Form Factor Overview

Form factors are essential for our understanding of internal hadron structure and the dynamics that bind the most basic elements of nuclear physics

- Pion and kaon form factors are of special interest in hadron structure studies
  - The pion is the lightest QCD quark system and also has a central role in our understanding of the dynamic generation of mass.
  - The kaon is of interest as it replaces one light quark with a heavier strange quark.
- Recent advances in experiments: last 5-10 years
  - Dramatically improved precision in F_p measurements
  - Improved experimental understanding of the meson production/reaction mechanism
- Current measurements – JLab 12 GeV next 5-10 years
  - F_p and exclusive meson studies up to highest possible Q^2 – potential to reach the regime in which hard QCD's signatures will be quantitatively revealed
  - Exclusive kaon cross sections at low t and possible F_{K+} extraction

The JLab 12 GeV kaon experiment (E12-09-011)

- Two different spectrometers involved corresponding to different acceptances:

  - HIGH MOMENTUM SPECTROMETER (HMS) – electron detection
    - Operating from 0.86– 5.1 GeV/c (max is 7.5) "hsdelta" refers to the momentum in this spectrometer

  - SUPER HIGH MOMENTUM SPECTROMETER (SHMS) kaon/pion detection
    - Operating from 2.7 – 6.8 GeV/c
    - The CUA built aerogel Cherenkov detector will be used for particle identification

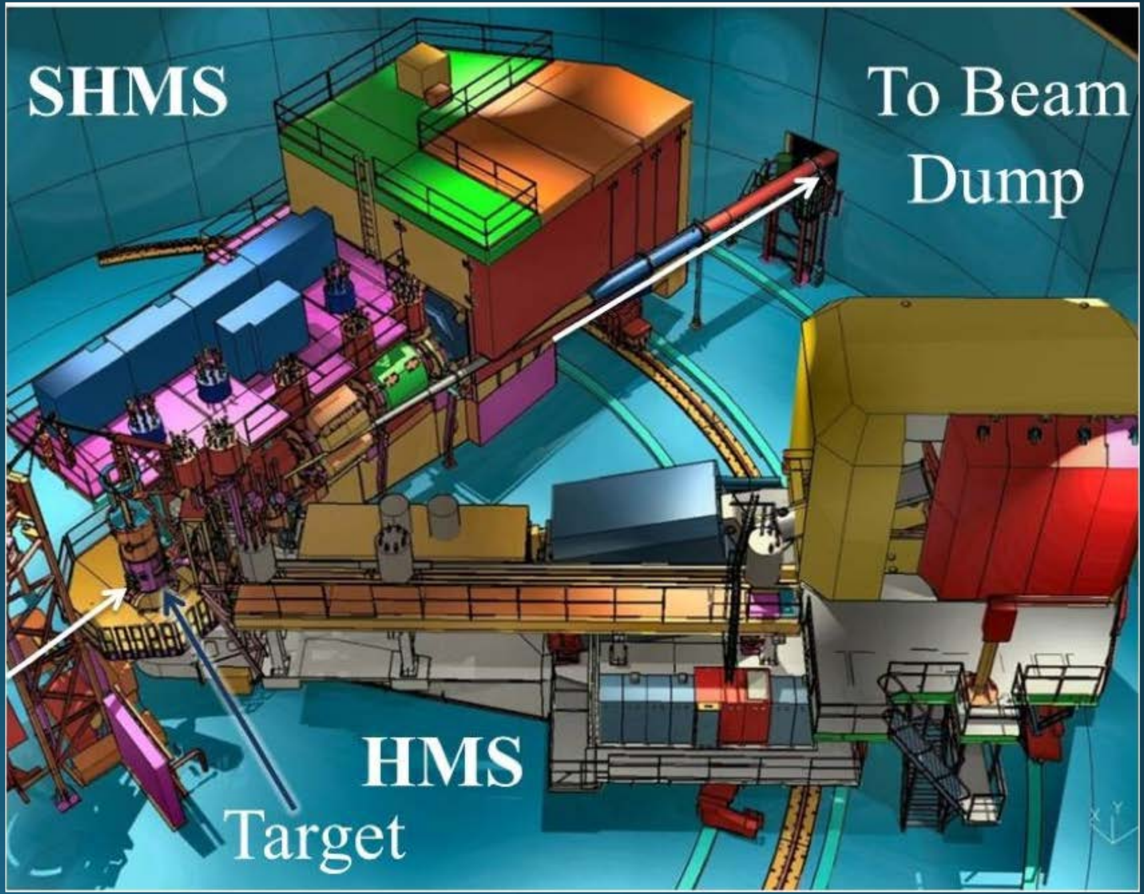


Figure 1: SHMS and HMS detectors shown in experimental setup

Projections using simc

- Edited input file with appropriate kinematics, and ran simc.
- Target length was adjusted for 10 cm.
- Input files were implemented to be suitable for root.
- 2D Histograms plot overlapped, and diamond cuts applied

fk12_2b_kaons.inp

```
; This is a CTP file

begin parm experiment
  ngen = 20000                   ;  POS: # of successes; NEG: # of tries
  EXPER%charge = 1.0             ;  total charge (mC)
  doing_phsp = 0                 ;  (ONE = TRUE)
  doing_kaon = 1                 ;  (ONE = TRUE)
  doing_pion = 0                 ;  (ONE = TRUE)
  which_pion = 0                 ;  (0=p->pi+,1=n->pi-,10/11 for pi+/pi- coherent)
  doing_decay = 1                ;  1=decay ON, 0=decay OFF.
  ctau = 371.3                   ;  decay length (cm)
end parm experiment

begin parm kinematics_main
  Ebeam = 3799.0                        ;  (MeV)
  dEbeam = 0.05                  ;  beam energy variation (%)
  electron_arm = 1               ;  1=hms,2=sos,3=hrsr,4=hrsl,5=shms
  hadron_arm = 5                 ;  1=hms,2=sos,3=hrsr,4=hrsl,5=shms
  spec%e%P = 857.0               ;  e arm central momentum (MeV/c)
  spec%e%theta = 20.18           ;  e arm angle setting (degrees)
  spec%p%P = 2669.2              ;  p arm central momentum (MeV/c)
  spec%p%theta = 5.64            ;  p arm angle setting (degrees)
end parm kinematics_main

begin parm target
  targ%A = 1.                    ;  target A
  targ%Z = 1.                    ;  target Z
  targ%mass_amu = 1.007276       ;  target mass in amu
  targ%mrec_amu = 0.             ;  recoil mass in amu (eep=A-1 system,pion=A-2)
  targ%rho = 0.0723              ;  target density (g/cm^3)
  targ%thick = 723.0             ;  target thick (mg/cm^2)
  targ%angle = 0.                ;  target angle (for solid target) (degrees)
  targ%abundancy = 100.          ;  target purity (%)
  targ%can = 2                   ;  1=beer can (fpi), 2=pudding can (nucpi)
end parm target

begin parm debug                 ;  (ONES give helpful debug info)
  debug(1) = 0                   ;  turns on output from brem.f
  debug(2) = 0                   ;  into/outa subs.
  debug(3) = 0                   ;  spit out values (init. and main loop).
  debug(4) = 0                   ;  mostly comp_ev, gen_rad diagnostics.
  debug(5) = 0                   ;  a bit of everything.
end parm debug

begin parm e_arm_accept
  SPedge%e%delta%min = -15.0     ;  delta min (SPECTROMETER ACCEPTANCE!)
  SPedge%e%delta%max =  15.0     ;  delta max
  SPedge%e%yptar%min = -40.0     ; .yptar.min = {TF} / 1000 (mrad)
  SPedge%e%yptar%max =  40.0     ; .yptar.max = {TF} / 1000
  SPedge%e%xptar%min = -90.0     ; .xptar.min = {TF} / 1000 (mrad)
  SPedge%e%xptar%max =  90.0     ; .xptar.max = {TF} / 1000
end parm e_arm_accept

begin parm p_arm_accept
```

Figure 2: A sample screenshot of an edited input file with the kinematics of the run 2b applied.

L/T Separation Example

- σ_L is isolated using the Rosenbluth separation technique
  - Measure the cross section at two beam energies and fixed W, Q^2, -t
  - Simultaneous fit using the measured azimuthal angle (ϕ_π) allows for extracting L, T, LT, and TT
- Careful evaluation of the systematic uncertainties is important due to the 1/ε amplification in the σ_L extraction
  - Spectrometer acceptance, kinematics, and efficiencies

- Magnetic spectrometers are a must for such precision cross section measurements
  - This is only possible in Hall C at JLab

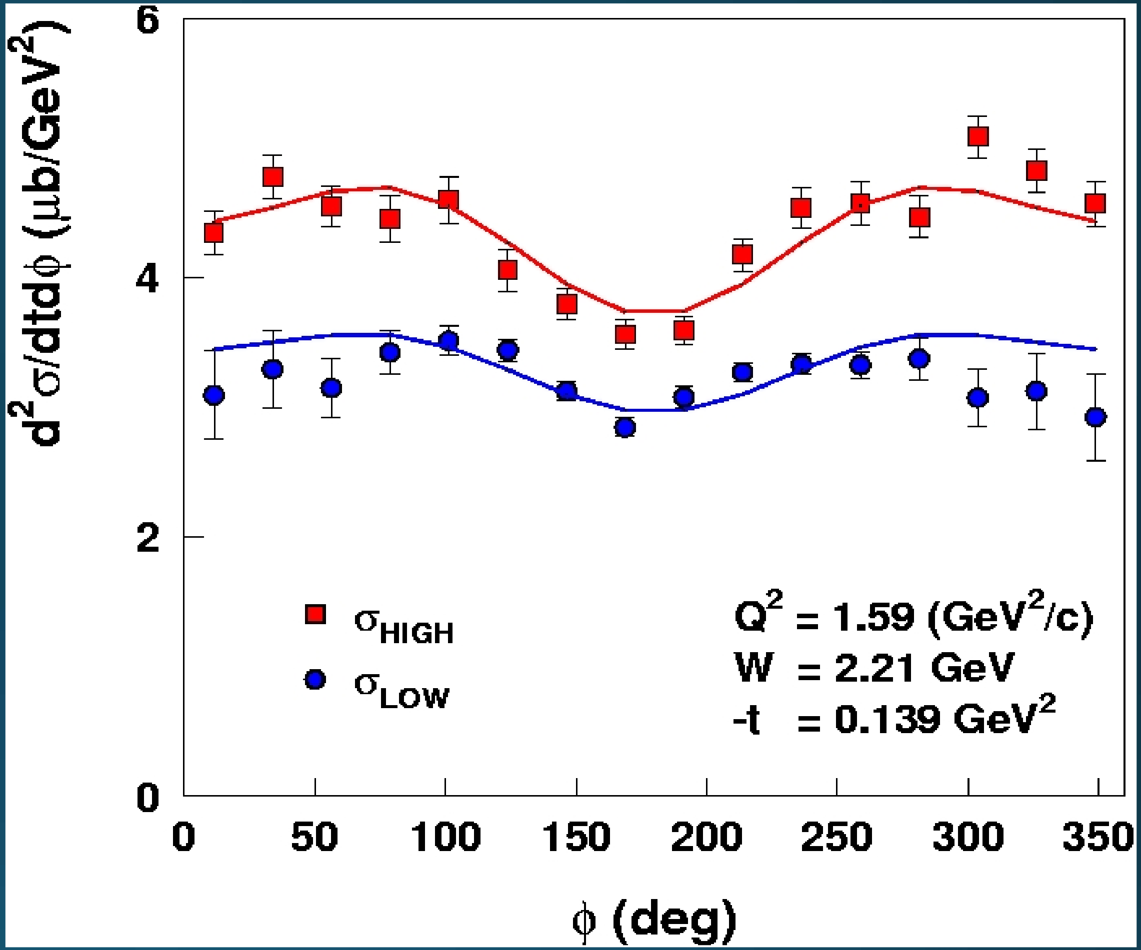
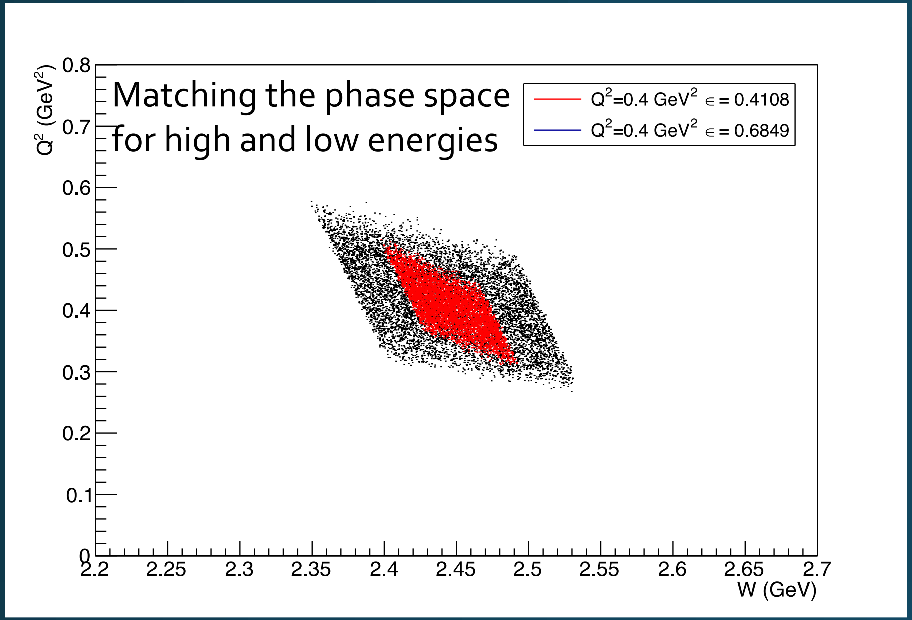


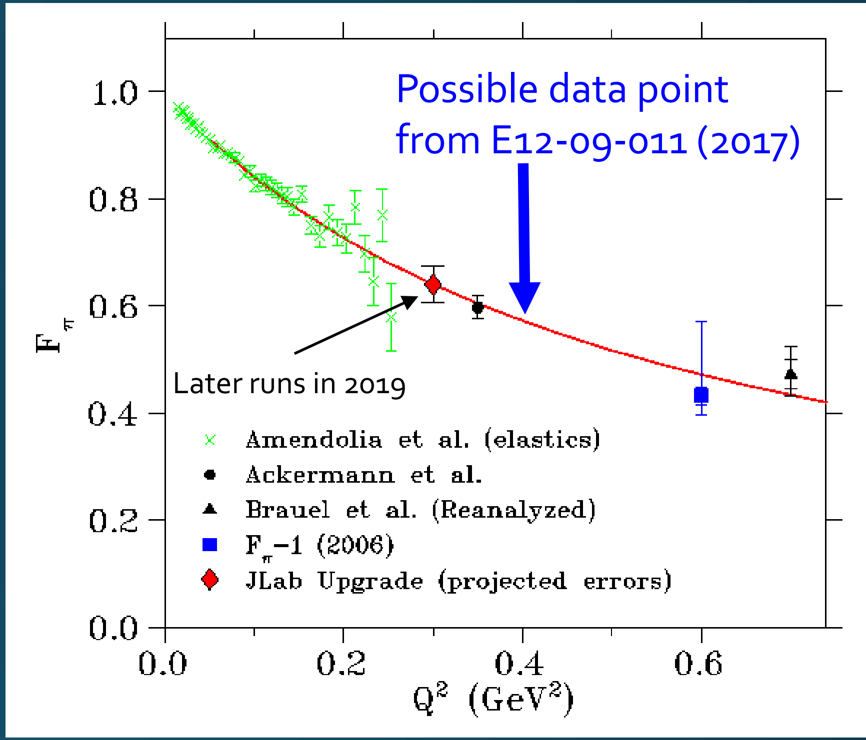
Figure 3 : Cross section σ_L projected as a function of ϕ.

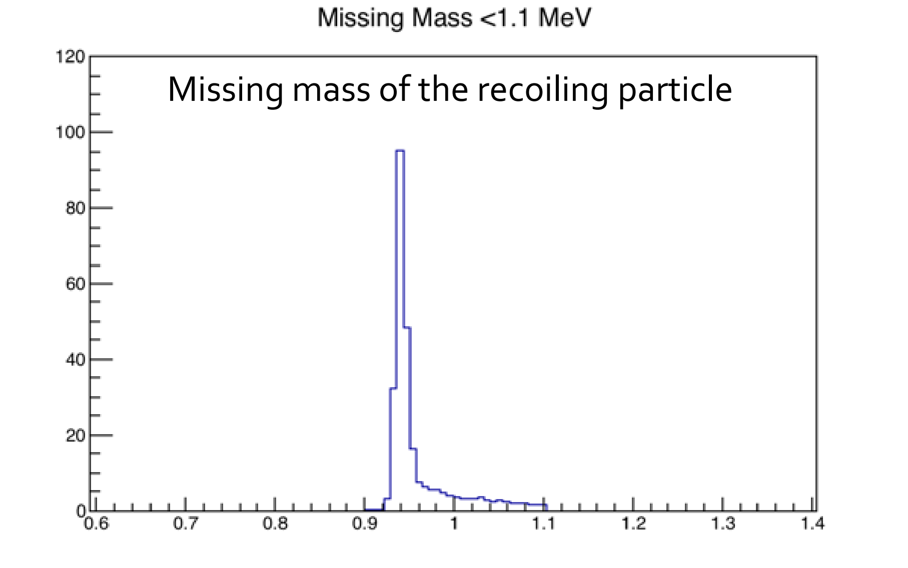
$$2\pi\frac{d^2\sigma}{dt\,d\phi} = \varepsilon\frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

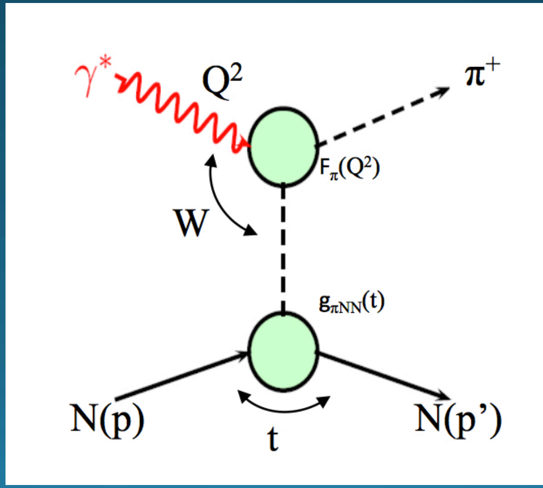
σ_L will give us F_π

Pions using the p(e,e'π+)n hypothesis for E12-09-011









Pions using the p(e,e′π+)n hypothesis for E12-09-011

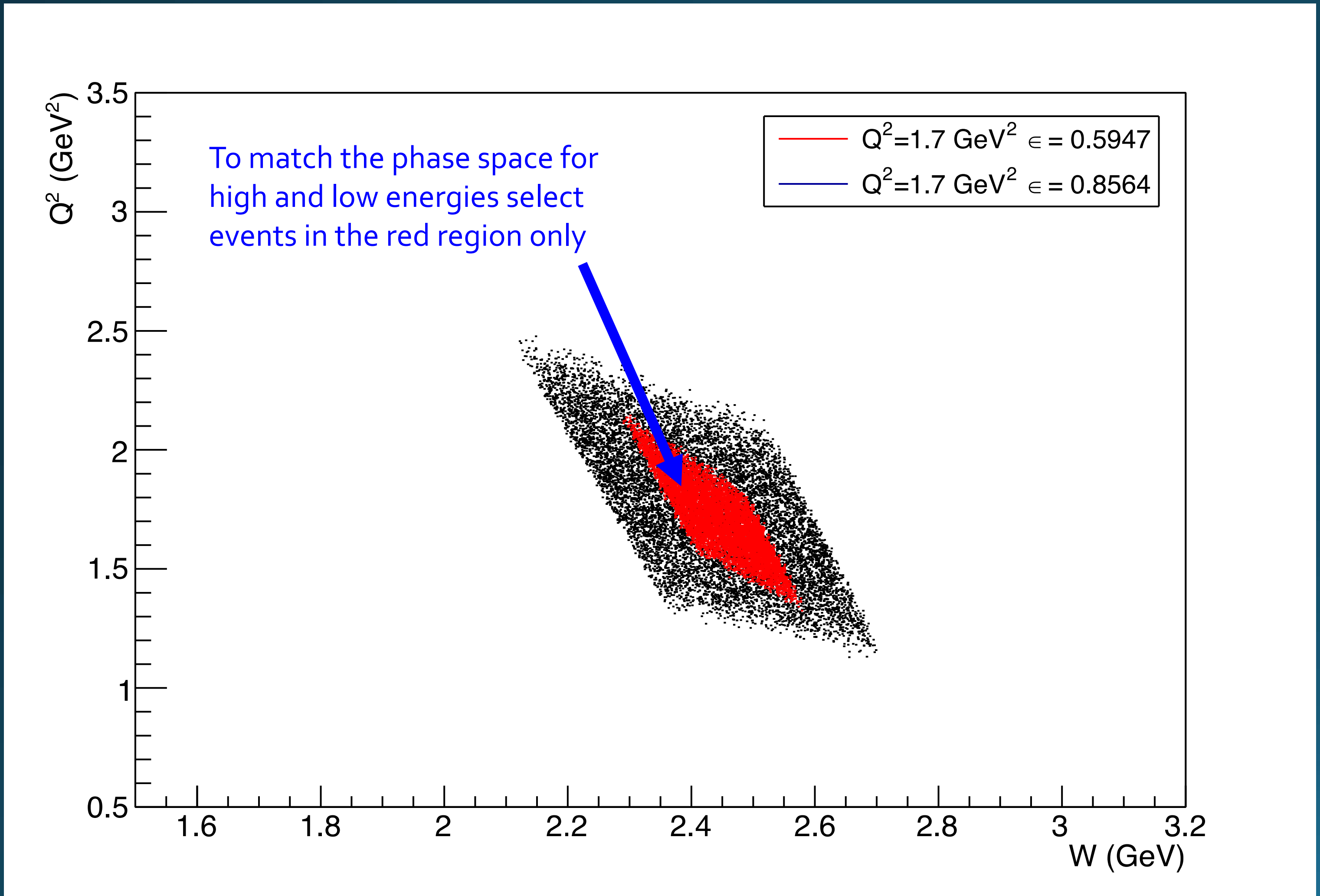


Figure 4: 2-D histograms overlapped in which number of pions were determined by applying appropriate cuts.

- Q^2 = 1.7 GeV^2 and W = 2.45 GeV
  - Pions@ low epsilon: 1.05 x 10^6
  - Pions @ high epsilon: 2.22 x 10^6
  - Standard cuts applied:
    - hsdelta: -8 to 8
    - ssdelta: -10 to 22;
    - hsyptar: -0.1 to 0.1
    - hsxptar: -0.1 to 0.1
    - Ssxptar: -0.04 to 0.04
    - Ssyptar: -0.06 to 0.06
    - **Missing mass cut <1.1**

Table 1: Summarizing Results from Simulations

Q2 (GeV^2)	W (GeV)	Current (uA)	R π+ (events/s)	Time (hrs)	N pions
0.4	2.45	35	6.0	125.8	2708204
0.4	2.45	35	18.6	84.5	5657198
1.7	2.45	70	9.55	30.5	1049062
1.7	2.45	70	31.3	19.7	2221976

Extraction of F_π from σ_L Jlab data – use a model

- JLab 6 GeV F_π experiments used the VGL/Regge model as it has proven to give a reliable description of σ_L across a wide kinematic domain.

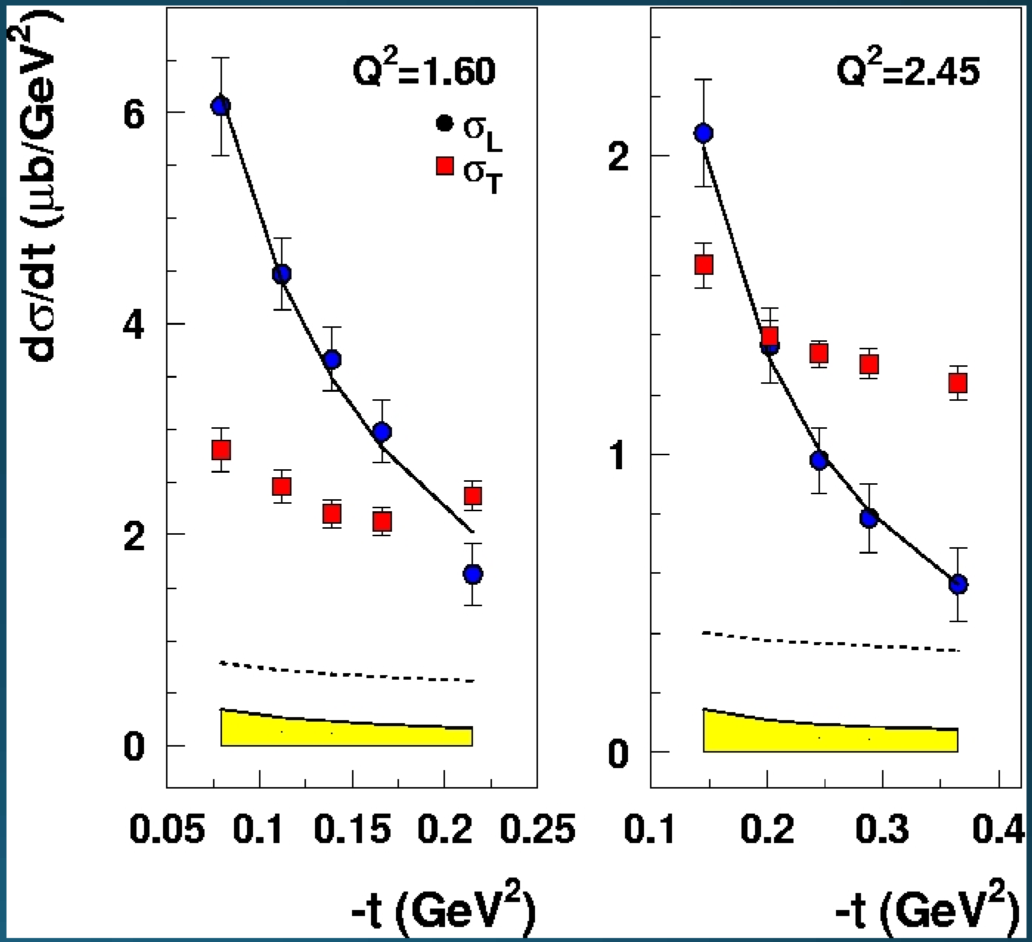
*[Vanderhaeghen, Guidal, Laget, PRC **57**, (1998) 1454]*

- Feynman propagator replaced by π and ρ trajectories
- Model parameters fixed by pion photoproduction data
- Free parameters: $\Lambda_\pi^2, \Lambda_\rho^2$

$$F_\pi(Q^2) = \frac{1}{1 + Q^2/\Lambda_\pi^2}$$

Fit of σ_L to model gives F_π at each Q^2

*[Horn et al., PRL **97**, (2006) 192001]*



Λ_π^2 = 0.513, 0.491 GeV²

Λ_ρ^2 = 1.7 GeV²

$t = m_\pi^2$

Projection of uncertainty on Fπ – Analytical Estimate

$$\frac{\Delta F_\pi}{F_\pi} = \frac{1}{2}\frac{1}{(\epsilon_1 - \epsilon_2)}\sqrt{\left(\frac{\Delta\sigma_1}{\sigma_1}\right)^2 (r+\epsilon_1)^2 + \left(\frac{\Delta\sigma_2}{\sigma_2}\right)^2 (r+\epsilon_2)^2}$$

Q2 (GeV^2)	W (GeV)	Current (uA)	R π+ (events/s)	Time (hrs)	N pions	epsilon	Ds/s	dFπ/Fπ
0.4	2.45	35	6.0	125.8	2708204	0.685	0.00061	
0.4	2.45	35	18.6	84.5	5657198	0.411	0.00042	0.00176
1.7	2.45	70	9.55	30.5	1049062	0.856	0.00097	
1.7	2.45	70	31.3	19.7	2221976	0.595	0.00067	0.0033

Extracting pion form factor uncertainties from simulation - first step: t- distribution

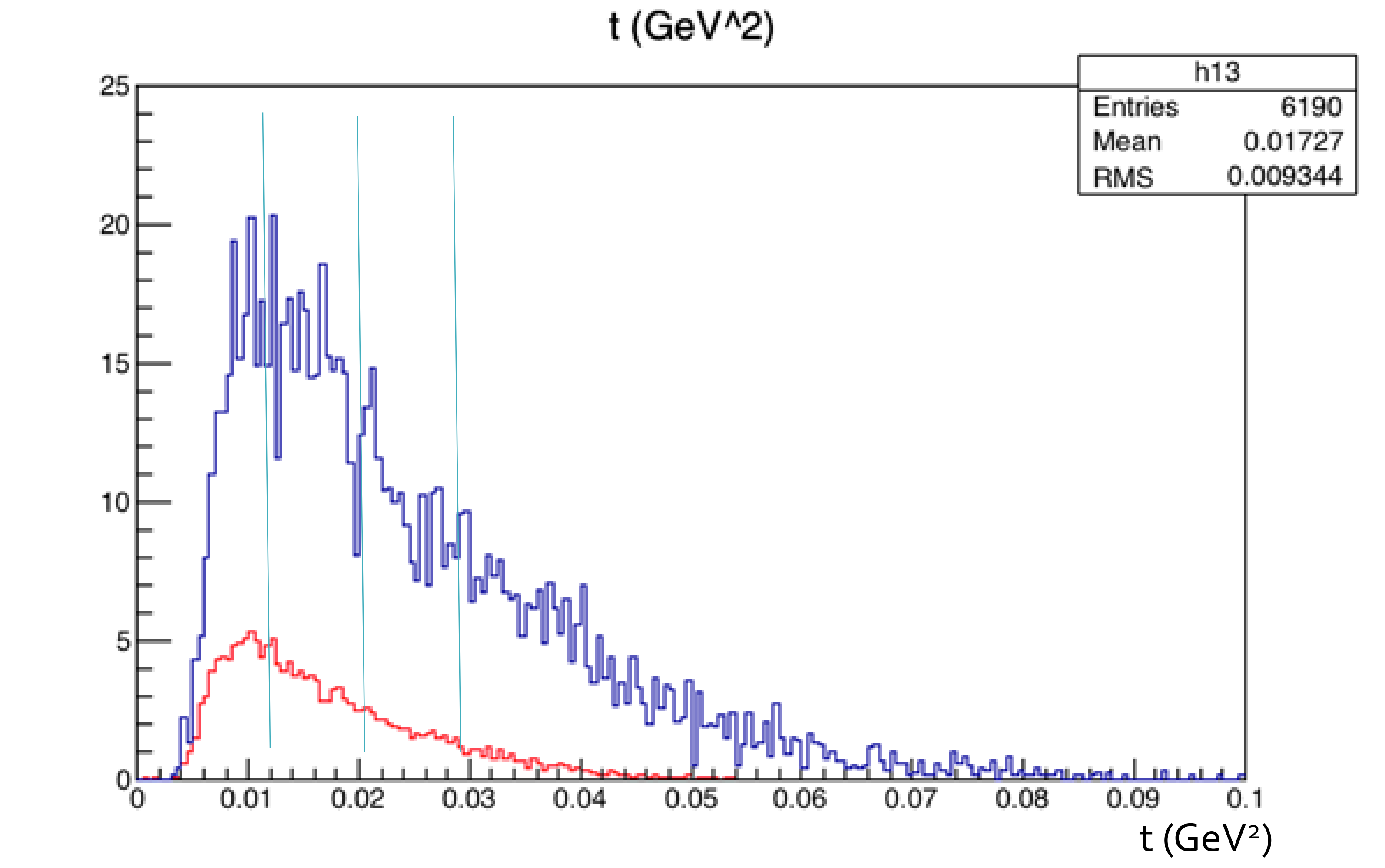


Figure 5: t-distribution plotted in the range of 0 to 0.1 GeV^2

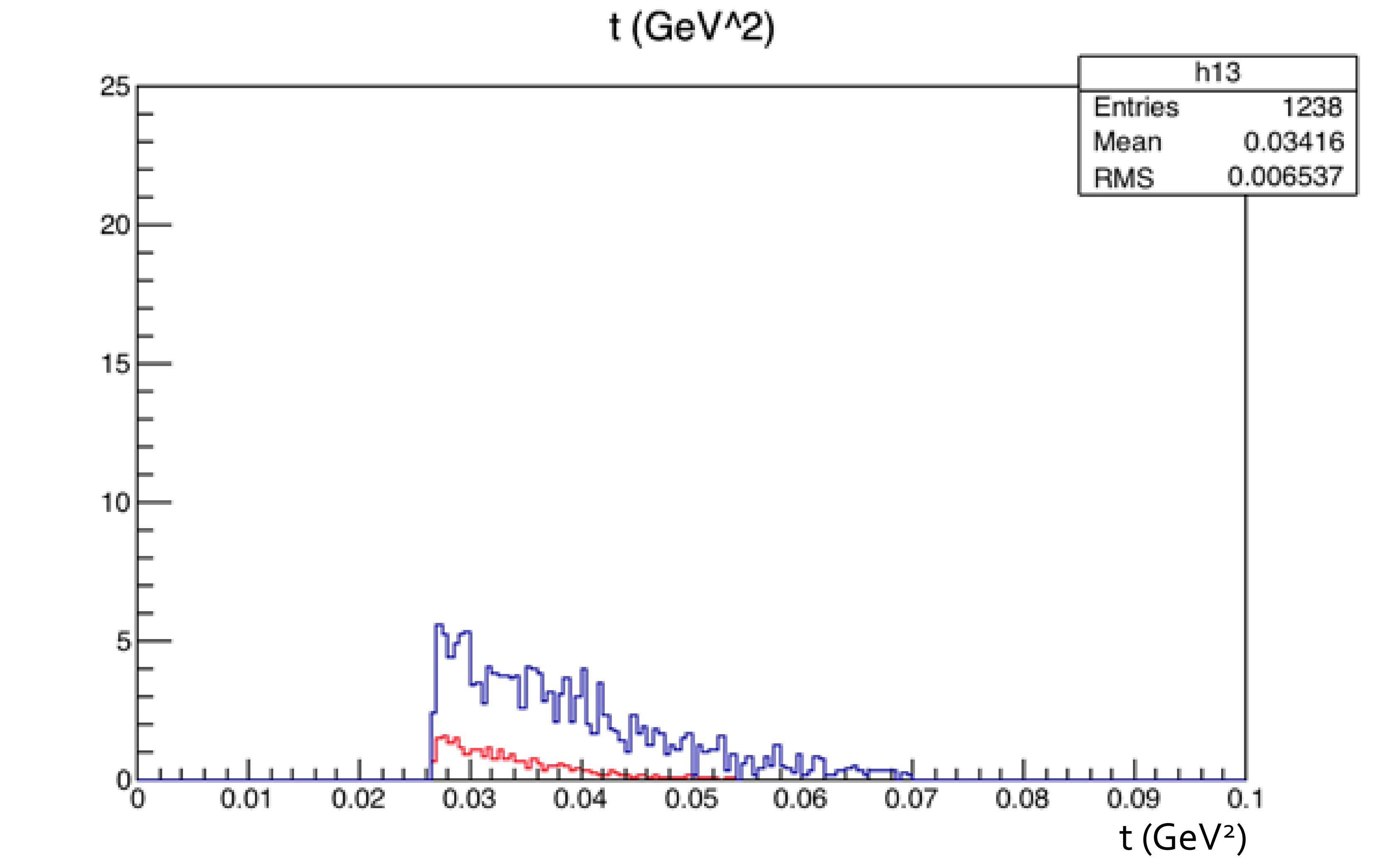


Figure 6: Sample of one cut applied to t at the range of 0.03 to 0.1 corresponding to the number of events in one of the bins.

Outlook

- To find the cross section as a function of ϕ for different bins in t and estimate uncertainties on the form factor
- To optimize projections for inelastic electron scattering.
- Make estimations of limiting dead time for kaon data acquisition.