50 years

of Institute of Nuclear Physics in Cracow

and

its contribution to relativistic nuclear physics

The Henryk Niewodniczański Institute of Nuclear Physics in Cracow

Professor Henryk Niewodniczański

(1900 – 1968)

Founder of the Institute.
Discovered magnetic dipole transitions in atomic spectra (1934).
Was the member of the JINR Scientific Council.

Professor Marian Mięsowicz

(1907 – 1992)

Founder of high energy physics in Cracow. Early work on liquid crystals (discovered anisotropy of viscosity in external magnetic field), later work on cosmic rays.

Aerial view of the Institute

Main fields of research

- Particle physics and astrophysics
- Nuclear physics
- Condensed matter physics
- Interdisciplinary research and applied physics

Personnel: 450 total

180 scientists with Ph.D

26 professors

About ¼ work in high energy physics
(CERN, DESY, BNL, KEK)

Physics with relativistic nuclei

Early days – Cosmic ray experiments:

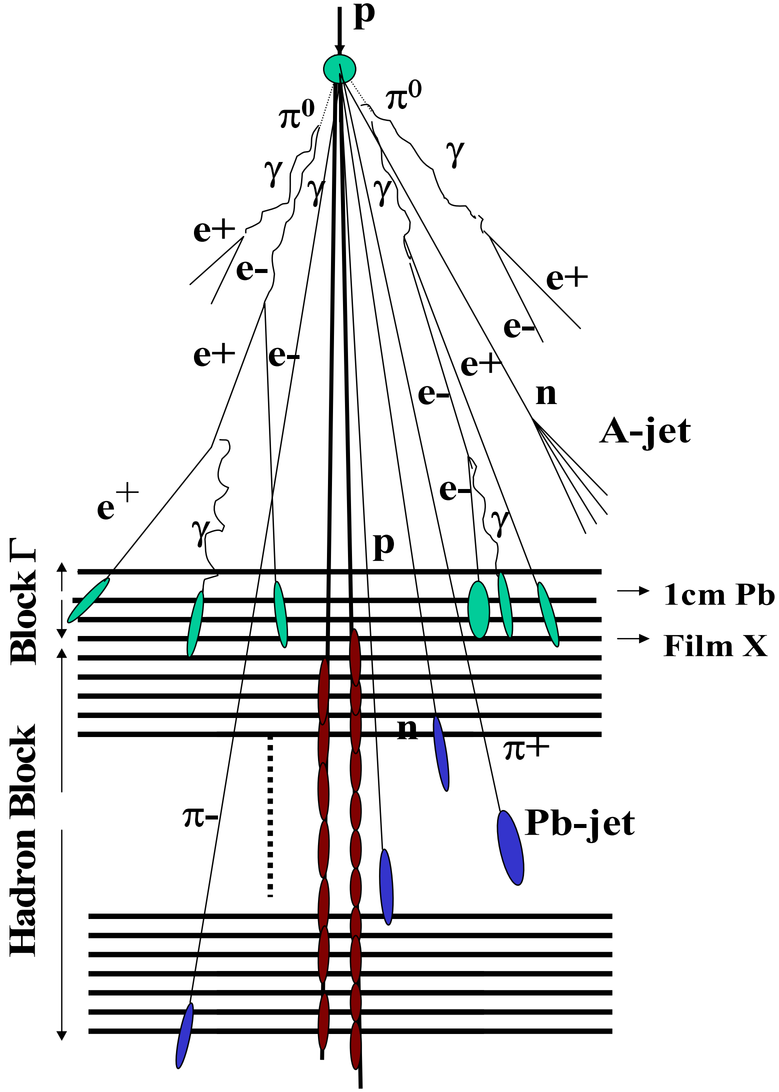
ICEF – International Cooperative Emulsion Flight Nuclear emulsion inradiated by cosmic rays in stratosphere – Some primaries were nuclei.

The Pamir Collaboration – calorimeters with X-ray films exposed at mountain altitude (4300 m). Observation of „Centauro" events and of strongly penetrating (long – flying) component. Possible interpretation: strange quark matter production by a primary cosmic ray nucleus in upper atmosphere, successive decays of a strangelet.

Review:

E. Gładysz-Dziaduś - Phys. Part. Nucl. 34 (2003) 285

$E_0 \sim 10^{15} - 10^{16}$ eV



PHOTON-HADRON FAMILIES in cosmic ray mountain experiments

TYPICAL EVENT

$\Sigma E_h < 30\,\%\, \Sigma E_{vis}$

$H \sim 100 - 1000$ m

CENTAURO

$\Sigma E_h >> \Sigma E_\gamma$

$N_h > N_\gamma$

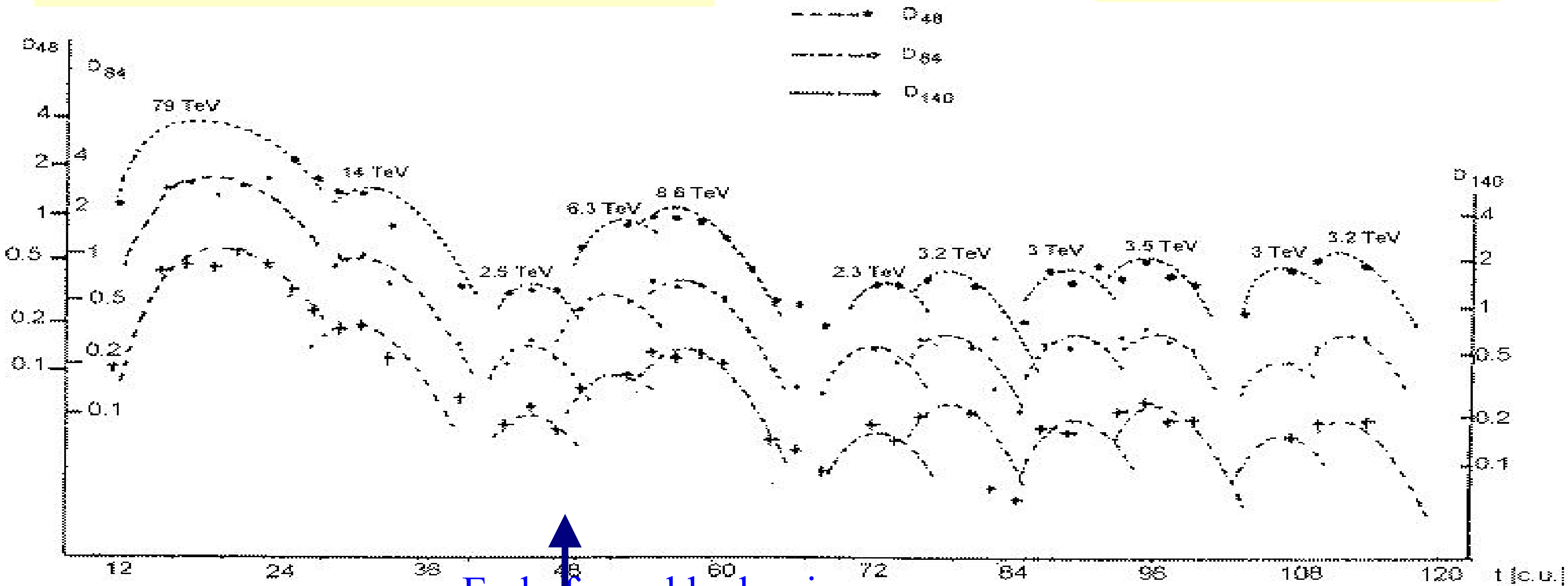
$Q_h = \Sigma E_h / \Sigma E_{vis} > 0.5$

$\Sigma E_{vis} = \Sigma E_h + \Sigma E_\gamma$

STRONGLY PENETRATING CASCADES in Pb CHAMBERS
STRANGELETS???

First observation:
Krakow group,17th ICRC, 1981
2 exotic cascades in Centauro-like event

Other events
Arisawa et al.,Nucl. Phys. B424(1994)241

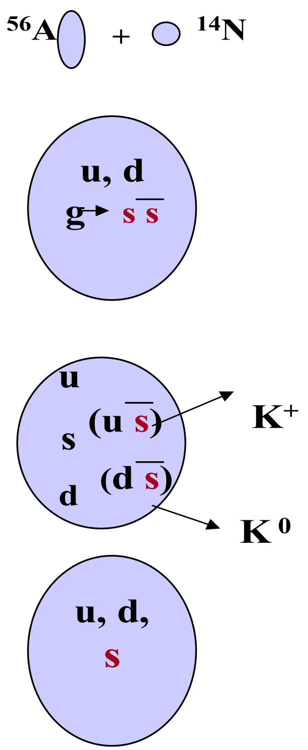


End of usual hadronic cascade ~1.5 Λint

60 cm Pb~3.6 Λ int

Cascades pass through the chamber practically without attenuation and revealed many-maxima character with small distances between humps

CENTAURO FIREBALL EVOLUTION



CENTRAL COLLISION

at the top of the atmosphere

E_p ~1740 TeV

QUARK MATTER FIREBALL
in the baryon-rich fragmentation region

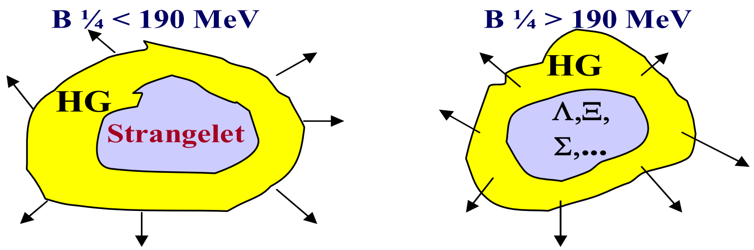
High μ_b suppresses production
of $(u\bar{u})$, $(d\bar{d})$, allowing for g → s $\bar{s}$

(pre-equilibrium)
KAON EMISSION
K^+, K^0 carry out:

strangeness, positive charge, entropy

SQM FIREBALL

Stabilizing effects of s quarks
→ long lived state



EXPLOSION

~75 nonstrange
baryons+ strangelet
(A ~ 10-15)

Strangeness distillation
mechanism :

C. Greiner et al., Phys.
Rev. D38 (1988)2797

A.Panagiotou et al., Phys. Rev. D45 (1992) 3134

Estimated for Chacaltaya Centauros:

- **Energy density**
- **$\varepsilon \sim 2.4$ GeV/fm^3,**
- **Temperature**
- **T ~ 130 MeV**
- **Baryon chemical potential**
- **$\mu b \sim 1.8$ GeV/fm^3**

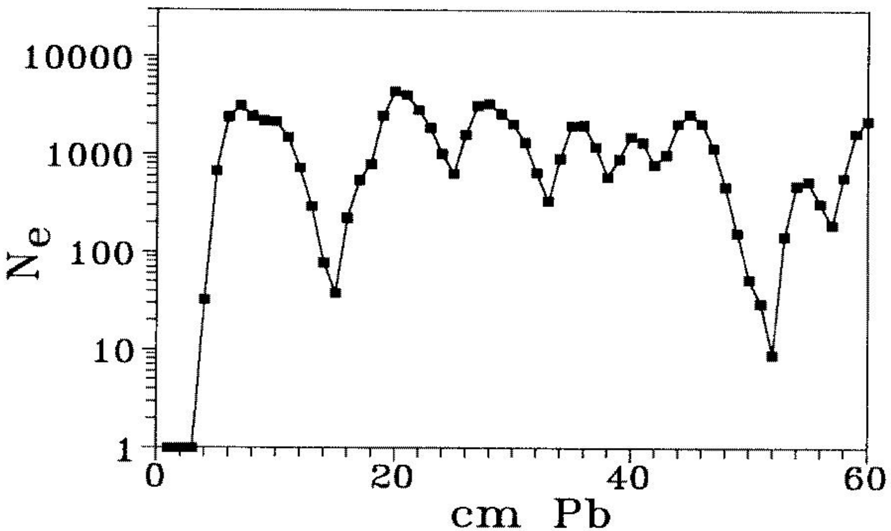
Sufficient for

PHASE TRANSITION

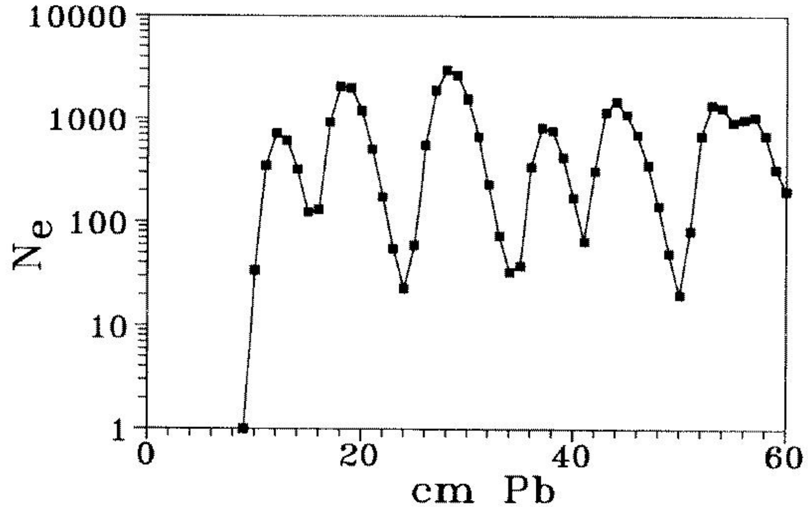
Possible

STRANGELET FORMATION

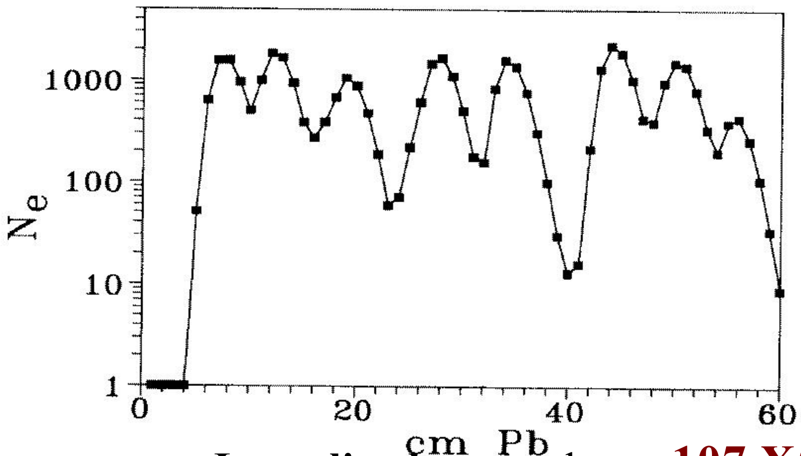
Strangelet passage through the Pb emulsion chamber



Unstable strangelet decaying into a bundle of 7 n
(En ~ Estr/Astr ~ 200 TeV)



Metastable strangelet
(Astr=15, Estr~200ATeV, τ~10^{-15} s)



Long-lived strangelet **~107 X0, ~3.5 Λ int**
(Astr=15, μq = 600MeV)

Simulated transition curves resemble the observed long many-maxima cascades

E. G.-D. and Z. Wlodarczyk, J. Phys., Nucl. Part. Phys. G23 (1997)2057

JACEE Collaboration – again emulsions irradiated in baloon flights:

Si, Ca + AgBr at ~ 1 TeV/nucleon

$N_{ch} > 1000$

$\varepsilon = 4$ GeV/fm ^{3} from Bjorken formula

Early indication that energy density necessary for a transition to the quark-gluon plasma can be achieved in high energy nuclear collisions

[T.H. Burnett et al., Phys. Rev. Lett. 50 (1983) 2062]

Experiments at accelerators

The Dubna synchrophasotron
2 m propane bubble chamber

p, d, He, C at 3.7 AGeV
Multiplicities of produced pa
π-π correlations, p-p correlation

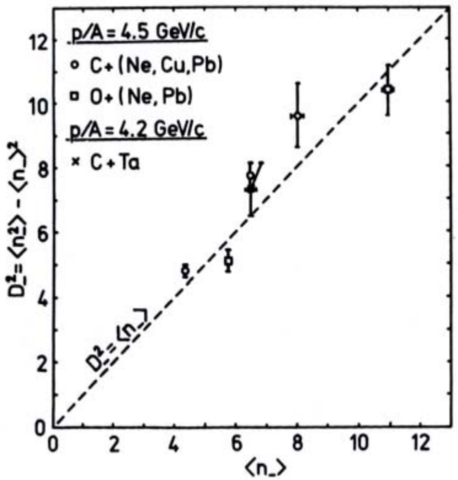


Fig. 23. Dispersion squared versus average multiplicity of negative secondaries from central collisions of ^{12}C and ^{16}O nuclei with several target nuclei. The dashed line corresponds to the Poisson distribution.[114]

[J.Bartke et al.., Yad. Fiz.. 32 (1980) 699]

1382 *J. Bartke*

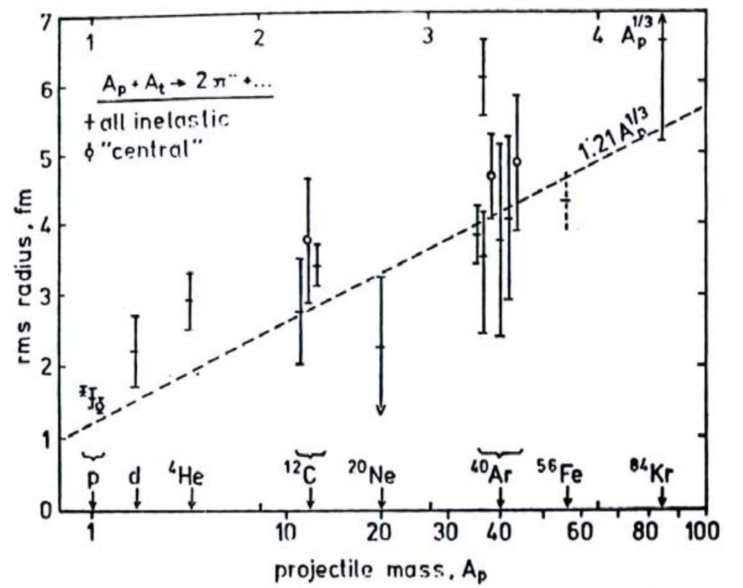


Fig. 45. Radii of the pion emission source in collisions of relativistic nuclei versus cubic root of the mass number of the projectile. The straight line represents the effective nuclear interaction radius of the projectile.[189]

[J. Bartke, Phys. Lett. 174 B (1986) 32]

Emulsion experiment at the Dubna synchrophasotron

The problem of „anomalons”:

E.M. Friedländer et al., Phys. Rev. Lett. 45 (1980) 1084

^{22}Ne at 4.2 AGeV

Convincing evidence against „anomalons”

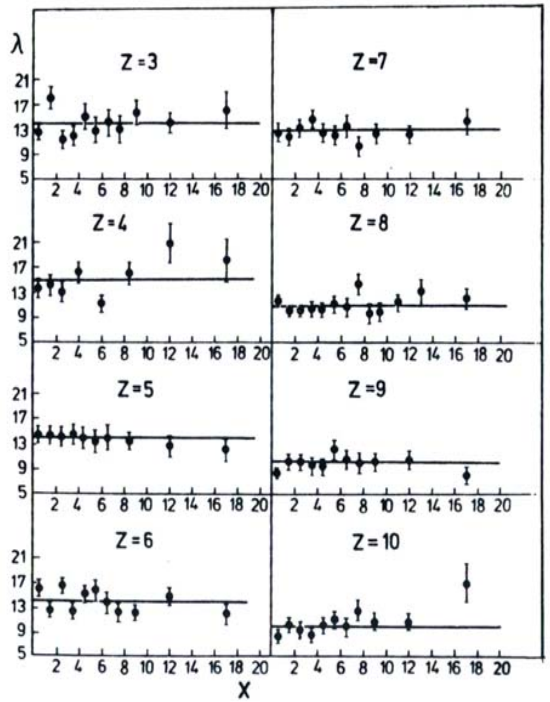


Fig. 8. Evidence against anomalons with charges $3 \leq Z \leq 10$ from the emulsion experiment with ^{22}Ne beam at Dubna. The plot shows experimental distributions of mean-free-path of secondary nuclei with different values of Z. From Ref. 71.

[B.P. Bannik et al.., Pisma Zh. Eksp.. Teor. Fiz. 39 (1984) 184;

Z. Phys. A321 (1985) 249]

Emulsion experiments at BNL and CERN

Comparative studies of nuclear collisions at various energies.

Evidence for „limiting fragmentation" (A.M. Baldin)

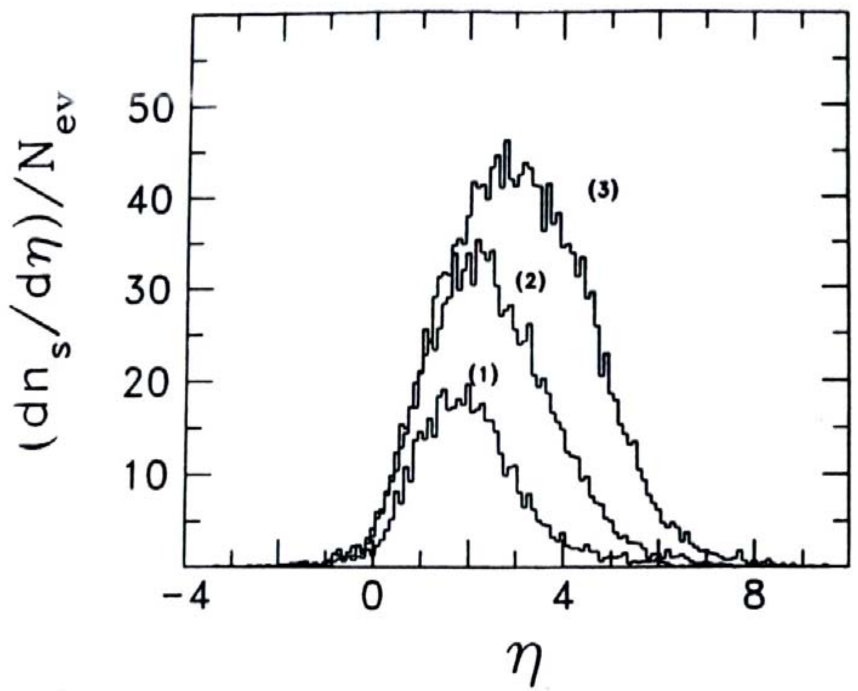


Fig. 50. Normalized pseudorapidity distributions in ^{16}O + Ag/Br interactions at three energies: (1) 14.6 GeV/nucleon, (2) 60 GeV/nucleon and (3) 200 GeV/nucleon.[79]

[L.M. Barbier et al.., Phys. Rev. Lett. 60 (1988 405]

Experiment NA35 at the CERN SPS

2m streamer chamber
^{16}O at 60 and 200 AGeV
^{32}S at 200 AGeV

Study of charged particle multiplicities
Evidence for important role of collisions geometry

Volume 205, number 4 PHYSICS LETTERS B 5 May 1988

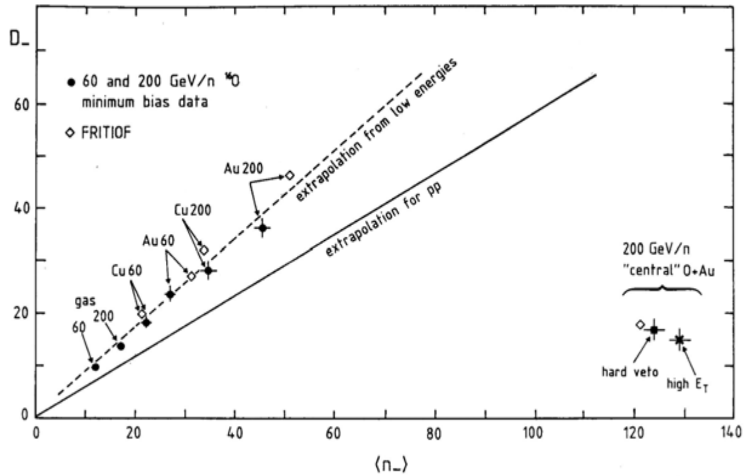


Fig. 4. Dispersion plotted against average multiplicity of negative particles from inelastic and central collisions of ^{16}O with several target nuclei. The solid line represents the dependence of D_- on $\langle n_- \rangle$ established for p–p collisions; the dashed line indicates a similar dependence for nucleus–nucleus collisions at low energies. D_- and $\langle n_- \rangle$ values obtained from the FRITIOF simulations are also shown.

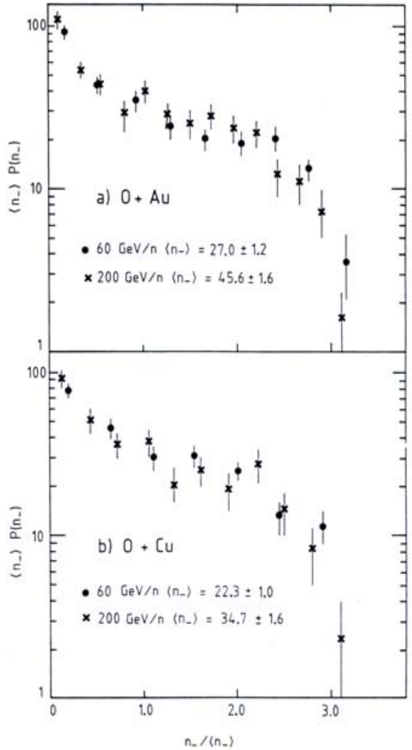


Fig. 3. Multiplicity distributions of negative particles for two energies of the ^{16}O projectile, presented in the KNO scaling variable, for Au(a) and Cu(b) targets.

[A. Bamberger et al., Phys. Lett. B205 (1988) 583]

Experiment NA35 at the CERN SPS

Spectra of charged kaons from decays in flight (τ-decays and „kinks”)

612c M. Kowalski / *Production of charged kaons in central S+S and O+Au collisions*

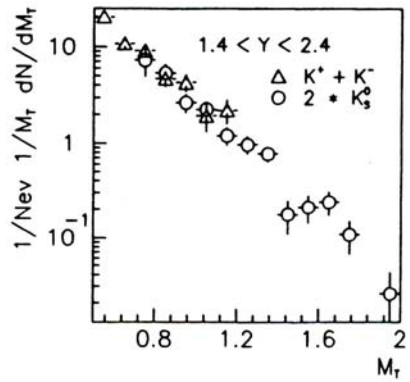


Fig. 1 Transverse mass distribution for charged and neutral kaons in S+S interactions

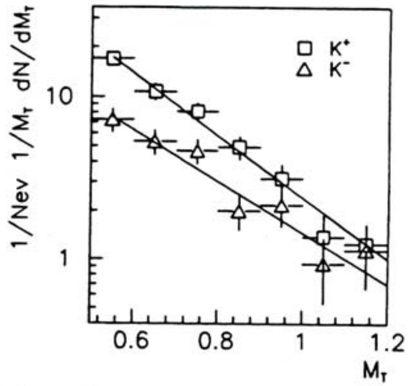
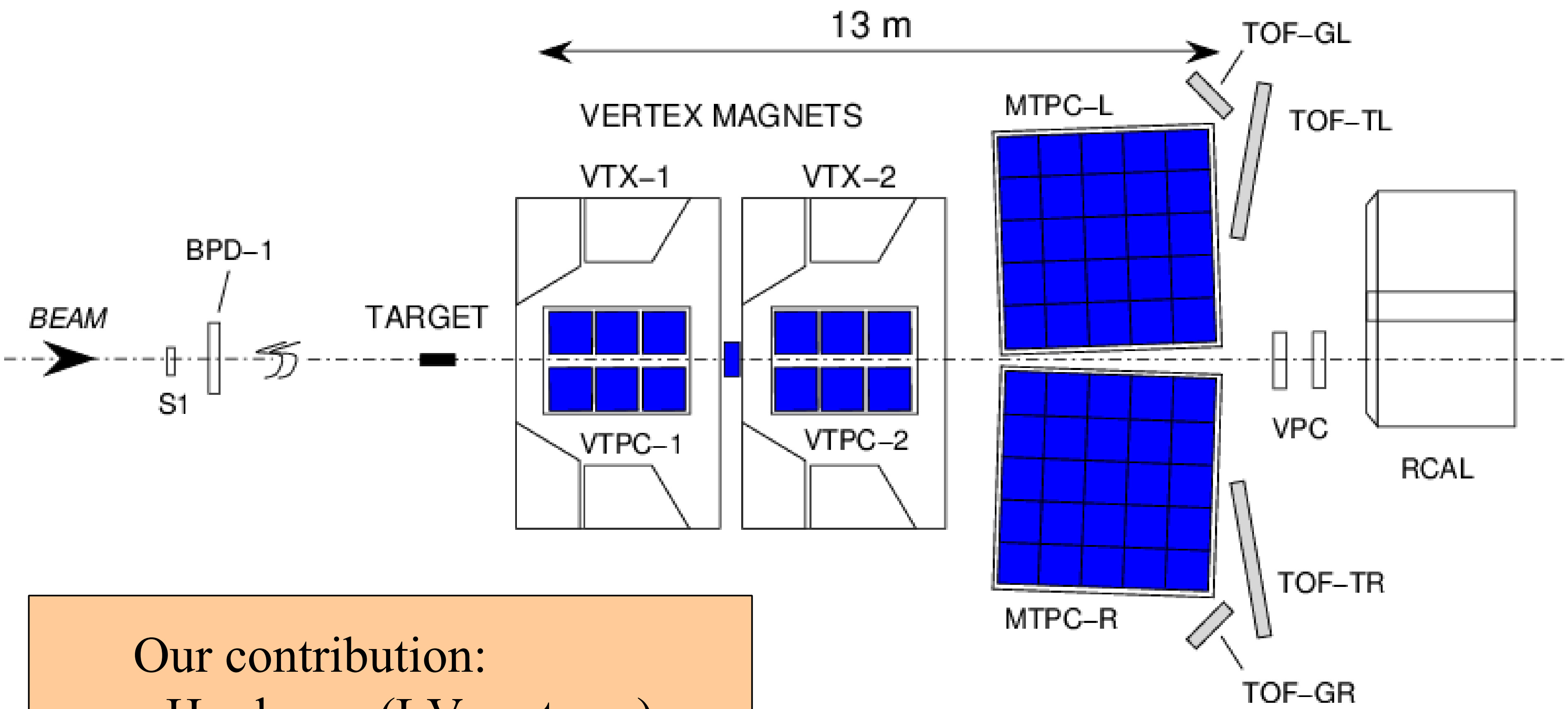


Fig. 2 Transverse mass distribution for positive and negative kaons in S+S interactions. The lines are the fit to the data.

M. Kowalski, Nucl. Phys. A544 (1992) 609c

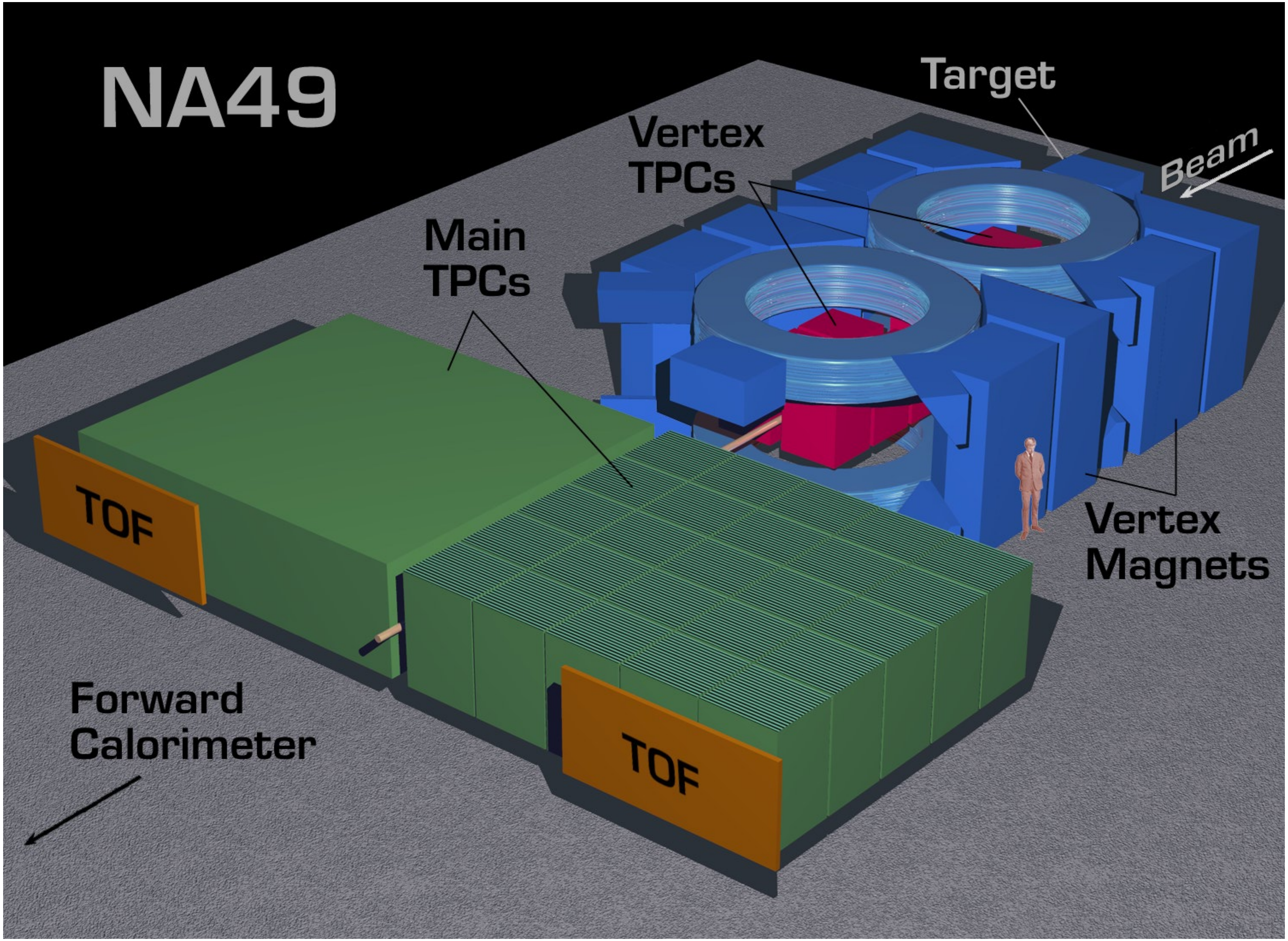
(data for K^0's are from J. Bartke et al., Z. Phys. C48 (1990) 191

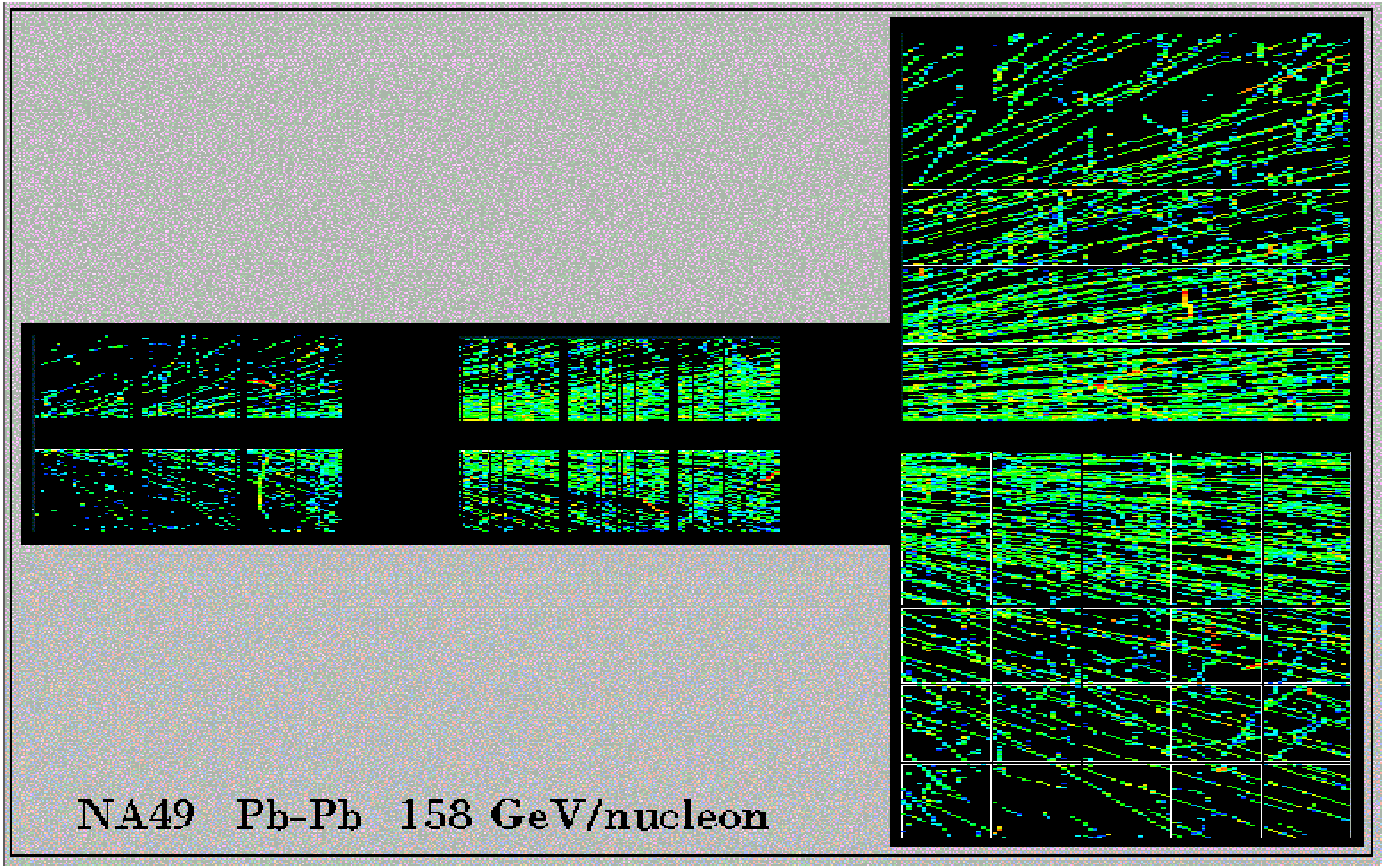
Experiment NA49 at the CERN SPS



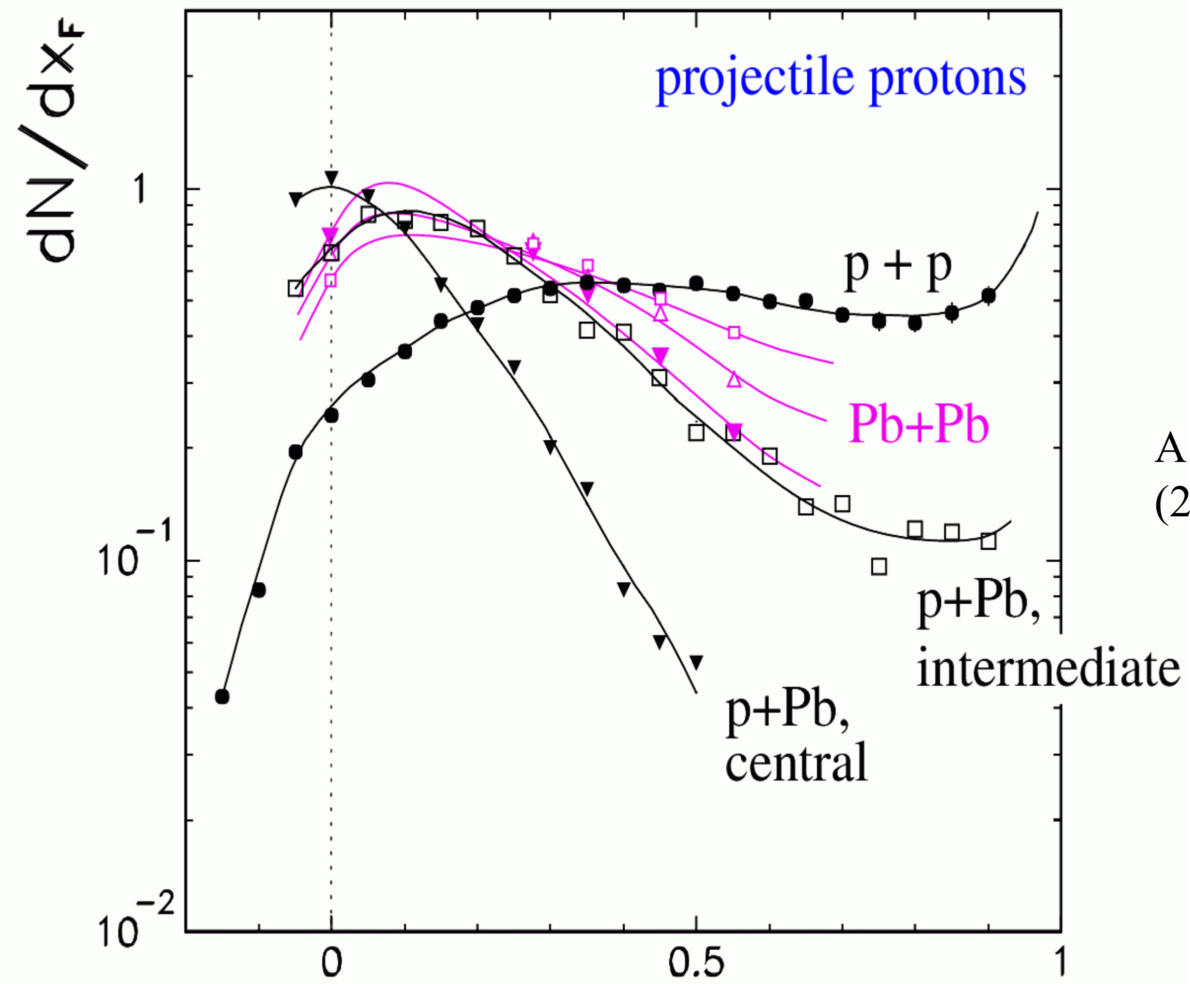
Our contribution:

- Hardware (LV systems)
- Calibration
- Data analysis


NA49
Target
Beam
Vertex
TPCs
Main
TPCs
TOF
TOF
Vertex
Magnets
Forward
Calorimeter


NA49 Pb-Pb 158 GeV/nucleon

1) Comparison of p+p, p+Pb, and Pb+Pb reactions



A.Rybicki, J.Phys.G:Nucl.Part.Phys.30 (2004) S743

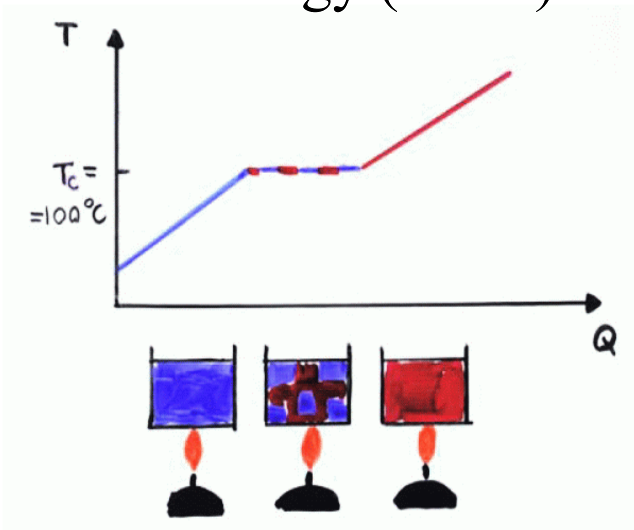
Common evolution for all collision types $x_F = \frac{p_L}{p_L^{BEAM}}$

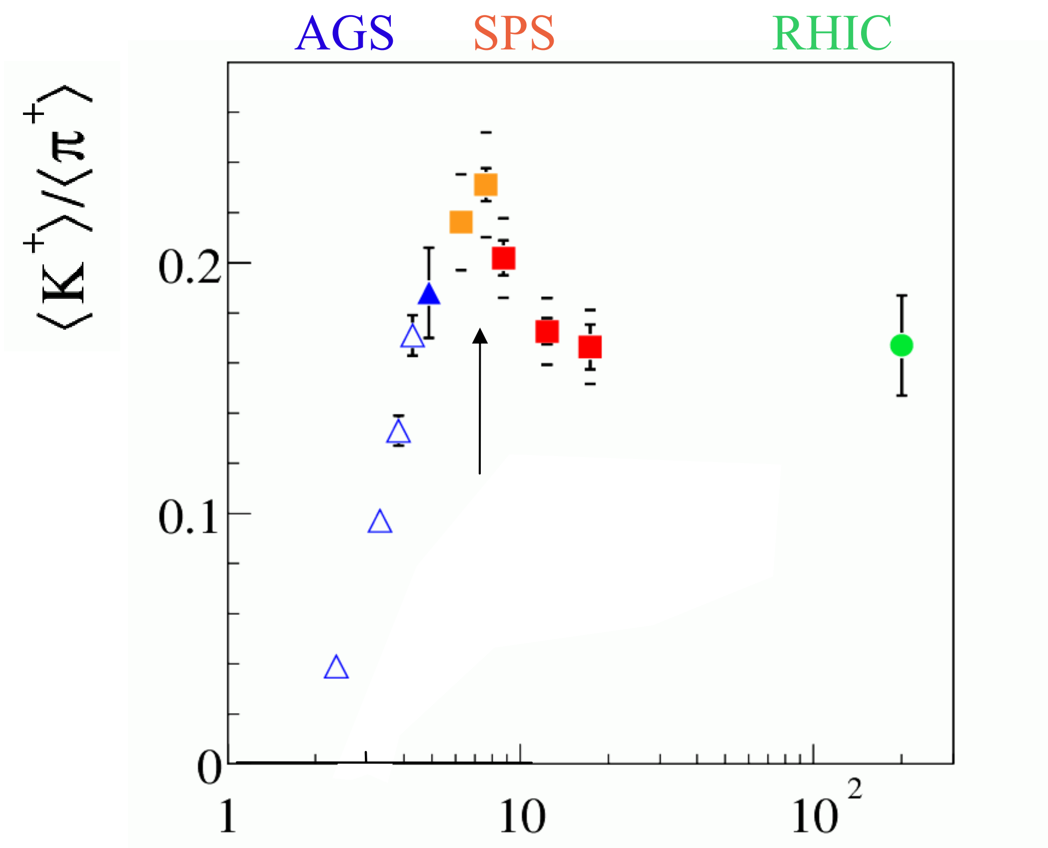
2) Energy dependence of central heavy ion collisions

Idea: phase transition = anomalies

hadronic matter --> quark-gluon plasma

Analogy (water):

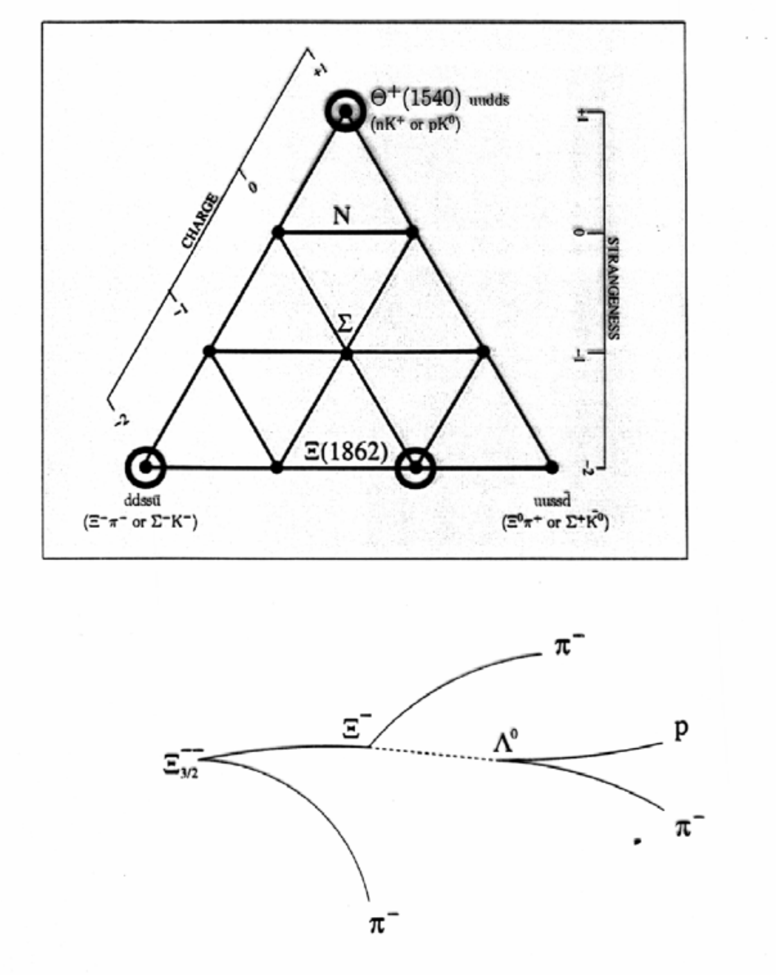


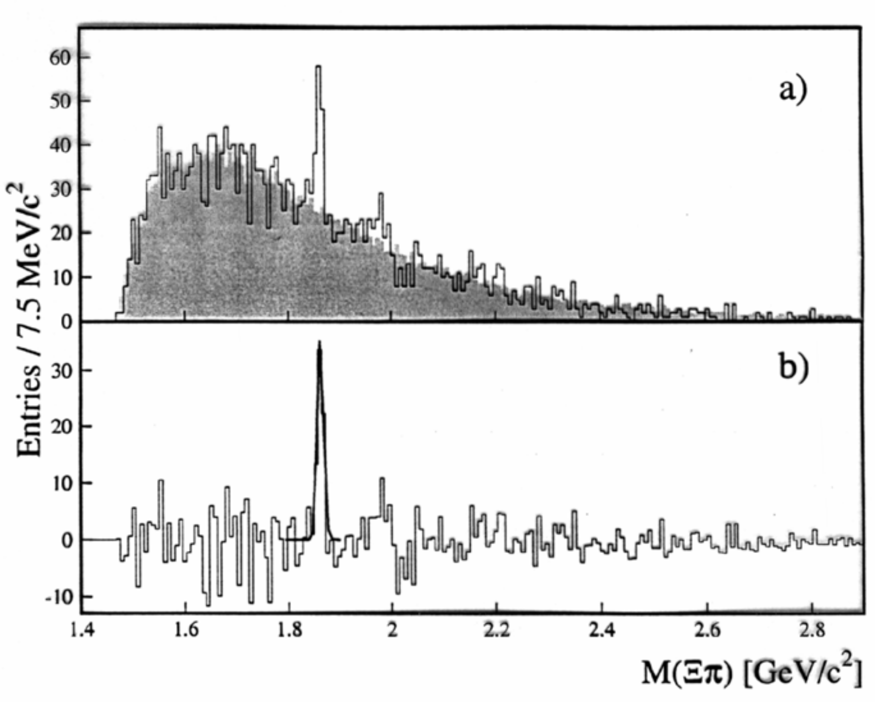


Collision energy [GeV/nucleon pair]

M.Gazdzicki,
J.Phys.G:Nucl.Part.Phys.30 (2004) S701

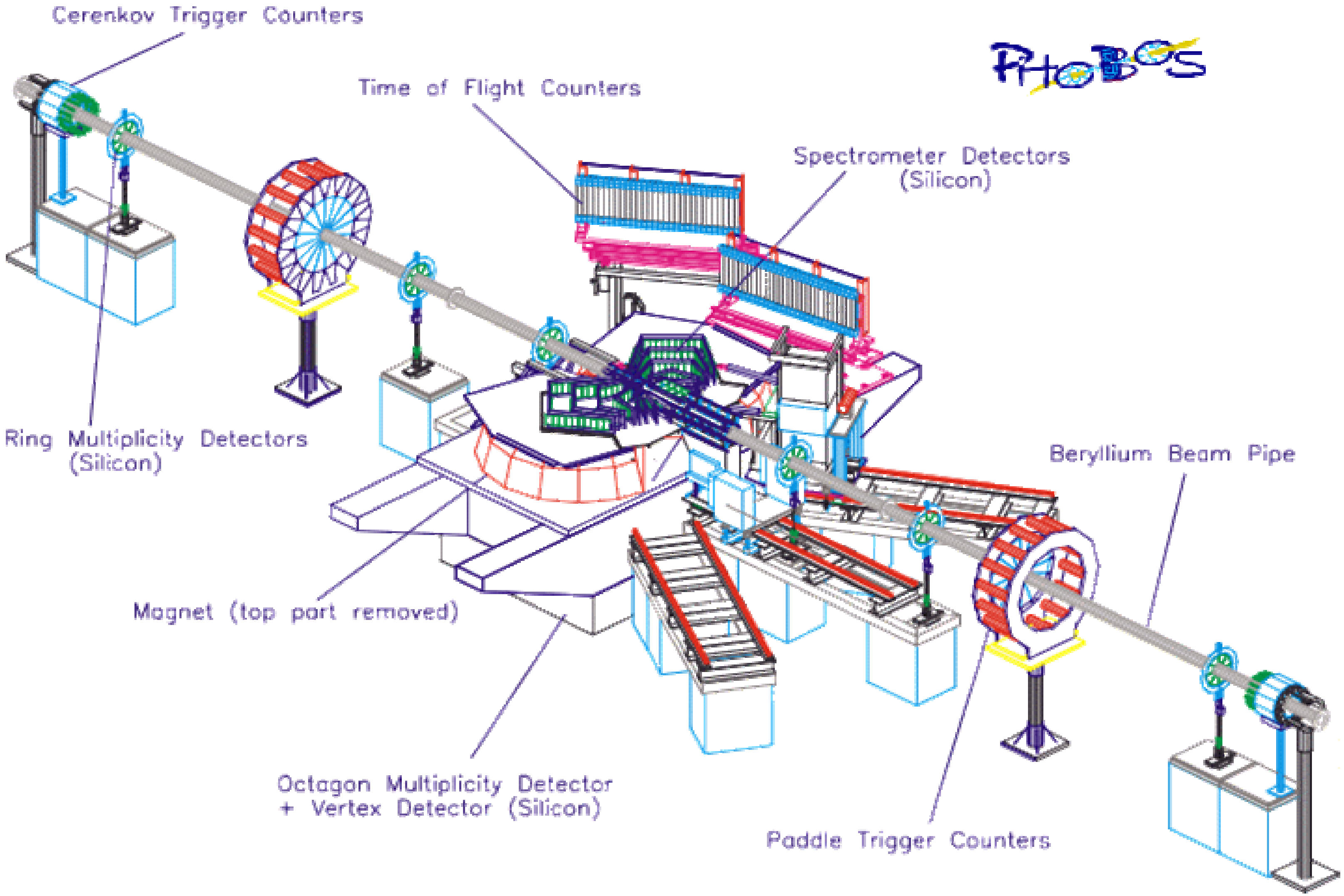
3) Penta-quarks





K.Kadija, J.Phys.G:Nucl.Part.Phys.30 (2004) S1359

PHOBOS experiment at RHIC



PHOBOS experiment at RHIC (ctnd)

Our contribution: - design and construction of mechanical support (carbon fibers technology)

- software

- data analysis

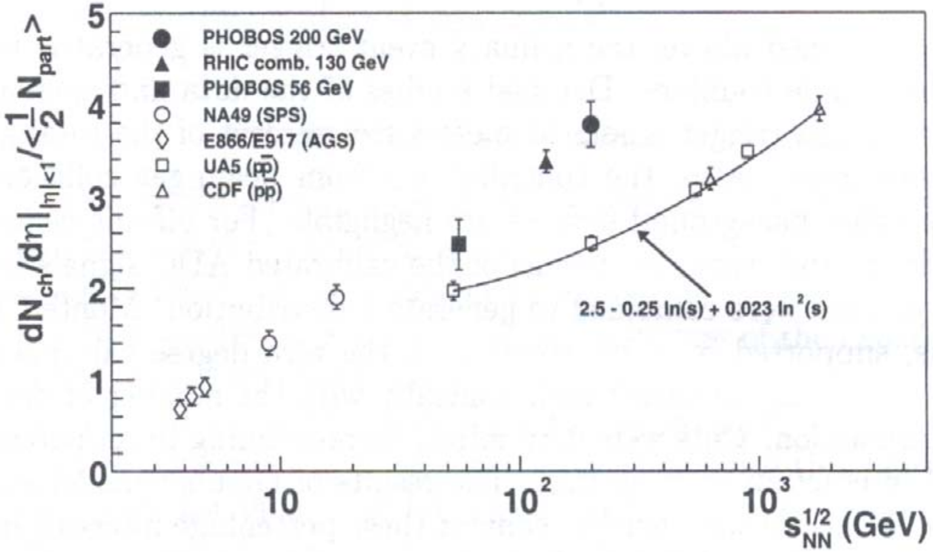


Fig. 3. Beam energy dependence of the charged particle multiplicity density per participant pair averaged over the region $|\eta| \leq 1$. Data are shown for central AuAu (AGS and RHIC) or PbPb (SPS) collisions as well as proton–antiproton collisions. See text for details and references.

B.B. Back et al.., Acta Phys.Pol. B33 (2002) 1419

PHOBOS experiment at RHIC (ctnd)

R Nouicer (for the PHOBOS Collaboration)

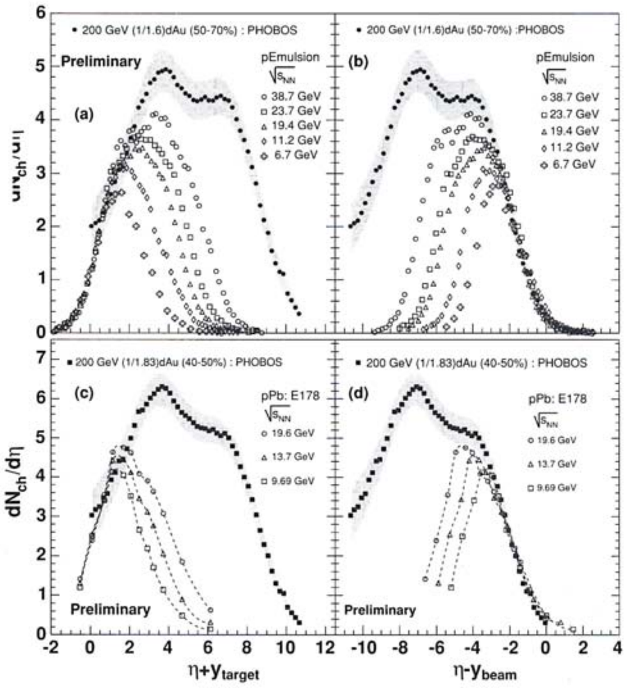


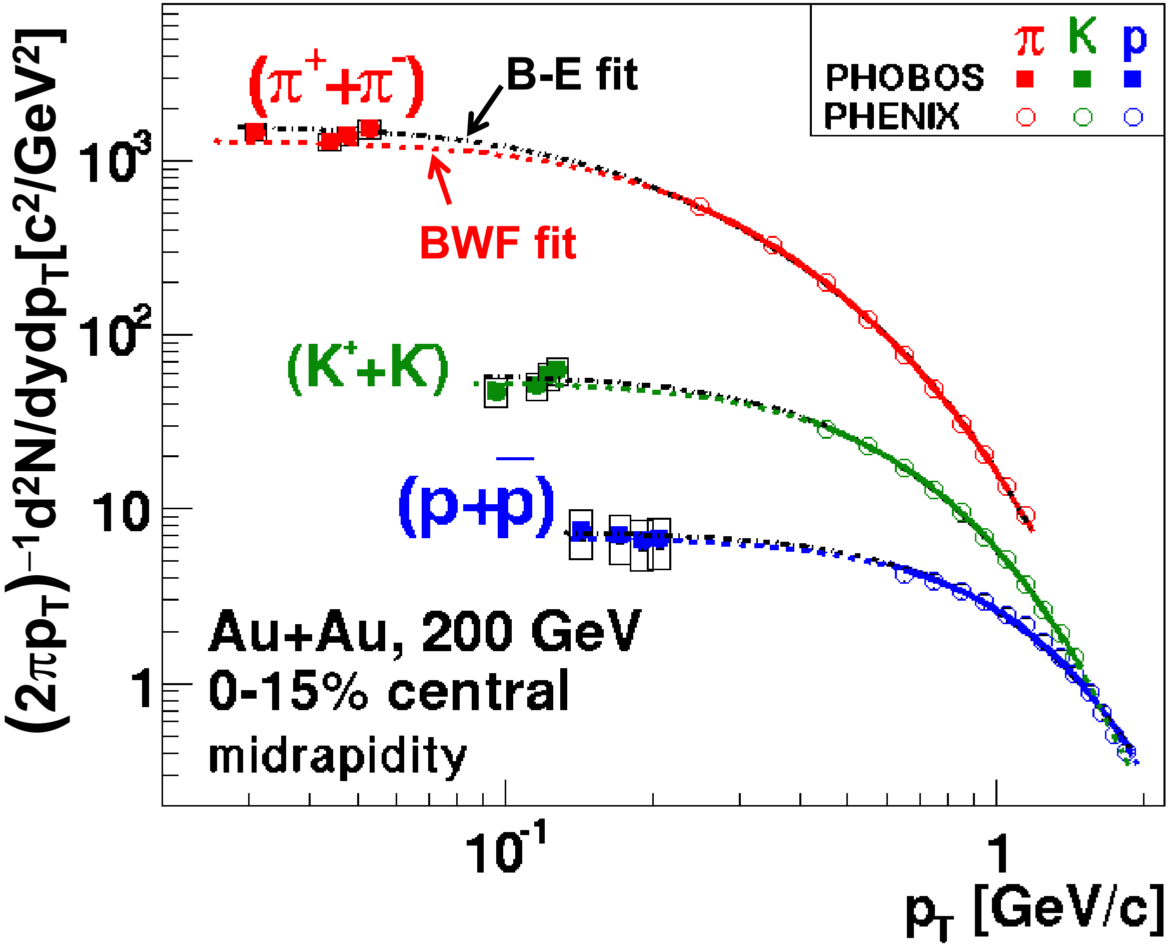
Figure 3. (a) Comparison of the pseudorapidity distribution of charged particles for d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV for centrality bin 50–70% with compilation of world data on p+Em collisions at five energies. The η measured in centre-of-mass system has been shifted to $\eta + y_{target}$ in order to study the fragmentation regions in the gold/Emulsion direction. (b) Similar to (a) but shifted to $\eta - y_{beam}$ in order to study the fragmentation regions in the deuteron/proton direction. (c) and (d) The same as (a) and (b) but for more central d+Au collisions and compared to p+pb collisions at three energies (for more details see text).

[B.B. Back et al., J.Phys.G: Nucl. Part. Phys. 30 (2004) S1133]

Recent results (presented at „Quark Matter 2005"):

- low transverse momentum particle spectra
- comparison Cu + Cu vs Au + Au
- elliptic flow

Low-p_T Spectra of Identified Particles
Au+Au at $\sqrt{s_{NN}}$ = 200 GeV



PHOBOS, PR C70, 051901 (R) (2004)
PHENIX, PR C69, 034909 (2004)

$$\frac{1}{2\pi}\frac{1}{m_T}\frac{d^2N}{dydm_T} = A\left[\exp(m_T / T) \pm 1\right]^{-1}$$

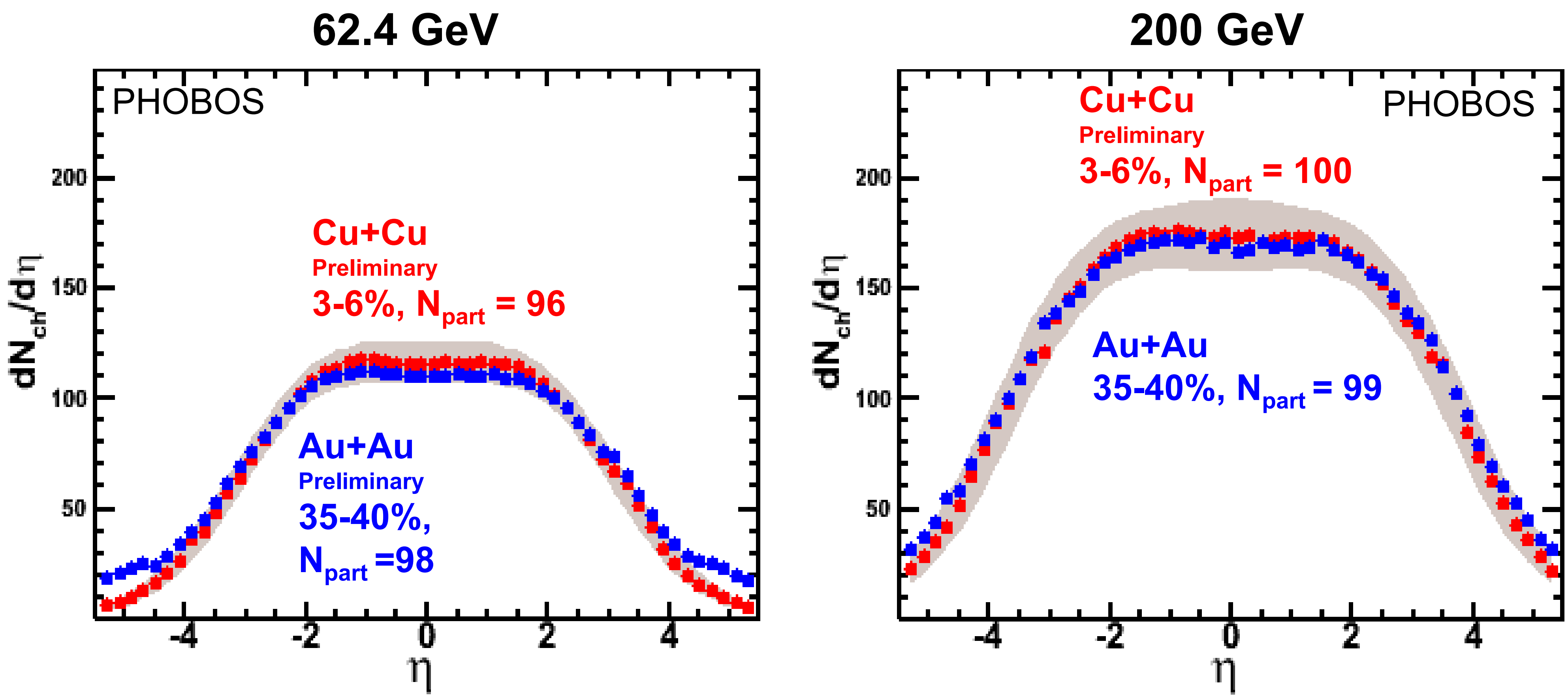
$$m_T = \sqrt{p_T^2 + m_h^2}$$

T= 229 MeV for $(\pi^+ + \pi^-)$
293 MeV for $(K^+ + K^-)$
392 MeV for $(p + \bar{p})$

Blast Wave Fit:
T_{fo} = 99 MeV
$\langle \beta_T \rangle$ = 0.54 c

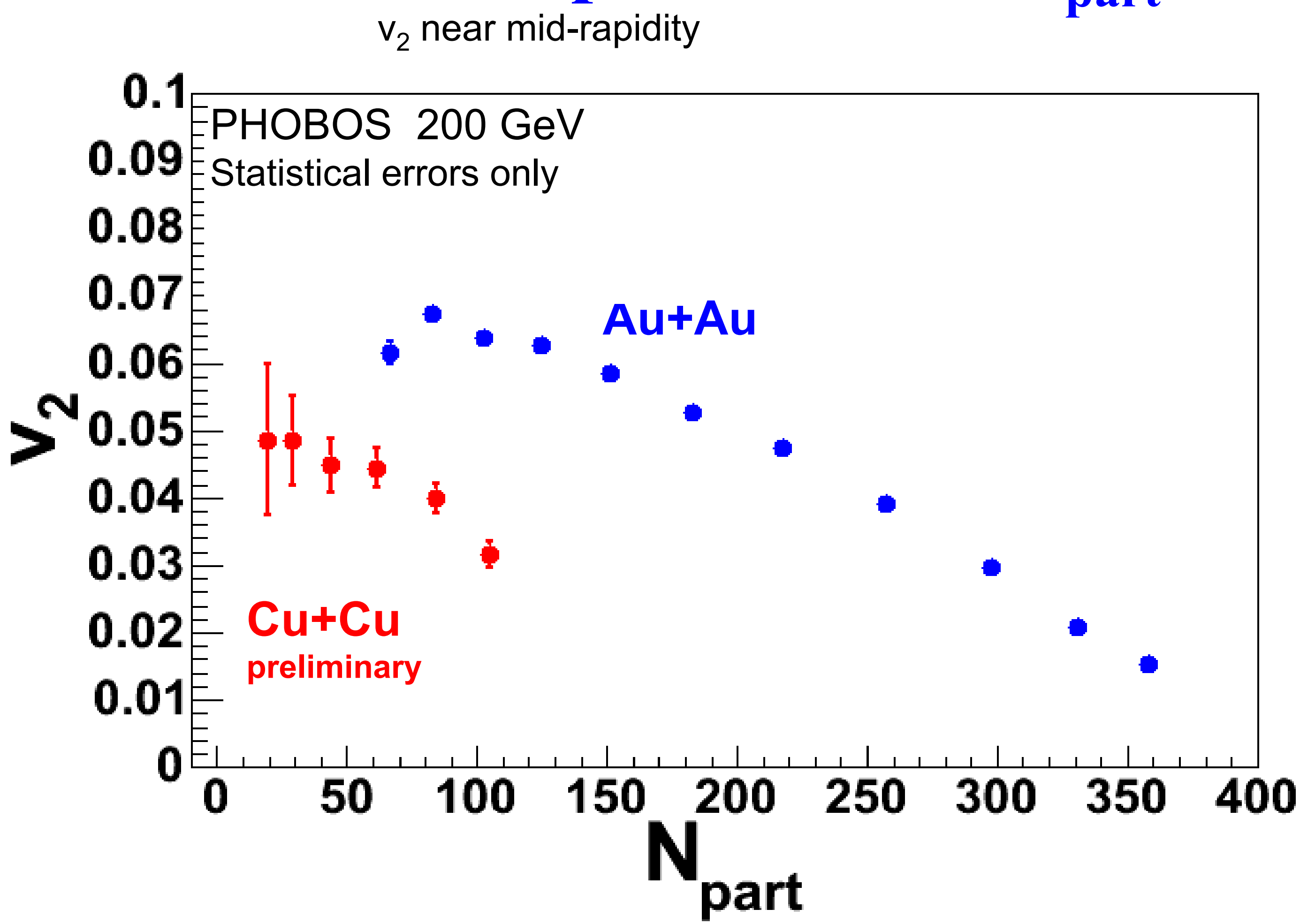
No enhancement in low-p_T yields for pions is observed
Flattening of $(p+\bar{p})$ spectra down to very low p_T, consistent with transverse expansion of the system

dN/dη in Cu+Cu vs Au+Au



Unscaled dN/dη very similar for Au+Au and Cu+Cu at same N_{part}

Elliptic Flow vs N_{part}



Substantial v_2 even for most central bin in Cu+Cu

LHC as Ion Collider

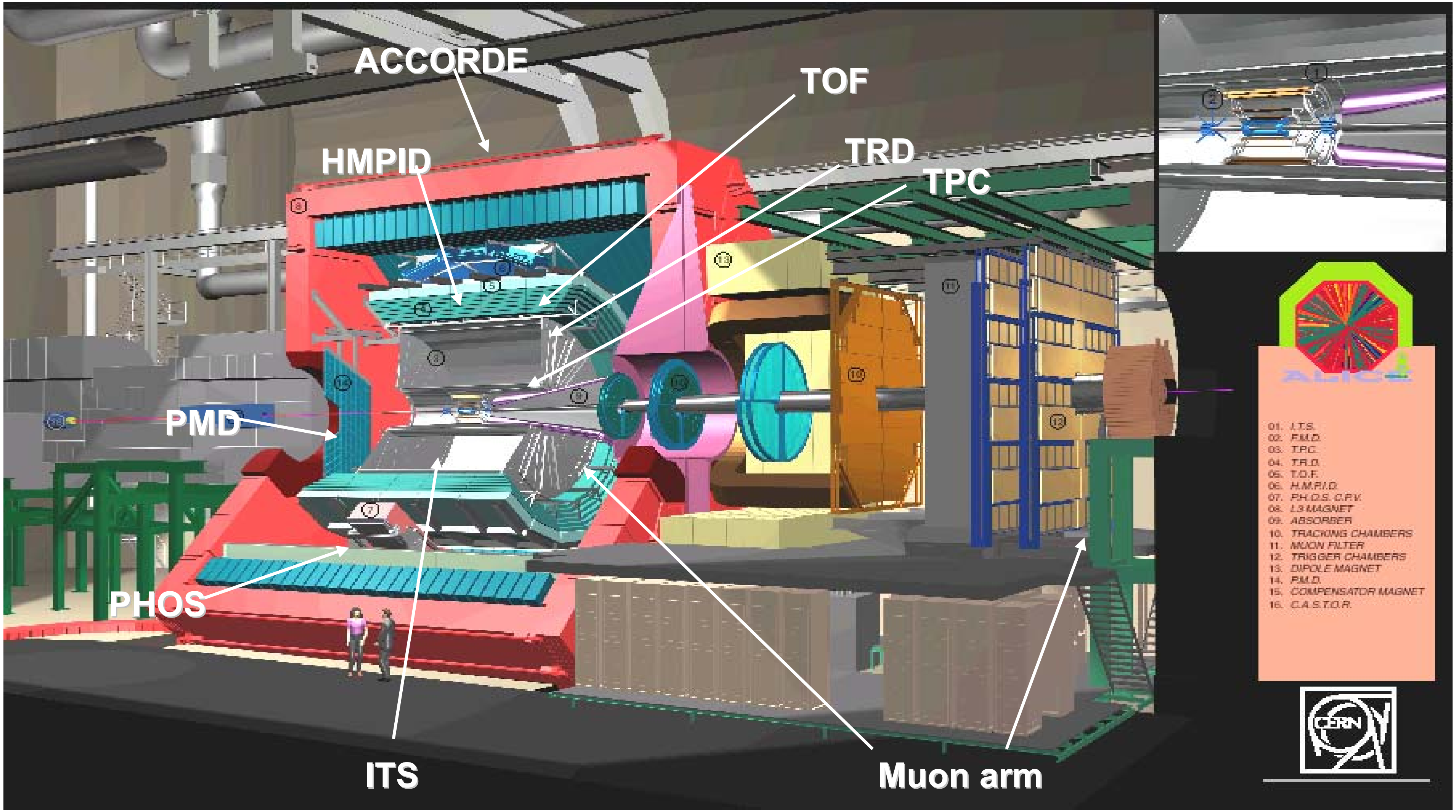
- Running conditions:

Collision system	$\sqrt{s_{NN}}$ (TeV)	L_0 ($cm^{-2}s^{-1}$)	$\langle \mathcal{L} \rangle / \mathcal{L}_0$ (%)	Run time (s/year)	σ_{geom} (b)
pp	14.0	10^{34} *		10^7	0.07
PbPb	5.5	10^{27}	70-50	10^6 **	7.7

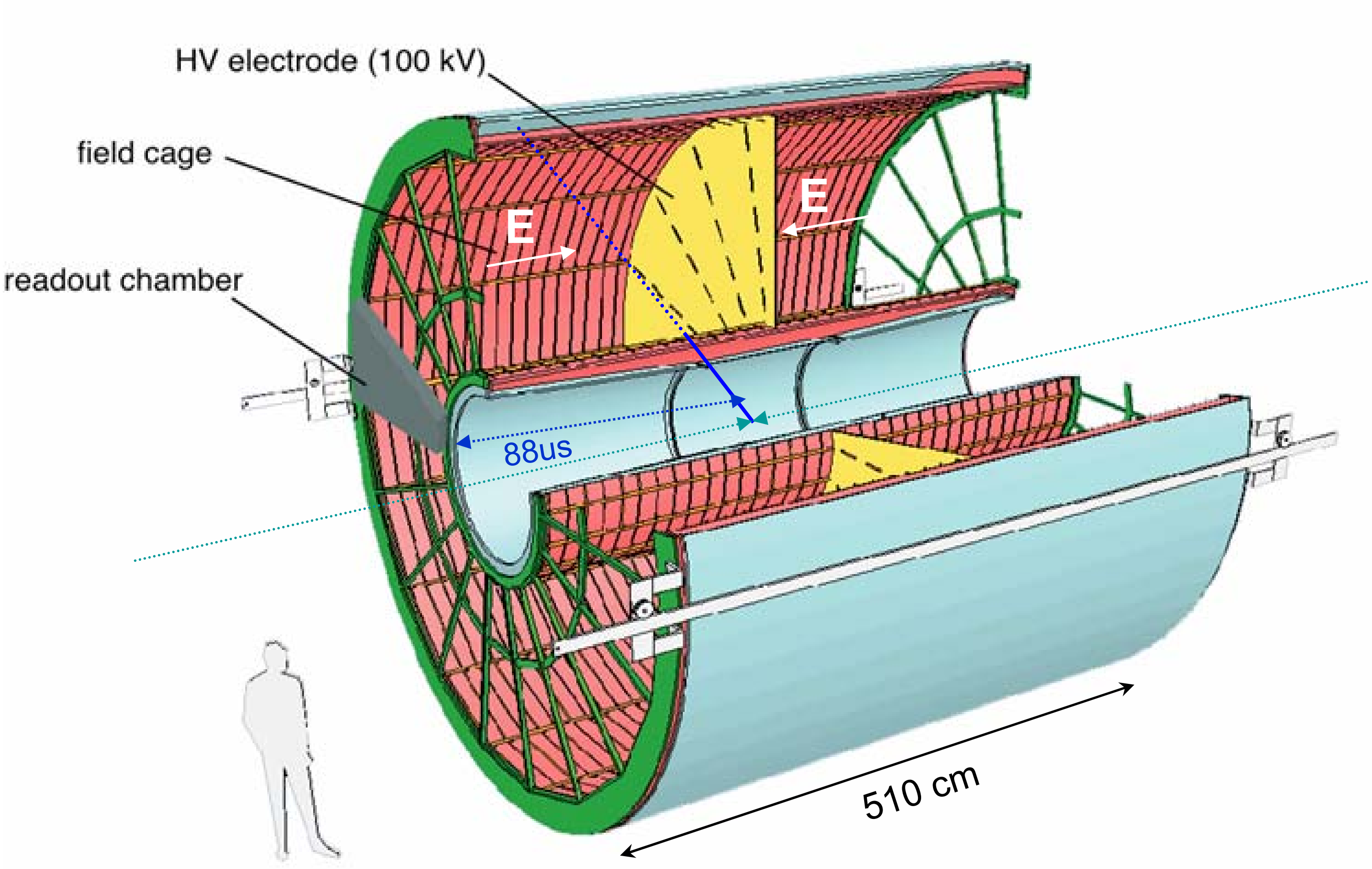
*L_{max}(ALICE) = 10^{31} ** $\mathcal{L}_{int}$(ALICE) ~ 0.7 nb^{-1}/year

- + other collision systems: pA, lighter ions (Sn, Kr, Ar, O) & energies (pp @ 5.5 TeV).

ALICE Detector



TPC layout

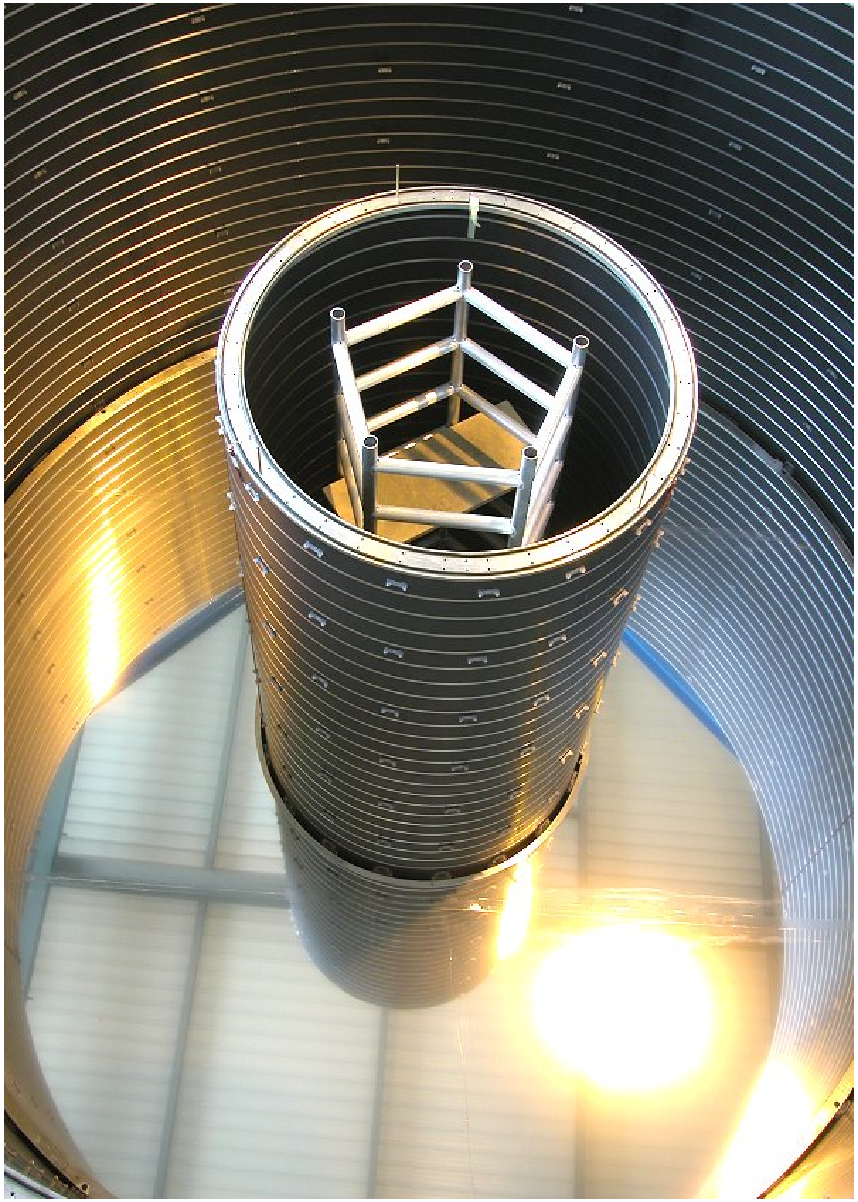


GAS VOLUME
88 m³

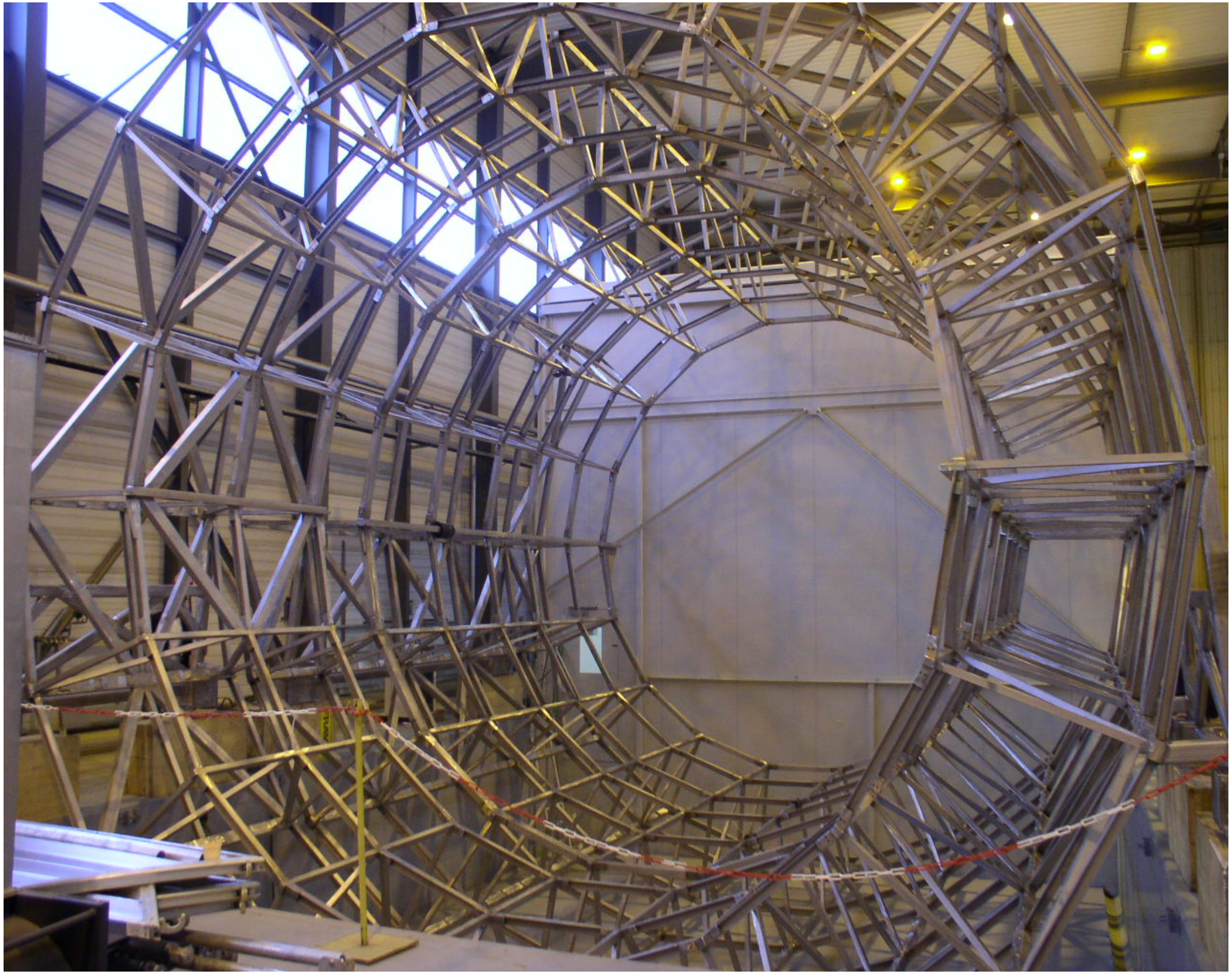
DRIFT GAS
90% Ne - 10% CO_2
Field cage finished
FEE finished
Read out chamber finished
At present pre-integration of field cage into experiment

<u>Readout plane segmentation</u>
18 trapezoidal sectors
each covering 20 degrees in azimuth

Mounting the TPC Central Electrode
With 10^{-4} parallelism to readout chambers

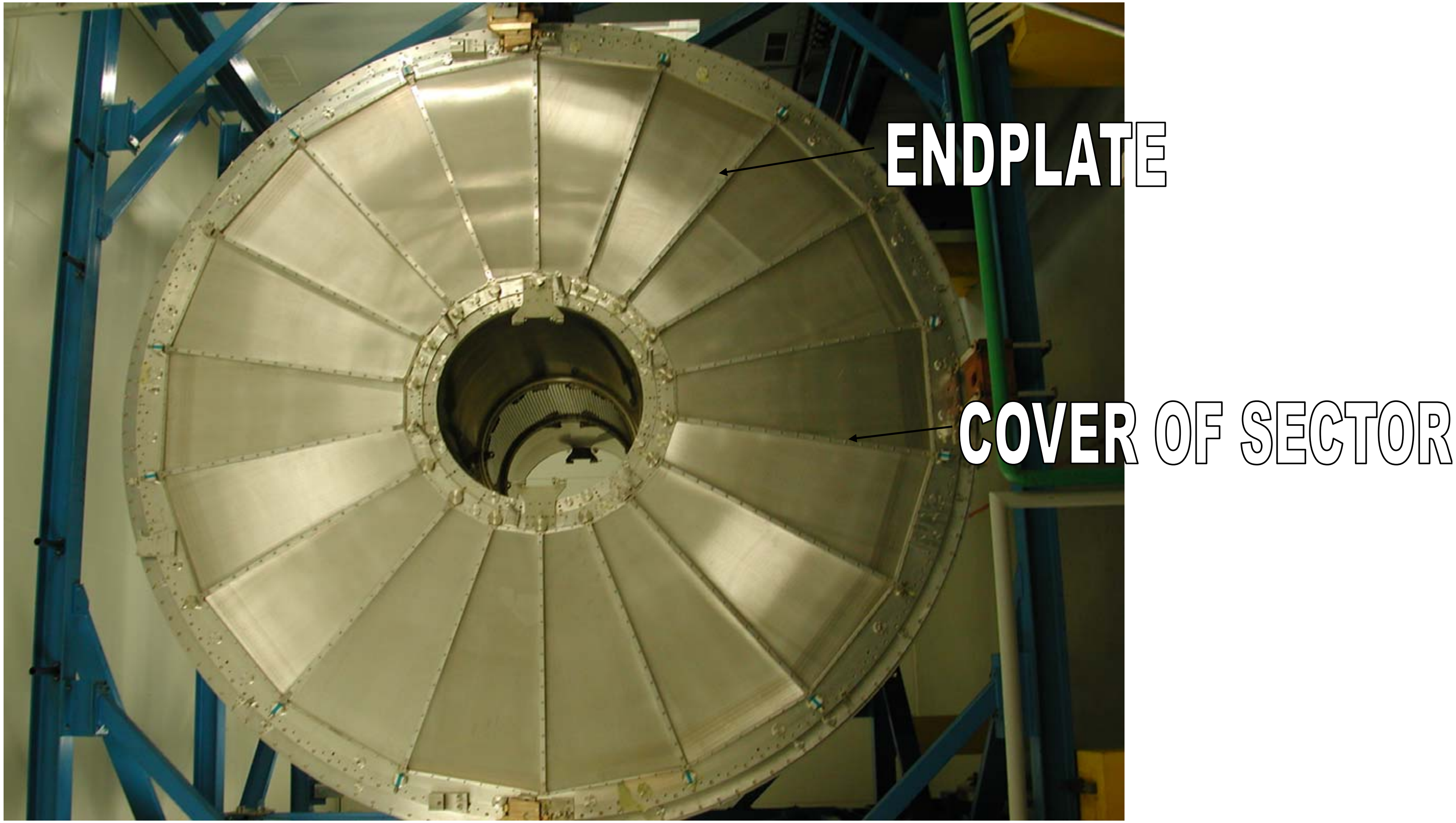


Preparing Space Frame for TPC/ITS/TRD/TOF Pre-Integration



Pre-Integration of ITS/TPC/TRD/ TOF ongoing at present moment

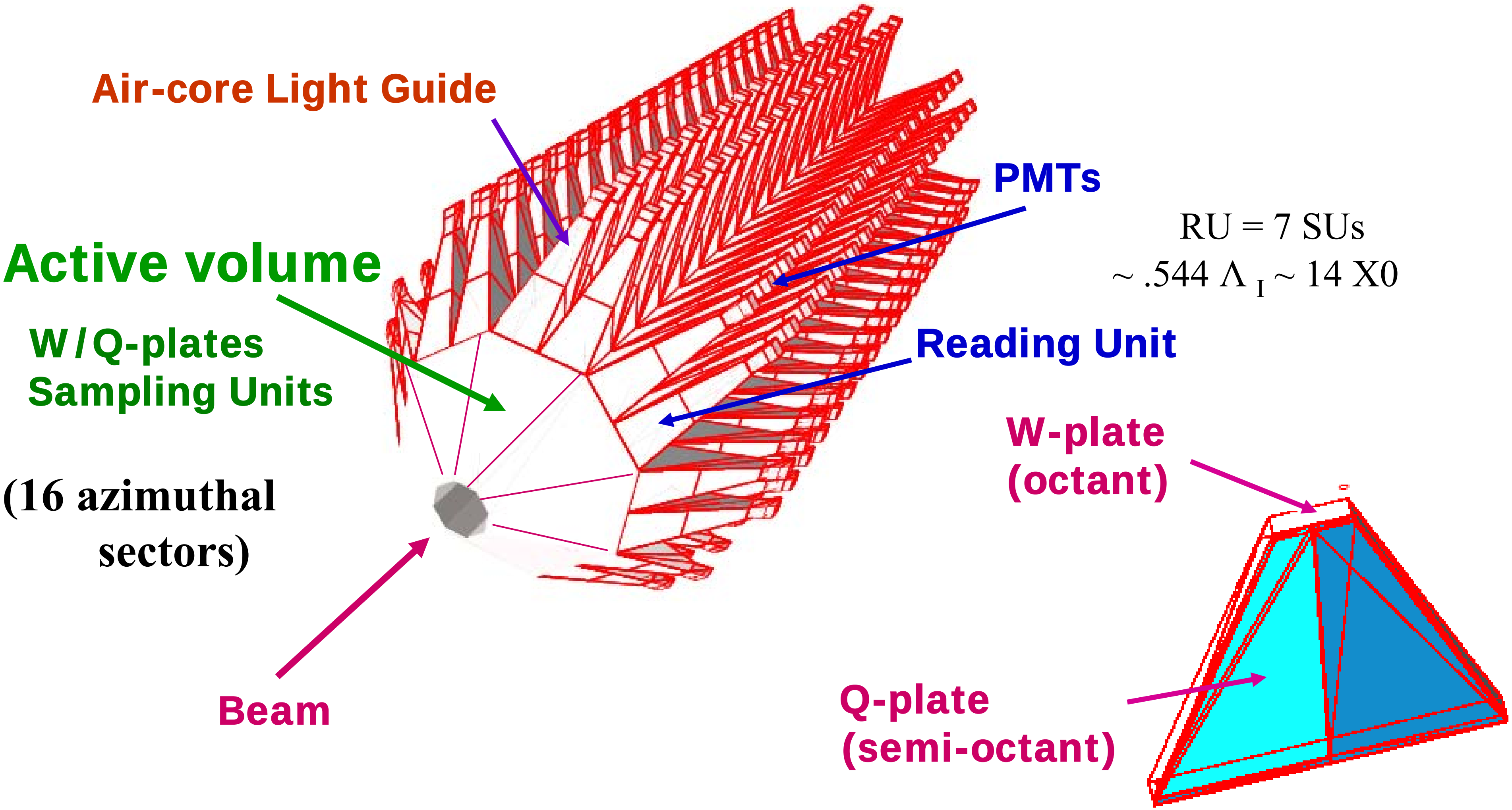
FIELD CAGE IN CLEANROOM



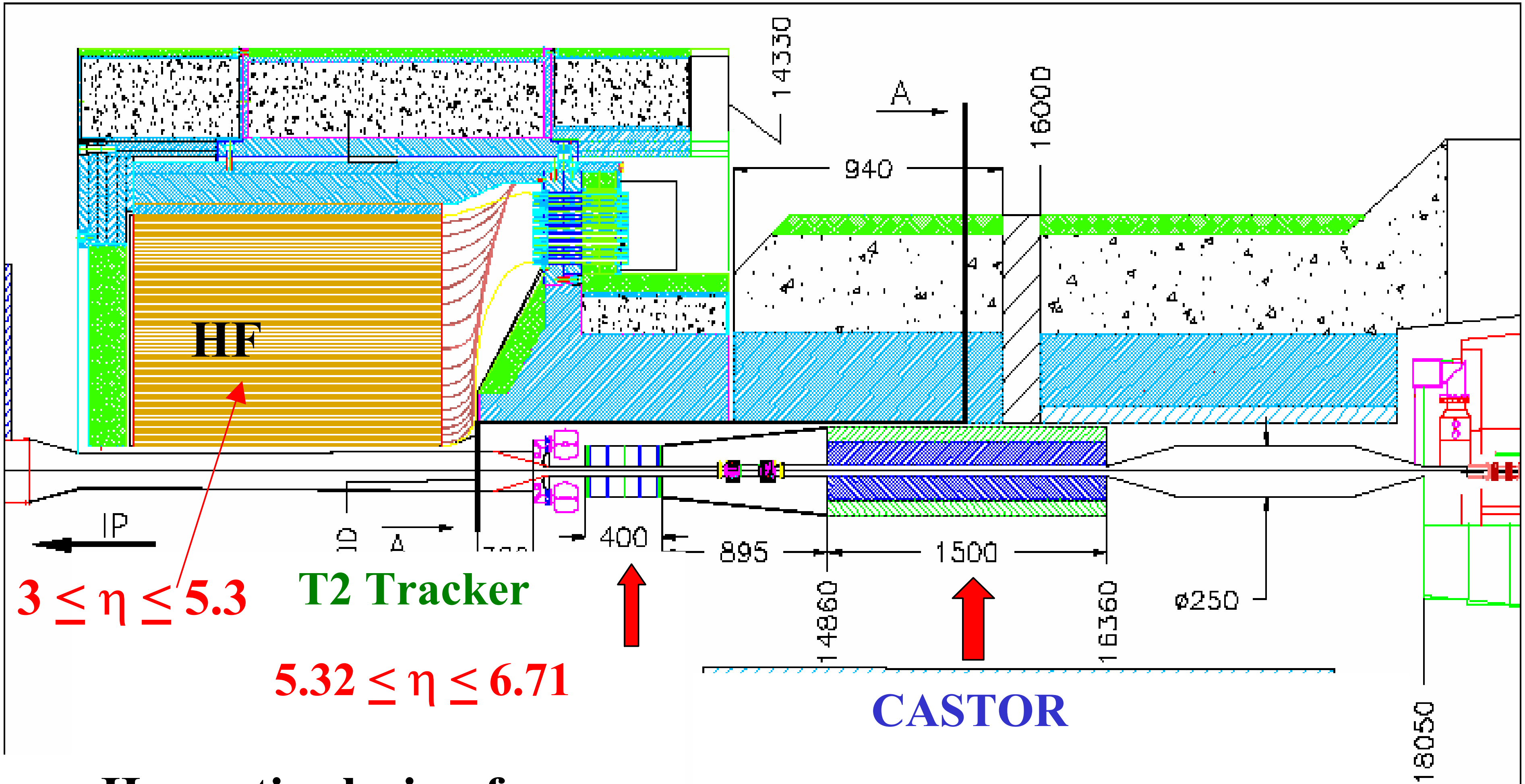
CASTOR CALORIMETER CONCEPTUAL DESIGN

- Cerenkov light is generated inside the quartz plates as they are traversed by the fast charged particles in the shower (shower core detector) developing in tungsten
- Azimuthal and longitudinal sampling sufficient for a study of structures in longitudinal development of cascades
- Large depth for detection of strongly penetrating objects

. **EM = 2RU (~ 28 X0)** **HAD = 18 RU (~10 Λ_I)**



CMS Very-Forward Region



$5.2 \leq \eta \leq 6.5$

Hermetic closing for 13 η units
Largest acceptance system among LHC experiments

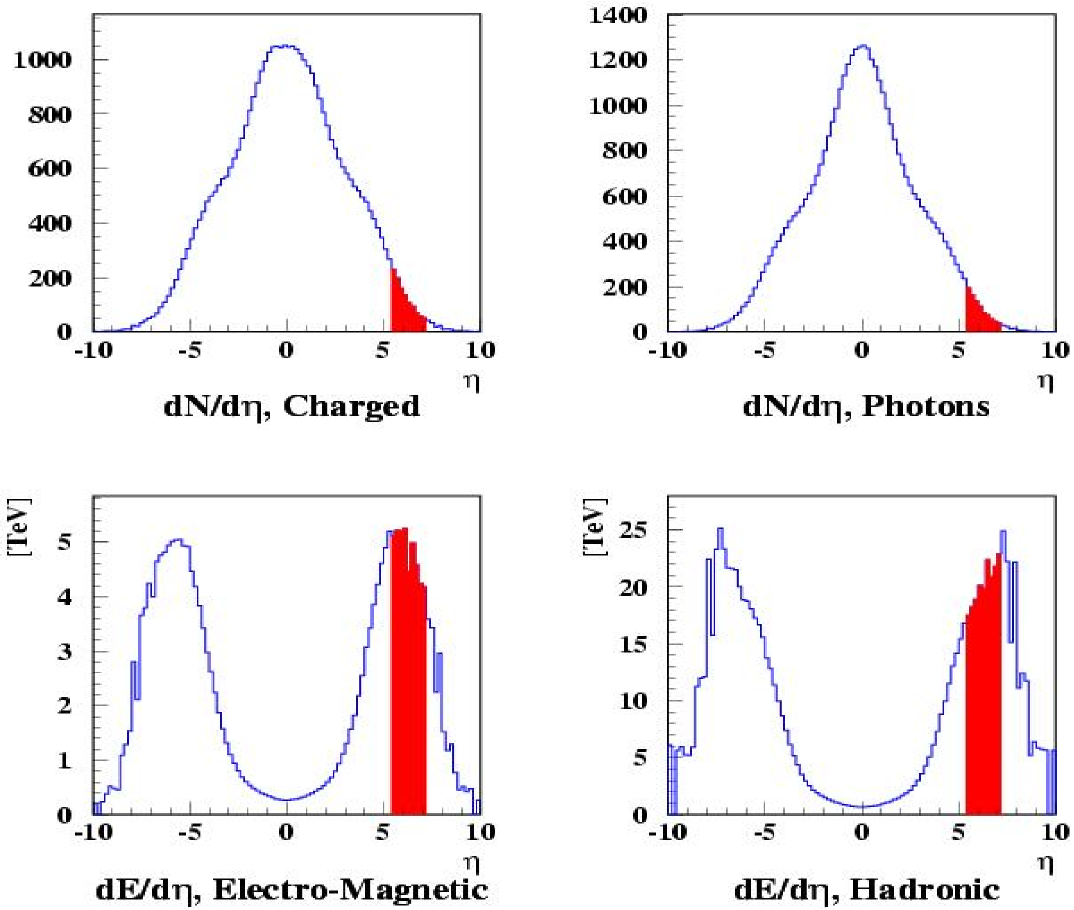
Inner radius ~ 31 mm

Outer radius ~ 135 mm active

Outer radius ~ 280 mm total

Collider experiments, in opposite to cosmic ray studies, explore mainly central rapidity region

HIJING Pb+Pb central



Measured energy fraction :

- SPS ~ 40 %

  evatron ~ 20%

  HC (central) ~ 5 %

CASTOR, similarly to cosmic ray detectors, will study the forward high energy flow region:

~ 32% of total energy flow

Main theoretical developments

1. The „wounded nucleon” model

A. Białas, M.Błeszyński, W. Czyż,
Nucl. Phys. B111 (1976) 461

2. A single-freezout statistical model

Assumptions:

- Chemical and thermal freeze-outs coincide
- Bjorken- type freeze-out hyper-surface
- All hadronic resonances contribute

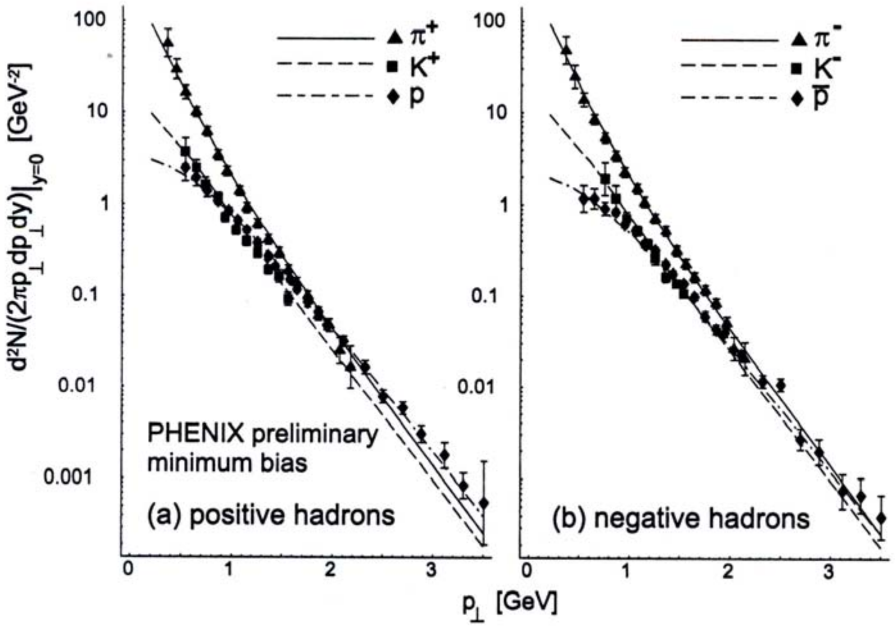


Fig. 1. The $p_\perp$-spectra at midrapidity of pions (solid line), kaons (dashed line) and protons or antiprotons (dashed–dotted line). The model calculation is compared to the PHENIX preliminary minimum-bias data [21], Au + Au collisions at $\sqrt{s}$ = 130 GeV A.

W. Florkowski, W. Broniowski, Acta Phys. Pol. 33 (2002) 1649