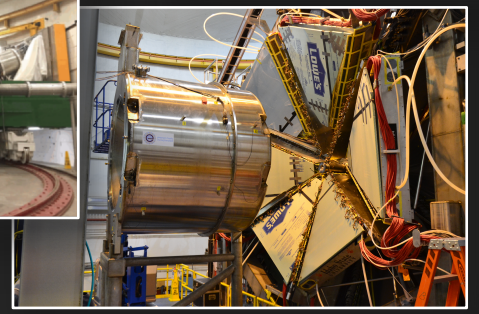
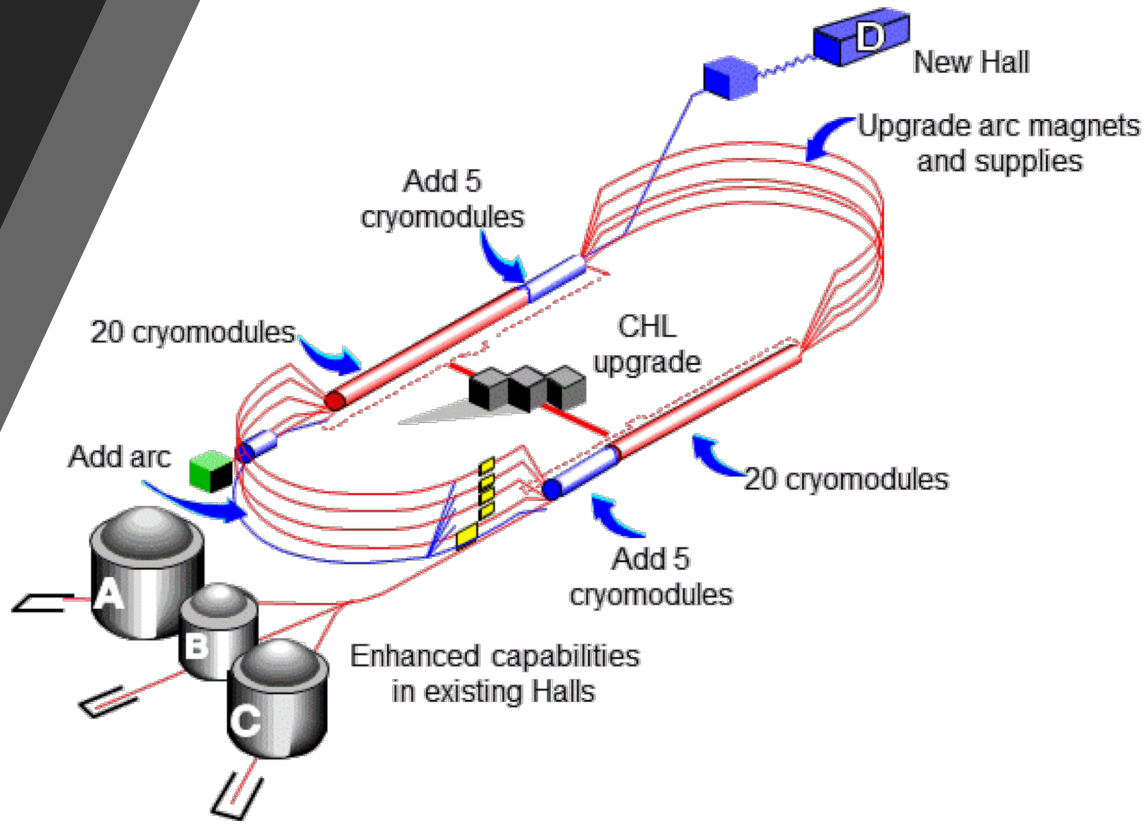
I primi risultati da JLab12

Quarto incontro nazionale di Fisica Nucleare - INFN2018

Jefferson Laboratory entered in the 12-GeV era

- Double maximum Accelerator energy to 12 GeV and add 10th arc
- Add new experimental Hall D
- Upgrade experimental equipment in Hall B and C





12-GeV Project Completion Approved September 27, 2017

Approval

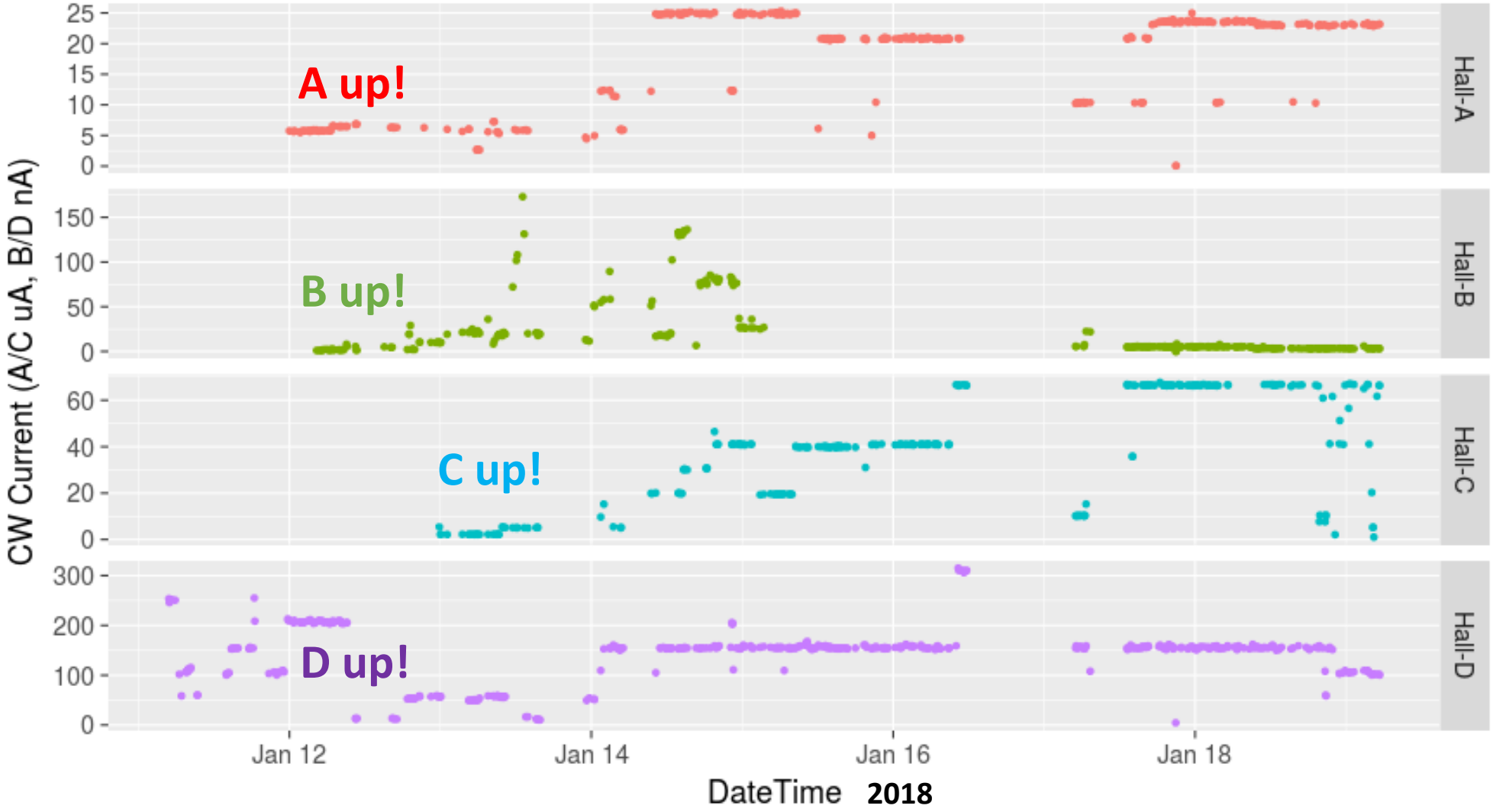
Based on the information presented above and at this review, Critical Decision 4, Approve Project Completion, is approved.

J Binkley — 9/27/17

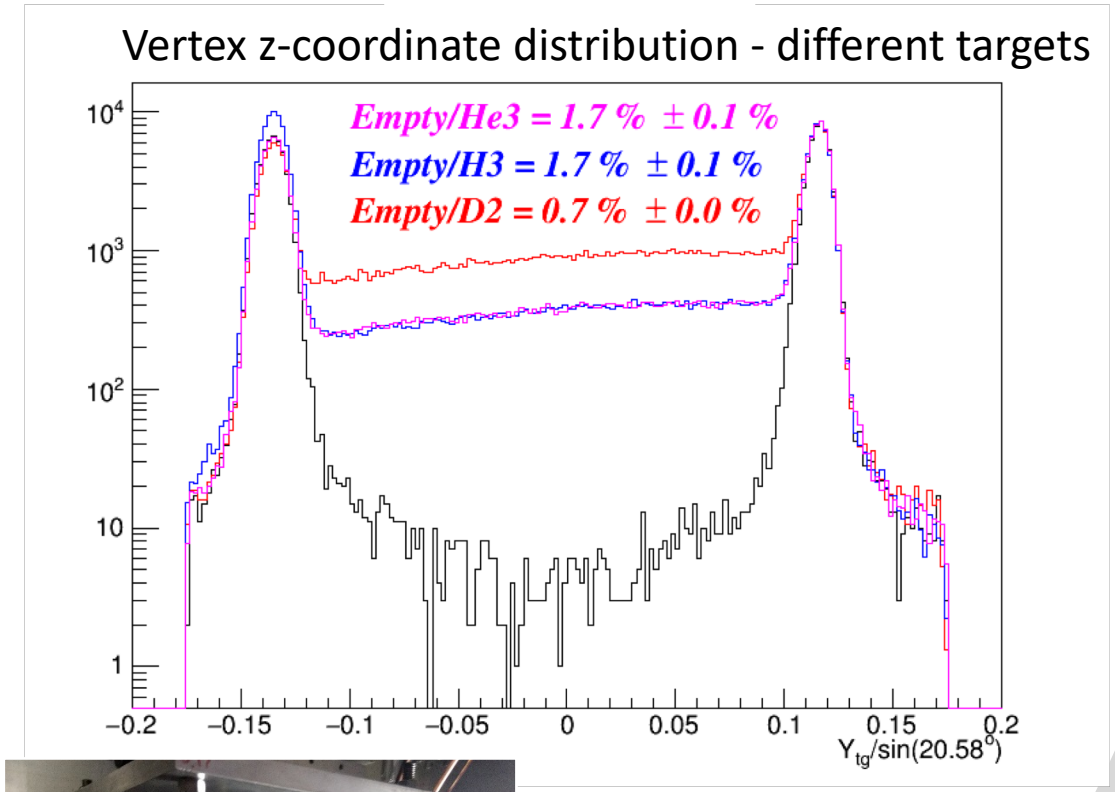
Dr. J. Stephen Binkley
Deputy Director for Science Programs
Office of Science

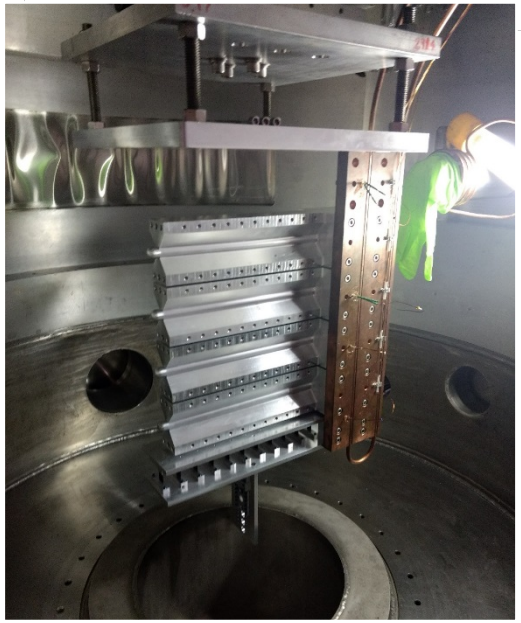
Date

Jefferson Laboratory entered in the 12-GeV era



4-Halls simultaneous operations started in January 2018





Hall-A target cell during installation

Hall-A in physics production

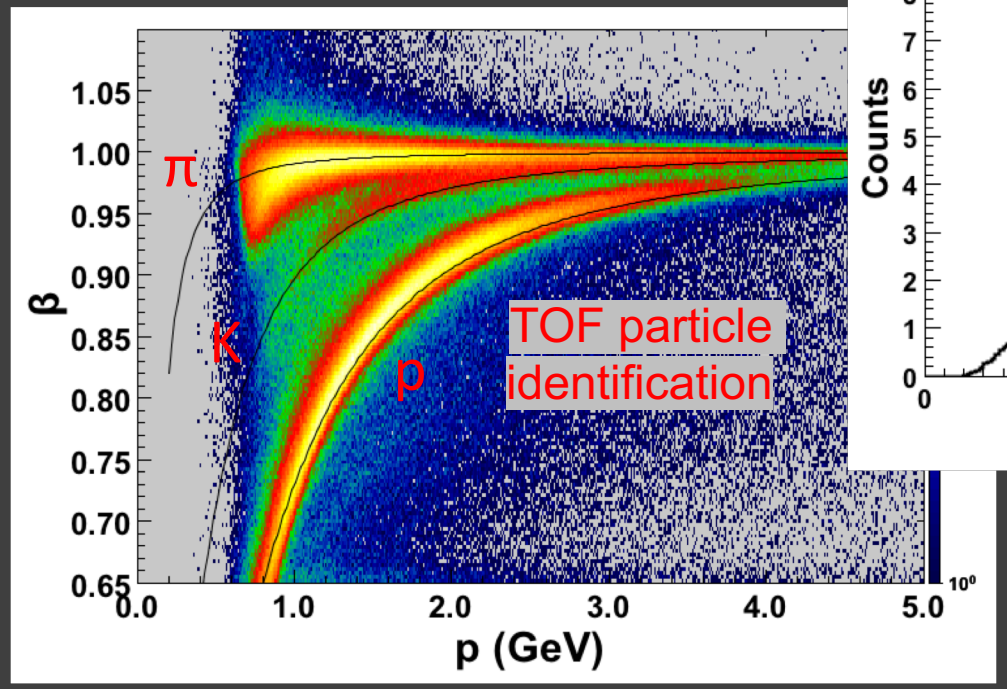
Hall A is currently running 4 parallel experiments on a tritium target:

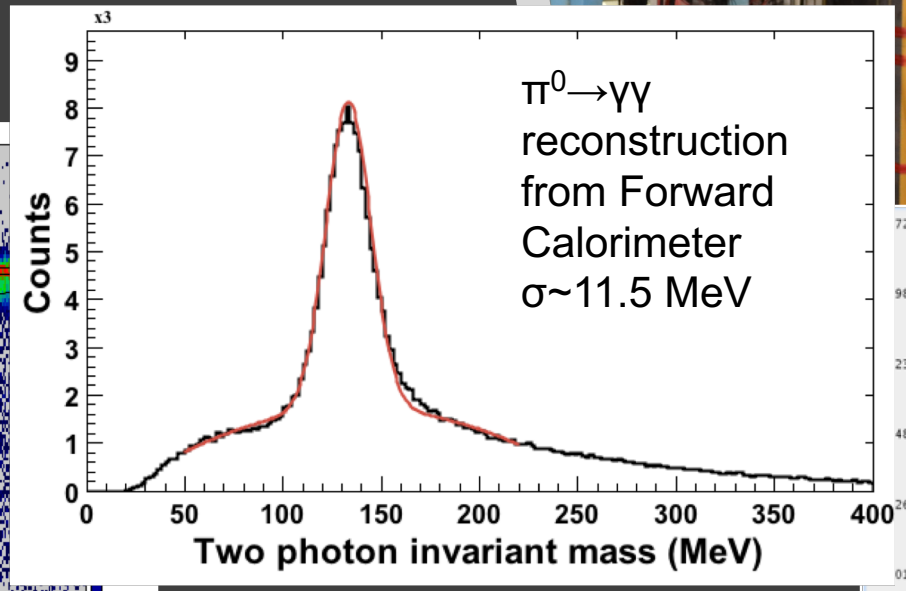
- **E12-010-103 (MARATHON)** : deep inelastic scattering on 3H and 3He to measure EMC effect
- **E12-11-112 (xB > 1):** precision test of the isospin dependence of two-nucleon short range correlations
- **E12-13-012 / E12-14-011 (quasi-elastic):** measure the proton and neutron momentum distributions in A = 3 asymmetric nuclei
- **E12-14-009 (Elastic):** charge radius of 3H and 3He

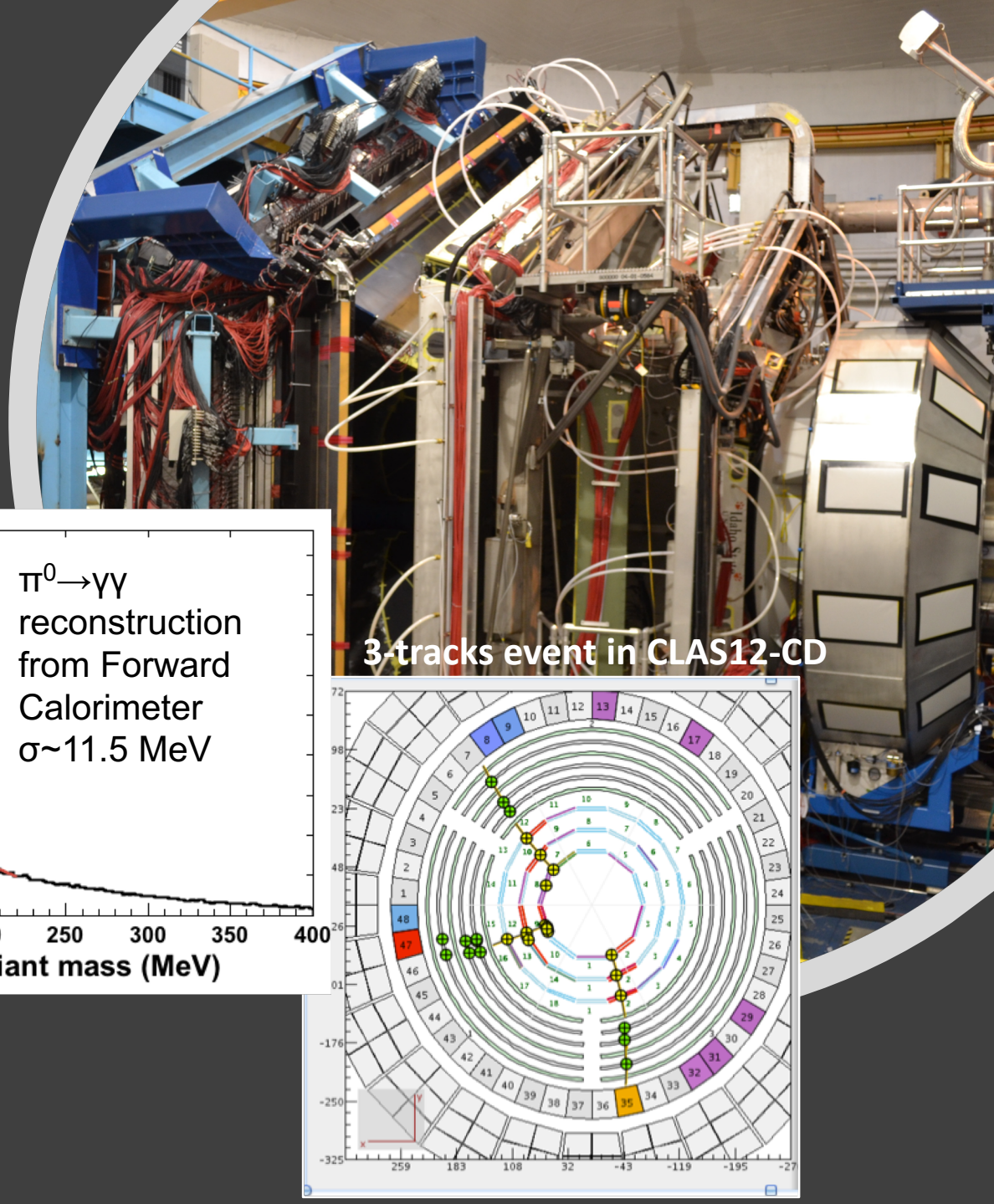
Already completed experiment: DVCS/GMp

Hall-B in physics production

- **Winter 2017:** engineering run – detector commissioning and calibration
- **Spring 2018:** physics production run started at a luminosity of ~5 x 10^{34} cm^{-2} s^{-1} – *run group A (11 experiments)*
  - Nucleon structure (TMDs, GPDs, DVCS)
  - Hadron Spectroscopy

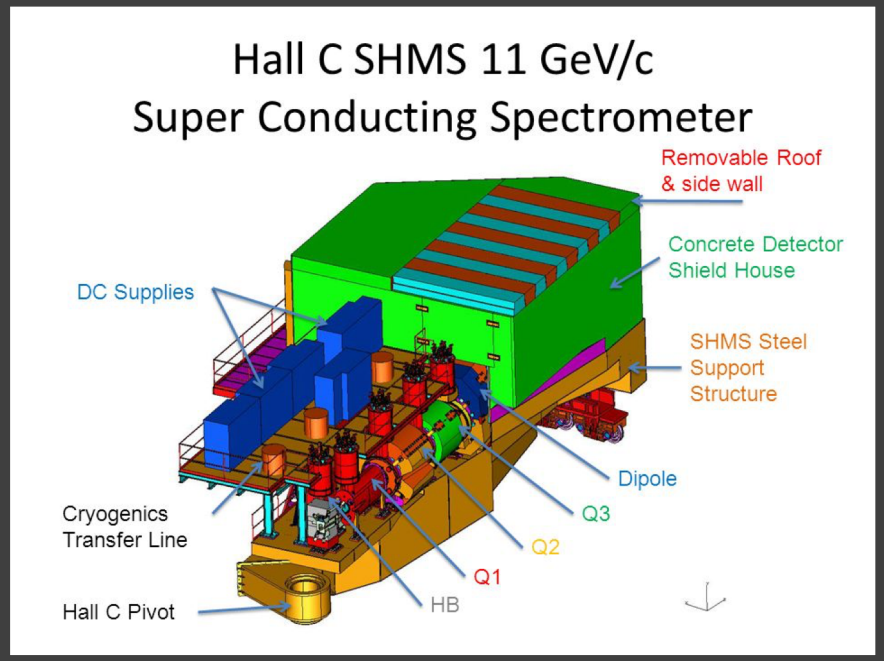




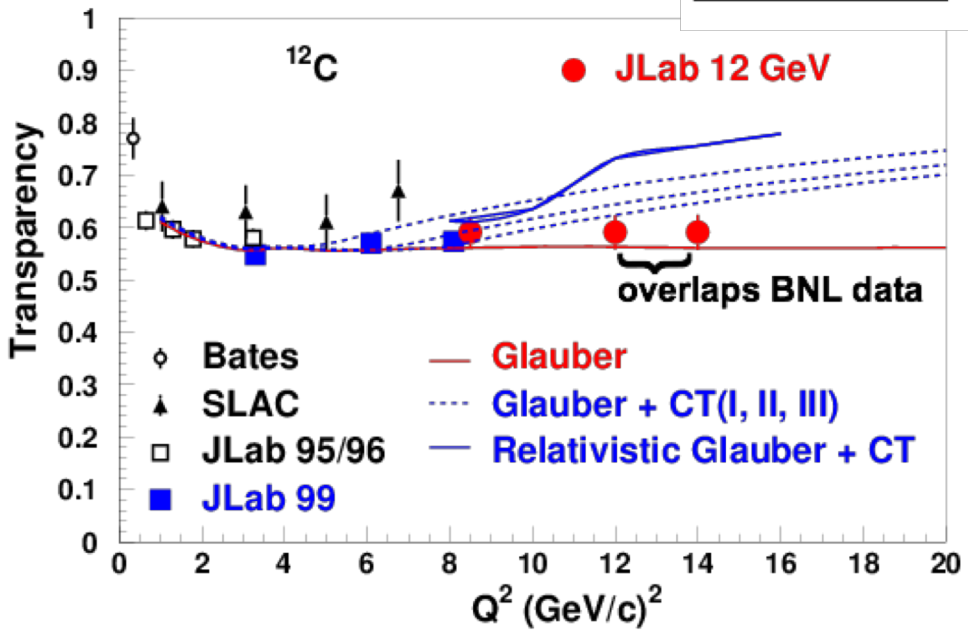


Hall-C in physics production

- Super High Momentum Spectrometer calibration data acquired
- Physics Program started:
  - $F_2^{H,D}$ structure functions (E12-10-008)
  - D(e,e'p) at high missing momentum (E12-10-003)
  - Color Transparency – $^{12}C(e,e'p)$ – explore high Q^2 where BNL A(p,2p) saw rise (E12-06-107)
  - TMD studies (SIDIS) underway (E12-09-017)



$$T = \frac{\sigma_N}{A\sigma_0}$$



Nuclear transparency: ratio of nuclei to nucleon cross-section for exclusive processes. QCD predicts increase in T at large Q^2

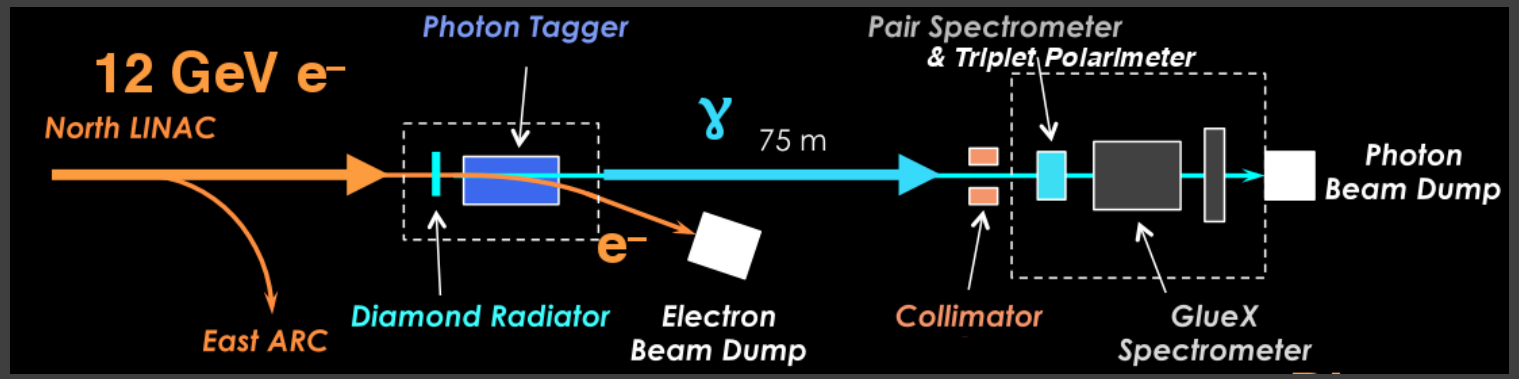
Hall-D in physics production

Hall D is running GlueX-I, a large-acceptance detector for experiments with a broad-band, linearly-polarized photon beam

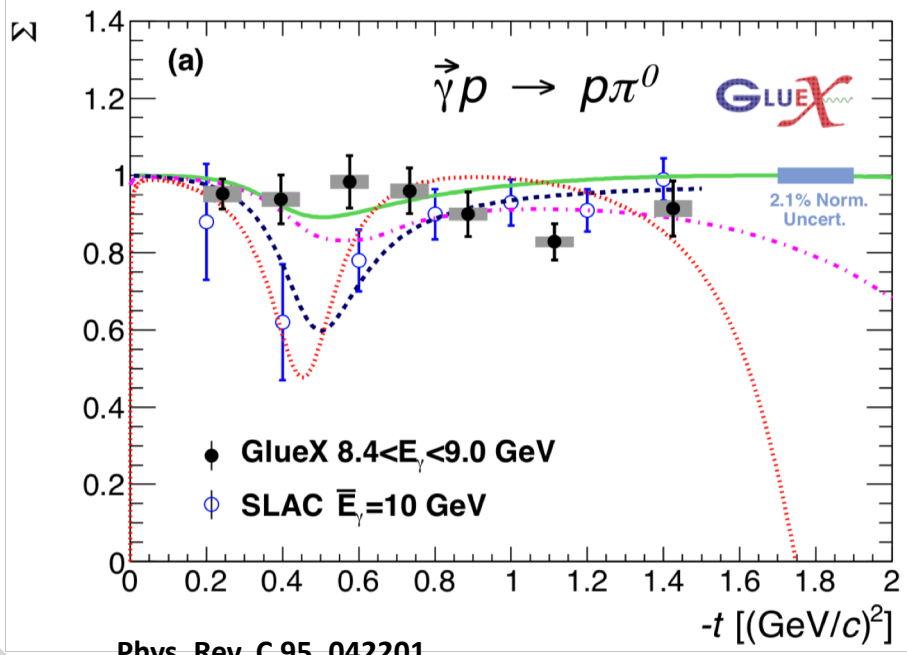
Main physics goal: meson spectroscopy

Data-taking periods:

- 2015/2016: detector commissioning – opportunistic physics
- Spring 2017: 20 PAC days accumulated, ~50B events collected.
- Spring 2018: ~150B events collected.
- Present estimate: GlueX-I is 80% complete.



First 12-GeV publication: beam asymmetry Σ for pion photoproduction by a linearly polarized photon beam



Phys. Rev. C 95, 042201

A selection of few recent results from JLab

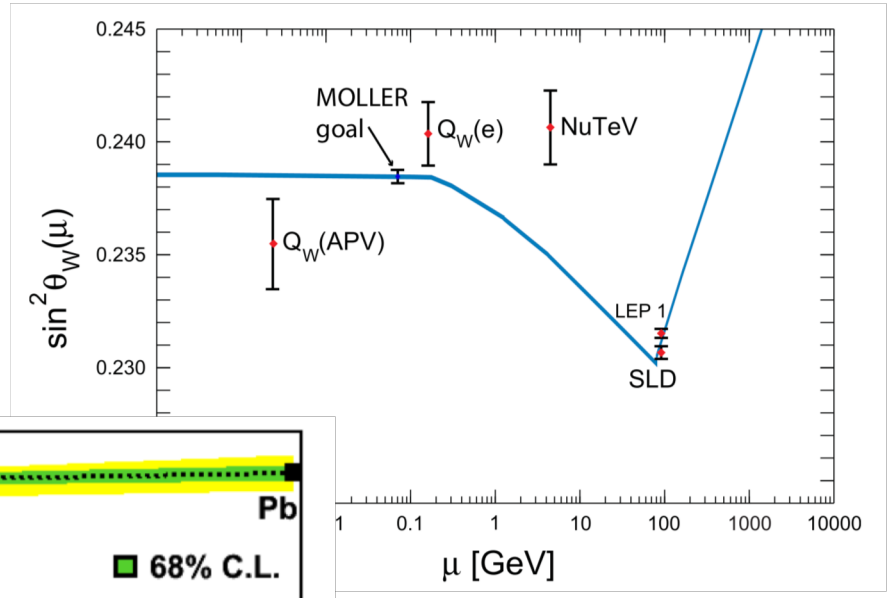
Physics explored at Jefferson Lab covers a very broad range of arguments

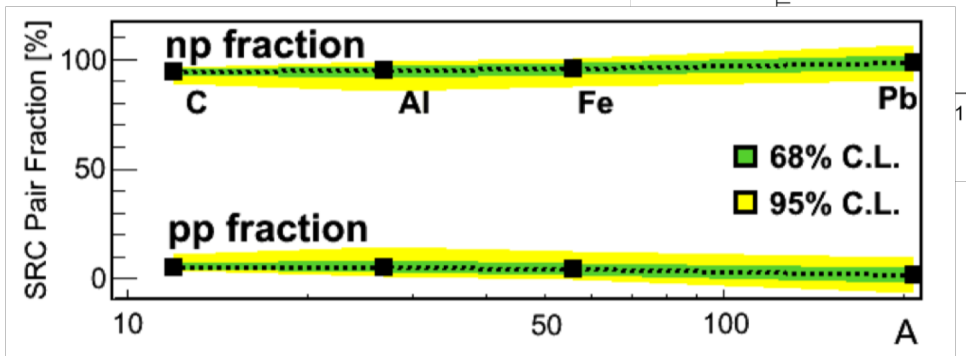
Due to the time constraints, in the following, I'll present a selection of few recent results**, biased by my experience and research activity:**

- **Spectroscopy:** search for LHCb pentaquark states in photoproduction
- **Nucleon structure:** form-factor measurements (Hall-A) and GPDs (Hall-B)
- **Beyond standard model:** light dark matter searches

Many other (even more) important topics would deserve a presentation by themselves!

- Nucleon/nuclear structure: TMDs
- Nuclear physics: hypernuclei / correlation functions
- Proton weak charge
- …





Search for LHCb hidden-charm pentaquark

LHCb in 2015 announced the discovery of two exotic structures in the p -J/ψ channel: Pc(4380) and Pc(4450), by measuring the decay $\Lambda_b^0 \rightarrow p\, J/\psi\, K^-$.

They claimed that the minimum quark content is ccuud: a **pentaquark** state.

Widths:

$P_c(4450)$: $\Gamma = 39$ MeV

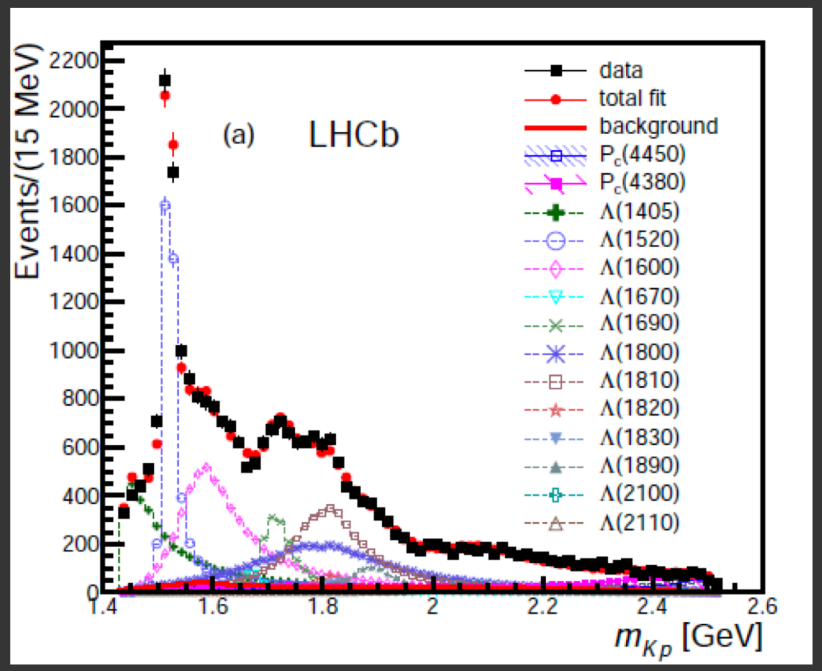
$P_c(4380)$: $\Gamma = 205$ MeV

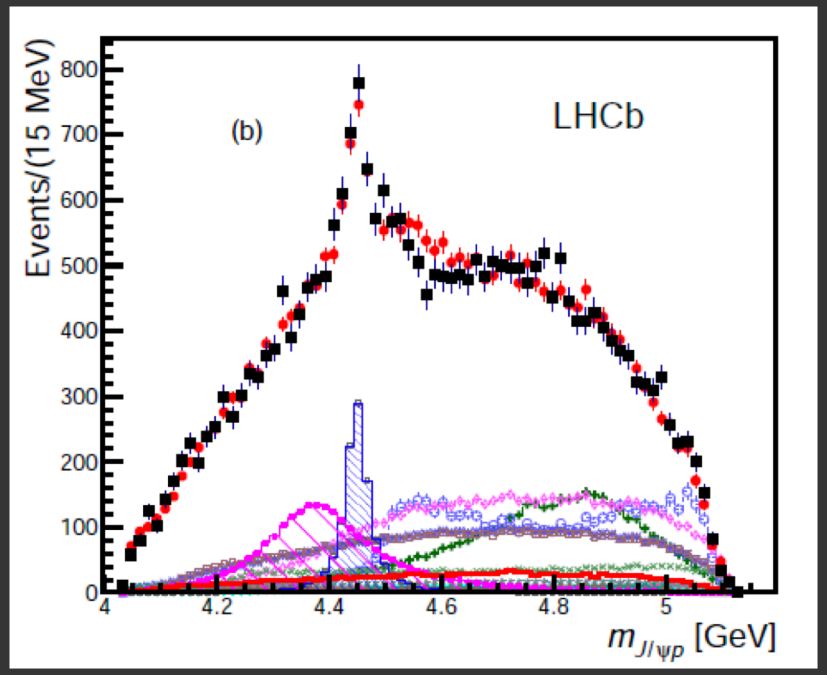
Quantum numbers (PWA most probable solution)

Pc(4450): $J^P = \frac{5}{2}^-$

Pc(4380): $J^P = \frac{3}{2}^+$

Although: "Acceptable solutions are also found for additional cases with opposite parity"

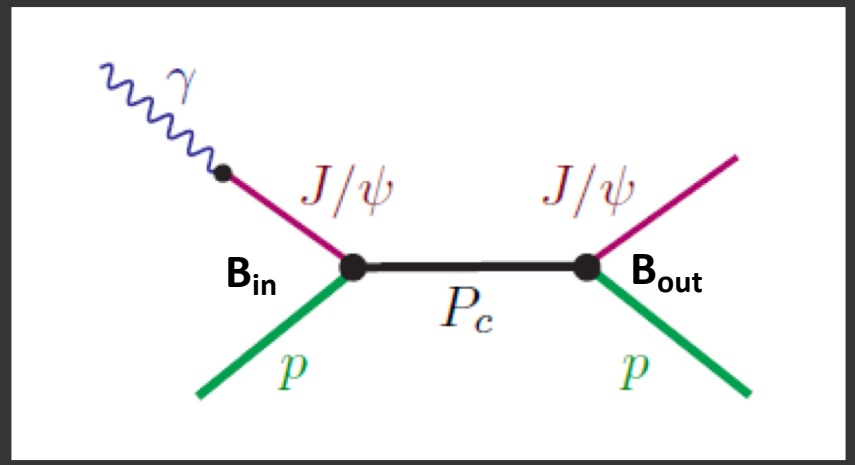




Search for LHCb hidden-charm pentaquark

A p -J/ψ resonance would appear as an s – channel resonance in the direct photo-production reaction:

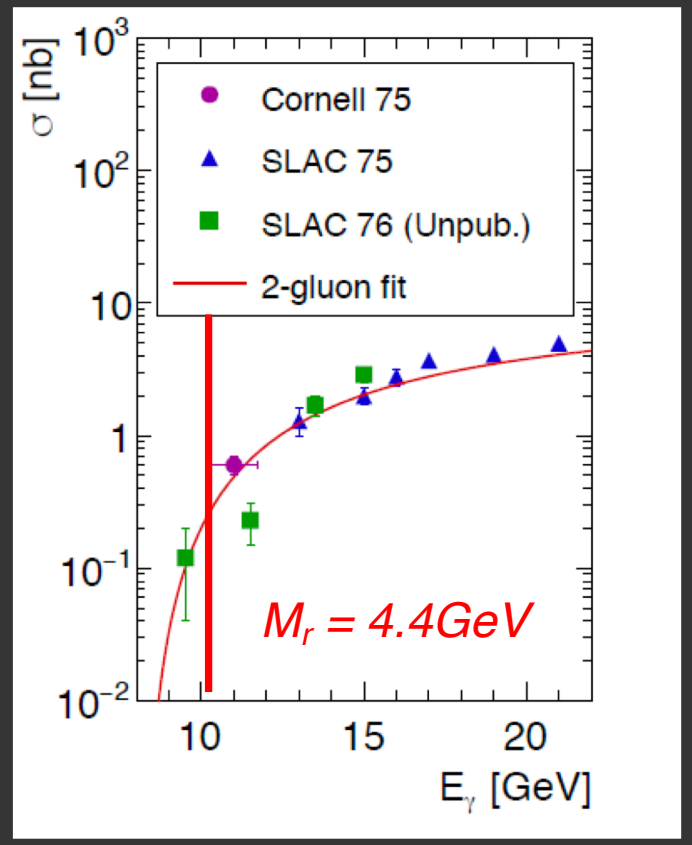
$$\gamma p \rightarrow pJ/\psi$$



The corresponding cross-section can be estimated from simple ingredients:

- Breit-Wigner elastic cross-section
- Vector Meson Dominance

Pc(4380) : 1.5 μbarn < $\sigma/(B^2_{out})$ < 50 μbarn
Pc(4450) : 12 μbarn < $\sigma/(B^2_{out})$ < 360 μbarn



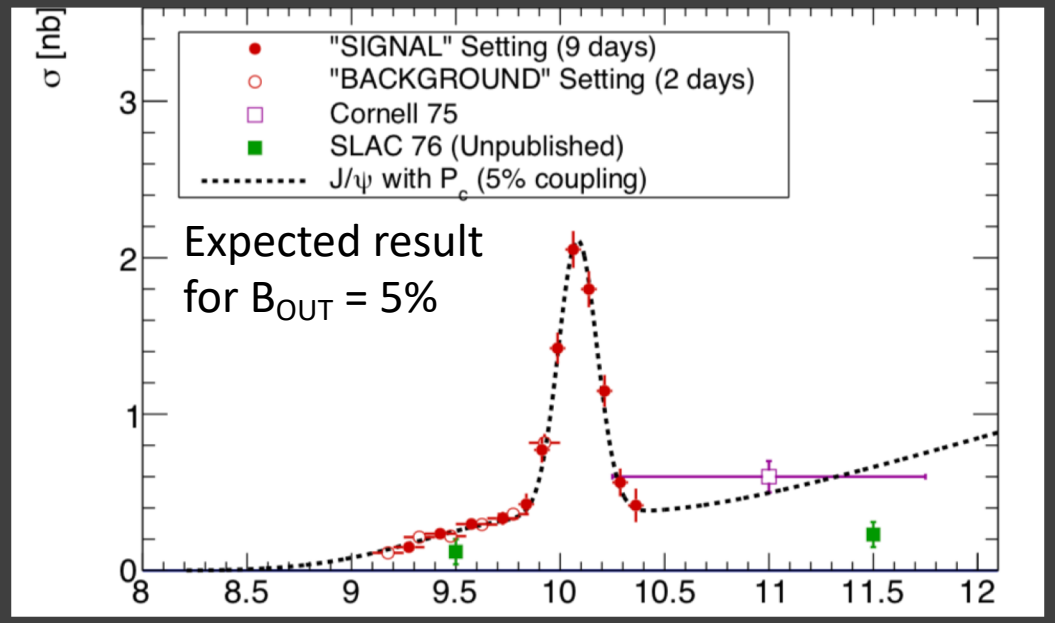
A comprehensive Pc search program is ongoing at JLab, with different experiments in all Hall

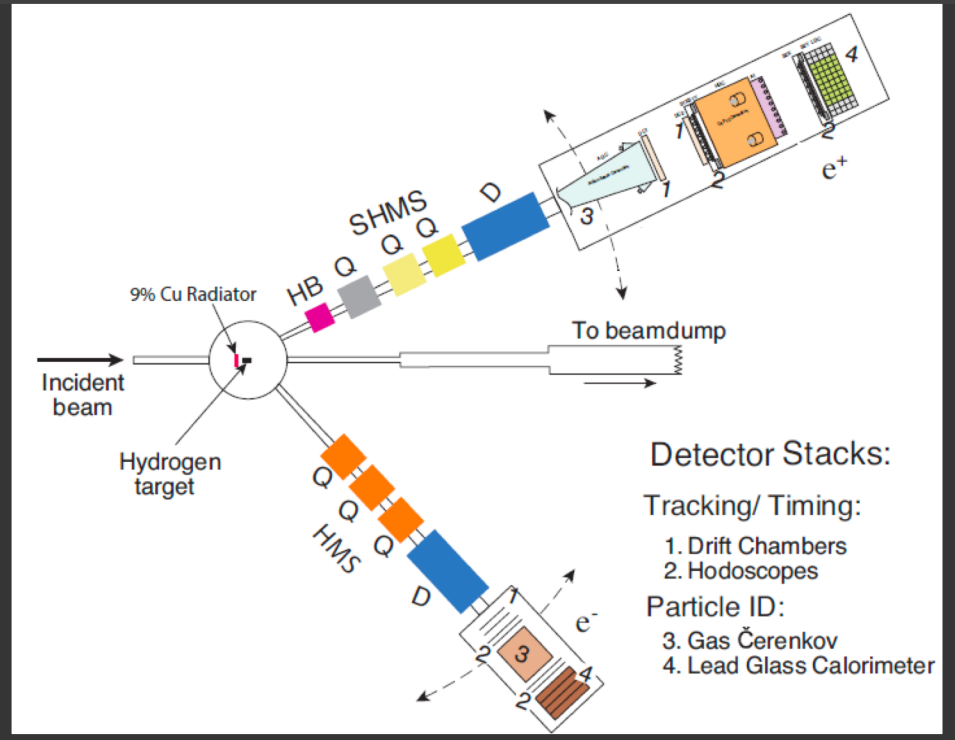
Hall-C pentaquark search

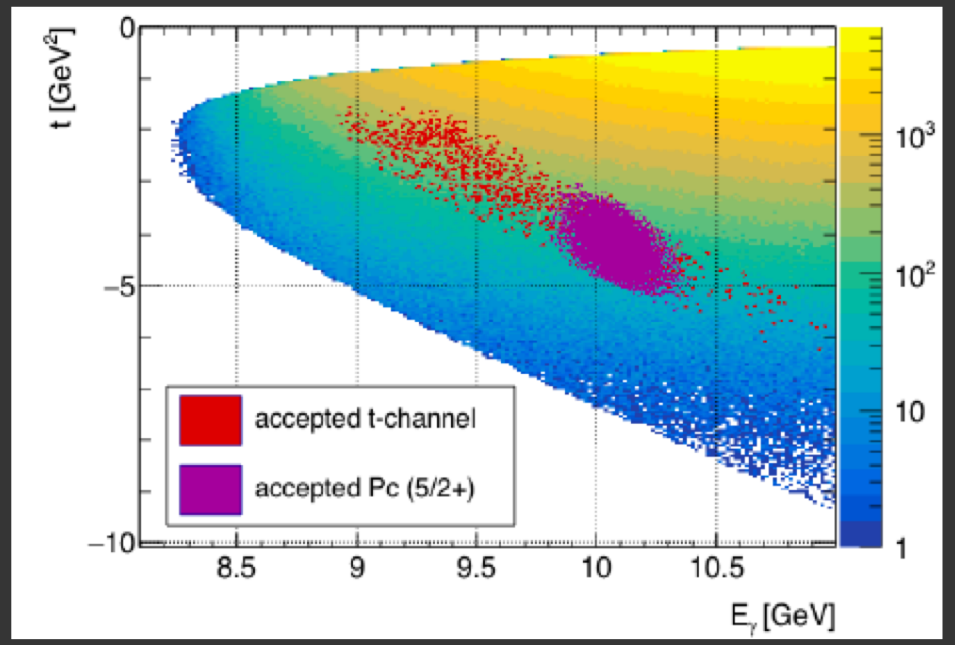
E12-16-007. Measure the elastic J/ψ photo-production on a hydrogen target through an untagged real photon beam.

High-impact experiment, scheduled for January 2019

- Bremmstrahlung photon beam: 11 GeV, 50 μA e^- beam impinging on a 9% X_0 copper radiator.
- e^+e^- pairs from J/ψ decay measured in coincidence trough the two high-momentum spectrometers, HMS and SHMS.
  - Spectrometers settings optimized to enhance s−channel resonance production over t−channel diffractive background
- Invariant mass of p- J/ψ system reconstructed *assuming elastic production*.







Hall-B pentaquark search

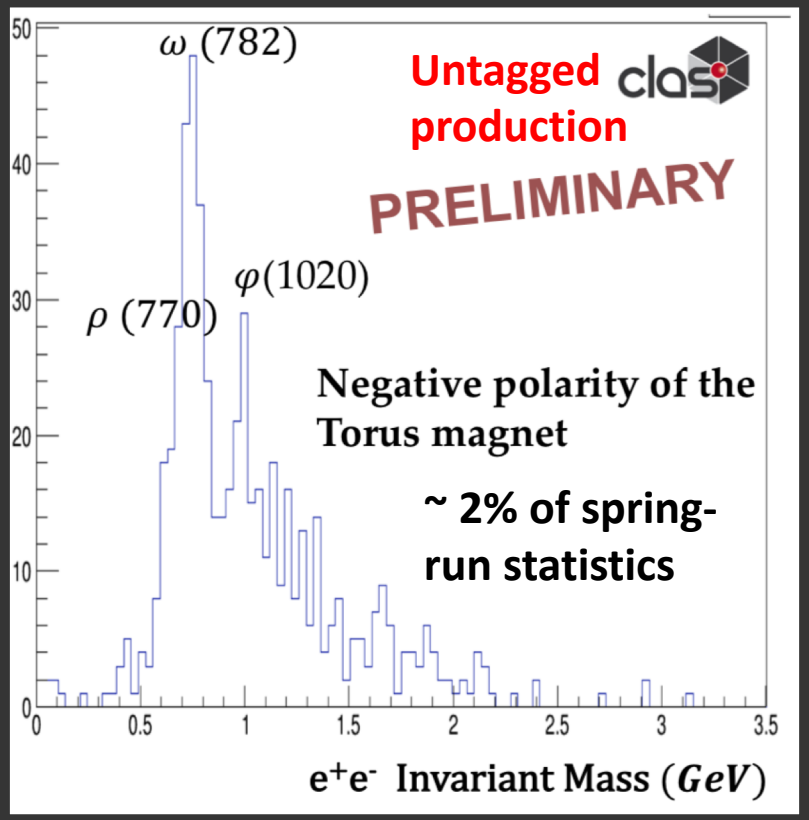
Two complementary approaches

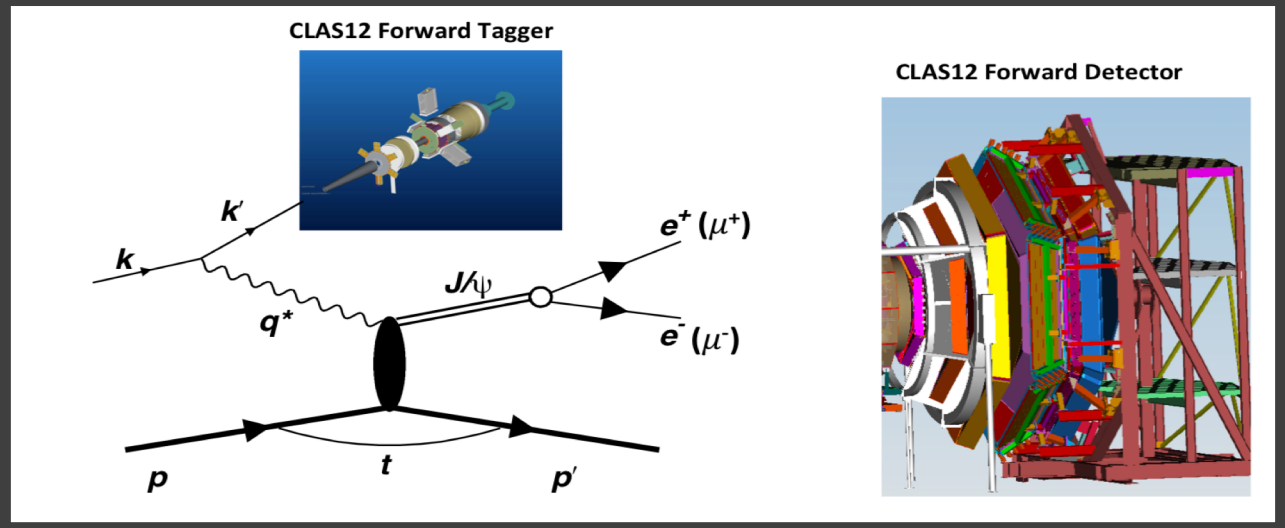
E12-11-005 MesonEx: Tagged photo-production → High resolution

- Scattered electron detected in Forward Tagger, $2.5 < E_e < 4.5$
- Measure in coincidence final state p and/or e^+e^- from J/ψ decay with CLAS12
- p- J/ψ invariant mass measured as missing mass on scattered e^- in FT

E12-12-001 Untagged photo-production → High luminosity

- Scattered electron at 0° not detected
- Measure final state p and e^+e^- from J/ ψ decay with CLAS12

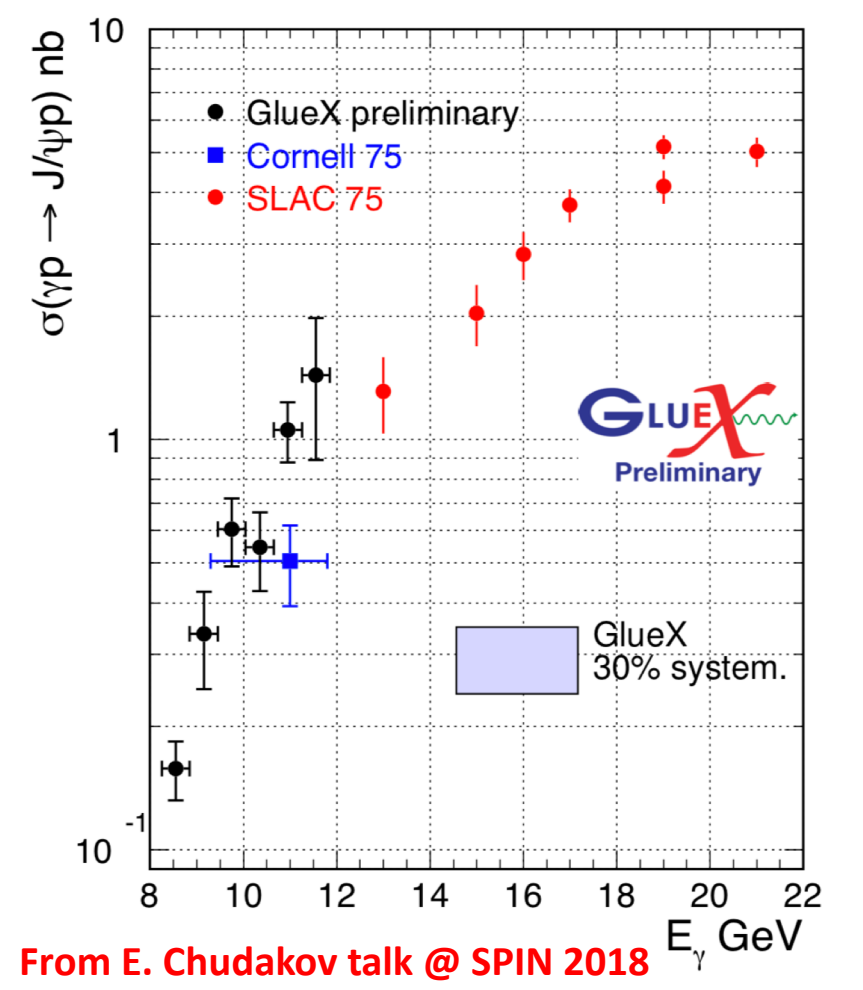




- CLAS12 successfully detected vector meson resonance through the $e^+ e^-$ decay
- **Analysis in early stage:** calibrations and procedures being optimized

From J. Newton presentation at DNP2018

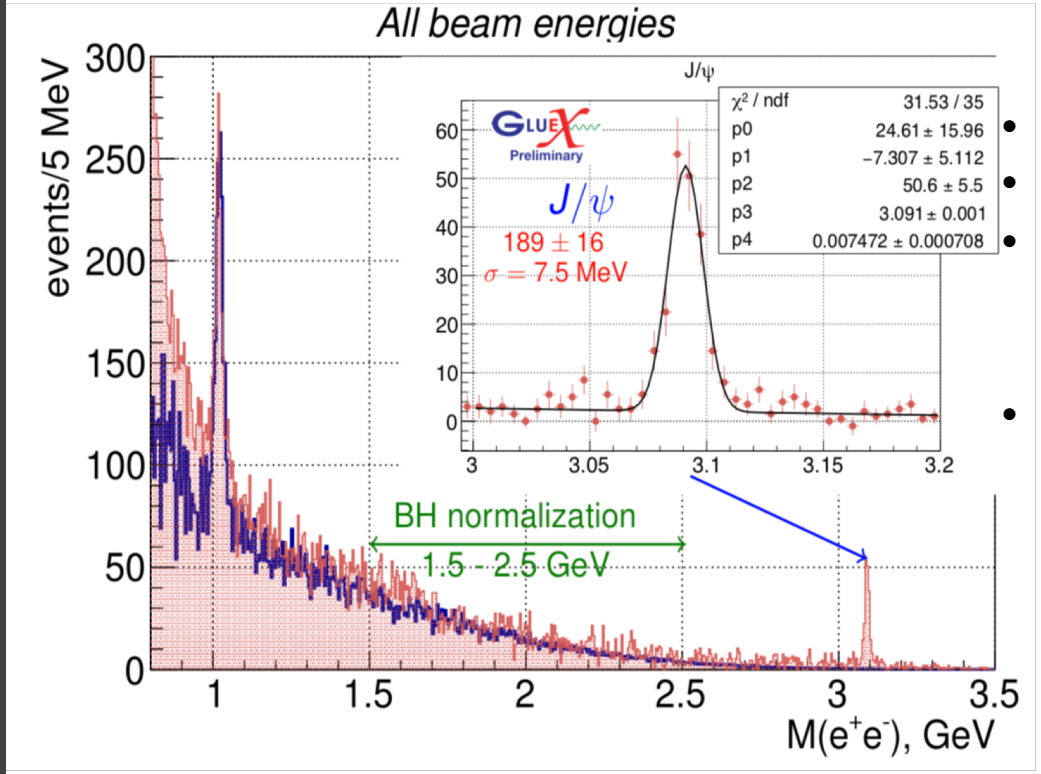
Hall-D pentaquark search



From E. Chudakov talk @ SPIN 2018

Pentaquark search with GlueX from 2016-2017 data:

$$\gamma p \to pJ/\psi \to pe^+e^-$$



- Tagged photon beam
- Measure both p and $e^+ e^-$
- Absolute normalization from Bethe-Heitler reaction
- Clear J/ψ peak in $e^+ e^-$ spectrum
  - (~ 70% 2016-2017 statistics)

Pentaquark search:

- No statistically-significant evidence for Pc pentaquark has been observed
- GlueX currently analyzing full data sample to finalize result before end of the year

Nucleon elastic form-factor measurements

Nucleon elastic electromagnetic form factors: describe the distribution of charge and magnetization in the nucleon

- Reveal the internal structure of the nucleon and nuclei, in terms of transverse spatial distribution of partons in nucleons and nuclei
- Different experimental methods for FF extraction:
  - "Traditional" elastic cross-section measurement and Rosenbluth separation
  - "Modern" technique: exploits polarization to access Ge Gm interference terms
    - Recoil polarization measurements $\mathrm{H}(\vec{e}, e'\vec{p})$ and $^2\mathrm{H}(\vec{e}, e'\vec{n})$
    - Beam-target polarization asymmetry measurement $\vec{\mathrm{H}}(\vec{e}, e'p)$

JLab FF measurement plan: **different experiments with complementary techniques**

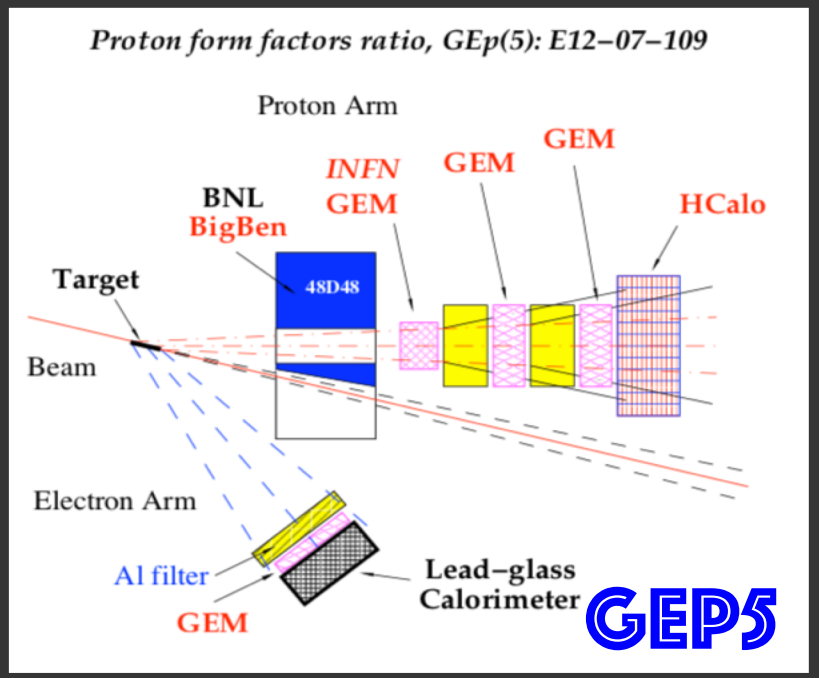
Quantity	Method	Target	$Q^2(\mathrm{GeV}^2)$	Hall	Beam Days
G_M^p *	Elastic scattering	LH_2	$7-15.5$	A	24
G_E^p/G_M^p	Polarization transfer	LH_2	$5-12$	A	45
G_M^n	$E-p/e-n$ ratio	LD_2-LH_2	$3.5-13.0$	B	30
G_M^n	$E-p/e-n$ ratio	LD_2, LH_2	$3.5-13.5$	A	25
G_E^n/G_M^n	Double polarization asymmetry	polarized $^3\mathrm{He}$	$5-8$	A	50
G_E^n/G_M^n	Polarization transfer	LD_2	$4-7$	C	50
G_E^n/G_M^n	Polarization transfer	LD_2	4.5	A	5

COMPLETED!

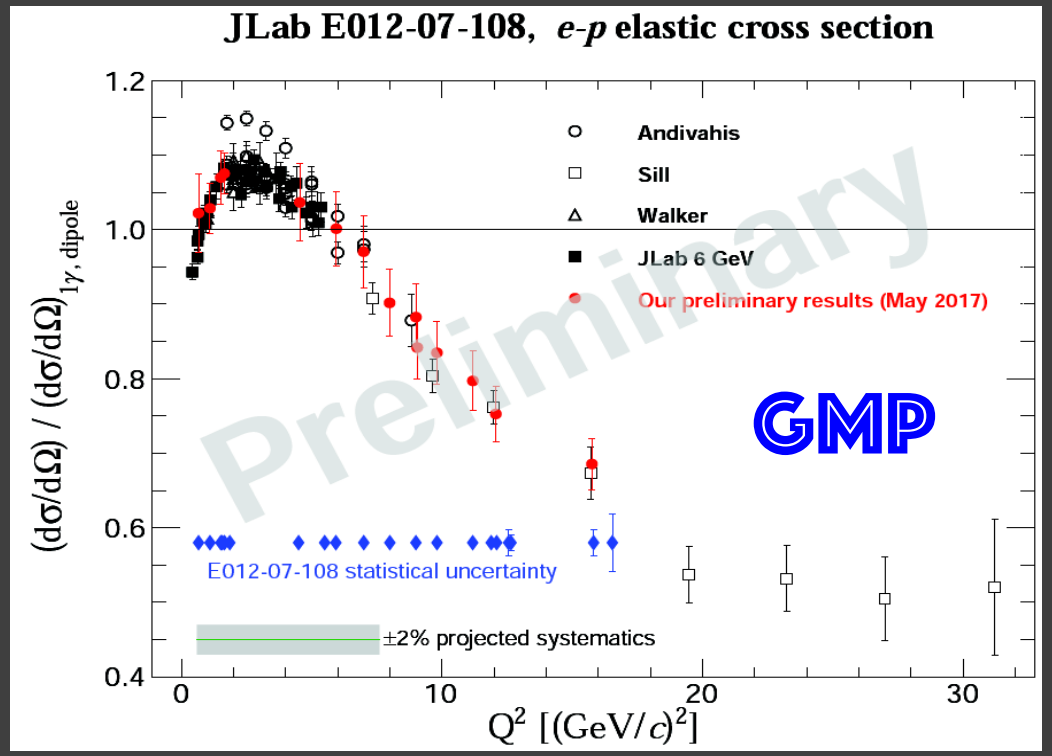
Hall-A experiments

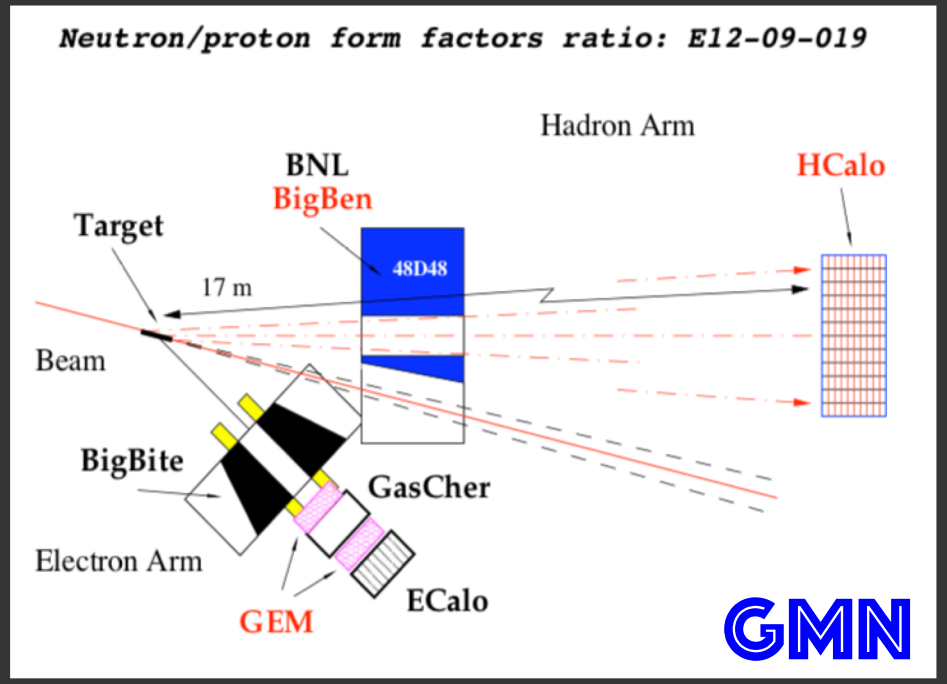
Complete measurement program exploiting two-arms spectrometer in different configurations

- Already-completed measurement of G_M^p(E12-07-108)
- New measurements foreseen in 2020: experimental setup with large INFN contribution (GEM, HCAL)



Preliminary result from E012-07-108 for ep elastic cross section in large Q^2 range – normalized to theoretical value with dipole EEFF.





GPDs measurements

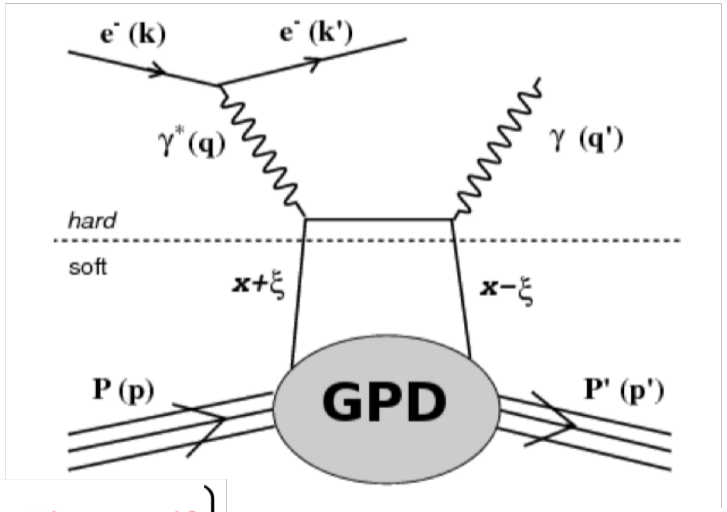
General parton distributions: correlations of longitudinal momentum and transverse position.
"Bidimensional version" of elastic form-factors

- Accessible via Deep Inelastic exclusive processes: DVCS and TCS
  - DVCS: $e^- N \to e^- N \gamma$
  - TCS: $\gamma N \to e^- N e^+ e^-$

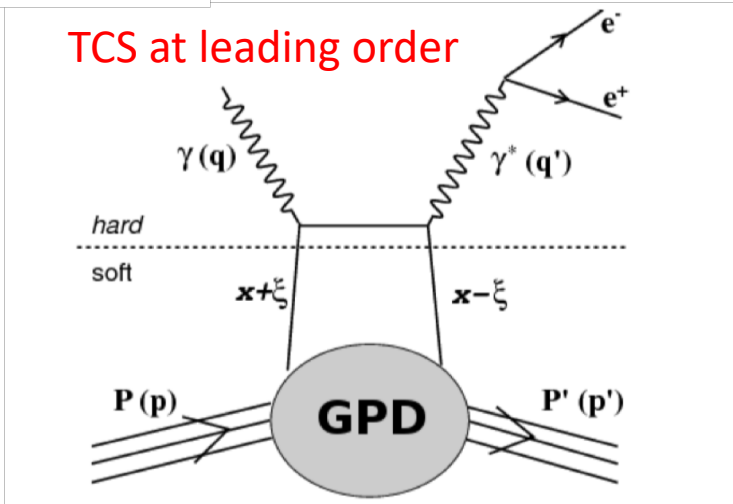
GPDs appear in DVCS / TCS through the Compton Form Factor: the two processes are sensitive to different parts of it.

$$\mathcal{H} = \sum_q e_q^2 \left\{ \mathcal{P} \int_{-1}^{1} dx H^q(x,\xi,t) \left[\frac{1}{\xi - x} - \frac{1}{\xi + x} \right] + i\pi \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t) \right] \right\}$$

DVCS at leading order



TCS at leading order



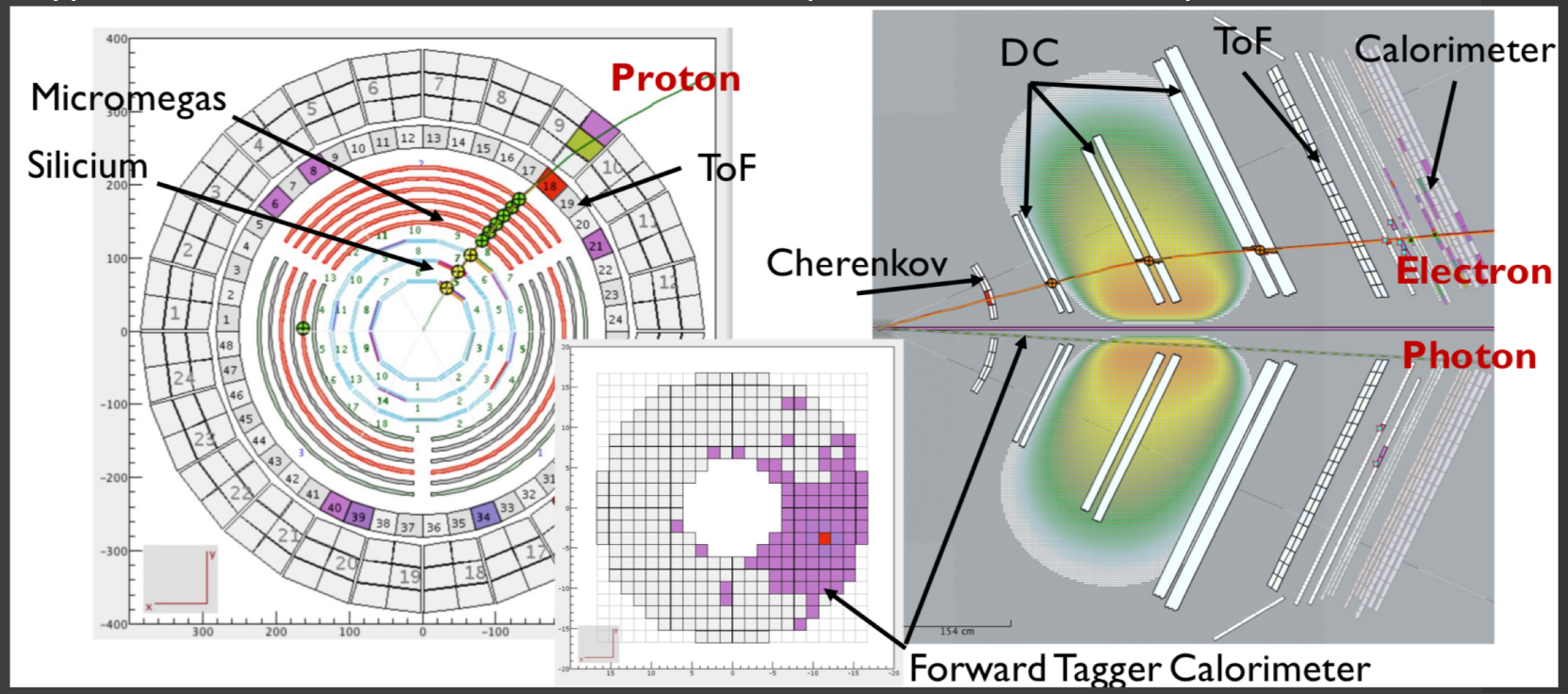
Imaginary part: DVCS spin asymmetries
Real part: DVCS cross-section / TCS angular distribution

Hall-B experiments

Exploit CLAS12 large acceptance spectrometer to measure the DVCS/TCS exclusive reactions in large phase-space area + Forward Tagger small-angle calorimeter to measure final state γ in DVCS

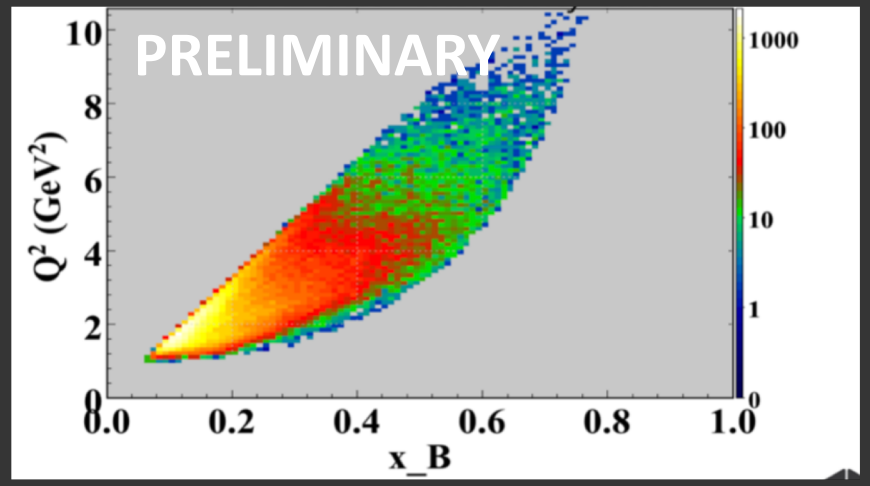
RG-A (2018): proton-target @ 11 GeV *Almost-complete run!*
RG-K (2018): proton-target @ 6.6 GeV
RG-B (2019): neutron-target @ 11 GeV

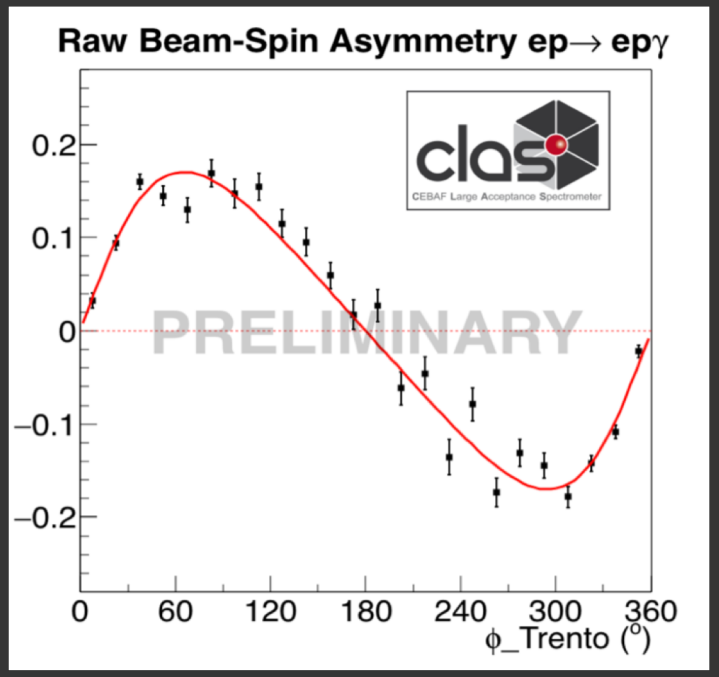
Typical DVCS event: e^- in CLAS12 Forward, p in CLAS12 central, γ in FT



PRELIMINARY RESULTS from RG-A

Events kinematics after exclusivity cuts



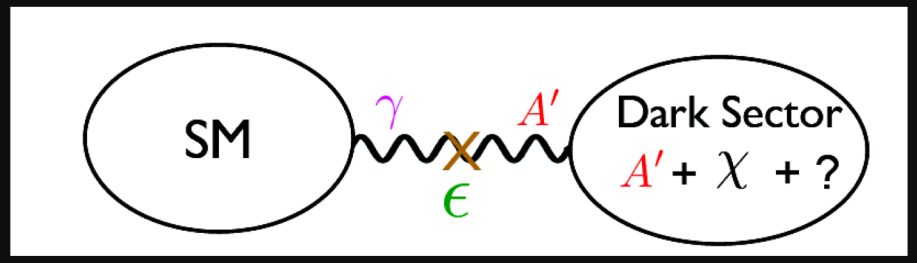


From G. Christiaens presentation at DNP2018

Search for light dark matter

Light dark matter (100-MeV range) is a new hypothesis to the explain the gravitationally observed relic abundance, alternative to the traditional WIMP (10-GeV range) hypothesis

- LDM requires a new interaction mechanism between the SM and the dark sector. The simplest: DM-SM interaction through a new U(1) gauge-boson ("dark-photon")



Accelerator based experiments in the GeV energy range are the ideal tool to search for LDM (direct-detection experiments have limited sensitivity to LDM – too low energy recoil)

At JLAB, a **comprehensive LDM experimental program** is running investigate both the existence of LDM particles and of dark photons

BDX @ JLAB

DARKLIGHT

APEX

HEAVY PHOTON SEARCH

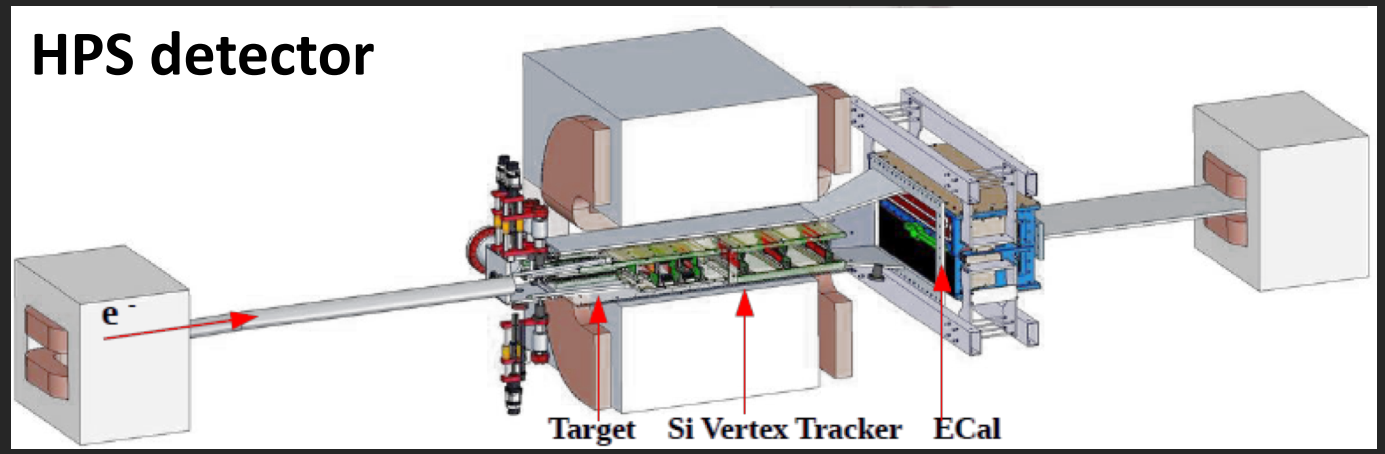
HPS experiment

HPS experiment in Hall-B: fixed-target A' search

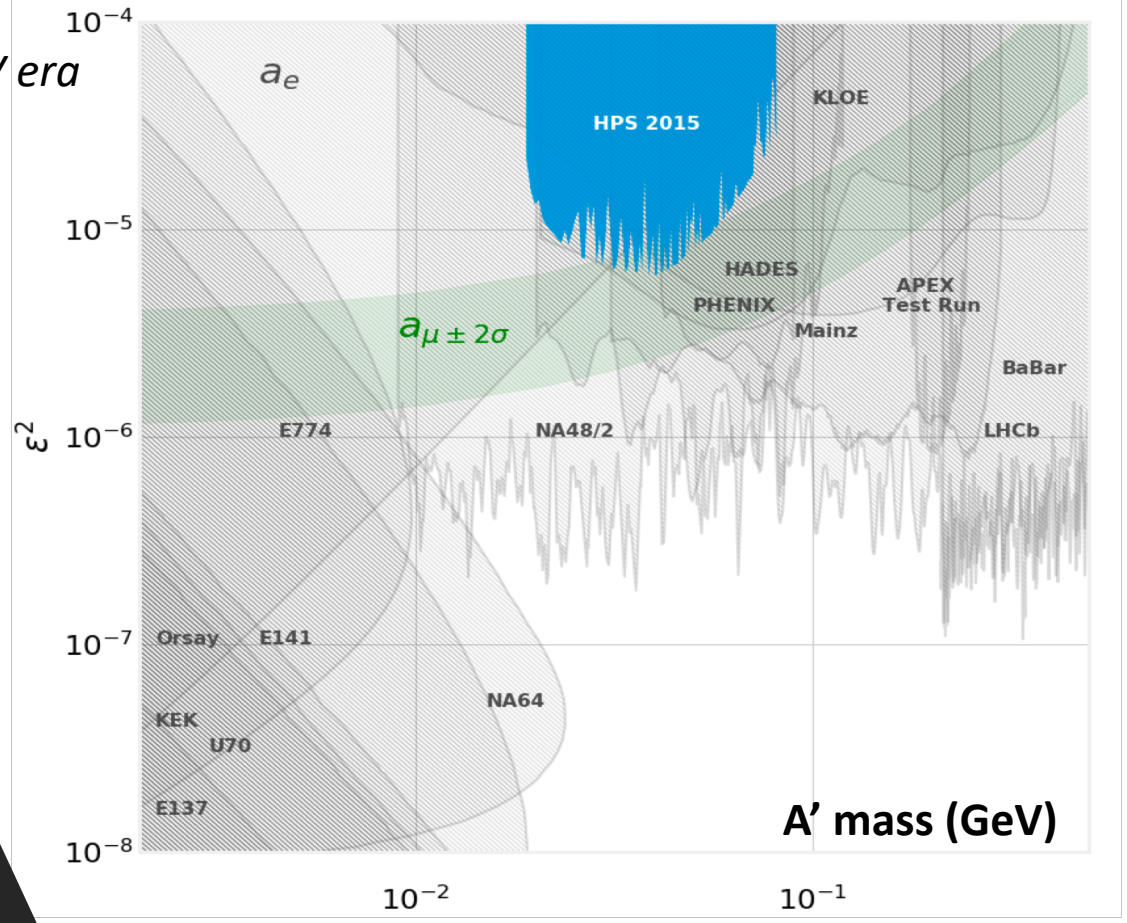
A' production via Bremsstrahlung-like process by e^- beam
A' detection via $e^+ e^-$ decay

Runs: 2015 (1.1 GeV) / 2016 (2.2 GeV)
Detector: compact forward spectrometer

- Thin W target ($10^{-3}X_0$)
- Dipole magnet and 6-layers Si-tracker for momentum analysis and vertexing
- $PbWO_4$ calorimeter for triggering and PID



First 12-GeV era publication from Hall-B



HPS **just published** exclusion limit from the analysis of the 2015 dataset (1.7 PAC days out of 180 approved)

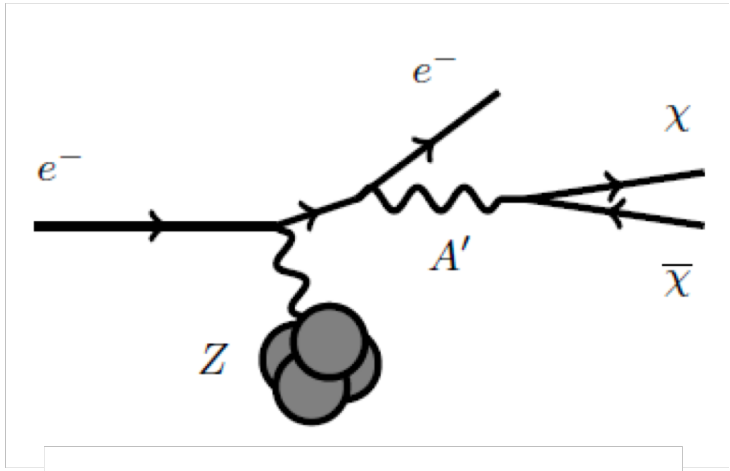
- The search established that **HPS operates as designed**
- No new territories have been explored
- Looking forward 2019 data taking

BDX experiment

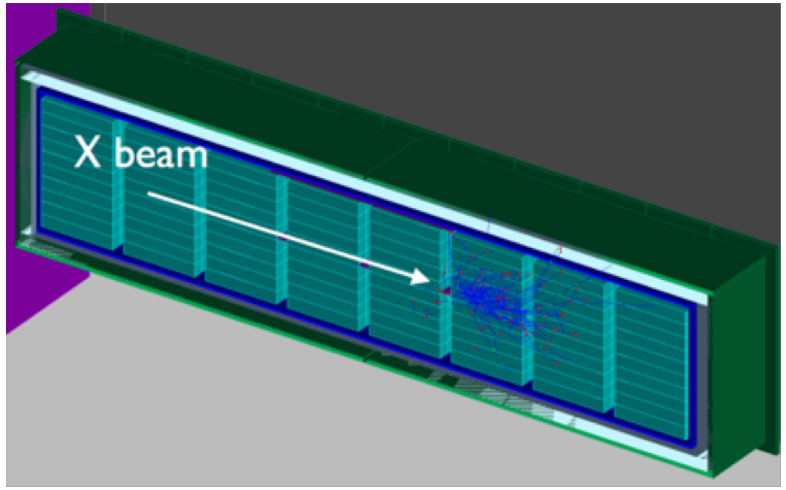
Beam Dump eXperiment: LDM direct detection in a e^- beam, fixed-target setup

LDM production

- High-energy, high-intensity e^- beam impinging on the dump
- LDM particles pair-produced radiatively, through A' emission

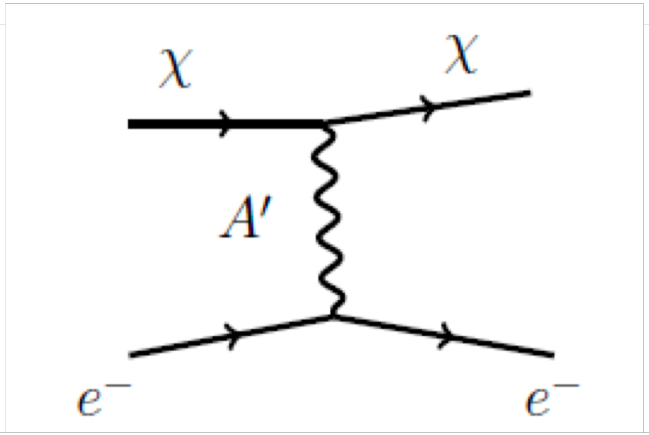


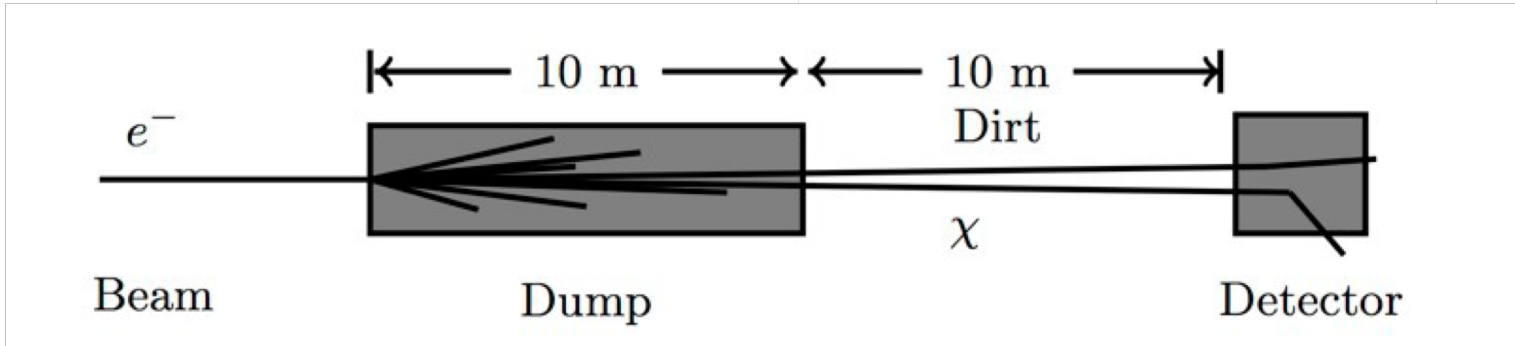
BDX detector: CsI(Tl)-based EM calorimeter, surrounded by two plastic-scintillator active veto layers



LDM detection

- Detector placed behind the dump at ~ 20m
- Neutral-current scattering on atomic e^- through A' exchange, recoil releasing visible energy
- Signal: high-energy - O(GeV) - EM shower



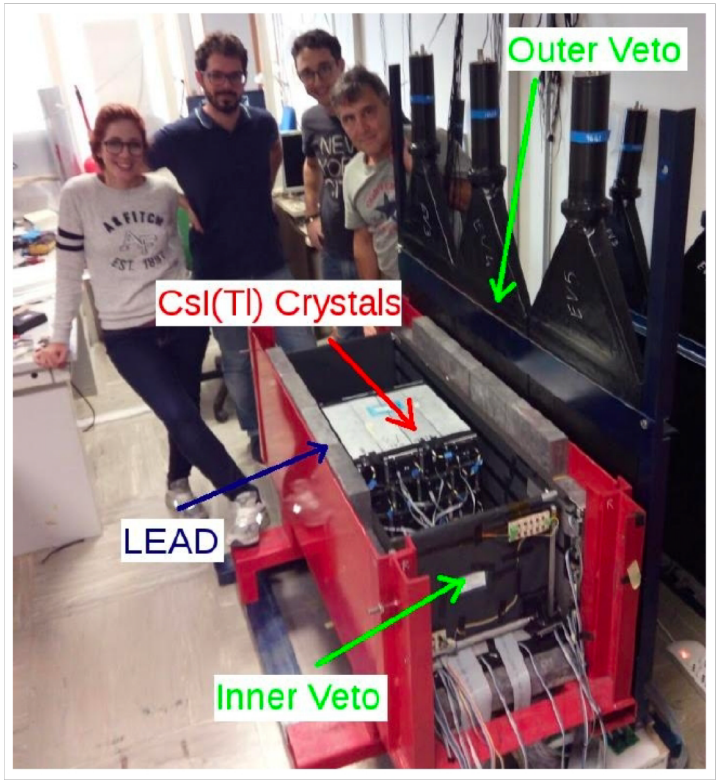


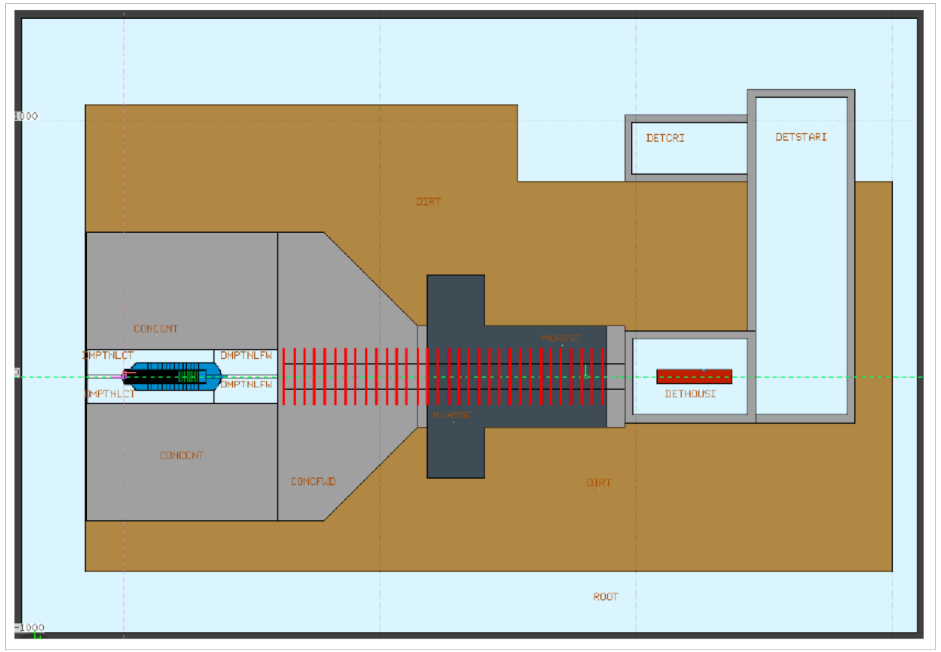
BDX experiment

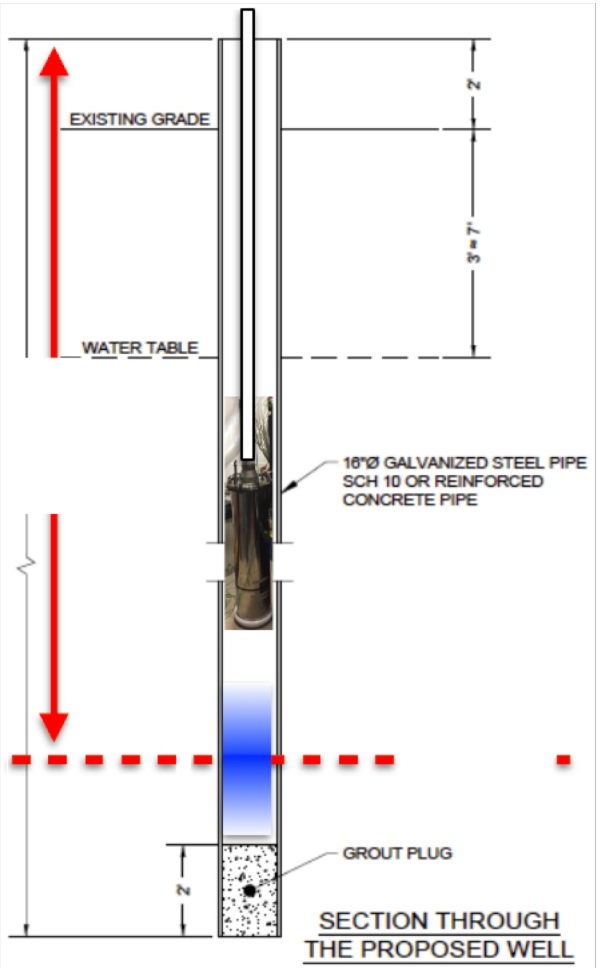
The BDX experiment proposal was supported by dedicated simulations and measurements of the foreseen background

- **Beam-unrelated (cosmogenic) background:** characterization of a small-scale prototype at INFN-LNS and INFN-CT in a similar overburden configuration.
- **Beam-related background:** Fluka-based MC simulations + on-site measurement behind Hall-A beam dump*, without shielding*, to evaluate the yield of muons and validate MC.

Experimental results are in very good agreement with simulations – results are being finalized toward a publication.





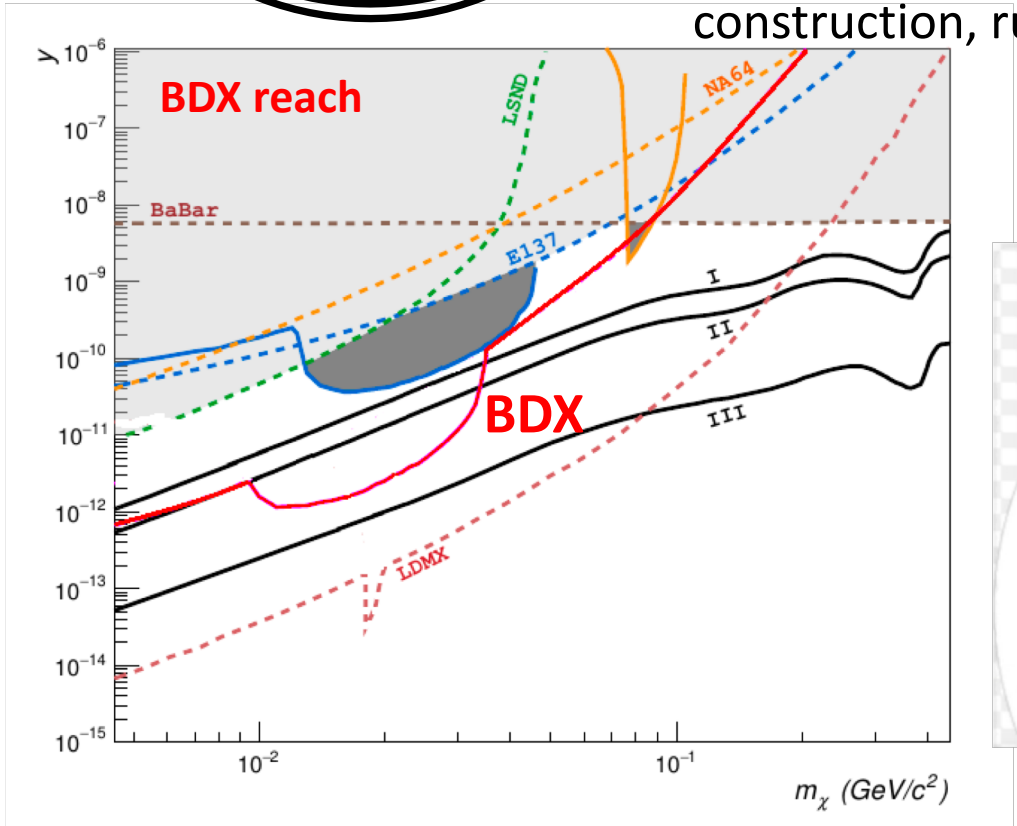


BDX experiment

BDX was officially approved by JLAB PAC46 in July 2018 with the highest scientific rating

The collaboration is currently working with JLab on designing the new facility and secure funding for the construction

Possible timeline: exploits 2020 long shutdown for construction, run in 2021-2022.



Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab

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