Nuclear Effects in a NaI Crystal

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TRIUMF
(PiENu Collaboration)

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The PiENu Experiment

- Aim: Precision measurement of the branching ratio:

$$R_{e/\mu} = \frac{\Gamma(\pi \to e\nu + \pi \to e\nu\gamma)}{\Gamma(\pi \to \mu\nu + \pi \to \mu\nu\gamma)}$$

- Standard Model Prediction: $R_{e/\mu}^{SM} = 1.2353(1) \times 10^{-4}$

The most precise SM weak interaction calculation involving quarks (<0.01%)

- Experimental Results:

$R_{e/\mu}^{\exp} = 1.2265 \pm 0.0034(stat) \pm 0.0044(syst) \times 10^{-4}$	TRIUMF ('92)
$R_{e/\mu}^{\exp} = 1.2346 \pm 0.0035(stat) \pm 0.0036(syst) \times 10^{-4}$	PSI ('93)
$R_{e/\mu}^{\exp} = 1.231 \pm 0.004(stat) \times 10^{-4}$	Average

GOAL: From 0.4%-0.5% precision to <0.1%

The PiENu Experiment

Statistical and Systematical Uncertainties

Source	E248	PiENu
Statistical	0.0028	0.0005
Low E tail	0.0025	0.0003
Acceptance difference	0.0011	0.0003
π^+ lifetime	0.0009	0.0002
Others	0.0011	0.0003
Total	0.0047	0.0006

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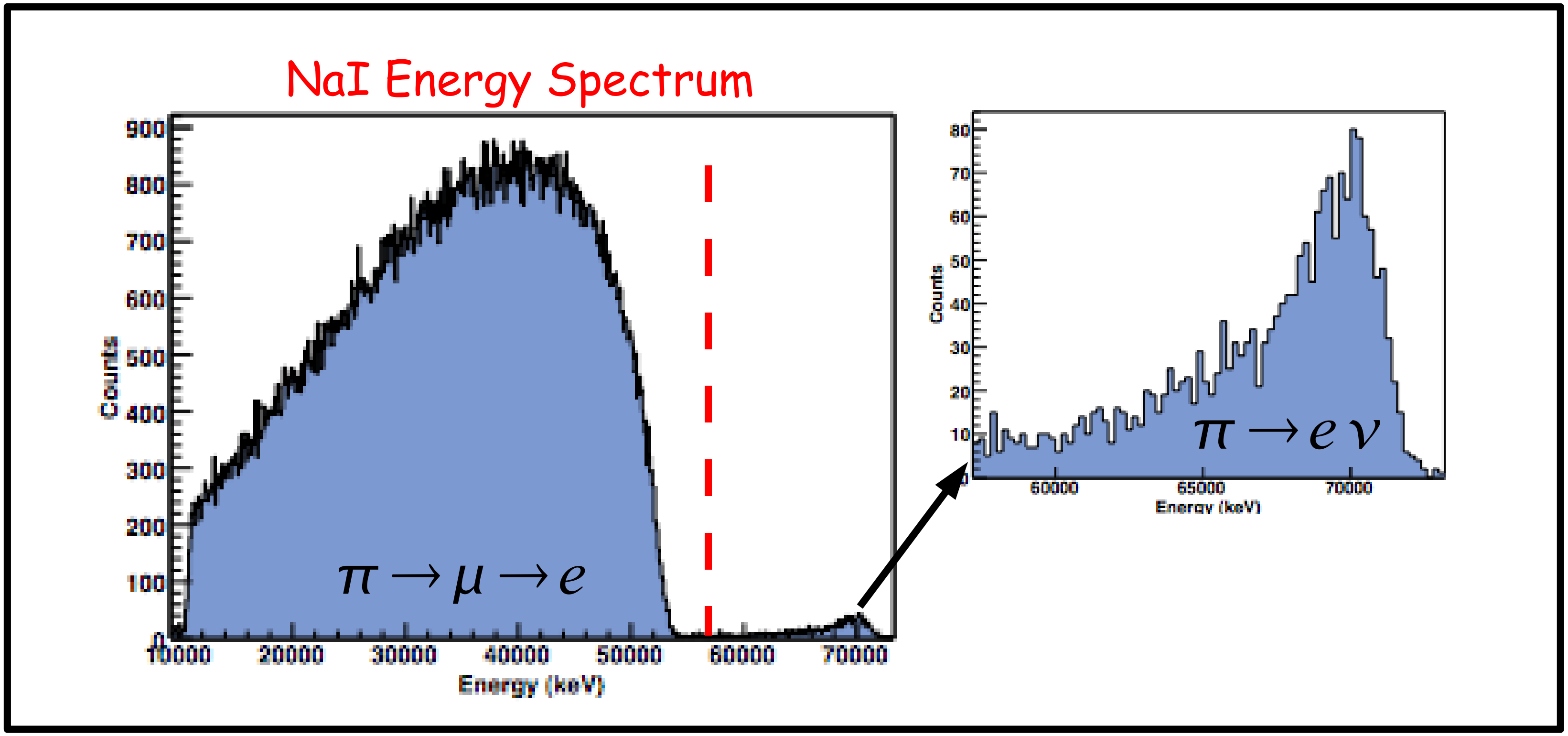
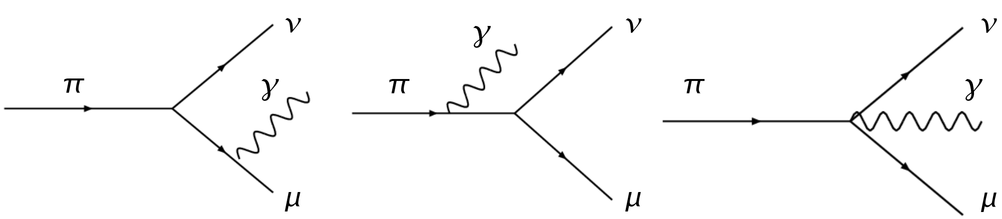
Limited by:
- Statistics
- Decays in Flight

The Low Energy Tail



Origin of the tail:

- Not all the energy is captured in NaI
- Radiative pion decays (~0.5%)

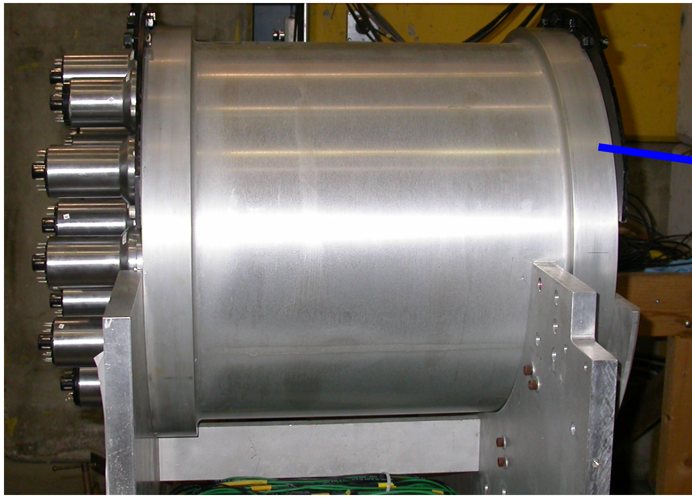


Consequences for a precise BR measurement:

- The low energy tail extends underneath $\pi \rightarrow \mu \rightarrow e$
- Need to know precisely the NaI lineshape
- Experimental and MC investigations needed

The NaI Crystal “BiNa”

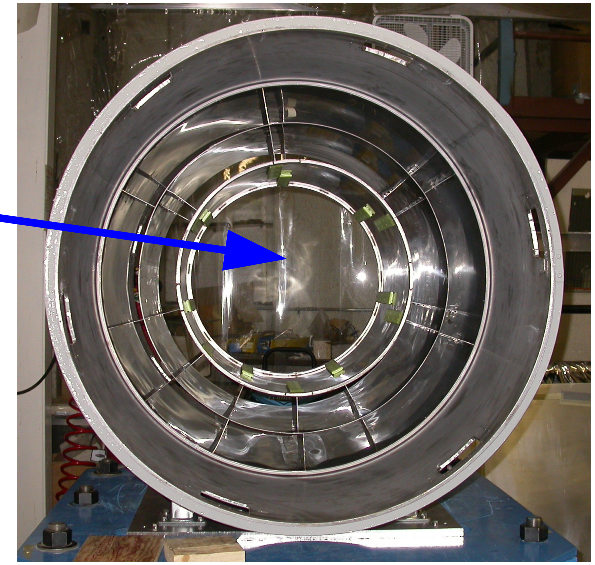
BiNa



19'

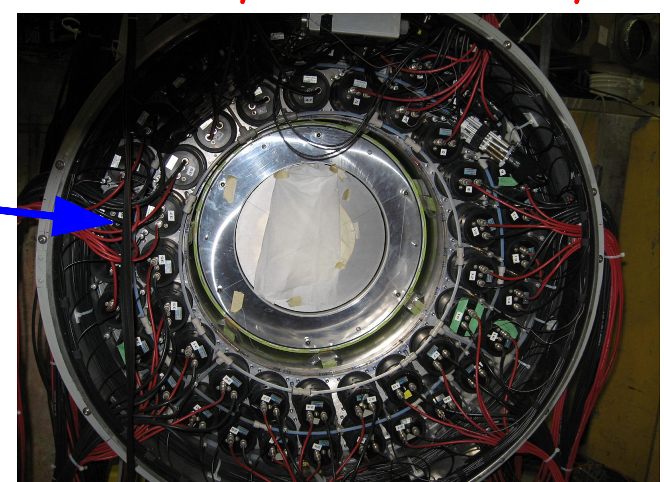
19'

Steel Frame



CsI Crystals (97)

Full Crystals Assembly



The Low Energy Tail

Optimal Procedure: Try to look at the low energy tail directly!

- Try to not rely on response function measurements or simulations
- Suppress $\pi \rightarrow \mu \rightarrow e$ events:
  - Fast (500MHz) pulse digitization in the target
  - Select fast decaying pions (t~<26ns)
  - Already used in the "old" PiENu experiment: very effective.

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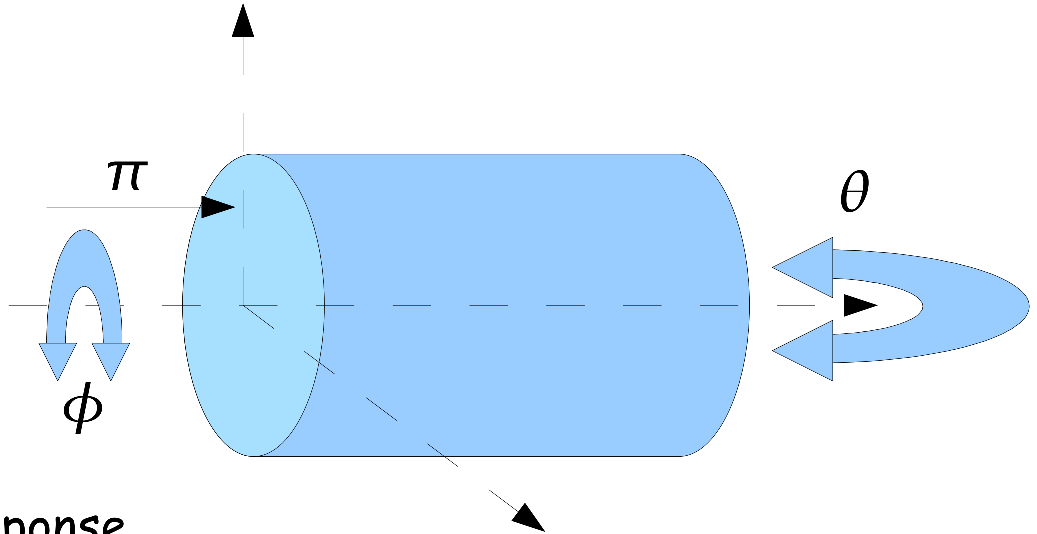
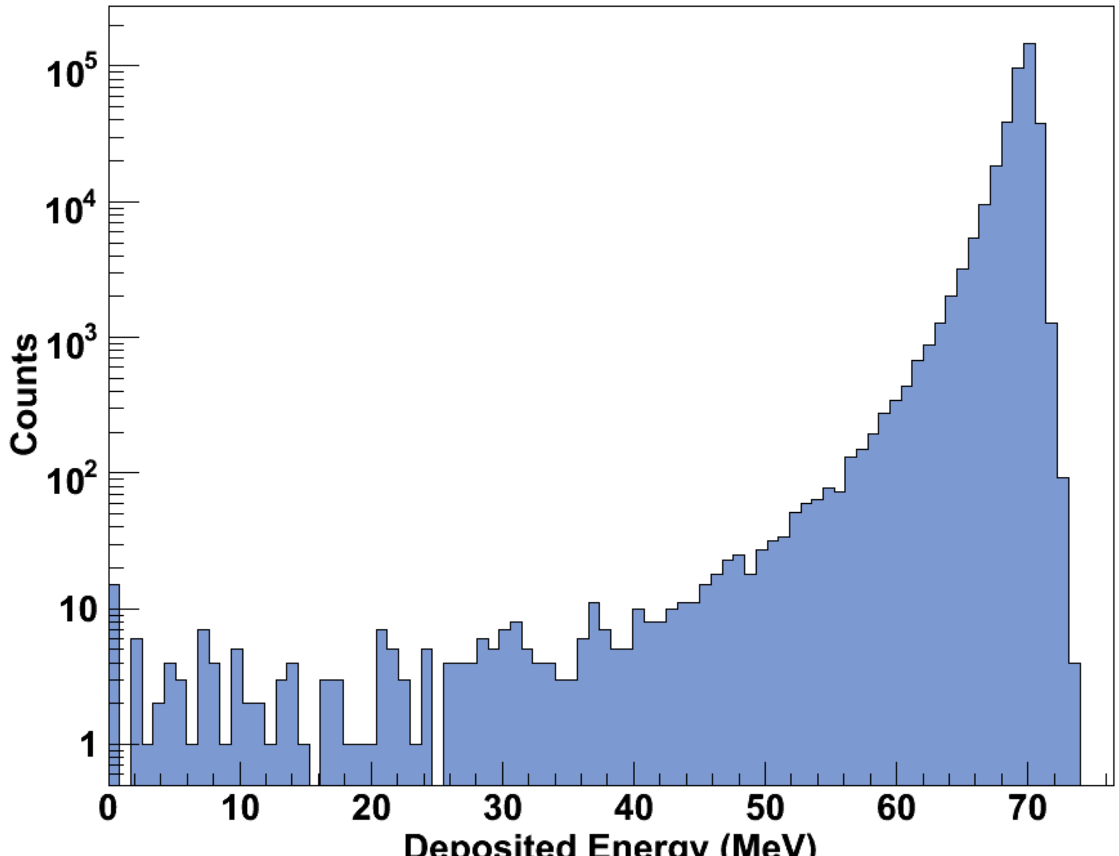
Dedicated Measurement Campaign planned

- Positron beam
- Hit the crystal's face varying:
  - Angle (polar θ and azimuthal ϕ)
  - Positions
  - Beam Momentum
- Experimental parameterization of the response
- Convolute with decay positrons energy
- Note: beam momentum spread contribution



MC Simulation

Expectation for the low energy tail

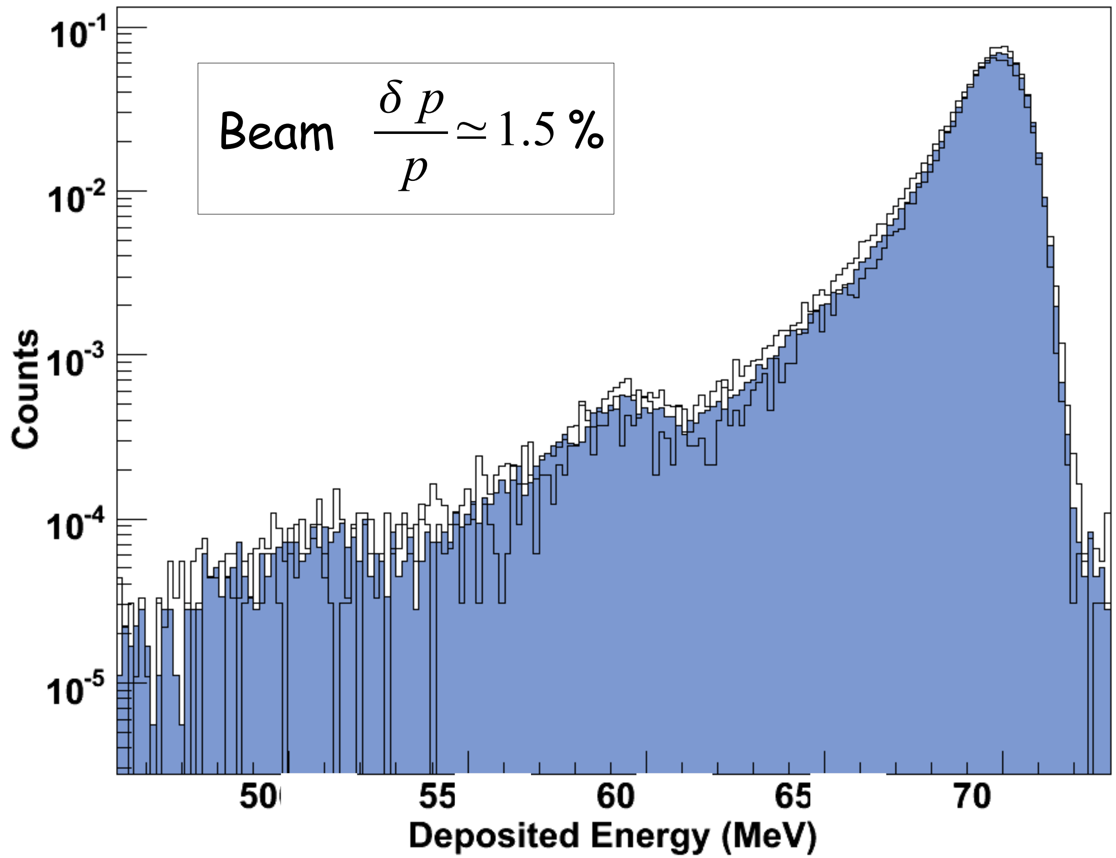


- Geant4 Simulation
- Low energy tail extending to very low energies
- Full simulation of the EM shower in the crystal :

  electrons / positrons / photons
- Compton, Photoeffect, Pair Production, Ionization, Bhabha/Moller scattering,..

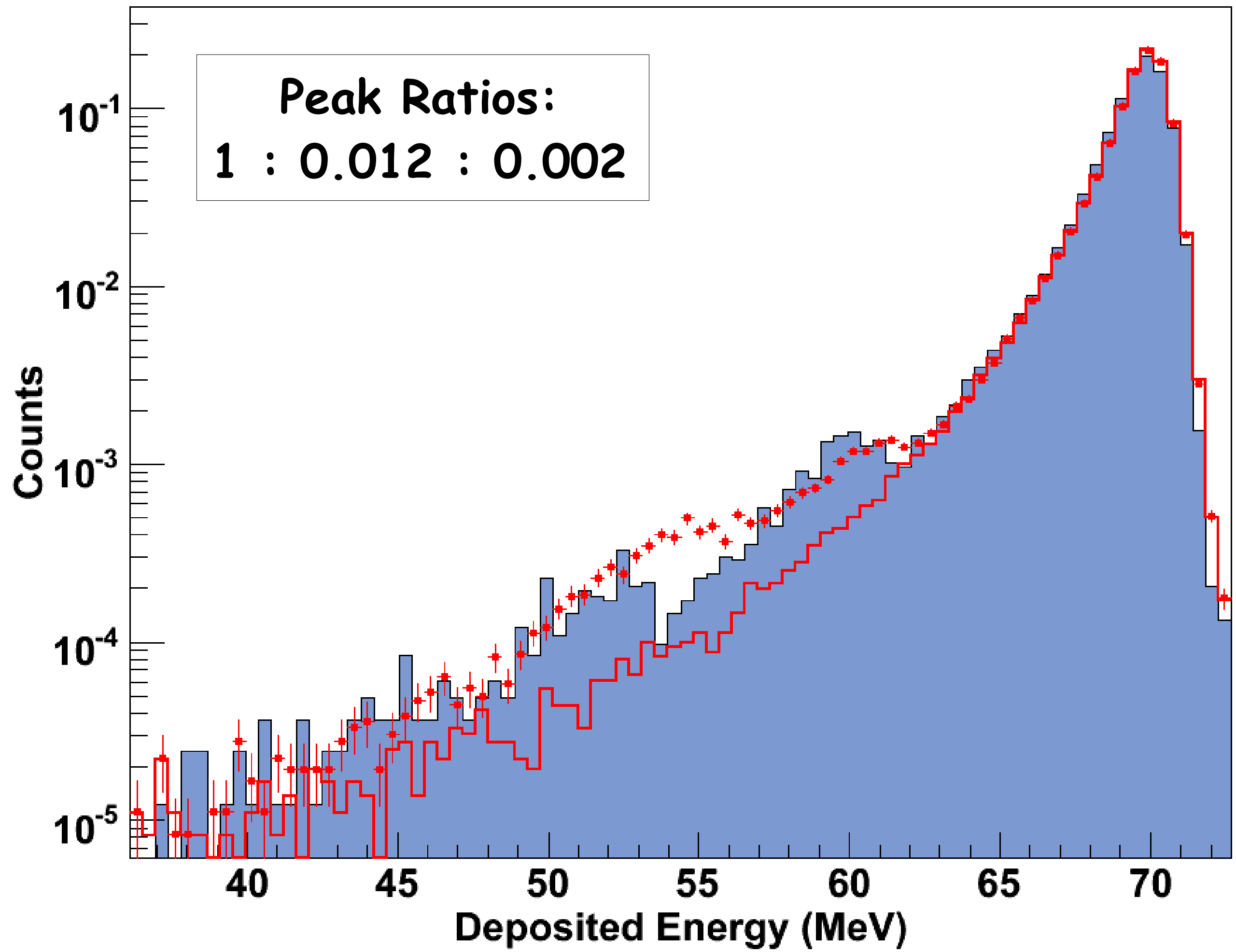
First Lineshape Measurements

Measurements at different Beam Momenta



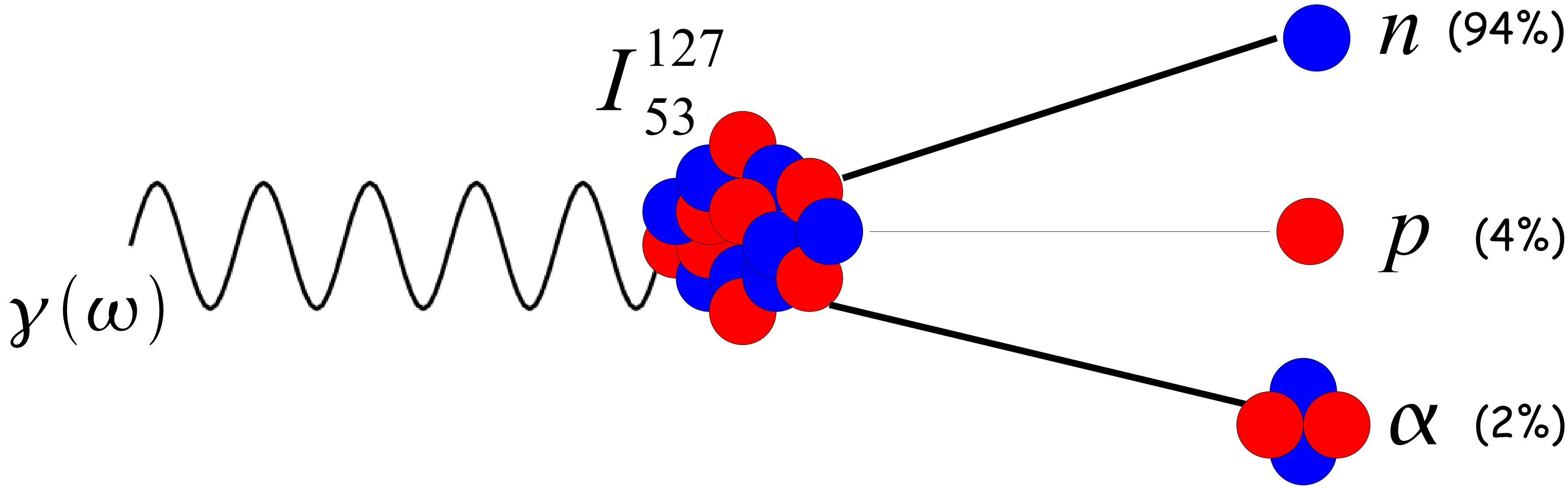
- Unexpected peaks appearing at lower energies
- Measurements at various beam momenta/magnet/slits settings
- Measurements at various angles and entrance positions
- Limited material in front of the crystal (only one scintillator)
- → The peaks are not from instrumental origin

MC Including Hadronic Interactions



- MC predicts the presence of structures
- Connected to hadronic processes (QGSP_BERT physics list)
- MC has to be improved for exactly reproducing the lineshape
- The low energy tail increases by ~0.8%

Nuclear Photoabsorption



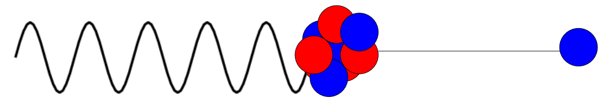
$$\sigma(\omega)=4\pi\alpha\omega\int d\Psi_f \left|\langle\Psi_f|D|\Psi_0\rangle\right|^2 \delta(E_f-E_0-\omega)$$

- Shower photons can be captured by Iodine nuclei
- Sodium gives a negligible contribution (>15 times less)
- Photoabsorption is mainly followed by neutron emission

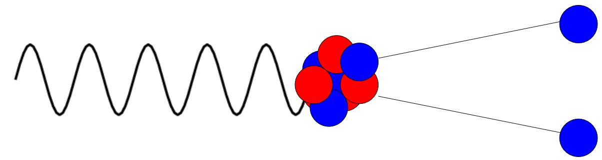
Neutrons in NaI

Separation Energies

$$I_{53}^{127} \rightarrow I_{53}^{126} + n \qquad E_{1n} = 9.14\,MeV$$



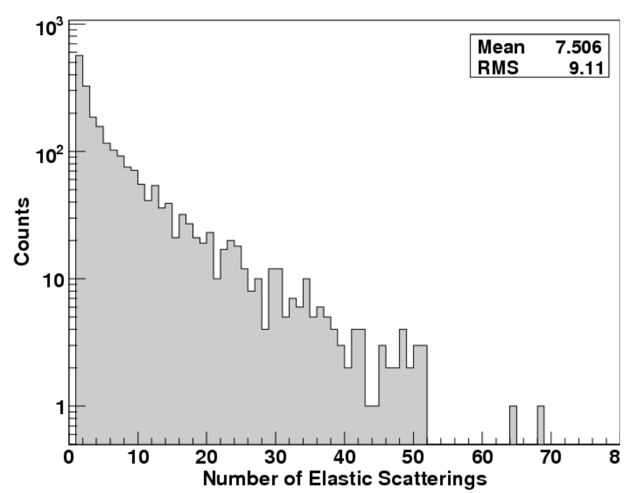
$$I_{53}^{127} \rightarrow I_{53}^{125} + 2n \qquad E_{2n} = 16.3\,MeV$$

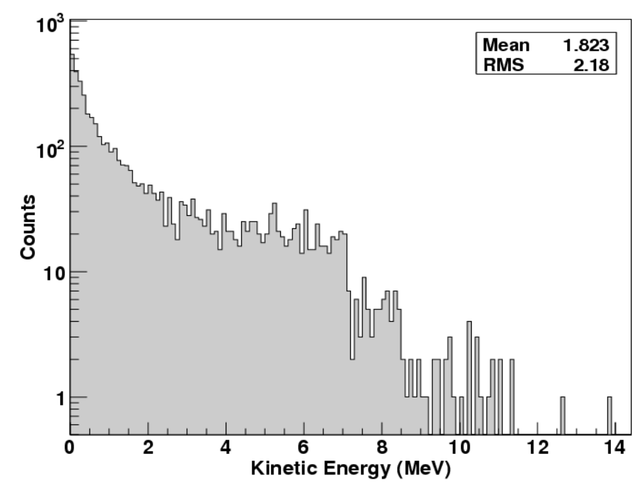


- If the neutron(s) escape the crystal without depositing any energy, at least E_{1n} or E_{2n} is not observed.

Energy Deposition Mechanisms

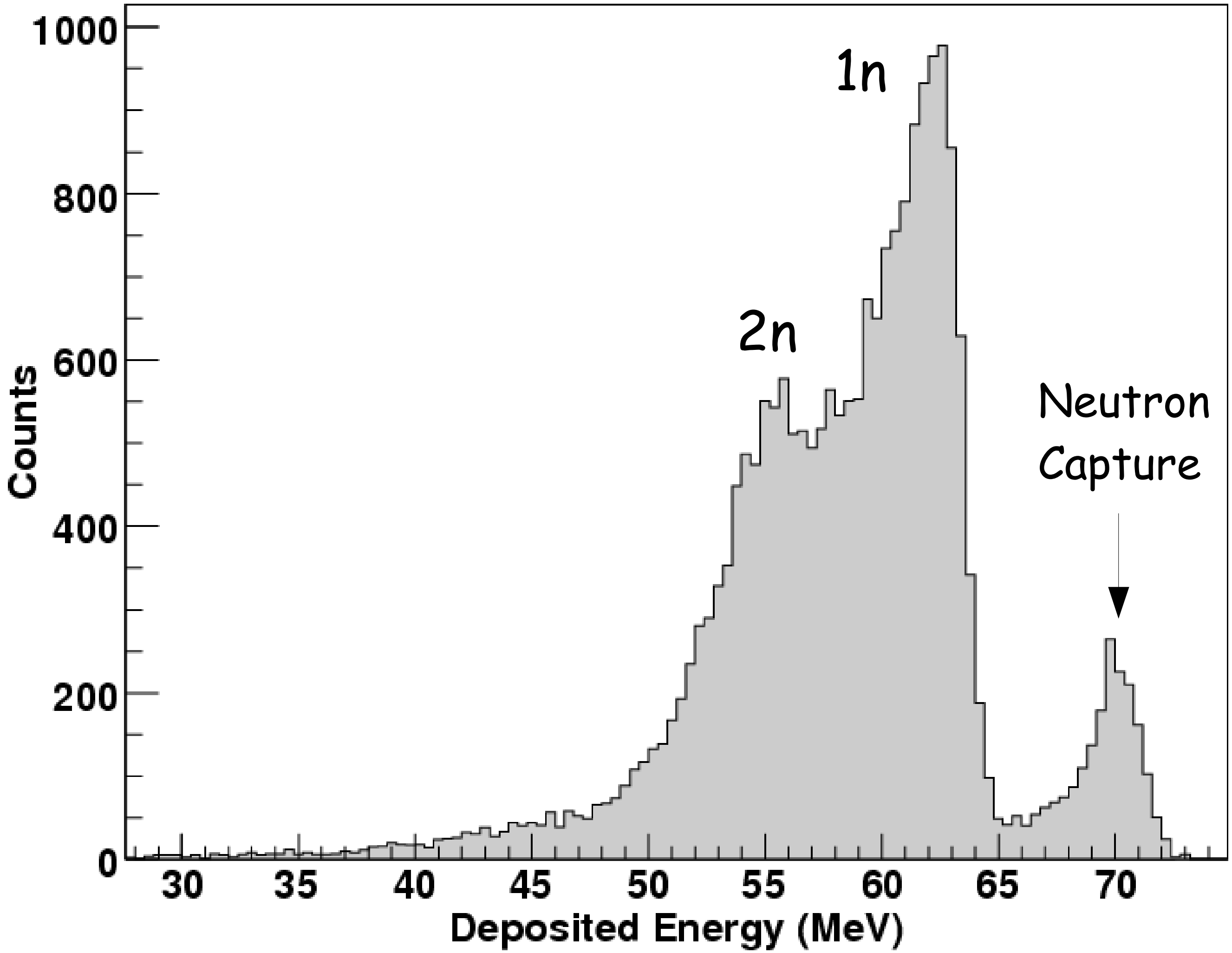
- Elastic Scattering
- Inelastic scattering
- Neutron absorption





Neutrons in NaI

Events with at least one Nuclear Photoabsorption



Conclusions

PiENu is a high precision experiment

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Nuclear effects observed: high resolution (<1% @70 MeV) and statistics

Consequence: increase of the tail by ~0.8%

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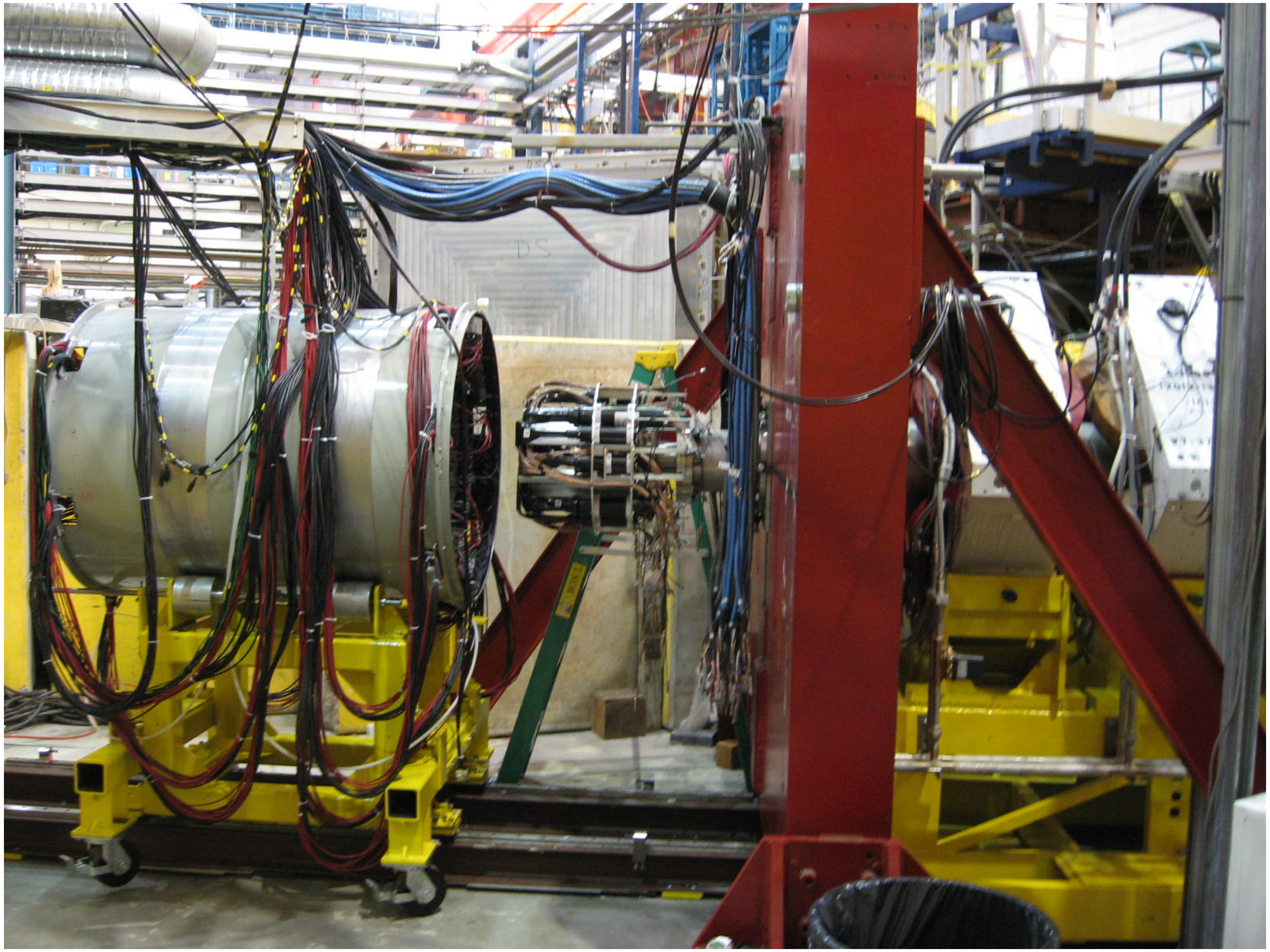
Effect observed for the first time in a NaI calorimeter

The PiENu Experiment is ready for taking data!



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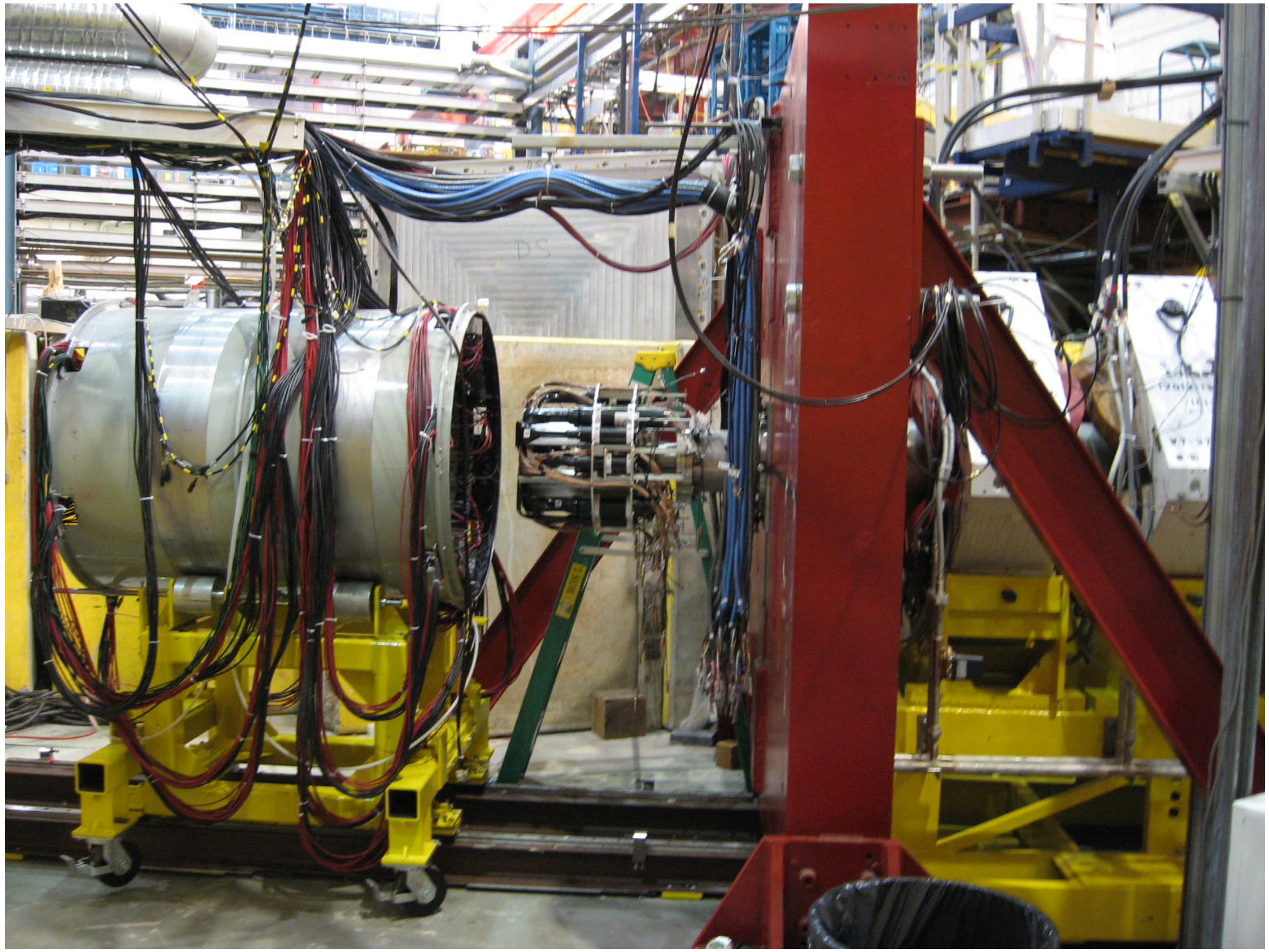

Thank You for the Attention!