Double Deeply Virtual Compton Scattering

Measuring DDVCS in Hall C
why and how?

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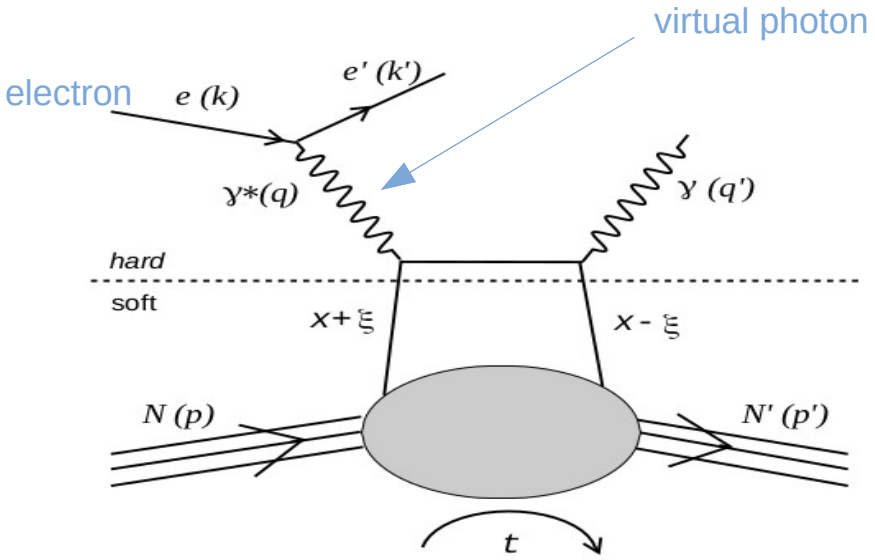
Hall A/C summer collaboration meeting

Jefferson Lab, June 17th, 2022

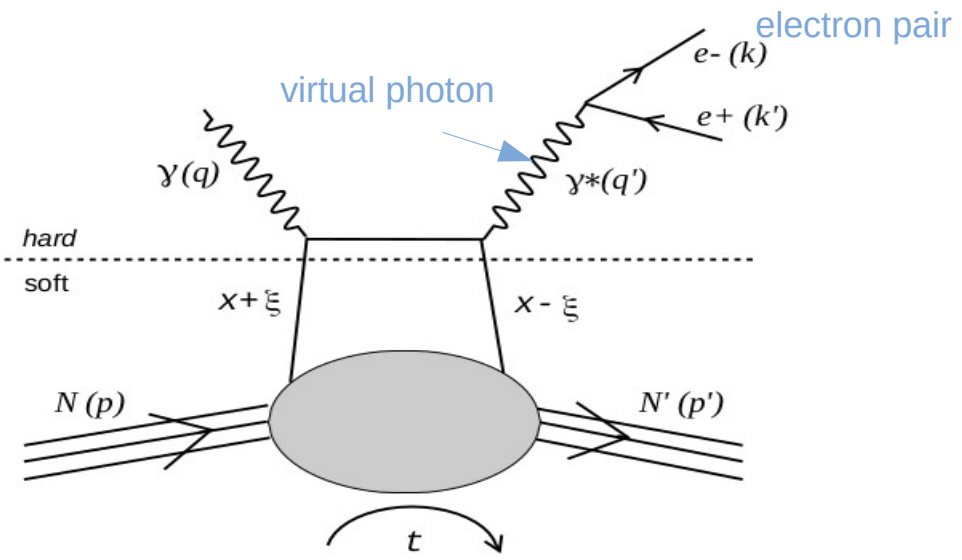
Hard exclusive Deep Virtual Compton Scattering

Initial lepton beam / virtual photon



Deeply Virtual Compton Scattering (DVCS)
Lot of efforts at JLab (Carlos M. talk this session, ...)

Final lepton pair / virtual photon



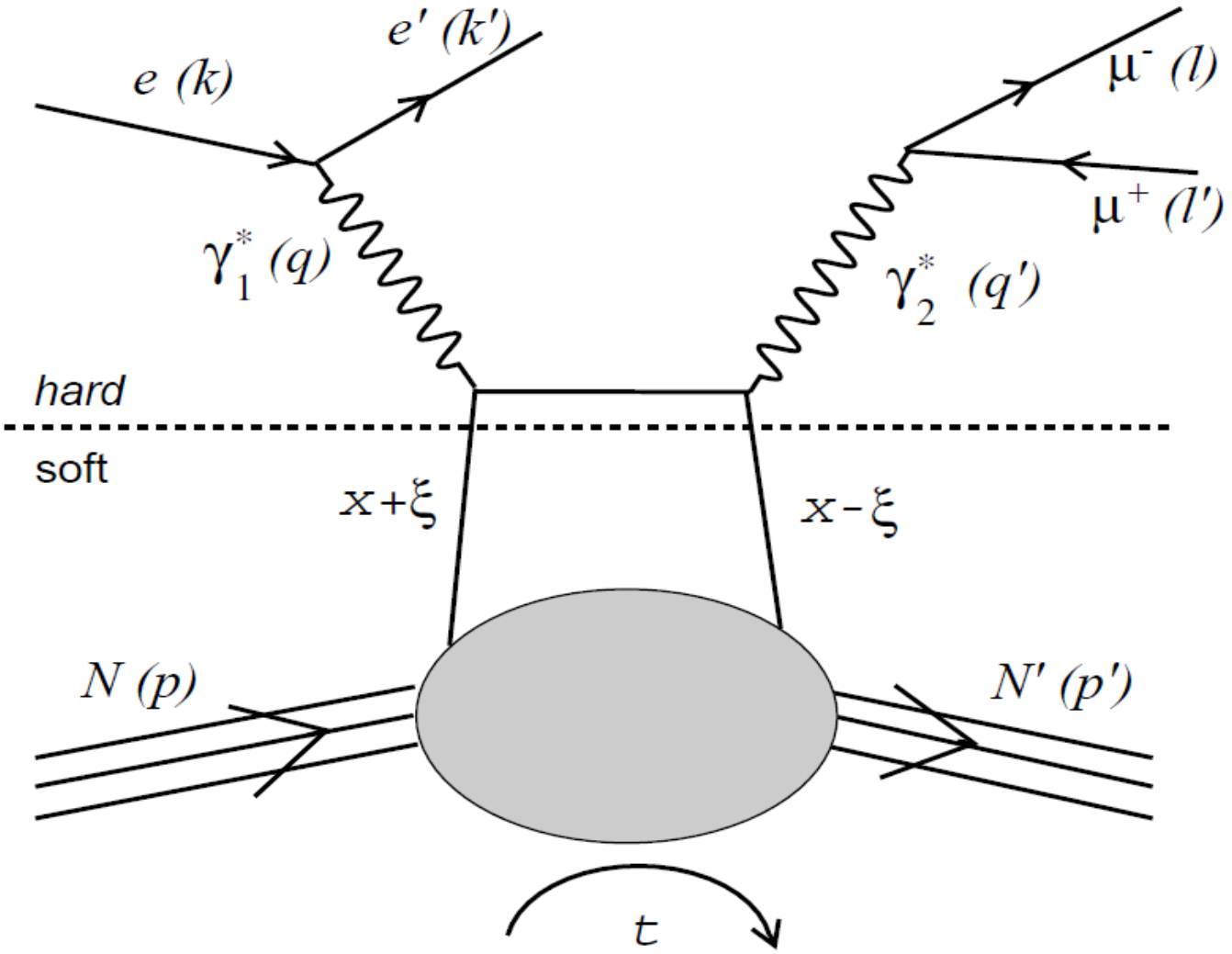
Timelike Compton Scattering (TCS)
some efforts for future (Vardan T. talk, ...)

Both reactions access same Generalized Parton Distributions, same kinematics

(Leading order, leading twist)

What if the 2 photons are virtual?

Double Deeply Virtual Compton Scattering



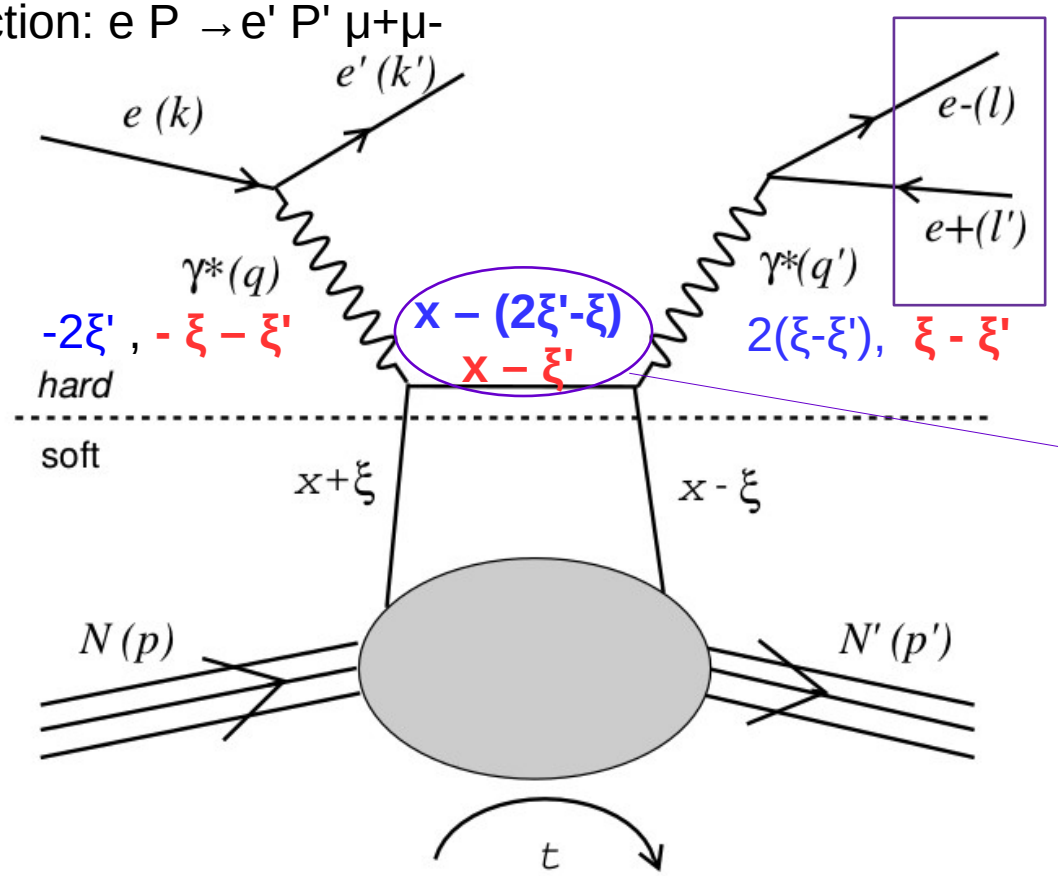
Q^2 /= Q'^2, perturbative regime, hard scale

Muon pair, not electrons: distinction between final leptons

7-differential unpolarized cross section (Q^2, Q'^2, t, xi (or xbj), lepton angles)

DDVCS Compton amplitude and definitions/notations

Reaction: e P → e' P' μ+μ-



μ+μ- → avoid antisymmetrisation

propagator for coefficient function
red, blue= 2 sets of definitions
blue = Guidal, Vanderhaeghen (& me)
red = others (Muller, Diehl, Wallon...)

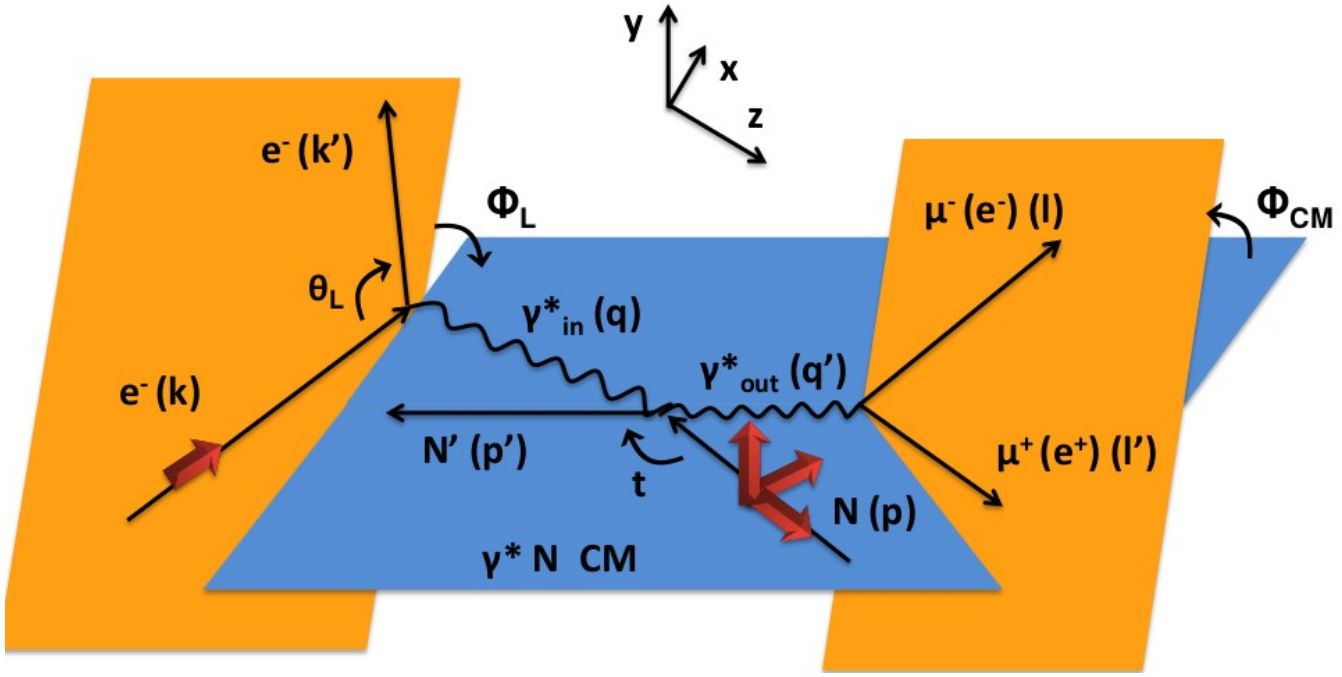
GPD from Im (CFF) extracted at this value

ξ = + component of P=(p+p') in light cone frame. GPDs depend on it. "skewness"
$\xi = -\Delta.\bar{q} / P.\bar{q} = (Q^2+Q'^2) / (2s + Q^2 – Q'^2 – 2m^2 + t)$
with $\Delta = (p'-p) = (q-q')$ and $t = \Delta^2$; $\bar{q} = (q+q')/2$, $P = (p+p')$ (standard in litterature)
notations: η in Belitski, Muller; ξ in Guidal, Vanderhaeghen; Wallon; Diehl (articles ref. next slide)

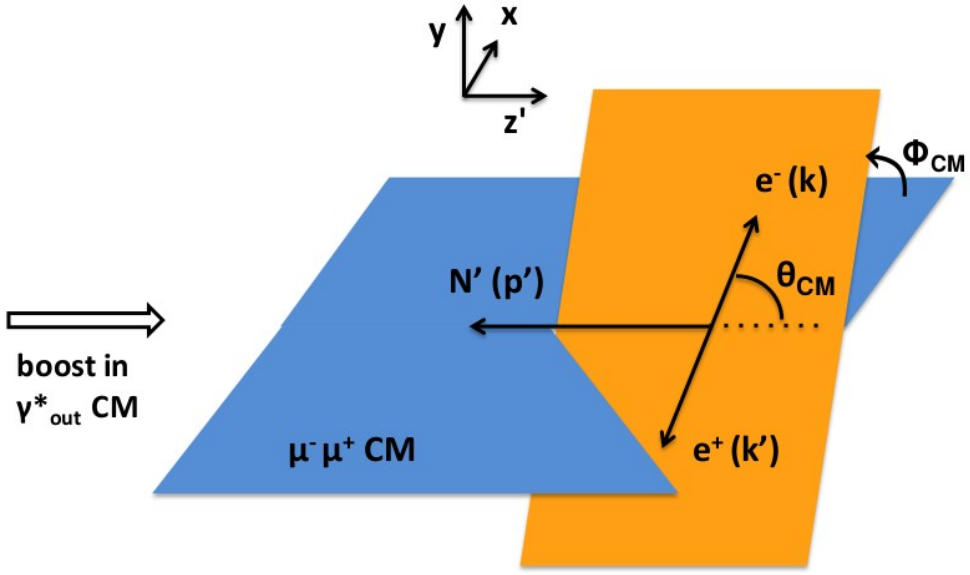
ξ' = + component of $\bar{q}=(q+q')/2$ in light cone frame. quark propagator depend on it (red notations)
can be related to x_{bj}
$\xi' = - \bar{q}^2 / 2P.\bar{q} = (Q^2 -Q'^2 + t/2)/ (2s + Q^2 – Q'^2 – 2m^2 + t)$ → Im(CFF) at $x = \pm\xi' \neq \xi$
notations: ξ in Belitski, Muller; ρ in Diehl; not explicited in Wallon; 2ξ-ξ' in Guidal, Vanderhaeghen

at asymptotic limits and q^2 or $q'^2 = 0$ → DVCS: ξ'=ξ; TCS: ξ'=-ξ. Im(CFFs) at $x = \pm\xi = \pm\xi'$

Notations, Angles



7 independent variables
For unpolarized x-sec



notation:
φ_L or φ_{LH} for "initial" angle
and φ, θ or φ_{CM}, θ_{CM} for "final" angles
cross section unpolarized=σ
beam spin asymmetry=A_{LU}

Extraction of GPDs from Compton Form Factors

DVCS amplitude decomposition into Compton Form Factors (TCS similar):

ξ, t = measurable
x = integrals

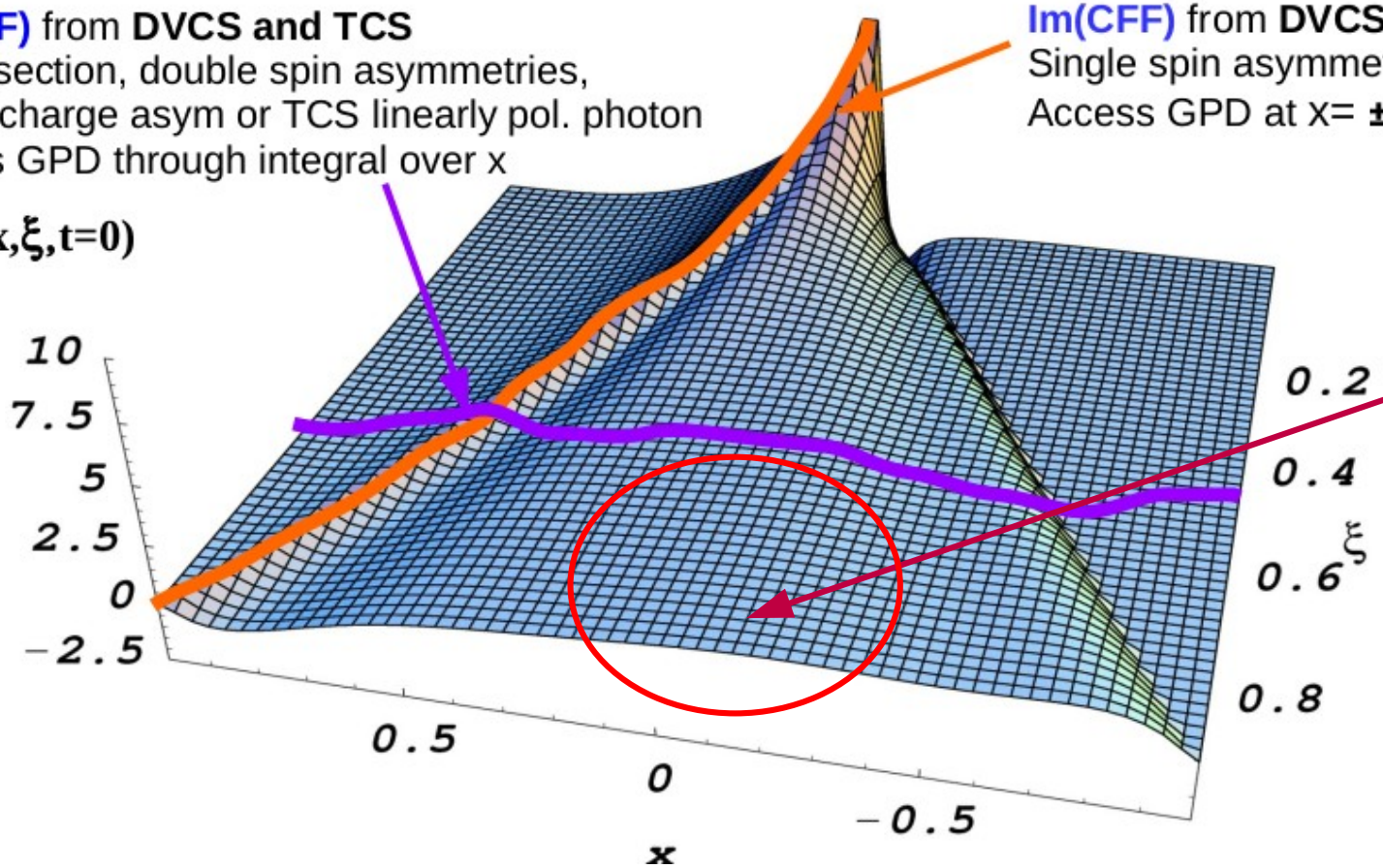
$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim \underbrace{P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx}_{\mathrm{Re}\,(\mathcal{H})} \underbrace{- i\pi H(\pm\xi,\xi,t)}_{\mathrm{Im}\,(\mathcal{H})} + \ldots$$

Probing GPD x vs ξ dependence with experimental observables:

Re(CFF) from **DVCS and TCS**
Cross section, double spin asymmetries,
DVCS charge asym or TCS linearly pol. photon
Access GPD through integral over x

Im(CFF) from **DVCS and TCS**
Single spin asymmetries, cross section
Access GPD at x= **±ξ**

GPD H(x,ξ,t=0)



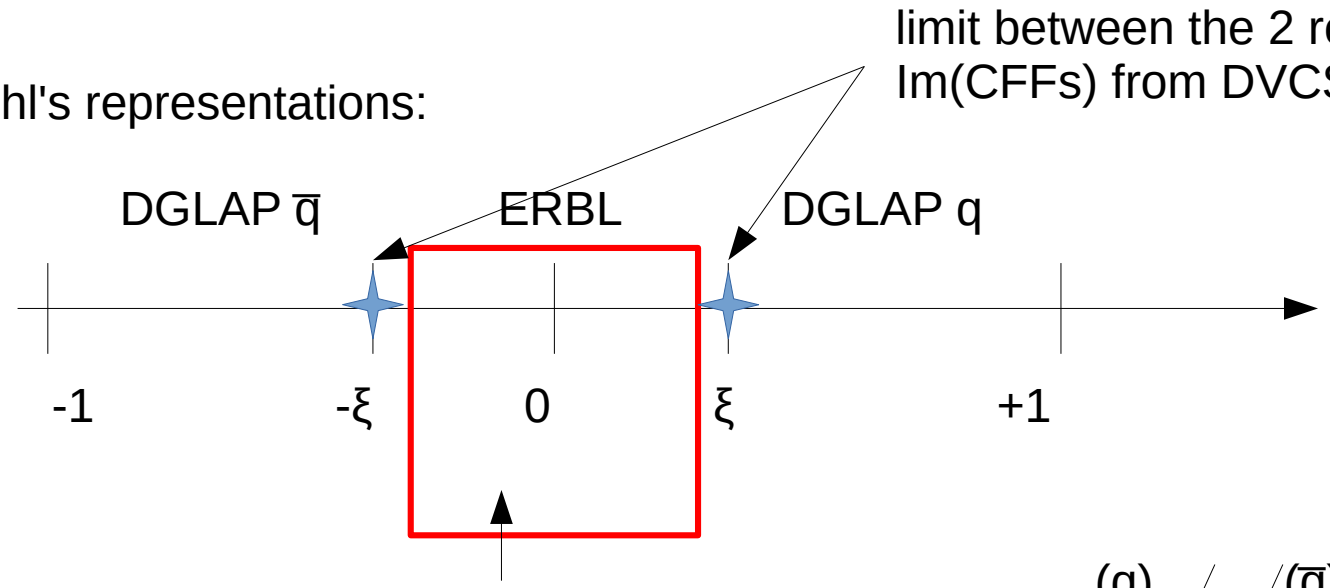
DDVCS
ERBL region
“off diagonal”
(propagator)

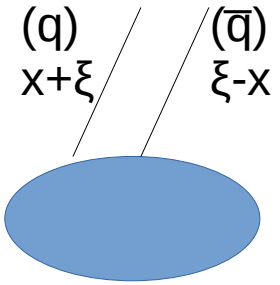
Access non-diagonal (x, xi) part with DDVCS

- DVCS and TCS get GPDs at the limit between DGLAP and ERBL regions
- ERBL region need constraints == DDVCS is best

ξ>|ξ'|: ERBL region; ξ<|ξ'| DGLAP region

M. Diehl's representations:



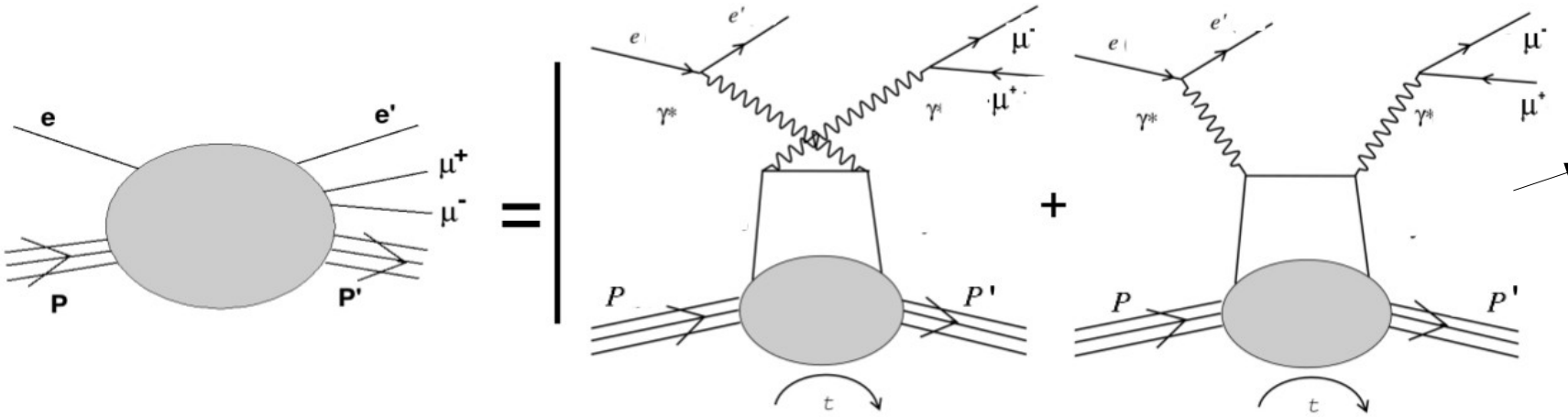


partonic interpretation from M. Diehl in ERBL region

Quark propagator normalized to ξ at asymptotic limit: (1-Q'²/Q²) / (1+ Q'²/Q²)
→ up to t/Q² factor, we play with respective value of Q² and Q'² to go "out of diagonal" for GPD
→ neglecting t, we are restricted to ξ>|ξ'|

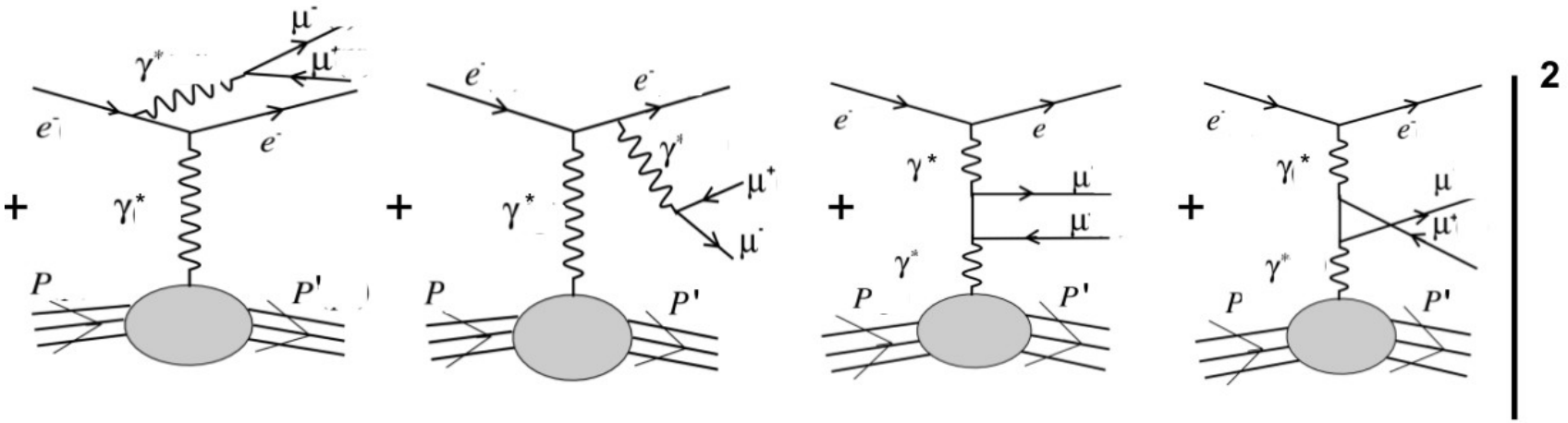
DDVCS + BH leading order diagrams

!!! Angular behavior



no favored direction for y* emission or decay leptons

DDVCS



BH_1

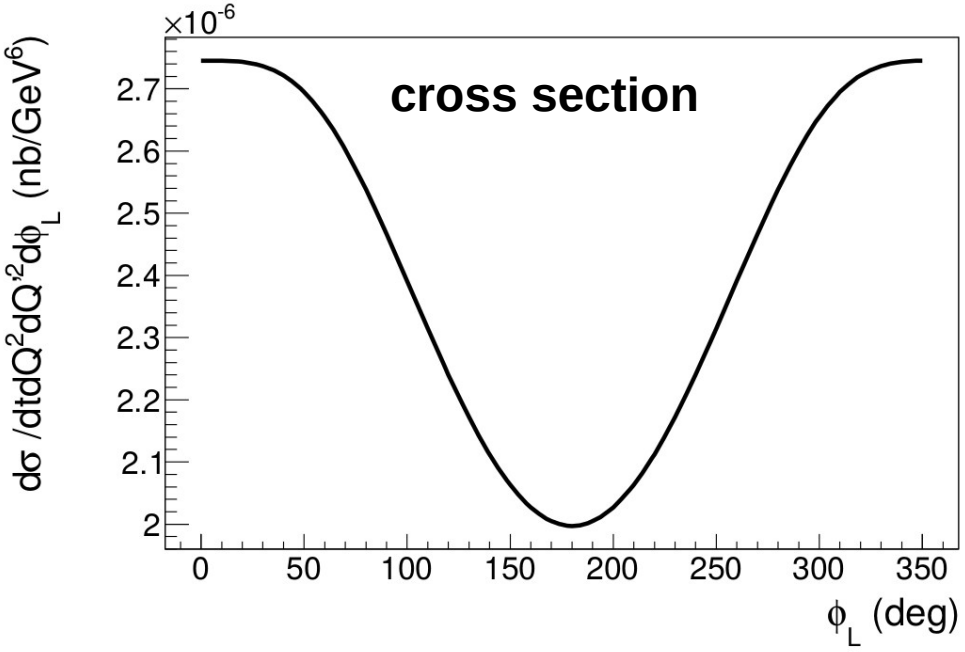
peak when y' becomes collinear to e related to φ_{LH}=0,
and depends $\cos\theta_{yy}$ (kinematics)
and "y"→e' angle

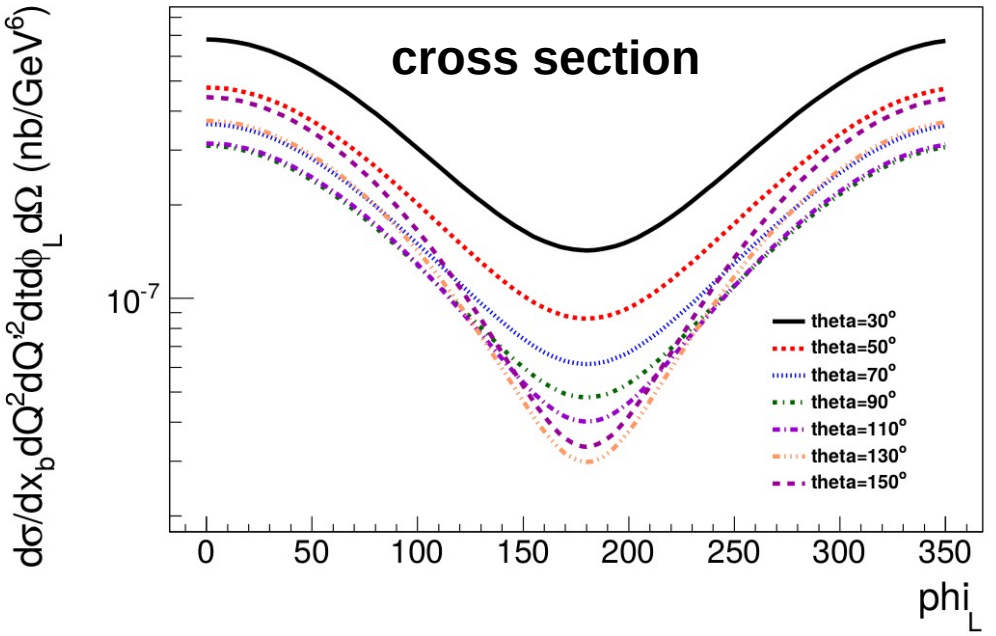
BH_2

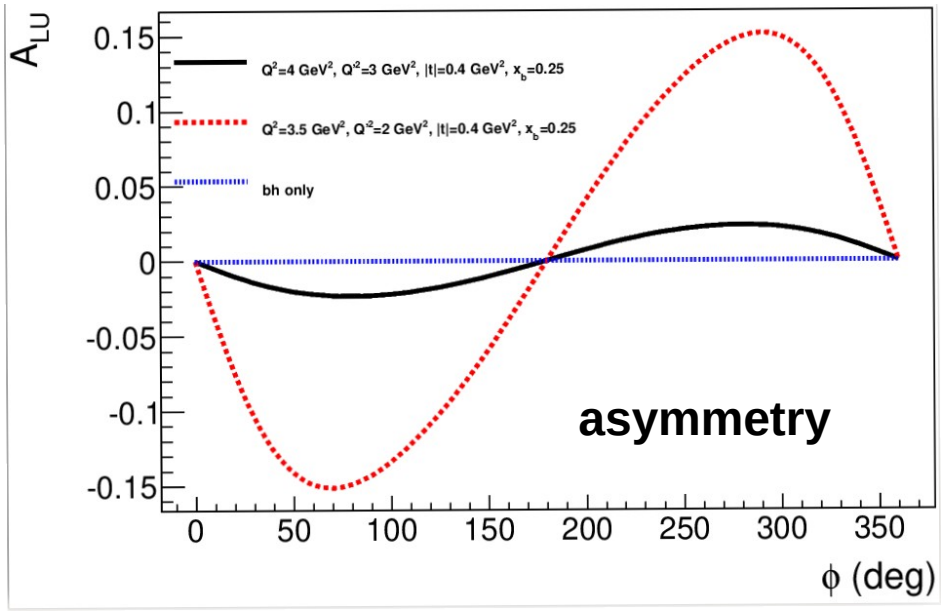
2 peaks when μ+ or μ- become collinear to y related to φ_{LH}=0 and 180°,
and depends $\cos\theta_{yy}$ (kinematics) which position the value of θ_{CM} for the peaks

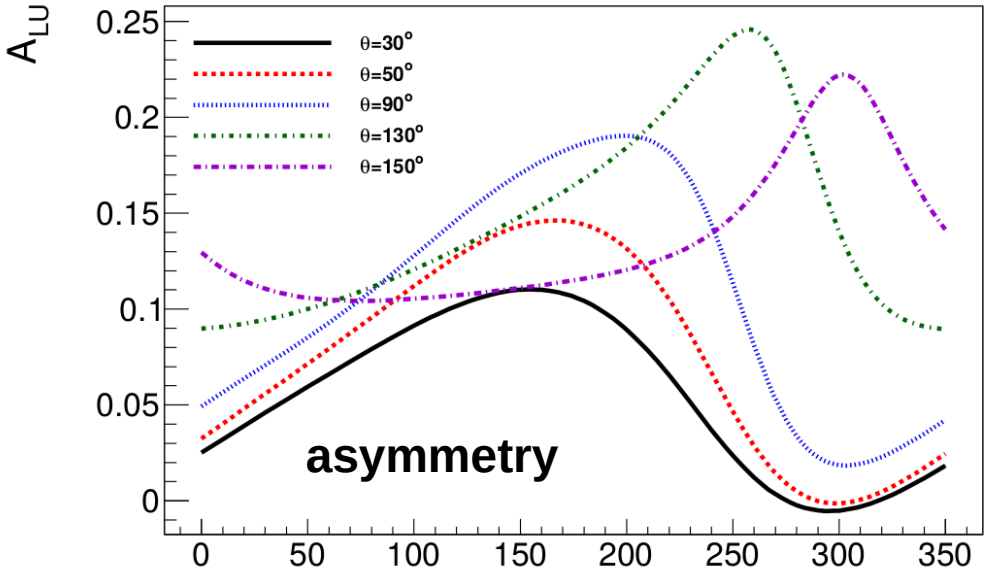
φ_L behavior. similar than DVCS; **but correlations with final angles and "BH2"**

Φ_{CM}, θ_{CM}: !!! difficult need good interpretation, redefinition of observables...





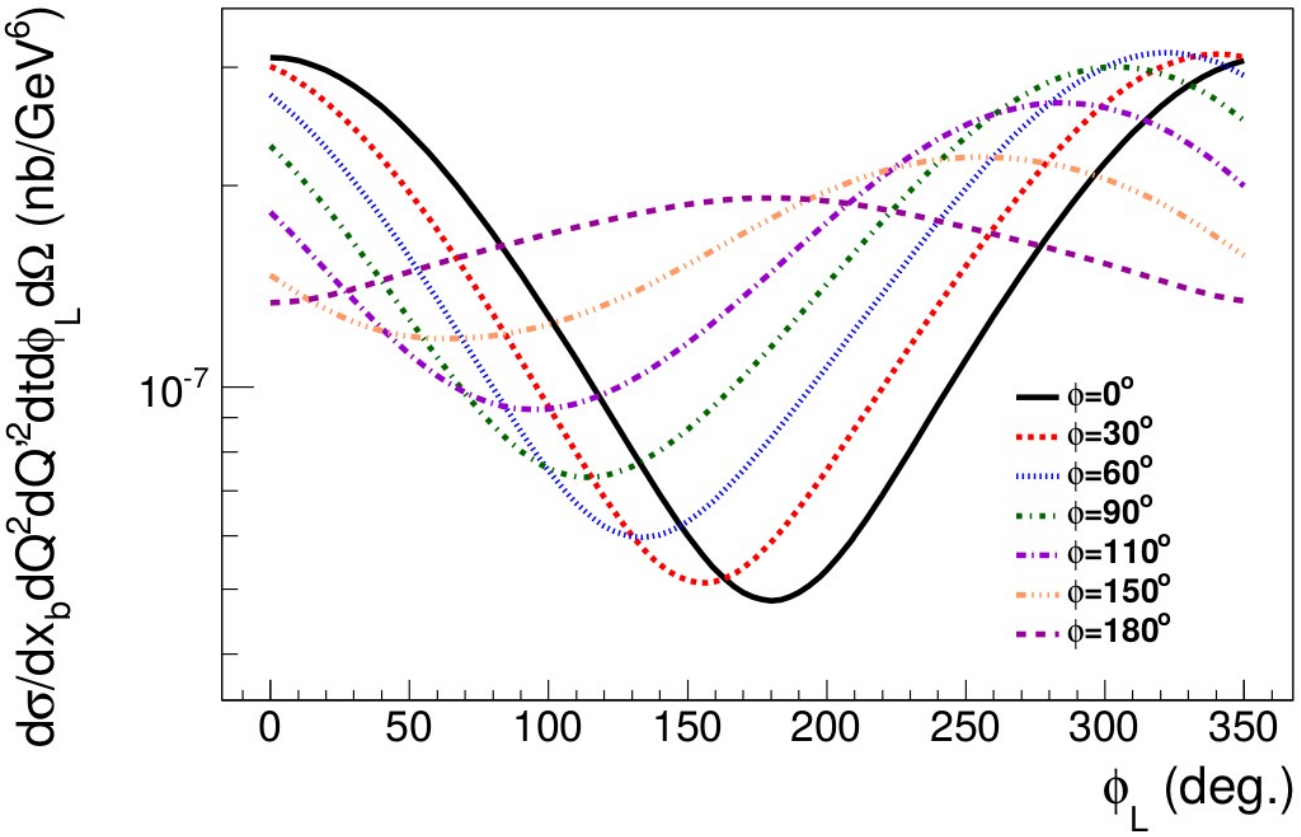




left= integrated over θ, right=not integrated

if not integrated over θ: strong correlation of A_{LU} with θ (rate of "BH2")

correlation between the azymutal angles in DDVCS



- To extract CFFs: 2D fits in φ_{CM}, φ_{LH}, as a function of ξ, ξ', t or ξ' replaced by $\langle Q^2/Q'^2 \rangle$ (bin)

- extract Im($\mathcal{H}$) (ξ', ξ, t) with unpolarized cross section and beam asym. (to measure first)

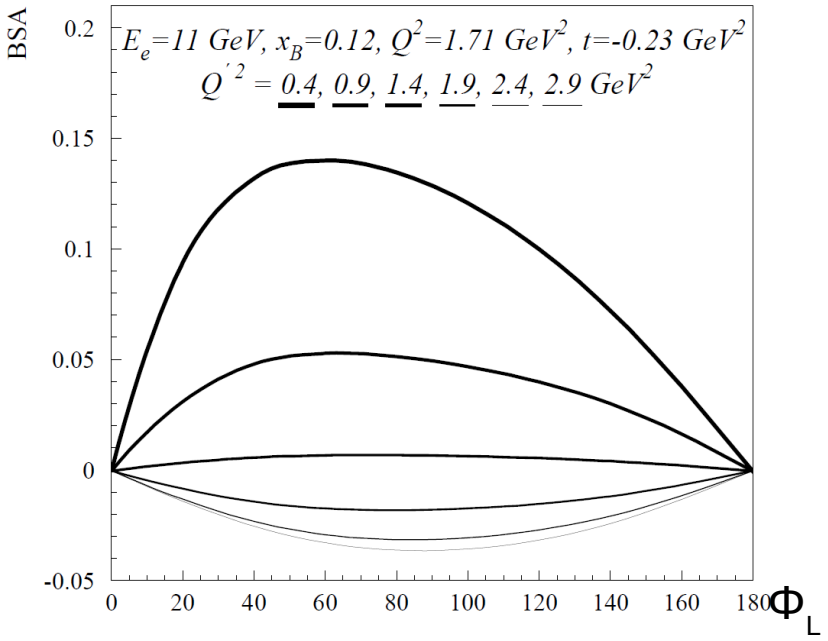
GPDs from DDVCS can be extracted, but one need to
1) take angular correlation into account (similar than TCS)
2) 2 or 3D fits of angles

Nucleon tomography and sign change in DDVCS beam spin asymmetry

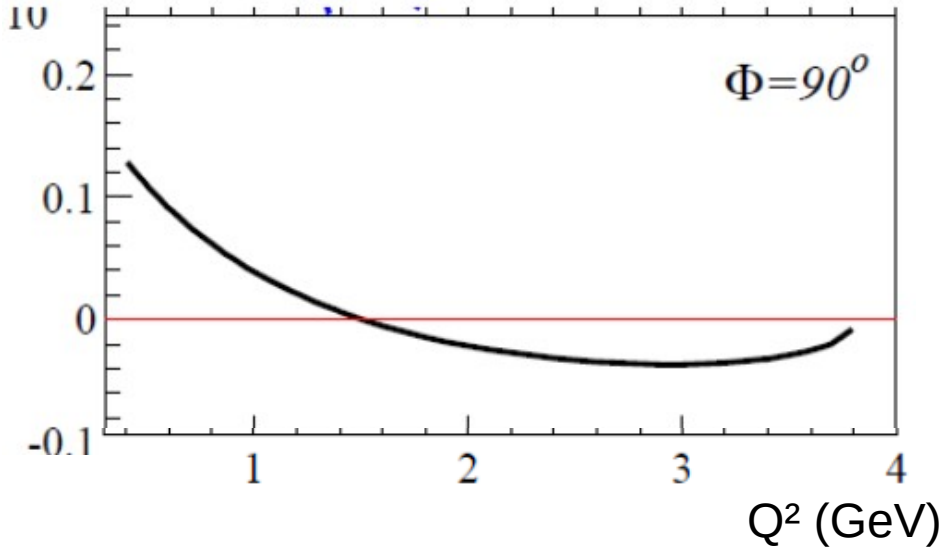
Calculations from M. Guidal

→ scan of BSA in Q'^2 at fixed Q^2

→ sign change in BSA vs Φ_L and vs φ_{CM} when $Q'^2 \approx Q^2$



asymmetry Q^2 scan



•Probing GPDs at x ≠ ξ → tomographic interpretations....

• Expectation of sign change for observables sensitive to Im (DDVCS) when moving from « spacelike » to « timelike » region

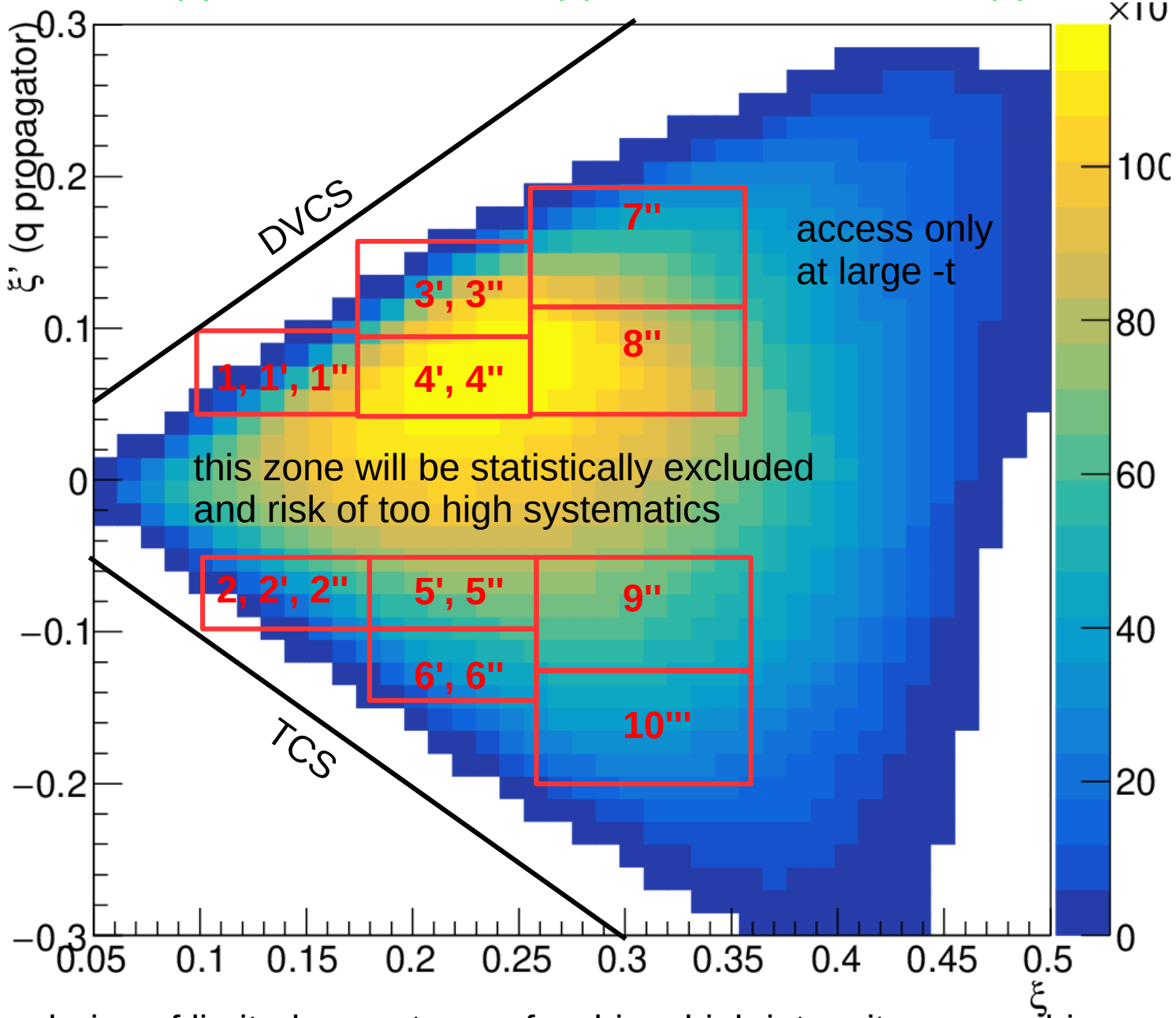
→ this reaction is unique for probing effects between these 2 regions.

• Cross section + beam spin asymmetry projects in development for JLab Hall A and B, for exploratory measurements with aim of future dedicated experiment at very high luminosity

SoLID: LOI12-15-005 (2015)
CLAS12 note: (2015), LOI12-16-004 (2016)

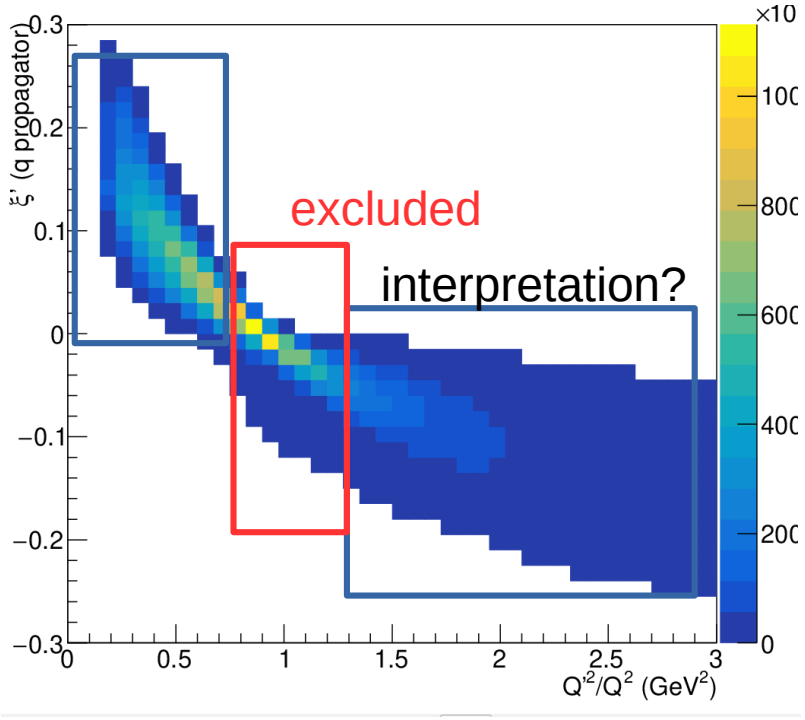
Binning in ξ, ξ', all t

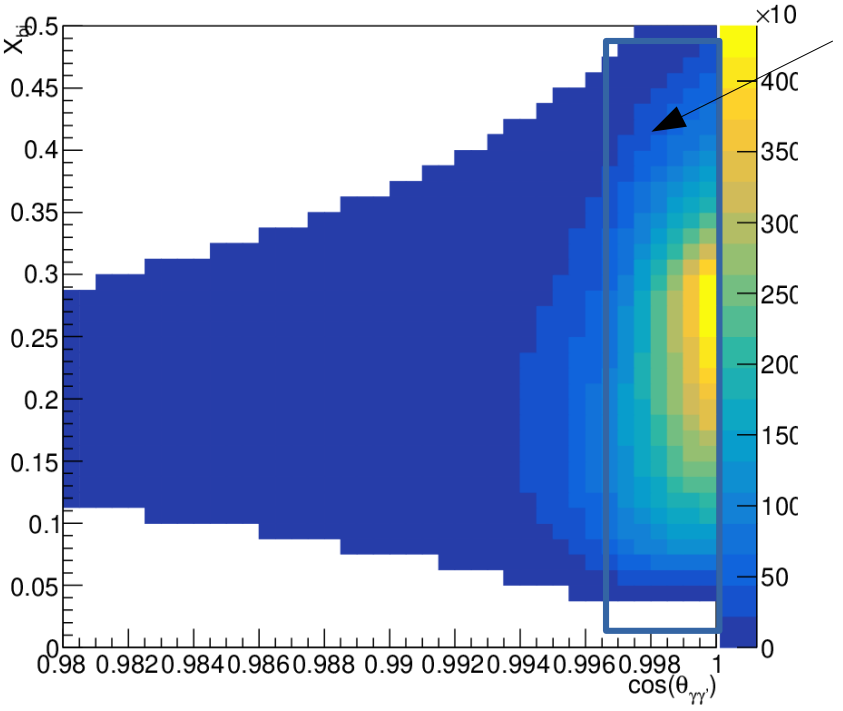
Bins in t: (1) 0 < -t < 0.15 GeV², (2) 0.15 < -t < 0.35 GeV², (3) 0.35 < -t < 0.55 GeV² (indicated ', '')



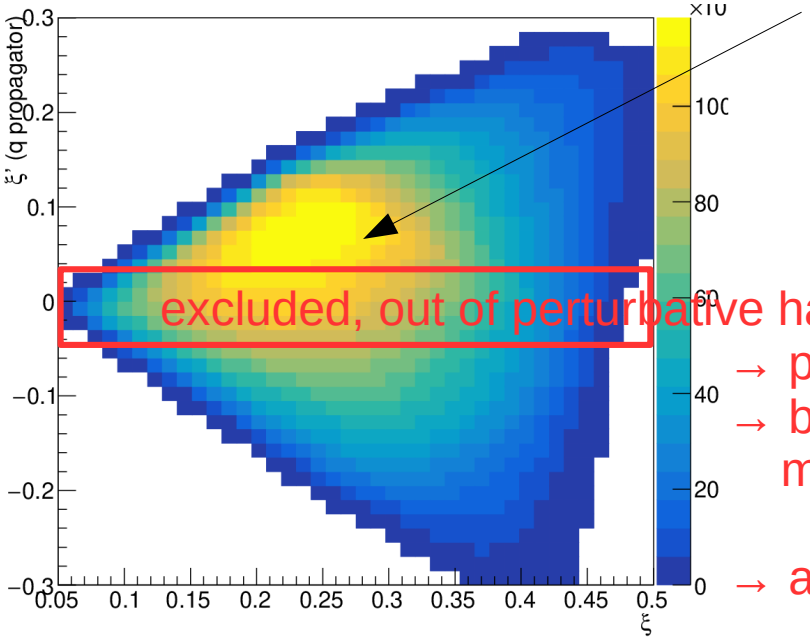
Bin in ξ	code # large/low t
A) .1 < ξ < .18 (all t bins)	
1) .05 < ξ' < .1	1, 7, 17
2) -.05 > ξ' >-.1	2, 8, 18
B) .18 < ξ < .26 (t bins 2 and 3)	
3) .1 < ξ' < .15	3, 9
4) .05 < ξ' < .1	4, 10
5) -.05 > ξ' > -.1	5, 11
6) -.1 > ξ' > -.15	6, 12
C) .26 < ξ < .36 (t bin 3)	
7) .12 < ξ < .2	13
8) .05 < ξ < .12	14
9) -.05 > ξ > -.12	15
10) -.12 > ξ > -.2	16

- choice of limited acceptance: few bins, high intensity → some bins may be empty or limited statistic
- no binning in Q² and Q'²: the above selections are cutting bands in the Q² vs Q'² distribution
- next 3 slides: same figure ξ' vs ξ, separated for the 3 bins in t





we want to stay here → forward region



where do we want to have measurement?
this show how much "out of diagonal" we can go

→ playing with larger t could get data in this region?

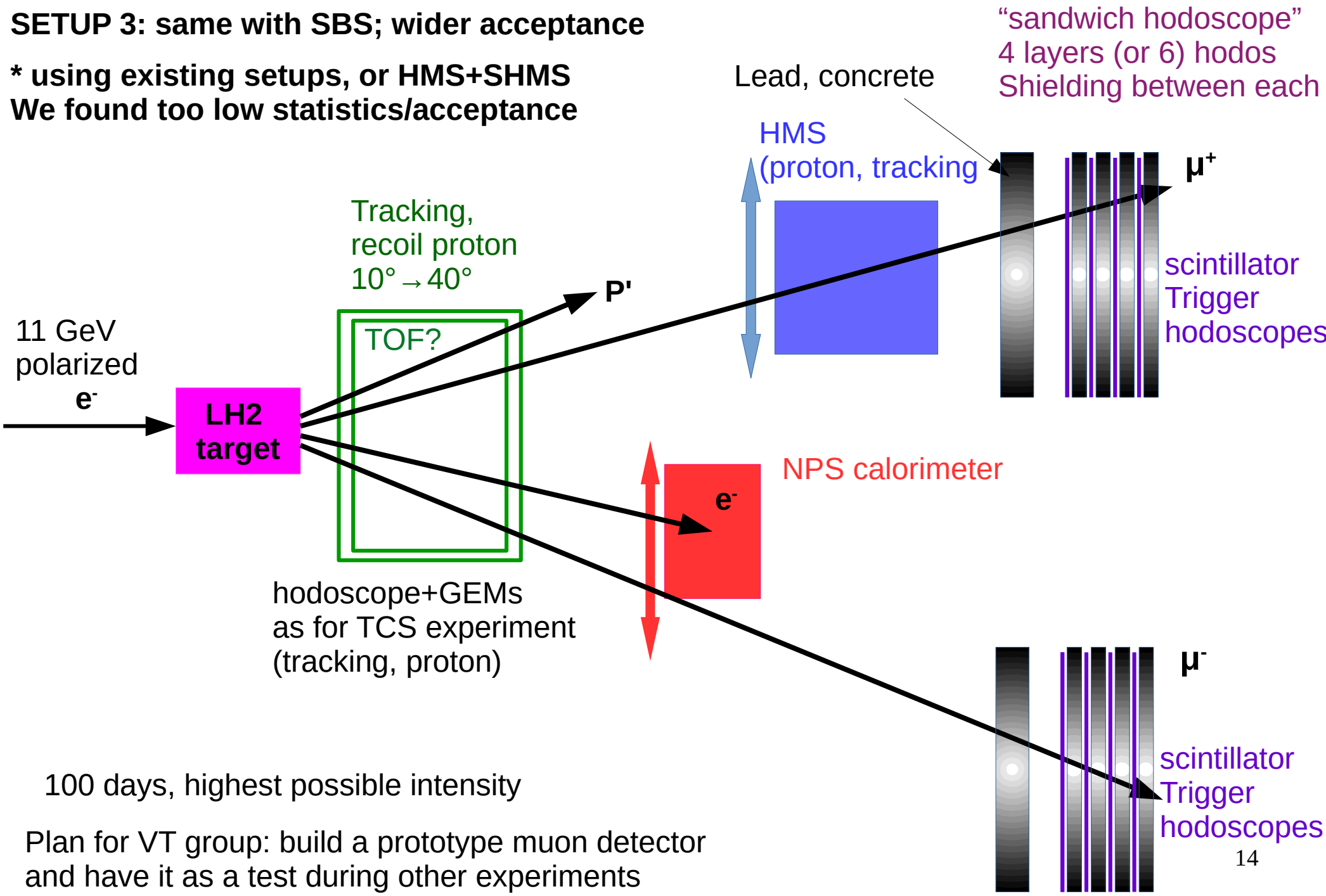
→ but in this case all approximations need to be waved and must be very carefull about interpretations

→ also need to be very carefull in this region: resolution in t !!!

SETUP 1: starting from DVCS with NPS

SETUP 3: same with SBS; wider acceptance

*** using existing setups, or HMS+SHMS**
We found too low statistics/acceptance



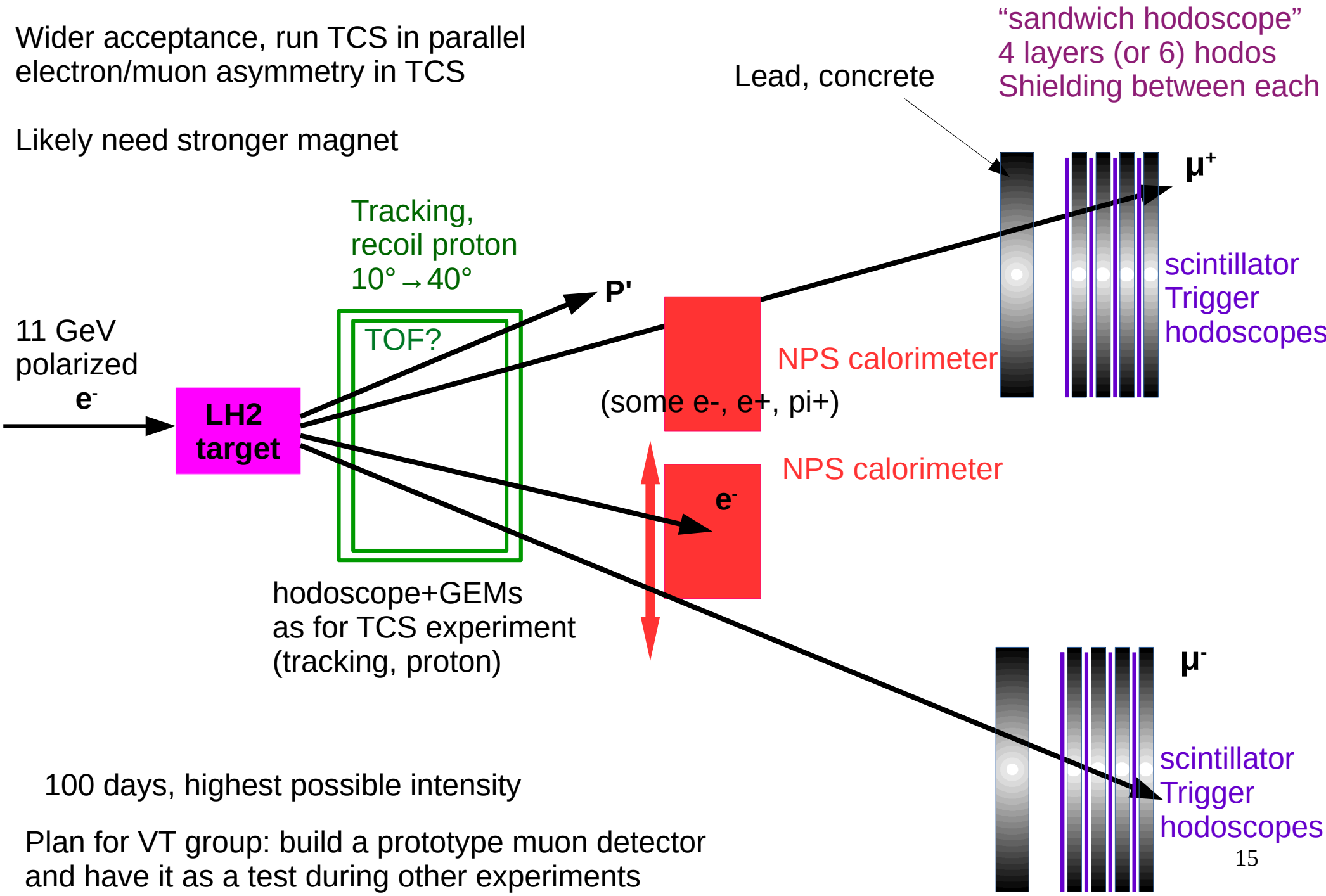
100 days, highest possible intensity

Plan for VT group: build a prototype muon detector and have it as a test during other experiments

SETUP 2: starting from TCS with NPS

Wider acceptance, run TCS in parallel
electron/muon asymmetry in TCS

Likely need stronger magnet



100 days, highest possible intensity

Plan for VT group: build a prototype muon detector
and have it as a test during other experiments

SUMMARY

- Golden Channel, strong physics

- GPDs extracted “off diagonal” == extension to xi=0 for tomographic interpretations

- ERBL region (qq, “mesons” exchange…)

- Need muon detectors

- Some options for setups in Hall C

- Challenging but feasible

Lot of work remaining, we need to work all together to make it feasible!

Our plans at VT (~ 2 years):

- publication of pheno studies/simulations, physics

- full GEANT4 for realistic simu of various setups

- prototype, then full muon detector

References

Theory:

A. Belitsky, S. Muller, PRL 90 n2, 022001-1, 2003

M. Guidal, M. Vanderhaeghen, PRL 90 n1, 022001-1, 2003

M. Diehl, Generalized Parton Distributions, physics report 388 (2003) 41-277
see around page 164, + other parts before and after

S. Wallon, Hard exclusive processes in perturbative QCD, from medium to asymptotical energies (updated 2017) see after page 109 + other parts after

Some past experimental studies:

LOI 2015 SoLID
LOI 2016 CLAS12
Shenying Zhao SPIN conference 2018

Slide, diagram, studies in this talk: MB