Is there

Life for the **H**eavy Ion **C**ommunity

after

the **R**ich **H**arvest **I**n **C**urrent

experiments ?

After **L**ive **I**s **C**ertainly **E**nsured !

IMAGINE

- VERY LARGE NUCLEI $A \to \infty$

  AND/OR

  VERY HIGH COLLISION ENERGY $s \to \infty$

$$\Downarrow$$

A CONTROLLED PERTURBATIVE REGIME

$$\alpha_s(Q_s) \ll 1$$

WHERE QUESTIONS CAN BE ANSWERED ...

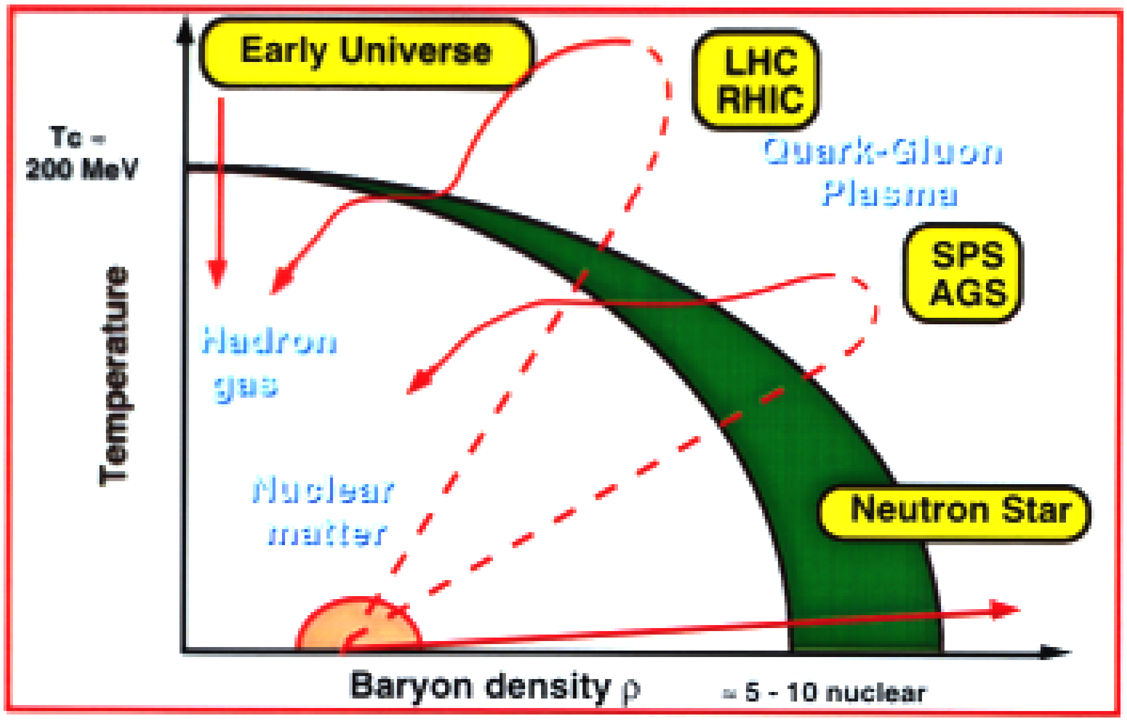
D. SON "Energy loss & parton thermalization"

A Large Ion Collider Experiment

- Physics at LHC
- ALICE

BNL,
27.10.2000

Physics at the Colliders



- **Subject: QCD-thermodynamics & QGP**
  - ⇨ **subject largely identical** at AGS/SPS/RHIC/LHC
  - ⇨ adress partially similar signals

- **Object: strong interaction bulk matter**
  - ⇨ **object very different** AGS->SPS->RHIC->LHC
    - ☆ $\sqrt{s} \approx 0.2 : 1 : 12 : 320$
    - ☆ $dn/dy \approx 300 : 500 : 1000 : 5000$
  - ⇨ **quantitative**
    - ☆ **better** initial conditions (ε, V, τ)
  - ⇨ **qualitative**
    - ☆ **different** type of matter
      - **dense** -> **hot** matter
      - **soft** (strings) -> **semi-hard** (p-QCD)
      - **phase transition** -> **'ideal' QGP**

SPS-RHIC-LHC

qualitative extrapolation for particle prod.

	SPS(20) 1/10	RHIC(200) 1	LHC(5500) 28
pp dn_{ch}/dy	1.8	2.4	5
	0.75	1	2
pp $<p_t>$ [GeV]	0.36	0.39	0.51
	0.92	1	1.31
A scaling dn/dy	$N_{part} \sim A$	?	$N_{coll} \sim A^{4/3}$
$A \approx 200$	1	3(50:50)	6
parton content p $3+\int g(x, 2GeV)$	4	10	30
shadowing	1	0.8	0.5
$(\#part*shadow)^2$	1/4	1	4

p-QCD calculations

	RHIC		LHC
Eskola			
dn(partons)/dy	1400 (p_0>1.1)	x4	5100 (p_0>2.1)
dEt/dy	2000	x8	17.000
Vogt (p_0>2 GeV)			
dn(partons)/dy	80-120	x40	1500-5000
dEt/dy	200-300	x40	5000-15.000

Quantitative Improvements

- Pb + Pb, central collisions (b=0)

	SPS(17)	RHIC(200)	LHC(5500)
dN_{ch}/dy	500	700-1500	3000-8000
ε [GeV/fm^3] (t0 = 1 fm/c)	≈2.5 1	3.5-7.5 2	15-40 10
V_f [fm^3]	$\approx 10^3$ 1	$\approx 7*10^3$ 7	$\approx 2*10^4$ 20
τ_{QGP} [fm/c]	≤ 1 1	1.5 - 4 3	4 - 10 7
τ_0 [fm/c]	≥ 1?	≈ 0.5	≤ 0.2 ?
τ_{QGP}/τ_0	1	6	>30

- quantitative gains

⇨ hotter - bigger - longer

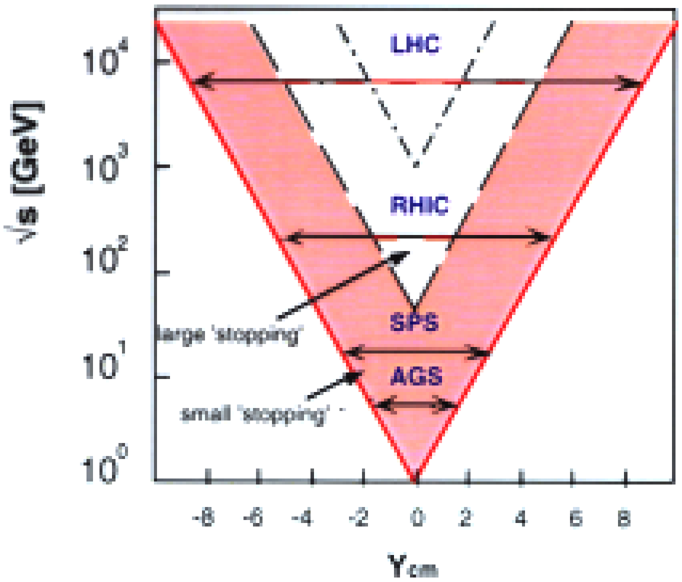
significant gain, independent in ε, V, τ

≈ x 10 from SPS -> LHC

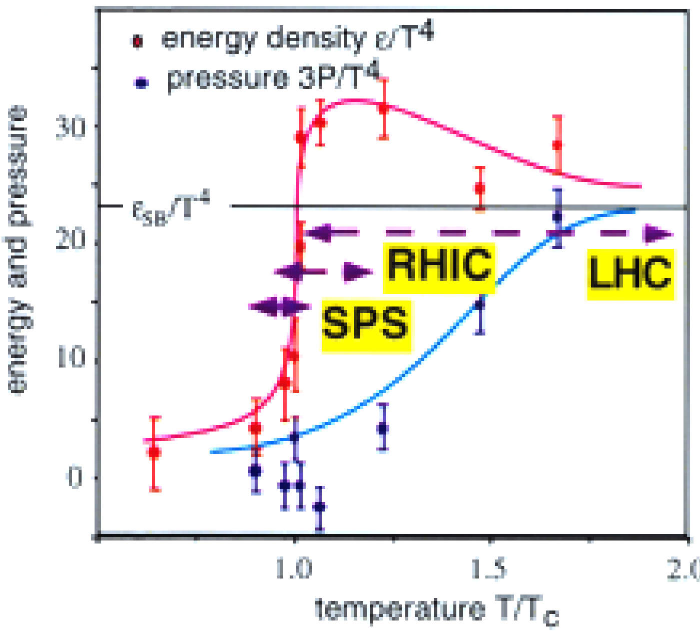
≈ x 3-5 from RHIC-> LHC

Qualitative Improvements

- **baryon density:**
  dense (baryons)
  -> hot (mesons)
  ➩ very different regime
  neutron star -> universe



- **energy density:**
  QGP -> ideal QGP
  ➩ **interacting plasma**
  $T/T_c \leq 1.5$ $(\varepsilon/\varepsilon_c \leq 5)$



- **energy scale:** soft (strings) -> semi-hard (minijets)

➩ **AGS/SPS:** soft, non-perturbative particle (E_t) production

☆ **QCD-phenomenology**

☆ pre-equilibrium phase, dynamics, ε_0, τ_0 => **guesses only**

➩ **RHIC/LHC:** semi-hard (p_0>2 GeV) production & evolution

☆ contribution to E_t < 50%(RHIC) > 90%(~~RHIC~~ LHC)

☆ p-QCD: *'approx'* **determined from first principles**

Quarkonium Suppression

- **high √s**

➩ **ϒ production** & suppression

☆ σ ≈ 0 @ SPS, LHC ≈ 10 x RHIC

☆ **RHIC marginal**

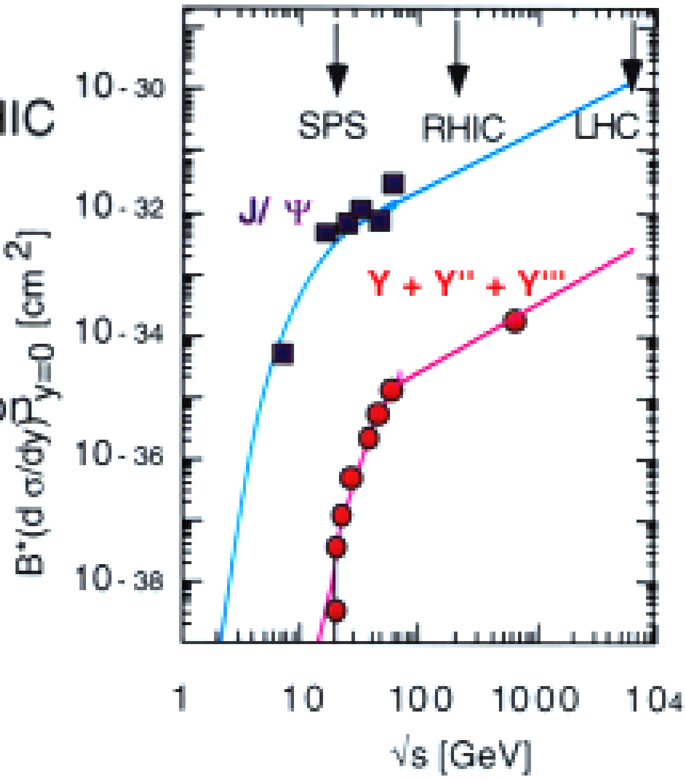
☆ **LHC ≈ ok**

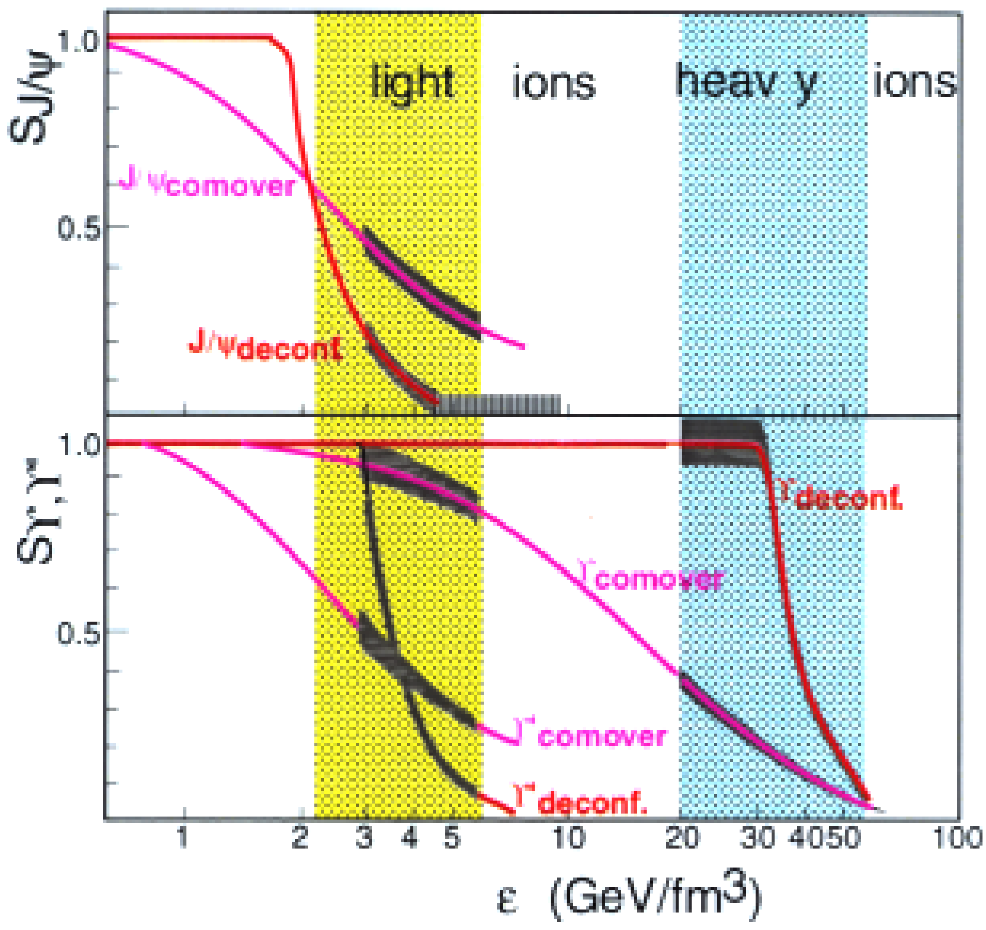
➩ **J/Ψ production** & suppression

☆ rates ok RHIC & LHC (>10^6)

☆ **LHC:** J/Ψ's from **b-decays**

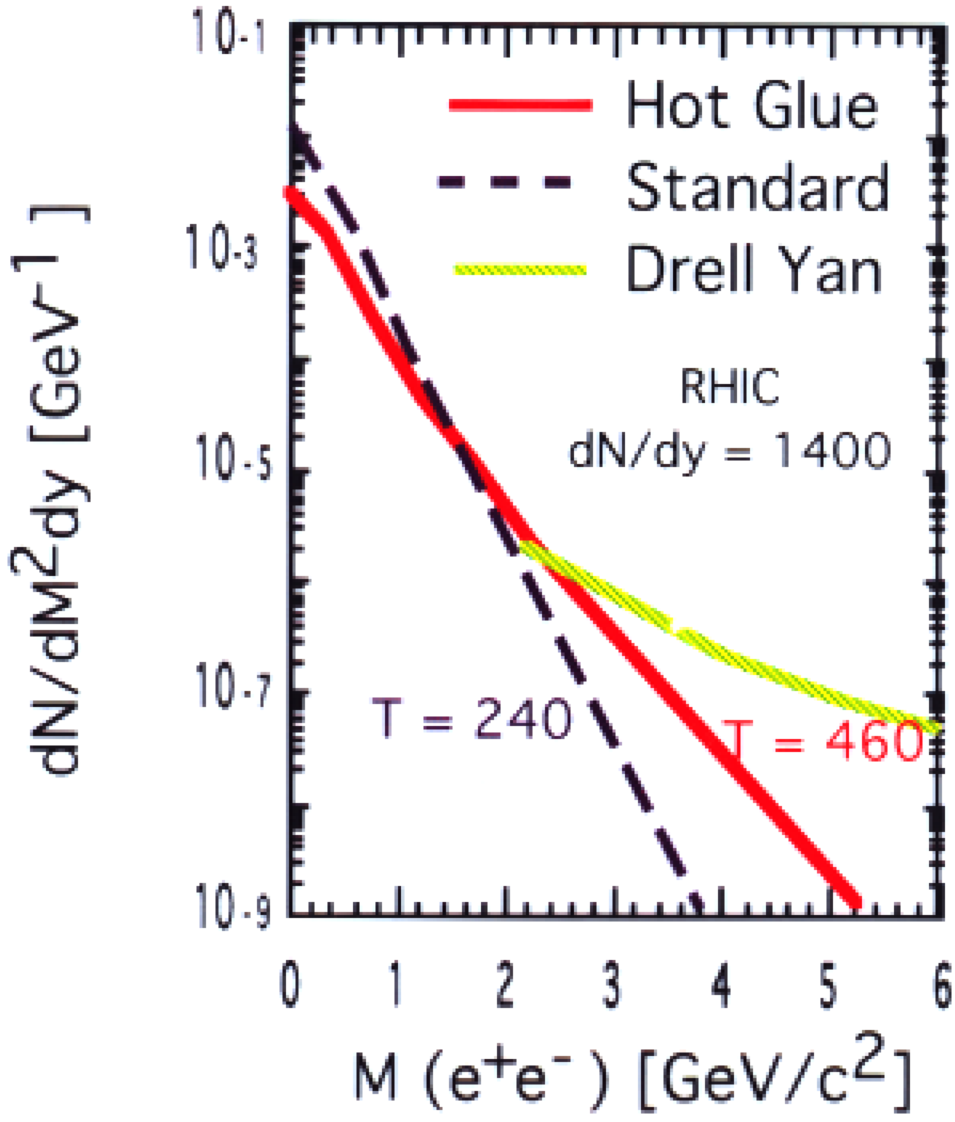
☆ **RHIC better** (at high p_t)





Change in Signals II

- **high T**
  - ⇒ **thermal radiation**
    - ☆ γ, l^+l^- rate increases strongly with T
  - ⇒ **charm production**
    - ☆ **pre-equilibrium** production
    - ☆ **thermal production**



Event-by-Event studies

- **precision tool at high multiplicity**
  - ➩ non-statistical **fluctuations** (phase transition !)
  - ➩ **correlations** between observables
  - ➩ accuracy ≈ √dN/dy
  - ➩ **SPS** : **RHIC** : **LHC** ≈ **1** : **1.4** : **3**

- **example: K/π ratios:**
  - ➩ **experimental accuracy** K/π ≈ 0.2, Δy=2, efficiency = 50%

dN/dy	500	1000	4000	8000
Δ(K/π)	13%	9%	4.5%	3%

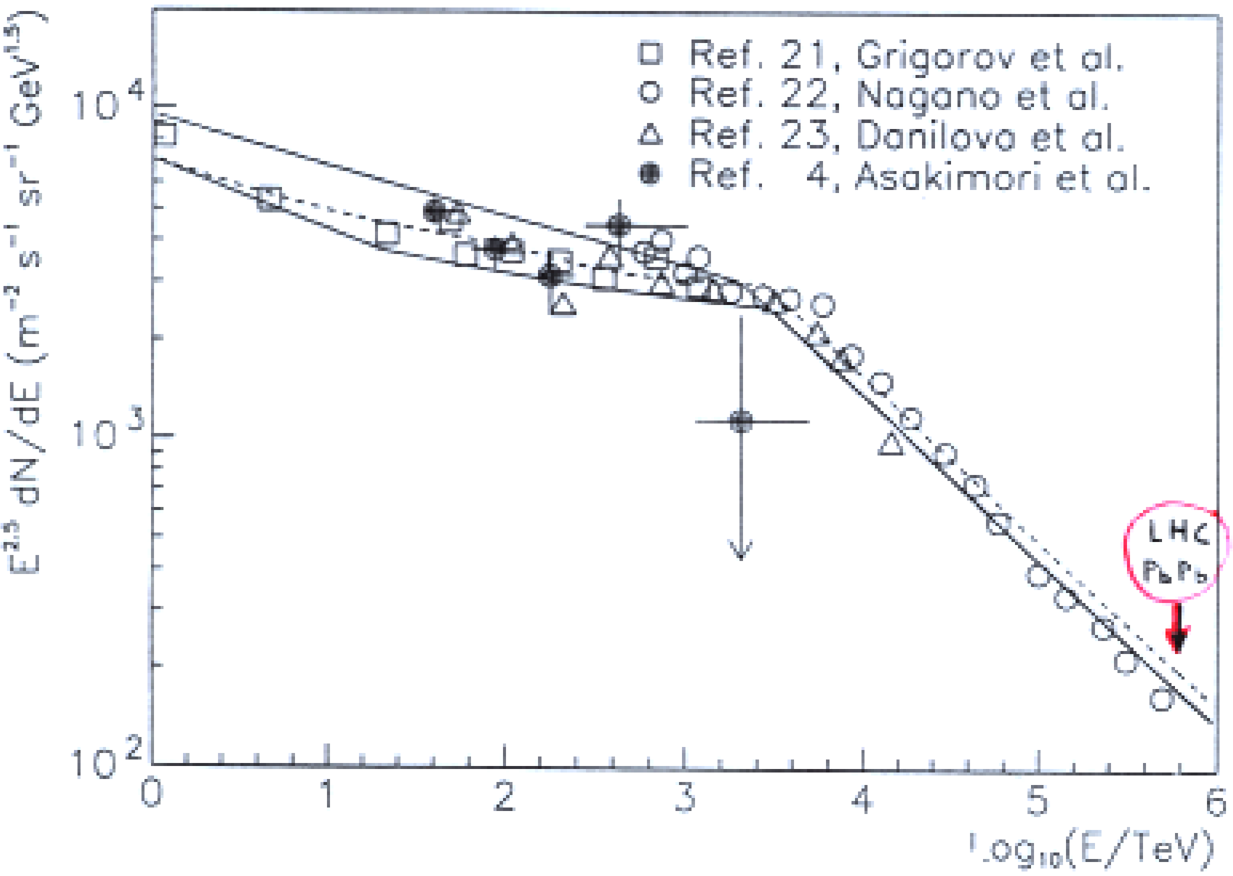
  - ➩ **conceivable fluctuations** on K/π of order **10%**

☆ K/π ≈ 0.2		thermal equilibrium		(T ≈ 150 MeV)
K/π ≈ 0.15		pp		(FNAL, high N_{ch})
	≈2.8σ	≈4σ	≈8σ	≈11σ

☆ thermal equil. changes ≈4% per 10 MeV (@ T_f = 150 MeV)

ΔT	>30	≈22	≈10	≈7 [MeV]

LHC and Cosmic Rays



Running Scenario

beams

- initial emphasis on $^{208}Pb+^{208}Pb$
- **pp, pA** running for comparison data
- **intermediate mass** ion (e.g. Ca) to vary ε

luminosity

	Pb-Pb	Ca-Ca	Ca-Ca	pp
<L> [$cm^{-2}s^{-1}$]	10^{27}	$3x10^{27}$	10^{29}	10^{30}
interactions/s	8000	8000	$3x10^5$	10^5

- **pp** running needs **defocused/displaced** beams
- **constant L** in AA by varying β*

data taking

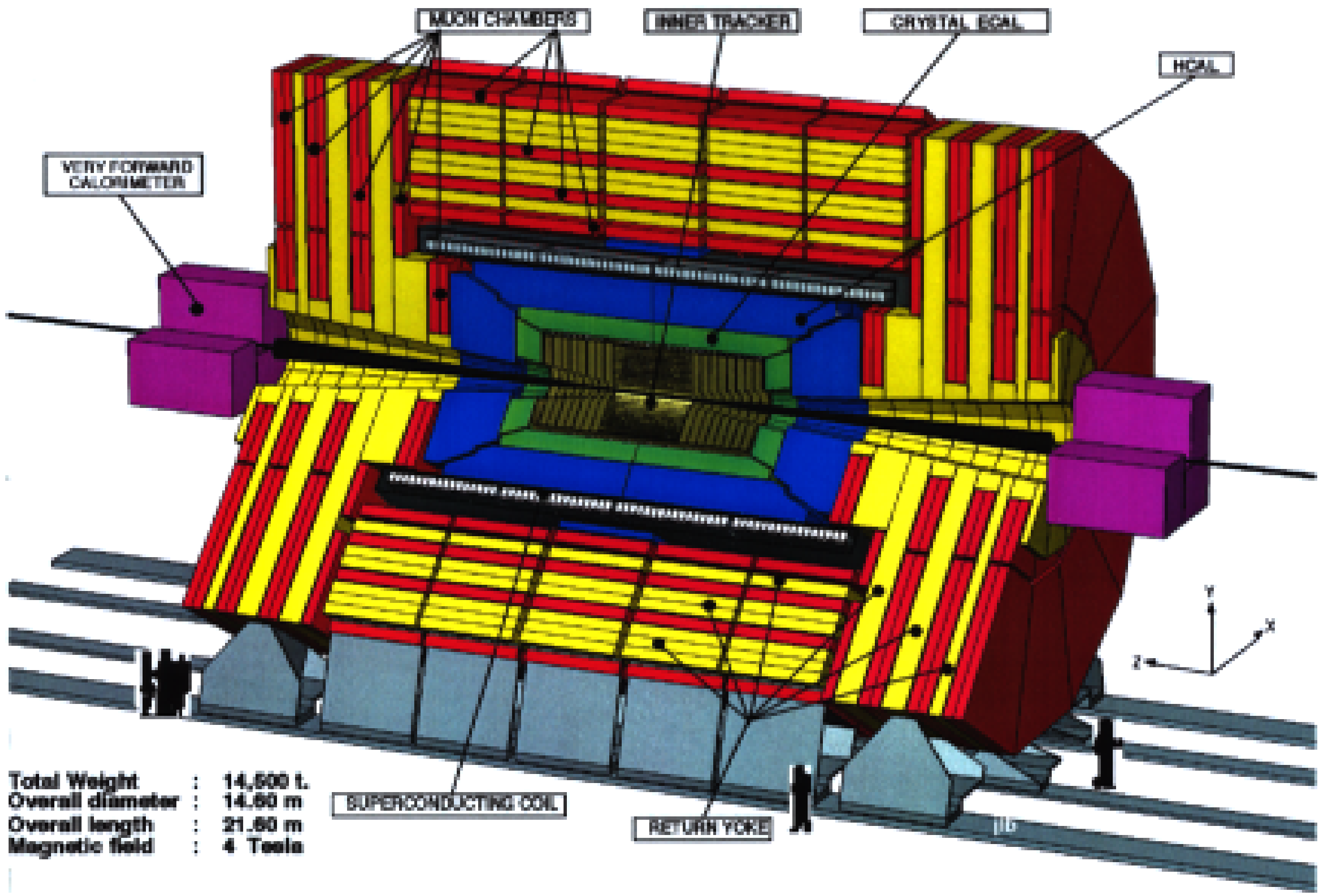
- AA ≈ 10%/LHC year (= **10^6s**), rest with pp
- data rate ≈ **50 Hz** (AA) to **500 Hz** (pp)
- **few 10^7** central AA events/year

charged multiplicity in Pb-Pb

- $(dN/dy)_{ch}$ = $(dN/dy)_\gamma$ ≈ **2000 - 8000**
- ignorance of structure functions

What to Expect From CMS

A Compact Solenoidal Detector for LHC

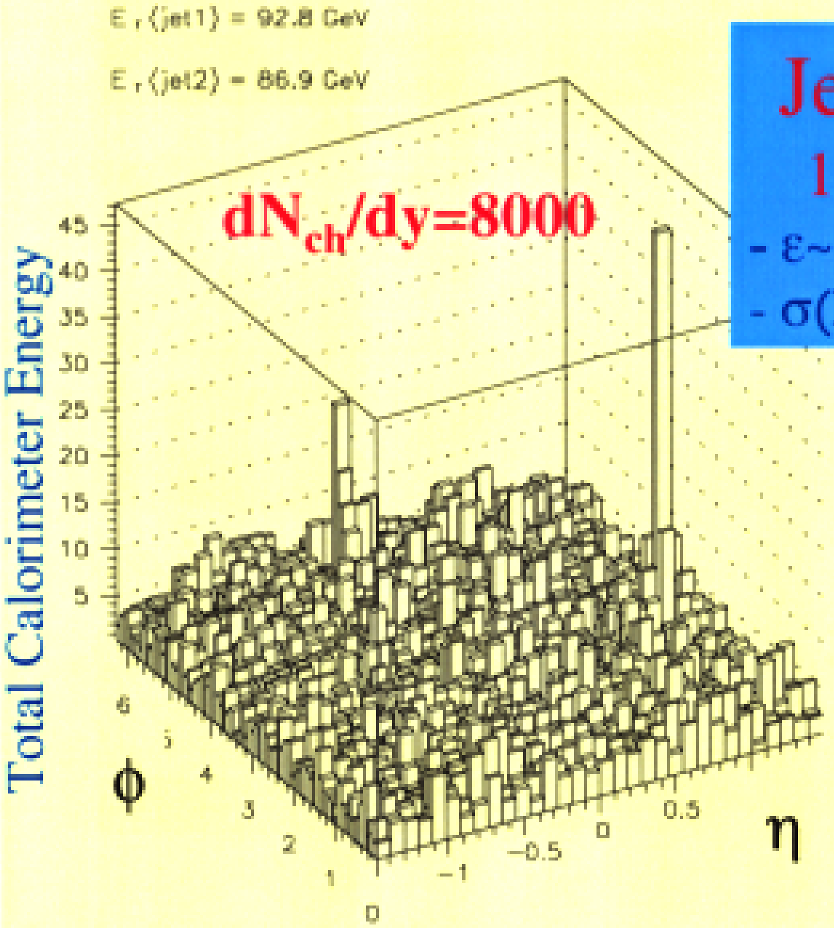


Physics Topics

- Event Characterization
- Quarkonium Production: Upsilon and J/Ψ.
- Jet Production:
  - Single/Double jet ratios.
  - Z and g tagged jets
- *Ultra-Peripheral Collisions: $\gamma\gamma$ and γ-Pomeron.*

Jets are Easy

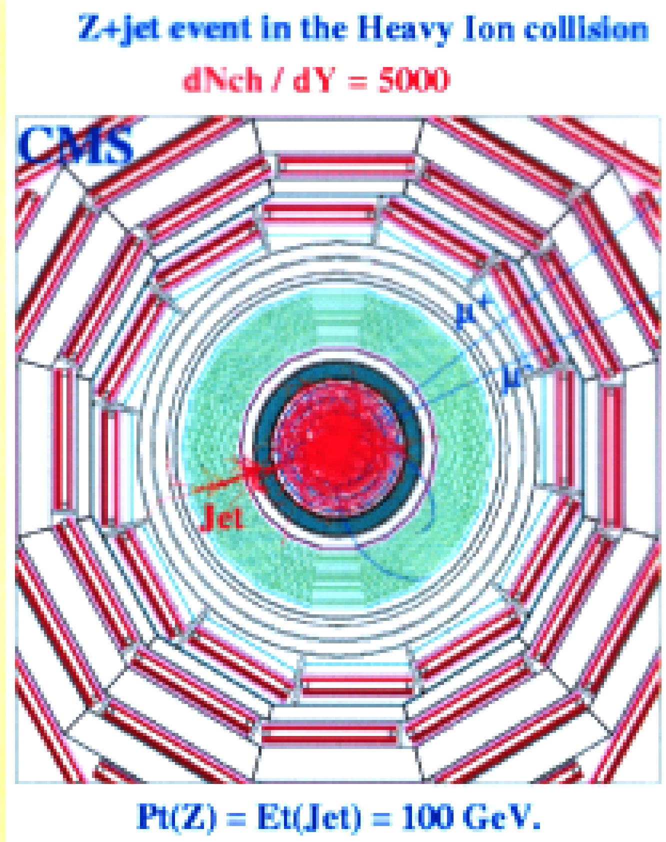
Jet quenching
- monojet/dijet enhancement
- jet-$Z^0 \rightarrow \mu\mu$ or jet-γ

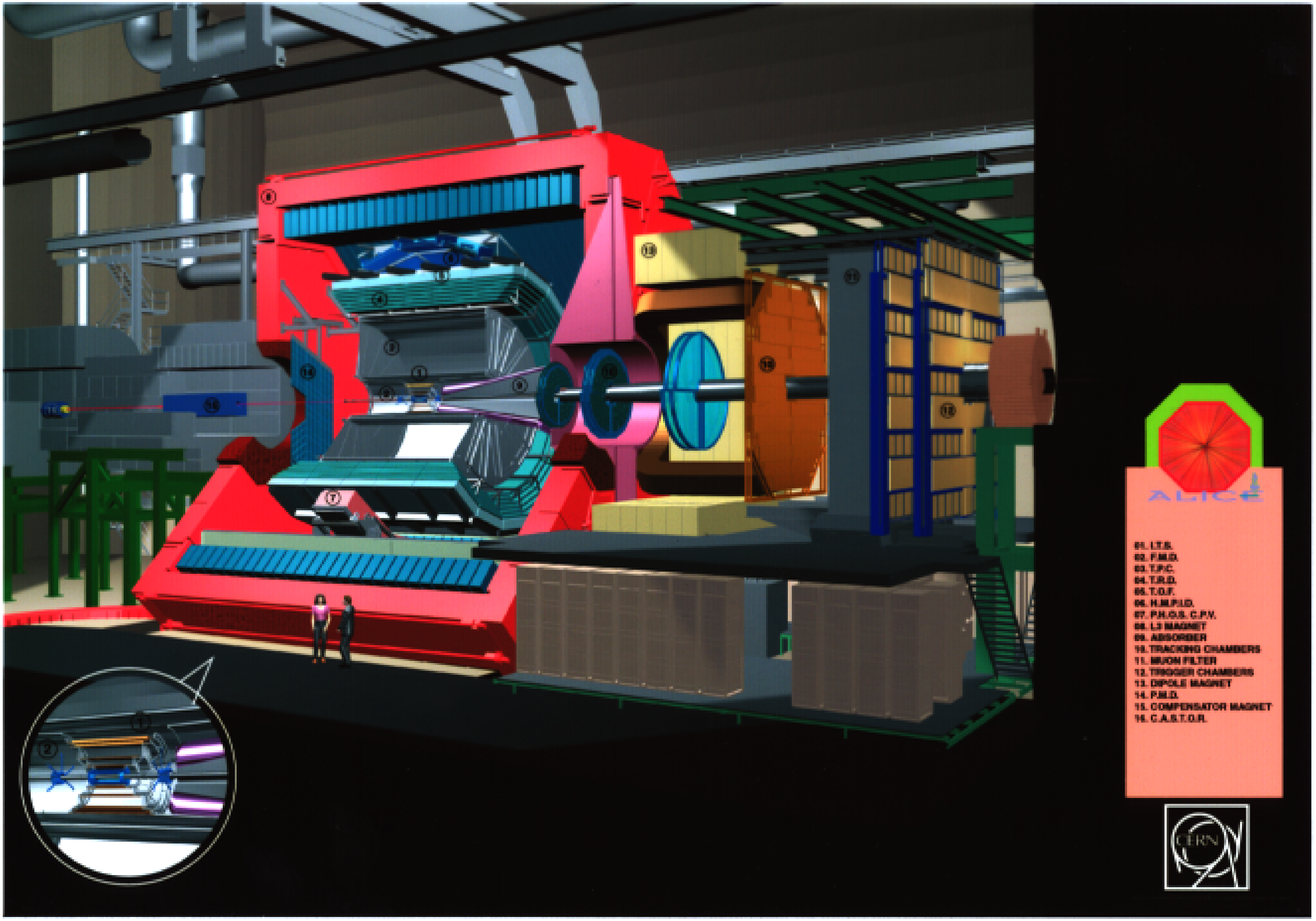


Jet Finding

100 GeV E_T

- ε~100%
- $\sigma(E_T)/E_T$=11.6%.

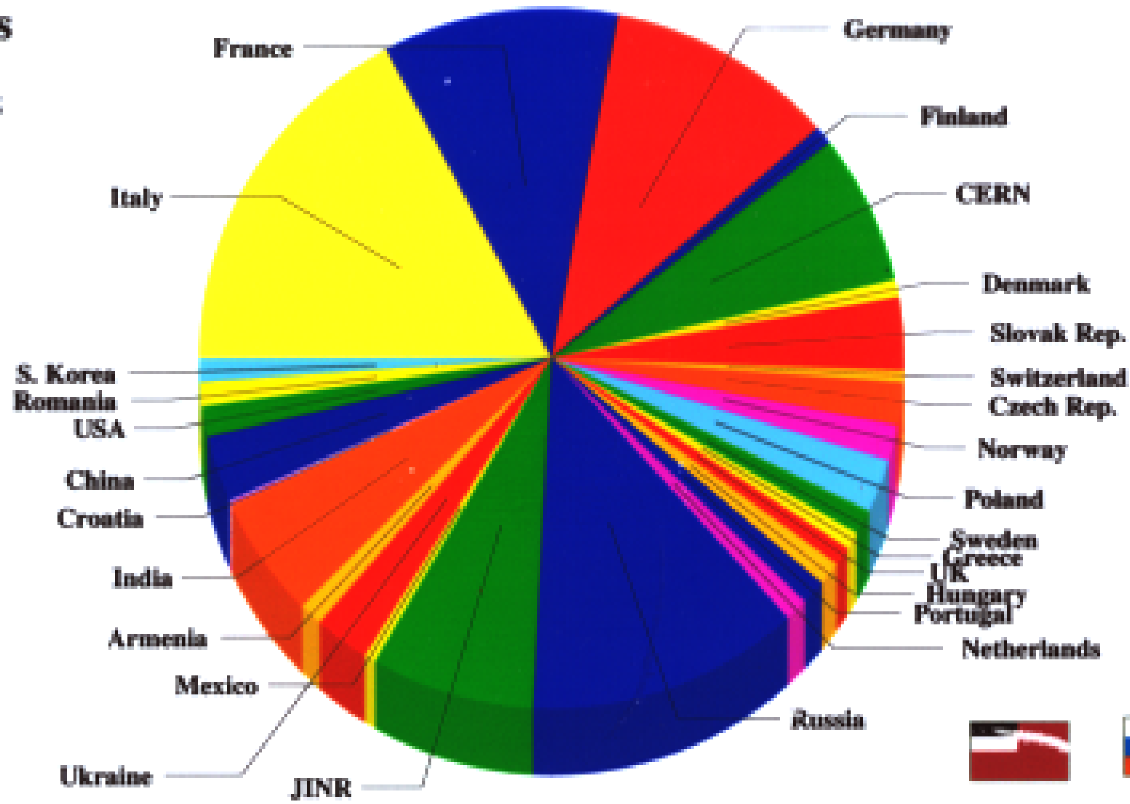


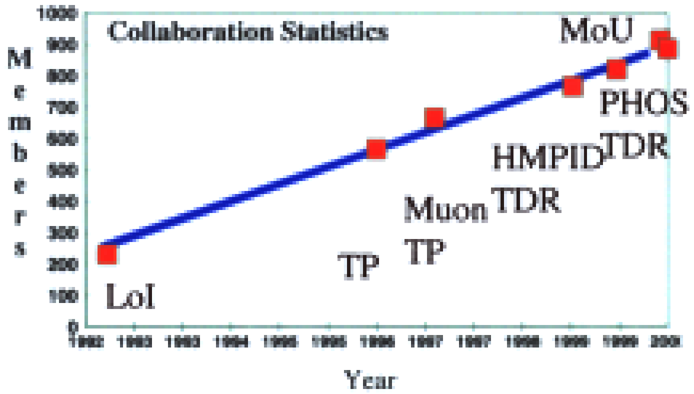

ALICE
01. I.T.S.
02. F.M.D.
03. T.P.C.
04. T.R.D.
05. T.O.F.
06. H.M.P.I.D.
07. P.H.O.S. C.P.V.
08. L3 MAGNET
09. ABSORBER
10. TRACKING CHAMBERS
11. MUON FILTER
12. TRIGGER CHAMBERS
13. DIPOLE MAGNET
14. P.M.D.
15. COMPENSATOR MAGNET
16. C.A.S.T.O.R.
CERN

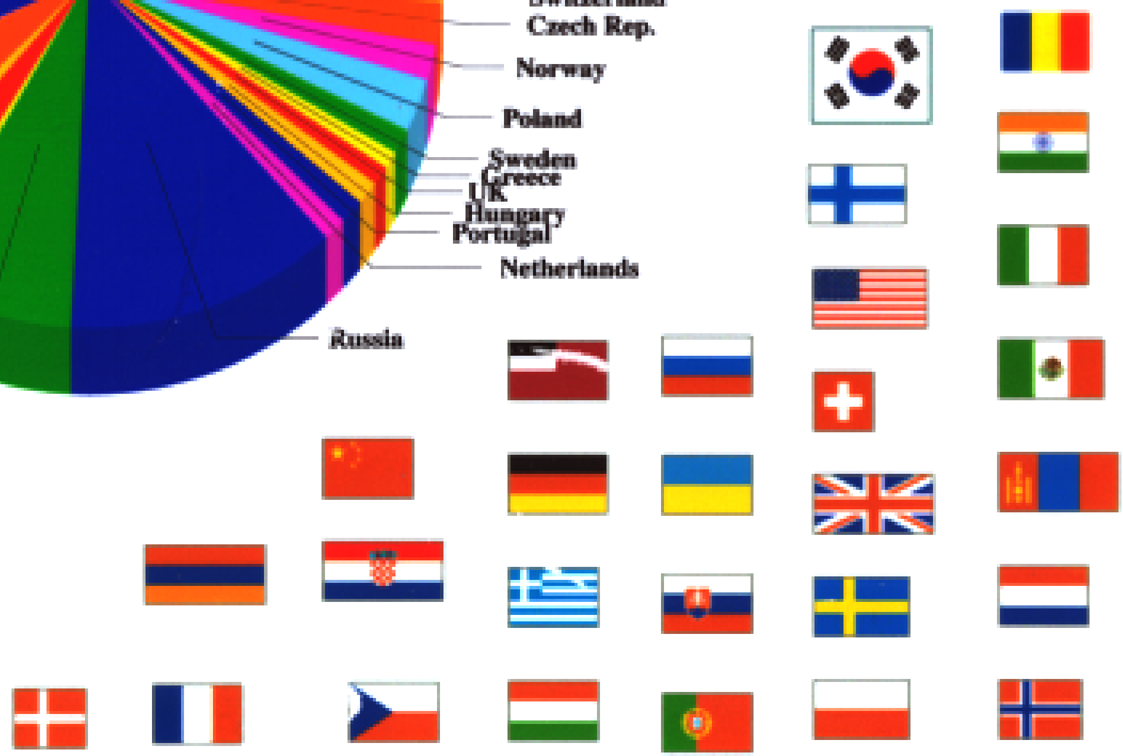
884 Members
(64% from CERN MS)

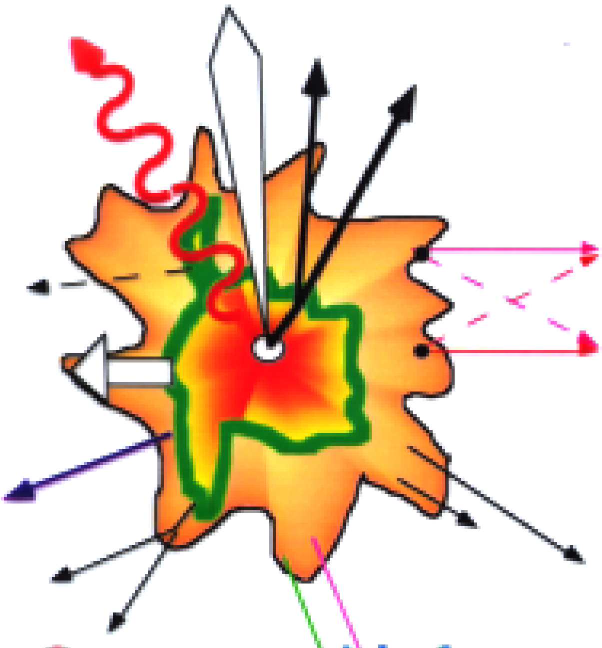
28 Countries

77 Institutes









Signals & Observables

- **general information**

  initial conditions, global features

  ➪ energy/particle density
  ➪ volume, lifetime ('dynamical evolution')
  ➪ .....

- **large x-section probes**

  phase transition, hadronic phase

  ➪ particle ratios ('strangeness enhancement')
  ➪ hadron properties ('resonance modification')
  ➪ .....

- **small x-section (penetrating) probes** **QGP**

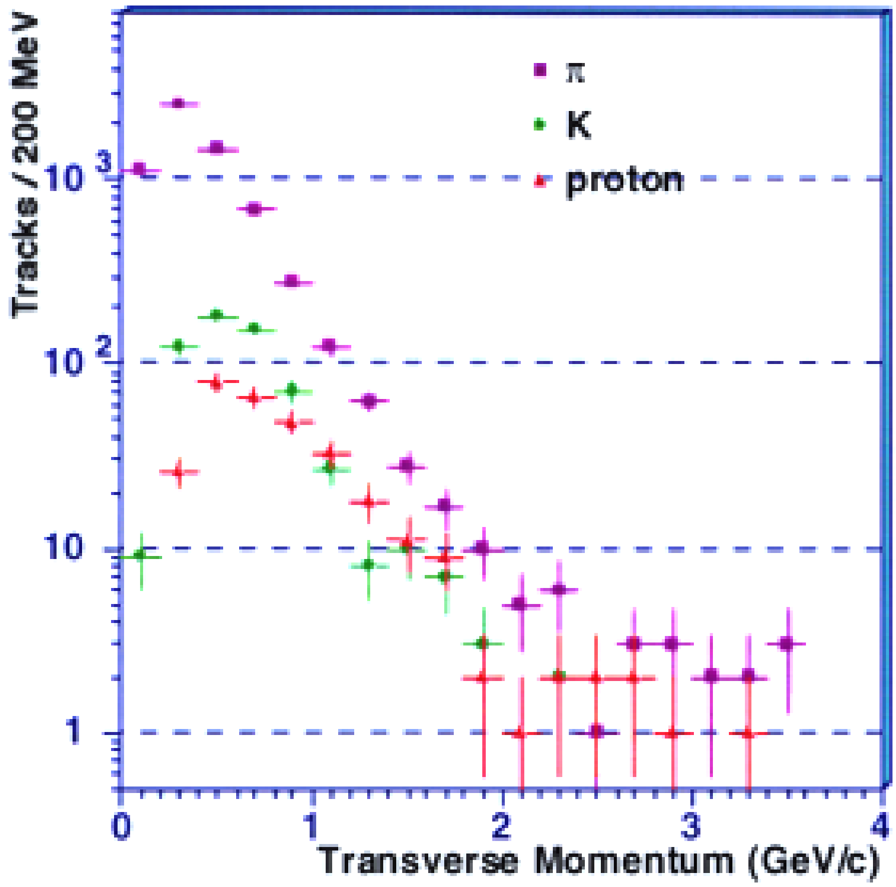
  ➪ open charm ? beauty ('pre-equilibrium stage')
  ➪ real & virtual photons ('thermal radiation')
  ➪ jets ('jet-quenching')
  ➪ J/Ψ & Υ production ('colour screening')

- **exotica**

  ➪ strangelets ➪ chiral condensates ➪ ....

Single Event Physics

- local (y,ϕ) / global (evt-by-evt) fluctuations
  - ⇒ common in phase transitions (critical phenomena)
  - ⇒ Observables in ALICE
    - ☆ forward energy => impact parameter
    - ☆ dN/dy => energy density (+ local fluctuations)
    - ☆ HBT => dynamical evolution (size, lifetime)
    - ☆ p_t-spectra => temperature, flow (π, K, p)
    - ☆ particle ratios => thermodynamics $(\pi, K, p, \Lambda, \gamma)$
    - ☆ N_{ch}/N_γ => isospin fluctuations ('chiral condensates')



<u>reconstructed/event</u>

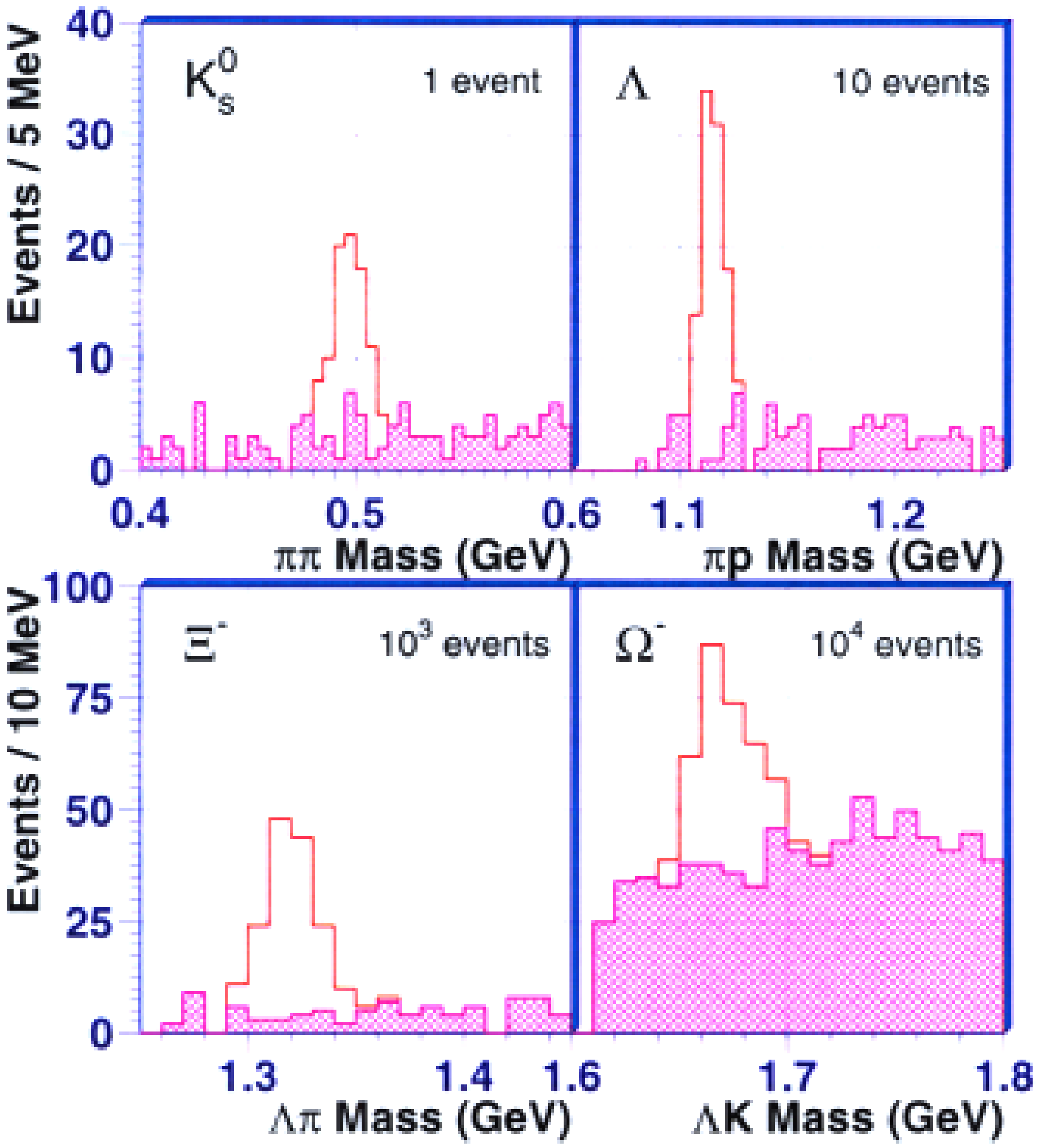
pions	≈ 6500
kaons	≈ 530
K^0_s	≈ 60
protons	≈ 300
Lambdas	≈ 10
gammas	≈ 500

Particle Ratios

- particle ratios ≈ 'nucleo-synthesis'
  - ⇒ **thermodynamic parameters** during hadronic phase
  - ⇒ **QGP/phase transition** => **strangeness** enhancement

- Observables in ALICE

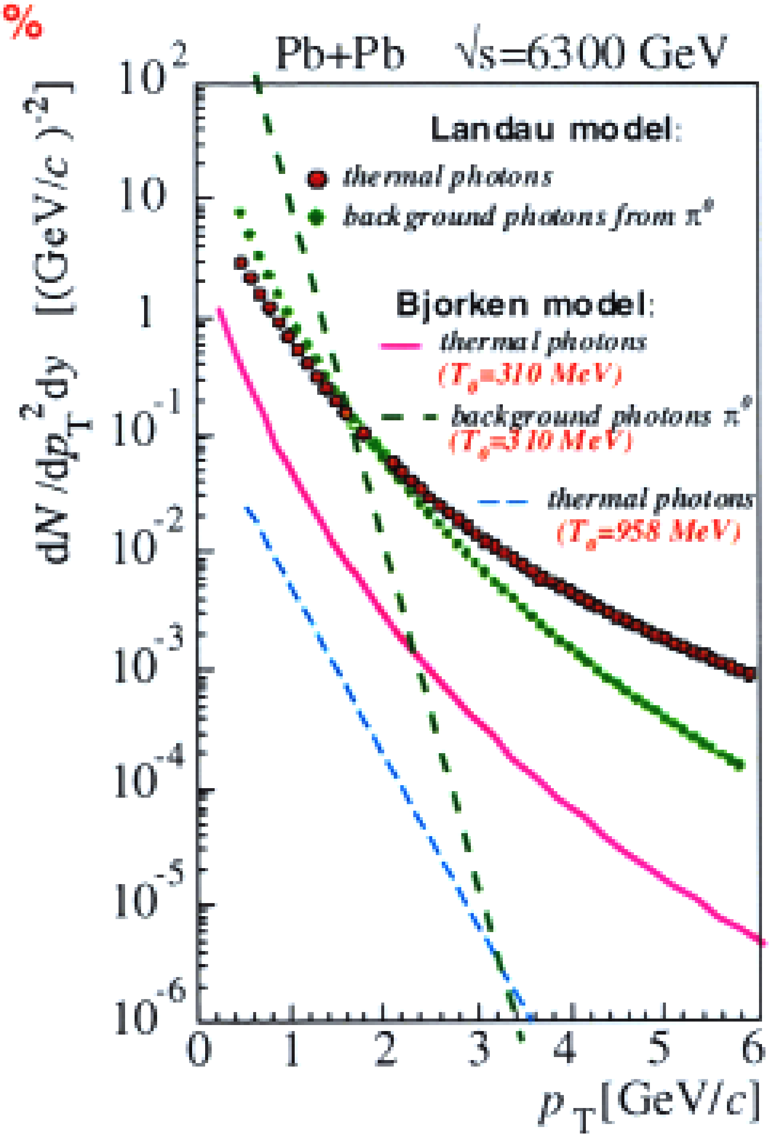
π, η, ω, ϕ, **p**, K, Λ, Ξ, Ω, **D, d, t,** α, ..



Photons

- **physics topics**
  - **thermal radiation** ($p_t \approx 1$ - 5 GeV)
    - ☆ direct / decay ≈ **few percent** to ≥ **100%**
  - $\pi^0/(\pi^+ + \pi^-)$ => isospin fluctuations
  - **meson p_t spectra** (π^0, η) at high p_t
  - hard **QCD photons** in pA => structure functions ?

- **accuracy**
  - limited by systematic errorrs to $\gamma_{direct}/\gamma_{decay} \approx$ **5%**

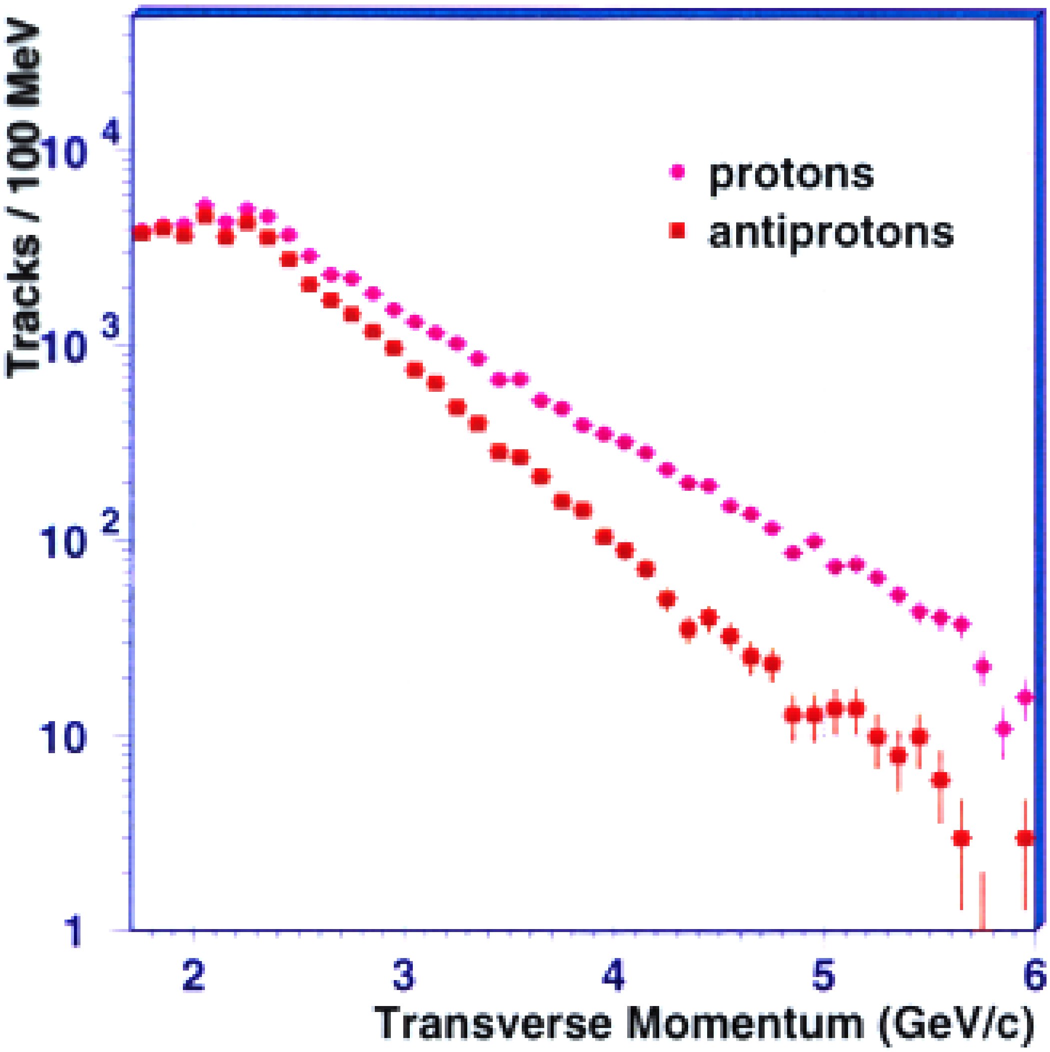


Jets

- **energy loss of partons in matter**
  - ➩ induced gluon radiation, $\Delta E \approx$ O(10) GeV/c
    - ☆ gluons > quarks
    - ☆ QGP > hadronic matter

$dE \approx \mu_D^2 \times L^2$	μ_D = Debye screening scale

  - ➩ jets with **calorimeters impossible** for $E_t \leq$ 50 - 100 GeV
  - ➩ jets with '**leading particles**' (p_t > few GeV/c)
  - ➩ **p**(**p-bar**) at high p_t tag **quark** (**gluon**) jets



HIJING
5×10^4 Pb-Pb

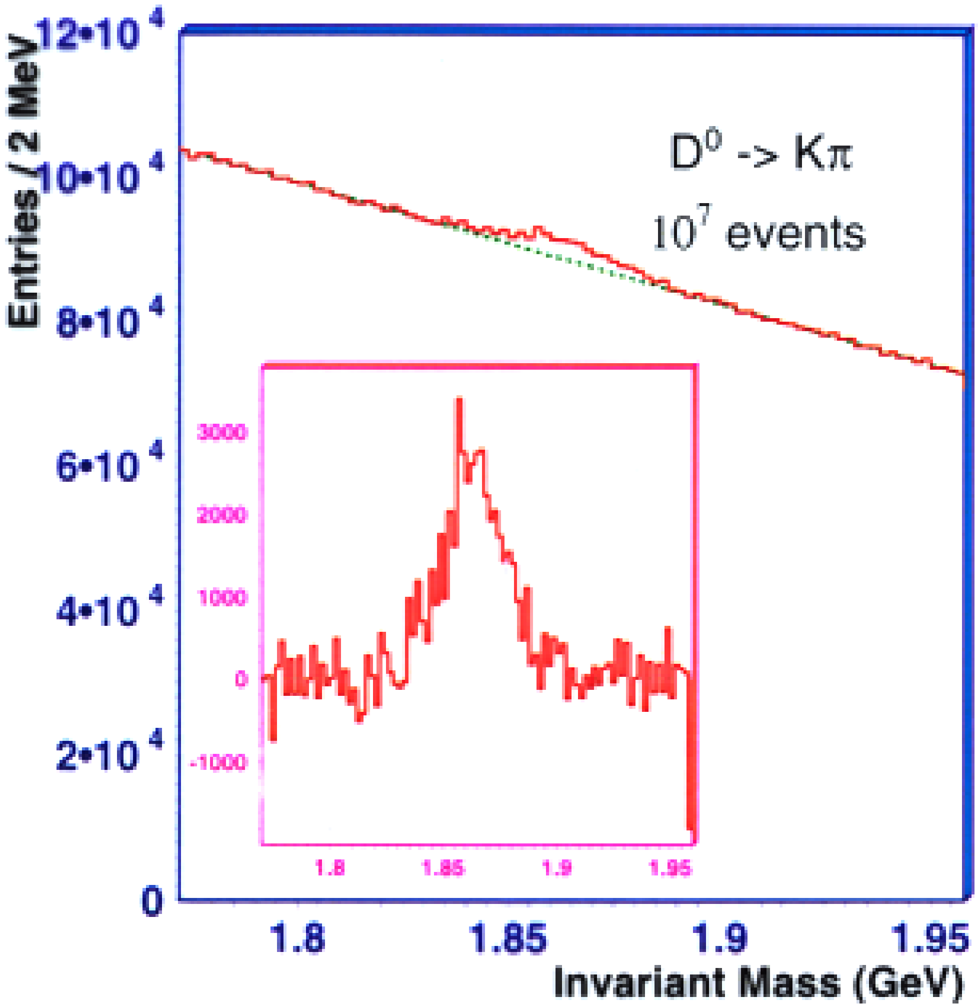
HMPID
acceptance

Open Charm

- **low p_t: mainly gluon-fusion**

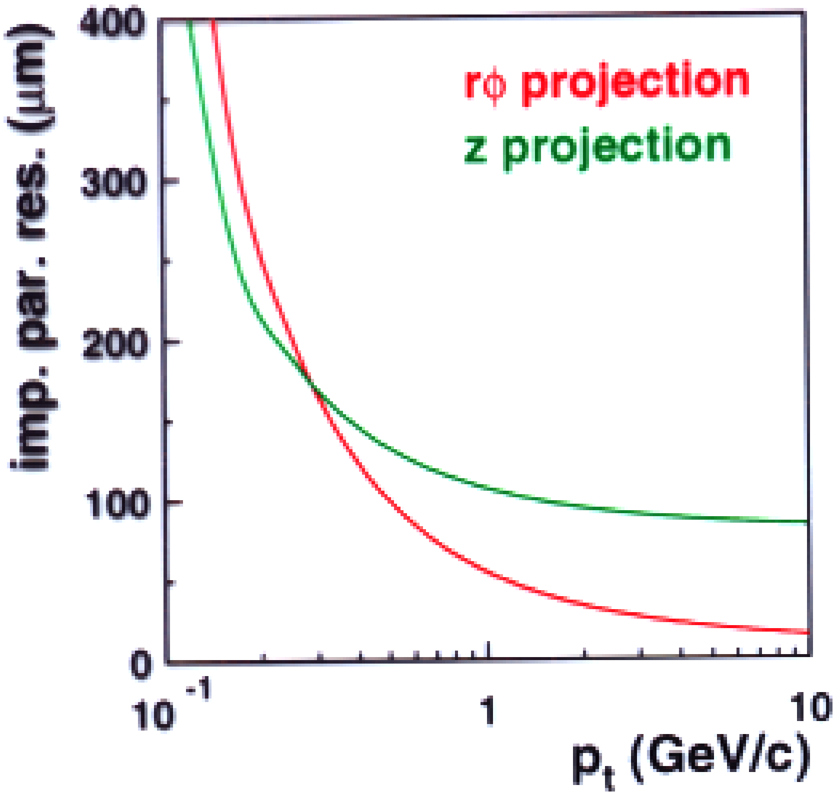
  gg-> cc-> (J/Ψ, D-mesons, ..)

  - ideal **normalization** for J/Ψ suppression
    - production ratio independent of e.g. **structure functions**
  - dense system of semi-hard/hard partons
    - **pre-equilibrium** + **thermal charm** production
    - sensitive to **early + hot phase** of collisions

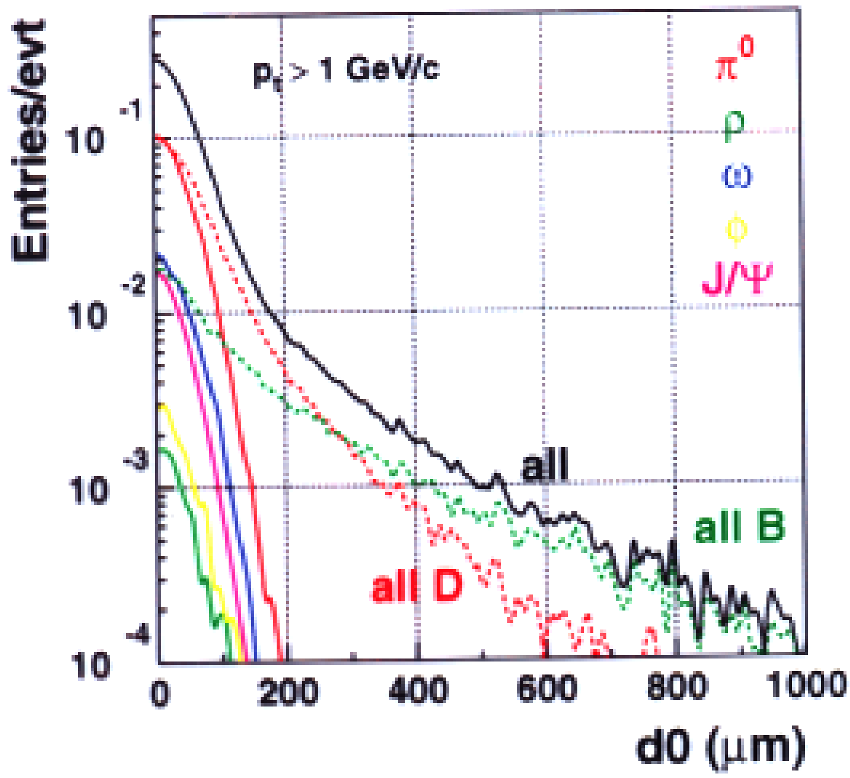


D^0 -> Kπ:	**$S/\sqrt{B} \approx 32$**
D^+-> Kππ:	**$S/\sqrt{B} \approx 30$**

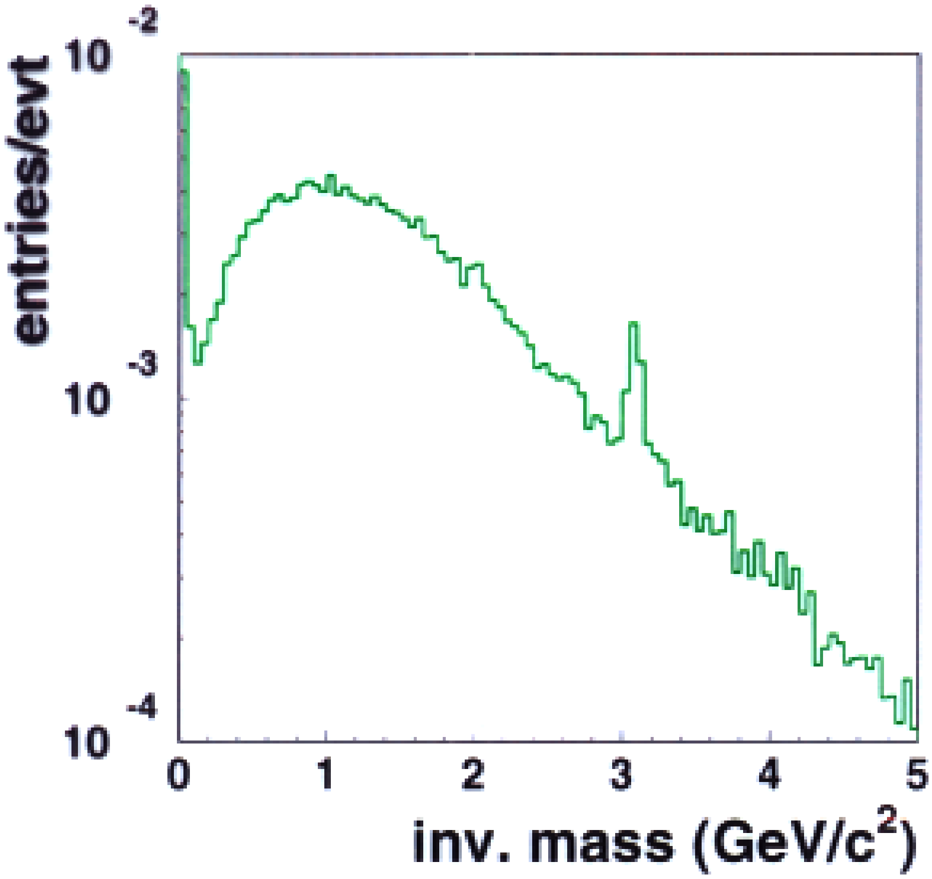
ITS

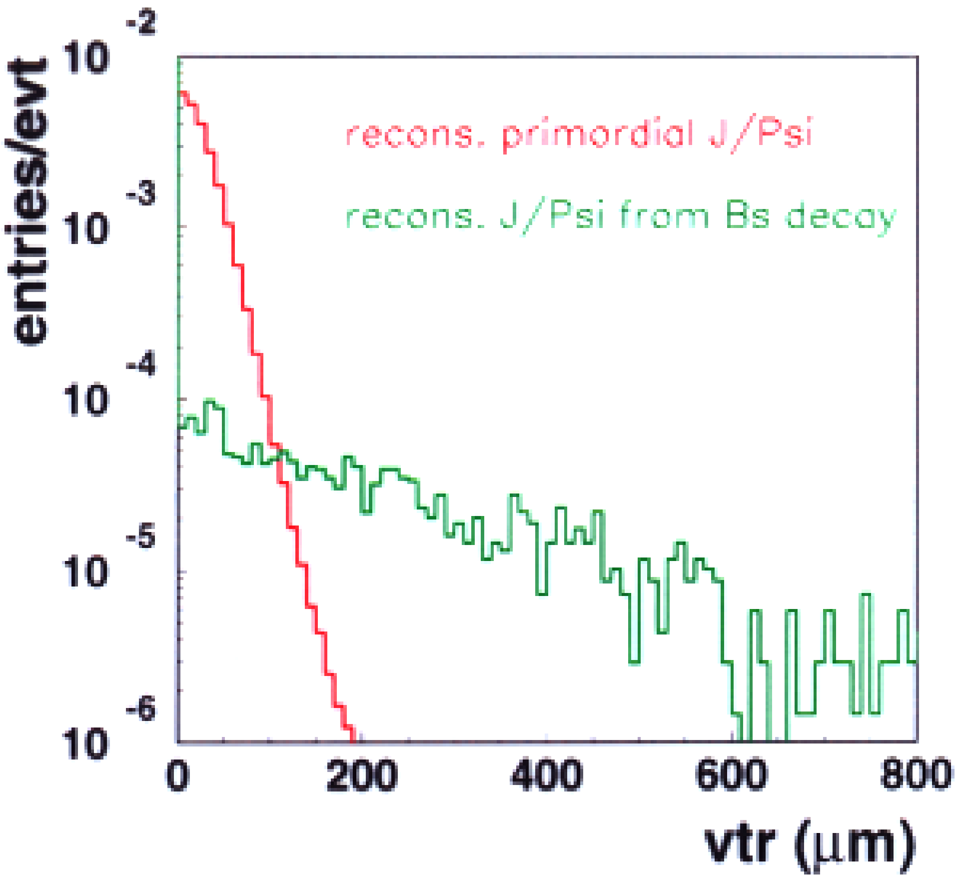


TRD



electrons


entries/evt
10^-2
10^-3
10^-4
0 1 2 3 4 5
inv. mass (GeV/c²)

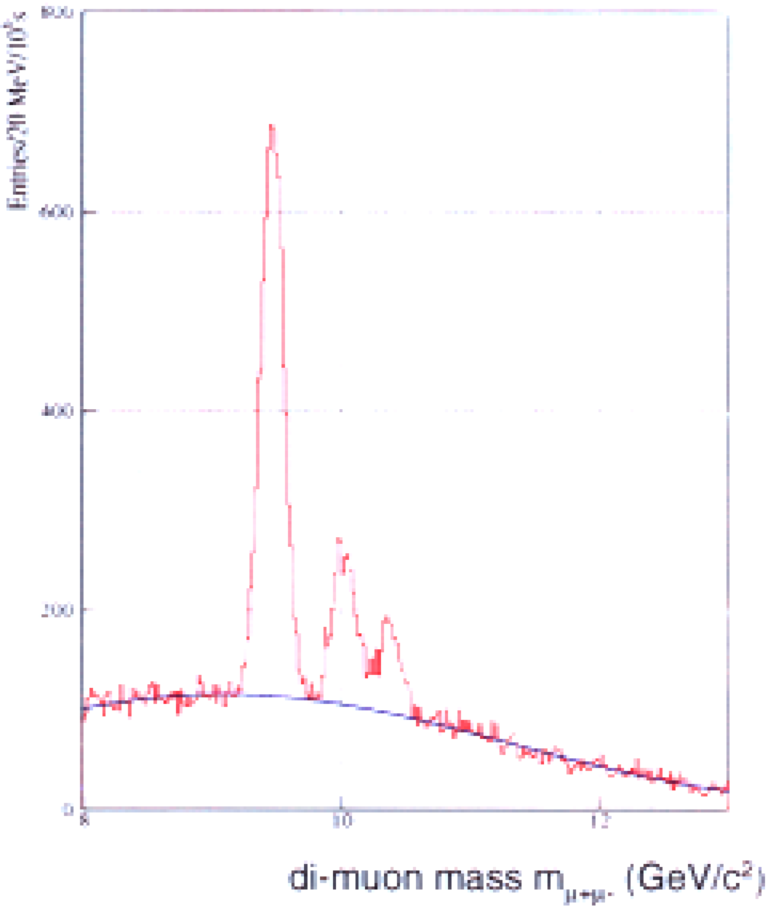

entries/evt
10^-2
10^-3
10^-4
10^-5
10^-6
recons. primordial J/Psi
recons. J/Psi from Bs decay
0 200 400 600 800
vtr (μm)

Lepton pairs

- **Deconfinement**

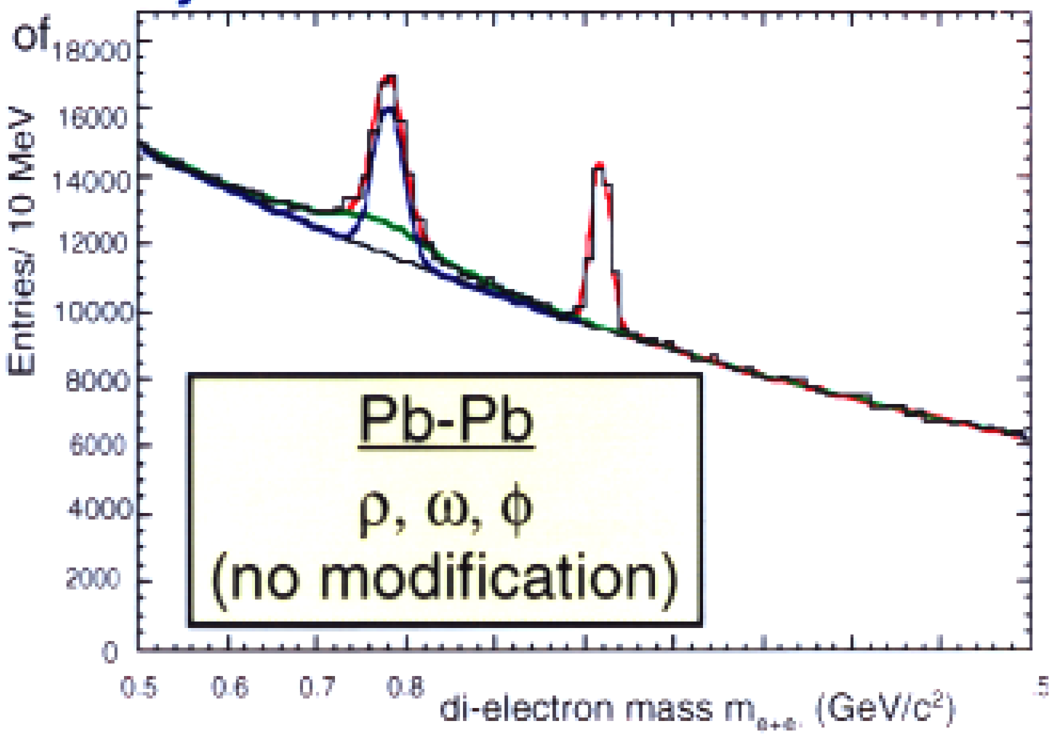
  suppression of heavy resonances (J/Ψ, Υ)

Pb-Pb
Υ production
(no suppression)



- **Chiral Symmetry Restoration**

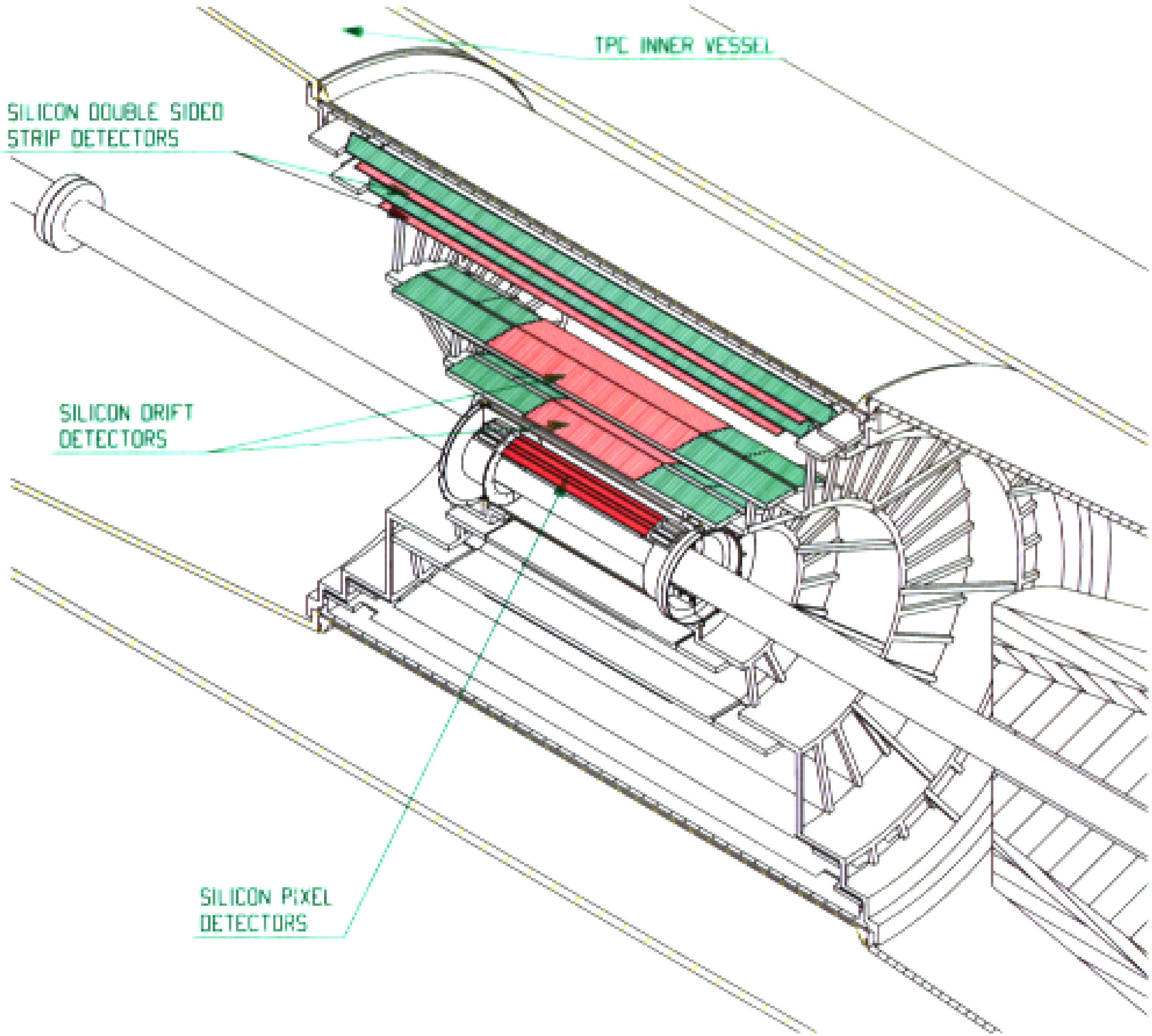
  modification of light hadron properties (mass, width)

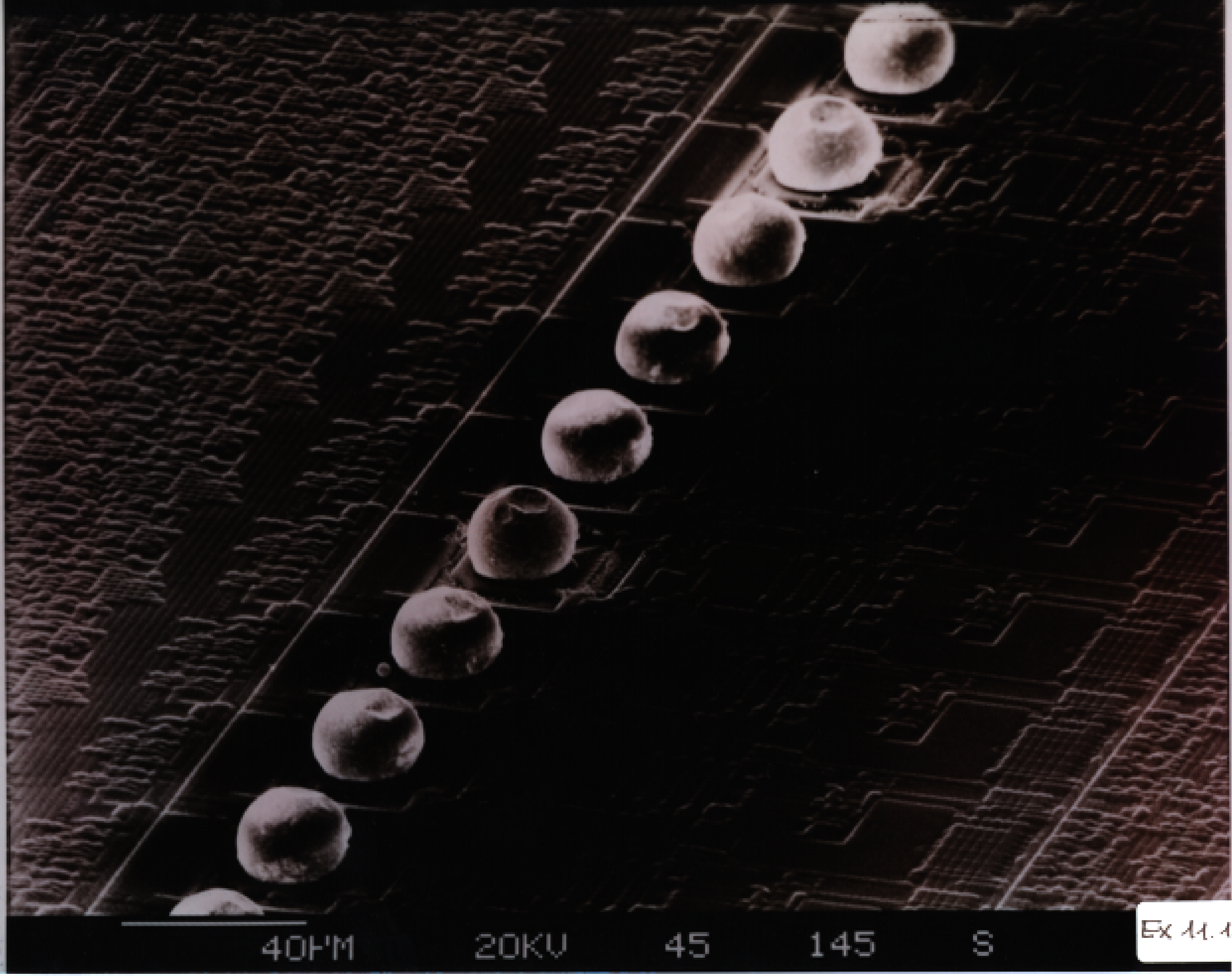


ALICE R&D program

- **Inner Tracking System**
  - Silicon Pixels (RD19) ✓ → !
  - Silicon Drift (INFN/SDI) ✓
  - Silicon Strips (double sided) → STAR
  - low mass support structure, cooling → STAR
- **TPC** (RD32) → STAR FTPC
  - low mass field cage
  - new read-out plane structures †
  - advanced digital electronics ? → !
- **PID**
  - Pestov Spark counters
  - Parallel Plate Chambers †
  - Multigap Resistive Plate Chambers ✓ → ! (RICE/STAR)
  - low cost PM's (for Scintillator readout) †
  - RICH with solid photocathode (CsI) (RD26) ✓ → STAR
- **e.m. calorimeter** (RD18)
  - new dense scintillating crystals ($PbWO_4$) ✓
- **misc**
  - Micro-Channel Plates ?
  - Quartz-fiber Calorimeters
  - ! DAQ, optical links, fast data switches, architectures, storage media ?
  - ? VLSI electronics (FE, TDC's, analogue storage, ...) ✓

† R&D aborted ✓ major breakthrough ? ongoing

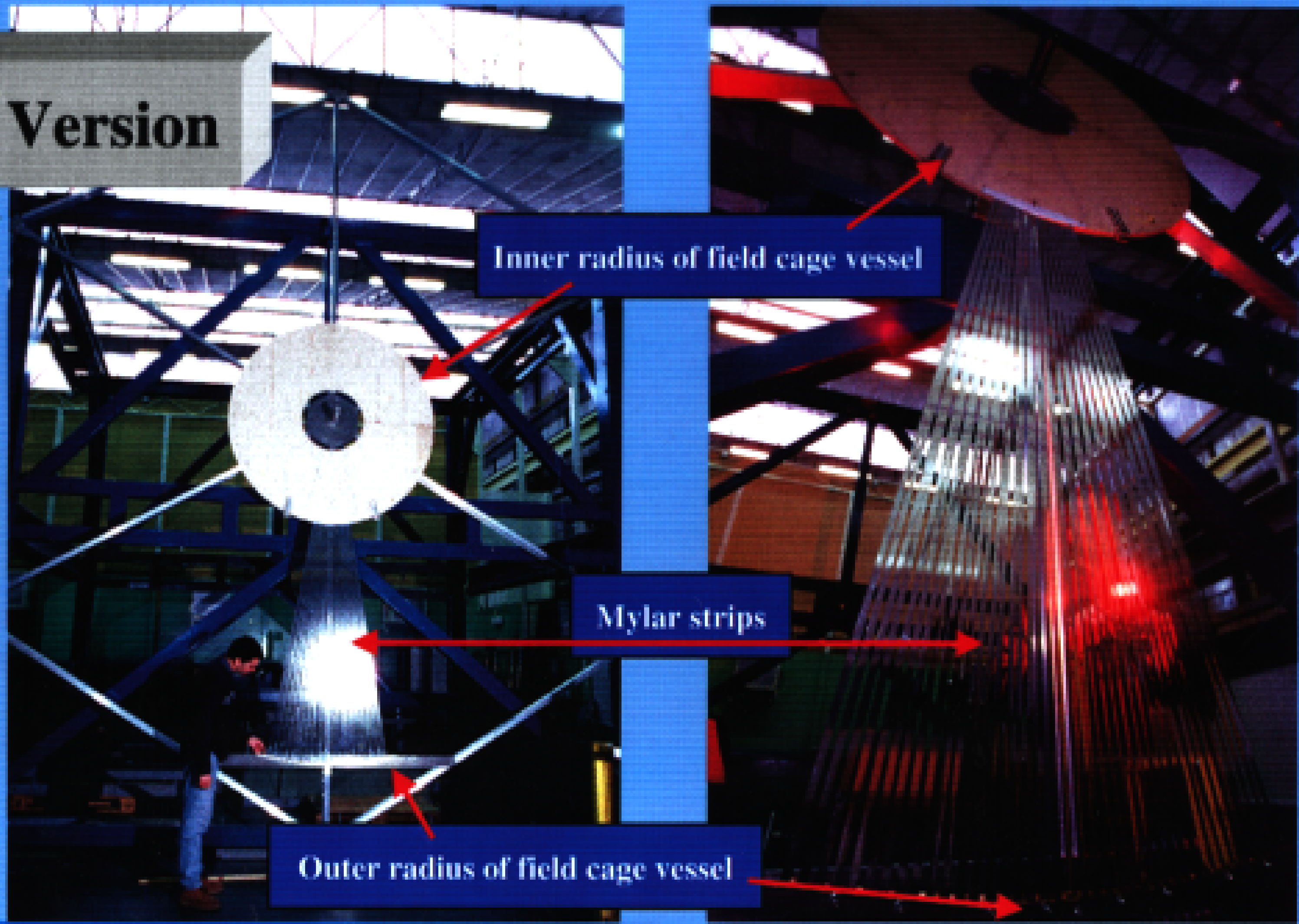

TPC INNER VESSEL
SILICON DOUBLE SIDED
STRIP DETECTORS
SILICON DRIFT
DETECTORS
SILICON PIXEL
DETECTORS



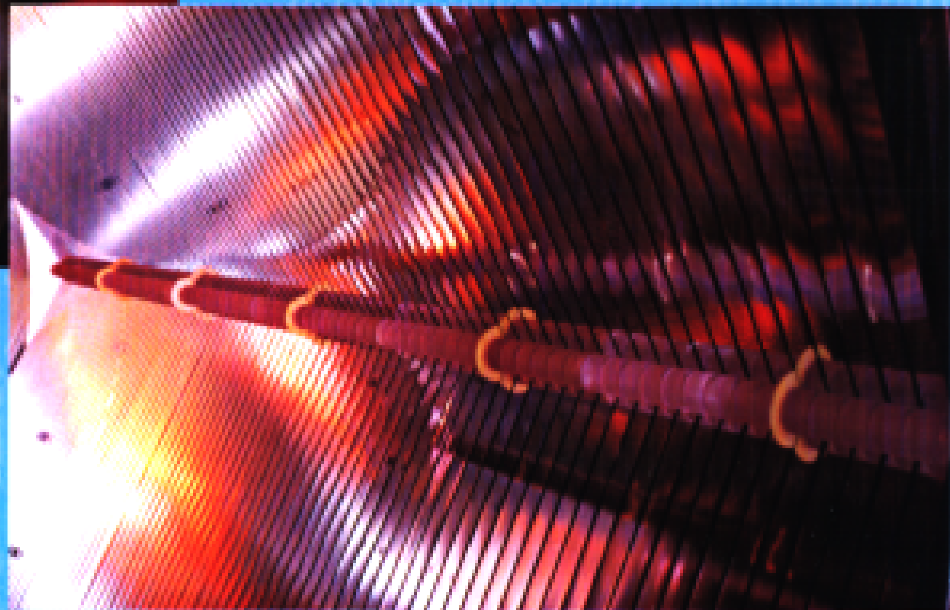
40µM
20KV
45
145
S
Ex 11.11.95/6

Prototyping: Central Electrode

Mylar Version



TPC Field Cage Prototype

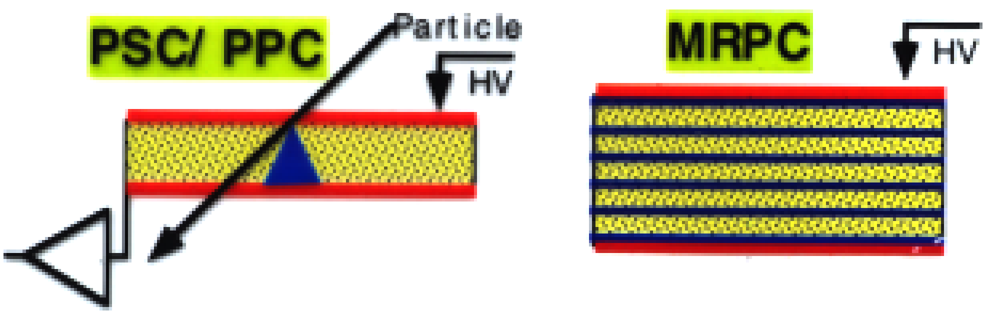


Time of Flight Detector

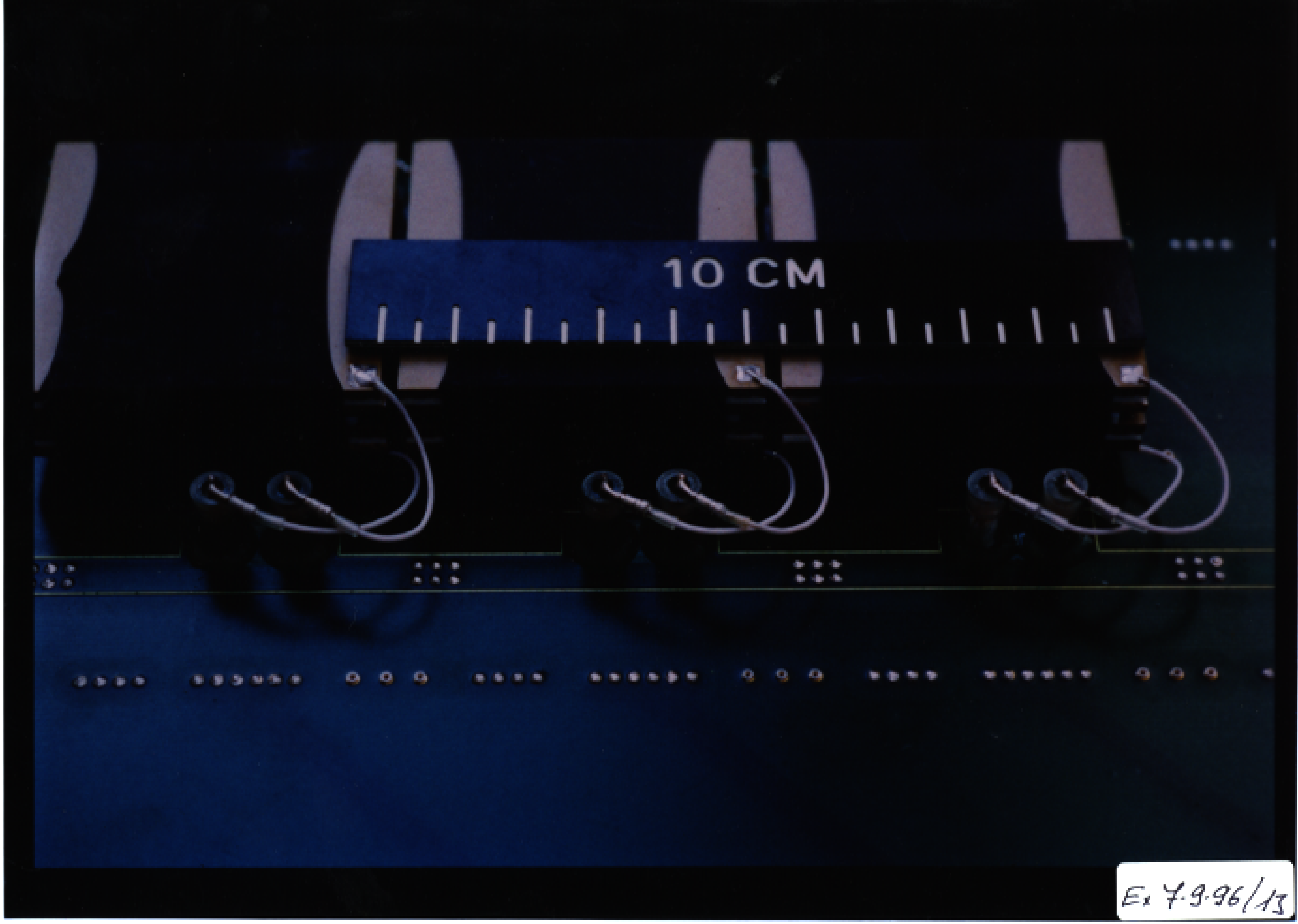
- **aim: Particle ID via TOF (e/π/K/p)**
  - ➩ **area** ≈ 100 m², **channels** ≈ 150,000, **resolution** σ ≈ 100 ps

- **TOF R&D**
  - ➩ **scintillator + PM:** σ ≈ 100 ps, **cost > 100 M$!**
  - ➩ **aim: same performance at 1/20 cost !**

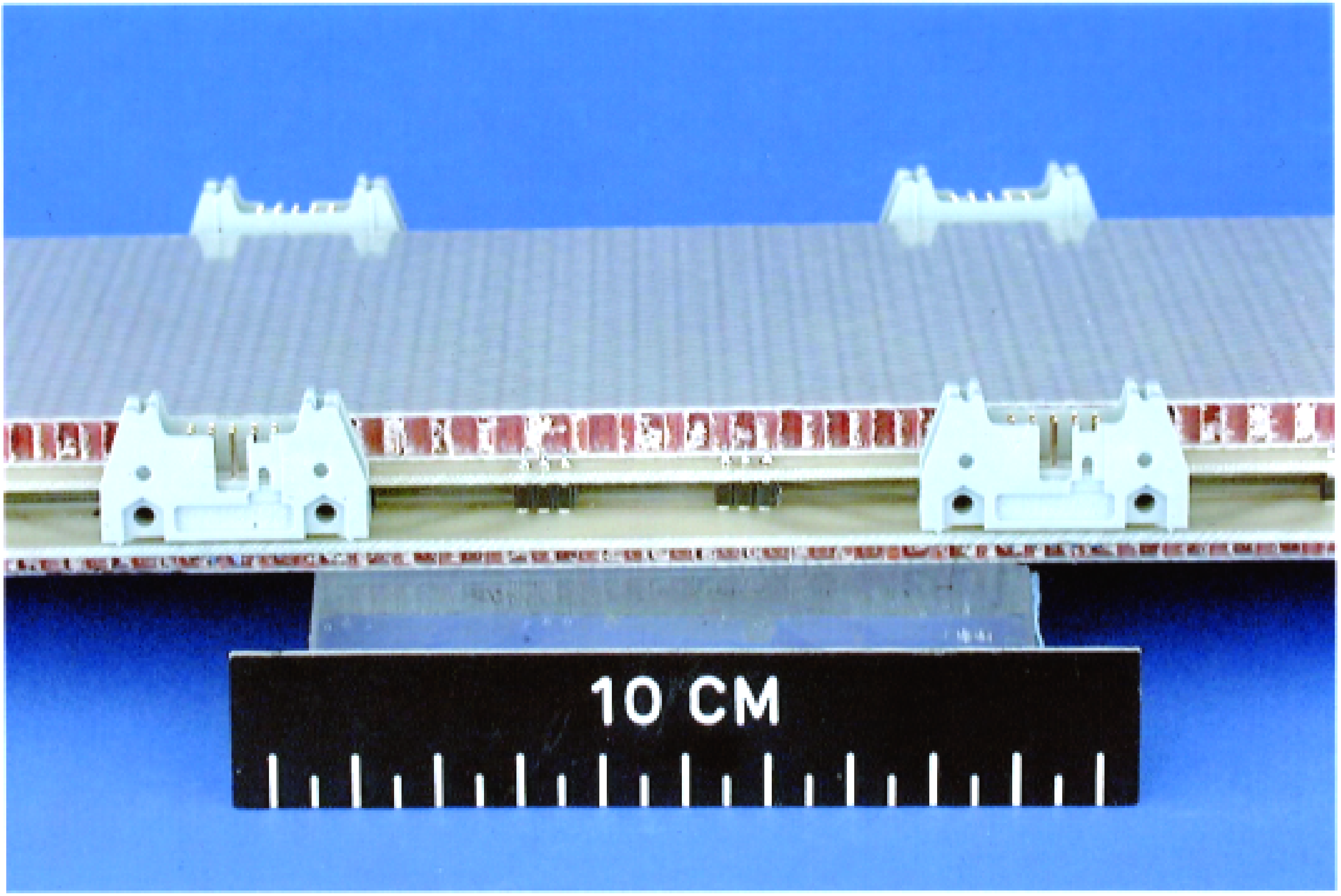
- **gas TOF counters**
  - ➩ **Pestov Spark Counter (PSC)**
    - ☆ 100 μm gap, > 5 kV HV, 12 bar, sophisticated gas
    - ☆ **resolution < 50 ps**, but only (!) **1/10 cost**
    - ☆ technology & materials **very challenging**
  - ➩ **Parallel Plate Counter (PPC)**
    - ☆ 1.2 mm gap, > 5 kV HV, 1 bar, simple gas
    - ☆ **1/20 cost,** but only **250 ps resolution**
    - ☆ **unstable operation, low signal**
  - ➩ **Multigap Resistive Plate Chamber (MRPC)**
    - ☆ many small gaps (eg 5 x 250 μm), 1 bar, simple gas
    - ☆ **1/20 cost, resolution < 100 ps**
    - ☆ **breakthrough** end 1998 after 4 years R&D !



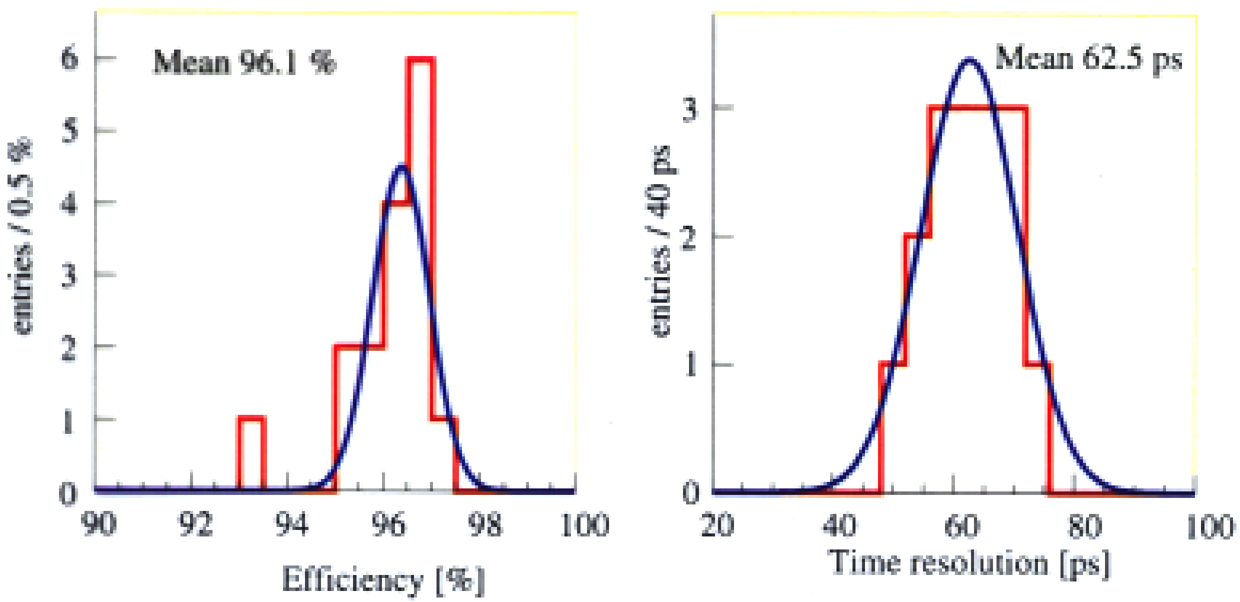

10 cm

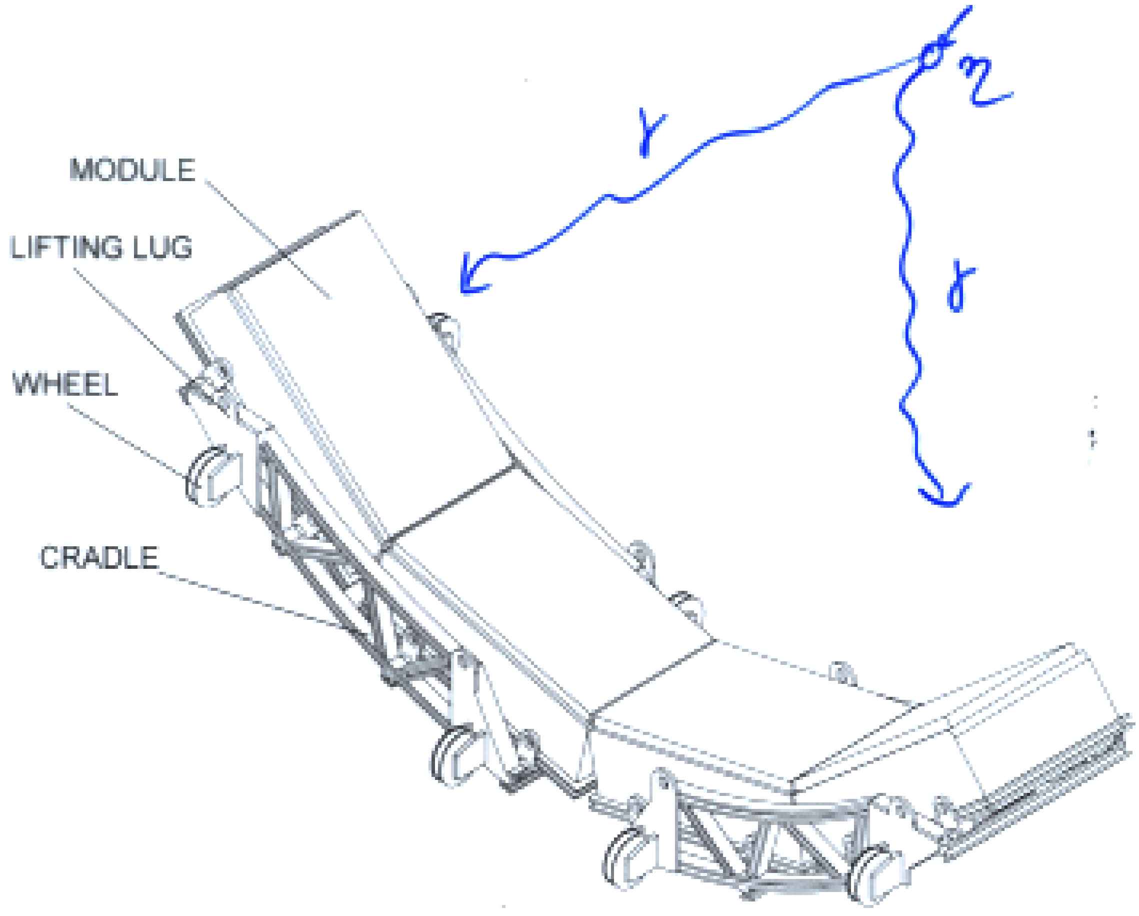


Ex 7.9.96/13

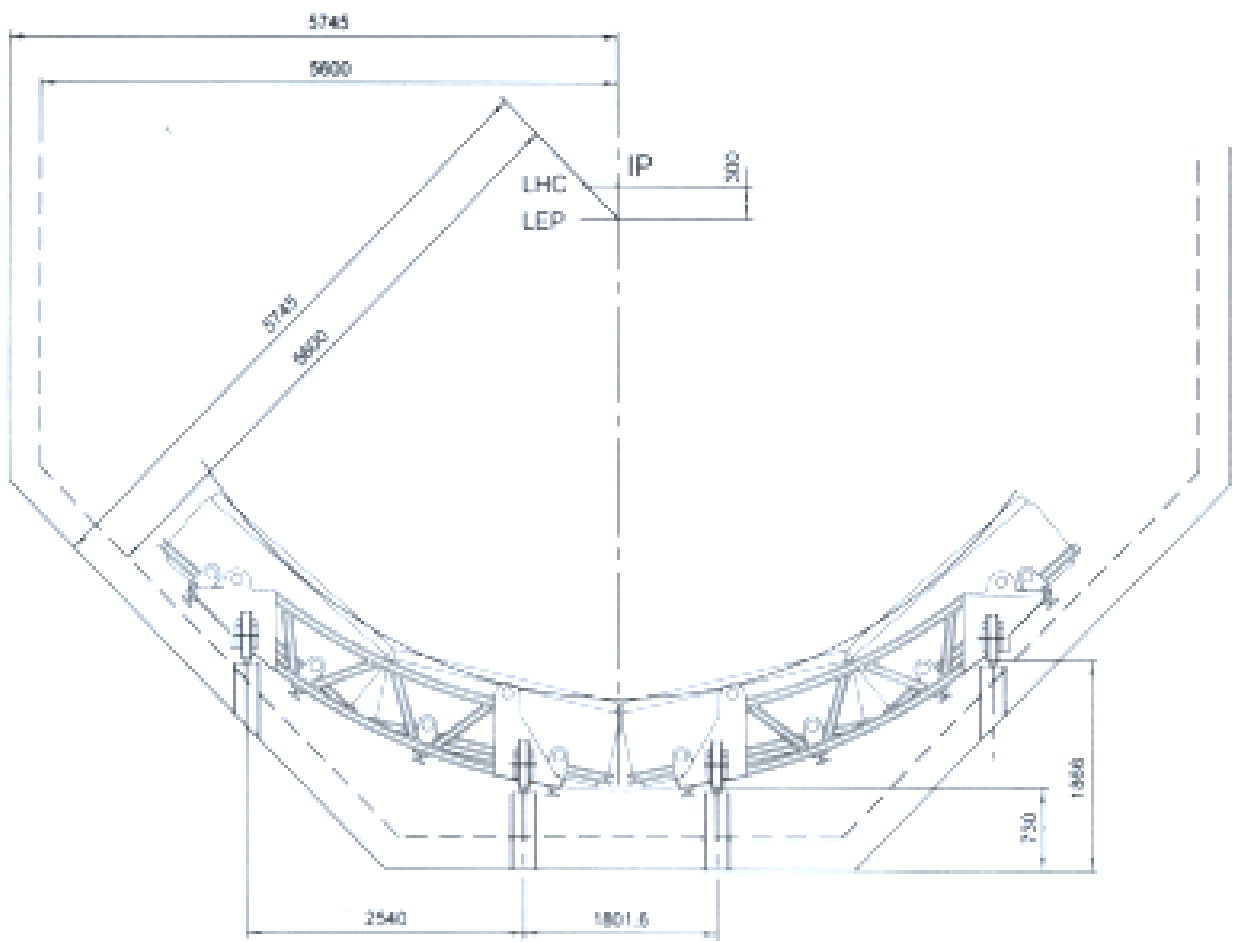

10 CM

8x2 cell strip detector 12.5 kV

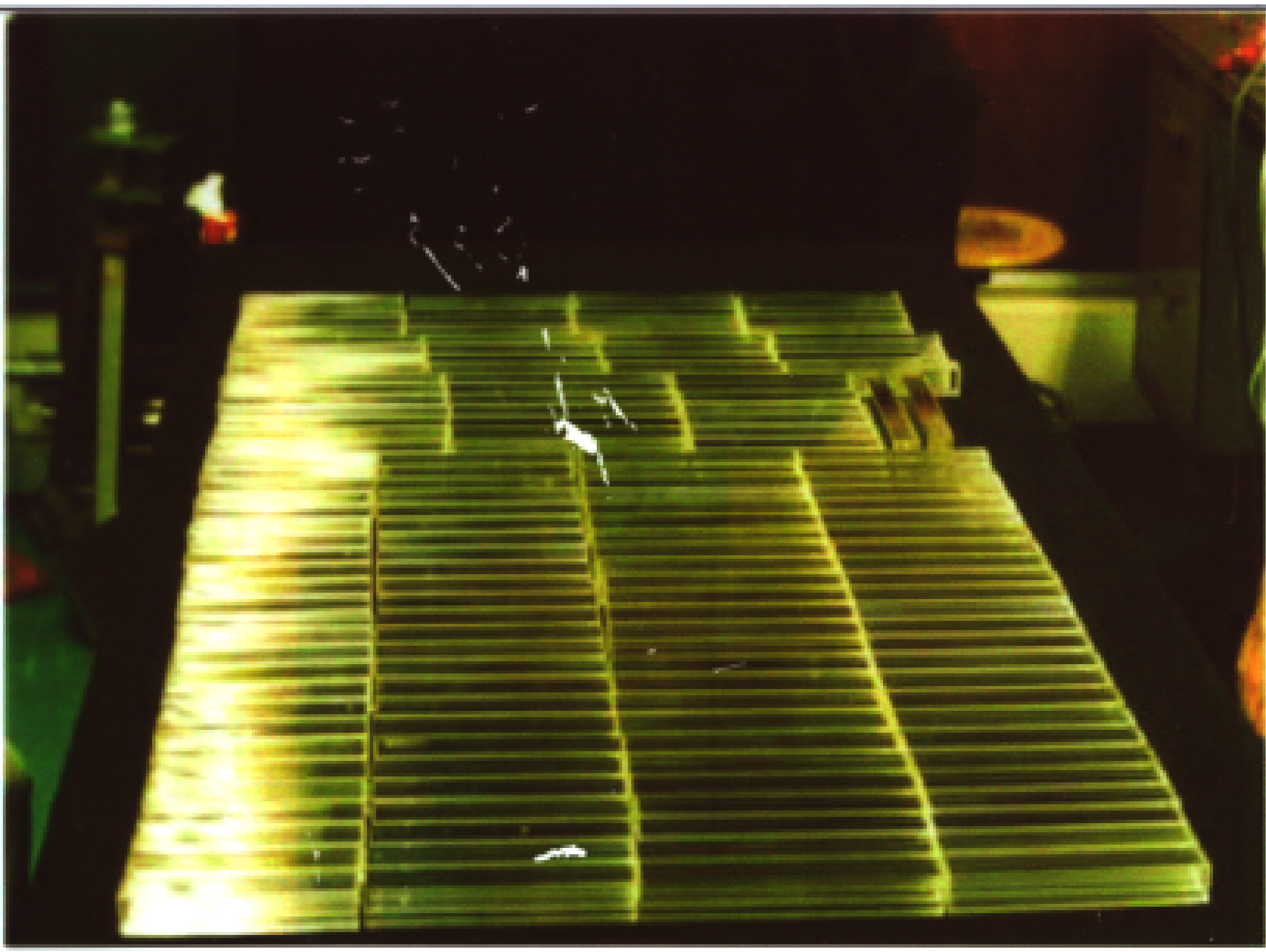


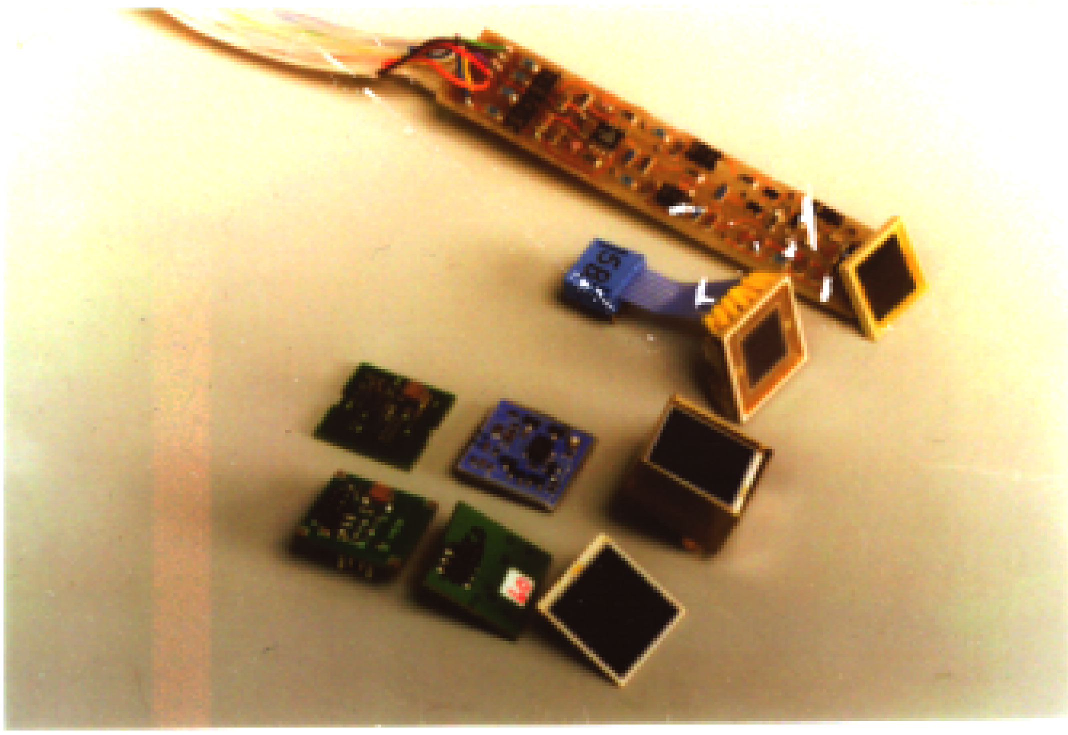


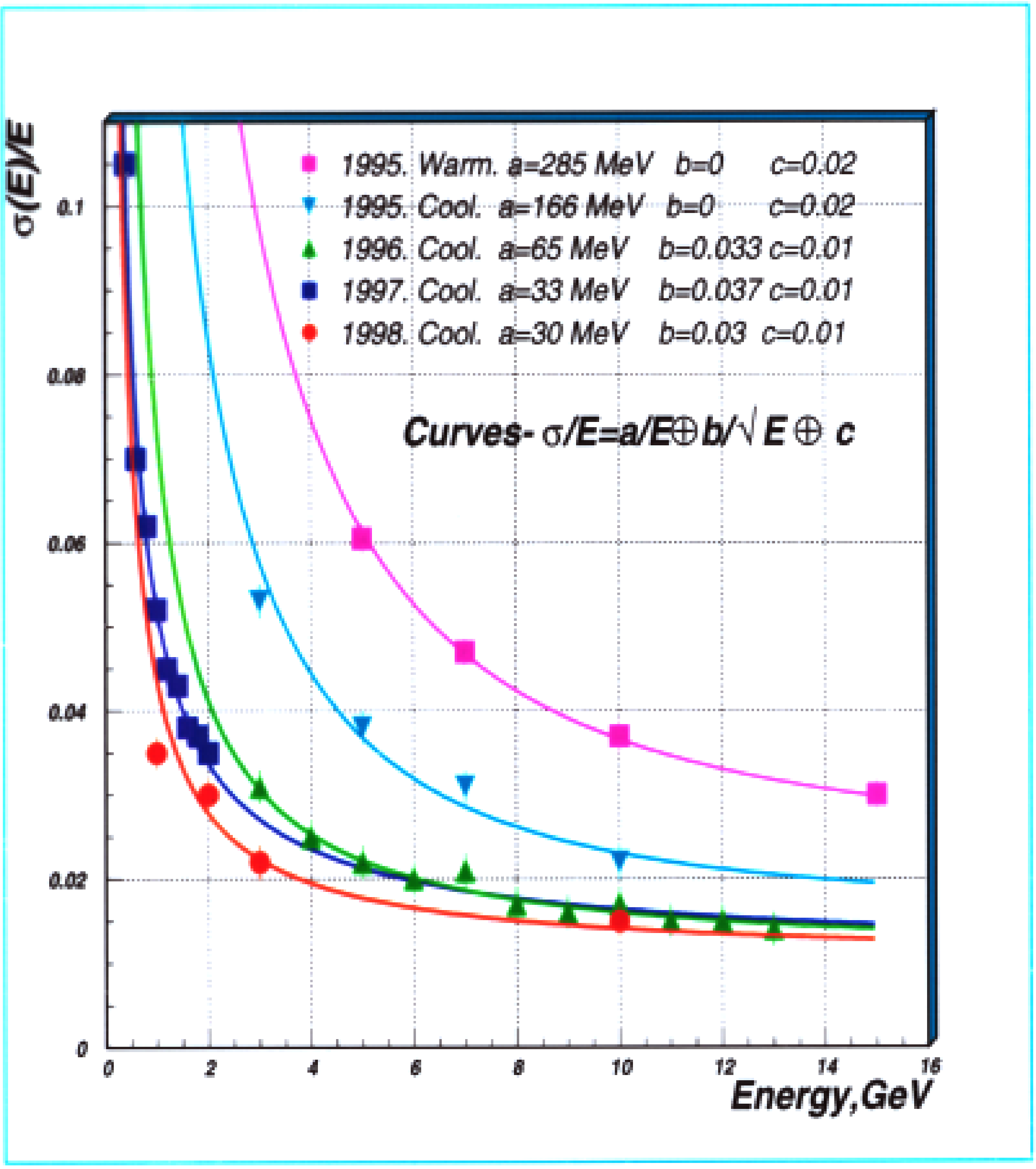
MODULE
LIFTING LUG
WHEEL
CRADLE



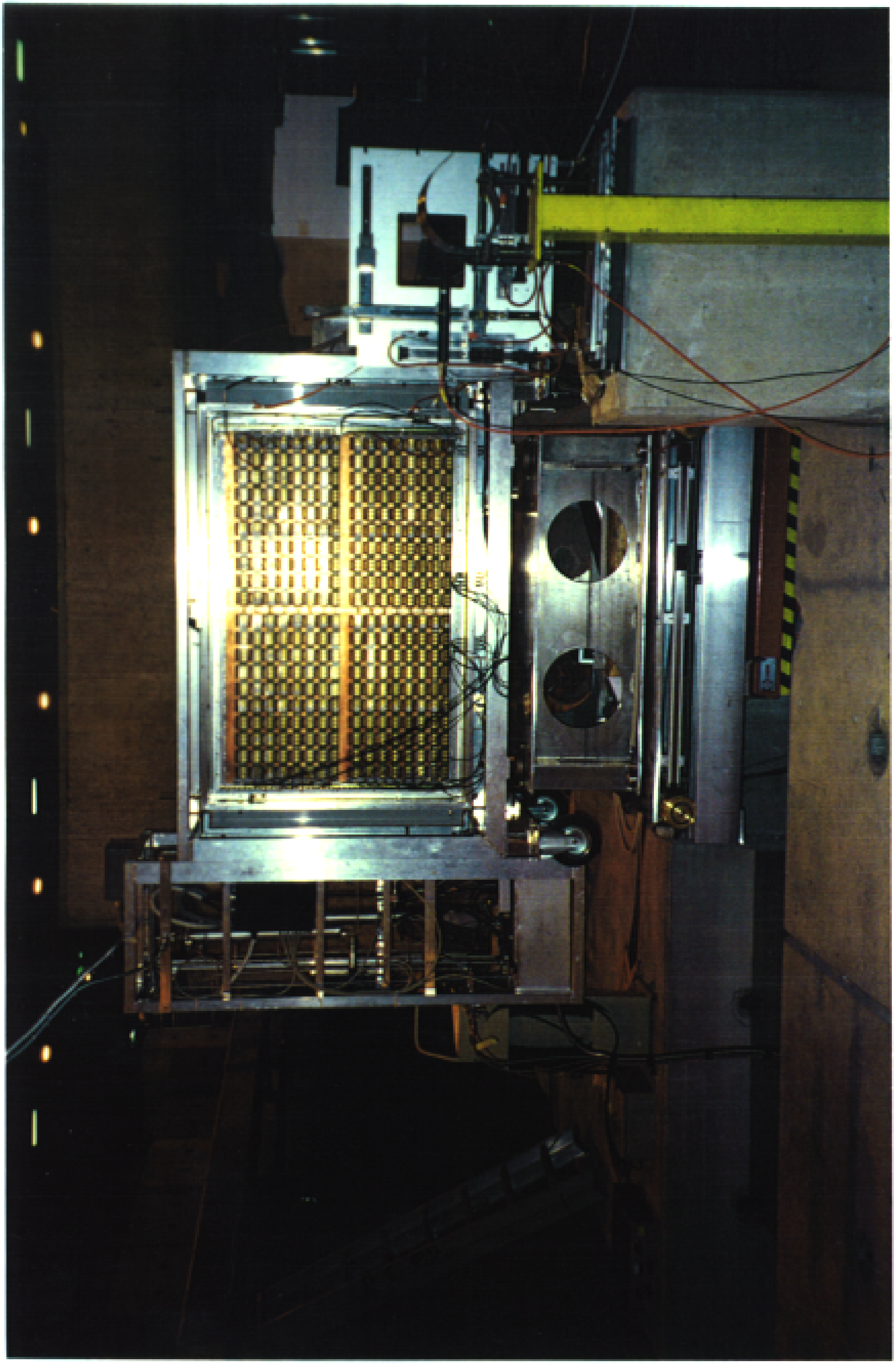
5745
5600
IP
LHC
LEP
300
5745
5600
1868
730
2540
1801.6



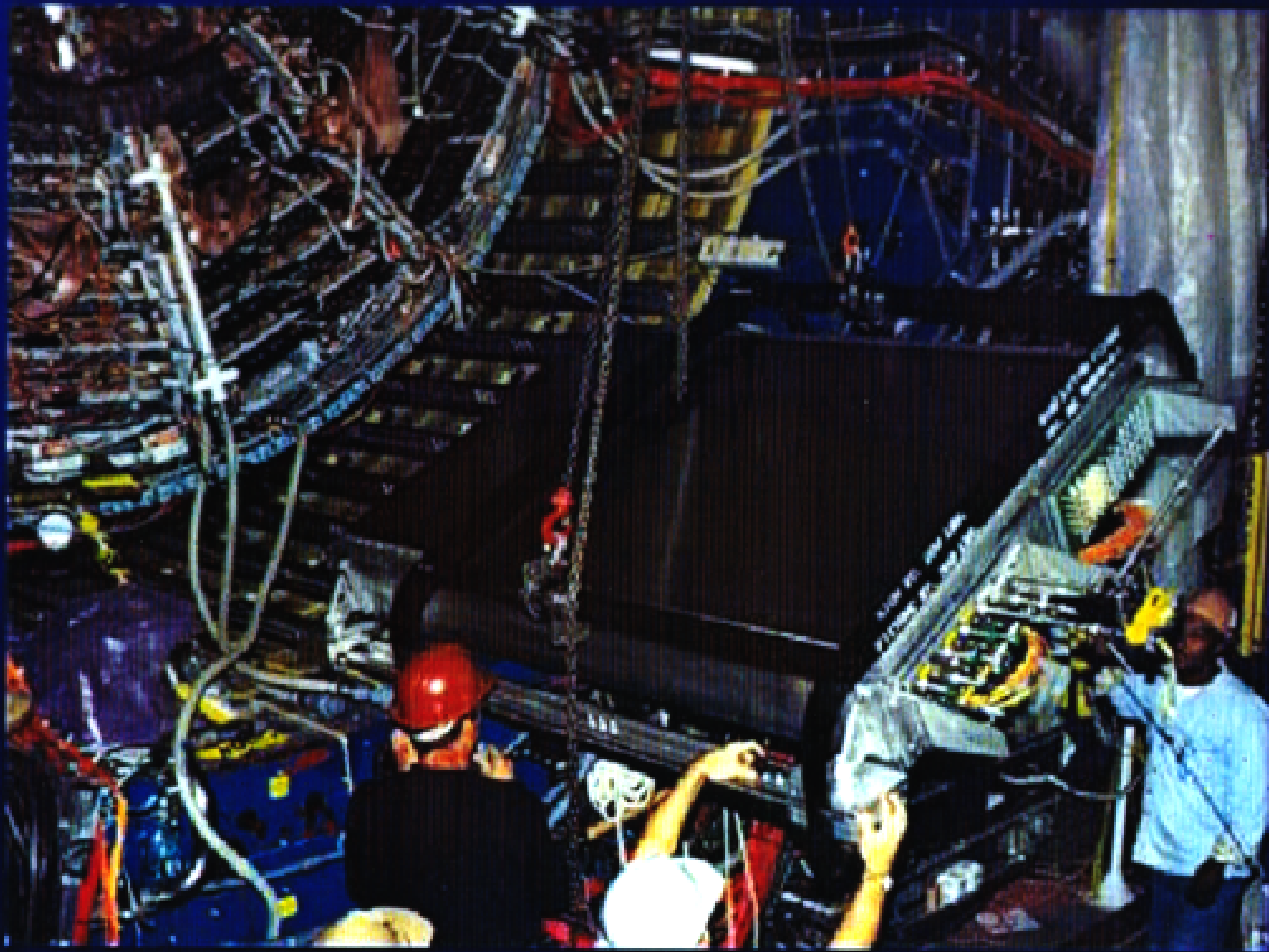




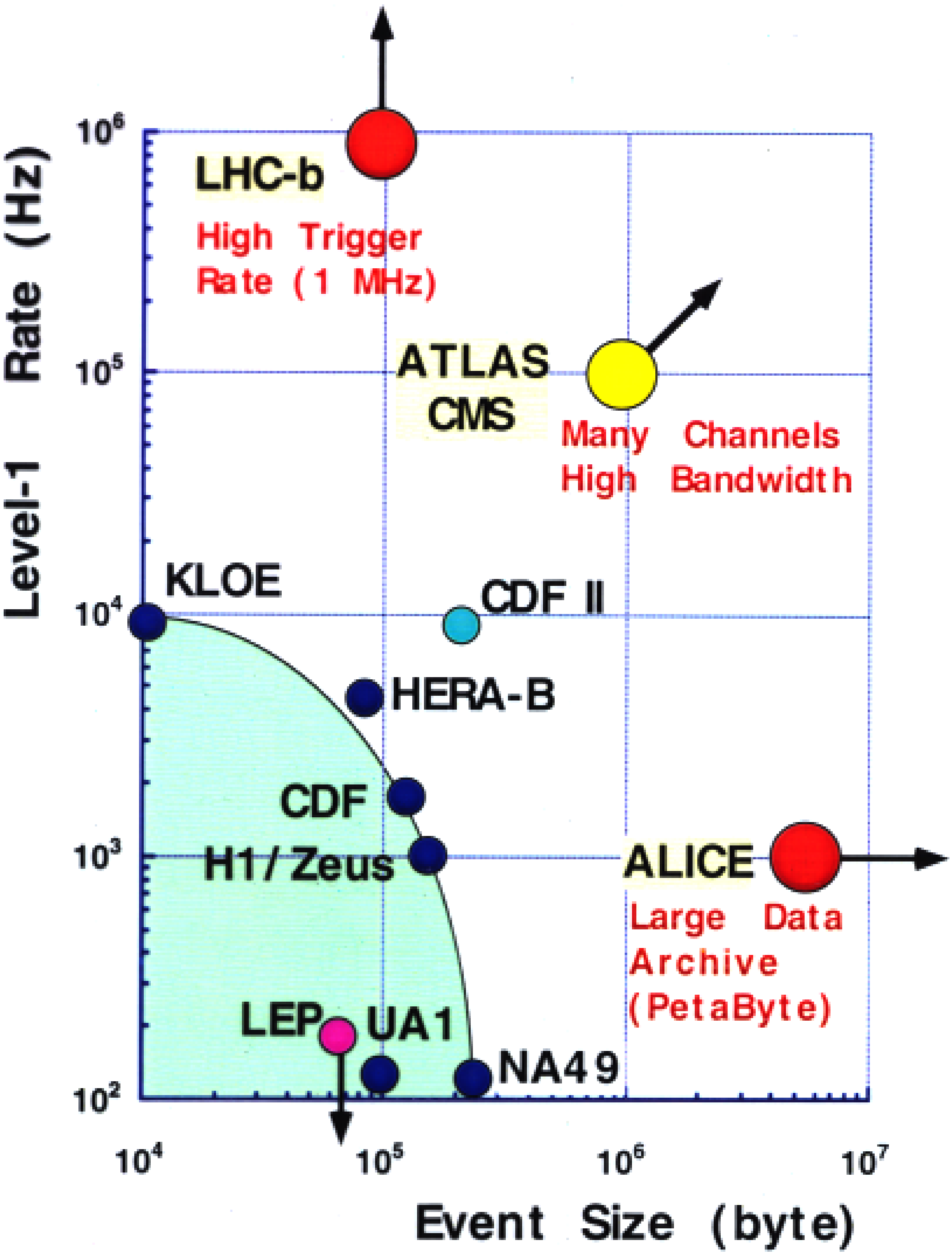
σ(E)/E
0.1
0.08
0.06
0.04
0.02
0
0
2
4
6
8
10
12
14
16
Energy,GeV
1995. Warm. a=285 MeV b=0 c=0.02
1995. Cool. a=166 MeV b=0 c=0.02
1996. Cool. a=65 MeV b=0.033 c=0.01
1997. Cool. a=33 MeV b=0.037 c=0.01
1998. Cool. a=30 MeV b=0.03 c=0.01
Curves- σ/E=a/E⊕b/√E ⊕ c



The RICH installation



Trigger and DAQ Trends



R&D status

● DAQ

➩ data volume: ≈ 3 Pbyte/y,   peak rate: ≈ 1.3 Gbyte/s

● 1st Data Challenge early 1999

➩ aim: 10 Tbyte @ 25 Mbyte/s

➩ reached: 7 Tbyte @ 14 Mbyt/s

  ☆ several hardware/software problems d'scovered & fixed

● 2nd Data Challenge early 2000

➩ aim: 80 Tbyte @ 100 Mbyte/s

  ☆ test scalability, new hard/software

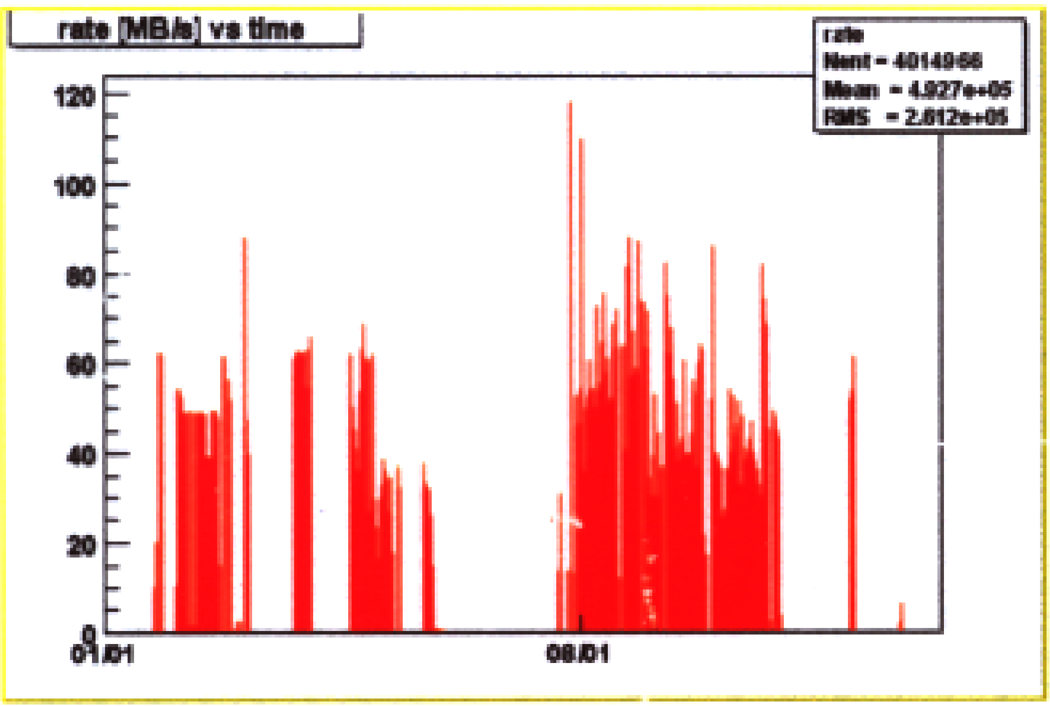
➩ reached: 15 Tbyte @ 28 Mbyt/s

  ☆ sustained: 60 Mbyt/s, peak: 115 Mbyt/s

  ☆ many unsuspected problems discovered, some fixed

  ☆ individual **components ok, combination unstable !**

  ☆ **challenge:**
  combine cheap mass components to powerfull system



Conclusion

- **LHC is the ultimate machine for HIC**
  - ➩ very significant step beyond RHIC
  - ➩ excellent conditions for experiment & theory (QCD)
  - ➩ not only latest, but possibly last at energy frontier
    - ☆ only ≈ logarithmic rise in energy density after LHC ?

- **ALICE is powerful next generation detector**
  - ➩ many evolutionary developments
    - ☆ (SDD, TPC, em cal, ...)
  - ➩ some big advances in technology
    - ☆ (electronics, DAQ, PID, pixels,...)

- **LHC HI expt. program good, but not ideal**
  - ➩ unlike BEVALAC/AGS/SPS/RHIC
    - ☆ regional, not yet global global effort !
  - ➩ intellectual input of 1/2 of community(US/Japan) missing
    - ☆ would limit the scientific output
    - ☆ hope that this limitation can be overcome