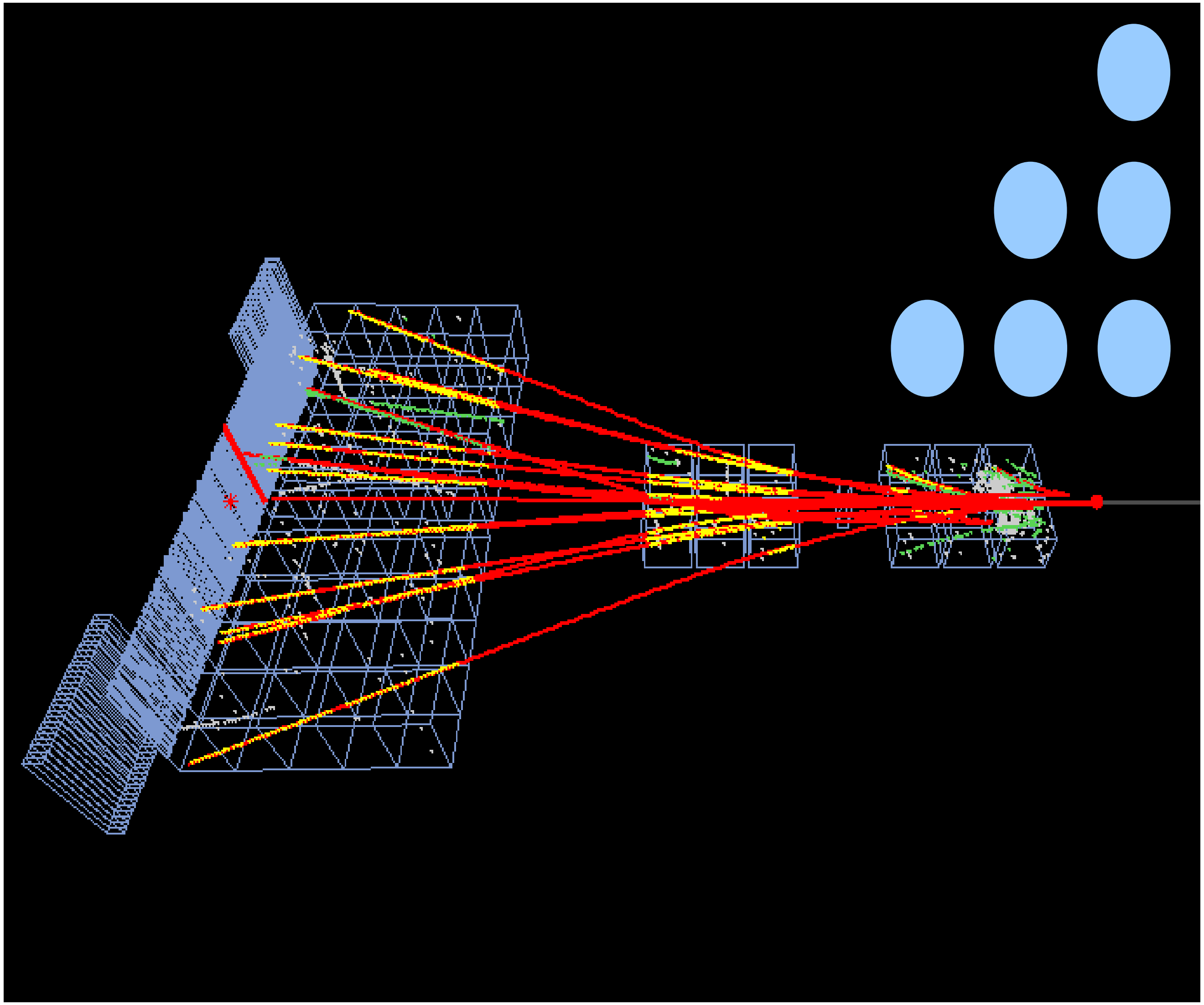
History, status and future of multi-particle production in high energy collisions



History

Status

Future

M. Gazdzicki
Frankfurt,Kielce

History

Disclaimer on history:

''Histories of science are as far from objective truth as can be imagined (as those given to the population in George Orwell's 1984).''

Thomas Samuel Kuhn (1922-1996)

Template:

19..	Experimental discoveries

19..	''statistical'' models of particle production in high energy collisions	19..	''dynamical'' models of particle production in high energy collisions

. . .

''statistical''	**''dynamical''**
all final(micro)-states are equally probable	some final-states are more probable than others

Problems: define all possible final(micro)-states

define probability distribution

≈1950 Discoveries of hadrons

≈1950/60 statistical hadron production

≈1950/70 S-matrix theory

≈1960/70 Discoveries of quarks and gluons

≈1980/00 statistical QGP hadronization

statistical parton production

≈1970/00 pQCD-based models

QCD-inspired models

≈1990/00 Discoveries of strongly interacting matter and its phase transition

2010+ future

2010+ future

≈1950 Discoveries of hadrons

Pioneering discoveries with cosmic-rays:

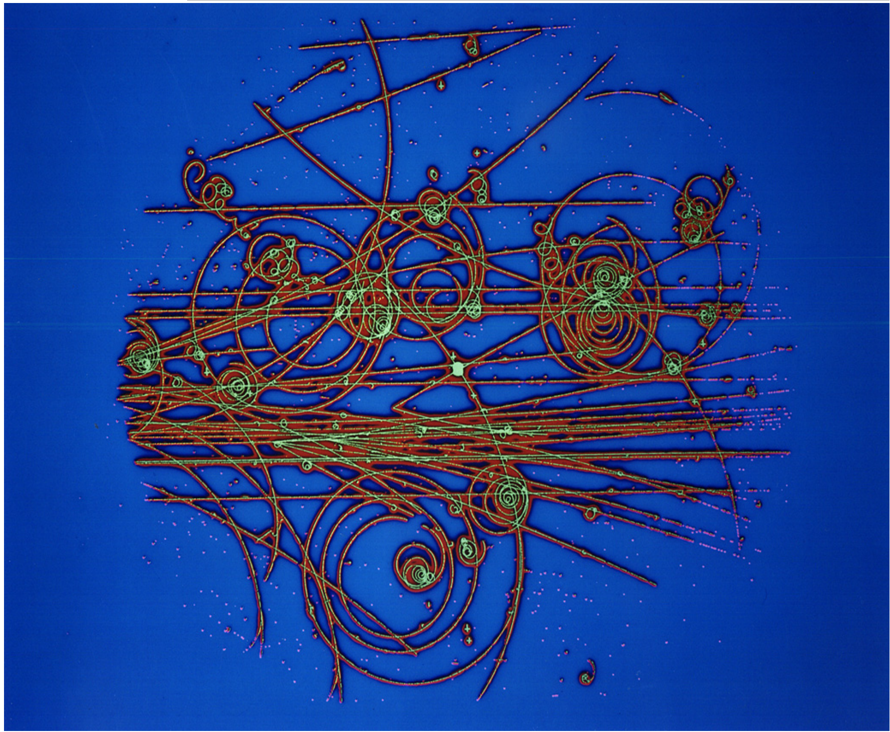
-1947: **pion** (emulsion, *Powell et al.*)
-1947: **kaon and Λ** (cloud chamber, *Rochester, Butler*)

Systematic studies with accelerators:

-1953:	Cosmotron at BNL -	**3 GeV**
-1954:	Bevatron at LBL -	**3 GeV**
-1959:	PS at CERN -	**28 GeV**
-1960:	AGS at BNL	**33 GeV**
-1976:	Main Ring at FNAL	**500 GeV**
-1976:	SPS at CERN	**400 GeV**

...

2010: about 1000 hadronic states



≈1950/60 statistical hadron production

$$f(m_T) \sim e^{-m_T/T}$$

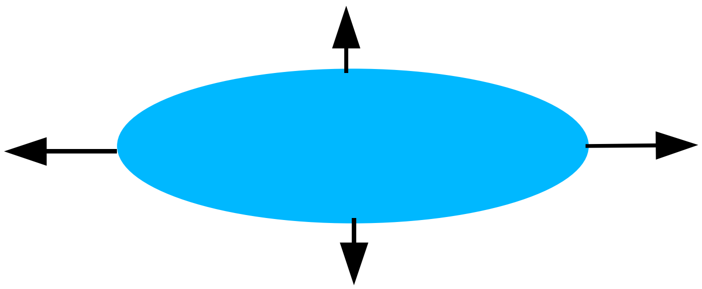
Pioneering ideas/models:

-1950: E. Fermi

statistical hadron production: $T = T_I \sim \sqrt{\sqrt{s_{NN}}}$

-1951: I. Pomeranchuk

freeze-out at $T = T_{FO} \approx m_\pi$



-1953: L. D. Landau

hydrodynamical expansion from T_I to T_{FO}

$T = f(m, v_T, T_{FO})$

-1965: R. Hagedorn

statistical hadron production at $T = T_H \approx$ 160 MeV

$m_T = (m^2 + p_T^2)$, $E = m_T * \cosh(y)$, $f(m_T) = 1/m_T \, dn/dm_T$

≈1940/70 S-matrix theory

Pioneering ideas/models:

-1941: W. Heisenberg
S-matrix theory as a theory of particle interactions

≈1960: T. Regge + G. Chew, S. Frautschi, J. Collins
Regge theory

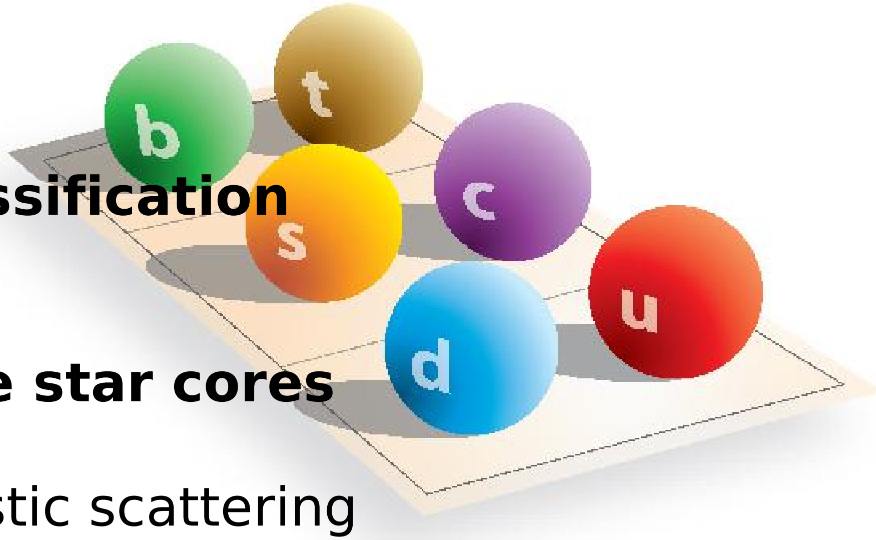
≈1970: G. Veneziano, S. Mandelstam
string model

-1976: A. Bialas, M. Bleszynski, W. Czyz
wounded nucleon model

$$\langle N \rangle_{AB} = w_{AB}/2 \circ \langle N \rangle_{NN}$$

≈1960/70 Discoveries of quarks and gluons

Pioneering ideas/experiments:



-1964: M. Gell-Mann, G. Zweig
quark model of hadron classification

-1965: D. Ivanenko, D. Kurdgelaidze
quark matter in superdense star cores

-1968: SLAC experiments: deep inelastic scattering
discovery of partons (now q, $\bar{q}$ and g)

-1972: M. Gell-Mann, H. Fritzsch, D. Gross, F. Wilczek, D. Politzer
qunatum chromodynamics as theory of strong interactions

-1978: E. Shuryak
QCD quark-gluon plasma ($T_c \approx$ 500 MeV)

-1979: experiments at DESY: three-jet events
discovery of gluons

≈1980/00 statistical QGP hadronization

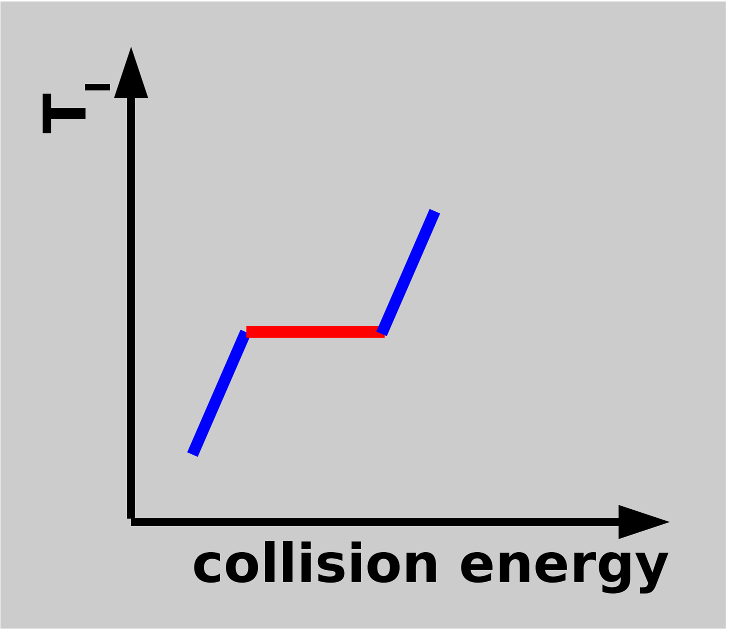
statistical parton production

Pioneering ideas/models:

-1980: R. Hagedorn, J. Rafelski
$T_C = T_H \approx$ 160 MeV

-1991: J. Rafelski
statistical QGP hadronization

≈1995: M.G., M. Gorenstein
statistical production of partons at $T > T_C$ and of hadrons at $T < T_C$



≈1970/90 pQCD-based models

QCD-inspired models

$$f(m_T) \sim m_T^{-P}$$

Pioneering ideas/models:

-1977: R. Field, R. Feynman
pQCD-based model of high p_T phenomena

≈1980: J. Rafelski, B. Mueller, T. Matsui, H. Satz
QCD-inspired models of QGP signals,
strangeness enhancement and J/ψ suppression

-1991: K. Geiger, B. Mueller, J. Ellis
QCD-inspired parton cascade and hadronization model

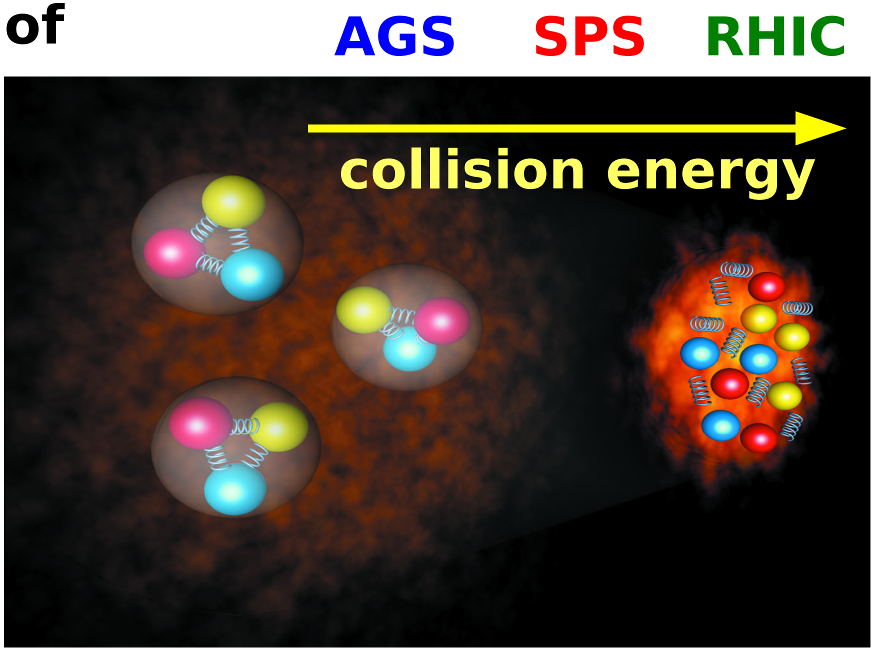
≈1990/00 Discoveries of strongly interacting matter and its phase transition

Pioneering ideas/experiments:

-1980/00: AGS/SPS/RHIC experiments with heavy ions
discovery of strongly interacting matter
(large volume, in ≈equilibrium)

≈2000: M.G., M. Gorenstein
statistical model predictions of
the phase transition at the SPS energies

≈2000: NA49 at the CERN SPS
discovery of phase transition of
strongly interacting matter



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2010+ future

2010+ future

Status

Disclaimer on status:

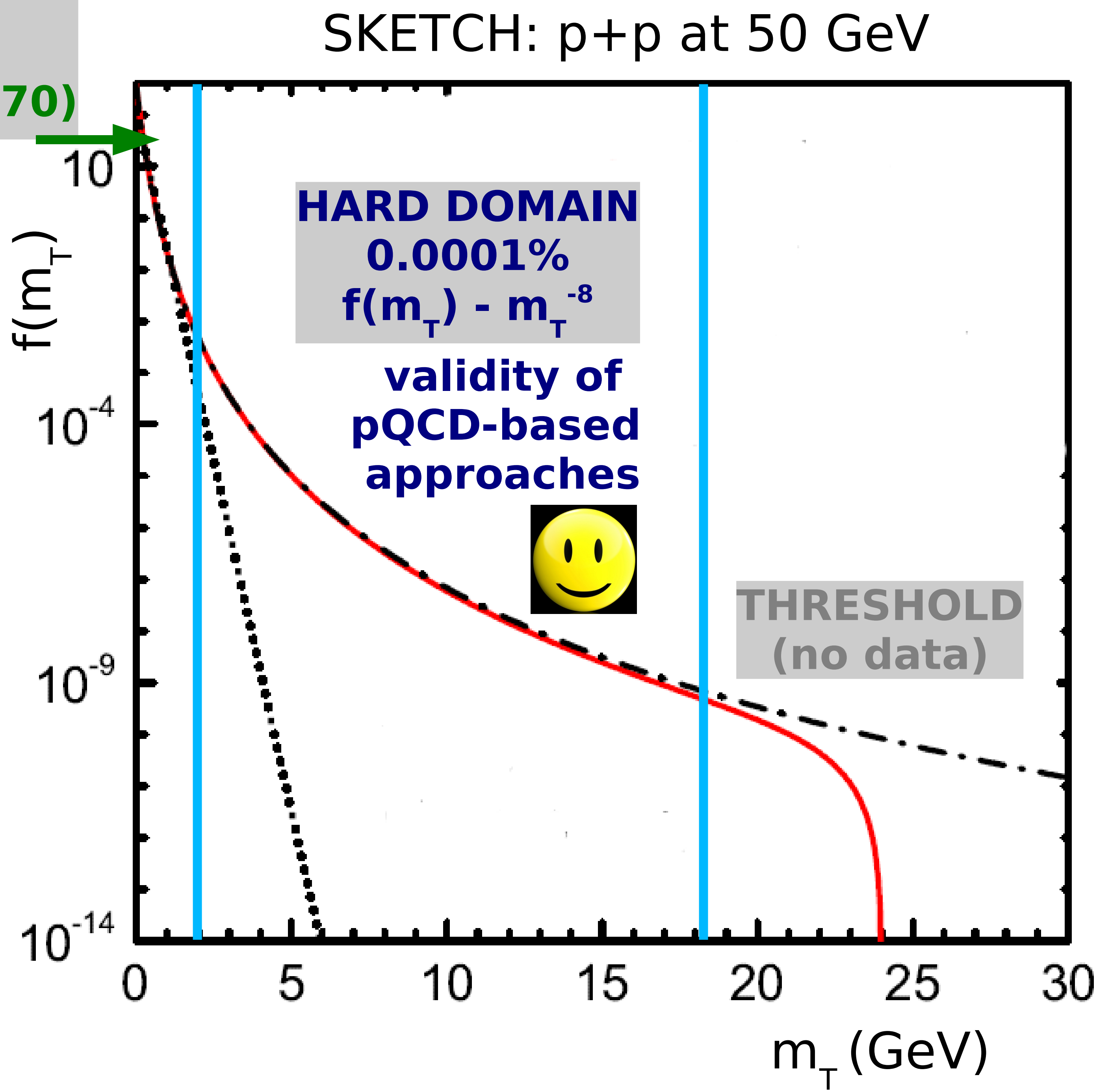
''CERN was built in order to find out how strong interactions work.
After 50 years we still do not know the answer.''

Lucien Montanet (1930-2003),
the sixth physicists to be employed at CERN

Sketch of the experimental m_T spectrum

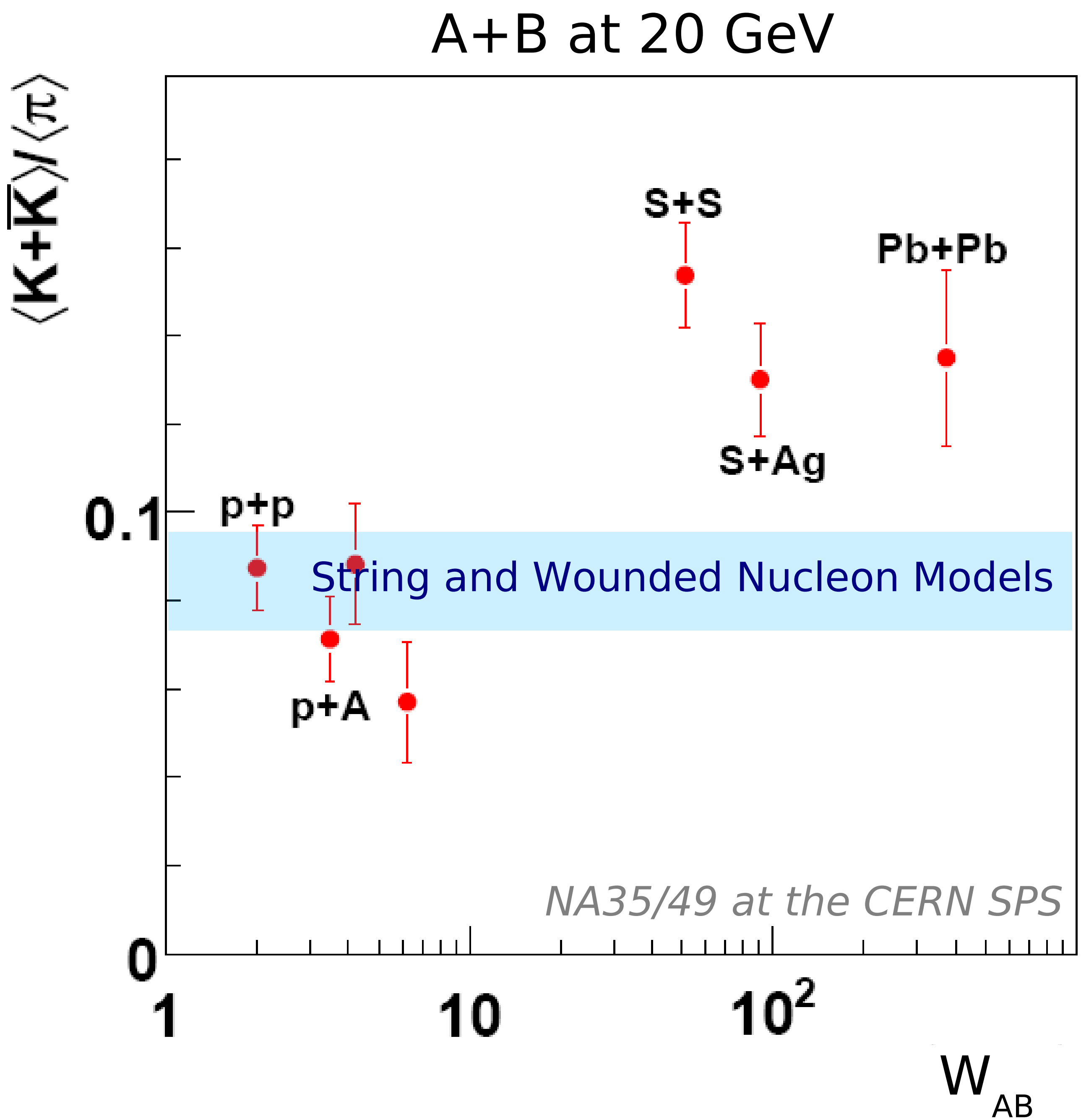
SOFT DOMAIN
99.9999%
$f(m_T)$ - $\exp(-m_T/0.170)$

validity of statistical approaches



String and Wounded Nucleon Models

SOFT/DYNAMICAL

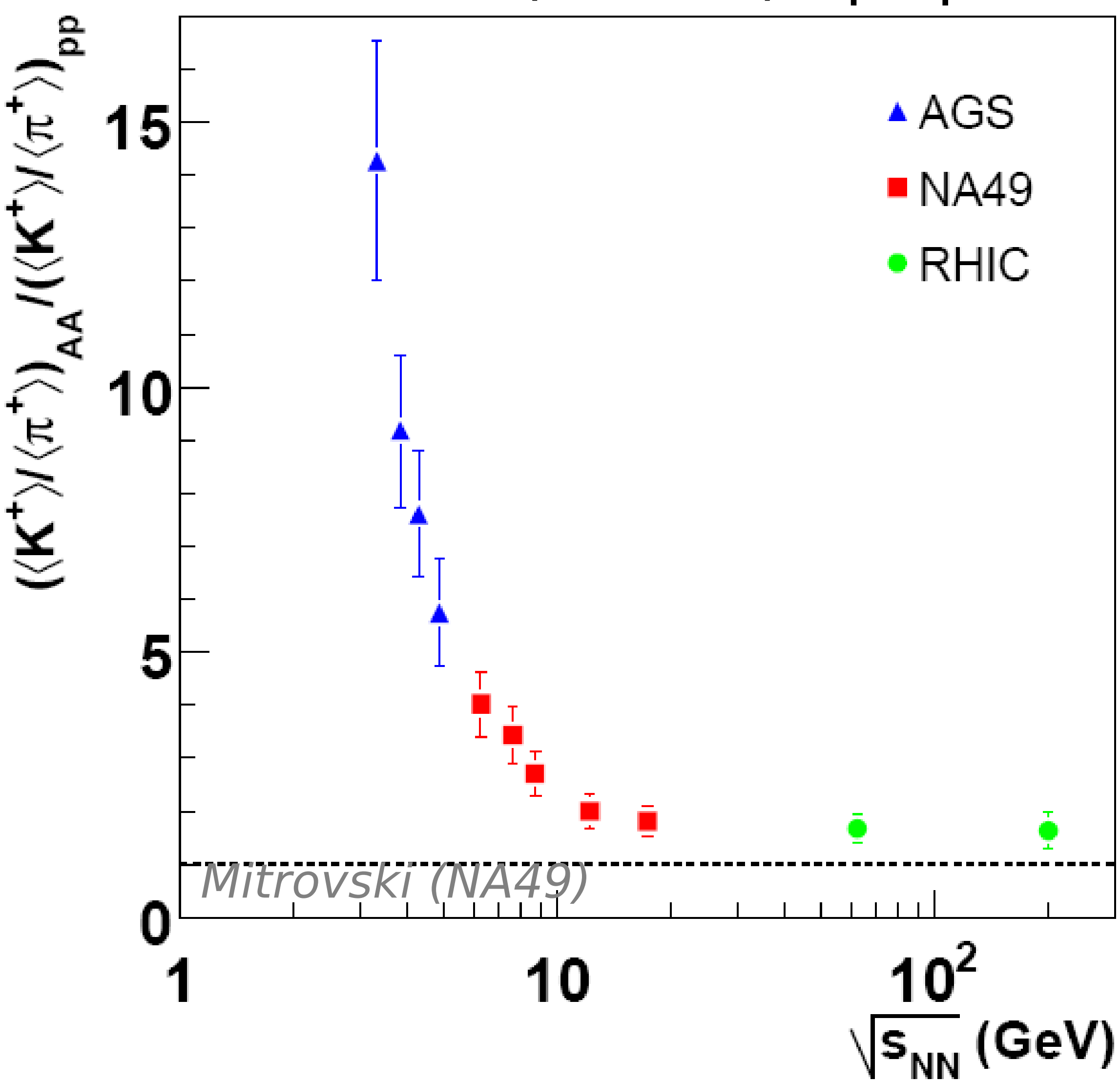


strangeness enhancement

QCD-inspired models of QGP signals: strangeness enhancement

SOFT/DYNAMICAL

Pb+Pb (Au+Au) / p+p



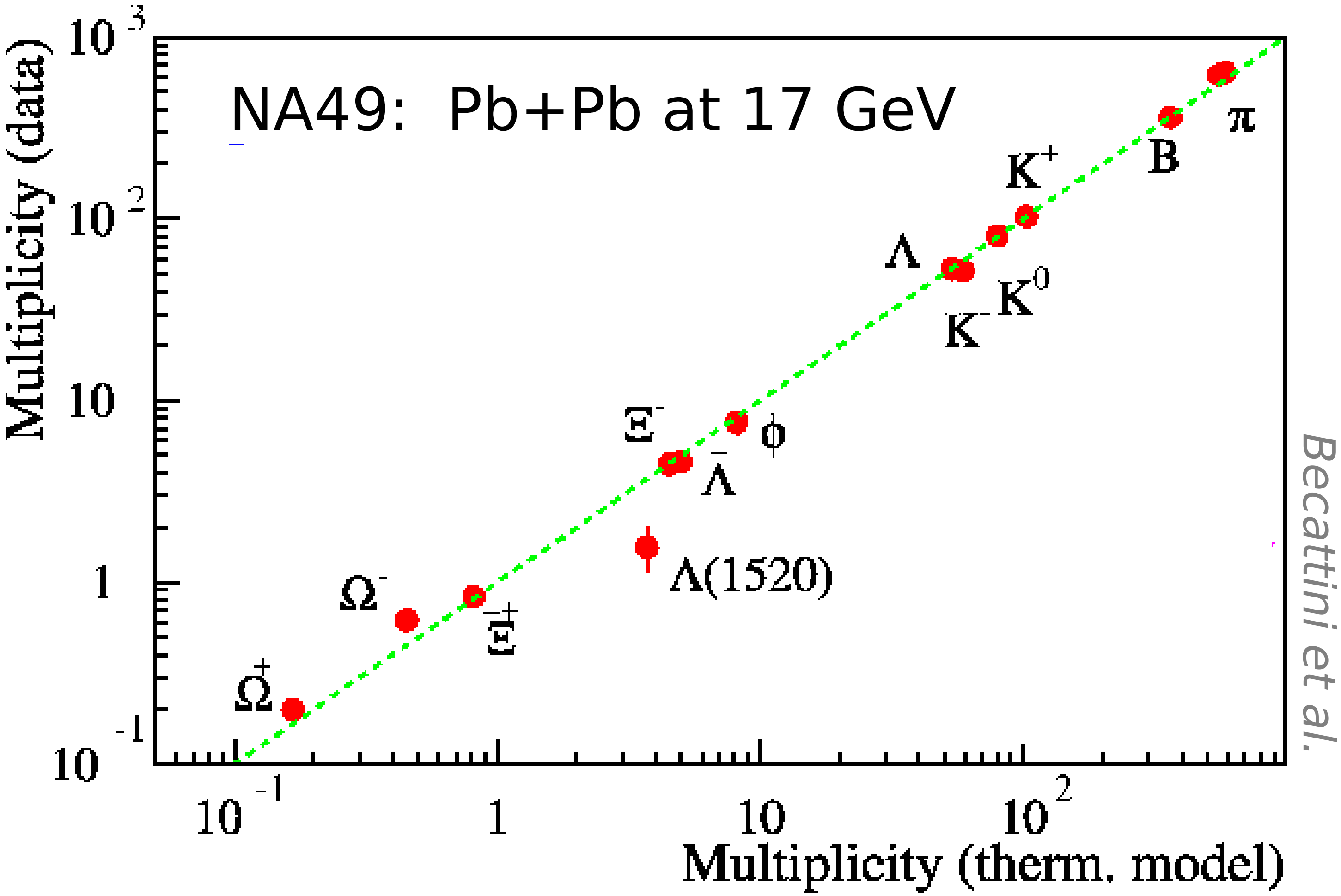
strangeness enhancement:

increases with decreasing collision energy

interpretation as the QGP signal is not obvious

Discoveries of strongly interacting matter (A)

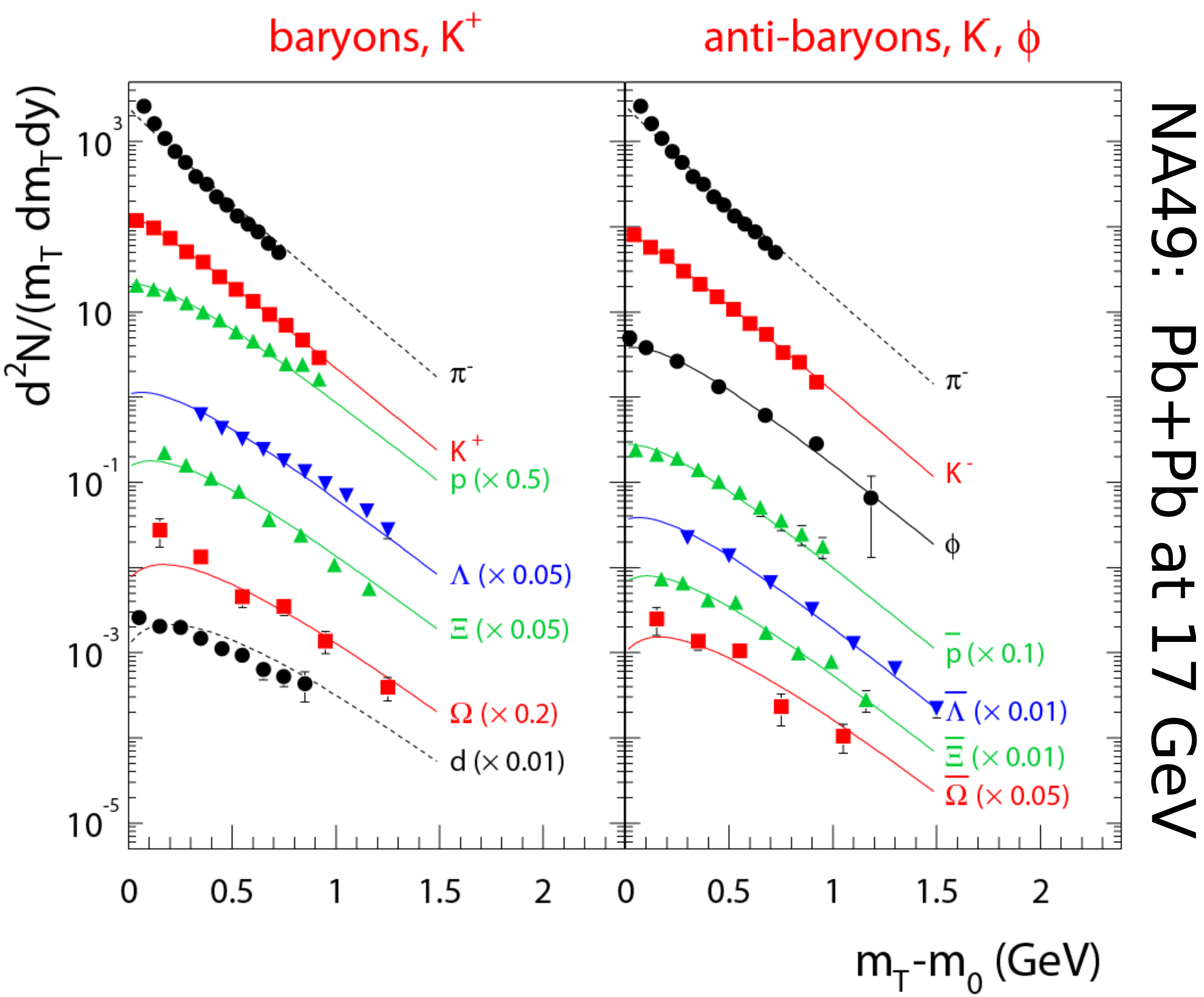
SOFT/STATISTICAL



success of hadron-resonance gas model in describing hadron yield systematics from AGS, SPS and RHIC

Discoveries of strongly interacting matter (B)

SOFT/STATISTICAL

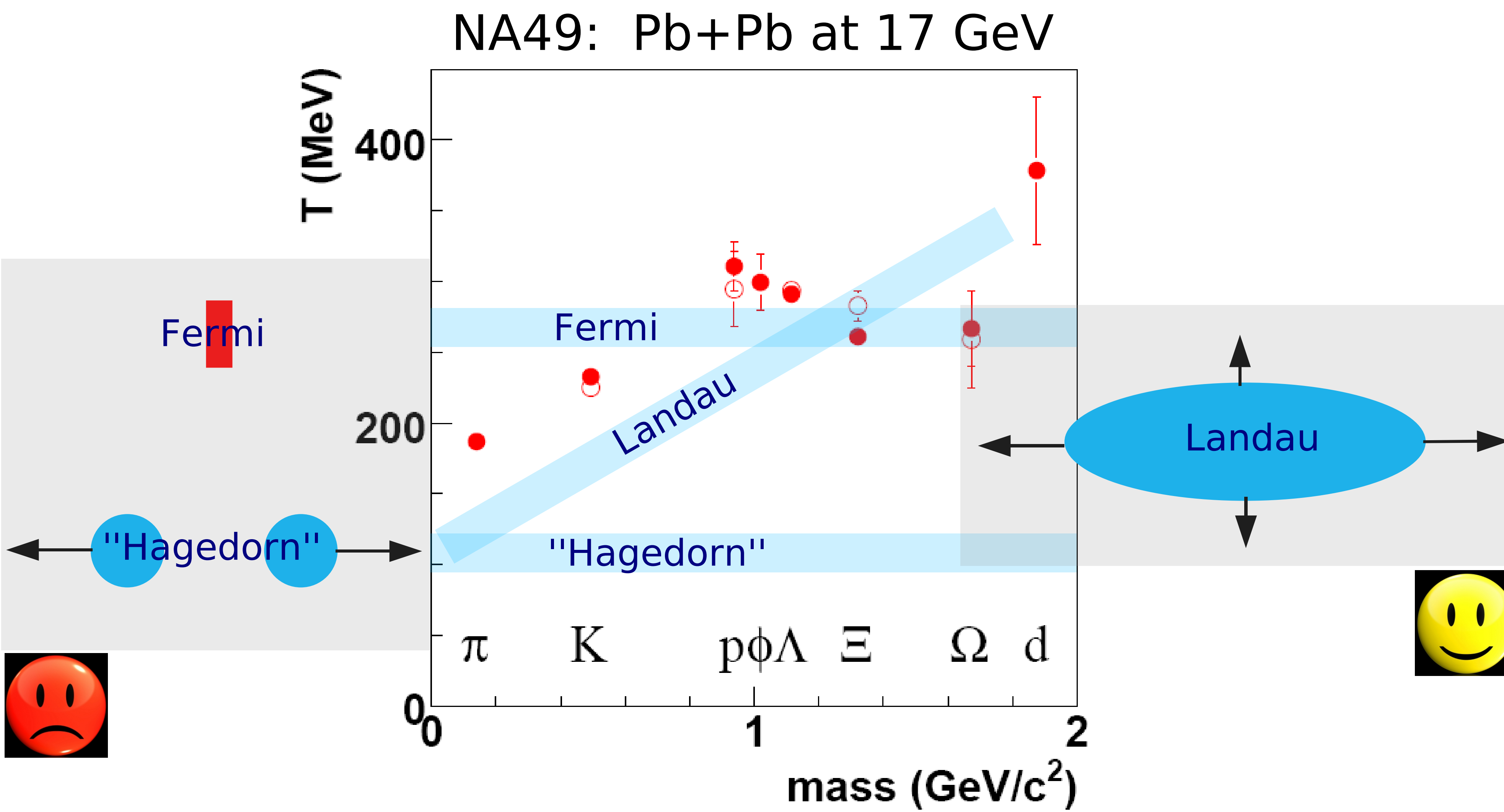


+Broniowski,
Florkowski
at RHIC

success of hydrodynamical models
in describing hadron spectra/(anisotropic flow)
systematics from AGS, SPS and RHIC

Discoveries of strongly interacting matter (C)

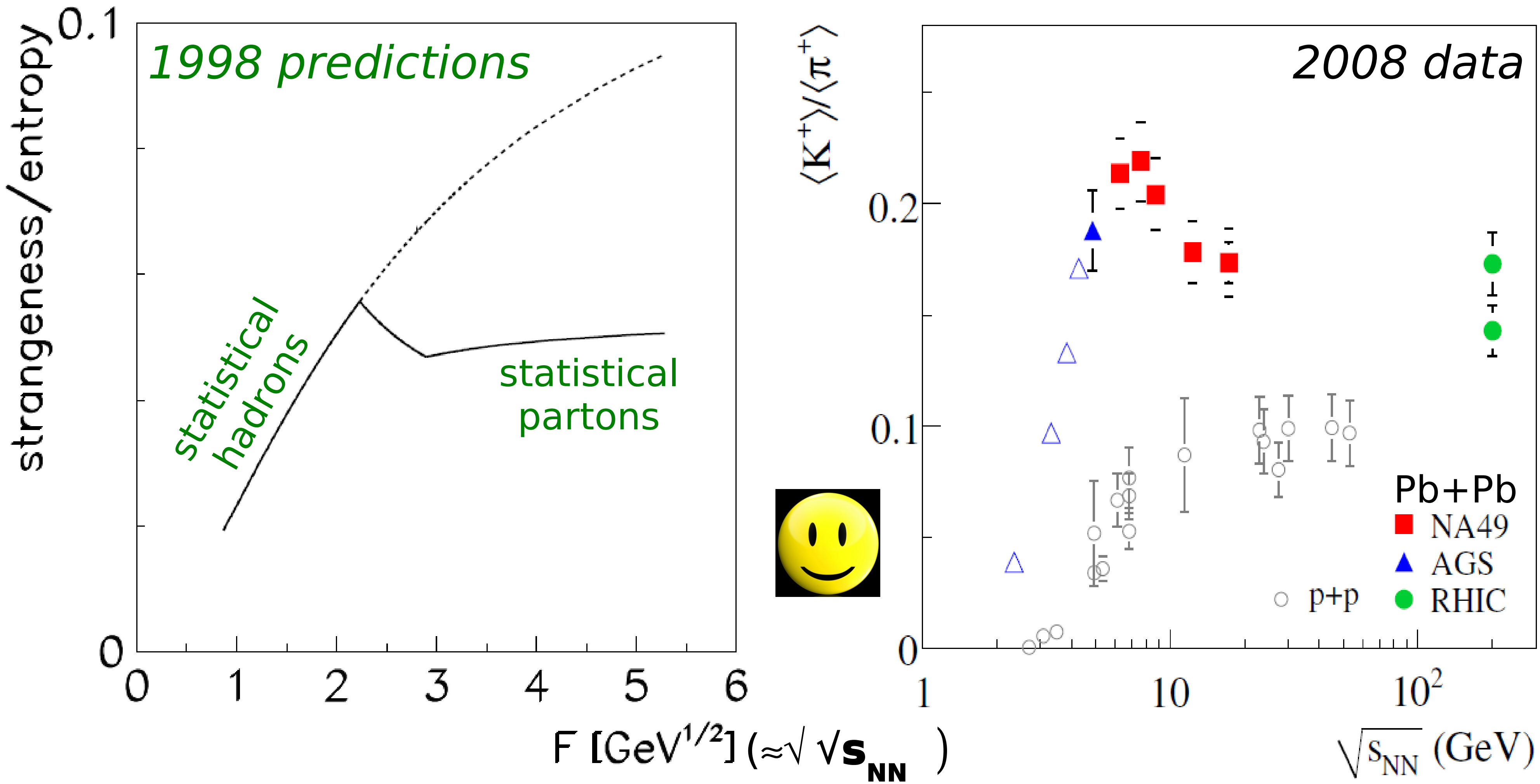
SOFT/STATISTICAL



non-statistical effects (e.g. collective flow) are large and sensitive to properties of the early stage (e.g. phase transition)

Discoveries of the phase transition (A)

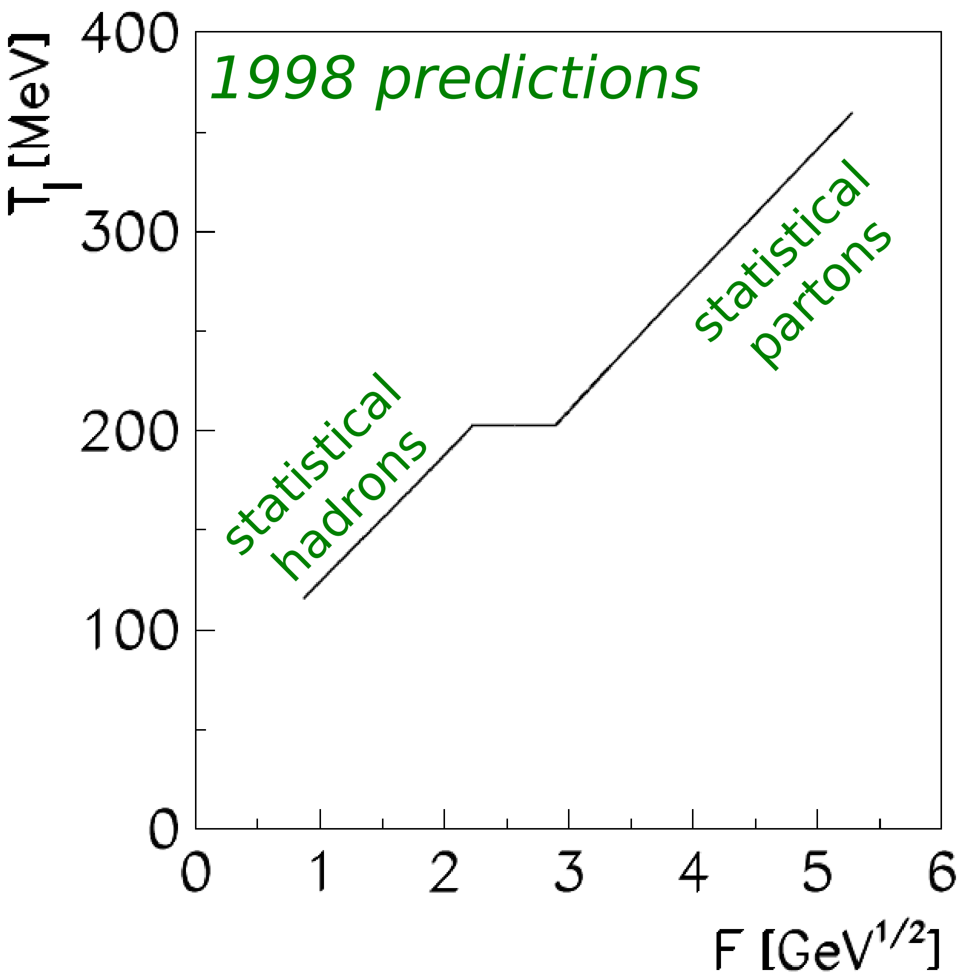
SOFT/STATISTICAL

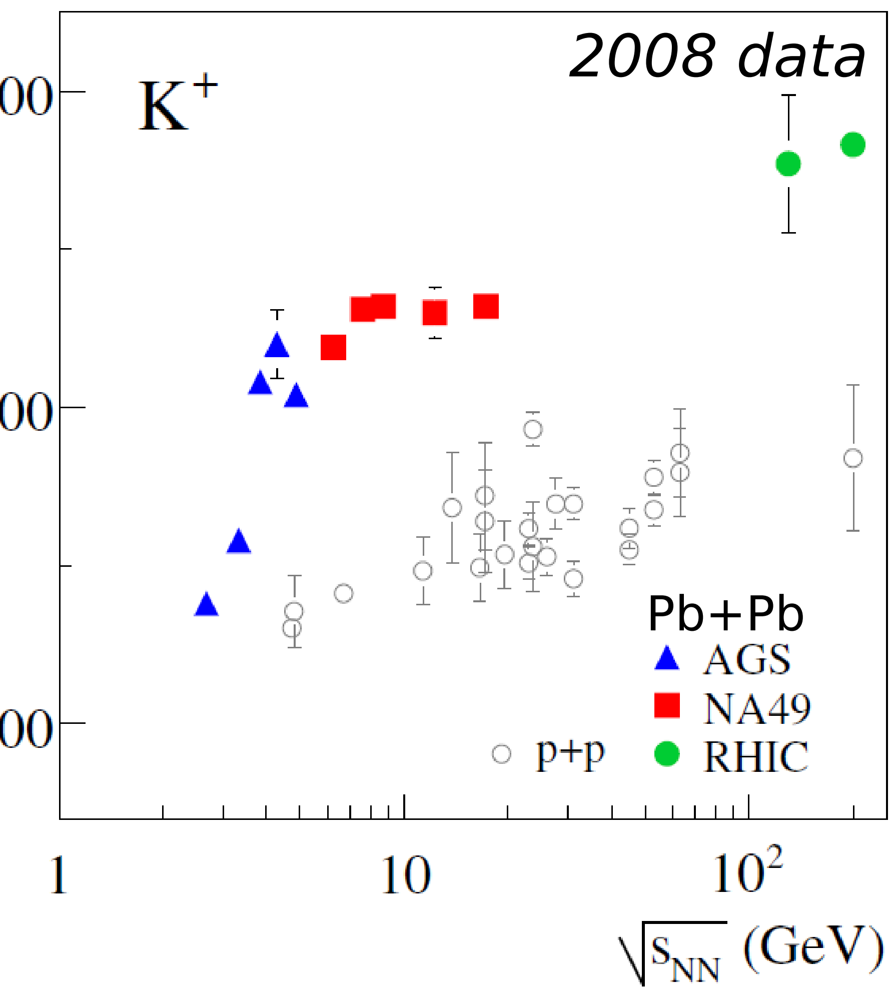


rapid changes in energy dependence of hadron production properties provide evidence for the phase transition

Discoveries of the phase transition (B)

SOFT/STATISTICAL



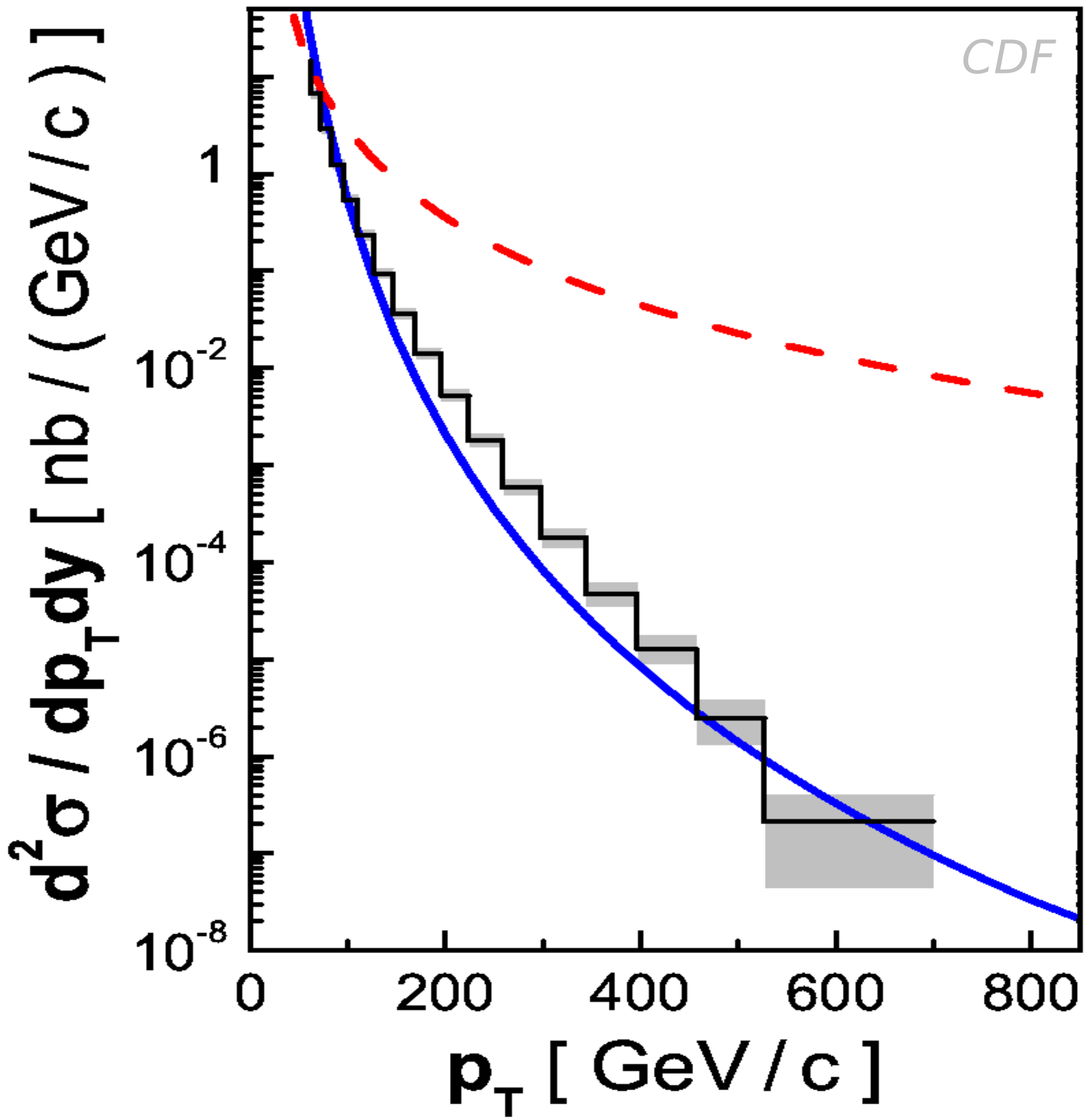


rapid changes in energy dependence of hadron production properties provide evidence for the phase transition

pQCD-based model of high p_T phenomena

HARD/DYNAMICAL

$p+\bar{p}$ at 1.8 TeV



Field, Feynman:
asymptotic free theory:

p_T^{-4}

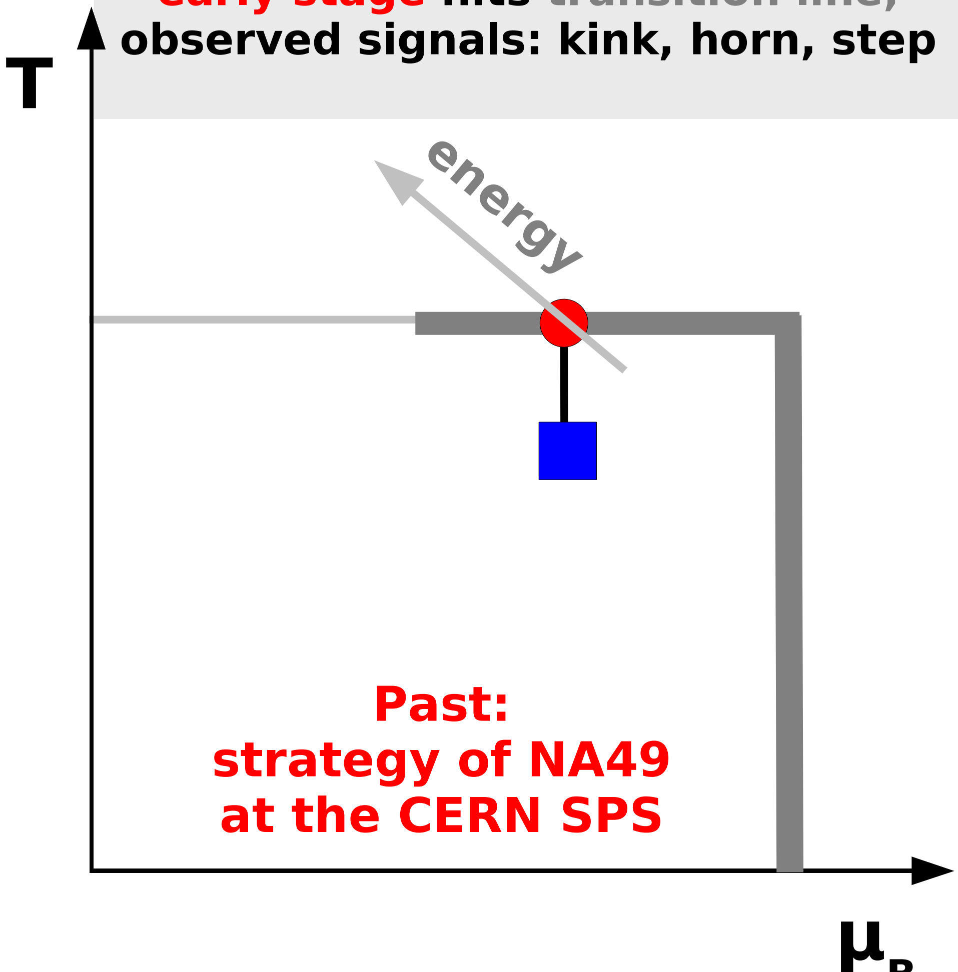
+
parton distribution,
parton fragmentation,
$2 \rightarrow 3$ processes,
conservation laws

p_T^{-8}

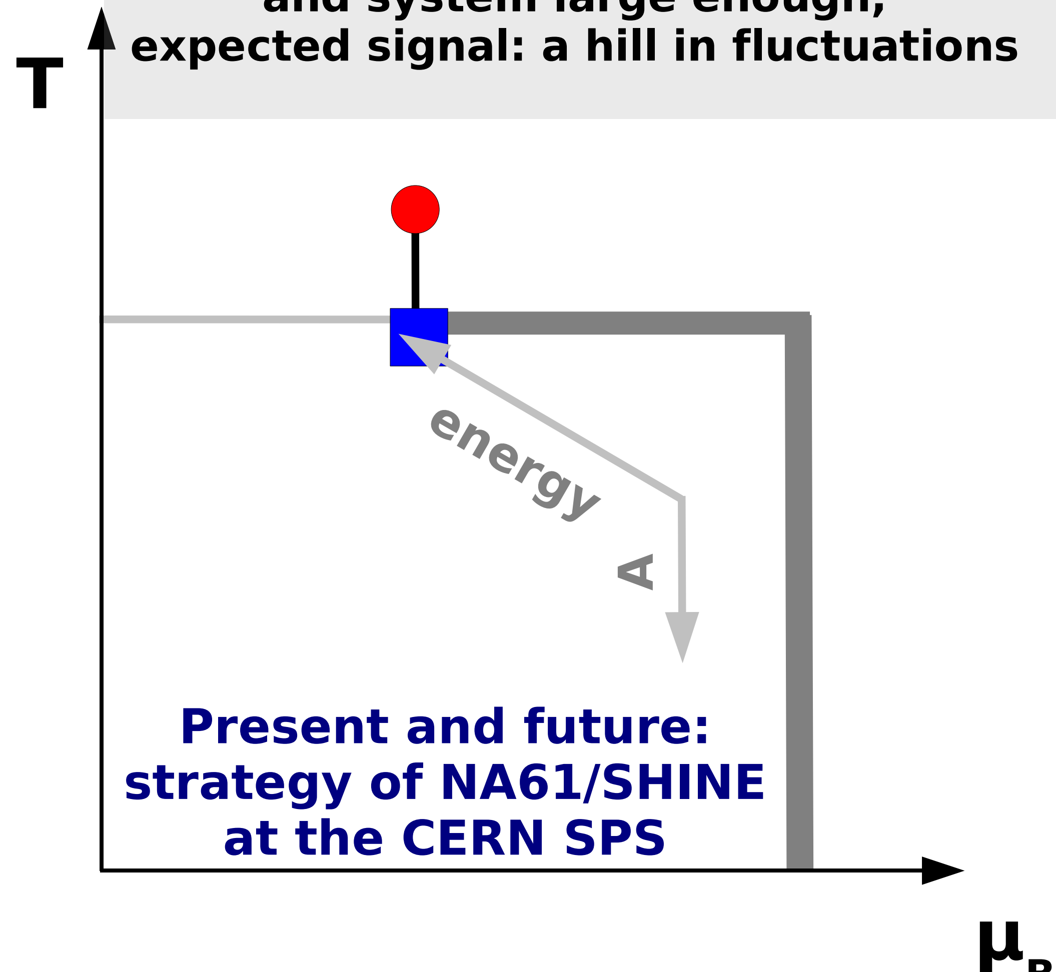
Properties of the transition line (A)

SOFT/STATISTICAL

Onset of Deconfinement:
early stage hits transition line,
observed signals: kink, horn, step

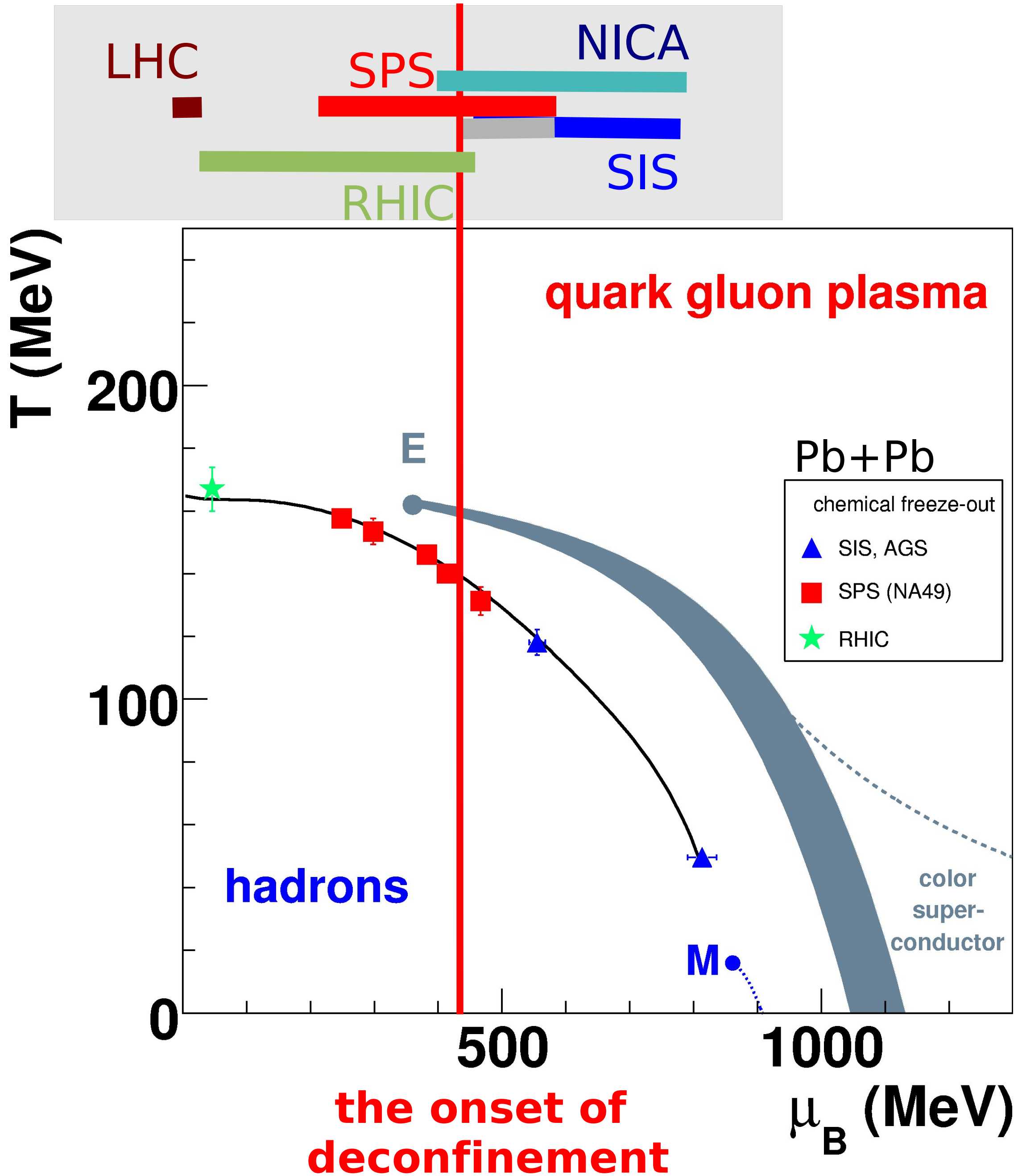


Critical Point:
freeze-out close to critical point,
and system large enough,
expected signal: a hill in fluctuations



Properties of the transition line (B)

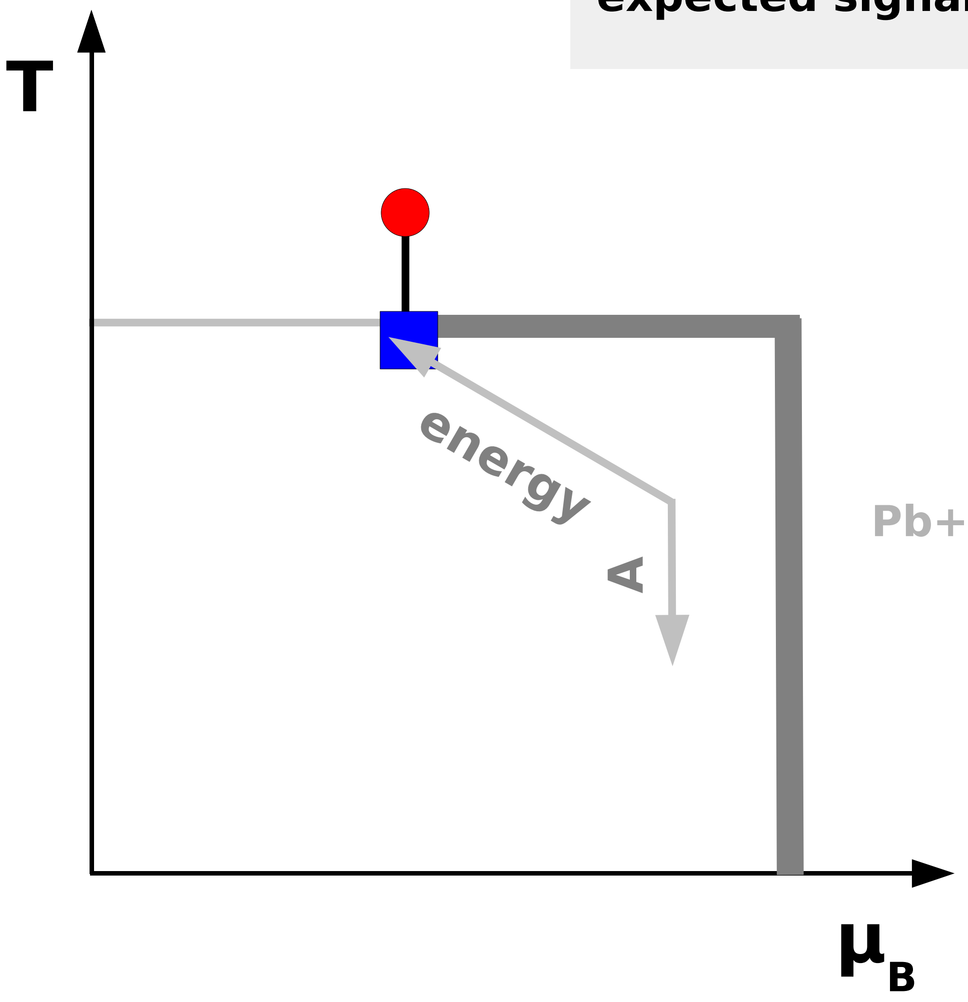
SOFT/STATISTICAL

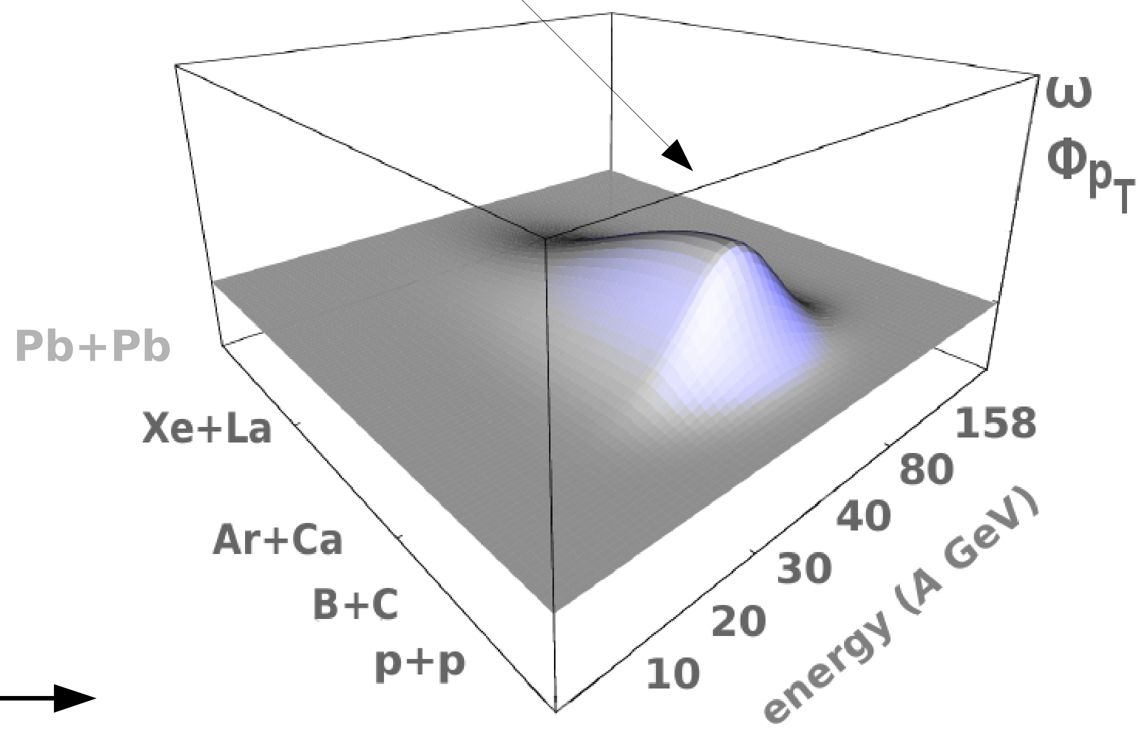


Properties of the transition line (C)

SOFT/STATISTICAL

Search for the critical point:
freeze-out close to critical point,
and system large enough,
expected signal: a hill in fluctuations

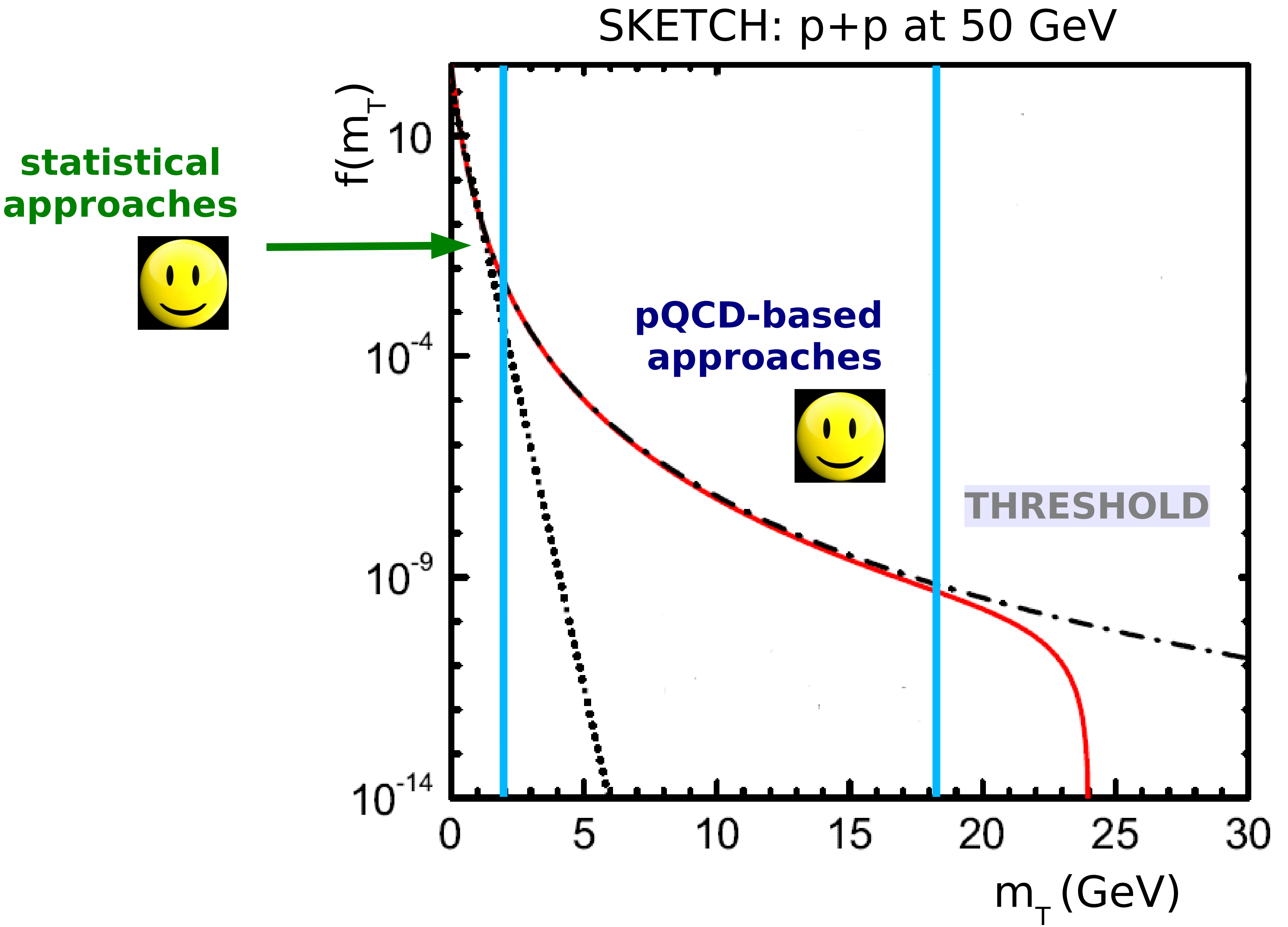




Stephanov et al., PRD60:114028
NA61 (M.G.), PoS CPOD2006:016

Towards unified description (A)

SOFT+HARD/STATISTICAL/DYNAMICAL



Towards unified description (A)

SOFT+HARD/STATISTICAL/DYNAMICAL

Towards unified description of multi-particle production in high energy collisions:

- solve QCD or develop quantitative approximations in the soft region

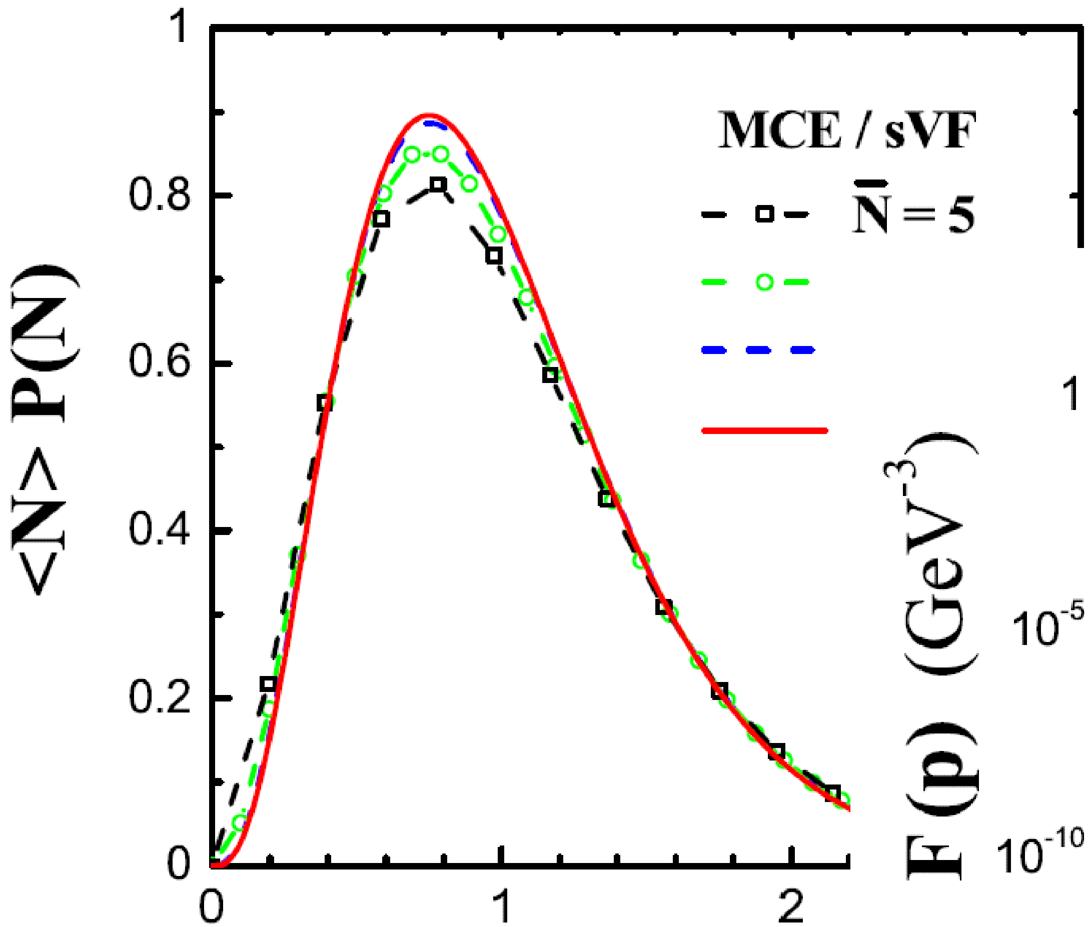
- extend statistical approach to the hard region

- new ideas

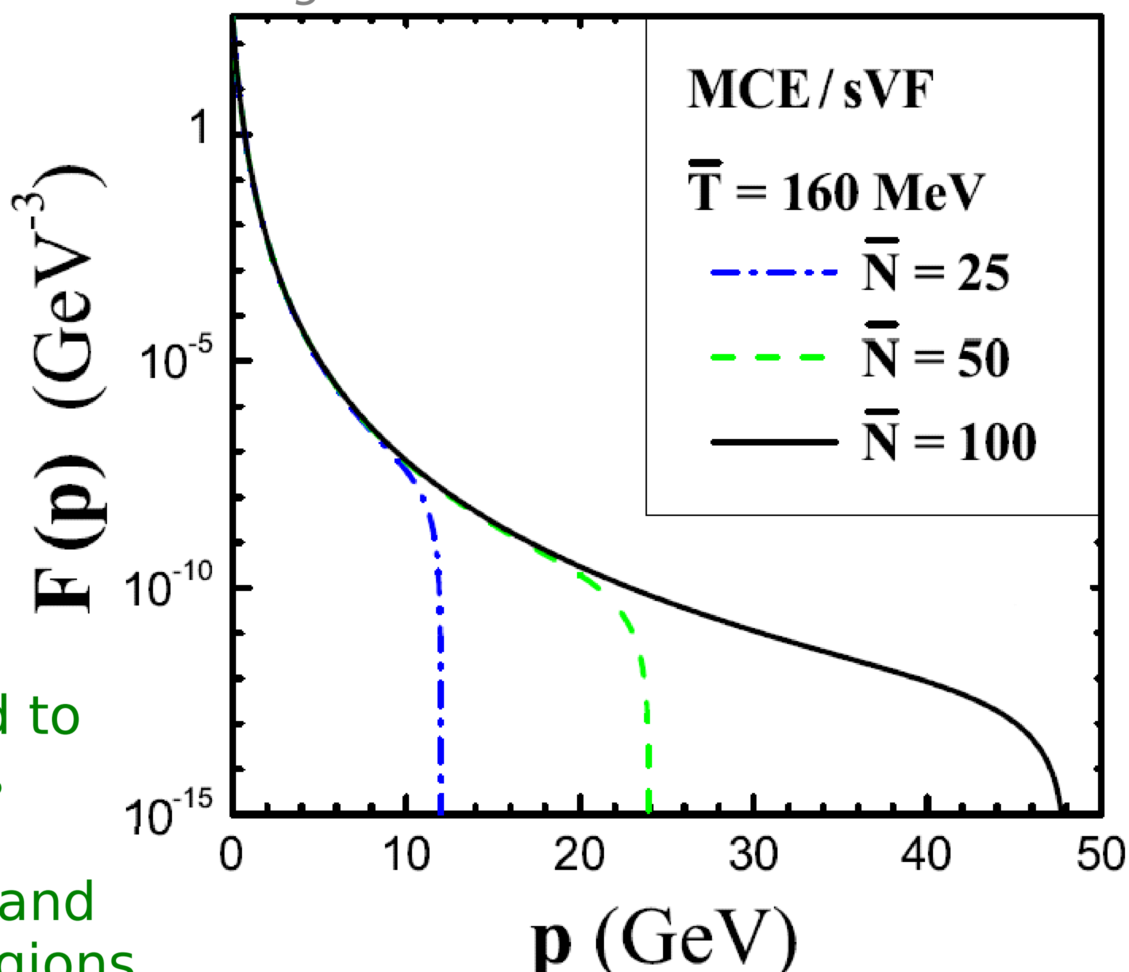
Towards unified description (B)

Volume fluctuations in micro-canonical statistical ensemble

SOFT+HARD/STATISTICAL



Begun et al.

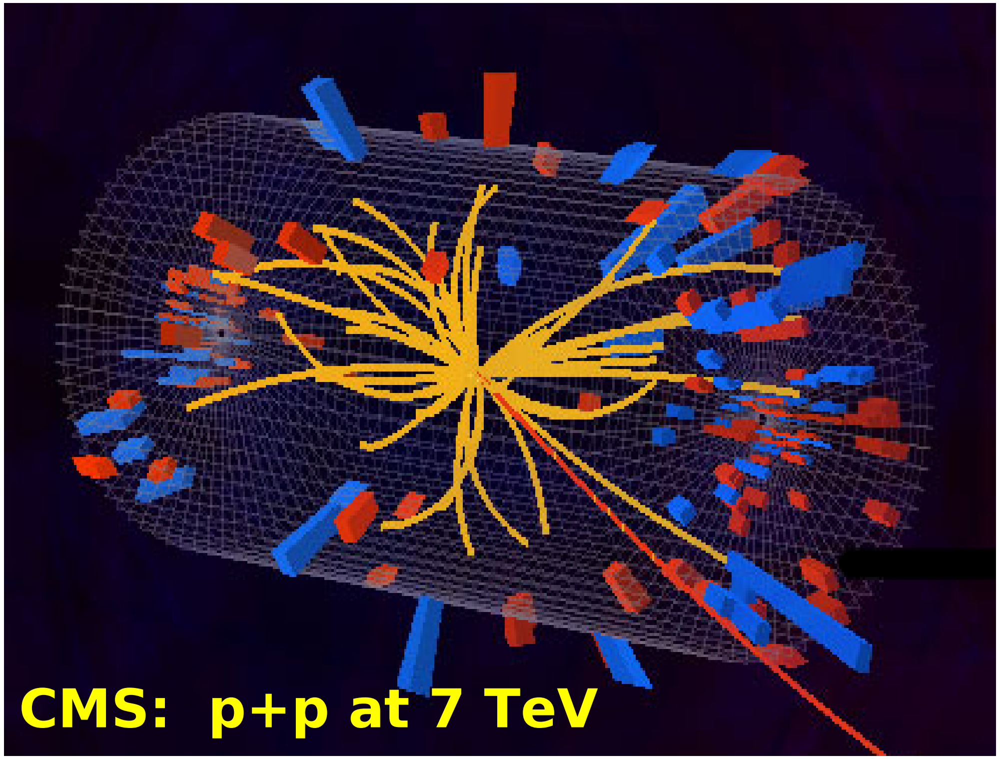


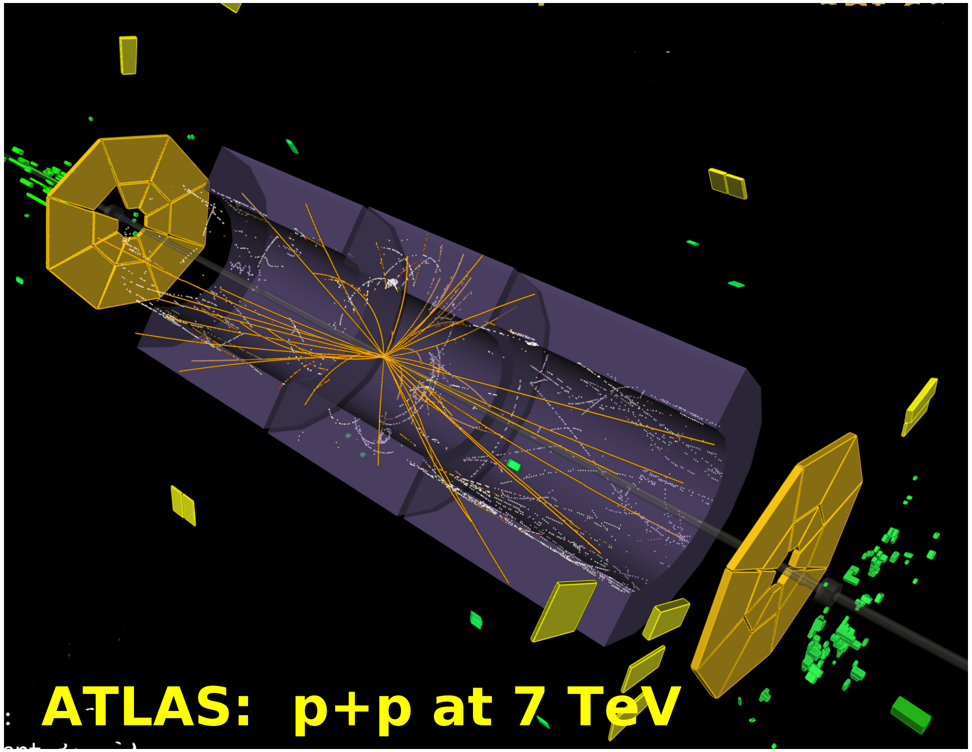
scaling V fluctuations fitted to multiplicity distributions

exponential spectra in soft and power law spectra in hard regions

Towards unified description (C)
SOFT+HARD/STATISTICAL/DYNAMICAL

LHC: a powerful tool to test various ideas

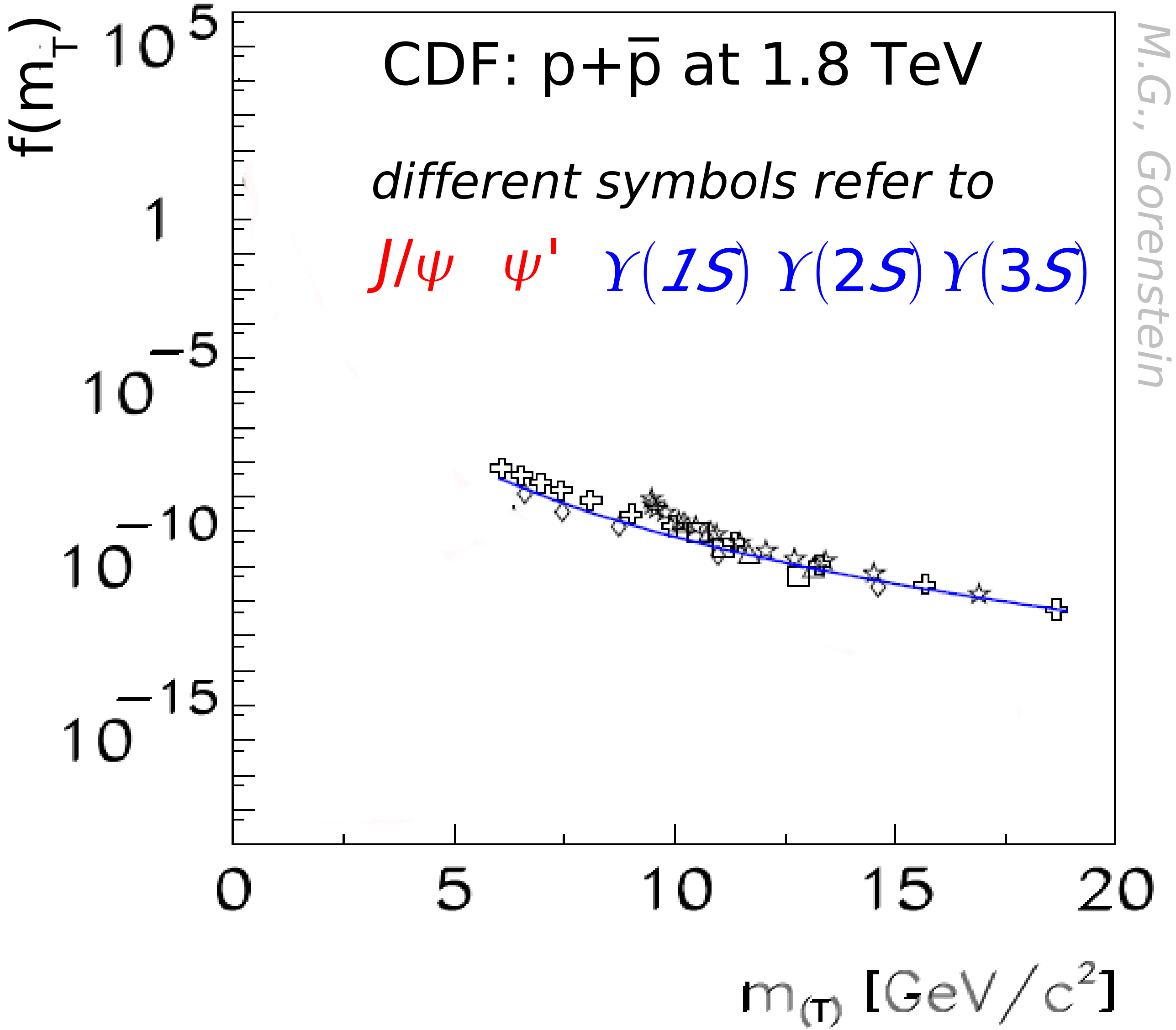




Towards unified description (D)

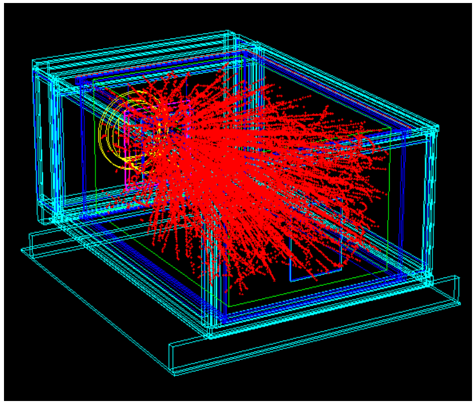
SOFT+HARD/STATISTICAL

e.g.: MCE/sVF: transverse mass spectra, $f(m_T)$, of different hadrons are the same as suggested by the Tevatron data

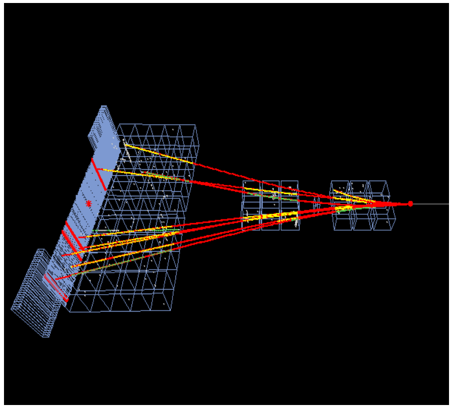


History, status and future of multi-particle production in high energy collisions

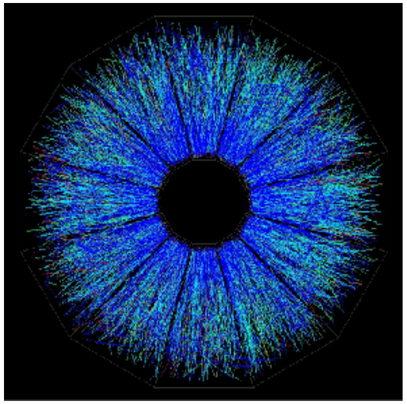
BNL AGS → CERN SPS → BNL RHIC → CERN LHC



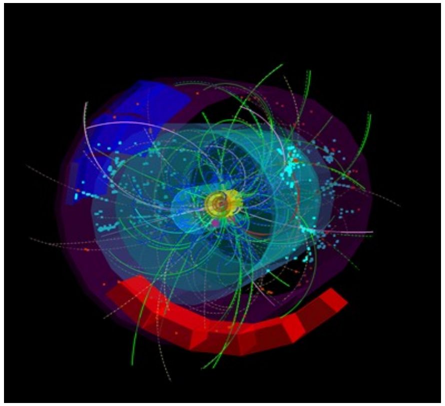
E895



NA61



STAR



ALICE

rich experimental data:

from p+p to Pb+Pb

from several GeV to several TeV

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2010+

2010+

Still many, many things to do

Additional slides