Comparison of Model Predictions to LHC Data

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Hadron-Hadron and Cosmic-Ray Interactions at Multi-TeV Energies

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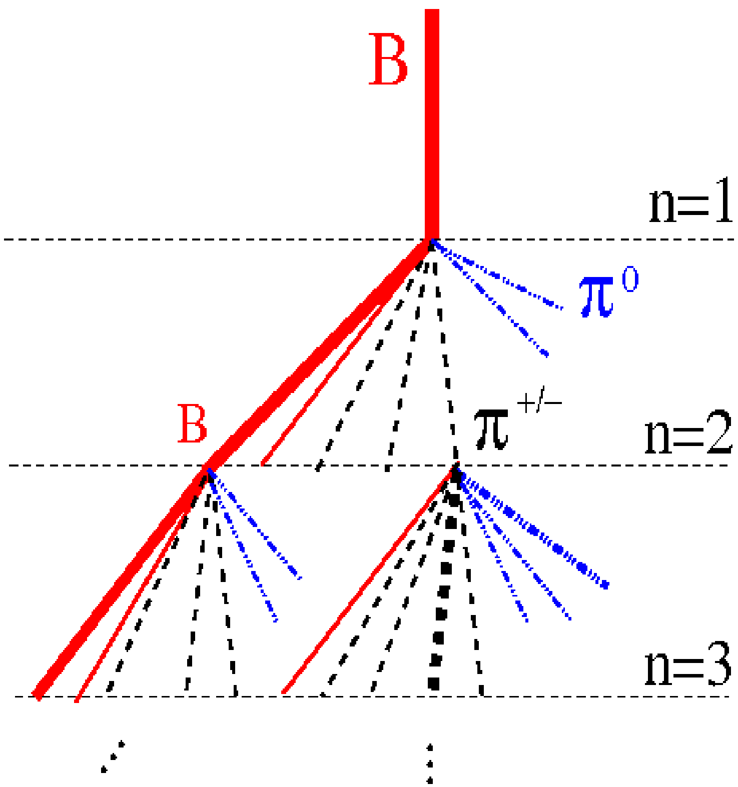
Outline

- **Hadronic Interaction Models for Cosmic Rays**
  - Models
  - Properties
- **Comparison to pre-LHC data**
  - Cross section
  - Multiplicity
  - Spectra
- **Comparison to available min bias LHC data**
  - CMS, ALICE, LHCb, ATLAS, ...

Air Shower Simulation



Thickness = amount of energy

- **Hadronic models for simulations :**
  - mainly soft physics + diffraction (forward region)
  - should handle p-, π-Air, K-Air and A-Air interactions
  - should be able to run at 10^6 GeV center-of-mass energy
  - models used for EAS analysis :
    - QGSJET01/II
    - SIBYLL 2.1
    - EPOS
    - ...

Hadronic Interaction Models

- **Theoretical basis :**
  - pQCD
  - Gribov-Regge
  - energy conservation

Pb : CR physic dominated by soft interactions

Pb : Gribov-Regge do not take into account energy conservation ...

- **Phenomenology (models) :**
  - string fragmentation
  - diffraction
  - higher order effects

Need Parameters !

- **Comparison with data to fix parameters :**
  - the more parameters, the more data you need

... or ...

  - the more data, the more parameters you need !

Hadronic Interaction Models in CORSIKA

(HDPM)

Old generation : QGSJET01 SIBYLL DPMJET 2 VENUS

All Glauber based

But differences in hard, remnants, diffraction …

semi-hard

soft

NEXUS

Attempt to get everything describe in a consistent way (energy sharing)

New generation : **QGSJET II** (DPMJET III) **EPOS**

Theory ++ :

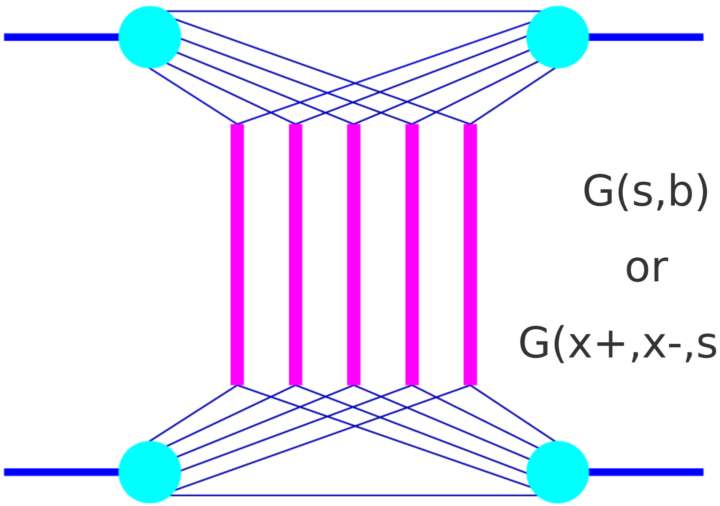
- **Fan diagrams**
- **diffraction**
- **optimized for CR**

Phenomenology ++ :

- **Nuclear effect**
- **High density effect (QGP)**
- **all type of data studied**

Only model used in HEP (SPS, RHIC, LHC)

Differences between Models

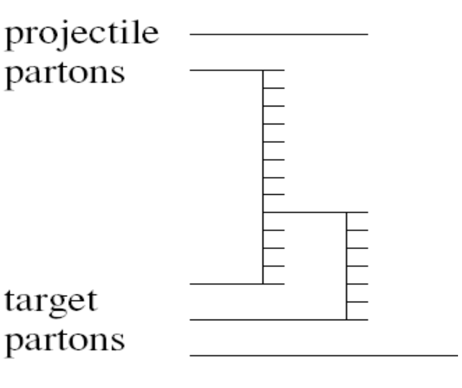


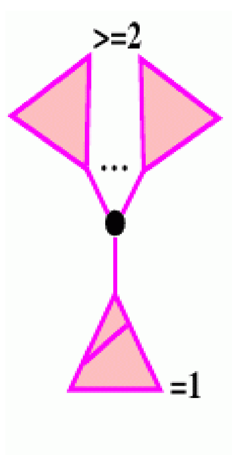
G(s,b)

or

G(x+,x-,s,b)

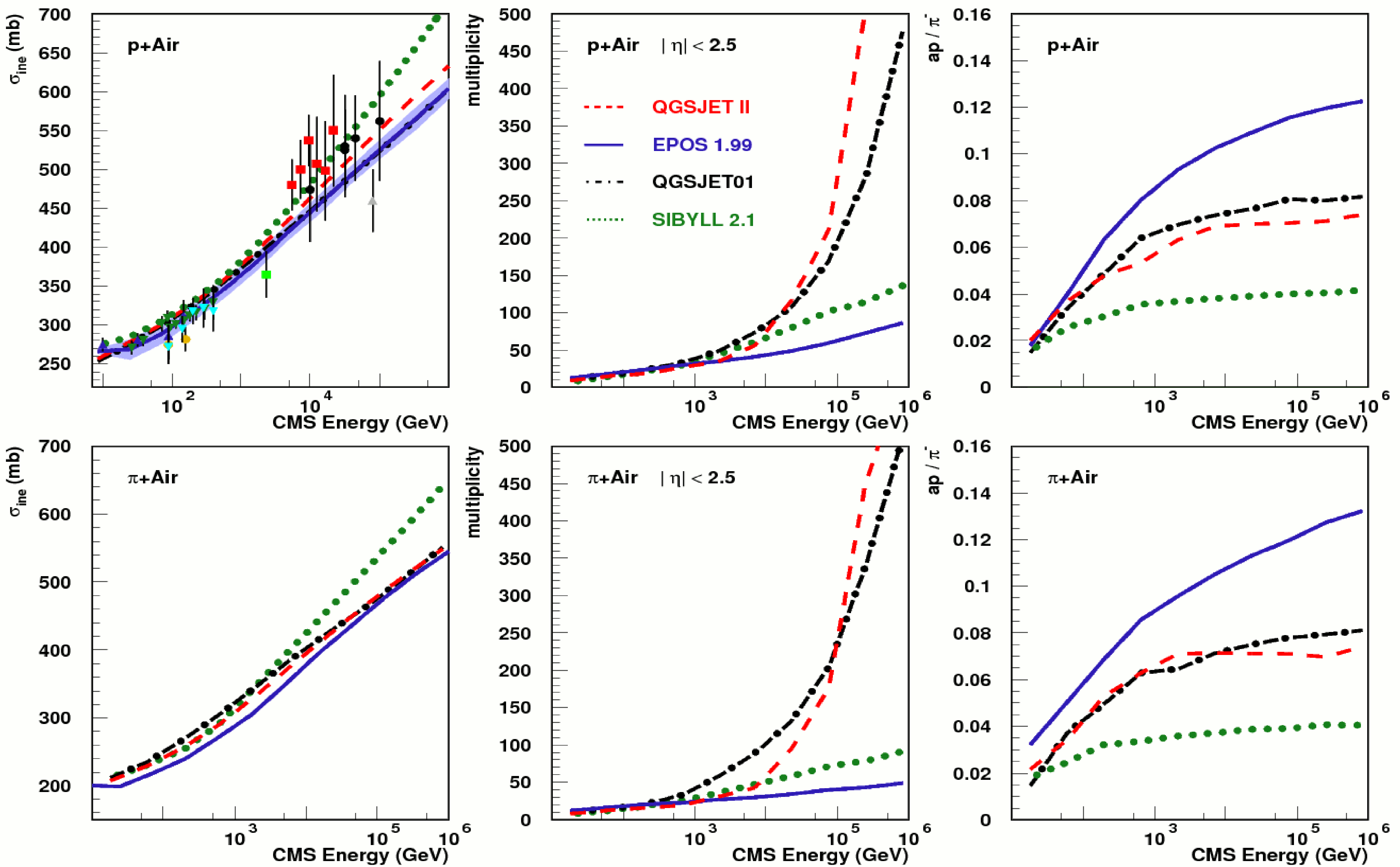
EPOS QGSJET II





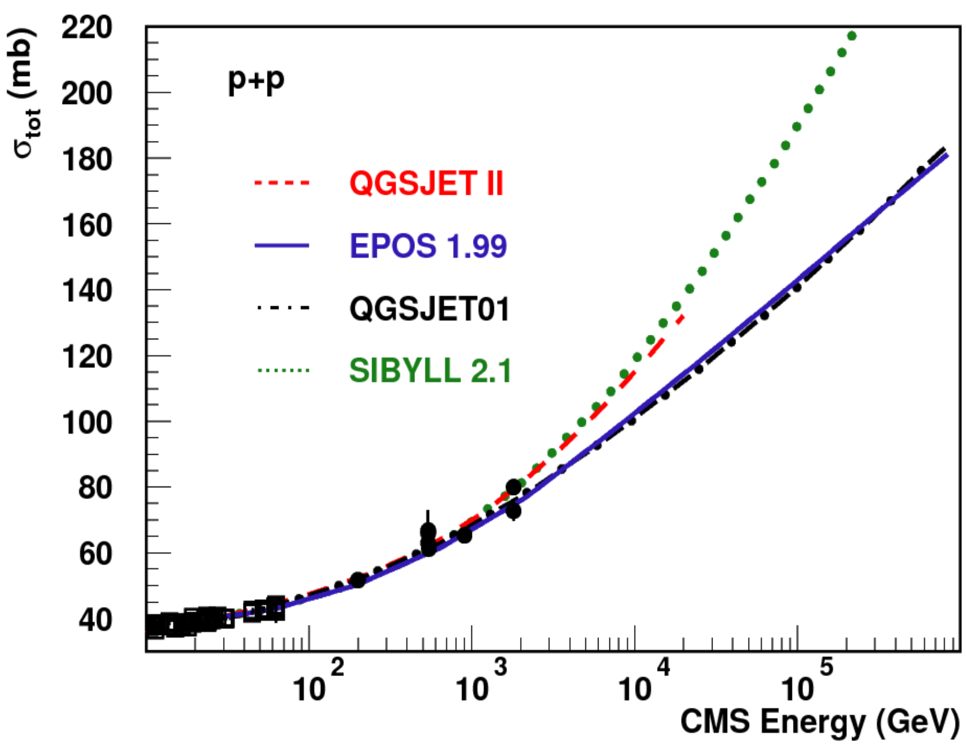
- **Gribov-Regge and optical theorem**
  - ➔ Basis of all models but
    - Classical approach for QGSJET and SIBYLL (no energy conservation for cross section calculation)
    - Parton based Gribov-Regge theory for EPOS (energy conservation at amplitude level)
- **pQCD**
  - ➔ Minijets with cutoff in SIBYLL
  - ➔ Same hard Pomeron (DGLAP convoluted with soft part : not cutoff) in QGS and EPOS but
    - No enhanced diagram in Q01
    - Generalized enhanced diagram in QII
    - Simplified non linear effect in EPOS
      - Phenomenological approach

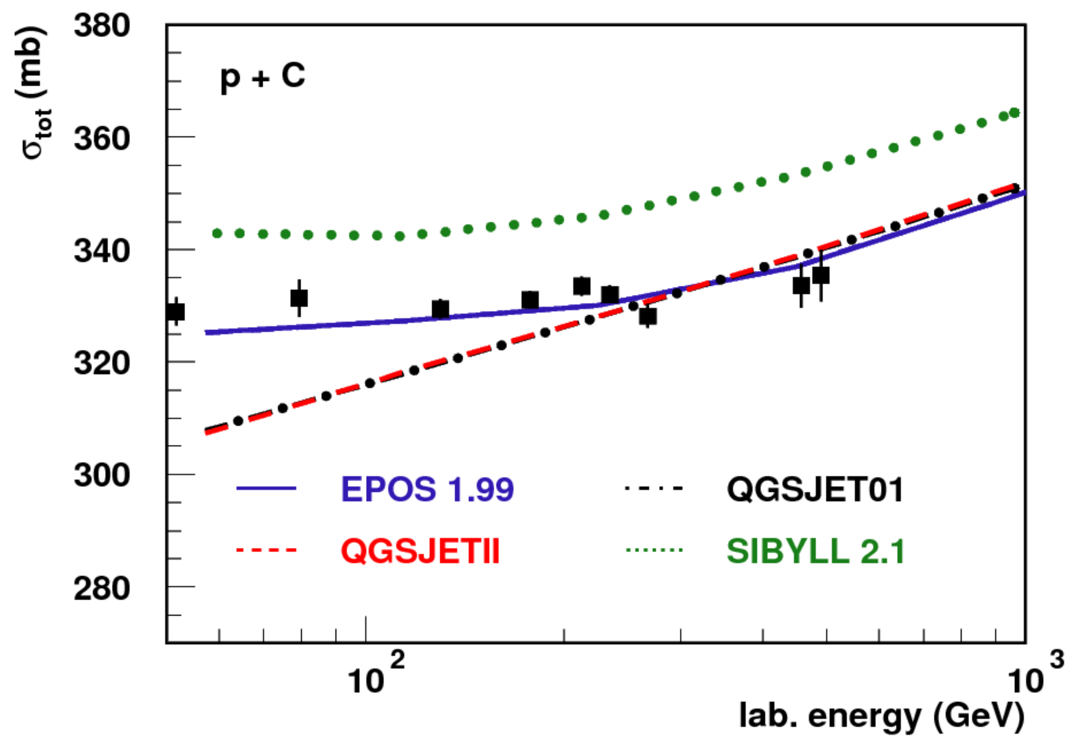
Extrapolations for Air Showers



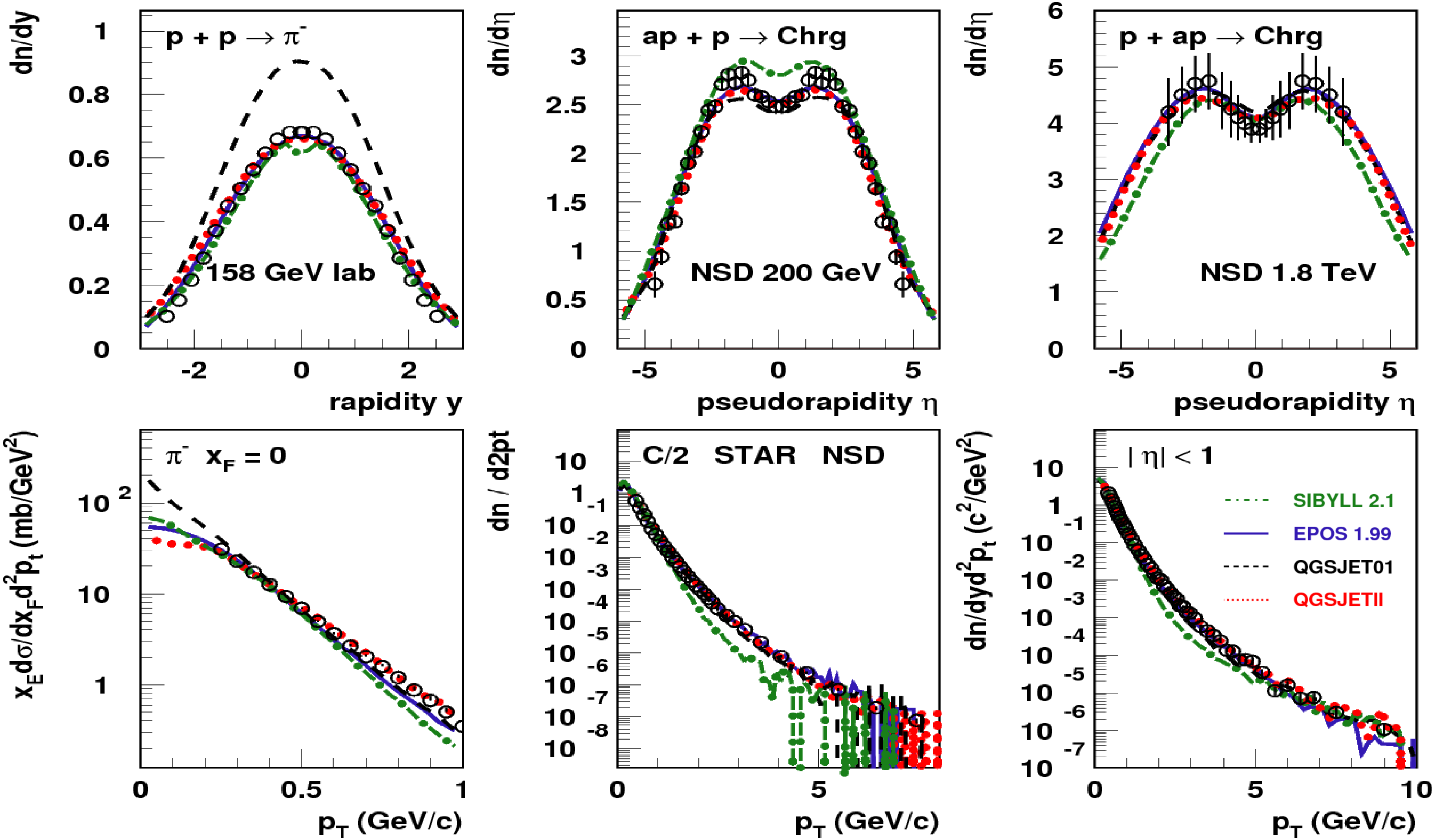
Cross Section

- Same cross section at pp level and low energy (data)
- extrapolation to pA or to high energy
  - different amplitude and scheme : different extrapolations

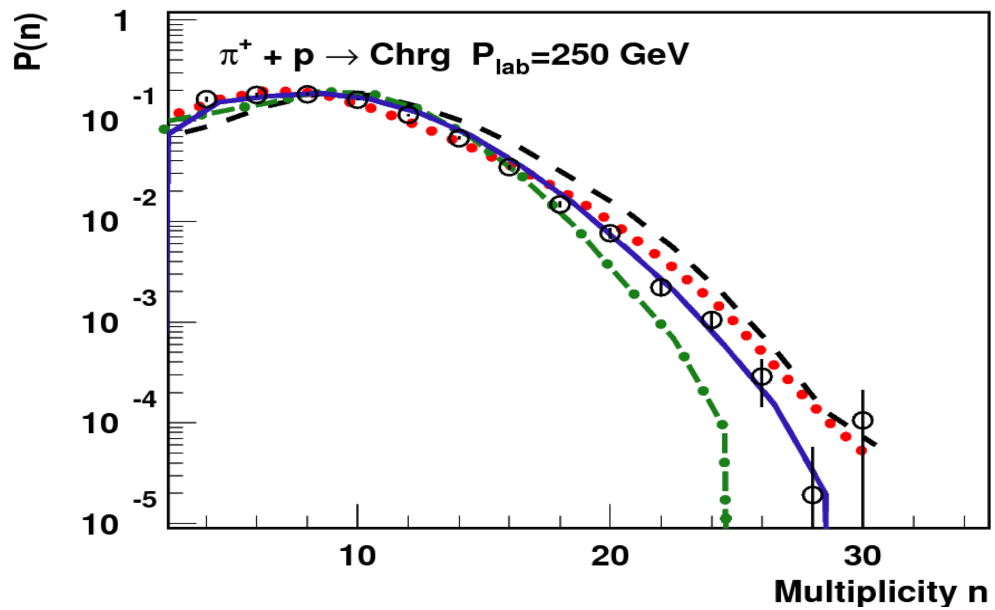




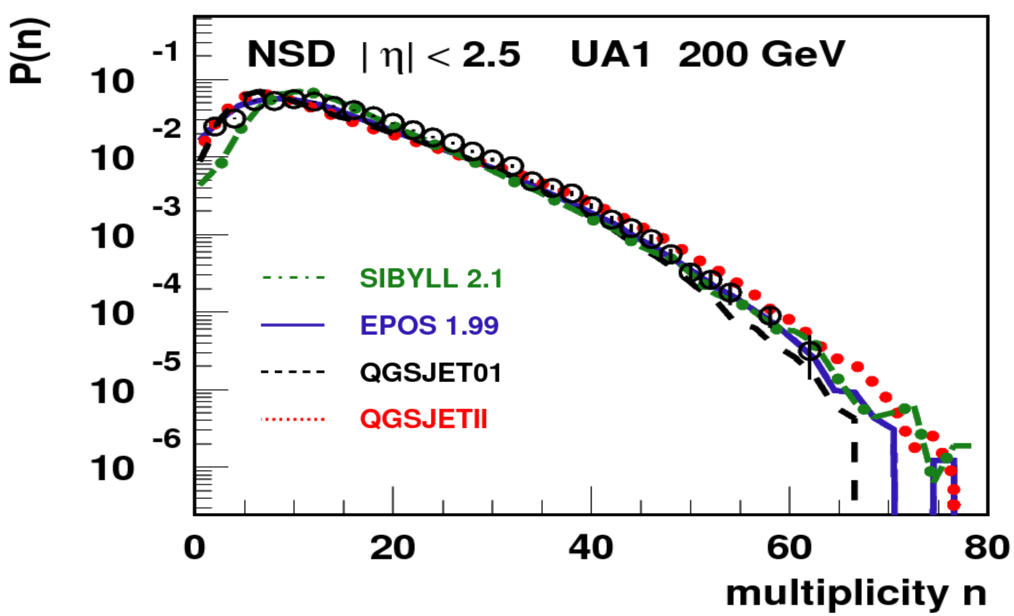
Pseudorapidity and p_T

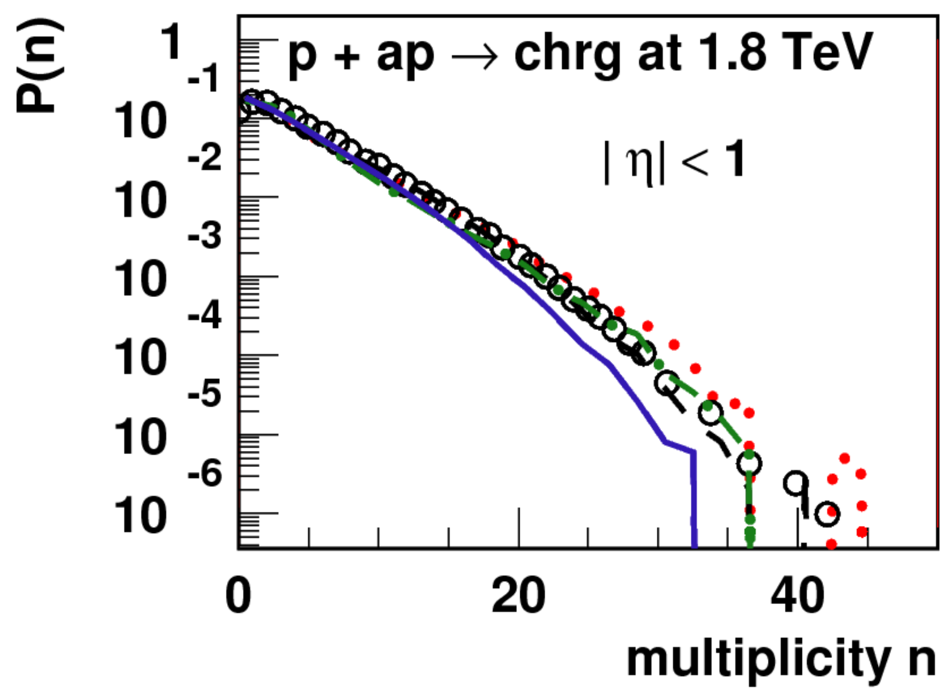


Multiplicity



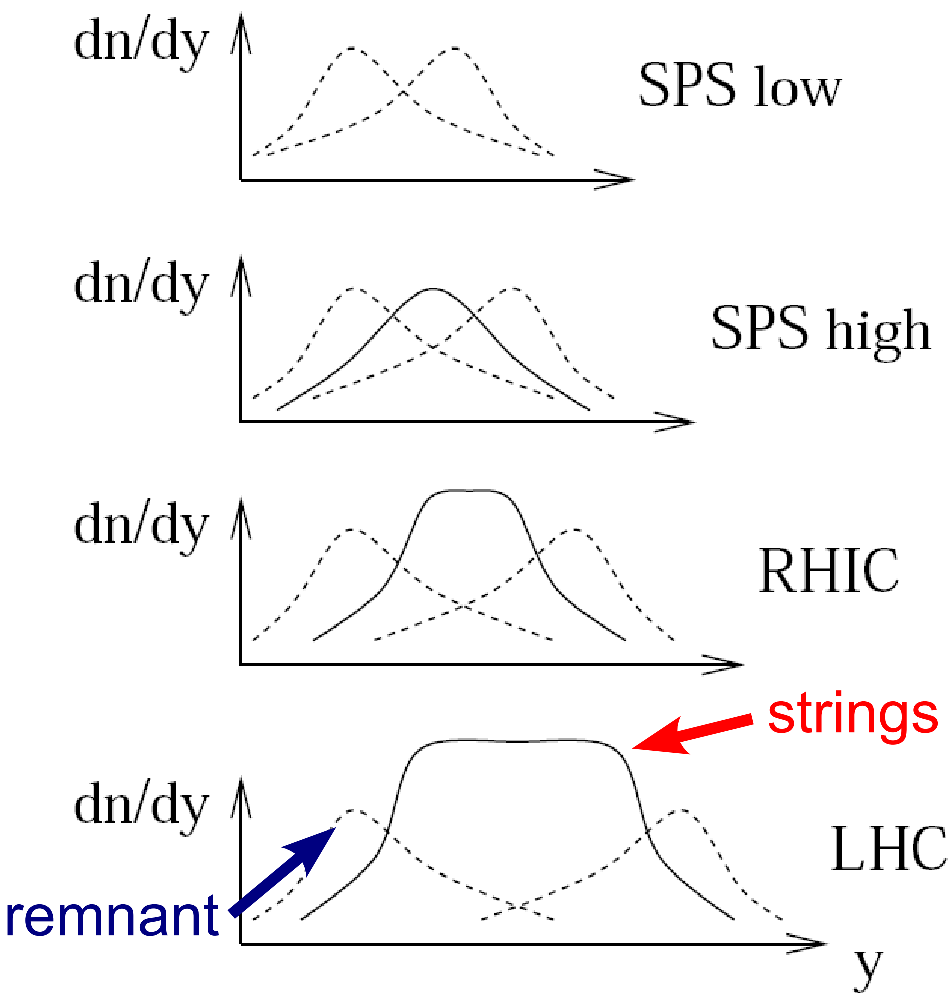
- Shape of distribution correct
- Agreement with existing data





Forward Spectra

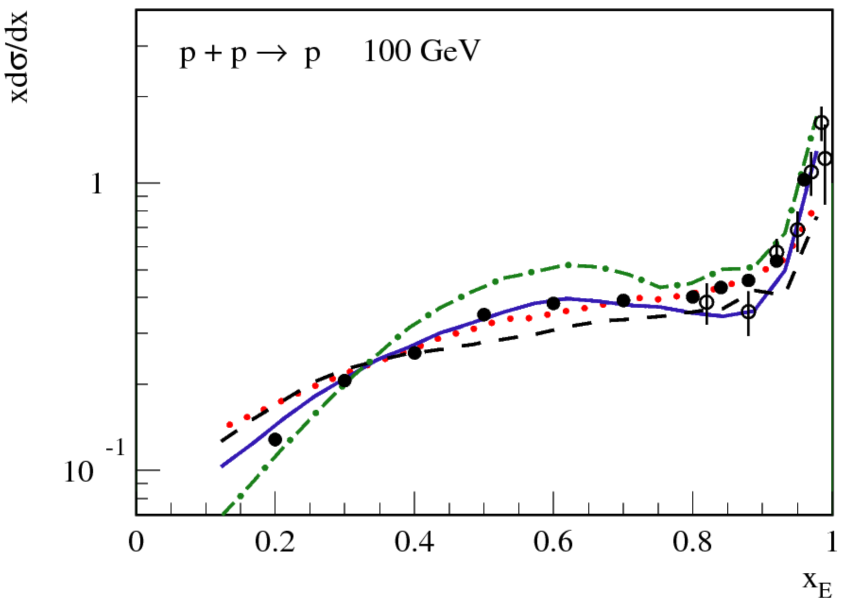
Forward particles mainly from projectile remnant

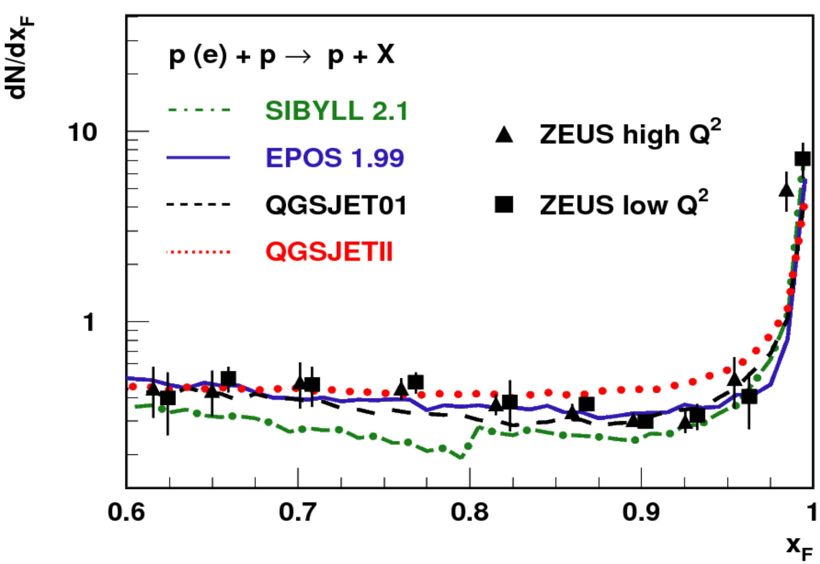


The inelasticity is closely related to diffraction and forward spectra

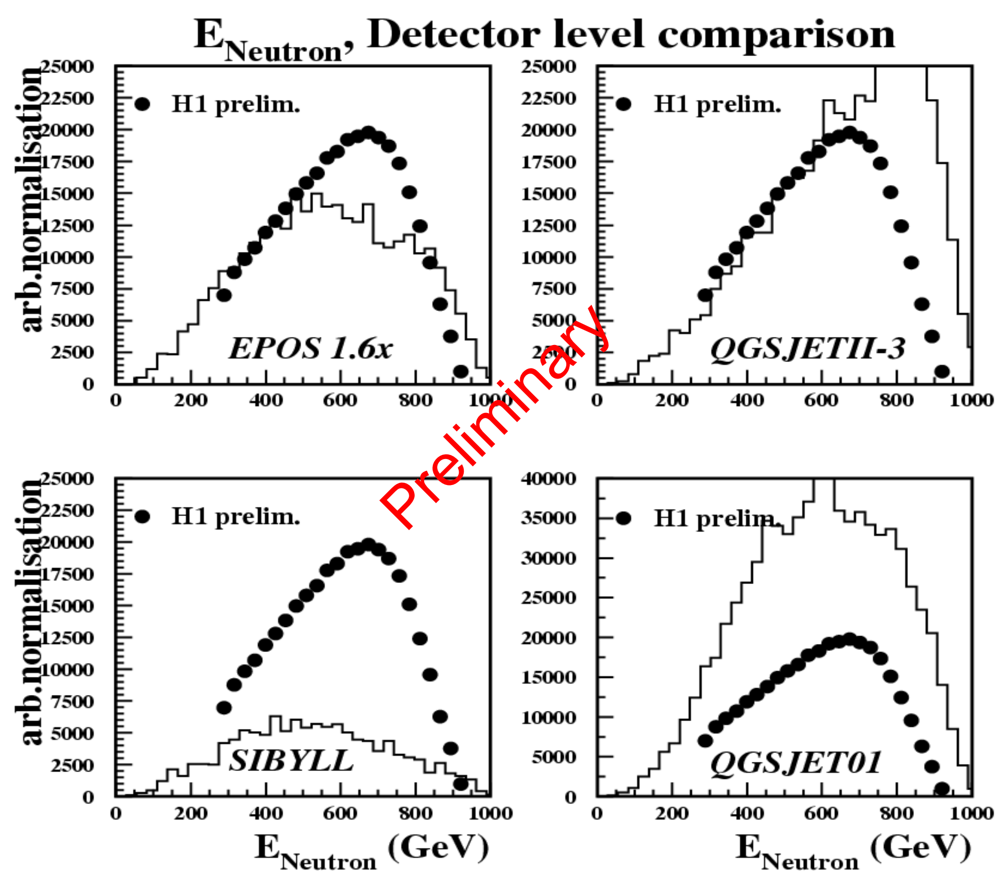
- SIBYLL
  - No remnant except for diffraction
  - Leading particle from string ends
- QGSJET
  - Low mass remnants
  - Low inelasticity at low energy
  - Lot of strings
- EPOS
  - Low and high mass remnants
  - Limited number of strings
  - Special hadronization

Forward Spectra



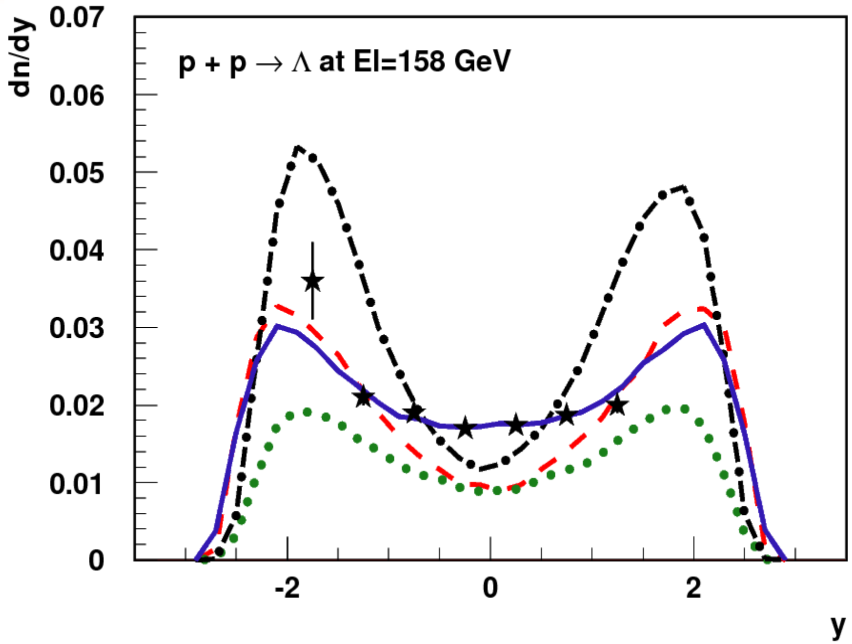


- most of the data at low energy (fixed target experiment)
- extrapolation tested with HERA data

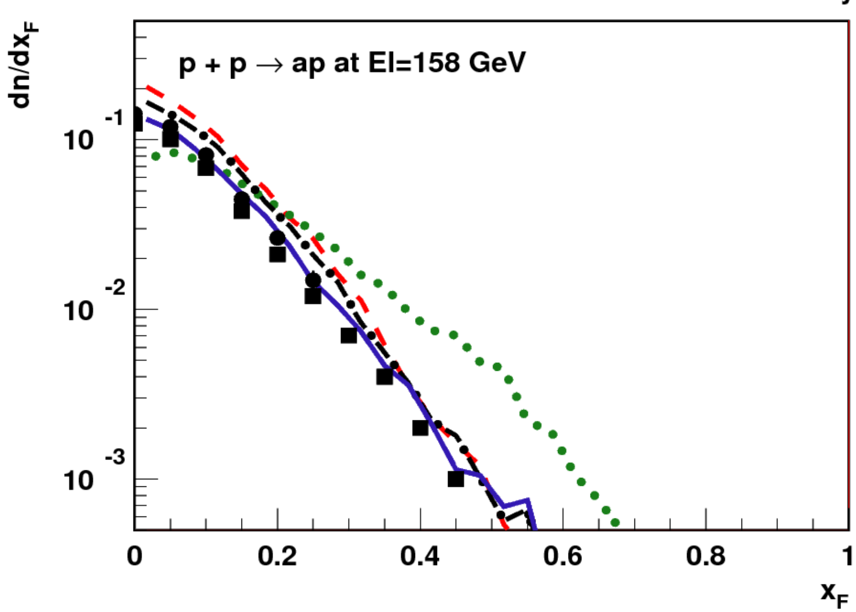


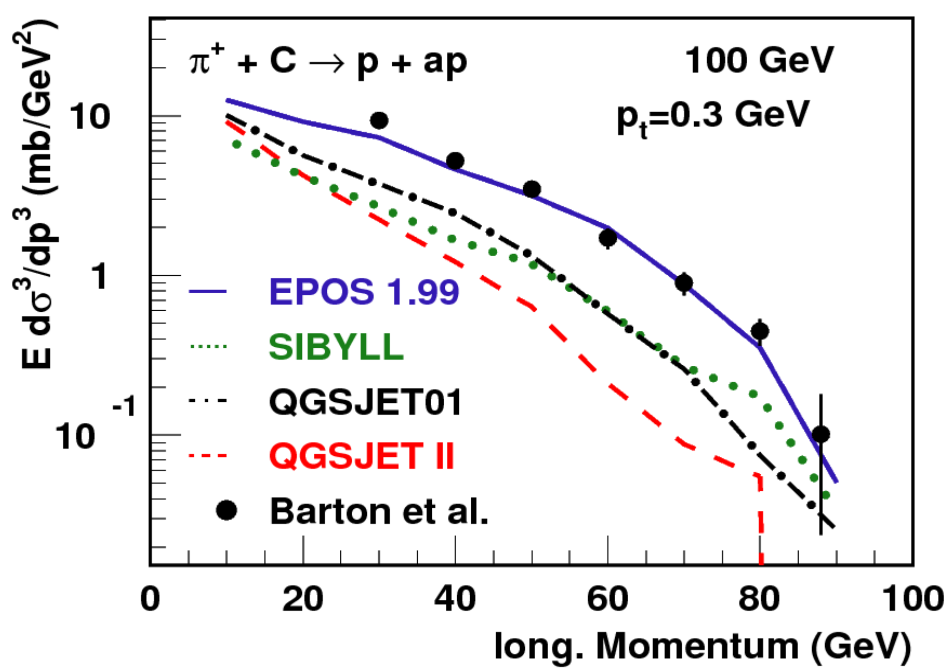
Analysis by A. Bunyatian

Baryon Forward Spectra

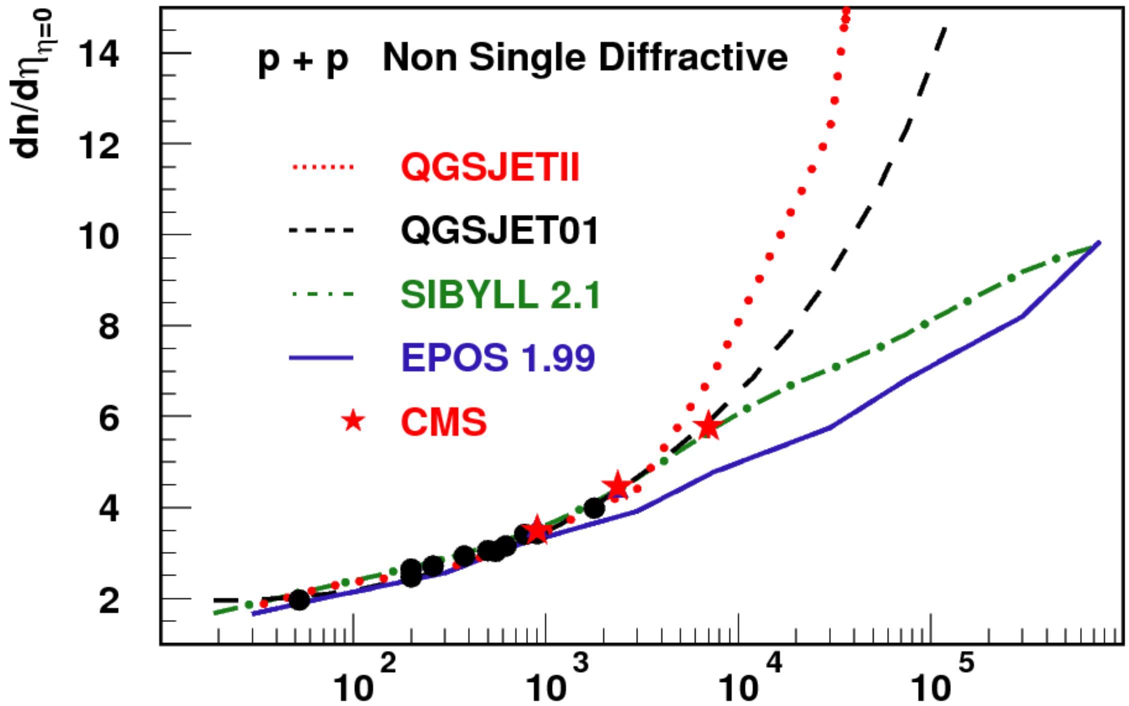


- Large differencies between mod.
- Need a new approach for a complete description (EPOS)
- problem even at low energy
- production most likely energy dependent



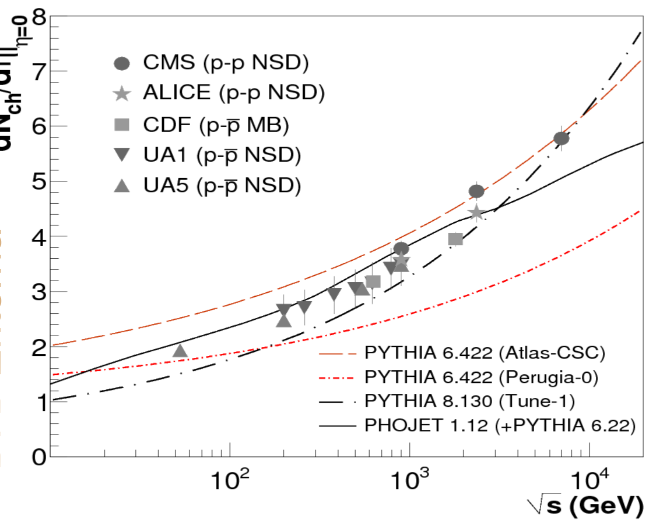


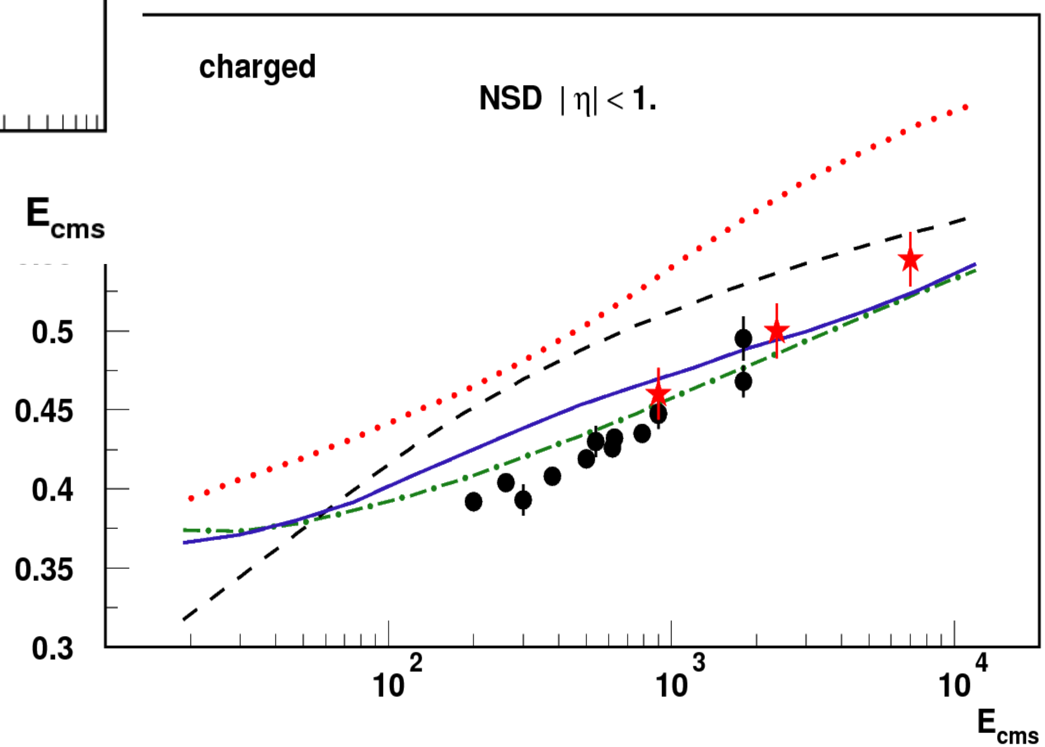
Mean Values



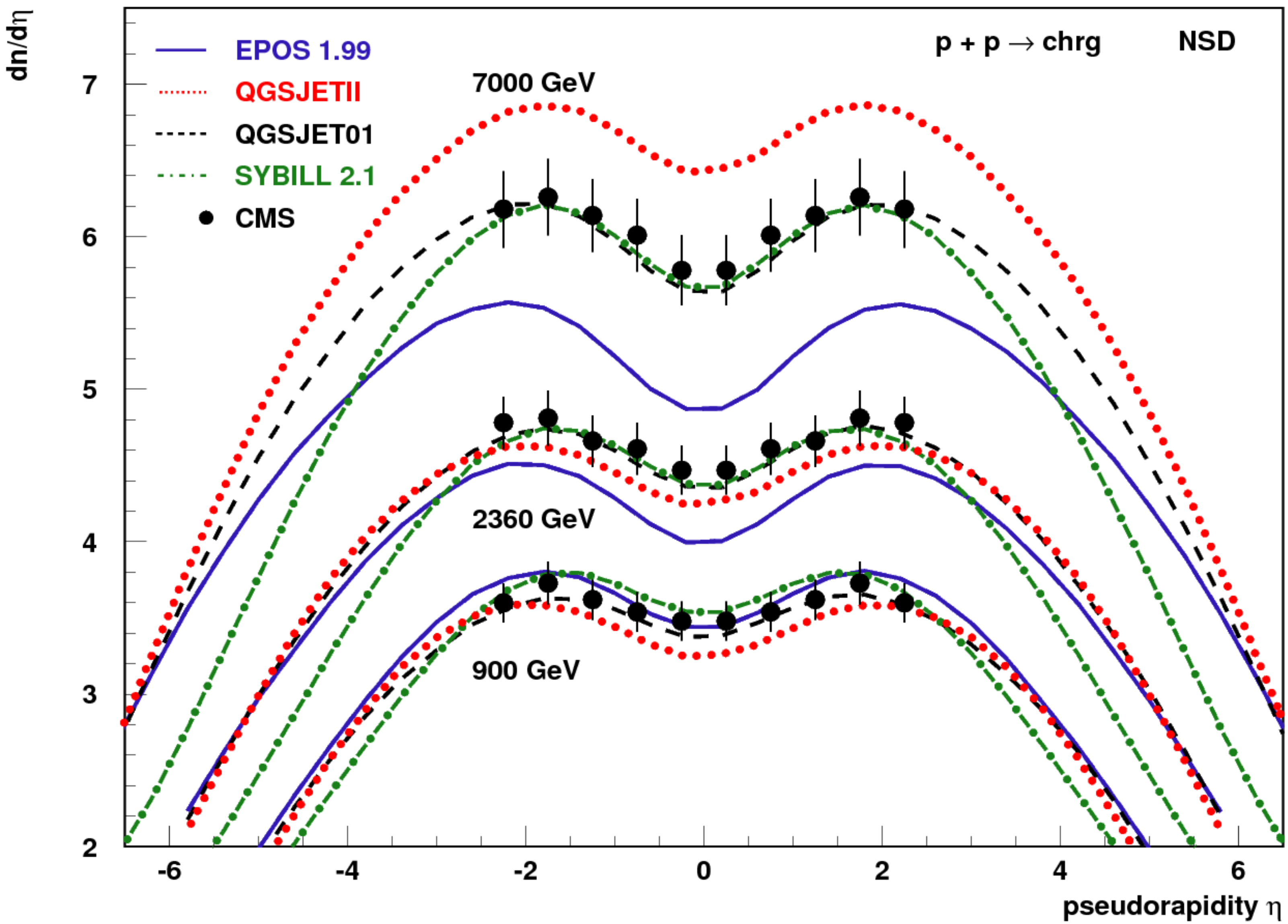
- **Energy dependence**
  - EPOS too low
  - QGSJETII too high
  - “old” models OK !

D. D'Enterria

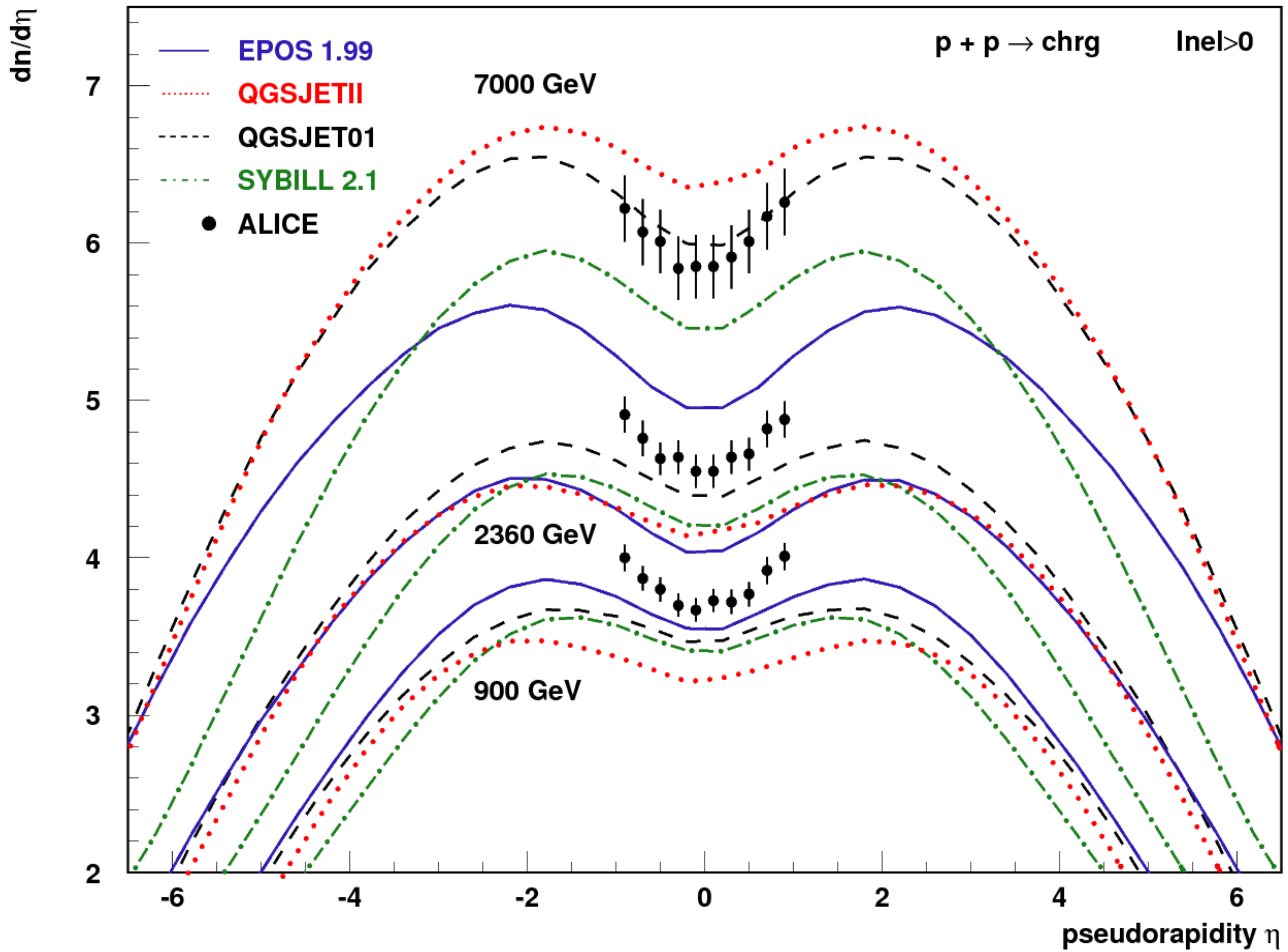




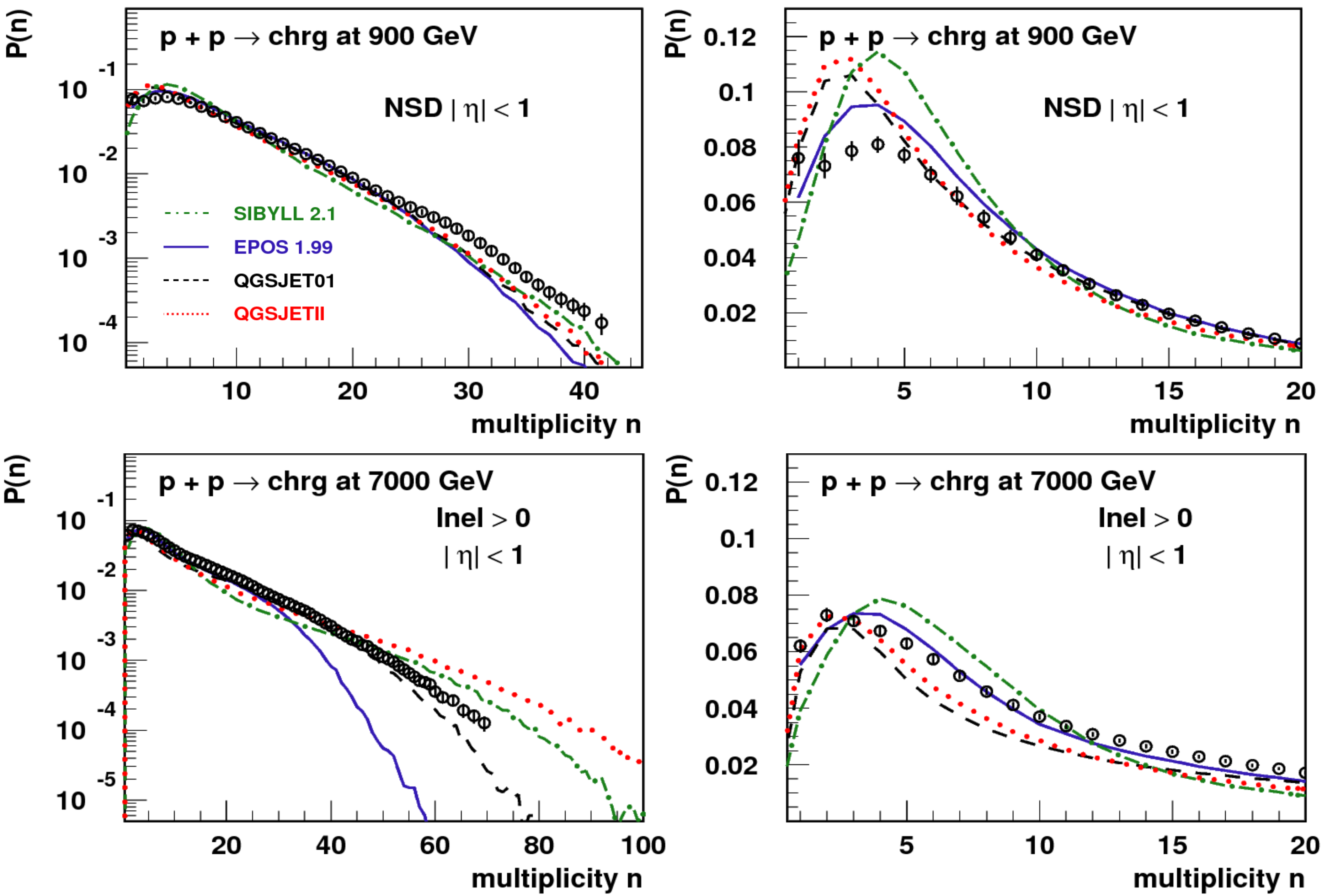
Pseudorapidity NSD CMS



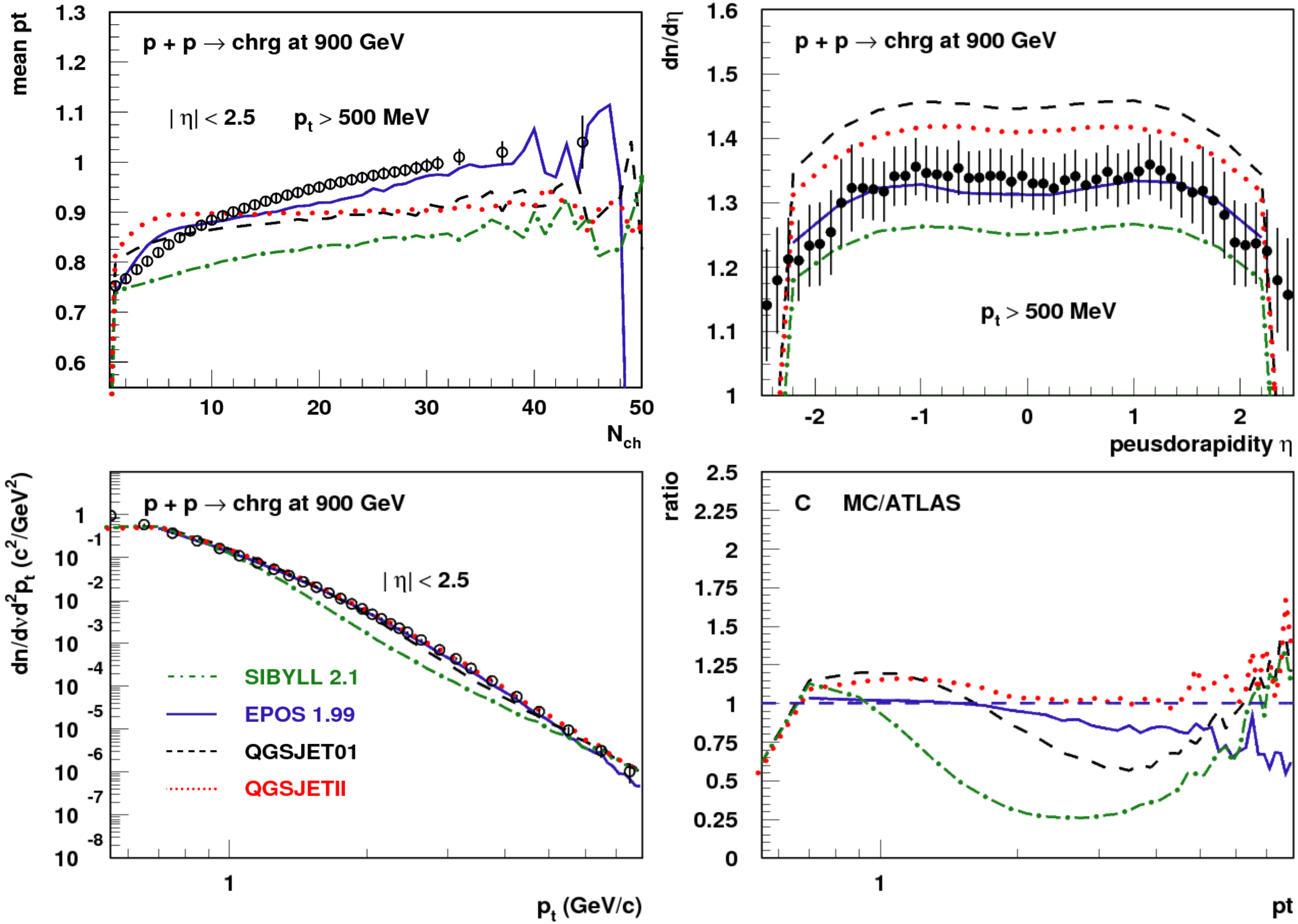
Pseudorapidity ALICE Inel>0



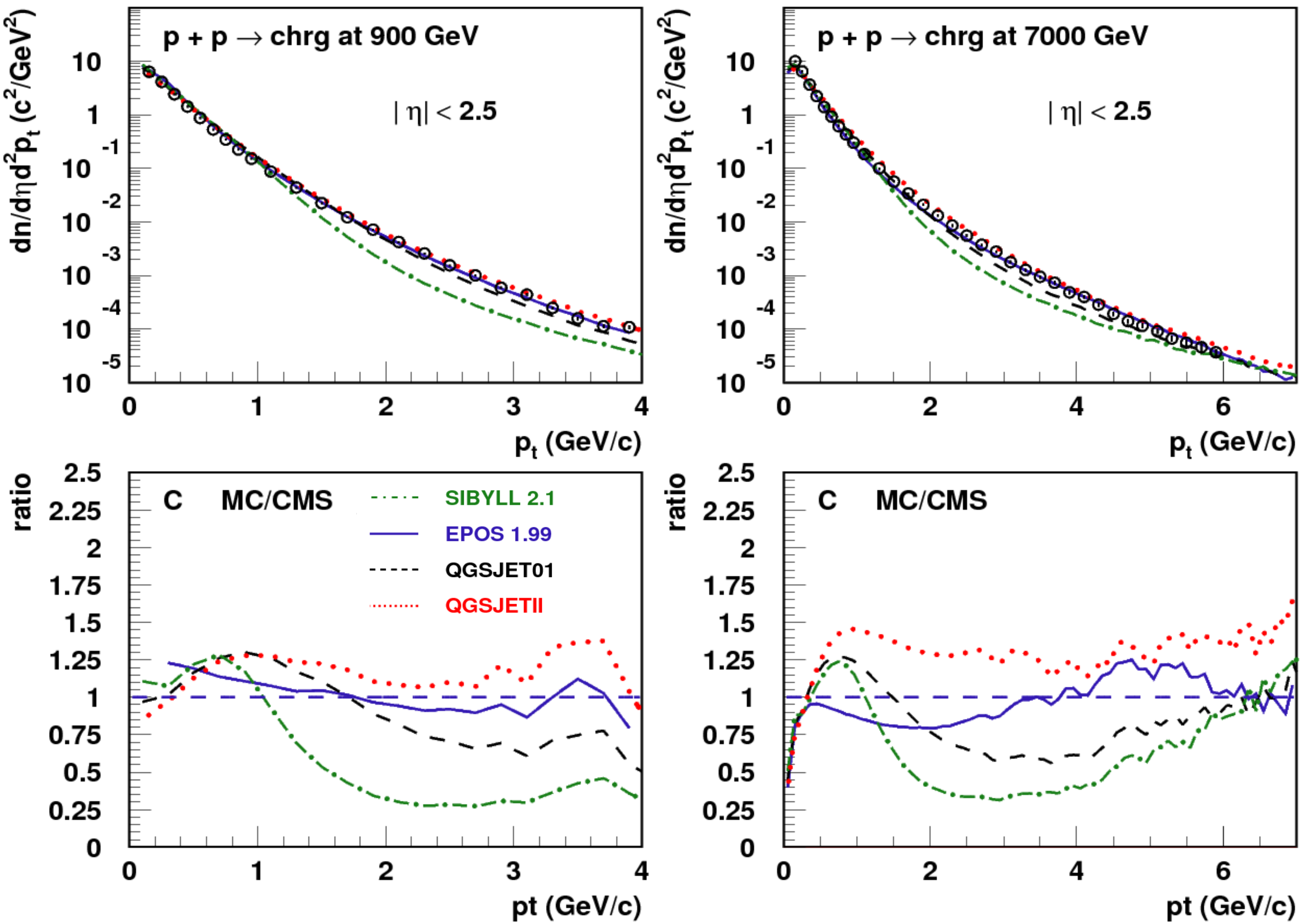
ALICE Multiplicity Distributions



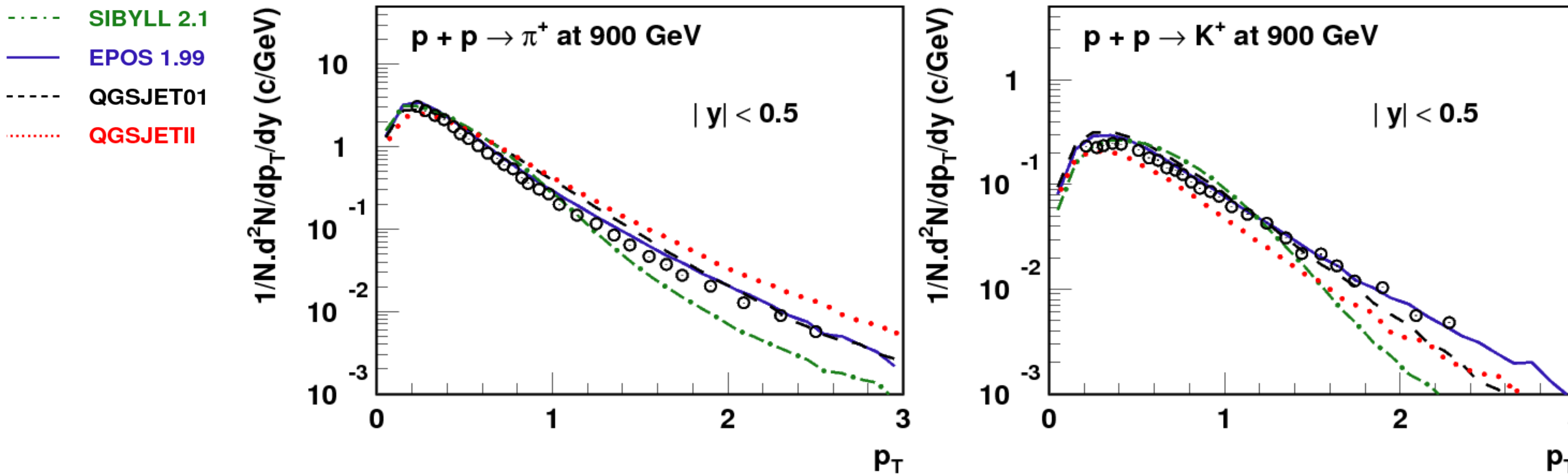
ATLAS Distributions

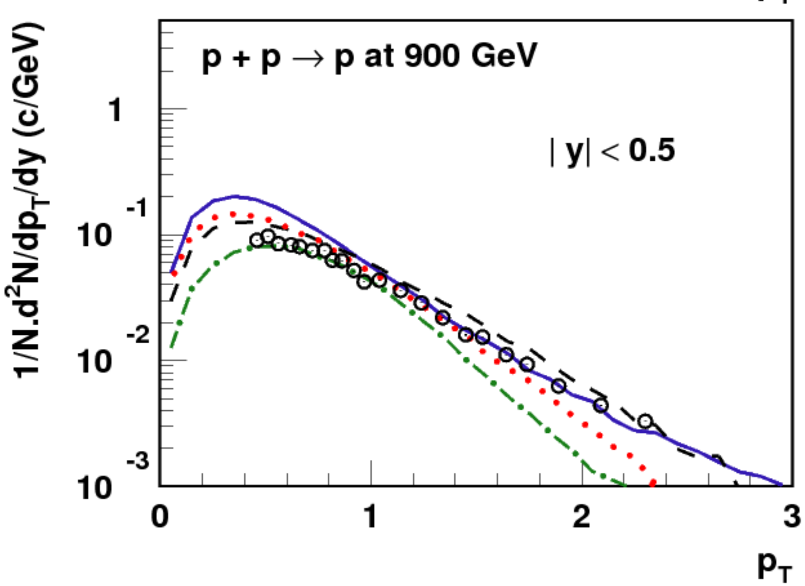


CMS Transverse Momentum



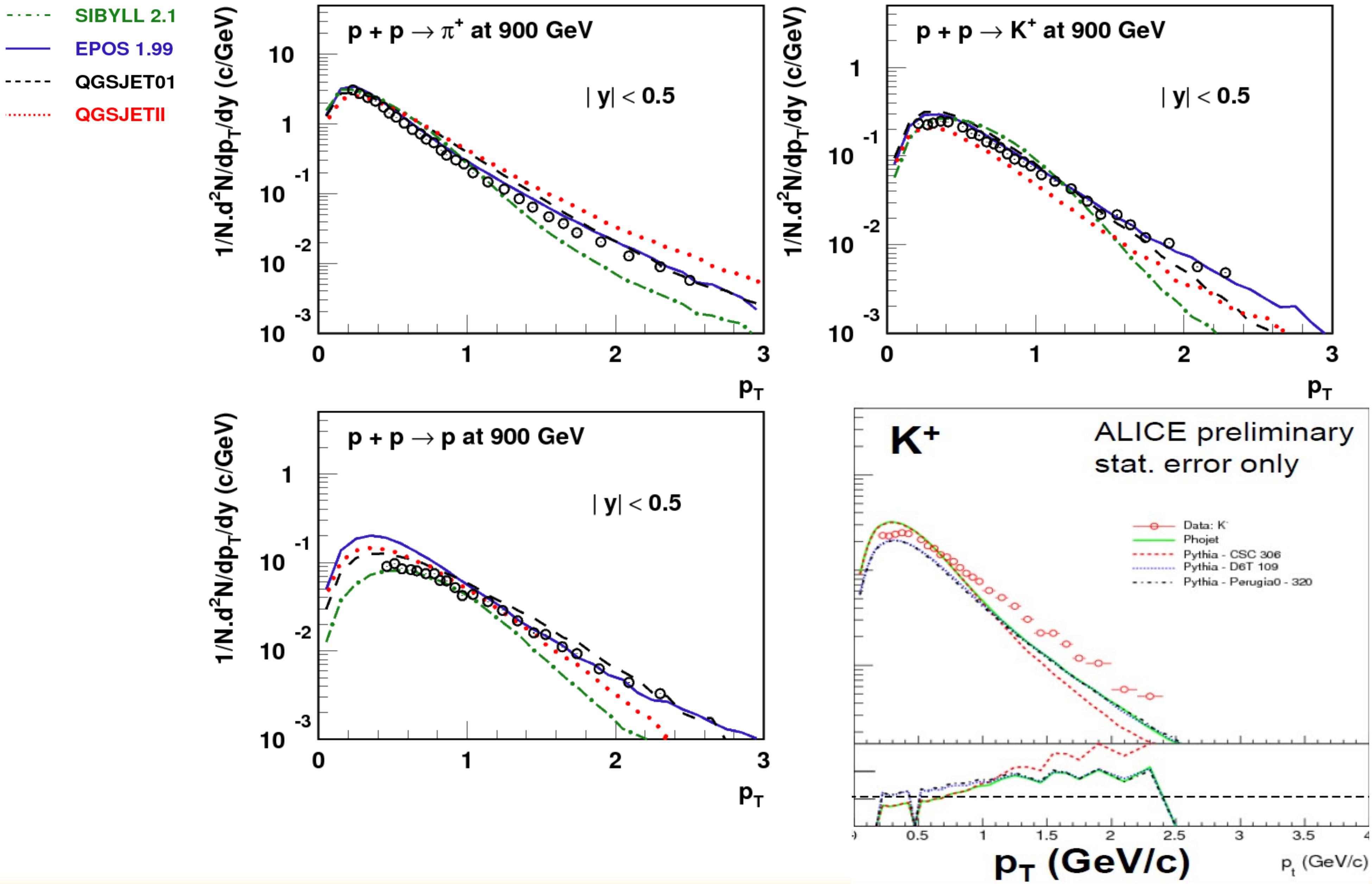
ALICE Identified Spectra 900 GeV



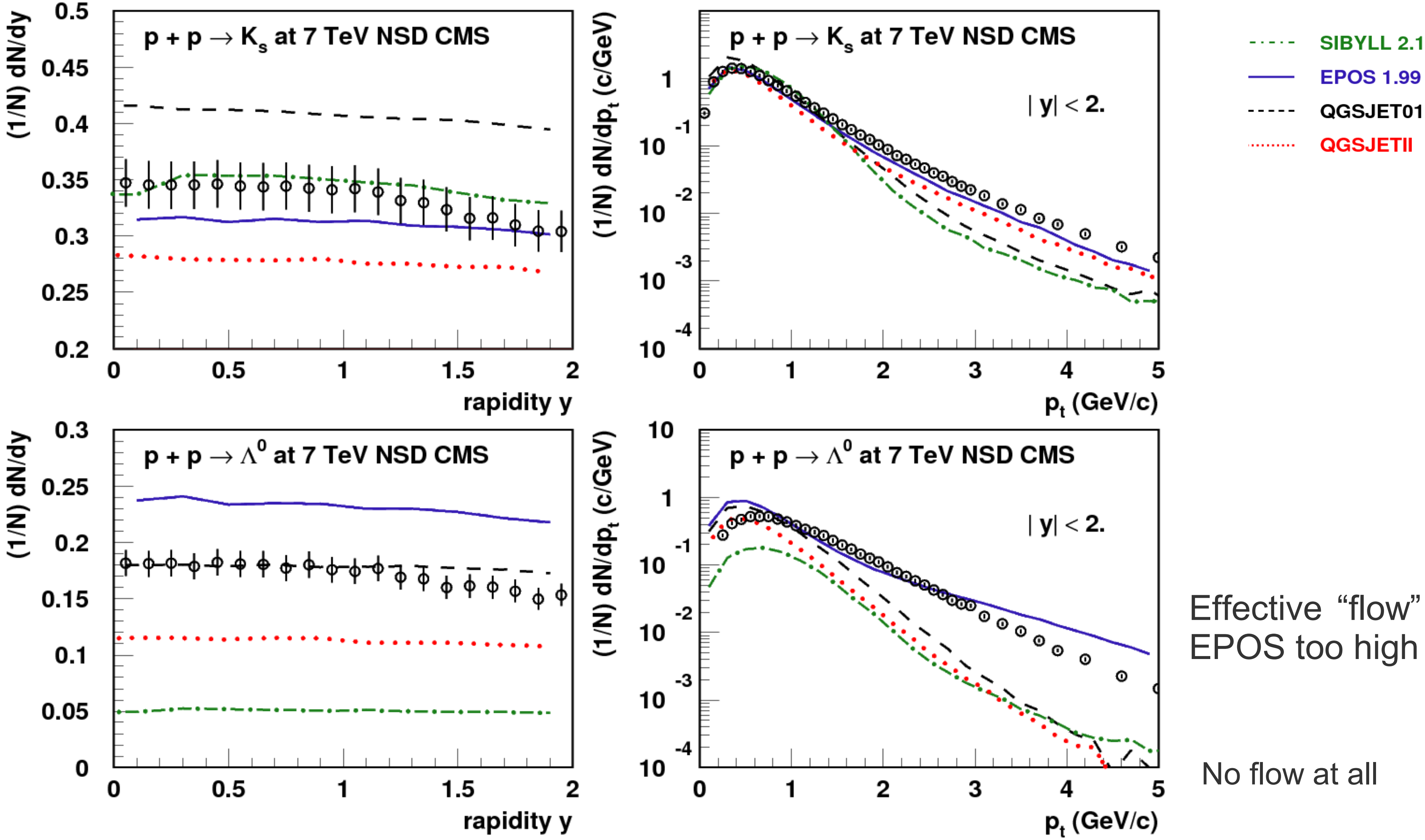


- **Individual particles**
  - EPOS OK (proton ?)
  - QGSJET01 OK !
  - QGSJETII Pion mean p_T too large

ALICE Identified Spectra 900 GeV



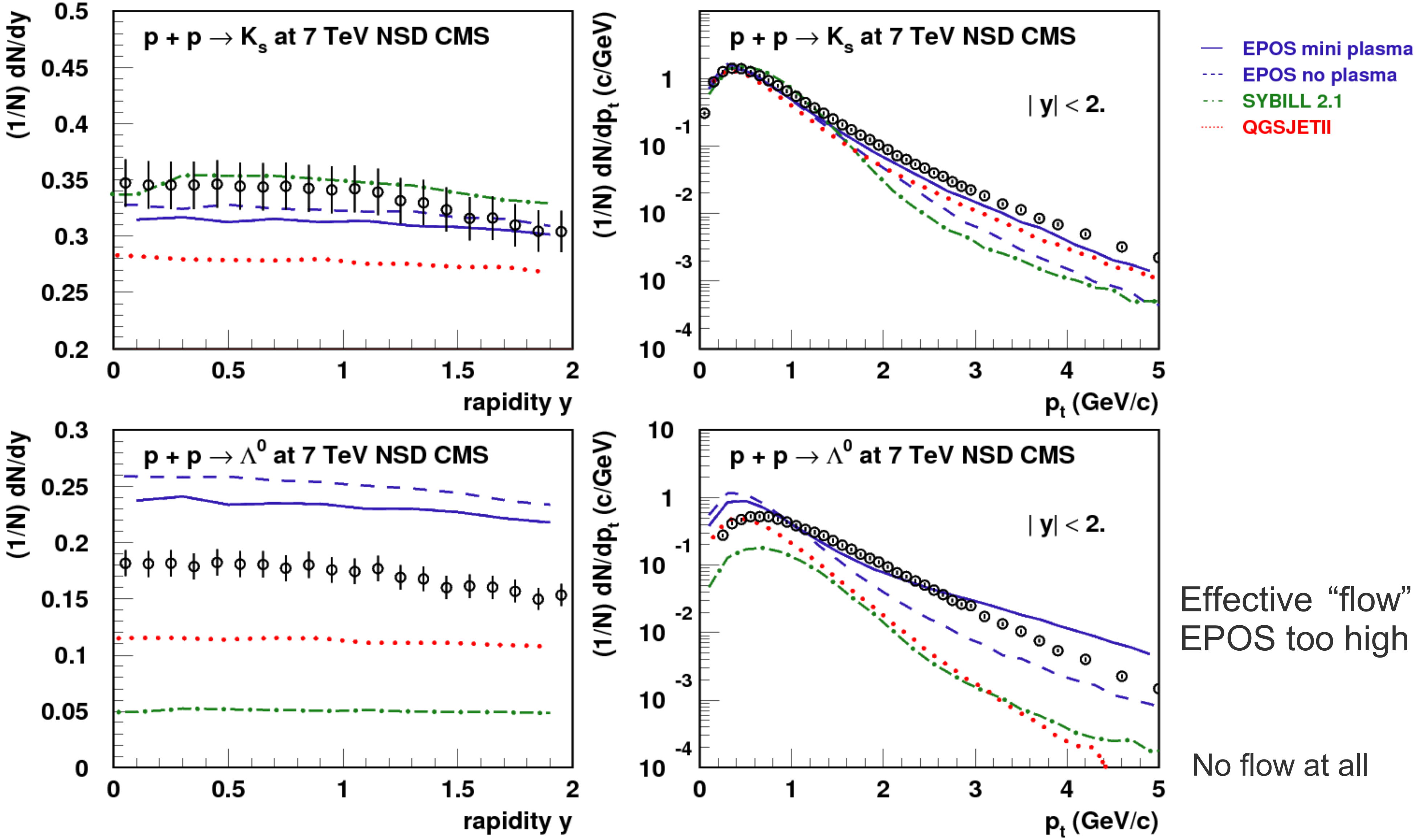
CMS Strangeness 7 TeV



Effective “flow” in EPOS too high

No flow at all

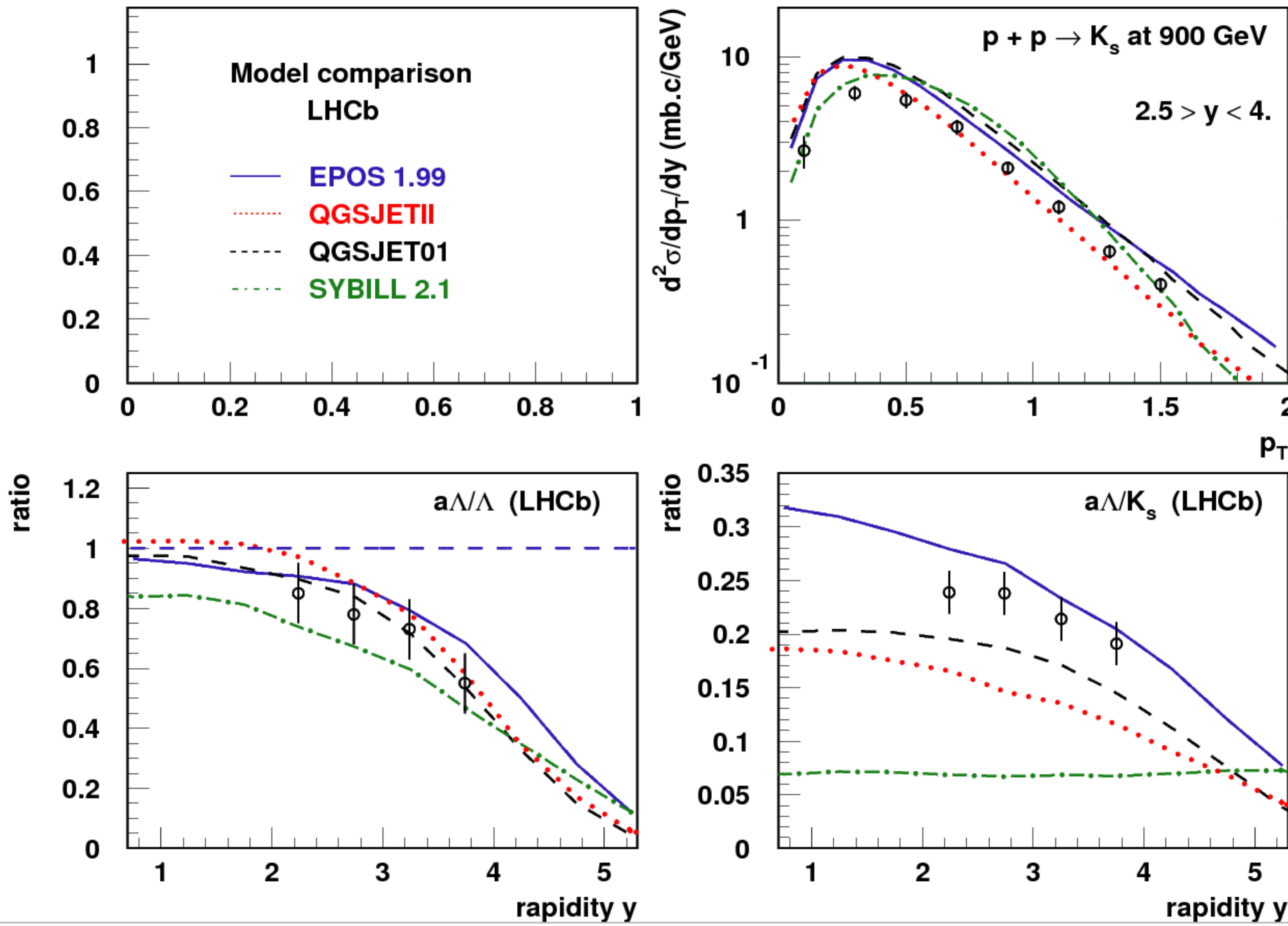
CMS Strangeness 7 TeV



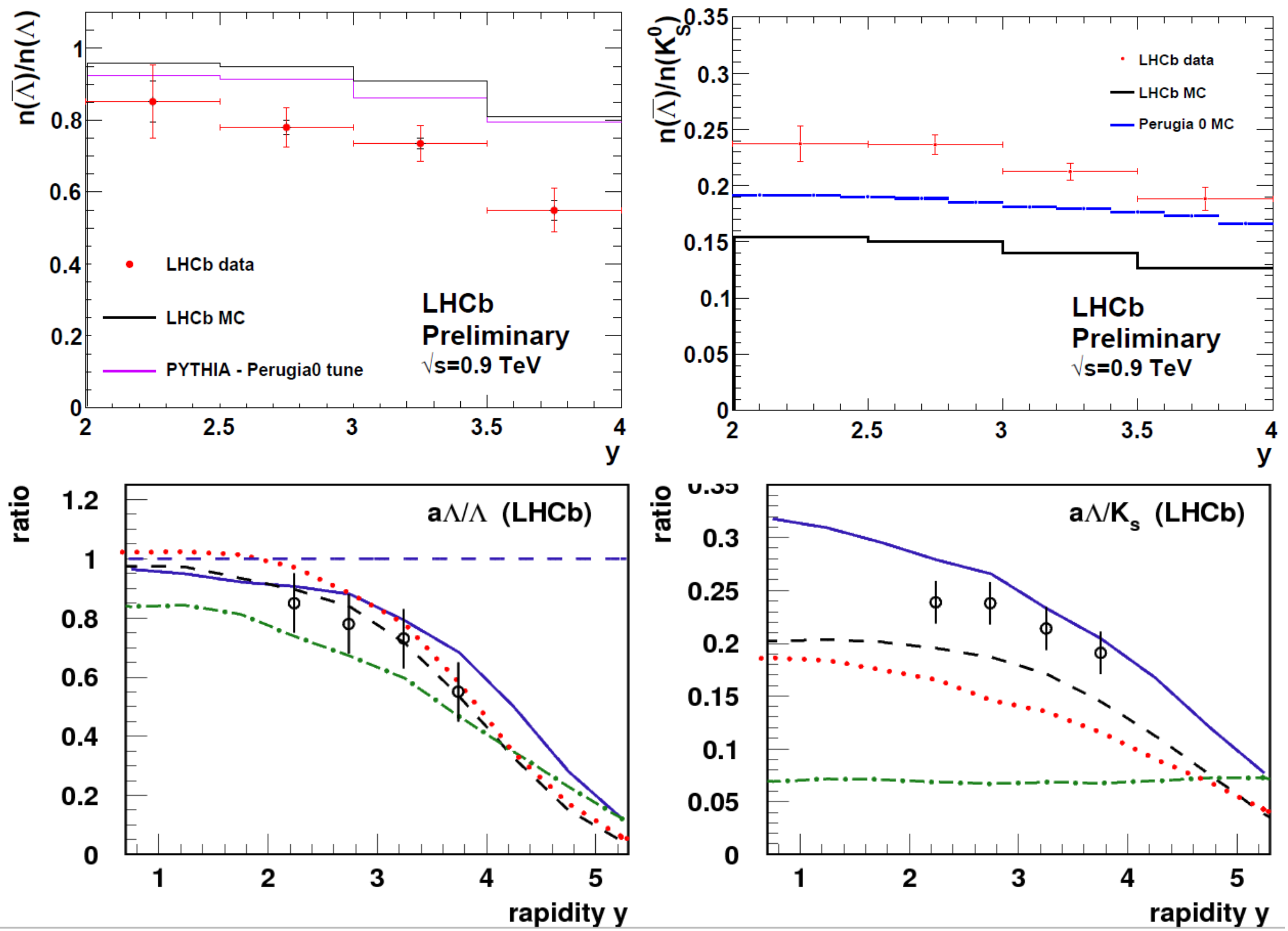
Effective “flow” in EPOS too high

No flow at all

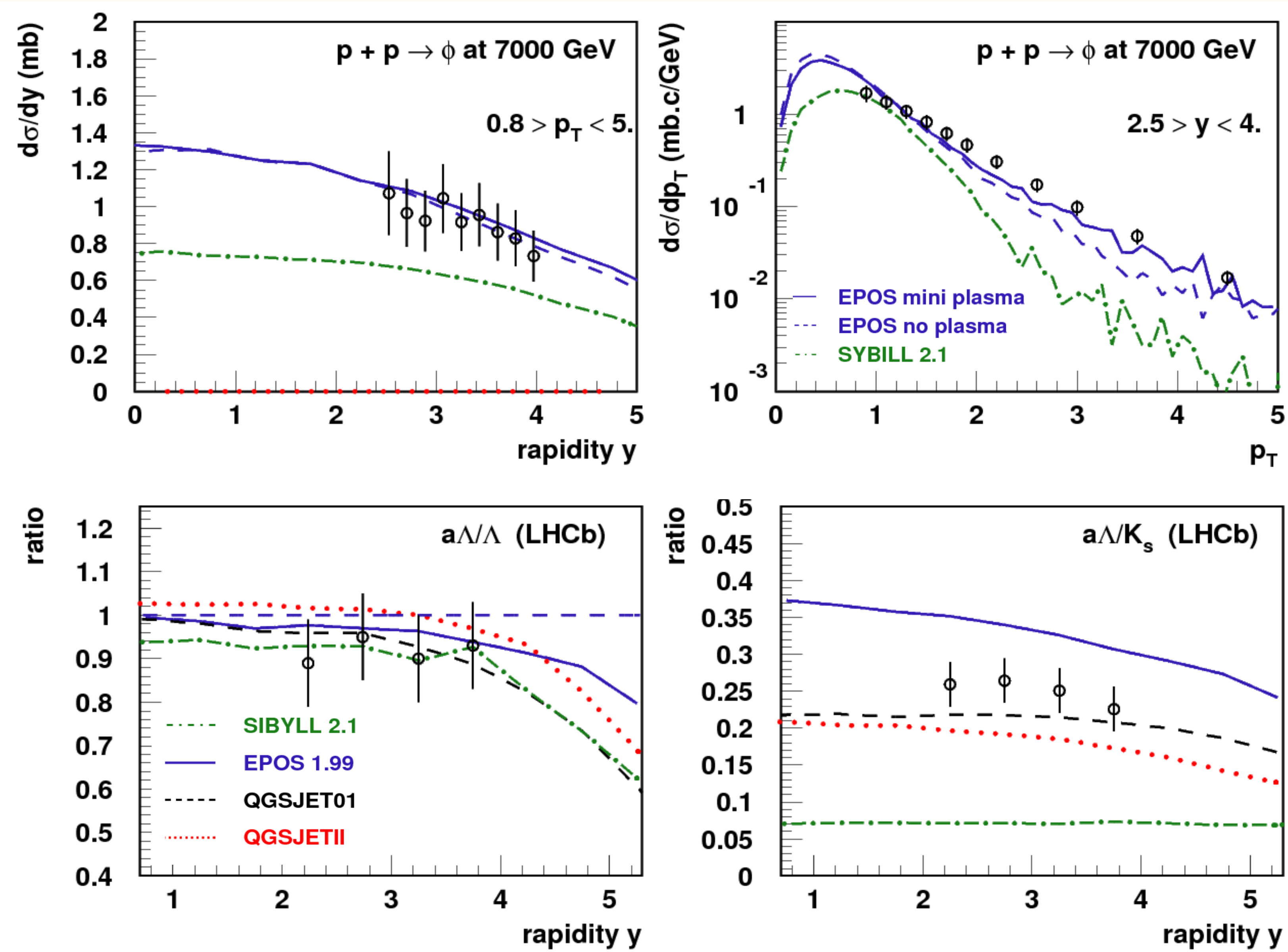
LHCb 900 GeV


Model comparison
LHCb
EPOS 1.99
QGSJETII
QGSJET01
SYBILL 2.1
p + p → K_s at 900 GeV
2.5 > y < 4.
$d^2\sigma/dp_T/dy$ (mb.c/GeV)
p_T
ratio
$a\Lambda/\Lambda$ (LHCb)
$a\Lambda/K_s$ (LHCb)
rapidity y

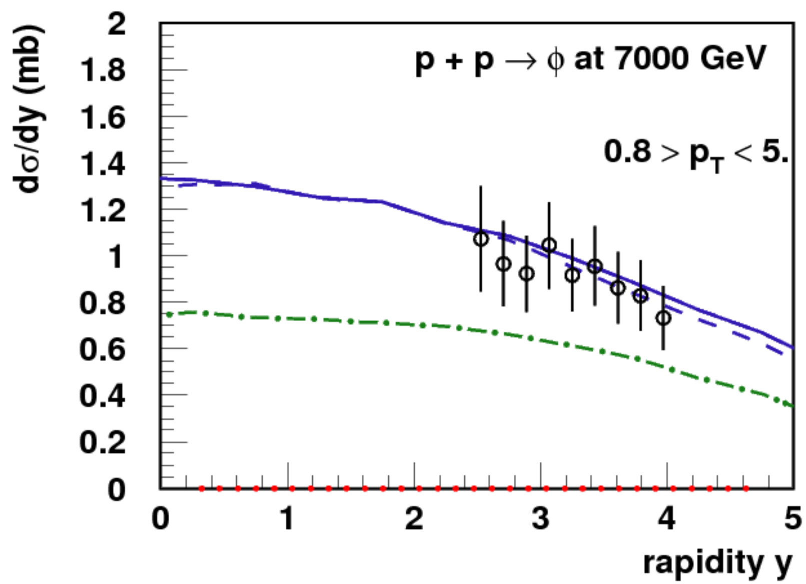
LHCb 900 GeV

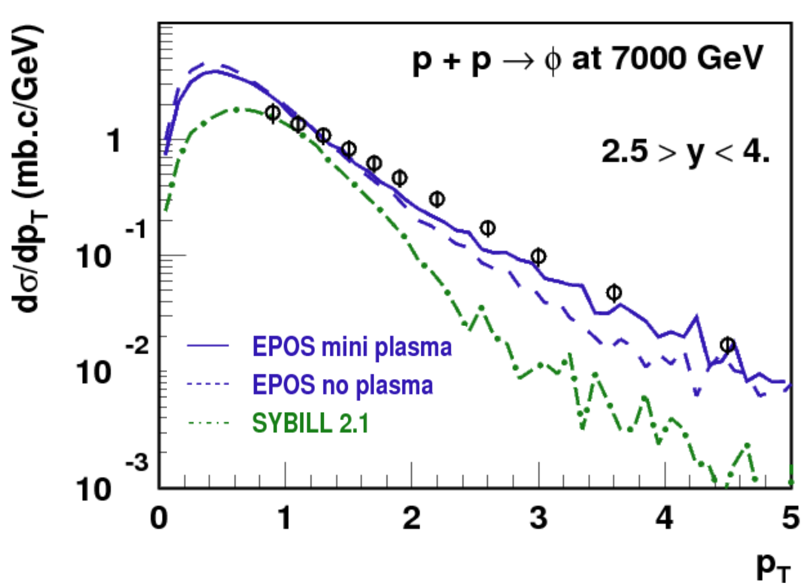

$n(\bar{\Lambda})/n(\Lambda)$
LHCb data
LHCb MC
PYTHIA - Perugia0 tune
LHCb
Preliminary
$\sqrt{s}$=0.9 TeV
y
$n(\bar{\Lambda})/n(K^0_S)$
LHCb data
LHCb MC
Perugia 0 MC
LHCb
Preliminary
$\sqrt{s}$=0.9 TeV
y
ratio
aΛ/Λ (LHCb)
rapidity y
ratio
aΛ/K_s (LHCb)
rapidity y

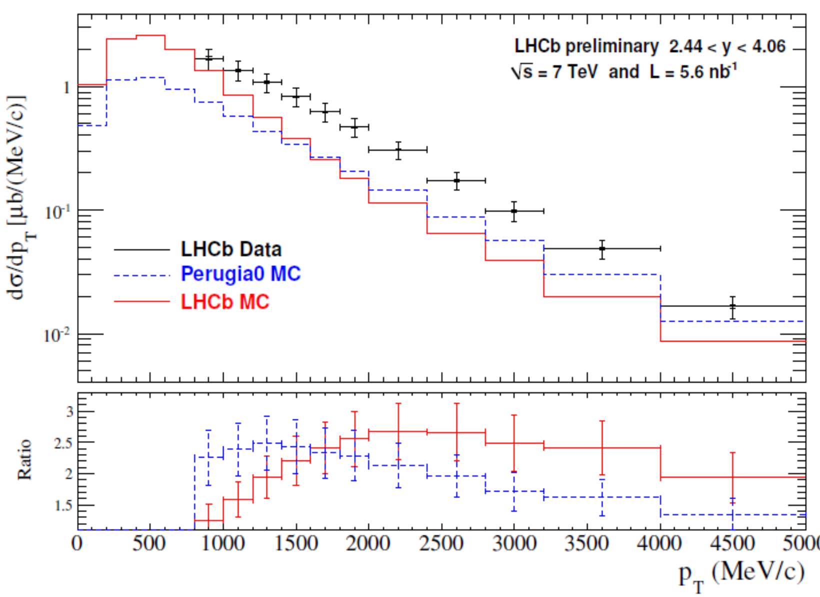
LHCb 7 TeV

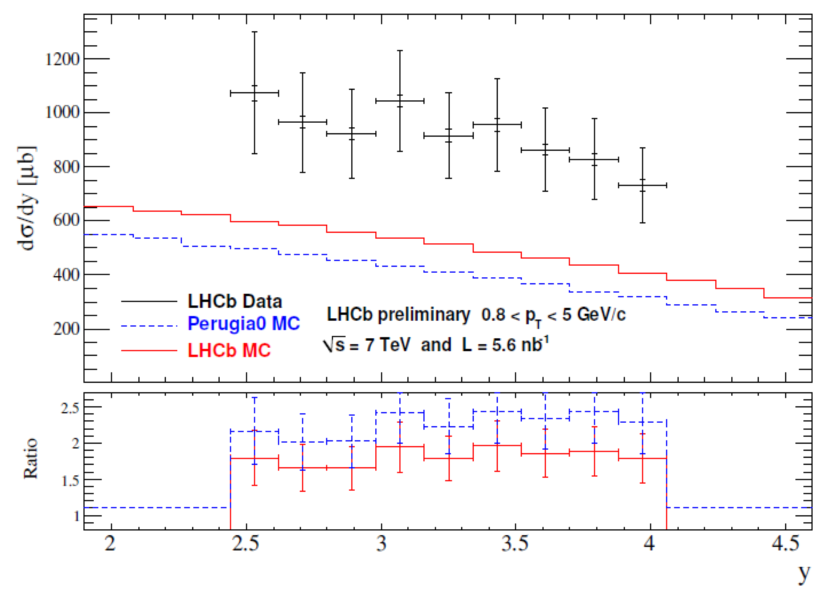

p + p → ϕ at 7000 GeV
0.8 > p_T < 5.
dσ/dy (mb)
rapidity y
p + p → ϕ at 7000 GeV
2.5 > y < 4.
dσ/dp_T (mb.c/GeV)
p_T
EPOS mini plasma
EPOS no plasma
SYBILL 2.1
aΛ/Λ (LHCb)
ratio
rapidity y
SIBYLL 2.1
EPOS 1.99
QGSJET01
QGSJETII
aΛ/K_s (LHCb)
ratio
rapidity y

LHCb 7 TeV


p + p → φ at 7000 GeV
0.8 > pT < 5.
dσ/dy (mb)
rapidity y


p + p → φ at 7000 GeV
2.5 > y < 4.
dσ/dpT (mb.c/GeV)
EPOS mini plasma
EPOS no plasma
SYBILL 2.1
pT


LHCb preliminary 2.44 < y < 4.06
√s = 7 TeV and L = 5.6 nb⁻¹
LHCb Data
Perugia0 MC
LHCb MC
dσ/dpT [μb/(MeV/c)]
Ratio
pT (MeV/c)

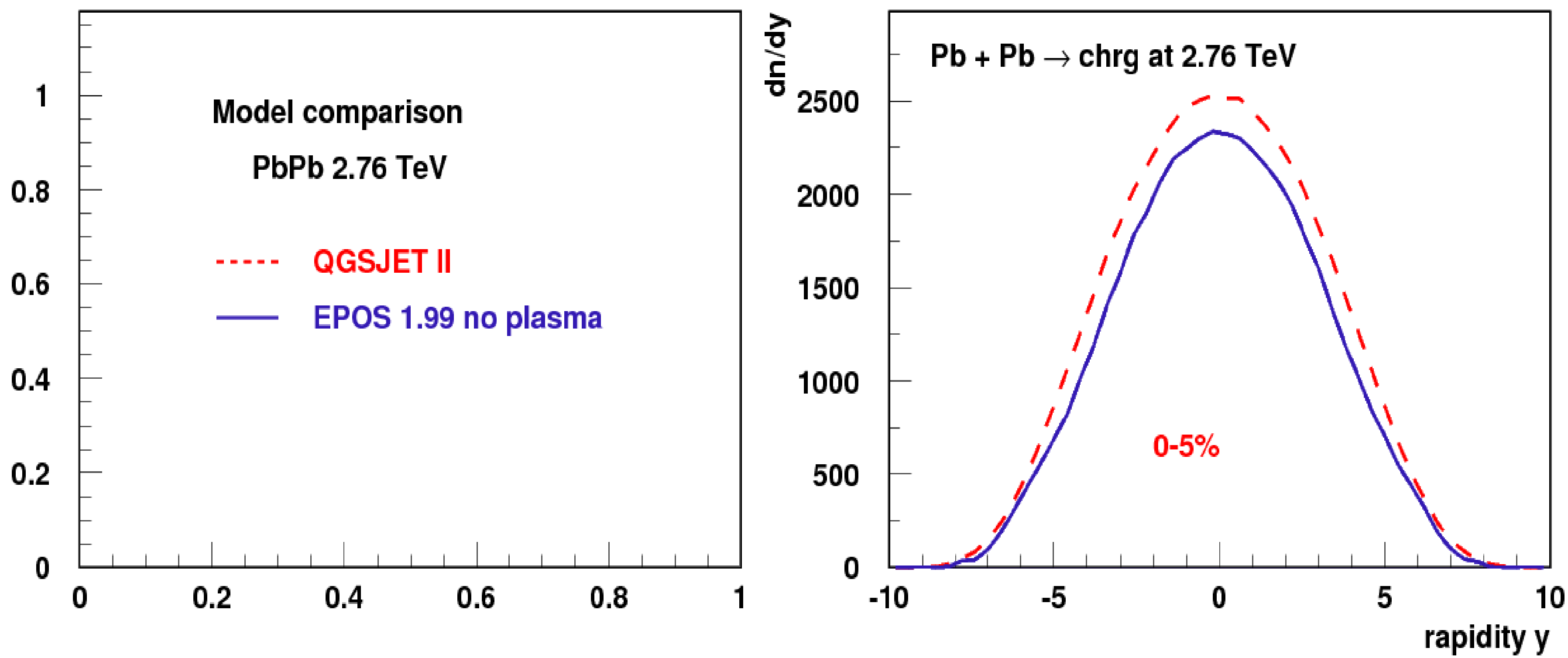

LHCb Data
Perugia0 MC
LHCb MC
LHCb preliminary 0.8 < pT < 5 GeV/c
√s = 7 TeV and L = 5.6 nb⁻¹
dσ/dy [μb]
Ratio
y

Summary

- **Even in the range of existing data, hadronic interaction models have different predictions :**
  - Large uncertainties in EAS simulations due to hadronic models.
  - Except EPOS, models dedicated to cosmic rays.
  - Good average description of pre-LHC data

- **Comparison to first LHC data (min Bias) :**
  - Average multiplicity better reproduce by “old” models QGSJET01 and SIBYLL
  - Except for SIBYLL (bug) all charged p_T well reproduced
  - For identified particle only EPOS closer to data (different behavior of baryons : collective effects ?)
  - LHCb data better described than with PYTHIA

PbPb 2.76 TeV



- EPOS results highly depends on plasma (cf Klaus talk)