Testing

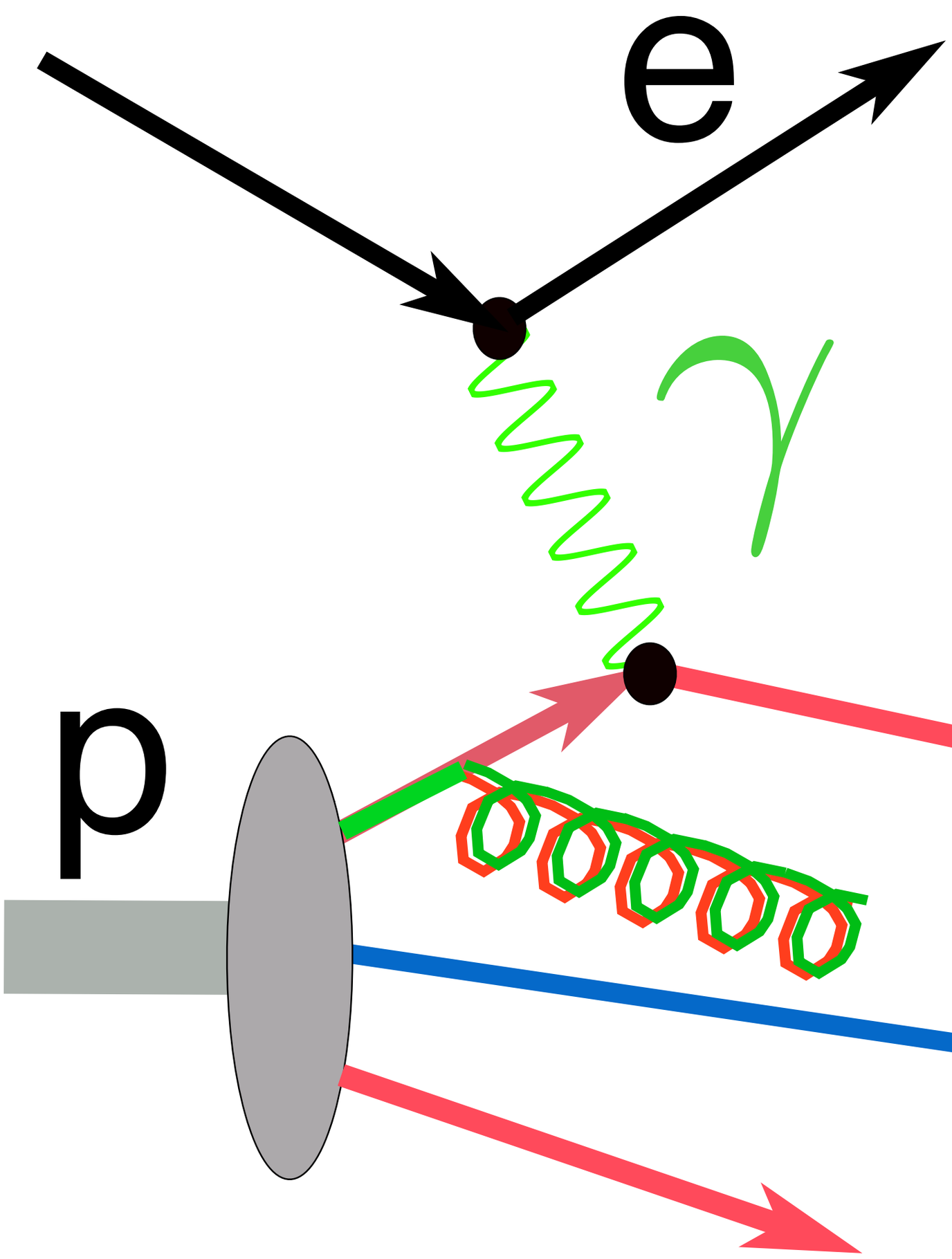
... ...

TESTING !!!!

The November 74 Revolution and thereabouts

- A WITNESS'S ACCOUNT

How do Quarks "Function"?



SLAC / MIT circa 1965

Feynman's Pointlike(?) Partons

Bjorken's Scaling

QCD's Asymptotic Freedom

Reliable Perturbative Results for Strong Interactions?*

H. David Politzer

Jefferson Physical Laboratories, Harvard University, Cambridge, Massachusetts 02138

(Received 3 May 1973)

An explicit calculation shows perturbation theory to be arbitrarily good for the deep Euclidean Green's functions of any Yang-Mills theory and of many Yang-Mills theories with fermions. Under the hypothesis that spontaneous symmetry breakdown is of dynamical origin, these symmetric Green's functions are the asymptotic forms of the physically significant spontaneously broken solution, whose coupling could be strong.

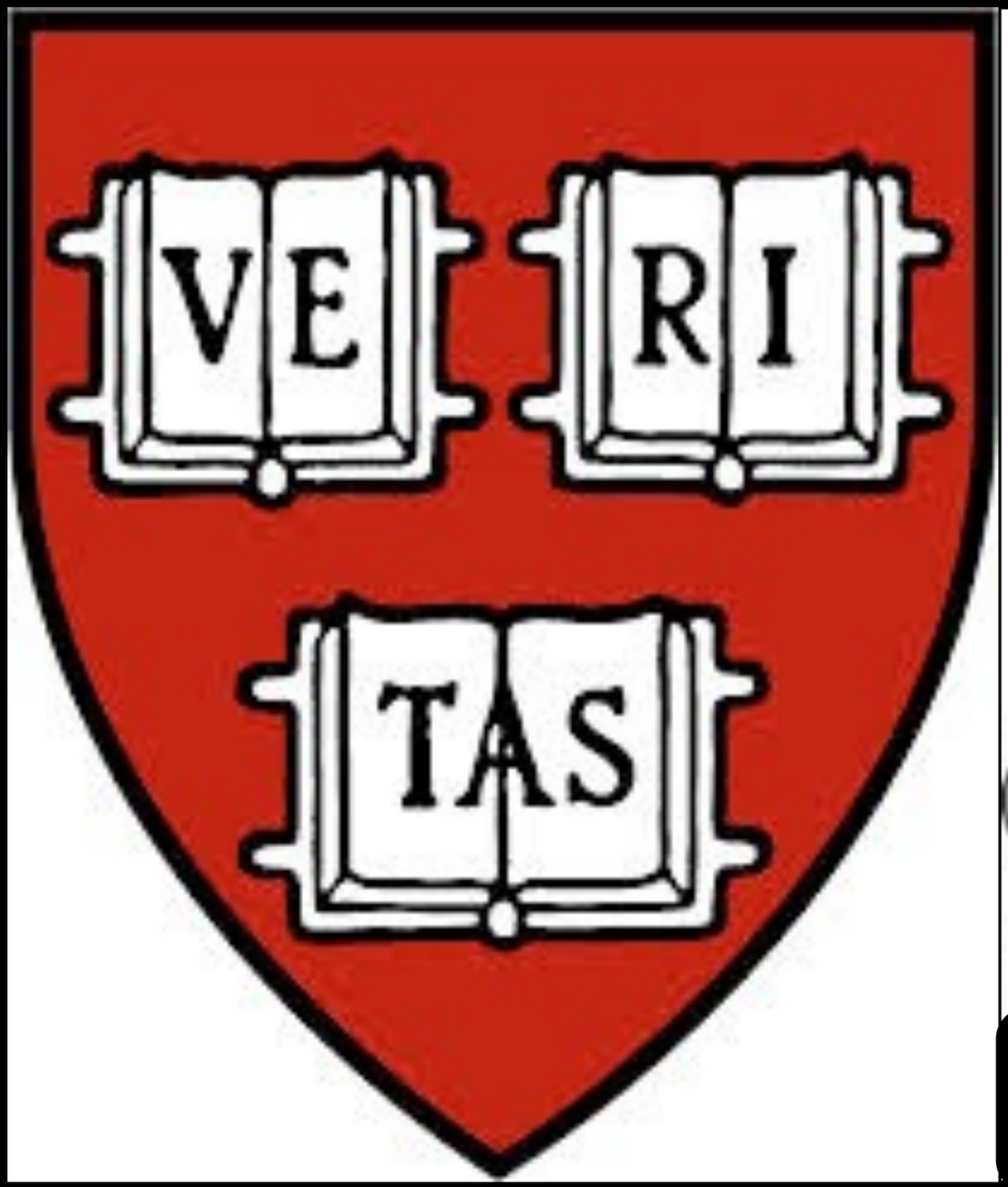
Ultraviolet Behavior of Non-Abelian Gauge Theories*

David J. Gross† and Frank Wilczek

Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540

(Received 27 April 1973)

It is shown that a wide class of non-Abelian gauge theories have, up to calculable logarithmic corrections, free-field–theory asymptotic behavior. It is suggested that Bjorken scaling may be obtained from strong-interaction dynamics based on non-Abelian gauge symmetry.



God Went to Princeton

The Dilemma of Attribution

David Politzer's Nobel Lecture

Witness account :

Frequent reference to work by ADR **et al.**

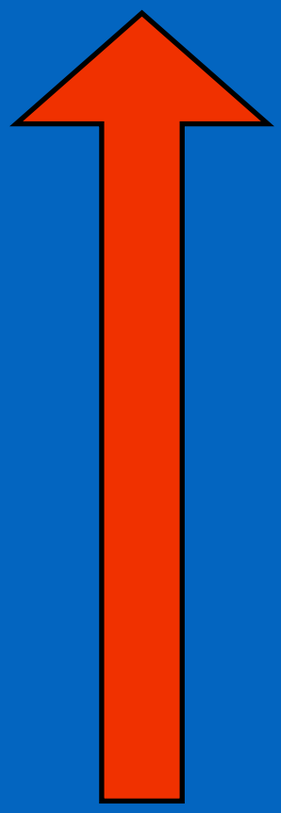
"I never travel without my diary. One should always have something sensational to read in the train."

Golda Meir:
Don't be humble...
you're not that great.

unlike

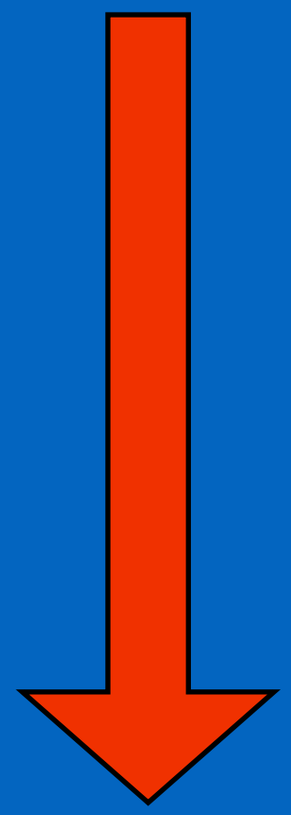
"et al."

right x, t

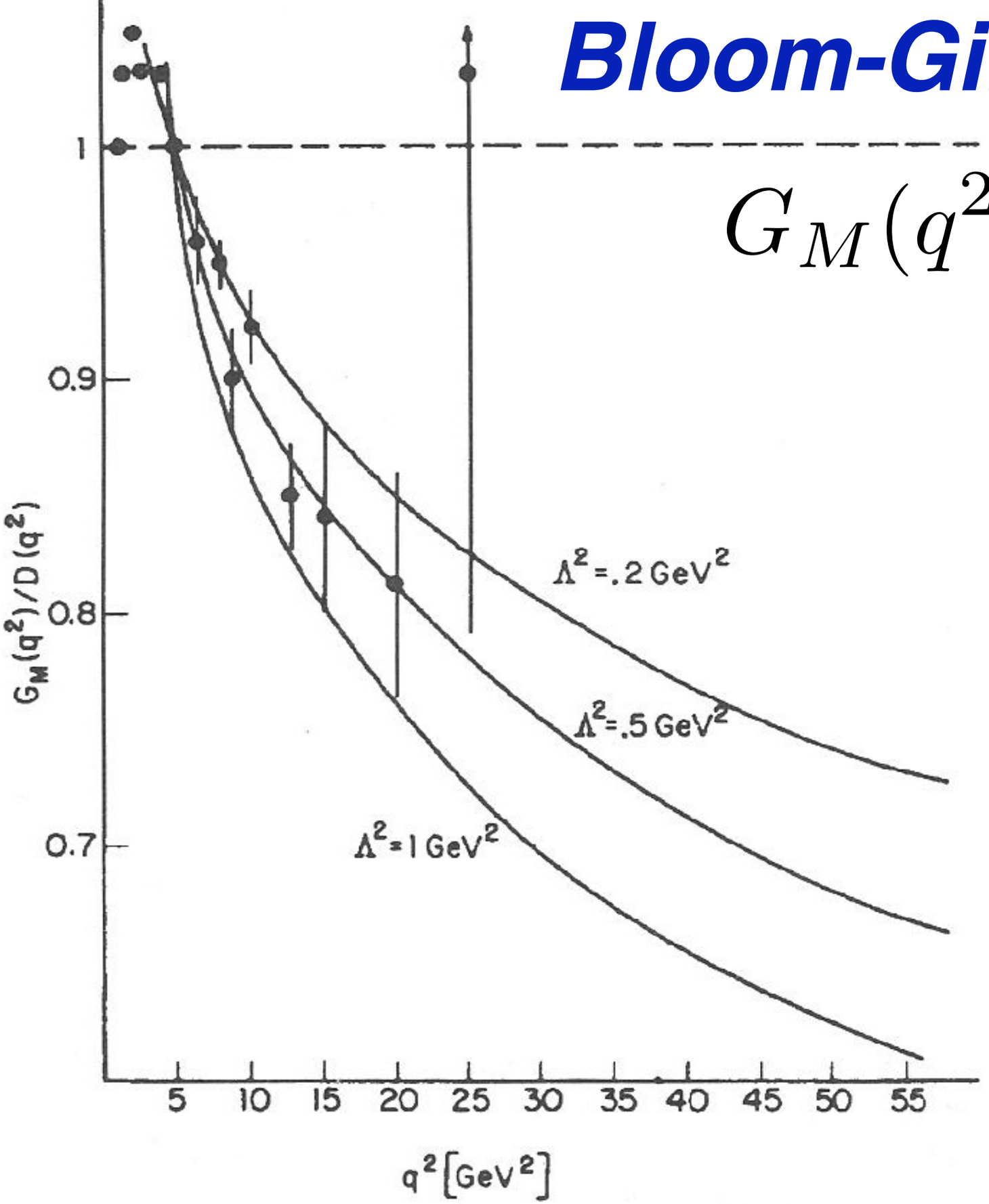


First two papers on Asymptotic Freedom (Theory)

First two papers on Asymptotic Freedom (Phenomenology)



Bloom-Gilman Duality



$$G_M(q^2) \leftrightarrow \nu\, W_2(\xi_p, q^2)$$

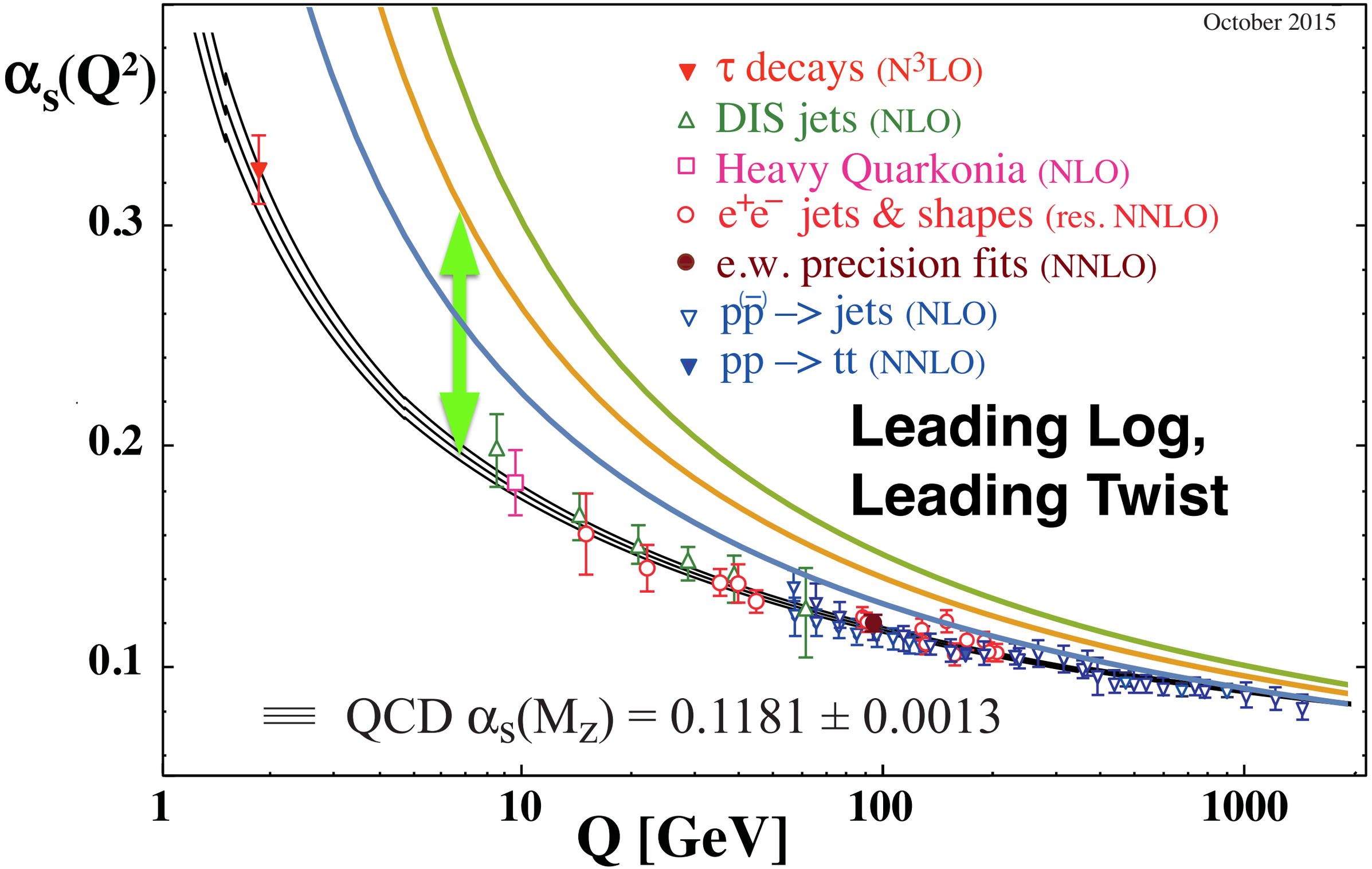
$$\alpha_s \equiv \frac{g_s^2}{4\,\pi} = \frac{12}{25\;\pi \ln[q^2/\Lambda^2]}$$

ADR PRL 26/3/74

$$\alpha_s \leftrightarrow \Lambda(\mathrm{QCD})$$

Gross & Treiman
PRL 25/3/74

B-G D-ity ← **QCD** *ADR, Georgi & Politzer*



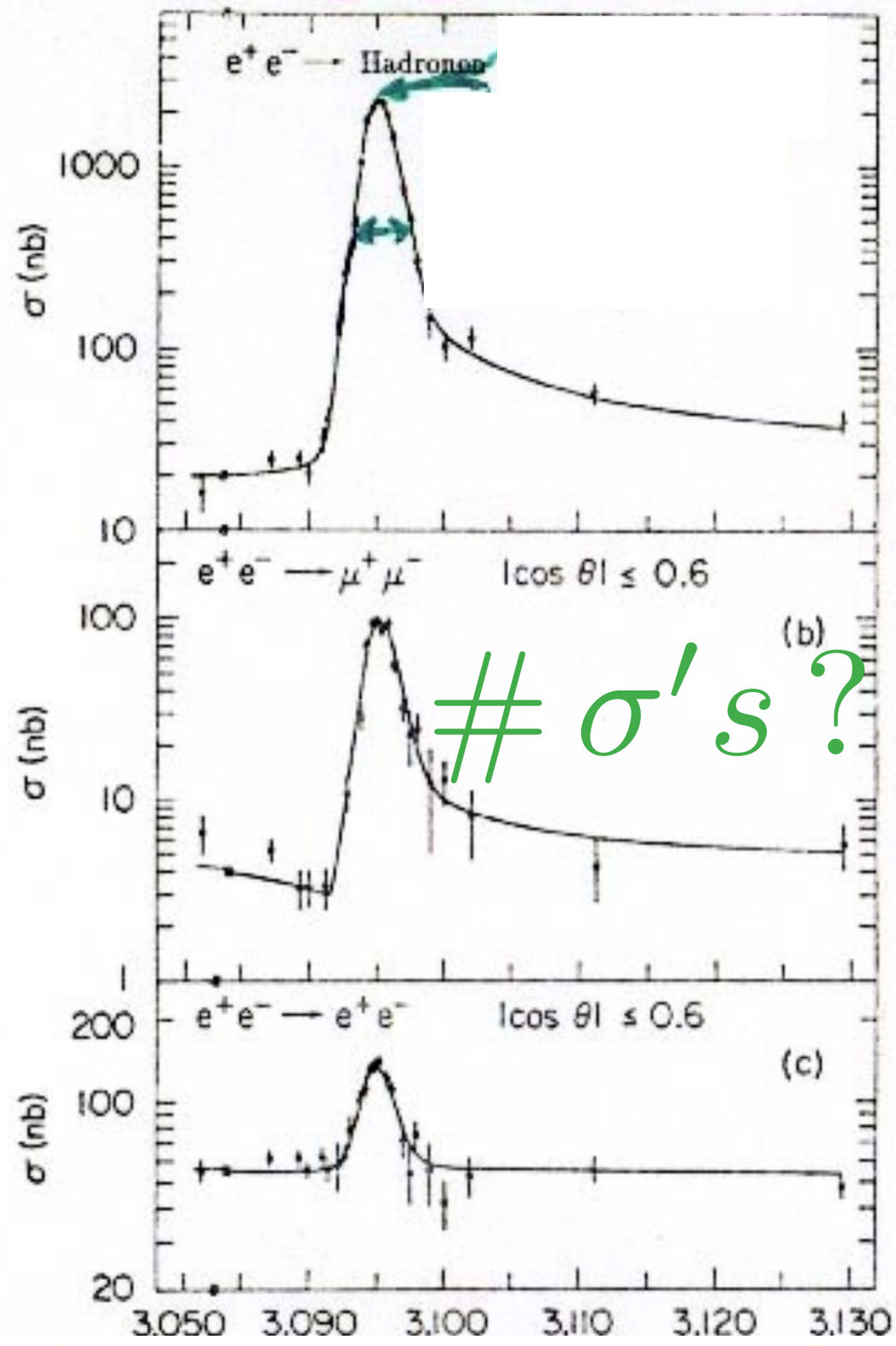
Λ_{QCD}

Only fundamental constant first measured by a theorist

If you would like your work to be ignored

BE A PHENOMENOLOGIST

NOVEMBER 1974



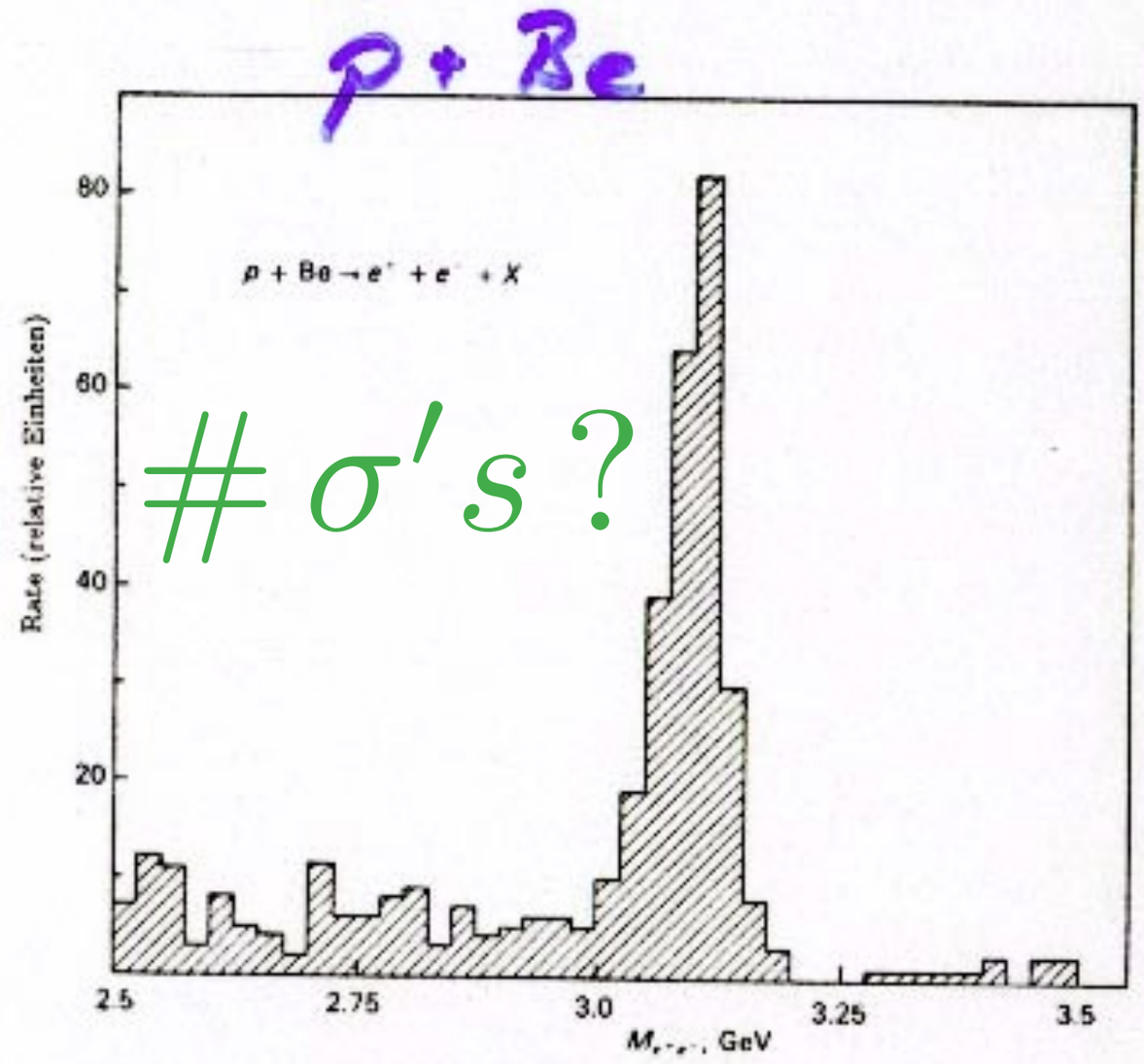
#σ's?

Augustin et al.

SLAC, Nov 13

Ψ

p + Be



#σ's?

Abbildung 5.10 Die Ergebnisse von Aubert et al. (1974) zeigen die schmale J/ψ-Resonanz in der Verteilung der invarianten Masse des e^+e^--Paars, das in inklusiven Reaktionen von Protonen an einem Berylliumtarget erzeugt wurde. Dies Experiment wurde am 28 GeV-AGS des Brookhaven National Laboratorys ausgeführt

Aubert et al.

BNL, Nov 12, J

Quarks, families, SU(3)xSU(2)xU(1) gauge theory…

1974: Not STANDARD

Considered by over-whelming majority:

A non-contageous tropical disease

FEVERISH REACTION

Phys. Rev. Lett. 34, many, (1975)

Published 6 January 1975

ALL UN-REFEREED !!

PRL

Are the New Particles Baryon-Antibaryon Nuclei?

Alfred S. Goldhaber and Maurice Goldhaber

Interpretation of a Narrow Resonance in e+ e- Annihilation

Julian Schwinger

Possible Explanation of the New Resonance in e+ e- Annihilation

S. Borchardt, V. S. Mathur, and S. Okubo

Model with Three Charmed Quarks **R. Michael Barnett**

Heavy Quarks and e+ e- Annihilation **Thomas Appelquist and H. David Politzer**

Is Bound Charm Found? **A. De Rújula and S. L. Glashow**

Possible Interactions of the J Particle

H. T. Nieh, Tai Tsun Wu, and Chen Ning Yang

Is the 3104-MeV Vector Meson the psi - Charm or the W0?

G. Altarelli, N. Cabibbo, R. Petronzio, L. Maiani, G. Parisi

Charm, EVDM and Narrow Resonances in e^+e^- Annihilation

Cesario A. Dominguez and Mario Greco

NCL

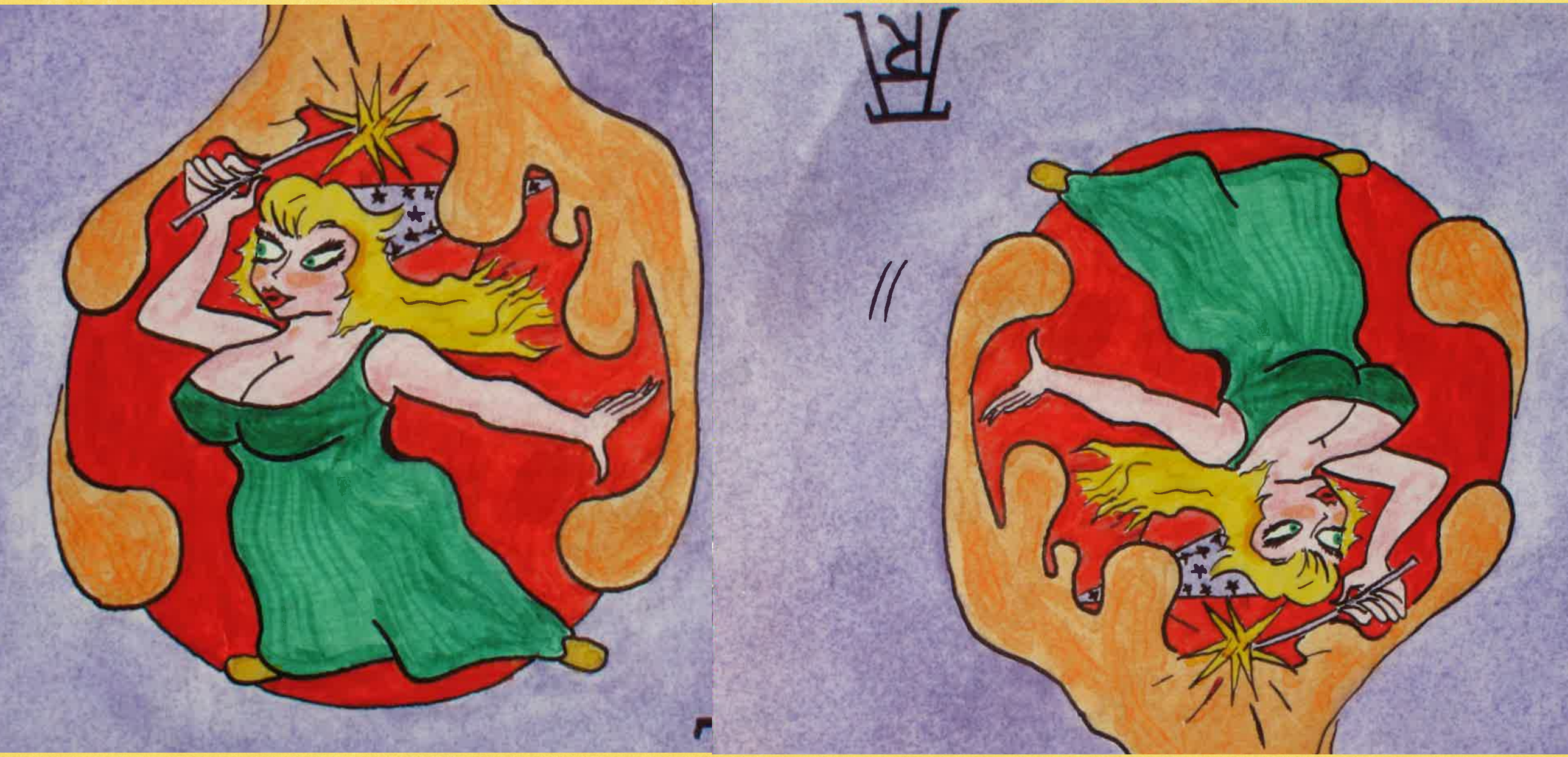
C.&M.: If you would like to have your work fully recognized

DO NOT BE PHENOMENOLOGISTS

750???

A weak lower limit
on the # of papers
on the 750-GeV
Di-photon

CHARMONIUM (name):
A VERY DISCREET CHARM



ONLY 3 GROUPS BET
FOR THE CORRECT INTERPRETATION

Heavy Quarks and $e^+ e^-$ Annihilation*

Thomas Appelquist† and H. David Politzer‡
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138
(Received 19 November 1974)

The effects of new, heavy quarks are examined in a colored quark-gluon model. The e^+e^- total cross section scales for energies far above any quark mass. However, it is much greater than the scaling prediction in a domain about the nominal two–heavy-quark threshold, despite $\sigma_{e^+e^-}$ being a weak-coupling problem above 2 GeV. We expect spikes at the low end of this domain and a broad enhancement at the upper end.

Harvard's papers on charmonium

Is Bound Charm Found?*

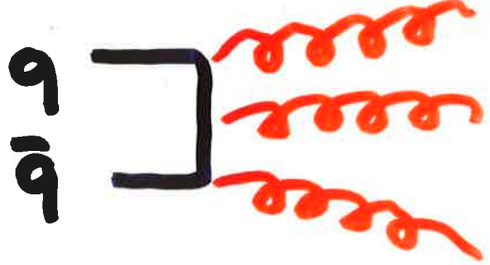
<= one full week after

A. De Rújula
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138

Cesareo D. & Mario G. and **Tom A. & David P.**

S. L. Glashow†
Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139
(Received 27 November 1974)

We argue that the newly discovered narrow resonance at 3.1 GeV is a $^3S_1$ bound state of charmed quarks and we show the consistency of this interpretation with known meson systematics. The crucial test of this notion is the existence of charmed hadrons near 2 GeV.

1^- 

"ABUSUS NON TOLLIT USUM"

$$\Gamma_{J/\psi}(\text{HADS}) \sim \frac{3}{2}\frac{M_{J/\psi}}{M_\varphi}\left[\frac{\alpha_s(3\text{GeV})}{\alpha_s(1\text{GeV})}\right]^6 *$$

$$\Gamma(\varphi \to 3\pi) \sim 42\,\text{keV}$$

... HOW TO FIND LESS DISCREETLY CHARMED PARTICLES IN

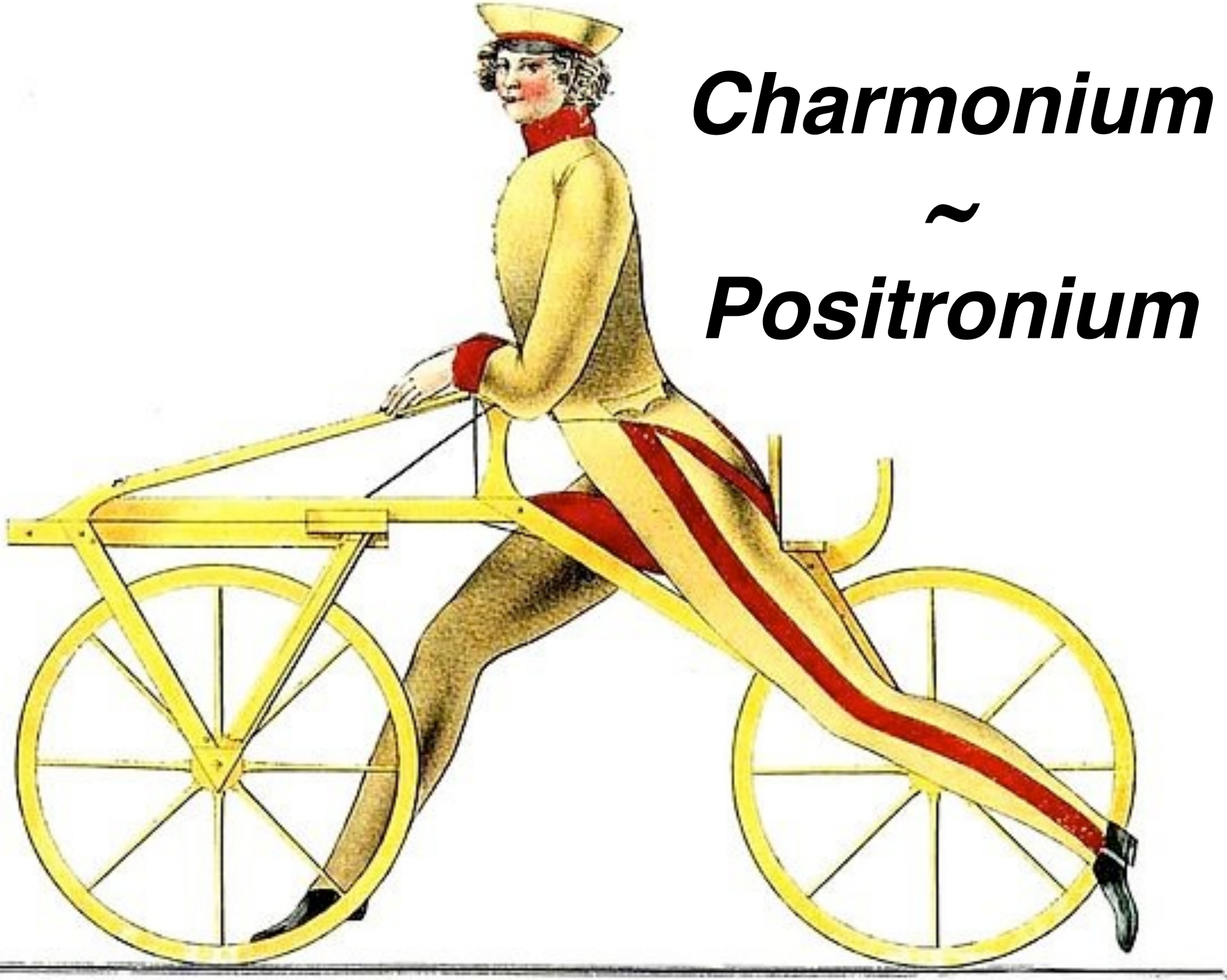
e^+e^- ANNIHILATION
J/ψ-SCATTERING
PP COLLISIONS
PHOTOPRODUCTION

ψ' Υ

$M(D^*)$ 3%

"CHROMOHYPERFINE SPLITTINGS"

Sleep -Less Night



Charmonium

~

Positronium

Appelquist
ADR
Glashow
Politzer

Eichten
Gottfried
Kinoshita
Kogut
Lane, Yan

Expe-
riment

Be a phenomenologist ???

This was an example why not be: no reference to theorists who suggested the search of charmonía

DGG 1975: ADR, Georgi, Glashow

Constituent Quarks + QCD "Hyperfine"

WE EXPLAIN (TOO WELL!) SPLITTINGS BETWEEN HADRONS IN SAME MULTIPLET

[eg Ξ^{-} - Λ $[uds]_{J=\frac{1}{2}}$]

AS "CHROMO HYPERFINE"

RELATIVISTIC VERSION

De Grand, Jaffe, Johnson, Kiskis, 1975

Post-dictions for ground-state mesons & baryons

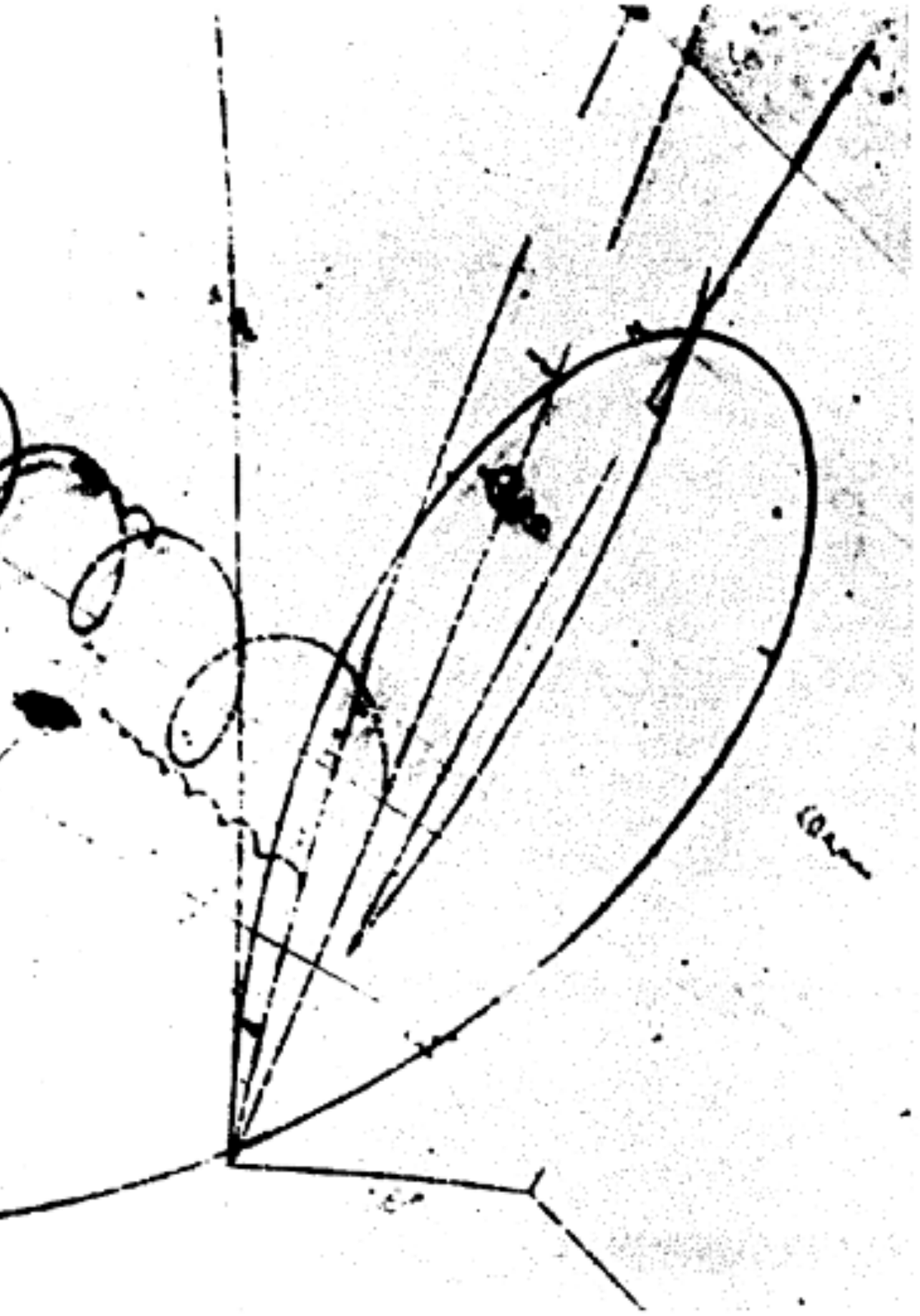
made of u,d,s OK

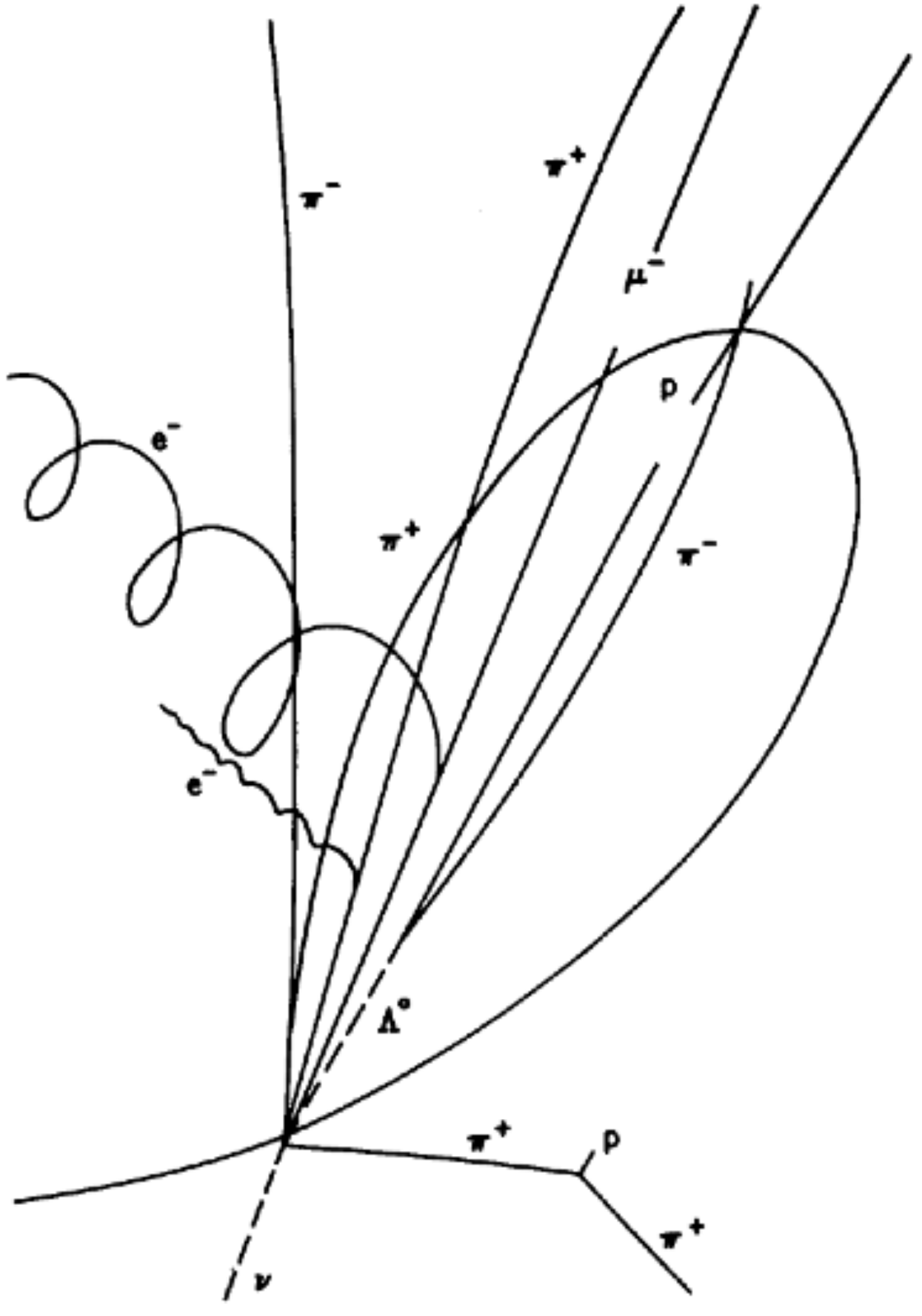
Of Course

Charmed Pre-dictions

	DGG PREDICTION (1975)	EXPERIMENT	
$D\,[c\bar{u}]_{J=0}$	1830 ± 30	1870	OK
$D^*_{J=1} - D$	130	140	7 % WRONG
$\Lambda_c^+ [c\underbrace{ud}_{I=0}]_{J=1/2}$	2250 ± 50	2260 ± 20	(cqq)
$\Sigma_c\,[c\underbrace{qq}_{I=1}] - \Lambda_c$	160	160 ± 10	???
$\Sigma_c^*\,(J=3/2) - \Lambda_c$	220	~ 220	
$F\,[c\bar{s}]_{J=0}$	1975	2041 (HJ!)	3 % WRONG

Brookhaven Bubble Chamber, 1975





$$\nu_\mu\, p \to \mu^-\ \Sigma_c^{++}[uuc]$$

$$\boxed{\Sigma_c^{++}} \to \pi^+\ \Lambda_c^+[udc]$$

$$\boxed{\Lambda_c^+} \to \pi^+\ \pi^+\ \pi^-\ \Lambda^0$$

$$\Lambda[uds] \to \pi^-[d\bar{u}]\ p[uud]$$

total recoiling hadron mass ($\Lambda\pi^+\pi^+\pi^+\pi^-$) 2426 ± 12 MeV.[12]

This mass is in reasonable agreement with the values predicted by De Rujula, Georgi, and Glashow[13] for the lowest-lying charmed-baryon states of charge +2, 2420 MeV ($J^P = \frac{3}{2}^+$, $I = 1$, Σ_C^*)

Nick Samios et al., 1975

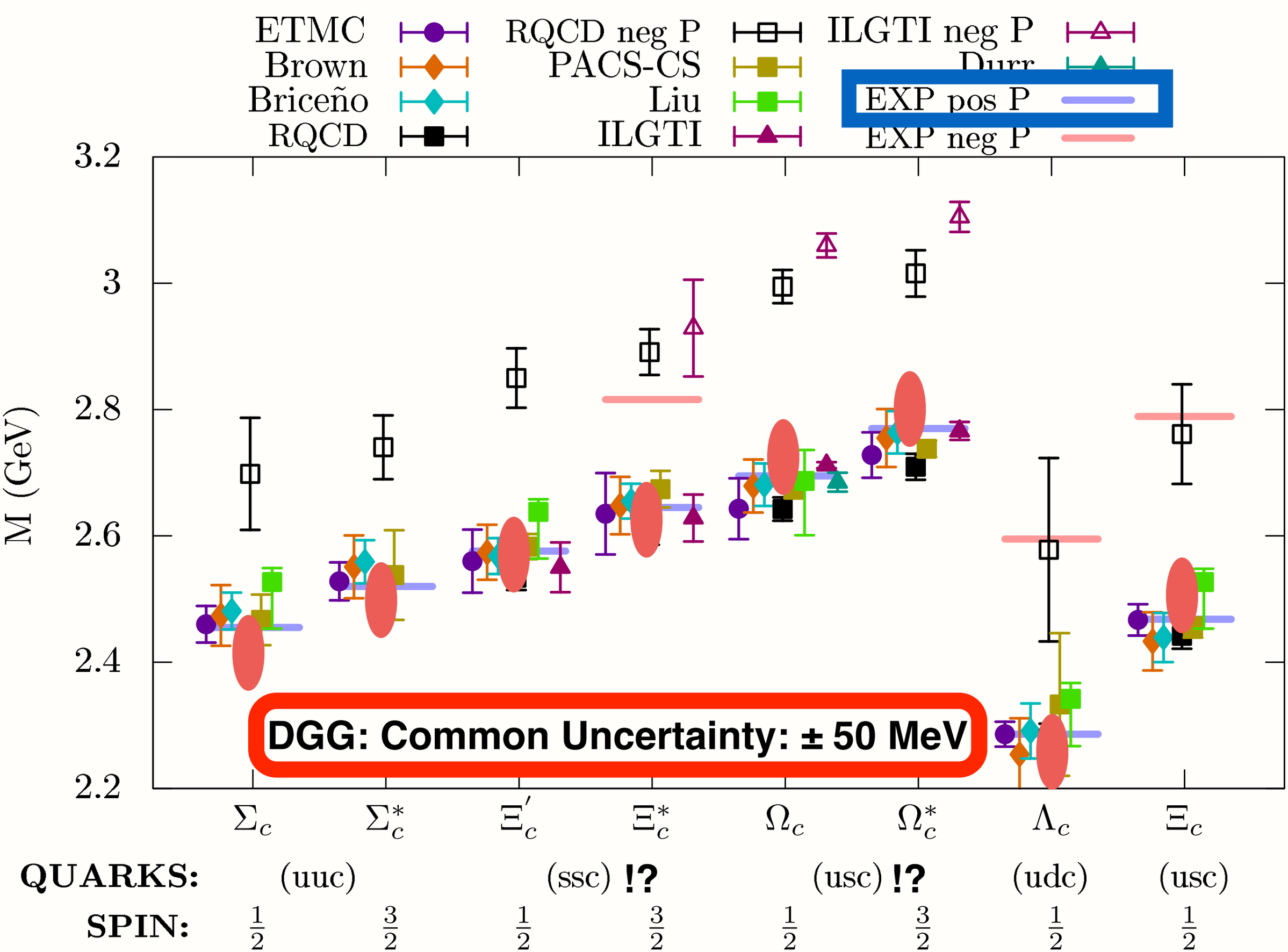
There are three π^+'s and thus three possible mass differences derivable from this event; these are observed to be 166 ± 15 MeV, 338 ± 12 MeV, and 327 ± 12 MeV. The first of these differences is in remarkable agreement with the 160 MeV predicted for the decay of a spin-$\frac{1}{2}$ charmed baryon Σ_C decaying into a charmed Λ_C.

Do not be a pheno-menologist ???

This was an

exceptional

counter- example

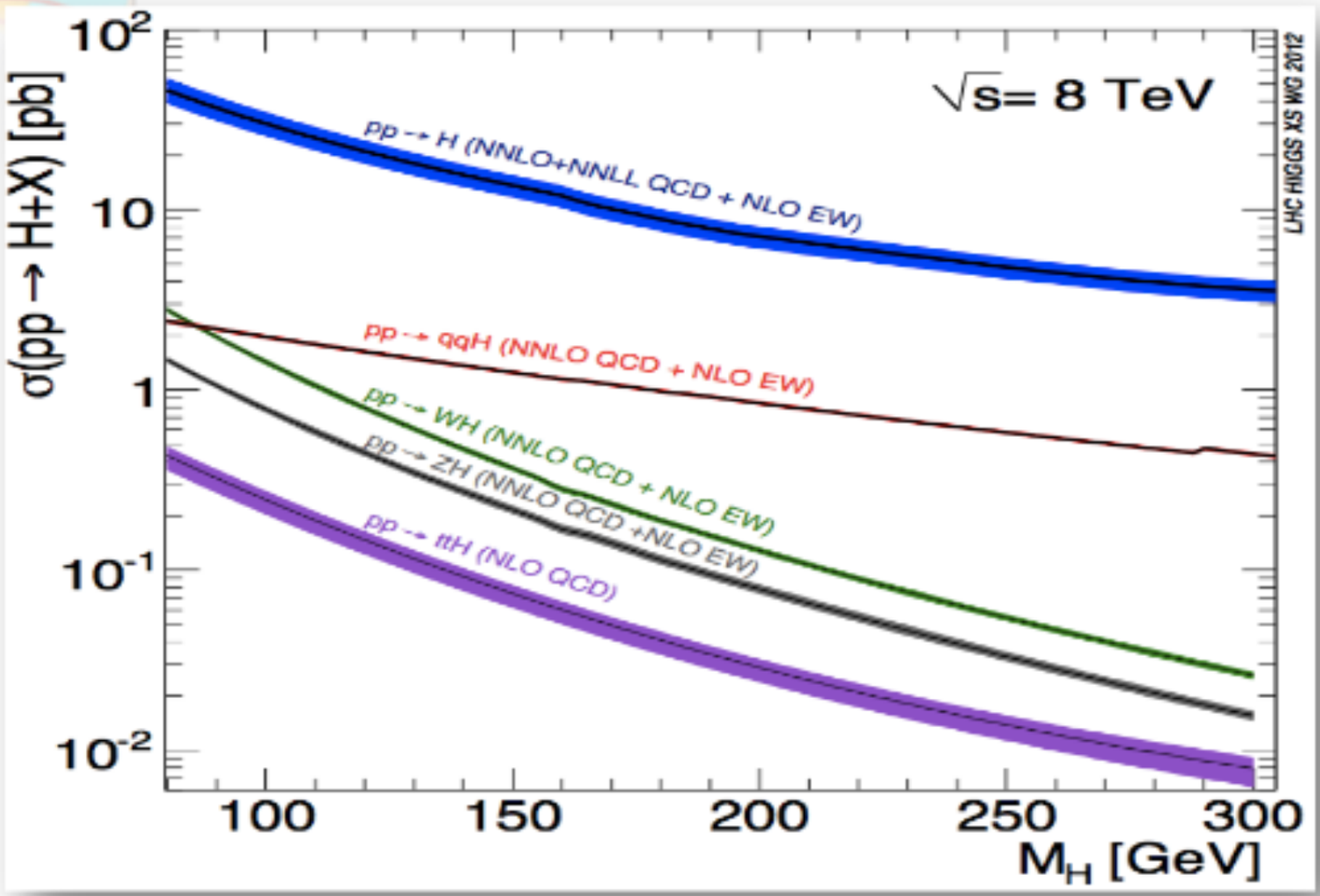


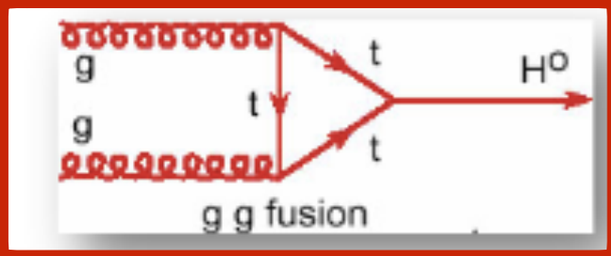
P. Perez-Rubio, S. Collins and G. S. Bali, Phys. Rev. D92 034504 (2015)

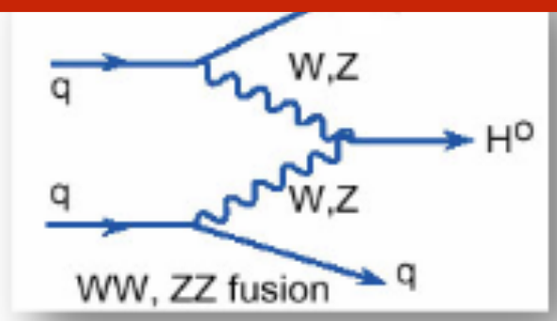
Peter M. is in the audience

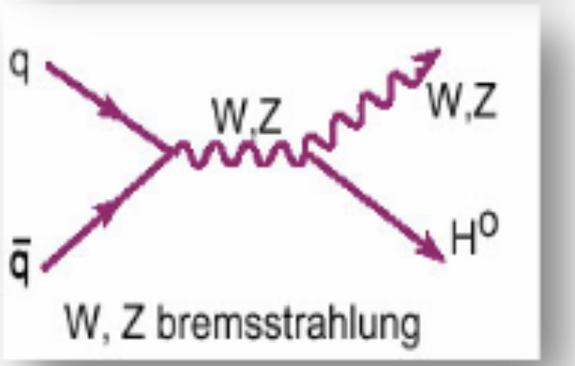
The WEINBERG OPERATOR

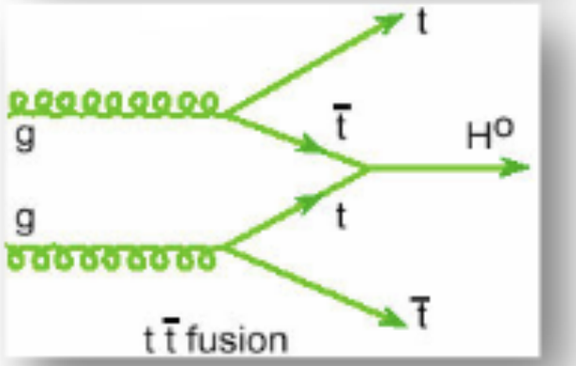
Higgs boson production





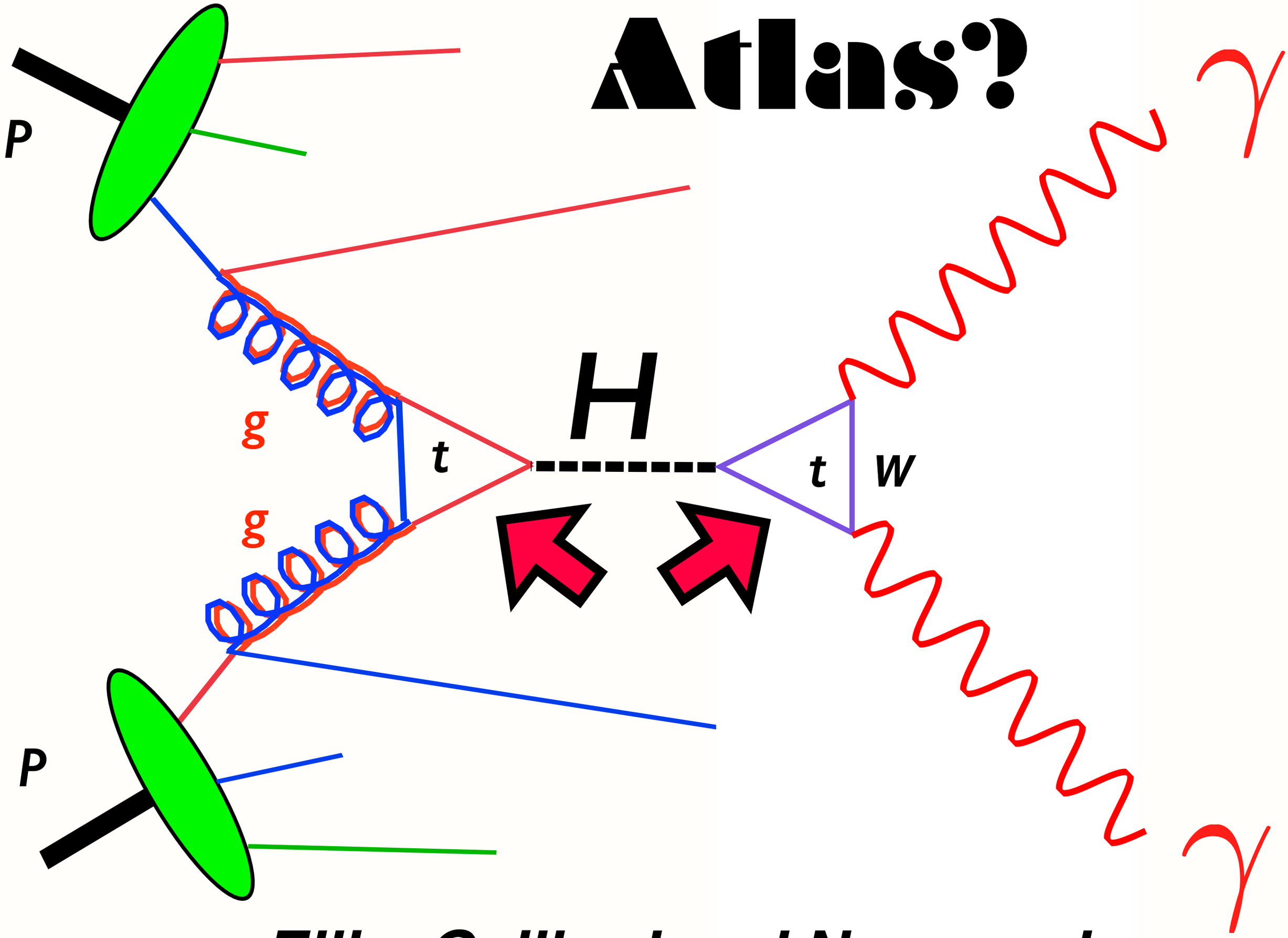






- $\sqrt{s}$=8 TeV: 25-30% higher σ than $\sqrt{s}$=7 TeV at low m_H
- All production modes to be exploited
  - gg VBF VH ttH
  - Latter 3 have smaller cross sections but better S/B in many cases

Atlas?



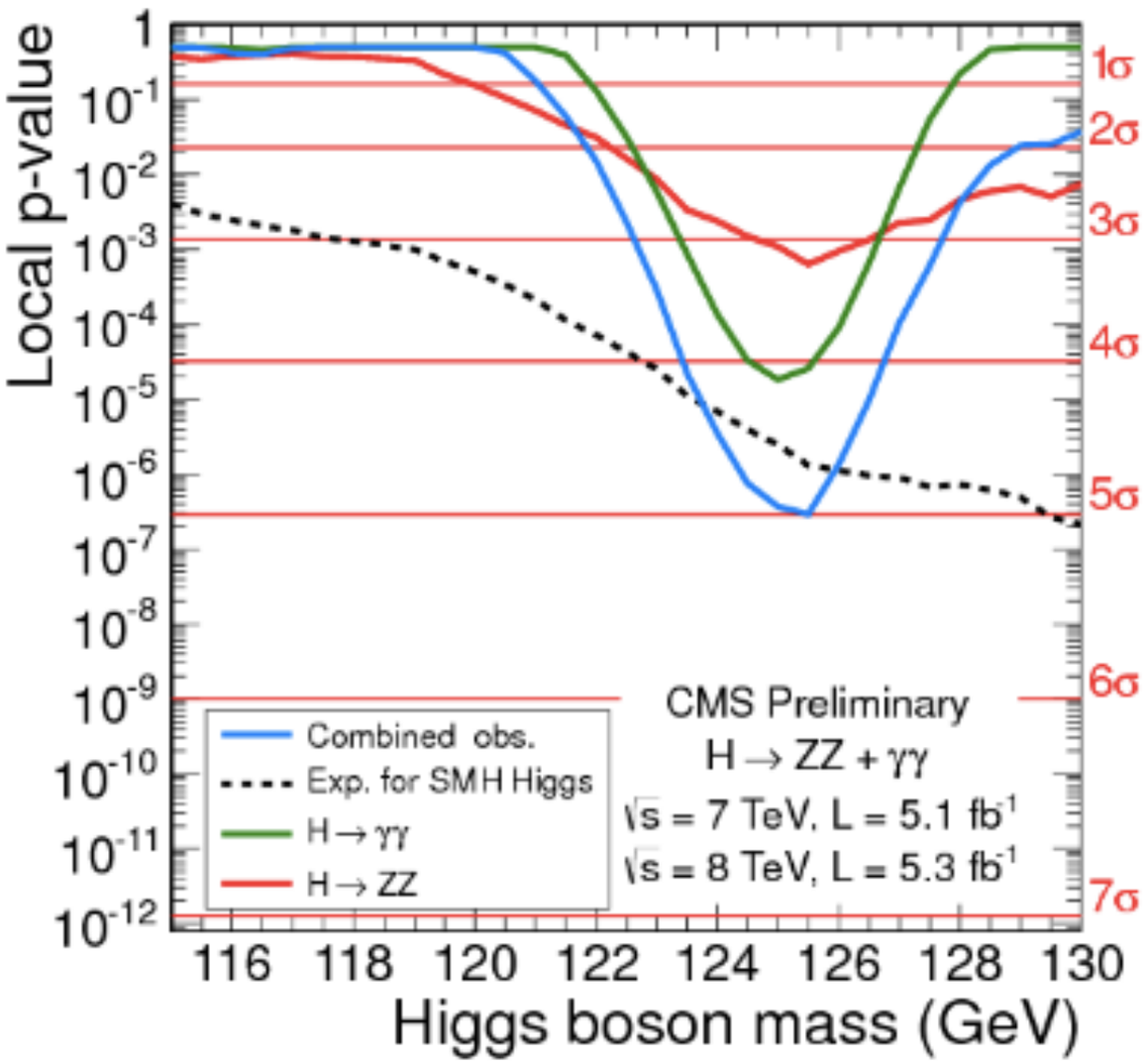
Ellis, Gaillard and Nanopoulos

Observables calculated to NNN...LO

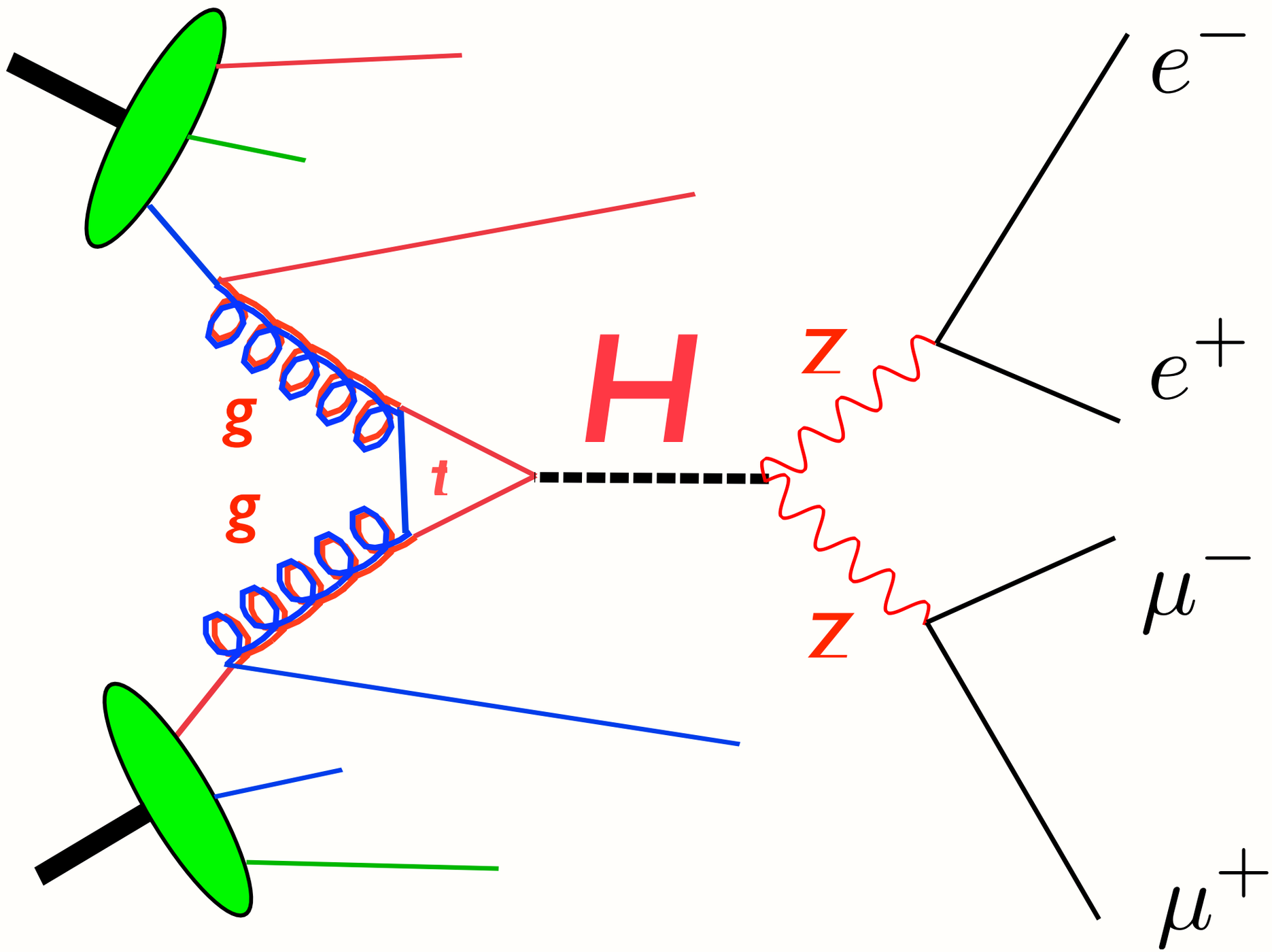
Not acknowledged

Joe Incandela. CMS Higgs discovery talk

Characterization of excess near 125 GeV



- **high sensitivity, high mass resolution channels: γγ+4l**
  - **γγ: 4.1 σ excess**
  - **4 leptons: 3.2 σ excess**
  - **near the same mass 125 GeV**
- **comb. significance: 5.0 σ**
- **expected significance for SM Higgs: 4.7 σ**



The 7 lepton observables are subtly quantum-mechanically entangled

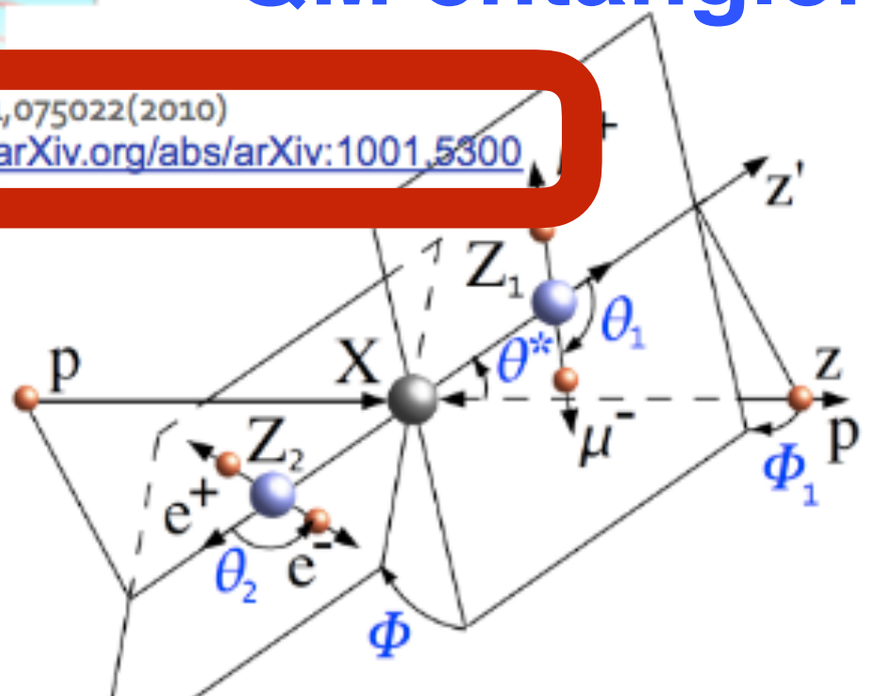
Background: also (but differently) entangled

Joe Incandela. CMS Higgs discovery talk

QM entanglement 4l, M(H) < 2 M(Z)

MELA

PRD81,075022(2010)
http://arXiv.org/abs/arXiv:1001.5300



Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

Who are the authors? Gioconda? Hamlet?

ADR, Lykken, Pierini, Rogan and Spiropulu

From below

to right at

CMS 5σ *Atlas?*

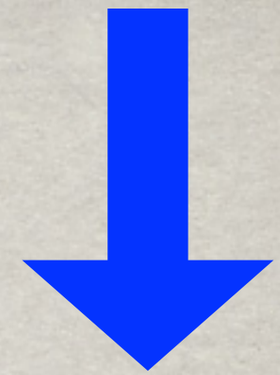
A matter of some…

SIGNIFICANCE

If you would like to have ~~your~~ work recognized

~~DO NOT~~ BE A PHENOMENOLOGIST

EVEN THE MOST FORMAL THEORIST AND THE MOST CABLE-CONNECTING EXPERIMENTALIST UNDERSTANDS (pe), $(e^+ e^-)$



$(c\,\bar{u})$

$(c\,\bar{c})$

IT TOOK ASYMPTOTIC FREEDOM & A FOURTH (CHARMED) QUARK TO HAVE THE SM BECOME THE STANDARD LORE

WHO INVENTED QUARKS ?

$$p = [u\,u\,d] \qquad \pi^+ = [u\,\bar{d}]$$

WHO INVENTED QUARKS ?

BUT **André Petermann in Nuclear Physics [63, 349, (1963)], in French! received December 30th, 1963**

Murray Gell-Mann's paper received by Physics Letters on January 4th 1964

George Zweig's unpublished work is a CERN preprint dated January 17th 1964

BUT BUT BUT …

Gell-Mann: These ideas were developed …
in March 1963; the author would like to thank
Professor Robert Serber for stimulating them.

R. Serber & R.B. Crease. Peace & War:
Reminiscences of a Life on the Frontiers of
Science, Columbia Univ. Press (1998) page 199