ALICE Experiment @LHC

(capabilities and status)

Grazyna Odyniec / LBNL

for the ALICE-USA Collaboration

Alice

Designed for the PbPb environment with <u>all</u> the capabilities of STAR and PHENIX

ALICE-USA Collaboration

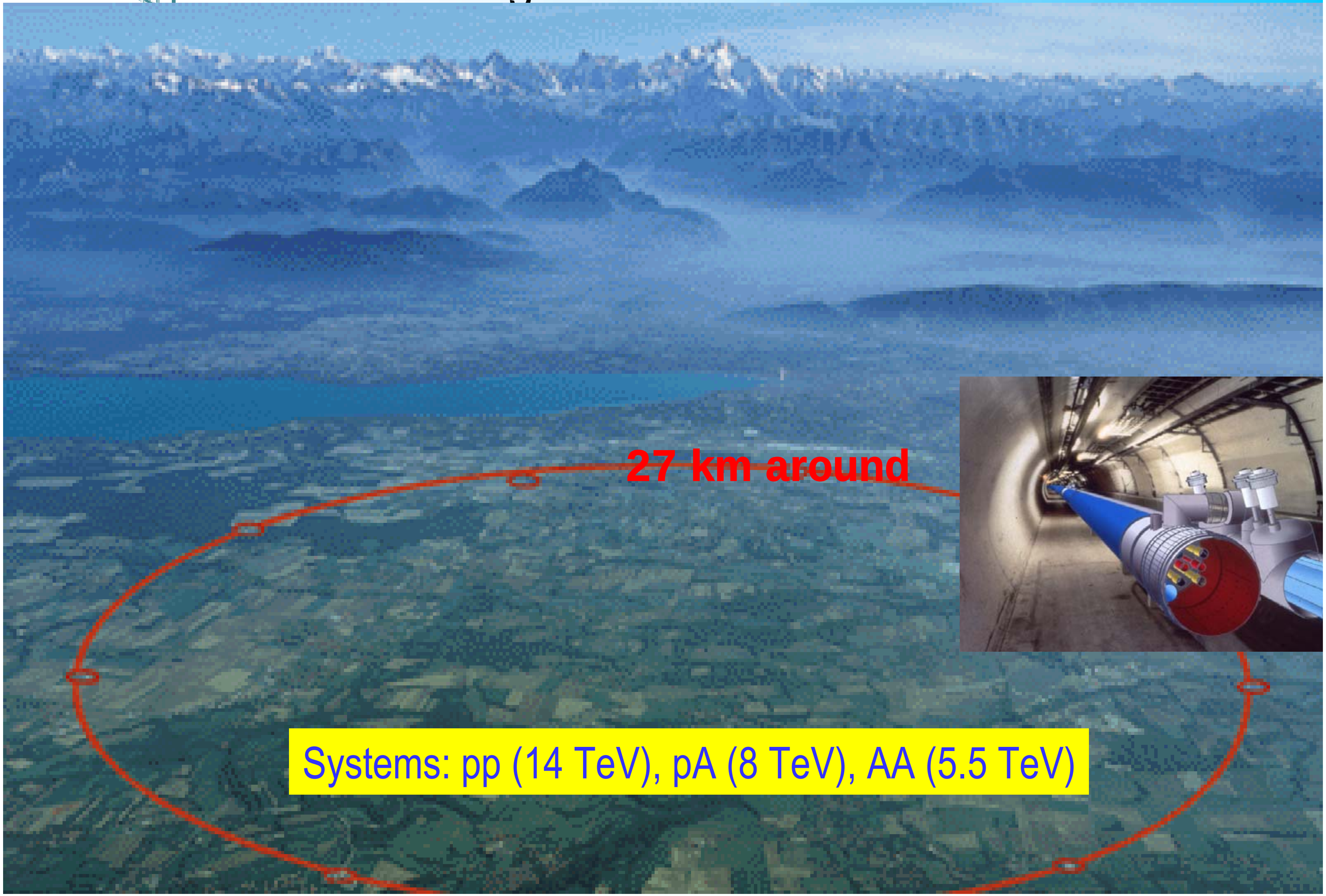
UC Davis
UCLA
Creighton U
U of Houston
Kent State U
LBNL
LLNL
MSU
ORNL
OSU
Purdue U
U of Tennessee
U of Washington
Wayne State U

Main focus:

high pt physics: jets, γ-jet, …

→ EMCal

Large Hadron Collider 2007/8



LHC on track

- LHC on track for start-up of pp operations in April 2007
- Pb-Pb scheduled for 2008
  - Each year several weeks of HI beams (10^6 s effective running time)
- Future includes other ion species and pA collisions.
  - LHC is equipped with two separate timing systems.

System	$\mathcal{L}_0$ [$cm^{-2}s^{-1}$]	$\sqrt{s_{NN\ max}}$ [TeV]	Δy
Pb+Pb	1 10^{27}	5.5	0
Ar+Ar	6 10^{28}	6.3	0
O+O	2 10^{29}	7.0	0
pPb	1 10^{30}	8.8	0.5
pp	1 10^{34}	14	0

First 5-6 years

2-3y	Pb-Pb	(highest energy density)
2y	Ar-Ar	(vary energy density)
1y	p-Pb	(nucl. pdf, ref. data)

At LHC

- LHC will accelerate and collide heavy ions at energies far exceeding the range of existing accelerators - energy jump by a factor of 28 !

- This is expected to result in:
  - A hotter and longer lived partonic phase
  - Increased cross sections and availability of new hard probes
  - New properties of initial state, saturation at mid-rapidity

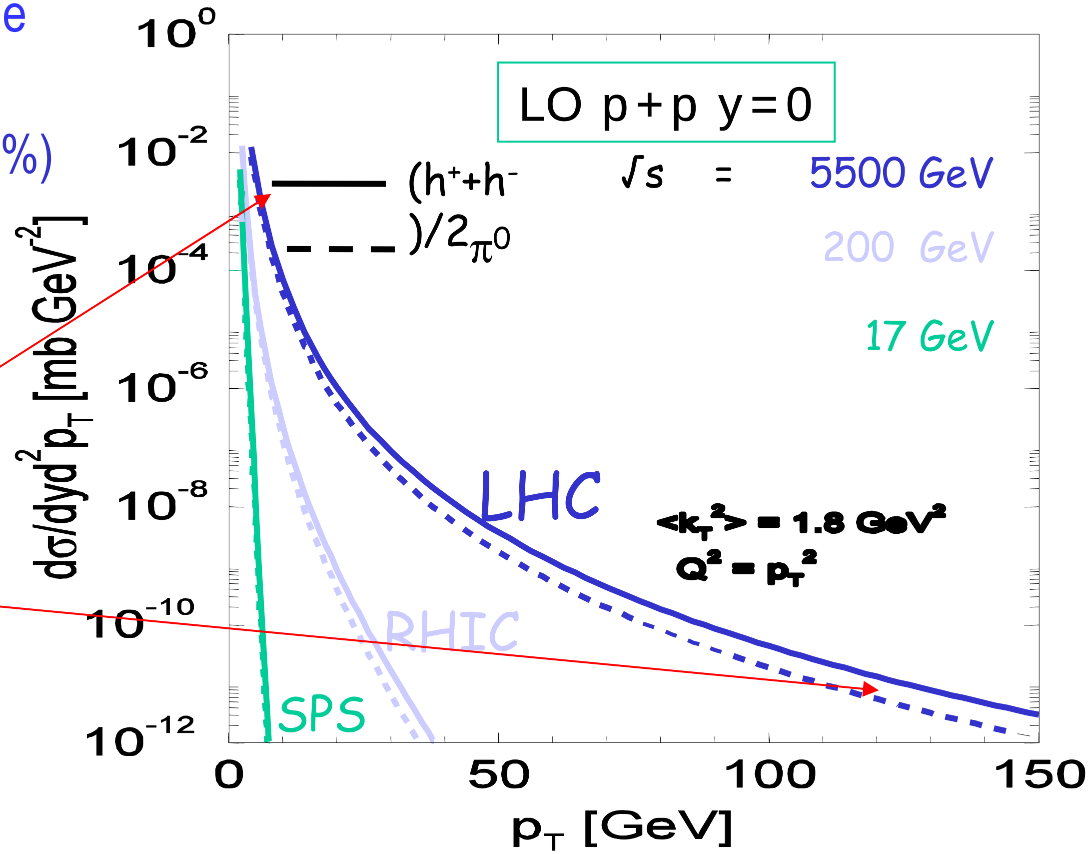
K.Kajantie, Nucl.Phys. A715 (2003) 432c:

"Qualitatively, in minimum-bias Pb+Pb (or Au+Au) collisions, SPS is 98% soft and 2% hard, RHIC is 50% soft and 50% hard and LHC is 2% soft and 98% hard" ⇒ each LHC HI min bias collision produces hadron of high p_t in the process involving perturbative scale Q >> LQCD"

New at LHC: dominance of hard processes

Initial hard processes dominate the total AA cross-section
($LHC: \sigma^{hard}/\sigma^{tot}$ = 98%, RHIC ~ 50%)

- Bulk properties dominated by hard processes;
- Very hard probes are abundantly produced.

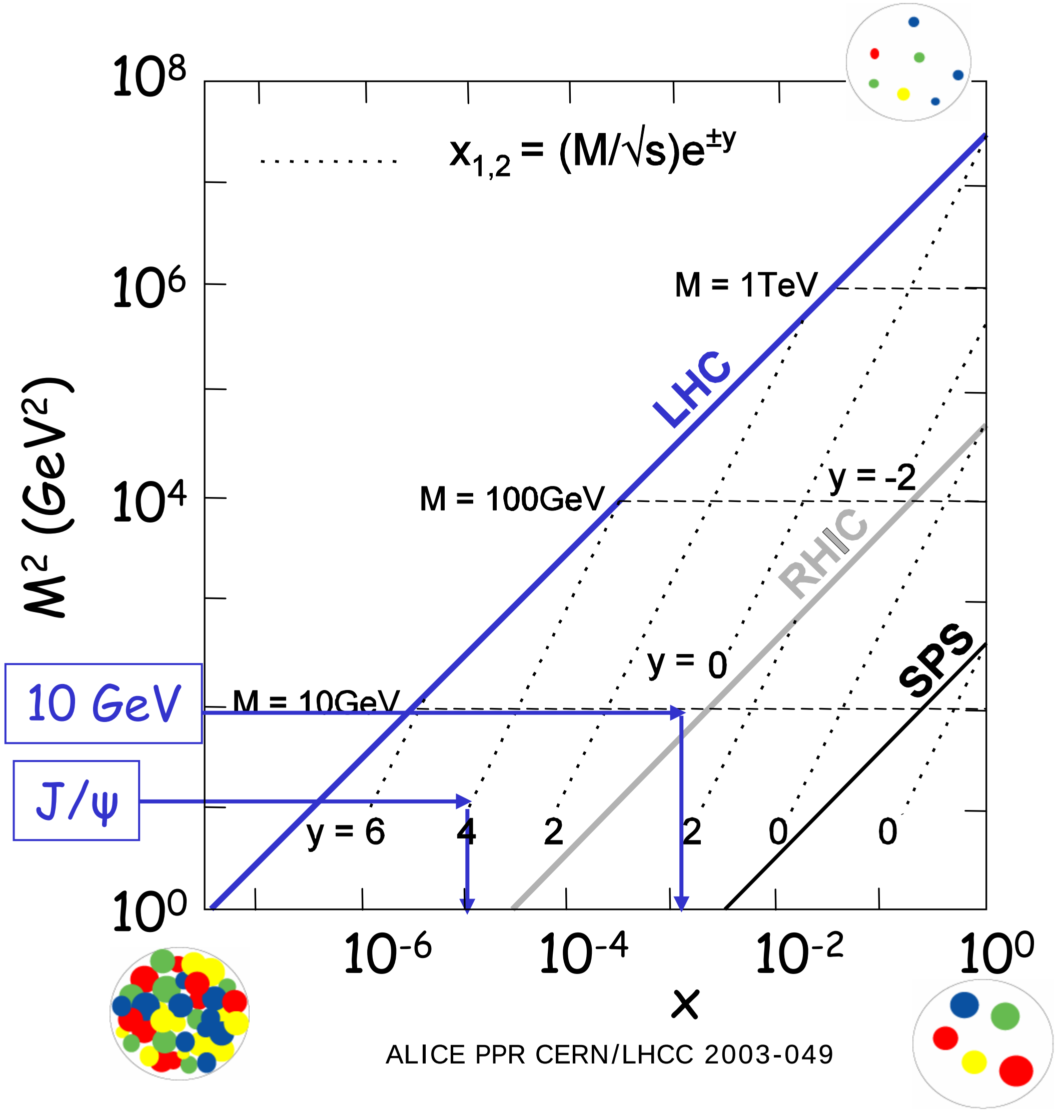


Happens at t=0 → probe matter at very early times (QGP ?)

Can be calculable by pQCD → predictions

Access to new region of x (x<<1):

- Probe initial partonic state in a novel Bjorken-x range (10^{-3}-10^{-5}):
  - nuclear shadowing,
  - high-density saturated gluon distribution.
- Larger saturation scale ($Q_S=0.2A^{1/6}\sqrt{s}$= 2.7 GeV): evolution (non-linear ?) of a saturated gluon distribution, which generates the bulk properties of the collision, measured at mid-rapidity.
- The QGP at LHC might evolve from a Color Glass Condensate in the initial state of the collision.



RHIC and LHC

Central collisions	SPS	RHIC	LHC
$s^{1/2}$(GeV)	17	200	5500
dN_{ch}/dy	500	650	3-8 x10^3
ε (GeV/fm^3)	2.5	3.5	15-40
V_f(fm^3)	10^3	7x10^3	2x10^4
τ_{QGP} (fm/c)	<1	1.5-4.0	4-10
τ_0 (fm/c)	~1	~0.5	<0.2

As compared to RHIC:

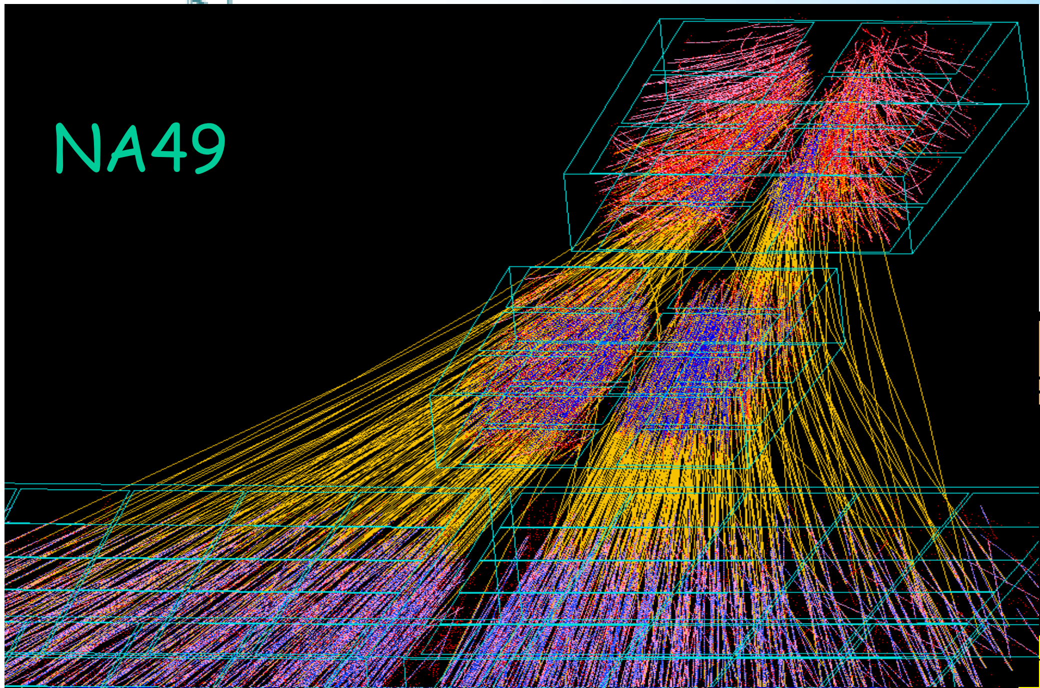
- Energy density higher ~x(4-10)
- Volume larger ~x3
- Life-time longer ~x2.5

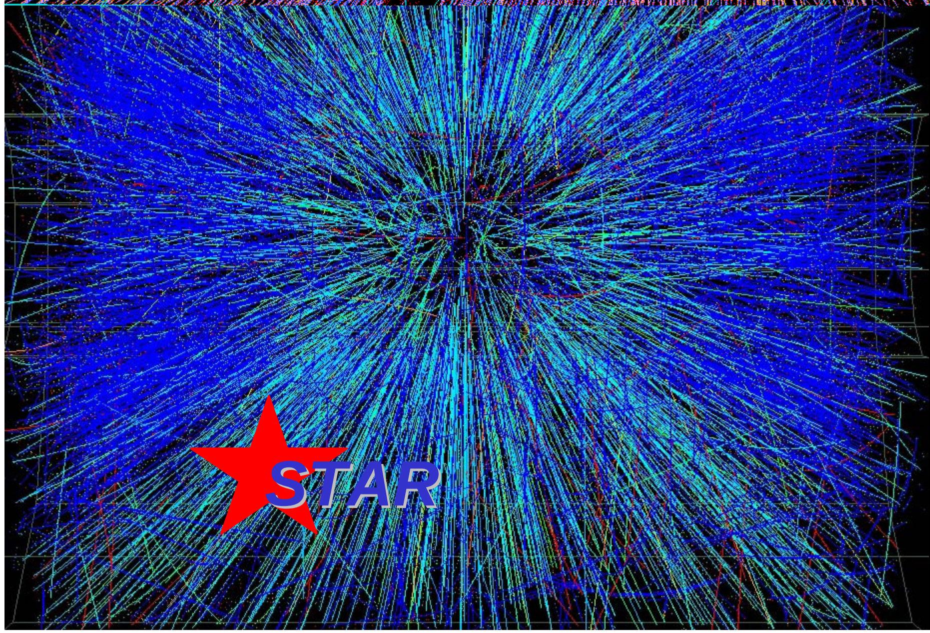
High rates for hard processes

(one year of running for -1<y<1):

- 5 10^{10} open charm pairs
- 2 10^9 open beauty pairs
- 1 10^9 jets (E_T>20 GeV)

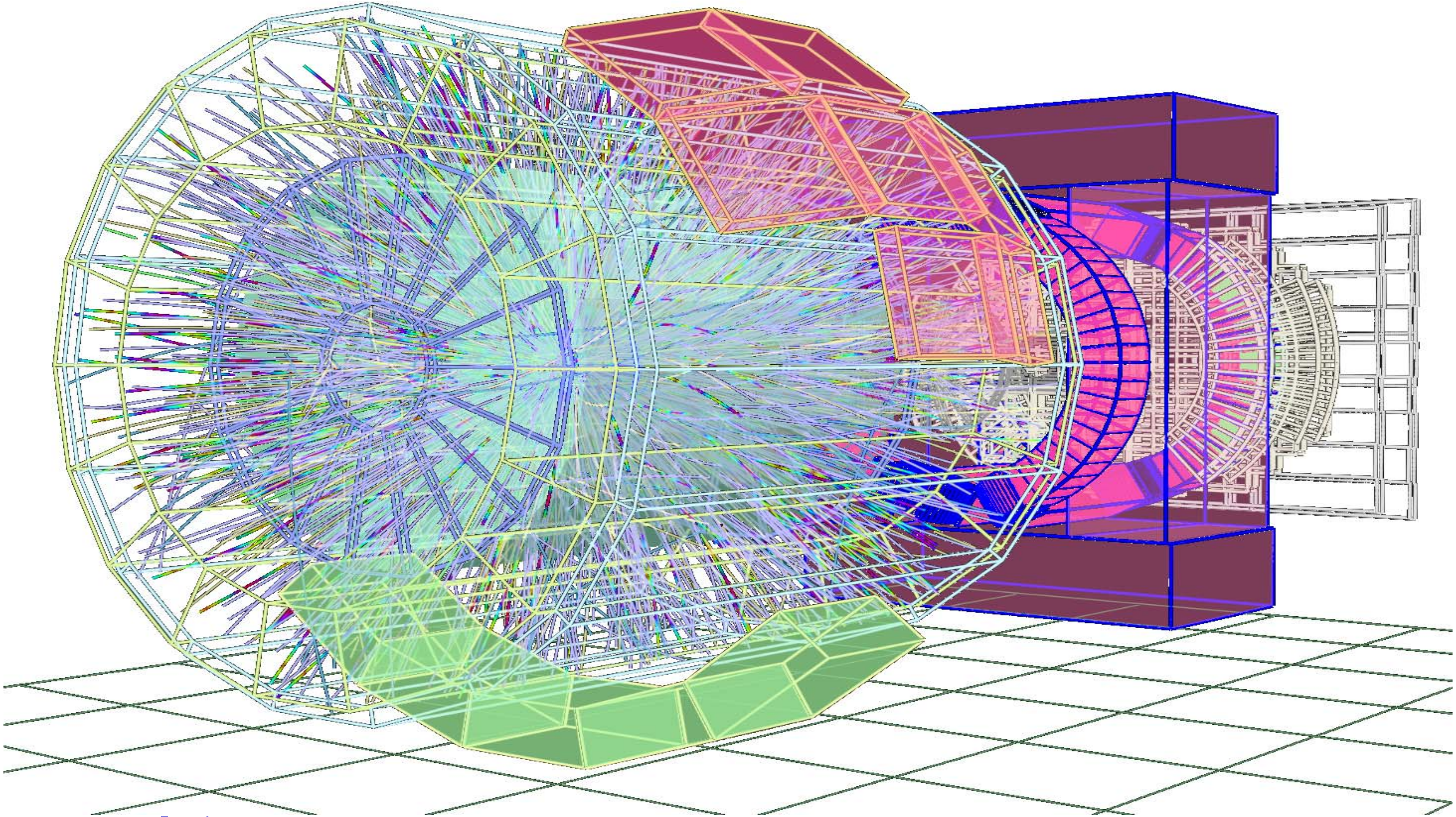
It is going to be a challenge !





ALICE 'worst case' scenario:

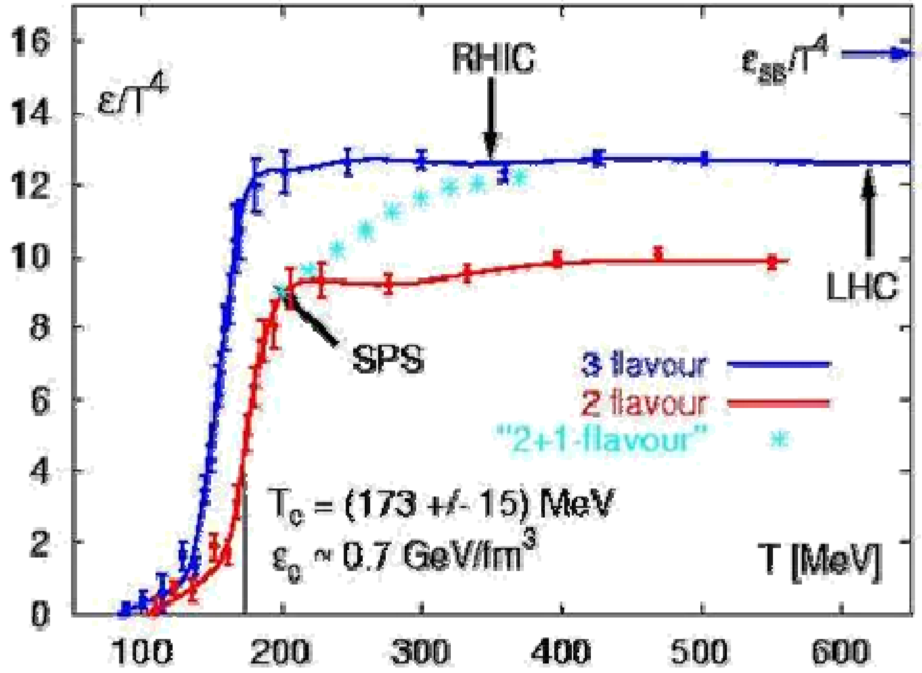
$dN/dy_{ch} = 8000$



Numerical predictions: Energy Density in Lattice QCD

with 2 and 3 light quarks and with 2 light and 1 heavy (strange) quark at μ_B=0

F.Karsh et al., Phys.Lett.B 478, 447 (2000)



not yet a Stefan-Boltzmann gas

LHC plasma ~ QCD plasma:

1. μ_B ~ = 0 at mid-rapidity

at LHC Δy=8.6 ! (RHIC = 5.3, SPS=2.9)

2. ε/T^4 continue to rise for T>T_c (2+1 flavor)

(significant non-perturbative effects in lattice formalism up to T~ 2x T_c)

μ_B ~ 0 and T~ 3-4 T_c (close to ideal conditions) makes comparison to theory reliable !

Predictions for the LHC ?

very, very difficult ….

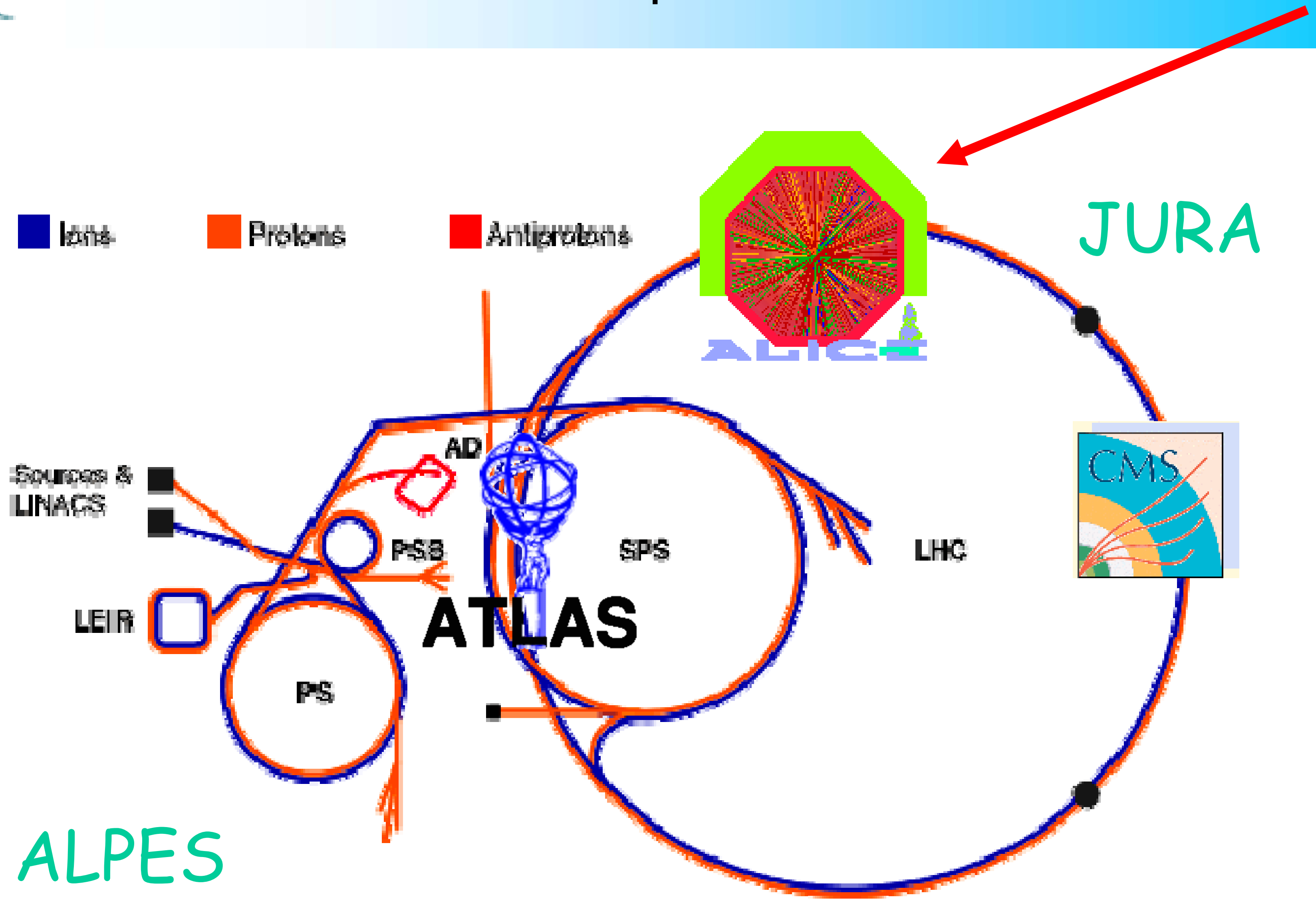
- Experience from the past:
  - Verified predictions: strangeness enhancement (SPS), jet quenching (RHIC);
  - Wrong predictions: large event by event fluctuations (SPS), particle density (RHIC);
  - Unexpected surprises: J/ψ suppression (SPS), large elliptic flow (RHIC).

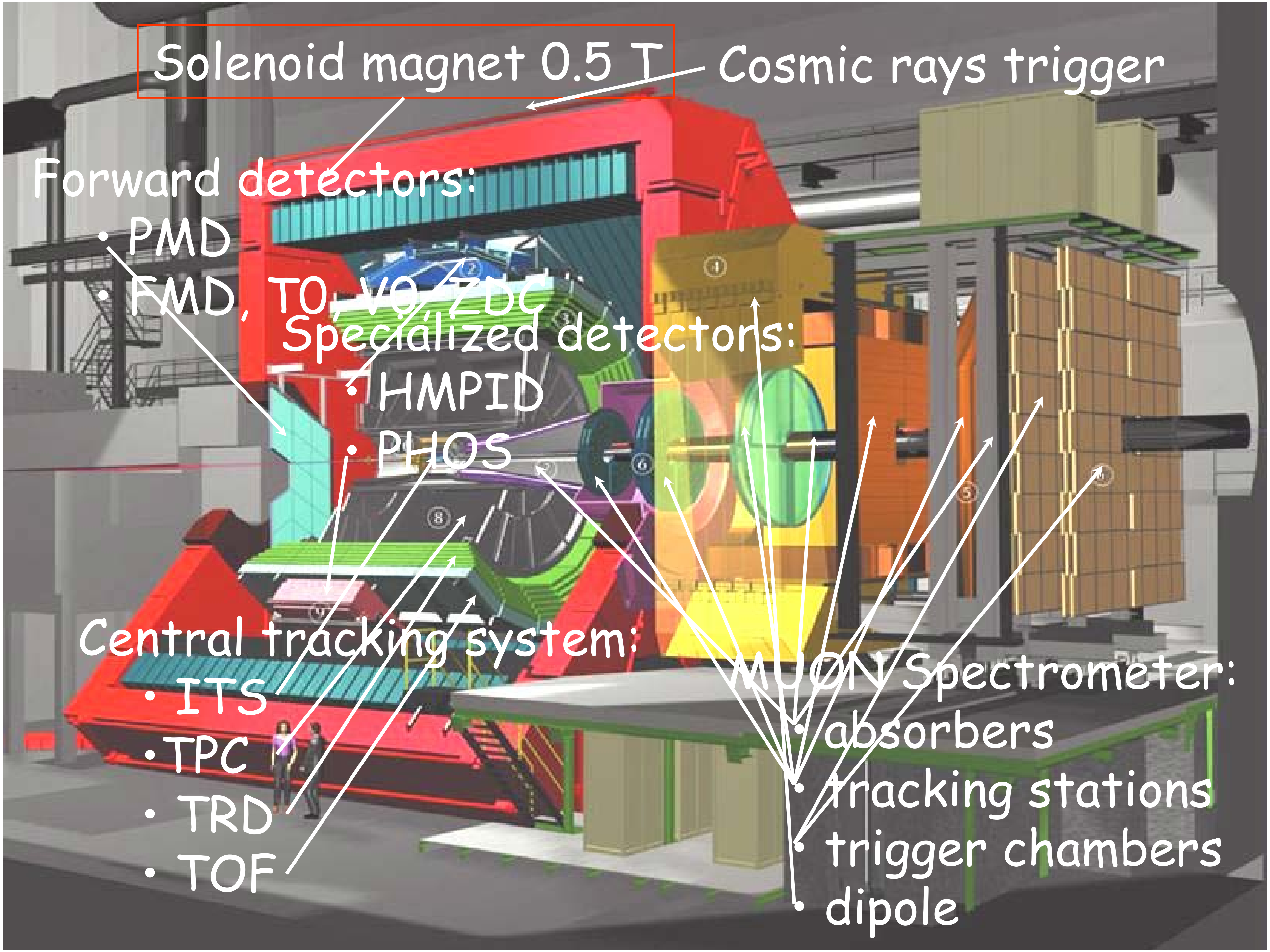
- Lesson for the future:

  while guided by theory and extrapolations be prepared for unexpected when making big steps in energy

SPS —×12→ RHIC —×28→ LHC

1+2 experiments




Solenoid magnet 0.5 T
Cosmic rays trigger
Forward detectors:
• PMD
• FMD, T0, V0, ZDC
Specialized detectors:
• HMPID
• PHOS
Central tracking system:
• ITS
• TPC
• TRD
• TOF
MUON Spectrometer:
• absorbers
• tracking stations
• trigger chambers
• dipole

ALICE Physics Program I

(has to cover in one experiment what at RHIC was covered by 4 !)

- Global observables:
  - multiplicities, η distributions
- Degrees of freedom as a function of T:
  - hadron ratios and spectra
  - dilepton continuum, direct photons
- Geometry of the emitting source:
  - HBT, impact parameter via zero-degree energy
- Early state manifestation of collective effects:
  - elliptic flow

ALICE Physics Program II

- Deconfinement:
  - charmonium and bottomium spectroscopy
- Energy loss of partons in quark gluon plasma:
  - jet quenching high pt spectra
  - open charm and open beauty
- Chiral symmetry restoration:
  - neutral to charged ratios
  - resonance decays
- Fluctuation phenomena - critical behavior:
  - event-by-event particle composition and spectra
- pp collisions in a new energy domain

Experimental Requirements

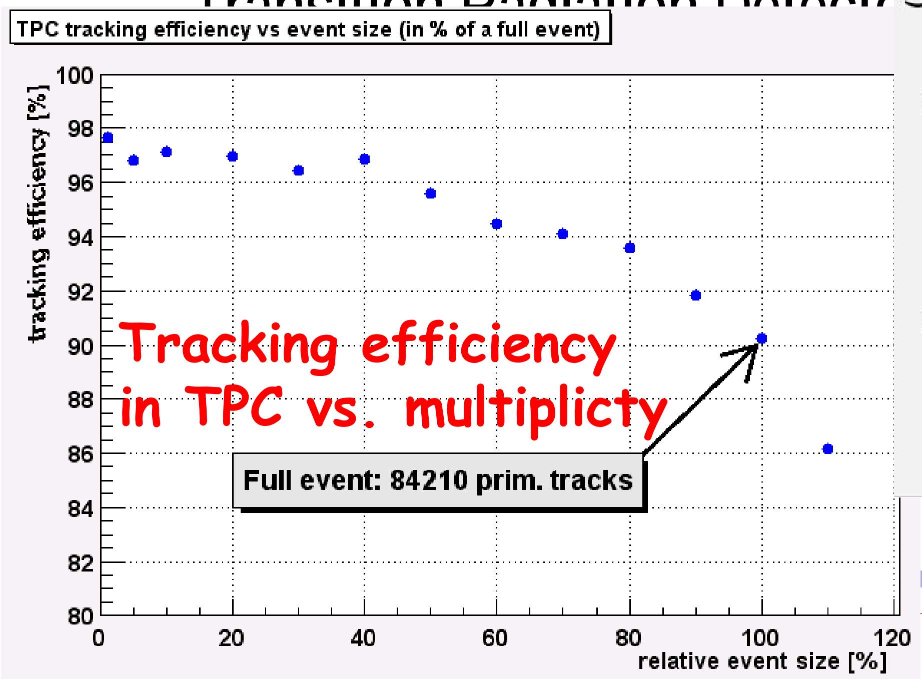
Challenge !

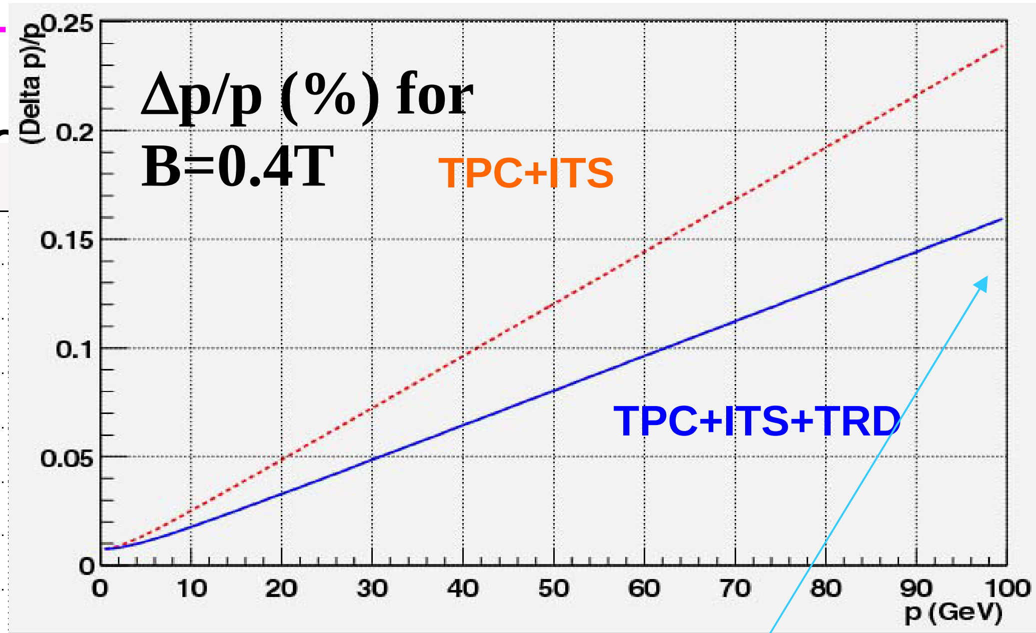
- ALICE must meet the challenge to measure flavor content and phase-space distribution event-by-event:
  - Most (2p * 1.8 units h) of the hadrons (dE/dx + ToF), leptons (dE/dx, transition radiation, magnetic analysis) and photons (high resolution EM calorimetry)
  - Track and identify from very low (< 100 MeV/c, soft processes) up to very high p_t (~100 GeV/c, hard processes)
  - Identify short lived particles (hyperons, D/B meson) through secondary vertex detection
  - Identify jets

how ALICE will do it ?

Excellent tracking

- robust, redundant tracking from 60 MeV to 100 GeV
  - long lever arm => very good momentum resolution
  - silicon vertex detector (ITS) 4 cm < r < 44 cm
    - stand-alone tracking at low p_t
  - Time Projection Chamber (T
  - Transition Radiation Detecto



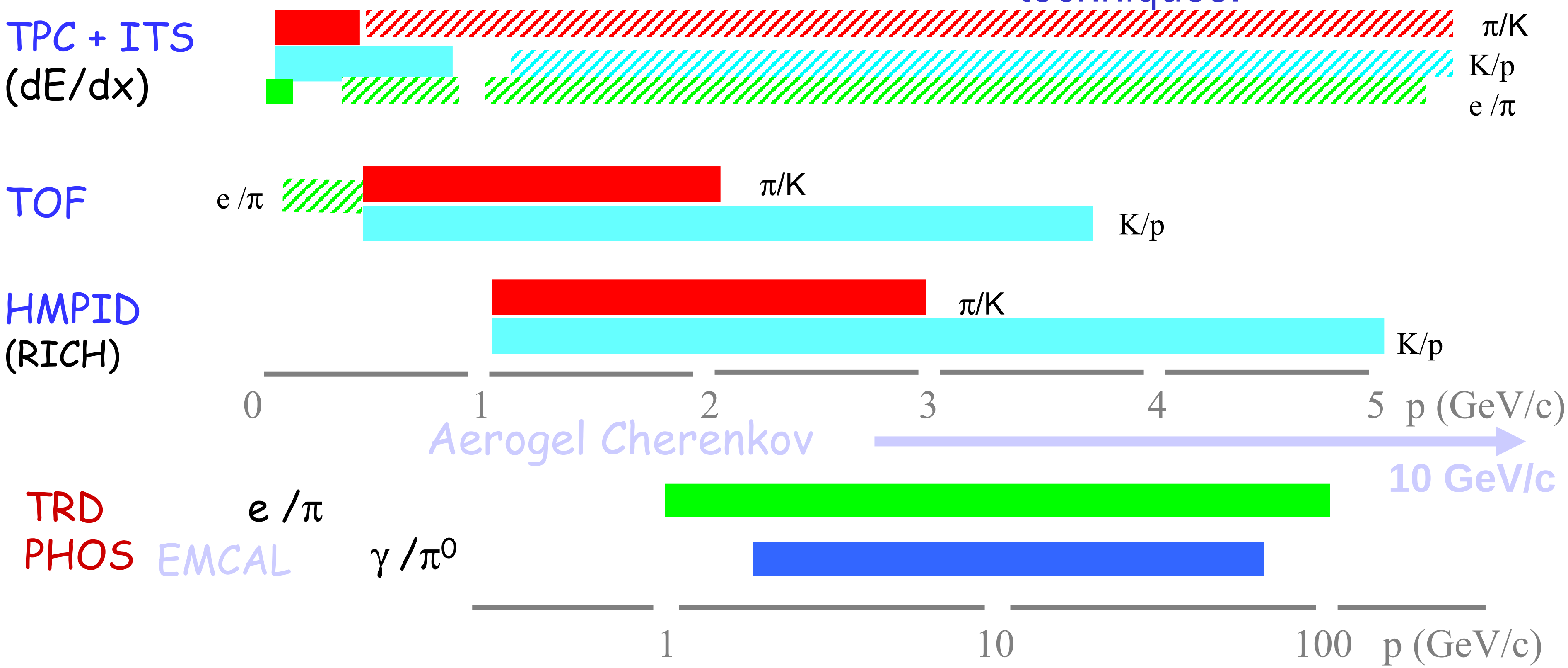


$\Delta p/p$ ~ 16% at 100 GeV

(~ 11% at $dN/d\eta$ = 2000)

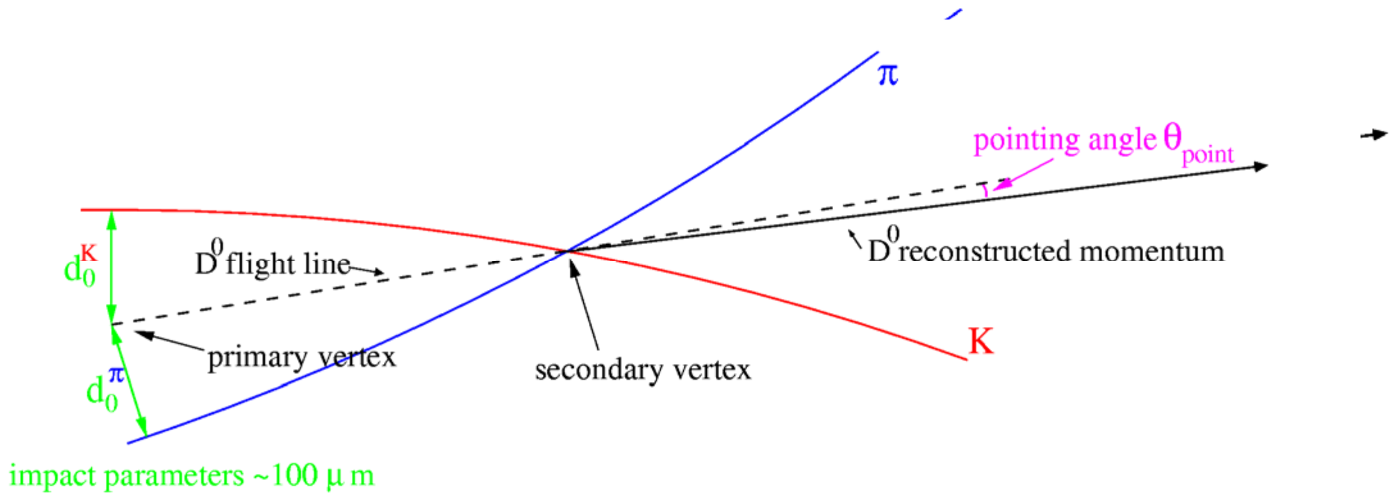
Broad range of PID

Alice uses ~all known techniques!



Vertexing e.g. exclusive charm in ALICE: $D^0 \rightarrow K^- \pi^+$

- Exclusive reconstruction → direct measurement of the p_t distribution → ideal tool to study R_{AA}
- Main selection: displaced-vertex selection
  - pair of opposite-charge tracks with large impact parameters
  - good pointing of reconstructed D^0 momentum to the primary vertex



→ Invariant mass analysis to "count" D^0

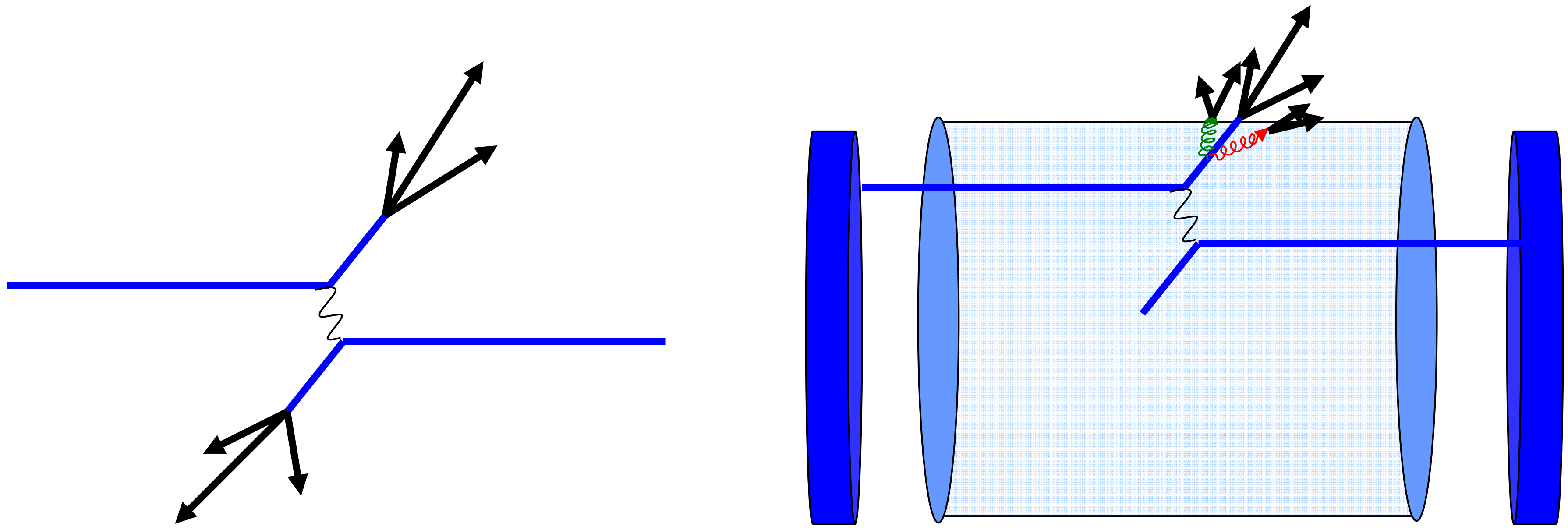
The ALICE program in 2007 onwards

σ^{PbPb} = 8barn; $L^{PbPb} = 10^{27} cm^{-2} s^{-1}$; t_0=04/2007 now !

- The first 15 minutes; $L_{int} = 1 \mu b^{-1}$
  - Event multiplicity, low p_t hadronic spectra, particle ratios
- The first month; $L_{int} = 0.1\text{-}1 nb^{-1}$
  - Rare high p_t processes: jets, D,B, quarkonia, photons, electrons
- The following years:
  - pA, A scan, E scan

ALICE-USA special focus: jets !

- Partons traversing a colored dense medium undergo energy and direction degradation characteristic of the medium through gluon radiation
- The degradation is reflected through the hadronisation process
- Materialize in detectors as jets of hadrons spatially localized in a narrow cone



Jet Phase Space

Jet physics will dominate the LHC heavy-ion program, ALICE will be the main contender in the race for jet quenching

0 1 2 10 100

$T=\Lambda_{QCD}$ Q_s p_t (GeV/c)

Mini-jets 100/event 1/event 100K/year

Bulk properties

Hard processes
Modified by the medium

ALICE Tracking & PID

Jets from Correlations and Leading Particles

Reconstructed Jets

how ?

Best signature of jet quenching: longitudinal and transverse (with respect to jet axis) distribution of individual hadrons :

- kinematic study:

  from unquenched to quenched jet by varying collision centrality from low/moderate p_T (quenching dominates) to highest p_T (quenching insignificant)

- path length dependence:

  e-by-e flow study

- specifics of fragmentation function:

  particle ratios ($\overline{\Lambda}/\Lambda$, $\overline{p}/p$,..) at high p_T [dE/dx(g)~ 2 dE/dx(q)]

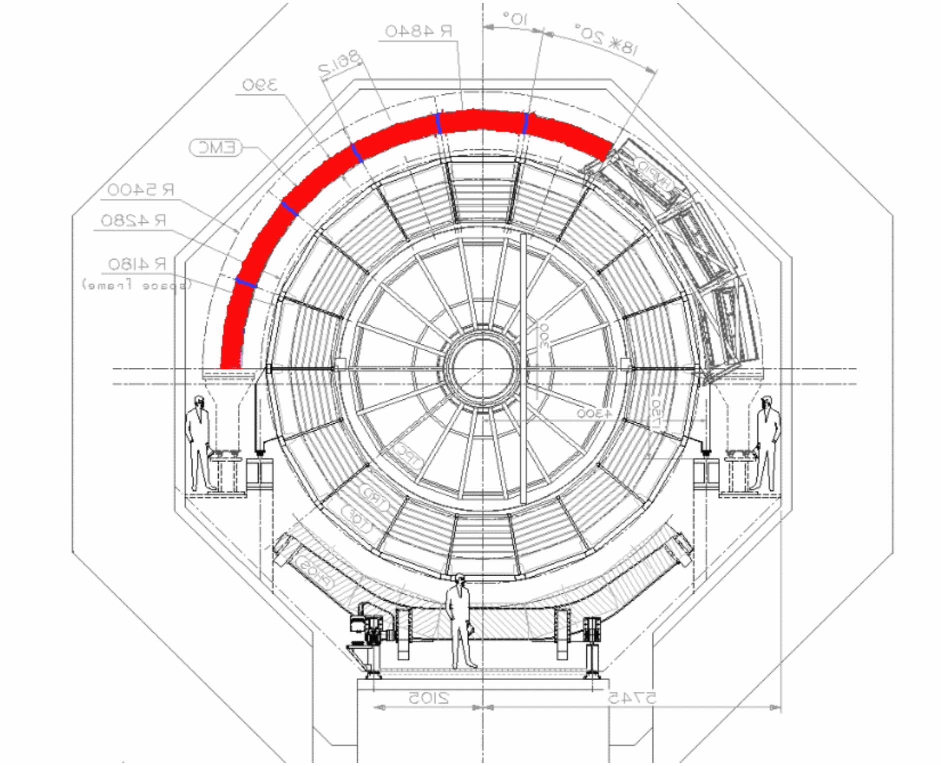
  modifications of heavy quark fragmentation function

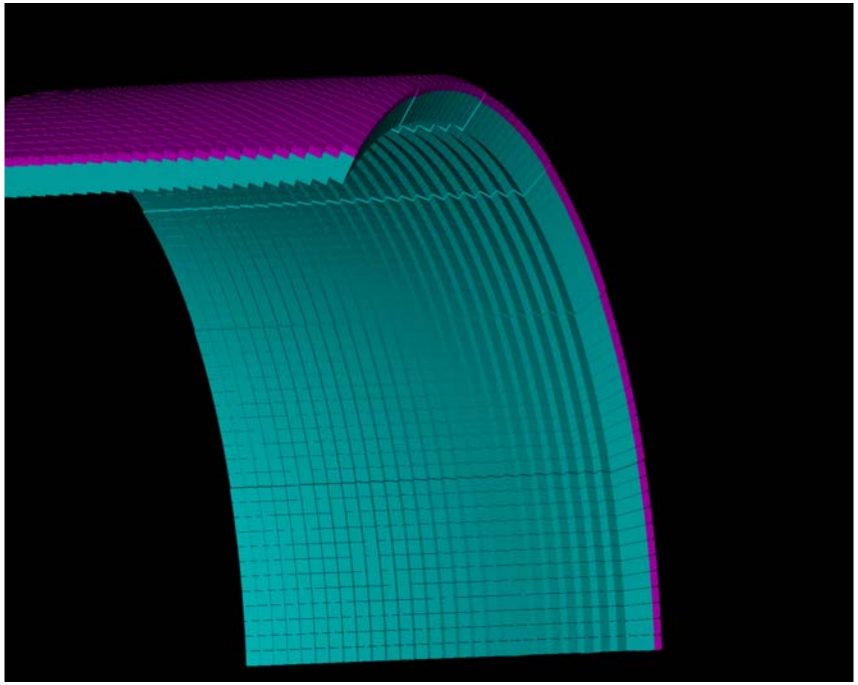
ALICE-USA building EMCal

Pb-scintillator sampling calorimeter

- $-0.7 < \eta < 0.7$
- $\Delta\phi = 120$ degrees

Energy resolution ~15%/√E





12 super-modules
13824 projective towers
tower: $\delta\eta \times \delta\phi \sim 0.014 \times 0.014$

EMCal :
- trigger (p_t sensitive) enhancing ALICE jet yields by factor of ~200 (!)
- jet composition PID - γ, $\pi 0$, e
- total jet energy (including neutral)
- γ-jet studies

Why an EMCal for ALICE (on one slide)?

CMS and ATLAS have world-class calorimetry with very broad kinematic coverage: what can ALICE add to jet physics in heavy ion collisions at the LHC?

Essential jet measurements: modification of fragmentation in dense matter + response of the medium to the jet

⇒ cross-sections are huge: rate not a primary issue
⇒ hermeticity not important in heavy ions
⇒ calorimetry insufficient: physics lies in detailed changes of fragmentation patterns and correlations, including low p_T

Requirements for jet measurements in heavy ions:

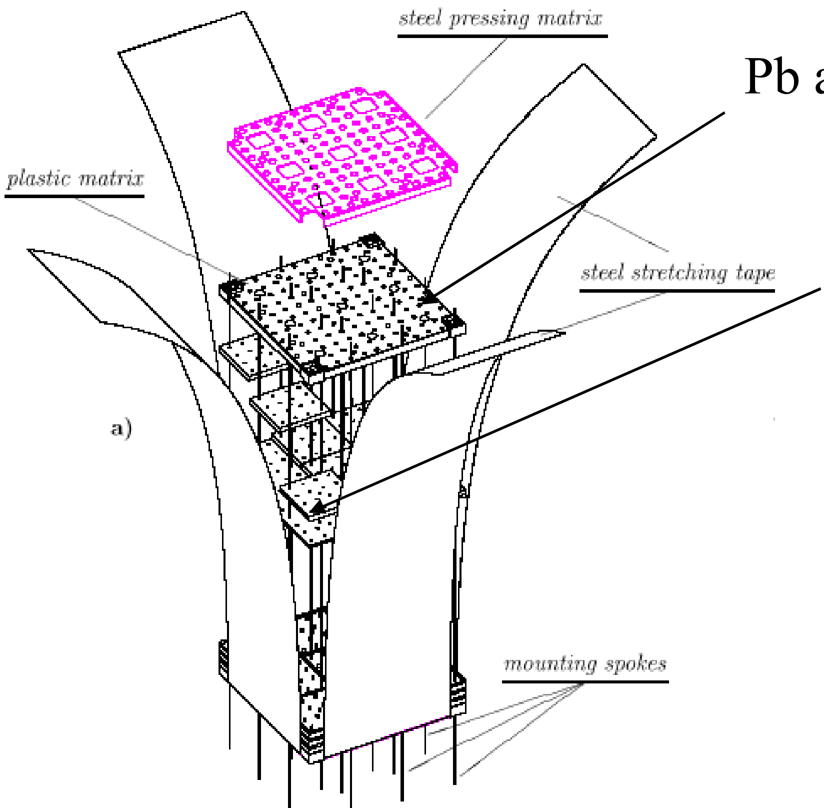
⇒ precise tracking over very broad kinematic range (TPC+ITS)
⇒ PID over broad kinematic range
⇒ detailed correlations of soft and hard physics
⇒ jet trigger (EMCAL)

ALICE+EMCal bring unique capabilities to LHC heavy ion program

Tower/module structure: "shashlik" design

Trapezoidal module: transverse size varies in depth from 63x63 to 63x67 mm^2

78 layers of 1.6 mm scint/1.6 mm Pb
Moliere radius ~ 2 cm



Pb absorber has dimensions of module

Towers defined by smaller optically isolated scinitillator tiles

Total Pb depth = 124 mm = 22.1 X0

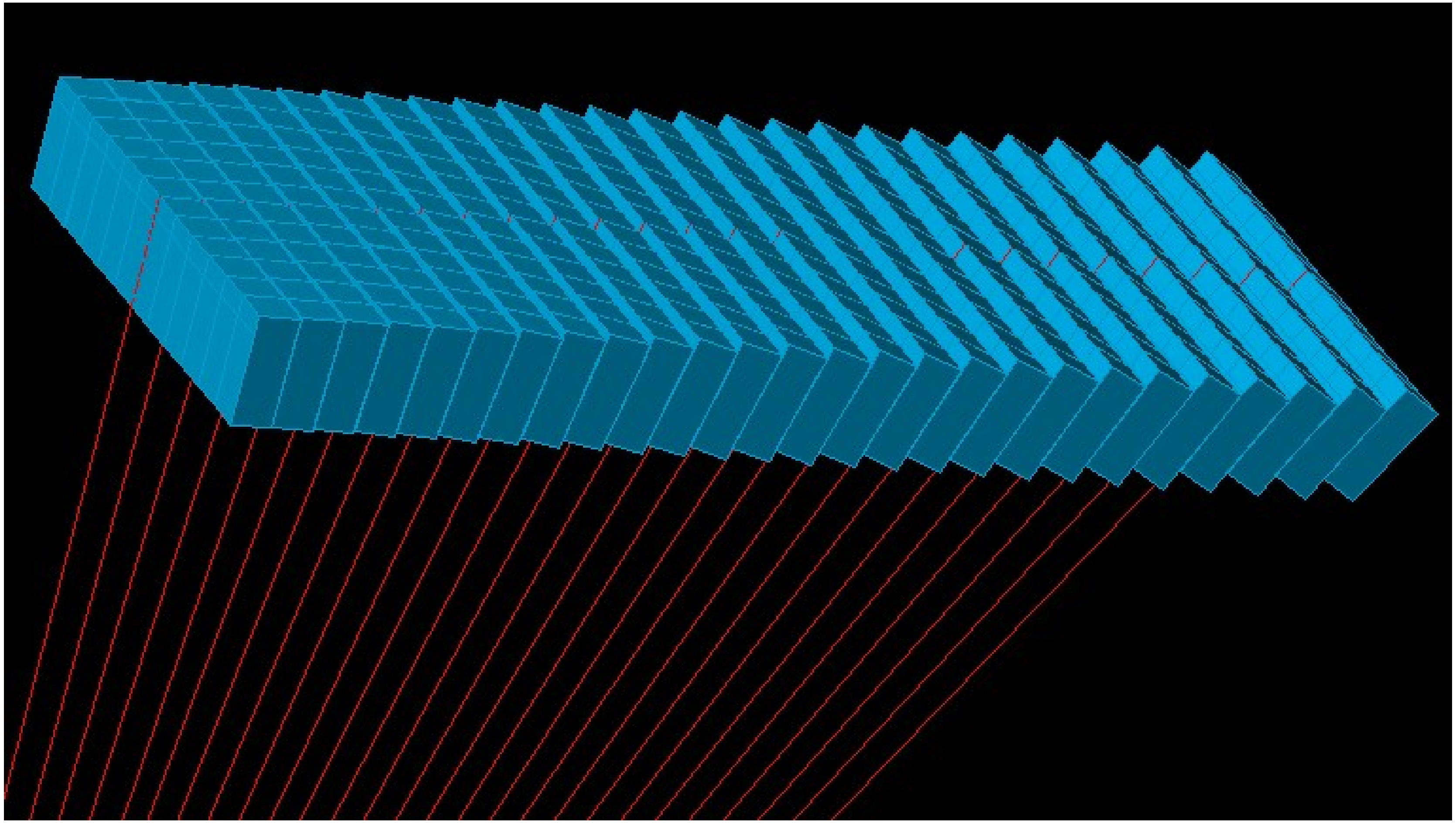
Comparisons:

PHOS = 180 mm/8.9 mm = 20.2 X0
ATLAS LiqAr/Pb = 25 X0
CMS PbWO = 25 X0

Supermodules

12 super modules, each has 1152 towers projective in η

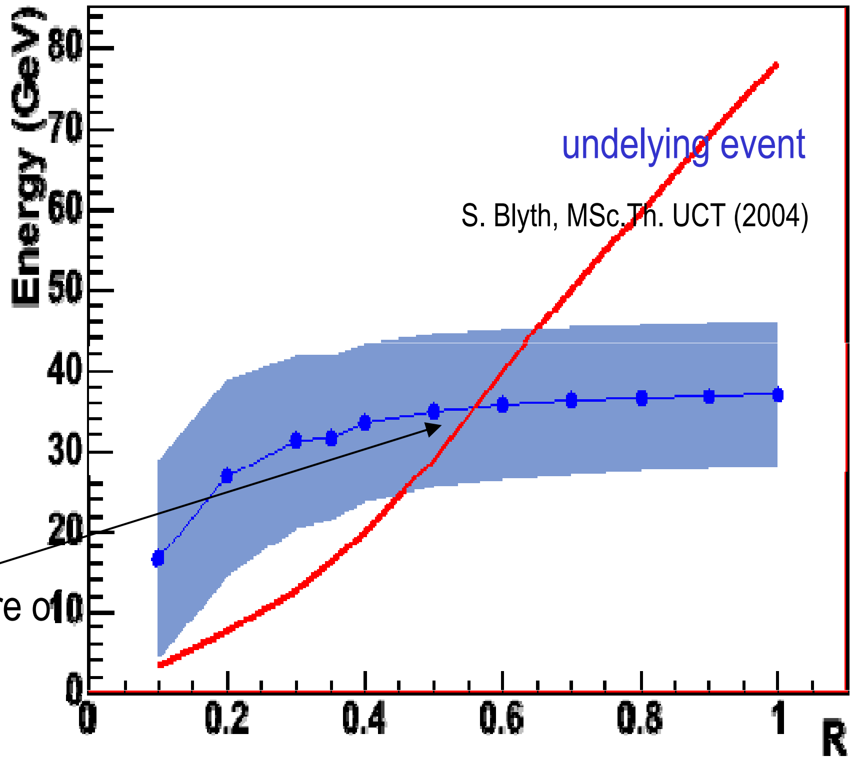
$0.0 < |\eta| < 0.7$, $\Delta\phi = 20^{o}$



Jet reconstruction in Alice

- JetFinder algorithm (S.Blyth MSc) developed (submitted to NIM)

  TPC+EMCal info

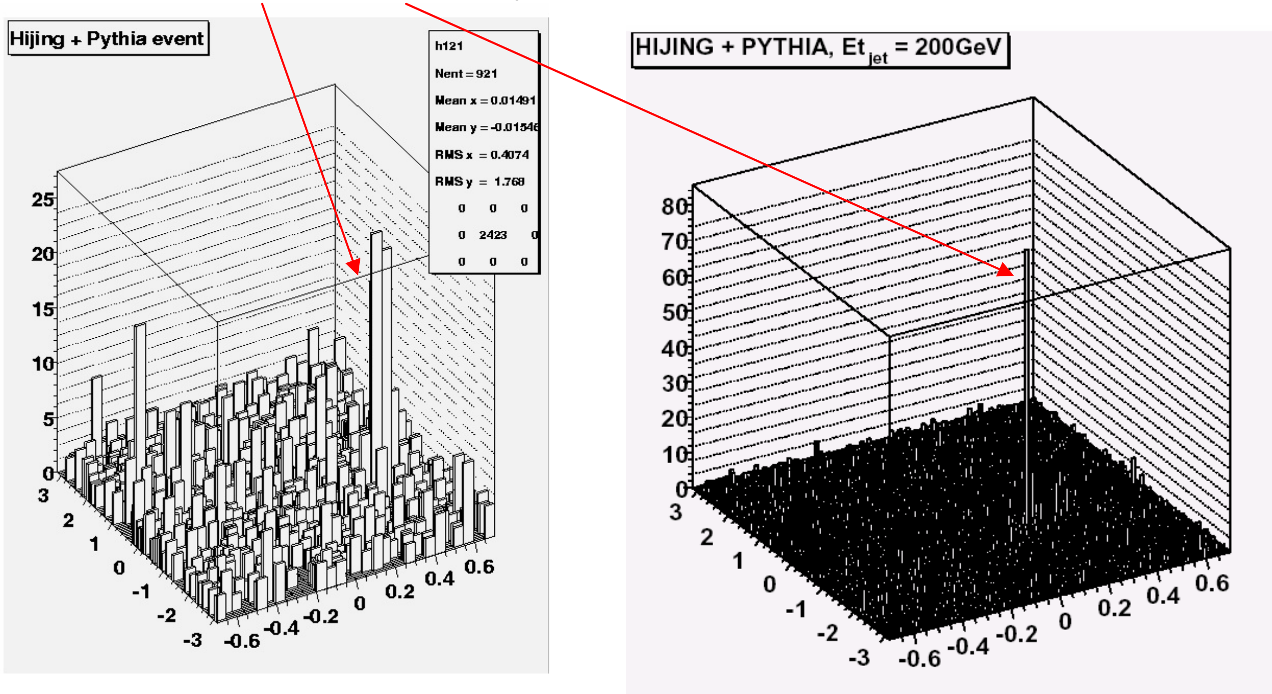


Main problem – fluctuations of underlying event (background fluctuations)

must avoid case where fluctuations in background are of the same order as signal…

Measurements: Jets in Pb+Pb events at LHC

100 and 200 GeV jets in central PbPb event

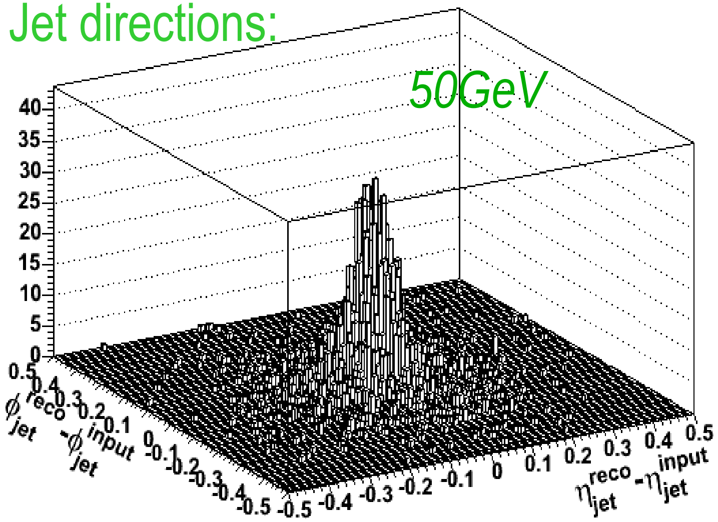


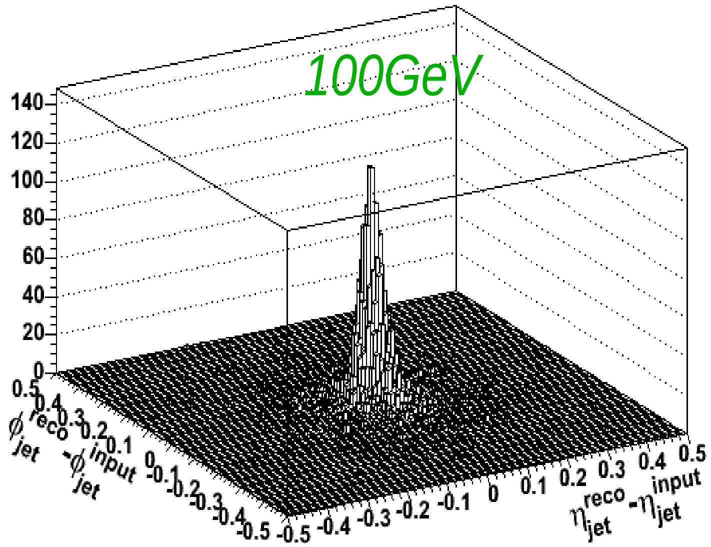
At higher p_t, jets are identifiable as distinct objects above the Pb+Pb background

Is there a measurable jet energy loss ?

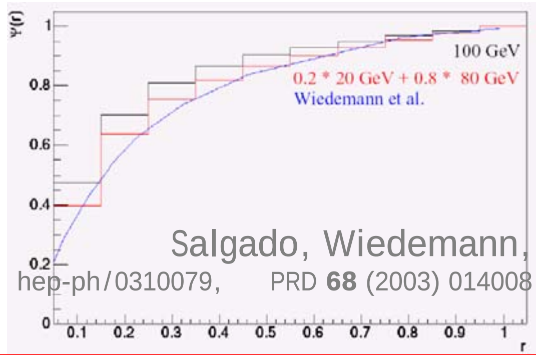
Reconstructed jet energy loss

Jet directions:

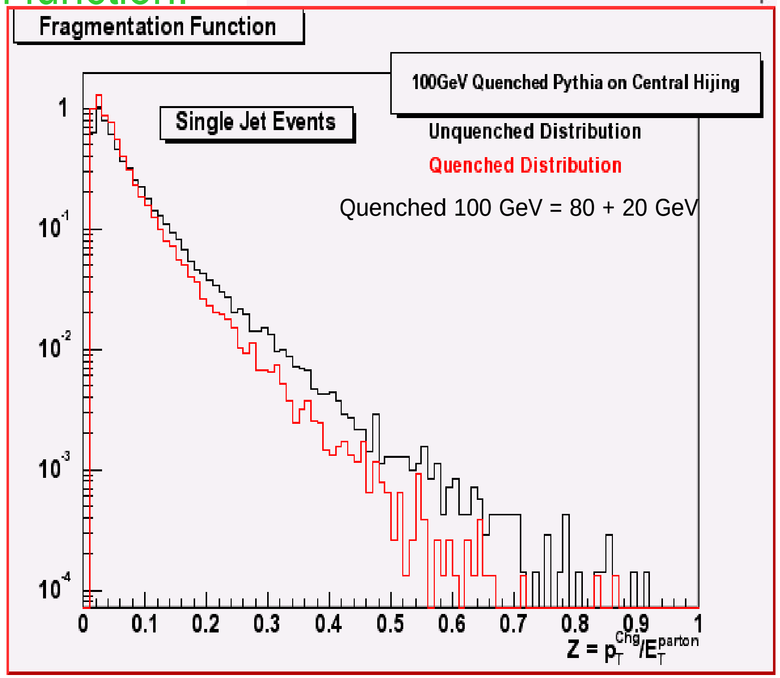


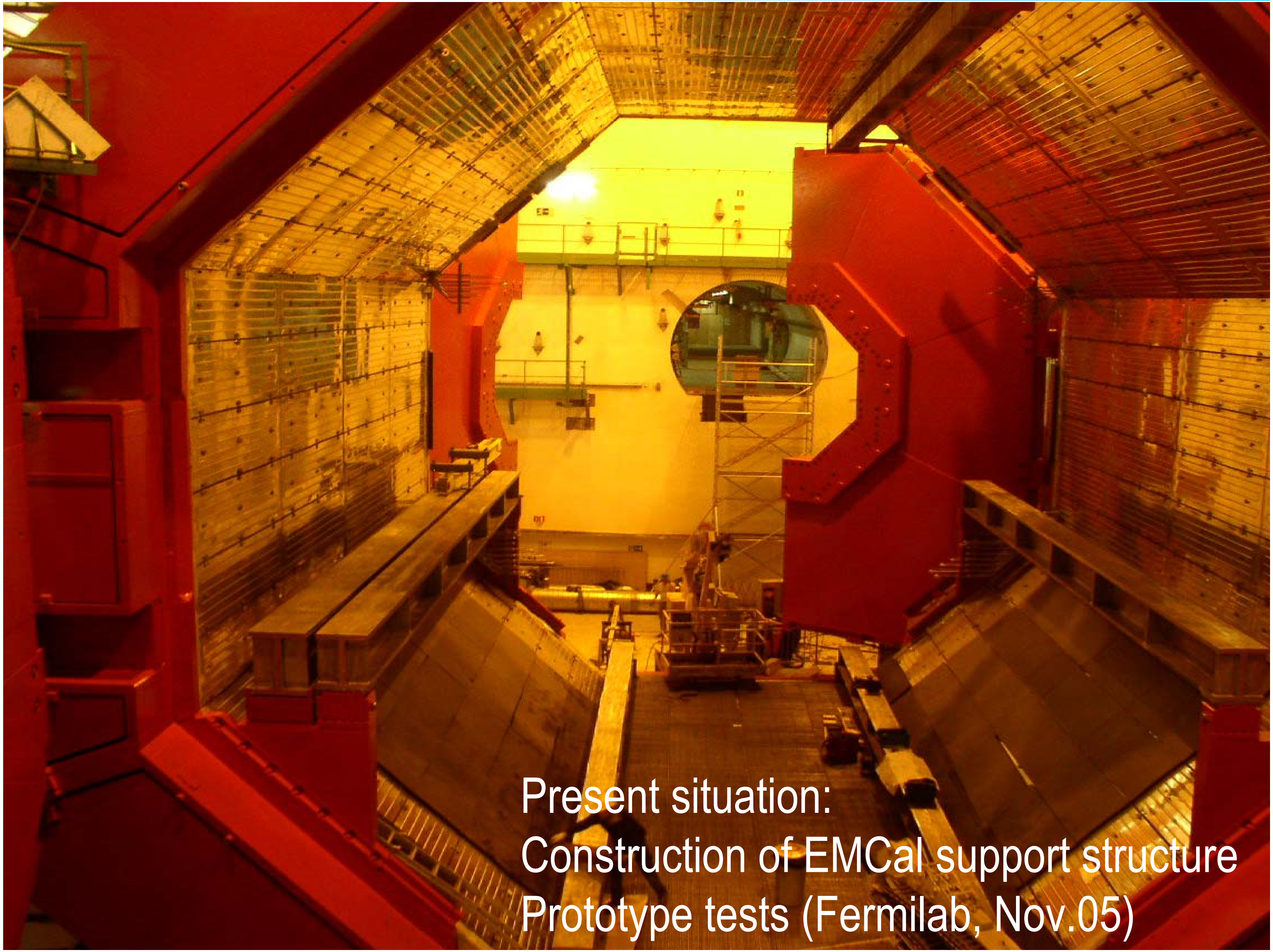


Excellent accuracy!



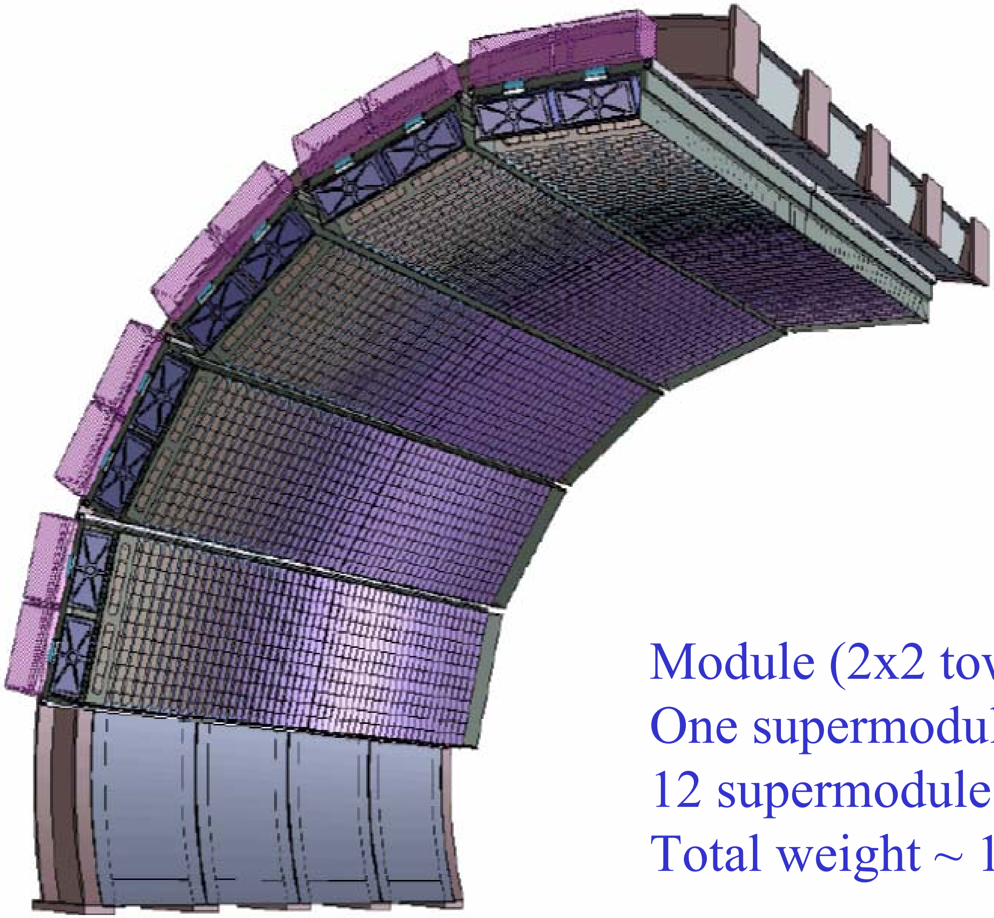
Jet fragmentation function:




Present situation:
Construction of EMCal support structure
Prototype tests (Fermilab, Nov.05)

Support structure

(critical path item)

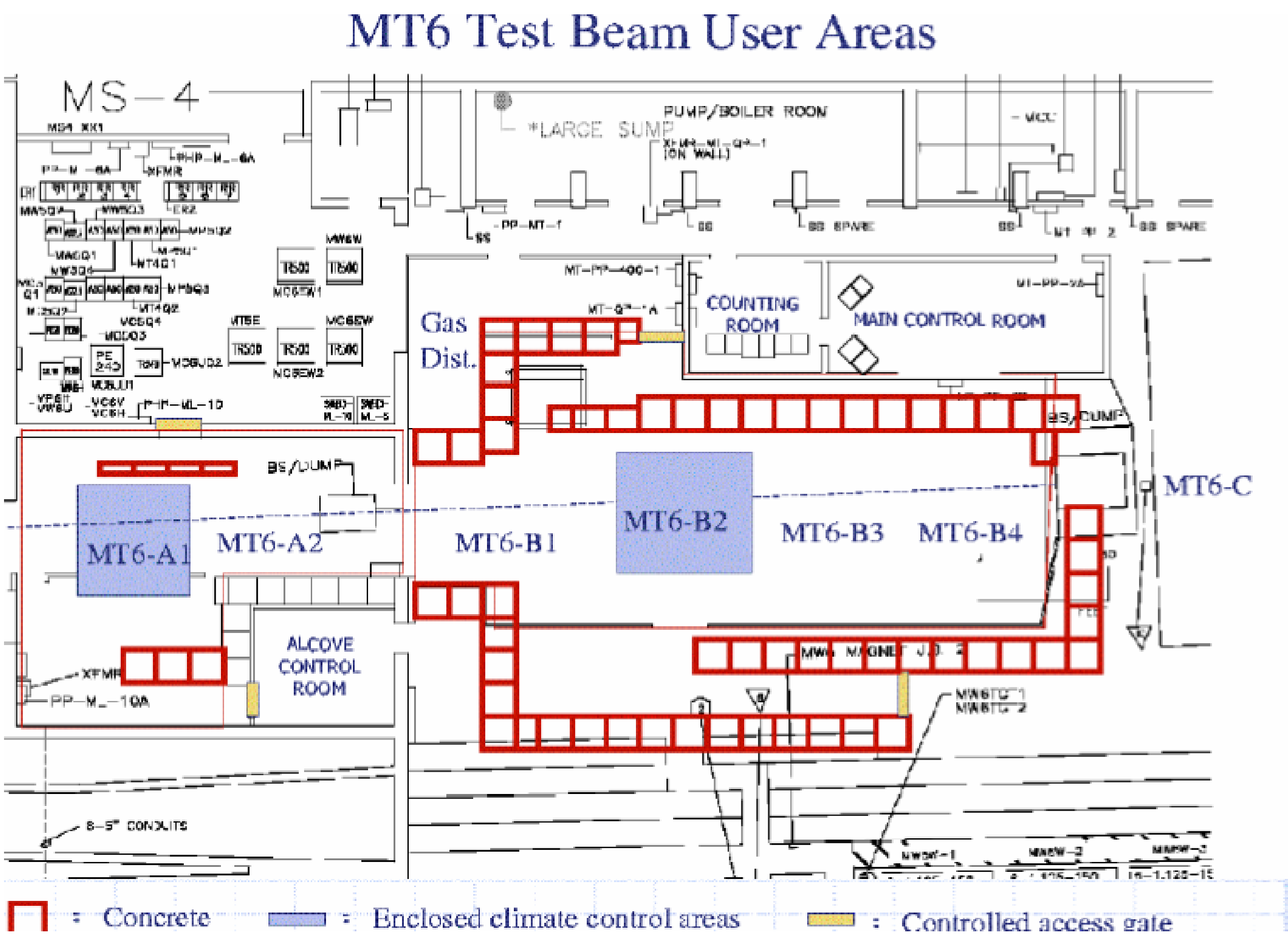


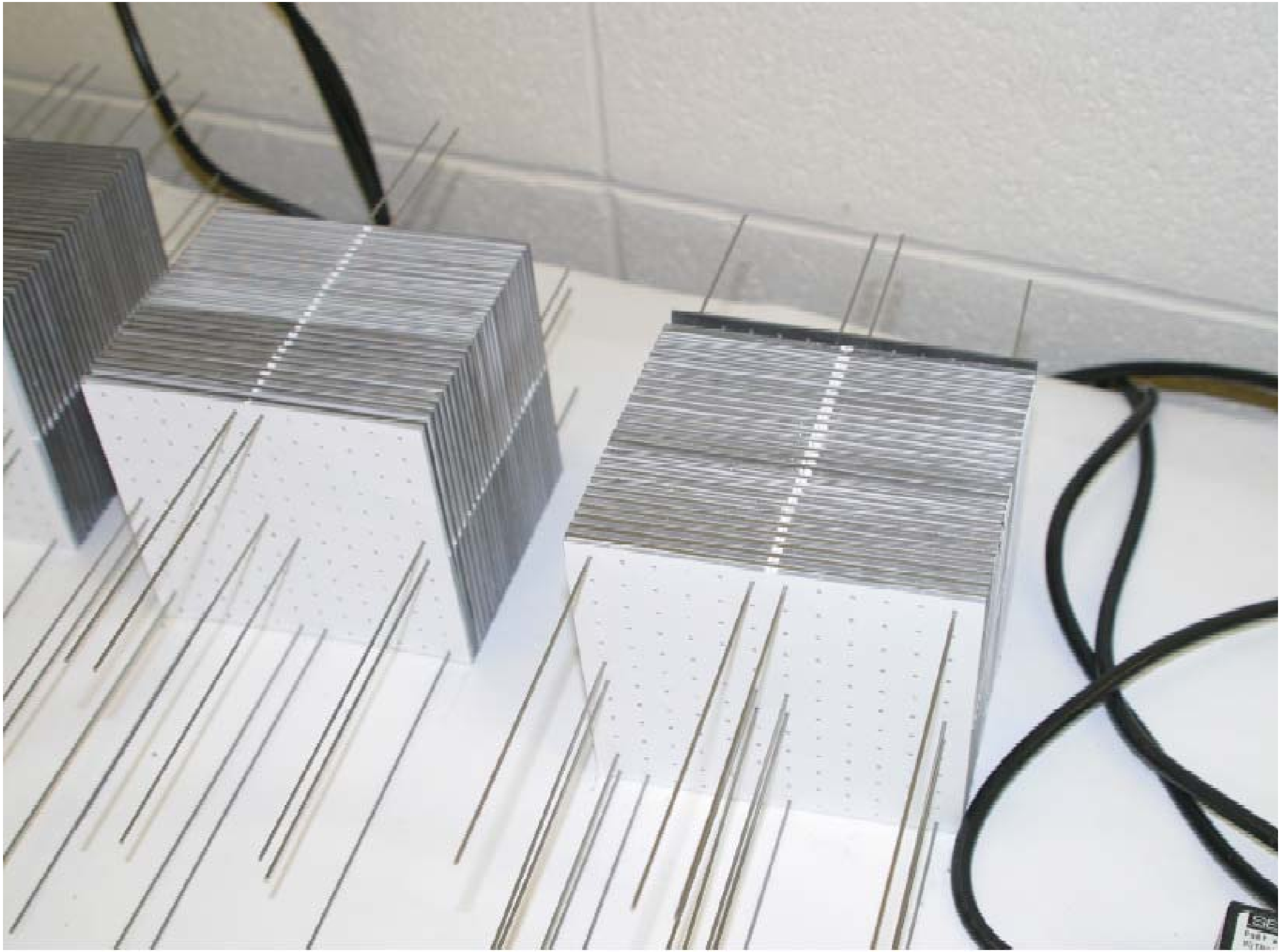
Module (2x2 towers)= 35 kg
One supermodule ~ 300 modules ~ 11 tons
12 supermodules
Total weight ~ 130 tons

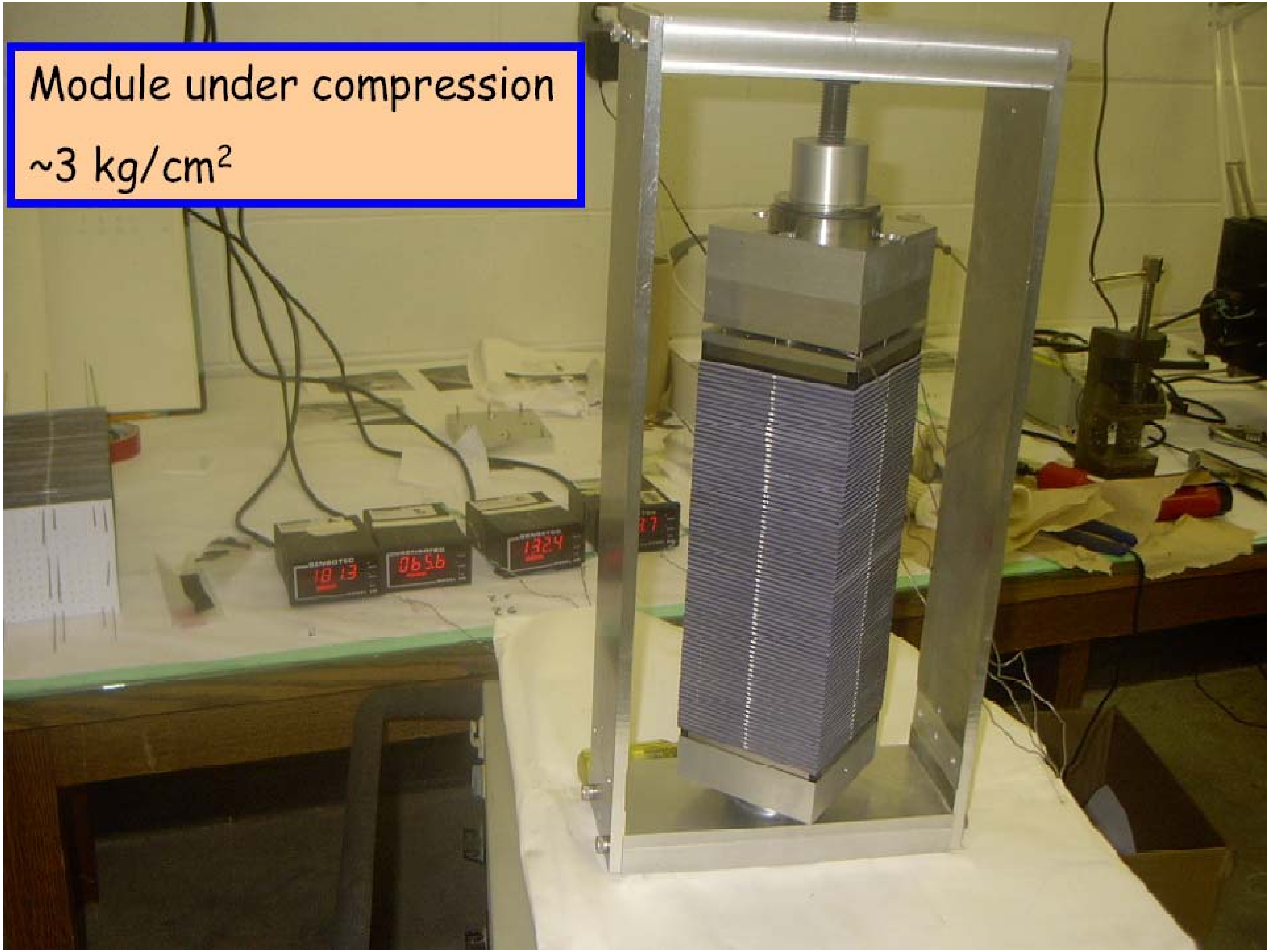
Test Beam @ FermiLab – November 05

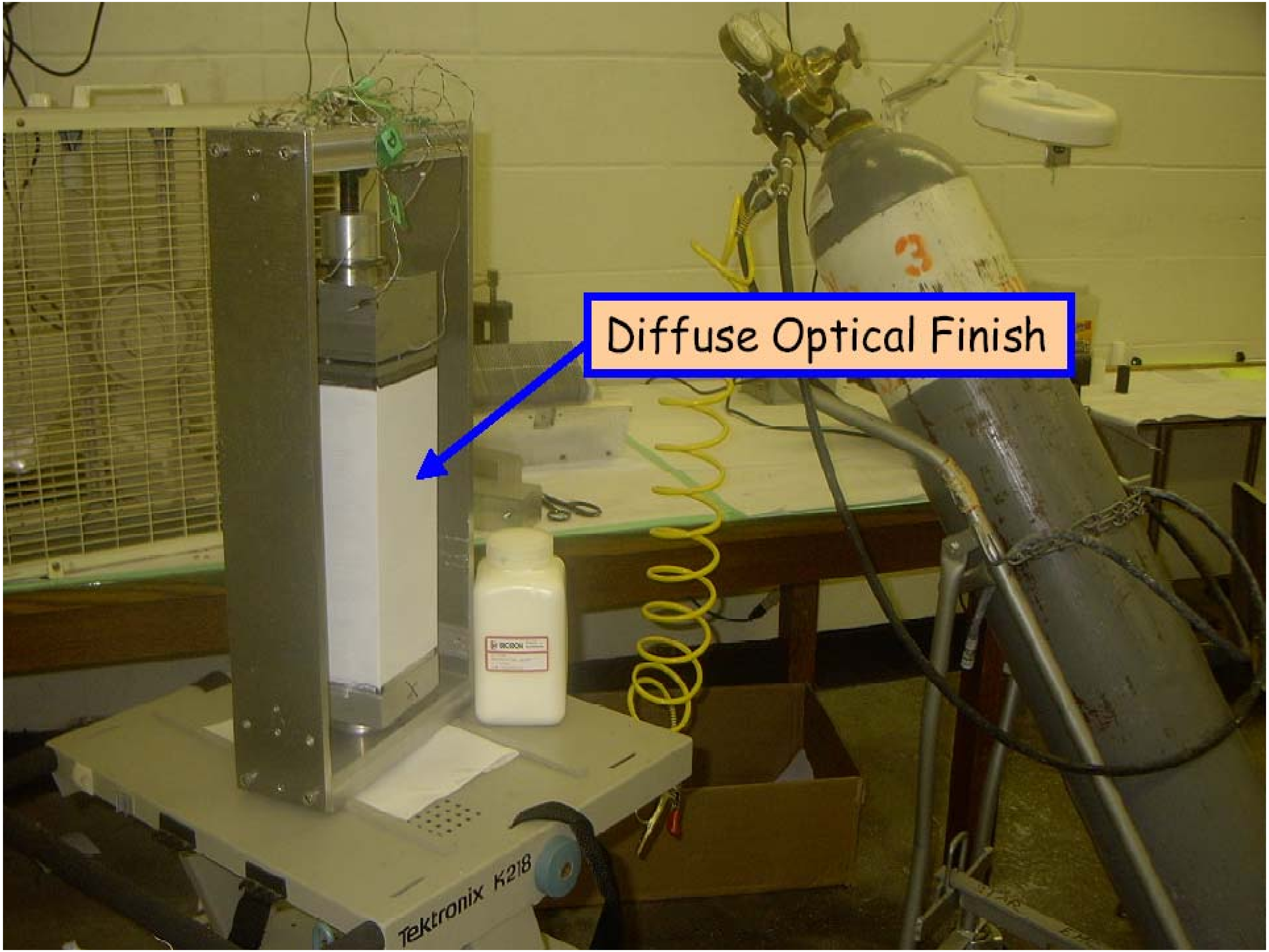
- 64 tower prototype and test infrastructure nearing completion at WSU
- ALICE/PHOS DAQ nearing completion at ORNL/BNL
- FermiLab meson test beam scheduled for 3 weeks in November
- Goal: Preliminary test results of our design

Fermi Lab Test Beam Area MT6



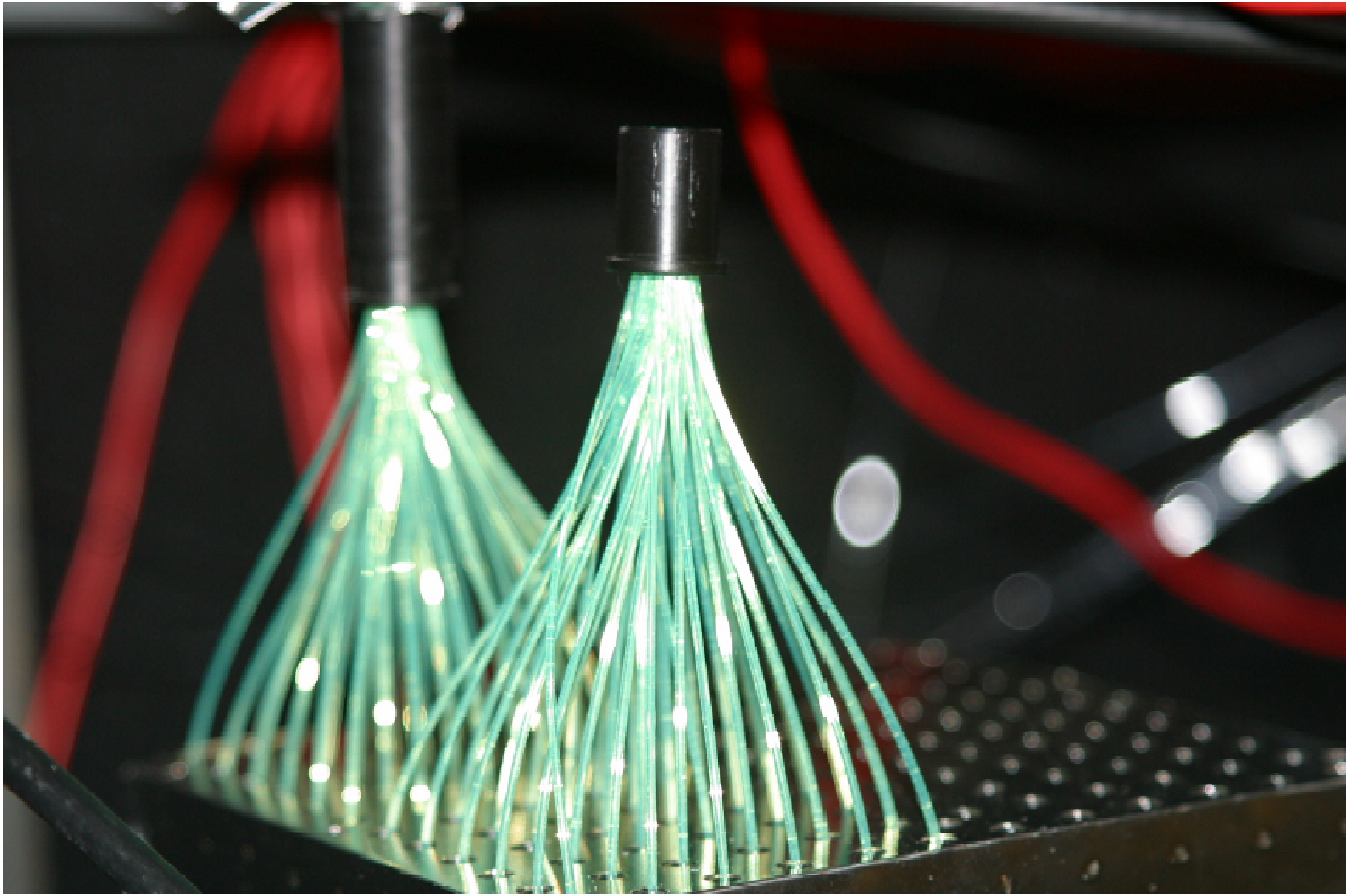



Module under compression
~3 kg/cm^2

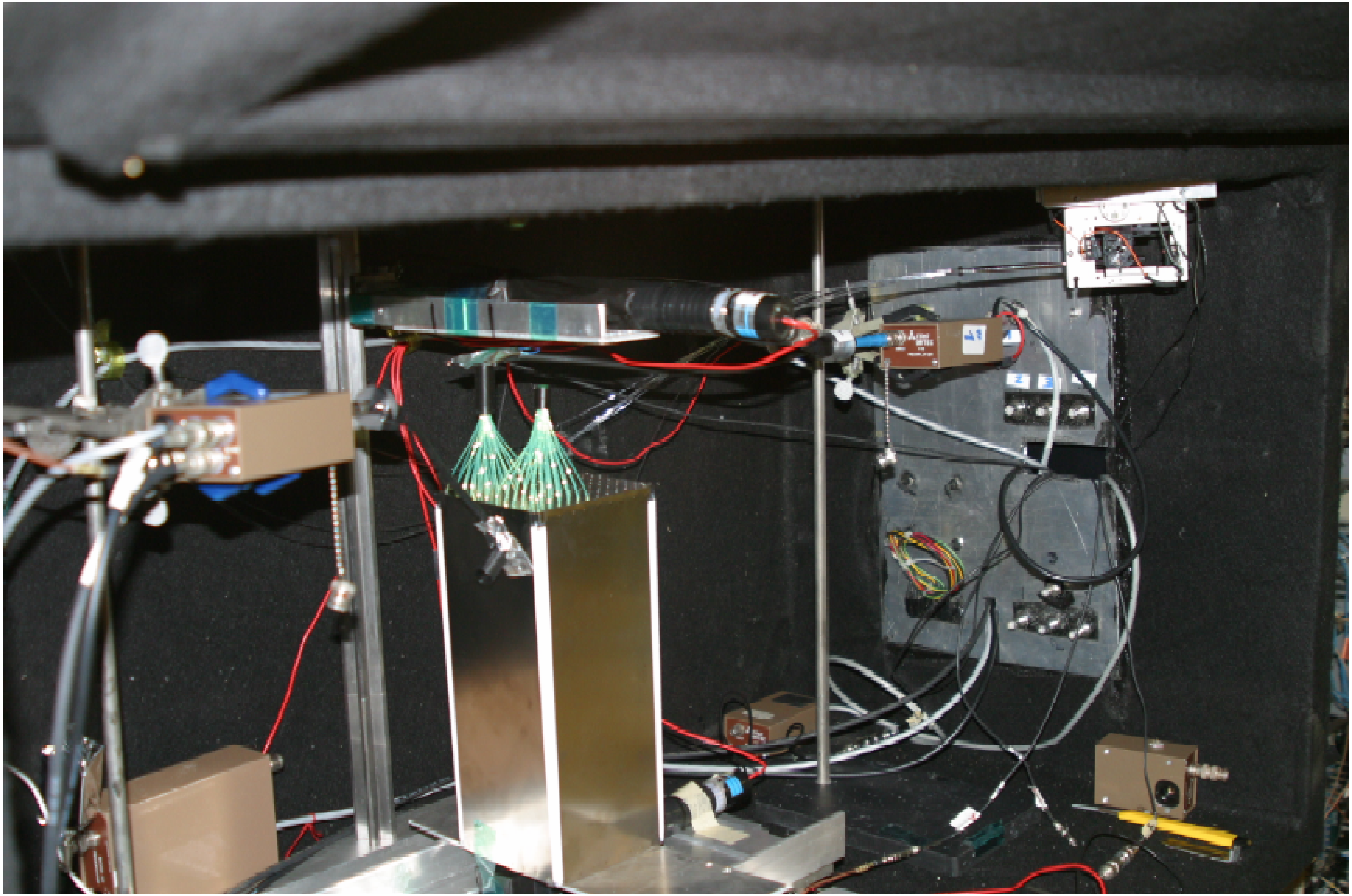

Diffuse Optical Finish
Tektronix K218

Modules 1 through 12

Fiber Bundle



Cosmic test




ALICE
ALICE-USA:
UC Davis
UCLA
Creighton U
U of Houston
Kent State U
LBNL
LLNL
MSU
ORNL
OSU
Purdue U
U of Tennessee
U of Washington
Wayne State U
9 6 2004