# Experimental Physics Division

http://epd.yerphi.am/EPD.htm


Hrachya Marukyan

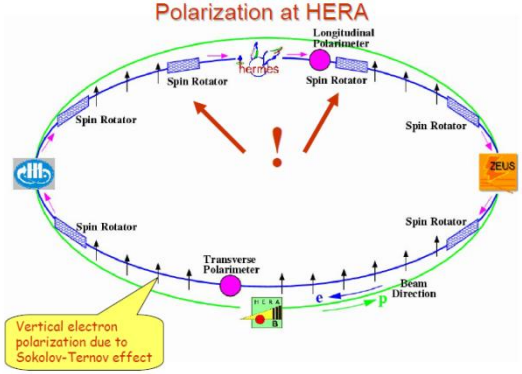
AANL in International Projects on Spin Physics

26 April 2024 , Yerevan, Armenia

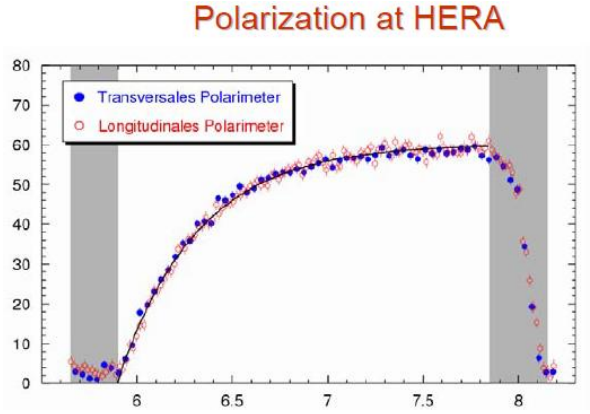
# Outline

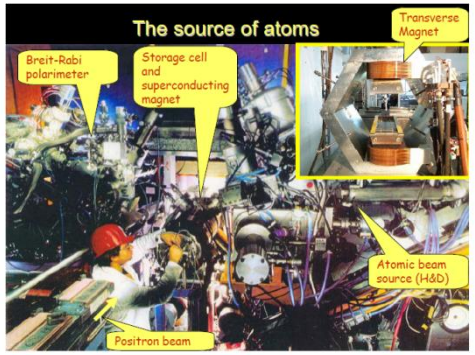
- AANL – DESY, HERMES Collaboration
- AANL – JLAB  Collaboration
- AANL – ePIC Collaboration
- AANL – COMPASS Collaboration
- AANL – NICA  collaboration
- AANL – SpinQuest Collaboration

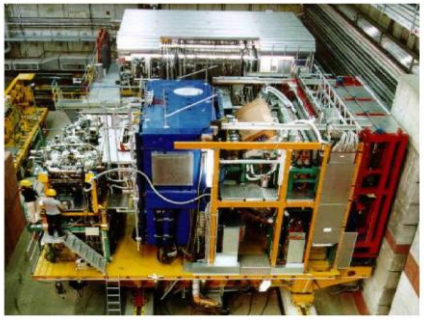
# DESY; HERMES Experiment; Hamburg-Germany



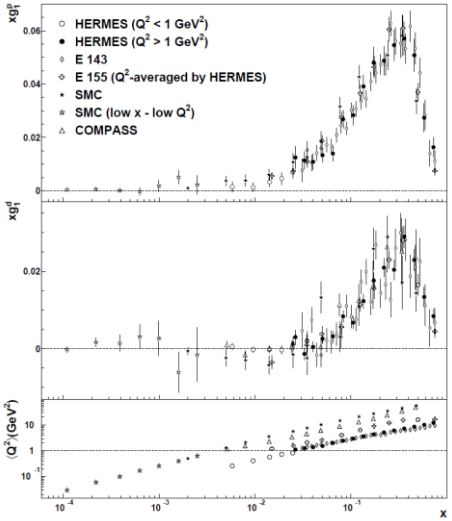


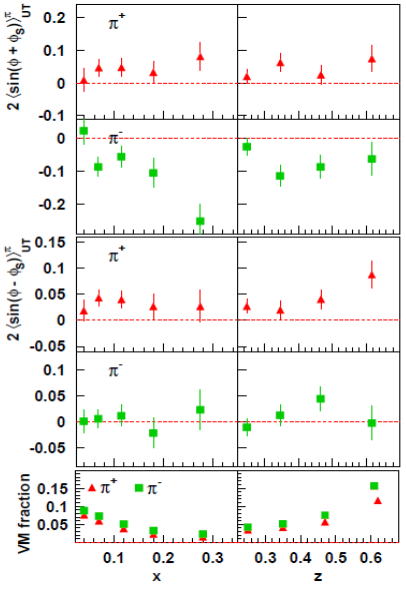


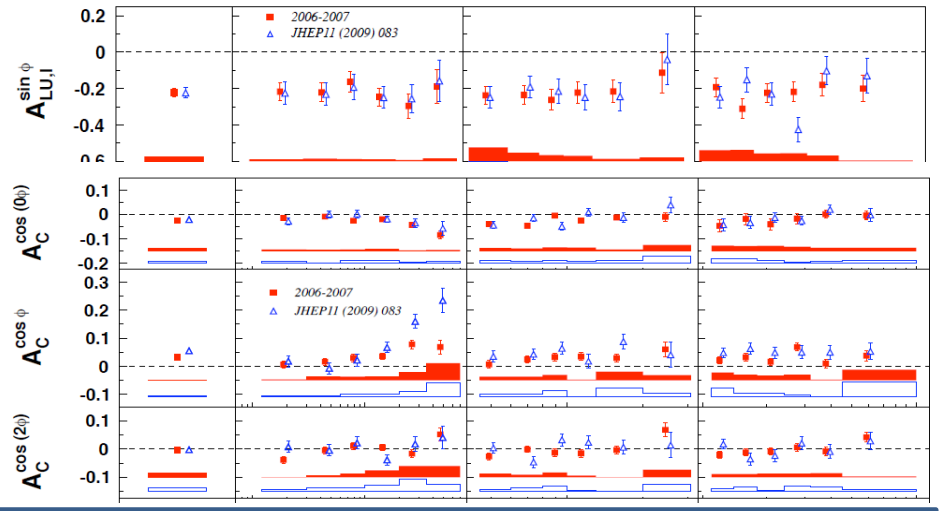



The experiment's goal was to investigate the quark–gluon structure of matter by examining how a nucleon's constituents affect its spin.Later developed into a pioneering experiment for measuring generalised parton distributions and a general-purpose experiment for the study of QCD processes. HERMES ~200 scientists from more than 13 countries.





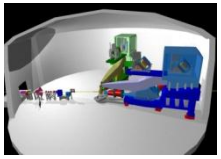

AANL scientists are co authors of many “spin-related” papers

Jefferson Lab

# TJNAF (Thomas Jefferson National Accelerator Facility); Virginia; Newport News-USA

## Hall-A

**H**igh **R**esolution **S**pectrometer Pair **(HRS)** and specialized large installation experiments.



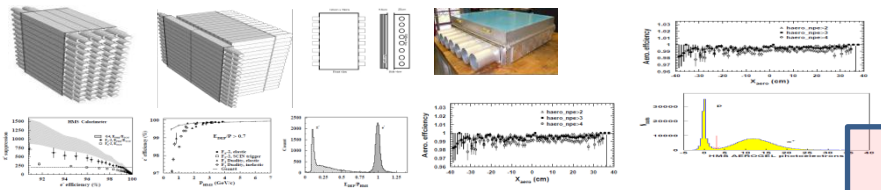
- ❑ Participation in the online design discussions of SBS (Super BigBite-Spectrometer),
- ❑ Participation in the construction of SBS, and planning of further activities of the Armenian group in Hall A,
- ❑ Participation in the experiment E12-09-019 GMn (Neutron Magnetic Form Factor),
- ❑ Preparation of the equipment for the experiment E12-17-004 (GEn-Recoil),
- ❑ Participation in the development of the method of restoring the transparency of lead glasses, and in the restoration works using the selected method:
  - Development of principles of construction of glass modules;
  - Building a calorimeter assembled from modules;
  - Calorimeter test.
- ❑ The final design and construction of the Electromagnetic Calorimeter for the SBS/GEp5 (Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 $(GeV/c)^2$ is underway.

## Hall-C

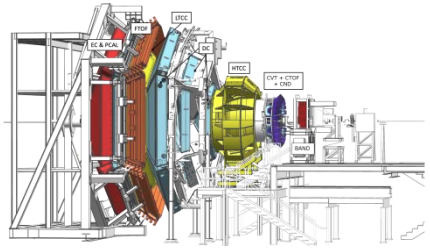
**S**uper **H**igh **M**omentum **S**pectrometer (**SHMS**) at high luminosity and forward angle

- ❑ Participation in the experiment E12-19-006 on the determination of the L-T separation of the cross section and the form-factor Fπ in exclusive electroproduction of pions in the range of large Q2,
- ❑ Participation in the experiment E12-10-008 on measurement of the cross section of exclusively scattered electrons from light and heavy nuclei for study of EMC effect,
- ❑ Participation in the experiment E12-06-105 on measurement of the Q2 dependence of the ratio A/2H and A/3He in a wide kinematic range,
- ❑ Participation in the work related to the Neutral Particle Spectrometer (NPS) project:
  - The NPS is currently under construction;
  - The procurement of lead tungstate crystals (PbWO4) from CRYTUR (Czech Republic), their size measurements and verification of optical characteristics was continued;
  - The Yerevan group contributed greatly to the optical isolation of calorimeter crystals, the preparation works of PMTs and cables;
  - Currently, all calorimeter crystals are housed in a heat-insulating box, and the PMTs of the three column cells are optically attached to the crystals and connected to the electronics system. Preliminary check by cosmic muons are underway, after which the rest of the PMTs will be installed;
  - The transfer of the calorimeter to the experimental hall is planned for the spring-summer months of next year, and the first experiments with NPS will be carried out by the end of 2023.

**Electromagnetic calorimeters and Aerogel Cherenkov detectors for HMS & SHMS**



## Hall-B



(**CEBAF** **L**arge **A**cceptance **S**pectrometer) **CLAS12** – 4π scattering angle, high luminosity, large acceptance

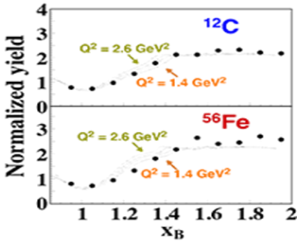
**Main Activities**

**6 GeV energy era**

- ❑ NN Short Range Correlations,
- ❑ Deuteron Wave Function,
- ❑ Timeline Compton Scattering,
- ❑ Electromagnetic Calorimeter construction.

**12 GeV energy upgrade**

- ❑ Preshower Calorimeter construction (**PCAL**),
- ❑ High Treshold Cherenkov Counter (**HTCC**),
- ❑ **E12-12-001/ E12-12-001A "**Timelike Compton Scattering and J/psi photoproduction on the proton in e+e- pair production with CLAS12 at 11 GeV",
- ❑ **E12-11-008**, "Heavy photon search at Jefferson Laboratory",
- ❑ **E12-07-104A, "**Coherent photoproduction of vector mesons on deuterium, Color Transparancy**".**

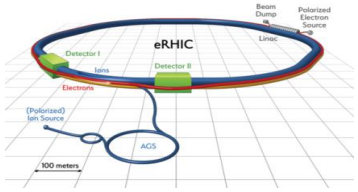



In 2020, the scientific journal Physical Review C celebrated its 50th anniversary. In honor of this event, they compiled a collection of important publications announcing major discoveries or open up new avenues of research and remaining central to the development of nuclear physics. Among these articles is our article our article **"Observation of nuclear scaling in the reaction A(e,e') at $x_B$>1**" (Phys. Rev. C 68, 014313 (2003)), https://journals.aps.org/prc/50th?fbclid=IwAR2PSrjrXwhThfaxdSKaZISN8ctJsEb1TYXXL4a3PPio0gZGwIUlTTSqyc

- ➢ Inclusive DIS
  - – Spin structure functions
  - – Valence PDFs at high Bjorken x
  - – Sum Rules, OPE, higher twist
  - – duality
- ➢ Semi-Inclusive DIS
  - – Flavor tagged SSF
  - – Transversity, TMD PDFs
- ➢ Exclusive Processes
  - – DVCS
  - – GPDs

AANL scientists are co authors of many "spin-related" papers

# BNL; ePIC (Electron Proton/Ion Collider); Upton, New York - USA

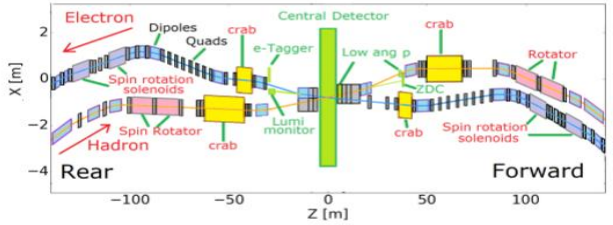



- Center of Mass Energies 20 GeV – 140 GeV
- Maximum Luminosity $10^{34}$ cm$^{-2}$s$^{-1}$
- Hadron Beam Polarization 80%
- Electron Beam Polarization 80%
- Ion Species Range p to Uranium
- Number of interaction regions up to two

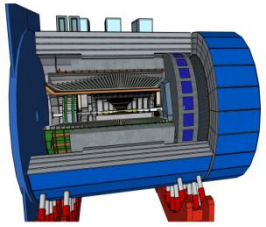
- Construction of the EIC and detectors will start in 2024 and finish before 2030 and it will be constructed at Brookhaven National Laboratory based on the RHIC accelerator.
- International collaboration includes 1297 members from 264 institutions and 36 countries. AANL has joined the EIC project in 2020 via submission of EoI.
- EIC will have collision rates 100-1000 times higher than that of any previous electron-proton collider. It will be the first machine where the proton and ion beams can be polarized.

## EIC Proposed IR (Interaction Region)

The facility must be able to accommodate 2 detectors at 2 interaction points (IP6 & IP8)
Current detectors are designed to provide full acceptance to all fragments produced in collisions
The central detector is based on 5 m long solenoid offset by 50 cm from the Interaction point.

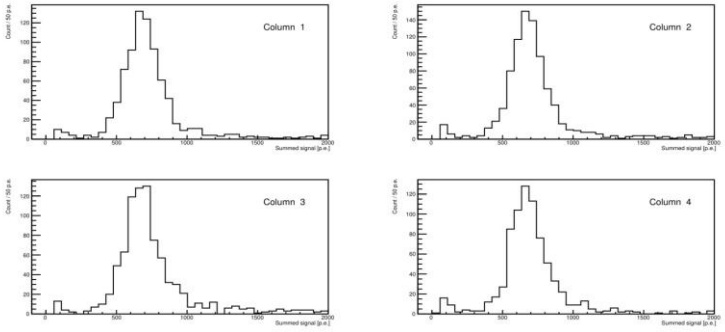



## EIC Proposed Detectors



**ECCE (EIC Comprehensive Chromodynamics Experiment)**
Key to the ECCE design is the selection of the 1.5 Tesla solenoid, originally built for the BaBar experiment at SLAC, was brought to BNL in 2015 .
It also comes with an instrumented flux return, serving as the sPHENIX outer hadronic calorimeter (oHCal), installed in RHIC Interaction Region 8 (IR8),
These two components can be moved to IR6 (primary EIC interaction region).

## Calorimeter Prototype tests at AANL



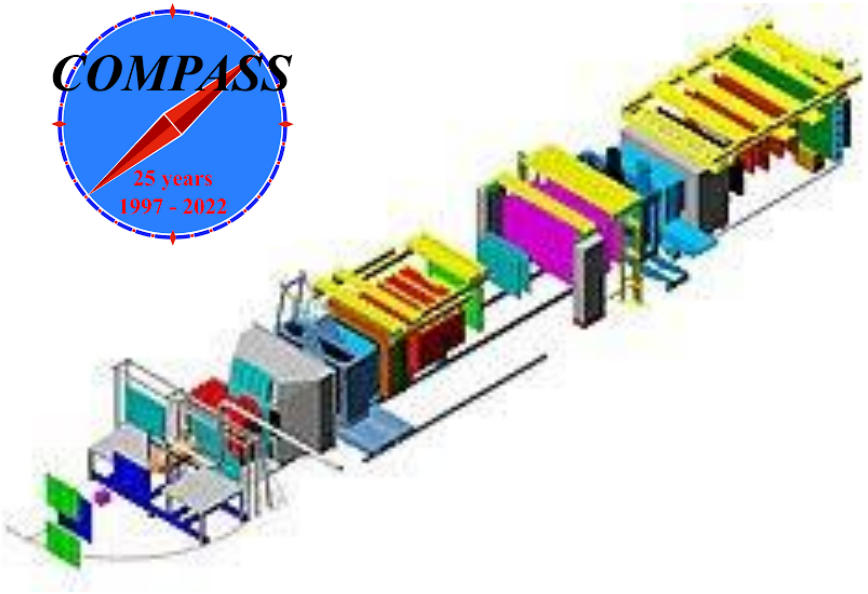

ECCE -> Detector 1 -> ePIC
Published papers 1: submitted to NIMA 12

## AANL EIC Group Experience and Proposed activities

Currently about 6 staff members + 6 students in 3 subgroups: Simulation, R&D and prototyping, physics proposal development. The group has designed and built electromagnetic calorimeters for Jefferson Lab's Halls A, B and C.
We took part in characterization of $PbWO_4$ crystals, PMTs, and construction of prototypes of calorimeter for the JLab Neutral Particle Spectrometer (NPS).
AANL group joined EIC Collaboration in 2020 and was member of ATHENA, ECCE and CORE detector groups.
We have prepared the required technical base at AANL (developed an **Advanced Center of Detector Technology)** and tested the optical properties of crystals acquired from CRYTUR (Czech Republic).
A prototype of EmCal of 4×4 configuration from 2.05×2.05×20.0 cm$^3$ $PbWO_4$ crystals was designed, constructed and tested.
Monte-Carlo simulations for calorimeter (EEMCAL and barrel EMCal) are ongoing (energy resolution, $\gamma$ and $\pi^0$ separation).
Our Physics interests: Structure of hadrons, SIDIS, exclusive reactions, spin physics.
Our Detector interests: Electron-Endcap Electromagnetic Calorimeter.

# CERN; COMPASS Experiment; Geneva-Switzerland

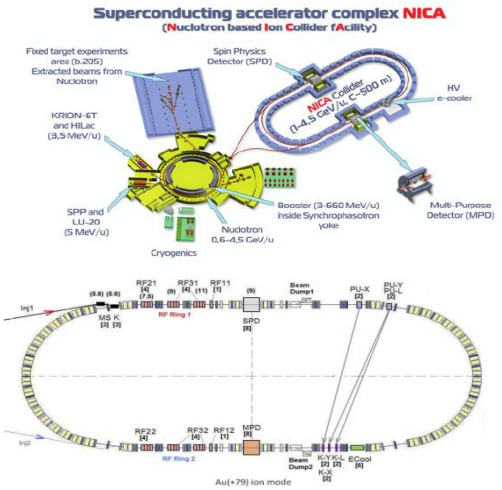
COMPASS is a high-energy physics experiment at the Super Proton Synchrotron (SPS) at CERN in Geneva, Switzerland. The purpose of this experiment is the study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams.




Phase-II of COMPASS is primarily dedicated to the transverse and 3D structure of nucleons using Deeply Virtual Compton scattering (DVCS), Hard Exclusive Meson Production (HEMP), SIDIS and polarised Drell-Yan (DY) reactions. Approved in 2010, it started in 2012 with a Primakoff run and a DVCS pilot run using a muon beam and a long liquid hydrogen target with a huge recoil detector. The first-ever polarised Drell-Yan measurement with a beam of negative pions and a polarised proton target was successfully performed in 2015 and the data taking was resumed in 2018. The years 2016 and 2017 were dedicated to DVCS measurement and simultaneously data on HEMP and SIDIS were collected. In 2021-2022 after long shut-down 2, further measurements of SIDIS off transversely polarised deuterons were performed.

AANL group actively involved (starting 2022) in analysis of asymmetries in SIDIS processes and in GPD ralated business. Published papers: 5

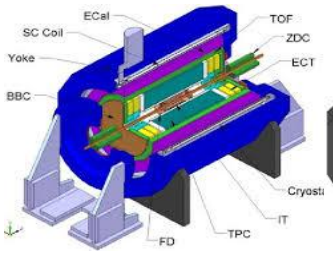
# JINR; NICA Collider; SPD Experiment; Dubna-Russia



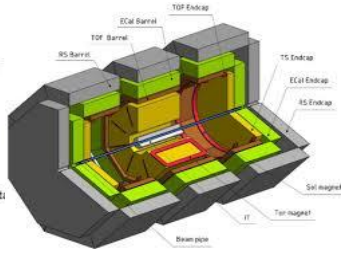

- A group of scientists from AANL is participating in SPD experiment at NICA since 2022 in a framework of MOU (five staff members and two students are involved in this project).
- We are planning to participate in construction of RICH detector for SPD, in NICA physics program (development of proposal, data taking and analysis). .
- We are ready to send 1-2 physicist-engineers of the AANL to JINR/NICA to participate in current activities of the detector design and constriction .
- We will study performance of the aerogel Cherenkov detectors and their readout systems using the JINR facilities, as well the newly created laboratory with appropriate equipments at AANL.
- The group of AANL has experience and expertise in technology to construct variety of electromagnetic and hadronic calorimeters, gas and aerogel Cherenkov detectors. We were deeply involved in construction of calorimeters and variety of other detectors for HERMES, JLab and CERN which would be very useful for SPD.
- The collaboration with NICA SPD will be essential for transferring the latest detector technologies and physics data analysis methods to AANL, to train and educate students and young scientists.

## Key Parameters of The NICA Collider

| | | | |
|---|---|---|---|
| Ring circumference, m | 503,04 | | |
| Number of bunches | 22 | | |
| R.m.s. bunch length, m | 0.6 | | |
| Ring acceptance, π mm·mrad | 40.0 | | |
| Long. Acceptance, Δp/p | ±0.01 | | |
| γtransition (Etransition, GeV/u) | 7.091 (5.72) | | |
| β*, m | 0.35 | | |
| **Ion Energy, GeV/u** | **1.0** | **3.0** | **4.5** |
| **Ion number/bunch, 1e9** | **0.275** | **2.4** | **2.2** |
| **R.m.s. emittance, h/v π mm·mrad** | **1.1/1.0** | **1.1/0.9** | **1.1/0 .76** |
| **R.m.s. Δp/p, 1e-3** | **0.62** | **1.25** | **1.65** |
| **IBS growth time, s** | **190** | **700** | **2500** |
| **Peak luminosity, cm$^{-2}$·s$^{-1}$** | **1.1e25** | **1e27** | **1e27** |




Multi Purpose Detector(MPD)




Spin Physics Detector (SPD)

Heavy ion colliding beams up to $^{197}Au^{79+}$ + $^{197}Au^{79+}$

at $\sqrt{S_{NN}}$ = 4 ÷ 11GeV, $L_{average}$ = 1x10$^{27}$ cm$^{-2}$ s$^{-1}$

Light-Heavy ion colliding beams of the same energy range and Longitudinally Polarized beams of protons and deuterons in collider mode:

p↑ *p*↑ $\sqrt{S_{pp}}$ = 12 ÷ 26 GeV

$L_{max} \approx$ 1x10$^{32}$ cm$^{-2}$s$^{-1}$

*d* ↑ d ↑ $\sqrt{S_{NN}}$ = 4 ÷ 13.8 GeV ,

Extracted beams of light ions and polarized protons and deuterons for fixed target experiments:

Li ÷ Au = 1 ÷ 4.5 GeV / u ion kinetic energy

P,p↑ = 5 ÷ 12.6 GeV kinetic energy

D, d↑ = 2 ÷ 5.9 GeV/u ion kinetic energy starting with 3 MeV/u

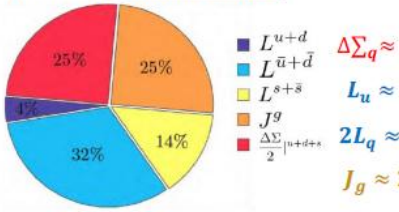
# Fermilab; SpinQuest Experiment; Batavia; Illinois -USA

## Physics Motivation

- **Spin crises:** 70% of the nucleon spin is missing!

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_{\bar{q}} + L_g$$

K.F. Liu *et al* arXiv: 1203.6388




$\Delta\Sigma_q \approx 25\%$

$L_u \approx -L_d$

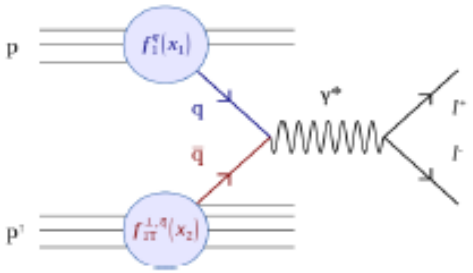
$2L_q \approx 46\%\ (0\%(valence) + 46\%(sea))$

$J_g \approx 25\%$


**OAM from sea quarks could contribute up-to half of the proton's spin**

$$p + p^{\uparrow} \rightarrow \mu^+\mu^- X$$

- Polarized Drell-Yan

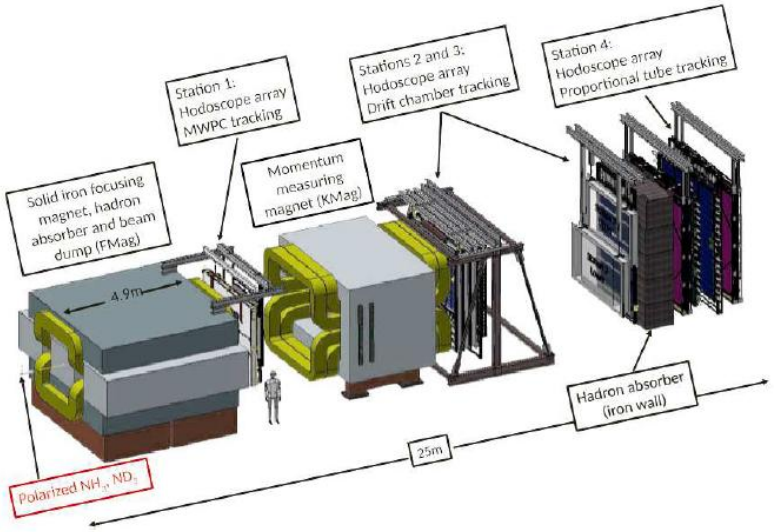



- L-R asymmetry in Drell-Yan production
- No fragmentation function
- Valence-sea quark: isolated

$$A_N^{DY} \propto \frac{\sum_q e_q^2 \left[ f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2 \right]}{\sum_q e_q^2 \left[ f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2 \right]}$$

## SpinQuest experiment at Fermilab

- A beam of protons is created by an accelerator at Fermilab, called the main Injector, and this beam of protons (**FNAL 120 GeV proton beam**) is directed at a target (**transversely polarized targets of $NH_3$ and $ND_3$**).
- Are the sea quarks orbiting around the spin axis of the nucleon?
- SpinQuest will investigate whether the sea quarks are orbiting around the center of the nucleon by exploring the nucleon in a particular way.




Thank you