

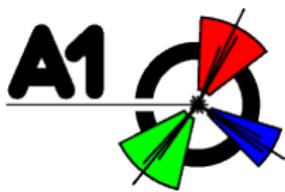
Transition form factor of the ${}^4\text{He}(\text{M}0^+)$ -Resonance

Bormio Winter Conference 2019

Simon Kegel

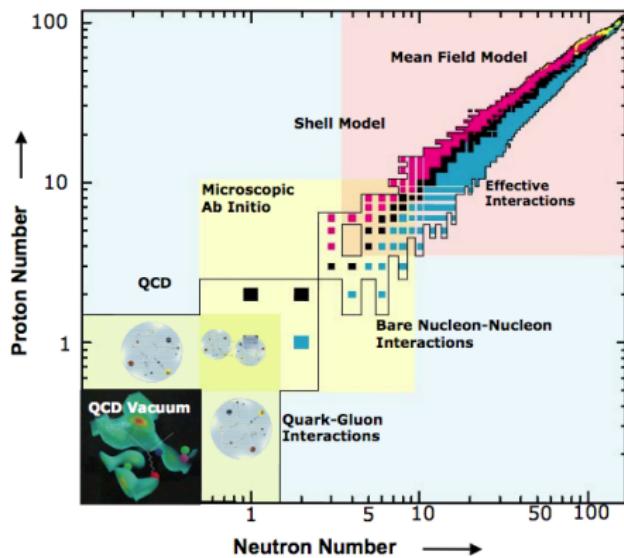
Institut für Kernphysik, JGU Mainz

25.01.19



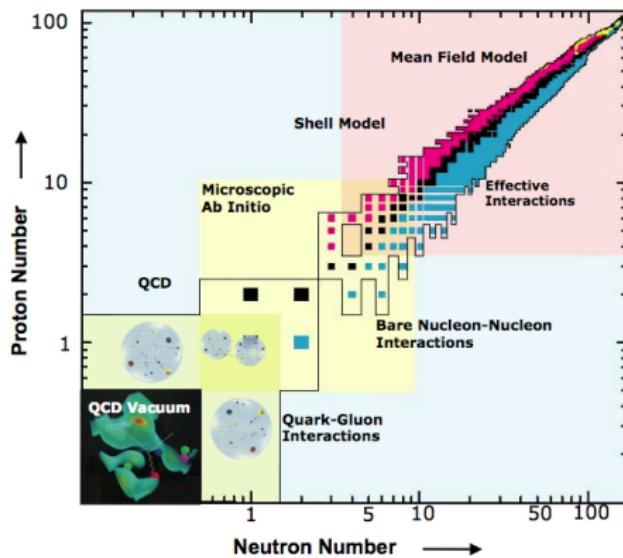
Theory of nuclear structure

- Lattice QCD to describe subhadronic processes



Theory of nuclear structure

- Lattice QCD to describe subhadronic processes
- Effective field theory (EFT) for nucleons inside the nucleus (non-pert. regime)



Effective field theory (EFT)

- EFT: Ab-initio calculations with pion-exchange diagrams

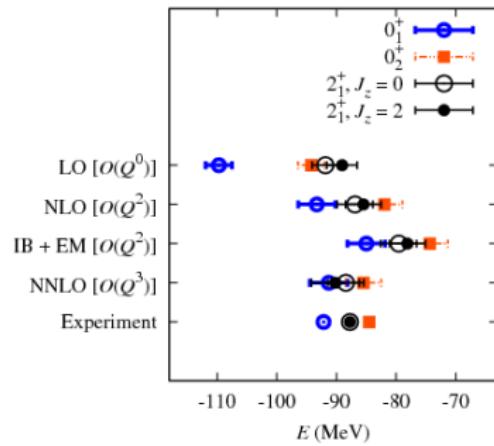
	Two-nucleon force	Three-nucleon force	Four-nucleon force
LO	X H	—	—
NLO	X H H K M H	—	—
N ³ LO	H H	H H H X *	—
N ³ LO	X H H K ... H H H K ...	H H H X ... H H H K ...	H H H ...

Effective field theory (EFT)

- EFT: Ab-initio calculations with pion-exchange diagrams
- Good agreement for topics like Hoyle-state ^{12}C , neutron skin ^{48}Ca , nuclear form factors, etc.

E. Epelbaum et al. *PRL* 106, 192501, G. Hagen *Nature Physics* 12, 186-190 (2016)

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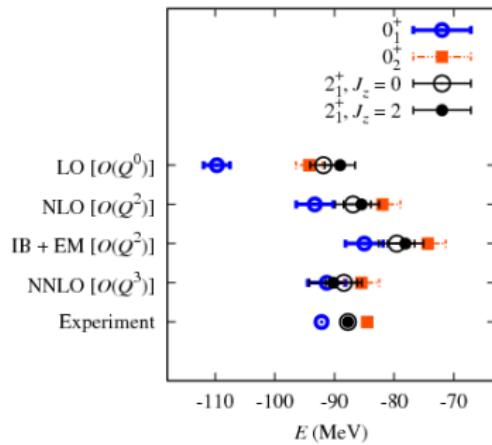


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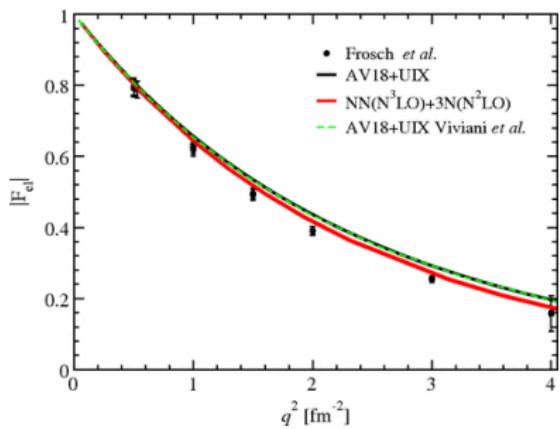
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Does it mean **everything** is well explained in EFT ?

EFT and ${}^4\text{He}$ resonance

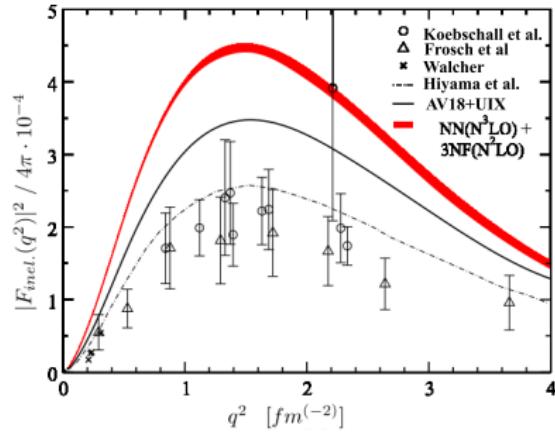
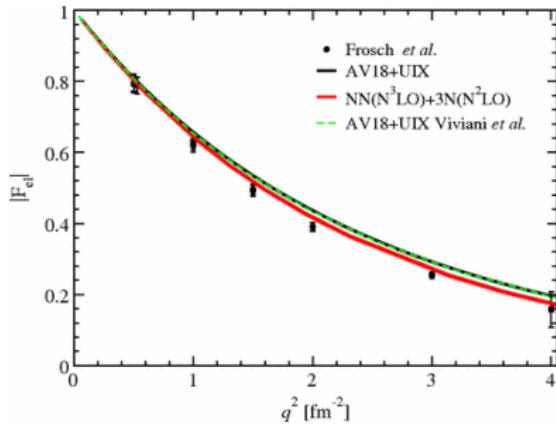
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EFT and ${}^4\text{He}$ resonance

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- Same potentials & methods $\text{FF}_{M0^+}(Q^2)$ FF of 0^+ -res. → Bad accordance!

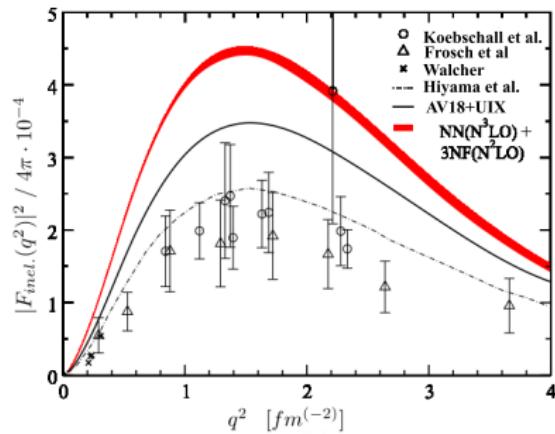
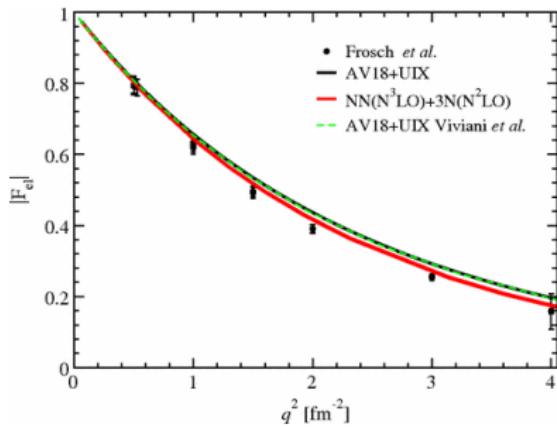
S. Bacca et al., *PRL* 110, 042503 (2013)



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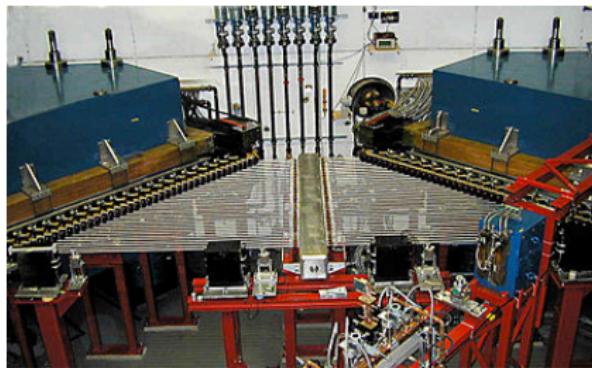
S. Bacca et al., *PRL* 110, 042503 (2013)



Theory: "We need new and better data!"

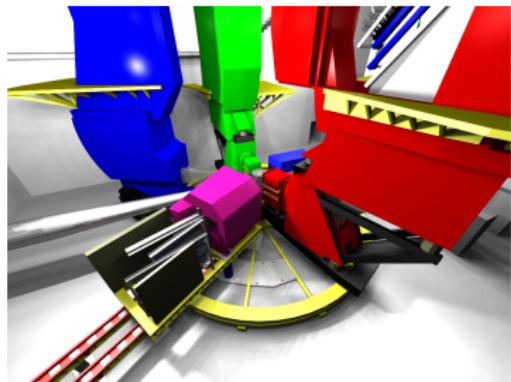
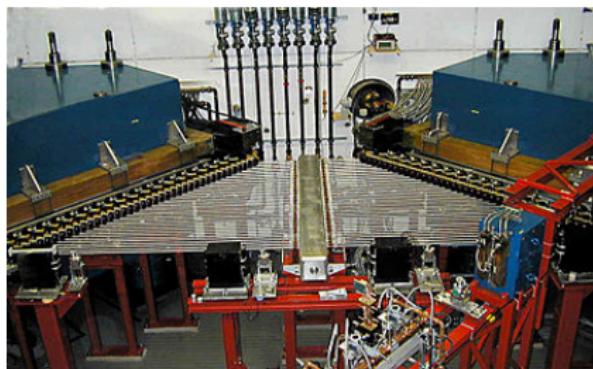
Experimental setup

- MAMI: Electron accelerator with high quality beam



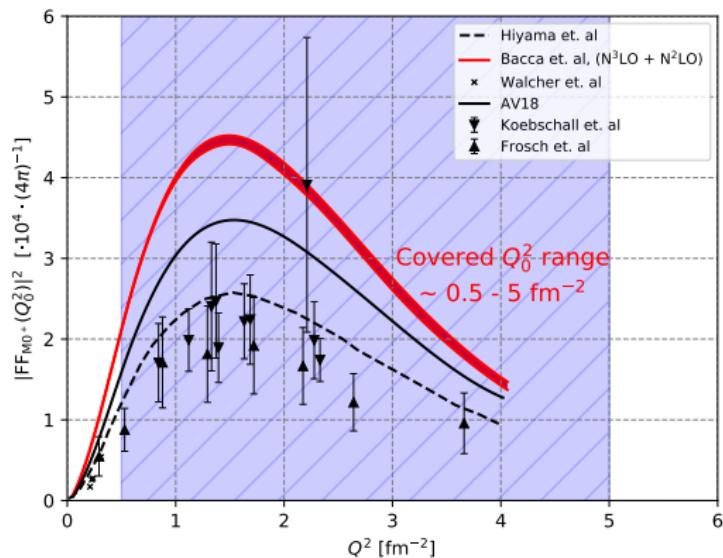
Experimental setup

- MAMI: Electron accelerator with high quality beam
- A1 : 3 high resolution magnetic spectrometers



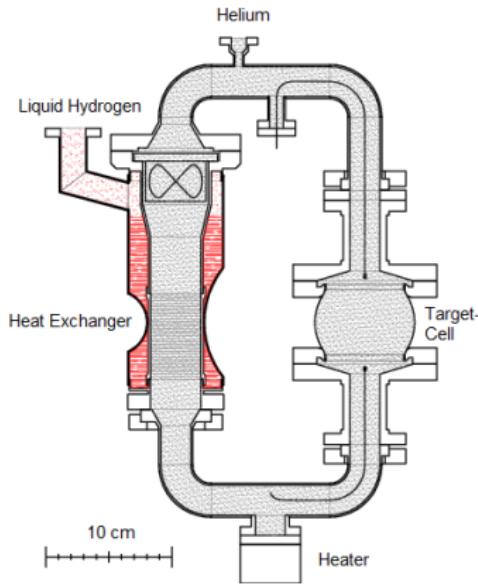
Experimental setup

- MAMI: Electron accelerator with high quality beam
- A1 : 3 high resolution magnet spectrometers
- Access on a wide range of Q^2 under best experimental conditions



Experimental setup

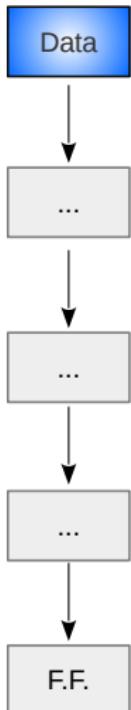
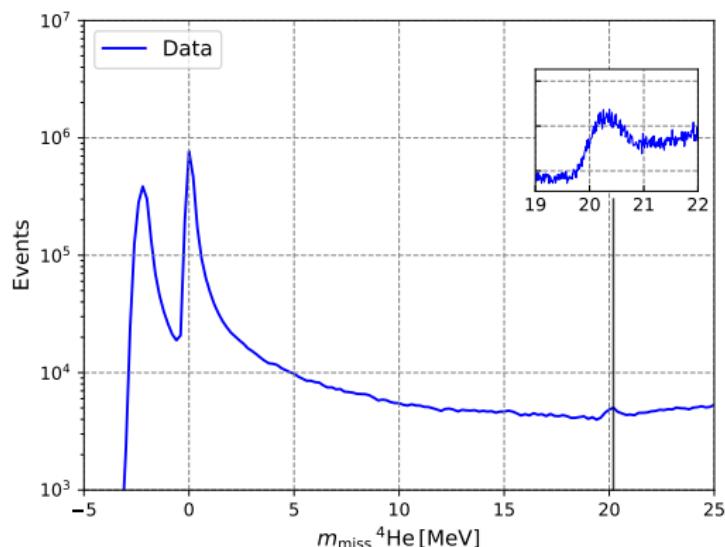
- Cryogenic helium target with aluminium cell
- Density of ^4He inside cell 200× larger than He under std. cond.



From data to cross sections to form factors

Determination of a form factor:

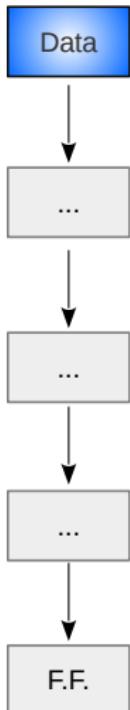
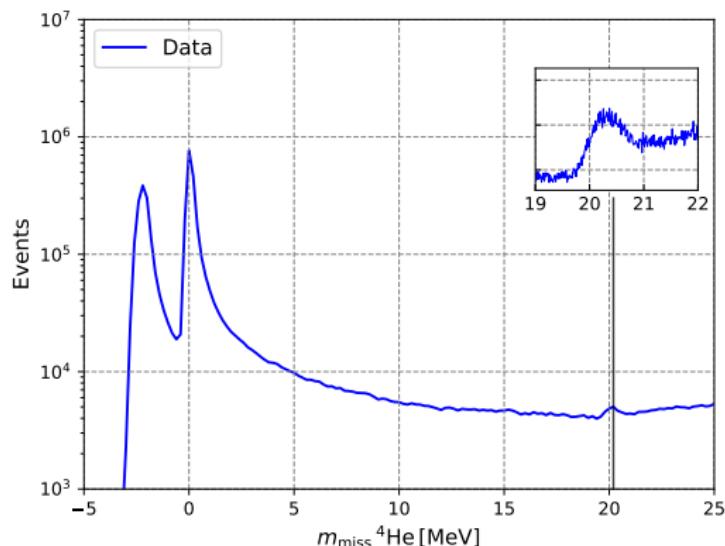
- $|FF_{M0^+}(Q^2)|^2 = (\frac{d\sigma}{d\Omega})_{\text{Exp.}} / (\frac{d\sigma}{d\Omega})_{\text{Mott}}$



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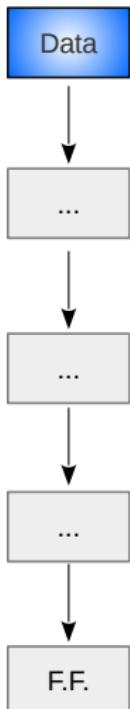
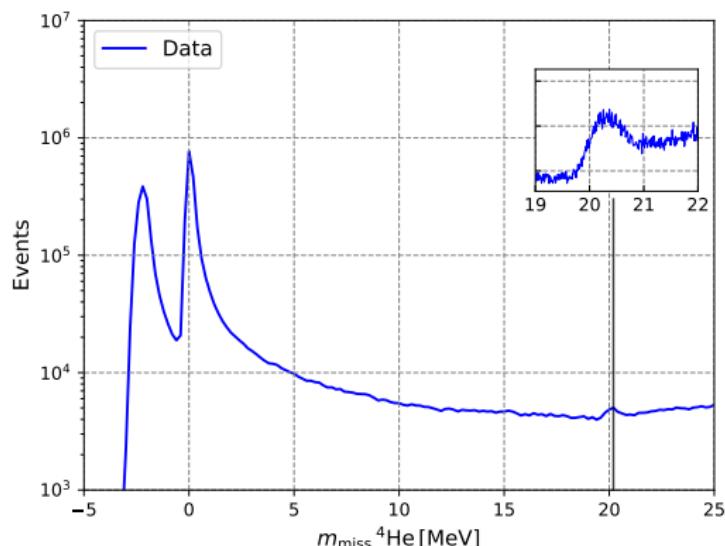
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- Data obtained by measuring scattered e^- at different kinematics / Q^2



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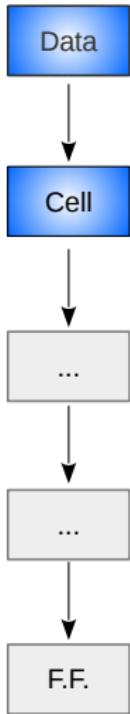
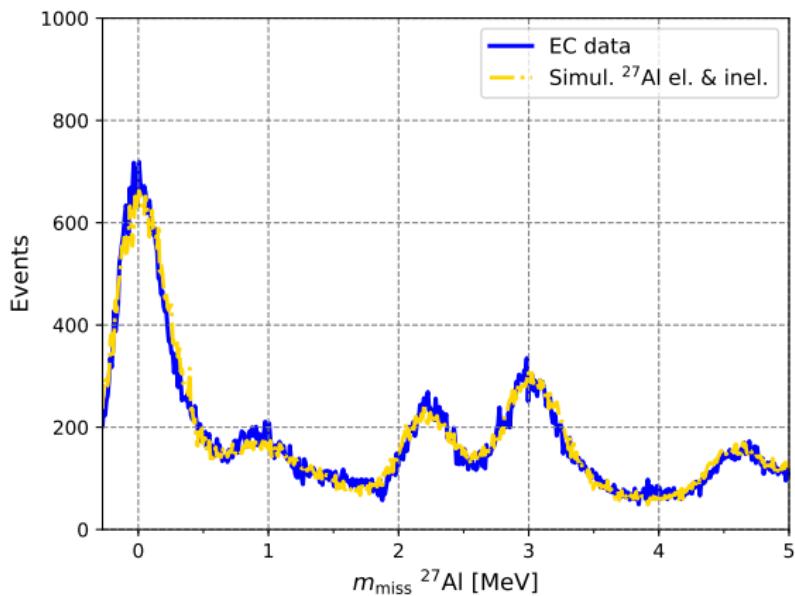
Determination of a form factor:

- $|FF_{M0^+}(Q^2)|^2 = (\frac{d\sigma}{d\Omega})_{\text{Exp.}} / (\frac{d\sigma}{d\Omega})_{\text{Mott}}$
- Data obtained by measuring scattered e^- at different kinematics / Q^2
- Investigation background, luminosity, det. efficiency, rad. corrections



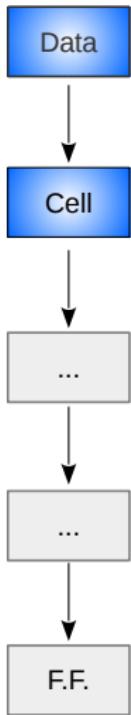
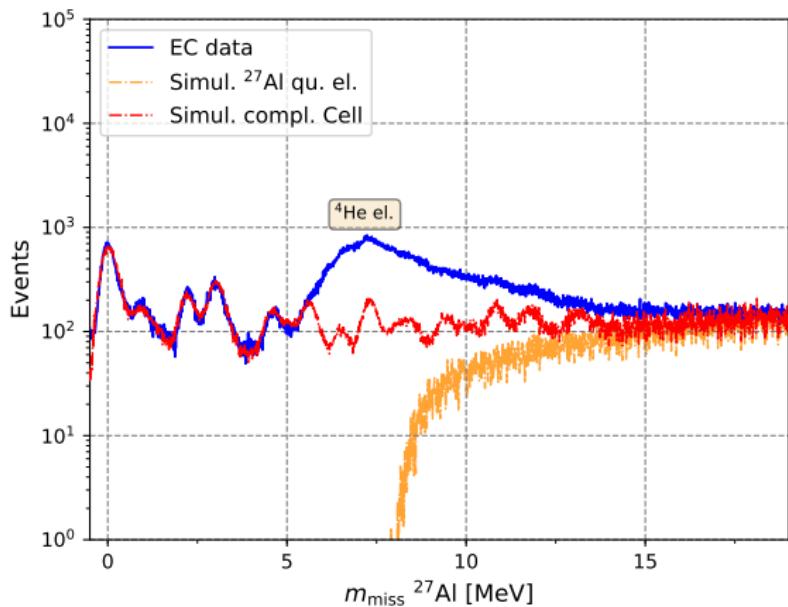
From data to cross sections to form factors

- Ground- and ex. states of ^{27}Al simulated
- Empty cell measurements to improve simulations of ^{27}Al



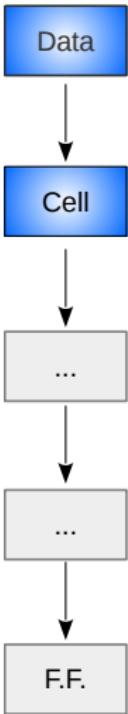
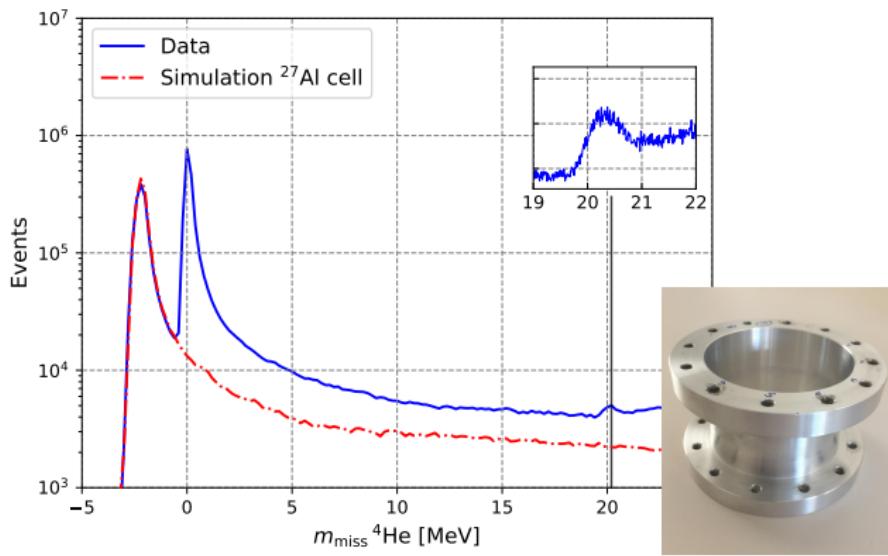
From data to cross sections to form factors

- ^{27}Al quasi elastic simulation
- Becomes dominant at higher m_{miss}



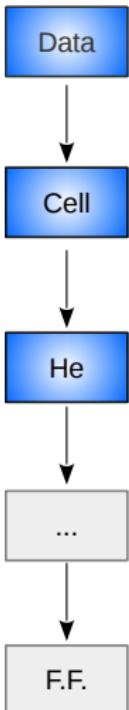
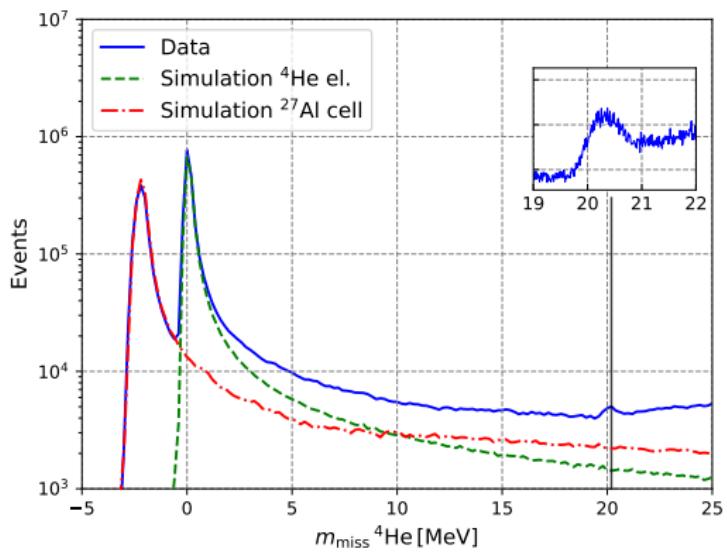
From data to cross sections to form factors

Complete alu-cell simulation:



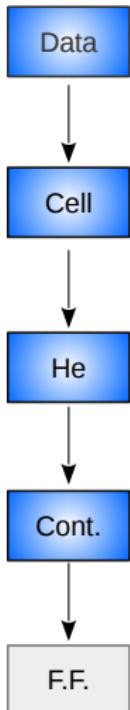
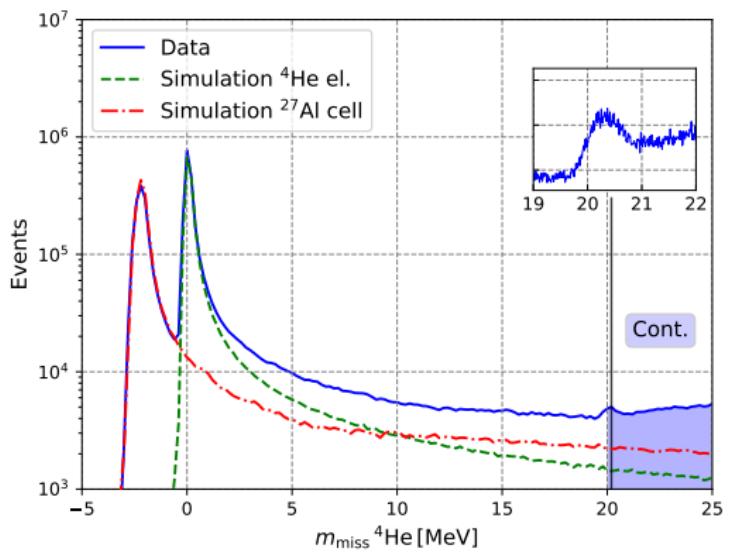
From data to cross sections to form factors

- ${}^4\text{He}$ ground state: Well measured!
C.R. Ottermann et. al, *Nucl. Physics A* 436(4), (1985)
- Simulation of el. line used to double-check / normalise data



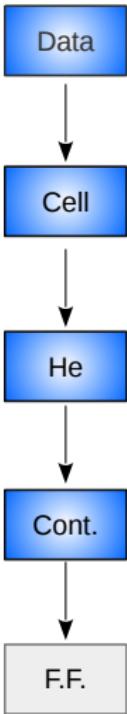
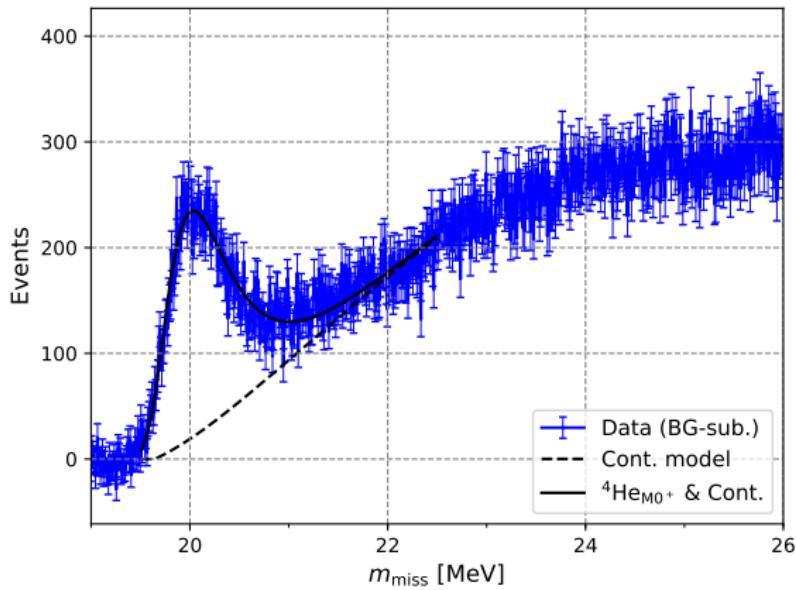
From data to cross sections to form factors

- ${}^4\text{He}$ continuum contains qu. el. processes and many other resonances
- Several model fits to describe the continuum of ${}^4\text{He}$



From data to cross sections to form factors

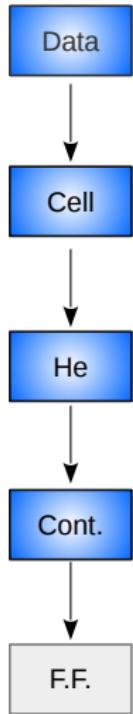
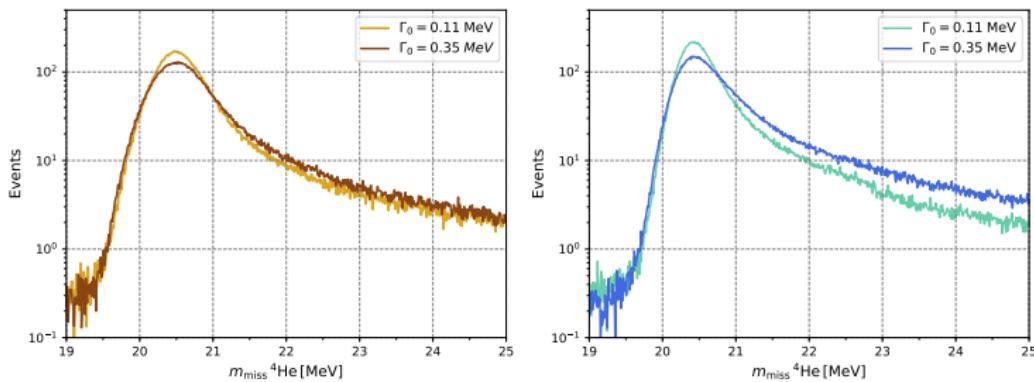
- ${}^4\text{He}$ continuum contains qu. el. processes and many other resonances
- Several model fits to describe the continuum of ${}^4\text{He}$
- To render the resonance, simulations were used



From data to cross sections to form factors

- Two models used for resonance: Voigt profile and a proposal by J.D. Jackson

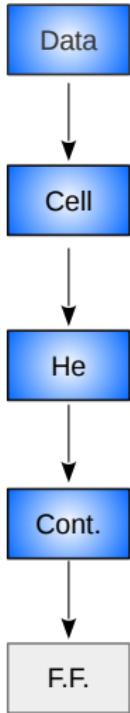
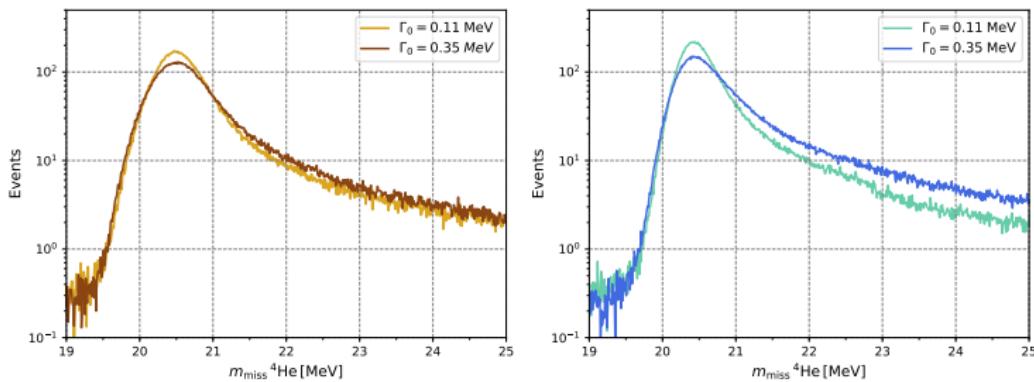
J.D.Jackson, *Nuove Cim.* 34, (1964)
Phelan & Marguiles, *Nuove Cim.* 58, (1968)



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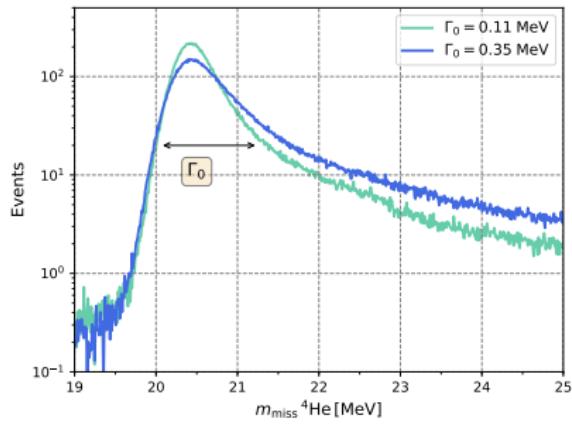
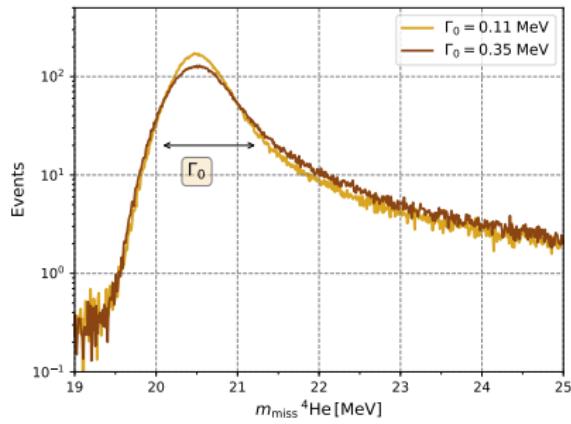
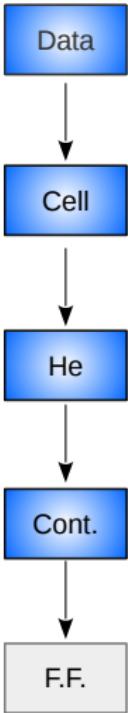
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- J.D.Jackson, *Nuove Cim.* 34, (1964)
- Phelan & Marguiles, *Nuove Cim.* 58, (1968)
- Radiative corrections included in the M.C.-simulation

M. Vanderhaeghen et al., *Phys.Rev.C62*, (2000)



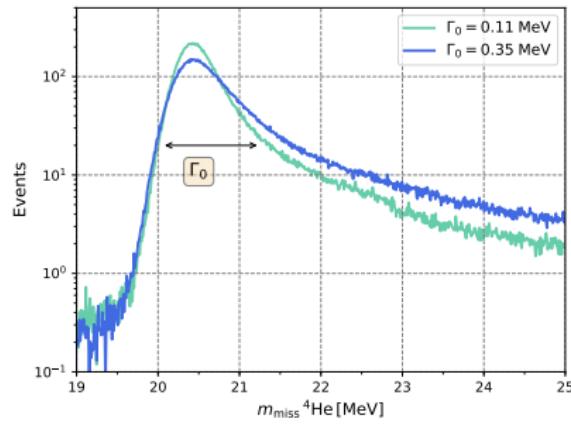
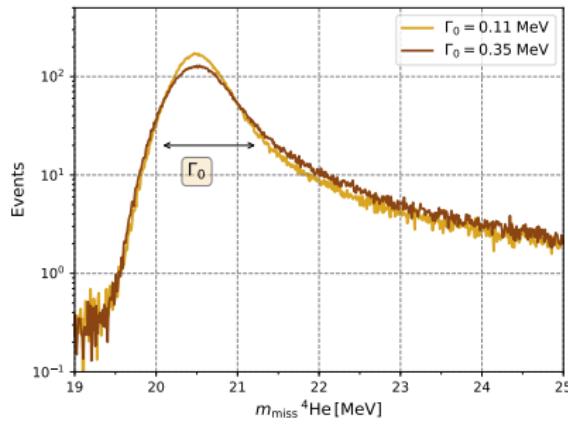
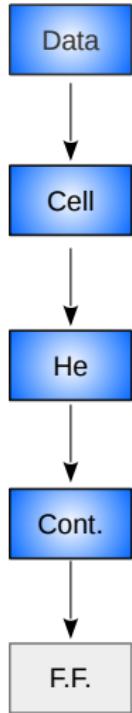
Intermezzo: FWHM Γ_0 of the resonance peak

- centr. value and FWHM Γ_0 are needed to sample the distributions



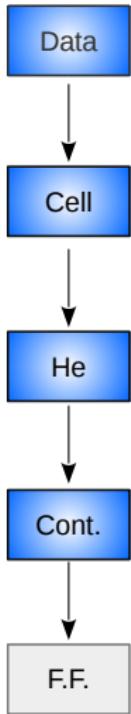
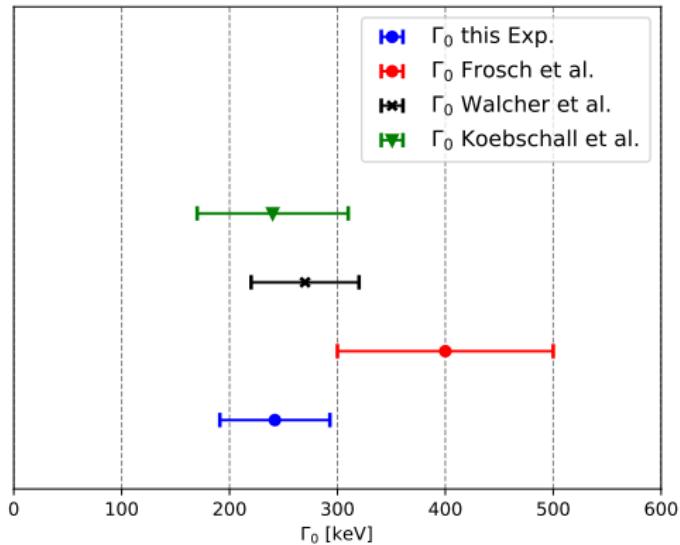
Intermezzo: FWHM Γ_0 of the resonance peak

- centr. value and FWHM Γ_0 are needed to sample the distributions
- Γ_0 not well known: determine Γ_0
- Scanning a range of diff. Γ_0 and optimising simul. to data



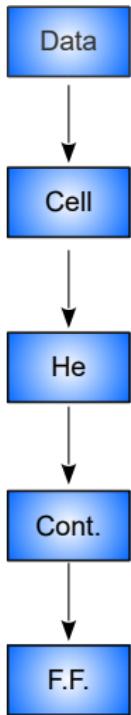
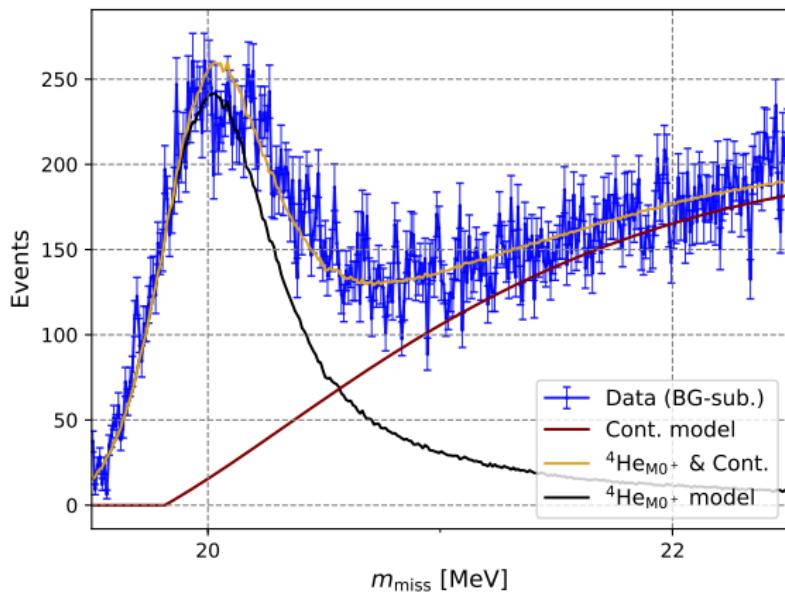
Intermezzo: FWHM Γ_0 of the resonance peak

- Γ_0 for two background & res. models independently
- dominant sys. errors: angular resolution and momentum resolution of spectrometers



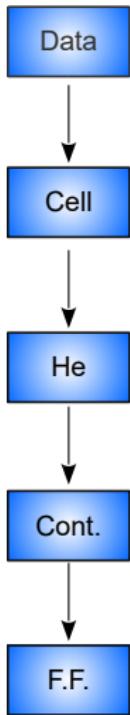
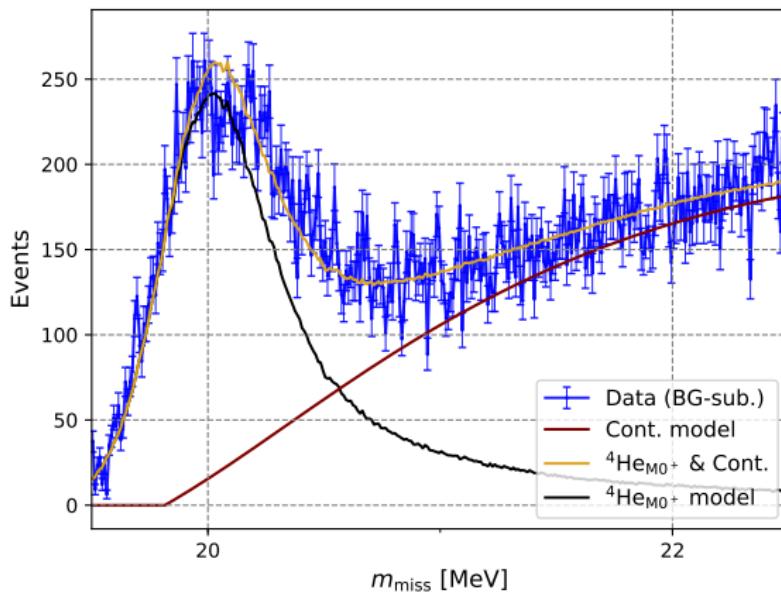
From data to cross sections to form factors

- Reminder: $\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp.}} \propto \text{"integrated events in peak of interest"}$



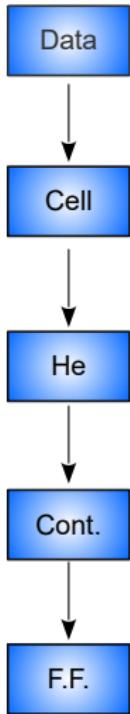
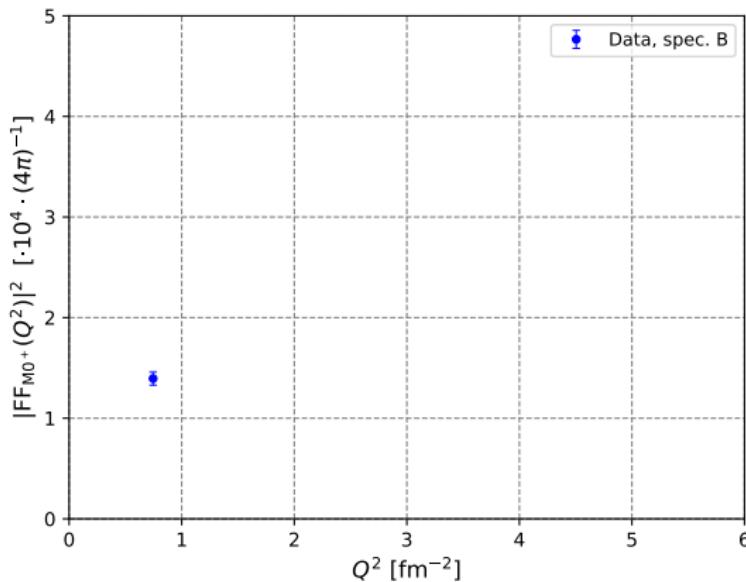
From data to cross sections to form factors

- **Reminder:** $\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp.}} \propto$ "integrated events in peak of interest"
- all uncertainties under control: background, rad. corrections, luminosity...
→ elastic line in each setup for relative determination



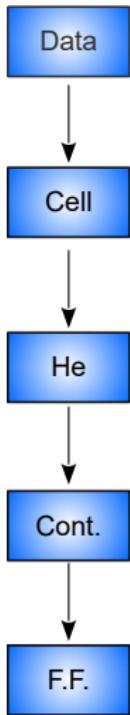
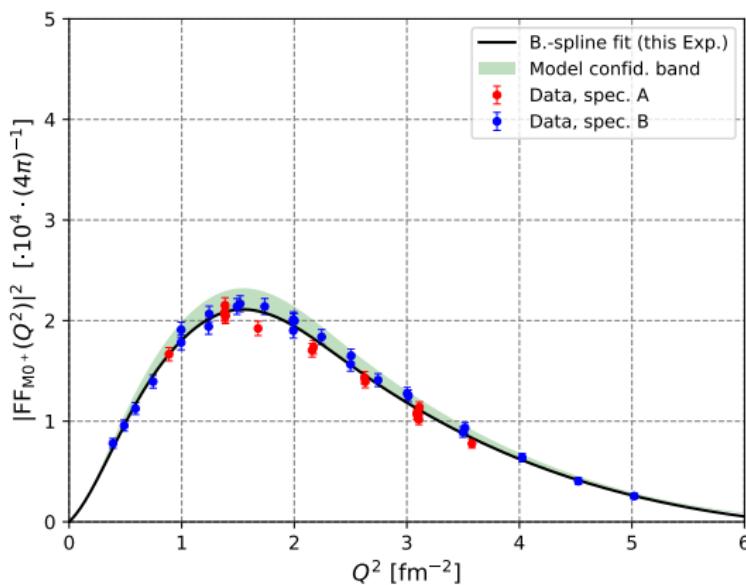
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- With uncertainties under control, one proceeds to calc. the form factor



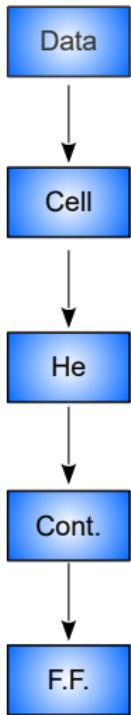
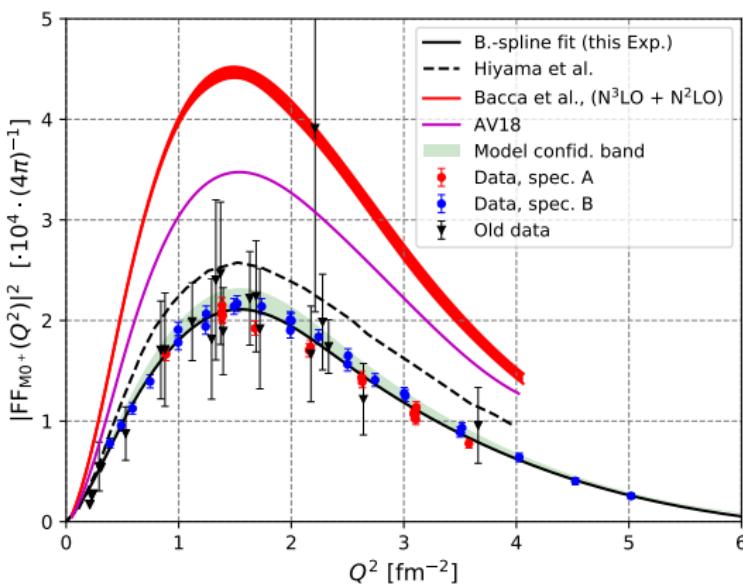
From data to cross sections to form factors

- With uncertainties under control, one proceeds to calc. the form factor
- 44 setups, 3 beam energies, with two spectrometers (**spec A** & **spec B**)



From data to cross sections to form factors

- Result of $|FF_{M0^+}(Q^2)|^2$ in agreement with older data
- None of the theories can describe the data



Summary & Outlook

Summary

- We performed a measurement for a precise determination of the transition form factor $\text{FF}_{\text{M}0^+}(Q^2)$ under optimal conditions with inclusion of the well measured g.s. of ${}^4\text{He}$ to reduce uncertainties
- FWHM Γ_0 of the resonance was determined in addition to reduce sys. errors
- The transition form factor $\text{FF}_{\text{M}0^+}(Q^2)$ was determined with smaller statistical and systematical errors over a large range of Q^2 with two different spectrometers. The data shows great consistence and is in agreement with the so far existing world data

Summary & Outlook

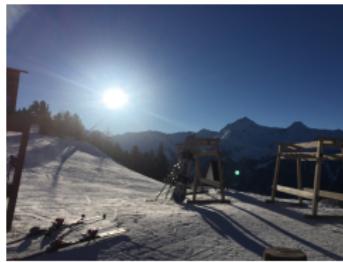
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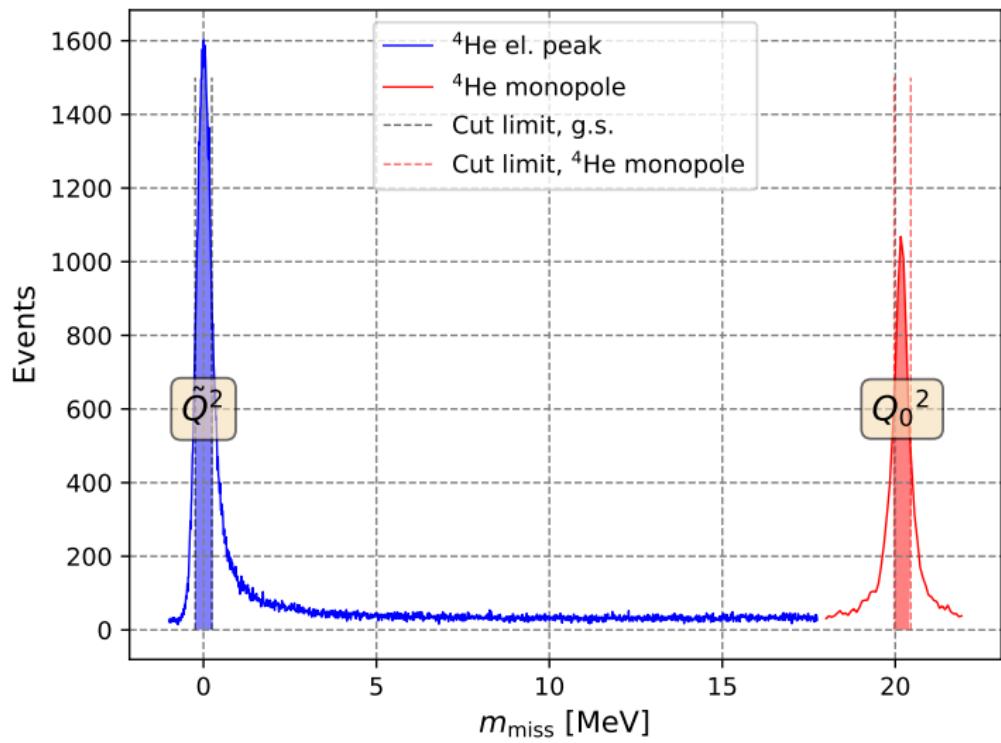
Outlook

- Turn is now to the theory:
There is no theory on the market to describe $|\text{FF}_{M0^+}(Q^2)|^2$ well!
- Improved measurement of Γ_0 by MAGIX target (S. Aulenbacher)

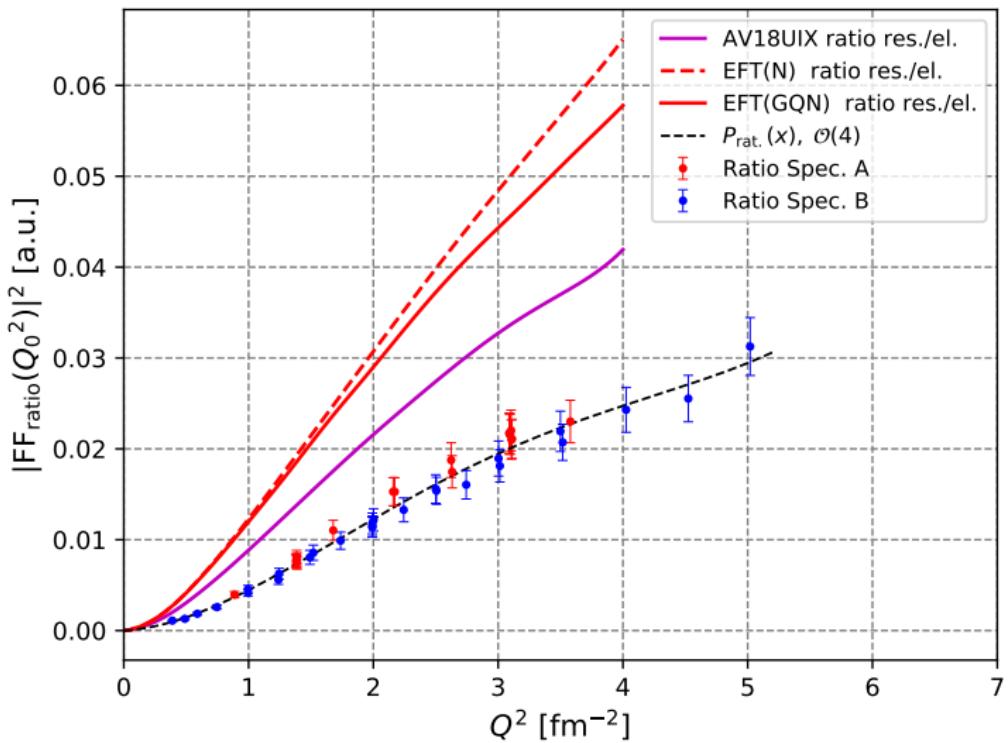
Thanks for Your Attention!



Form factor ratio

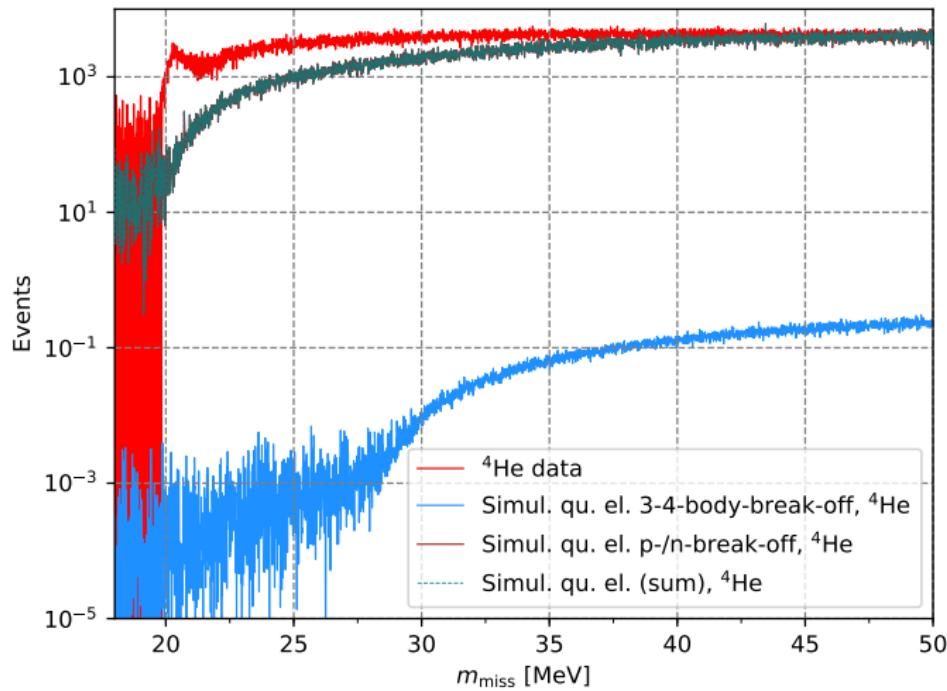


Form factor ratio



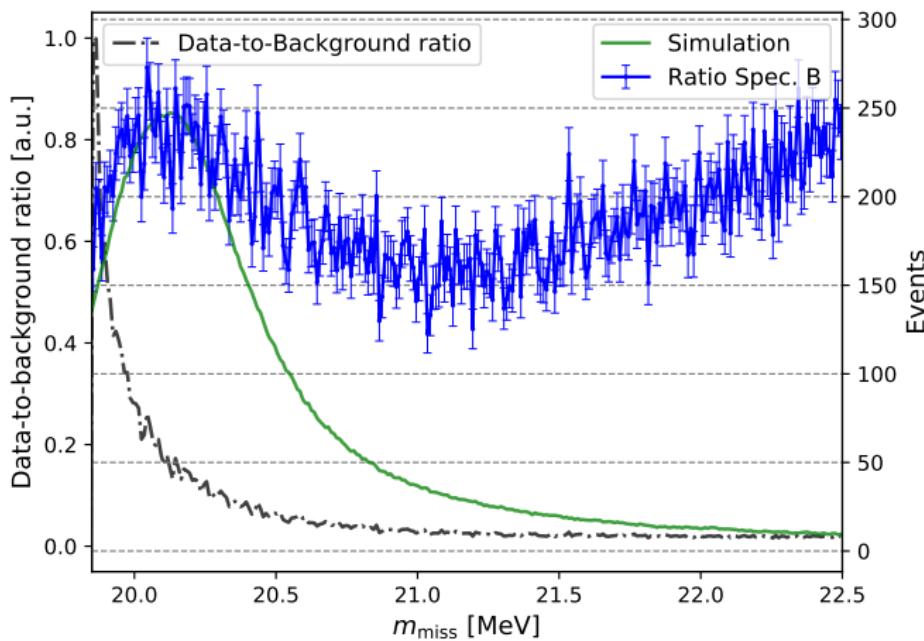
^4He quasi elastic

- Inclusion of 2-body break-up and 3-4 body break-up



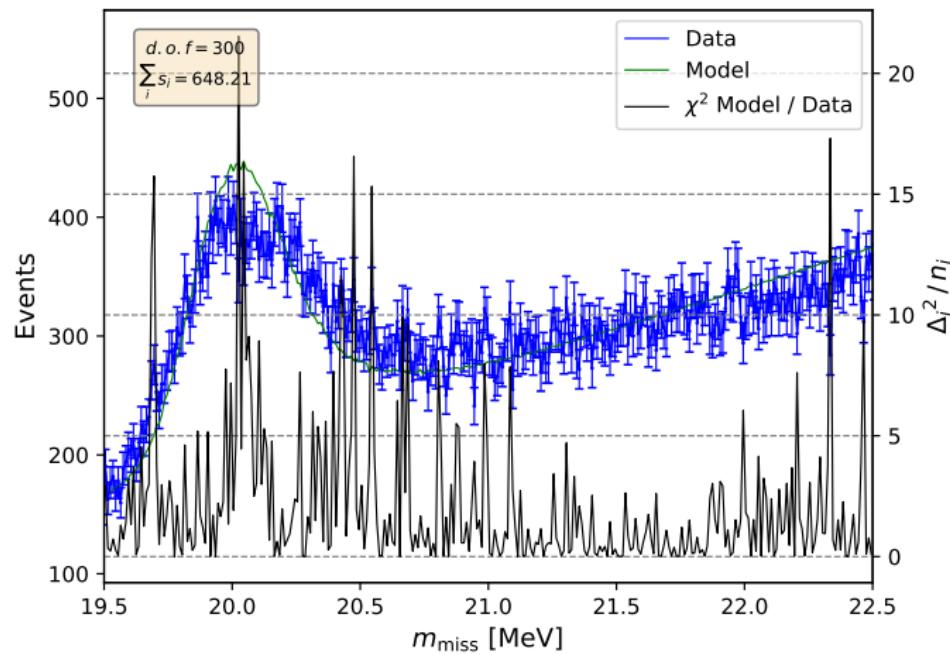
Data-to-background ratio

- Ratio of data to background, normalised to max. at 19.85 MeV



Determination Γ_0

- Simul. of a certain Γ_0 , determine χ^2 to data



Determination Γ_0

- Simul. of a certain Γ_0 , determine χ^2 to data
- Optimise with respect to best χ^2

