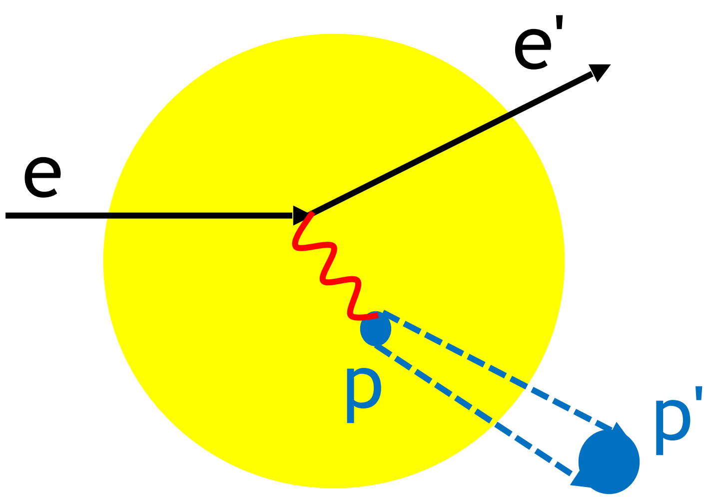
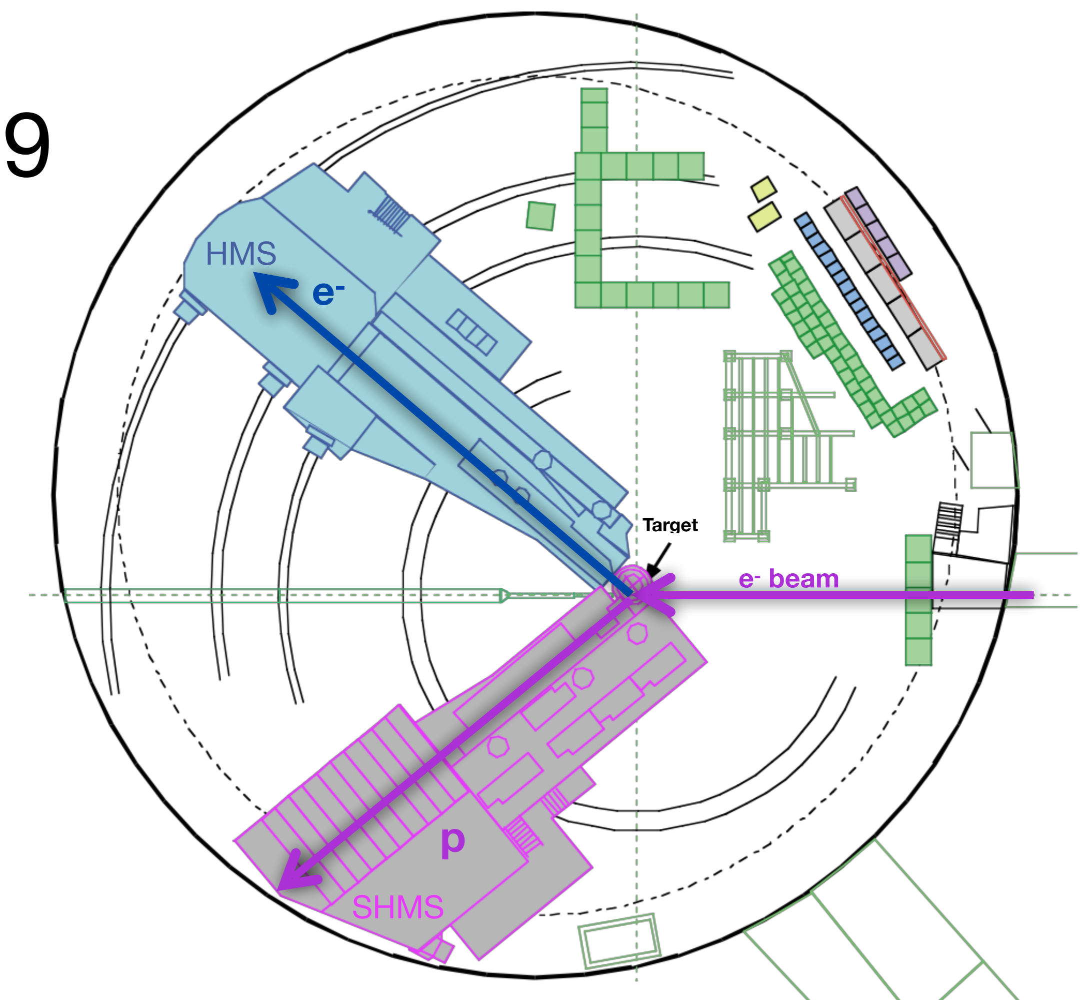
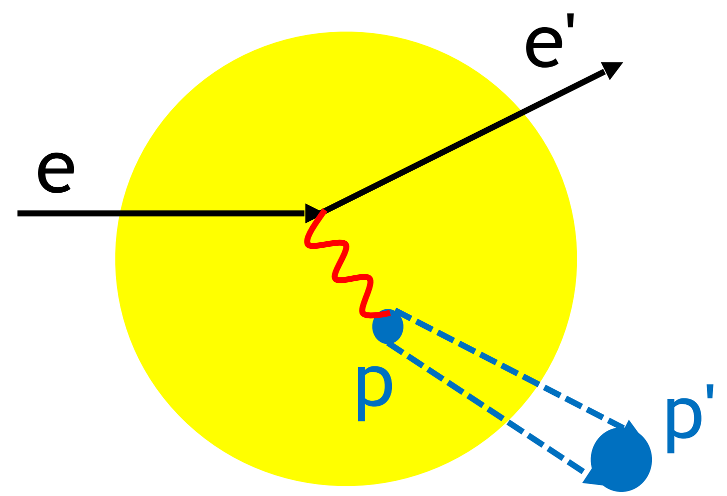
Update on the Color Transparency Experiment

28 January 2019
John Matter



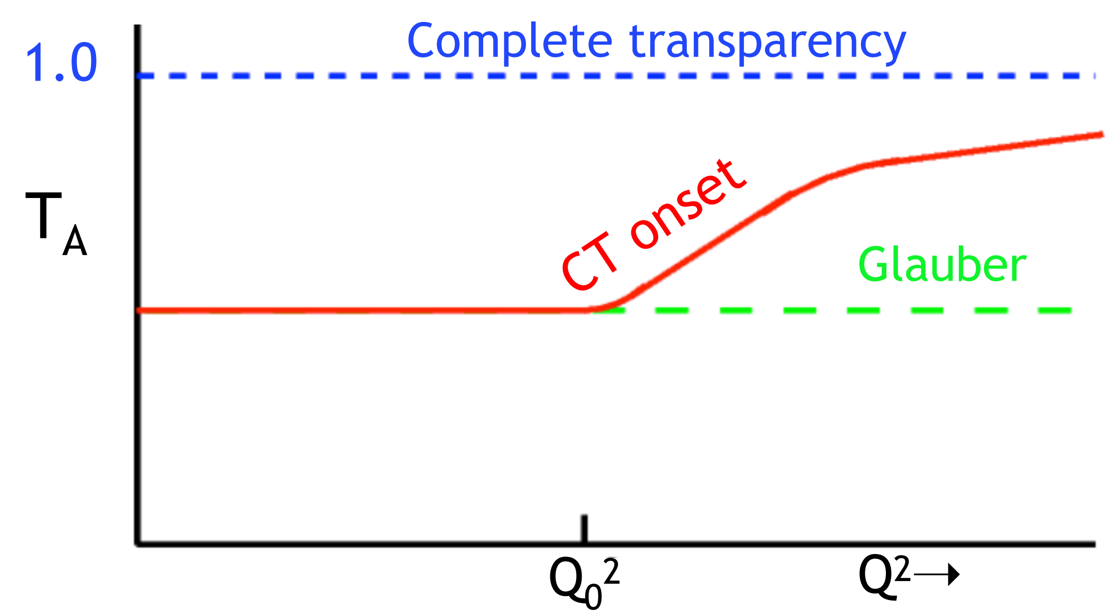


Summary

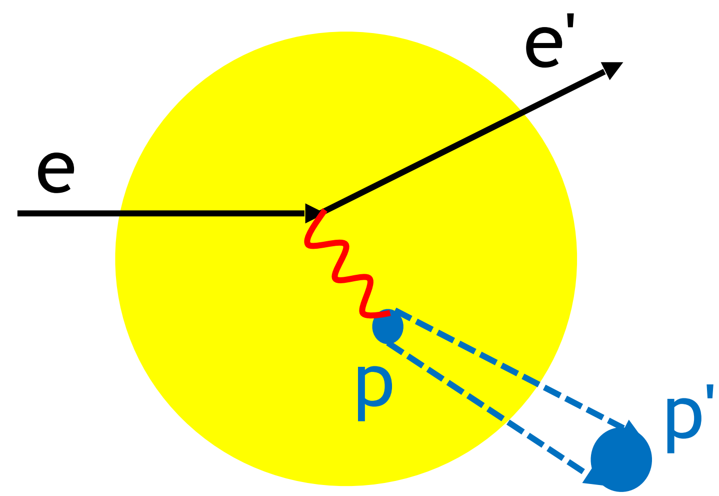


$$T = \frac{\sigma_N / A}{\sigma_0}$$

- CT Definition
- Why do we care?
- A Brief History
- E12-06-107



CT Definition

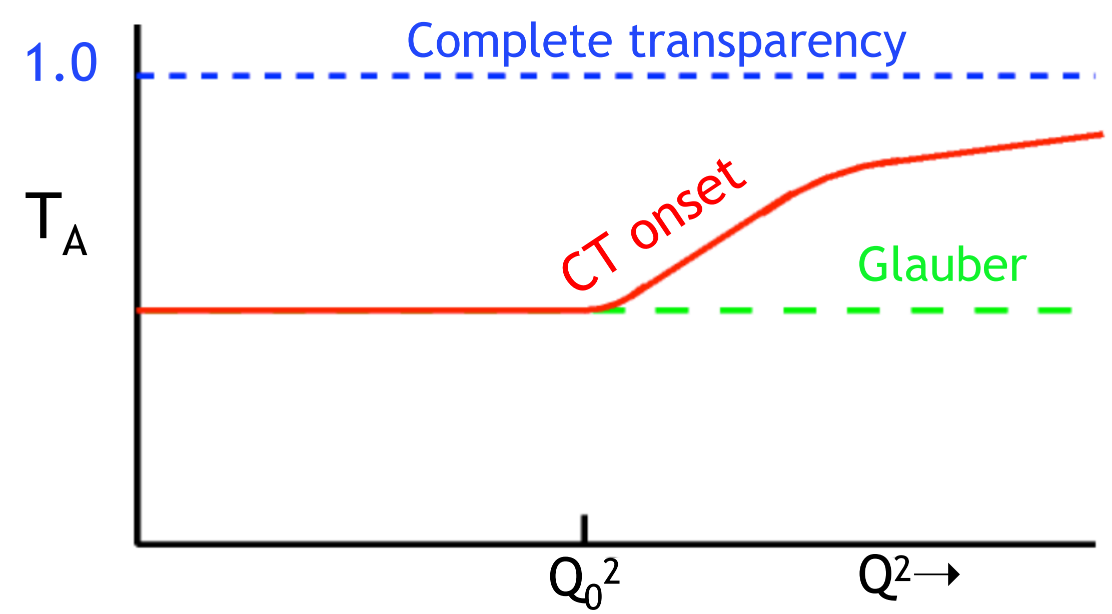


- Color transparency: the vanishing of initial and final state interactions of hadrons with the nuclear medium in exclusive processes at large momentum transfer Q^2

$$T = \frac{\sigma_N / A}{\sigma_0}$$

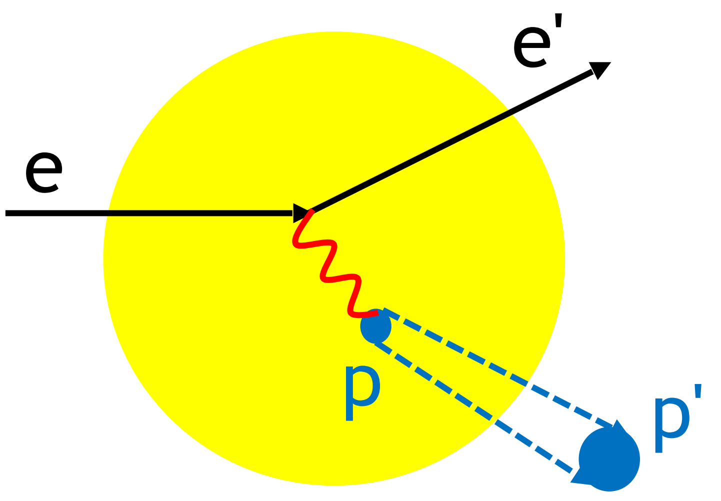
- Not predicted in a strongly interacting hadronic picture

- Arises in quark-gluon picture; the color field of singlet objects vanishes as size is reduced



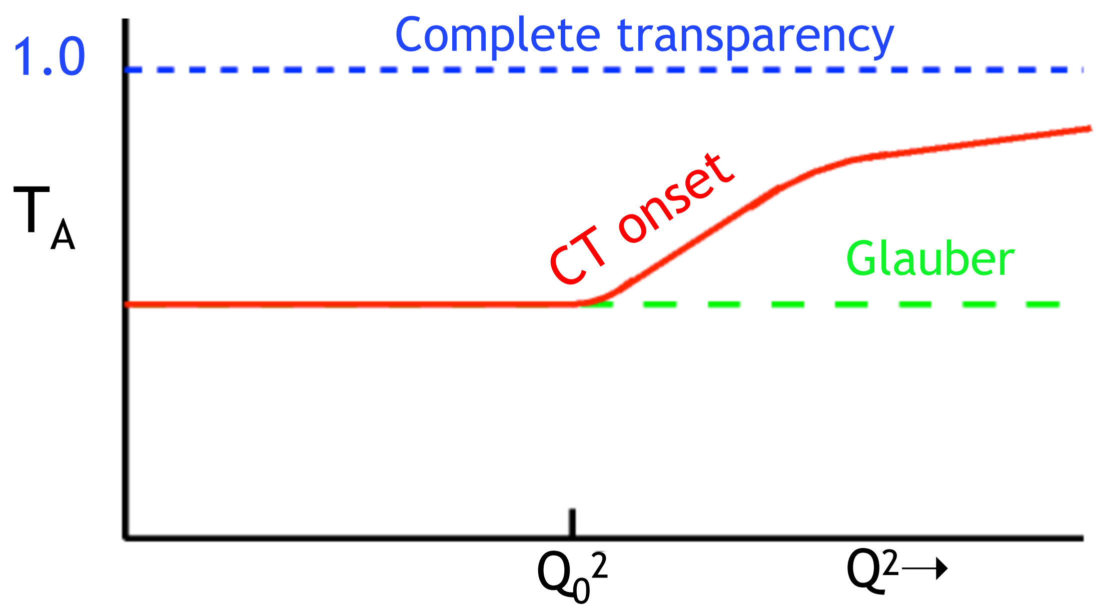
- Point-like configuration (PLC): small, color-neutral quark system formed that passes through nuclear medium undisturbed

CT Definition



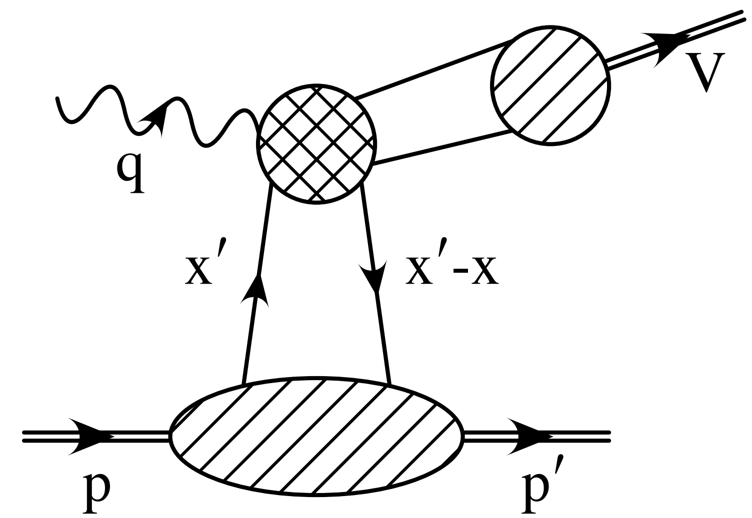
- Transparency *T* is a ratio of cross sections
- Conventional Glauber calculations predict **constant** *T*
- Clear signature of CT would be dramatic **rise** in *T* around Q^2 = 10 GeV^2

$$T = \frac{\sigma_N / A}{\sigma_0}$$



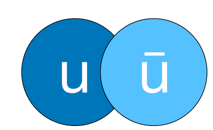
A Brief History

- CT is well-established at high energies!
  - Vanishing FSI assumed for QCD factorization theorems and Bjorken scaling
- Clear experimental evidence exists of CT onset in meson production
- No unambiguous signs of CT onset for baryons
- Where is the onset in Q^2?



CT Experiments

Meson



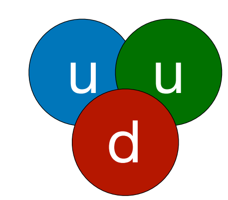
A(π,di-jet): FNAL

A(γ, π^- p): Jlab

A(e, e'π^+): JLab

A(e, e'ρ^0): DESY & JLab

Baryon



A(p,2p): BNL

A(e,e'p): SLAC, JLab

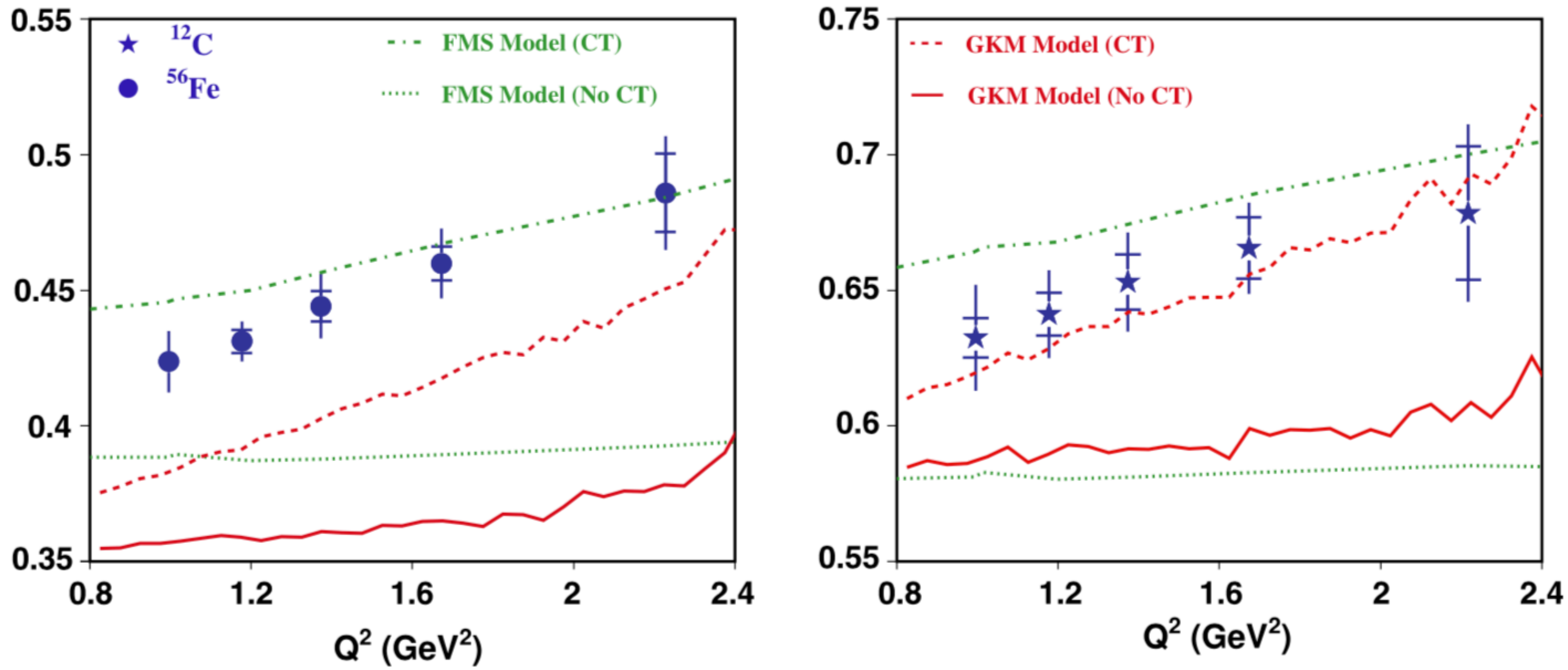
A Brief History

$$T = \frac{\sigma_N/A}{\sigma_0}$$

Clear onset of CT for mesons

- Meson electroproduction
- Quasielastic A(p,2p)
- Quasielastic A(e,e'p)

A(e,e'ρ^0)



PRC 68, 021001R (2003)
PRL 99, 242502 (2007)
PRC 81, 055209 (2010)
PRB 712, 326 (2012)

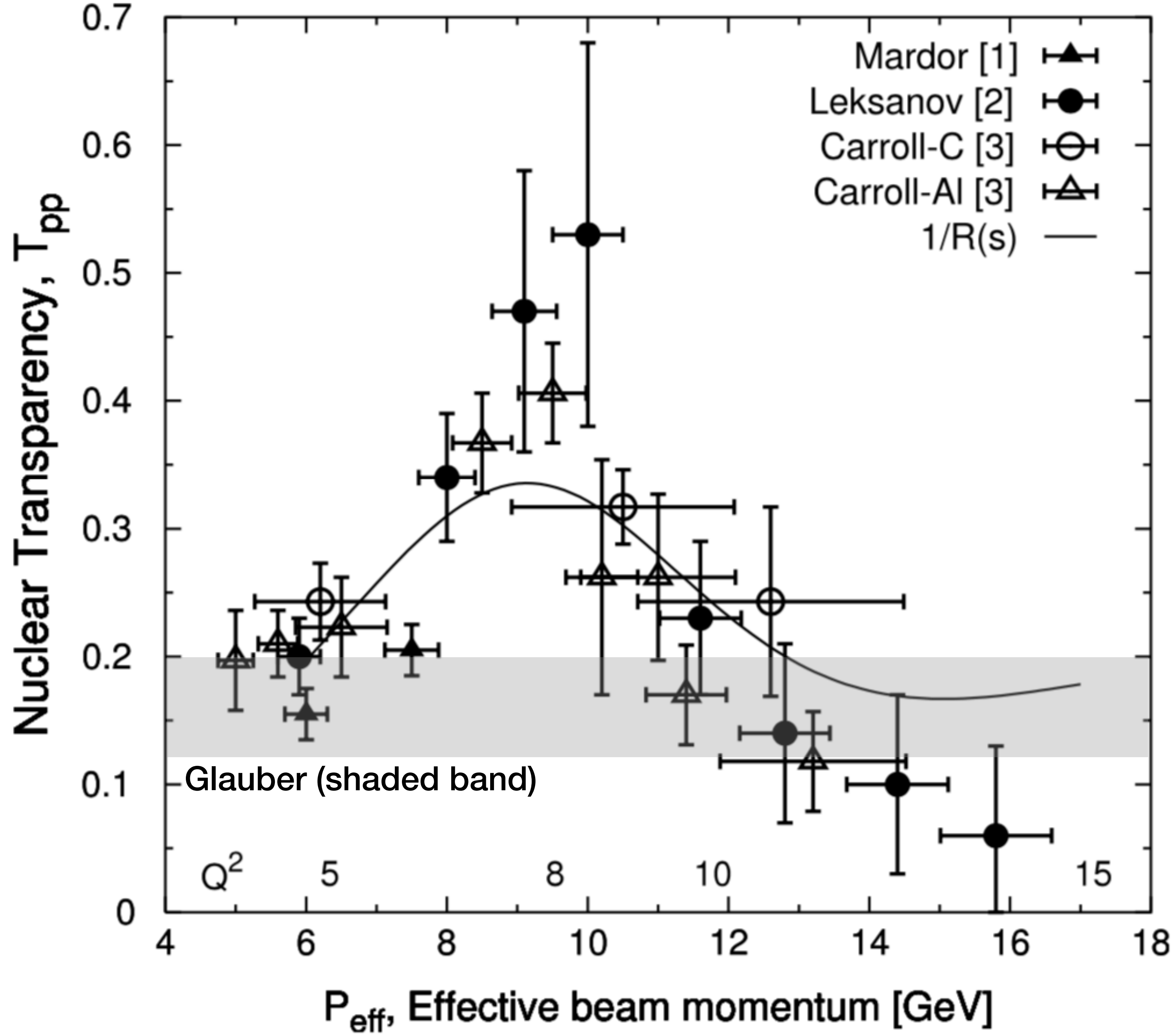
A Brief History

$$T = \frac{\sigma_N / A}{\sigma_0}$$

Ambiguous rise/fall

- Meson electroproduction
- Quasielastic A(p,2p)
- Quasielastic A(e,e'p)

A(p,2p) BNL



PRL 87, 212301 (2001)
PRL 81, 5085 (1998)
PRL 61, 1698 (1988)

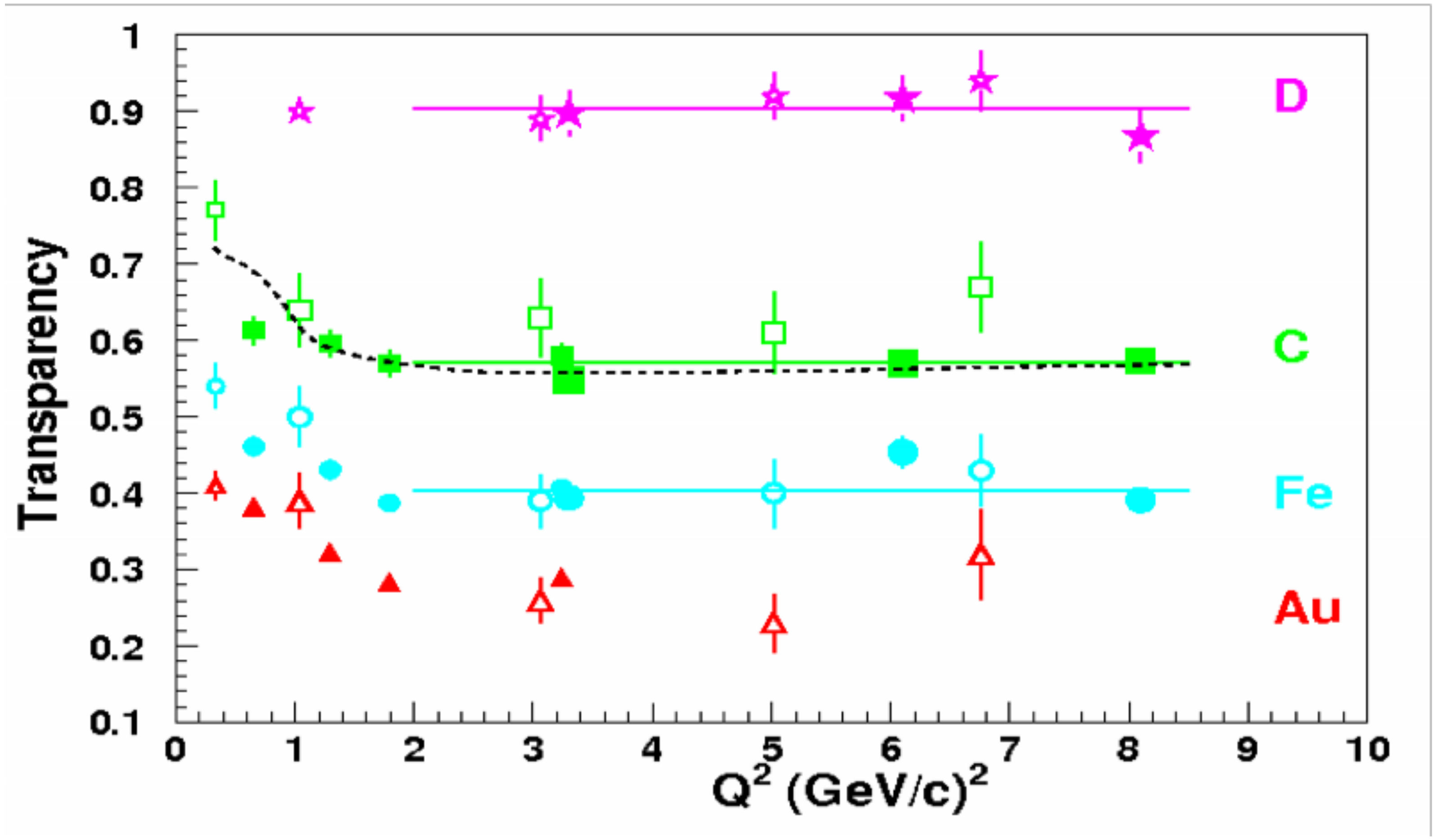
A Brief History

$$T = \frac{\sigma_N / A}{\sigma_0}$$

No onset…
yet!

- Meson electroproduction
- Quasielastic A(p,2p)
- Quasielastic A(e,e'p)

A(e,e'p)

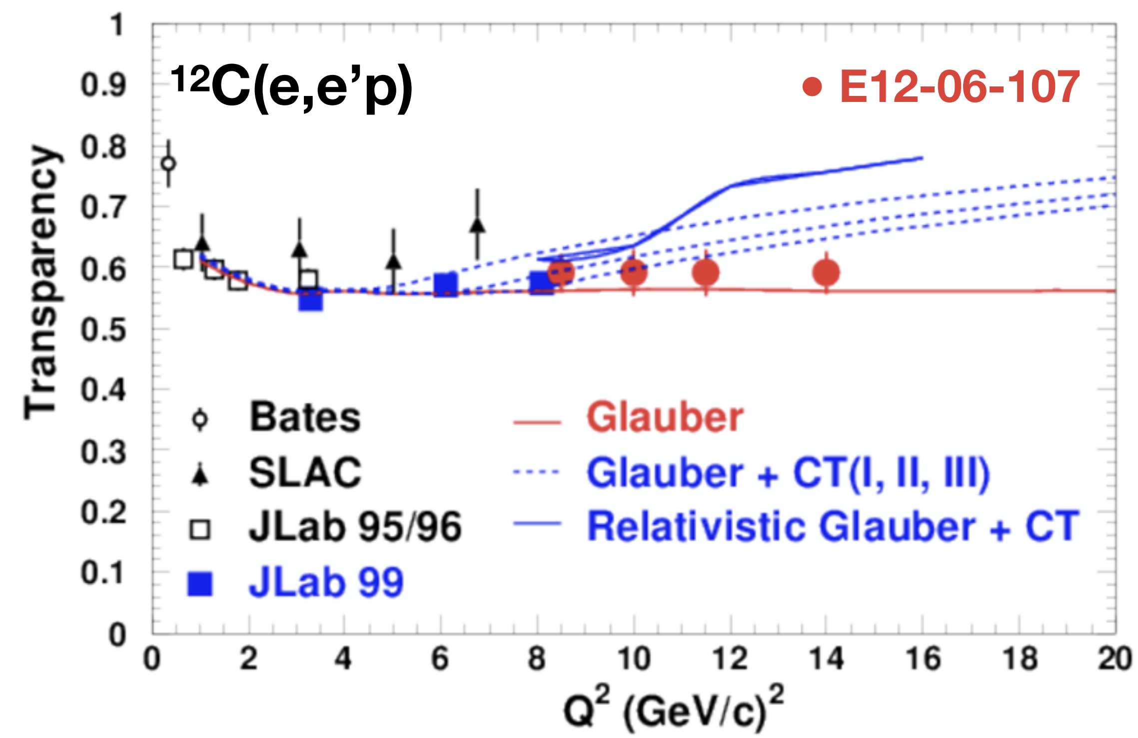


Solid points = JLab
Open points = other

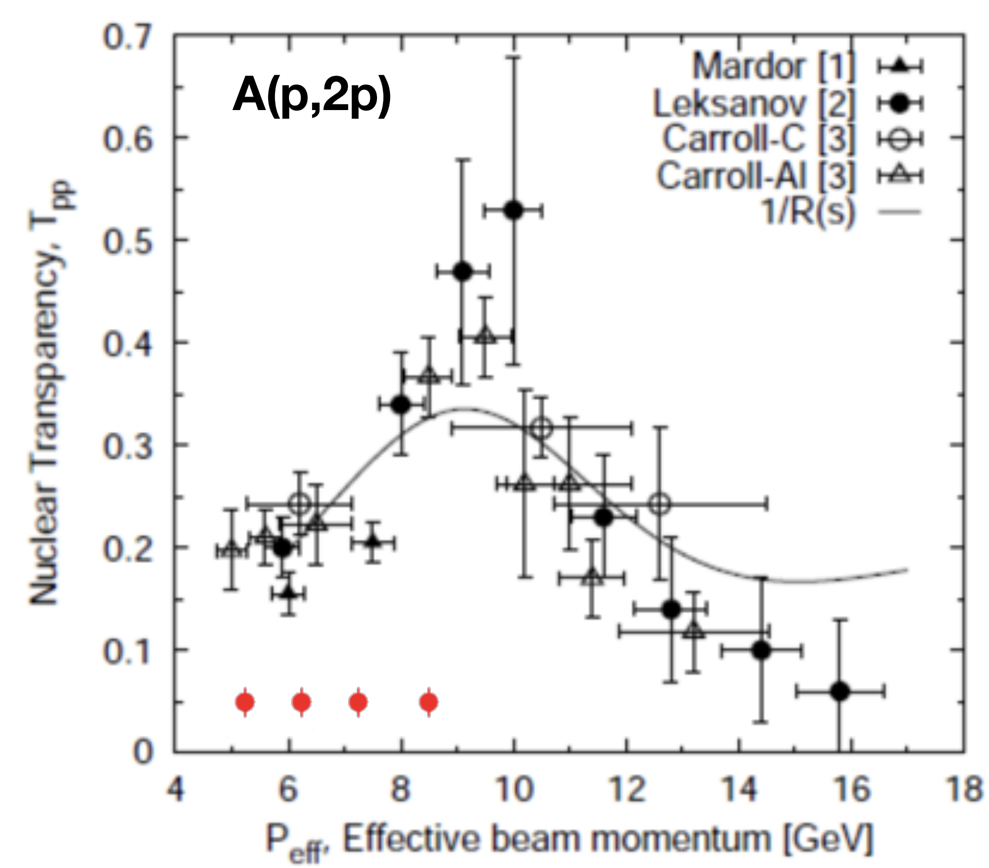
PRL 72, 1986 (1994)
PRB 351, 87 (1995)
PRL 80, 5072 (1998)
PRC 66, 044613 (2002)
PRC 72, 054602 (2005)
PRC 45, 780 (1992)

E12-06-107

- Coincidence trigger:
  proton in SHMS, electron in HMS
- Targets: 10 cm LH_2 (Hee'p check),
  6% ^{12}C (production), Al dummy (background)
- Q^2 = 8—14.3 GeV^2



Beam	Q^2 [GeV^2]	SHMS angle [deg]	SHMS central P [GeV/c]	HMS angle [deg]	HMS central P [GeV/c]
6.4 GeV beam	8.0	17.1	5.122	45.1	2.131
10.6 GeV beam	9.5	21.6	5.925	23.2	5.539
10.6 GeV beam	11.5	17.8	7.001	28.5	4.478
10.6 GeV beam	14.3	12.8	8.505	39.3	2.982



E12-06-107

- Coincidence trigger:
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- Targets: 10 cm LH_2 (Hee'p check),
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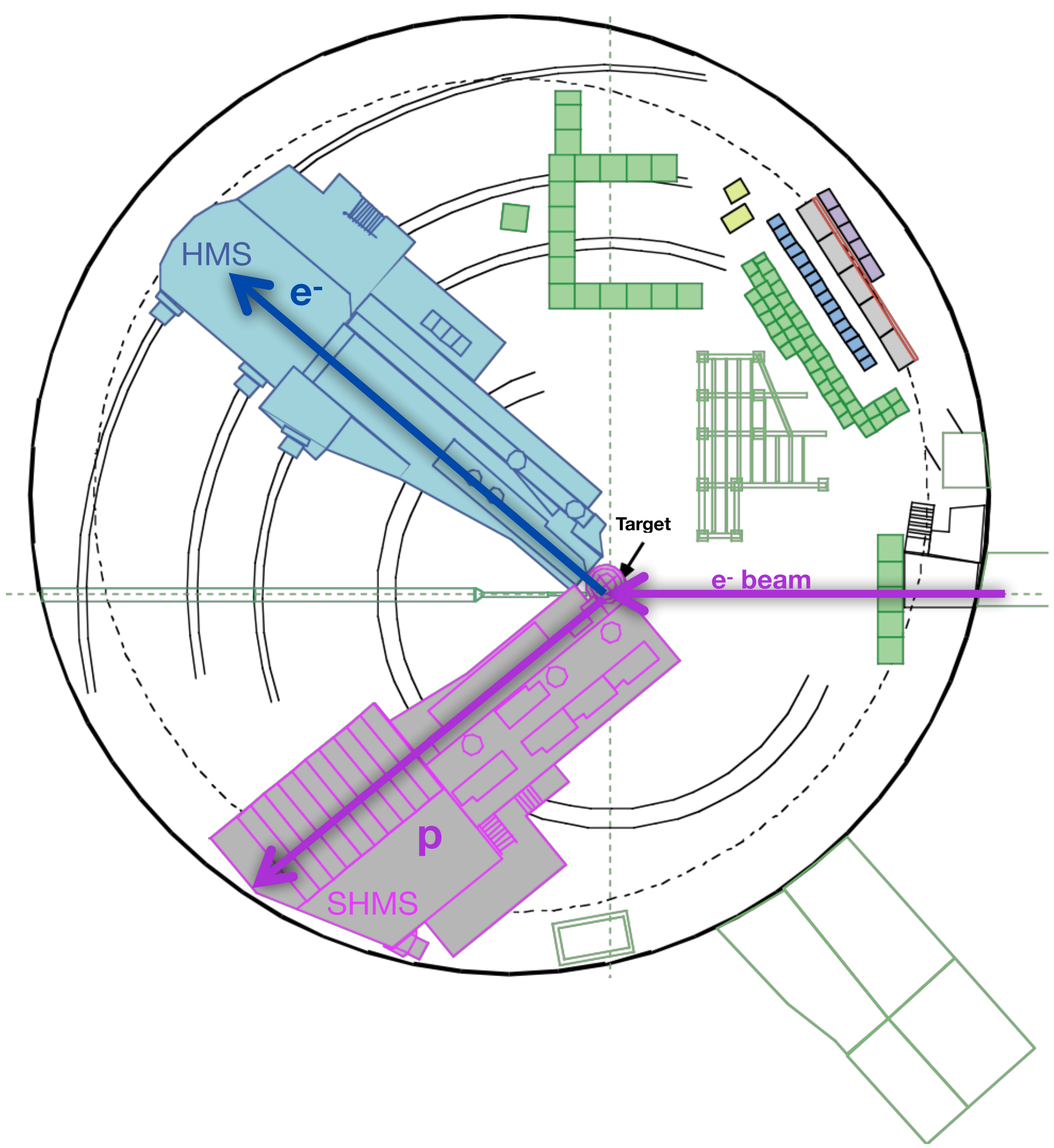
- $Q^2 = 8 - 14.3\ GeV^2$



		Event Selection
PID		0.8 < H.cal.etottracknorm <1.15
PID		H.cer.npeSum > 0.0
PID		P.hgcer.npeSum < 0.1 || P.hgcer.npeSum < 0.1
Kinematics		0.6 < P.gtr.beta < 1.4
Kinematics		0.8 < H.gtr.beta < 1.2
Kinematics		-8 < H.gtr.dp < 8
Kinematics		-10 < P.gtr.dp < 15
Kinematics	LH2	0.85 < H.kin.primary.W < 1.03
Kinematics	C12	P.kin.secondary.emiss < 0.1
Kinematics	C12	abs(P.kin.secondary.pmiss) < 0.1

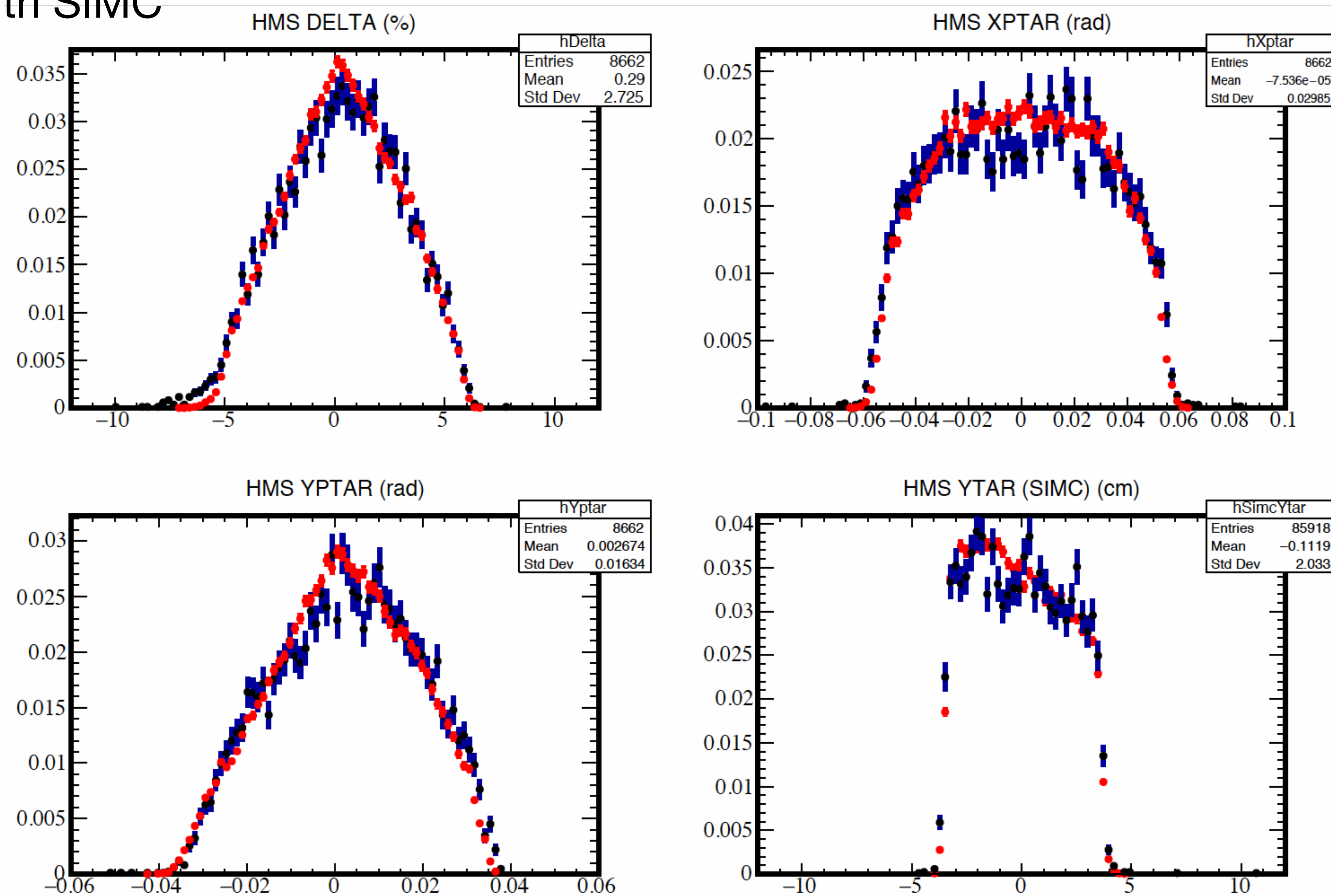
E12-06-107 Optics

Holly Szumila-Vance

Track reconstruction agrees with SIMC

Blue = data
Red = MC

LH2 Q^2=8 Gev^2



E12-06-107
Optics

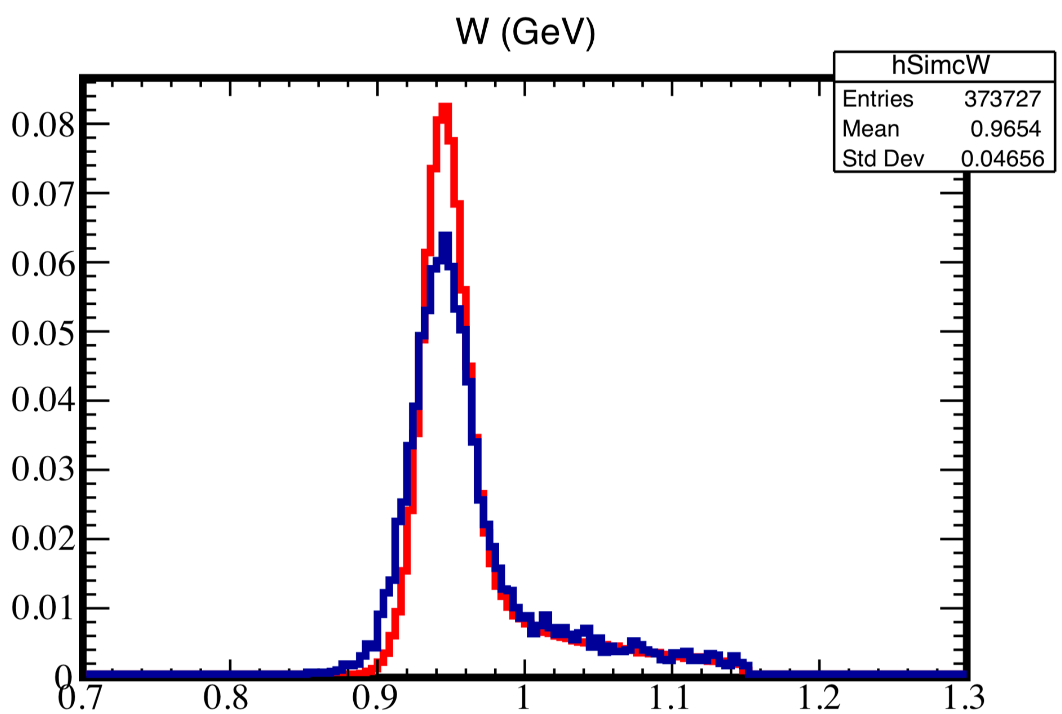
Holly
Szumila-Vance

Invariant mass looks good
across range of momenta

Blue = data
Red = MC

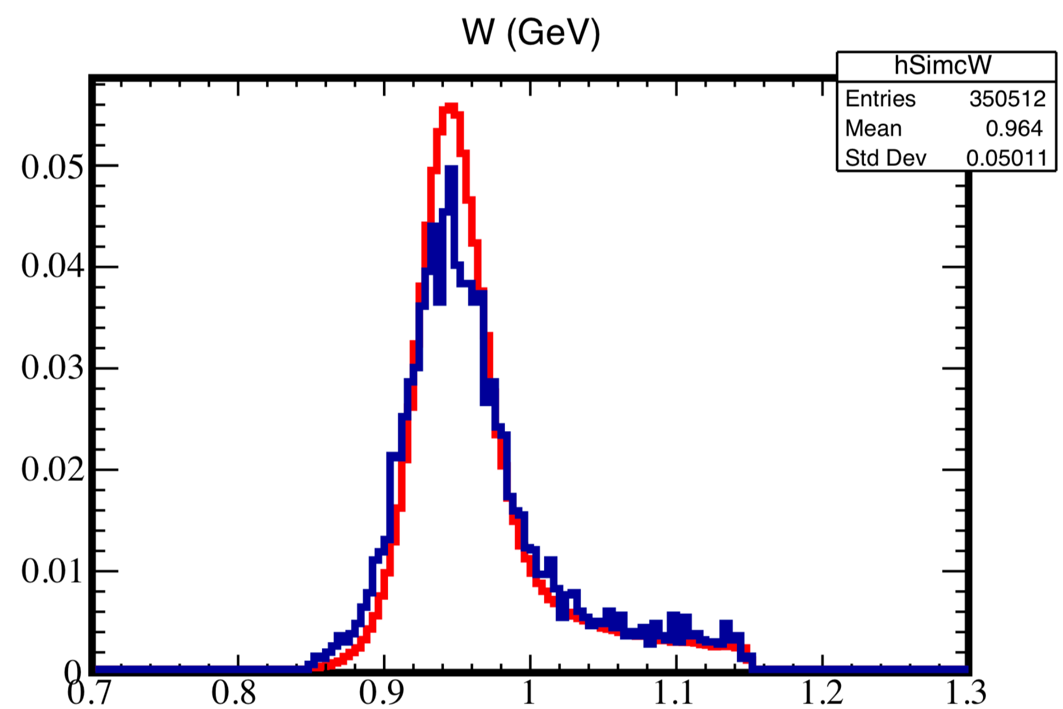
LH2, Q^2=8 Gev^2

HMS p_0 = 2.131 GeV



LH2 Q^2=9.5 Gev^2

HMS p_0 = 5.539 GeV



E12-06-107 Optics

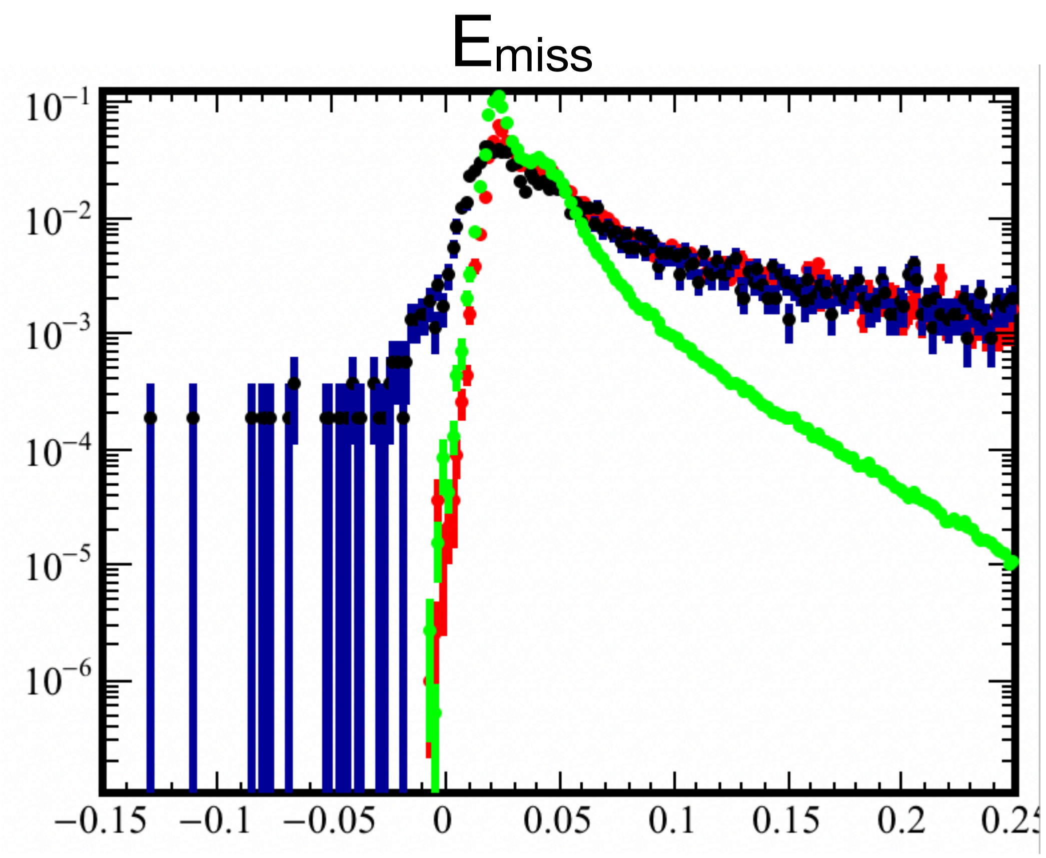
Holly
Szumila-Vance

E_{miss}

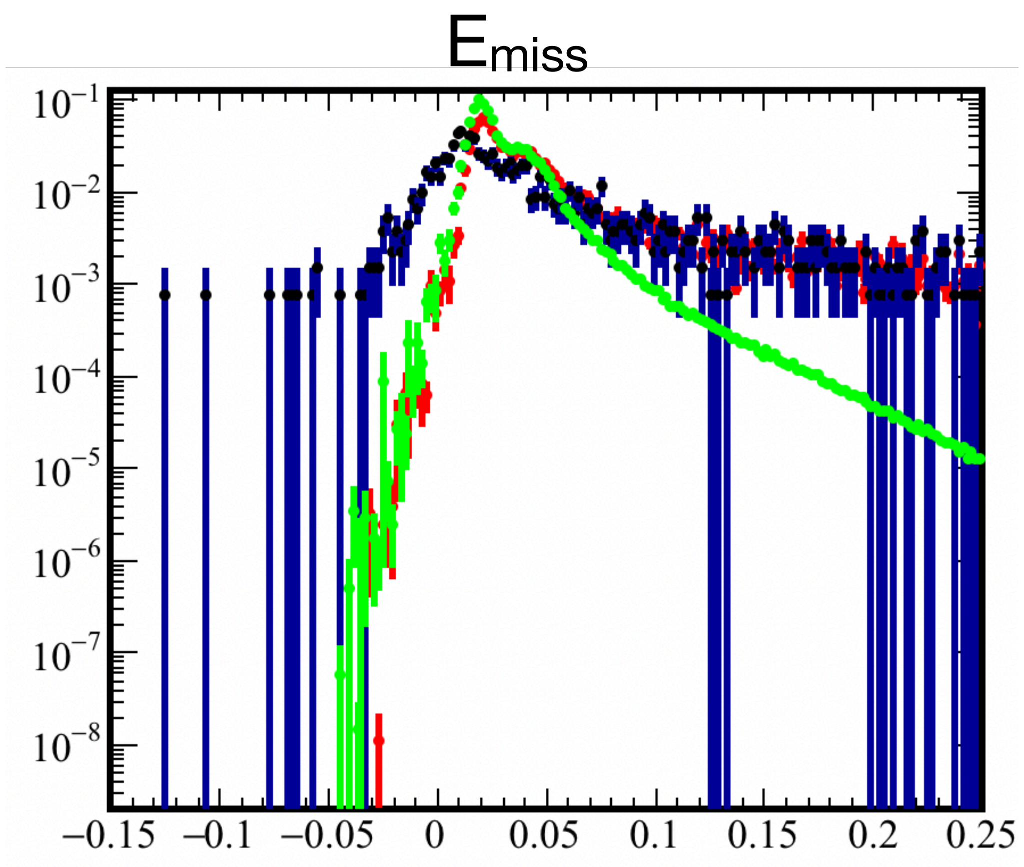
Radiative effects in agreement with SIMC

Blue = data
Green = MC without radiative effects
Red = MC with radiative effects

6% C12 target, Q^2=8 Gev^2

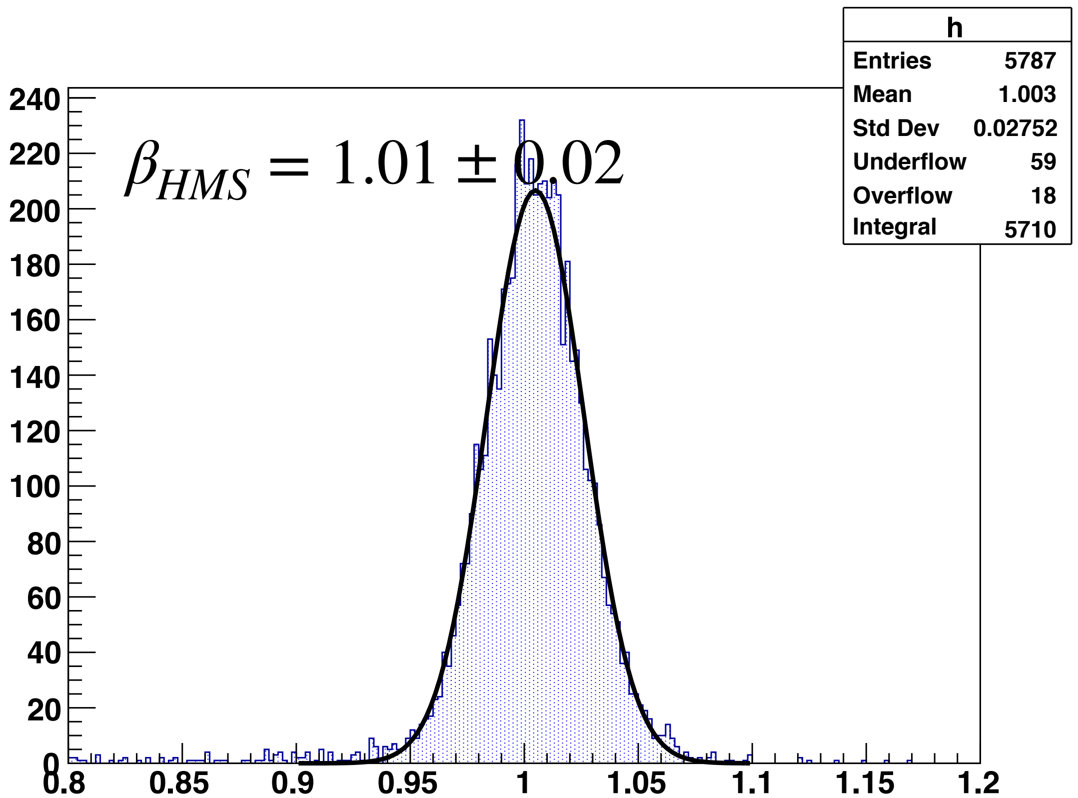


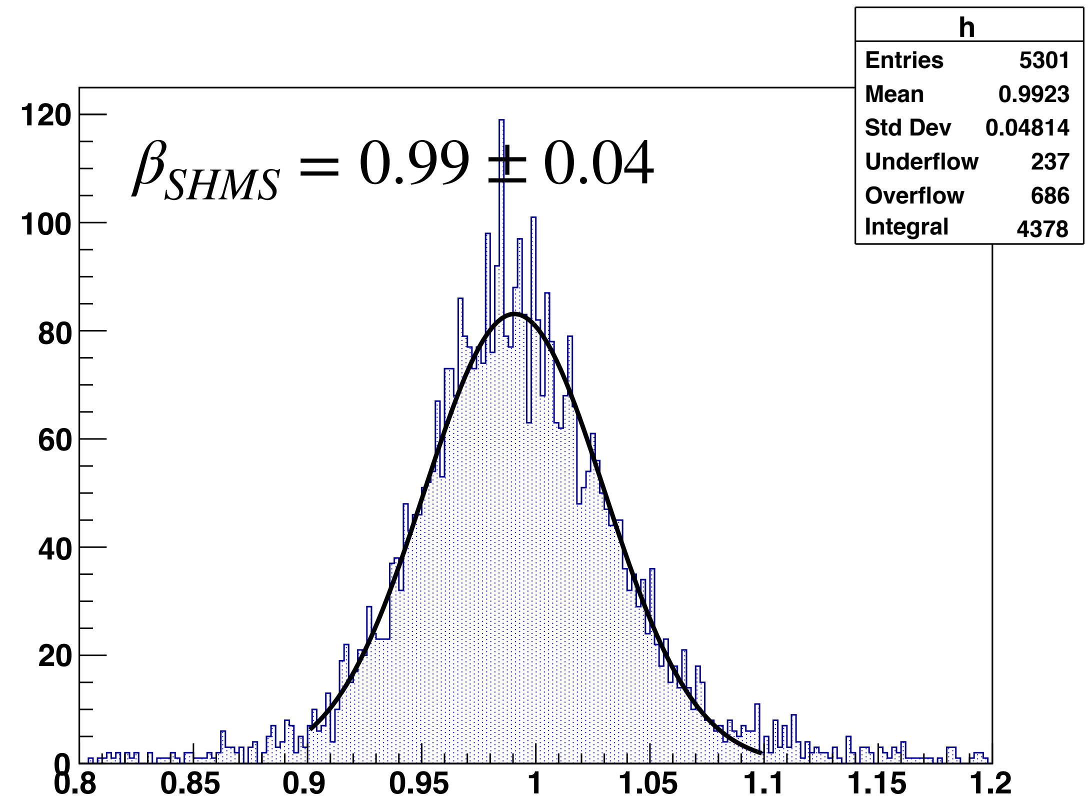
1.5% C12 target, Q^2=9.5 Gev^2

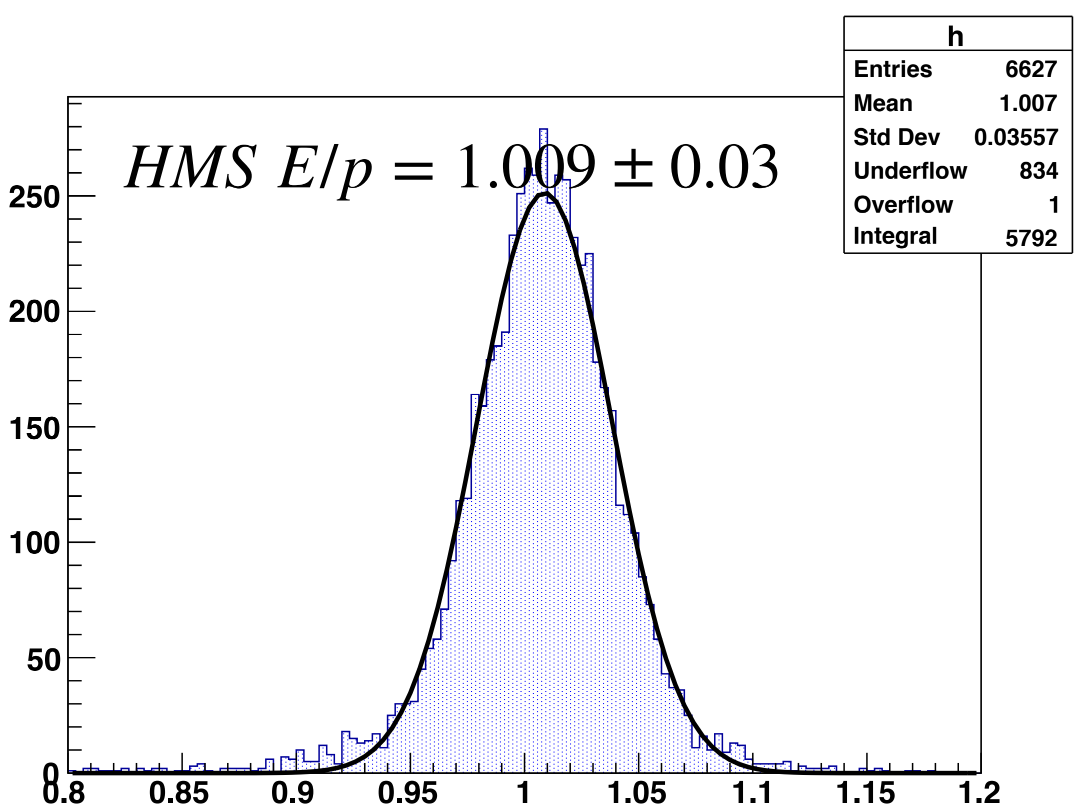


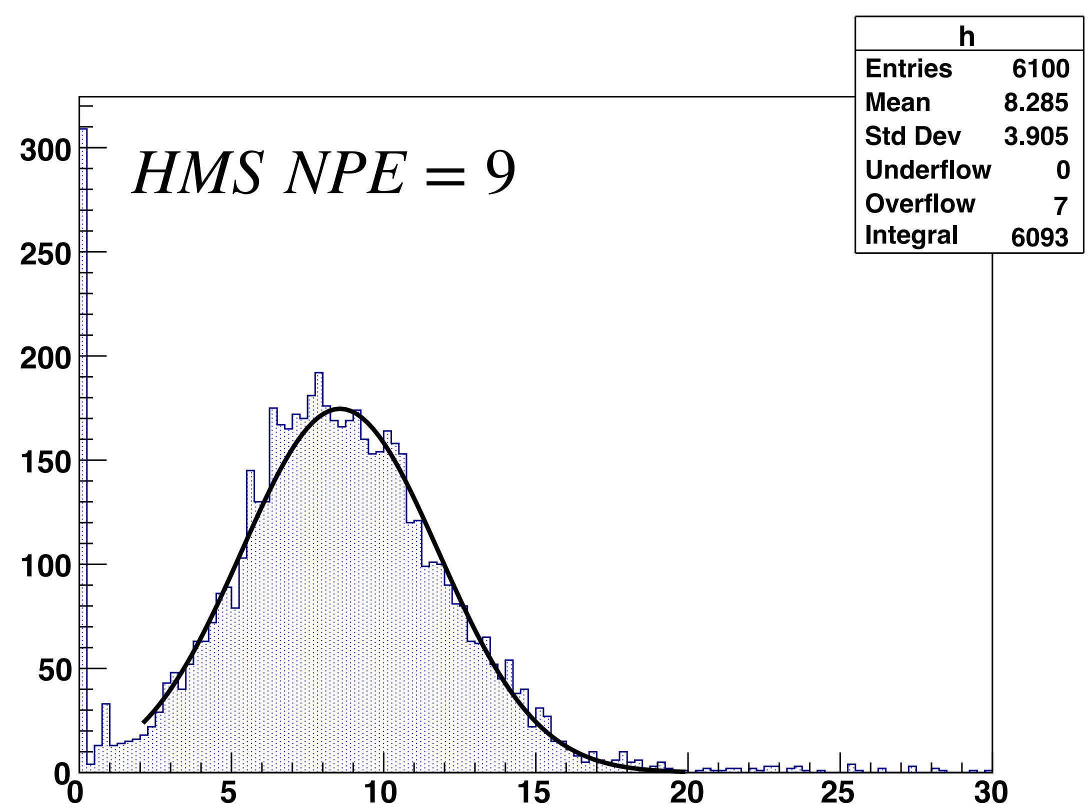
E12-06-107 Calibrations

Deepak Bhetuwal









E12-06-107 Coincidence time

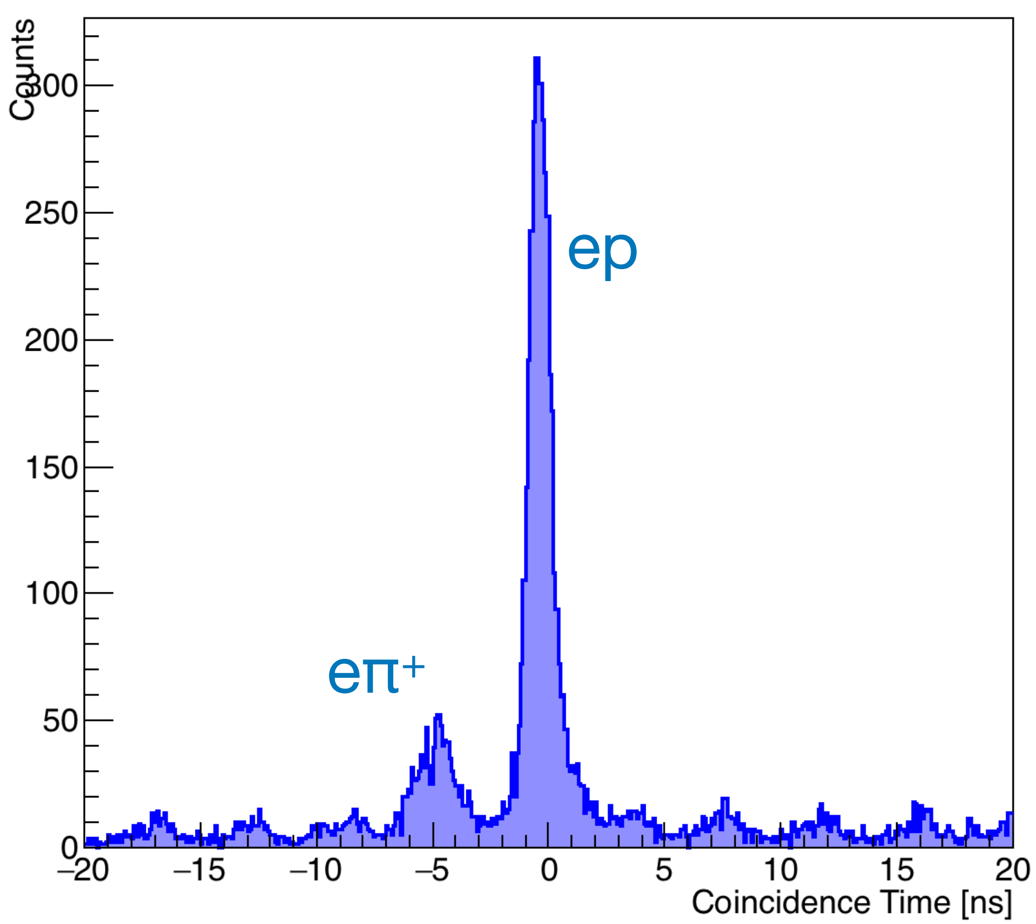
$$t_{coin} = t_e^{tar} - t_p^{tar}$$

$$t^{tar} = t^{trigger} - \Delta t^{corr}$$

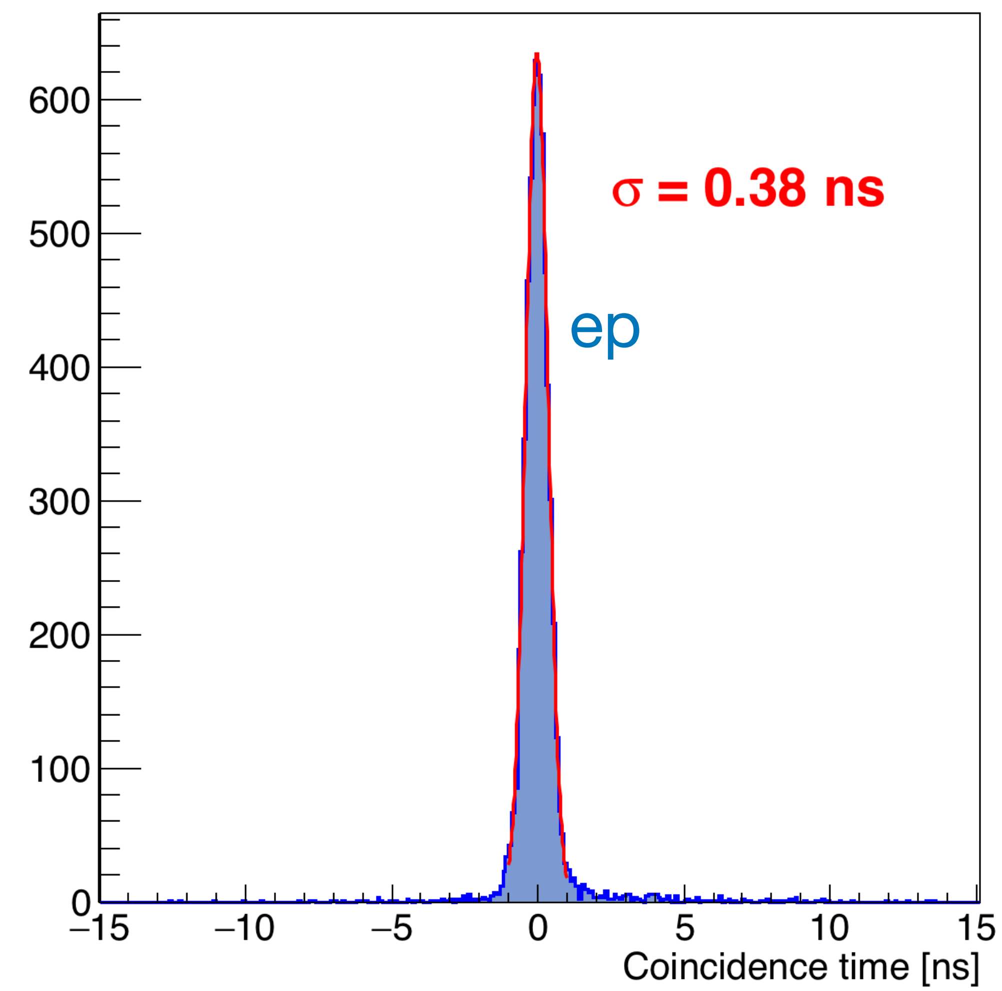
Each particle time corrected for:

- Particle traveling along central ray to focal plane
- Path length variations
- Difference in time between hodoscope start and focal plane time

Special run taken to observe accidentals



Typical CT run showing very low accidental rate



E12-06-107
Efficiency

Example: HMS Calorimeter

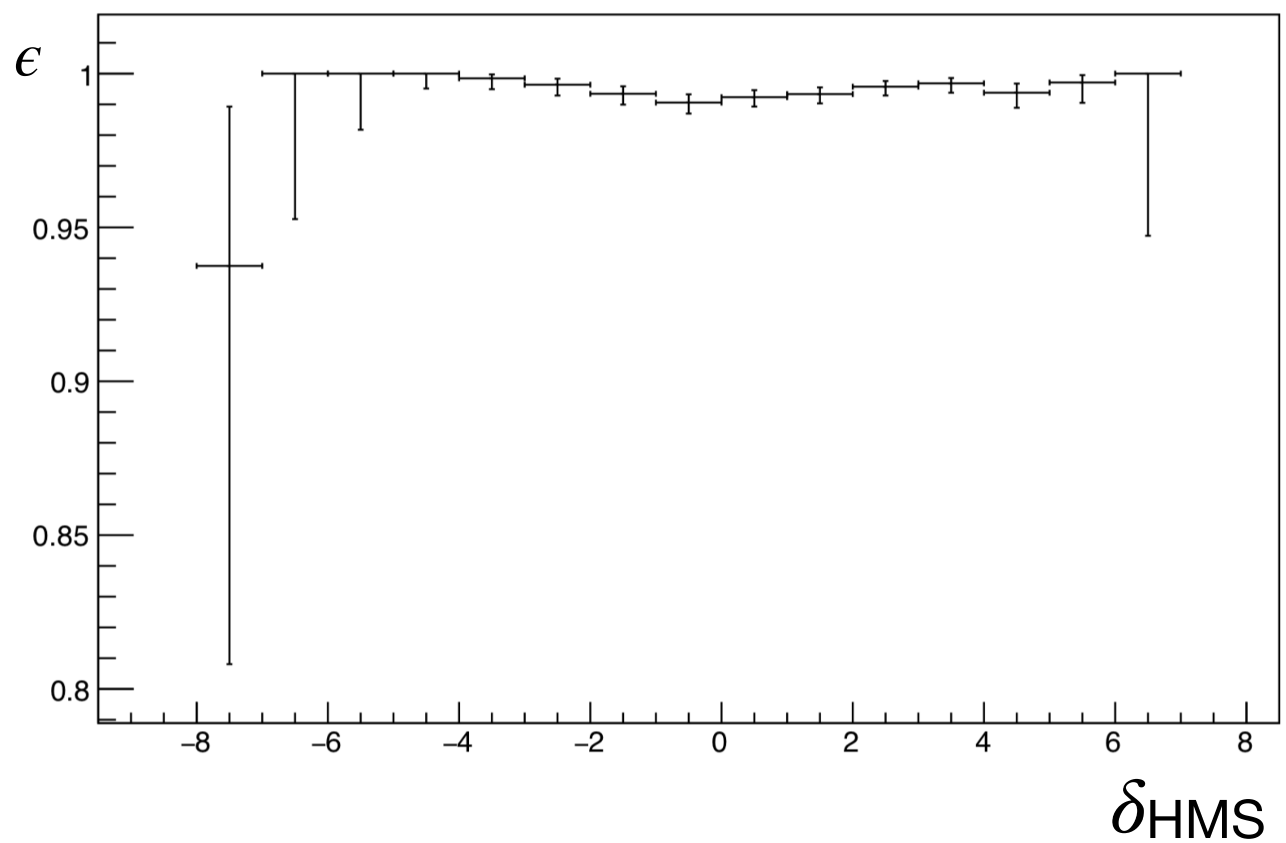
should = (β cut) && (δ cut) && (H.cer.npeSum>1.0)

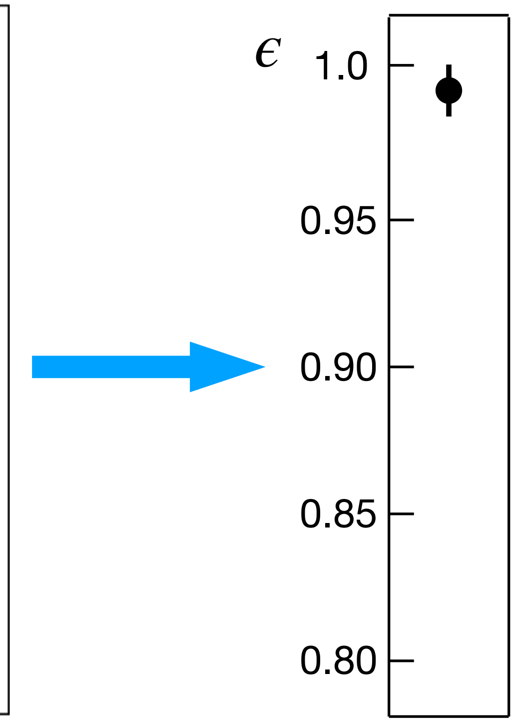
did = should && (H.cal.etottracknorm ≅ 1)

$$\epsilon_i = \frac{n_{i,did}}{n_{i,should}}$$

$$\epsilon = \frac{\sum_i w_i \epsilon_i}{\sum_j w_j}$$

$$w_i = 1/\sigma_i^2$$

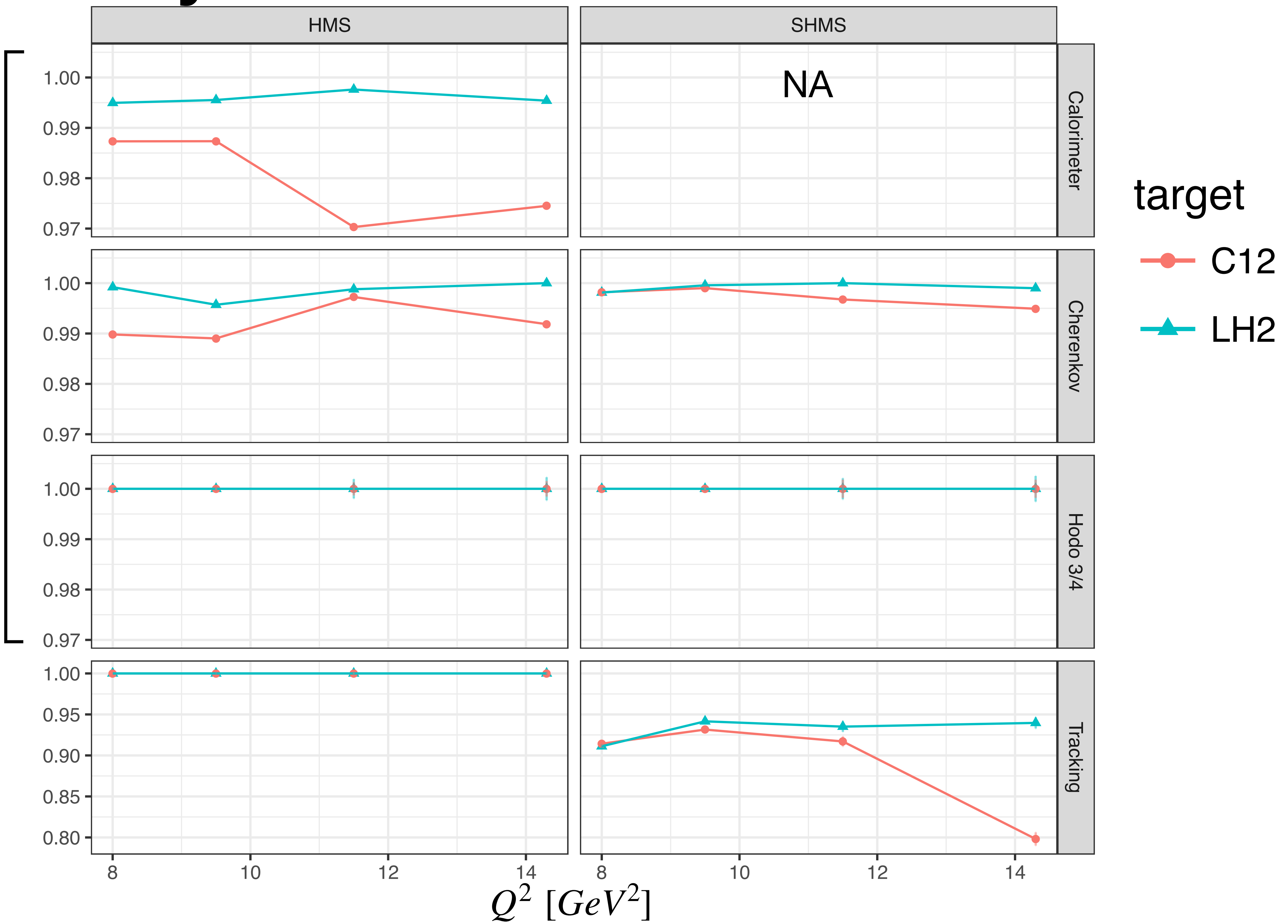




E12-06-107 Efficiency

Calorimeter, Cherenkov, hodo 3/4 mostly ~99%

SHMS tracking efficiency is 80—95%



E12-06-107
SHMS proton absorption

Can get estimate based on geometry/materials (should confirm with the detector gods)

Working on a Google spreadsheet* for this purpose

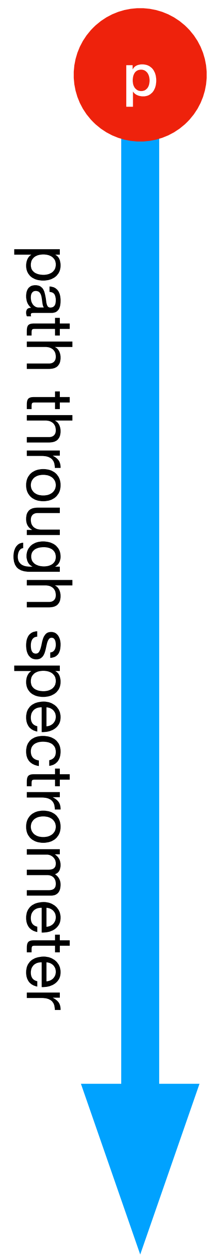
Current estimate is ~**9%**

fx =1-EXP(-K33)

	A	B	C	D	E	F	G	H	I	J	K
1		Component	Material	Thickness (inch)	Thickness (cm)	Density (g/cm^3)	X (g/cm^2)	lambda_T (g/cm^2)	lambda_I (g/cm^2)	lambda_avg (g/cm^2)	X/lambda
2	Target and spectrometer	LH2 (after scattering in 10cm loop)	LH2		5.00E+00	7.08E-02	3.54E-01	4.28E+01	5.20E+01	4.74E+01	7.47E-03
3		Scattering exit window	Al	5.00E-03	1.27E-02	2.70E+00	3.43E-02	6.97E+01	1.07E+02	8.85E+01	3.88E-04
4		Air	Air		3.00E+01	1.23E-03	3.68E-02	6.13E+01	9.01E+01	7.57E+01	4.85E-04
5		HB entrance	Al	1.00E-02	2.54E-02	2.70E+00	6.86E-02	6.97E+01	1.07E+02	8.85E+01	7.75E-04
6		Dipole exit	Al	2.00E-02	5.08E-02	2.70E+00	1.37E-01	6.97E+01	1.07E+02	8.85E+01	1.55E-03
7											
8	NGCER	Entrance window	Tedlar	2.00E-03	5.08E-03	1.50E+00	7.62E-03	6.17E+01	9.03E+01	7.60E+01	1.00E-04
9		Gas	CO2 @ 1.0 ATM		2.00E+02	1.66E-03	3.32E-01	6.07E+01	8.89E+01	7.48E+01	4.44E-03
10		Mirror	SiO2		3.00E-01	2.20E+00	6.60E-01	6.52E+01	9.78E+01	8.15E+01	8.10E-03
11		Mirror support	Rohacell		1.80E+00	1.10E-01	1.98E-01	-	-	7.00E+01	2.83E-03
12		Exit window	Tedlar	2.00E-03	5.08E-03	1.30E+00	6.60E-03	6.17E+01	9.03E+01	7.60E+01	8.69E-05
13											
14	DC	Entrance window	Mylar	1.00E-03	2.54E-03	1.39E+00	3.53E-03	5.89E+01	8.49E+01	7.19E+01	4.91E-05
15	new chambers are different than old!	Gas	50/50 Ethane/Ar	1.25E-01	3.18E-01	1.54E-03	4.89E-04	6.86E+01	1.01E+02	8.48E+01	5.77E-06
16		Wire	25 micron W+Be/Cu		3.54E-05	1.91E+01	6.76E-04	1.10E+02	1.85E+02	1.48E+02	4.58E-06
17	cal article has a list	Cathode	1 mil kapton	1.00E-03	2.54E-03	5.40E+00	1.37E-02	5.92E+01	8.55E+01	7.24E+01	1.90E-04
18	https://hallcweb.jlab.org/D	Exit window	Mylar	1.00E-03	2.54E-03	1.39E+00	3.53E-03	5.89E+01	8.49E+01	7.19E+01	4.91E-05
19											
20	HODO	Scintilator (x3)	PVT		1.50E+00	1.04E+00	1.56E+00	5.73E+01	8.13E+01	6.93E+01	2.25E-02
21											
22	HGCER	Entrance window	Al	1.00E-01	2.54E-01	2.70E+00	6.86E-01	6.97E+01	1.07E+02	8.85E+01	7.75E-03
23		Gas	CO2 @ 0.5ATM		1.14E+02	9.17E-04	1.04E-01	6.07E+01	8.89E+01	7.48E+01	1.39E-03
24		Mirror	SiO2		3.00E-01	2.63E+00	7.90E-01	6.52E+01	9.78E+01	8.15E+01	9.69E-03
25		Exit window	Al	1.00E-01	2.54E-01	2.70E+00	6.86E-01	6.97E+01	1.07E+02	8.85E+01	7.75E-03
26											
27	AERO	Entrance window	Al		1.30E-01	2.70E+00	3.51E-01	6.97E+01	1.07E+02	8.85E+01	3.97E-03
28		Aerogel	Aeorogel		9.00E+00	1.43E-01	1.29E+00	6.50E+01	9.73E+01	8.12E+01	1.58E-02
29		Air	Air		1.71E+01	1.23E-03	2.10E-02	6.13E+01	9.01E+01	7.57E+01	2.78E-04
30		Exit window	Al		1.60E-01	2.70E+00	4.32E-01	6.97E+01	1.07E+02	8.85E+01	4.88E-03
31											
32											
33										SUM	9.31E-02
34											
35										ABSORPTION	8.89%

* https://docs.google.com/spreadsheets/d/1LeaFrQjKTuOeliKTEN8QAHqDkFCYzW18bMMjTKu1ejQ/

E12-06-107
SHMS proton absorption



Target, magnets | NGCER | DC | HODO | HGCER | AERO

`fx` =1-EXP(-K33)

	A	B	C	D	E	F	G	H	I	J	K
1		Component	Material	Thickness (inch)	Thickness (cm)	Density (g/cm^3)	X (g/cm^2)	lambda_T (g/cm^2)	lambda_I (g/cm^2)	lambda_avg (g/cm^2)	X/lambda
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4		Air	Air		3.00E+01	1.23E-03	3.68E-02	6.13E+01	9.01E+01	7.57E+01	4.85E-04
5		HB entrance	Al	1.00E-02	2.54E-02	2.70E+00	6.86E-02	6.97E+01	1.07E+02	8.85E+01	7.75E-04
6		Dipole exit	Al	2.00E-02	5.08E-02	2.70E+00	1.37E-01	6.97E+01	1.07E+02	8.85E+01	1.55E-03
7											
8	NGCER	Entrance window	Tedlar	2.00E-03	5.08E-03	1.50E+00	7.62E-03	6.17E+01	9.03E+01	7.60E+01	1.00E-04
9		Gas	CO2 @ 1.0 ATM		2.00E+02	1.66E-03	3.32E-01	6.07E+01	8.89E+01	7.48E+01	4.44E-03
10		Mirror	SiO2		3.00E-01	2.20E+00	6.60E-01	6.52E+01	9.78E+01	8.15E+01	8.10E-03
11		Mirror support	Rohacell		1.80E+00	1.10E-01	1.98E-01	-	-	7.00E+01	2.83E-03
12		Exit window	Tedlar	2.00E-03	5.08E-03	1.30E+00	6.60E-03	6.17E+01	9.03E+01	7.60E+01	8.69E-05
13											
14	DC	Entrance window	Mylar	1.00E-03	2.54E-03	1.39E+00	3.53E-03	5.89E+01	8.49E+01	7.19E+01	4.91E-05
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16		Wire	25 micron W+Be/Cu		3.54E-05	1.91E+01	6.76E-04	1.10E+02	1.85E+02	1.48E+02	4.58E-06
17	cal article has a list	Cathode	1 mil kapton	1.00E-03	2.54E-03	5.40E+00	1.37E-02	5.92E+01	8.55E+01	7.24E+01	1.90E-04
18	https://hallcweb.jlab.org/D	Exit window	Mylar	1.00E-03	2.54E-03	1.39E+00	3.53E-03	5.89E+01	8.49E+01	7.19E+01	4.91E-05
19											
20	HODO	Scintilator (x3)	PVT		1.50E+00	1.04E+00	1.56E+00	5.73E+01	8.13E+01	6.93E+01	2.25E-02
21											
22	HGCER	Entrance window	Al	1.00E-01	2.54E-01	2.70E+00	6.86E-01	6.97E+01	1.07E+02	8.85E+01	7.75E-03
23		Gas	CO2 @ 0.5ATM		1.14E+02	9.17E-04	1.04E-01	6.07E+01	8.89E+01	7.48E+01	1.39E-03
24		Mirror	SiO2		3.00E-01	2.63E+00	7.90E-01	6.52E+01	9.78E+01	8.15E+01	9.69E-03
25		Exit window	Al	1.00E-01	2.54E-01	2.70E+00	6.86E-01	6.97E+01	1.07E+02	8.85E+01	7.75E-03
26											
27	AERO	Entrance window	Al		1.30E-01	2.70E+00	3.51E-01	6.97E+01	1.07E+02	8.85E+01	3.97E-03
28		Aerogel	Aeorogel		9.00E+00	1.43E-01	1.29E+00	6.50E+01	9.73E+01	8.12E+01	1.58E-02
29		Air	Air		1.71E+01	1.23E-03	2.10E-02	6.13E+01	9.01E+01	7.57E+01	2.78E-04
30		Exit window	Al		1.60E-01	2.70E+00	4.32E-01	6.97E+01	1.07E+02	8.85E+01	4.88E-03
31											
32											
33										SUM	9.31E-02
34											
35										ABSORPTION	8.89%

* https://docs.google.com/spreadsheets/d/1LeaFrQjKTuOeliKTEN8QAHqDkFCYzW18bMMjTKu1ejQ/

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NGCER

List of each component of the system

	A	B	C	D	E	F	G	H	I	J	K
1		Component	Material	Thickness (inch)	Thickness (cm)	Density (g/cm^3)	X (g/cm^2)	lambda_T (g/cm^2)	lambda_I (g/cm^2)	lambda_avg (g/cm^2)	X/lambda
8	NGCER	Entrance window	Tedlar	2.00E-03	5.08E-03	1.50E+00	7.62E-03	6.17E+01	9.03E+01	7.60E+01	1.00E-04
9		Gas	CO2 @ 1.0 ATM		2.00E+02	1.66E-03	3.32E-01	6.07E+01	8.89E+01	7.48E+01	4.44E-03
10		Mirror	SiO2		3.00E-01	2.20E+00	6.60E-01	6.52E+01	9.78E+01	8.15E+01	8.10E-03
11		Mirror support	Rohacell		1.80E+00	1.10E-01	1.98E-01	-	-	7.00E+01	2.83E-03
12		Exit window	Tedlar	2.00E-03	5.08E-03	1.30E+00	6.60E-03	6.17E+01	9.03E+01	7.60E+01	8.69E-05

material properties

contribution to absorption

$$A = 1 - exp\left\{ -\sum_i \frac{x_i}{\lambda_i} \right\}$$

* https://docs.google.com/spreadsheets/d/1LeaFrQjKTuOeliKTEN8QAHqDkFCYzW18bMMjTKu1ejQ/

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Listed all the sources I consulted in notes columns.

Corrections are welcome!

J	K	L	M	
lambda_avg (g/cm^2)	X/lambda		Notes	
4.74E+01	7.47E-03			
8.85E+01	3.88E-04	https://hallcweb.jlab.org/DocDB/0009/000918/001/target-cell-hdcf-2pt5-10cm.pdf		
7.57E+01	4.85E-04	Estimate from eng drawing	Old theses list ~15 cm	
8.85E+01	7.75E-04	https://hallcweb.jlab.org/wiki/index.php/Main_Page#SHMS_Entrance_Window_and_Vacuum_vessel		
8.85E+01	1.55E-03			
7.60E+01	1.00E-04	polyvinylflouride [(CH2CHF2)n]; http://www.dupont.com/content/dan	http://pdg.lbl.gov/2014/AtomicNuclearProperties/HTML/polyvinylchloride	
7.48E+01	4.44E-03	https://hallcweb.jlab.org/DocDB/0007/000794/002/Cerenkovs_HallC	https://hallcweb.jlab.org/DocDB/0009/000933/001/shms-cerv6.pdf	htt
8.15E+01	8.10E-03			
7.00E+01	2.83E-03	There appear to be many types of rohacell. The cell to the right is the	http://www.matweb.com/search/datasheettext.aspx?matguid=a4736	htt
7.60E+01	8.69E-05			
7.19E+01	4.91E-05	https://hallcweb.jlab.org/document/howtos/shms_drift_chambers.pd	The active area of each wire plane consists of alternating 20 μm gold tung	
8.48E+01	5.77E-06			
1.48E+02	4.58E-06	Assume all interaction due to tungsten; tech note says 20 micron, not 25; <t>=pi*(.0025/2)^2		
7.24E+01	1.90E-04	Tech note says 5 mil; also that EACH wire plane is sandwiched with 5 m	[(C22H10N2O5)n]	
7.19E+01	4.91E-05			
6.93E+01	2.25E-02	polyvinyltoluene [(2-CH3C6H4CHCH2)n]; https://hallcweb.jlab.org/document/howtos/shms_scintillator_hodoscope.pdf; this is only for the plasti		
8.85E+01	7.75E-03			
7.48E+01	1.39E-03	https://hallcweb.jlab.org/wiki/index.php/SHMS_Heavy_Gas_Cerenkov		
8.15E+01	9.69E-03	Mirrors from Sinclair Glass. Wenliang's thesis, presentations don't mention the material. Some kind of glass that Sinclair bent; they explicitly list s		
8.85E+01	7.75E-03			

* https://docs.google.com/spreadsheets/d/1LeaFrQjKTuOeliKTEN8QAHqDkFCYzW18bMMjTKu1ejQ/

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- Empirically, compare elastic ep yields in HMS singles and coincidence runs

$$A = 1 - \left(\frac{n_{ep,\ coin}}{Q_{coin}} \middle/ \frac{n_{ep,\ singles}}{Q_{singles}} \right)$$

- Will have this soon

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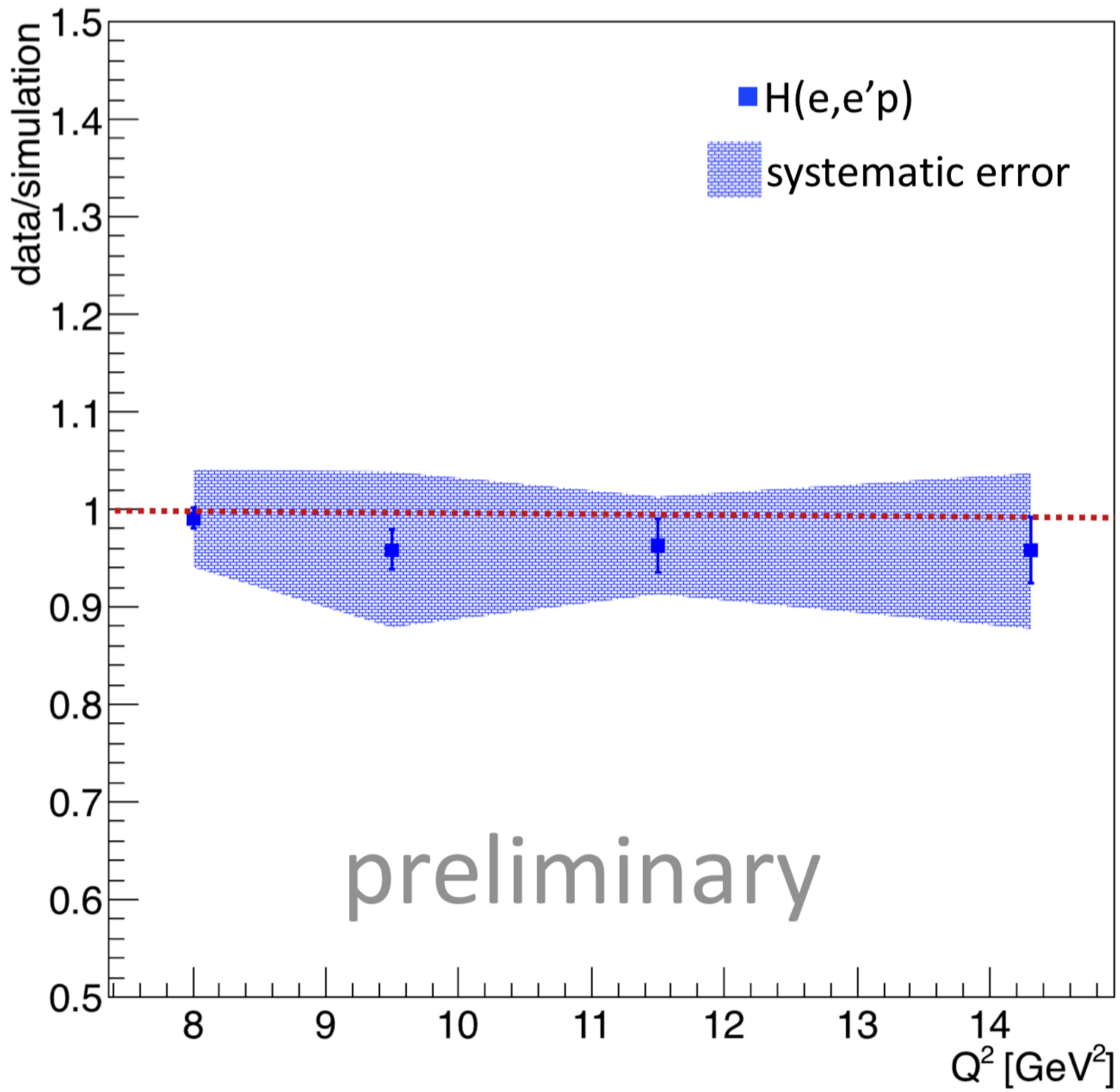
Preliminary results



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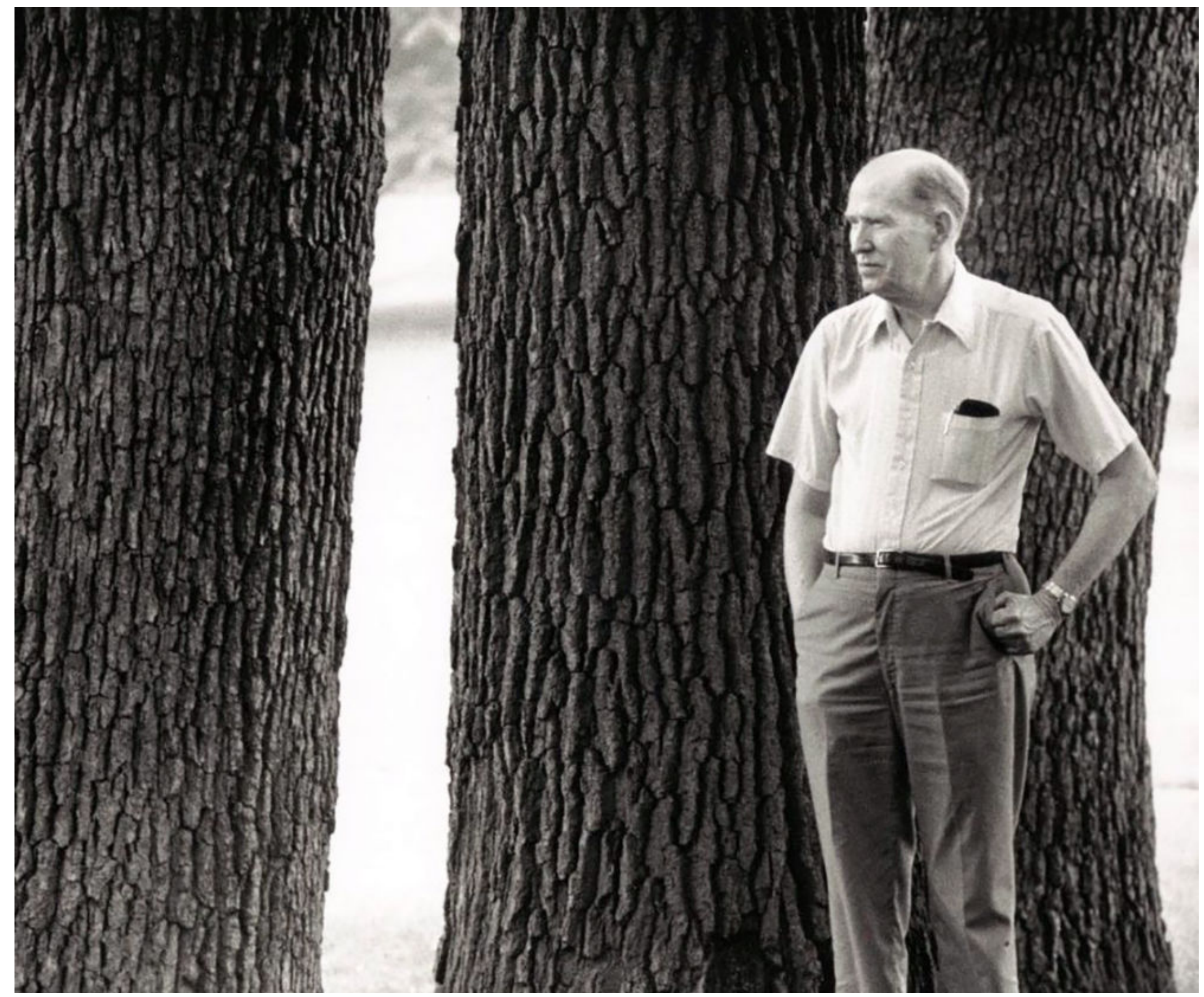
We hope to have transparency results by the end of the year, until then…

"let's be patient: much
remains
to be known: there may
come
re-evaluation:
    if we don't have
    the truth, we've
        shed
        thousands of errors"

from *Tape For The Turn Of The Year*
A. R. Ammons, 1965



https://www.theparisreview.org/interviews/1394/a-r-ammons-the-art-of-poetry-no-73-a-r-ammons