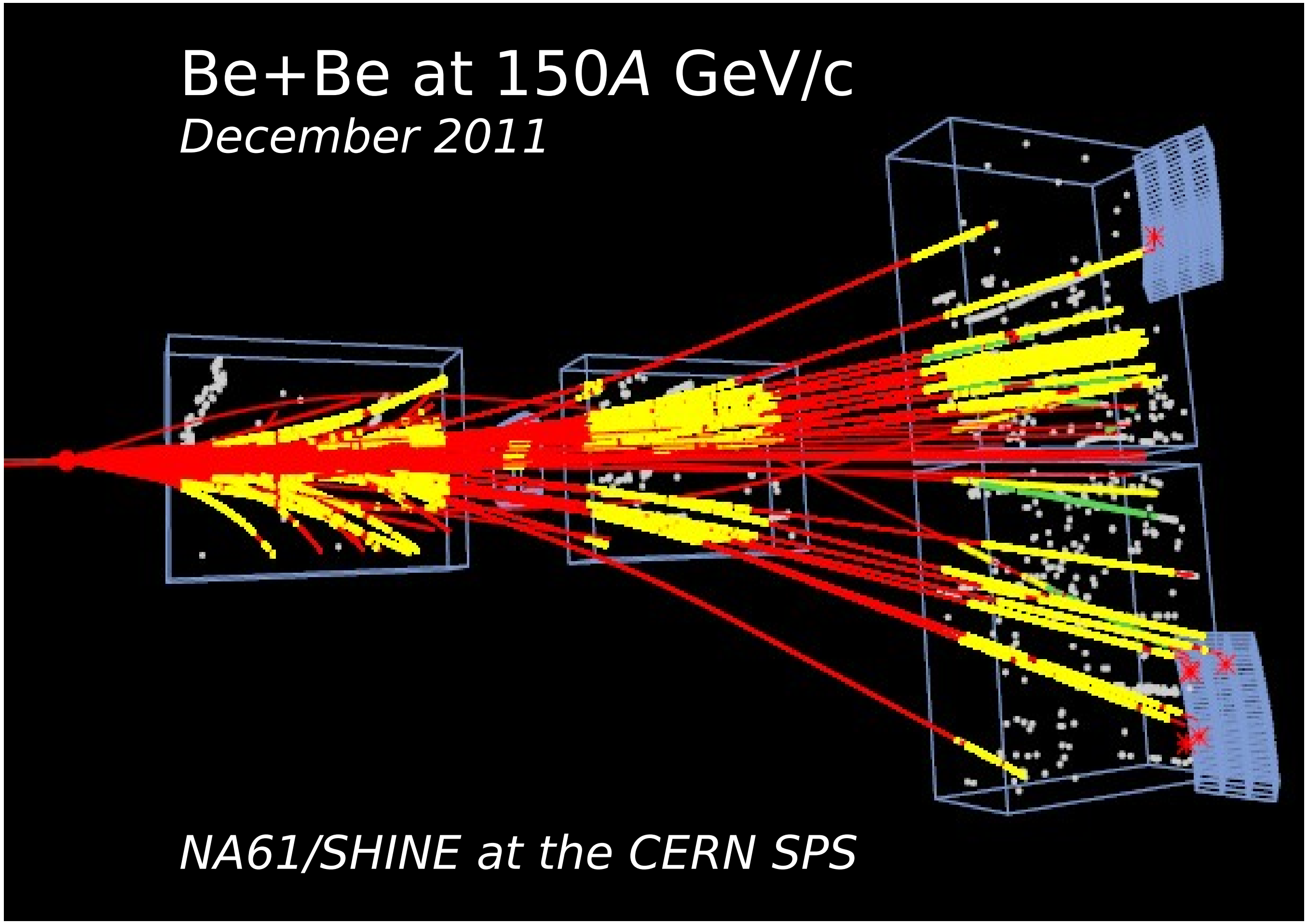
History, status and future of multi-particle production in high energy collisions



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).''

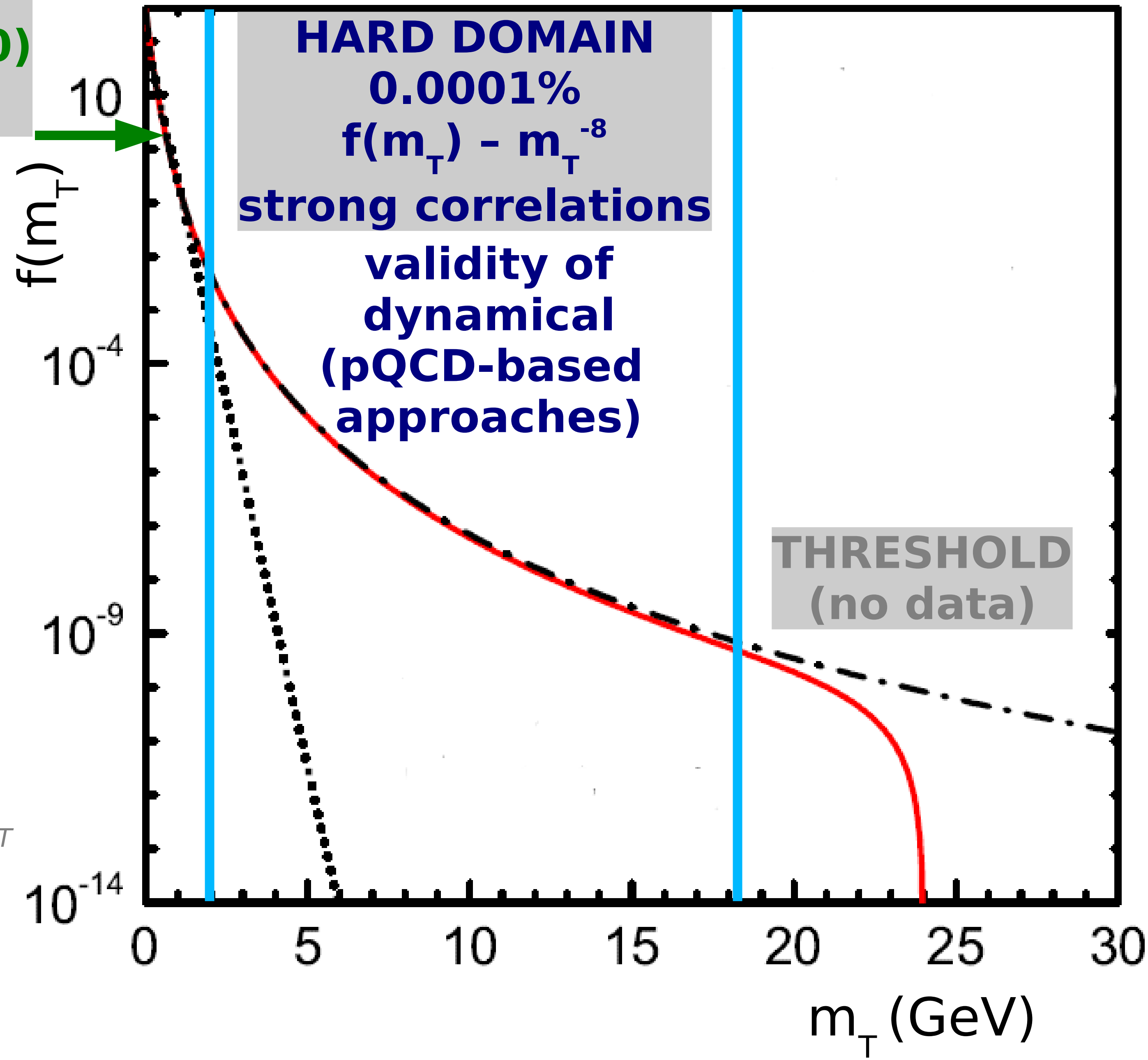
Thomas Samuel Kuhn (1922-1996)

Experimental and theoretical status

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

validity of statistical approaches

SKETCH: p+p at 50 GeV



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

Template:

19.. Experimental discoveries

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

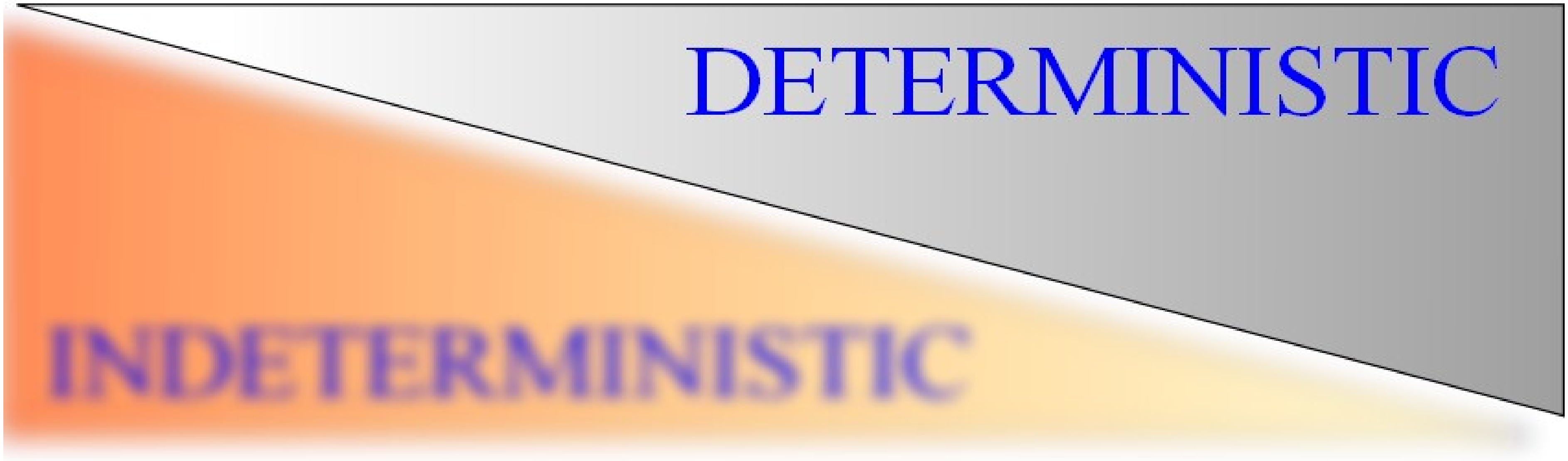
19.. ''dynamical'' models of particle production in high energy collisions

. . .

''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



maximal indeterminism

all states are equally probably

micro-canonical ensemble

statistical models

maximal determinism

only a single state has non-zero probability

classical dynamical models

≈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

2014+ future

2014+ future

≈1950 Discoveries of hadrons

Pioneering discoveries with cosmic-rays:

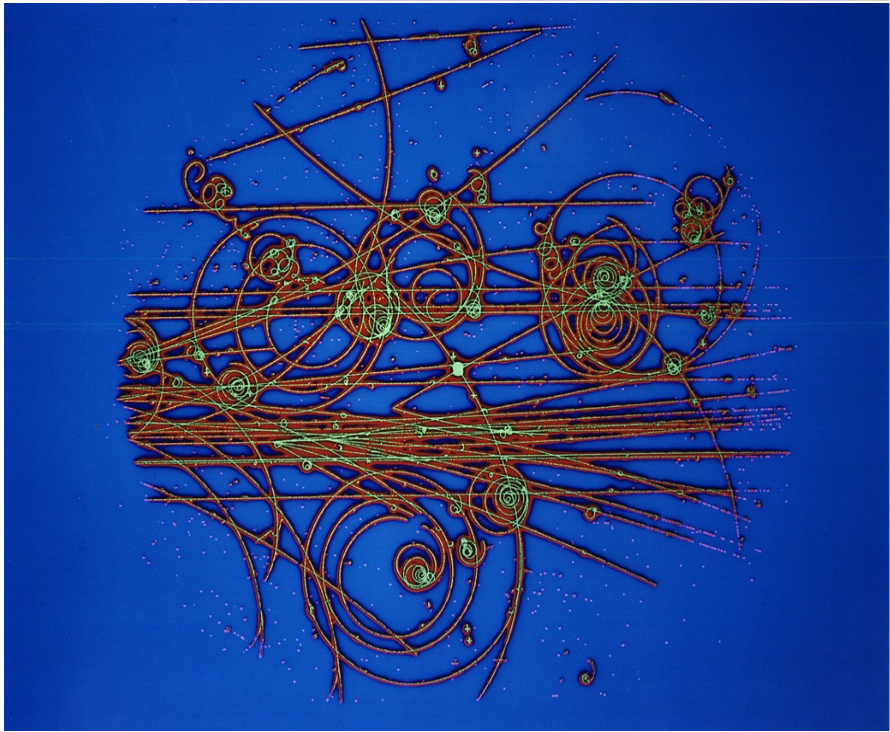
-1947: **pion** (emulsion, *Powell et al.*)
-1947: **kaon and Λ** (cloud chamber, *Rochester, Butler*)

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**
-1967	U-70 at IHEP	**70 GeV**
-1976:	Main Ring at FNAL	**500 GeV**
-1976:	SPS at CERN	**400 GeV**
...		
-2000:	RHIC	**20 000 GeV**
-2009:	LHC	**30 000 000 GeV**

maximum energy in the fixed target system

2010: about 1000 hadronic states



≈1950/60 statistical hadron production

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

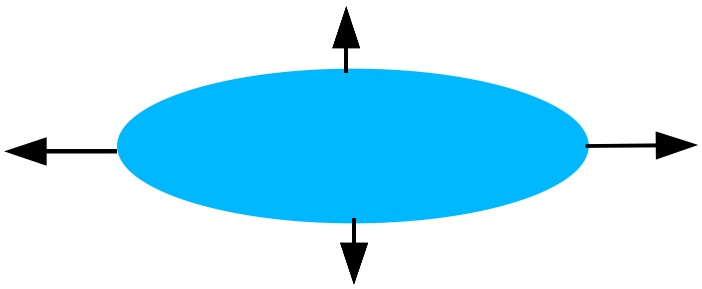
Pioneering ideas/models:

-1950: E. Fermi

statistical hadron production: $T = T_I \sim s_{NN}^{1/4}$

-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

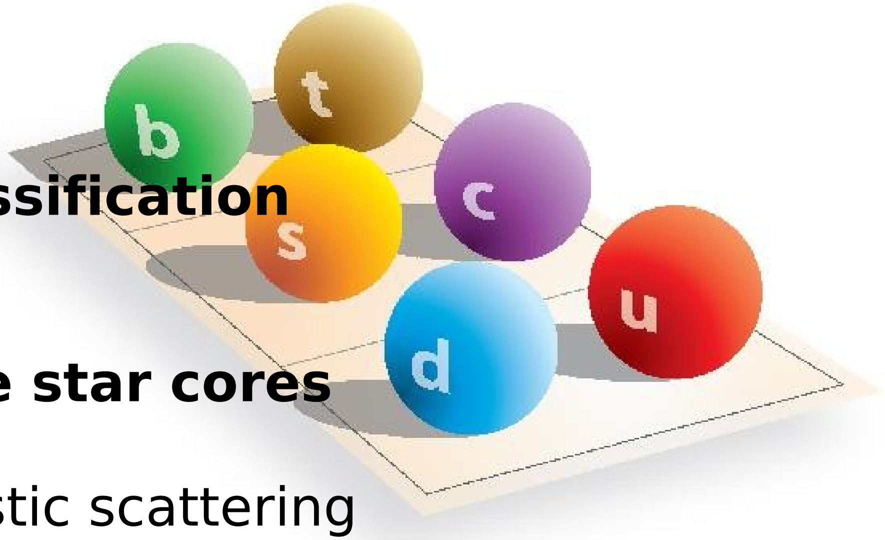
≈1960: T. Regge + G. Chew, S. Frautschi, J. Collins
Regge theory

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

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

$$<N>_{AB} = w_{AB}/2 \circ <N>_{NN}$$

≈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

≈1975: 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

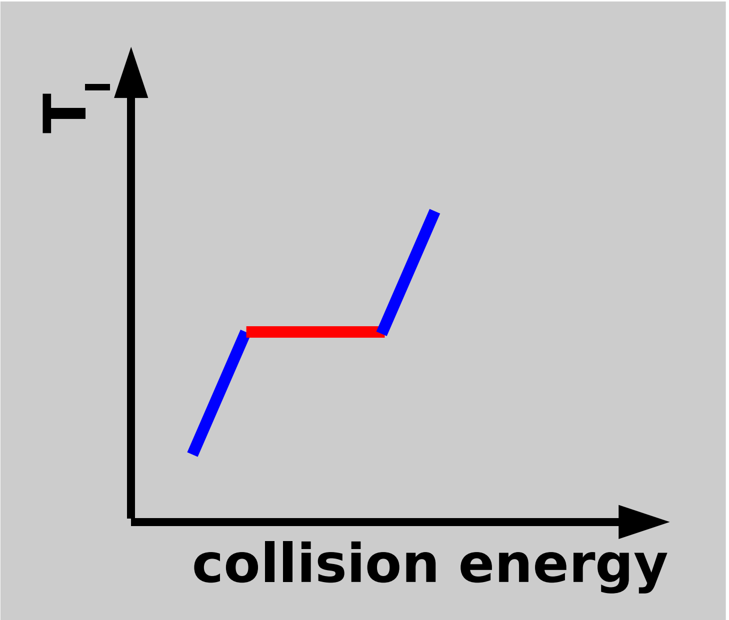
statistical parton production

Pioneering ideas/models:

-1975: N. Cabibbo, G. Parisi
$T_C = T_H \approx$ 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 $T < T_C$
transition at the SPS energies



≈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

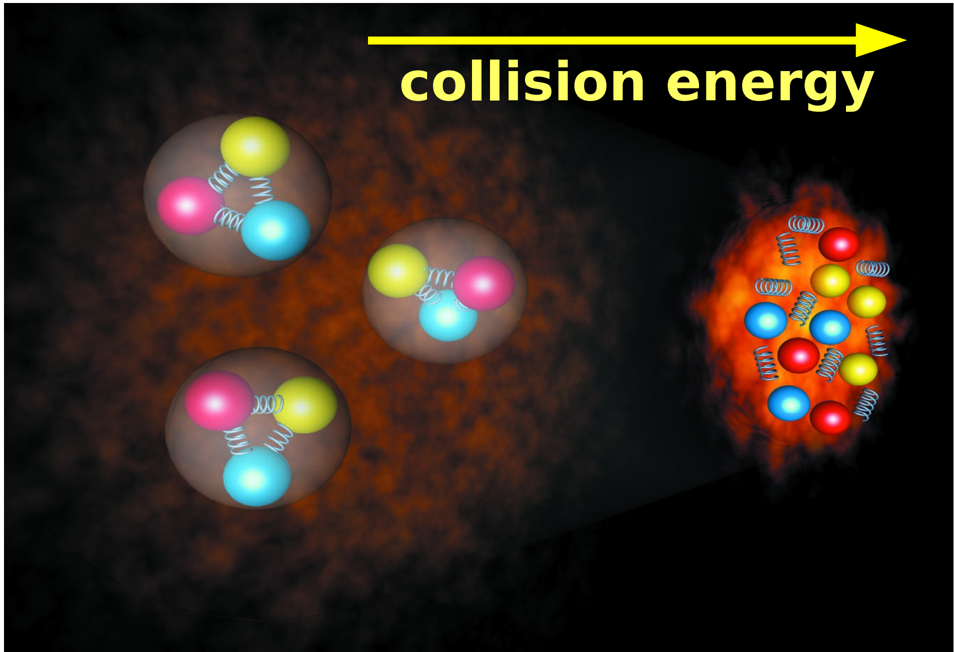
≈1990/00 Discoveries of strongly interacting matter and its phase transition

Pioneering ideas/experiments:

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

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

AGS SPS RHIC LHC



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2014+ future

2014+ future

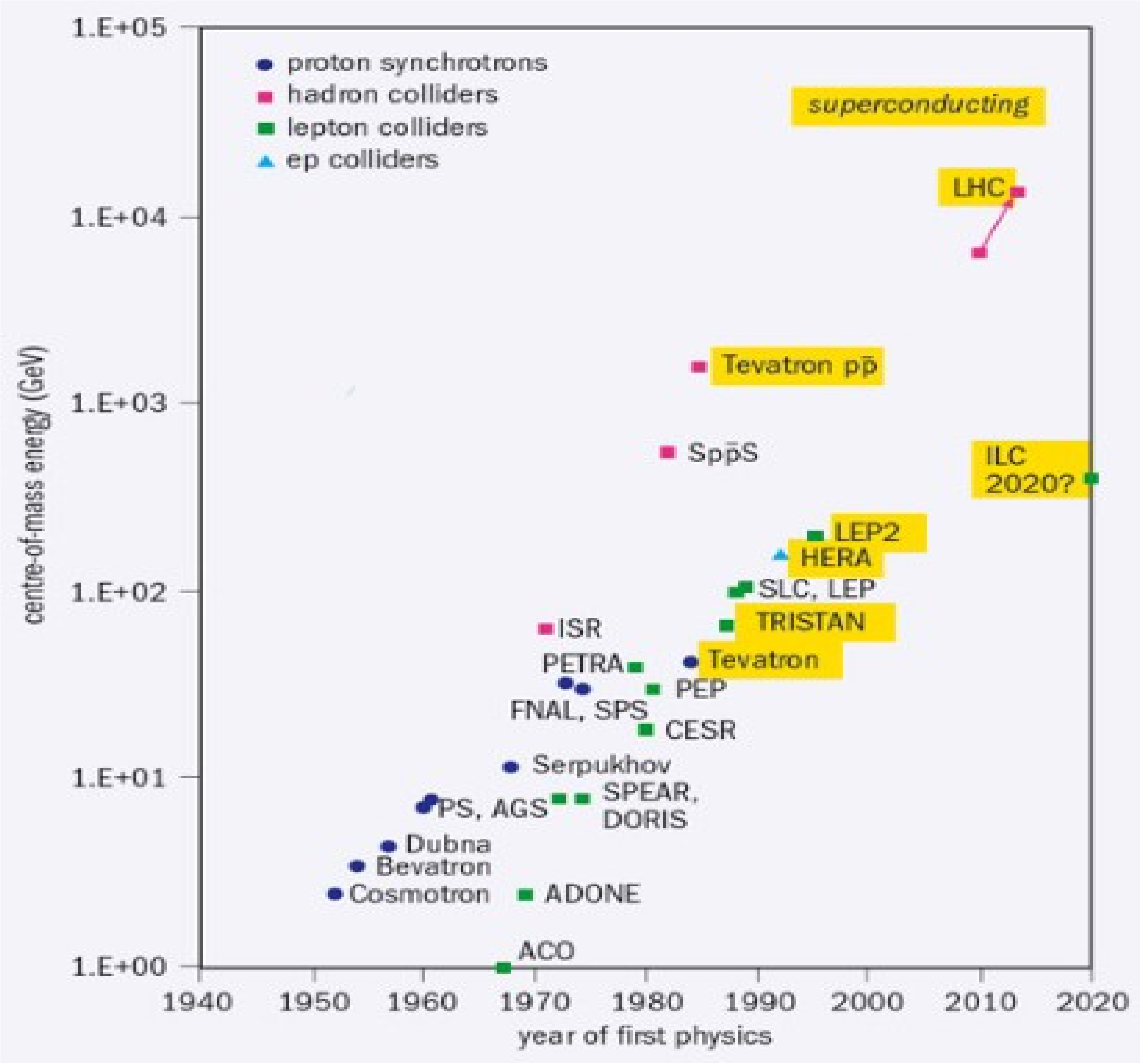
Status

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.''

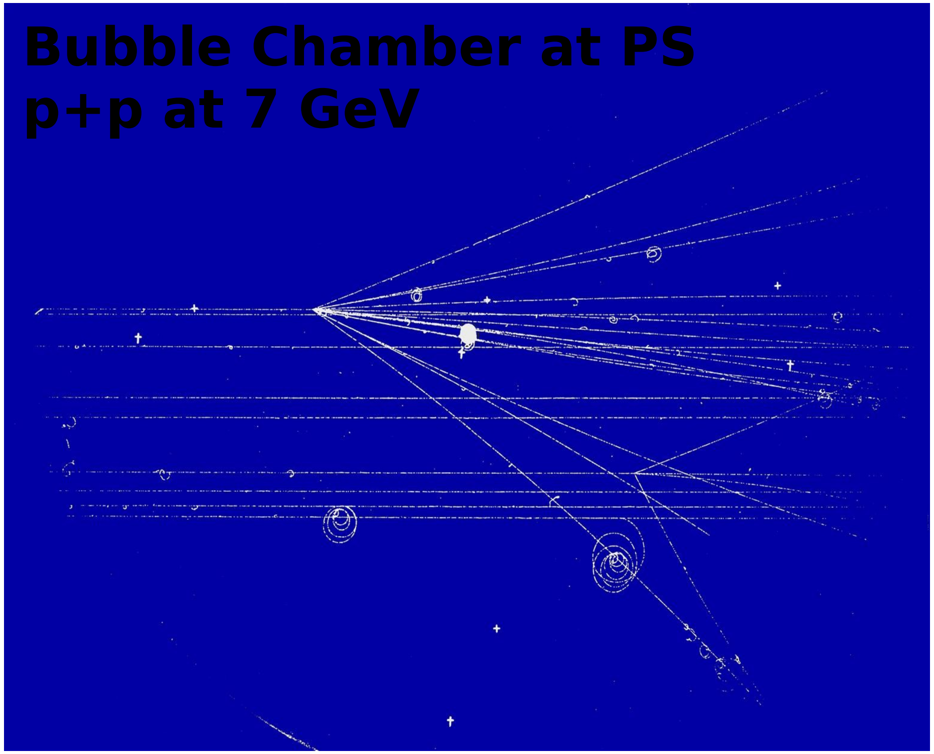
Lucien Montanet (1930-2003),
the sixth physicists to be employed at CERN

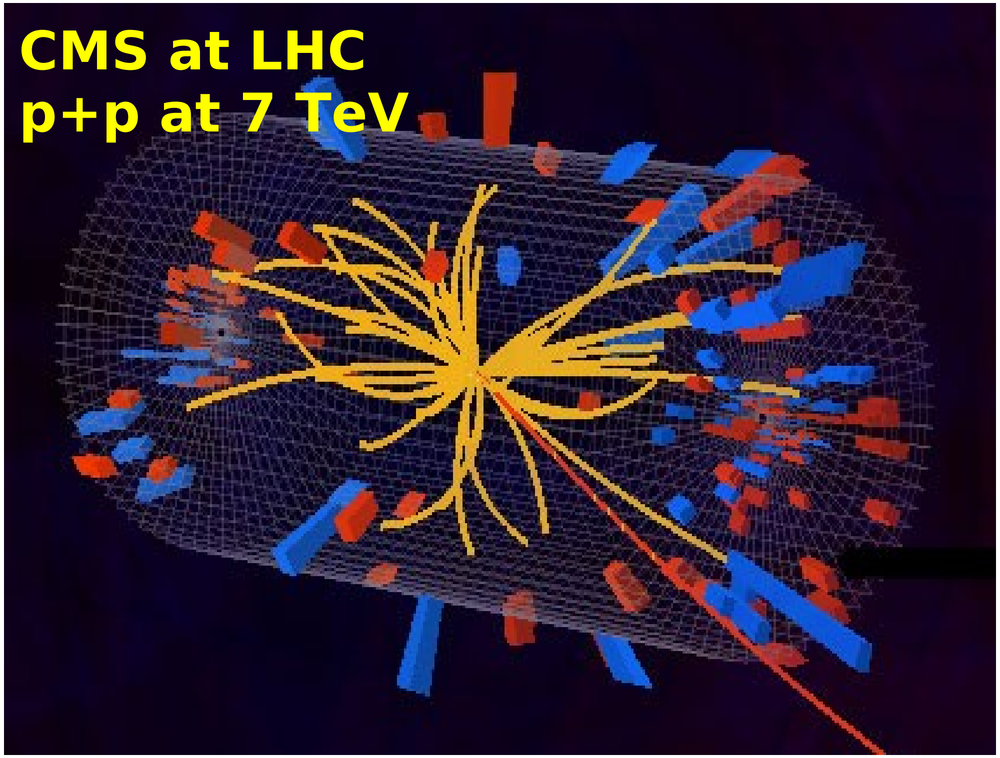
Basic experimental tools: accelerators



Cern Courier, October 2011

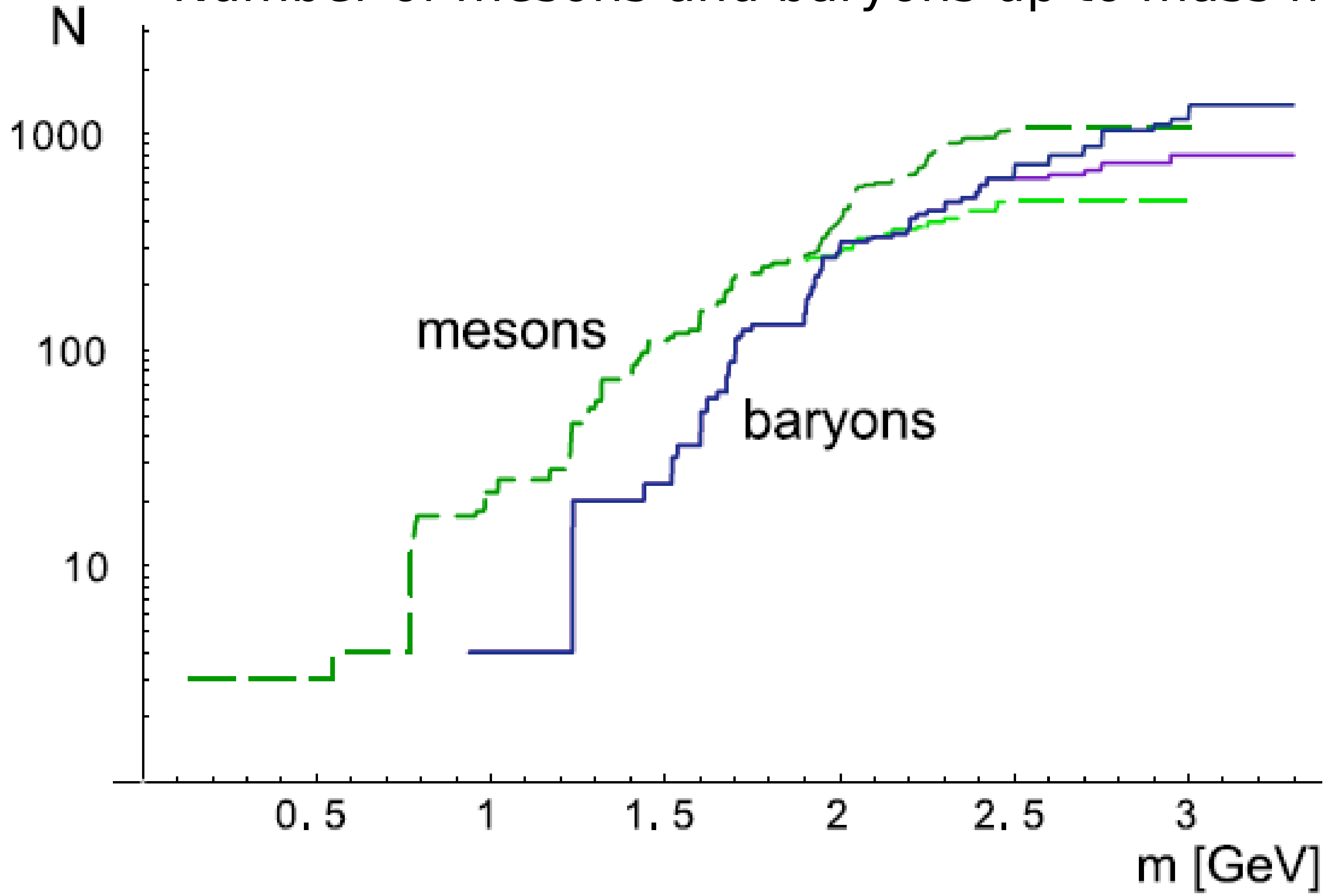
Basic experimental tools: experiments





Basic products and messengers: hadrons

Number of mesons and baryons up to mass m



Broniowski, Florkowski, Glozman

Expereimental and theoretical status

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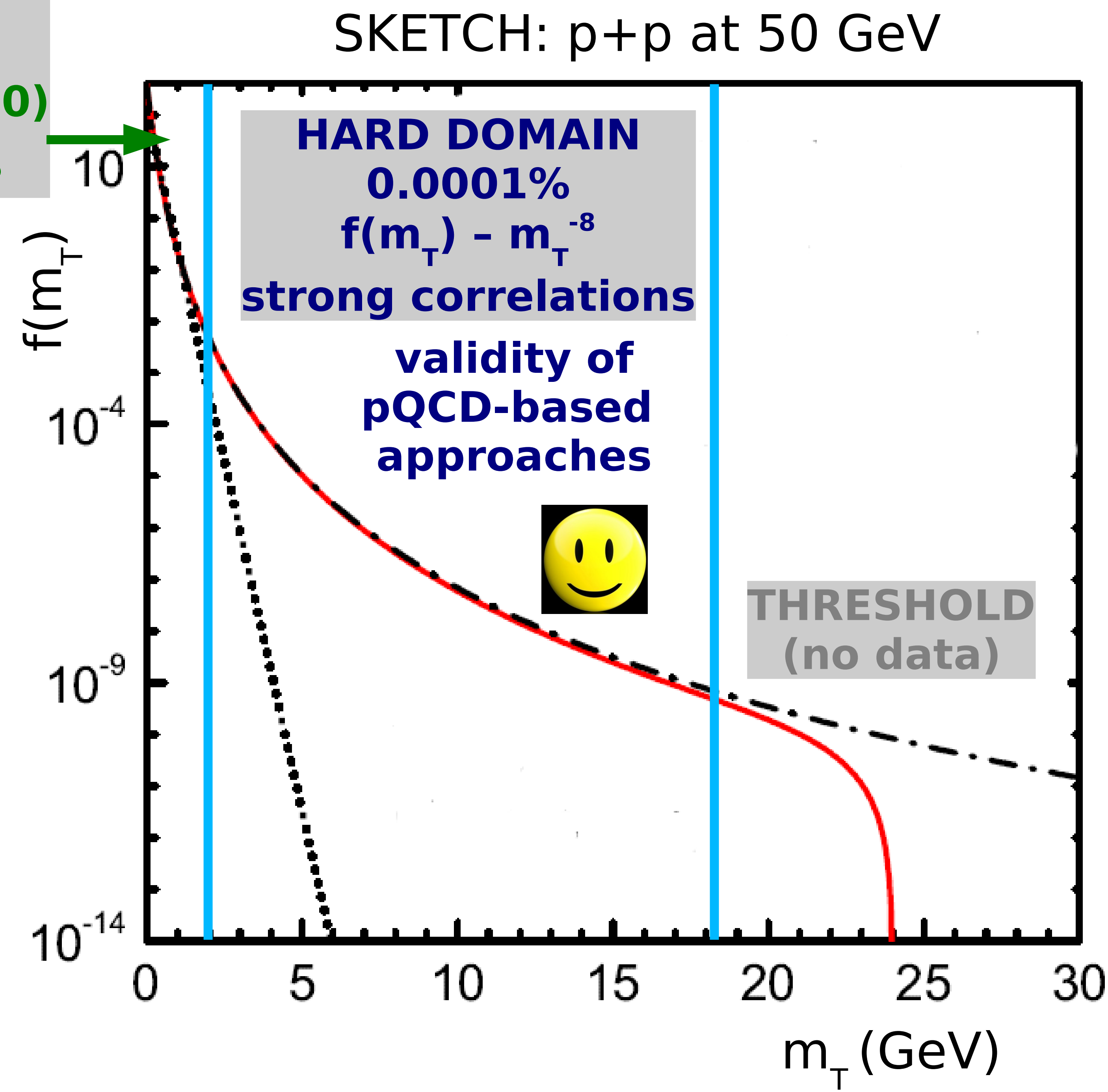
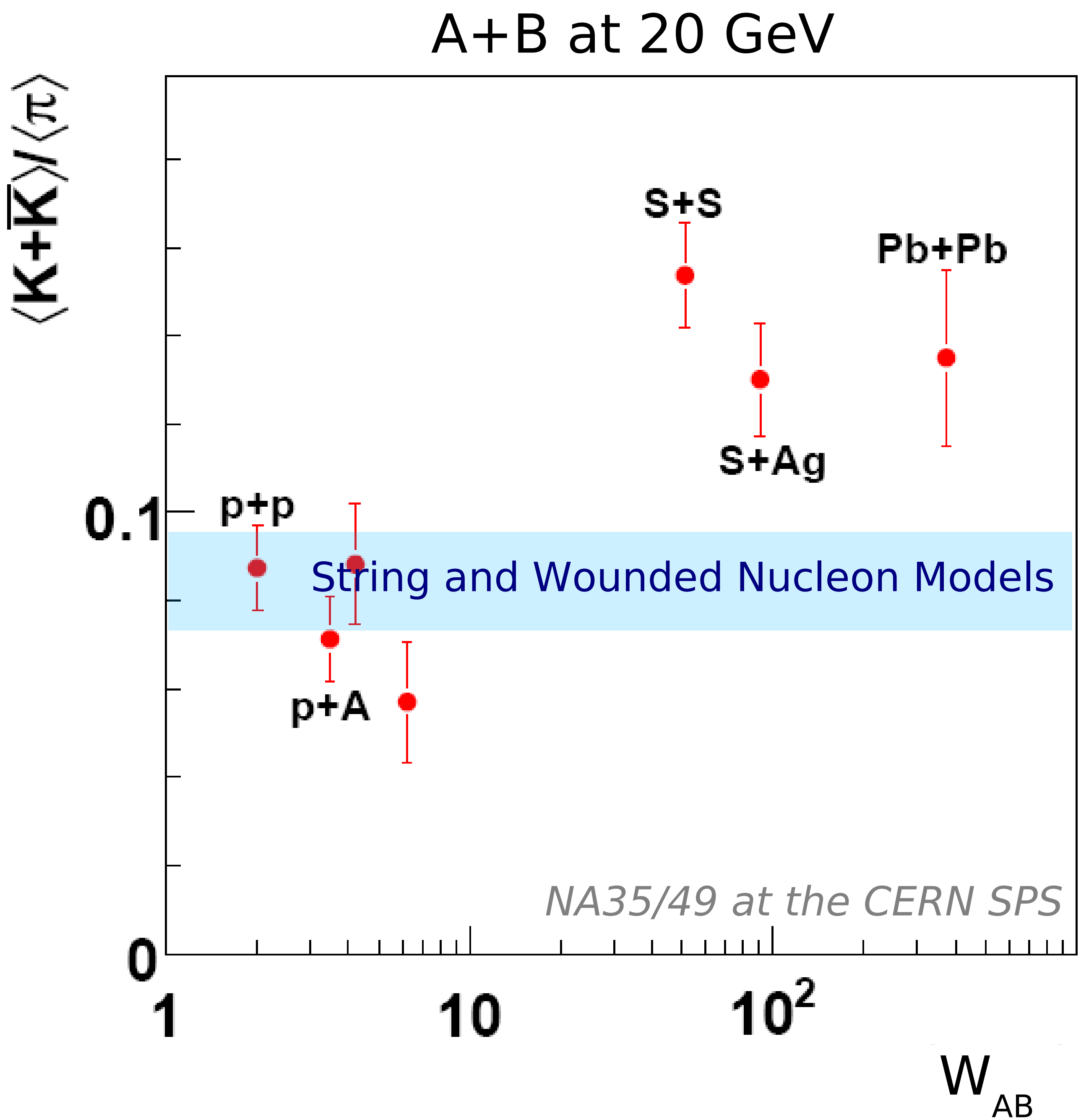
validity of statistical approaches



String and Wounded Nucleon Models

SOFT/DYNAMICAL

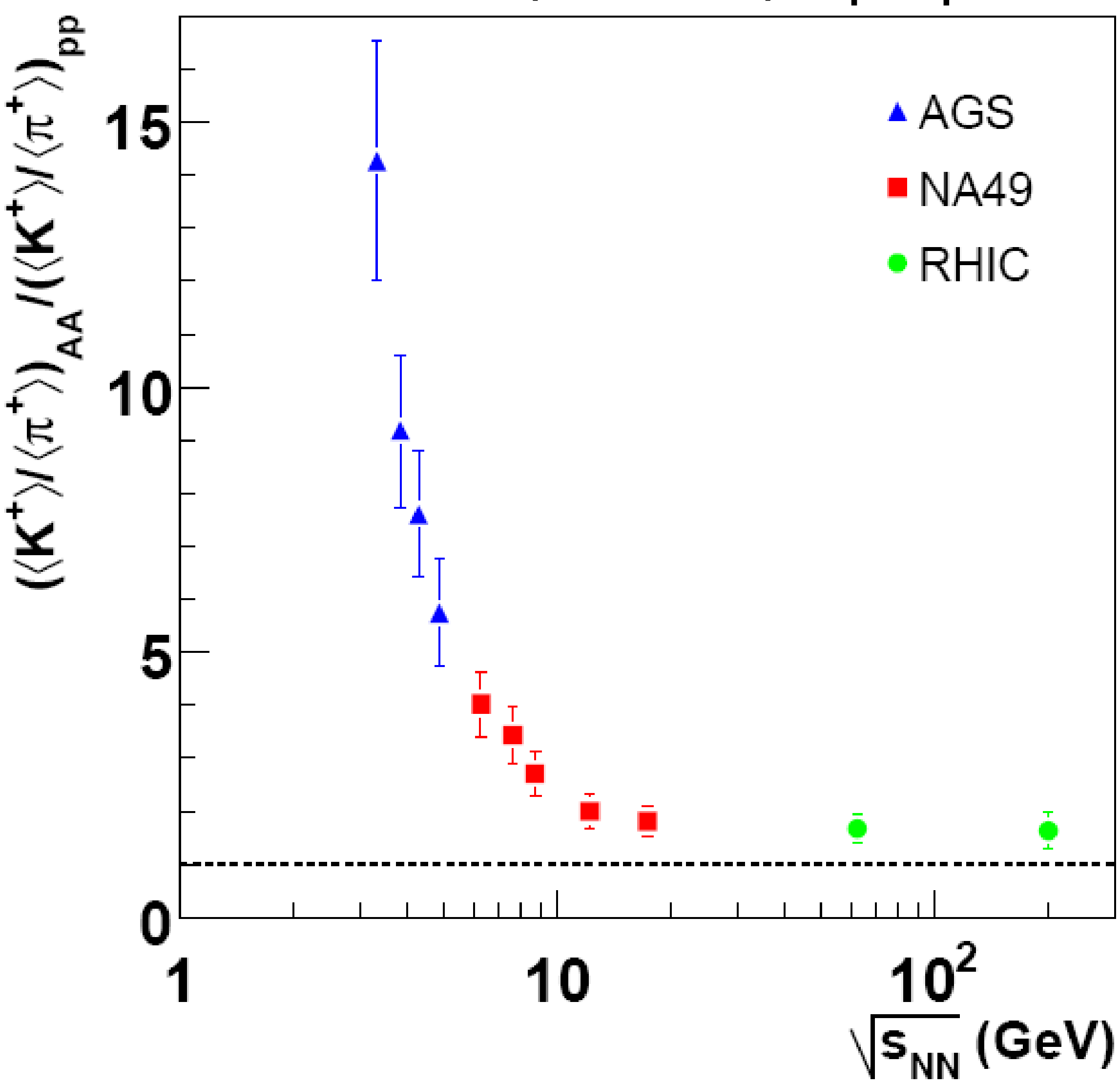


strangeness enhancement

QCD-inspired models of QGP signals: strangeness enhancement

SOFT/DYNAMICAL

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



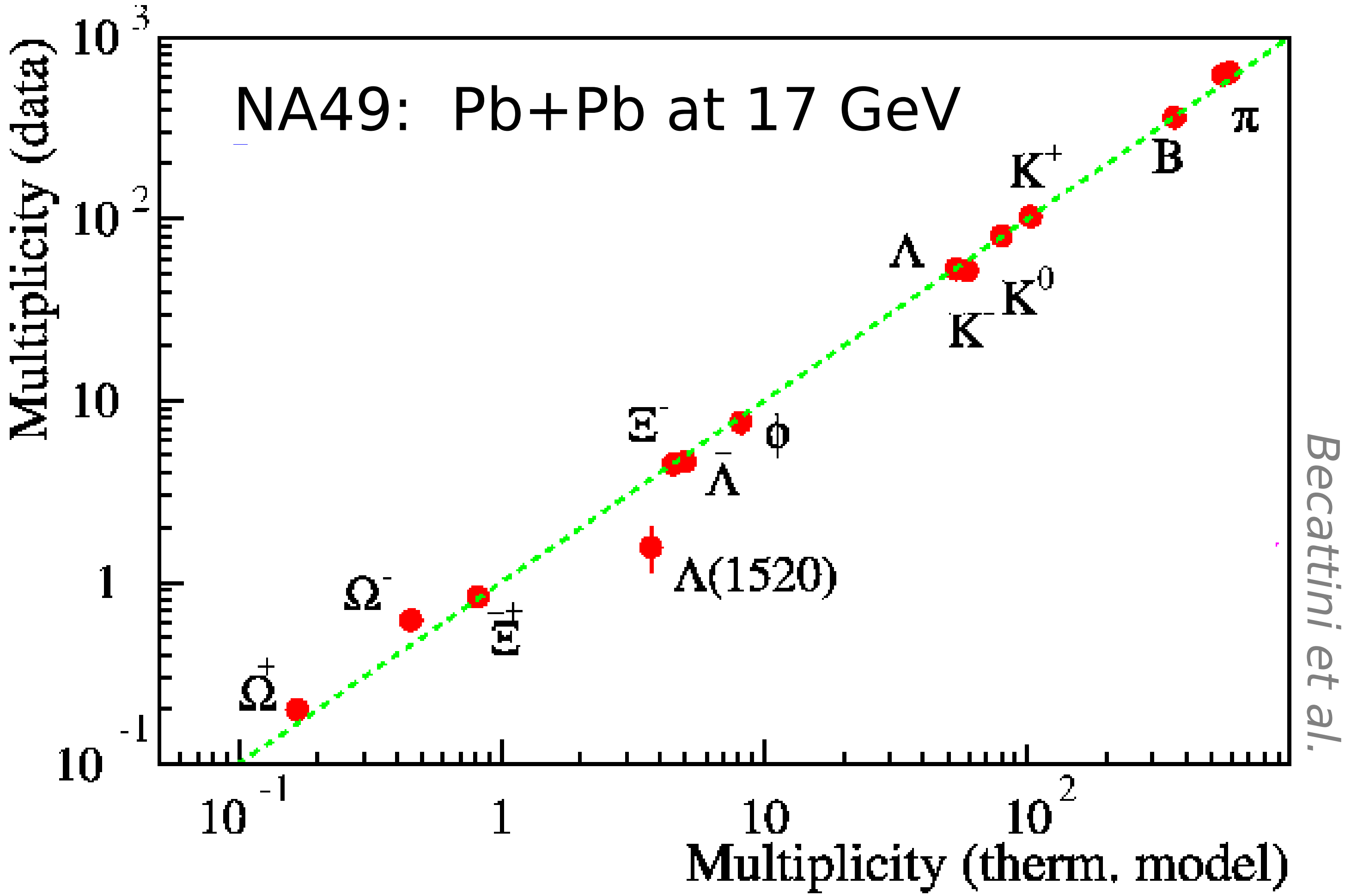
strangeness enhancement:

increases with decreasing collision energy

interpretation as the QGP Is far from obvious

Discoveries of strongly interacting matter (A)

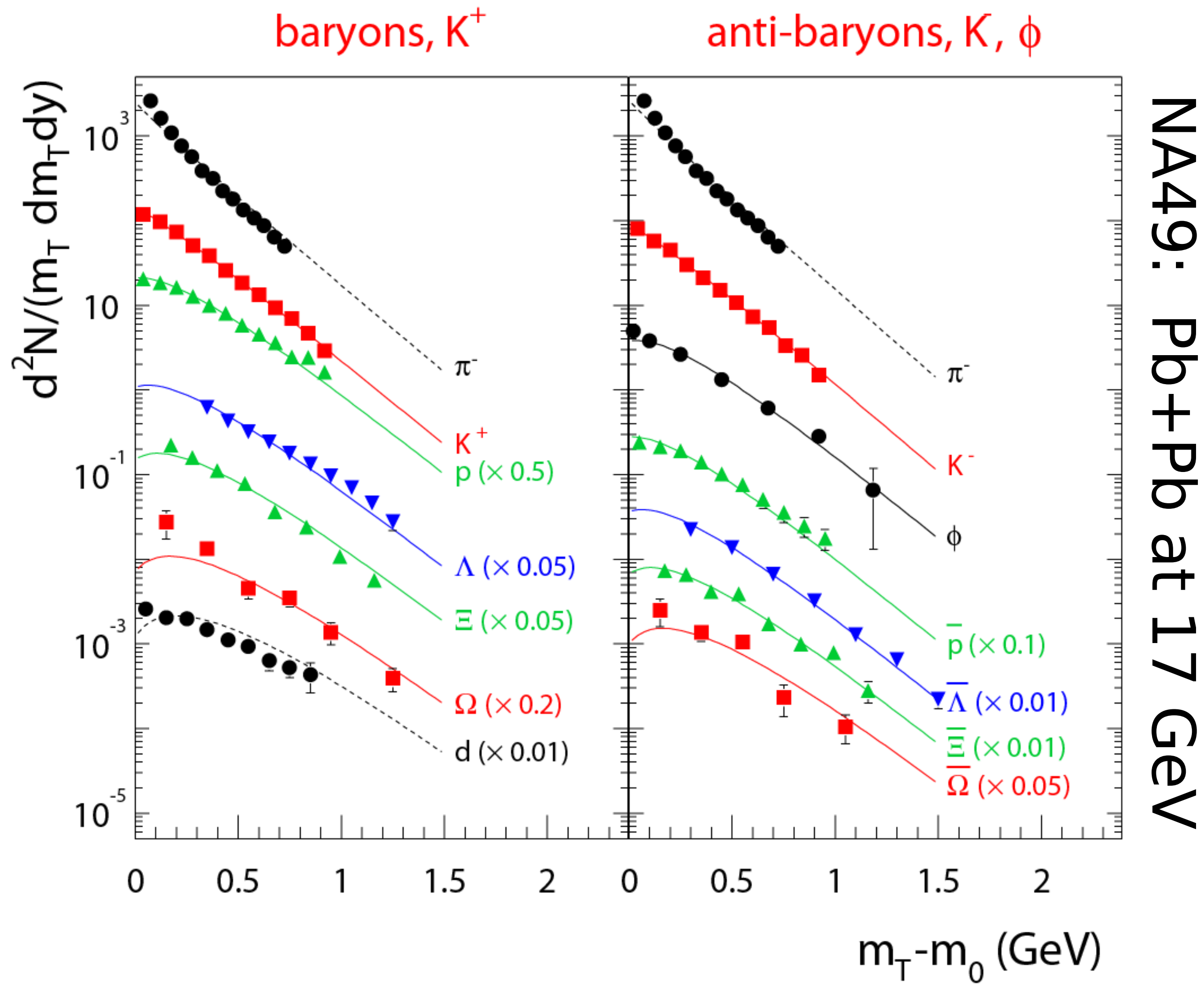
SOFT/STATISTICAL



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

Discoveries of strongly interacting matter (B)

SOFT/STATISTICAL

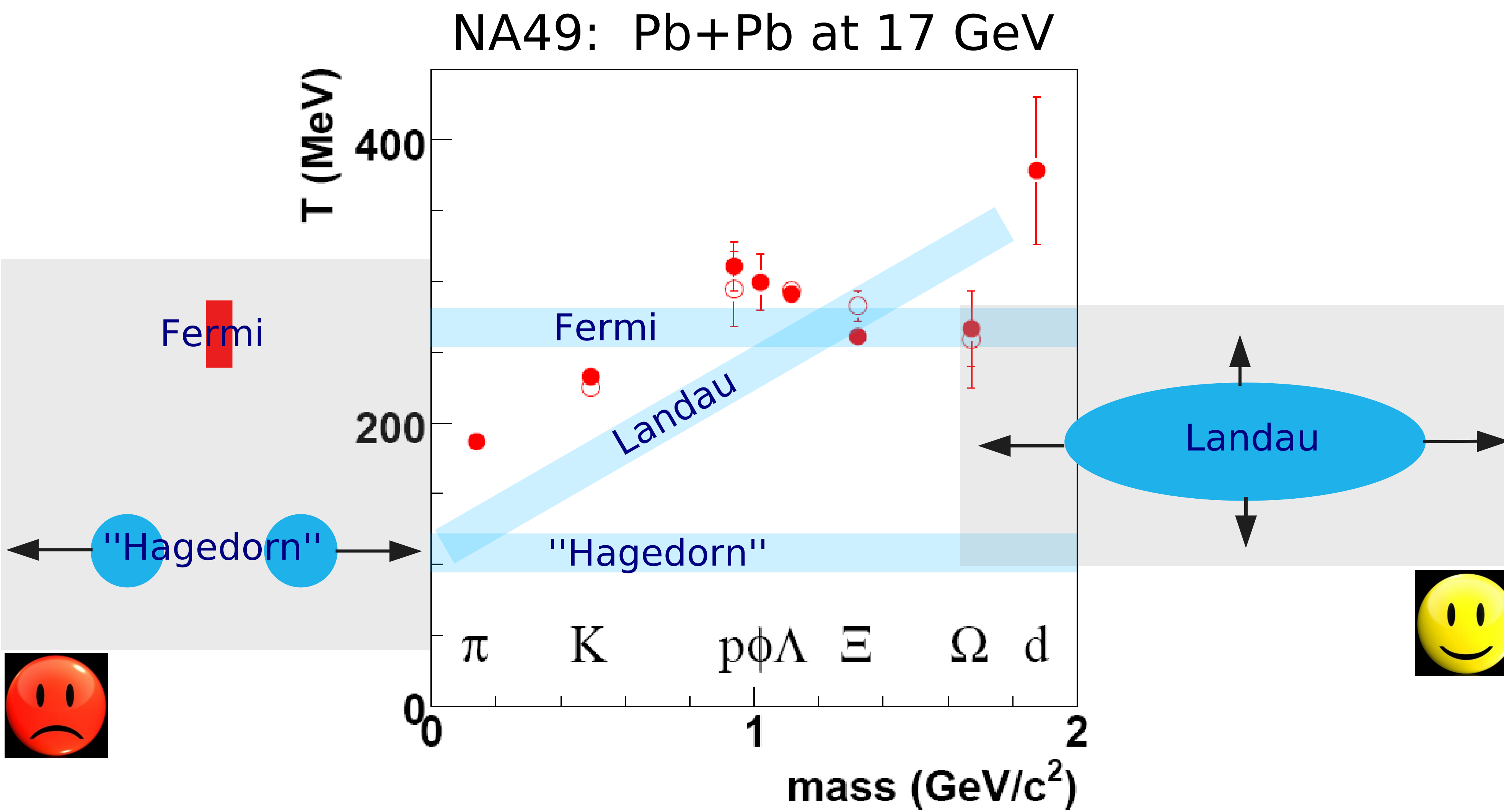


+Broniowski, Florkowski at RHIC

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

Discoveries of strongly interacting matter (C)

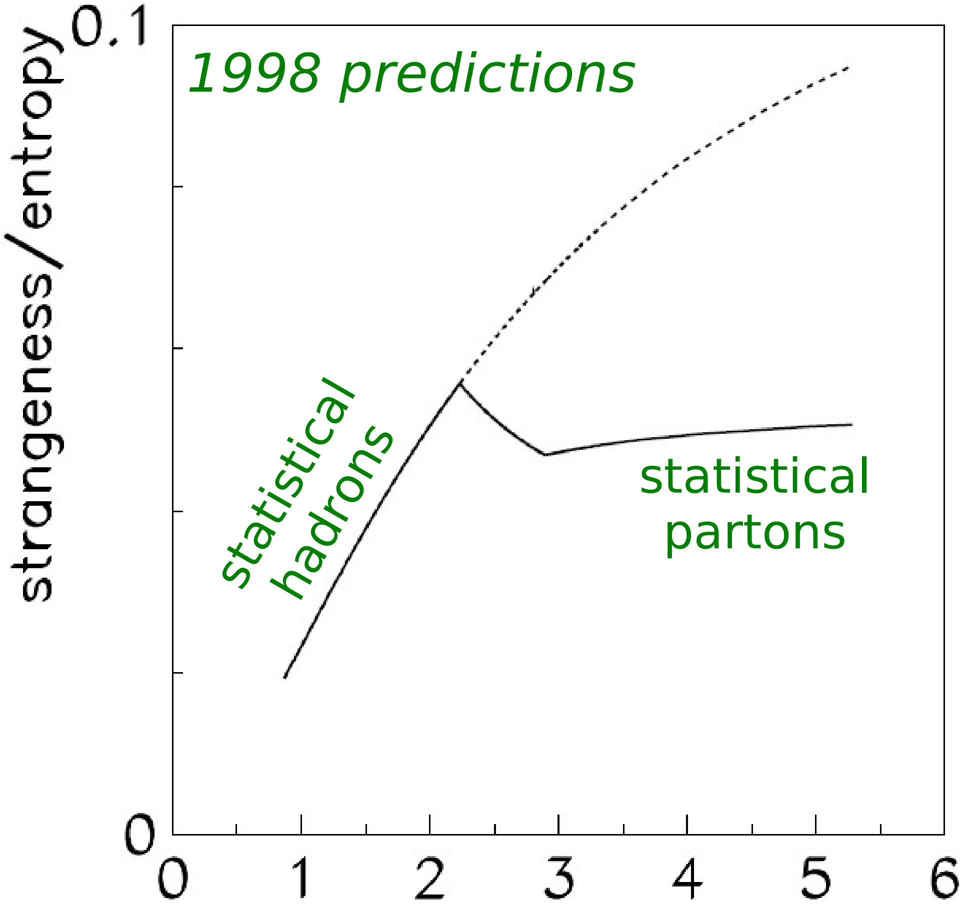
SOFT/STATISTICAL

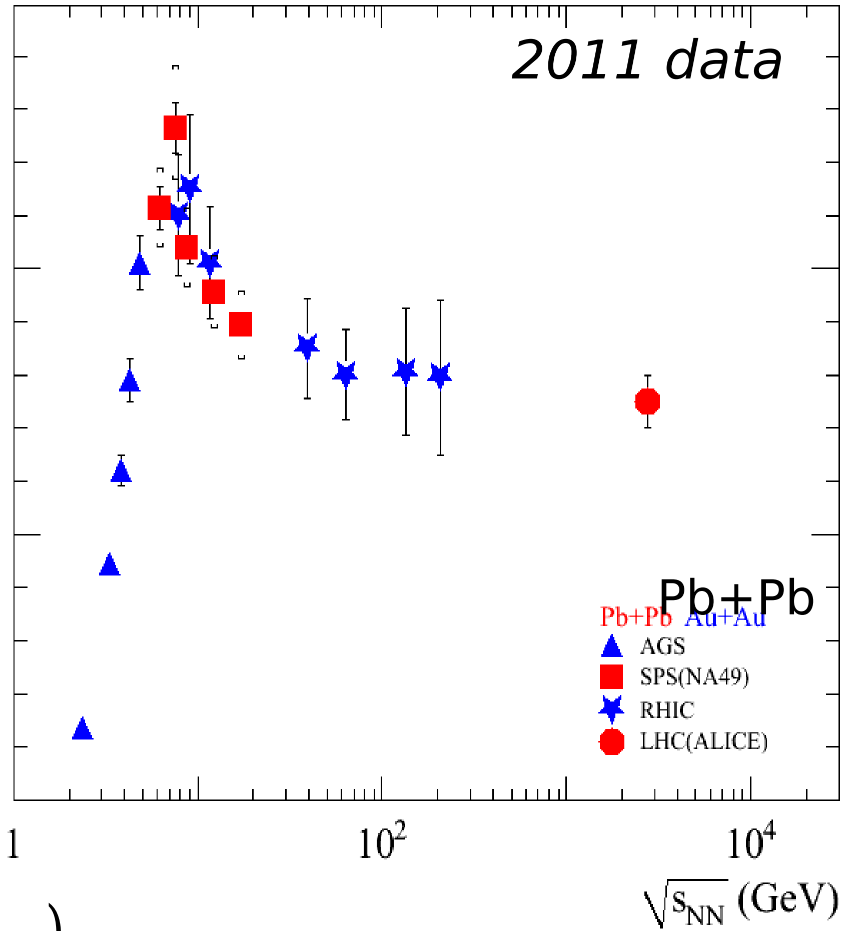


non-statistical effects (e.g. collective flow) are large and sensitive to properties of the early stage (e.g. phase transition)

Discoveries of the phase transition (A)

SOFT/STATISTICAL

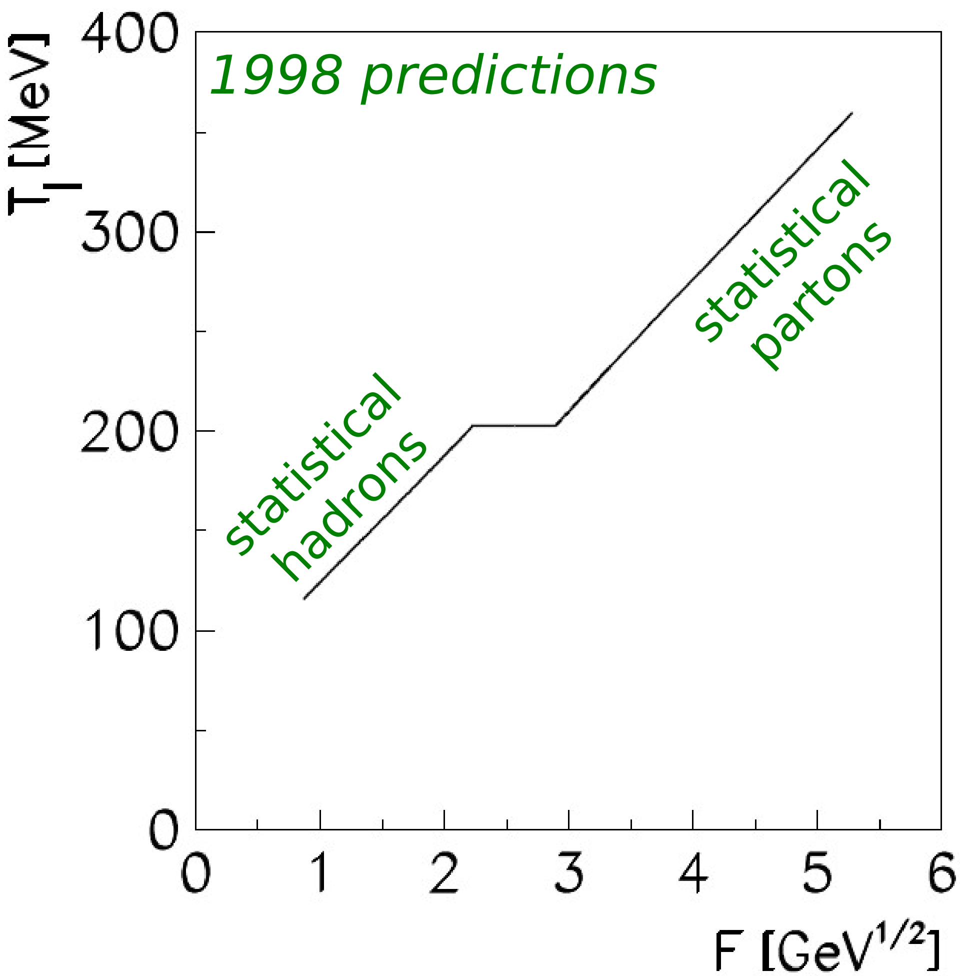


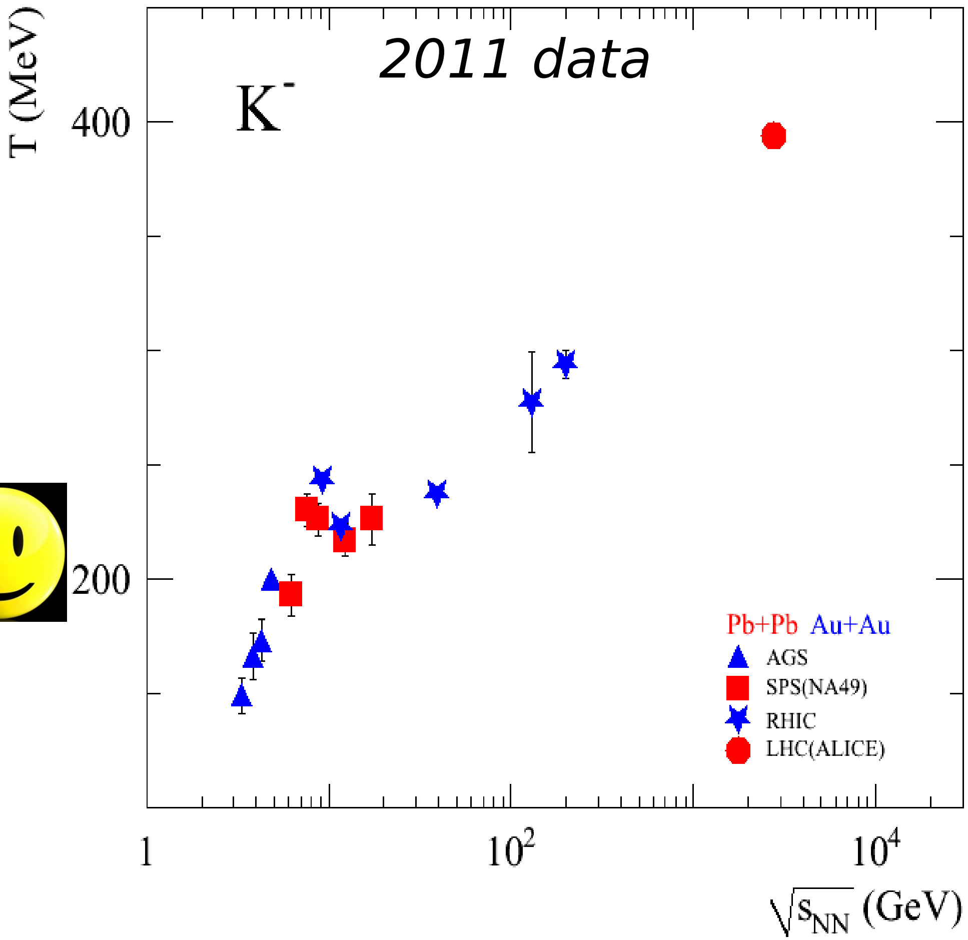


rapid changes in energy dependence of hadron production properties provide evidence for the phase transition

Discoveries of the phase transition (B)

SOFT/STATISTICAL

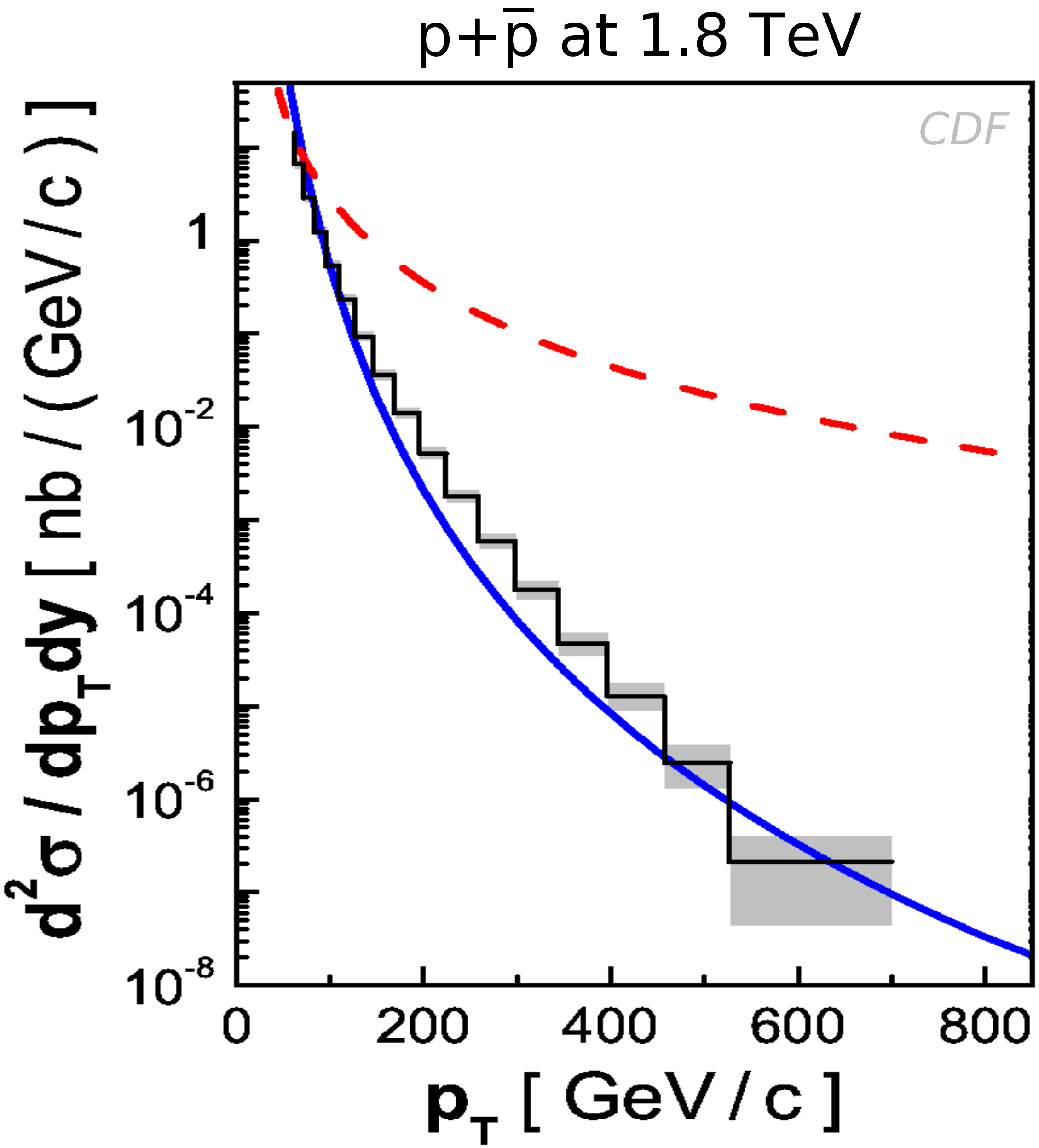




rapid changes in energy dependence of hadron production properties provide evidence for the phase transition

pQCD-based model of high p_T phenomena

HARD/DYNAMICAL



Field, Feynman:
asymptotic free theory:

p_T^{-4}

+
parton distribution,
parton fragmentation,
2 → 3 processes,
conservation laws

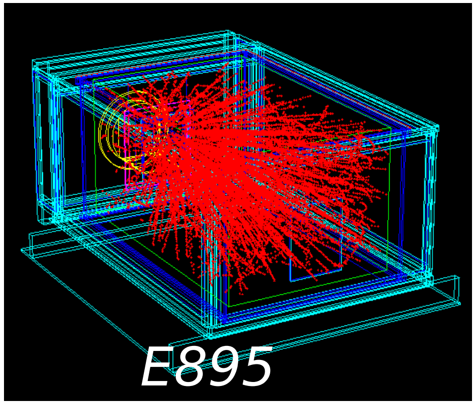
p_T^{-8}

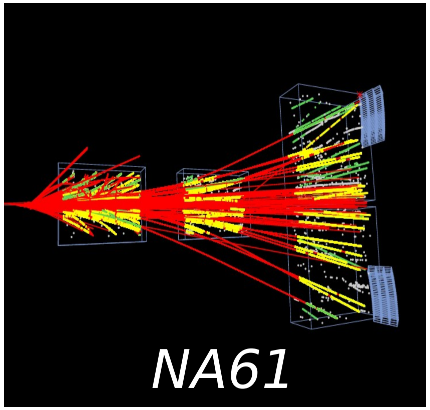
Future

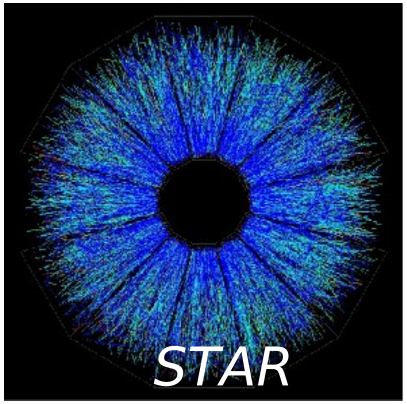
SOFT/STATISTICAL/DYNAMICAL

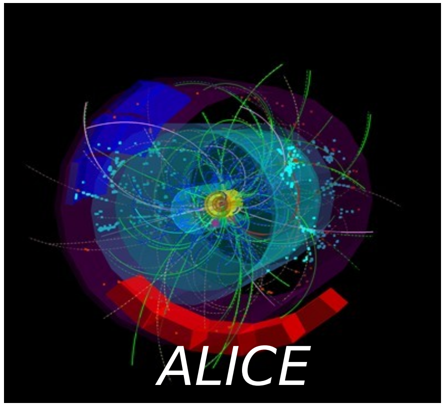
Event-by-event fluctuations (A)

BNL AGS → CERN SPS → BNL RHIC → CERN LHC







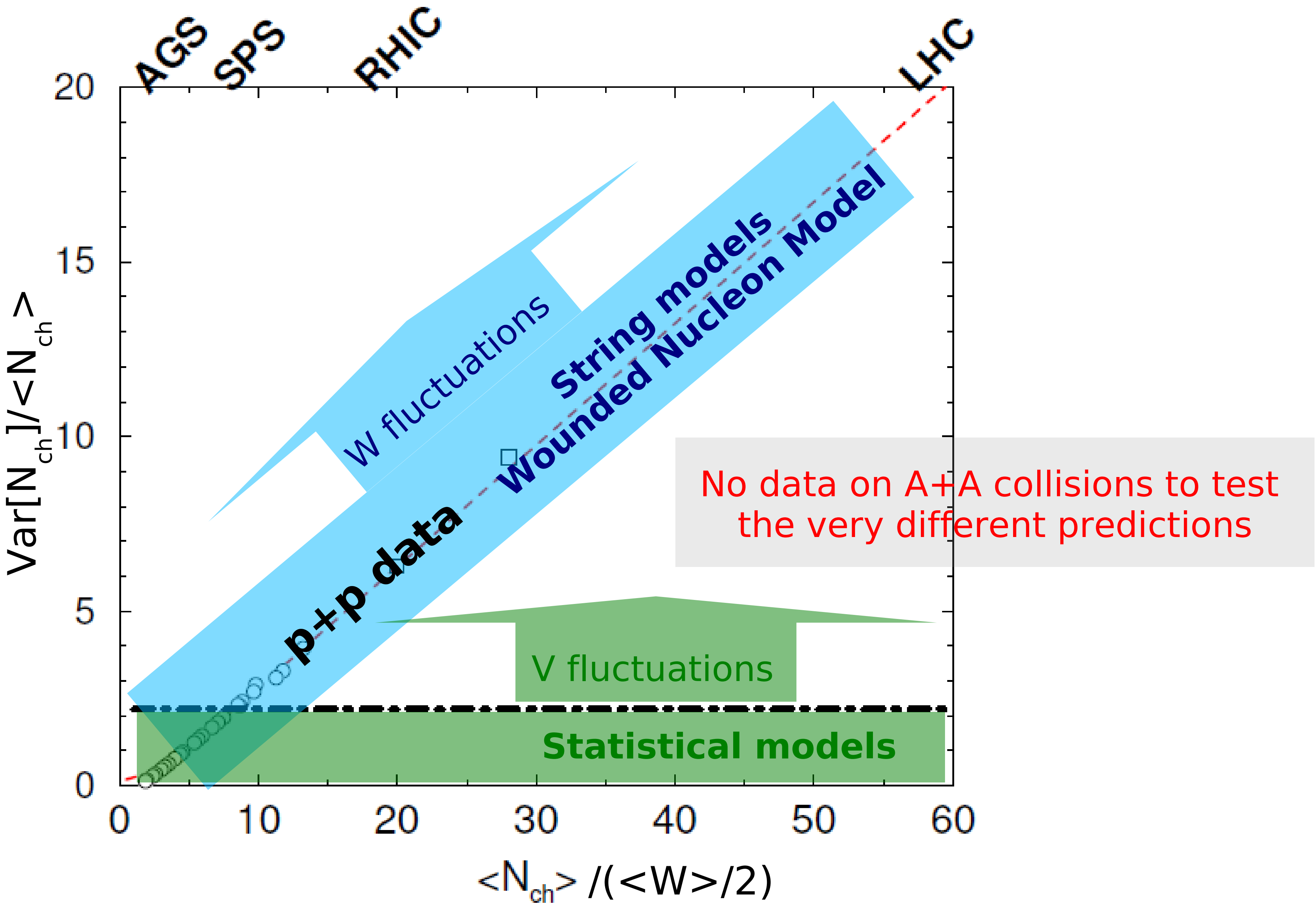


→ rich experimental data on single particle spectra
in Pb+Pb and p+p interactions
from several GeV to several TeV

→ but due to an incomplete acceptance of detectors
poor data on event-by-event fluctuations

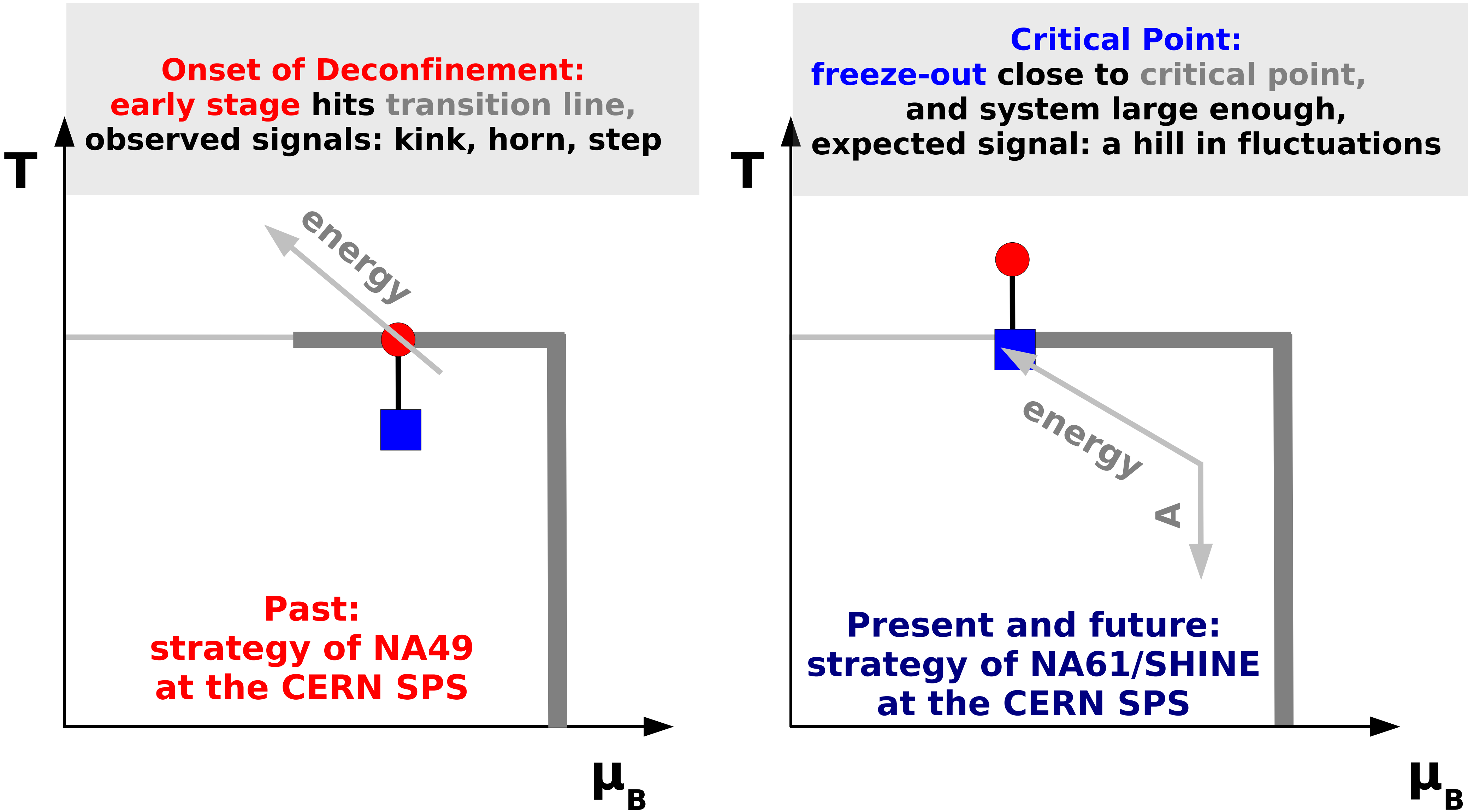
Event-by-event fluctuations (B)

SOFT/STATISTICAL/DYNAMICAL



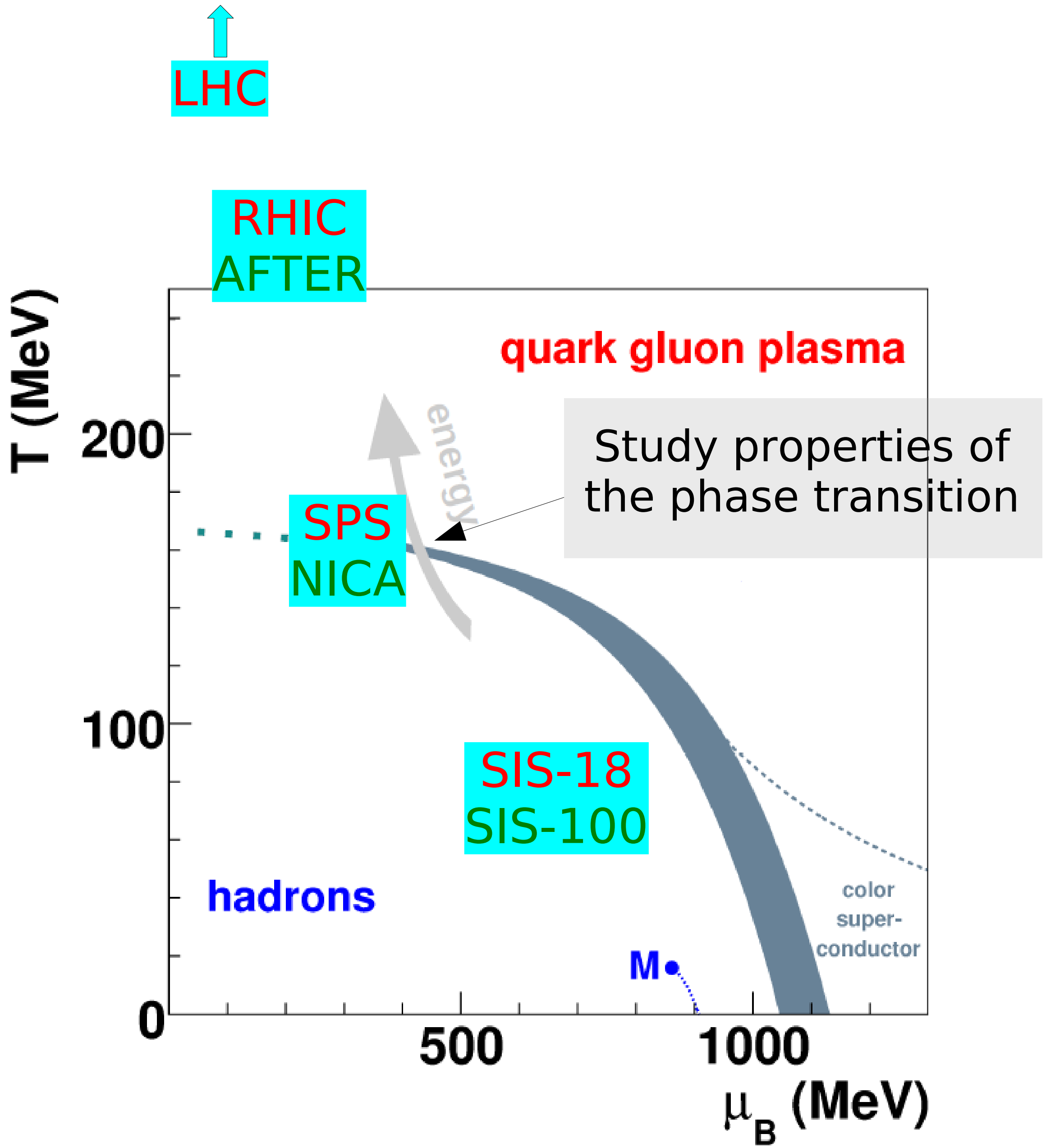
Properties of the transition line (A)

SOFT/STATISTICAL



Properties of the transition line (B)

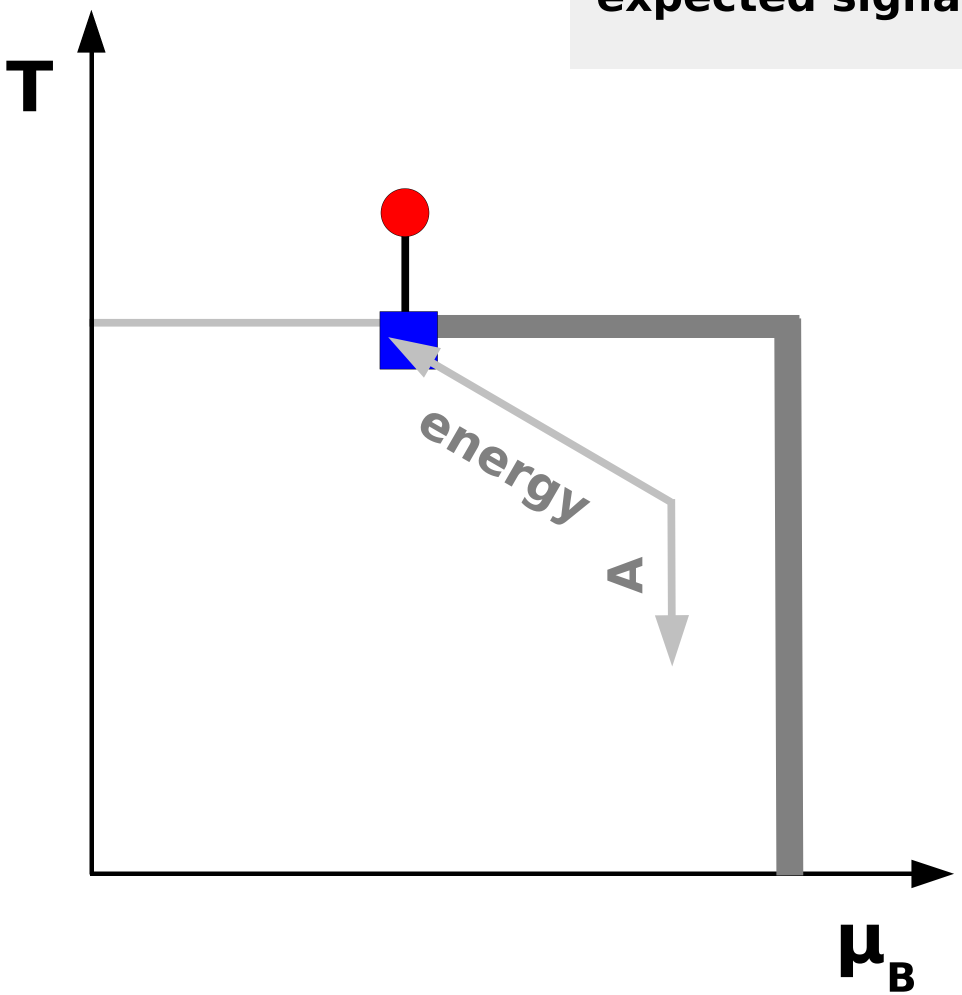
SOFT/STATISTICAL

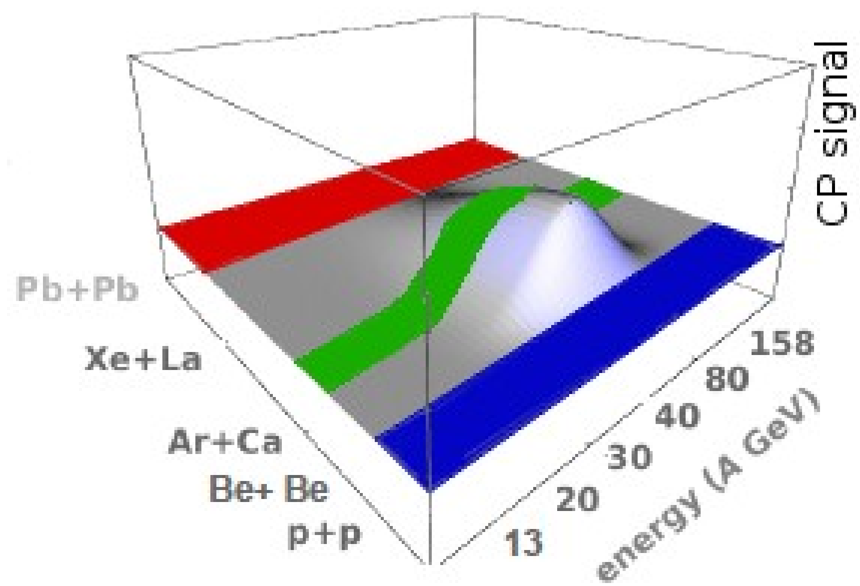


Properties of the transition line (C)

SOFT/STATISTICAL

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

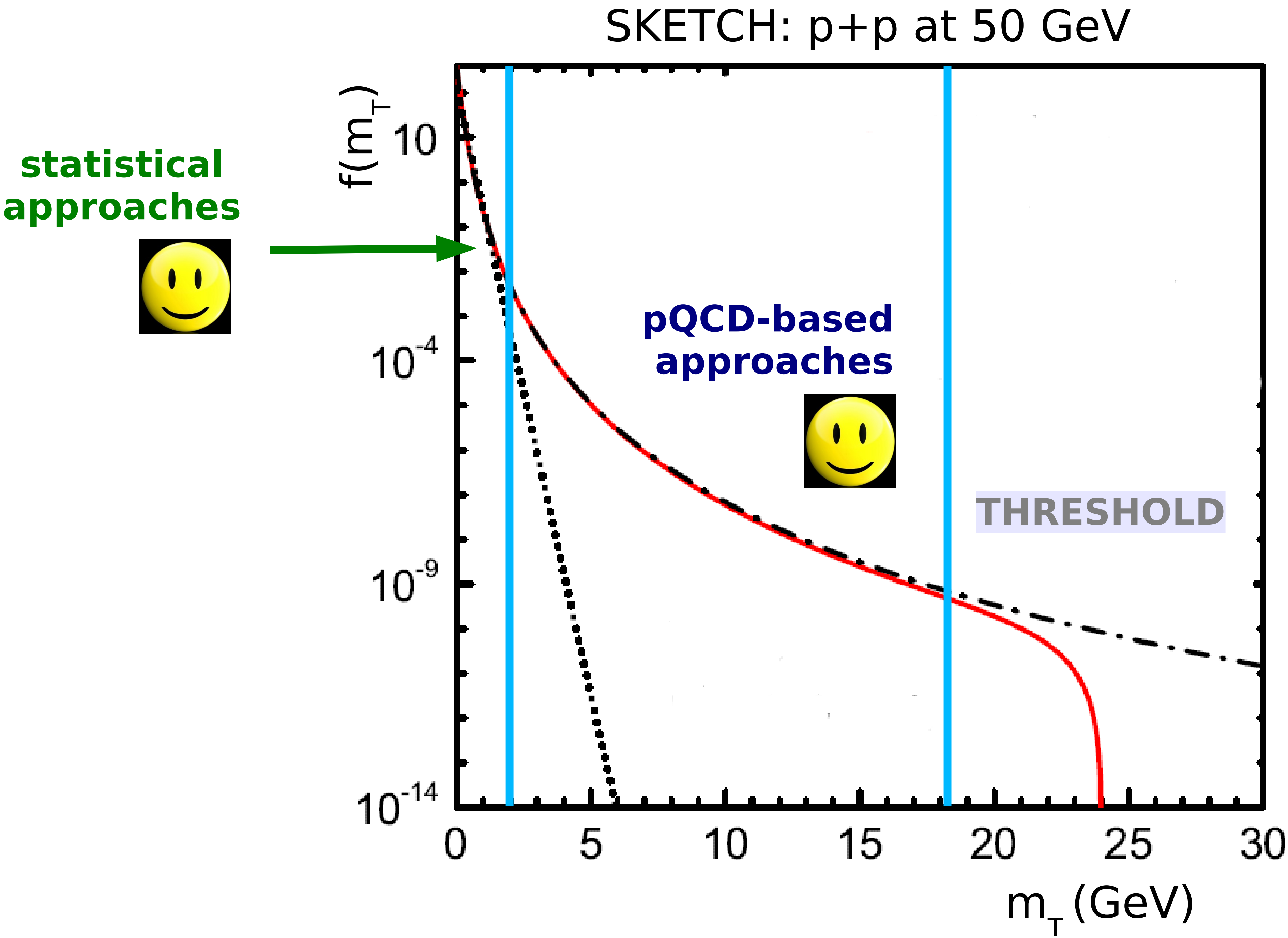




Stephanov et al., PRD60:114028
NA61/SHINE, PoS CPOD2006:016

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/hydrodynamical approaches to the hard region, fluctuations and collisions of small systems (e.g. p+p, p+Pb, Be+Be) (e.g. volume/temperature fluctuations, hydrodynamics of unstable medium)

- new ideas

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2014+

2014+

Still many, many things to do

Additional slides