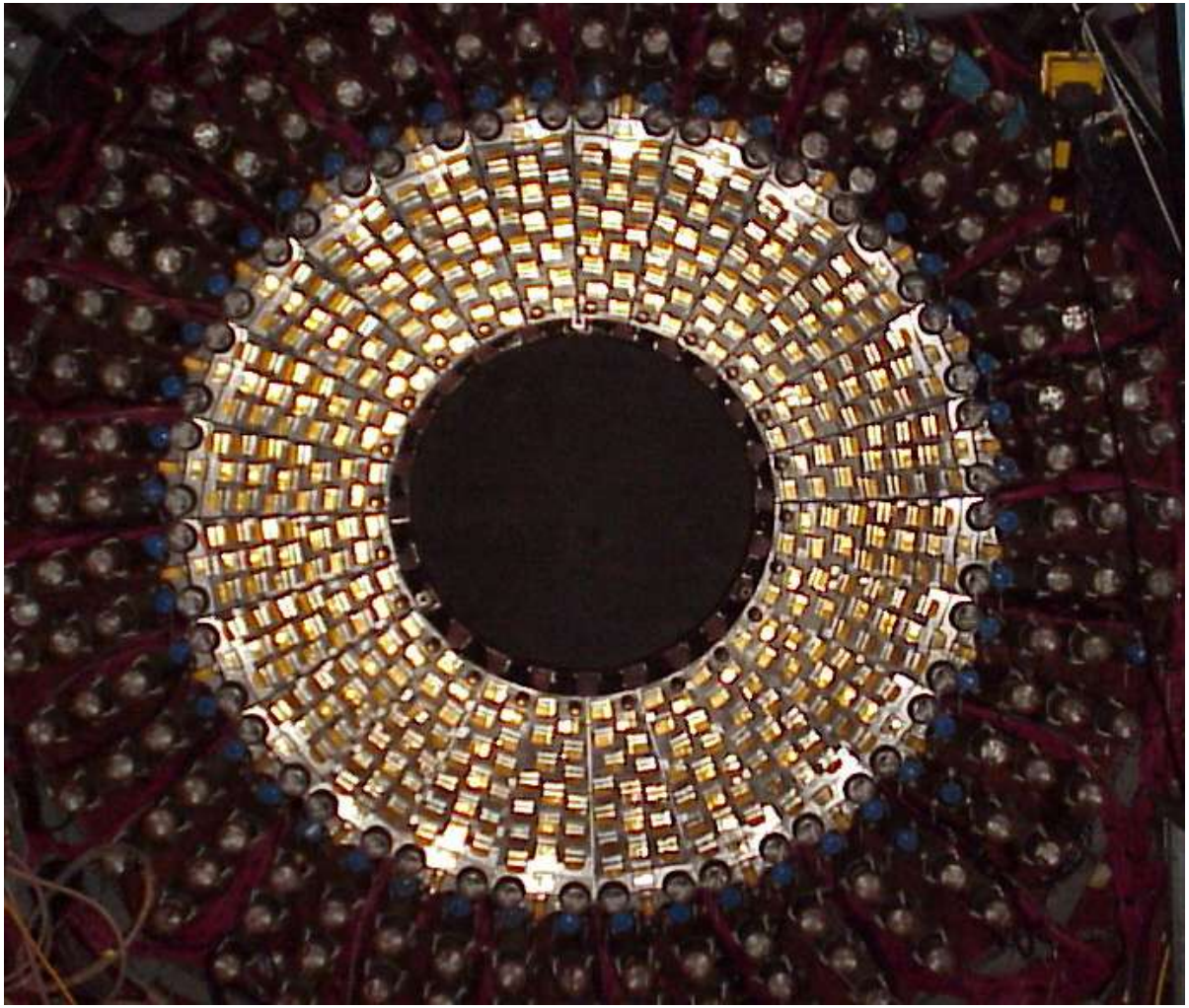
E949 Photon Veto Measurements



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Outline

- Sources of inefficiency
- E949 photon detectors
- E949 π° rejection
  - $K^+ \rightarrow \pi^+\pi^0$ rejection optimized for $K^+ \rightarrow \pi^+\nu\bar{\nu}$ and $\pi^0 \rightarrow \nu\bar{\nu}$ searches
- Work in progress:
  - Single photon detection efficiency
    - Comparison with Monte Carlo
  - Effect of dead material (carbon)

Sources of inefficiency

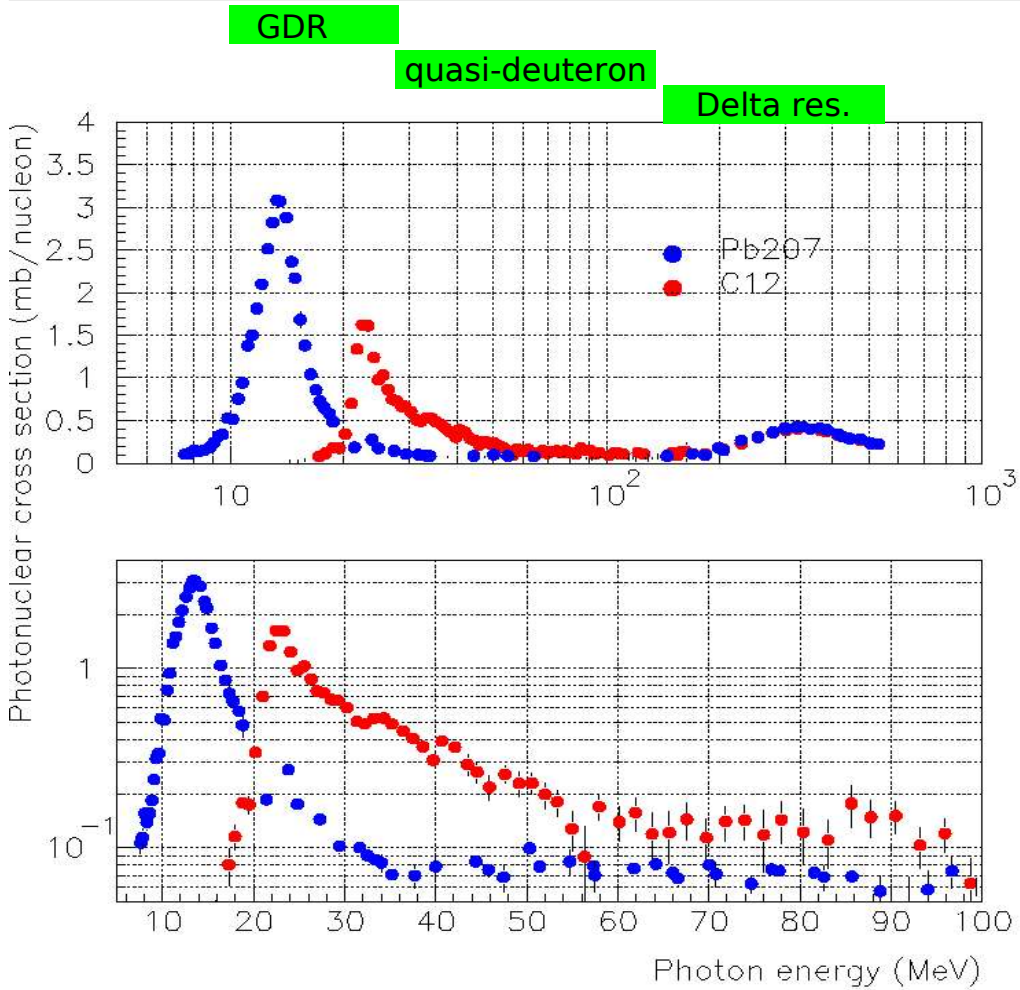
In E949, most photons of interest come from $K\pi 2$ decays ($p(\pi)$=205 MeV/c)

⇒ $E(\gamma)$ = 20-200 MeV

Main sources of photon detection inefficiency are:

- Sampling fluctuations
  - Contribution falls rapidly with energy. In E949, only significant at the lowest energies around 20 MeV
- Punchthrough
  - Calculable from photon mass attenuation coeffs (e.g. see PDG book)
  - Pretty small in most parts of E949
- Photonuclear interactions
  - Dominant effect. Difficult to simulate.
  - Cross sections generally known (well-measured for Pb and C)
  - Outgoing particles less well-measured; model usually needed

Photonuclear interactions



Compilation of measurements from http://cdfe.sinp.msu.ru

E949 photon energies span several different mechanisms

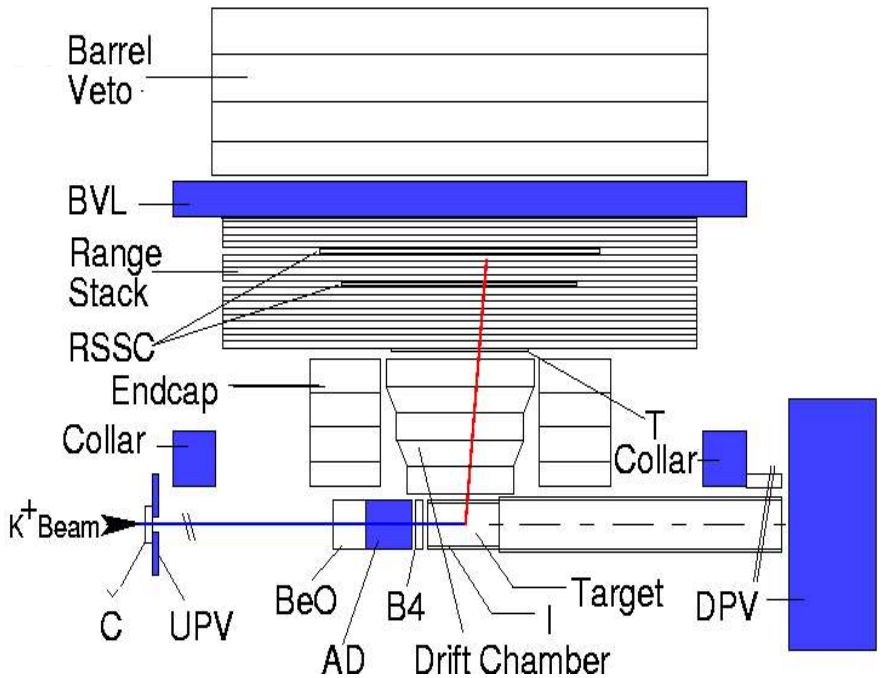
- Giant dipole resonance (GDR)
- "quasi-deuteron" region
- Pion production

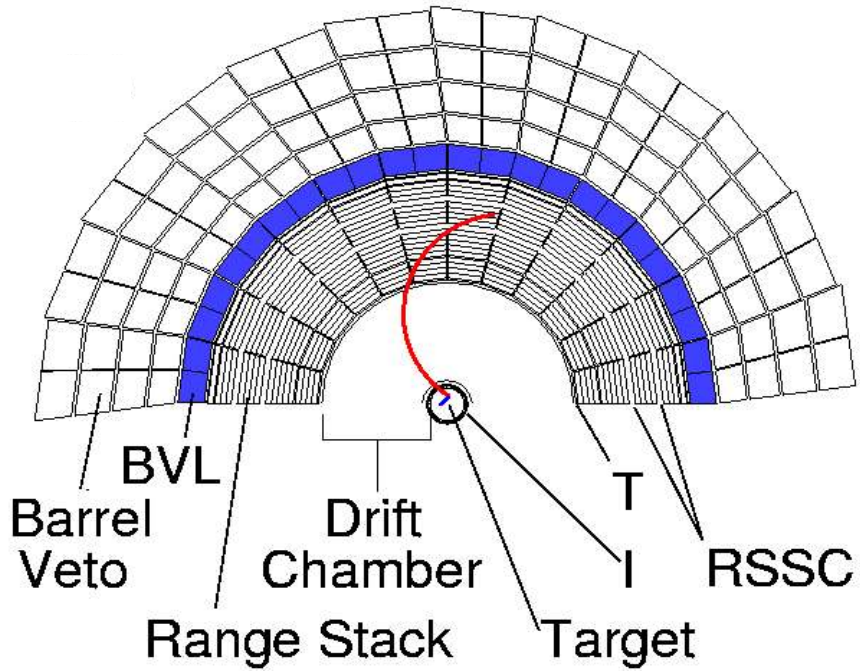
Interaction probability in carbon can be significant

- Prob $\propto \rho \cdot \sigma / A \cdot \delta x$
- ρ(scint) ~ 1/12 ρ(Pb) but scint typically 5 times thicker in sampling calorimeters. Higher cross section in carbon (for some energies) also compensates.
- Effect on inefficiency depends on outgoing particles (neutrons, protons, alphas, photons...)

Photonuclear modelling for low-Z materials seems to be difficult

E949 photon detectors

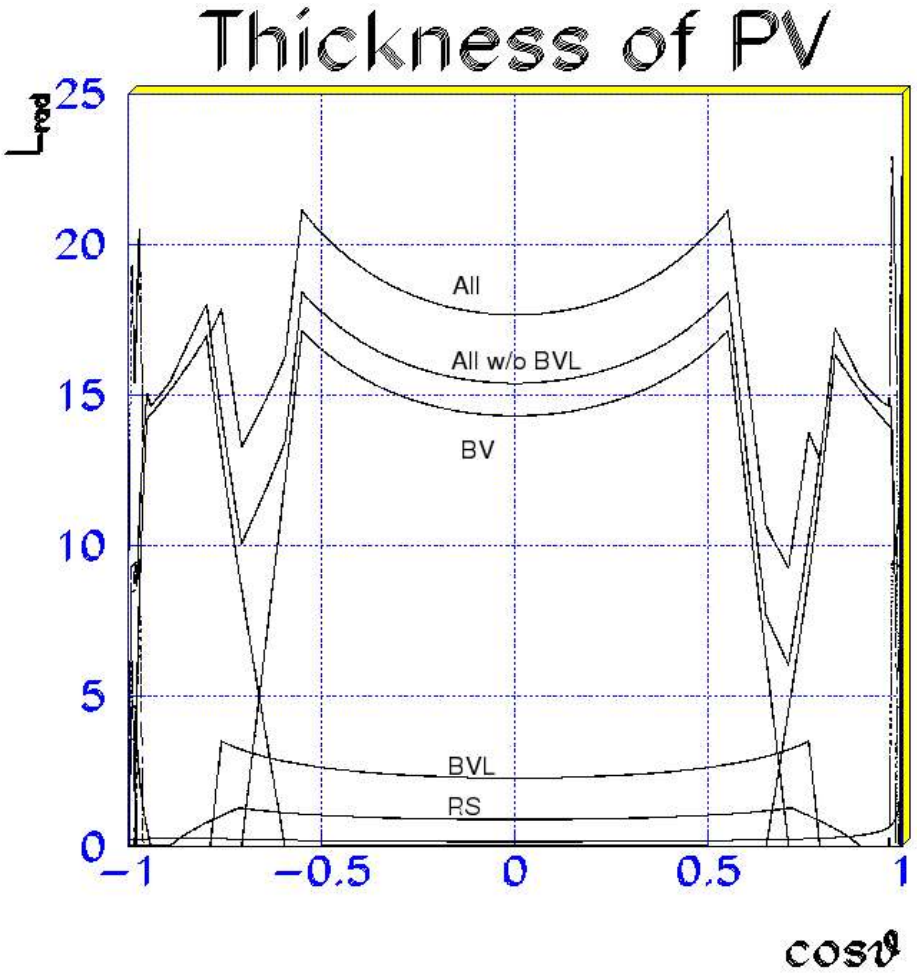


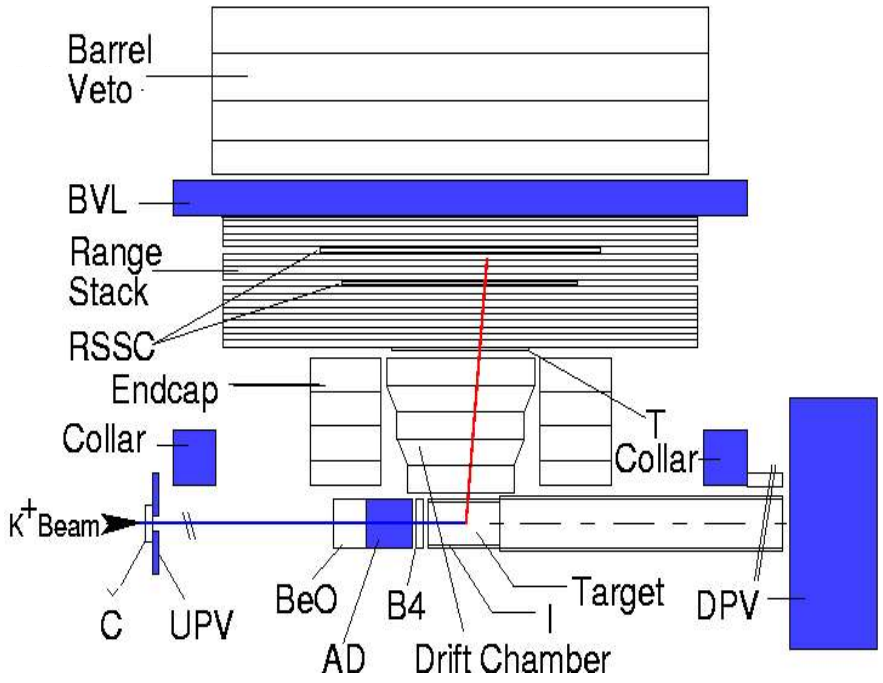


Detector	Material	X0	Npe/MeV(vis)
Target	BCF10	~0.19	~30
Range Stack	BC408	0.8	~12/side
BVL	1mm Pb, 5mm BC408	2.29	~30/side
Barrel Veto	1mm Pb, 5mm BC408	14.3	~10/side
EndCap	Pure CsI	13.5	~200
Collar	2mm Pb, 5mm BC404	9	26

Almost everything in E949 is a photon detector!

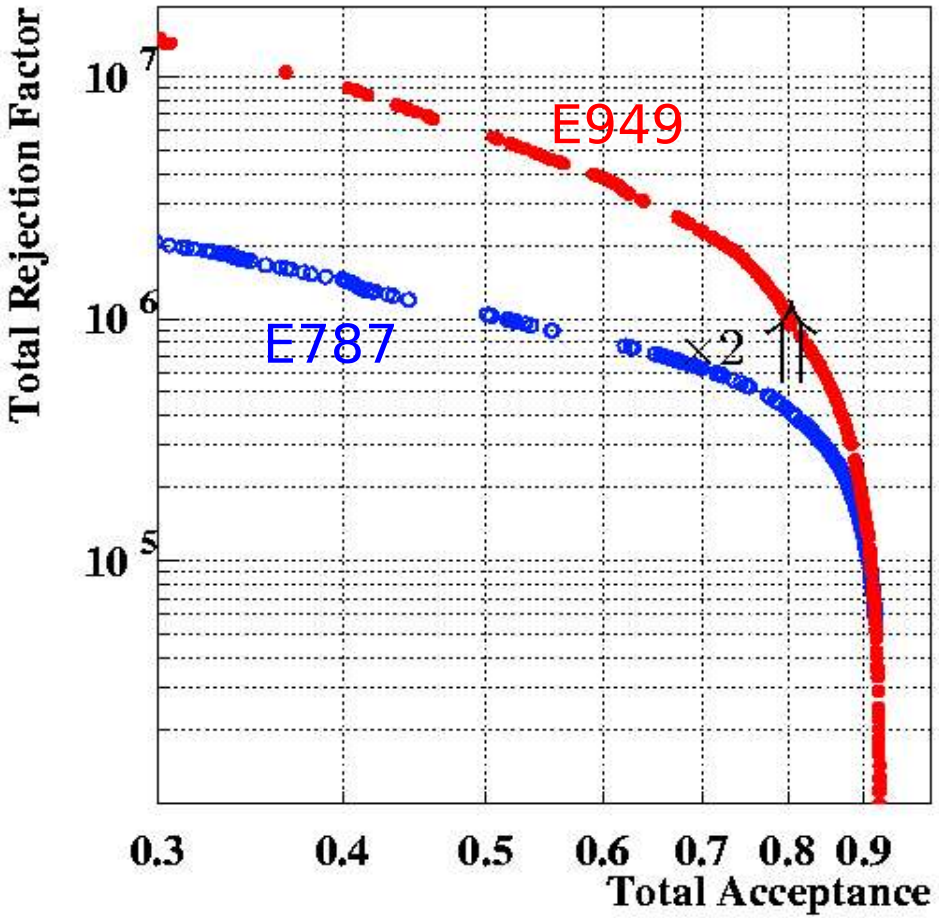
E949 PV vs angle

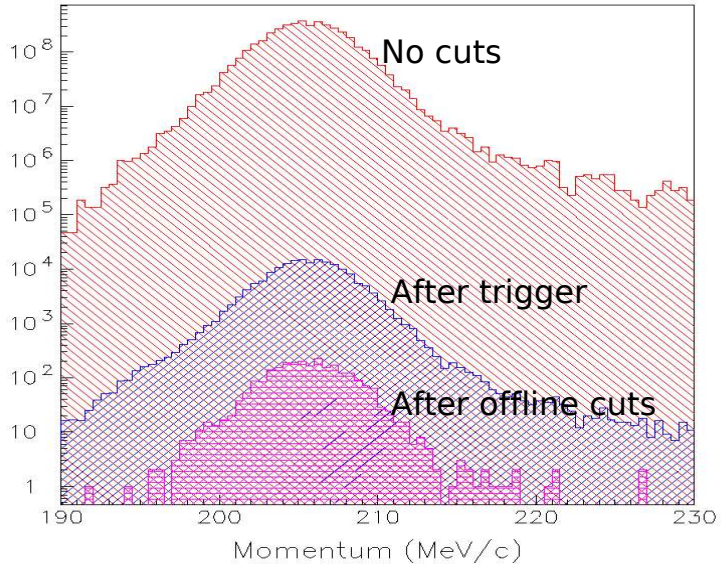




E949 π° Rejection

Rejection measured with Kπ2 selected kinematically

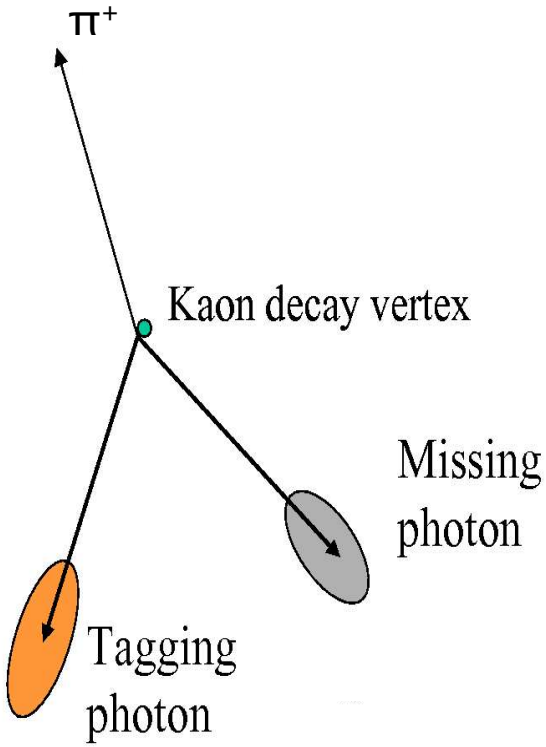




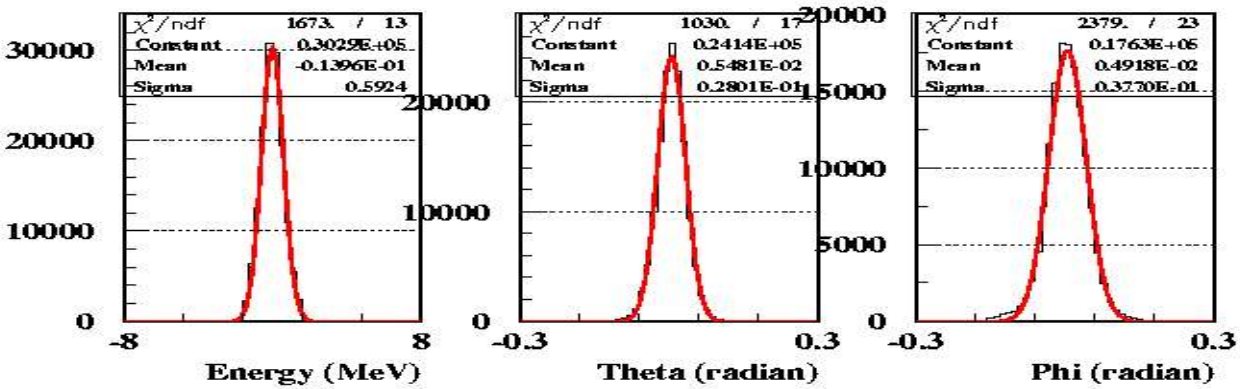
- Typically for πνν analysis (Acc ~ 0.8):
  - 3-5ns (full width) time windows
  - ~0.5 - 4 MeV (vis) threshold

Single photon detection inefficiency (SPI)

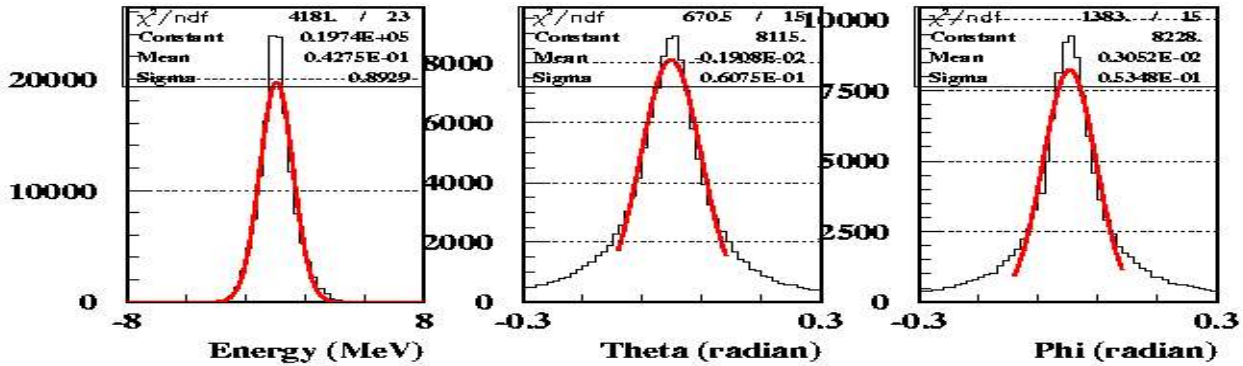
Constrained fit. Kπ2 decays



E949 Monte Carlo: tagging photon resolution



Missing photon resolution



E(γ)=20-200 MeV

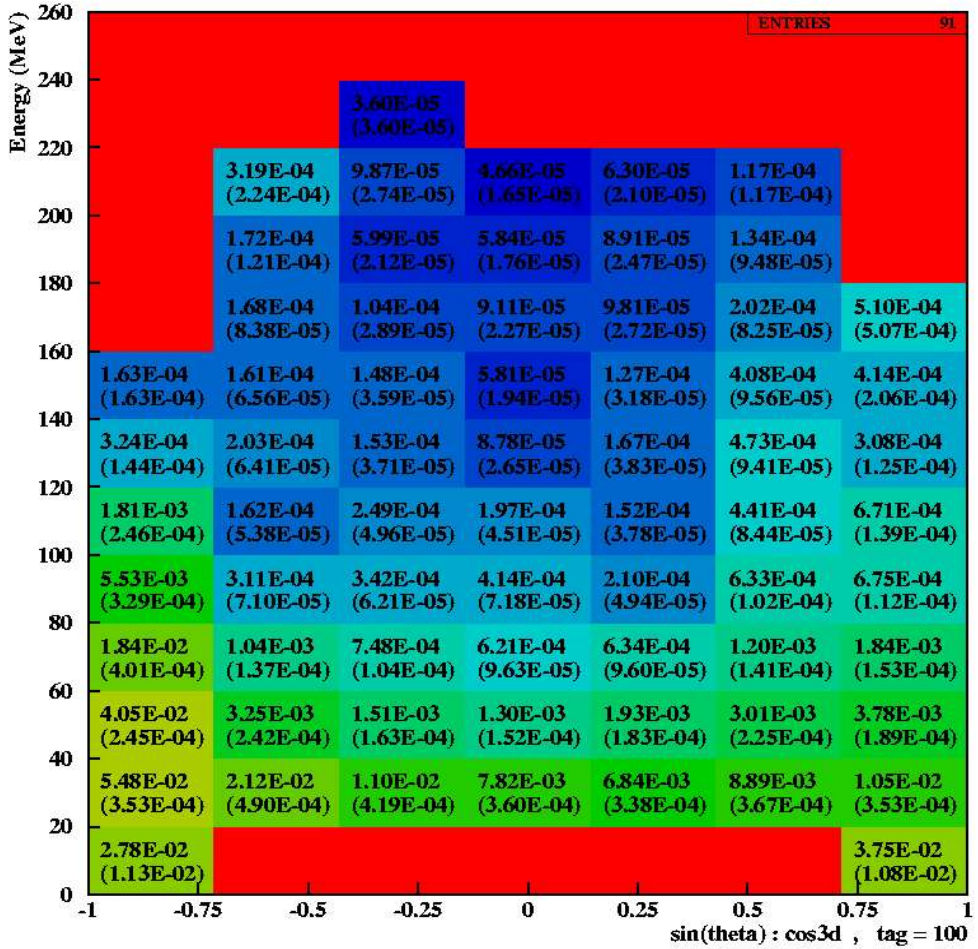
SPI analysis

SPI Analysis:

- Dedicated trigger:
  Kπ2 trigger with only one cluster in BVL
- Offline analysis:
  - More refined clutstering (RS,BVL,BV)
  - Kinematic fit
  - Remove tagging photon
  - Apply photon veto
  - Survivors → "numerator map"
    - Correct for random veto loss, trigger loss, incorrect removal of tagging photon (~50% correction overall)
  - "Denominator map" from Kπ2 triggers

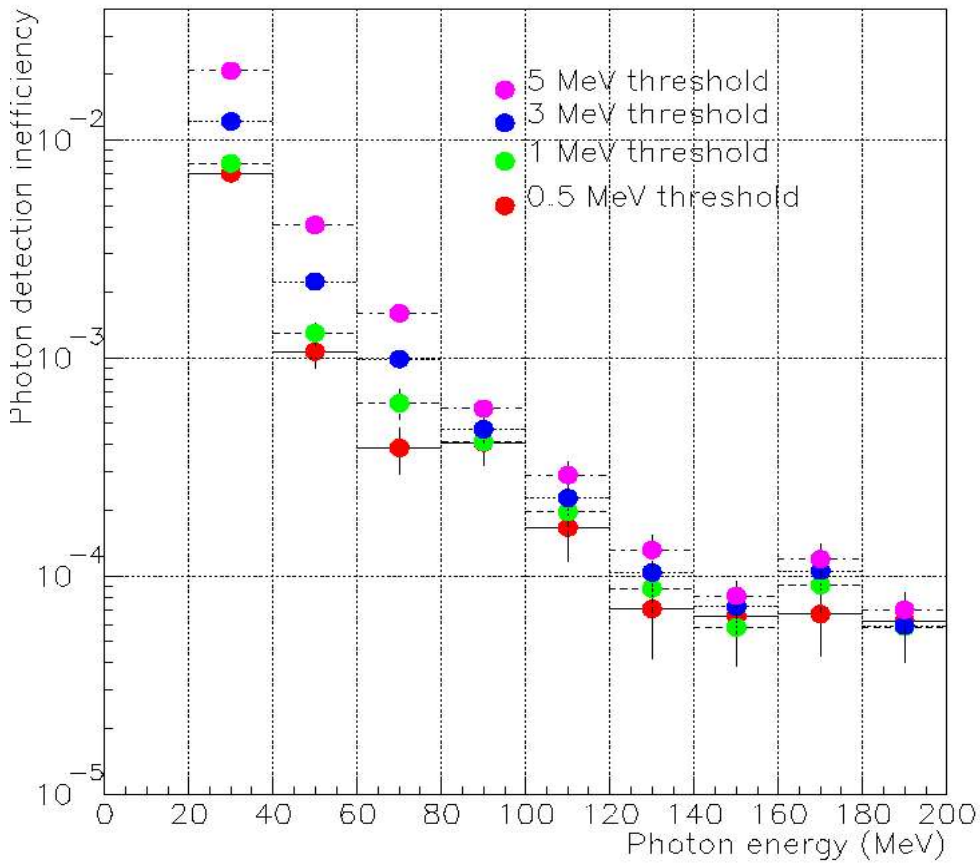
SPI = ratio of maps

1 MeV (vis) threshold

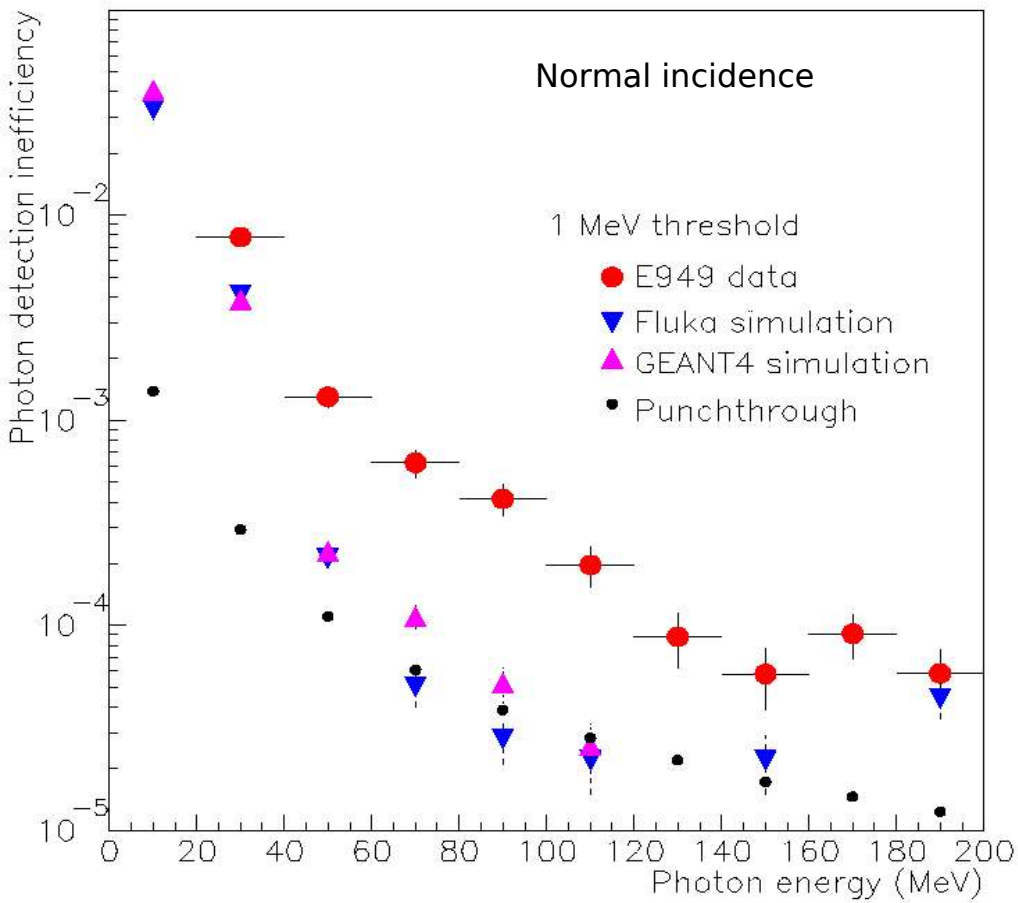


Threshold dependence

E949 measurements. Normal incidence



Comparison with simulation

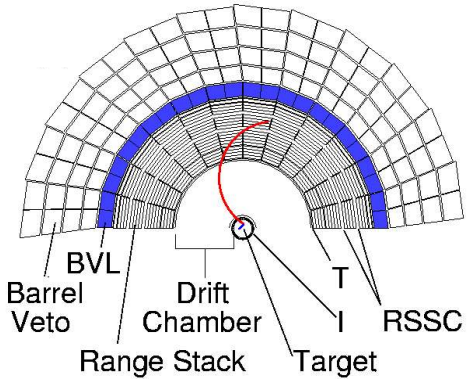


Disclaimer: this analysis is still very raw

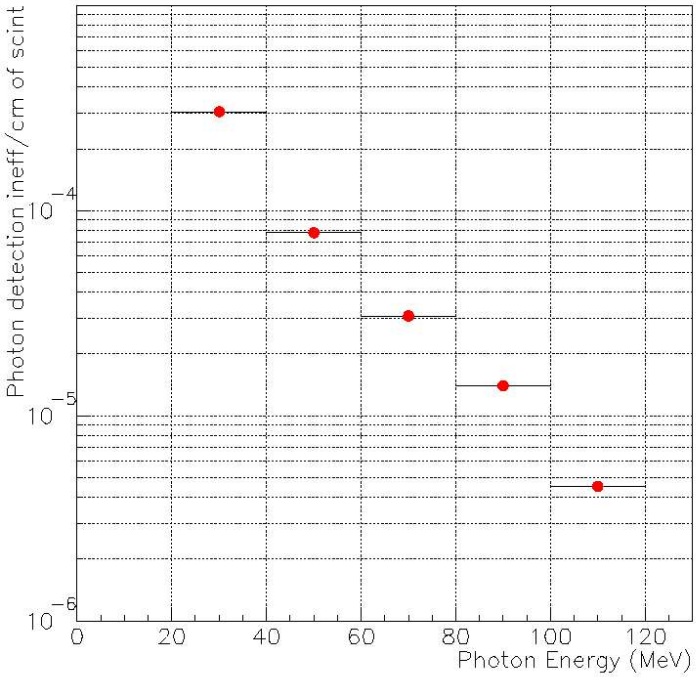
- Known issues
  - Resolution effects (energy/angle) not unfolded from E949 data
  - Simulations are highly idealized
    - Planar geometry (mainly affects back-scattered stuff; small effect?)
    - No timing windows (up to x2 effect for some energies, according to G4)
    - No rate effects (maybe x1.3?)
  - Non-trivial dependence on detection threshold

Effect of dead material

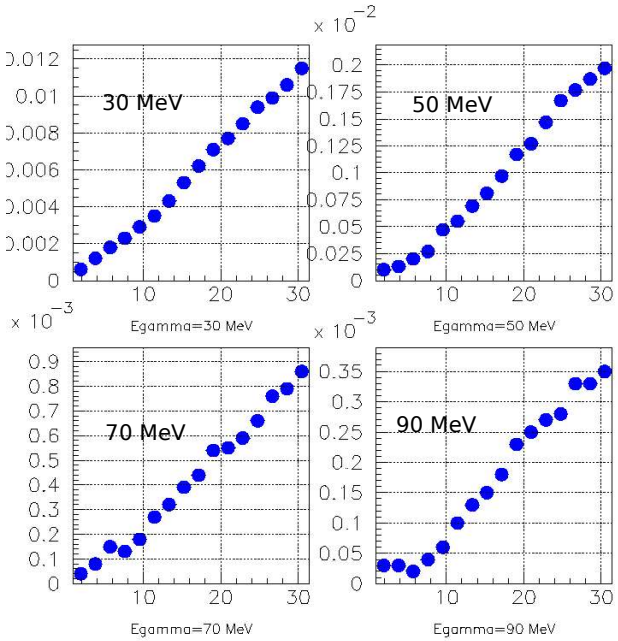
The effect of dead material in front of the PV is of some interest, for example to KOPIO. Effect of “dead” carbon was examined by measuring the SPI after “turning off” (in software) one layer at a time of the RS. (1.905cm scintillator)



Detection inefficiency per cm of scintillator



Inefficiency vs thickness (cm)



Conclusion and future work

Single photon detection inefficiency has been measured in E949

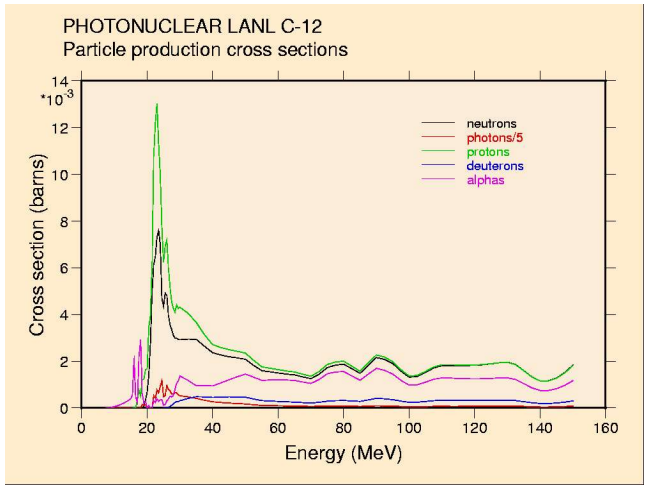
Still lacking a detailed understanding

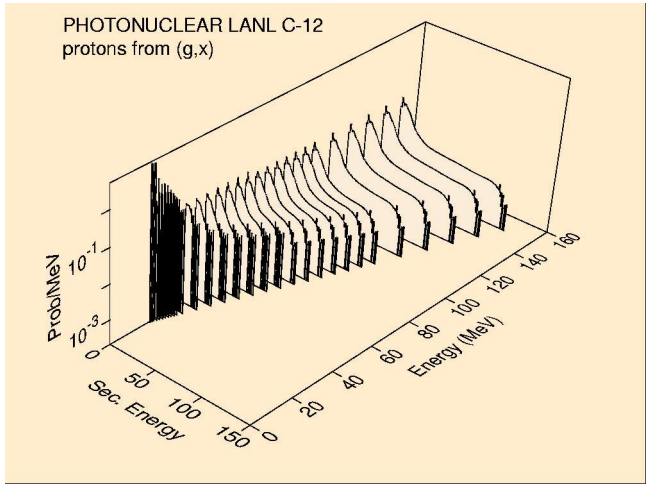
- Physics of photonuclear interactions, esp. Light materials
- Detector effects

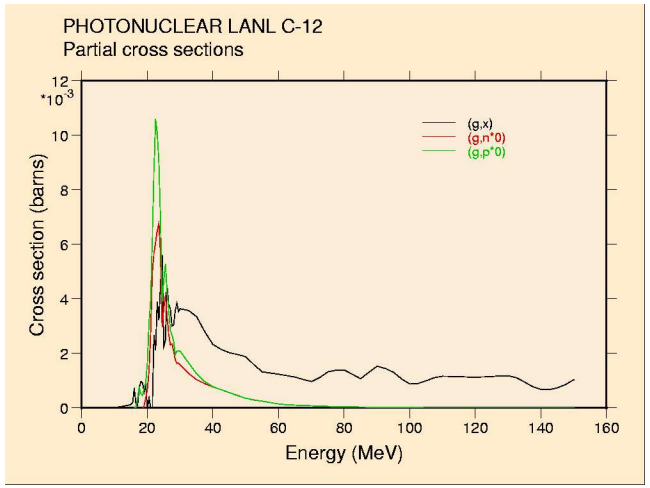
Continuing comparions of Fluka vs G4

We have started looking at IAEA Project: “Compilation and Evaluation of Photonuclear Data for Applications”

- A kind of “PDG” for photonuclear data (http://iaeand.iaea.or.at/photonuclear)
- Cross sections and spectra up to 140 MeV available in tabular form. A combination of measurements and theoretical input. Used by MCNPX.
- Hope to incorporate in E949 Monte Carlo







Backup material

Photon veto parameters

Parameters optimized for “pnn1” analysis

A(offline) = 0.905

System	Half-width (ns)	E thresh (MeV)
BV	4.50	0.20
BVL	2.00	0.00
RS	1.50	3.80
EC	2.25	3.80
EC inner ring	1.75	1.00
Target	1.30	4.79
I-counter	2.25	0.40
V-counter	2.00	1.60
Collar	1.25	0.80
Microcollar	1.50	2.80
BV single energy, single time	9.50	4.80
BV single energy, both times	1.00	2.80
BV both energy, single time	11.00	8.80
BVL both energy, single time	2.50	17.60
RS no energy, both times	2.00	

Photon veto parameters

Single photon ineff.
1 MeV threshold.

Time windows set
by eye.

System	Half-width (ns)	E thresh (MeV)
BV	5.02	1.00
BVL	3.31	1.00
RS	2.73	1.00
EC	5.92	1.00
EC inner ring	1.75	1.00
Target	6.86	1.00
I-counter	4.97	1.00
V-counter	5.68	1.00
Collar	4.22	1.00
Microcollar	3.53	1.00
BV single energy, single time	17.70	1.00
BV single energy, both times	13.98	1.00
BV both energy, single time	12.82	1.00
BVL both energy, single time	22.14	1.00
RS no energy, both times	15.66	