RESULTS ON NEUTRAL PION ABOVE THE RESONANCES AT Q^2=1.92 and 2.32 GeV^2

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pour la

"DVCS HALL A collaboration" (experiment E00-110 and E03-106)

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Neutral Pion is a bad guy. It has no charge nor spin.

All the usual first order disappears

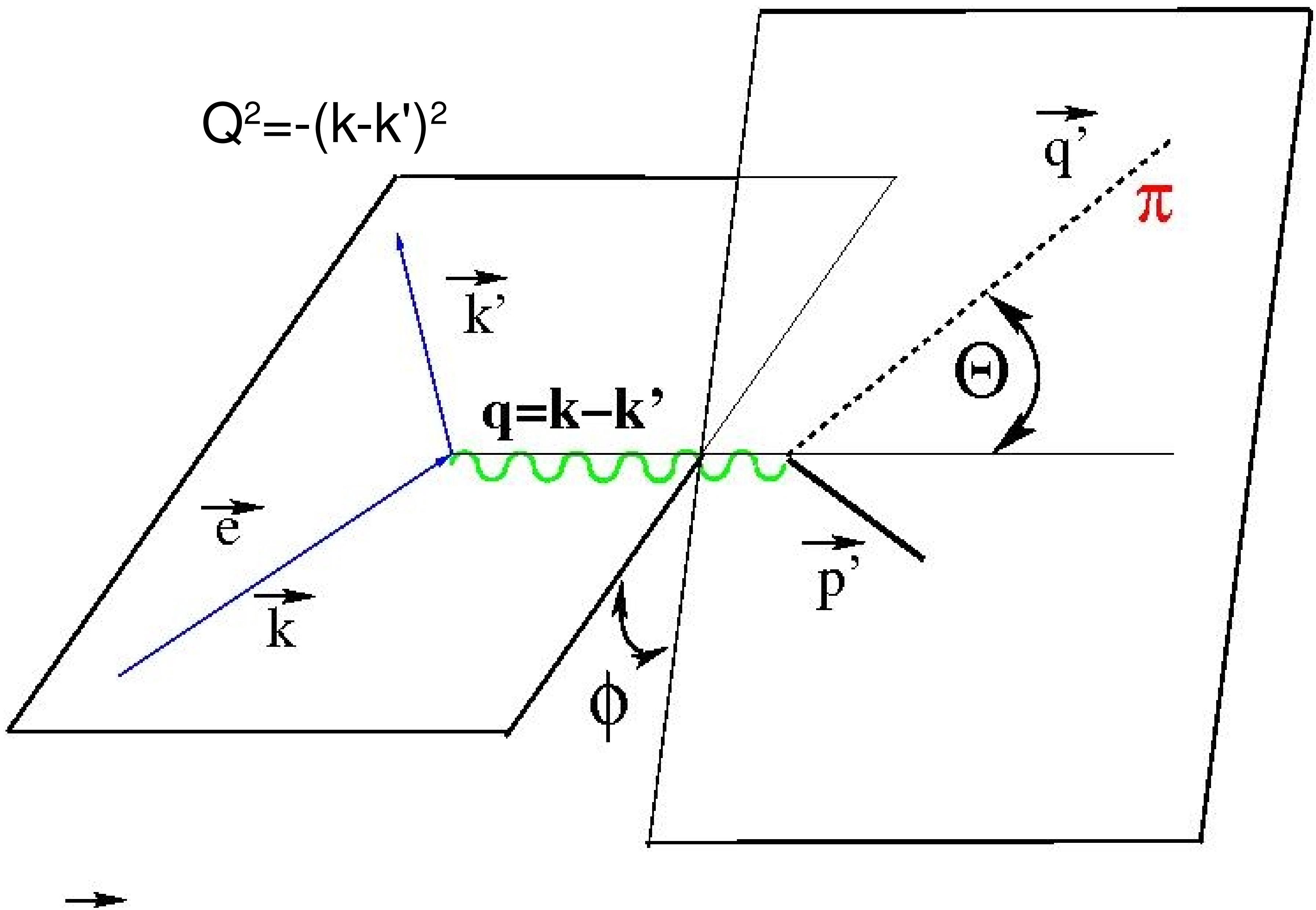
But when you do VCS or DVCS you get it for free

and when It costs no money ....

1) Convince you that our data are fine

2) Show that our data raise a lot of questions

3) show that there are some hints to answer
at this questions



Q²=-(k-k')²
k'
q'
π
Θ
q=k−k'
e
k
p'
ϕ

$$\frac{d^4\sigma}{d^2\Omega_e dk' dt} = \Gamma \frac{d\sigma}{dt} \equiv d\sigma$$

$$\Gamma = \frac{\alpha}{2\pi^2}\frac{k'}{k}\frac{W^2-M^2}{2MQ^2}\frac{1}{1-\epsilon} \quad \epsilon = \frac{1}{1-2\frac{|\vec{q}|^2}{Q^2}tan^2\frac{\theta_e}{2}}$$

$$\begin{aligned} d\sigma \quad = \quad & d\sigma_T + \epsilon \cdot d\sigma_L \\ & +\sqrt{2\epsilon(1+\epsilon)} \cdot d\sigma_{TL} \times \cos\phi \\ & +\epsilon \cdot d\sigma_{TT} \times \cos 2\phi \\ & +\lambda \cdot \sqrt{2\epsilon(1-\epsilon)} \cdot d\sigma_{TL'} \times \sin\phi \end{aligned}$$

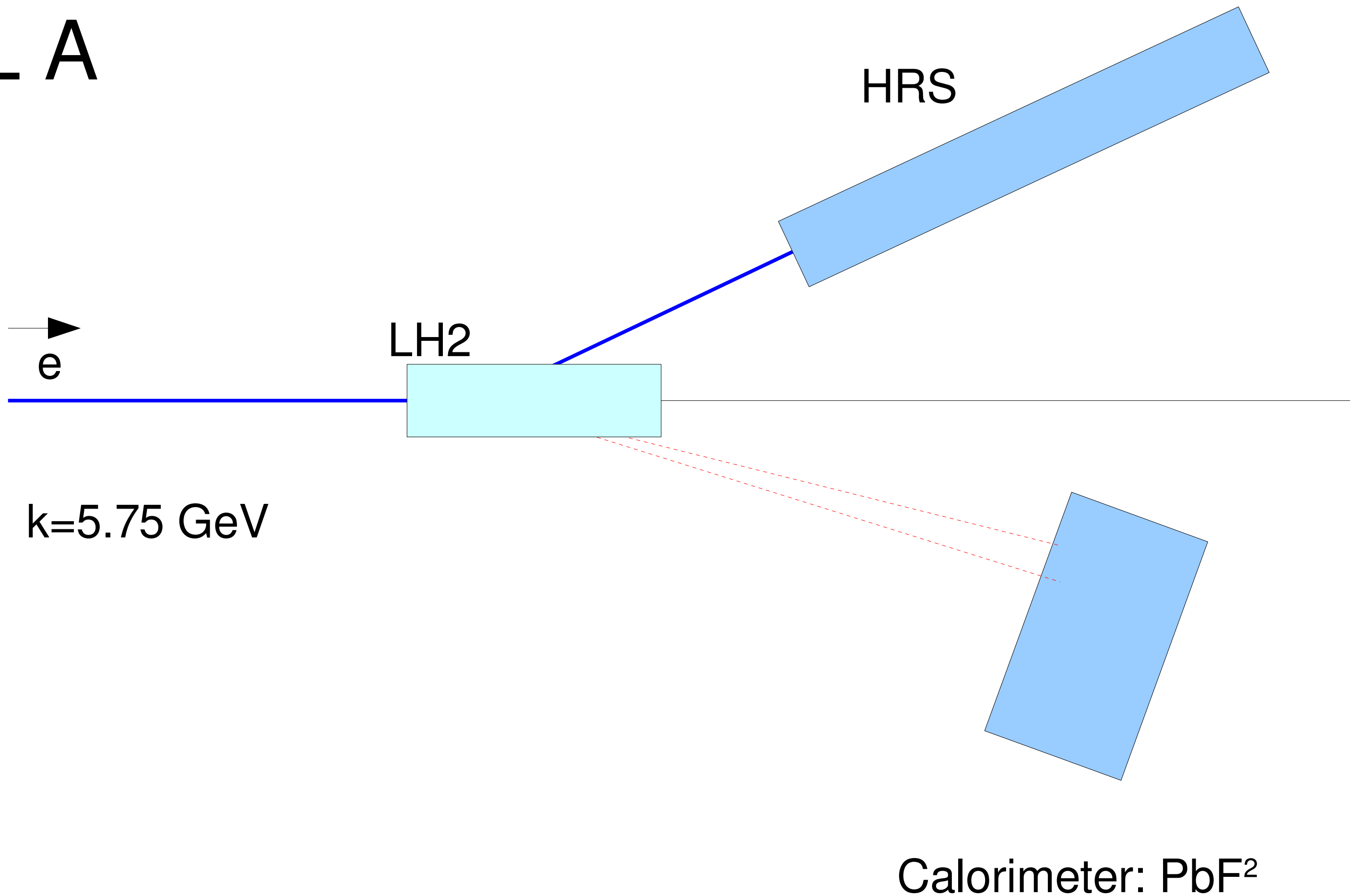
$$d\sigma_{TL} \propto \sin\Theta$$
$$d\sigma_{TT} \propto \sin^2\Theta$$
$$d\sigma_{TL} \propto \sin\Theta$$

$e+p \rightarrow e'+p'+\pi^0$

$\hookrightarrow \gamma\gamma$

Exclusive and Forward

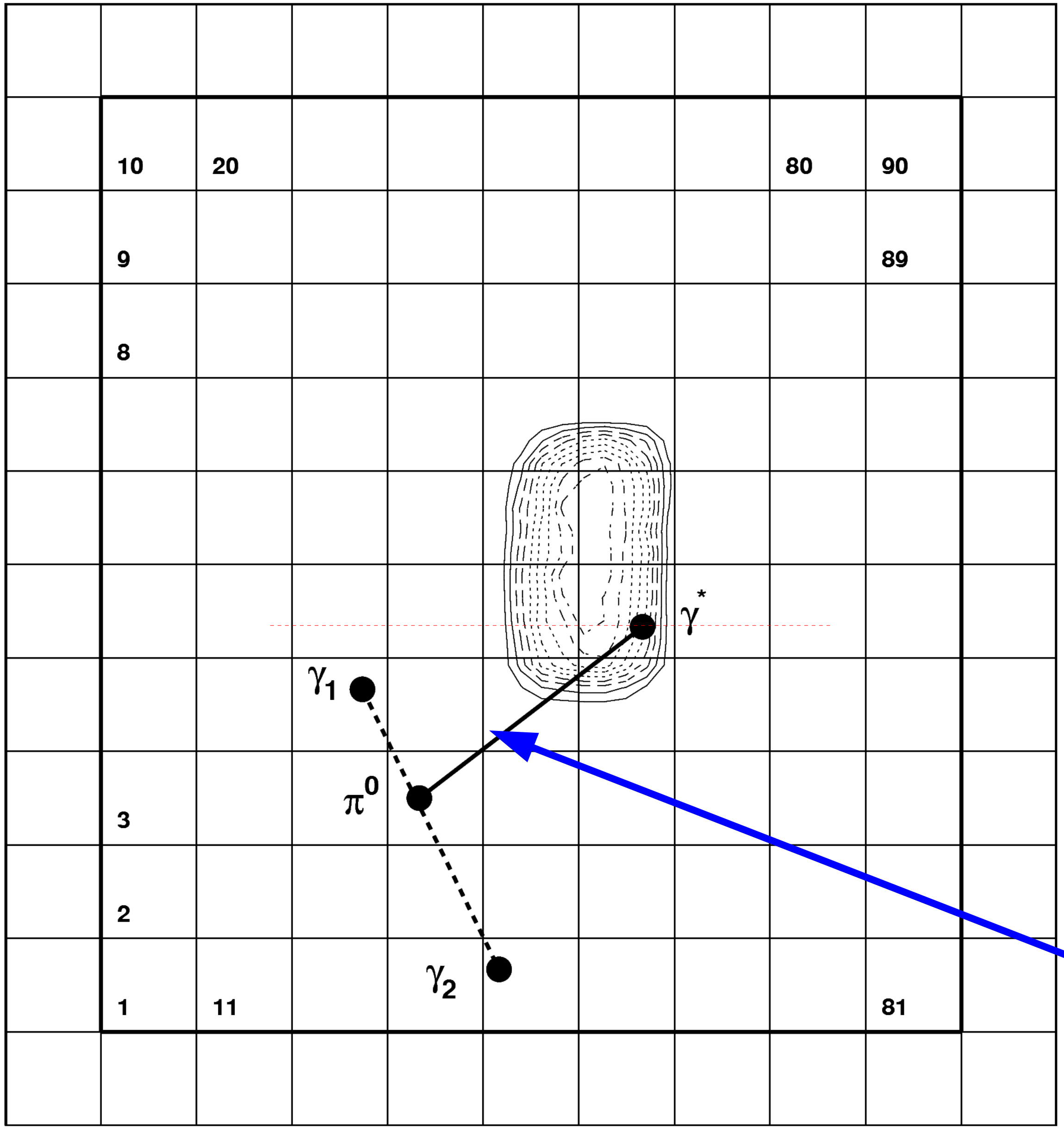
HALL A



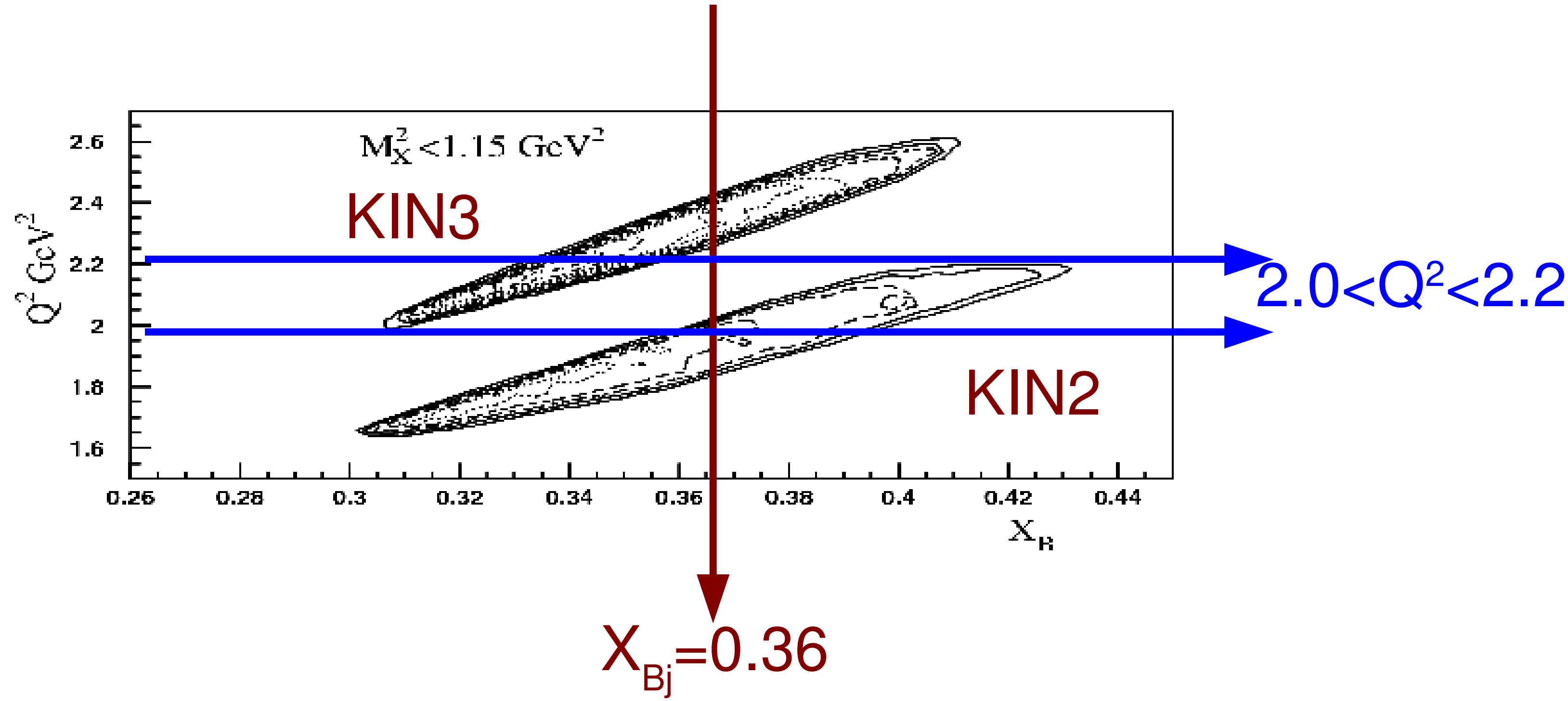
Homogeneity of the acceptance

Good Matching HRS-Calorimeter

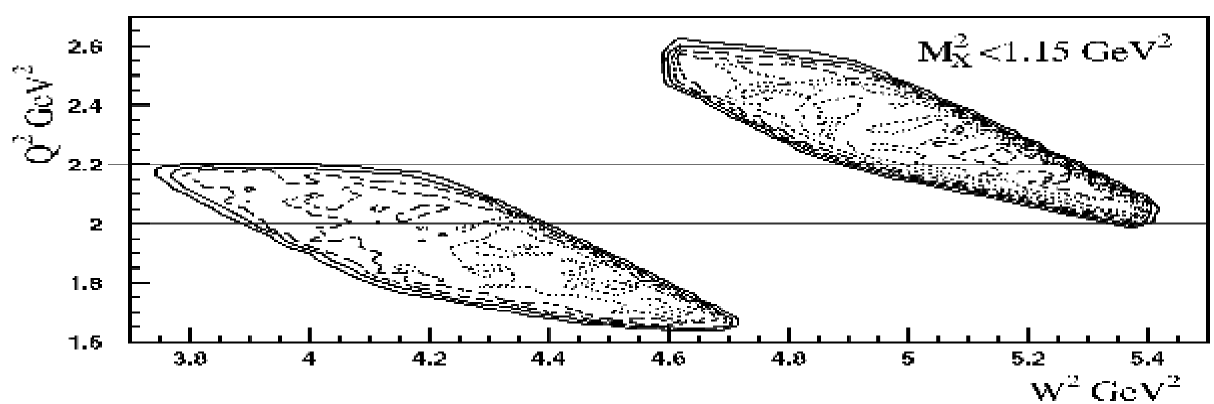
Acceptance homogeneity



$-(t\_t_{min})$



M_X^2 <1.15 GeV^2
KIN3
KIN2
2.0<Q^2<2.2
X_Bj=0.36
Q^2 GeV^2
2.6
2.4
2.2
2
1.8
1.6
0.26
0.28
0.3
0.32
0.34
0.36
0.38
0.4
0.42
0.44
X_B



M_X^2 <1.15 GeV^2
Q^2 GeV^2
2.6
2.4
2.2
2
1.8
1.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
W^2 GeV^2

1) Use HRS to know virtual photon (Q^2,W,ε)

2) Select the exclusive event by missing mass

using deposited energy in the calorimeter

2) use only shower positions in the calo to

access t and ϕ

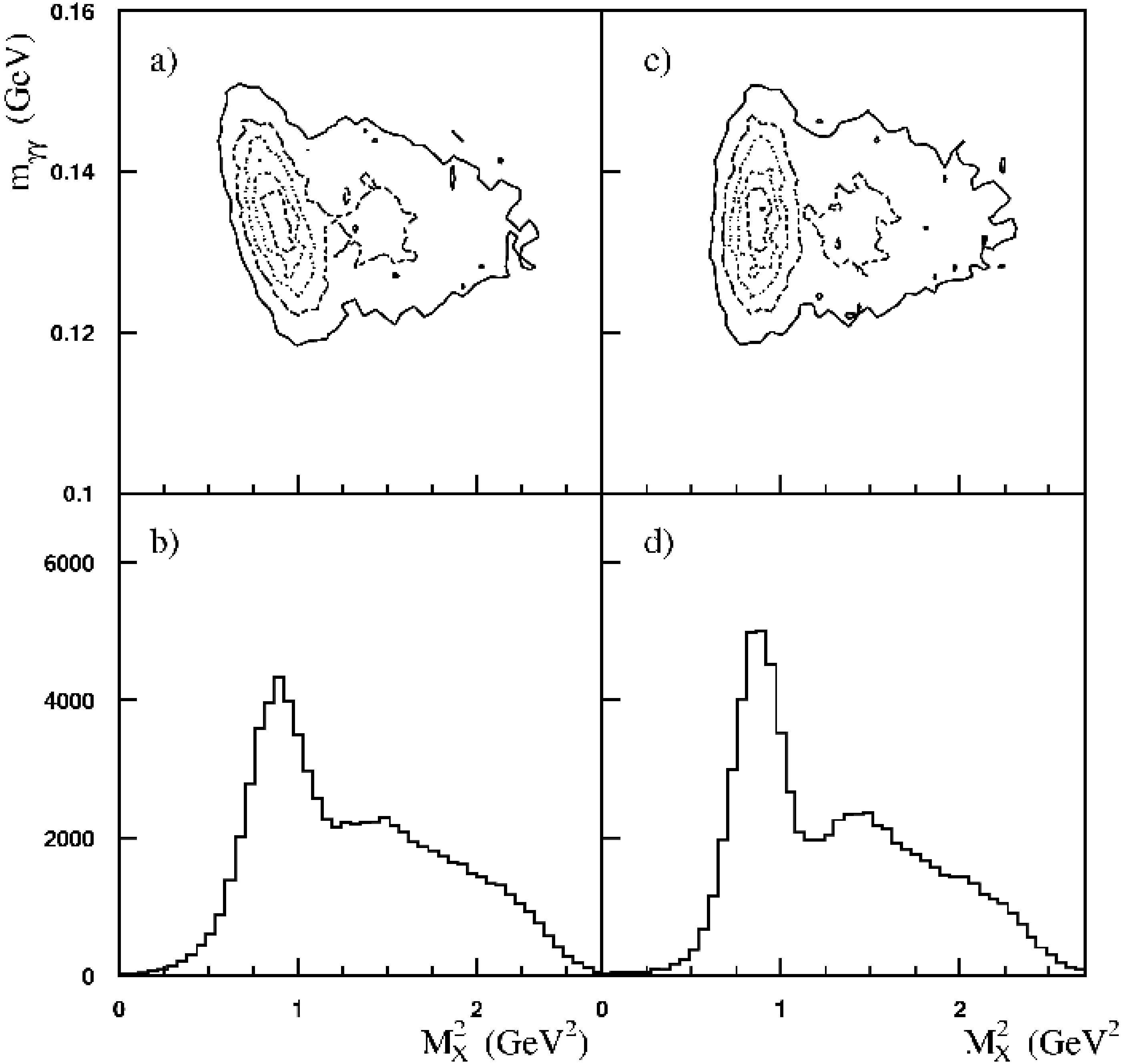
In the goal to improve the missing mass cut which is crucial
to the Fourier analysis (term in cos ϕ ==> σ_{LT})

DVCS calibration is improved by:

1) constraint on the invariant mass of the two photons

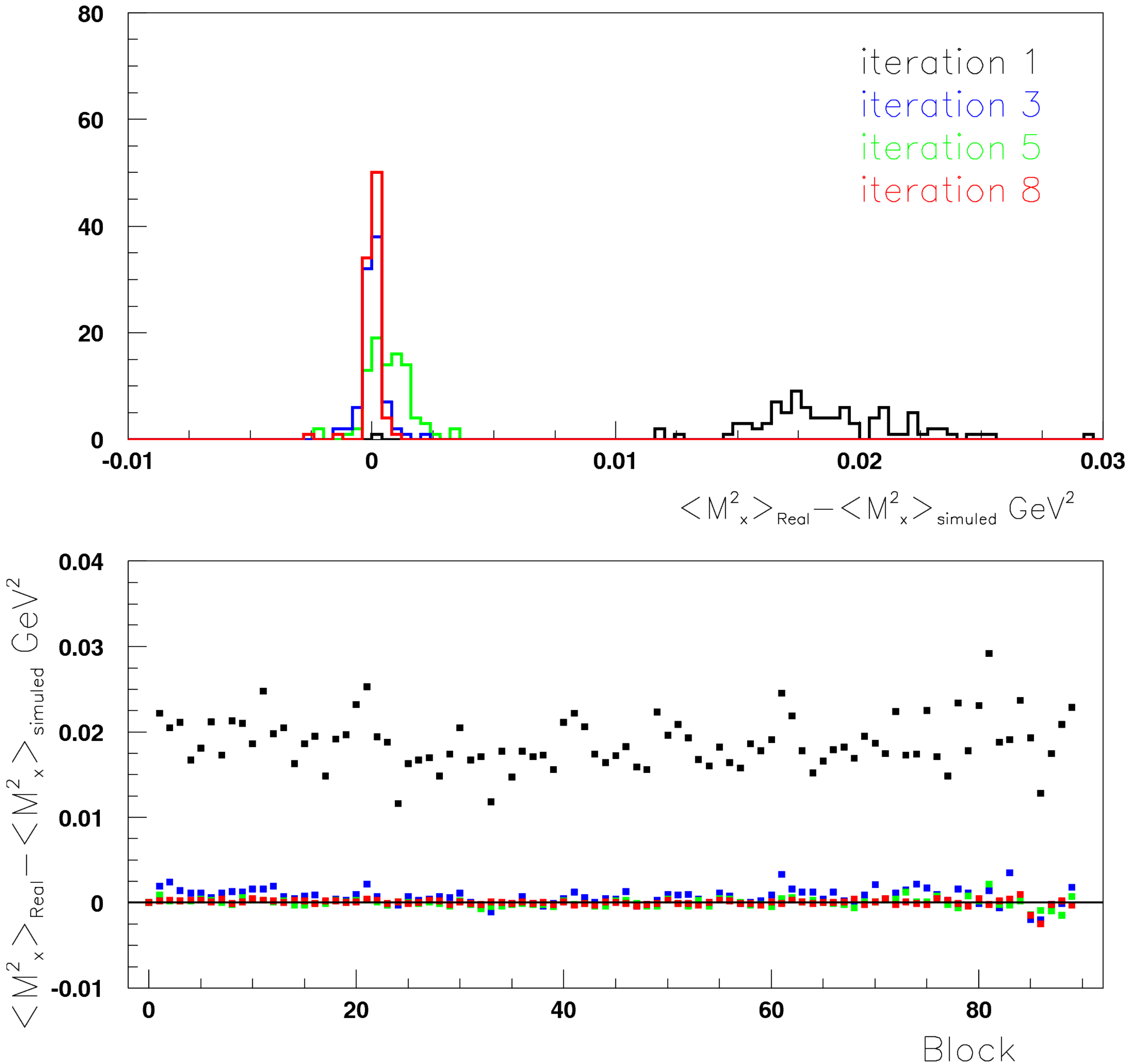
2) a calibration block to block on the raw data base on exclusive peak in M_X^2

3) adjustment block to block of simulated events resolution on Raw data resolution

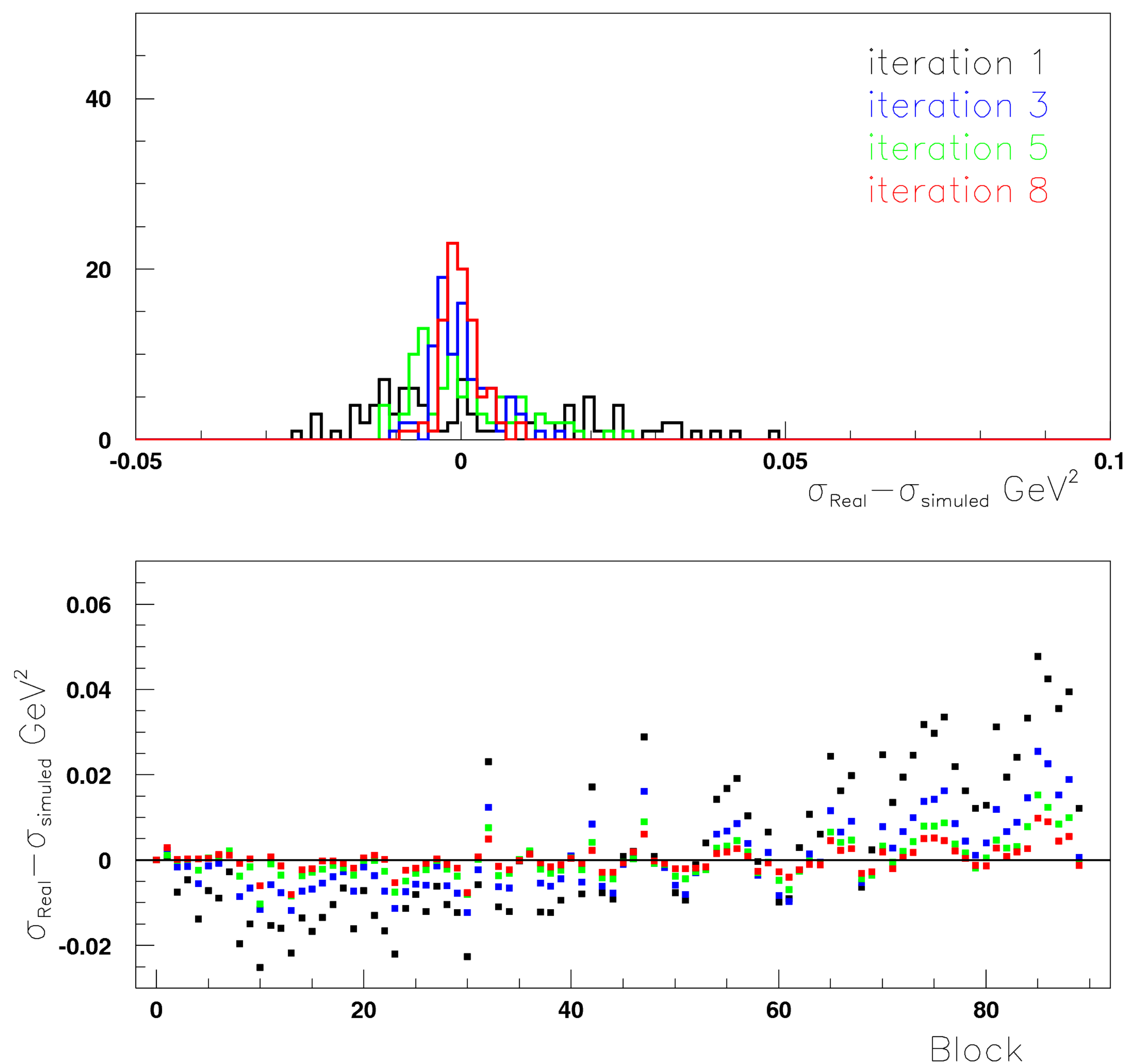


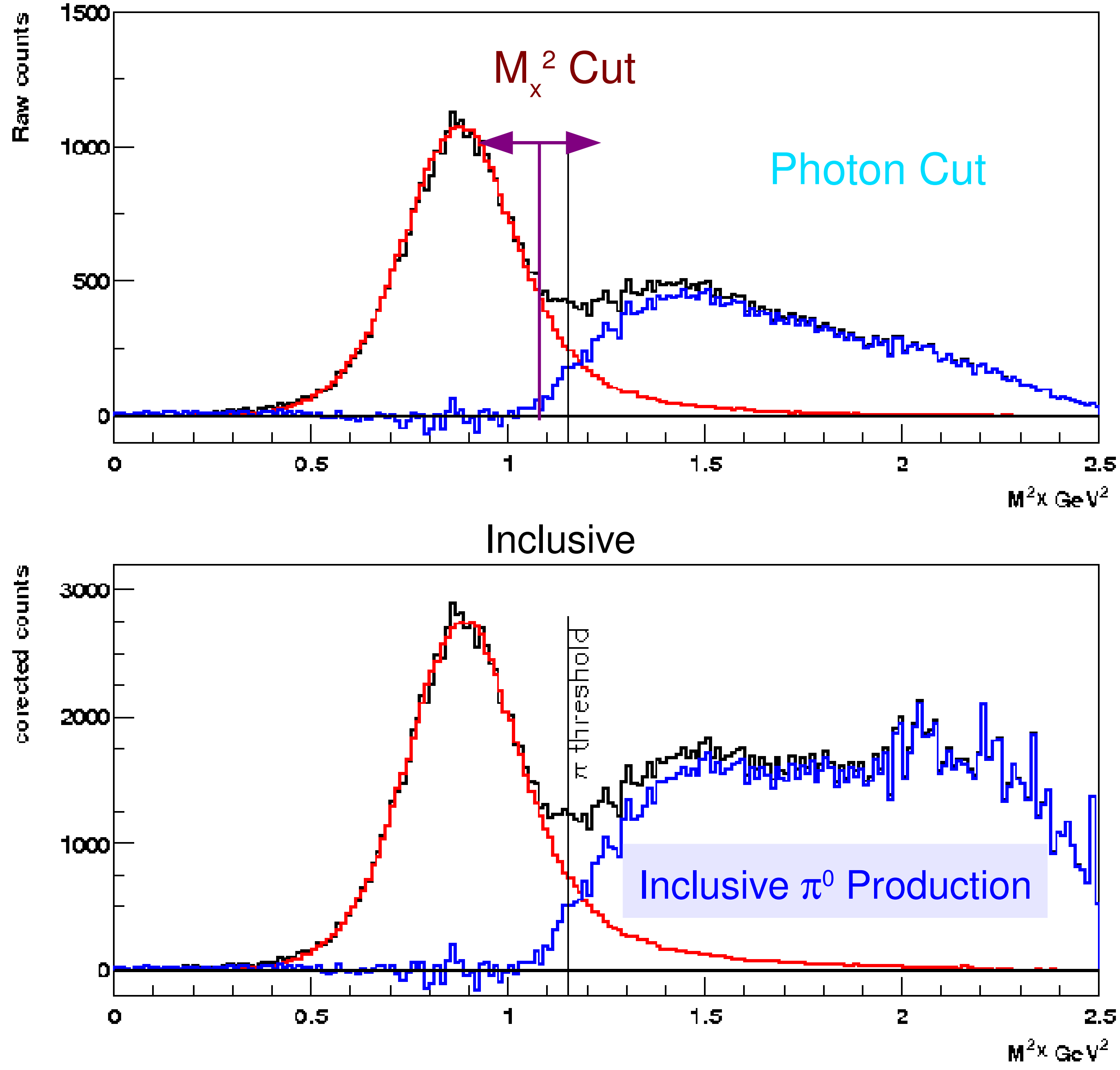
a)
b)
c)
d)
$m_{\gamma\gamma}$ (GeV)
0.16
0.14
0.12
0.1
6000
4000
2000
0
0
1
2
M_X^2 (GeV^2)
M_X^2 (GeV^2)

KIN3 adjustment Block to Block



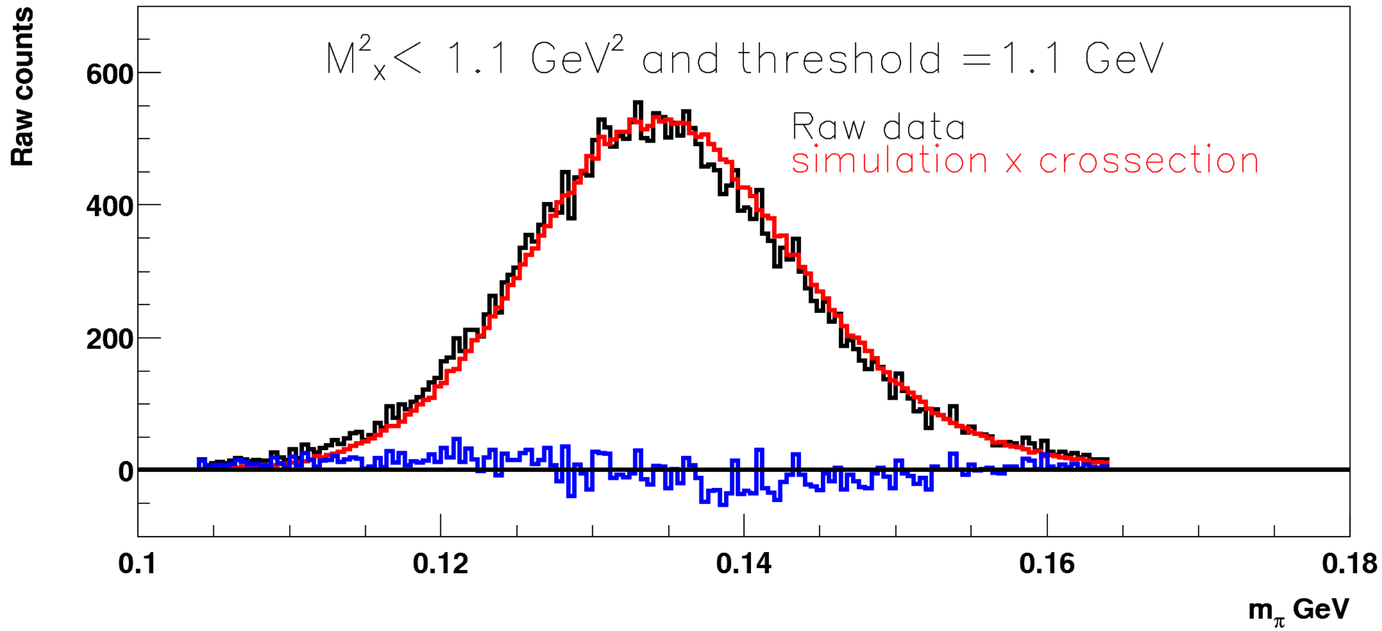
KIN3 adjustment Block to Block





Raw counts
1500
1000
500
0
M_x^2 Cut
Photon Cut
0
0.5
1
1.5
2
2.5
M^2x GeV^2
Inclusive
corected counts
3000
2000
1000
0
π threshold
Inclusive π^0 Production
0
0.5
1
1.5
2
2.5
M^2x GeV^2

Check all things are ok with invariant mass of the two photons



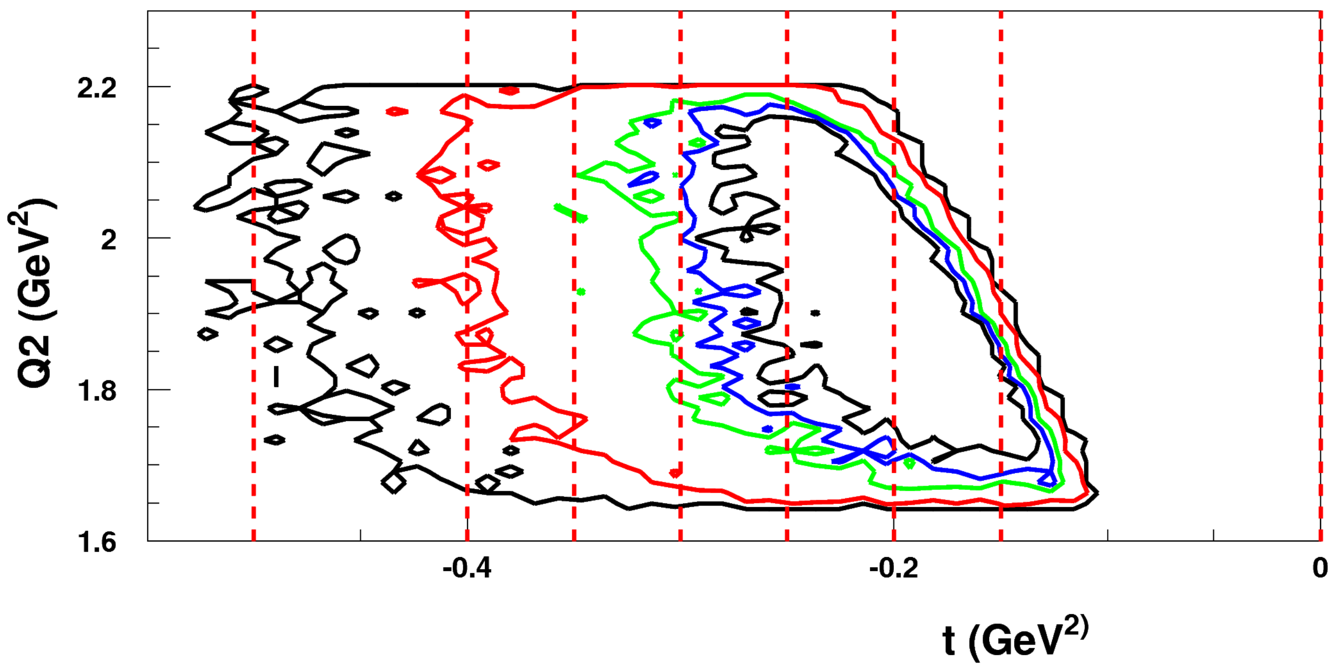
The calorimeter calibration is donne Block by Block on M^2_x

zThen the π^0 invariante masse can be used to estimate this calibrationz.

The blue curve show the residual shift between raw data and the simulated

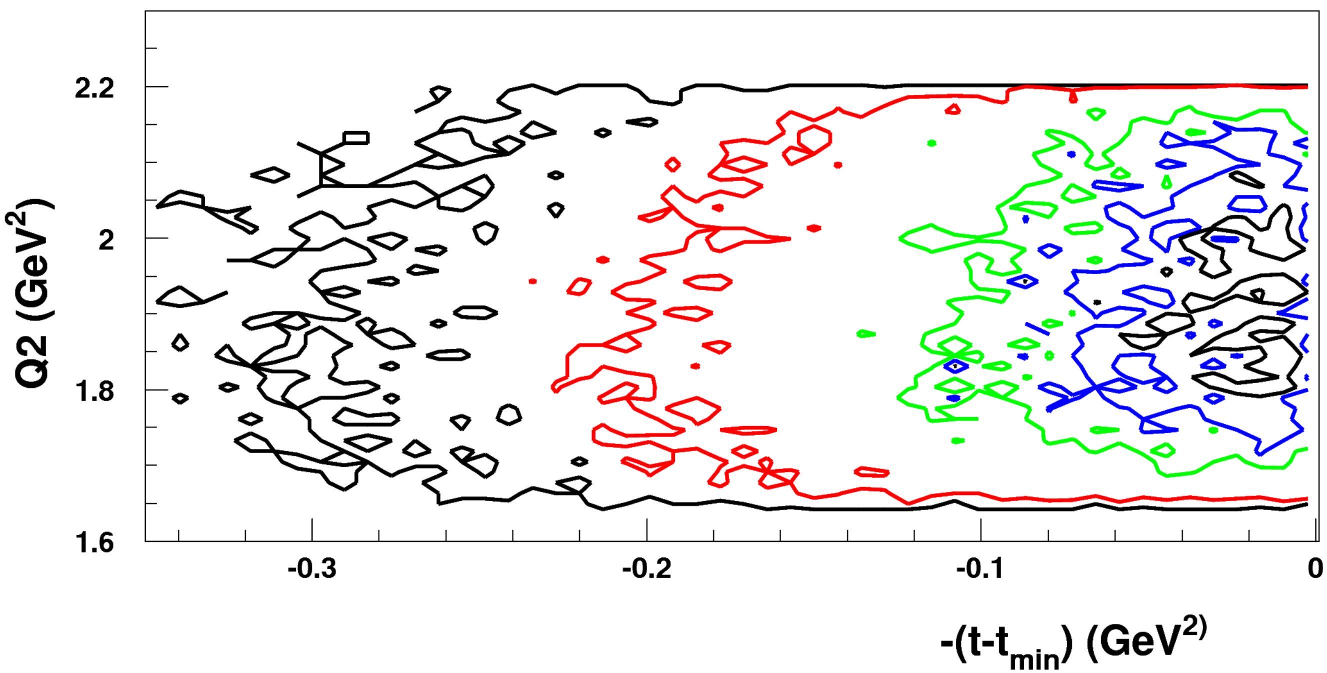
.	$<m_\pi^{exp}-m_\pi^0>$	$sqrt(<(m_\pi^{exp}-m_\pi^0)^2>)$
raw	−0.00051 GeV	0.00965 GeV
simuled	+0.00011 GeV	0.00921 GeV

KIN2 raw events

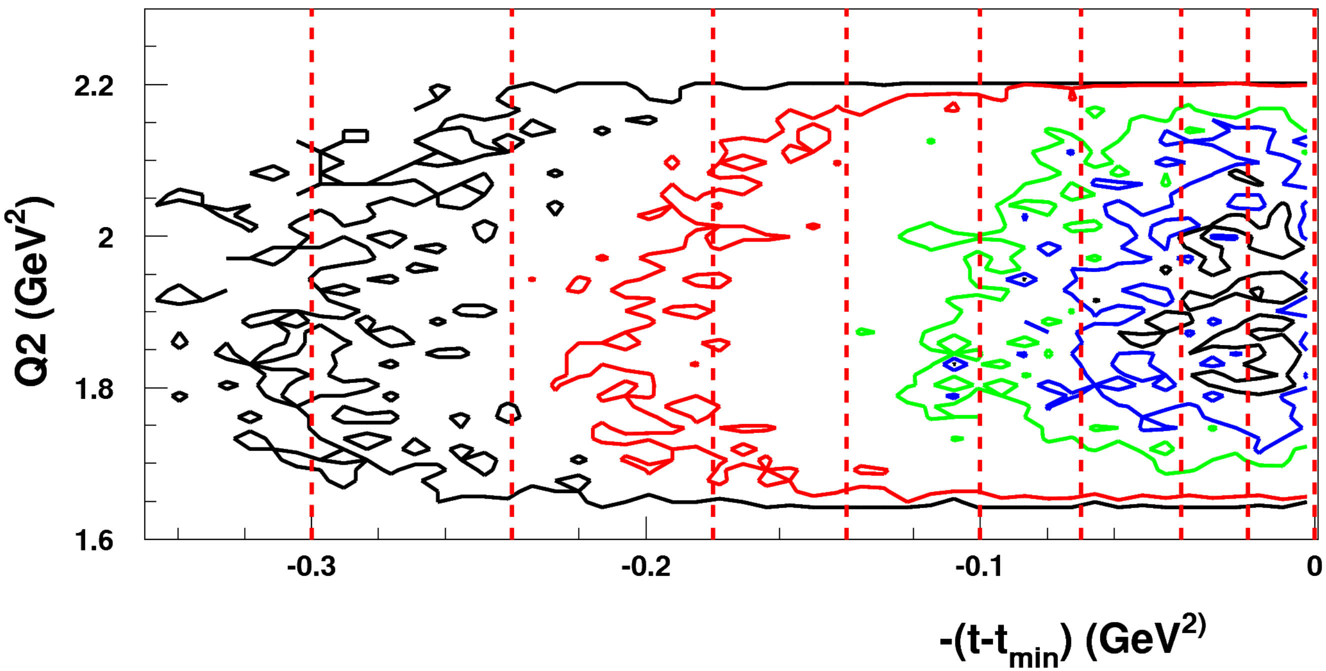


t is not a good variable in forward angle because in a t bin several Θ^* are mixed. The relevant variable is $(t - t_{min})$.

KIN2 raw events

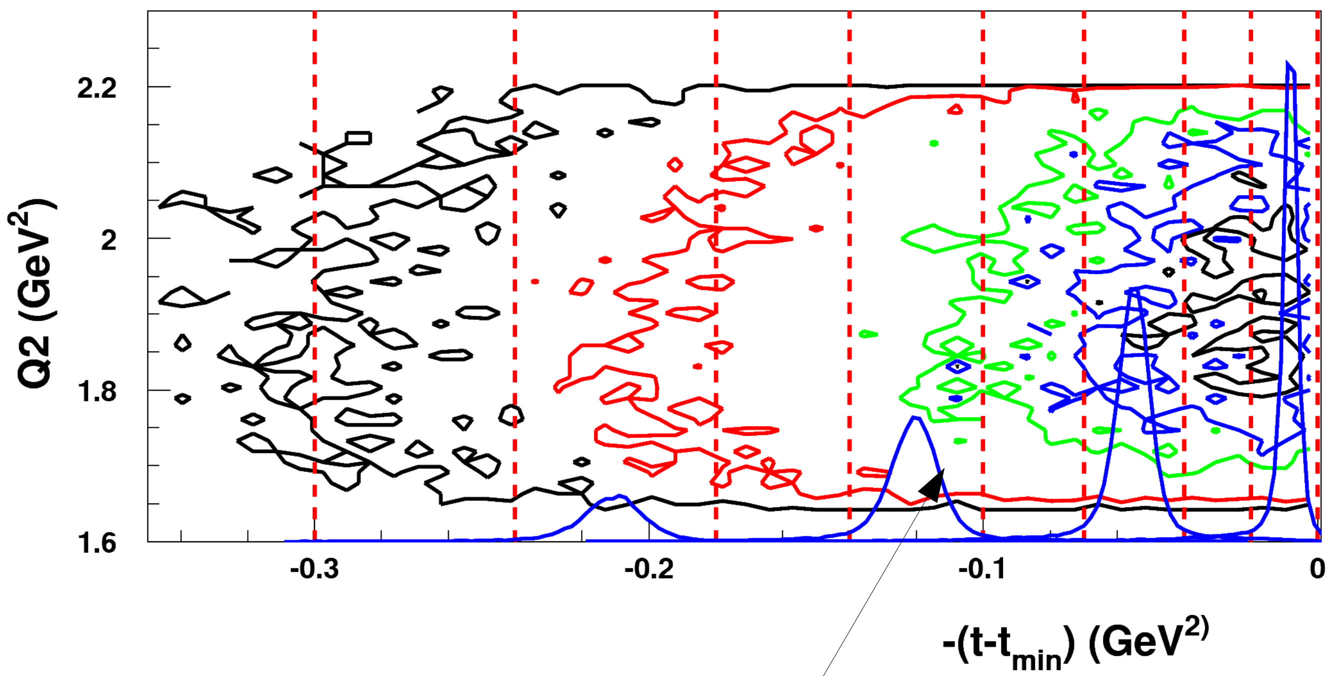


KIN2 raw events

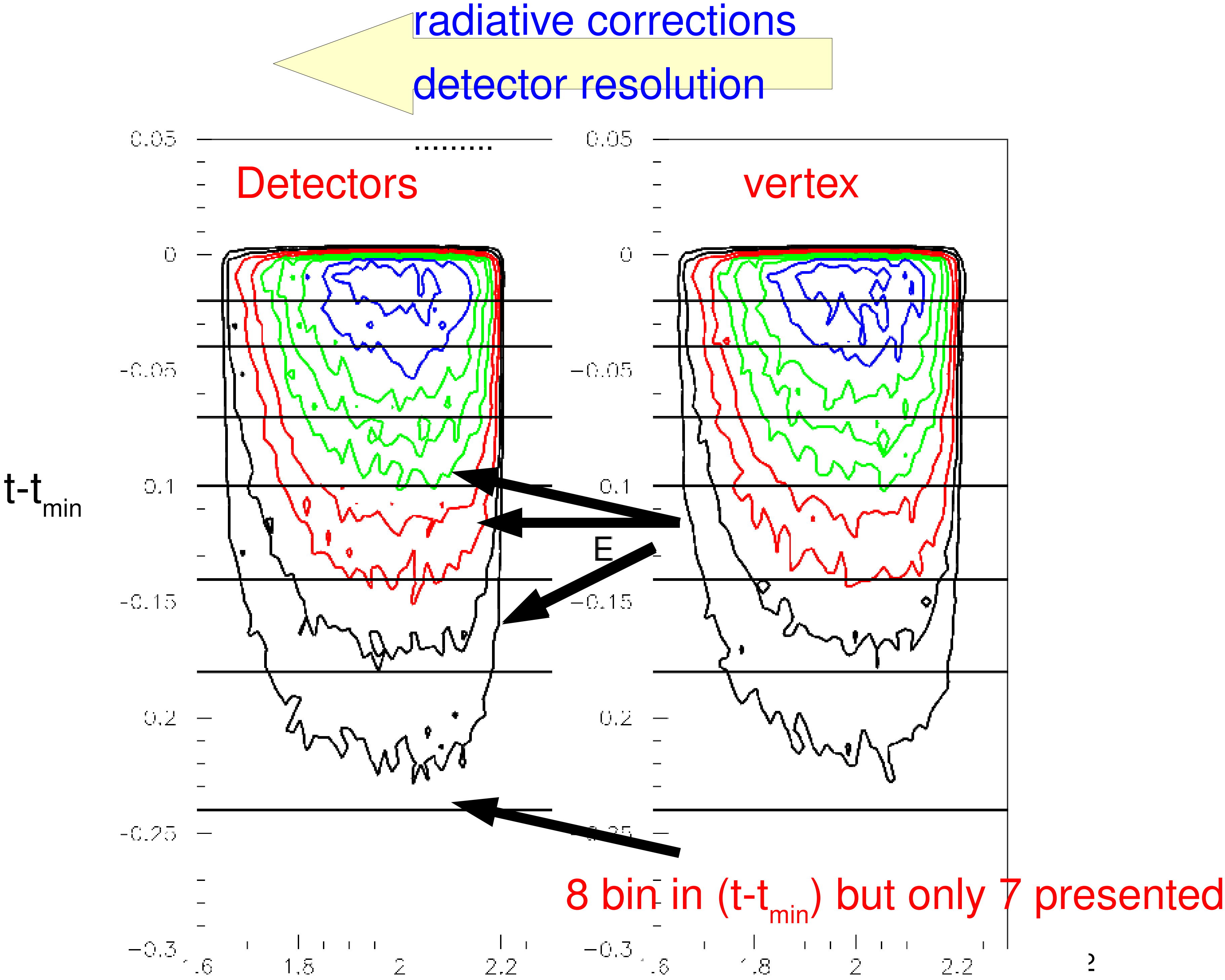


8 bin in $(t\text{-}t_{min})$

KIN2 raw events



t-t_{min} resolution in the bins


radiative corrections
detector resolution
Detectors
vertex
t-t_min
E
8 bin in (t-t_min) but only 7 presented
0.05
0
-0.05
0.1
-0.15
0.2
-0.25
-0.3
1.6
1.8
2
2.2

Hadronic tensor formalisme

D. Drechsel and L. Tiator J.Phys. G Nucl. 18(1992)449

http://www.kph.uni-mainz.de/MAID/maid2003/maid2003.html

$$d\sigma = \frac{\pi}{|\vec{q^*}|\,\frac{W^2-M^2}{2W}} \times \Big[\overbrace{\frac{W_{xx}\quad W_{yy}}{2} + \epsilon_L \cdot W_{zz}} + \sqrt{2\epsilon_L(1+\epsilon)}\cdot\big(-\mathcal{R}e[W_{xz})\big) + \epsilon\cdot\frac{W_{xx}-W_{yy}}{2} + \lambda\cdot\sqrt{2\epsilon_L(1-\epsilon)}\cdot\big(-\mathcal{I}m(W_{yz})\big)$$

$\mathrm{Here}: \epsilon_L = \epsilon\frac{Q^2}{\nu^2}$

$r_T(W,Q^2,t)+\epsilon_L r_L(W,Q^2,t)$

$\cos\phi \quad \sin\Theta^*.\ r_{TL}(W,Q^2,t)$

$\cos 2\phi \quad \sin^2\Theta^*.\ r_{TT}\ (W,Q^2,t)$

$\sin\phi.\sin\Theta^* \quad .r_{TL'}(W,Q^2,t)$

We adjuste The 3x8 quantities $r_T+\epsilon_L r_L$, r_{TT} and r_{TL}

to the experimental unpolarized data 8 $(t-t_{min})$x24(ϕ bins)

We adjuste The 1x8 quantities $r_{TL'}$

to the experimental polarized data 8 $(t-t_{min})$x13(ϕ bins)

HRS

Efficiency

Acceptance

Calorimeter

Acceptance

threshold trigger

Radiative corrections

Check with elastic at Q^2=3.07 GeV^2

$(d\sigma/d\Theta_e)_{exp.}$=684 $pb.sr^{-1}$

$(d\sigma/d\Theta_e)_{Kelly}$=675 $pb.sr^{-1}$

e+P-->e+P+ω

$\omega \to \pi^0 + \gamma$

<1%

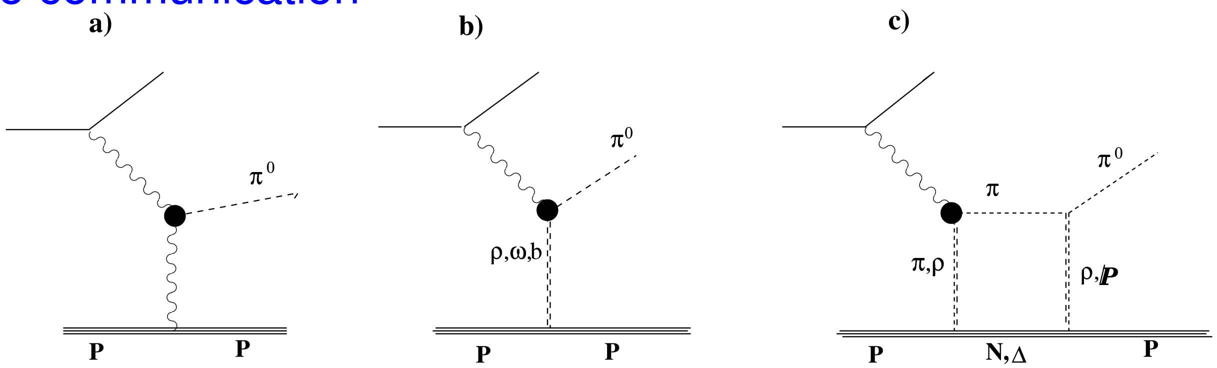
Systematic errors are evaluated by changing the cuts in M^2_x and photon detection threshold

$t_{\rm min} - t$ (GeV^2)	KIN3			KIN2		
	$\frac{d\sigma_T}{dt} + \epsilon \frac{d^3\sigma_L}{dt}$ nb/GeV^2			nb/GeV^2		
0.010	379	± 9	±34	438	± 8	±13
0.030	401	±11	±30	449	±10	±13
0.055	416	± 9	± 24	476	± 9	±12
0.085	410	±10	± 24	495	±11	±15
0.119	447	± 10	±23	531	±13	±15
0.159	423	±12	±33	505	±20	±19
0.207	423	±12	±37	500	±25	±20
	$d\sigma_{TL}/dt$					
0.010	−4	± 9	± 2	+4	±7	±4
0.030	15	±11	±15	-10	± 9	± 3
0.055	7	± 9	± 2	-9	± 8	± 7
0.085	−1	±10	±10	-17	±10	±3
0.119	−1	±10	±13	-33	±12	±3
0.159	−19	±13	±17	-40	±20	±10
0.207	−23	±14	±9	-84	±24	±9
	$d\sigma_{TT}/dt$					
0.010	17	±22	±16	-42	± 17	± 4
0.030	−59	±24	±27	-72	± 19	± 4
0.055	−45	±20	±9	-121	± 18	± 6
0.085	−59	±22	±25	-144	± 22	± 11
0.119	−123	±23	±24	-205	± 25	± 9
0.159	−88	±27	±12	-168	± 37	± 17
0.207	−89	±29	±20	-197	± 44	± 20
	$d\sigma_{TL'}/dt$					
0.010	6	±39	±40	60	± 41	± 18
0.030	9	±46	±35	114	± 49	± 20
0.055	88	±37	±7	21	± 44	± 20
0.085	108	±41	±58	39	± 54	± 13
0.119	99	±39	±28	97	± 56	± 13
0.159	97	±44	±46	173	± 71	± 15
0.207	140	±41	±33	21	± 76	± 48

Table 1: Separated cross sections in Kinematics 3 at $Q^2 = 2.3$ GeV^2,and Kinematics 2 at $Q^2 = 1.9$ GeV^2 as functions of $t_{\rm min} - t$. The first quoted error is statistical, the second is the systematic error (threshold cuts,and apparatus added quadratically) See table of sources of systematic errors. The cross sections are corrected for radiative effects.

J.M. LAGET private communication

C. Weiss private communication



Primakoff

--> 0

meson exchange

in the t channel

meson exchange

in the t channel

+

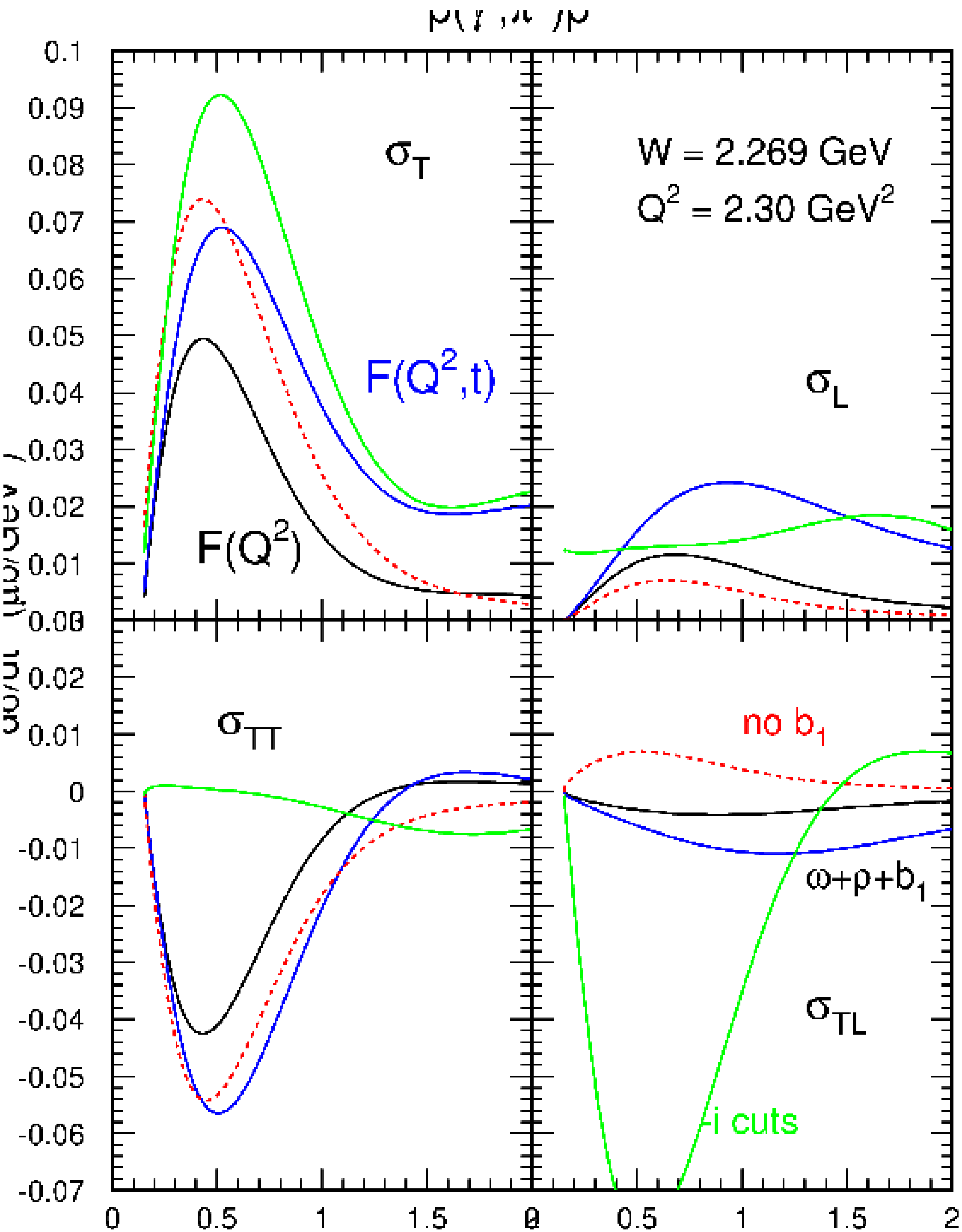
Re-Scattering

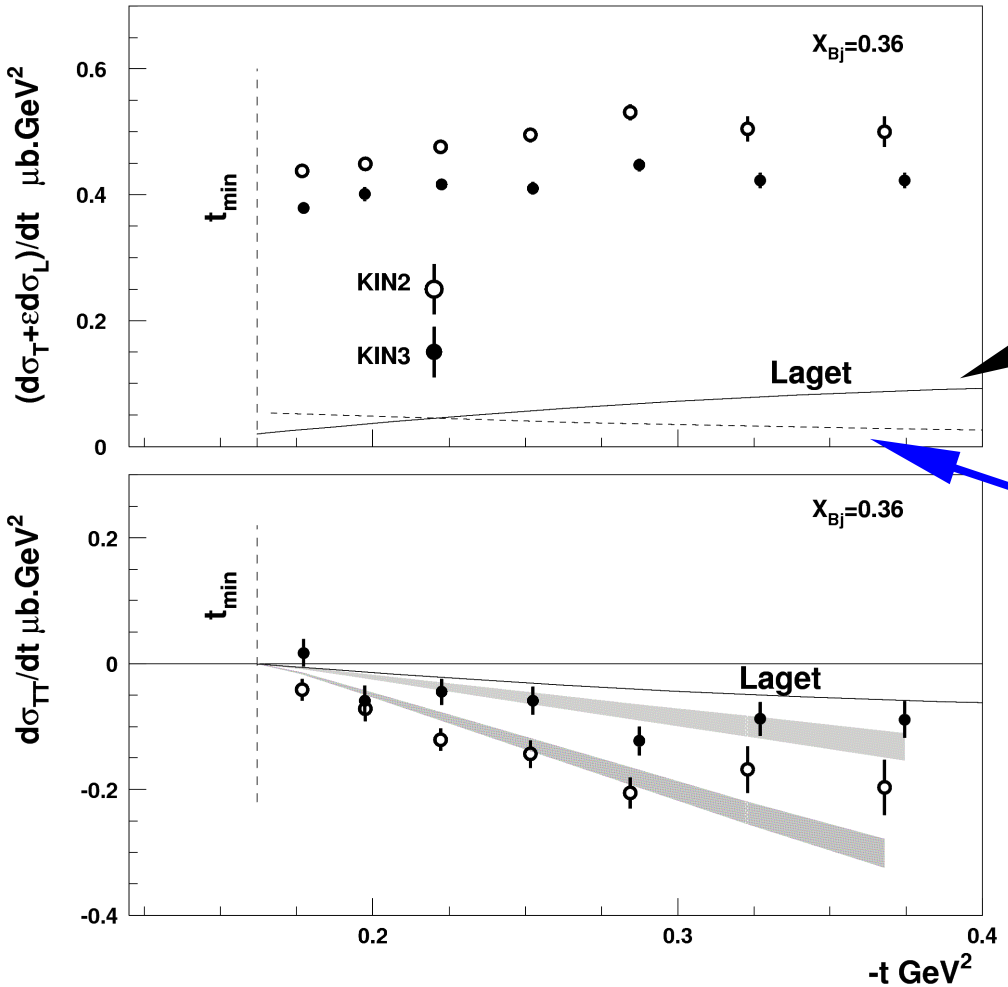
1) work well for photo-production
2) " " for Desy electro-production
a low Q^2 ~ 1.GeV
3) reproduce the longitudinal part of the π^+,
HALL C results (T.Horn et al)
4) fail to reproduce the transverse part of the π^+,
HALL C results

Used to fix the parameters:

coupling constant and form factor

J.M.LAGET
april 25 07





Sorry Jean Marc but it does not work !!

M. Vanderhaeghen estimation of the longitudinal part base on GPD but we are not in a range of applicability of It

1) t channel exchange do not reproduce:

a) The size

b) The shape

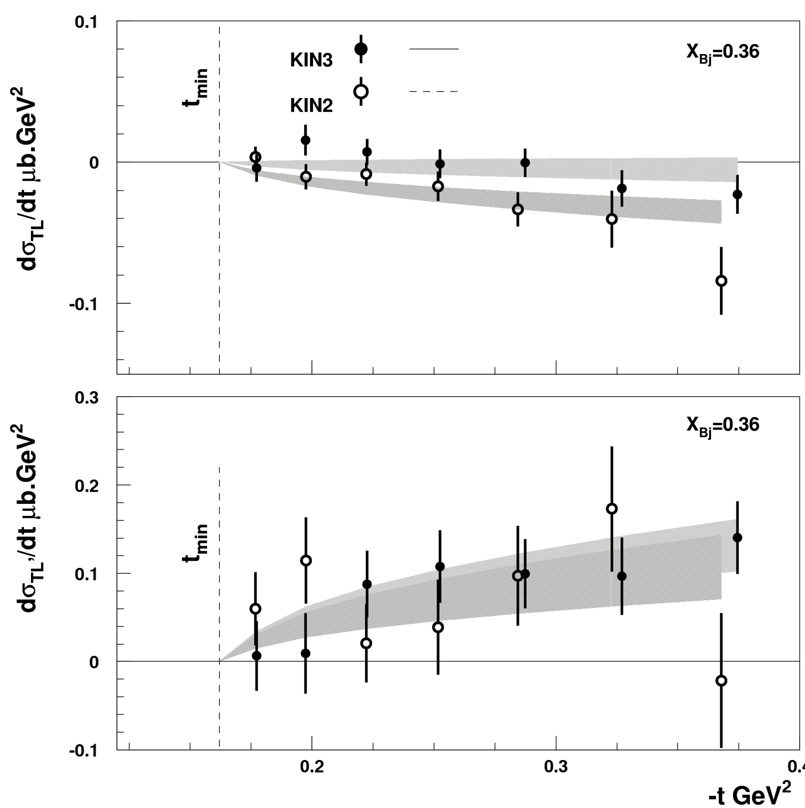
2) t dependence is relatively smooth in our range

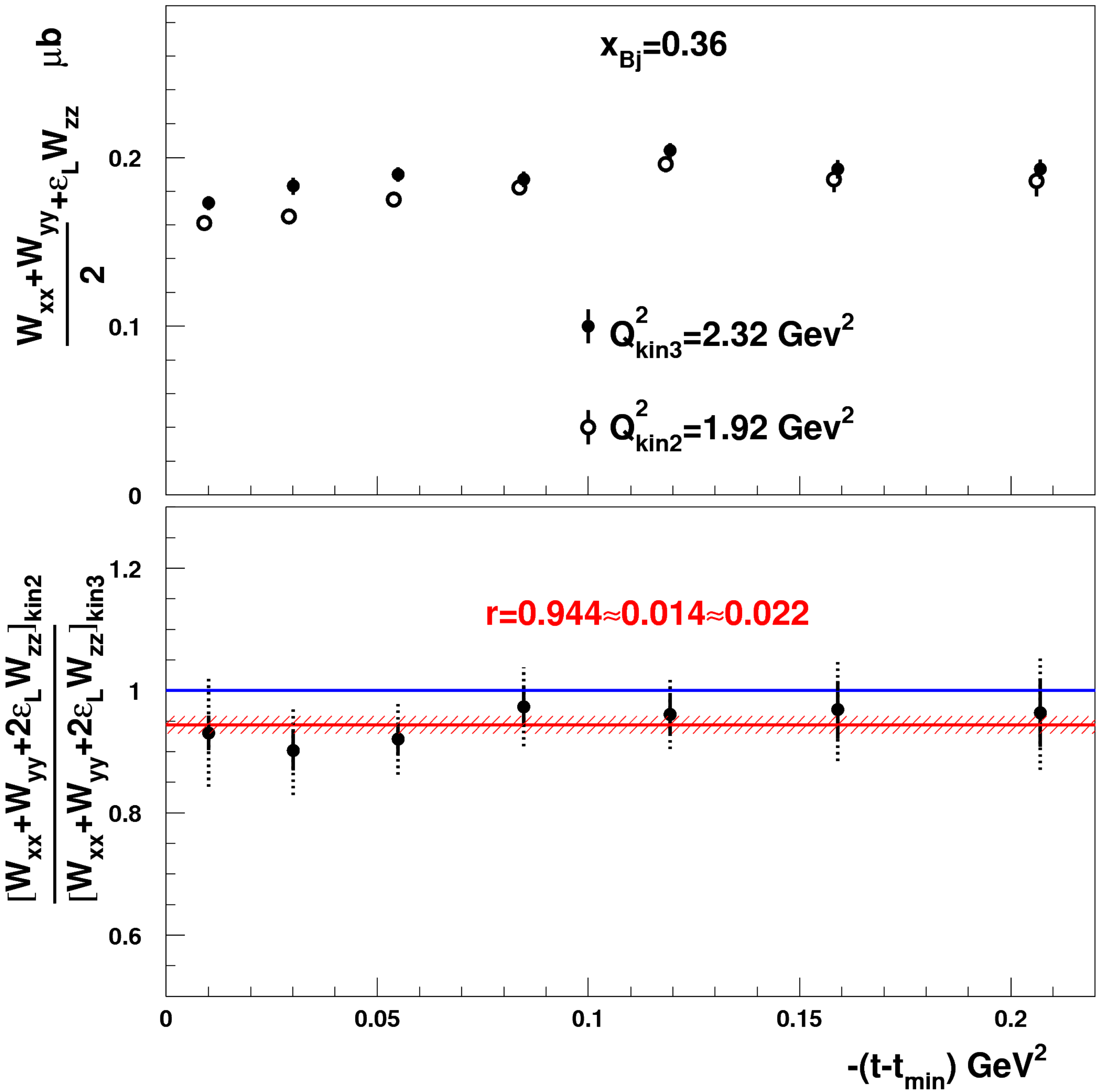
		KIN2 $x_{Bj} = 0.365$		
$\frac{W_{xx}-W_{yy}}{2}$	$=$	$d\sigma_{TT}\frac{\lvert\mathbf{q}^*\rvert k^*_\gamma}{\pi}\cos 2\phi$	$=$	$[-657 \pm 46 \pm 49] \times \cos 2\phi \sin^2\theta^*$
$\mathcal{R}e(W_{xz})$	$=$	$-d\sigma_{TL}\sqrt{\frac{\epsilon}{\epsilon_L}}\frac{\lvert\mathbf{q}^*\rvert k^*_\gamma}{\pi}\cos\phi$	$=$	$[+15.2 \pm 3.2 \pm 3.5] \times \cos 2\phi \sin\theta^*$
$\mathcal{I}m(W_{yz})$	$=$	$-d\sigma_{TL'}\sqrt{\frac{\epsilon}{\epsilon_L}}\frac{\lvert\mathbf{q}^*\rvert k^*_\gamma}{\pi}\sin\phi$	$=$	$[-46 \pm 15 \pm 16] \times \sin\phi \sin\theta^*$
		KIN3 $x_{Bj} = 0.365$		
$\frac{W_{xx}-W_{yy}}{2}$	$=$	$d\sigma_{TT}\frac{\lvert\mathbf{q}^*\rvert k^*_\gamma}{\pi}\cos 2\phi$	$=$	$[-432 \pm 61 \pm 70] \times \cos 2\phi \sin^2\theta^*$
$\mathcal{R}e(W_{xz})$	$=$	$-d\sigma_{TL}\sqrt{\frac{\epsilon}{\epsilon_L}}\frac{\lvert\mathbf{q}^*\rvert k^*_\gamma}{\pi}\cos\phi$	$=$	$[+2.9 \pm 3.2 \pm 4.6] \times \cos 2\phi \sin\theta^*$
$\mathcal{I}m(W_{yz})$	$=$	$-d\sigma_{TL'}\sqrt{\frac{\epsilon}{\epsilon_L}}\frac{\lvert\mathbf{q}^*\rvert k^*_\gamma}{\pi}\sin\phi$	$=$	$[-70 \pm 12 \pm 16] \times \sin\phi \sin\theta^*$

Table 1: Parametrization of the hadronic tensor for the two kinematic at x_{Bj} constant. The first error is the statistical error the second contain the statistical and the systematic errors added quadratically.

at this Q2

first measurements





In our $(t-t_{min})$ range

1) $W_T+\varepsilon_L W_L$ stay roughly constant with $-(t\_t_{min})$

2) $-(t-t_{min})$ dependence stay the same when Q^2 change

$$r = \frac{W_T + 0.192 W_L}{W_T + 0.133 W_L}$$

$$r = 0.944 \pm 0.014 \pm 0.022$$

$$r = \frac{W_T + 0.192 W_L}{W_T + 0.133 W_L}$$

$$r = 0.944 \pm 0.014 \pm 0.022$$

1) let assume that W_L is dominant then

$W_L(Q^2=2.32)=1.44\ W_L(Q^2=1.92)$

Which will be surprising ...... Strong increase with Q^2

2) let assume that W_T is dominant then

$W_T(Q^2=2.32)=1.06\ W_T(Q^2=1.92)$

Which is more reasonable

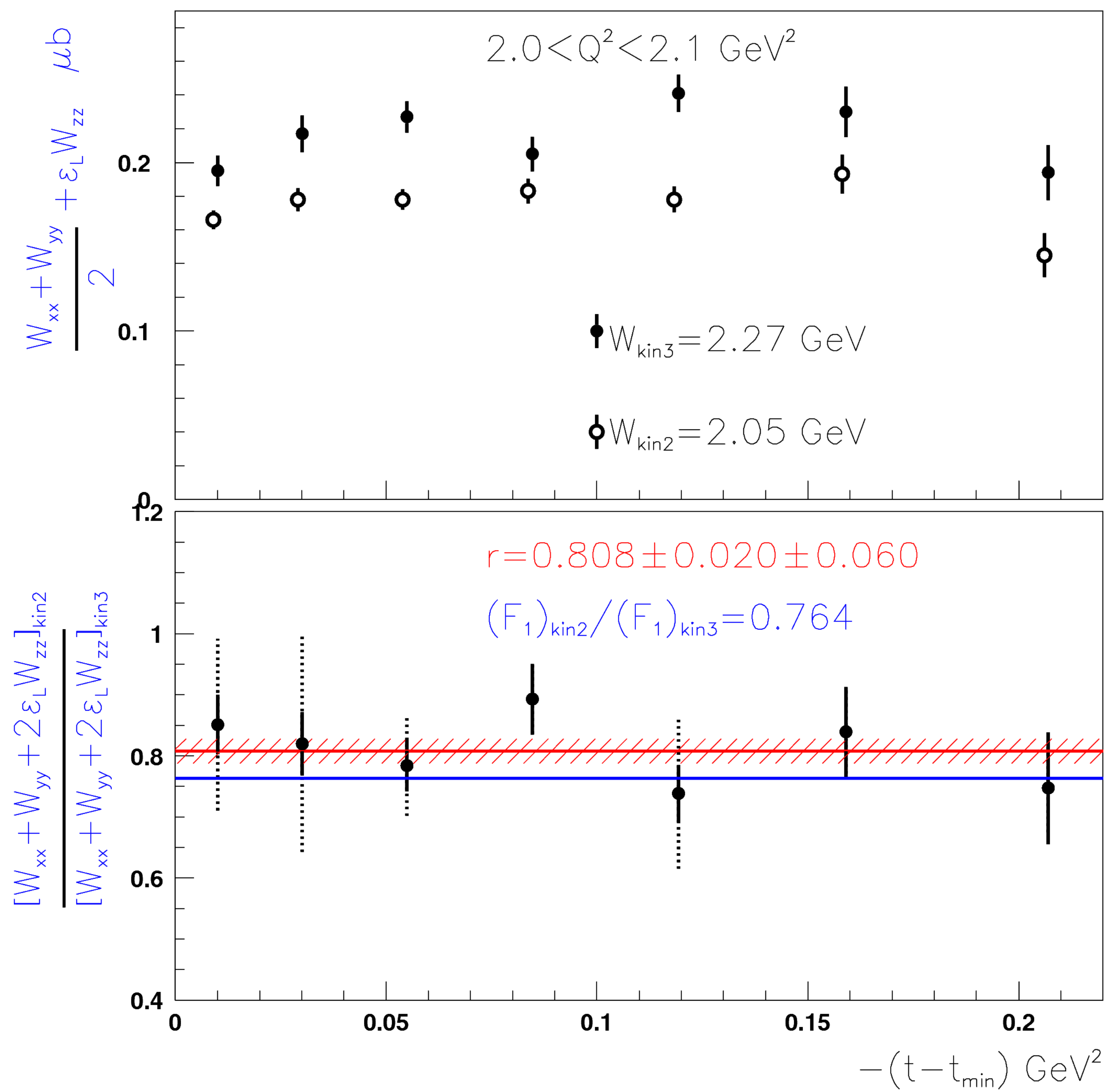
3) $W_{TT}(1.92)=-657$ x $\cos 2\phi \sin^2\Theta$ nb

$W_{TT}(2.32)=-432$ x $\cos 2\phi \sin^2\Theta$ nb

$W_T+\varepsilon_L W_L \sim 200$ nb

All this 3 facts seem in favor of $W_T >> \varepsilon_L W_L$ but it is only a conjecture which will be infirmed or proved in the next experiment...

Note: If $W_T >> \varepsilon_L W_L$ and W_T is at the leading order independent of Q^2 to obtain W_L experimentally will require at all Q^2 a transverse-longitudinal separation . Remember that GPD from π^0 are only in W_L !!!



2.0<Q²<2.1 GeV²
W_kin3=2.27 GeV
W_kin2=2.05 GeV
(W_xx+W_yy)/2 + ε_L W_zz μb
0.2
0.1
0
r=0.808±0.020±0.060
(F_1)_kin2/(F_1)_kin3=0.764
[W_xx+W_yy+2ε_L W_zz]_kin2 / [W_xx+W_yy+2ε_L W_zz]_kin3
1.2
1
0.8
0.6
0.4
0
0.05
0.1
0.15
0.2
−(t−t_min) GeV²

What have we learn in our range in forward direction:

$\Delta=-(t-t_{min})$

SURE ==> 1) Exchange in the t channel does not work

What have we learn in our range in forward direction:

$\Delta = -(t - t_{min})$

SURE ==> 1) Exchange in the t channel does not work

Strong conjecture ==> 2) $W_T(Q^2, X_{Bj}, \Delta) + \varepsilon_L W_L(Q^2, X_{Bj}, \Delta) \sim W_T(Q^2, X_{Bj}, \Delta)$

What have we learn in our range in forward direction:

$\Delta=-(t-t_{min})$

SURE ==> 1) Exchange in the t channel does not work

Strong conjecture ==> 2) $W_T(Q^2,X_{Bj},\Delta)+\varepsilon_L W_L(Q^2,X_{Bj},\Delta) \sim W_T(Q^2,X_{Bj},\Delta)$

SURE ==> 3) $W_T(Q^2,X_{Bj},\Delta)=W_T(Q_0^{\ 2},X_{Bj},\Delta).(1+0.13/Q^2+.....)$

No Q^2 dependence ==> Photons prob point like object ??? quarks ???

$\Delta=-(t-t_{min})$

What have we learn in our range in forward direction:

SURE ==> 1) Exchange in the t channel does not work

Strong conjecture ==> 2) $W_T(Q^2,X_{Bj},\Delta)+\varepsilon_L W_L(Q^2,X_{Bj},\Delta) \sim W_T(Q^2,X_{Bj},\Delta)$

SURE ==> 3) $W_T(Q^2,X_{Bj},\Delta)=W_T(Q_0{}^2,X_{Bj},\Delta).(1+0.13/Q^2+.....)$

No q2 dependence ==> Photons prob point like object ??? quarks ???

Puzzling coincidence ?? ==> 4) $W_T(Q^2,X_{Bj},\Delta)\sim D(\Delta).F_1(Q^2,X_{Bj})$

Transverse part of HALL C π^+ data(T. Horn et Al) was recently and successfully reproduce by a Lund fragmentation models (jetset part of PYTHIA code) M.Kaskulov et Al arXiv:0804:1834

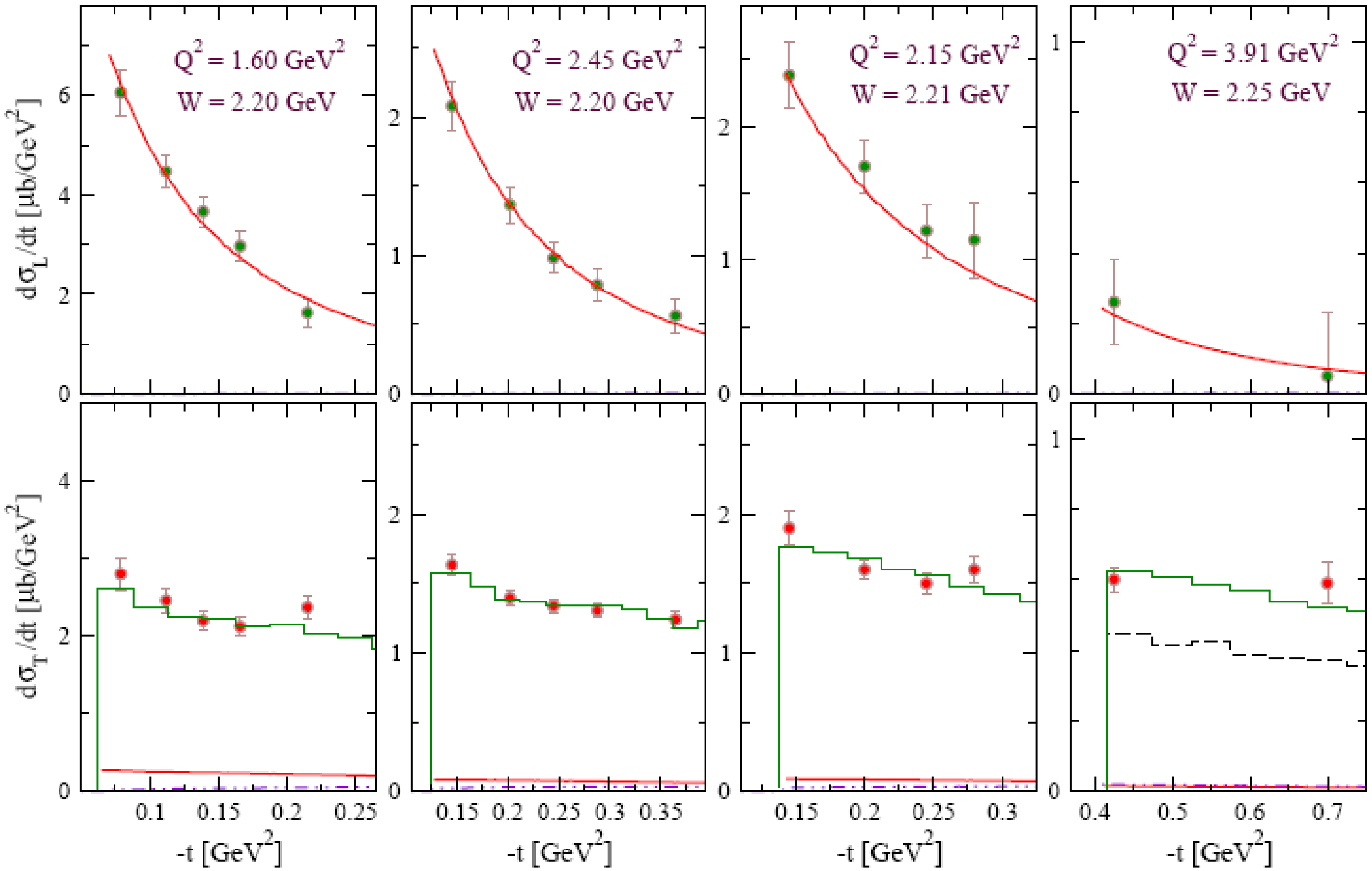
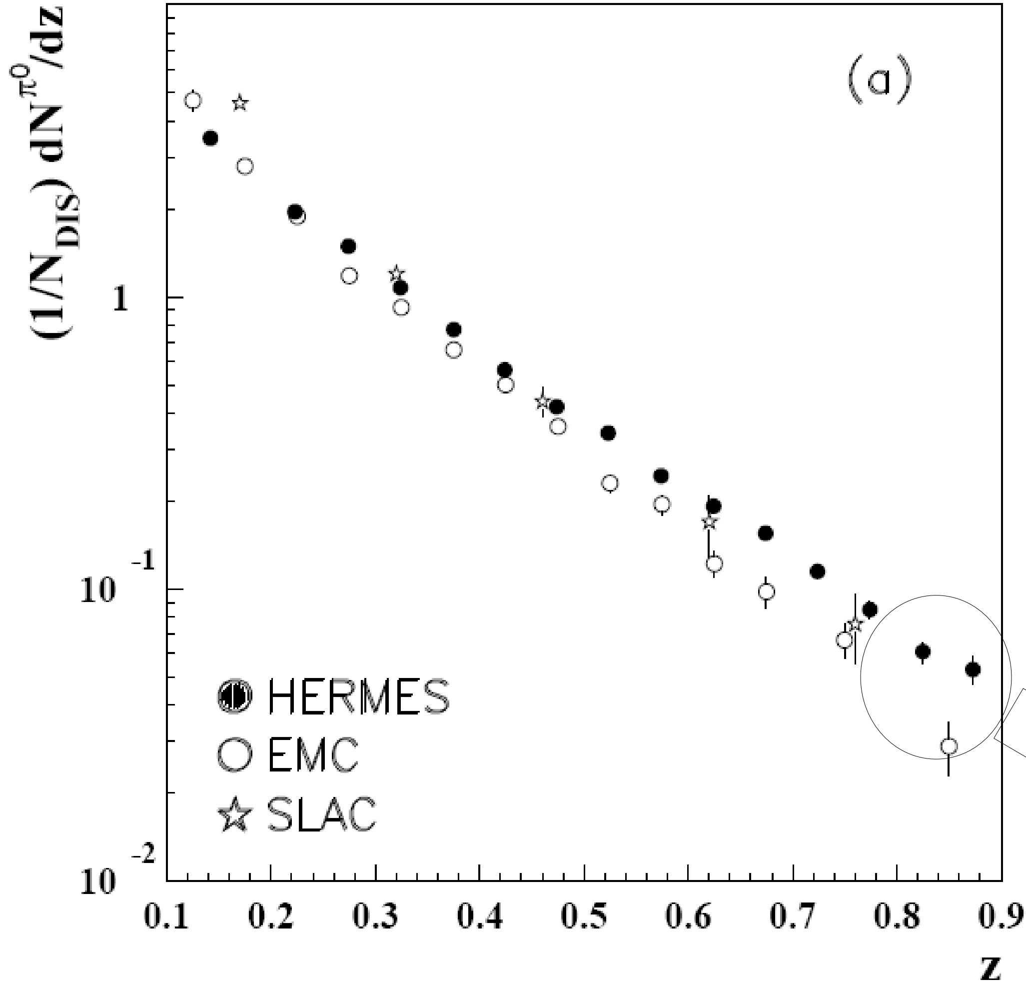


FIG. 2: The longitudinal $d\sigma_{\rm L}/dt$ (top panels) and transverse $d\sigma_{\rm T}/dt$ (bottom panels) differential cross sections of the reaction $p(e,e'\pi^+)n$ at values of $Q^2 = 1.60$ (2.45) GeV^2 [3] and $Q^2 = 2.15$ (3.91) GeV^2 [4]. The solid curves are the contribution of the hadron–exchange model and the histograms are the contribution of the DIS pions for the average transverse momentum of partons $\sqrt{\langle k_{\rm t}^2\rangle} = 600$ MeV. The dashed histogram in the lower right panel shows the contribution of the DIS pions for the value of $\sqrt{\langle k_{\rm t}^2\rangle} = 1$ GeV. The hardly visible dot–dot–dashed curves describe the contribution of the ρ–meson Reggeon exchange.

All things look like the semi inclusive Deep inelastic
But here we are fully exclusive. But can we consider that

SIDIS -->Exclusive when z-->1 ??

and then used the SIDIS Factorization ??

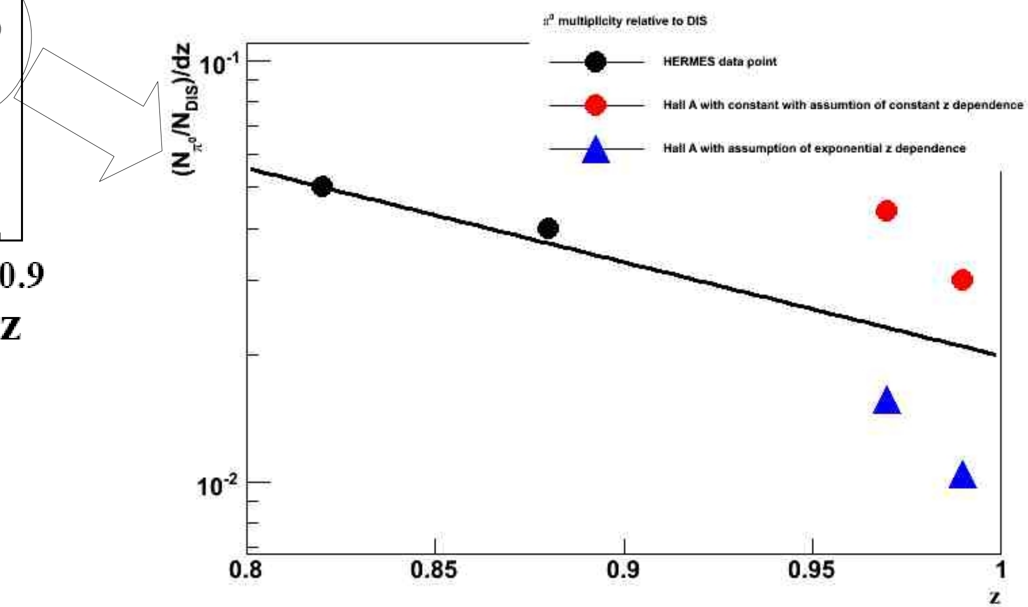


Multiplicity of Charged and Neutral Pions in Deep-Inelastic Scattering of 27.5 GeV Positrons on Hydrogen

Authors: The HERMES Collaboration: A. Airapetian, et al

ArXiv : arXiv:hep-ex/0104004v2

$$z = \frac{P.p_h}{P.q} = \frac{E_h}{\nu} \approx \frac{q_{\pi^0}'}{\nu}$$



$$\sigma(t - t_{min}) = \sigma_{t_{min}} e^{2(t - t_{min})}$$

t slope from Kubarovsky et al.

arXiv:0802.1678 [hep-ex]

In red : assumption of constant t dependence

In blue : average with an assumption of exponential t dependence

It unsettling ..? but if yes

there is a lot of questions :

What role play $p_t=q^*\sin\Theta$?

It is the same that the SIDIS $p_\perp$??

$$\Delta=(q^*/q'^*)P_T^2$$

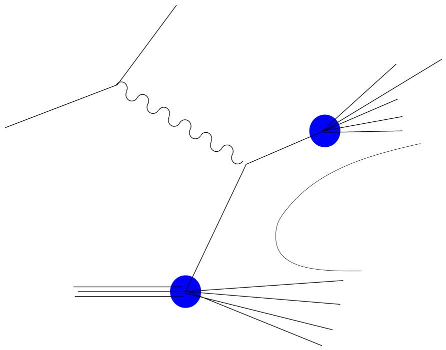
Can we interpret X_{Bj} and P_T like the probability to find a quark with a fraction of proton momentum X_{Bj} and a tranverse momentum P_T ??

What is the meaning to give at the
TT TL and TL' components ???

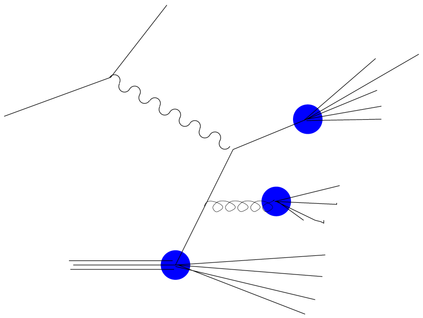
If exclusive π^0 is in some way like SIDIS or access at some equivalent informations, then it will present some advantages over SIDIS if we are interested on the origin of the P_t.

1) No need to remove events produced by decay of leading mesons Vectors

2) No need to care with the target fragmentation



3) No need to take care of jet produce by Gluon radiation



Experimentally what have we learned ?

1) With a high resolution spectrometer (The best !) and a Calorimeter which match well the spectrometer acceptance cross section measurements at a level few % accuracy are doable .

2) High statistic ,and accuracy measurement allow to explore physic even with a limited lever arm

3) in forward direction $t-t_{min}$ is the relevant variable experimentally and not t

In a close future 2010 :

-- We will add third point in Q^2 and do a full transverse-longitudinal separation on the 3 kinematics
(experiment E007007)

--at Q2=1.92 GeV2 measurement we will have on the deuterium with L-T separation
(experiment E008025)

With the 12 Gev :

we have a full already approved program of DVCS and π^0 covering a large range in x_{Bj} and Q^2(up to 9 GeV^2)
(Experiment E12-06114)

π^0 a bad guy ? ......

...... perhaps not !