π^0 Lifetime Analysis for ^{12}C and ^{208}Pb

Dustin McNulty
MIT/UMass
mcnulty@jlab.org

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DataSets Analyzed

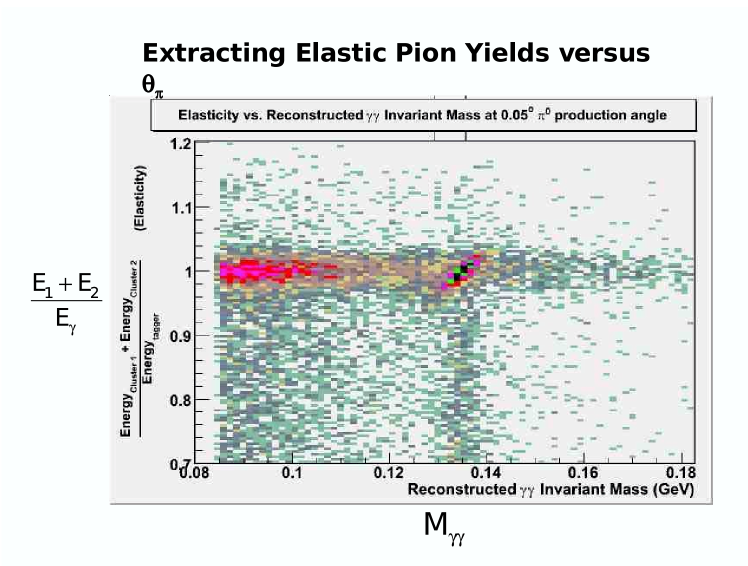
Target	Total Runs	Run Number Ranges
^{12}C	160	4740 – 4768, 4976 – 5059; 5159 – 5242
^{208}Pb	76	4882 – 4913, 5083 – 5114, 5266 – 5330

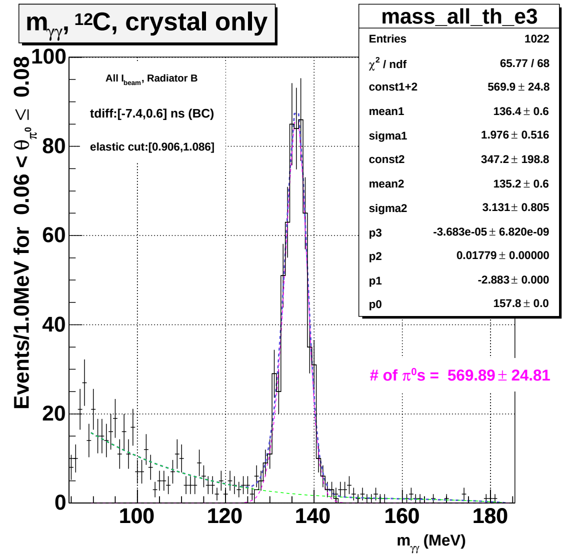
Table 1: Run number ranges used in this analysis for ^{12}C and ^{208}Pb targets. Both sets consist of only radiator B runs.

General Cuts and Event Selection

- Accepted $PbWO_4$ hits only (excluding inner and outer-most layer)
- Minimum cluster energy: 0.1GeV
- Best timing candidate selection with tdiff cut: $\pm$4ns

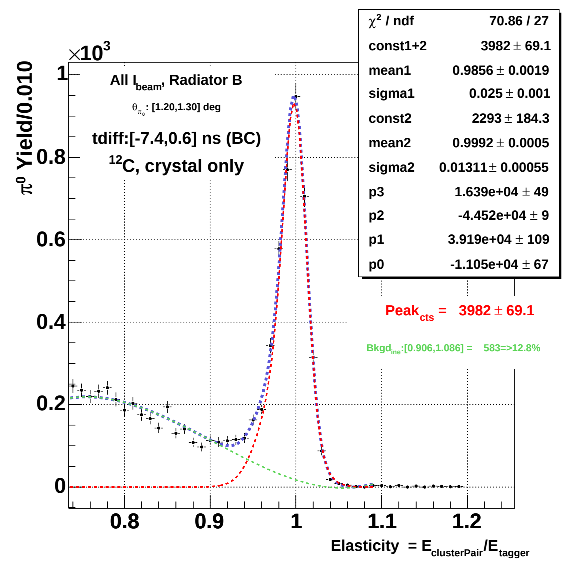
Analysis Details: π^0 Yield Extraction



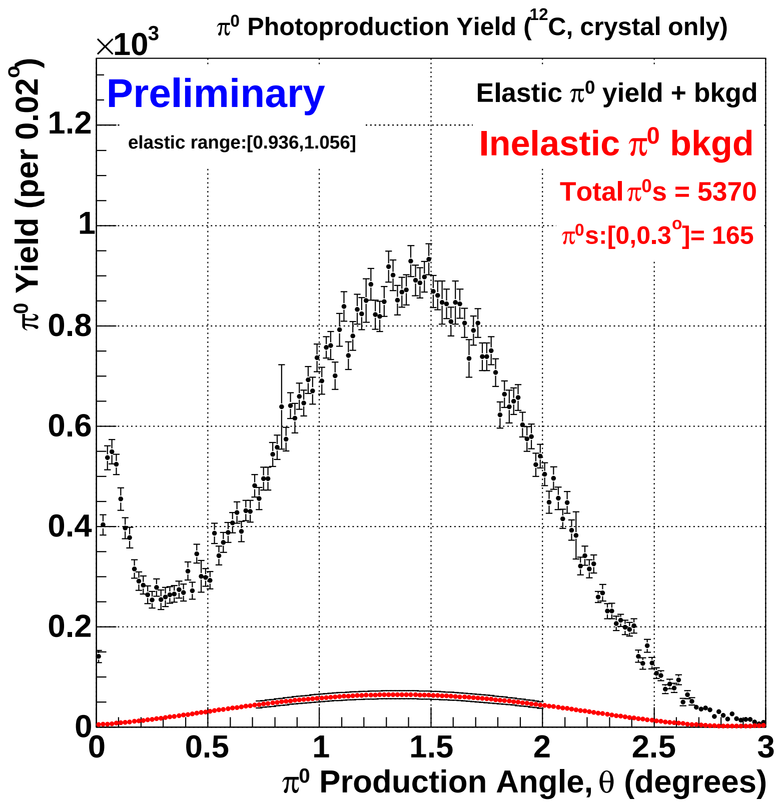


- For each θ_{π^0} bin, apply elastic cut and form $m_{\gamma\gamma}$ distributions; perform fit and extract peak counts = uncorrected yield.

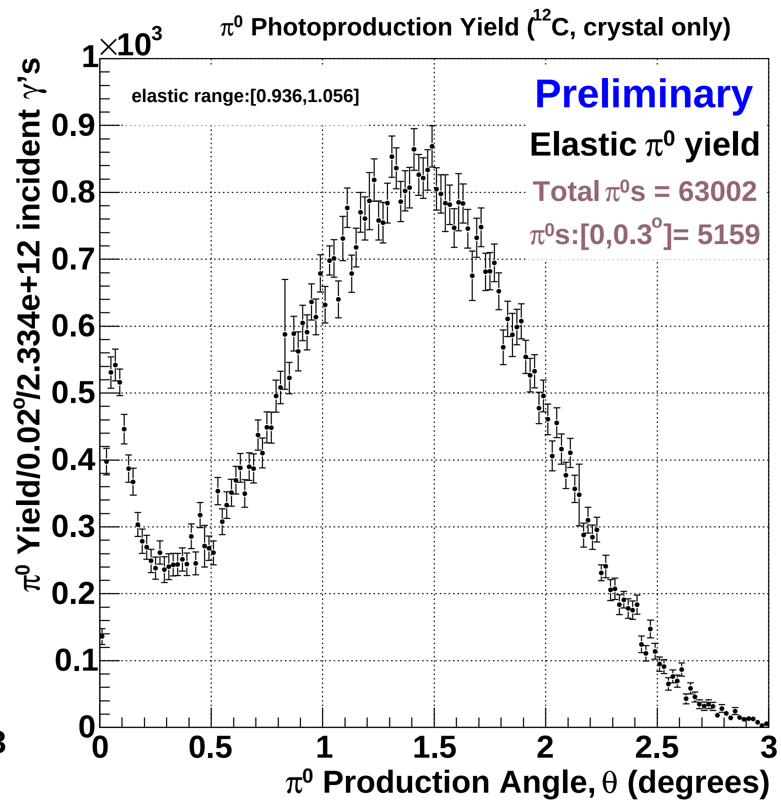
- Correct for inelastic bkgd by evaluating π^0 elasticity distribution explicitly for each θ_{π^0}; evaluate inelastic bkgd under the elastic peak using fit and subtract from yield.



^{12}C Yield

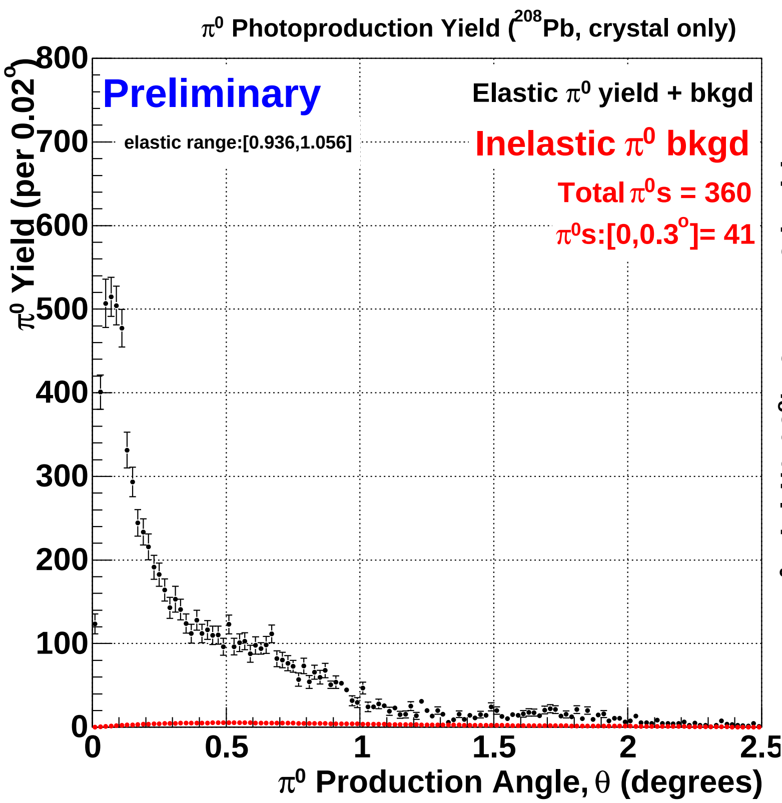


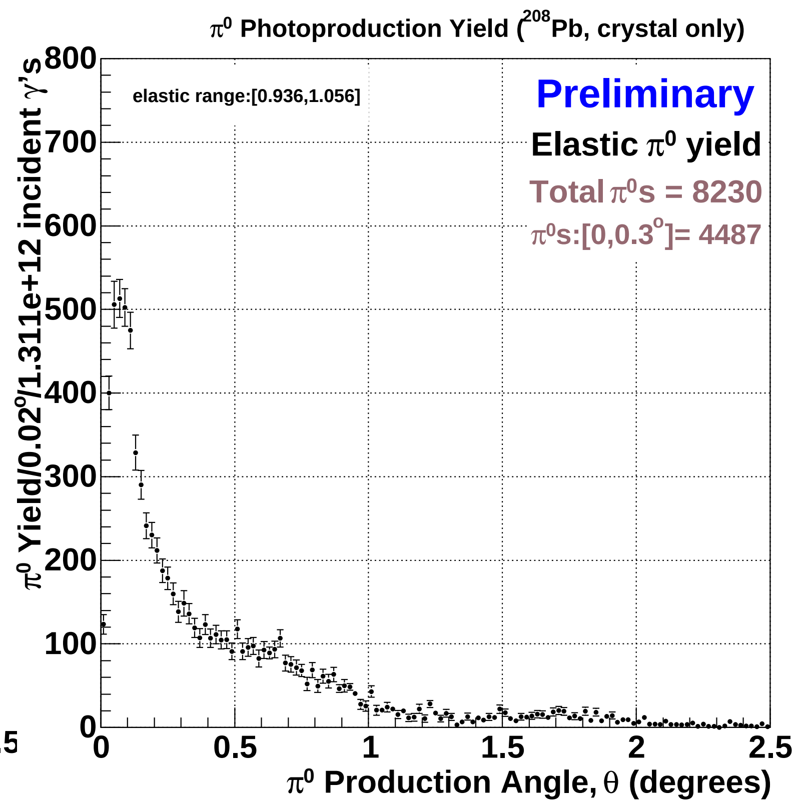
π0 Photoproduction Yield (12C, crystal only)
×10^3
Preliminary
elastic range:[0.936,1.056]
Elastic π0 yield + bkgd
Inelastic π0 bkgd
Total π0s = 5370
π0s:[0,0.3°]= 165
π0 Yield (per 0.02°)
π0 Production Angle, θ (degrees)



π0 Photoproduction Yield (12C, crystal only)
×10^3
elastic range:[0.936,1.056]
Preliminary
Elastic π0 yield
Total π0s = 63002
π0s:[0,0.3°]= 5159
π0 Yield/0.02°/2.334e+12 incident γ's
π0 Production Angle, θ (degrees)

^{208}Pb Yield


π0 Photoproduction Yield (208Pb, crystal only)
Preliminary
Elastic π0 yield + bkgd
Inelastic π0 bkgd
elastic range:[0.936,1.056]
Total π0s = 360
π0s:[0,0.3°]= 41
π0 Yield (per 0.02°)
π0 Production Angle, θ (degrees)


π0 Photoproduction Yield (208Pb, crystal only)
elastic range:[0.936,1.056]
Preliminary
Elastic π0 yield
Total π0s = 8230
π0s:[0,0.3°]= 4487
π0 Yield/0.02°/1.311e+12 incident γ's
π0 Production Angle, θ (degrees)

Experimental Efficiencies: ^{12}C

	Losses (%)
Description	^{12}C
Photon Absorption in Target	5.41 ± 0.02
Best (tdiff) Candidate selection	2.5 ± 0.3
Elasticity Cut: $[0.906, 1.086]$	1.7 ± 0.3
Veto Cut: all flags $(0, 1, 2, 3)$	1.97 ± 0.12
Branching Ratio $\pi^0 \nrightarrow \gamma\gamma$	1.2 ± 0.03
Total	12.8 ± 0.5

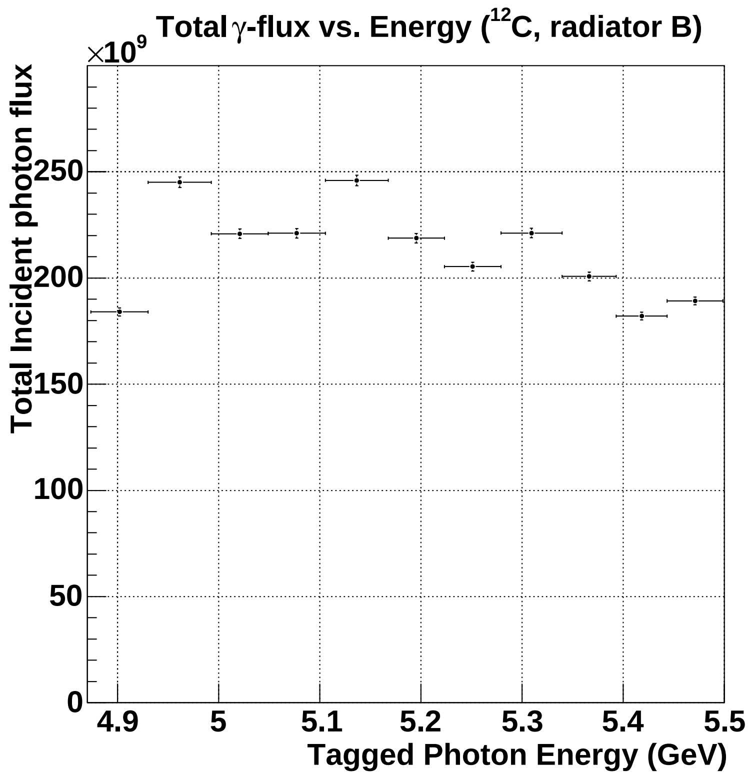
Table 2: Summary of non-geometric losses.

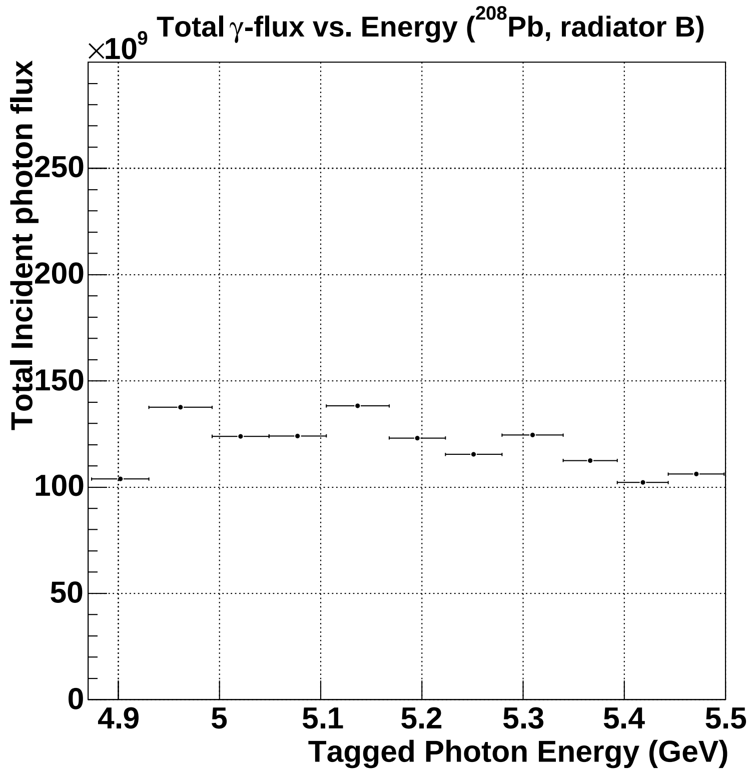
Experimental Efficiencies: ^{208}Pb

Description	Losses (%) ^{208}Pb
Photon Absorption in Target	5.92 ± 0.01
Best (tdiff) Candidate selection	1.1 ± 0.3
Elasticity Cut: $[0.906, 1.086]$	1.7 ± 0.3
Veto Cut: all flags $(0, 1, 2, 3)$	1.97 ± 0.12
Branching Ratio $\pi^0 \nrightarrow \gamma\gamma$	1.2 ± 0.03
Total	11.9 ± 0.4

Table 3: Summary of non-geometric losses.

Photon Flux

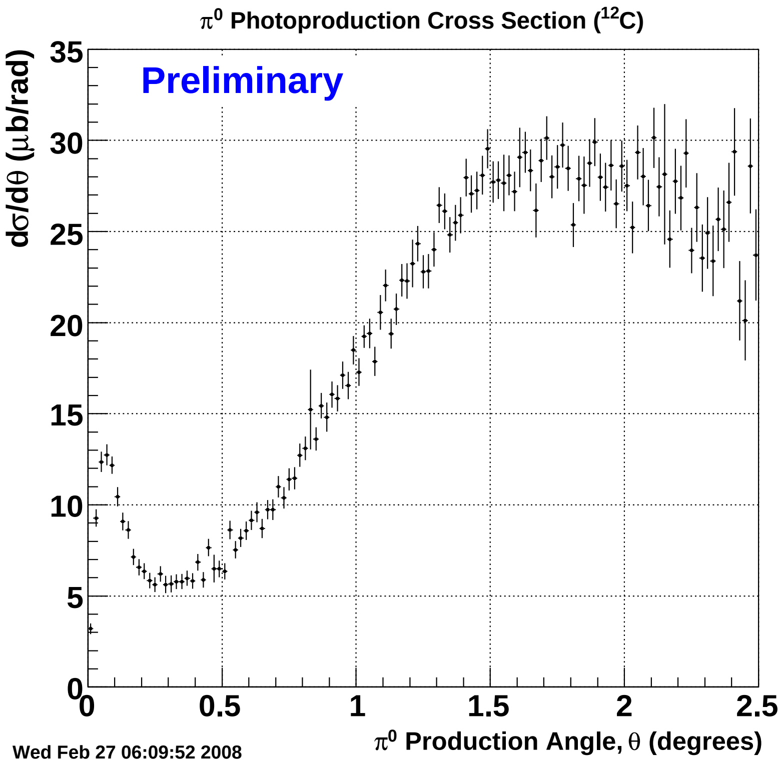


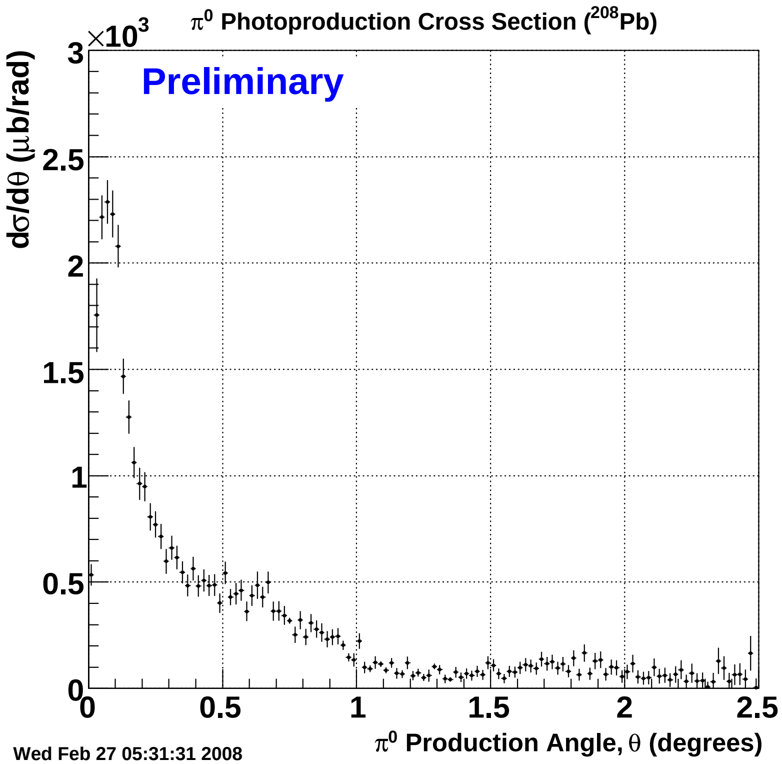


Flux for ^{12}C: 2.33×10^{12} γ's

Flux for ^{208}Pb: 1.31×10^{12} γ's

Cross Sections





Yield Fit, $\Gamma_{\gamma\gamma}$ Extraction: Procedure

- Parameterize yield using sum of 4 theoretical shapes–smeared according to experimental resolutions.

$\longrightarrow$ Calculate theory input shapes (cross sections) energy-weighted according to experimental flux.

$\longrightarrow$ Create π^0 event generator based on above cross sections and run through Primsim Monte Carlo.

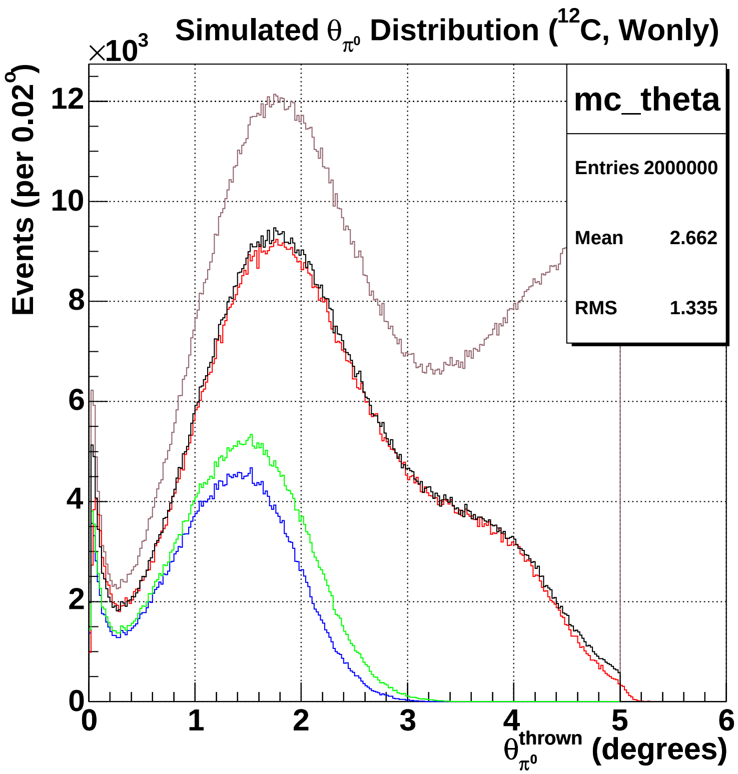
$\longrightarrow$ Digitize simulated data and reconstruct events using same algorithms as for real data. Produce simulated yield distributions with built-in experimental resolutions.

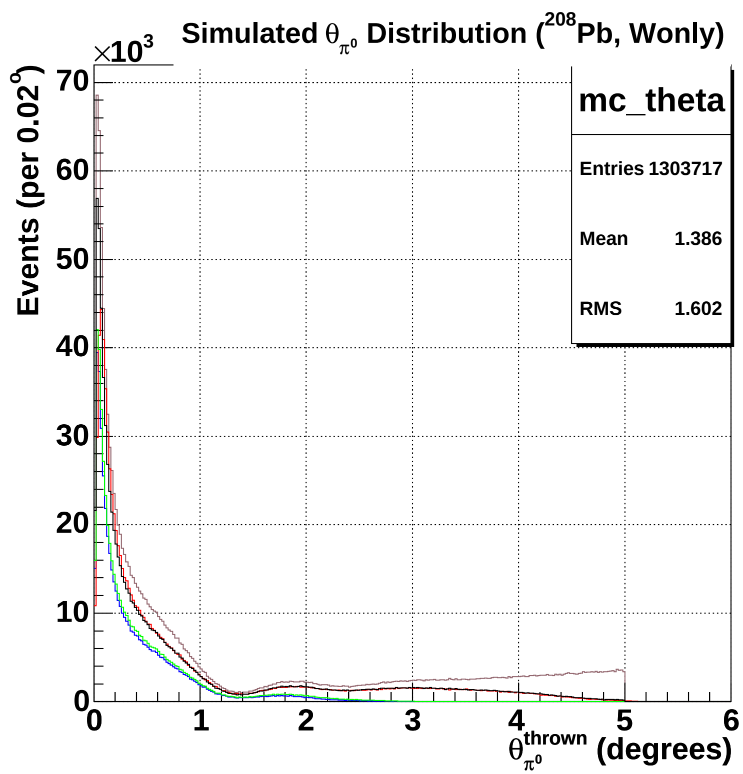
- Freely vary amplitudes of 4 shapes and minimize χ^2.

Yield Fit, $\Gamma_{\gamma\gamma}$ Extraction: Theory Input Shapes

- Primakoff shape variations: None. All calculations use Sergey's Coulomb form factor.
- Nuclear Coherent shape variations: Use Sergey's strong form factor calculation with and without 2-step contribution (F_I), and vary energy dependence k^α, where α = 1.0, 2.0, and 2.9.
- Interference shape variations: Use standard fitting approach – parameterize phase angle and apply value (ϕ) from fit to scale interference shape. Alternate "predicted phase" approach – calculate $\phi(\theta_{\pi^0}) = |\phi_C(\theta_{\pi^0}) - \phi_S(\theta_{\pi^0})|$ based on Sergey's form factors and apply to interference calculation $\rightarrow$ no free parameter (not ready yet).
- Nuclear Incoherent shape variations: Tulio's Cascade MC and Sergey's Glauber calculation (both from Fall 2007).

MC Shape Generation: Exmpl. Thrown & Det. Spectra





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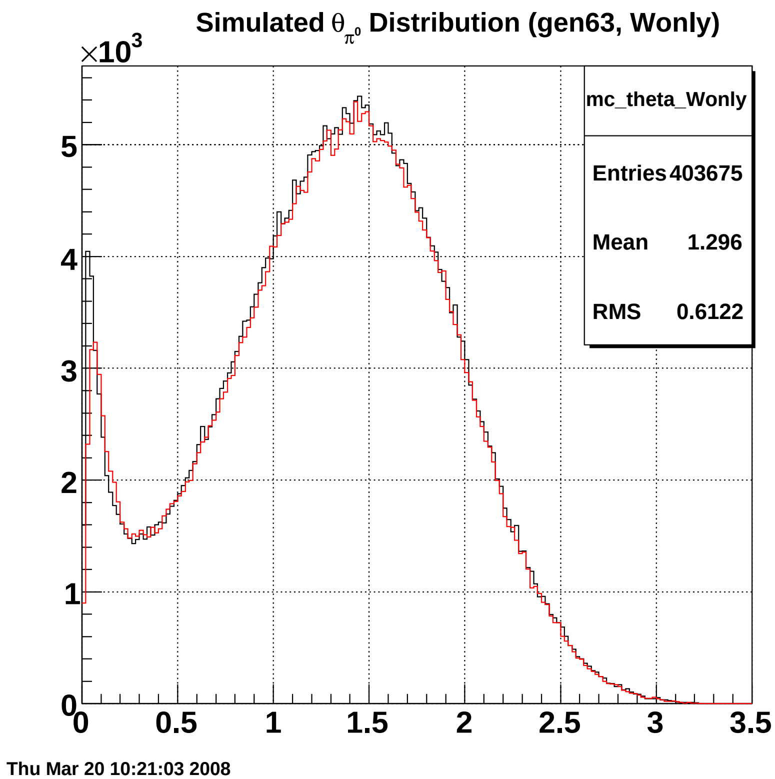
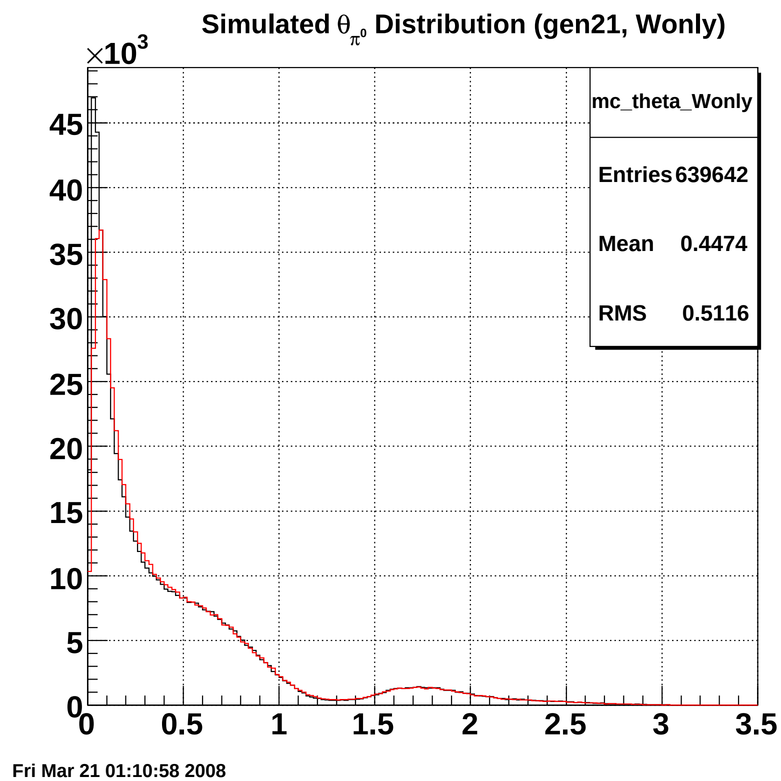
MC Shape Generation: Exmpl. Thrown & Det. Spectra

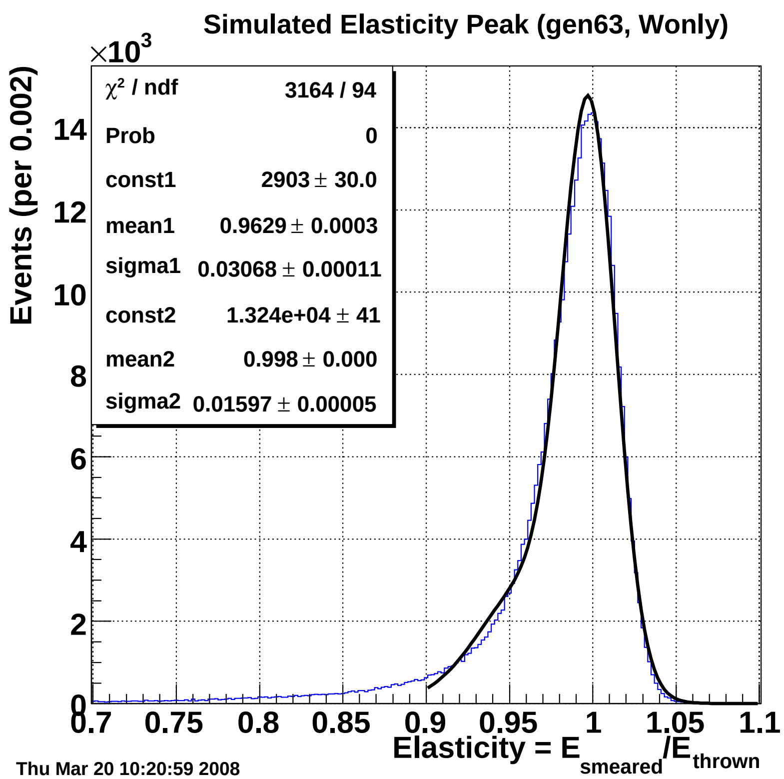


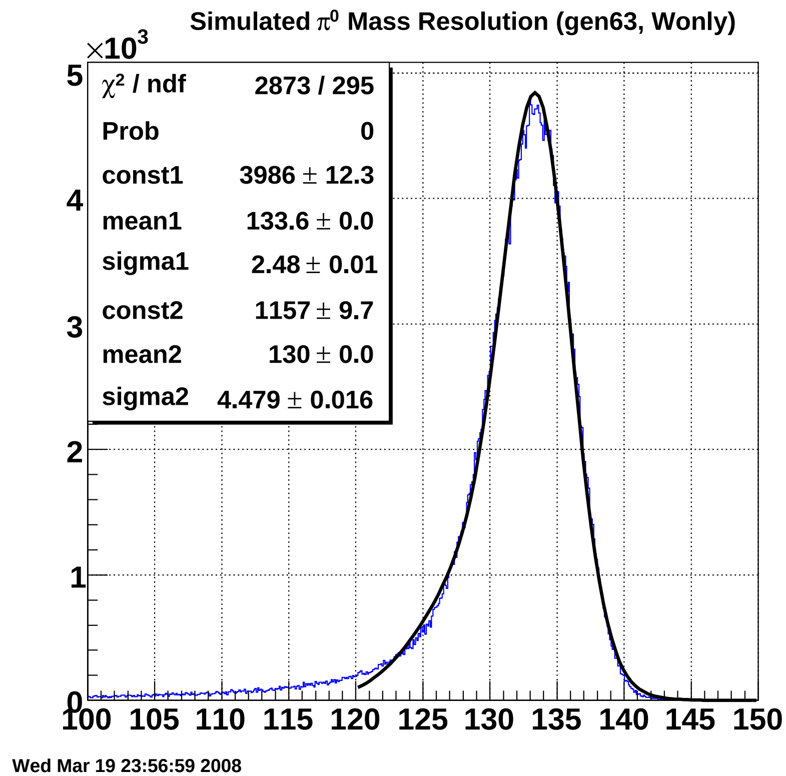


^{12}C: —θ_{π^0} Thrown —θ_{π^0} Detected

^{208}Pb: —θ_{π^0} Thrown —θ_{π^0} Detected

MC Shape Generation: Reconstructed x and $m_{\gamma\gamma}$

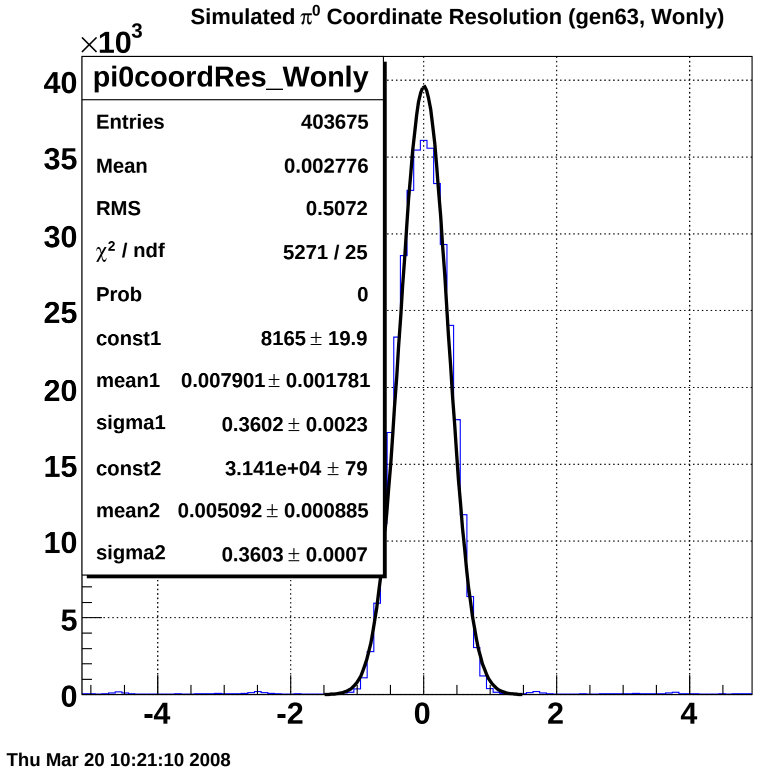


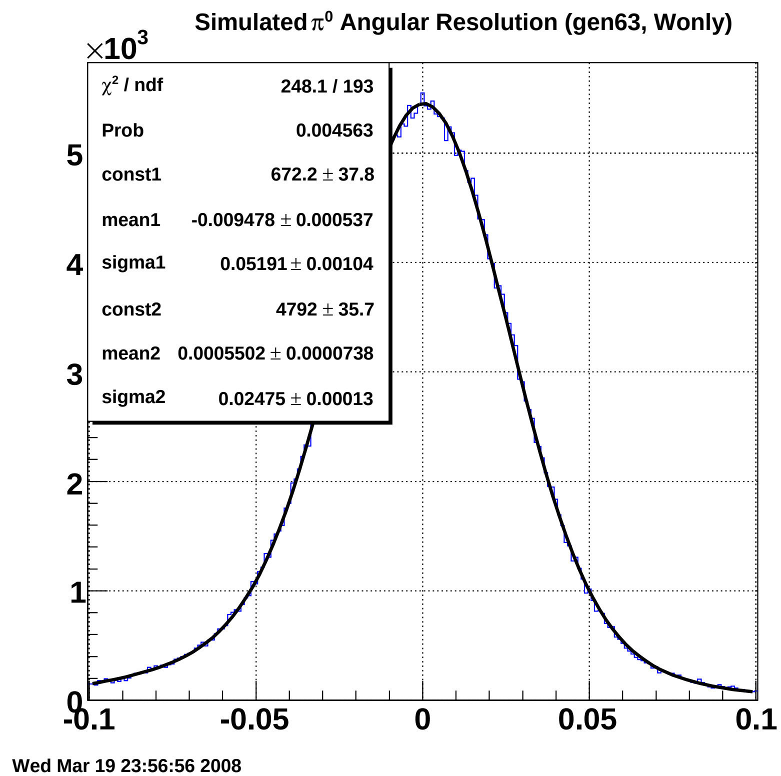


Energy Resolution: $\sim$ 1.86 %

$m_{\gamma\gamma}$ Res: $\sim$ 2.9 MeV

MC Shape Generation: Recon. Coord. and θ_{π^0} Res.

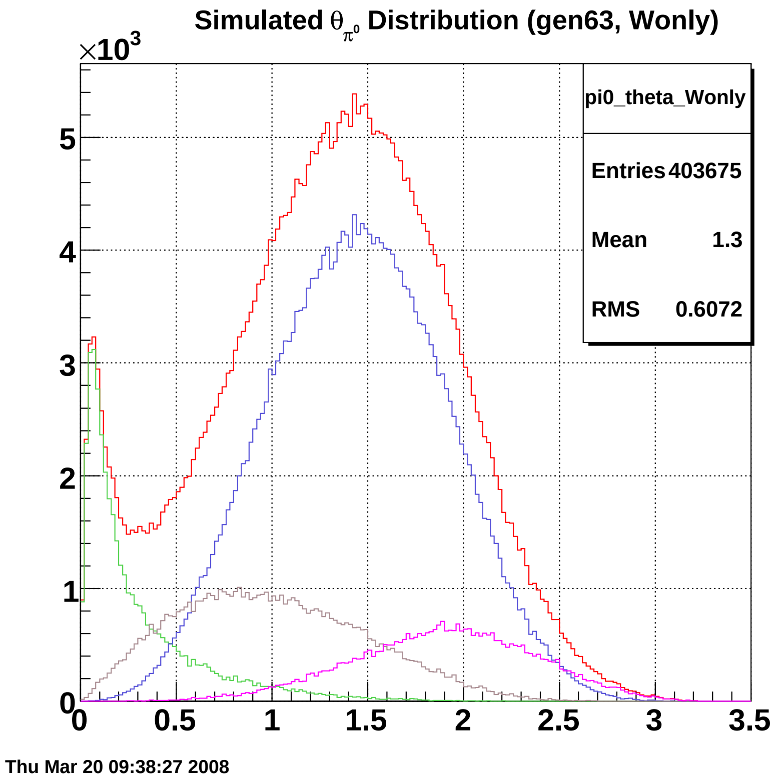


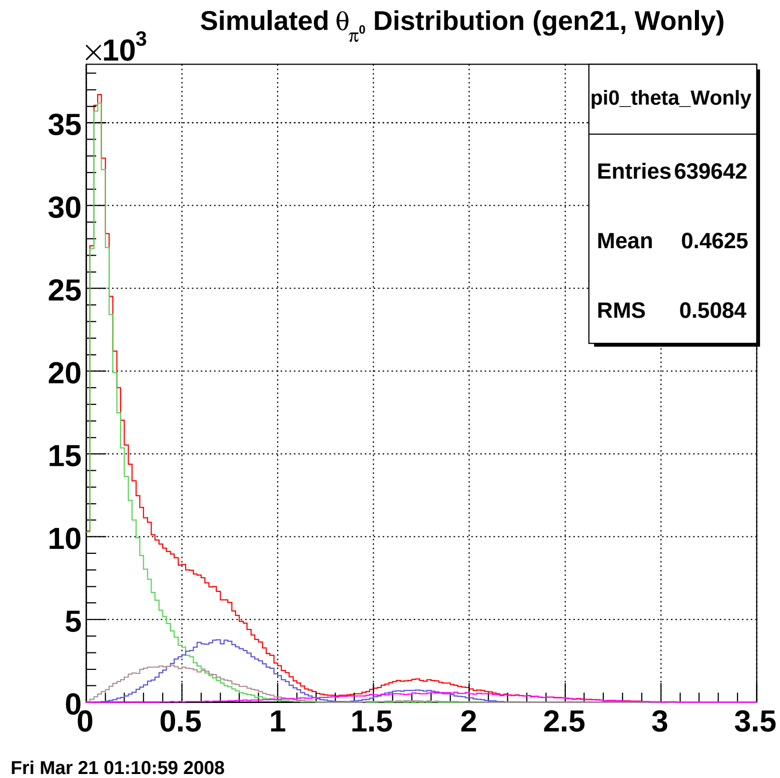


Coord Resolution: $\sim$ 3.6 mm

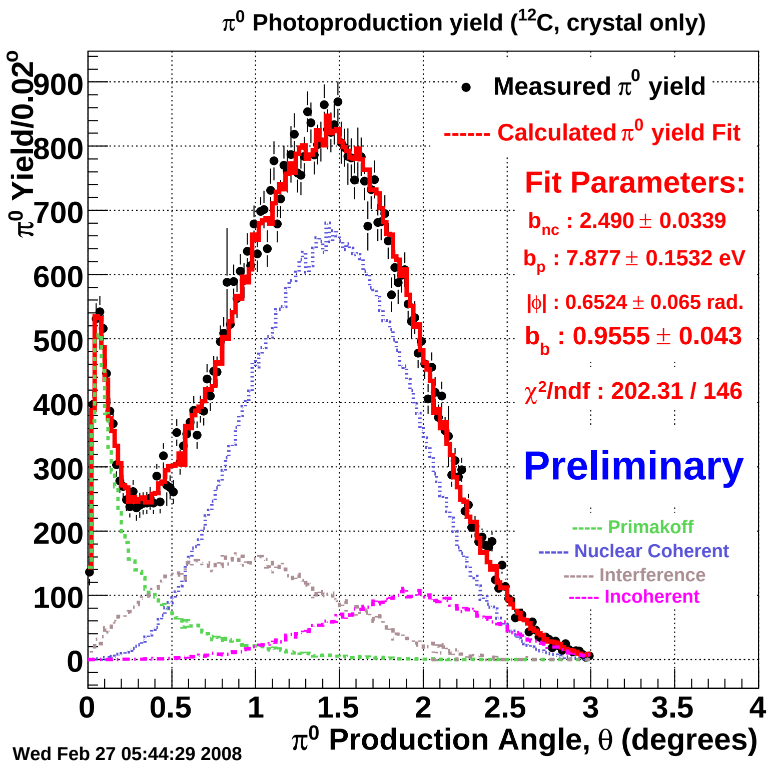
Angular Res: $\sim$ 0.028 $^\circ$

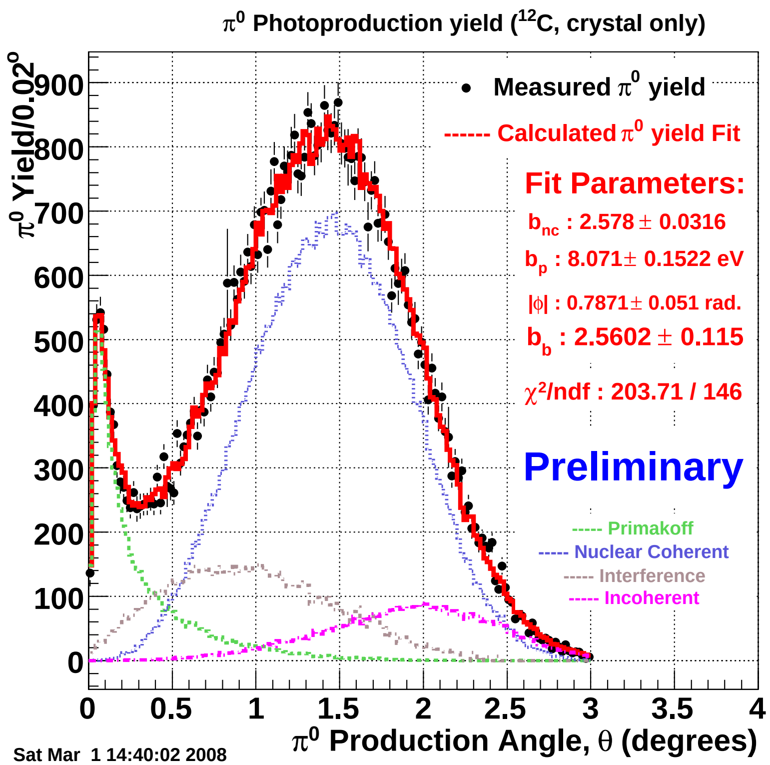
MC Shape Generation: Exmpl Fit Input Shapes (smeared)



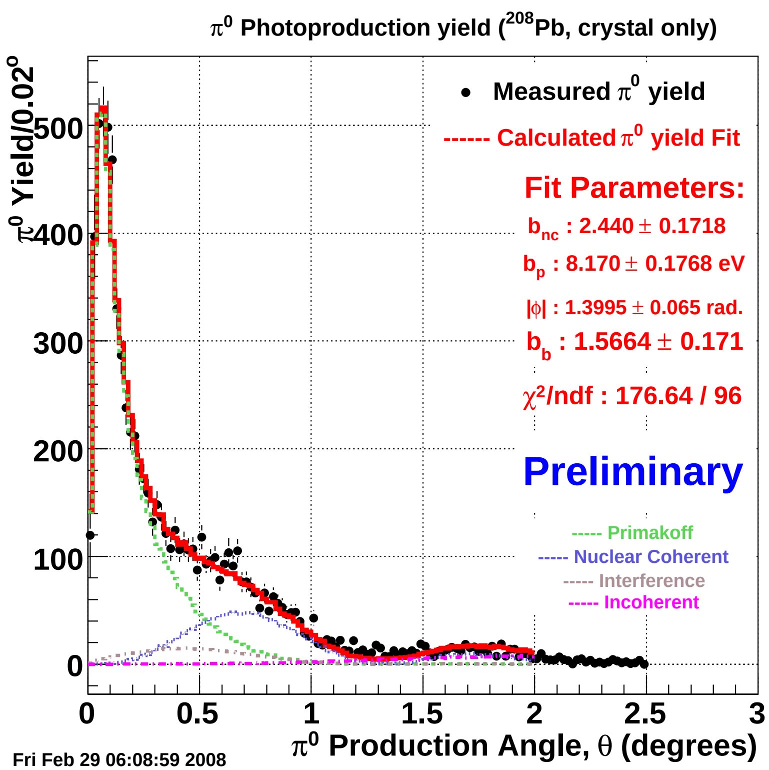


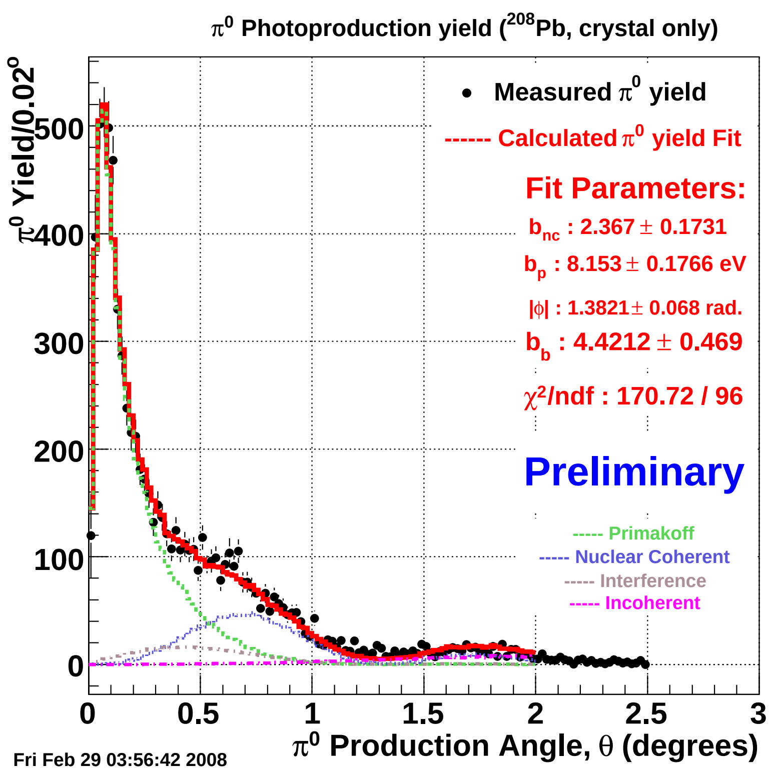
Sample Yield Fit for ^{12}C: SI (left) and TI (right)



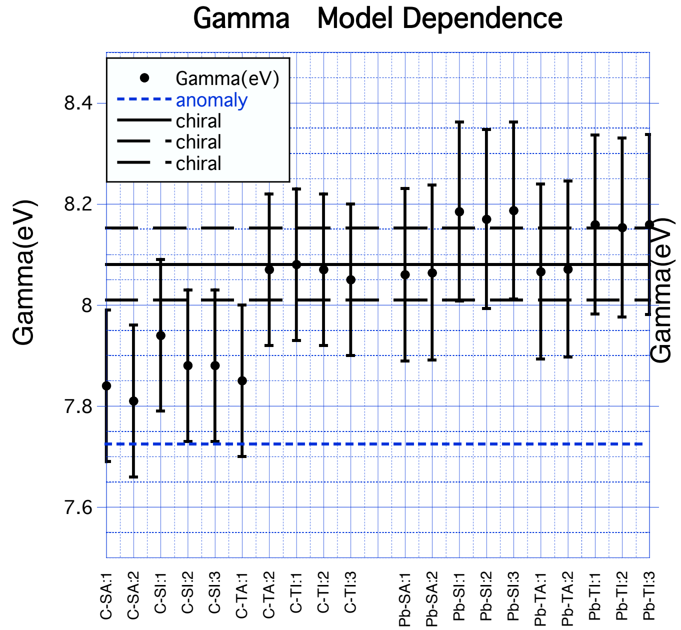


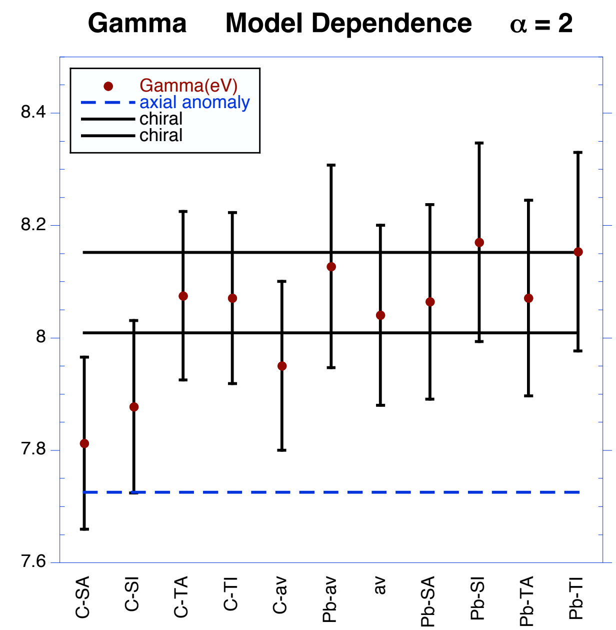
Sample Yield Fit for ^{208}Pb: SI (left) and TI (right)





$\Gamma_{\gamma\gamma}$ Results: All fits (left) and $\alpha = 2$ w/avg's (right)





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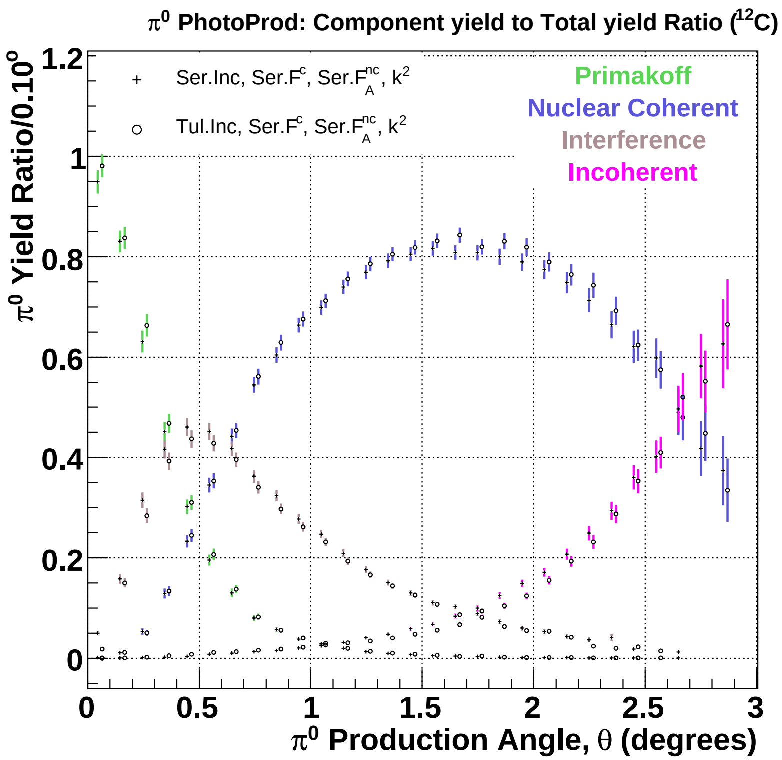
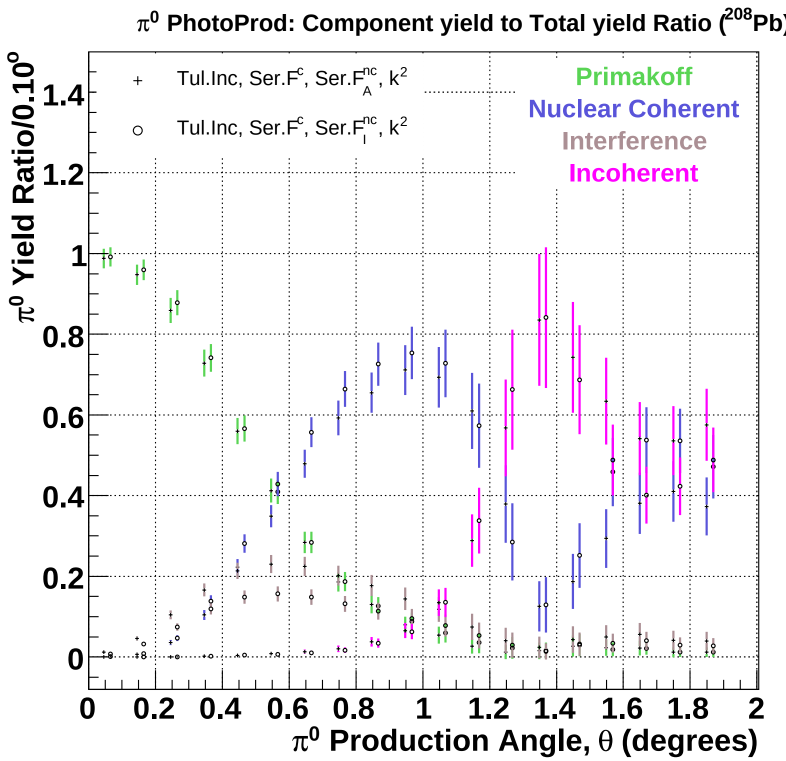
Yield Ratio Comparisons: ^{12}C(left) and ^{208}Pb (right)





Preliminary Systematic Error Table

Description	$\Gamma_{\gamma\gamma}$ dev (%)
$m_{\gamma\gamma}$ fits + inelast bkgd corr.	± 1.0
Inelastic bkgd shape uncert.	± 0.75
Photon flux	± 1.1
Experimental efficiencies	± 0.5
Fiducial Acceptance	± 0.3
Event Selection	± 1.0
π^0 bkgd from ω and ρ decay	± 1.0
Target thickness	± 0.1
branch ratio	± 0.03
Tagged Photon Energy	± 0.1
Total Systematic Error	$\pm 2.3\%$

Preliminary Theoretical Input (Model) Error Table

Description	$\Gamma_{\gamma\gamma}$ dev (%)	
	^{12}C	^{208}Pb
Incoherent XS shape uncert.	± 1.35	± 0.11
Nuclear coh. XS energy dep.	± 0.16	± 0.06
F_{NC} intermediate state	± 0.02	± 0.73
π-N cross section uncertainty		
Total Model Error	± 1.38	± 0.74

Preliminary Result Summary

target	$\Gamma_{\gamma\gamma}$	fitting error	model error	total error
C-av	7.95	0.15(1.9%)	0.11(1.4%)	0.24(3.0%)
Pb-av	8.13	0.18(2.2%)	0.055(0.7%)	0.26(3.2%)
Pb+C av	8.06	0.14(1.8%)	0.12(1.6%)	0.22(2.7%)

Table 4: Values of the extracted value of $\Gamma(\pi^0 \to \gamma\gamma)$ and the errors in eV(%). The averages were taken over all of the fits including the variations in α. The total error adds in quadrature the fitting, model, and the systematic error assumed to be 2.3%.

Future Work

To finish the analysis and make a final report we need:

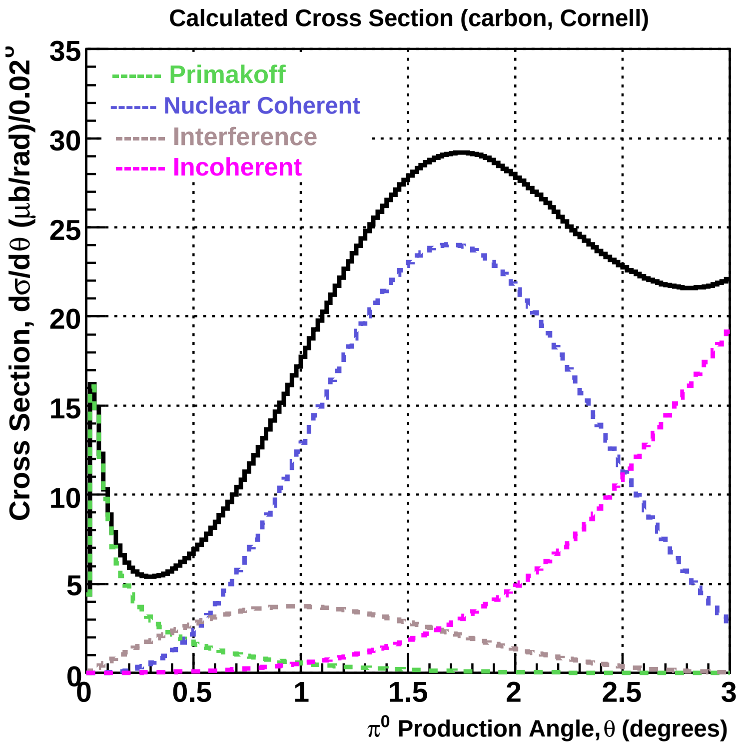
- Theoretical fit with the predicted phase angle
- Include the effect of the $\omega \rightarrow \pi^0\gamma$ production in ^{12}C and ^{208}Pb
- Evaluate effect of varying the π N cross sections in F_{NC} (we anticipate that this should be a small effect)
- Finish and write-up systematic error evaluations
- Include a discussion of the fitting error matrix and the correlations

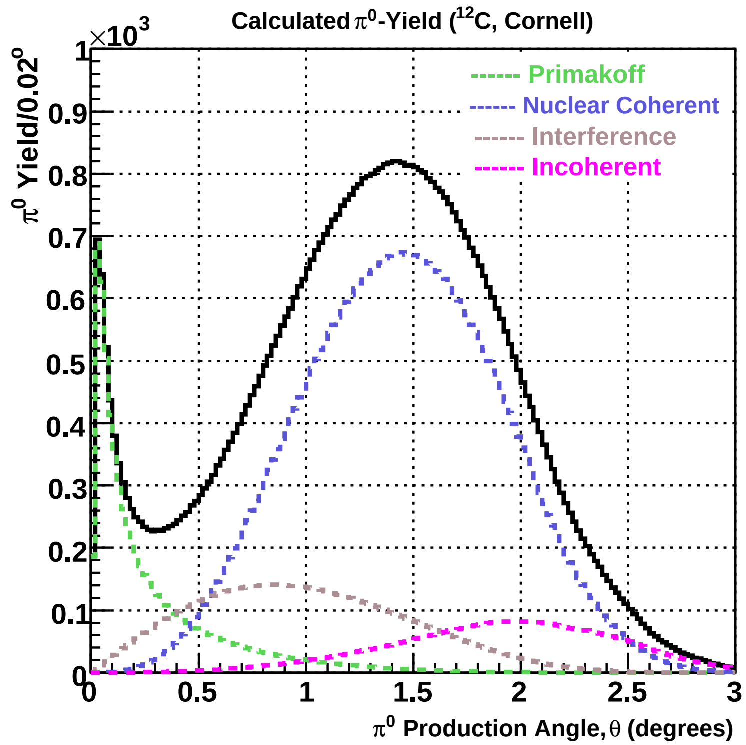
(Extra Slide) Target Thickness

Target	Density, ρ ($g/cm^3 \pm$ %err)	Thickness, t (mil±%err)	actual $N_t = \rho \times t$ 10^{23} atoms/cm^2	"effective" N_t 10^{23} atoms/cm^2
^{12}C	2.1983 ± 0.009	380.31 ± 0.04	1.0648 ± 0.05	1.0655 ± 0.1
^{208}Pb	$\sim 11.39\pm$	$\sim 12 \pm 0.3$	$\sim 0.010079\pm$	$\sim 0.010079\pm$

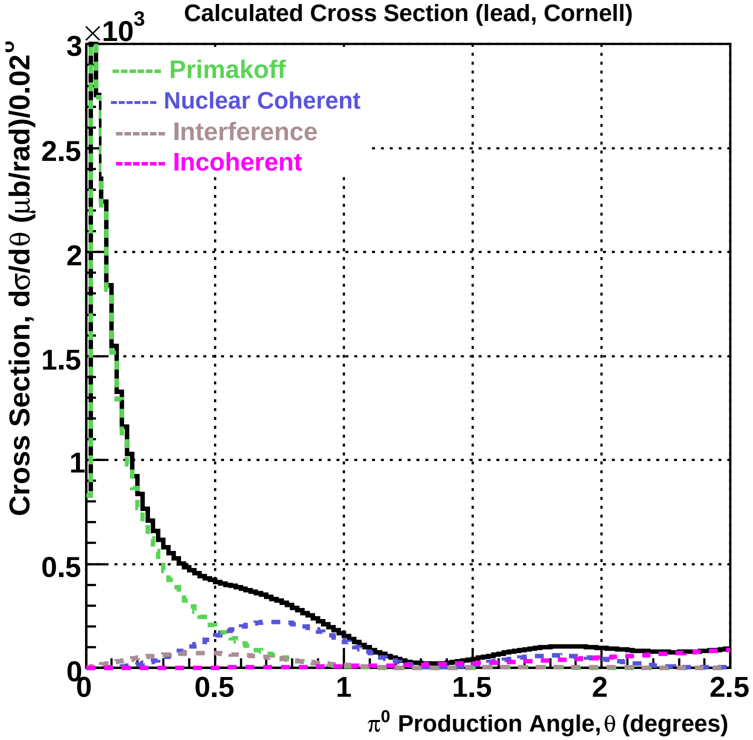
Table 5: Summary of target density and thickness analyses. The "effective" value quoted in the last column factors in the effect of trace impurities in the target (0.19% Oxygen) which act to increase the number of ^{12}C atoms/cm^2 due to their larger Z. There is assumed to be no impurities in the ^{208}Pb target. Note that the overall precision of the measurement is roughly $10\times$ better than was proposed.

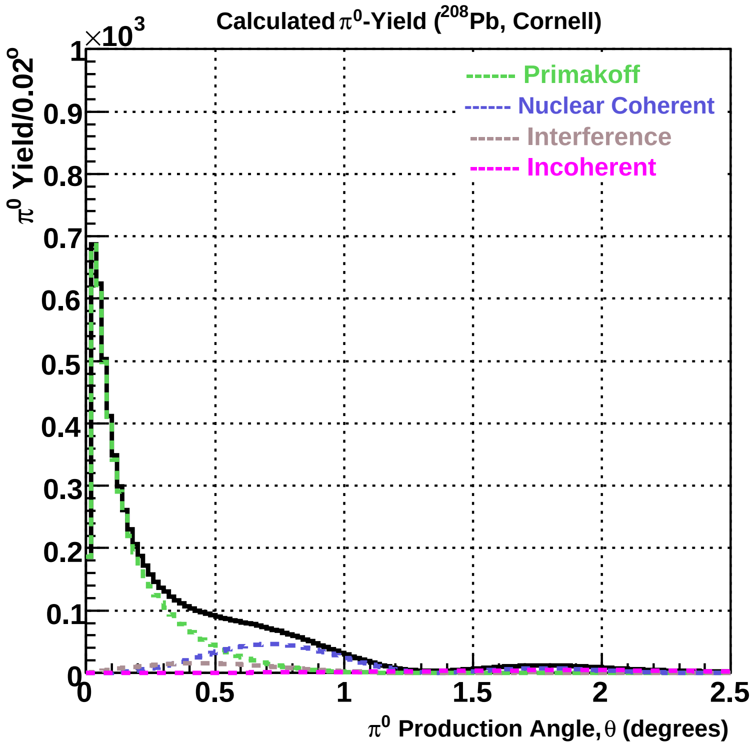
(Extra Slide) Theory Input Shape: ^{12}C Example





(Extra Slide) Theory Input Shape: ^{208}Pb Example





(Extra Slide) Yield Ratio ^{12}C, ^{208}Pb Comparison