SoLID Overview

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July 23rd 2014

6th workshop on hadron physics in China and opportunities in US

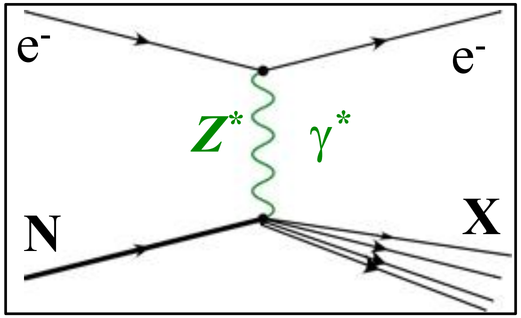
Lanzhou, China

Outline

- CLEO magnet
- PVDIS
  - Measurements
  - Baffles
  - GEMs for PVDIS
  - Preshower and shower calorimeter
  - Light Gas Cerenkov
  - Data rates
- SIDIS, J/Psi
  - Heavy Gas Cerenkov
  - MRPC
  - Data rates
- Conlusion

PV Deep Inelastic Scattering

off the simplest isoscalar nucleus and at high Bjorken x



$$A_{PV} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_A \frac{F_1^{\gamma Z}}{F_1^{\gamma}} + g_V \frac{f(y)}{2}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}\right]$$

$Q^2 >> 1\ GeV^2$, $W^2 >> 4\ GeV^2$

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y)b(x)\right]$$

$x \equiv x_{Bjorken}$

$y \equiv 1 - E'/E$

$$Y = \frac{1-(1-y)^2}{1+(1-y)^2 - y^2\frac{R}{R+1}}$$

$$R(x, Q^2) = \sigma^l/\sigma^r \approx 0.2$$

$$A_{\rm iso} = \frac{\sigma^l - \sigma^r}{\sigma^l + \sigma^r}$$

At high x, A_{iso} becomes independent of pdfs, x & W, with well-defined SM prediction for Q^2 and y

$$= -\left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right)\frac{2C_{1u} - C_{1d}\left(1+R_s\right) + Y\left(2C_{2u} - C_{2d}\right)R_v}{5+R_s}$$

$$R_s(x) = \frac{2S(x)}{U(x)+D(x)} \xrightarrow{\text{Large } x} 0$$

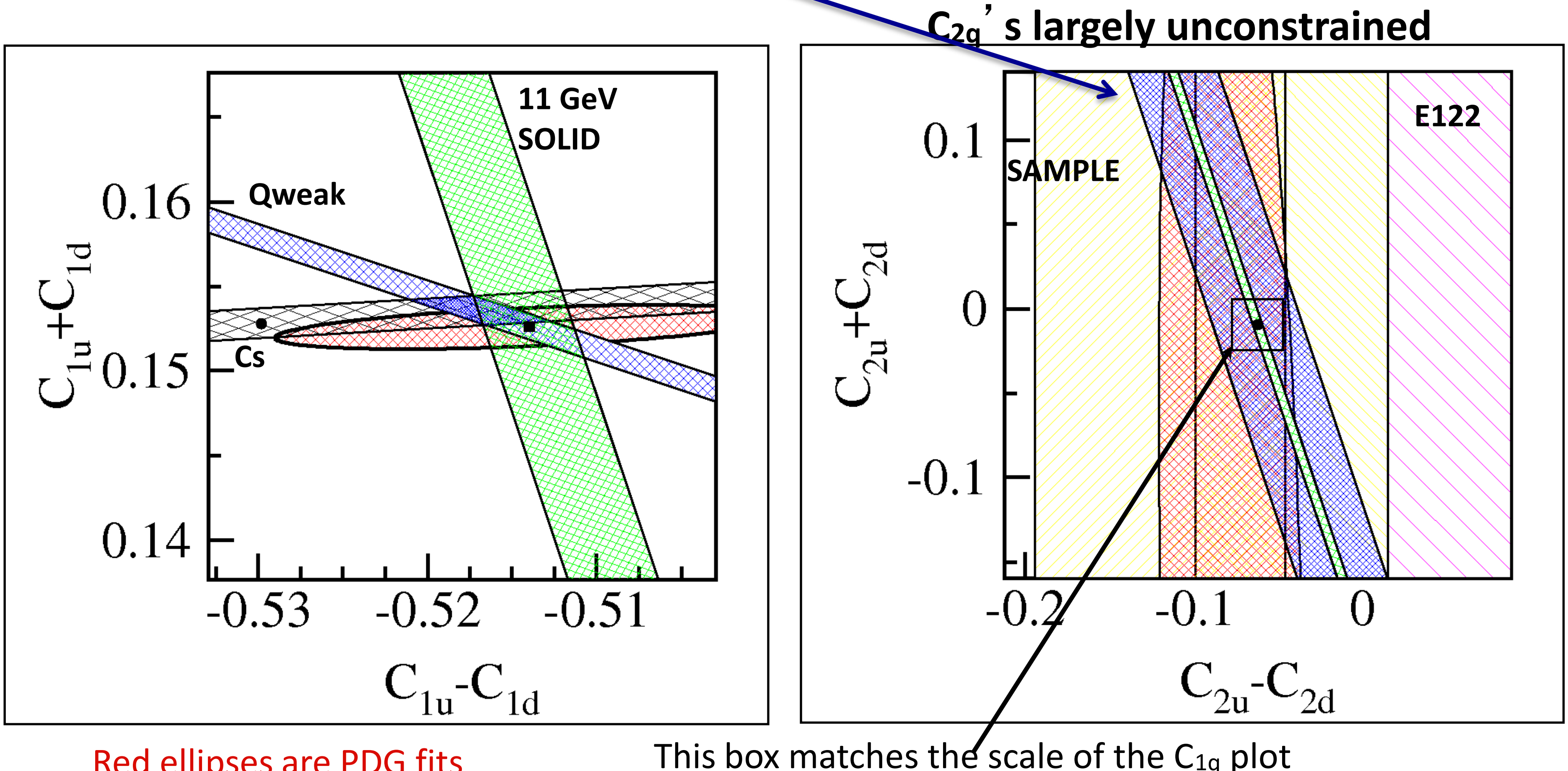
$$R_v(x) = \frac{u_v(x)+d_v(x)}{U(x)+D(x)} \xrightarrow{\text{Large } x} 1$$

Interplay with QCD

- Parton distributions (u, d, s, c)
- Charge Symmetry Violation (CSV)
- Higher Twist (HT)
- Nuclear Effects (EMC)

SOLID Goal

Measure A_{PV} for e-^{2}H DIS to 0.6% fractional error (stat + syst + theory) at high x, y

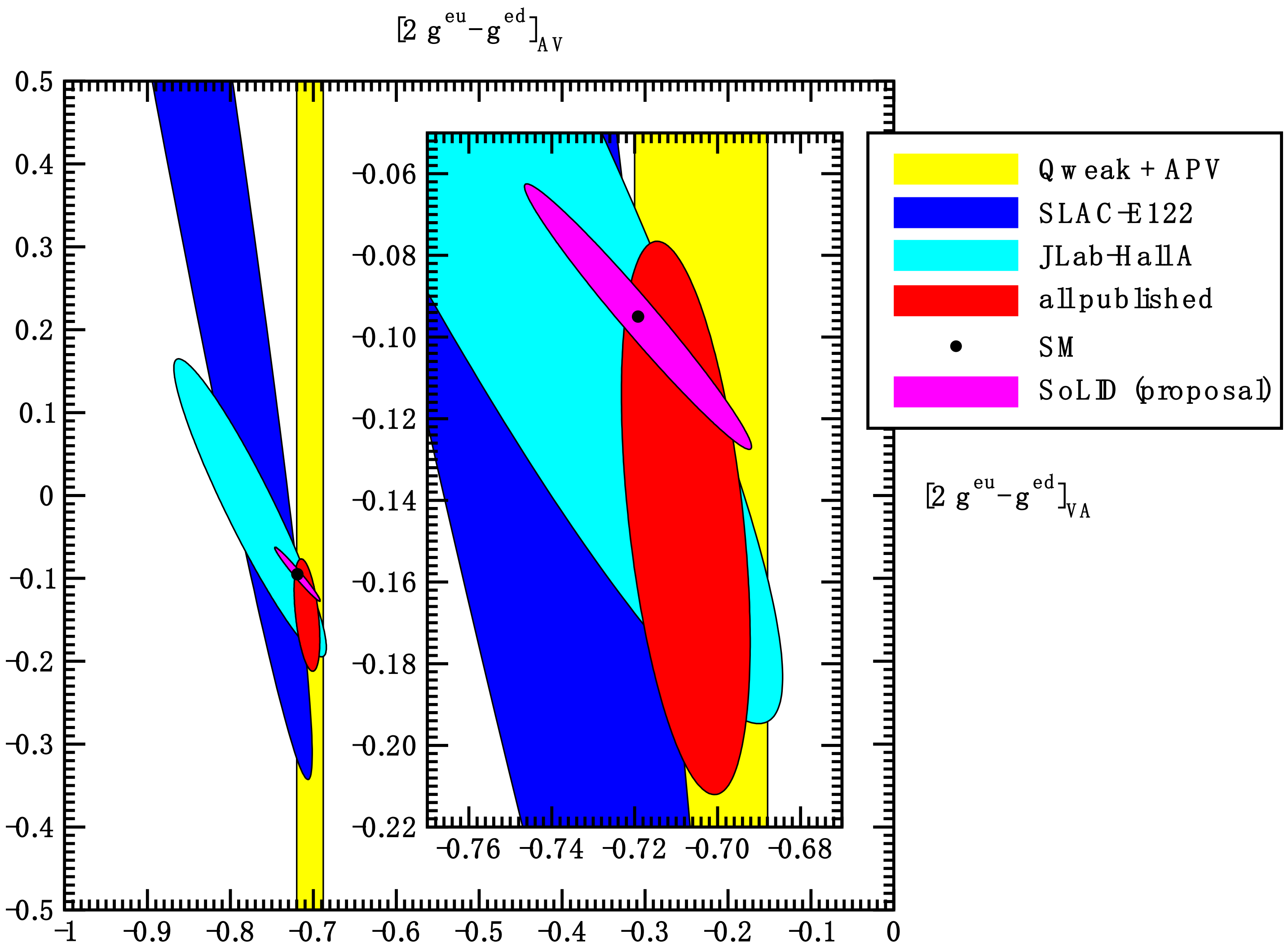


Red ellipses are PDG fits

Green bands are the proposed measurement of SOLID

unique TeV-scale sensitivity

SoLID PVDIS Projected Result



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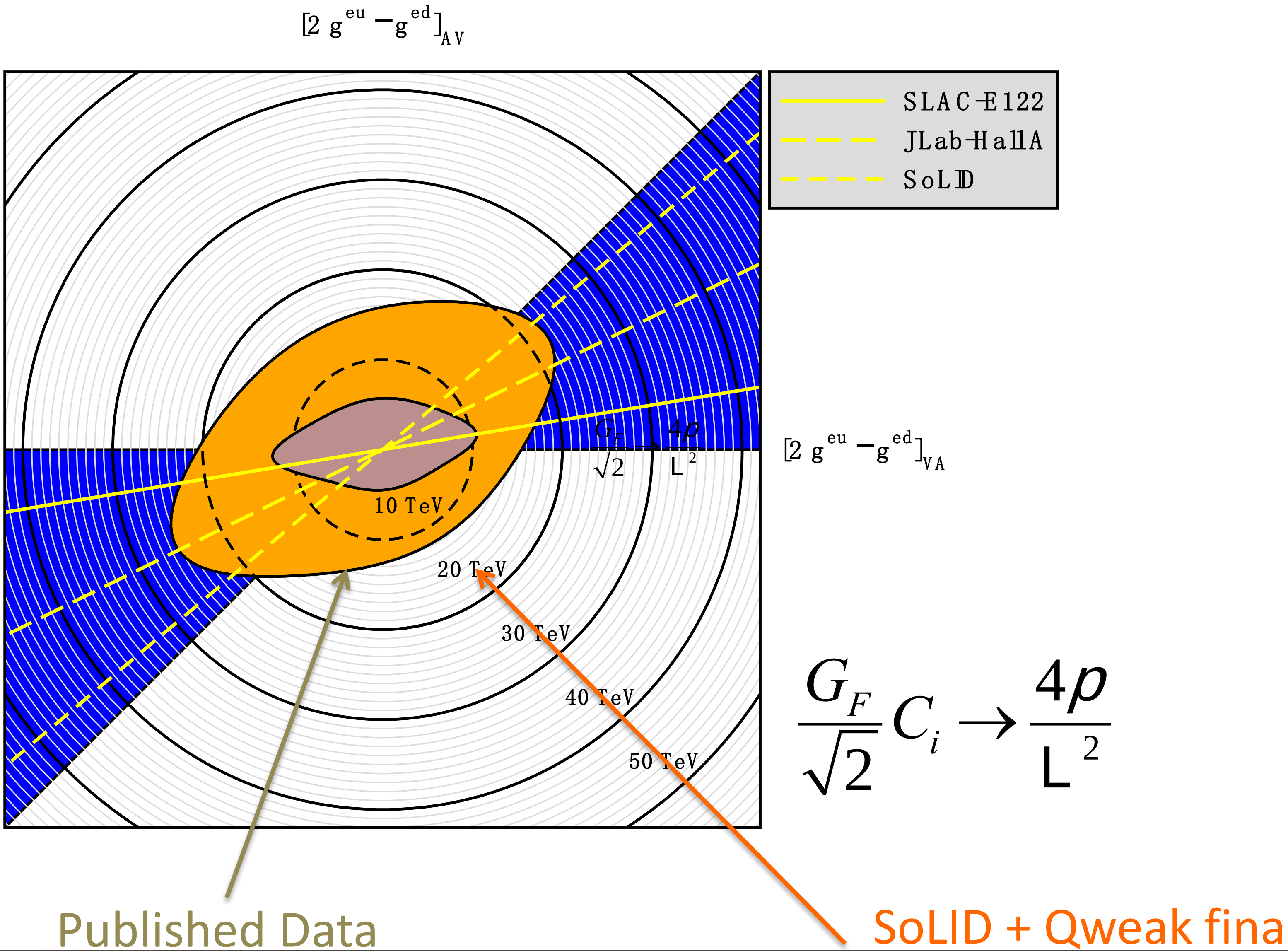
Mass Limits for Composite Theories



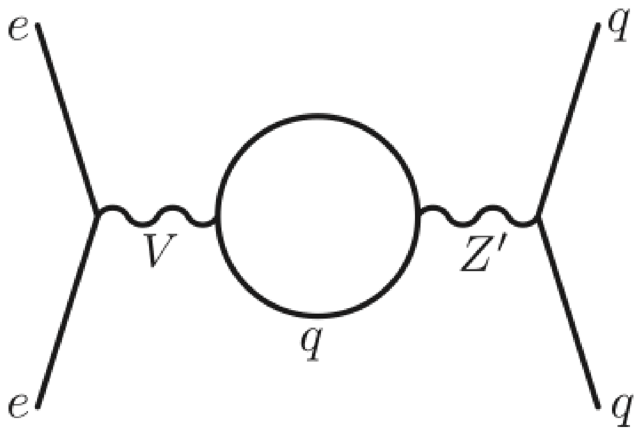
$$\frac{G_F}{\sqrt{2}} C_i \rightarrow \frac{4\pi}{\Lambda^2}$$

New Physics Examples

Leptophobic Z'

- *Virtually all GUT models predict new Z's*
- *LHC reach ~ 5 TeV, but....*
- *Little sensitivity if Z' doesnt couple to leptons*
- *Leptophobic Z' as light as 120 GeV could have escaped detection*

Since electron vertex must be vector, the Z' cannot couple to the C_{1q}'s if there is no electron coupling: can only affect ***C_{2q}'s***



SOLID can improve sensitivity:
100-200 GeV range

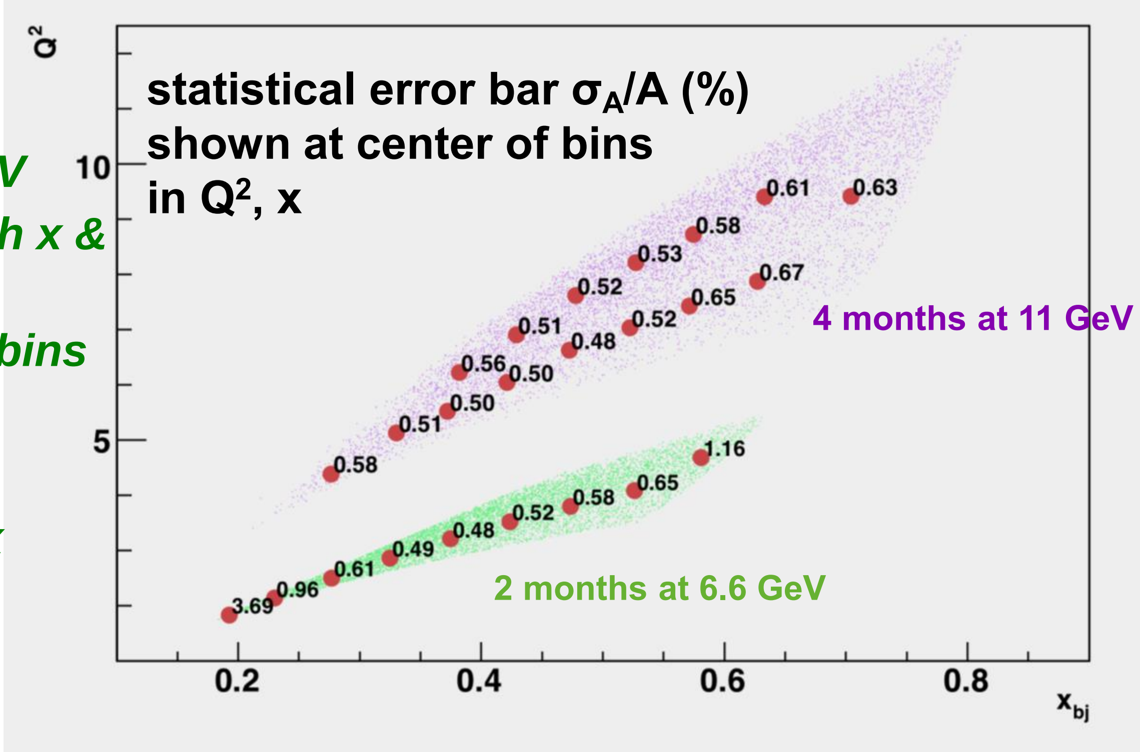
arXiv:1203.1102v1
Buckley and Ramsey-Musolf

Program of Measurements

Requires 12 GeV upgrade of JLab and a large superconducting solenoid

Requirements

- *High Luminosity with E > 10 GeV*
- *Large scattering angles (for high x & y)*
- *Better than 1% errors for small bins*
- *x-range 0.25-0.75*
- *W^2 > 4 GeV^2*
- *Q^2 range a factor of 2 for each x*
– (Except at very high x)
- *Moderate running times*



Strategy: **sub-1% precision** over broad kinematic range: **sensitive Standard Model test** *and* **detailed study of hadronic structure contributions**

$$A = A\left[1 + \beta_{HT}\frac{1}{(1-x)^3 Q^2} + \beta_{CSV}x^2\right]$$

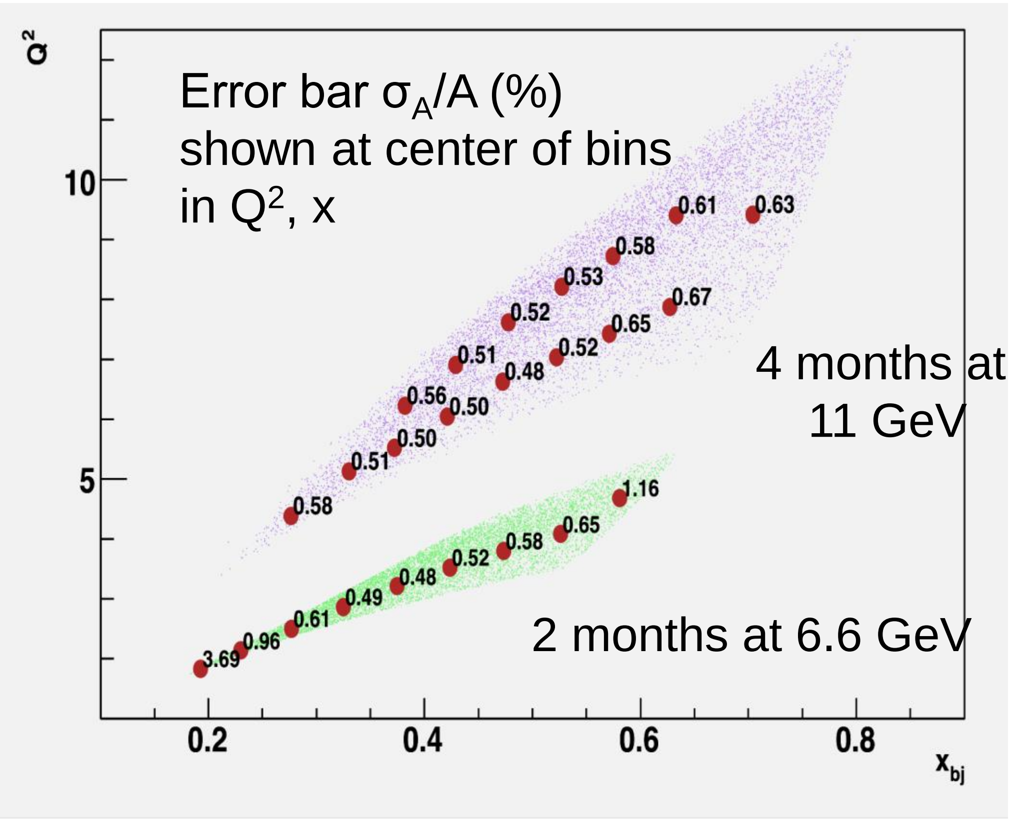
If no CSV, HT, quark sea or nuclear effects, ALL Q^2, x bins should give the same answer within statistics modulo kinematic factors!

Error Budget (%)

Statistics	0.3
Polarimetry	0.4
Q2	0.2
Radiative Corrections	0.3
Total	0.6

Running time

<u>Strategy:</u> sub-1% precision over broad kinematic range for **sensitive Standard Model test** *and* **detailed study of hadronic structure contributions**



Untangle Physics with fit:

$$A = A\left[1 + \beta_{HT}\frac{1}{(1-x)^3 Q^2} + \beta_{CSV}x^2\right]$$

Beam Time Request:

LD_2: 245 Days

LH_2: 113 Days

Energy(GeV)	4.4	6.6	11	Test
Days(LD2)	18	60	120	27
Days(LH2)	9	-	90	14

180 Days are Approved

Baffles

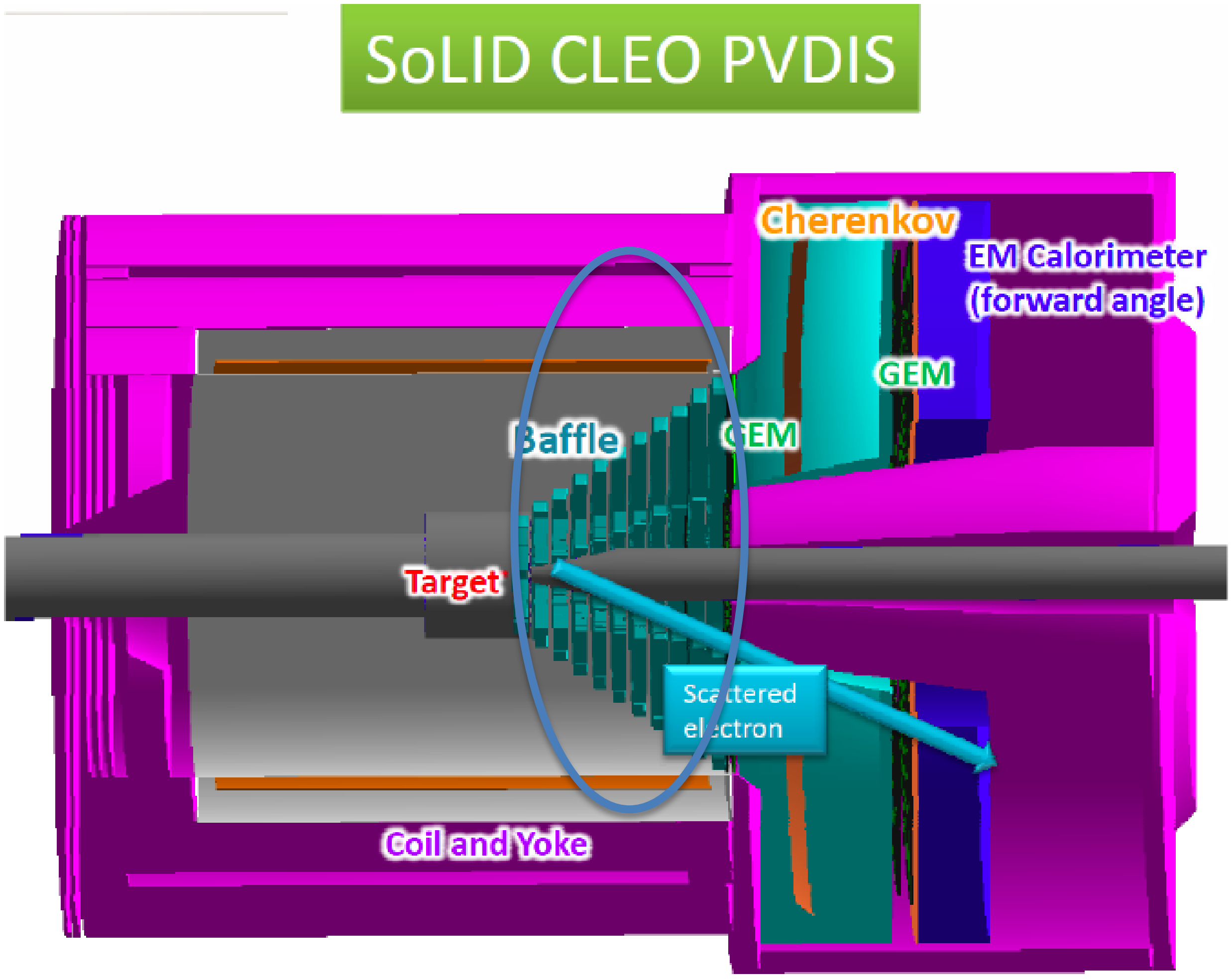
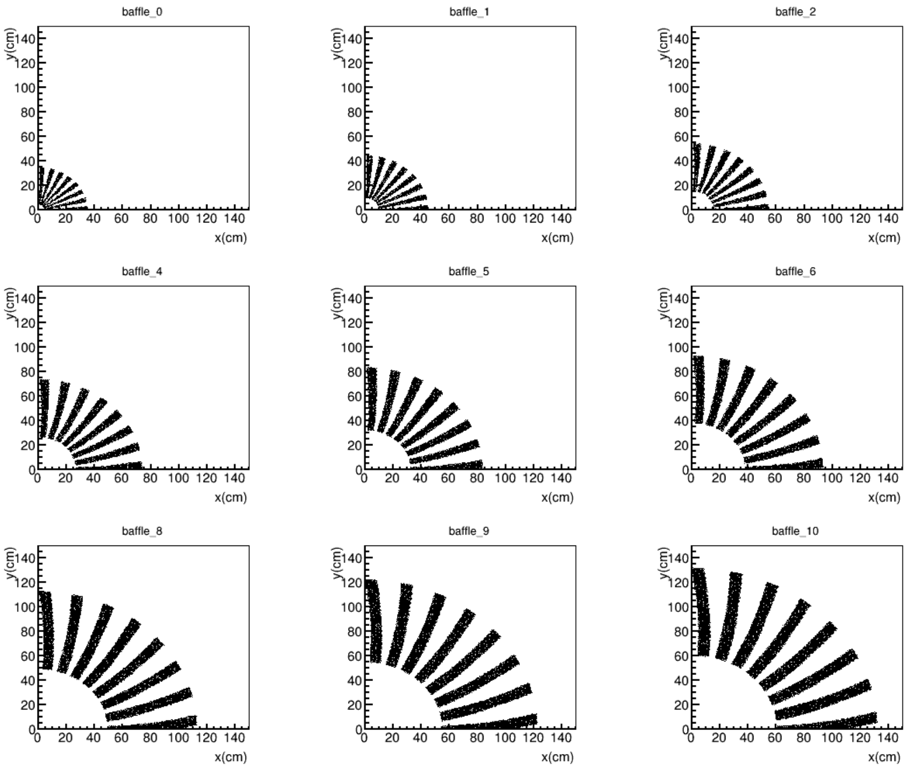


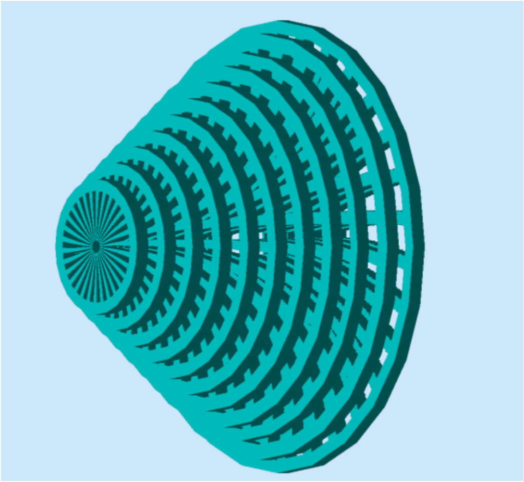
Figure 24: The experimental layout of SoLID PVDIS based on the CLEO magnet. The arrow shows a scattered electron.

PVDIS Baffle

1st to 11th, 9cm thick lead plane each

Placed right after the target, enough material to block photons, pions and secondary particles.



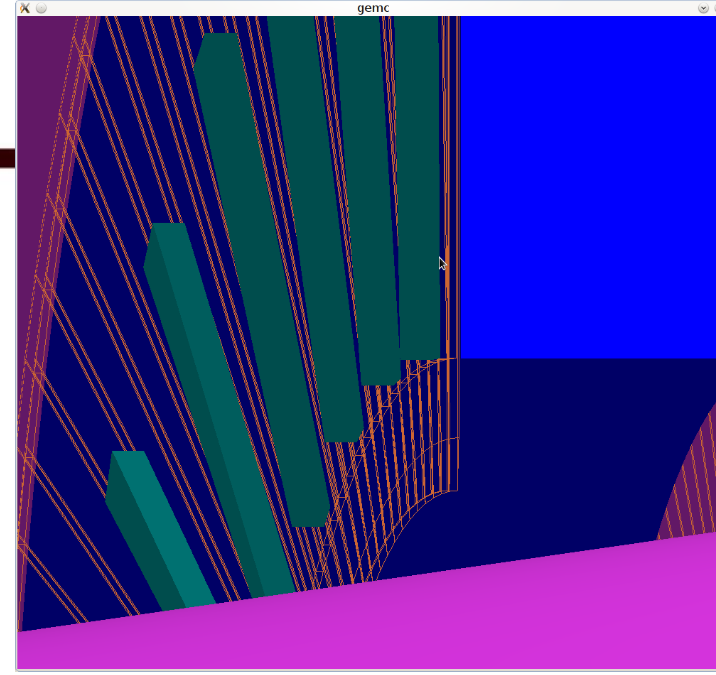


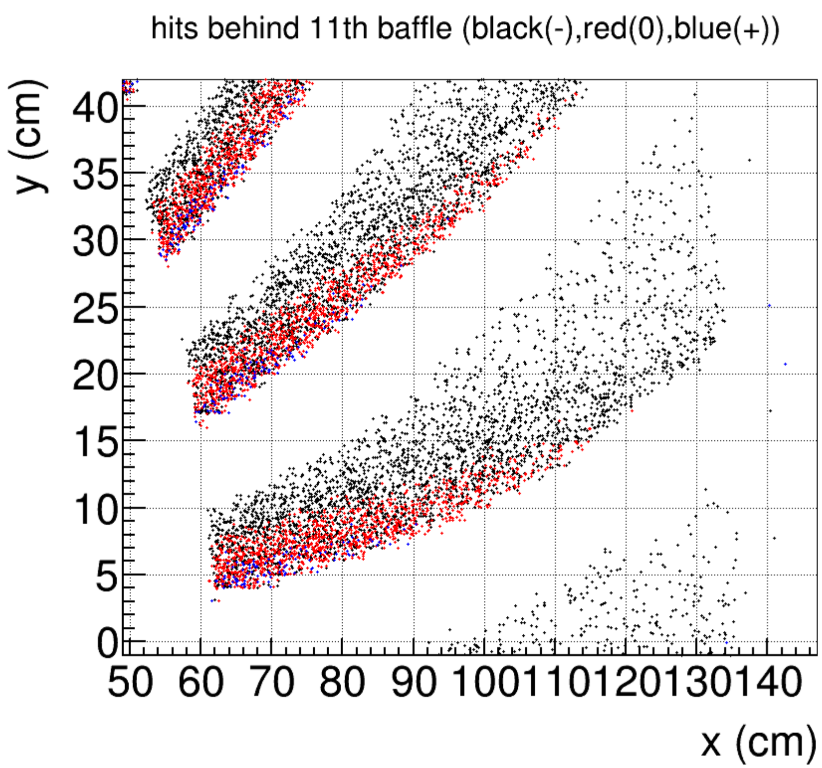
Design guideline:
Follow charge particle bending in SoLID CLEO field, preserve the same azimuthal slice and block line of sight

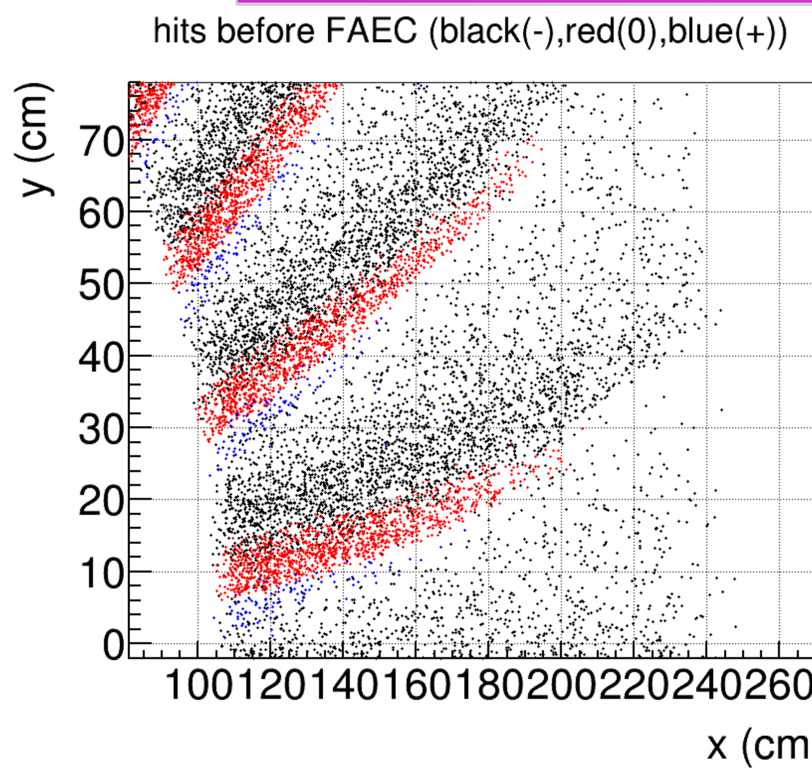
PVDIS Baffle

12^{th} , 5cm lead plane (EC photon block)

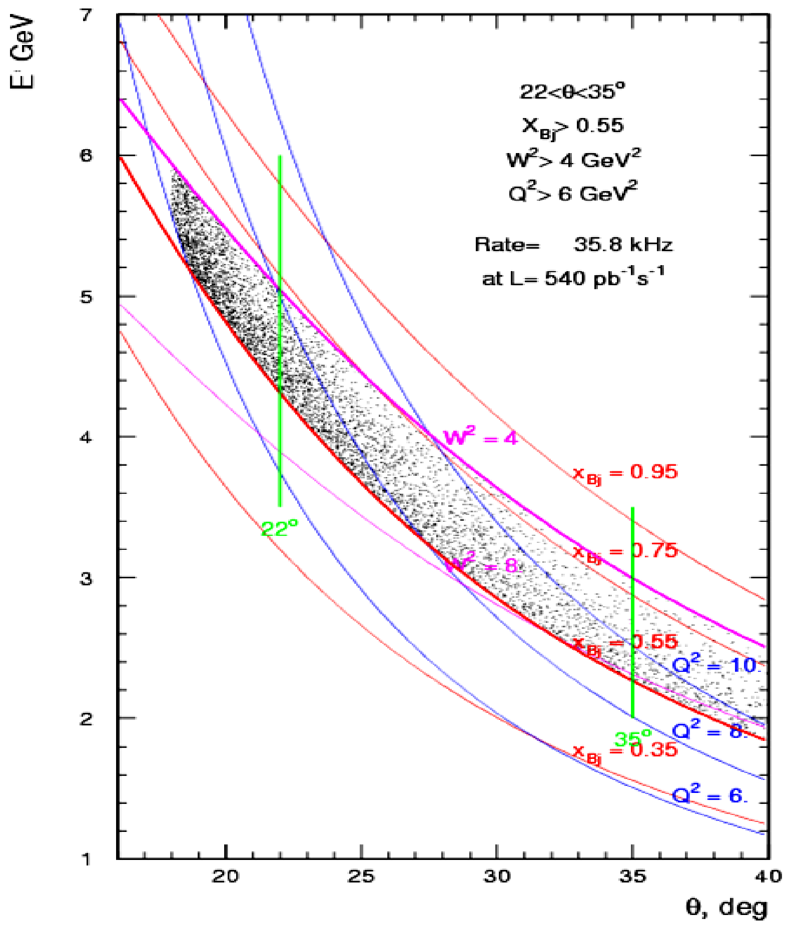
High energy electrons has least bending, only separate from photons before EC

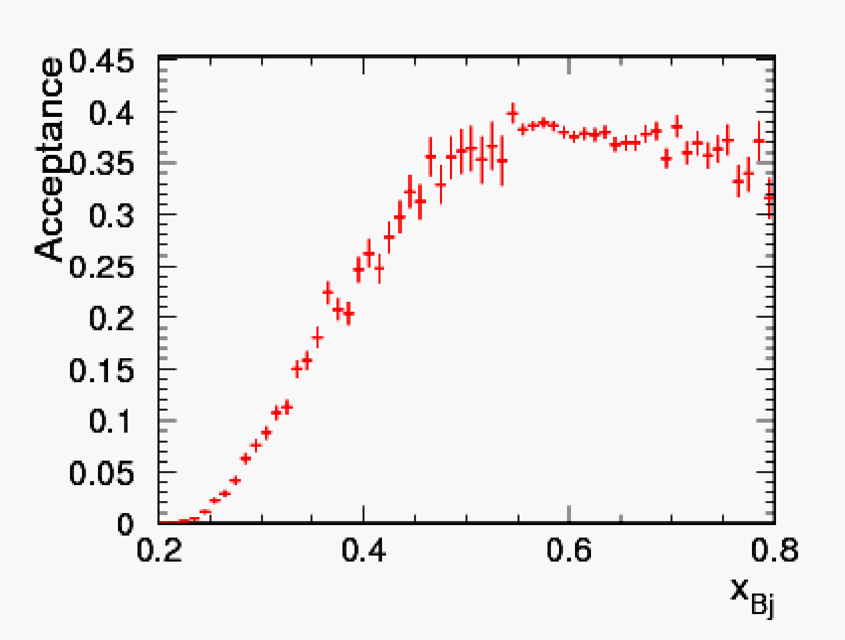






Spectrometer Acceptance





GEM trackers

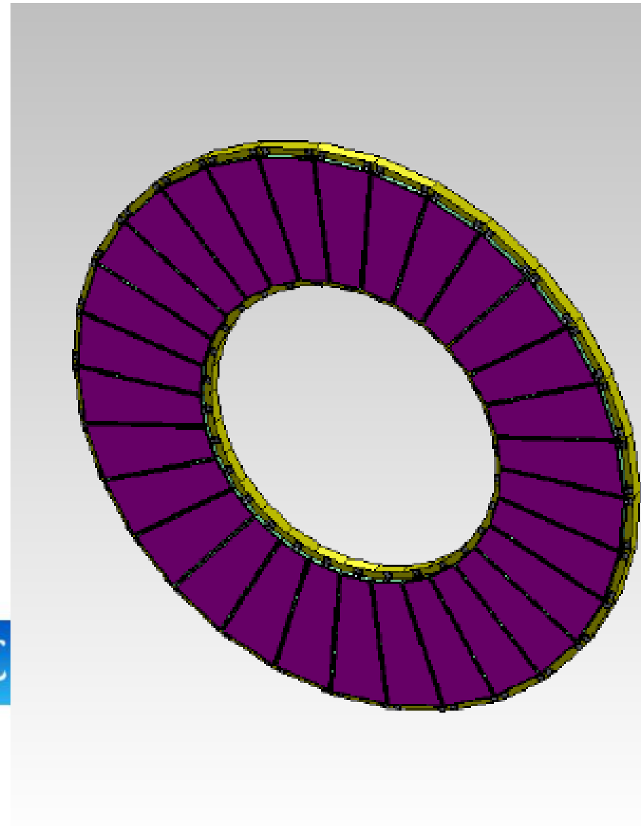
- 30 sectors
- 5 planes for PVDIS
- 164 K channels

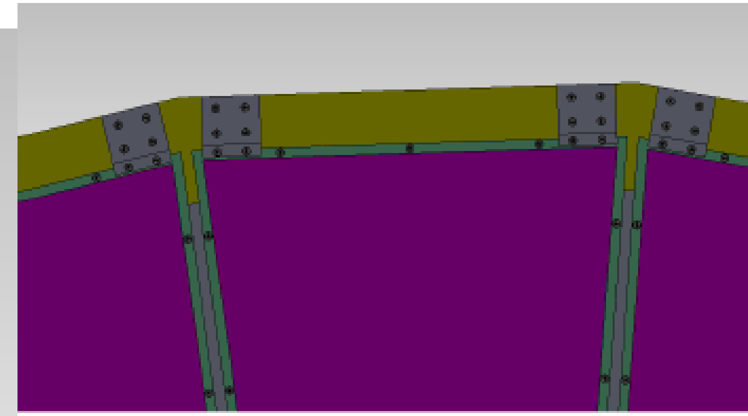
China Institute of Atomic Energy (CIAE)

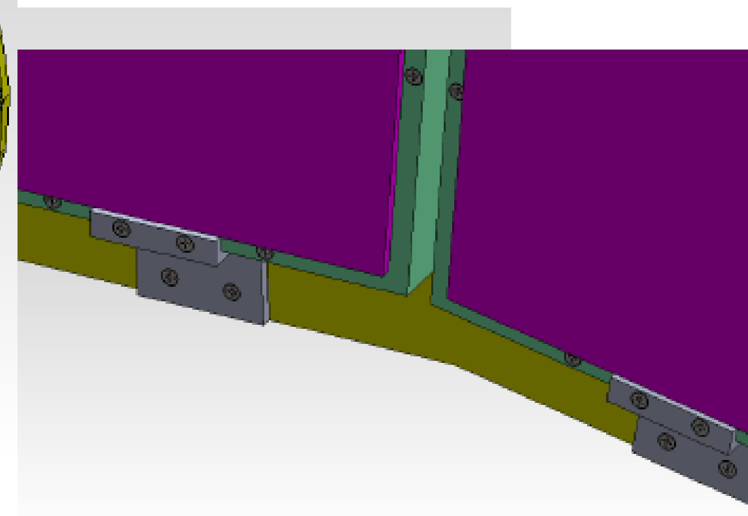
Lanzhou University

Tsinghua University

University of Science and Technology of China (USTC)



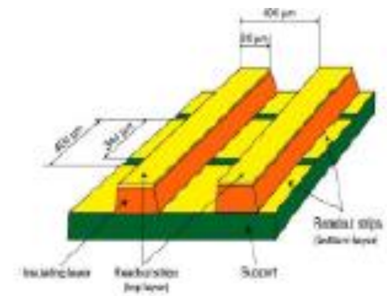


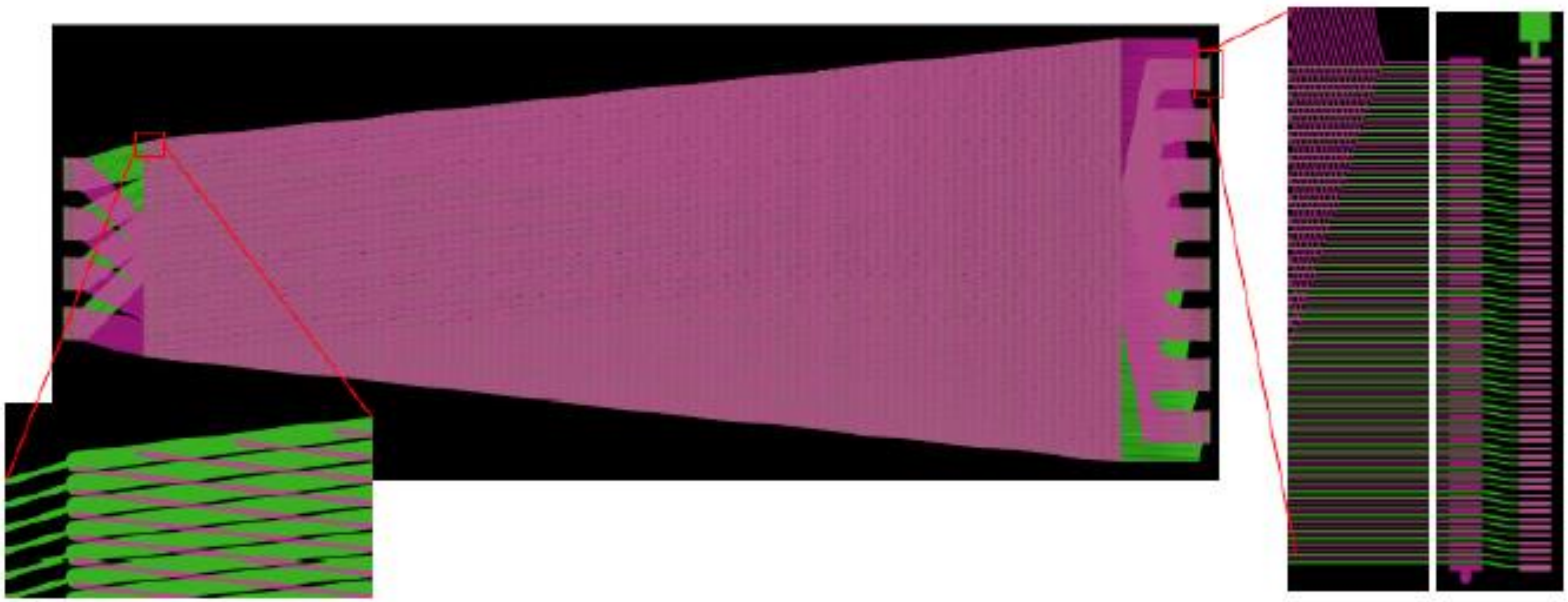


N. Linayage
University of Virginia

GEM sector

- COMPASS-like 2D stereo angle (12°) U/V readout board
- Pitch = 550 µm, top strips = 140 µm, bottom = 490 µm
- R/O support: 3mm Rohacell foam sandwiched between 100 µm fiberglass
- 12 connectors 8 on the top and 4 bottom part of the r/o board
- 64 strips from top layer and 64 from bottom on each Panasonic connectors





APV25 readout

- Switch Capacitor Array ASIC with buffer length 192 samples at 40 MHz : 4.8 us Look back 160 samples : 4 us

- APV readout time :

t_APV = 141 x number_of_sample / 40 MHz

t_APV(1 sample) = 3.7 us.

Max rate APV front end :

270 KHz in 1 sample mode

90 KHz in 3 samples mode

Will be triggered at max 60 KHz in 3 samples

100KHz Max in 1 sample

Deadtimeless electronics / parallel read and write

- APV25 used for baseline design : other chips could be considered when available

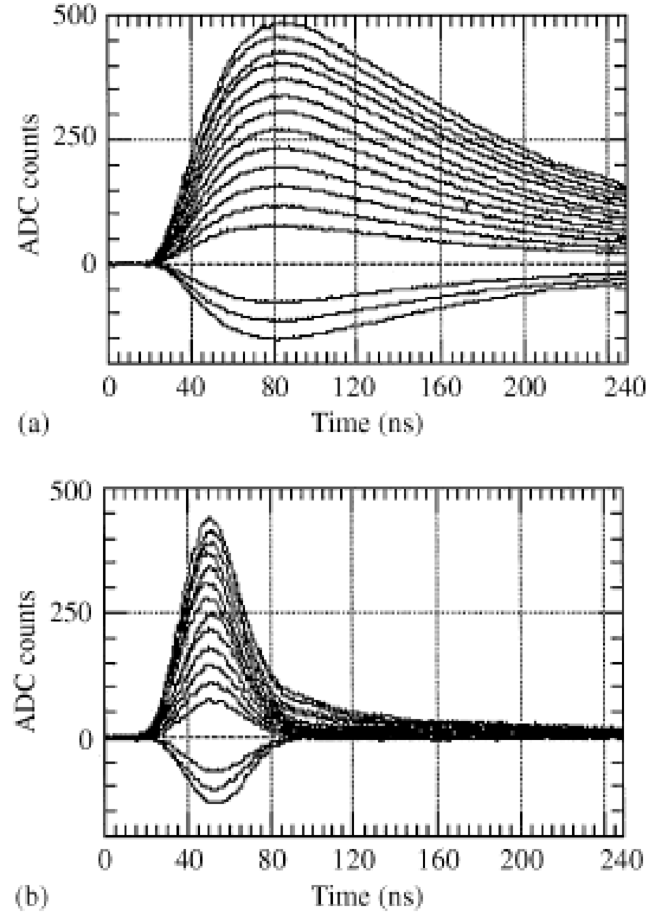


Fig. 5. Response curve of the APV25 as a function of the input signal. (a) Peak mode, (b) deconvolution mode.

Electromagnetic calorimeter

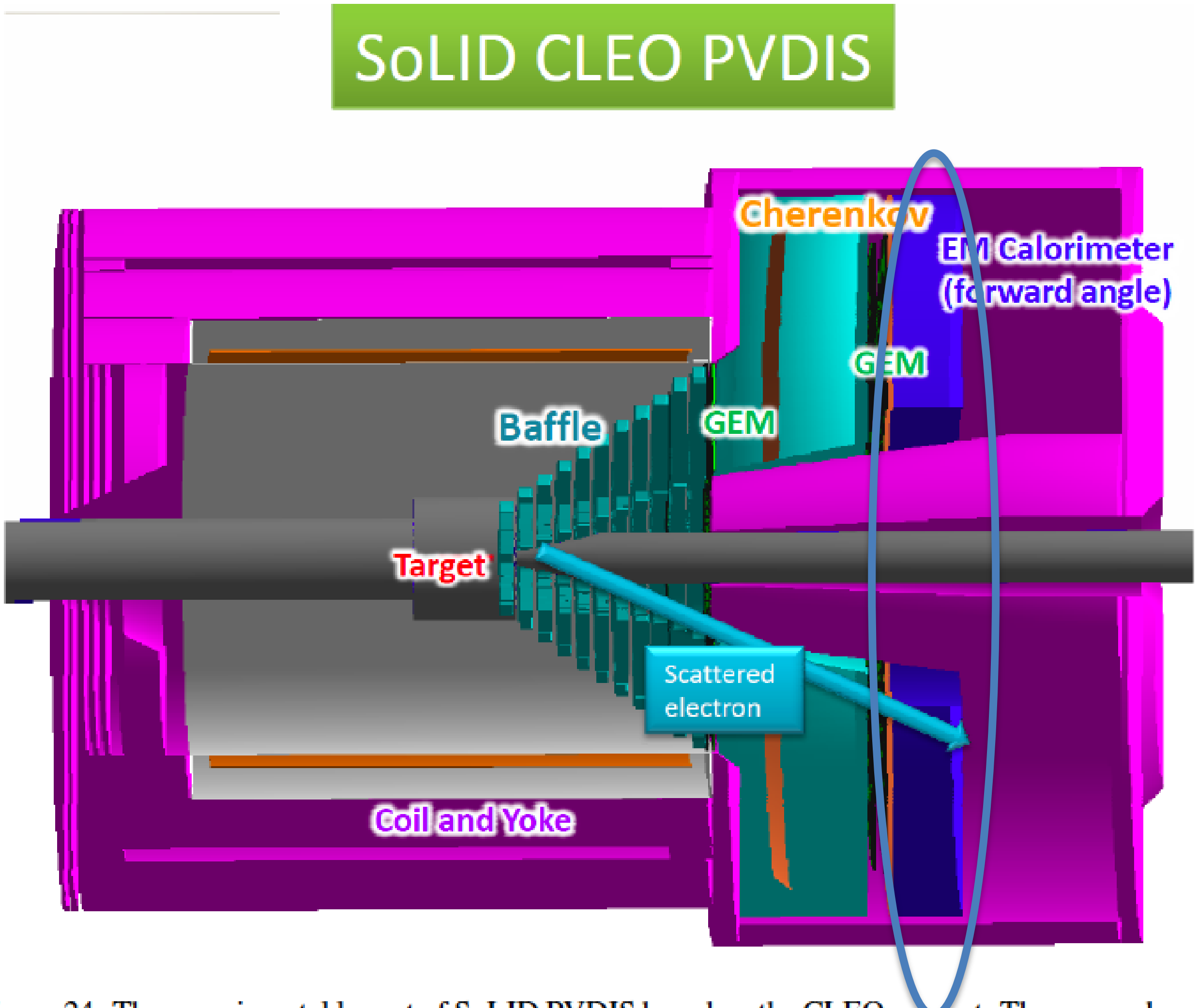
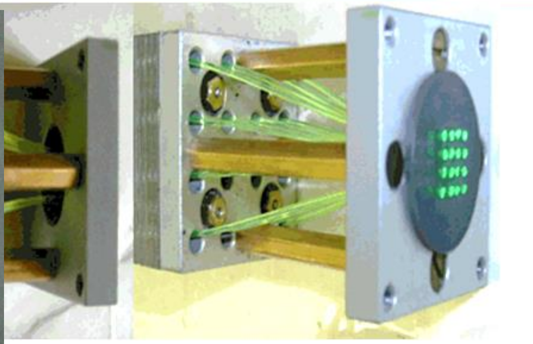
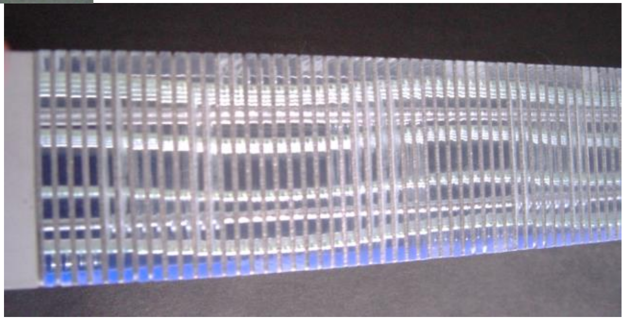


Figure 24: The experimental layout of SoLID PVDIS based on the CLEO magnet. The arrow shows a scattered electron.

Calorimeter

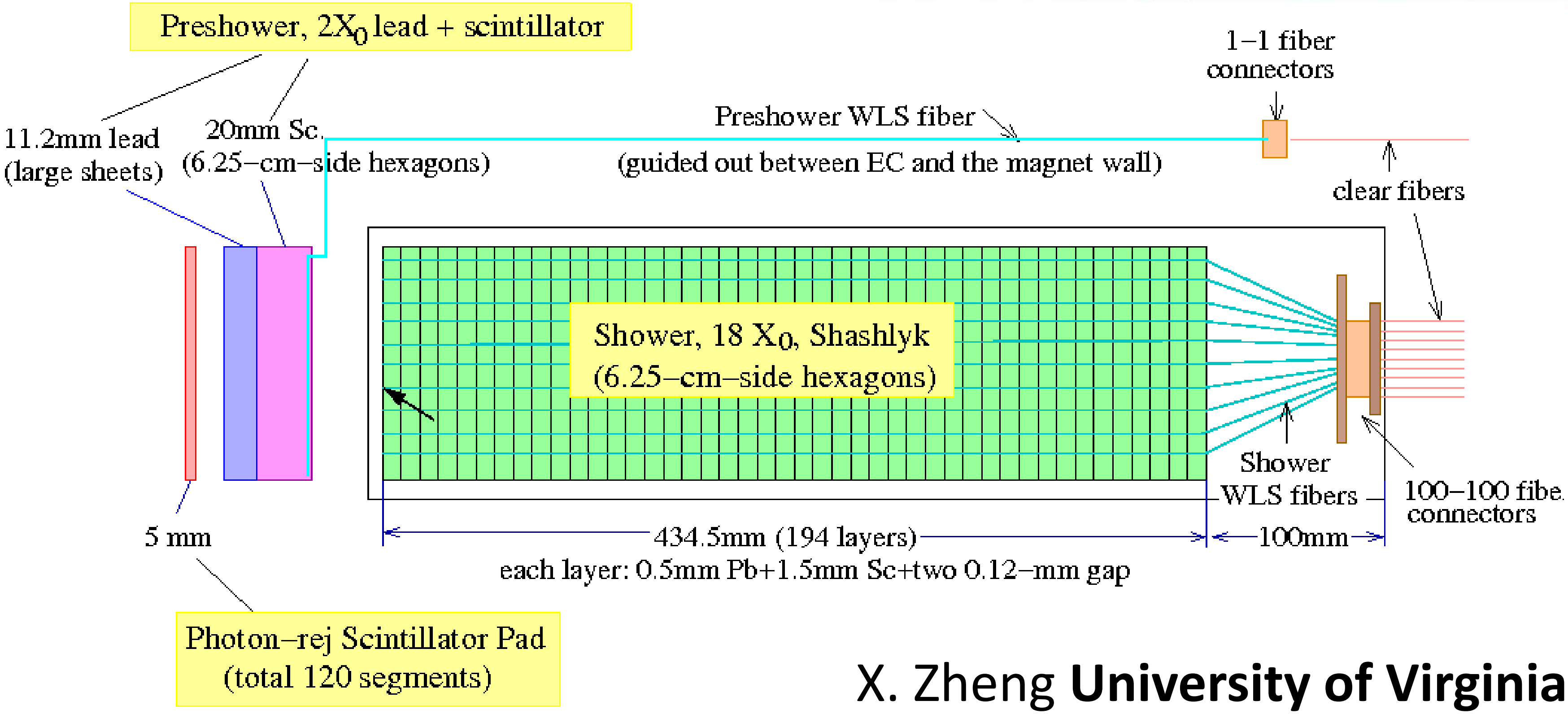
IHEP, COMPASS Shashlik, 2010





- Lead-scintillator sampling calorimeter
- WLS fibers [$1/(9.5mm)^2$] collect and guide out light → one PMT per module.
- Good and tunable energy resolution
- Radiation hardness: ~ 500 krad tested by IHEP
- transverse size can be customized
- Light collection and readout straightforward
- Well developed technology, used by many experiments,
- IHEP production rate about 200/month

Calorimeter shashkyk module



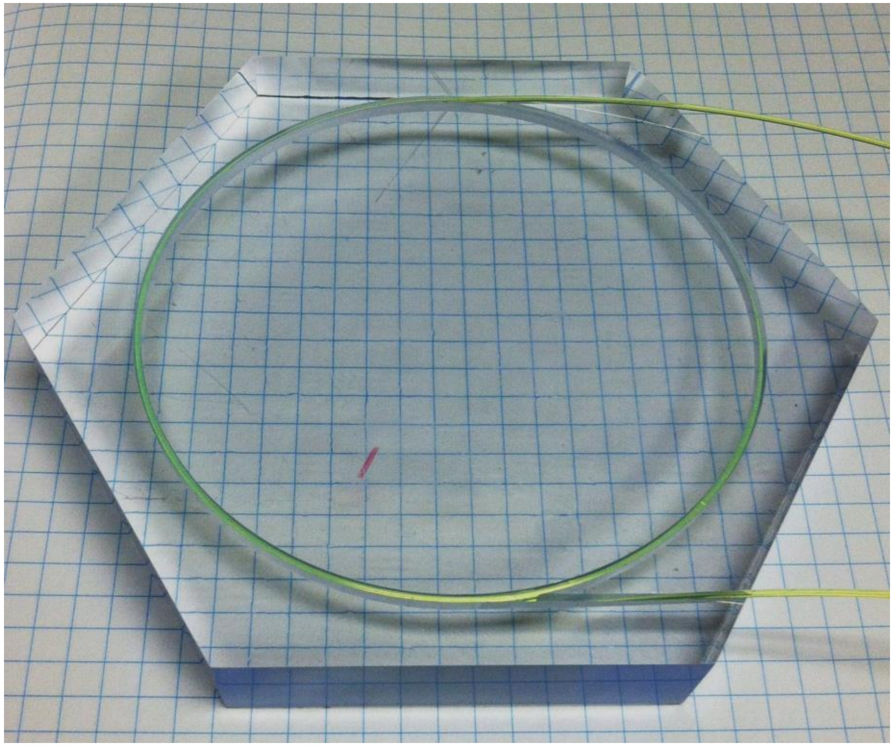
X. Zheng **University of Virginia**

C. Feng **Shandong University**

- Readout similar to Preshower
- Forward: between heavy gas and MRPC, 60 azimuthal x 4 radial
- Large angle: in front of EC, 60 azimuthal

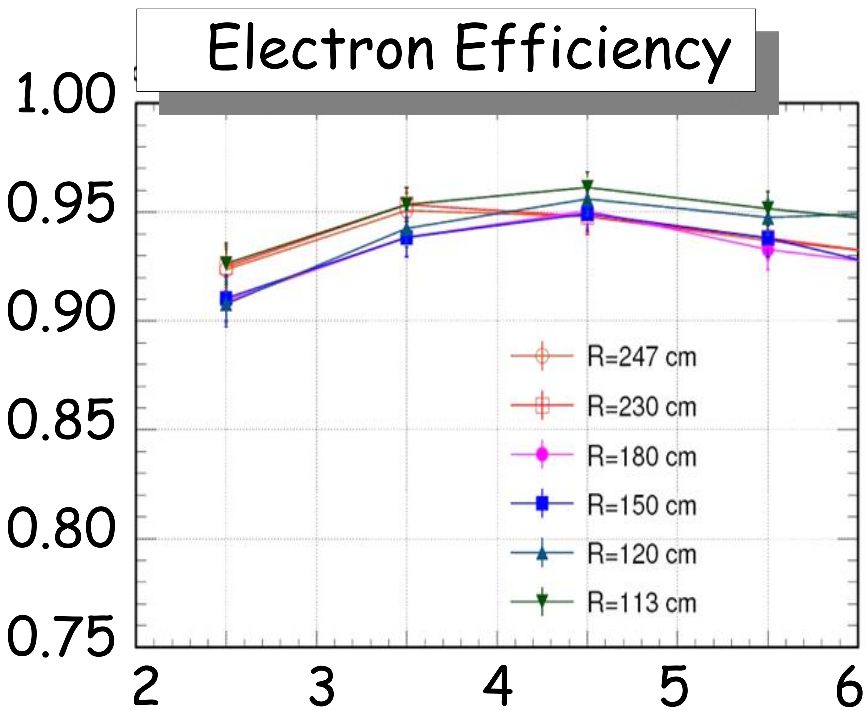
Pre-R&D: preshower prototype testing

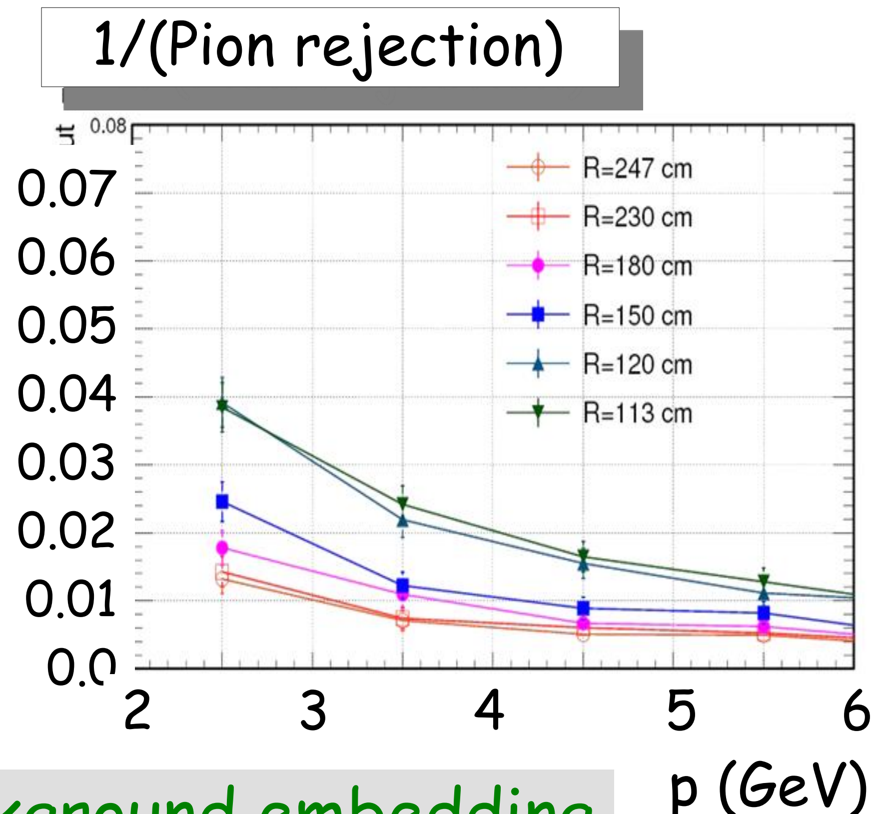
- Tested:
- WLS fiber: Y11, BCF91A (55%), BCF92 (35%)
- wrapping: printer paper, Tyvek homewrap (10% higher), aluminized mylar (17% higher)



Performance — PID, PVDIS

- Background worsens PID. Will record full waveform over 40 ns





2D-cut PID, with latest background embedding

PVDIS (forward angle): p=2.3~6 GeV

Light Gas Cerenkov

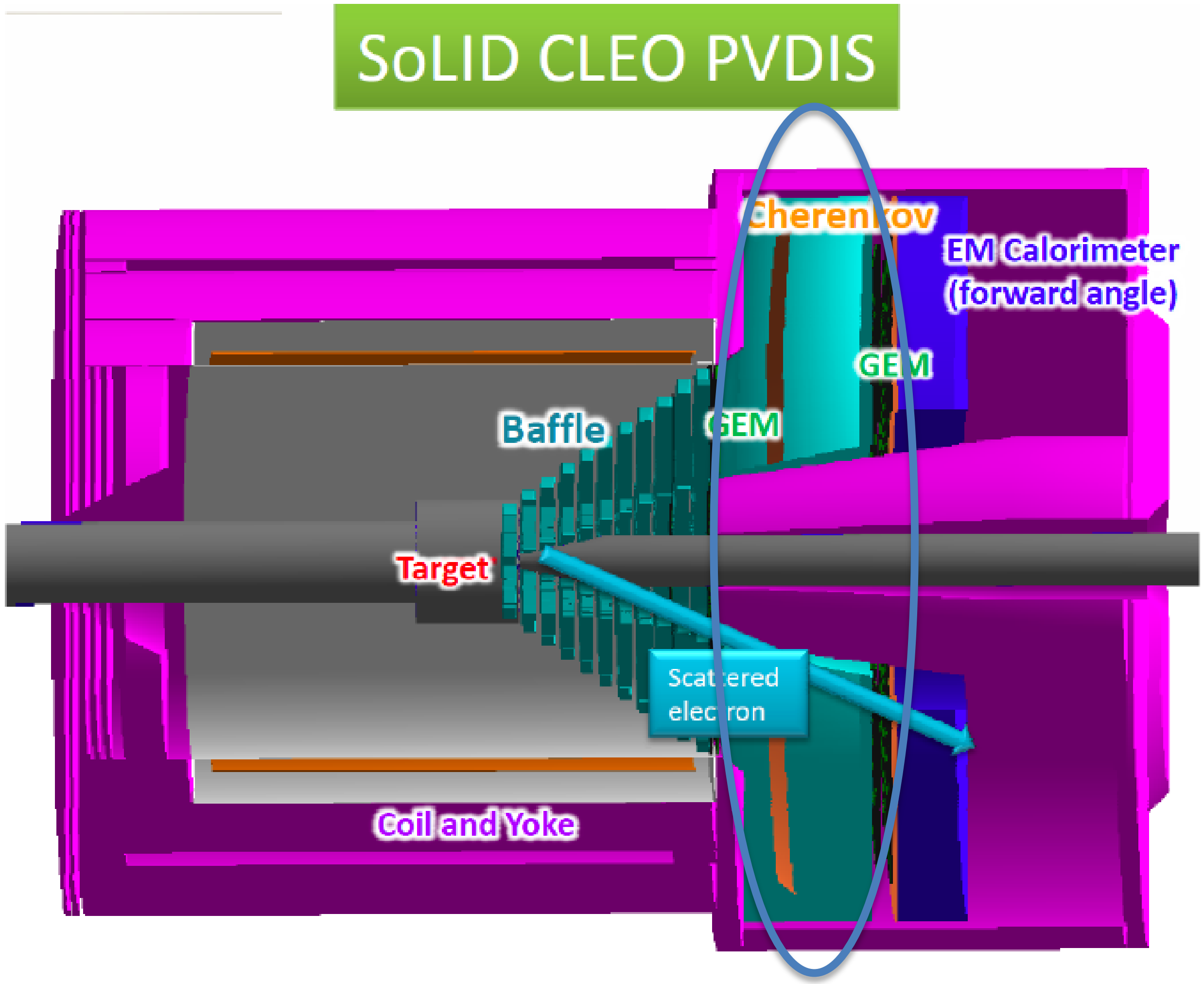
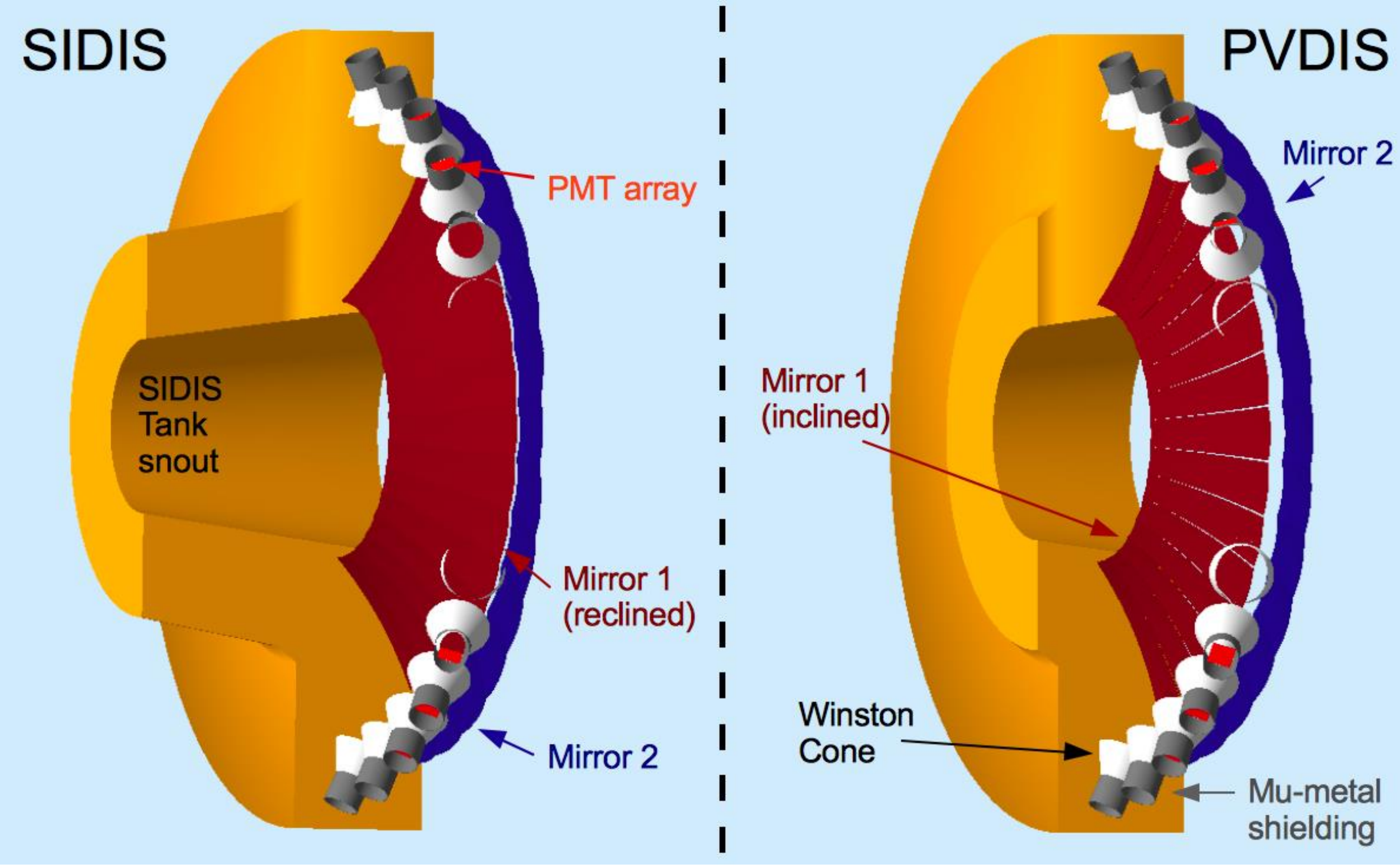


Figure 24: The experimental layout of SoLID PVDIS based on the CLEO magnet. The arrow shows a scattered electron.

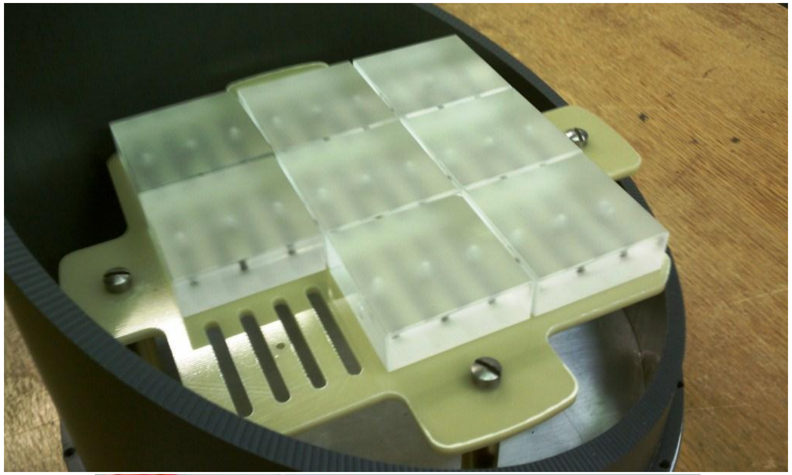
LGC geometric / material characteristics

- Cherenkov is designed to maximize component use between the two configurations.



PMT Assembly

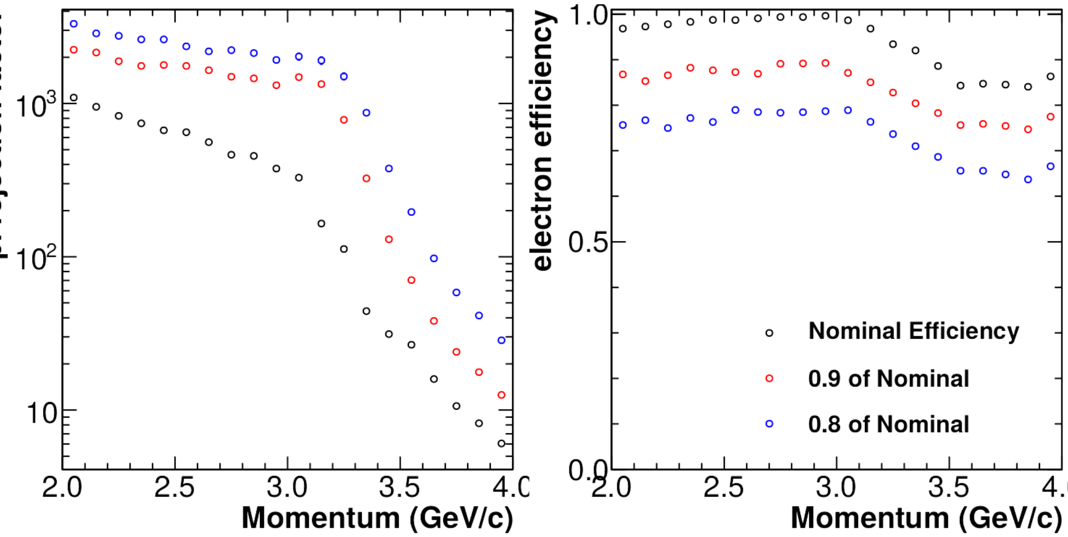
- All components are common without adjustment between both configurations.
- PMT assembly is:
  - 3 x 3 array of Hamamatsu H8500C-03 maPMTS
    - 64 pixel PMT array for each H8500C
    - Average QE ~ 15%
  - Reflective cone
  - Mu-metal shielding.
    - 0.04” thickness with 0.125” thick steel reinforcement
    - Reduce B_T and B_L from 95 and 135 gauss (respectively) to < 50 gauss.

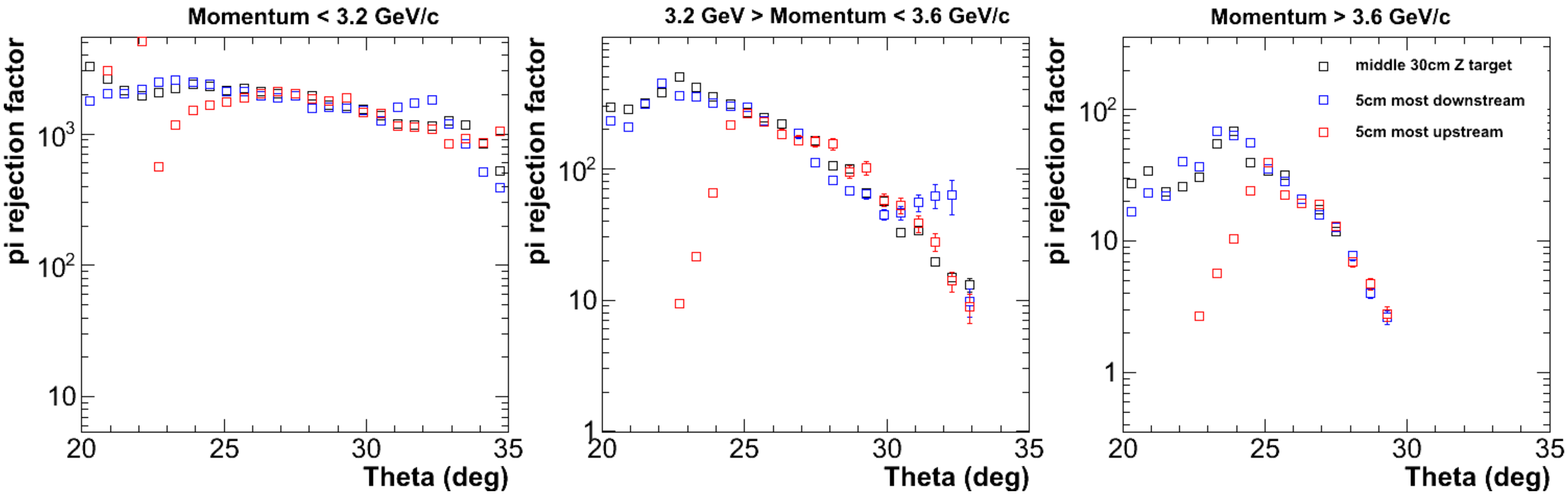


Z. Meziani **Temple University**

Light gas Cerenkov pion rejection

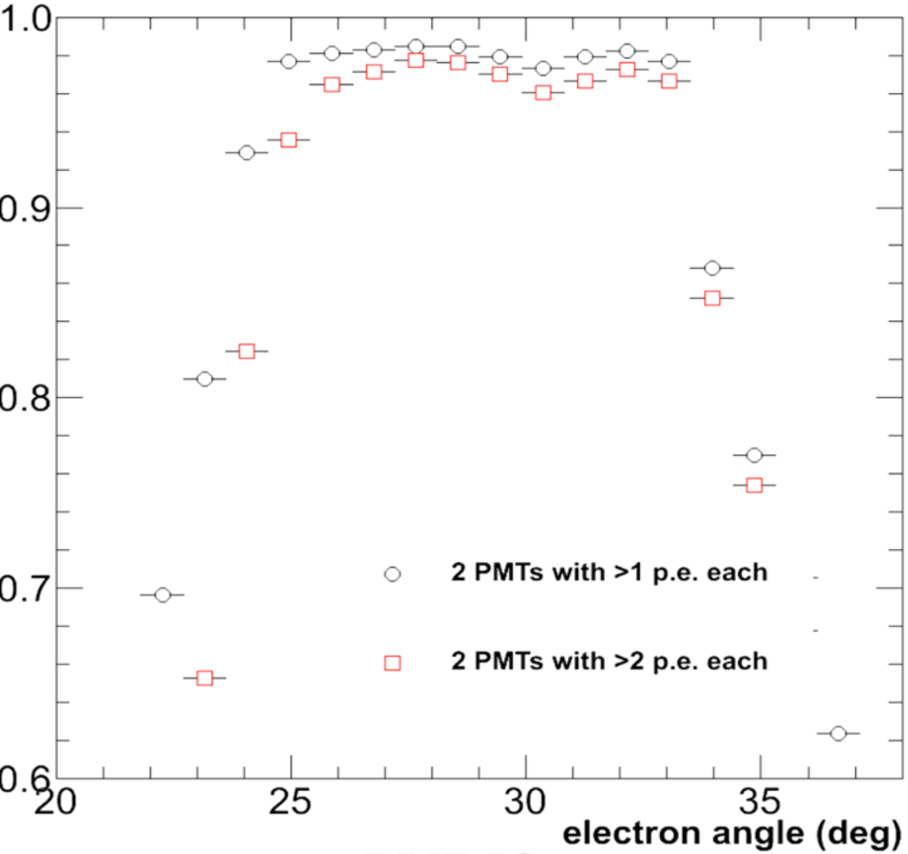
pi rejection factor is the inverse pi acceptance after selection cut.



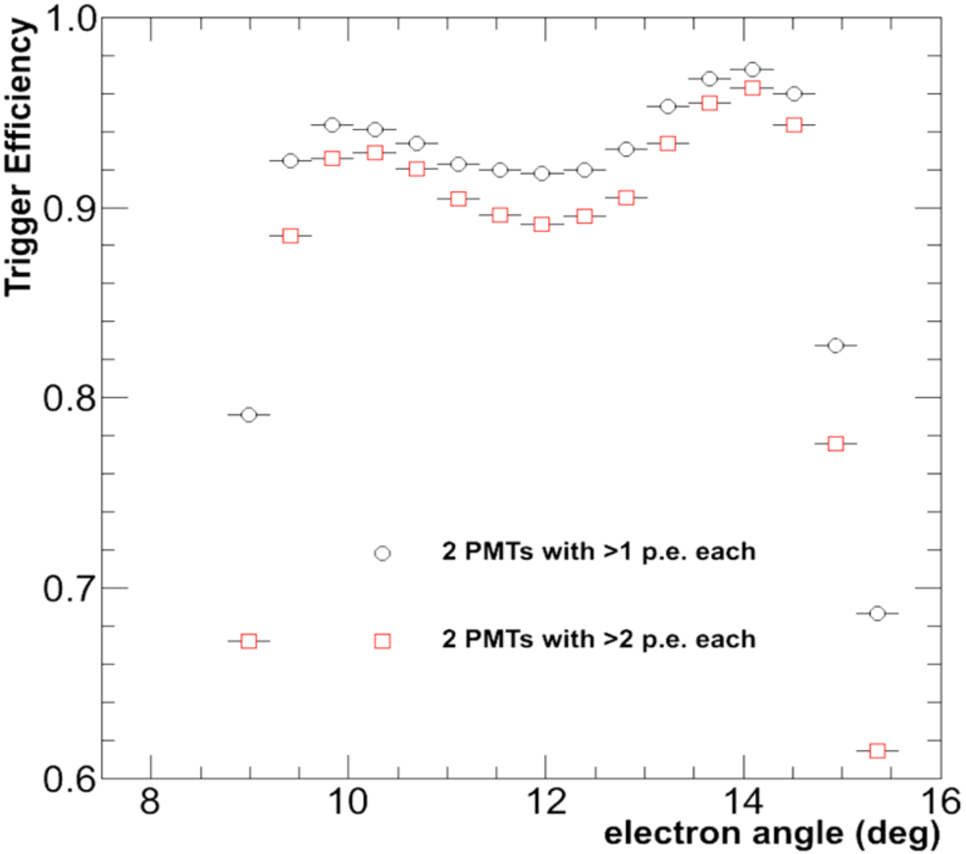


Jefferson Lab

Light gas Cerenkov efficiency

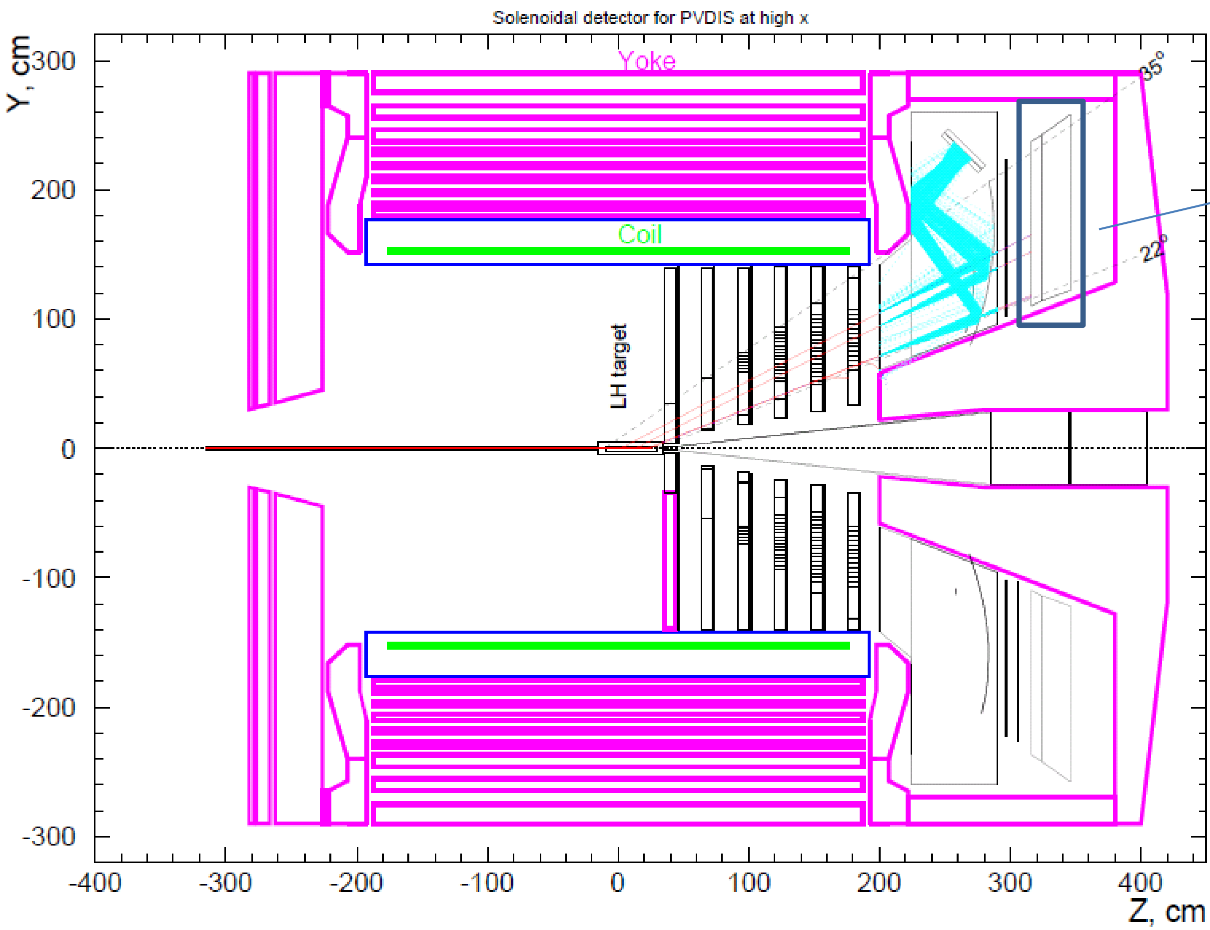


PVDIS



SIDIS

Detector layout and trigger for PVDIS



Trigger

Calorimeter and Gas Cerenkov

200 to 500 KHz of electrons

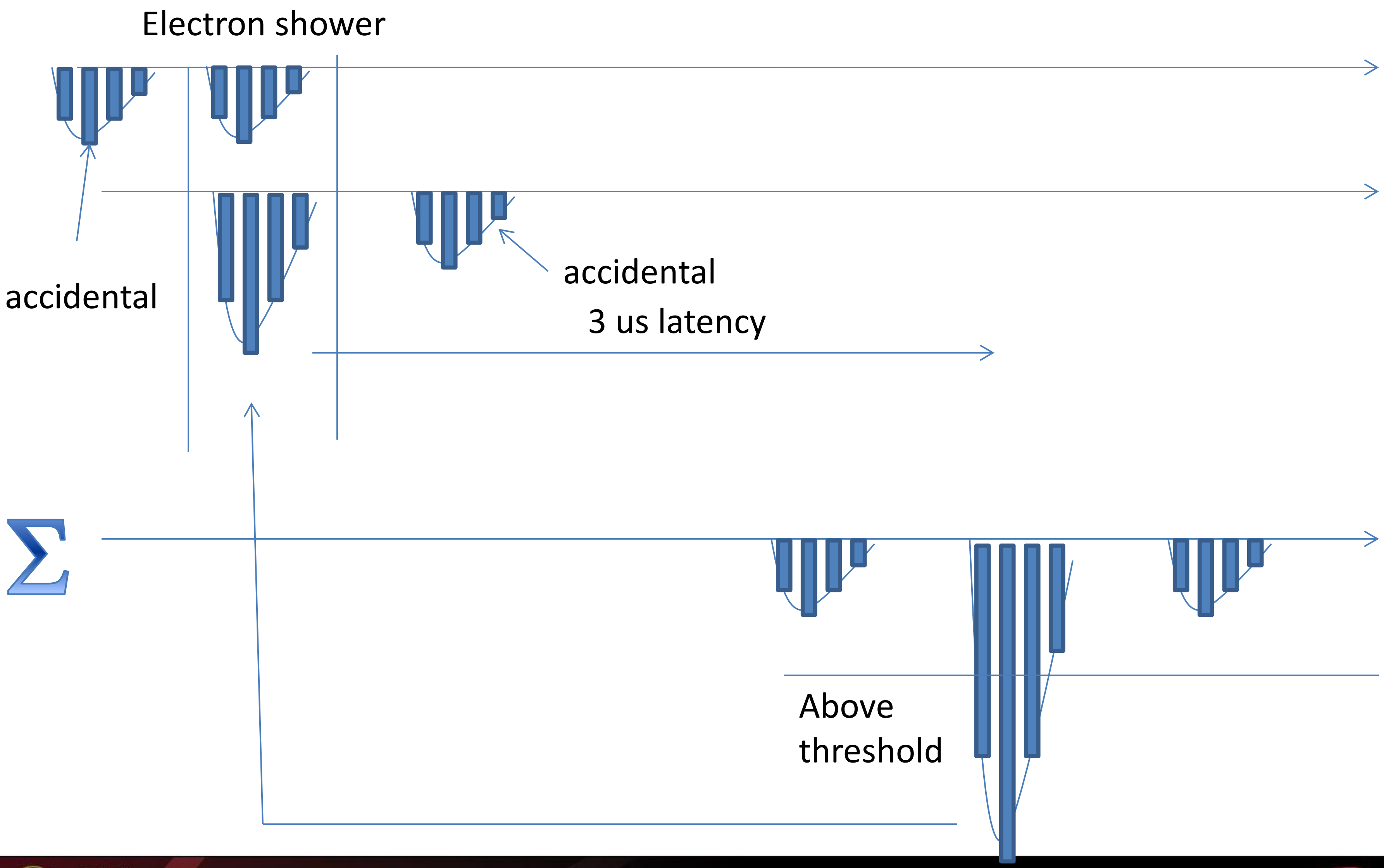
30 individual sectors to reduce trigger rate

Max 60 KHz/sector = 1.8 MHz total max

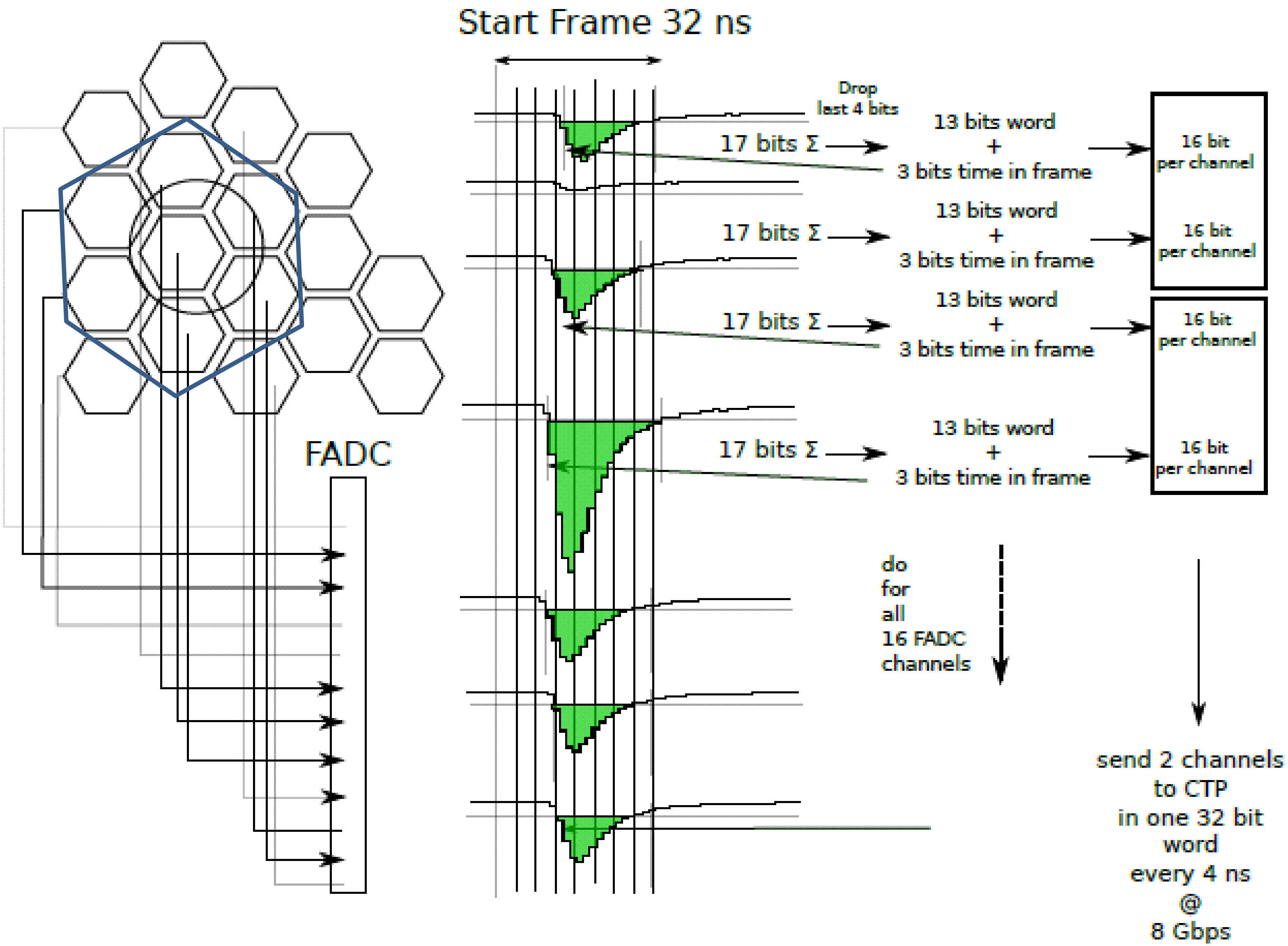
Expect 30 KHz of trigger rates

Pipelined Hall D DAQ

Use 250 MHz sampling FADC

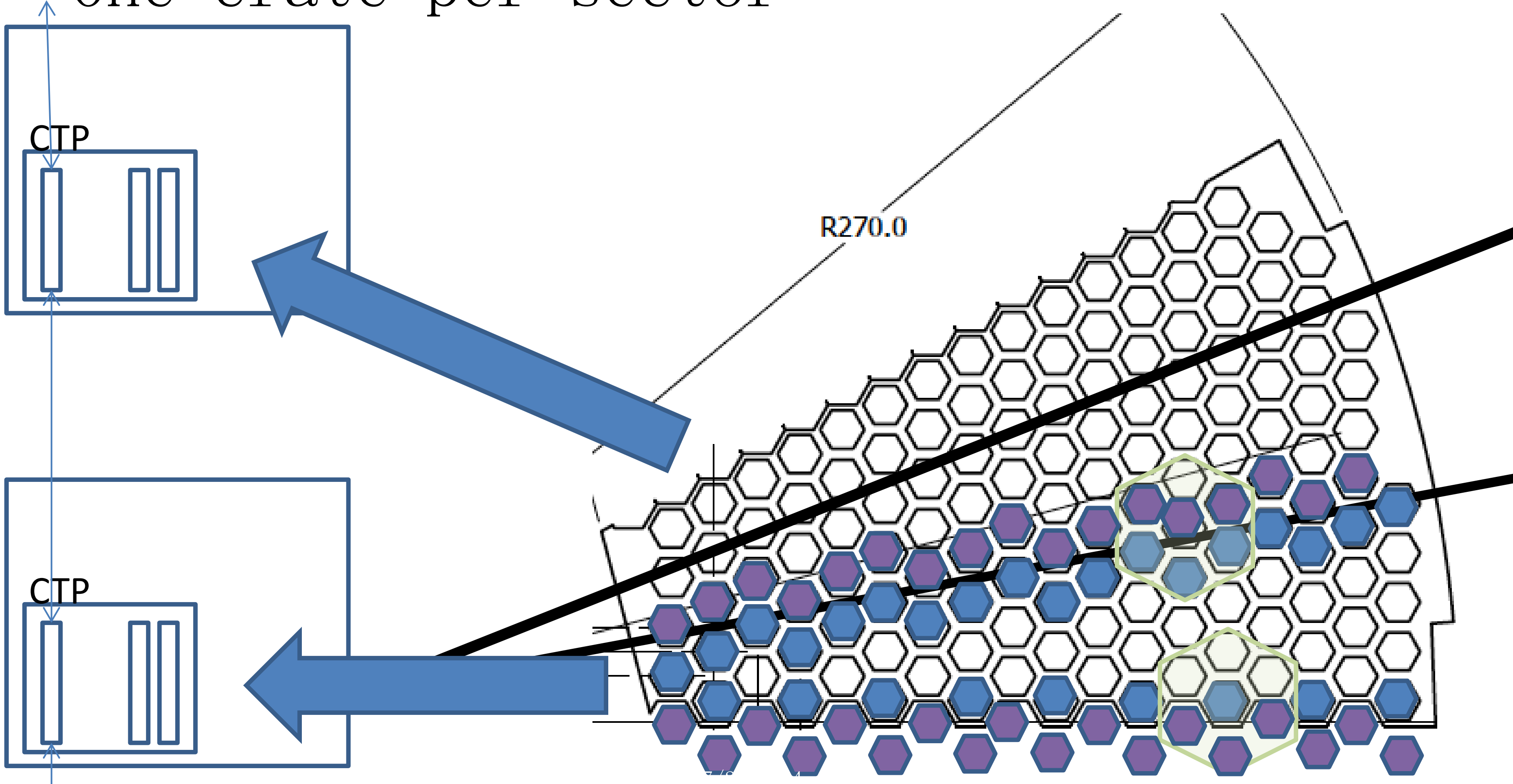


ECAL trigger

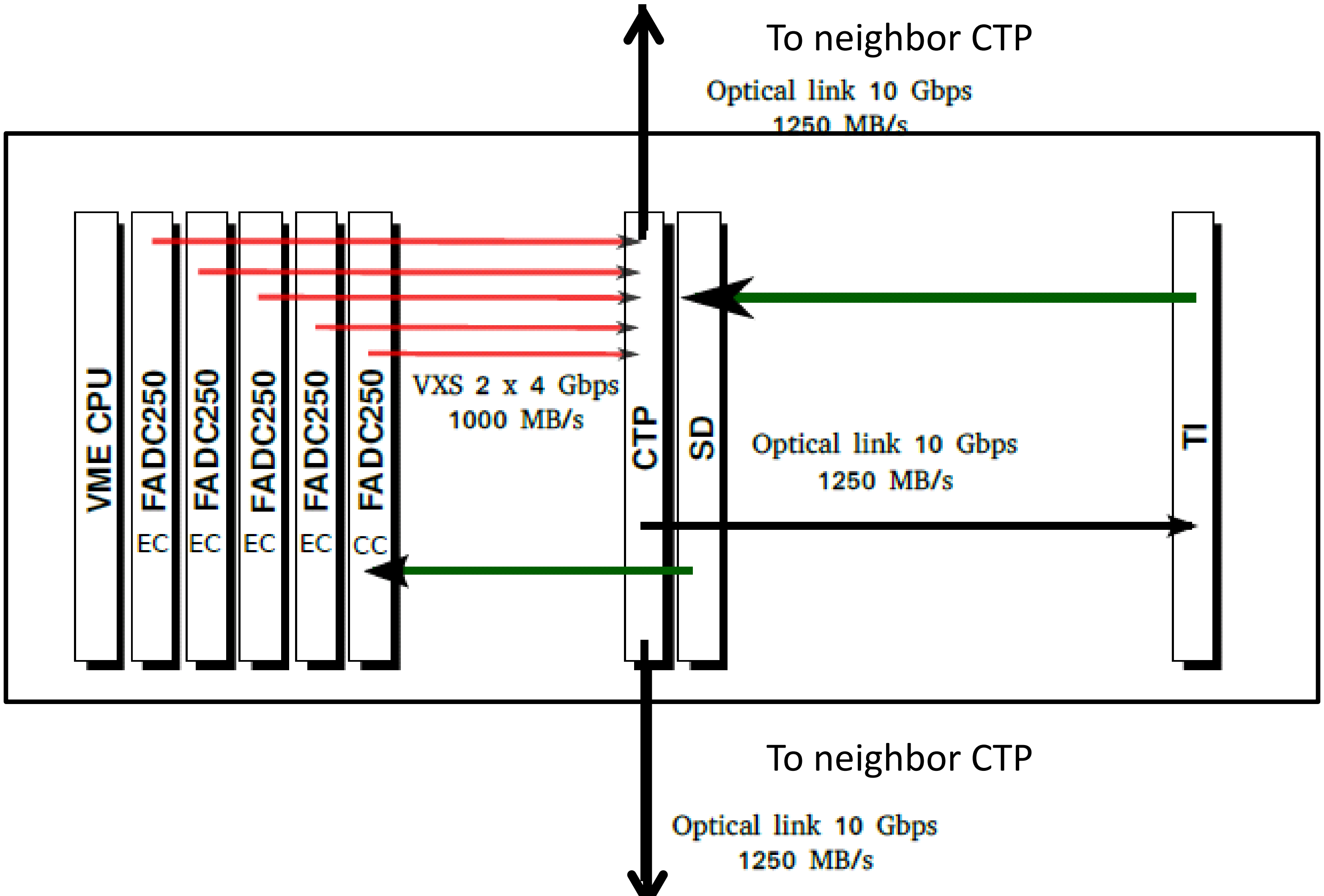


Calorimeter Geometry

- Detector segmented in 30 sectors
- One crate per sector

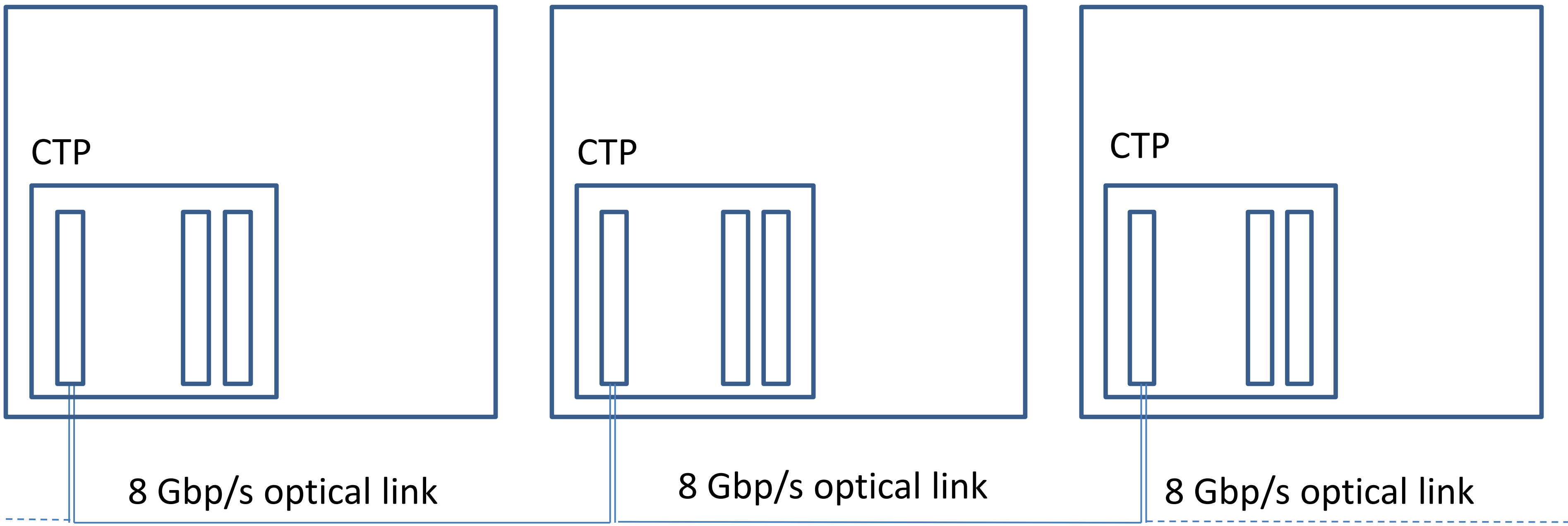


CTP connections



Neighboring sectors

New CTP : has two additionnal optical links
Can send Cerenkov and calorimeter edges to other sectors.



36 calorimeters
9 Cherenkov

= 150ns overhead + 5 ns per m+ 300 ns (data) = 500 ns

Trigger decision = 500 ns (Transfer) + 1us (clustering) < 4 us (APV)

Event size FADC PVDIS with waveform

Detector	Total number of channels	Number of channels firing	Number of samples	Max size detector bytes	Minimal size detector bytes	Typical size
Shower	58	7	10	2784	336	**772**
Preshower	58	7	10	2784	336	**772**
Gas Cerenkov	9	3	10	432	144	**432**
			Max total size	6 KB	0.816KB	**1.544KB**
Max rate	Assuming 100 MB/s per crate	One crate		16 KHz	121 KHz	**60 KHz**

FADC data rate for 30 KHz = 60 MB/s

GEM event occupancy and size

Sector	Rate	XY	Bytes	3 samples (bytes)
0	199	398	184	552
1	147	294	96	288
2	107	214	80	240
3	102	204	72	216
4	102	204	72	216
Total hits / sector	657		432	1296
Data rate / sector	30000		157680000	473040000
Data rate (sector Mb/s)			157,68	473.1
Total detector	19710		4730.4	14191.2
Occupancy detector	0.14			

- Data rate to front end reading 3 samples
- Use 4 Gigabit link = 512 MB/s not an issue with SRS

GEM event occupancy and size

Sector	Rate	XY	Bytes	3 samples (bytes)
0	23	46	184	552
1	12	24	96	288
2	10	20	80	240
3	9	18	72	216
4	9	18	72	216
Total hits / sector	63		504	1296
Data rate / sector	30000		1512000	77760000
Data rate (sector Mb/s)			15.12	45.36
Total detector	1620		453.6	1360.8
Occupancy detector	0.013			

- Rates with deconvolution 3 samples readout
- Total rate ~ 110 MB/s per sector = 3.5 GB/s total
- Processing before recording to reduce by about 15 using L3 farm to 250 MB/s

SIDIS , J/Psi

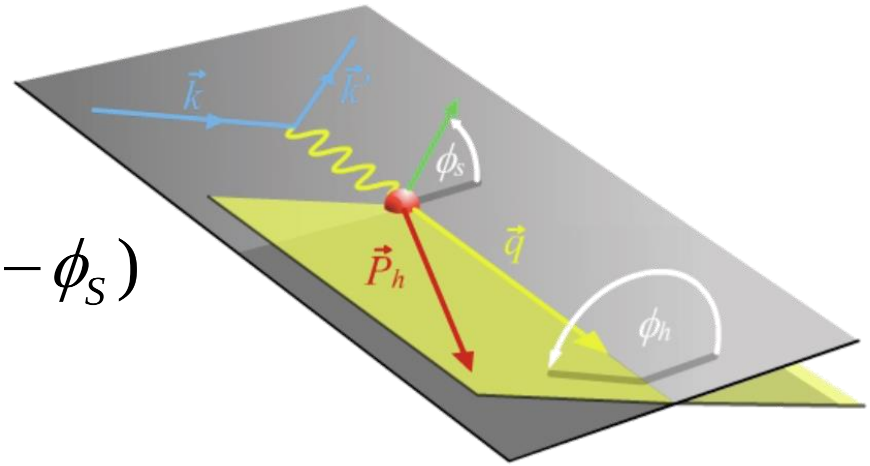
- Measurement semi-inclusive pion production for transversity measurement detect one pions with scattered electron
  - **E12-10-006 T Polarized n (3He), 90 days**
  - **E12-11-007 L polarized n (3He), 35 days**
  - **E12-11-108 T polarized p (NH3), 120 days**
- Measurement of J/ψ production at threshold detect 3 particles : scattered electron and pair e+e- from J/ψ decay
  - Threshold J/ψ: E12-12-006, LH2, 60 days

Separation of Collins, Sivers and pretzelocity effects through angular dependence

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$= A_{UT}^{Collins}\sin(\phi_h + \phi_S) + A_{UT}^{Sivers}\sin(\phi_h - \phi_S)$$

$$+ A_{UT}^{Pretzelosity}\sin(3\phi_h - \phi_S)$$



$$A_{UT}^{Collins} \propto \langle \sin(\phi_h + \phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$

$$A_{UT}^{Sivers} \propto \langle \sin(\phi_h - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$

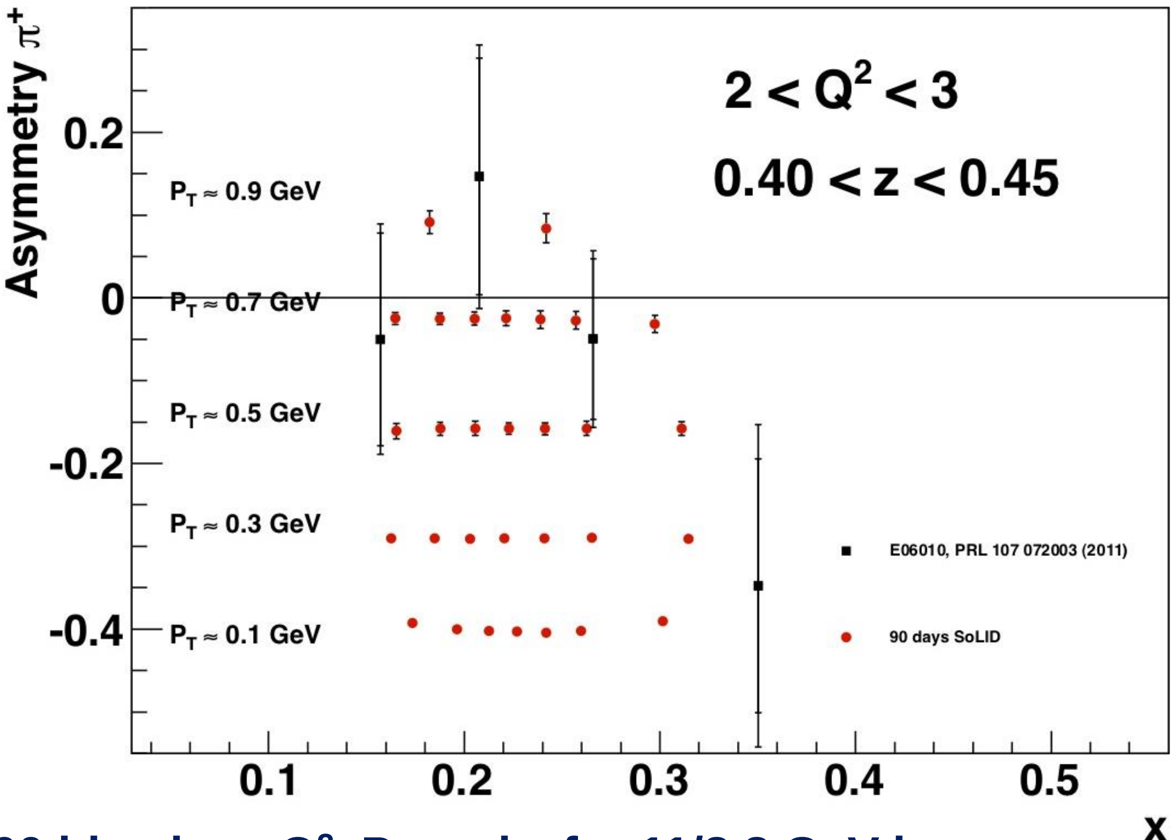
$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

Collins frag. Func. from e^+e^- collisions

SIDIS SSAs depend on 4-D variables (x, Q^2, z and P_T)

Large angular coverage and precision measurement of asymmetries in 4-D phase space is essential.

Projected Data (E12-10-006)

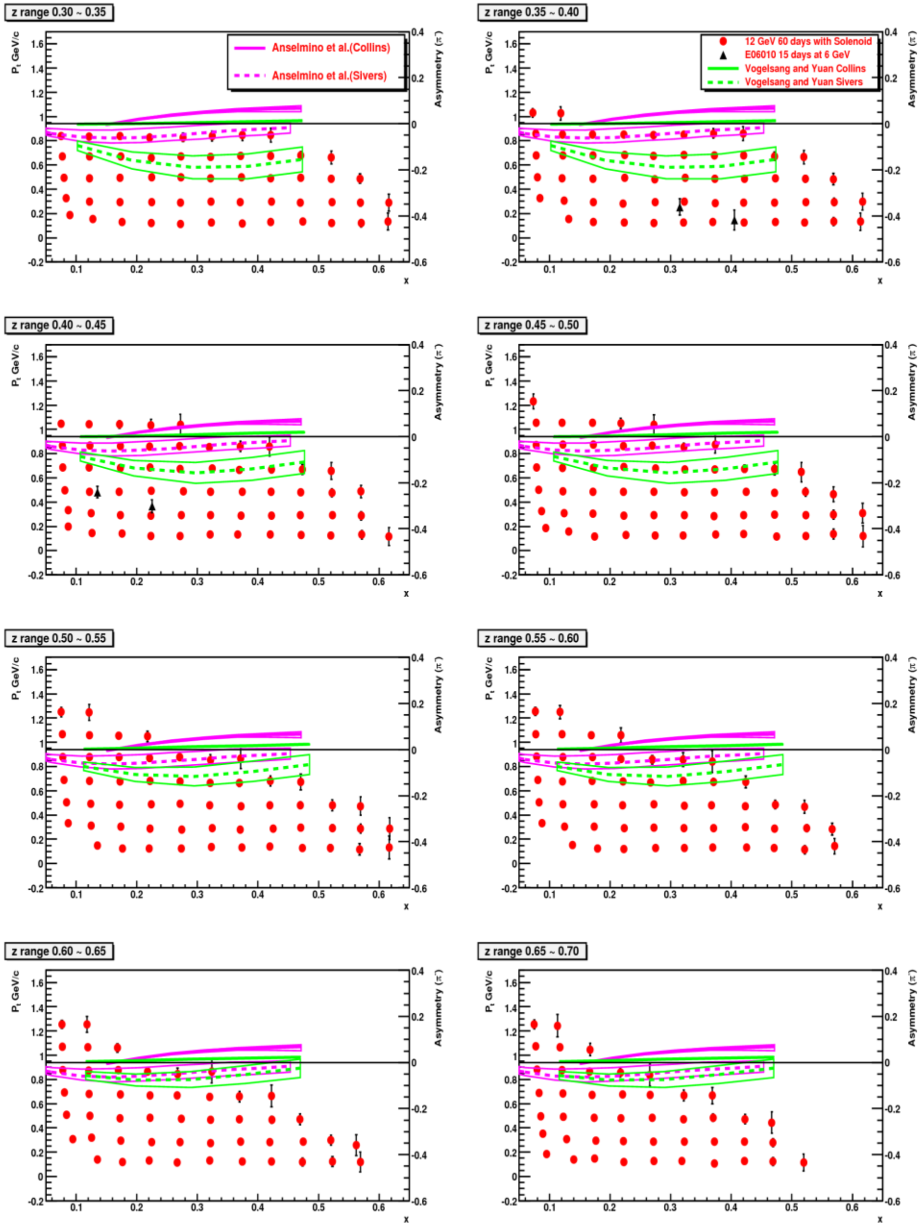


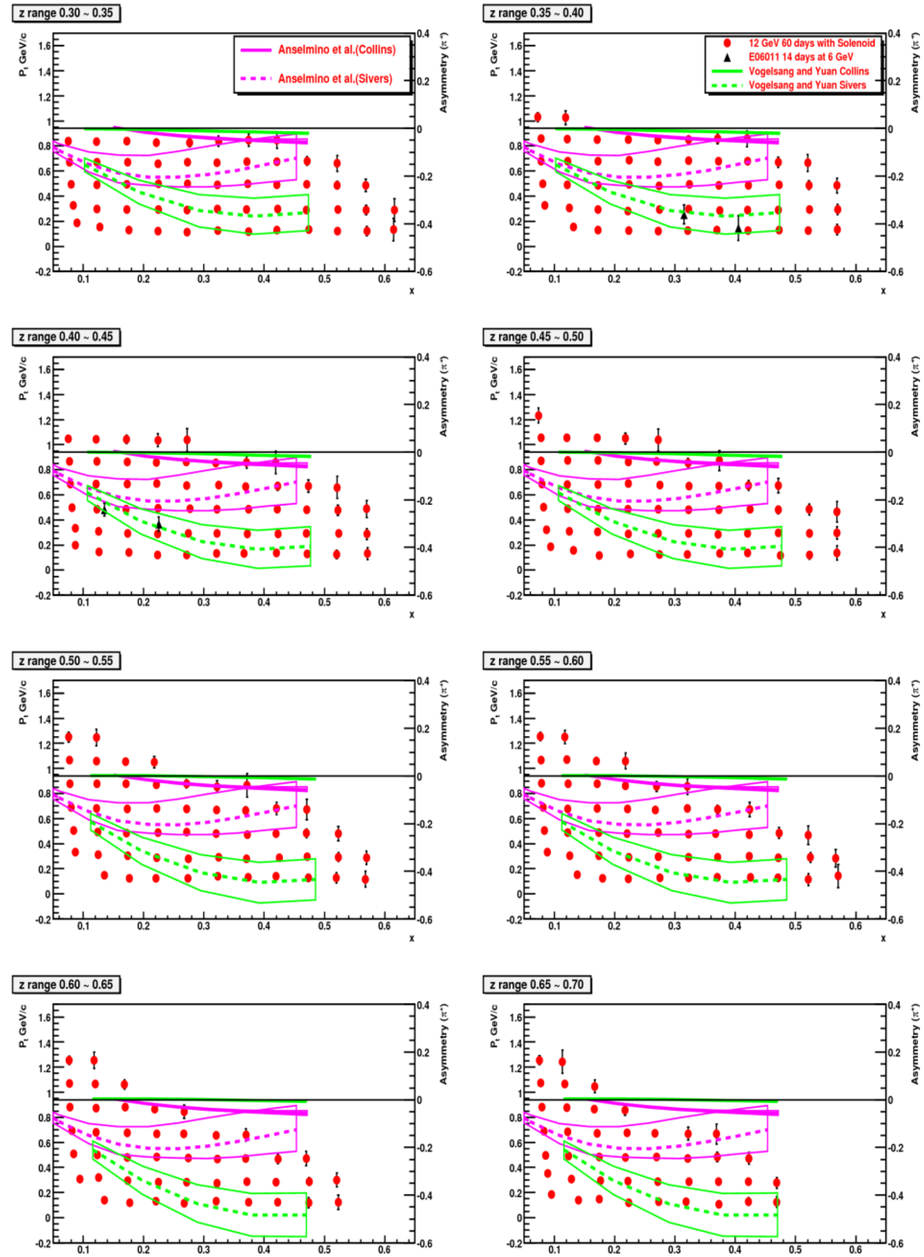
- Total 1400 bins in x, Q^2, P_T and z for 11/8.8 GeV beam.
- z ranges from 0.3 ~ 0.7, only one z and Q^2 bin of 11/8.8 GeV is shown here. π^+ projections are shown, similar to the π^- .

E12-10-006 Spokespersons: Chen, Gao (contact), Jiang, Qian and Peng

X. Qian et al in PRL 107, 072003

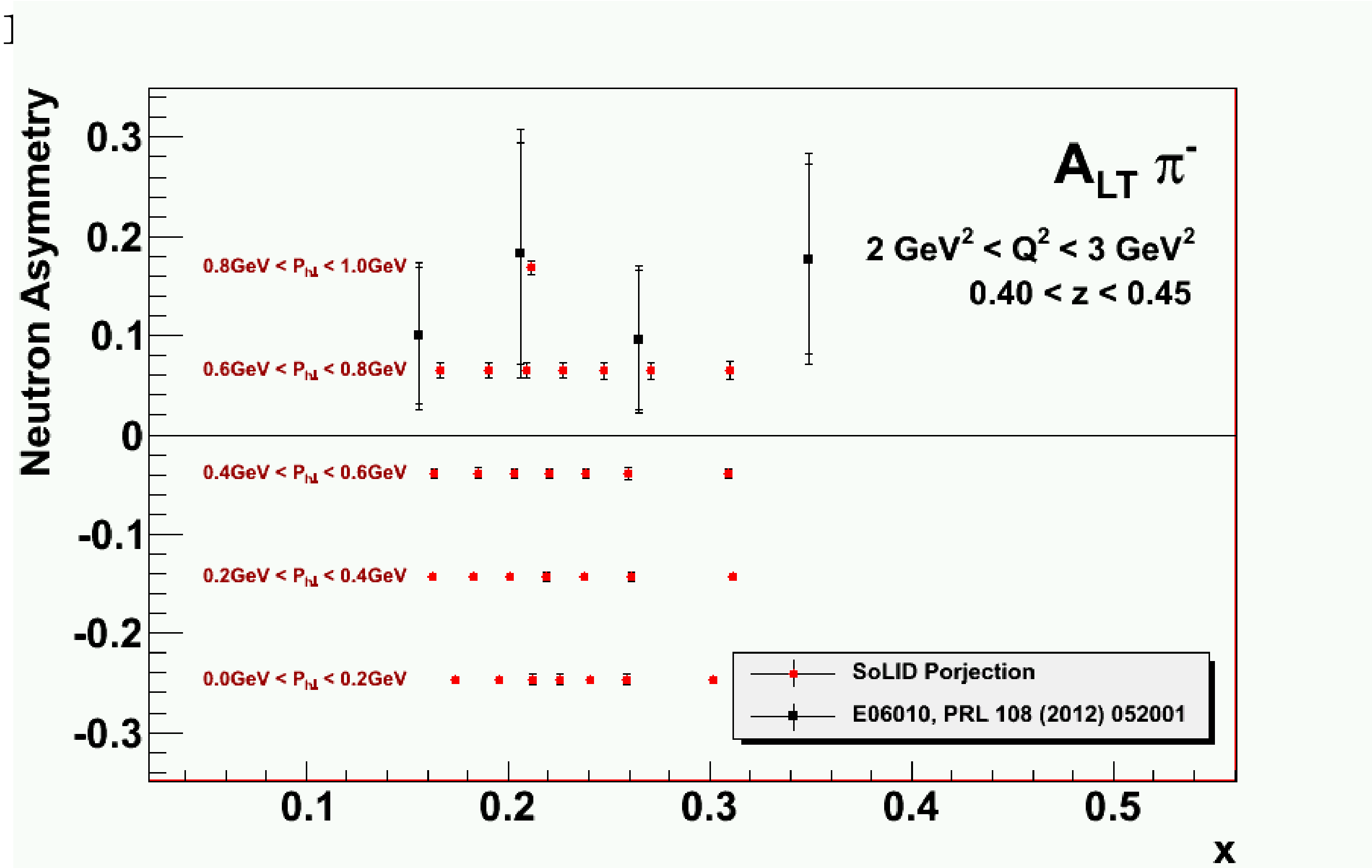
Power of SOLID (example)





SoLID E12-11-007 Projection for A_{LT} (Partial)

- E12-11-007 and E12-10-006:
  Neutron A_{LT} Projection of one out of 48 Q^2–z bins fo

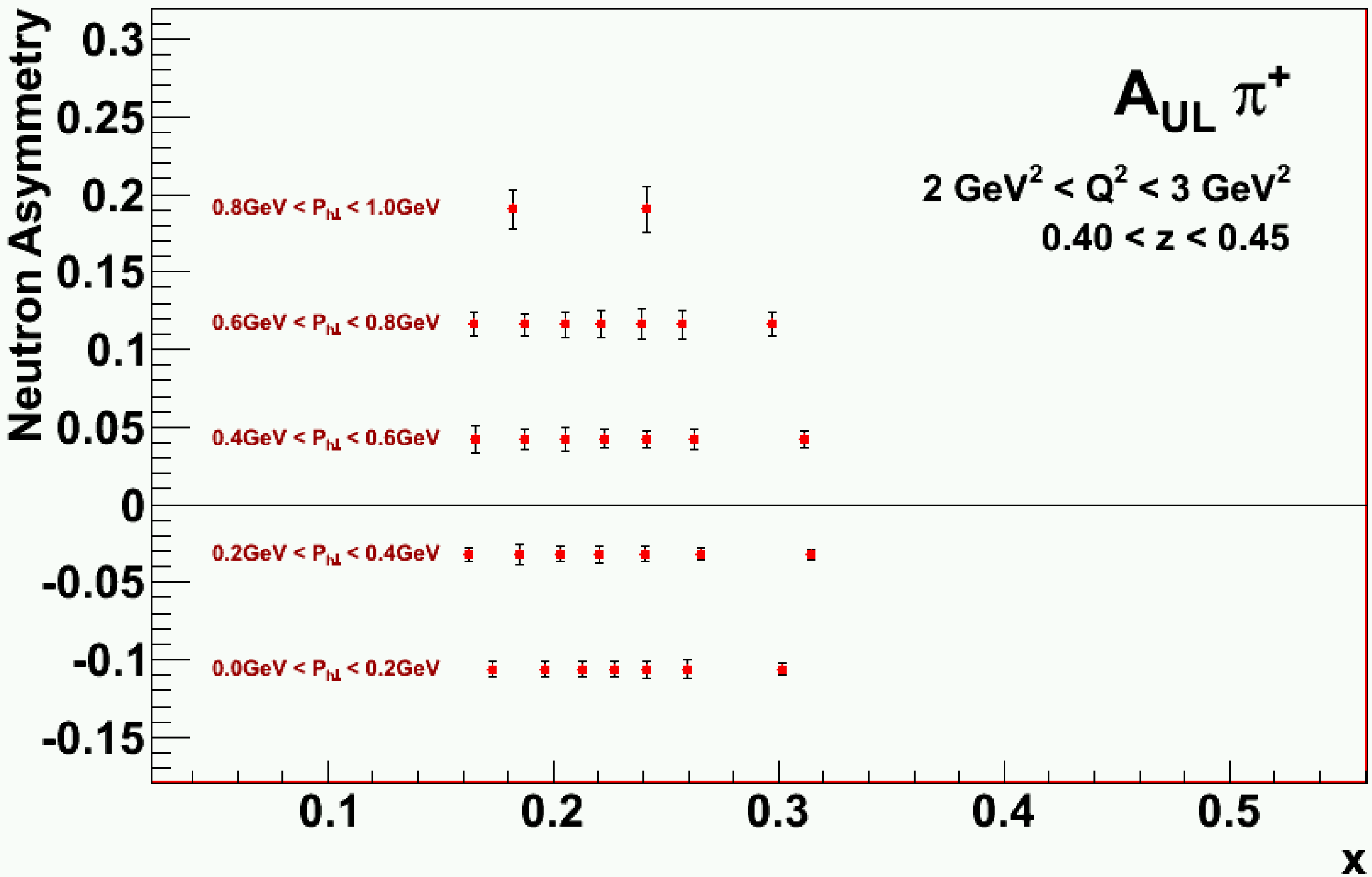


E12-11-007 spokespersons: J.P. Chen, J. Huang, Yi Qiang, W.B. Yan (USTC)
E06010 Results, J. Huang et al., PRL108, 052001 (2012)

SoLID E12-11-007 Projection/A_{UL} (Partial)

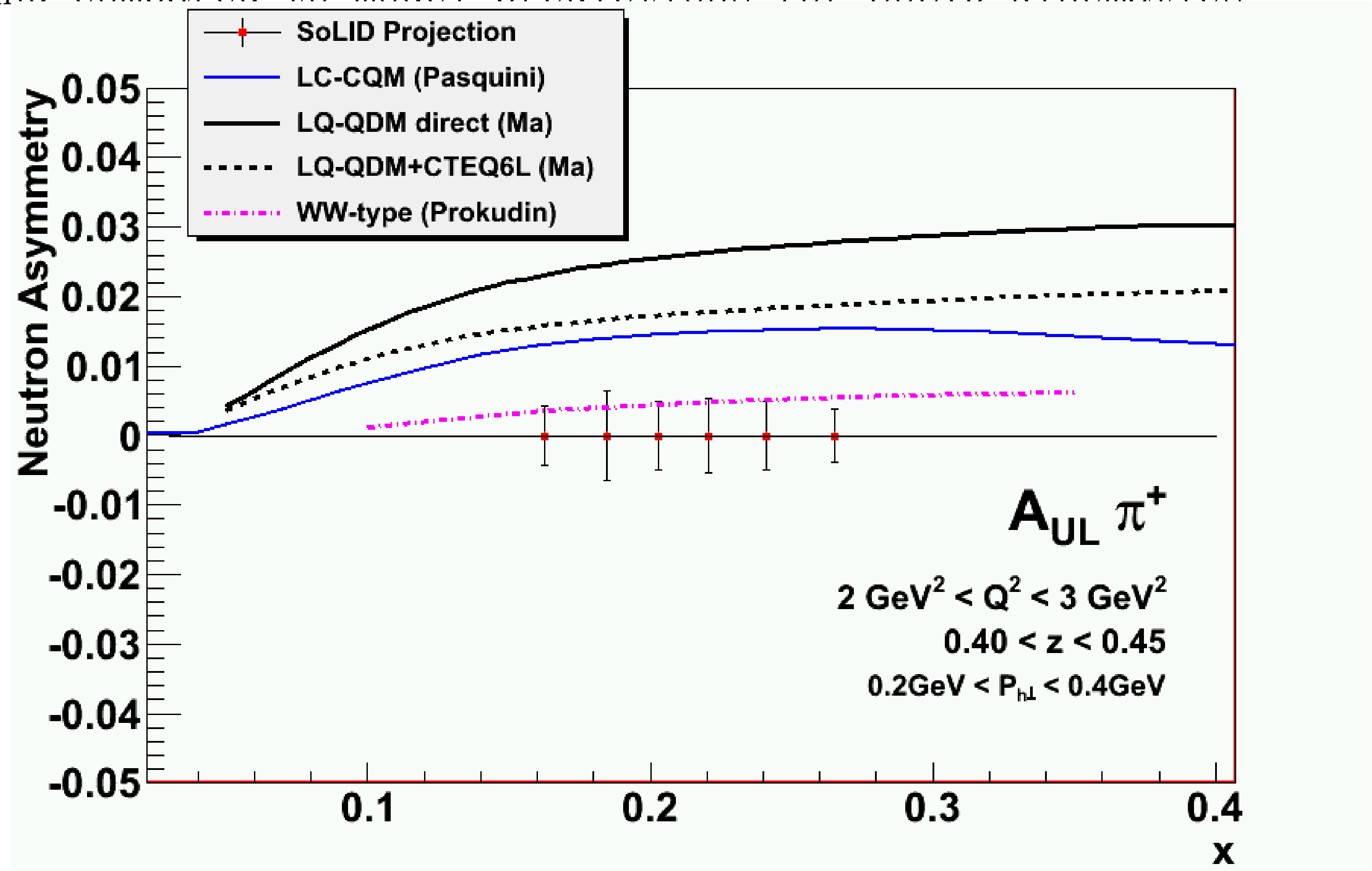
- Projection of a single Q^2–z bin for π^+

(one out of 48 Q^2-z bins)

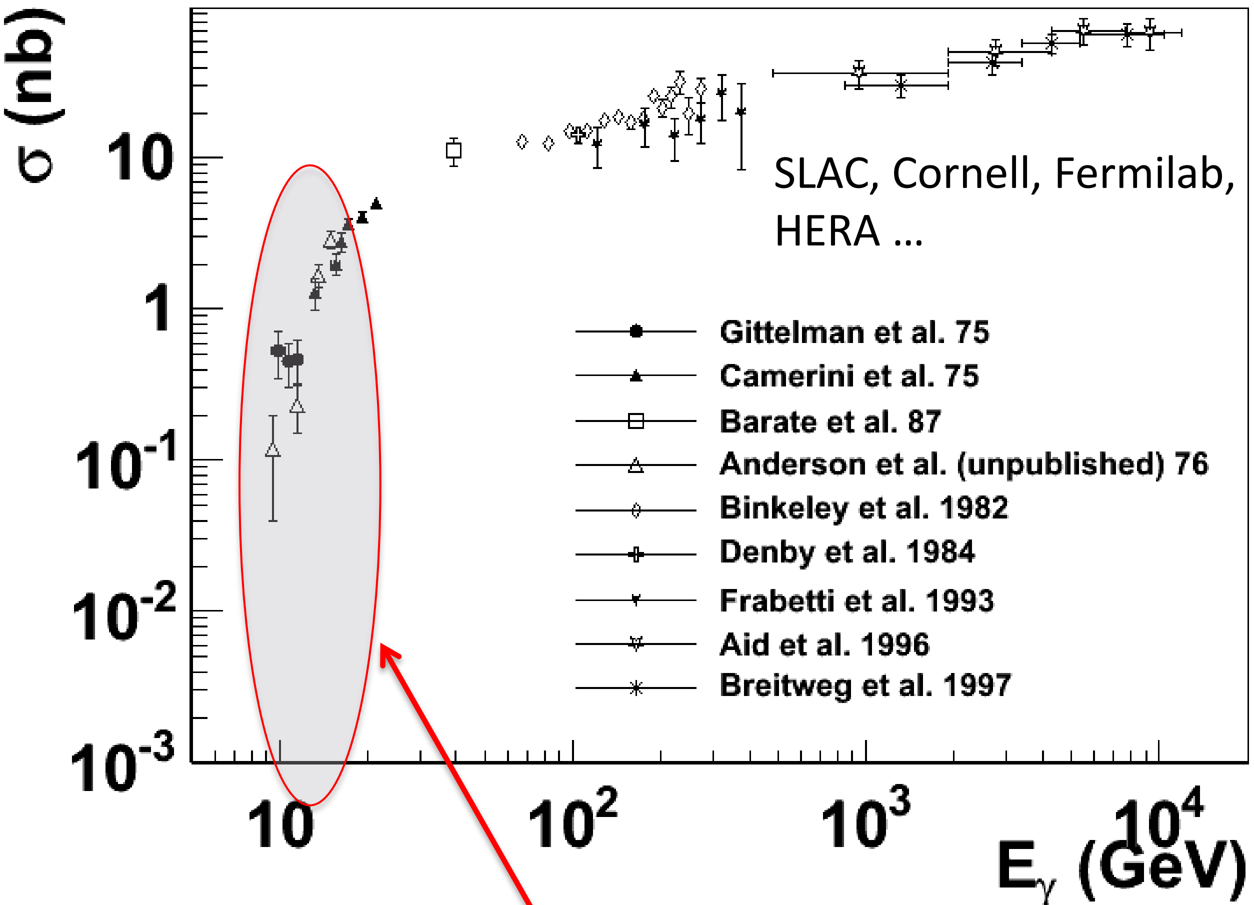


SoLID E12-11-007 Projection/A_{UL} (Partial)

- Projection of a single Q^2–z–PT bin for π^+ (no existing measurement)
  And compared to model predictions for SoLID kinematics



J/ψ production at threshold

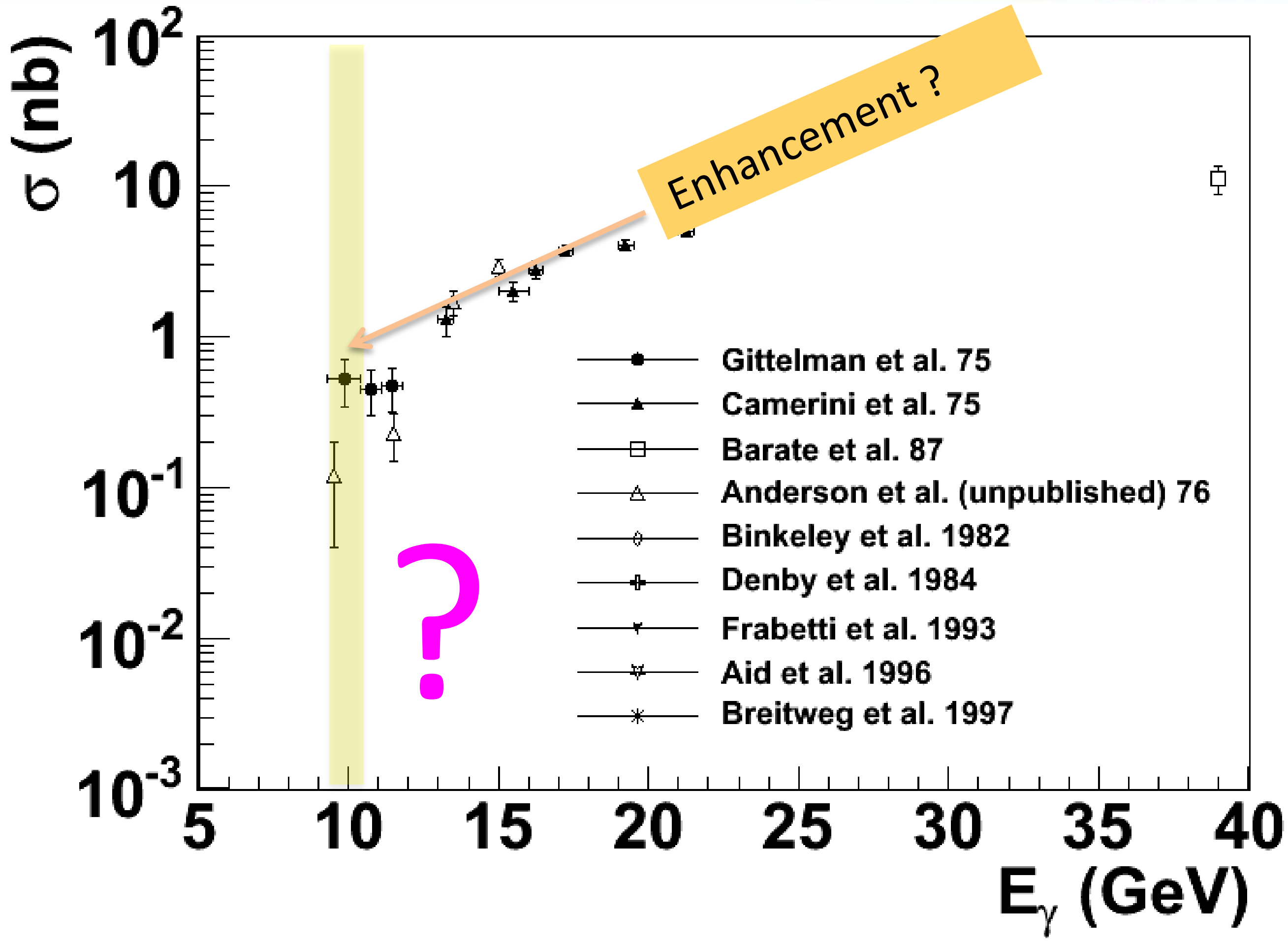


The physics focus is this threshold region

More data exist with inelastic scattering on nuclei, such as A-dependence.

Not included are the most recent results from HERA H1/ZEUS at large momentum transfers and diffractive production with electro-production

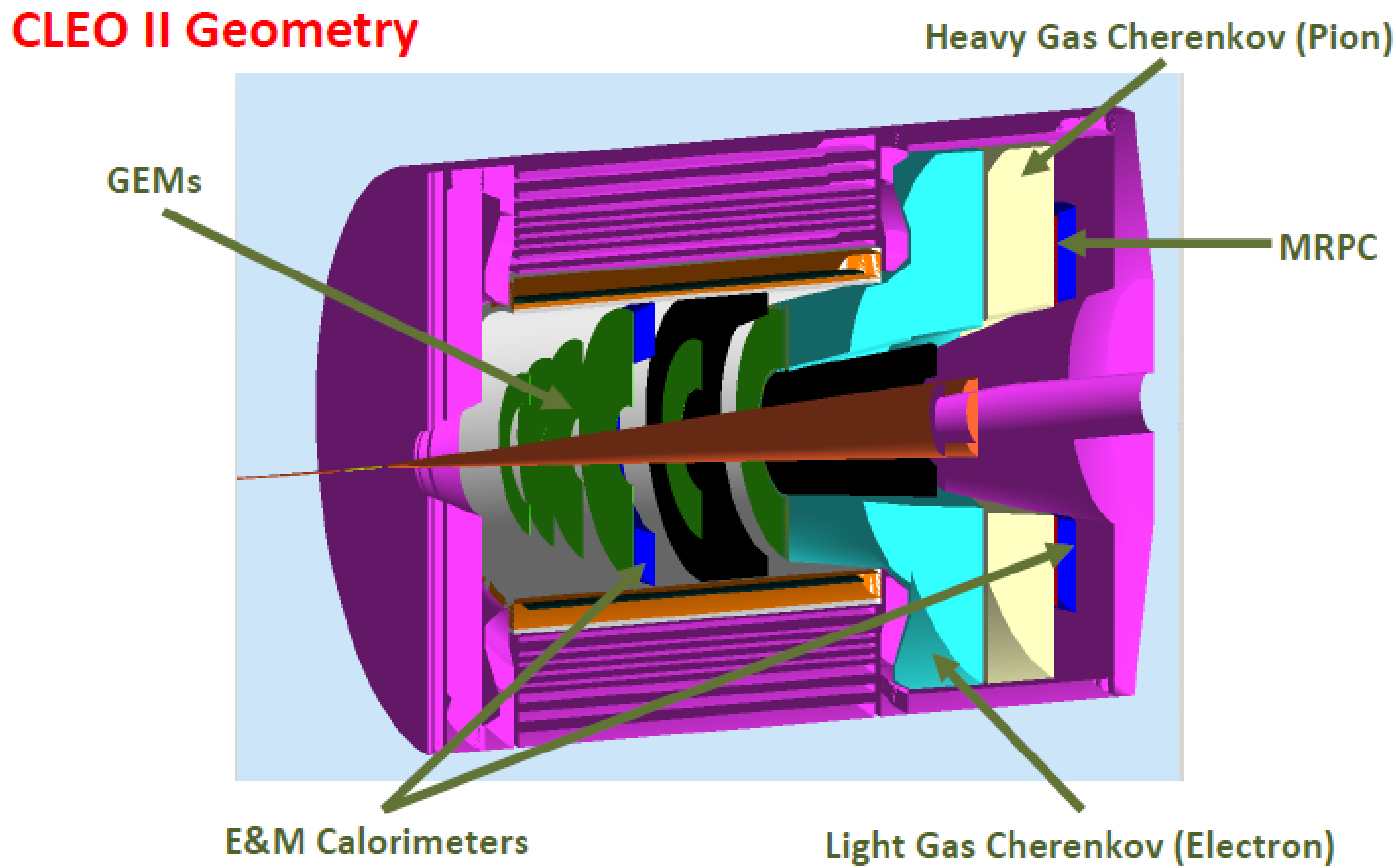
Near Threshold J/ψ production



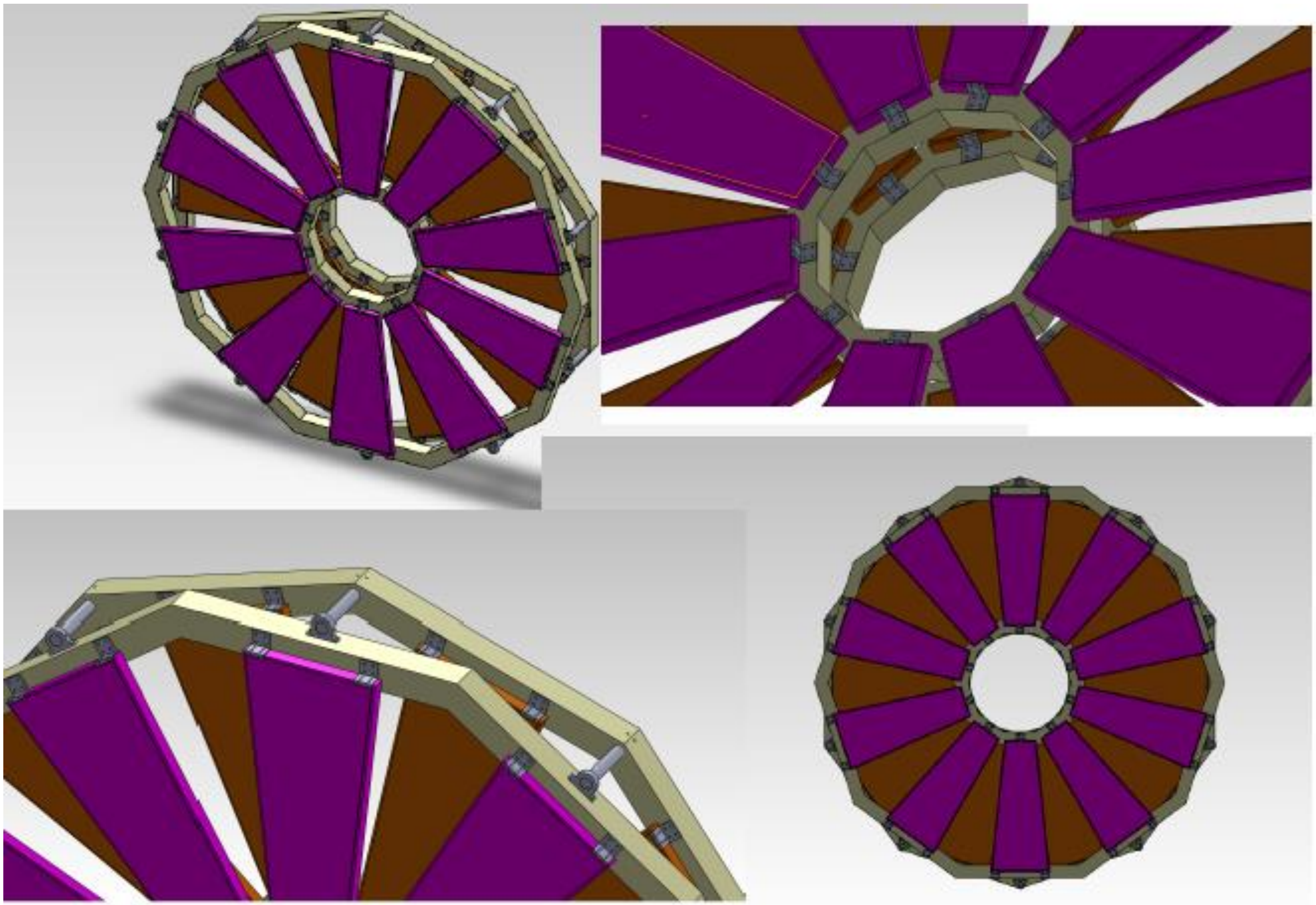
Intense experimental effort (SLAC, Cornell …) shortly after the discovery of J/ψ

But near threshold not much since (**~40 years till now**)

SoLID SIDIS / J/ψ layout



GEM plane for SIDIS



Heavy gas Cerenkov

- Useful momentum range: 2.5-7.6 GeV/c
- Cover 8° - 14.8° angular range
- Kaon contamination goal <1%

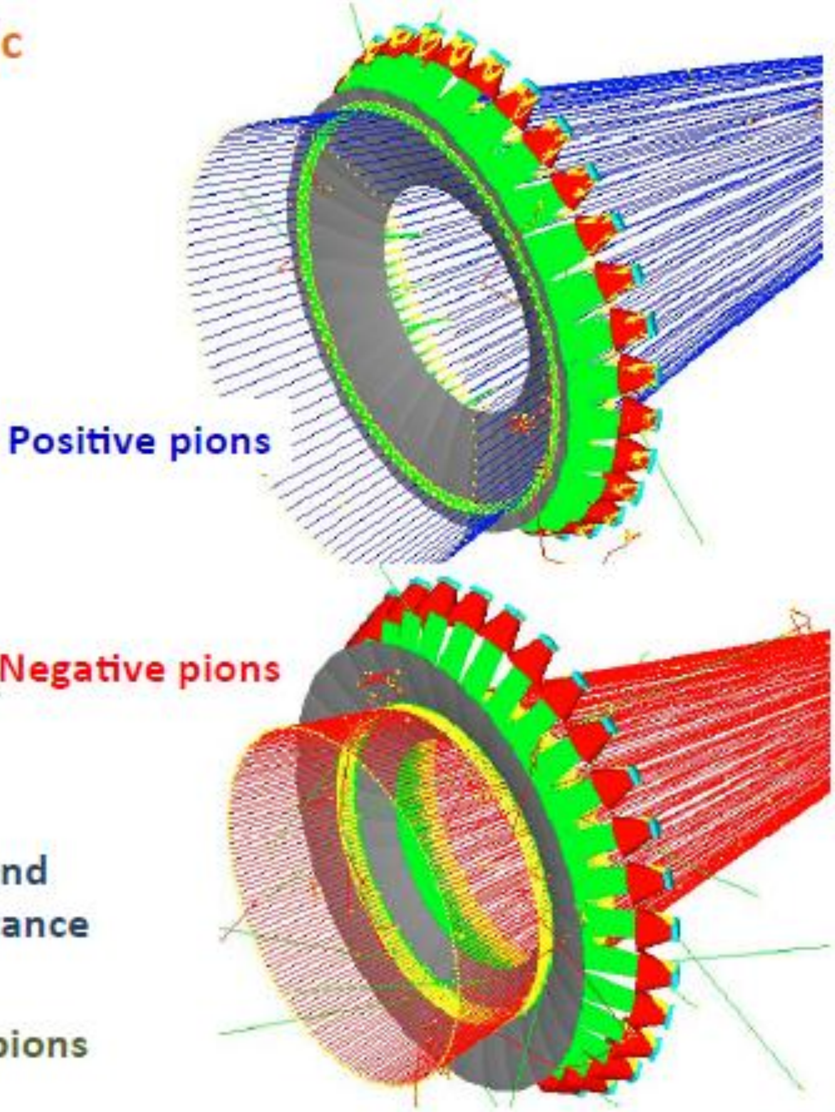
- Radiator: C_4F_8O at 1 .5 atm at 20 ^{0}C, n=1.002, 1m thick

- Mirrors: one spherical mirror per sector. Al+MgF_2 reflective coating

- Photodetectors: maPMTs tiled 4x4=16 per sector with a total of 30 sectors

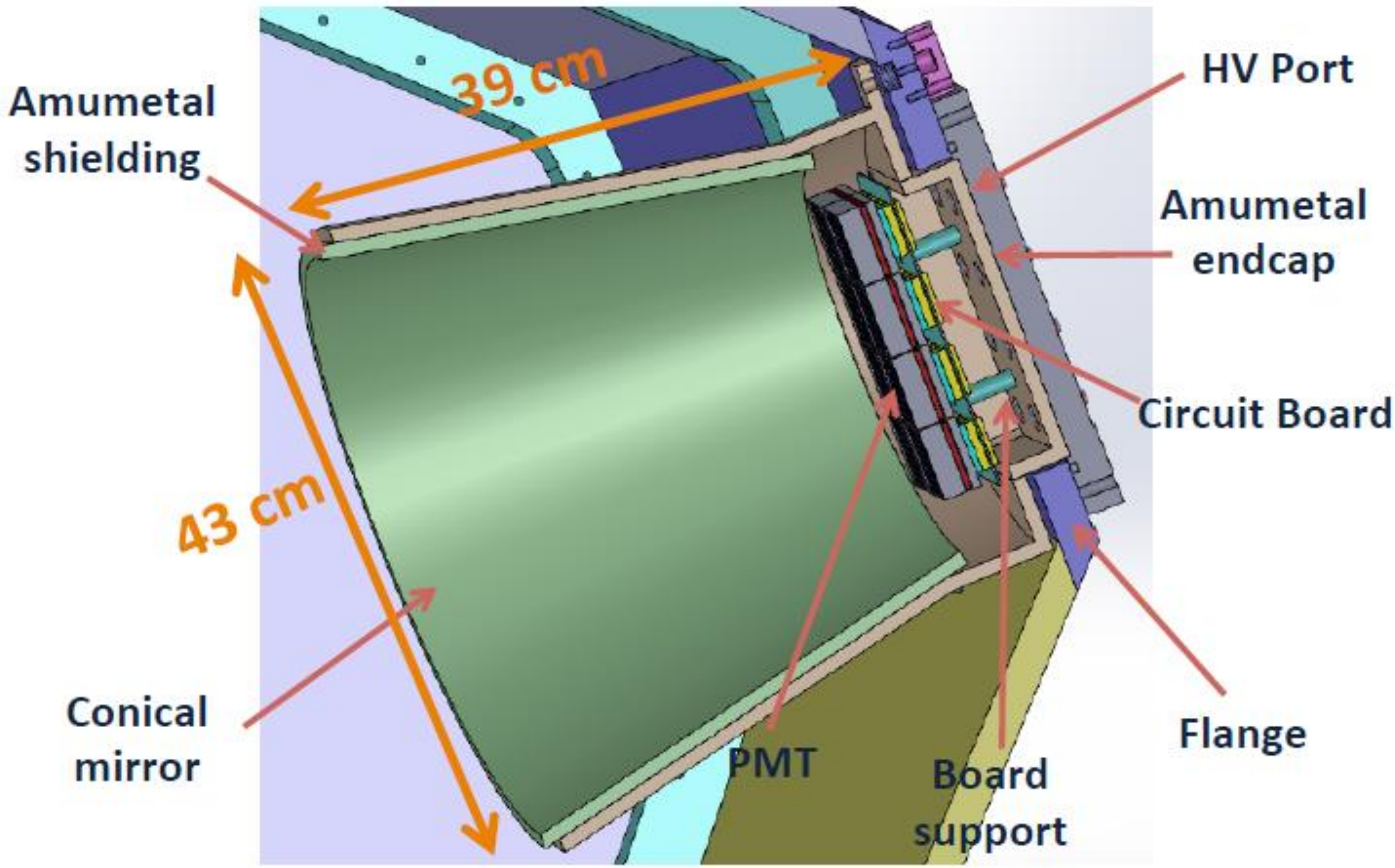
- maPMTs array shielded with a mu-metal cone, and embedded mirror to enhance the angular acceptance

- Optics optimized for both positive and negative pions



Heavy Gas Cerenkov PMT setup

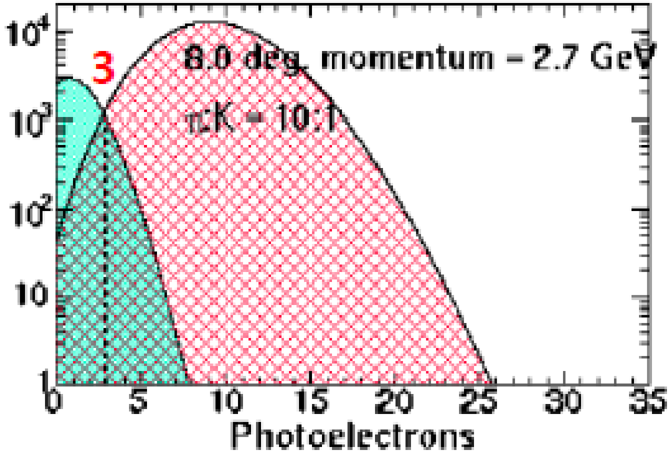
H. Gao **Duke University**



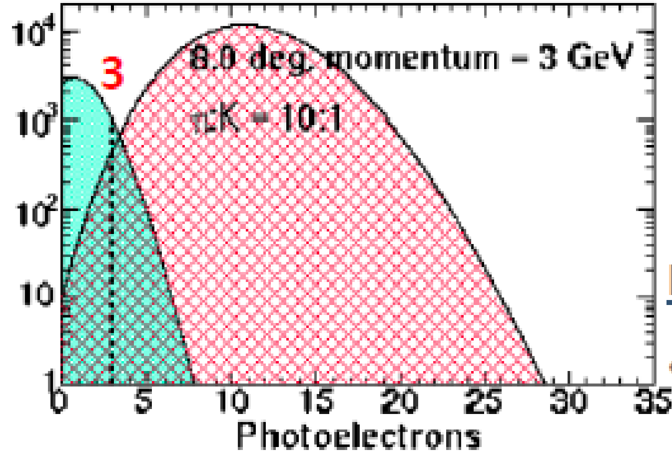
Jefferson Lab

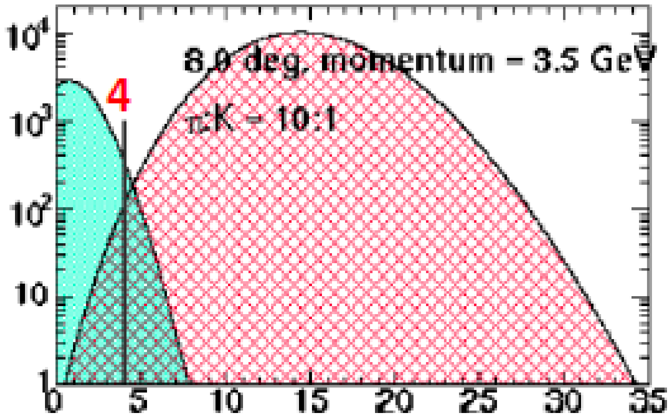
Kaon rejection / pion efficiency

pion efficiency: 99.0%
kaon contamination: 0.8%

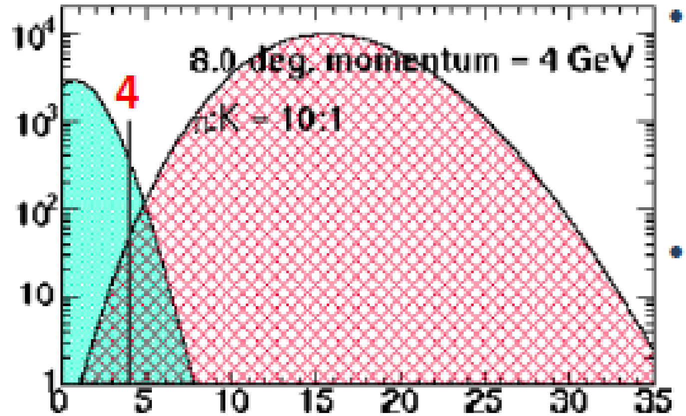


pion efficiency: 99.6%
kaon contamination: 0.8%





pion efficiency: 99.7%
kaon contamination: 0.3%



pion efficiency: 99.8%
kaon contamination: 0.3%

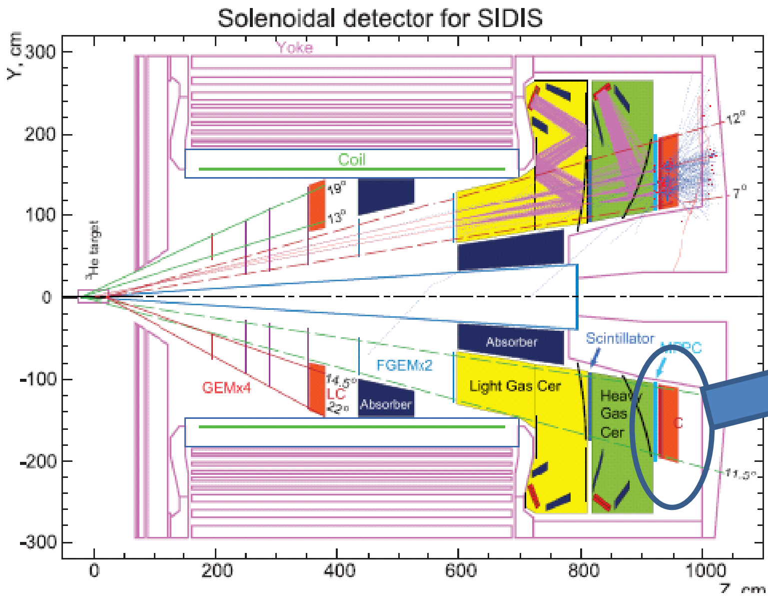
Pion distributions

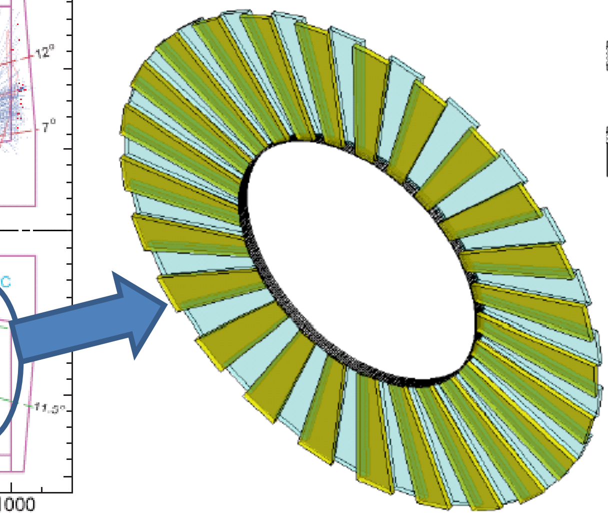
Kaon distributions

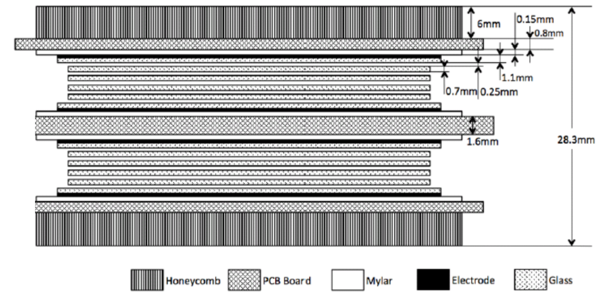
Hypothesis:

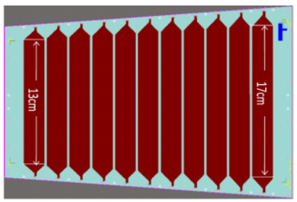
- kaon:pion = 1:10
- PMT resolution: 1 p.e. (from measurements)
- kaons give at most 1 p.e. below threshold

SoLID MRPC High resolution TOF

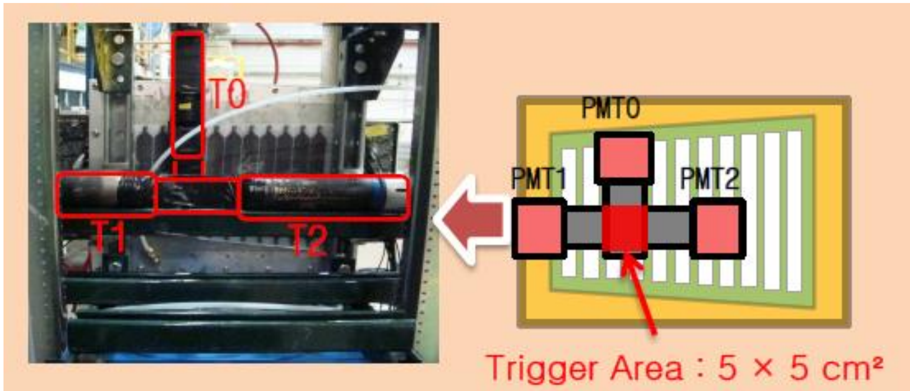


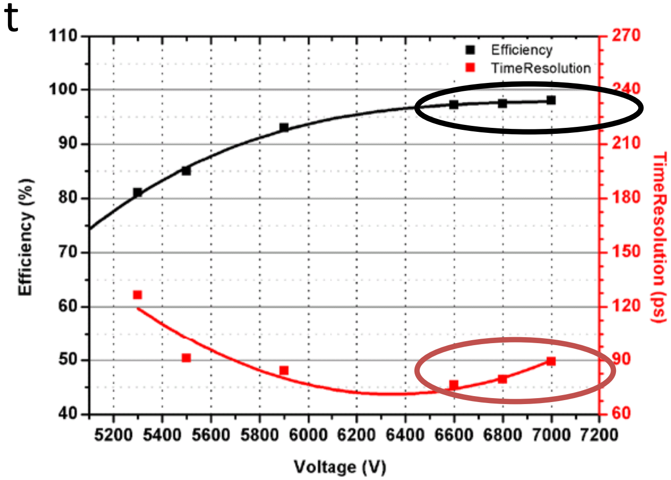






Test in beam at JLAB in 2011 during g_{2p} experiment





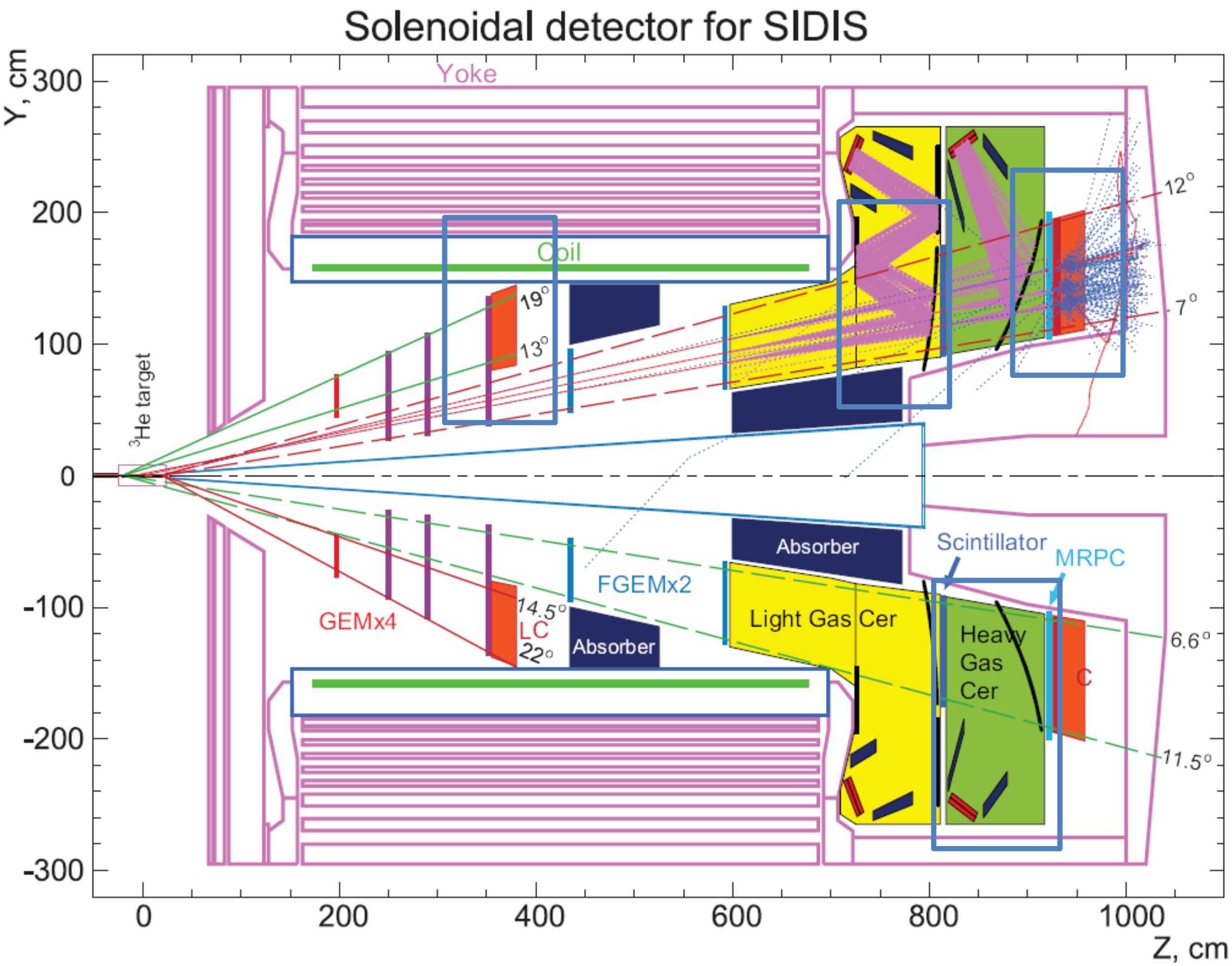
Better than 95 % efficiency

Timing resolution ~ 85 ps

A MRPC prototype for SOLID-TOF in JLab

Y. Wang, X. Fan (Tsinghua University)DOI: 10.1088/1748-0221/8/03/P03003 **JINST 8 (2013) P03003**

Detector layout and trigger for SIDIS



Trigger

Calorimeter
+
Cerenkov
+
MRPC

Coincidences and threshold for global 60 KHz trigger rates

GEM event occupancy and size

Sector	Rate	XY	Bytes	3 samples (bytes)
0	1	2	8	24
1	2	4	16	48
2	1	2	8	24
3	1	2	8	24
4	1	2	8	24
5	1	2	8	24
Total hits / sector	7	14	56	1296
Total detector	210	420	1680	5040
Data rate / sector			168000000	504000000
Data rate (sector Mb/s)			168	504
Occupancy detector	0.0015			

- Using deconvolution gives 168 MB/s for 100 KHz

FADC data

Detector	Rate	Hits	Type	Data Size per hit
LC	120 kHz	1	Energy, Hits	8 Byte x 2 (PS/SH)
FC	200 MHz	10	Energy, Hits	8 Byte x 2 (PS/SH)
LGC	40 MHz	3	Energy, Hits	8 Byte x 2 (split)
HGC	60 MHz	4	Energy, Hits	8 Byte x 2 (split)
MRPC	850 MHz	45	Hits	4 Byte
SC	300 MHz	15	Energy, Hits	8 Byte
Total				2.04kB

204 MB/s at 100 KHz

SIDIS data rate

- By using deconvolution and recording only time and amplitude : 100 KHz trigger rates achievable
- 60 KHz of coincidence can be recorded
- 40 KHz for pure singles
- 368 MB/s than can be reduced with L3
- Will test GEM readout capabilities to take more singles (theoretical 270 KHz)

New proposals

- Parasitic measurement
  - di-hadron: parasitic to E12-10-006
  - A_y: parasitic to E12-10-006/E12-11-108

- New experiment :
  - EMC-PVDIS: new beam time 71 days on 48Ca

- New ideas :
  - Dimuons channels
  - Dark photon
  - More exclusive reactions : DVCS, DVMP …
  - ….

Sub-Systems Coordinators

1) Magnet: Robin Wines/ Paul Reimer; JLab, Argonne
2) GEM-US: Nilanga Liyanange / Bernd Surrow; Uva, Temple
3) GEM-China: Zhengguo Zhao / Xiaomei Li; USTC, CIAE, Lanzhou, Tshinhua, IMP
4) Calorimeter: Xiaochao Zheng / Wouter Deconick/Chufeng Feng, Uva, W&M, Shandong (China), Argonne
5) Light Gas Cherenkov: Zein-Eddine Meziani / Michael Paolone, Temple
6) Heavy Gas Cherenkov: Haiyan Gao / Mehdi Meziane, Duke
7) MRPC TOF : Yi Wang / H. Gao / A, Camsonne , Tsinghua/Duke/JLab
8) DAQ/Electronics: Alexandre Camsonne / Rory Miskimen/Ron Gilman, JLab, UMass, Rutgers
9) Simulation: Seamus Riordan / Zhiwen Zhao; Umass, Uva, Duke, Syracuse
10) Reconstruction and Analysis Software: Ole Hansen; JLab
11) Supporting Structure and Baffle: Robin Wines/Seamus Riordan; JLab, Argonne, Umass
12) Hall Infrastructure Modifications: Robin Wines/Ed Folts; JLab
13) Installation: Ed Folts/Robin Wines; JLab, all user groups.

Conclusion

- Two programs based on the CLEO magnet
- Use of GEMs for high rate capability
- Electromagnetic calorimeter using Shashlyk
- SIDIS setup add additional PID detectors
- Large acceptance high luminosity capability and azimuthal symmetry will give unprecedented accuracy for PVDIS, SIDIS and J/ψ
- New proposals welcomed PreCDR at

http://hallaweb.jlab.org/12GeV/SoLID/download/doc/solid_precdr.pdf

for more details