Performance and simulation of PEN CsI Calorimeter

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PEN Collaboration

Overview

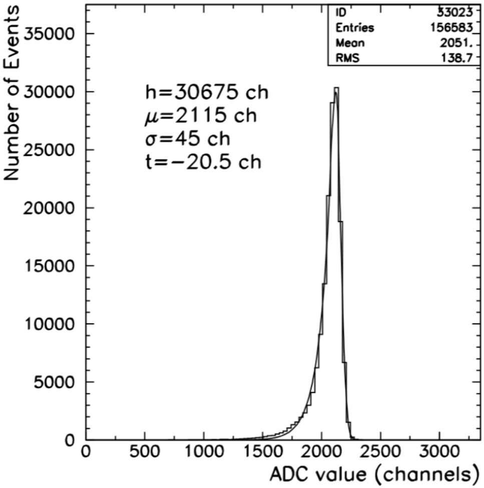
- First Crystals
- PEN Detector/Experiment
- Energy collection
- Pen approach to analysis
- Monte Carlo simulation
- Radiative decays and large solid angle
- Tail Analysis
- Summary

In the beginning - first crystals

1997: 44 crystals produced by Bicron

70 MeV monoenergetic positrons

Responses added



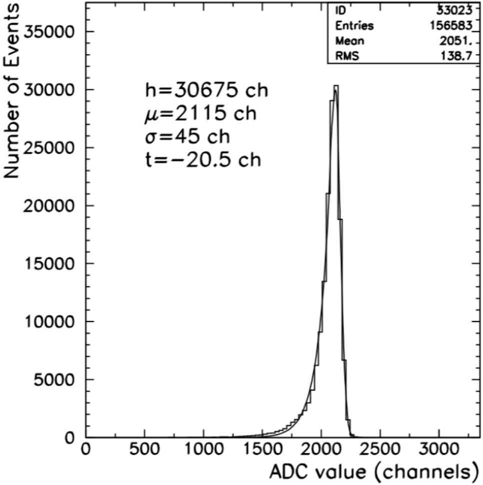
In the beginning - first crystals

1997: 44 crystals produced by Bicron

70 MeV monoenergetic positrons

Responses added

Exponential gaussian fit



$\sigma = 1.8$ MeV (FWHM 4.3 MeV at 70)

6.1% (Penny Slocum's thesis)

240 crystals produced for PiBeta experiment $\pi^+ \rightarrow \pi^0 \beta^+ \nu$

Crystal technica produced remaining 196

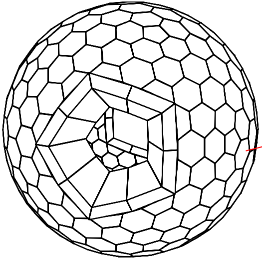
Hexagonal, pentagonal, tetragonal pyramids

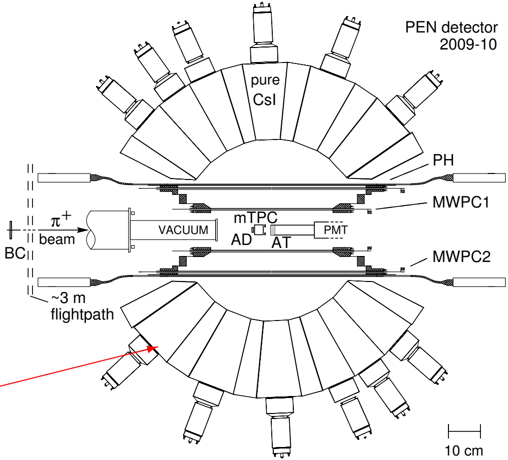
85% of total light output in first 20 ns

40-110 photoelectrons/MeV

Detector Setup

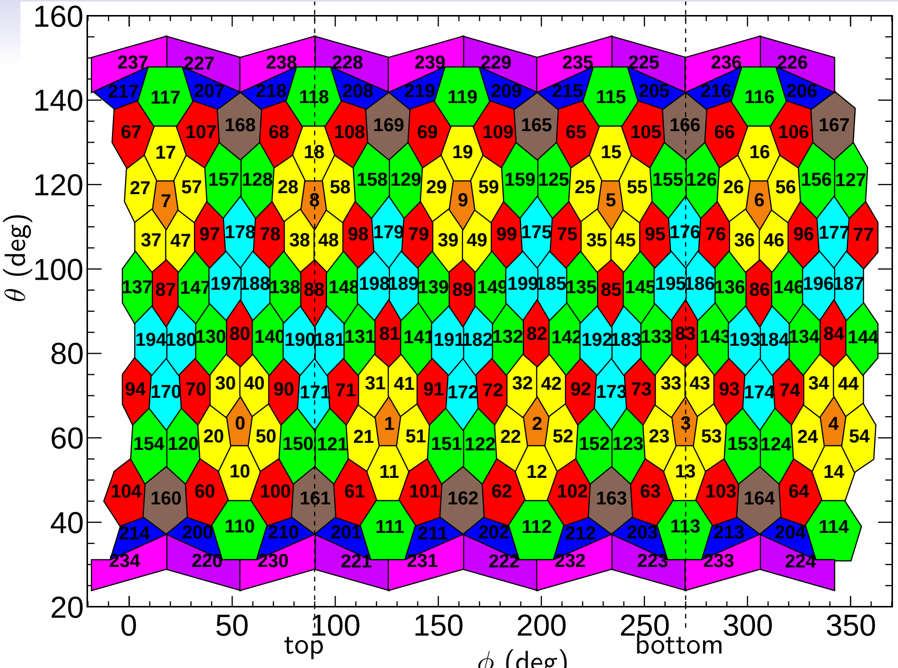
- πE1 beamline at PSI
- stopped π^+ beam
- active target counter
- 240 module spherical pure CsI calorimeter
- central tracking
- beam tracking
- digitized waveforms





BC: Beam Counter
AD: Active Degrader
AT: Active Target

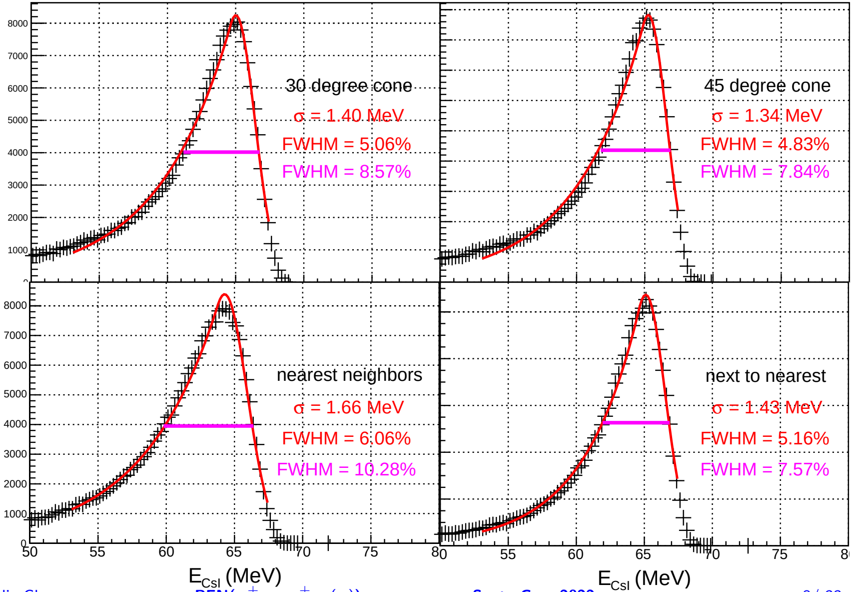
PH: Plastic Hodoscope (20 stave cylindrical)
MWPC: Multi-Wire Proportional Chamber (cylindrical)
mTPC: mini-Time Projection Chamber


θ (deg)
ϕ (deg)
160
140
120
100
80
60
40
20
0
50
100
150
200
250
300
350
top
bottom
237 227 238 228 239 229 235 225 236 226
217 117 207 218 118 208 219 119 209 215 115 205 216 116 206
67 107 168 68 108 169 69 109 165 65 105 166 66 106 167
17 18 19 15 16
27 7 57 157 128 28 8 58 158 129 29 9 59 159 125 25 5 55 155 126 26 6 56 156 127
37 47 97 178 78 38 48 98 179 79 39 49 99 175 75 35 45 95 176 76 36 46 96 177 77
137 87 147 197 188 138 88 148 198 189 139 89 149 199 185 135 85 145 195 186 136 86 146 196 187
194 180 130 80 140 190 181 131 81 141 191 182 132 82 142 192 183 133 83 143 193 184 134 84 144
94 170 70 30 40 90 171 71 31 41 91 172 72 32 42 92 173 73 33 43 93 174 74 34 44
154 120 20 0 50 150 121 21 1 51 151 122 22 2 52 152 123 23 3 53 153 124 24 4 54
10 11 12 13 14
104 160 60 100 161 61 101 162 62 102 163 63 103 164 64
214 200 110 210 201 111 211 202 112 212 203 113 213 204 114
234 220 230 221 231 222 232 223 233 224

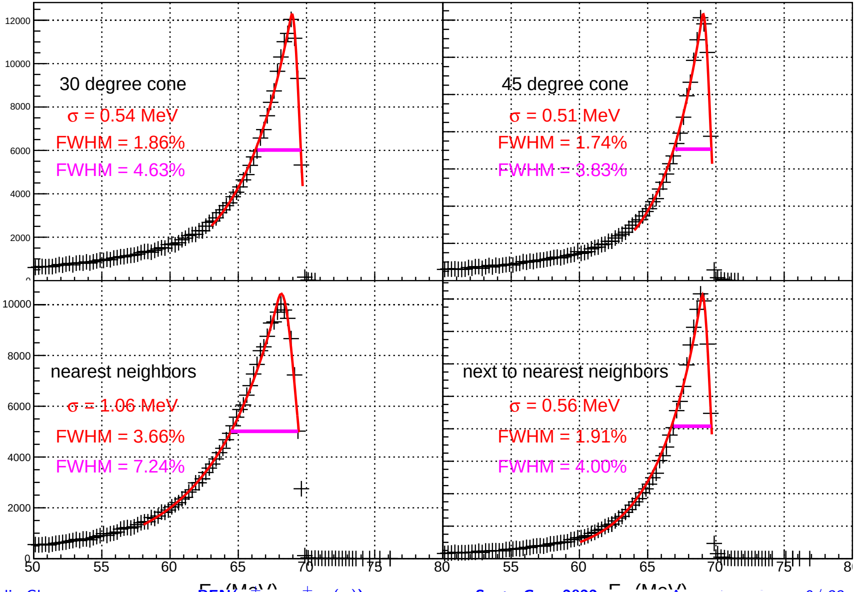
Current methods of energy collection

- 30 degree cone
- 45 degree cone
- Main crystal + nearest neighbors (up to 7)
- Main crystal + nearest neighbors + next to nearest neighbors (up to 13)

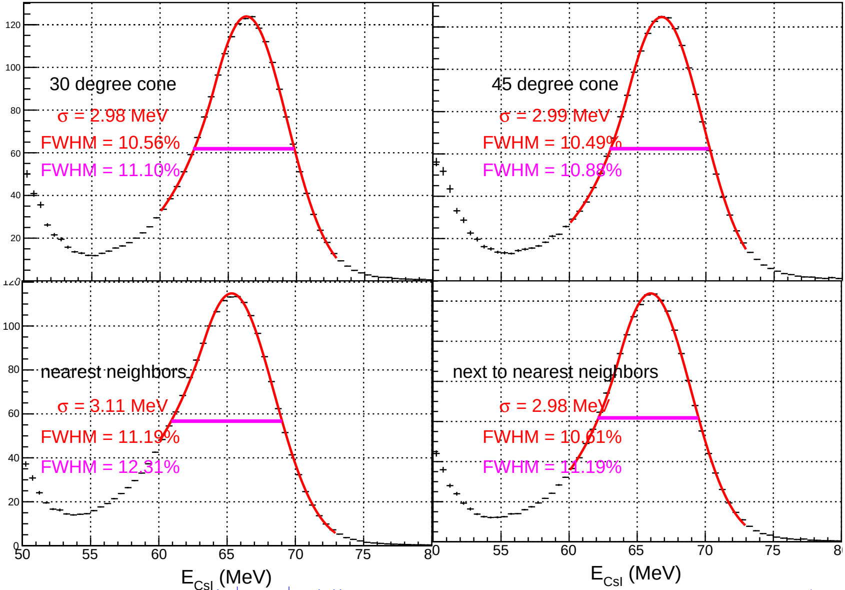
Geant CsI energy responses



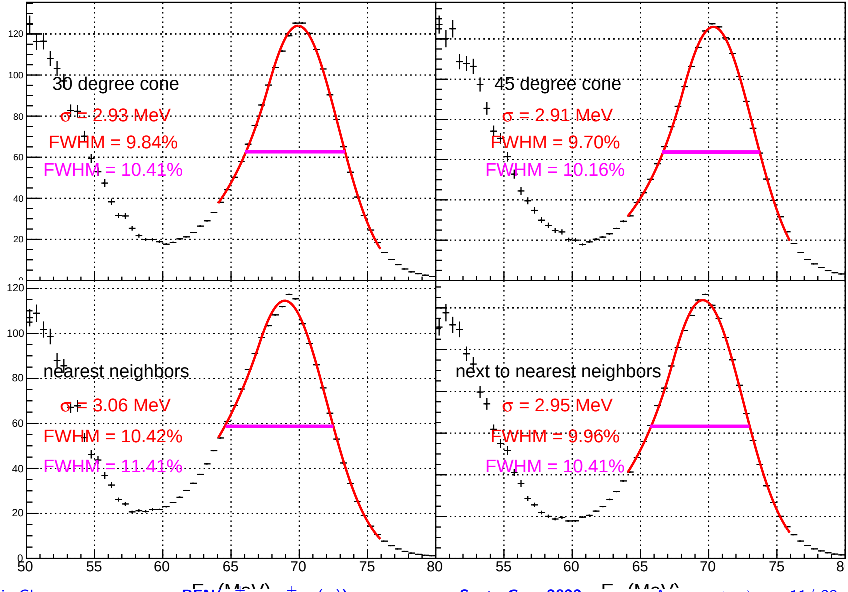
Geant total energies (CsI + Tgt + Hod)



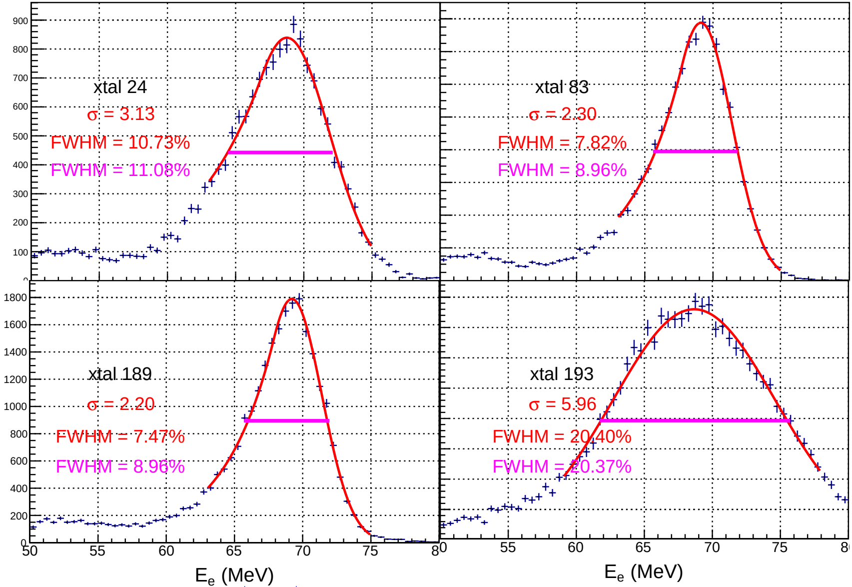
Measured CsI energy



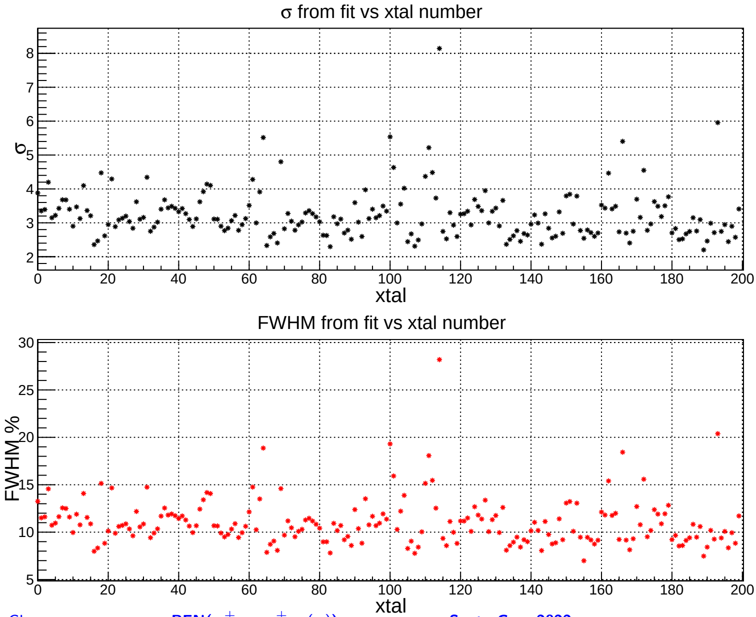
Measured energy (CsI + Tgt + Hod)



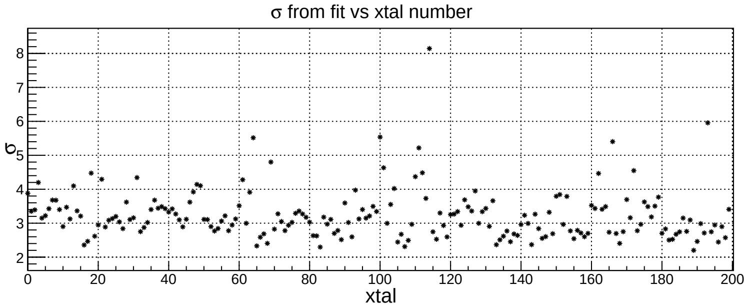
xtal + nearest neighbors spread

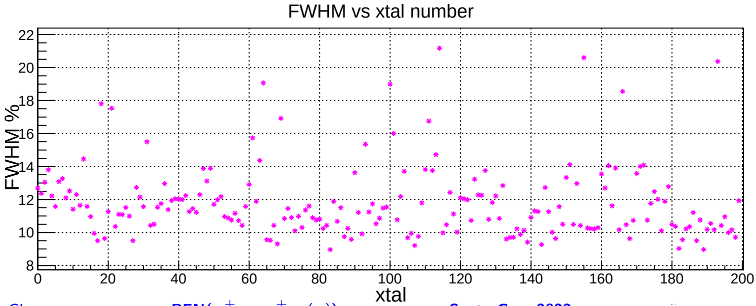


xtal + nearest neighbors spread



xtal + nearest neighbors spread



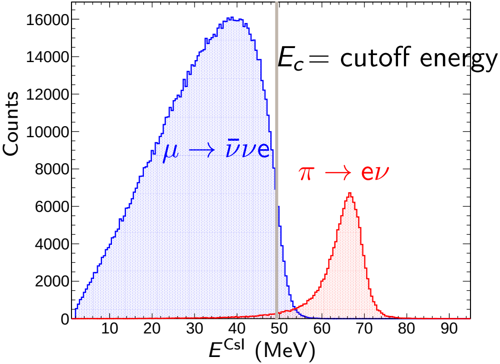


PEN analysis approach

$$R^{\text{exp}}_{\pi 2e} = \frac{N_{\pi \to e\nu(\gamma)}}{N_{\pi \to \mu\nu(\gamma)}} \times \text{corrections}$$

With

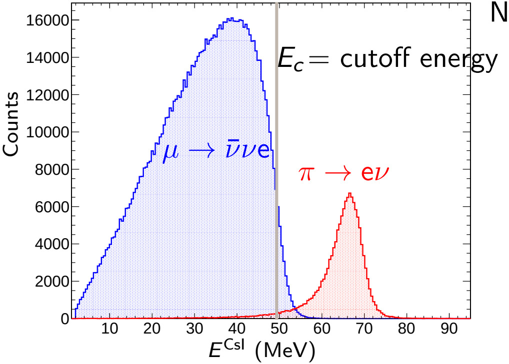
$$N_{\pi \to e\nu(\gamma)} = N_{\text{tail}} + N_{\text{peak}}$$



PEN analysis approach

Rewrite

$$R_{\pi 2e}^{\text{exp}} = \frac{N_{\text{peak}}}{N_{\pi\to\mu\nu(\gamma)}} \times (1 + \epsilon_{\text{tail}}) \times \text{corrections}$$



Need:

$N_{\pi\to\mu\nu(\gamma)}$

N_{peak}

Tail fraction

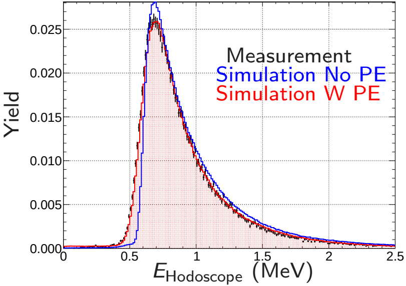
Challenges

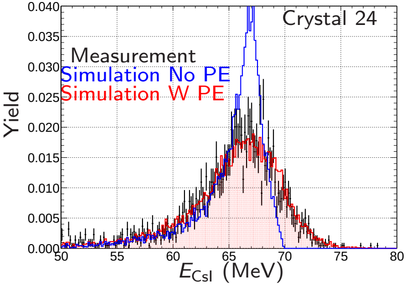
Geant gives energies, timings, and positions

Requires additional physics input to simulate full detector response

In the Experiment:

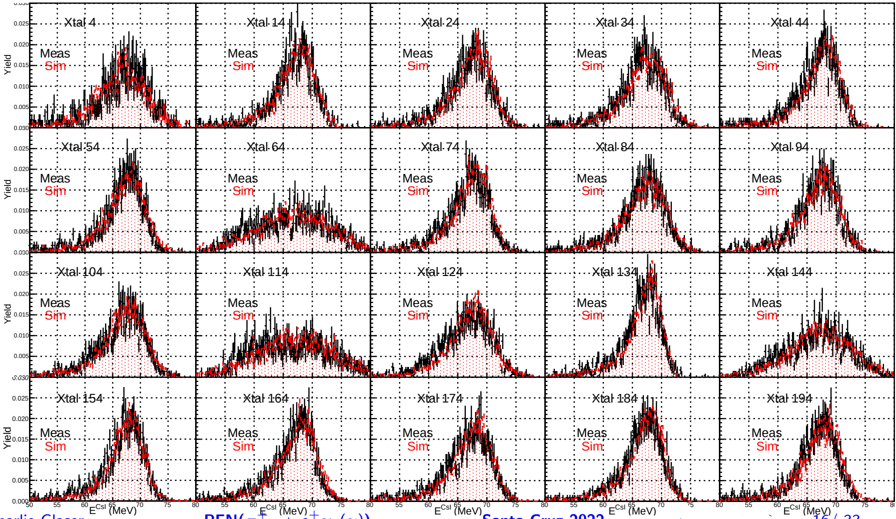
- digitized energies and timings of detector elements
- mTPC, beam counters, and target waveforms
- photoelectron (pe) statistics smear signal



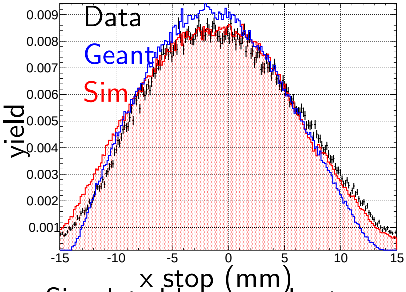


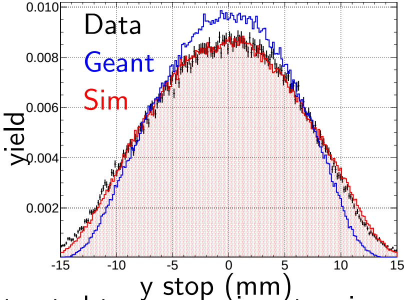
CsI - Unique Xtals

- Optical and Response Non-uniformities, $\Delta\Omega$ Coverage
- 240 PMTs = 240 different quantum efficiencies



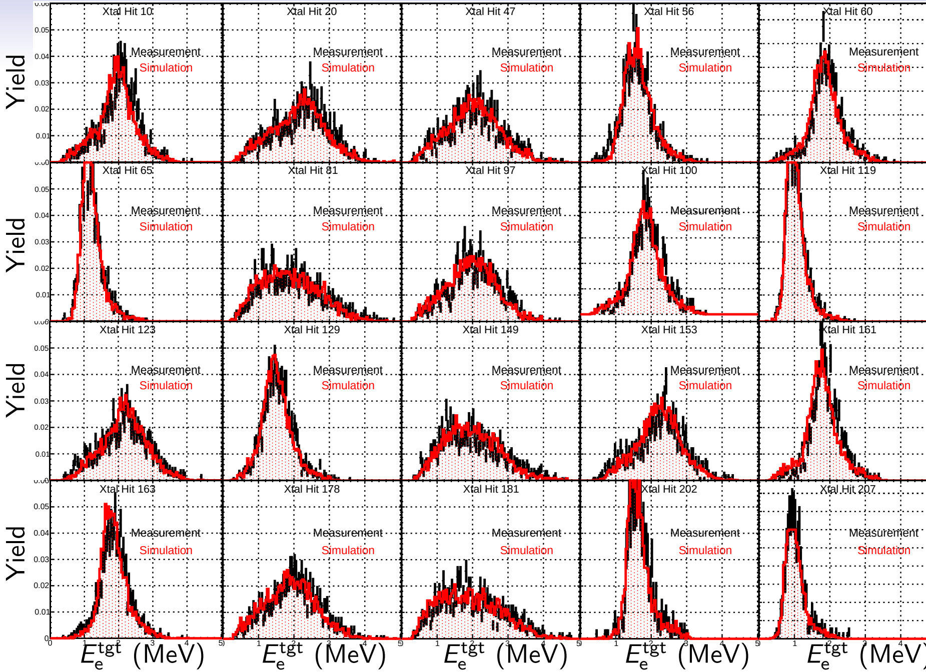
Correct stopping position



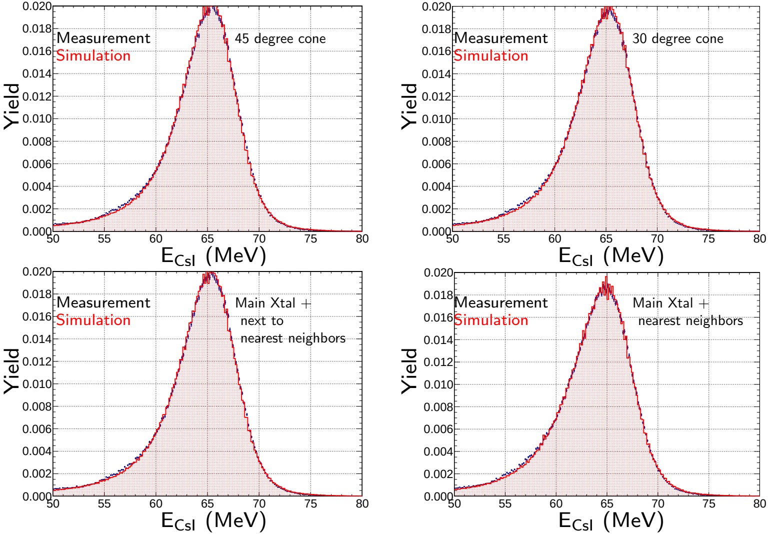


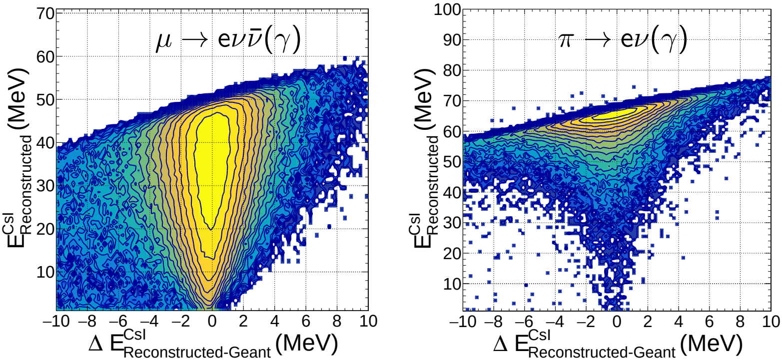
Simulated beam and mtpc constructed to ensure pion stopping positions consistent with data

Target energy deposition independent check


Xtal Hit 10
Xtal Hit 20
Xtal Hit 47
Xtal Hit 56
Xtal Hit 60
Xtal Hit 65
Xtal Hit 81
Xtal Hit 97
Xtal Hit 100
Xtal Hit 119
Xtal Hit 123
Xtal Hit 129
Xtal Hit 149
Xtal Hit 153
Xtal Hit 161
Xtal Hit 163
Xtal Hit 178
Xtal Hit 181
Xtal Hit 202
Xtal Hit 207
Measurement
Simulation
Yield
E_e^{tgt} (MeV)

CsI

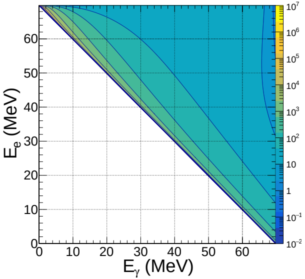

Measurement
Simulation
45 degree cone
30 degree cone
Main Xtal + next to nearest neighbors
Main Xtal + nearest neighbors
Yield
E_CsI (MeV)
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
50
55
60
65
70
75
80

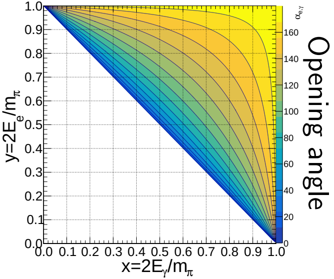


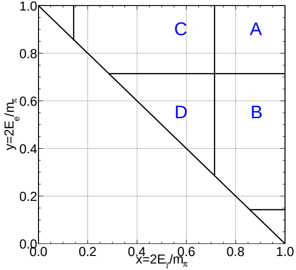
Offset due to software cuts applied equally to Data and Sim

Regions of $\pi \to e\nu\gamma$

All decays are radiative



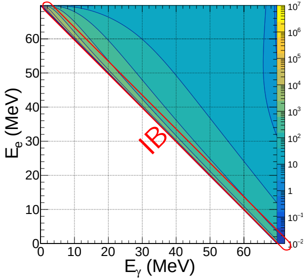


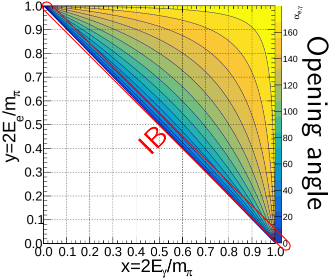


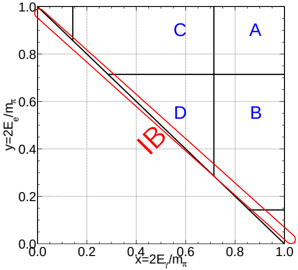
Phase space broken into regions

Regions of $\pi \to e\nu\gamma$

All decays are radiative



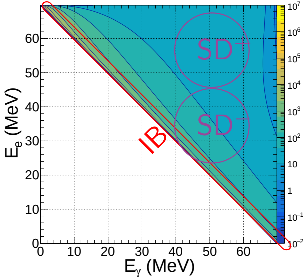


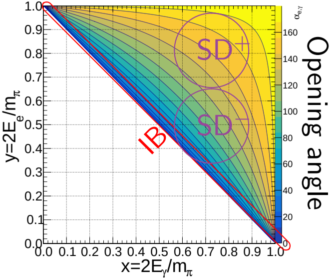


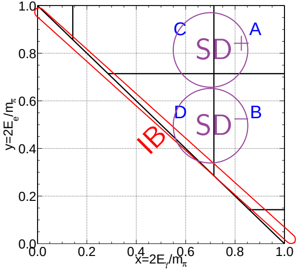
Inner Bremsstrahlung dominated

Regions of $\pi \to e\nu\gamma$

All decays are radiative



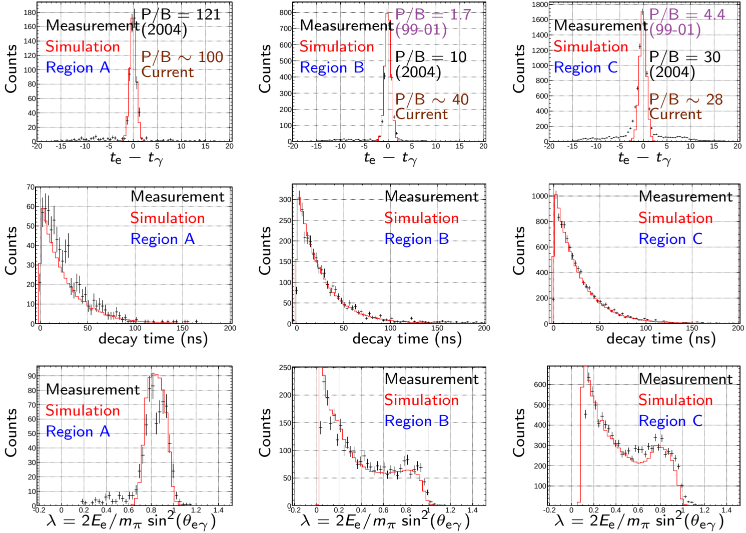




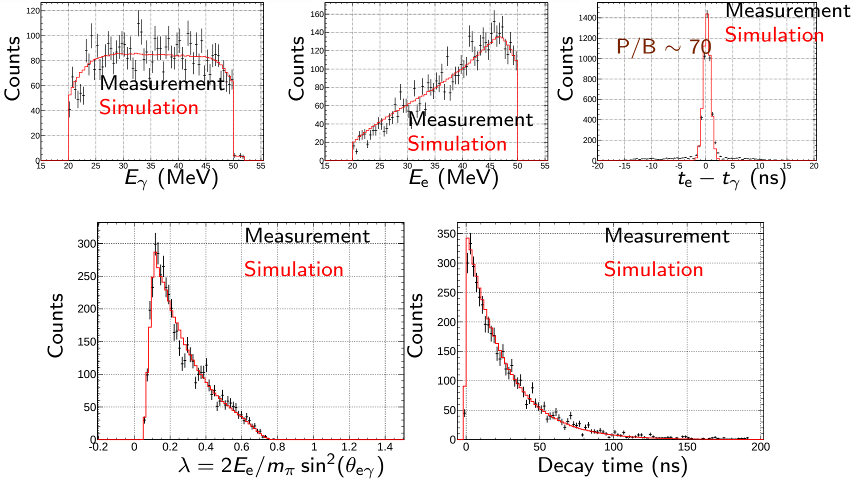
Inner Bremsstrahlung dominated

Structure Dependent
$SD^{+} \sim (F_V + F_A)^2$
$SD^{-} \sim (F_V - F_A)^2$

Radiative Decays $\pi \to e\nu\gamma$



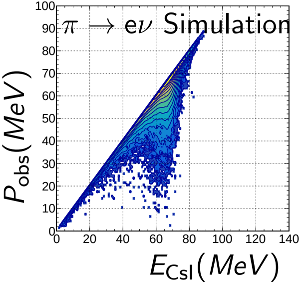
Region D

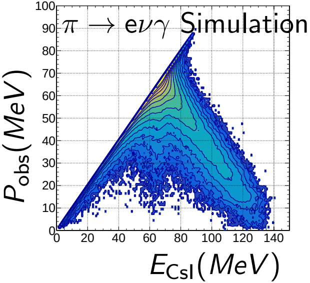


Can ID hard radiative Decays

PEN is first to look at region D in detail $(SD^-, F_V - F_A)$

Invariant Mass



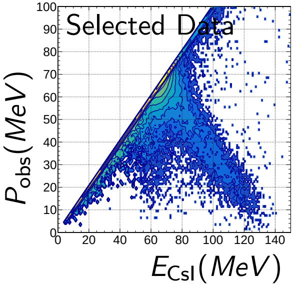


PEN indirectly measure p_ν

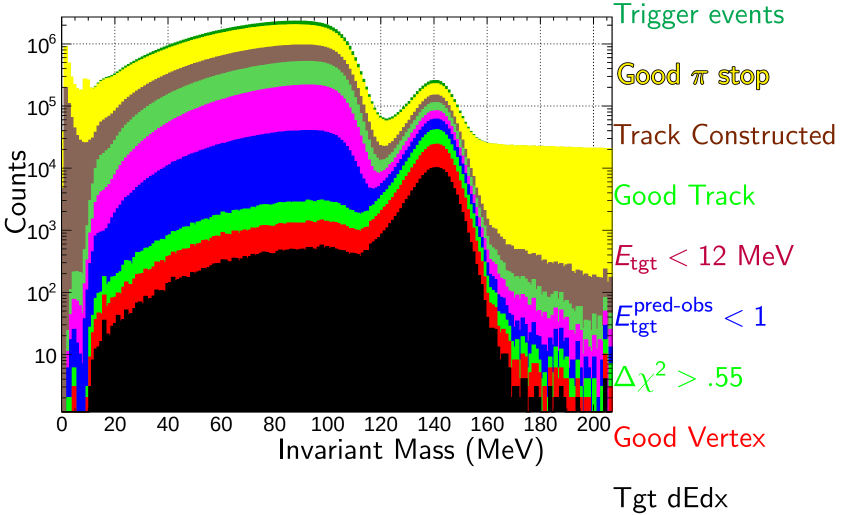
$$\underbrace{\vec{p}_e + \vec{p}_\gamma}_{p_{obs}} = -\vec{p}_\nu$$

$$\underbrace{E_\gamma + E_e}_{E_{obs}} + \underbrace{E_\nu}_{p_\nu c} = m_\pi c^2$$

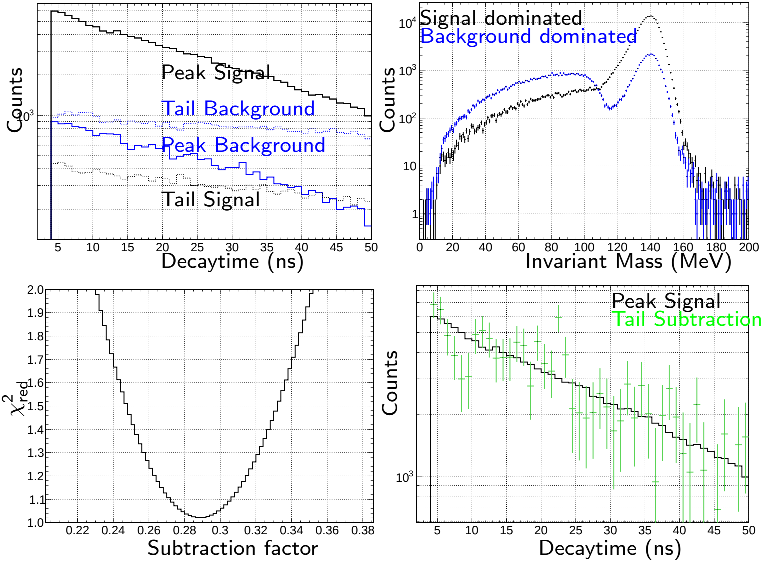
$$E_{obs} + p_{obs} c = m_\pi c^2$$



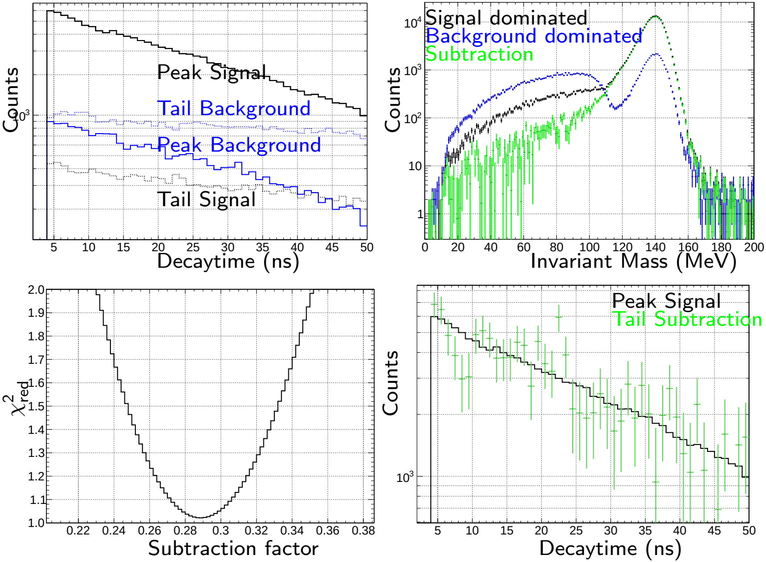
Tail Trigger



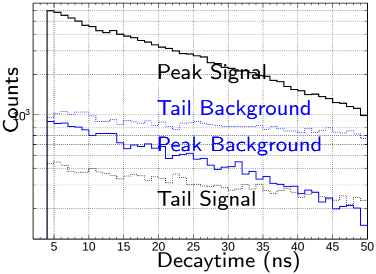
Subtraction

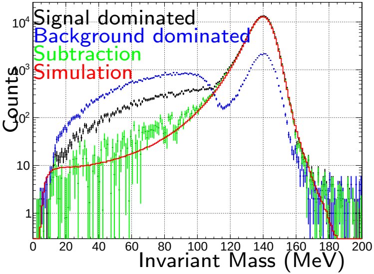


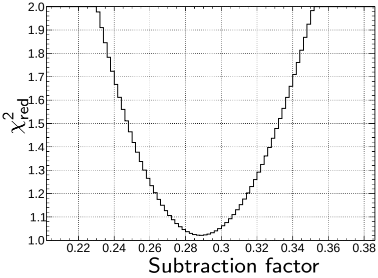
Subtraction

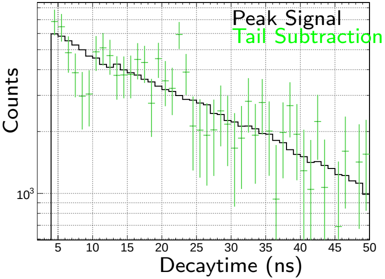


Subtraction

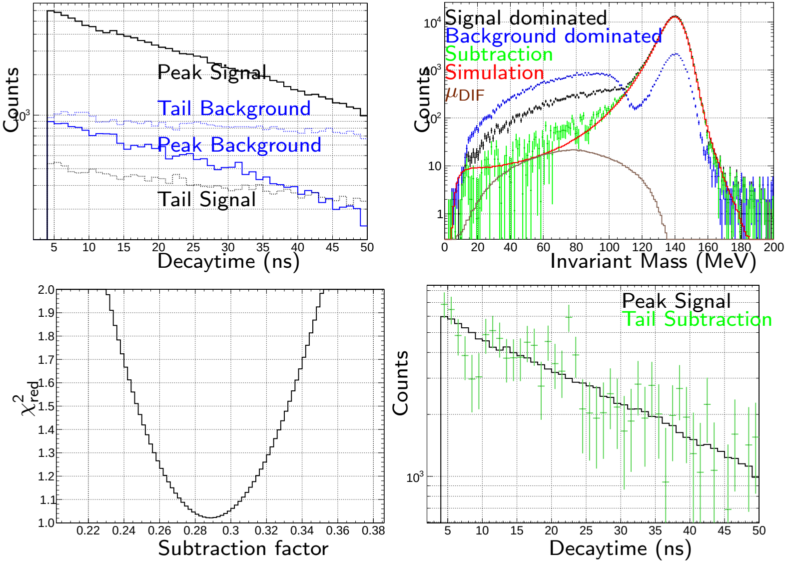




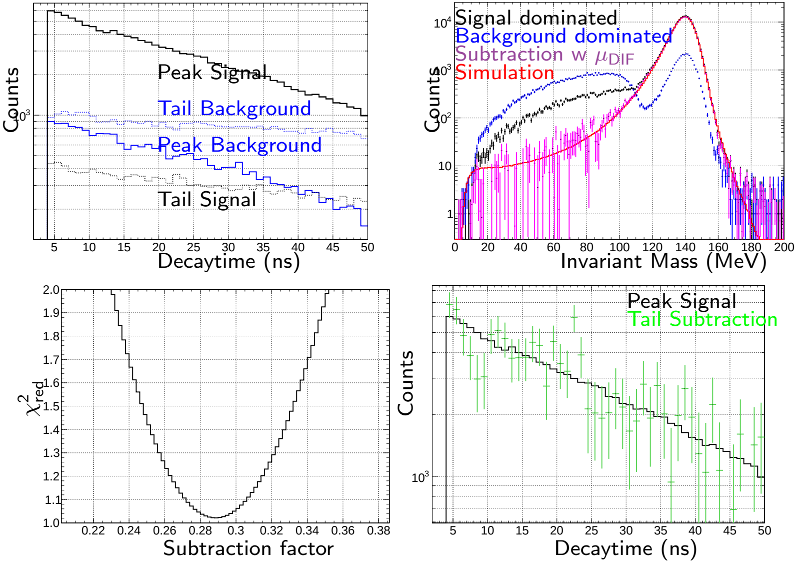




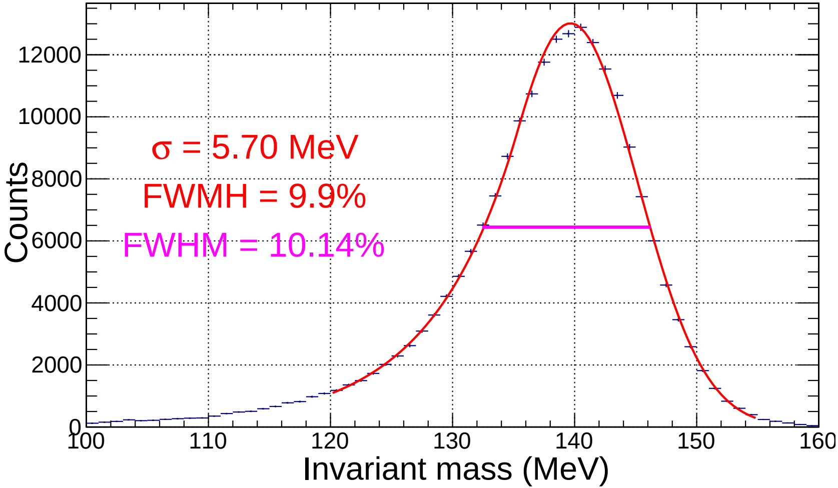
Subtraction



Subtraction



Invariant mass resolution



Photonuclear Absorption

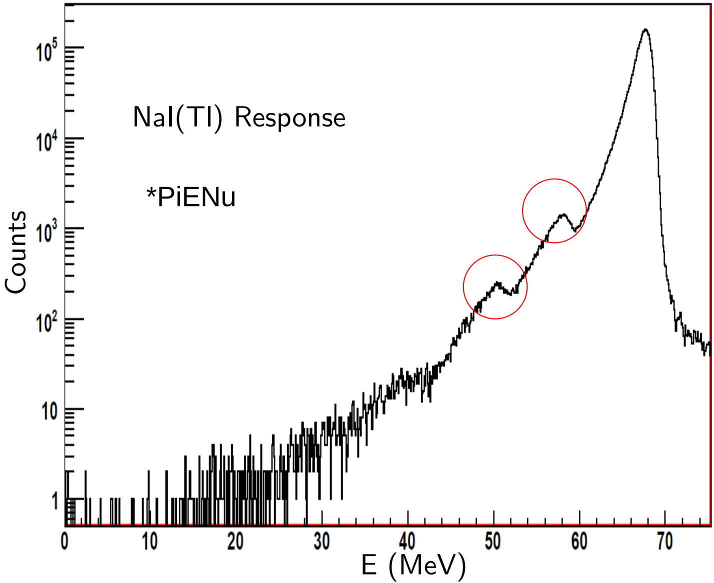
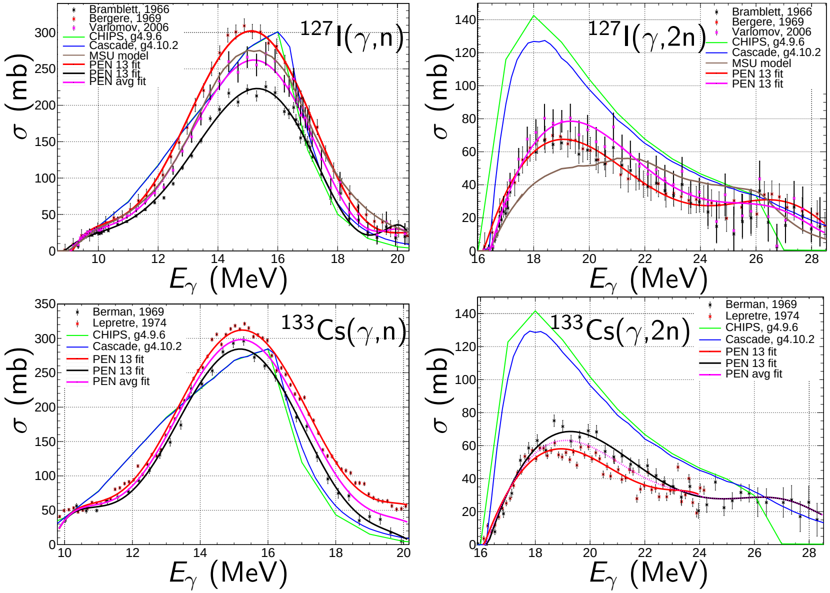
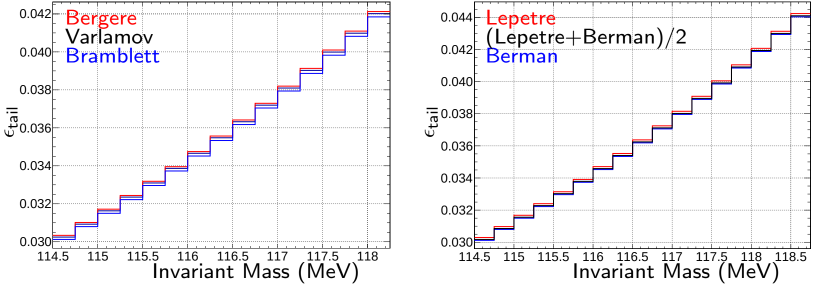


Photo nuclear X-sections



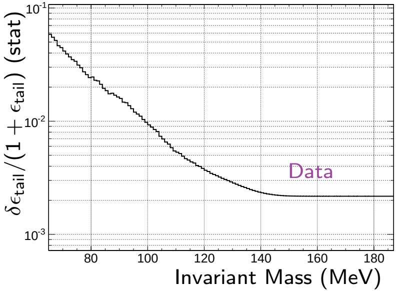
$^{127}I/^{133}Cs$



Higher $\sigma \Rightarrow$ higher tail fraction

$\delta\epsilon_{tail}$ studied with various cross sections

$\delta\epsilon_{\text{tail}}/(1+\epsilon_{\text{tail}})$



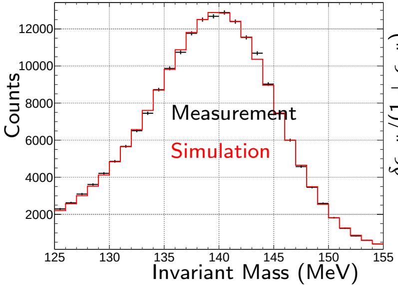
Statistical too high

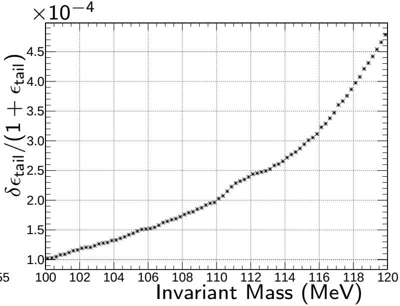
Simulation needed!

Systematics from :

Gain Variation

Photo-nuclear physics





Summary

- Resolution depends on how energy is determined
- PEN calorimeter has various xtals with various resolutions
- GEANT is supplemented to simulate a more realisitc response
- The large solid angle coverage permits study of radiative decays in all phase space
- The simulation includes methods and means for systematic tail study - photo nuclear effect

Family

Current and former PIBETA and PEN collaborators

L. P. Alonzi , K. Assamagan , V. A. Baranov , W. Bertl ,
C. Broennimann , S. Bruch , M. Bychkov , Yu.M. Bystritsky , M. Daum ,
T. Fl "ugel , E. Frlež , C. Glaser, R. Frosch, K. Keeter, V.A. Kalinnikov ,
N.V. Khomutov , J. Koglin , A.S. Korenchenko , S.M. Korenchenko ,
M. Korolija , T. Kozlowski, N.P. Kravchuk , N.A. Kuchinsky,
D. Lawrence , M. Lehman, W. Li , J. S. McCarthy , R. C. Minehart ,
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, S. Ritt , , P. Robmann , O.A. Rondon-Aramayo , A.M. Rozhdestvensky
, T. Sakhelashvili , P. L. Slocum , L. C. Smith , N. Soić RB,
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*, E.P. Velicheva , M. Vitz, V.P. Volnykh, Y. Wang , C. Wigger ,
H.-P. Wirtz , K. Ziock .

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