Search for ω-mesic states

Experimental constraints on the ω-nucleus optical potential

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for the

CBELSA/TAPS-Collaboration

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

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Content

- Motivation
- Analysis
- Results
- Comparison with Theory
- Summary

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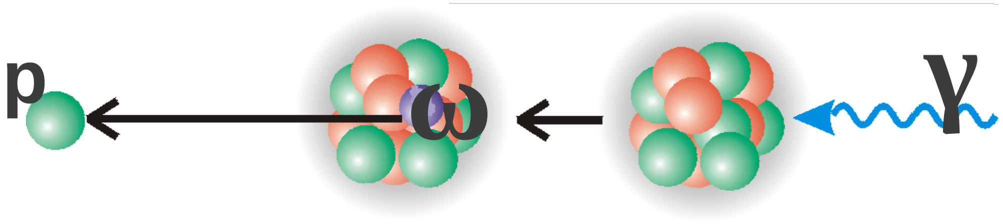
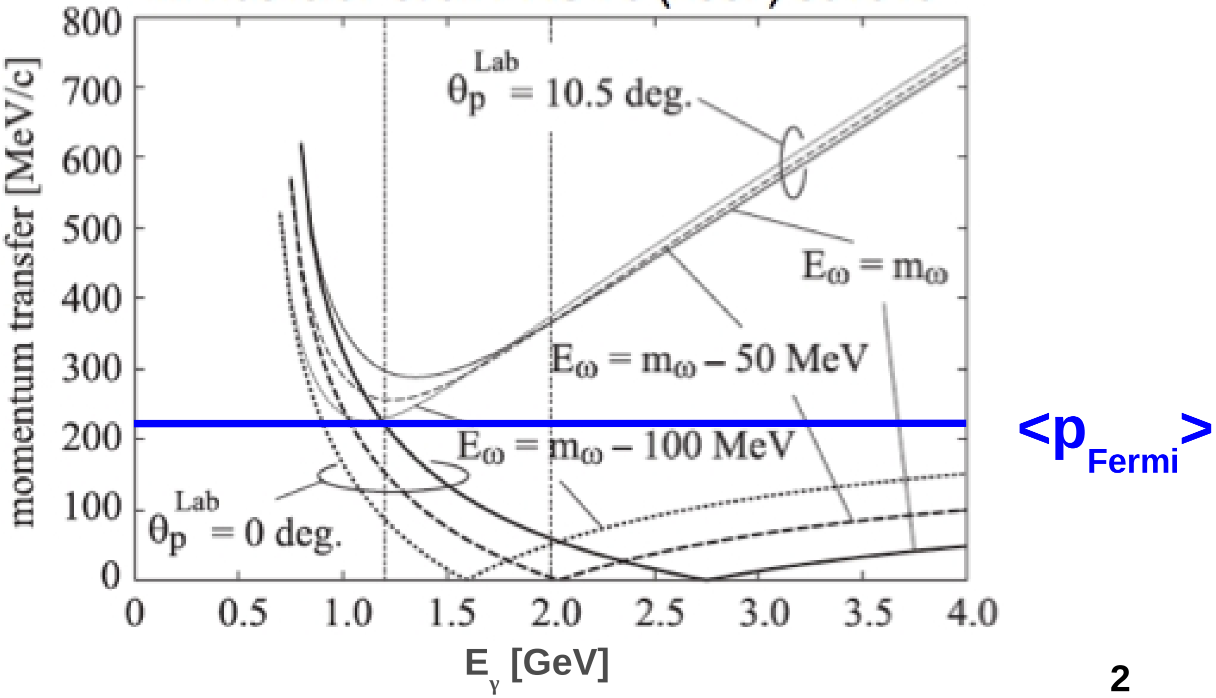
Motivation

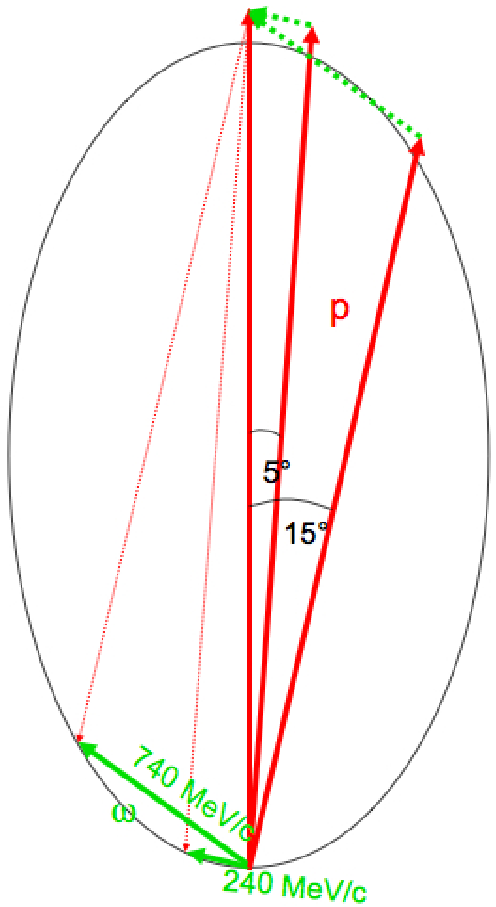
- Is there an attractive potential between the nucleus and the ω-meson?
- 1st step: Production of ω-meson
- 2nd step: Capture of ω-meson
- Identifying bound states → select low momentum ω
- $\gamma + A \rightarrow \omega \otimes_{(Z-1)}(A-1) + p$
- Recoilless production: Request for forward going proton



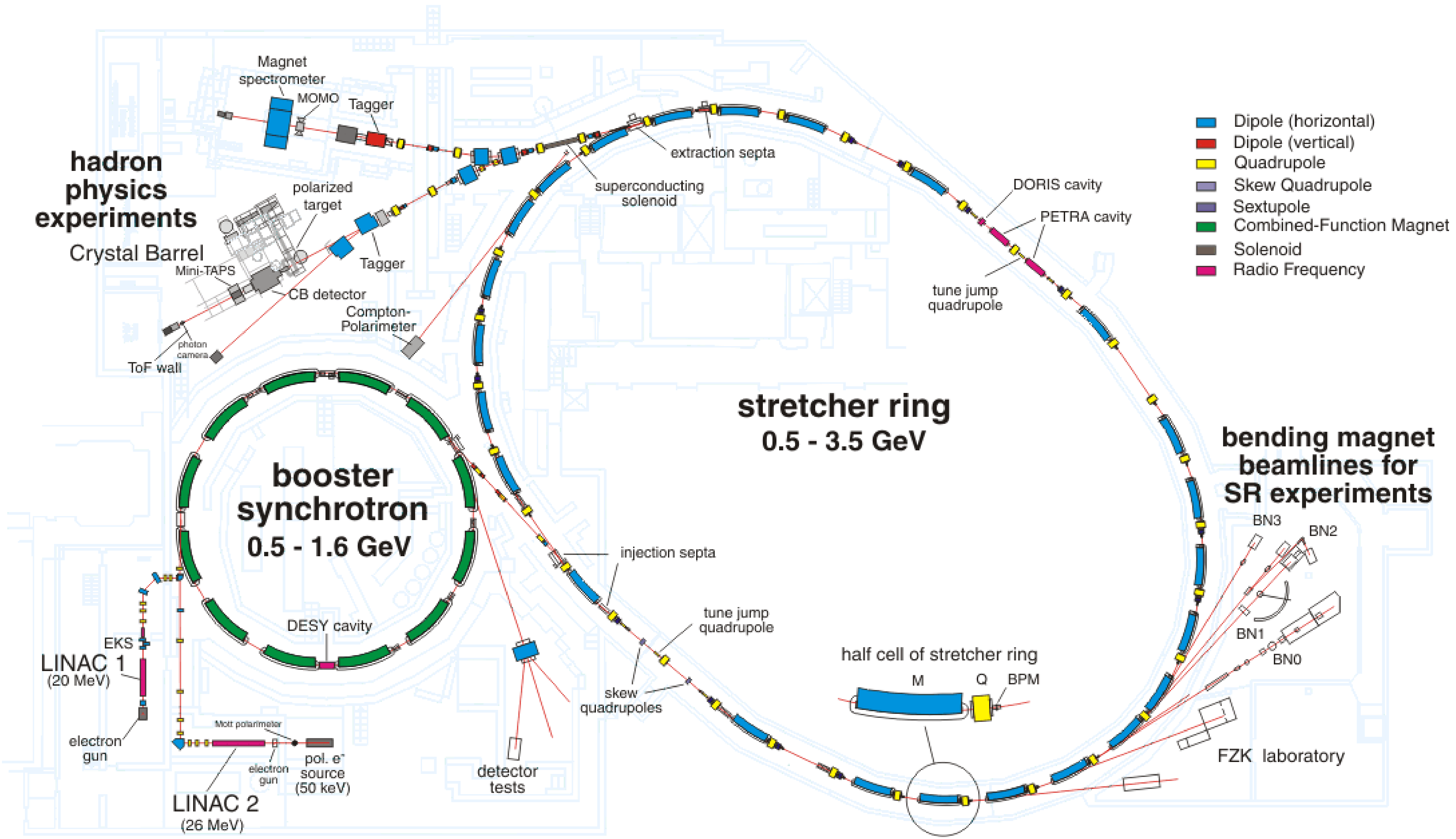
E_γ = 2750 MeV

M. Kaskulov et al. PRC 75 (2007) 064616



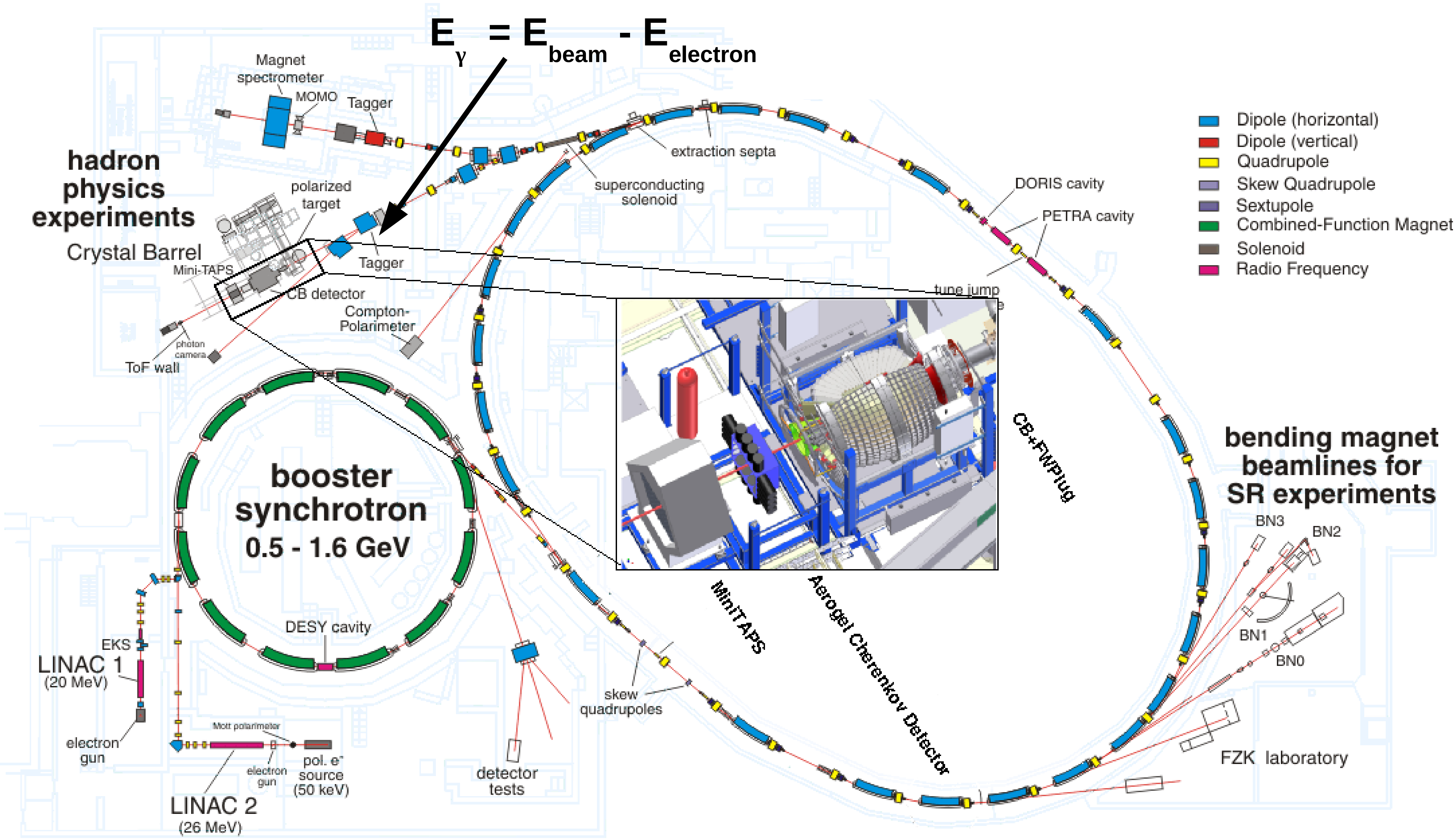


ELSA accelerator @ Bonn



ELSA accelerator @ Bonn

$E_\gamma = E_{beam} - E_{electron}$

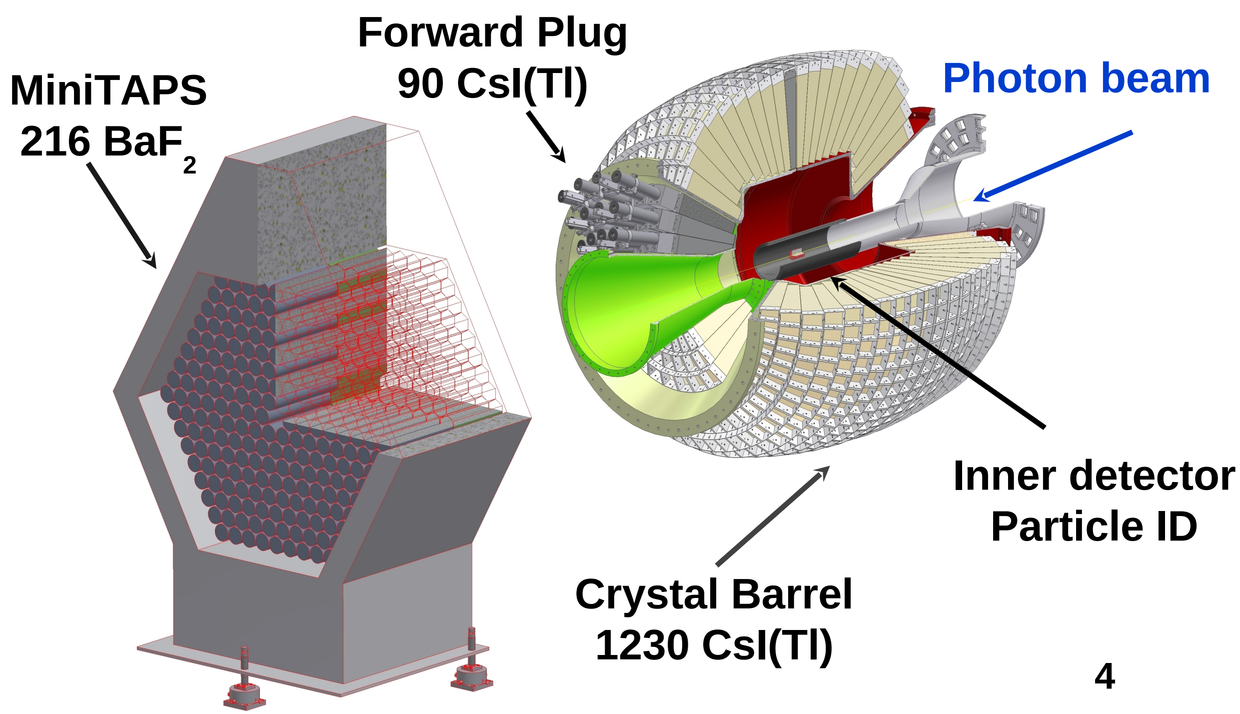


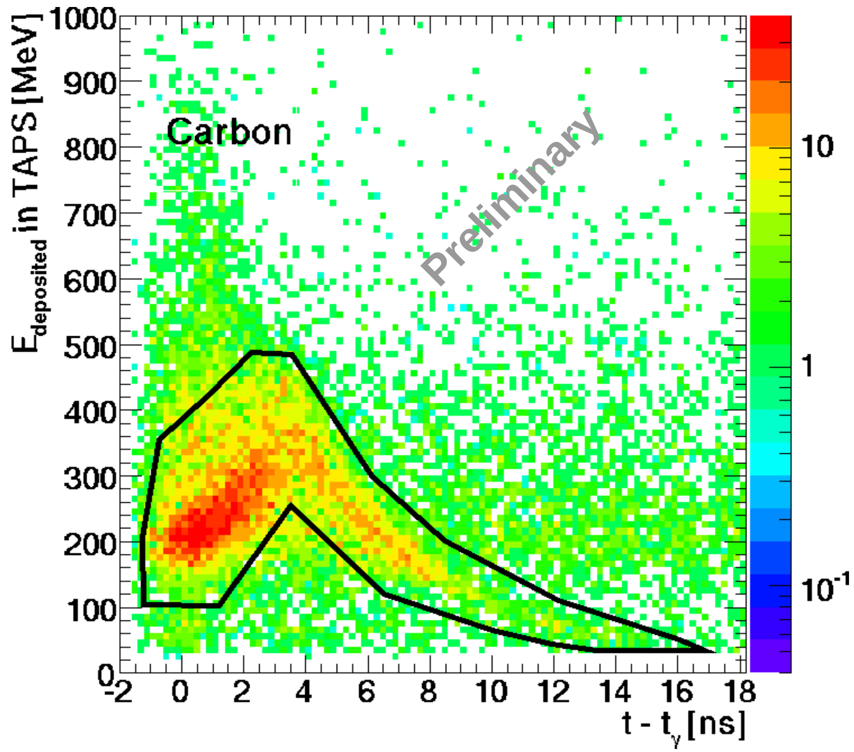
Experimental setup

- ELSA@Bonn: e^- beam 3.2 GeV → E_γ = 1250 - 3100 MeV
- Photoproduction of ω-meson
- Two dedicated Carbon beamtimes
- Same setup for all beamtimes → LH_2 data as reference
- CBELSA/TAPS setup very well suited for multi-photon final states!
- Identifying bound states → select low momentum ω
- Identification of proton in TAPS detector by $E_{deposited}$ vs. ToF
  - Insufficient resolution

$\gamma + {}^{12}C \rightarrow \omega \otimes {}^{11}B + p$

$\omega \rightarrow \pi^0\gamma \rightarrow 3\gamma$ (BR 8.18 %)

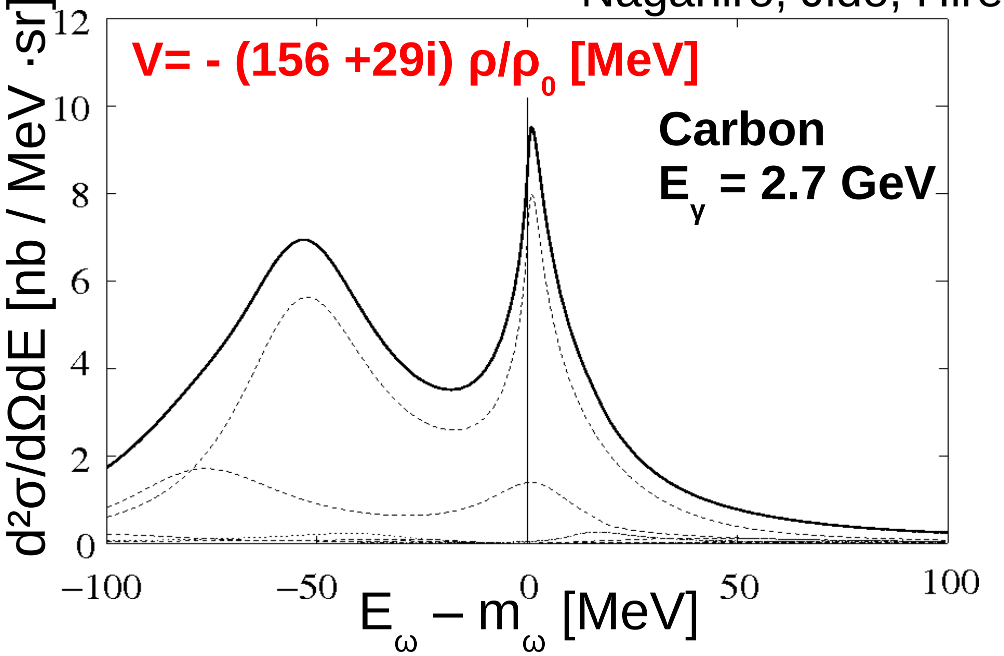


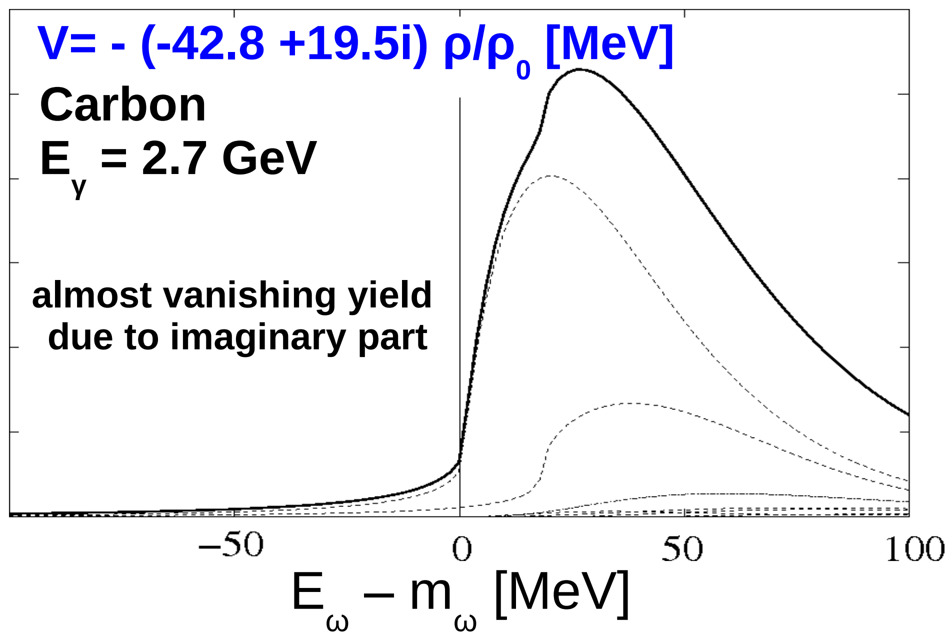


Signatures for bound states

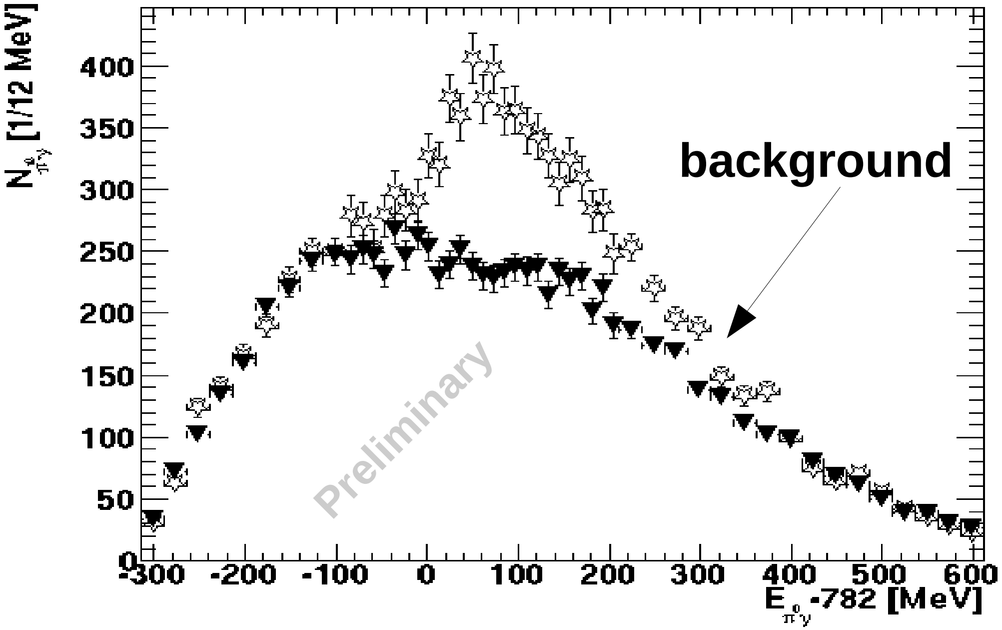
- Would potential between nucleus and ω-meson be attractive or repulsive?
- Would this attractive potential be sufficiently deep to form a bound meson-nucleus system?
  - Kinetic energy spectrum would be changed!
  - Two options:
    - Missing mass spectroscopy (inclusive measurement): measuring momentum of forward going proton
    - Decay spectroscopy (semi-exclusive measurement): measuring decay of ω-bound state in coinc. with forward going proton

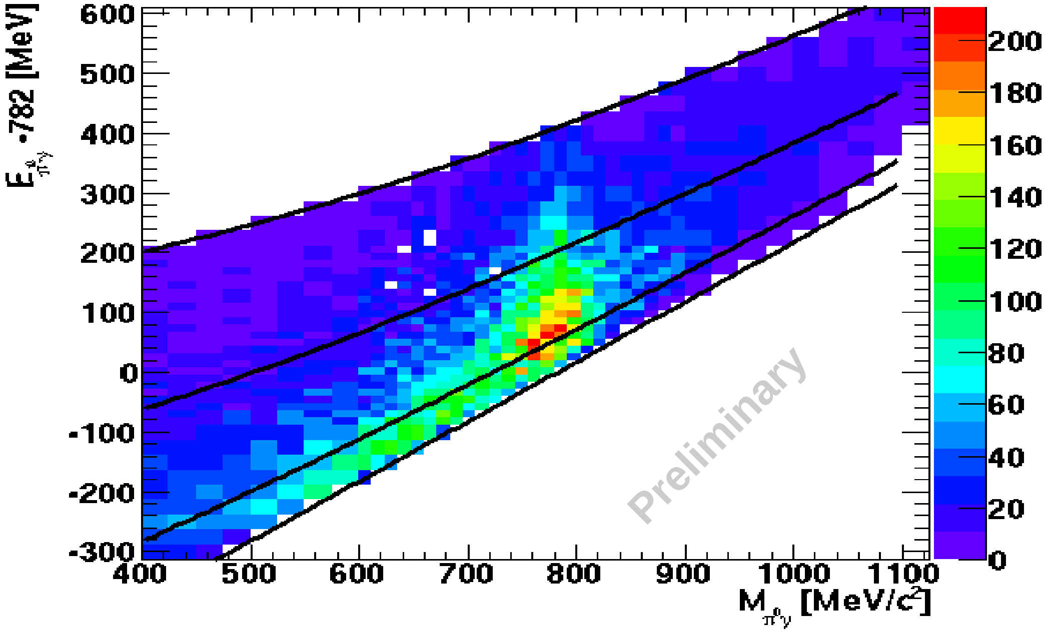
Nagahiro, Jido, Hirenzaki, Nucl. Phys. A 761 (2005), 92



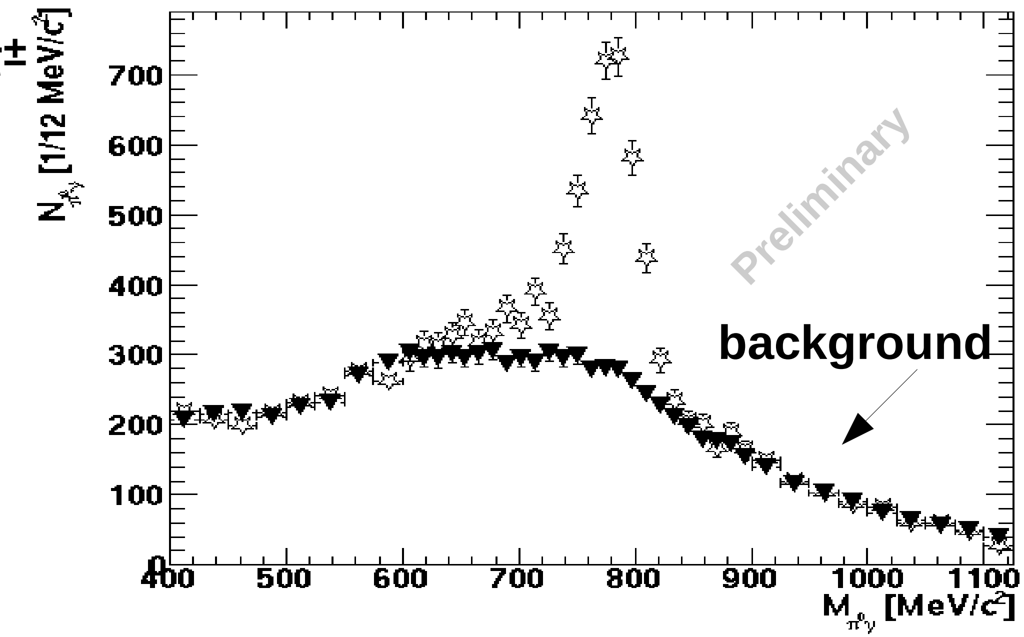


Analysis: Background + Signal

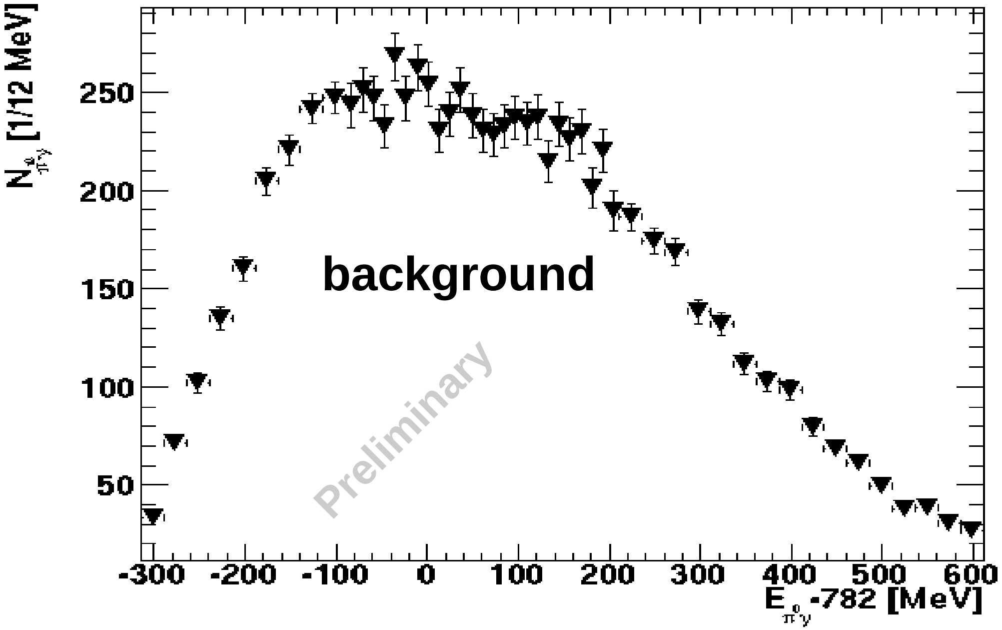


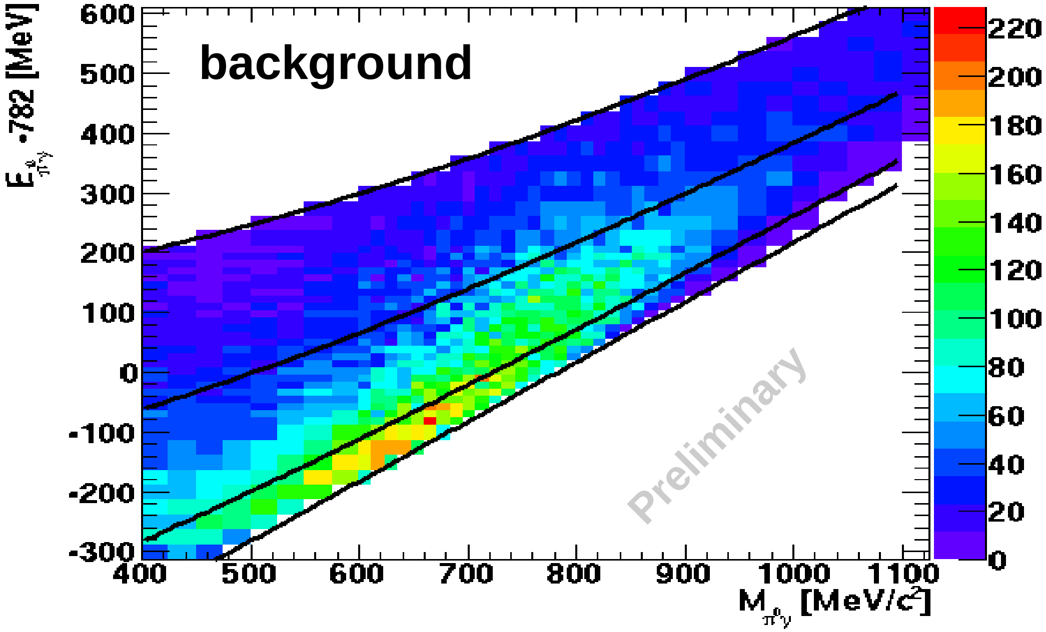


- Selecting ==3 neutrals and ==1 charged
- Anti-cut on Aerogel-Cherenkov reject $e^{\pm}/\pi^{\pm}$
- E_{beam}>1250 MeV ($\pi^0\pi^0$ cross-section)
- E^{γ_3}>200 MeV (suppress photons from $\pi^0\pi^0$)
- $1° < \Theta_{proton} < 11°$ (slow ω's)
- Proton band cut
- Missing mass cut (quasi-free reaction)
- $T_{\pi 0}$ > 120 MeV (suppress π^0-rescattering)
- Cluster threshold > 50 MeV (split-off)

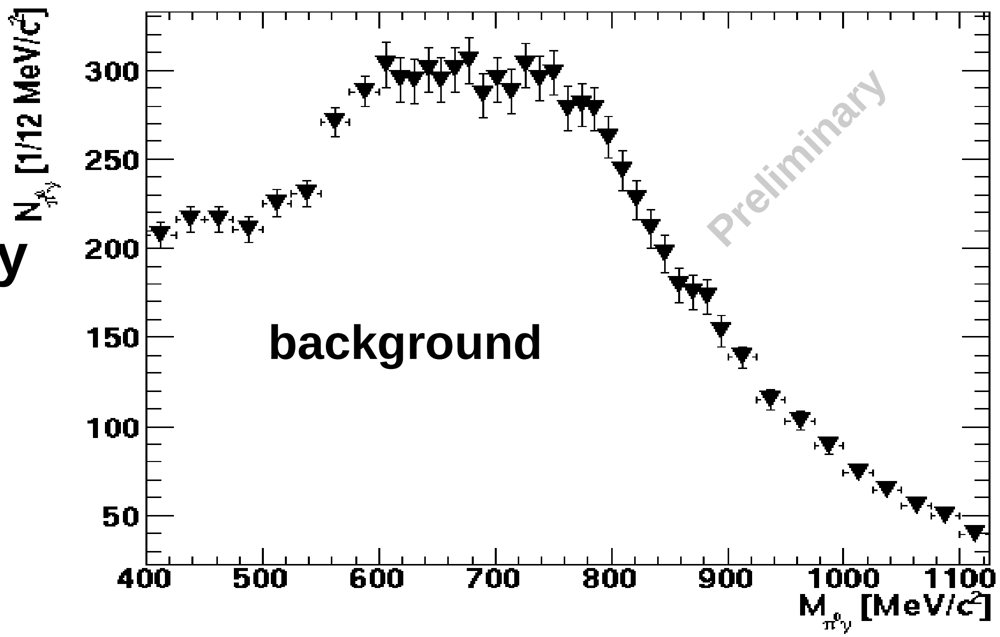


Analysis: Background determination

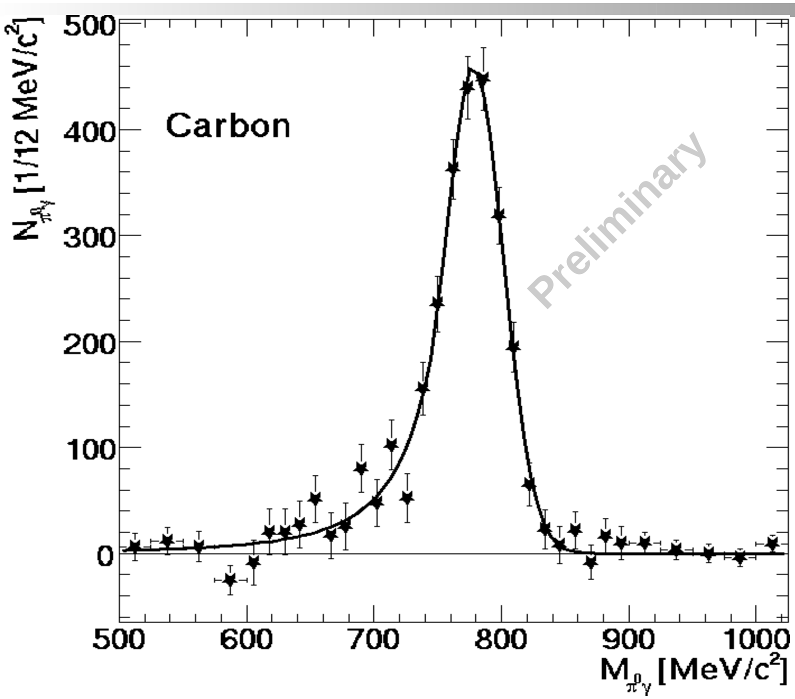




- Background contribution is derived from same dataset!
- $\pi^0\pi^0/\ \pi^0\eta \rightarrow 4\ \gamma$ events
- 1 neutral omitted, analysed in same way
- All combinations taken into account
- Background gradually scaled in momentum bins separately 0, 300, 600, 900 MeV/c



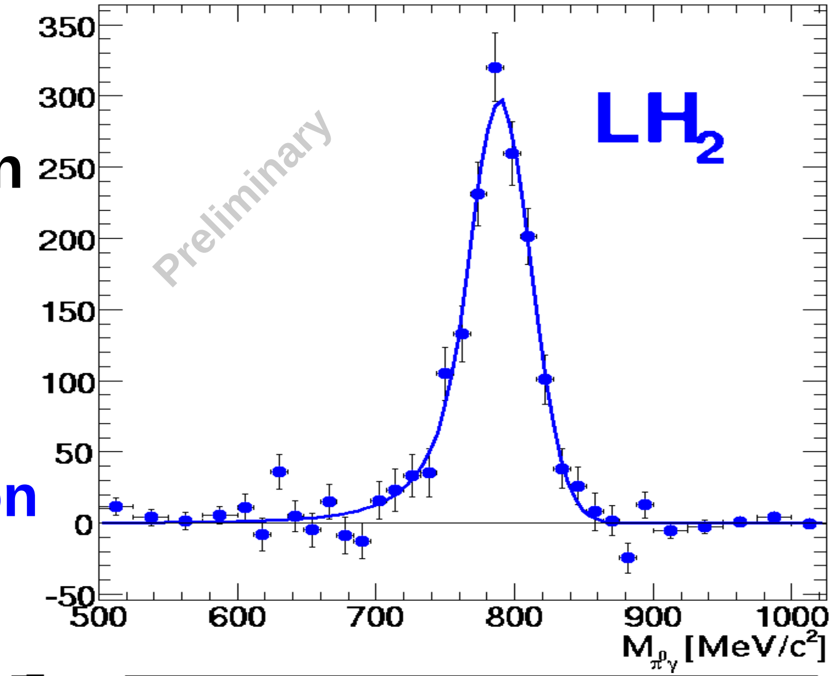
Analysis: Signal spectra (counts)

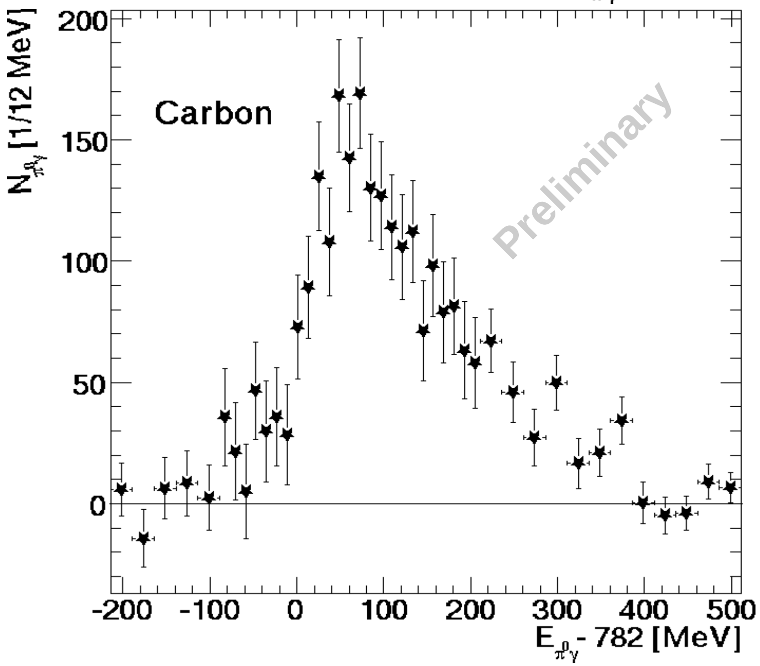


Fit-functions

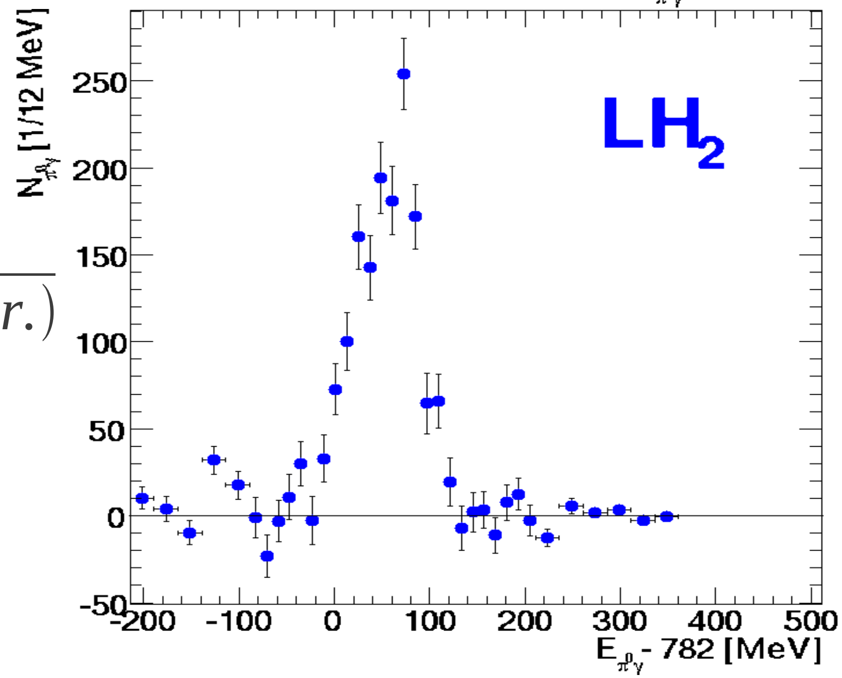
CrystalBall-Function → Gaussian with power-law low-mass tail

Novosibirsk-Function → Gaussian with low-mass tailing



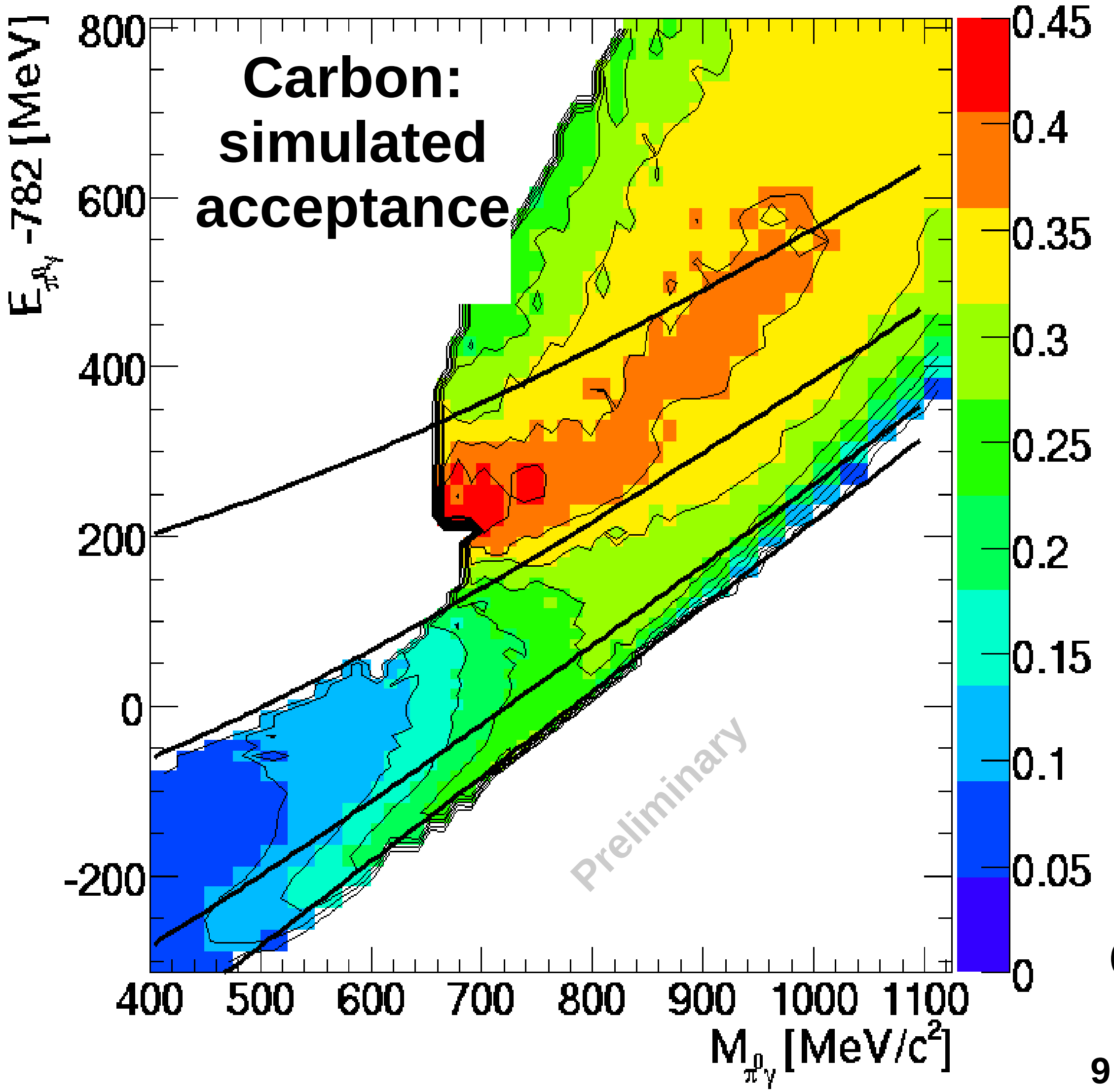


$$\Delta\, Sig. = \sqrt{(Sig. + 2 \cdot Backgr.)}$$



Cross section determination: Acceptance

- $\pi^0\gamma$ pair in coincidence with proton in TAPS ($1^0 < \theta_p < 11^0$)
- Pixelwise acceptance correction applied!



- GEANT3 detector simulation to determine acceptance of the experimental setup
- $400 < M_{\pi 0\gamma} < 1200$ MeV/c²
- Proton and ω correlated in Θ/Φ
- Fermi motion included (Carbon!)
- Detector features implemented
- Systematic uncertainty ≈ 10%

Contour lines: increments by 10%

Systematic uncertainties

Cross section: $\sigma = N_{event} / (\epsilon \cdot n_{target} \cdot N_{\gamma} \cdot BR)$

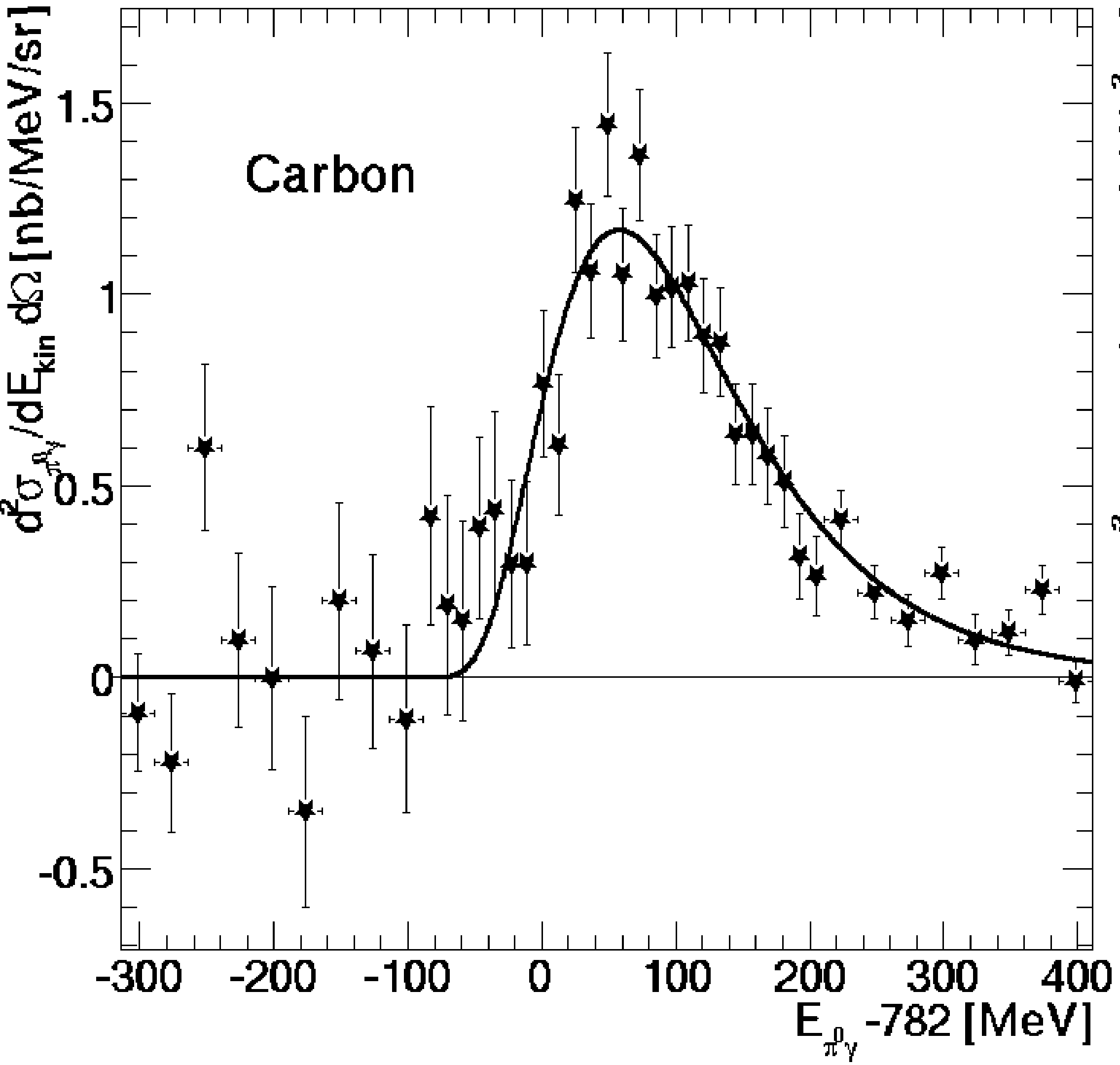
Fits	**10-15%**
Acceptance	**≲ 10%**
Photon flux	**5-10%**
Photon shadowing	**≈5%**
Total	**≈20%**

Systematic errors added quadratically

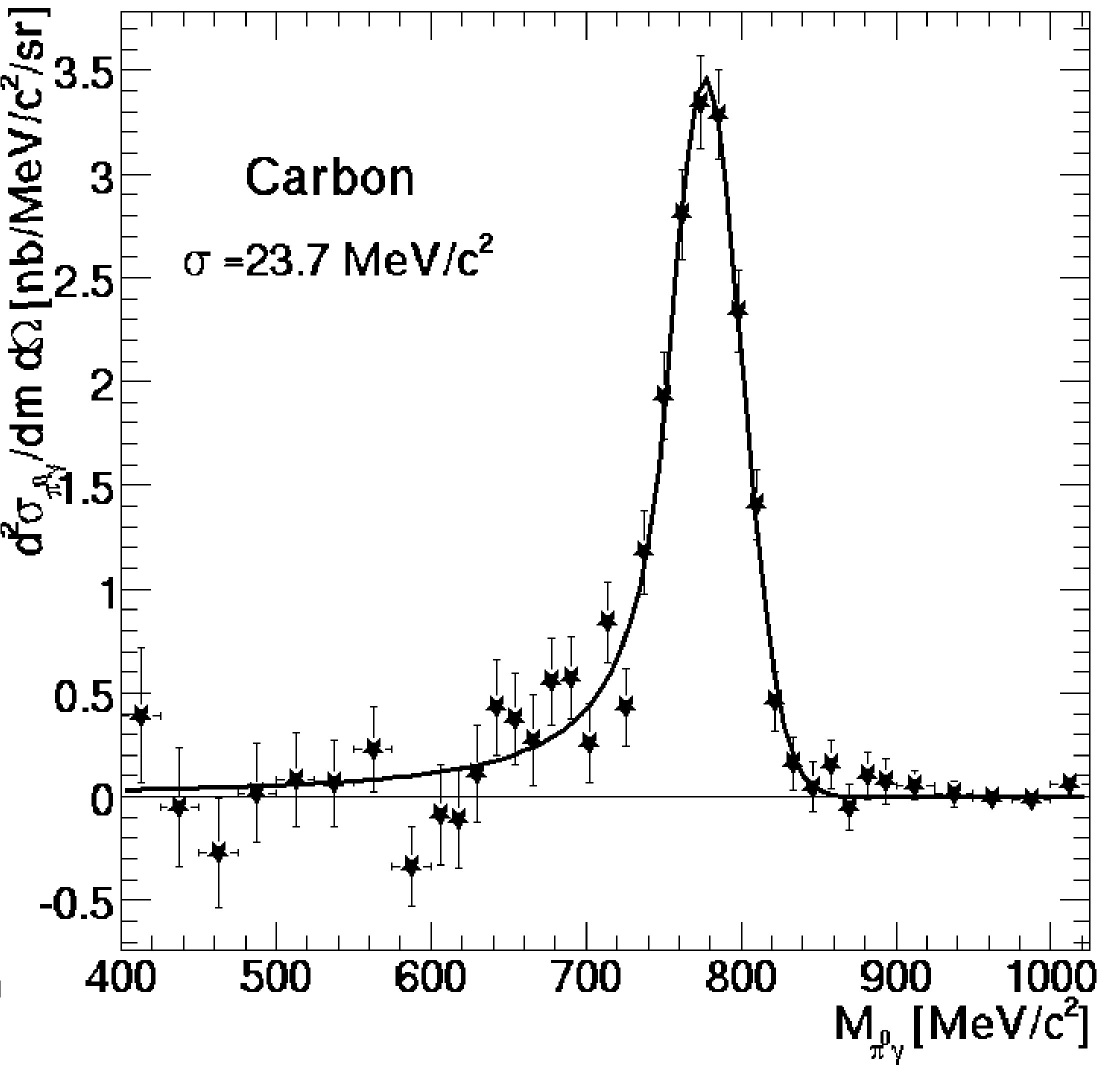
$$\sigma_{total}^{syst} = \sqrt{(\Sigma_i \sigma_i^2)}$$

Cross sections: Carbon

kinetic energy



invariant mass



- **Bound state region: $E_{\pi 0\gamma}$ - 782 MeV < 0 MeV**
- **No structures; small yield in [-100;0] MeV**

- **Tailing towards small masses**

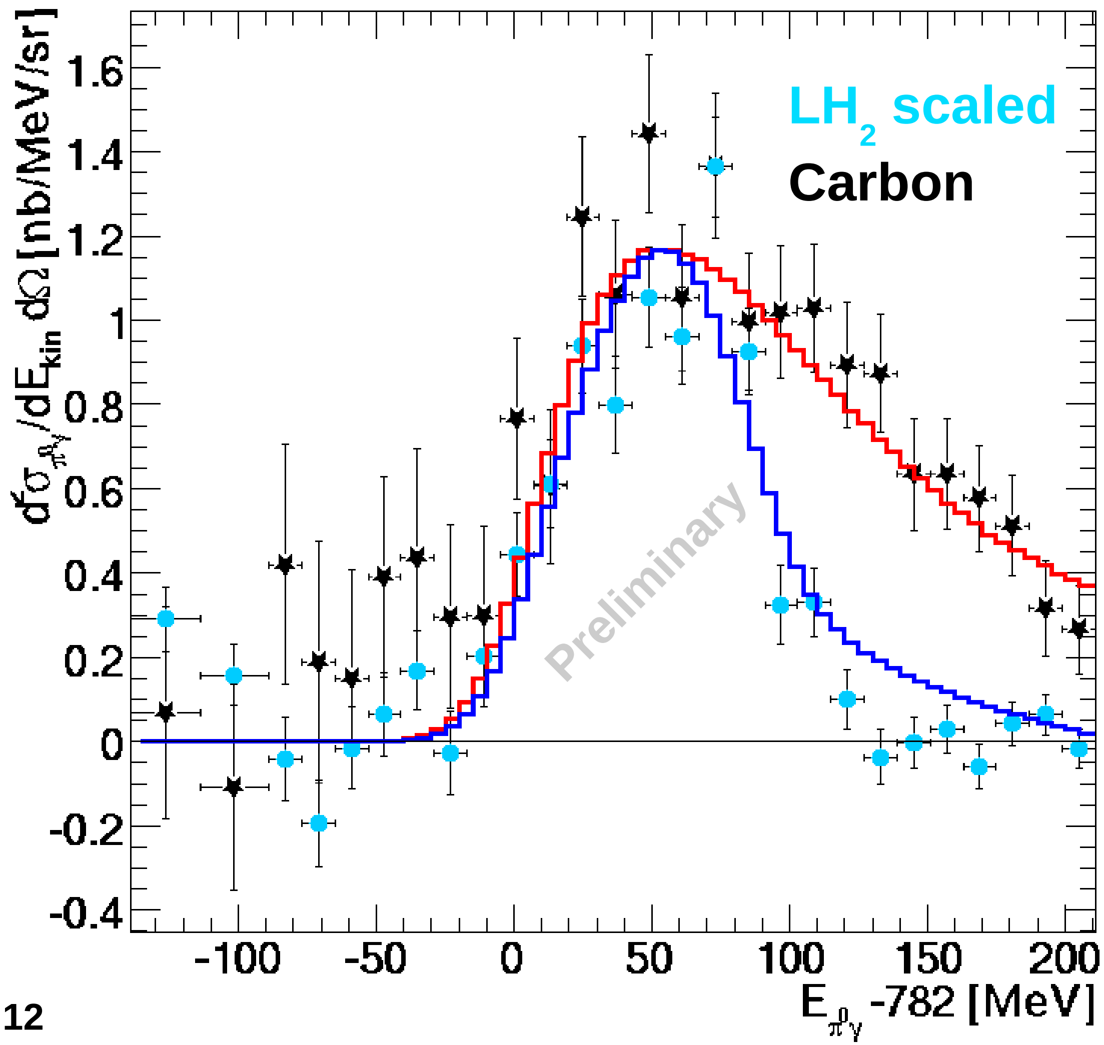
Cross sections: Comparison

GEANT start distribution (scaled to exp. fit)

	peak value (fit)	
LH_2	52 MeV	(60±3) MeV
Carbon	52 MeV	(58±5) MeV

potential
neither strongly attractive nor repulsive

Folded with experimental resolution
σ = 16.7 MeV



Theoretical predictions (I)

H. Nagahiro, S. Hirenzaki (private communications)

Example: V= - (156 +70i) ρ/ρ_0 [MeV]

Calculations for

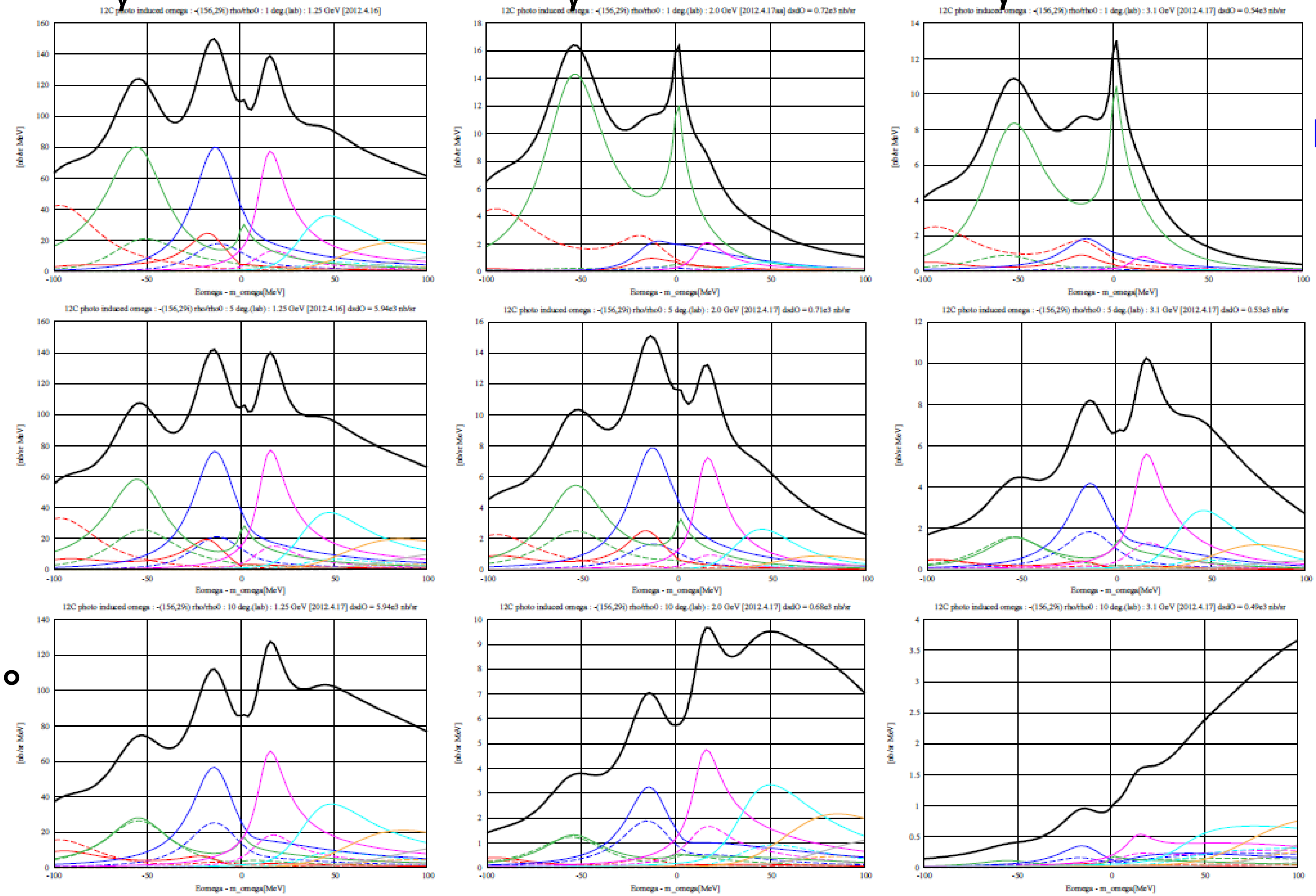
- **3 different energies**
- **3 different proton angles**

E_γ = 1.25 GeV | **E_γ = 2.0 GeV** | **E_γ = 3.1 GeV**

Θ_p=1°

Θ_p=5°

Θ_p=10°



W($\rho=\rho_0$) ≈ 70 MeV
Kotulla et al. PRL 100 (2008) 192302

Black: Total yield

Color: Individual states of $\omega\otimes^{11}B$

Theoretical predictions (II)

H. Nagahiro, S. Hirenzaki (private communications)

Example: V= - (0 +70i) ρ/ρ_0 [MeV]

Calculations for

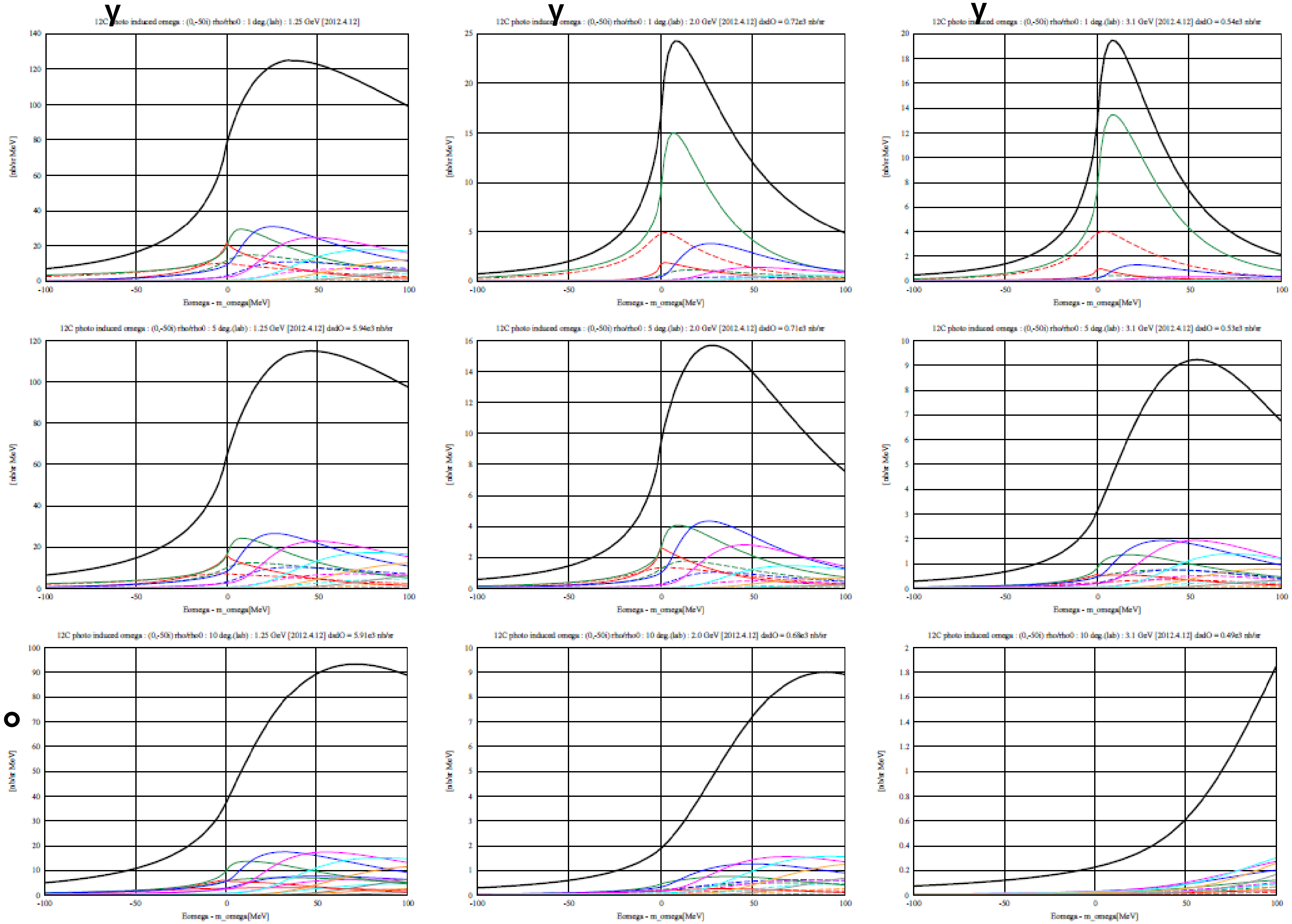
- 3 different energies
- 3 different proton angles

E_γ = 1.25 GeV E_γ = 2.0 GeV E_γ = 3.1 GeV

Θ_p=1°

Θ_p=5°

Θ_p=10°



W($\rho=\rho_0$) ≈ 70 MeV
Kotulla et al. PRL 100 (2008) 192302

Black:
Total yield

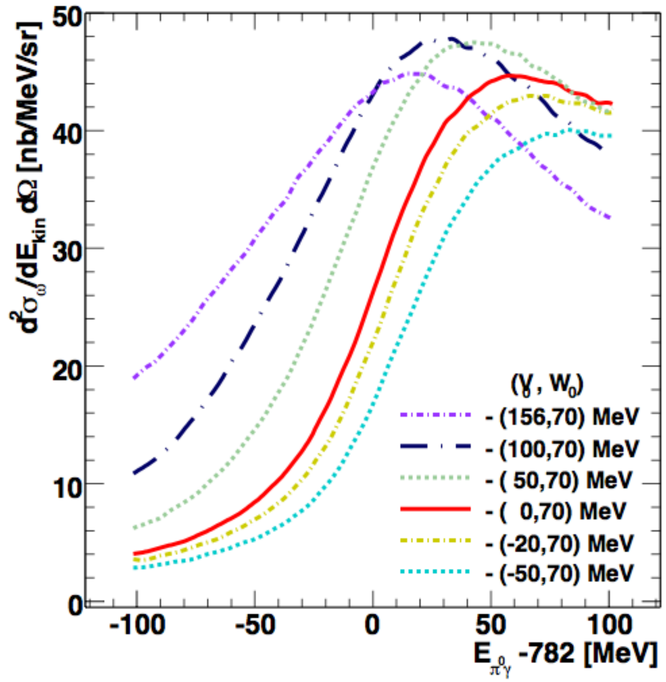
Color:
Individual states of $\omega \otimes {}^{11}B$

Yield below 0 MeV

Theoretical predictions (III)

- E_γ = 1250 - 3100 MeV weighted $1/E_\gamma$
- Θ_{proton} = 1° - 11° (integrated over angles)
- Resolution FWHM = 35 MeV folded in

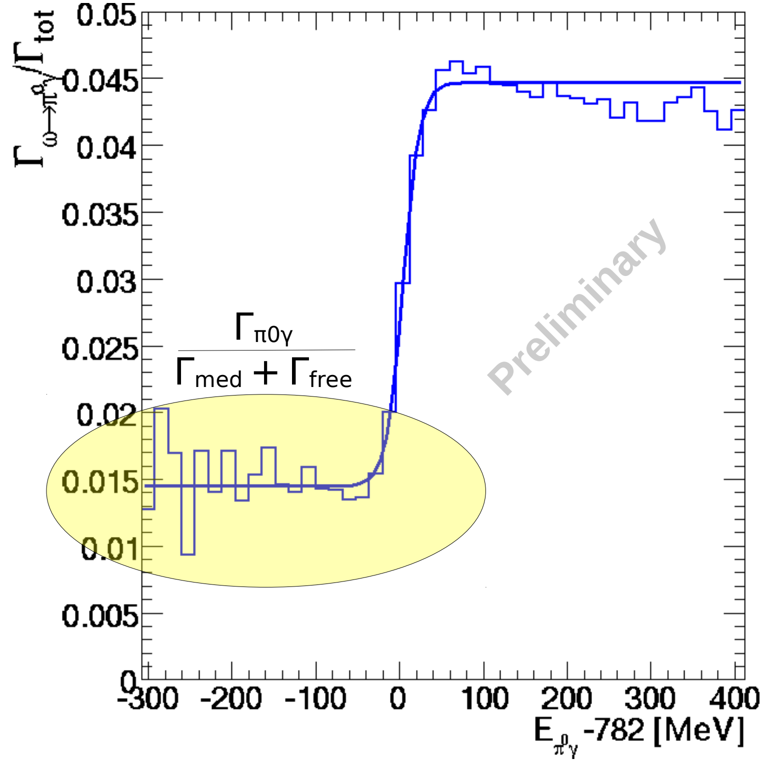
formation cross section



- Peak position sensitive to potential depth

- No structures due to large ω in-medium width: $W(\rho=\rho_0) = \Gamma/2 \approx 70$ MeV for p_ω = 1.1 GeV

free BR = 0.0818

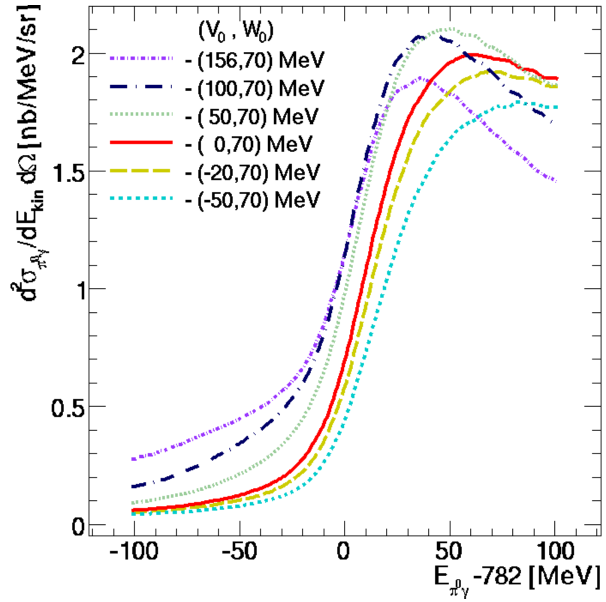


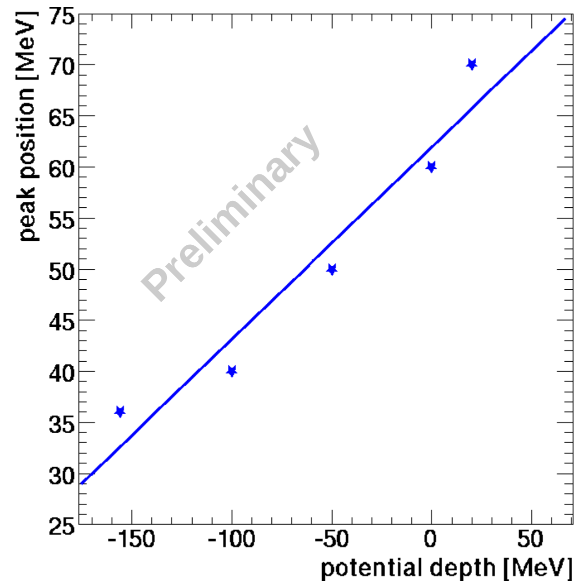
- effective BR for $\pi^0\gamma$ decay from GiBUU

for details see: http://gibuu.hepforge.org

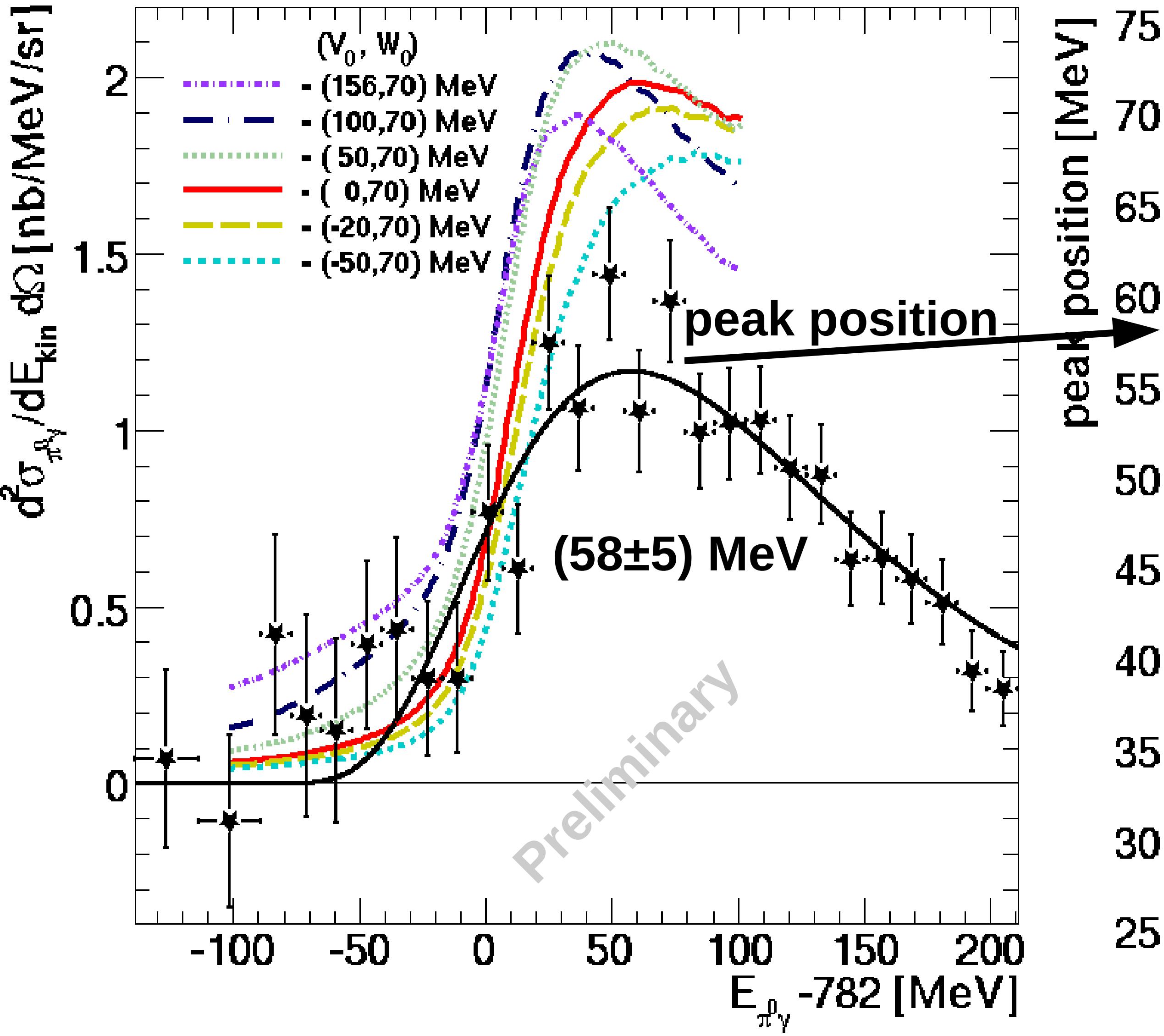
expected $\pi^0\gamma$ cross section:

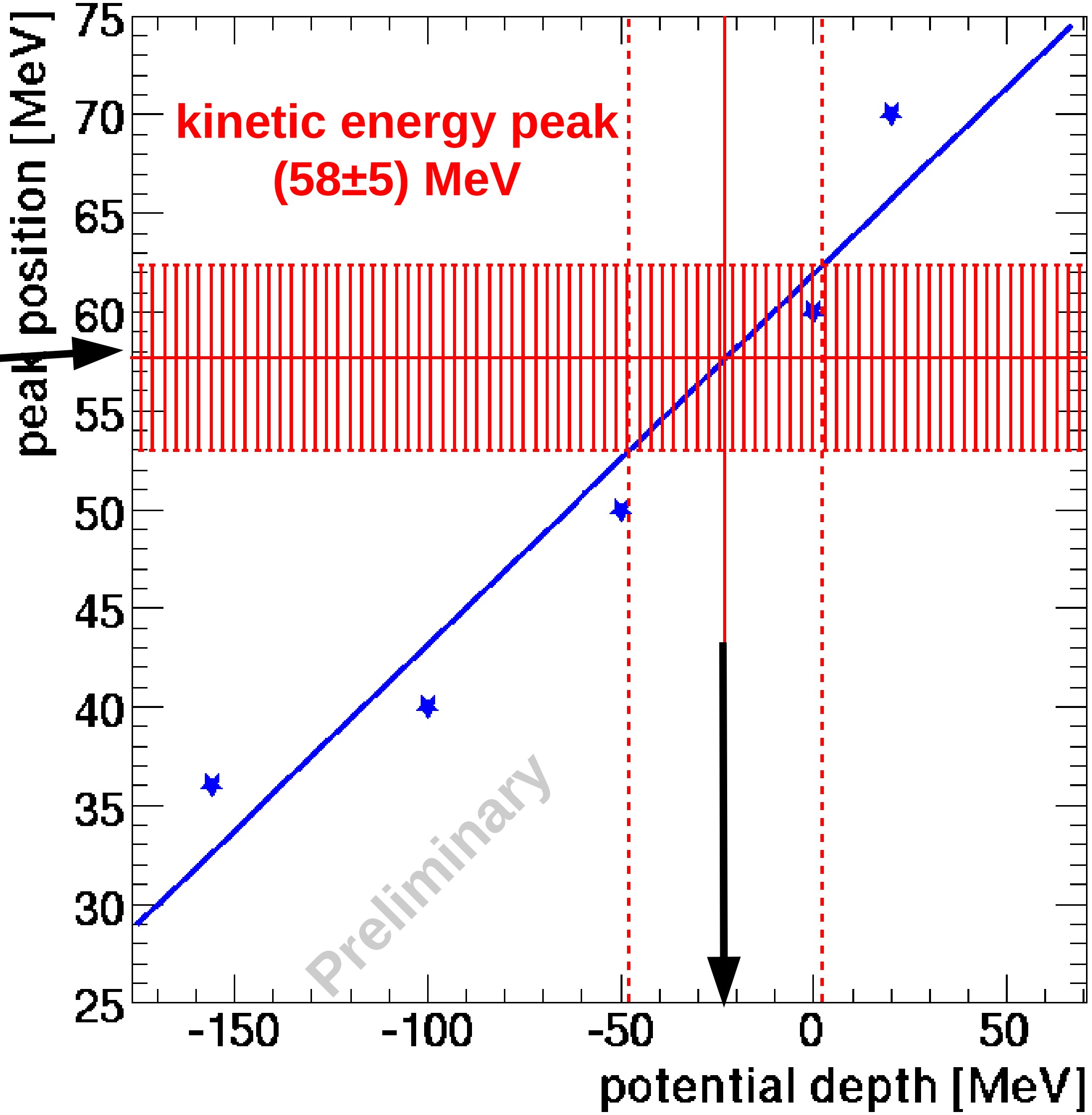
$\sigma_{\pi 0\gamma} = \sigma_{formation} \otimes \Gamma_{\omega\to\pi 0\gamma}/\Gamma_{tot}$





Comparison with experiment



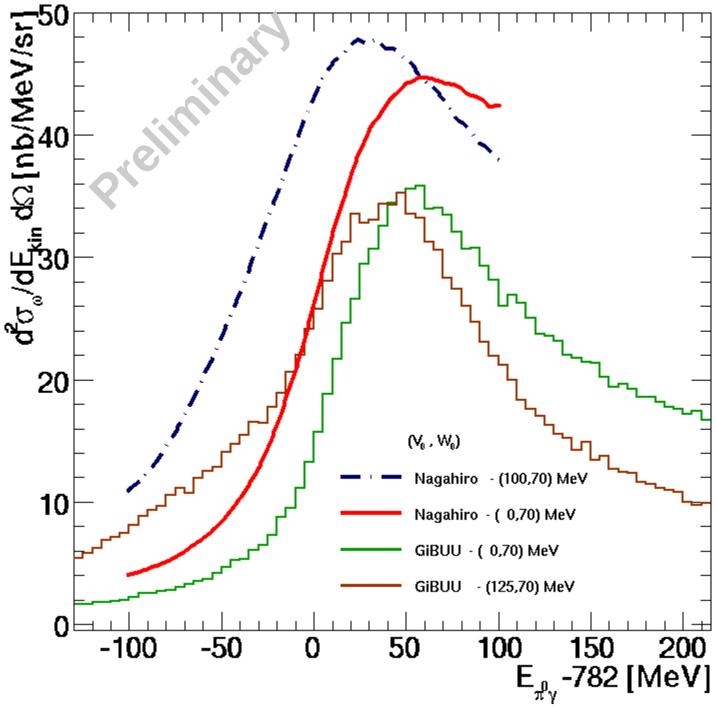


- Cross section in bound state region comparable to theoretical predictions
- Yield due to large in-medium width of ω?

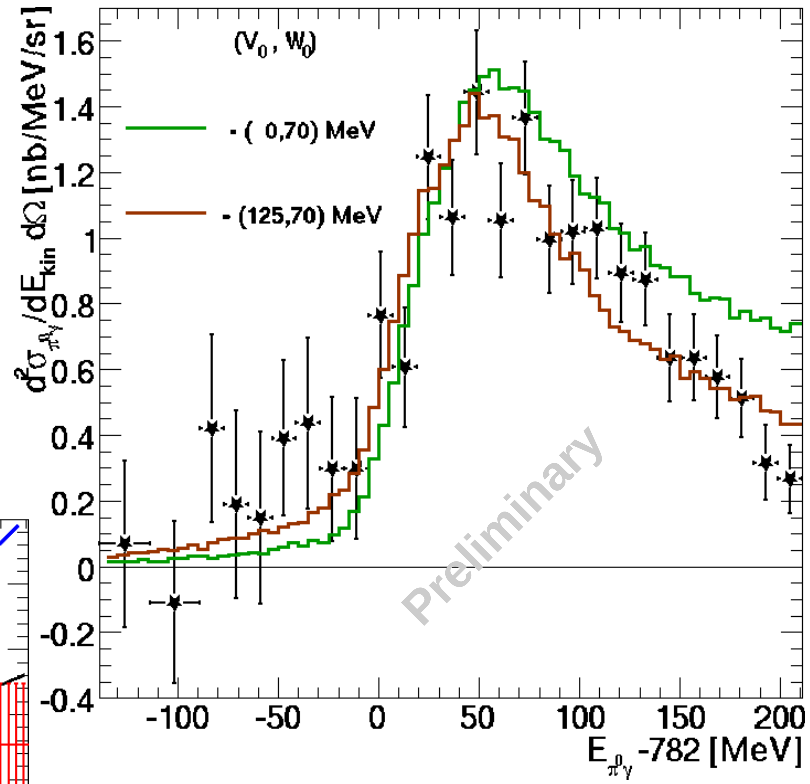
$V_0(\rho=\rho_0) \approx -(20 \pm 25)$ MeV

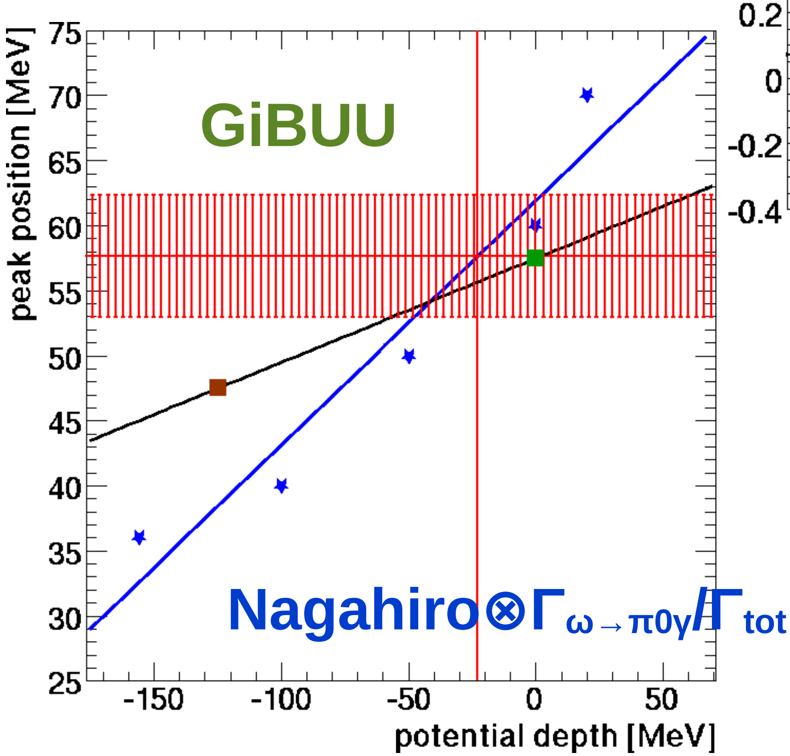
Comparison with GiBUU

Formation cross sections:
GiBUU ↔ Nagahiro et al.



Comparison: experiment ↔ GiBUU





good agreement between quantum mechanical and transport calculation

within model dependencies:

$V_0(\rho=\rho_0) \approx$
- 20 ± 25 (stat) ± 10 (syst) MeV

Summary

- No significant structure at negative energies observed
- Cross section in bound state region comparable to theoretical predictions
- Comparison of data and theoretical calculations by Nagahiro et al. show that the real part of the ω-nucleus potential can be constrained to:

  $V_0(\rho=\rho_0) \approx -20 \pm 25\,(\mathrm{stat}) \pm 10\,(\mathrm{syst})$ MeV

- Imaginary part of the ω-nucleus potential:

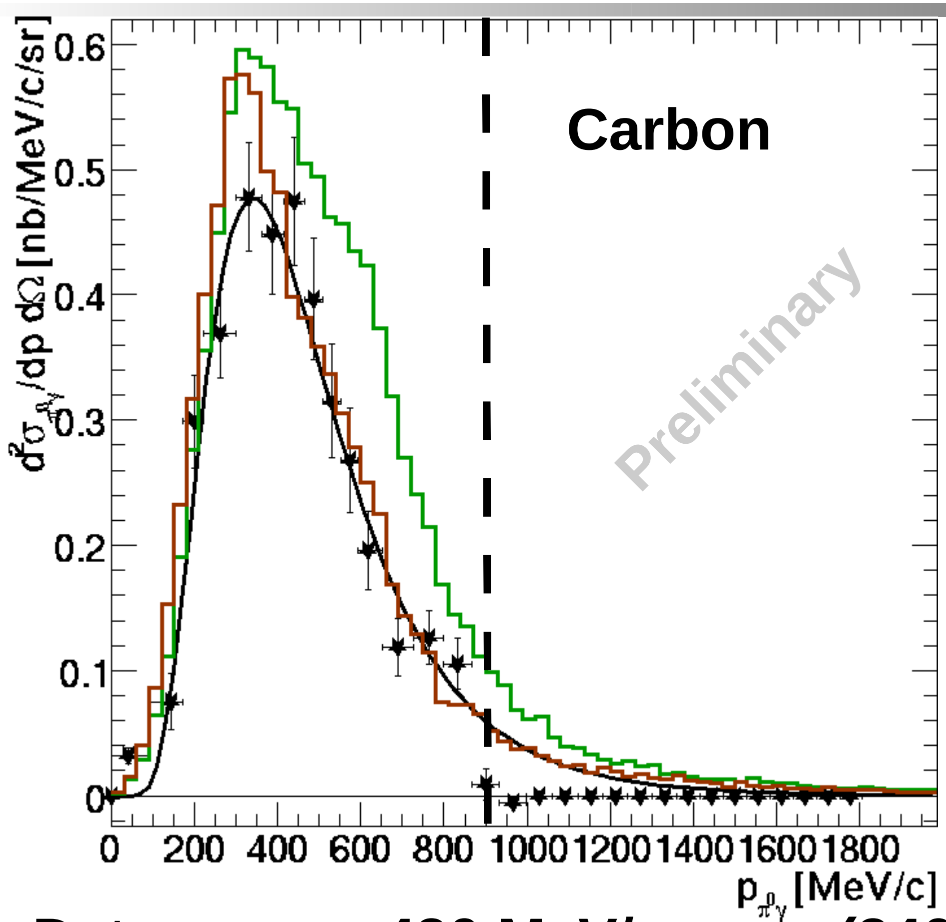
  $\Gamma(\rho=\rho_0) \approx 140$ MeV $> |V_0| >$ binding energy

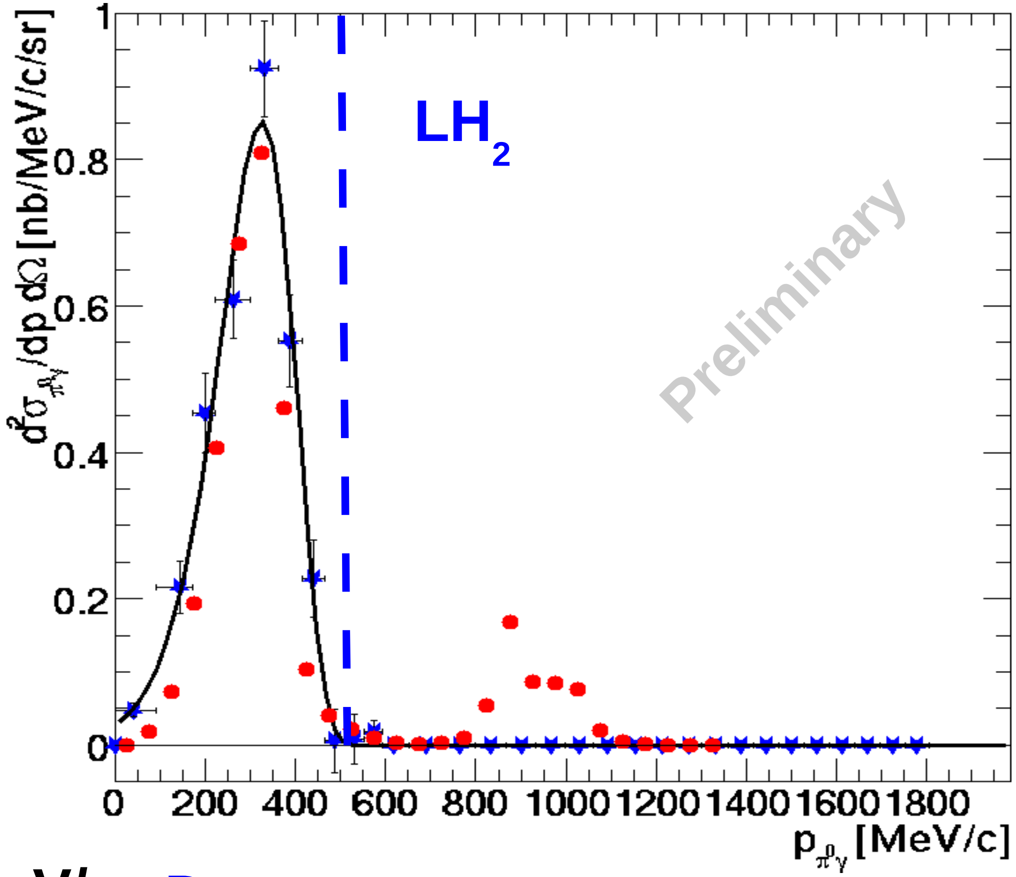
  - Conclusion:
    Unfortunately ω not a good case to search for bound states

Thank you for your attention!

Backup

Momentum distribution





- **Data: <p> = 430 MeV/c, p_{max}=(340±10) MeV/c**
- **GiBUU: Collisional Broadening (Γ=150 MeV)**
  <p> = 465 MeV/c, p_{max} = 315 MeV/c

  GiBUU: Coll. Broadening + Mass shift
  <p> = 415 MeV/c, p_{max} = 315 MeV/c
- **Difficult to distinguish different scenarios**

- **Data:**
  <p> = 290 MeV/c, p_{max} = 325 MeV/c
- **GiBUU:**
  <p> = 300 MeV/c, p_{max} = 325 MeV/c