Strangeness measurements up to Tevatron and predictions for LHC

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ALICE

A Large Ion Collider Experiment

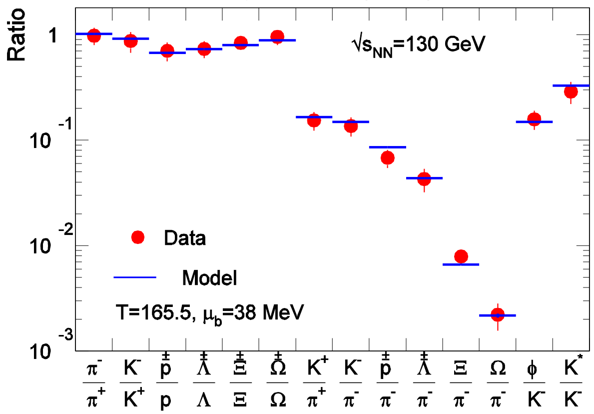
CERN

European Organisation for Nuclear Research

heavy-ion collisions

statistical model: grand-canonical ensemble

Nucl. Phys. A 772 (2006) 167



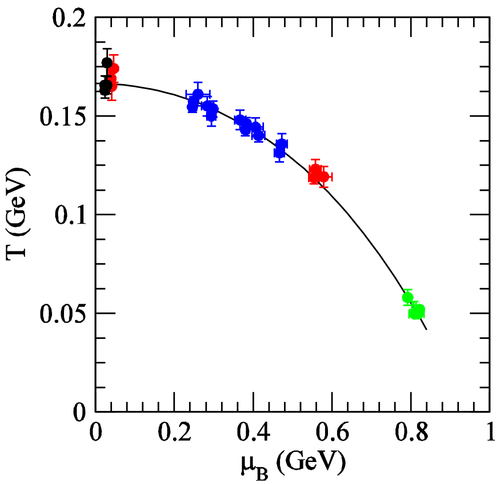
→ 2 parameters T, μ_B

Phys. Rev. C 74 (2006) 034903

$\bar{h}/h$ Ratio		mixed Ratio	
π^+/π^-	$0.9998^{+0.0002}_{-0.0010}$	K^+/π^+	$0.180^{+0.001}_{-0.001}$
K^+/K^-	$1.002^{+0.008}_{-0.002}$	K^-/π^-	$0.179^{+0.001}_{-0.001}$
$\bar{p}/p$	$0.989^{+0.011}_{-0.045}$	p/π^-	$0.091^{+0.009}_{-0.007}$
$\bar{\Lambda}/\Lambda$	$0.992^{+0.009}_{-0.036}$	Λ/p	$0.473^{+0.004}_{-0.006}$
$\bar{\Xi}^+/\Xi^-$	$0.994^{+0.006}_{-0.026}$	Ξ^-/Λ	$0.160^{+0.002}_{-0.003}$
$\bar{\Omega}^+/\Omega^-$	$0.997^{+0.003}_{-0.015}$	Ω^-/Ξ^-	$0.186^{+0.008}_{-0.009}$

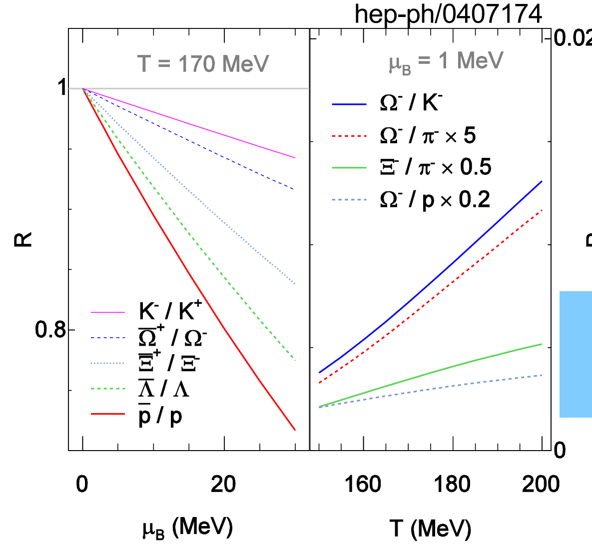
→ calculate predictions for LHC

Phys. Rev. C 73 (2006) 034905



freeze-out curve
→ extrapolate to LHC

hep-ph/0407174



→ extract parameters from data

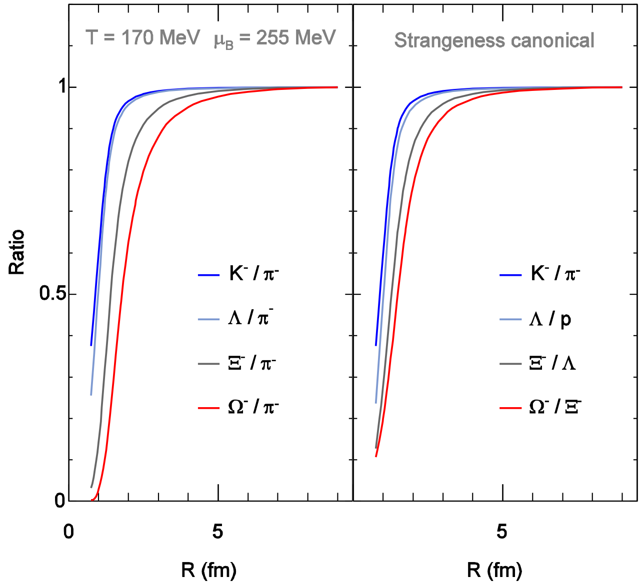
small colliding systems

canonical ensemble

small systems / peripheral collisions, low energies

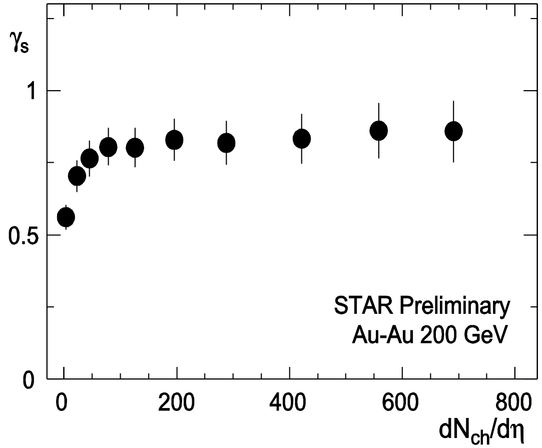
suppressed phase-space for particles related to conserved charge

$$n_i^{canonical} \approx n_i^{grand-canonical} \frac{I_S(x)}{I_0(x)}$$



suppression beyond canonical expectation

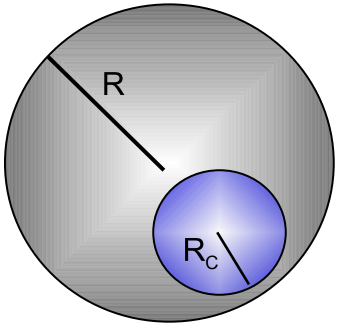
J. Phys. G 31(2005) S101



deviations: strangeness understauration factor γ_S

alternative: **small cluster** (R_C) in fireball (R): $R_C \leq R$

→ **chemical equlibrium** in subvolumes



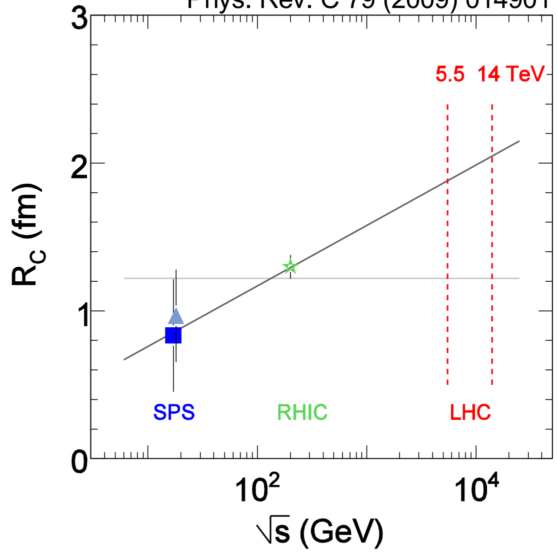
predictions for pp interactions at LHC

extrapolation of cluster size

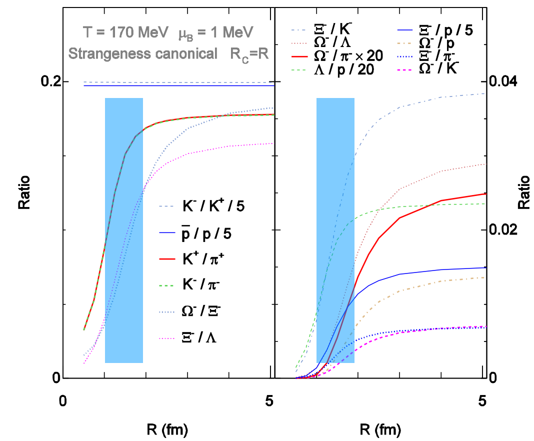
what defines R_C in p+p?

- initial size of p+p system: R_C const
- final state of large number of produced hadrons:
  → increase with √s and multiplicity

Phys. Rev. C 76 (2007) 064903
Phys. Rev. C 79 (2009) 014901



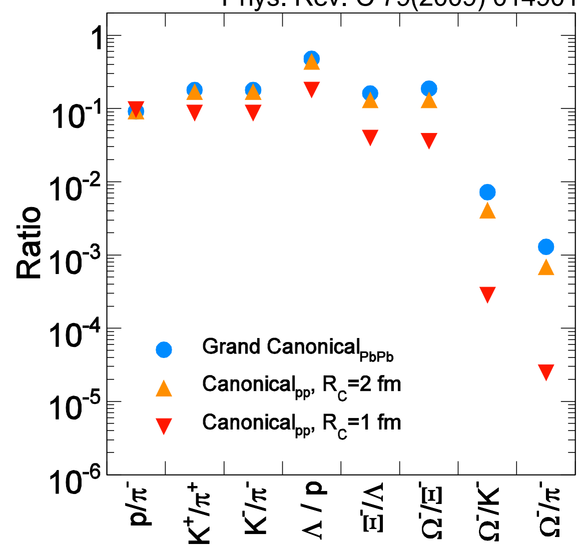
measurement of cluster size



significant increase of ratios at $R_C \approx 1.5$ fm

→ **determine R_C from data**

Phys. Rev. C 79(2009) 014901



sensitivity increases with strangeness difference

→ **R_C from Ω / π**

what do we know about pp ?

soft physics

- multiplicity distributions
- spectra and mean-pt
- strangeness production

event characterisation / scaling behaviour

- c.m. energy √s
- multiplicity
- hard vs soft events

	ISR	***SppS***	***Tevatron***
√s (GeV)	~ 10	~ 100	~ 1000

multiplicity distribution

ISR Phys Rev D 30 (1984) 528 **√s = 30 - 62 GeV**

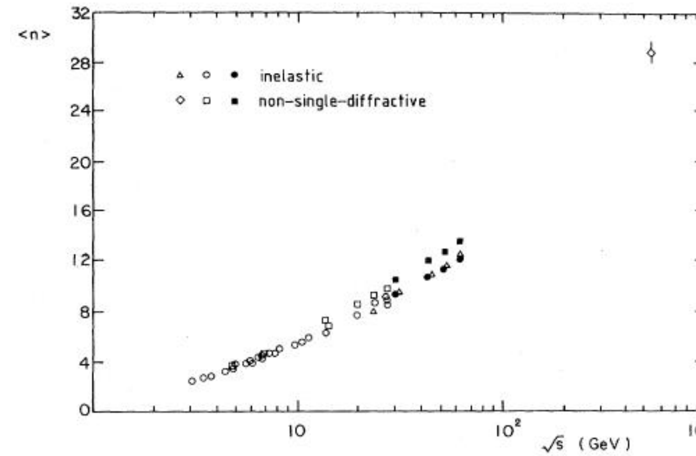
4π detector **p+p**

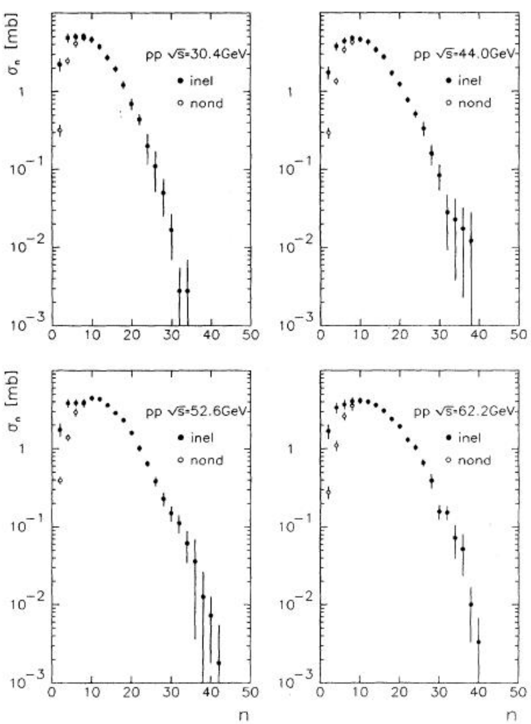
energy dependence of <n>

Feynman scaling and *limiting fragmentation* predict <n> ~ *ln s*

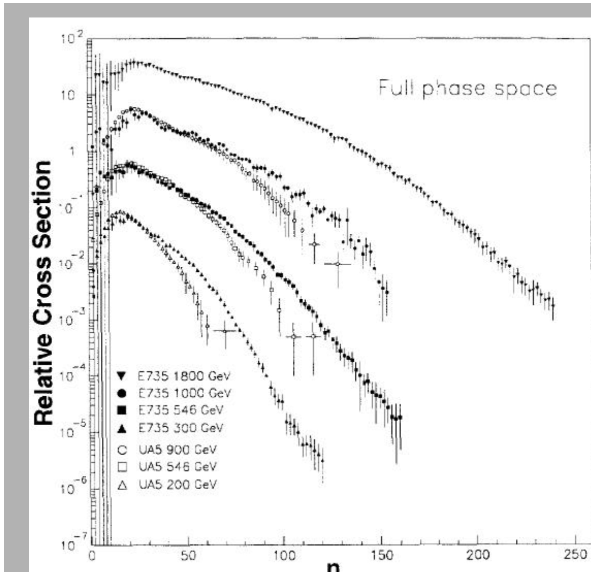
in data <n> rises faster

$$\rightarrow \langle n \rangle = A + B \ln s + C \ln^2 s$$





non single diffractive events: both p destroyed

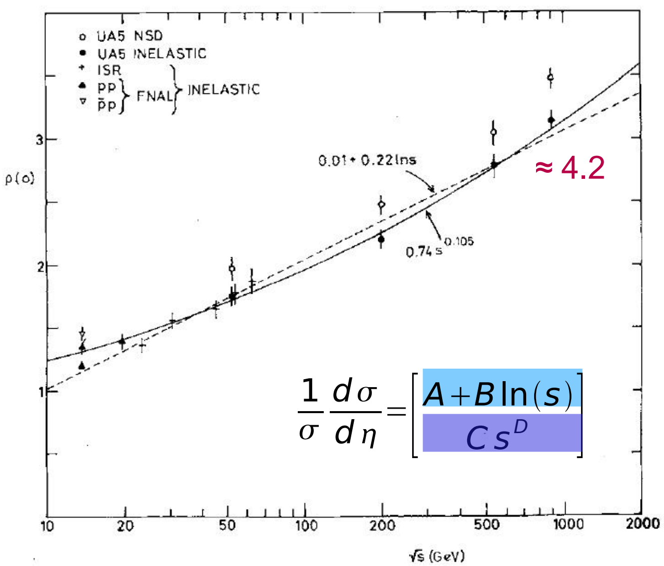


E735
Phys Lett B 435 (1998) 453
√s = 300 - 1800 GeV

UA5
data
√s = 200 - 900 GeV

multiplicity density vs √s

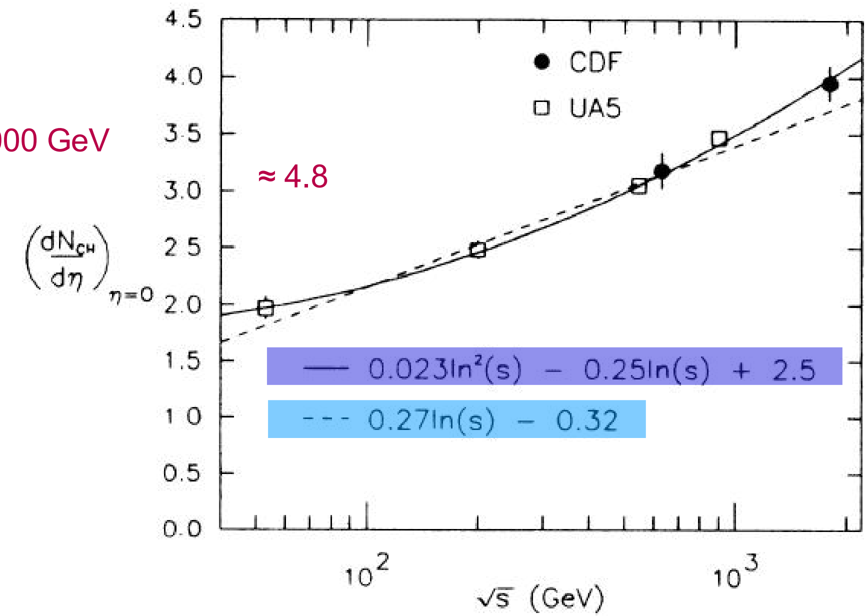
UA5 Z Phys C 33 (1986) 1 **√s = 200, 900 GeV**



at √s = 14,000 GeV

CDF Phys Rev D 41 (1990) 2330 **√s = 630, 1800 GeV**

pt > 50 MeV/c



multi-particle production in

- statistical hydrodynamical models
  determined by initial energy density
- parton-parton interactions with string fragmentation models
  described by multiple parton-parton scattering
  or number of strings

charged particle midrapidity density

- scales ~ with *ln (s)* at lower √s → available energy
- increases at SppS and Tevatron faster than *ln s*

KNO scaling

Koba, Nielsen, Olesen Nucl Phys B 40 (1971) 317

scaling of multiplicity distribution in high energy hadron collisions

" the normalised multiplicity distribution keeps its form independently of the beam energy and just scales up as ln s "

multiplicity distribution

cross section for the multiplicity being *n* at the c.m. energy √s

independent of √s except through n / <n>

$$P_n(s) = \frac{\sigma_n(s)}{\sigma_{tot}(s)} = \frac{1}{\langle n \rangle} \psi(n/\langle n \rangle)$$

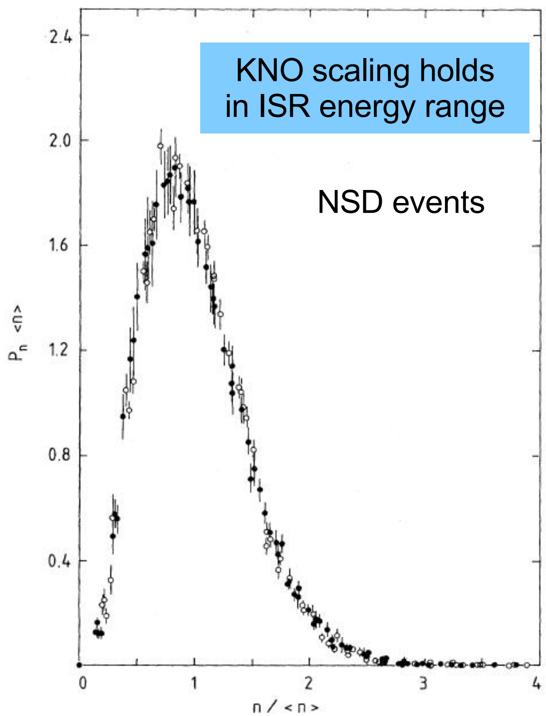
average multiplicity at c.m. energy √s

<n> $P_n(s)$ is only a function of n / <n>

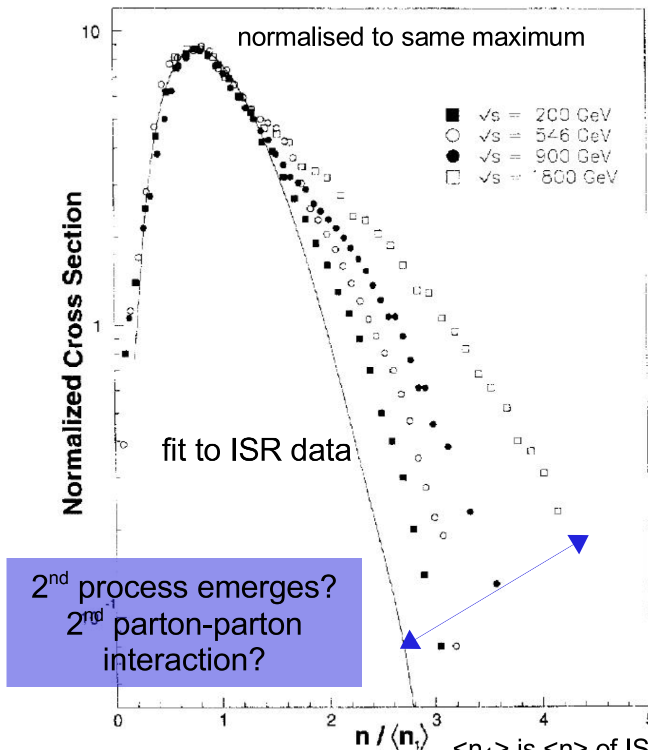
multiplicity distribution

ISR Phys Rev D 30 (1984) 528 **√s = 30 - 62 GeV**

4π detector **p+p**



E735 Phys Lett B 435 (1998) 453 **√s = 300 - 1800 GeV**



1st component
KNO-like scaling with
const cross section
(32mb)

2nd component
cross section
increases with √s
(18mb at 1800 GeV)

$\langle n_1 \rangle$ is $\langle n \rangle$ of ISR-shape
distribution (with KNO scaling)

UA5 Z Phys C 43 (1989) 357 **√s = 200 - 900 GeV**

KNO scaling breaks at full phase space
negative binomial distribution describes data
(except 900 GeV full phase space)

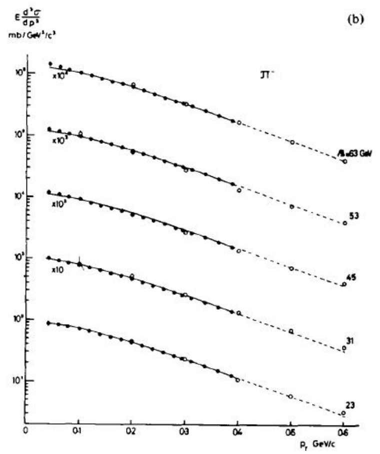
CDF Phys Rev D 56 (1997) 3811 **√s = 1800 GeV**

multiple jet events:
kinematic independent double parton interactions
cross section ~ 15 mb

shape of pt spectra

ISR Phys Lett 64B (1976) 111 **√s = 23 - 63 GeV**

π: 40 < pt < 400 MeV/c **p+p**



√s = 63 GeV

53

45

31

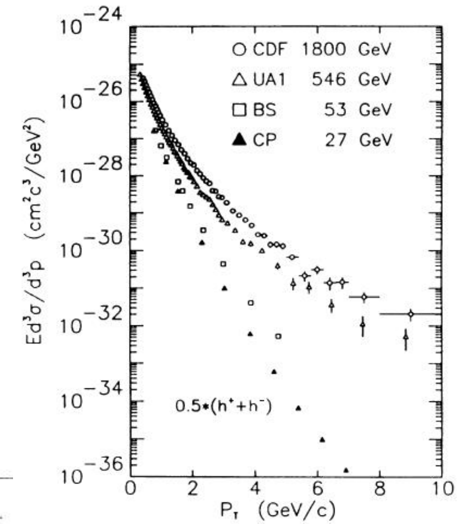
23

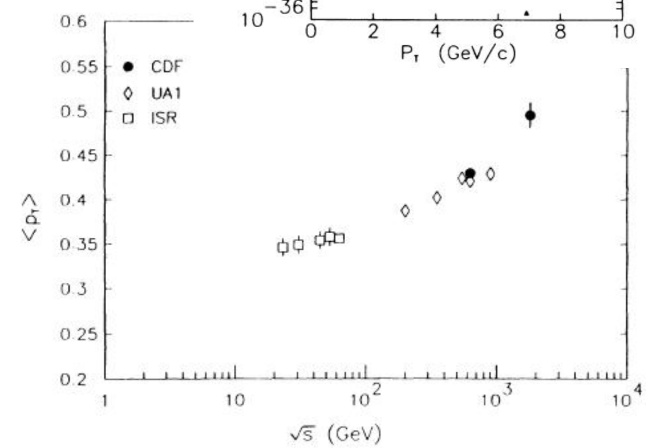
turnover at low pt
exp(pt) fails
exp(mt) better
→ ***shape dictated by transverse energy***

CDF Phys rev Lett 61 (1988) 1819 **√s = 630, 1800 GeV**

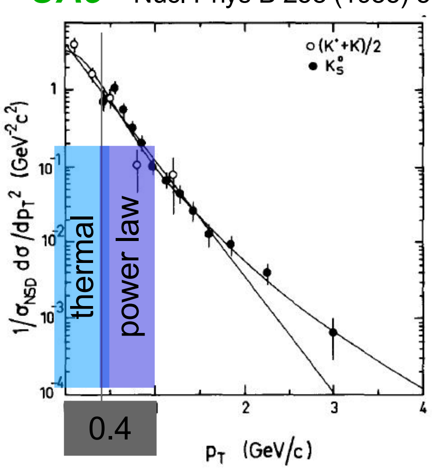
pt > 0.4GeV/c

power law in measured range





UA5 Nucl Phys B 258 (1985) 505 **√s = 540 GeV**



$$E\frac{d^3\sigma}{d^3p} = \left[\begin{array}{c} A\exp(-b\,m_t) \\ C\dfrac{p_0^n}{(p_0+p_t)^n} \end{array}\right]$$

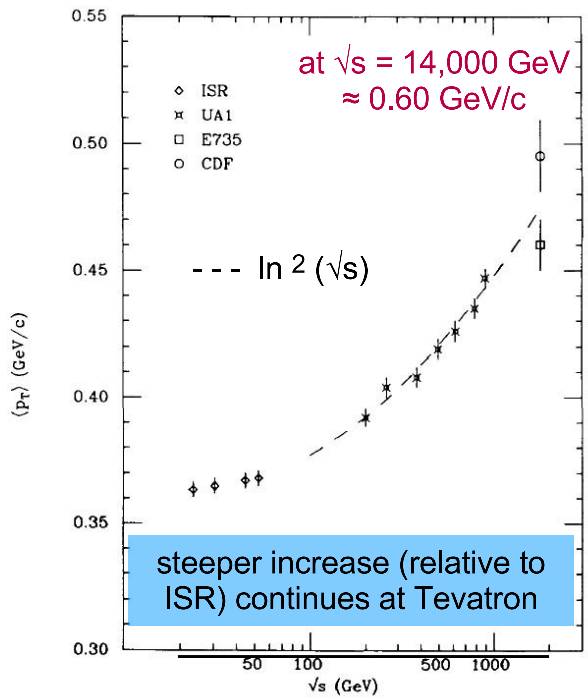
mean-pt vs √s and multiplicity

UA1 Nucl Phys B 335 (1990) 261 **√s = 0.2 - 0.9 TeV**

magnetic and calorimetric analysis

pt > 0.25 GeV/c

pt spectra extrapolated with power law
thermal distribution results in 6% higher <pt>



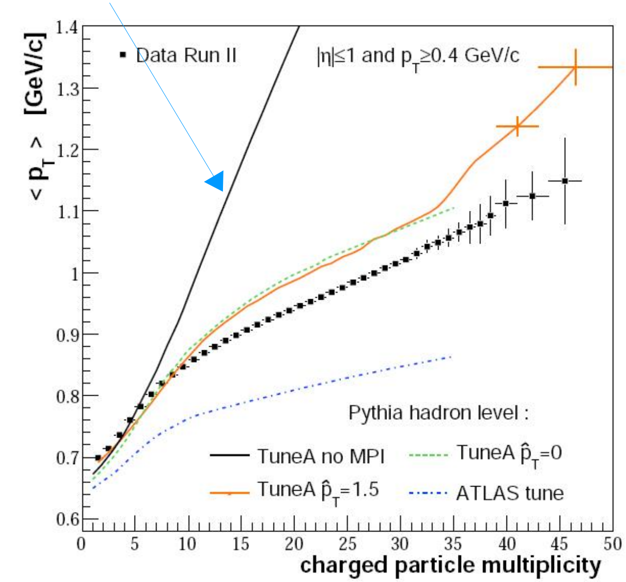
CDF 0904.1098 [hep-ex] **√s = 1.96 TeV**

pt > 0.4GeV/c
- power law @ pt < 10 GeV/c
- Pythia tune A @ pt < 20 GeV/c
- *"more sophisticated parametrisation"* above

→ *min bias collisions are mixture of hard and soft processes*

$$f = A\left(\frac{p_0}{p_t + p_0}\right)^n + B\left(\frac{1}{p_t}\right)^s$$

2 ↔ 2 interactions
hard collisions ↔ large Nch
→ rises too fast



underlying event

CDF Phys. Rev. D 65 (2002) 092002 **$\sqrt{s}$ = 1.8 TeV**

pp event =

hard scattering → pQCD

hard scattered partons + initial & final state rad.

→ jets

+

underlying event

beam beam remanents + hard scattering from initial and final state radiation

particles from break-up of protons

Herwig, Isajet, BBR dominate UE

+

Pythia solution

multiple parton scattering

semi-hard 2-to-2 scattering

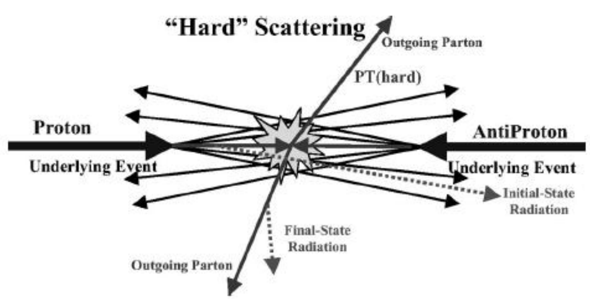


FIG. 1. Illustration of the way the QCD Monte Carlo models simulate a proton-antiproton collision in which a hard 2-to-2 parton scattering with transverse momentum, p_T(hard), has occurred. The resulting event contains particles that originate from the two outgoing partons (*plus initial and final-state radiation*) and particles that come from the breakup of the proton and antiproton (*"beam-beam remnants"*). The "hard scattering" component consists of the outgoing two "jets" plus initial and final-state radiation. The "underlying event" is everything except the two outgoing hard scattered "jets" and consists of the "beam-beam remnants" plus possible contributions from the "hard scattering" arising from initial and final-state radiation.

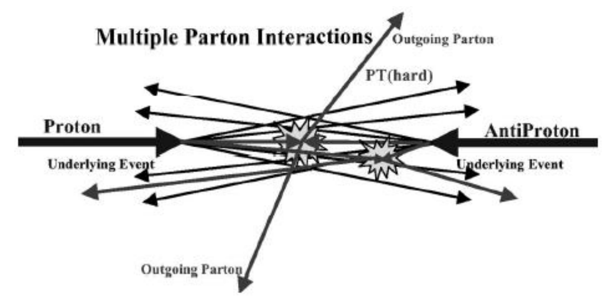
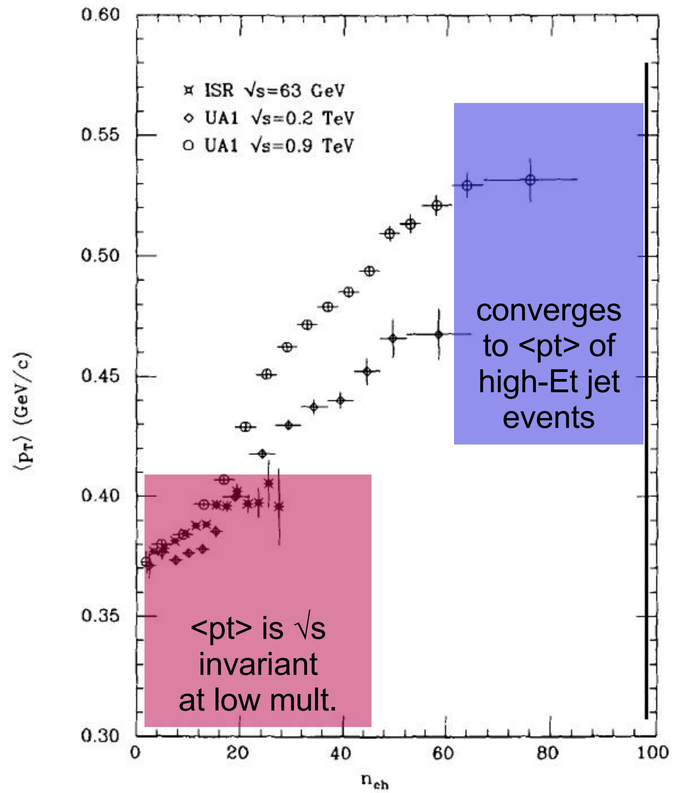


FIG. 2. Illustration of the way PYTHIA models the "underlying event" in proton-antiproton collision by including multiple parton interactions. In adddition to the hard 2-to-2 parton-parton scattering with transverse momentum, p_T(hard), there is a second "semi-hard" 2-to-2 parton-parton scattering that contributes particles to the "underlying event."

mean-pt vs multiplicity

UA1 Nucl Phys B 335 (1990) 261 **√s = 0.2 - 0.9 TeV**

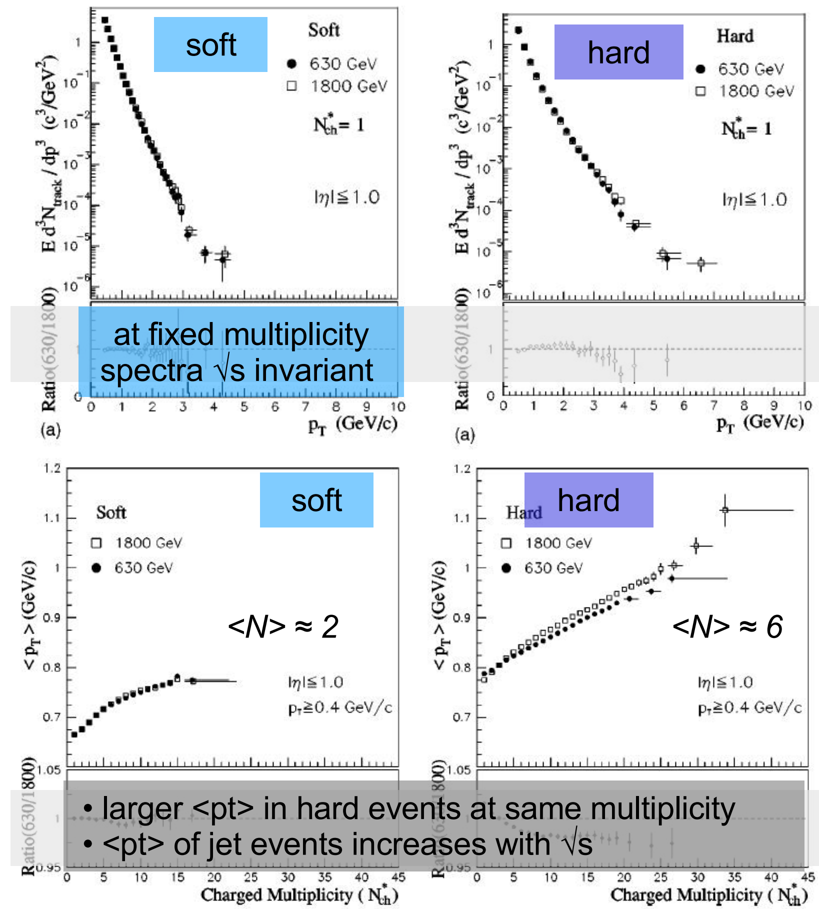
pt > 0.25 GeV/c



CDF Phys. Rev. D 65 (2002) 072005 **√s = 1800, 630 GeV**

hard events: *Et* or *pt > 1.1GeV* in jet cone of *R = 0.7*
soft events: no high-pt jet

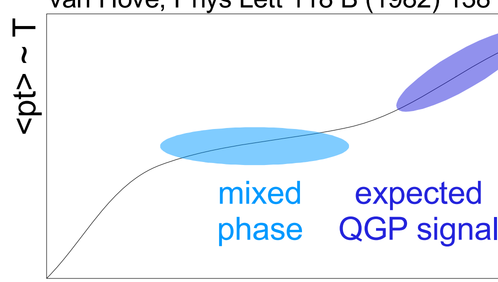
pt distribution *pt > 0.4GeV/c*



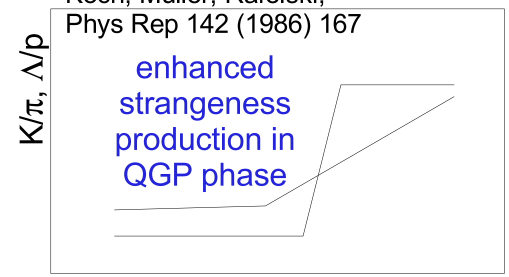
QPG search in $\bar{p}p$ at $\sqrt{s}$ = 1.8 TeV

E 735 at Tevatron C0 intersection region of the Fermilab collider

van Hove, Phys Lett 118 B (1982) 138



Koch, Muller, Rafelski, Phys Rep 142 (1986) 167

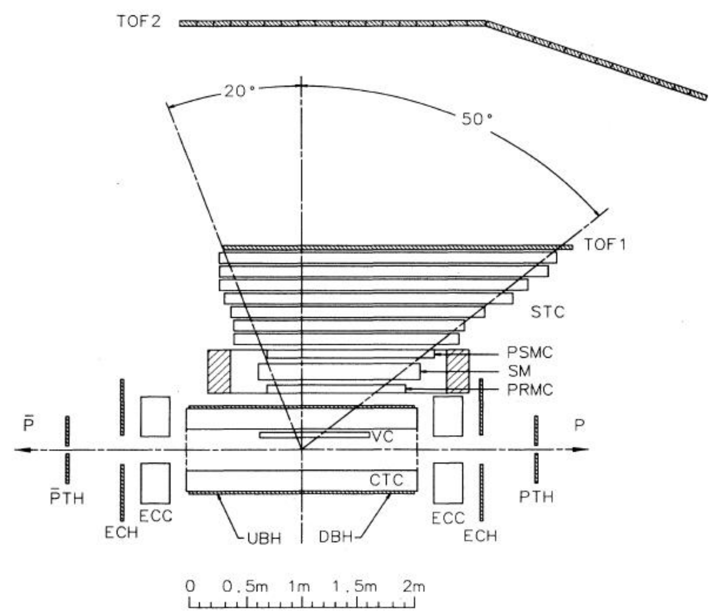


→ ruled out by SppS and Tevatron data

Observables
- <pt> vs multiplicity
- strange / non-strange vs mult.
  - π, p, γ
  - K, Λ, Ξ, ϕ

at $\sqrt{s}$ energy
1800 GeV, 300, 546, 1000 GeV
compare to SppS at 200, 546, 900 GeV

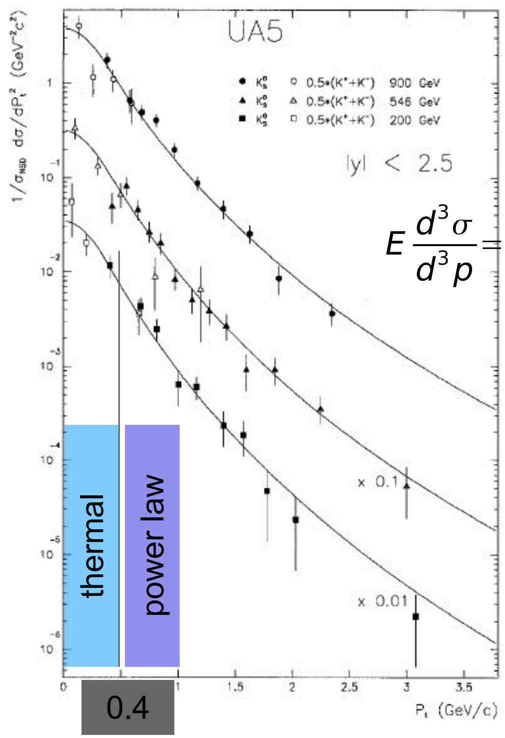
detector set-up
- multiplicity hodoscope |eta| < 3.25 → Nch
- magnetic spectrometer -0.36 < eta < 1.0
  18 degree azimuthal acceptance, p > 150 MeV/c
  pre- and post-magnet drift chambers → tracking
- ToF → pid



K/π ratio vs √s at Sp$\bar{p}$S

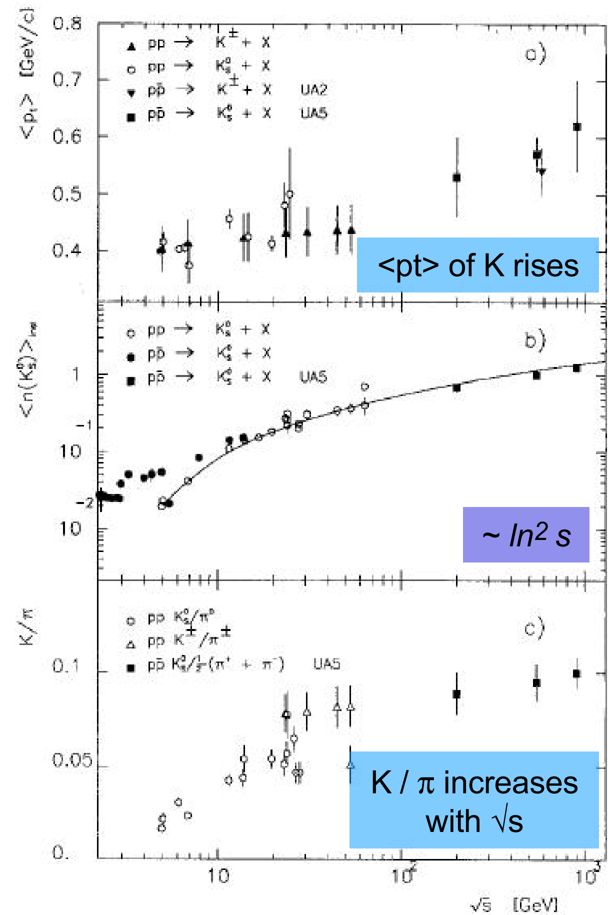
UA5 Z Phys C 41 (1988) 179 **√s = 0.2 - 0.9 TeV**
Phys Lett B 199 (1987) 311

no B field → PID by decay topology
V0's: K0s, momentum from decay kinematics
kinks: K in 3 prong decay, momentum!



$$E\frac{d^3\sigma}{d^3p} = \begin{cases} A\exp(-b\,m_t) \\ C\dfrac{p_0^n}{(p_0+p_t)^n} \end{cases}$$

p_0 and n correlated → fix p_0



faster than expected from ISR

<pt> might increase with multiplicity

like charged particles, width and height (dn/dy) scale with *ln s*

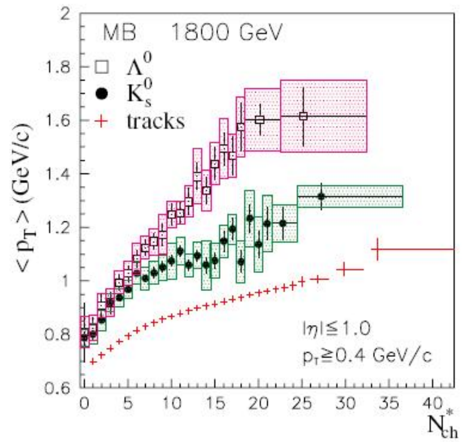
canonical suppression diminishes as <K> increases

V0 yield vs multiplicity

CDF Phys. Rev. D 72 (2005) 052001 **√s = 1800, 630 GeV**

comparative study of event structure

- as function of multiplicity
- as function of Et
  hard events: *Et* or *pt > 1.1GeV* in jet cone of *R = 0.7*
  soft events: no high-pt jet



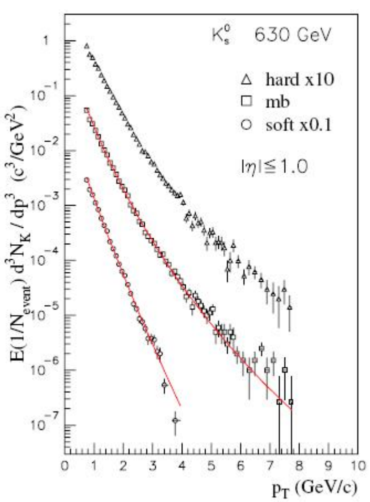
mean-pt
increases with mass

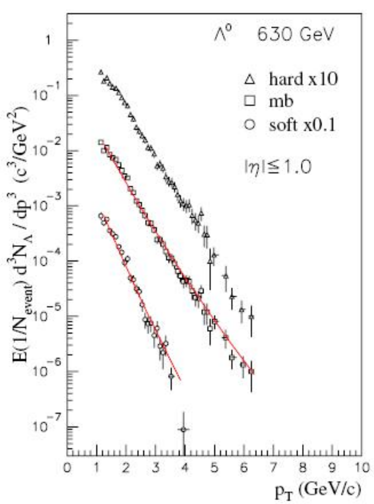
at low multiplicity:
√s invariant

pt distribution
pt (K0s) > 0.8 GeV/c
pt (Λ) > 1.1 GeV/c

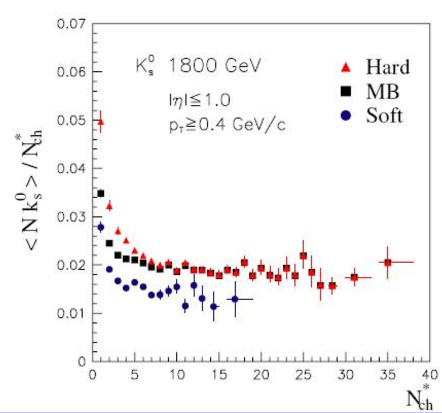
} extrapolate with power law down to pt = 0.4 GeV/c part below missed

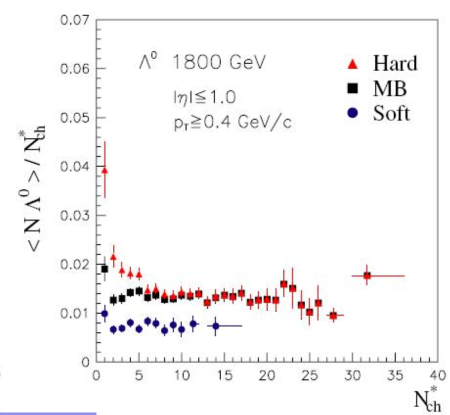
→ only high-pt measured → pQCD part
→ soft physics missed ?





V0 / Nch vs multiplicity
const
yield dominantly in extrapolated part
→ might be artifact of extrapolation





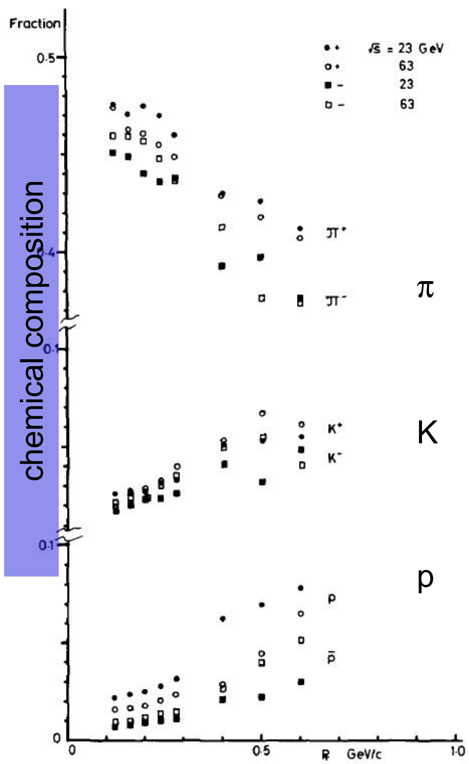
→ hard events favour larger K/π and larger <pt> at same mult.

K/π ratio vs pt

ISR Phys Lett 64B (1976) 111 **√s = 23 - 63 GeV**
Nucl Phys B 116 (1976) 77

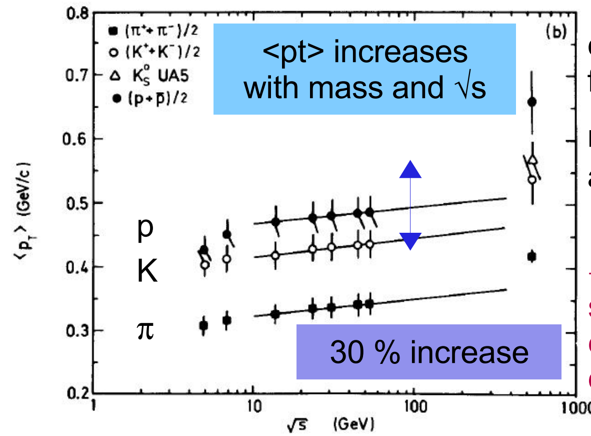
π: 40 < pt < 400 MeV/c
K: 100 < pt < 300 MeV/c
p: 100 < pt < 500 MeV/c

p+p



pt (GeV/c)

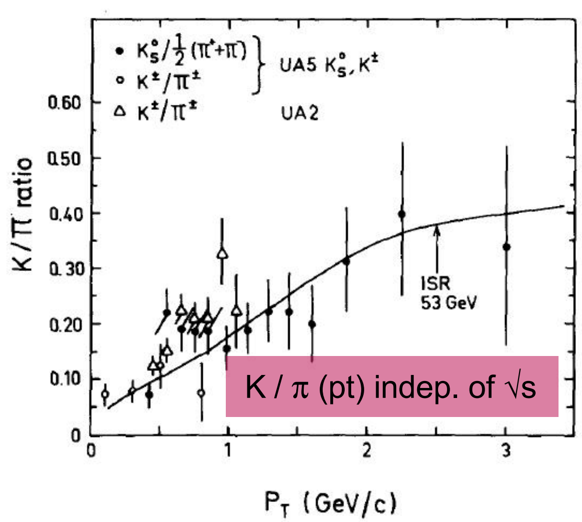
UA5 Nucl Phys B 258 (1985) 505 **√s = 540 GeV**



common velocity field

more energy available

→ <pt> of K increases stronger than expected from ISR data



const for pt > 3 GeV/c due to jet fragmentation ?

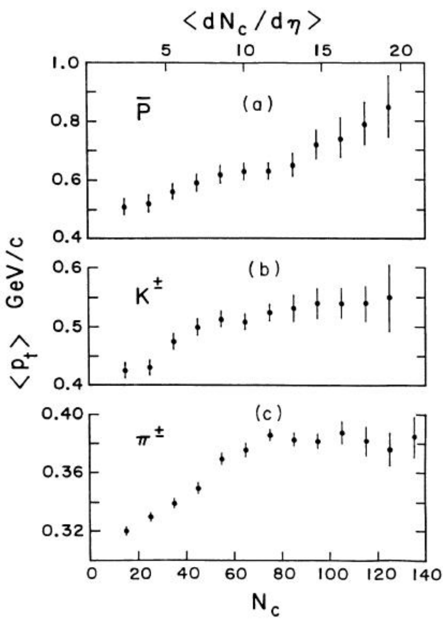
strangeness vs multiplicity

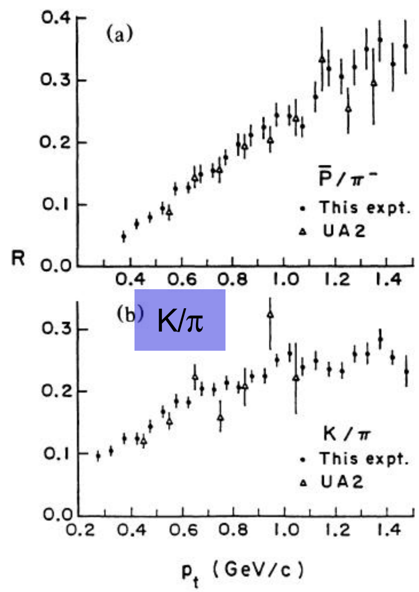
E 735 Phys Rev Lett 64 (1990) 991 **√s = 1800 GeV** ***Run I data***

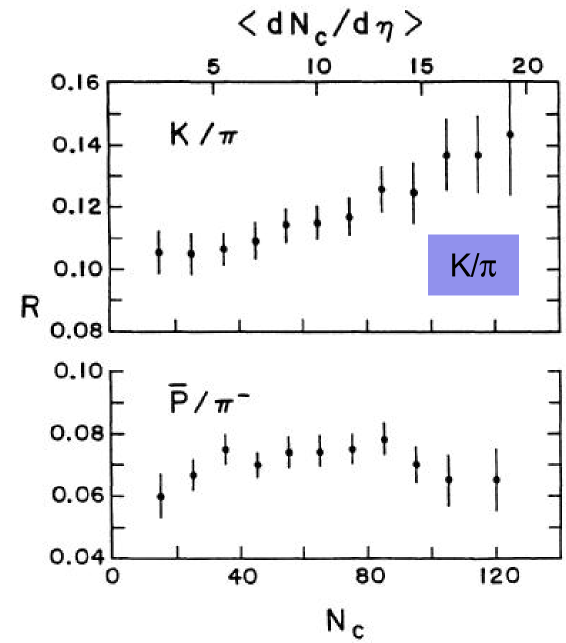
K/π *0.25 < pt < 1.5 GeV/c*

$$dN/dp_t^2 = \begin{cases} A\exp(-a\,p_t) & \text{K} \\ B(p_t+p_0)^{-n} & \pi \end{cases}$$

- plateau in <pt> of π and K?
- K/π (pt) is √s invariant
- K/π increases with multiplicity







strangeness vs √s and multiplicity

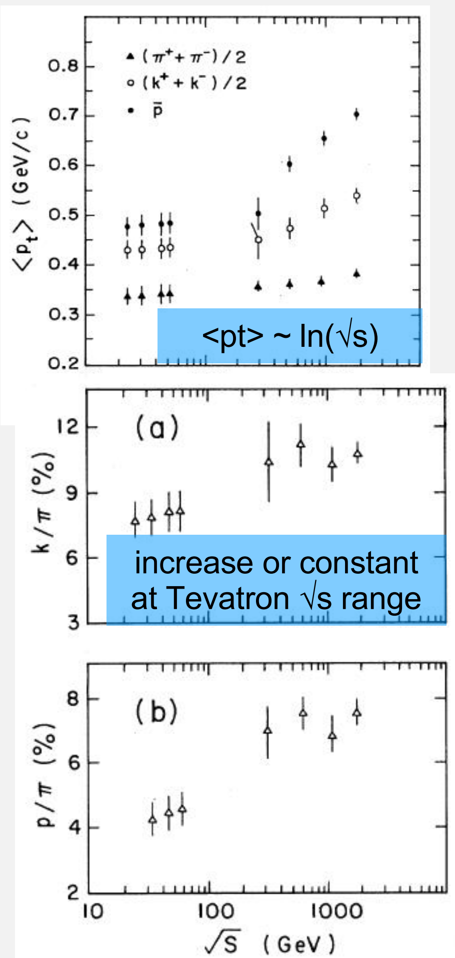
E 735 Phys. Rev. D 48 (1993) 984 **√s = 300, 540, 1000, 1800 GeV** ***Run II data***

K/π *0.25 < pt < 1.5 GeV/c*

$$dN/dp_t^2 = \begin{bmatrix} A\exp(-a\,p_t) \\ B(p_t+p_0)^{-n} \end{bmatrix}$$

K <pt> = 2 / a

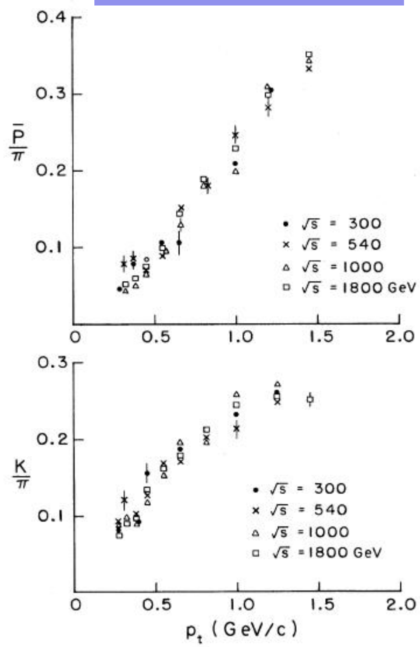
π <pt> = $2p_0$ / (n-3)



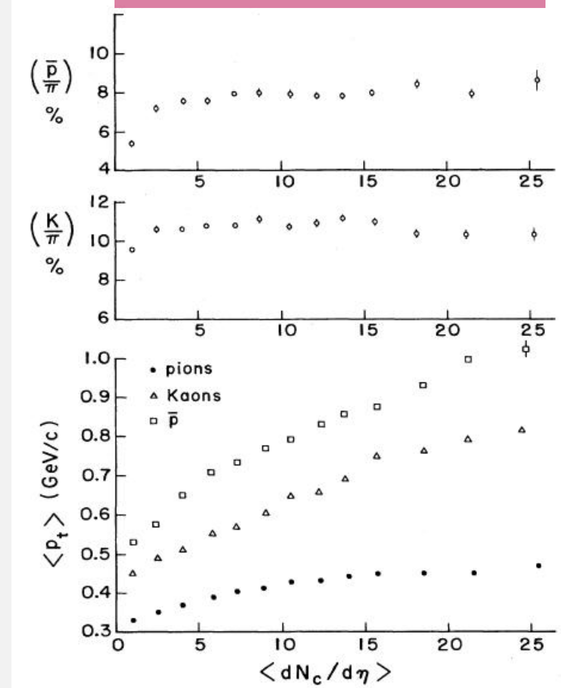
<pt> ~ ln(√s)

increase or constant at Tevatron √s range

increase with pt is √s invariant



K/π rise and <pt> flattening vanished, see PRL 64



hyperon production vs multiplicity

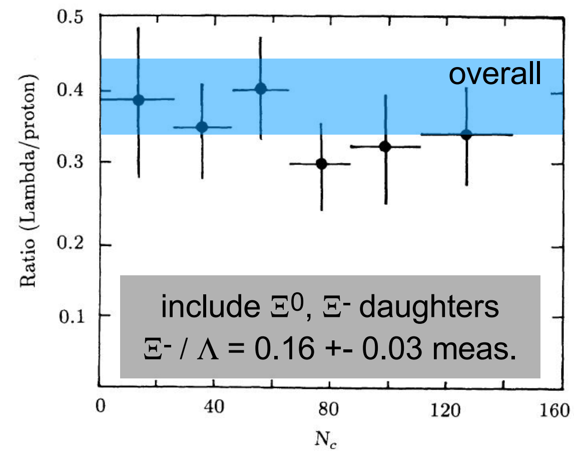
E 735 Phys. Rev. D 46 (1992) 2773 **√s = 1.8 TeV**
Nucl. Phys. A 544 (1992) 343c
Nucl. Phys. A 525 (1991) 165c

Λ / Nch, Λ / p *0.5 < pt < 1.5 GeV/c*

p = p + Λ + Σ⁺

Λ = Λ + Σ⁰ + Ξ⁰ + Ξ⁻

$$\frac{dn}{p_t dp_t} = A\exp(-b\,p_t)$$



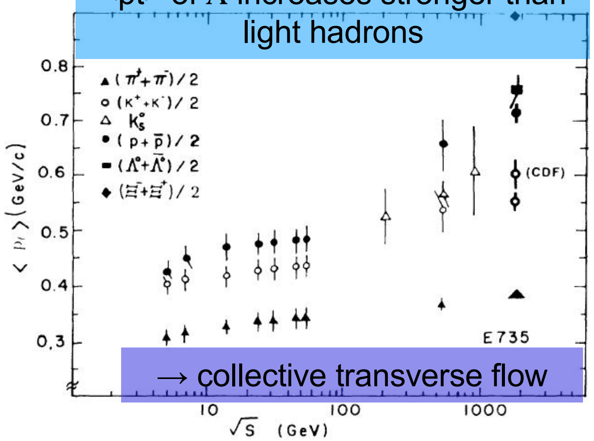
overall

include Ξ⁰, Ξ⁻ daughters
Ξ⁻ / Λ = 0.16 +- 0.03 meas.

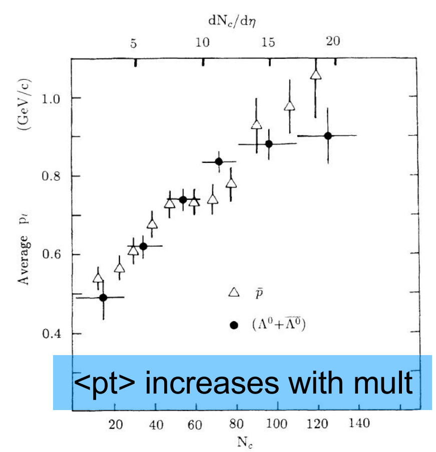
Λ / p vs multiplicity is constant

p / π is const → Λ / π flat too

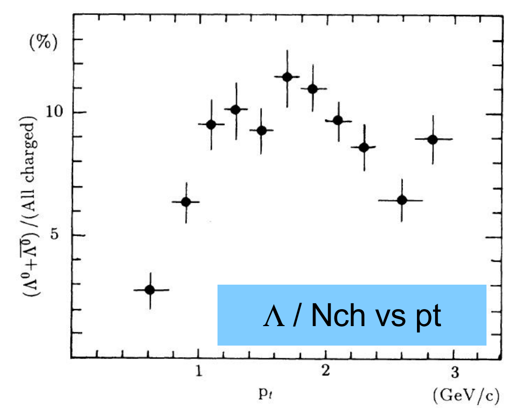
<pt> of Λ increases stronger than light hadrons



→ collective transverse flow



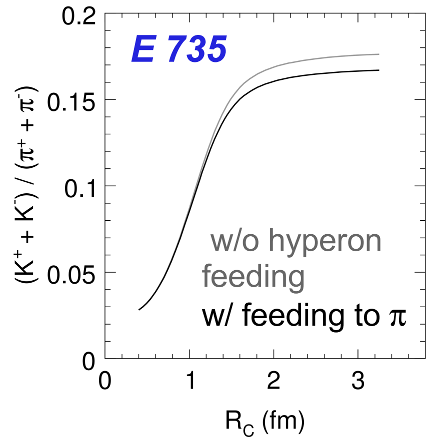
<pt> increases with mult



Λ / Nch vs pt

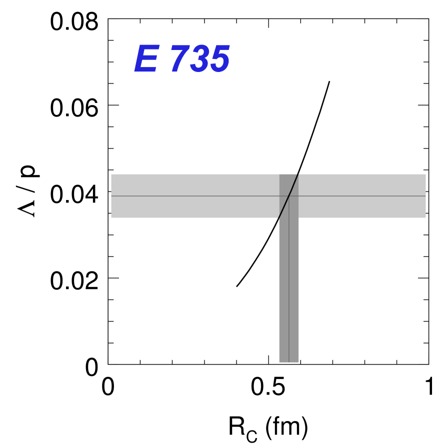
comparison statistical model vs data

Statistical model hep-ph/0407174



K/π vs multiplicity
- overall K/π ≈ 0.1
- K/π (multiplicity) ≈ 0.1 *E735*
- CDF K/π not comparable to model due to pt cut-off

→ consistent with statistical model with significant canonical suppression of strange-particle phase-space



Λ/p vs multiplicity
- overall Λ/p ≈ 4%
- Λ/p vs multiplicity const
- CDF Λ/p not comparable to model due to pt cut-off

→ consistent with statistical model

→ canonical suppression seems stronger than in K data

→ **more data** – *on multi-strange hyperons* – needed to check whether model applies in jet-dominated regime

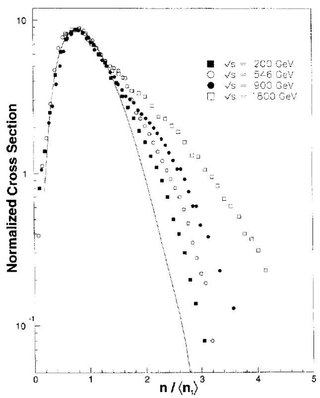
strangeness canonical
T = 170 MeV, μB = μQ = 0

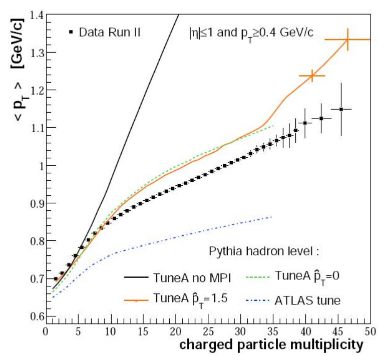
summary

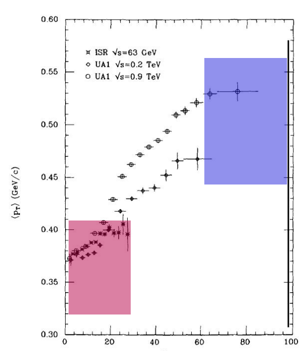
multiplicity and <pt>

- mean multiplicity rises stronger than *ln s* at all energies
- KNO type distribution exhibits shoulder
- spectra consist of two components, thermal and power law
- mean-pt vs mult. rises moderately
→ complex event structure in p+p
→ no QPG signature

- low multiplicity: mean-pt ~ √s invariant







strangeness production

- <pt> increases with mass, multiplicity and √s
- K/π increases with √s
- K/π vs multiplicity is constant → no QPG signature
- data show significant canonical suppression