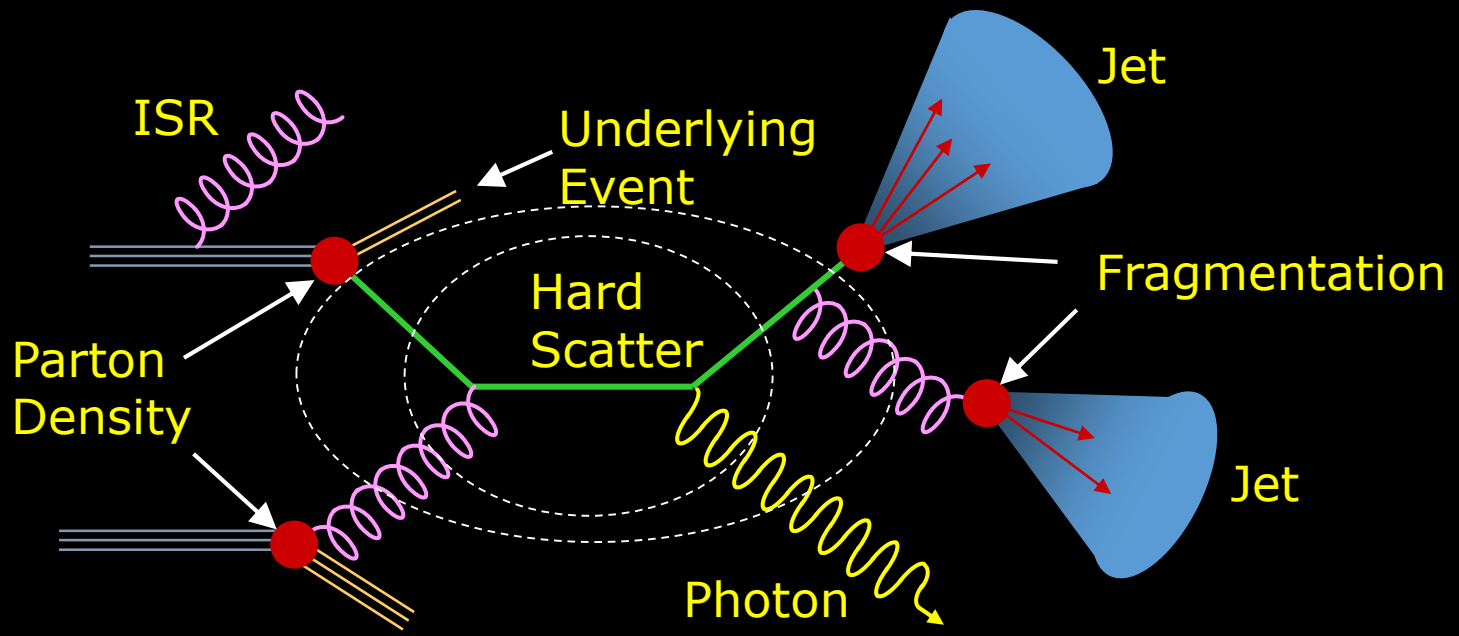
FNAL E683: Photoproduction of Jets

Don Lincoln

(Marj's Second* Ph.D. Student, first to stay in academia)

* Chris Moore was #1

Quantum Chromodynamics [General Primer]

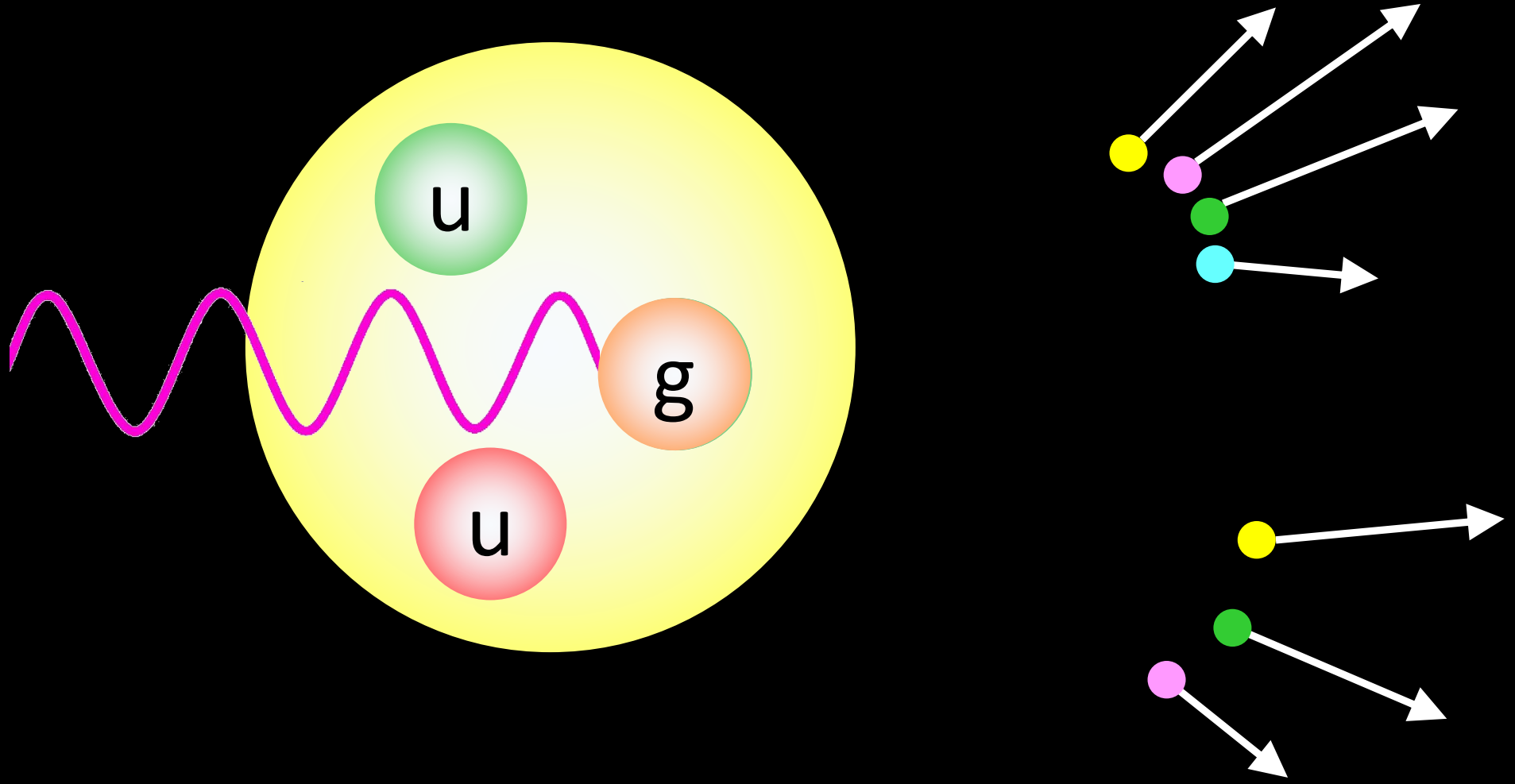


Calculable at Leading Order [LO] perturbation theory [1980 – 1990s]

Calculable at Next to Leading Order [NLO] perturbation theory [1990 – 2000s]

Intractable in perturbation theory [present]

Photoproduction processes [E683 Primer]



E683 Initial Goals

- Study jet production by γp scattering
- Compare with πp (E609, E683) and pp scattering (E609)

- Study A-dependencies of photon scattering (H, D, Be, C, Al, Cu, Sn, Pb)

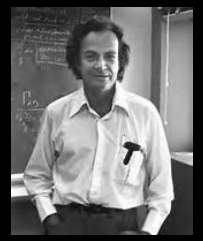
- Cross-sections (e.g. scattering probabilities, binned in p_T)
- Photon structure functions

E683 History

Year	Spokesperson	Status	Institutions
1981	Cormell	Unconsidered	ANL, FNAL, Lehigh, Athens, UPenn, Rice, Wisconsin
1982	Cormell	Deferred	ANL, FNAL, Lehigh, Athens, UPenn, Rice, Wisconsin

Interlude: Historical context

Higgs Field
CP Violation
Solar Neutrino Problem
Quarks Proposed
Don Born

Scaling



QCD Developed

Gluon Discovered
(3 jet events)

Hadronic Jets [UA1]
E683 Proposed

1964

1979

1981

1960

1970

1980

Jets in e^+e^-

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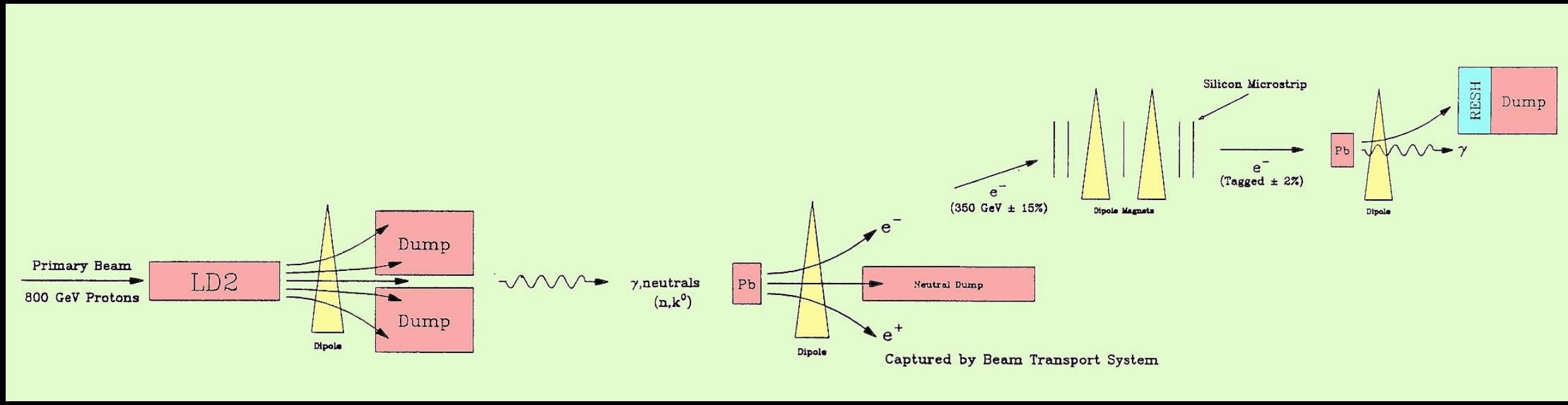
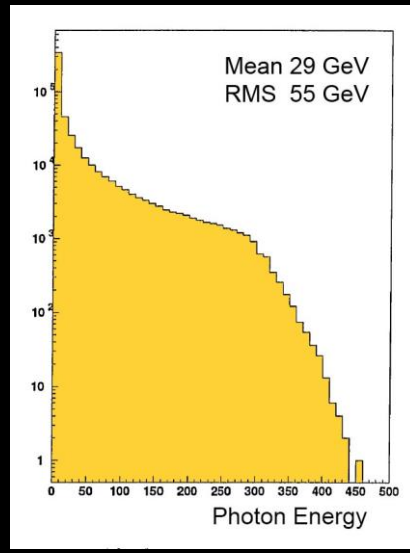
Year	Spokesperson	Status	Institutions
1981	Cormell	Unconsidered	ANL, FNAL, Lehigh, Athens, UPenn, Rice, Wisconsin
1982	Cormell	Deferred	ANL, FNAL, Lehigh, Athens, UPenn, Rice, Wisconsin
1983	Cormell	Deferred	ANL, FNAL, Lehigh, Athens, UPenn, Rice, Wisconsin
1984	Cormell	Approved	ANL, FNAL, Lehigh, Athens, UPenn, Rice, Wisconsin
1985	Cormell	Approved	Arizona, FNAL, Lehigh, Rice, Vanderbilt, Wisconsin
1986	Corcoran	Approved	Arizona, FNAL, Lehigh, Rice, Vanderbilt, Wisconsin
1987	Corcoran	Approved	Ball State, Houston, Lehigh, Maryland, Michigan, UTAustin, Rice, Vanderbilt, Wisconsin
1988	Corcoran	Approved	Ball State, Iowa, Maryland, Michigan, Rice, Vanderbilt
1990	Corcoran	Test Run	
1991	Corcoran	Run	Ran June 1991 – January 1992

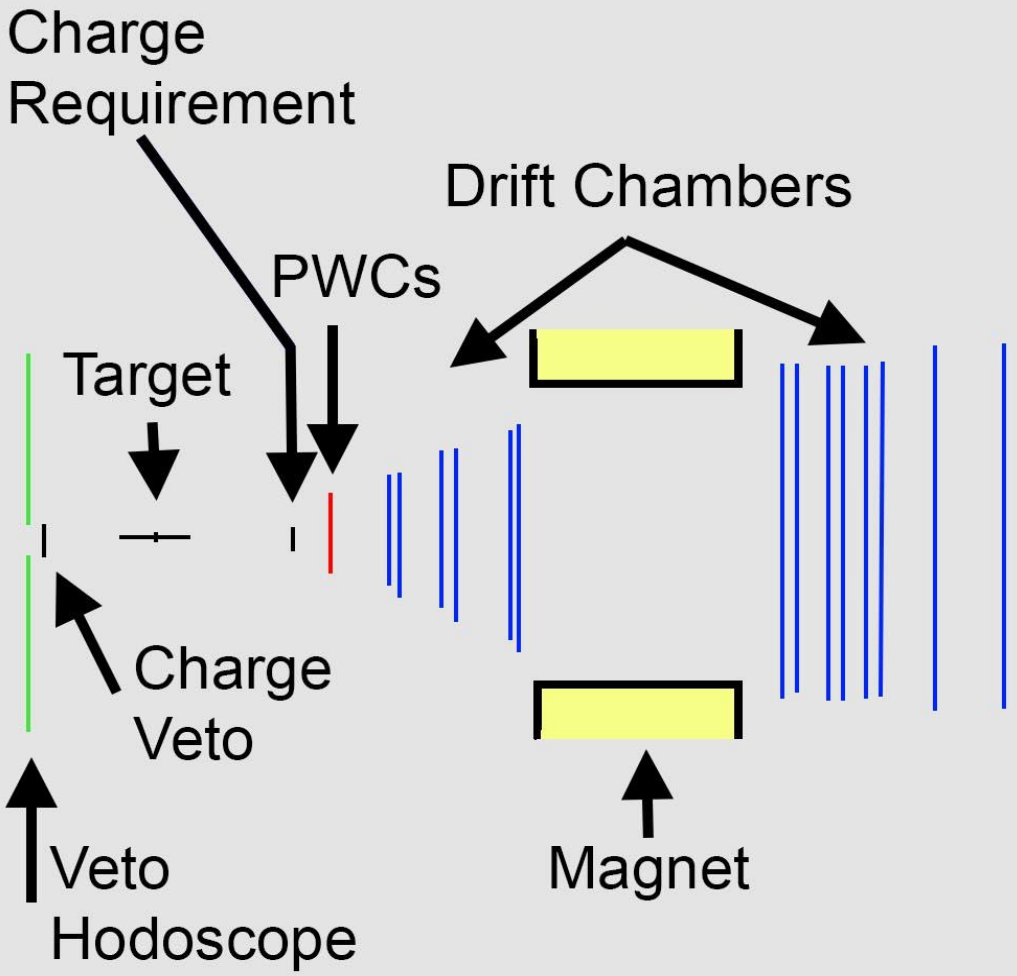
E683 Beamline: Highest energy **real** photon beam in the world



Bremsstrahlung photons: $[p \rightarrow \pi^{o} \rightarrow \gamma \rightarrow e^{-} \rightarrow \gamma]$

Photon energy spectrum

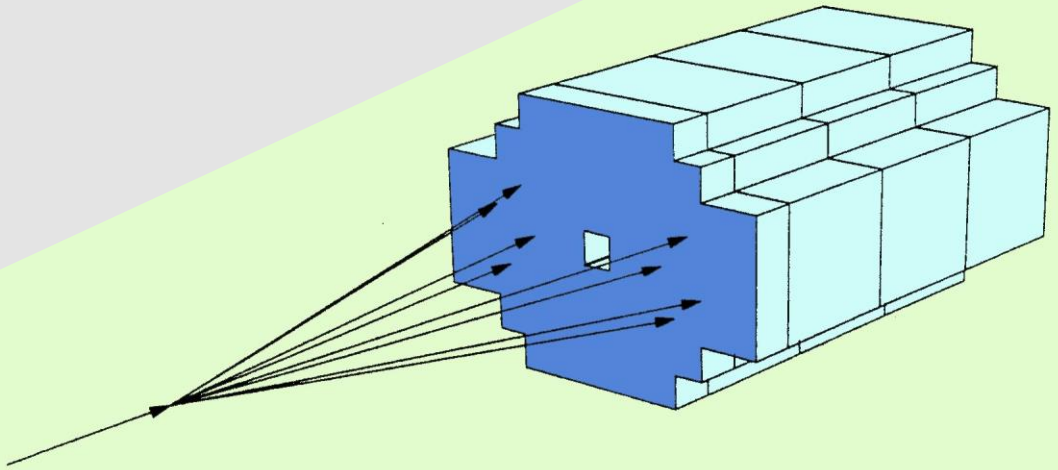


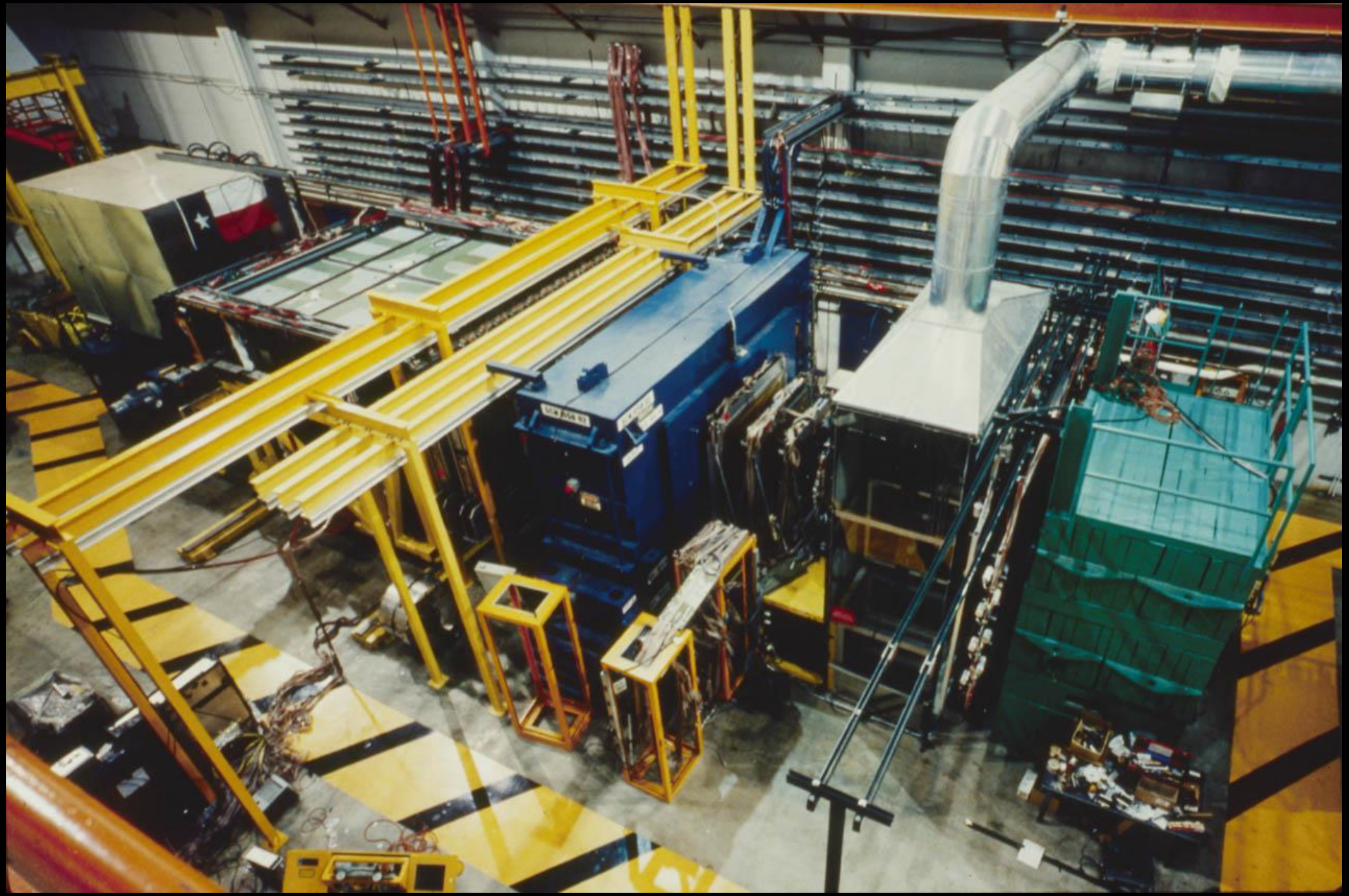


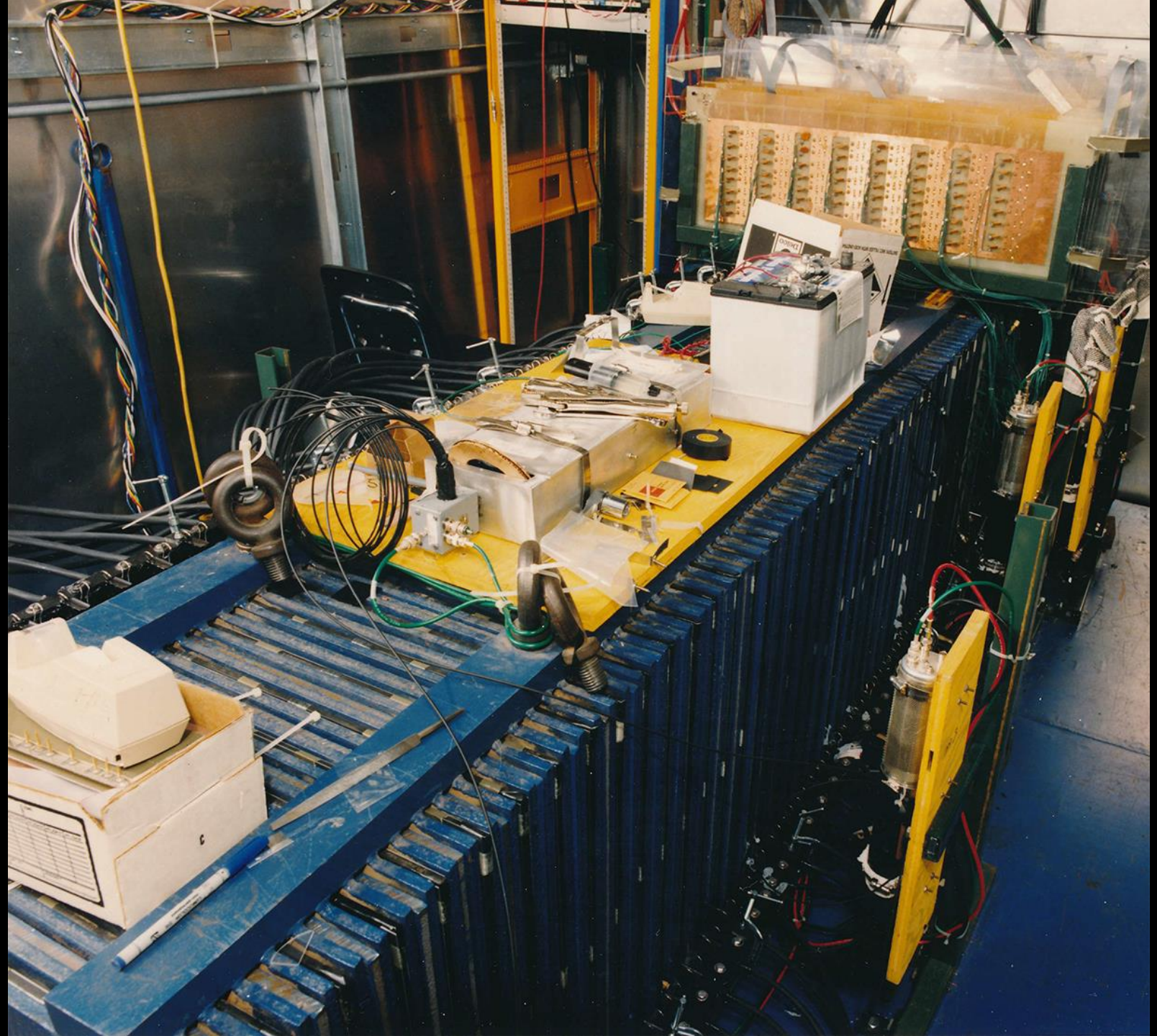
Main

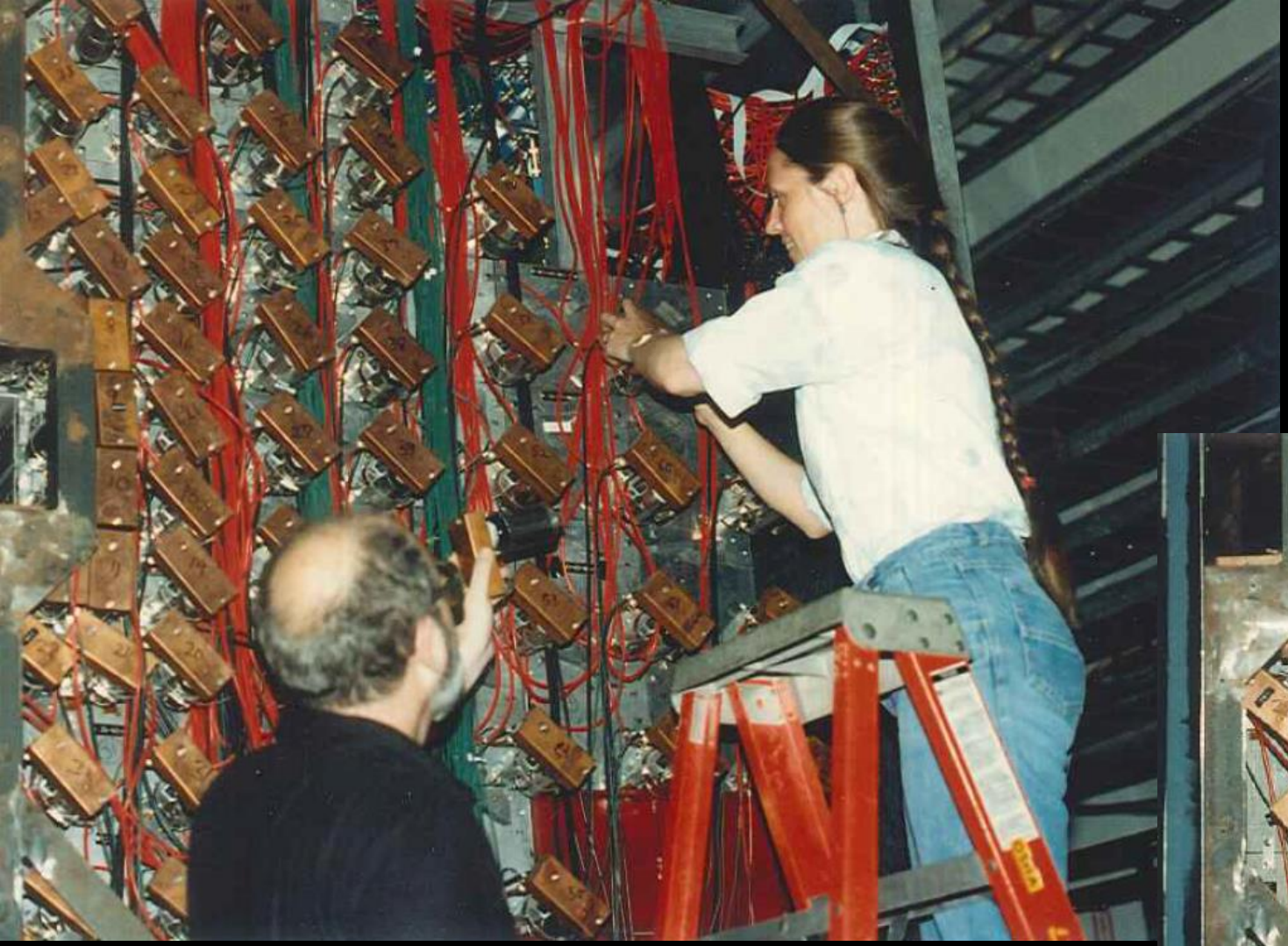
Calorimeter

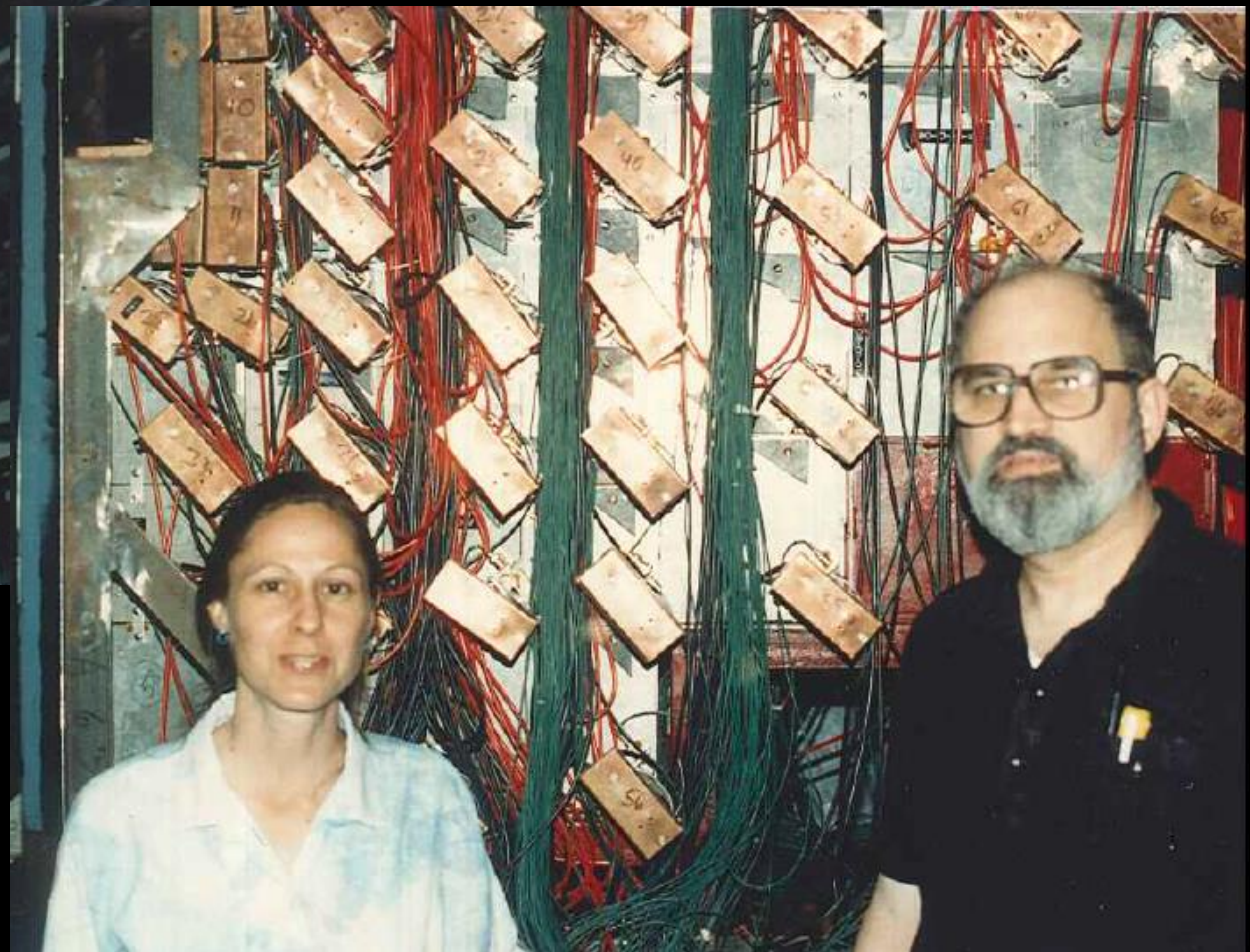
Beam
Calorimeter











Leading by example…

Cleanup after 1987 fire in the “Wide band” hall where the E683 experiment was damaged.

That was fun. Not.

E683: Ph.D. Theses

- Q. Zhu (Rice, 93) A study of photon-nucleus collisions at high transverse energy
- D. Naples (Maryland, 93) A-Dependence of photoproduced jets and comparison with hadroproduction
- D. Lincoln (Rice, 94) Observation of jet photoproduction and comparison to Monte Carlo simulation

published

- M. Traynor (Rice, 96) Search for evidence of photoproduction of higher-twist ACD events at Experiment 683 at Fermi National Accelerator Laboratory
- C. Halli (Maryland, 97) Studies of hydrogen and deuterium di-jet production
- G. Morrow (Rice, 98) Experimental Observation of the photon structure function at 21 GeV

unpublished

+ 5 M.A. theses

Observation of Jet Production by Real Photons

D. Adams,[6] S. Ahmad,[6] N. Akchurin,[3] P. Birmingham,[7] H. Breuer,[4] C. C. Chang,[4] S. Cihangir,[2] M. D. Corcoran,[6] W. L. Davis,[1] H. R. Gustafson,[5] H. Holmgren,[4] P. Kasper,[2] J. Kruk,[6] D. Lincoln,[6] M. J. Longo,[5] J. Marraffino,[2] J. McPherson,[3] H. E. Miettinen,[6] G. Morrow,[6] G. S. Mutchler,[6] D. Naples,[4,*] Y. Onel,[3] J. Skeens,[6] G. P. Thomas,[1] M. M. Traynor,[6] J. W. Waters,[7] M. S. Webster,[7] J. P. Xu,[6] and Q. Zhu[6,†]

(E683 Collaboration)

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[2]*Fermilab, Batavia, Illinois 60510*
[3]*University of Iowa, Iowa City, Iowa 52242*
[4]*University of Maryland, College Park, Maryland 20742*
[5]*University of Michigan, Ann Arbor, Michigan 48109*
[6]*Rice University, Houston, Texas 77005*
[7]*Vanderbilt University, Nashville, Tennessee 37235*
(Received 14 June 1993)

Interactions of high energy photons on a hydrogen target have been studied using a large acceptance segmented calorimeter. The event topology clearly shows the production of dijet final states as predicted by perturbative QCD. The energy flow in the photon (forward) direc… expectations and to that produced in πp interactions.

PACS numbers: 13.87.Ce, 12.38.Qk, 13.60.Hb

Jets arise from the fragmentation of partons in hard scattering processes. Jets have been observed in many experiments in hadron-hadron interactions [1] as well as in deep inelastic lepton-hadron interactions [2] and e^+e^- annihilations [3]. Single high p_t hadrons and energy flow distributions have been studied in earlier, lower energy, photoproduction experiments [4], but until now no observation has been made of jet production by a real photon beam. Recent results from the DESY ep collider HERA show evidence for hard scattering in quasireal-photon-

in experiment
Fermilab, whi
ranging from 5
the p_t range c
bremsstrahlun
on a lead radi
The incoming
310 GeV/c, a
The energy of
array of silico

A Dependence of Photoproduced Dijets

D. Naples,[4,*] N. Akchurin,[3] P. Birmingham,[7] H. Breuer,[4] C. C. Chang,[4] S. Cihangir,[2] M. D. Corcoran,[6] W. L. Davis,[1] H. R. Gustafson,[5] H. Holmgren,[4] P. Kasper,[2] D. Lincoln,[6] M. J. Longo,[5] J. Marraffino,[2] J. McPherson,[3] H. E. Miettinen,[6] G. Morrow,[6] G. S. Mutchler,[6] Y. Onel,[3] G. P. Thomas,[1] M. M. Traynor,[6] J. W. Waters,[7] M. S. Webster,[7] J. P. Xu,[6] and Q. Zhu[6,†]

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[5]*University of Michigan, Ann Arbor, Michigan 48109*
[6]*Rice University, Houston, Texas 77251*
[7]*Vanderbilt University, Nashville, Tennessee 37235*
(Received 21 October 1993)

We present a measurement of the A dependence of $k_{T\phi}$, the out-of-plane component of the dijet …eam. We also present the same … detector. Both data sets are … A dependence of comparable …clear behavior is also extracted.

…ucleus collisions. Luo, Qui, and Sterman …that this measurement can be related to …tz force experienced by partons undergo… …ttering in nuclear matter. This relation …n nonleading power perturbative QCD.

RAPID COMMUNICATIONS

PHYSICAL REVIEW D VOLUME 56, NUMBER 9 1 NOVEMBER 1997

Emergence of jet dominance in γp interactions at fixed-target energies

D. Alton,[1,*] D. Lincoln,[6,†] N. Akchurin,[3] P. Birmingham,[7] C. C. Chang,[4] M. D. Corcoran,[6] W. L. Davis,[1,‡] H. R. Gustafson,[5] C. Halli,[4] H. Holmgren,[4] P. Kasper,[2] M. J. Longo,[5] J. Marraffino,[2] J. McPherson,[3] G. Morrow,[6] G. S. Mutchler,[6] D. Naples,[4,*] Y. Onel,[3] G. P. Thomas,[1] M. M. Traynor,[6,§] J. W. Waters,[7] M. S. Webster,[7] and Q. Zhu[6,‖]

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[6]*Rice University, Houston, Texas 77005*
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(Received 4 October 1996)

In Fermilab experiment E683 we have used a large solid angle calorimeter to study the production of hadronic events with large transverse energy in γp and πp collisions at center-of-mass energies from 20 to 25 GeV. We observe a sudden shift in γp event topology with increasing transverse energy, indicative of the emergence of jet dominance. This is the first observation of such a shift in event topology in fixed-target interactions. πp interactions in the same kinematic region and under identical triggering conditions exhibit only a slight shift in event topology. [S0556-2821(97)50421-8]

PACS number(s): 13.60.Hb, 13.85.Hd, 13.87.Ce

The production of particles with large momentum transverse to the beam direction in high energy hadronic interactions is well understood in terms of the hard scattering of the constituents of hadrons, quarks, and gluons, followed by the fragmentation of these constituents into ''jets.'' Ideally a jet

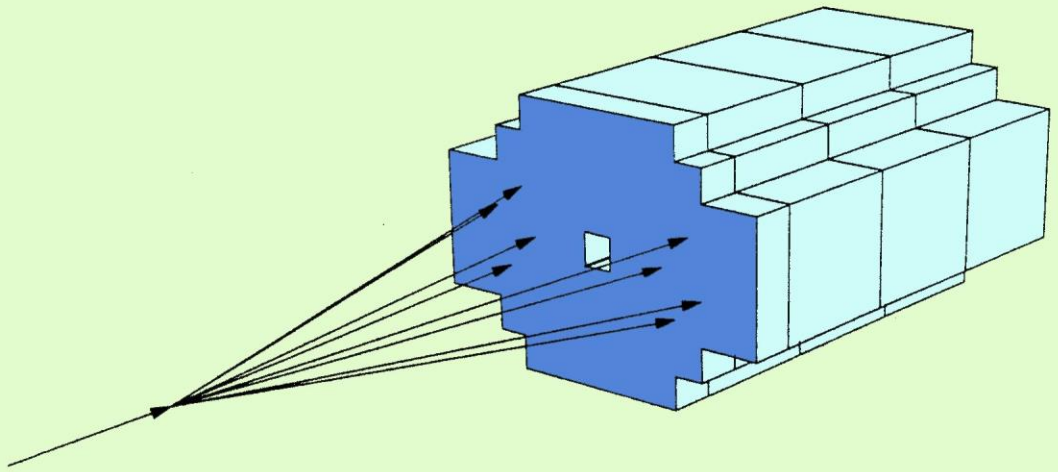
present in hadron-hadron interactions, the event structure is complicated by the presence of the so-called ''underlying event,'' that is, the remnants of the beam and target partons which did not participate in the hard scattering process.

A simple phenomenological model by Åkesson and

3 papers

Basic message:

Non-perturbative QCD is required



Modern jet-centric mindset [perturbative QCD dominated]

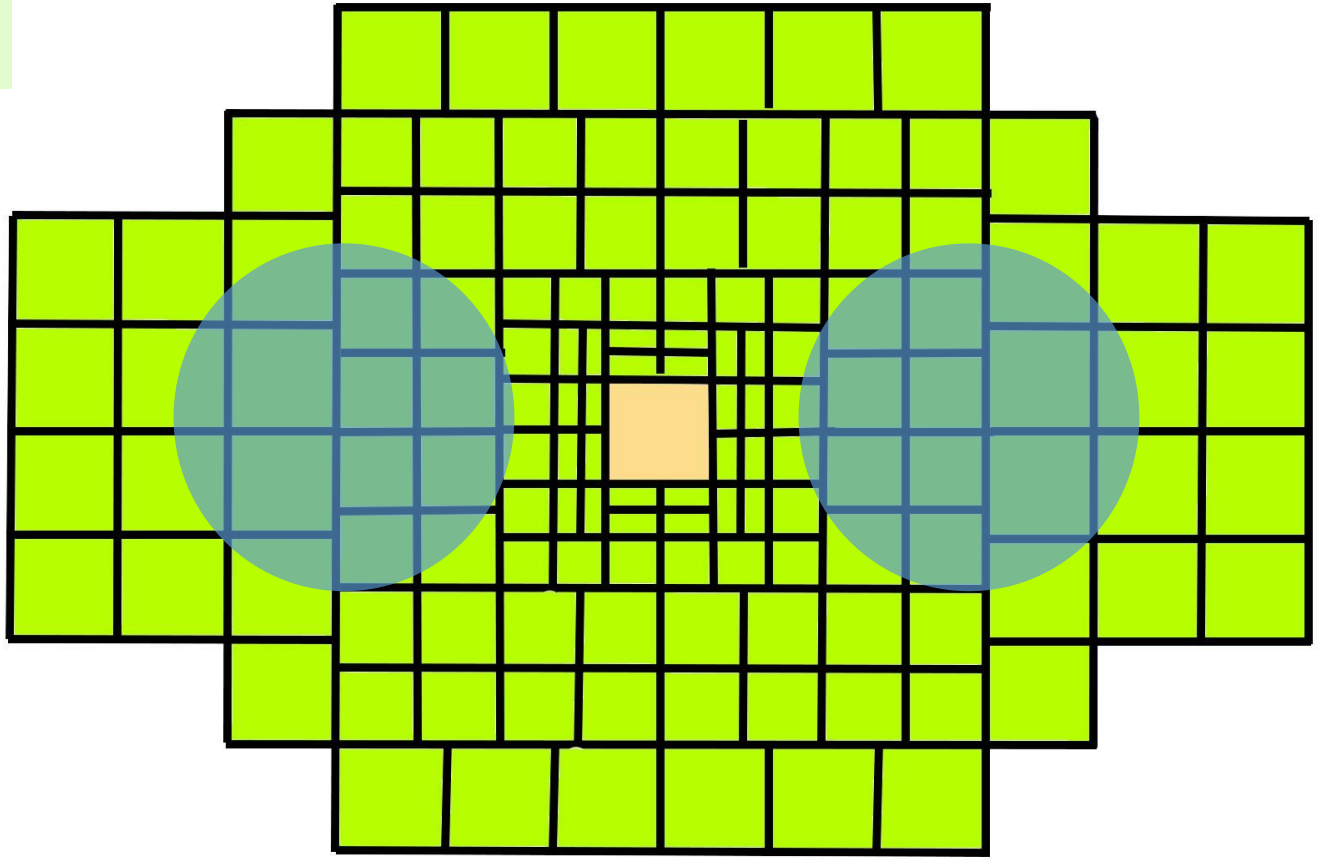
Jet studies at such low energy in hadron interactions is problematic

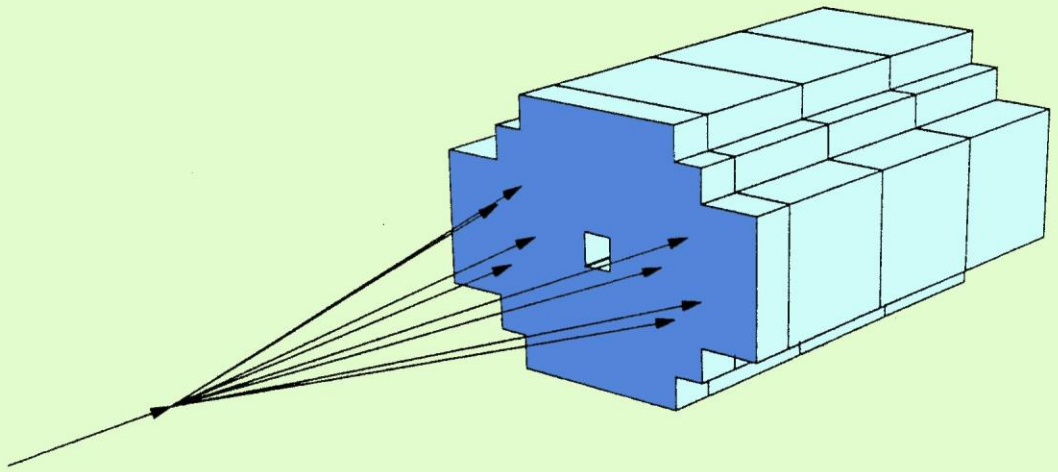
CM energy ~ 20 GeV

Typical jet transverse energy ~ 3 GeV

Non-perturbative QCD scale ~3 – 5 GeV

Trigger biases?





1970 – 1980s mindset
[low E_{CM} jet process not yet observed]

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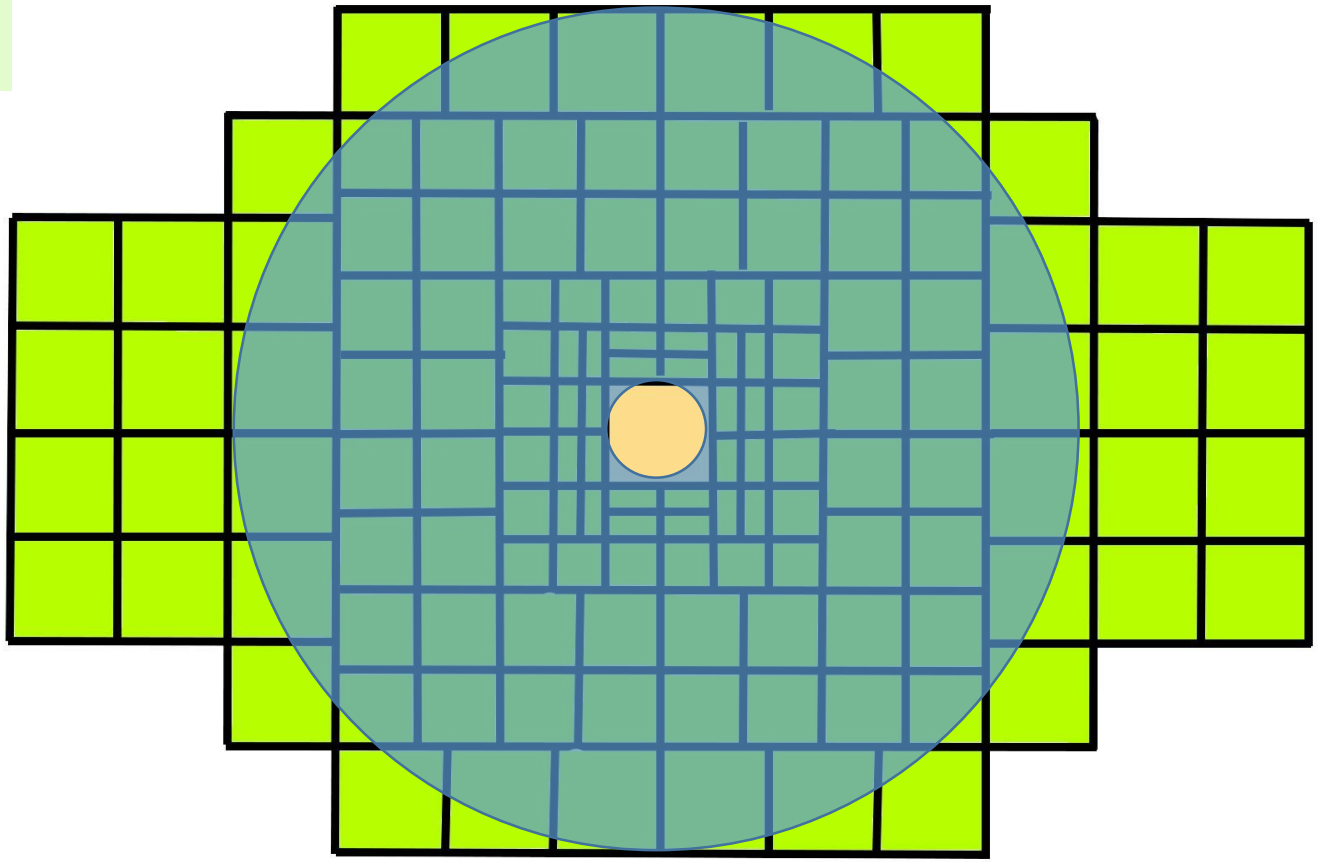
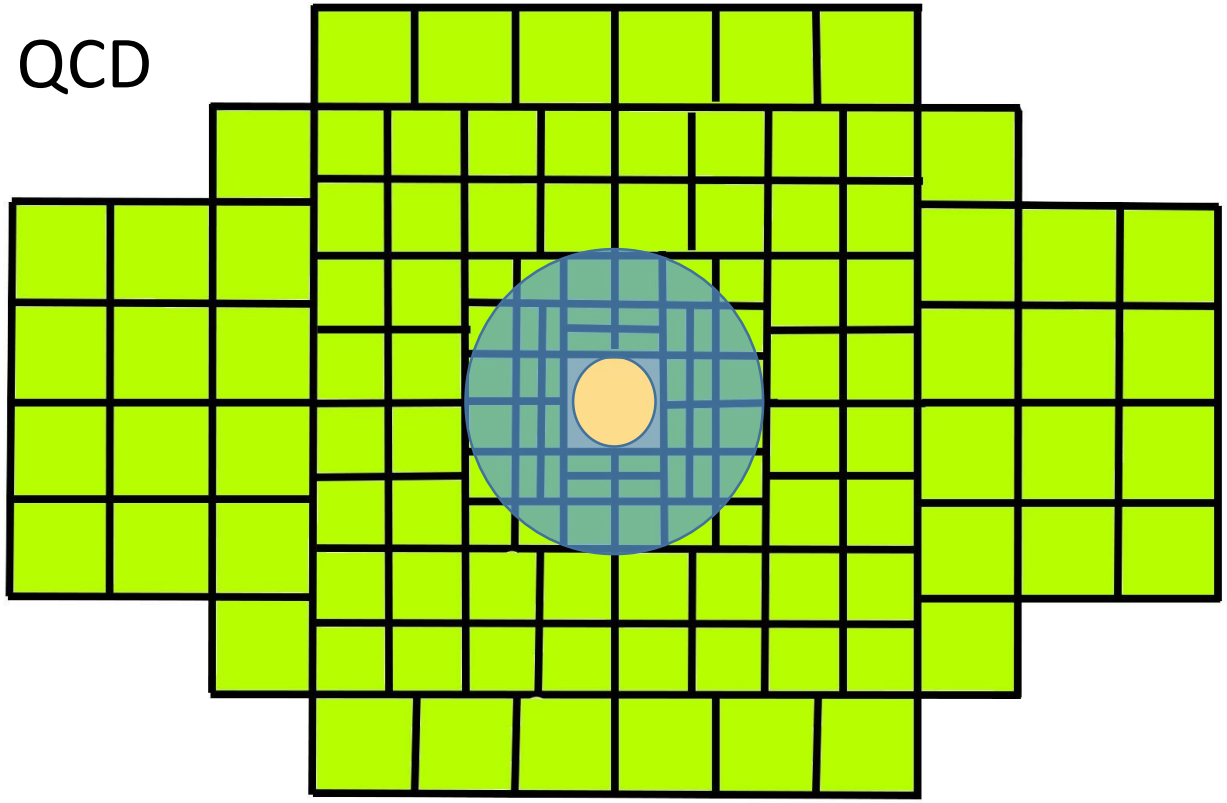
Typical jet transverse energy ~ 3 GeV

Non-perturbative QCD scale ~3 – 5 GeV

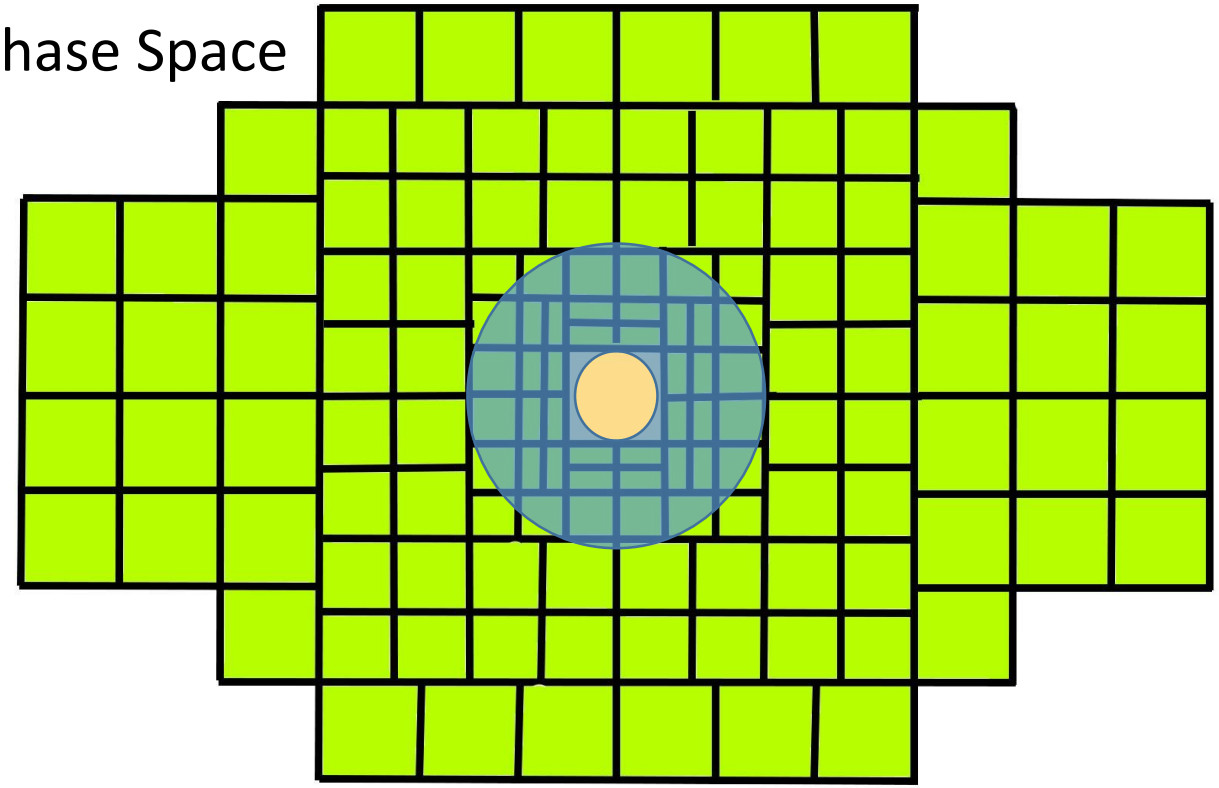
Trigger biases?



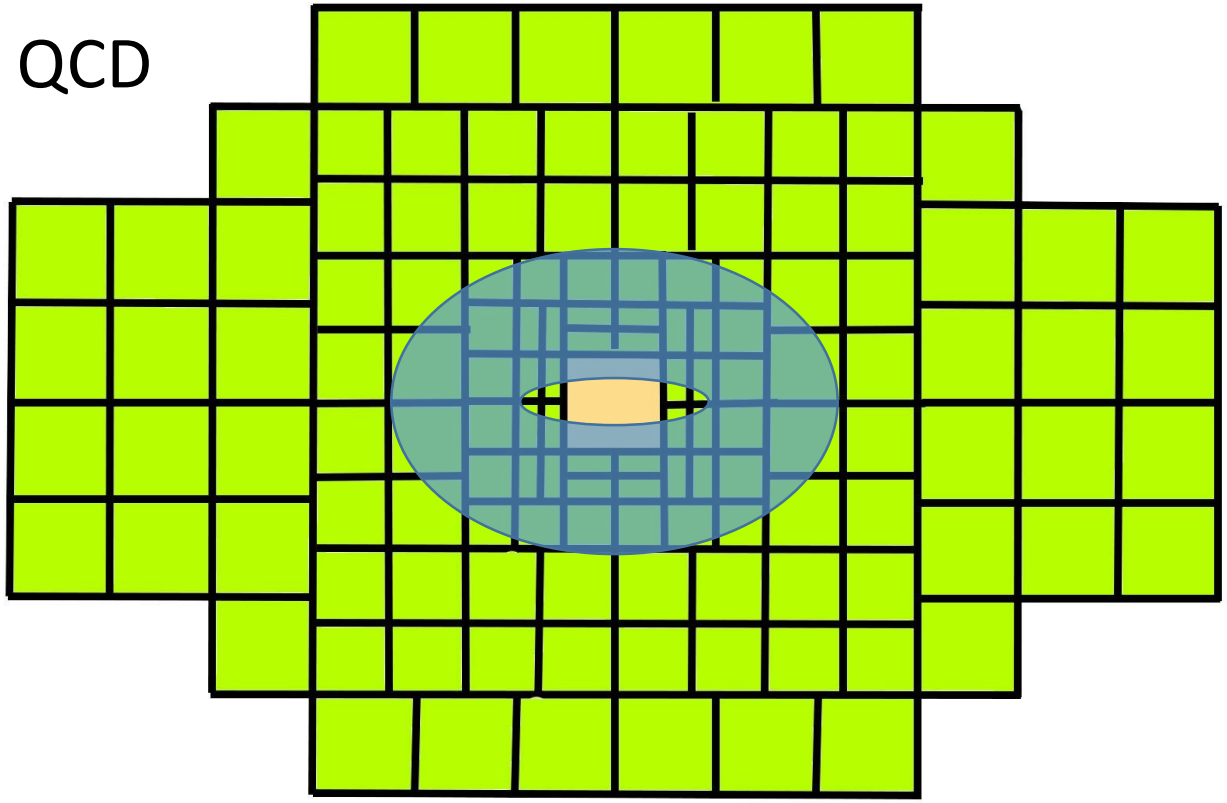
QCD



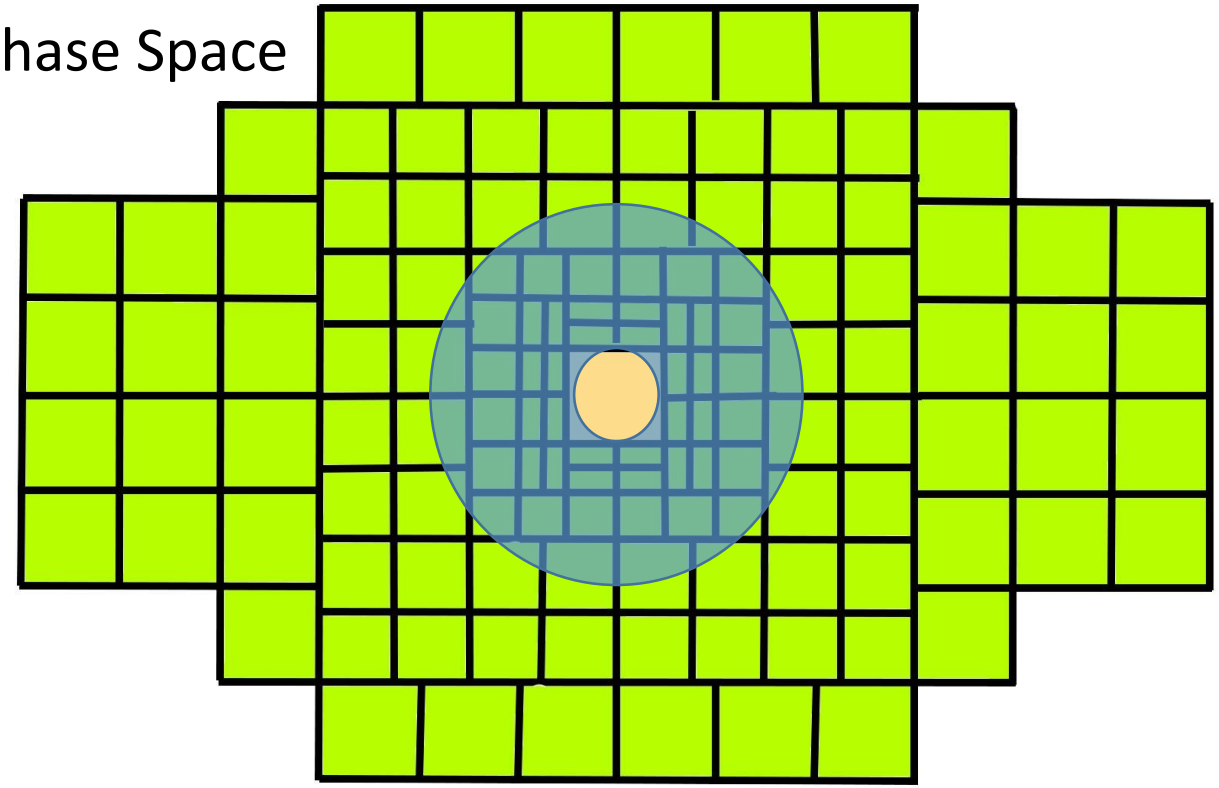
Phase Space



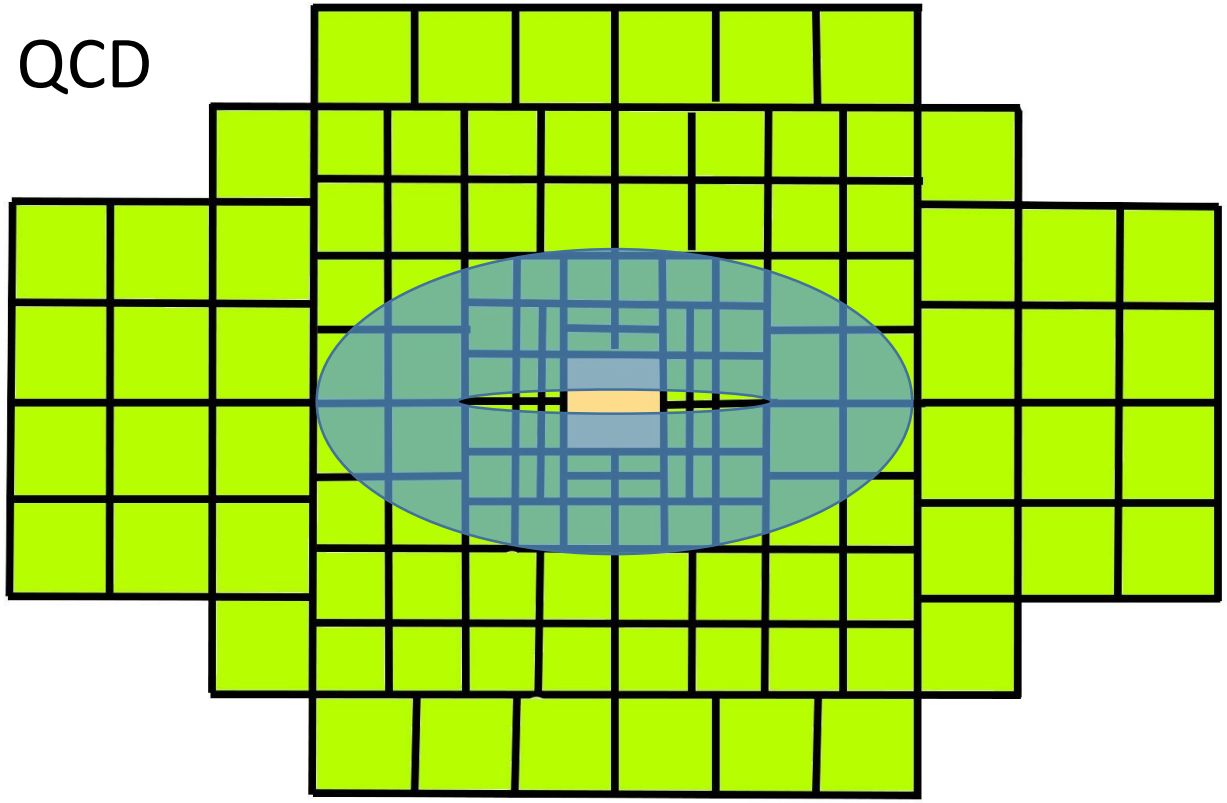
QCD



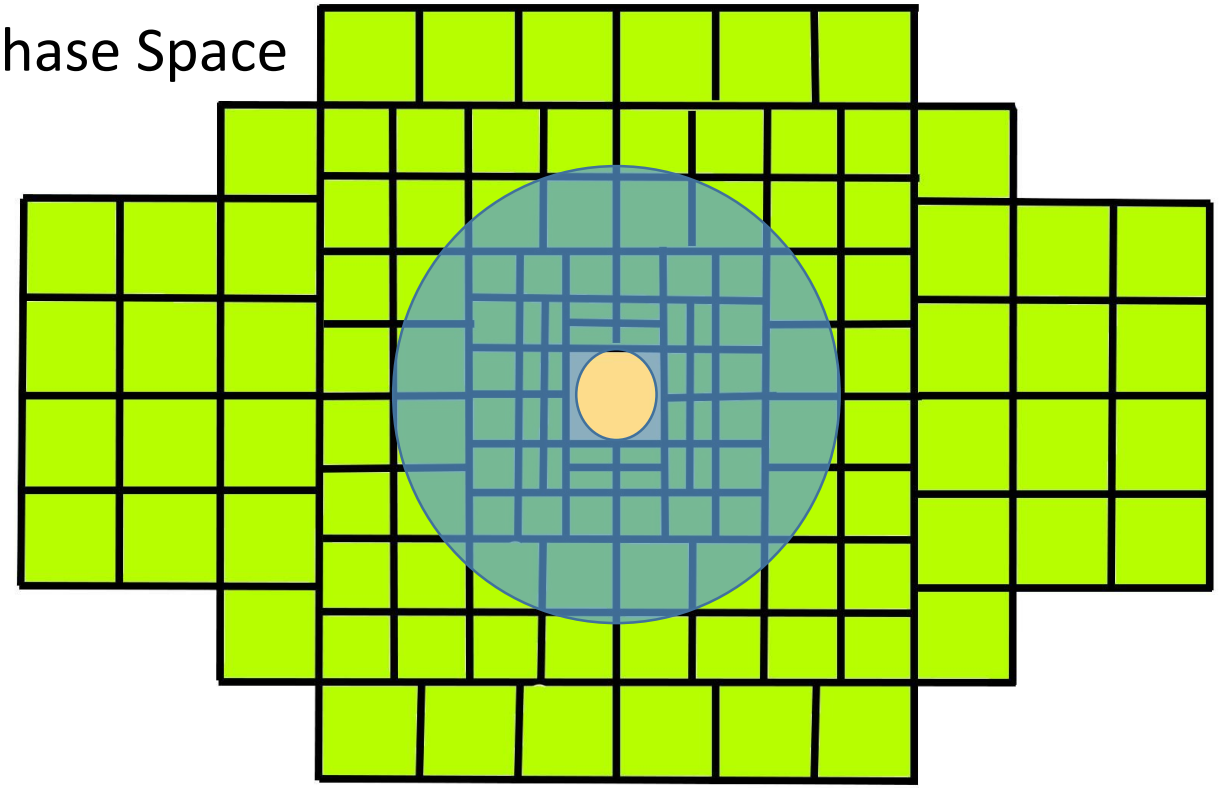
Phase Space



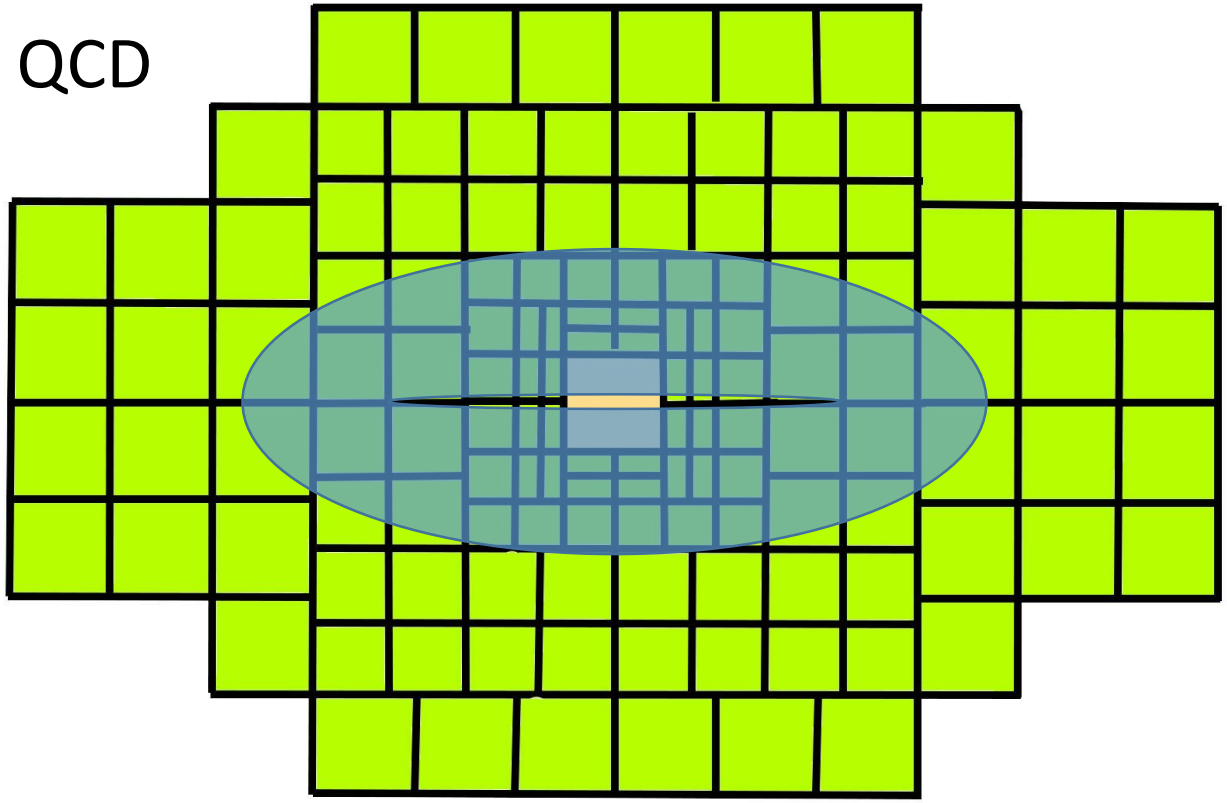
QCD



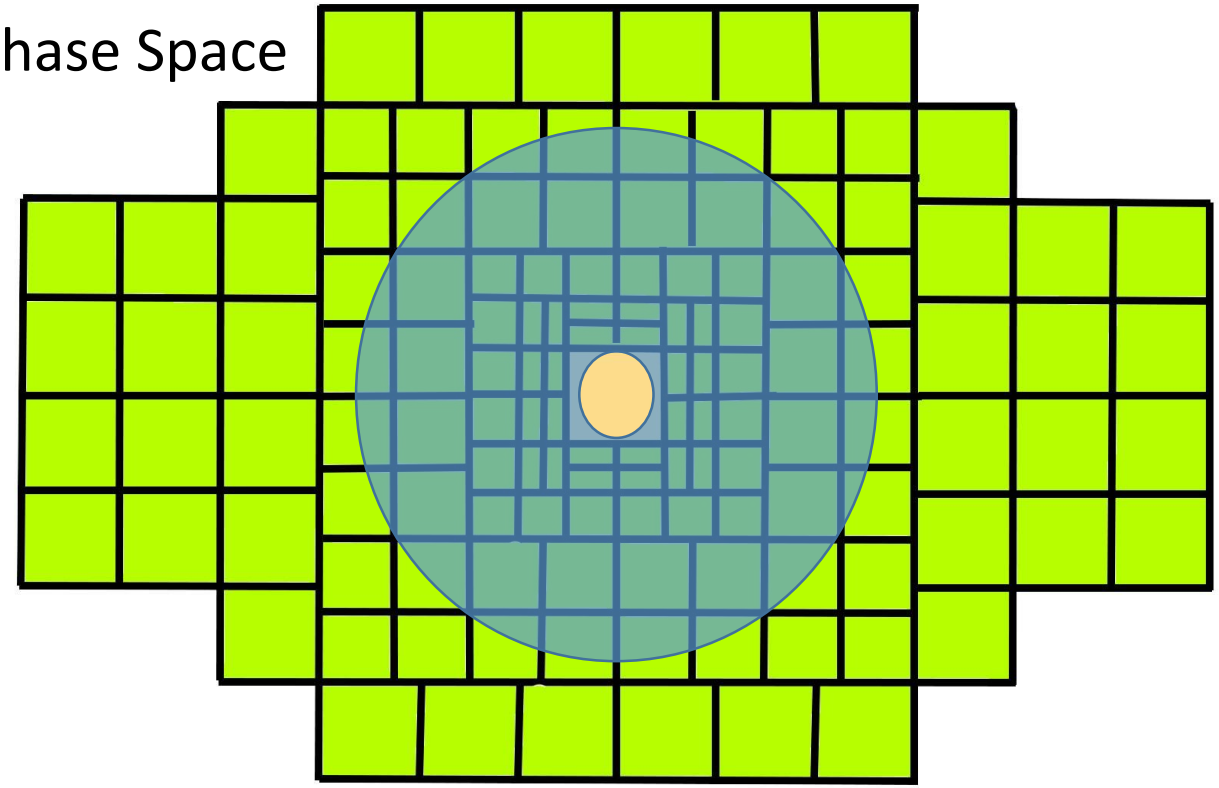
Phase Space



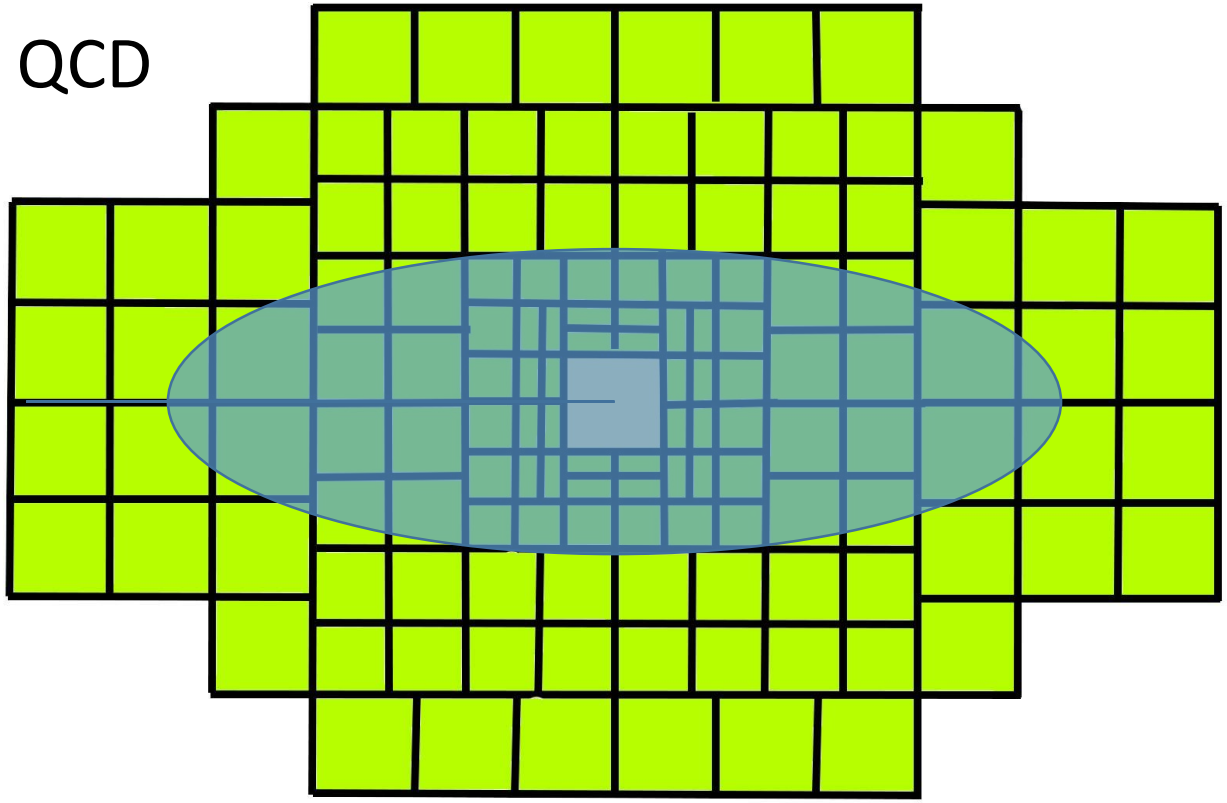
QCD



Phase Space



QCD



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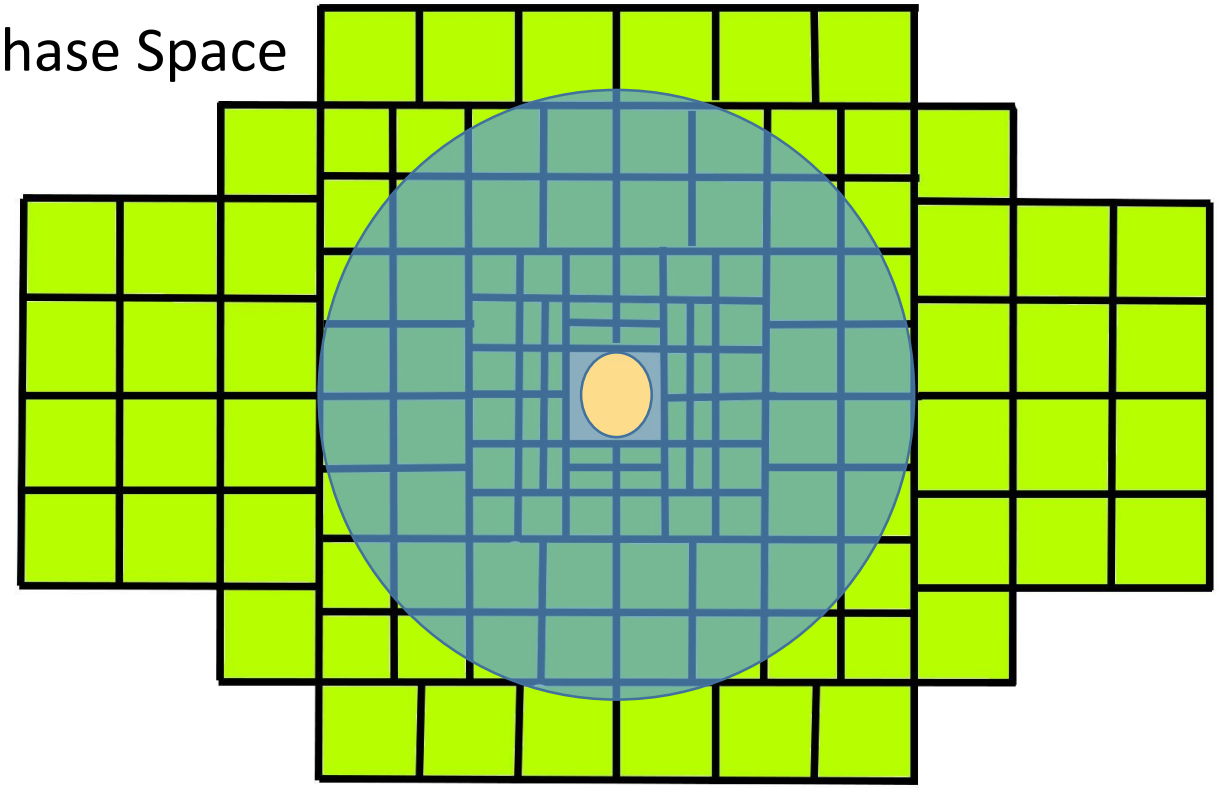


Planarity: Geometrical variable

Find eigenvalues (λ_{max}, λ_{min}) and eigenvectors

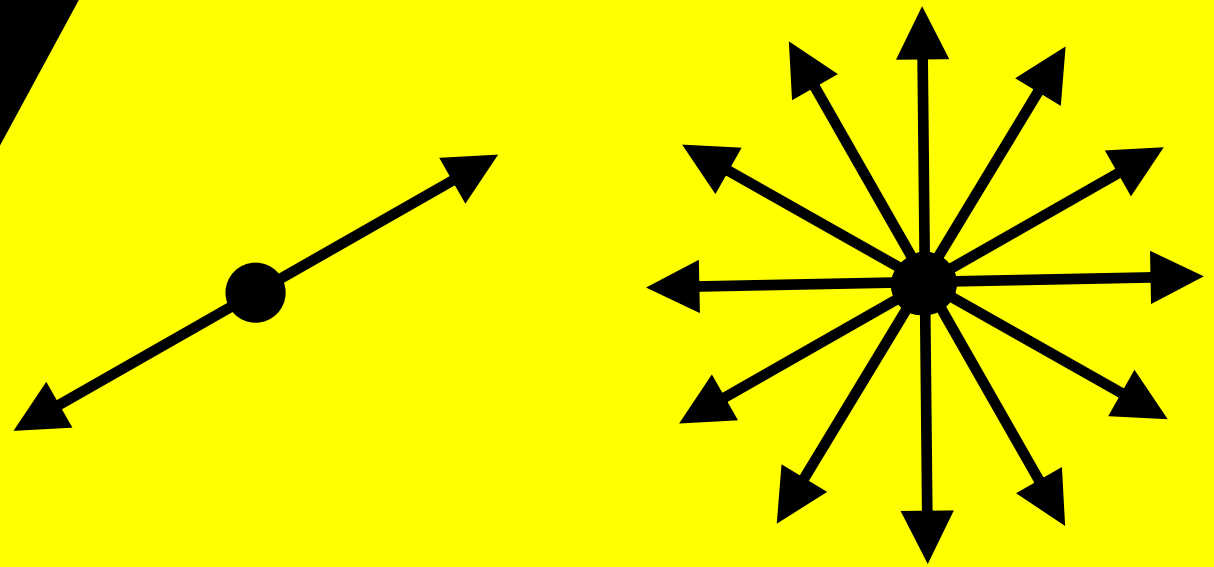
$$\begin{pmatrix} \sum p_x^2 & \sum p_x p_y \\ \sum p_x p_y & \sum p_y^2 \end{pmatrix}$$

Define planarity

$$P = \frac{\lambda_{\max} - \lambda_{\min}}{\lambda_{\max} + \lambda_{\min}}$$

Define transverse momentum fraction

$$x_{\perp} = \frac{\Sigma |\vec{p}_{\perp}|}{E_{CM}}$$



P = 1

P = 0

RAPID COMMUNICATIONS

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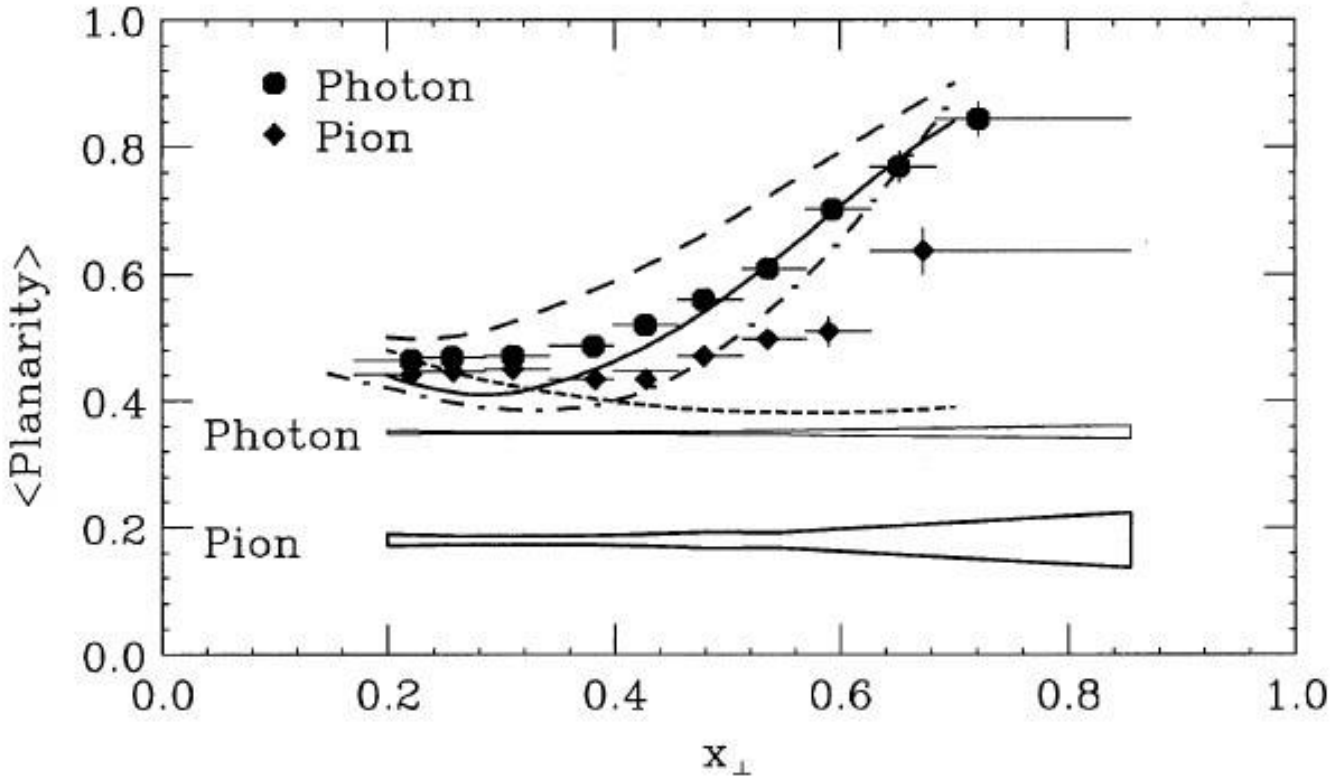
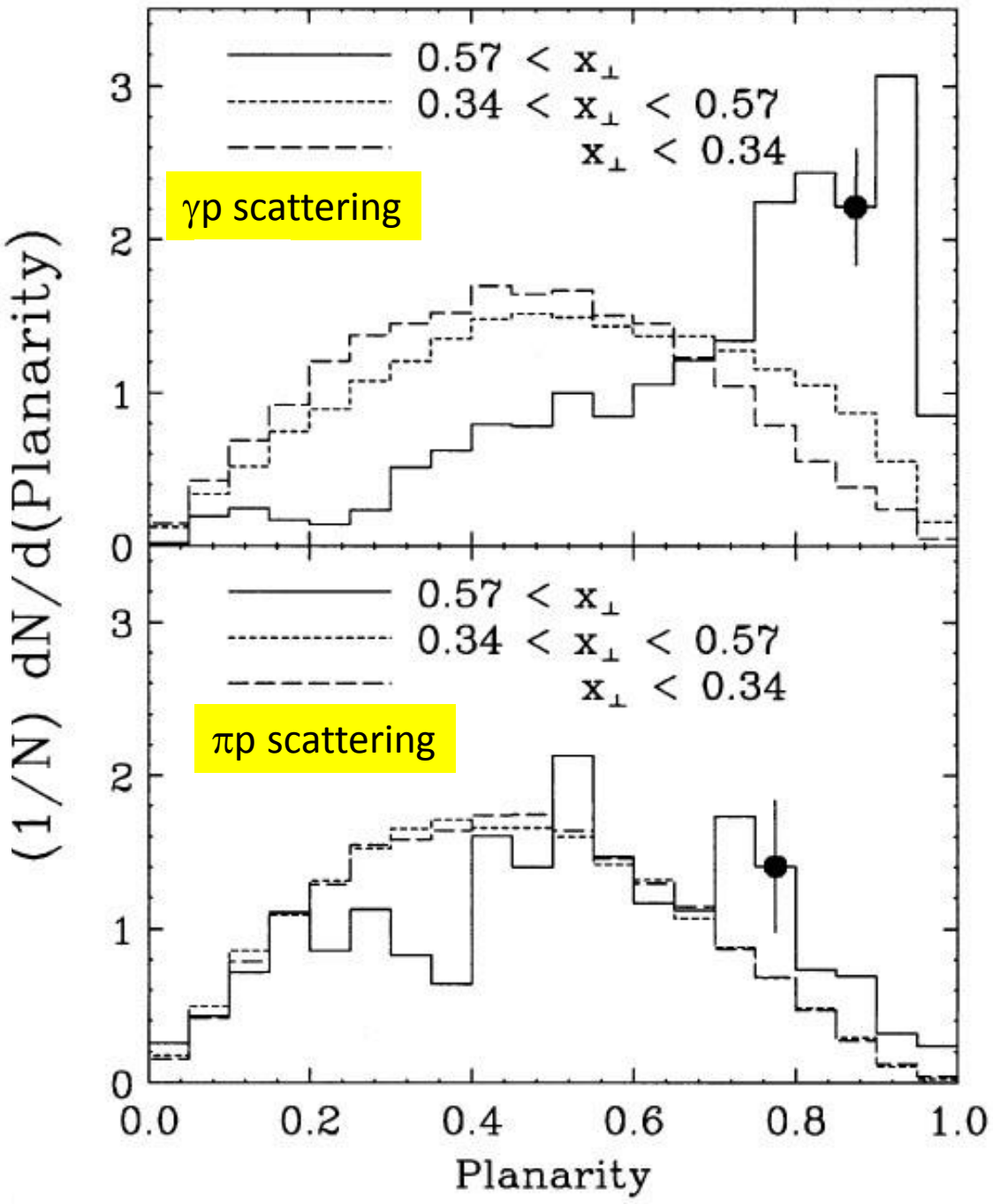
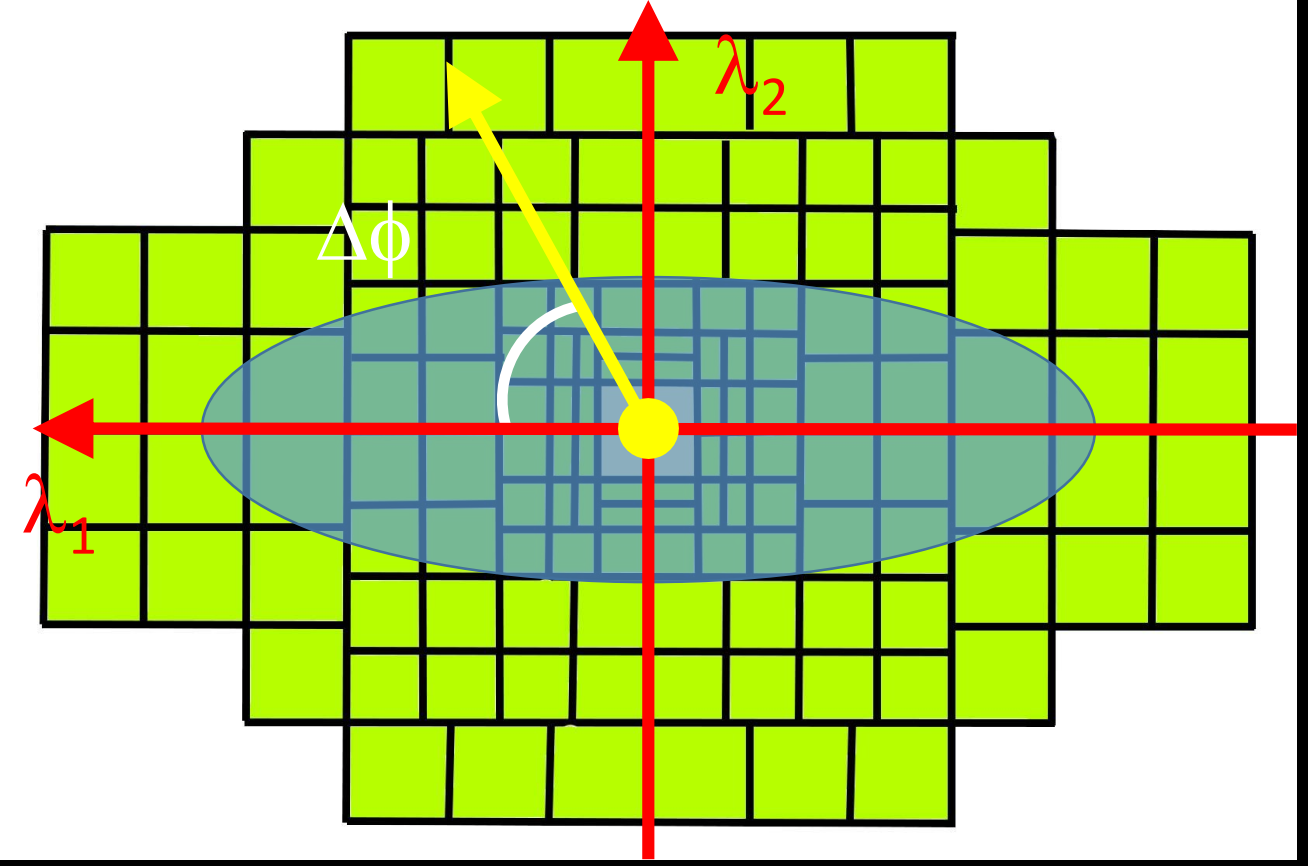
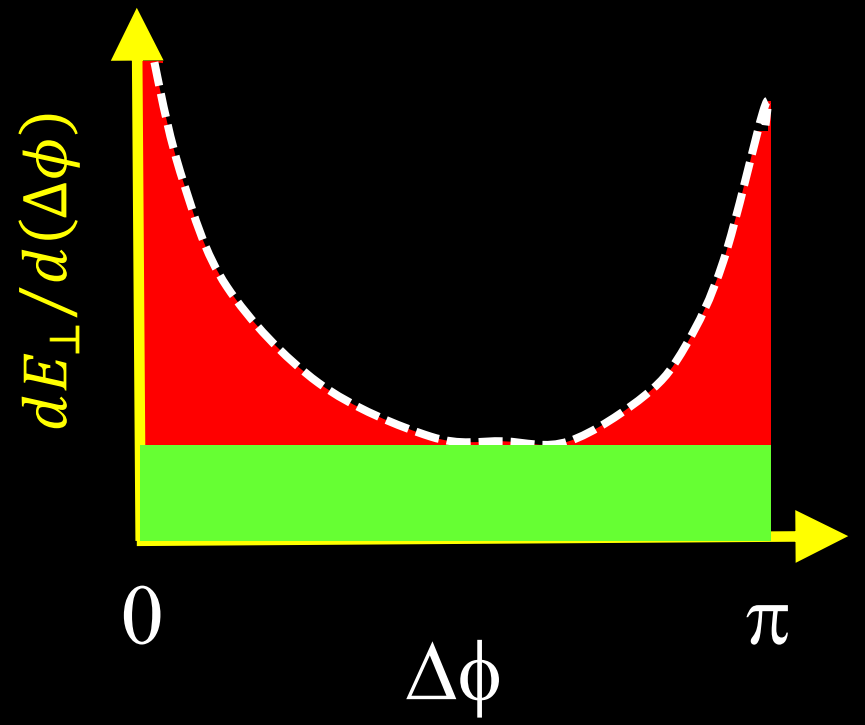


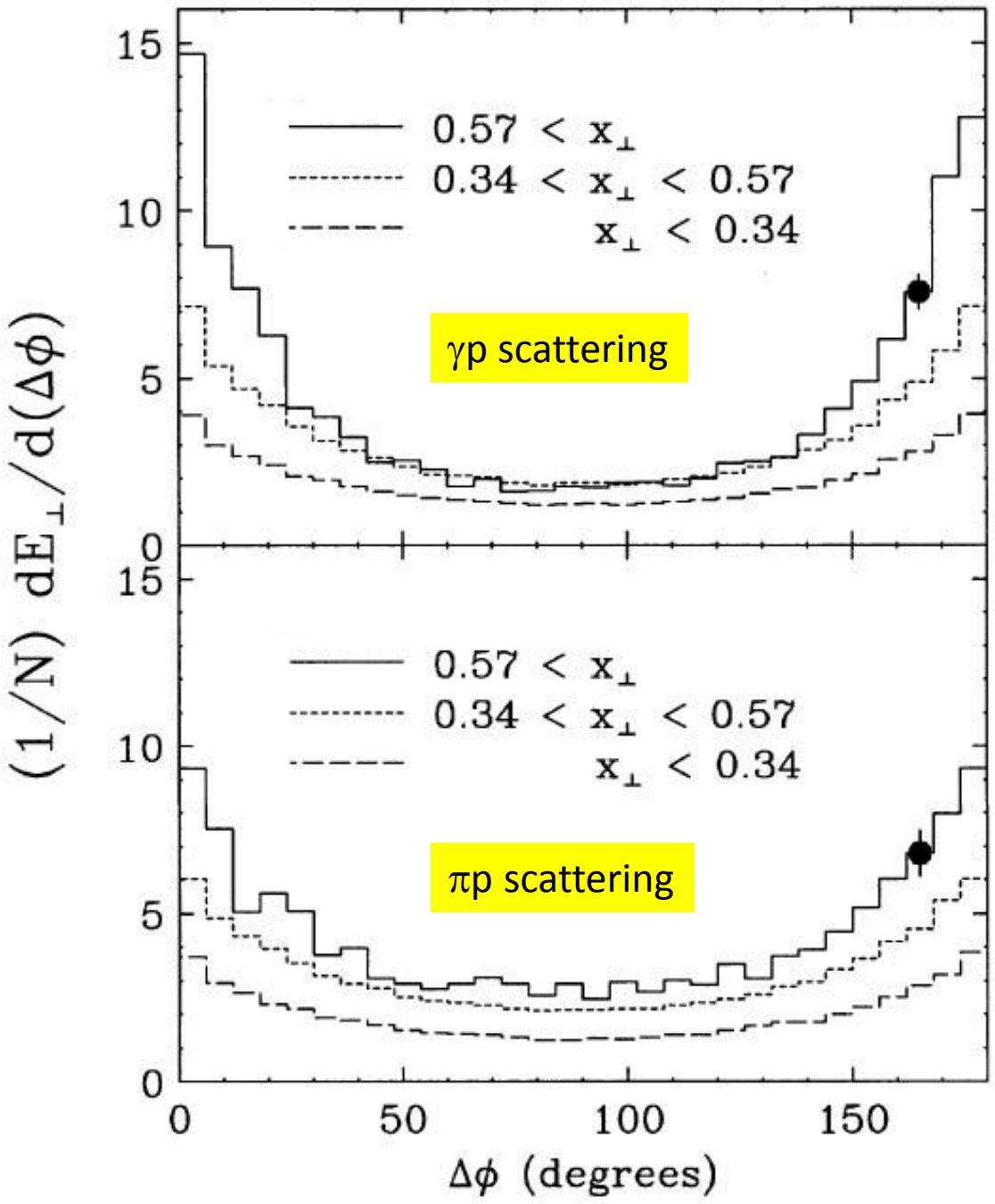




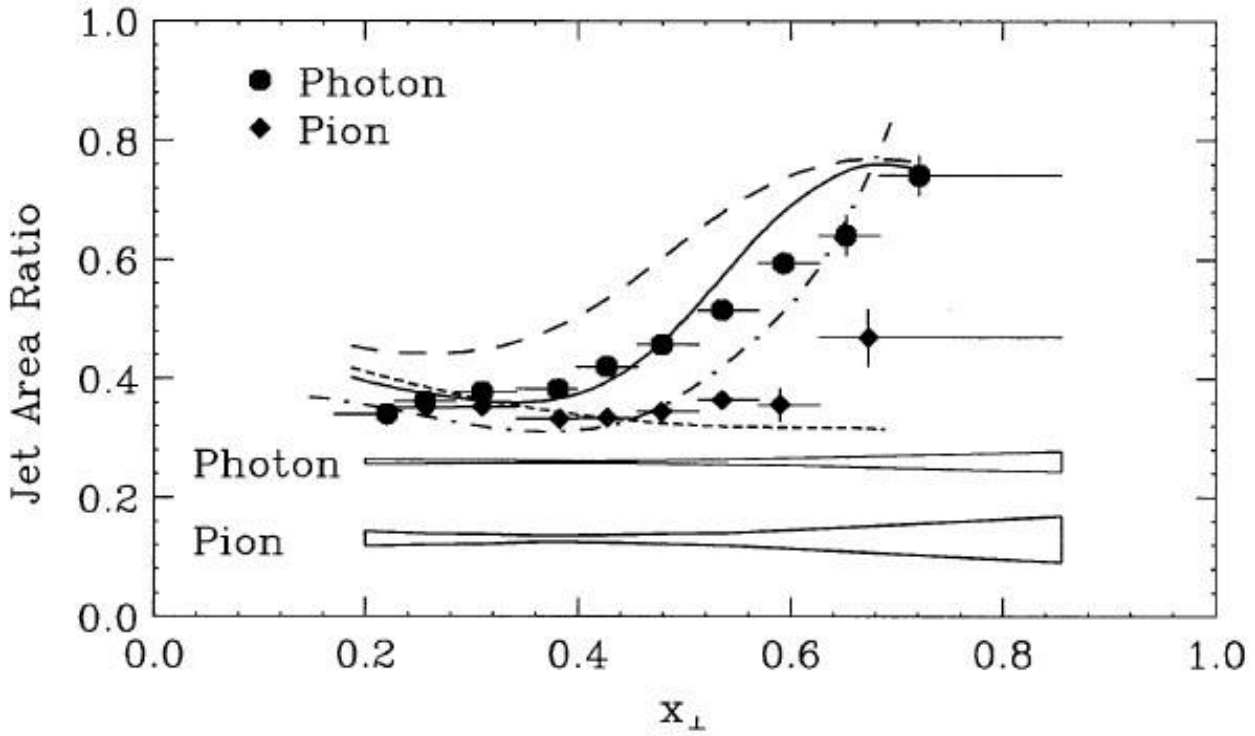
$$\begin{pmatrix} \sum p_x^2 & \sum p_x p_y \\ \sum p_x p_y & \sum p_y^2 \end{pmatrix}$$



Jet Area Ratio = $\dfrac{\text{red}}{\text{red} + \text{green}}$



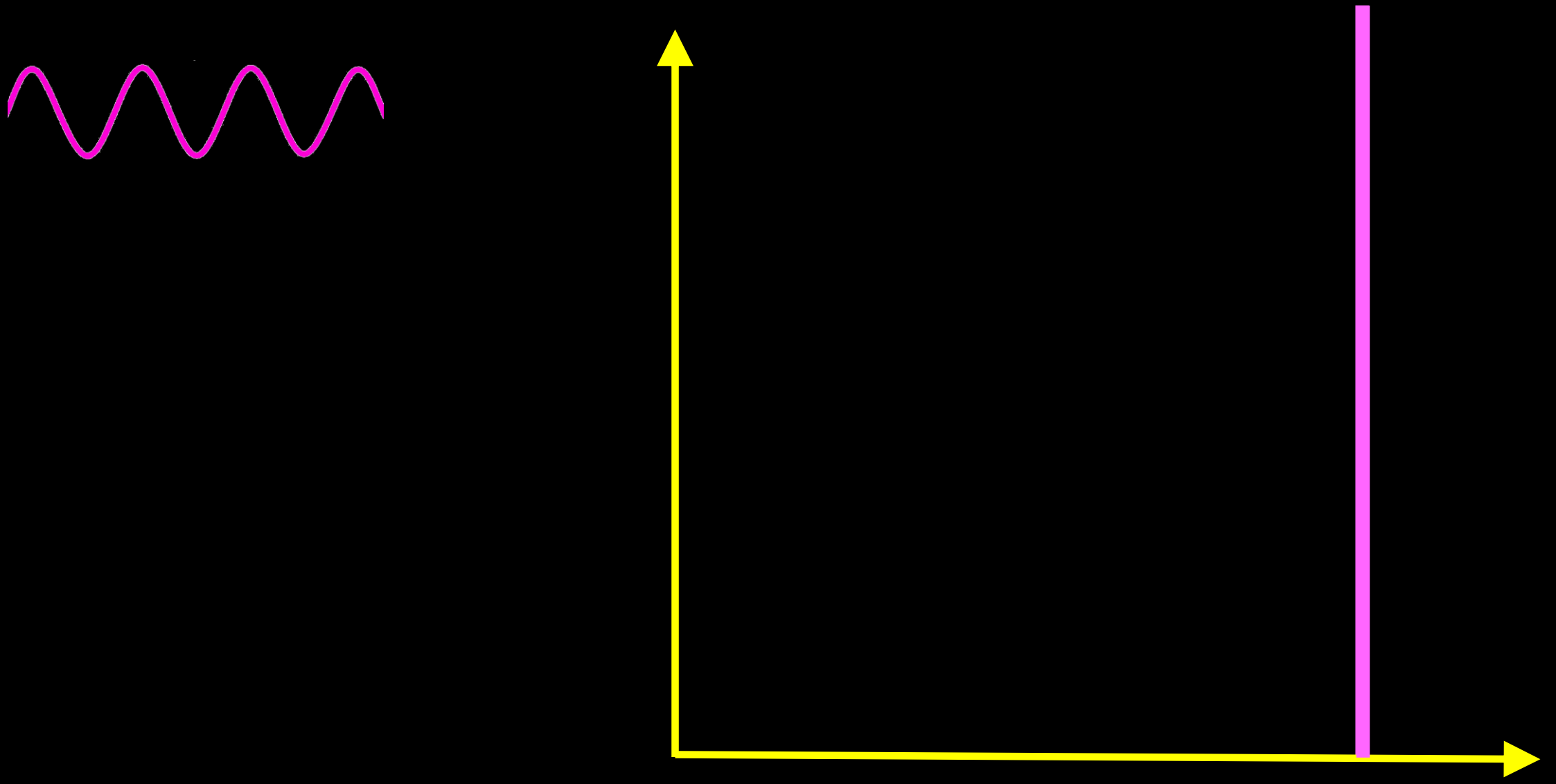
Jet production in γp scattering becomes evident at lower transverse energy than in πp scattering.



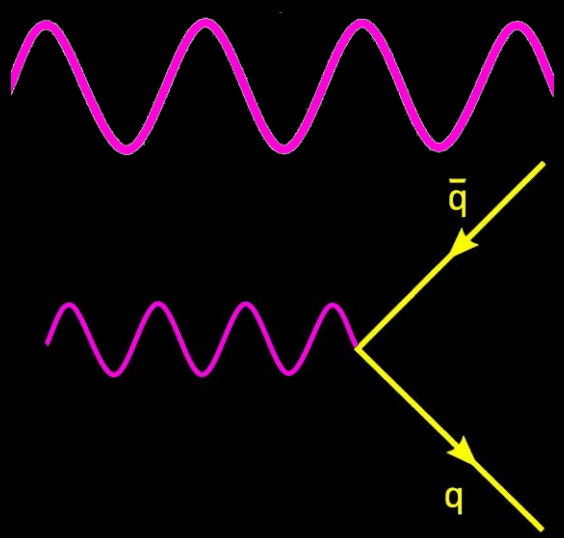
E683 Summary

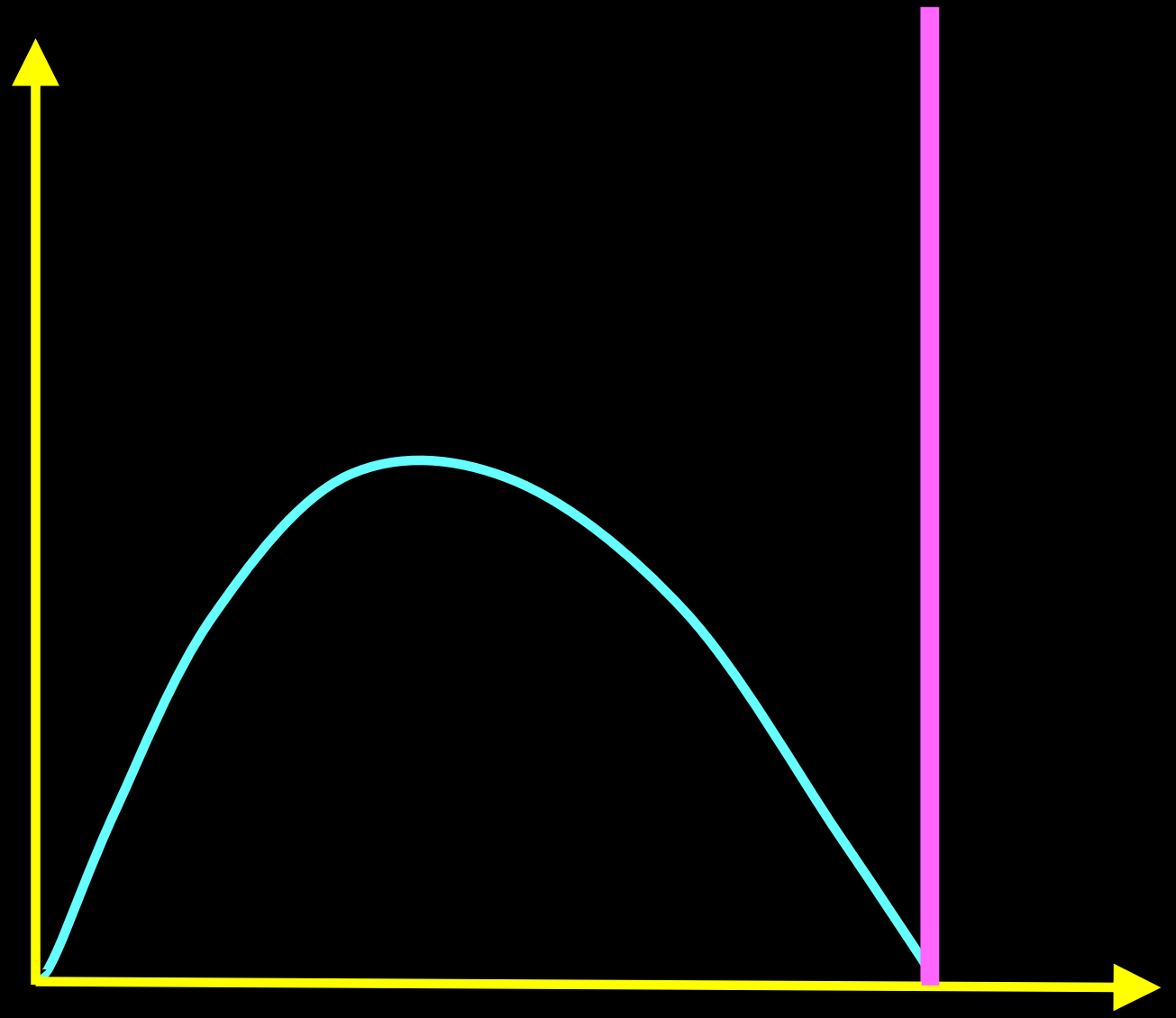
- Experiment had grand goals
  - Measure jet cross section & determine jet structure
- Energy scale very low for perturbative QCD tests
  - Non-perturbative effects dominated many measurements
- Experimental goals realigned to explore this tricky theoretical realm in which perturbation techniques are ineffective.
- 6 Ph.D. theses, 5 M.A. theses, 3 papers in PRL or PRD-RC
- None of this would have been possible without Marj

Photon Structure [momentum fraction]

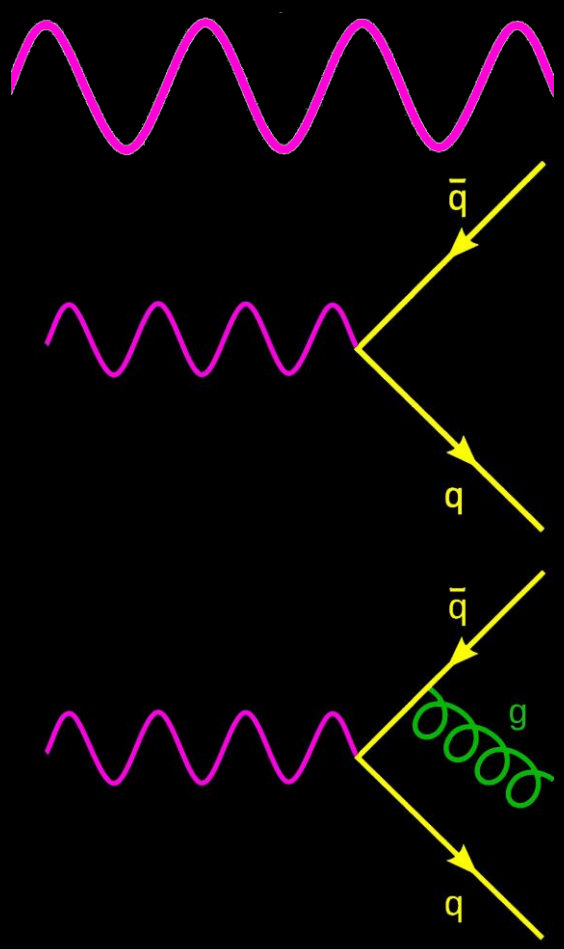


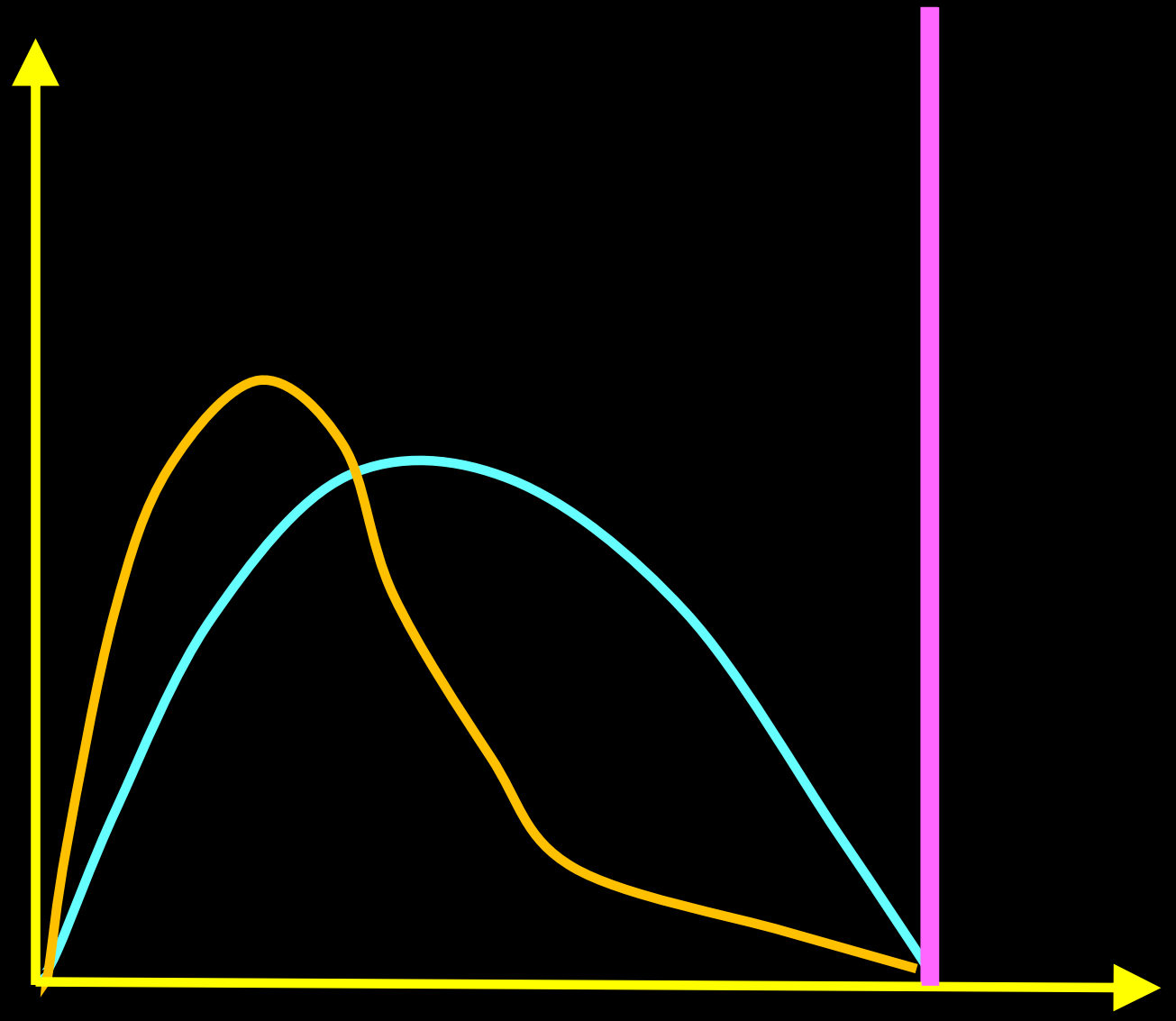
Photon Structure [momentum fraction]





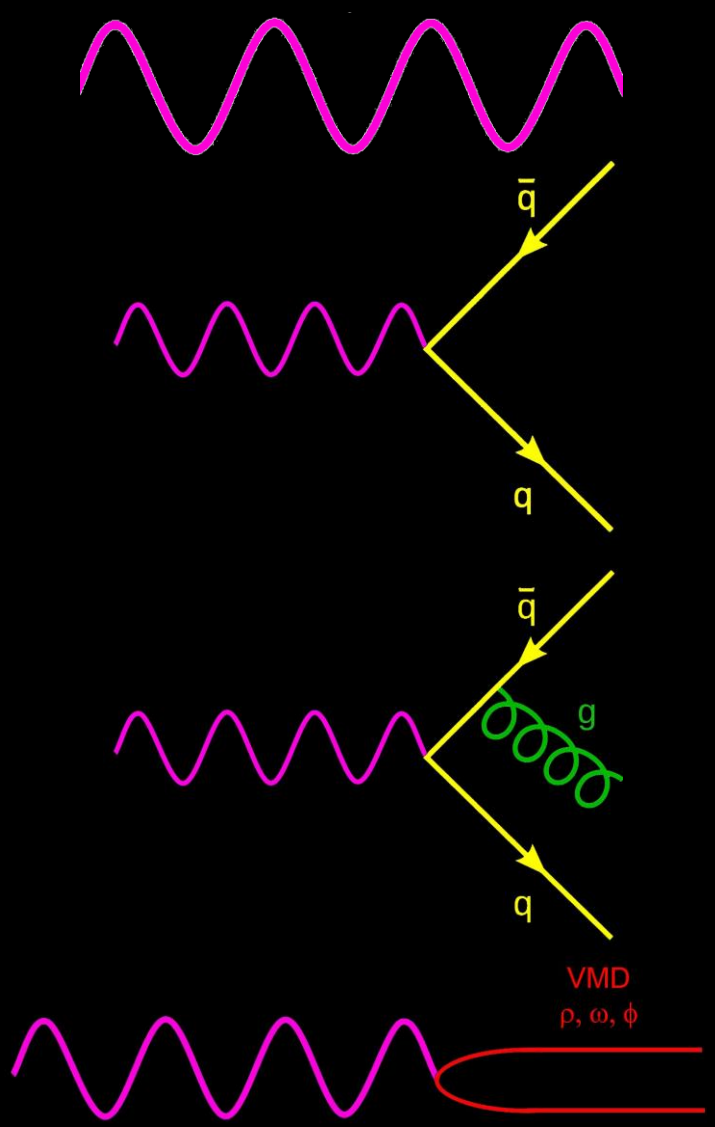
Photon Structure [momentum fraction]

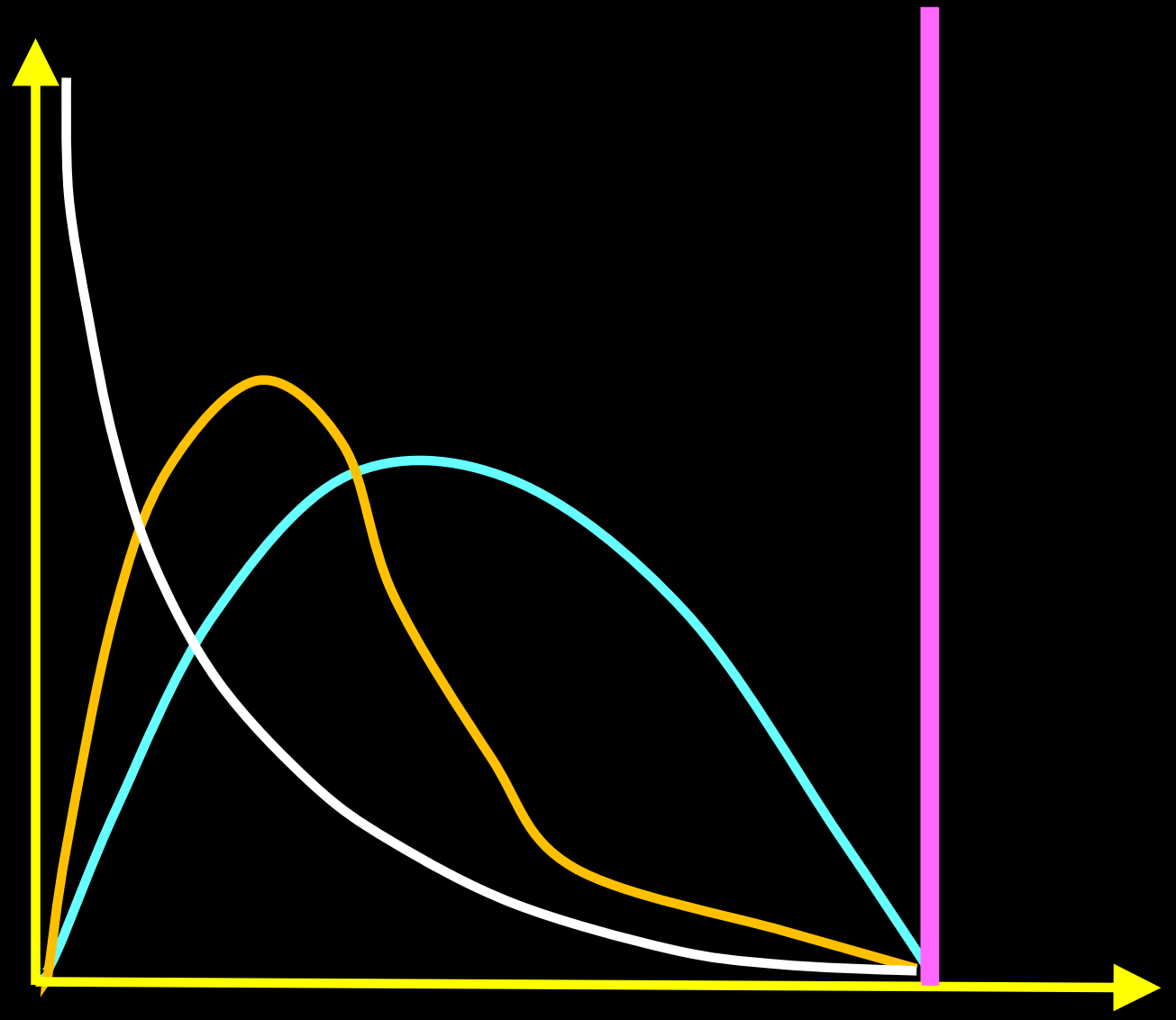




Photon momentum fraction

Photon Structure [momentum fraction]





Photon momentum fraction

Observation of Jet Production by Real Photons

D. Adams,[6] S. Ahmad,[6] N. Akchurin,[3] P. Birmingham,[7] H. Breuer,[4] C. C. Chang,[4] S. Cihangir,[2] M. D. Corcoran,[6] W. L. Davis,[1] H. R. Gustafson,[5] H. Holmgren,[4] P. Kasper,[2] J. Kruk,[6] D. Lincoln,[6] M. J. Longo,[5] J. Marraffino,[2] J. McPherson,[3] H. E. Miettinen,[6] G. Morrow,[6] G. S. Mutchler,[6] D. Naples,[4,*] Y. Onel,[3] J. Skeens,[6] G. P. Thomas,[1] M. M. Traynor,[6] J. W. Waters,[7] M. S. Webster,[7] J. P. Xu,[6] and Q. Zhu[6,†]

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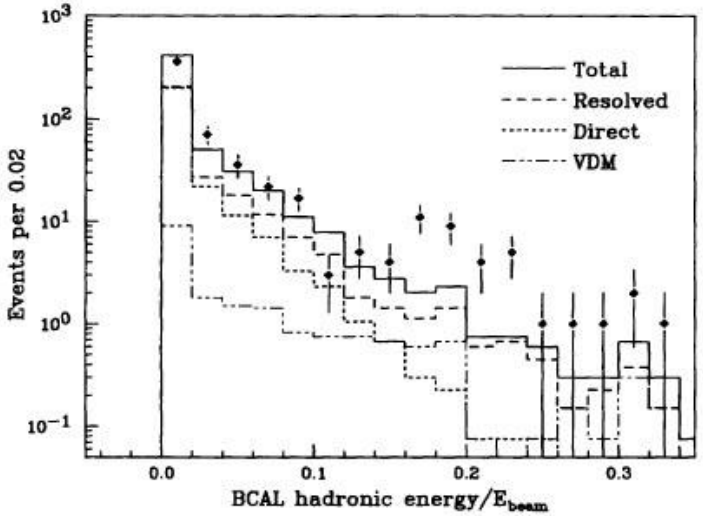
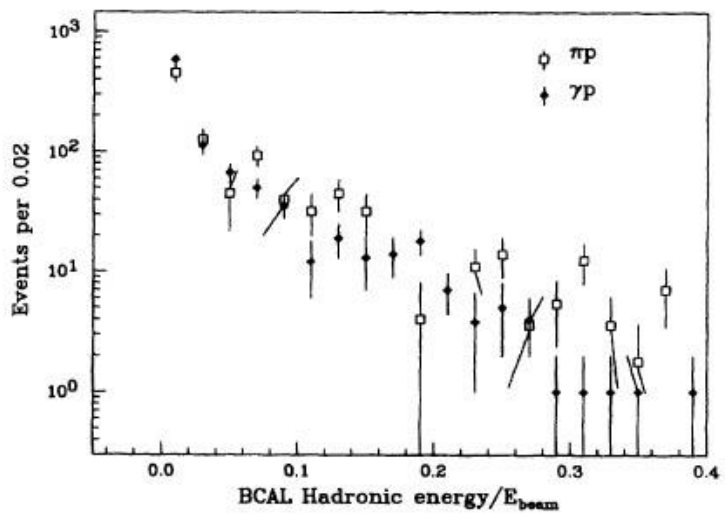
Interactions of high energy photons on a hydrogen target have been studied using a large acceptance segmented calorimeter. The event topology clearly shows the production of dijet final states as predicted by perturbative QCD. The energy flow in the photon (forward) direction is compared to Monte Carlo expectations and to that produced in πp interactions.

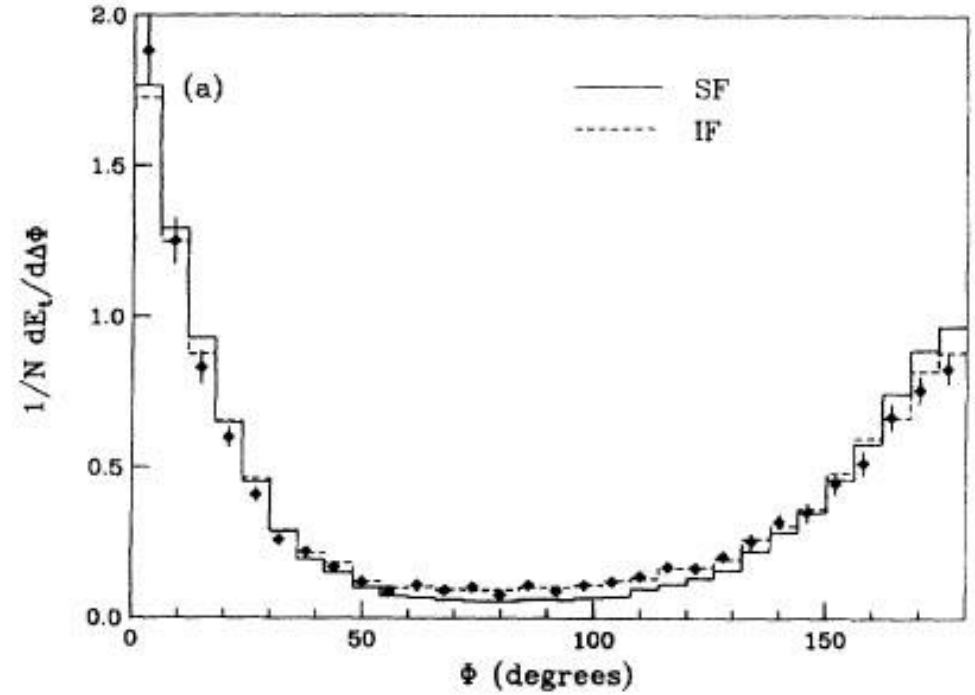
PACS numbers: 13.87.Ce, 12.38.Qk, 13.60.Hb

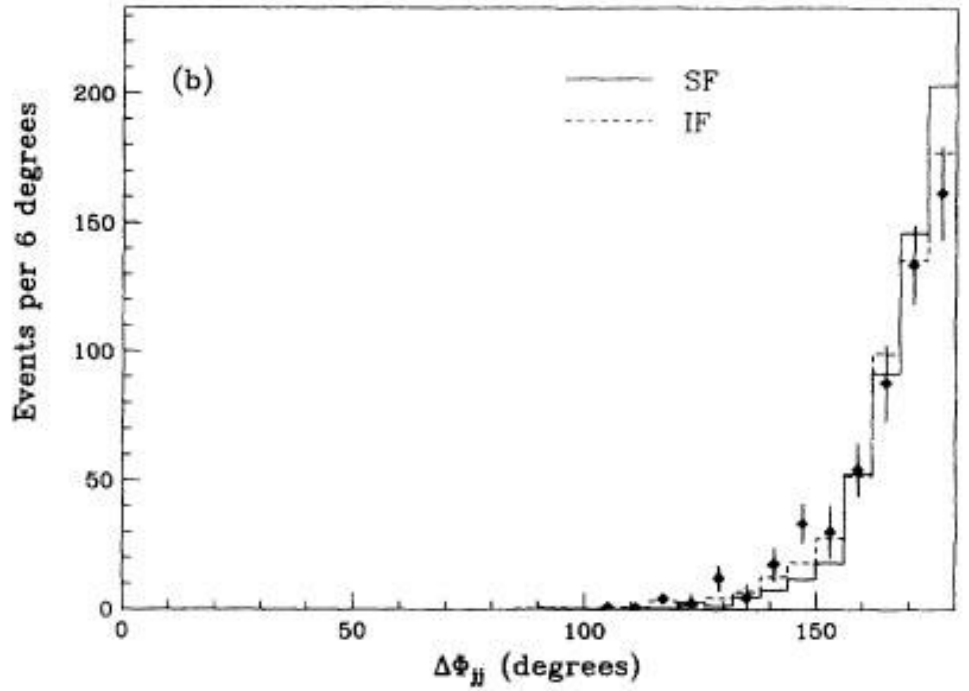
Jets arise from the fragmentation of partons in hard scattering processes. Jets have been observed in many experiments in hadron-hadron interactions [1] as well as in deep inelastic lepton-hadron interactions [2] and e^+e^- annihilations [3]. Single high p_t hadrons and energy flow distributions have been studied in earlier, lower energy, photoproduction experiments [4], but until now no observation has been made of jet production by a real photon beam. Recent results from the DESY ep collider HERA show evidence for hard scattering in quasireal-photon-

in experiment E683 in the wide band photon beam at Fermilab, which has incident tagged photon energies ranging from 50 to 400 GeV. Jets have been observed in the p_t range of 3–9 GeV/c. Photons were produced by bremsstrahlung from a secondary electron beam incident on a lead radiator which was 20% of a radiation length. The incoming electron beam had a mean momentum of 310 GeV/c, and an rms momentum spread of $\pm 15\%$. The energy of the incoming electrons was tagged by an array of silicon microstrip detectors. After the electron









A Dependence of Photoproduced Dijets

D. Naples,[4,*] N. Akchurin,[3] P. Birmingham,[7] H. Breuer,[4] C. C. Chang,[4] S. Cihangir,[2] M. D. Corcoran,[6] W. L. Davis,[1] H. R. Gustafson,[5] H. Holmgren,[4] P. Kasper,[2] D. Lincoln,[6] M. J. Longo,[5] J. Marraffino,[2] J. McPherson,[3] H. E. Miettinen,[6] G. Morrow,[6] G. S. Mutchler,[6] Y. Onel,[3] G. P. Thomas,[1] M. M. Traynor,[6] J. W. Waters,[7] M. S. Webster,[7] J. P. Xu,[6] and Q. Zhu[6,†]

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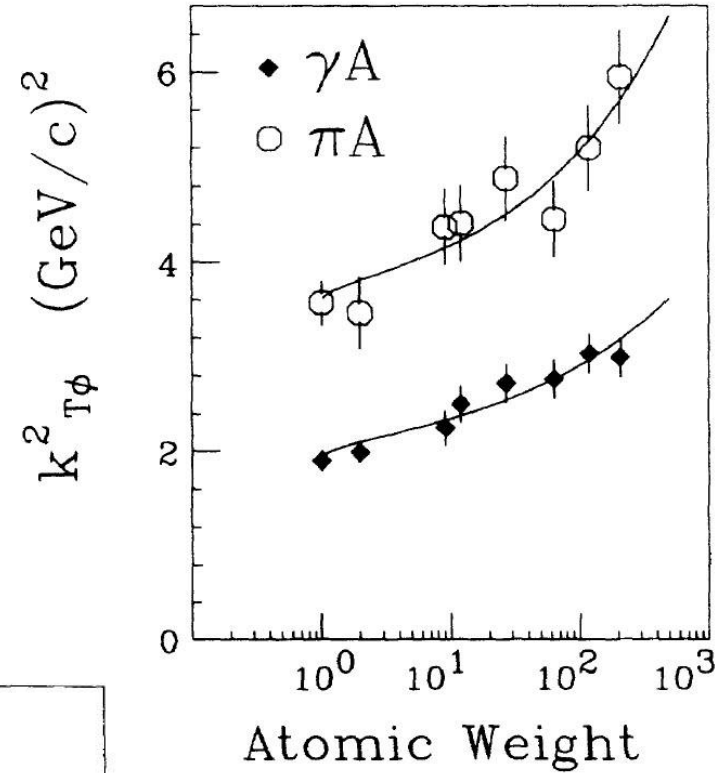
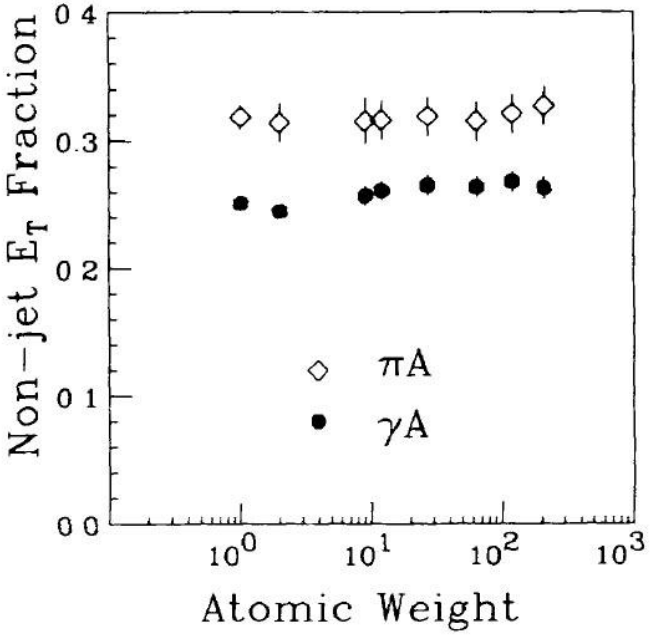
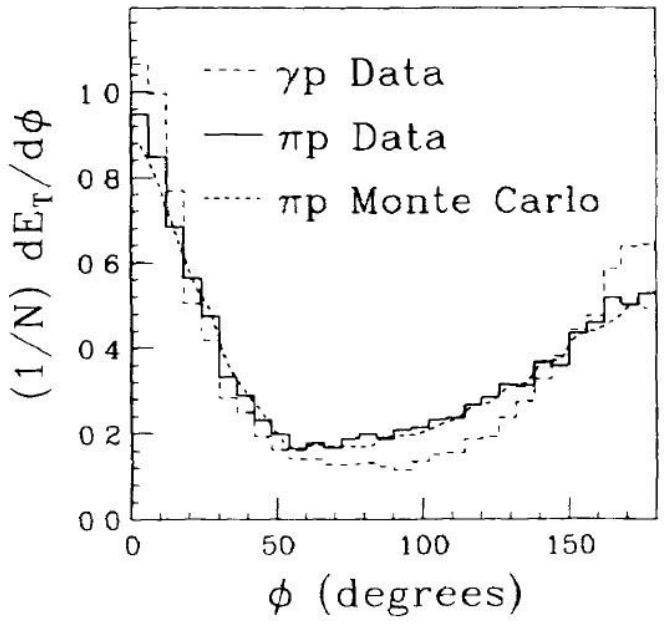
We present a measurement of the A dependence of $k_{T\phi}$, the out-of-plane component of the dijet transverse momentum, in dijet events produced with a real photon beam. We also present the same measurement for dijets produced from pion-nucleus collisions in our detector. Both data sets are taken at a mean $\sqrt{s}$ of 21 GeV in the p_T range 3–7 GeV/c. A clear A dependence of comparable magnitude is seen in both processes. The energy dependence of the nuclear behavior is also extracted.

PACS numbers: 13.87.Ce, 13.60.Hb, 25.20.Lj, 25.80.Ls

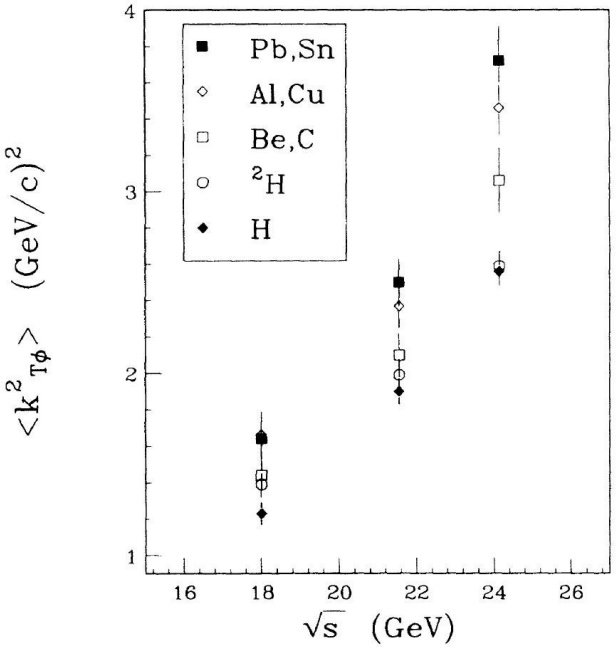


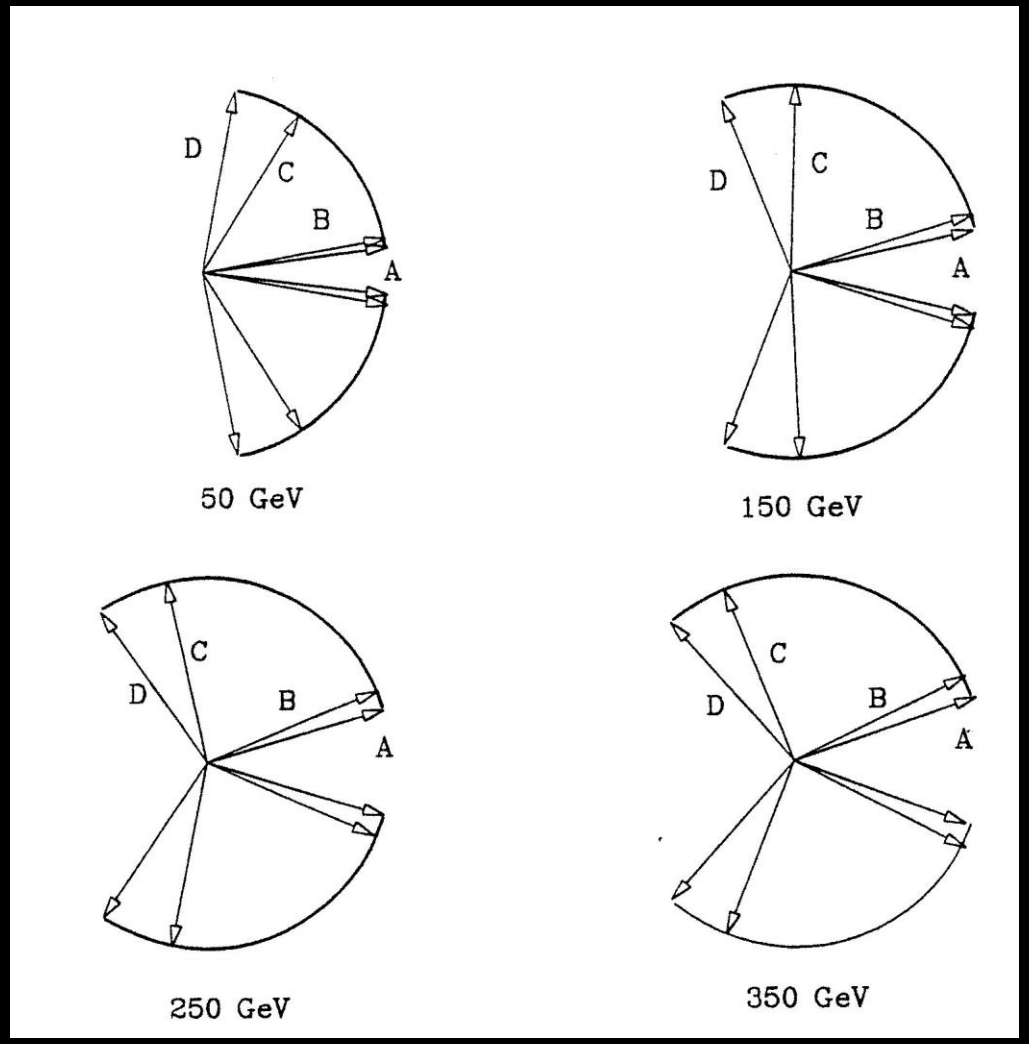


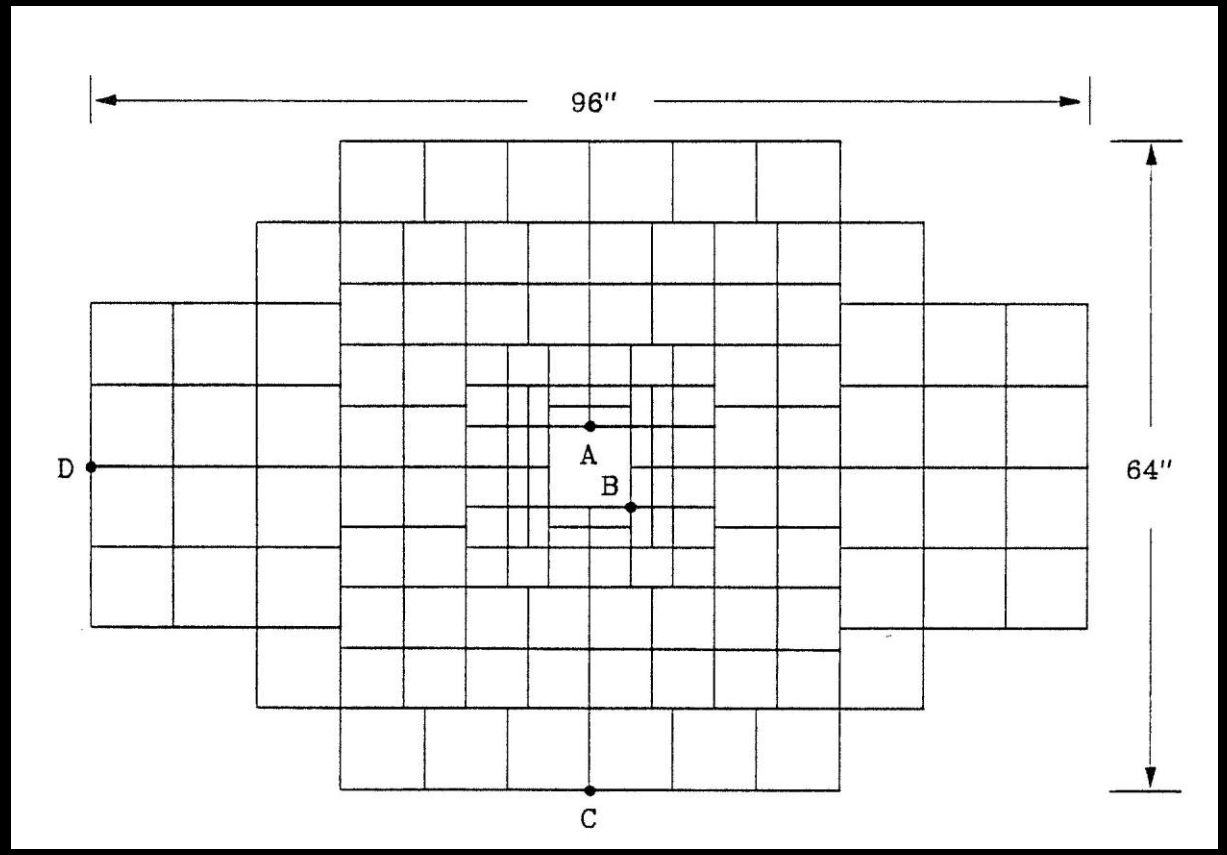
(a)



(b)




D
C
B
A
50 GeV
D
C
B
A
150 GeV
D
C
B
A
250 GeV
D
C
B
A
350 GeV


96"
64"
D
A
B
C