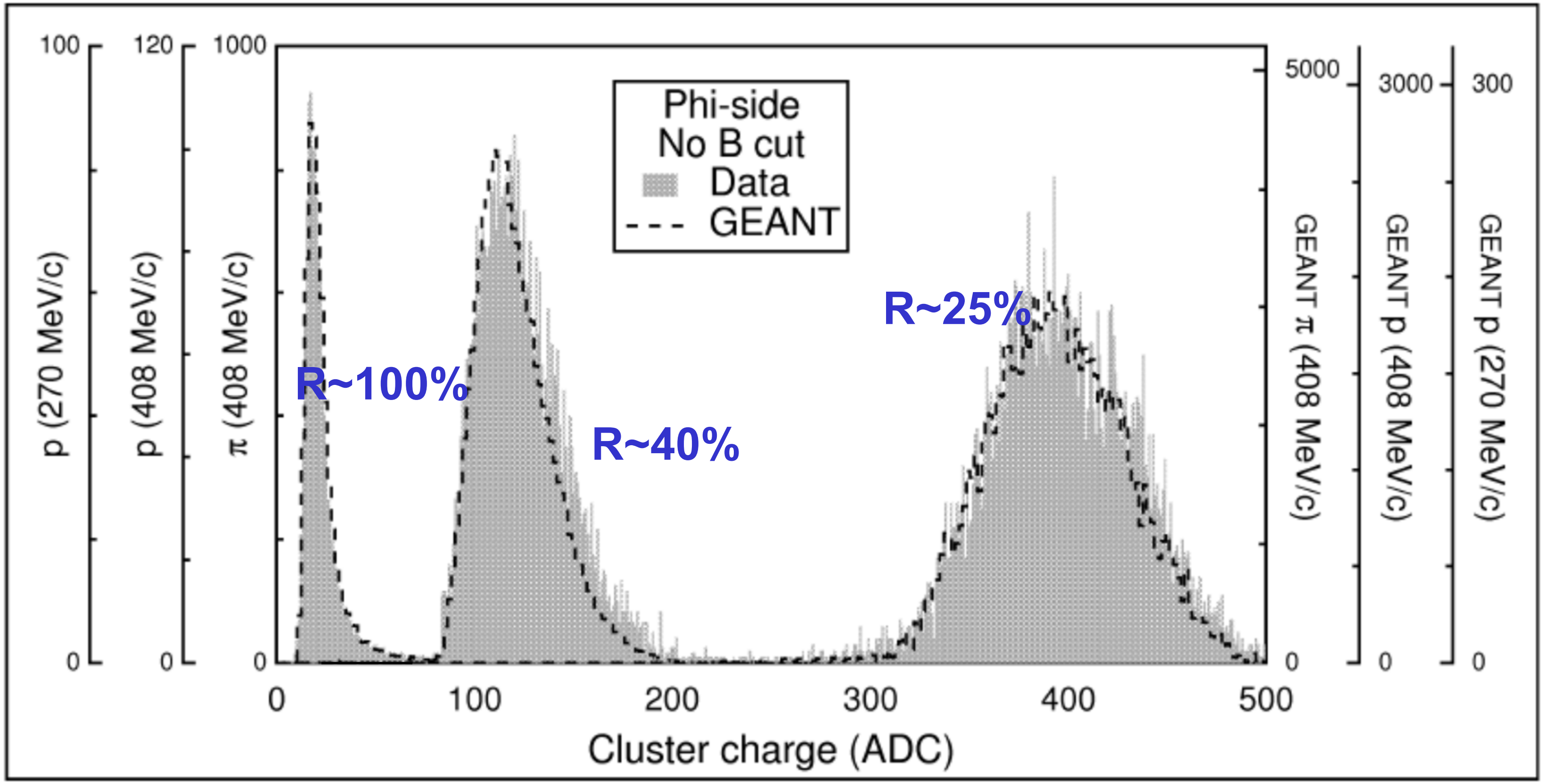
Response function

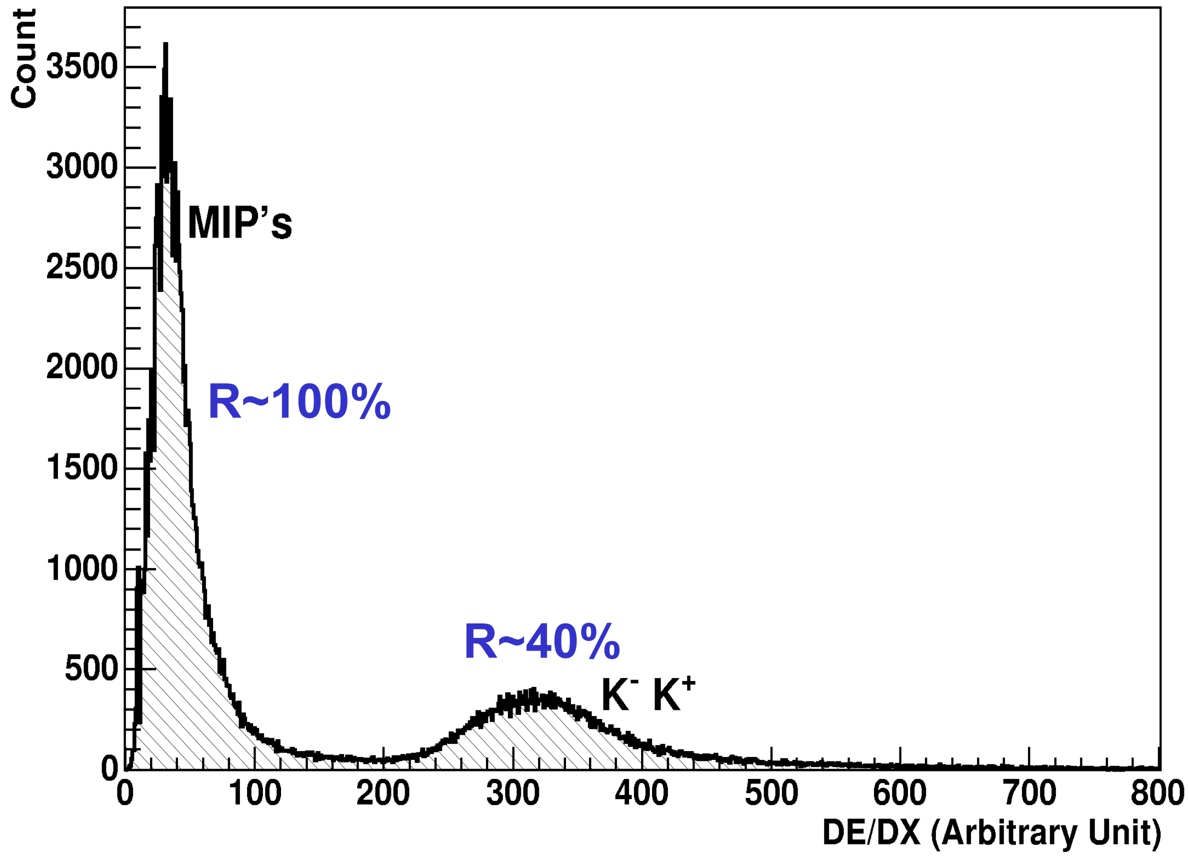


NaI(Tl) scintillator

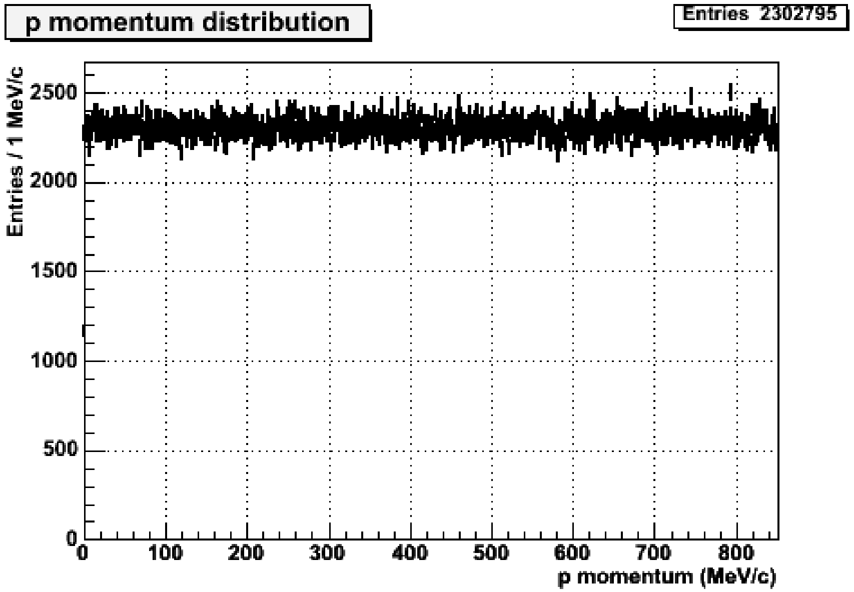
Plastic scintillator

There are actually 2
monoenergetic radiation
Sources…

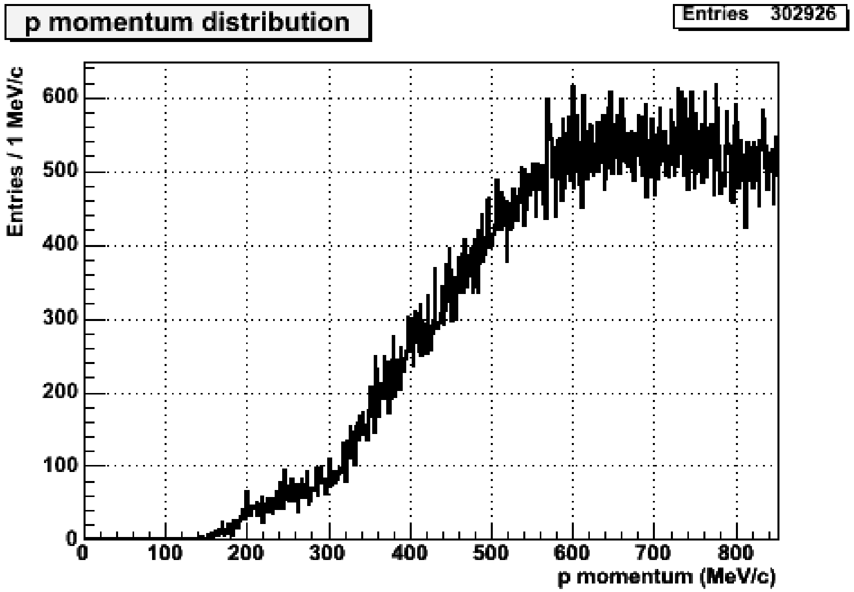

Phi-side
No B cut
▨ Data
- - - GEANT
R~100%
R~40%
R~25%
p (270 MeV/c)
p (408 MeV/c)
π (408 MeV/c)
GEANT π (408 MeV/c)
GEANT p (408 MeV/c)
GEANT p (270 MeV/c)
100
120
1000
0
5000
3000
300
0
100
200
300
400
500
Cluster charge (ADC)


Count
3500
3000
2500
2000
1500
1000
500
0
MIP's
R~100%
R~40%
K⁻ K⁺
0
100
200
300
400
500
600
700
800
DE/DX (Arbitrary Unit)

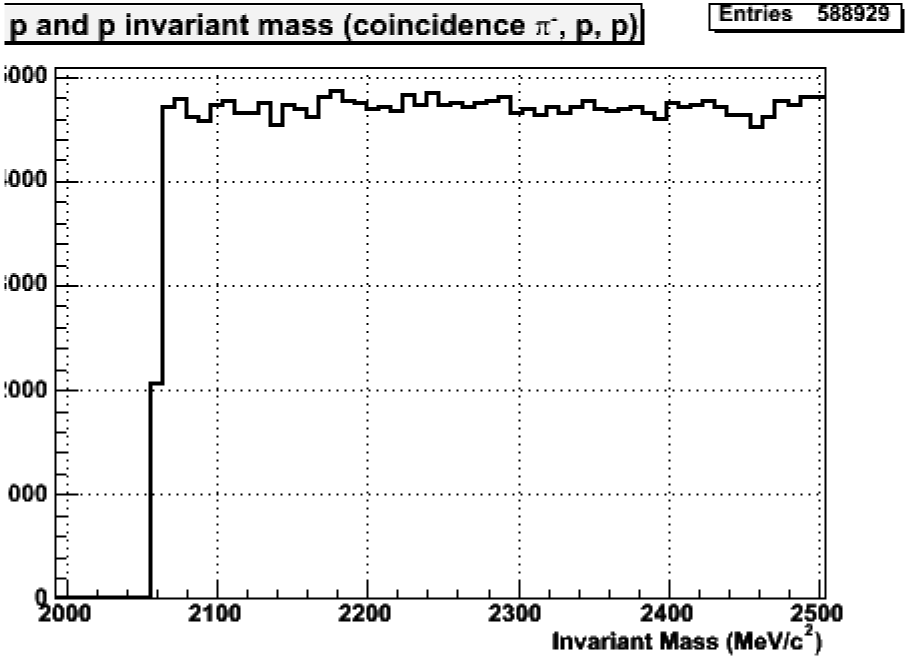
Acceptance effect on proton momentum distribution

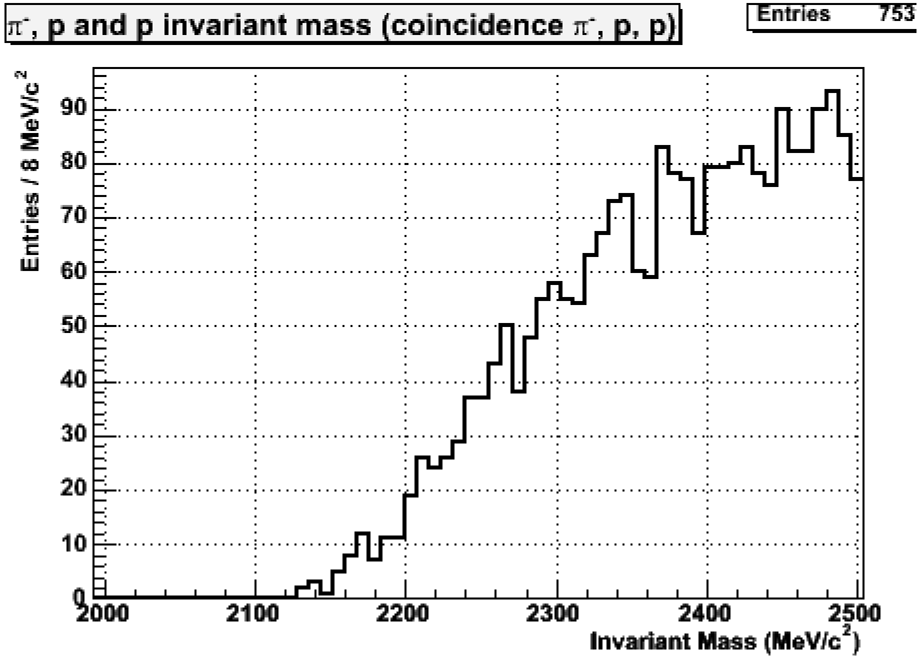


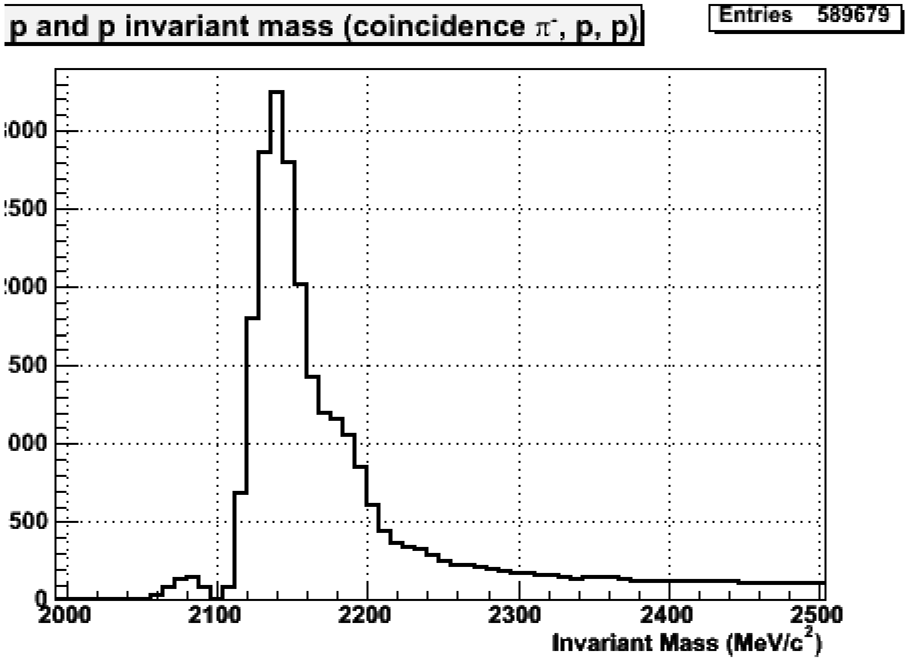
Original distribution

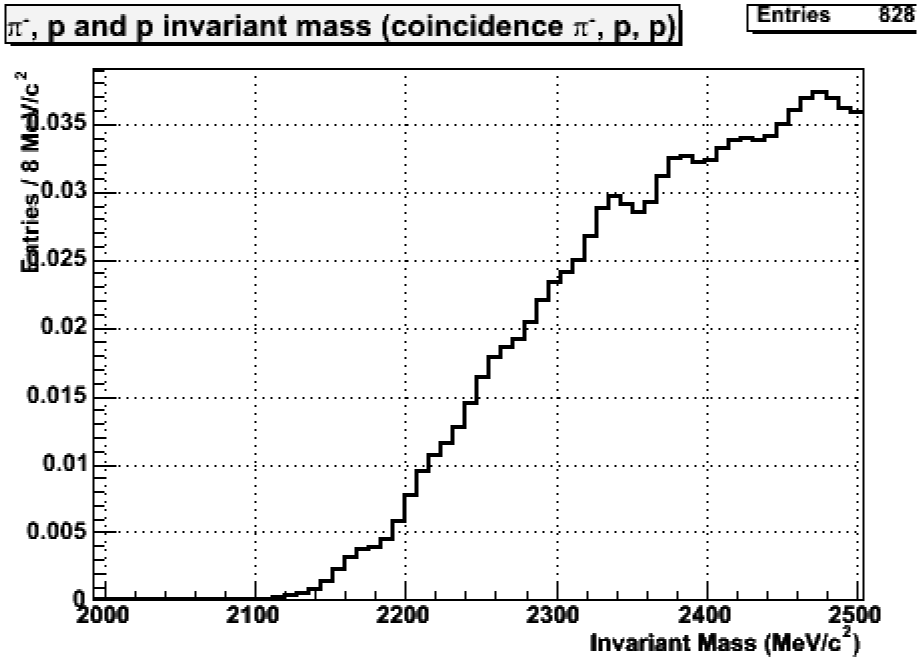


Reconstructed distribution

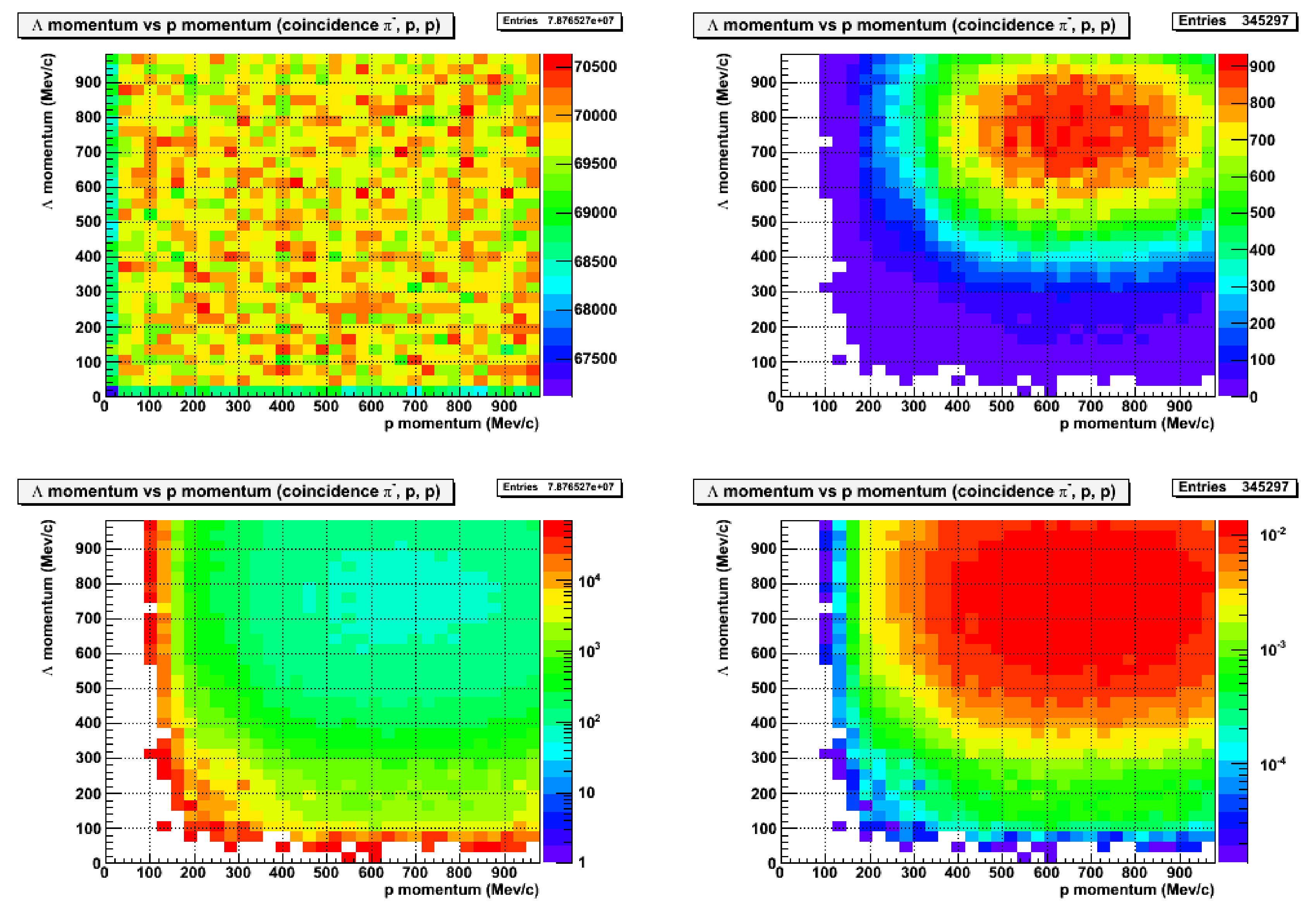

p and p invariant mass (coincidence π⁻, p, p)
Entries 588929
0
000
2000
2100
2200
2300
2400
2500
Invariant Mass (MeV/c²)


π⁻, p and p invariant mass (coincidence π⁻, p, p)
Entries 753
Entries / 8 MeV/c²
0
10
20
30
40
50
60
70
80
90
2000
2100
2200
2300
2400
2500
Invariant Mass (MeV/c²)

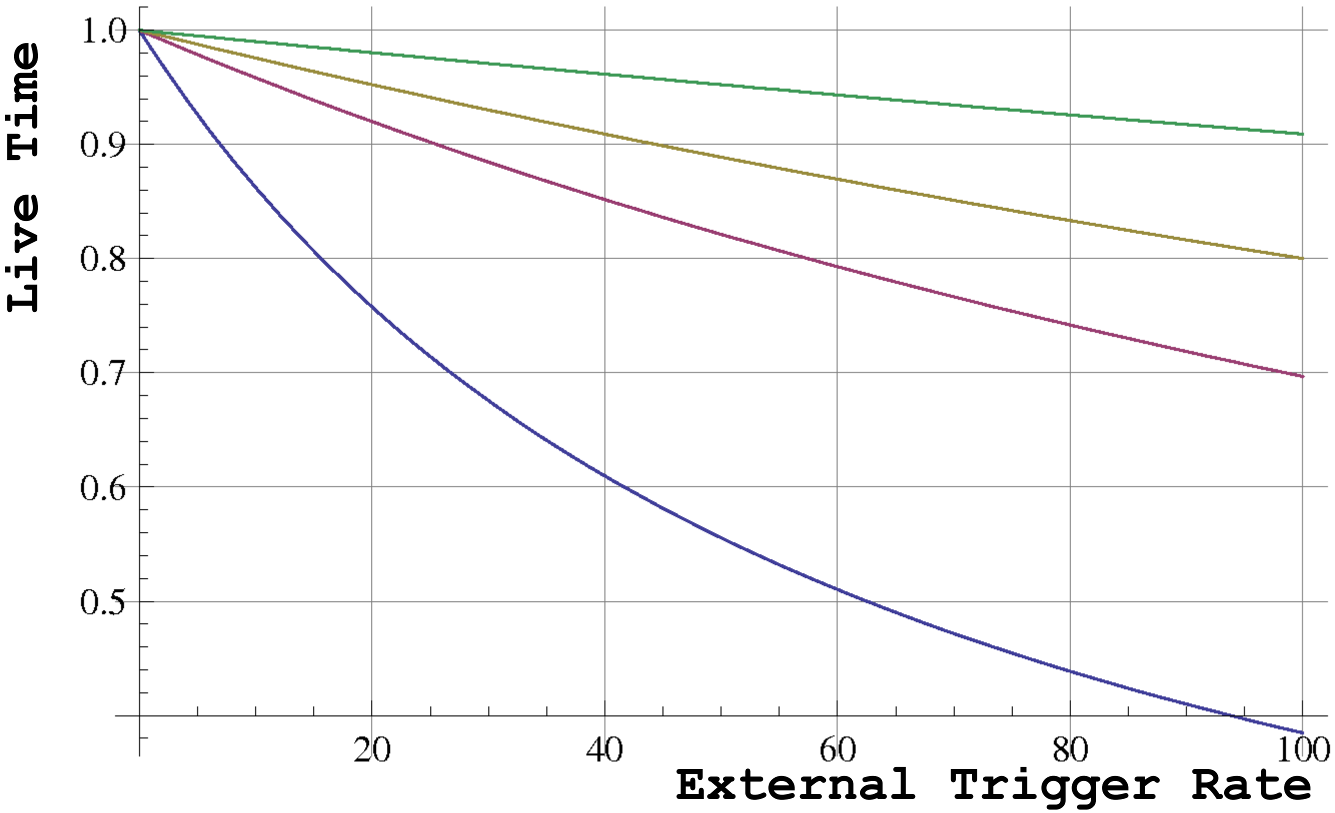

p and p invariant mass (coincidence π⁻, p, p)
Entries 589679
0
500
000
500
2000
2500
3000
2000
2100
2200
2300
2400
2500
Invariant Mass (MeV/c²)


π⁻, p and p invariant mass (coincidence π⁻, p, p)
Entries 828
Entries / 8 MeV/c²
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
2000
2100
2200
2300
2400
2500
Invariant Mass (MeV/c²)

Λp acceptance



Dead time measurements



Live time= $1 - T_{dead}/T$