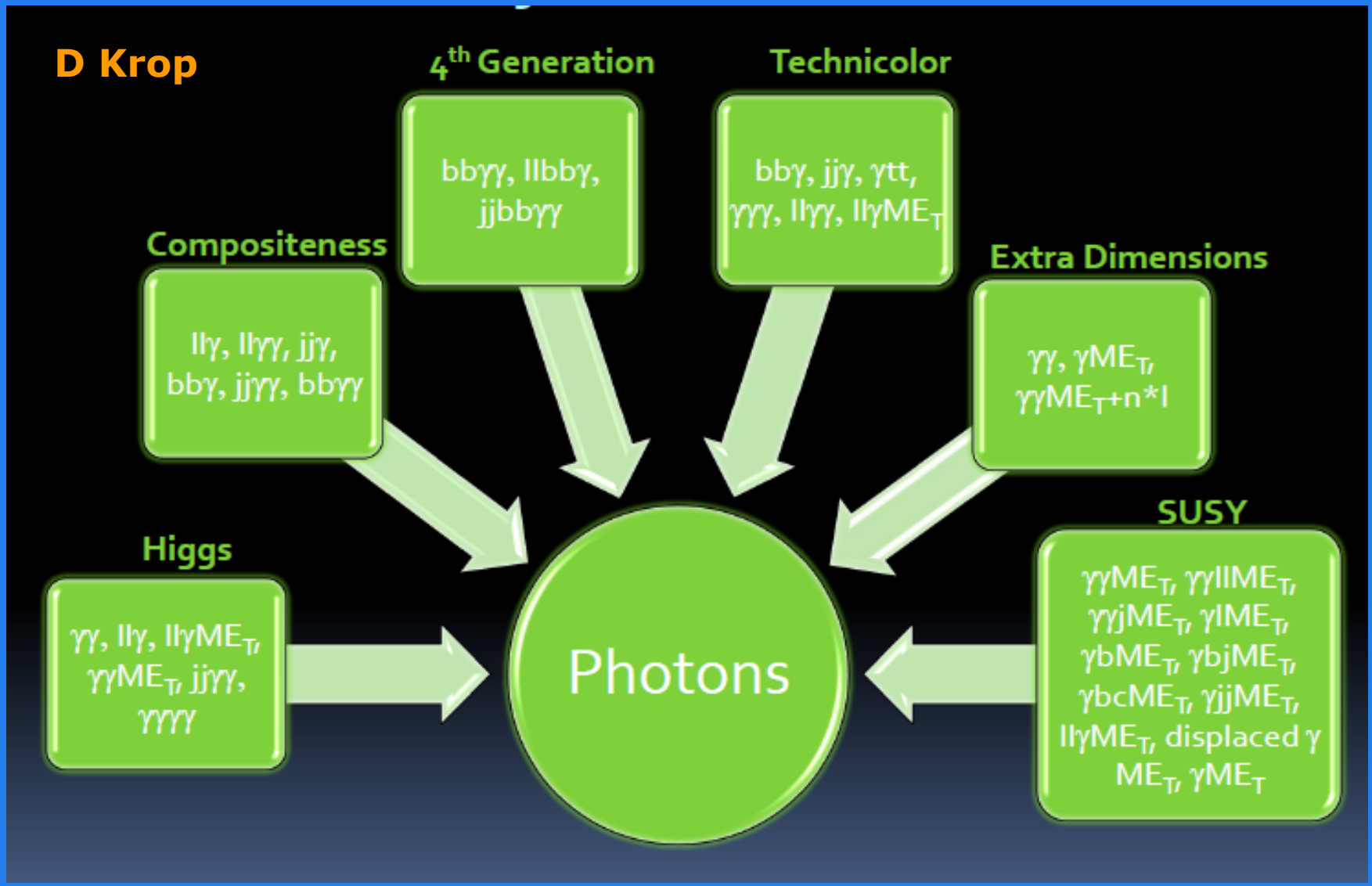
Experimental Summary

P J BUSSEY

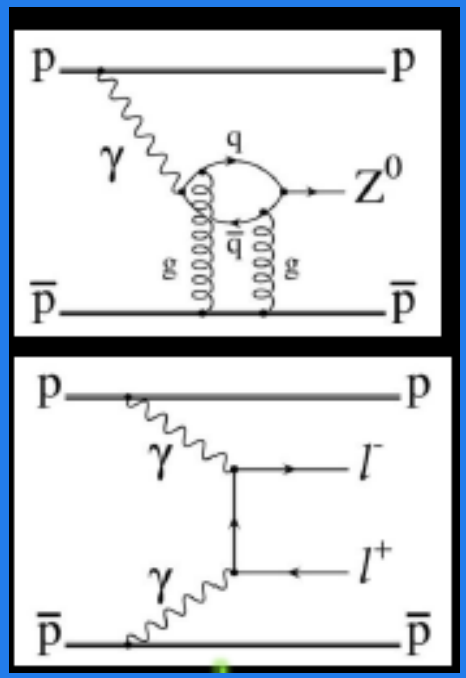
University of Glasgow | Experimental Particle Physics

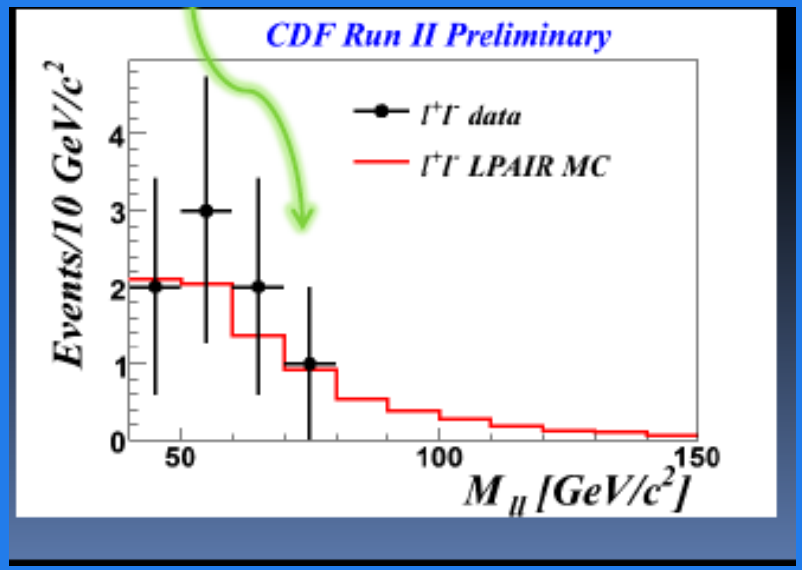
PHOTON 09 – an unprecedentedly rich treasure chest of photon physics results

ELECTROWEAK PHYSICS AT THE TEVATRON



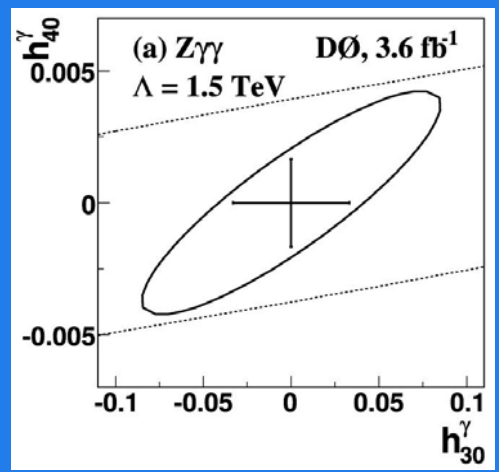
CDF – photon diffractive physics and photon-photon physics.





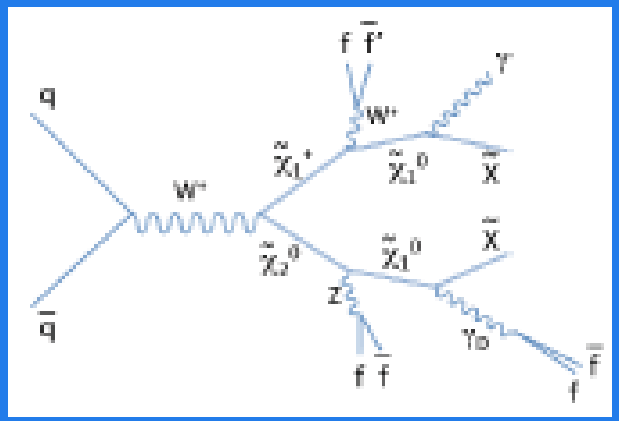
Z sought, muon pairs observed

γ + MET triple gauge coupling limits on anomalous parameters

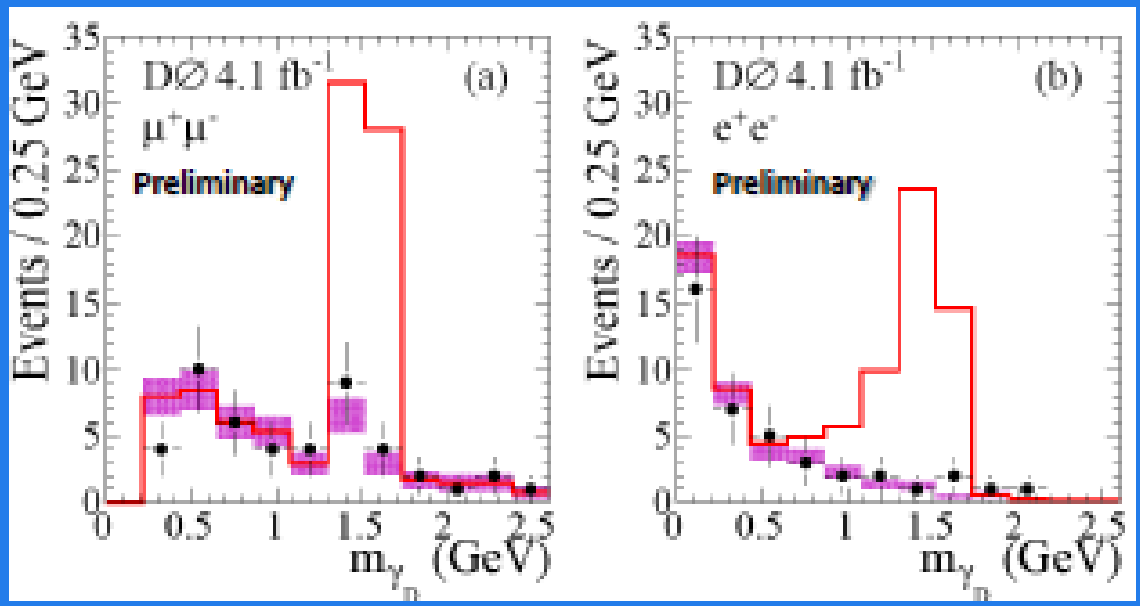


Recent model [*PRD 79, 15014 (2009)*] combining SUSY with a hidden valley (dark sector) to explain positron excesses in astrophysical observations (Pamela, ATIC, Fermi) and DAMA modulation signal.

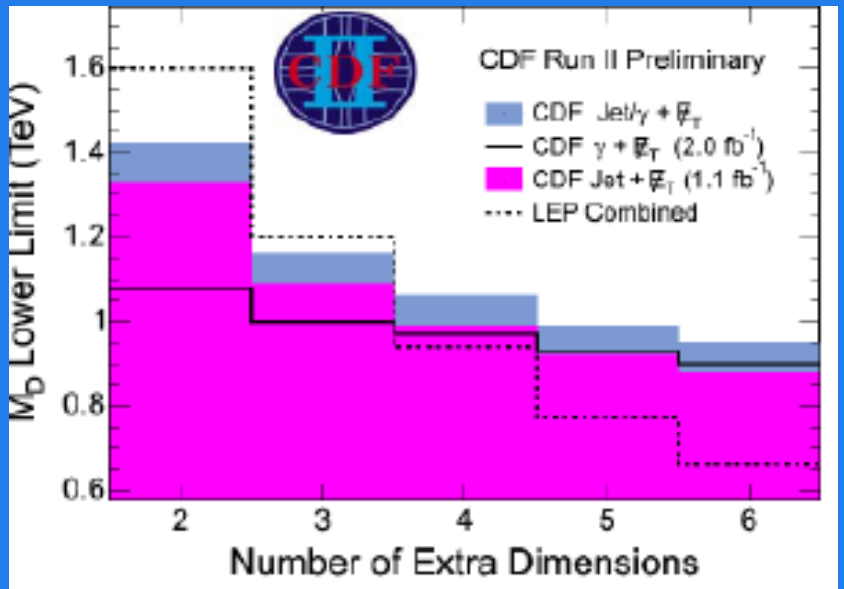
Can lead to excess γ+MET+*l*+*l*- at colliders.

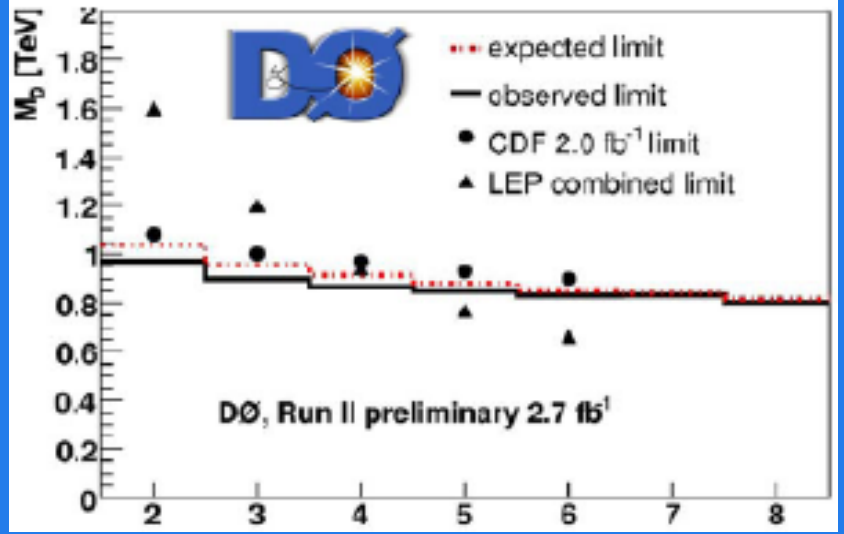


Limits from D∅

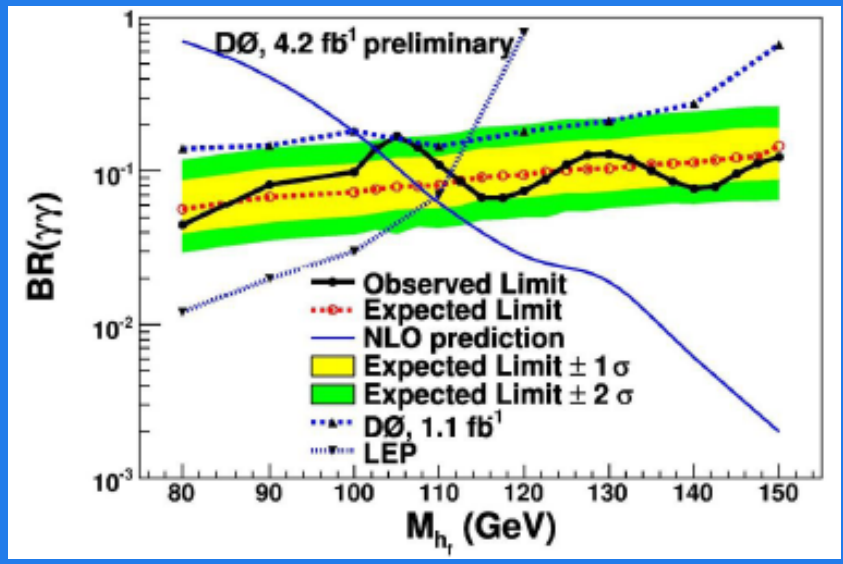


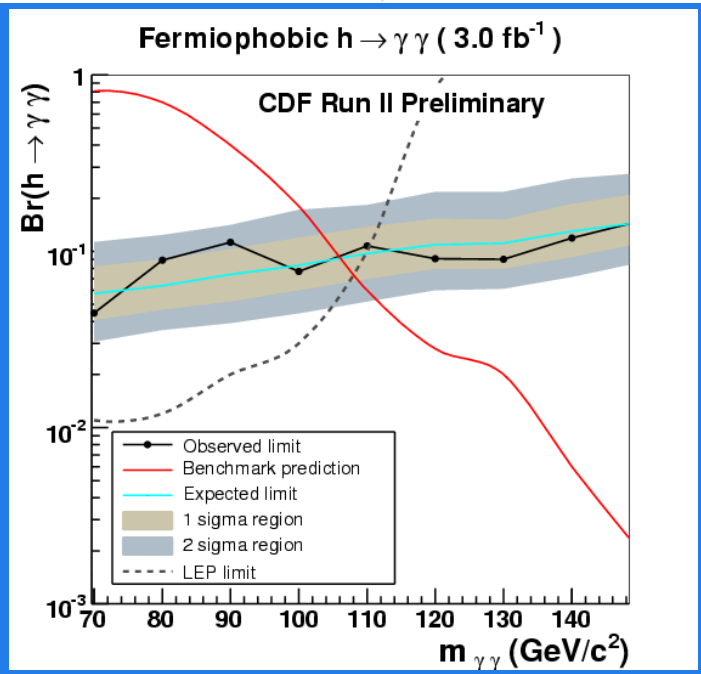
γ+MET LED Search



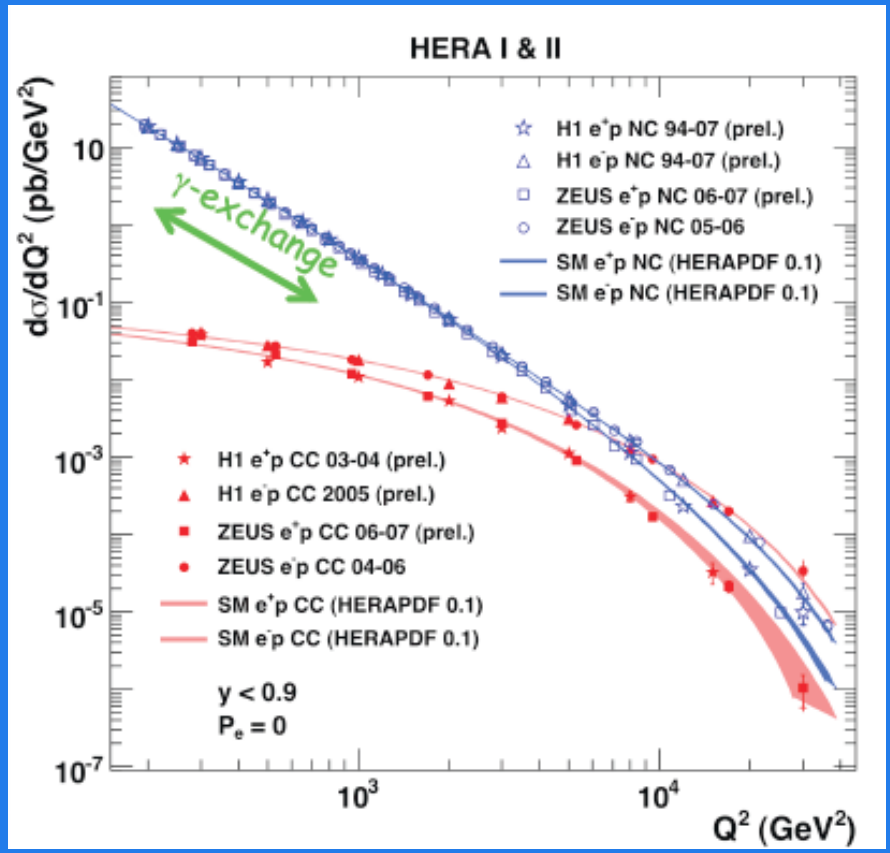


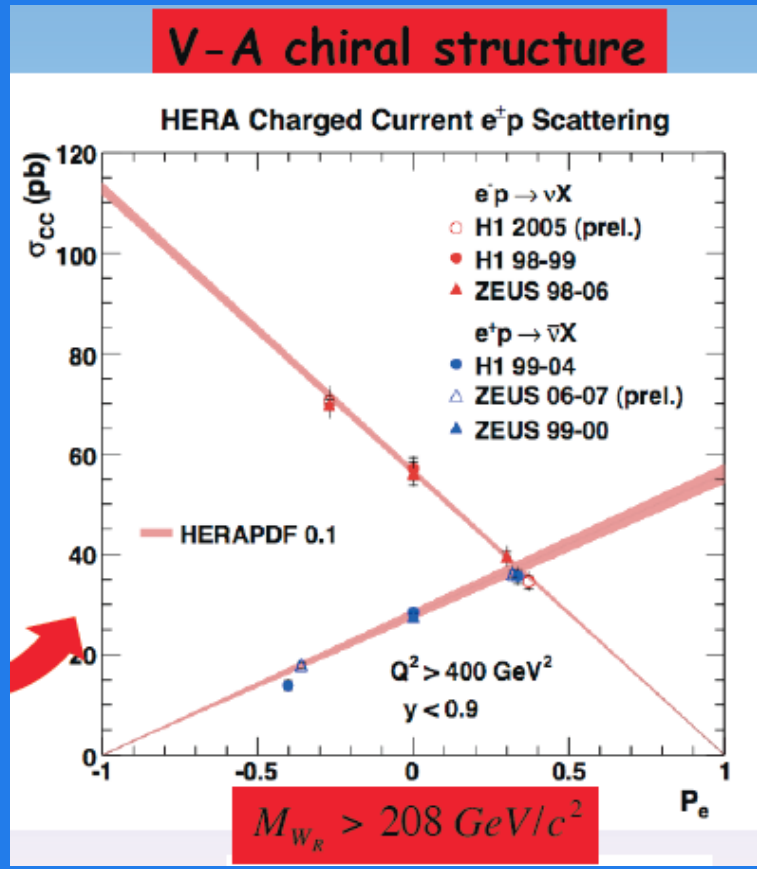
Fermiophobic Higgs





Electroweak physics at HERA





$$\text{NC}: \quad \frac{d\sigma}{dQ^2} \sim \frac{1}{Q^4}$$

$$\text{CC}: \quad \frac{d\sigma}{dQ^2} \sim \frac{1}{(Q^2 + M_W^2)^2}$$

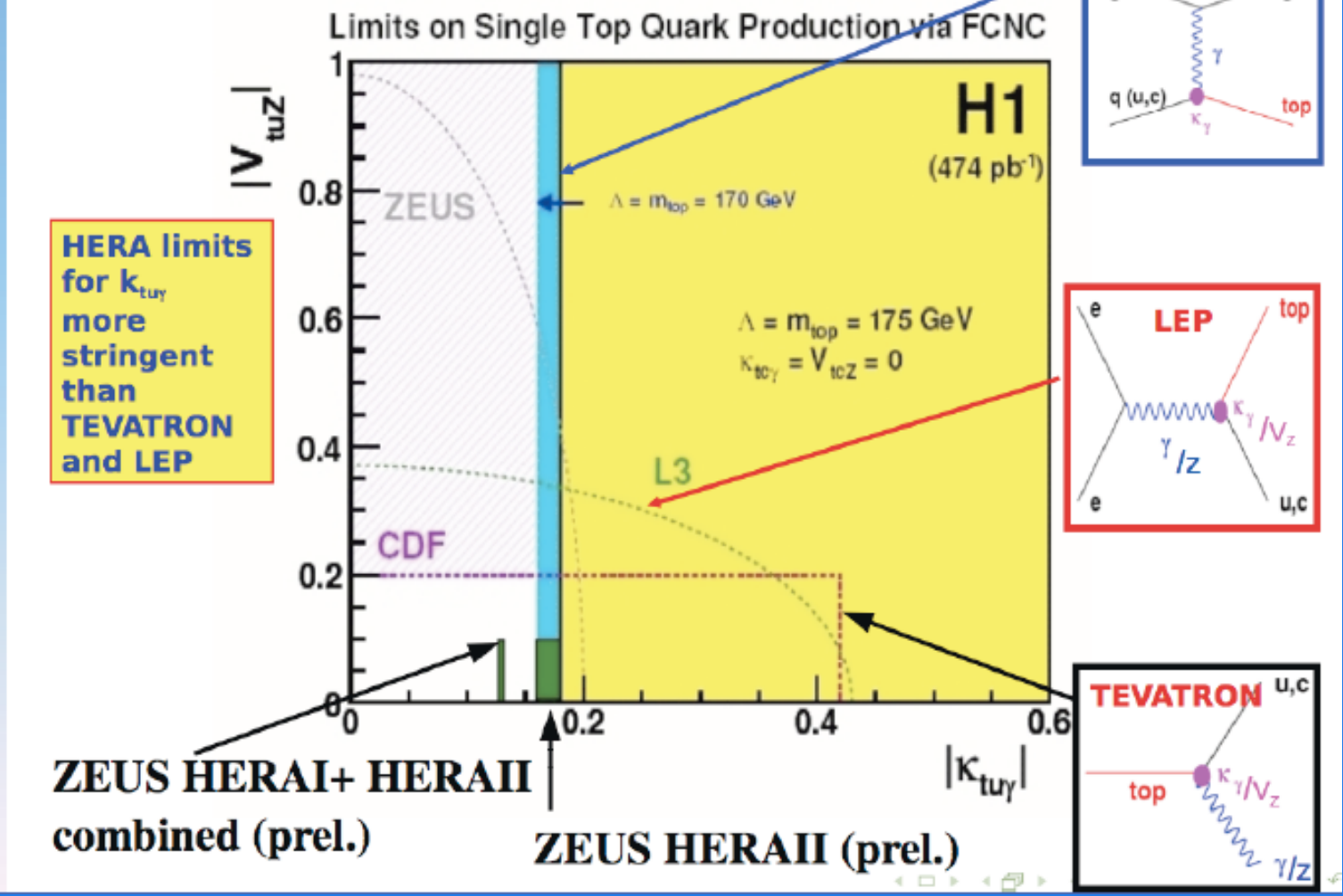
Good agreement with SM expectations overall

Limits on Single Top production via FCNC. Photon coupling

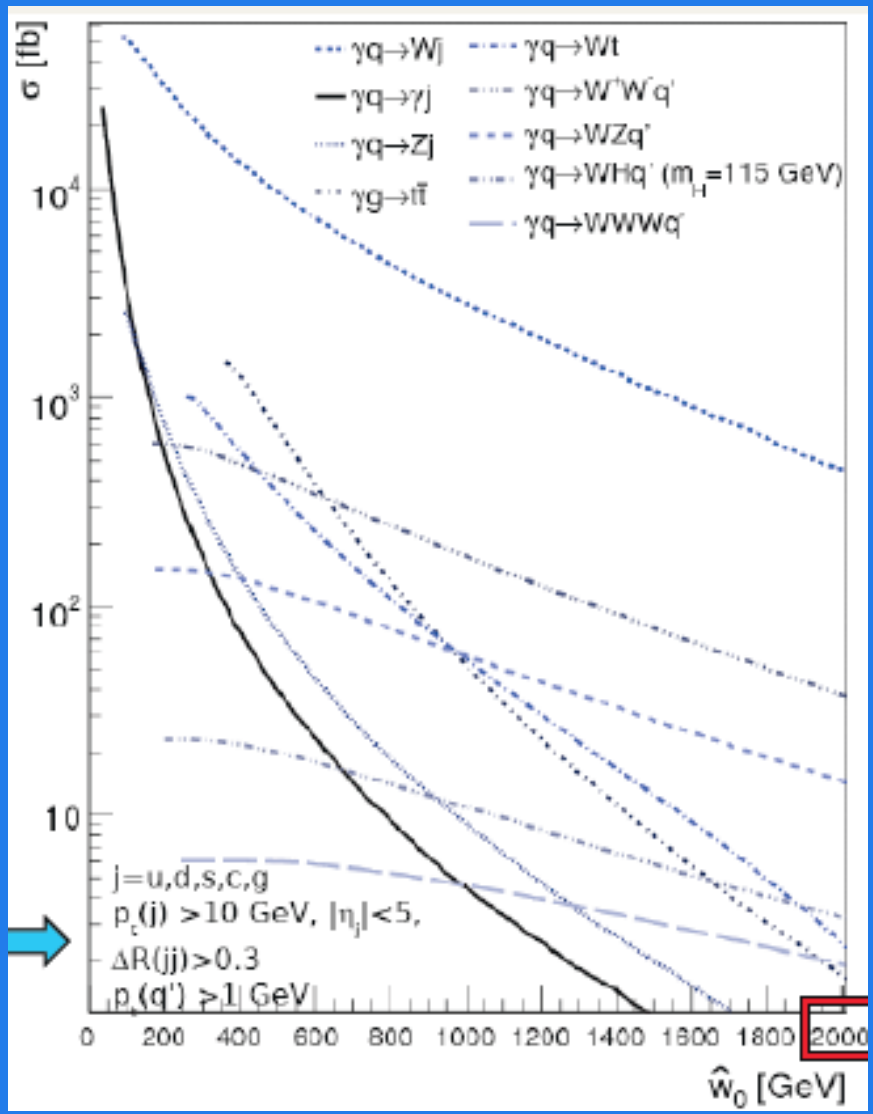
No excess ➔ limits, H1: $\sigma < 0.25$ pb, $k_{tu\gamma} < 0.18$, ZEUS: $\sigma < 0.13$, $k_{tu\gamma} < 0.13$

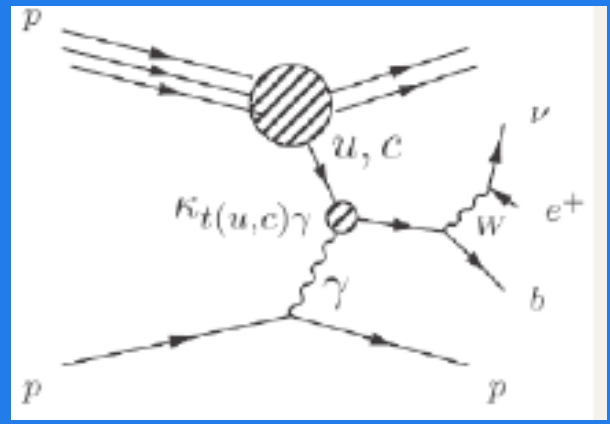
(slight excess)

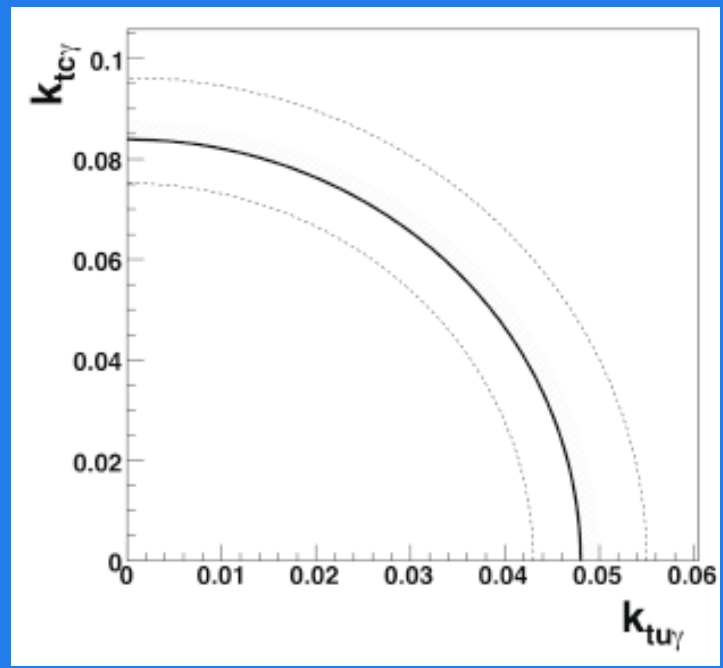
Stefano Antonelli at DIS09



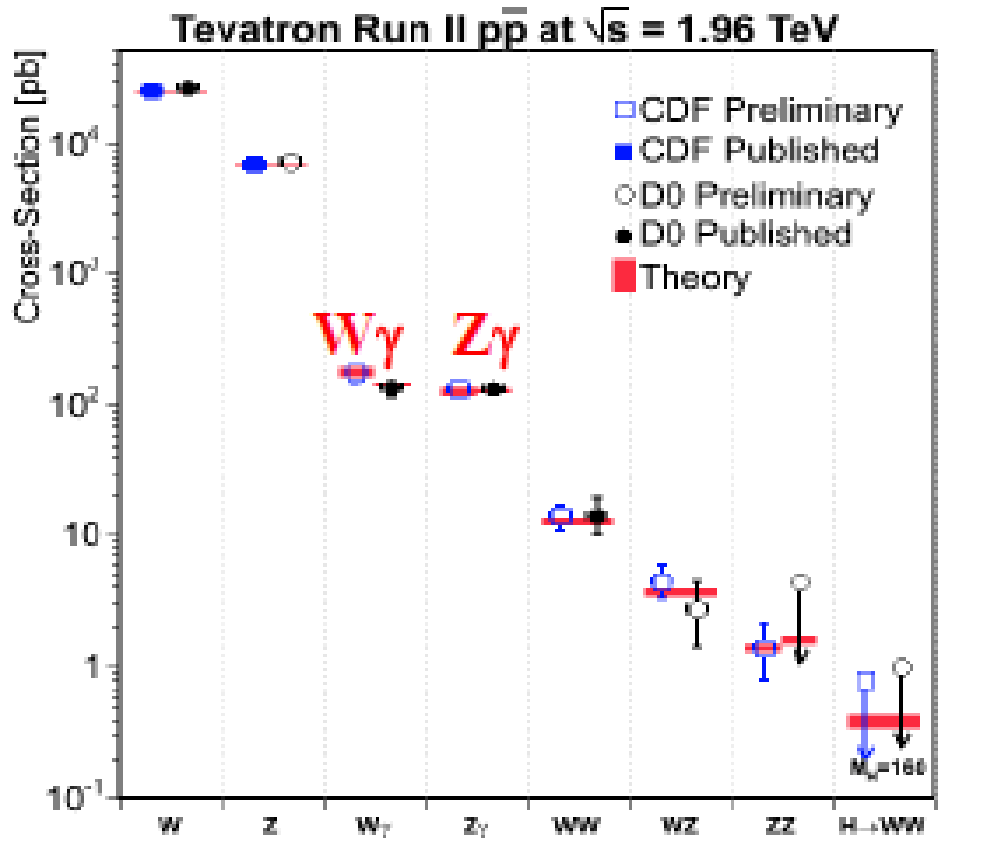
Anomalous single top photoproduction at LHC







Similar sensitivity to FCNC as have analyses based on rare top decays.



Suen Hou

Extending Wγ and Zγ searches to LHC

Very much higher sensitivity

Relevant for triple G B and new physics studies

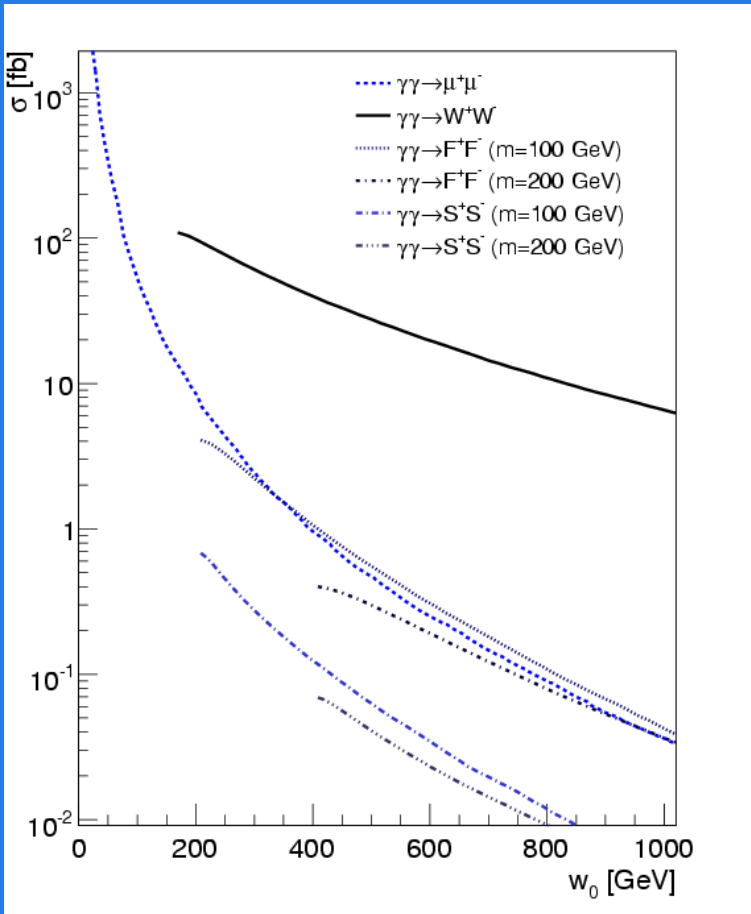
	conditions	√s=1.96 TeV	√s=14 TeV
$W^{\pm}\gamma$	E_T^{γ}>7 GeV, $\Delta R(\ell,\gamma)$>0.7	19.3	**451**
$Z^0\gamma$	E_T^{γ}>7 GeV, $\Delta R(\ell,\gamma)$>0.7	4.7	**219**
W^+W^-	W width inlcuded	12.4	112
$W^{\pm}Z^0$	Z, W on mass shell	3.7	48
Z^0Z^0	Z on mass shell	1.4	15

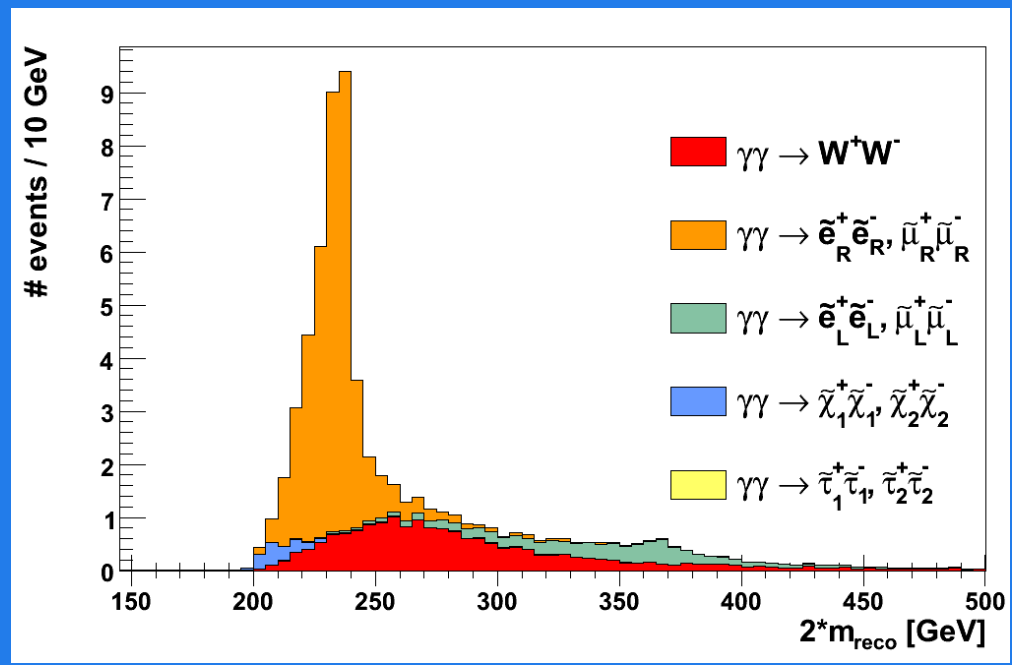
U. Baur et al.; PRD 53 1098, PRD 57 2823

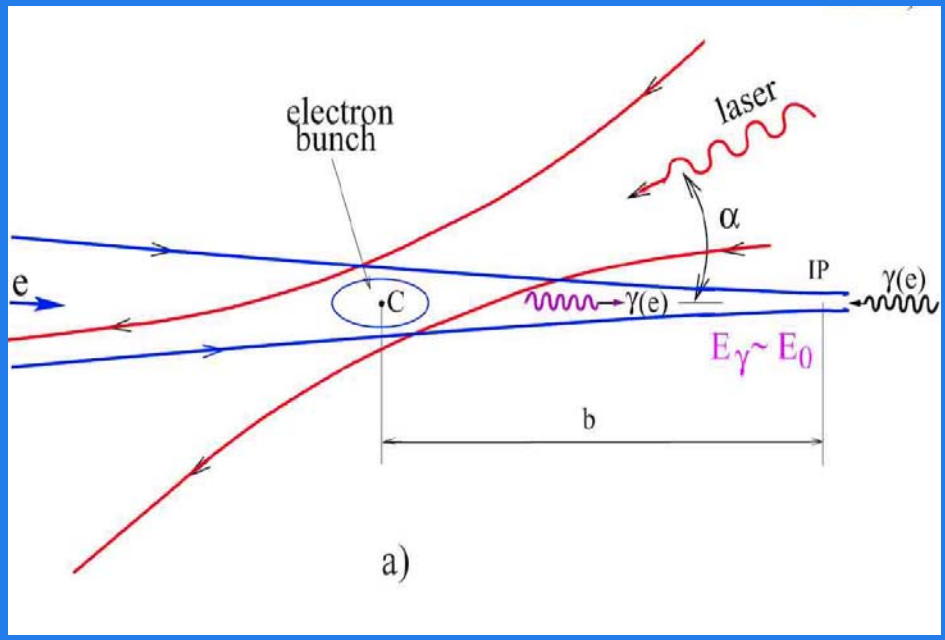
S. Frixione et al., JHEP 0206 029, JHEP 0308 007

Useful γγ cross sections but large WW background

With suitable cuts one can largely separate out the WW background, enabling study of new states, masses etc.

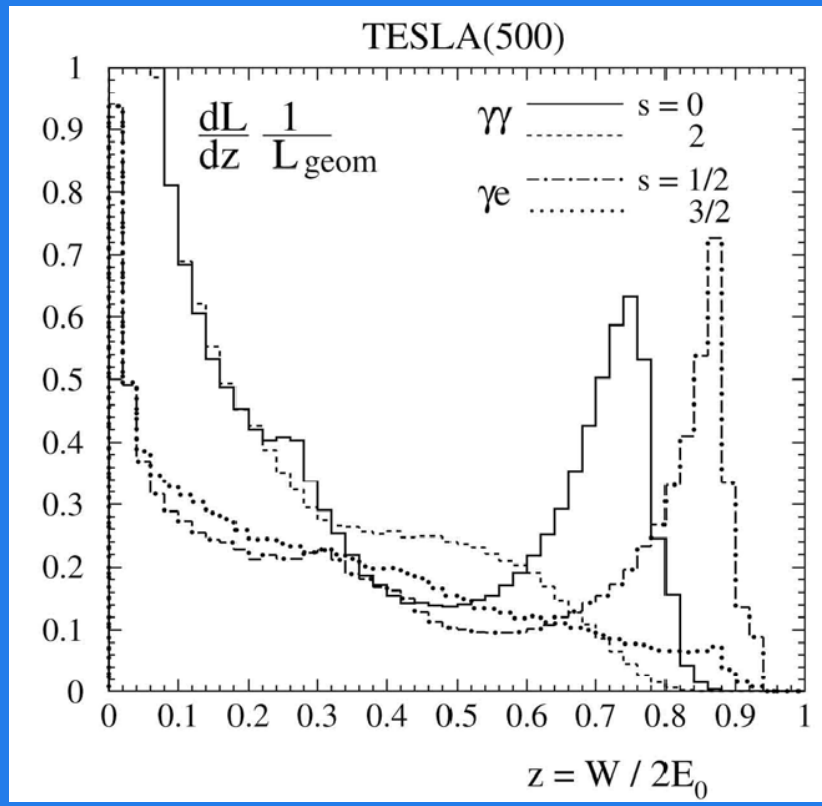






Backscattering of laser off the electron/positron beams.

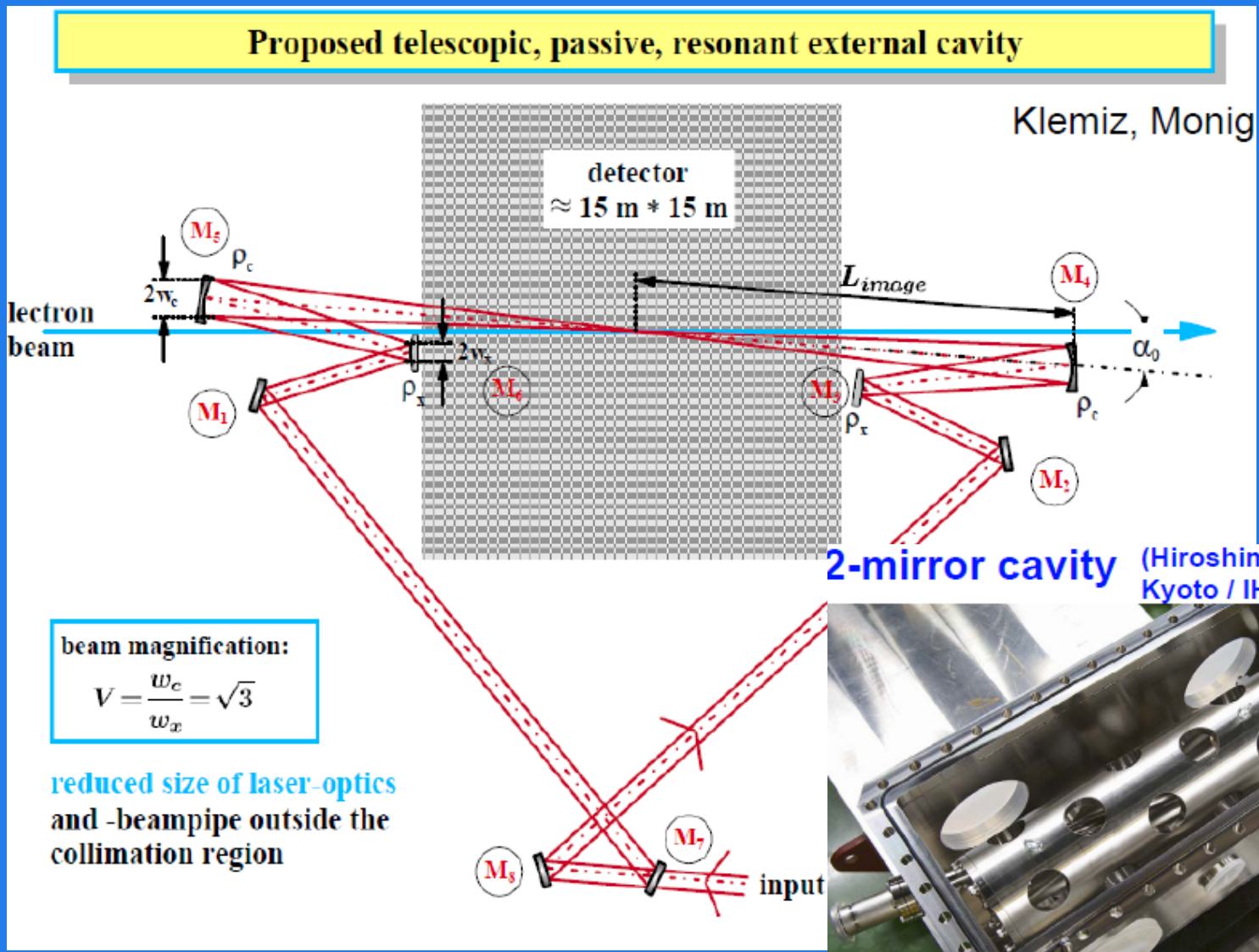
Great power is needed

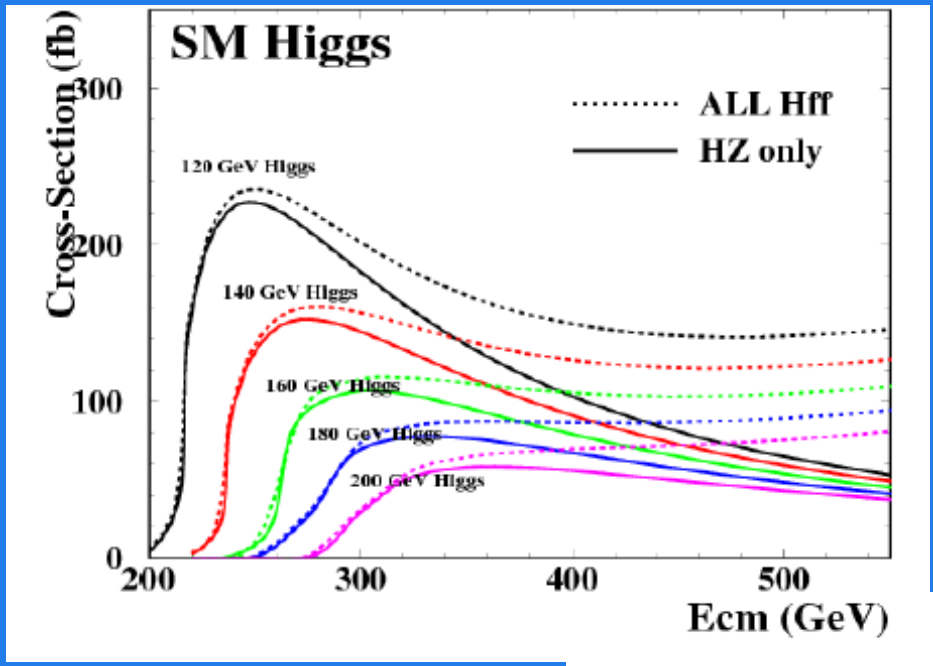


eγ and γγ spectra

T Takahashi

Laser cavity to enable laser pulse stacking, being tested now





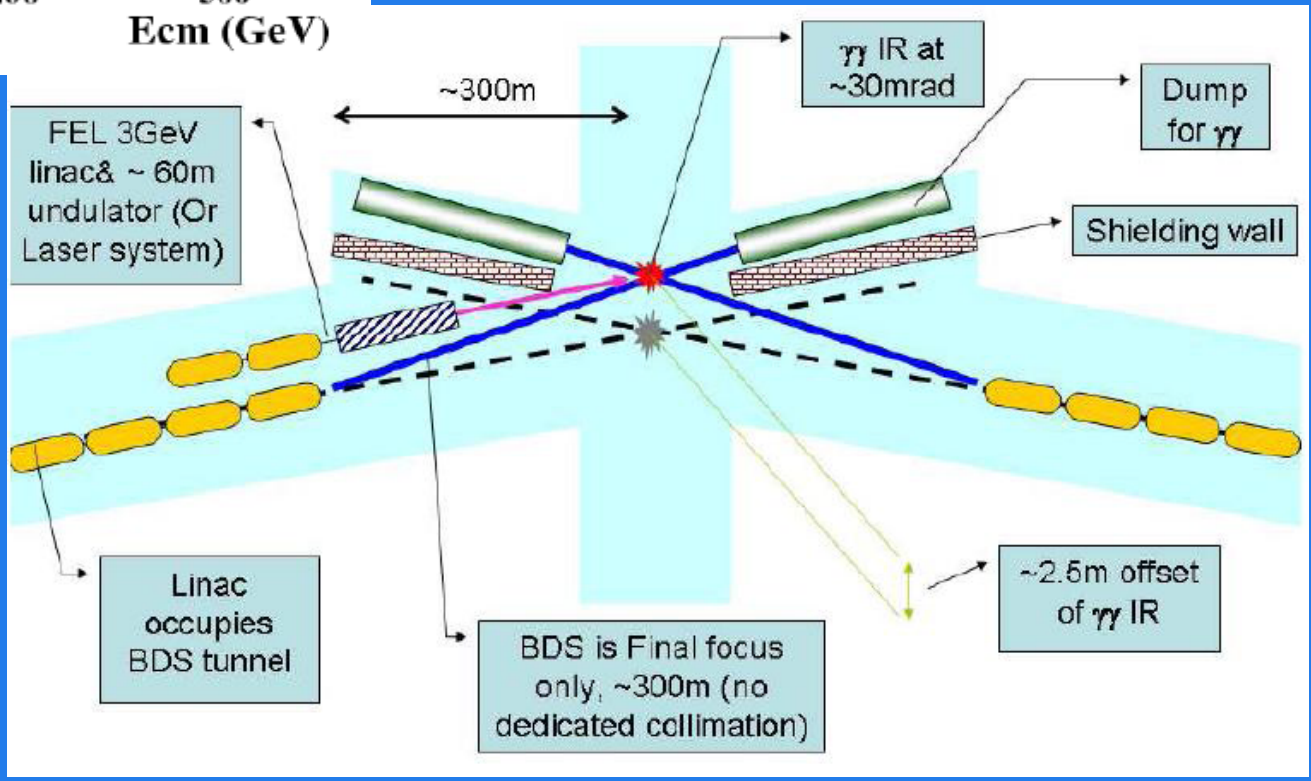
J Gronberg

Early Photon Collider Project

Combine with dedicated Higgs Factory,

a few 100 GeV,

staged.



Recent developments in the international consultations.

Summary of the ILCSC Meeting, 12 February 2009, KEK

Gamma-Gamma ILC Precursor

At its 31 October 2008 meeting, ILCSC received a proposal for a gamma-gamma Higgs factory as a precursor to the ILC; ILCSC asked the GDE and Research Directors to form a group to study this suggestion, and a report of the study was presented to this meeting. A 180 GeV gamma-gamma precursor would cost about half that of the 500 GeV ILC, but would produce much less physics. A better alternative for early Higgs studies would be a ~ 230 GeV e+e- collider for studying the Higgs through ZH production; this would be ~ 30% more costly than the gamma-gamma collider. ILCSC decided not to pursue the gamma-gamma collider further at this time (as the ILC precursor).

However Laser Compton Scattering could have technical applications. The technical developments continue!

And now…. for something completely different!

J Jaeckel. **Low energy photon experiments**

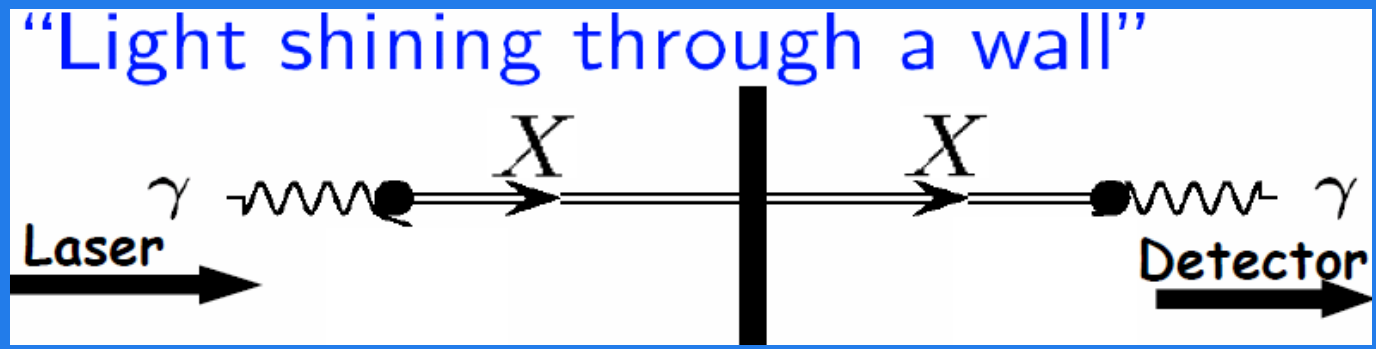
Axions, WIMPs, WISPs… and other weird stuff

- **Various technical problems: "naturalness problem", "fine tuning", "strong CP problem (→ AXIONS)**

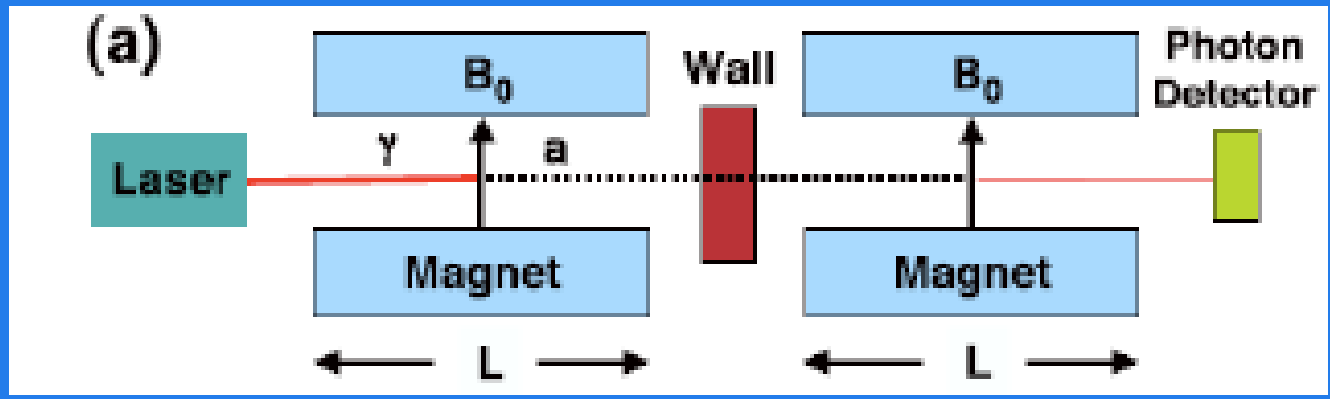
- **Dark Matter**
- **Dark Energy**
- **Standard Model has many free parameters**
- **Neutron EDM, DAMA anomaly, PAMELA, (g-2)**

Case for Weakly Interacting Sub-eV Particle searches

E.G.



ALPs, MCPs ... WISPs in general



Classic scheme: photon regeneration. Make photons, turn them into axions, pass through wall, reconstitute photons, detect them.

Or: get axions from sun or galaxy

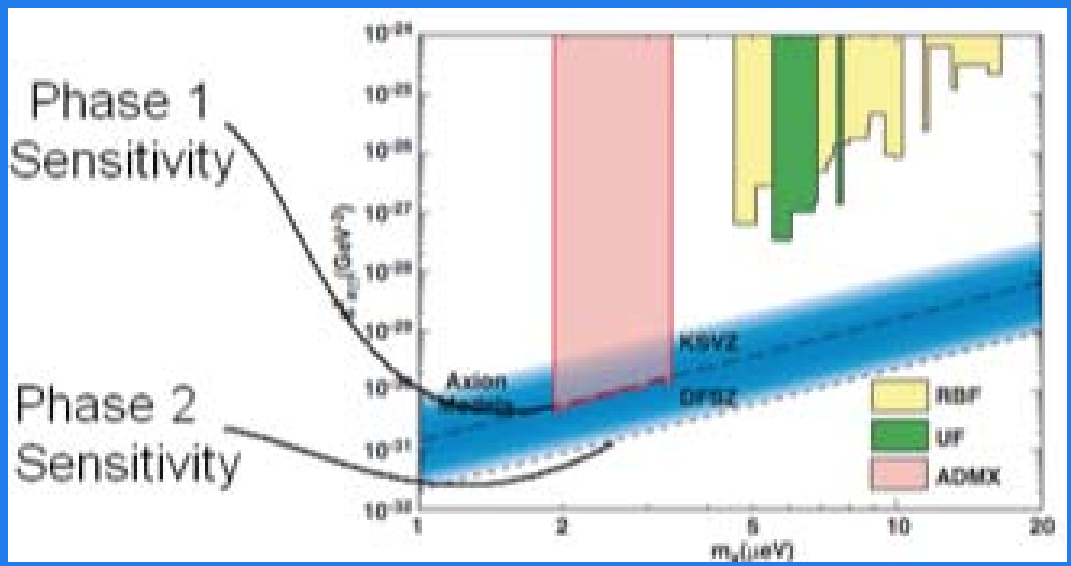
Or: use polarisation effects (no wall)

Cosmological relic axions — ADMX

Solar axions — CAST, Tokyo Helioscope

polarization experiments — PVLAS, Q&A

photon regeneration — ALPS, BMV, GammeV, LIPSS, OSQAR

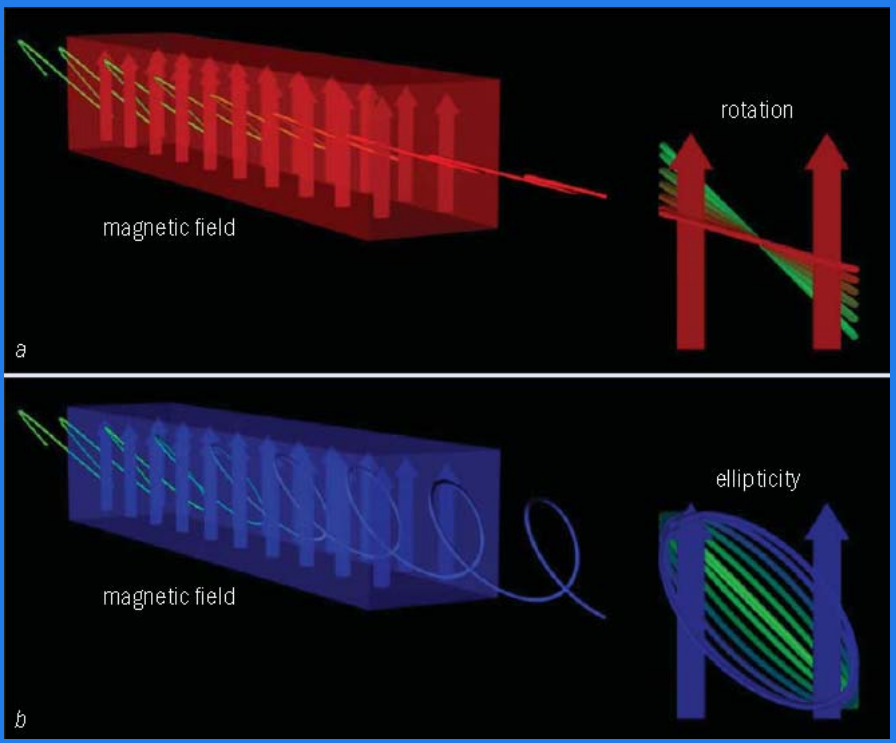


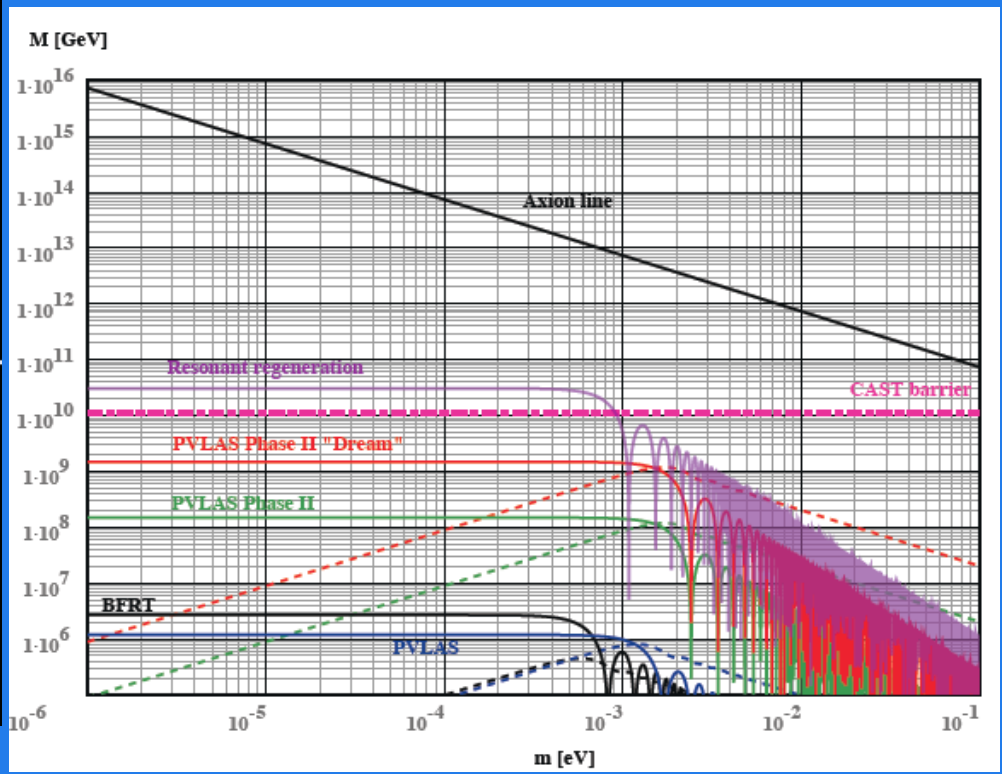
ADMX (microwave cavity, mag field) has achieved desired sensitivity and will exceed it.

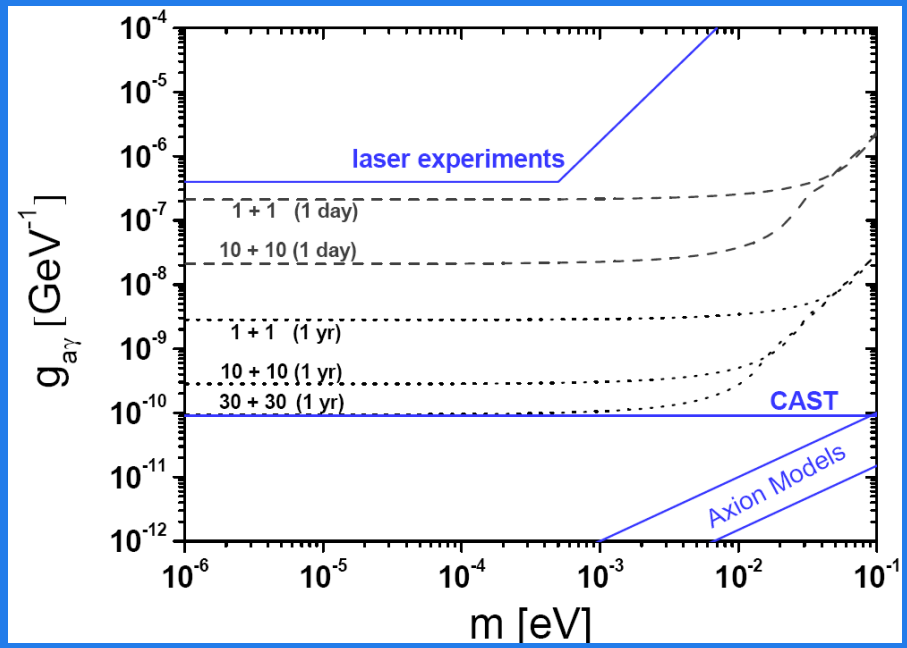
(narrow mass range)

Polarisation: magnetic field induces space dichroism

Challenge – beat CAST and reach AXION line!



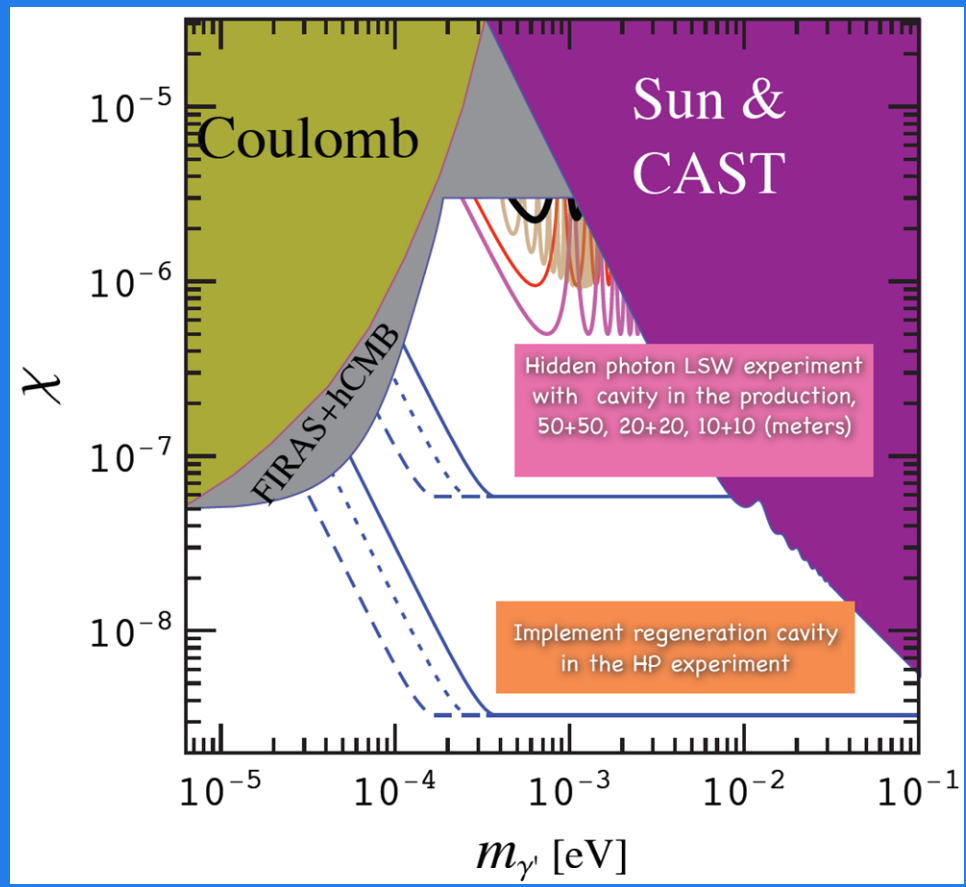




ALPS improvements

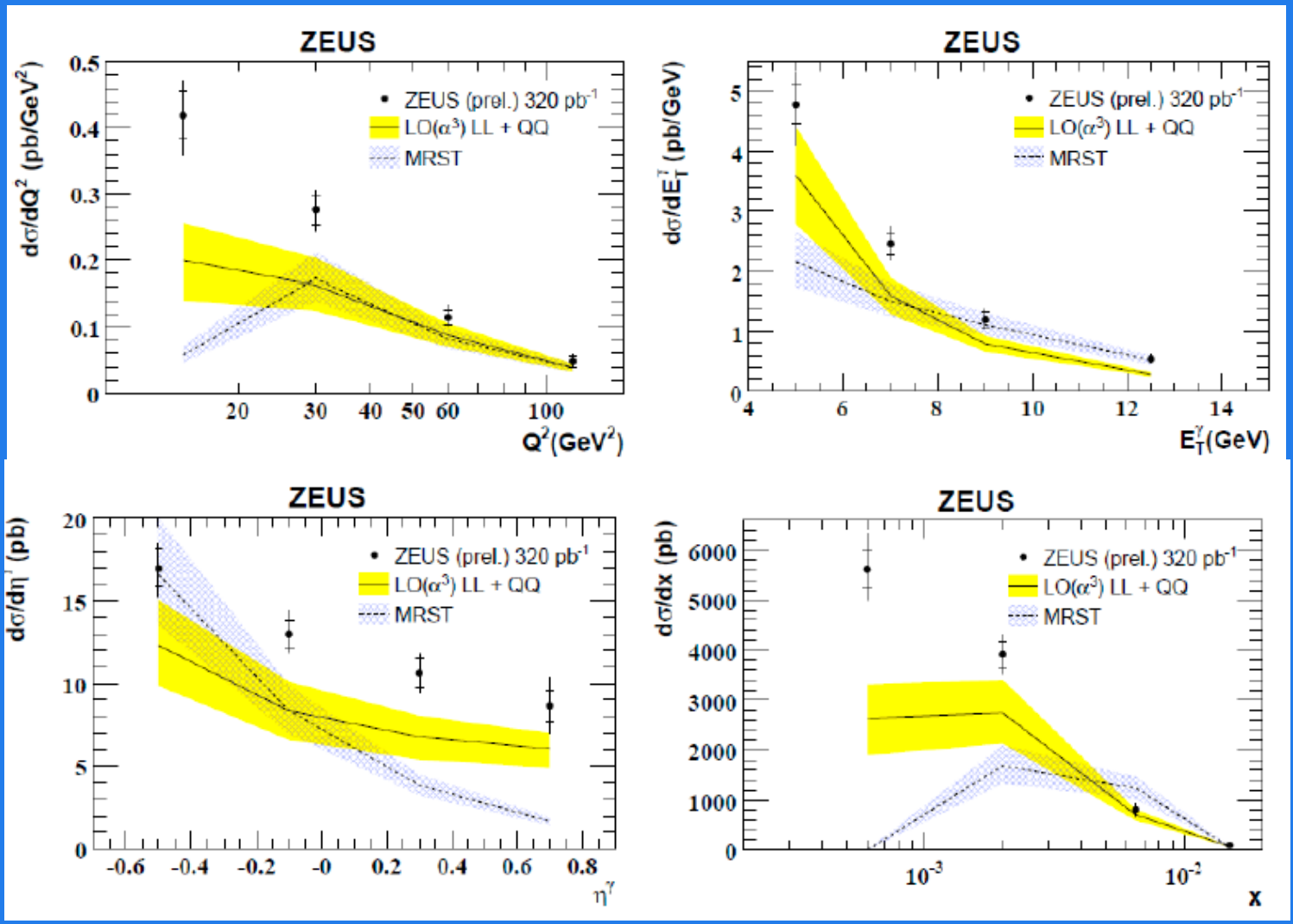
Hidden photons!
Just need a
long vacuum tube!

SHIPS, CASTeV



ZEUS: inclusive prompt photons in DIS.

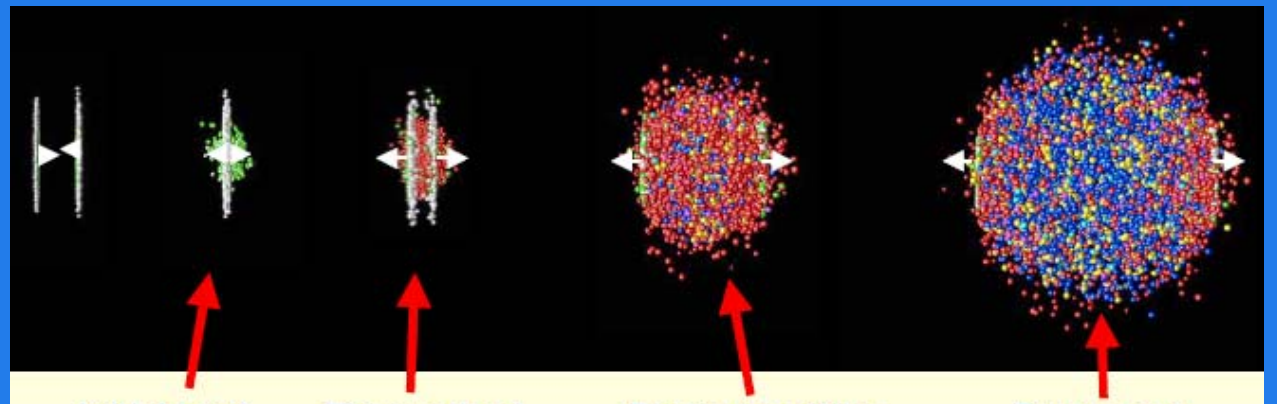
Compare with **Gehrmann-de Ridder et al** and **MRST**
(MRST lacks QQ diagrams.)



G Reygers

Prompt photons at RHIC

PHENIX



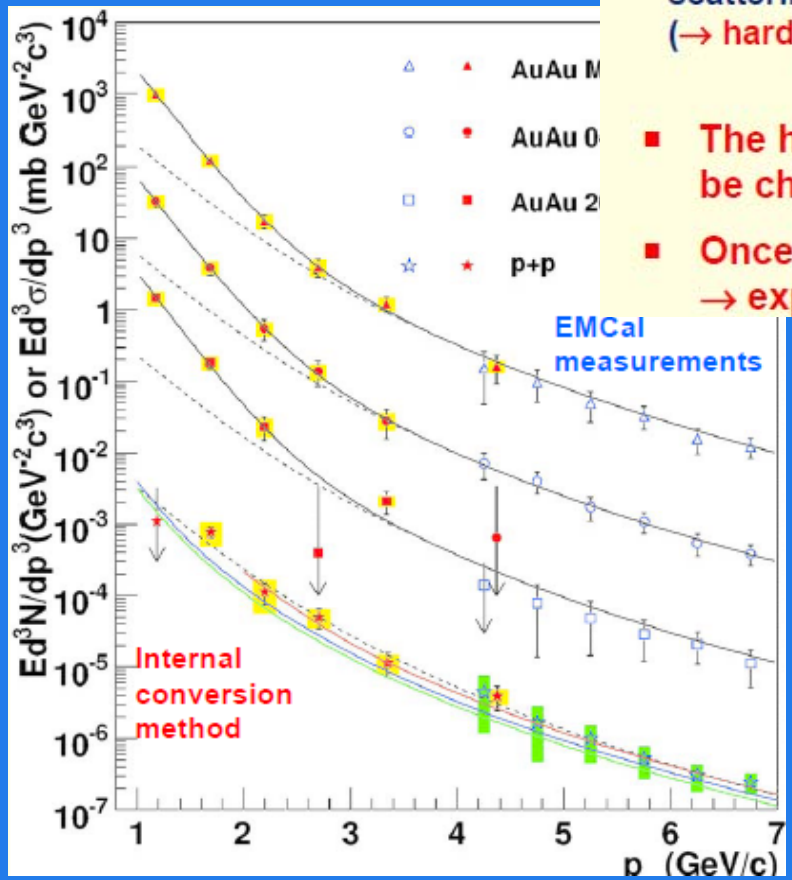
Initial hard parton-parton scatterings ($\rightarrow$ hard γ)

Thermalized medium (QGP!?), $T_0 > T_c$, $T_c \approx 170$ - 190 MeV ($\rightarrow$ thermal γ)

Phase transition QGP $\rightarrow$ hadron gas

Freeze-out

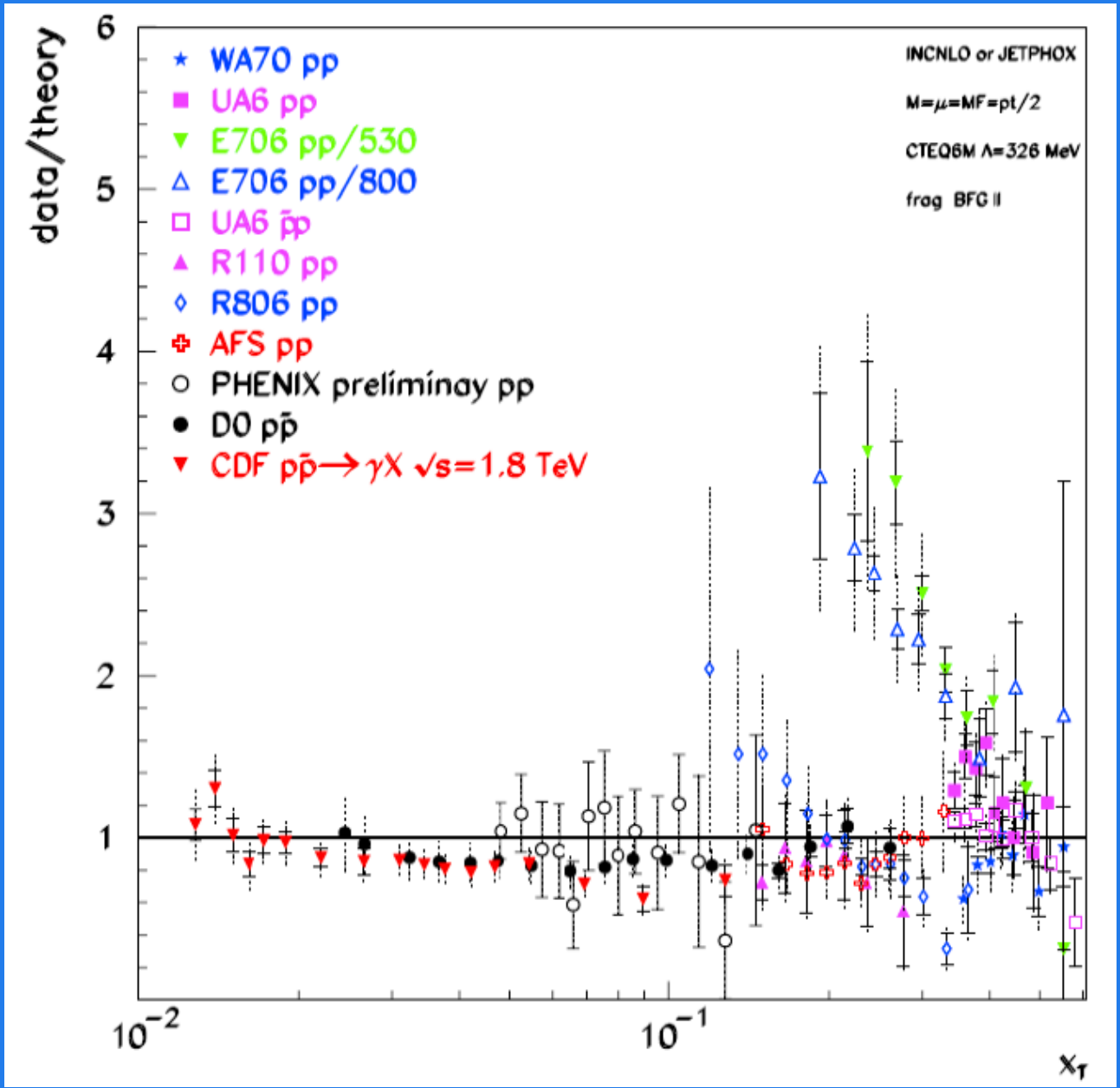
- The hope is to create a thermalized medium that can (locally) be characterized by a temperature T.
- Once produced photons leave the fireball unscathed $\rightarrow$ experimental access to the temperature of the fireball



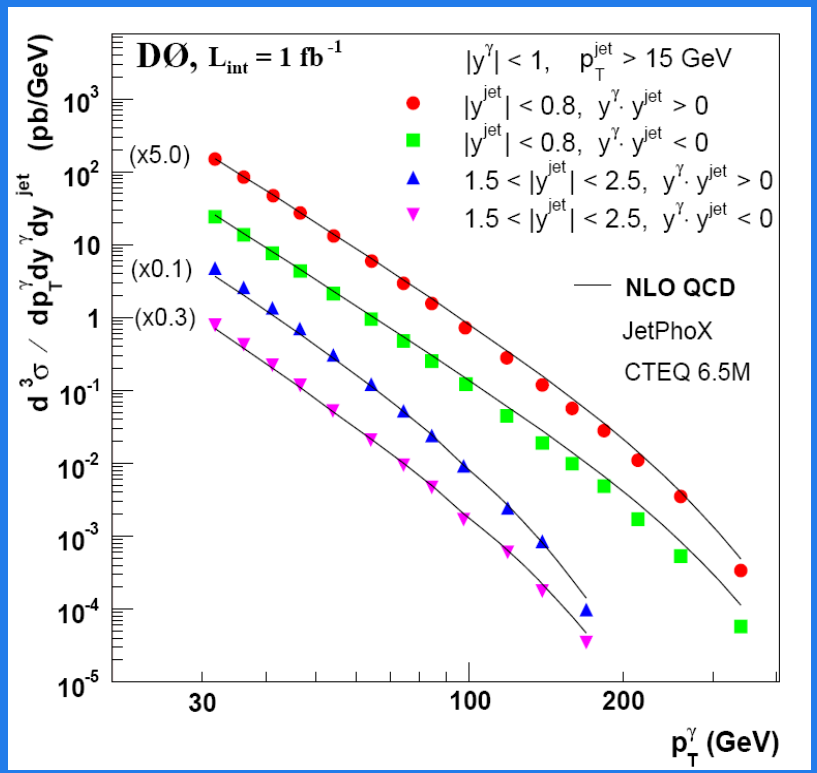
T = (221 ± 23 ± 18) MeV

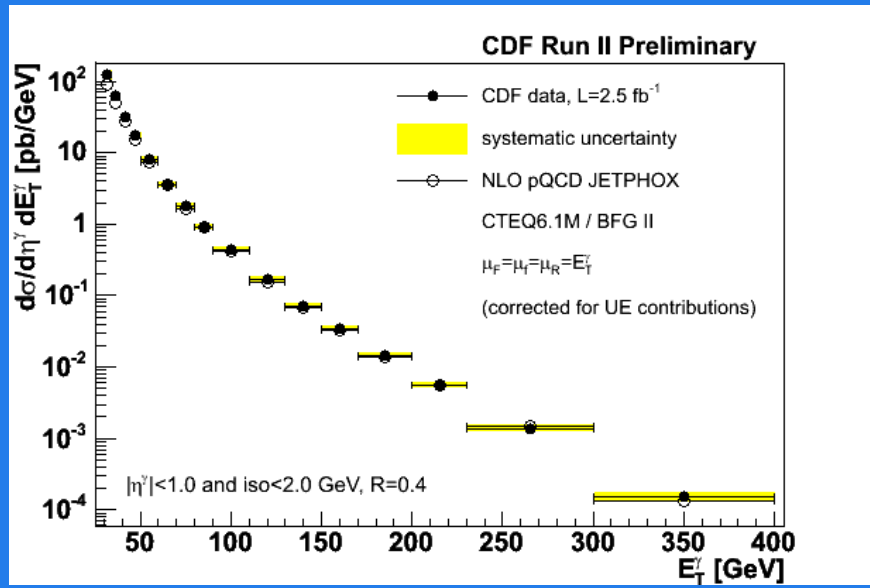
$T_{initial} > T_c \approx 170$ - 190 MeV $\rightarrow$ evidence for the formation of a quark-gluon plasma

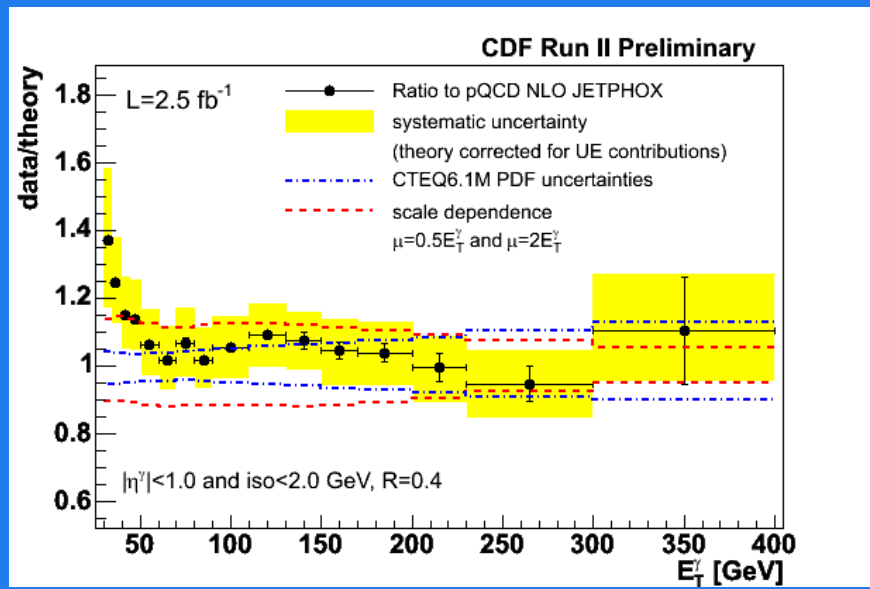
PHENIX and Tevatron results



A Kumar Prompt photons in PP at the Tevatron



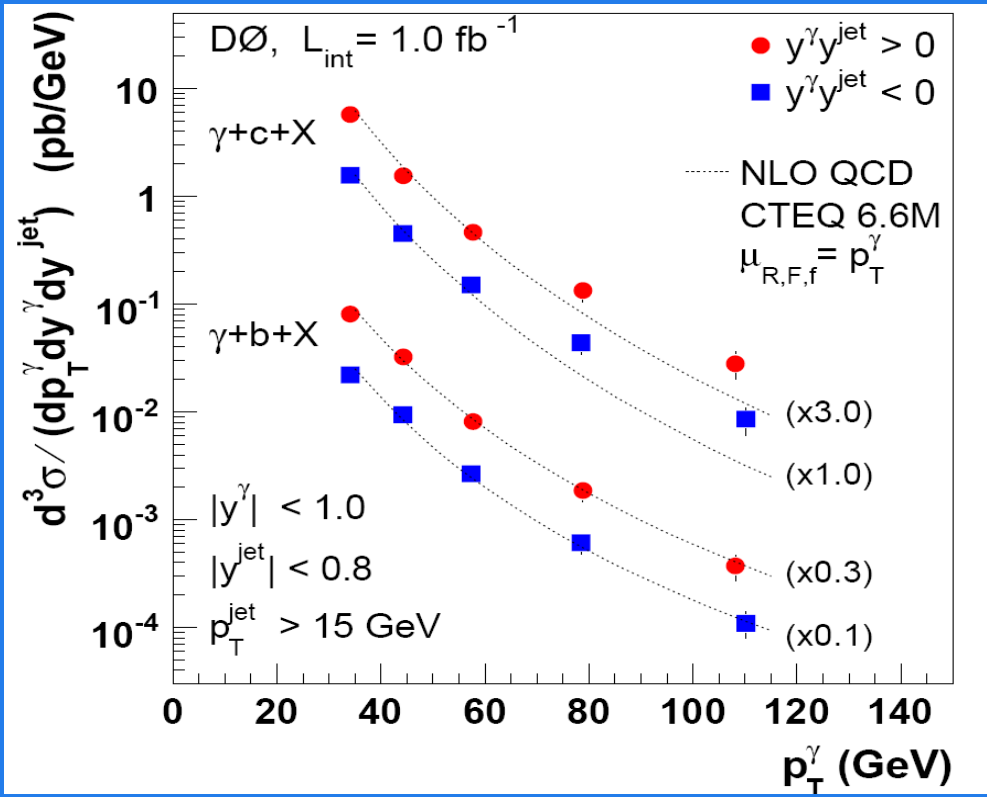




Prompt photon + jet results from CDF and D0

Prompt photon + Heavy flavour.

Reasonable agreement with NLO



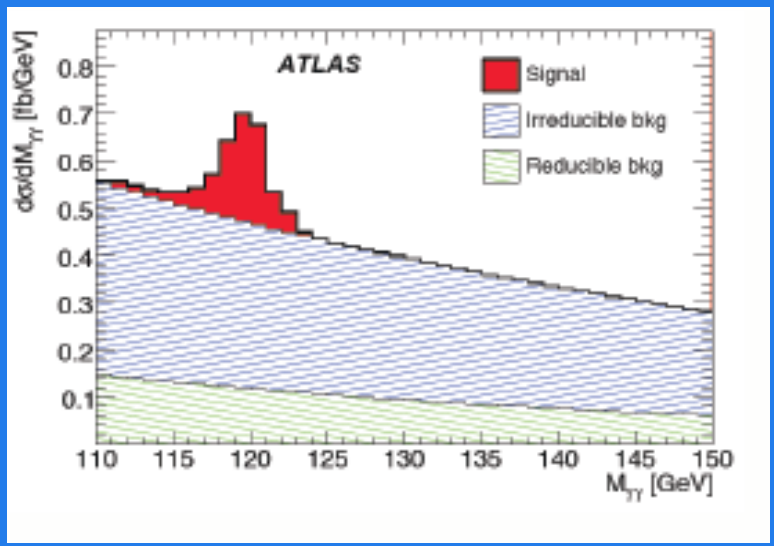
How rare the Higgs photons are!

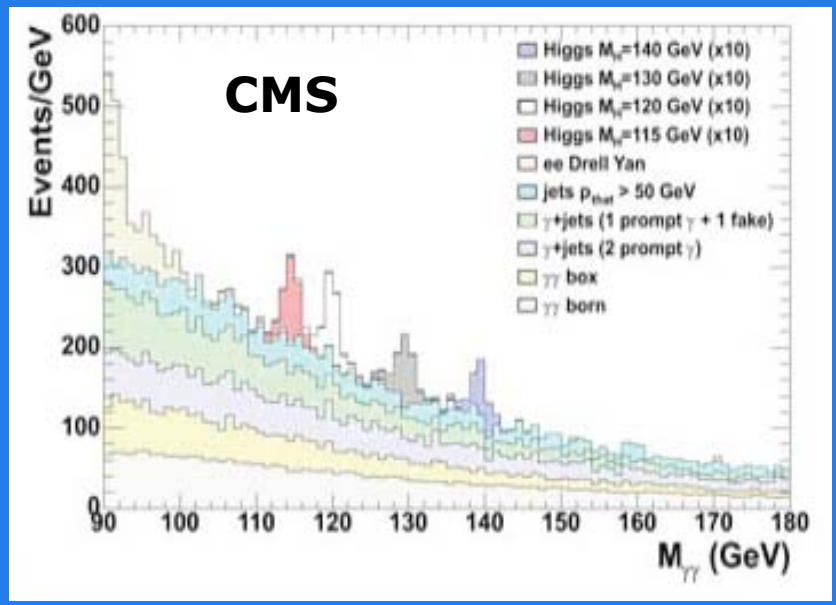
D Joffe

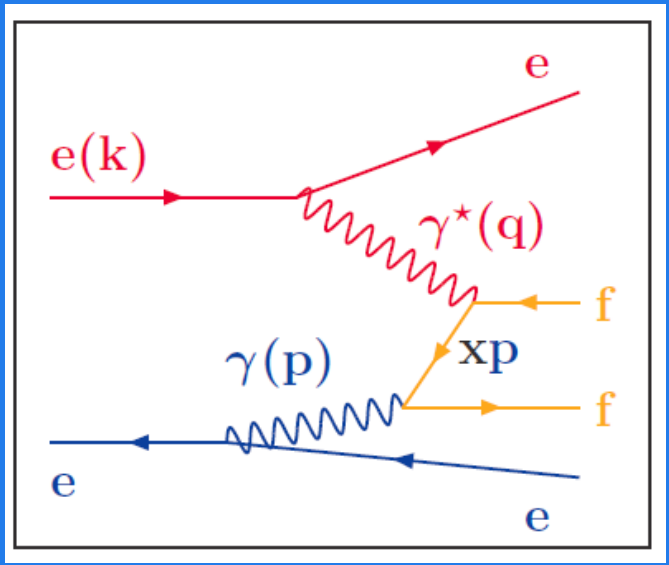
Photons at LHC.

A very important topic!

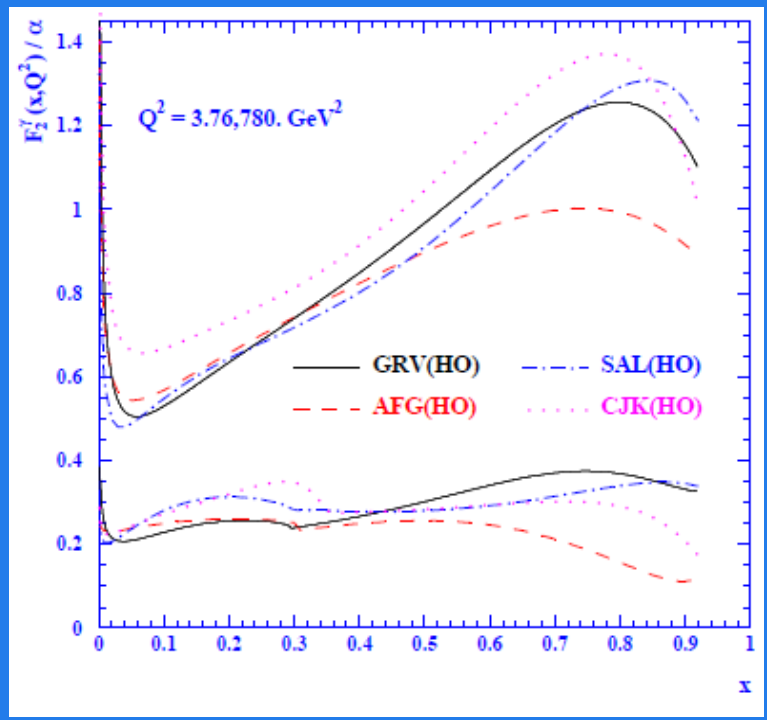
Process	Events for $10fb^{-1}$	σ (nb)
Direct photon	10^7 (p_T > 20 GeV/c)	100
Photon pairs	10^4 (p_T > 20 GeV/c)	15
H→γγ	~200	$2x10^{-5}$

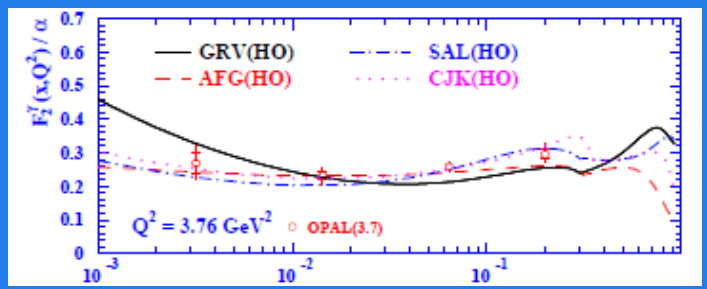


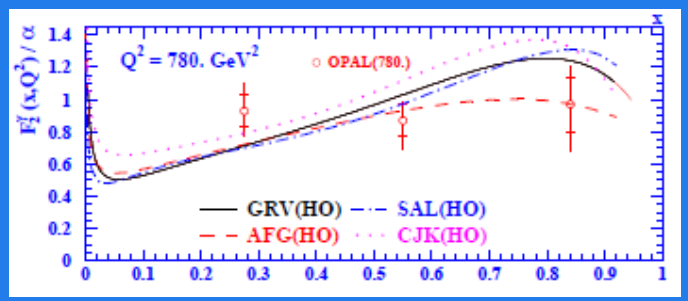




$$\frac{d^2\sigma}{dx\,dQ^2} \approx k(x, y, Q^2) \cdot F_2^{\gamma}(x, Q^2, P^2)$$

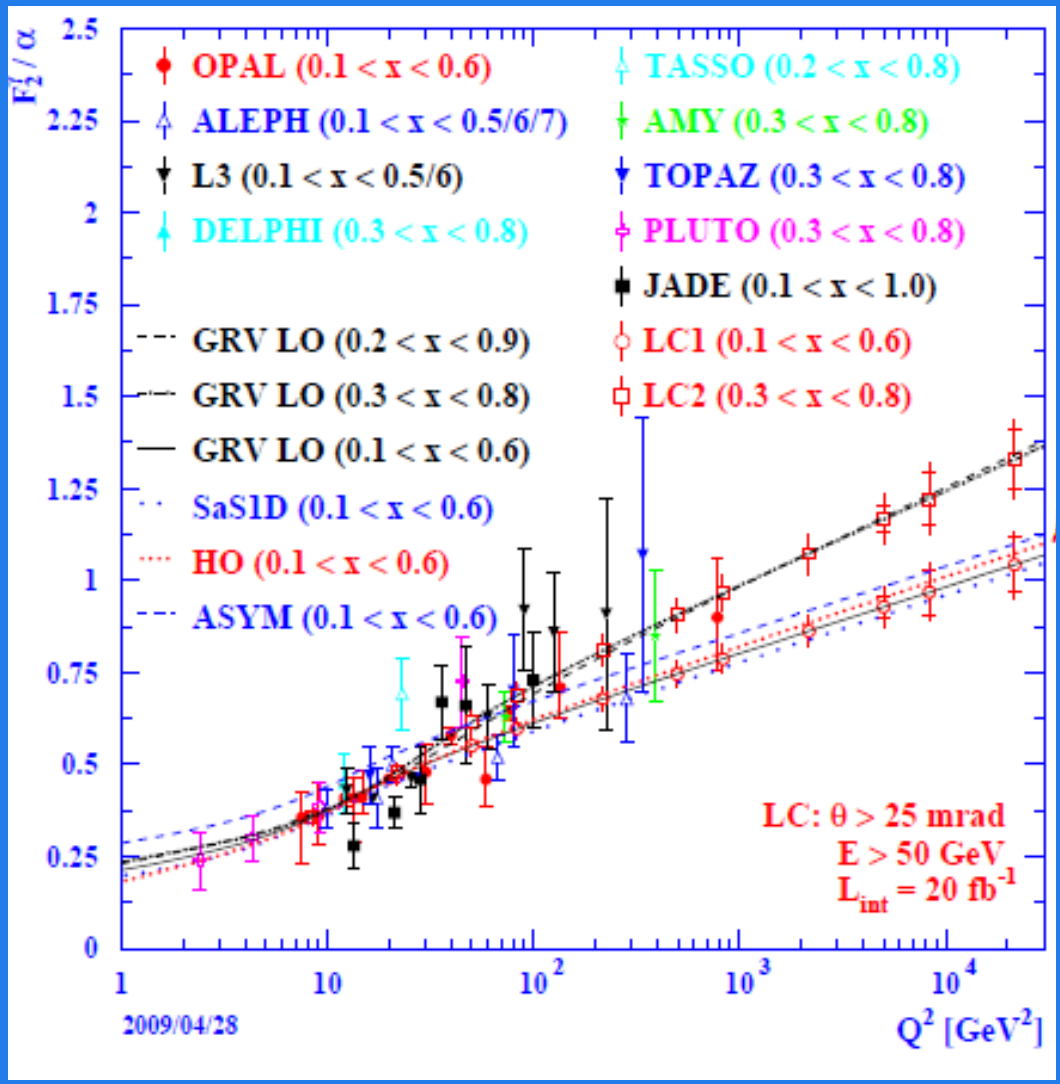






Recent HO fits and how they describe low Q^2 and high Q^2 data

Collection of data to show variation with Q^2



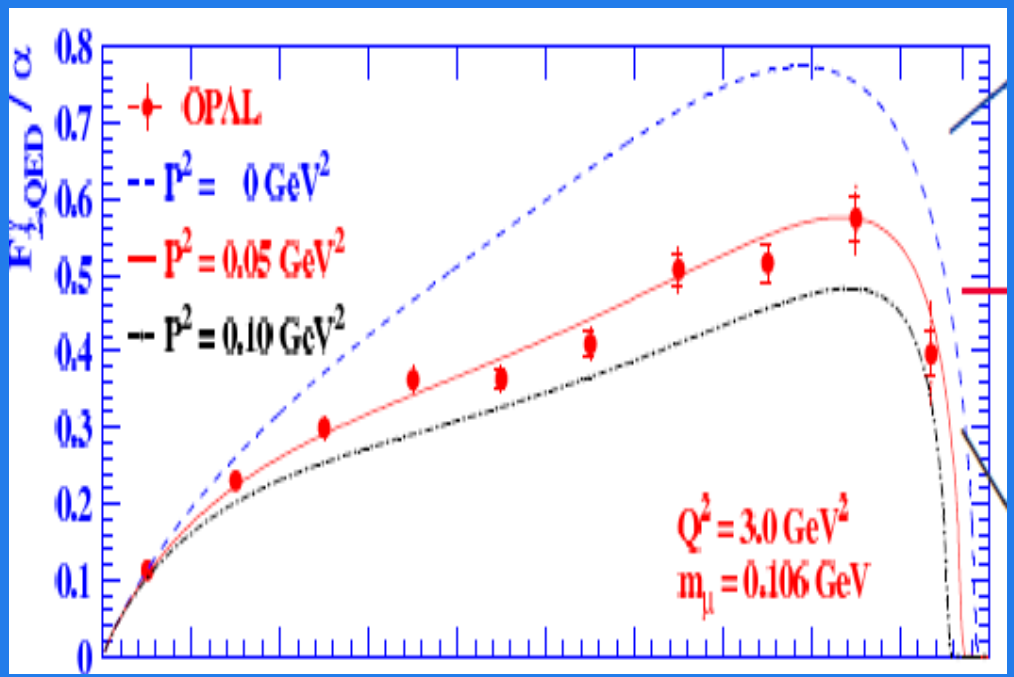
Photon leptonic structure function.

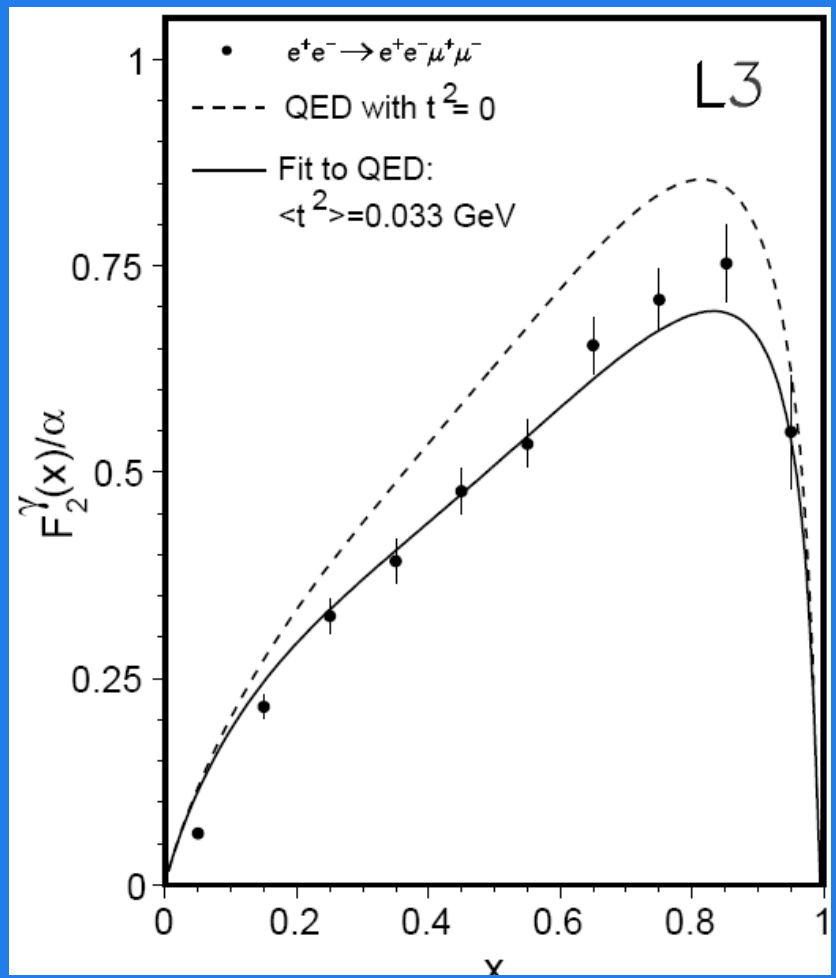
K Dehmelt

Use two-photon production of lepton (muon) pairs, one of which is much more virtual than the other.

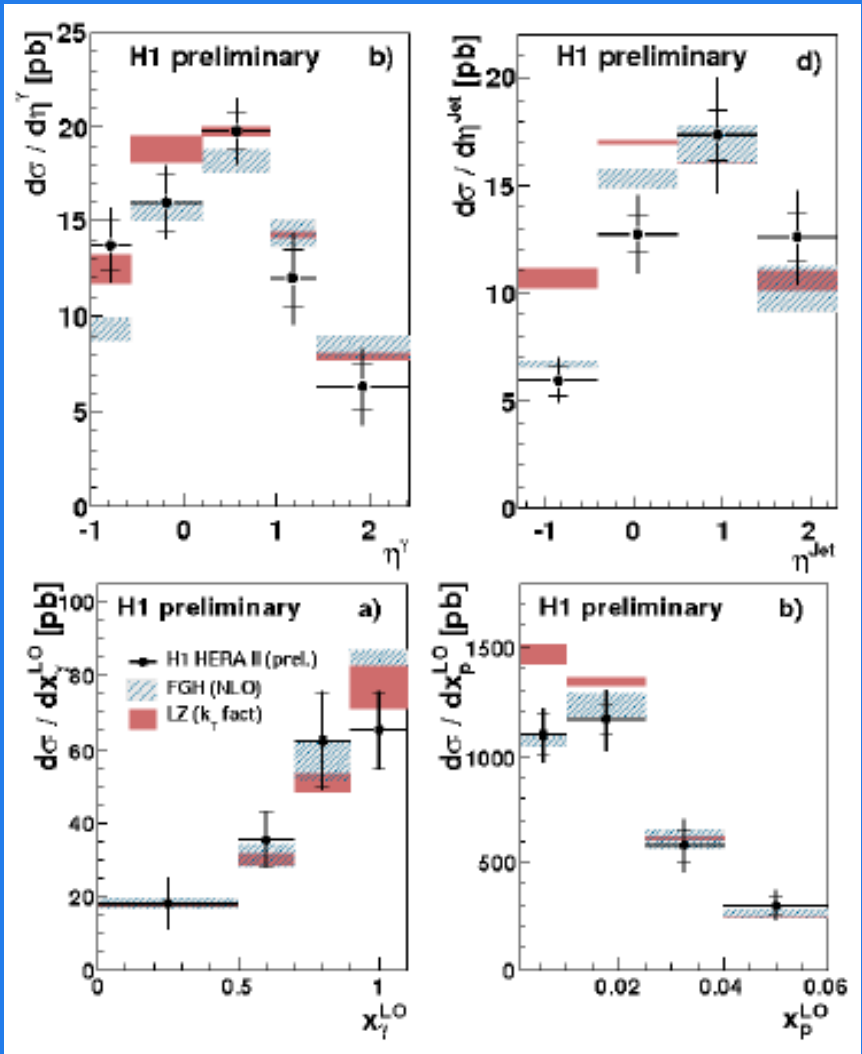
Fit to GALUGA M.C.

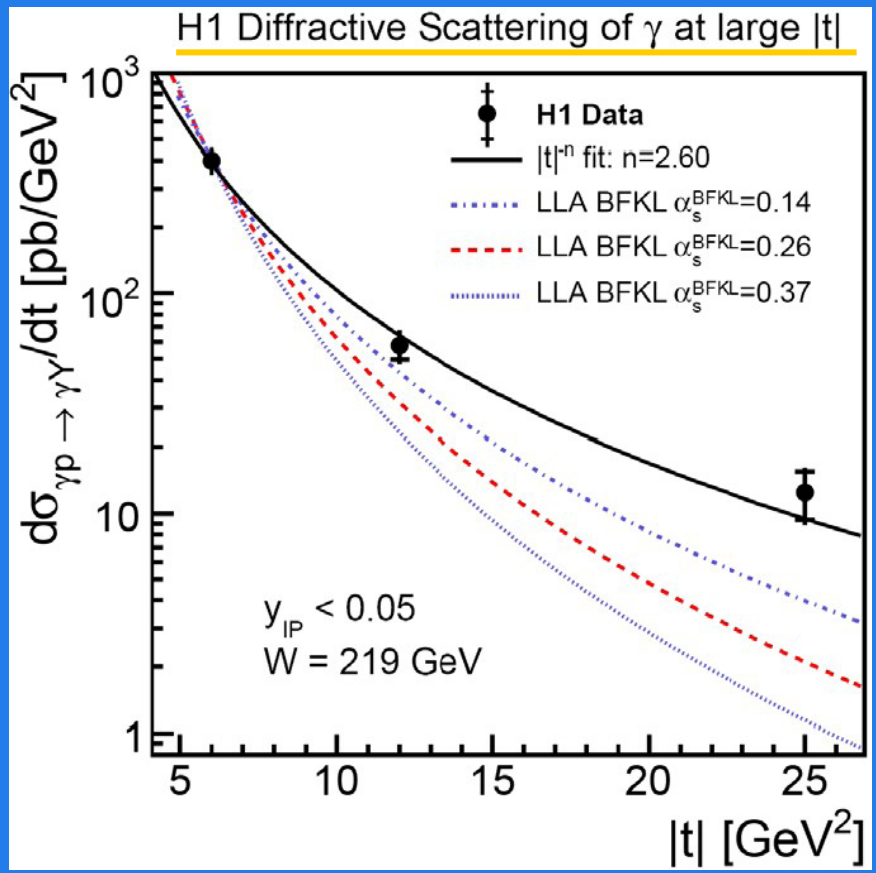
Nisius: fit to Vermaseren MC





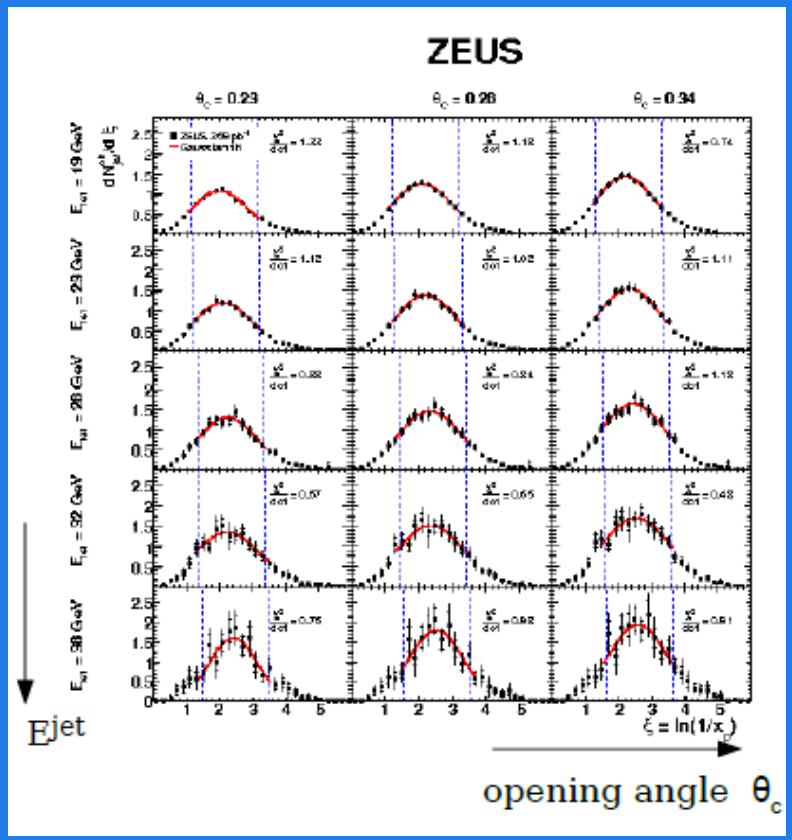
In both cases the target photon has a small effective (virtual mass)^2

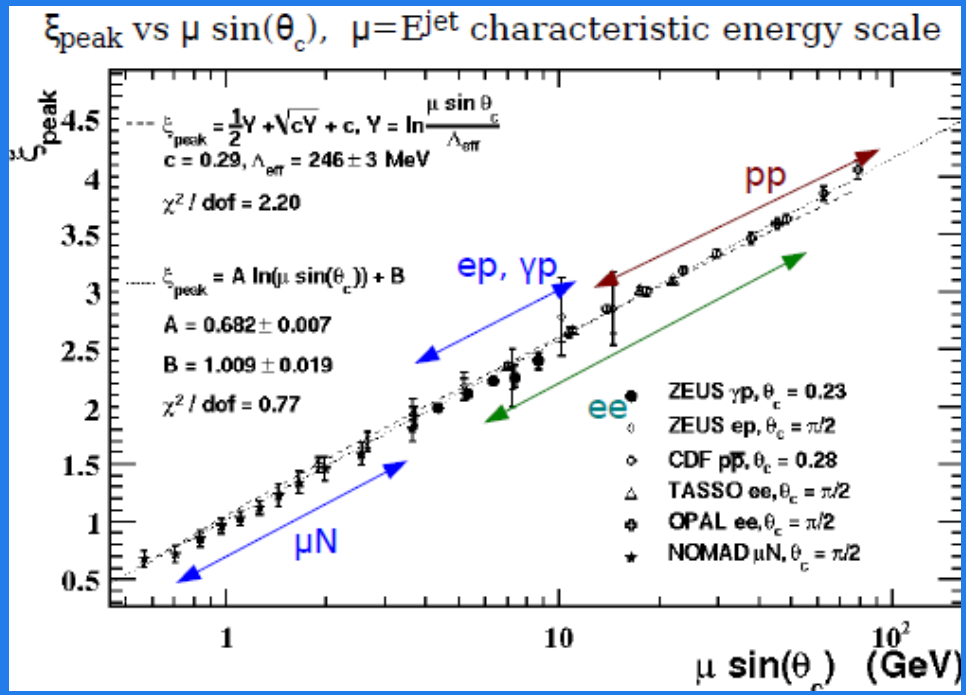




Prompt photons + jet cf FGH NLO and LZ kt factorisn. reasonable description.

Scaled momentum distributions in dijet events



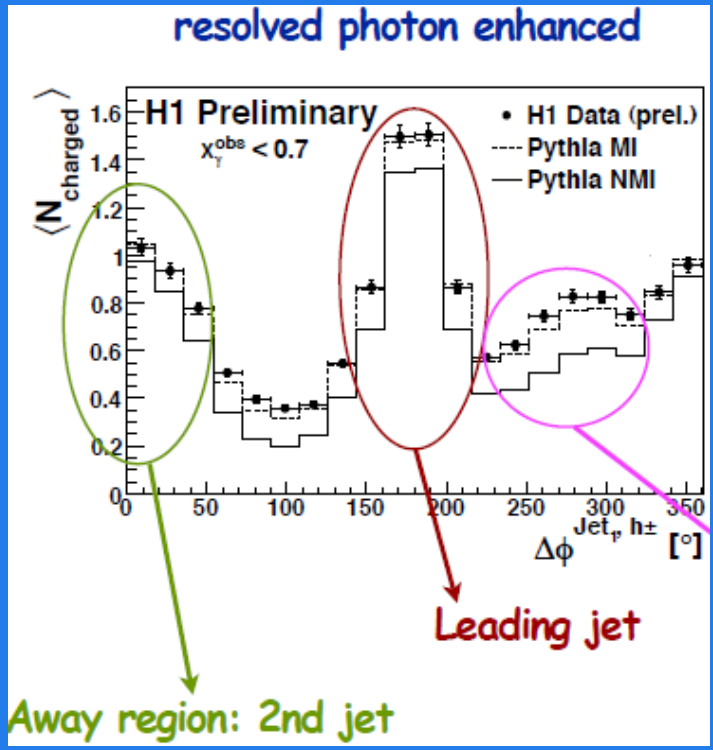


Plot position of peak versus characteristic energy scale

Universal description!

G Grindhammer

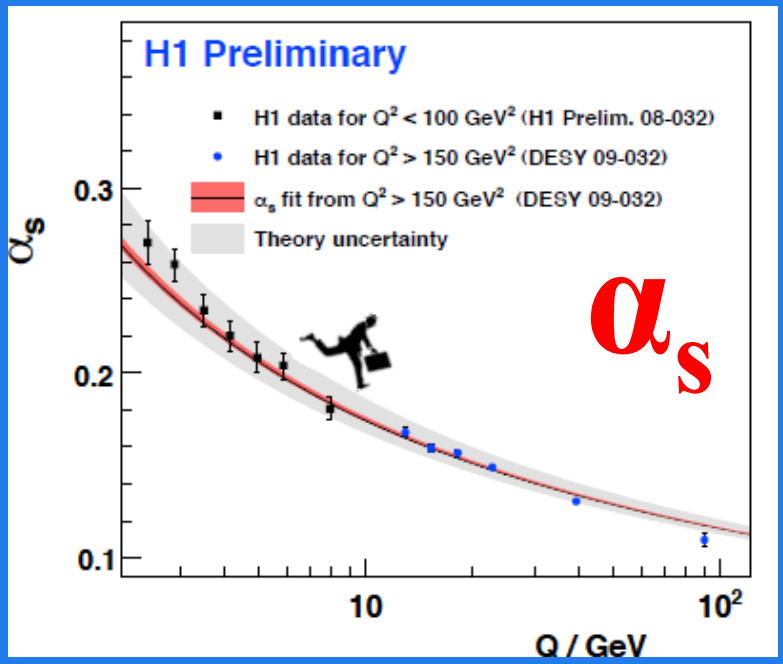
Study of underlying event in photoproduction

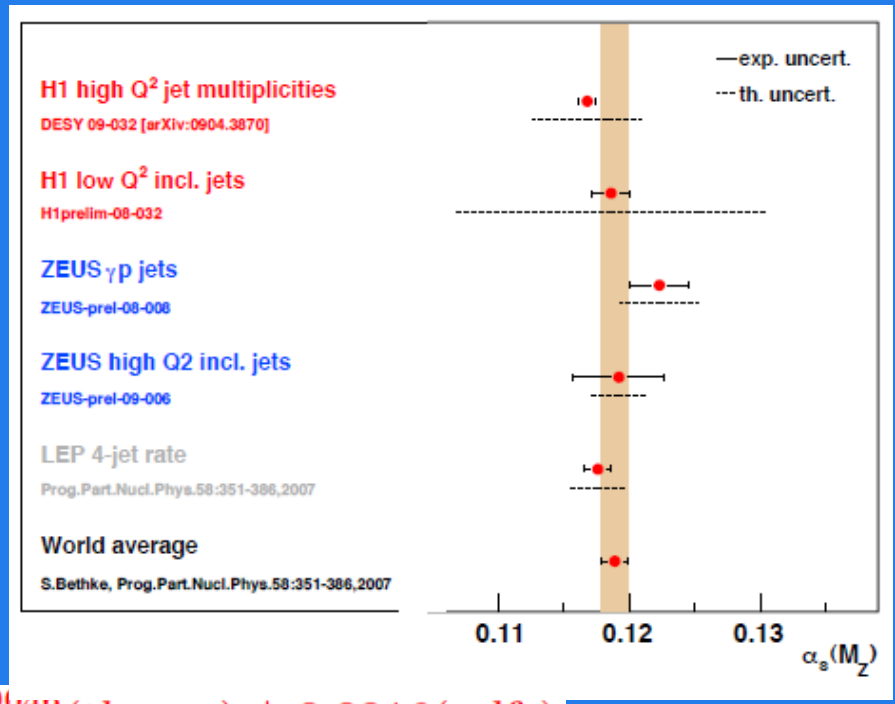


for <charged particle multiplicities> Pythia + MPI provides a reasonable description of the data

interestingly, Cascade (no MPI) is only somewhat worse in describing the data, signicantly better than Pythia w/o MPI.

further studies are needed





$$\alpha_s(M_Z) = 0.1168 \pm 0.0007(\text{exp}) \,^{+0.0040}_{-0.0030}(\text{theory}) \pm 0.0016(\text{pdfs})$$

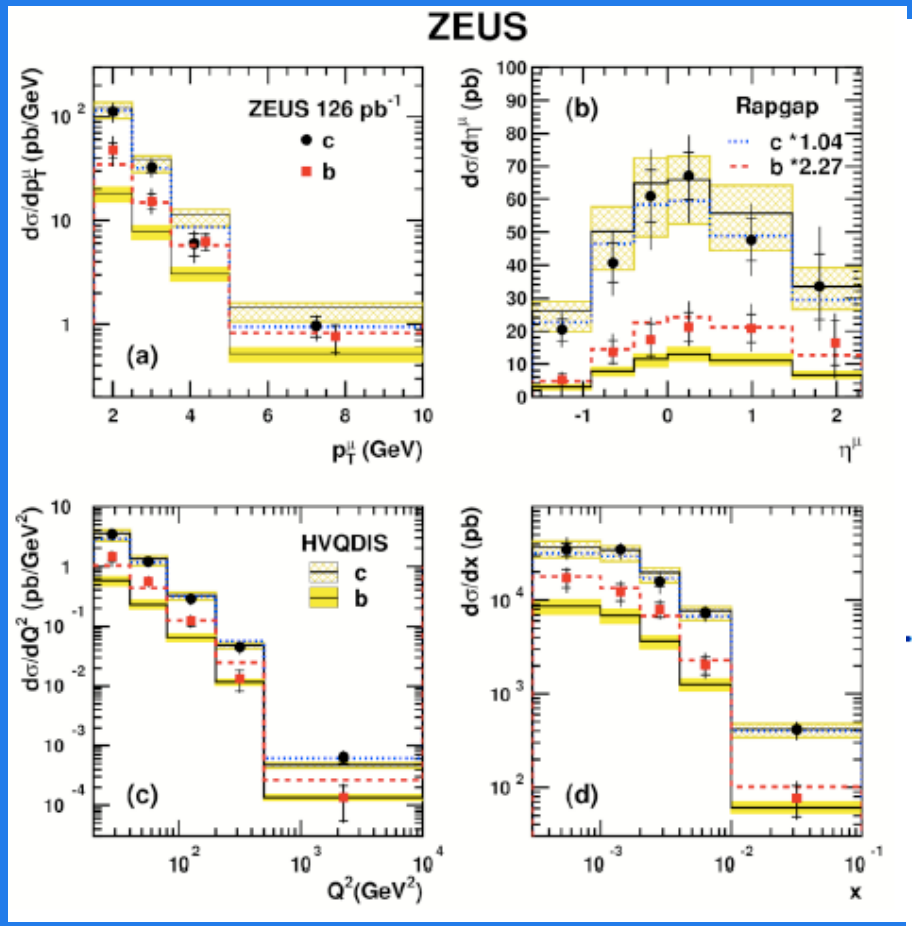
ZEUS – fit to jets in DIS and in γp:

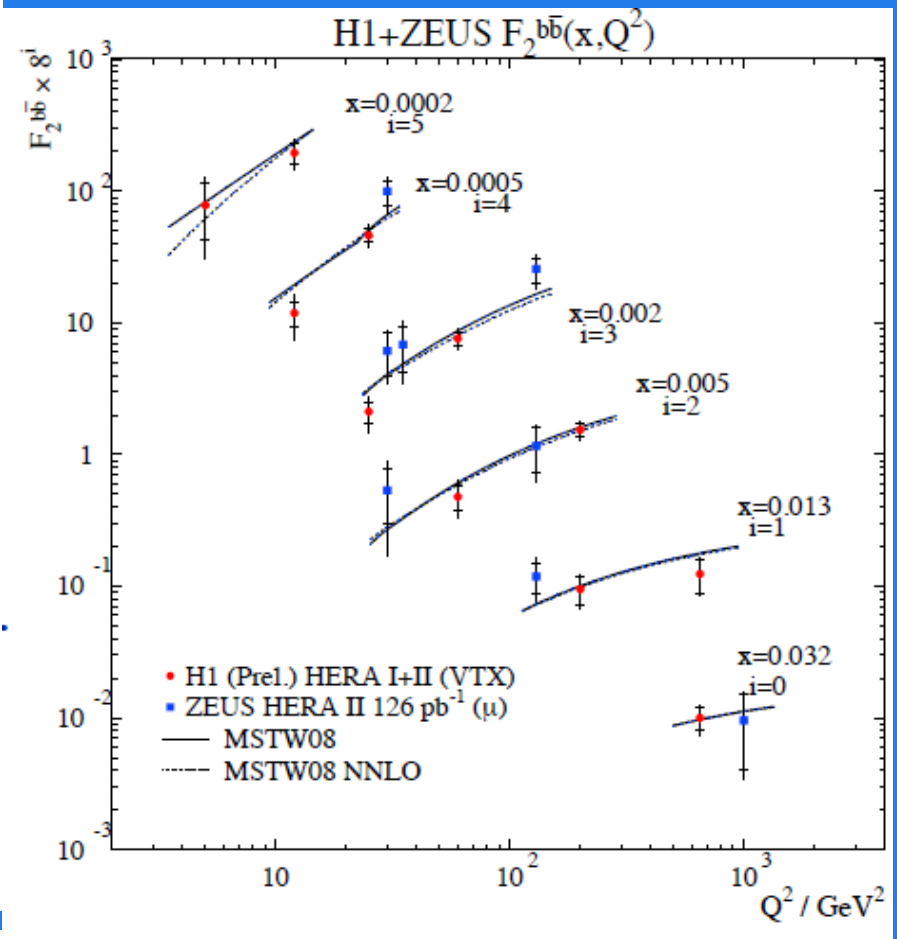
$$\alpha_s(M_Z) = 0.1192 \pm 0.0009(\text{stat}) \,^{+0.0035}_{-0.0032}(\text{exp}) \,^{+0.0020}_{-0.0021}(\text{th})$$

$$\alpha_s(M_Z) = 0.1223 \pm 0.0001(\text{stat}) \,^{+0.0023}_{-0.0021}(\text{exp}) \,^{+0.0029}_{-0.0030}(\text{th})$$

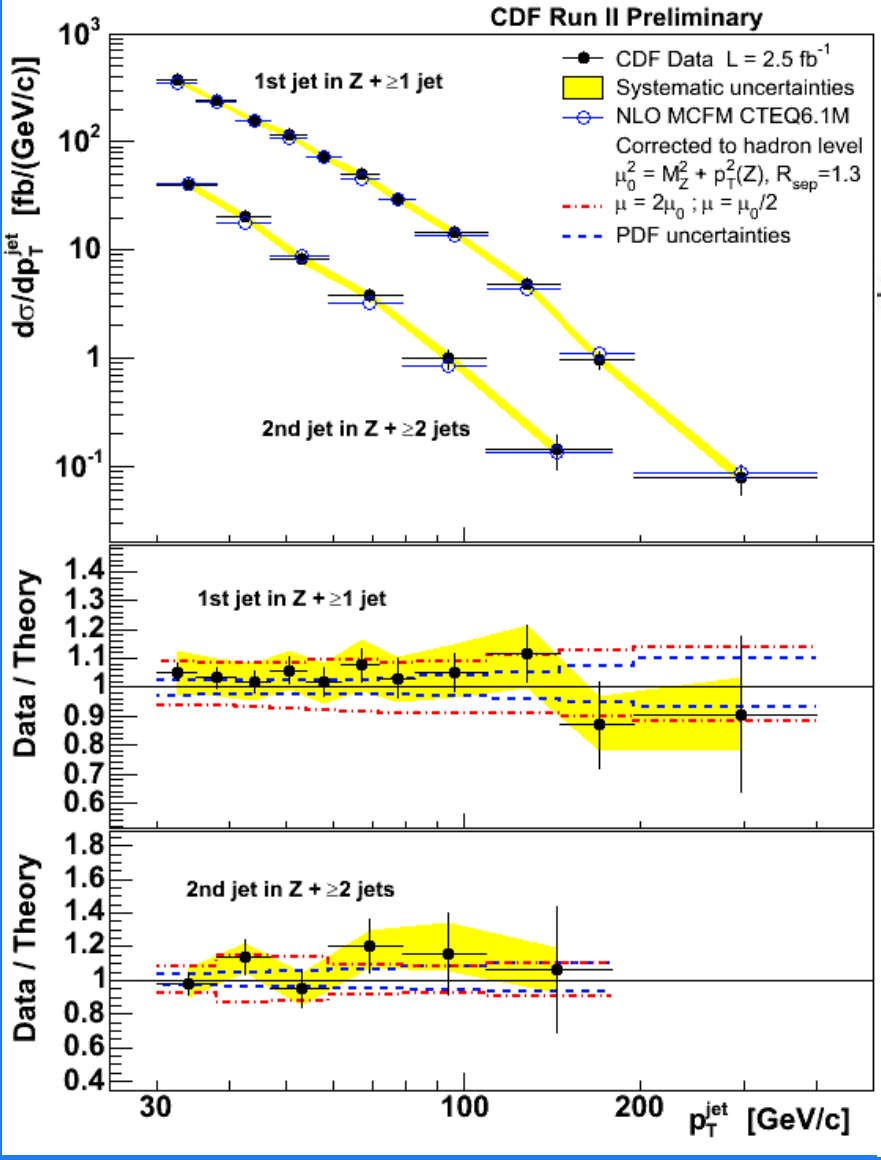
H1 - fit theory, then fit theory ± its errors.
ZEUS - fit result and then apply Jones method (apply theory errors to result.)

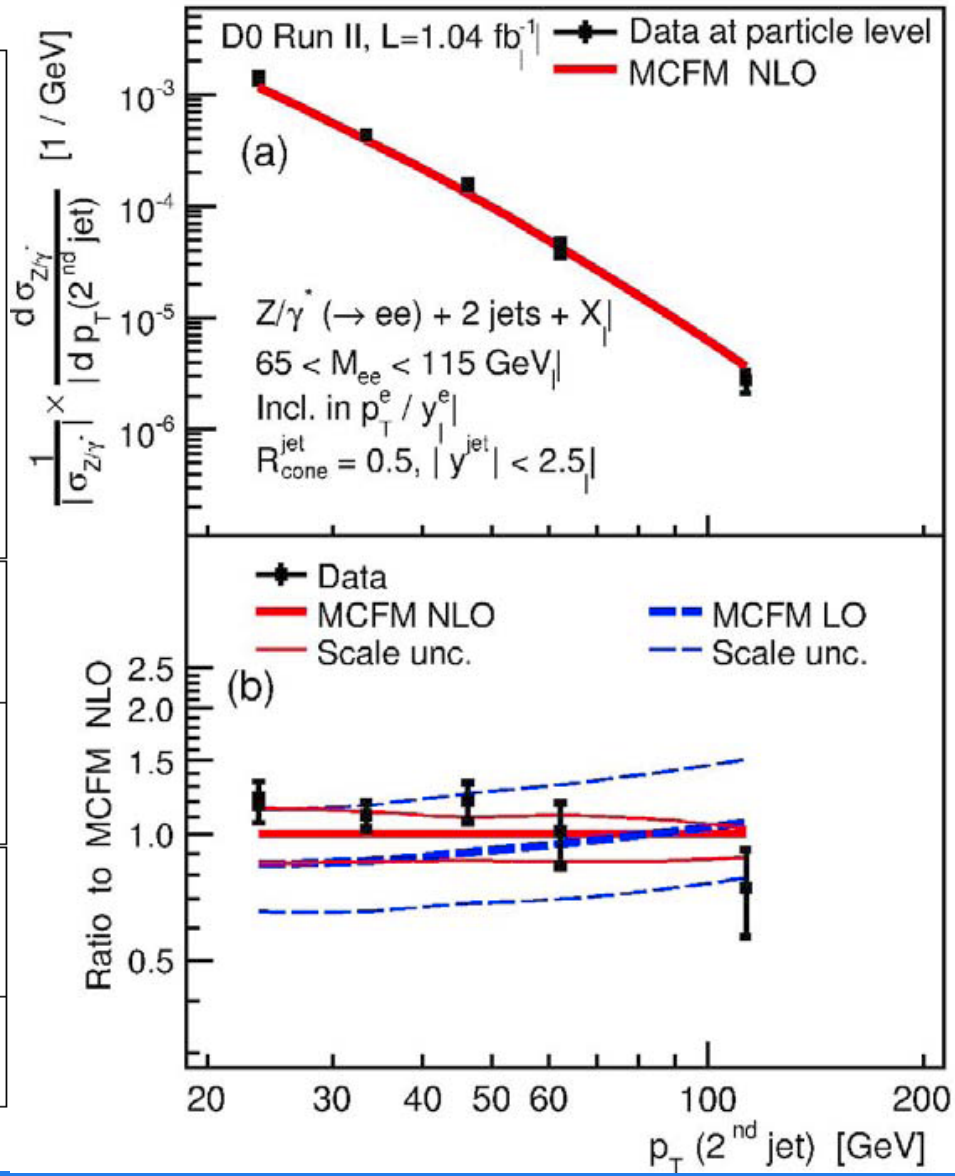
Charm and beauty in DIS at HERA





HVQDIS describes c DIS well but is low for b DIS

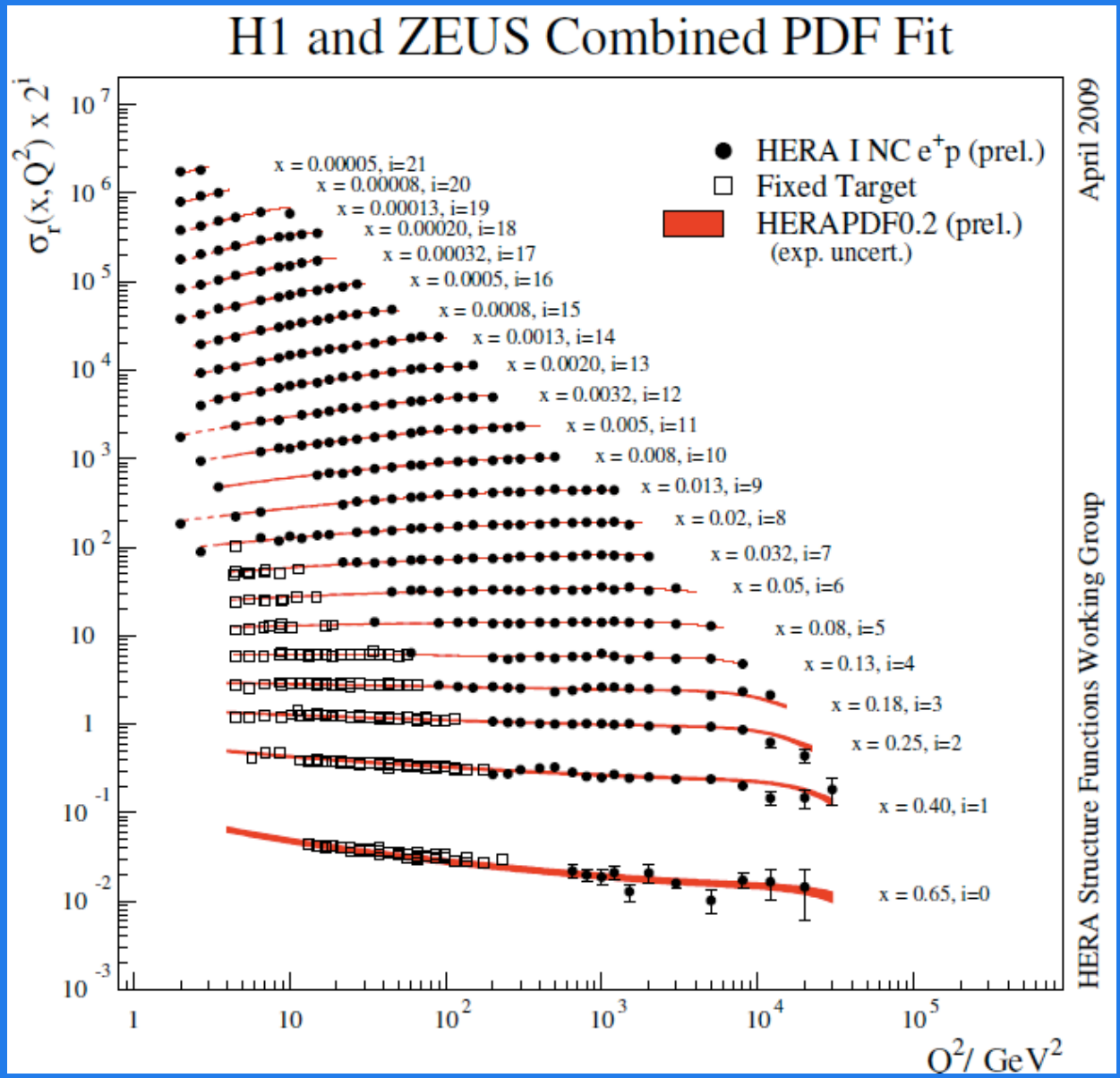

CDF Run II Preliminary
CDF Data L = 2.5 fb-1
Systematic uncertainties
NLO MCFM CTEQ6.1M
Corrected to hadron level
μ0² = MZ² + pT²(Z), Rsep=1.3
μ = 2μ0 ; μ = μ0/2
PDF uncertainties
1st jet in Z + ≥1 jet
2nd jet in Z + ≥2 jets
dσ/dpT^jet [fb/(GeV/c)]
Data / Theory
pT^jet [GeV/c]


D0 Run II, L=1.04 fb-1
Data at particle level
MCFM NLO
(a)
Z/γ* (→ ee) + 2 jets + X
65 < Mee < 115 GeV
Incl. in pT^e / y^e
Rcone^jet = 0.5, |y^jet| < 2.5
1/σZ/γ* × dσZ/γ*/d pT(2nd jet) [1 / GeV]
Data
MCFM NLO
Scale unc.
MCFM LO
Scale unc.
(b)
Ratio to MCFM NLO
pT (2nd jet) [GeV]

Jets at the LHC

- ATLAS: calibration procedure $\Rightarrow$ Response flat in p_T and η within 5%, good energy resolution. 65% of the energy carried by charged pions $\Rightarrow$ track-based correction improves jet energy resolution by $\simeq$ 10%.
- CMS: factorized jet corrections. Full event information with particle flow $\Rightarrow$ jet energy resolution improved by 40% at 40 GeV.c^{-1}.
- Dijet cross-section measurement: jet energy scale dominant source of uncertainties (results in 30% error on dijet cross-section at $M_{qq} = 1$ TeV for 10 fb^{-1} of data). Early data: additional 10% uncertainty on luminosity.

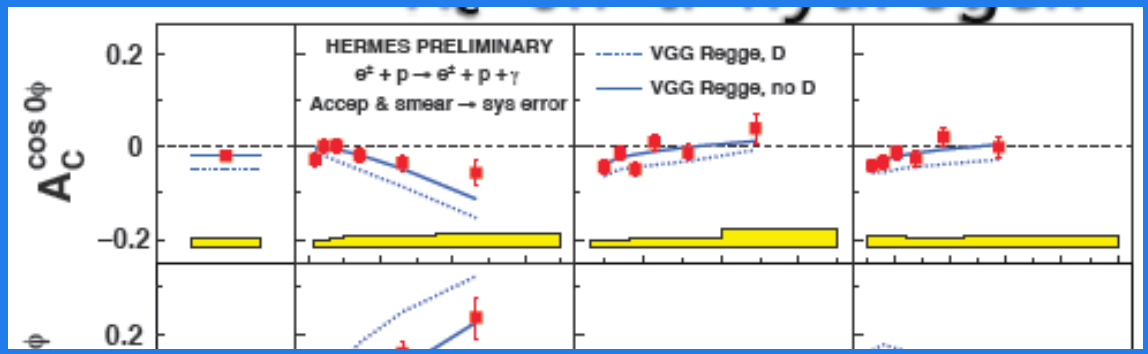
It all appears to be under control!

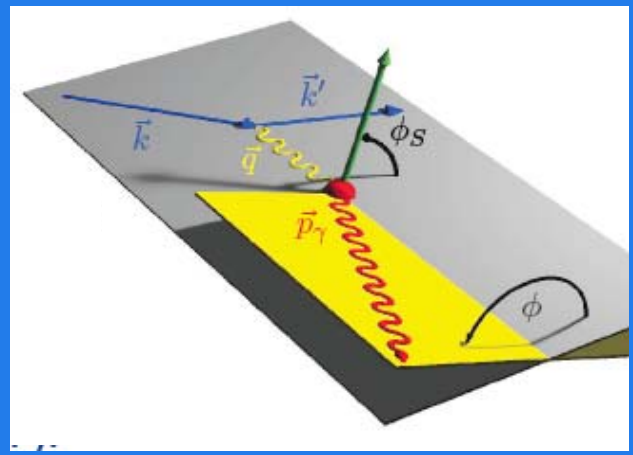


At the top of HERA's achievments, and destined for a classic place in the history of particle physics!

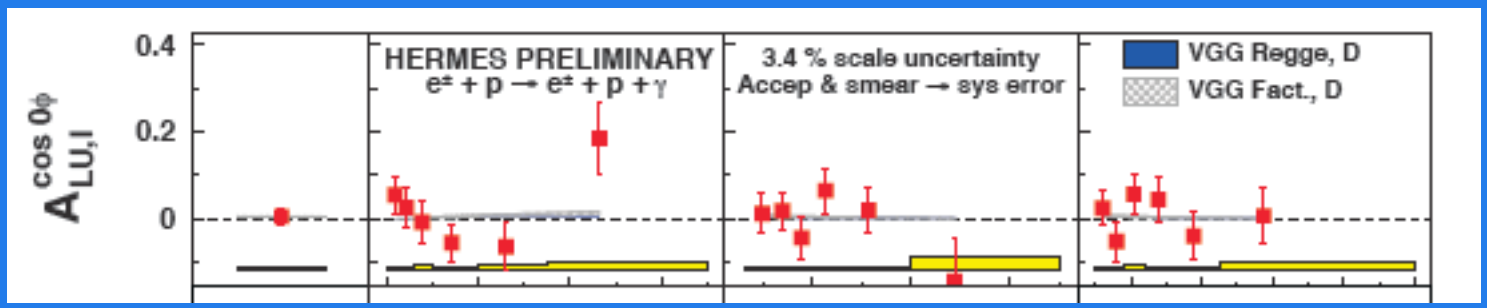
Is enabling the proton PDFs to be evaluated to new levels of accuracy, essential for LHC physics.

Azimuthal Asymmetries in DVCS





Beam-charge asymmetry $A_C(\Phi)$:

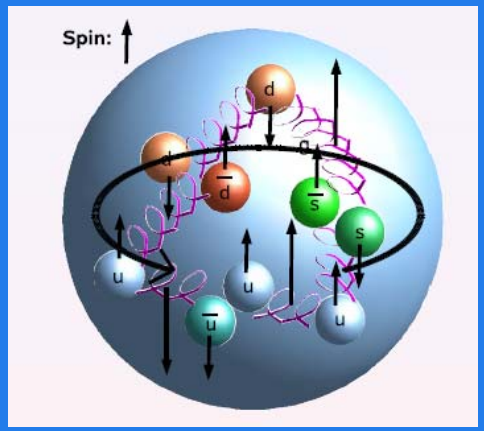


Beam-helicity asymmetry $A_{LU}^{I}(\Phi)$:

hydrogen target

GPD model: VGG Phys. Rev. D60 (1999) 094017 & Prog. Nucl. Phys. 47 (2001) 401

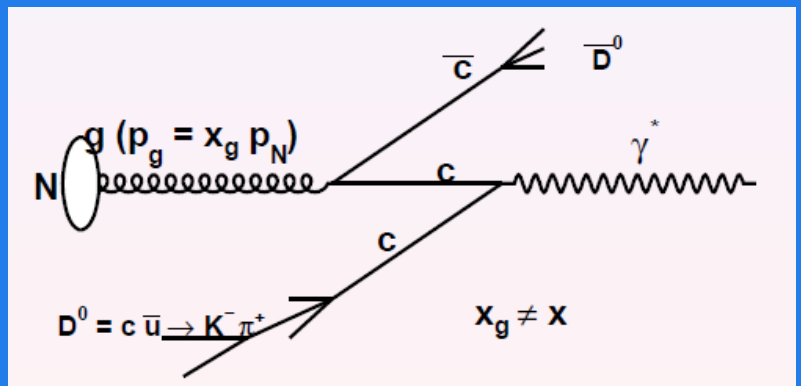
Measurement of the helicity contribution of gluons, ΔG at the COMPASS experiment

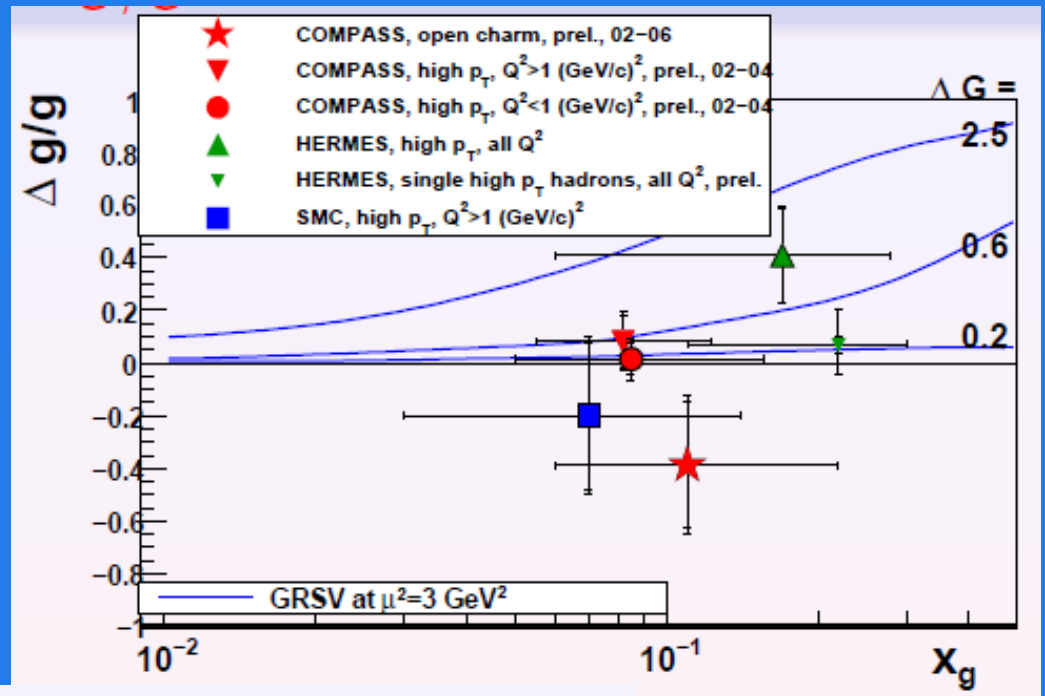


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Spin: Quarks, Gluons; orbital angular momentum: Quarks, Gluons

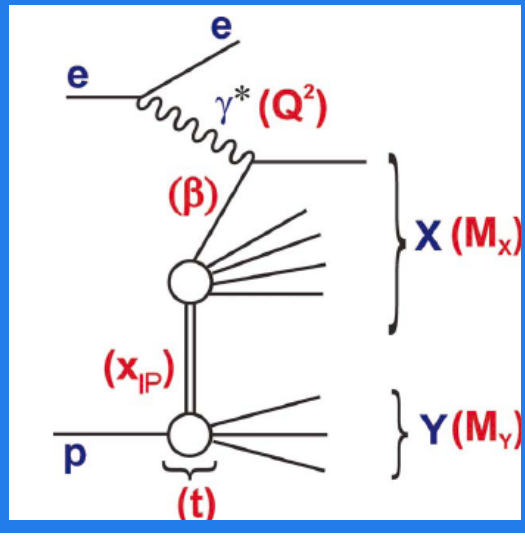
DIS with muons

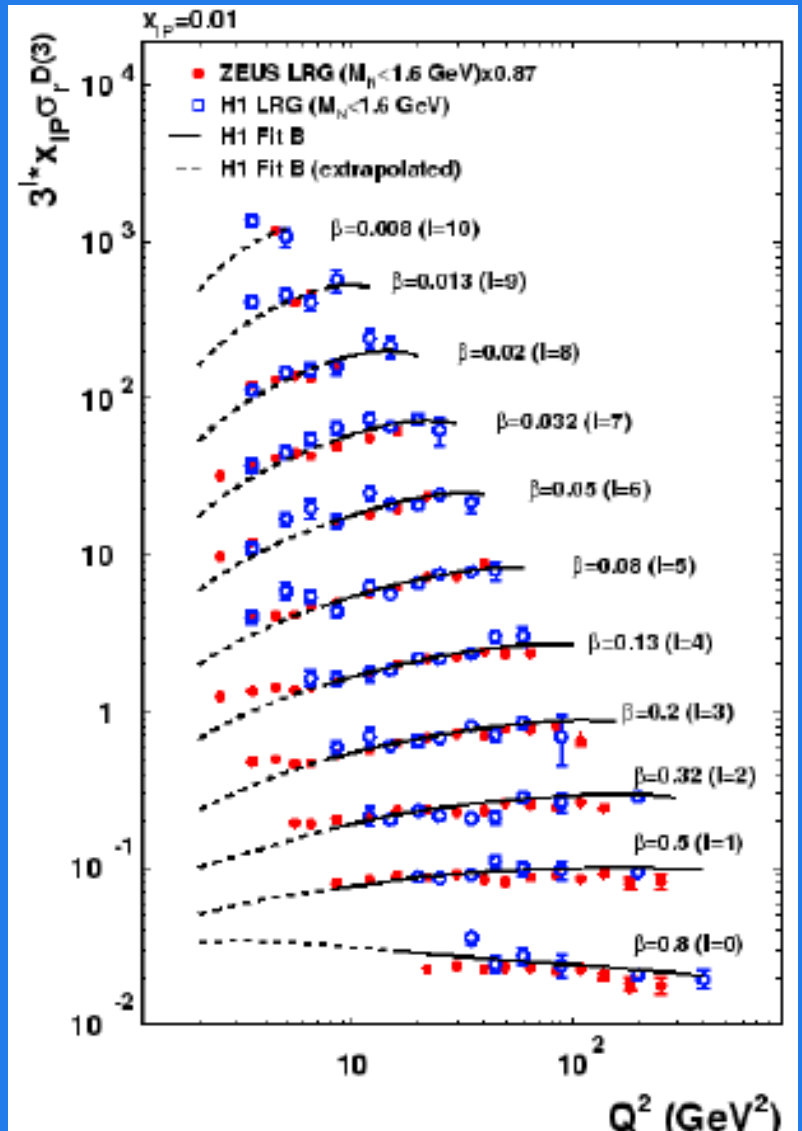


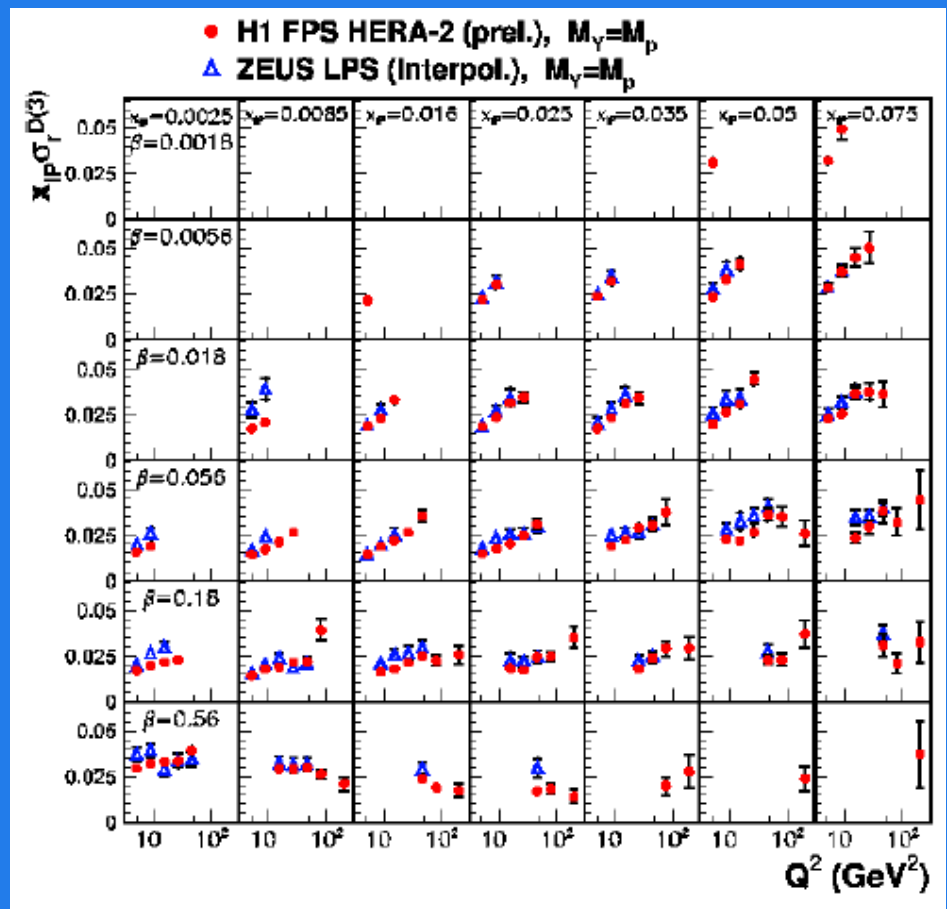


- Spin Puzzle $\Delta\Sigma_{DIS} \approx 0.25 \leftrightarrow \Delta\Sigma_{QM} \approx 0.6$ cannot be explained by large helicity contribution from gluons.
- $\Delta g/g$ small at $x_g \approx 0.1$
  scenarios with large $\Delta G \approx 2-3$ are excluded

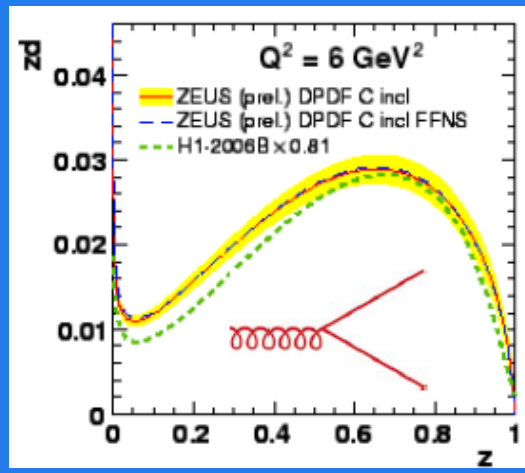
Large H1/ZEUS data sets: rapidity gap measurements and leading proton



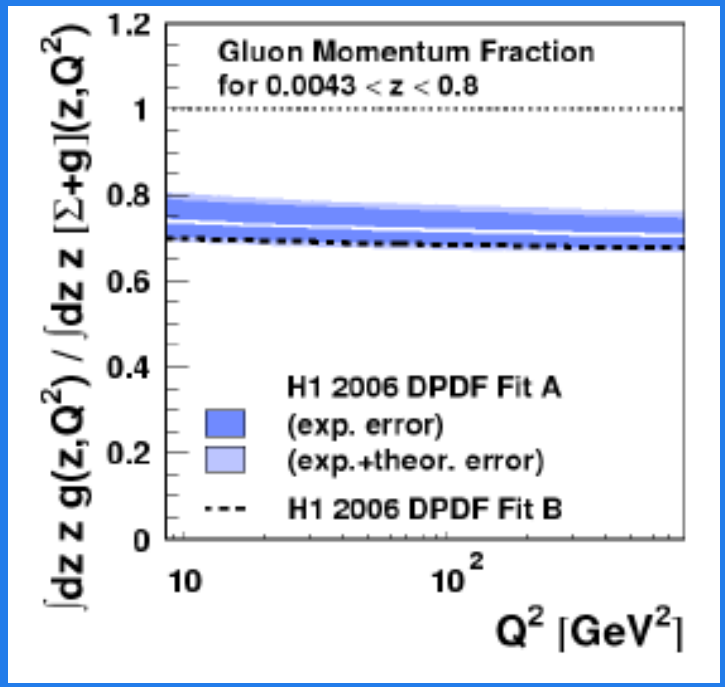




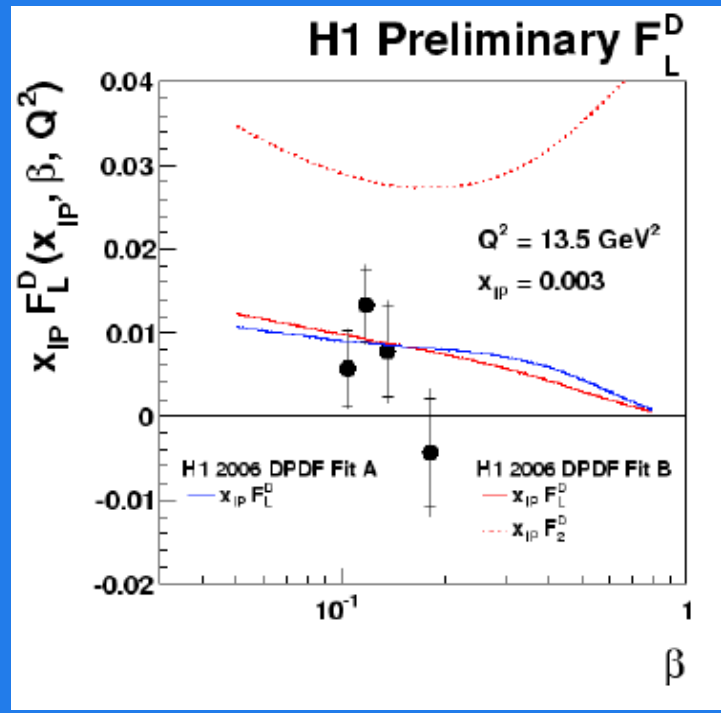
Study partons within the "pomeron"



· **High z** behaviour of quarks looks similar to photon structure function



First F_L measurements



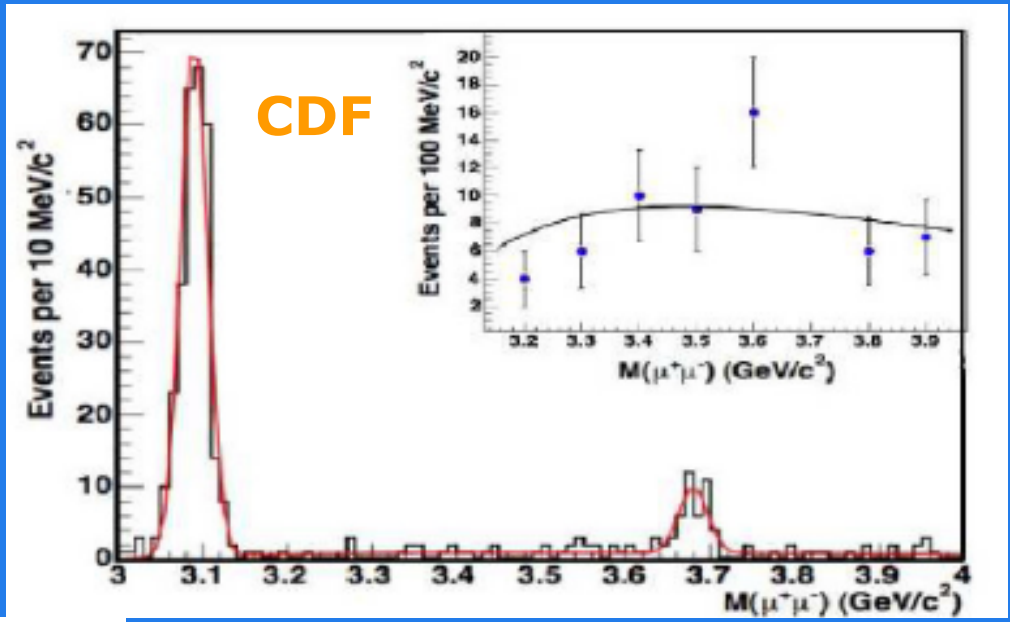
J Nystrand

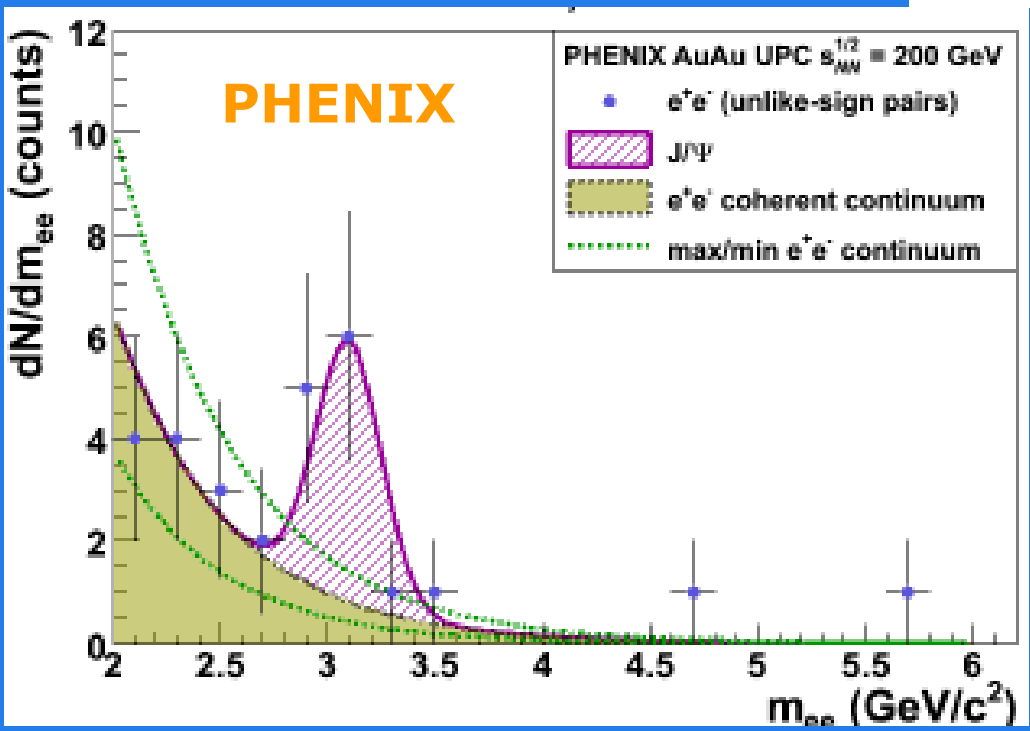
Photons in hadron colliders

γγ →μμ or ee

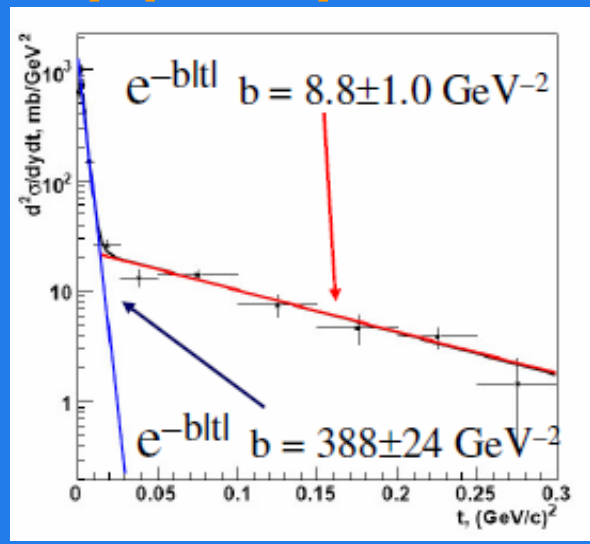
γ+pom →resonances

STARLIGHT Monte Carlo





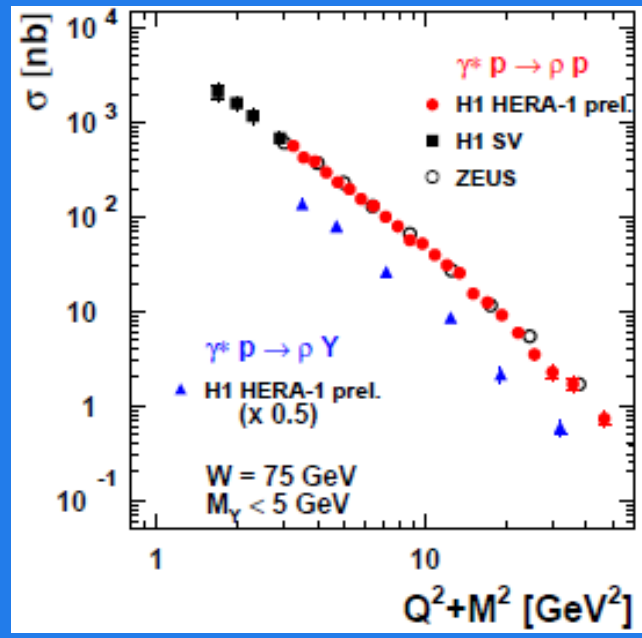
STAR ρ photoproduction

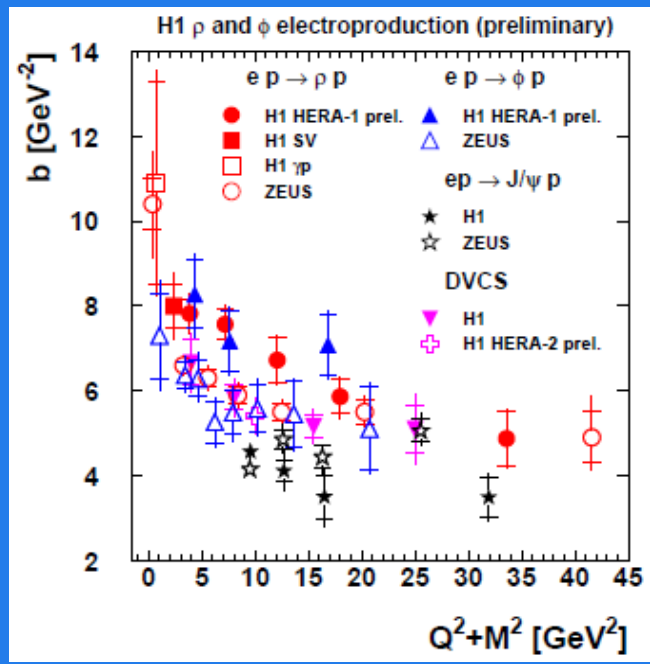


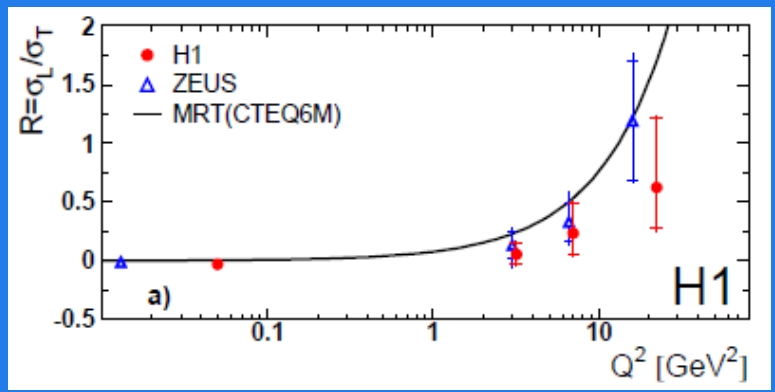
What we have learnt from VM production? H1, ZEUS based on HERA data show:

- Vector Meson production and DVCS cross sections rise with energy if a hard scale, Q^2 or M^2, is present.
- The exponential slope of the t distribution decreases with $Q^2 + M^2$ and levels off at $b \sim 5$ GeV^{-2}
- The ratio, σ_L/σ_T, increases with Q^2, but is independent of W
- The effective Pomeron trajectory has a larger intercept and smaller slope than those extracted from soft interactions

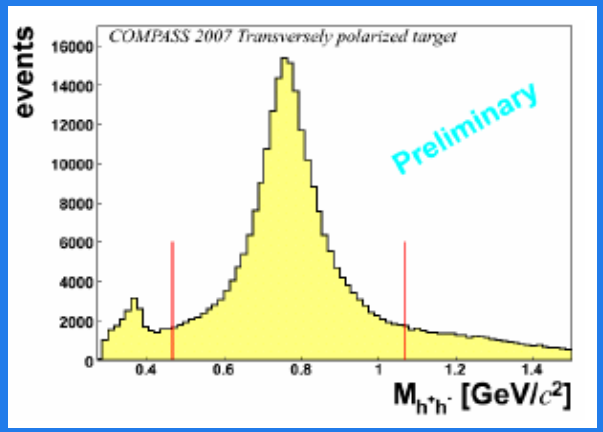
All these features are compatible with expectations of hard diffraction → pQCD



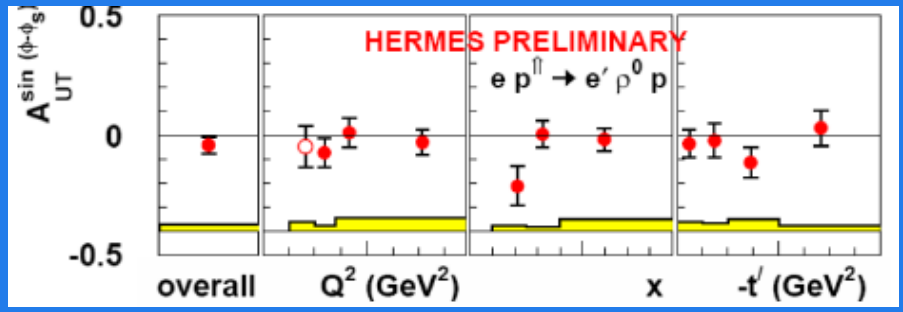


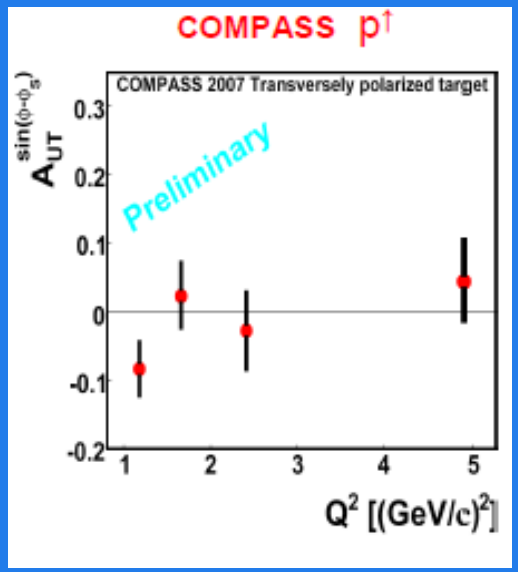


Exclusive processes at COMPASS



Nice rho signal (muoproduction off polarised ammonia target)





Agreement with HERMES

New results on transverse target spin asymmetries for ρ^0 production

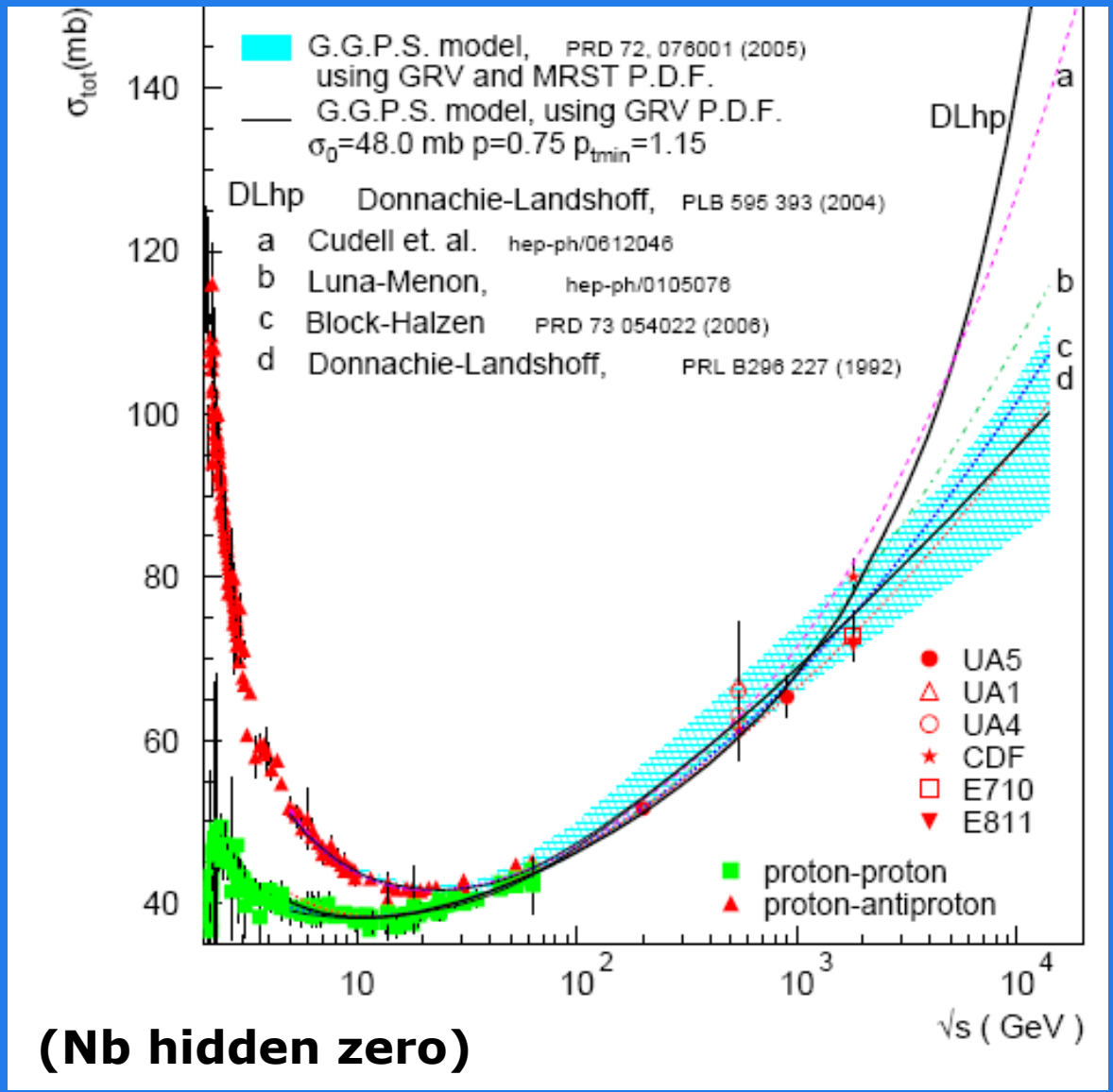
compatible with 0 both for the proton and the deuteron targets
ongoing work on L/T separation, and coh./incoh. separation for d

Published results on double spin asymmetry for ρ^0 production on d

compatible with 0 in a wide x and Q^2 range
precise upper limits on contribution of unnatural parity exchanges

Further work will continue!

H Stenzel Total Cross Section Measurements



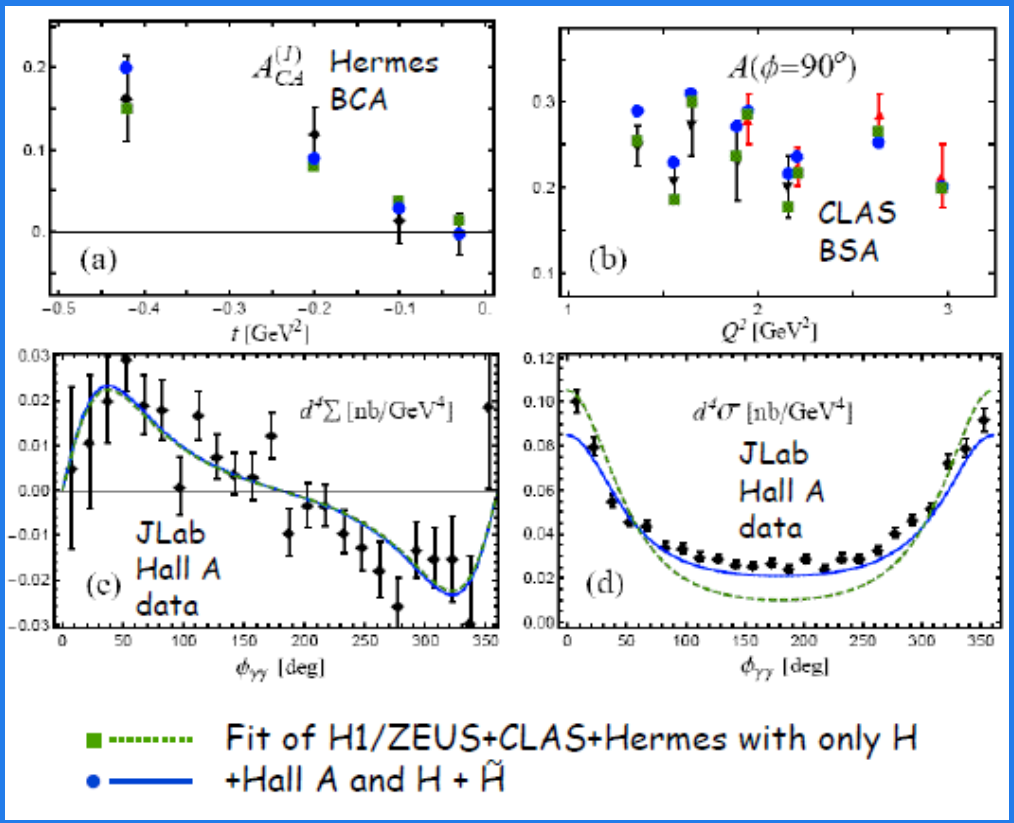
(Nb hidden zero)

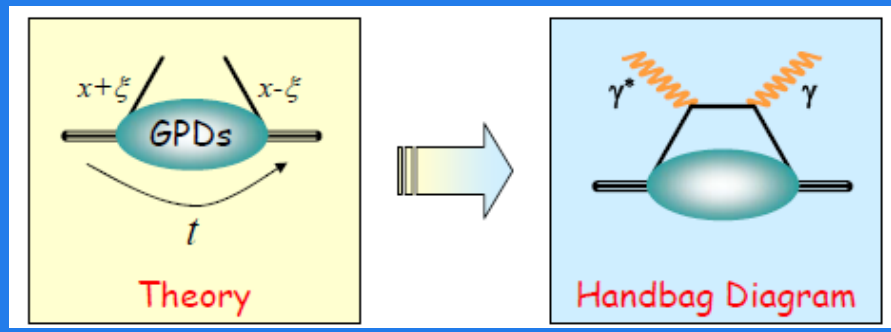
New results from E710 and E811 at FNAL

The theories give divergent predictions for LHC!

ATLAS and TOTEM will hope to sort this out!

Aim is to study Deeply Virtual Compton Scattering so as to obtain Generalised PDFs

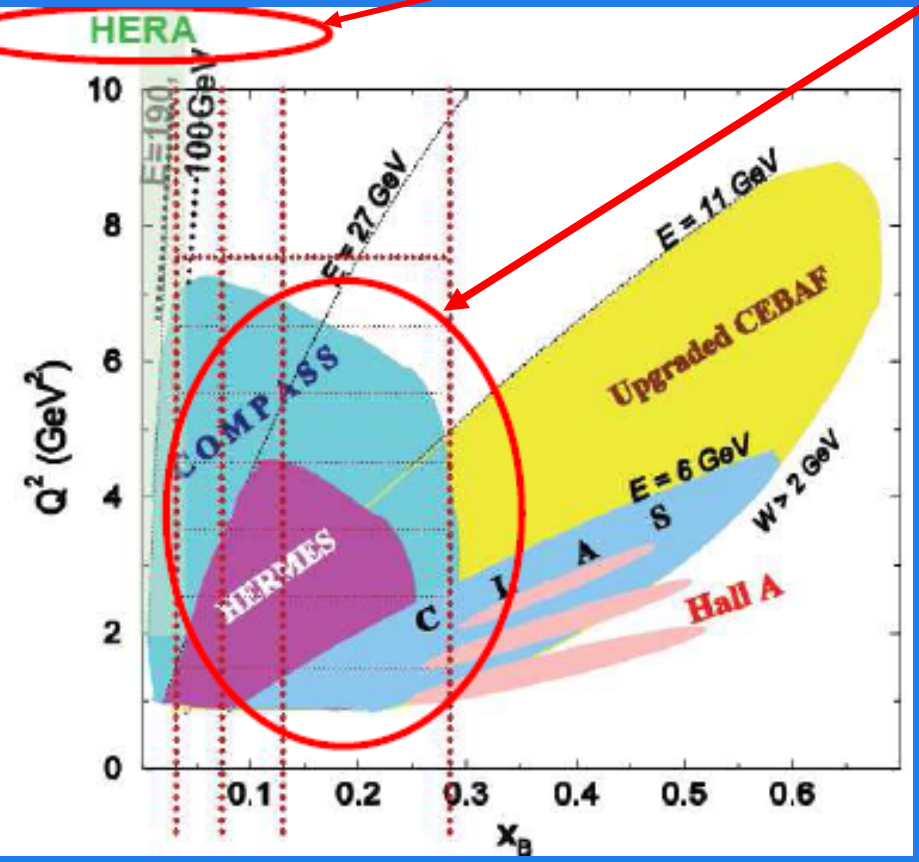


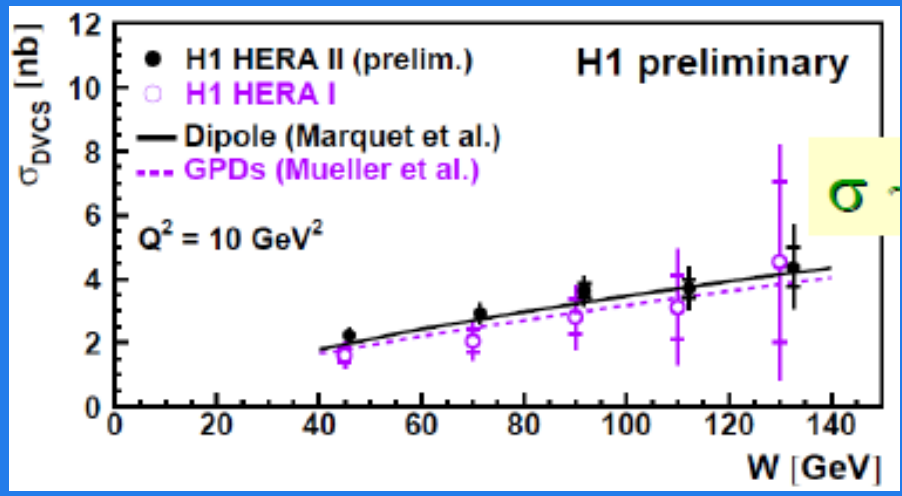


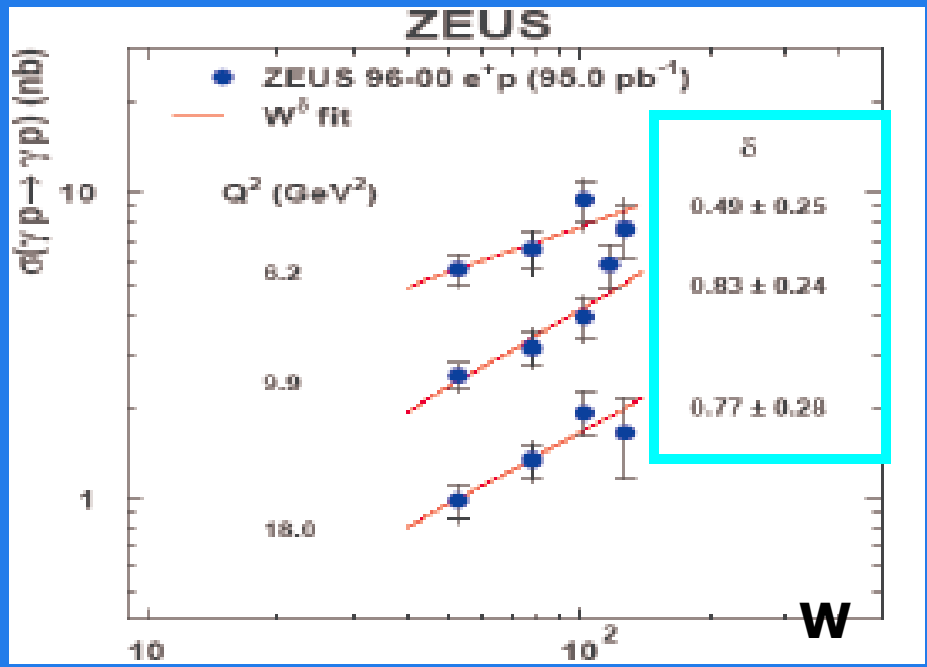
Measure cross sections and asymmtries

Fit data and compare with theories.

L Schoeffel DVCS from HERA to CERN



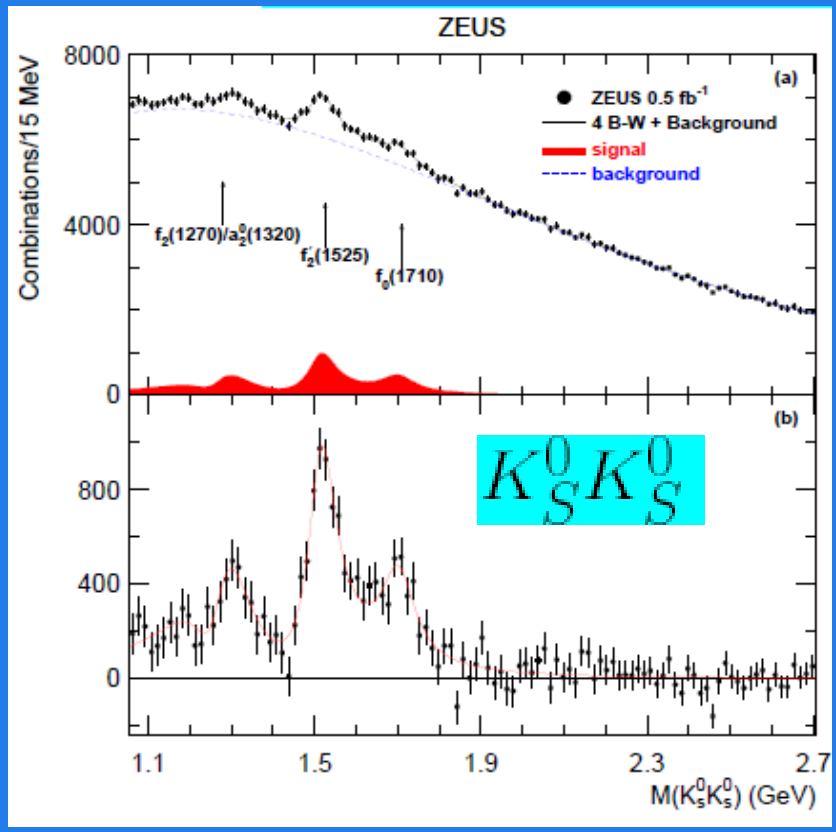


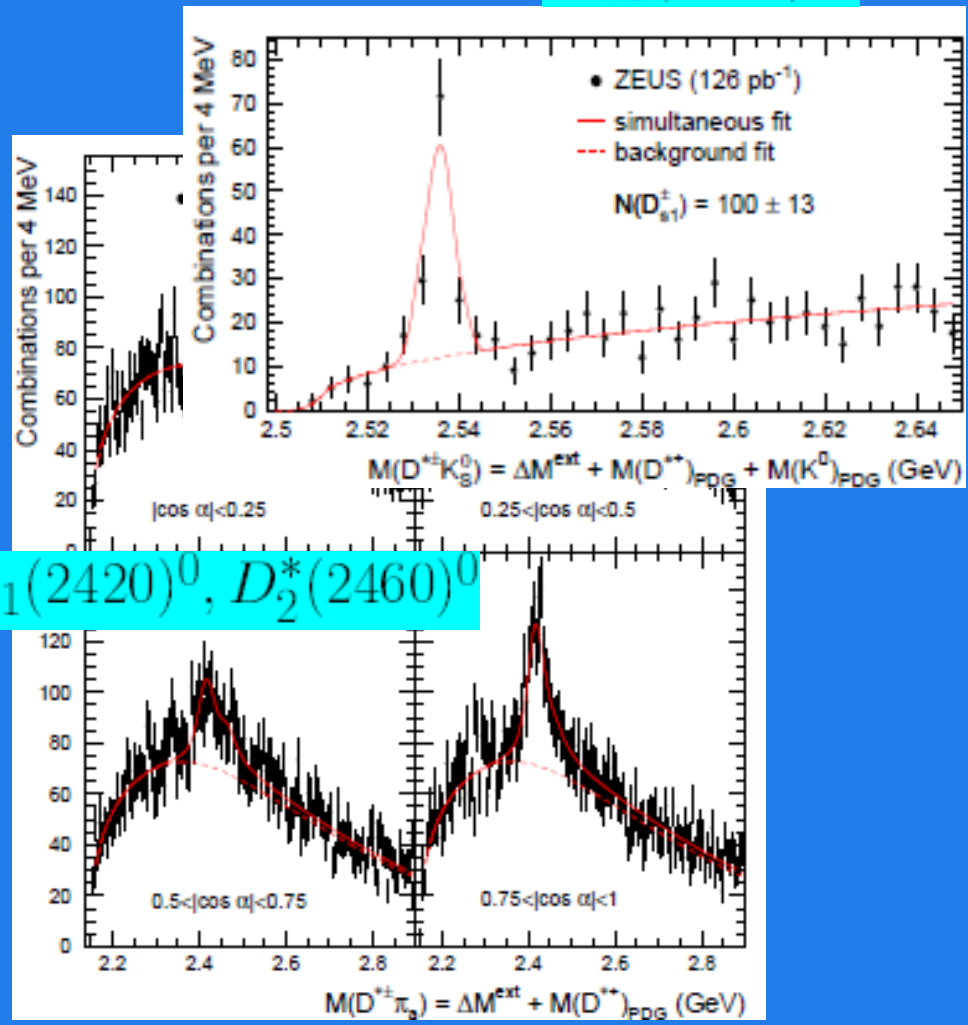


At HERA DVCS is hard and suitable for pQCD

More to come from COMPASS

$D_{s1}(2536)^{\pm}$





$D_1(2420)^0$, $D_2^*(2460)^0$

$f_2(1270)/a_2(1320)$, $f_2'(1525)$, $f_0(1710)$

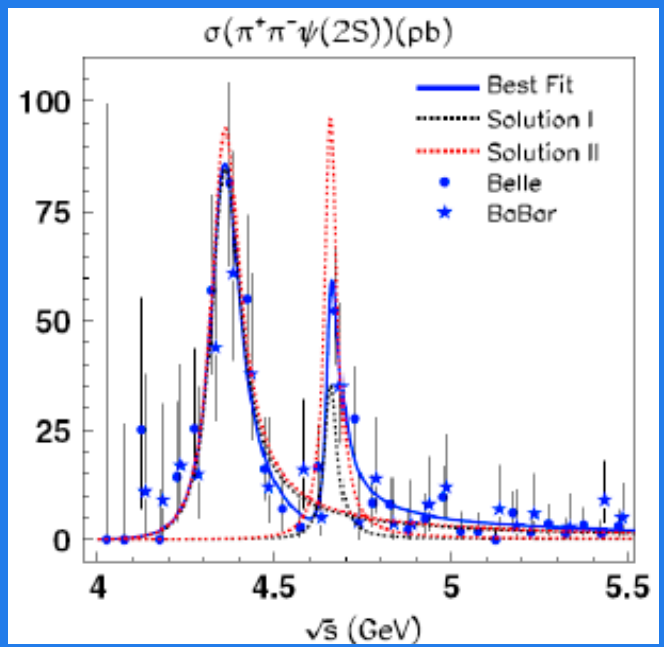
H1 had proposed a charm pentaquark signal but with more H1/ZEUS statistics:

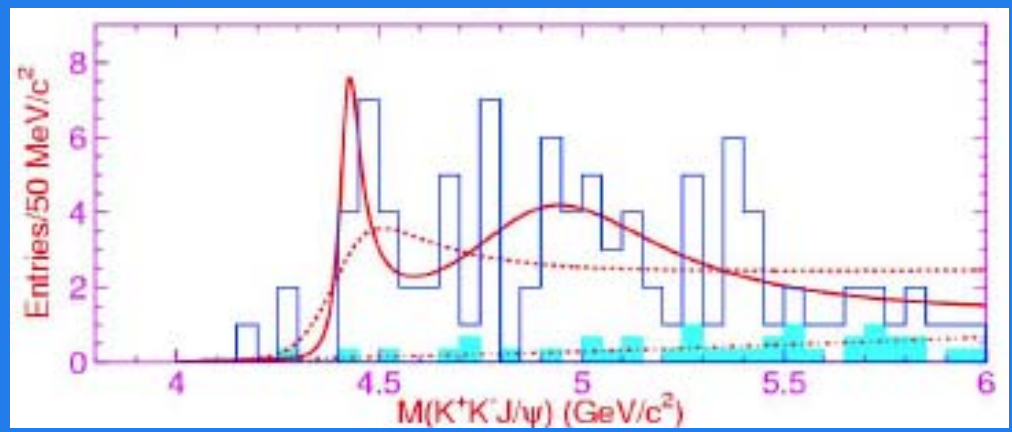
Θ_c^0 pentaquark at 3.1 GeV is ruled out

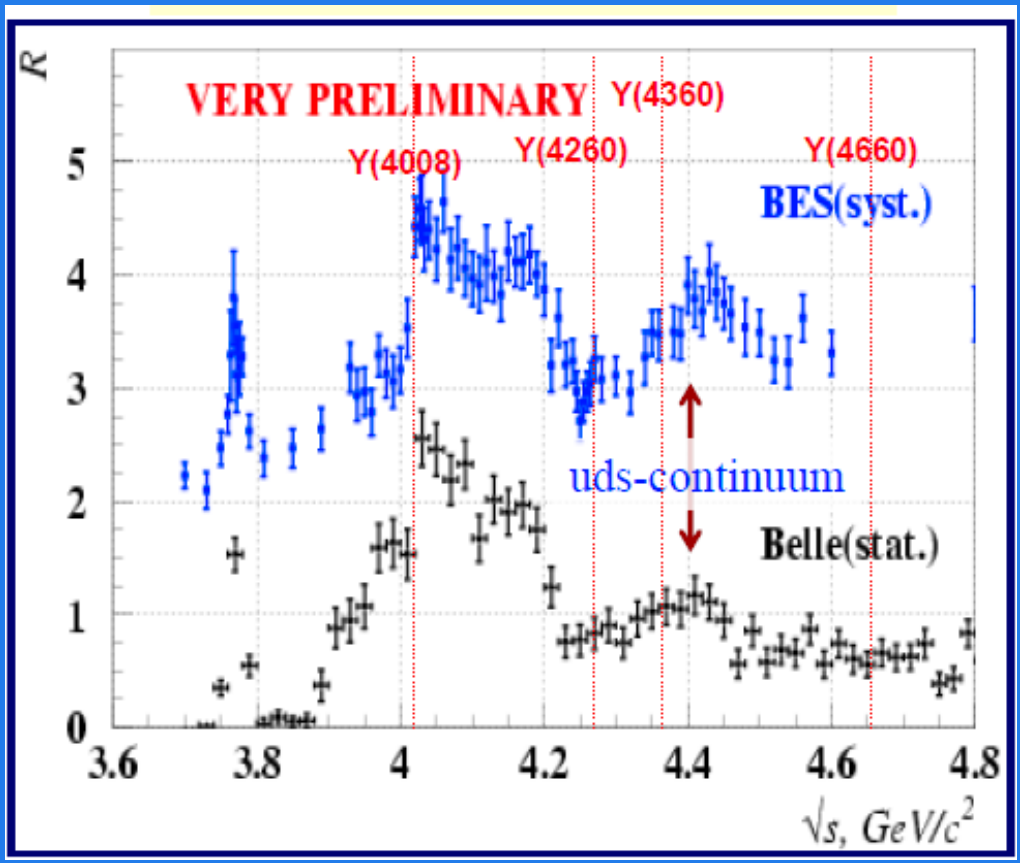
Sizeable production of excited D mesons at ZEUS ($D_1^0, D_2^{*0}, D_{s1}^+$)

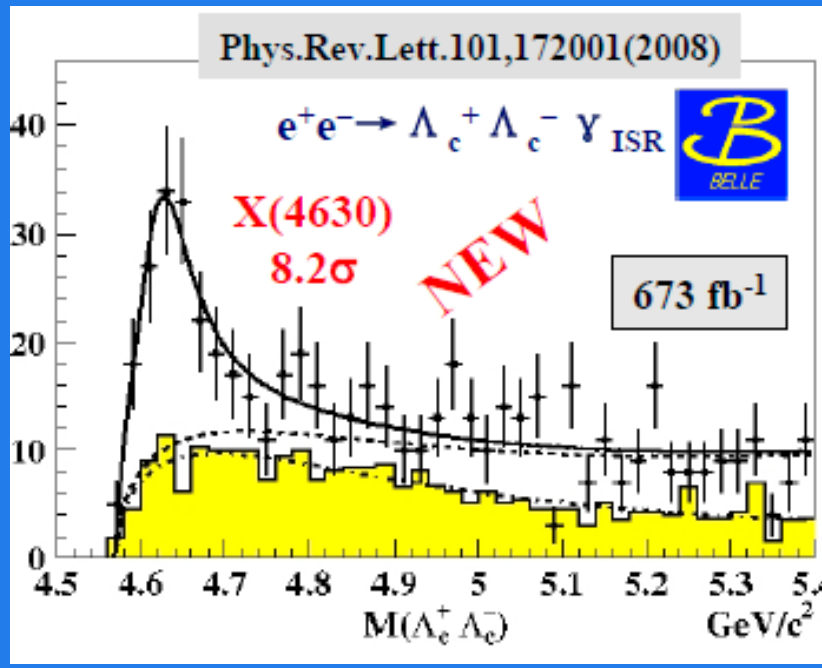
X. L Wang Charmonium via ISR at BaBar and Belle

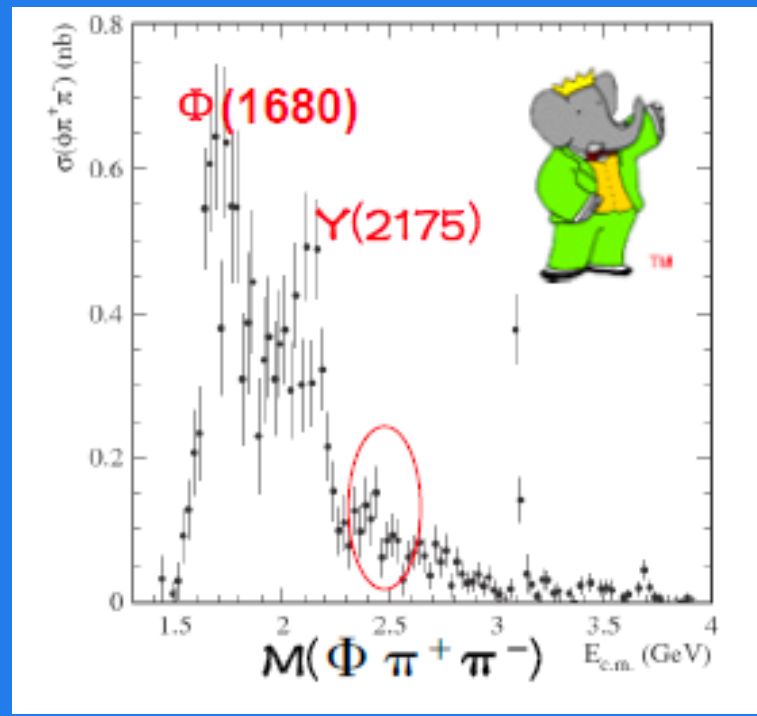
- Exotic structures: Y(2175),Y(4008), Y(4260), Y(4360), Y(4660).
- Observations of $e^+e^- \rightarrow J/\psi K^+K^-$ & $J/\psi K_S K_S$.
- Measurements of $e^+e^- \rightarrow D\bar{D}$, DD^*, $D^*\bar{D}^*$, $D\bar{D}\pi$, no evidence of Y structures at these channels.
- Measurements of $e^+e^- \rightarrow \Lambda_c^+ \Lambda_c^-$, X(4630).





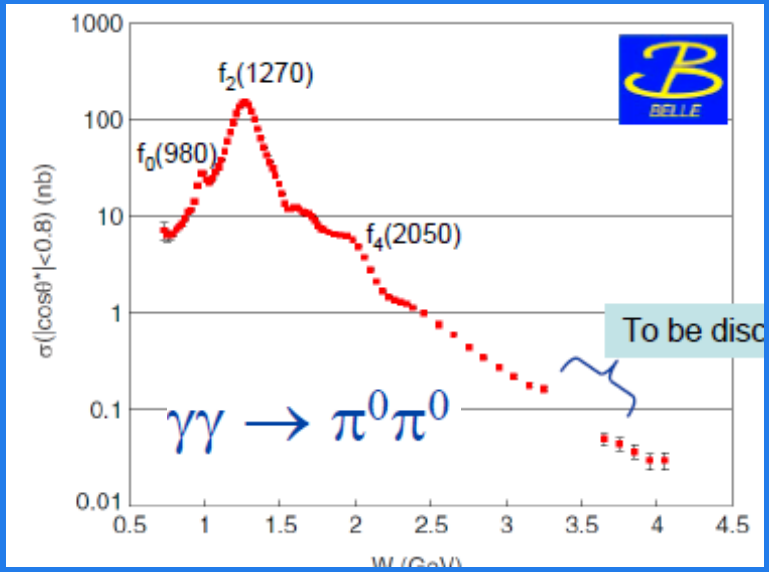


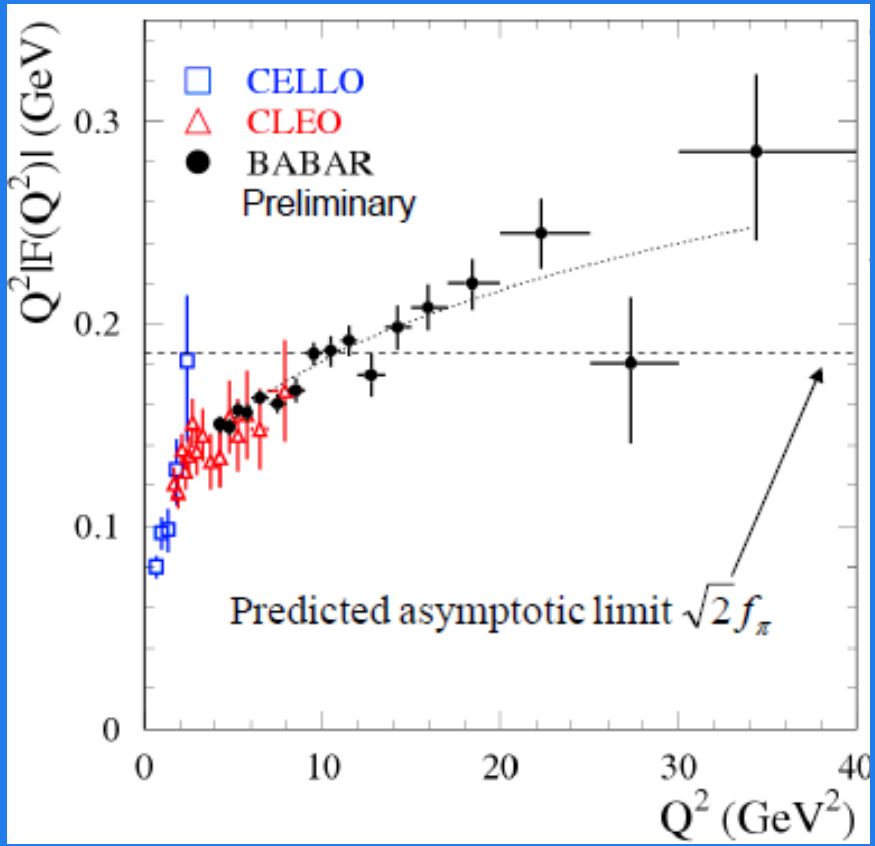


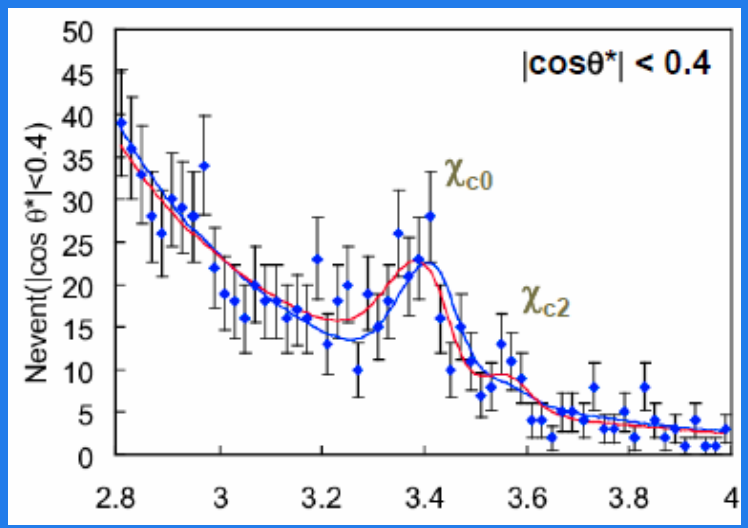


Very rich collection of states and candidates to study

S Li One and Two Photon processes at BaBar and Belle



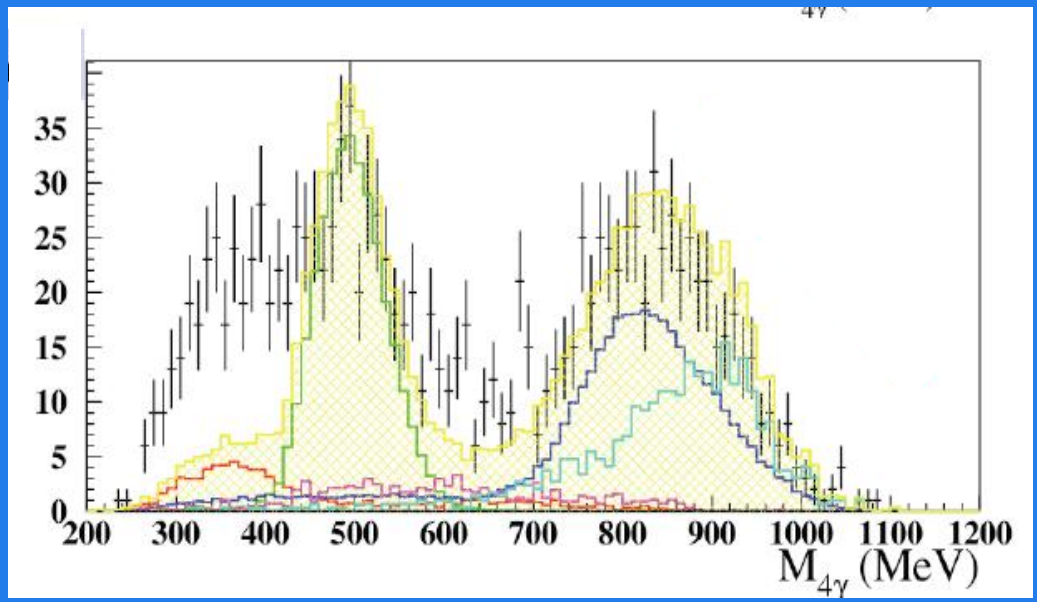


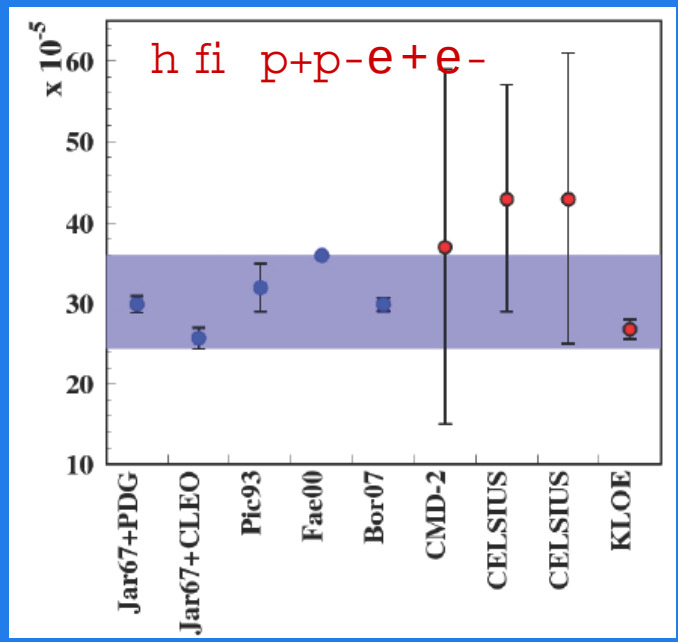


π° transition form factor

Also several vector meson production cross sections

- Measurement of BR(f→a_0(980) g)
- Large couplings of f_0(980)/a_0(980) to f and to KK
- Upper limit set for f →KKg
- Precise measurement of the main w BR's and of BR(f→wp^0)
- Excess of events in the s(600) mass region for e^+e^-→ e^+e^- p^0p^0
- Gluonium content @ 3s level in h¢using the Rosner model
- BR + first measurement of the CPV plane asymmetry for h→$p^+p^-e^+e^-$
- New analysis has been started on h/h¢→p^+p^-g





Apologies

I have had to make some difficult selections here….

No time to review the variety of talks of a more applied nature:

Sugawara – proposal

Weckert – new directions for DESY, many fascinating developments

Potdevin – interesting detector developments


CONCLUSIONS

This has been an outstandingly fine conference for experimental high energy photon physics.

The subject is going from strength to strength!

HERA is producing definitive results, and there is a wide range of results from other labs.

Look forward to a new phase of photon physics at LHC