Upcoming Hall C Measurements of F_2 Structure Functions at Large Bjorken x from H(e,e') and D(e,e') Inelastic Scattering

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Carnegie Mellon University

Outline

- Physics motivation
- Experiment setup
- Run plan

E12-10-002 Schedule

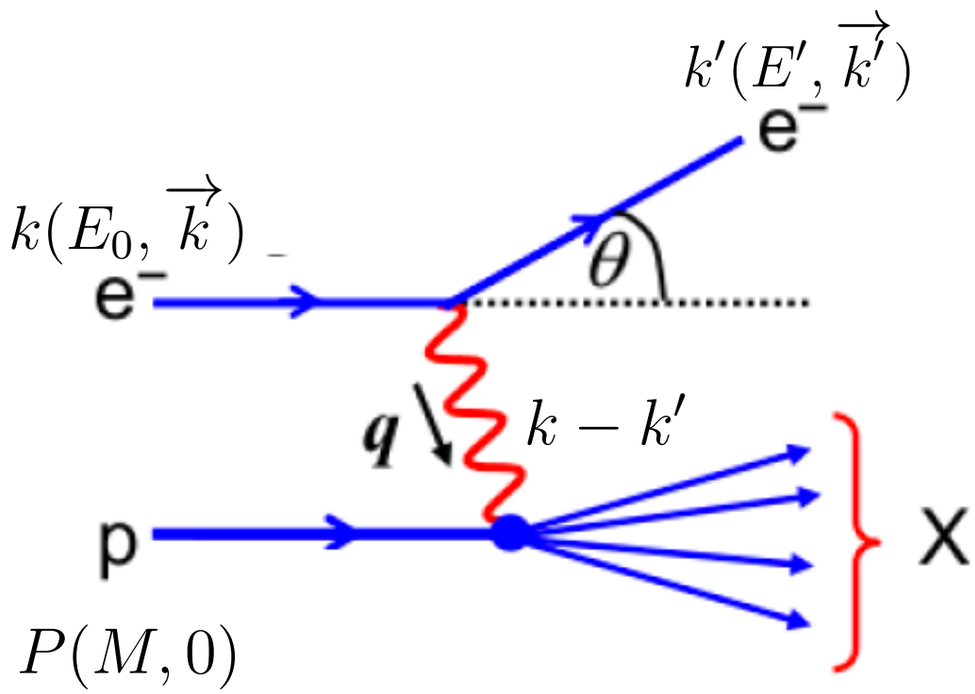
75	12/12/17	Tuesday	SHMS Comm./E12-10-002	
76	12/13/17	Wednesday	SHMS Comm./E12-10-002	
124	01/30/18	Tuesday	E12-10-002/E12-10-008	10.6/65/-/250
125	01/31/18	Wednesday	E12-10-002/E12-10-008	10.6/65/-/250
126	02/01/18	Thursday	E12-10-002/E12-10-008	10.6/65/-/250
127	02/02/18	Friday	E12-10-002/E12-10-008	10.6/65/-/250
128	02/03/18	Saturday	E12-10-002/E12-10-008	10.6/65/-/250
129	02/04/18	Sunday	E12-10-002/E12-10-008	10.6/65/-/250
130	02/05/18	Monday	E12-10-002/E12-10-008	10.6/65/-/250
131	02/06/18	Tuesday	E12-10-002/E12-10-008	10.6/65/-/250
132	02/07/18	Wednesday	E12-10-002/E12-10-008	10.6/65/-/250
133	02/08/18	Thursday	E12-10-002/E12-10-008	10.6/65/-/250
134	02/09/18	Friday	E12-10-002/E12-10-008	10.6/65/-/250
135	02/10/18	Saturday	E12-10-002/E12-10-008	10.6/65/-/250
136	02/11/18	Sunday	E12-10-002/E12-10-008	10.6/65/-/250
137	02/12/18	Monday	E12-10-002/E12-10-008	10.6/65/-/250
138	02/13/18	Tuesday	E12-10-002/E12-10-008	10.6/65/-/250
139	02/14/18	Wednesday	E12-10-002/E12-10-008	10.6/65/-/250
140	02/15/18	Thursday	E12-10-002/E12-10-008	10.6/65/-/250
141	02/16/18	Friday	E12-10-002/E12-10-008	10.6/65/-/250
142	02/17/18	Saturday	E12-10-002/E12-10-008	10.6/65/-/250
143	02/18/18	Sunday	E12-10-002/E12-10-008	10.6/65/-/250
144	02/19/18	Monday	E12-10-002/E12-10-008	10.6/65/-/250
145	02/20/18	Tuesday	E12-10-002/E12-10-008	10.6/65/-/250
146	02/21/18	Wednesday	E12-10-002/E12-10-008	10.6/65/-/250
147	02/22/18	Thursday	E12-10-002/E12-10-008	10.6/65/-/250
148	02/23/18	Friday	E12-10-002/E12-10-008	10.6/65/-/250

E12-10-002 2-day run on Dec.12, 13 at 6.4 GeV for R measurement

E12-10-002/008 starts on Jan.30,2017 and runs for 25 days

Inelastic Scattering

- Initial state nucleon target is excited or blown apart and ends up with many hadrons in final state



$$Q^2 = -q^2 = 4E_0E' sin^2\frac{\theta}{2}$$

$$E' = \frac{E_0 - \frac{W^2 - M^2}{2M}}{1 + \frac{2E_0}{M} sin^2\frac{\theta}{2}}$$

$$\nu = E_0 - E' \quad y = \frac{\nu}{E_0}$$

$$x = \frac{Q^2}{2M\nu} = \frac{Q^2}{W^2 + Q^2 - M^2}$$

x=1: elastic scattering

$$W^2 = (P + q)^2 = M^2 + 2M\nu - Q^2$$

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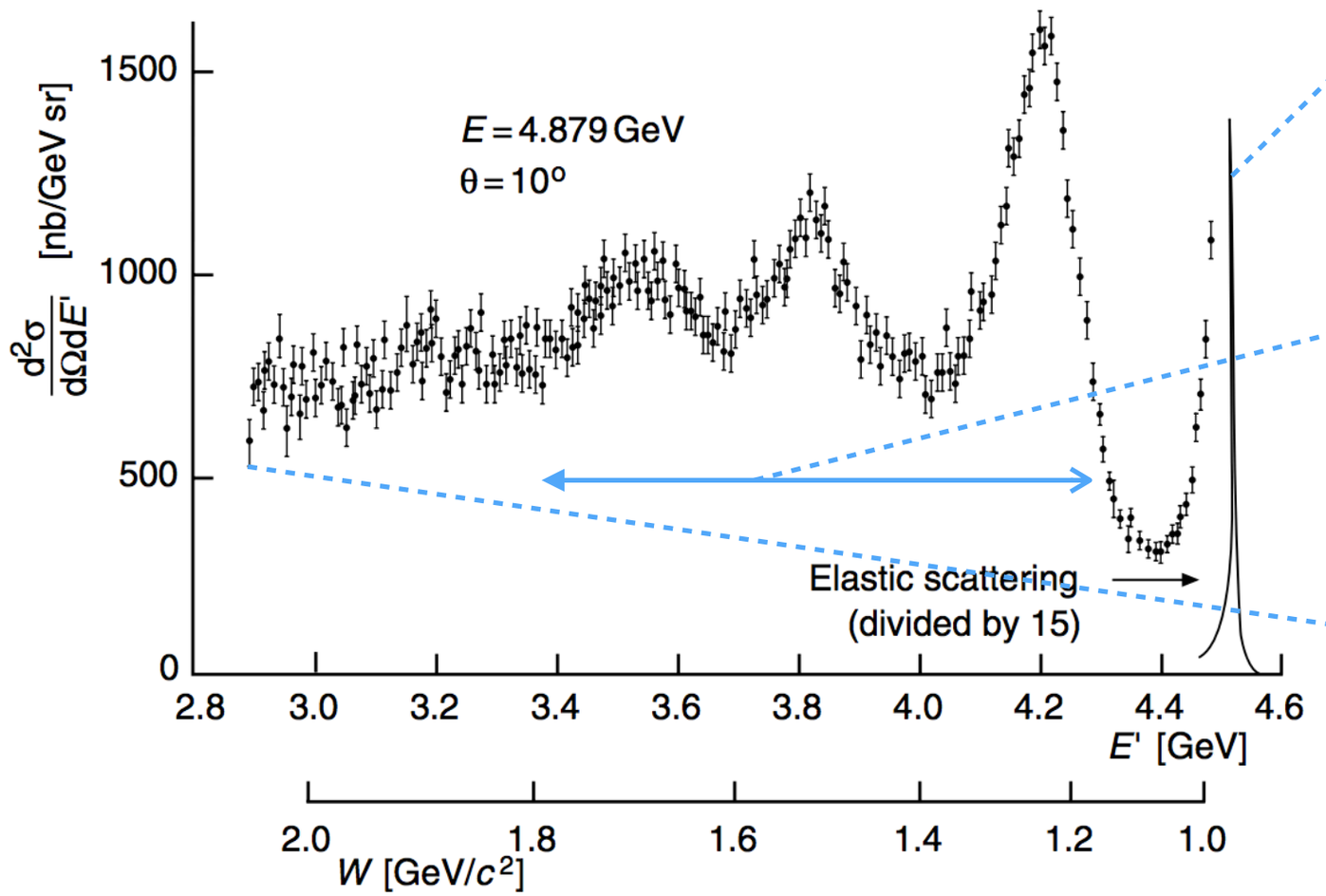


Elastic scattering

e.g. e+p->e+p, $W=M_p$

Resonance region

e.g. e+p->e+Δ, $W=M_\Delta$

Deep inelastic scattering

e.g. e+p->e+(X=many hadrons)
$W^2>M_p^2$

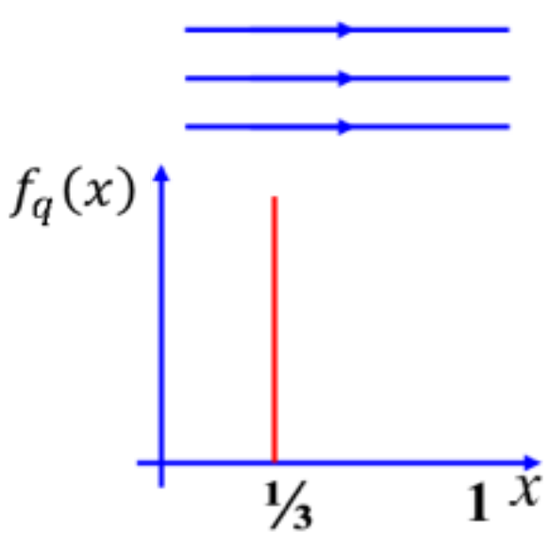
Expression for differential cross section:

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E_0 sin^4\frac{\theta}{2}}[\frac{1}{\nu}F_2(x,Q^2)cos^2\frac{\theta}{2} + \frac{2}{M}F_1(x,Q^2)sin^2\frac{\theta}{2}]$$

Parton Distribution Functions

- Parton distribution functions keep track of the dynamics of quarks and gluons inside nucleons

Three non-interacting quarks



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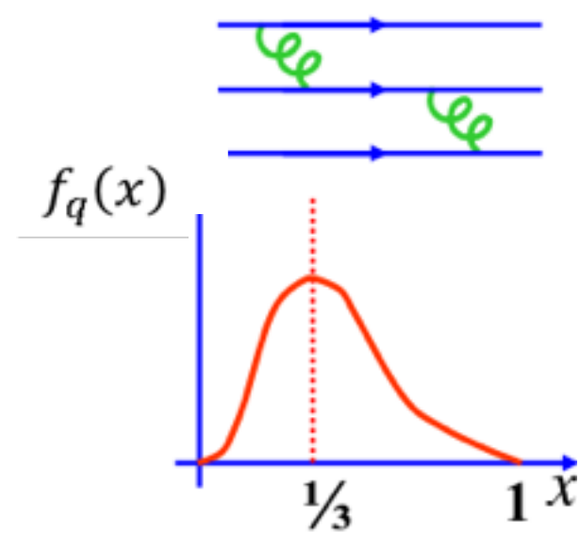
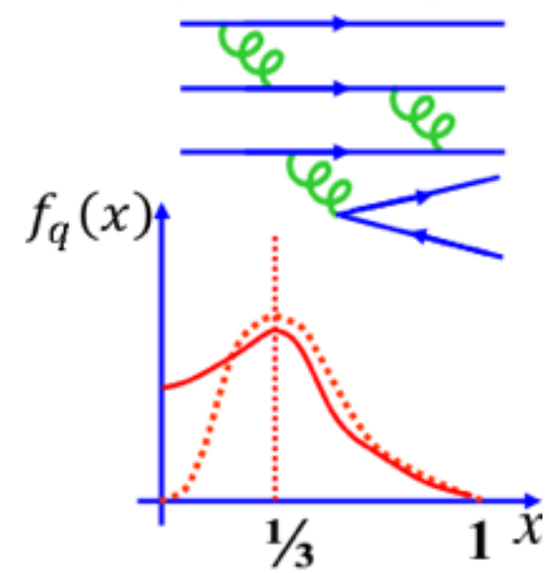


Three interacting quarks with sea of quarks, anti-quarks and gluons



- Parton distribution functions are extracted from global fits to measurements of cross sections from DIS and other processes

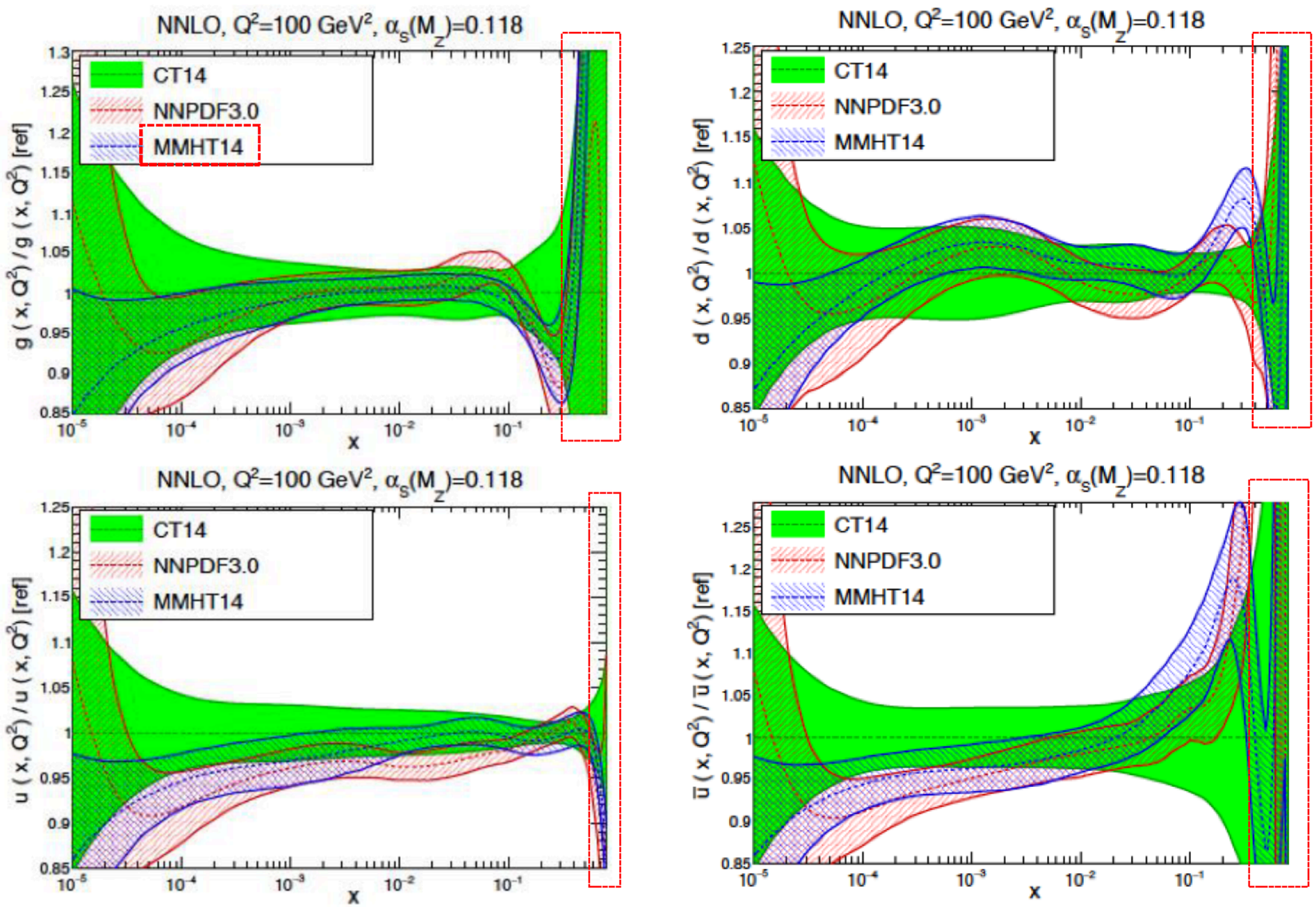
$$\sigma^{DIS} \sim \sum_q \int dx f_q(x, \mu^2) \sigma^{hard}(x/, Q^2/\mu^2)$$

→ Perturbative QCD calculations

from fits to a large set of data

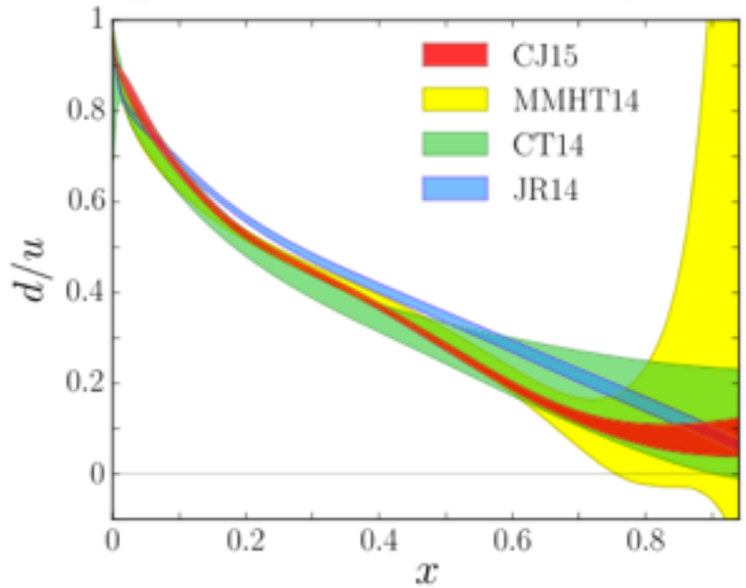
Constrain PDFs at Large x

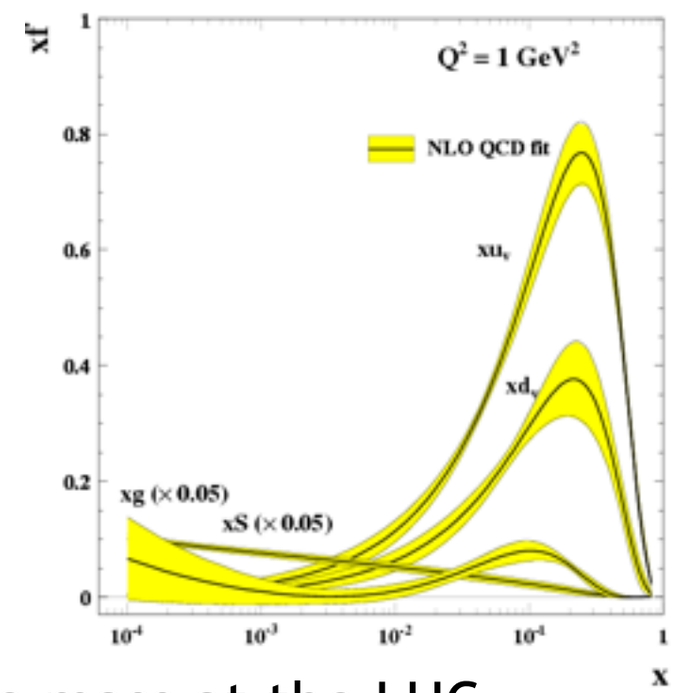
➢ Typical PDFs extraction still lacking in the required precision at low x and large x



Why It's Important to Know PDFs at Large x?

➢ Relevant for studies of the non-perturbative dynamics of nucleons: d/u ratio at x=1 can give hints of how quarks are confined





➢ Poor knowledge of PDFs at large x propagates to low x

- Perturbative QCD evolution moves strength from large x, low Q^2 to low x, high Q^2
- The x-dependence of PDFs is parametrized at low Q^2 where most of their strength is at large x

➢ Partons need large energy to create a particle with large mass at the LHC

$$x = \frac{M}{\sqrt{s}} e^{y}$$

Experiments at JLab Focused on Large x

- Several approved experiments at Jefferson Lab and a theory-experiment Collaboration, CTEQ-JLab, to constrain valence PDFs at large x

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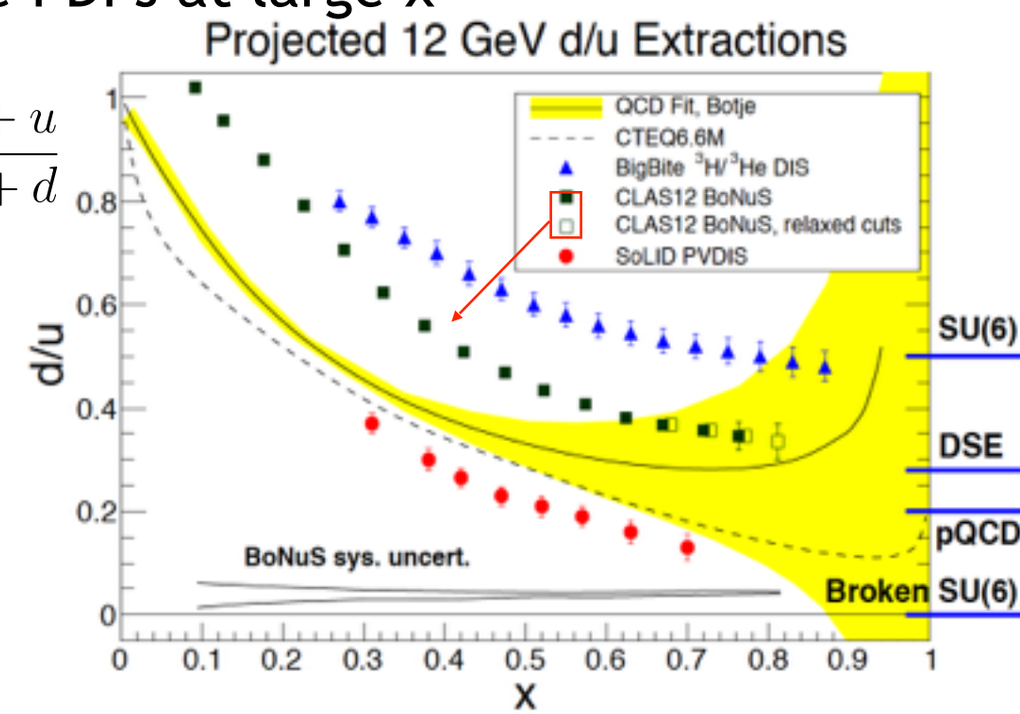
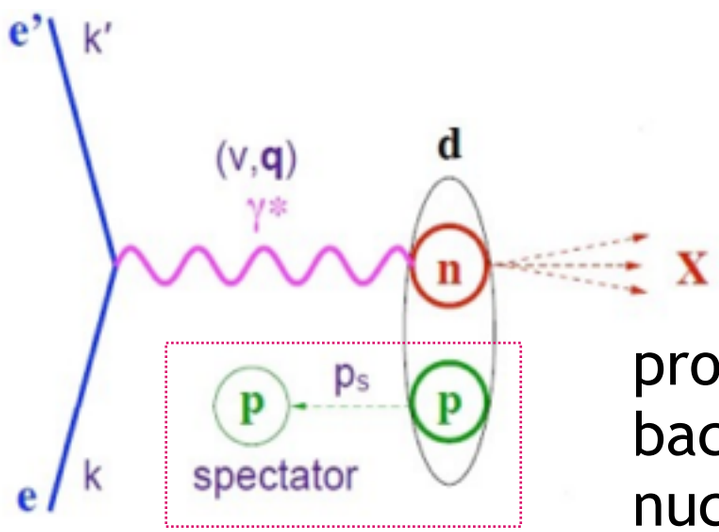


Experiments:

-> CLAS12 **BONuS**: accesses F_2^n via **spectator tagging in deuterium**



protons with low momentum and backward angles to minimize nuclear effects and target fragmentation effects - VIP

- F_2^n is extracted from ratio of tagged and inclusive events

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Experiments:

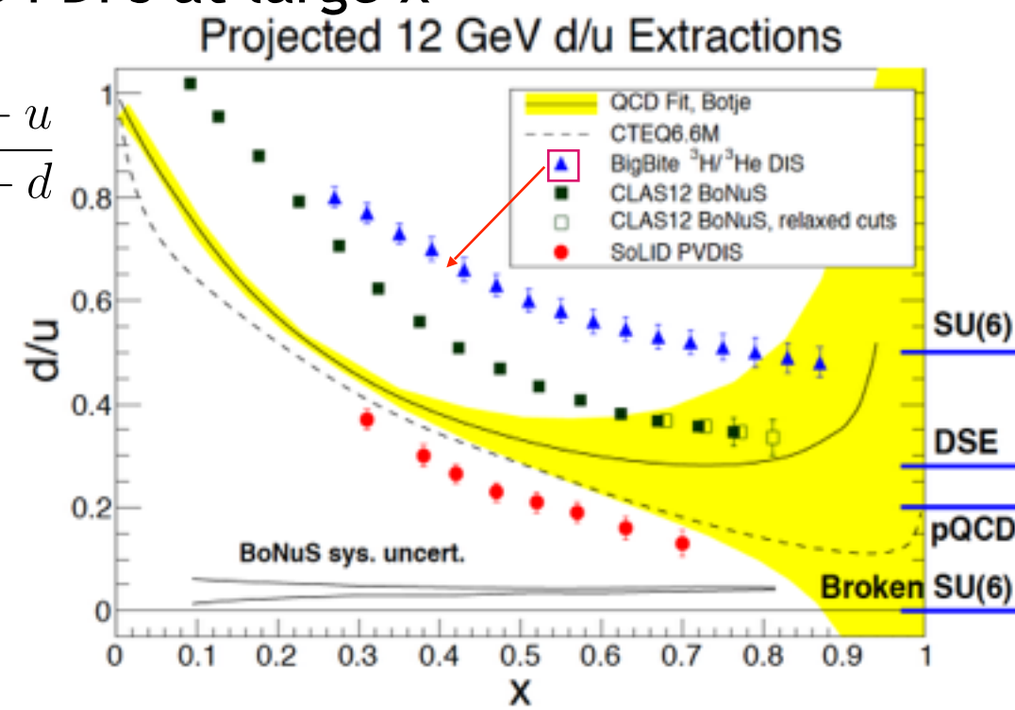
-> Hall A **MARATHON (2017)**: accesses F_2^n/F_2^p via **DIS off mirror nuclei, ^{3}H and ^{3}He**

$$\frac{F_2^n}{F_2^p} = \frac{2\mathcal{R} - F_2^{^3\mathrm{He}}/F_2^{^3\mathrm{H}}}{2F_2^{^3\mathrm{He}}/F_2^{^3\mathrm{H}} - \mathcal{R}}$$

experimental input

theoretical input

$$\mathcal{R} = \frac{R(^3\mathrm{He})}{R(^3\mathrm{H})} \qquad R(^3\mathrm{He}) = \frac{F_2^{^3\mathrm{He}}}{2F_2^p + F_2^n} \qquad R(^3\mathrm{H}) = \frac{F_2^{^3\mathrm{H}}}{F_2^p + 2F_2^n}$$



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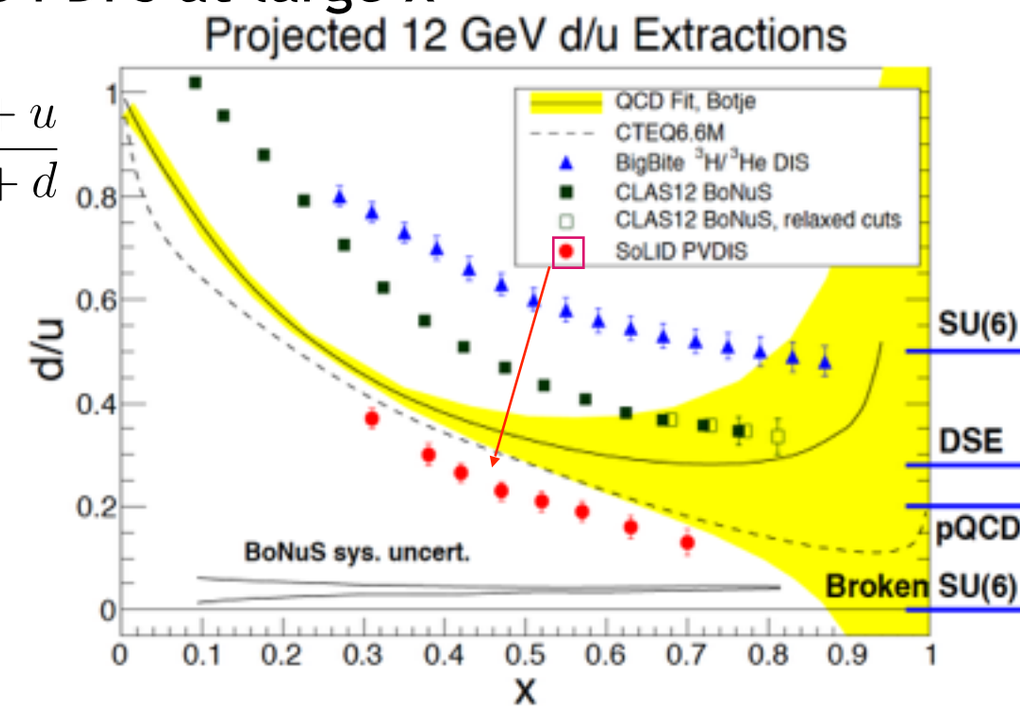

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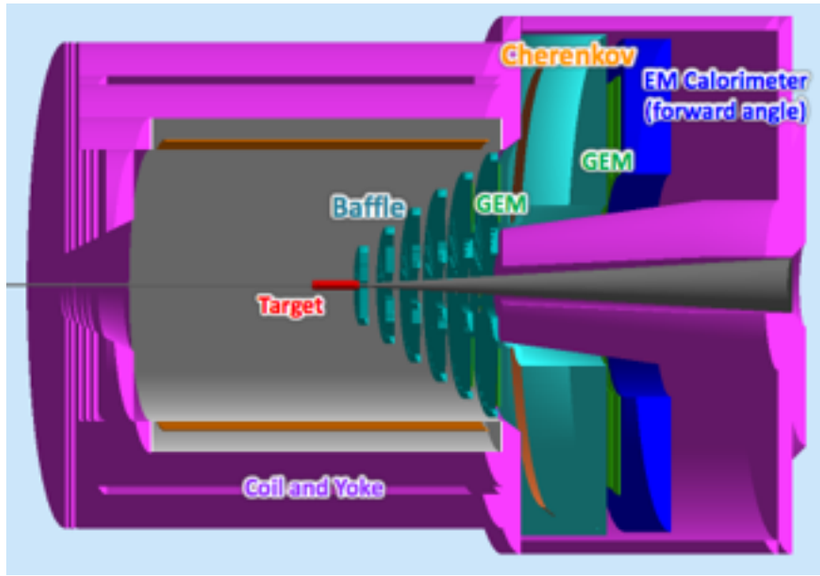
-> Hall A **SoLID PVDIS**: accesses d/u via measurements of parity violating asymmetries in H



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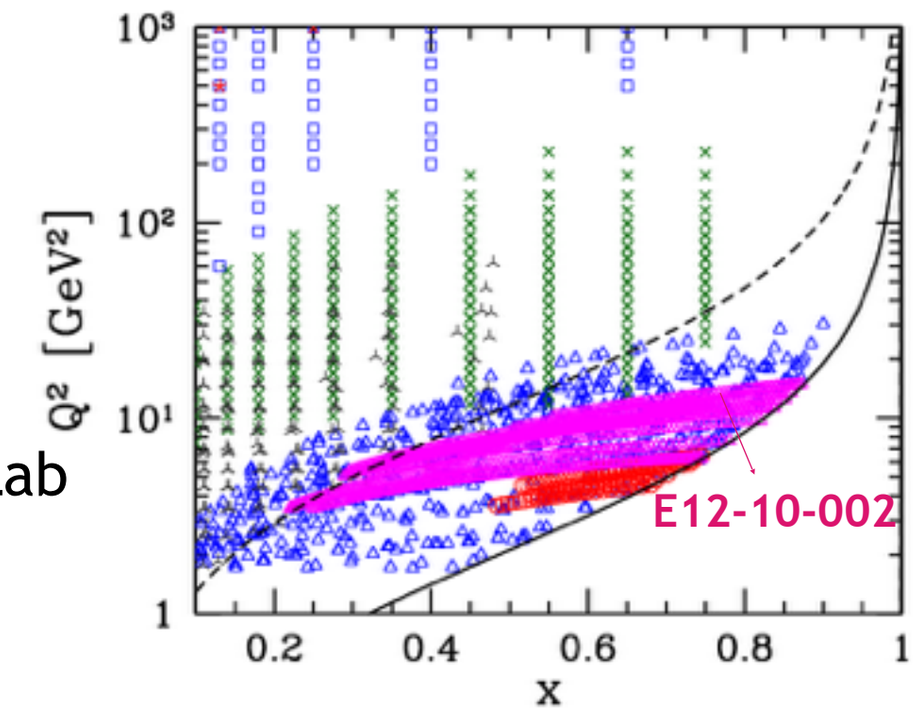
Experiments:

-> Hall C **E12-10-002 (2017)**: accesses F_2^p and F_2^d via **IS off proton and deuteron**

- DIS: constrain nucleon's PDFs within CTEQ-JLab framework



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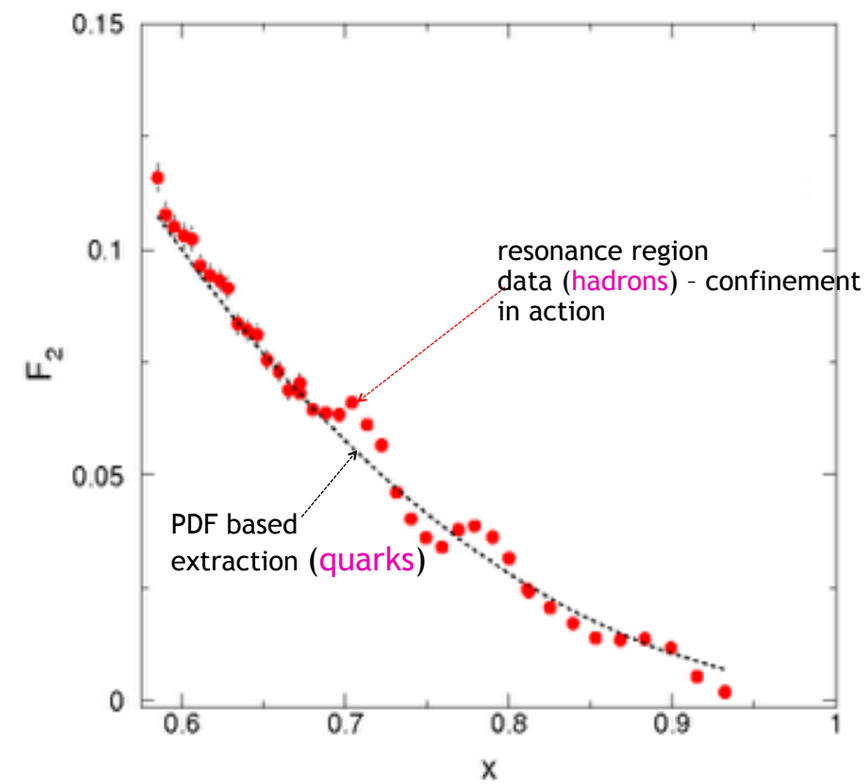
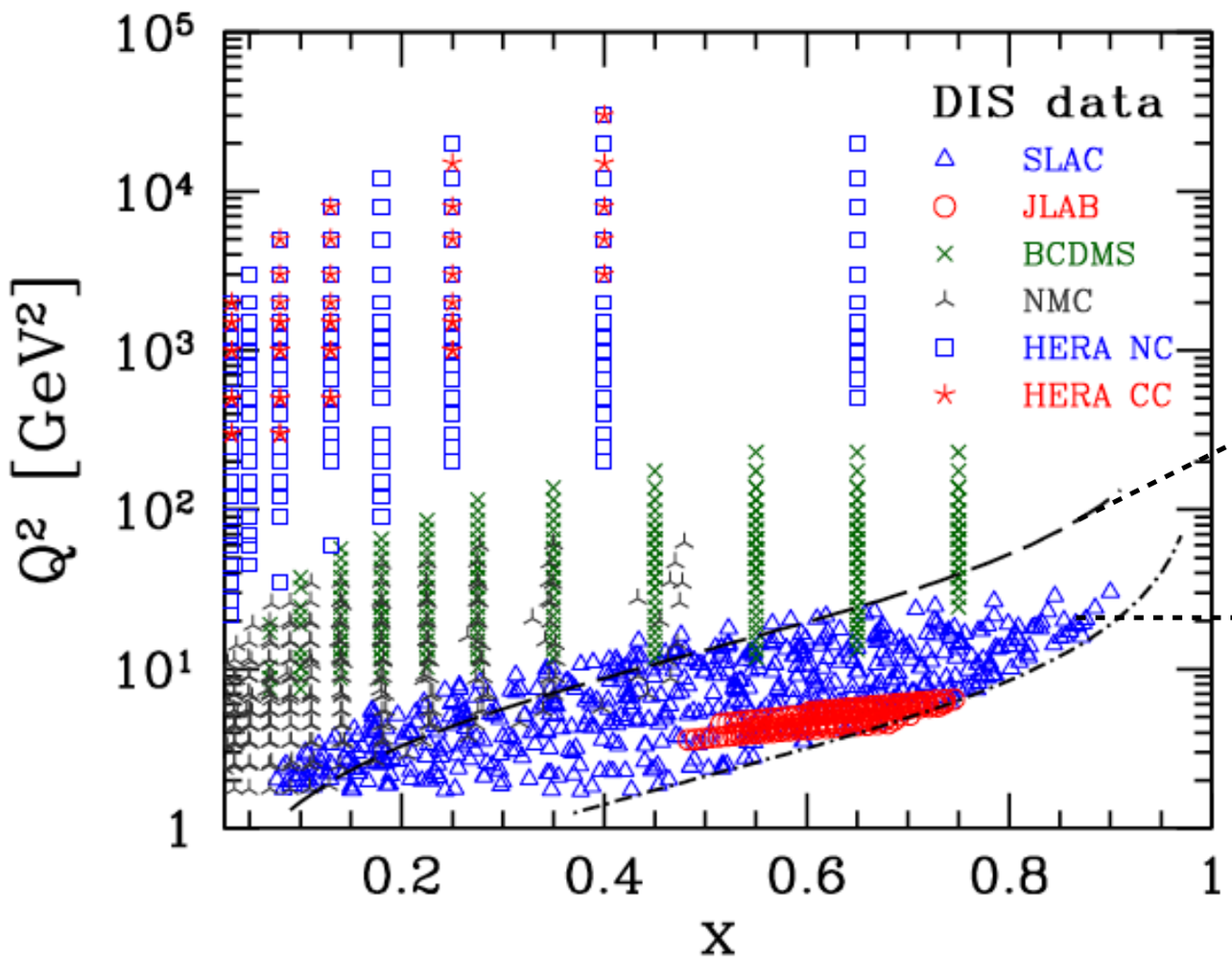
- Resonance region: study confinement and transition from confinement to asymptotic freedom, quark-hadron duality
- Resonance region: possibly include averaged resonance region data in the CJ fits



CTEQ-JLab Global PDF Fits

➢ Relax kinematic cuts to include large x, low Q^2 data in PDF fits



Kinematic cut of almost all other PDF analysis before CJ

$W^2 > 12.25$ GeV^2

$W^2 > 3$ GeV^2

CTEQ-JLab cut includes more data at large x

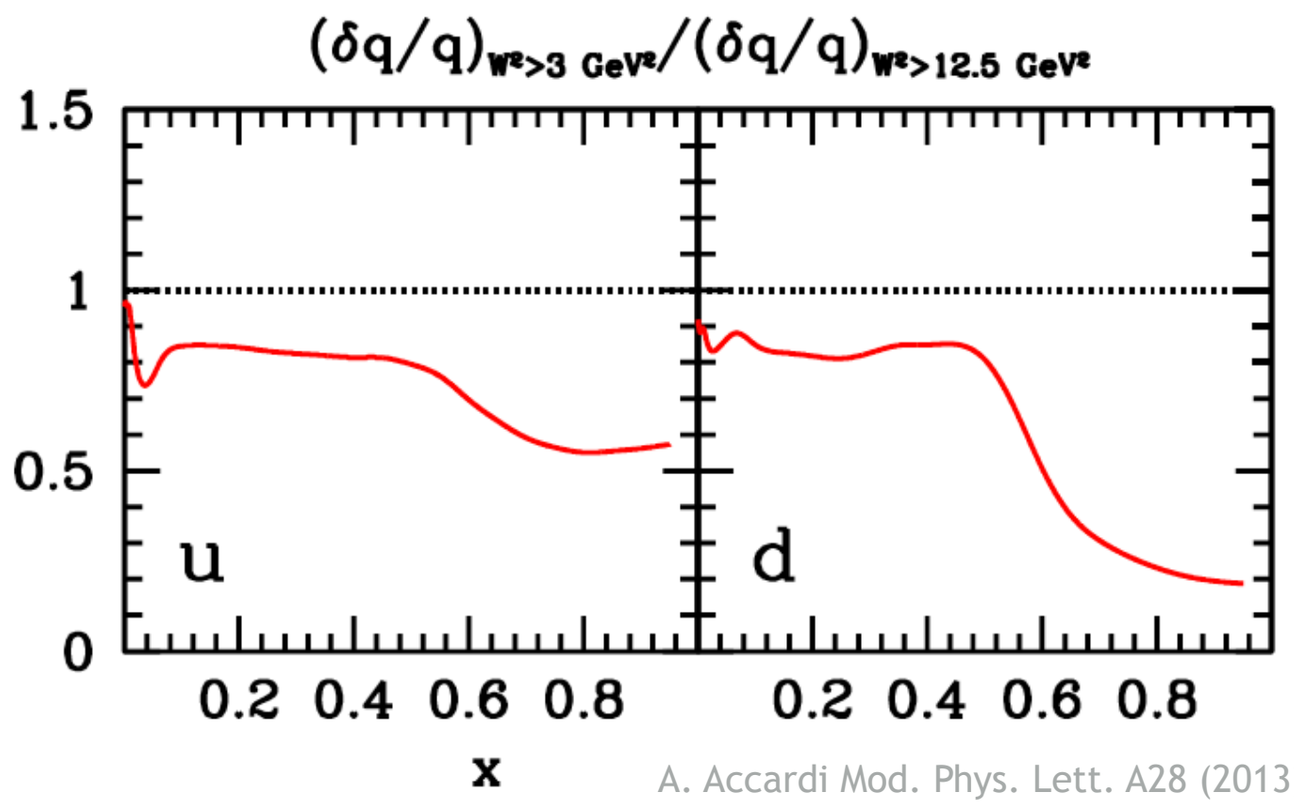
Include non-perturbative corrections: data with low W are used

Include nuclear corrections: use of deuterium data requires careful treatment of nuclear corrections

Results from CTEQ-JLab Fits

➢ Compare to previous analyses:

greatly reduced experimental errors, up to 80% on the d quark PDF at large x

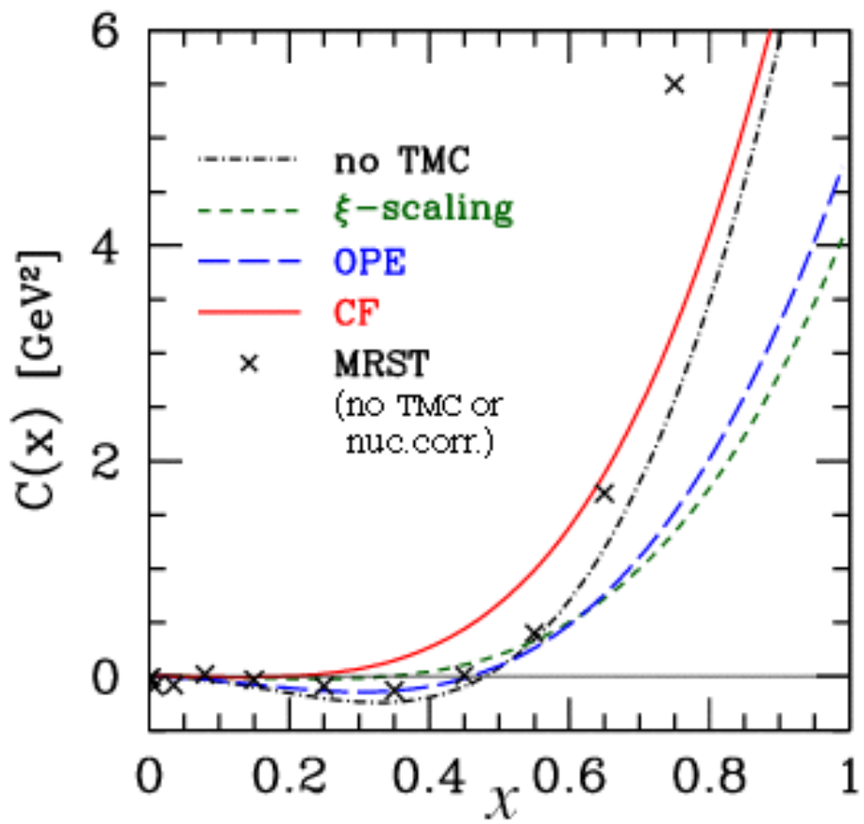


A. Accardi Mod. Phys. Lett. A28 (2013)

Results from CTEQ-JLab Fits

➢ **Highlights: regarding the universality of PDFs**

Non-perturbative $1/Q^2$ corrections: dynamical and kinematical higher-twist

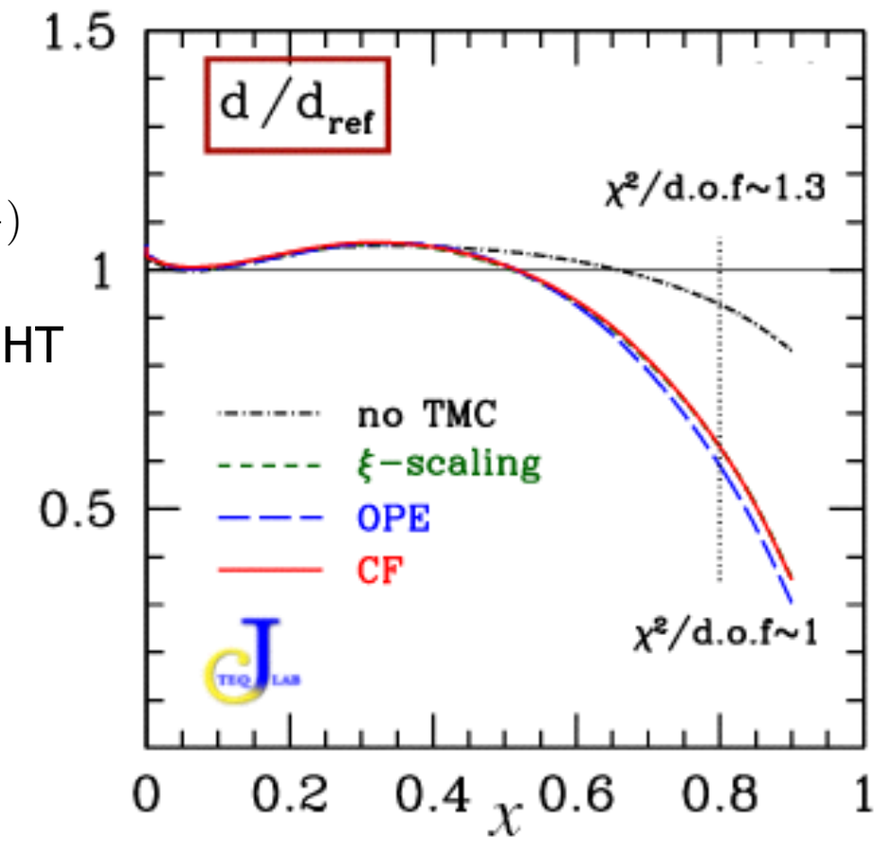


$$F_2(x,Q^2) = F_2^{LT}(x,Q^2)(1+\frac{C(x)}{Q^2})$$

kinematical HT goes in here

dynamical HT

$$C(x) = c_1 x^{c_2}(1+c_3 x)$$



A. Accardi et al., Phys. Rev. D 81, 034016 (2010)

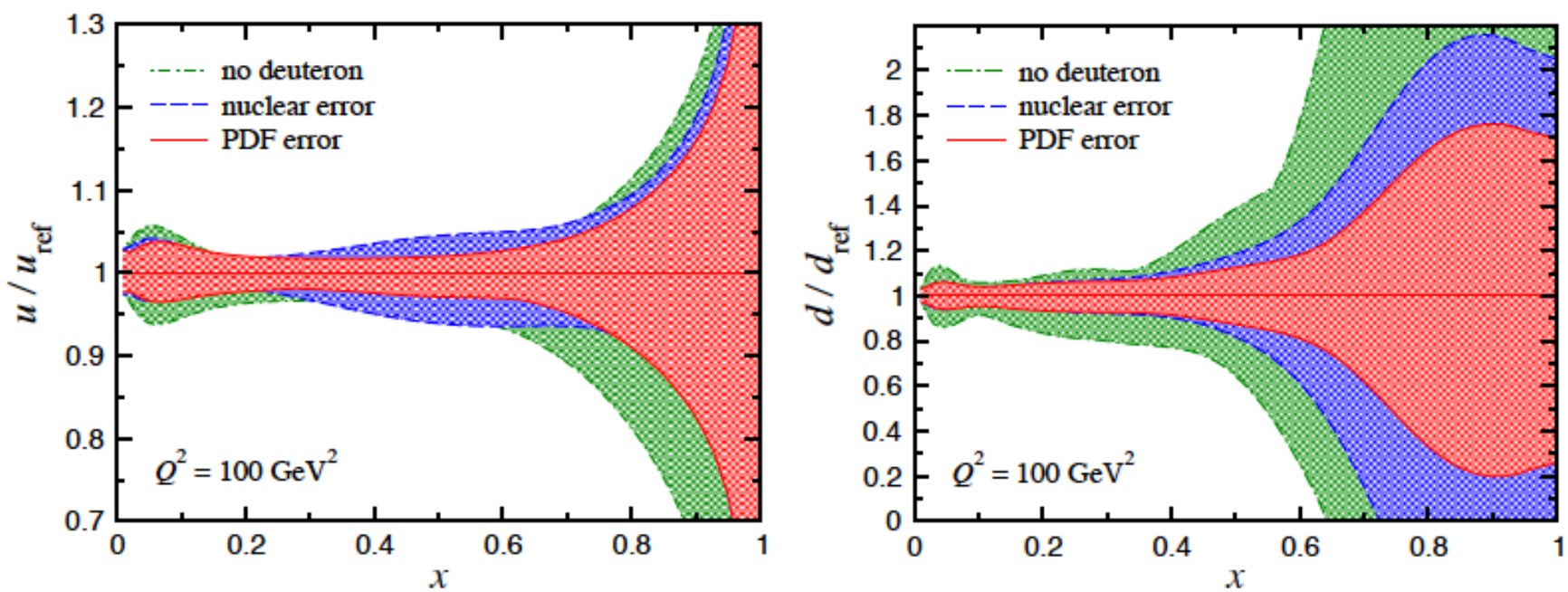
1) The dynamical HT extraction depends on the kinematical HT (TMC) prescription used

2) Almost identical results for the d-quark distribution when different prescriptions of TMCs are used in conjunction with the dynamical HT

Results from CTEQ-JLab Fits

➢ **Highlights: regarding nuclear corrections**

Nuclear effects in deuterium: binding, Fermi motion (well known), off-shellness (less well known)



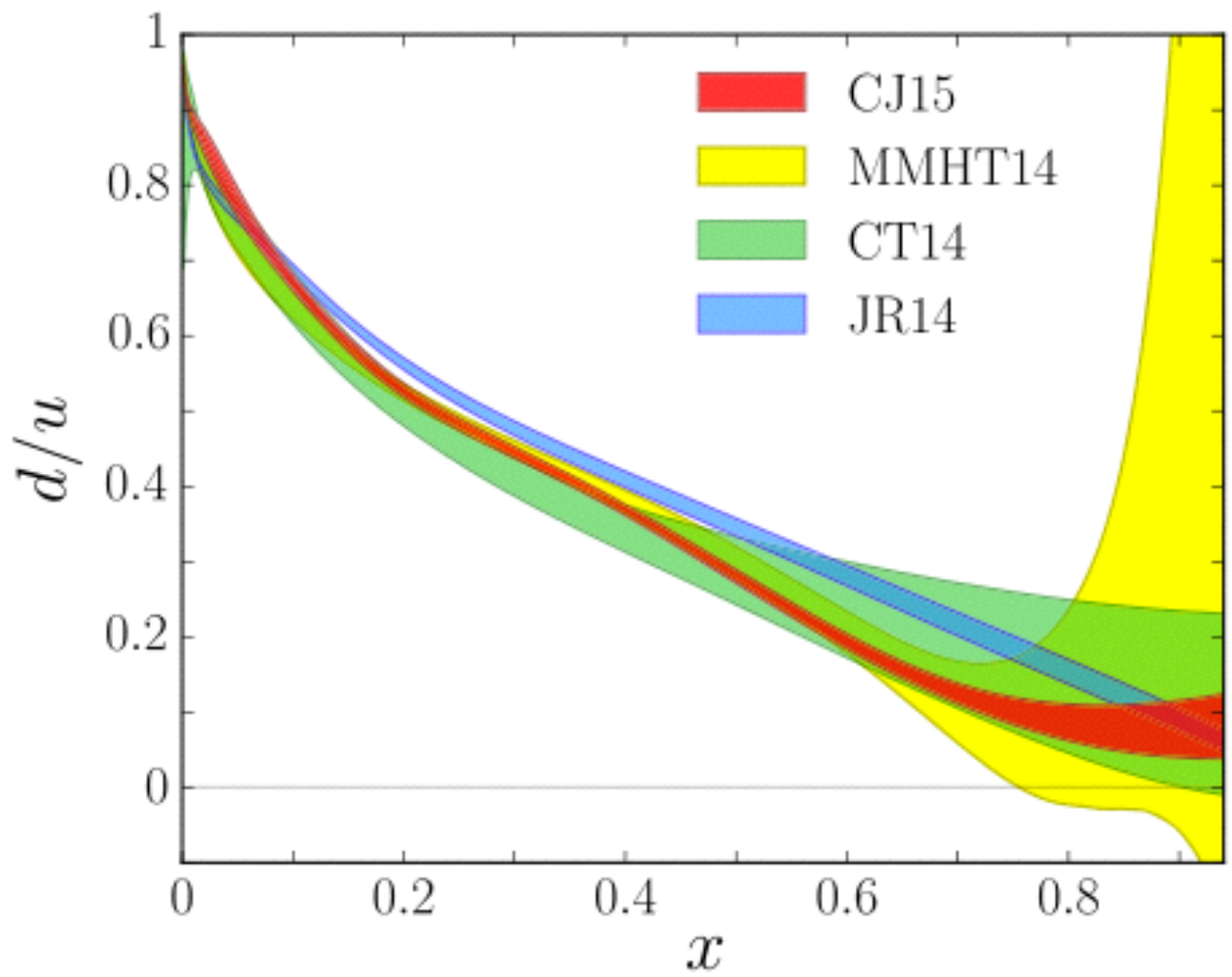
J. F. Owens, A. Accardi, W. Melnitchouk, Phys. Rev. D 87, 094012 (2013)

- Global fits without deuterium data show:
  modest increase in the error band for u for x>0.7
  significant increase in the error band for d
- Smaller error band for d if deuteron hence nuclear correction included

Results from CTEQ-JLab Fits

➢ **Highlights: regarding d/u at large x**

Improvement in uncertainty of d/u extraction



A. Accardi et al., Phys. Rev. D 93, 114017 (2016)

How do we practically run E12-10-002?

Inclusive Cross Section Measurements

➢ F_2 structure function obtained from cross section measurements

$$\frac{d^2\sigma}{d\Omega dE'} = (N_{measured} - BG)\frac{1}{N_e N_t}\frac{1}{d\Omega dE'}\frac{1}{A}\frac{1}{\varepsilon}$$

absolute cross section
with radiative effects

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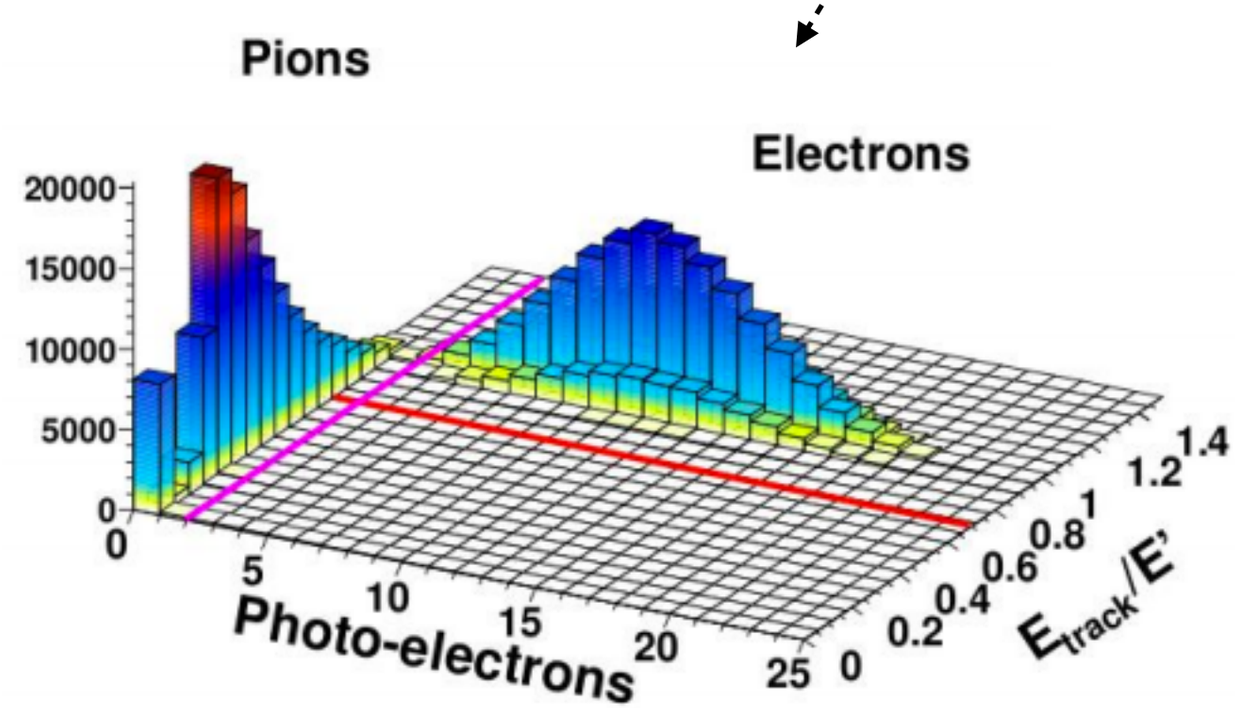

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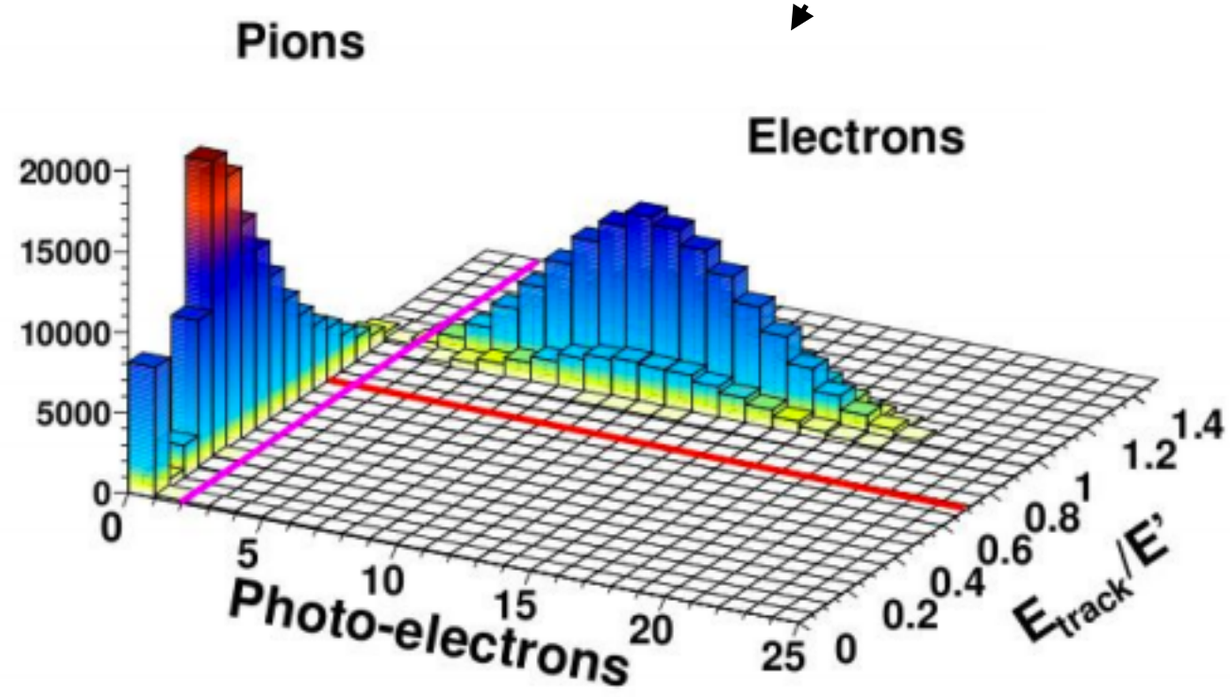

Background

- cryogenic target endcaps
- e- from decay of π^0 produced in the target
- contamination from pion response in PID

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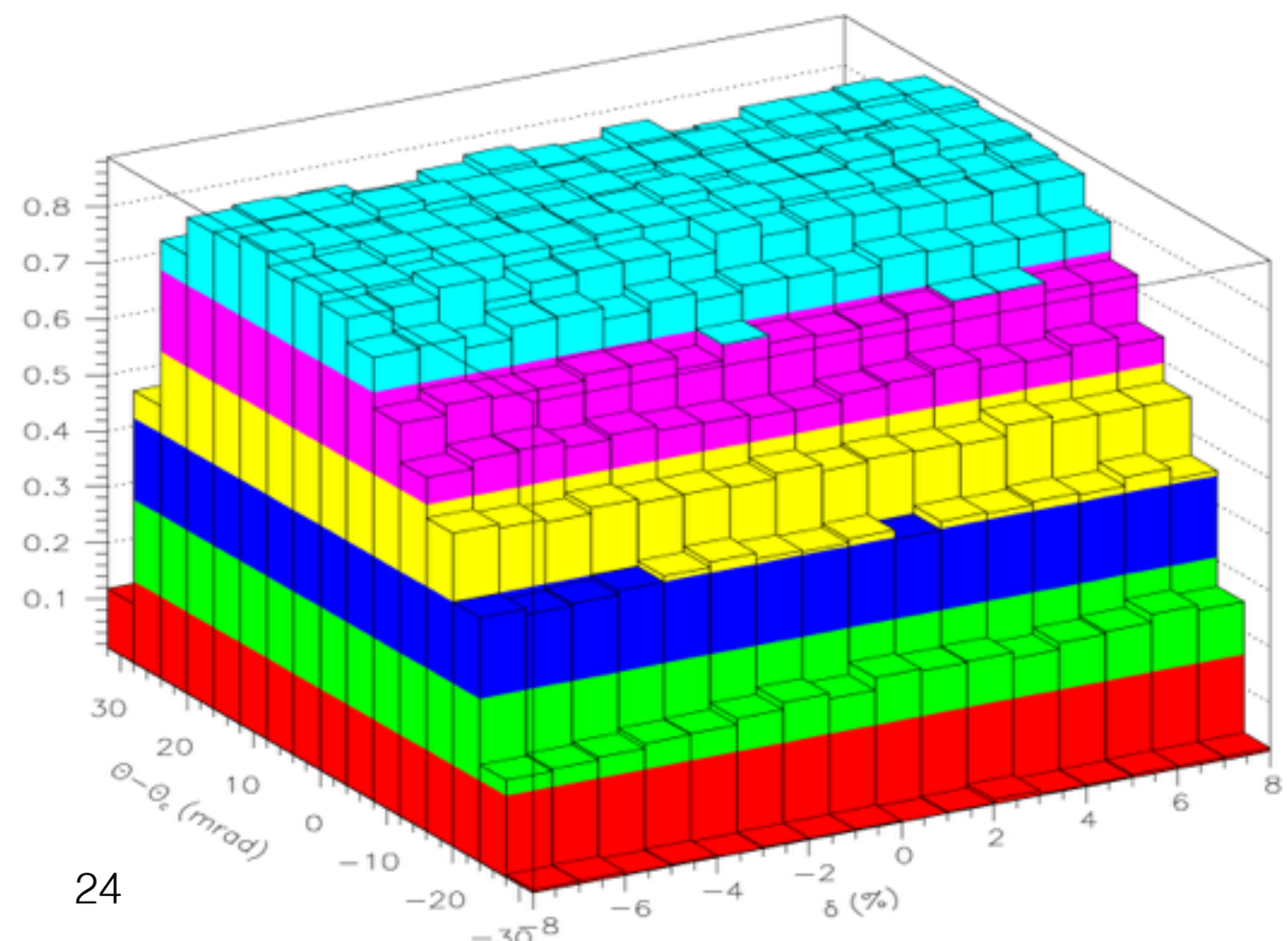
absolute cross section
with radiative effects

acceptance



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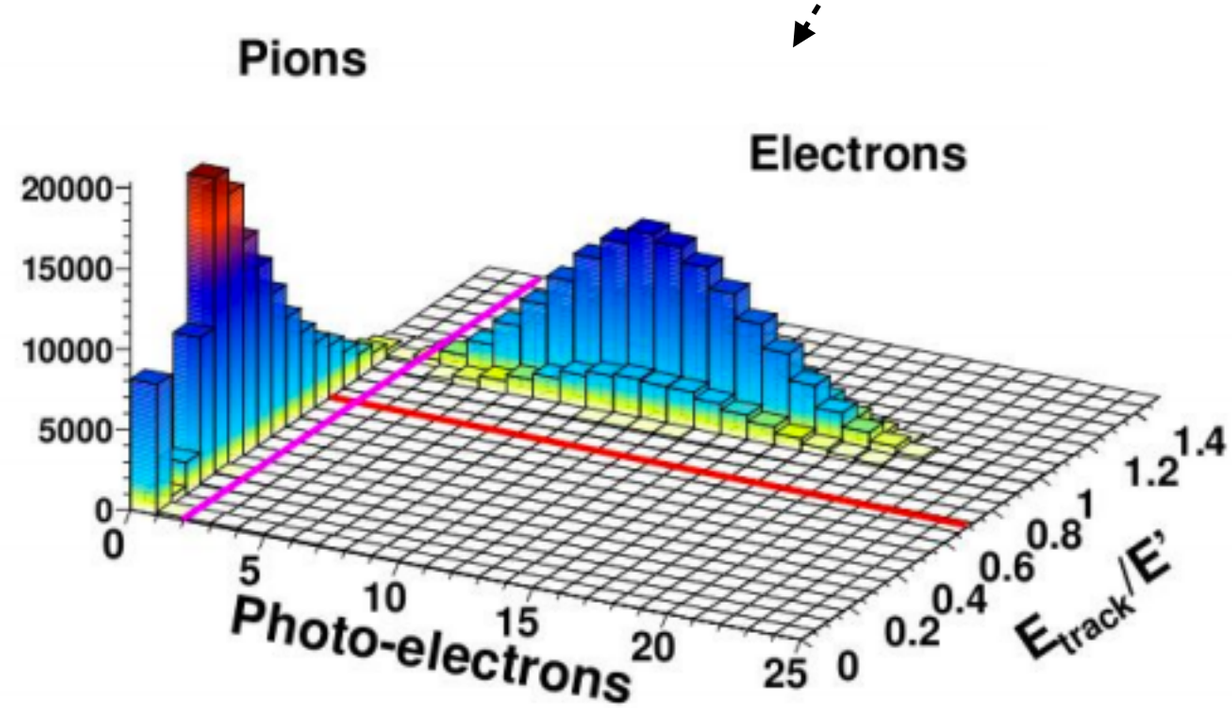
<u>experimental efficiencies</u>

detectors
front-end electronics
DAQ

absolute cross section
with radiative effects

acceptance



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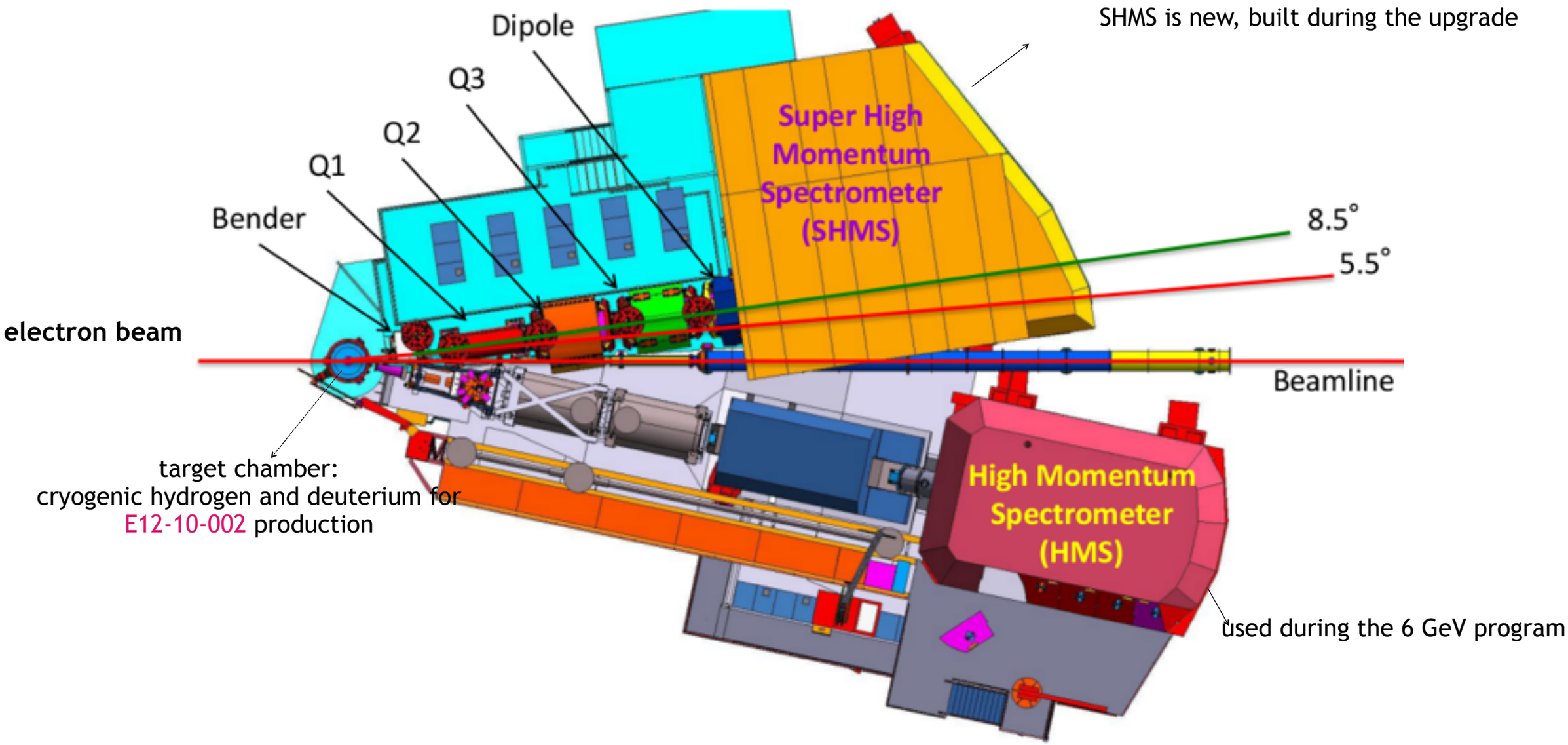
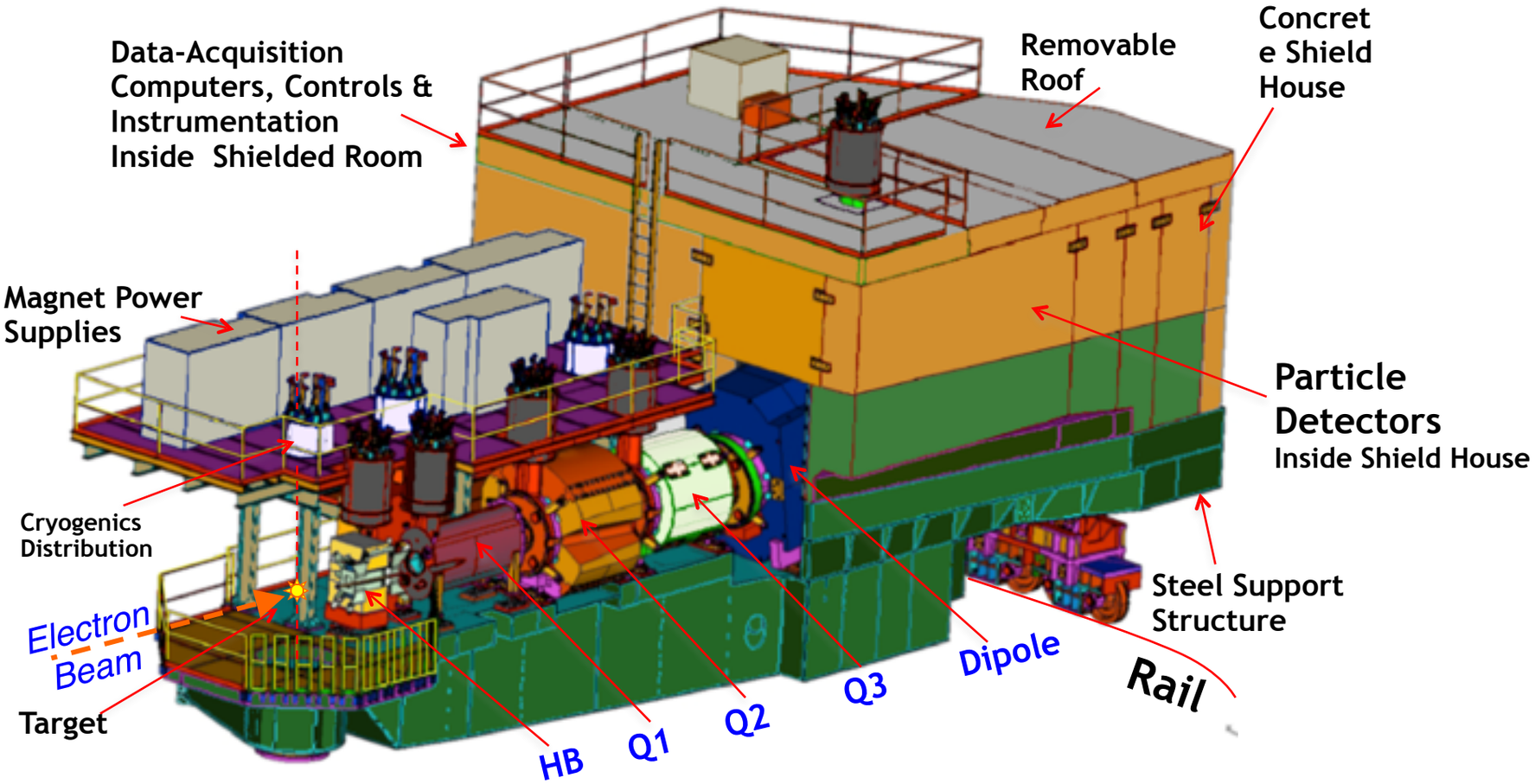
Hall C Setup


SHMS is new, built during the upgrade
Dipole
Q3
Q2
Q1
Bender
Super High Momentum Spectrometer (SHMS)
8.5°
5.5°
electron beam
Beamline
target chamber:
cryogenic hydrogen and deuterium for
E12-10-002 production
High Momentum Spectrometer (HMS)
used during the 6 GeV program

SHMS Magnets



Central Momentum:
2-11 GeV/c

Scattering Angle:
5.5 to 40 degrees

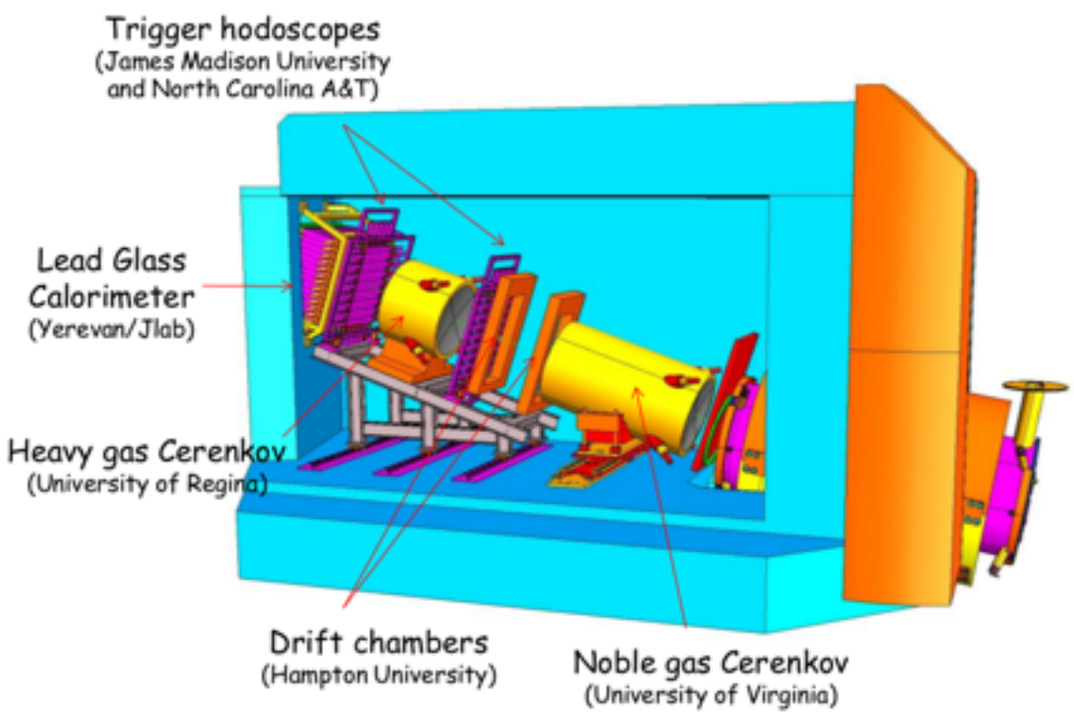
Solid Angle Acceptance:
4.0 msr

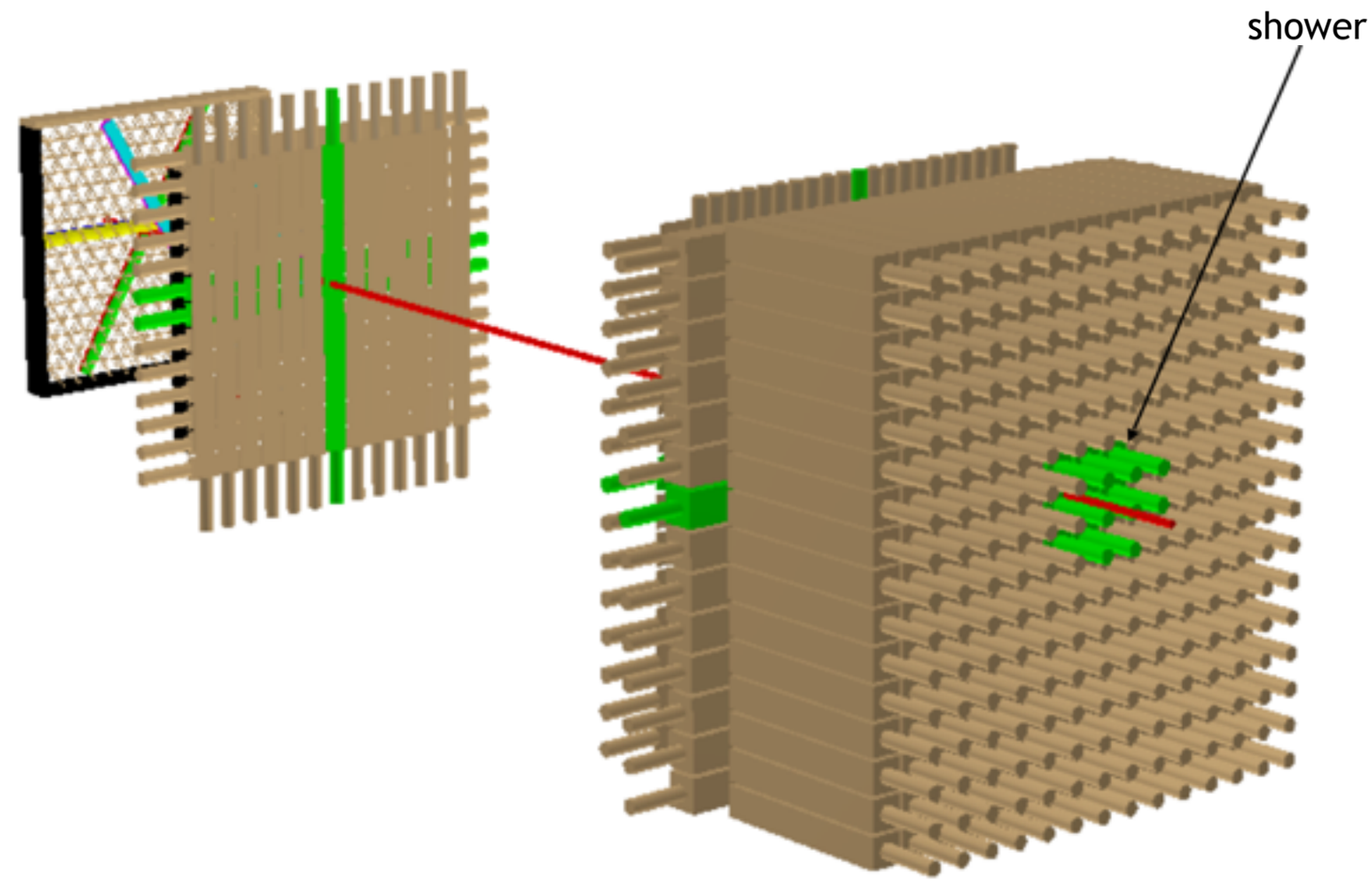
Momentum Acceptance:
$-10\% < \delta < 22\%$

Momentum Resolution:
0.03%-0.08%

- Horizontal bender provides a 3 deg initial bend to allow small angle detection
- Q1(v), Q2(h), Q3(v) focus in horizontal and vertical directions
- Dipole defocuses in the vertical direction

SHMS Detector Hut





- Particle identification
  - Noble gas Cherenkov
  - Heavy gas Cherenkov
  - Lead Glass Calorimeter
- Trigger
  - Hodoscope + PID
- Tracking
  - Drift chamber

E12-10-002 Running Conditions

- Unpolarized Beam

  energy: 10.6 and 6.4 for R measurement

  current: 30 μA or larger

- Targets

  10 cm hydrogen - production

  10 cm Deuterium - production

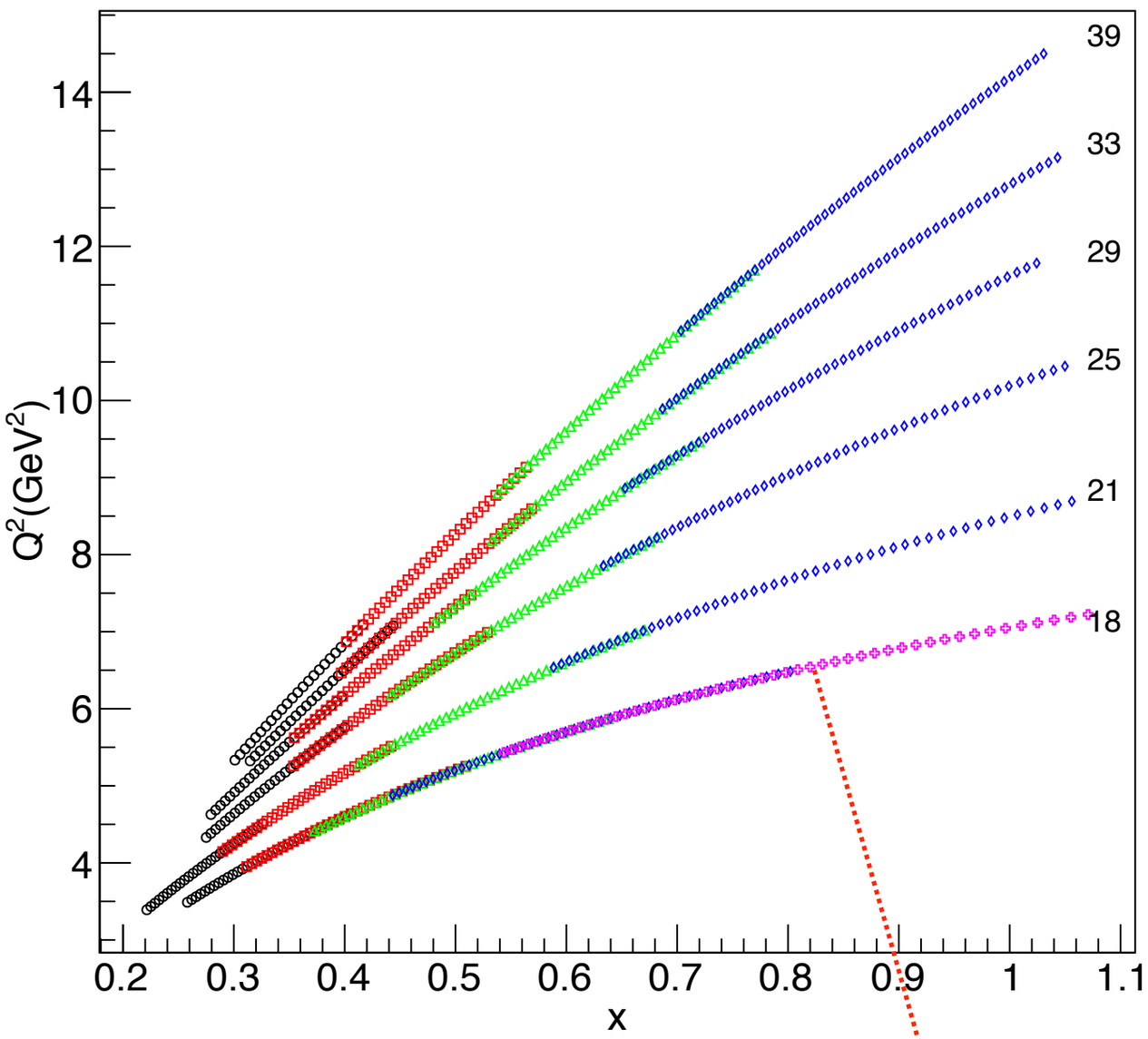
  Al foils - background measurement

- SHMS is used to take most of the production data

- HMS is used to measure highest Q^2 point and for cross-calibration with SHMS

E12-10-002 Run Plan

➢ SHMS is used to take most of the production data



SHMS kinematic settings with 10.5732 GeV beam

Angle	Momentum(GeV/c)
18	3.5, 4.0, 4.5, 5.0, 5.7
21	2.7, 3.3, 4.0, 5.1
25	2.5, 3.0, 3.5, 4.4
29	2.0, 2.4, 3.0, 3.7
33	1.7, 2.1, 2.6, 3.2
39	1.3, 1.6, 2.0, 2.5

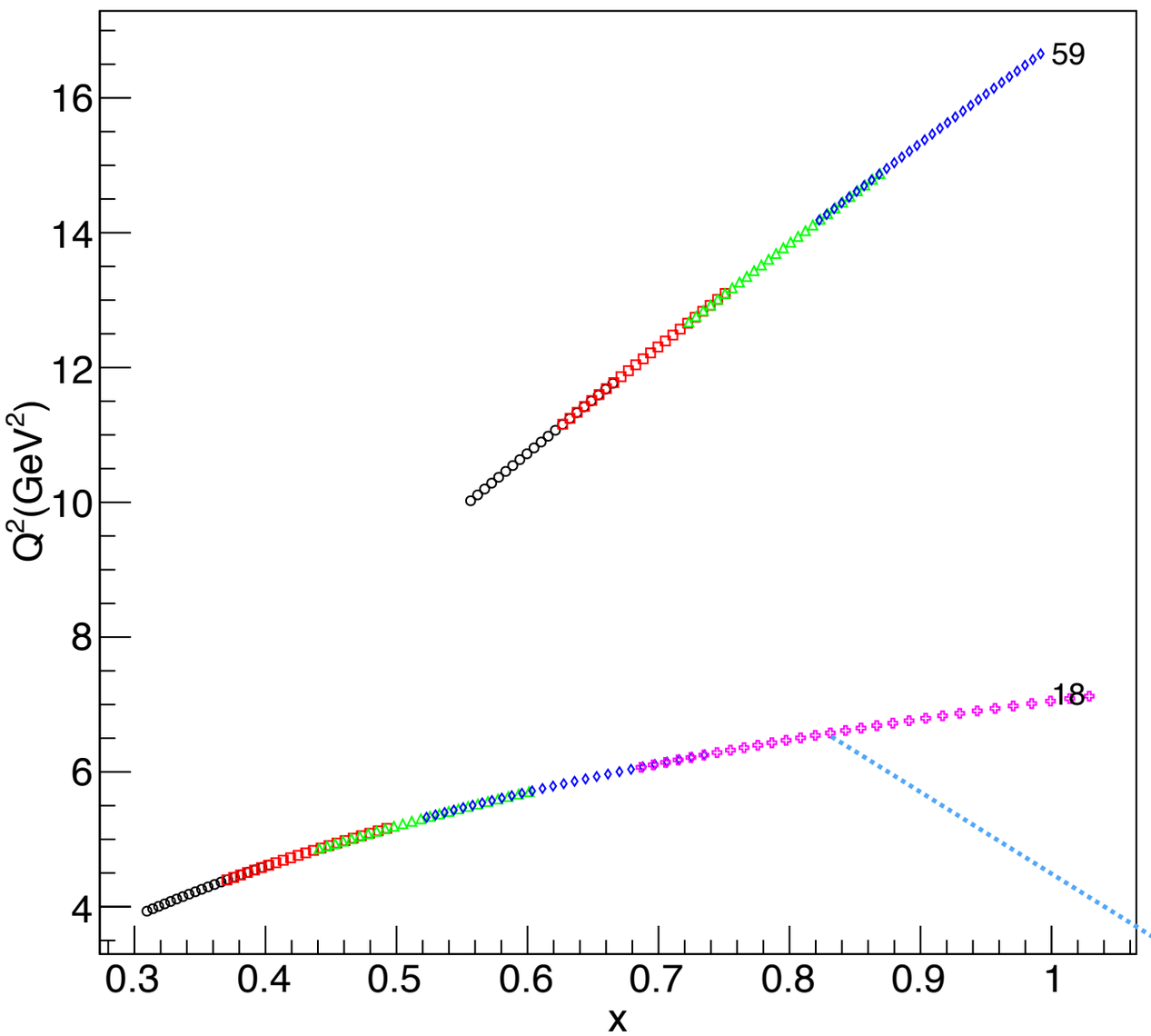
➢ 6 angle changes

➢ 25 momentum changes

different colors for different central momentum settings
cover a wide kinematic range because of large momentum acceptance

E12-10-002 Run Plan

➢ HMS is used to measure highest Q^2 point and for cross-calibration with SHMS



HMS kinematic settings with 10.5732 GeV beam

Angle	Momentum(GeV/c)
18	4.1, 4.6, 5.1, 5.6, 6.4
59	1.05, 1.18, 1.35, 1.50

59 deg: Production to push to highest x, Q^2

18 deg: commissioning data to cross-calibrate HMS and SHMS

➢ 2 angle changes

➢ 9 momentum changes

covered range is smaller than SHMS because of smaller momentum acceptance

During the SHMS production running at 21,25, 29, 33, 39 deg the HMS will take production data at 59 deg

Production Rate, SHMS

$$N_{measured} = cross\,section * N_{beam} * N_{target}$$

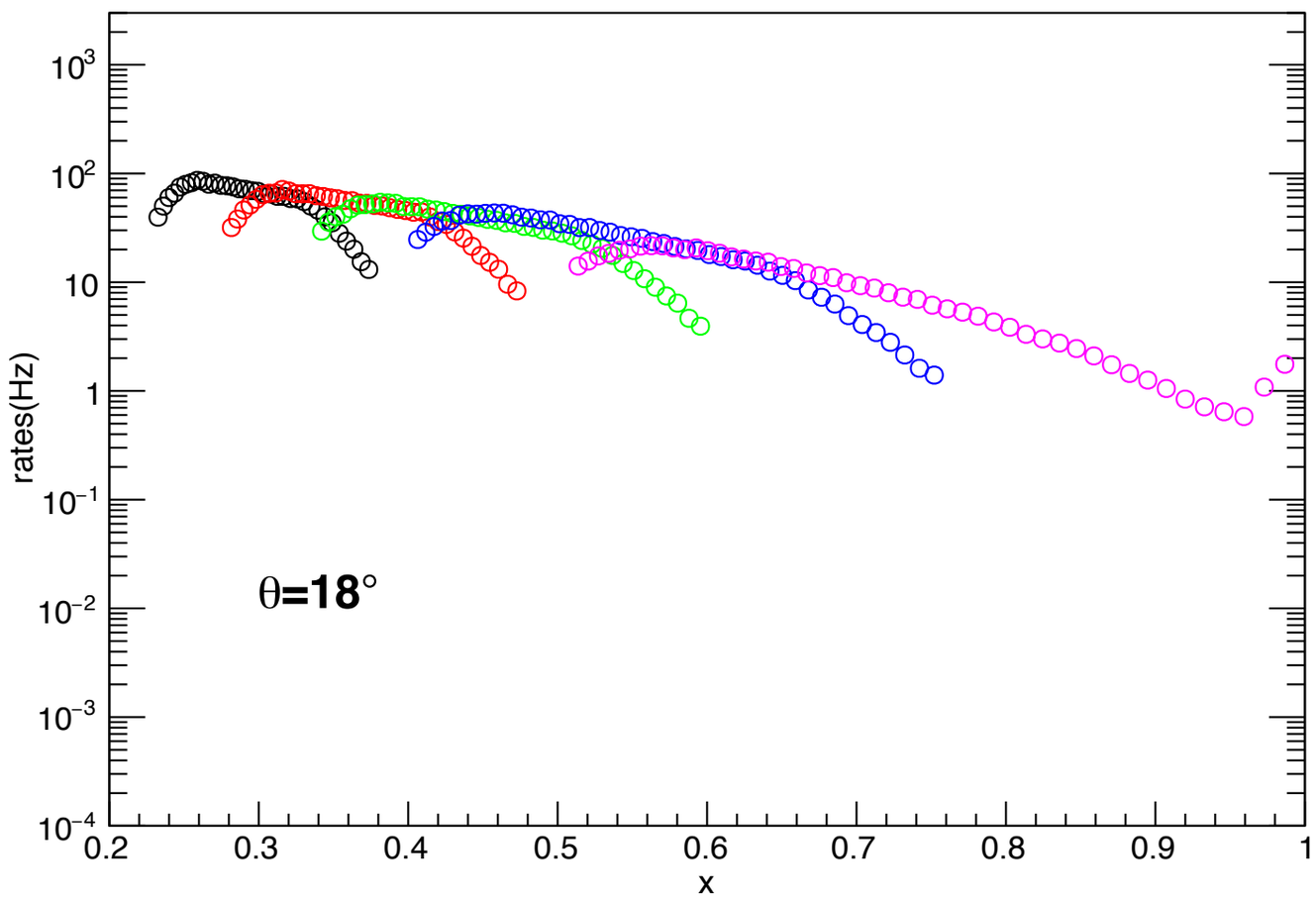
$$rate = \frac{d\sigma}{d\Omega dE'} * d\Omega * dE' * \frac{I}{Q_e} * \frac{N_A * \rho * t}{A}$$

beam current

target length

bin size of scattered electron energy

elementary charge



- Input parameters:

  target length: 10 cm

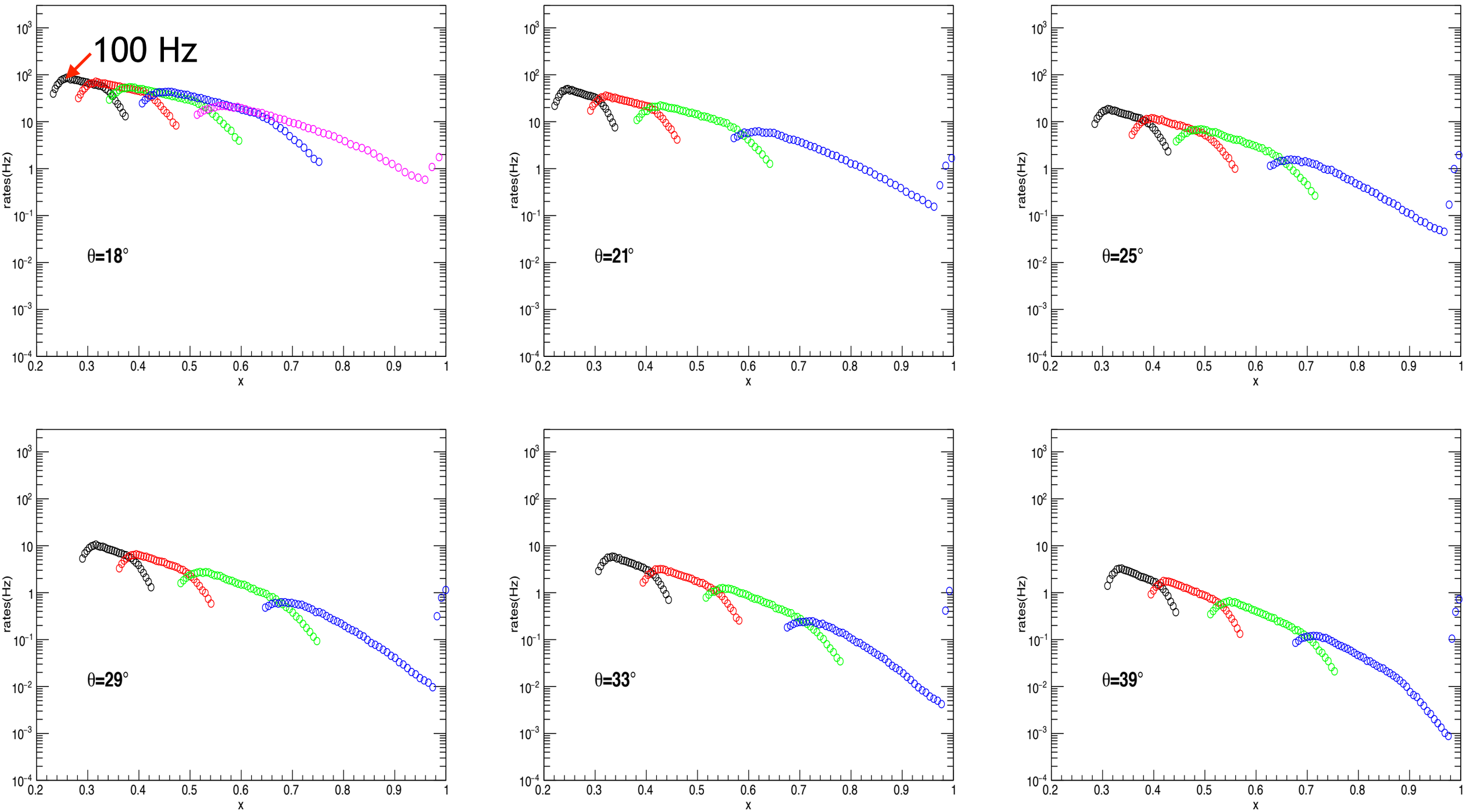
  beam current: 30 μA

  bin size: W^2 bin of 0.1 GeV^2

- Shape due to detector acceptance effect

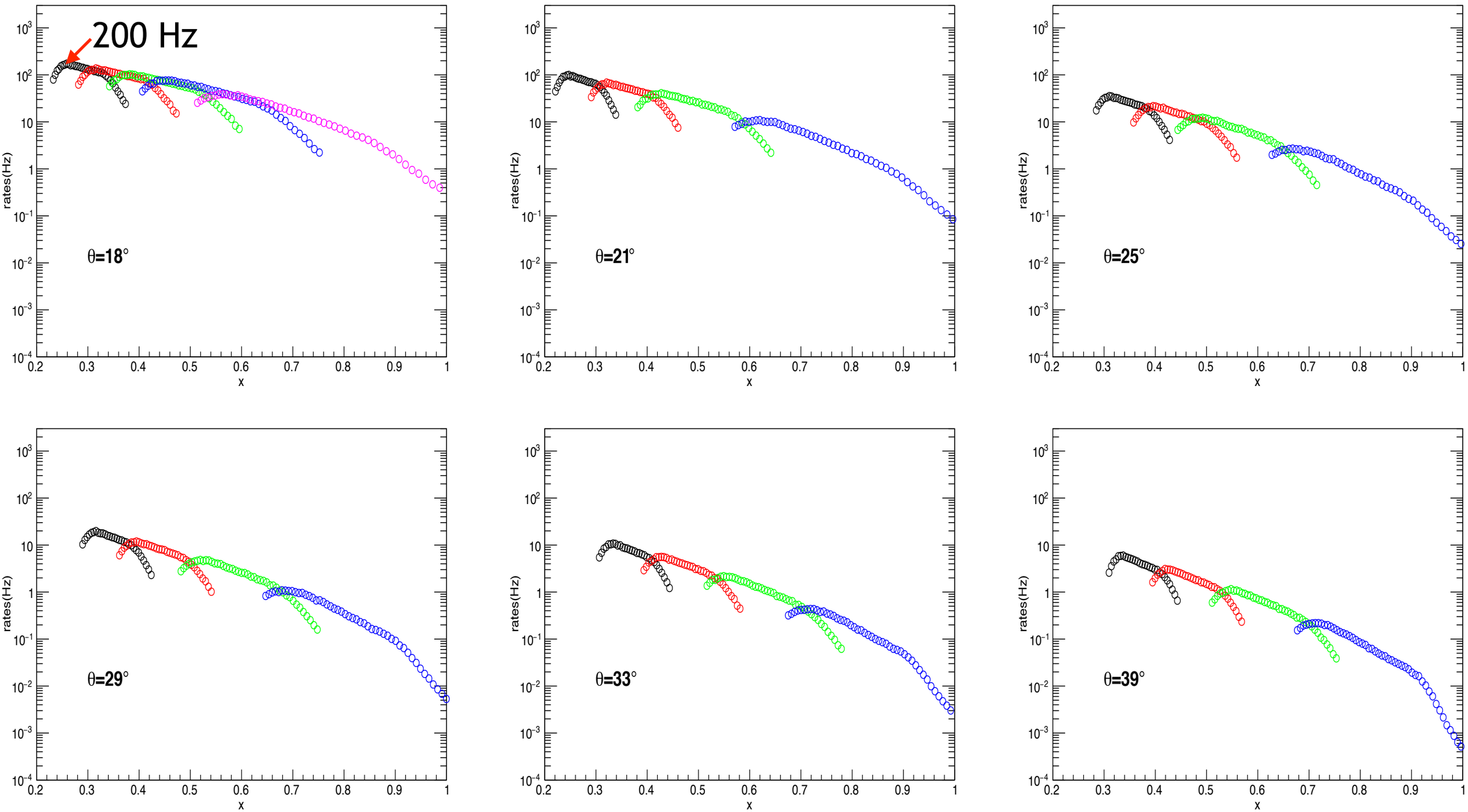
Production Rates on H target, SHMS

➢ Rate plots for all kinematics

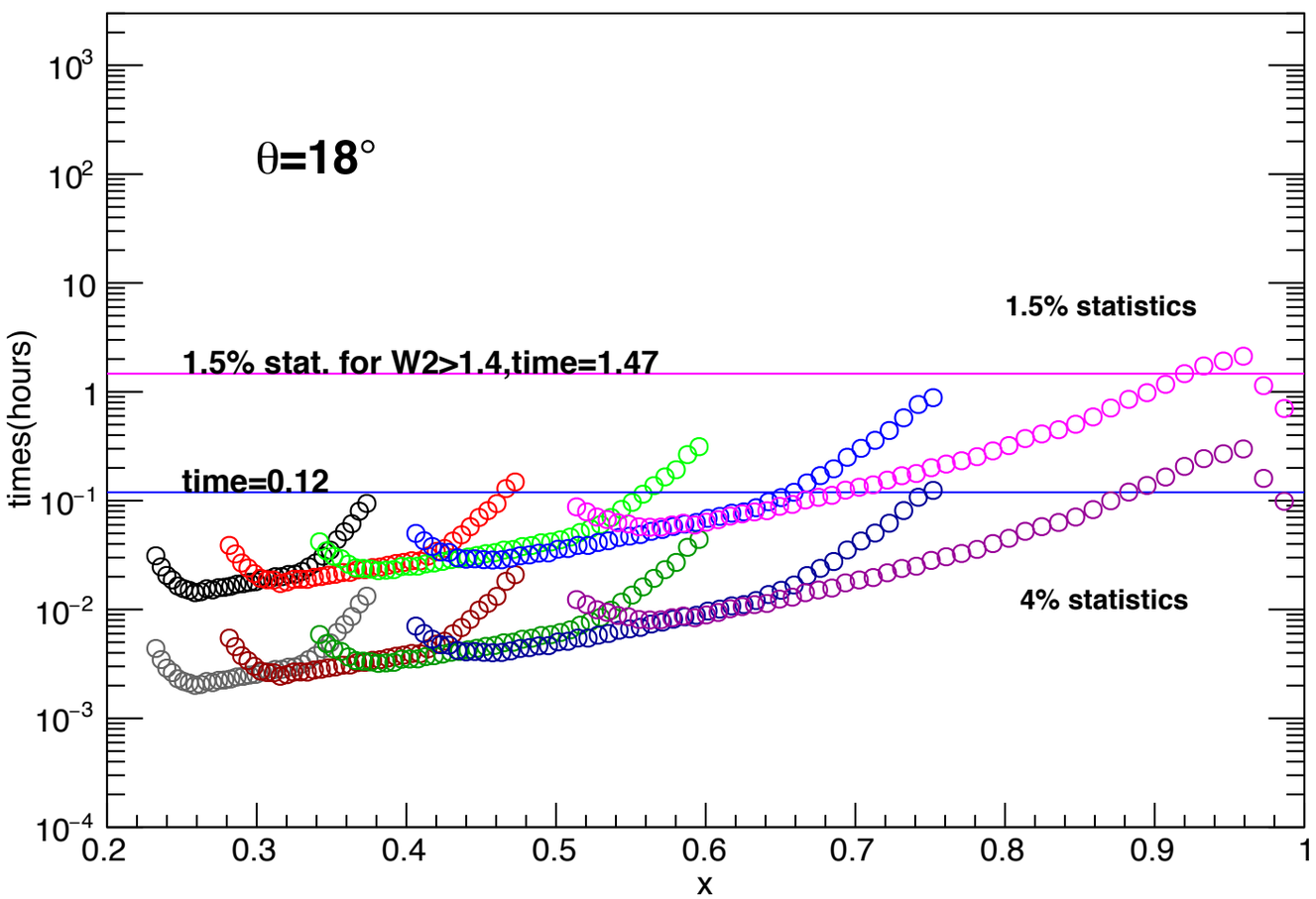


Production Rates on D target, SHMS

➢ Rate plots for all kinematics



Production Time Estimation, SHMS



- Input parameters:

  Target length: 10 cm

  Beam current: 30 μA

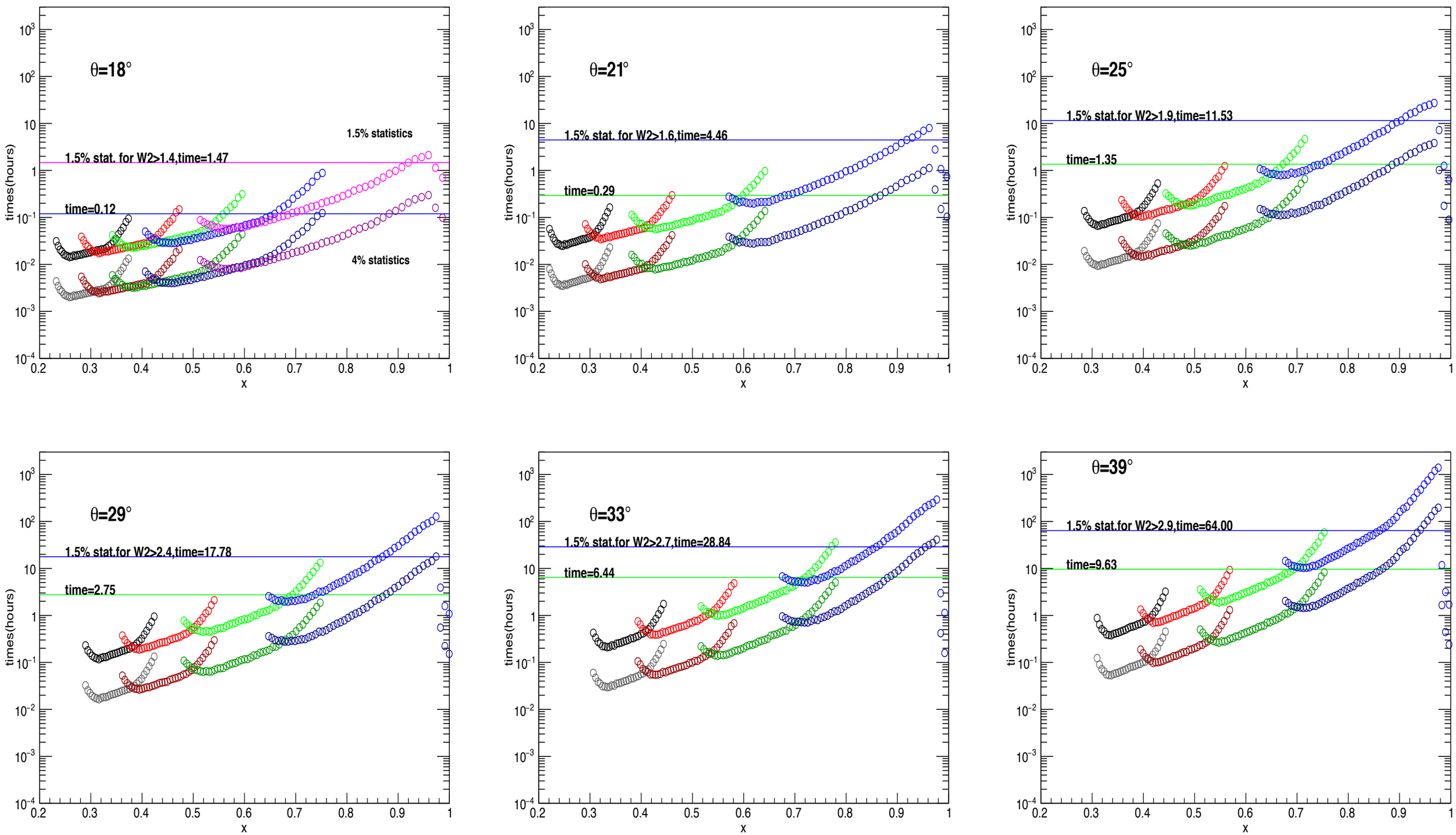
  bin size: W^2 bin of 0.1 GeV^2

- Shape due to detector acceptance effect

- Shown are times corresponding to different statistical precisions

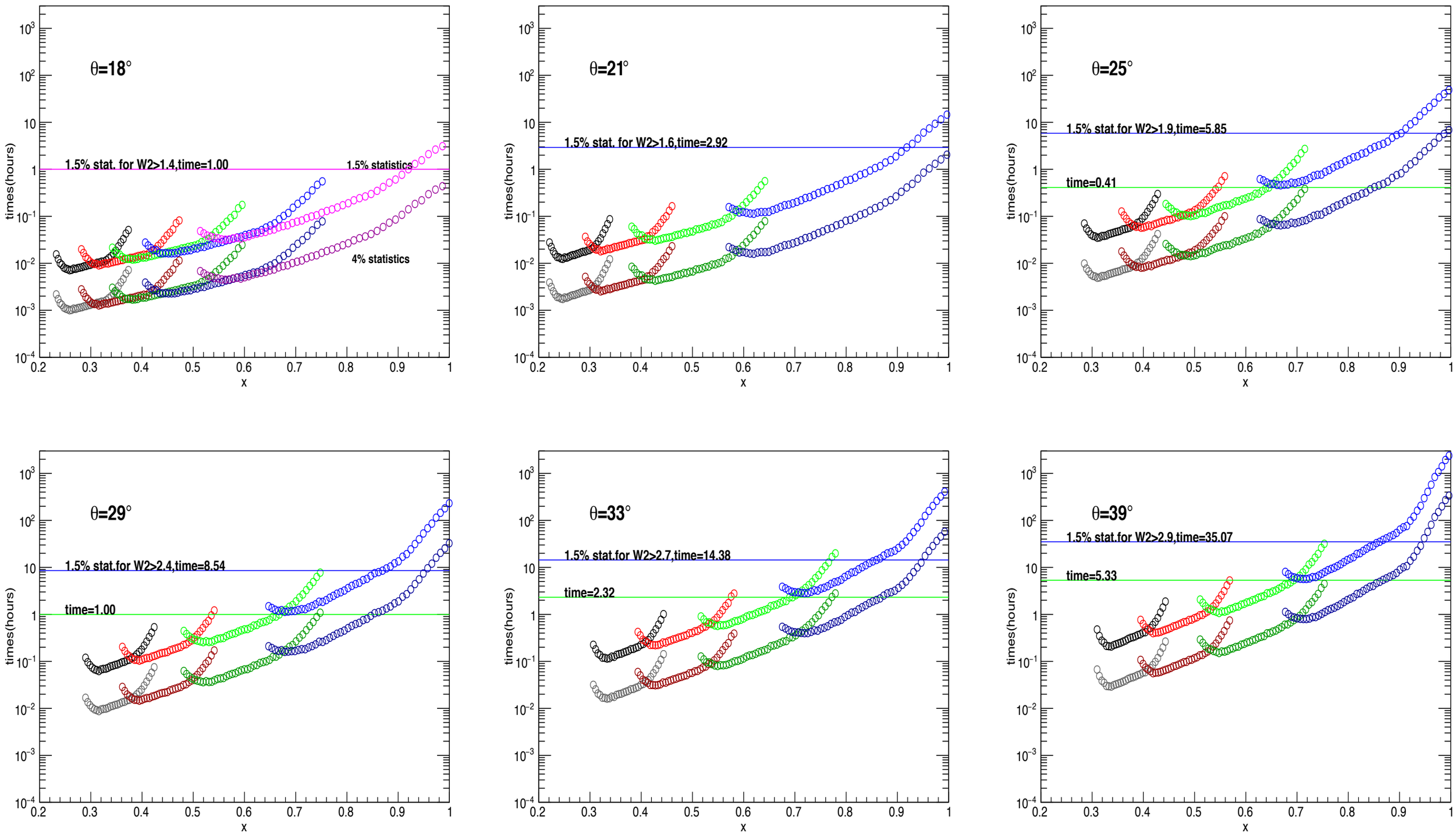
H Production Time Estimation, SHMS

➢ Time estimations for all kinematics



D Production Time Estimation, SHMS

➢ Time estimations for all kinematics



Production Time Estimation: Preliminary

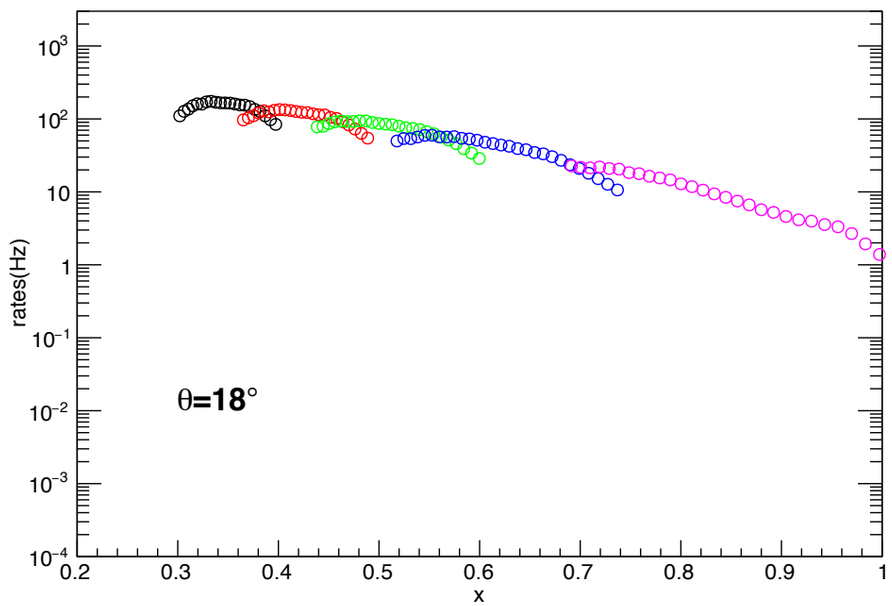
- 1.5% statistics in W^2 bin of 0.1 GeV^2

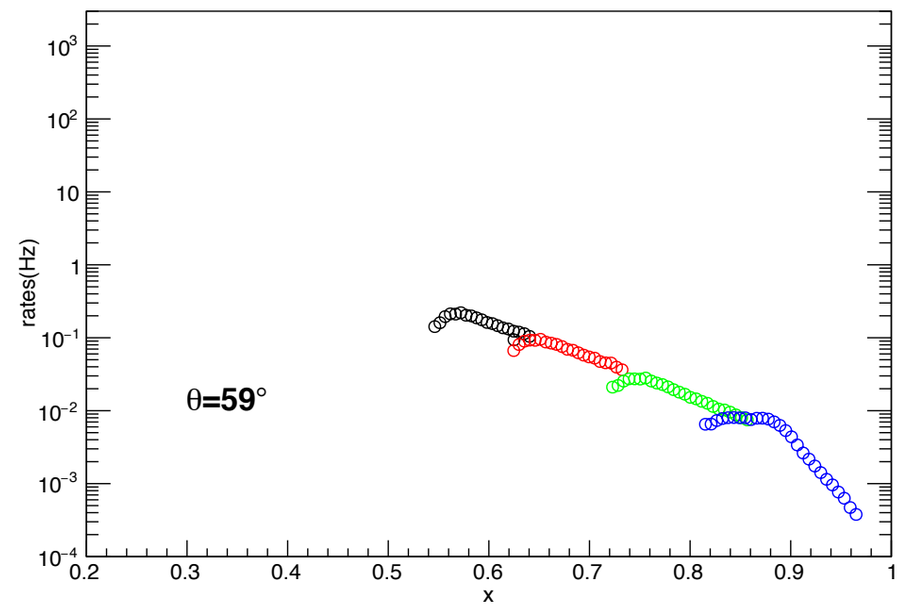
Angle(deg)	Time(h) H target	Time(h) D target	1.5% stat. for W^2>?
18	2	2	1.4
21	5	3	1.6
25	13	7	1.9
29	21	10	2.4
33	37	18	2.7
39	75	42	2.9

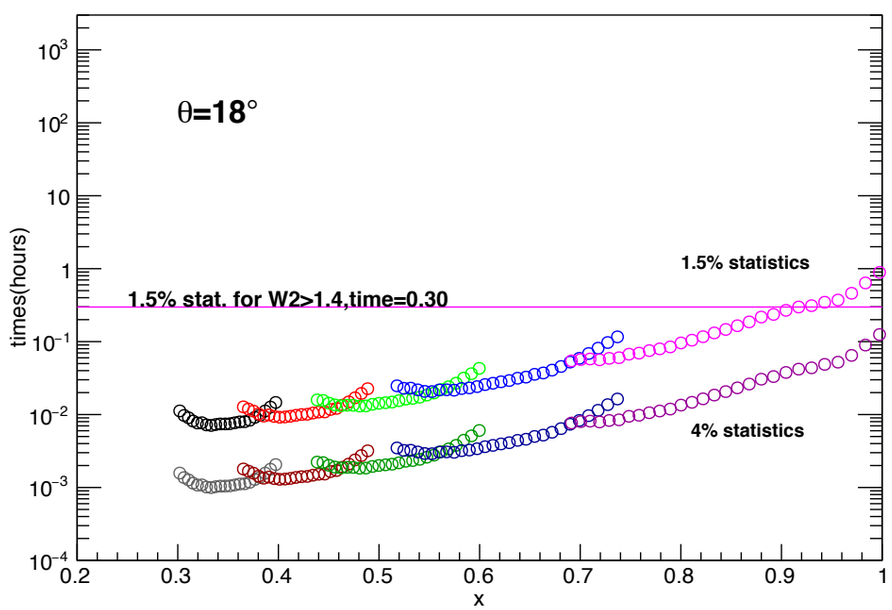
statistical precision will be less than 1.5 % below the W^2 cuts

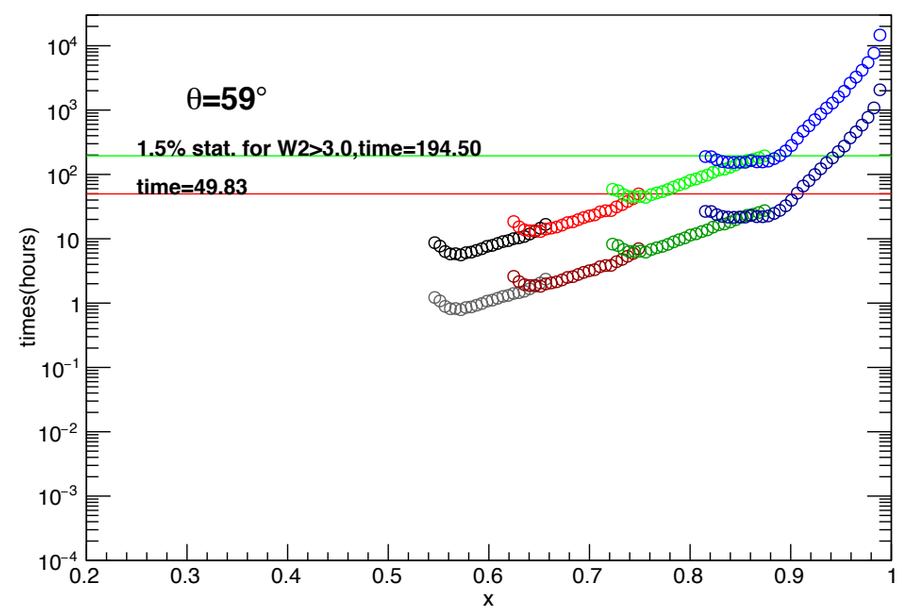
- Total time for H running: 153 h
- Total time for D running: 82 h
- Dummy run time: 15% of D target
- May still be changed to compromise between time and statistics

Production Rates on H target, HMS





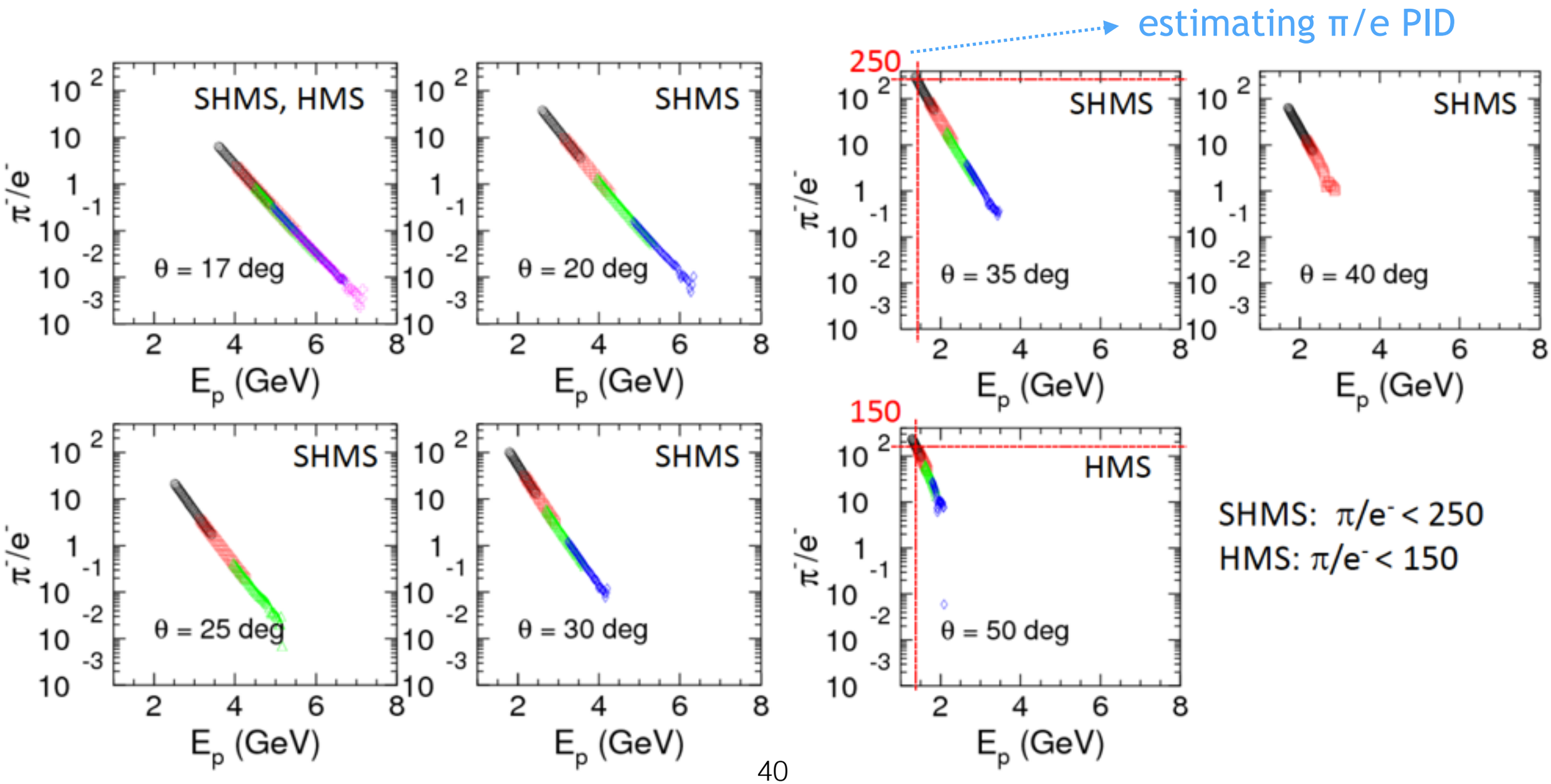




- Rate at large angle is low
- HMS will stay at 59 deg after taking data at 18 deg

π^-/e^- Ratios for H

- Target length: 10 cm
- Beam current: 40 μA
- Pion cross section: Wiser's fit to π^+ and π^- production on H



SHMS: $\pi/e^- < 250$
HMS: $\pi/e^- < 150$

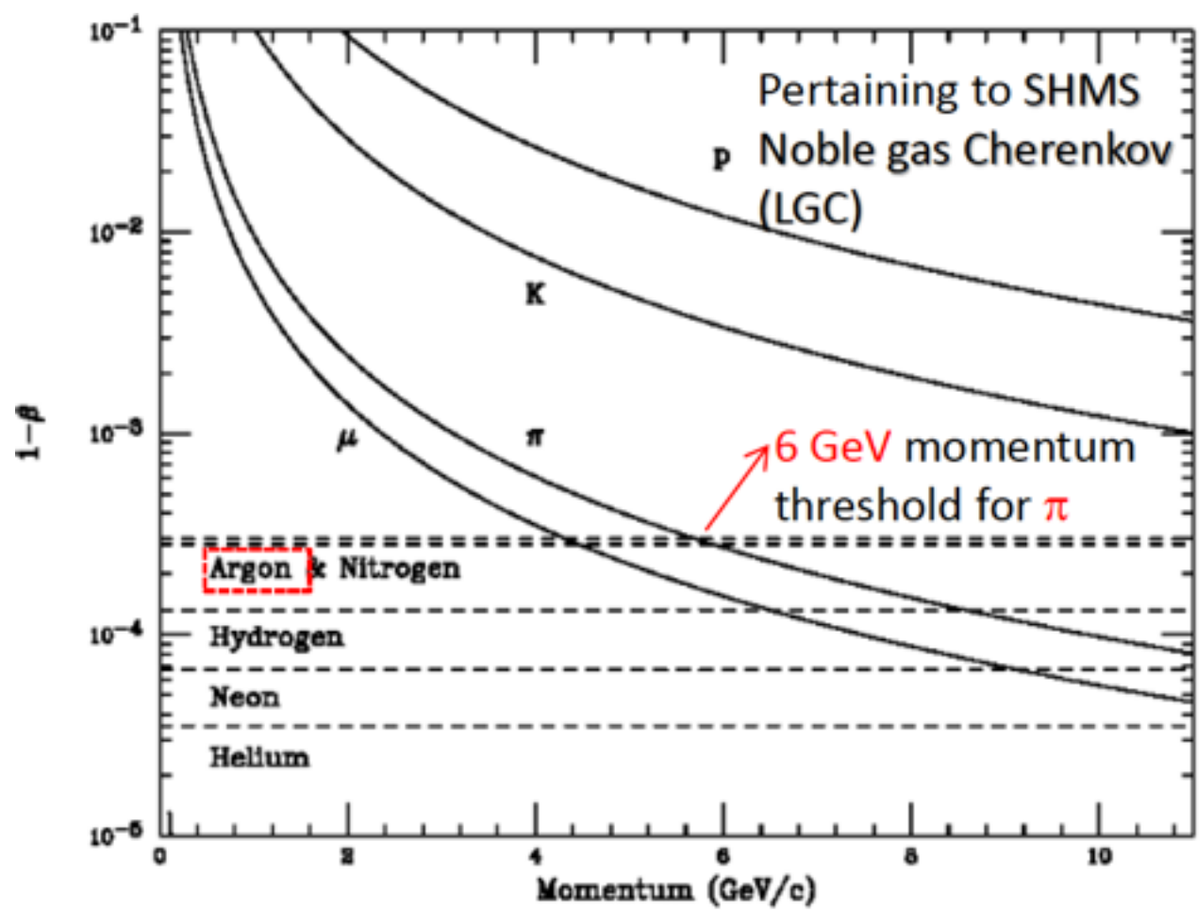
SHMS Running Parameters: Cherenkov

- For momenta between 1.4 and 4 GeV, π/e < 250

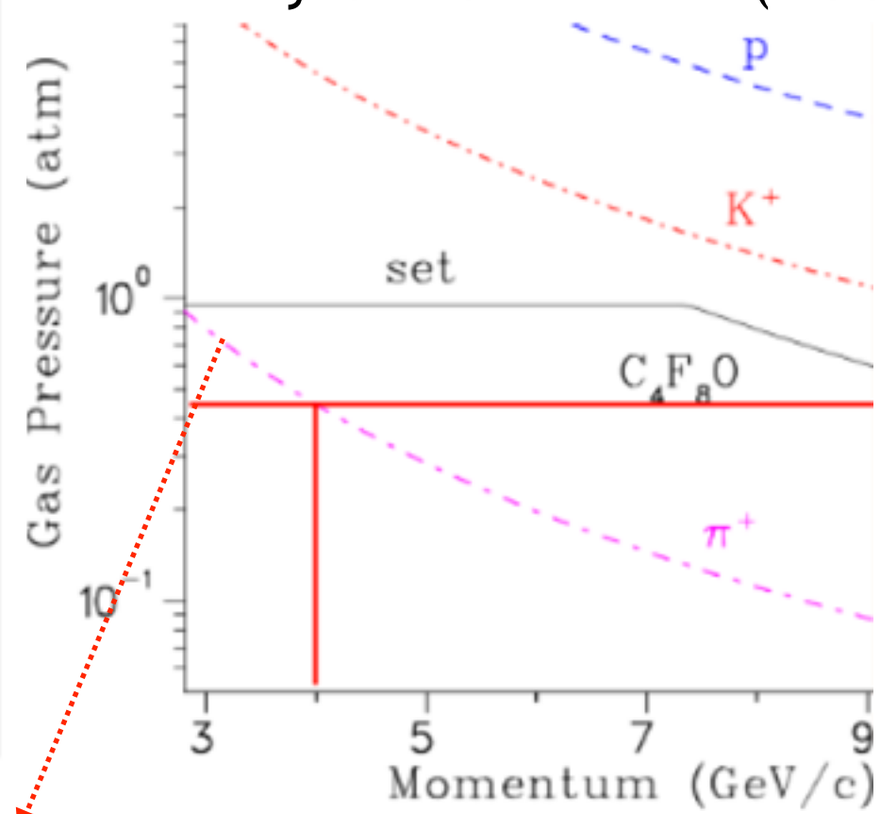
  Cherenkov rejection: HGC - 25:1 & LGC (Ar) - 25:1

- For momenta > 4 GeV, π/e < 2.5

  Cherenkov rejection: LGC (Ar) - 25:1



Pertaining to SHMS
Heavy Gas Cherenkov (HGC)

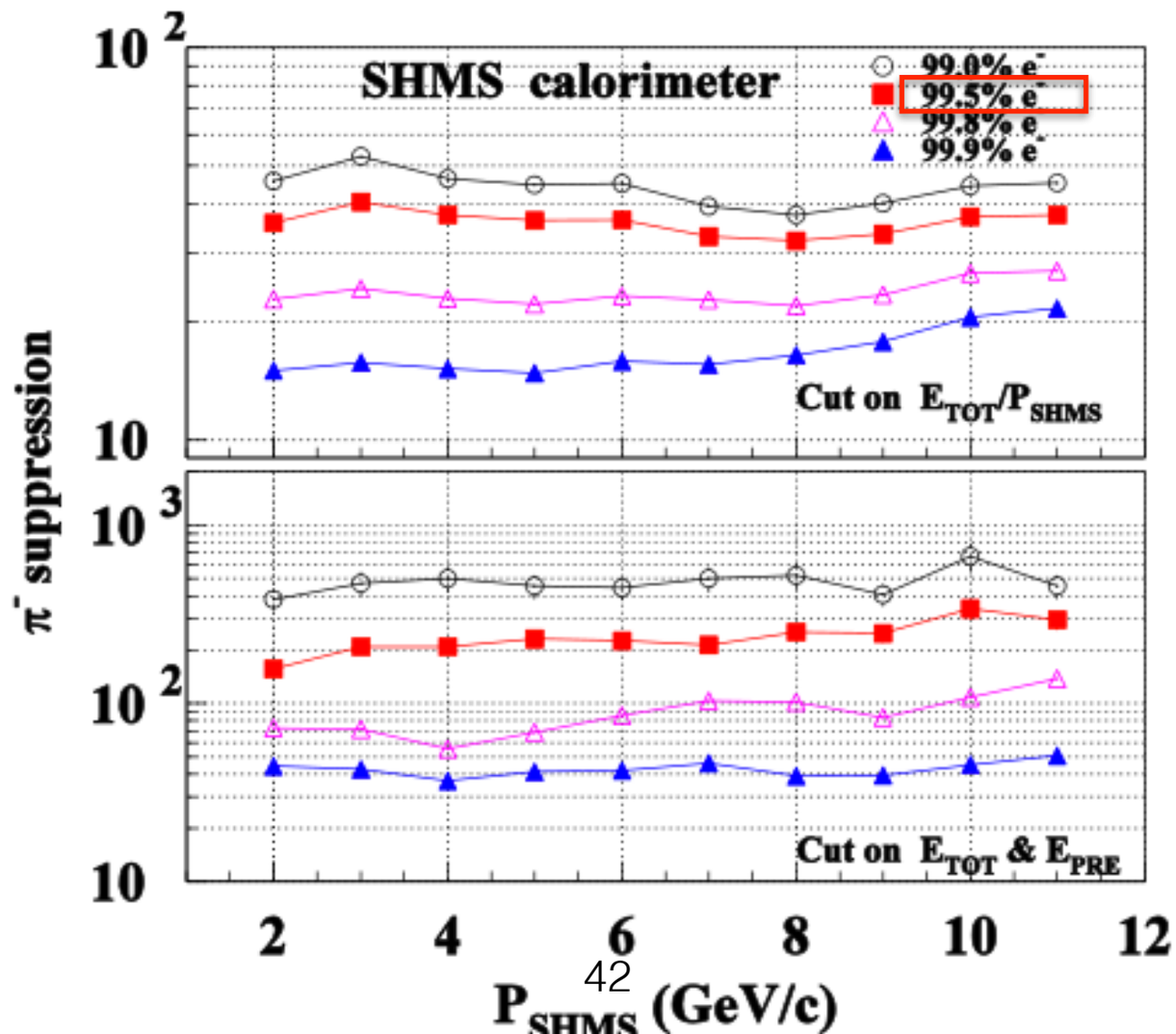


C_4F_8O at 0.45 atm gives a 4 GeV momentum threshold for π

HGC can separate π/e when momentum is smaller than 4 GeV/c

SHMS Running Parameters: Calorimeter

- For momenta between 1.4 and 4 GeV, π/e < 250
  Cherenkov rejection: HGC - 25:1 & LGC (Ar) - 25:1
  Calorimeter rejection: 150-200 (99.5 efficient)
  } π contamination 0.3%
- For momenta > 4 GeV, π/e < 2.5
  Cherenkov rejection: LGC (Ar) - 25:1
  Calorimeter rejection: 200 (99.5 efficient)
  } π contamination 0.1%



HMS Running Equipments

- For momenta between 1.4 and 4 GeV, π/e < 150

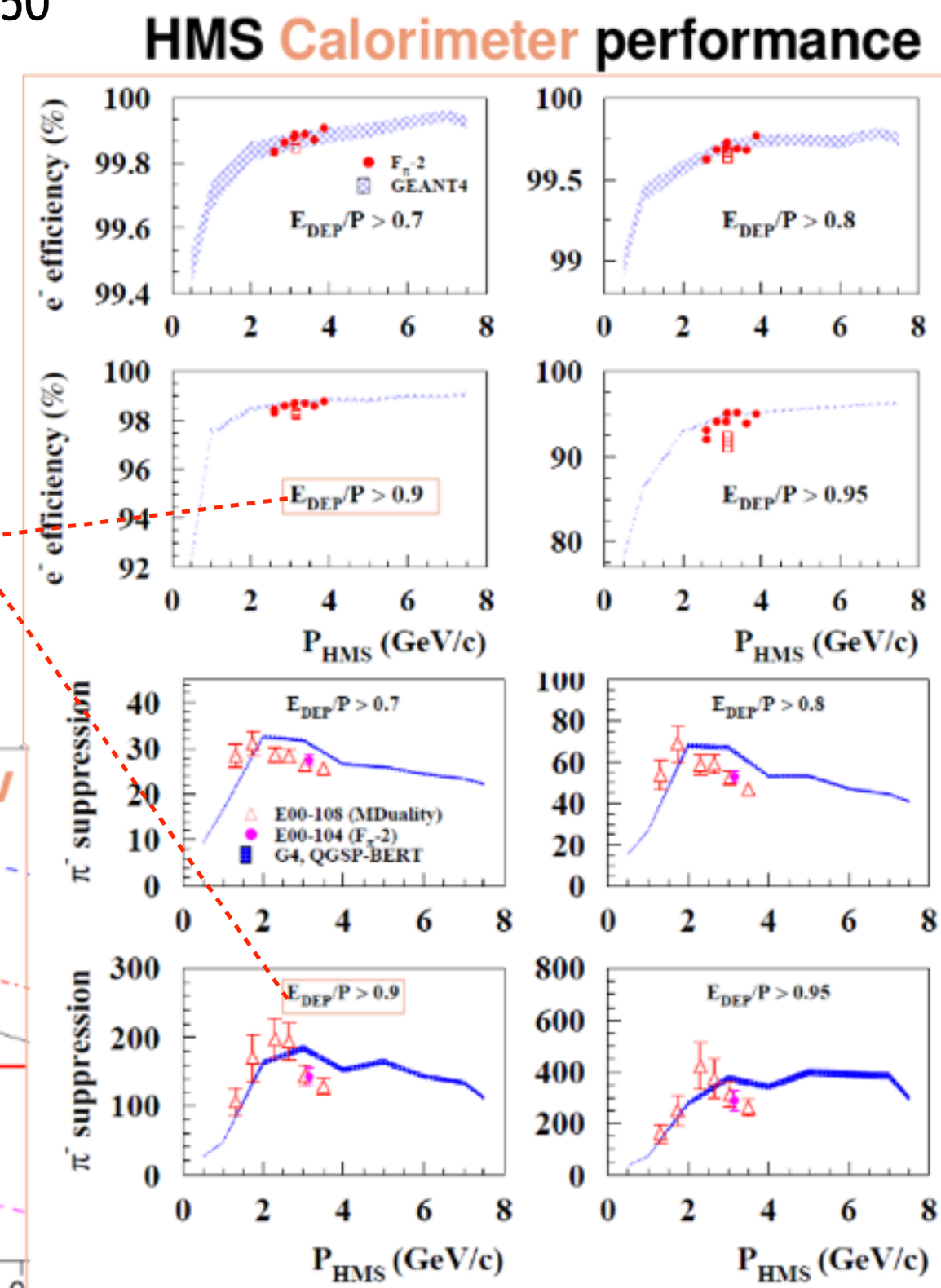
  Cherenkov rejection: 100:1

  Calorimeter rejection: 100-180
  → 1.5% π contamination

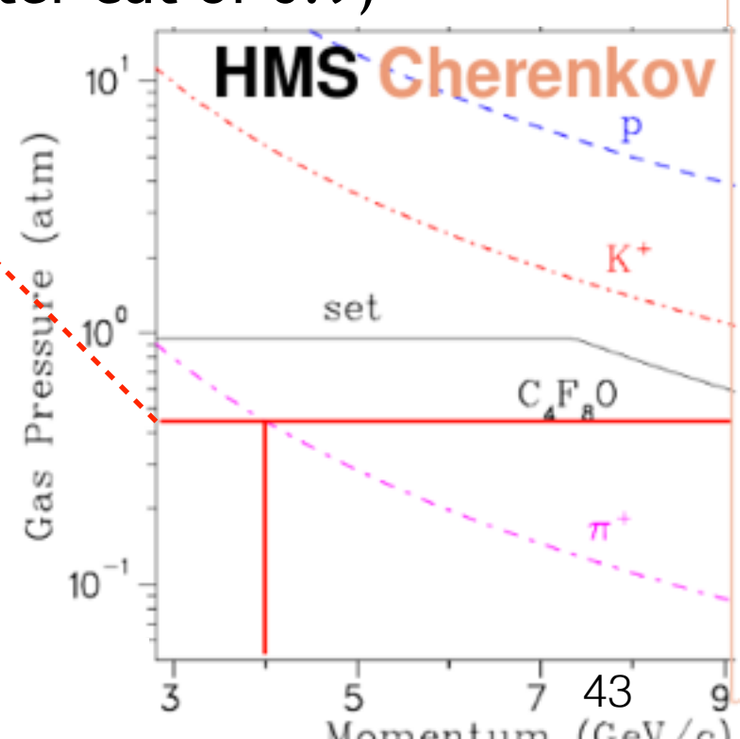
- For momenta > 4 GeV, π/e < 2.5

  Calorimeter rejection: 150
  → 1.6% π contamination

Momenta between 1.4 and 7 GeV: calorimeter π rejection factor between 100 and 200 can be achieved while keeping the e efficiency larger than 98% (for calorimeter cut of 0.9)



C_4F_8O at 0.45 atm gives a 4 GeV momentum threshold for π

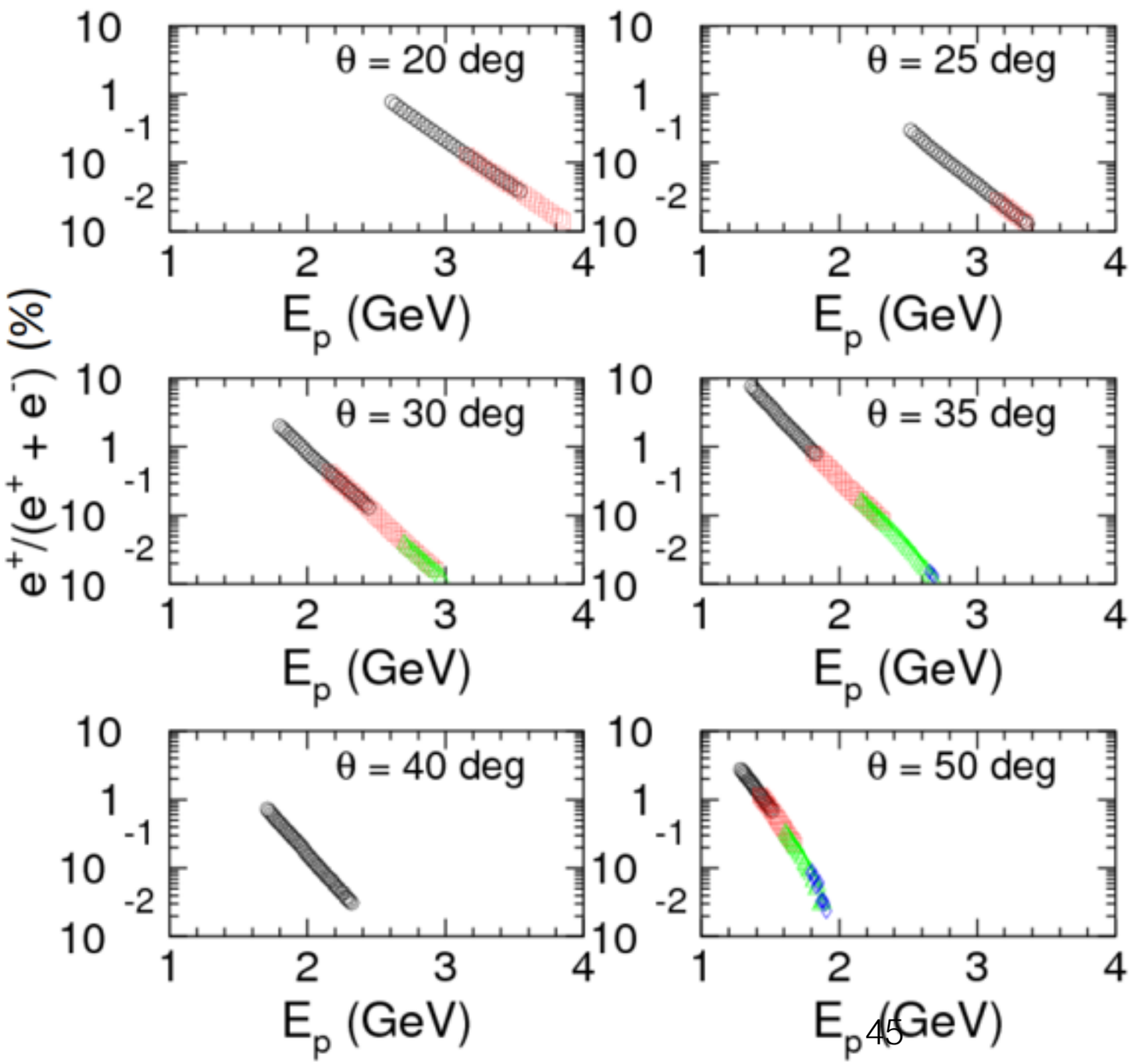


The Charge Symmetric Background

- Neutral pions decay into photon-electron-positron $\pi^0 \rightarrow \gamma + e^- + e^+$
- Secondary electrons will pass PID cuts and be detected $e^-_{total} = e^-_{DIS} + e^-_{bg}$
- Number of positrons is the same as number of background electrons
- Subtract background electrons to get electrons from actual scattering
- Need more time to get statistics

e^+/e^- Ratios for H

- Target length: 10 cm
- e^+ cross section: P. Bosted's code based on Wiser's fit to π+ and π- production on H



We will measure charge symmetric background with the same spectrometer that detects the scattered electrons.

Going from Cross sections to F_2: Determination of R

- Cannot claim a precise extraction of F_2 from cross section without a precise knowledge of R

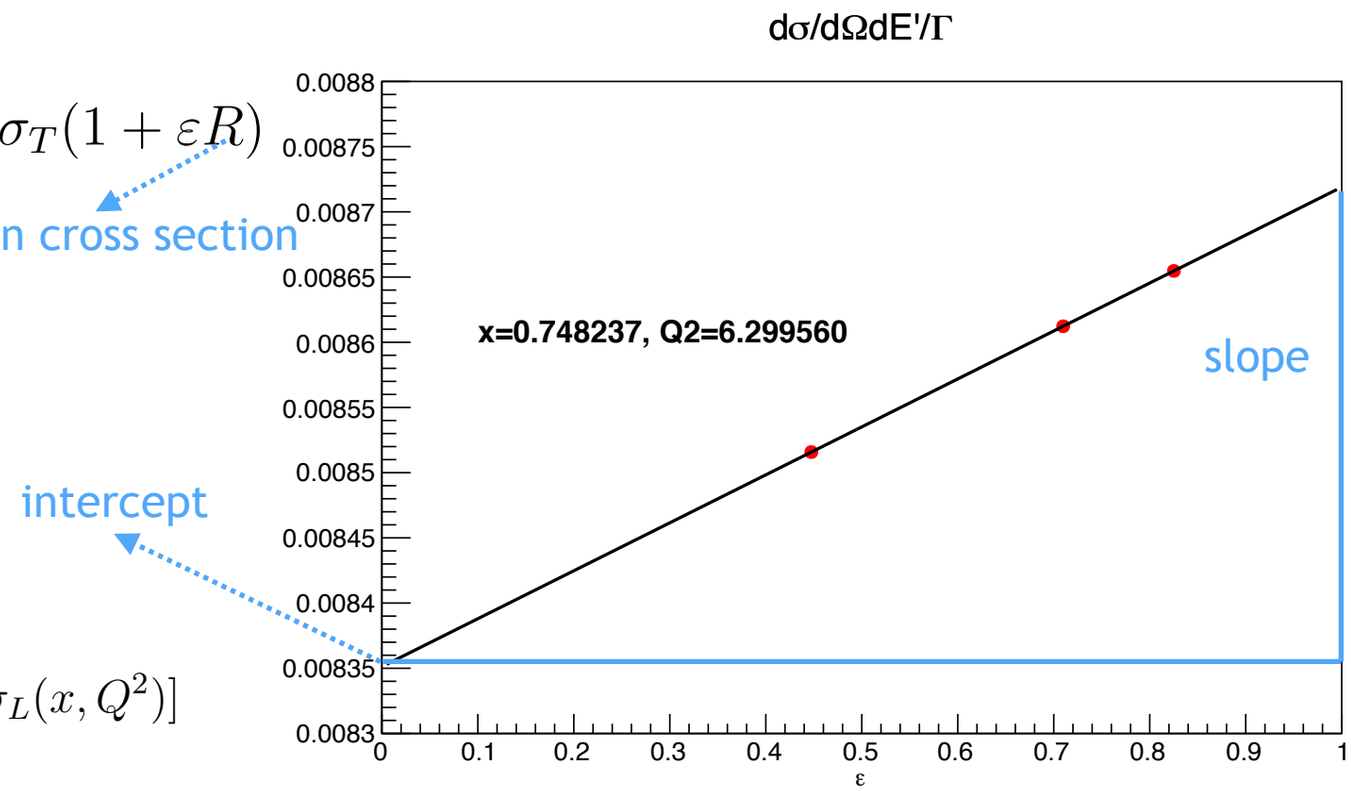
$$\frac{d\sigma}{d\Omega dE'} = \Gamma(\sigma_T(x,Q^2) + \varepsilon\sigma_L(x,Q^2)) = \Gamma\sigma_T(1+\varepsilon R)$$

ratio of longitudinal and transverse photo absorption cross section

$$\varepsilon = \frac{1}{1 + 2\frac{\nu^2+Q^2}{Q^2}tan^2\frac{\theta}{2}}$$

$$F_1(x,Q^2) = \frac{\kappa M}{4\pi^2\alpha}\sigma_T(x,Q^2)$$

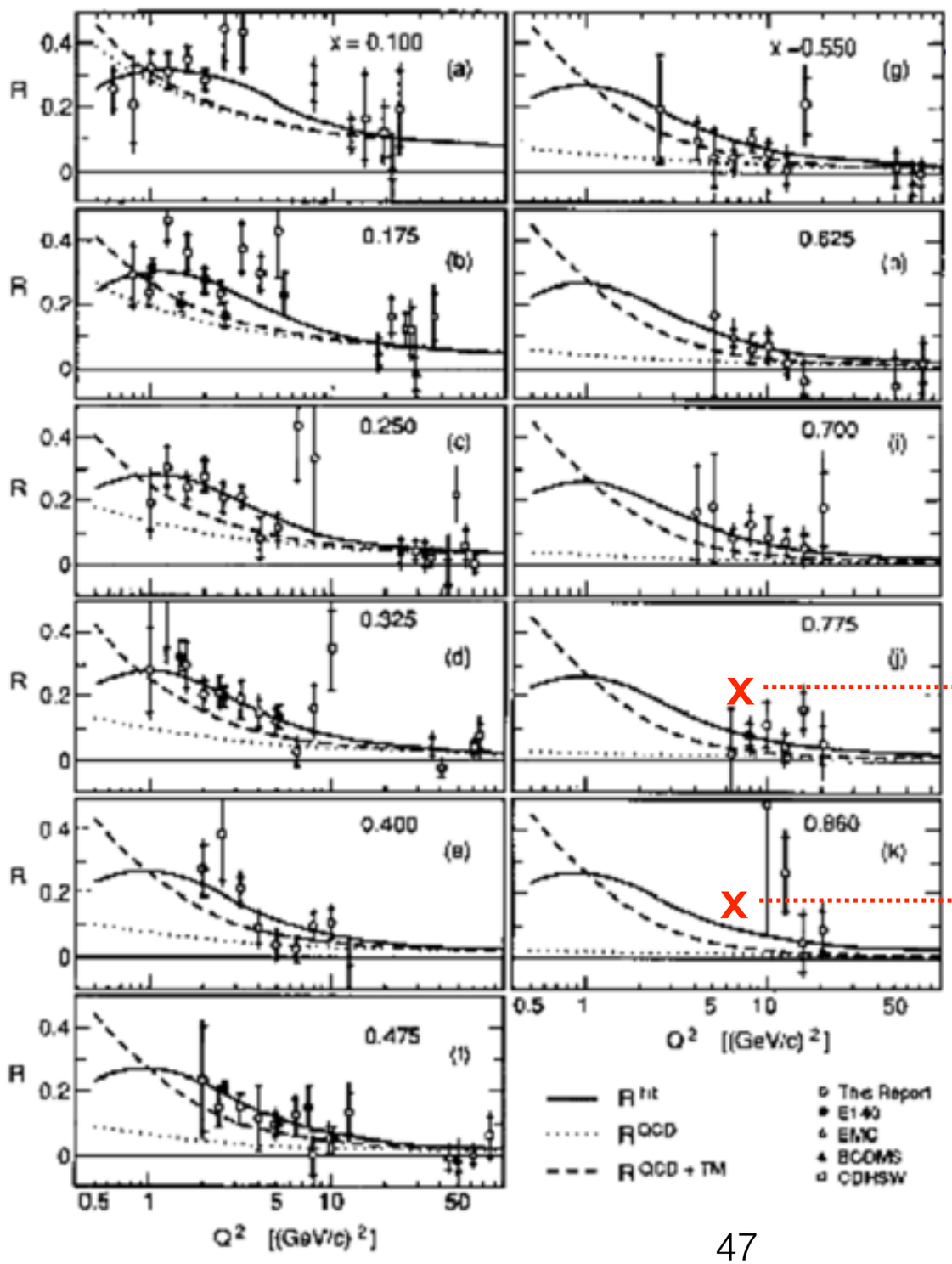
$$F_2(x,Q^2) = \frac{\kappa}{4\pi^2\alpha}\frac{\nu}{1+\nu^2/Q^2}[\sigma_T(x,Q^2) + \sigma_L(x,Q^2)]$$



- Measurements at different beam energies than 10.6 GeV to extract R, especially in the region of large x and large Q^2

Determination of R

R from R1990 parametrization (SLAC)



Measure R at large x low Q^2, where data are scarce or none

x=0.748, Q^2=6.299

x=0.855, Q^2=6.655

Summary

- Measurements of F_2 at large x help us to better constrain the valence content of the nucleon
- E12-10-002 is scheduled in Hall C in few months from now
- We are in the process of finalizing the run plan

Groups involved in preparation for running:

- E12-10-002
  Students: Abel Sun (CMU), Deb Biswas (HU)
  Spokespeople: Eric Christy, Thia Keppel, Simona Malace (contact), Ioana Niculescu
- E12-10-008
  Students: Kayla Craycraft (UT), Abishek Karki (MSU)
  Spokespeople: John Arrington, Aji Daniel, Dave Gaskell (contact), Nadia Fomin

some slides have been modified from talks by S. Malace

Thank you.