Measurement of the N→Δ Transition Form Factors at low Q^2

Hamza Atac
Temple University

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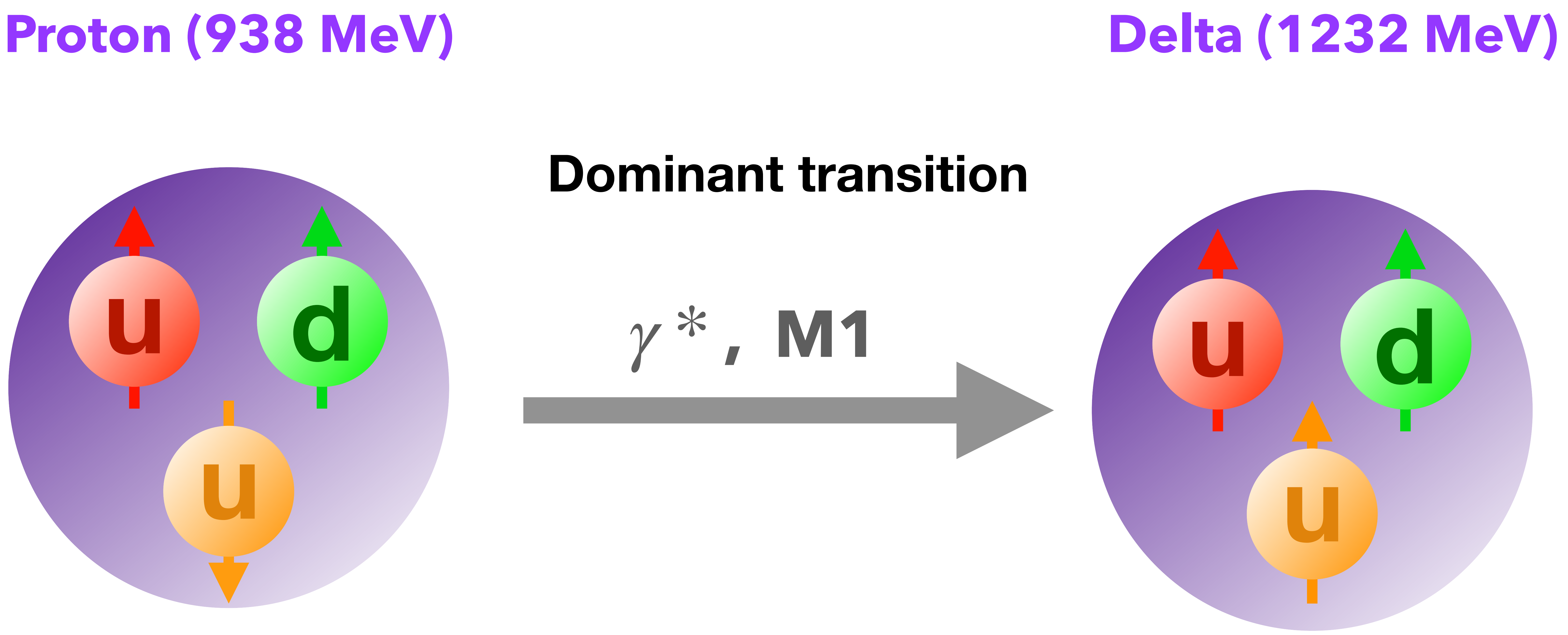
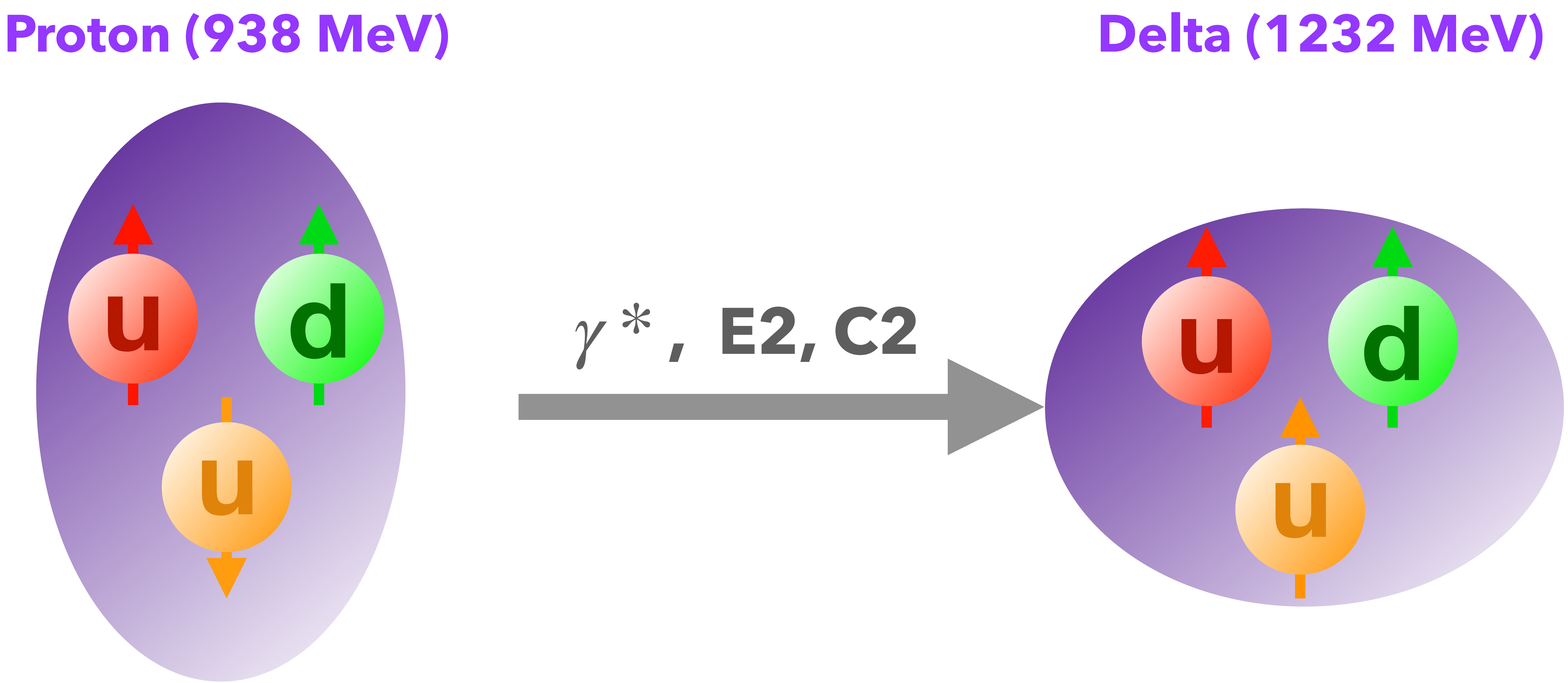
The N-Δ transition



The first excited state of the proton, the Delta, can be reached through a magnetic spin flip of one of the quarks (M1).
(spherical S-wave proton WF -> spherical S-wave Delta WF)

The N-Δ transition



It can also be reached through a quadrupole (E2 or C2) transition from proton to delta. (The quadrupole amplitudes are associated with the existence of non-spherical components in the proton and Delta WF)

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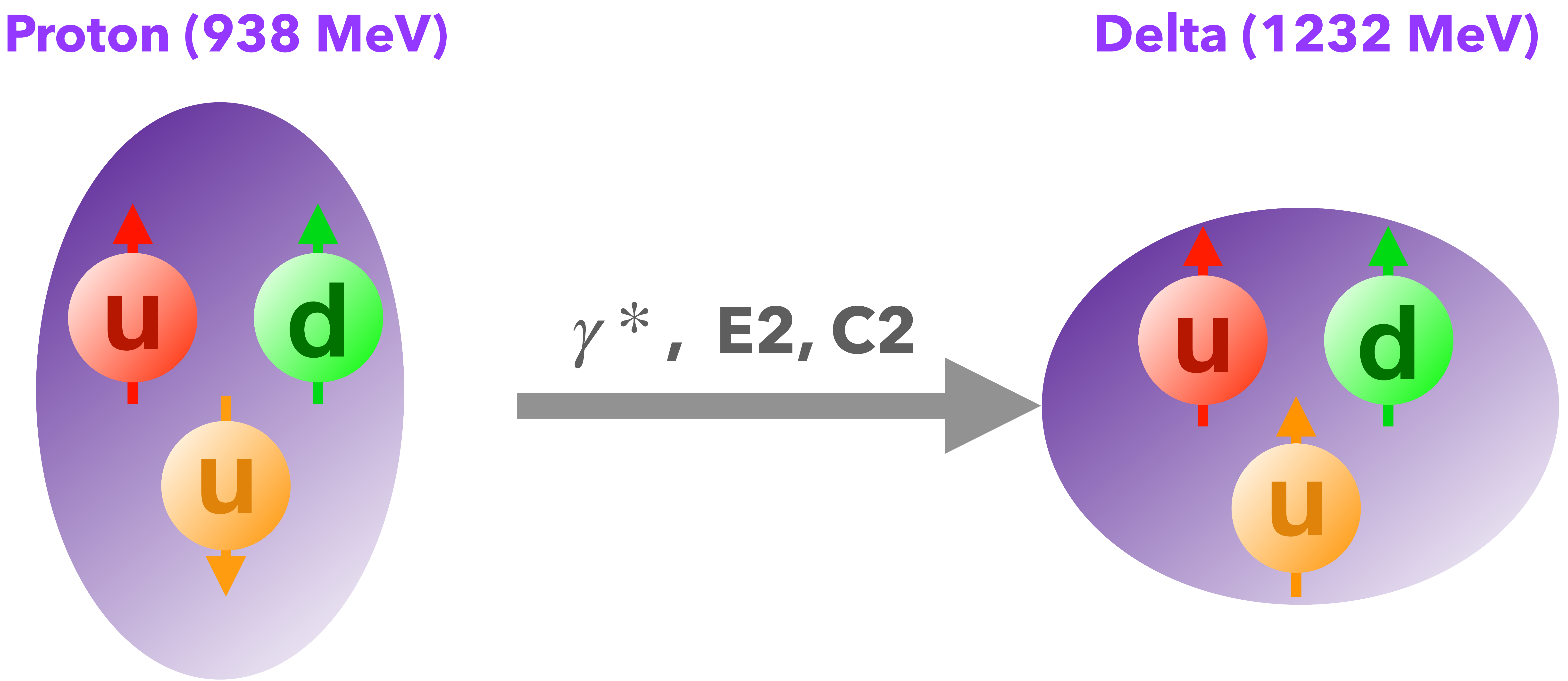

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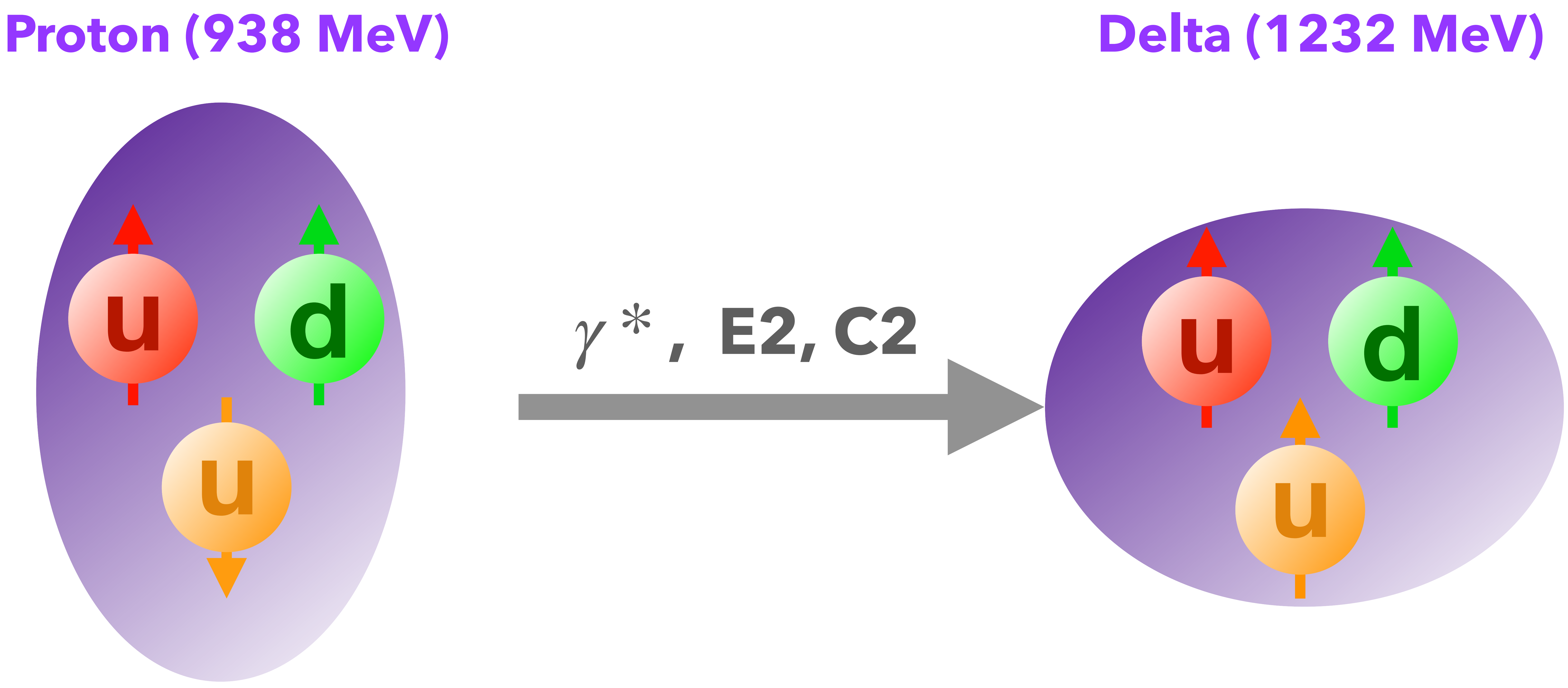
The quadrupole to dipole ratio (E2/M1 or C2/M1) is non-zero... Why?

Electric-Quadrupole to **M**agnetic-Dipole **R**atio = **EMR** = E2/M1

Coulomb-Quadrupole to **M**agnetic-Dipole **R**atio = **CMR** = C2/M1

The N-Δ transition



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Non-central (tensor) interactions between quarks can account for some of the spherical deviation, but not all...

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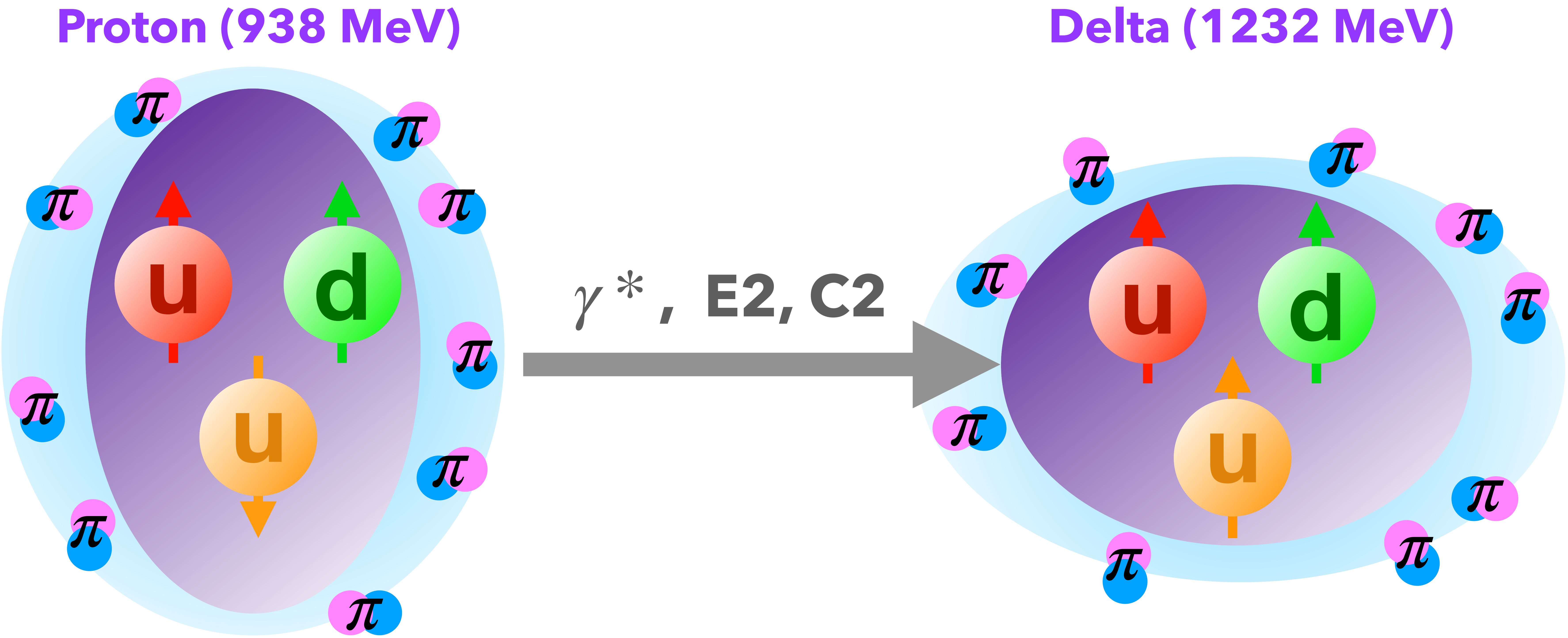

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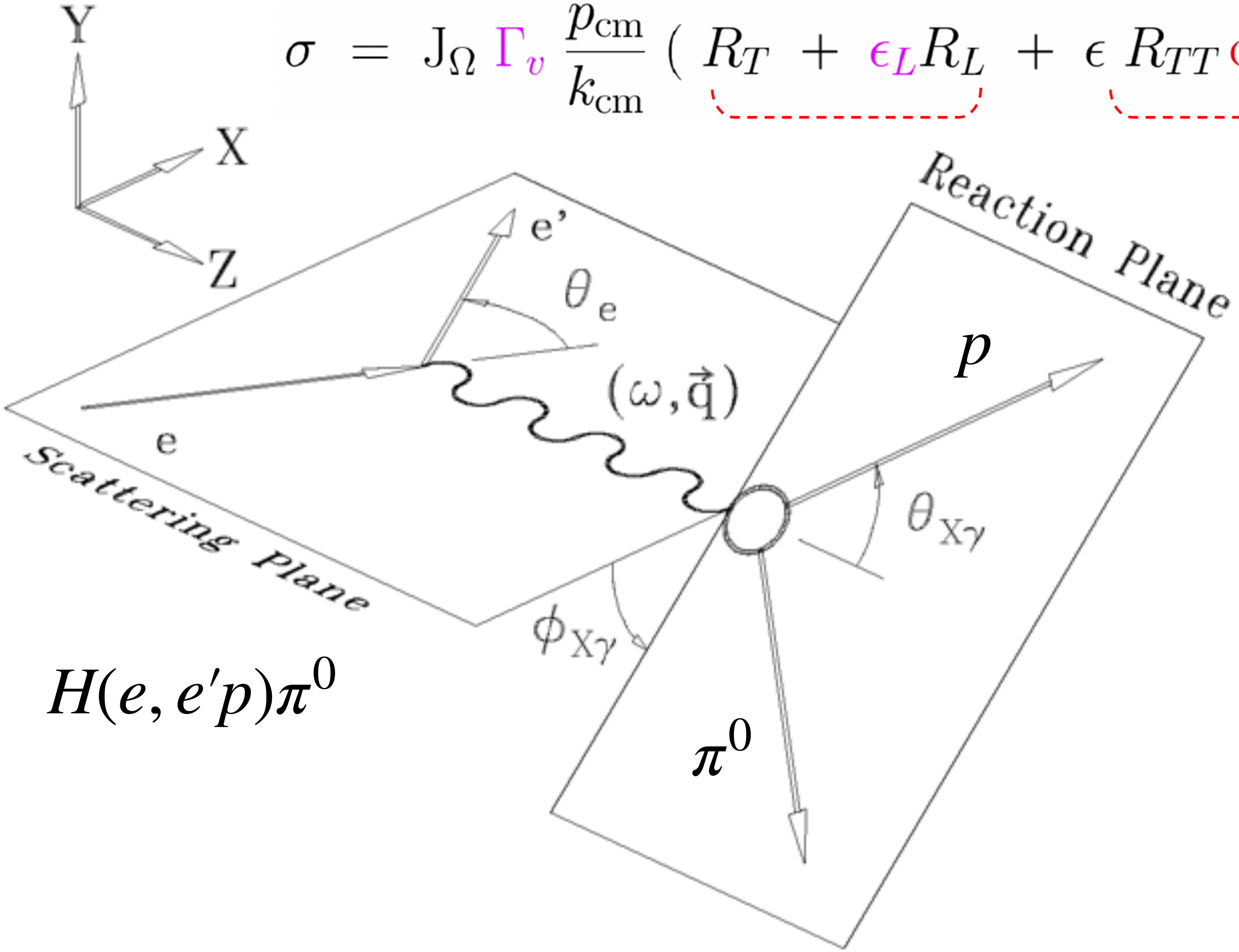
The dynamics of a meson cloud are important to describe the structure of the nucleon.

Experimental Methodology

$$\sigma = J_\Omega \Gamma_v \frac{p_{cm}}{k_{cm}} \left(R_T + \epsilon_L R_L + \epsilon R_{TT} \cos 2\phi_{X\gamma} - v_{LT} R_{LT} \cos \phi_{X\gamma} \right)$$



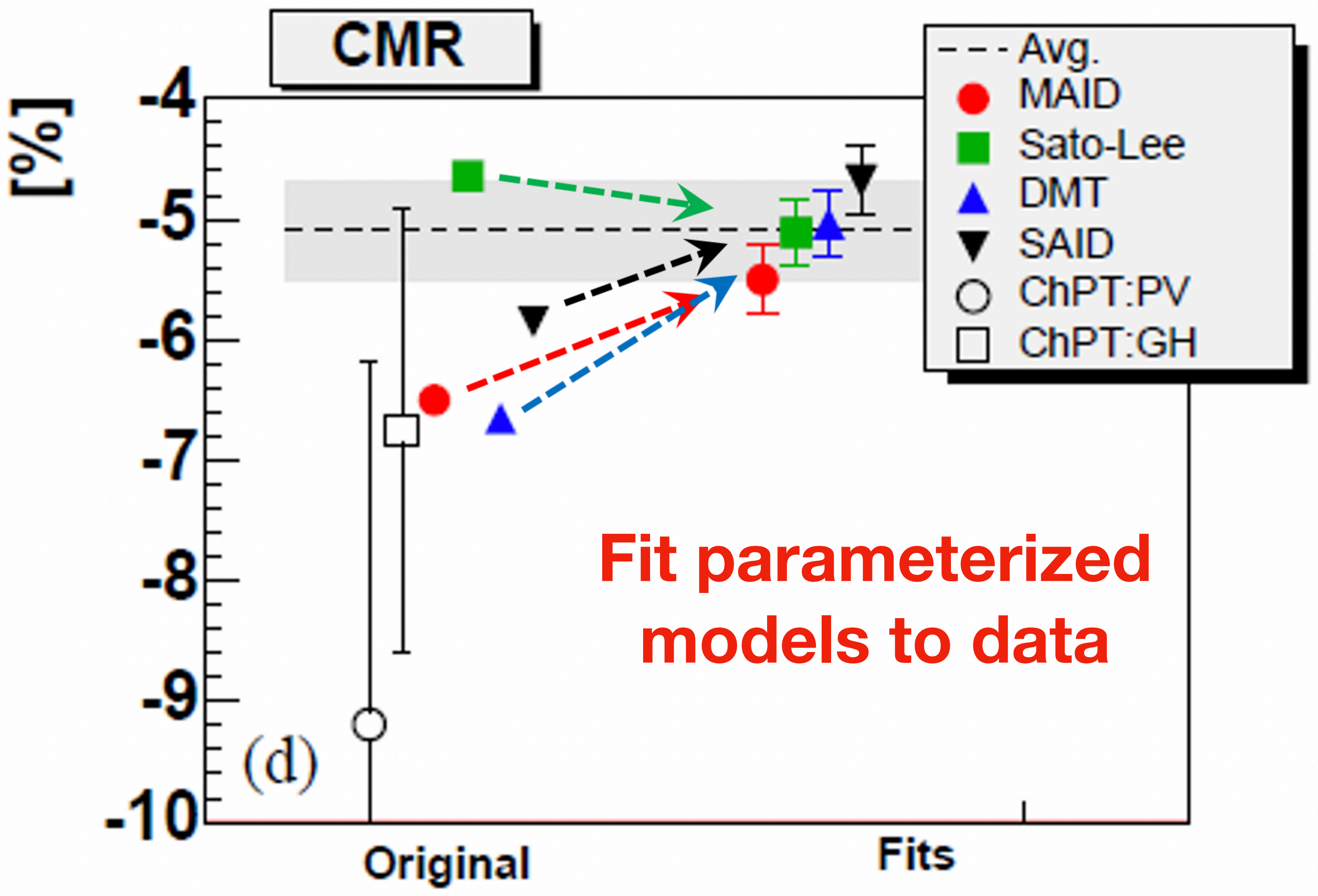
$H(e, e'p)\pi^0$

For a given $\theta_{X\gamma}$, one can measure at least 3 $\phi_{X\gamma}$ to simultaneously extract $R_T + R_L, R_{TT}$ and R_{LT}.

$R_{TT} \rightarrow$ sensitive to the **EMR**

$R_{LT} \rightarrow$ sensitive to the **CMR**

$R_T + R_L \rightarrow$ sensitive to $M1$

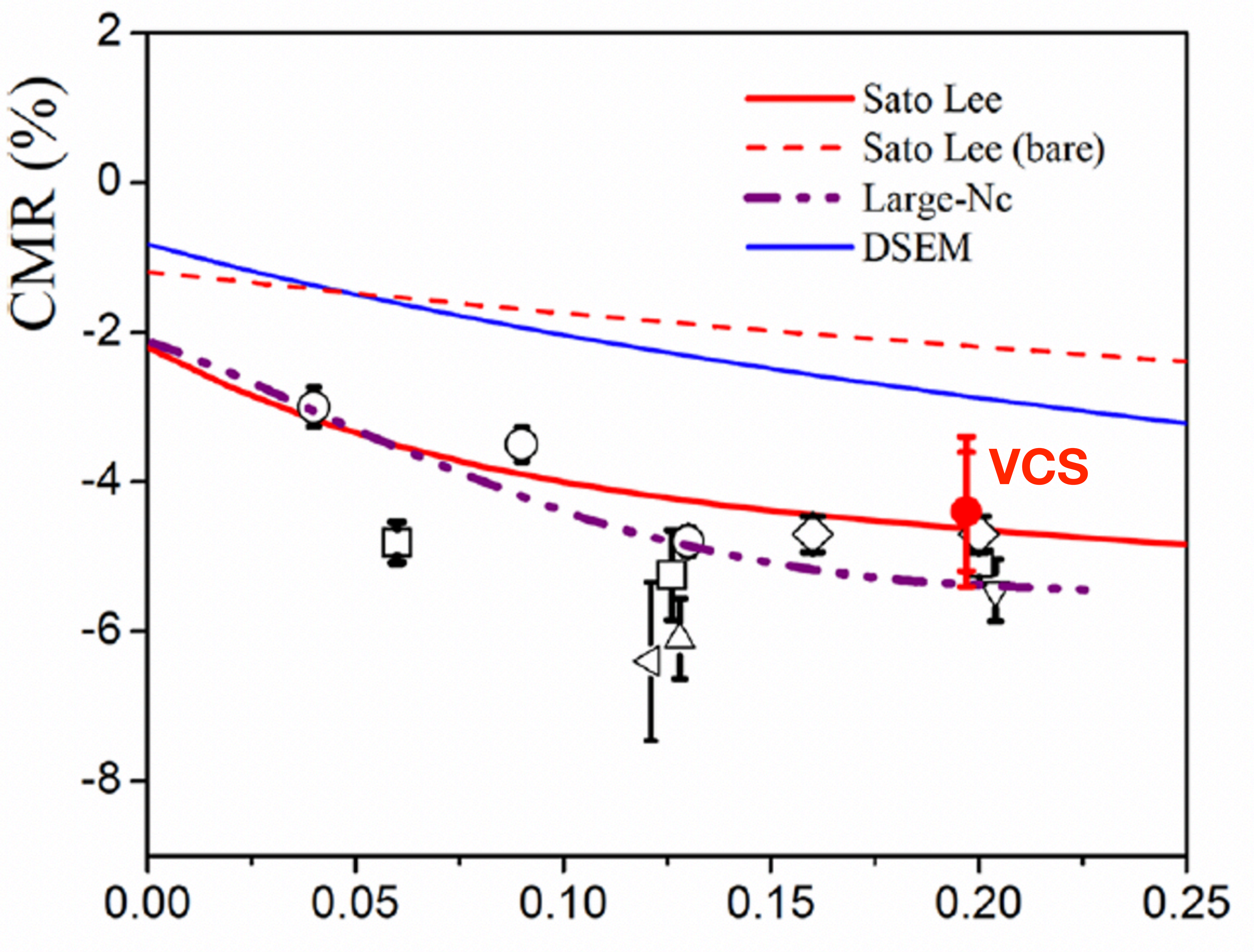


Cross-checks on Extraction Methods: VCS

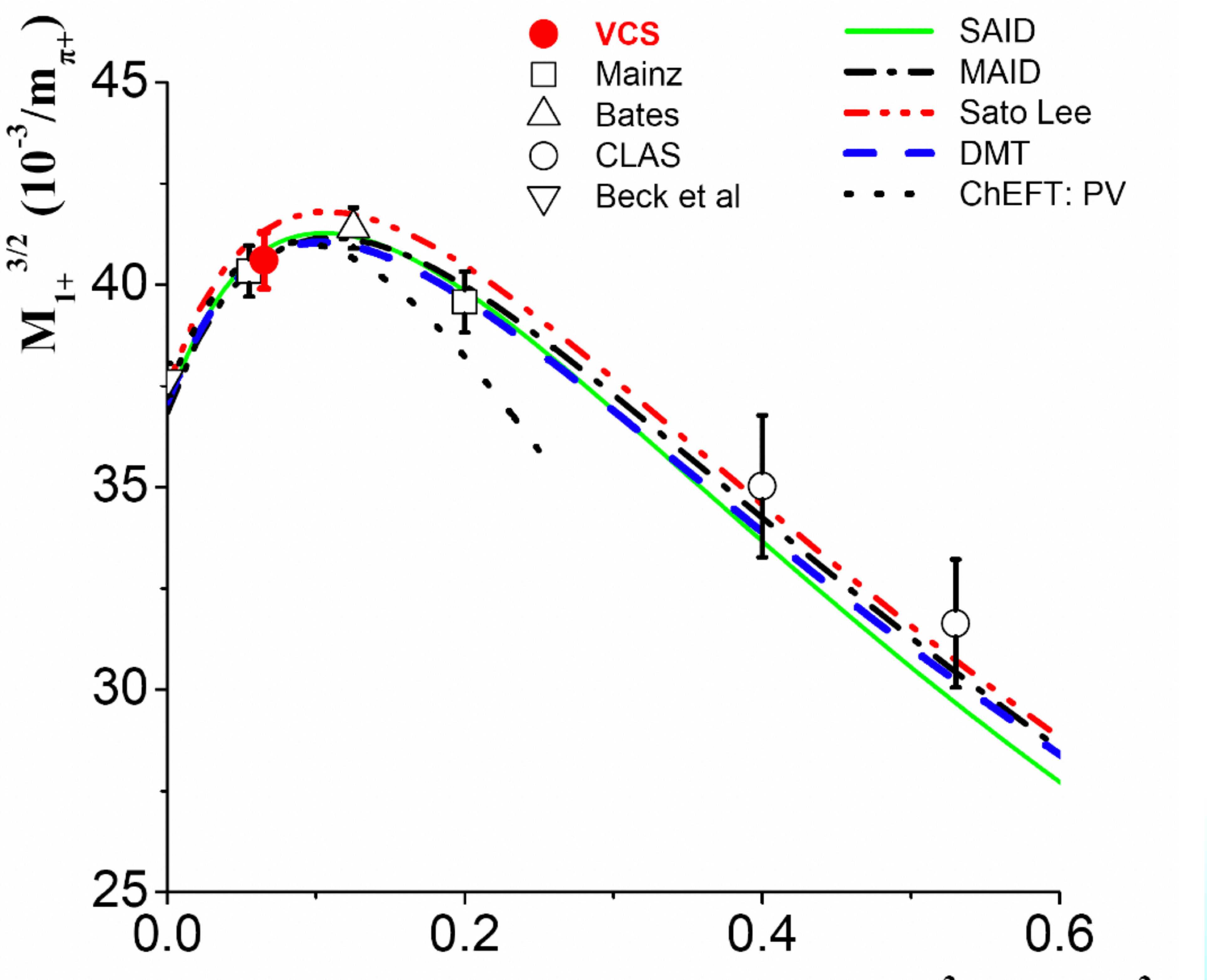
$\Delta^+ \rightarrow N\pi$ ~ 99% H(e,e'p)π^0 , H(e,e'π^+)n

$\Delta^+ \rightarrow p\gamma$ < 1% **VCS**: H(e,e' p)γ

The excitation process is the same, but the backgrounds are very different:
Stringent test of the theoretical framework & control of theoretical model uncertainties



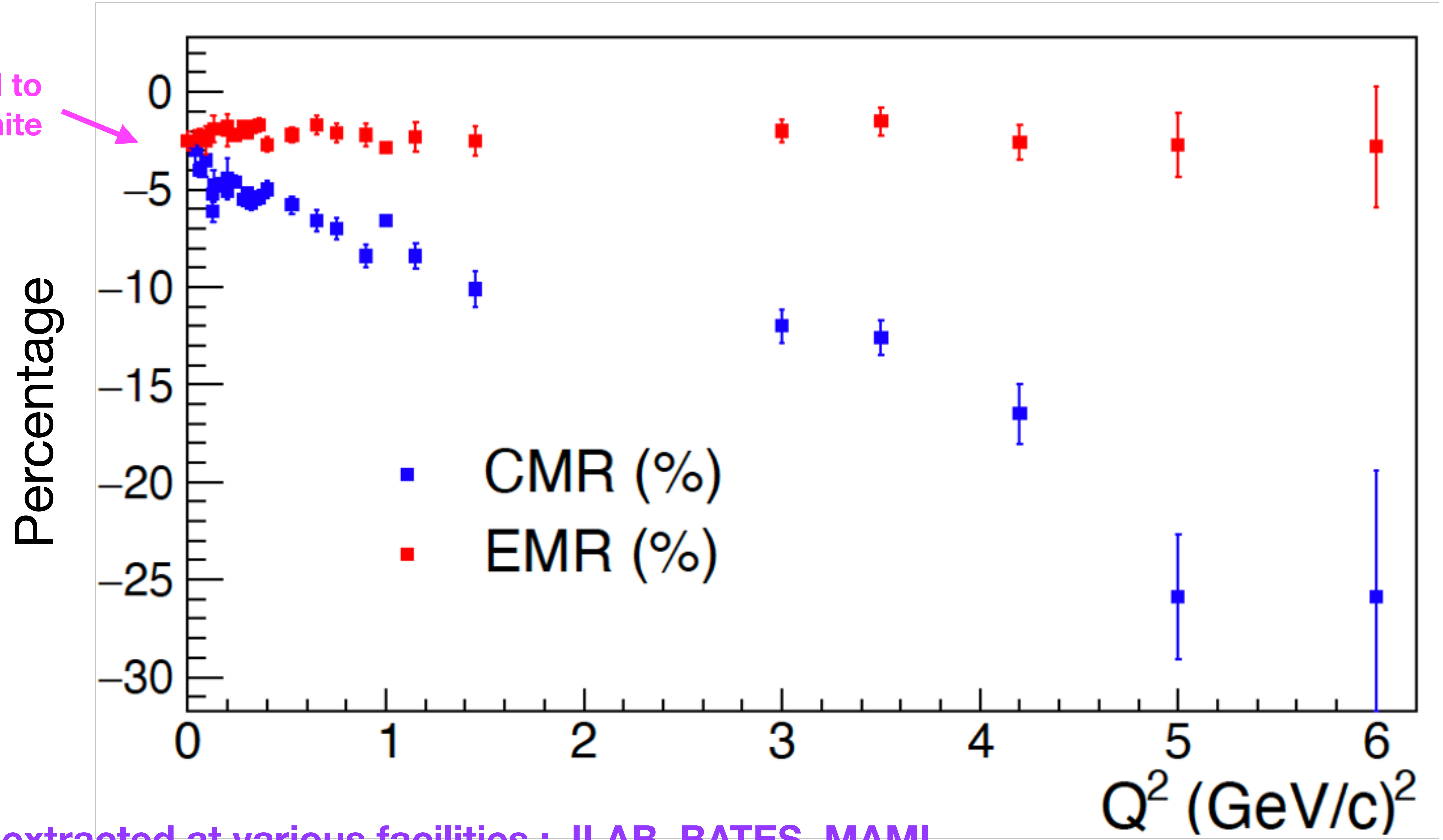
Eur. Phys. J. A (2019) 55: 182



Phys. Rev. C 78, 018201 (2008)

World data and status of TFFs

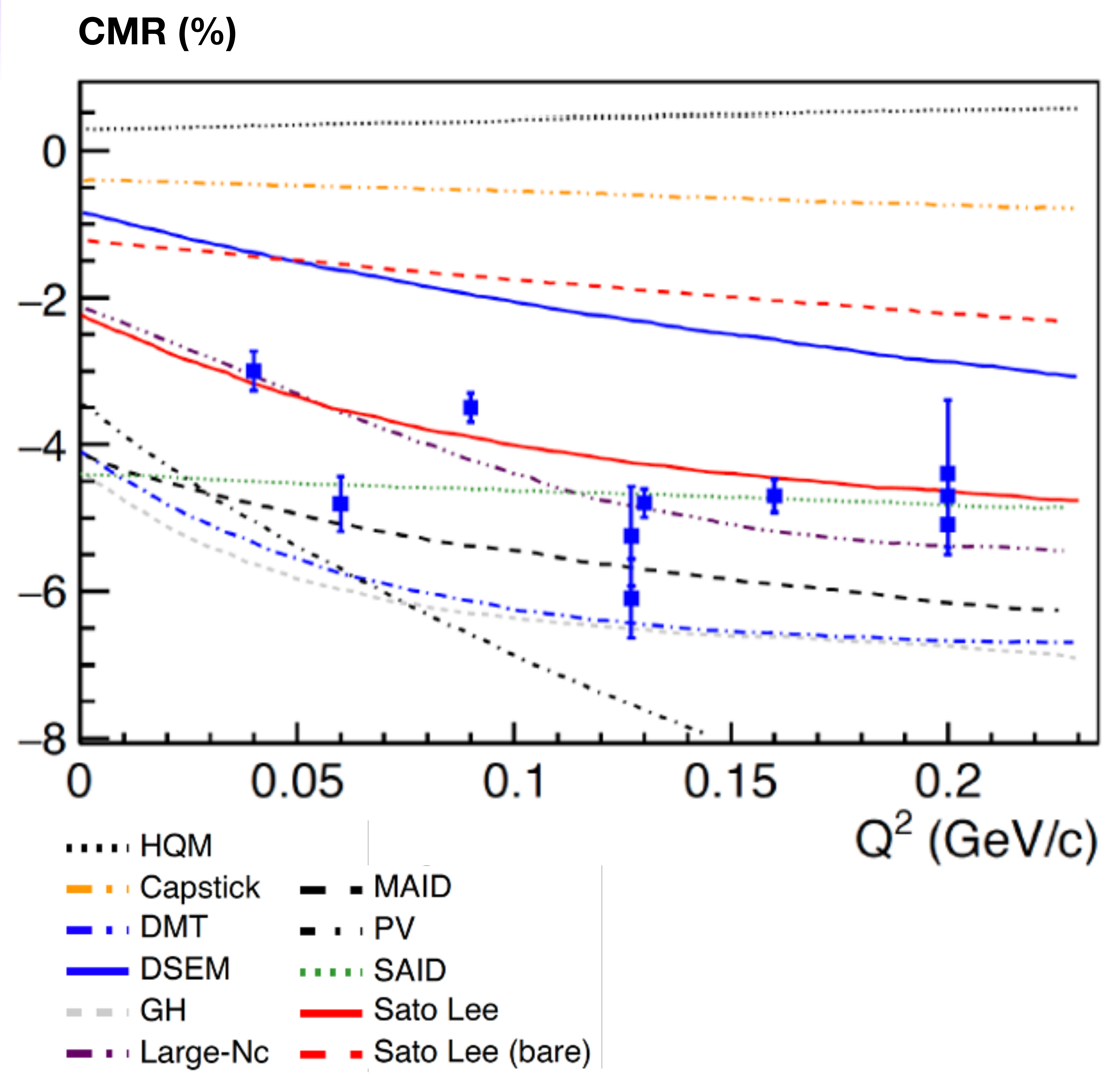
CMR & EMR predicted to converge at a small finite value as $Q^2 \to 0$

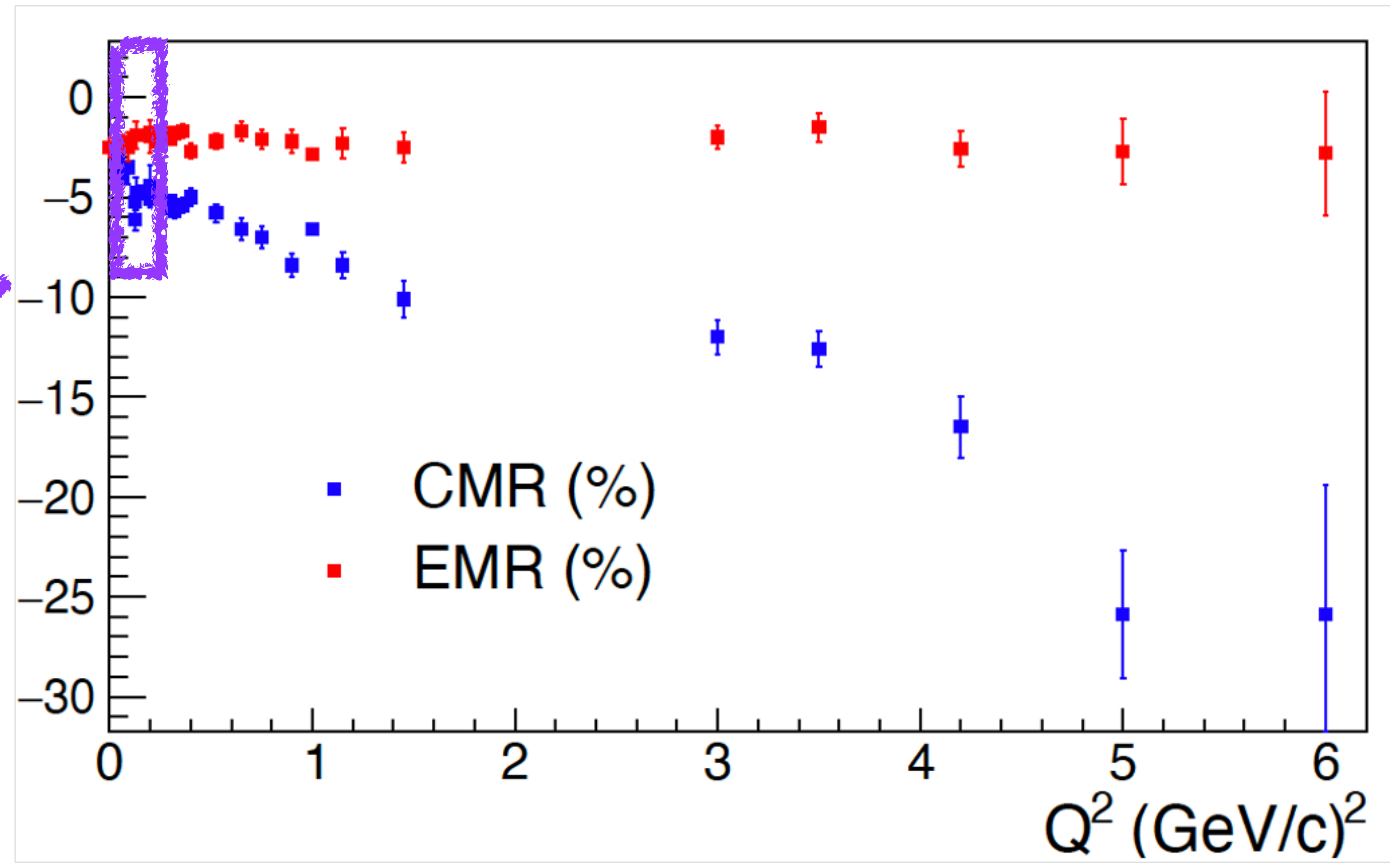


TFFs has been extracted at various facilities : JLAB, BATES, MAMI

At large Q^2, no direct indication of EMR → 100% and CMR → constant (predicted in pQCD regime)

Low Q² N-Δ transition form factors





- **Low Q^2 landscape is an important region to measure:**
  - Mesonic cloud effects are predicted to be:
    - changing most rapidly over all Q^2
  - Provides an excellent test bed for ChEFT and LQCD calculations
  - Tests the predicted convergence of EMR and CMR as $Q^2 \rightarrow 0$.
  - Sparsely measured region.

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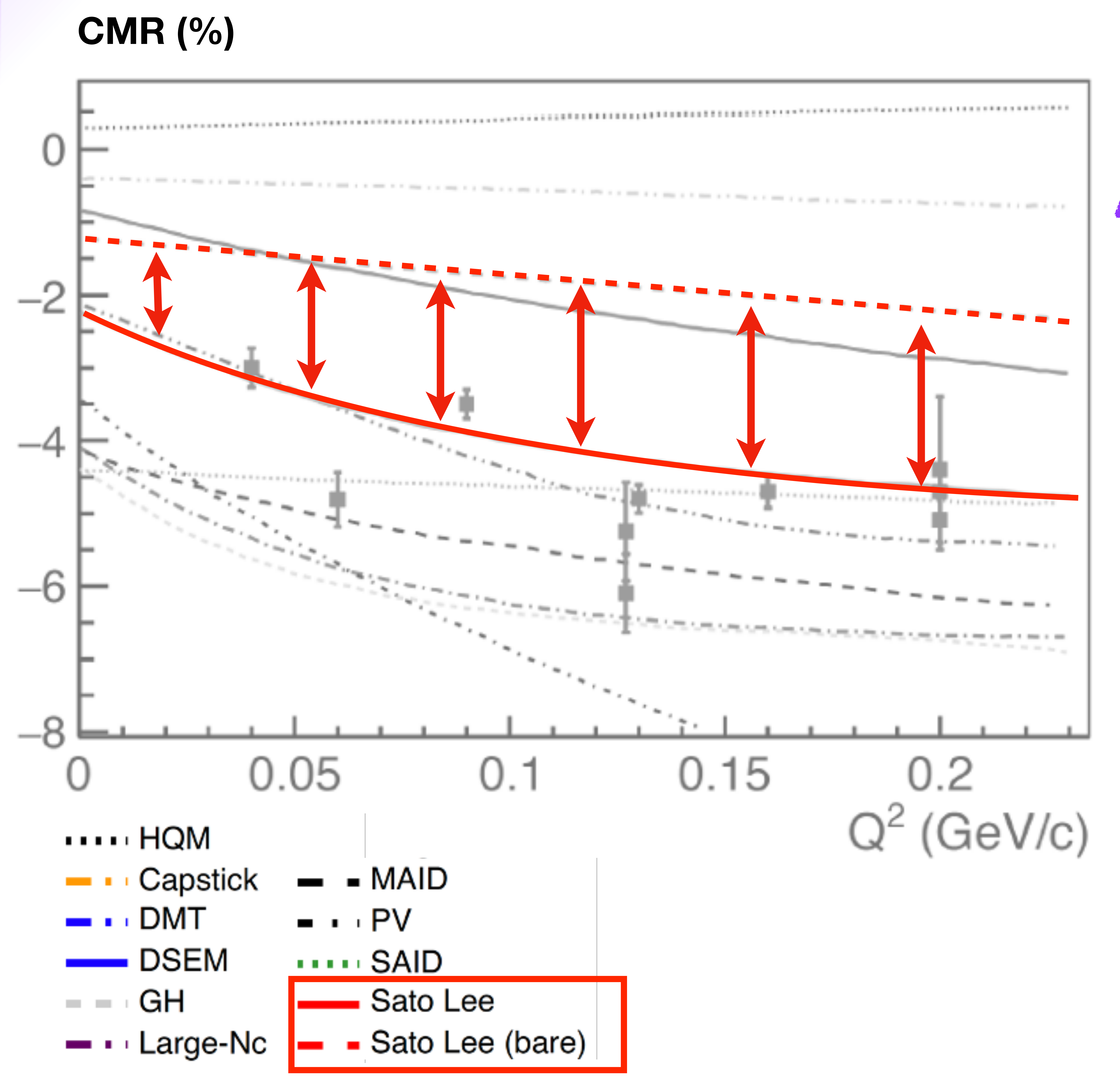

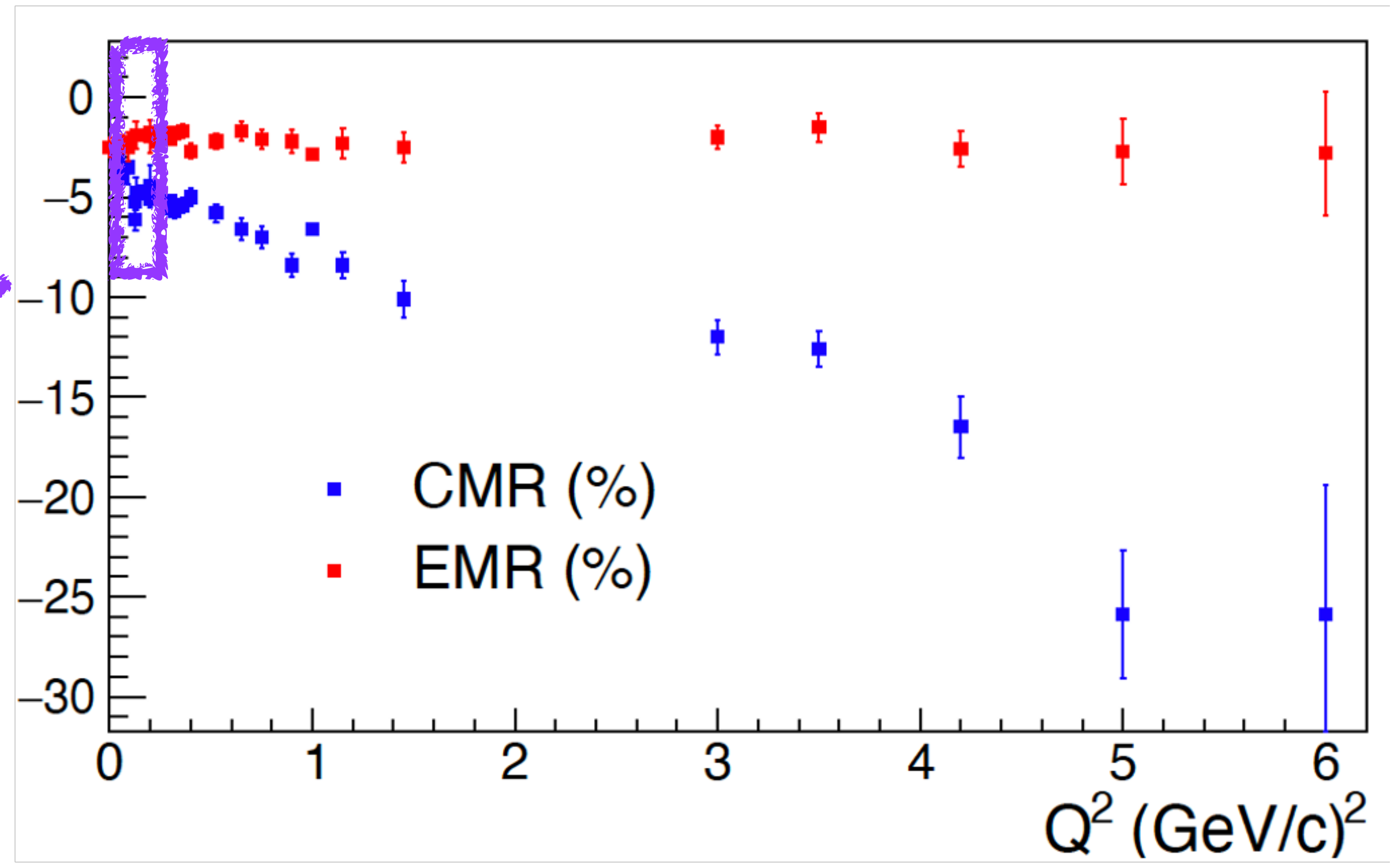

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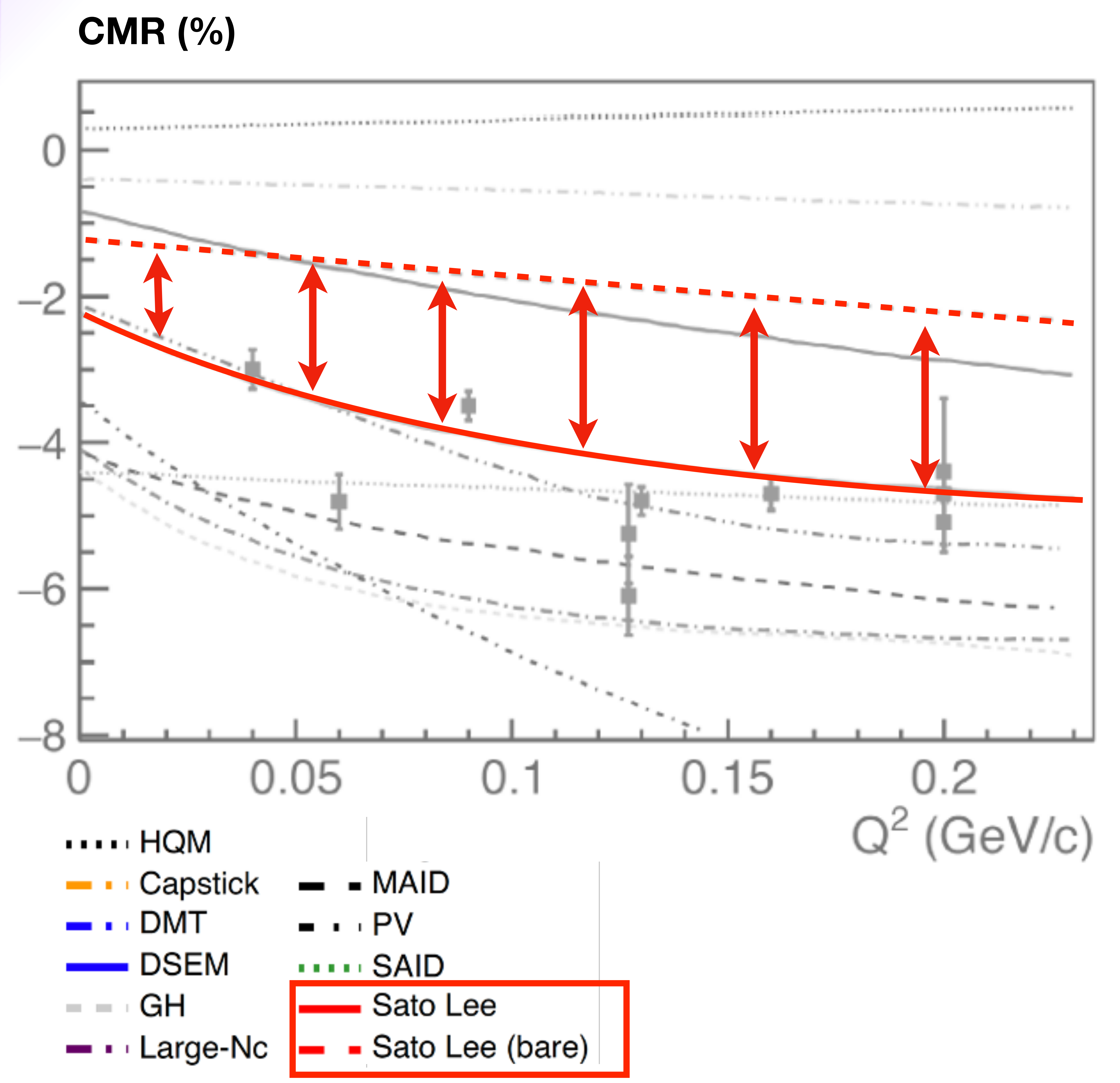
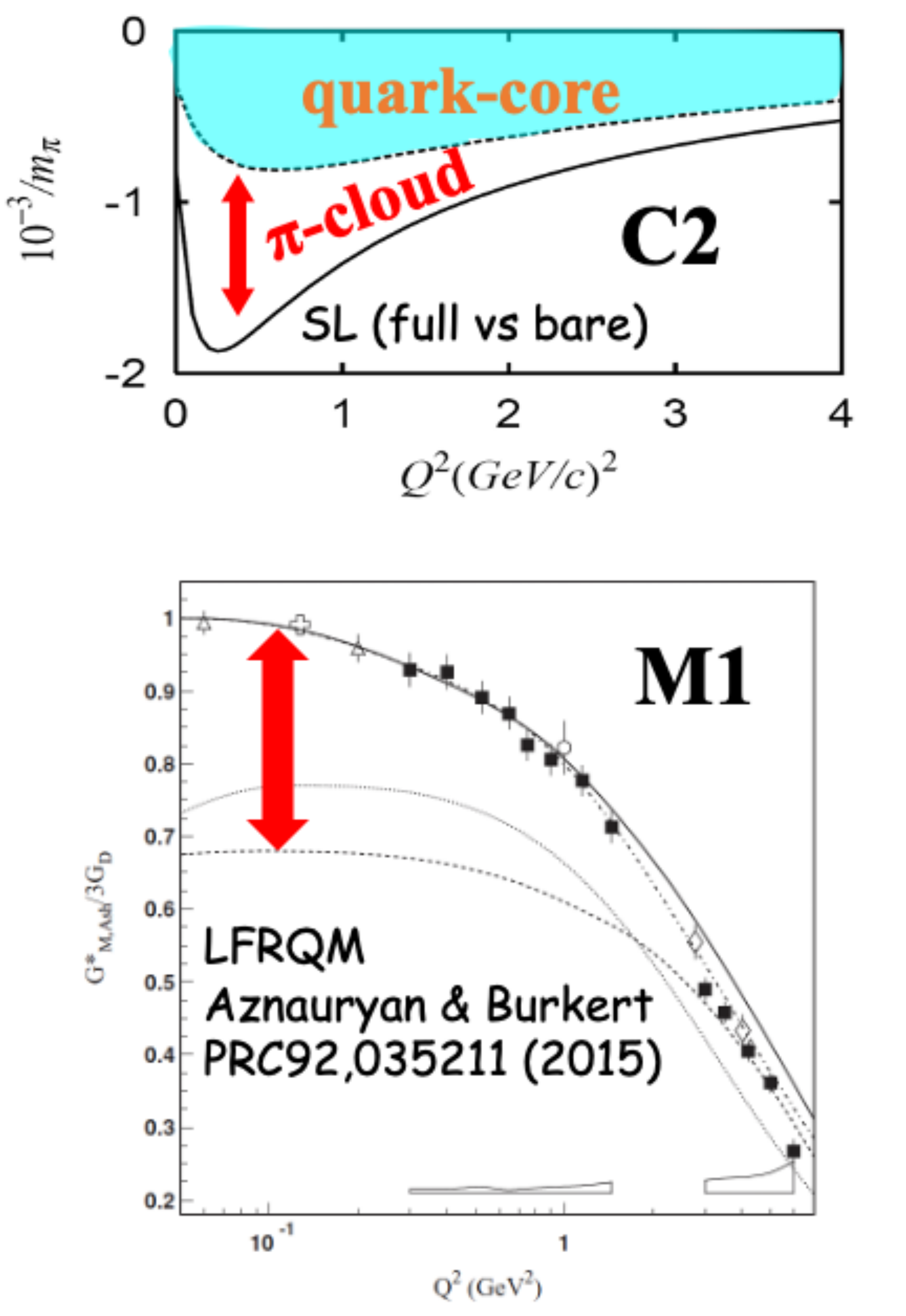


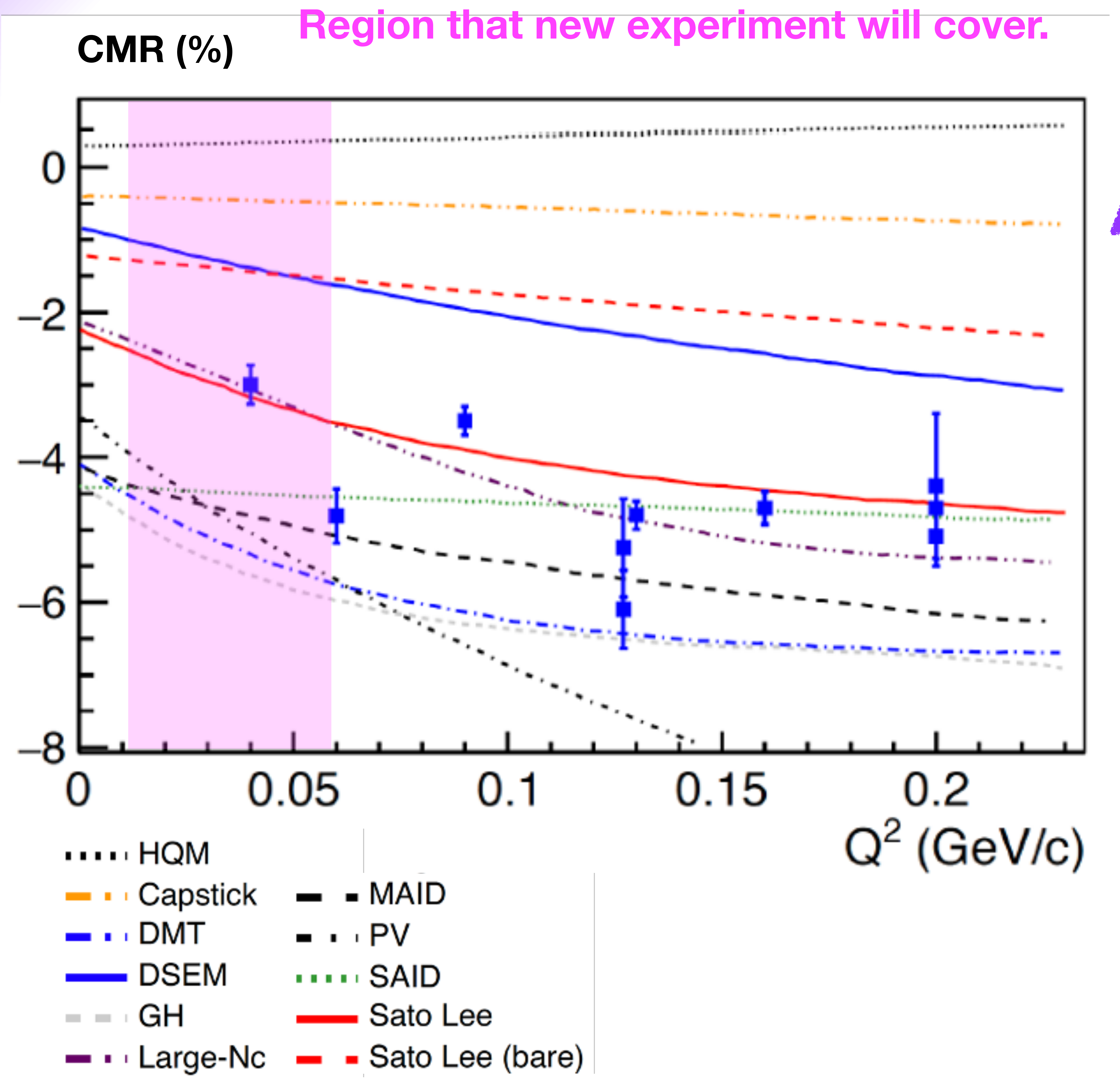


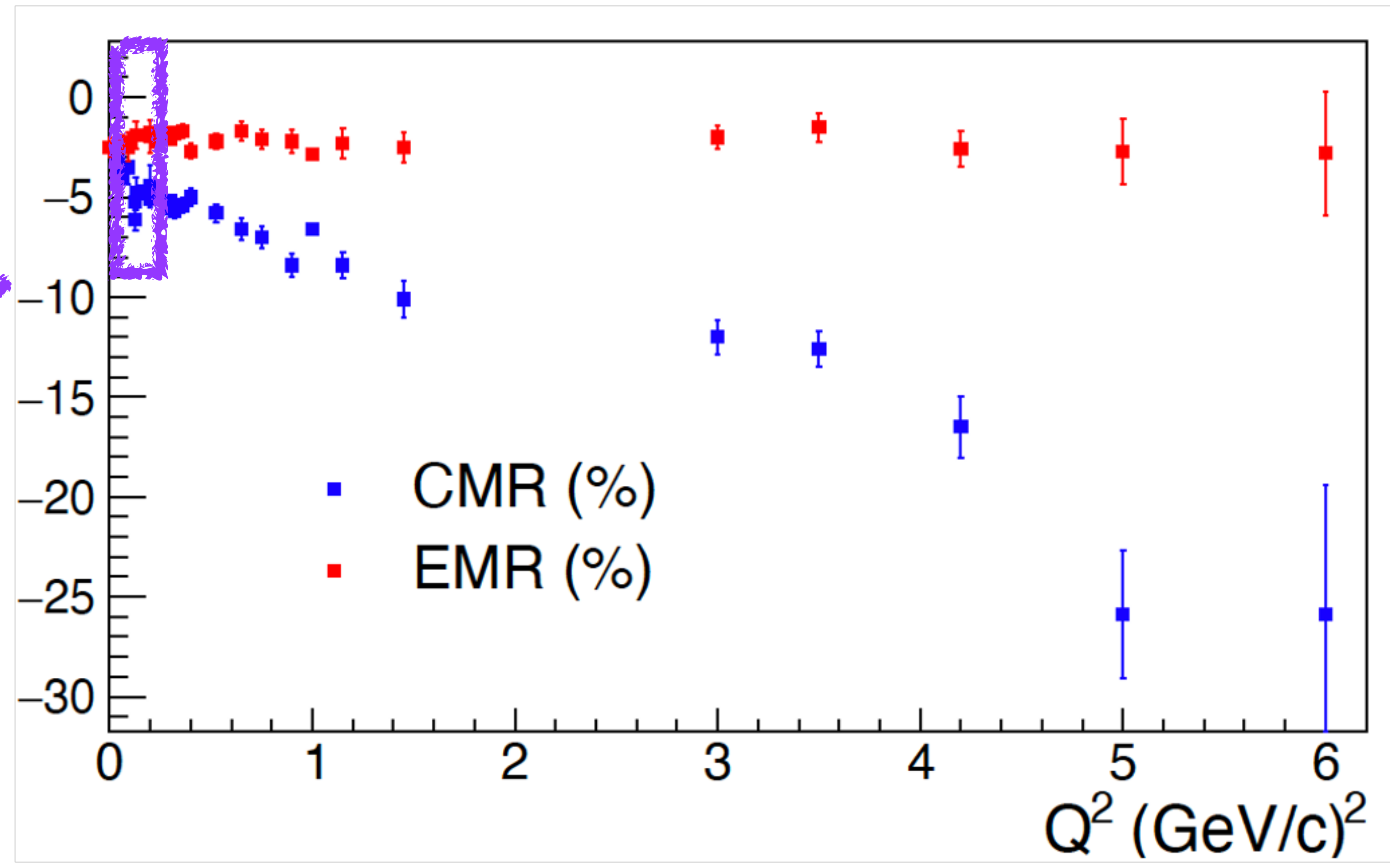
Signature of pion cloud

Dominant role of mesonic d.o.f. at large distance scale:

Mesonic cloud ~ 50% of the quadrupole amplitude magnitude & 1/3 of the magnetic dipole strength

Low Q^2 N-Δ transition form factors





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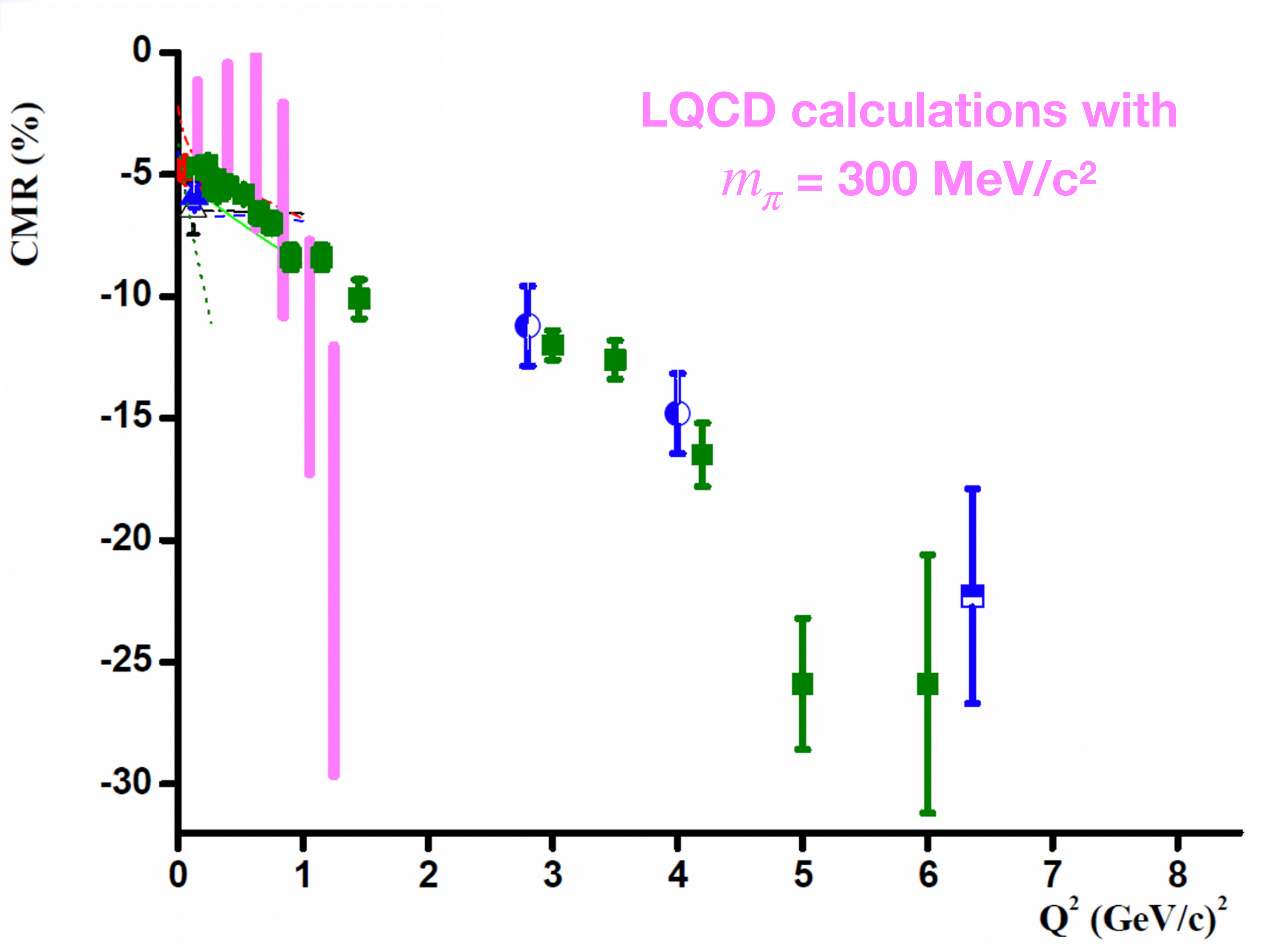
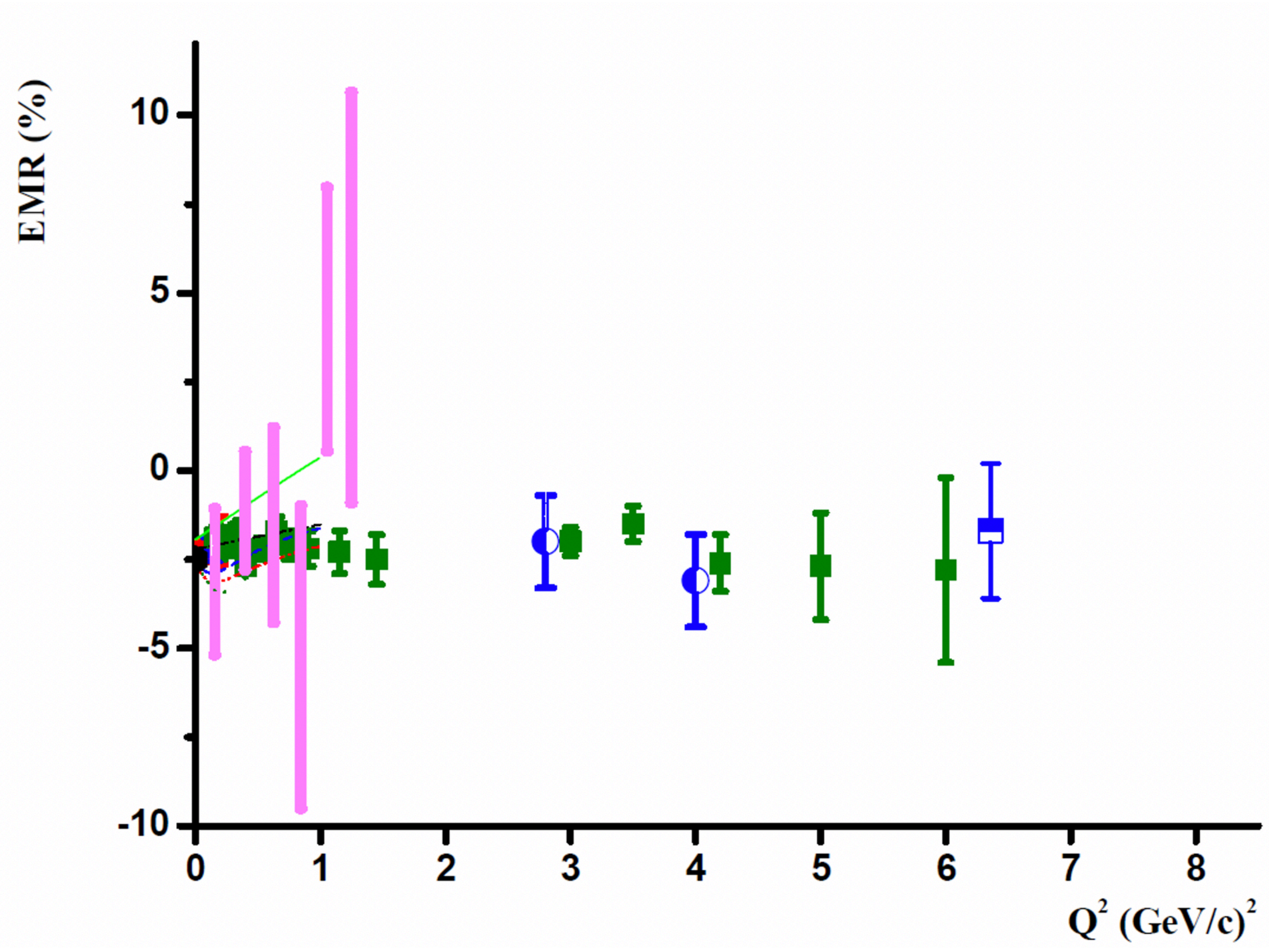
Lattice Calculations



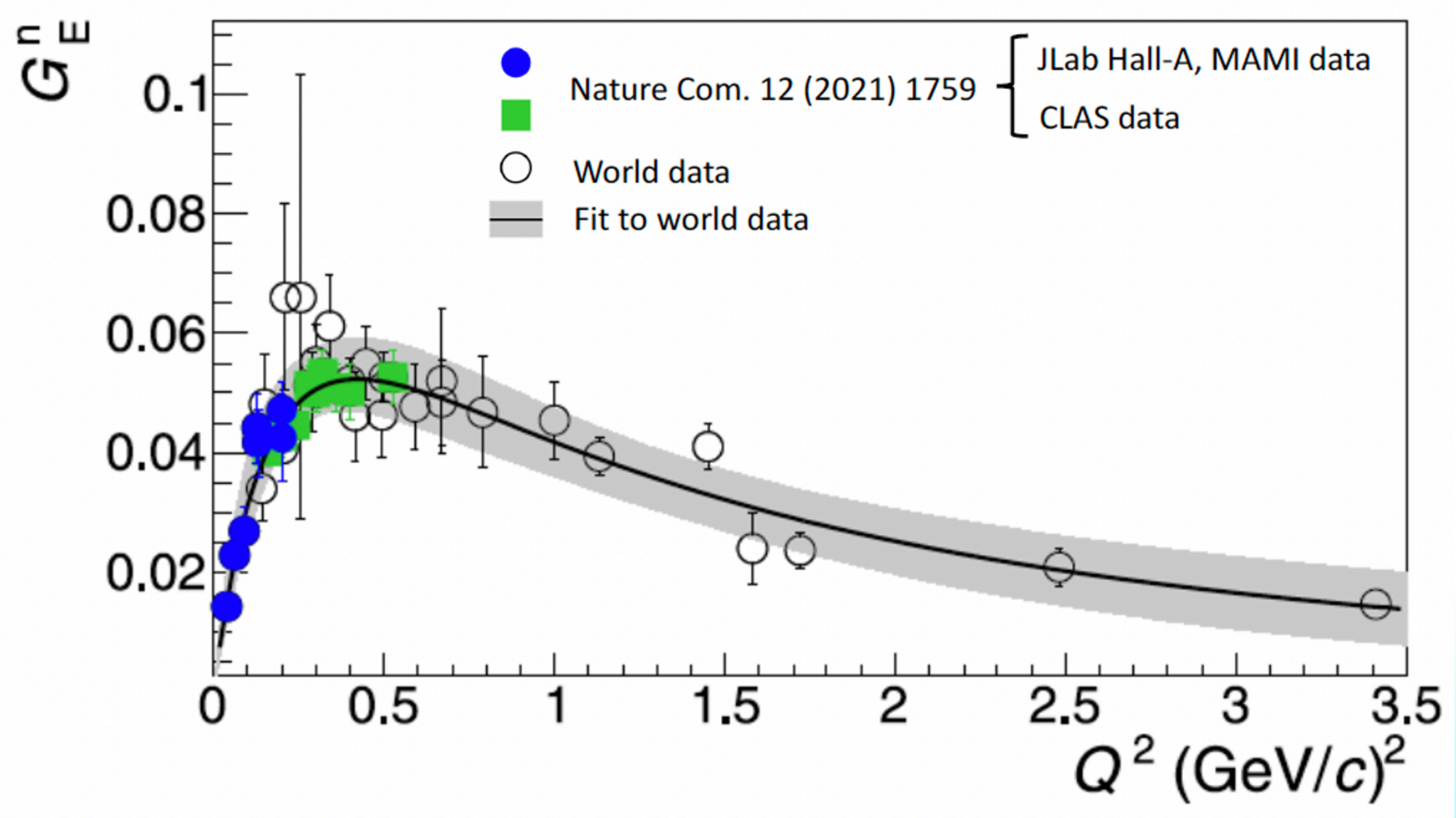


- Updated LQCD calculations are in progress → new calculations will have a physical pion mass and uncertainties comparable to experiment.
- Low Q^2 data will provide a precision benchmark for LQCD calculations.

Connections to the neutron structure

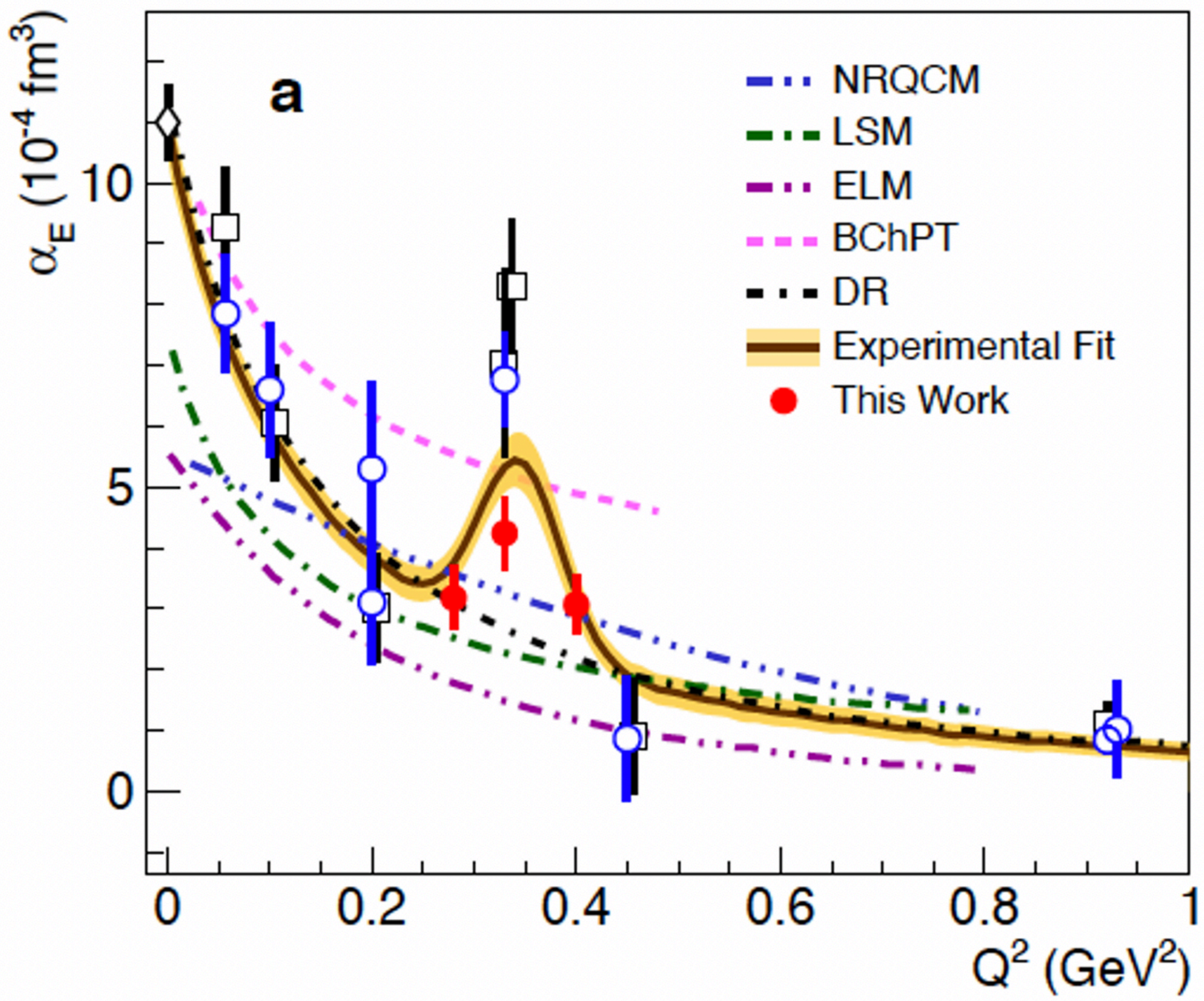
- There are long-known relations between the TFFs and the neutron FFs.
  - Pascalutsa, V. & Vanderhaeghen, M. : Phys. Rev. D 76 (2007) [Large-Nc]
  - Grabmayr, P. & Buchmann, A. J. : Phys. Rev. Lett. 86 (2001) [SU(6)]

- G_E^n extraction from TFFs show strong agreement with world data.
  - Allows access to low-Q^2 region where direct measurement of G_E^n is difficult.

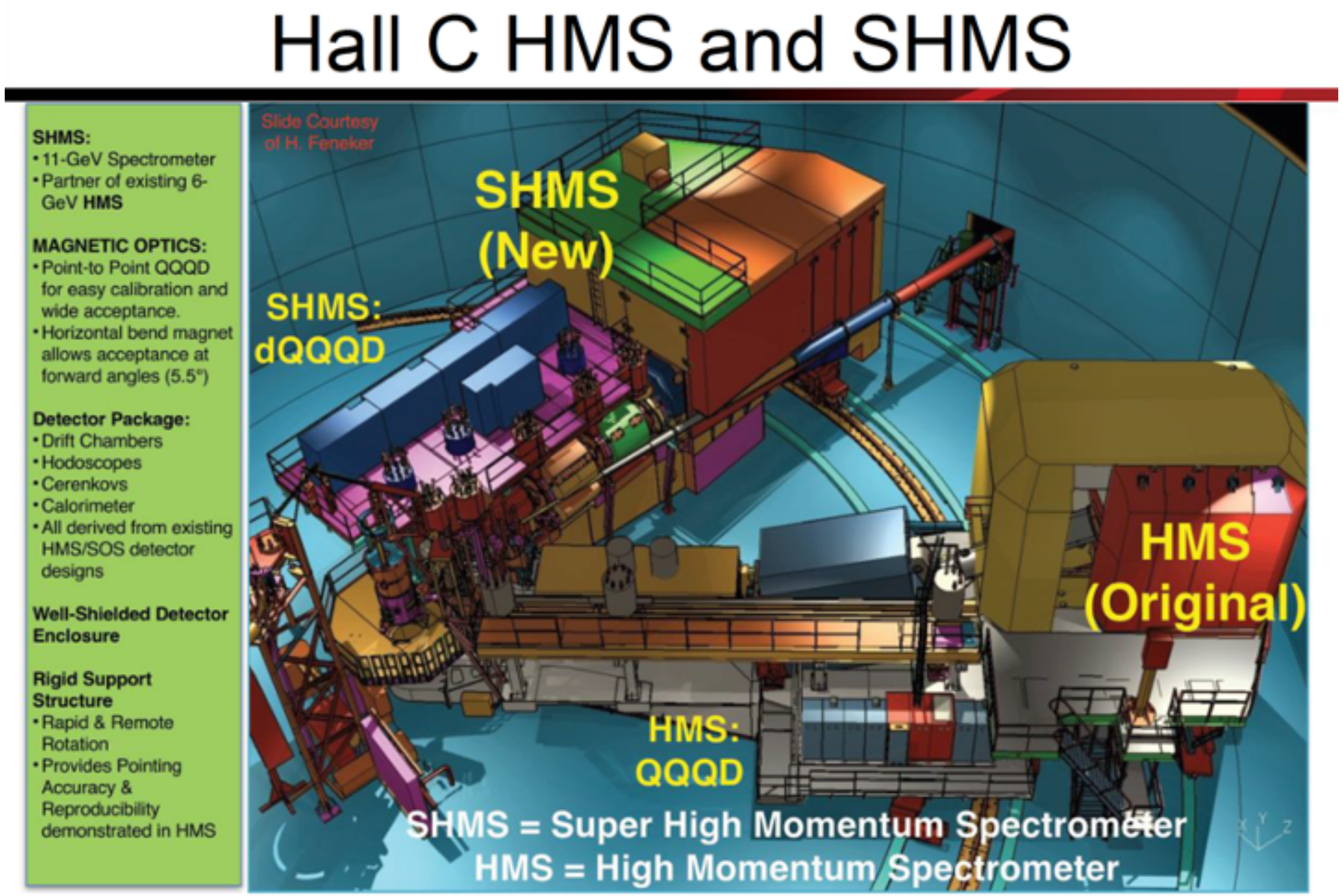


Impact on other domains of nuclear physics

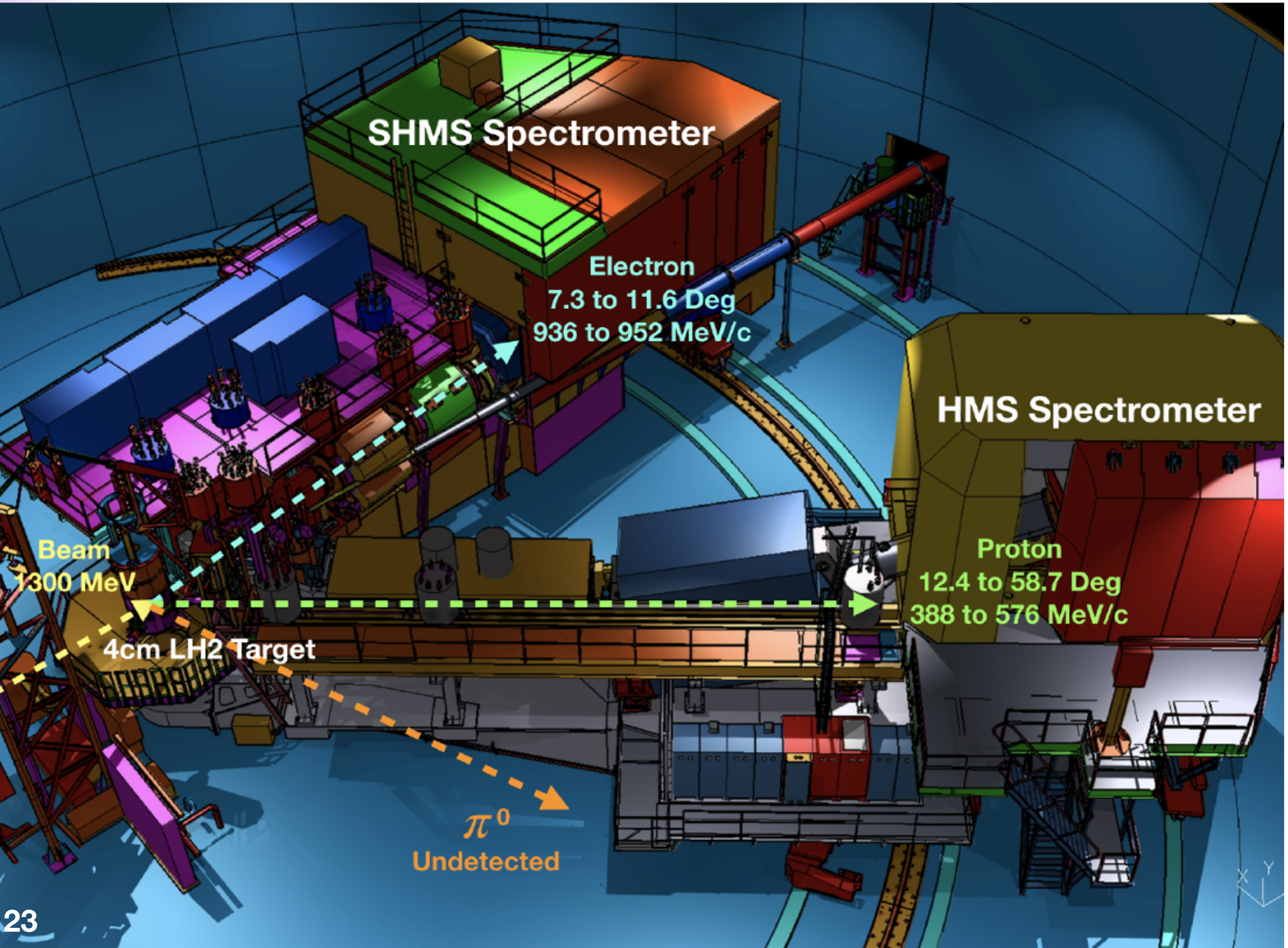
- Generalized polarizabilities (GPs) of the proton:
  - The TFFs enter as an input in the VCS cross section over the Δ resonance region – their precise knowledge is necessary for the precise extraction of the GPs from the measured cross sections
  - Physics of interest:
    - Electric polarizability puzzle
    - Interplay of paramagnetism & diamagnetism in the proton
    - Extraction of the polarizability radii and imaging of the induced polarization density.



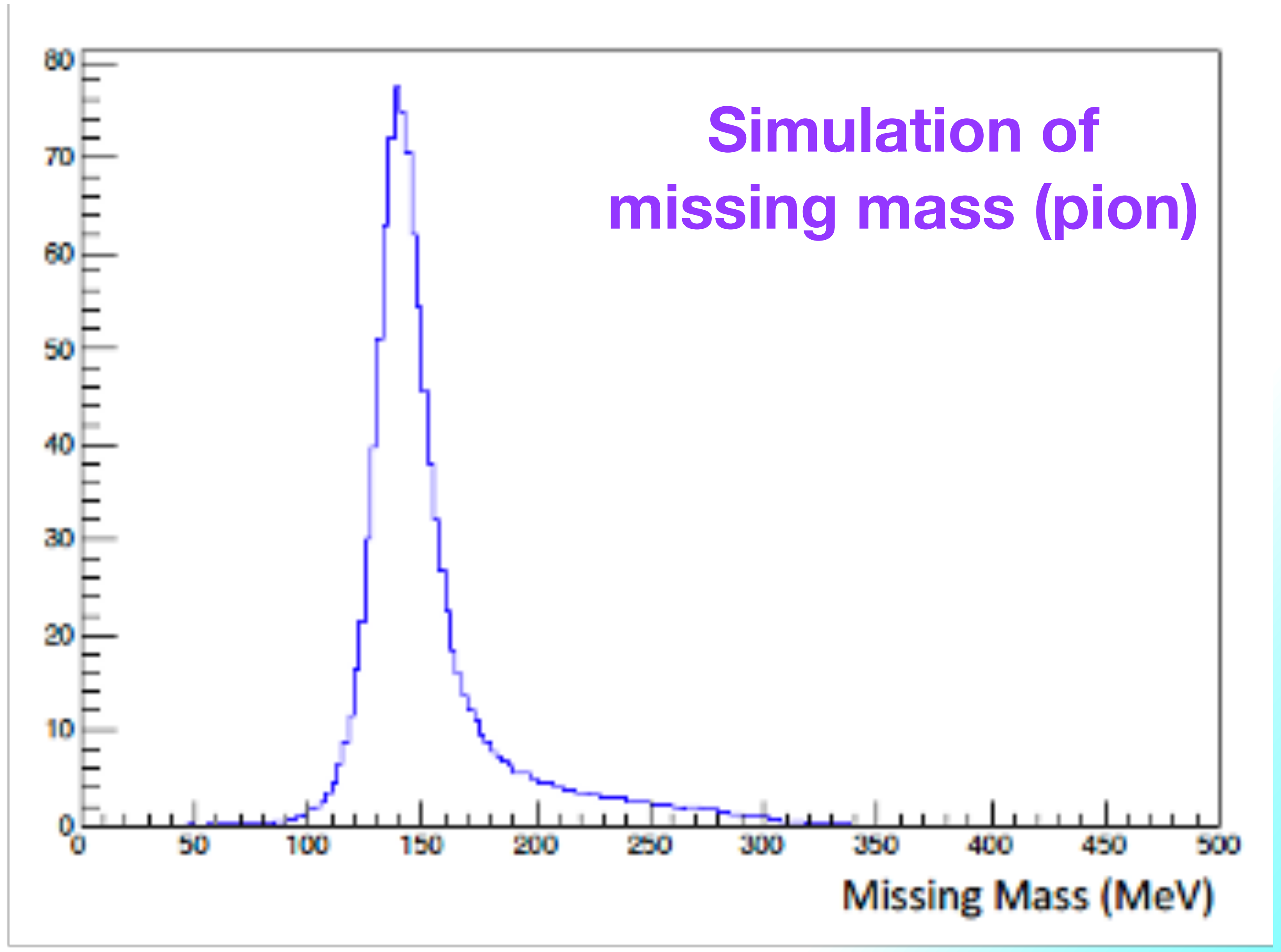
New Experiment



Experimental Setup



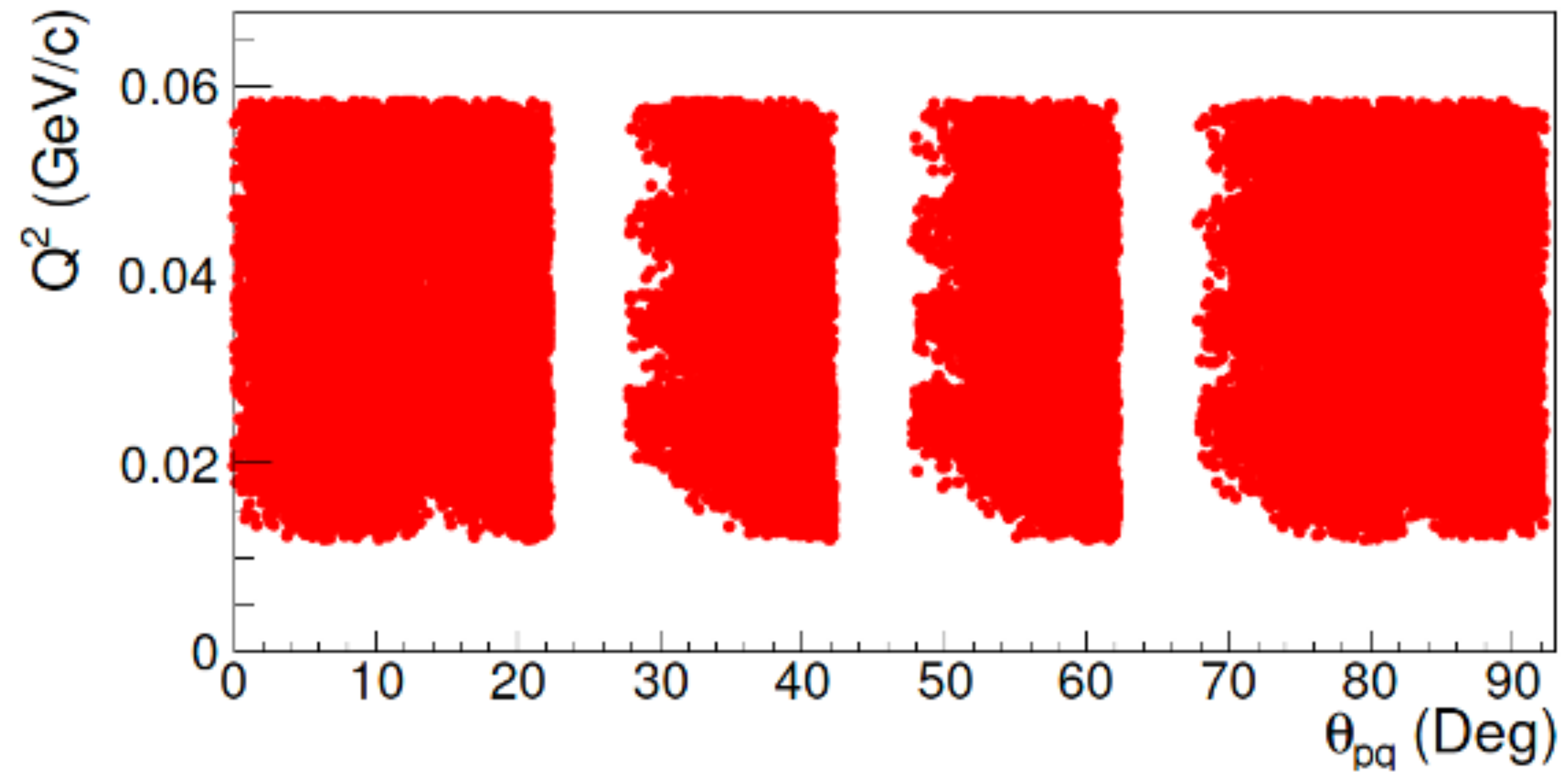
- **Standard Hall-C equipment**
  - 1300 MeV electron beam
  - Detect proton and electron in coincidence
  - Reconstruct pion from missing mass.



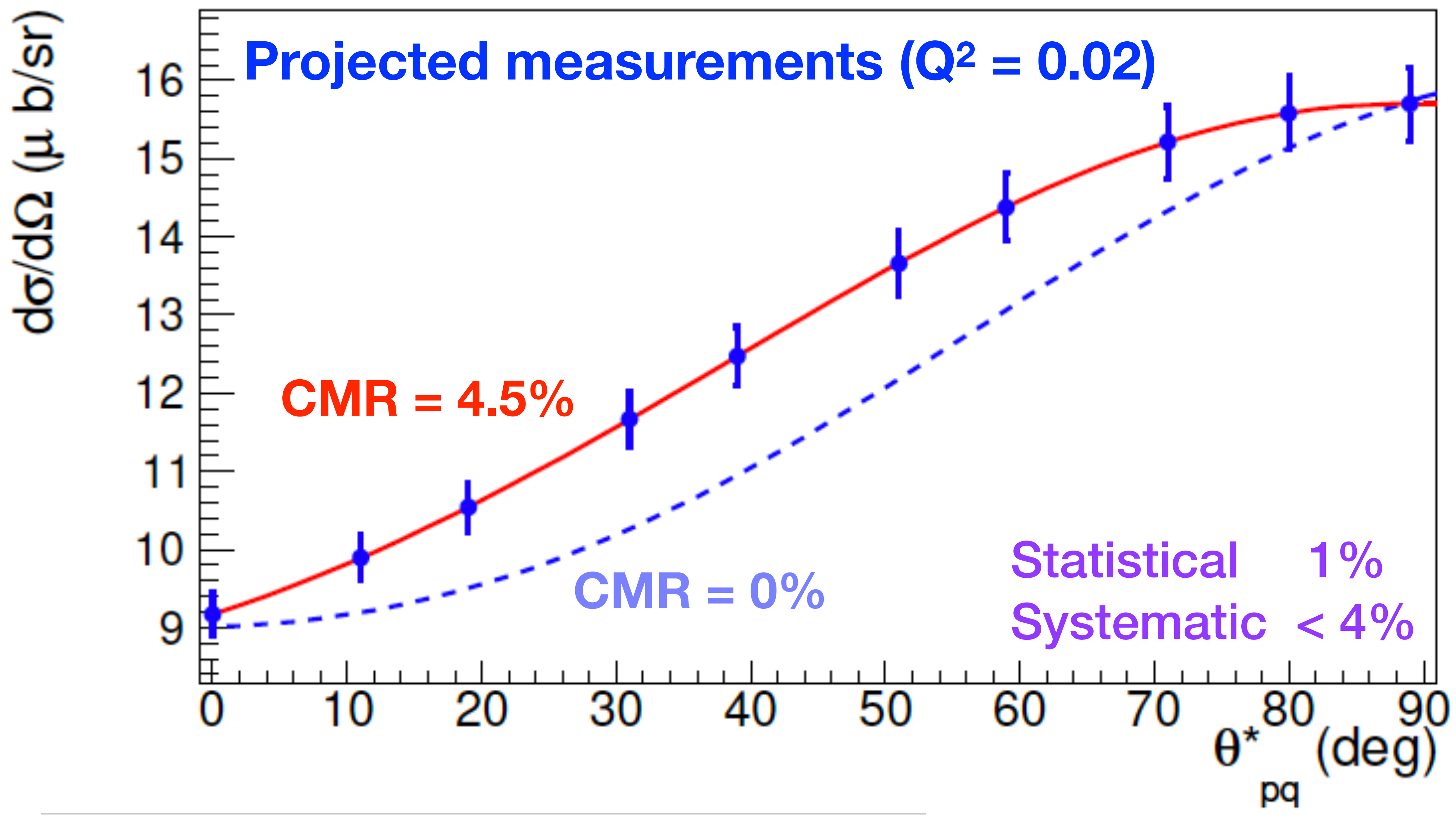
Measurement Settings

Setting	SHMS θ (deg)	SHMS P (MeV/c)	HMS θ (deg)	HMS P (MeV/c)	S/N	Time (hrs)
1a	7.29	952.26	18.77	532.53	2	7
2a			25.17	527.72	2	7
3a			33.7	506.61	3.2	6
4a			42.15	469.66	4.3	5
5a			50.44	418.56	4.9	5
6a			54.47	388.38	4.9	5
7a			12.37	527.72	2.7	6
1b	8.95	946.93	22.01	547.54	1.2	6
2b			28.24	542.61	1.4	6
3b			36.52	520.95	2.5	5
4b			44.64	483.08	3.4	4
5b			52.68	430.78	3.7	4
6b			56.53	399.92	3.5	4
7b			12.46	535.98	1.6	5
1c	10.37	941.61	24.40	562.00	1.5	9
2c			30.47	556.95	1.9	9
3c			38.52	534.79	3.5	6
4c			46.47	496.06	4.4	6
5c			54.17	442.64	4.8	6
6c			57.85	411.16	4.8	6
7c			12.69	543.24	2	6
1d	11.63	936.28	26.24	575.96	1.8	12
2d			32.16	570.80	2.5	11
3d			40.01	548.17	4.5	8
4d			47.73	508.64	5.5	8
5d			55.18	454.17	6.9	7
6d			58.71	422.13	6	8
7d			12.47	548.17	2.1	10

- **Cover a Q^2 range of 0.015 to 0.055 $(GeV/c)^2$**
  - 28 arm configurations
  - Coverage for 9 Q^2 bins.
  - 8 days production
  - 3 days other (dummy, calibration, etc..)

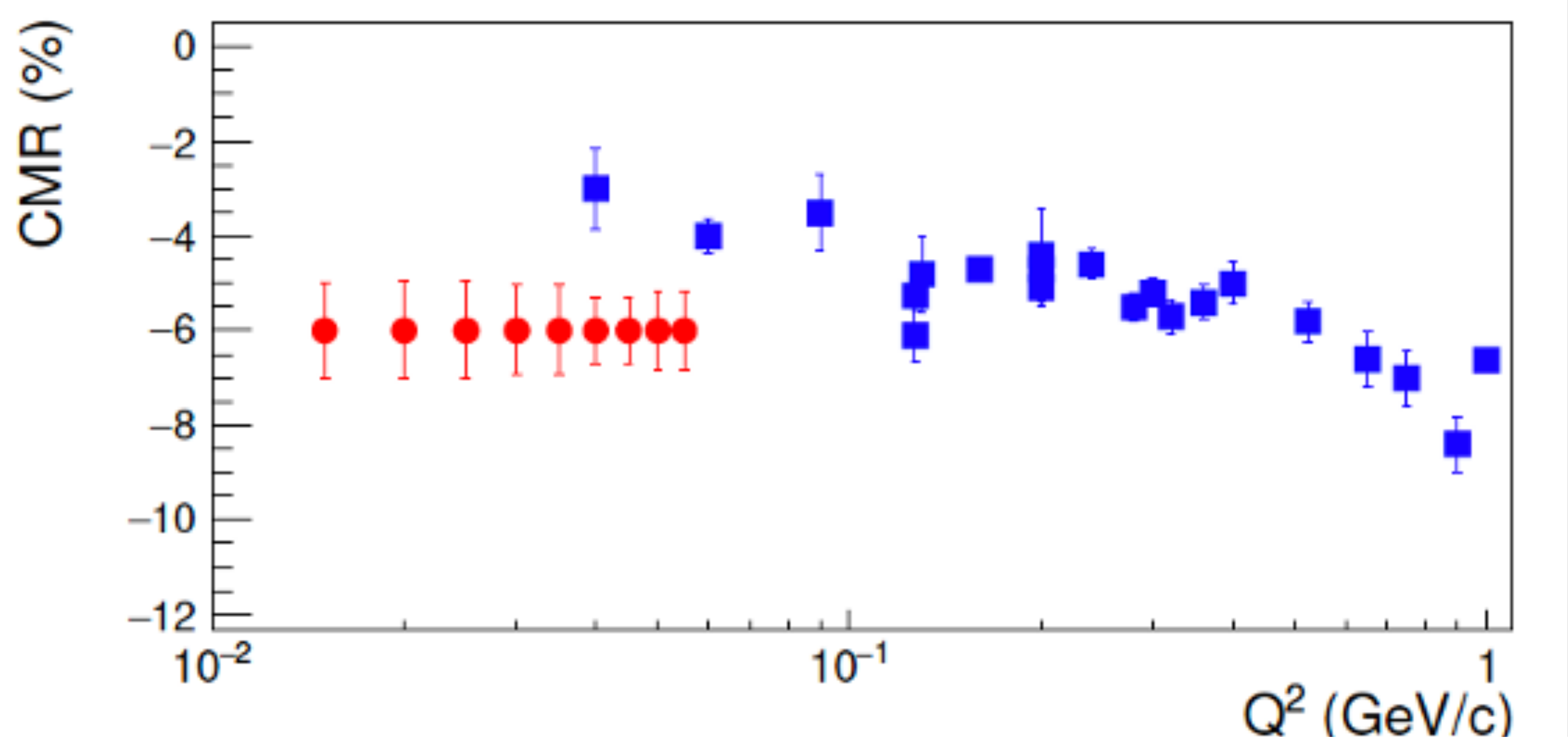


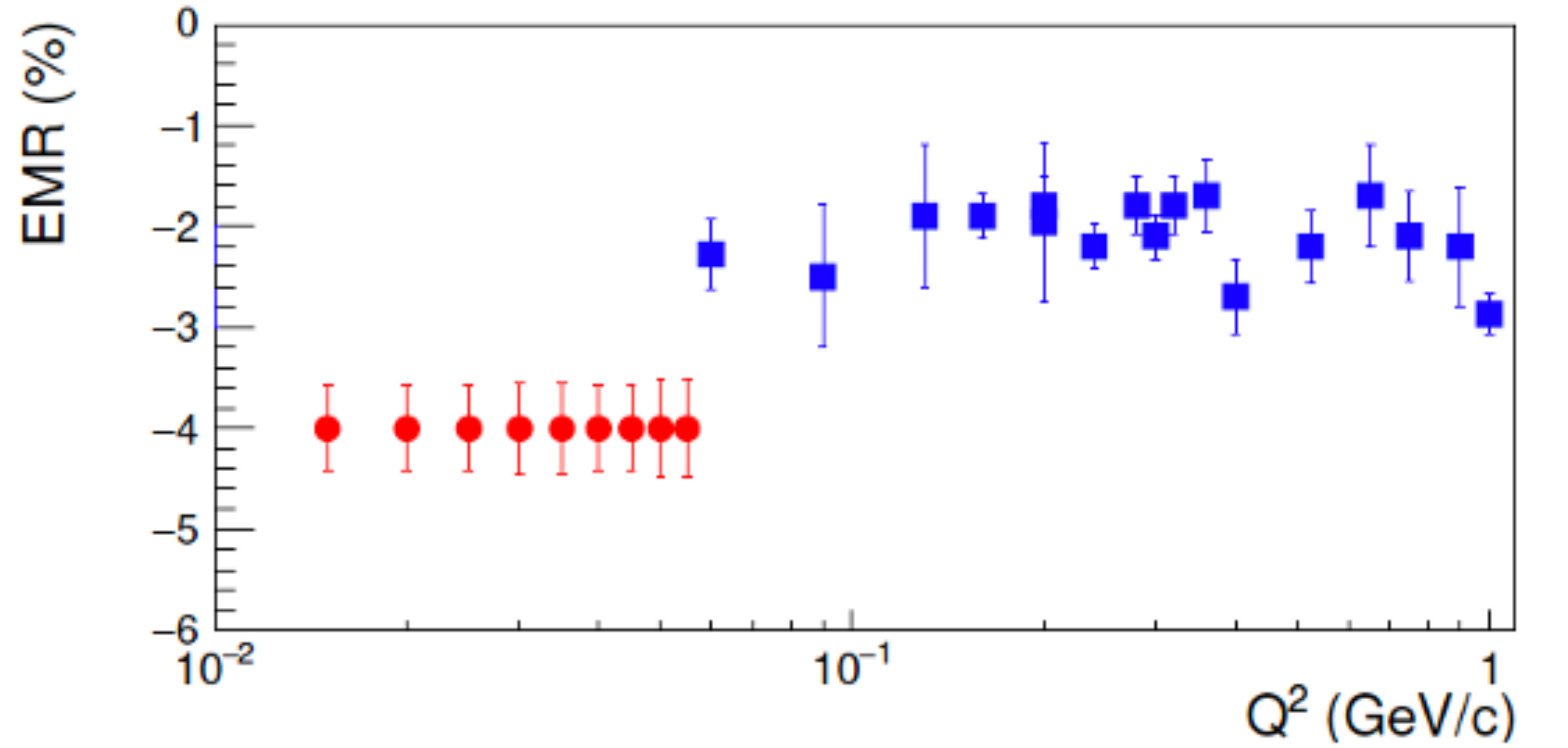
Projected CMR and EMR measurements



Resolution	2% - 3%
Acceptance	1%
Scattering angle	0.4% - 0.6%
Beam energy	0.7% - 1.2%
Beam charge	1%
Target density	0.5%
Detector efficiencies	0.5%
Target cell background	0.5%
Target length	0.5%
Dead-time corrections	0.5%
Total	2.8% - 3.8%

- High precision in very low Q^2 region that is sparsely populated
  - Region where pion-cloud effects are expected to be prominent





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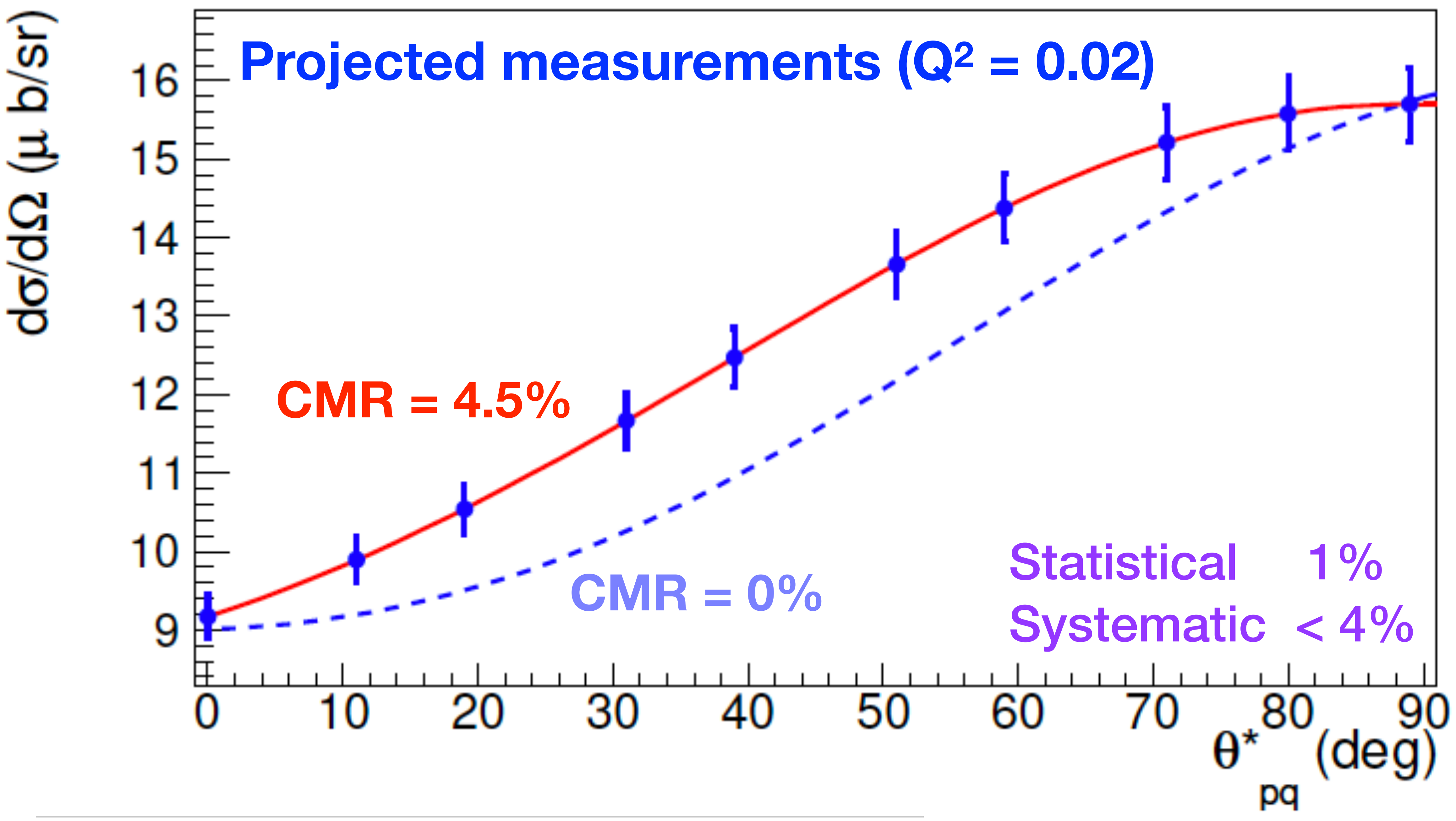

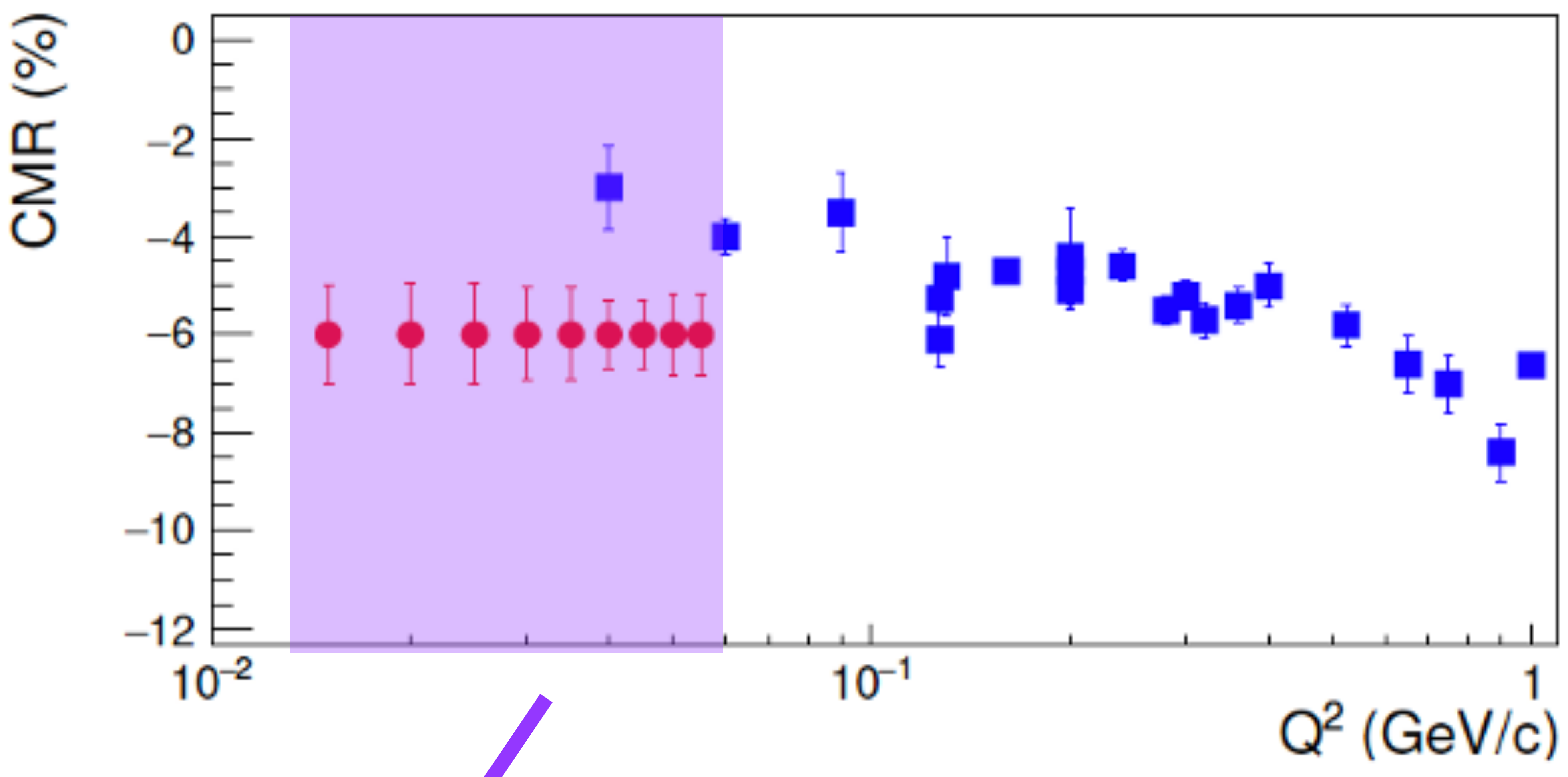

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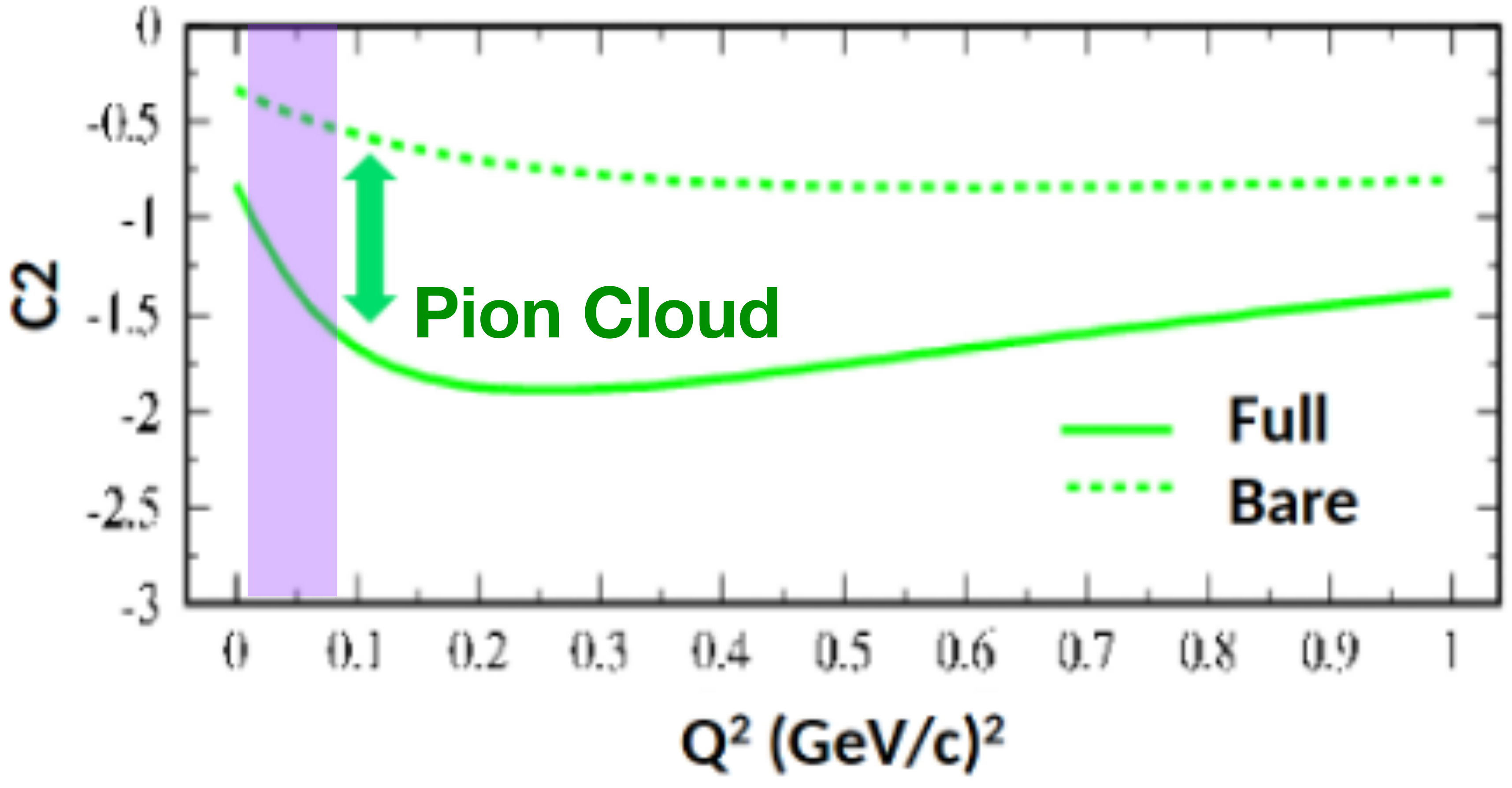
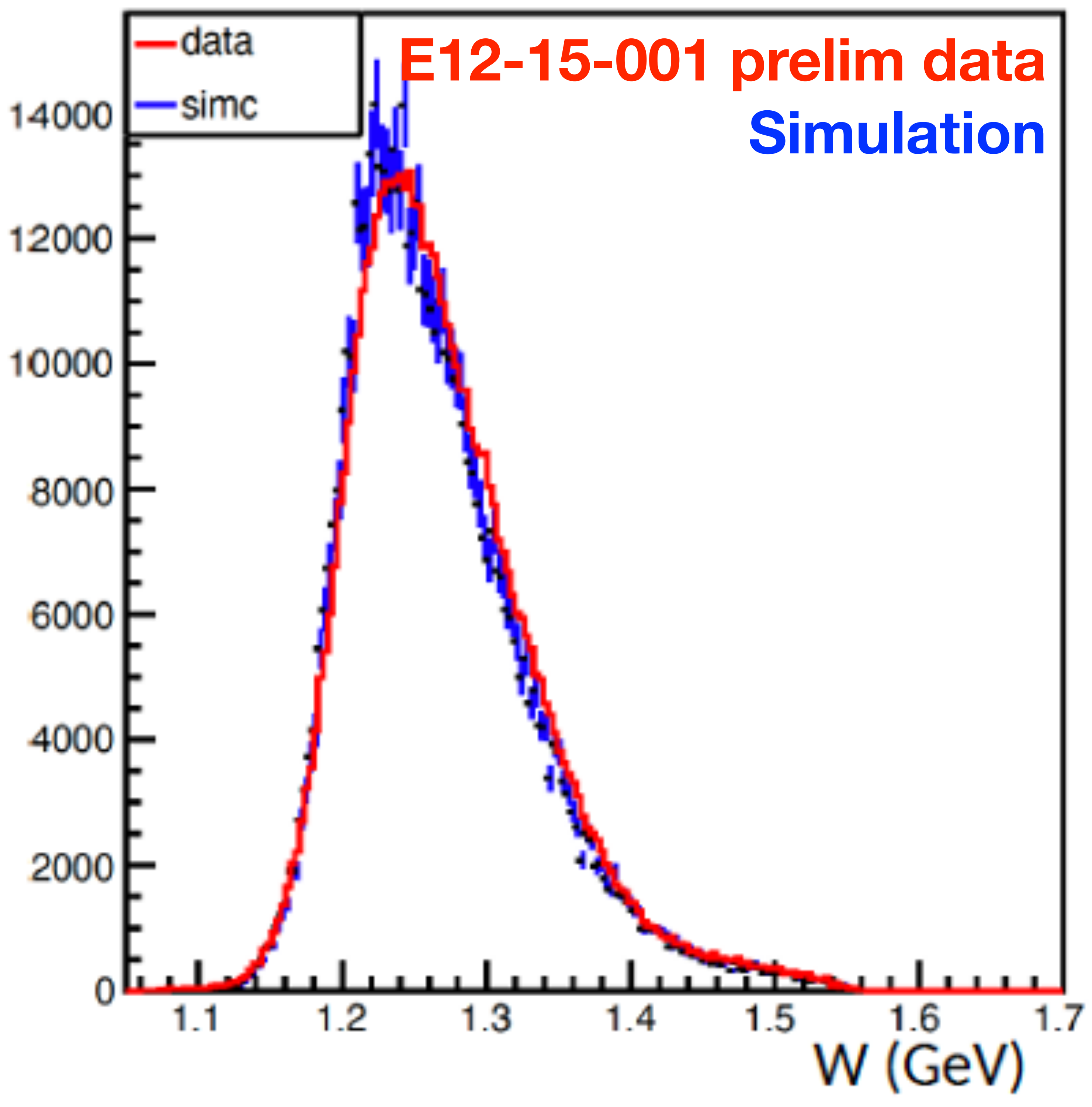


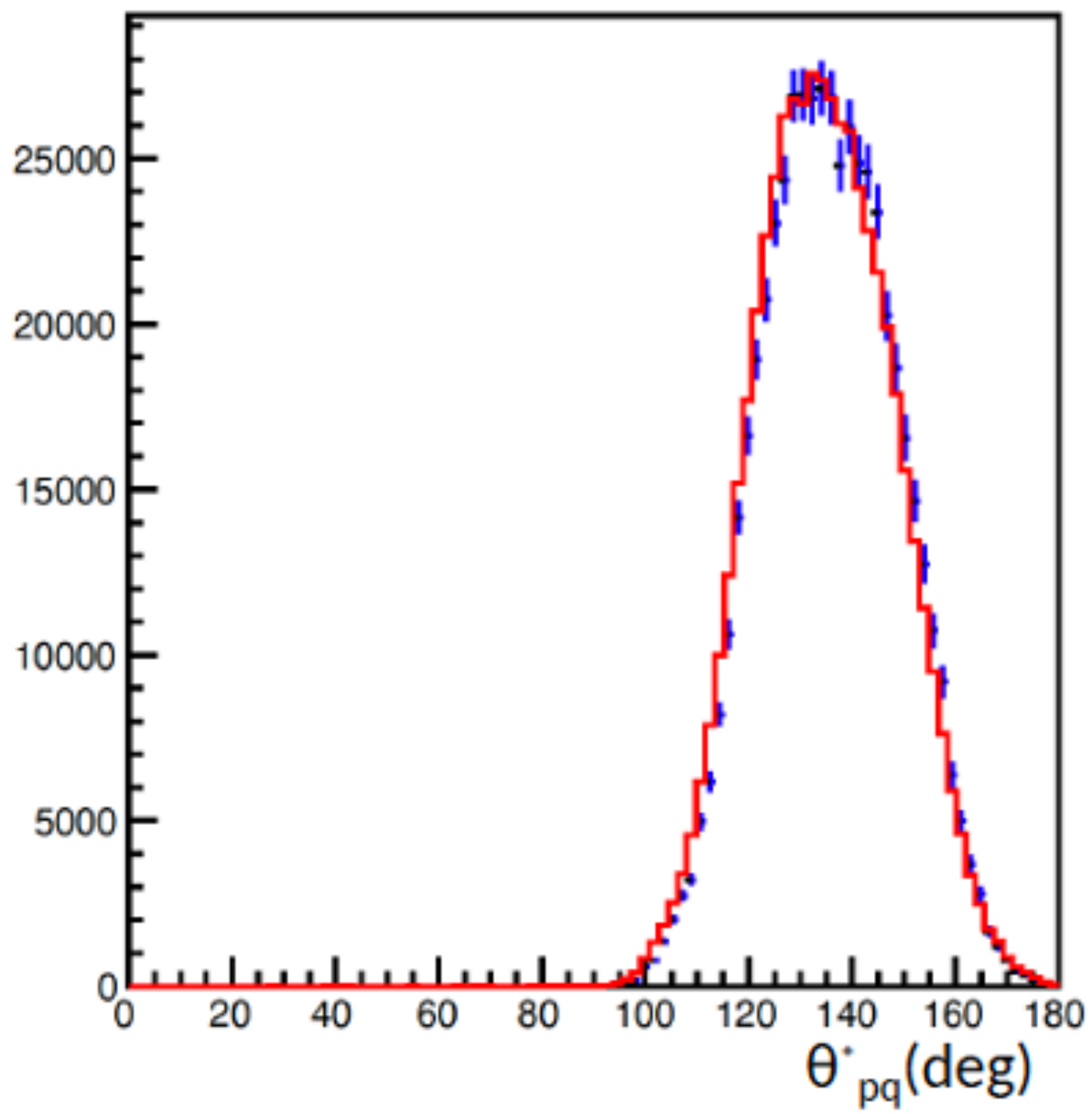
- **Experiment was approved with A- rating by PAC50**

Readiness in experimental & theoretical methodology/tools

VCS Experiment E12-15-001 ran in Hall-C (2019) with a similar set-up at Q^2 = 0.33 (GeV/c)2

Main difference with proposed experiment: Lower Q^2 -> lower beam energy and lower central momentum settings





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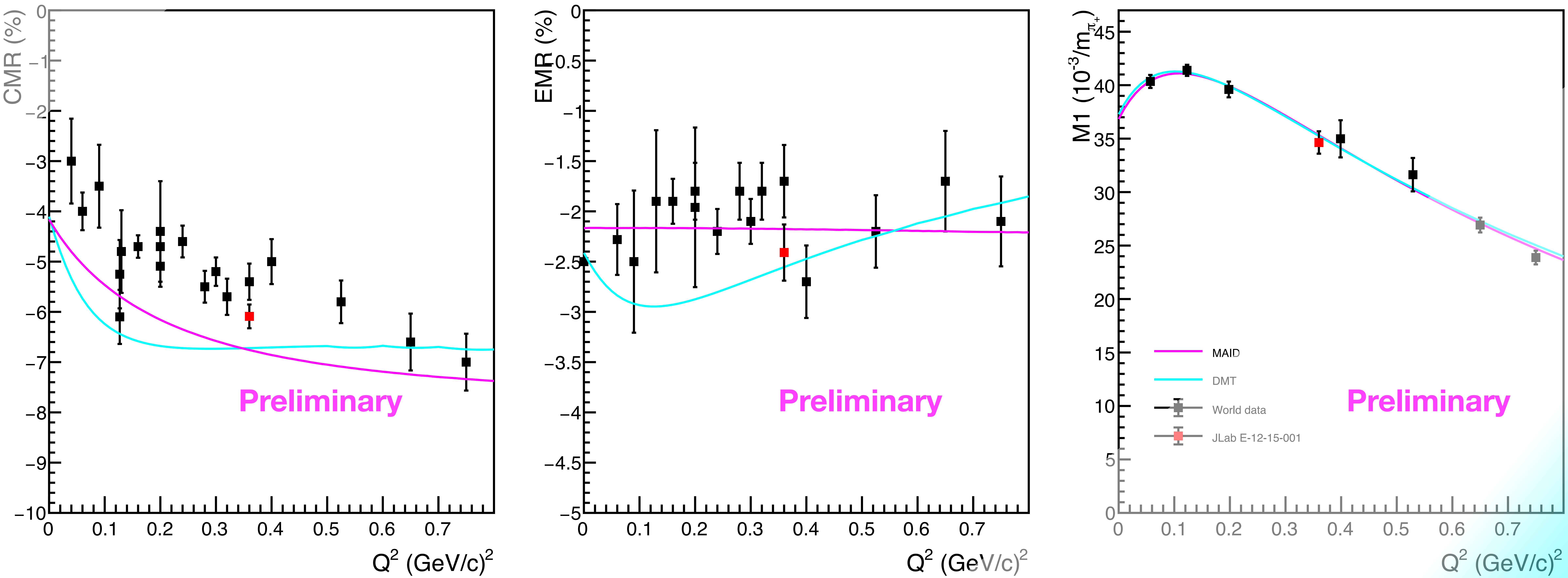
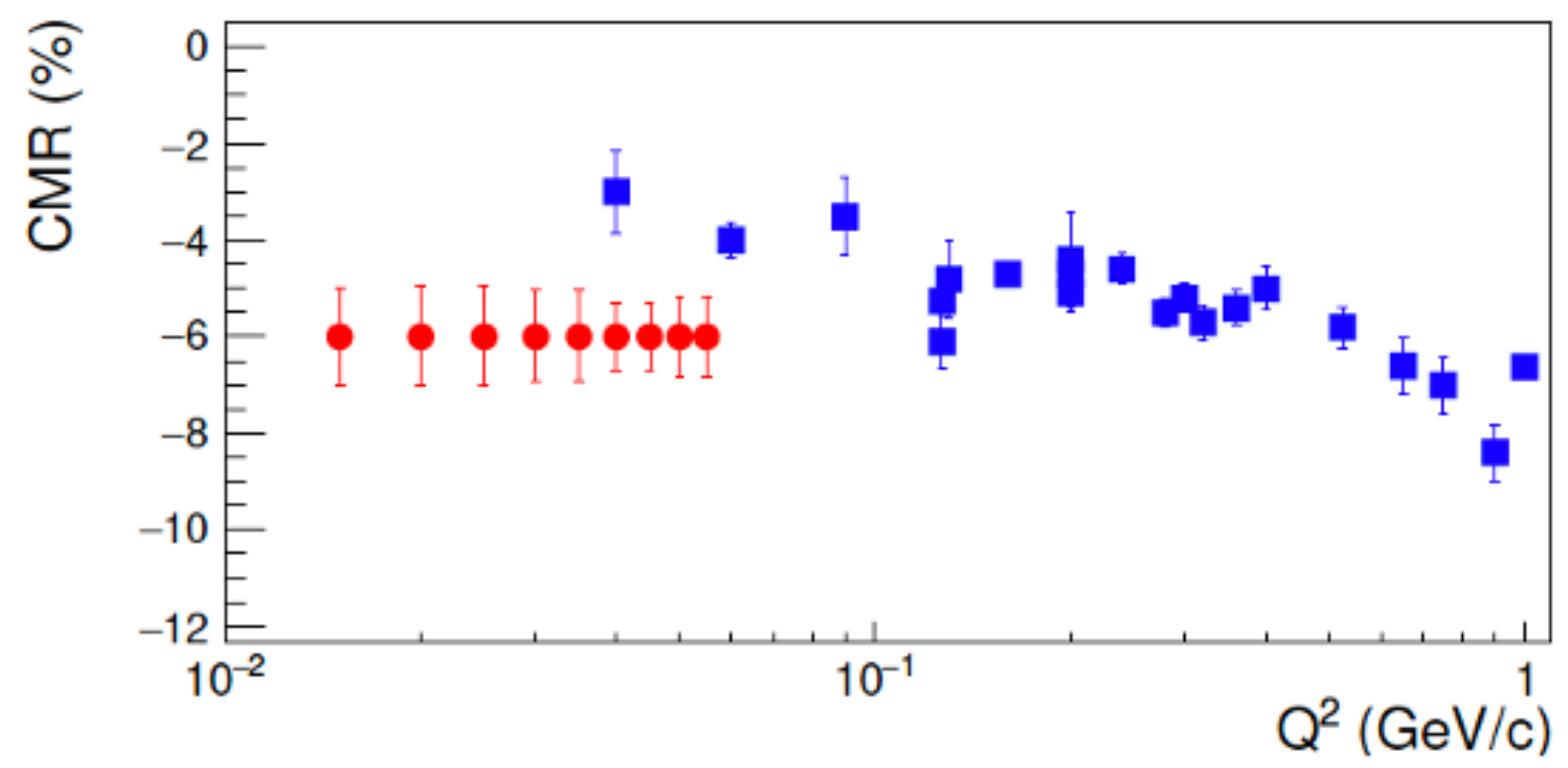


Summary

- **The N→Δ TFFs represent a central element of the nucleon dynamics**
  - We will extend these measurements in the low Q^2 region:
    - Test bed for ChEFT calculations
    - High precision benchmark data for the Lattice QCD calculations
    - New constraints and input to the theoretical models
    - Insight to the mesonic-cloud dynamics within a region where they are dominant and rapidly changing
    - Insight to the origin of non-spherical components in the nucleon wave-function
    - Will test if the QCD prediction that CMR & EMR converge as $Q^2 \to 0$
- **Experiment was approved with A- rating by PAC50**
  - 11 days (8 production, 3 calibration)
  - Beam energy: 1.3 GeV (flexible within +/- 0.1 GeV)
  - Hall C standard SHMS and HMS setup with a 4 cm LH2 target



Thank you!