Physics of the MIPP Experiment

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Fermilab
For the MIPP collaboration

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The MIPP Experiment

- **M**ain **I**njector **P**article **P**roduction (FNAL E907)
  - Approved Nov. 2001
  - Use secondary beams of $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ from 5 GeV/c to 100 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
  - Open geometry, large acceptance:
    - Tracking and momentum measurement of ~all charged particles with TPC and chambers
    - PID of charged particles with dE/dx, ToF, threshold Cherenkov, RICH
  - High statistics

6 beam species

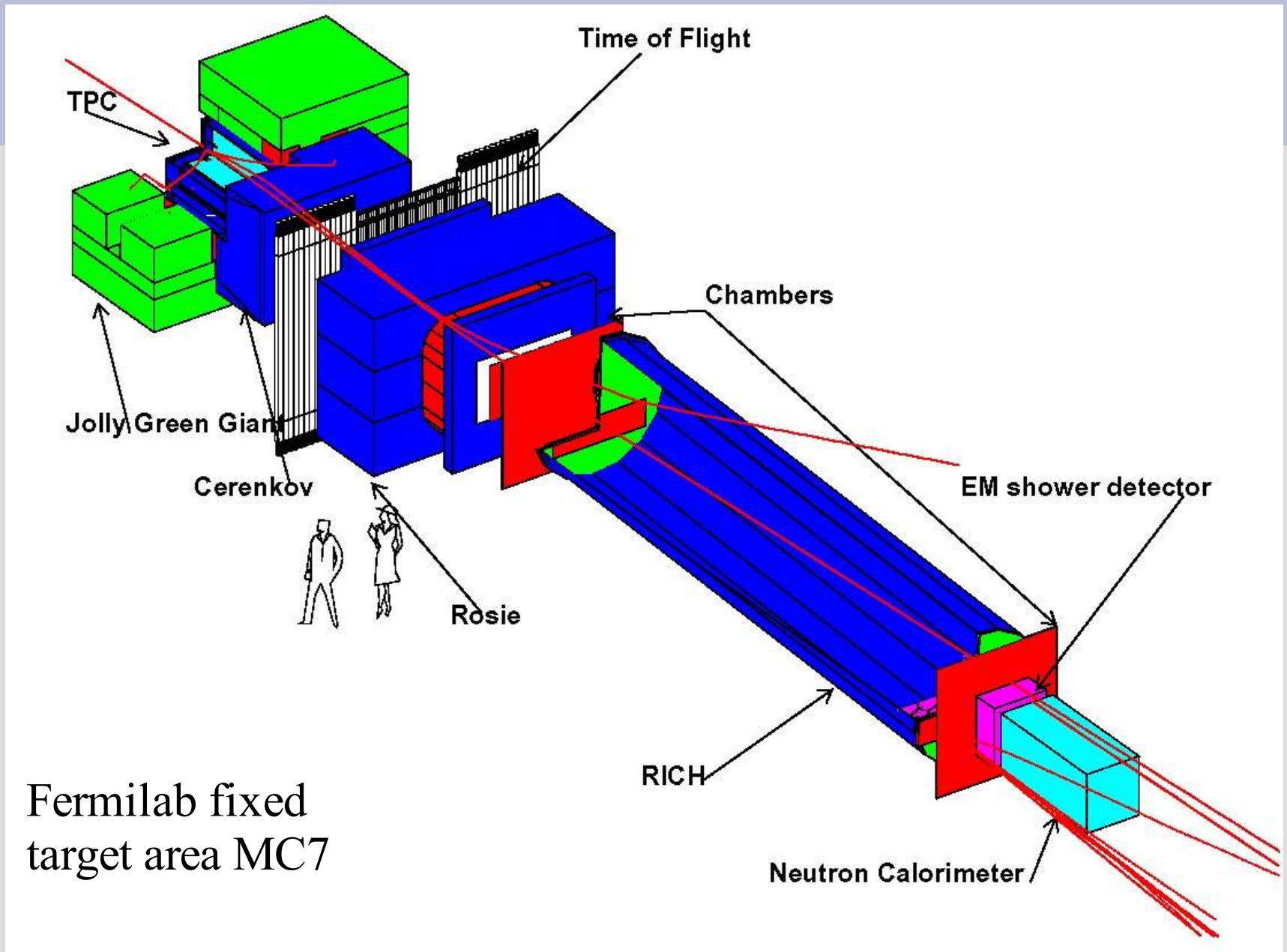
Large range of energies

Many targets

What the bubble chamber experiments always wanted but could not do in the 70's and 80's.

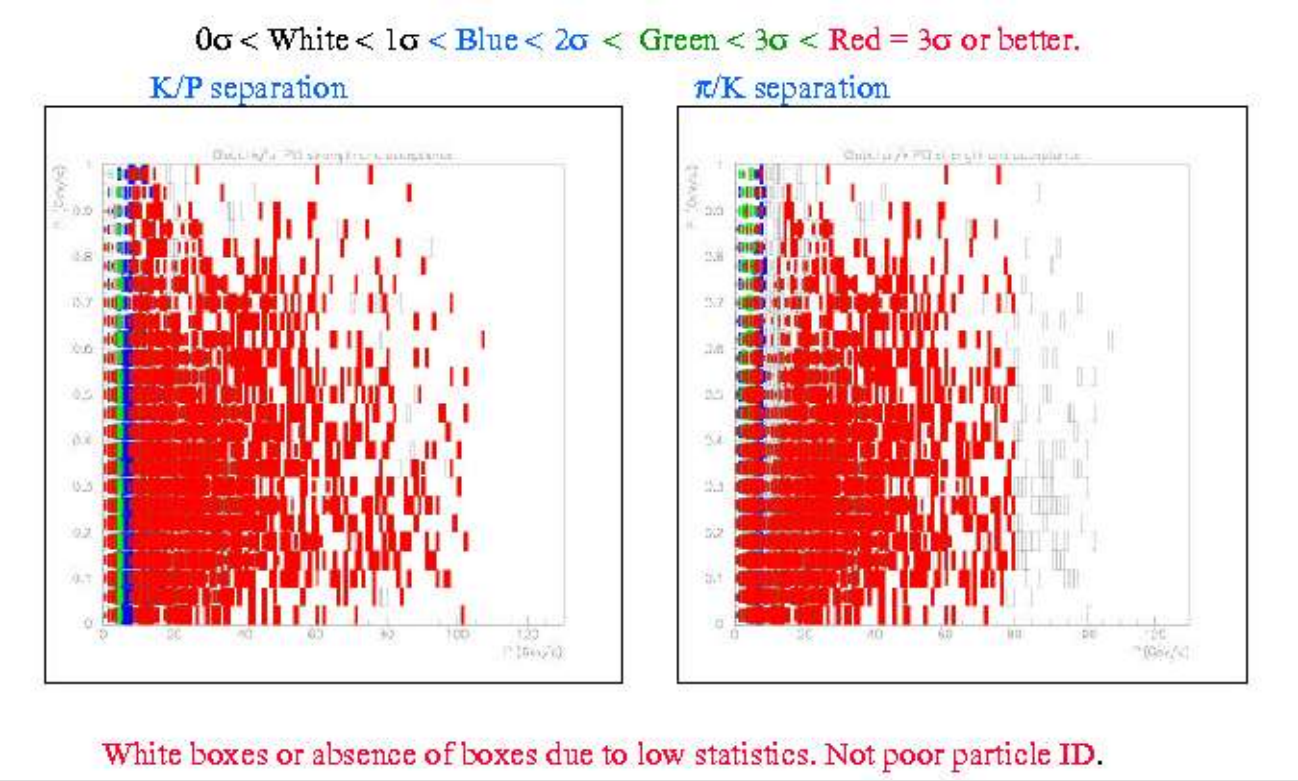
Similar to BNL E910 and HARP

MIPP Detector



Fermilab fixed target area MC7

MIPP Particle ID Capabilities



Physics of the MIPP Experiment

- Non-perturbative QCD hadron dynamics
  - Scaling laws
- Light meson spectroscopy
  - Glueballs, pentaquarks, etc.
- Nuclear Physics
  - Strangeness production in nuclei
  - Nuclear scaling
  - Propagation of flavor through nuclei
- Service measurements
  - Atmospheric νs (p and π cross sections on nitrogen)
  - Shower models in Geant4 and MARS (all nuclear cross sections)
  - ν-factory/ μ-collider target design (production of πs)
  - MINOS target measurement (120 GeV/c proton primary beam)
  - Proton radiography - stockpile stewardship - national security

Why non-perturbative QCD?

- It is not understood
  - >99% of the total QCD cross section is non-perturbative. We cannot calculate these cross sections. Structure functions for perturbative QCD are non-perturbative and derived from data.
  - All existing data are low statistics, with poor particle id, sometimes conflicting.
- MIPP will take high statistics, low systematics data with 6 beam species on lH_2
  - Missing neutral channels available from constrained fit

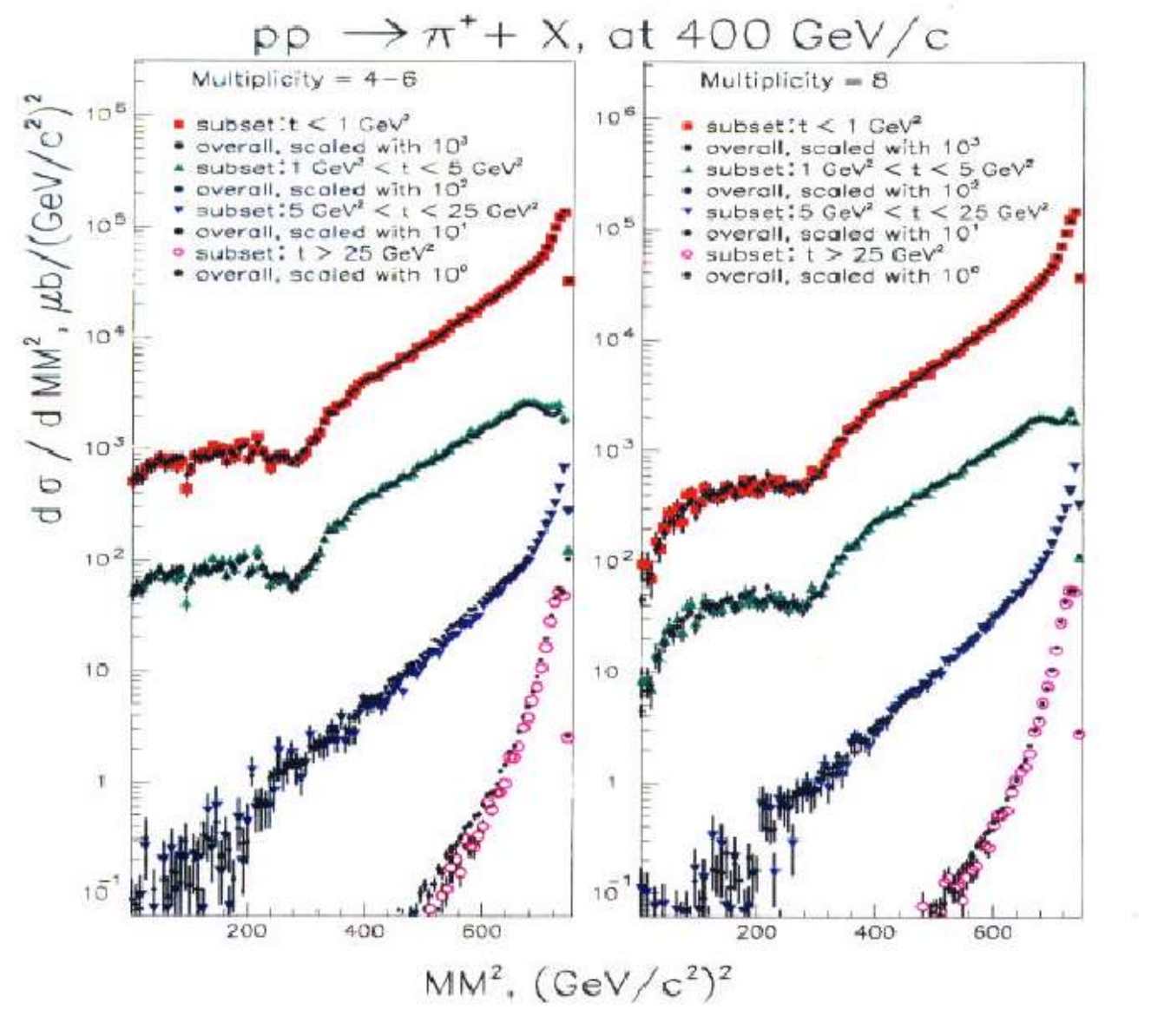
Scaling Law of Particle Fragmentation

- States that the ratio of a semi-inclusive to an inclusive cross section is a function of the invariant mass M^2 only

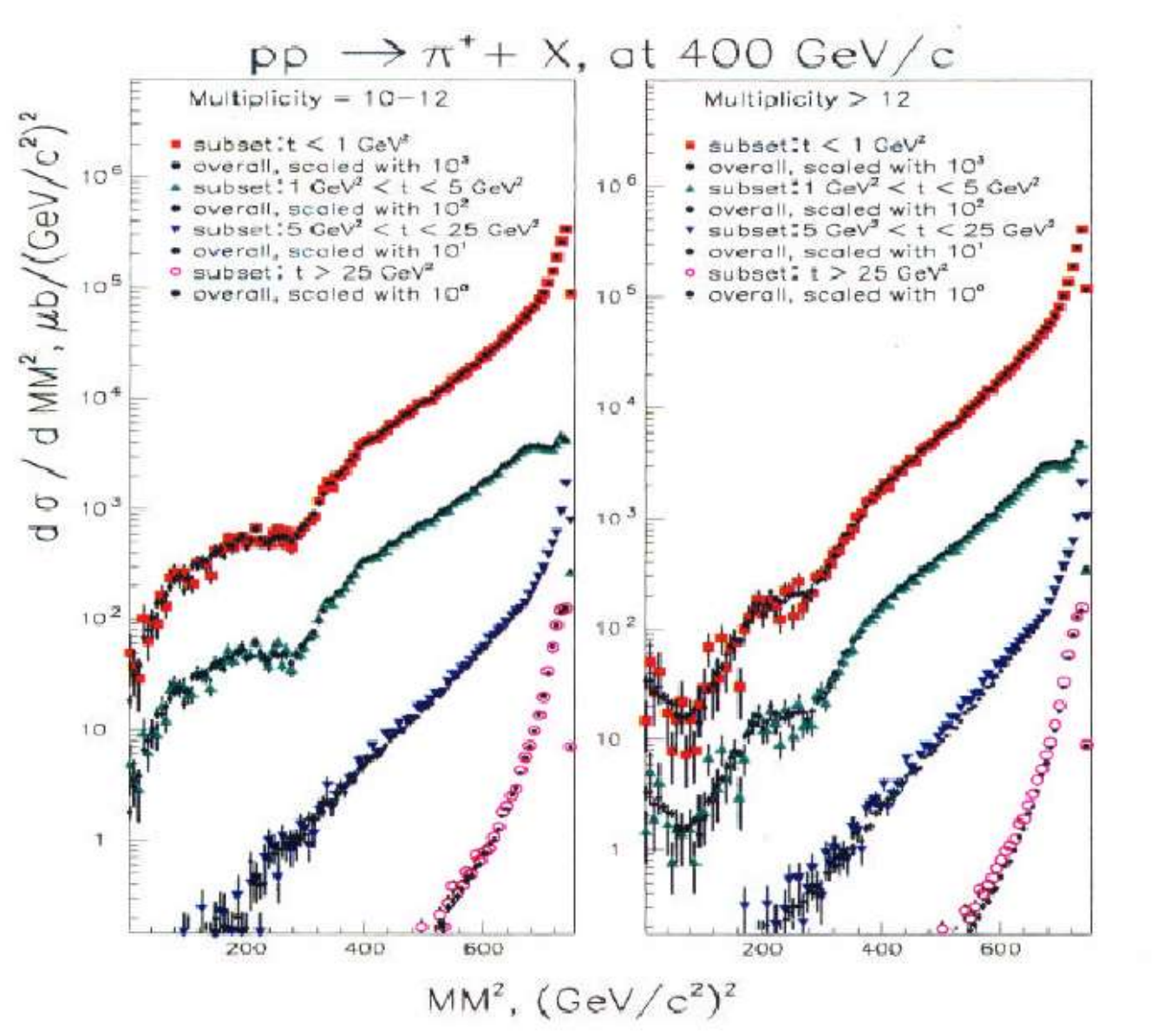
$$\frac{\sigma\left(a+b\rightarrow c+X_{subset}\right)}{\sigma\left(a+b\rightarrow c+X\right)}\equiv\frac{\sigma_{subset}\left(M^2,s,t\right)}{\sigma\left(M^2,s,t\right)}=\beta_{subset}\left(M^2\right)$$

  - M^2, s, and t are Mandelstam variables
  - R. Raja, PRD18(1978)204
- EHS data confirms this scaling in 12 reactions, but only at fixed s (Y. Fisyak, R. Raja, Proceedings of DPF1992)
- MIPP will test this in 36 reactions as a function of both s and t for various particle types a, b, and c.

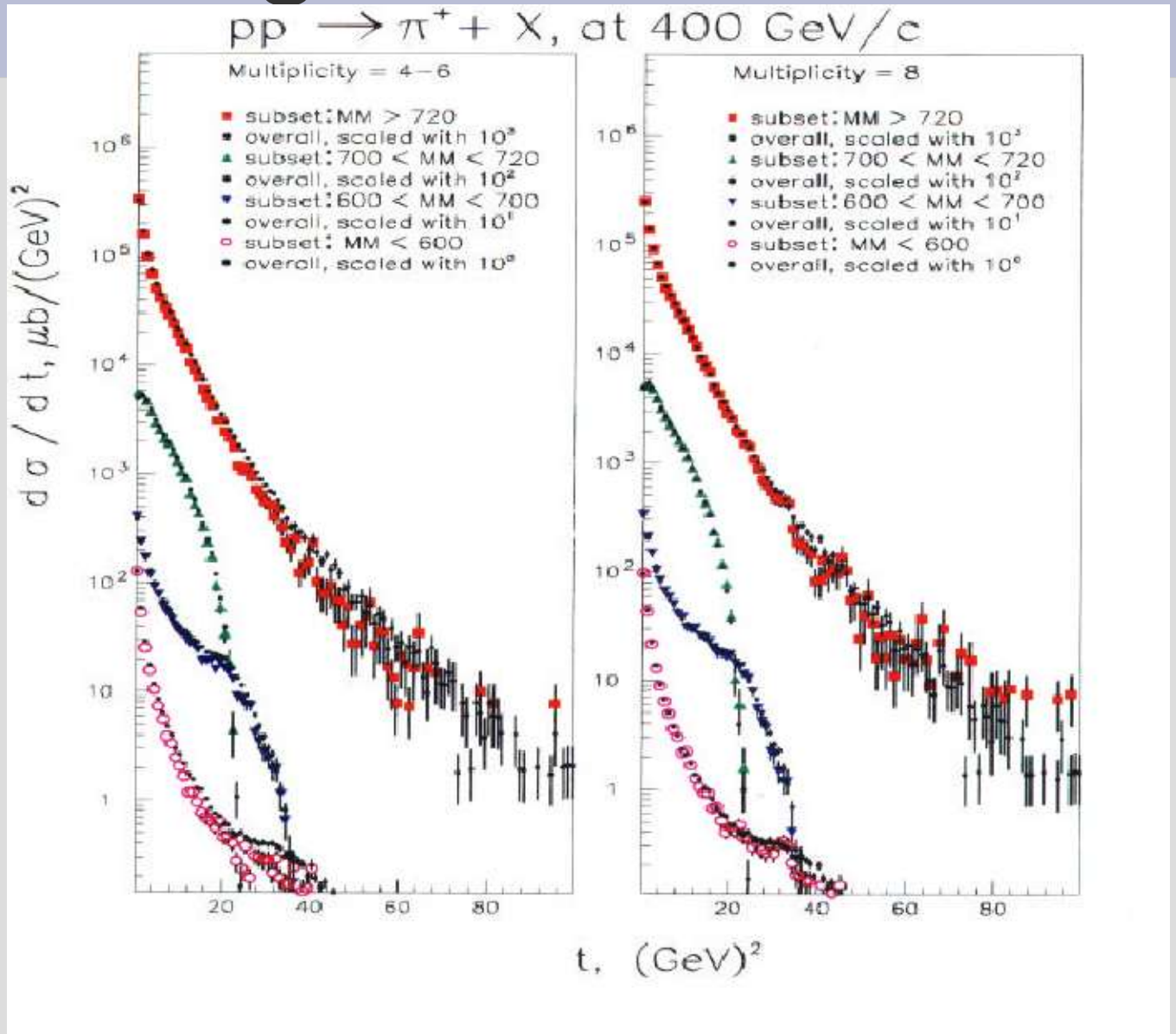
Scaling Law · EHS results



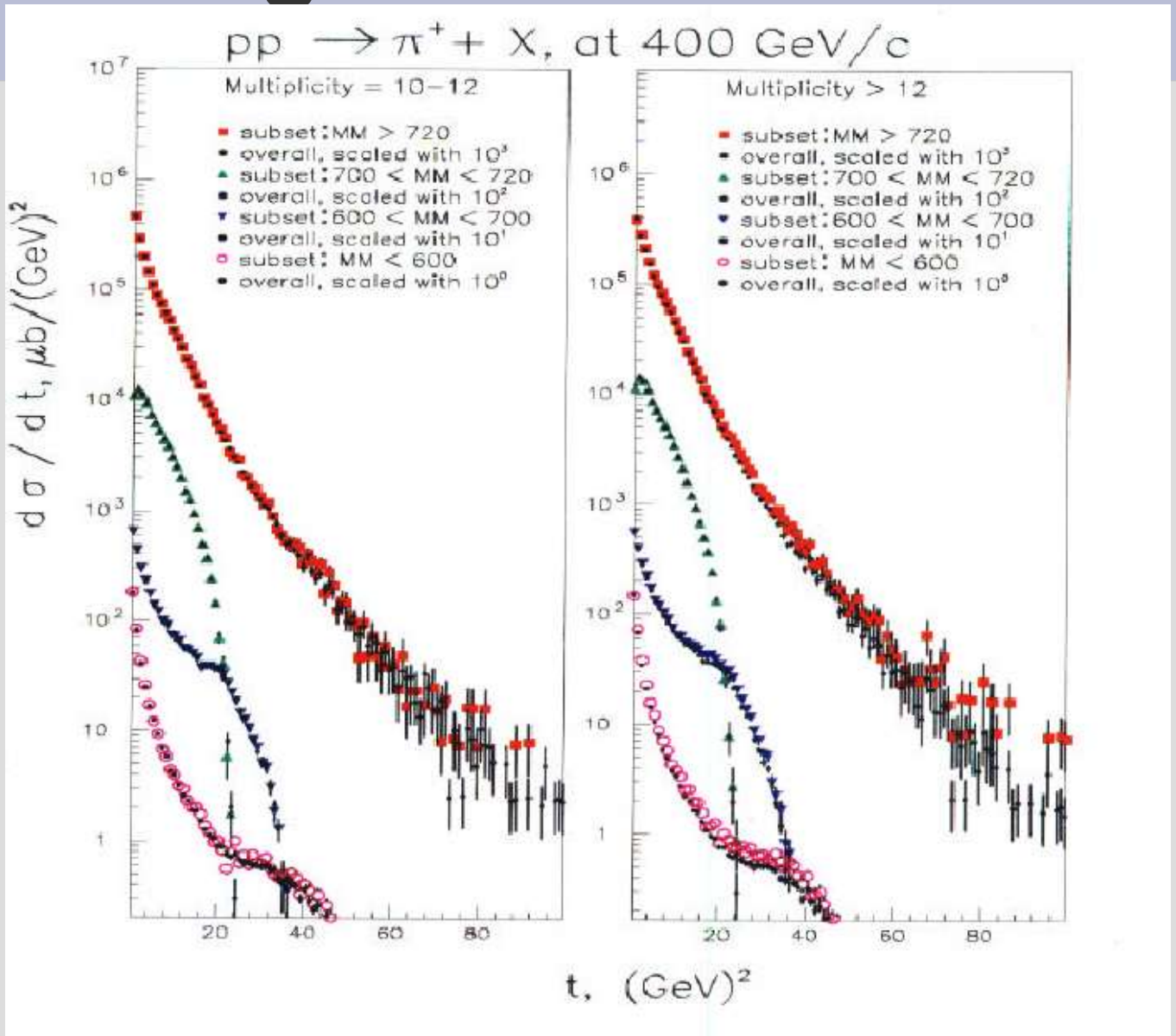
Scaling Law · EHS results



Scaling Law · EHS results

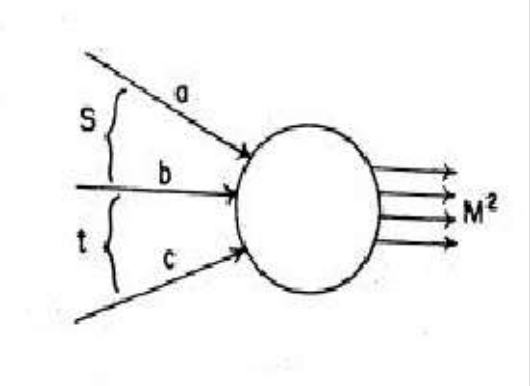


Scaling Law · EHS results

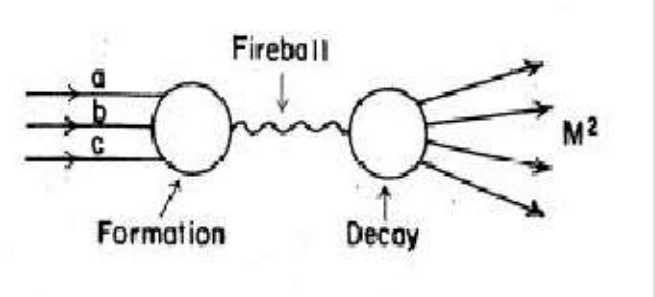


Scaling Law of Particle Fragmentation

- Scaling Law follows naturally if the reaction factorizes into a two step process:
  - Formation of a pseudo-resonance
  - Decay into final state



$$\frac{\sigma\left(a+b+c\rightarrow X_{subset}\right)}{\sigma\left(a+b+c\rightarrow X\right)}\equiv\frac{F\left(M^2,s,t\right)D_{subset}\left(M^2\right)}{F\left(M^2,s,t\right)D\left(M^2\right)}=\beta_{subset}\left(M^2\right)$$



  - Fast equilibrium after scattering

36 Reactions in MIPP

$\pi^+ + p \rightarrow \pi^+ + X$	$\pi^- + p \rightarrow \pi^+ + X$	$K^- + p \rightarrow \pi^+ + X$
$\pi^+ + p \rightarrow K^+ + X$	$\pi^- + p \rightarrow K^+ + X$	$K^- + p \rightarrow K^+ + X$
$\pi^+ + p \rightarrow p + X$	$\pi^- + p \rightarrow p + X$	$K^- + p \rightarrow p + X$
$\pi^+ + p \rightarrow \pi^- + X$	$\pi^- + p \rightarrow \pi^- + X$	$K^- + p \rightarrow \pi^- + X$
$\pi^+ + p \rightarrow K^- + X$	$\pi^- + p \rightarrow K^- + X$	$K^- + p \rightarrow K^- + X$
$\pi^+ + p \rightarrow \bar{p} + X$	$\pi^- + p \rightarrow \bar{p} + X$	$K^- + p \rightarrow \bar{p} + X$
$K^+ + p \rightarrow \pi^+ + X$	$p + p \rightarrow \pi^+ + X$	$\bar{p} + p \rightarrow \pi^+ + X$
$K^+ + p \rightarrow K^+ + X$	$p + p \rightarrow K^+ + X$	$\bar{p} + p \rightarrow K^+ + X$
$K^+ + p \rightarrow p + X$	$p + p \rightarrow p + X$	$\bar{p} + p \rightarrow p + X$
$K^+ + p \rightarrow \pi^- + X$	$p + p \rightarrow \pi^- + X$	$\bar{p} + p \rightarrow \pi^- + X$
$K^+ + p \rightarrow K^- + X$	$p + p \rightarrow K^- + X$	$\bar{p} + p \rightarrow K^- + X$
$K^+ + p \rightarrow \bar{p} + X$	$p + p \rightarrow \bar{p} + X$	$\bar{p} + p \rightarrow \bar{p} + X$

Symmetry relations

- Among the 36 reactions there are
  - 15 crossing symmetry relations
  - 3 C symmetry relations
- For example: $\pi^+ p \rightarrow \pi^+ X$ and $\pi^- p \rightarrow \pi^- X$ should have same $\beta(M^2)$ for all subsets of X
- Or: $p^- p \rightarrow \pi^+ X$ and $\pi^- p \rightarrow p X$

  central production diffractive

Search for Resonances with Scaling Law

- The scaling law can be used to search for resonances
  - Scaling applies to a continuum of states that populate a cut in M^2.
  - If X is also a resonance in some subset then interference will occur in that subset in the mass range of the resonance.
  - This will result in deviations from scaling.

Light Meson Spectroscopy

- Some of the light mesons predicted by SU(3) have not been observed
- MIPP is in a good position to search for exotica
  - Large acceptance, complete pid
  - Compare production with 6 different beams in one experiment

Pentaquark Search with MIPP

- May need higher statistics:
  - Currently limited to 60 Hz trigger rate
    - TPC electronics can be upgraded
    - MIPP will then take triggers at 1kHz
  - Currently minimum bias trigger
    - MIPP could use special triggers for searches

Nuclear Physics with MIPP

- Strangeness production in nuclei - RHIC connection
  - MIPP is fixed target, good forward coverage
- Propagation of flavor through nuclei
  - $K^{\pm}$ beam · How fast is strangeness exchanged?
- Nuclear Scaling (y-scaling) $\frac{d\sigma}{d\Omega\, dE} = \sigma_{beam\,N} F(y)$
  - Verified in ep scattering and with low energy hadron beams (KEK E352)
  - Probe transition from quasielastic scattering to DIS

MIPP Service Measurements

- Service measurements
  - Atmospheric νs (p and π cross sections on nitrogen)
  - Shower models in Geant4 and MARS (all nuclear cross sections)
  - ν-factory/ μ-collider target design (production of πs)
  - MINOS target measurement (120 GeV/c proton primary beam)
  - Proton radiography - stockpile stewardship - national security
- Data set will be made public
  - Test your own theory

Summary

- The Main Injector Particle Production Experiment (FNAL E907) will collect a large sample of minimum bias data
- MIPP will address a broad range of physics topics
- We plan to start a new effort to study non-perturbative QCD

- MIPP is looking forward to first data and results soon