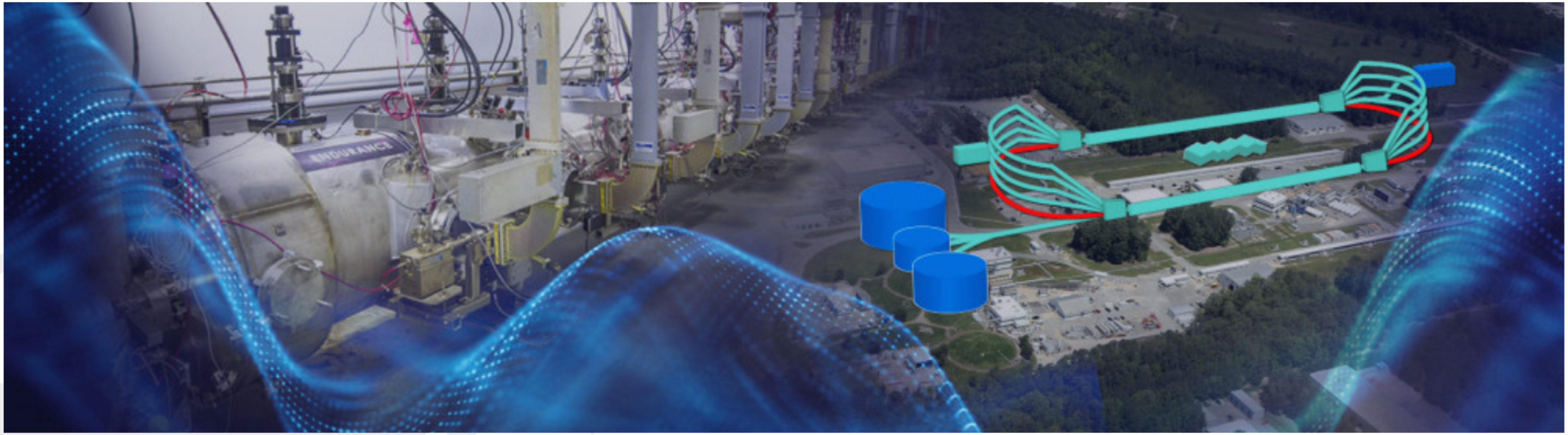
Prospects of DVCS @ 22GeV at JLab



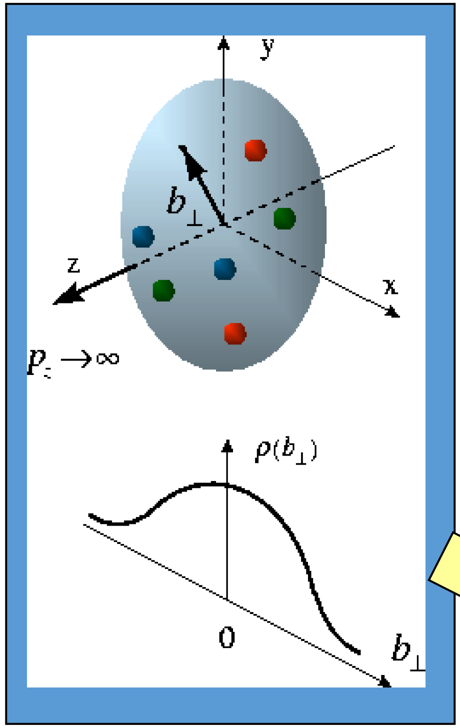
SCIENCE AT THE LUMINOSITY FRONTIER: JEFFERSON LAB AT 22 GEV

Volker Burkert, Jefferson Lab

January 23, 2023 to January 25, 2023

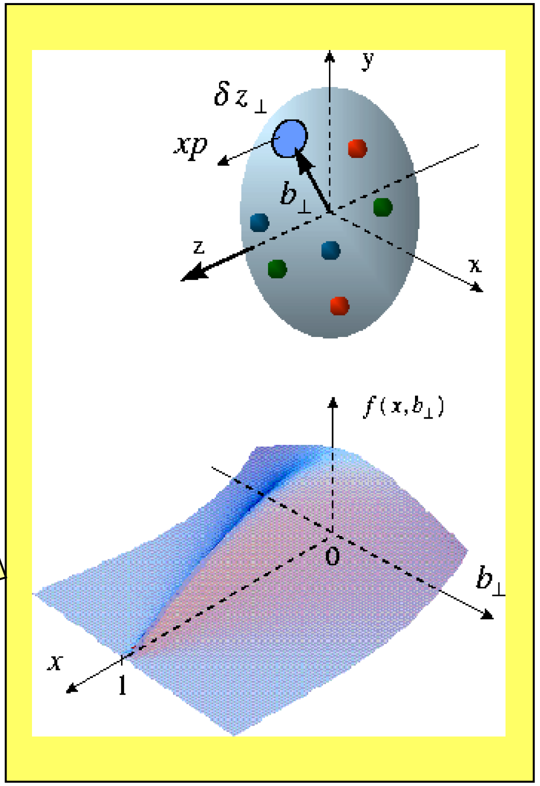
GPDs and 3D Imaging of Nucleons

Last 70 years



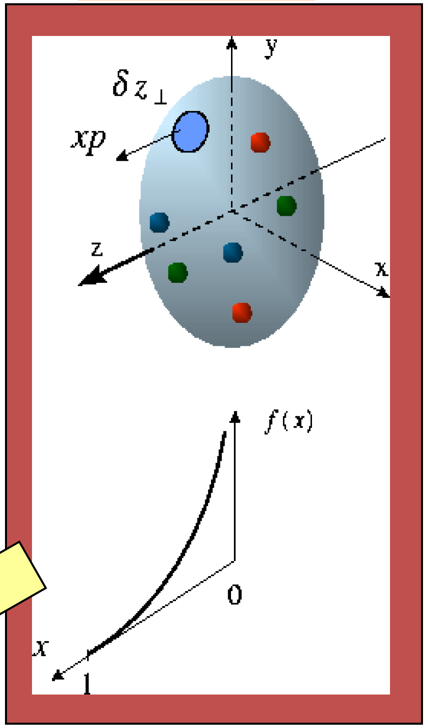
Elastic form factors → Transverse charge & current densities $F_1(t)$, $F_2(t)$.

Last 20 years



Deeply exclusive processes → GPD's and (2+1)D images in transverse space and longitudinal momentum.
4 chiral even GPDs H, E, H̃, Ẽ (x,ξ,t)

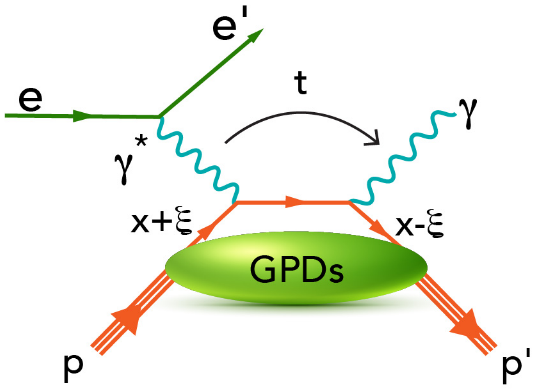
Last 55 years



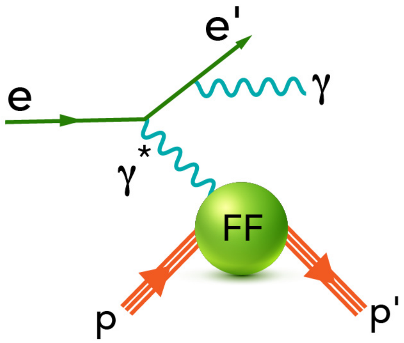
DIS structure functions → Longitudinal parton momentum & helicity densities, $F_2(x)$, $g_1(x)$.

DVCS +BH - path to probing GPDs (CFFs)

DVCS



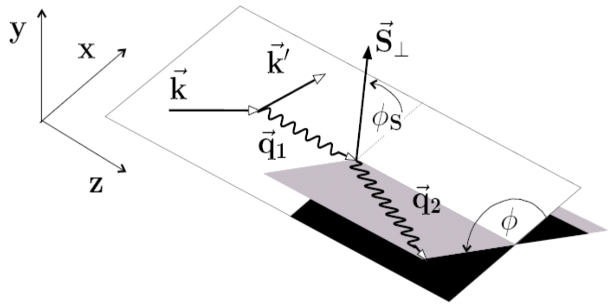
BH



Interference

$\xi \sim x_B/(2-x_B)$

$k = t/4M^2$



Polarized beam, **unpolarized** target:

$\Delta\sigma_{LU} \sim \sin\phi \; \mathrm{Im}\{F_1 H + \xi(F_1+F_2)\tilde{H} + kF_2 E\}d\phi$ ⟹ $H(\xi,t)$

Unpolarized beam, **longitudinal** target:

$\Delta\sigma_{UL} \sim \sin\phi \; \mathrm{Im}\{F_1\tilde{H}+\xi(F_1+F_2)(H+\xi/(1+\xi)E)\}d\phi$ ⟹ $\tilde{H}(\xi,t)$

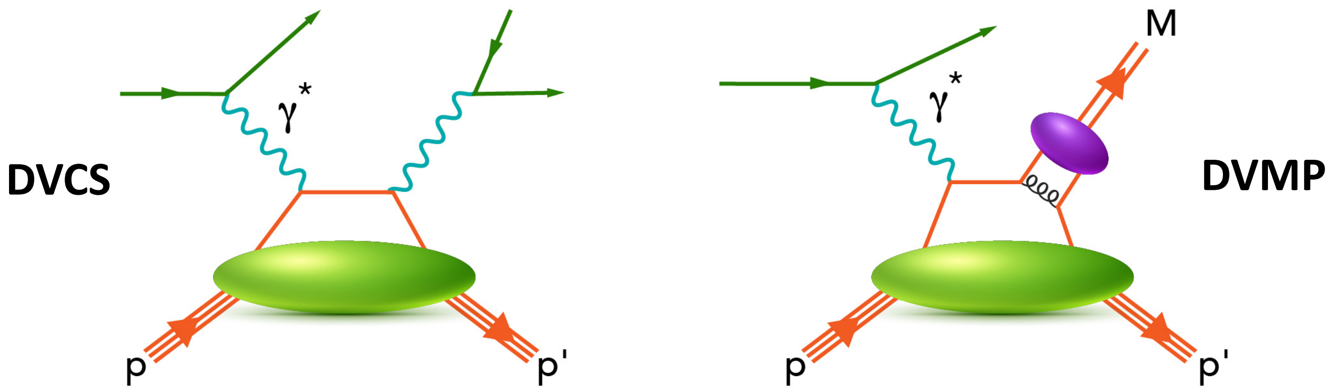
Unpolarized beam, **transverse** target:

$\Delta\sigma_{UT} \sim \cos\phi \; \sin(\phi_s-\phi)\mathrm{Im}\{k(F_1 E - F_2 H)\}d\phi$ ⟹ $E(\xi,t)$

Unpolarized cross section:

Re(CFFs), separate h.t. contributions to DVCS ⟹ $\mathcal{Re}(T^{DVCS})$

Observables sensitive to GPDs/CFFs



	$\mathcal{I}m$	$\mathcal{R}e$
$\mathcal{H}$	A_{LU}	σ
$\tilde{\mathcal{H}}$	A_{UL}	A_{LL}, A_{LT}
$\mathcal{E}$	A_{UT}	

	Meson	Flavor
$\mathcal{H},\mathcal{E}$	ρ^+	$u-d$
	ρ^0	$2u+d$
	ω	$2u-d$
	ϕ	g

Enables flavor separation of GPDs

Prospects - Hall A/C

- There have been no specific DVCS estimates for Hall A/C for the July/September meetings or after that.

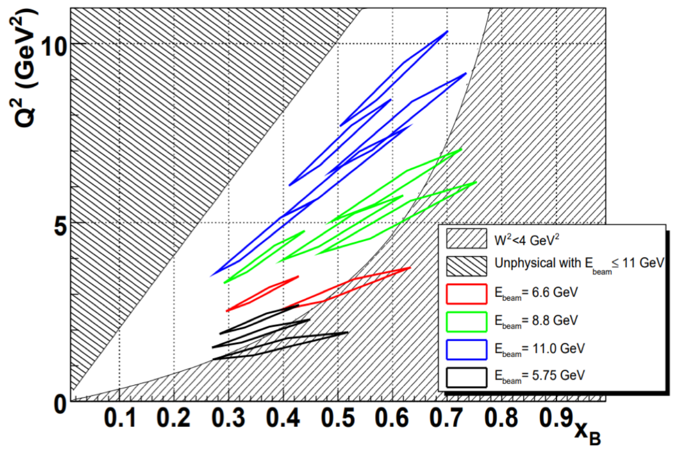
- With respect to 11 GeV kinematics, at 22 GeV phase space is roughly extended by a factor of 2 in Q^2 (**no significant differences in x_B and** t).

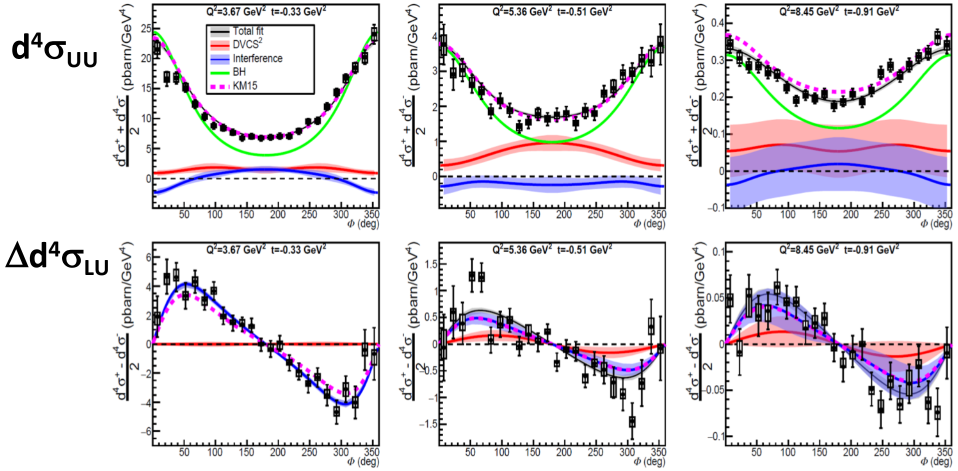
- **The full 11 GeV program can be done at 22 GeV at a higher value of Q^2.**

(from: Carlos Munoz Camacho)

Hall A data from Jlab@12 program

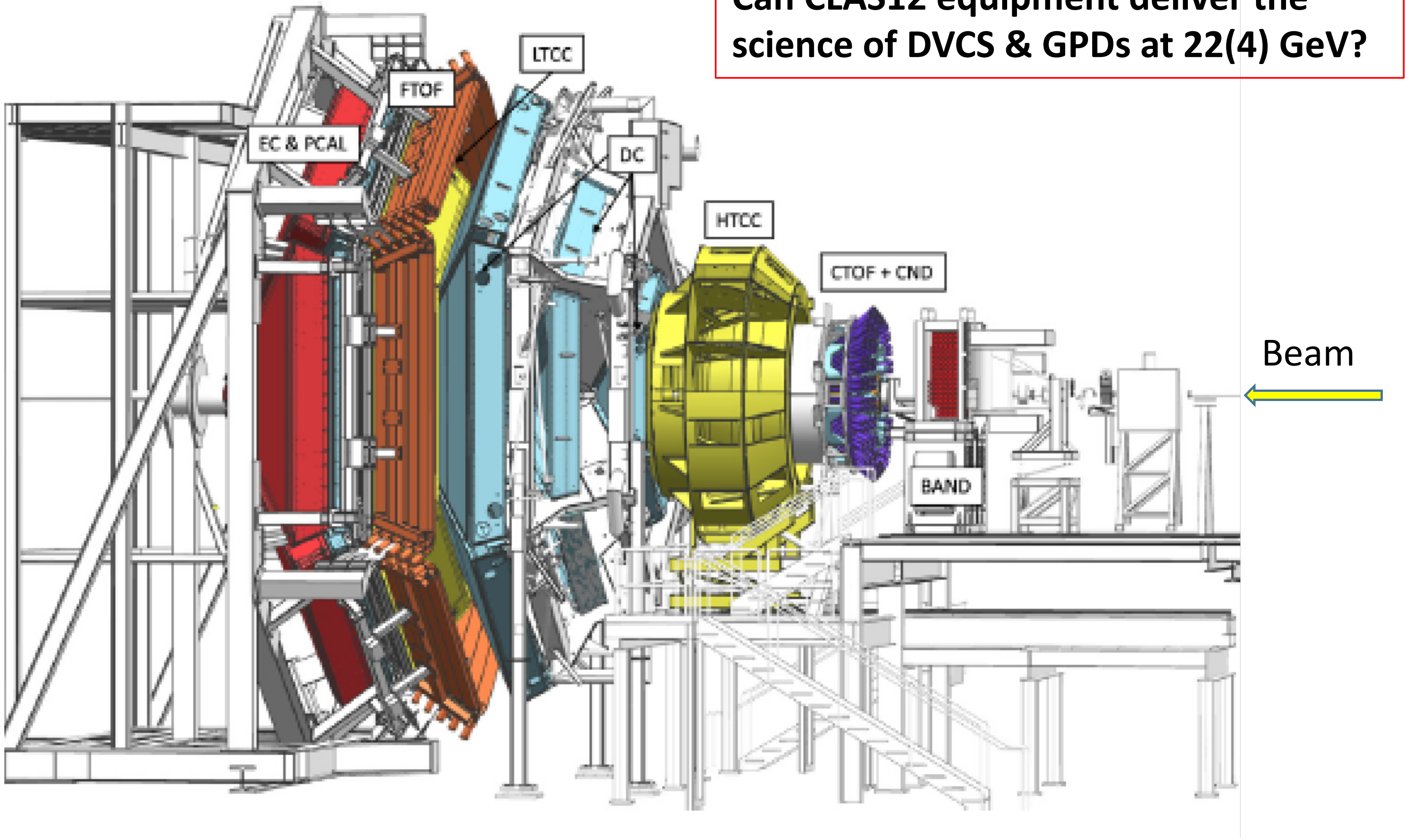
Explore high x_B region for the first time





Phys. Rev. Lett. 128 (2022) 25, 252002

The CLAS12 Spectrometer at Jefferson Lab



Can CLAS12 equipment deliver the science of DVCS & GPDs at 22(4) GeV?

Baseline equipment

Forward Detector (FD)

- TORUS magnet (6 coils)
- HT Cherenkov Counter
- Drift Chamber System
- LT Cherenkov Counter
- Forward ToF System
- Pre-Shower Calorimeter
- E.M. Calorimeter

Central Detector (CD)

- SOLENOID magnet (5T)
- Central Tracker (SVT, MM)
- Central Time-of-Flight
- Central Neutron Detector

Beamline

- Liquid & solid targets
- Moller Polarimeter
- Photon Energy Tagger

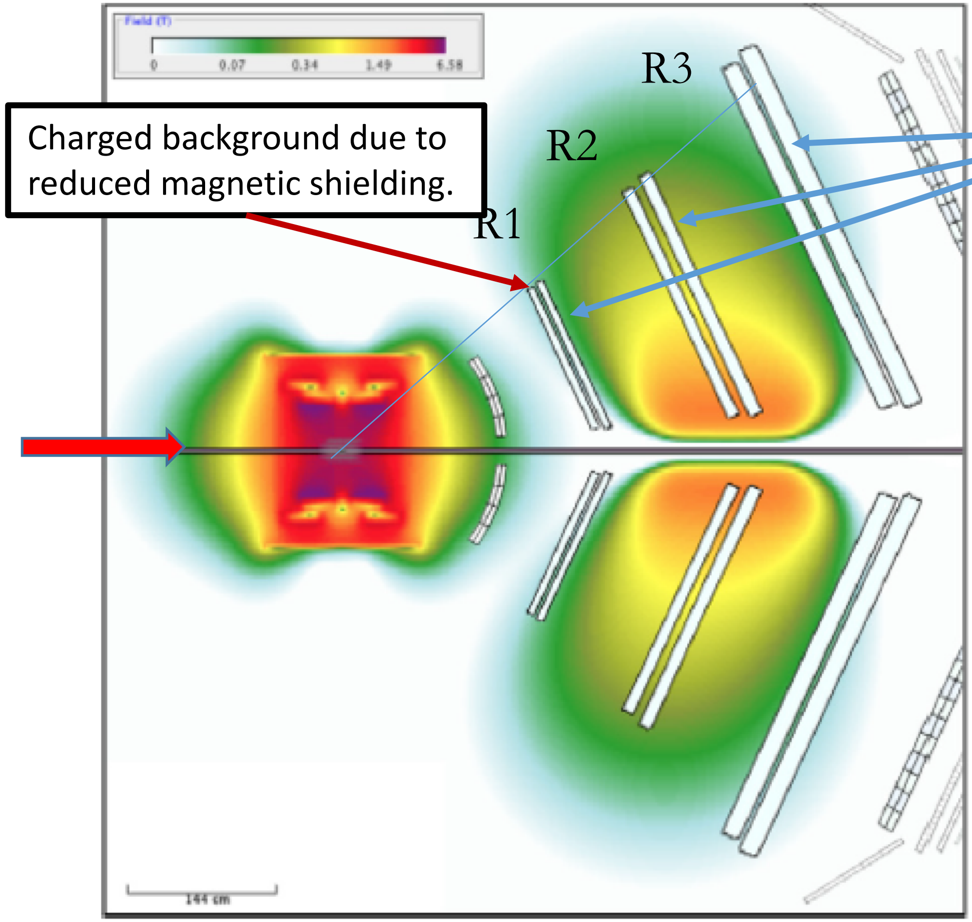
Ancillary equipment

- RICH Detector 2 sectors
- Polarized Target (long.)

Nuclear Inst. and Methods in Physics Research, A 959 (2020) 163419 + 17 articles on all subsystems.

Can CLAS12 @ 22GeV operate at 11 GeV luminosities?

- CLAS12 luminosity limited by accidental occupancy of DC R1.



High occupancy in part of R1 limits acceptable operating luminosity.

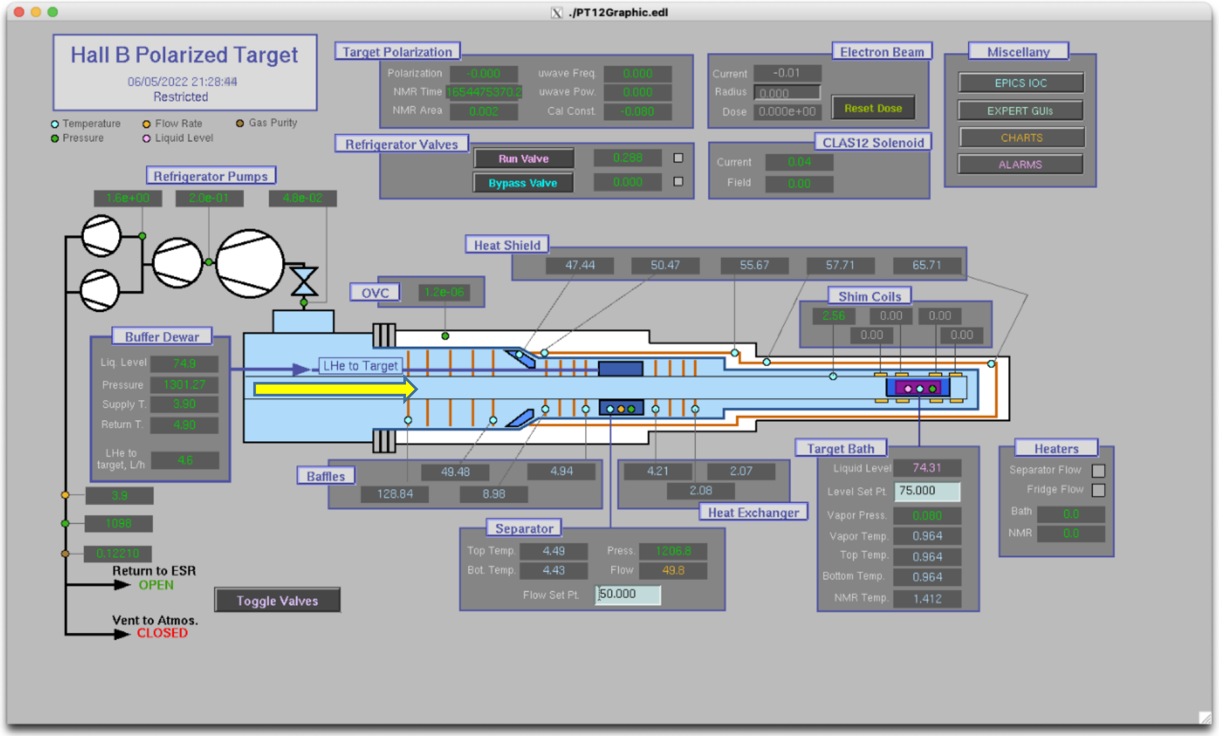
	R1	R2	R3
CLAS12 @ 11 GeV	**2.6%**	**0.76%**	**1.18%**
CLAS12 @ 24 GeV	**2.8%**	**0.77%**	**1.23%**

Accidental occupancies increase by less than 10% at 24 GeV compared to 10.6 GeV.
➔ **higher resolution tracking layers to double luminosity.**

Z. Meador, L. Elouadrhiri

Polarized targets for CLAS12

Target in use to measure DVCS and all other processes on longitudinal polarized protons and deuterons(neutrons).



Exploits full acceptance of the CLAS12 configuration

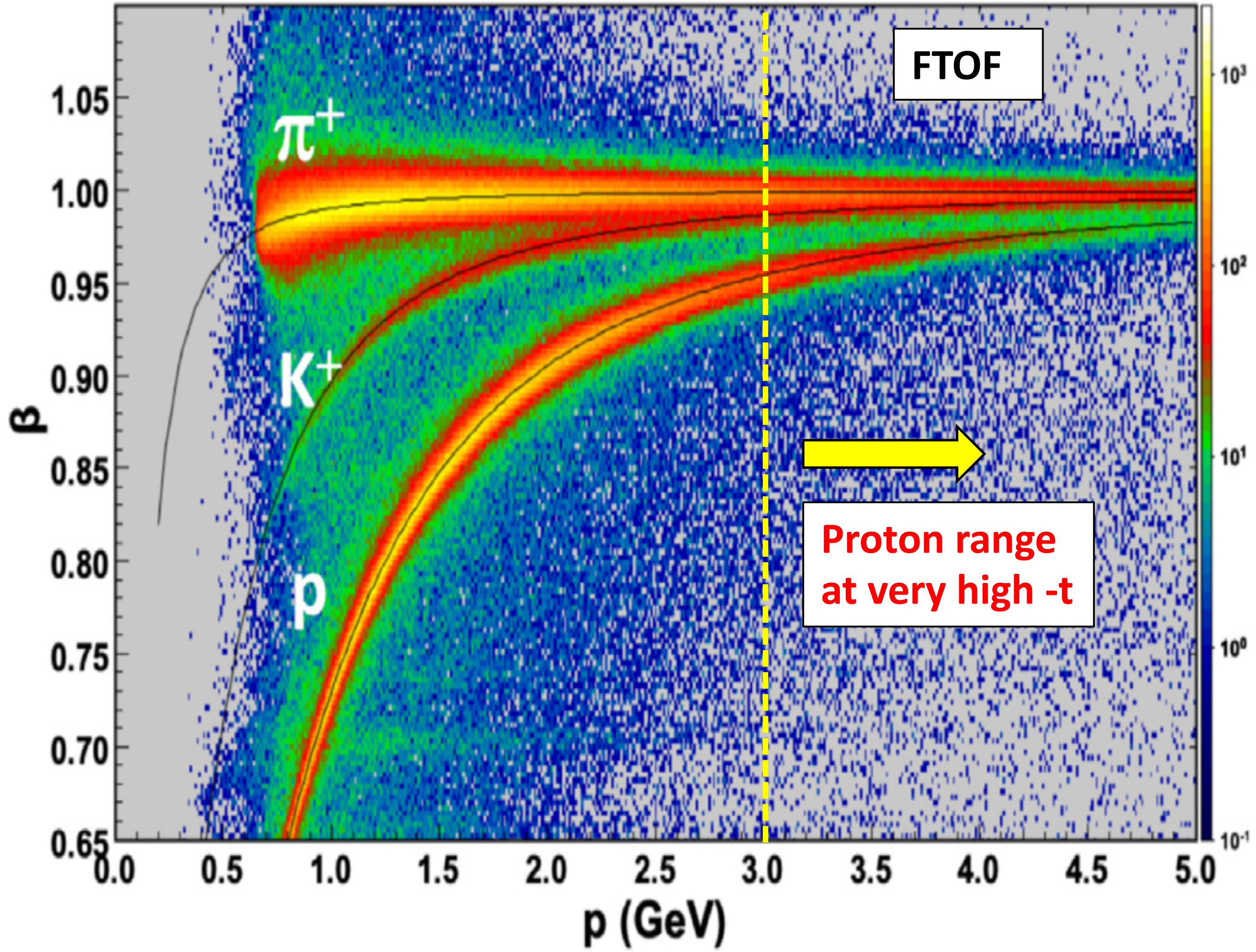
Longitudinal polarized target operational with full CLAS12 acceptance in operation.

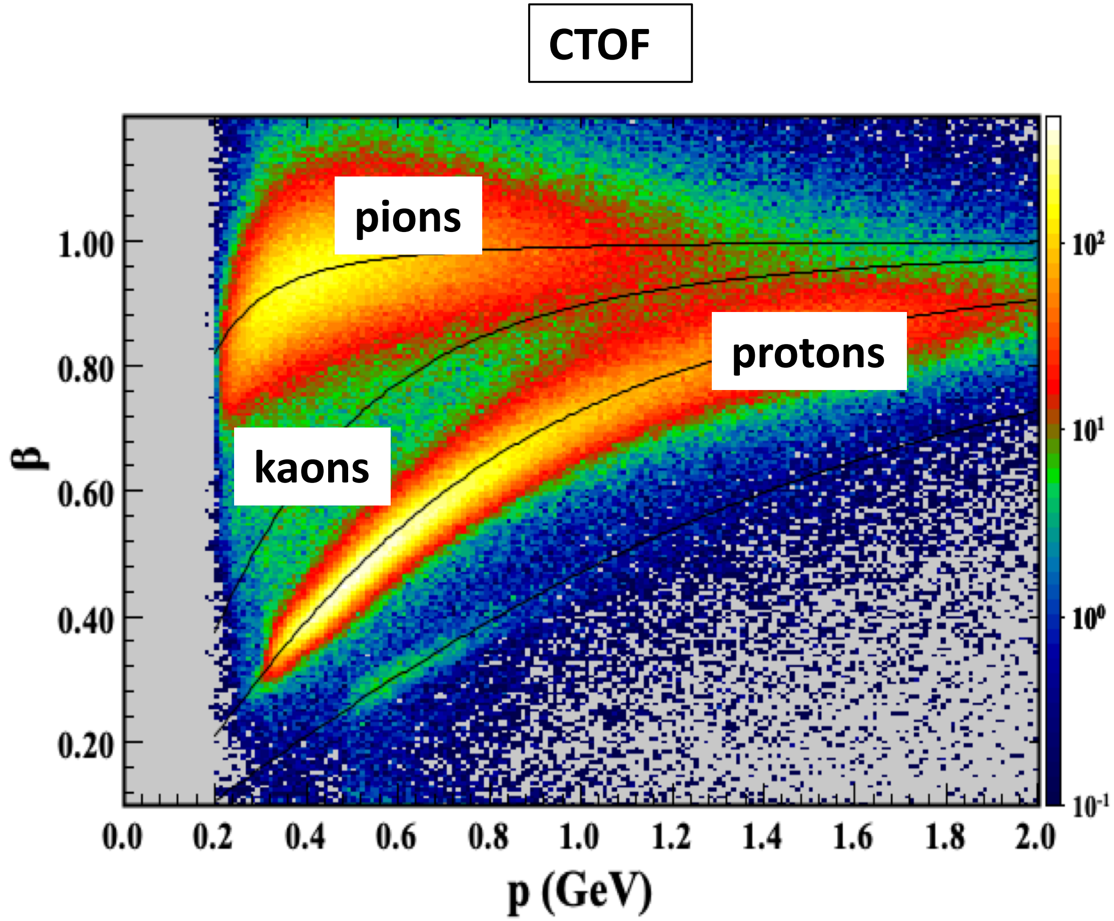
$$\Delta\sigma_{UL} \sim \sin\phi \; \mathrm{Im}\{F_1\widetilde{\mathcal{H}}+\xi(F_1+F_2)(\mathcal{H} +\xi/(1+\xi)\mathcal{E})\}d\phi$$

Transverse polarized target in development for CLAS12 experiments. Access GPD *E* in Ji sum rule.

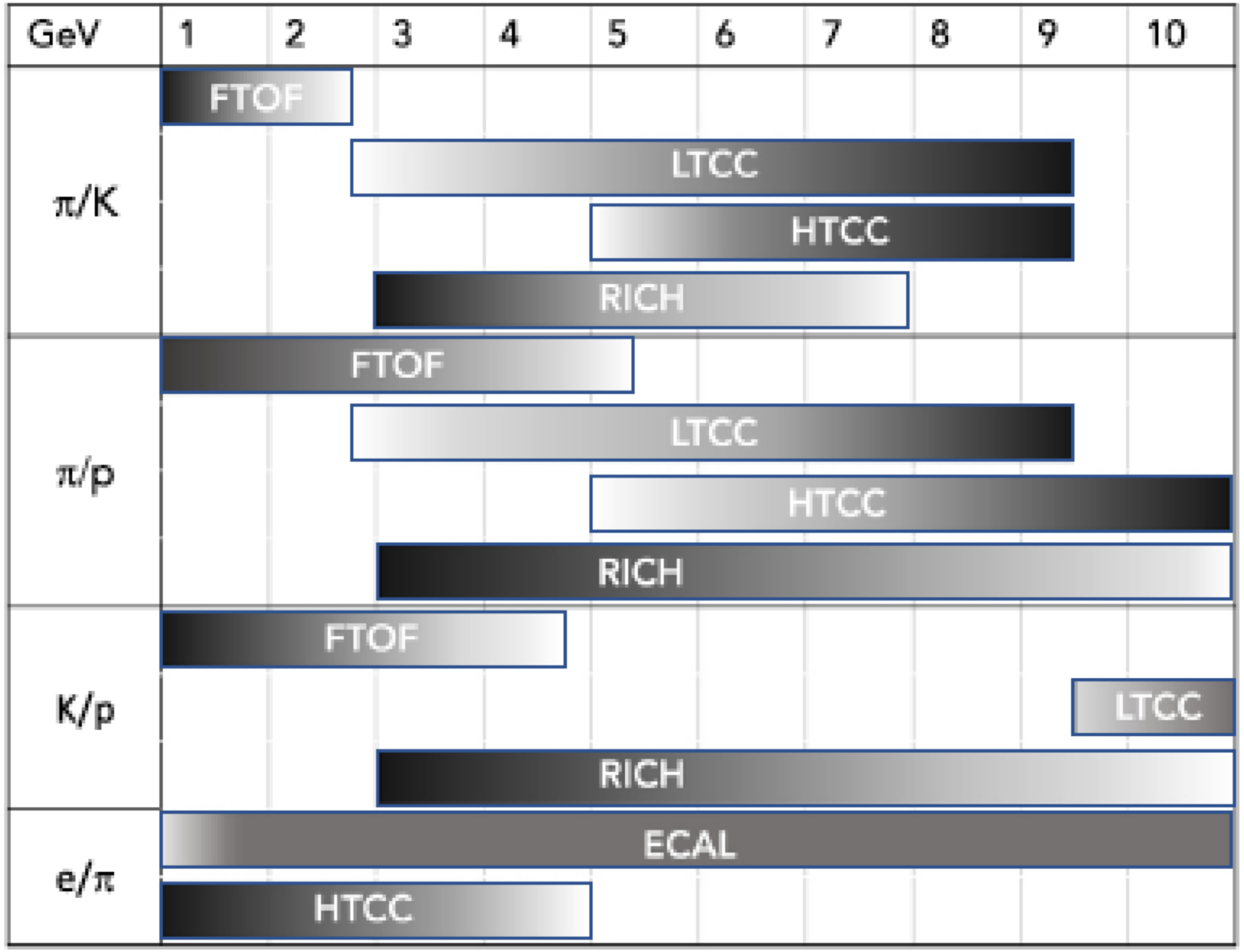
$$\Delta\sigma_{UT} \sim \cos\phi \; \sin(\phi_s-\phi)\mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E})\}d\phi$$

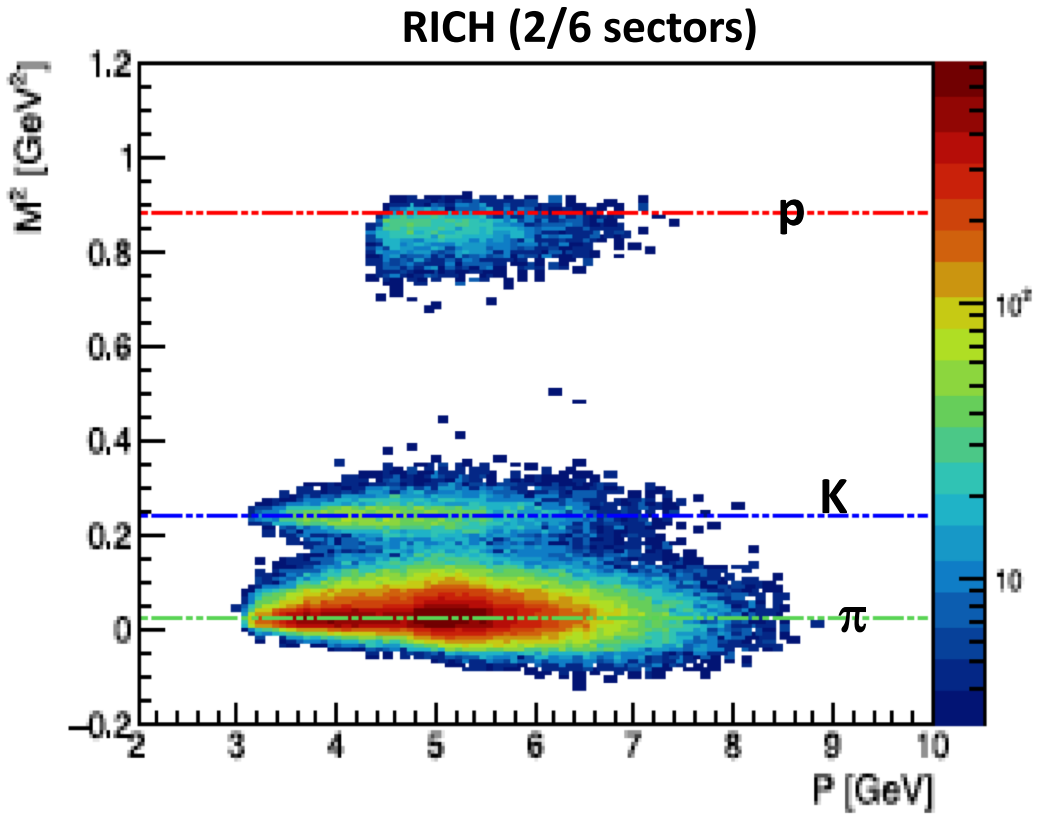
CLAS12 Charged Particle Identification in FTOF & CTOF





Particle ID in CLAS12 (forward)



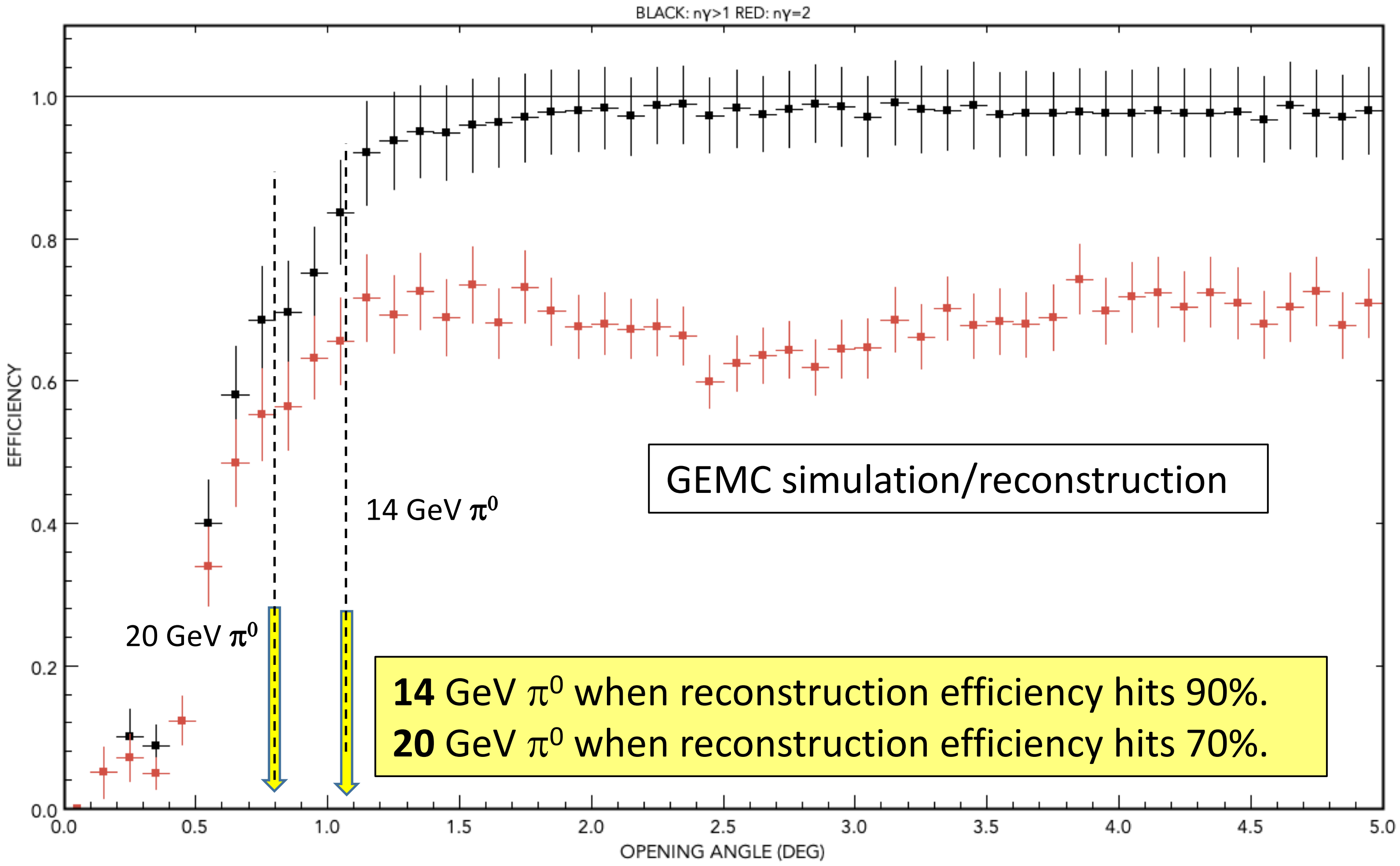


π^o and γ detection in ECAL

C. Smith

π^0 production is the largest background to DVCS.

- 1γ escapes detection
- 2γ merge to appear as 1γ at highest energy



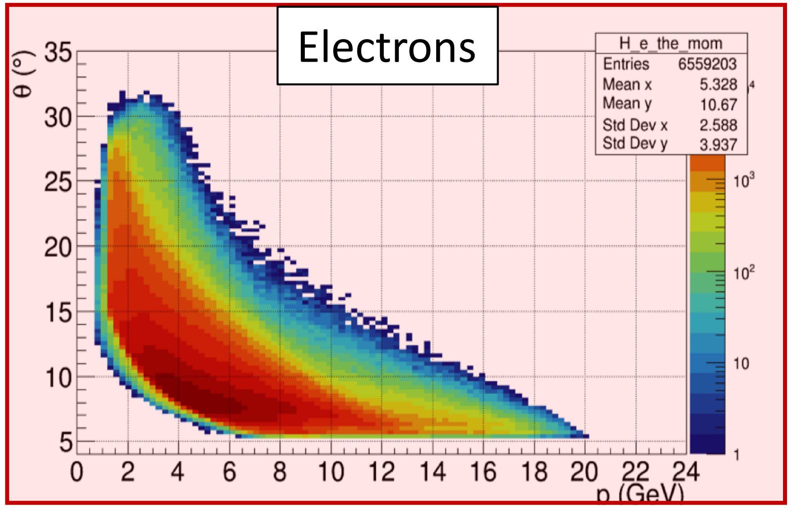
2 or more photons are reconstructed

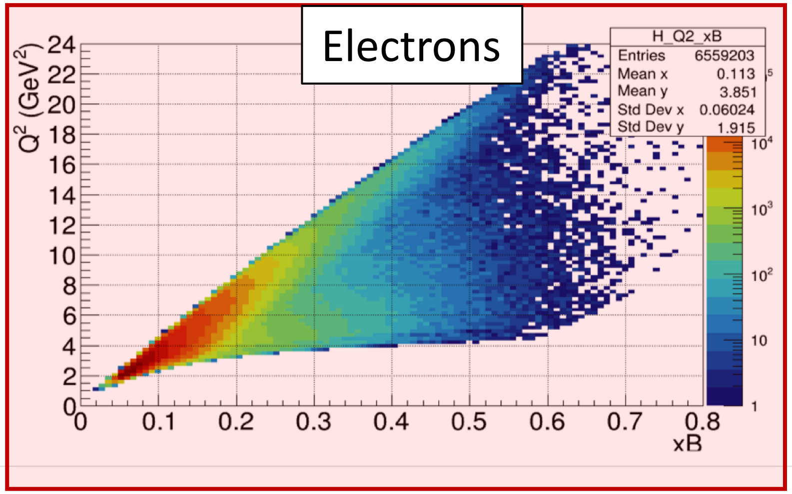
Exactly 2 photons are constructed

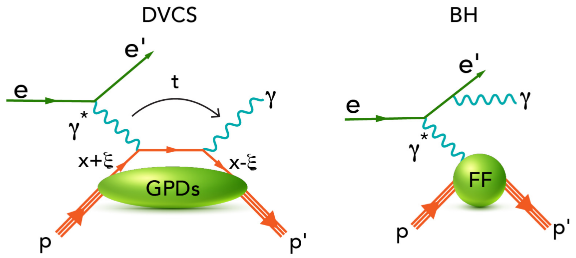
- At 24 GeV beam energy most π^0 events will be reconstructed in ECAL.

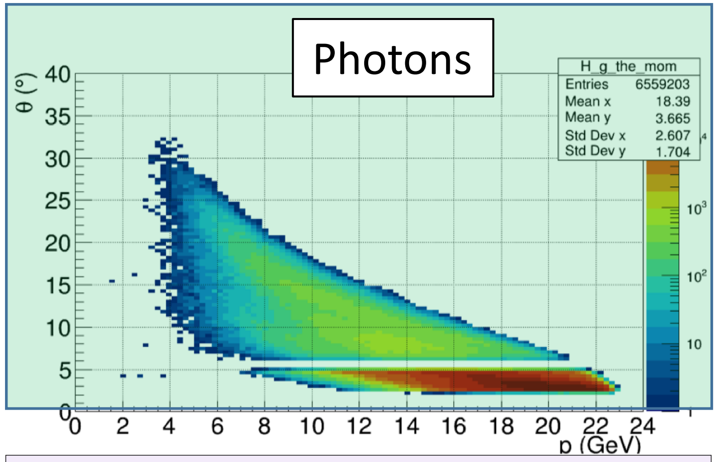
DVCS @ 24 GeV – electron – photon – proton detection

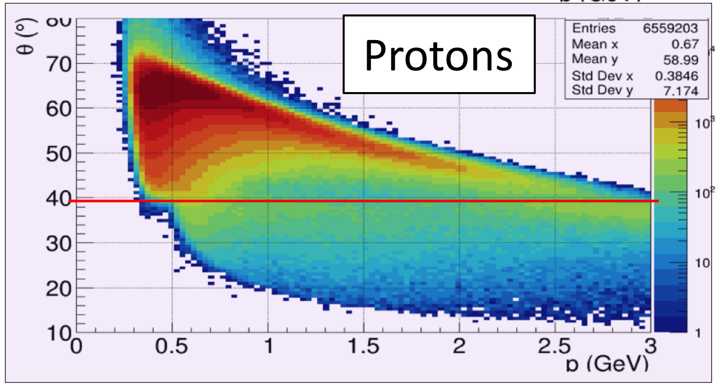
F.X. Girod

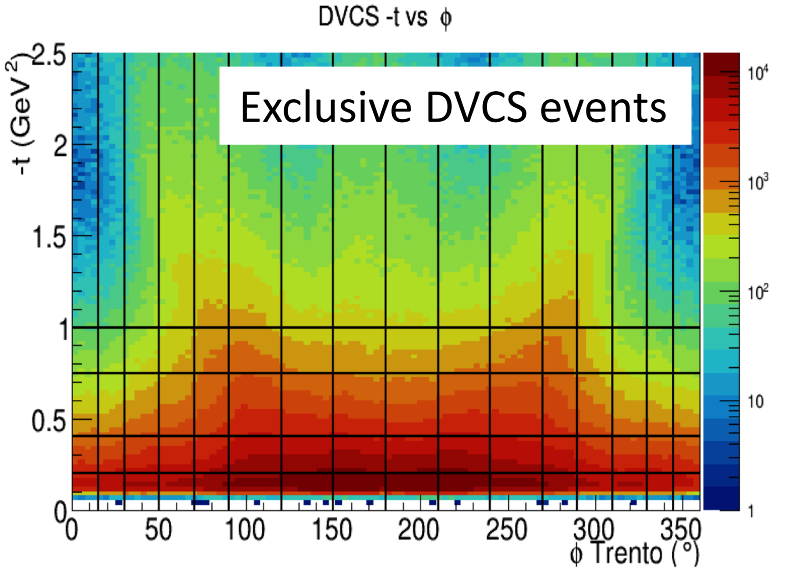


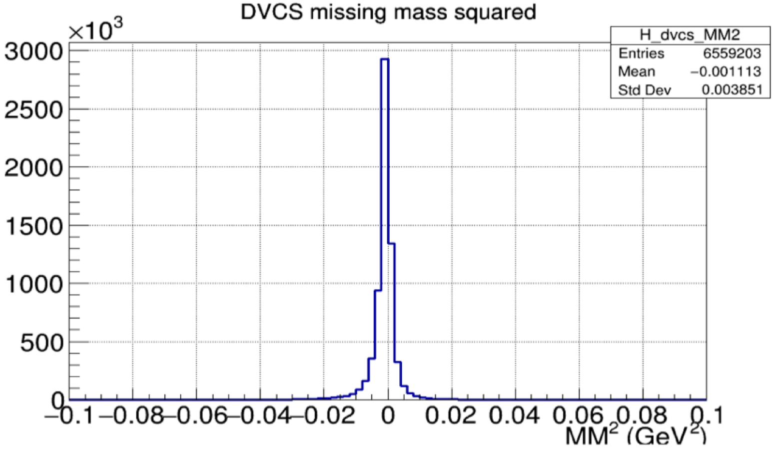










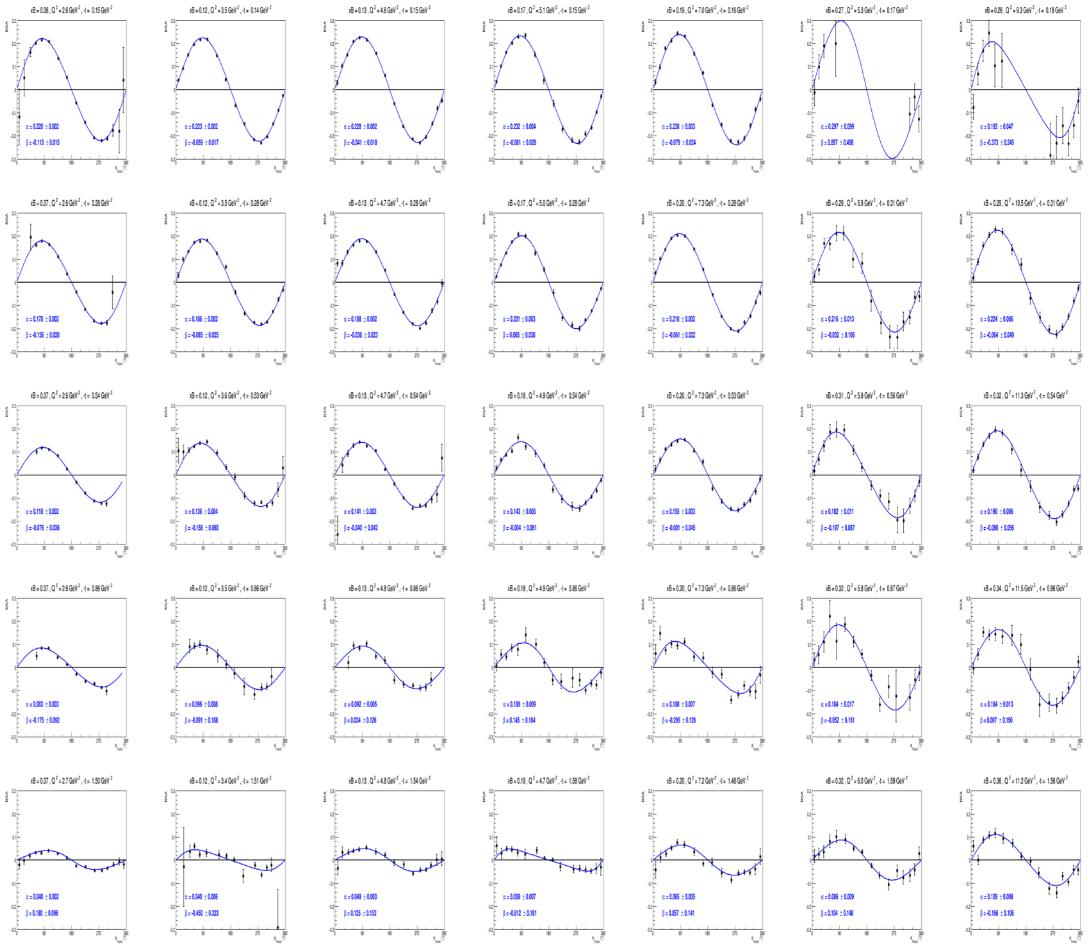


Beam spin asymmetry A_{LU} (E=24GeV)

From full simulations & reconstructions

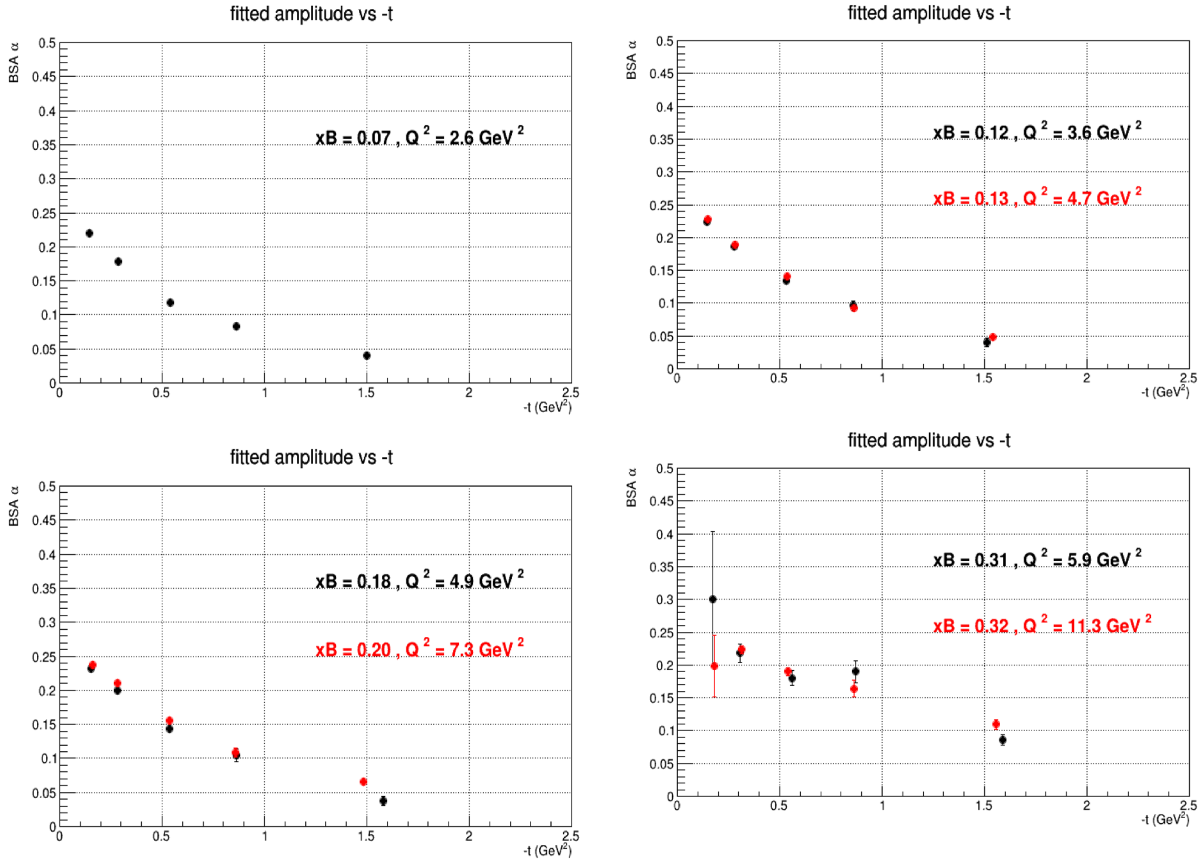
$2.6 < Q^2 < 11.5$ GeV^2

$0.15 < -t < 1.6$ GeV^2



$0.07 < x_B < 0.36$

$A_{LU} = \alpha \sin\phi / (1 + \beta \cos 2\phi)$



F.X. Girod

3D imaging of quarks in the proton

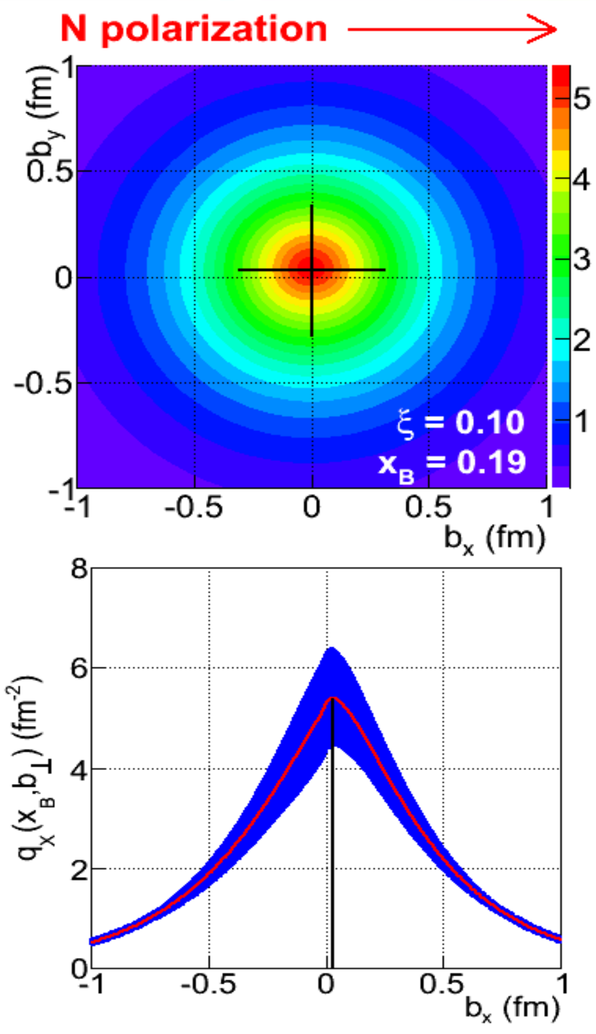
Analysis from simulated data (VGG) with CLAS12 response (11GeV).

From the **DVCS cross section and polarization observables** the Compton Form Factors $\mathcal{H}(\xi,t)$, $\mathcal{E}(\xi,t)$ may be determined at **fixed values of ξ versus *t*.**

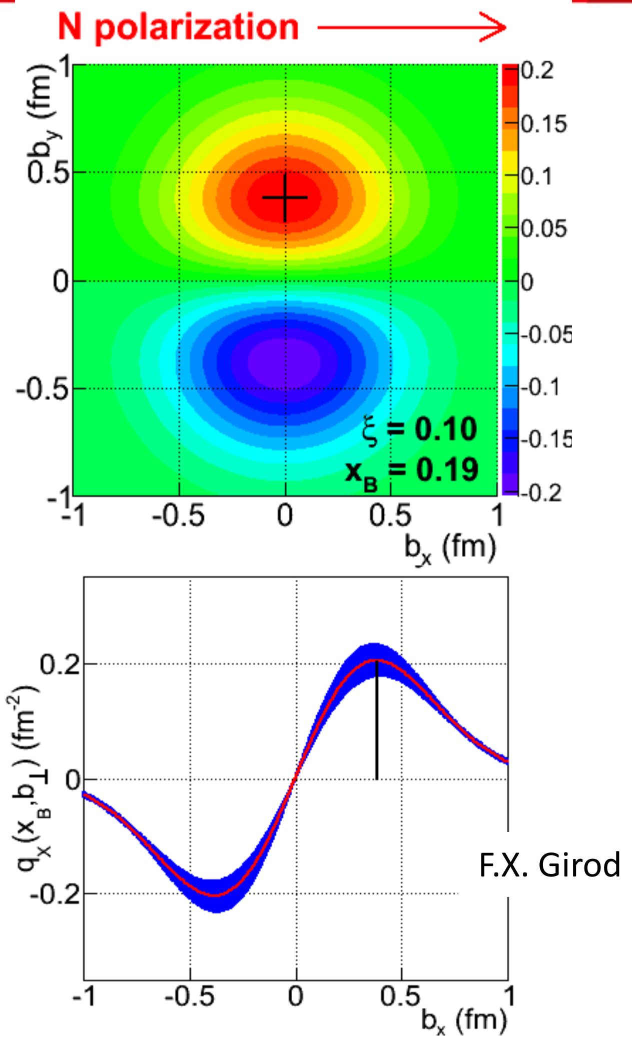
A Fourier transform in t in **LC kinematics** determines the quark distribution in impact parameter(b_x , b_y) space at fixed ξ, x_B.

M. Burkardt

$$\rho_X(x,\vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2}\left[H(x,0,t) - \frac{E(x,0,t)}{2M}\frac{\partial}{\partial b_y}\right] e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp}$$

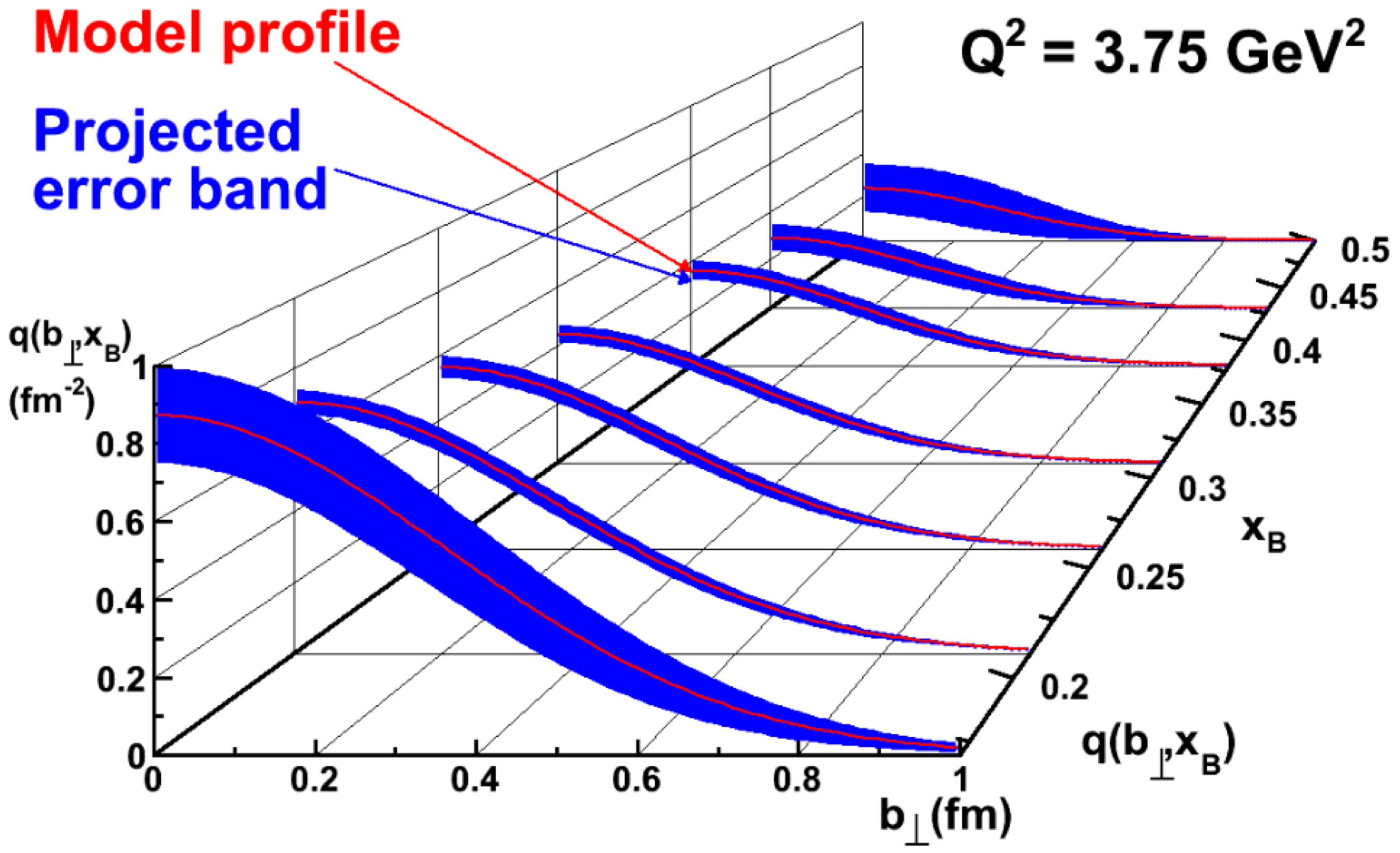


Contribution of ***H+E***



Contribution of ***E***

Proton transverse profile in valence quark domain



Beyond 3D Imaging – Gravitational FFs

P. Schweitzer

$$\int_{-1}^{1} \mathrm{d}x\, x H_q(x,\xi,t) = \boxed{A_q(t)} + \xi^2 \boxed{D_q(t)},$$

$$\int_{-1}^{1} \mathrm{d}x\, x E_q(x,\xi,t) = B_q(t) - \xi^2 \boxed{D_q(t)},$$

$$B_q(t) = 2\boxed{J_q(t)} - \boxed{A_q(t)}$$

Gravitational form factor of the EMTs

$$\langle p', \vec{s}'|T_a^{\mu\nu}(0)|p,\vec{s}\rangle = \bar{u}(p',\vec{s}')\Bigg[\boxed{A_a(t)}\frac{P^\mu P^\nu}{M_N} + \boxed{D_a(t)}\frac{\Delta^\mu\Delta^\nu - g^{\mu\nu}\Delta^2}{4M_N} + \bar{C}_a(t)\, M_N\, g^{\mu\nu} + \boxed{J_a(t)}\frac{P^{\{\mu}i\sigma^{\nu\}\lambda}\Delta_\lambda}{M_N} - S_a(t)\frac{P^{[\mu}i\sigma^{\nu]\lambda}\Delta_\lambda}{M_N}\Bigg]u(p,\vec{s})$$

$a = q, G$

GPDs => Compton Form Factors (CFFs)

$$\mathrm{Re}\mathcal{H}(\xi,t) + i\,\mathrm{Im}\mathcal{H}(\xi,t) = \sum_q e_q^2 \int_{-1}^{1} dx \left[\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right] H_q(x,\xi,t)$$

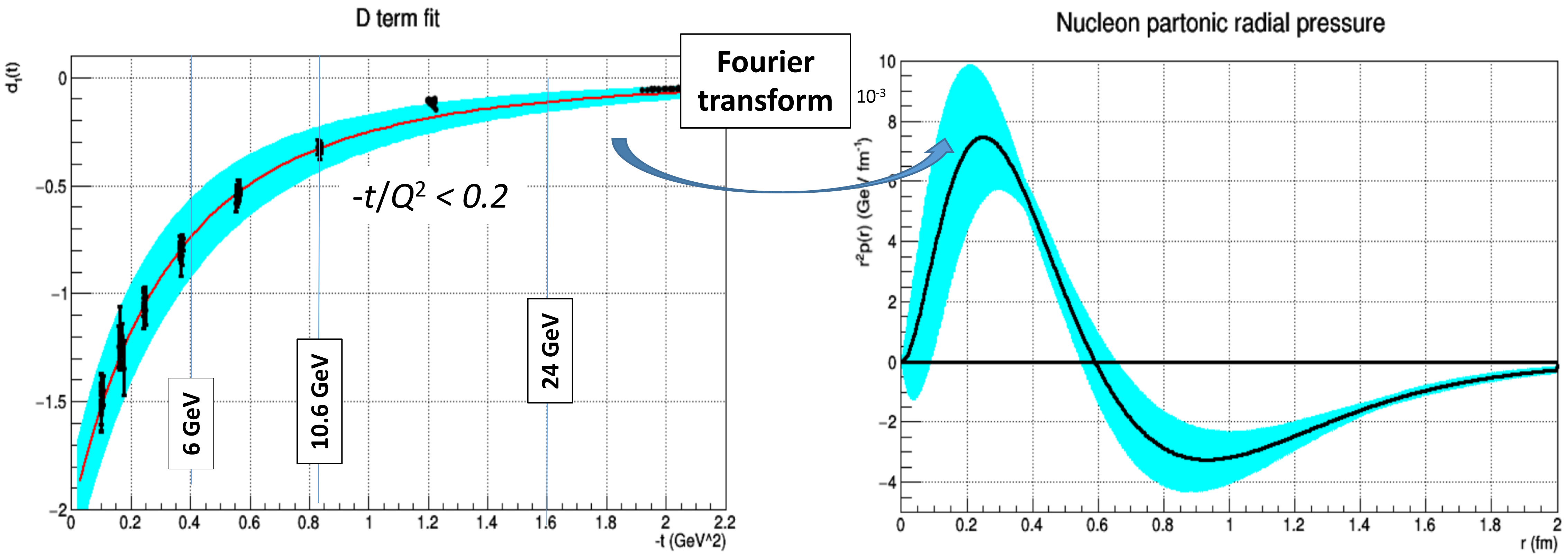
$$\mathrm{Re}\mathcal{H}(\xi,t) = \boxed{\mathcal{C}_{\mathcal{H}}(t)} + \frac{1}{\pi}\mathrm{P.V.}\int_0^1 \mathrm{d}\xi' \left[\frac{1}{\xi-\xi'} - \frac{1}{\xi+\xi'}\right]\mathrm{Im}\mathcal{H}(\xi',t)$$

Dispersion relation

$C_{\mathcal{H}}(t) \rightarrow D_q(t)$

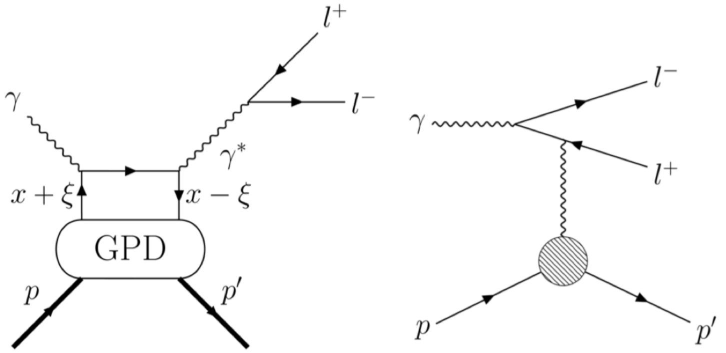
From GFF $D_q(t)$ to distribution of forces (pressure)

Fitting the dispersion relation to $\mathrm{Im}\mathcal{H}(\xi,t)$, $\mathrm{Re}\mathcal{H}(\xi,t)$



22 GeV required to cover sufficient range in t for extraction of mechanical properties.

TCS at 10.6 GeV – CLAS12



P. Chatagnon et al., Phys.Rev.Lett. 127 (2021) 26, 262501

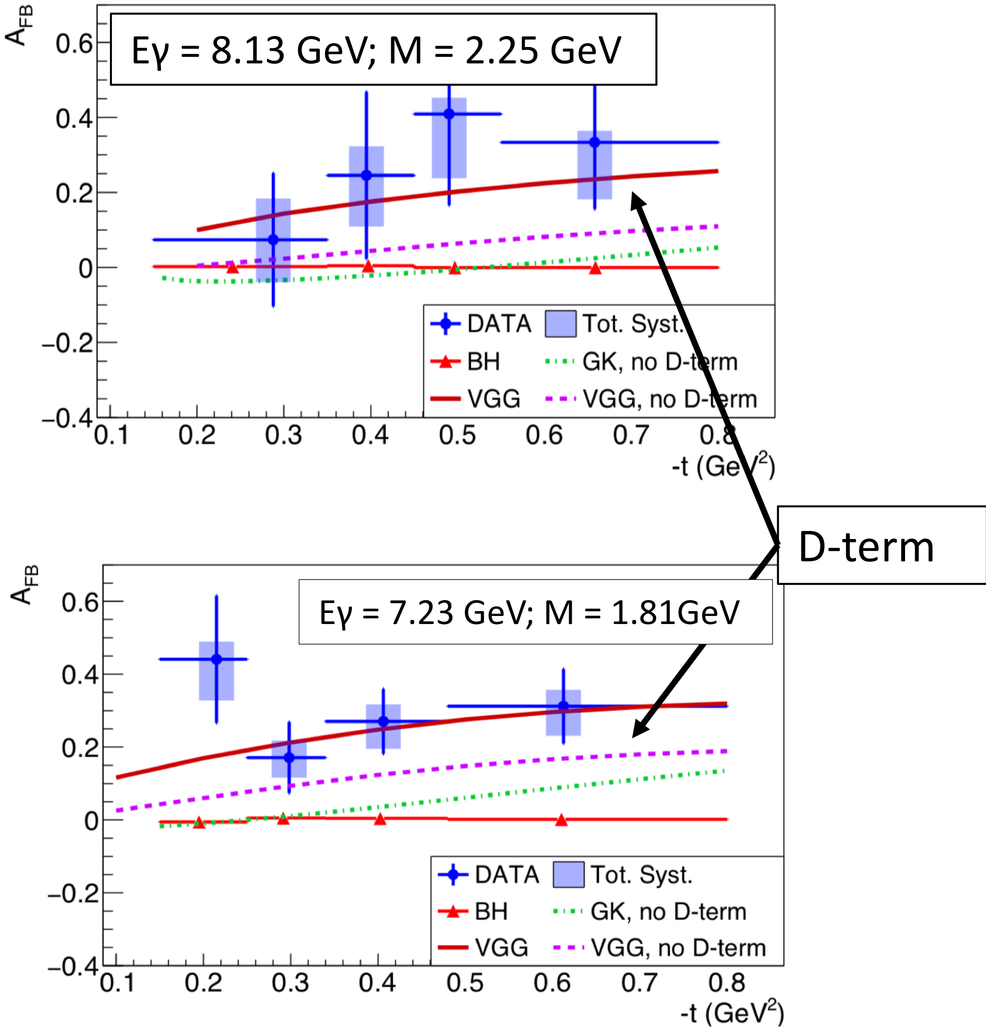
In addition to the BSA from the polarized beam, TCS has a forward-backward asymmetry, which **directly** relates to **Re$\mathcal{H}$** through the interference term with BH.

$$A_{FB}(\theta,\phi) = \frac{d\sigma(\theta,\phi) - d\sigma(180^\circ-\theta,180^\circ+\phi)}{d\sigma(\theta,\phi) + d\sigma(180^\circ-\theta,180^\circ+\phi)},$$

$$\frac{d^4\sigma_{INT}}{dQ'^2dtd\Omega} = A\frac{1+\cos^2\theta}{\sin\theta}[\cos\phi\,\mathrm{Re}\tilde{M}^{--} - \nu\cdot\sin\phi\,\mathrm{Im}\tilde{M}^{--}]$$

$$\tilde{M}^{--} = \left[F_1\mathcal{H} - \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4m_p^2}F_2\mathcal{E}\right]$$

→ **First test of universality of GPDs/CFFs.**



TCS is measured at 22 GeV simultaneously with DVCS

Summary

- **Hall A/C - High luminosity and precision DVCS data in valence quark region.**
  - **Precision scaling tests**
  - **High resolution imaging**
  - **Double the range in Q^2 from 11 GeV, at fixed range in t, x_B.**

- **Hall B/CLAS12 – Cover continuous Q^2 vs x_B space simultaneously at moderate luminosity**
  - **CLAS12 provides excellent particle identification**
  - **Large continuous kinematic coverage in same setting**
  - **Use longitudinally polarized solid targets with full solid angle coverage**
  - **Transversely polarized target concept developed (to access GPD $\mathcal{E}$ in Ji's spin sum rule)**

- **Combining 22 GeV DVCS data with previous 6 and 11 GeV data**
  - **construct more complete images of the protons valence quark domain**
  - **determine force, mass, and angular momentum distributions.**

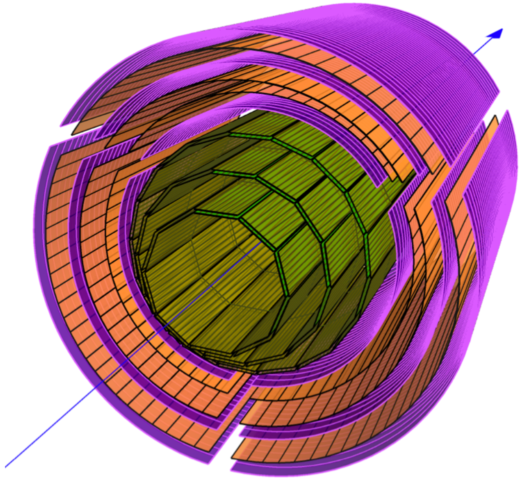
- **TCS is measured simultaneously, direct access to *D*-term and test of universality**

Additional slides for discussion

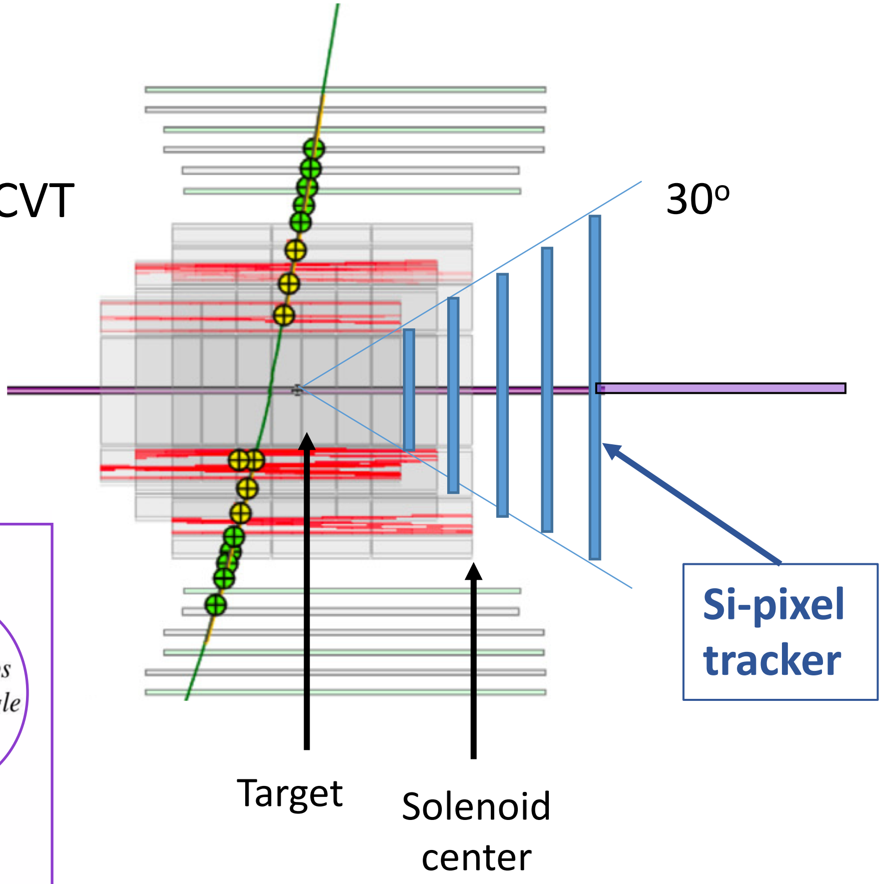
Desirable CLAS12 upgrades

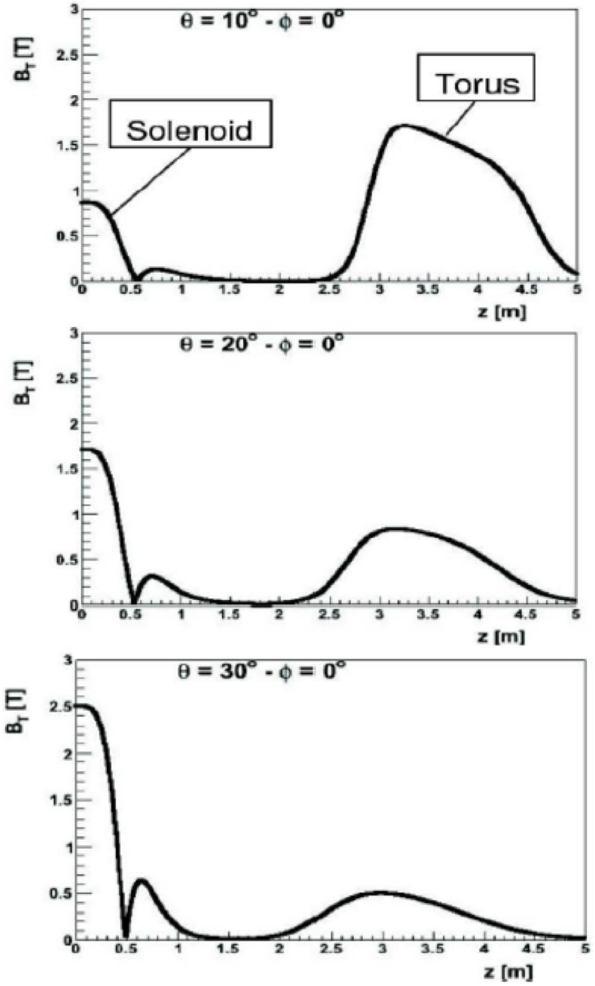
- Improve tracking resolution in forward detectors with pixel tracking layers
  - **Missing particle mass resolution**
- Large angle electromagnetic calorimeter for photon and electron detection
  - **High t- science (photon detection)**
  - **2-photon exchange science (electron detection)**
- 0-degree spectrometer with high resolution electron detection
  - **Exotic meson spectroscopy**

Improving forward tracking & vertexing (concept)

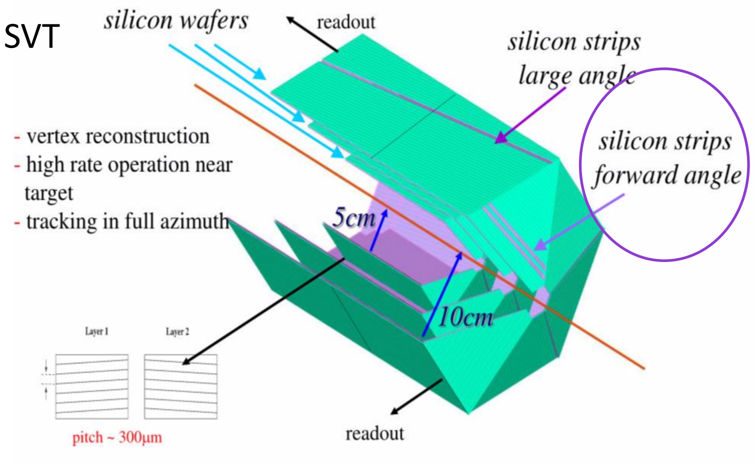


CLAS12-CVT





CLAS++ SVT



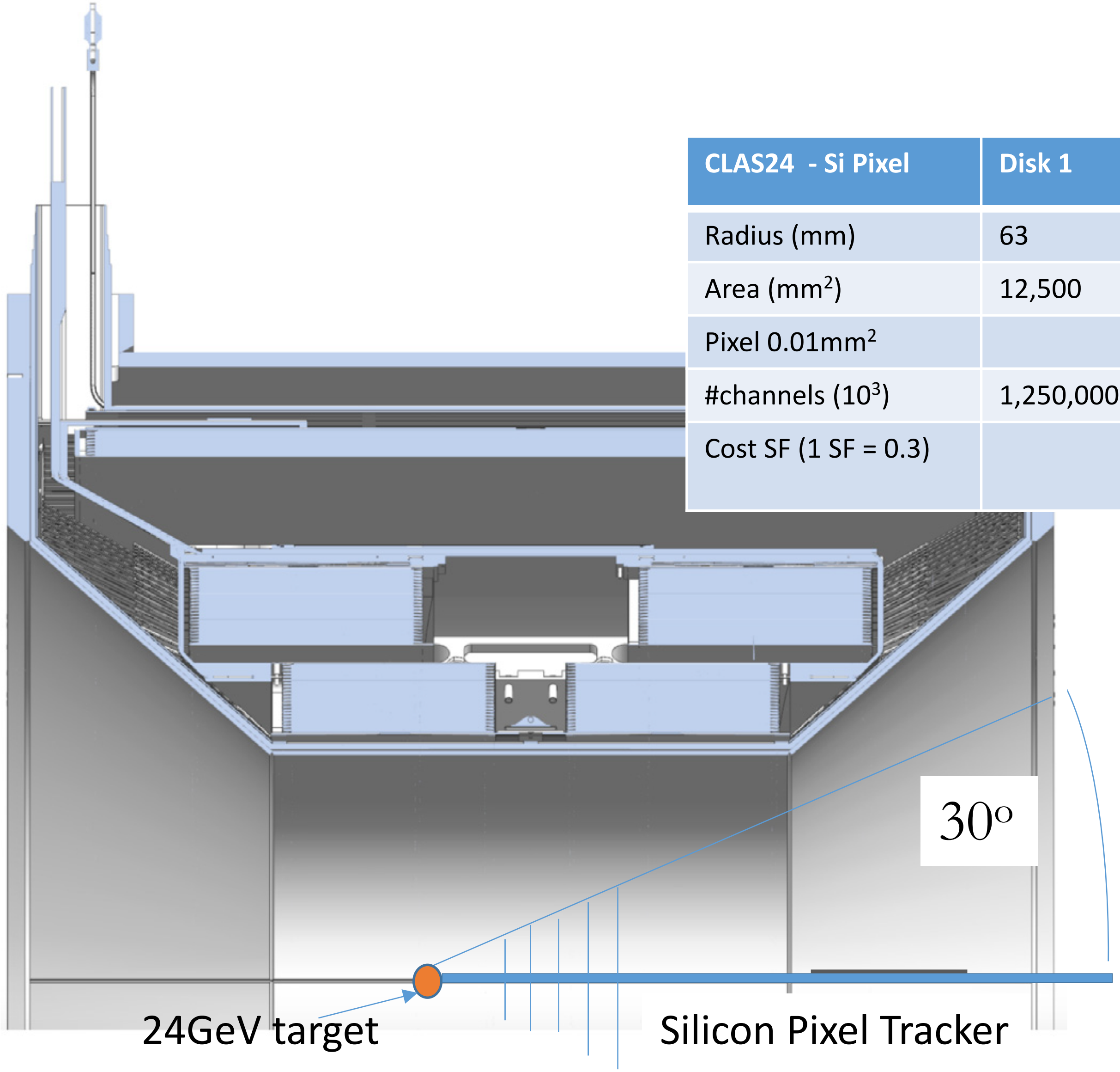
CLAS12 + Silicon pixel tracker

Silicon Pixel Tracker cost estimate
(CMS phase 2, upgrade)

Y. Gotra

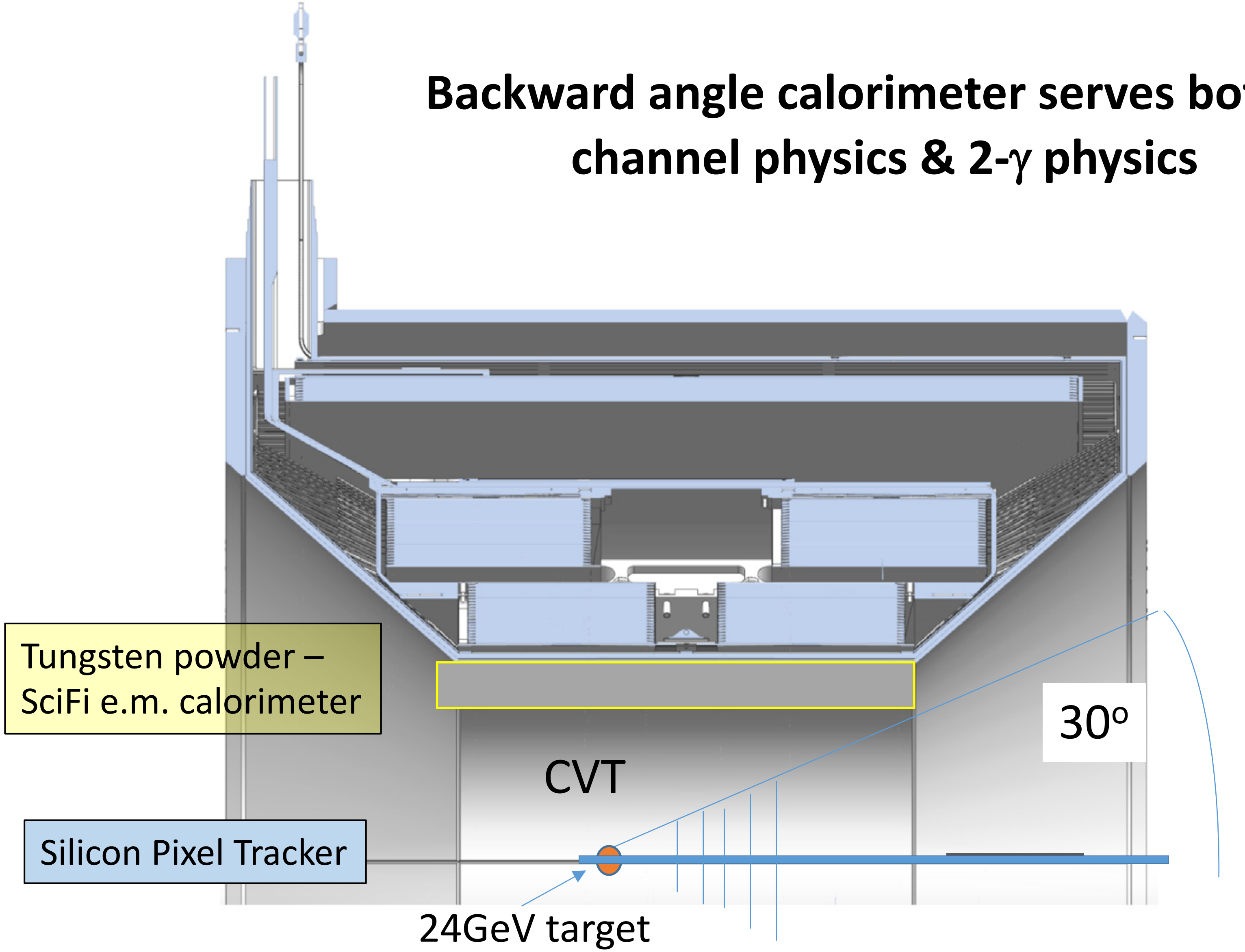
CLAS24 - Si Pixel	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5	total
Radius (mm)	63	83	103	123	143	
Area (mm^2)	12,500	21,600	33,300	47,500	64,300	179,200
Pixel 0.01mm^2						
#channels (10^3)	1,250,000	2,160,000	3,330,000	4,750,000	6,430,000	17,920,000
Cost SF (1 SF = 0.3)						**5,376,000+ inflation**

Pixel size : 100 x 100 μm



CLAS12 + $\gamma/e^{+/-}$ detection at large angles

Backward angle calorimeter serves both u-channel physics & 2-γ physics



Prototype.
Y. Sharabian

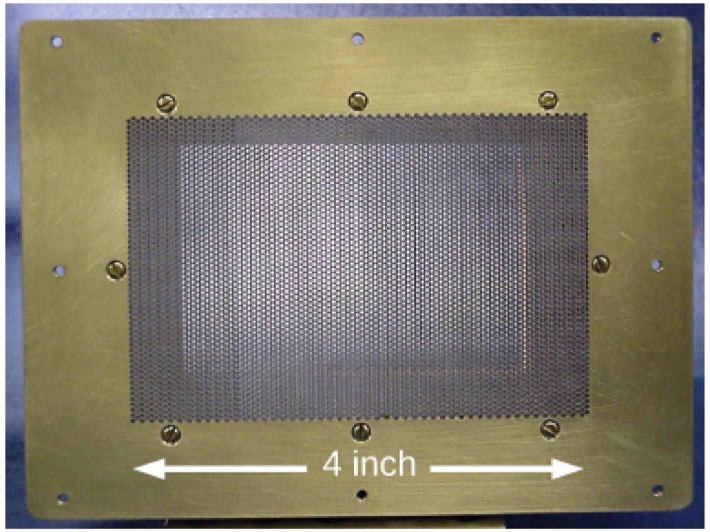


Figure 3: Active volume casing. Perforated area of $L \times H$ = 4"×2.626"

0-degree energy tagging system (schematic)