Measurement of Hadron Production in DIS

on behalf of the H1 Collaboration

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• inclusive charged particle spectra in DIS
• strange particle spectra in DIS
• comparison to pp
Introduction

- measurement of hadron production in DIS constrain
  - at small $p_t$:
    hadronization parameters, also for strange particles
  - at large $p_t$:
    parton evolution
- measurement of hadron production in pp constrain
  - hadronization
  - but also multiparton interaction and UE parameters
Charged particle spectra in DIS

- **kinematic range:**  $ep \rightarrow e' X$
  - $e : 26.7 \text{ GeV}$; $p : 920 \text{ GeV}$; $\sqrt{s} = 319 \text{ GeV}$
  - $5 < Q^2 < 100 \text{ GeV}$
  - $0.05 < y < 0.6$
  - $0.0001 < x_{bj} < 0.01$

- **tracks**  $-2 < \eta < 2.5$, $p_t > 0.150$ (0.5) GeV in lab-frame

- **measurement in hadronic center-of-mass frame:**
  - $\eta^*$ and $p_t^*$
  - $\eta^* < 0$: target (p-remnant) hemisphere
  - $\eta^* > 0$: $\gamma$ - hemisphere
  - central: $0 < \eta^* < 1.5$
  - current: $1.5 < \eta^* < 5$
Charged particle spectra in DIS

- at small $p_t^*$: ~ flat plateau
  - hadronization → described by MC
- at large $p_t^*$: rising towards photon (hard scale)
  - parton shower cascade → not described by MC
  - small dependence on parton densities

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charged particle spectra in DIS

- dependence on hadronization parameters
  - at small $p_t^*$:
    - hadronization is important: sensitivity to tune
  - at large $p_t^*$:
    - hadronization plays little role
Charged particle spectra in DIS

- dependence on parton shower model:
  - RAPGAP: virtuality ordered collinear PS (a la PYTHIA/LEPTO)
  - DJANGOH: PS from Color Dipole Model (ARIADNE)
  - HERWIG++: angular ordered collinear PS
  - CASCADE: angular ordered small-x improved CCFM PS

→ for $p_t^* < 1$ GeV
  → small sensitivity on PS (except CASCADE) → sensitive to hadronization

→ for $p_t^* > 1$ GeV
  → collinear parton shower (RAPGAP & HERWIG++) below data
  → Color Dipole Model best
  → small x improved CCFM shower to high
charged particle spectra in bins of $Q^2$ and $x$

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- at small $p^*_{t} < 1$ GeV
  - plateau at $\sim 1.6 - 2.0$ particles independent of $Q^2$
  - plateau size shrinks with increasing $Q^2$
  - “all” models describe measurements (except CASCADE)
charged particle spectra in bins of $Q^2$ and $x$

- at large $p^*_t > 1$ GeV
  - models with collinear parton shower fail at small $x$ and small $Q^2$, while become better/good at large $Q^2$
  - small $x$ improved CCFM parton shower is good at small $x$ and small $Q^2$, while fails at larger $Q^2$
- Color Dipole Model is reasonable over full range
charged particle spectra as fct of $p_{t}^{*}$ in bins of $Q^{2}$ and $x$

- spectra fall over 4-5 orders of magnitude at small $x$
- particle spectra as fct of $p_{t}^{*}$ give constraints on hardness of partons in parton shower
  - collinear shower models generate too soft spectra compared to measurement
  - small $x$ improved (CCFM) shower generates hard spectrum → closer to measurement at large $p_{t}^{*}$
- Color Dipole shower is best

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charged particle spectra in 2 regions of \( \eta^* \)

- **\( 0 < \eta^* < 1.5 \):**
  - region sensitive to higher order radiation (parton shower)
  -> data not described by collinear parton shower models

- **\( 1.5 < \eta^* < 5 \):**
  - region sensitive to hard scattering
  -> at large \( p_t^* \) → data significantly larger than collinear shower predictions
$K^0_s$ production in DIS

- mechanisms for strange particle production in DIS:

- dominant production mechanism is hadronization at small $p_t$!
- role of quark mass in hadronization process!
- phase space: $e p \rightarrow e' K^0_s X$ at $\sqrt{s} = 319$ GeV
  - $7 < Q^2 < 100$ GeV
  - $0.1 < y < 0.6$
  - $0.5 < p_t < 3.5$
  - $-1.3 < \eta < 1.3$

$\rightarrow$ measure: $K^0_s \rightarrow \pi^+ \pi^-$
$K^0_s$ cross sections

- $K^0_s$ cross section as function of $(Q^2$ and) $\eta_K$ reasonably well described in shape
- small normalization difference with $\lambda_s = 0.286$ (LEP–ALEPH tune) strangeness suppression factor

- $K^0_s$ cross section as function of $p_T$ is not well described by simulation: independent of $\lambda_s$
$K^0_s$ to inclusive charged particle ratio

- ratio as function of $\eta$
  - reasonably well described in shape
  - well described in rate for $\lambda_s = 0.286$

- ratio as function of $p_T$
  - NOT well described in shape independent of $\lambda_s$

- ratio of $K^0_s$ production to $\pi$ production increases sensitivity to strangeness suppression, since some model uncertainties cancel
Λ baryon production in DIS at large $Q^2$

- phase space:
  - $145 < Q^2 < 20000 \text{ GeV}$
  - $0.2 < y < 0.6$
  - $p_t > 0.3 \text{ GeV}$
  - $-1.5 < \eta < 1.5$

→ reasonable description of data with models
→ some dependence on $\lambda_8$
\( \Lambda \) to DIS ratio

- \( \Lambda_s \) production shows similar \( Q^2 \) and \( x \) dependence as inclusive DIS
  - shape reasonably well reproduced by models
  - rate is sensitive to \( \lambda_s \)
- different \( \lambda_s (=0.220) \) as compared to small \( Q^2 \) and \( K^0_s \) (\( \lambda_s =0.286 \)) preferred
strange/charged particle ratio in UE in pp

- $d\eta/d\eta$ for inclusive particle production is described by special min-bias tune
  - models are off by 30% in $K^0_s$ and 50% in $\Lambda$ production
  - more than in DIS!

- measurement of strangeness production in transverse region to jets in pp:
  - small deficit in $K^0_s$ but significant deficit in $\Lambda$ production $\rightarrow$ tune!
  - transverse region is sensitive to multiparton interactions but also to parton shower
Conclusion

- charged particle spectra in DIS give important information of
  - hadronization at small $p_t$
    - inclusive spectra at small $p_t$ are reasonably well described with hadronization parameters obtained from LEP
  - higher order contributions (parton shower) at larger $p_t$
    - collinear parton shower models fail to describe “large” $p_t$ tail
    - small $x$ improved parton shower comes closer to data at small $x$
- strange particle production in DIS:
  - spectra of $K^0_s$ are reasonably well described using strangeness suppression $\lambda_s$ factor from LEP
  - spectra for $\Lambda$ prefers smaller $\lambda_s$ than for $K^0_s$
- DIS spectra provide a crucial test for hadronization and parton shower models: → no contribution from multiparton interactions!
  - note: inclusive particle spectra and strangeness production in pp involve more components....