Generalized Polarizabilities of the proton with Virtual Compton Scattering

Hall C experiment E12-15-001

Marie Boër, Temple University, on behalf of

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Z.E. Meziani, M. Paolone*, M. Rehfuss, N. Sparveris*, et al (*cospokesperson)

January 29, 2019 Hall C collaboration meeting

OUTLINE

1) Motivations: Generalized Polarizabilities and Virtual Compton Scattering

2) Models and interpretations

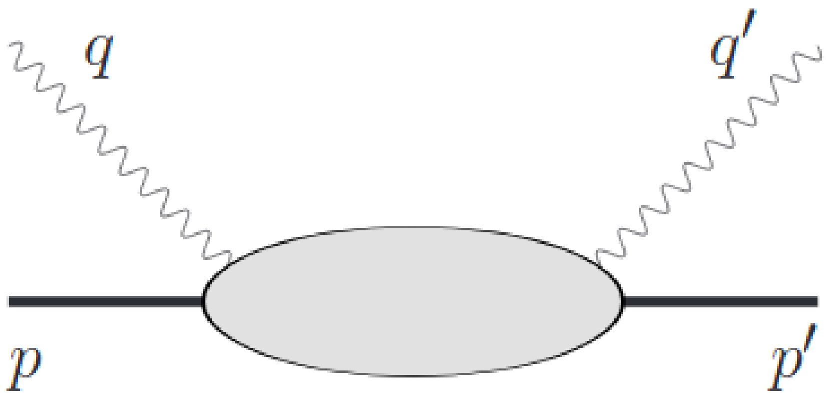
3) Hall C E12-15-001 experiment

4) Projections

Motivations

The nucleon has an internal structure

→how does it behaves under an external electromagnetic field?



general Compton scattering process

Polarizabilities, α, β accessible in Real Compton Scattering: $q^2 = q'^2 = 0$

electric: sensitive to charges in the nucleon, ability to form a dipole
→ value of α, β : rigidity of the nucleon. much smaller than nucleon dimension (strong binding)

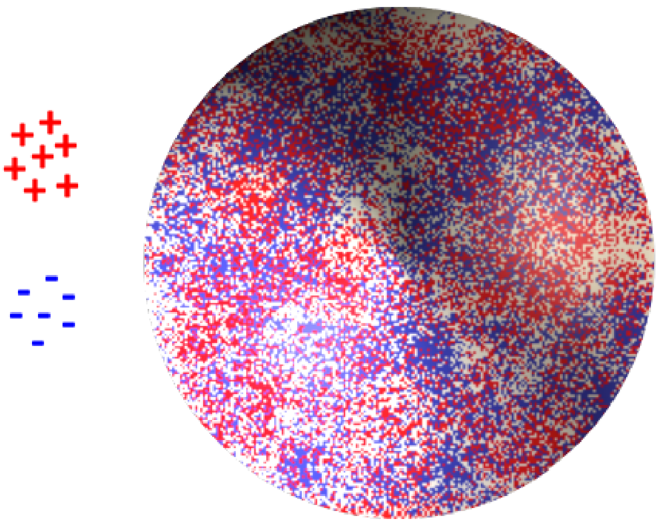
magnetic: spin response of the nucleon to a changing EM field (high beam energy)
→ value of β vs α: diamagnetic and paramagnetic relative contributions (opposite direction)

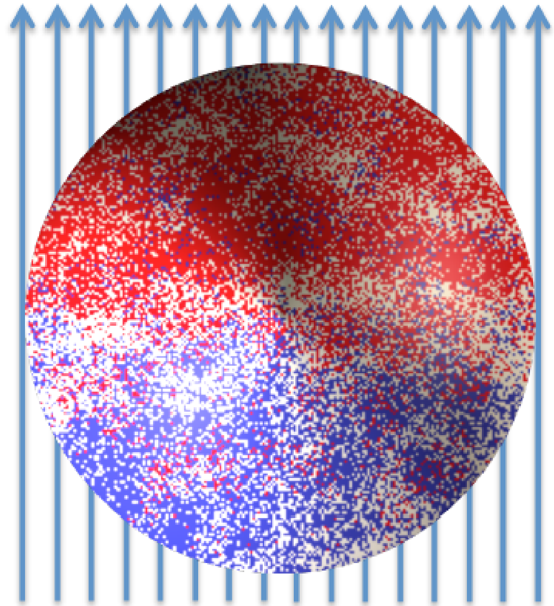
Generalized polarizabilities, accessible in Virtual Compton Scattering: $q^2 < 0$, $q'^2 = 0$

⇒ $\alpha_E(Q^2)$ and $\beta_M(Q^2)$, generalization of polarizabilities as a function of the scale Q^2
⇒ Access densities of electric charge and magnetization in the nucleon, disformed by EM field
⇒ can be related to form factors, but distortion due to EM field

Scalar Polarizablities

Response of internal structure to an applied EM field

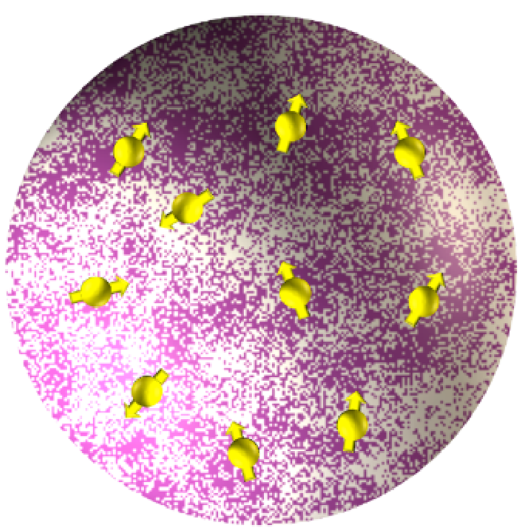


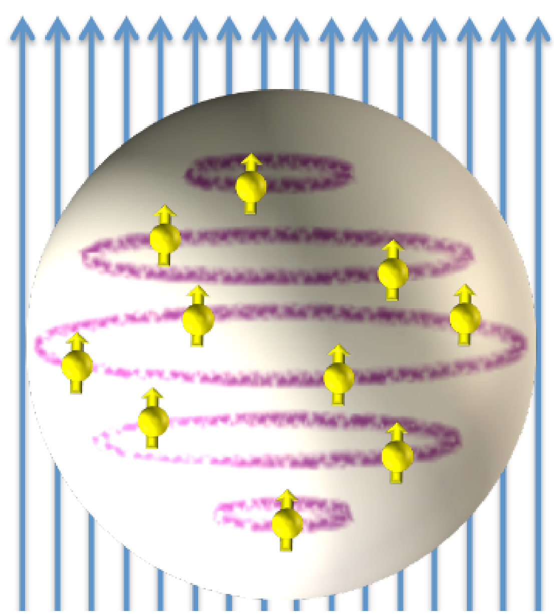


"stretchability"

$\vec{d}_{E\ \mathrm{induced}} \sim \alpha \vec{E}$

External field deforms the charge distribution





"alignability"

$\vec{d}_{M\ \mathrm{induced}} \sim \beta \vec{B}$

$\beta_{para} > 0$

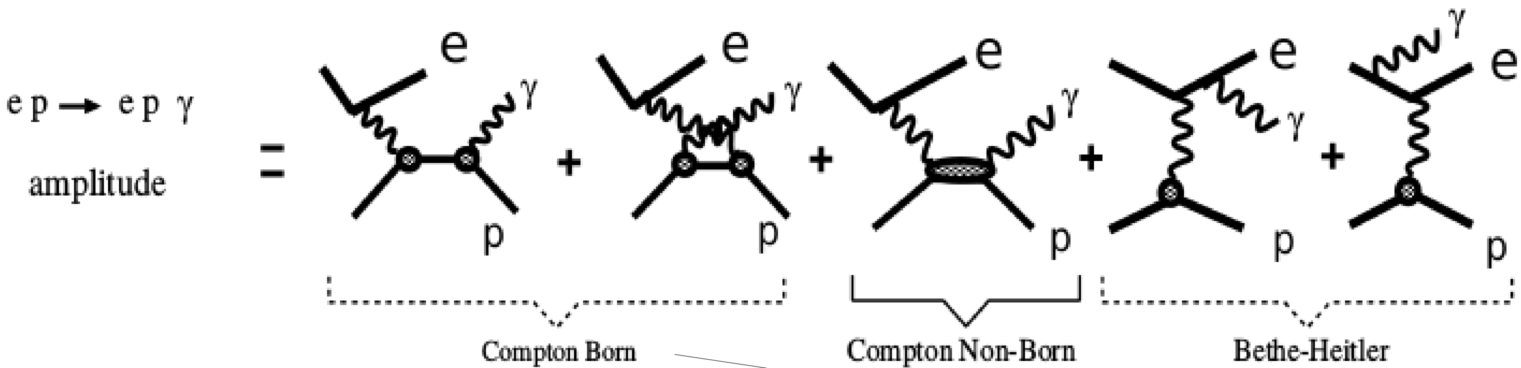
$\beta_{diam} < 0$

Paramagnetic: proton spin aligns with the external magnetic field

Diamagnetic: π-cloud induction produces field counter to the external one

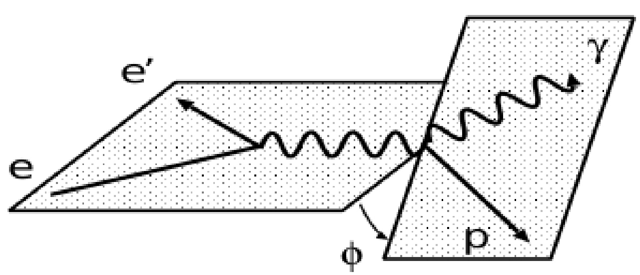
Virtual Compton Scattering and Bethe-Heitler

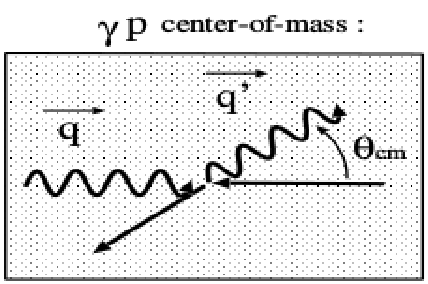
Reaction: e P → e' P' γ = Bethe-Heitler (BH) + Virtual Compton Scattering (VCS)



depend on the GPs
6 lowest order GPs: 4 with spin flip GPs,
2 non spin flip = scalar GPs → **this talk**

BH and born VCS calculable, depend on Form Factors





- unpolarized cross section depends on 4 independent variables
- depend on virtual photon polarization ε
- 2 angles: Φ, Θ_{cm} → Φ dependence on interference term allows for extracting GPs
- VCS amplitude real below π threshold, complex above (on shell resonances)

Methods to extract the scalar GPs

Measurement: unpolarized cross section,
asymmetries from cross sections at opposite angles →

$$A_{(\phi_{\gamma^*\gamma}=0,\pi)} = \frac{\sigma_{\phi_{\gamma^*\gamma}=0} - \sigma_{\phi_{\gamma^*\gamma}=180}}{\sigma_{\phi_{\gamma^*\gamma}=0} + \sigma_{\phi_{\gamma^*\gamma}=180}}$$

Model dependent extraction of the GPs: 2 approach

1) Low energy expension theorem (LEX): expension in q'.
only for real non-Born term, i.e. below π threshold

$$d^5\sigma = d^5\sigma^{BH+Born} + q'_{cm} \cdot \phi \cdot \Psi_0 + \mathcal{O}(q'^2_{cm})$$

$$\Psi_0 = v_1 \cdot (P_{LL} - \frac{1}{\epsilon} P_{TT}) + v_2 \cdot P_{LT}$$

→

$$P_{LL} = \frac{4M}{\alpha_{em}} \cdot G_E^p(Q^2) \cdot \alpha_E(Q^2)$$

$$P_{TT} = [P_{TT\ spin}]$$

$$P_{LT} = -\frac{2M}{\alpha_{em}} \sqrt{\frac{q^2_{cm}}{Q^2}} \cdot G_E^p(Q^2) \cdot \beta_M(Q^2) + [P_{LT\ spin}]$$

2) Dispersion Relations (DR)
(B. Pasquini et al approach)
valid above π threshold

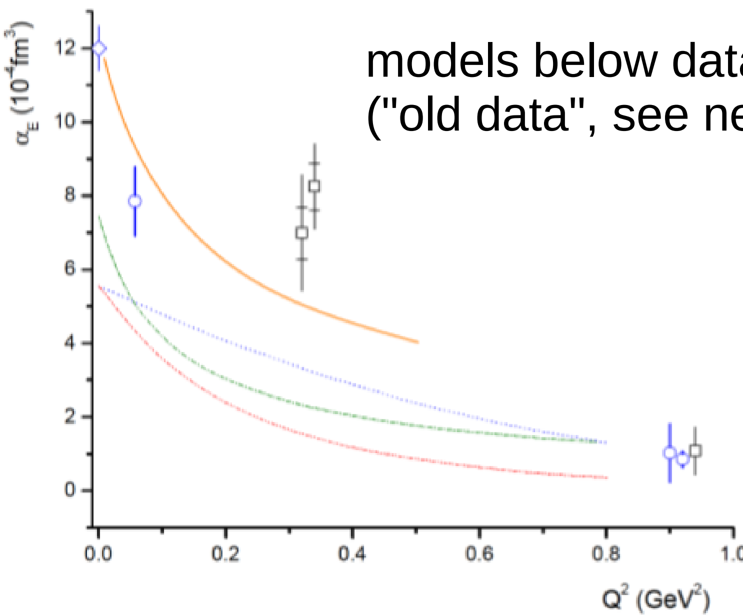
VCS: 12 invariant amplitudes, include non-Born terms
amplitudes and GPs parametrized by fit of cross sections vs q²

For this experiment: DR method only, above threshold. LEX not valid

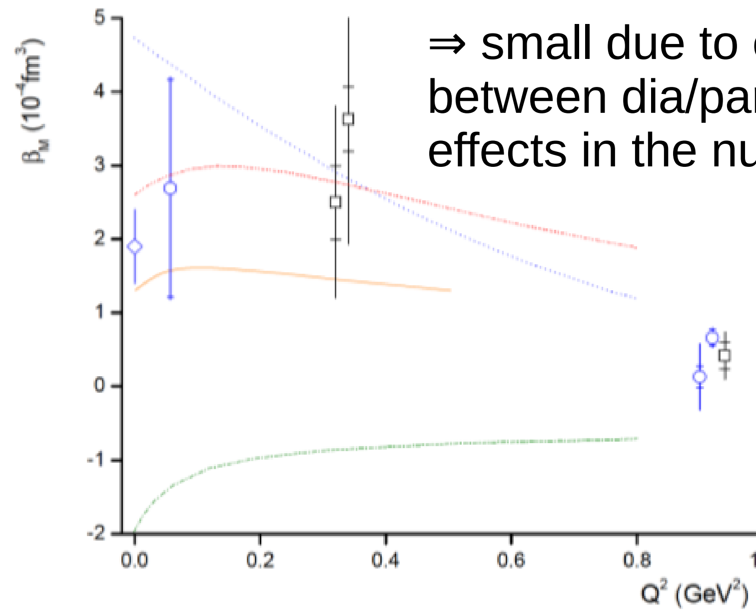
Models projections

HBChPT
NRQCM
Effective Lagrangian Model
Linear Sigma Model

T.R. Hemmert et al	Phys. Rev. D 62, 014013 (2000)
B. Pasquini et al	Phys. Rev. C 63, 025205 (2001)
A. Yu. Korchin and O. Scholten	Phys. Rev. C 58, 1098 (1998)
A. Metz and D. Drechsel	Z. Phys. A 356, 351 (1996)



models below data
("old data", see next slide)



⇒ small due to competition between dia/para-magnetic effects in the nucleon

All theoretical calculations predict a smooth fall off for α_E

None of the models can account for the non trivial structure of α_E suggested by the data

→ it is why there is need of new measurements

Lattice QCD

Currently: $Q^2=0$ calculations exist but at unphysical quark masses

Near Future: calculations at the physical point for $Q^2=0$
first calculations for $Q^2\neq0$

Spatial dependence of induced polarizations in an external EM field

Nucleon form factor data ➔ light-front quark charge densities

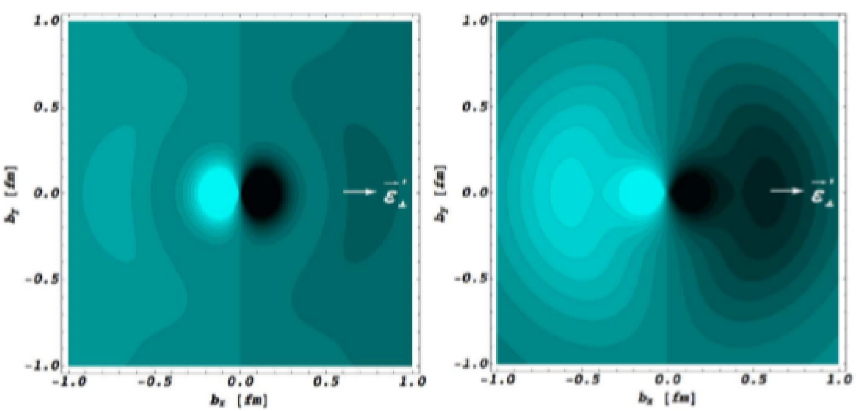
Formalism extended to the deformation of these quark densities when applying an external e.m. field:

GPs ➔ spatial deformation of charge & magnetization densities under an applied e.m. field

Induced polarization in a proton when submitted to an e.m. field

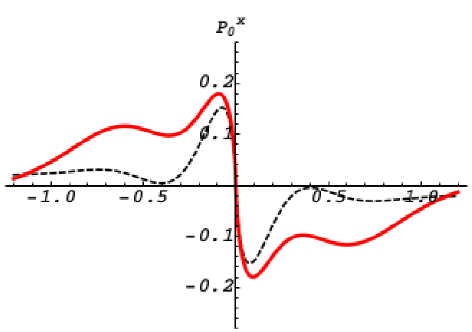
impact parameter representation = FT of GP

GP I GP II



Light (**dark**) regions ➔ **largest** (**smaller**) values

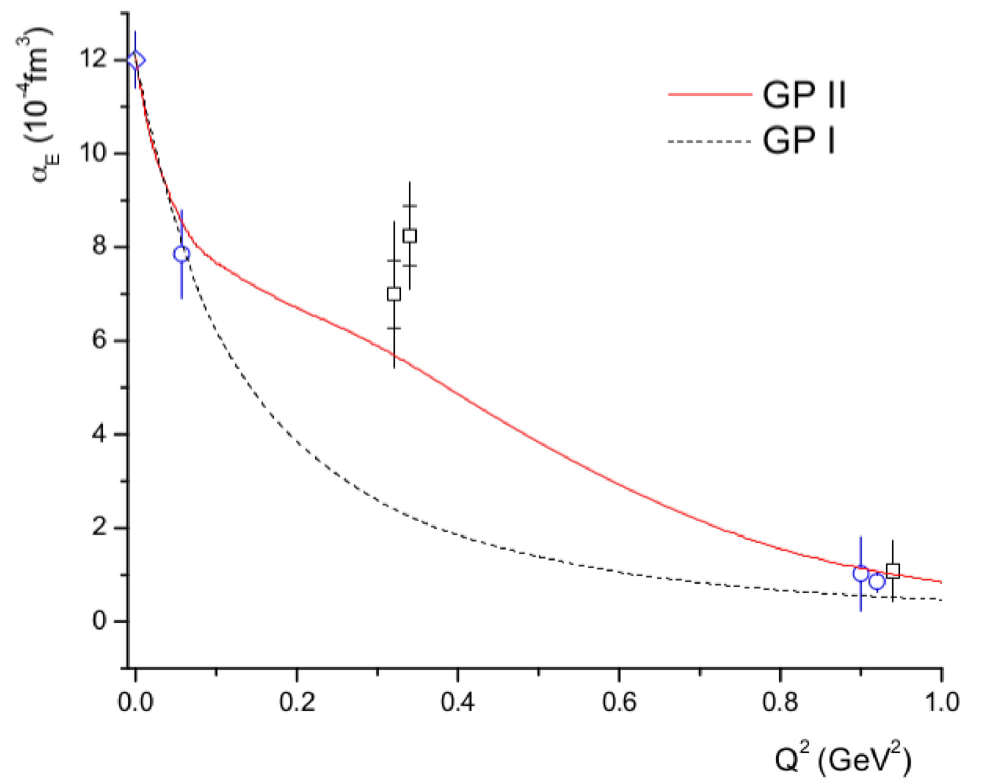
x-axis, as indicated)



Induced polarization along b_y=0

Phys. Rev. Lett. 104, 112001 (2010)

M. Gorchtein, C. Lorce, B. Pasquini, M. Vanderhaeghen



Recent measurements in the world

measurements for α_E:

⇒ MAMI, A1/1-09, Fonvielle et al. Below and above π threshold

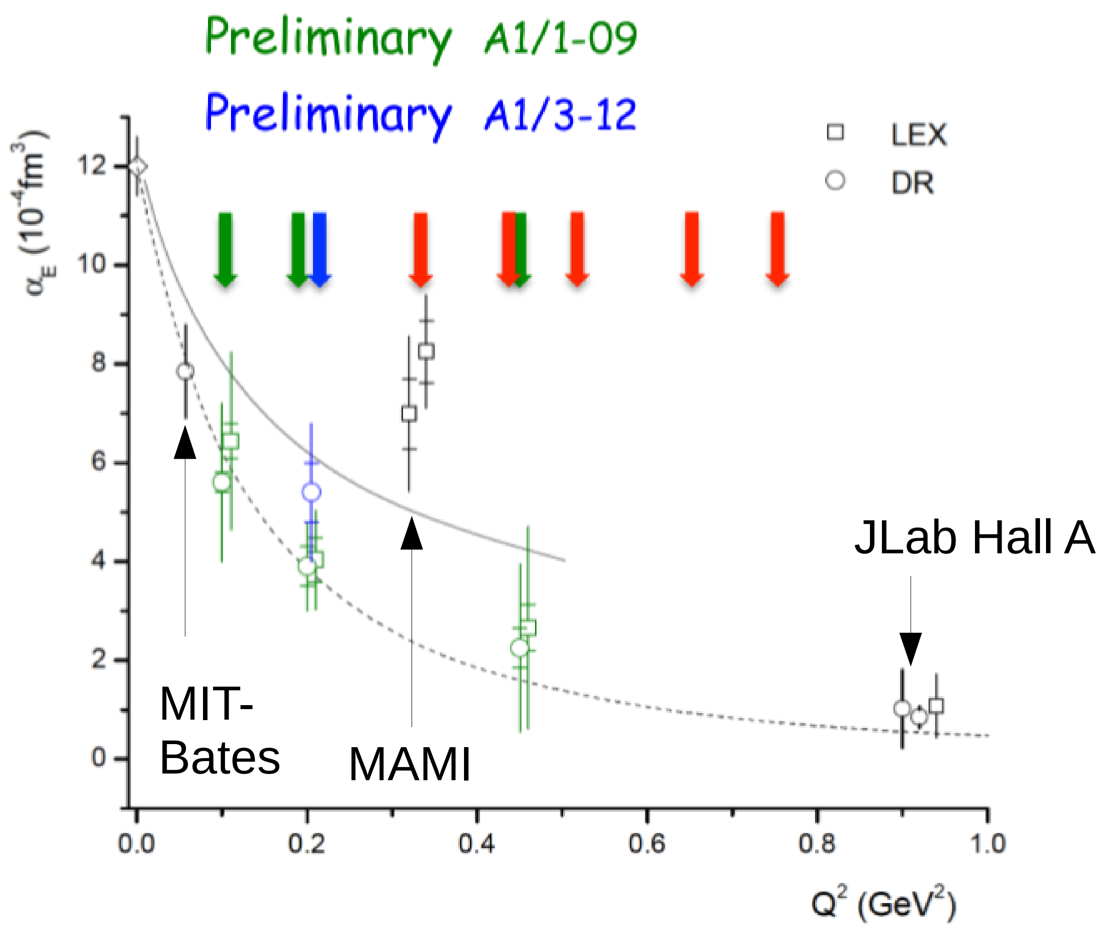
⇒ MAMI, A1/3-12, Sparveris et al. Above π threshold

⇒ **JLab, this experiment: 1) check MAMI results, 2) extend to higher Q^2**

→ black: older results

MAMI: $Q^2 < 0.45$ GeV^2; ε = 0.62

JLab: $Q^2 > 0.33$ GeV^2; ε = 0.97, higher energy and intensity



1st point will check MAMI older data

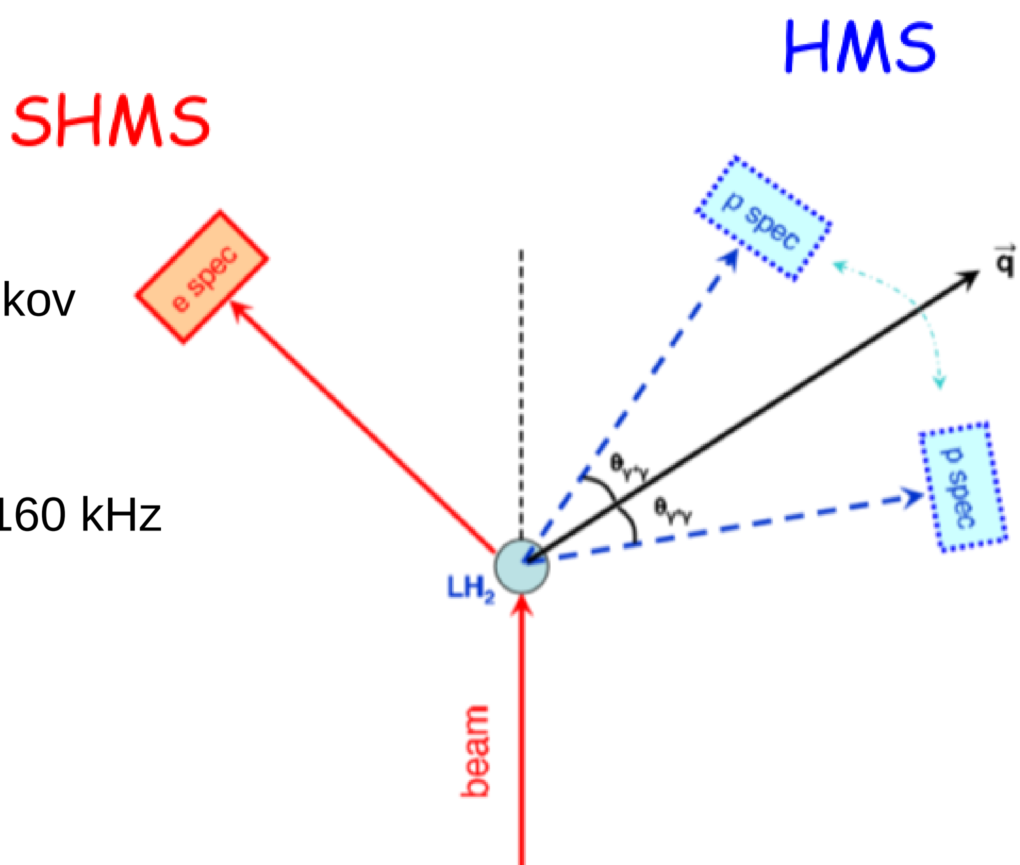
Hall C experiment E12-15-001

Contact person: N. Sparveris
Co-spokesperson: A. Camsonne, M. Jones, M. Paolone

Anticipated schedule: June 25, 2019 → July 7, 2019
Run phase 1 = 13 days

target: 10 cm unpolarized LH2
beam: electron, 50→85 μA, E = 4.55 GeV
→modified compared to proposal, was: 8 days on 15 cm target ≡ similar luminosity

e P →e' P' X
X ≡ γ



"standard"
Noble Gas Cherenkov
with Argon
+ calorimeter

combined rates < 160 kHz

"standard"
proton ID: TOF

combined rates < 300 kHz
→smooth efficiency, >96%

coincidence measurement: e+P

Experiment kinematics *

* see updates next slide

	Kinematical Setting	$\theta_{\gamma^*\gamma}{}^\circ$	$\theta_e{}^\circ$	$P'_e(MeV/c)$	$\theta_p{}^\circ$	$P'_p(MeV/c)$	S/N	beam time (days)
Part I	Kin Ia	155	7.97	3884.4	37.20	893.20	1.1	0.5
	Kin Ib	155	7.97	3884.4	51.26	893.20	2.7	0.5
	Kin IIa	140	7.97	3884.4	33.08	859.90	1	0.45
	Kin IIb	140	7.97	3884.4	55.38	859.90	3.7	0.55
	Kin IIIa	120	7.97	3884.4	27.85	794.68	0.9	0.45
	Kin IIIb	120	7.97	3884.4	60.61	794.68	6.2	0.55
	Kin IVa	165	9.39	3820.5	40.85	1010.40	1.3	0.5
	Kin IVb	165	9.39	3820.5	48.45	1010.40	2.4	0.5
	Kin Va	155	9.39	3820.5	38.34	995.20	1	0.5
	Kin Vb	155	9.39	3820.5	50.96	995.20	3.2	0.5
	Kin VIa	128	9.39	3820.5	31.84	919.43	0.7	0.95
	Kin VIb	128	9.39	3820.5	57.46	919.43	7.8	0.55
Part II	Kin VIIa	165	11.54	3708.6	40.81	1175.25	2.6	1.5
	Kin VIIb	165	11.54	3708.6	47.35	1175.25	5	2
	Kin VIIIa	160	11.54	3708.6	39.73	1167.72	2.2	1.5
	Kin VIIIb	160	11.54	3708.6	48.43	1167.72	6.3	2
	Kin IXa	140	11.54	3708.6	35.52	1117.38	1.2	1.5
	Kin IXb	140	11.54	3708.6	52.64	1117.38	8	2

Part I:
8 days approved

Part II: will be
re-proposed

SHMS: one change of setting through Part I
same position & momentum through out Part II

Part	I	I	I	II	II
Q^2	0.33 (GeV/c)	0.43 $(GeV/c)^2$	0.52 $(GeV/c)^2$	0.65 $(GeV/c)^2$	0.75 $(GeV/c)^2$

Kinematics and beam time (updated, phase 1)

E (MeV)	$\Theta_{\gamma\gamma}$ (deg)	Q^2 (GeV^2)	P_e (MeV)	θ_e (deg)	P_p (MeV)	θ_p (deg)
4550	155	0.33	4020.55	8.0	930.34	37.69
4550	155	0.33	4020.55	8.0	930.34	51.39
4550	140	0.33	4020.55	8.0	882.13	33.68
4550	140	0.33	4020.55	8.0	882.13	55.41
4550	120	0.33	4020.55	8.0	815.69	28.60
4550	120	0.33	4020.55	8.0	815.69	60.48
4550	165	0.45	3970.49	9.05217	1010.40	41.01
4550	165	0.45	3970.49	9.05217	1010.40	48.61
4550	155	0.45	3970.49	9.05217	995.20	38.50
4550	155	0.45	3970.49	9.05217	995.20	51.11
4550	128	0.45	3970.49	9.05217	919.43	31.99
4550	128	0.45	3970.49	9.05217	919.43	57.62

projections for the run in July 2019

Choice of kinematics, angles and analysis

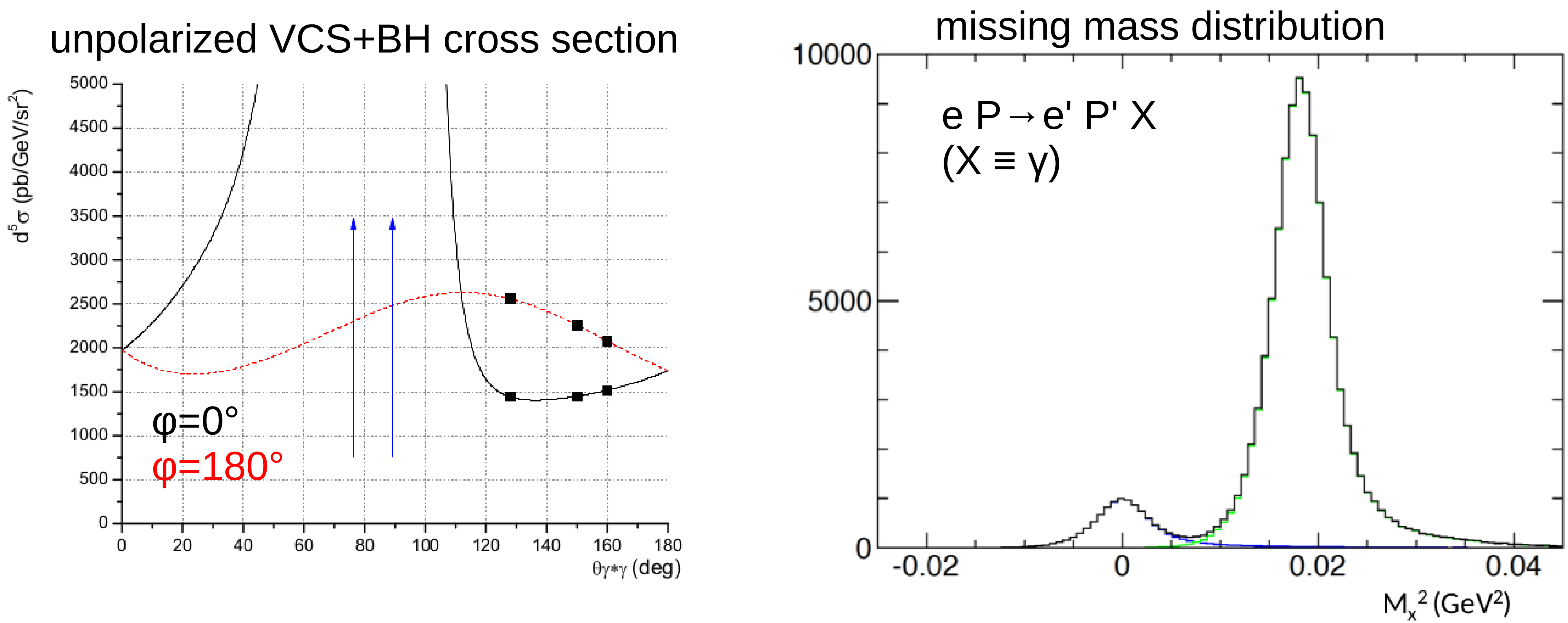


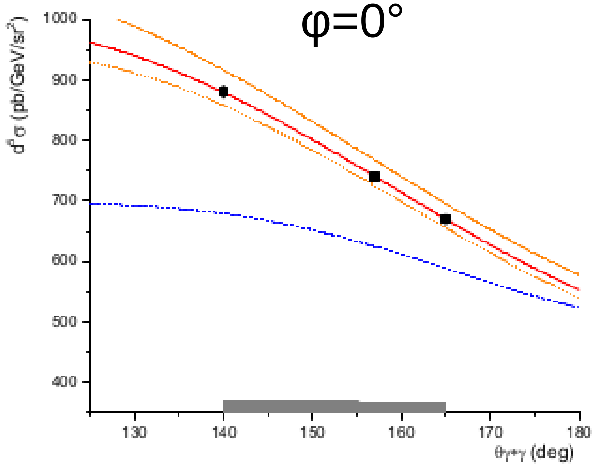
FIG. 7: Left panel: Projected cross sections at $Q^2 = 0.43\ (GeV/c)^2$. The solid and dashed curves correspond to cross sections at $\phi_{\gamma^*\gamma} = 0°$ and 180°. The two arrows are pointing to the two BH peaks. Right panel: The reconstructed missing mass spectrum.

- Away from the BH peaks → near singularities at φ = 0°
- At $\Theta_{\gamma\gamma}$ > 120° (avoid too large BH)
- Q^2 = 0.3 → 0.75 GeV^2 most unknown part of spectra for α_E
- Above π threshold: more sensitive to GPs

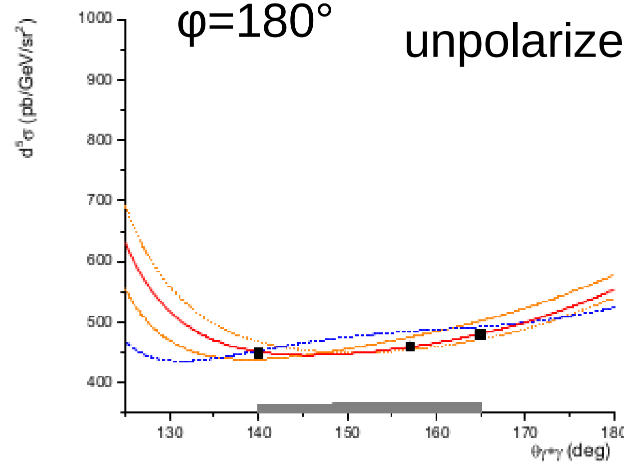
- coincidence: e (SHMS) + P (HMS)
- analysis via missing mass for γ: peak at M=0
- relatively low angle for e' (>8°)

Projected cross sections and asymmetry

φ=0°



φ=180°



unpolarized cross sections

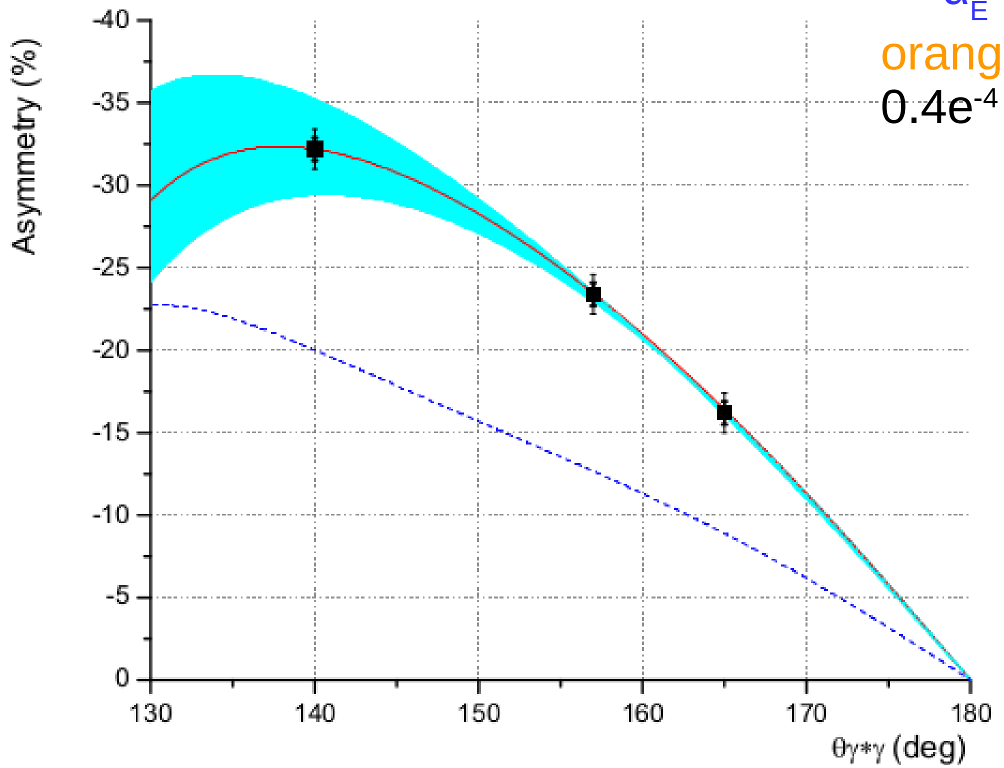
$—$ α_E=4.8e^{-4} fm^3, β_M=1.1e^{-4} fm^3

--- α_E=1.5e^{-4} fm^3

orange zone (top), blue zone (bottom):

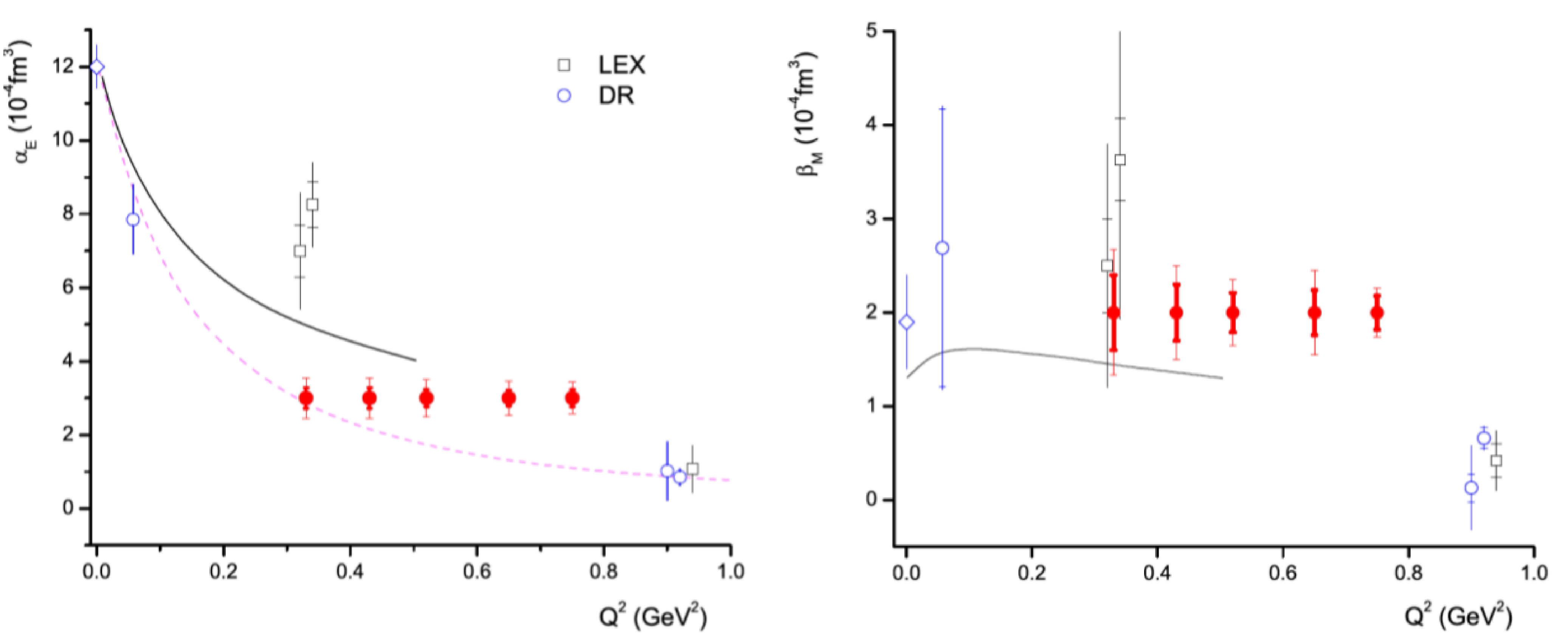
0.4e^{-4} < β_M < 1.6 e^{-4}

asymmetry



Proposed projected result for α β_M

proposed projection (not updated)



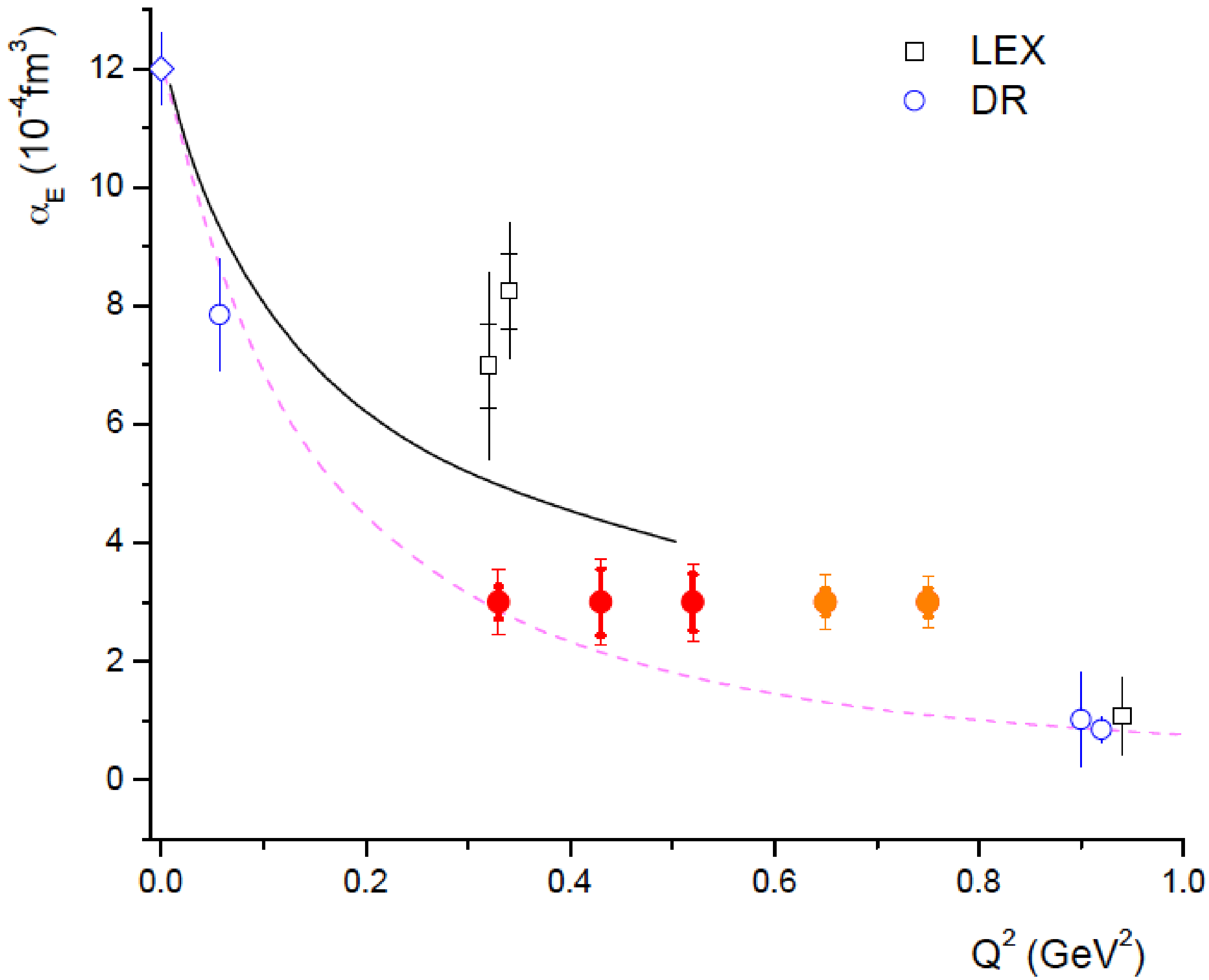
Phase 1:

- 1st point: approved, this summer (100% of data)
- 2nd and 3rd points: 30% this summer (stat+syst. = same)

Phase 2:

- 4th and 5th points, and more statistics on other points

Projections of expected result for α_E



updated to new experimental schedule

- 1st point: approved, this summer (100% of data)
- 2nd and 3rd points: 30% this summer (stat+syst. = same)
- 4th and 5th points: phase 2

Manpower at Temple University for VCS

Currently involved, for hall C experiments:

2 tenured professors + 1 assistant professor: Z.E. Meziani, M. Paolone, N. Sparveris
2 postdocs: H. Atac, M. Boër
5 grad students: N. Deokar, B. Duran, S. Jia, R. Li, M. Rehfuss

Upcoming experiments in 2019 for the group:

1) J/Ψ + pentaquark: expected to start next week

will benefit from the analysis

2) VCS (this talk): summer 2019

3) A_{1N}: expected in the fall

+ many people interested in the VCS proposal from other institutions

SUMMARY

• Measurement of Generalized Polarizabilities of the nucleon with VCS+BH
→intrinsec property of the nucleon
→partonic structure / dynamic of the nucleon

• Precision improvement (x2), will also check of past experiments

• Extension of Q^2 range of past measurements for $\alpha_E(Q^2)$ →structure

• Paramagnetic vs Diamagnetic effects with β_M

Recent and current efforts for the E12-15-001 experiment:
- updated simc, more precise spectrometer response
- exploring other models for interpretation