Rosenbluth Separation of electropion production cross-section from Hydrogen and Carbon

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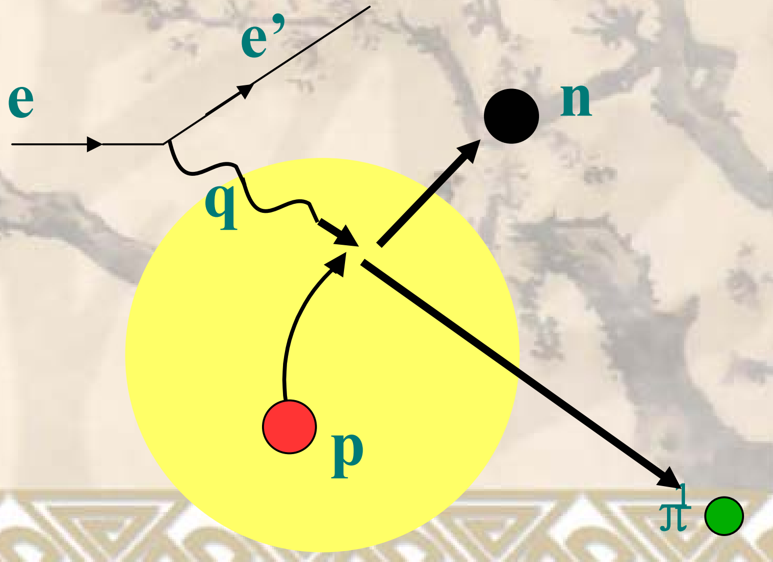
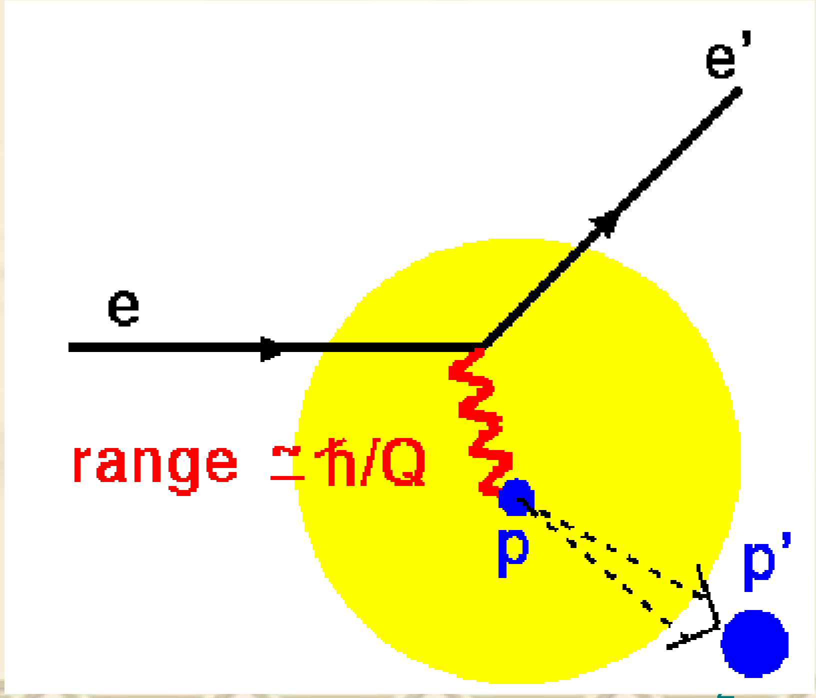
- Motivation
- Overview of E01-107
- Method Description
- Preliminary results
- Summary



Motivation of E01-107

- Search for Color-Transparency
- **Colour Transparency is a phenomenon predicted by QCD in which hadrons produced at large momentum transfer can pass through nuclear matter with little or no interaction**

- $\bar{q}q$ or qqq that have small transverse size are preferentially selected at large Q^2 **(Quantum mechanics)**
- The hadron can propagate out of the nucleus before returning to its equilibrium size **(Relativity)**
- Reduced interaction, $\sigma_{PLC} \propto (r_{PLC})^2$



From Ben Clasie

Motivation of Rosenbluth Separation

- Measuring Nuclear Transparency
  - Nuclear Transparency is defined by :

$$R_T = \frac{Y_{data}^{nucleus} / Y_{SIMC}^{nucleus}}{Y_{data}^{hydrogen} / Y_{SIMC}^{hydrogen}}$$

    - Expected Yield can be calculated used realistic nucleon momentum distributions **<u>under quasi-free assumption</u>**.
  - Quasi-free assumption can be verified by carrying out Rosenbluth separation.

$$\frac{\sigma_L^{hydrogen}}{\sigma_T^{hydrogen}} \sim \frac{\sigma_L^{nucleus}}{\sigma_T^{nucleus}}$$

Kinematics

- Electro pion five-fold DXs can be written as:

$$\frac{d^5\sigma}{d\Omega_e dE_e d\Omega_\pi} = \Gamma \frac{d^2\sigma}{d\Omega_\pi}$$

Γ : virtual photon flux.

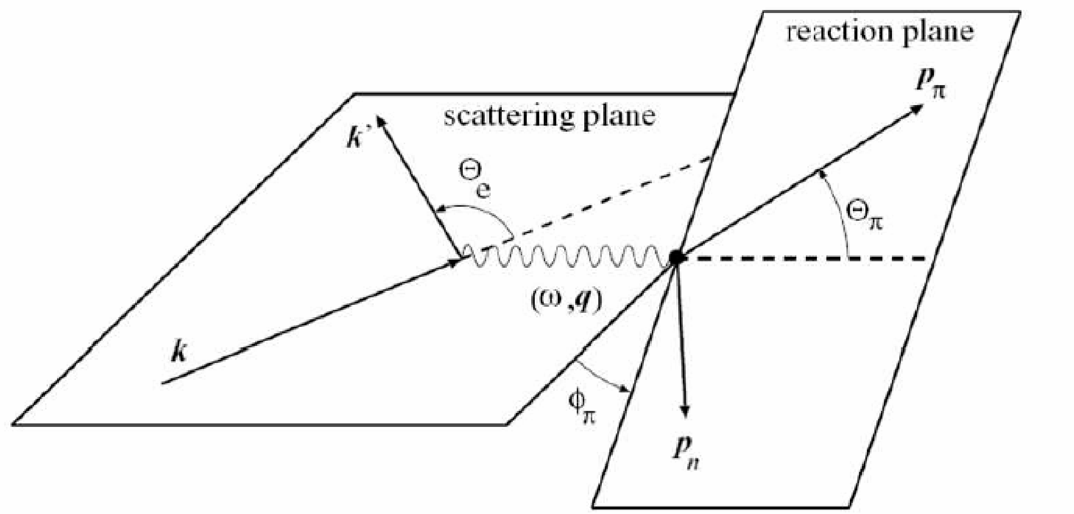


FIGURE 1. The $(e, e'\pi)$ reaction in lab frame.

- Photo pion DXs can be decomposed by virtual photon polarization:

In parallel kinematics ($\theta_\pi = 0$)

$$\frac{d^2\sigma}{d\Omega_\pi} = \epsilon\frac{d^2\sigma_L}{d\Omega_\pi} + \frac{d^2\sigma_T}{d\Omega_\pi} + \sqrt{2\epsilon(\epsilon+1)}\frac{d^2\sigma_{LT}}{d\Omega_\pi}\cos(\phi_\pi) + \epsilon\frac{d^2\sigma_{TT}}{d\Omega_\pi}\cos(2\phi_\pi)$$

ε : virtual photon polarization

Average method

$$<\frac{d^2\sigma_1}{d\Omega_\pi}>=<\epsilon_1>\cdot<\frac{d^2\sigma_{L1}}{d\Omega_\pi}>+<\frac{d^2\sigma_{T1}}{d\Omega_\pi}>$$

$$<\frac{d^2\sigma_2}{d\Omega_\pi}>=<\epsilon_2>\cdot<\frac{d^2\sigma_{L2}}{d\Omega_\pi}>+<\frac{d^2\sigma_{T2}}{d\Omega_\pi}>$$

- If we define:

$$<\frac{d^2\sigma_{T1}}{d\Omega_\pi}>=\frac{\int\int\int\int\int_{\Delta\Omega_1}\frac{d^2\sigma_T}{d\Omega_\pi}(x,y,z)C(x,y,z,w,\epsilon)dxdydzdwd\epsilon}{\int\int\int\int\int_{\Delta\Omega_1}C(x,y,z,w,\epsilon)dxdydzdwd\epsilon}$$

$$<\epsilon_1>=\frac{\int\int\int\int\int_{\Delta\Omega_1}\epsilon(1)C(x,y,z,w,\epsilon)dxdydzdwd\epsilon}{\int\int\int\int\int_{\Delta\Omega_1}C(x,y,z,w,\epsilon)dxdydzdwd\epsilon}$$

$$<\frac{d^2\sigma_{L1}}{d\Omega_\pi}>=\frac{\int\int\int\int\int_{\Delta\Omega_1}\epsilon(1)\frac{d^2\sigma_L}{d\Omega_\pi}(x,y,z)C(x,y,z,w,\epsilon)dxdydzdwd\epsilon}{\int\int\int\int\int_{\Delta\Omega_1}\epsilon(1)C(x,y,z,w,\epsilon)dxdydzdwd\epsilon}$$

Rosenbluth Separation

- By performing experiment at two values of virtual photon polarization, we can extract longitudinal and transverse electro-pion production DXs:
  - If we assume:

$$< \frac{d^2\sigma_{L1}}{d\Omega_\pi} >=< \frac{d^2\sigma_{L2}}{d\Omega_\pi} >$$

$$< \frac{d^2\sigma_{T1}}{d\Omega_\pi} =< \frac{d^2\sigma_{T2}}{d\Omega_\pi} >$$

$$< \frac{d^2\sigma_L}{d\Omega_\pi} >= \frac{< \frac{d^2\sigma_1}{d\Omega_\pi} > - < \frac{d^2\sigma_2}{d\Omega_\pi} >}{< \epsilon_1 > - < \epsilon_2 >}$$

$$< \frac{d^2\sigma_T}{d\Omega_\pi} >= \frac{< \frac{d^2\sigma_1}{d\Omega_\pi} > \cdot < \epsilon_2 > - < \frac{d^2\sigma_2}{d\Omega_\pi} > \cdot < \epsilon_1 >}{< \epsilon_1 > - < \epsilon_2 >}$$

Overview of E01-107

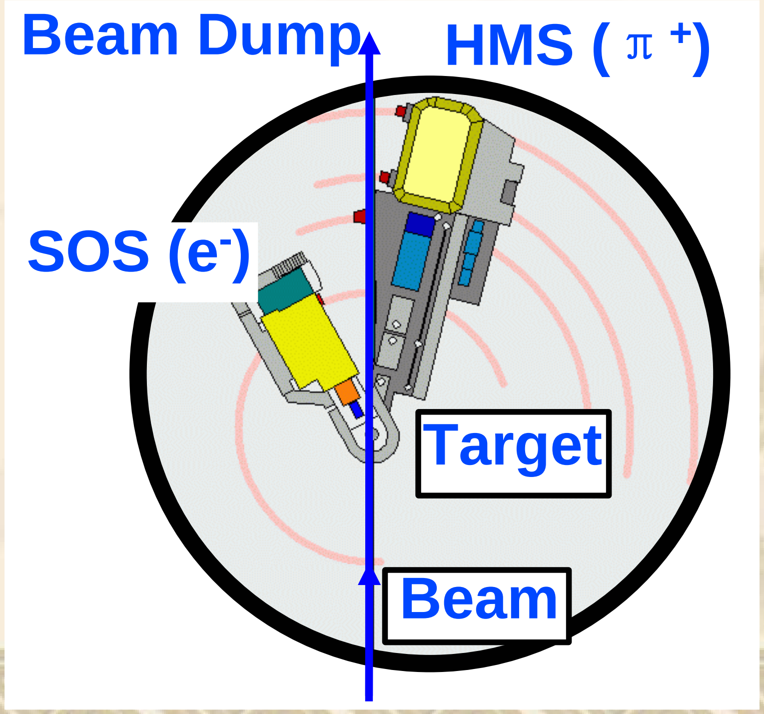
- Spokespersons: *D. Dutta*, *R. Ent* and *K. Garrow*
- Experiment ran at Jefferson Lab in Hall C in 2004
- Standard Hall C equipment was used

$(e,e' \pi^+)$

Electron beam energy (4.0 to 5.8 GeV)

Electron in the SOS (0.73 to 1.73 GeV/c)

Pion in the HMS (2.1 to 4.4 GeV/c)



From Ben Clasie

Kinematics

LH_2, LD_2, ^{12}C, ^{63}Cu and ^{197}Au targets at each kinematic setting

	Q^2 (GeV^2)	W (GeV)	-t (GeV^2)	E_{beam} (GeV)	θ_{hms} (deg)	P_{hms} (GeV/c)	θ_{sos} (deg)	P_{sos} (GeV/c)		x_{BJ}
	1.1	2.3	0.05	4.0	10.6	2.8	27.8	-1.2	0.50	0.21
	2.15	2.2	0.16	5.0	13.4	3.2	28.9	-1.7	0.56	0.35
	3.0	2.1	0.29	5.0	12.7	3.4	37.8	-1.4	0.45	0.44
	4.0	2.2	0.40	5.8	11.5	4.1	40.4	-1.5	0.39	0.50
	4.8	2.2	0.52	5.8	10.6	4.4	52.7	-1.1	0.26	0.54
L-T separation	2.15	2.2	0.16	4.0	10.6	3.2	50.8	-0.7	0.27	0.35
L-T separation	4.0	2.1	0.44	5.0	10.6	3.9	55.9	-0.9	0.25	0.52
W vs k_π test point	2.15	1.7	0.37	4.0	20.0	2.1	32.3	-1.7	0.63	0.50

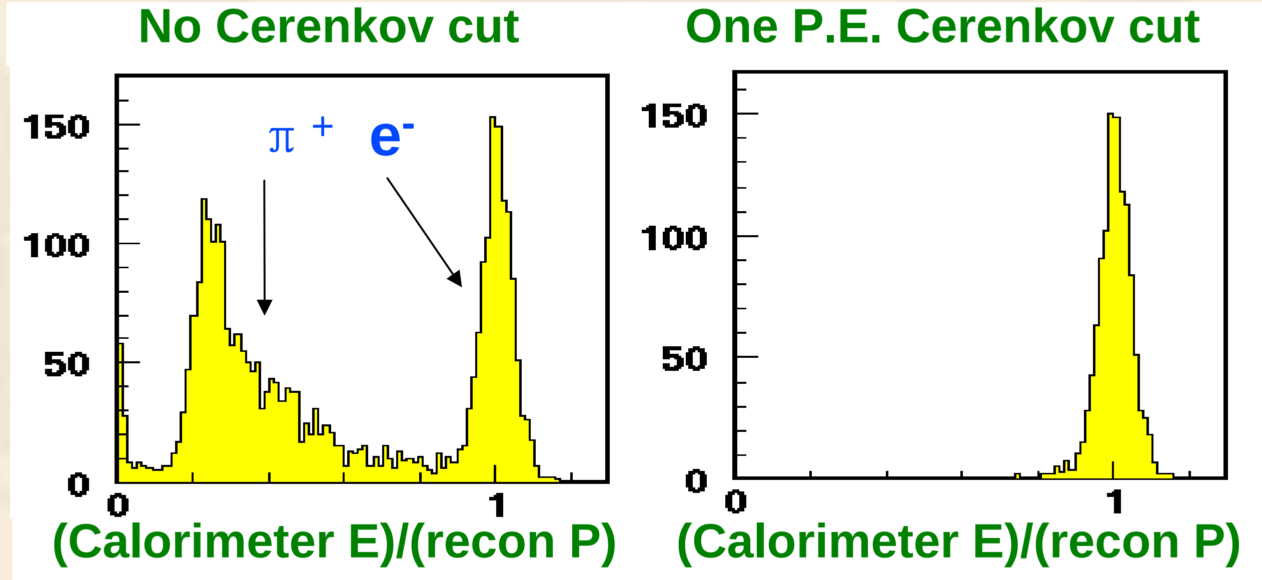
(k_π = momentum of the virtual pion)

From Ben Clasie

Particle Identification (PID)

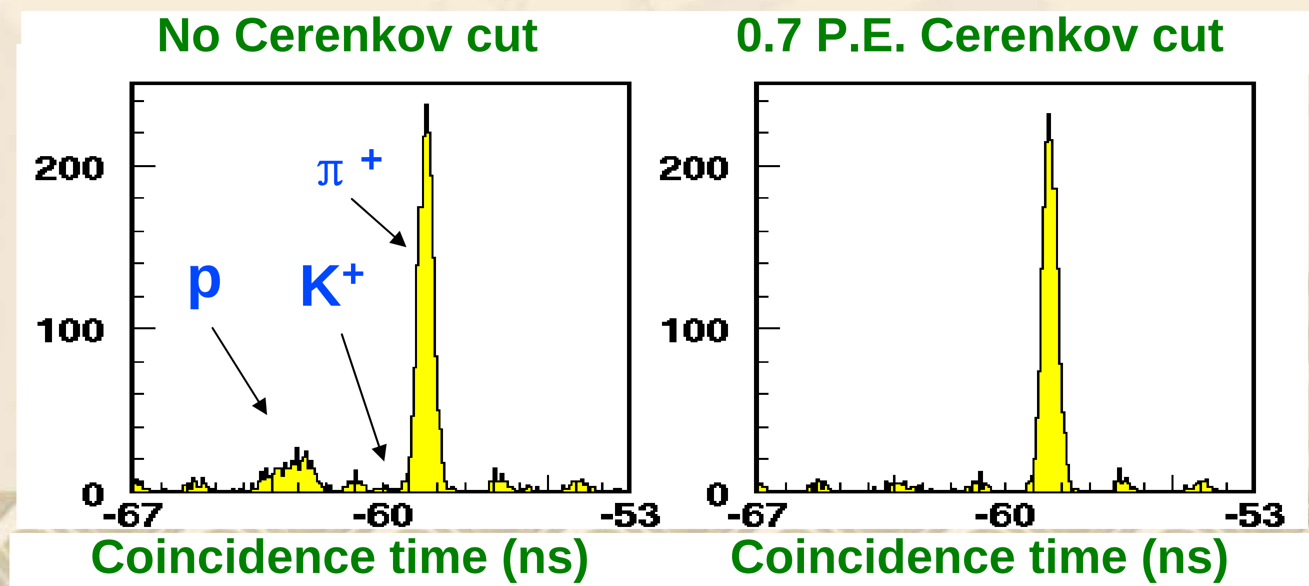
Electron arm (SOS) at 1.4 GeV

Cerenkov effic = 99.4%



Pion arm (HMS) at 3.2 GeV

Cerenkov effic = 98.5%



From Ben Clasie

Cross-section extraction

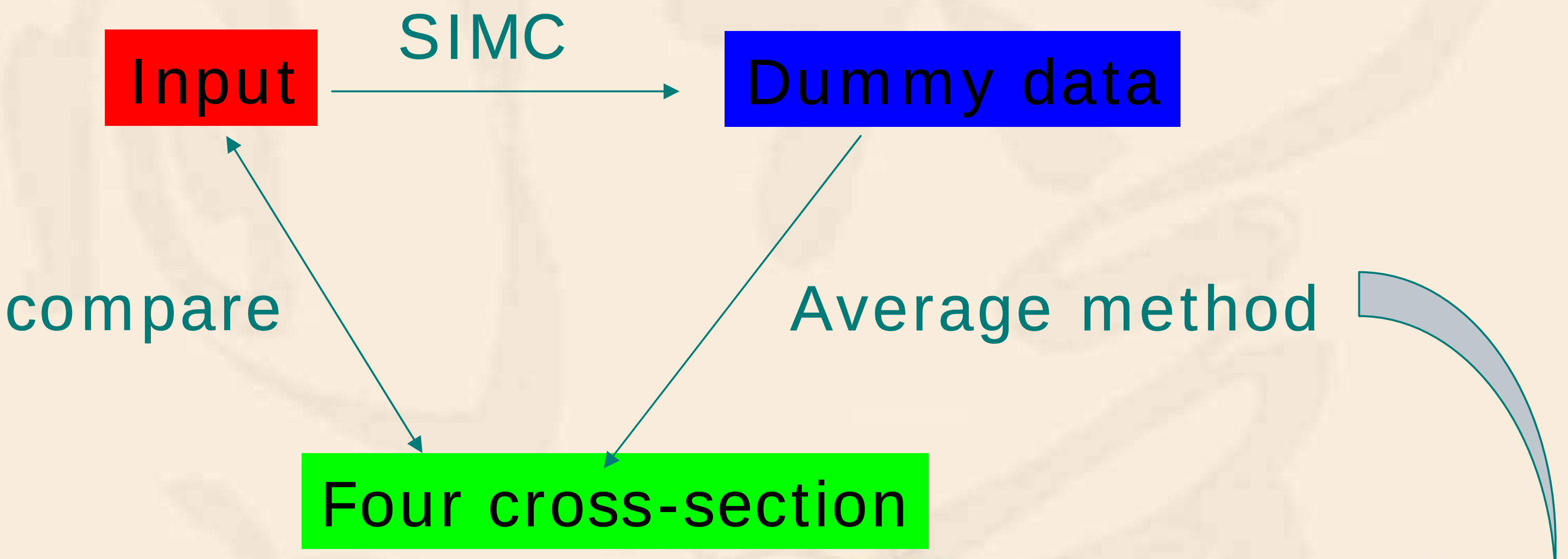
- Data yield:
  - PID and coincident cut
  - Dummy subtraction
  - Random coincident subtraction
  - Correct detector Cherenkov eff, electronic dead time, trigger eff, block corr, sync corr …
- SIMC yield
- Average DXs:

$$< \frac{d^2\sigma}{d\Omega} >= \frac{\int_{\Delta\Omega} \frac{d^2\sigma}{d\Omega} d\Omega}{\int_{\Delta\Omega} d\Omega} = \frac{\int_{\Delta\Omega} \frac{d^2\sigma}{d\Omega} d\Omega}{\Delta\Omega}$$

$$< \frac{d\sigma}{d\Omega} >_{exp} = \frac{Y_{exp}}{Y_{sim}} < \frac{d\sigma}{d\Omega} >_{MC}$$

- Set SIMC DXs = 1 in order to simplify.

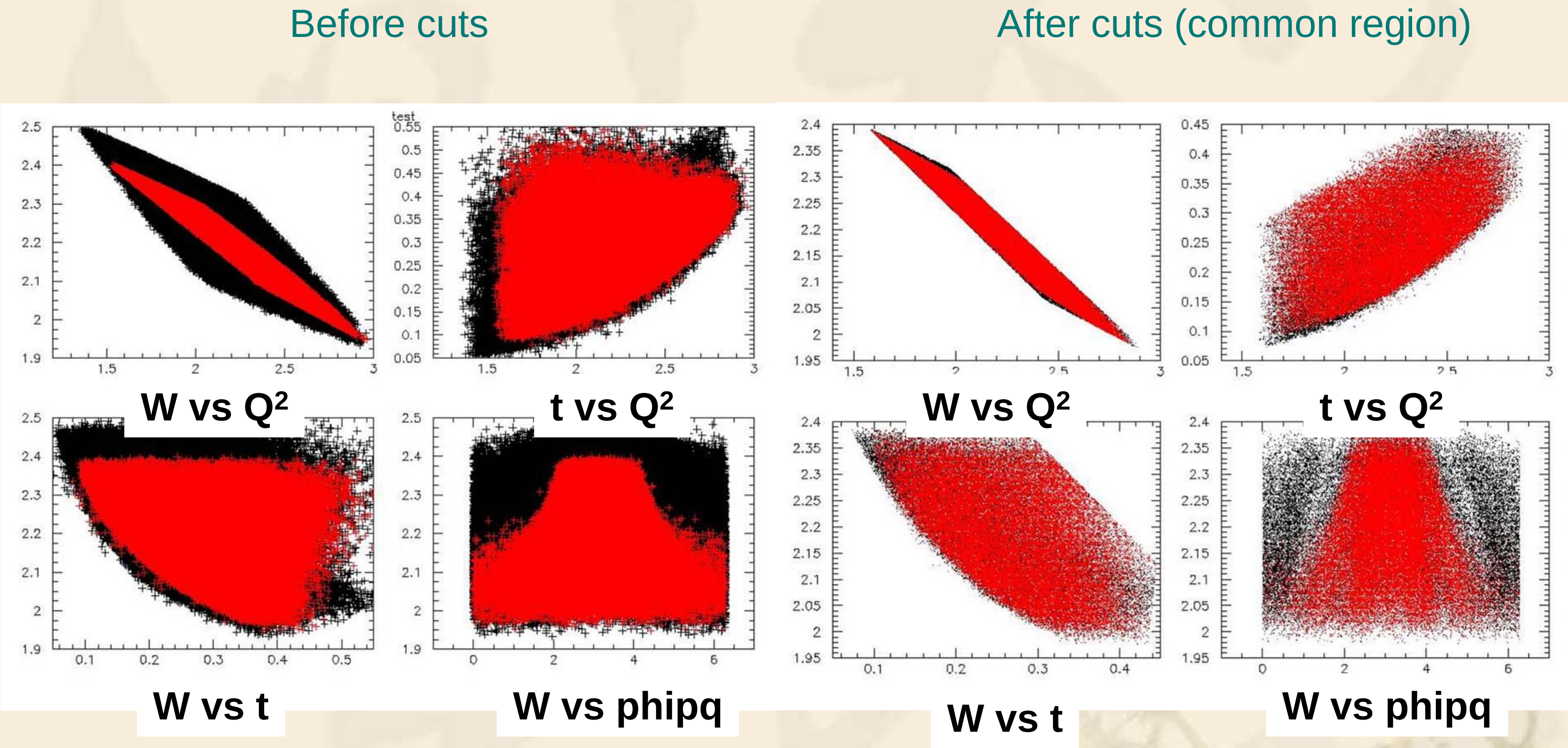
Analyzing the SIMC dummy data (method evaluation)



$$< \frac{d^2\sigma_L}{d\Omega_\pi} >= \frac{< \frac{d^2\sigma_1}{d\Omega_\pi} > - < \frac{d^2\sigma_2}{d\Omega_\pi} >}{< \epsilon_1 > - < \epsilon_2 >}$$

$$< \frac{d^2\sigma_T}{d\Omega_\pi} >= \frac{< \frac{d^2\sigma_1}{d\Omega_\pi} > \cdot < \epsilon_2 > - < \frac{d^2\sigma_2}{d\Omega_\pi} > \cdot < \epsilon_1 >}{< \epsilon_1 > - < \epsilon_2 >}$$

Phase space at $Q^2 = 2.15\ GeV^2$



- Red: high epsilon
- Black: low epsilon

Contribution from LT and TT DXs

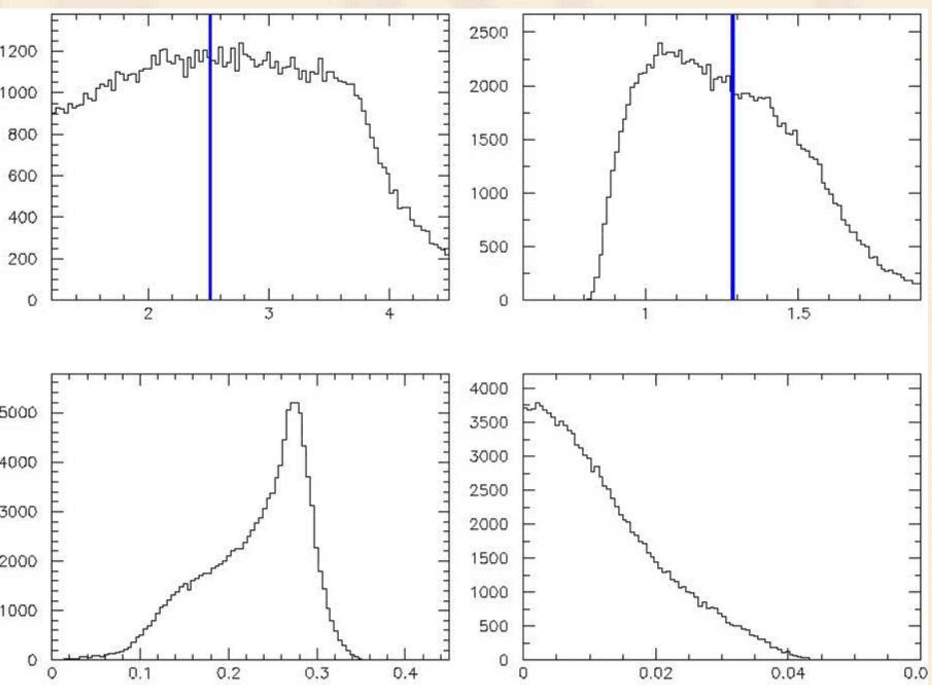
- LT and TT may have noticeable contribution in LT separation.
- Solutions:
  - Obtain LT and TT from theory, correct for their contribution. (Model dependence and large systematic uncertainties.)
  - Use fitting procedure or maxima-likelihood method to fit L, T, LT and TT (poor statistics for L and T, inaccurate reconstructed phi).
  - Divide ϕ into 3, extract DXs in each phi bin then average. (larger statistical error, not applicable for carbon data due to poor phi coverage)

$$\bar{\sigma} = \frac{\sigma_1(\varphi_1) + \sigma_2(\varphi_2) + \sigma_3(\varphi_3)}{3}$$

Two parameterizations as input

- Jochen's parameterization at this kinematics' range:

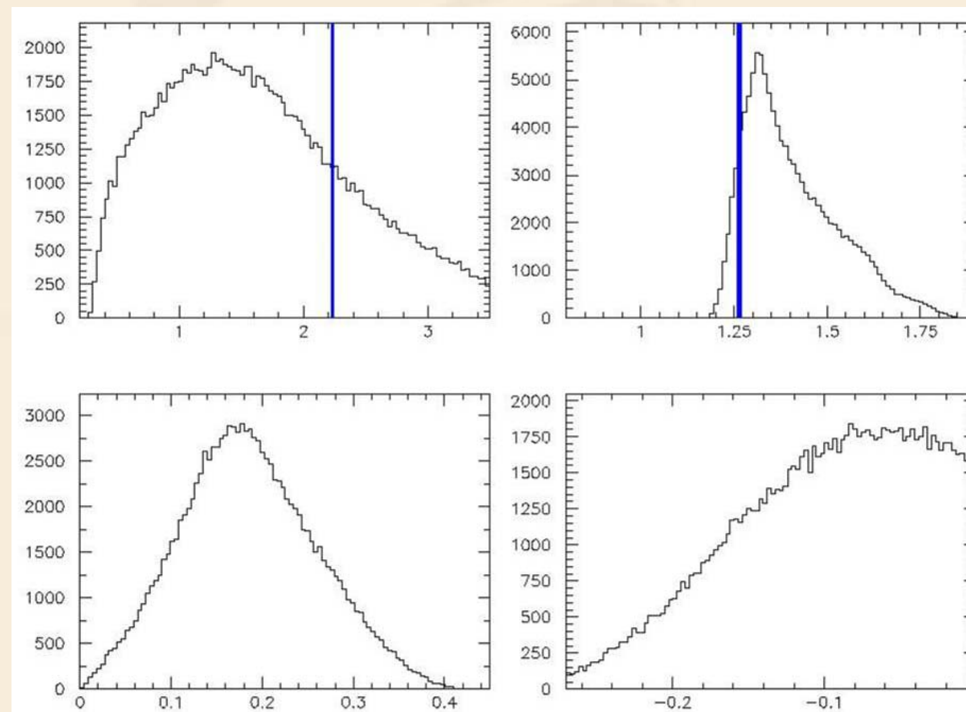
sigL sigT



sigLT sigTT

- Tanja's parameterization in this kinematics' range:

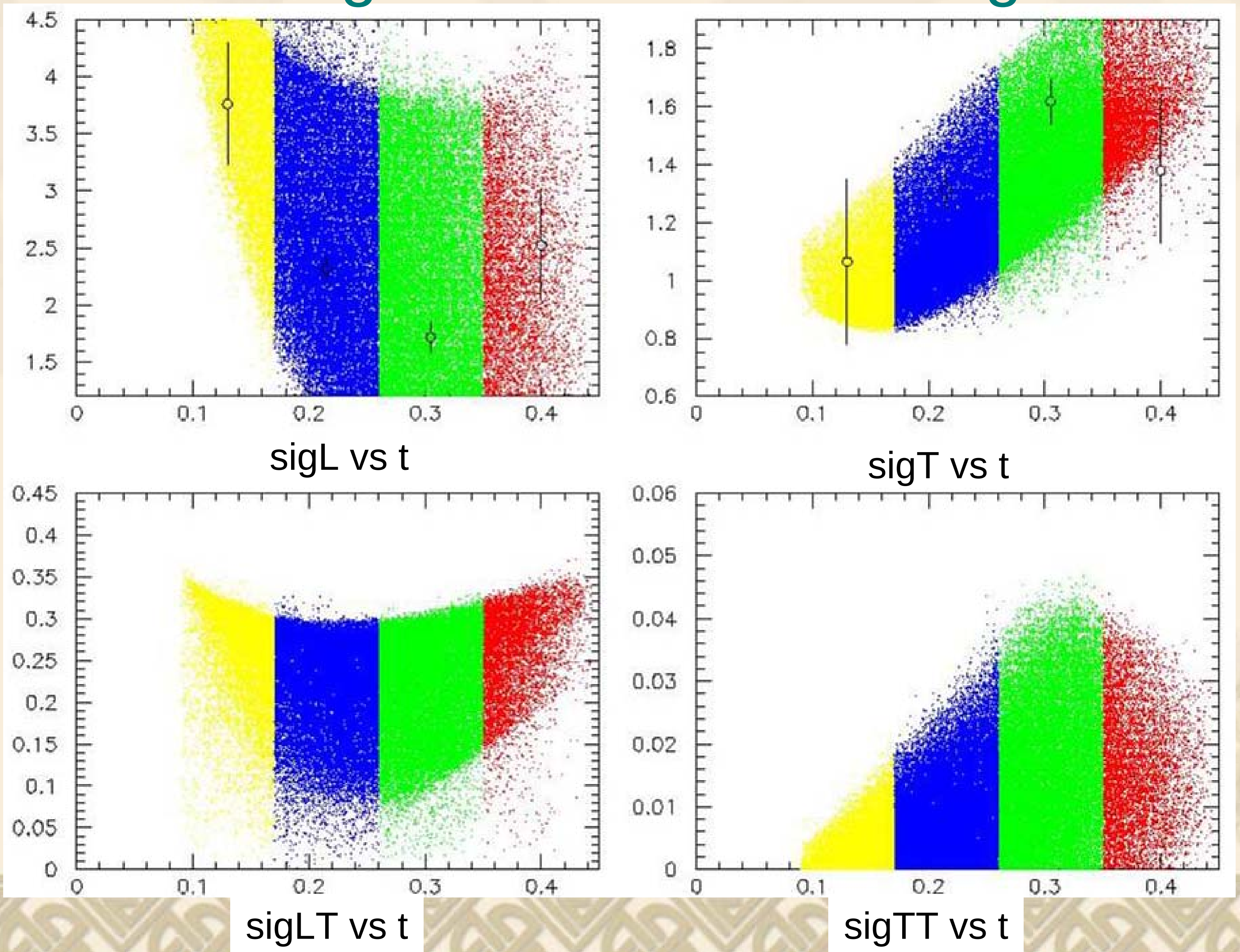
sigL sigT



sigLT sigTT

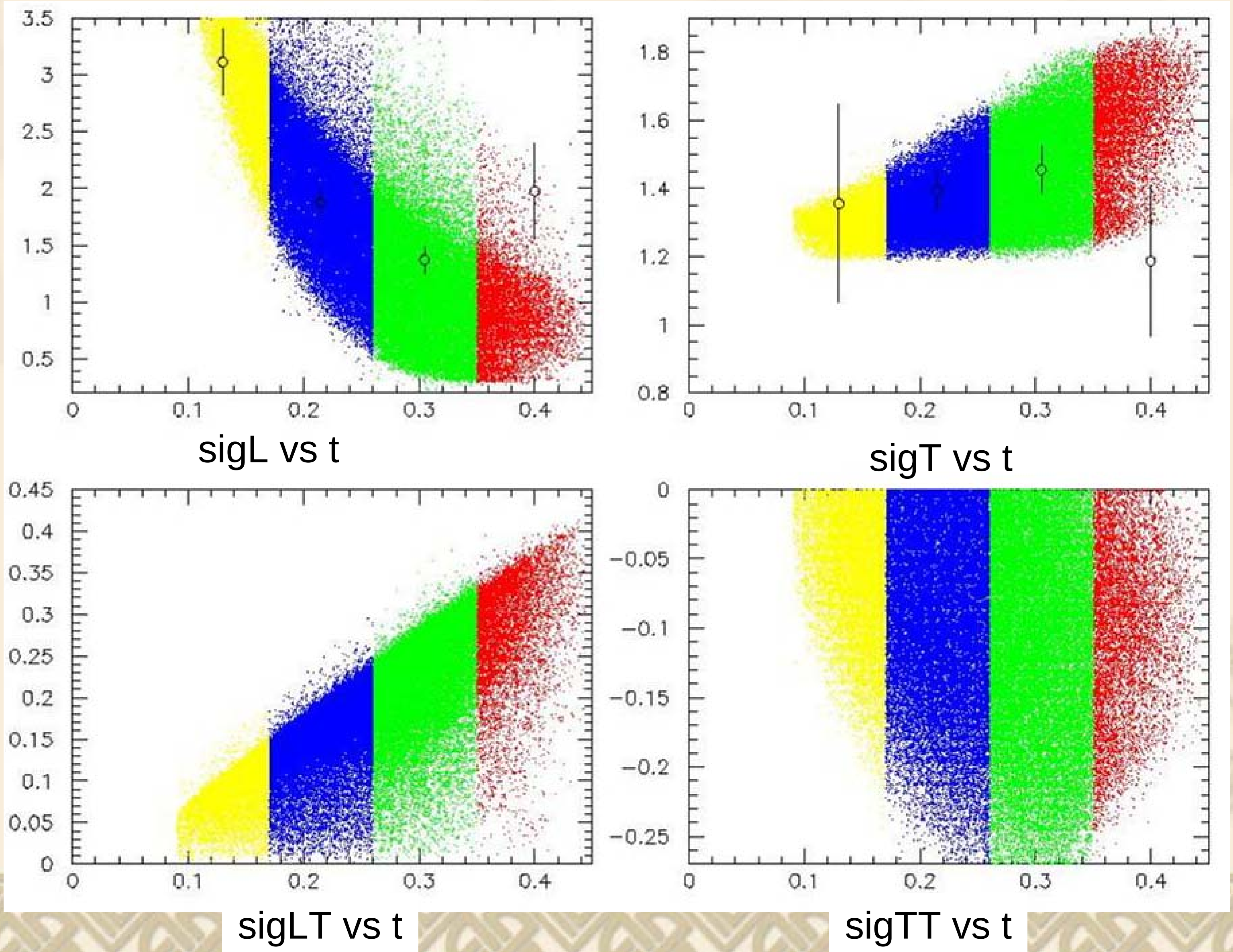
t-dependence (Jochen's model)

- Divide t region into four small regions.

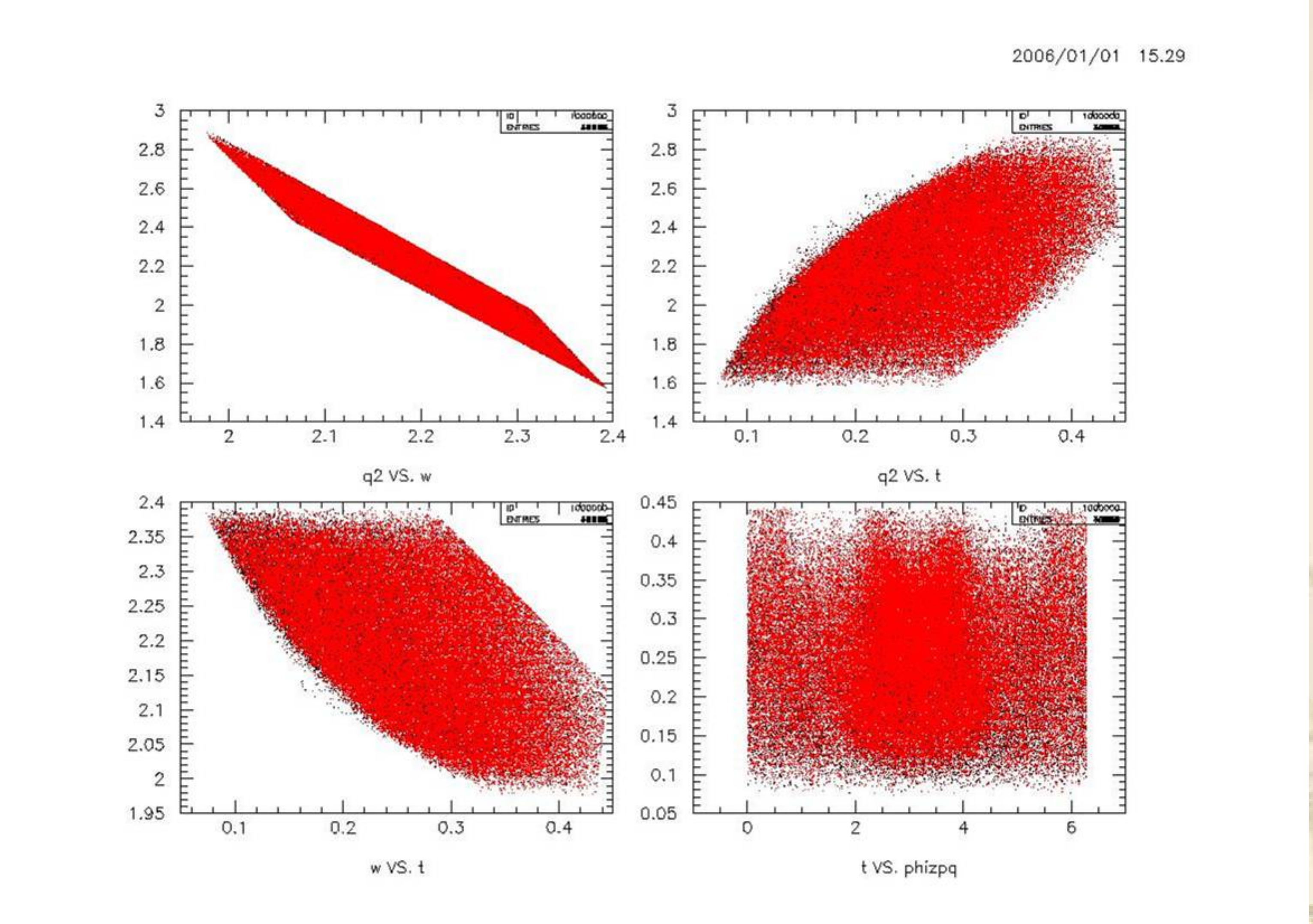


t-dependence (Tanja's model)

- Divide t region into four small regions.

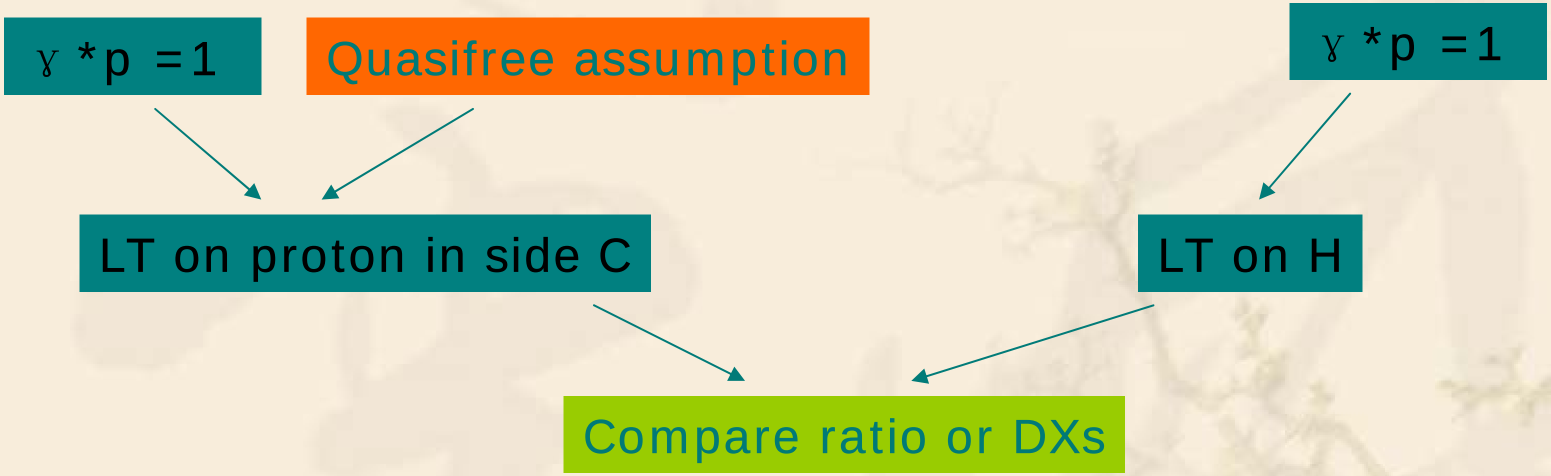


Phase space comparison between data and SIMC at $Q^2 = 2.15\ GeV^2$

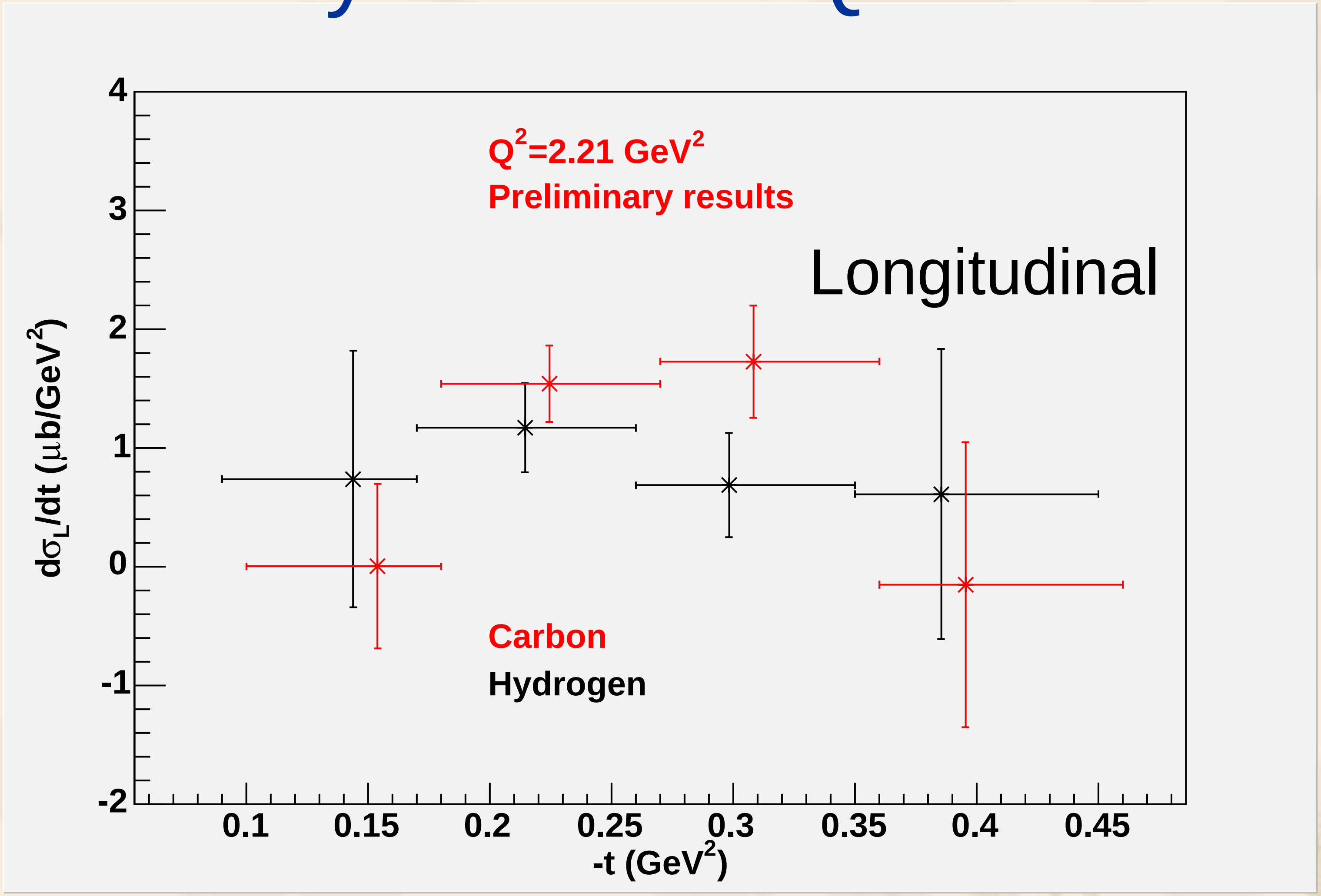


LT separation on Carbon

- Analyze the Carbon data at two Q^2.
  - Under quasi-free assumption
  - Set γ^*p CM DXs=1 (γ^* : virtual photon)



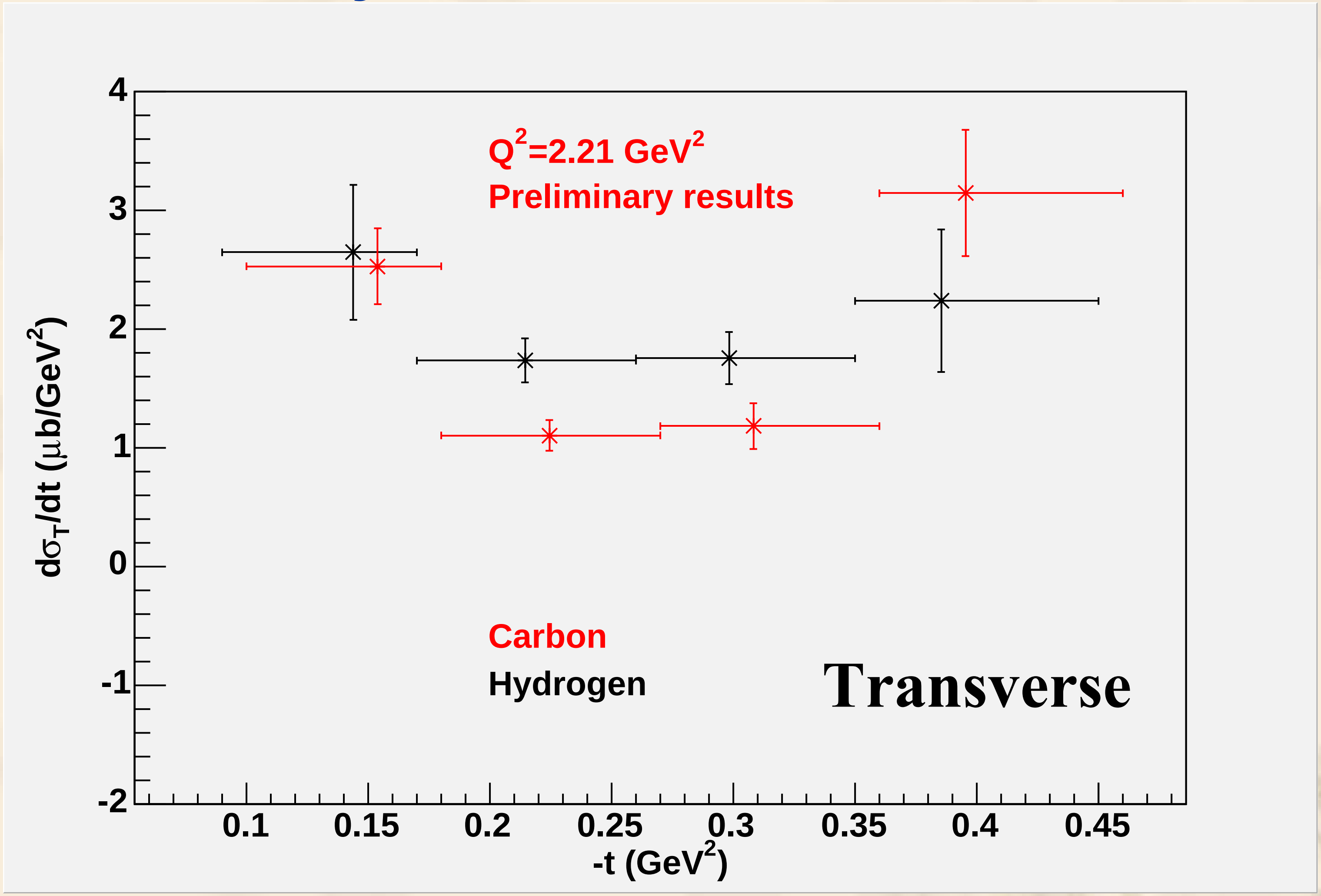
Preliminary results at Q^2 =2.15 GeV^2



statistical uncertainties only

Carbon points have be shifted by 0.01 for clarity

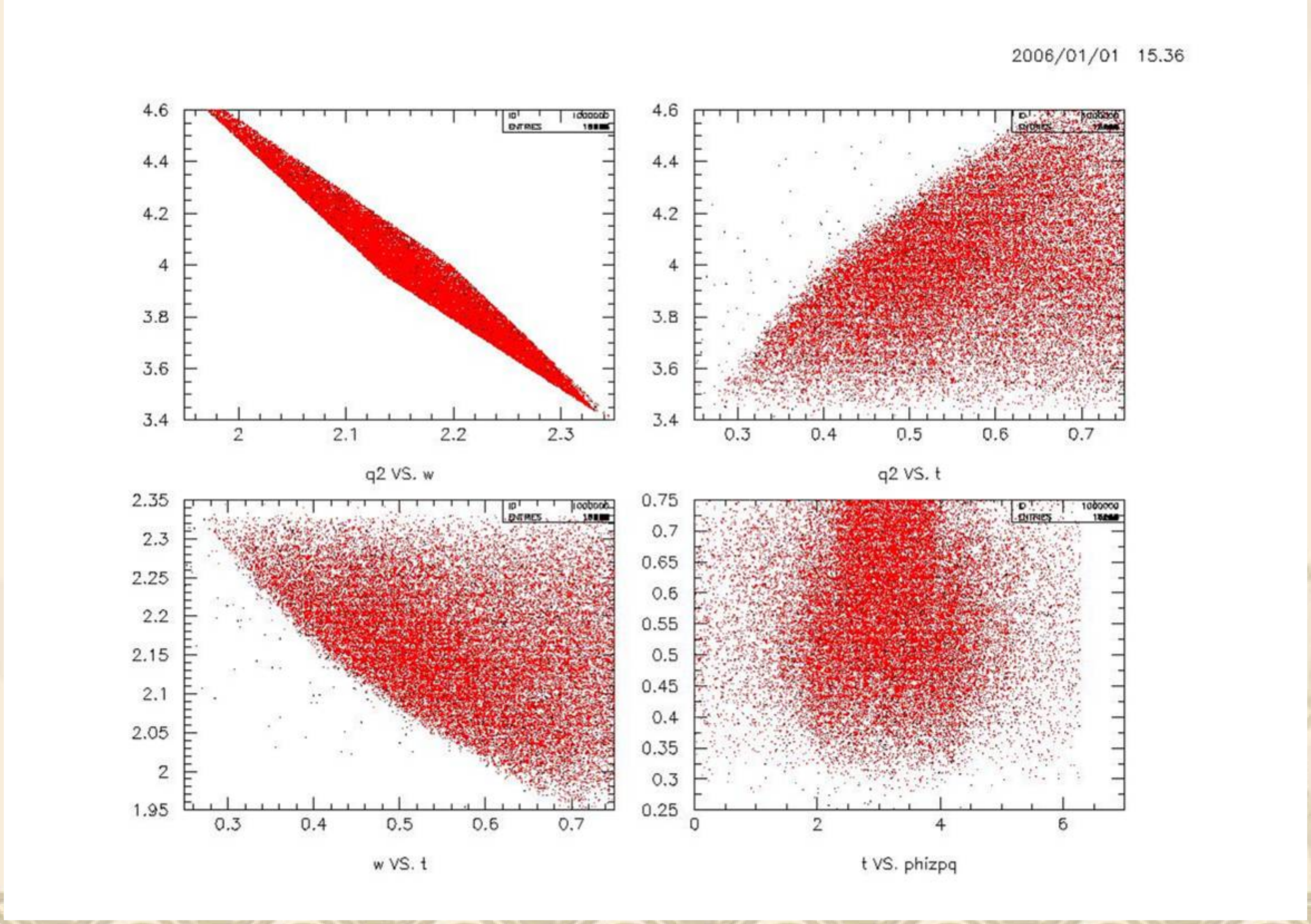
Preliminary results at $Q^2 = 2.15\ GeV^2$



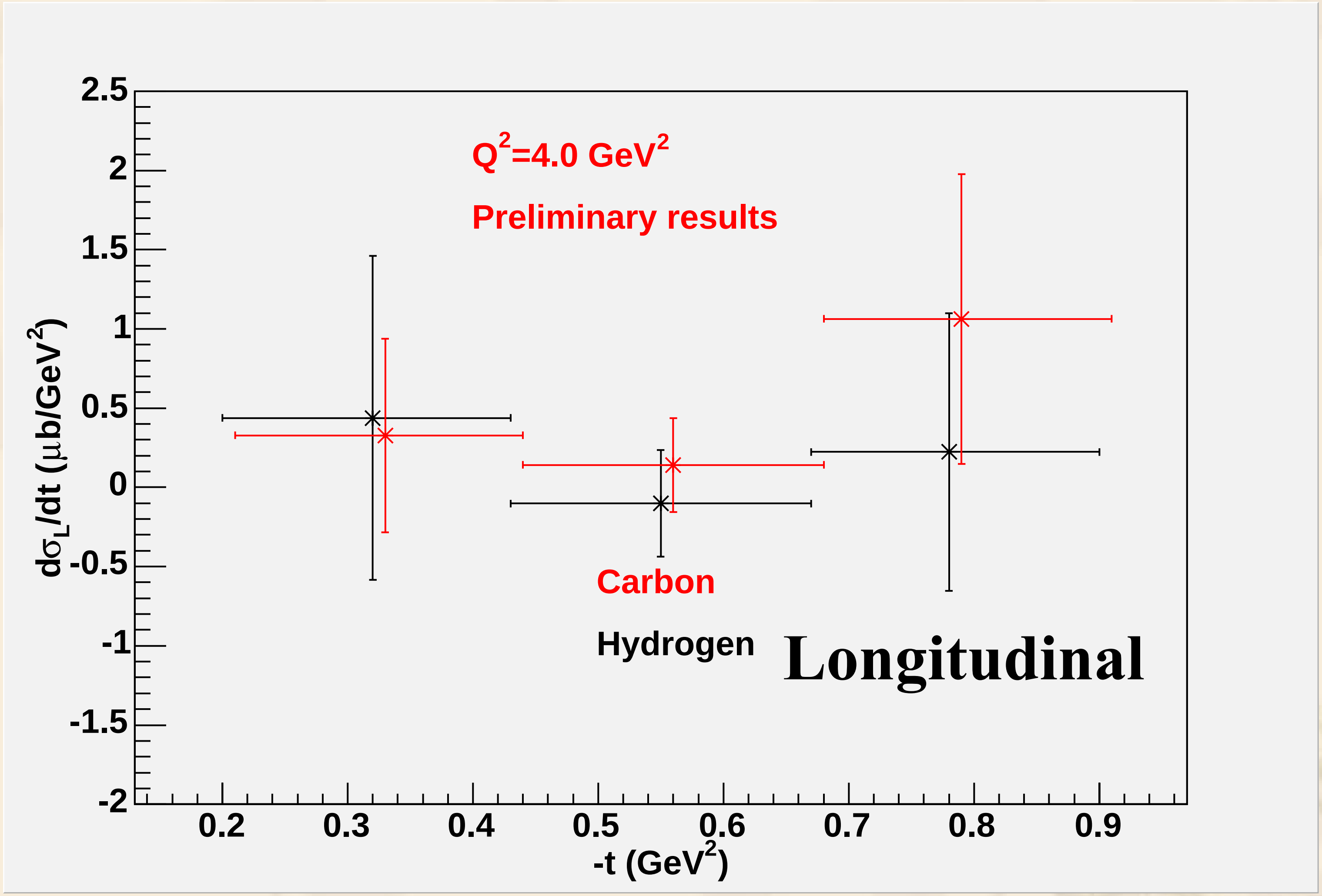
statistical uncertainties only

Carbon points have be shifted by 0.01 for clarity

Phase space comparison between data and SIMC at $Q^2 = 4.0$ GeV^2



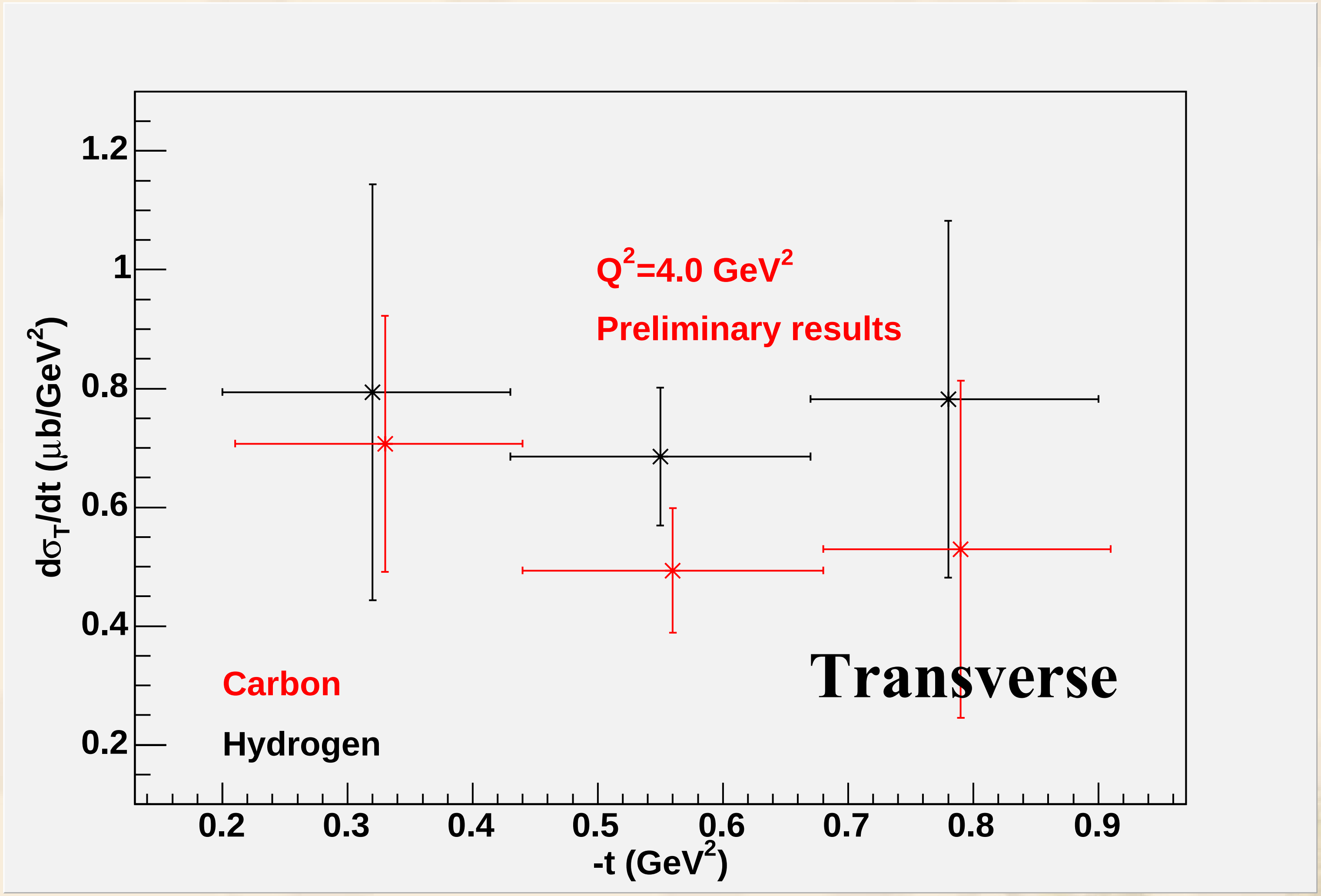
Preliminary results at Q^2 =4.0 GeV^2



statistical uncertainties only

Carbon points have be shifted by 0.01 for clarity

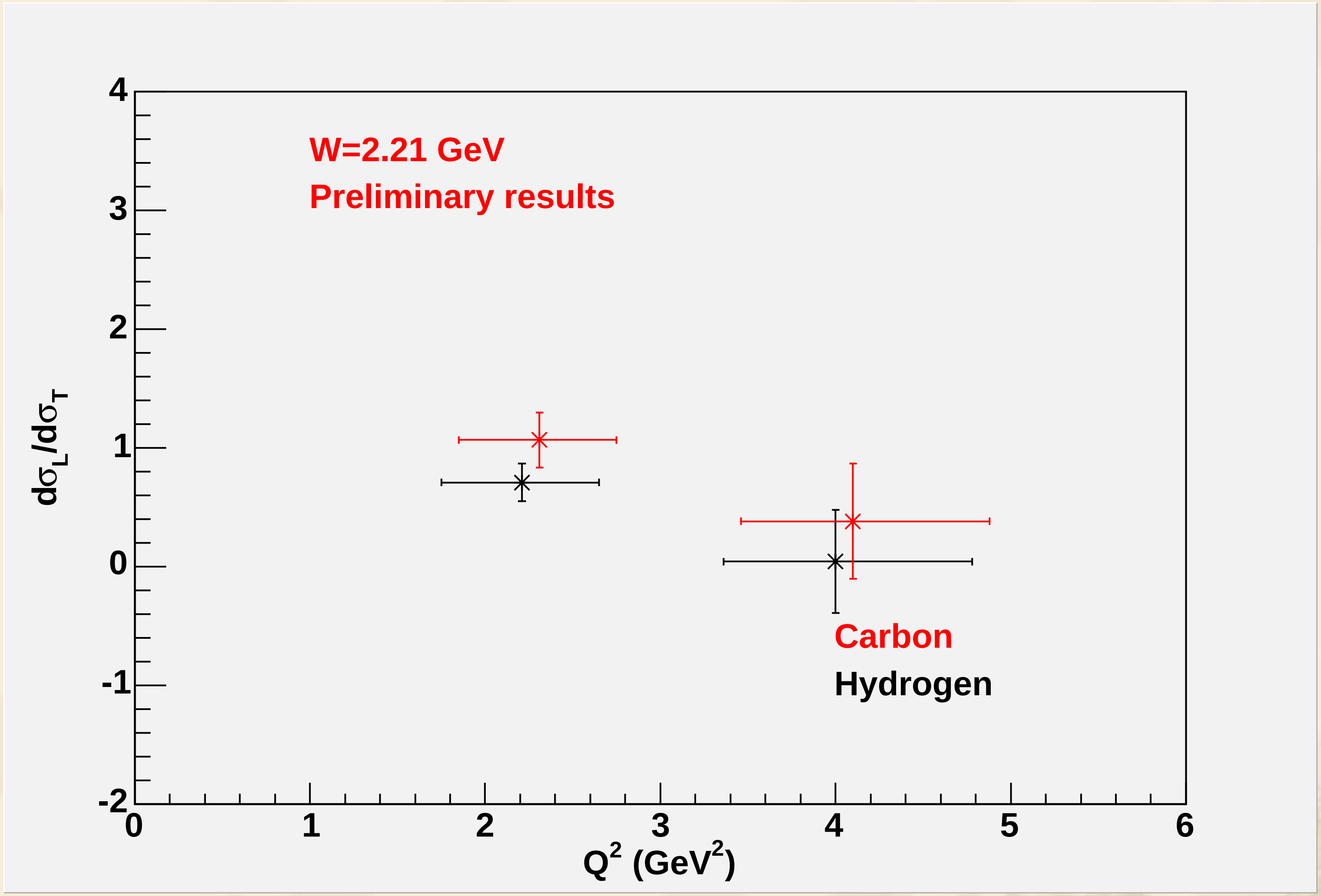
Preliminary results at Q^2 =4.0 GeV^2



statistical uncertainties only

Carbon points have be shifted by 0.01 for clarity

Preliminary results on ratio



statistical uncertainties only

Carbon points have be shifted by 0.1 for clarity

Systematic uncertainty estimation

- SOS Cerenkov Efficiency 0.5 (pt to pt)
- HMS Cerenkov Efficiency 1.0 (pt to pt)
- Charge 1.0 (Normalization)
- Target thickness 1.0 (Normalization)
- HMS and SOS trigger efficiency 2.0 (Pt to Pt)
- Computer dead time 0.1
- Coincidence blocking 0.1
- Tracking efficiency 0.5
- Pion absorption 3.0 (normalization)
- Pion absorption (between target) 1.0
- Kinematics Ebeam 0.5
- Kinematics sstheta 0.5

Hydrogen DXs: 7.99 %

- Kinematics spcentral 0.5
- Kinematics hstheta 0.3
- Kinematics hpcentral 0.3
- Pion decay 2.0 (Pt to Pt)
- Collimator punch-through 3.0 (Pt to Pt)
- Radiative correction 2.5 (Pt to Pt)
- Acceptance 5.0 (Pt to Pt)
- Dummy subtraction 0.2 (Pt to Pt)
- HMS electronic dead time 0.4
- SOS electronic dead time 0.3
- Target boiling 1.0 (Normalization)
- Carbon spectral function 1.0 (Normalization)
- Model dependence 10.0

Carbon DXs: 12.84 %

The estimated systematic uncertainties at this stage are 7% pt-pt, 3.6% normalization and 10% model dependent. We expect to improve several of these uncertainties.

Summary

- **E01-107 will provide the FIRST nuclear transparency data from (e,e π^+) reactions.**
- **Rosenbluth separation has been carried out for the first time with (e,e' π^+) on Carbon at Q^2 = 2.15 and 4.0 GeV^2 and Hydrogen at Q^2 = 4.0 GeV^2.**
- **Preliminary results are in good agreement with quasi-free assumptions for Q^2 = 2.15 and 4.0 GeV^2.**
- **Need more careful study on LT and TT contribution.**
- **Rosenbluth separation for Copper and Gold targets will be carried out in the near future.**

E01-107 collaboration

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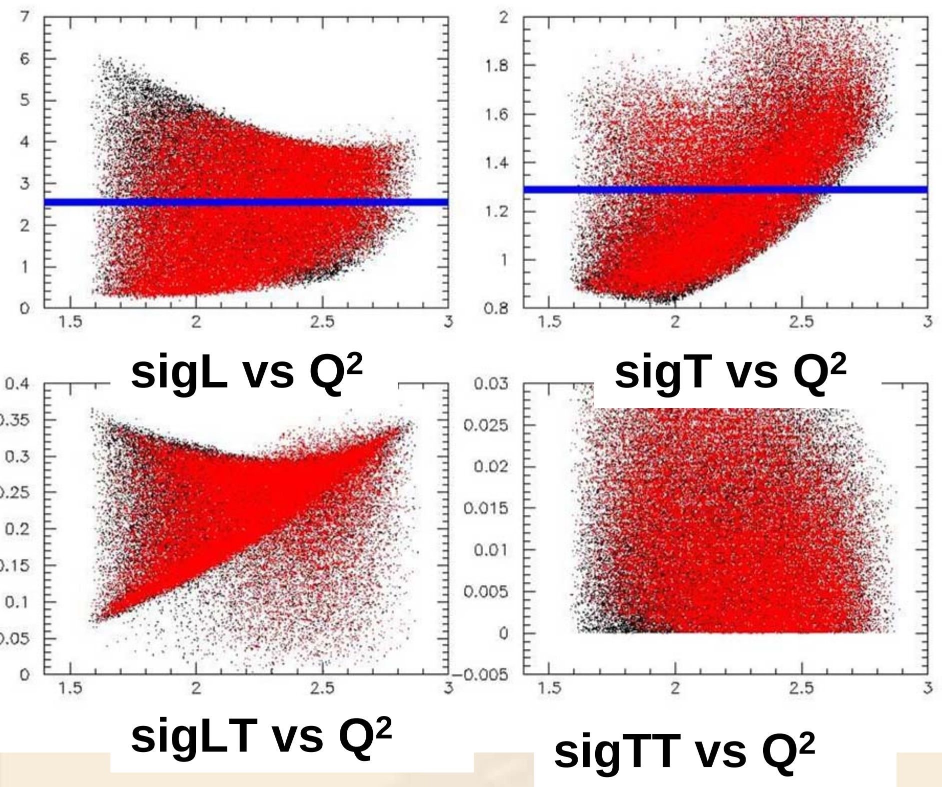
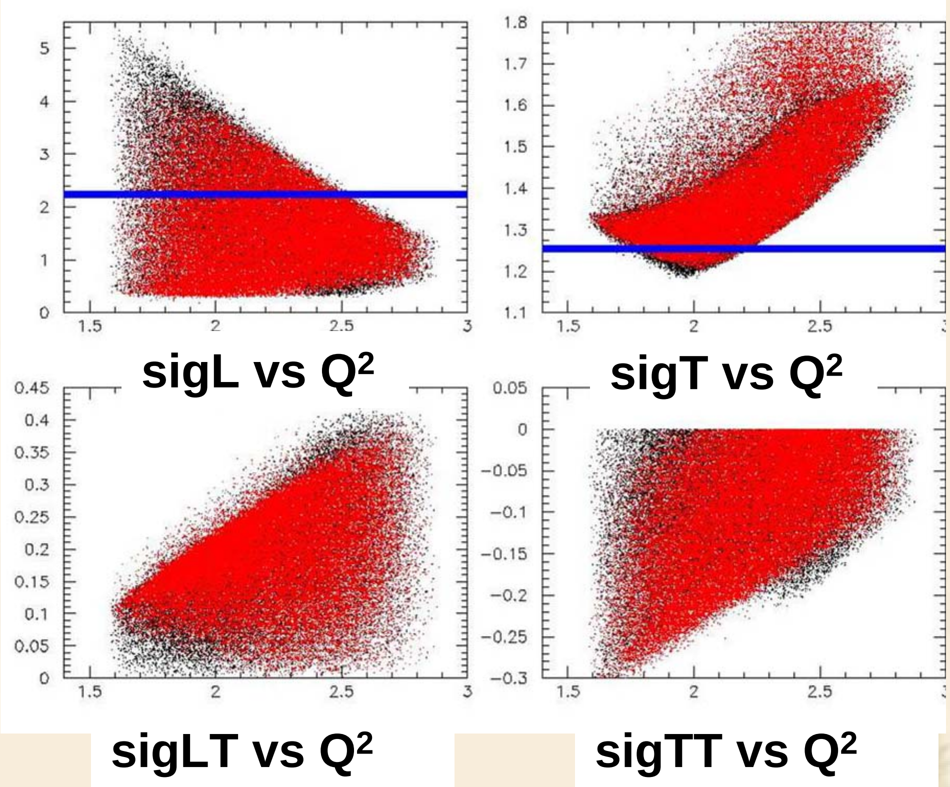
Two parameterizations as input

- Jochen's parameterization at this kinematics' range:

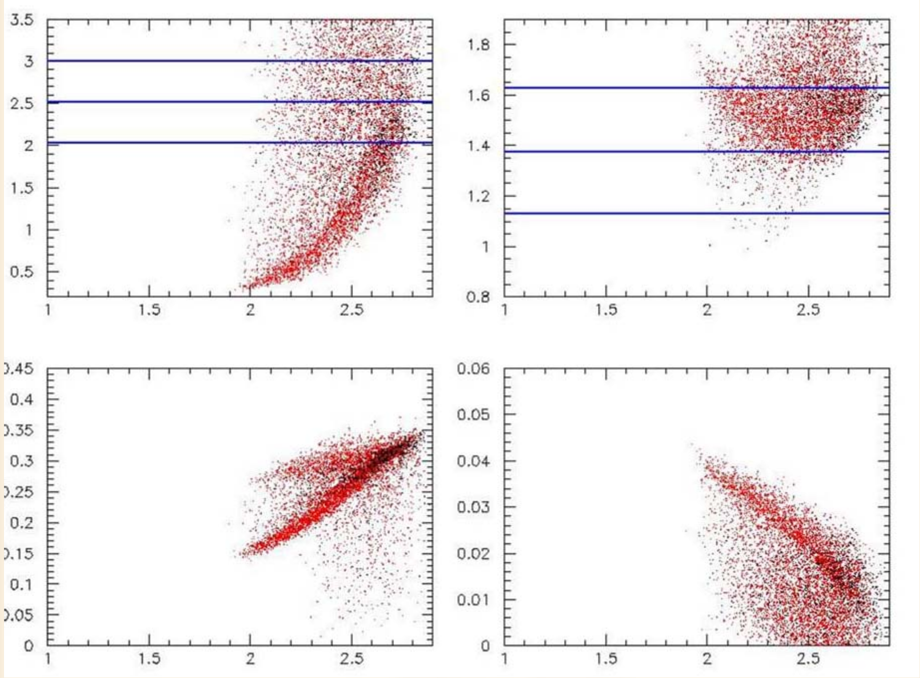


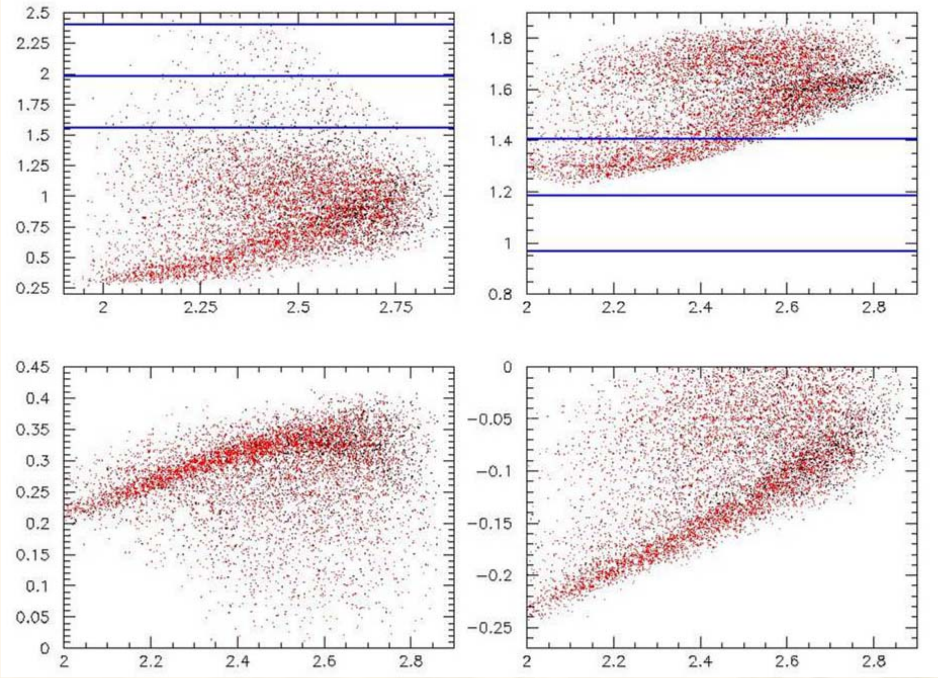
- Tanja's parameterization in this kinematics' range:



t-dependence

- Divide t region into four small regions.
- Do the comparison on all four bins for different models.



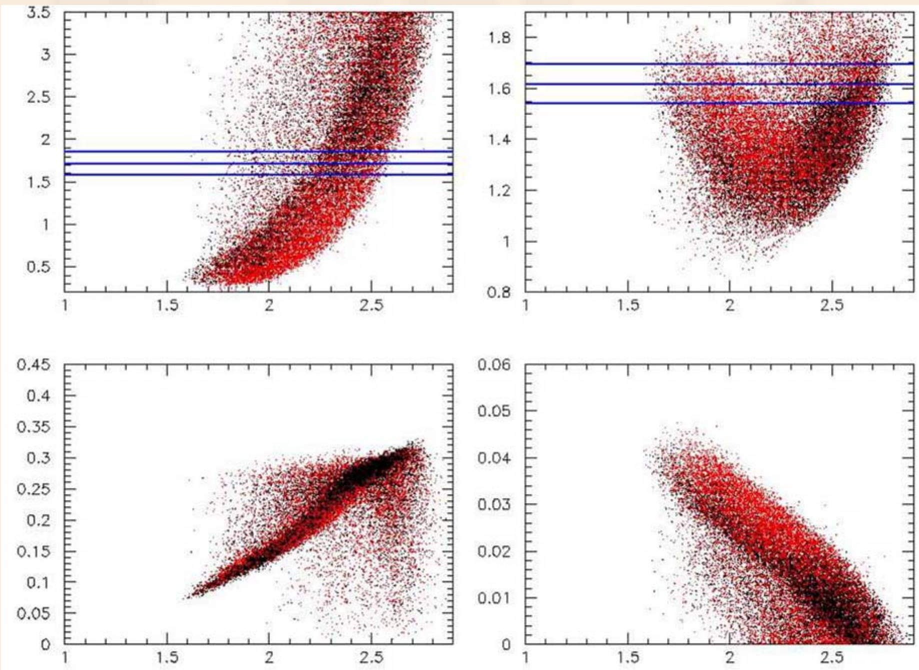


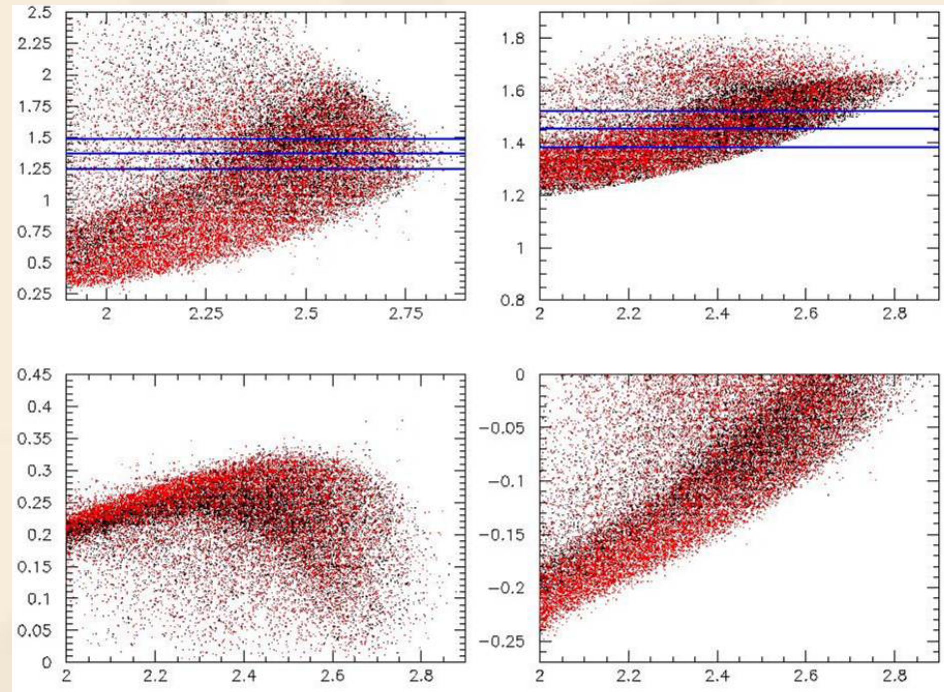
Jochen’s

(0.45 > t > 0.35)

Tanja’s

t-dependence



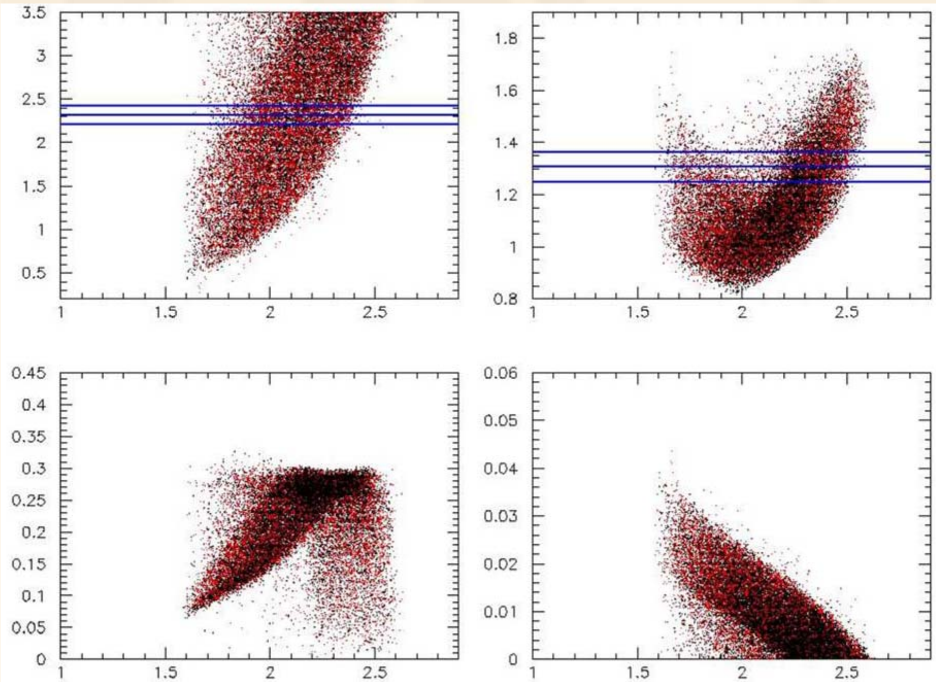


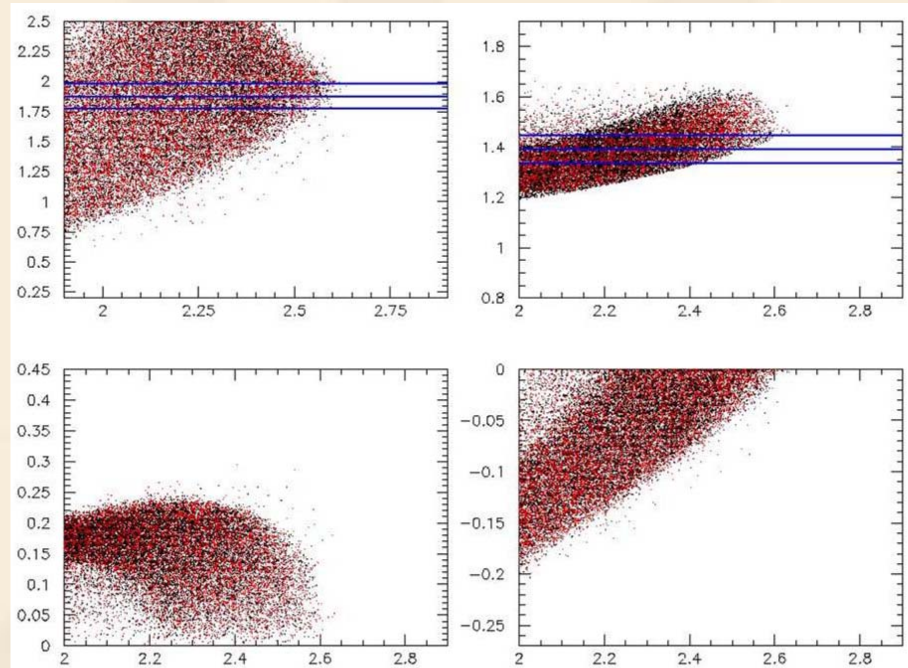
Jochen's

(0.35 > t > 0.26)

Tanja's

t-dependence



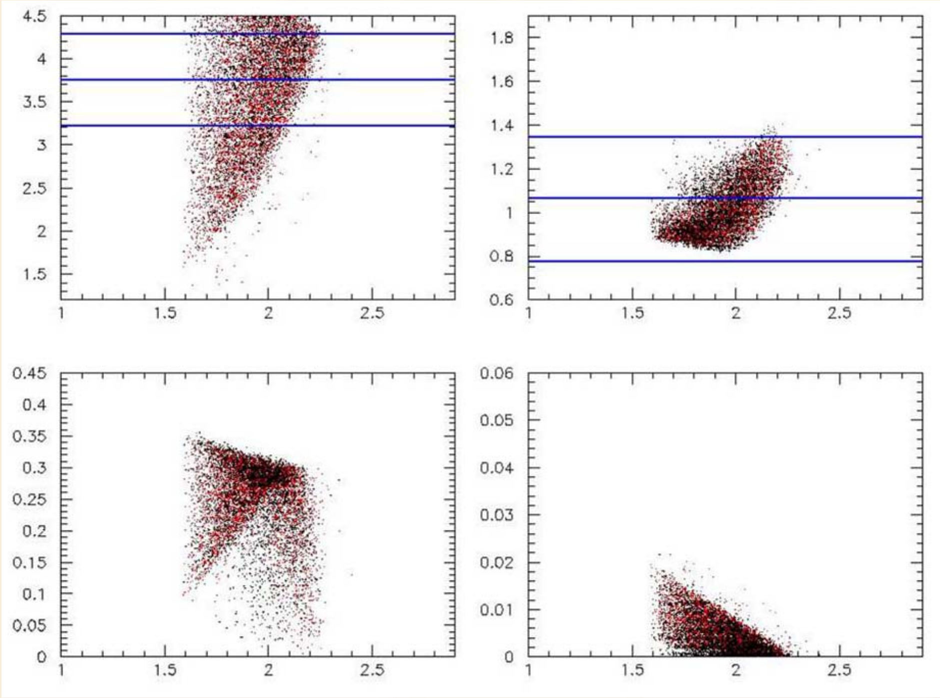


Jochen’s

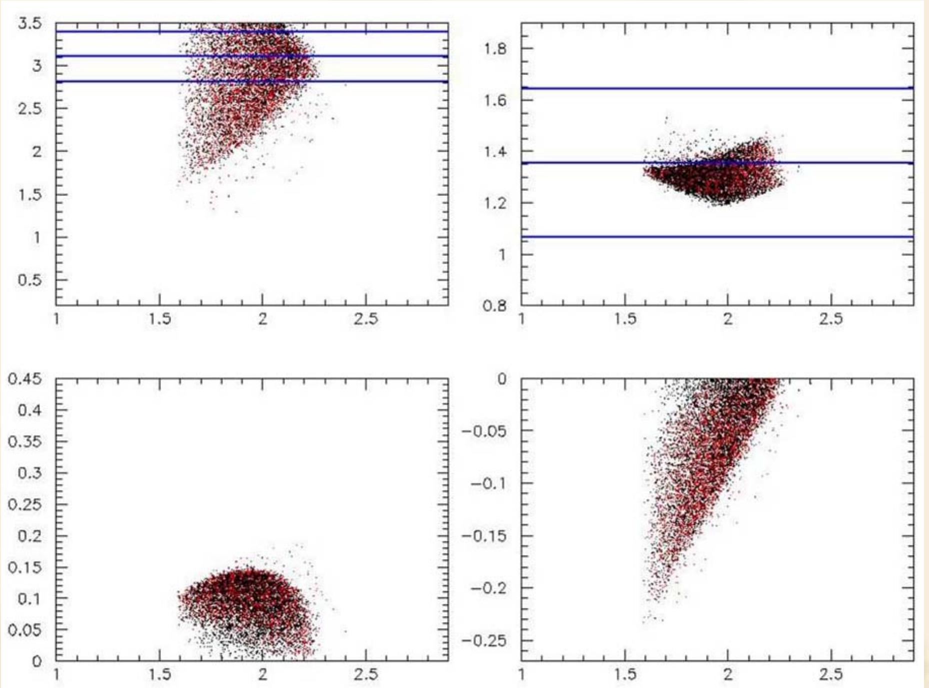
(0.26 > t > 0.17)

Tanja’s

t-dependence



Jochen's

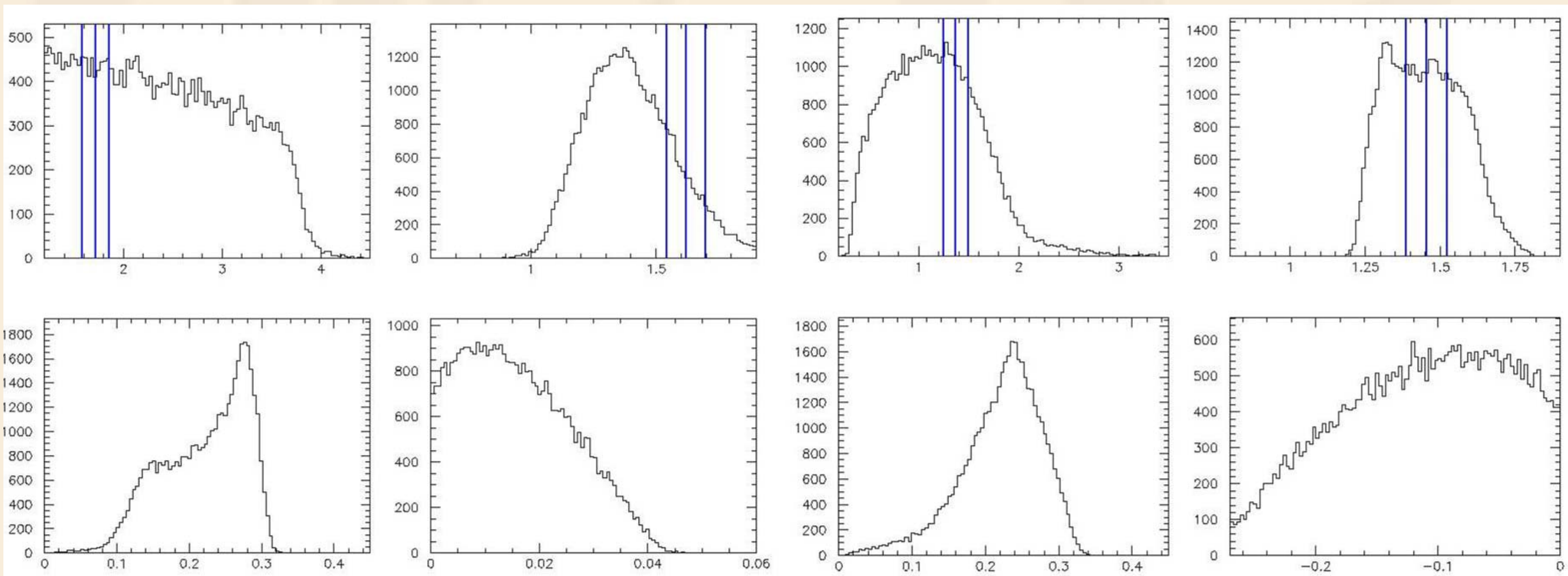


Tanja's

(0.35 > t > 0.26)

t-dependence

sigL sigT sigL sigT

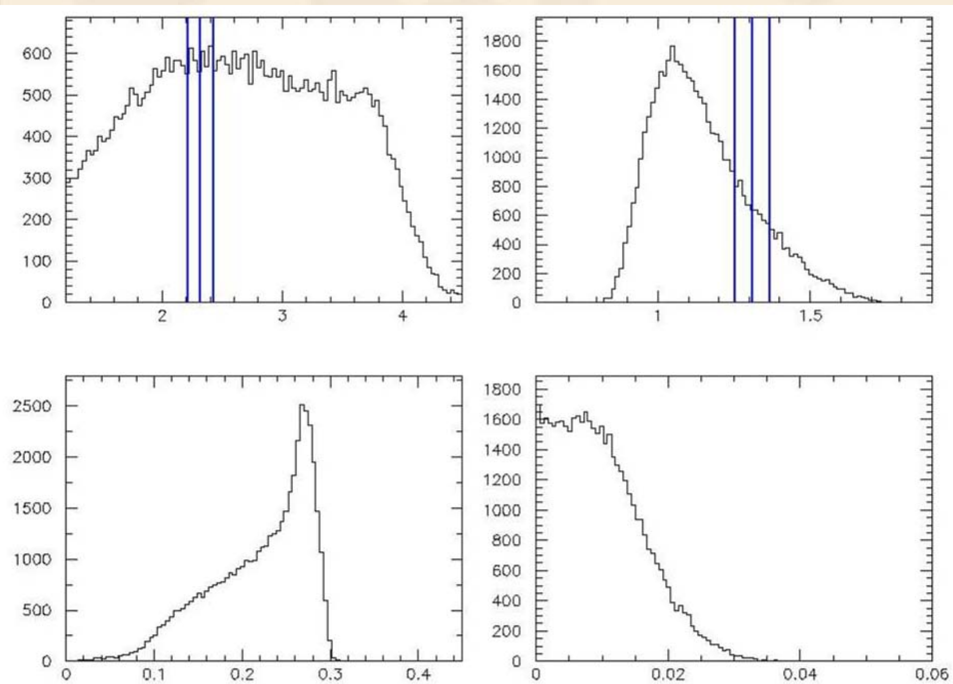


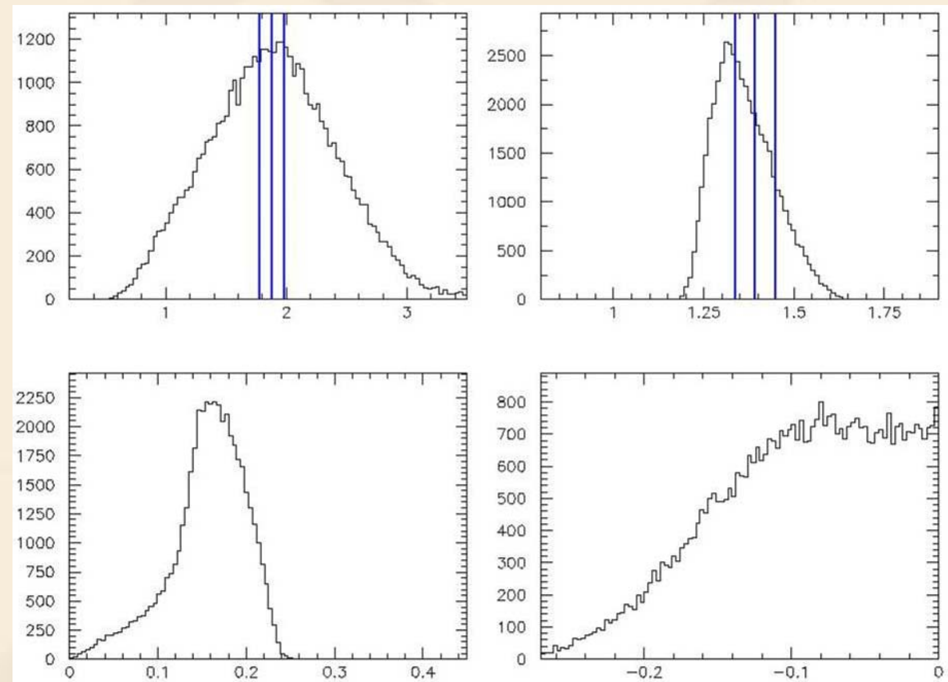
sigLT sigTT sigLT sigTT

Jochen’s (0.35 > t > 0.26) Tanja’s

t-dependence

sigL sigT sigL sigT





sigLT sigTT sigLT sigTT

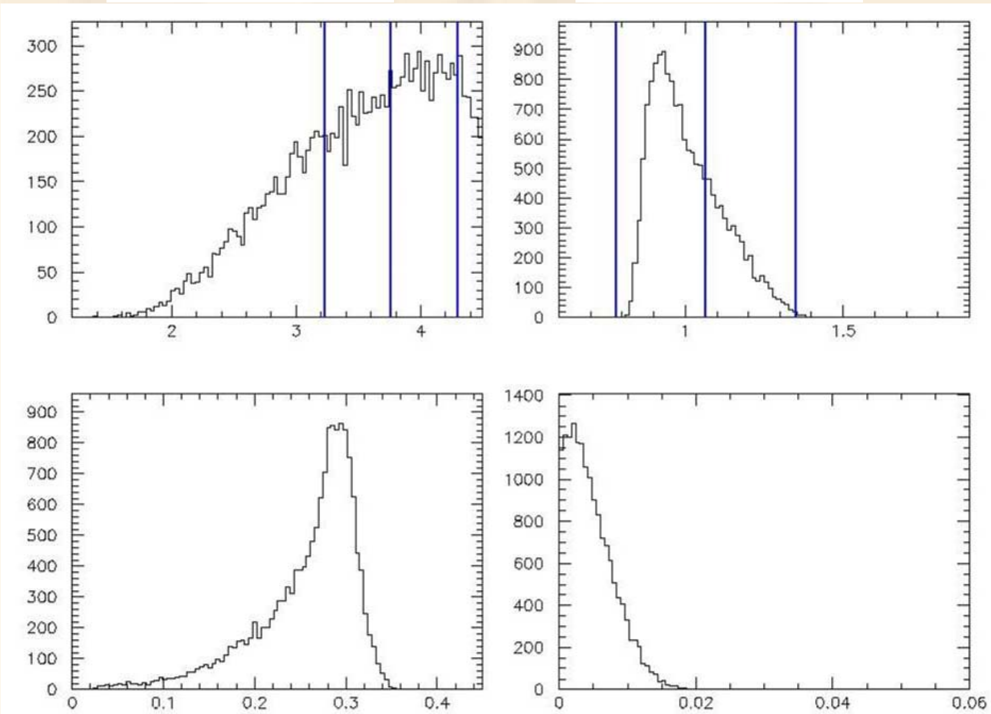
Jochen's

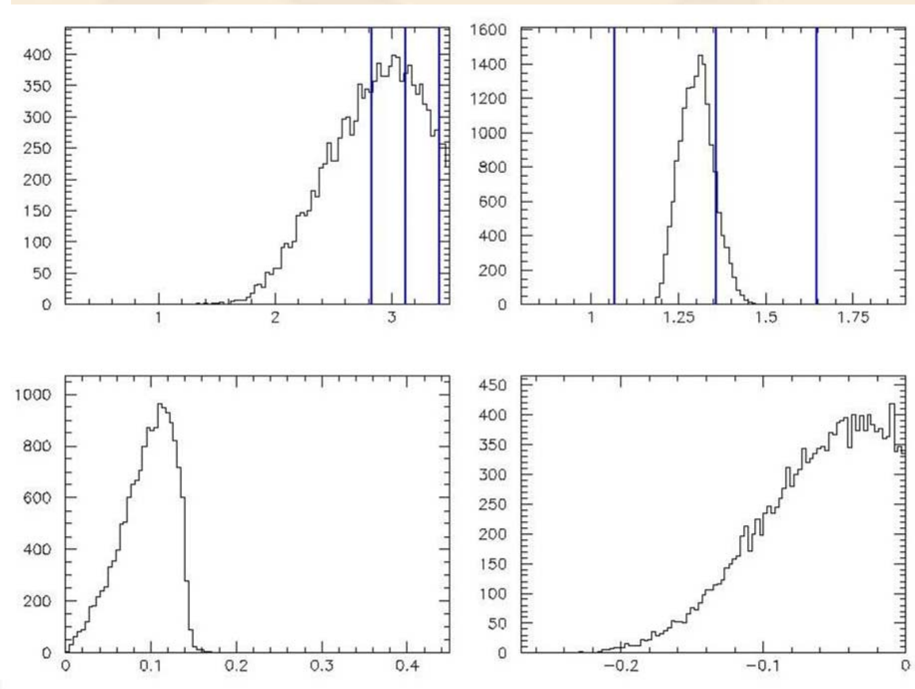
(0.26 > t > 0.17)

Tanja's

t-dependence

sigL | sigT | sigL | sigT



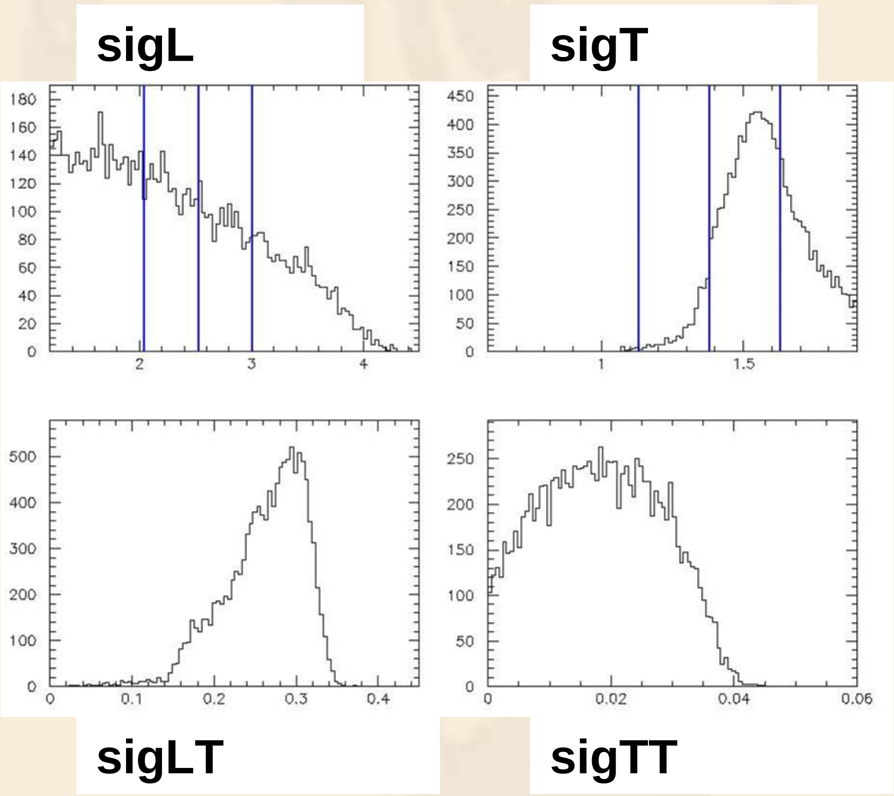


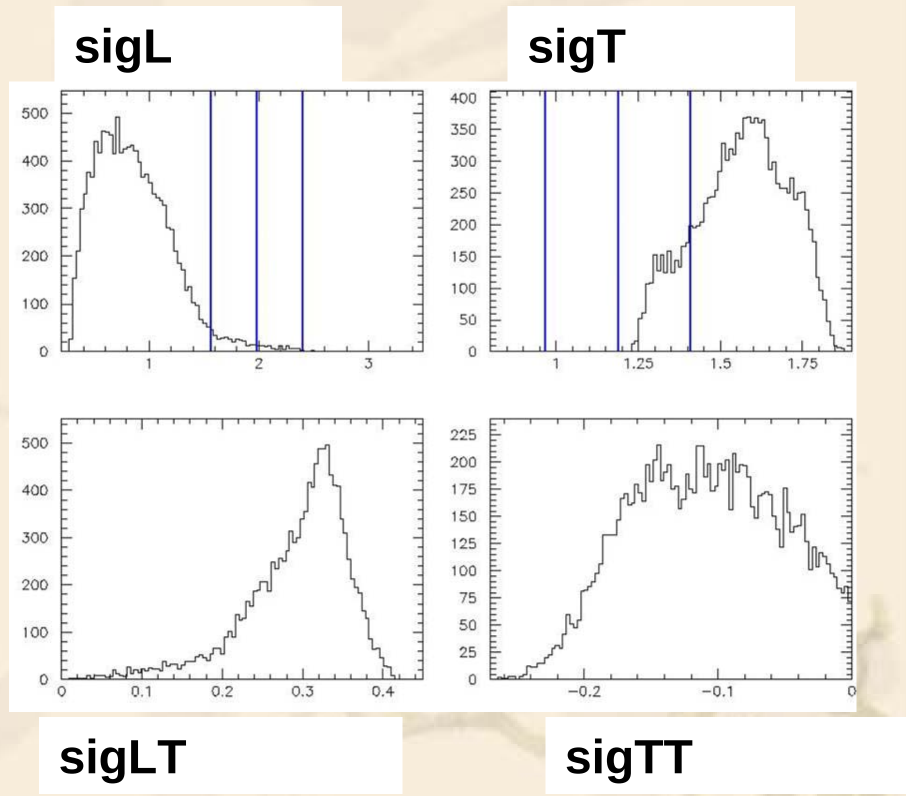
sigLT | sigTT | sigLT | sigTT

Jochen's (0.35 > t > 0.26) Tanja's

t-dependence

- Divide t region into four small regions.
- Do the comparison on all four bins for different models.





Jochen's

(0.45 > t > 0.35)

Tanja's