Coulomb Sum Rule (^4He target)

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Coulomb Sum Rule

e⁻-P elastic scattering

$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{Mott}[\frac{G_E^2(Q^2)}{1+\tau} + \frac{\tau G_M^2(Q^2)}{\epsilon(1+\tau)}]$$

e⁻-Nuclear quasi-elastic scattering

$$\frac{d^2\sigma}{d\Omega d\omega} = \sigma_{Mott}[\frac{Q^4}{\vec{q}^4} R_L(|\vec{q}|,\omega) + \frac{Q^2}{2\vec{q}^2\epsilon} R_T(|\vec{q}|,\omega)]$$

- Virtual photon polarization: $\epsilon(|\vec{q}|,\omega) = [1 + \frac{2\vec{q}^2}{Q^2}\tan^2\frac{\theta}{2}]^{-1}$
- Mott cross-section: $\sigma_M = \frac{\alpha^2\cos^2(\frac{\theta}{2})}{4E^2\sin^4\frac{\theta}{2}}$
- Four momentum square: $Q^2 = \vec{q}^2 - \omega^2 = 4EE'\sin^2(\frac{\theta}{2})$
- $\tau = \frac{Q^2}{4M}$

Rosenbluth separation

- charge information:
- magnetization information:

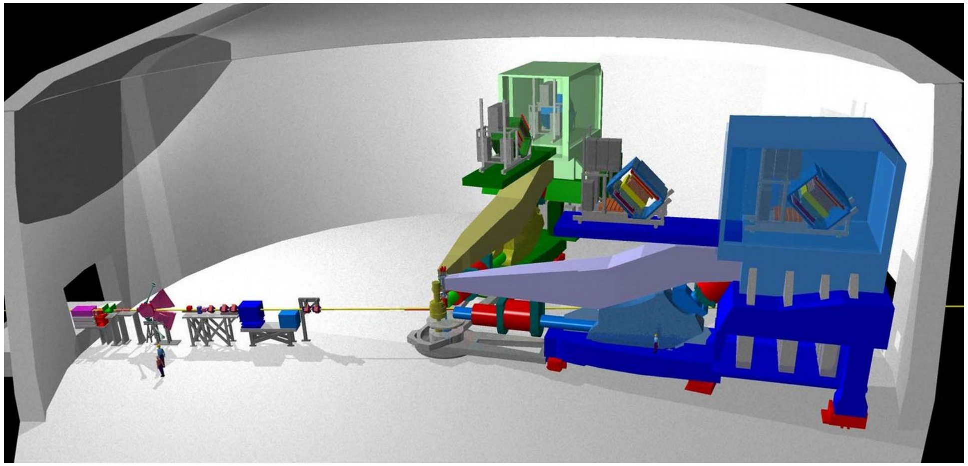
- $G_E^2(Q^2)$
- $G_M^2(Q^2)$

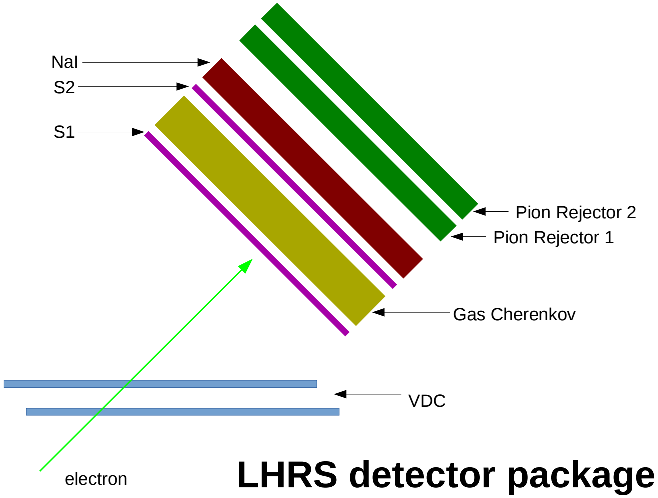
- $R_L(|\vec{q}|,\omega)$
- $R_T(|\vec{q}|,\omega)$

Coulomb Sum $\quad S_L(|\vec{q}|) = \int_{\omega^+}^{|\vec{q}|} d\omega \frac{R_L(\omega,|\vec{q}|)}{ZG_{Ep}^2(Q^2)+NG_{En}^2(Q^2)}$

At large $|q| >> 2k_f$, S_L should go to 1. Any sigificant deviation from this would be an indication of relativistic or medium effects distorting the nucleon form factor!

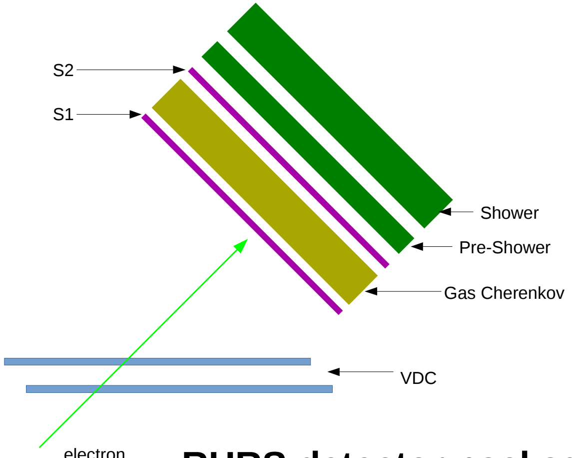
Experiment Setup





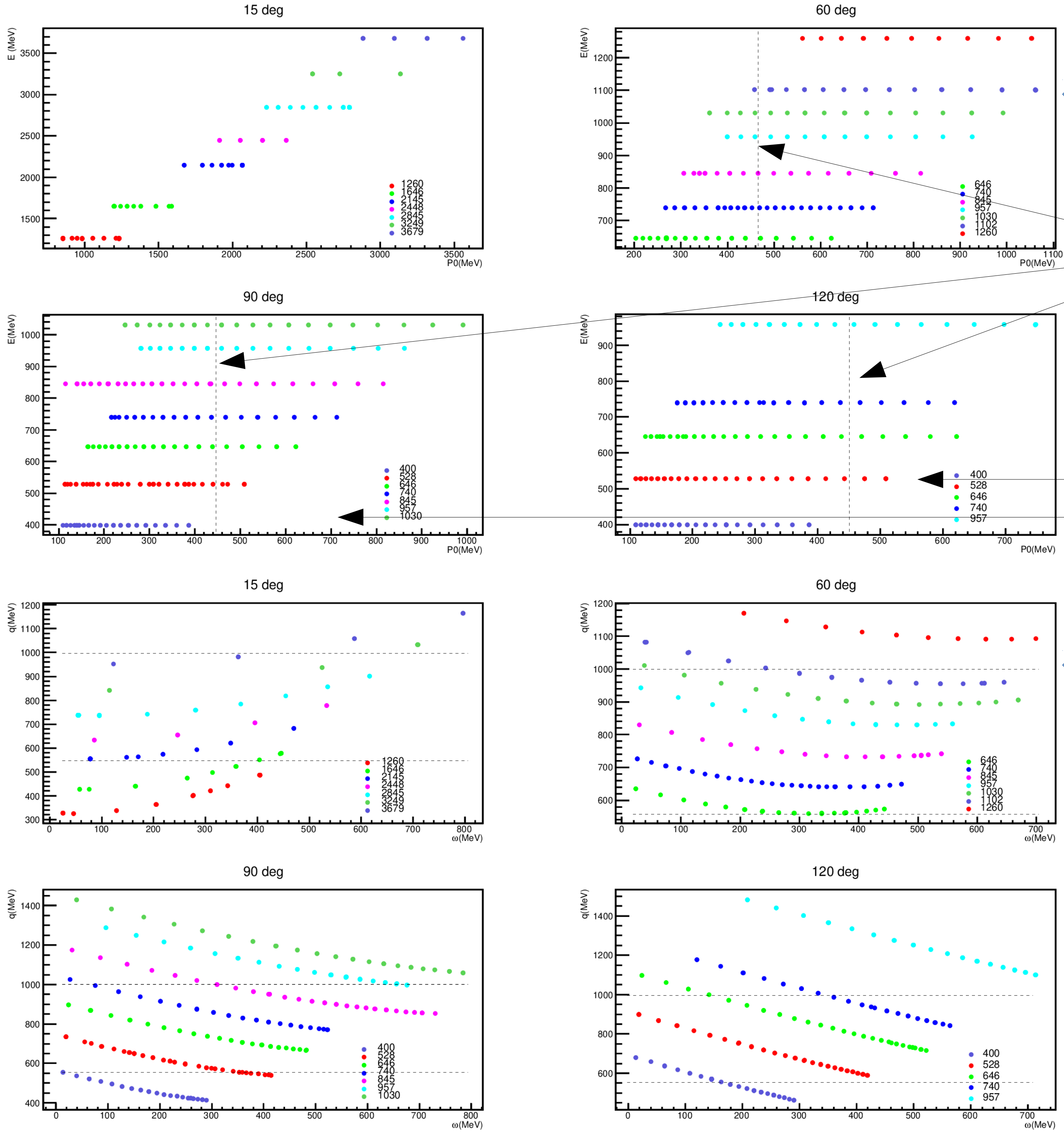
LHRS detector package

- 550 MeV/c ≤ **|q|** ≤ 1000 MeV/c
- Beam energy: 0.4 - 4 GeV
- Scattered electron energy: 0.1 - 4 GeV
- Scattering angle: 15◦ , 60◦ , 90◦ and 120◦
  (The number of kinematics is larger)
- LHRS and RHRS independent(redundant) measurements for most settings
- Targets: ^{4}He, ^{12}C, ^{56}Fe, ^{208}Pb



RHRS detector package

Kinematics



4He kinematics in E(beam energy) and P0(HRS central momentum)

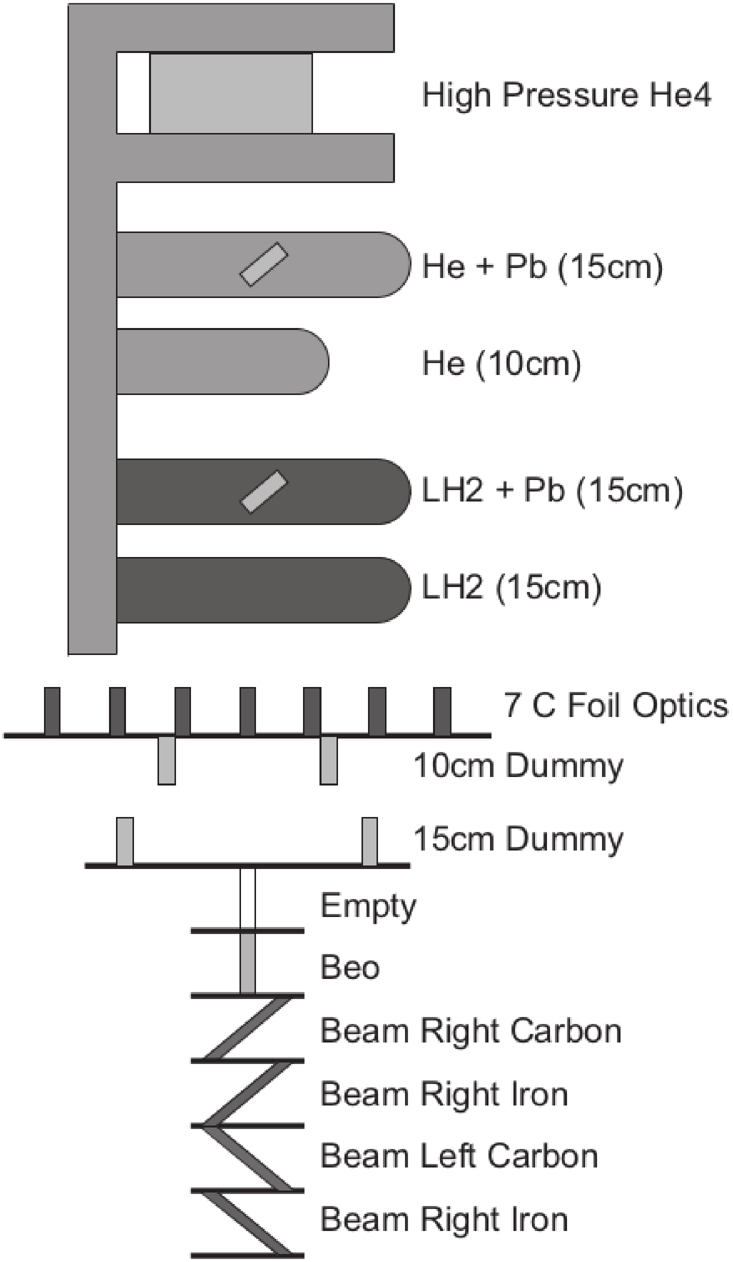
A lot of kinematics at low momentum.

Runs at large angle (90deg, 120deg) reach very low central momentum P0.

4He kinematics in ω and q

The spectrums are not along constant q: interpolation between spectrums is necessary!

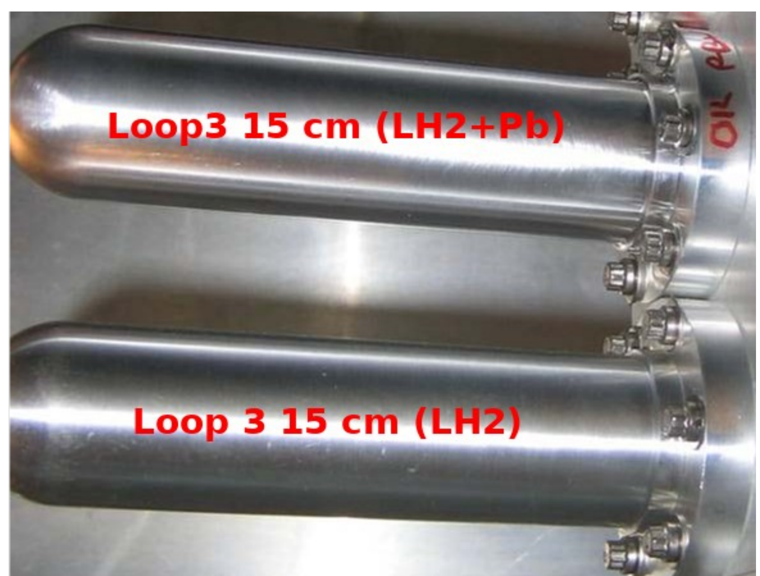
Extended Targets



Loop1(high pressure ^{4}He gas): racetrack, 10 cm, 0.12 g/cm^3 6.3K, 1.4 MPa

Loop3, top (Pb foil kept in liquid H_2): 15 cm

Loop3, bottom (liquid H_2): 15 cm, 0.0723 g/cm^3 7.0 K, 170 psi.



Acceptance at Low Momentum

The low momentum acceptance is important for CSR experiment:

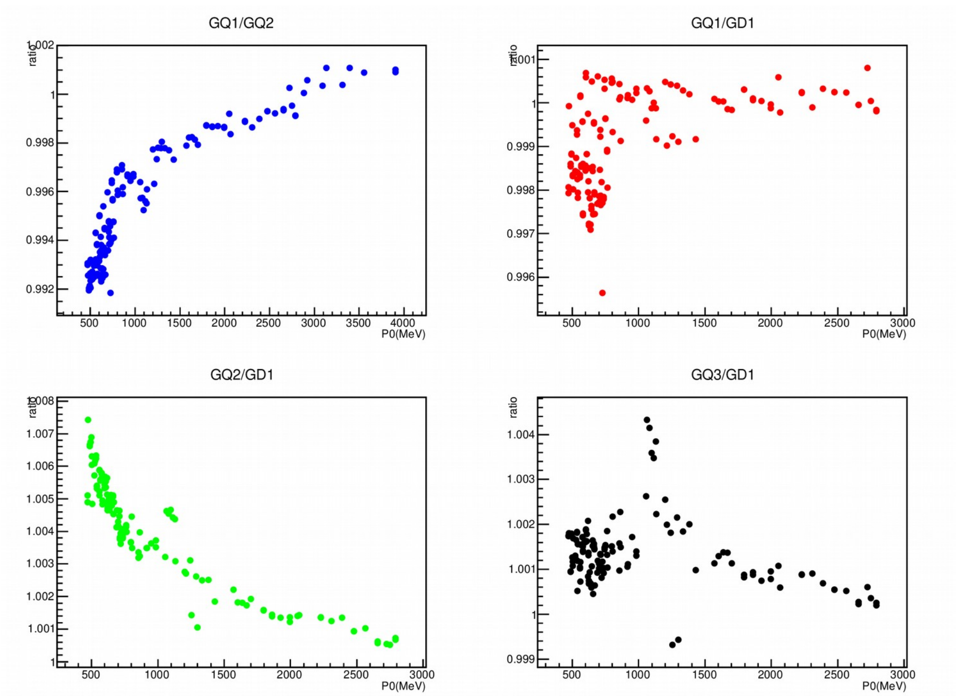
- The HRS behavior is different when P0 < 450 MeV:

P0 > 450 MeV, field ratio between magnets kept nearly constant so optics property does not change with P0.
P0 < 450 MeV, field ratio between magnets change with P0 by ~3%.

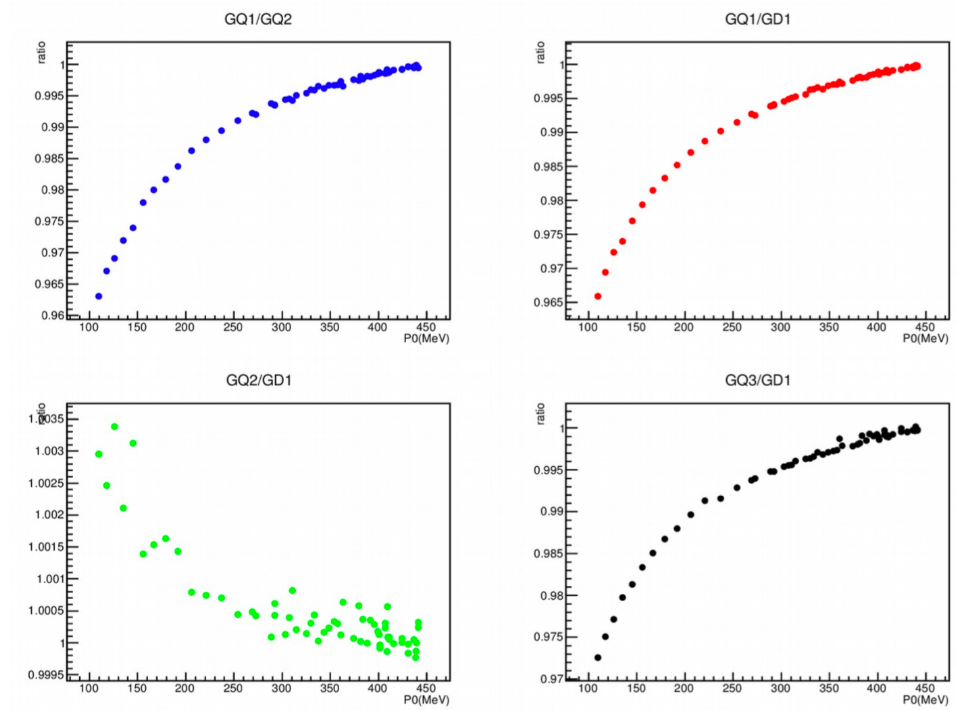
- The multiple scattering is inverse-proportional to particle's momentum:

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\Big[1 + 0.038 \ln(x/X_0)\Big]$$

at very low momentum (<200 MeV), the effect of multiple scattering is big.



field ratio above 450 MeV



field ratio below 450 MeV

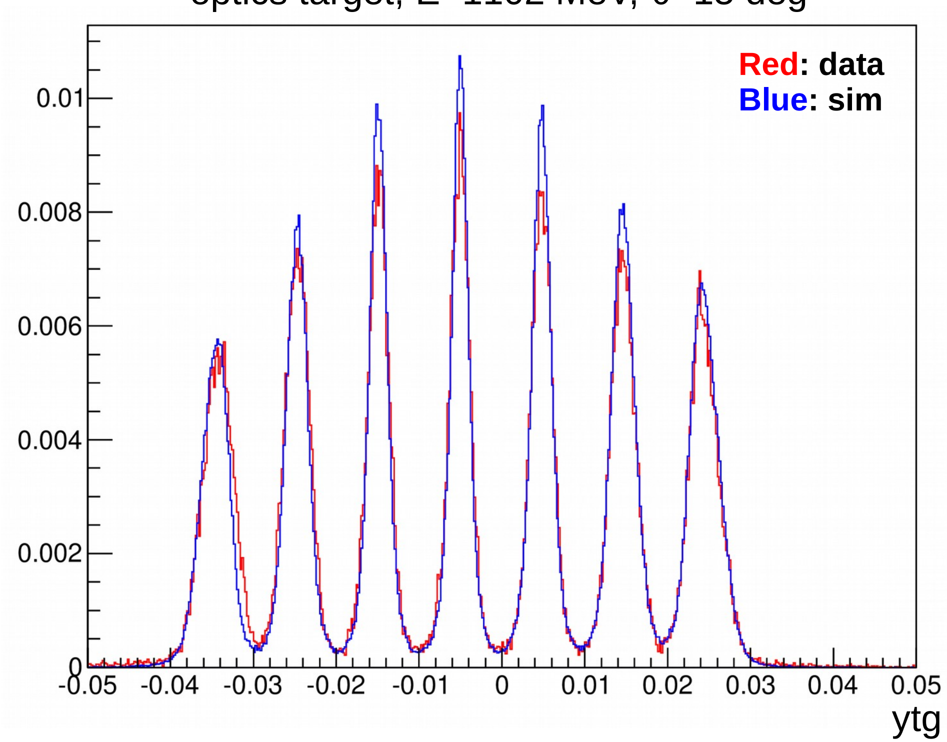
Extended Target Acceptance

Acceptance is a function $A(\delta, \theta_{tg}, \varphi_{tg}, y_{tg})$ which tells the possibility of a particle passes through spectrometer and reaches detectors. The main difference between acceptance used for foil target (^{12}C and ^{56}Fe) and extended target (^{4}He and ^{1}H) is the extra dimension ytg.
The extend target acceptance is extracted from Monte-Carlo simulation program SAMC.

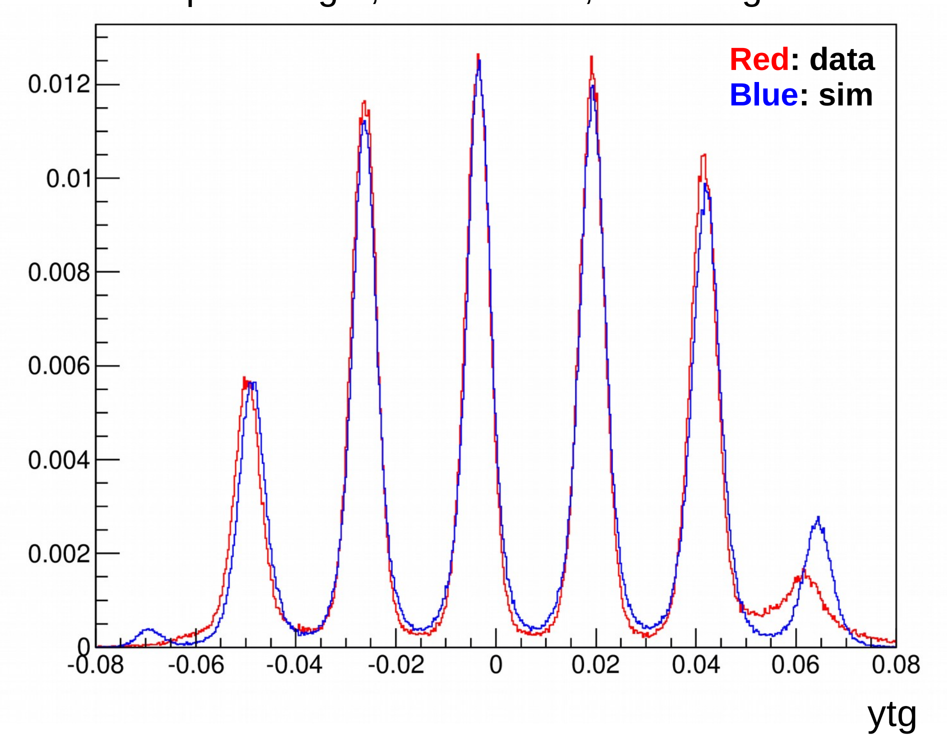
A comparison between data and simulation on optics target (sieve slit not inserted) is done to check the performance of monte-carlo:

- Events generated outside target, and include multiple scattering, energy loss before and after main scattering;
- Radiative effects includes internal and external bremsstrahlung are included;
- Events are weighted by cross sections calculated Sum-Of-Gauss fit to world data.

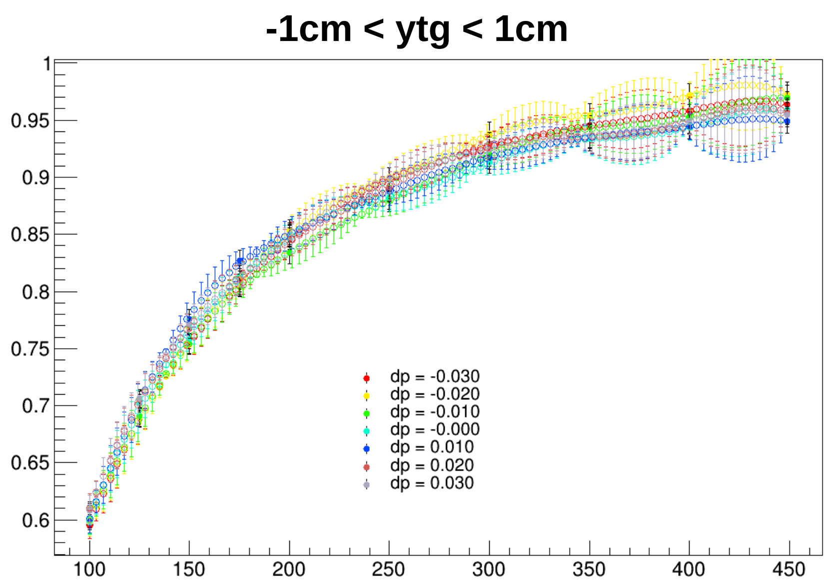
optics target, E=1102 MeV, θ=15 deg

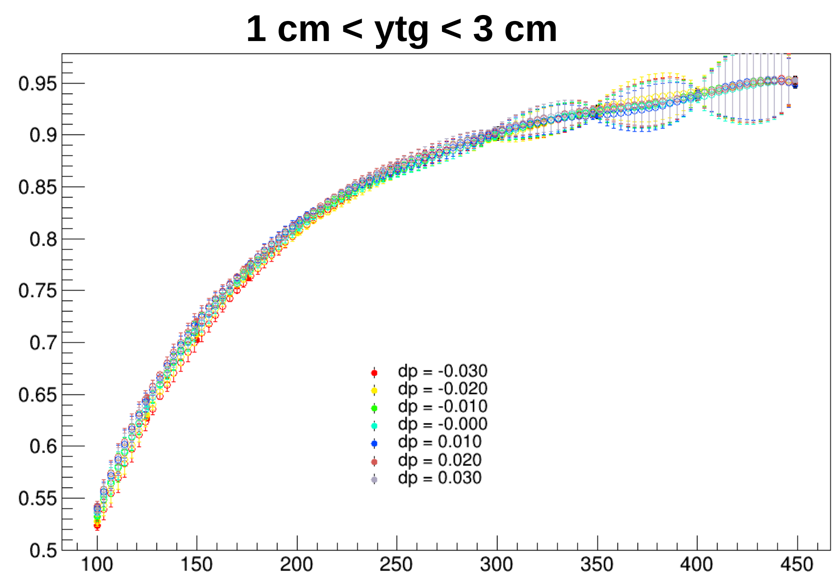


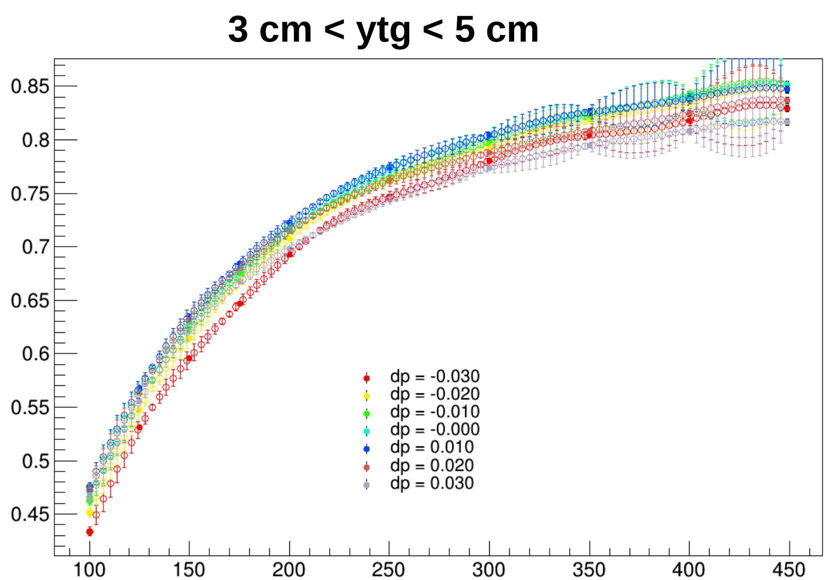
optics target, E=399 MeV, θ=35 deg

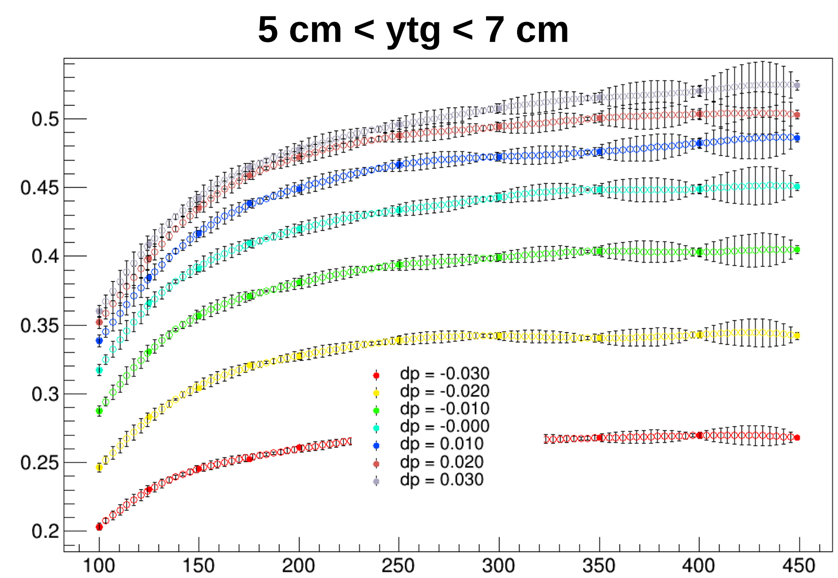


Extended Target Acceptance



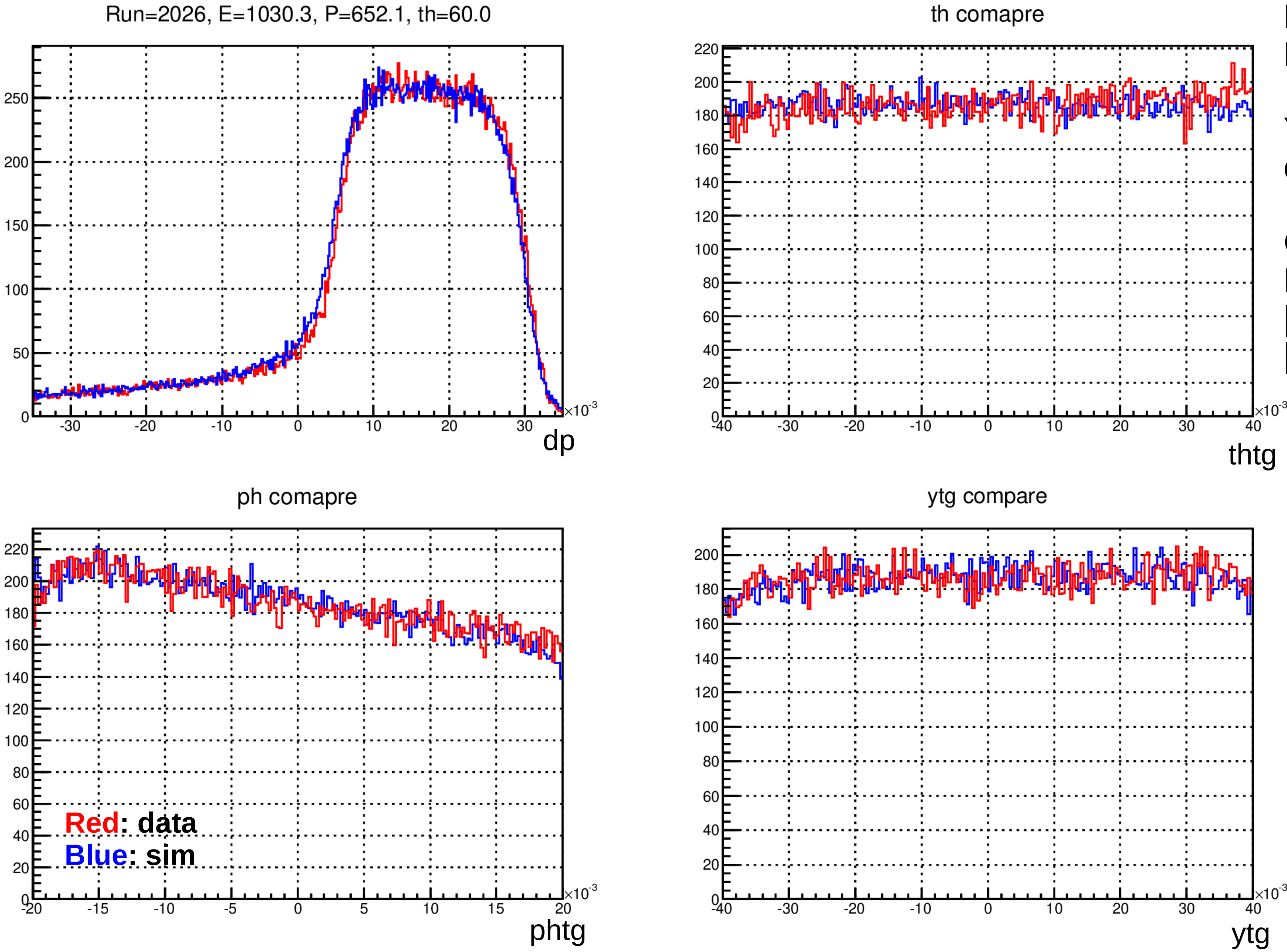






- Monte-Carlo simulations with P0 from 450 MeV to 100 MeV;
- Acceptance sum over thtg and phtg, bin with dp and ytg;
- An interpolation is done between acceptance at different P0;

LH2 Elastic Cross Section



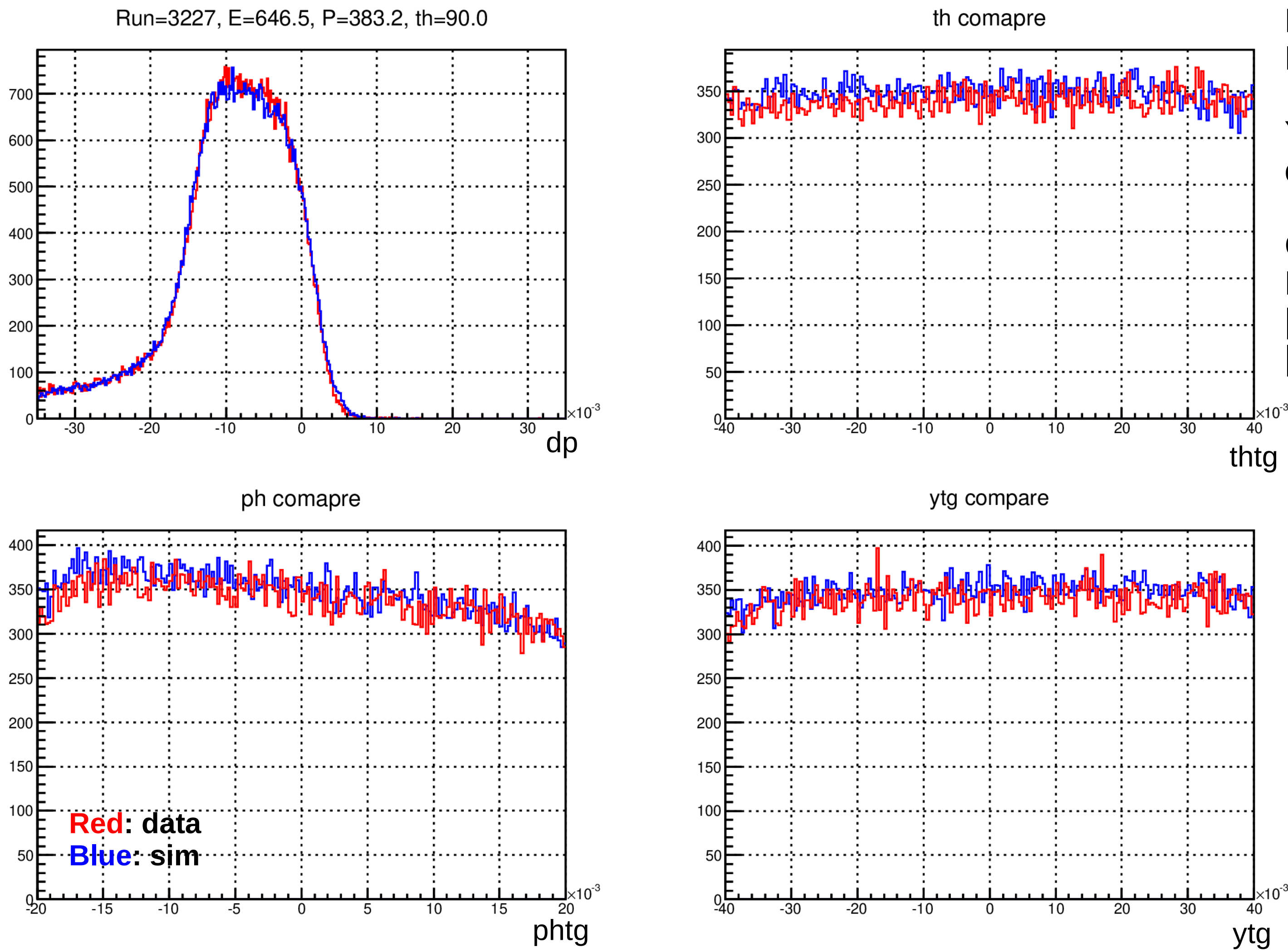
LH2 elastic run at 60 deg, E=1030.3 MeV, P0=652.1 MeV

Y^{Data}/Y^{MC} =0.9711 +/- 0.0221
cross section=8.240e-33 cm^{-2}

Cuts:
PID cut,
|δ|<3.5%,|thtg|<40mrad,|phtg|<20mrad
|ytg|<0.04

There are many LH2 elastic runs at different angles, with momentum down to ~230 MeV. They can be used to check the quality of acceptance and other correction of data at very low mom. The Monte-Carlo is weighted by cross sections calculated from proton elastic form factor fit of world data. The comparison between data and simulation is absolute.

LH2 Elastic Cross Section

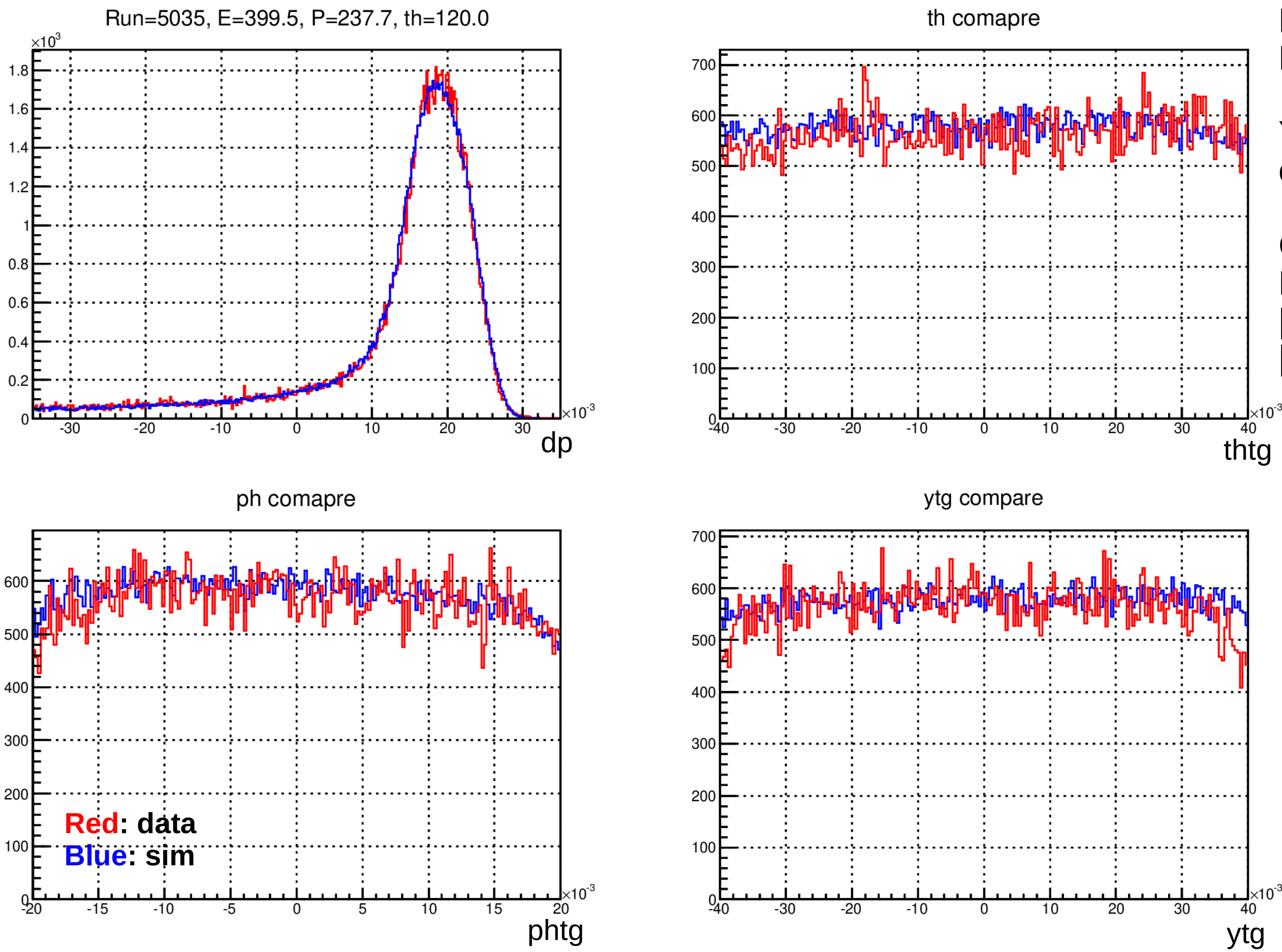


LH2 elastic run at 90 deg,E=646.5 MeV,P0=383.2 MeV

Y^{Data}/Y^{MC} =0.9753 +/- 0.0259
cross section=7.316e-33 cm^{-2}

Cuts:
PID cut,
|δ|<3.5%,|thtg|<40mrad,|phtg|<20mrad
|ytg|<0.04

LH2 Elastic Cross Section



LH2 elastic run at 120 deg, E=399.5 MeV,P0=237.7 MeV

Y^{Data}/Y^{MC} =0.9716 +/- 0.0205

cross section=1.129e-32 cm^{-2}

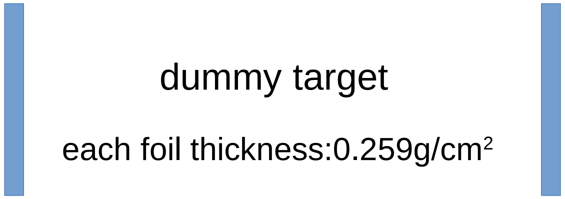
Cuts:

PID cut,

$|\delta|<3.5\%$,$|thtg|<40mrad$,$|phtg|<20mrad$

$|ytg|<0.04$

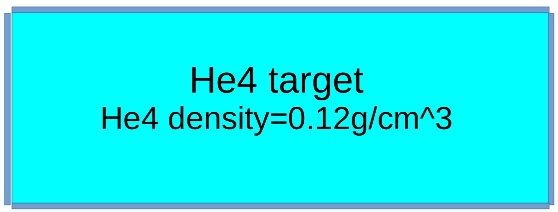
Window Subtraction



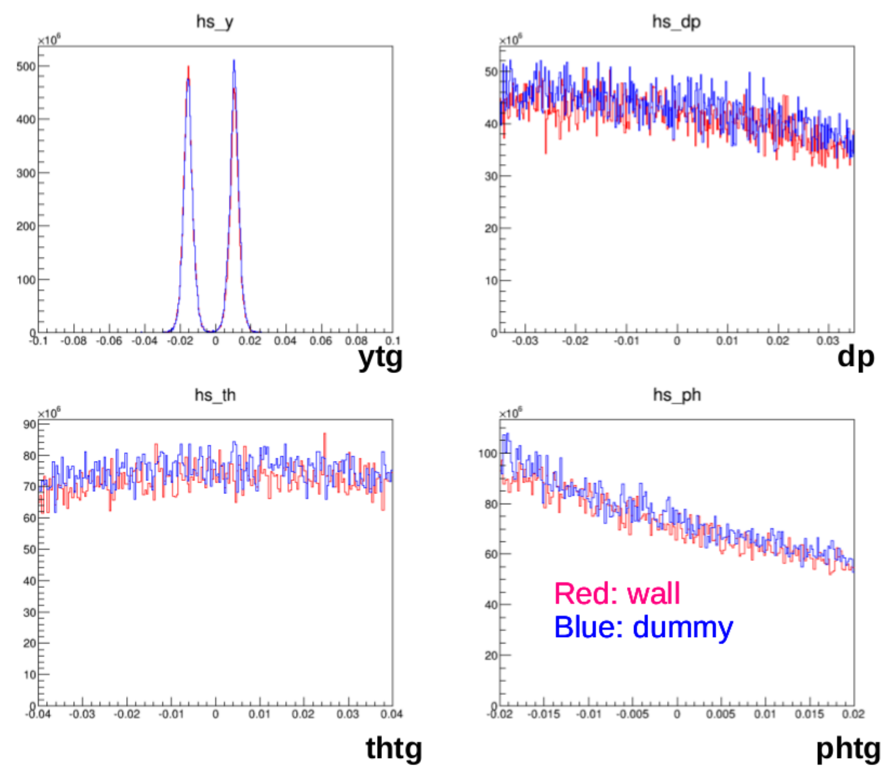
Use SAMC to simulate the external radiation effect of different aluminum thickness and He4 gas before or after scattering on windows.
The simulation runs are weighted by F1F209 fitting.

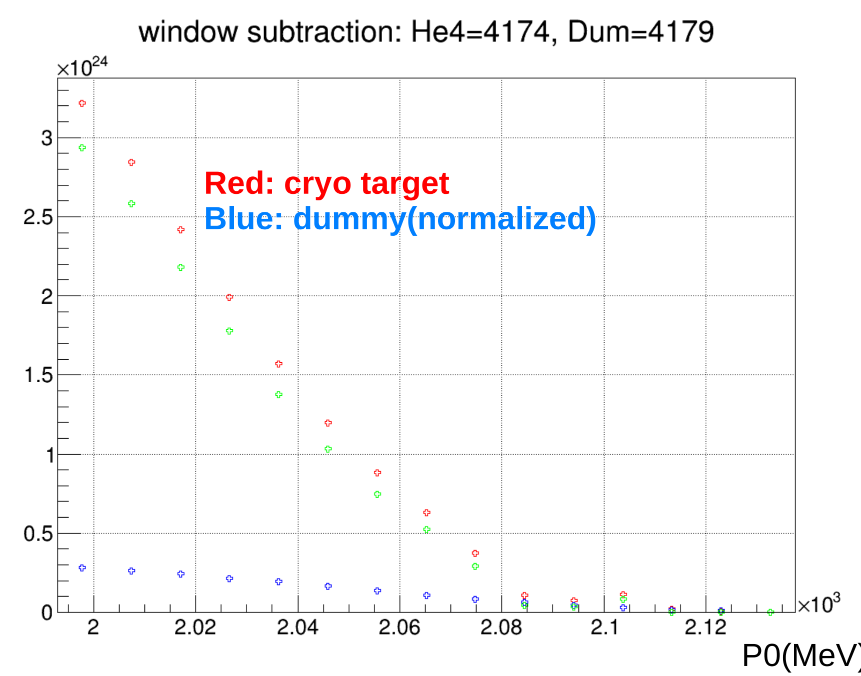
The radiation factor was put into the following formula:

$$Y_{corrected} = Y_{cryotarget} - Y_{dummy} \frac{T_{wall}}{T_{dummy}} \frac{R_{wall}}{R_{dummy}}$$

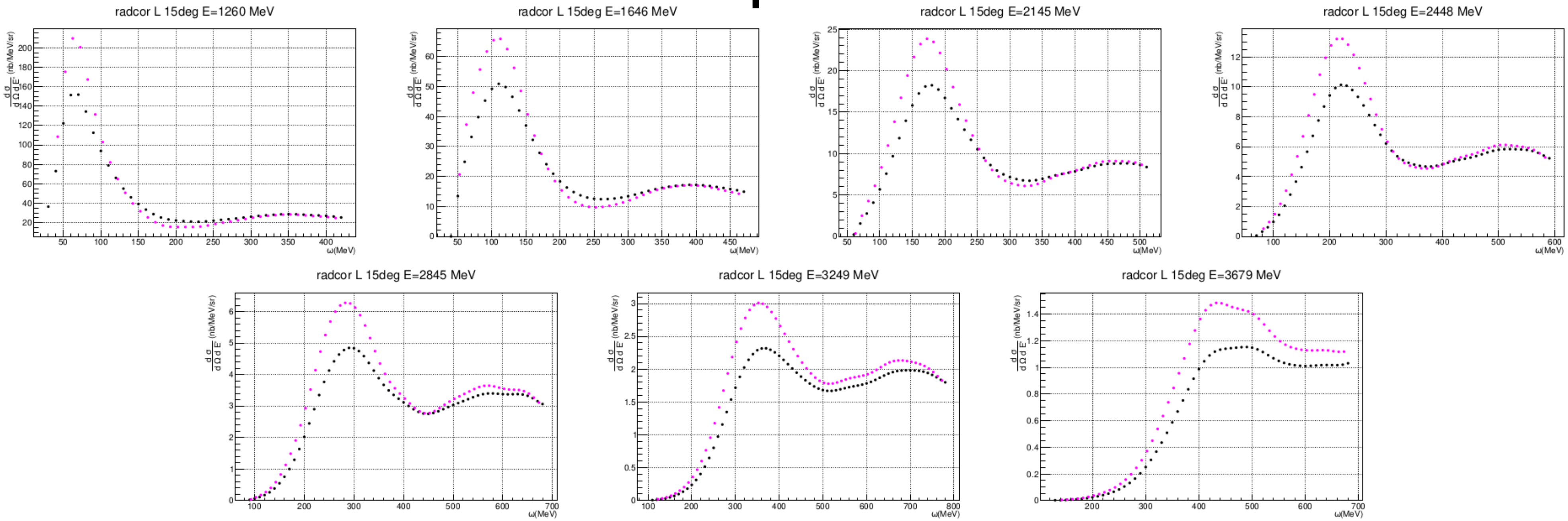


entr window: 0.073 g/cm^2
exit window: 0.076 g/cm^2

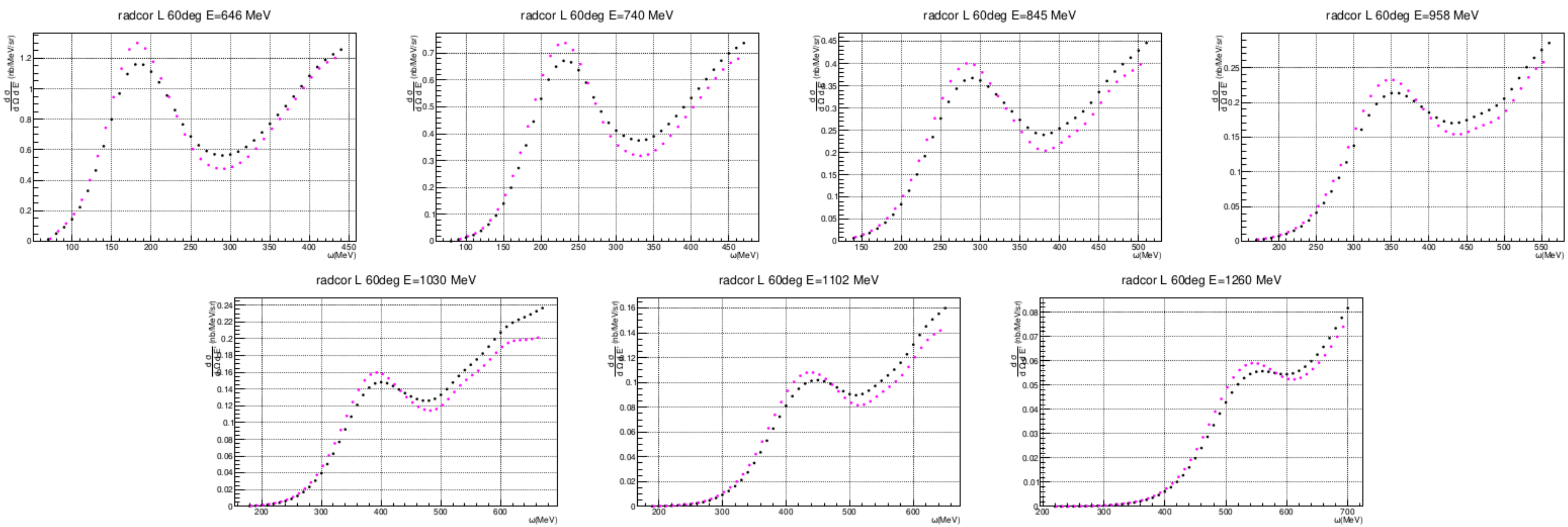




^{4}He Spectrum



^{4}He raw and radiative corrected spectrum at 15 deg.



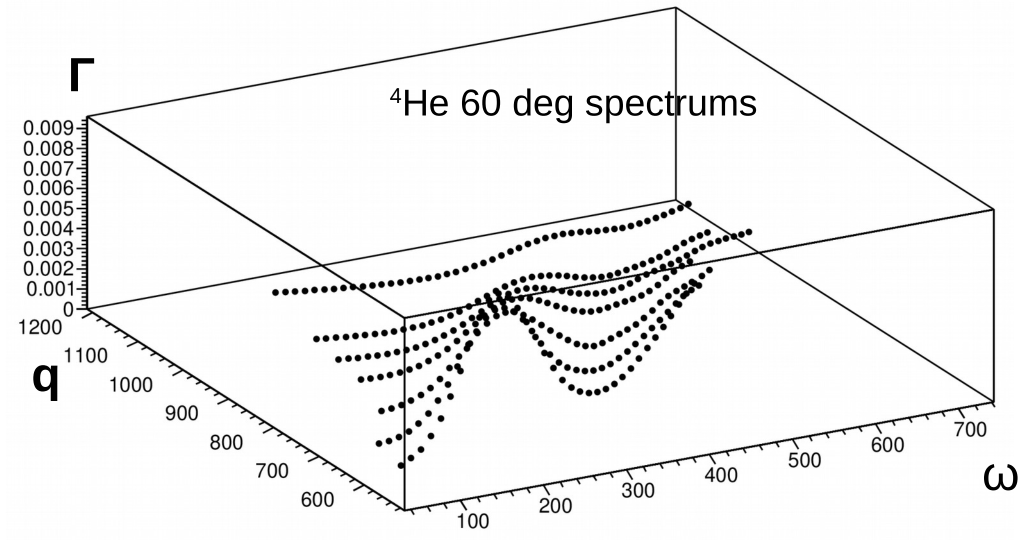
^{4}He raw and radiative corrected spectrum at 90 deg.

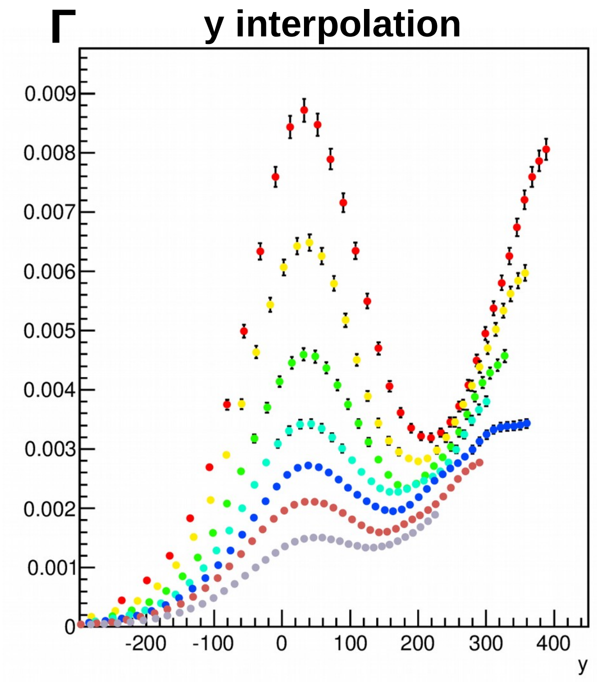
Interpolation

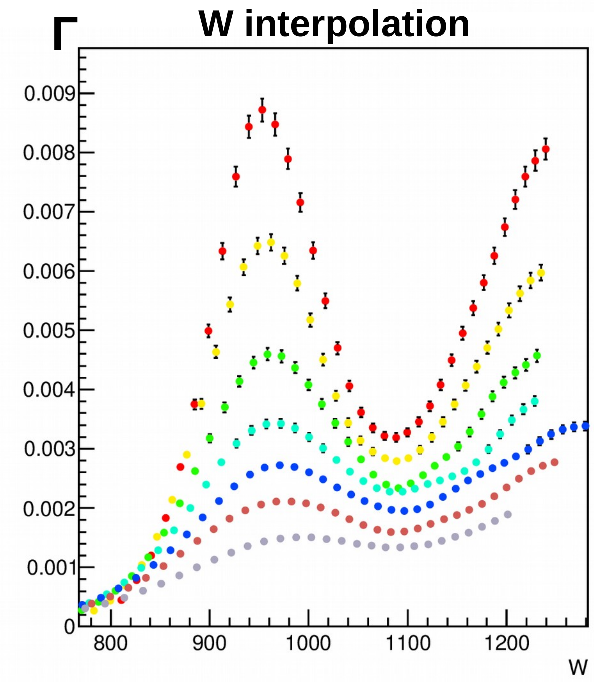
- The R_L should be integrated along a constant |**q**|
- The measured spectrum is along constant beam energy not constant |**q**|
- Interpolation between measured spectrum in (|**q**|,ω) is necessary
- The interpolation method should following paths that passes through correspond features in each spectrum.
- Two interpolation methods are used:
- (1) y* interpolation, y* is quasi-elastic scaling variable:

$$\omega + M_A = \left(y^2 + 2y|\mathbf{q}| + M^2 + \mathbf{q}^2\right)^{1/2} + \left(y^2 + M_{A-1}^2\right)^{1/2}$$

(2)W interpolation, W is invariant mass.

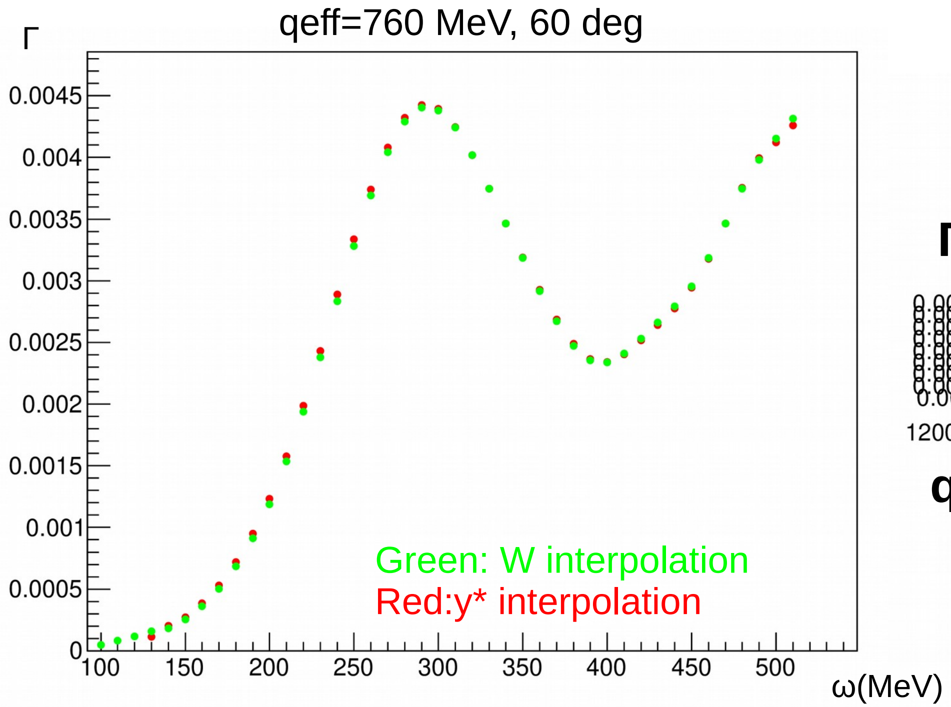


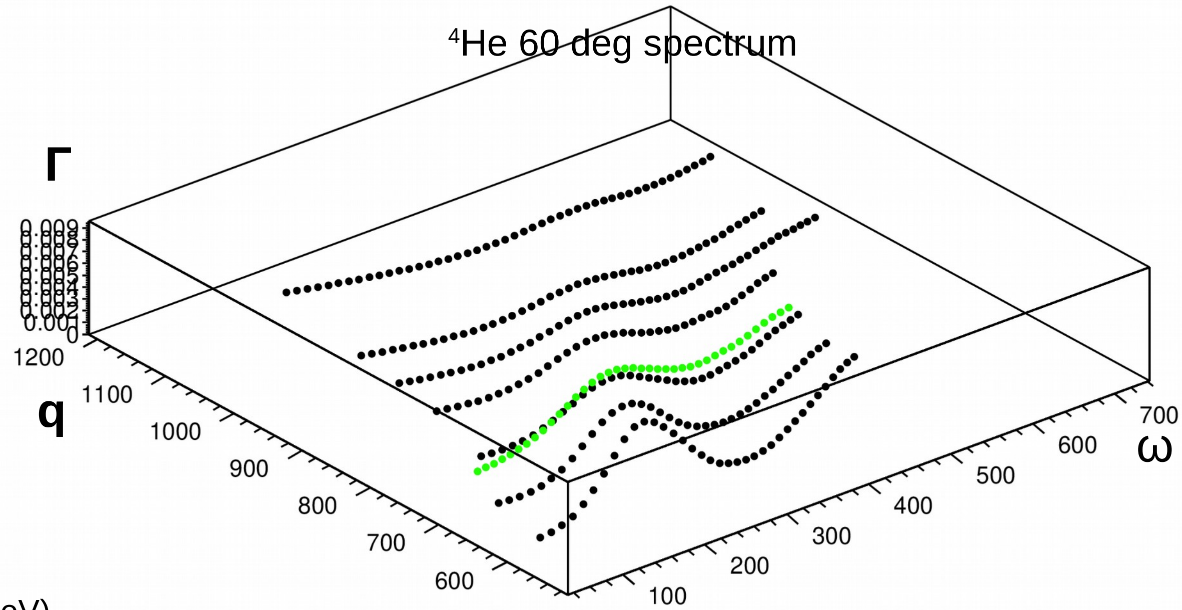


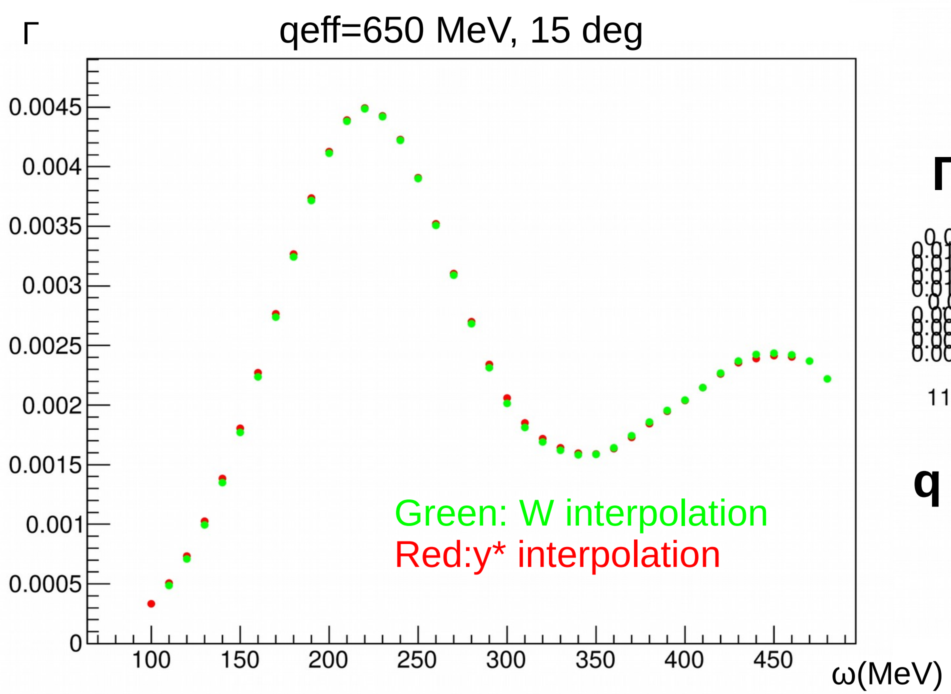


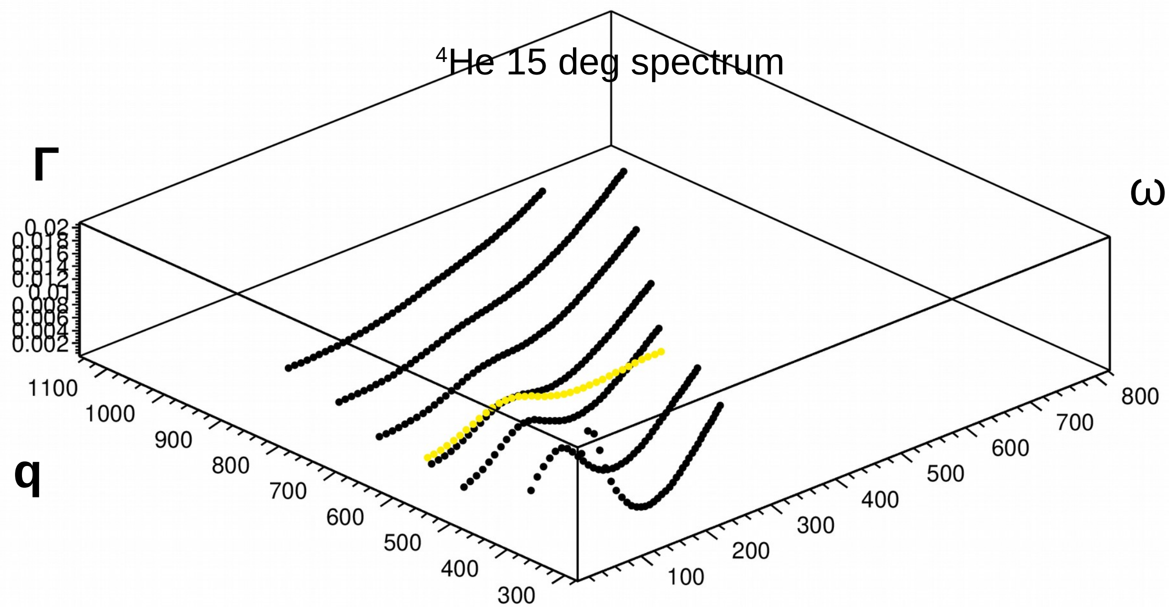
y interpolation aligns the quasi-elastic peak better, while W interpolation aligns the dip region better.

Interpolation









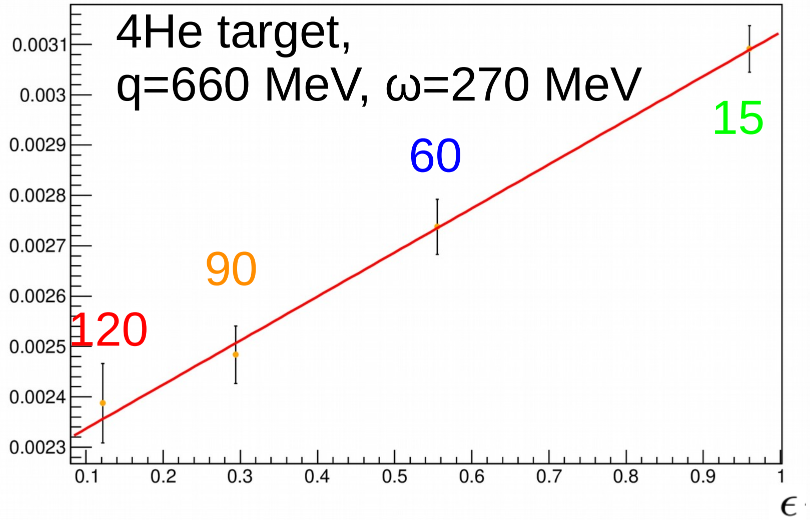
Rosenbluth Separation

$$\frac{d^2\sigma}{d\Omega d\omega}\frac{\epsilon}{\sigma_{Mott}} = \epsilon\frac{Q^4}{\vec{q}^4}R_L(|\vec{q}|,\omega) + \frac{Q^2}{2\vec{q}^2}R_T(|\vec{q}|,\omega)$$

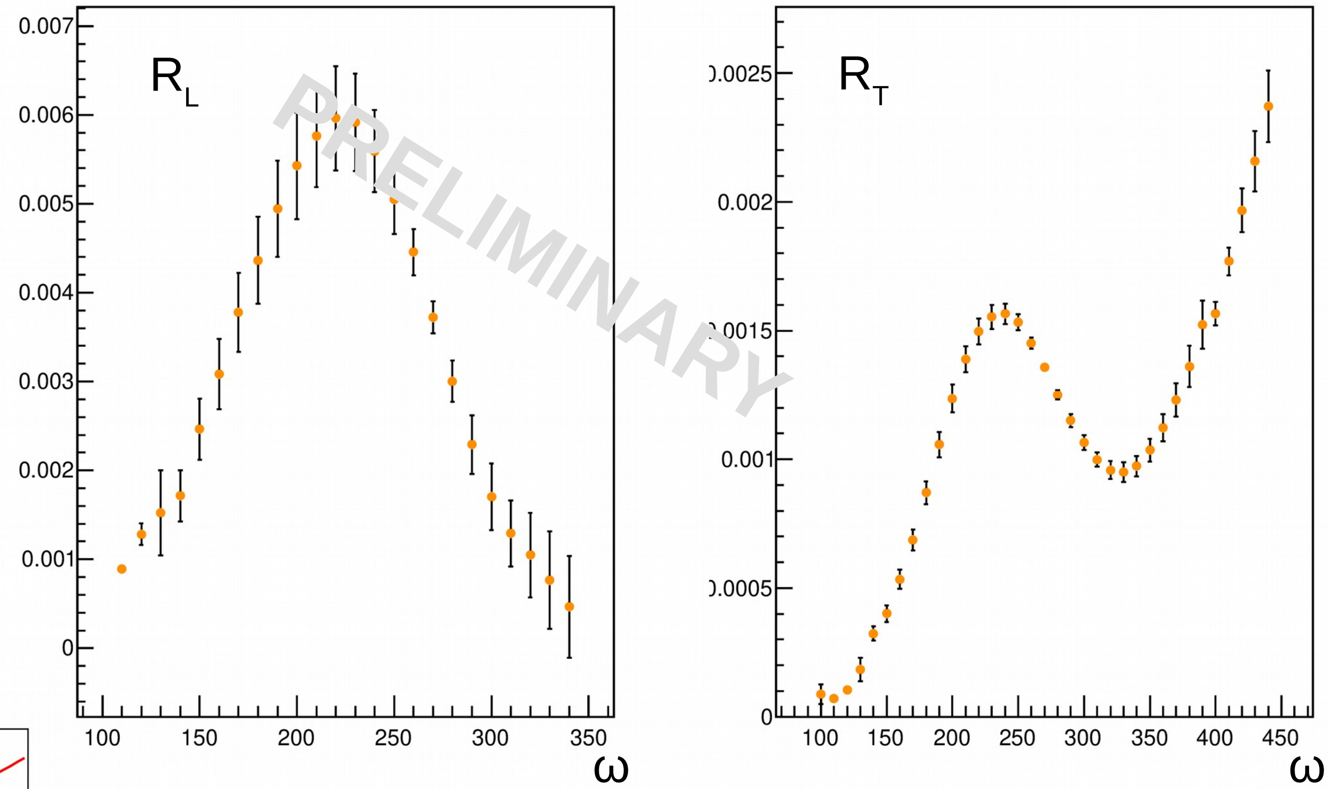
XS at same |q| and ω but different angles from interpolation are plotted together and fitted with linear fit:

$$\text{Slope} = \frac{Q^4}{\vec{q}^4}R_L$$

$$\text{Intercept} = \frac{Q^4}{2\vec{q}^2}R_T$$



^{4}He CSR at q=660 MeV



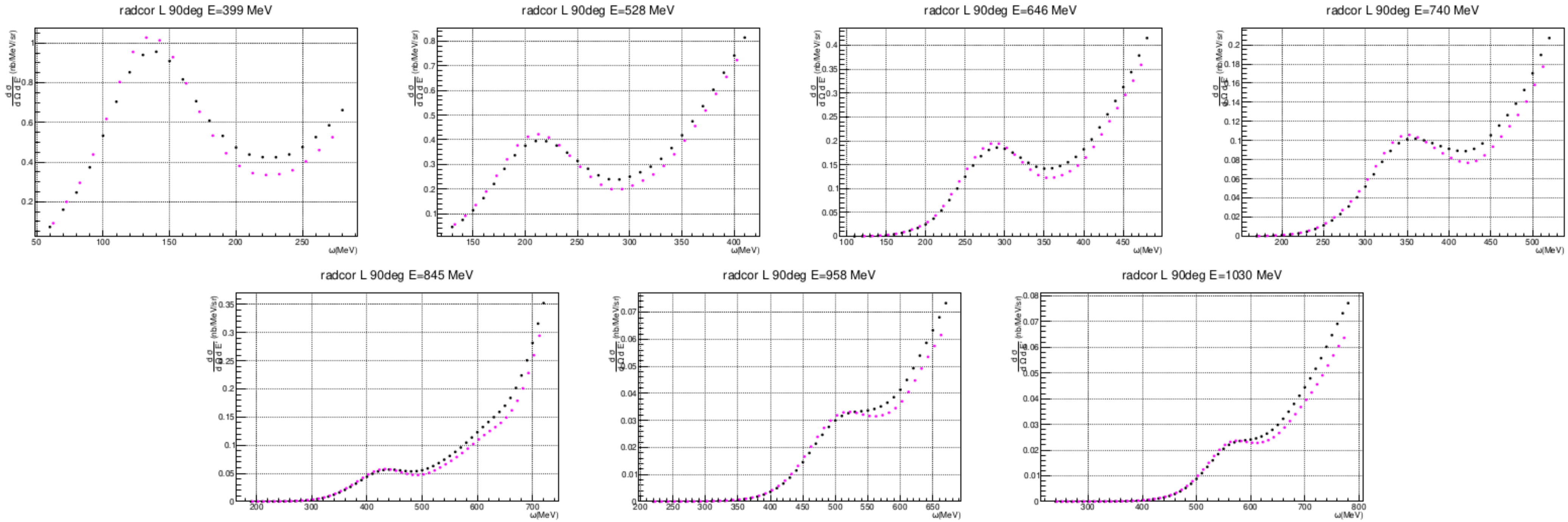
Summary

Recent work:

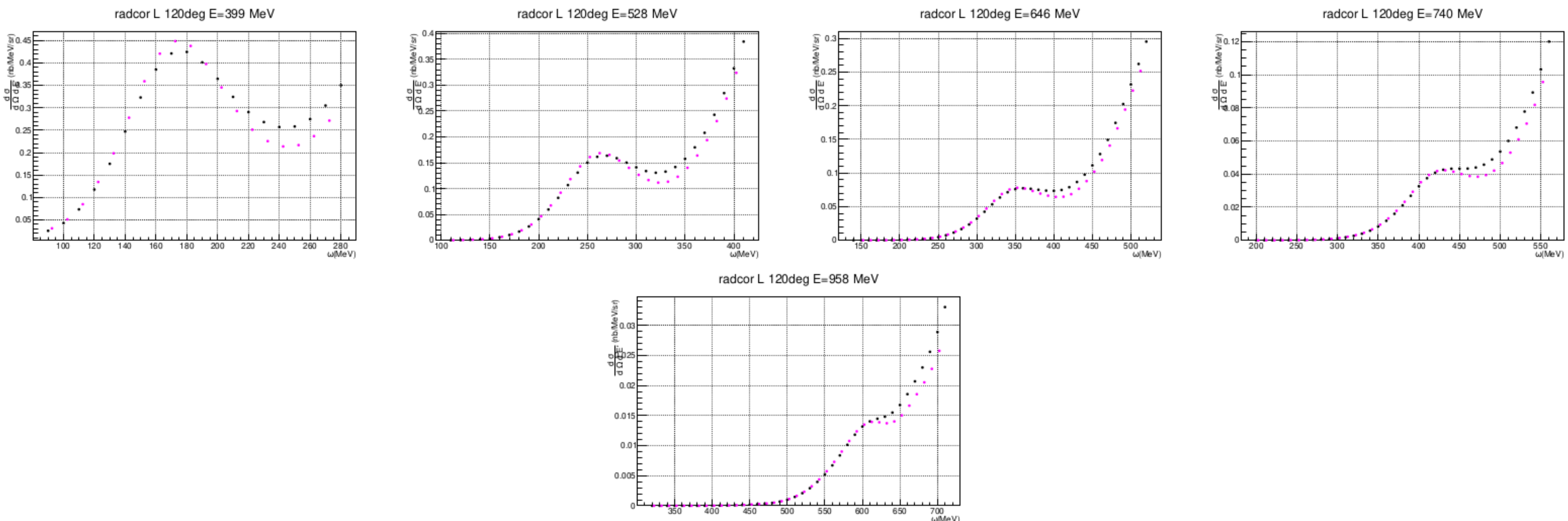
- **Get extended target acceptance at low momentum, and check with LH2 elastic;**
- **Extract ^{4}He spectrums for 4 angles;**

Plans:

- **Interpolation and LT separation;**
- **Compare with world data;**



^{4}He raw and radiative corrected spectrum at 90 deg.



^{4}He raw and radiative corrected spectrum at 120 deg.