DDVCS with SoLID

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Jefferson Laboratory Hall A

VT GPDs workshop

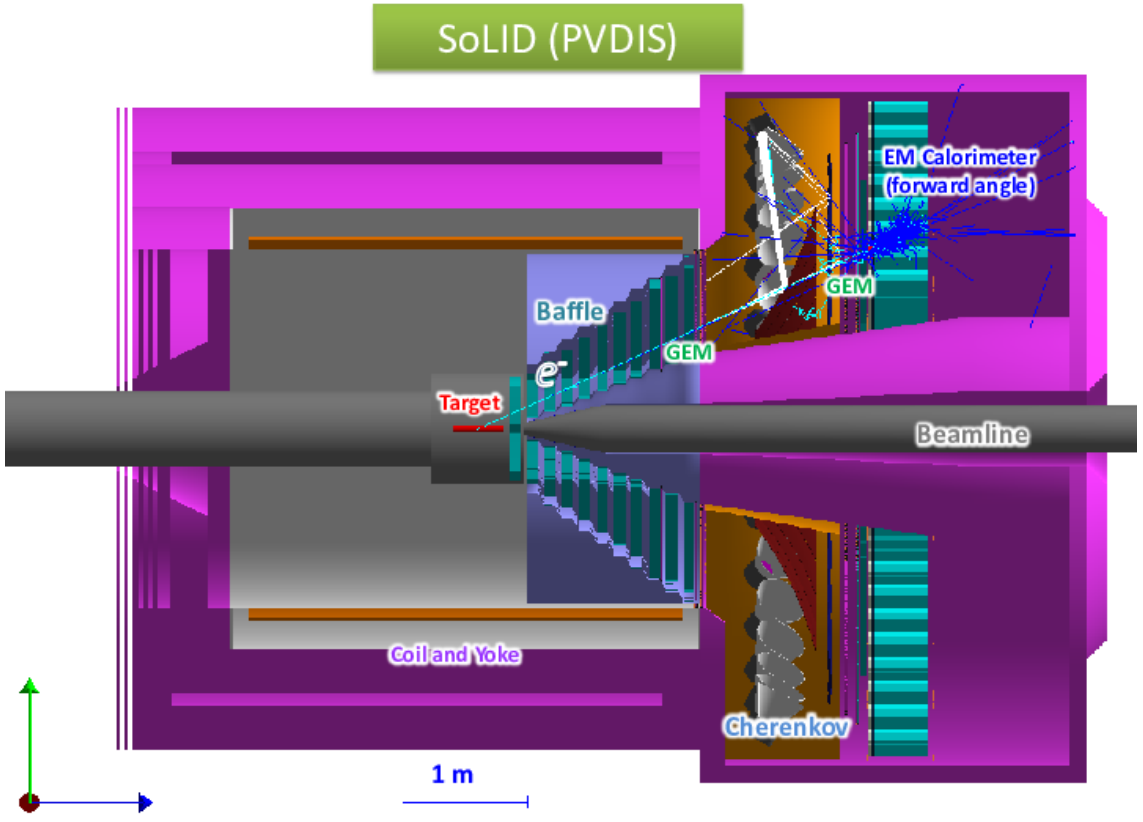
July 18th 2022

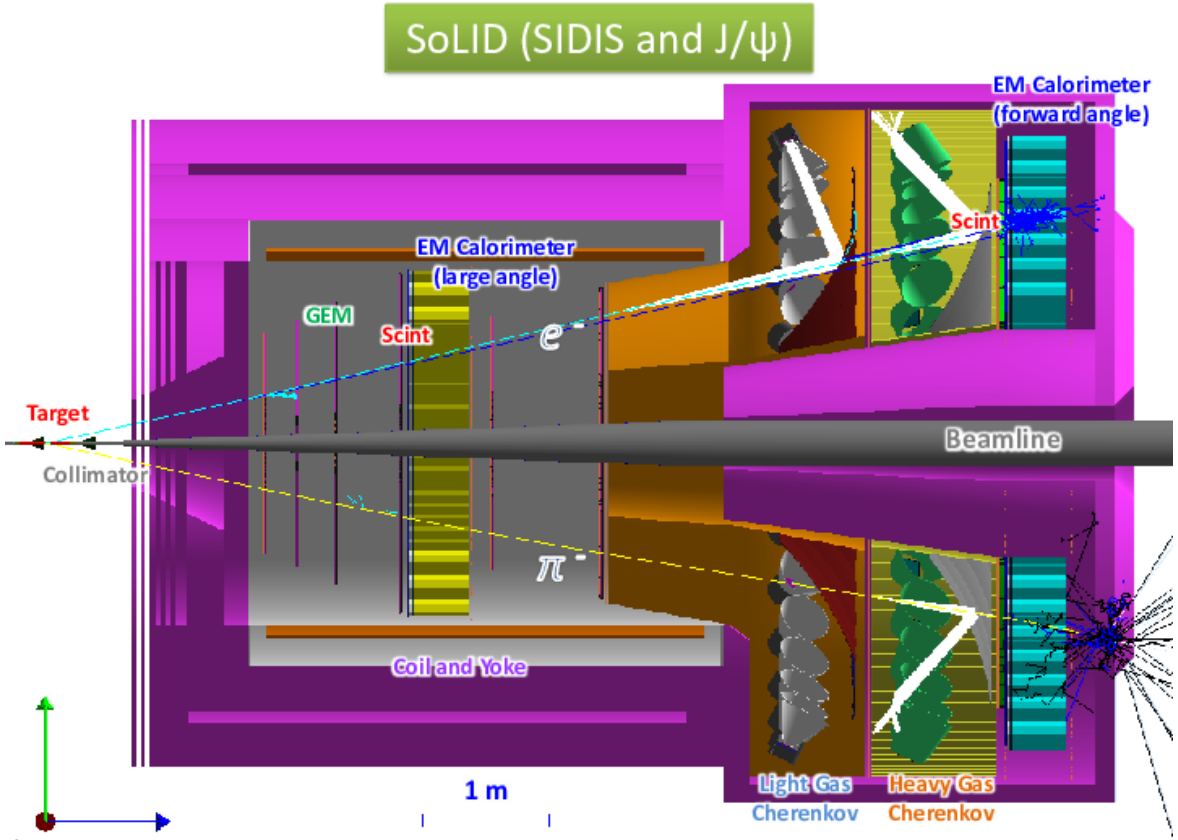
Outline

- SoLID overview
- SoLID DDVCS using J/Psi setup
- SoLID DDVCS using dedicated setup
- SBS GEM operation experience
- Future plans
- Conclusion

SoLID program

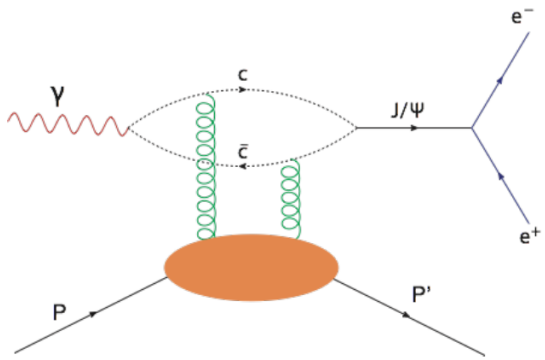
- SoLID detector : CLEO magnet + GEM trackers + Cerenkov + ECal
- 2 detector setup : PVDIS 60 uA, SIDIS 15 uA He3, J/Psi 3uA 15 cm LH2 target

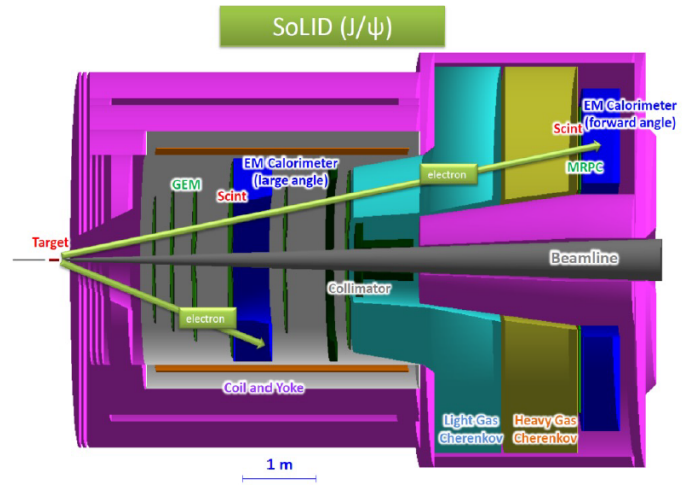


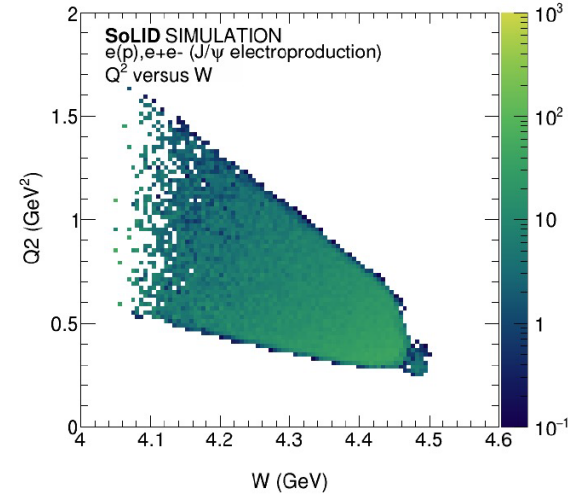


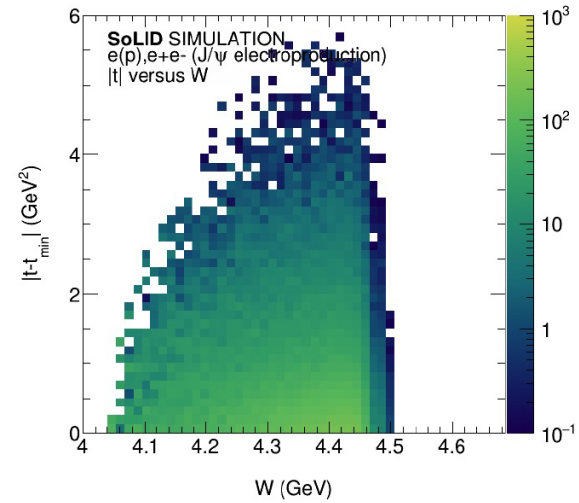
SoLID Experiment Overview

- 50 days of $3\,\mu\mathrm{A}$ beam on a 15 cm long LH_2 target at $1 \times 10^{37}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - 10 more days include calibration/background run
- SoLID configuration overall compatible with SIDIS
  - **Electroproduction trigger**: 3-fold coincidence of e, e^-e^+
  - **Photoproduction trigger:** 3-fold coincidence of p, e^-e^+
  - **Additional trigger:** 4-fold coincidence of ep, e^-e^+
  - And (inclusive) 2-fold coincidence e^+e^-









$$e^- + p \longrightarrow e^- + p + J/\psi\,(e^+ + e^-)$$

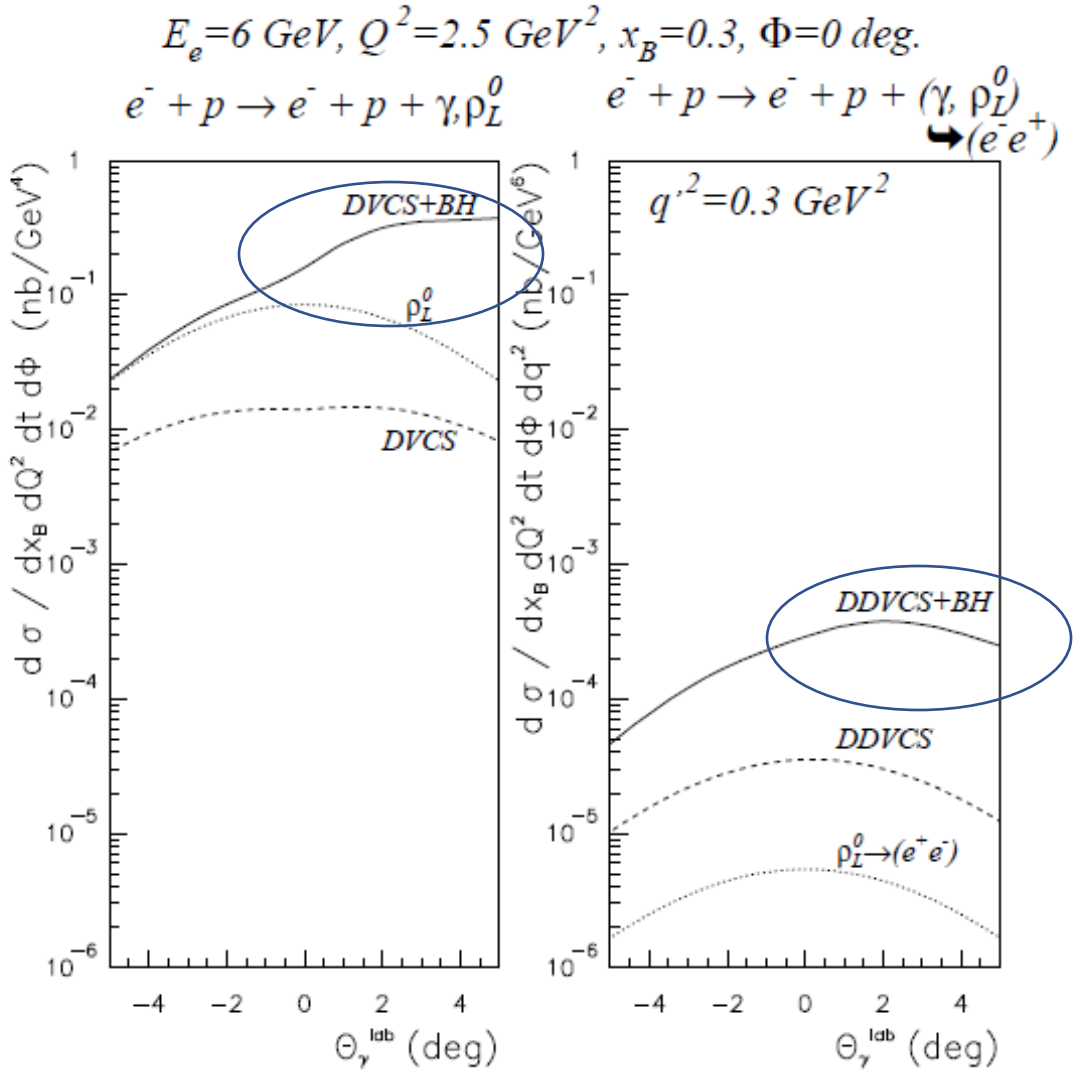
DVCS / Double DVCS

$$\gamma^* + p \longrightarrow \gamma'(*) + p'$$

$$\gamma'(*) \longrightarrow l^+ + l^-$$

Guidal and Vanderhaegen : Double deeply virtual Compton scattering off the nucleon (arXiv:hep-ph/0208275v1 30 Aug 2002)
Belitsky Radyushkin : Unraveling hadron structure with generalized parton distributions (arXiv:hep-ph/0504030v3 27 Jun 2005)

DDVCS cross section



- VGG model
- Order of ~0.1 pb = 10^{-36}cm^2
- About 100 to 1000 smaller than DVCS
- Virtual Beth and Heitler
- Interference term enhanced by BH
- Contributions from mesons small when far from meson mass

Double Deeply Virtual Compton Scattering

$\Delta = p1-p2 = q2-q1$

$p = p1+p2$

$q = ½ (q1+q2)$

$Q^2 = -q^2$

$\xi = \frac{Q^2}{2p.q}$

$\eta = \frac{\Delta.q}{p.q}$

scattered proton

$Q^2 = -(k-k')^2$

$x_{bj} = \frac{Q^2}{2p_1q_1}$

scattered electron

outgoing virtual photon

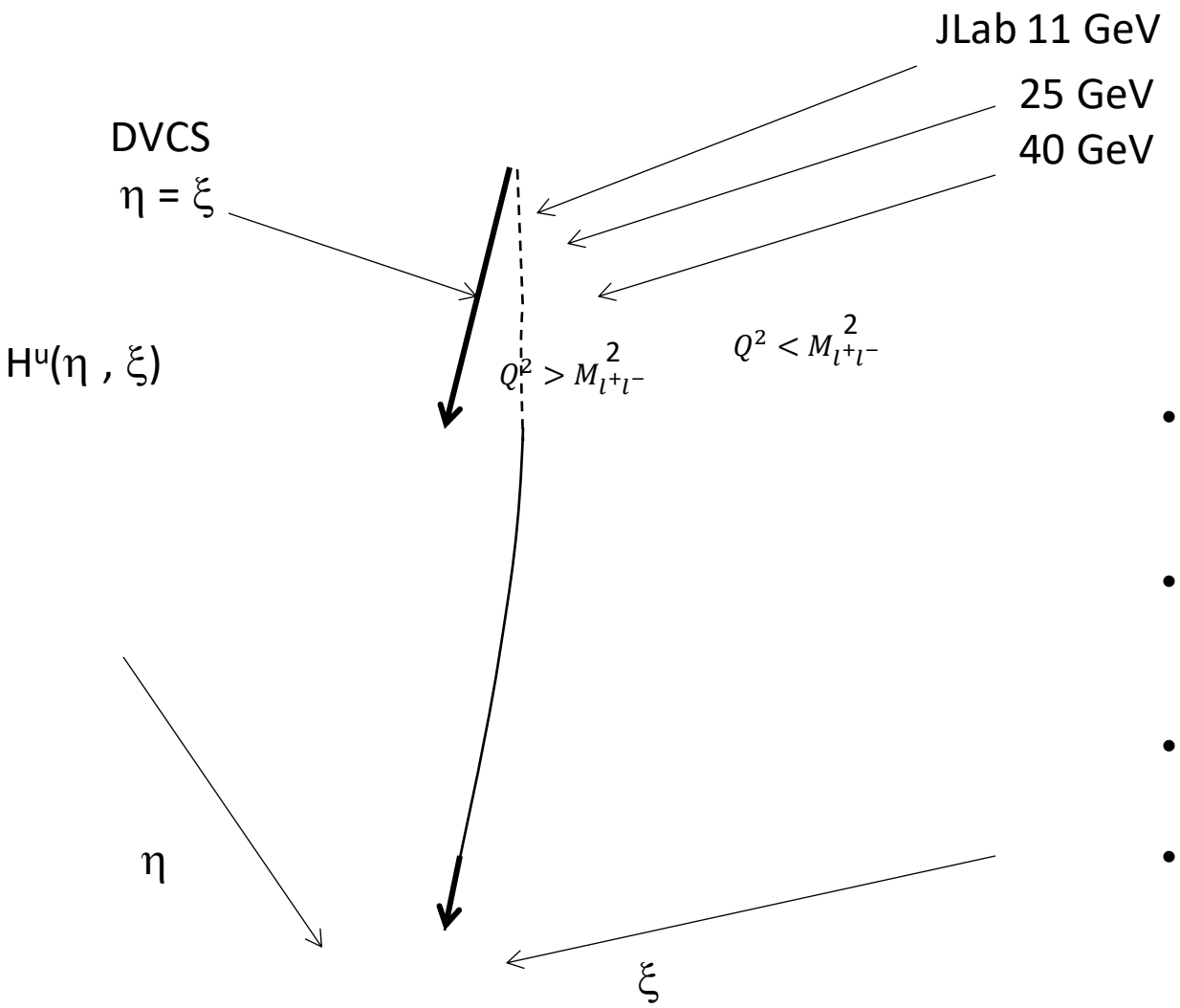
lepton pair from virtual photon

Belitsky Radyushkin : Unraveling hadron structure with generalized parton distributions (arXiv:hep-ph/0504030v3 27 Jun 2005)

$$\left\{ \begin{array}{c} A_{\rm LU}^{\sin\phi} \\ A_{\rm LU}^{\sin\varphi_\mu} \end{array} \right\} = \frac{1}{\mathcal{N}} \int_{\pi/4}^{3\pi/4} d\theta_\mu \int_0^{2\pi} d\varphi_\mu \int_0^{2\pi} d\phi \left\{ \begin{array}{c} 2\sin\phi \\ 2\sin\varphi_\mu \end{array} \right\} \frac{d^7\overrightarrow{\sigma} - d^7\overleftarrow{\sigma}}{dx_B\, dy\, dt\, d\phi\, dQ'^2\, d\Omega_\mu}$$

$$\propto \Im\mathrm{m} \left\{ F_1\mathcal{H} - \frac{t}{4M_N^2} F_2\mathcal{E} + \xi(F_1+F_2)\widetilde{\mathcal{H}} \right\} ,$$

Kinematical coverage

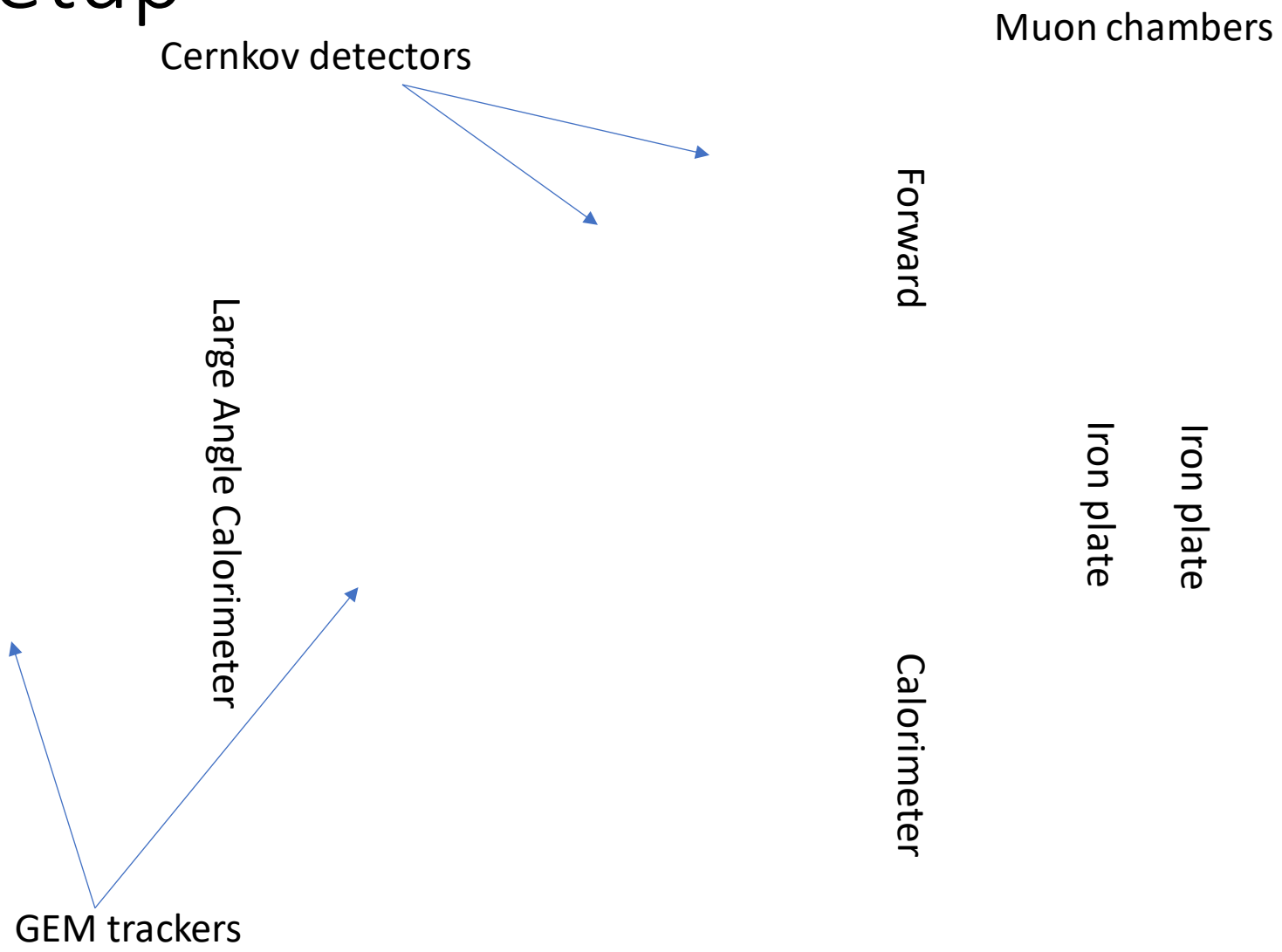


- DVCS only probes η = ξ line
- Example with model of GPD H for up quark
- Jlab : $Q^2>0$
- Kinematical range increases with beam energy (larger dilepton mass)

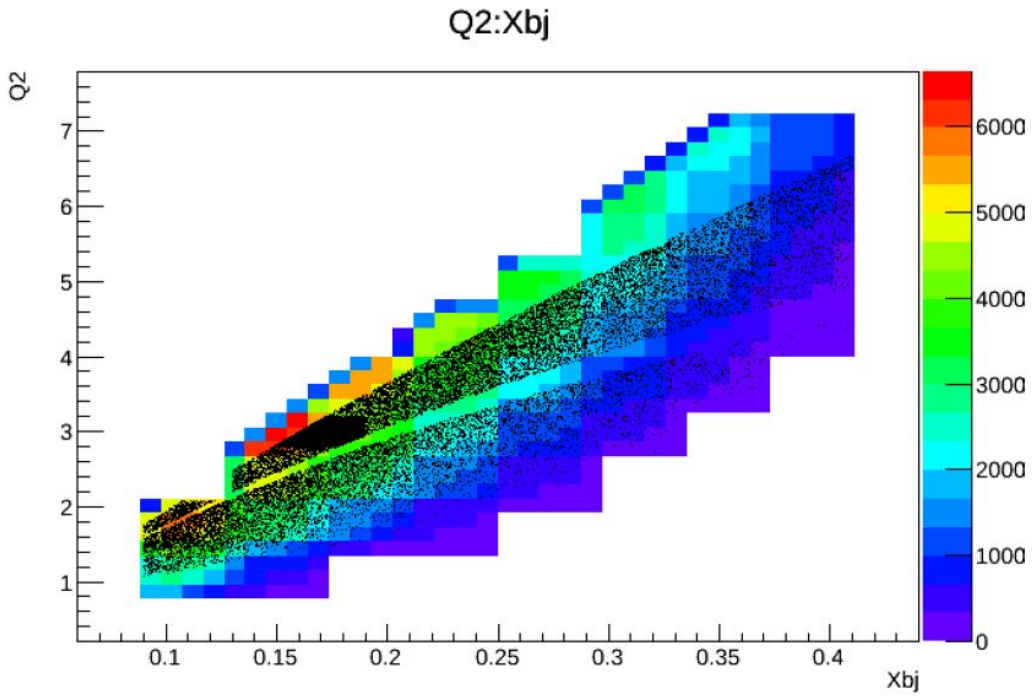
DDVCS LOI

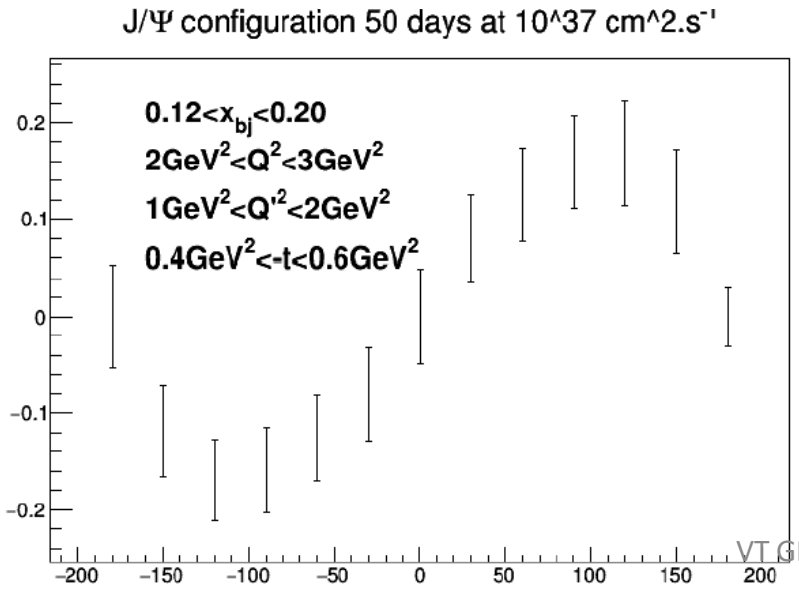
- PAC 43 : Measurement of Double Deeply Virtual Compton Scattering (DDVCS) in the di-muon channel with the SoLID spectrometer (Boer,Camsonne,Gnanvo,Sparveri,**Voutier**,Zhao)

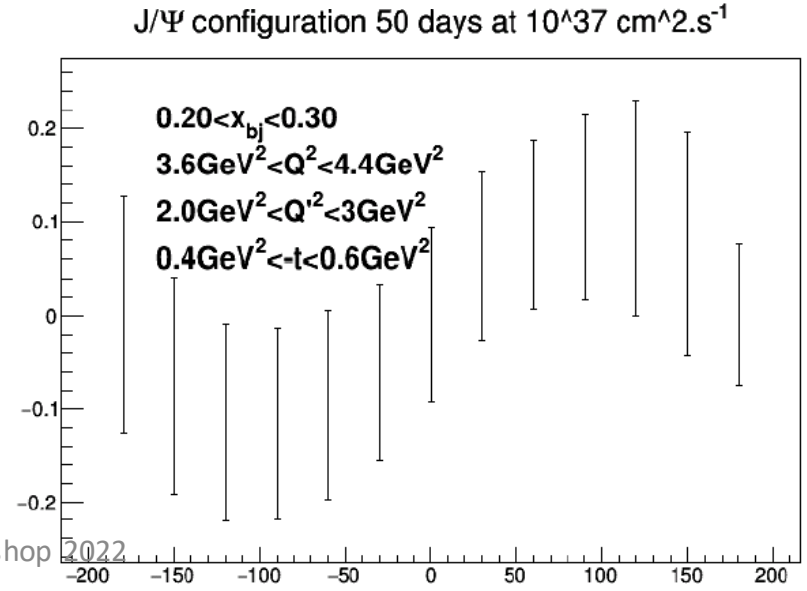
SoLID JPsi Setup



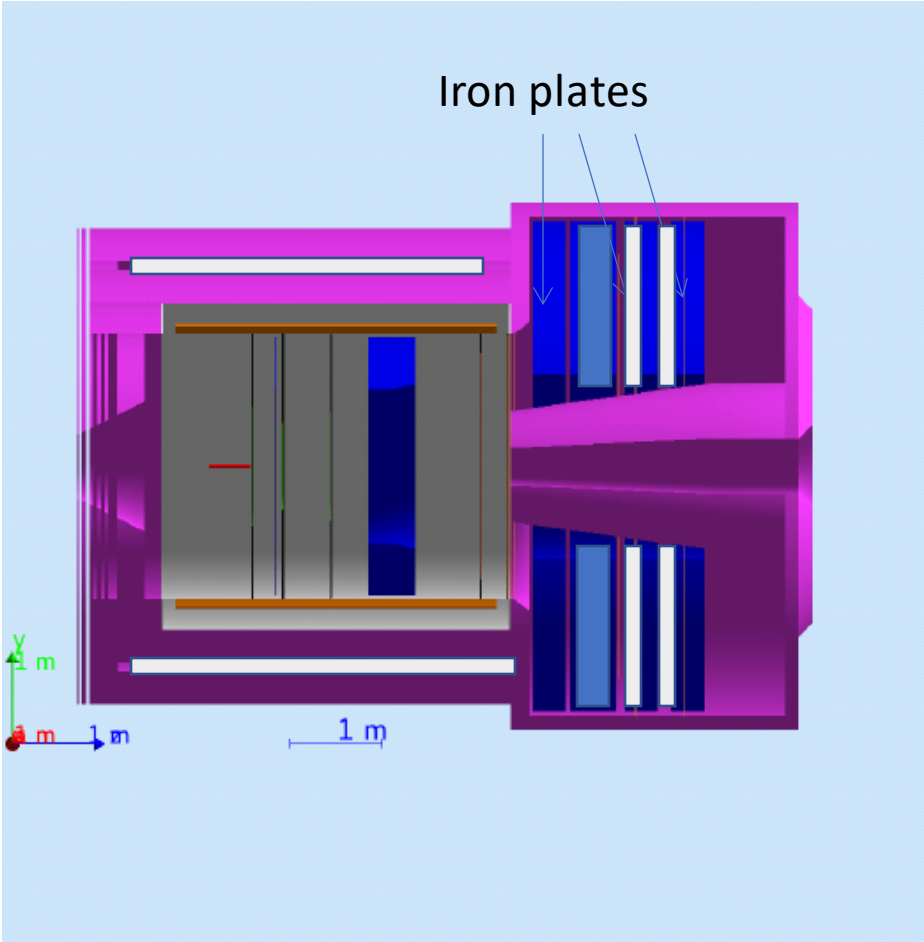
Counts J/psi setup 60 days at 10^37 $cm^{-2}s^{-1}$







Dedicated setup

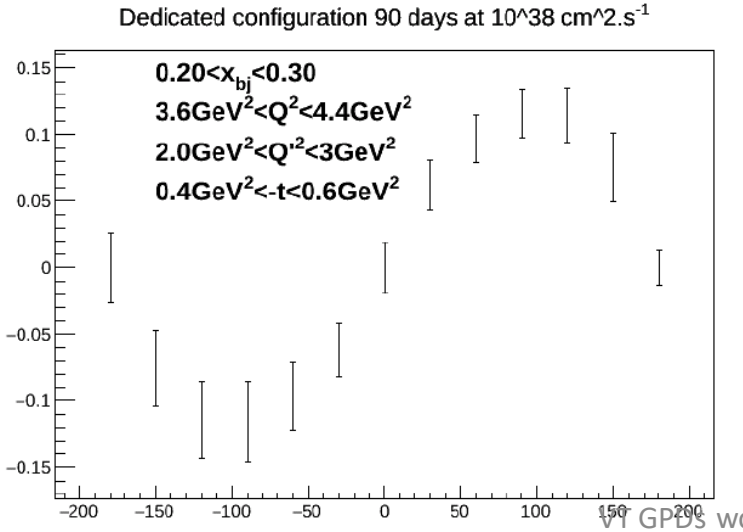


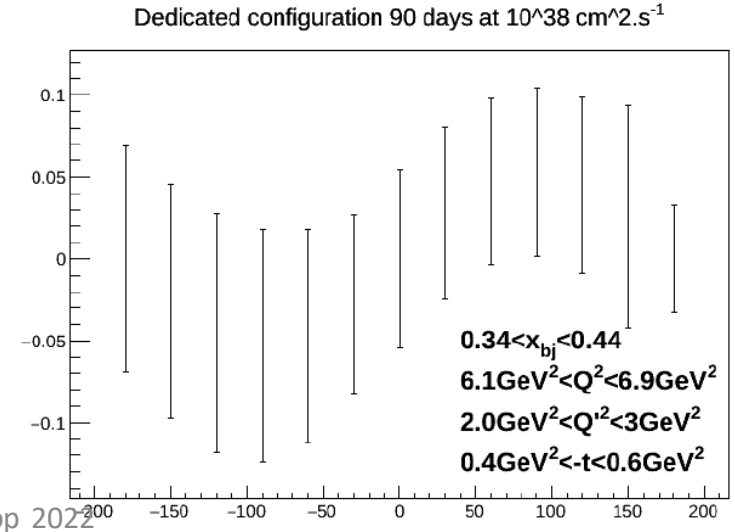
- Target moved 2m from Jpsi position inside and switch to 45 cm target
- Iron plate from 3rd layer yoke in front and behind calorimeter

- Remove Gas Cerenkov

- Try to reach 10^{38} $cm^{-2}s^{-1}$
- 10 uA on 45 cm target

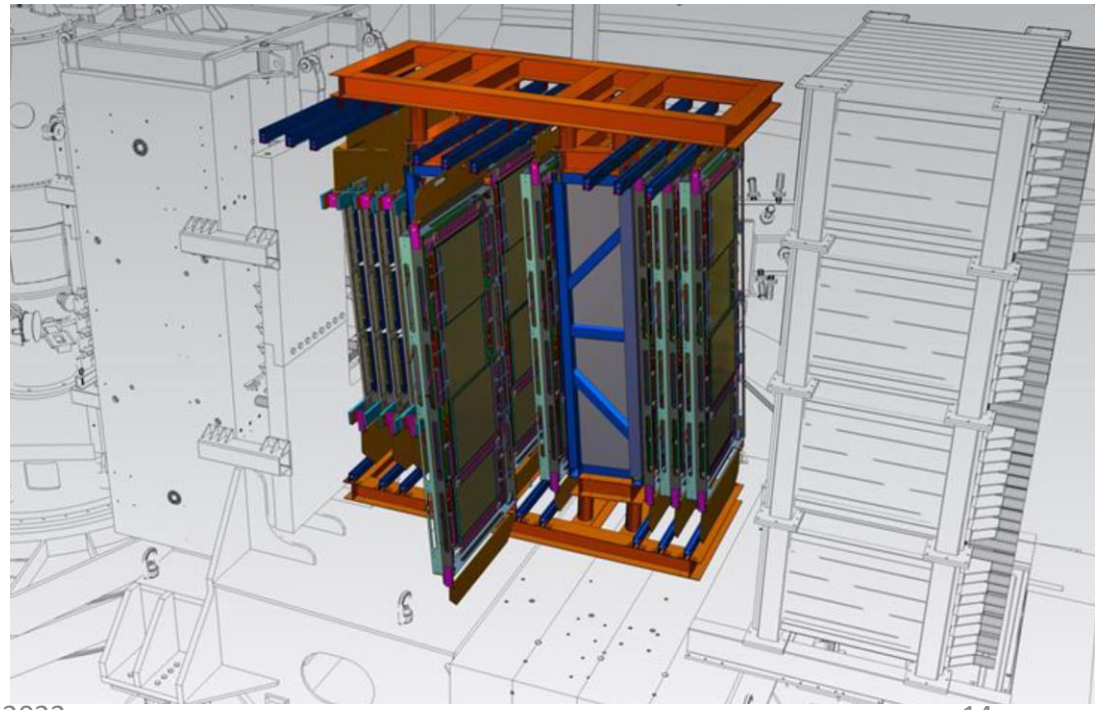
Expected accuracy dedicated setup 90 days at 10^{38} $cm^{-2}s^{-1}$





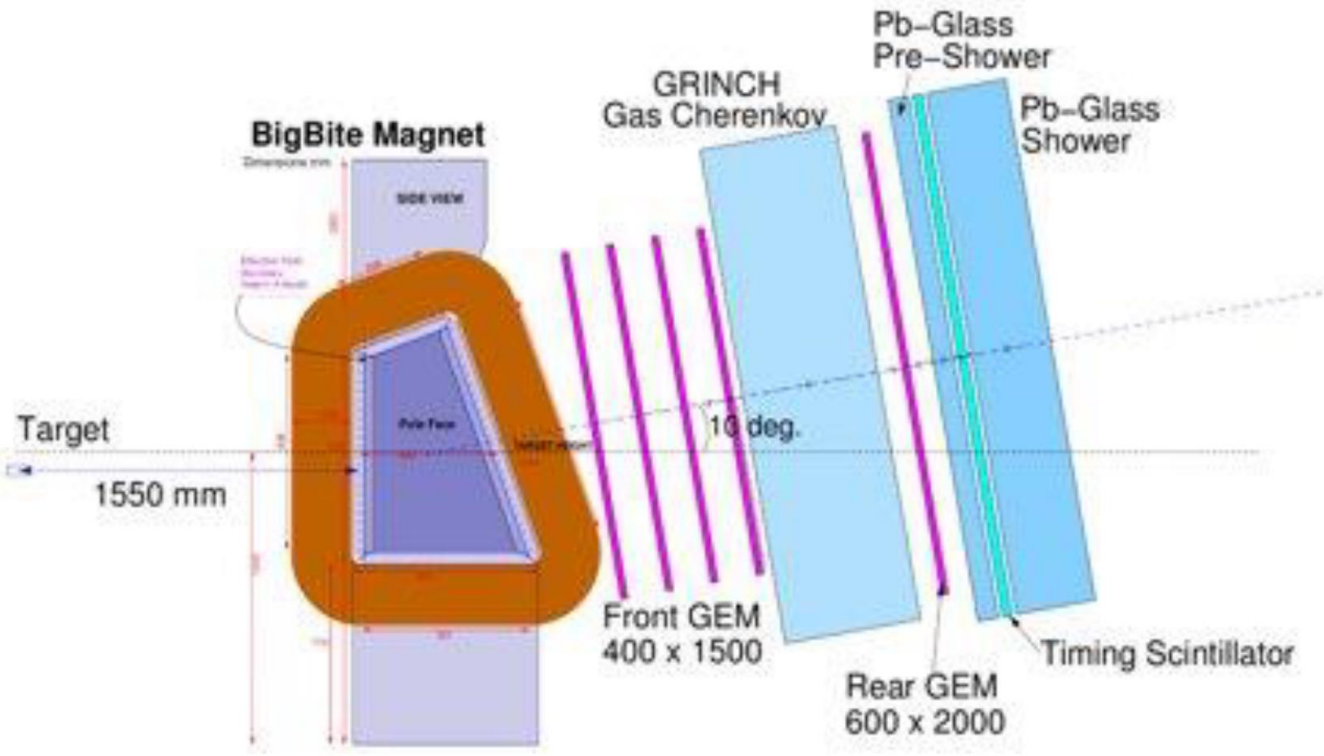
SBS Gep proton polarimeter arm

- GEM tracker after SBS magnet
- GEM trackers before and after CH2 analyzer for recoil proton measurement
- HCAL for coincidence trigger with electron arm ECAL (Lead Glass)



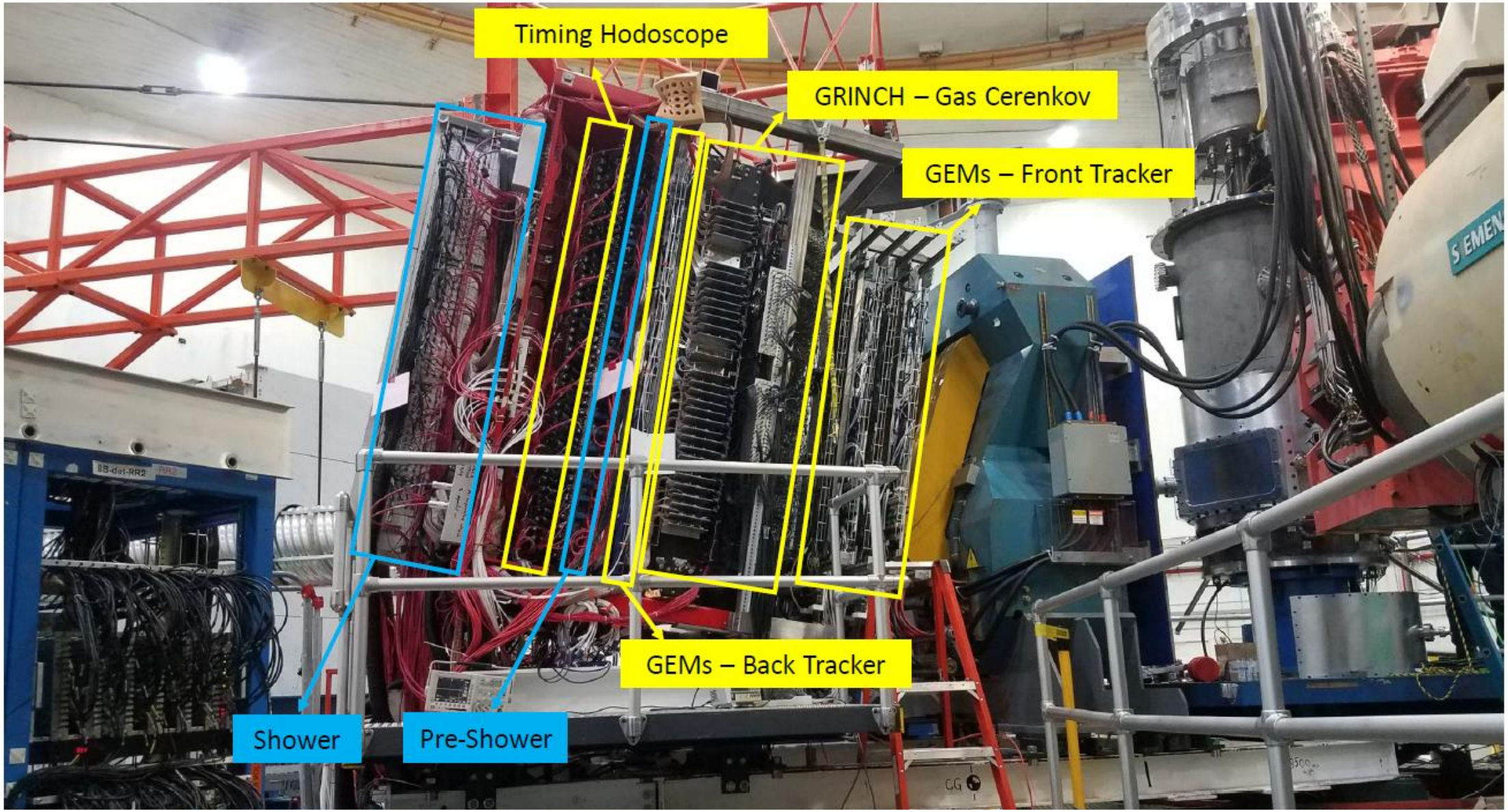
Bigbite Electron Spectrometer - BB

- A non-focusing, large momentum and angular acceptance spectrometer
- The spectrometer consists of a single dipole magnet and a detection system
- Current detection system includes:
  - 5 layers of GEM detectors (UVa, INFN)
  - GRINCH gas Cerenkov detector (W&M, JMU, NC A&T)
  - A shower and preshower (JLab, UConn, Yerevan)
  - A timing Hodoscope plane (Glasgow U, JLab)
- High background rates due to open configuration
- GEM detectors to handle high rate



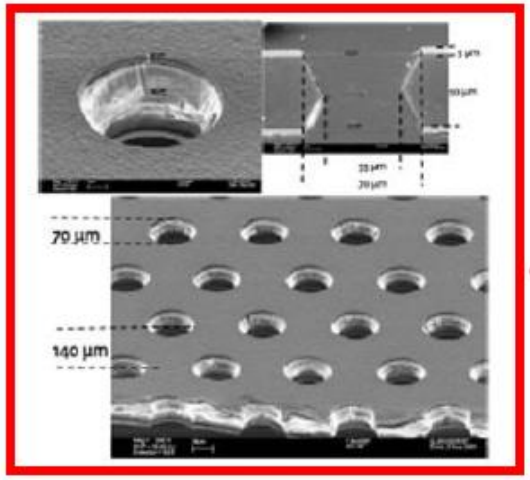
BB Electron Arm

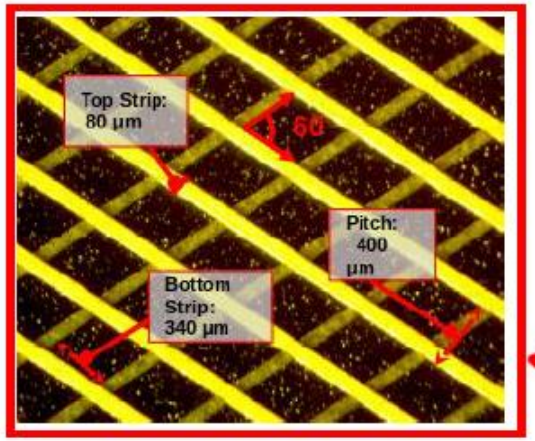
Bigbite Spectrometer in GMn Experiment

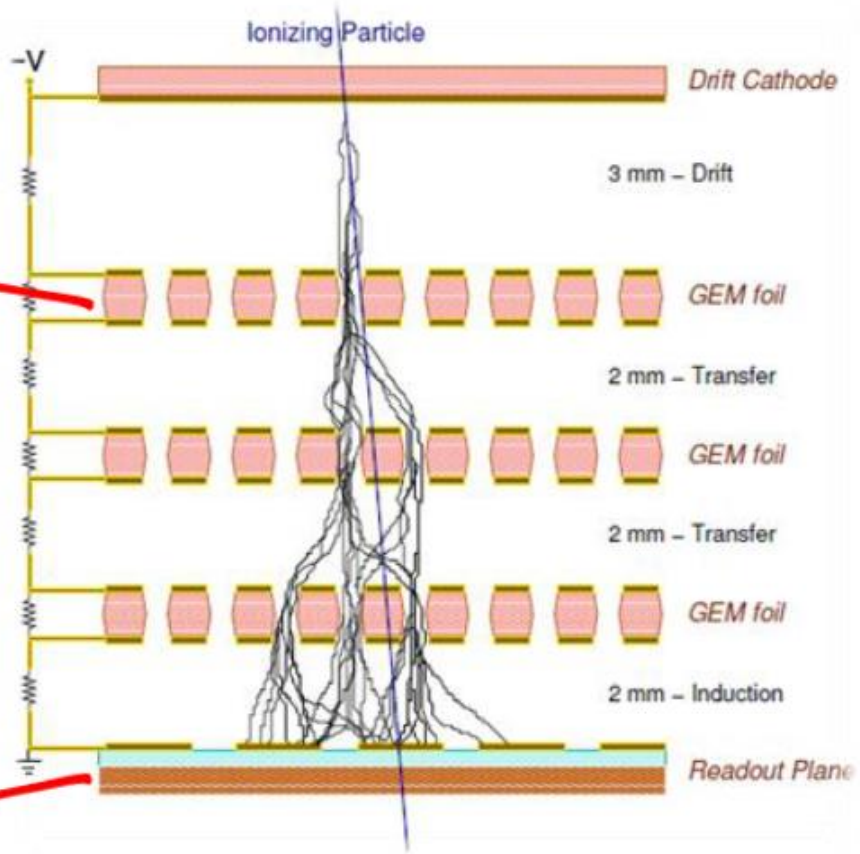


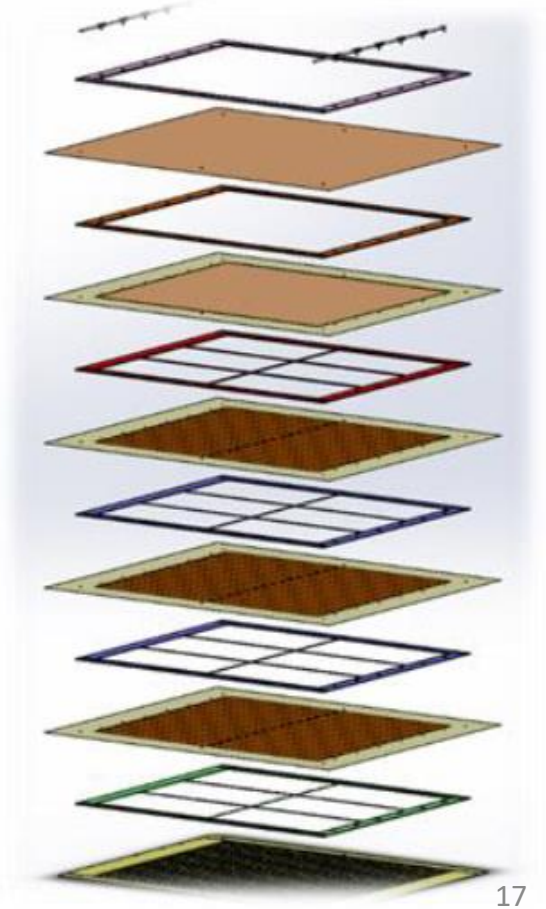
GEM Detector

- GEM (Gas Electron Multiplier) detectors consist of GEM foils and a **2D** readout plane
- Compass triple foil structure
- High Rate (2 MHz/cm^2), high space resolution (70 um)







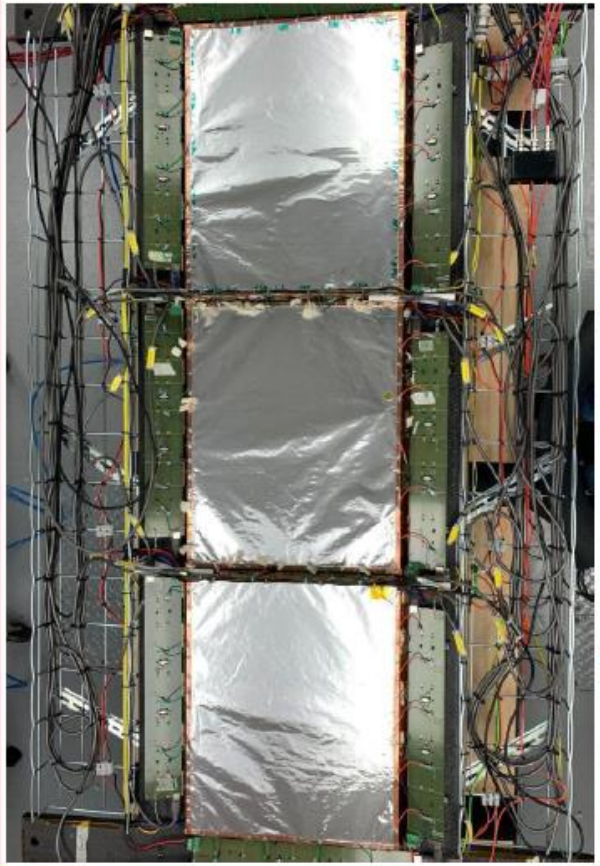


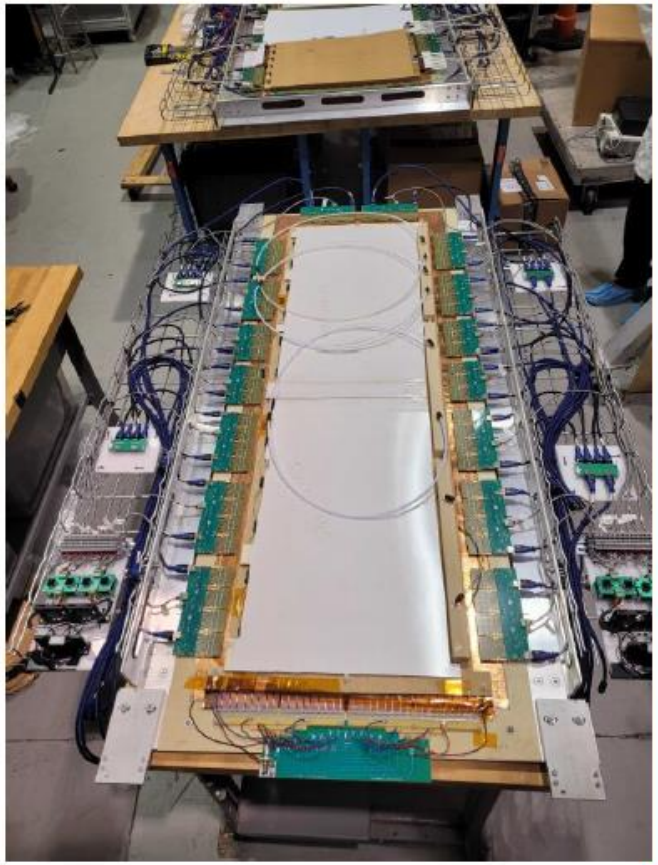
GEM Detectors in Bigbite

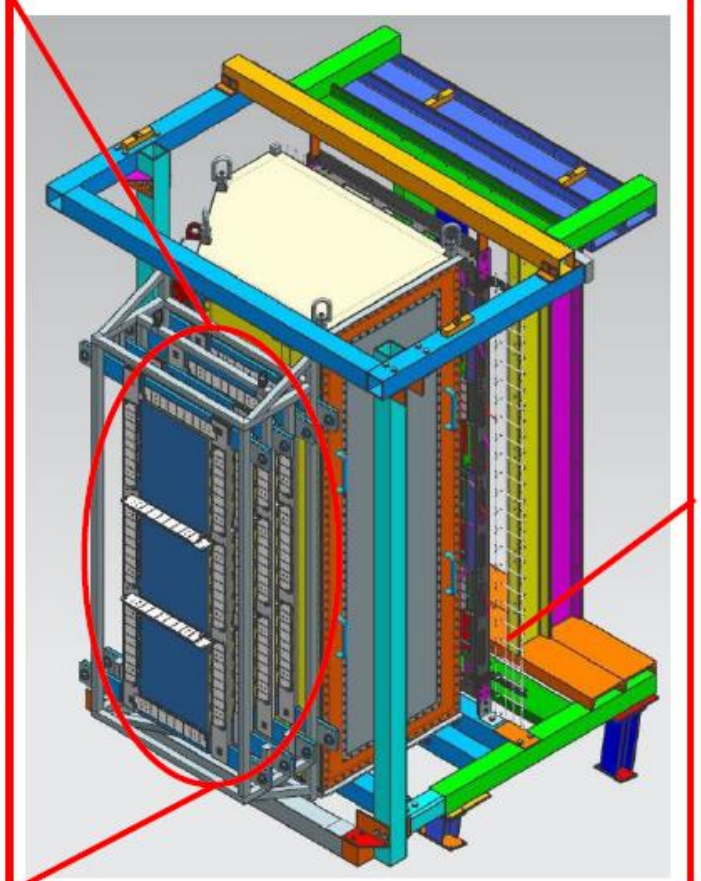
40X150 cm^2 layers, made of 3 40X50 GEM modules

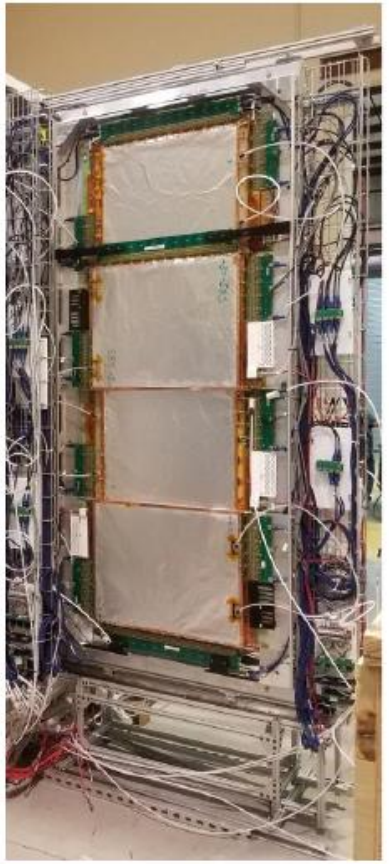
40X150 cm^2 layer, made of a single module, no dead area in active area

60X200 cm^2 layers, made of 4 60X50 GEM modules







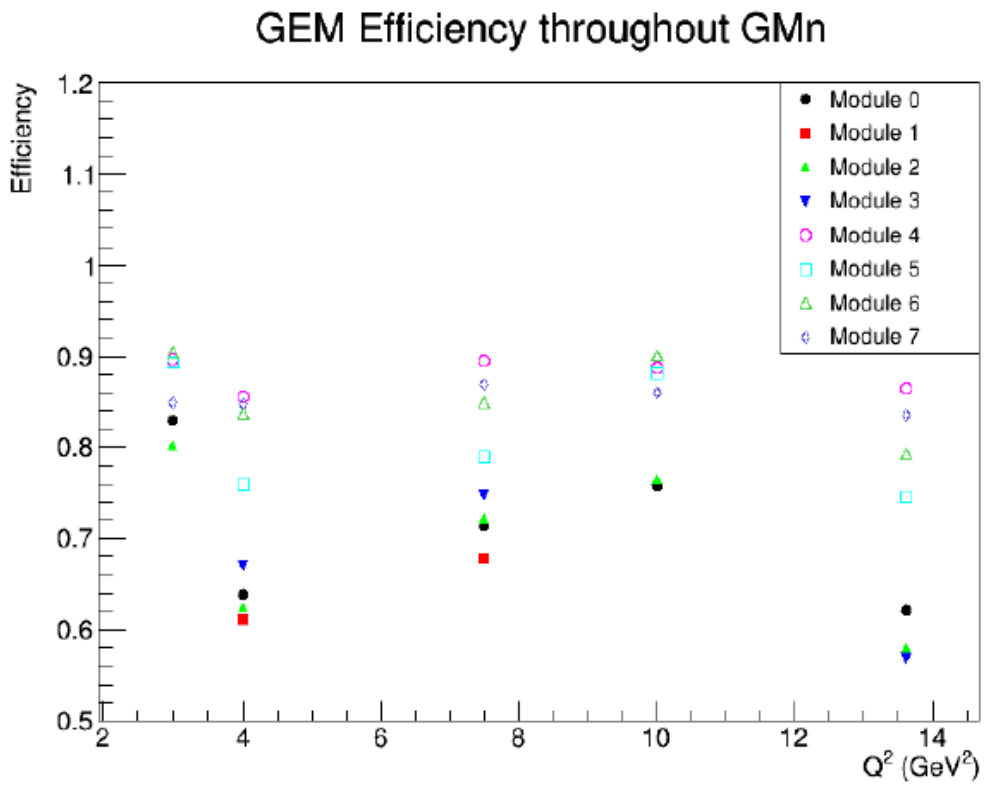


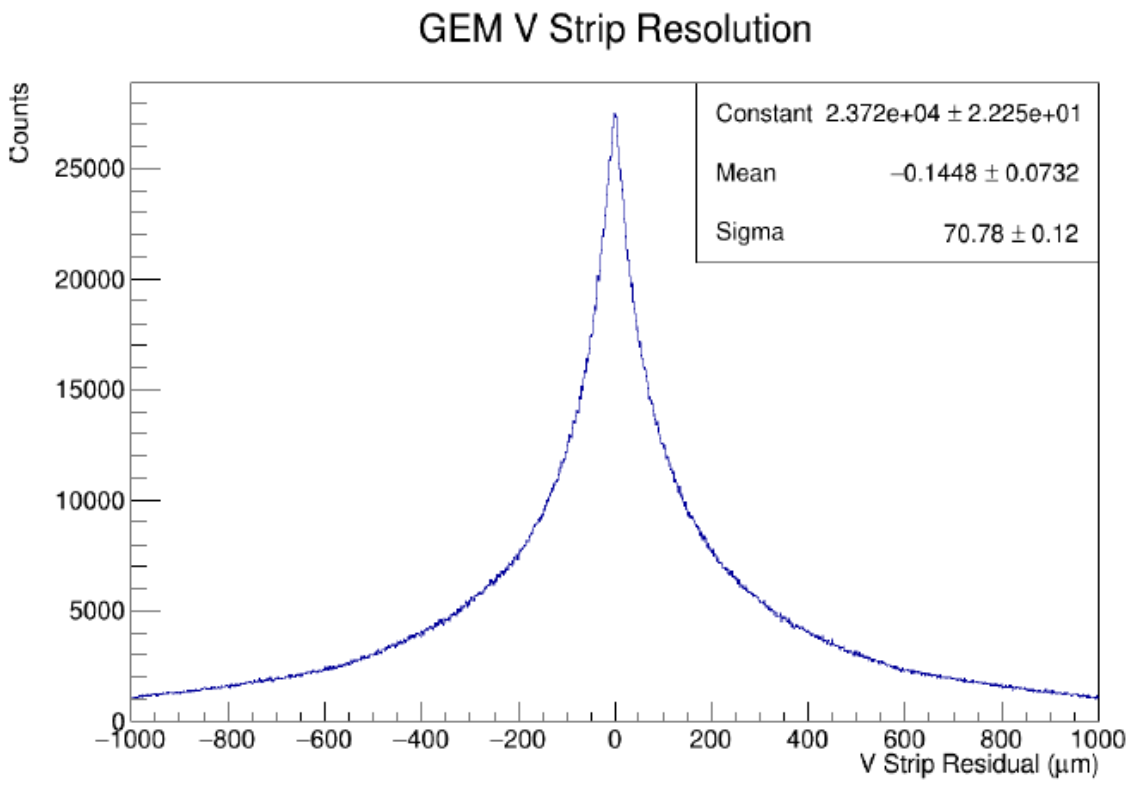
INFN XY **UVa UV** **Bigbite Detectors** **UVa XY**

These layers are among the largest GEM layers ever built

GEM Detector Performance in GMn

- Efficiency varies from module to module due to different rates seen by different modules
- Backtrackers has consistently higher efficiency due to low rates
- Position resolution around 70 um





Plot courtesy of Sean Jeffas

Tracking Algorithm

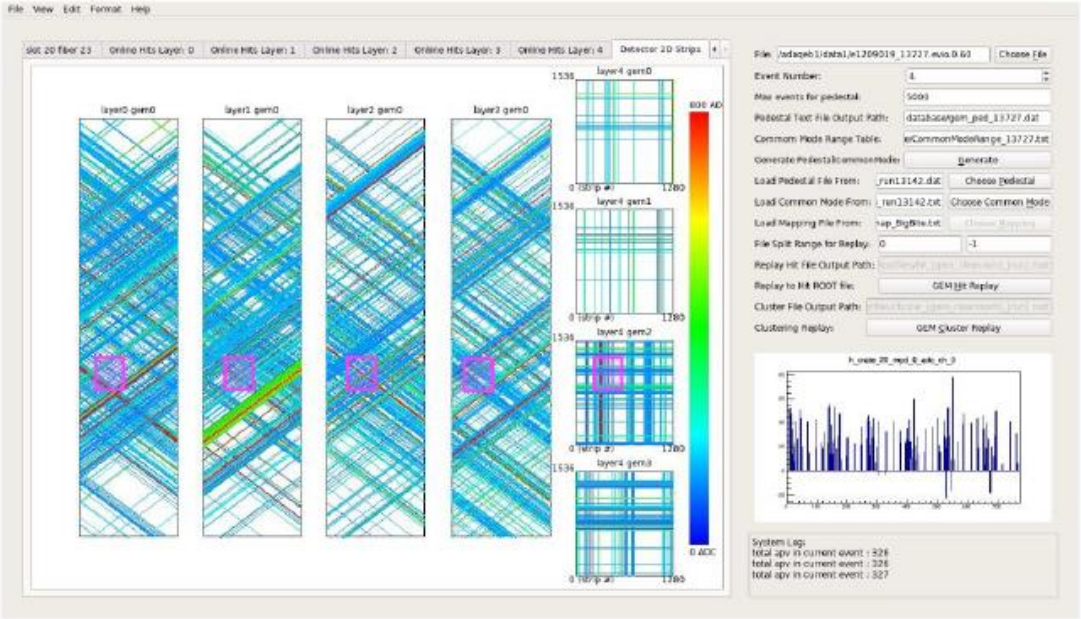
- 5 GEM layers out of electromagnetic field, high rate, large quantity of combinations

Tracking algorithm in a nutshell:

- Perform 1D clustering of strips along each dimension in each GEM chamber
- Form all possible 2D combinations within calorimeter-defined region
- Divide each tracking layer into a uniform 2D rectangular grid, accumulate a list of 2D hit candidates in each grid bin (bin size 1 x 1 cm^2)
- Loop all possible combinations from hits in outermost layers (within search region)
- Form straight-line projection
- Loop all possible combinations from each inner layer (minimum 3 layers)
- Find the hit combination with best X^2/ndf

Tracking algorithm credit goes to **Prof. Andrew Puckett and Dr. Weizhi Xiong**

What we're up against, II (run 13727, 12 uA LD2, $Q^2 = 4.5\ GeV^2, E = 4\ GeV$)



- This is the same event as previous slide, but requiring max ADC sample on a strip greater than 100, a typical offline threshold for cluster maxima that is higher than online threshold

□ = approximate size of calorimeter-constrained track search region at each layer

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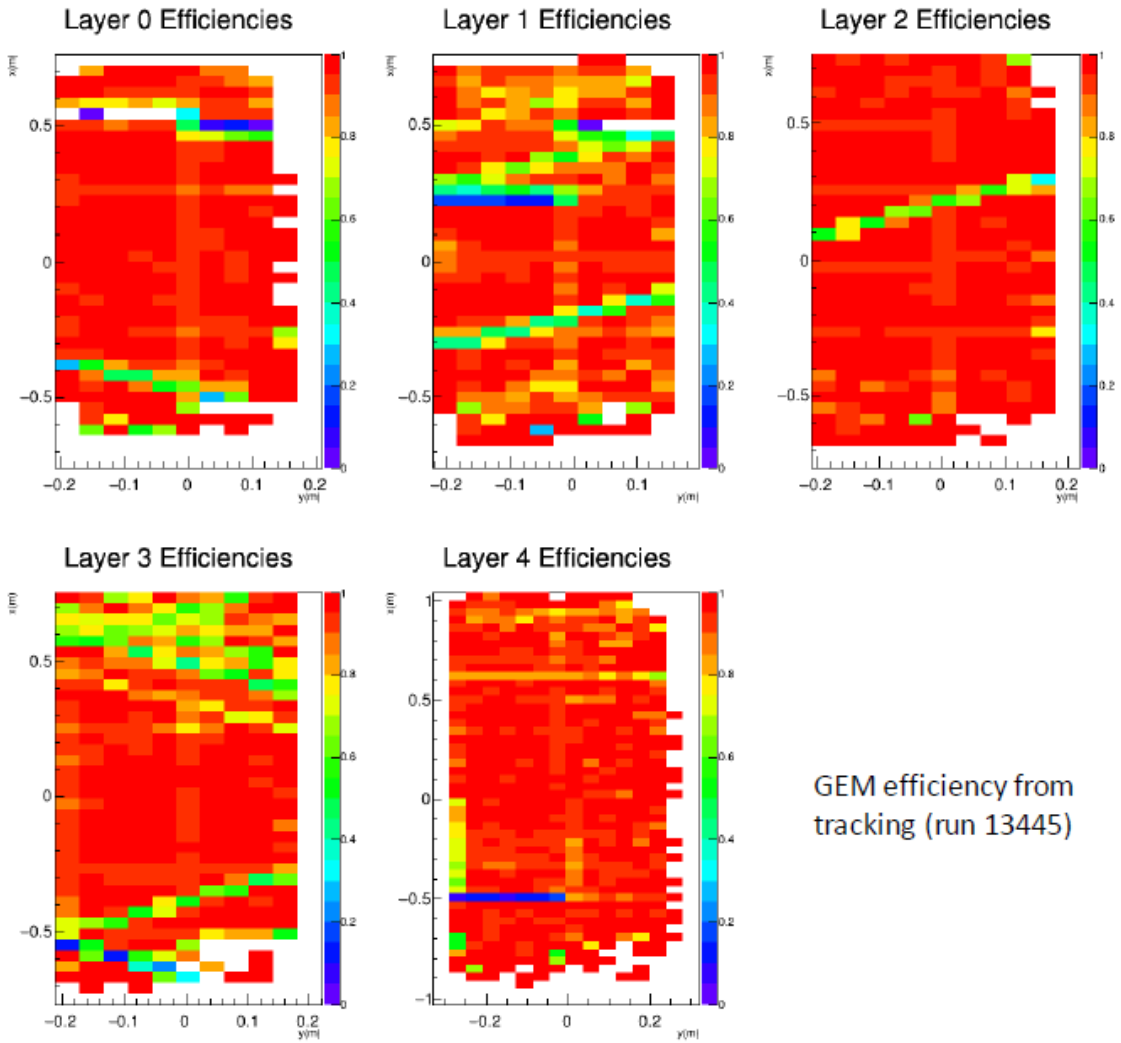
Slide courtesy of Prof. Andrew Puckett

Tracking Performance

- **Average > 90% under low occupancy, > 60% under high occupancy in GMn**
- Low efficiency area due to dead channels on GEM detectors and APV chips
- While occupancy increases, efficiency drops
  - GEM gain drop due to high voltage system design
  - Larger number of possible 2D combinations, more fake tracks
  - More noise hits due to negative signals, common mode sagging towards the lower side under high occupancy – offline correction developed (Sean Jeffas from UVa)
- We took a set of high beam current (high occupancy) runs to study this effect, the analysis work is in progress, further improvements will be made in future



GEM efficiency from tracking (run 13445)

Estimated Rates in GMn

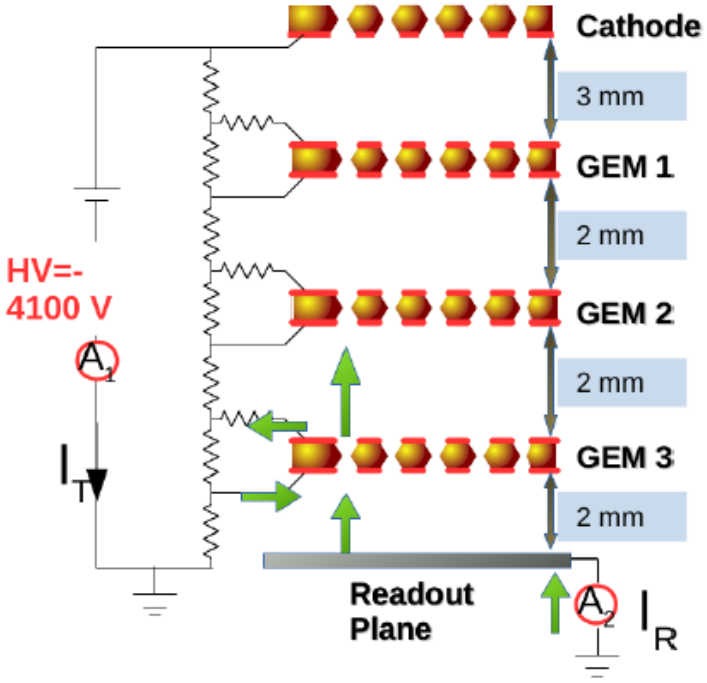
- Background comes from: beamline structure, target window...
- A majority background rate comes from low energy photons, less than 1% conversion rate, can be rejected by tracking
- Estimated from GEM gain factor measurement, not precise
- Rates are about a factor of 2 – 3 times higher than expected

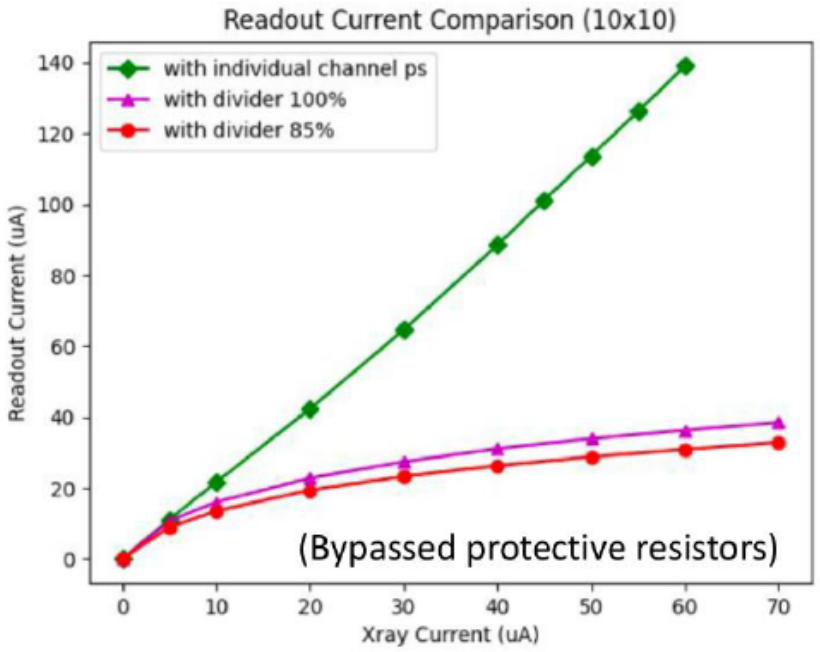
SBS Period	Target	E_beam (GeV)	Beam Current (uA)	BB Angle (Deg)	BB Distance (m)	Q^2 $(GeV/c)^2$	Extrapolated I_excess	Rate
SBS-4	LD2	3.728	1.75/3.75/7/10	36	1.8	3.0	(R. 28) E. 28	**159.6 KHz/cm²**
SBS-7	LH2	7.906	1/2/4/8/10	40	1.85	9.8	(R. 38) E. 40	**228 KHz/cm²**
SBS-8	LH2	5.965	1/2/3/4/5/8	26.5	2.0	4.5	(R. 40) E. 48	**273.6 KHz/cm²**
SBS-11	LD2	9.91	2/4/8/10/11/12	42	1.55	13.5	(R. 71) E. 105	**598.5 KHz/cm²**
SBS-14	LD2	5.965	1/2/7.5/8/10	46.5	1.85	7.4	(R. 42) E. 49	**279.3 KHz/cm²**

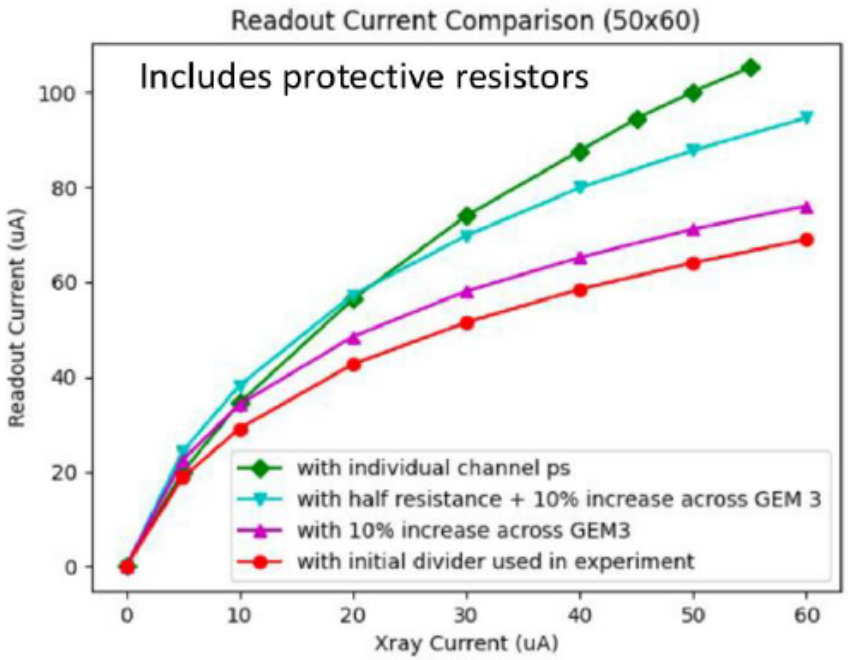
12 uA on LD2 ~ 8.10^{37}

Further Improvement for High Rate

- Under high rate, the large current flowing through GEM detector will change the HV distribution on each GEM foils
- A HV drop on 3rd GEM foil was observed
- Increased the HV distributor resistor for GEM3 by 10% before GMn
- A new solution using a parallel HV unit to provide HV for each GEM foil separately



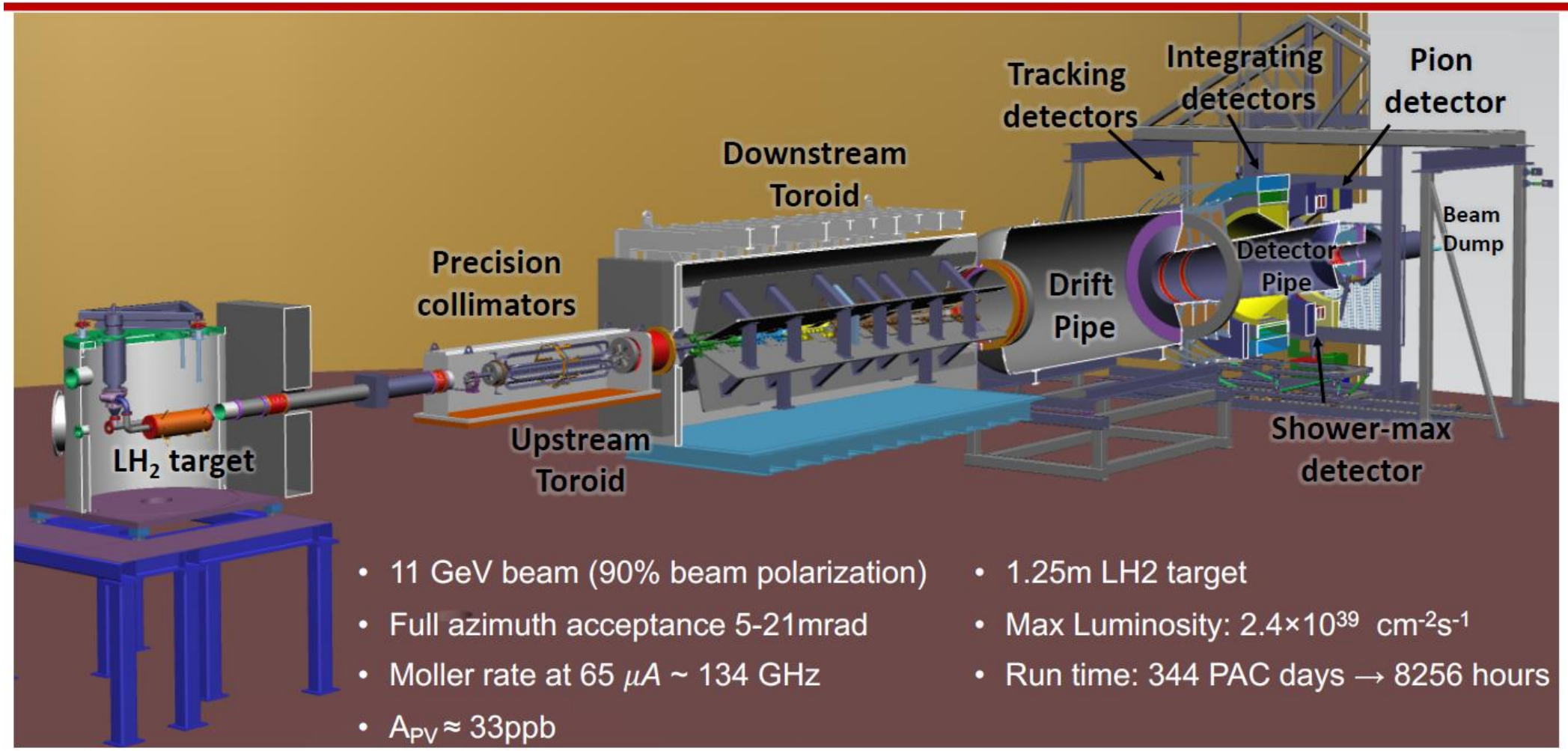




Physics Programs with SBS/BB

- Major measurements of nucleon form factors using SBS/BB Spectrometers
  - ❑GMn (E12-09-019): Precision Measurement of the Neutron Magnetic Form Factor at up to $Q^2 = 18\ (GeV/c)^2$. Data collection **completed February 2022 (see Eric's talk)**
  - ❑nTPE (E12-20-010): Measurement of the Two-Photon Exchange Contribution to the Electron-Neutron Elastic Scattering Cross Section. Data collection **completed February 2022**
  - ❑GEn-II (E12-09-016): Measurement of the Neutron Electromagnetic Form Factor Ratio GEn/GMn at High Q^2. Scheduled **this coming fall**
  - ❑GEn-RP (E12-17-004): Measurement of the Ratio GEn/GMn by the double polarized $^2H(e, e'n)$ Reaction
  - ❑GEp-V (E12-07-109): Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 $(GeV/c)^2$ Using Recoil Polarization Method

Moller experiment



- 11 GeV beam (90% beam polarization)
- Full azimuth acceptance 5-21mrad
- Moller rate at 65 μA ~ 134 GHz
- $A_{PV} \approx$ 33ppb
- 1.25m LH2 target
- Max Luminosity: 2.4×10^{39} $cm^{-2}s^{-1}$
- Run time: 344 PAC days → 8256 hours

Higher luminosity ?

- Current could go up to 80 uA
- Target length up to 1.25 meter ~ 2.4.10^39 cm-2.s-1
- Tracker occupancy and photon background
  - Reduce amount of Copper in GEM
  - Micromegas option
  - Build smaller chambers and add more channels
  - Study complement with 2D pad readout
  - Superconducting tracker option
- Calorimetry
  - Study liquid scintillator and cryogenics calorimeter option
  - Superconducting detector to replace PMT
  - MCP PMT or LAPPD
- Cerenkov
  - Superconducting detector to replace PMT
  - MCP PMT or LAPPD
  - HBD type Cerenkov for Large Angle calorimeter

With existing 40 cm and 60 uA ~ 5. 10^38 $cm^{-2}s^{-1}$ technically doable mostly matter of cost

Studies higher luminosity

- Quick study by Weizhi Xiong
- VMM3 25 ns shaping time
- 3 x luminosity : current tracking not working

- Plan to translate SoLID in new framework to have full tracking with ACTS
- Study efficiency with full tracking
- Study improved setup : more planes, pixelllized plane, vertex tracker

Plan

- SoLID starting to accept new proposal : 1 new proposal approved in PAC50
- Dust off event generator
- New implementation of SoLID using DD4Hep to be able to use full tracking software
- Generate event and background at 10^38 cm-2.s-1 and study tracking
- Evaluate missing mass resolution and pion/muon identification for J/Psi setup, improved J/Psi setup, dedicated DDVCS setup
- Ideally quantify impact of DDVCS on GPD extraction accuracy

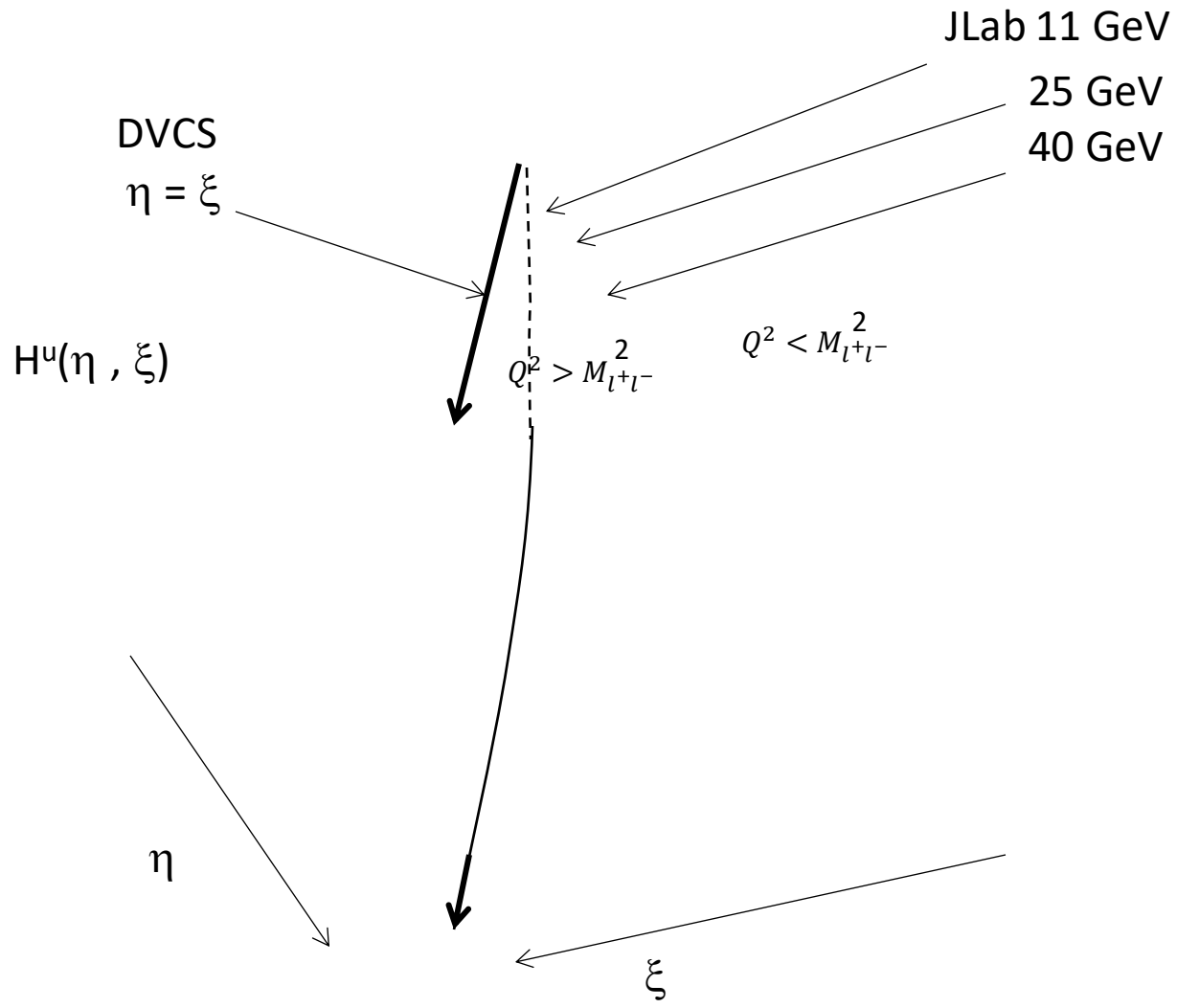
SoLID preRD

- Gas Cerenkov can operate at rates higher than expected from SoLID
- Fast APV GEM readout deployed for SBS
- VMM prototype
- TOF electronics
- FADC trigger developements

- Second round
- ECal testing
- Test electronics high rate and high radiations

DDVCS and 22 GeV energy upgrade

- Current kinematic a bit limited in terms of Q2 and Q'2
- Higher beam energy give better range



DDVCS and positrons

- Same as for DVCS : access to real part of DDVCS

- Look at Eric Voutier talk on Friday

Conclusion

- Hall A and C high luminosity halls luminosity ranging from 10^{36} up to 5.10^{38} $cm^{-2}.s^{-1}$
- SuperBigBite proof of concept of SoLID in smaller scaler and starts to give results. Promising results from GEM
- SoLID preRD on going
- Large acceptance detector like SoLID striving to keep running at highest luminosity
  - Approved experiments SIDIS and J/Psi
  - Future possible dedicated DDVCS setup