Properties of the Resonance Λ(1520) as Seen in the Forward Electroproduction at JLab Hall A

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- Where we are now
- JLab Hall A Experiment
- BW Analysis
- Pole Position
- Summary

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Where we are now – PDG08

[C. Amsler *et al.* [RPP] Phys Lett B **667**, 1 (2008)]

$\Lambda(1520)$ D_{03}

$I(J^P) = 0(\frac{3}{2}^-)$ Status: ****

Λ BARYON
($S = -1$, $I = 0$)
$\Lambda^0 = u\,d\,s$

- Discovered by FERRO-LUZZI 62; the elaboration in WATSON 63 is the classic paper on the Breit-Wigner analysis of a multichannel resonance.
- Production and formation experiments agree quite well, so they are listed together here.

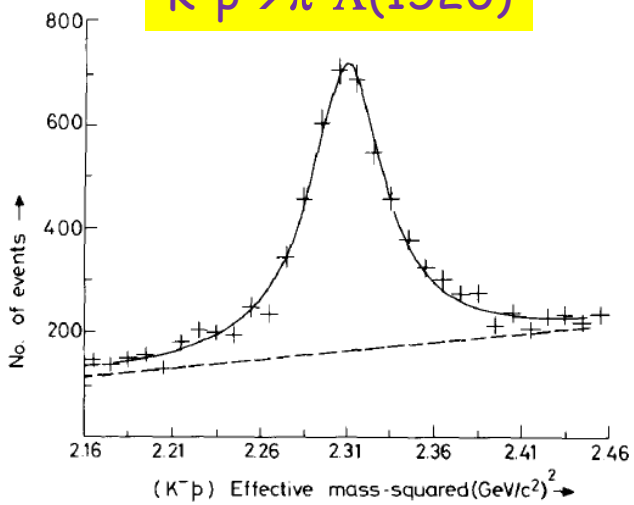
$\Lambda(1520)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
1519.5 ±1.0 OUR ESTIMATE					
1519.50±0.18 OUR AVERAGE					
1517.3 ±1.5	300	BARBER	80D	SPEC	$\gamma p \to \Lambda(1520) K^+$
1519 ±1		GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
1517.8 ±1.2	5k	BARLAG	79	HBC	$K^- p$ 4.2 GeV/c
1520.0 ±0.5		ALSTON-...	78	DPWA	$\overline{K}N \to \overline{K}N$
1519.7 ±0.3	4k	CAMERON	77	HBC	$K^- p$ 0.96–1.36 GeV/c
1519 ±1		GOPAL	77	DPWA	$\overline{K}N$ multichannel
1519.4 ±0.3	2000	CORDEN	75	DBC	$K^- d$ 1.4–1.8 GeV/c

$\Lambda(1520)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
15.6 ±1.0 OUR ESTIMATE					
15.59±0.27 OUR AVERAGE					
16.3 ±3.3	300	BARBER	80D	SPEC	$\gamma p \to \Lambda(1520) K^+$
16 ±1		GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
14 ±3	677	[1] BARLAG	79	HBC	$K^- p$ 4.2 GeV/c
15.4 ±0.5		ALSTON-...	78	DPWA	$\overline{K}N \to \overline{K}N$
16.3 ±0.5	4k	CAMERON	77	HBC	$K^- p$ 0.96–1.36 GeV/c
15.0 ±0.5		GOPAL	77	DPWA	$\overline{K}N$ multichannel
15.5 ±1.6	2000	CORDEN	75	DBC	$K^- d$ 1.4–1.8 GeV/c

$K^- p \to \pi^0 \Lambda(1520)$



W. Cameron *et al* Nucl Phys **B131**, 399 (1977)

- The latest experimental inputs in RPP for the mass and width of the $\Lambda(1520)$ are dated before 1980

Current Parameters of the Λ(1520)

[C. Amsler *et al.* [RPP] Phys Lett B **667**, 1 (2008)]

Mass (MeV)	Width (MeV)	Year		
1517.3±1.5	16.3±3.3	1980	SPEC $\gamma p \to \Lambda(1520) K^+$	Resonance Production
1517.8±1.2	14 ±3	1979	HBC $K^- p$ 4.2 GeV/c	
1519.7±0.3	16.3±0.5	1977	HBC $K^- p$ 0.96–1.36 GeV/c	
1519.4±0.3	15.5±1.6	1975	DBC $K^- d$ 1.4–1.8 GeV/c	
1520.0±0.5	15.4±0.5	1978	DPWA $\overline{K}N \to \overline{K}N$	Resonance Formation
1519 ±1	15.0±0.5	1977	DPWA $\overline{K}N$ multichannel	
average 1519.5±1.0	average 15.6±1.0	2008	PDG08=PDG10	

- Works used different approaches:
  - In study various inelastic reactions
  - The distribution was described by BW (rel/non-rel) and non-coherent BG
  - Description of BG is different in different works
  - The Res width considered as energy dependent/independent
  - Interference effects with other resonances was taken into account differently
- Works neglected different threshold effects corresponding to other channels

- We extract Res parameters using high quality data and estimate a sensitivity of the treatment

Where we Are and What we are going to Do

- Without any justification, all those papers, which assume **Γ(W)** of the **Λ(1520)**, describe the total width as having the threshold behavior related only to the **K^-p** channel

  Meanwhile, different thresholds, corresponding to other decay channels (e.g. $\pi\Sigma$), should also affect the W-dependence of the total width

- All the described approaches would be completely equivalent for an ideally narrow resonance

  But, for the case of a finite width, such as the **Λ(1520)**, they should provide different results at some level of accuracy

- In what follows, we extract the resonance parameters from new measurements and estimate the **sensitivity** of our results to how the experimental data was treated

Jlab Hall A Experiment E04-012

[Y. Qiang *et al* Phys Rev C **75**, 055208 (2007)]

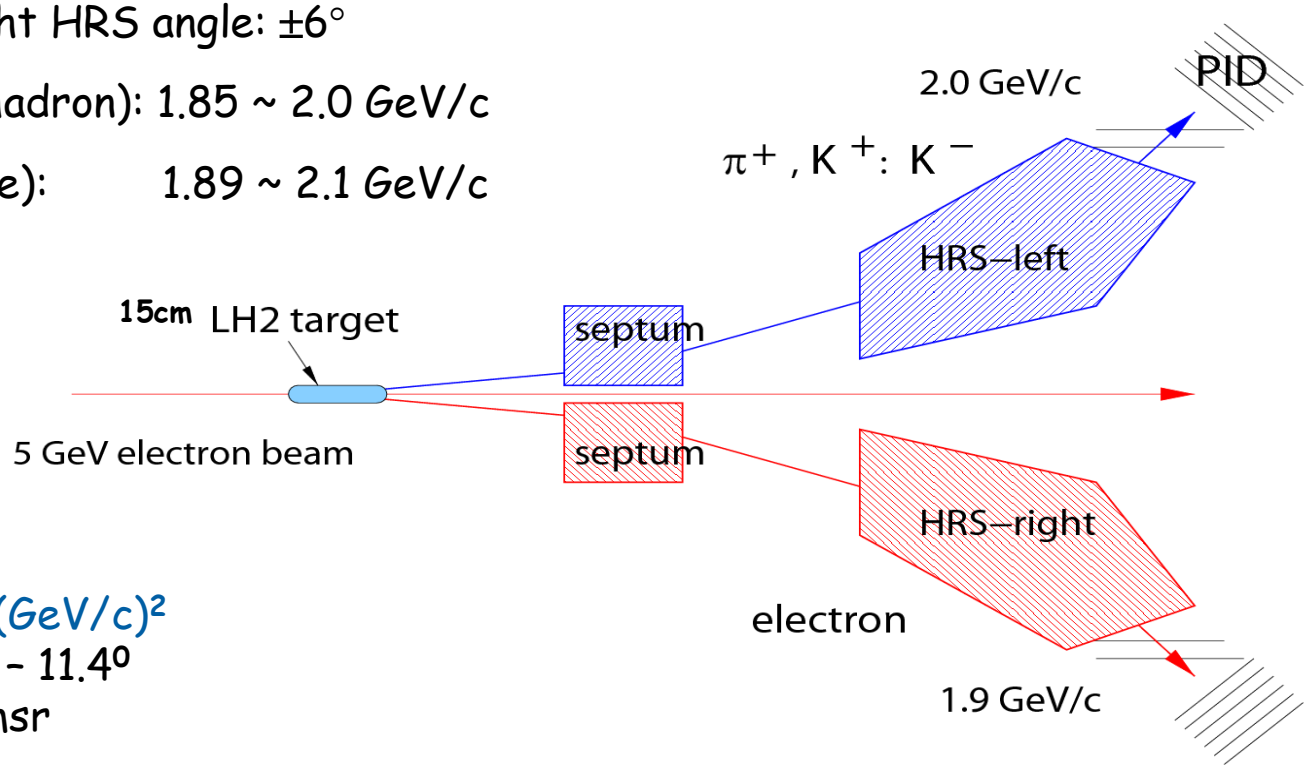
$e + p \rightarrow e' + K^+(\pi^+, K^-) + MM$

- Beam Energy: 5.09 GeV

  Left and Right HRS angle: ±6°

  Left HRS (hadron): 1.85 ~ 2.0 GeV/c

  Right HRS (e): 1.89 ~ 2.1 GeV/c



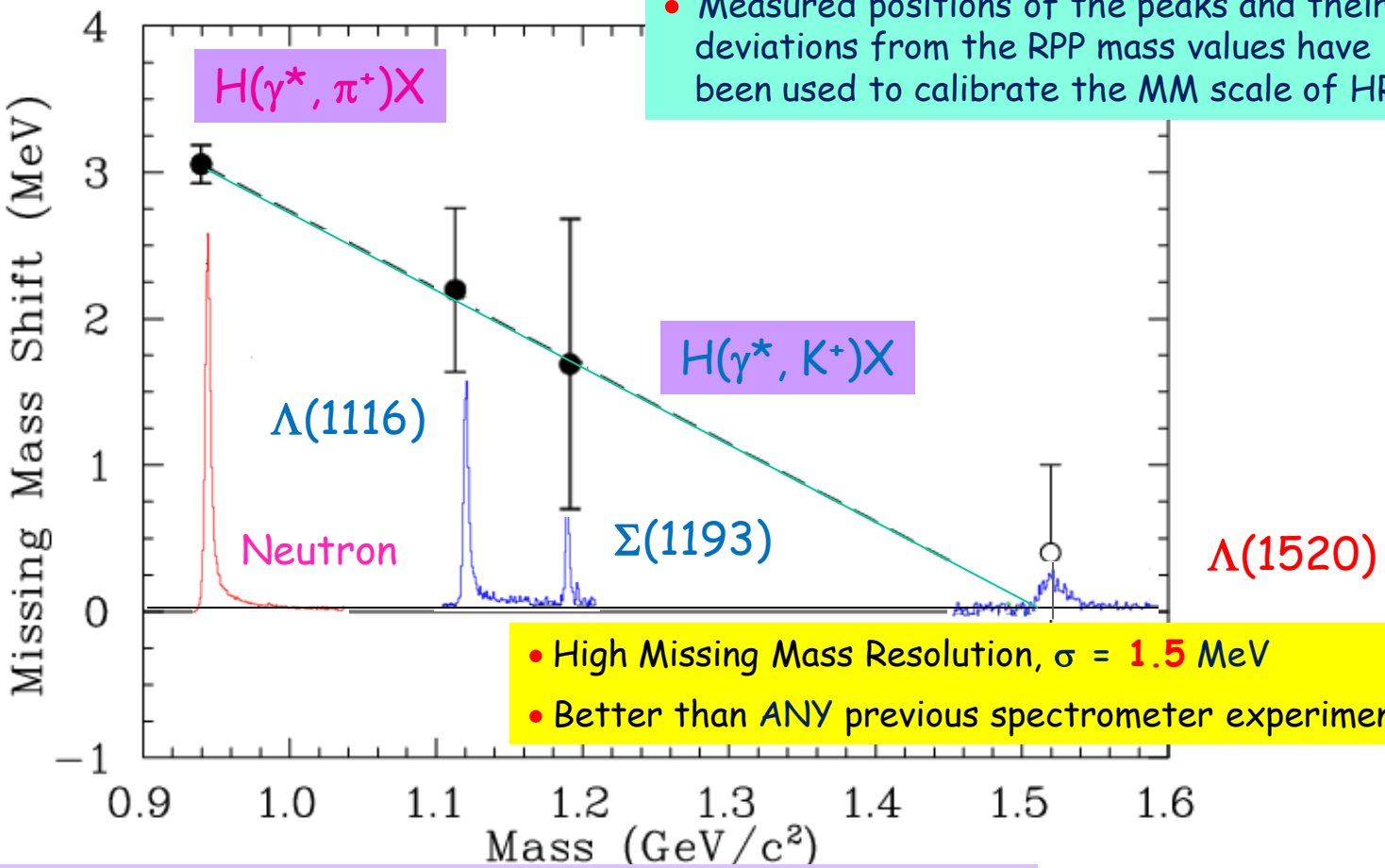
- Q^2 ~ 0.1 $(GeV/c)^2$

  θ_{γ^*K} ~ 5.6^0 – 11.4^0

  $\Delta\Omega_{\gamma^*K}$ ~ 38 msr

Missing Mass Calibration

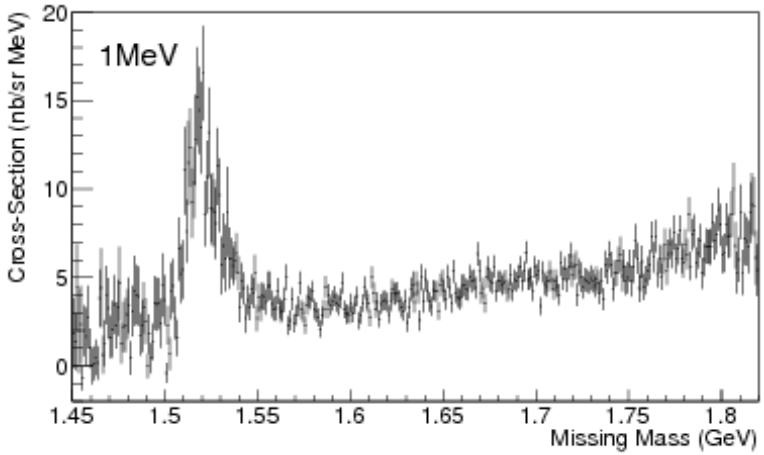
- Measured positions of the peaks and their deviations from the RPP mass values have been used to calibrate the MM scale of HRSs



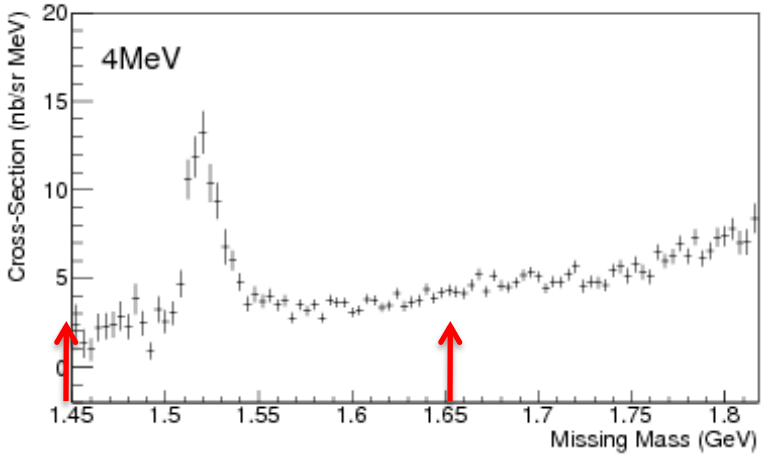
- High Missing Mass Resolution, σ = 1.5 MeV
- Better than ANY previous spectrometer experiment

- **Systematics** for **Mass** and **Width** is ~1 MeV
  - Same peak positions in 4 different quadrants of the same HRS, < 0.2 MeV
  - Extrapolation is a main source of uncertainties, ~1 MeV

MM Distribution for $\gamma^* p \rightarrow K^+ X$ @ E04-012



- **1** MeV binning, is good to look for missing narrow resonances



- **4** MeV binning, is appropriate for studying the well known resonance **Λ(1520)** with resolution σ = **1.5** MeV

- For the Mass interval: **1.45 – 1.65** GeV, the **statistics** is **13,070** detected events

Best-Fit Procedure

[Y. Qiang *et al* arXiv:1003.5612 [hep-ph]]

- We describe the MM spectra in the form:

$$\mathrm{Fit} = BW + BG$$

- The BW contribution may be written as

$$BW = A_{BW}\ \Gamma(M_X)\ D(M_X)$$

In the non-relativistic form

$$D^{-1}_{nrel}(M_X) = (M_X - M_0)^2 + \Gamma^2(M_X)/4$$

In the relativistic form

$$D^{-1}_{rel}(M_X) = (M_X^2 - M_0^2)^2 + M_0^2\,\Gamma^2(M_X)$$

- **Resonances** (if any) are revealed in the MM distribution inclusively, being summed over all possible decay modes

$\Lambda(1520)$ Decay Modes

[C. Amsler *et al.* [RPP] Phys Lett B **667**, 1 (2008)]

- Let us recall that the total width is the sum of partial ones for all decay channels

$$\Gamma = \sum_i \Gamma_i$$

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\overline{K}$	$45 \pm 1\%$
Γ_2	$\Sigma\pi$	$42 \pm 1\%$
Γ_3	$\Lambda\pi\pi$	$10 \pm 1\%$
Γ_4	$\Sigma(1385)\pi$	
Γ_5	$\Sigma(1385)\pi(\rightarrow \Lambda\pi\pi)$	
Γ_6	$\Lambda(\pi\pi)_{S\text{-wave}}$	
Γ_7	$\Sigma\pi\pi$	$0.9 \pm 0.1\%$
Γ_8	$\Lambda\gamma$	$0.85 \pm 0.15\%$
Γ_9	$\Sigma^0\gamma$	

Dominant Modes

- Every partial width should have its own energy dependence, corresponding to the threshold and kinematical properties of the particular decay channel

Best-Fit Results

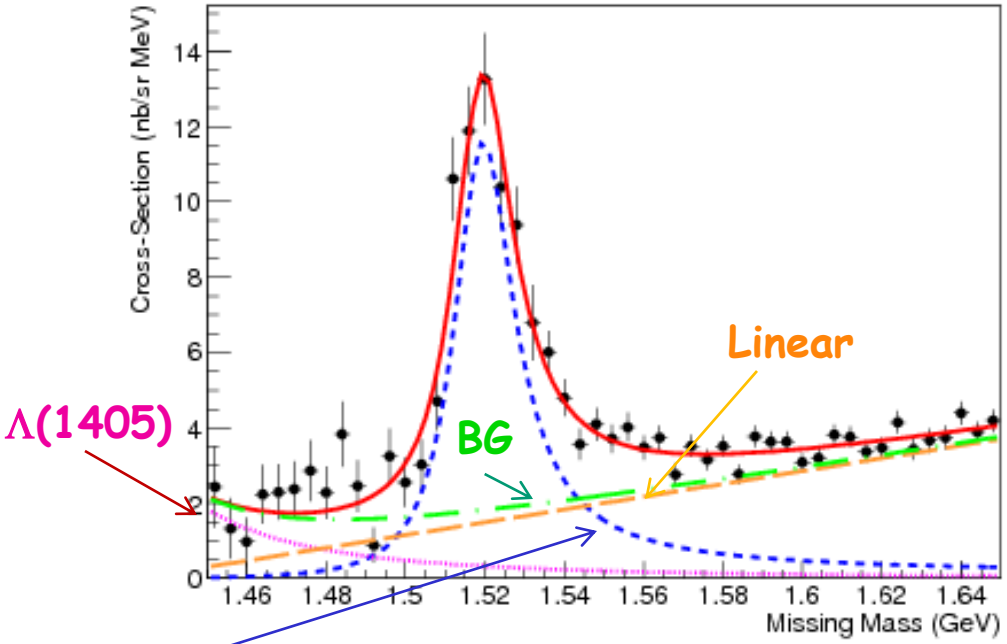
[Y. Qiang *et al* arXiv:1003.5612 [hep-ph]]

$$M_{BW} = M_0[1 + \frac{1}{8}(\Gamma_0/M_0)^2]$$

$$\Gamma_{BW} = \Gamma_0[1 - \frac{1}{8}(\Gamma_0/M_0)^2]$$

We applied MM resolution, σ = **1.5** MeV, in fitting

We did not take into account any Res with M > 1670 MeV



BW [Asymmetry form due to **Γ(W)**]

- Least-Squares: χ^2/dof=**1.46**

M = 1520.4 ± 0.6 MeV
Γ= 18.6 ± 1.9 MeV

- Log-Likelihood: χ^2/dof=**1.50**

M = 1520.3 ± 0.6 MeV
Γ= 17.8 ± 1.9 MeV

- Shift of the **width** under different **BG** descriptions may reach ~**1 MeV**
- **Mass** is less sensitive

- Our attempts to look for the **Σ(1480)** contribution (coherently and incoherently) were unsuccessful due to relative large uncertainties

Intermediate Conclusion I

- The width of $\Lambda(1520)$ is sufficiently small, so the relativistic and non-relativistic forms give practically the same M_0 and Γ_0 (at the present level of accuracy)

- By definition, the **Log-Likelihood** fitting always provides a larger value of χ^2, than the **min-χ^2** fitting

  However, formally they should be equivalent at asymptotically high statistics

  In this sense, the present statistics is not asymptotical yet (**13k**)

  The differences for both M_0 and Γ_0 are comparable to the statistical uncertainties of those **BW** parameters

  In terms of χ^2/dof, which is typically ~1.5 in our studies here

  the Log-Likelihood fitting is up to 0.05 higher than min-χ^2

- The M_0 has a smaller statistical uncertainty and is less affected by any change of fitting procedure than the Γ_0

S-matrix Pole corresponding to the Λ(1520)

[Y. Qiang *et al* arXiv:1003.5612 [hep-ph]]

- Finally, we are looking for a solution of

$$W_p = M_0 \left[1 - i\,\Gamma(W_p)/M_0\right]^{1/2}$$

Its complex solution gives the pole mass $M_p = \mathrm{Re}\, W_p$ and width $\Gamma_p = -2\,\mathrm{Im}\, W_p$

- We found that $M_p < M_{BW}$ and $\Gamma_p < \Gamma_{BW}$ with the mass difference exceeding the statistical uncertainty (**min-χ^2 values**)

$$M_p = 1518.8\ \mathrm{MeV}\,, \quad \Gamma_p = 17.2\ \mathrm{MeV}$$

- Such relation for masses may be rather general (**model independent**), as suggested by comparison with the mass pairs (**BW** and **pole**) shown for other resonances in Listings of RPP

Intermediate Conclusion II

- Let us evaluate $M_p - M_{BW} = -\frac{1}{4} M_0 (\Gamma_0/M_0) \Gamma_0'$ and $\Gamma_p - \Gamma_{BW} = \frac{1}{8} \Gamma_0 (\Gamma_0/M_0) (3\Gamma_0' - M_0 \Gamma_0'')$

$$\Gamma_0 = \Gamma(M_0) \qquad \Gamma_0' \equiv d\Gamma(M_X)/dM_X \qquad \Gamma_0'' \equiv d^2\Gamma(M_X)/(dM_X)^2 \quad \text{taken at } M_X = M_0$$

Parametrically $\Gamma_0' \sim \Gamma_0$ and $\Gamma_0'' \sim \Gamma_0$

- If M_0 is not far from threshold of a decay channel, the $\Gamma(M_X)$ is an increasing function near M_0 and $\Gamma_0' > 0$, providing $M_p < M_{BW}$

- Relation for the widths is less definite
  In accordance with our numerical solution all three main contributions lead to $\Gamma_p < \Gamma_{BW}$

Summary

	Mass (MeV)	Width (MeV)
PDG08 BW:	1519.5±1.0	15.6±1.0
Our BW:	1520.4±0.6(stat)±1.0(syst)	18.6± 1.9(stat)±1.0(syst)
Our Pole:	1518.8	17.2

- Even without accounting for the systematic uncertainty, both M_0 and Γ_0 are in reasonable agreement with their RPP average
- It is worth to note, however, that the uncertainties in the later works are larger than those in all the earlier works

  This may hint that the uncertainties stated in the earlier works (and, therefore, in the average) are too **optimistic**

Mass (MeV)	Width (MeV)	Year
1517.3±1.5	16.3±3.3	1980
1517.8±1.2	14 ±3	1979
1519.7±0.3	16.3±0.5	1977
1519.4±0.3	15.5±1.6	1975
1520.0±0.5	15.4±0.5	1978
1519 ±1	15.0±0.5	1977
average 1519.5±1.0	average 15.6±1.0	2008

- Having the BW mass and width, we also give the **first** estimate of the **pole** parameters for the **Λ(1520)**
- The pole values for both mass and width tend to be lower than the BW values

- If pretending to have width uncertainty **<1 MeV**, one should study details of **BG**