Measurement of Double Deeply Virtual Compton Scattering in the di-muon channel

DDVCS @ SoLID

Marie Boer, Alexandre Camsonne, Kondo Gnanvo, Nikos Sparveris, Eric Voutier*, Zhiwen Zhao et al.

Status

Phase 1 : DDVCS run **parasitic** to the **J/ψ @ SoLID** experiment.
Phase 2 : high luminosity **dedicated** run with specific detector configuration.

" The PAC endorses the phase of this experiment that would be in the run group led by the E12-12-006, which is at lower luminosity than the second phase. This run would be enough to **demonstrate operation of the muon system** and **observe the reaction**, albeit at relatively low Q^2. Consideration of this phase will still require a **run group proposal**, **vetted by the SoLID collaboration** using whatever are the appropriate internal means. The second, high luminosity, phase must be considered as a separate proposal, along with whatever other physics goals might be achieved in the new run group defined by this high luminosity configuration. "

We wish to discuss today phase 1 of the DDVCS@SoLID experiment.

DDVCS Group

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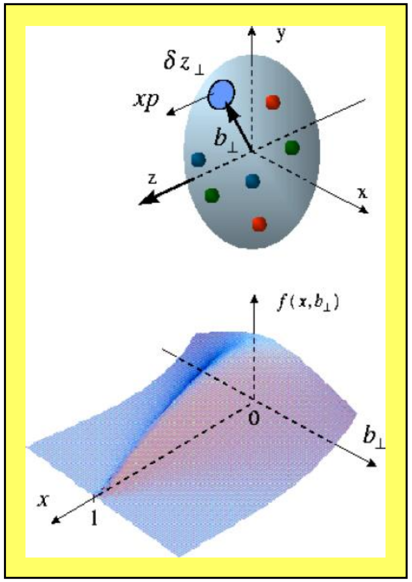
Parton Imaging

- **GPDs** offer the unprecedented possibility to access the **spatial distribution** and **dynamics** of **partons** inside the nucleon.



M. Burkardt, PRD 62 (2000) 071503 M.Diehl, EPJC 25 (2002) 223

GPDs can be interpreted as a 1/Q resolution **distribution** in the **transverse plane** of partons with **longitudinal momentum** x.

GPDs = GPDs(Q^2,ξ,η,t)

- Beyond the already probed (Q^2,t) dependences of the nucleon structure, the (ξ,η)-**dependences** are the **new unknown** major **physics components**.
- **GPDs** encode the **correlations between partons** through the (ξ,η)-**dependences**.
- As today, **DDVCS** constitutes the only channel to experimentally access **GPDs at** $\eta \neq \xi$.

Physics Impact of DDVCS

Generalized Parton distributions

$$H^q, E^q, \widetilde{H}^q, \widetilde{E}^q(x,\xi,t)$$

Link to DIS at $\xi=t=0$

$$H^q(x,0,0) = q(x) = -\bar{q}(-x)$$
$$\tilde{H}^q(x,0,0) = \Delta q(x) = -\Delta\bar{q}(-x)$$

No similar relations for E^q and $\tilde{E}^q$

Link to form factors (sum rules)

$$\int_{-1}^{1} dx H^q(x,\xi,t) = F_1^q(t) \ , \ \int_{-1}^{1} dx E^q(x,\xi,t) = F_2^q(t)$$
$$\int_{-1}^{1} dx\, \tilde{H}^q(x,\xi,t) = g_A^q(t) \ , \ \int_{-1}^{1} dx \tilde{E}^q(x,\xi,t) = h_A^q(t)$$

Access to **quark angular momentum** (Ji's sum rule)

$$J_q = \frac{1}{2}\Delta\Sigma_q + L_q = \frac{1}{2}\int_{-1}^{1} x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0) \right]$$

Physics Impact of DDVCS

- ***Nucleon tomography***

$$q(\eta, b_\perp) = \frac{1}{(2\pi)^2} \int d^2\Delta_\perp \; H^q(\eta, 0, -\Delta_\perp^2) \exp[-i \, b_\perp \cdot \Delta_\perp]$$

The measurement of the uncorrelated ξ-dependence at fixed η will allow for an **model independent** experimental **determination** of the **transverse parton densities** at zero-skewdness, which is today obtained from an model-dependent extrapolation of DVCS data.

- ***Nuclear force distribution***

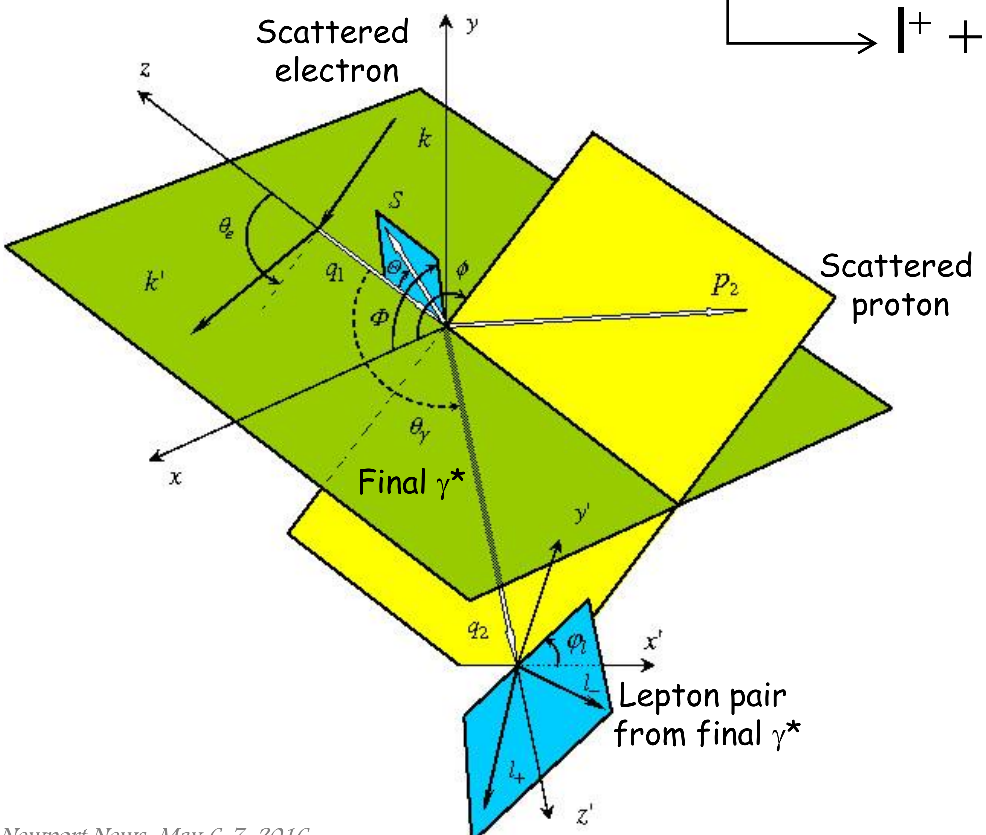
$$\int_{-1}^{1} d\eta \; \eta \sum_q H^q(\eta, \xi, t) = \sum_q M_2^q(t) + \frac{4}{5} \sum_q d_1^q(t) \xi^2$$

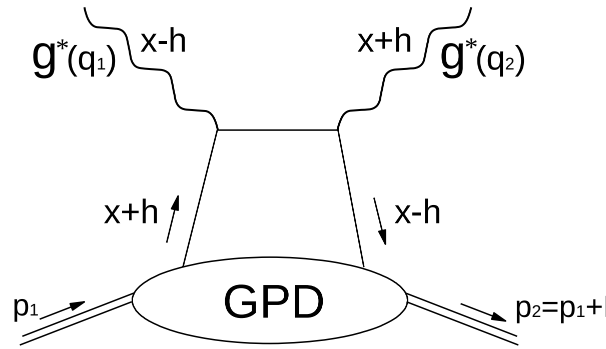
The ξ-dependence at the first Mellin moment of GPDs contains information about the **spatial distribution of forces** experienced by partons inside the nucleon, encoded within the so-called **D-term**.

Reaction Process

M. Guidal, M. Vanderhaeghen, PRL 90 (2003) 012001   A.V. Belitsky, D. Müller, PRL 90 (2003) 022001

$$e + p \longrightarrow e + p + \gamma^*$$
$$\gamma^* \longrightarrow l^+ + l^-$$





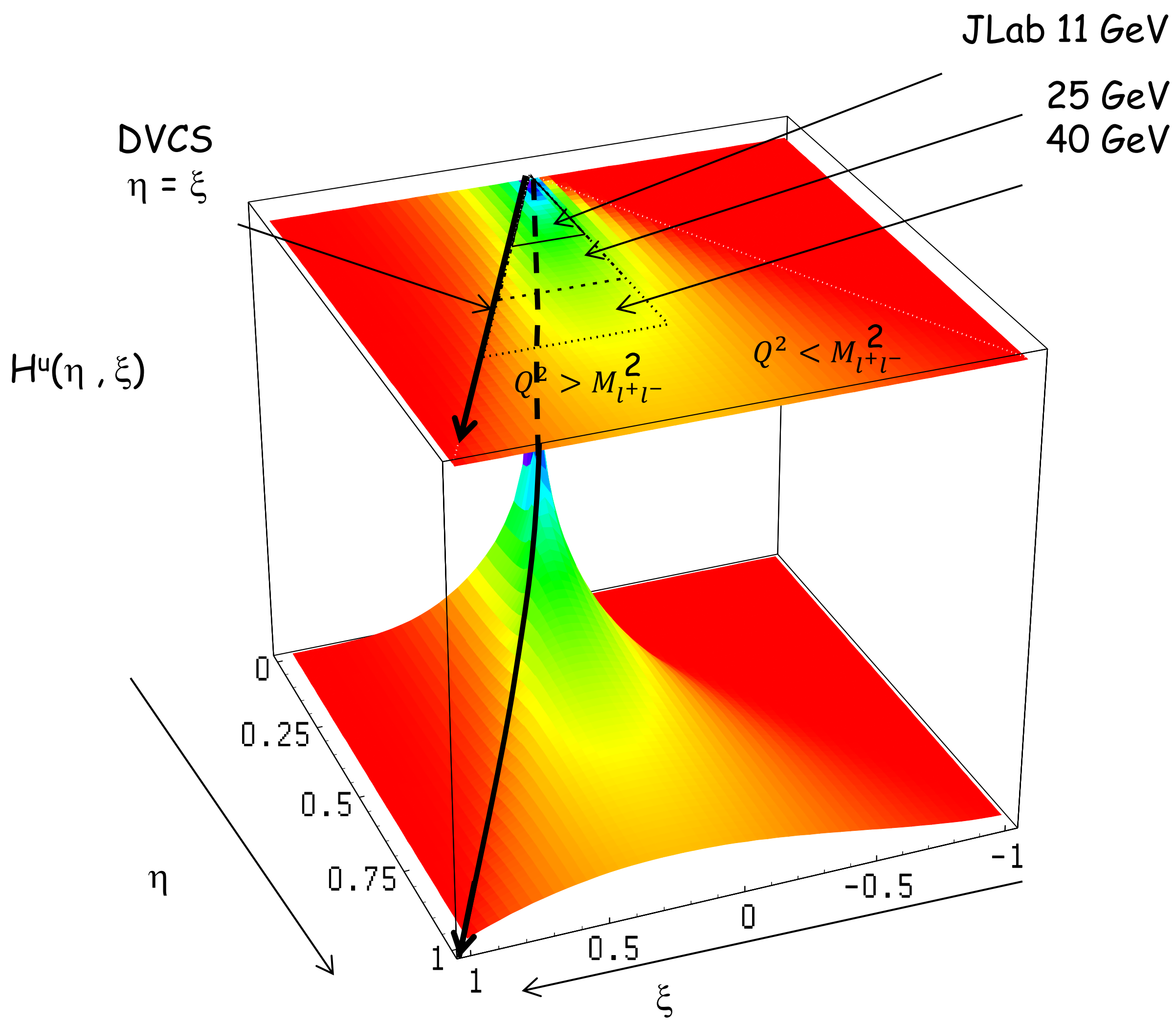
$$Q^2 = -q_1^2 \quad Q'^2 = q_2^2 \quad x_B = \frac{Q^2}{2p_1 \cdot q_1}$$

$$p = \frac{p_1 + p_2}{2} \quad q = \frac{q_1 + q_2}{2}$$

$$D = p_1 - p_2 = q_2 - q_1 \quad x = \frac{Q^2}{2p \cdot q} \quad h = \frac{D \cdot q}{p \cdot q}$$

$$x \propto Q^2 - Q'^2 + \frac{D^2}{2} \quad h \propto Q^2 + Q'^2$$

Kinematic Coverage

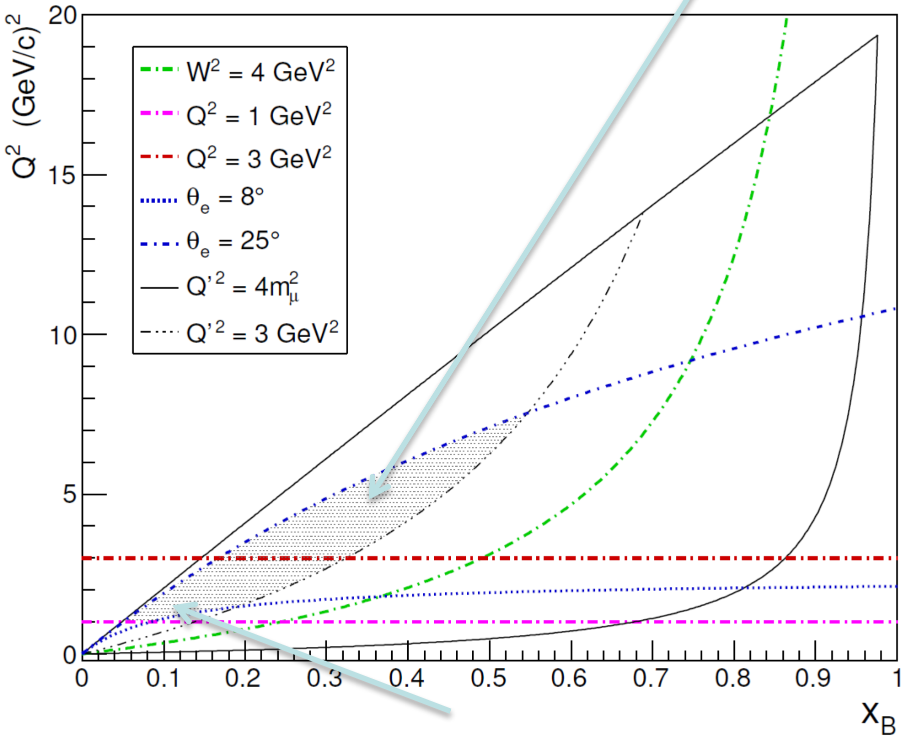


- DVCS only probes $\eta = \xi$ line
- Example with model of GPD H for up quark
- Jlab : $Q^2 > 0$
- Kinematical range increases with beam energy (larger dilepton mass)

Kinematic Coverage

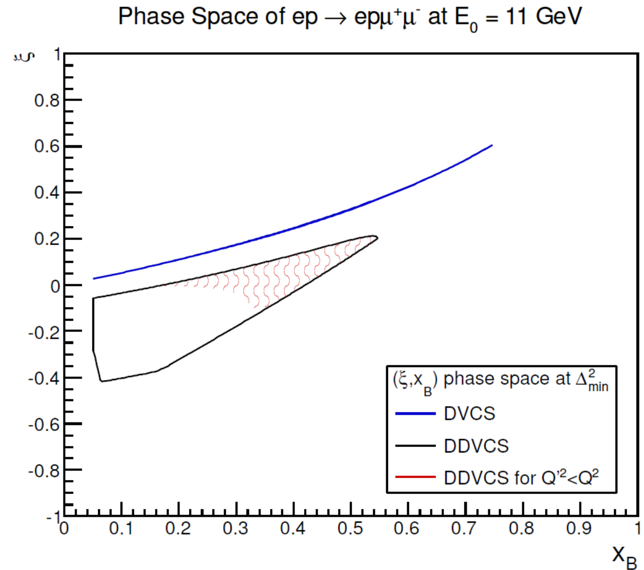
Ideally want Q'^2 to be high enough to be away from pion production and have $Q'^2 < Q^2$

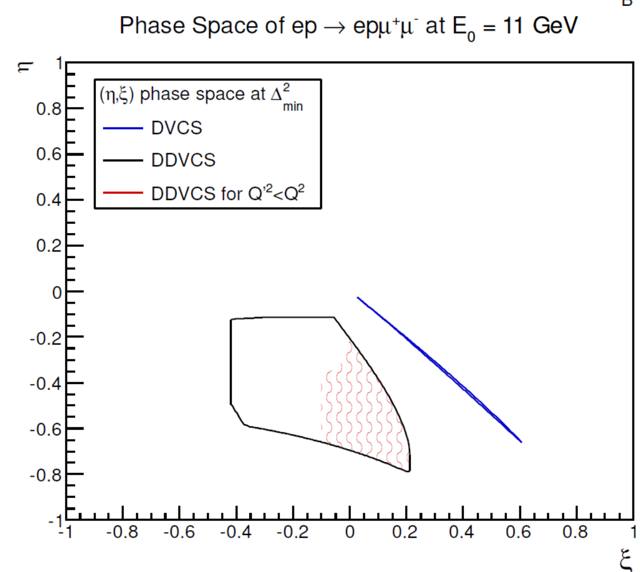
Dedicated experiment



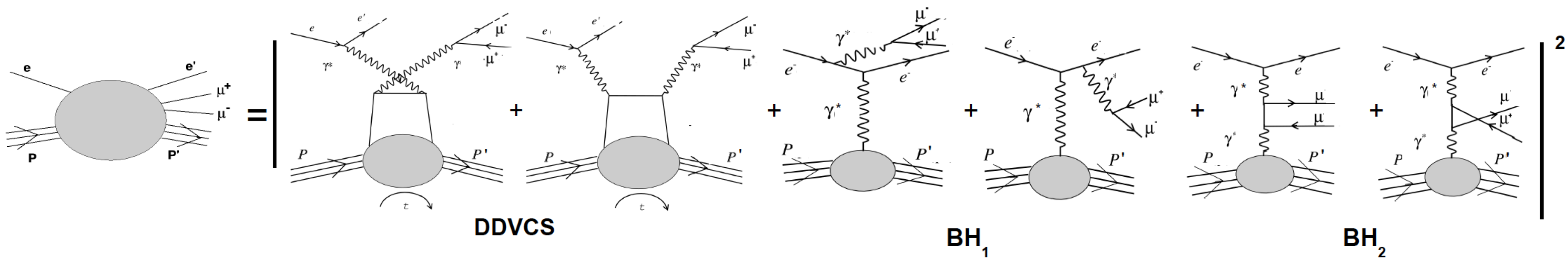
Parasitic experiment first exploratory measurement

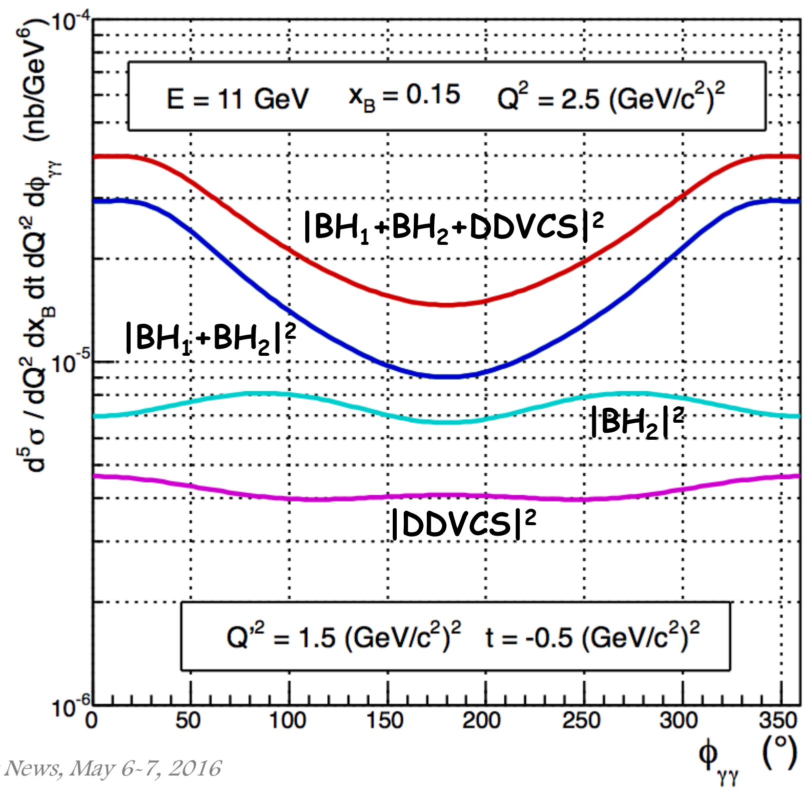
Need luminosity and improved Q'^2 and Q^2 coverage hence SoLID





Cross Section



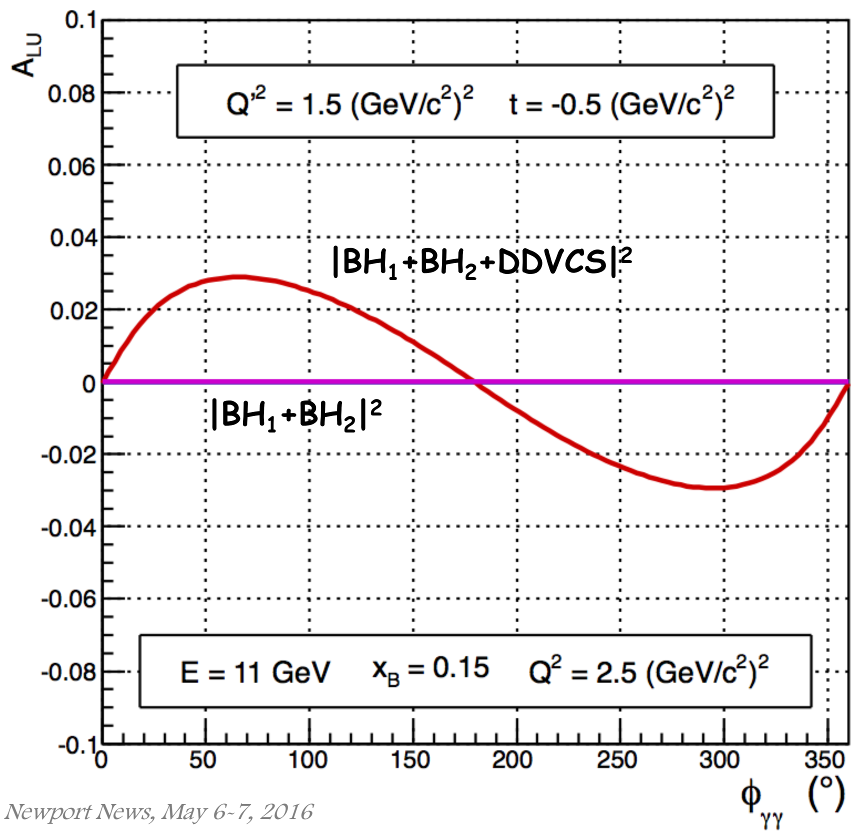


- Cross sections, calculated within the twist-2 VGG approach, are about **two orders of magnitude smaller than DVCS**.
- **Additional Bethe-Heitler** like contributions with **different ϕ-dependence** interfere with the pure small DDVCS amplitude.
- **Muon pair detection** in the final state allows to circumvent electron indiscernability.

Beam Spin Asymmetry

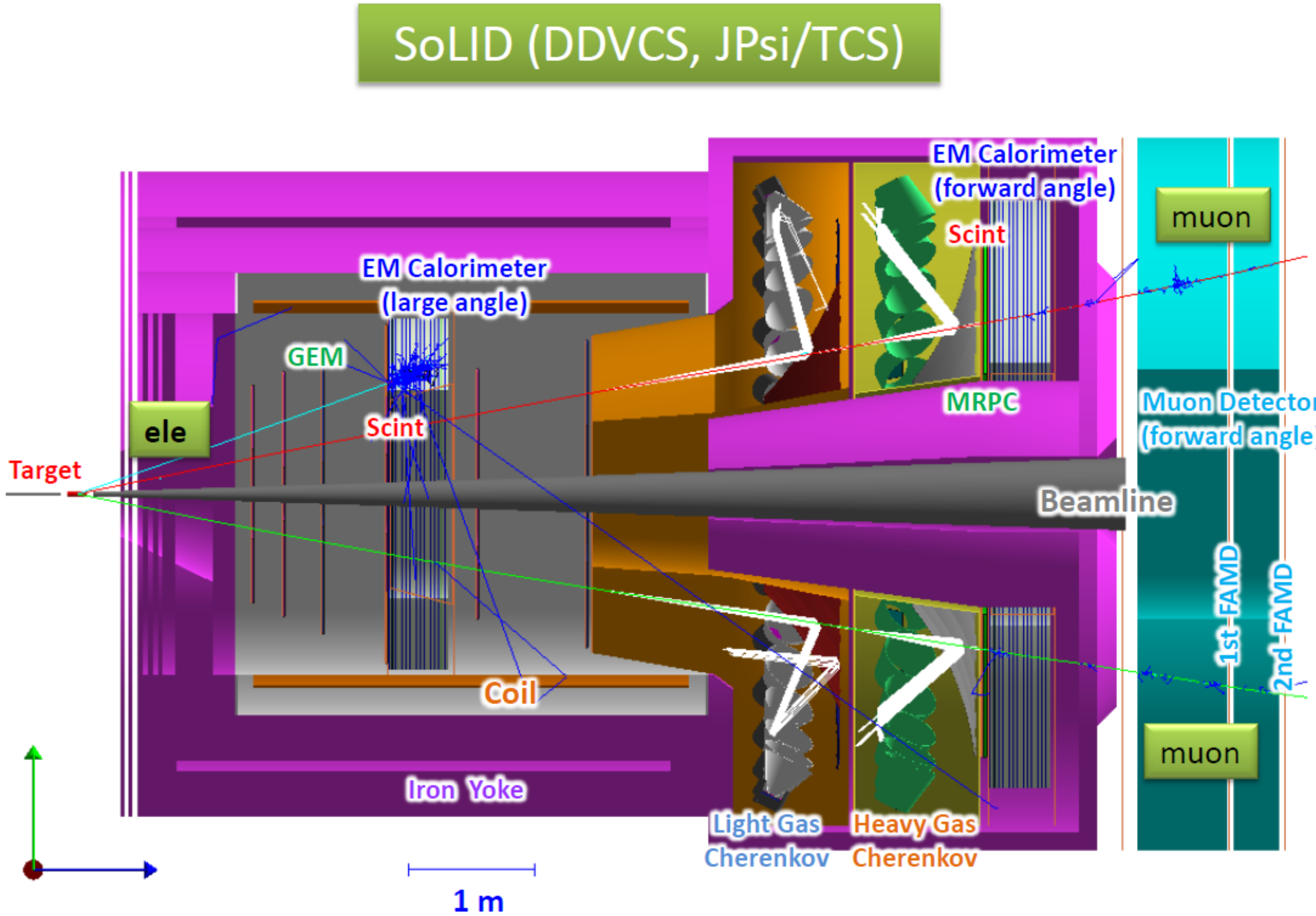
$$\begin{Bmatrix} A_{\rm LU}^{\sin\phi} \\ A_{\rm LU}^{\sin\varphi_\mu} \end{Bmatrix} = \frac{1}{\mathcal{N}} \int_{\pi/4}^{3\pi/4} d\theta_\mu \int_0^{2\pi} d\varphi_\mu \int_0^{2\pi} d\phi \begin{Bmatrix} 2\sin\phi \\ 2\sin\varphi_\mu \end{Bmatrix} \frac{d^7\overrightarrow{\sigma} - d^7\overleftarrow{\sigma}}{dx_B\,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

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

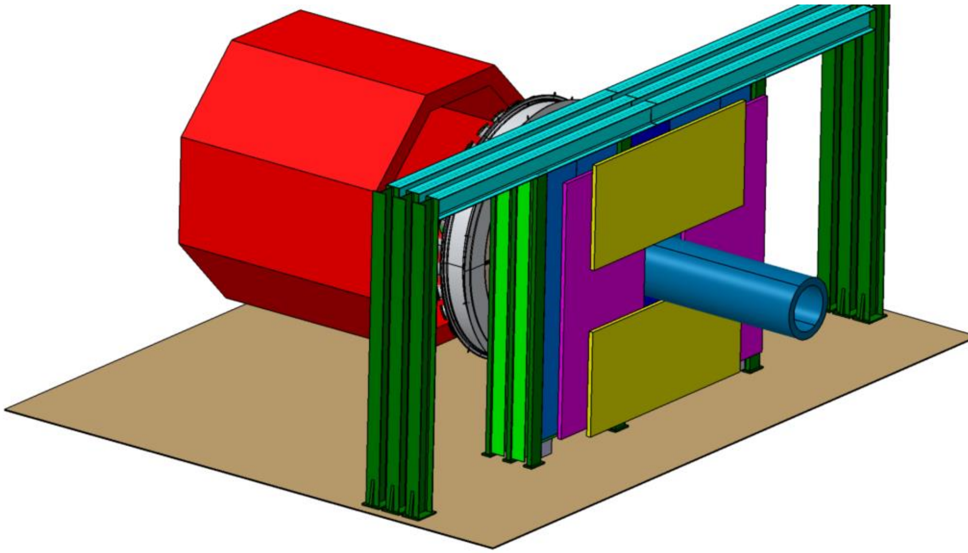


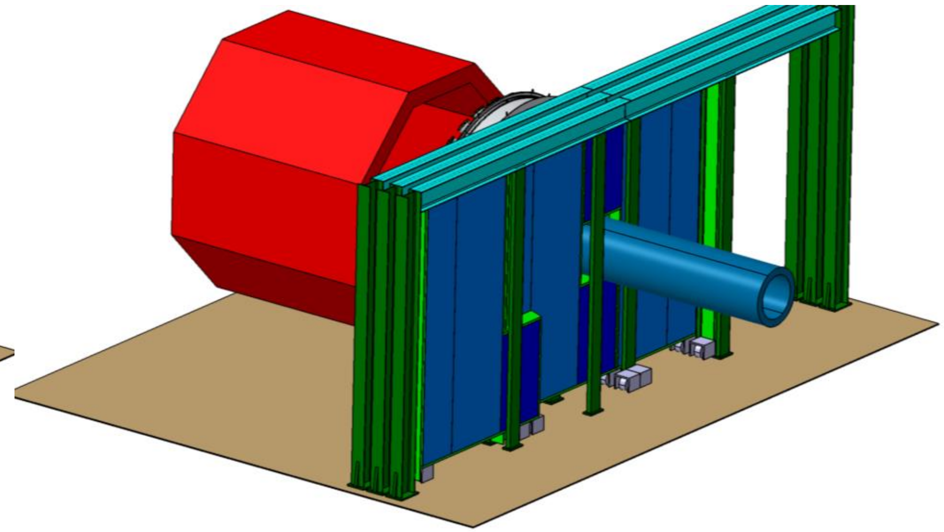
The BSA of the DDVCS process allows to access the same linear combination of the Compton form factors than the BSA of DVCS, however at $\eta \neq \xi$.

Detector Configuration



Mechanical Design





Preliminary design from IPNO : Christine Legalliard / Dominique Marchand /Eric Voutier
start to interact with SoLID Hall A designer

Need to figure cable management and interference with End Cap motion

Very rough estimate : 200 K$ to 500 K$

Will have more accurate design if approved

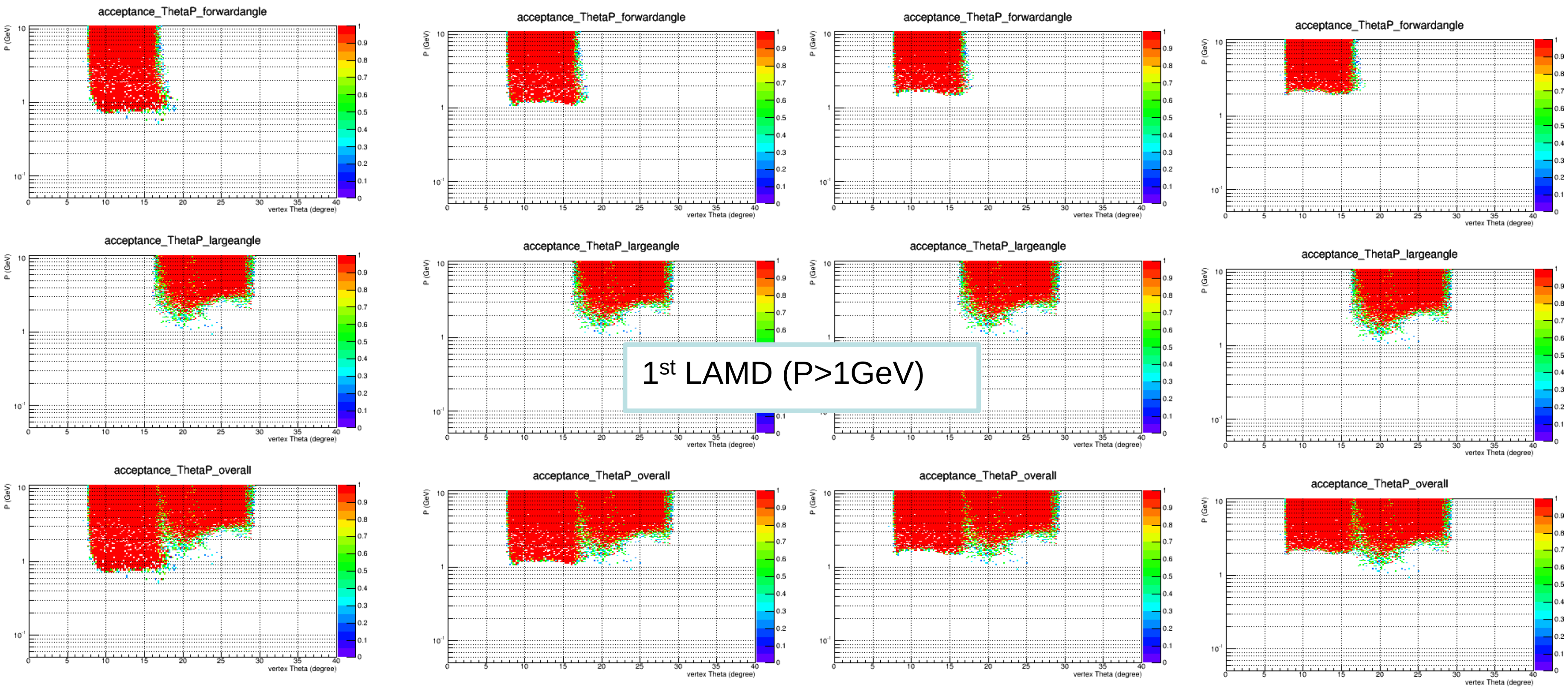
Electronics

4/25/2016

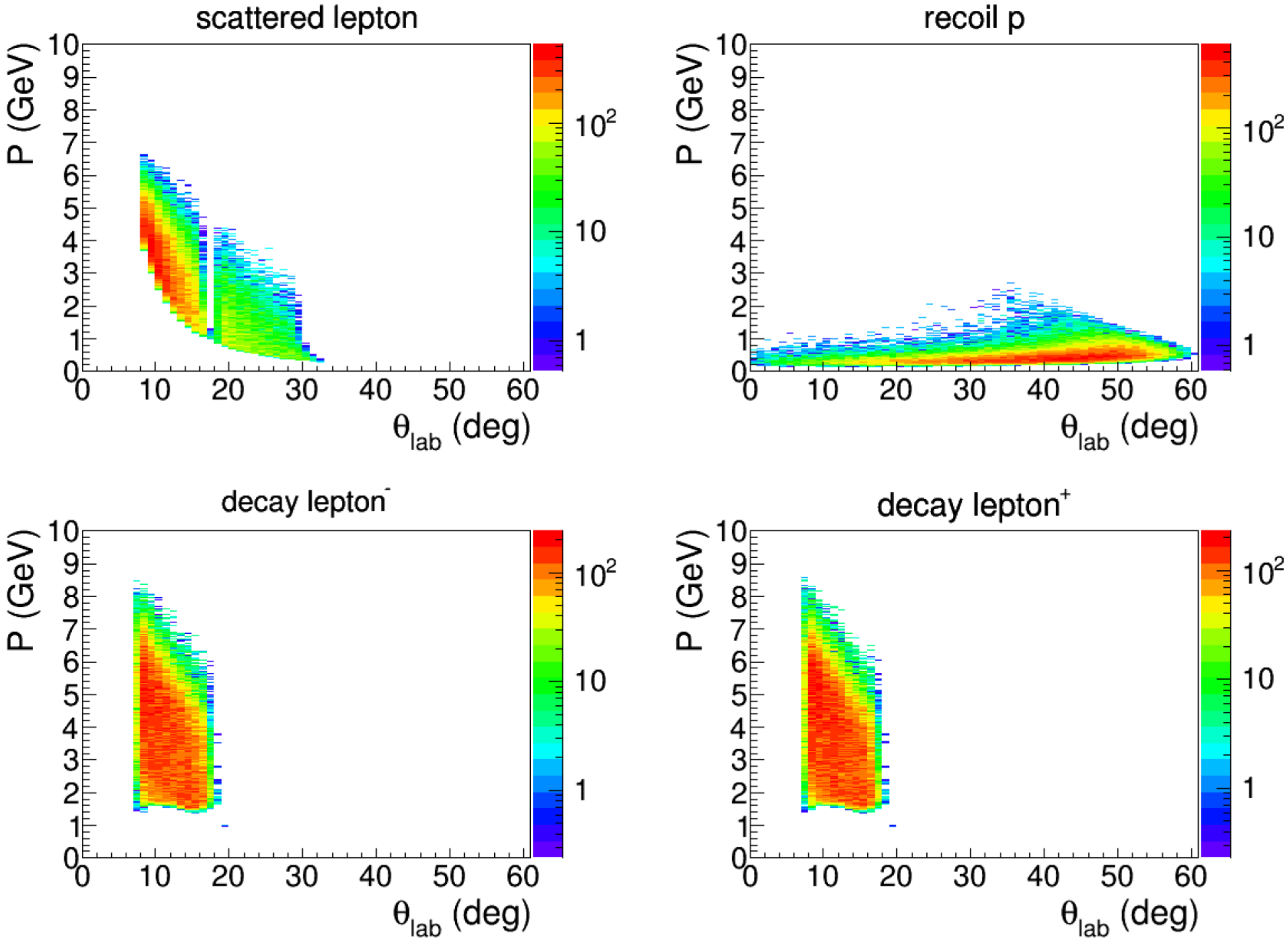
Preliminary Estimate for SoLID Muon Electronics				2016-April-25
96-Channel, 1ns TDC				
Item	**Quantity**	**Cost**	**Extended**	**Notes**
Fully assembled Boards	85	$1,500	$127,500	**85 boards * 96 channels == 8160 detector "channels"**
6U VXS crate	6	$12,000	$72,000	Includes crate/power supply/fan tray. 16 boards/crate
VTP	6	$8,500	$51,000	**Could be used to readout data
Signal Distribution Module	6	$1,250	$7,500	
Trigger Interface	6	$1,200	$7,200	
Single Board Computer*	6	$4,000	$24,000	*** consider low budget VME controller IF VTP is used for primary readout**
Trigger Fiber Optics, etc.	1	$8,000	$8,000	Patch panels, patch cords, trunk lines
Total			$297,200	

Acceptance

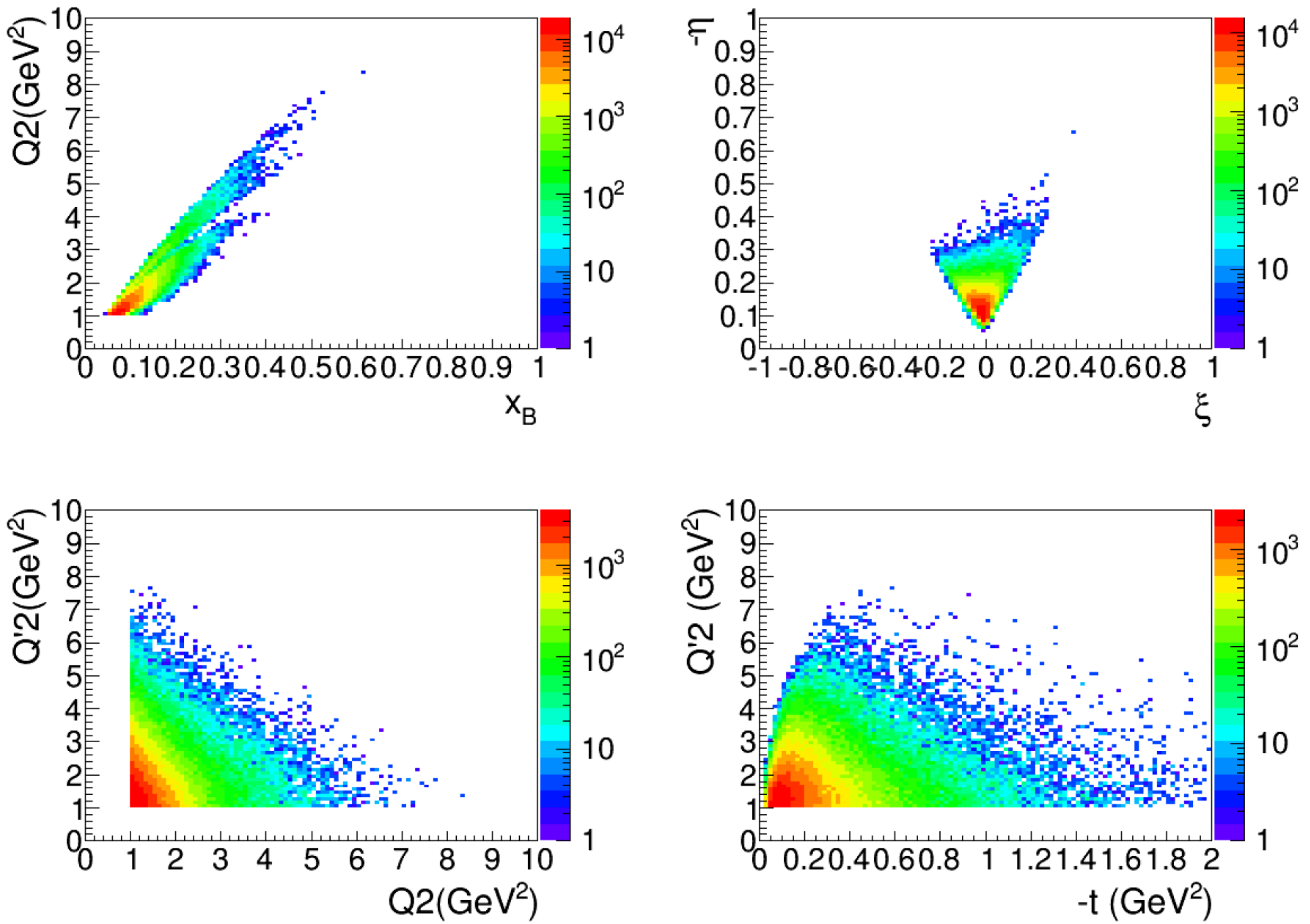
1st FAMD (P>0.7GeV)	2nd FAMD (P>1GeV)	3rd FAMD (P>1.5GeV)	4th FAMD (P>2GeV)



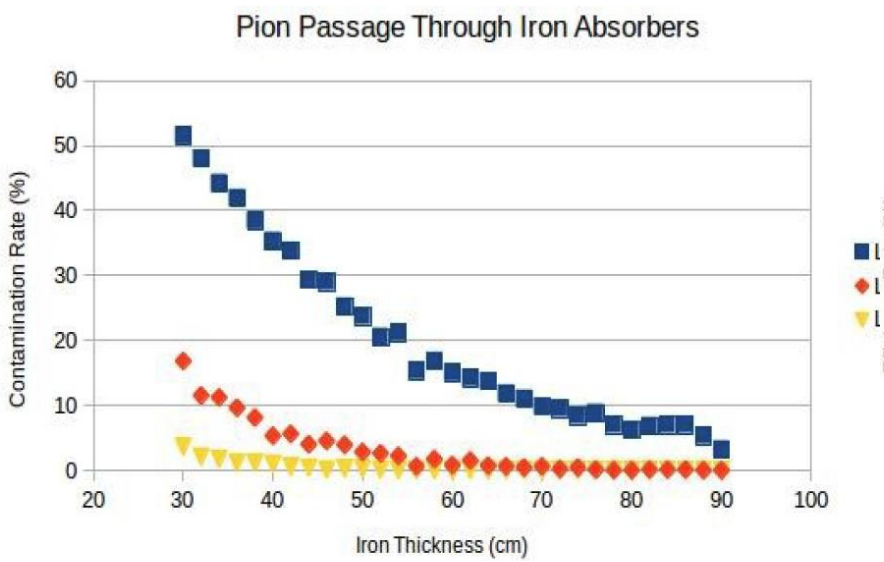
Detector acceptance

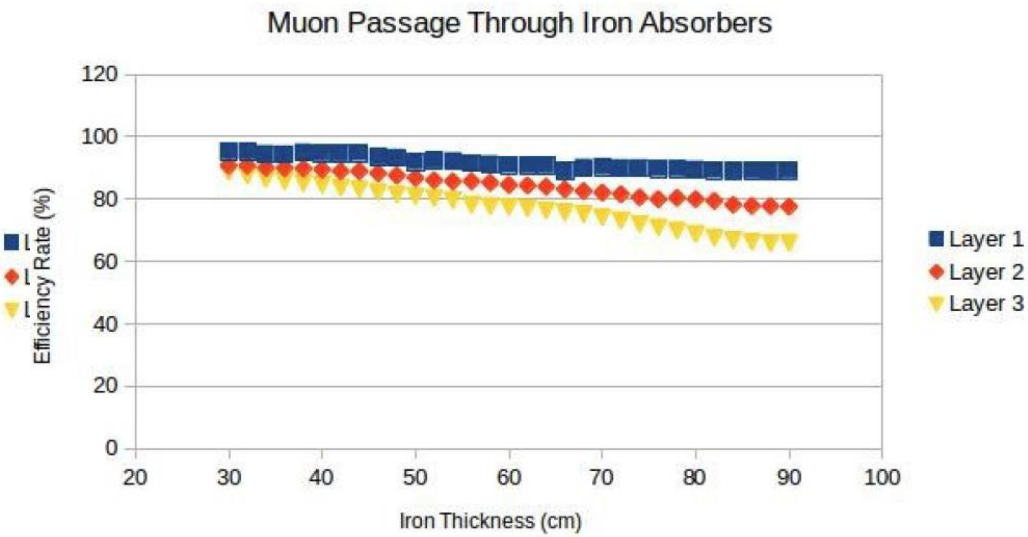


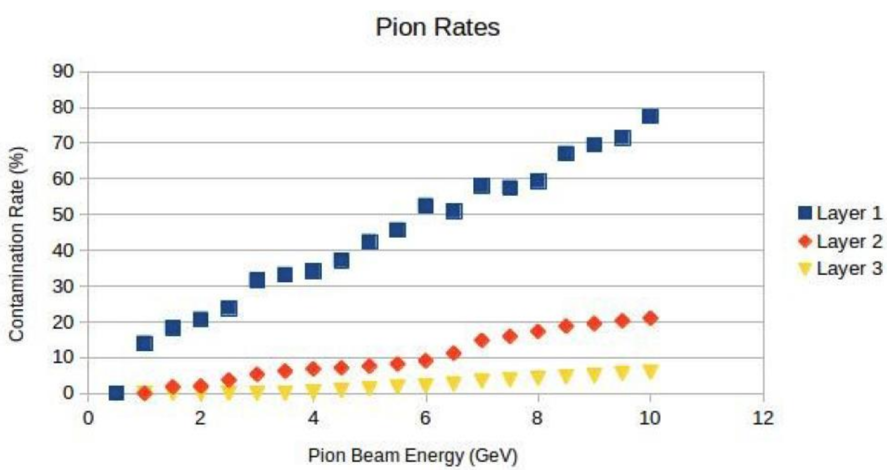
Kinematical coverage

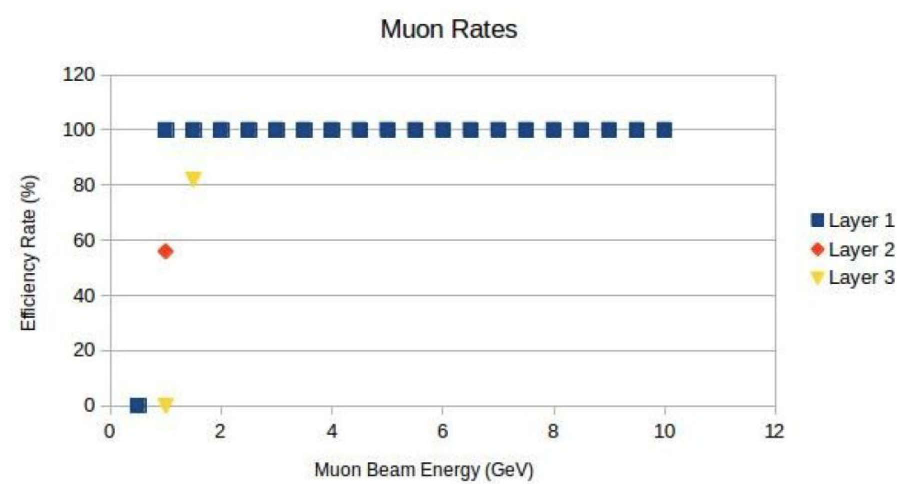


Muon Discrimination

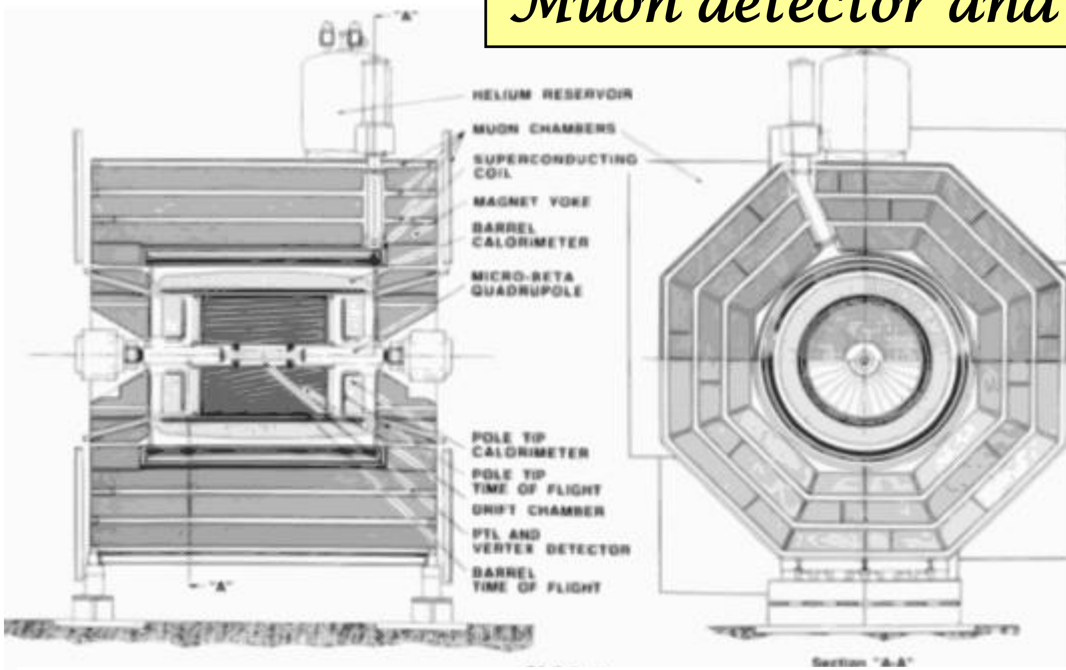








Muon detector and trigger



CLEO muons chambers as baseline detector

Larocci chambers

116 *D. Bortoletto et al. / Muon identification detector for CLEO II*

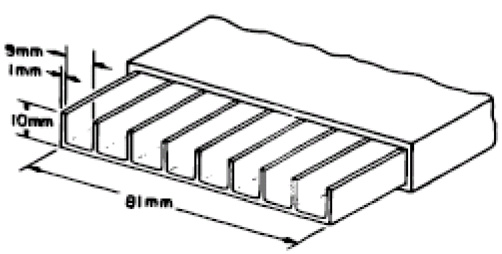


Fig. 2. Cross section of a plastic proportional counter.

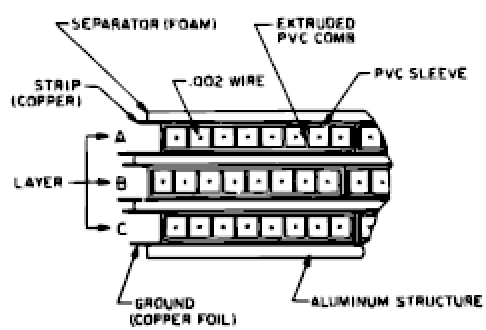
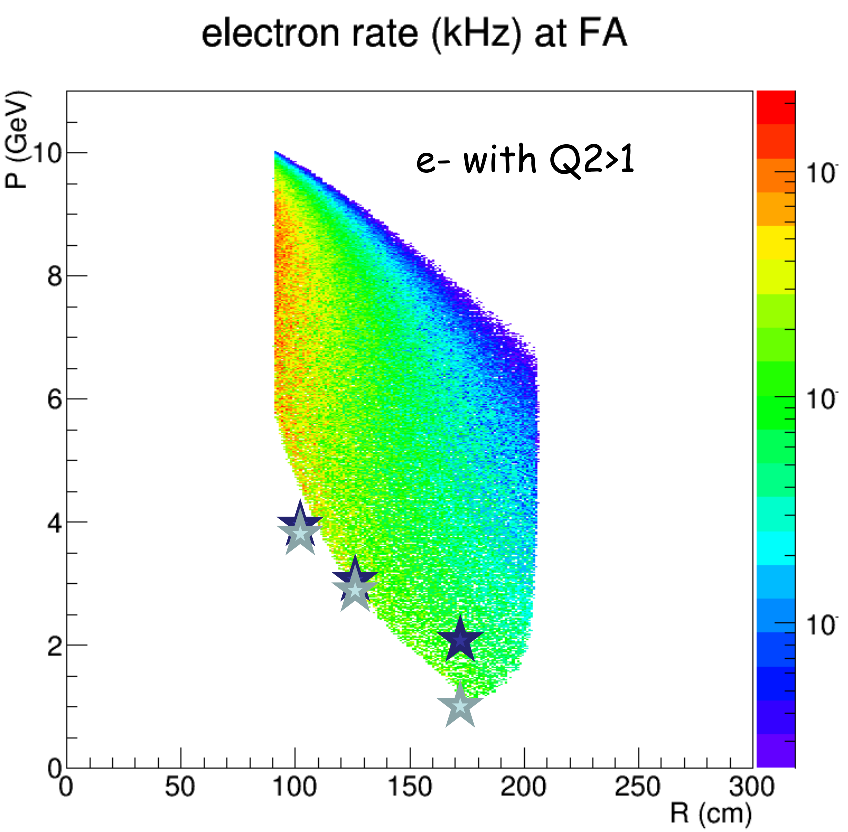
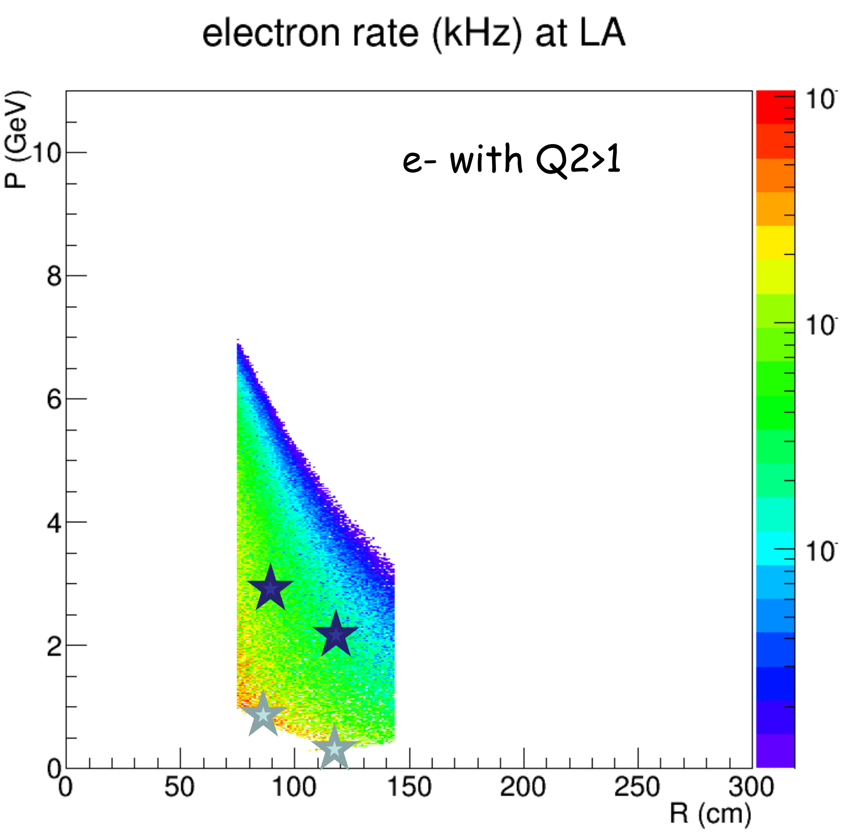


Fig. 3. Partial cross section of a unit, showing the slightly staggered three layers of counters, interleaved with foam boards carrying the copper pickup strips on one side and copper shield on the other.

Wire based trigger, look for coincidence between two planes

ele Trigger at EC





- Jpsi and TCS ele trigger (red): by FAEC with 4GeV (r=105-115cm), 3GeV (r=115-145cm) and 2GeV (r=145-235cm), by LAEC with 3GeV (r=80-100cm) and 2GeV (r=100-140cm)
- DDVCS ele trigger on Q2=1 (blue): by FAEC with 4GeV (r=105-115cm), 3GeV (r=115-145cm) and 1GeV (r=145-235cm), by LAEC with 1GeV (r=80-100cm) and 0.5GeV (r=100-140cm) (as we don't have 0.5GeV trigger curve for now, use 1GeV curve instead)

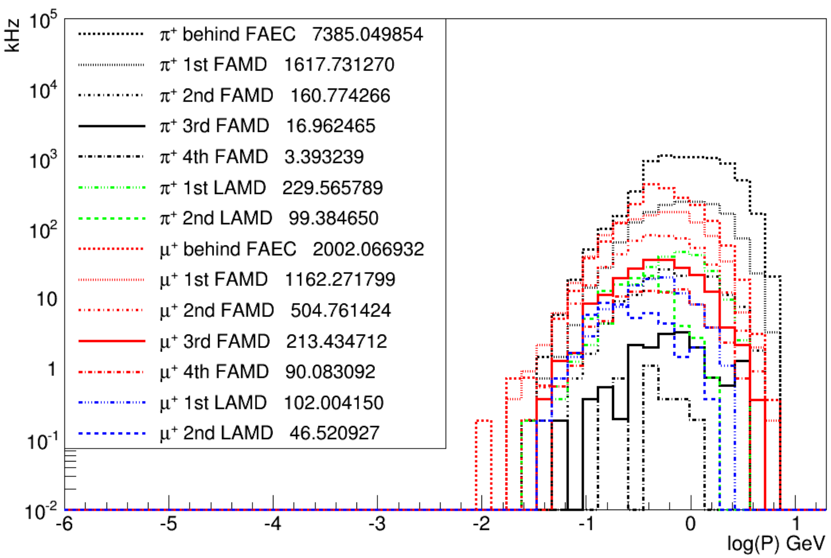
Muon trigger rate

- Muon Trigger (2nd FAMD+1st LAMD)^2
  (((161+284+505+869)+(230+162+102+144))*1e3)^2*30e-9/1e3=181kHz
- Muon Trigger (2nd FAMD)^2
  ((161+284+505+869)*1e3)^2*30e-9/1e3=100kHz
- Muon Trigger (3rd FAMD+1st LAMD)^2
  (((17+29+213+379)+(230+162+102+144))*1e3)^2*30e-9/1e3=49kHz
- Muon Trigger (3rd FAMD)^2
  ((17+29+213+379)*1e3)^2*30e-9/1e3=12kHz
- Muon Trigger (4th FAMD+1st LAMD)^2
  (((4+5+90+157)+(230+162+102+144))*1e3)^2*30e-9/1e3=24kHz
- Muon Trigger (4th FAMD)^2
  ((4+5+90+157)*1e3)^2*30e-9/1e3=2kHz

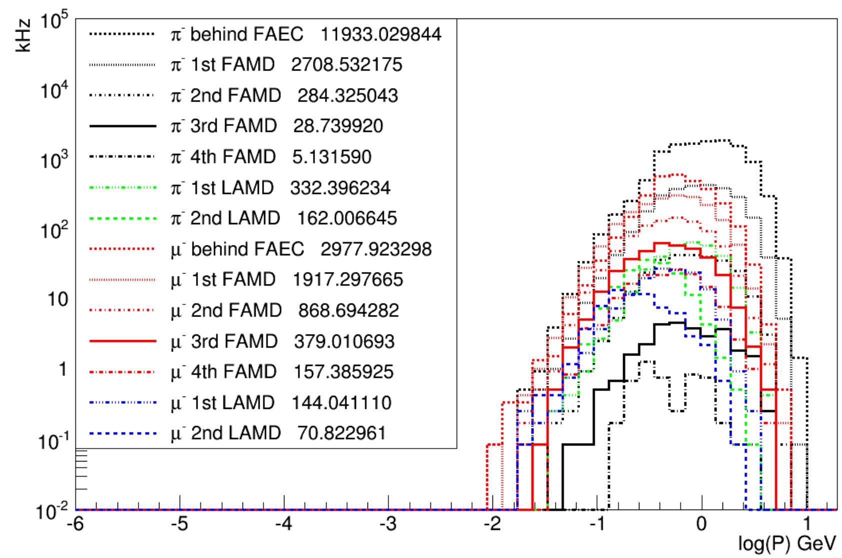
Use “HallD” pion generator instead of “Wiser”

1st LAMD is before LGC, 2nd LAMD is previous 1st LAMD
Simulation JLAB_VERSION 1.3 instead of 1.2

background, from π^+ at target



background, from π^- at target

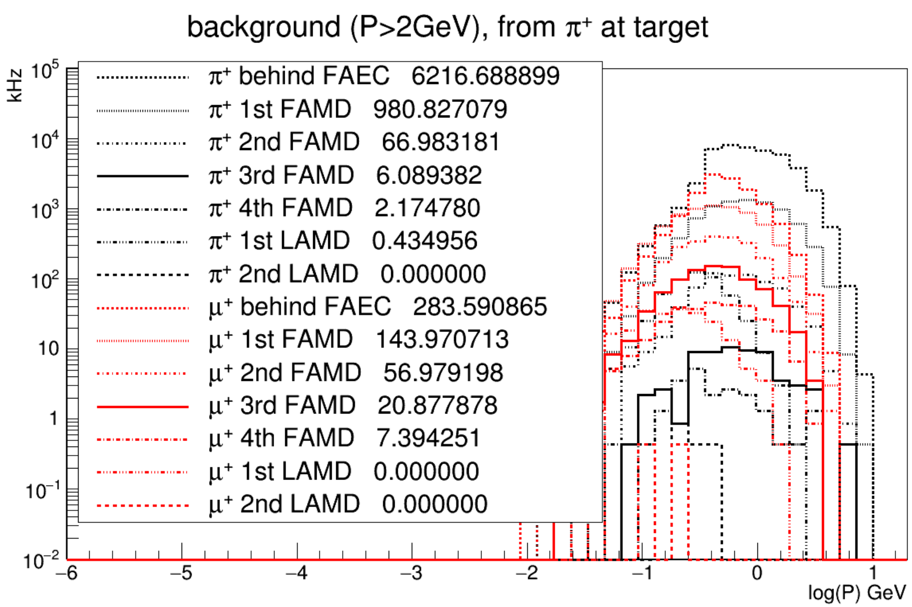


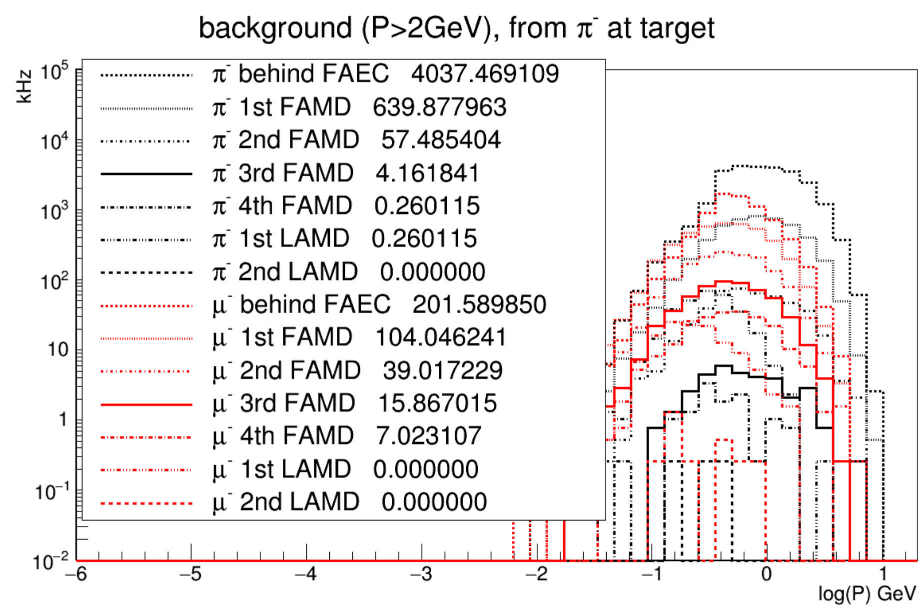
Random coincidence background

- At 4th FAMD, pip(2.2kHz), pim(0.26kHz), muonp(7.4kHz),muonm(7.0kHz)
- Two hadron 6ns time coincidence (2.2+7.4)*1e3*(0.26+7.0)*1e3*6e-9=0.418Hz
- Then hadron and ele 6ns time coincidence (520)*1e3*(0.418)*6e-9=0.0013Hz
- Then vertex cut between 3 particles. 0.0013/3/3=0.000145Hz

Time resolution 1ns, 6 sigma cut is 6ns
Vertex resolution 0.75cm, 6 sigma cut 5cm, factor 3 reduction for 15cm long target

Cut with P>2 GeV because BH muon has P>2GeV at 4th FAMD



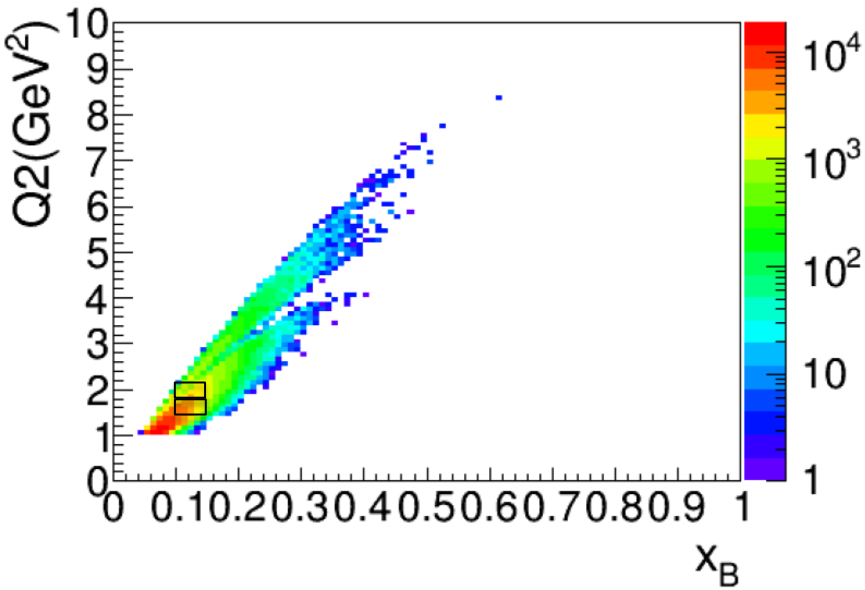


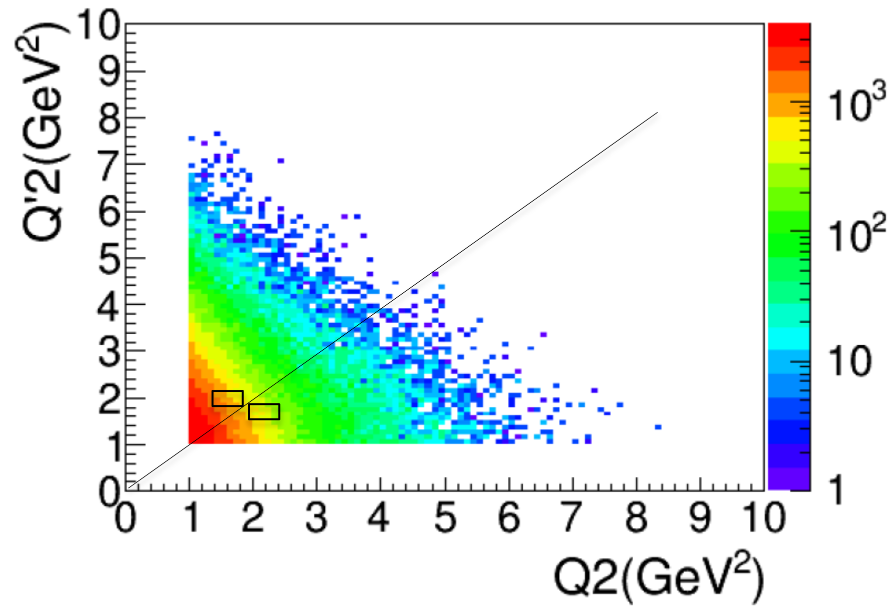
Signal to background

- BH signal 0.126Hz at 3rd FAMD
- Signal/(random coincidence background)=0.126/0.00762=17

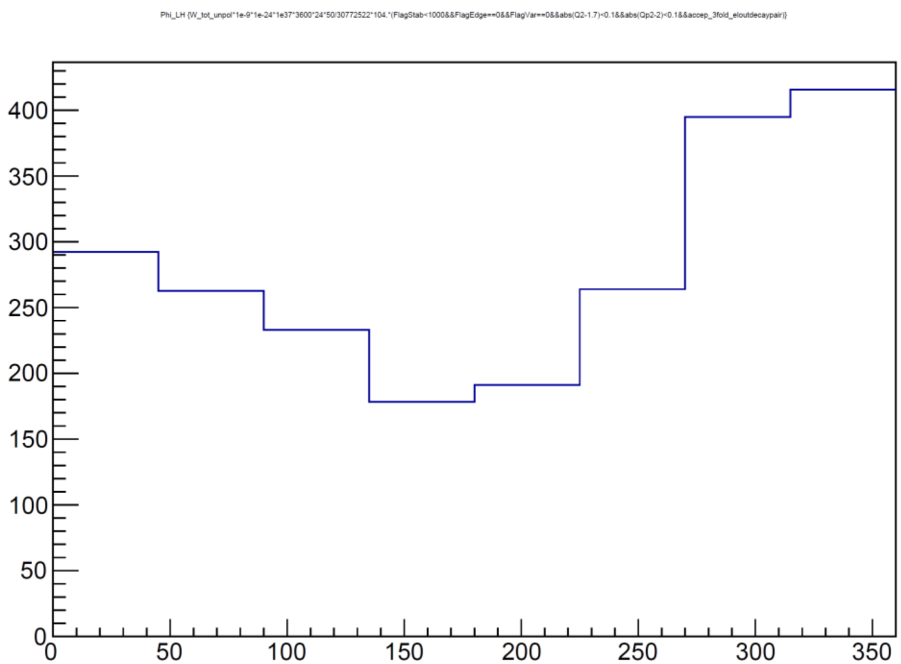
- BH signal 0.084Hz at 4th FAMD
- Signal/(random coincidence background)=0.084/0.000145=579

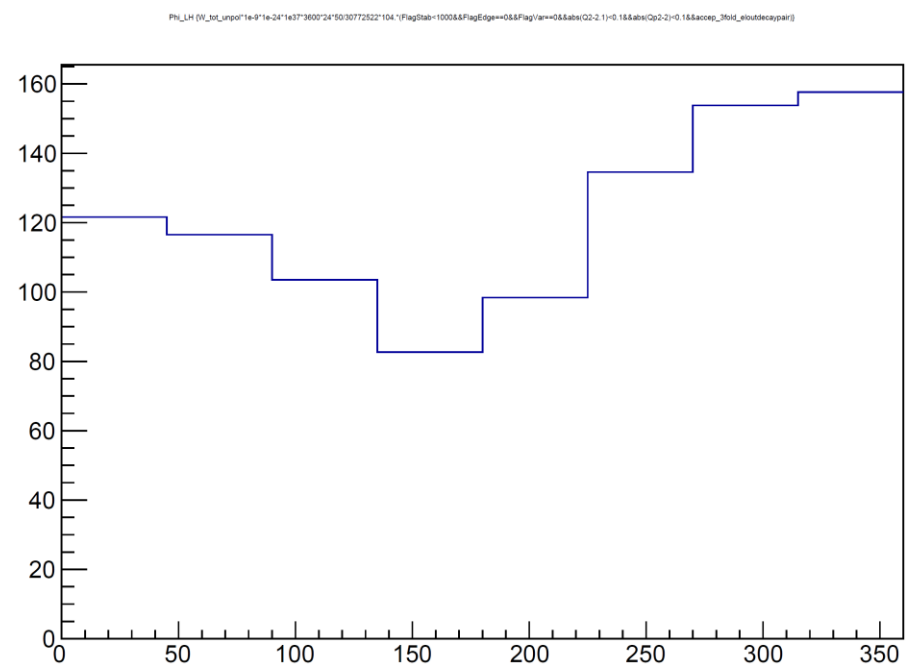
Expected Results





Expected Results





Two bins : 8 bins in Phi

$Q^2 > Q'^2$: 2.0 $GeV^2 < Q^2 < 2.2$ GeV^2 1.9 $GeV^2 < Q^2 < 2.1$ GeV^2

$Q^2 < Q'^2$: 1.6 $GeV^2 < Q^2 < 1.8$ GeV^2 1.9 $GeV^2 < Q^2 < 2.1$ GeV^2

Asymmetries from 5 to 10 %

Optimizing kinematic and binning

Conclusion

- Addition of **muon detection** capabilities based on the CLEO muon detector is a good opportunity for the **SoLID** performances.
- It will allow investigation of the experimentally unknown **DDVCS** reaction channel, of importance for the **partonic tomography** of the nucleon.
- It will enhance the **statistical reach** of the **J/ψ** experiment, and will contribute to the **physics impact** of the **J/ψ SoLID run-group**.

The **DDVCS** experiment would run with a **specific trigger**, and **parasitically** to the **J/ψ experiment**.

ECT workshop dedicated to dileptons production with dedicated session on muon DDVCS
October 24th to 28th 2016
Study $Q'^2 > Q^2$ kinematical range (not clear GPDs)

To do list

- Optimize kinematic and binning
- Check event generator
- Check two pions background
- Missing mass resolution