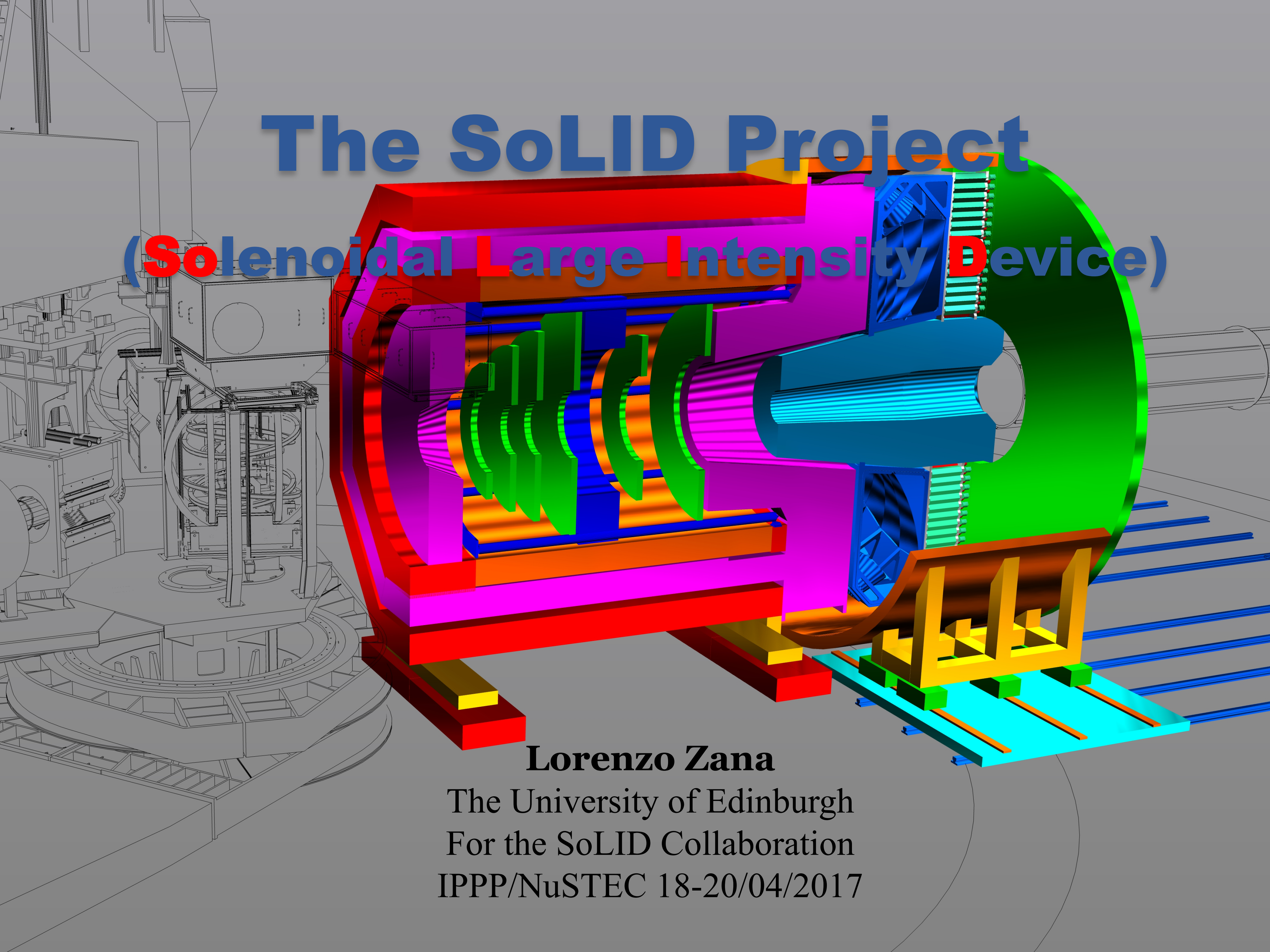
The SoLID Project

(Solenoidal Large Intensity Device)



Lorenzo Zana
The University of Edinburgh
For the SoLID Collaboration

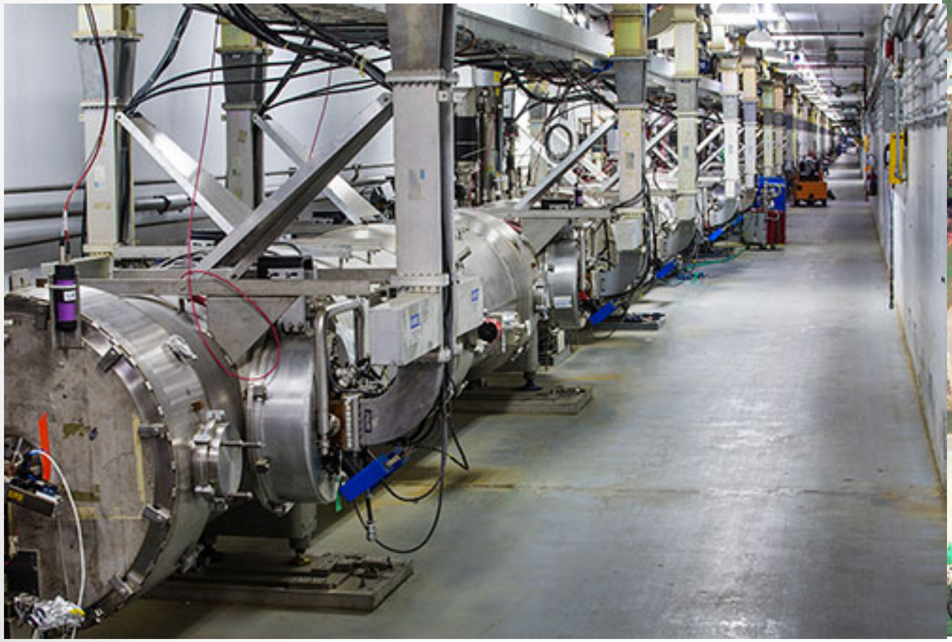
IPPP/NuSTEC 18-20/04/2017

Outline

- SoLID Overview
  - Magnet
  - Detectors
- Physics:
  - SIDIS,
  - PVDIS,
  - J/Psi
- Summary
- Different projects of interest

Thomas Jefferson Laboratory

12GeV Upgrade Just completed



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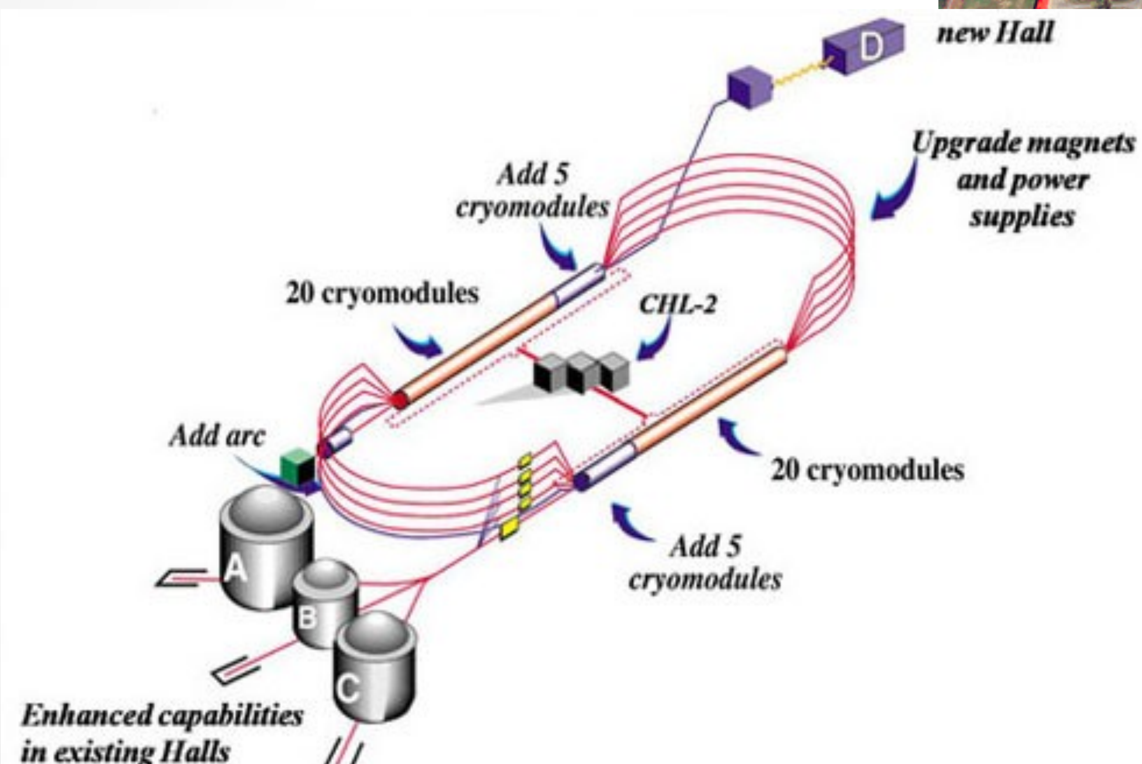
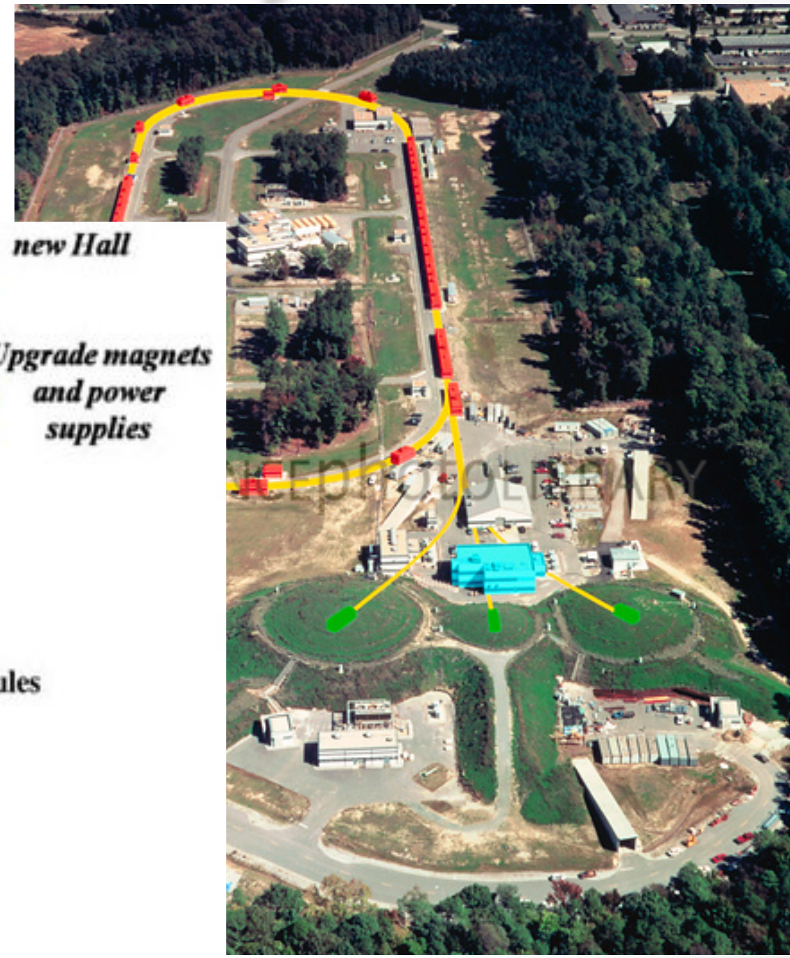
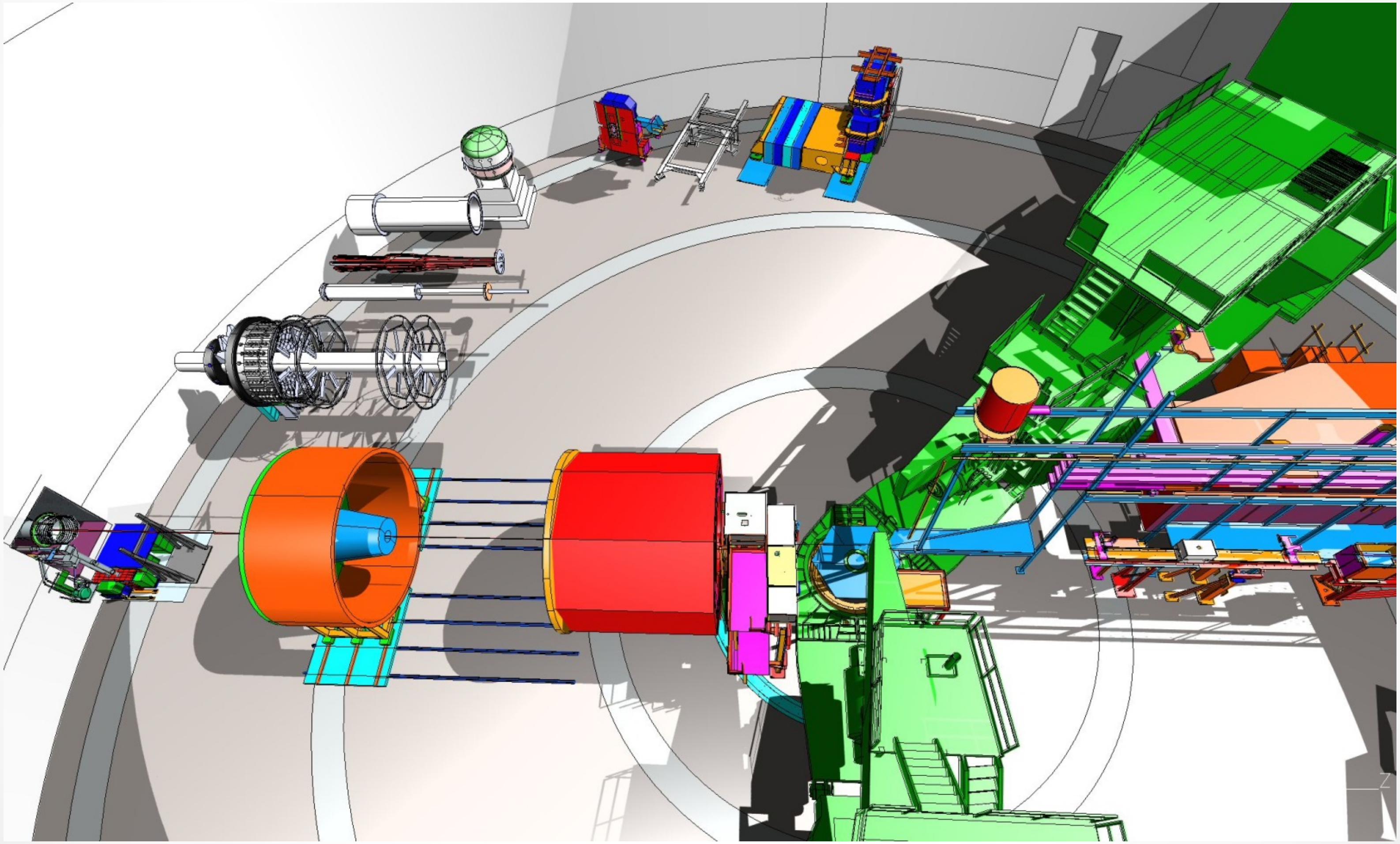




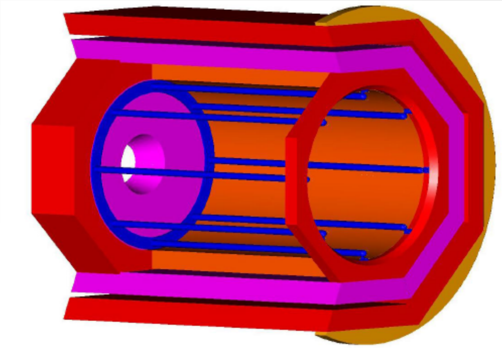
SoLID in Hall-A

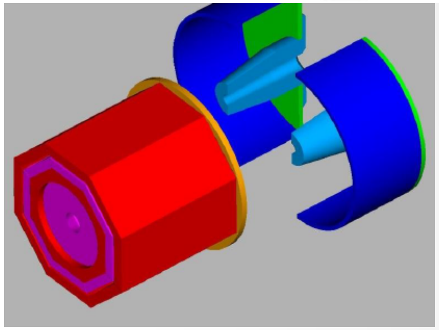


Overview of the SoLID project

- SoLID apparatus is designed to fully exploit the JLab 12 GeV upgrade
- Large acceptance detector to handle high luminosity($10^{37} - 10^{39}$ cm^{-2} s^{-1})
- Reach ultimate precision for SIDIS (TMDs), providing three-dimensional imaging of nucleon in momentum space
- PVDIS in high-x region providing sensitivity to new physics at 10 – 20 TeV , and sensitive to QCD physics
- Threshold J/ψ , probing strong color field in the nucleon, trace anomaly
- 5 highly rated experiments approved
  - Three SIDIS experiments, one PVDIS, one J/ψ production
  - Run group experiments: di-hadron, Inclusive-SSA, and much more…
  - Strong collaboration (250+ collaborators from 70+ institutes, 13 countries)
- Significant international (Chinese, USA, Europe) contributions and strong theoretical support

Magnet





◆ **CLEO-II Solenoid Magnet:** from Cornell Univ.

Goals:

→Acceptance: Φ: 2π, θ: 8°-24° (SIDIS), 22°-35° (PVDIS),
P: 1.0 – 7.0 GeV/c,

→ Resolution: δP/P ~ 2% (requires 0.1 mm tracking resolution)

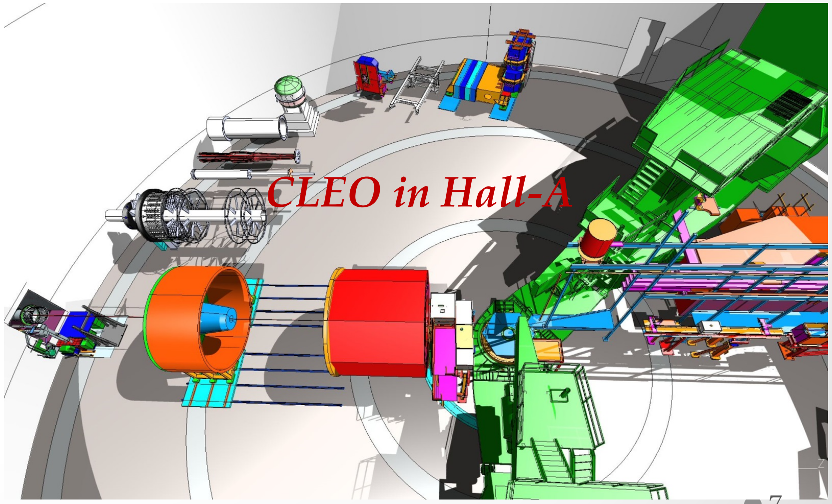
→ Fringe field at the front end < 5 Gaus

Status:

→ CLEO-II magnet formally repqested and agreed in 2013:
Built in 1989 and operated until 2008, uniform central field at 1.5 T,
Inner radius 2.9 m, coil radius 3.1 m and coil length 3.5 m

→ Site visit in 2014, disasembly in 2015

CLEO at Cornell



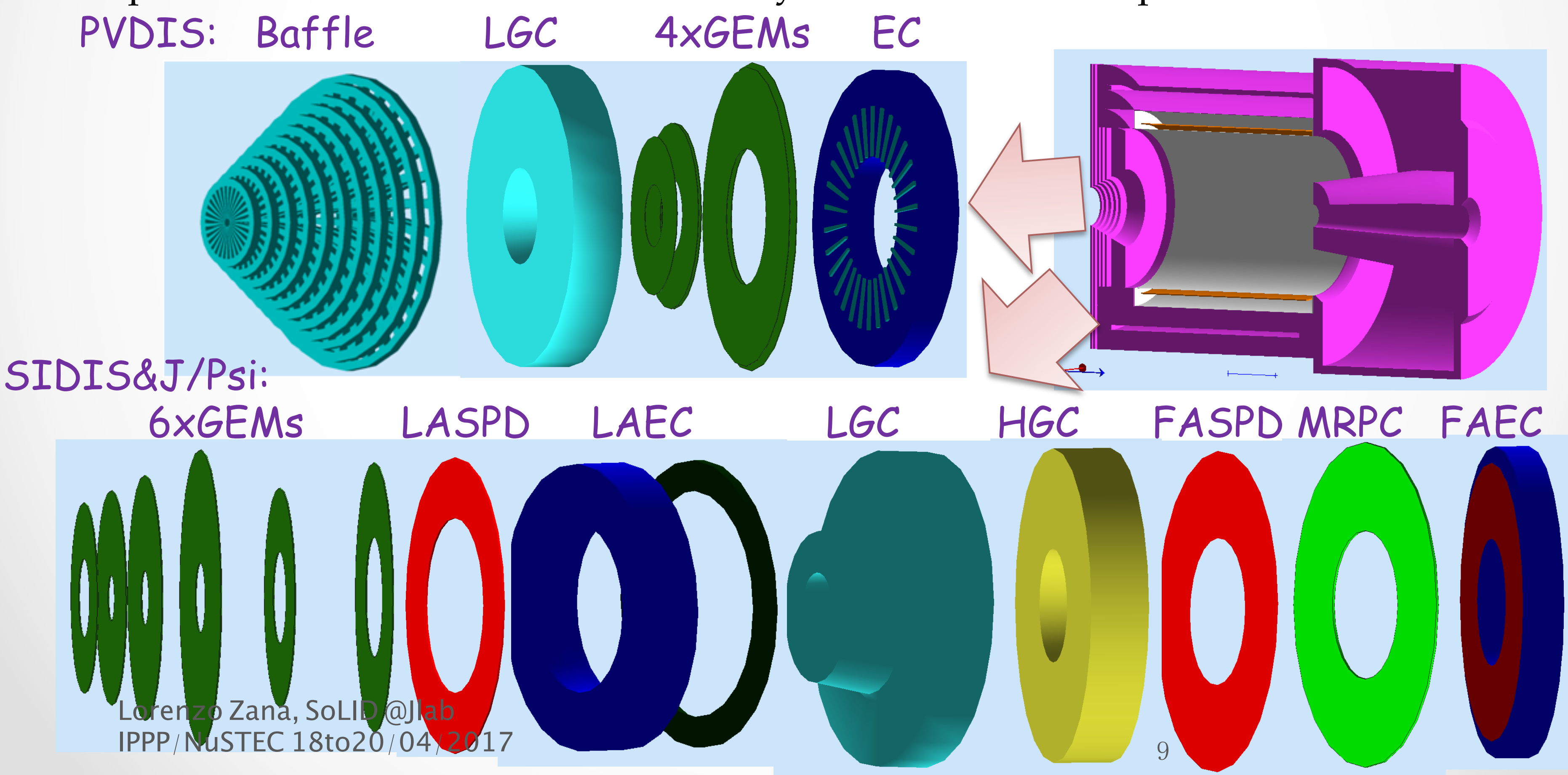
Cleo Magnet at Jlab (Dec 2016)

Coil collar in JLab test lab high bay

Cryostat leaving Cornell

SoLID Overview

- ◆ High Intensity ($10^{37} \sim 10^{39}$ cm^{-2}s^{-1}) and Large Acceptance
- ◆Take advantage of new developed detector techniques, fast electronics and data acquisition.
- ◆ Sophesticated MC simulation and analysis software developments



Physics Overview

◆ Semi-Inclusive Deep Inelastic Scattering (SIDIS):

→ Transversely Polarized 3He, E12-10-006 (90 days, A),

→ Longitudinally Polarized 3He, E12-11-007 (35 days, A),

→ Transversely Polarized Proton, E12-11-108 (120 days, A),

→ Two new bonus runs: Ay and Di-Hadron,

→ And can be more ...

◆ Parity Violation Deep Inelastic Scattering (PVDIS):

→ PVDIS with LH2 and LD2, E12-10-007 (169 days, A)

→ proposing new experiments, e.g. EMC with Calcium

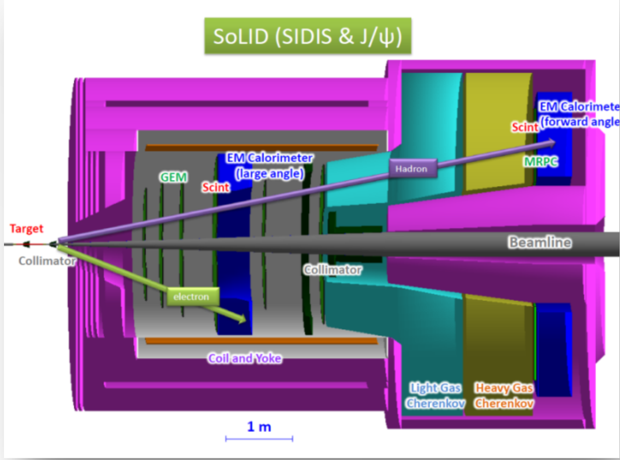
◆ J/ψ :

→ Near Threshold Electroproduction of J/ψ at 11 GeV, E12-12-006 (60 days, A-)

◆ Developing GPD program:

More ...

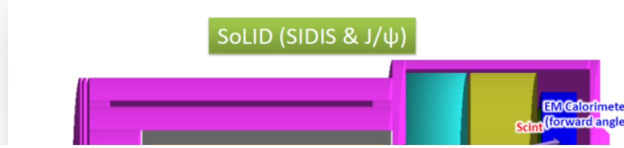
SiDIS

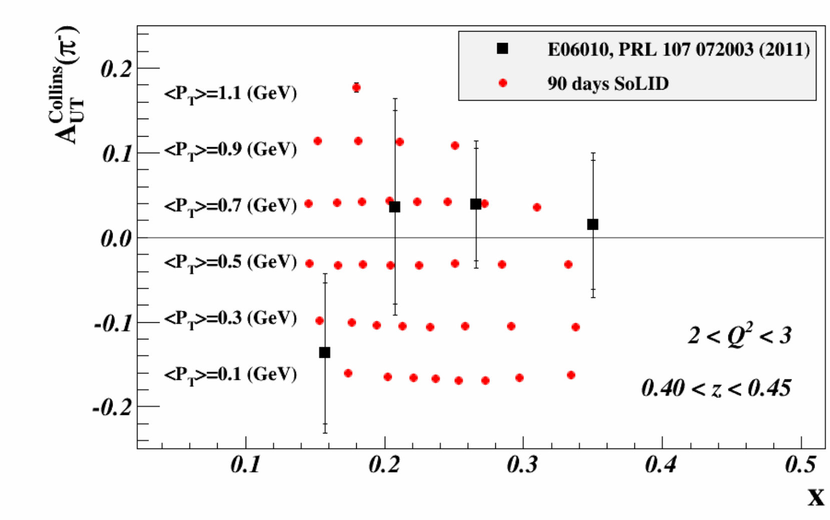


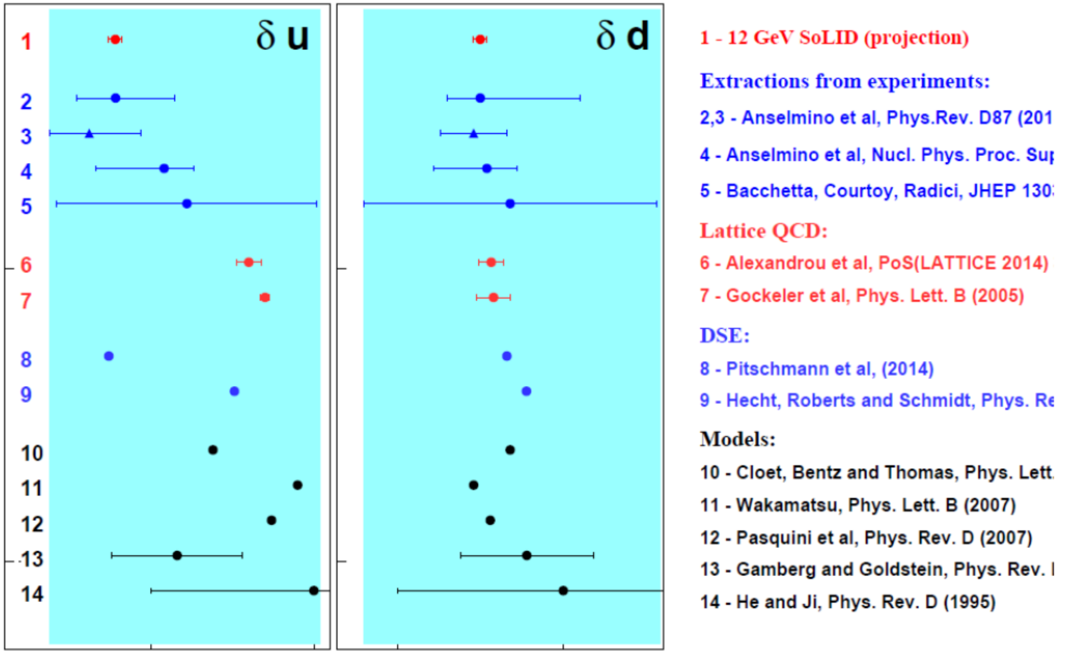
- Single Spin Asymmetry on Transverse ^{3}He for 90 days (rating A)
- Single and Double Spin Asymmetry on ^{3}He for 35 days (rating A)
- Single and Double Spin Asymmetries on Transverse ^{1}H for 120 days (rating A)
- Two run group experiments: di-hadron and Inclusive-SS using existing data from above experiments

- Key of SoLID-SIDIS program:
  - Large Acceptance + High Luminosity
  - 4-D mapping of asymmetries
  - Tensor charge, TMDs ...
  - Lattice QCD and QCD Dynamics models.

SiDIS



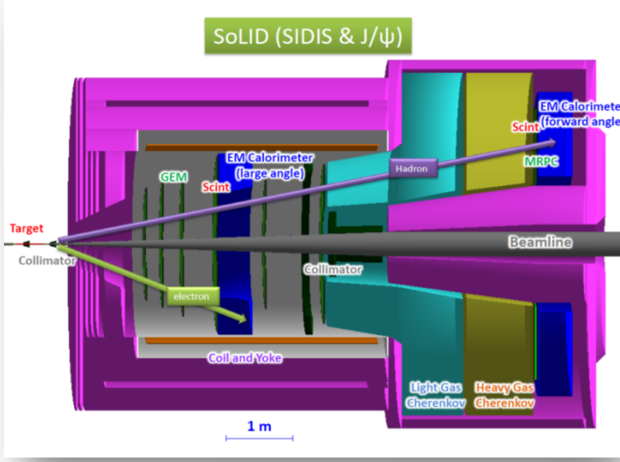




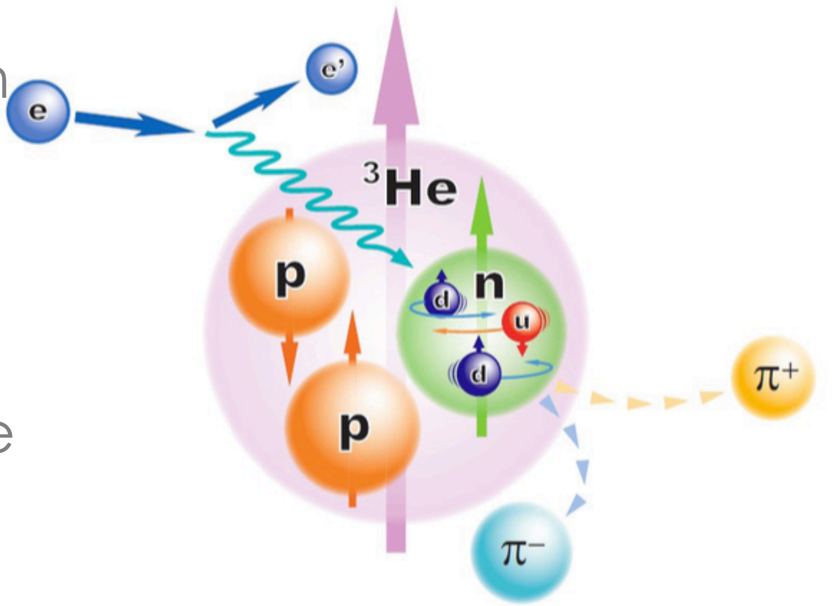
- Collins Asymmetries in 6 of 1400 bins in x, Q^2 , P_T and z
- Collins Asymmetries~ Transversity x Collins Function

- 12GeV SoLID projection together with existing extractions and predictions for Tensor charges

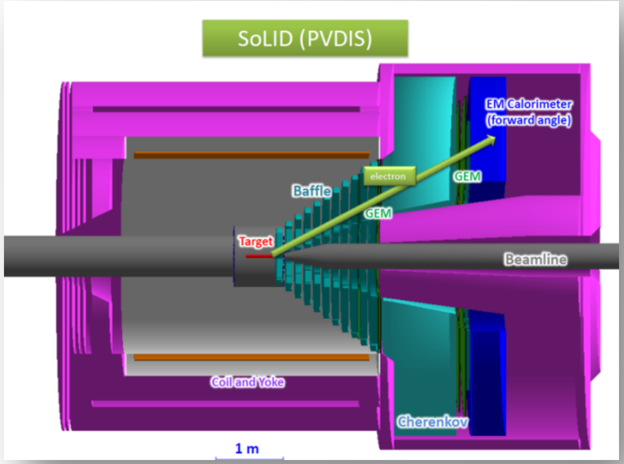
SiDIS



- A unique combination of large acceptance and high luminosity : truly utilize 12-GeV upgrade to its full potential
- A comprehensive program with both proton and "neutron" targets in the same setup allows for flavor separation with better control of systematics
- Multi-dimensional binning of the data with high precision help reduce theoretical uncertainties in extracting TMDs



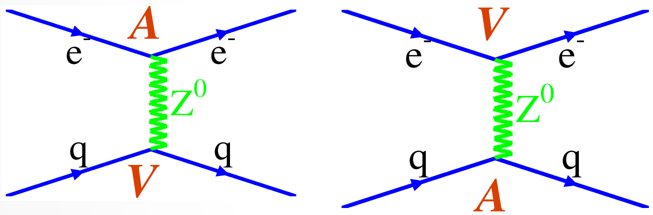
PVDIS



- **P**arity **V**iolation **D**eep **I**nelastic **S**cattering:

→ Measure the asymmetry between left- and right-handed electron scatterings which can access:
  - ✓ Flavor dependent quark distributions (u,d,s)
  - ✓ Charge symmetry violations
  - ✓ Higher twist effects
  - ✓ Nuclear medium effects
  - ✓ More ...

$$C_{1q} = 2g_A^e g_V^q \qquad C_{2q} = 2g_V^e g_A^q$$



$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -\left(\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\right)(Y_1 a_1 + Y_3 a_3)$$

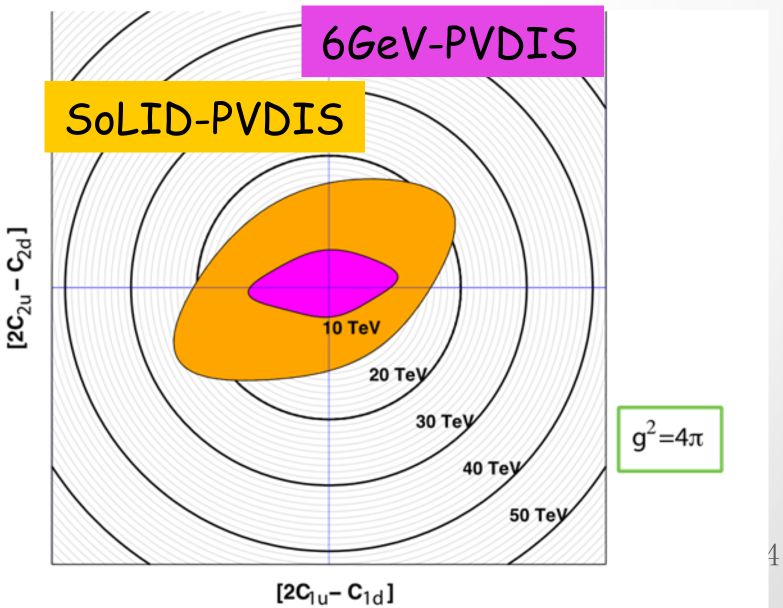
$$a_1(x) = \frac{6}{5}(2C_{1u} - C_{1d})\left(1 + \frac{0.6s^+}{u^+ + d^+}\right),$$

$$a_3(x) = \frac{6}{5}(2C_{2u} - C_{2d})\left(\frac{u^+ - d^+}{u^+ + d^+}\right) + \ldots$$

HT, New phys

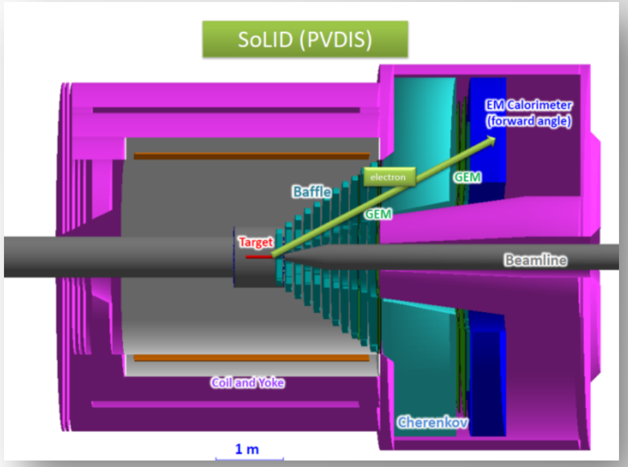
Standard Model:

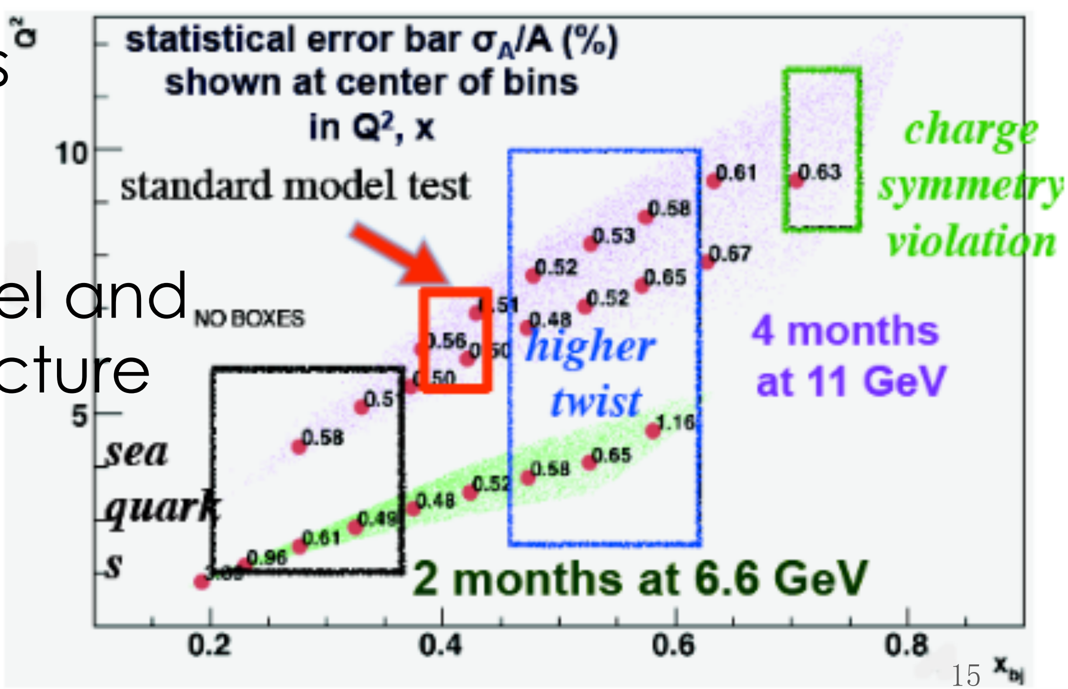
$$g_{VA}^{eu} = C_{2u} = g_{VA}^{ed} = -C_{2d} = \frac{1}{2} - 2\sin^2\theta_W$$



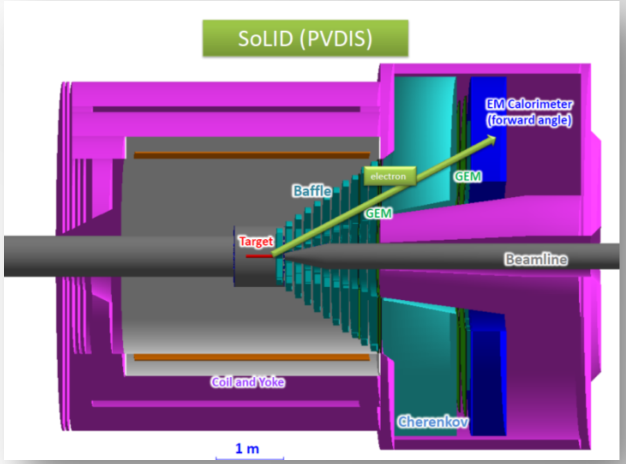
PVDIS

- High luminosity and large acceptance
- Large scattering angles (for high x and y)
- Better than ~ 1% errors for small (x,Q^2) bins for $0.25 < x < 0.75$ and $W^2 > 4 GeV^2$ in moderate running times
- Sub 1% precision over a broad kinematic range
- A test of Standard Model and access to hadronic structure contributions





PVDIS

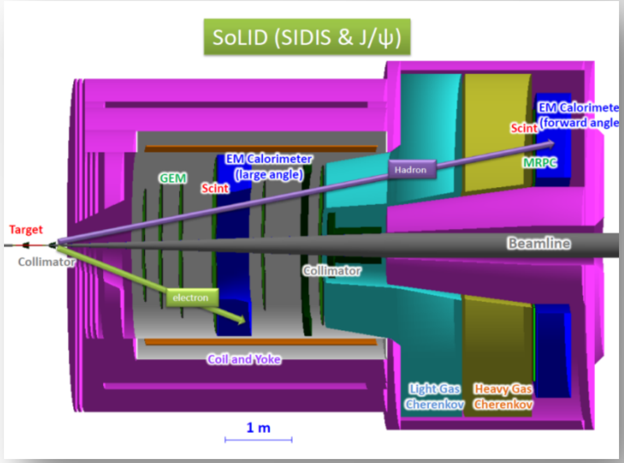


- A precision test of the Standard Model with unique sensitivity to new PV physics in 10 – 20 TeV scale
- Search for Charge Symmetry Violation (CSV) at partonic level - important for PDF and NuTeV anomaly
- Test of QCD higher twist corrections (quark quark correlations)
- Measurement of d/u quark ratio for proton with no nuclear corrections
- Nuclear medium effects on quark distributions in heavy nuclei

PVDIS features:

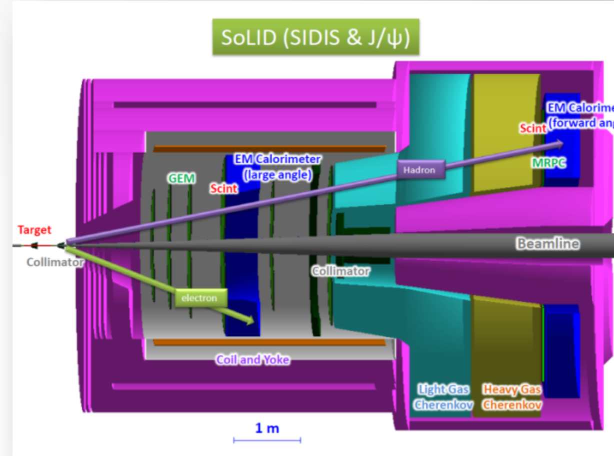
- Large PV asymmetries (at large Q^2 values)
- Manageable backgrounds
- Ability to reach higher precision beam polarimetry with high beam energies of DIS

J/ψ



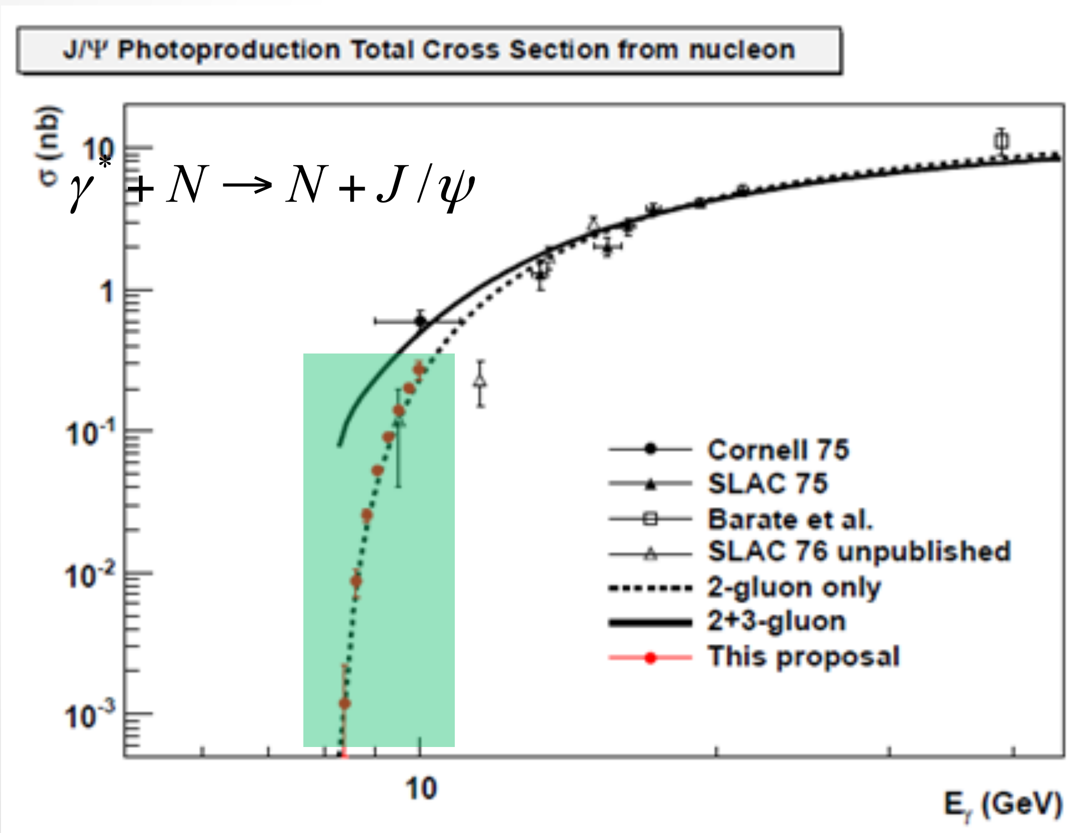
- Electro-production :
  $e + p^{+} \rightarrow e' + p'^{+} + J/\psi(e^{-}e^{+})$
  - Detect $e^{-}e^{+}$ pair and scattered e^{-}
- Photo-production :
  $\gamma + p^{+} \rightarrow p'^{+} + J/\psi(e^{-}e^{+})$
  - Detect $e^{-}e^{+}$ pair and recoiled p^{+}
- J/ψ threshold at 8.2 GeV and cross section measurement upto 11 GeV with SoLID
- A measurement near the threshold could shed light on the conformal (trace) anomaly

J/ψ

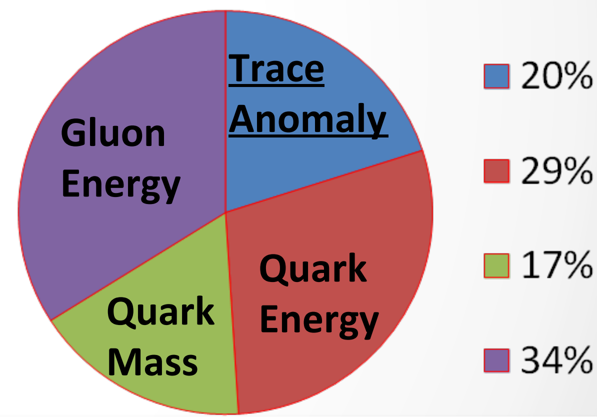


◆ **Near Threshold Electroproduction of J/ψ**

→ Probes strong gluonic interaction between two color neutral objects J/ψ and nucleon near threshold:

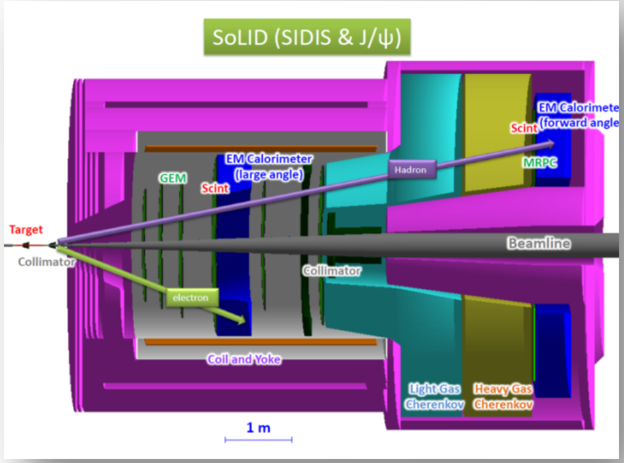


Proton Mass Budget



Trace anomaly of QCD energy momentum tensor plays an essential part in proton mass budget

J/ψ



- SoLID: unique combination of large acceptance and high luminosity allow for complete kinematic determination for electro- and photo-production of J/ψ with unprecedented precision in previously unexplored region near threshold
- Probe strong color force in nucleon
- Important for QCD conformal (trace) anomaly, origin of proton mass, and its budget
- Open a window for future studies of J/ψ-nucleon interaction, search for exotic J/ψ-nuclear bound state due to QCD van der Waals force
- and more

Development at this time

- SIDIS
  Strong science case: workshops (Stony Brook, ECT, INT)
  More Detailed Comparison with CLAS12/SBS
  Further Study systematics
  Tracking improvement
  Kaon identification (TOF)
- PVDIS
  Improve Background study/Baffle
  Further Q2/performance/systematics
  Tracking improvement to 90%
- J/y
  More detail on Bin Migration
  Further evaluation of Background
- Developing GPD program
  DVMP with Polarized 3He
  Others (TCS, DVCS with polarized targets)

Current Timetable

- Spring 2017: Update pCDR -> Draft MIE
- Summer 2017: Science Review
- February 2018: Budget briefing to have SoLID in 2017/2018: CD0
- FY2020: CD3, start full project

Summary

Full exploitation of JLab 12 GeV Upgrade

→ **SOLID:** A **Large Acceptance** Detector **THAT** Can Handle **High Luminosity** (10^{37}-10^{39})

Rich, vibrant and important physics program to address some of the most fundamental questions in Nuclear and Particle Physics

•Unprecedented precision in three-dimensional imaging of nucleon in momentum space, No competition in the proposed program on TMD

•PVDIS probing new physics in 10-20 TeV region complementary to LHC search, improving sensitivity to leptophobic Z' in 100-200 GeV;

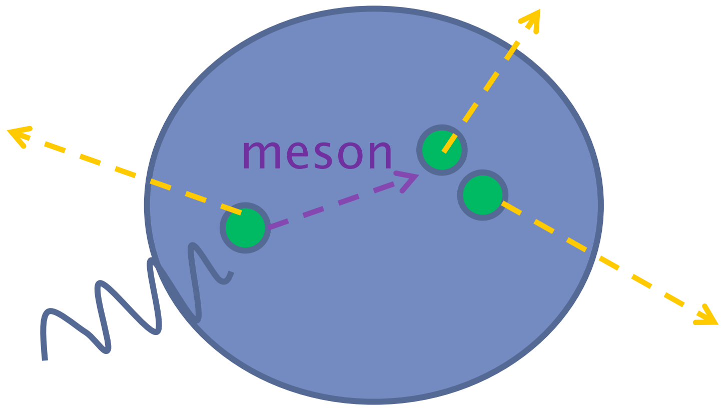
- QCD bonus: sensitivity to charge symmetry violation and high-twist effects

• J/ψ production: unprecedented precision in a completely unexplored kinematic region near the threshold, probing strong color field in the nucleon, and QCD conformal anomaly, no competition

SoLID will provide the community with a general-purpose solenoidal detector capable to operate at high luminosities while still maintain large acceptance. Much more physics is foreseen with such a device, such as di-hadron detection, SSA measurements, and tagged DIS experiments, and much more!

Other Projects of interest: Proton Knockout

- Earler work on (γ,3N) in light nuclei indicated the main mechanism for 3N knockout is Meson production from a nucleon plus reabsorption (meson,NN) (meson,NNN)



- Smaller contribution of direct 3N knockout (photon coupling to 3N current) and 2N + final state interaction
  (e.g D.P. W et. al. Phys.Lett. B553 (2003) 25-30)

- At higher energies of CLAS data initial 2-meson and 3-meson production may contribute leading to possibilities for high multiplicity emission

CLAS analysis:

low missing mass fragments

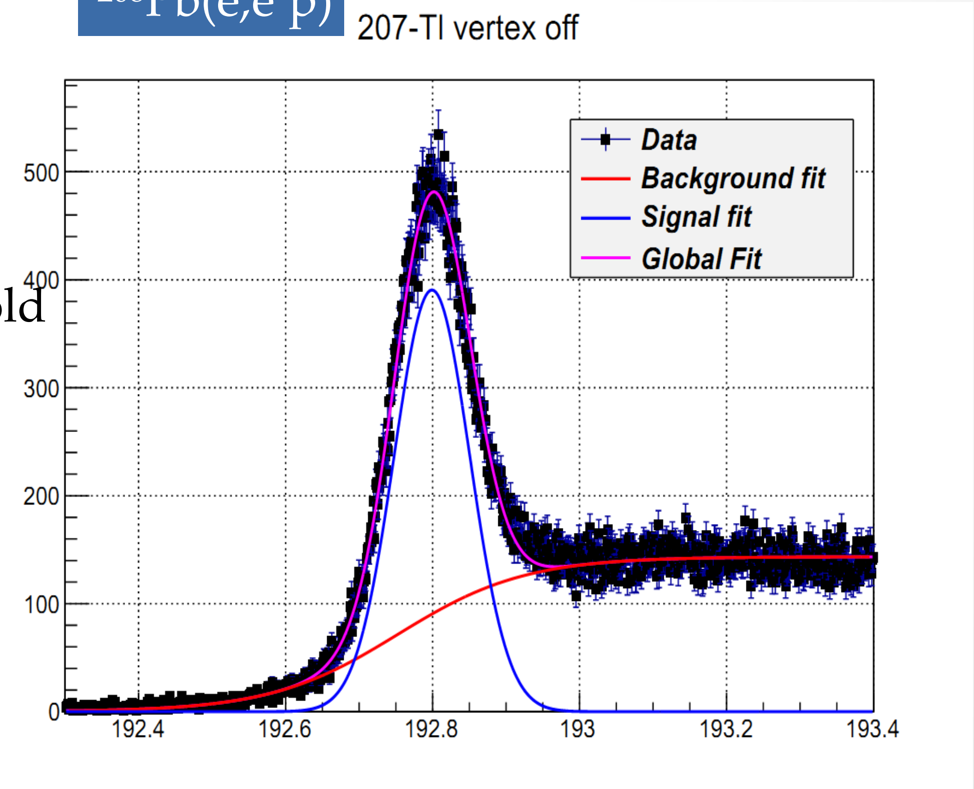
Reconstruct mass of recoiling system using detected electron and proton(s) 4-vectors

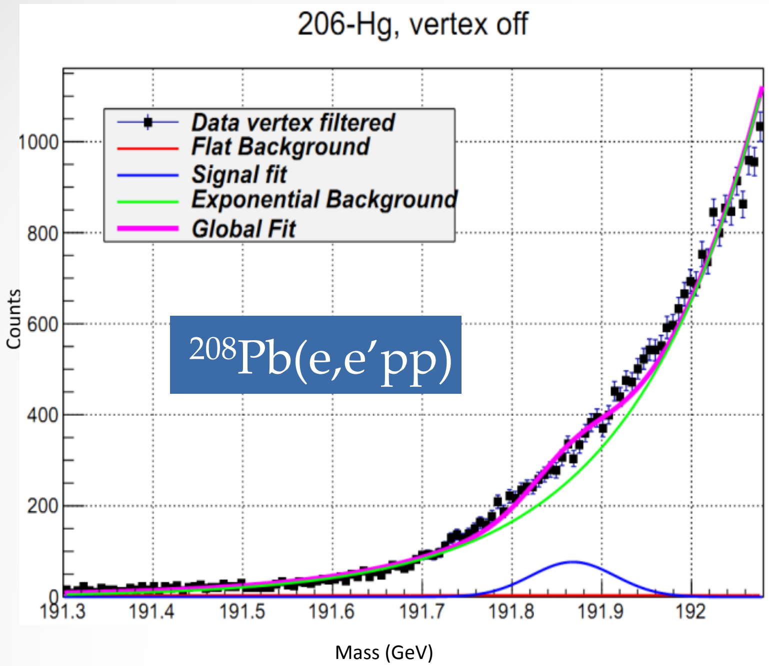
Low missing mass fragment particularly interesting

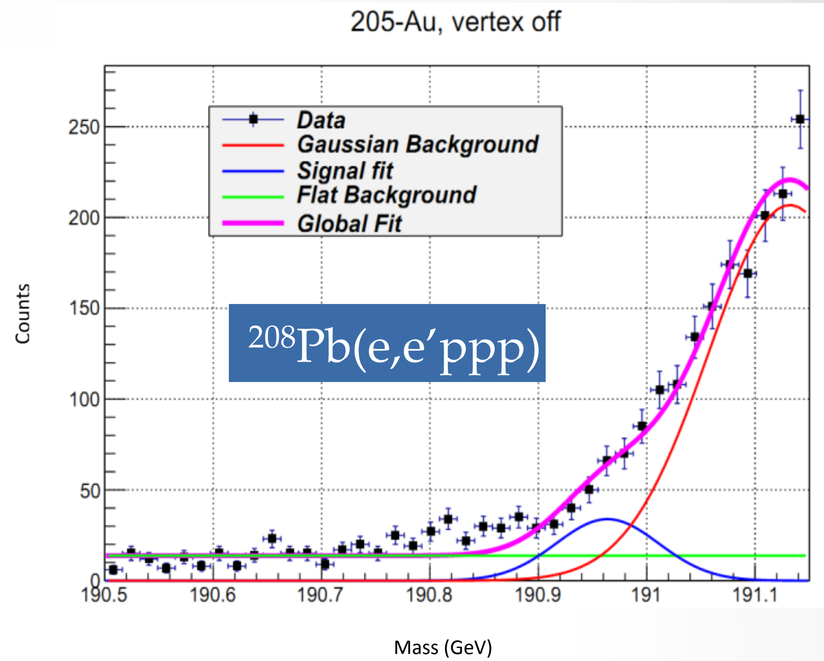
First crude analysis – fit near threshold using gaussian having width of CLAS resolution

Simple guess for background shape

$^{208}Pb(e,e'p)$




206-Hg, vertex off
Data vertex filtered
Flat Background
Signal fit
Exponential Background
Global Fit
^{208}Pb(e,e'pp)
Counts
Mass (GeV)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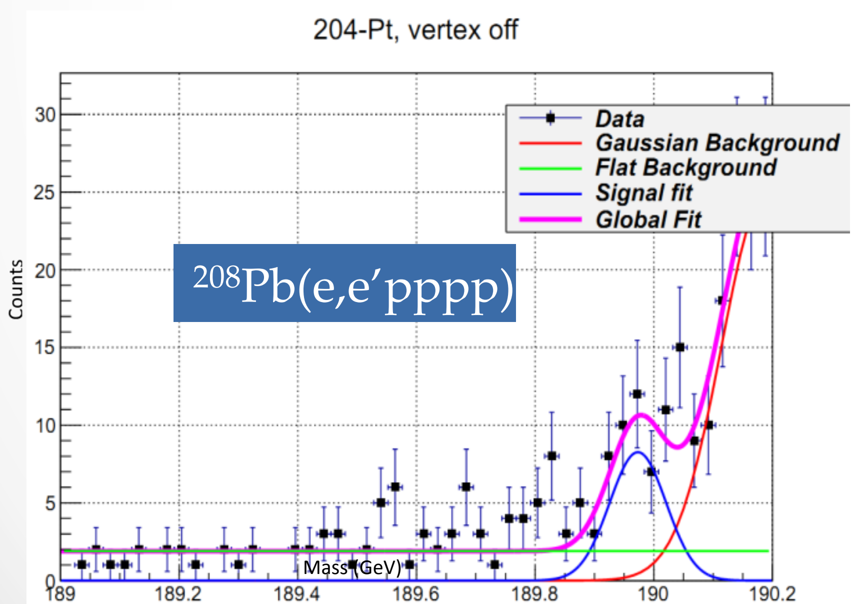
Global Fit
^{208}Pb(e,e'ppp)
Counts
Mass (GeV)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Gaussian Background
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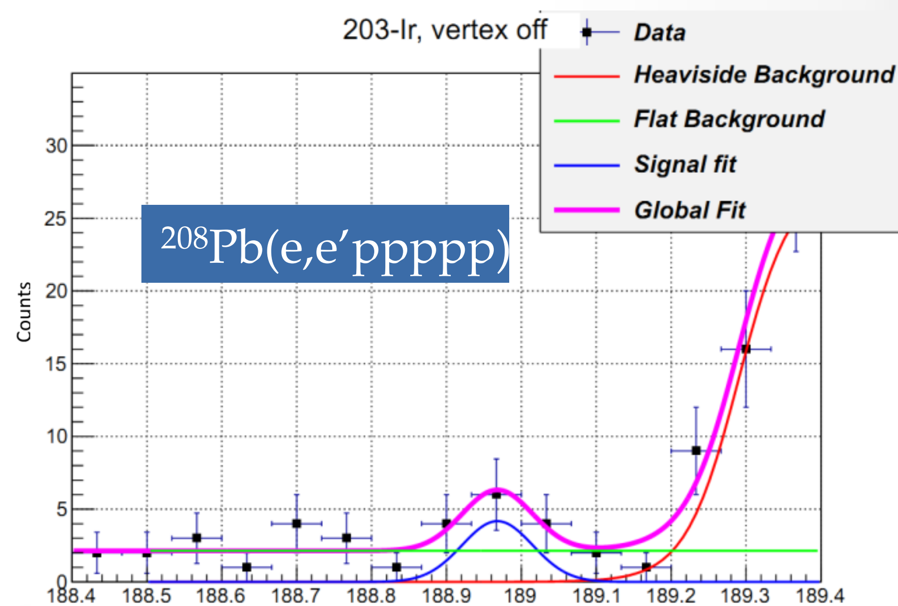
Signal fit
Global Fit
^{208}Pb(e,e'pppp)
Counts
Mass (GeV)


203-Ir, vertex off
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Signal fit
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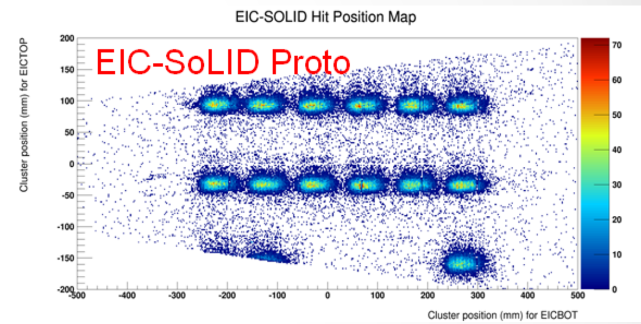
^{208}Pb(e,e'ppppp)
Counts

Backup Slides

Detectors

◆ **GEM:** by UVa and Chinese collaborators

Goals: →5 planes (PVDIS) and 6 planes (SIDIS/JPsi), area~37 m^2 (165K outputs),
→work in high rate and high radiation environment.
→tracking eff.>90%, radius resolution ~ 0.1 mm,

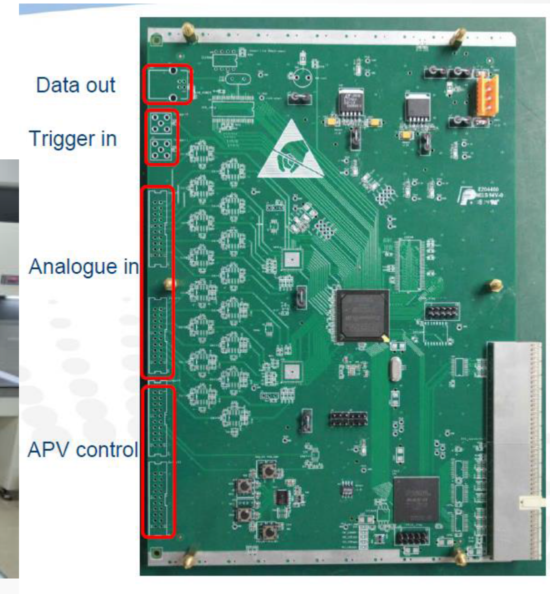


Status:

- **UVa:** First full size prototype assembled, and beam test at Fermi Lab Oct 2013
- **China:** CIAE/USTC/Tsinghua/LZU)

✓ 30x30 cm prototype constructed and readout tested, and now moving to 100cmx50cm construction
✓ Gem foil production facility under development at CIAE
✓ Continue on read-out electronics desgin and test

Test board for APV25

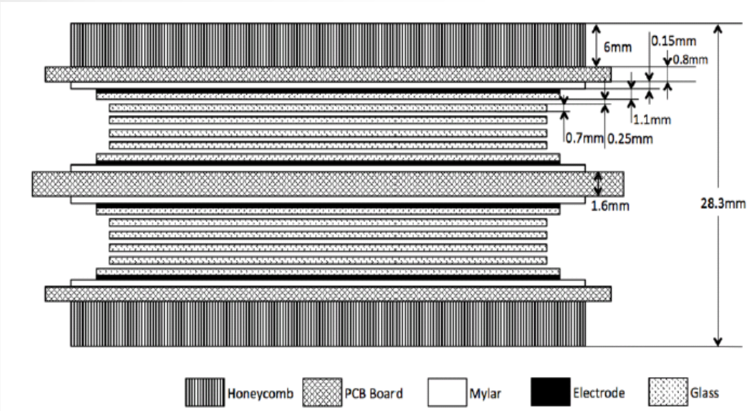


30cmx30cm GEM prototype

100cmx50cm GEM foil

Detectors

◆ **Multi-gap Resistive Plate Chamber:** by Tsinghua, Duke and Rutgers

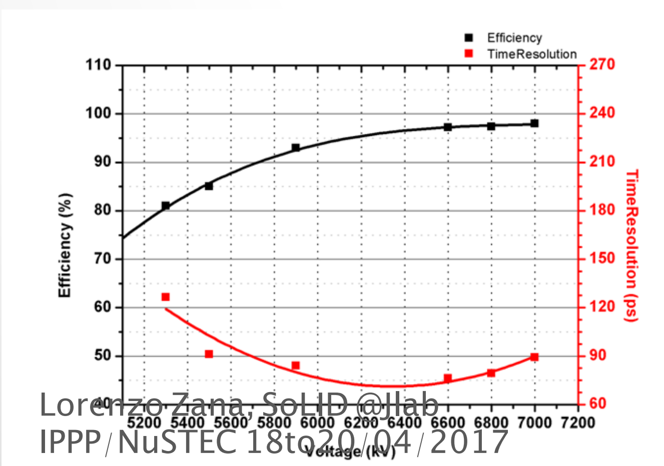


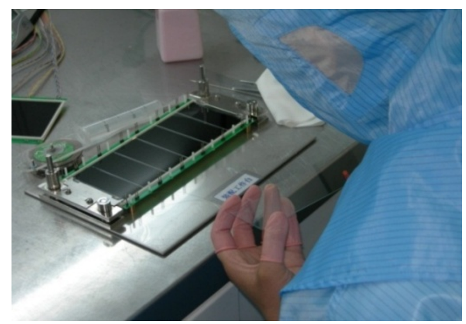
Goals:

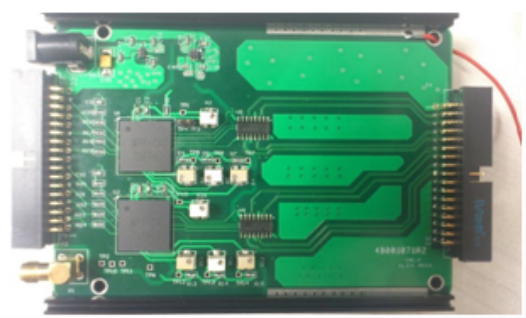
→ For SIDIS only, between FASPD and FAEC
→ 50 super-modules, each contains 3 modules, 1650 strips and 3300 output channels.
→ Timing resolution < 100ps
→ Works at high rate up to 10 KHz/cm2
→ Photon suppression > 10:1
→ π/k separation up to 2.5GeV/c

Status:

→ Prototype Developed at Tsinghua
→ Beam test at Hall-A in 2012
→ New facility for mass production
→ Read-out electronics design





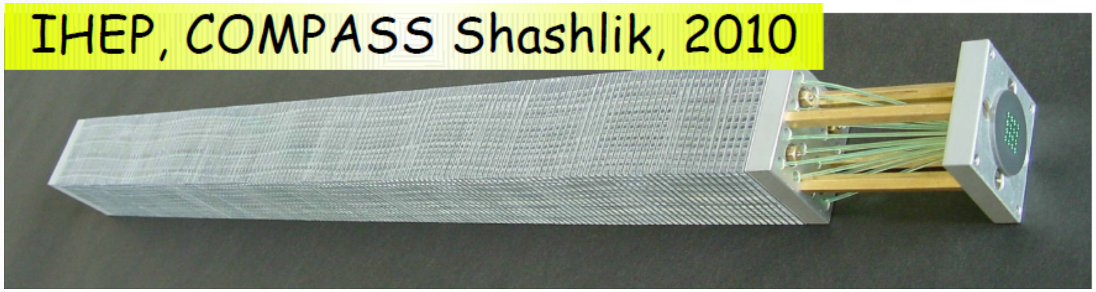


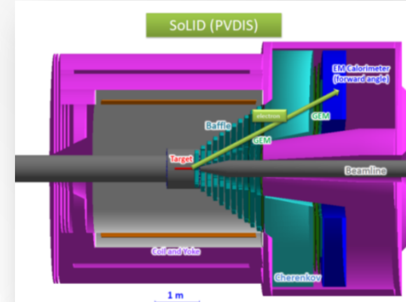
Pre-Amp

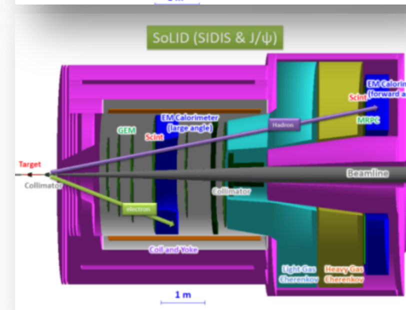
Tsinghua-FPGA TDC

Detectors

◆ **Electromagnetic Calorimeters (EC):** by UVa, W&M, ANL ...

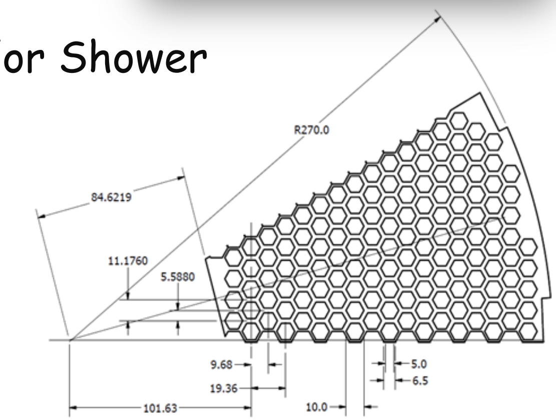






__Goals:__

→ Shashlyk sampling calorimeters
→ 1800 modules (2 R.L.) for PreShower, 1800 modules (18 R.L) for Shower
→ Modules re-arranged for PDVIS<->SIDIS
→ electron eff.>90%, E-Resolution~10%/√E,
  π suppresion > 50:1
→ Rad. Hard (<20% descreasing after 400K Rad)



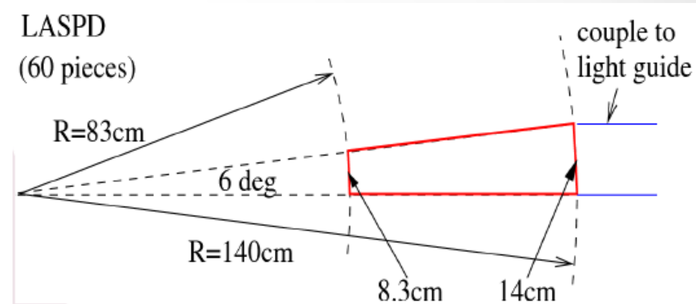
	θ (deg)	z (cm)	R(cm)	P (GeV/c)	Max π/e	Area (m²)
PVDIS FAEC	22 - 35	(320,380)	(110,265)	2.3 - 6	~200	~ 18.3
SIDIS FAEC	7.5 - 14.85	(417,475)	(98,230)	1 - 7	~200	~ 13.6
SIDIS LAEC	16.3 - 24	(-65,-5)	(83,140)	3-6	~20	~ 4.0

Detectors

◆ **Scintillating Pedal Detectors (SPD):** by UVa and Duke ...

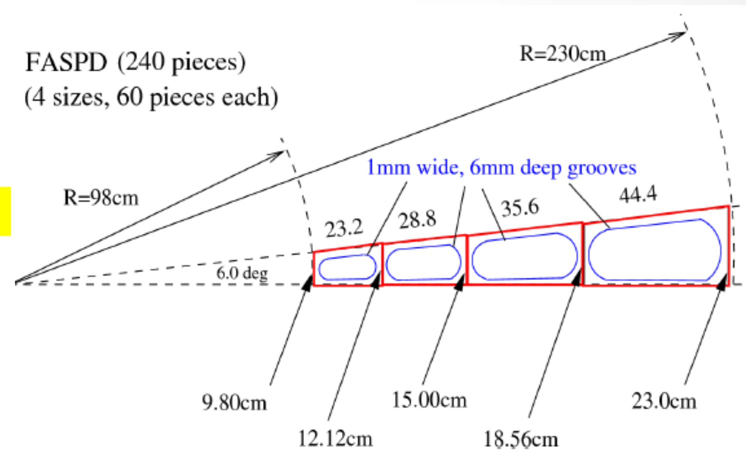
Goals:

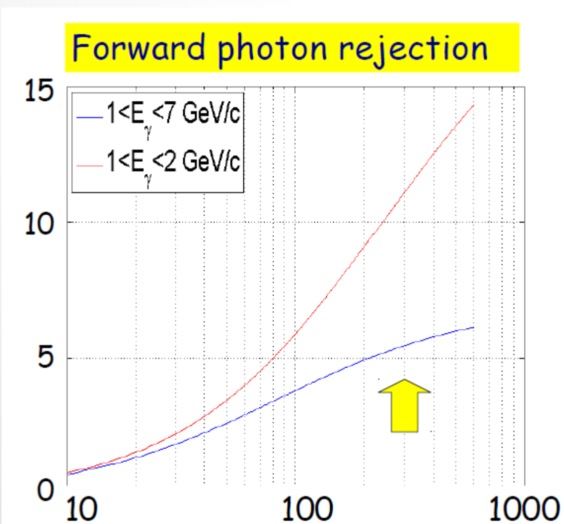
→ For SIDIS only
→ Two planes (in front of LAEC and FAEC):
  LASPD: 60 modules, 5 mm or thicker, photon rej. 10:1
  FASPD: 60 modules x 4 radius, photon rej. 5:1
→ LASPD timing resolution < 150ps

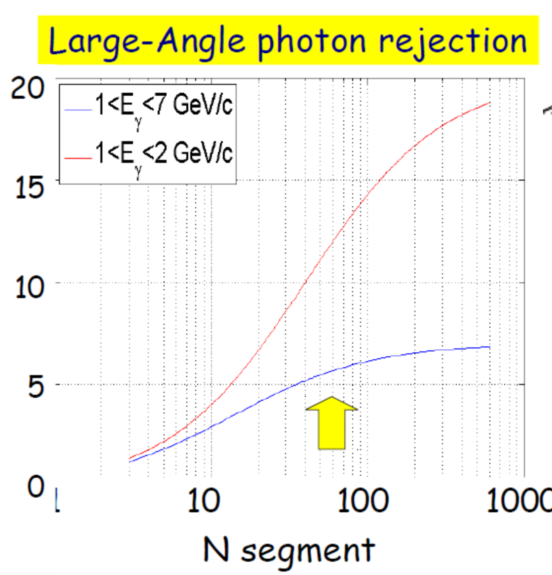


Status:

→ Design and Simulation
→ Pre-R&D at UVa and JLab







Triggers&DAQ

◆ Triggers:

→ Estimation based on sophesticated Geant simulation and well-tone physics models

→ PVDIS: LGC+EC provide electron triggers, 27 KHz/sector, 30 sectors

→ SIDIS: Coincident trigger between electrons and hardrons within a 30 ns window:

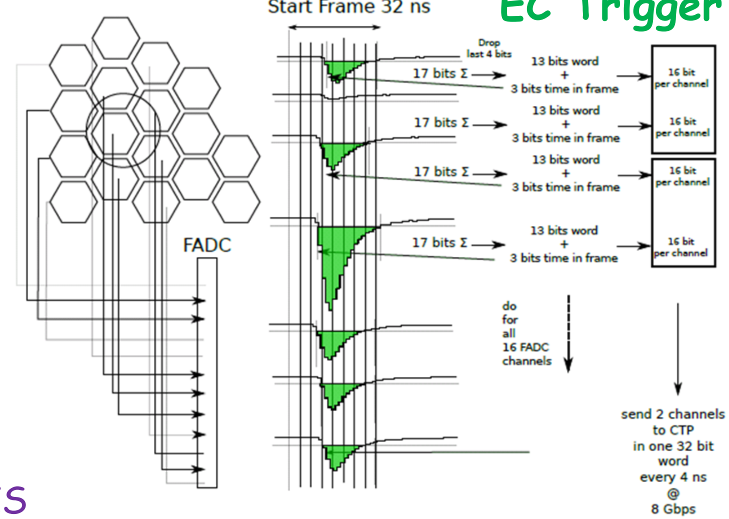
LASPD+LAEC provide electron triggers, 25 KHz

LGC+FASPD+MRPC+FAEC provide electron trigger, 129 KHz

FASPD+MRPC+FAEC provide hardron trigger, 14 MHz

} 66 KHz + 6 KHz (eDIS)

EC Trigger



◆ Read-Out and Data Aquisition System:

→ Use fast electronics to handle the high rates (FADC, APV25, VETROC, etc.)

→ Read out EC clusters to reduce background

→ Current design can take the trigger rates

60 KHz per sector for PVDIS, and 100 KHz overall for SIDIS

→ Use Level-3 to further reduce the events size

→ Learn new developments from others (e.g. Hall-D)

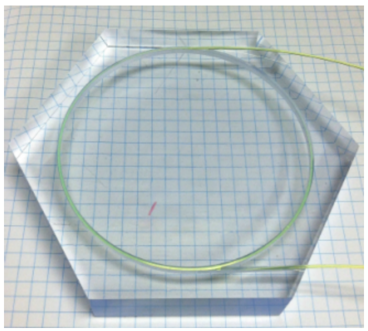
Detectors

◆ **Electromagnetic Calorimeters (EC):** continue ...

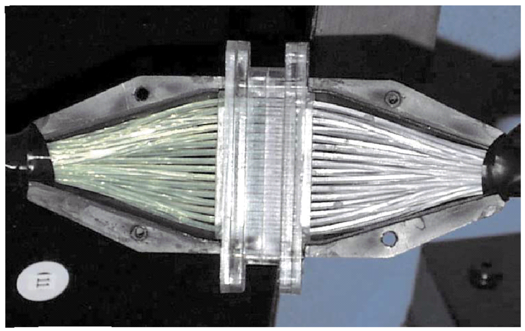
Status:

→ Sophesticated Geant Simulation
→ Active Pre-R&D at UVa and Jlab
→ Sample&PMT tests and Pre-Amp design

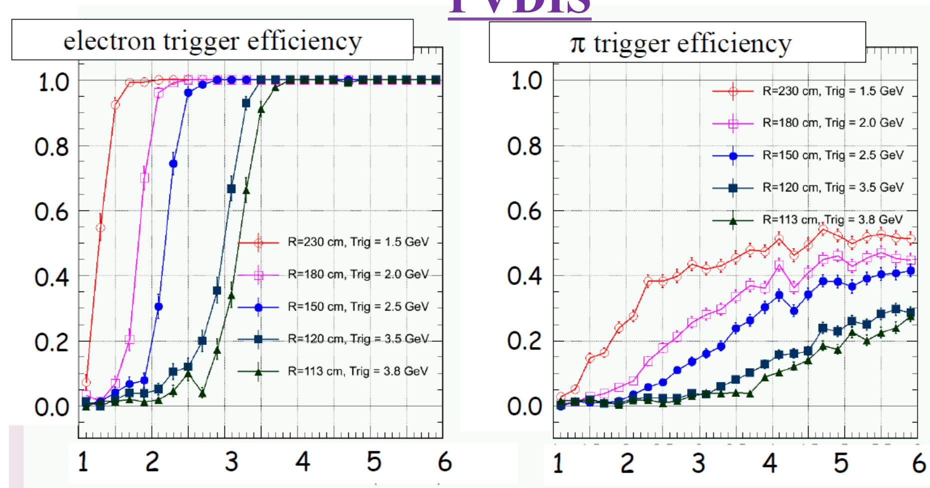
PreShower module



Fiber connectors

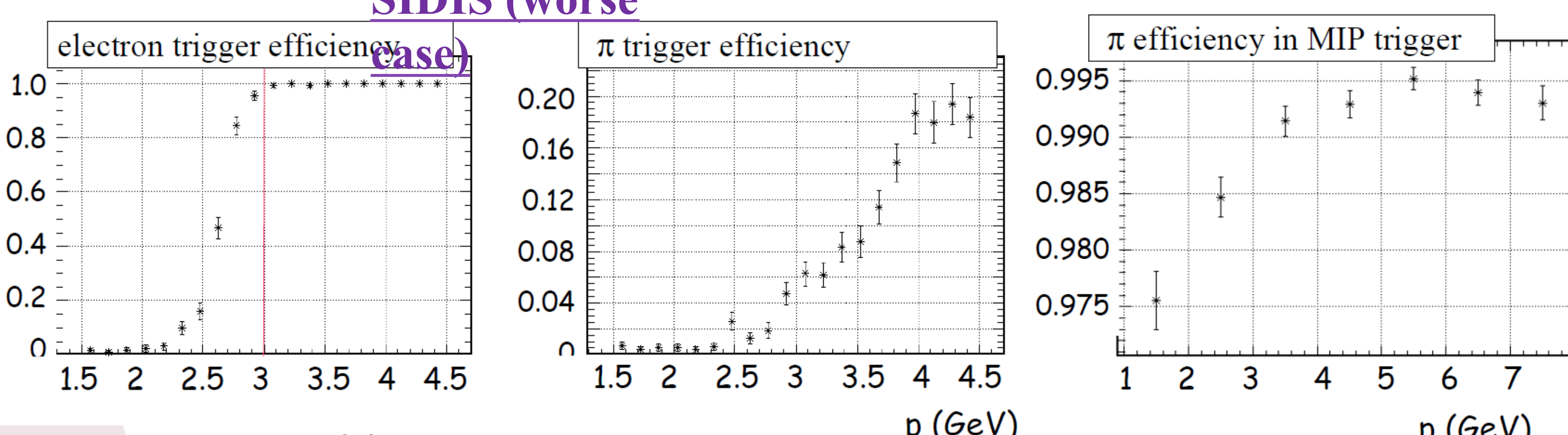


PVDIS



preserve DIS electron of x>0.35

SIDIS (worse case)



threshold: 2.6 GeV → 3 GeV momentum

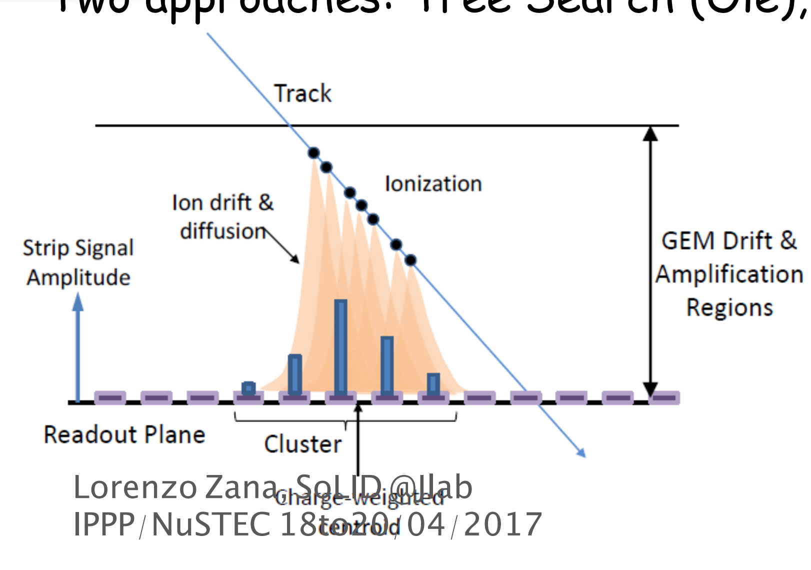
Simulation&Software

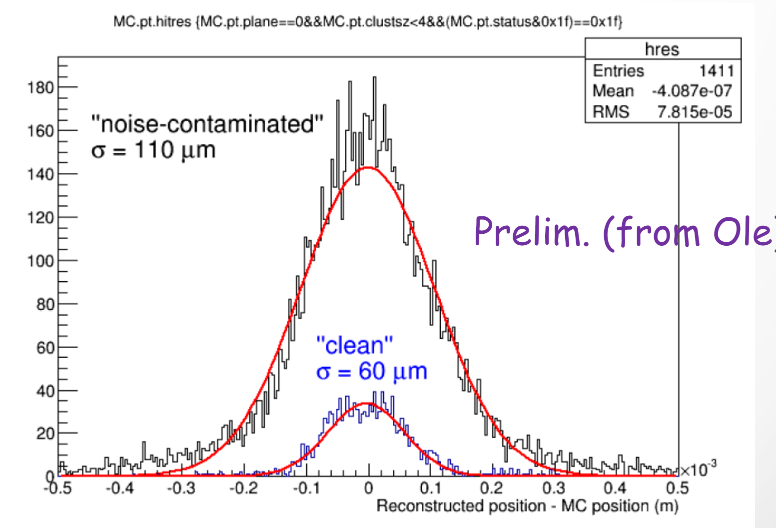
◆ GEMC:

- SoLID full setup in GEMC (Geant4) with realistic materials
- EM background produced from 11GeV e- on targets with the physics models in Geant4
- Hadron background, generated from event generators (Wiser fit) on both target and target windows, then passed into GEMC

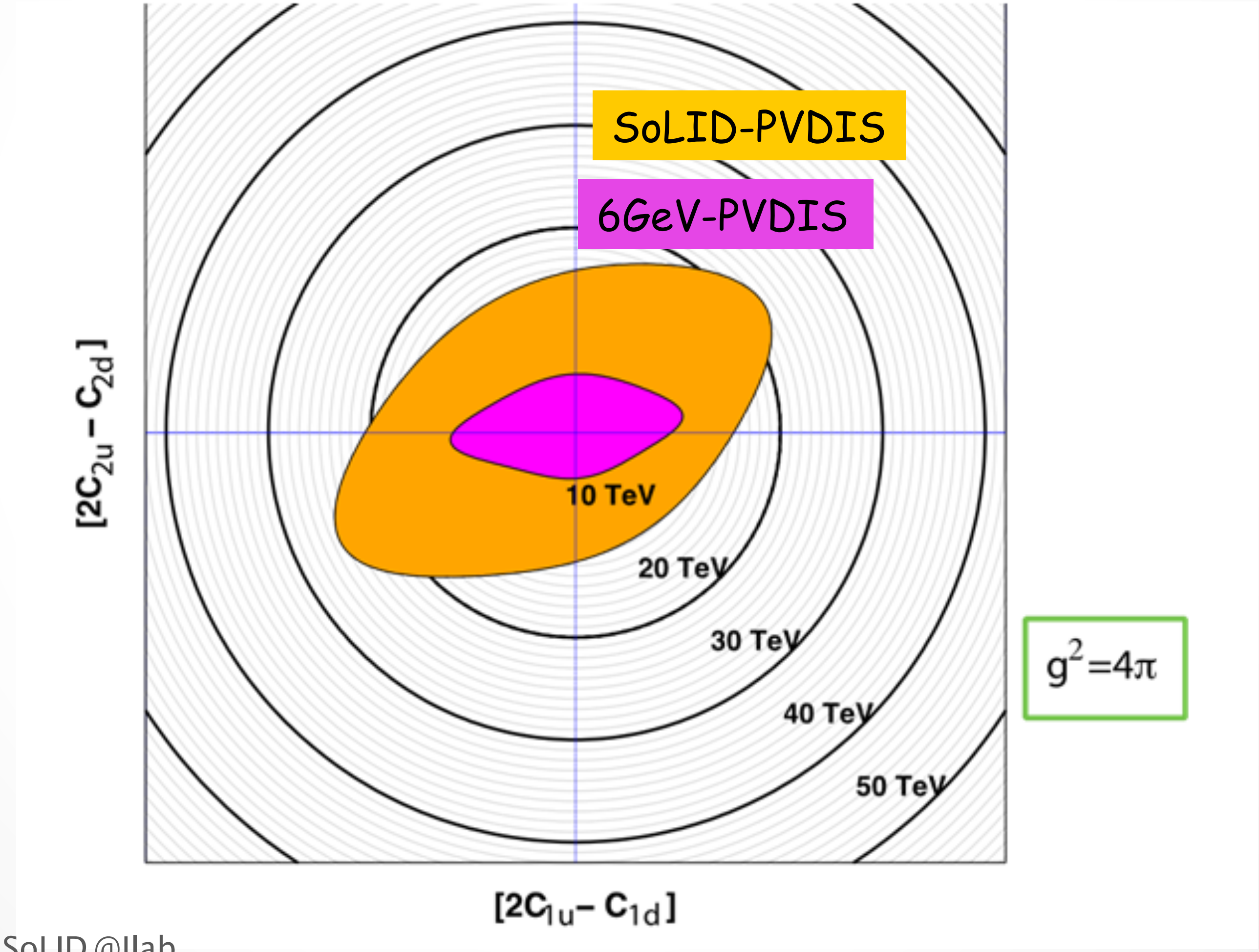
◆ GEM Tracking Reconstruction:

- Can reconstruct charged particles traveling in the strong magnetic filed
- Need fast processing time for high rates with backgrounds
- Two approaches: Tree Search (Ole), Progressive Tracking (Weizhi Xiong, Duke)

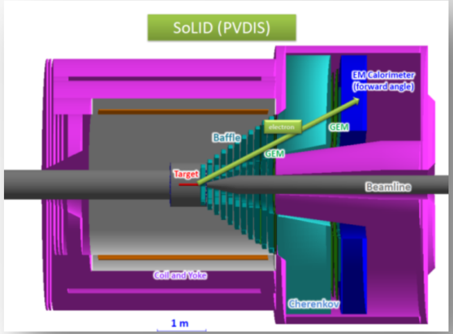




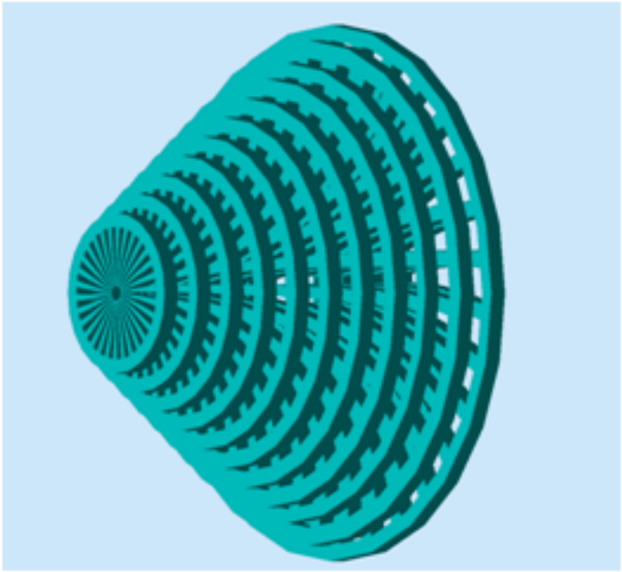
Power of SoLID-PVDIS



Baffle

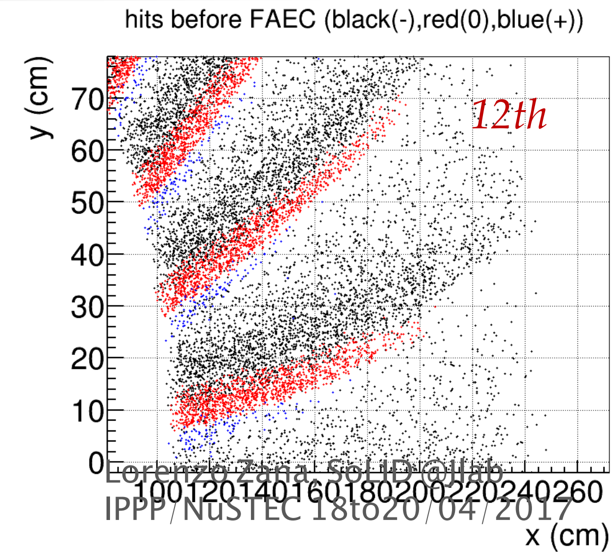


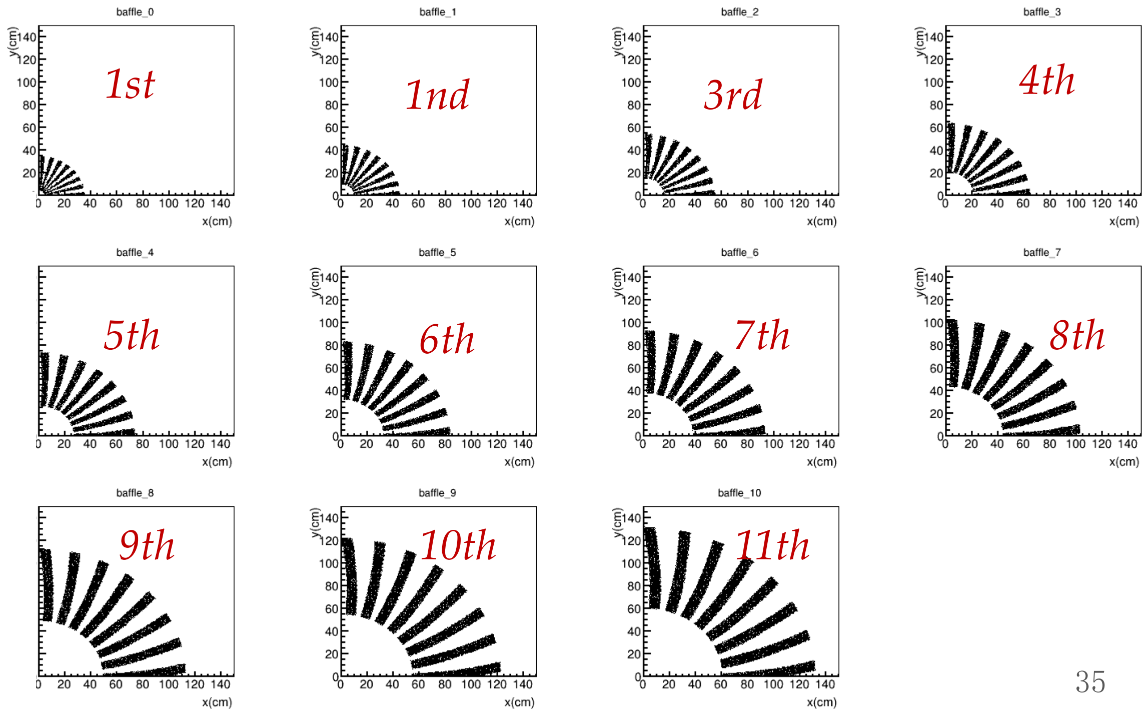
◆ **PVDIS Baffle:**



Goals:

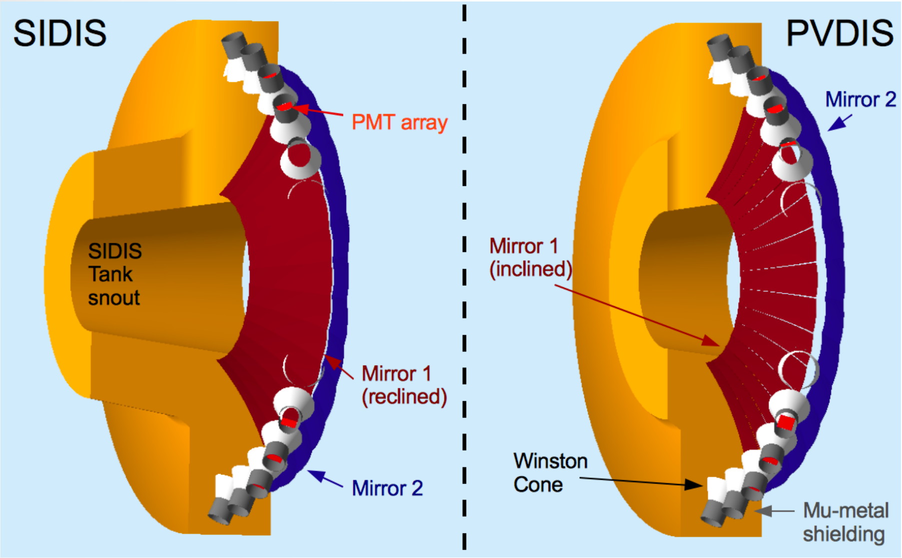
→ For PVDIS only
→ 11 layers of 9cm thick lead and one layer of 5cm lead
→ Right after the target to block photons, pions and secondary particles.
→ Follow charge particle bending in the field, preserve the same azimuthal slice and block line of sight.





Detectors

- **Light Gas Cherenkov Counter (LGC):** by Temple University

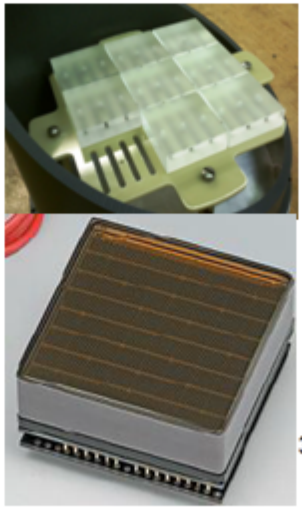


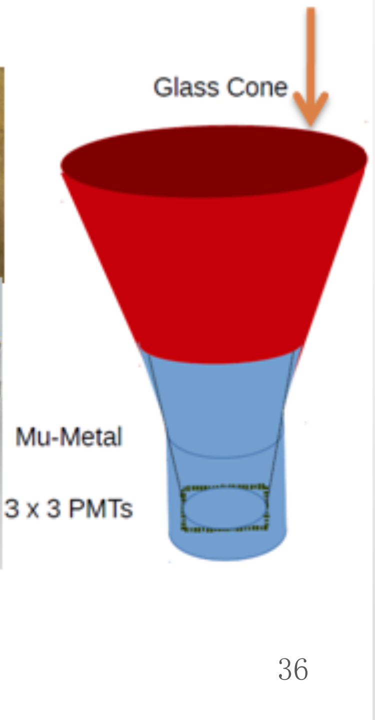
Goals:

→2 m C02 (SIDIS/Jpsi), 1 atm
→1 m C4F8O (65%)+N2 (35%) (PVDIS), 1 atm
→30 sectors, 60 mirrors, 270 PMTs, Area~20m^2
→N.P.E>10, eff.>90%, π suppresion > 500:1
→Work at 200G field (100G after shielding)

Status:

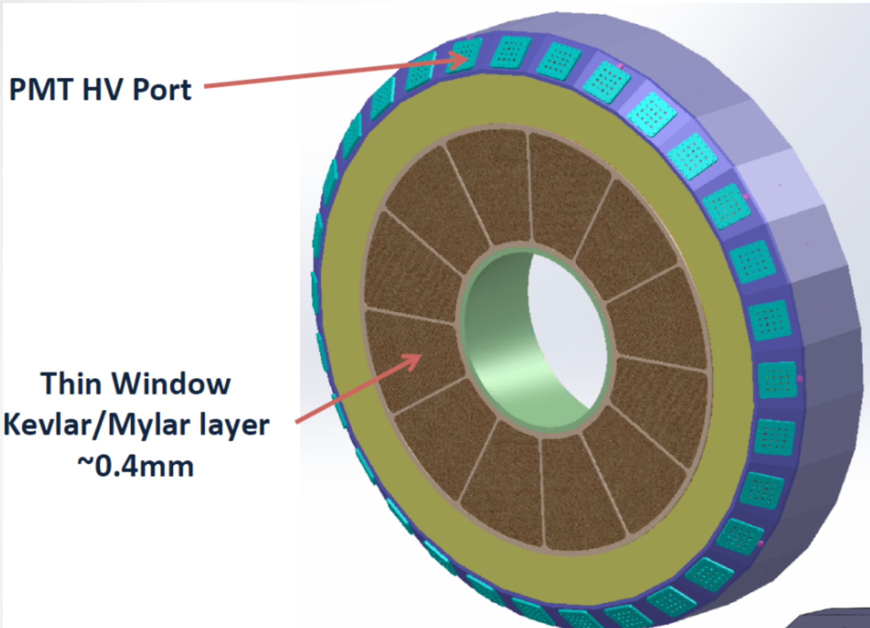
→ Support Structure and Mounting Design
→ u-metal Shielding design
→ Pre-R&D ongoing at Temple





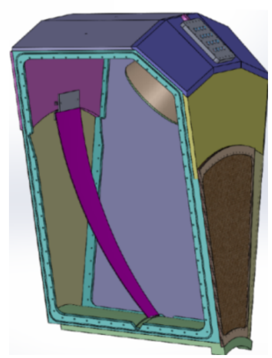
Detectors

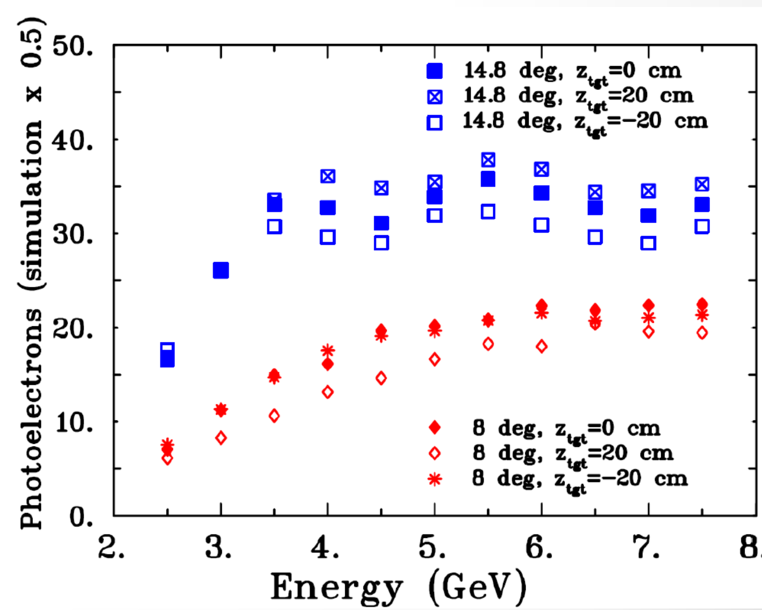
◆ **Heavy Gas Cherenkov Counter (HGC):** by Duke University



Goals:

→for SIDIS only
→1 m C4F8O at 1.5 atm
→30 mirrors, 480 PMTs, area~20 m^2
→N.P.E>10, eff.>90%, Kaon suppresion > 10:1,
→Work at 200G field (100G after shielding)

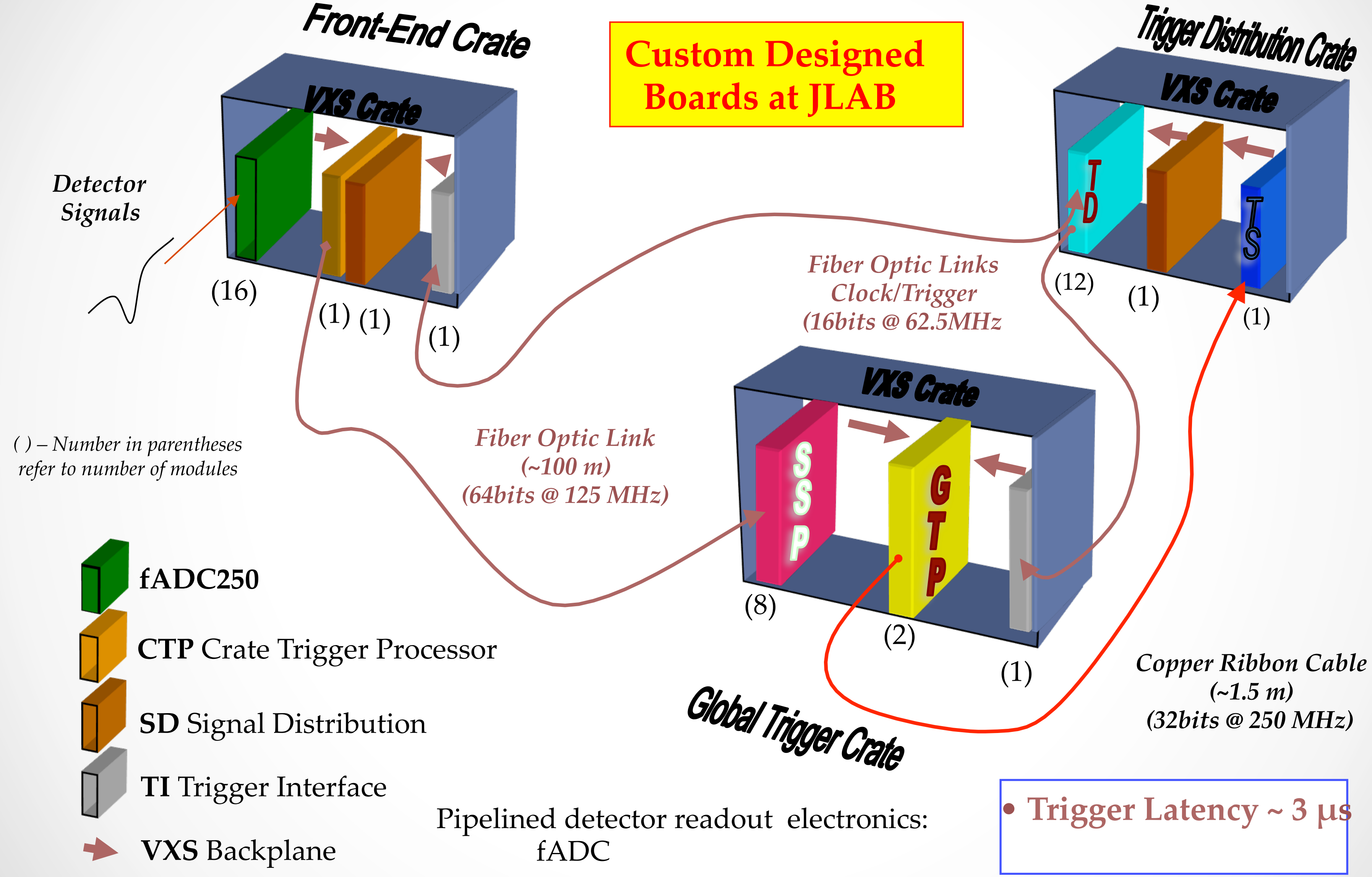




Status:

→ Optimize the design with MC
→ Designs of Support Structure, Mounting, Shielding, etc.
→ Magnet field test with MaPMT H8500 (S. Malance, JINST 8 P09004,2013) and H12700
→ Prototype-Test will happen at Duke soon

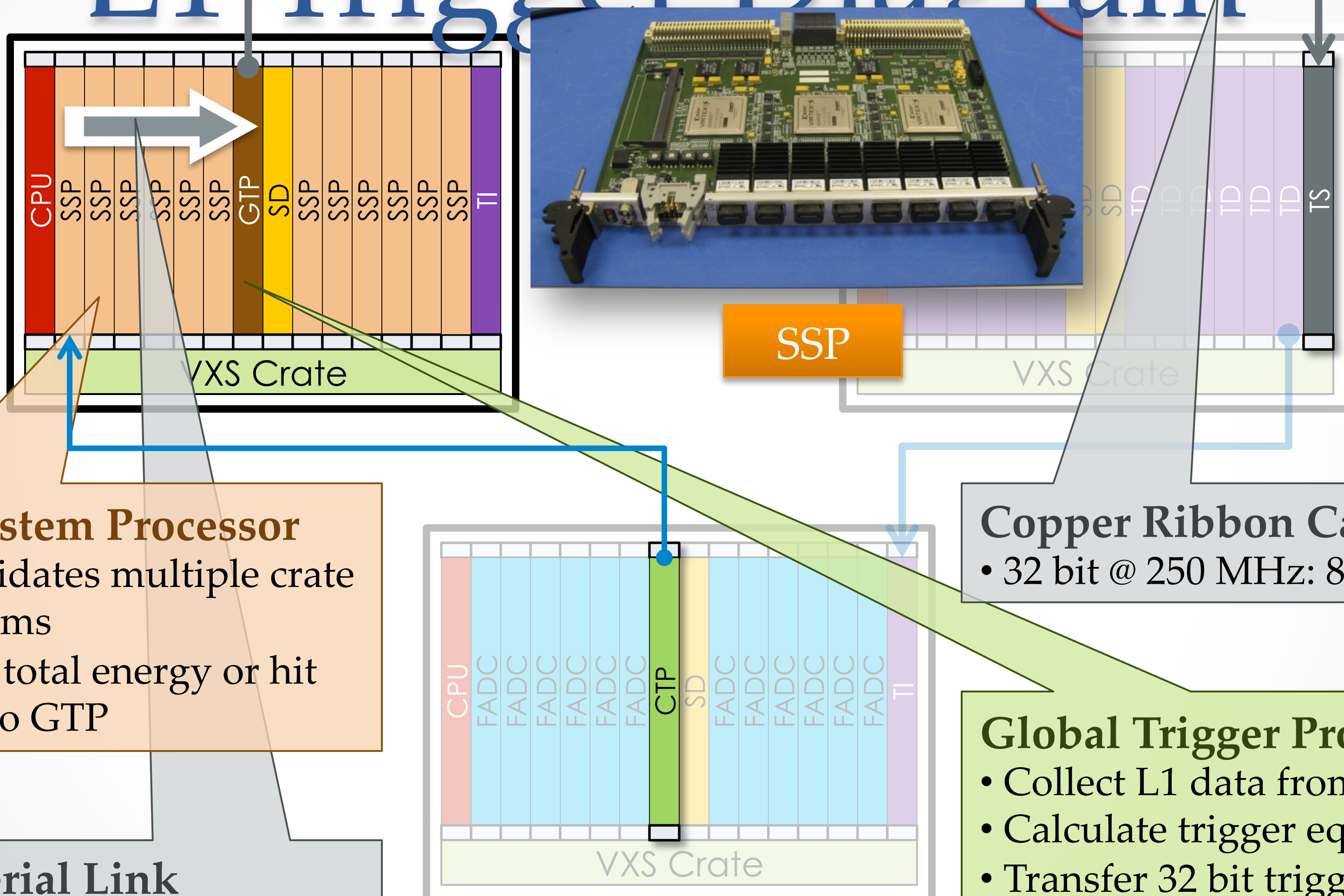
Level-1 Trigger Electronics



Pipelined detector readout electronics: fADC

- Trigger Latency ~ 3 μs

L1 Trigger Diagram



Sub-System Processor
- Consolidates multiple crate subsystems
- Report total energy or hit pattern to GTP

VXS Serial Link
- 32 bit @ 250 MHz: 8 Gbps

Copper Ribbon Cable
- 32 bit @ 250 MHz: 8 Gbps

Global Trigger Processor
- Collect L1 data from SSPs
- Calculate trigger equations
- Transfer 32 bit trigger pattern to TS