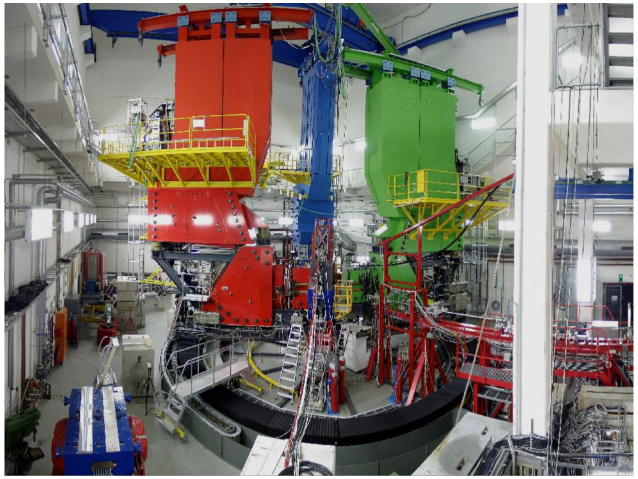 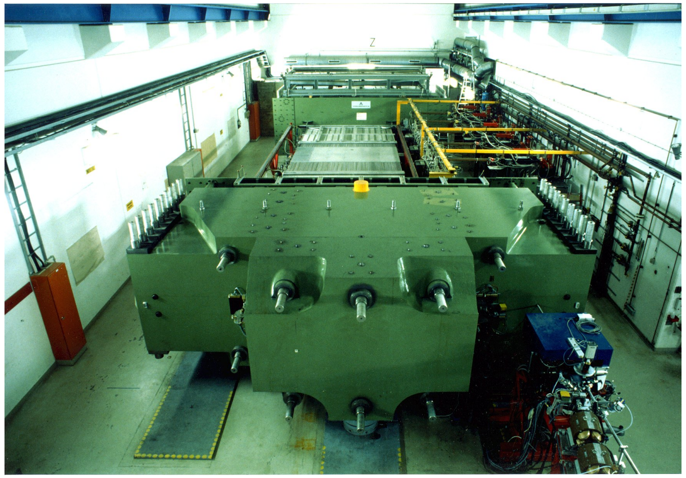 

Accessing neutrino physics with nuclear experiments at MAMI

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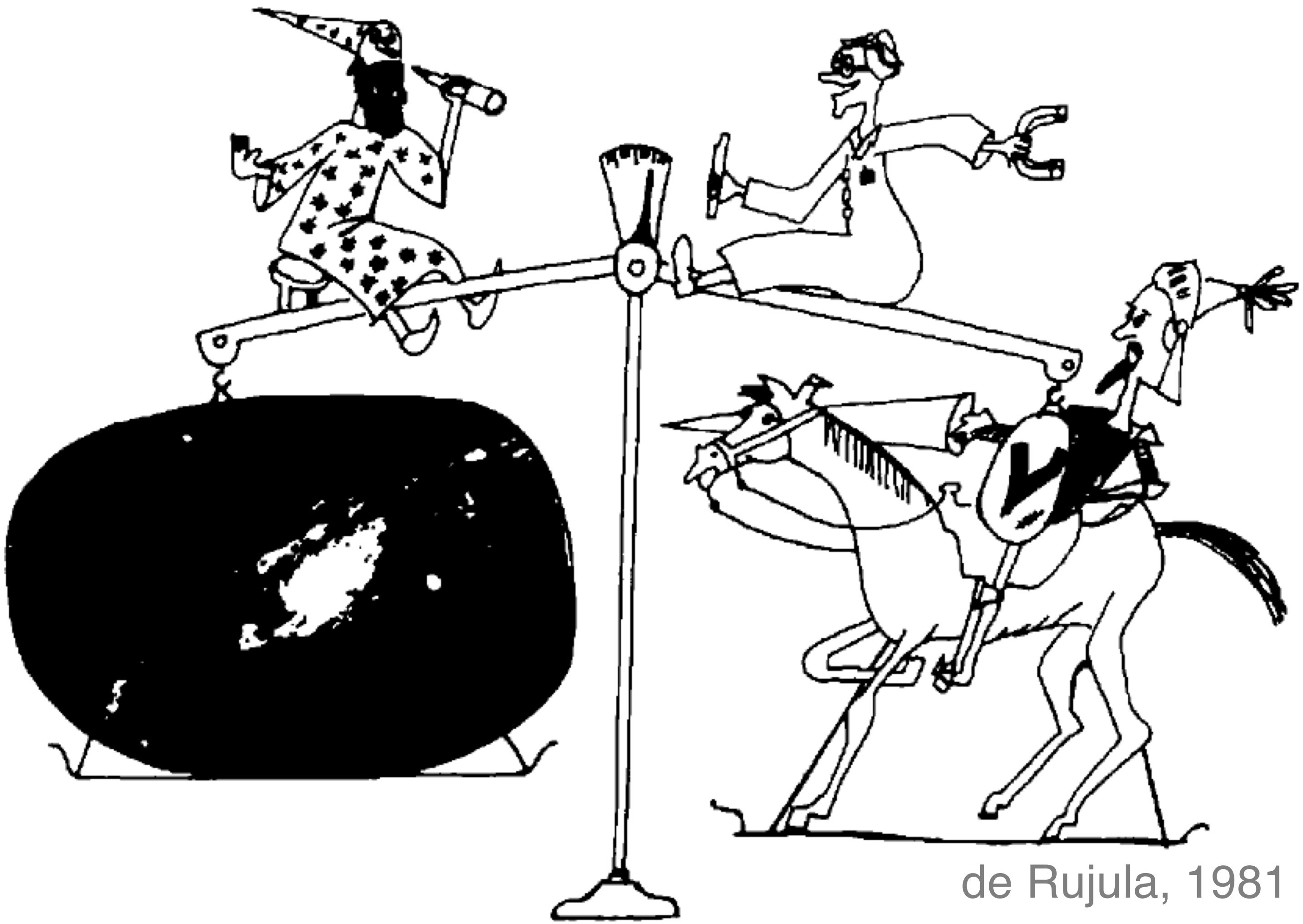
ELBA 2019

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

JG|U

SLOVENIAN RESEARCH AGENCY

Motivation

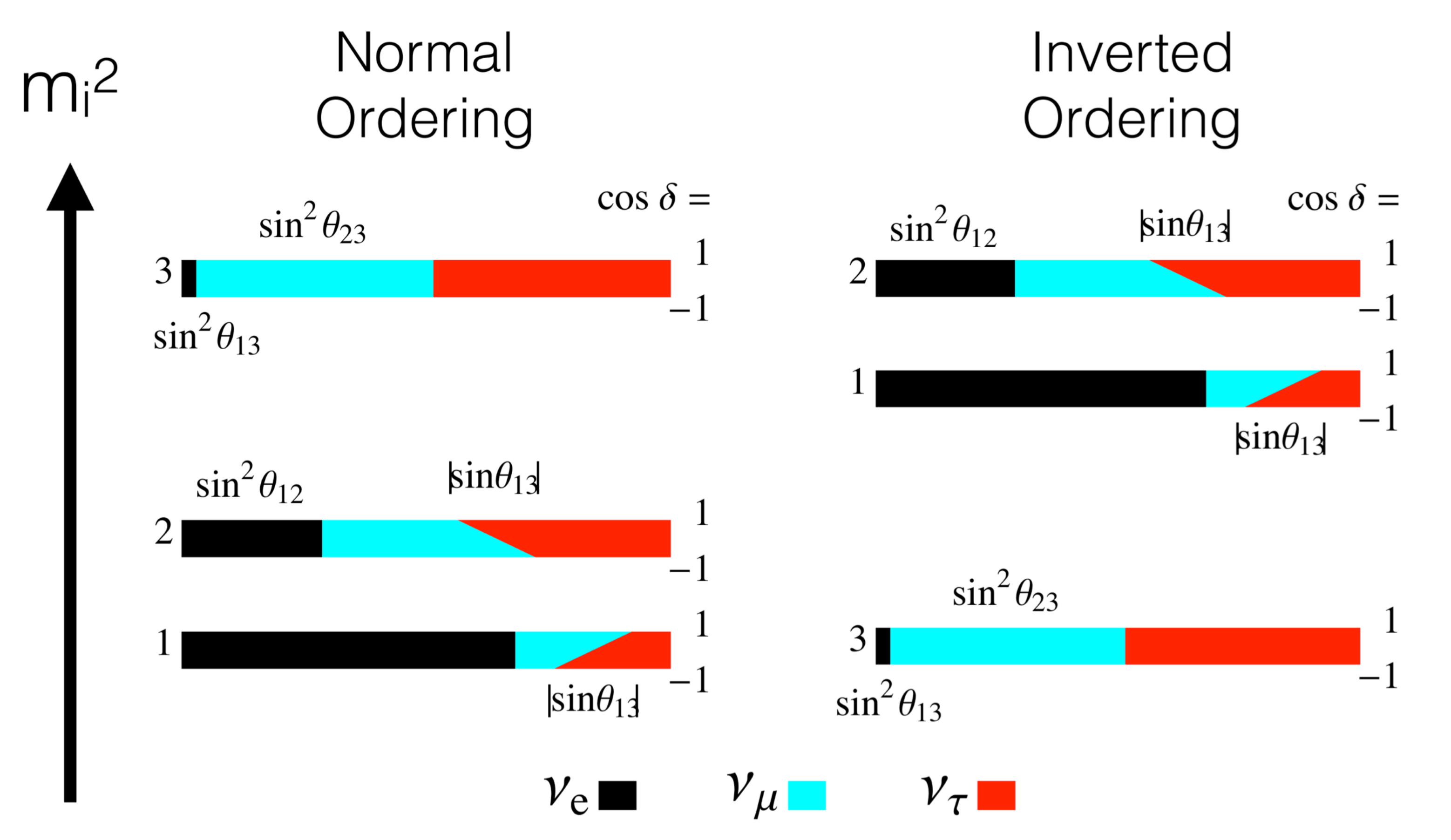


de Rujula, 1981

Precise determination of neutrino properties is a priority and motivates experiments also in nuclear physics.

Current knowledge

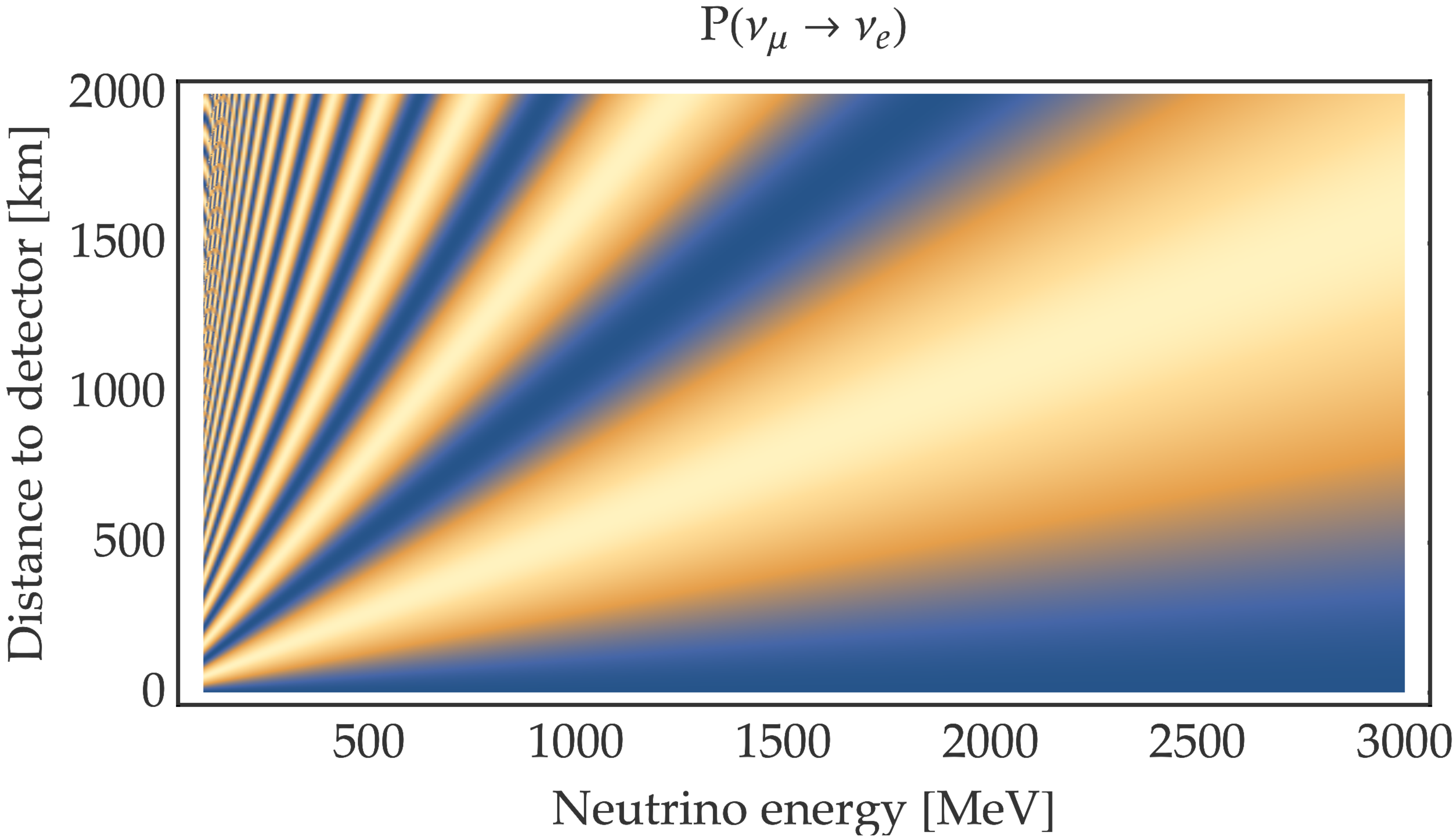
	θ_{12}	θ_{13}	θ_{23}	$\Delta m^2_{21}/10^{-5}$	$\Delta m^2_{3j}/10^{-3}$	δ_{CP}
Normal Ordering	$33.56^{+0.77}_{-0.75}$	$8.46^{+0.15}_{-0.15}$	$41.6^{+1.5}_{-1.2}$	$7.50^{+0.19}_{-0.17}$	$2.524^{+0.039}_{-0.040}$	261^{+51}_{-59}
Inverted Ordering	$33.56^{+0.77}_{-0.75}$	$8.49^{+0.15}_{-0.15}$	$50.0^{+1.1}_{-1.4}$	$7.50^{+0.19}_{-0.17}$	$-2.514^{+0.038}_{-0.041}$	277^{+40}_{-46}



Neutrino oscillations

- The properties of neutrinos determined through the measurement of probability of flavor oscillation:

$$P(\nu_\alpha \to \nu_\beta) \simeq \sin^2 2\theta \sin^2 \left(\frac{\Delta m^2 L}{4E} \right)$$



Neutrino experiments

T2K

L = 295 km

E_m = 600 MeV

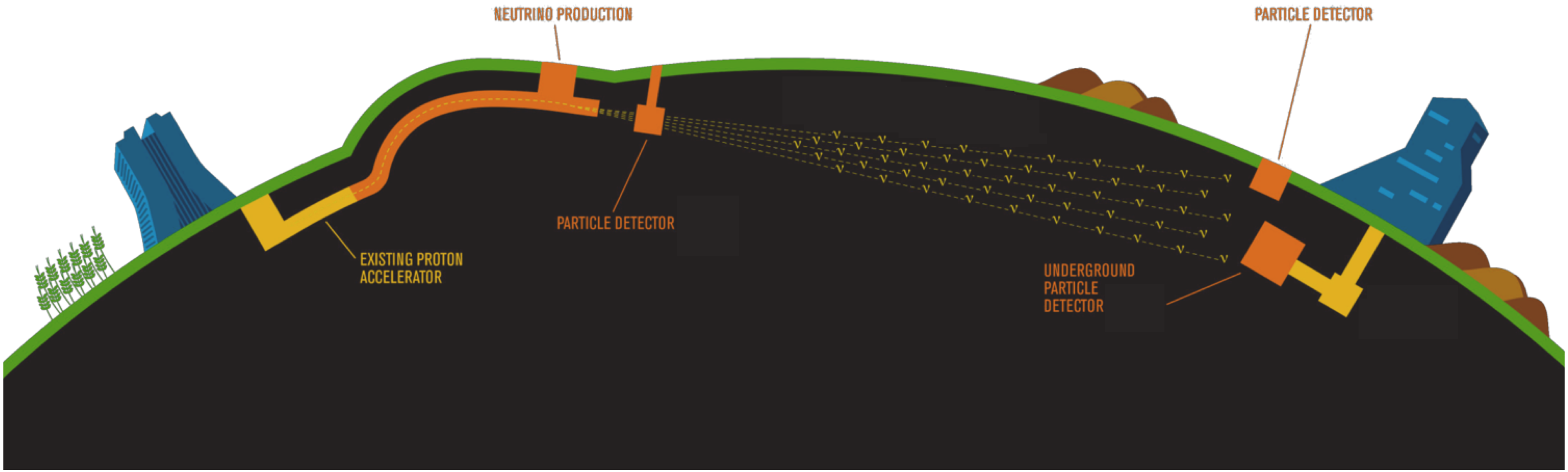
H_2O, ^{12}C

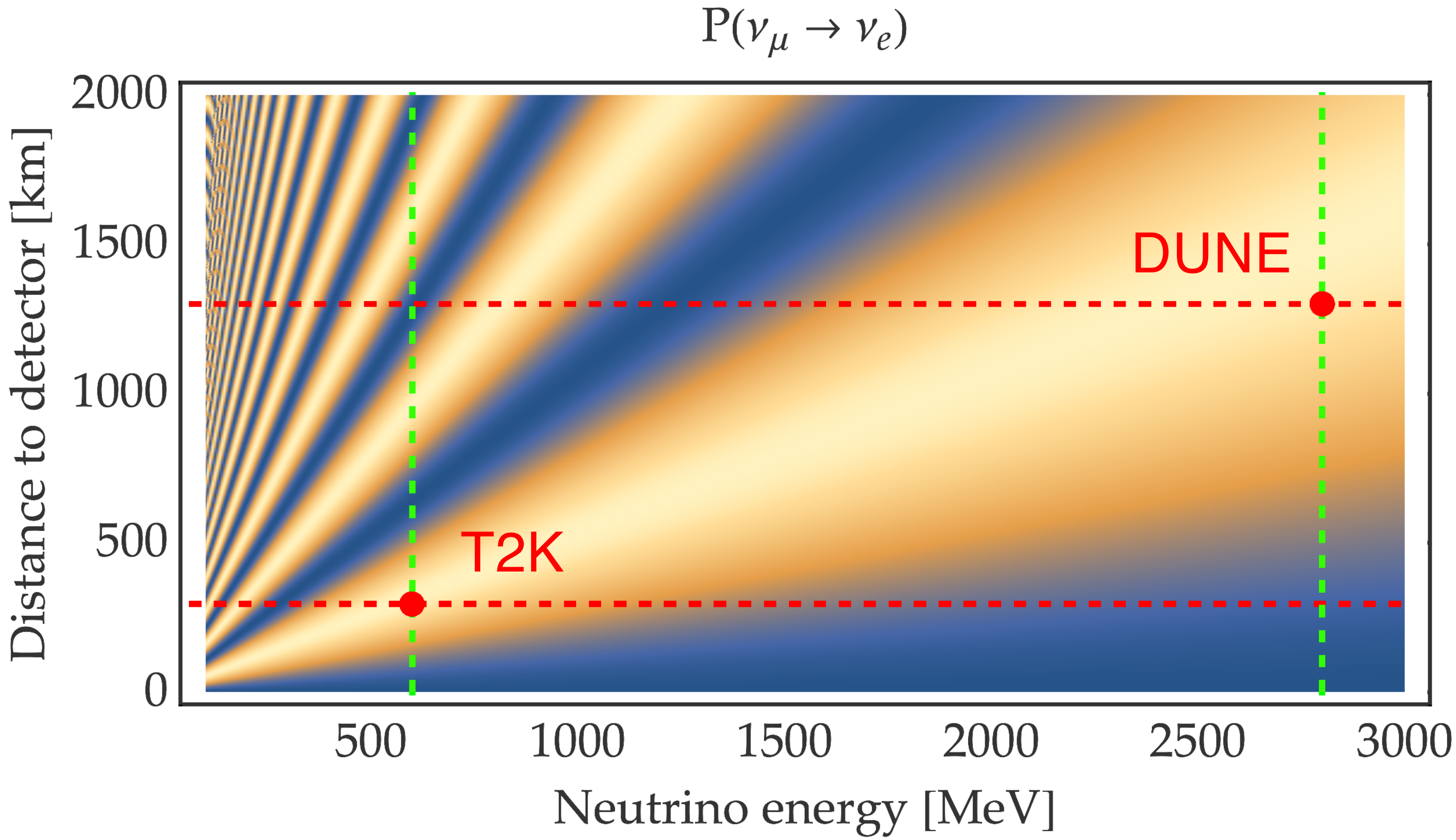
DUNE
DEEP UNDERGROUND NEUTRINO EXPERIMENT

L = 1300 km

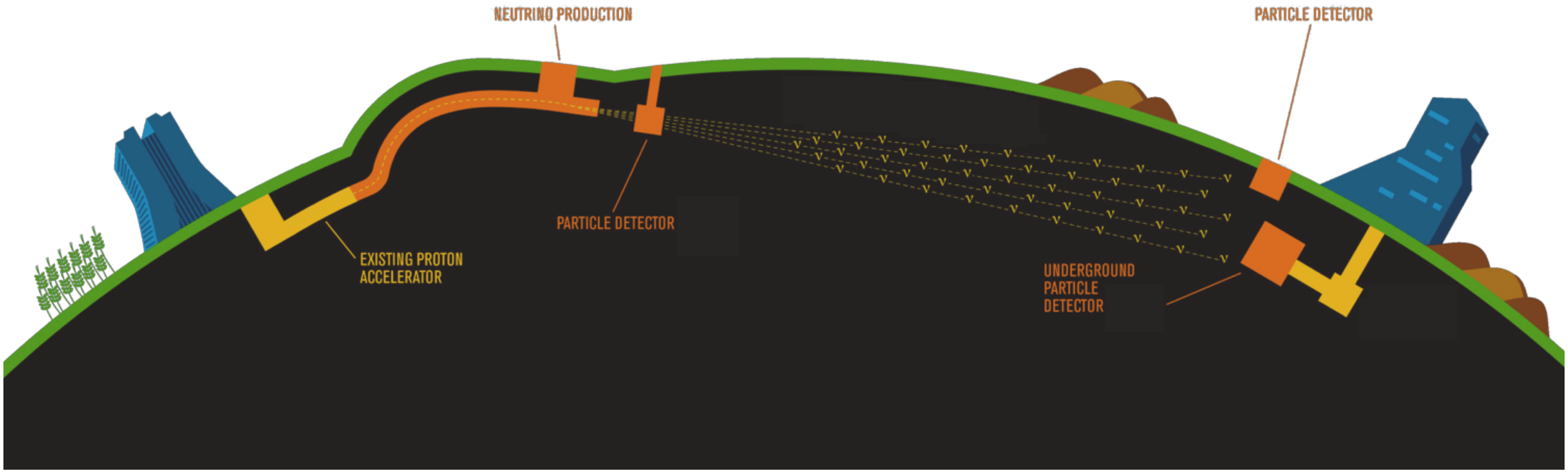
E_m = 1800 MeV

^{40}Ar





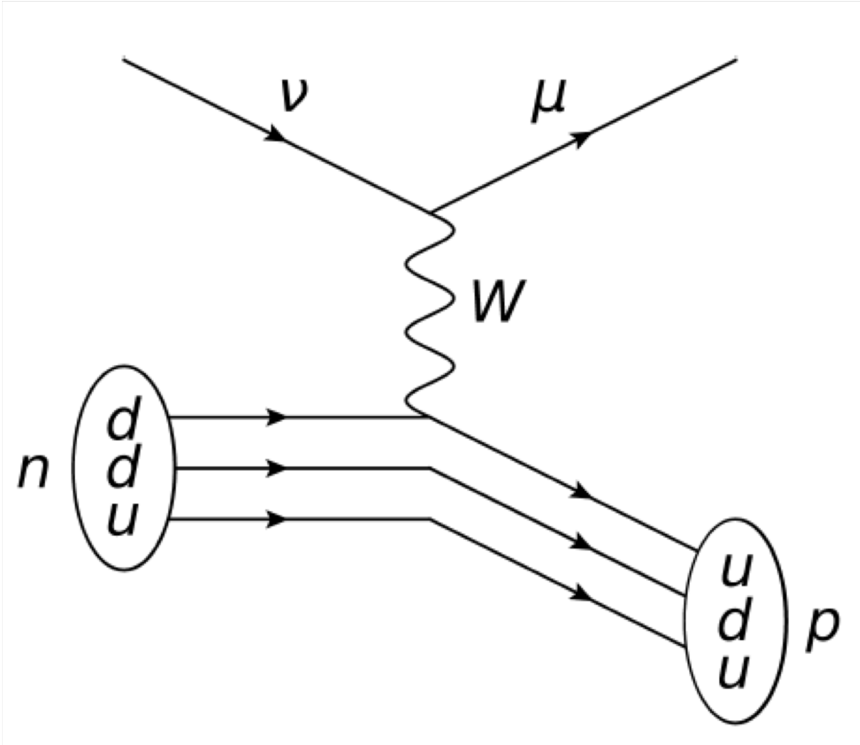
$P(\nu_\mu \to \nu_e)$
Distance to detector [km]
Neutrino energy [MeV]
0
500
1000
1500
2000
500
1000
1500
2000
2500
3000
DUNE
T2K

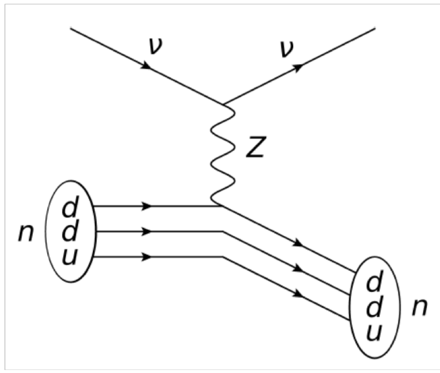


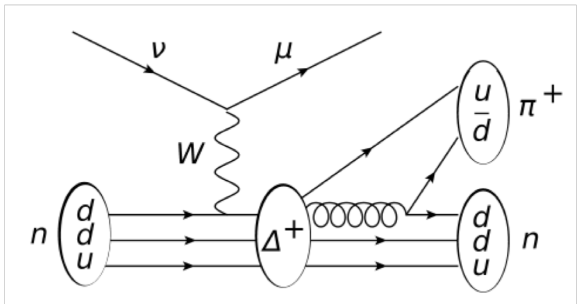
NEUTRINO PRODUCTION
PARTICLE DETECTOR
PARTICLE DETECTOR
EXISTING PROTON ACCELERATOR
UNDERGROUND PARTICLE DETECTOR

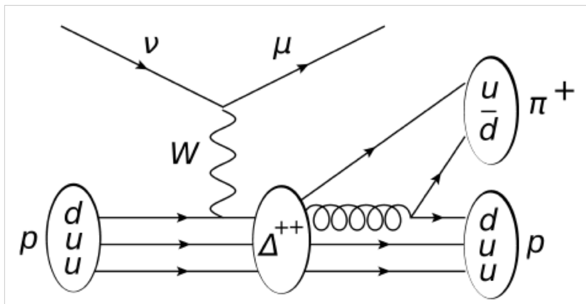
Interactions with neutrinos

- In detector neutrino interacts with nuclear medium, at low energies predominantly through **CCQE**.
- Contributions of other processes are also present: NCQE, CCRES, … and accompanying effects: FSI, SRC.
- **Cherenkov detector (SK):** Only final lepton is detected.









Problem of energy reconstruction

- Detected rates in the far detector:

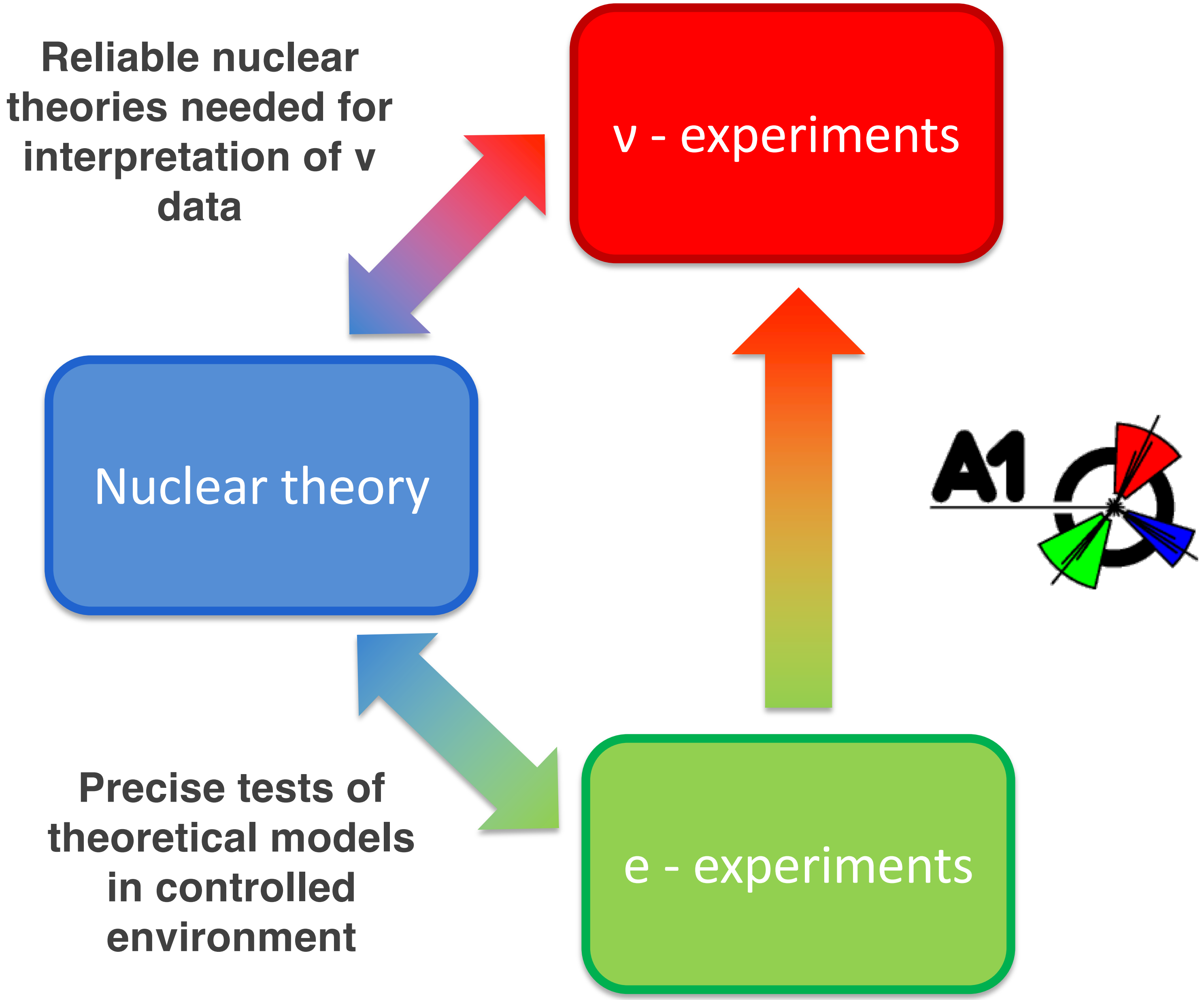
$$N^{\alpha\to\beta}(\vec{p}_n) = \sum_i \Phi_\alpha(E_{True}) \cdot P_{\alpha\beta}(E_{True}) \cdot \sigma^i_\beta(\vec{p}_{True}) \cdot \varepsilon_\beta(\vec{p}_{True})$$

$$E_{true} = \frac{m_p^2 - m_\mu^2 - E_n^2 + 2E_\mu E_n - 2\vec{k}_\mu \cdot \vec{p}_n + |\vec{p}_n|^2}{2(E_n - E_\mu + |\vec{k}_\mu|\cos\theta_\mu - |\vec{p}_n|\cos\theta_n)}$$

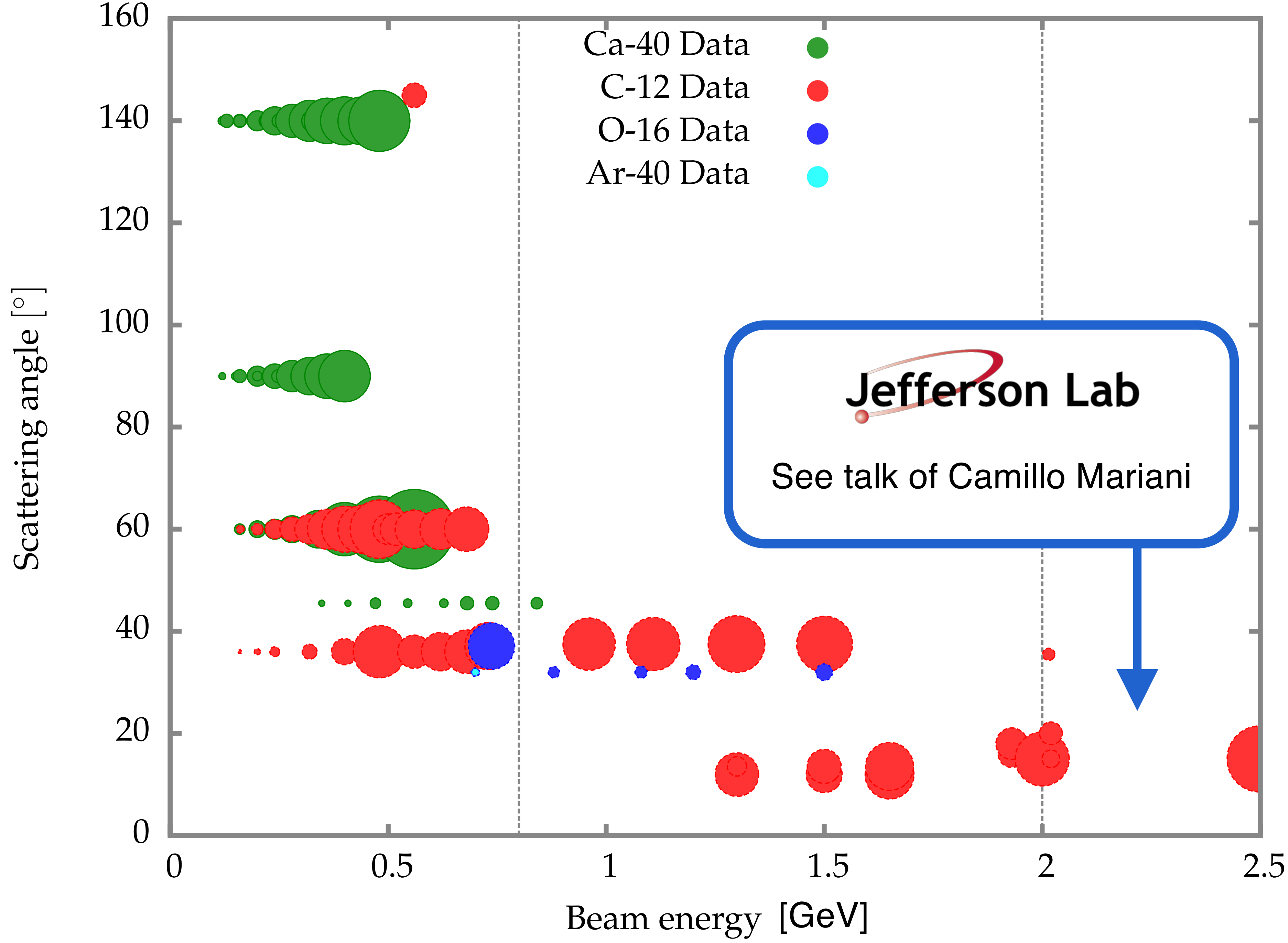
- **Energy reconstructed assuming specific process. The target nucleon embedded in nucleus is not at rest.**

- **Precise description of ν-N interaction needed!**

Importance of electron scattering

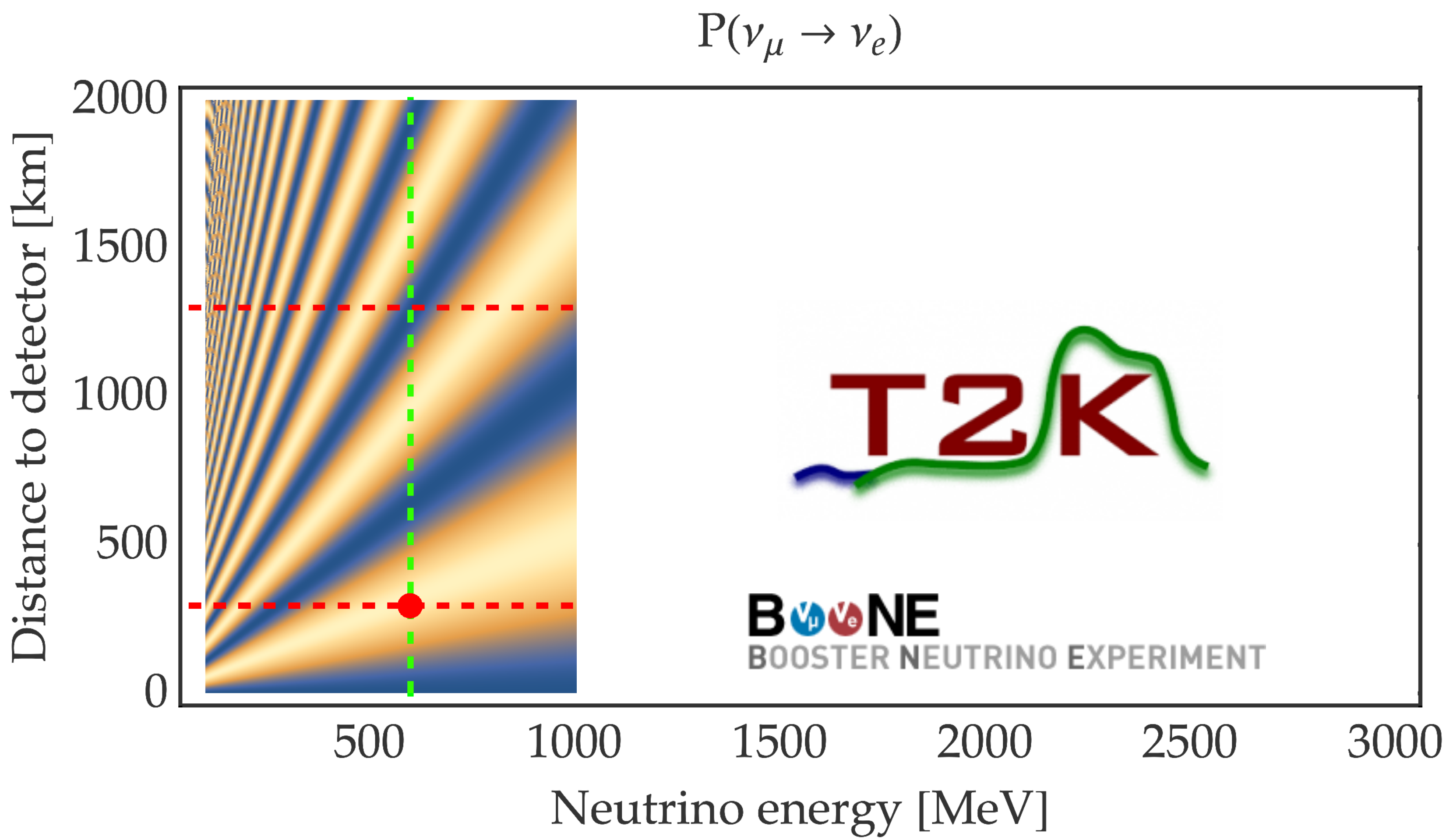


Existing Inclusive data



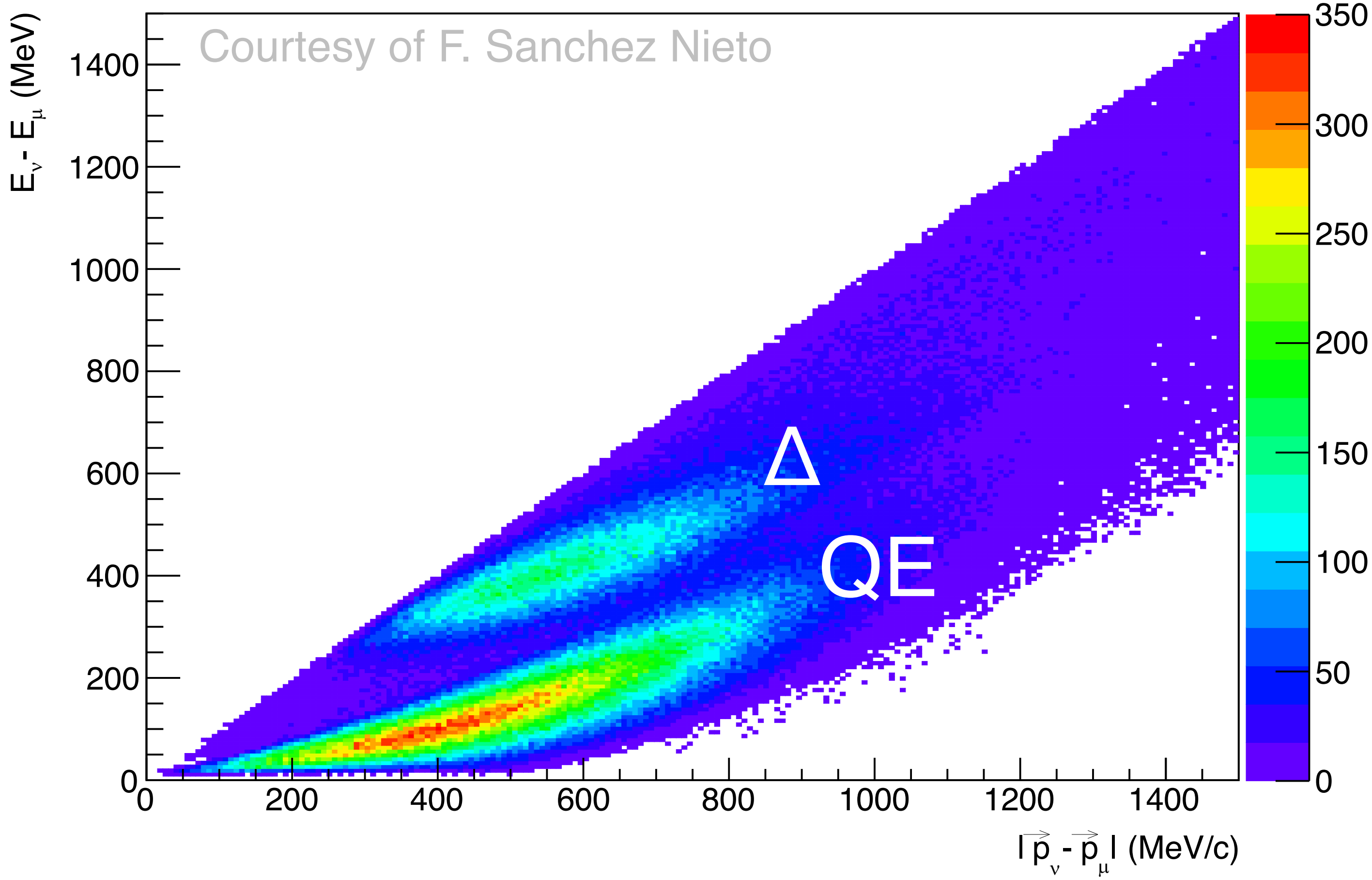
A1 Collaboration @ Mainz

- High precision electron scattering experiments below 1GeV.
- Large angular coverage but small angular acceptance.



Kinematics relevant for T2K

- Relative cross-section for CCQE and CCΔ on ^{16}O.

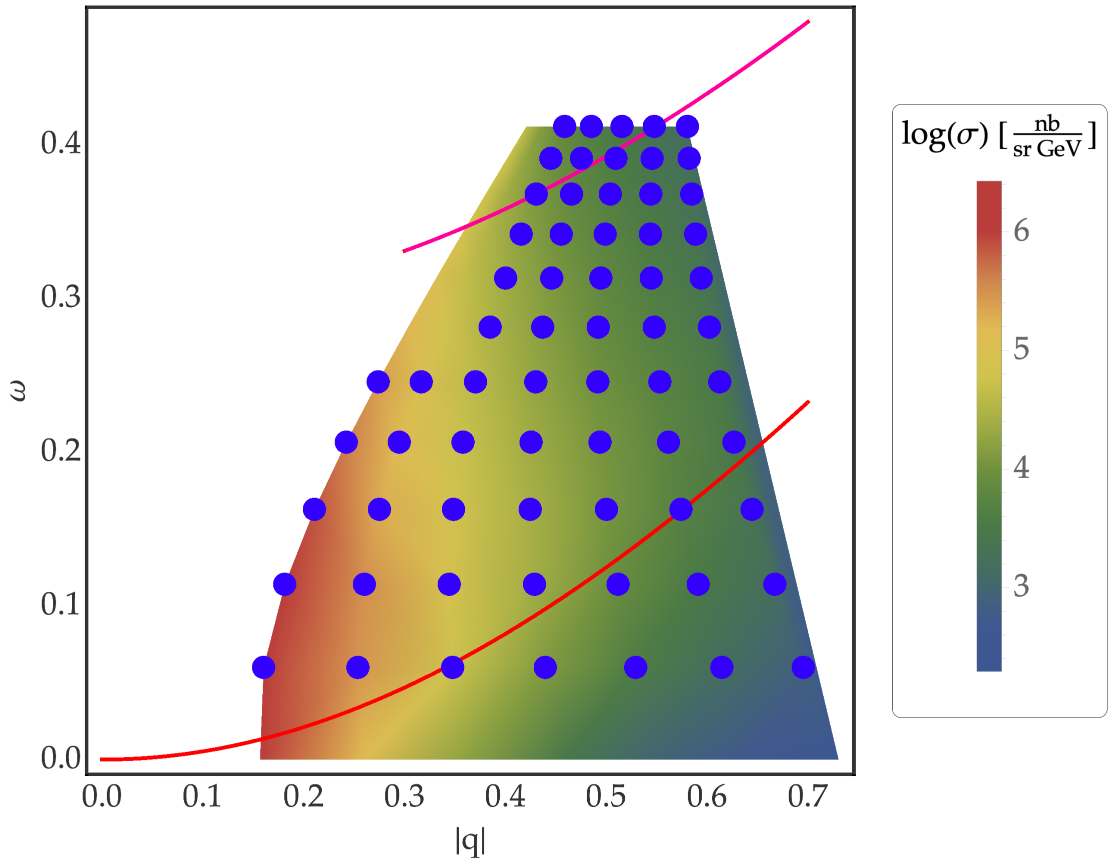


- A1 optimized for experiment in this kinematic region.
- Almost no data available.

New $^{16}O(e,e')$ experiment

$$d\sigma = d\sigma_0 \times \left[v_L R_L + v_T R_T \right]$$

- Dominating terms $\mathbf{R_L}$ and $\mathbf{R_T}$ sensitive to magnetic density and currents!
- Measurements at kinematics sensitive to R_T are proposed.
- Extend the program for ^{16}O Coulomb sum rule.



The MAMI experiment

Electron Beam:

- Energy: 600 MeV
- Current: > 20μA

Spectrometer A:

- Data taking

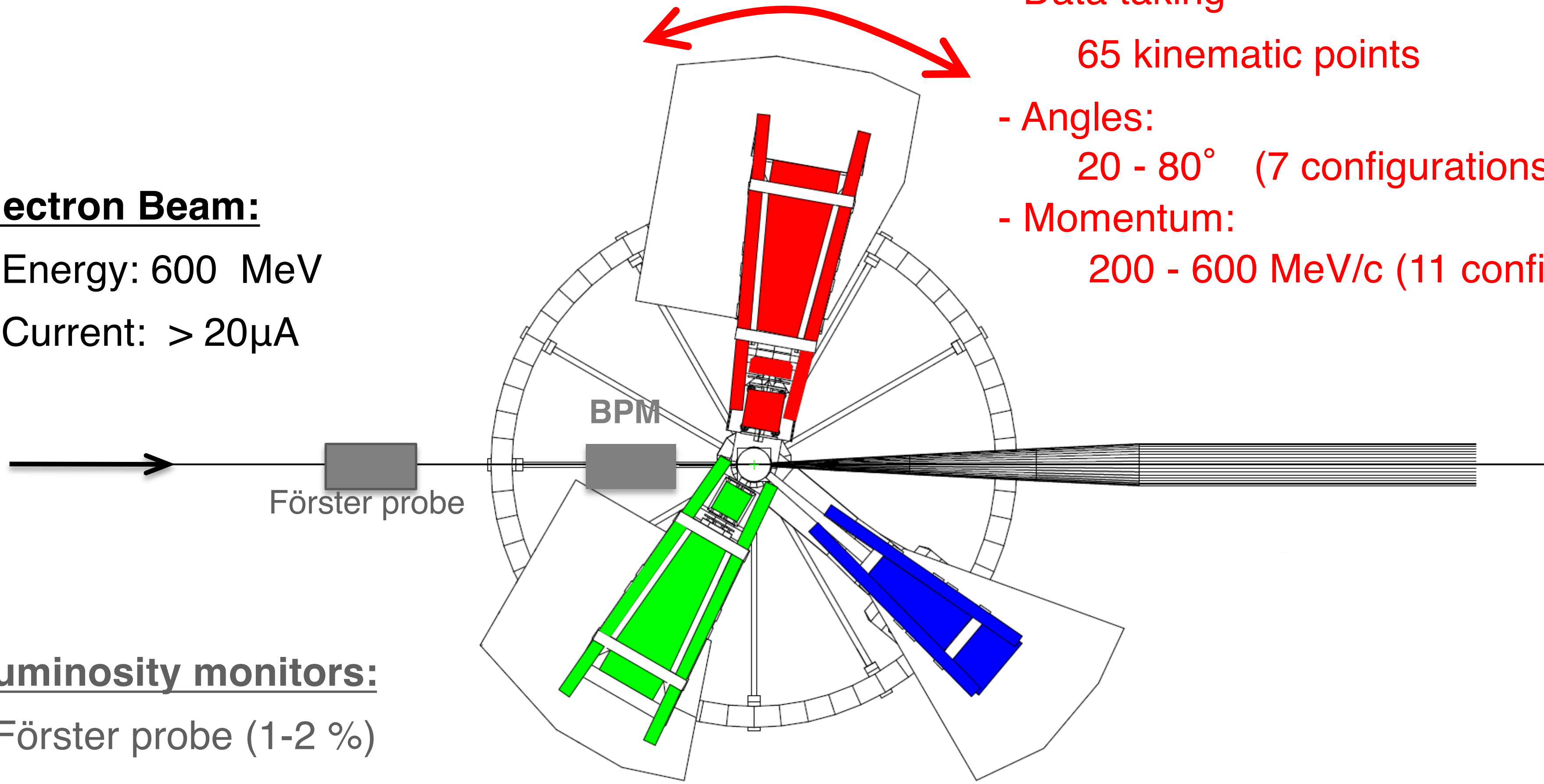
  65 kinematic points

- Angles:

  20 - 80°   (7 configurations)

- Momentum:

  200 - 600 MeV/c (11 configurations)



Luminosity monitors:

- Förster probe (1-2 %)

Spectrometer C:

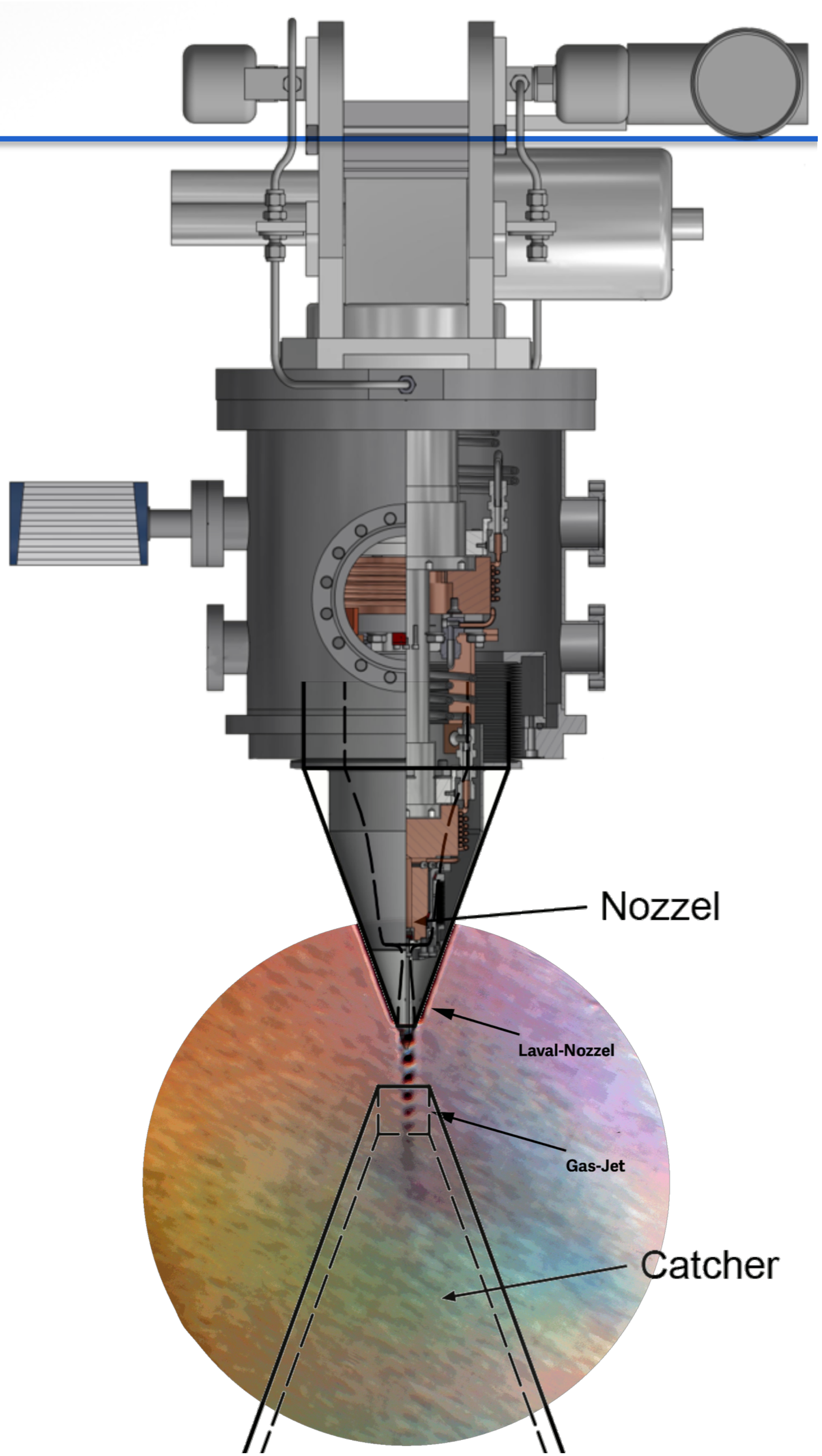
- Not used

Spectrometer B:

- Luminosity monitor (const. setting)
- Momentum: 600
- Angles: 50°

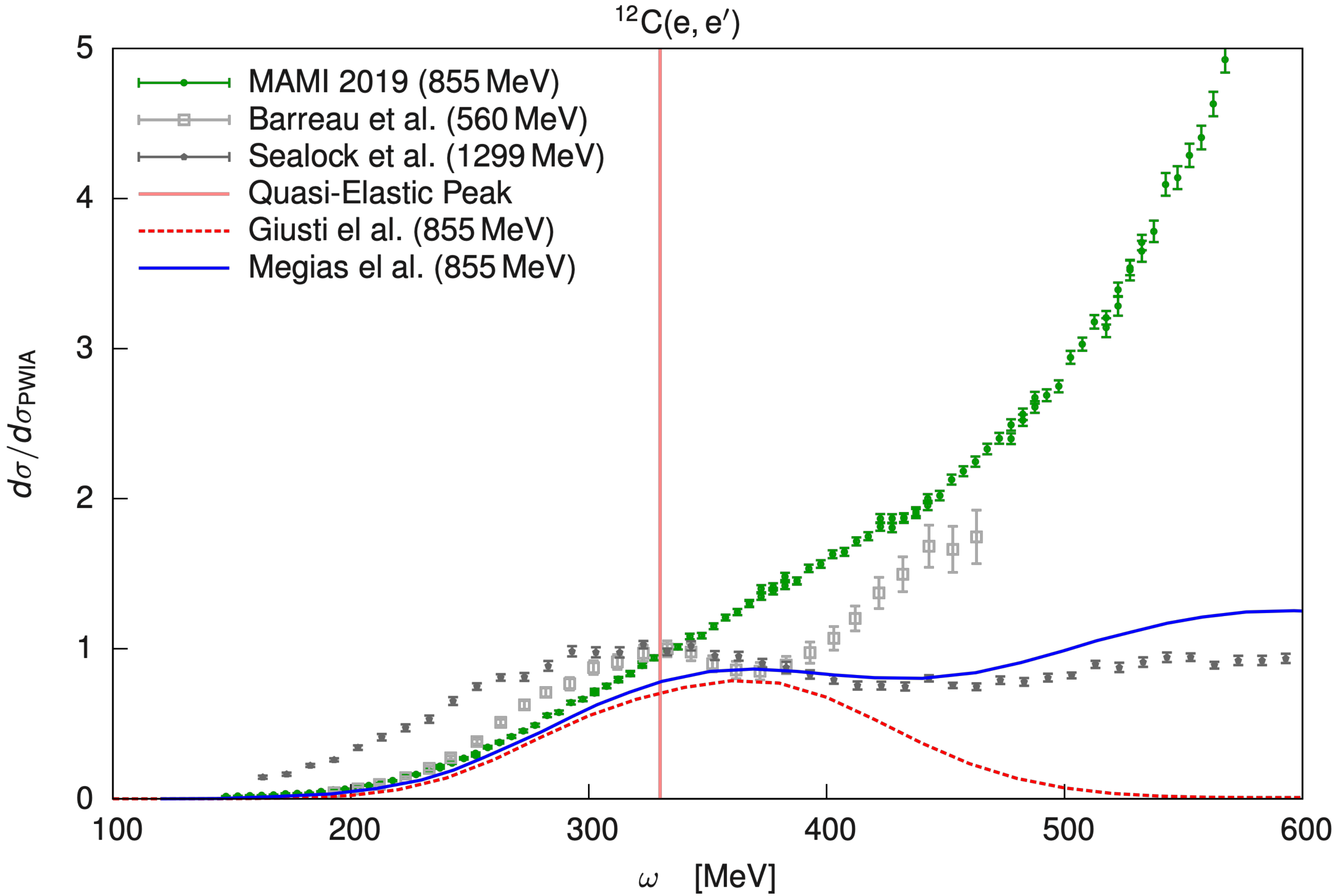
Hypersonic jet target

- Target developed for MAGIX, but could be used also in A1.
- No metal frame near the vertex.
- No target walls.
- Width of the jet 2mm (point-like target)
- Originally designed for ^{1}H, but applicable also for ^{40}Ar and ^{16}O.
- Density of **2.7×10^{-3} g/cm^{3}** at 15 bar.
- Luminosity of **1.7×10^{34}/cm^{2}s** can be achieved at MAMI.



Pilot experiment

- $^{12}C(e,e')$ cross-section measurement at beam energy of 855 MeV.
- With outstanding resolution and luminosity old data can be matched within minutes.

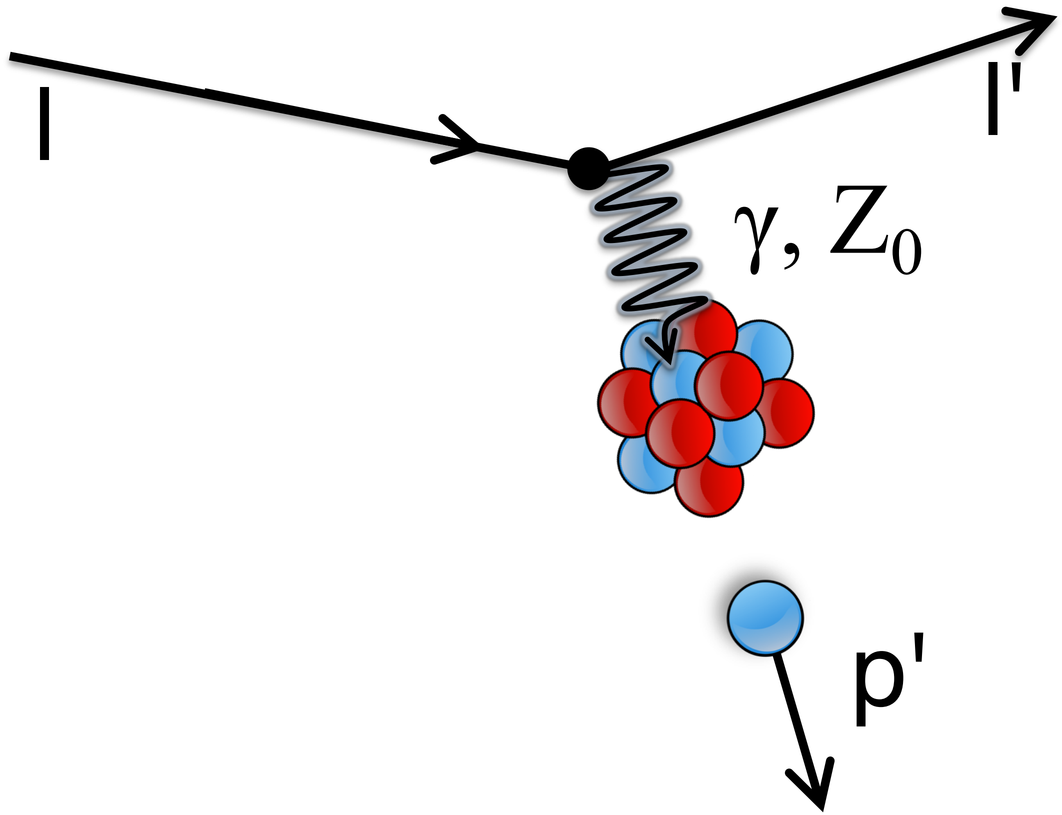


Summary

- Most important questions of today's physics related to neutrinos.
- Neutrino experiments rely on Monte-Carlo simulations, which depend on nuclear structure models.
- Present theoretical models are still deficient.
- **A new experimental program at A1 could provide new valuable input to theories relevant for T2K, MiniBooNE, MicroBooNE and DUNE.**
- Experiments on ^{12}C, ^{16}O and ^{40}Ar are being planned.
- Quasi-elastic experiments on ^{12}C ^{16}O, (^{40}Ar) interesting also in the context of fundamental nuclear physics – for validation of modern ab-initio theories.

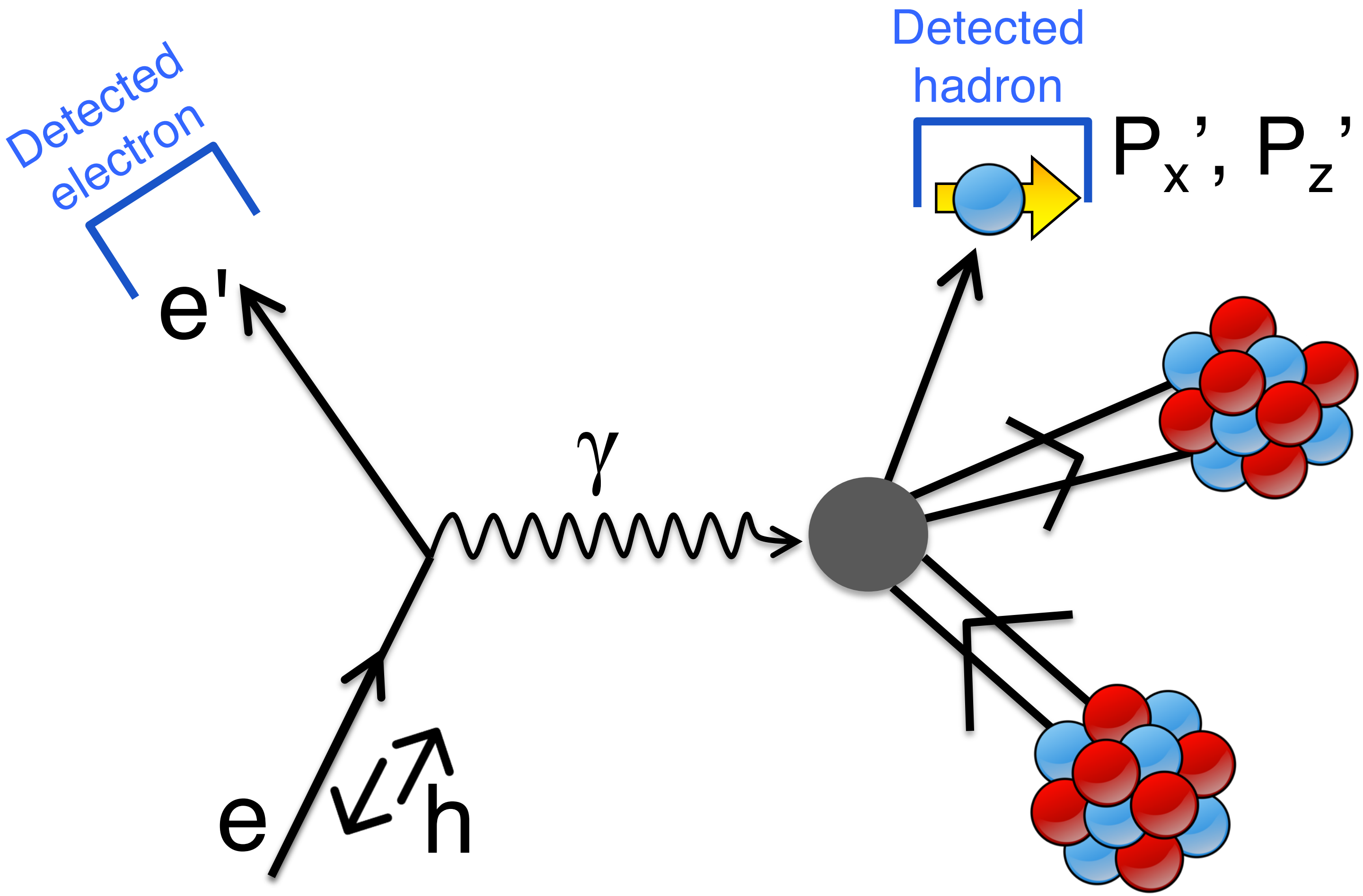
Further ideas!?

- Inclusive reactions (l,l') sensitive to properties of interaction potential.



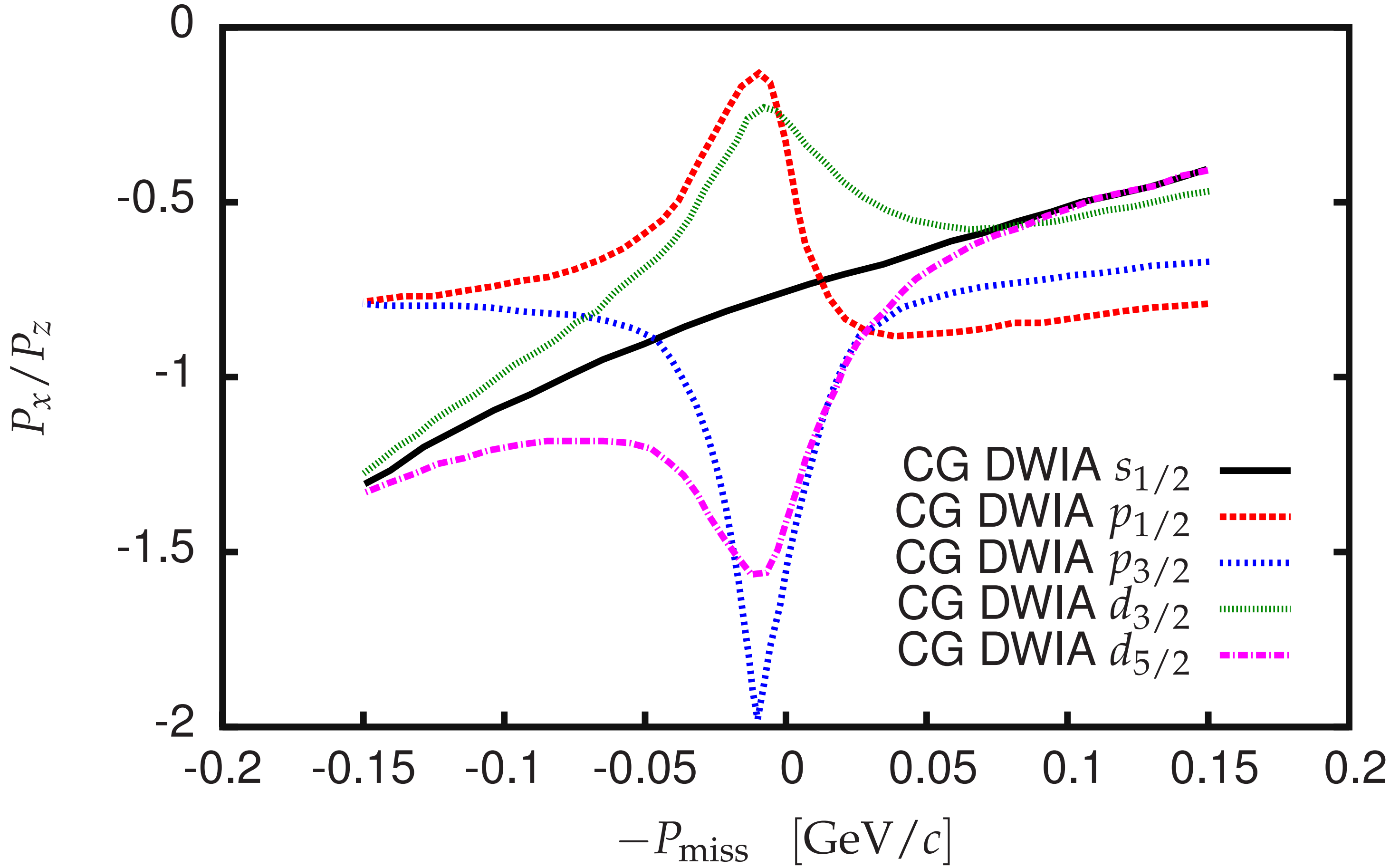
- The exclusive processes (l,l'p) sensitive to details of the initial nucleon ground-state wave-function.

Double polarized electron scattering



$$P_x', P_z' = \frac{\Delta\sigma(h_\pm, \vec{S})}{\sigma_0}$$

$^{40}Ar(\vec{e},e'\vec{p})$ experiment @ MAMI

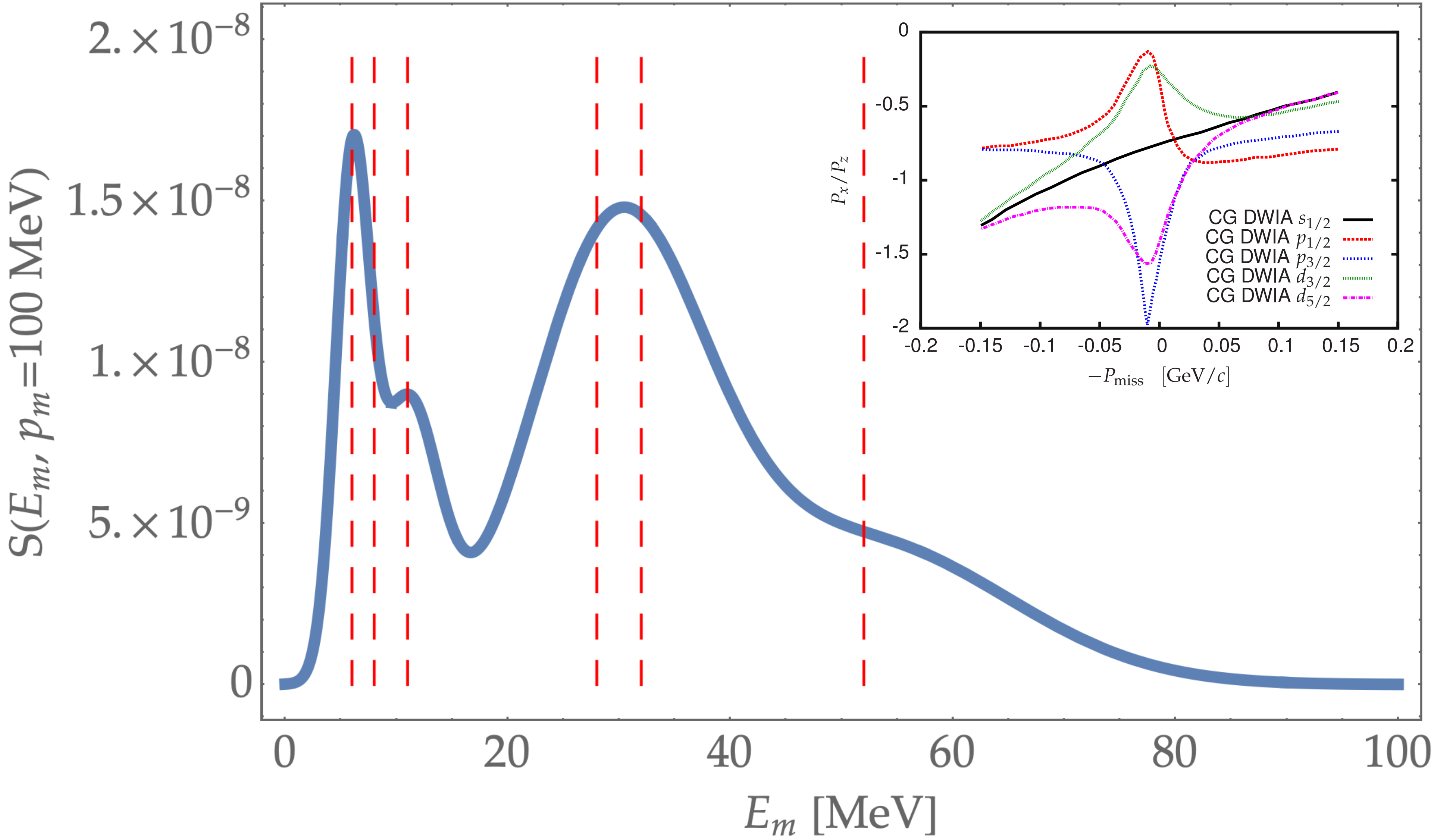


- Theoretical description provided by C. Giusti and A. Deltuva.

- Double polarization experiment offers a unique opportunity to study details of the nucleon wave function, not accessible in CS measurement: **Angular momentum dependence, effects of LS Coupling !!!**

$^{40}Ar(\vec{e},e'\vec{p})$ experiment @ MAMI

- Can we distinguish different subshells? Tests need to be done.



Thank you!