Hadronic Final States and QCD: Summary

Thomas Gehrmann (Univ. Zürich)

on behalf of the other conveners:

G. Grindhammer, V. O'Dell, R. Walczak

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Hadronic Final States and QCD

- 44 Talks: 19 Theory, 25 Experiment, >15h
- New results from H1, ZEUS, HERMES, CDF, D0, RHIC, CLAS
- Apologies if your favourite result is only briefly mentioned

Hadronic Final States

- Vector boson production
- Underlying Event
- Monte Carlo Tools
- QCD at small x
- Specific final states: hadrons/photons
- Precision Physics with Jets
- New Jet Algorithms

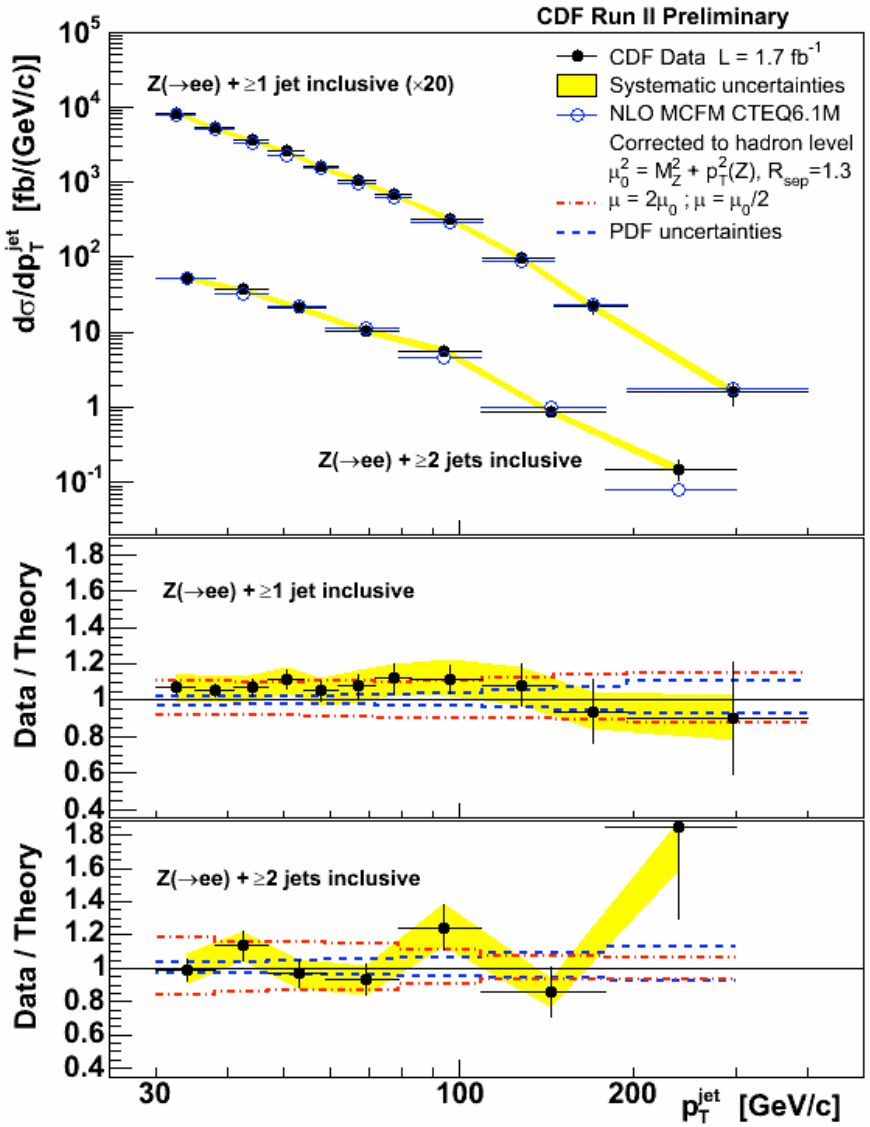
Vector Bosons

Benchmark process

- Verify theoretical description: fixed order, event generators
- Determine parameters: partons, couplings
- Background to searches

Well-described at NLO

- Theory error starts to dominate

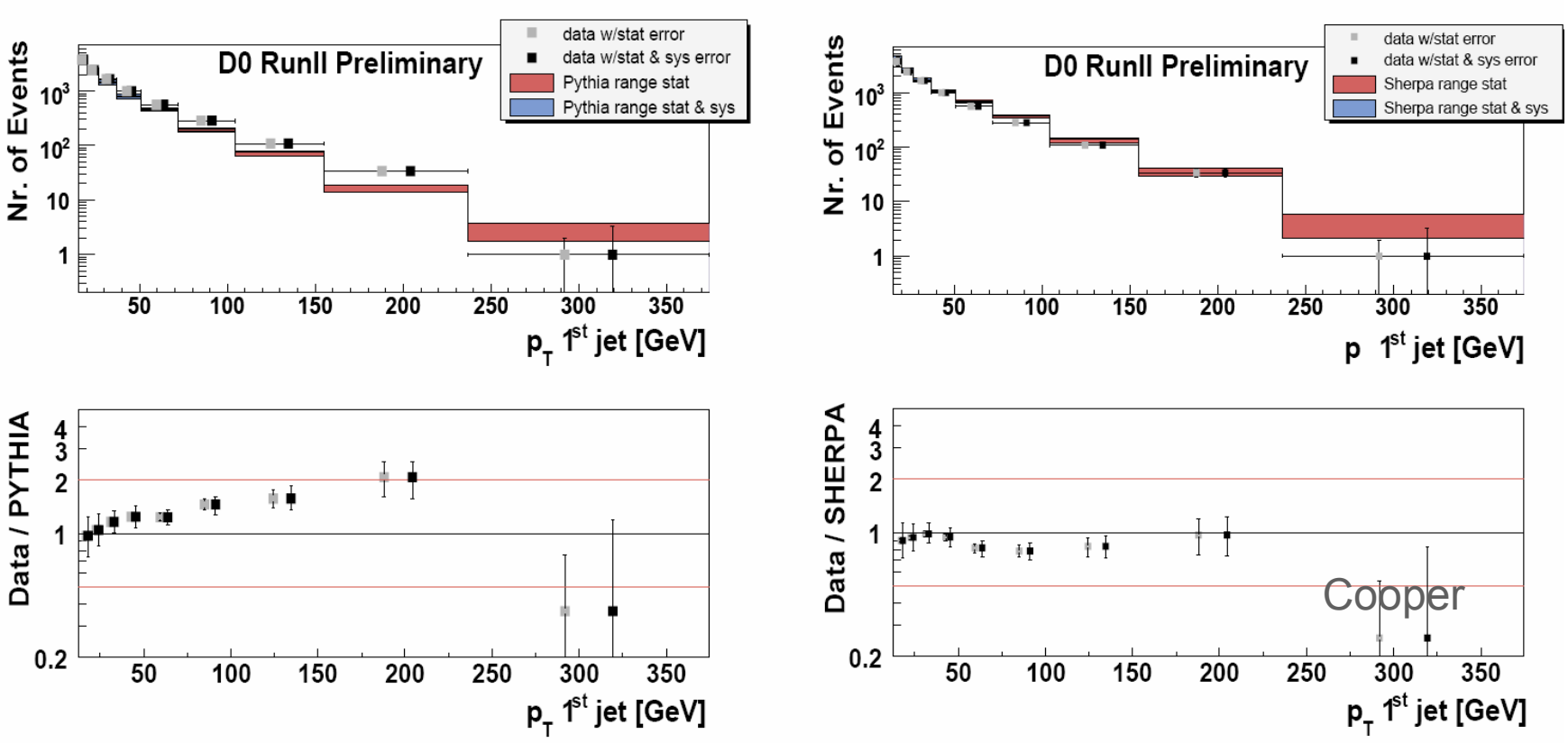


Z+jets from CDF

Cooper

Vector Bosons

Comparing Monte Carlo generators to (Z/γ) + jets from D0



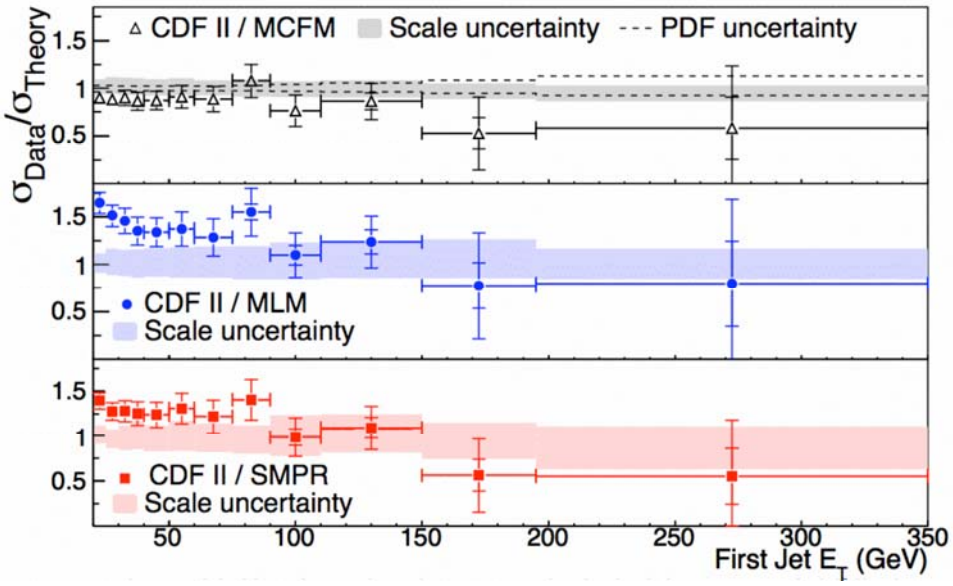
SHERPA: includes matching of parton shower and matrix element

Vector Bosons

Theory

- Best description by fixed-order NLO
- Different ME/PS prescriptions

W + jets from CDF



Cooper

Vector Bosons

QCD corrections to vector boson pair production

$\sigma(pp \to W^*W^* \to \ell\bar{\nu}\bar{\ell}'\nu')$ [fb], LHC, $M_W/2 \le \mu_{ren,fac} \le 2M_W$						
	$q\bar{q}$		gg	$\frac{\sigma_{gg,3gen}}{\sigma_{gg,2gen}}$	$\frac{\sigma_{NLO}}{\sigma_{LO}}$	$\frac{\sigma_{NLO+gg}}{\sigma_{NLO}}$
	LO	NLO	NNLO			
σ_{tot}	$875.8(1)^{+54.9}_{-67.5}$	$1373(1)^{+71}_{-79}$	60.00(1) $53.64(1)^{+14.0}_{-10.8}$	1.12	1.57	1.04 1.04
σ_{std}	$270.5(1)^{+20.0}_{-23.8}$	$491.8(1)^{+27.5}_{-32.7}$	29.79(2) $25.89(1)^{+6.85}_{-5.29}$	1.15	1.82	1.06 1.05
σ_{bkg}	$4.583(2)^{+0.42}_{-0.48}$	$4.79(3)^{+0.01}_{-0.13}$	1.4153(3) $1.3837(3)^{+0.40}_{-0.31}$	1.02	1.05	1.30 1.29

Kauer

Total cross section

Reconstruction cuts

Higgs search cuts

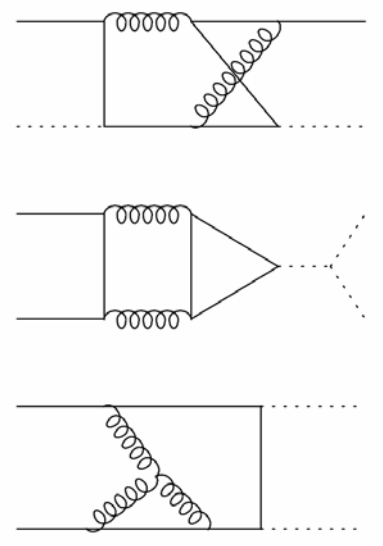
Higgs search cuts enhance importance of gluon-gluon contribution

Rapid recent progress on NLO corrections for multi-particle processes

Vector Bosons

Towards vector boson pairs at NNLO

Virtual Two-loop



Chachamis

Double real radiation

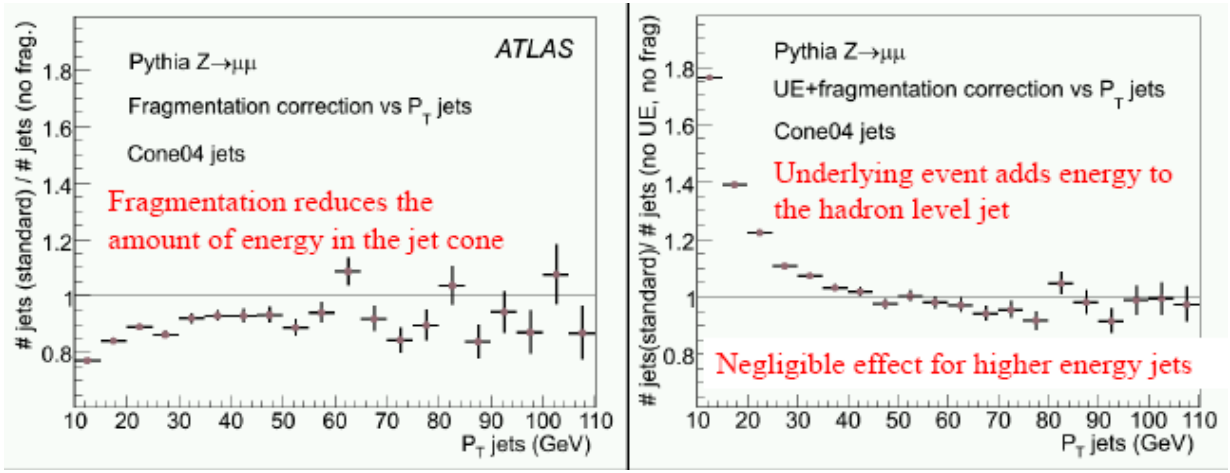
- matrix elements known
- require subtraction on infrared singularities for numerical implementation

- state-of-the-art in two-loop
- recently completed in high-energy limit

Vector Bosons

Use vector boson plus jets production to calibrate event reconstruction at ATLAS

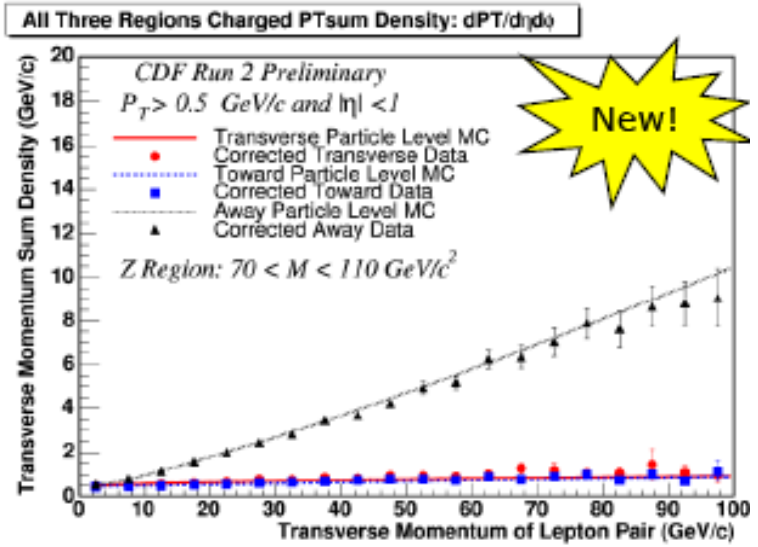
- here: corrections for hadronization and underlying event



Dobson

Underlying Event

- all event activity besides hard interaction
- models in Monte Carlo generators
- require tuning to data
- extrapolation to LHC highly uncertain



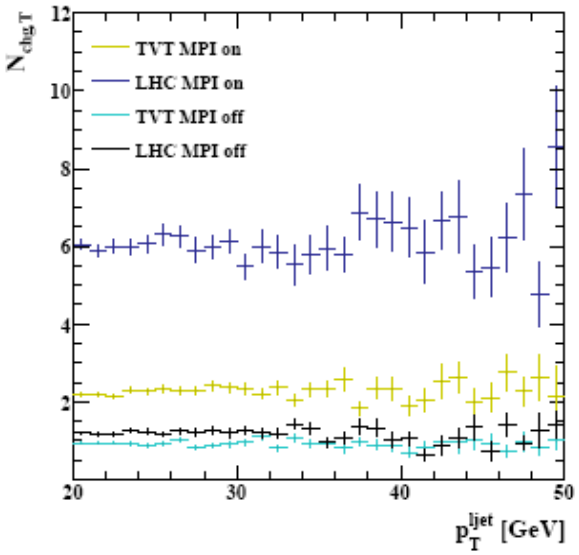
Metha

New CDF data on UE in Drell-Yan + jets

- **UE model tuned to jet data**
- **provides good description of Drell-Yan**

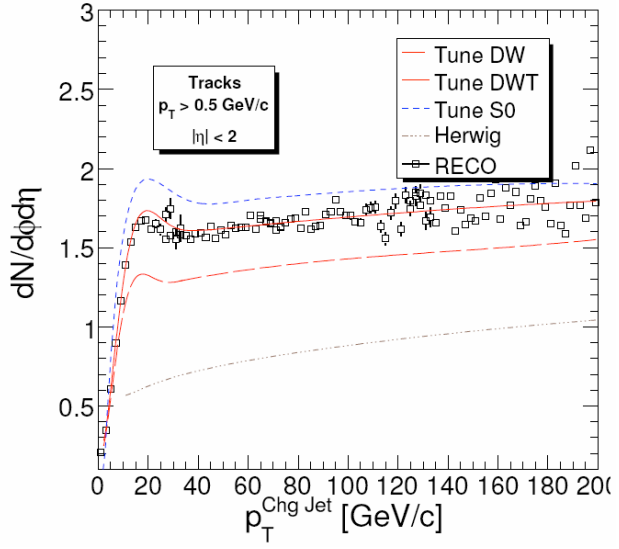
Underlying Event

UE in HERWIG++



Bähr

Tuning with 'first LHC data'



Here: 100 pb^{-1}

Bechtel

Alternative: subtract UE on event-by-event basis using jet areas (Cacciari)

Monte Carlo Tools

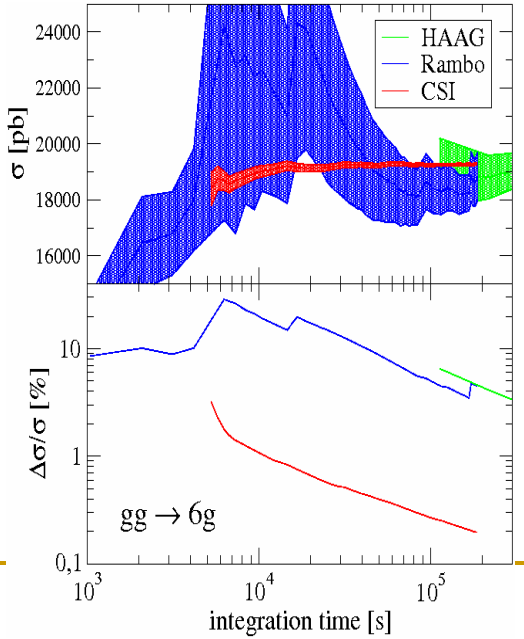
Modern MC programs

- include matching of ME&PS
- link to leading-order multi-parton generators
- prepare for inclusion of NLO corrections
- are written in C++

- **SHEPRA** (Krauss, Höche)
- **HERWIG++** (Bähr)

New features in SHERPA

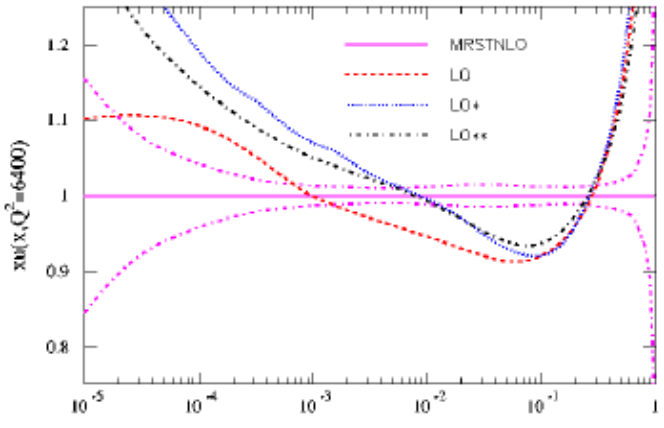
- Initial state dipole showers
- Cluster fragmentation and hadronization
- New phase space and matrix element generator: COMIX



Monte Carlo Tools

Parton distributions for Monte Carlo

- Monte Carlo programs are LO
- LO parton distributions only yield poor fit of data
- improved LO partons
  - give up momentum sum (LO*)
  - modify scale in QCD evolution (LO**)



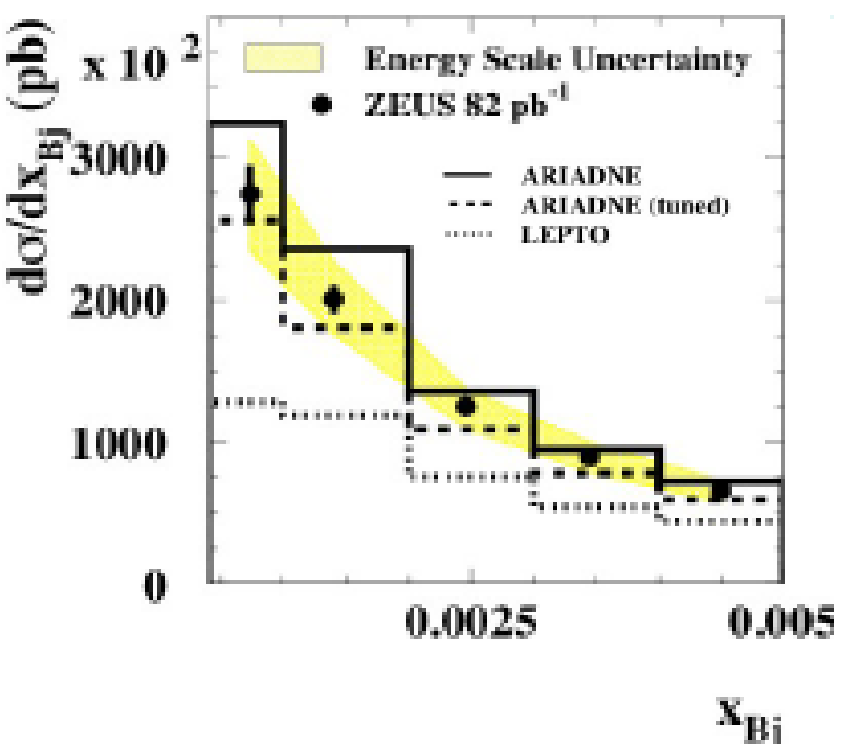
Sherstnev

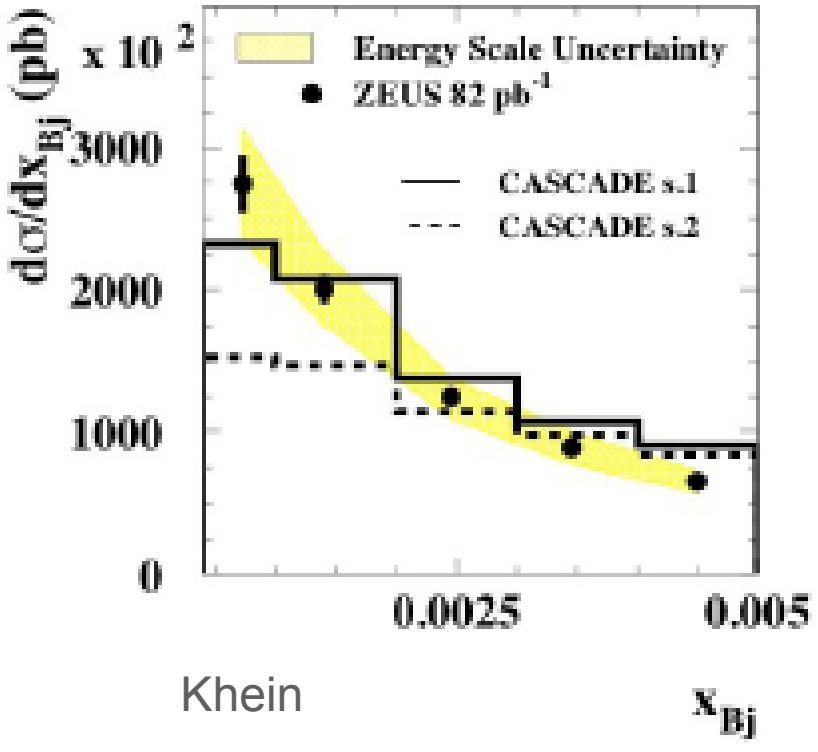
Alternative: consider partons as part of MC tuning
→ parton set for each generator

Low-x Jet Physics

ZEUS measured forward jet cross section

- data not described by DGLAP-based NLO QCD
- only ARIADNE (colour dipole model) in agreement





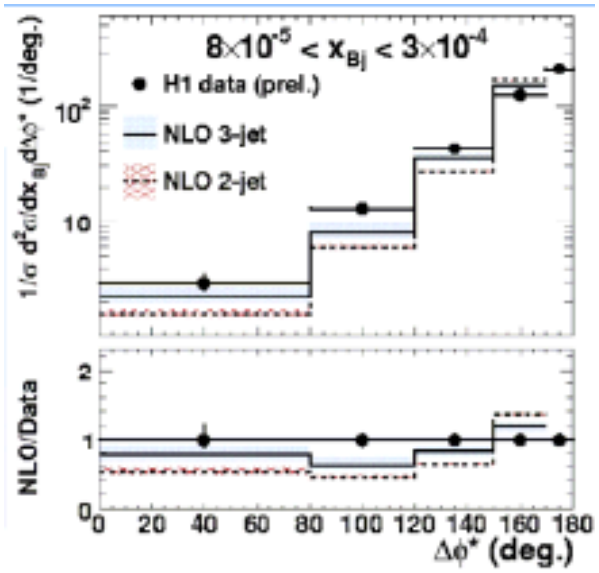
Khein

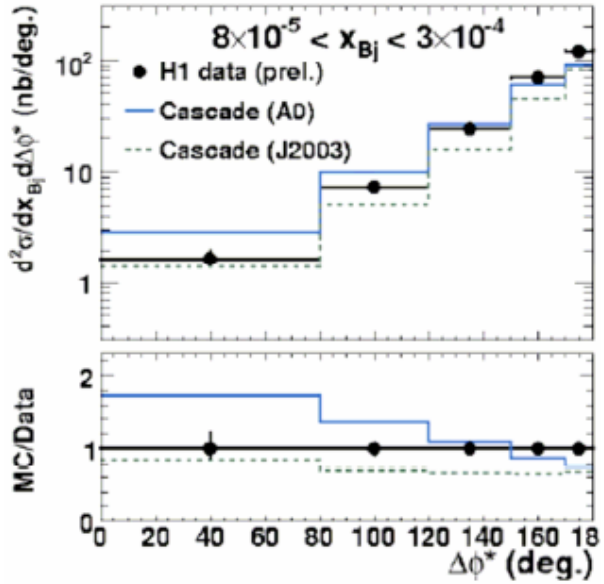
Low-x Jet Physics

- H1 measured azimuthal correlation of jets at low-x
- Data not fully described by DGLAP-based NLO

- Data sensitive to unintegrated gluon
- may enter fit of unintegrated pdf

Hautmann

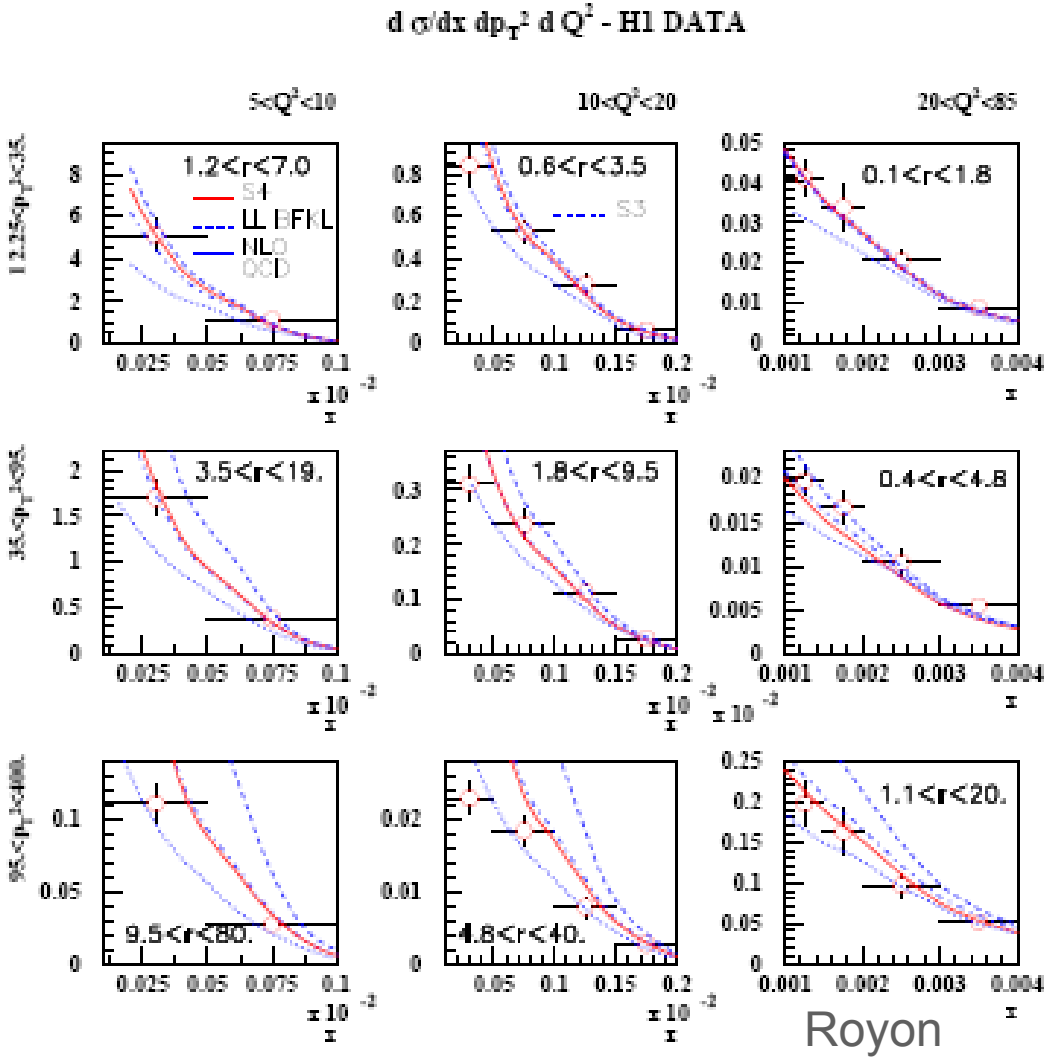




Turnau

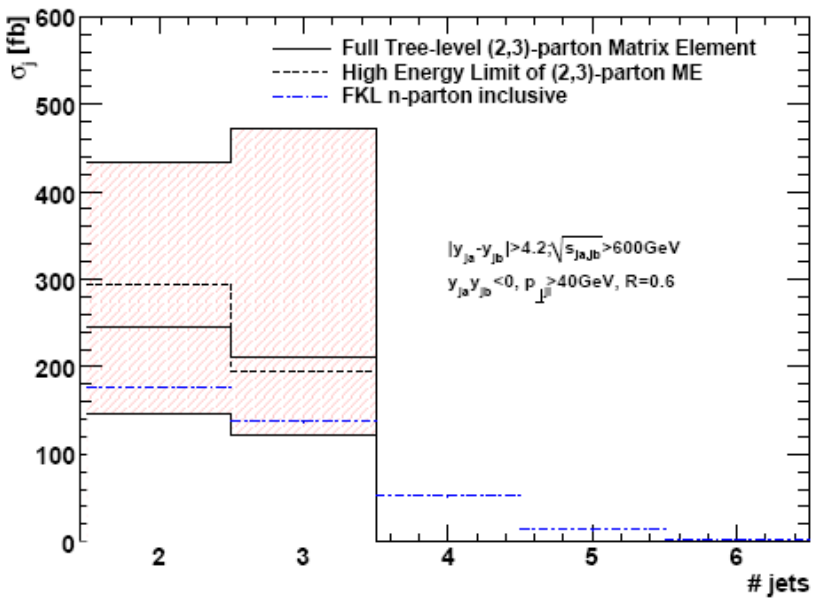
Low-x Jet Physics

- Fit NLL BFKL to H1 data on triple differential forward jet data ($r=p_T^2/Q^2$)
- model yet unknown NLL impact factor
- small scale and scheme dependence at NLL
- good description of data over full kinematic range



Royon

High-Energy Limit

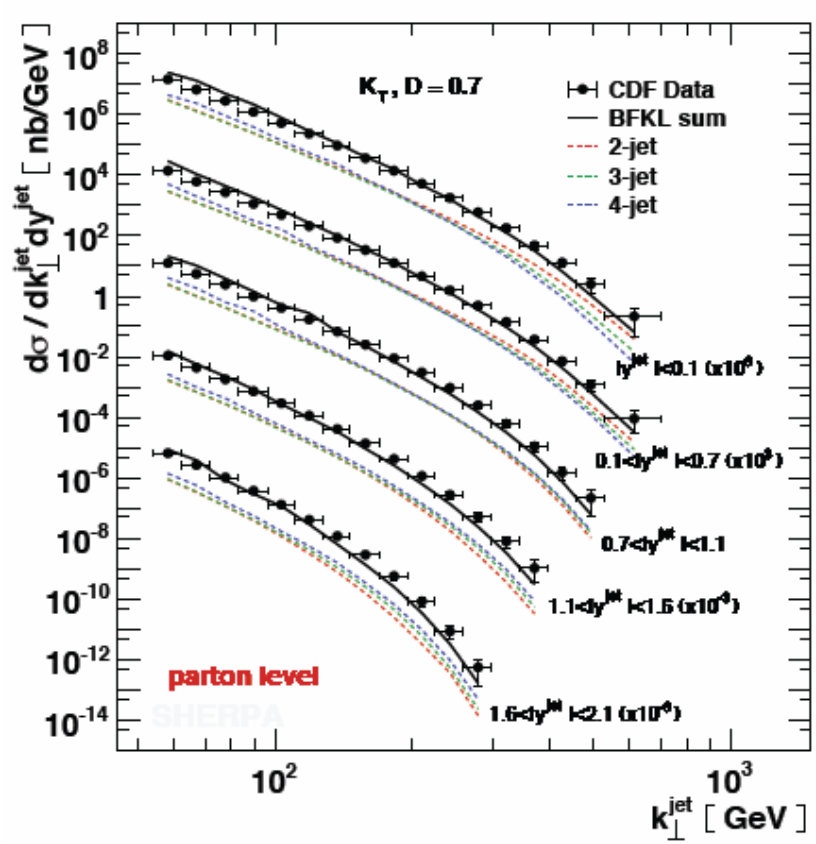


White

- Use high-energy factorisation of QCD matrix elements (BFKL) to compute approximate multi-particle amplitudes
- improve by imposing kinematical constraints
- computation is highly efficient
- reasonable agreement with matrix element generators

High-Energy Limit

- Reformulate BFKL evolution as parton shower
- determine unintegrated pdf by undoing last DGLAP branching
- yields LL BFKL Monte Carlo

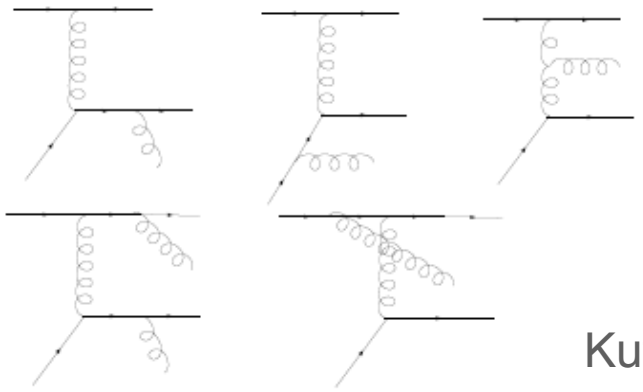


Höche

High-Energy Limit

Calculations in k_T factorisation

- require computation of off-shell scattering amplitudes
- obtained by coupling to external current, e.g. QCD Compton



Kutak

Recent results

- Isolated Photons in photon-proton and proton-proton
  Zotov, Saleev
- Photon isolation and infrared cut-offs still controversial

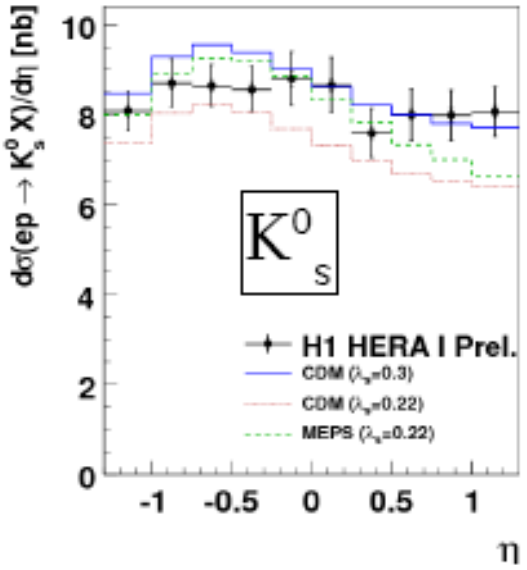
Eikonal approximation

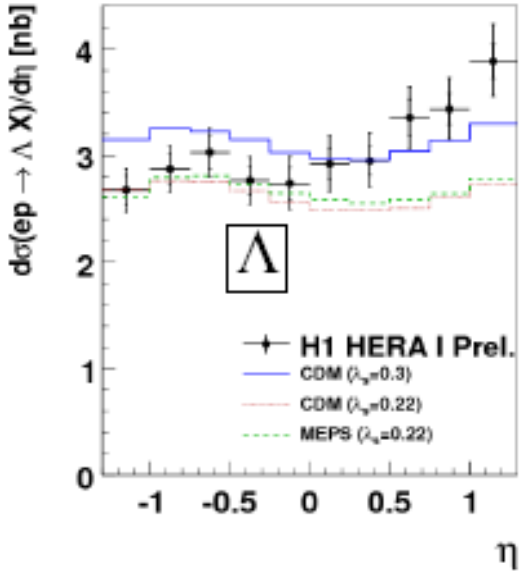
- Progress towards two-loop heavy quark form factor

Kidonakis

Strangeness

- H1 measured strangeness production in DIS
- overall agreement in lab frame
- discrepancies seen in Breit frame hemispheres
- constant strangeness fraction in hadron fragementation fails to explain all data
- K/π and baryon/meson ratios also measured
- include in tuning of generators ?



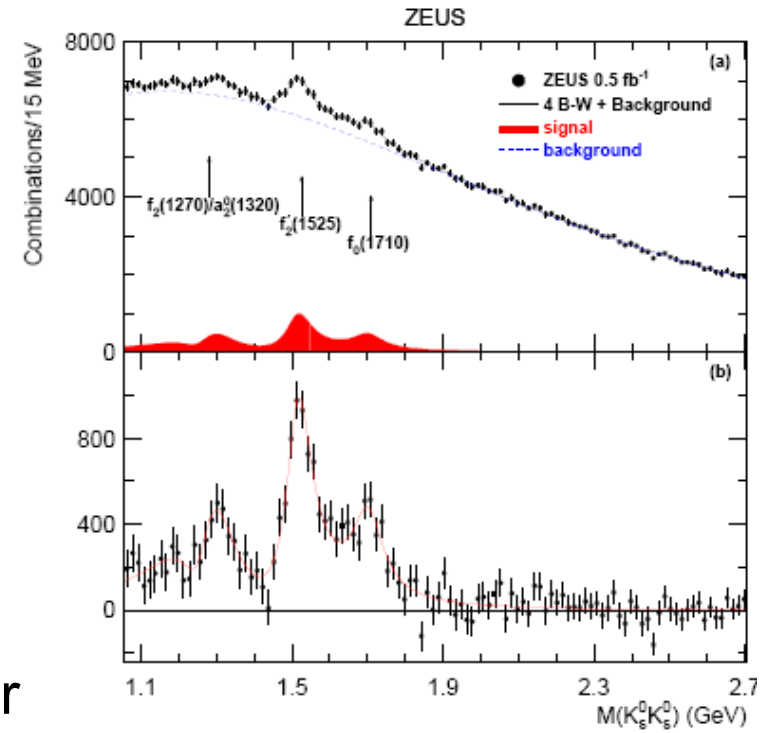


Falkiewicz

Hadron Pair Spectroscopy

- ZEUS has studied K^0-K^0 mass distributions
- Fit including interference of resonances yields clear evidence for $f_0(1710)$,
- Mass 1692 ± 6 MeV
- Width 125 ± 12 MeV
- $f_0(1710)$ also observed in photon-photon (L3): glueball candidate ?

- HERMES: study Bose-Einstein correlations in hadron pairs on nuclear targets (Gapienko)



Karshon

Hadron Spectroscopy

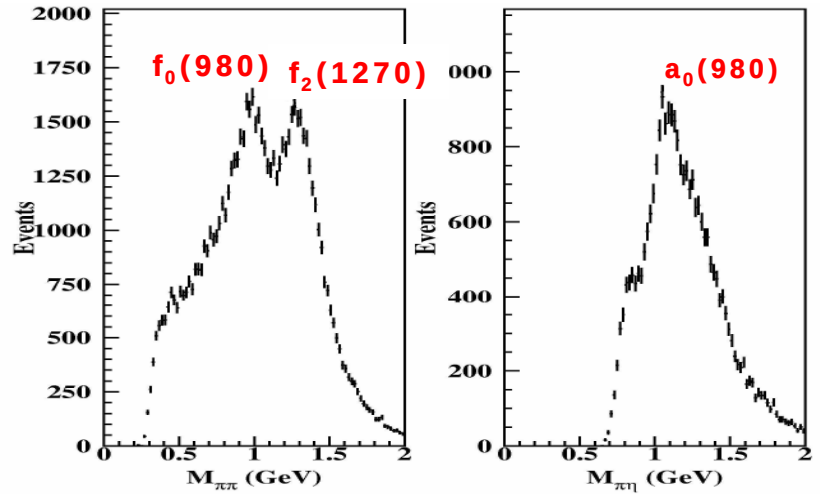
Physics programme of CLAS experiment at TJNAF includes

- Measurement of form factors
- Study of nucleon resonances
- Strangeness production
- Search for exotic states

First look at CLAS data show clear peaks associated to known meson in

$ep \rightarrow (e')p\pi^0\pi^0$

$ep \rightarrow (e')p\pi^0\eta$

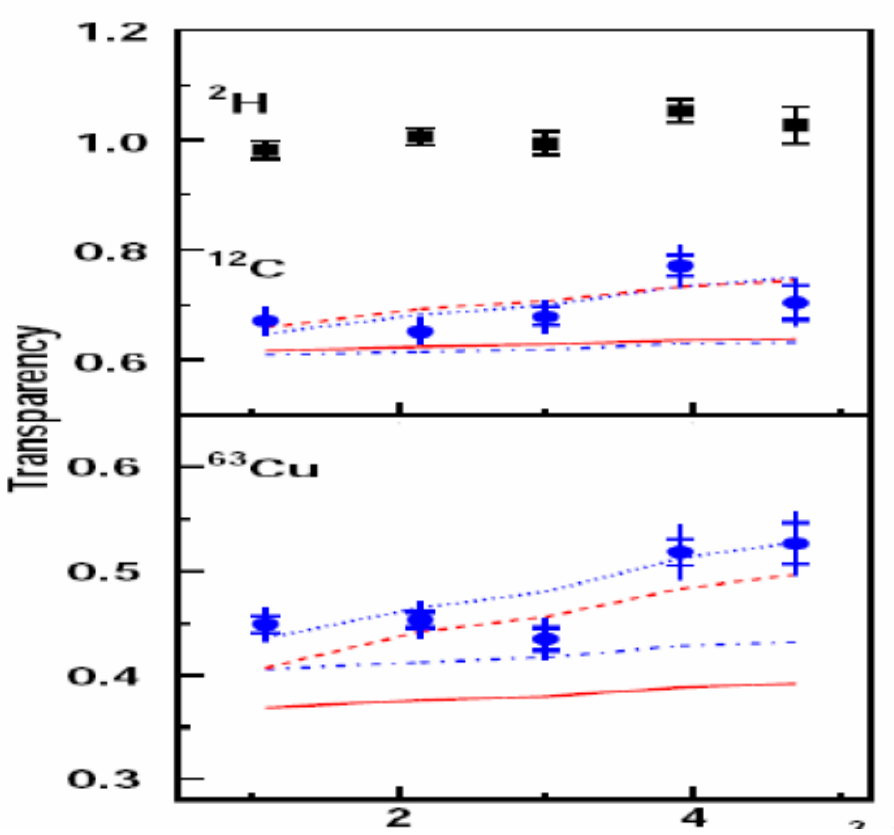


De Vita

Hadron Production at High Density

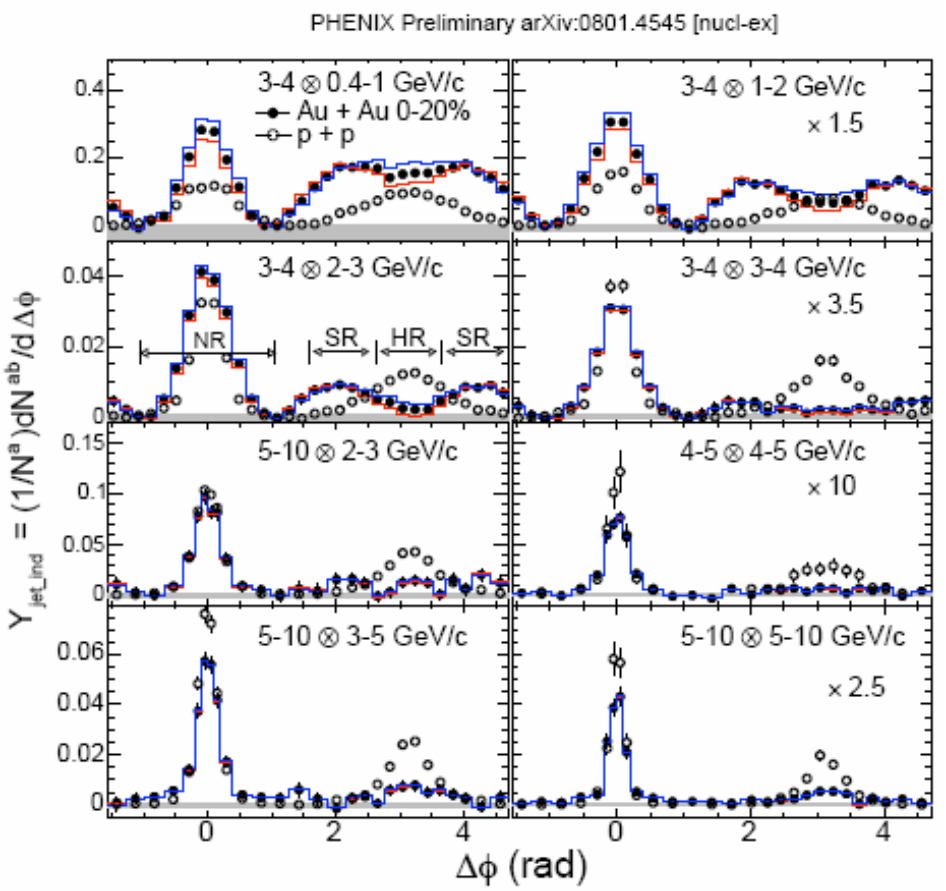
New results from TJNAF Hall C

- Colour transparency: measure ratio of absorption and scattering cross sections
- Use different nuclear targets



Gilfoyle

Hadron Production at High Density



Caines

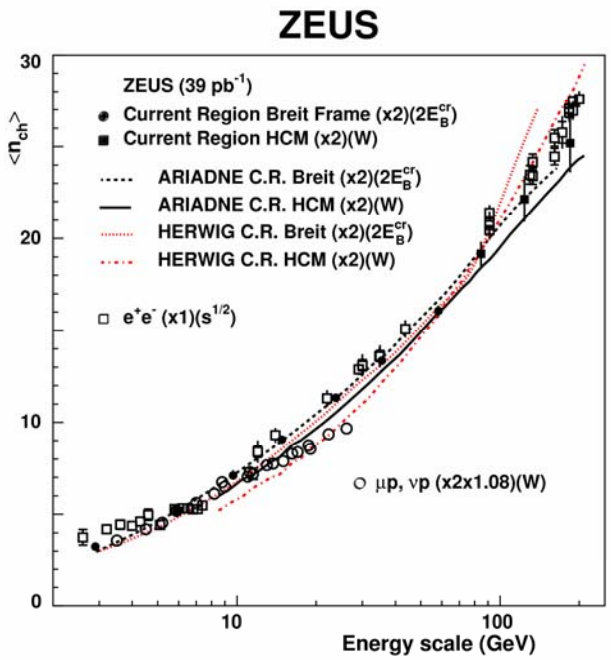
- RHIC measurement of jet quenching
- Observe Mach cone
- Determine sound velocity in QGP: v ~ (0.2..0.3)c

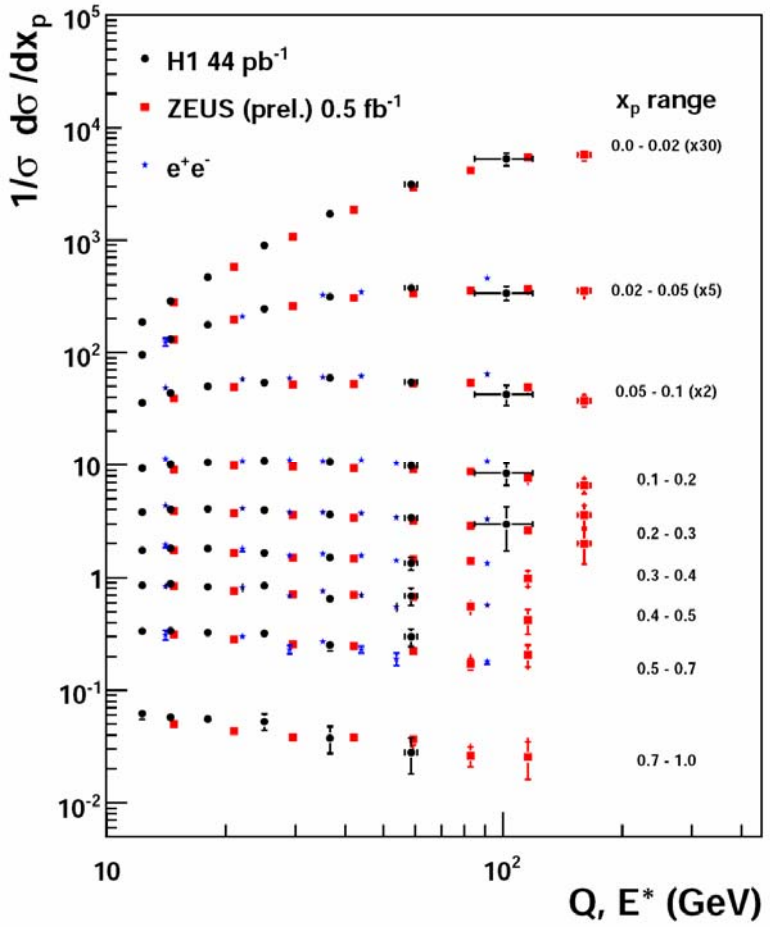
- RHIC jets are single high-momentum hadrons
- More realistic jets?
- Use new jet finders?

(Soyez, Cacciari)

Charged Hadron Multiplicities

- Compare Breit frame current region with e^+e^- results
- Measure hadron energy distributions



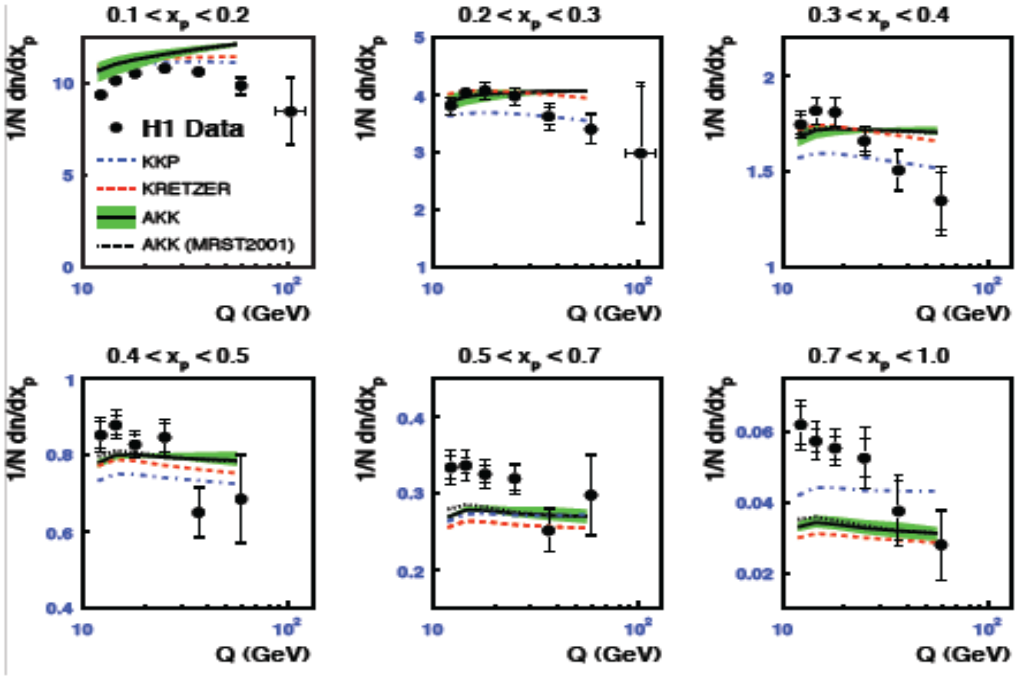


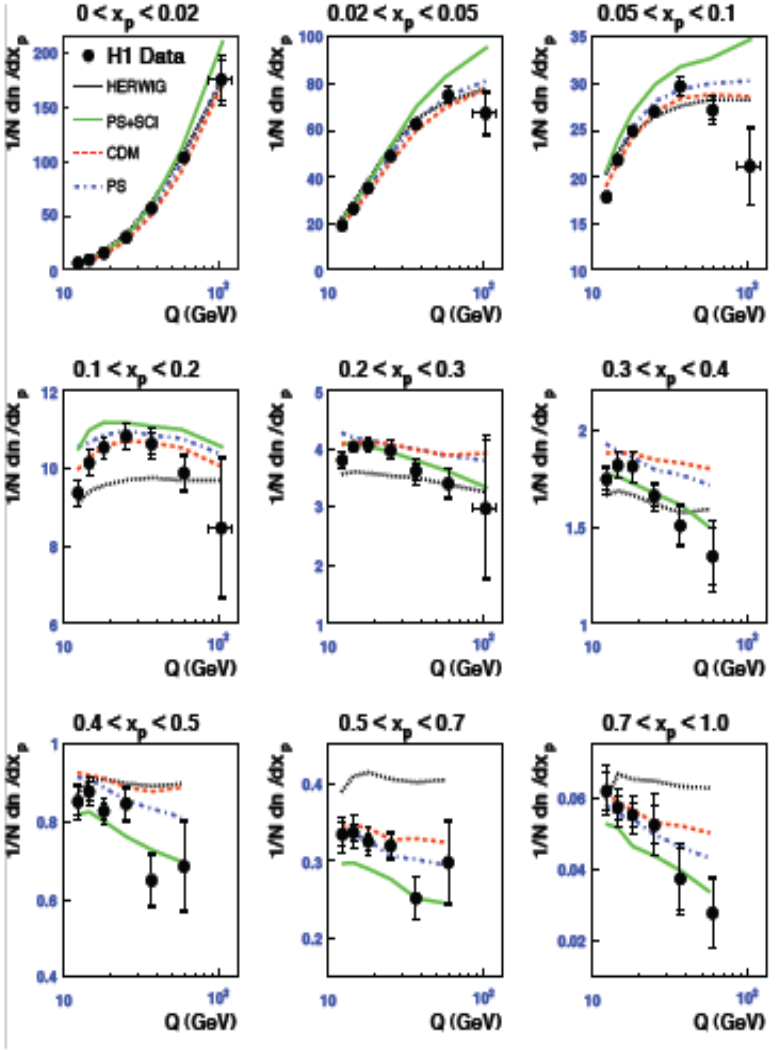
Tymieniecka

Charged Hadron Fragmentation

H1 scaled momentum distributions

- **test hadronization in MC programs**
- **provide fragmentation functions**
- **QCD scaling violations**

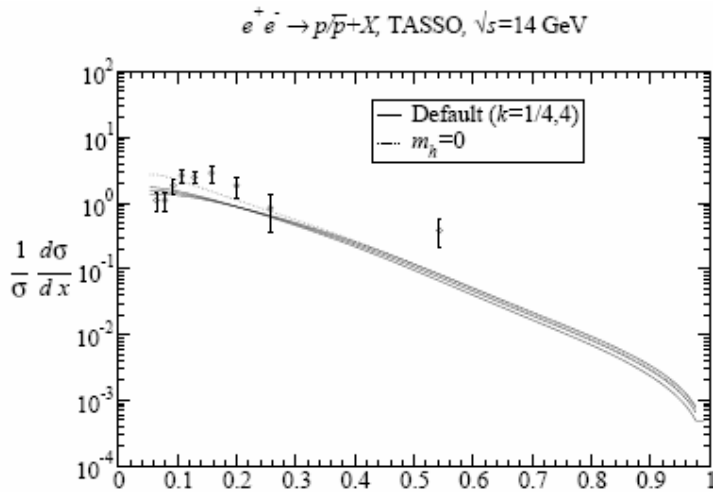




Traynor

Fragmentation Functions

- Improved NLO fit of fragmentation functions
- No HERA data available yet!
- Could add information on charge asymmetry
- Towards NNLO: diagonal time-like three-loop splitting functions calculated (Moch)

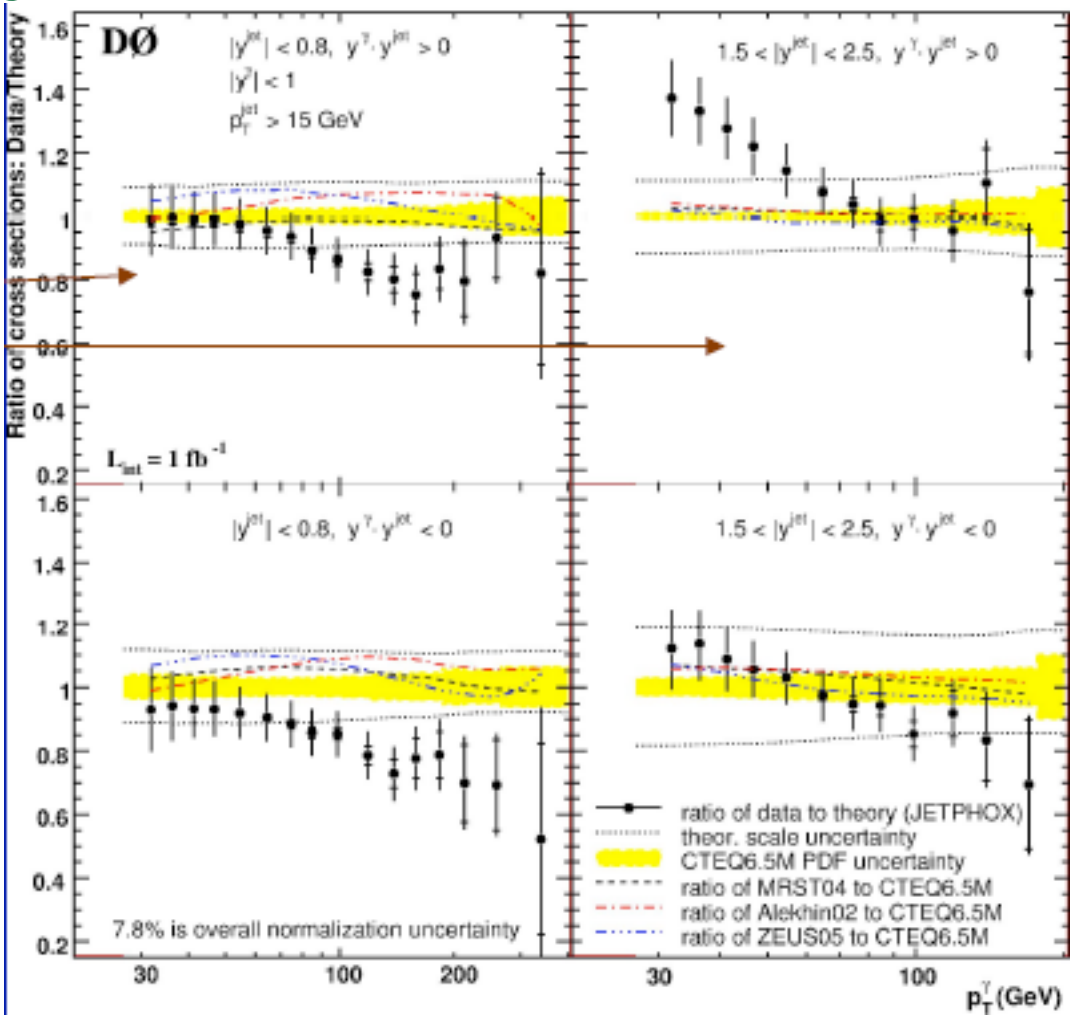


Kniehl

- FFs for $\pi^{\pm}$, $K^{\pm}$, $p/\overline{p}$, K^0_S and $\Lambda/\overline{\Lambda}$,
- FFs for $\Delta_c\pi^{\pm}$, $\Delta_c K^{\pm}$, $\Delta_c p/\overline{p}$, *separate* fits
- data from e^+e^-, $pp(\overline{p})$
- hadron mass effects, fitted in e^+e^-
- slight overshoot for pions: decays from heavier particles?
- mass deficiency for kaons: complicated decay channels?

Isolated Photons

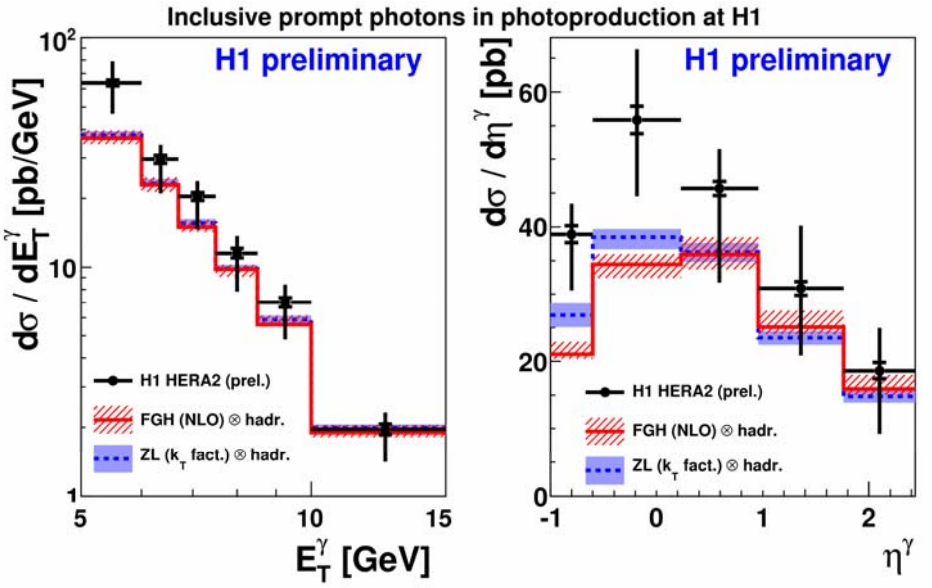
- New measurement of Photon+jet at D0
- NLO theory challenged if jet and photon are in same hemisphere
- Interplay of direct photon radiation with fragmentation understood?
- New CDF analysis on photons in association with bottom/top



Campanelli

Isolated Photons

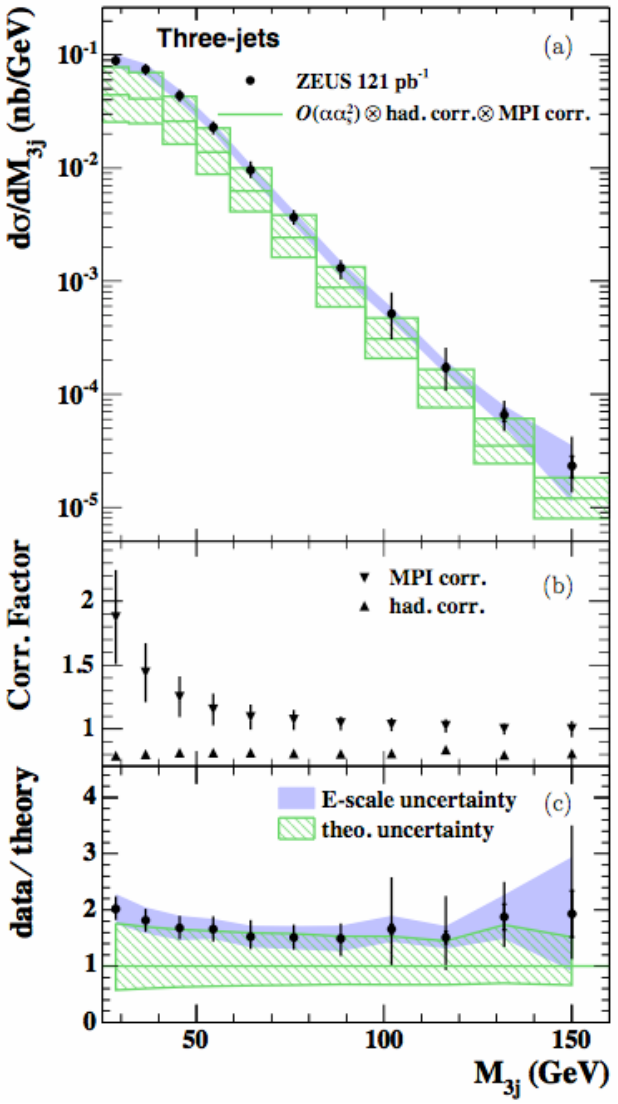
- First HERA II results in photoproduction from H1
- data above NLO and kT-factorization predictions
- Photon plus jet better described
- Photon structure sufficiently well understood?



Nowak

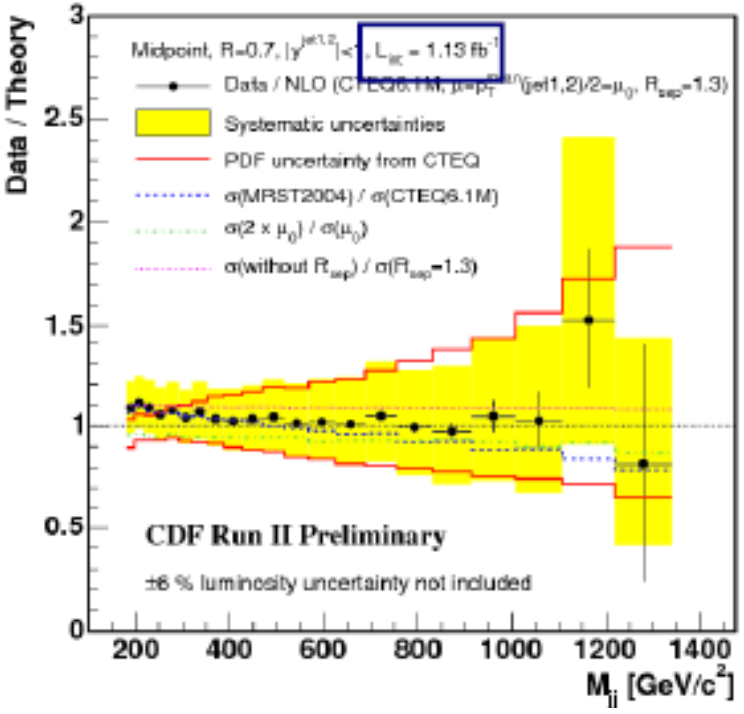
Jets in Photoproduction

- ZEUS measurements of 2j,3j,4j in photoproduction
- Probe parton distributions in resolved photon
- Test multi-jet description in event generators: 3j and 4j largely underestimated by HERWIG/PYTHIA
- Contains information on underlying event and/or multiple interactions



Namsoo

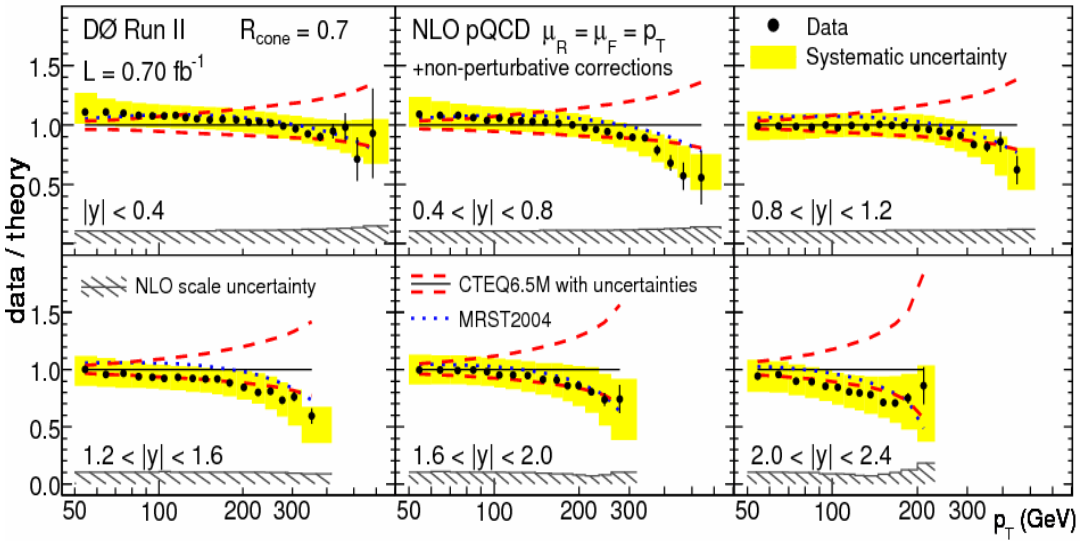
Precision Physics with Jets



Metha

New Tevatron measurements of jets

- good agreement with NLO theory
- data discriminate different pdf sets
- will be included in future fits



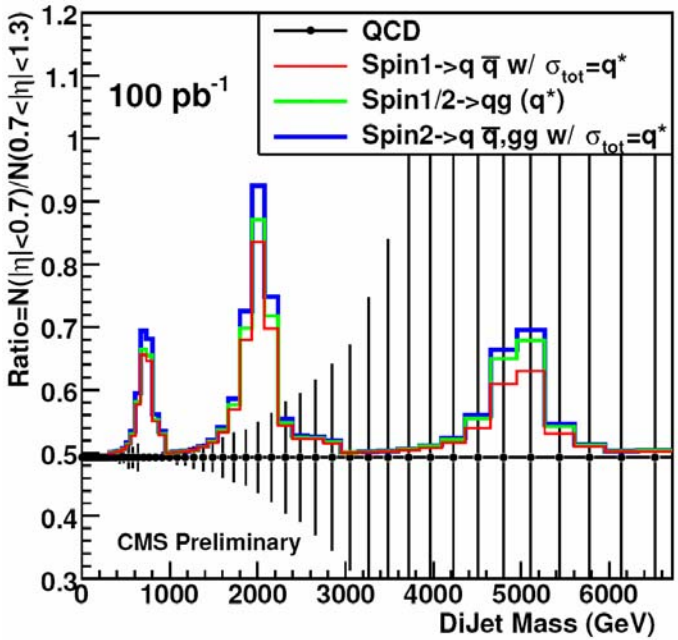
Jet energy scale ~ 1..2 % at D0

- best precision jet measurement at hadron collider so far

Voutilainen

Precision Physics with Jets

- jet cross sections at LHC: precise measurements already at low luminosity
- high discovery potential for new strongly interacting states
- potential limits on contact interactions

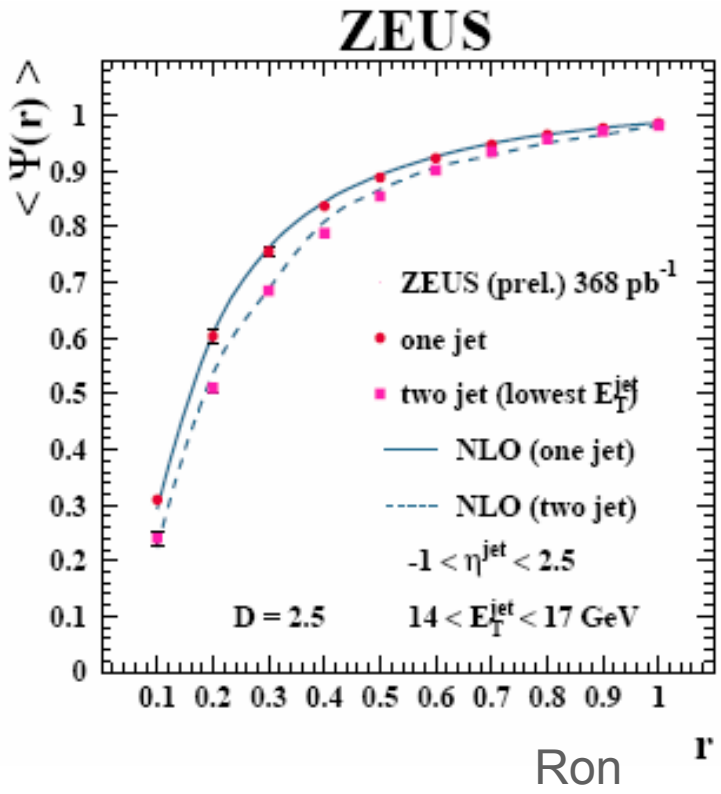


Schieferdecker

Precision Physics with Jets

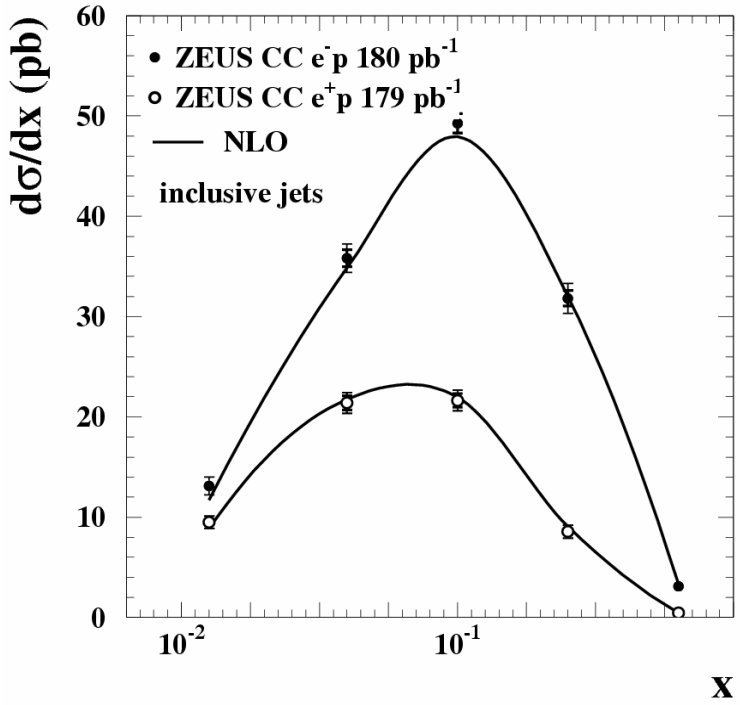
ZEUS measurement of jet profile

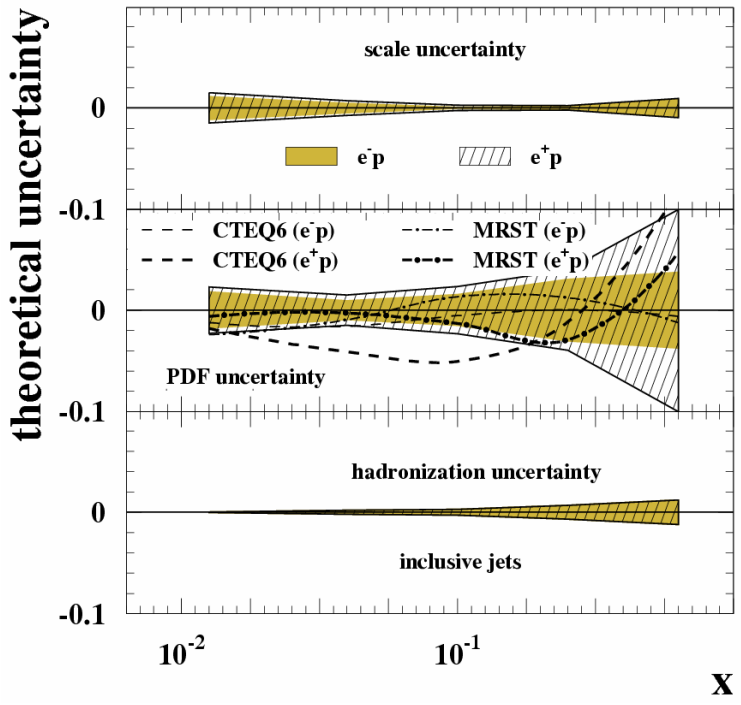
- Probe difference between quark and gluon jets
- 1j sample: q-initiated
- 2j sample: sizable gluon contribution, expect broader jets
- Data well reproduced by ARIADNE und NLO QCD



Precision Physics with Jets

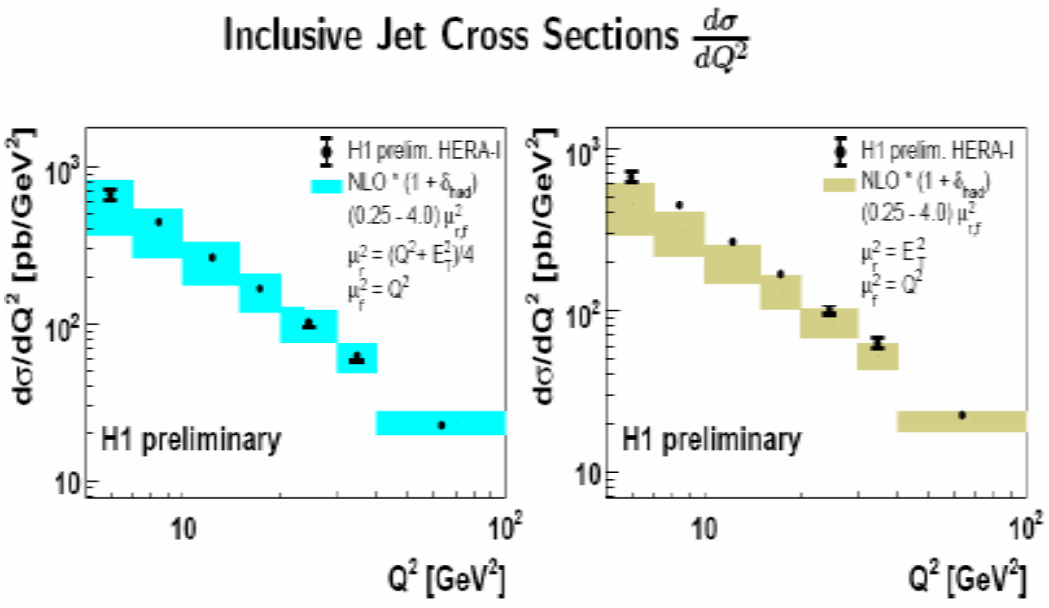
- ZEUS measurement of jets in CC DIS
- constrain high-x partons from inclusive jets
- also measured 2j, 3j, evidence for 4j



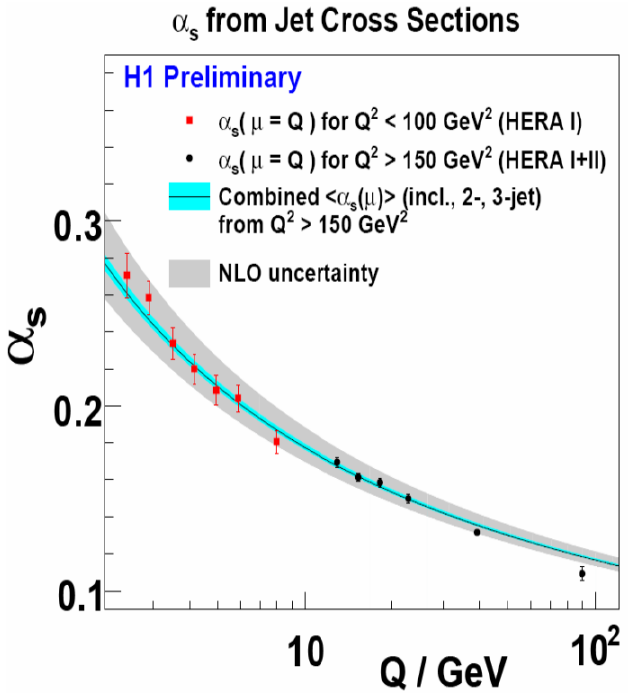


Theedt

Precision Physics with Jets



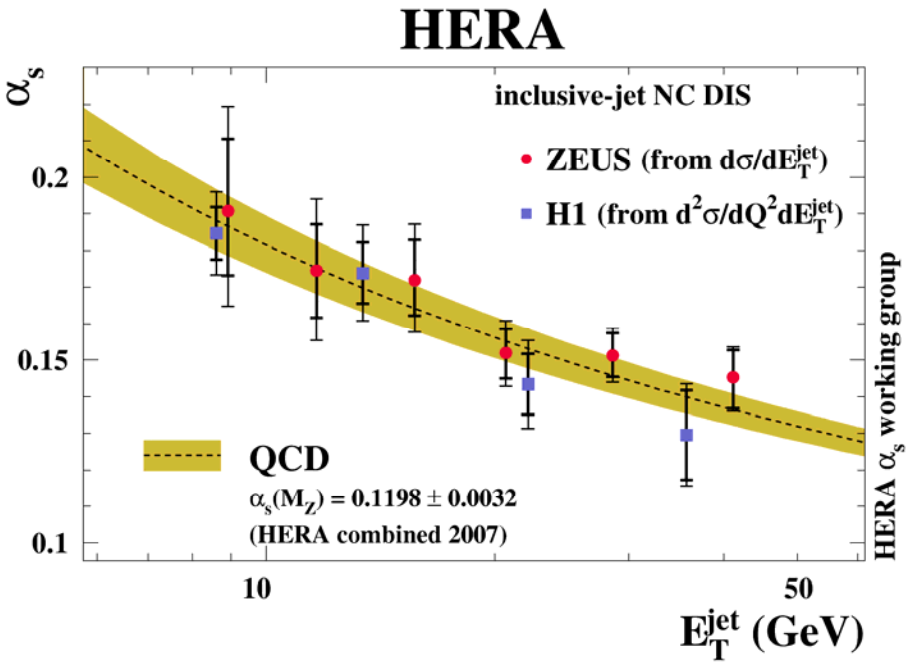
Gouzevitch



- measured DIS cross sections for: 2j, 3j, incl. jets
- $\alpha_s = 0.1182 \pm 0.0008\,(exp) \pm 0.0041(th) \pm 0.0018\,(pdf)$
- error dominated by NLO theory, need NNLO

Precision Physics with Jets

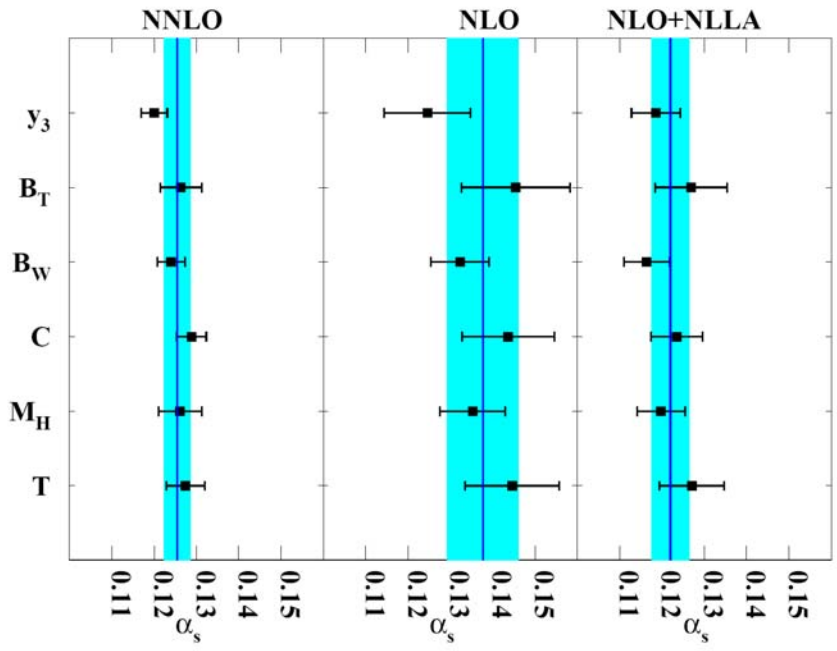
- new combined determination of strong coupling by H1+ZEUS
- use data on inclusive jet cross section
- theory error using uncertainty band method
- at present: only two data samples included
  $\alpha_s(M_Z)=0.1198\pm0.0019\pm0.0026$
- more to follow



Kluge

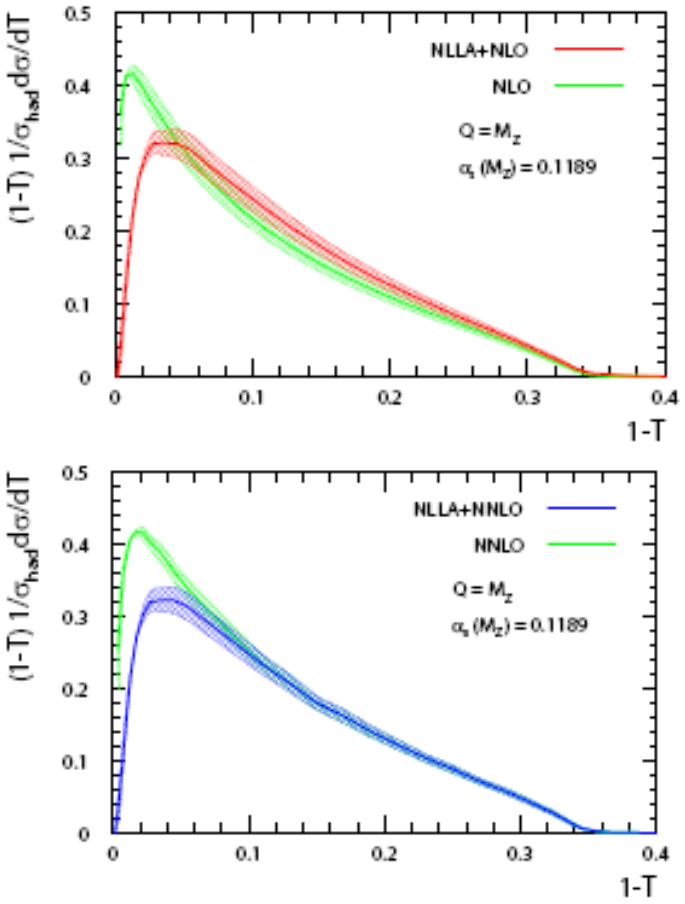
Precision Physics with Jets

- Calculation of NNLO QCD corrections to event shapes at LEP completed recently
- Considerably improved consistency between different shapes
- Reduced scale dependence
- Extract strong coupling constant:
  $\alpha_s(M_Z)=0.1240 \pm 0.0033$
- Still dominated by theory uncertainty



Stenzel

Precision Physics with Jets

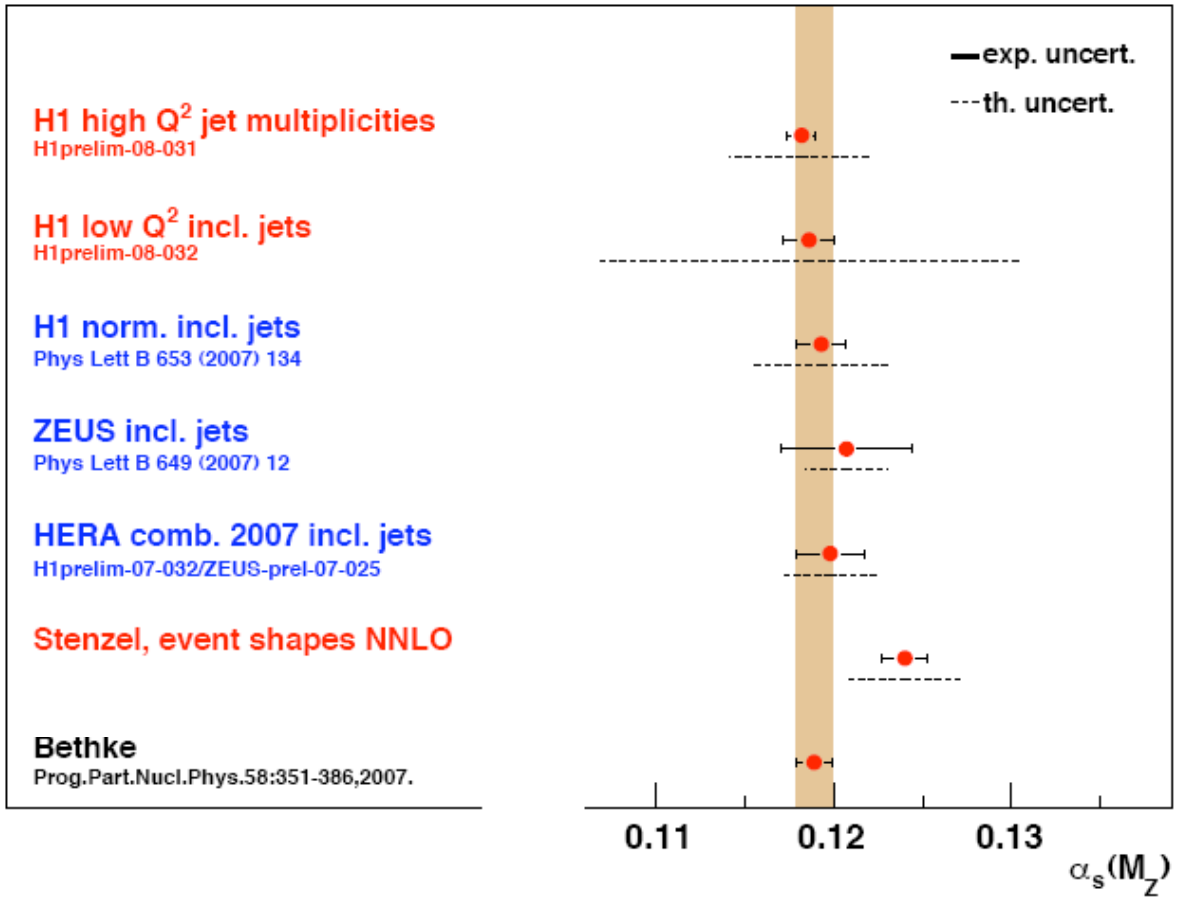


Luisoni

Matching NNLO+resummation

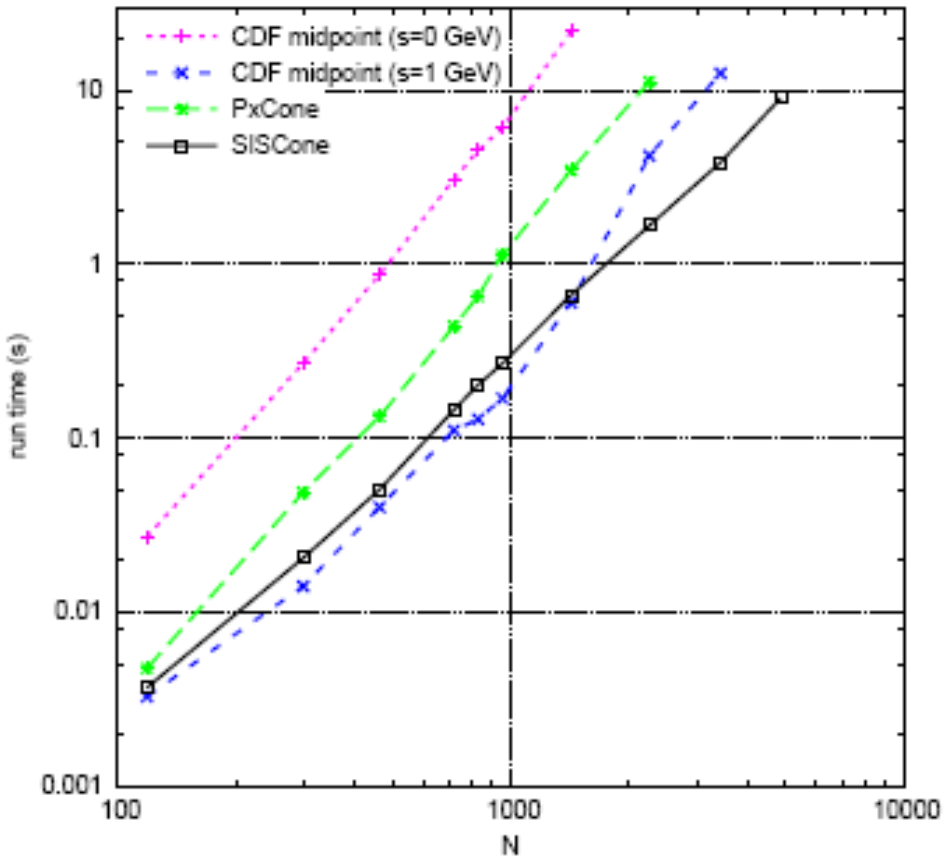
- derived to NLL for all shapes
- small effect in three-jet region
- in progress: new determination of strong coupling constant

Precision Physics with Jets



α_s at DIS 2008

Improved Jet Algorithms



Soyez, Rojo-Cachon

New developments

- ensure infrared safety
- provide numerical efficiency

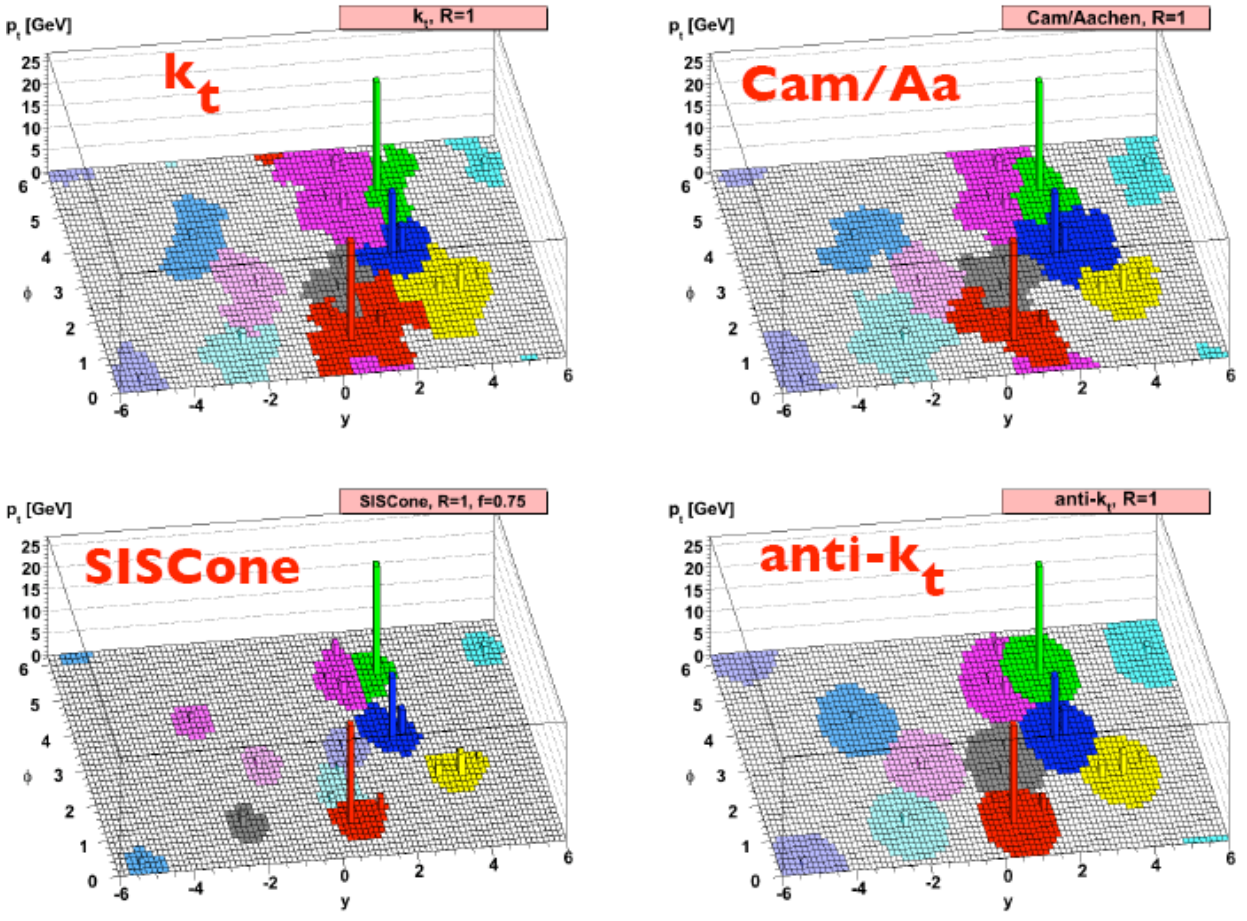
- Seedless Cone (SISCone)
- Fast k_T implementation
- Anti-k_T algorithm (p = -1)

$$d_{ij} = \min(k_{t,i}^{2p}, k_{t,j}^{2p}) \ (\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2)$$

Improved Jet Algorithms

Jet Areas

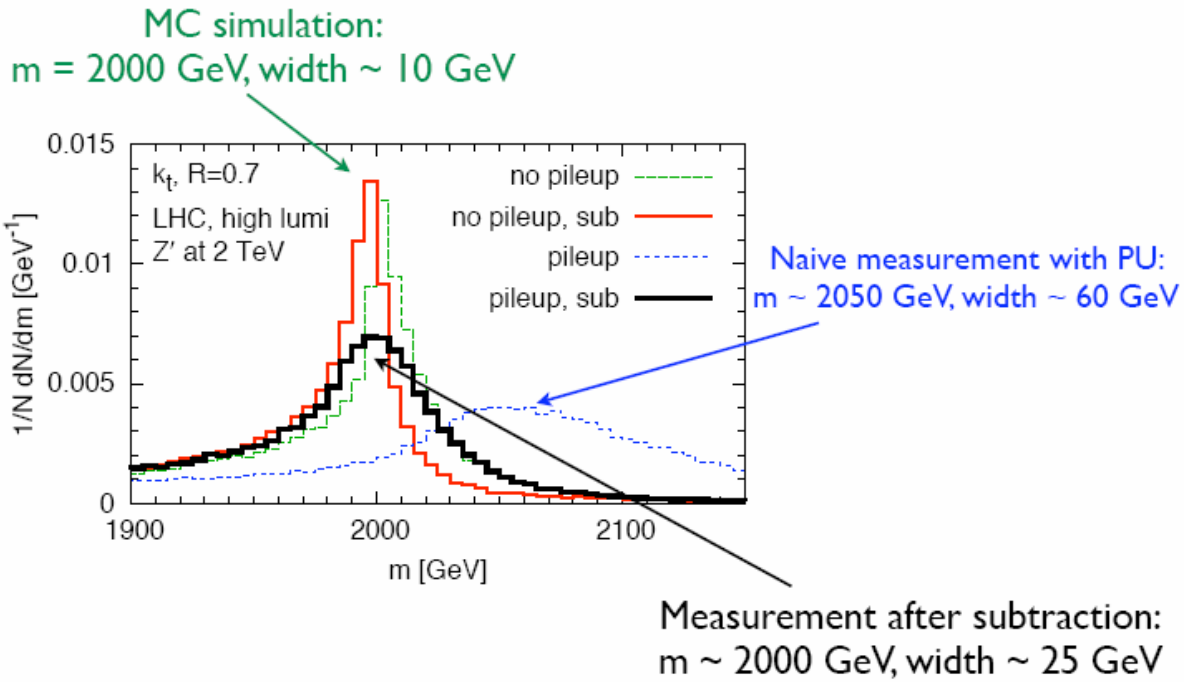
- include zero-energy ghost particles in clustering
- passive area: mimics pointlike radiation
- active area: mimics pileup and underlying event



Cacciari

Improved Jet Algorithms

Use jet area to disentangle hard and underlying processes



Instead of a Summary of the Summary

Many thanks to all participants of the working group for great talks and lively discussions