Latest results on jets and the hadronic final state at HERA

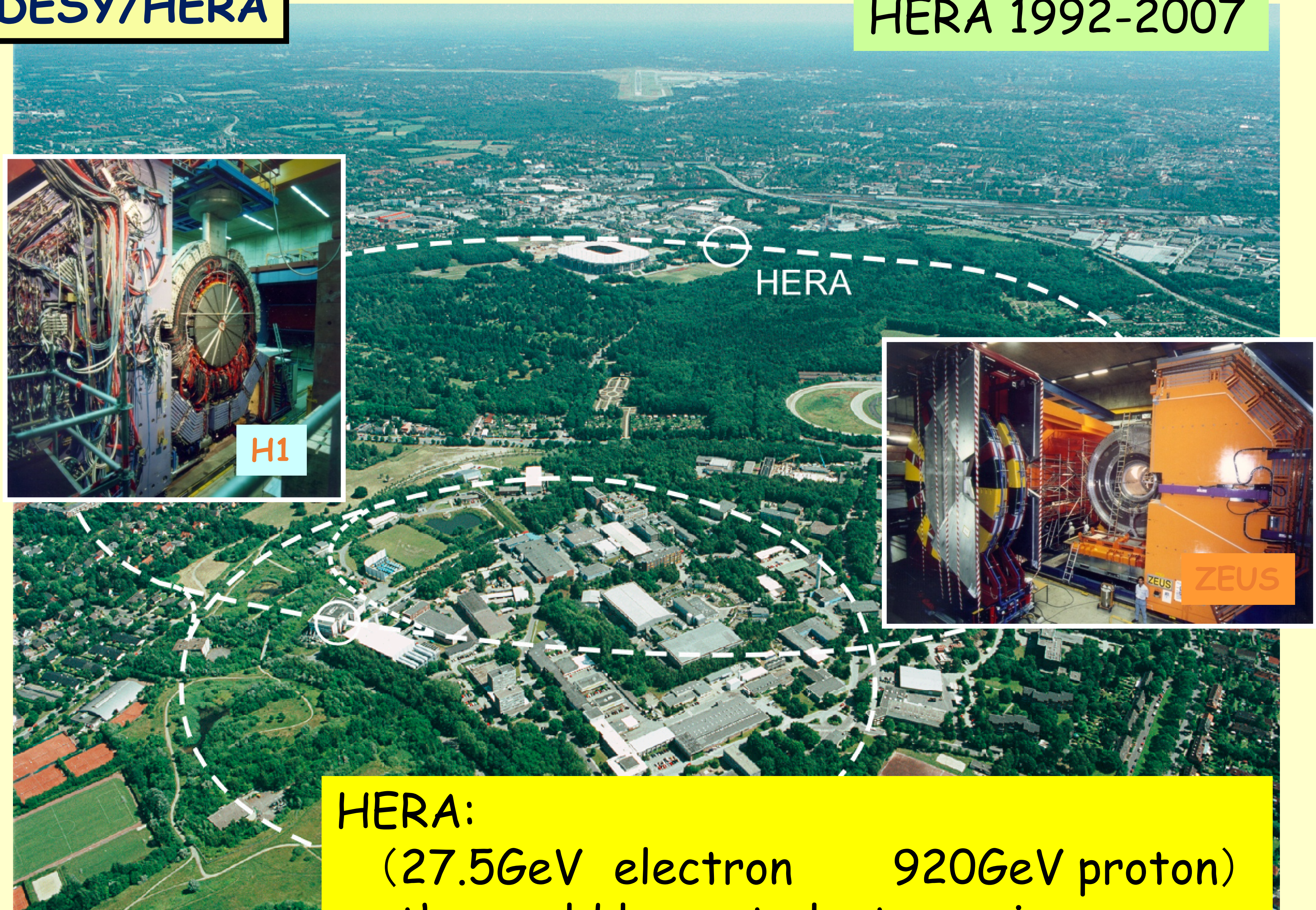
XLVI International Symposium on Multiparticle Dynamics (ISMD2016)
Seogwipo KAL Hotel, Jeju Island (30-Aug-2016)

Katsuo Tokushuku (KEK)

On behalf of the H1 and ZEUS collaborations

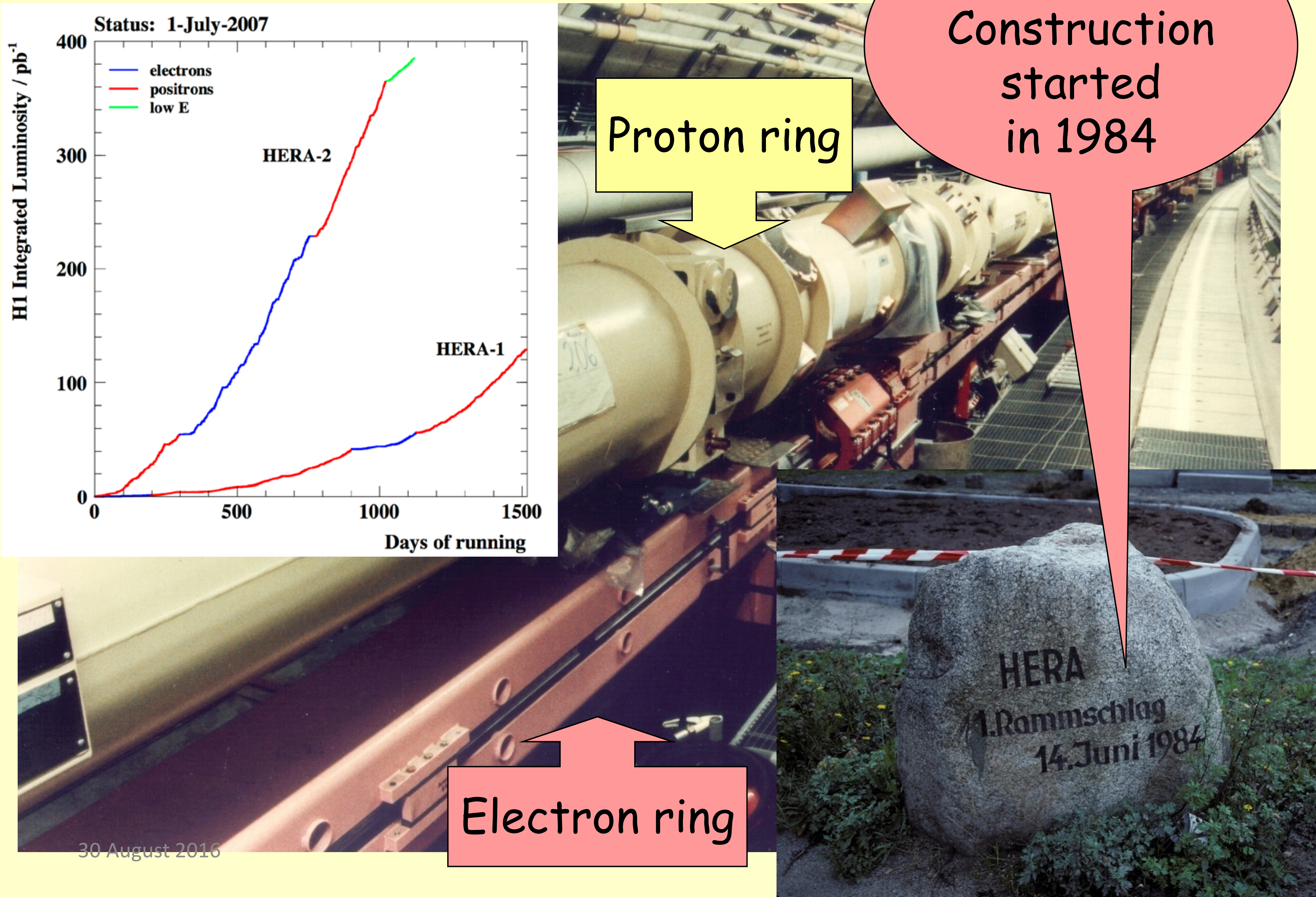
DESY/HERA

HERA 1992-2007



HERA:
(27.5GeV electron 920GeV proton)
the world largest electron microscope

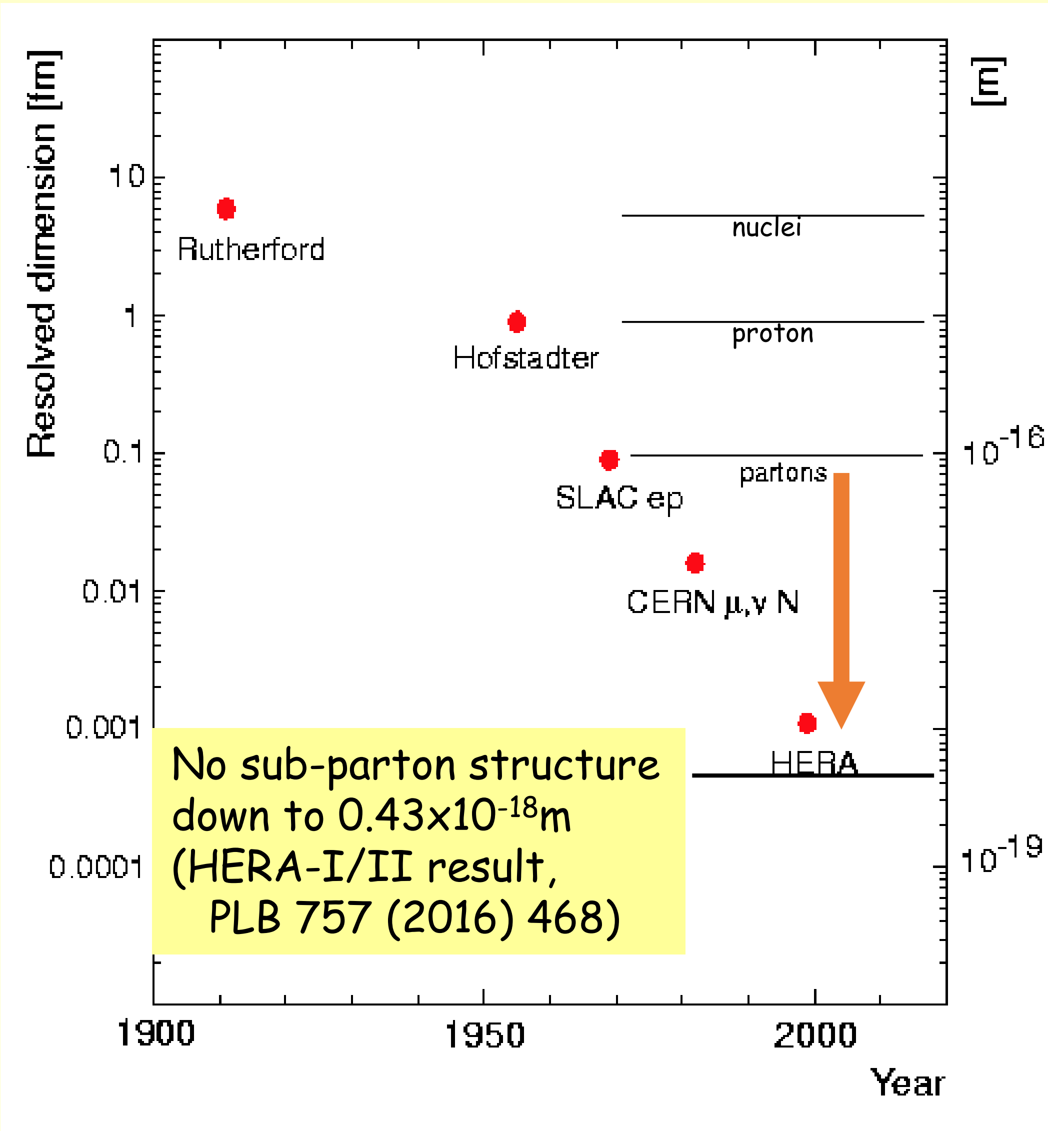
A view of the HERA ring tunnel



Tunnel Construction started in 1984

Resolution ~ $(\text{Wavelength})^{-1} \sim \hbar / Q$

$$Q^2 \equiv (q_i - q_f)^2$$



No sub-parton structure down to 0.43×10^{-18}m (HERA-I/II result, PLB 757 (2016) 468)

Progress in accelerator enables us to investigate the smaller structure.

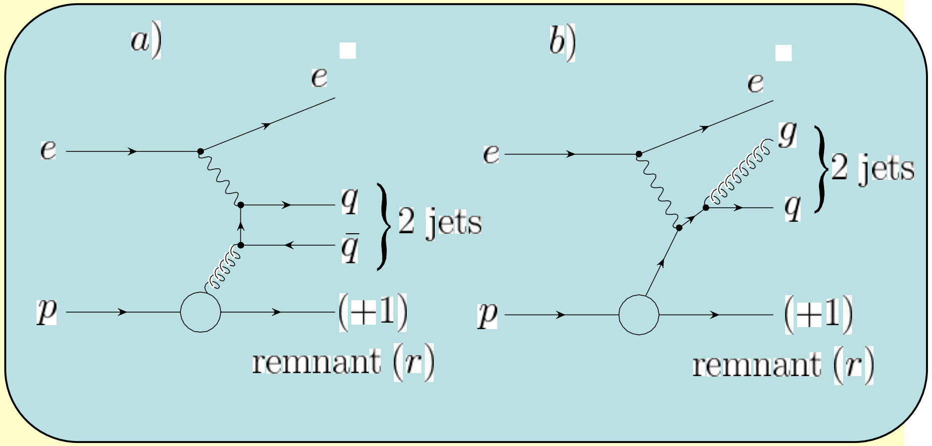
HERA:
(27.5GeV electron(positron) vs. 920 GeV proton)

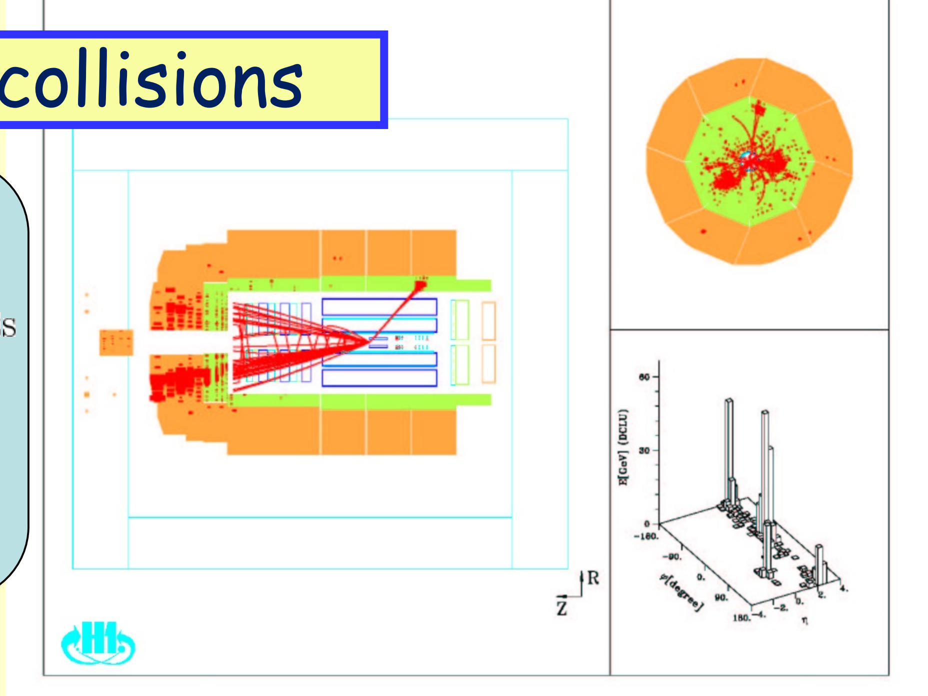
$Q^2_{max} = s = 4E_eE_p \sim 10000\text{GeV}^2$

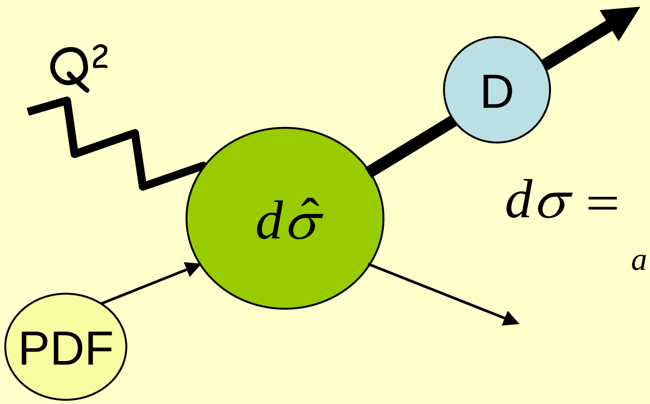
cf. in the rest frame
$s = 2E_eM_p$

In order to obtain the same CMS energy as HERA in a fixed target experiment, it requires 54TeV electron beam.

Particle Production in *ep* collisions







$$d\sigma = \sum_{a=q,\bar{q},g} \int dx f_a(x, \mu_F ; \alpha_s) d\hat{\sigma}(xP, \mu_F ; \mu_R ; \alpha_s(\mu_R)_s) D(z, \mu_{F'} ; \alpha_s)$$

source parton distribution — Hard scattering cross section — Fragmentation Function

HERA: A good test bench for QCD under control of photon virtuality (Q^2)

Particle Production in *ep* collisions

In this talk, I will present recent results on particle production at HERA.

- Perturbative topics at small α_s
  - Jet cross section at DIS (H1)
  - Prompt photon at DIS (ZEUS)

- Non-perturbative topics at small α_s
  - Search for instanton process (H1)

- Non-perturbative topics at large α_s
  - Pentaquark searches (ZEUS)

Dijet update :H1

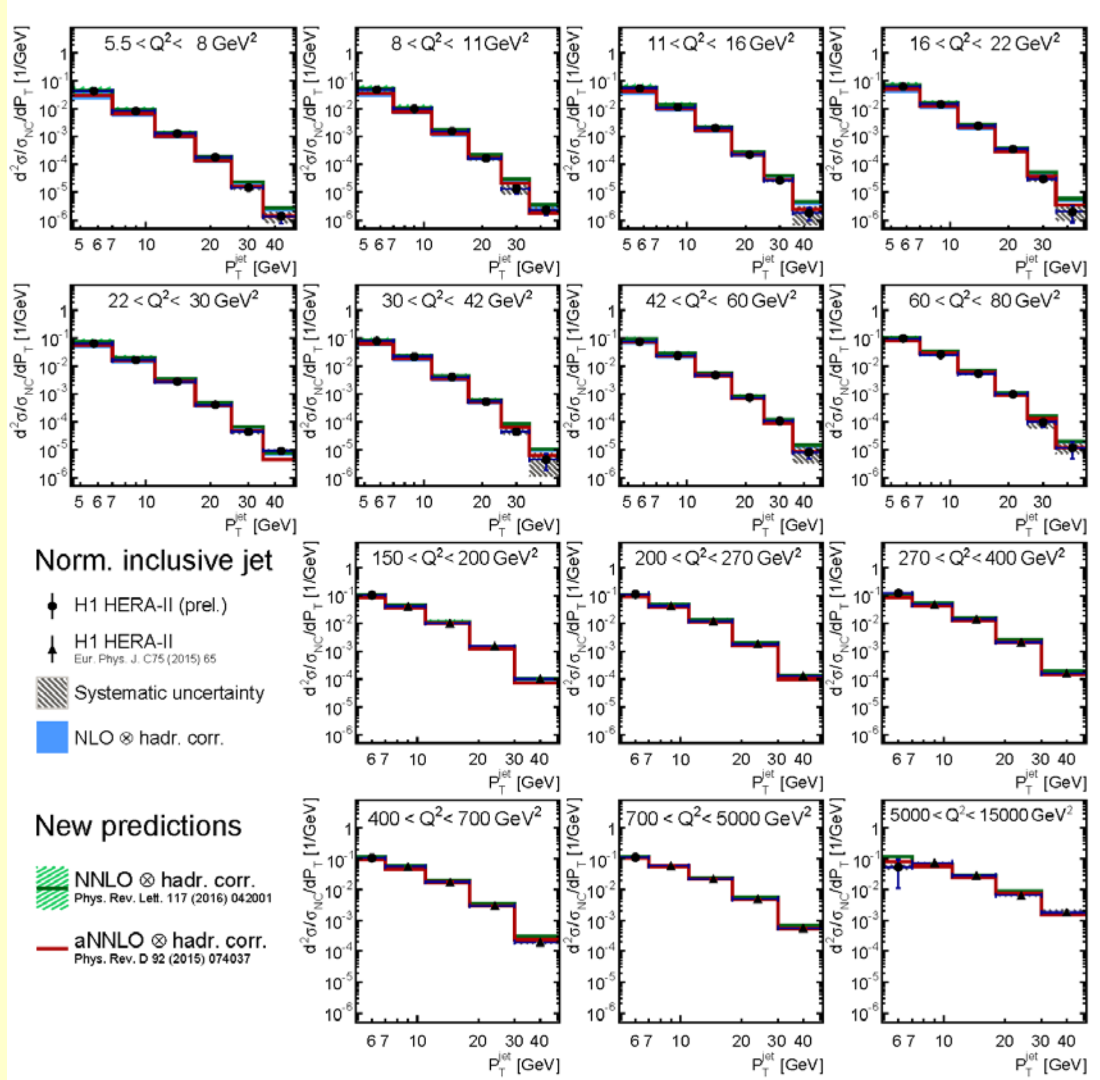
H1prelim-16-061 and
H1prelim-16-062

Inclusive-/di-/tri-jet production at low Q^2 (5-100 GeV^2) with HERA-II data
(high-Q^2 results (150-15000 GeV^2 were published as EPJ C75 (2015) 2)

Normalized cross section to the inclusive DIS cross section. -> less correlation with the inclusive cross section -> suitable for the global fit.

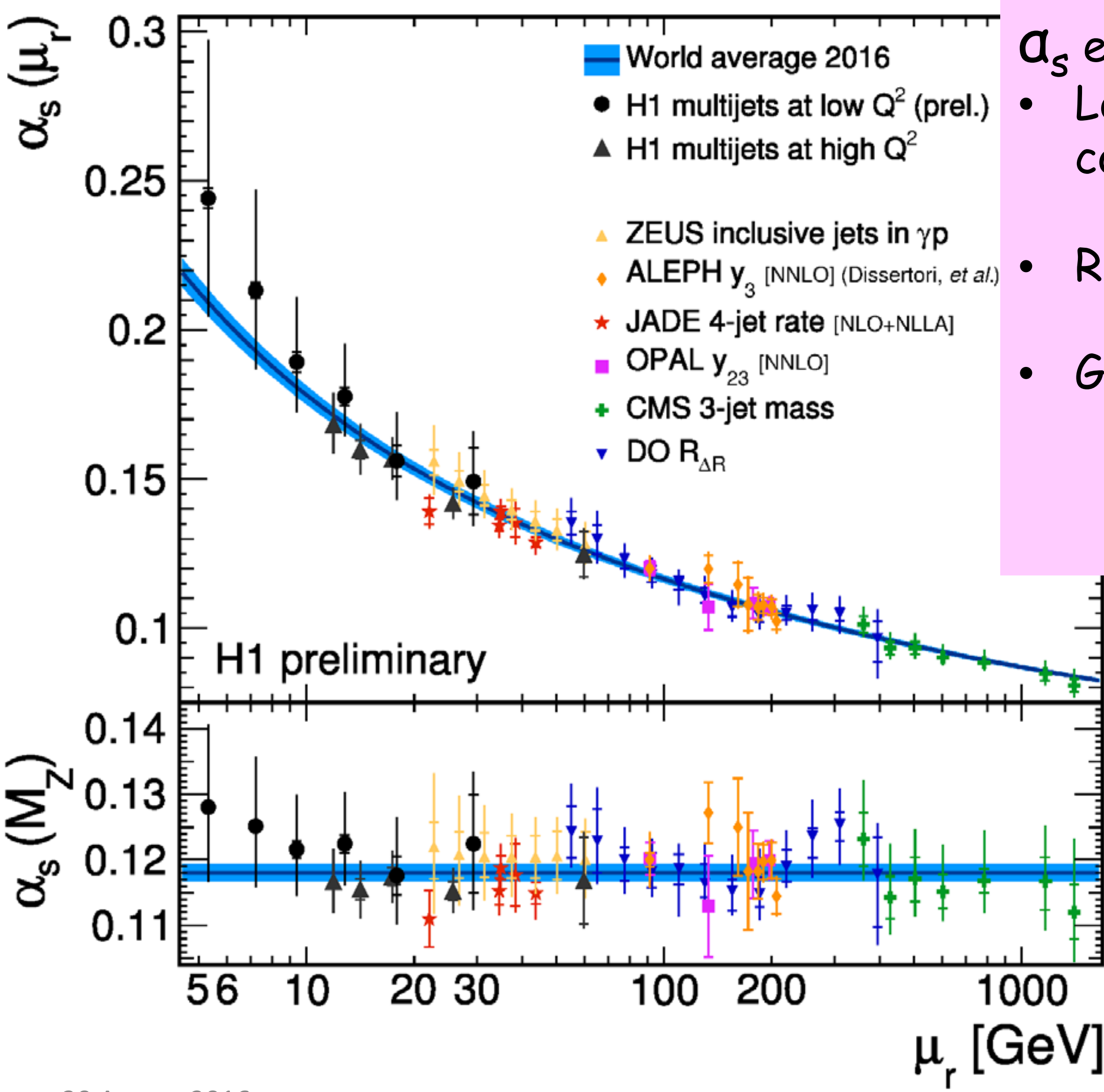
- Jets in the Breit frame.
  Pt_{jet} : 4.5 – 50 GeV
  Pt_{jet2}: 5 - 50 GeV (for di-jet)
  Pt_{jet3}: 5.5-50 GeV (for tri-jet)
- η^{lab}_{jet} : -1 – 2.5
- y : 0.2-0.6

Comparison with NLO/NNLO predictions



Dijet update :H1

H1prelim-16-062

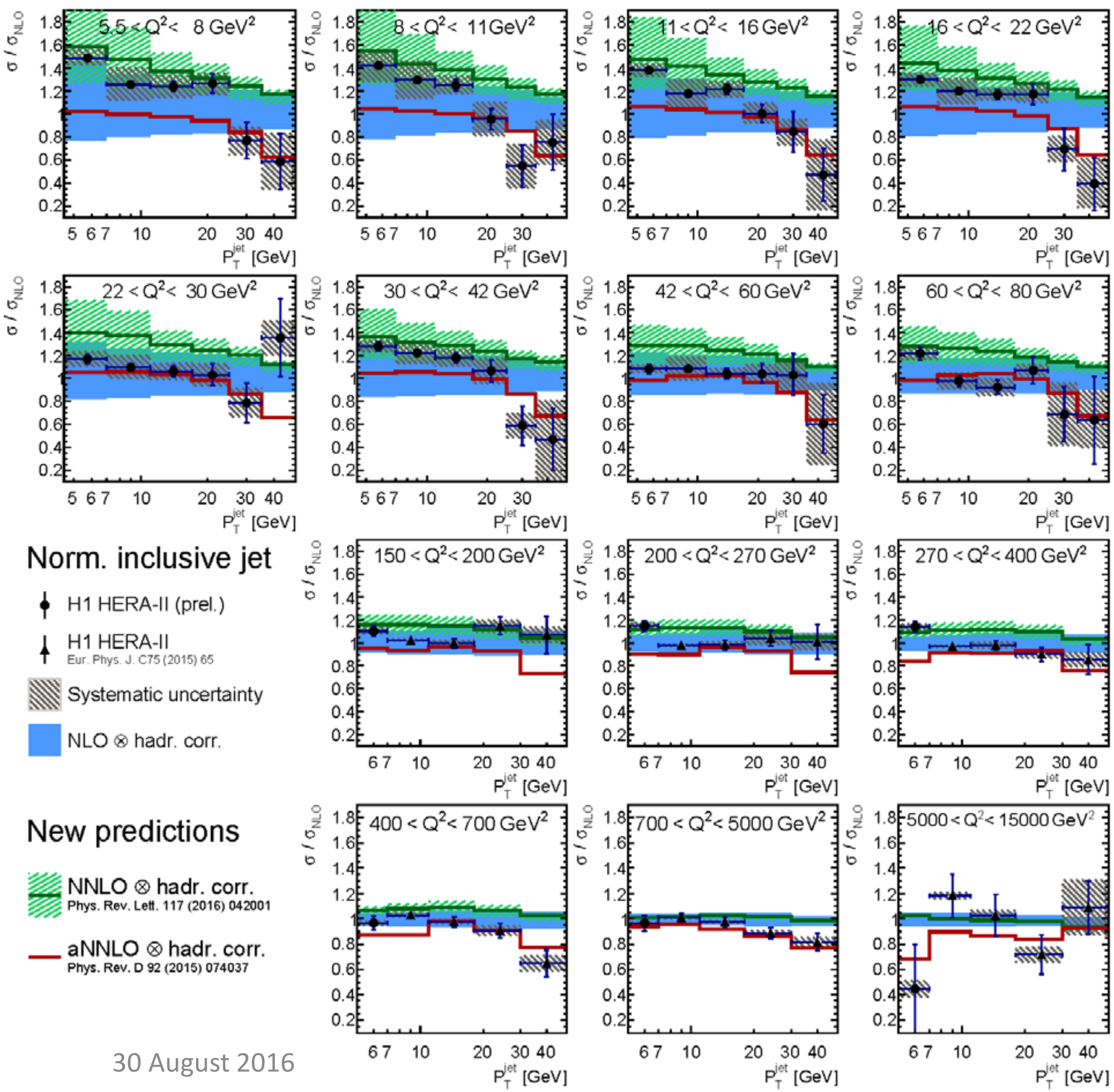


α_s extraction @NLO

- Low scale points are covered with this analysis
- Running! at μ: 5-30 GeV
- Global fit in progress
  expected precision for $\alpha_s(Mz)$: 0.4%

Inclusive-jet:H1

H1prelim-16-062



- Comparison with NLO/aNNLO/NLO

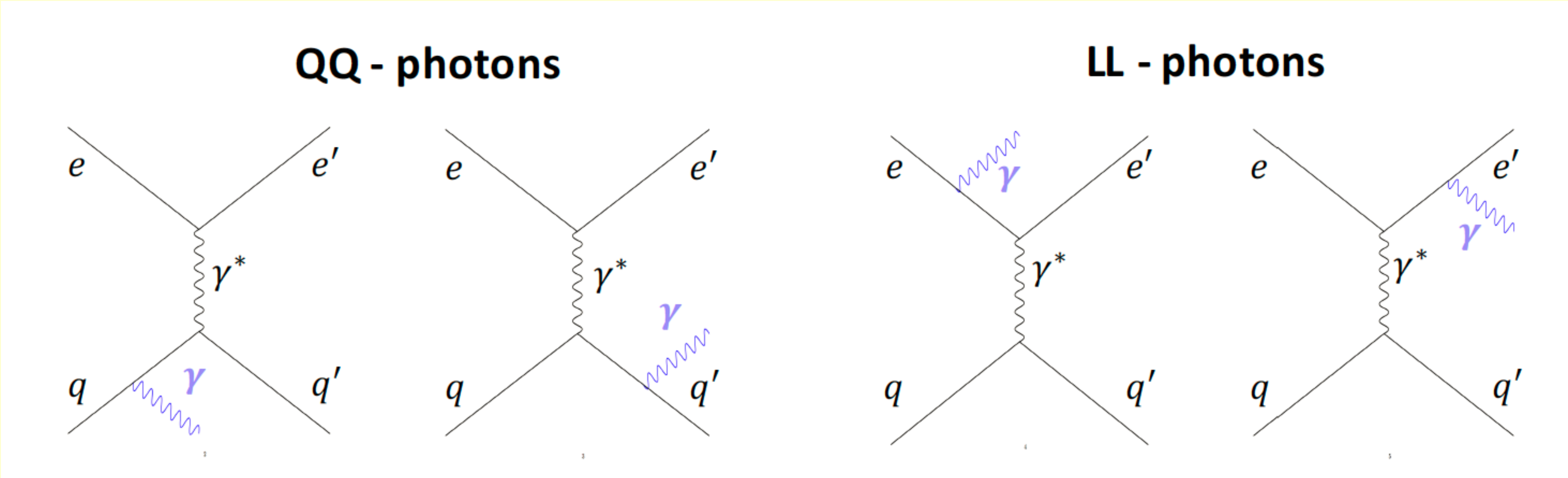
  aNNLO: Biekoetter, Klasen, Kramer, PRD92. (2015) 074037

  NNLO: Currie, Gehrmann, Niehues, PRL 117 (2016) 042001

- Good agreement with Data
- NNLO~NLO within uncertainty: Converging!
- Better Pt description with NNLO !

$$\mu^2_r = \mu^2_f = (1/2)(Q^2 + P^2_T)$$
$$(\mu^2_f = Q^2, \text{ for } Q^2 > 150)$$

Prompt Photon : ZEUS



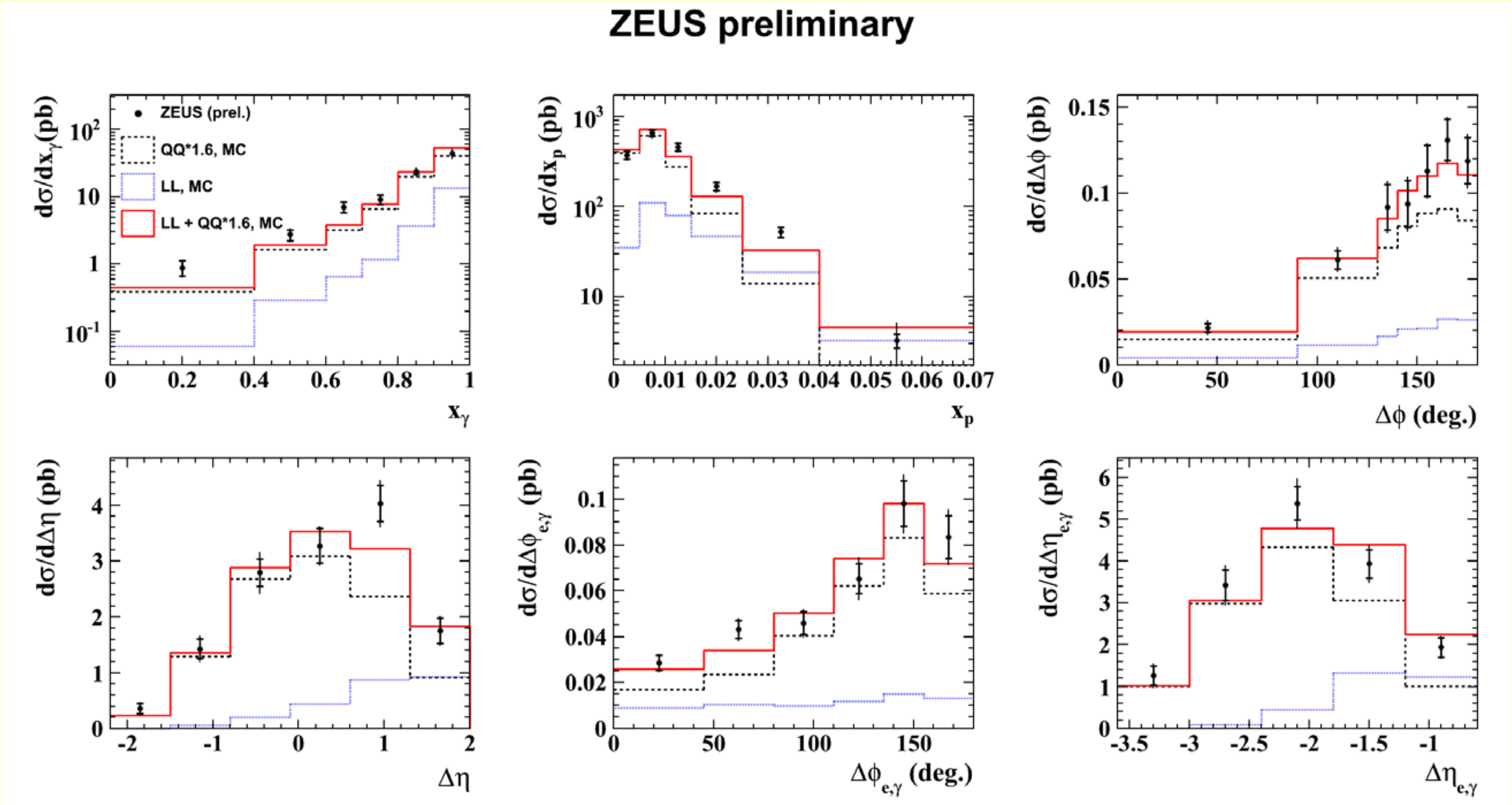
In the previous publications, inclusive distributions of photons and jets (PLB 715 (2012) 88) and those with x_γ (separation at 0.8) (JHEP 1408 (2014) 023) were shown and were with theories of NLO and K_T factorization.

Further tests with various jet-photon variables.

Prompt Photon : ZEUS

Q^2 : 10 – 350 GeV^2
Jet: Et>2.5 GeV, η_{jet} : -1.5 – +1.8
Photon: Et: 4-15 GeV, η : -0.7 - +0.9
(with isolation cuts)

ZEUSprelim-16-01

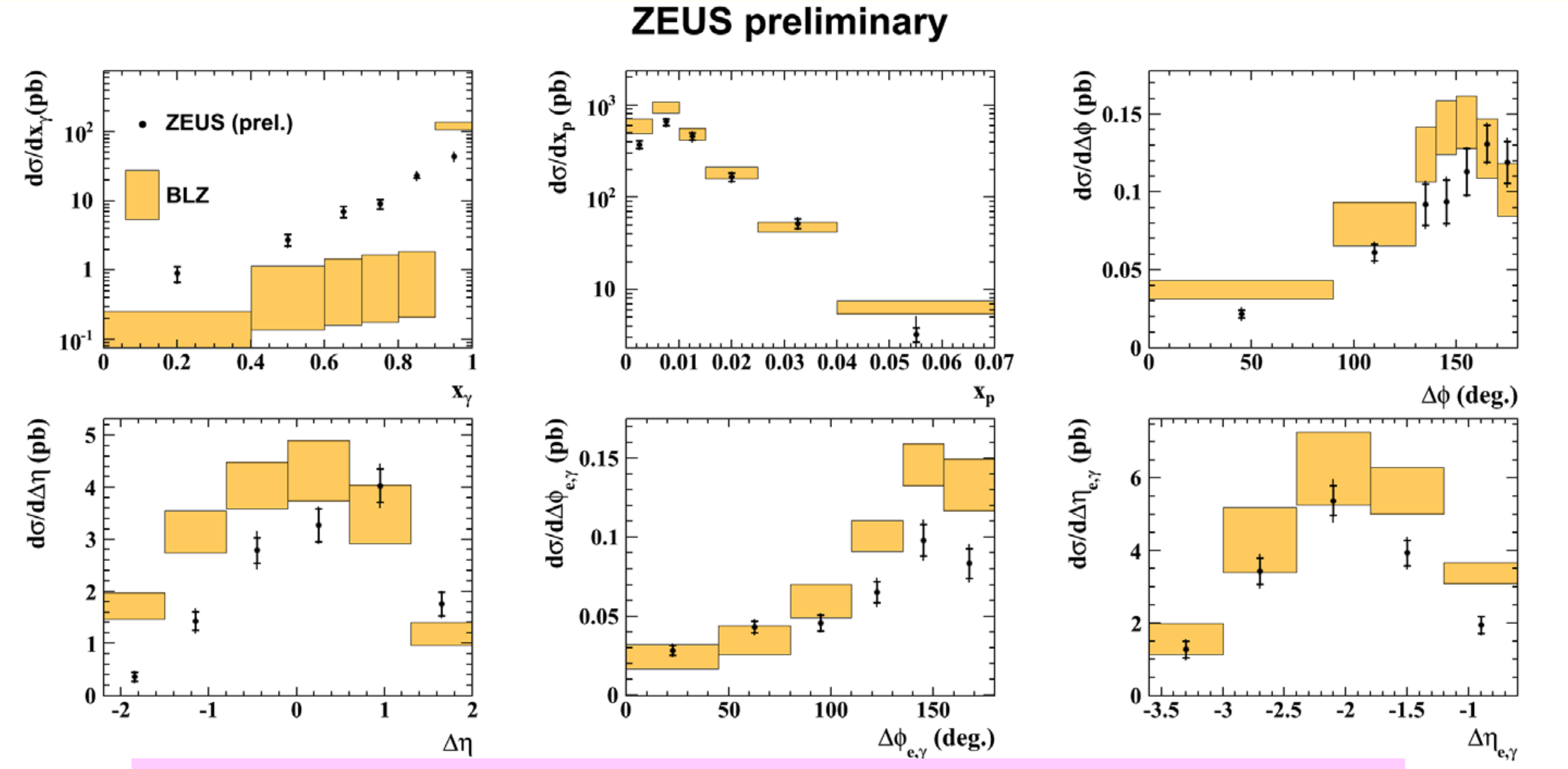


Comparison with Pythia : Good agreement once LL and QQ contribution is normalized.

Prompt Photon : ZEUS

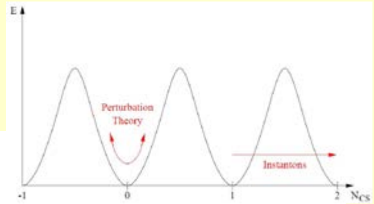
Q^2 : 10 – 350 GeV^2
Jet: Et>2.5 GeV, η_{jet} : -1.5 – +1.8
Photon: Et: 4-15 GeV, η : -0.7 - +0.9
(with isolation cuts)

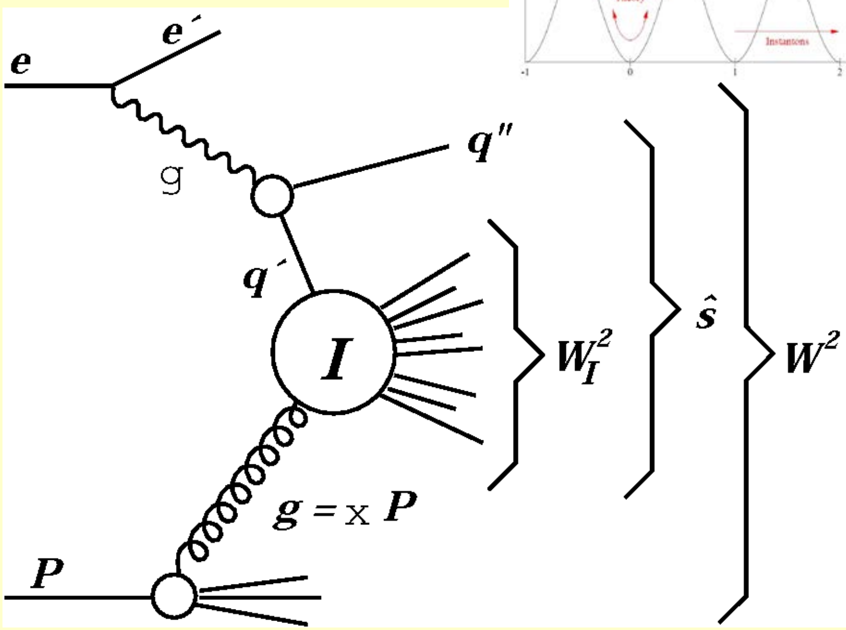
ZEUSprelim-16-01



Comparison with Baranov-Lipatov-Zotov (BLZ) theory with KT factorisation: (PRD 81 (2010) 09434).
A fair agreement except x_γ and $\Delta\eta$.

Instanton



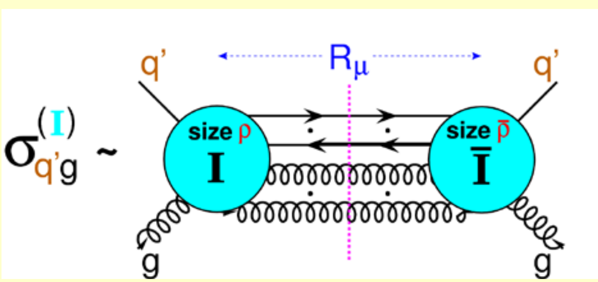


In QCD, certain processes violate the conservation of chirality. – Instantons.

--> Non-perturbative fluctuation of the gluon field. Tunnelling between 2 vacuum states.

Ringwald and Schrempp pointed out that instanton-induced events can be seen in DIS. The cross section is calculable in a certain kinematical region (defined by q' and g (Q'^2,x')--> instanton size (r) and distance Rμ) .

σ=10 ~ 100 pb.



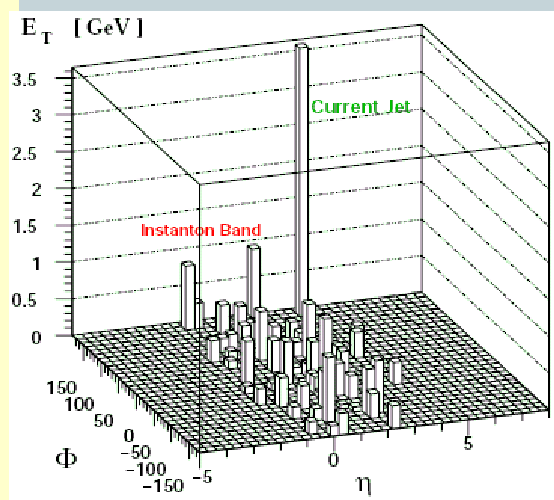
$$q + g \xrightarrow{I} \sum_{n_f} (q_R + \bar{q}_R) + ng$$

$$q + g \xrightarrow{\bar{I}} \sum_{n_f} (q_L + \bar{q}_L) + ng$$

Events are simulated by the QCDINS. Events are expected to have distinct signature.

Many quark and gluons -->

fireball like



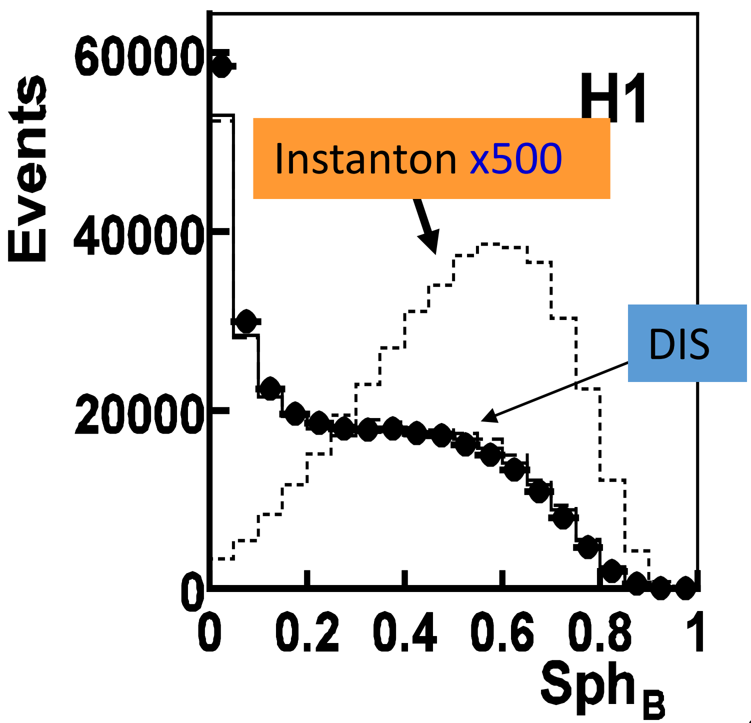
Instanton HERA-1 Results : H1

EPJ. C **25**, 495 (2002)

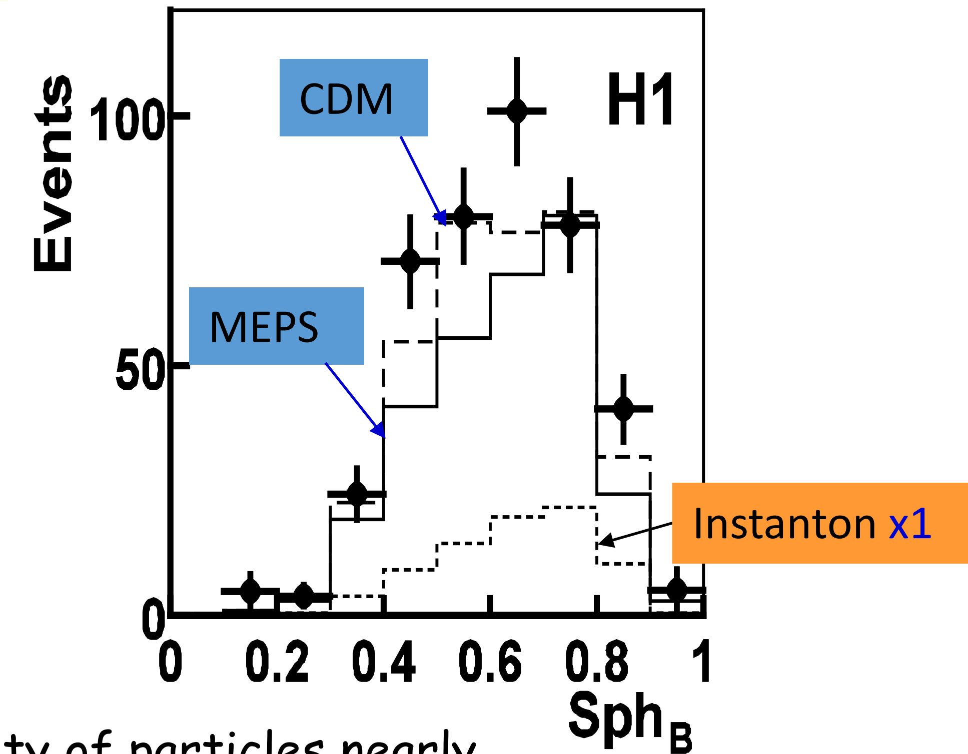
Instanton events have different particle emission patterns from the normal DIS.
But the expected production rate is not so large

After the selection cut to enhance the instanton-like sample, the difference in the two normal-DIS MC's predictions are still large
(IntL=21.1pb^{-1} Q^2=10-100GeV^2)

One example

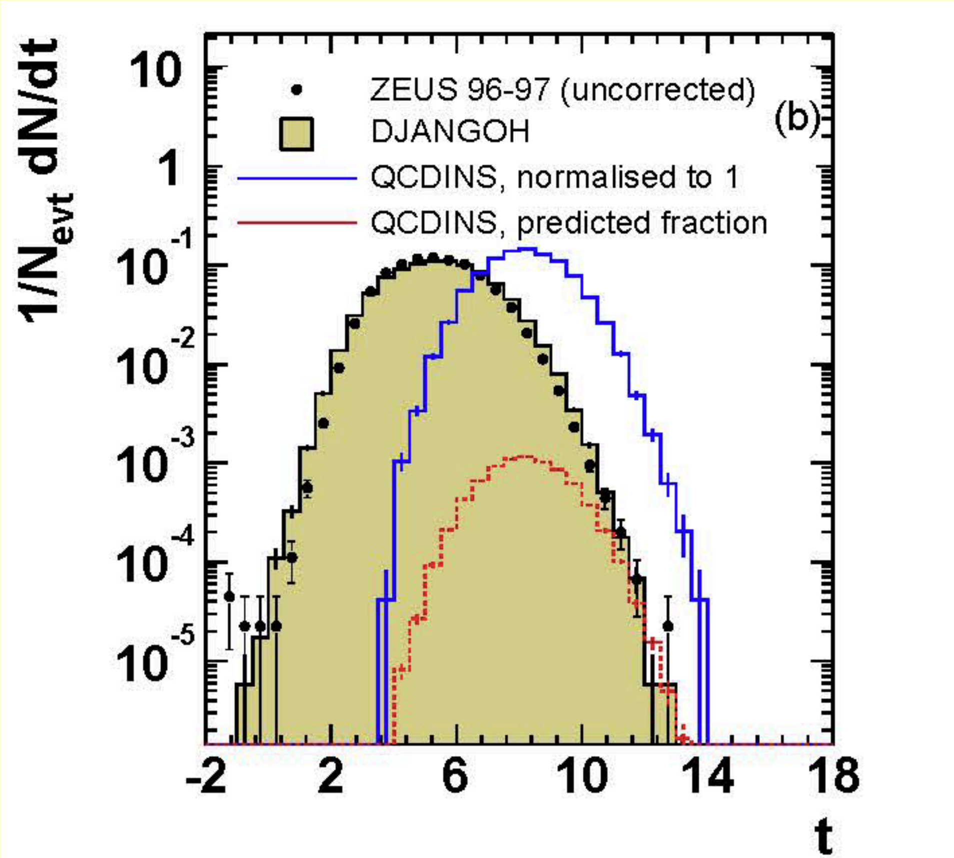


After Enrichment cuts.



Sphericity of particles nearly I-rest frame

Instanton HERA-I Results : ZEUS



t: combination of several separation variable.s

EPJ C 34(2004) 255

IntL =38pb^{-1} Q^2>120GeV^2

Assuming all data with t>t0 is the instanton events, very conservative limit was set as

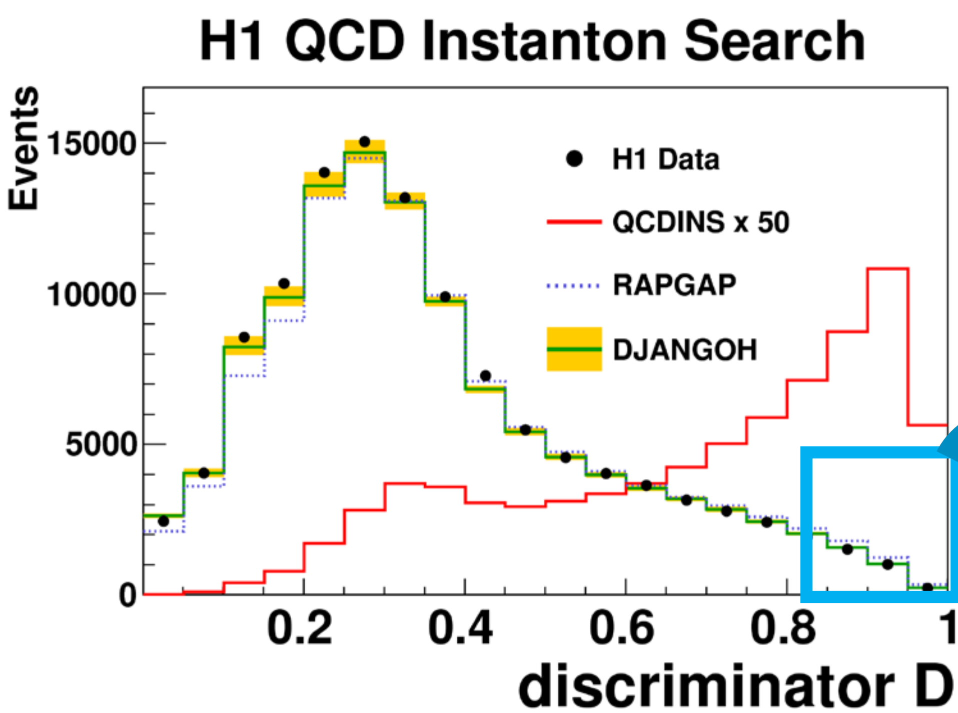
σ<26pb (95%CL),

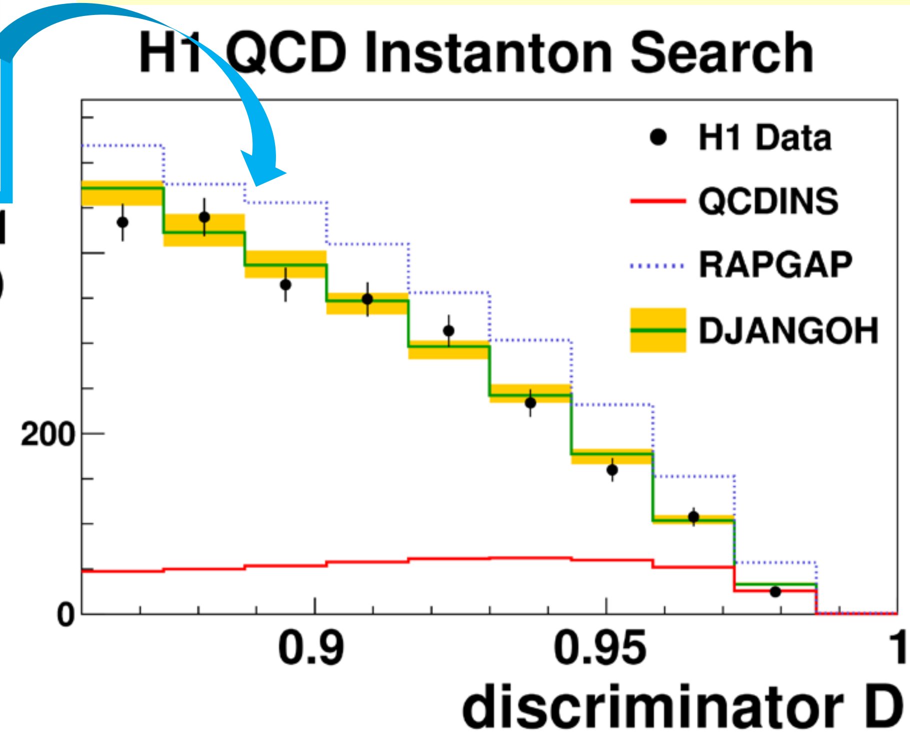
while the prediction is 8.9pb

Instanton: HERA-II Results: H1

EPJ C76 (2016) 7, 1

the high statistics of HERA-II data
(IntL = 351 pb^{-1})
-> higher Q^2 (Q2> 150 GeV^2)

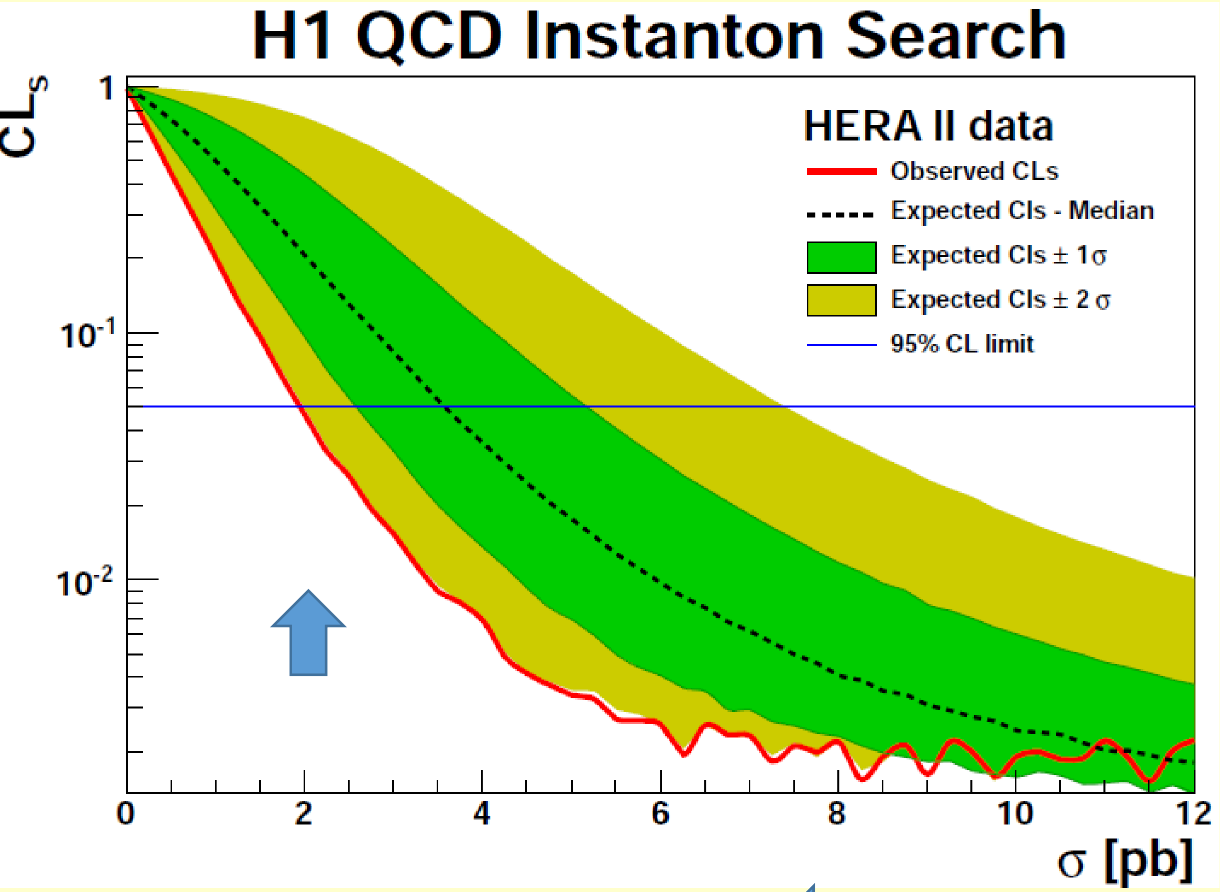




30 August 2016

Instanton: HERA-II Results

EPJ C76 (2016) 7, 1



Observed limit: 2pb
while the prediction is
10 ± 3 pb^{-1}
in the kinematic region of
$150<Q2<15000GeV^2$,
$0.2<y<0.7$

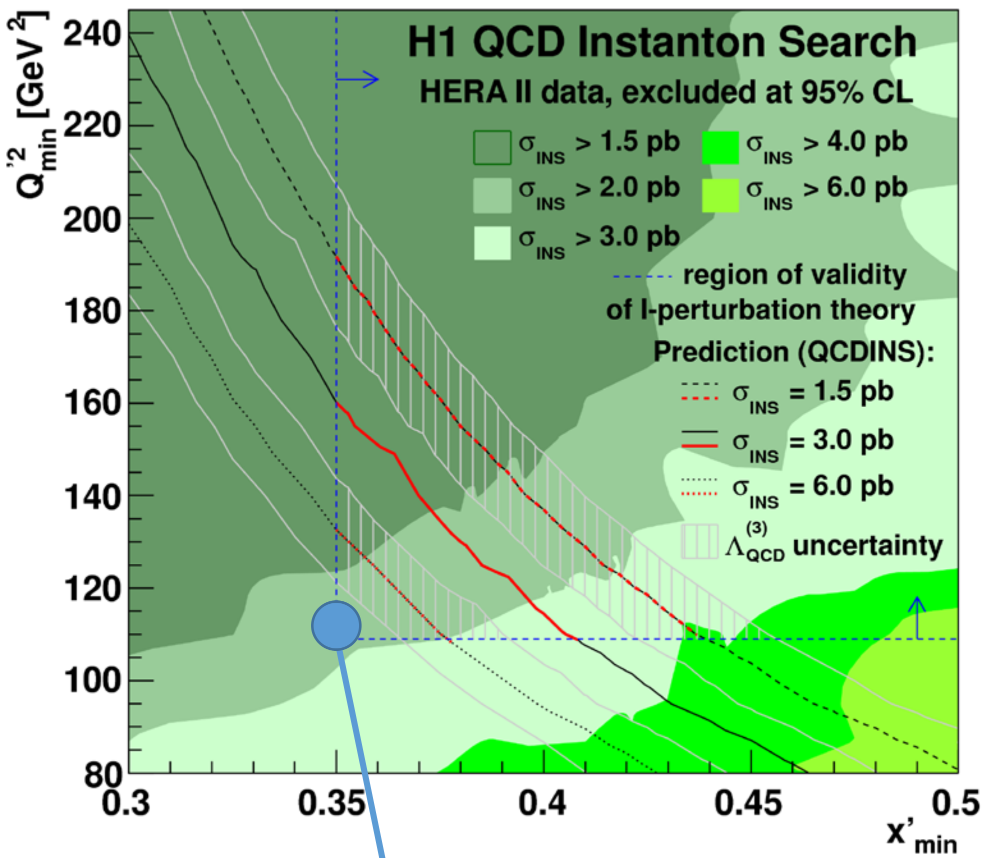
$Q'^2min=113GeV^2$,
x 'min=0.35

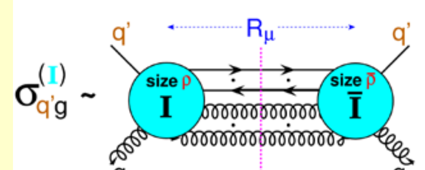
Challenge to the theory!

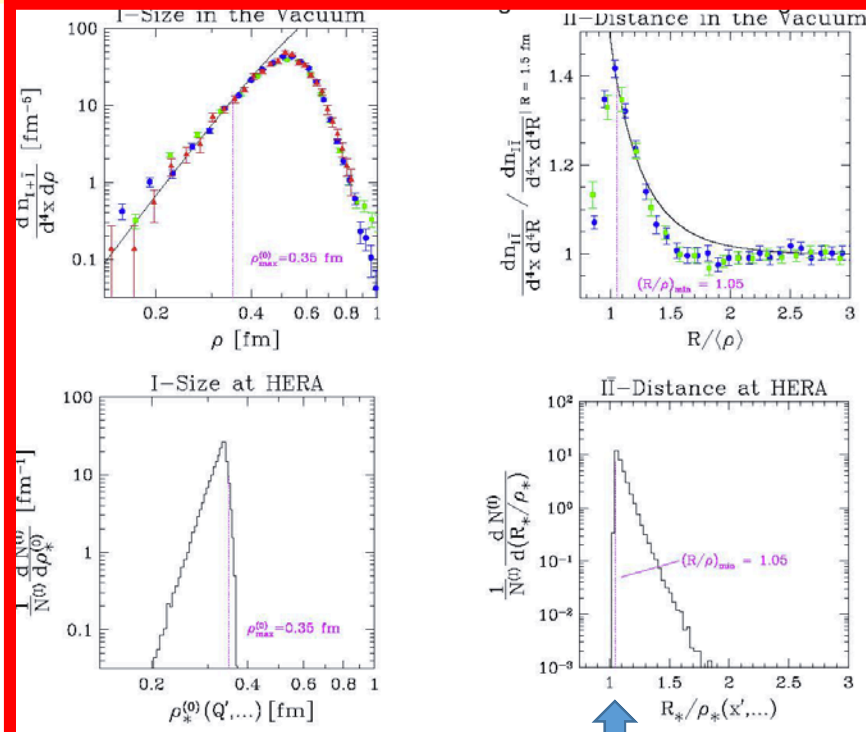
Prediction from QCDINS

Instanton: HERA-II Results

EPJ C76 (2016) 7, 1







Q'² ~ 113GeV²

x' ~ 0.35

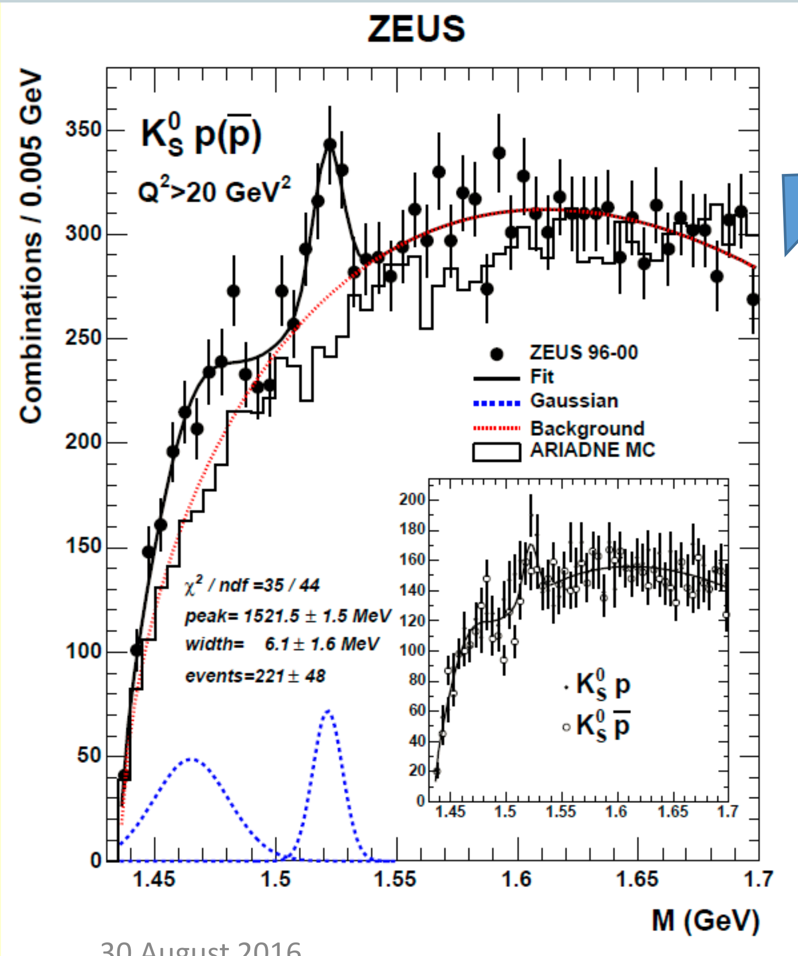
Ringwald and Schrempp
PLB503 (2001) 331

95% CL Cross section limit as a function of Q'^2min and x'min

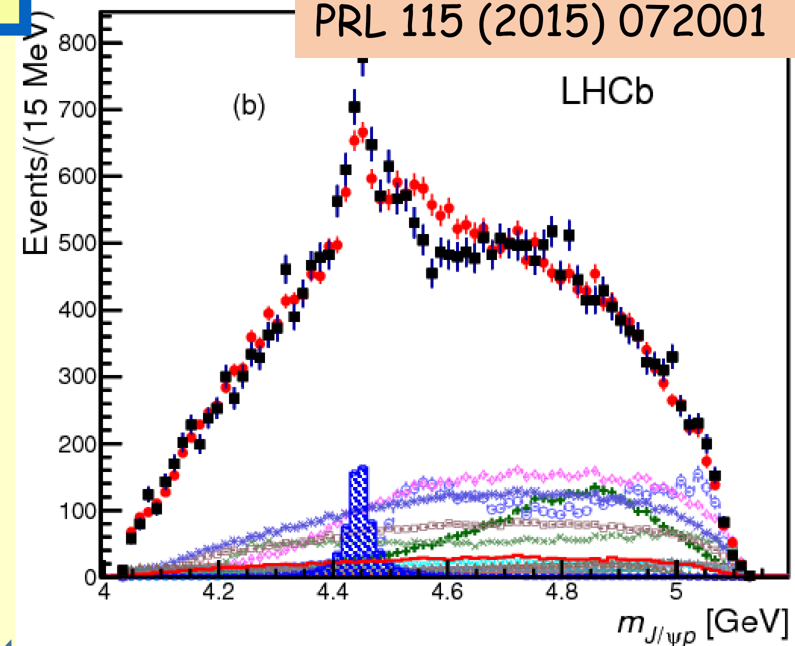
Q'^2min=113GeV² , x 'min=0.35 -> 10pb with QCDINS

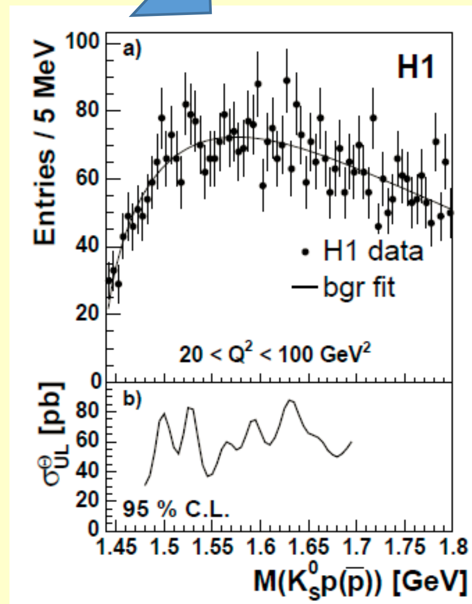
Pentaquark in pK system

Search for a narrow baryonic state
Decaying to pK_{0s} at HERA-I:
ZEUS observed a peak consistent to
Θ^+ ($uudd\bar{s}$)   PLB 591 (2004)



New excitement from
LHCb Λ_b -> (p J/Ψ) K
PRL 115 (2015) 072001



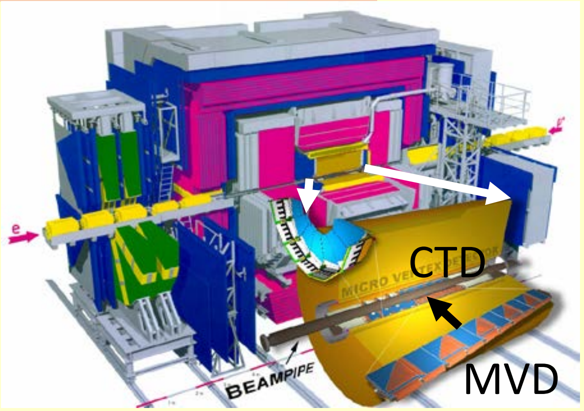


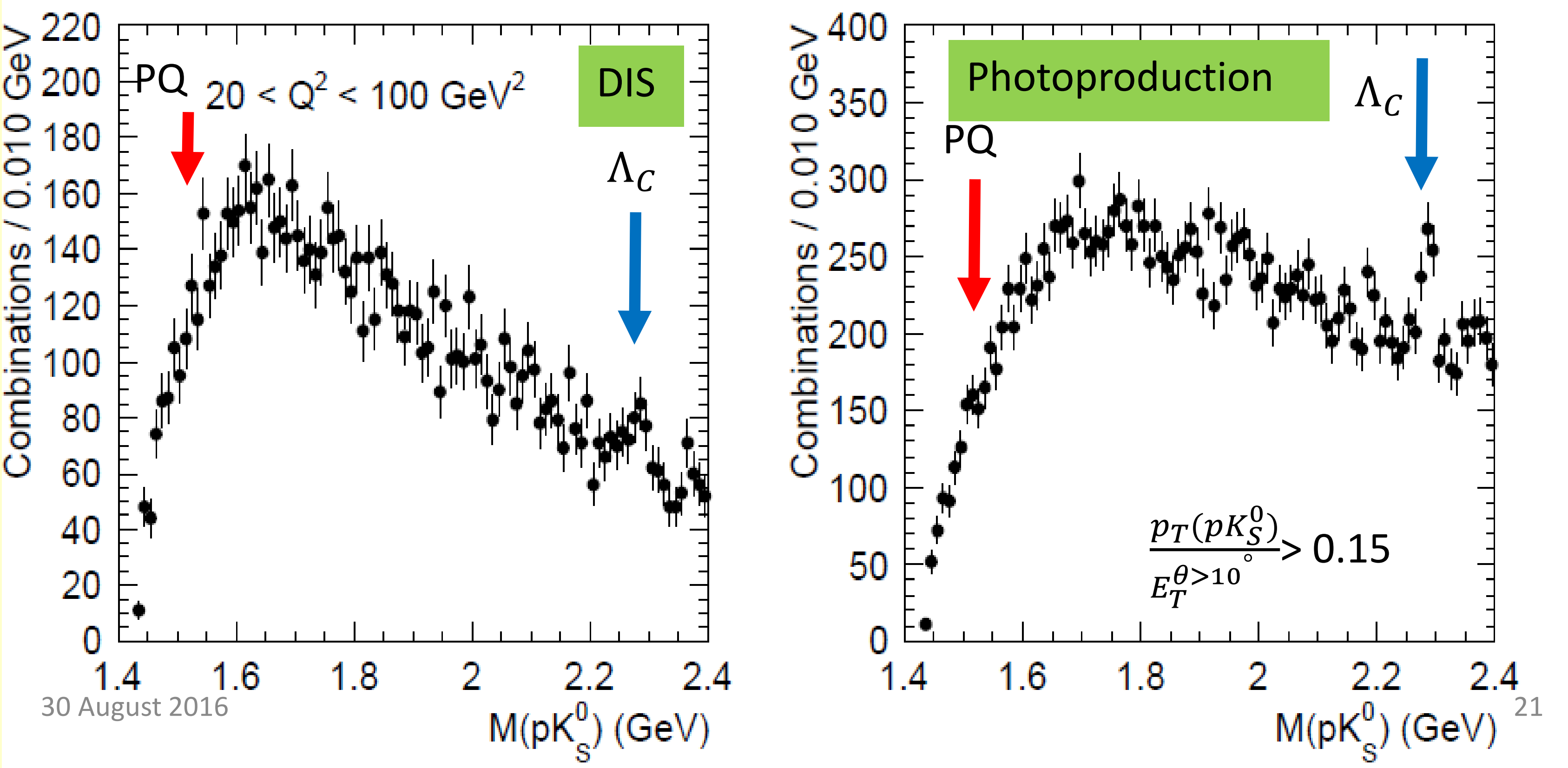
H1 did not see the peak but still two results were compatible.
->
We needed HERA-II data

Pentaquark in pK system: ZEUS HERA-II

PLB 759 (2016) 446

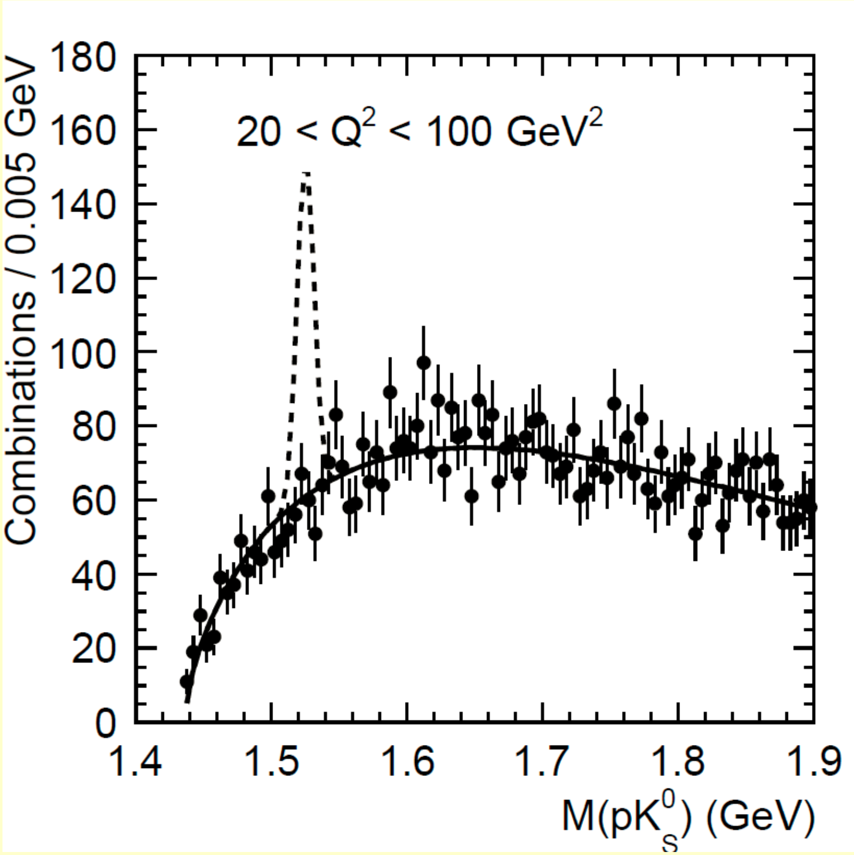
DeDx from micro vertex detector (MVD) (Si-strip)
: Better PID





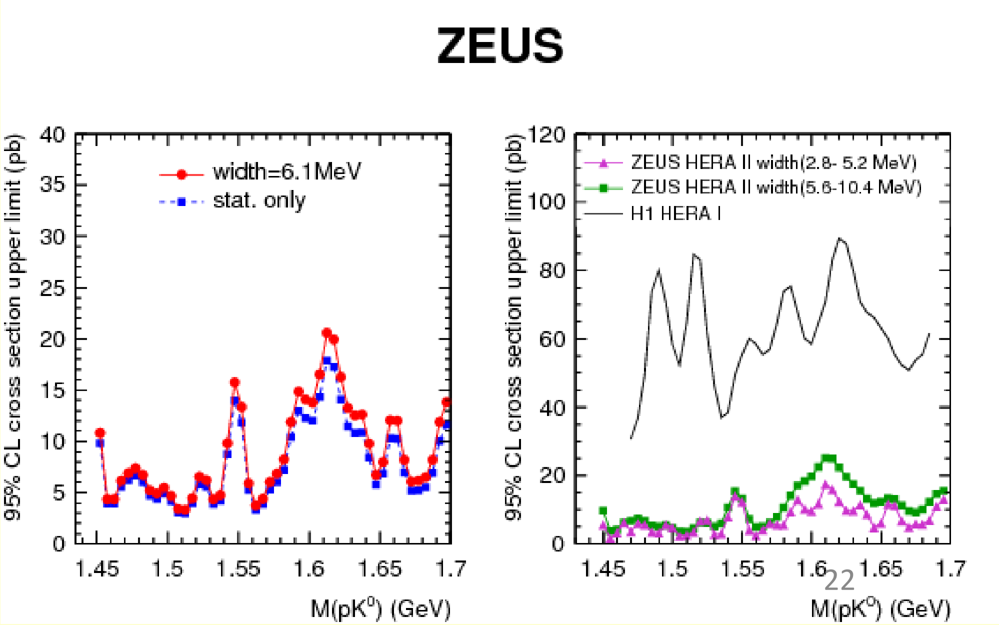
Pentaquark in pK system

PLB 759 (2016) 446



The dashed line represents the Θ^+ signal as would be observed if it had the same strength as reported in the ZEUS HERA I analysis (expected 286 events).

The structure in the HERAI data is assumed to be a background fluctuation.



Summary

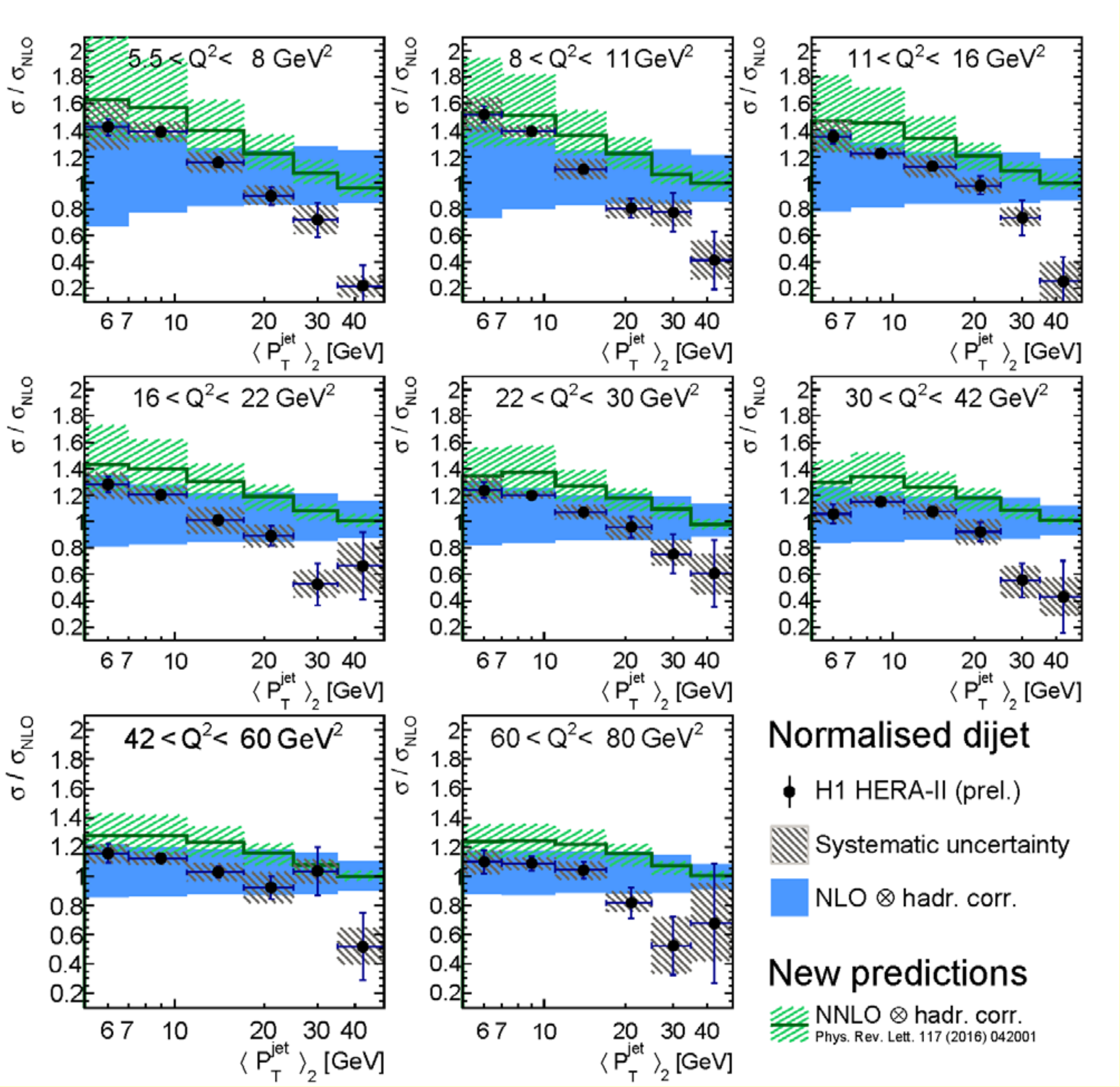
- With the recent results from H1/ZEUS, I am trying to demonstrate that HERA covers the diverse area of the QCD.

- Jet production:
  NLO->NNLO better description of data.
  Extraction of α_s is on-going
- Prompt photon:
  In progress on the comparison with the theories
- Instanton:
  Stringent limit: Challenge to the theory?
- Strange penta-quark (pK^0_S, $p\bar{K}^0_S$) at 1.52GeV
  Not confirmed with HERA-II data

More plots

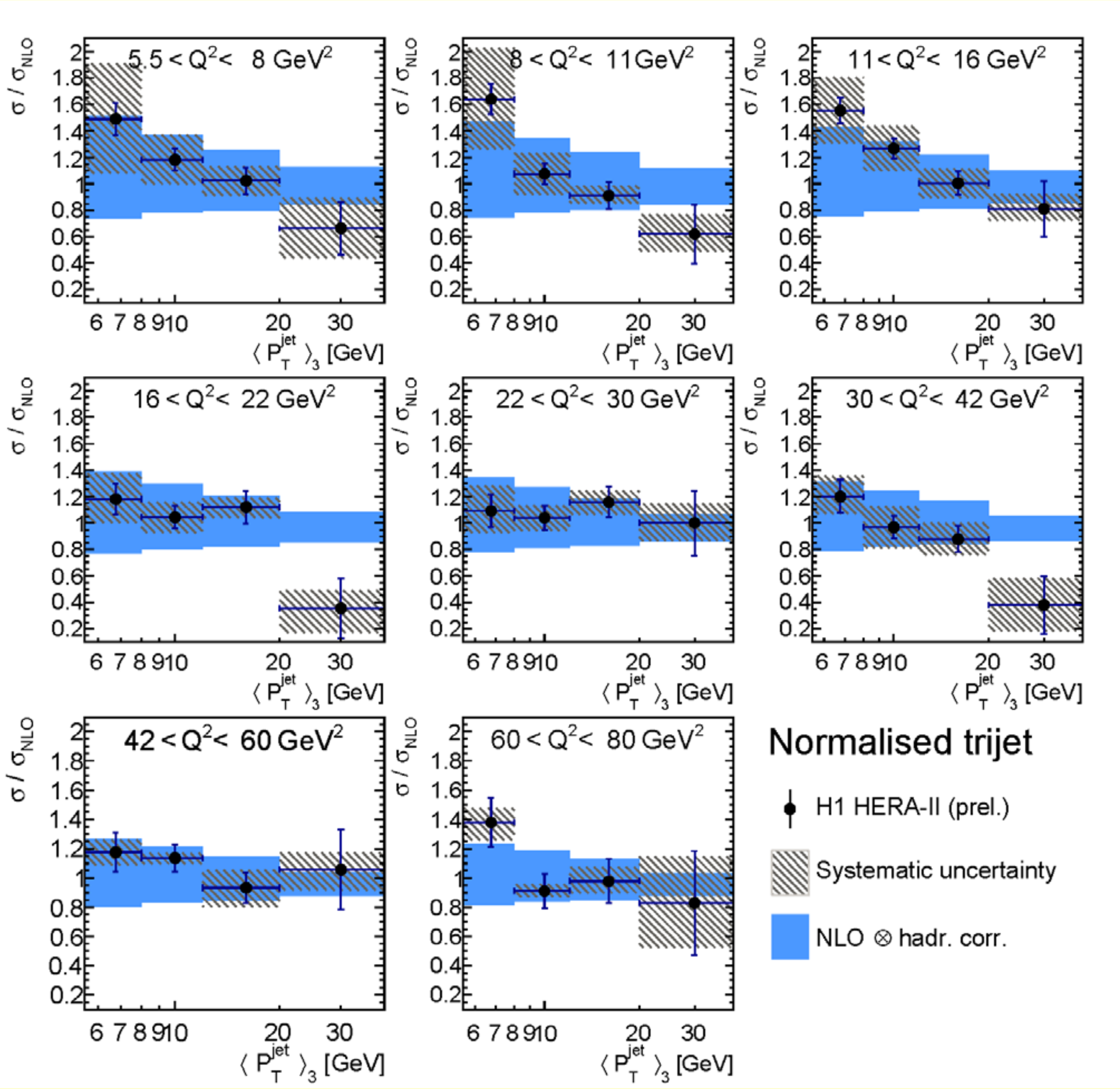
Di-jet:H1

H1prelim-16-062

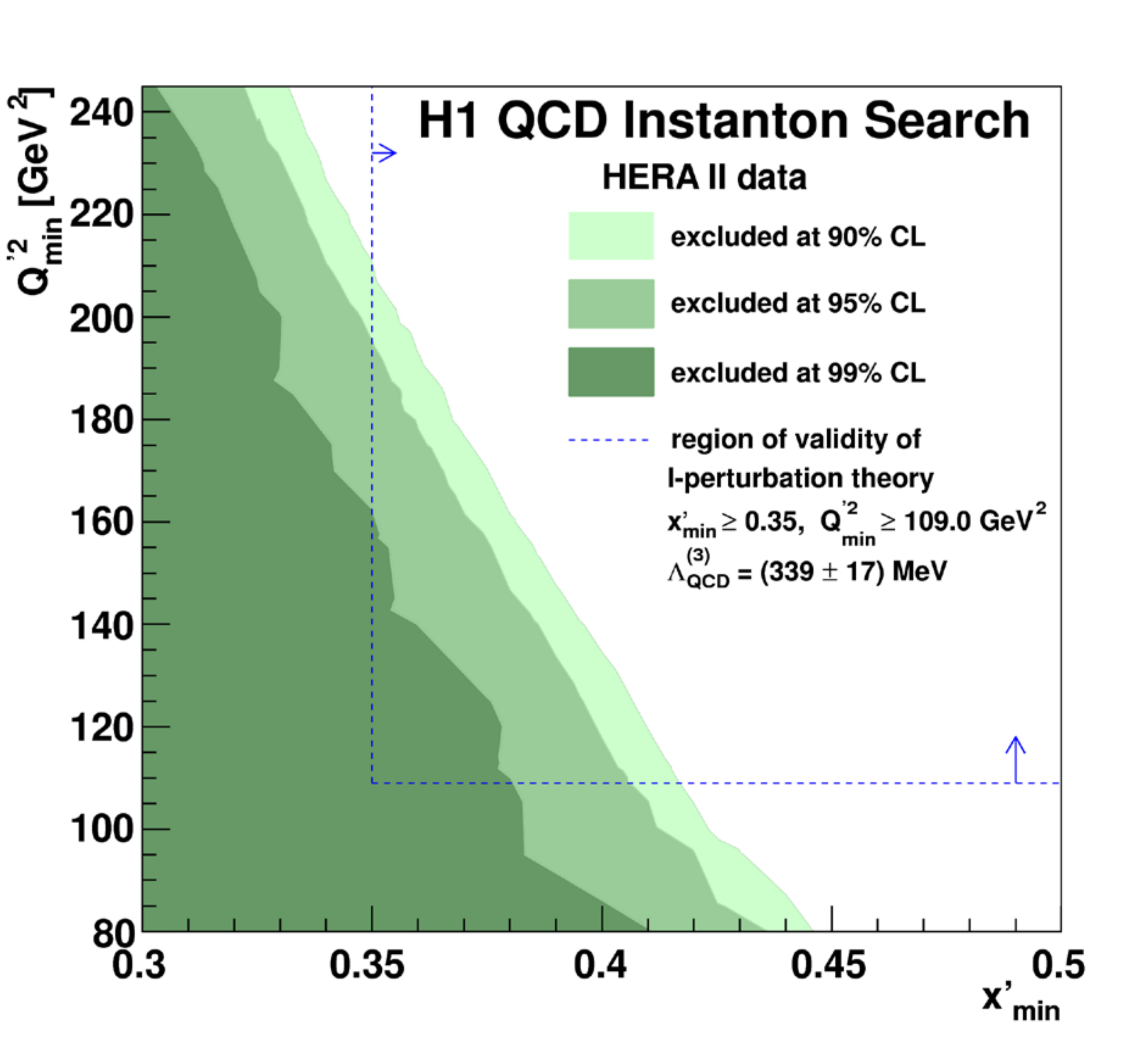


tri-jet:H1

H1prelim-16-062

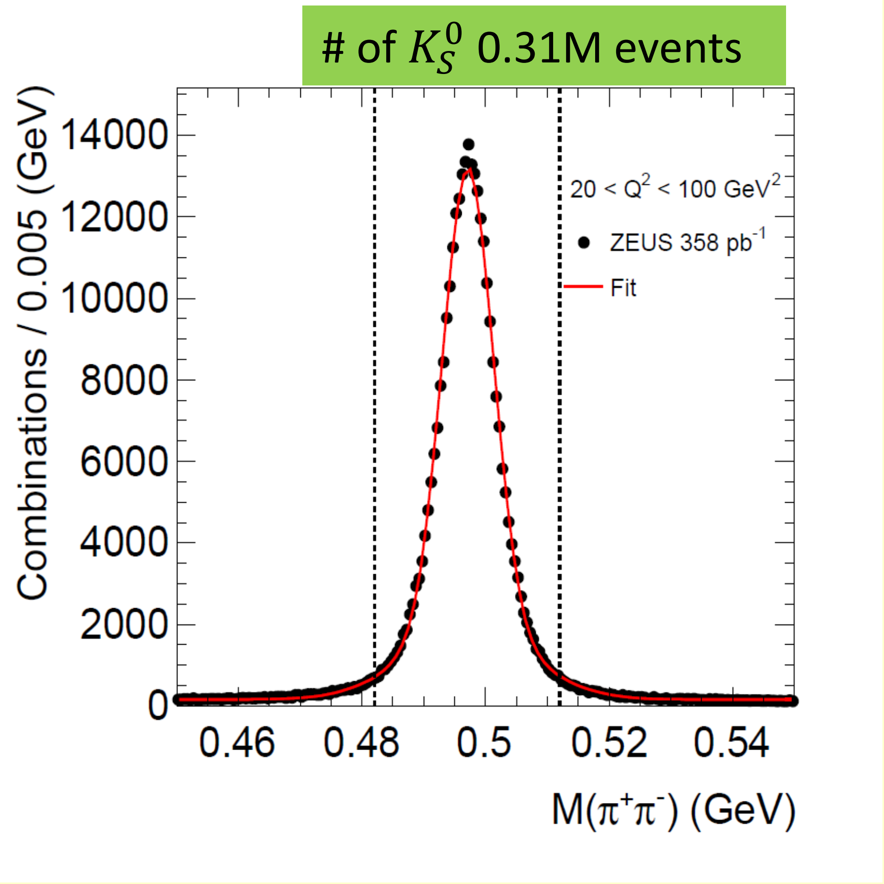


Instanton: HERA-II Results



Pentaquark in pK system: ZEUS HERA-II

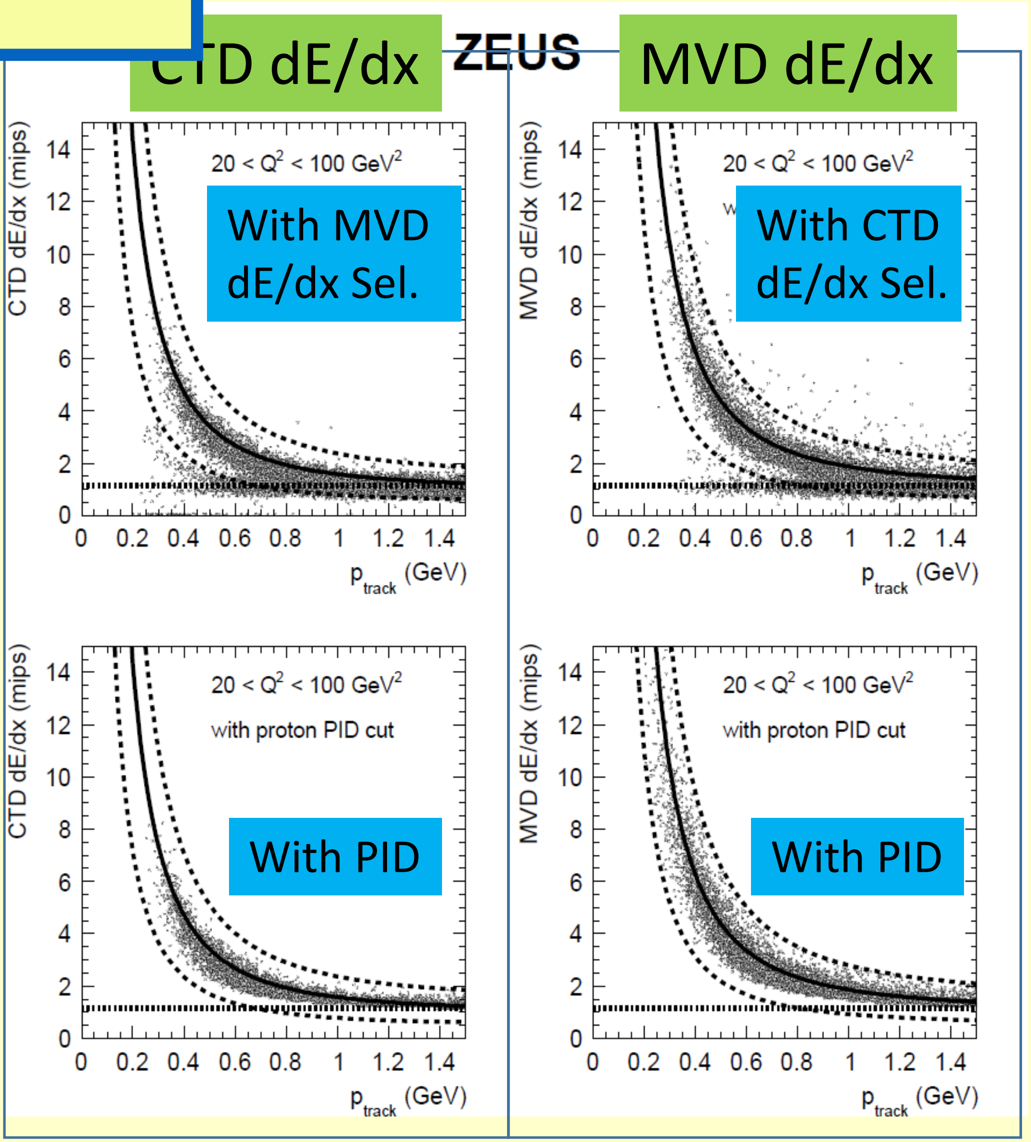
$K_S^0 \rightarrow \pi^+\pi^-$ selection



Pentaquark in pK system: ZEUS HERA-II

- Track selections
  - not used as π of K_S^0
  - 0.2 < p(p) < 1.5 GeV
  - CTD innermost layer = 1
  - CTD outermost layer >= 3
  - PID by both of CTD and MVD dE/d
- CTD dE/dx
  - Maximum ~70 hits with full length track.
  - Truncated mean method.

    (the lowest 10% and the highest 30% hits are excluded from the mean.)
  - Resolution for protons ~9.4%.
- MVD dE/dx
  - Nominal 6 hits with full length track.
  - Calculation with probability density function of hit.
  - Resolution for protons ~11.7%.



Pentaquark in pK system: ZEUS HERA-II

- Q^2 requirement
  - $20 < Q^2 < 100$ GeV²
- pK_S^0 requirements
  - $0.5 < p_T < 3.0$ GeV
  - $|\eta| < 1.5$