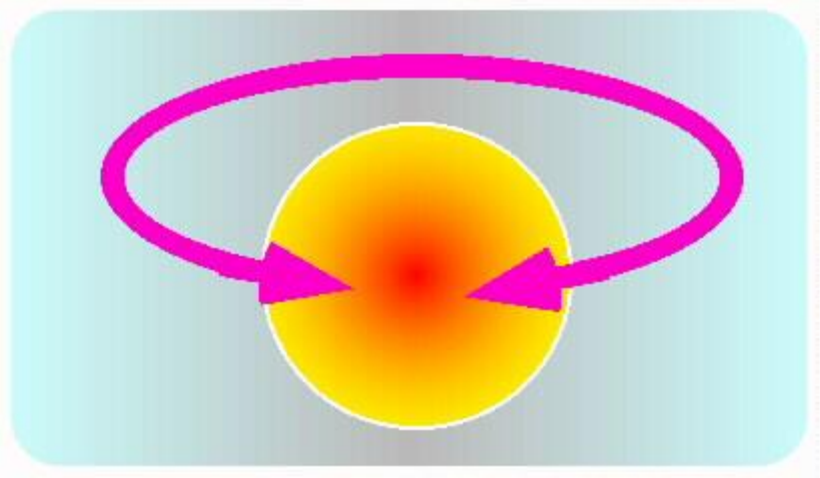
Heavy Ions @ LHC

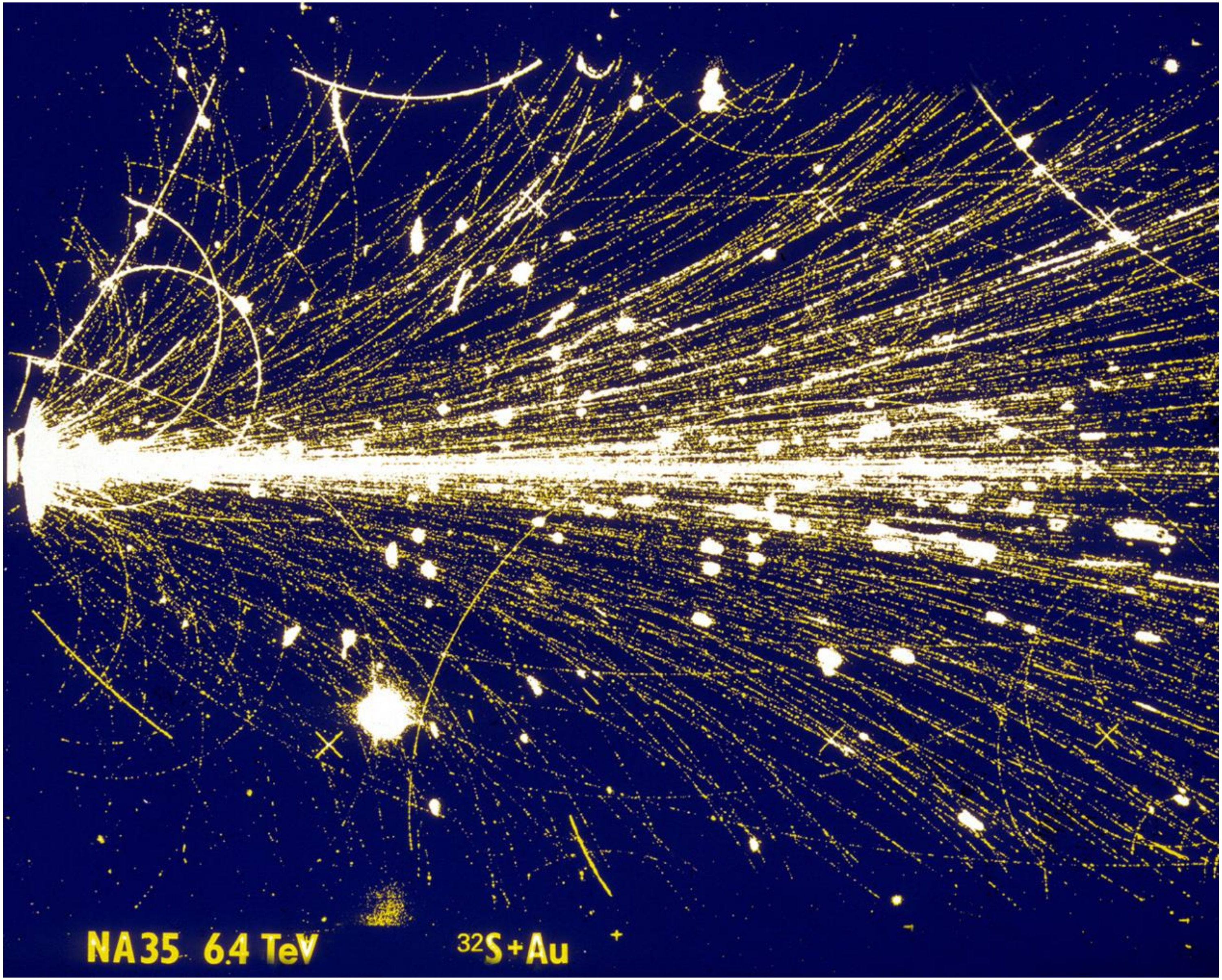
- **Heavy Ion Physics**
  - (in VERY general terms)

- **Heavy Ion Physics at LHC**

- **ALICE**
  - Collaboration
  - Detector
  - Performance



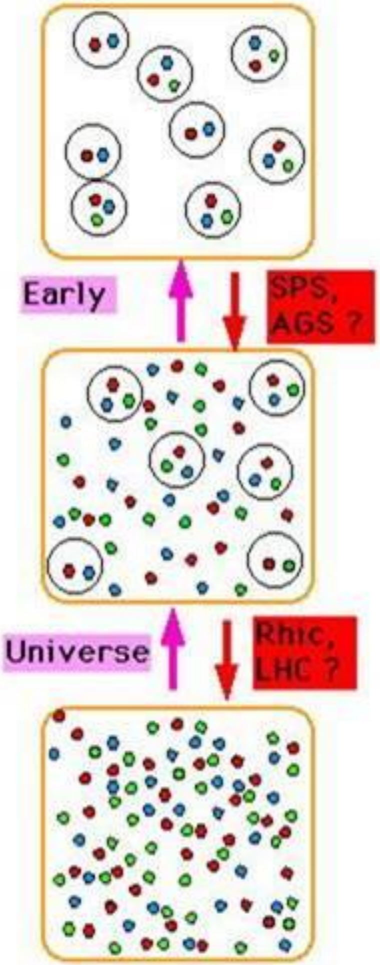
Pretty Messy …



NA35 streamer chamber picture, ca 1990

The QCD Phase transition

- QCD prediction:
  - ⇨ increase of ε => new phase of matter



hadronic matter

ε(nucleus) $\approx$ 0.13 GeV/fm³
ε(proton) $\approx$ 0.5GeV/fm³
q's are confined
q's have large 'effective' mass
$m_u \approx m_d \approx 1/3\, m_p \approx 300$ MeV
$m_s \approx 500$ MeV

phase transition

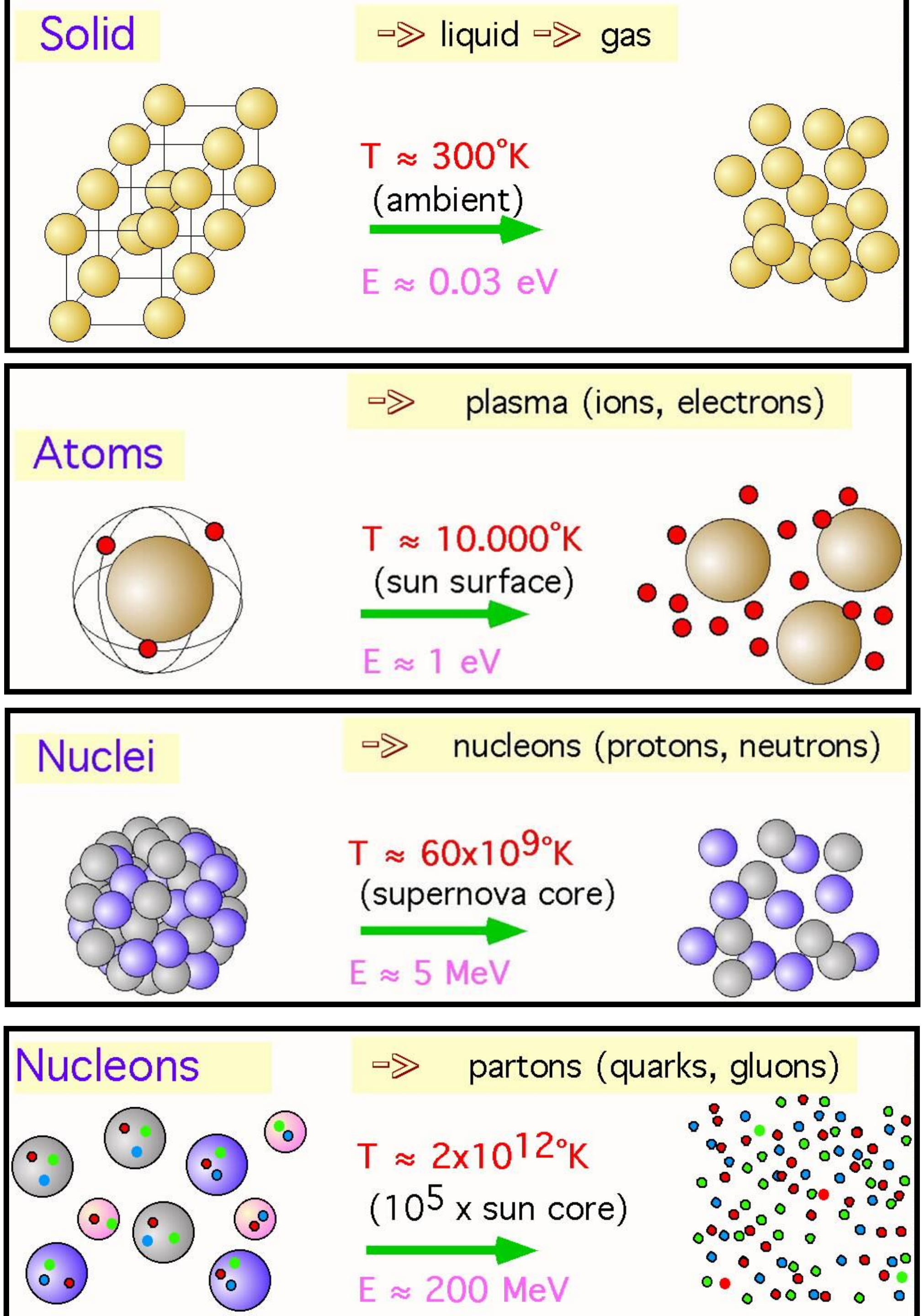
hadrons & 'vacuum' melt
1st or 2nd order transition ?
latent heat, critical fluctuations

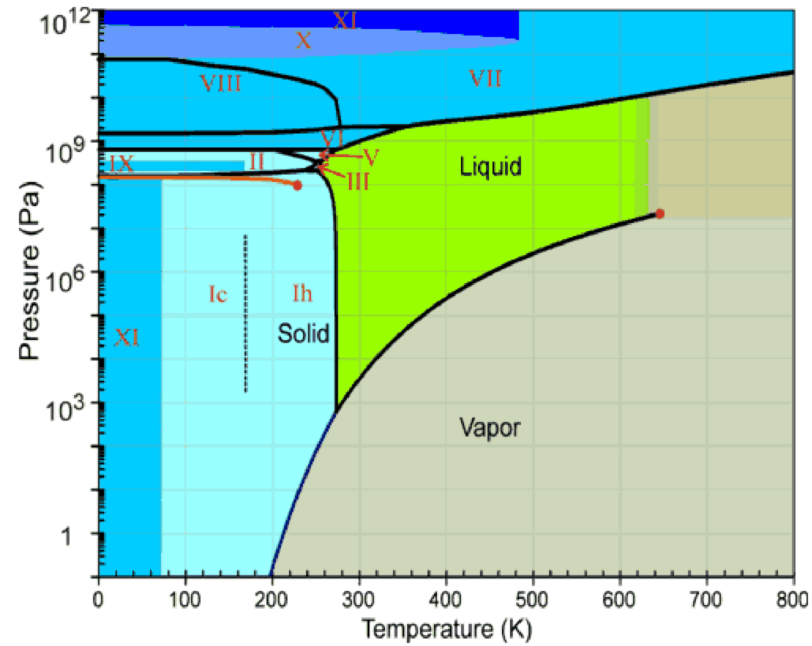
Quark-Gluon-Plasma

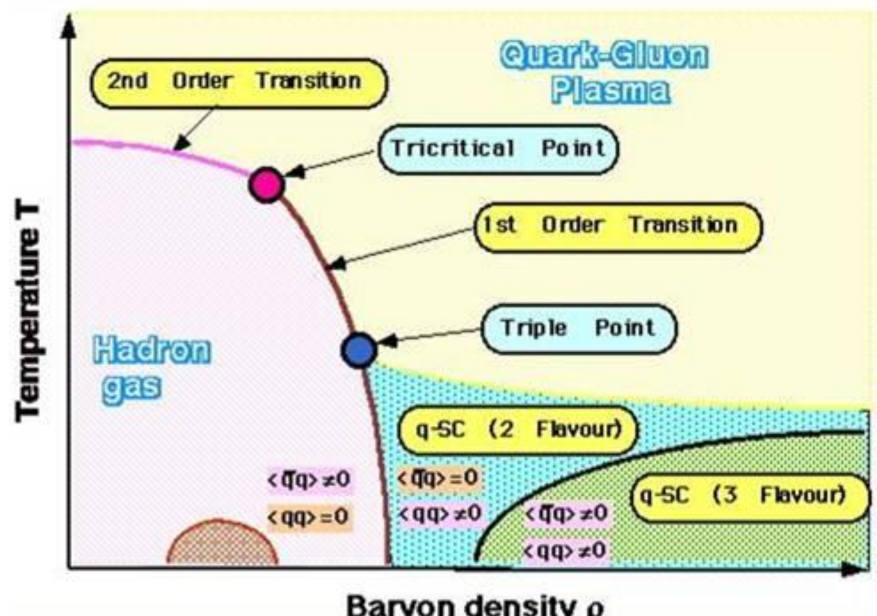
$\varepsilon > 1\text{-}2$ GeV/fm³
T> 150 MeV
$\rho \approx 5 - 10\rho$(nucleus)
q's are deconfined
colour conductivity
q's have small 'bare' mass
chiral symmetry restored
$m_u \approx m_d \approx 5$ MeV
$m_s \approx 150$ MeV

- **QGP = true ground state of QCD**
  - ⇨ **I) melting matter => deconfinement**
  - ⇨ **II) melting vaccum** (gluon condensate) **=>chiral symmetry restoration**
    - ✪ dynamical **origin** of constituent **mass**
- **Phase transitions involving elementary quantum fields**
  - ⇨ **phase transitions** and spontaneous **symmetry breaking central to HEP**
  - ⇨ QCD transition is the only one accessible dynamically
- **Cosmology & Astrophysics**
  - ⇨ early **Universe** at ~ 1 μs
  - ⇨ interior of **neutron stars**
- **new domain of hot & dense QCD**
  - ⇨ **surprises ?**

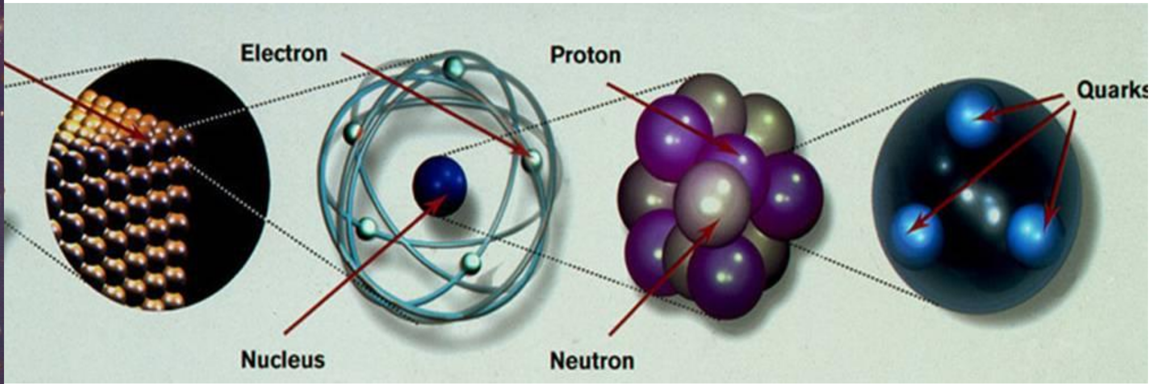
Melting Matter
(deconfinement)







The Dark Mystery of Mass



What stuff is the Universe made of ??

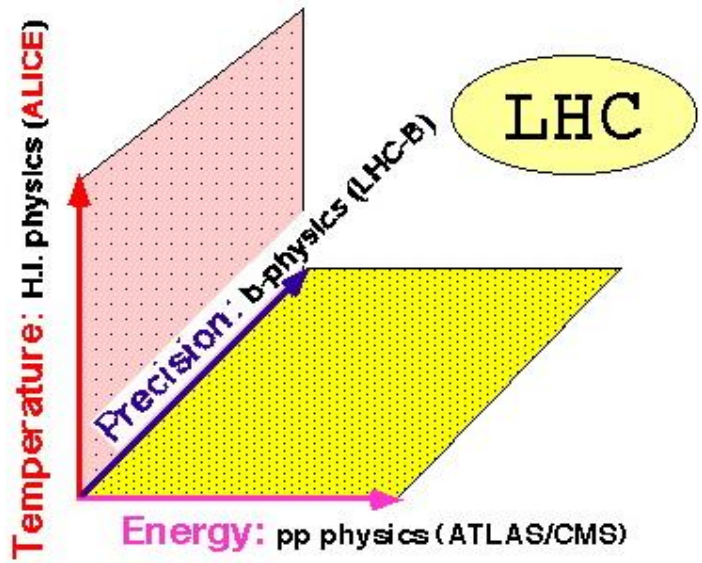
- **Elementary Particles** **0.1%**
  - ⇨ 12 **matter particles** (quarks, leptons)
    - only 4 relevant today (u, d, e, ν)
  - ⇨ 13 **force particles** (3 massive, 10 massless)
- **Composite Particles (hadrons)** **4%**
  - ⇨ hundreds…
    - only 2 are relevant (p,n), making nuclei
  - ⇨ **luminous normal matter** (stars, galaxies) **0.05%**
  - ⇨ **dark normal matter** (gas, planets, ..) **3.95%**
- **Dark Matter** **23%**
  - ⇨ made of **unknown particles**
- **Dark Energy** **73%**
  - ⇨ **vacuum energy**
    - of completely unknown origin
  - ⇨ should be infinite or exactly 0

We don't know **how** and **why** for ~ 5%

We don't even know **what** for the other 95%

Physics at LHC

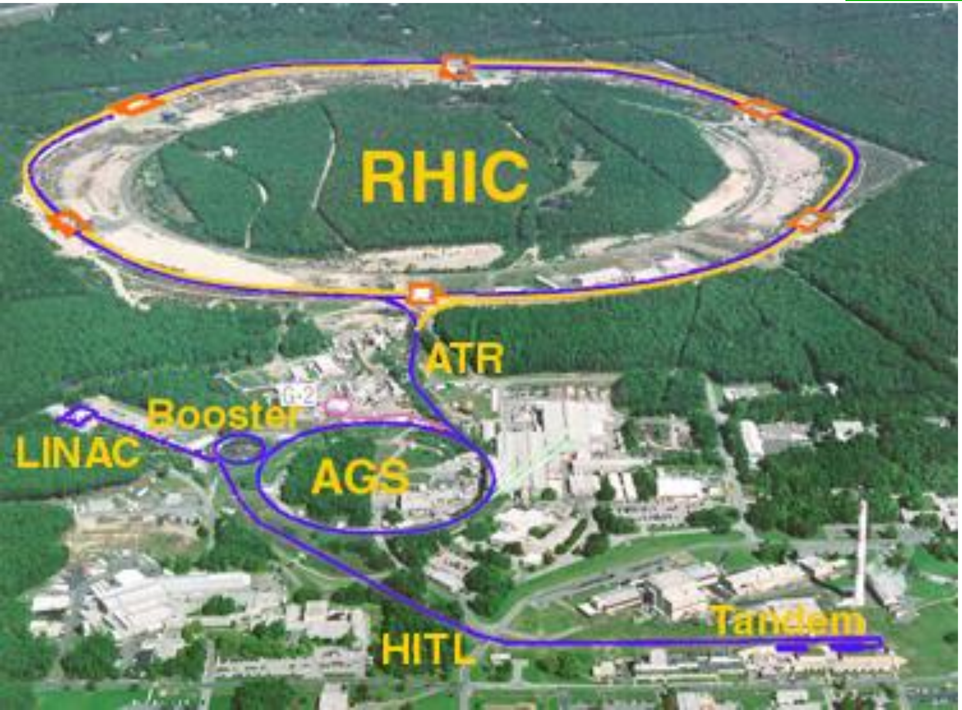
- **Common Questions**
  - generation of mass
    - **elementary** particles => Higgs => ATLAS/CMS
    - **composite** particles => QGP => ALICE
  - missing symmetries
    - **SuperSymmetry**: matter <-> forces => ATLAS/CM
    - **Chiral Symmetry**: mass of light quarks => ALICE
    - **CP Symmetry**: matter <-> antimatter => LHC-B

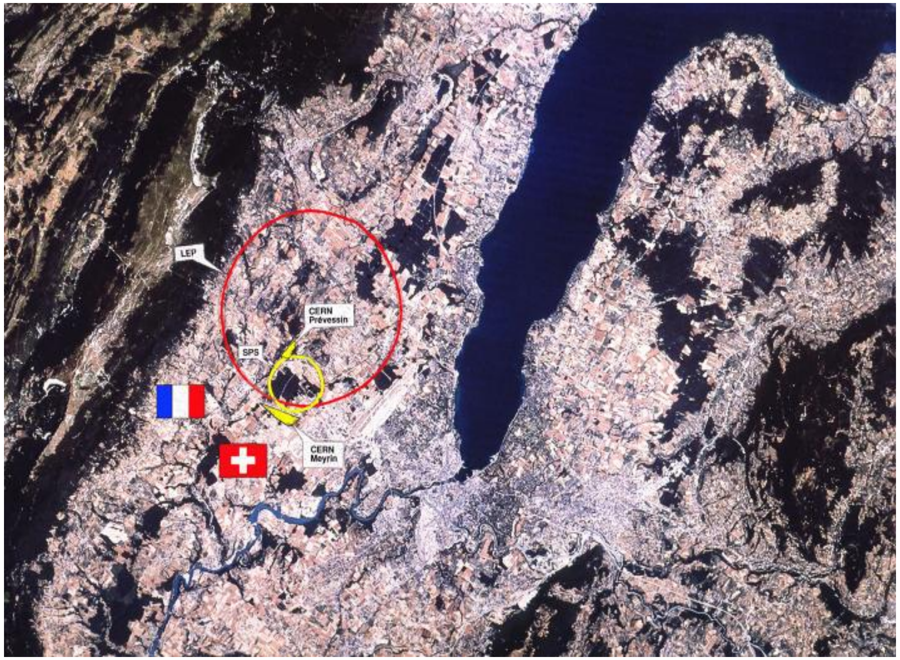


- **Different Approaches**
  - 'Concentrated Energy'
    => (single) high mass particles
  - 'Distributed Energy'
    => interaction between matter & vacuum
  - 'Borrowed Energy'
    => indirect effects of very high mass particles

Current hunting ground for Quark Gluon Plasma

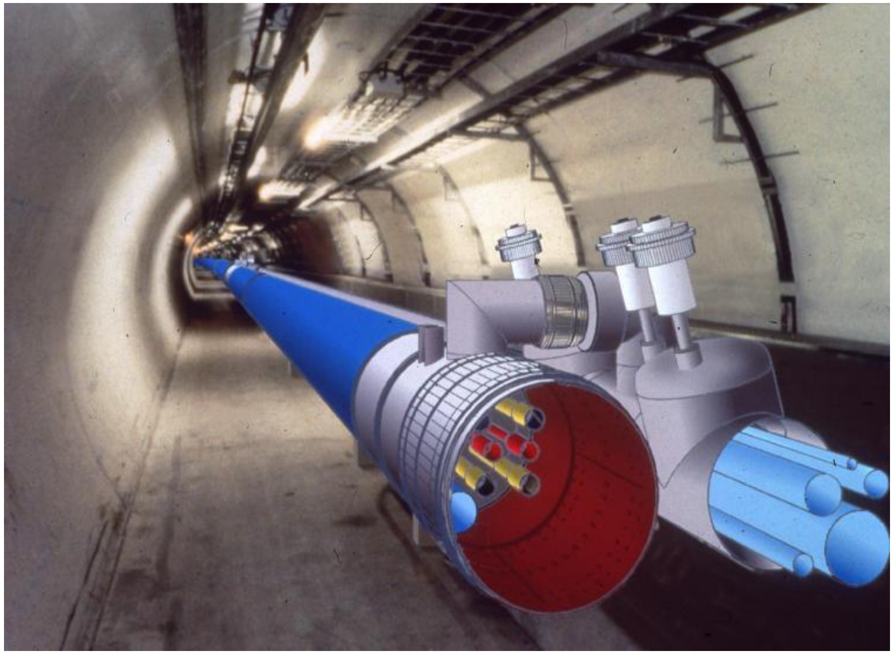
The Relativistic Heavy Ion Collider





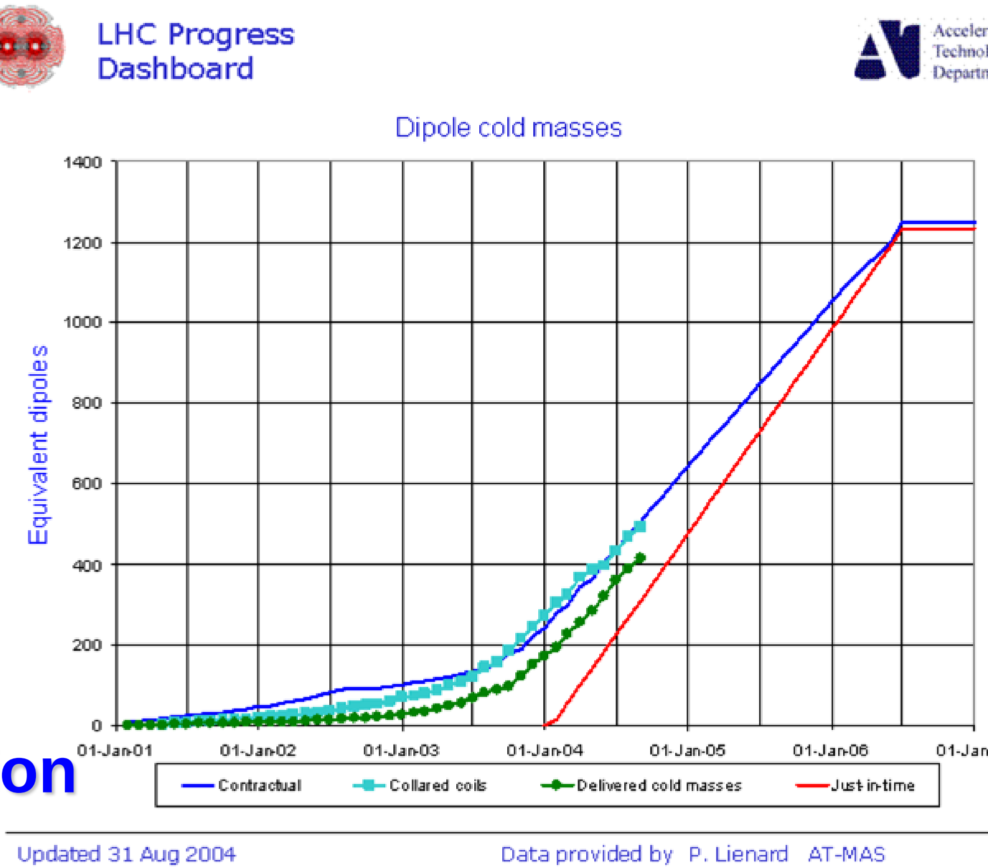
Future place for studying the Quark Gluon Plasma

The Large Hadron Collider



LHC Status

- **long & winding road to LHC**
  - ⇨ first discussion on HI in LHC: 1990
  - ⇨ LHC approved 1994 /1996
  - ⇨ start-up several times postponed
- **financial problems**
  - ⇨ some 20% cost overrun (~800 MCHF)
- **technical problems**
  - ⇨ Cryoline installation late > 1 year
- **machine well into construction**
  - ⇨ > 1/3 of magnets produced
- **LHC start-up still expected in 2007**



⇨ first heavy ion run in 2008

LHC Magnets


Main Dipole


MQW
21/8/2002 09:24


Insertion (Japan)


Transfer Lines

Heavy Ions in LHC

- **energy**
  - ⇨
  - ⇨

E_{beam} **= 7 x Z/A** [TeV]
√s = 5.5 TeV/A (Pb-Pb), **14 TeV** (pp)

- **beams**
  - ⇨ **possible combinations: pp, pA, AA**
    - constant magnetic rigidity/beam ('single magnet')
  - ⇨ expected heavy ion running
    - **~ 6 weeks heavy ion runs**, typically after pp running (**like at SPS**)
    - initial emphasis on Pb-Pb
    - pp and pA comparison runs
    - intermediate mass ion (eg Ar-Ar) to vary energy density
  - ⇨ later options: different ion species, lower energy AA and pp
- **luminosity**

	Pb-Pb	Ar-Ar	pp
L [$cm^{-2}s^{-1}$]	10^{27}	$3x10^{27}$ to 10^{29}	10^{29} to $3x10^{30}$
Rate [kHz]	8	8 to 250	7 to 200

H.I. Physics@LHC: Caveat

BIG Step ahead: SPS —x 12→ RHIC —x 28→ LHC

Predictions are notoriously difficult, in particular if they concern the future..

- **long distance QCD is difficult to predict**
  - ⇨ Theory well known, not so its consequences or manifestation
  - ⇨ HEP@LHC: Theory unknown, but each candidate makes precise predictions
- **the fate of 'expectations' at SPS and RHIC**
  - ⇨ some expectations turned out **right**:
    - **SPS**: strangeness enhancement — **RHIC:** particle ratios, jet-quenching
  - ⇨ some turned out **wrong**:
    - **SPS**: large E-by-E fluctuations — **RHIC:** multiplicity dN/dy
  - ⇨ a number of **unexpected** surprises:
    - **SPS**: J/Psi suppression — **RHIC:** elliptic flow, 'HBT-puzzle'
- **lesson when preparing ALICE at LHC**
  - ⇨ **guided** by theory and expectations, but **stay open minded** !
- **'conventional wisdom'**
  - ⇨ **soft physics**: smooth extrapolation of SPS/RHIC — necessary, but boring ???
  - ⇨ **hard physics**: new domain at LHC

Hard Processes at the LHC

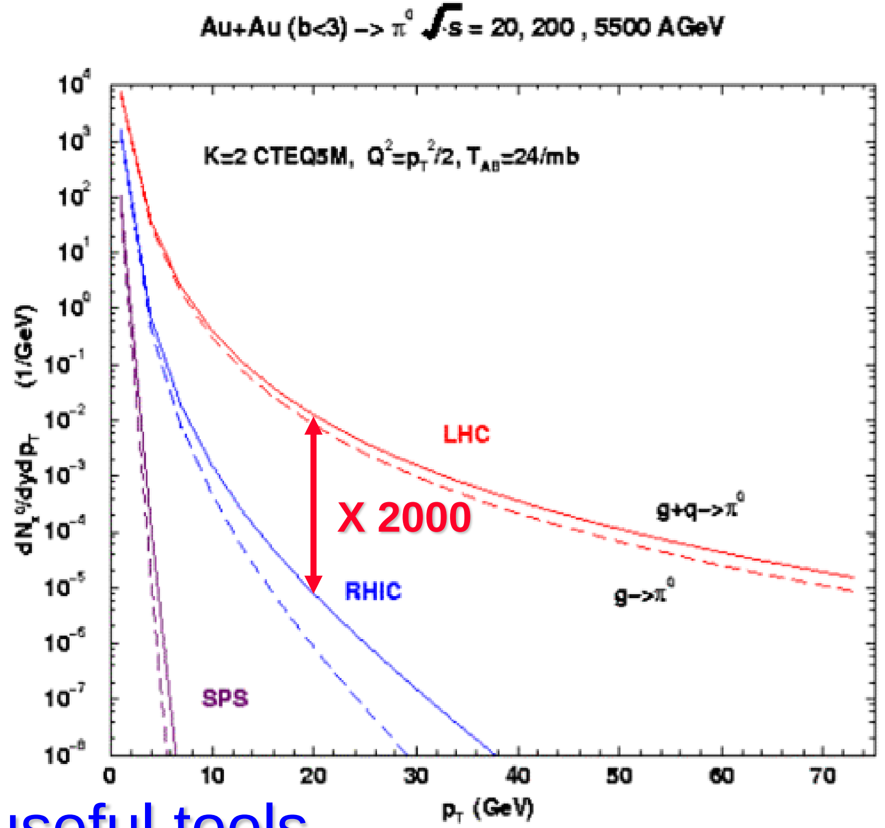
- Main novelty of the LHC: large hard cross section

$$\sigma^{hard} / \sigma^{tot}$$

~2% at SPS

~50% at RHIC

~98% at LHC

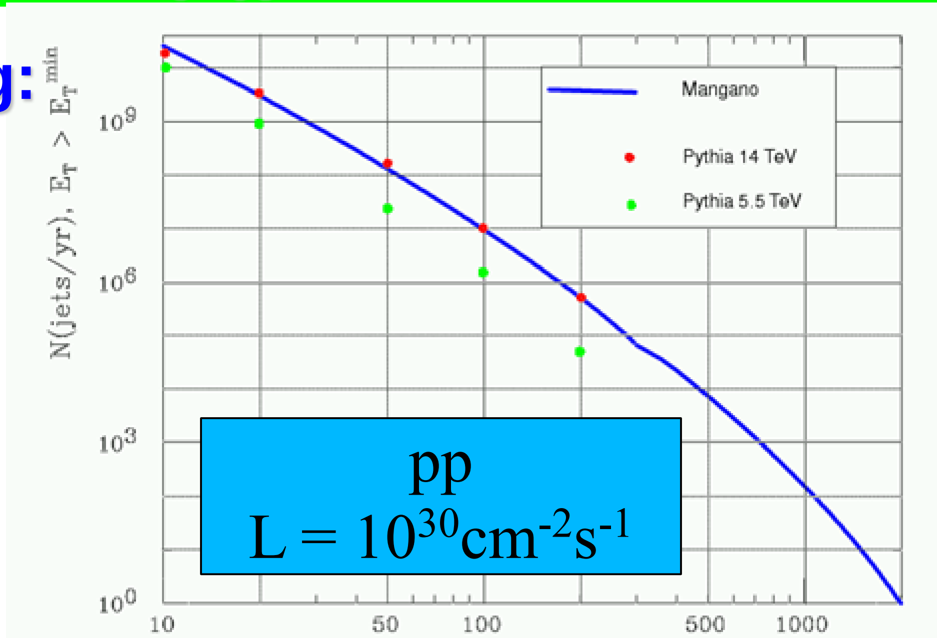


- Hard processes are extremely useful tools
  - ⇨ **happen at t = 0** (initial stage of the collision)
  - ⇨ have **large virtuality *Q*** and **small "formation time"** $\Delta t \propto 1/Q$
  - ⇨ ***probe matter at very early times (QGP) !!!***

hard processes can be calculated by pQCD → predicted

Jets in ALICE $|\eta|<0.9$

- **ideal energy for jet-quenching: around 100 GeV**
  - ⇨ pQCD applicable
  - ⇨ jets measurable above soft background
  - ⇨ energy loss still relatively large effect
    - $\Delta E/E$ ~ O(10%), decreasing with E !



Pb Pb rates:

p_t jet > (GeV/c)	jets/event	accepted jets/month
5	**$3.5\ 10^{2}$**	**$4.9\ 10^{10}$**
50	**$7.7\ 10^{-2}$**	**$1.5\ 10^{7}$**
100	$3.5\ 10^{-3}$	$8.1\ 10^{5}$
150	**$4.8\ 10^{-4}$**	**$1.2\ 10^{5}$**
200	**$1.1\ 10^{-4}$**	**$2.8\ 10^{4}$**

Reasonable rate up to E_T ~300 GeV

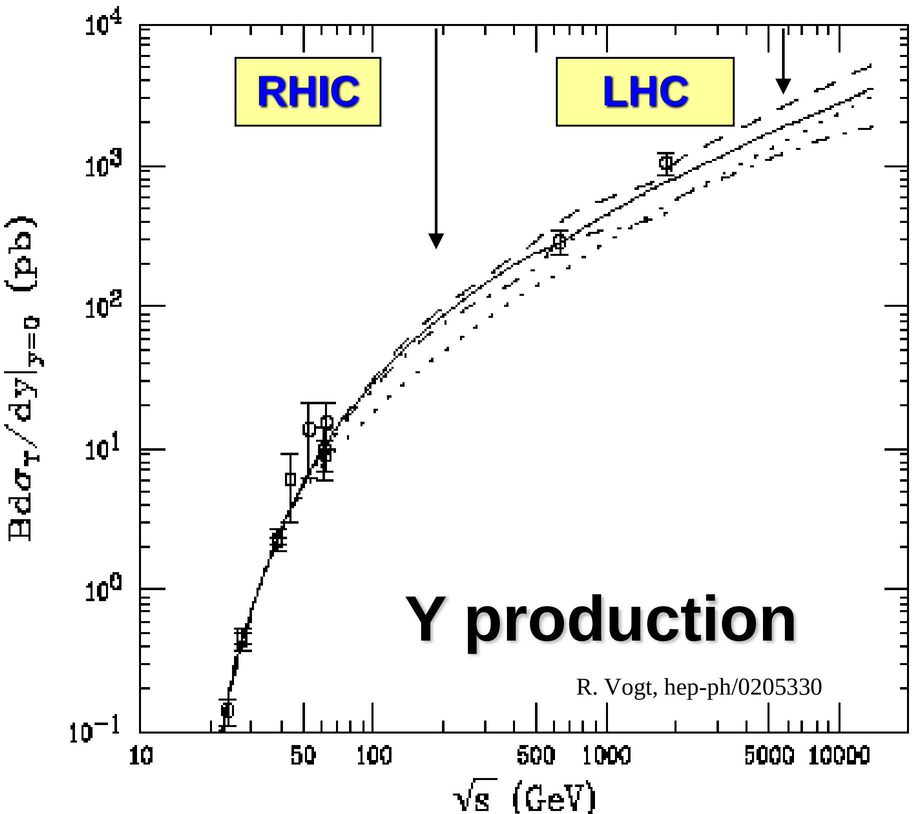
Heavy Quarks & Quarkonia

- **copious heavy quark production**
  - **charm** @ LHC ~ **strange** @ SPS
    - hard production => 'tracer' of QGP dynamics (statistical hardonization ?)
    - 2 m_c ~ saturation scale => change in production ?
    - jet-quenching with heavy quarks visible in inclusive spectra ?

N($q\bar{q}$) per central AA (b=0)

	SPS	RHIC	LHC
charm	0.2	10	200
bottom	---	0.05	6

- **Y dσ/dy LHC ~ 20 x RHIC**
  - Y will probably need higher Lumi at RHIC
  - even at LHC Y'' is difficult



Initial Conditions

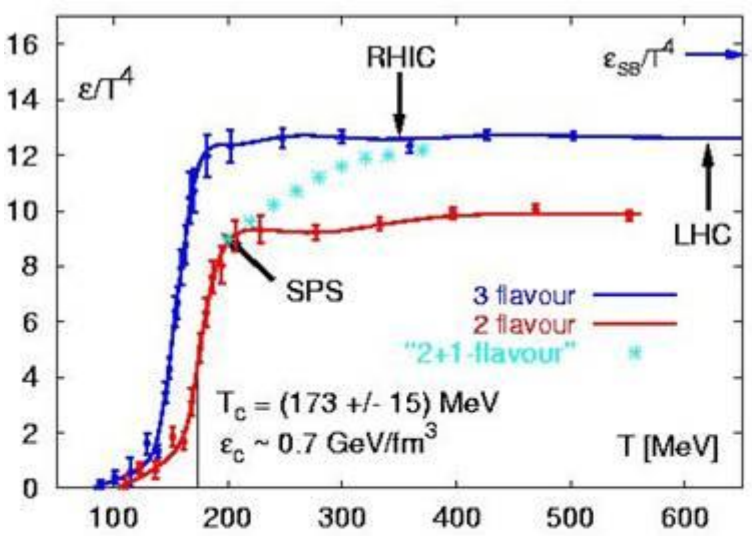
- my pre-RHIC guess (QM2001)
  - ⇨ **still expect conditions to be significantly different**
  - ⇨ **only LHC will give the final answer on dn/dy!**

Central collisions	SPS	RHIC	LHC
$s^{1/2}$(GeV)	17	200	5500
dN_{ch}/dy	430	700-1500	2-8 x10^3
ε $(GeV/fm^3)_{\tau 0=1fm}$	2.5	3.5-7.5	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

Significant gain in ε, V, τ

≈ x 10 SPS -> LHC

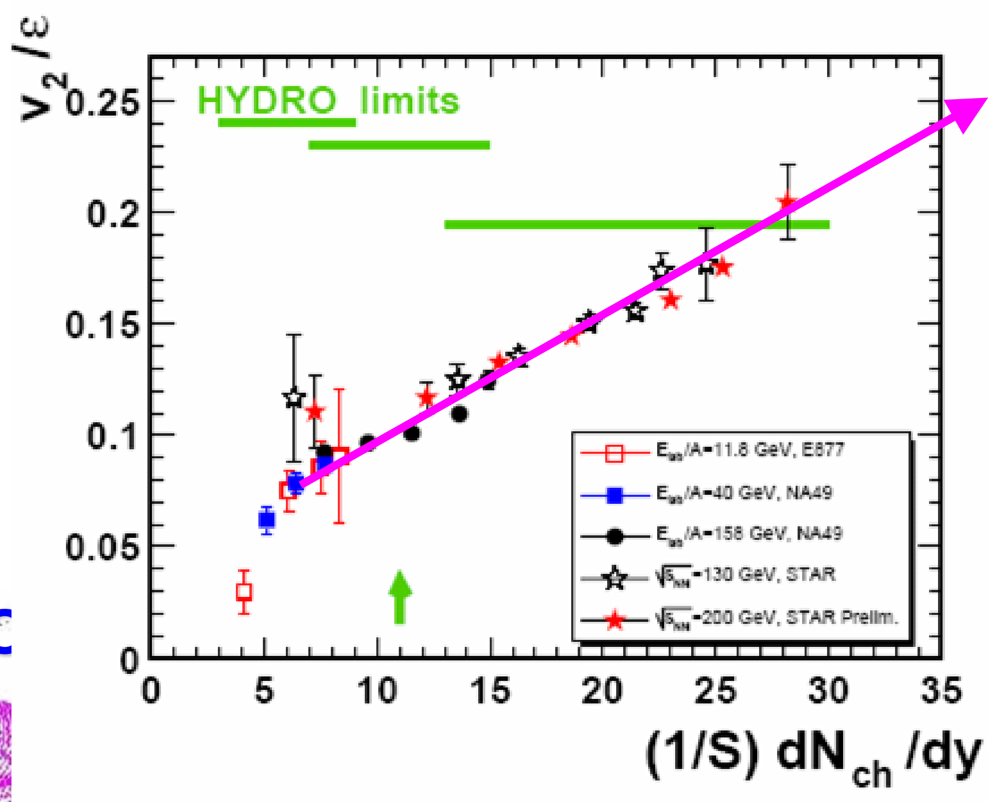
≈ x 3-5 RHIC -> LHC



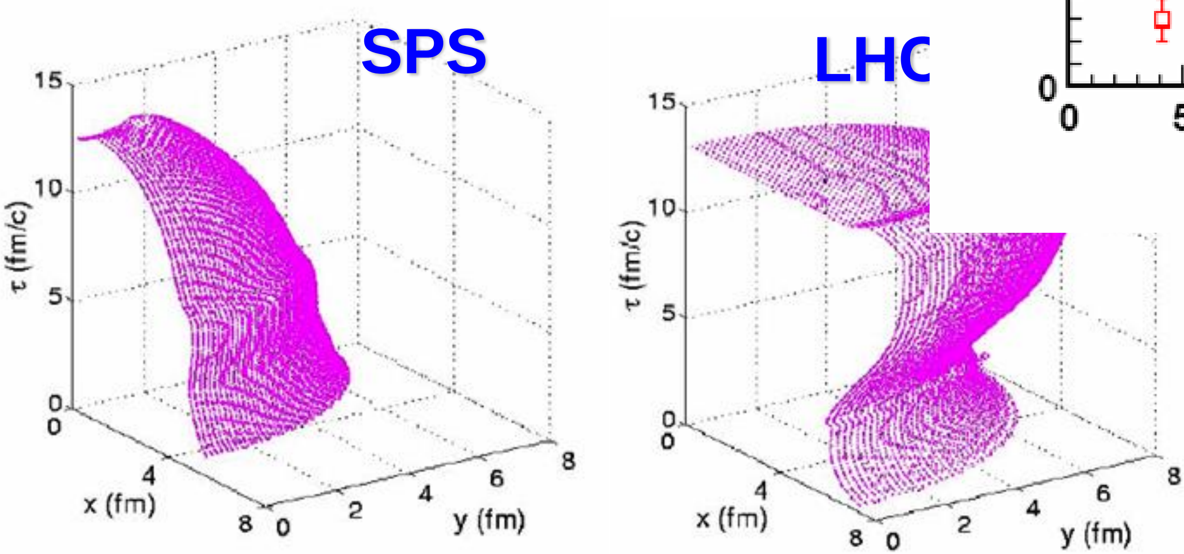
Hotter-Bigger-Longer lived

The Soft Stuff

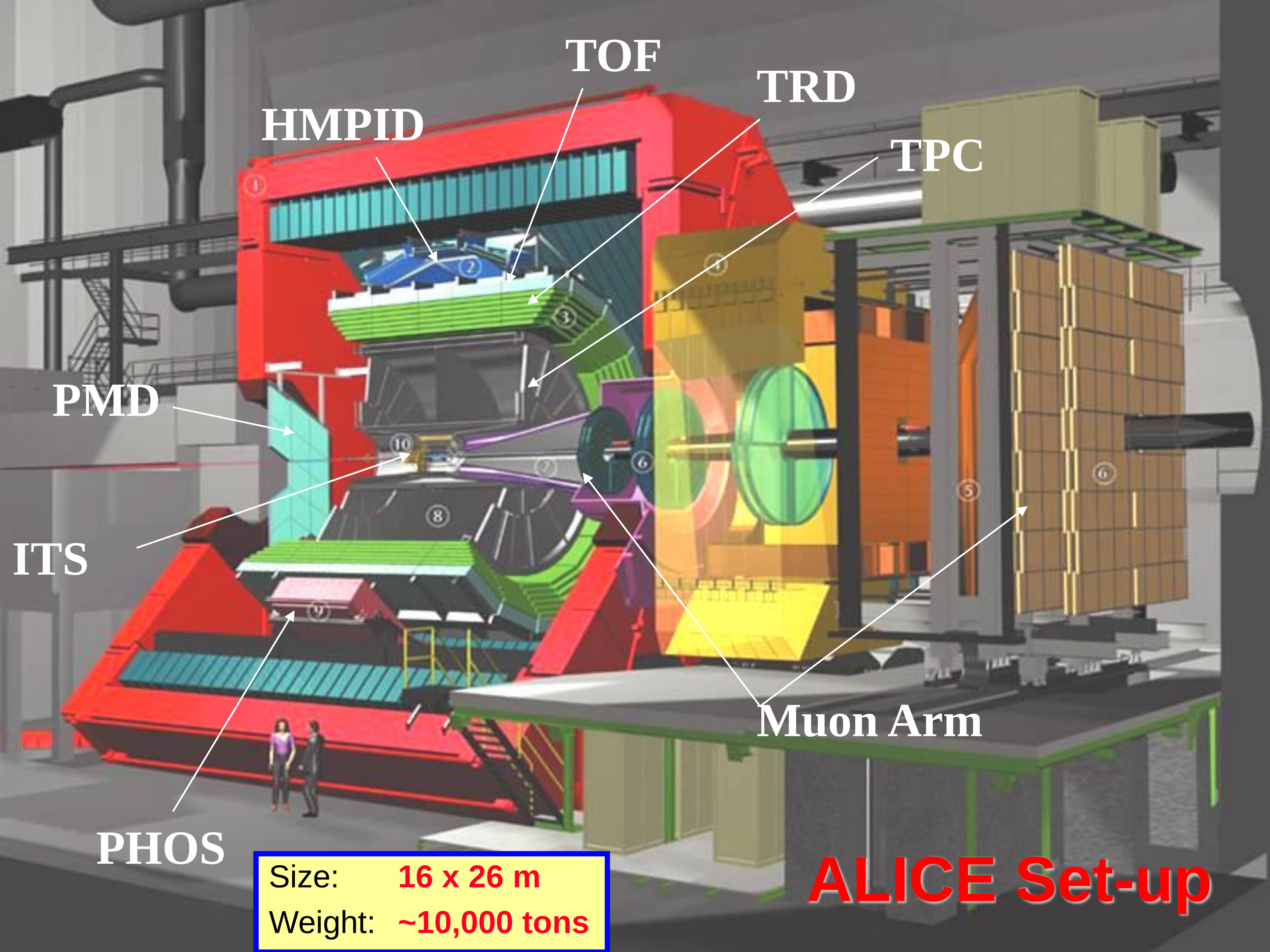
- **changes in expansion dynamics & freeze-out ARE expected**
  - ⇨ thermal freeze-out temperature ?
  - ⇨ how will charm fit into particle ratios ?
  - ⇨ Event-by-Event fluctuations ?
    - ✪ measurement accuracy ~ √#particles
  - ⇨ will elliptic flow continue to rise ?
  - ⇨ will the measured transverse HBT volume (finally) increase ?



Freeze-out Hyper surface



Biggest surprise would be none..

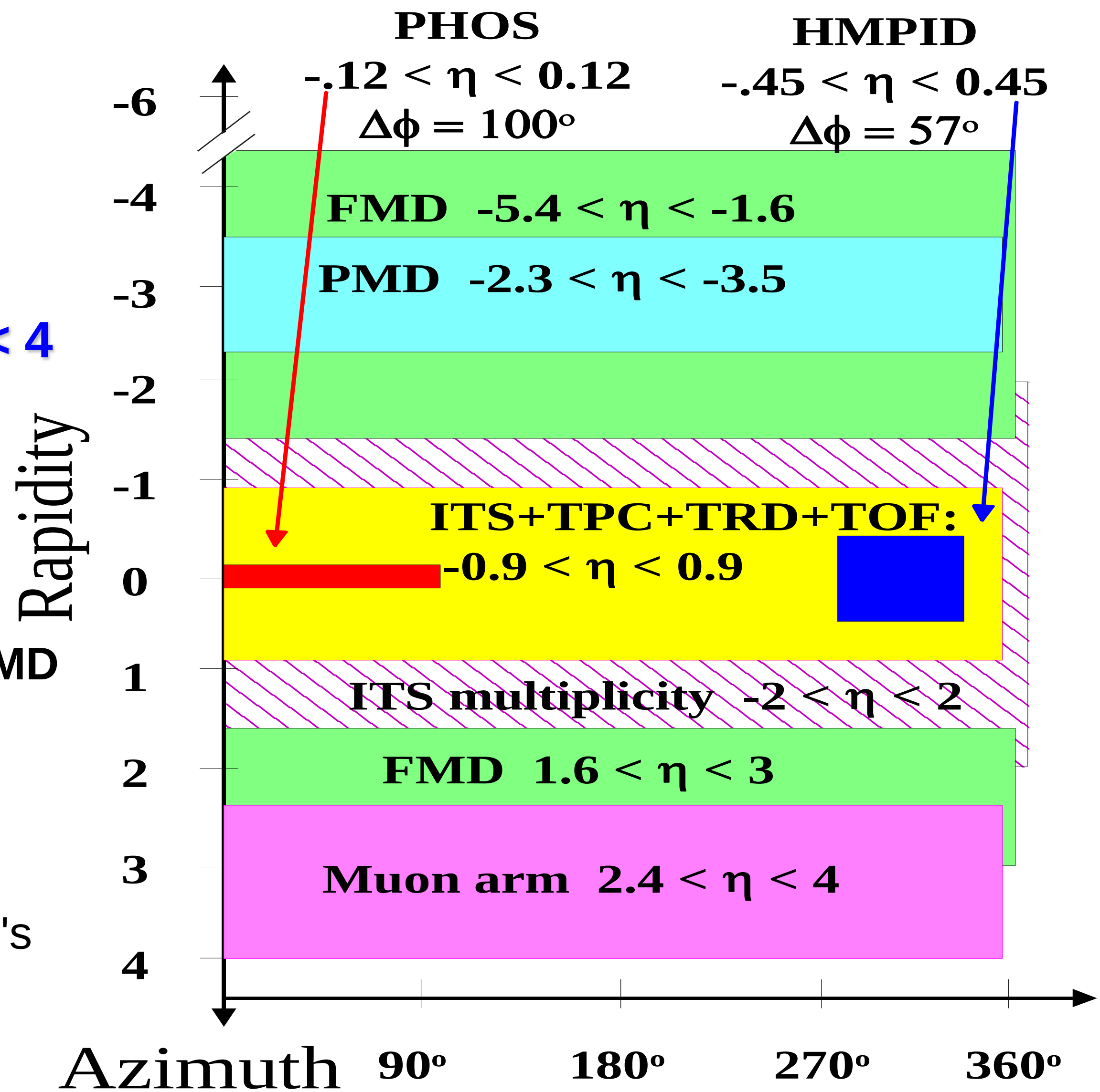


ALICE Set-up

Size:	16 x 26 m
Weight:	~10,000 tons

ALICE Acceptance

- **central barrel** -0.9 < η < 0.9
  - ⇨ tracking, PID
  - ⇨ single arm **RICH** (HMPID)
  - ⇨ single arm **em. calo** (PHOS)
- **forward muon arm** 2.4 < η < 4
  - ⇨ absorber, dipole magnet tracking & trigger chambers
- **multiplicity** -5.4 < η < 3
  - ⇨ including photon counting in **PMD**
- **trigger & timing dets**
  - ⇨ **Zero Degree Calorimeters**
  - ⇨ **T0:** ring of quartz window PMT's
  - ⇨ **V0:** ring of scint. Paddles



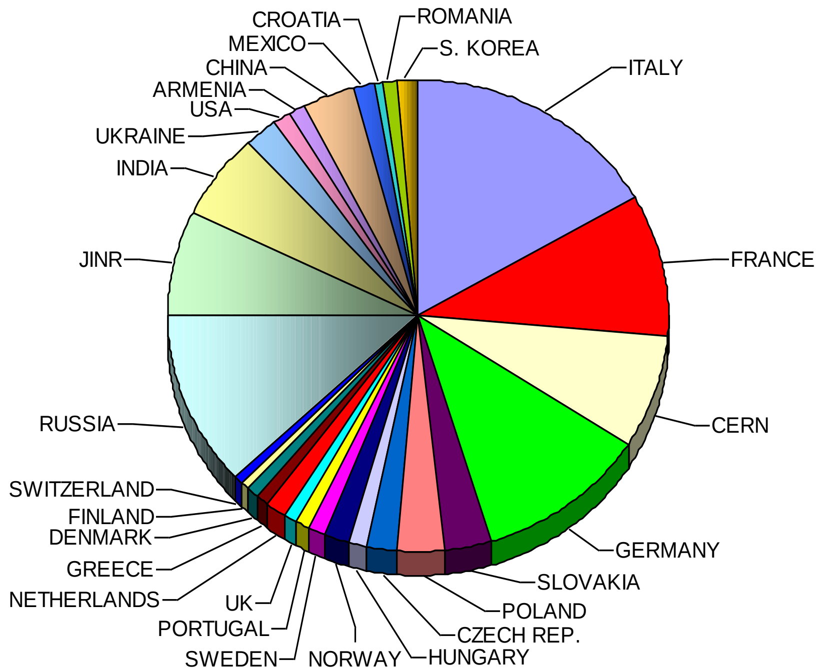
ALICE Collaboration

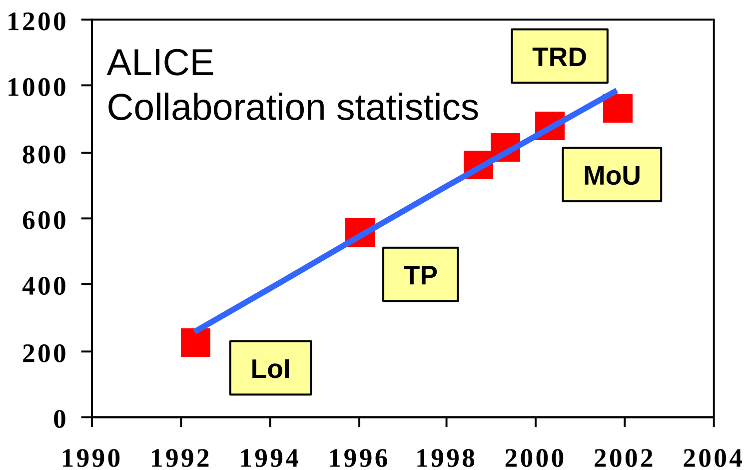
~ 1000 Members

(63% from CERN MS)

~30 Countries

~80 Institutes

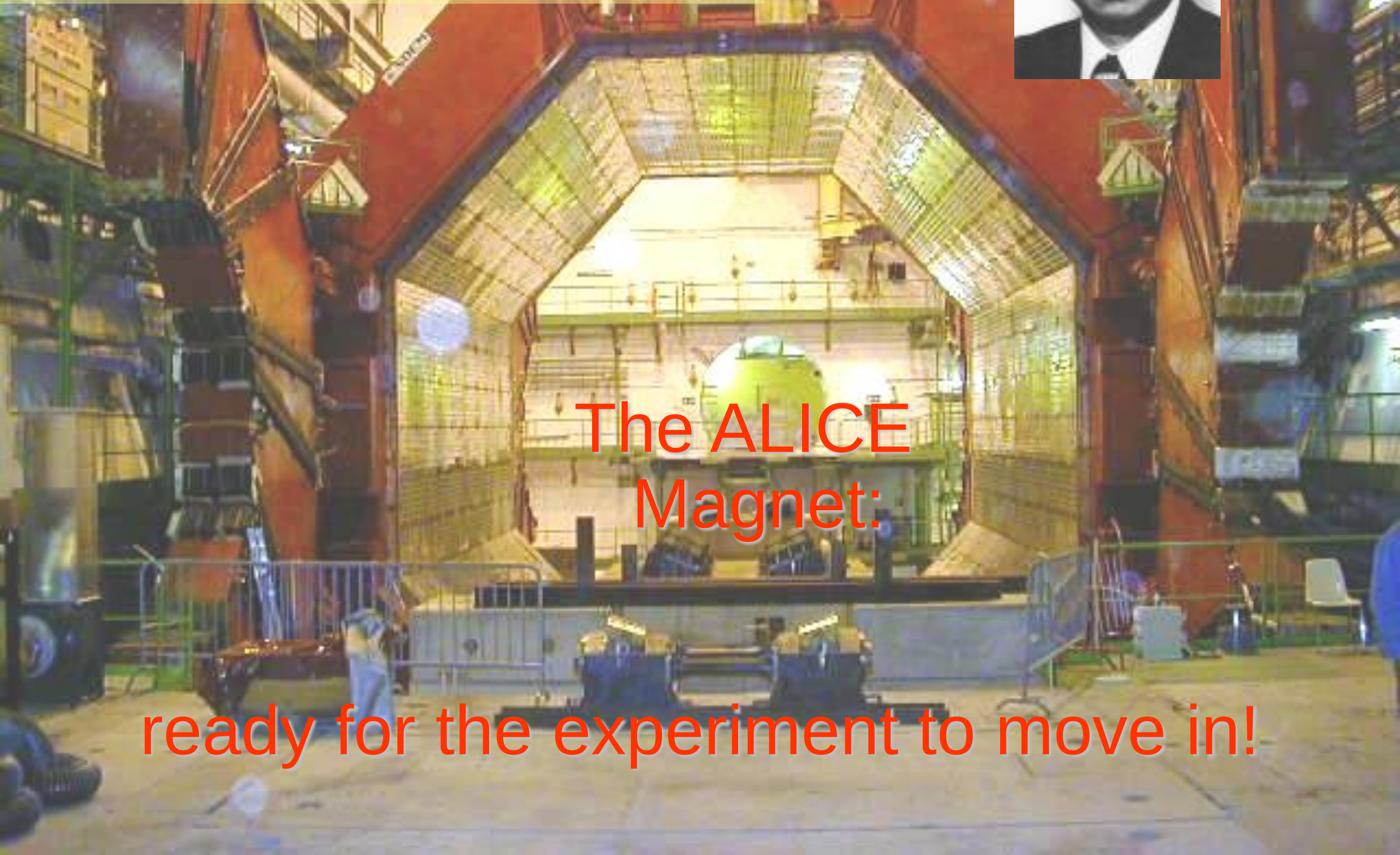




ALICE Design Philosophy

- **General Purpose Heavy Ion Detector**
  - **one single dedicated HI expt** at LHC
    - **ATLAS/CMS** will contribute, but **priority is pp** physics
    - AGS/SPS: several (6-8) 'special purpose expts'
    - RHIC: 2 large multipurpose + 2 small special purpose expts
- **cover essentially all known observables of interest**
  - **comprehensive** study of **hadrons** at midrapidity
    - large acceptance, excellent tracking and PID
  - **state-of-the-art** measurement of direct **photons**
    - excellent resolution & granularity EM calo (small but performing !)
  - dedicated & **complementary** systems for **di-electrons and di-muons**
  - cover the complete spectrum: **from soft** (10's of MeV) **to hard** (100's of GeV)
- **stay open for changes & surprises**
  - **high throughput** DAQ system **+** powerful **online intelligence** ('PC farm', HLT)
    - flexible & scalable: minimum design prejudice on what will be most interesting

- **still largest magnet**
  - magnet volume: 12 m long, 12 m high
  - 0.5 T solenoidal field



The ALICE Magnet:

ready for the experiment to move in!


CICERON
CICERON

ALICE R&D

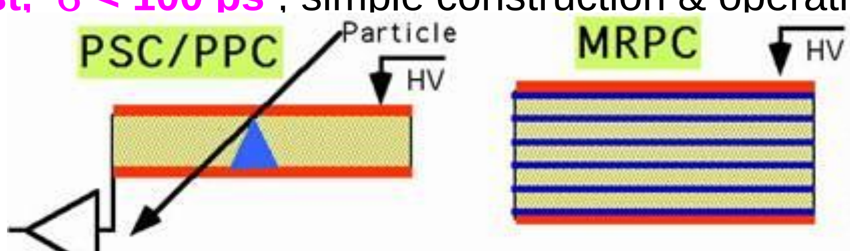
1990-1996: Strong, well organized, well funded R&D activity

- **Inner Tracking System (ITS)**
  - ⇨ Silicon Pixels (RD19)
  - ⇨ Silicon Drift (INFN/SDI)
  - ⇨ Silicon Strips (double sided)
  - ⇨ low mass, high density interconnects
  - ⇨ low mass support/cooling
- **TPC**
  - ⇨ gas mixtures (RD32)
  - ⇨ new r/o plane structures
  - ⇨ advanced digital electronics
  - ⇨ low mass field cage
- **em calorimeter**
  - ⇨ new scint. crystals (RD18)
- **PID**
  - ⇨ Pestov Spark counters
  - ⇨ Parallel Plate Chambers
  - ⇨ Multigap RPC's (LAA)
  - ⇨ low cost PM's
  - ⇨ solid photocathode RICH (RD26)
- **DAQ & Computing**
  - ⇨ scalable architectures with COTS ?
  - ⇨ high perf. storage media ?
  - ⇨ GRID computing ?
- **misc**
  - ⇨ micro-channel plates
  - ⇨ rad hard quartz fiber calo.
  - ⇨ VLSI electronics

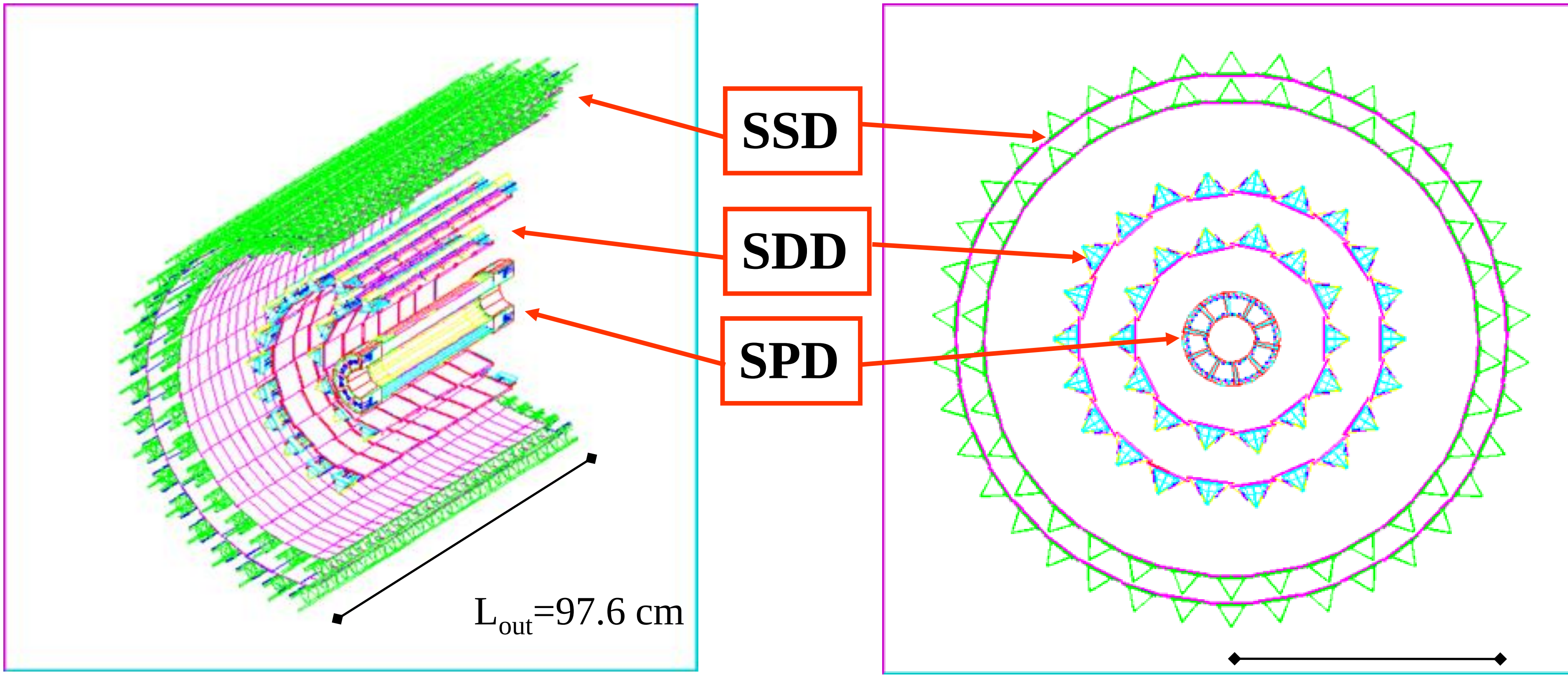
• R&D made effective use of long (frustrating) wait for LHC
• was vital for all LHC experiments to meet LHC challenge !

Time of Flight Detectors

- **aim: state-of-the-art TOF at ~1/10 current price !**
  - requirements: area > 150 m^2, channels ~ 150,000, resolution σ < 100 ps
  - existing solution: scintillator + PM, **cost > 120 MSF !**
    - R&D on cheaper fast PM's in Russia failed to deliver
- **gas TOF counters + VLSI FEE**
  - **Pestov Spark Counter** (PSC)
    - 100 μm gap, > 5 kV HV, 12 bar, sophisticated gas
    - **σ < 50 ps,** some 'tails' (?), but only (!) **~ 1/5 cost**
    - technology & materials **VERY challenging**
  - **Parallel Plate Chamber** (PPC)
    - 1.2 mm gap, 1 bar, simple gas & materials
    - **1/10 cost,** but only **σ = 250 ps**
    - **unstable operation, small signal**
  - **Multigap Resistive Plate Chambers** (MRPC)
    - breakthrough end 1998 after > 5 years of R&D !
    - many small gaps (10x250 μm), 1 bar, simple gas & materials
    - **~ 1/10 cost, σ < 100 ps** , simple construction & operation,..



Inner Tracking System (ITS)



- **6 Layers, three technologies** **(keep occupancy ~constant ~2% for max mult)**
  - ⇨ **Silicon Pixels** (0.2 m^2, 9.8 Mchannels)
  - ⇨ **Silicon Drift** (1.3 m^2, 133 kchannels)
  - ⇨ **Double-sided Strip** (4.9 m^2, 2.6 Mchannels)

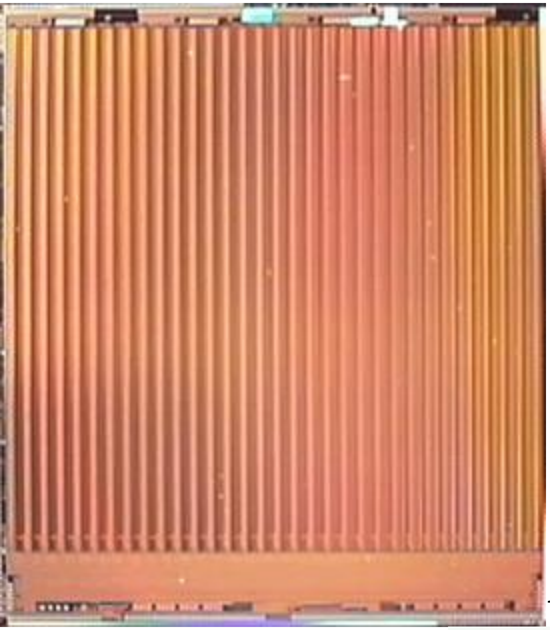
Material Budget: < 1% X_0 per layer !

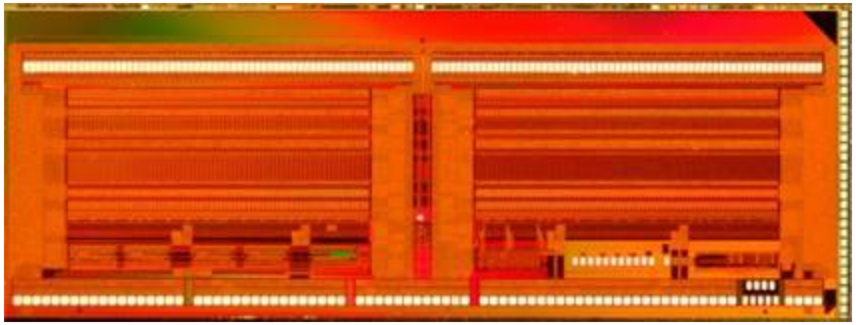
Major technological challenge!

ITS Electronics Developments

(all full-custom designs in rad. tol., 0.25 μm process)

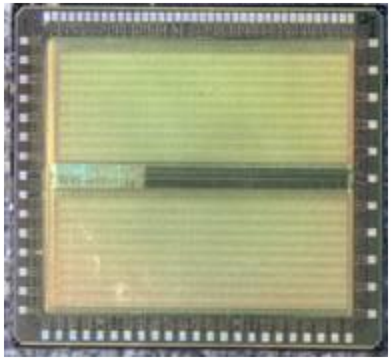
ALICE PIXEL CHIP
50 μm x 425 μm pixels
8192 cells
Area: 12.8 x 13.6 mm^2
13 million transistors
~100 μW/channel

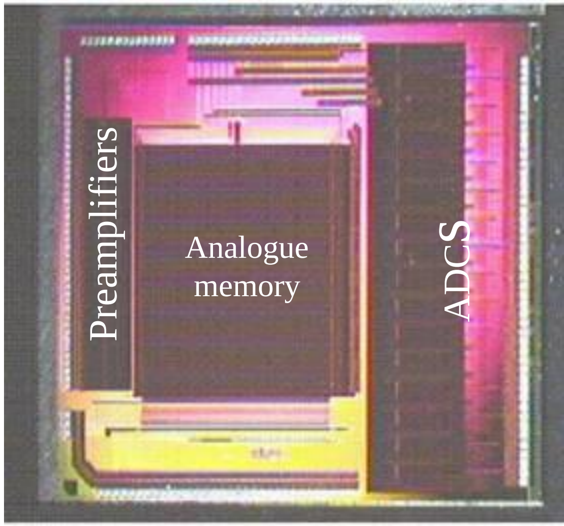




ALICE SSD FEE
HAL25 chip:
128 channels
Preamp+s/h+
serial out

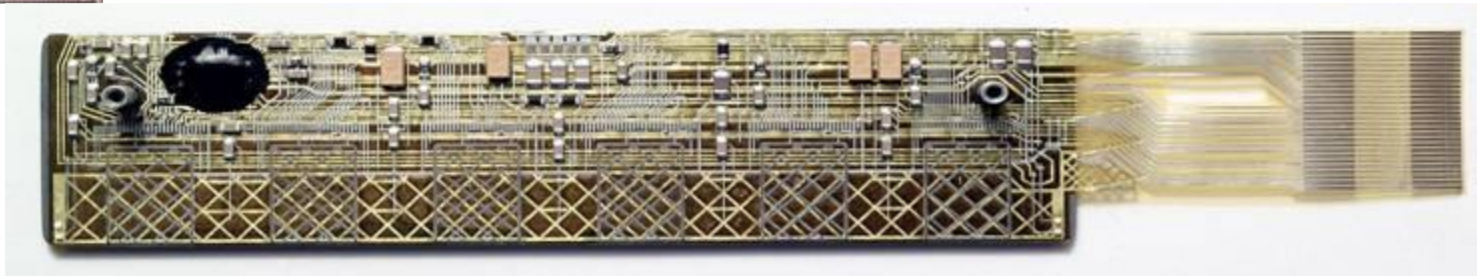
ALICE SDD FEE
Pascal chip:
64 channel preamp+ 256-deep
analogue memory+ ADC
Ambra chip:
64 channel
derandomizer
chip

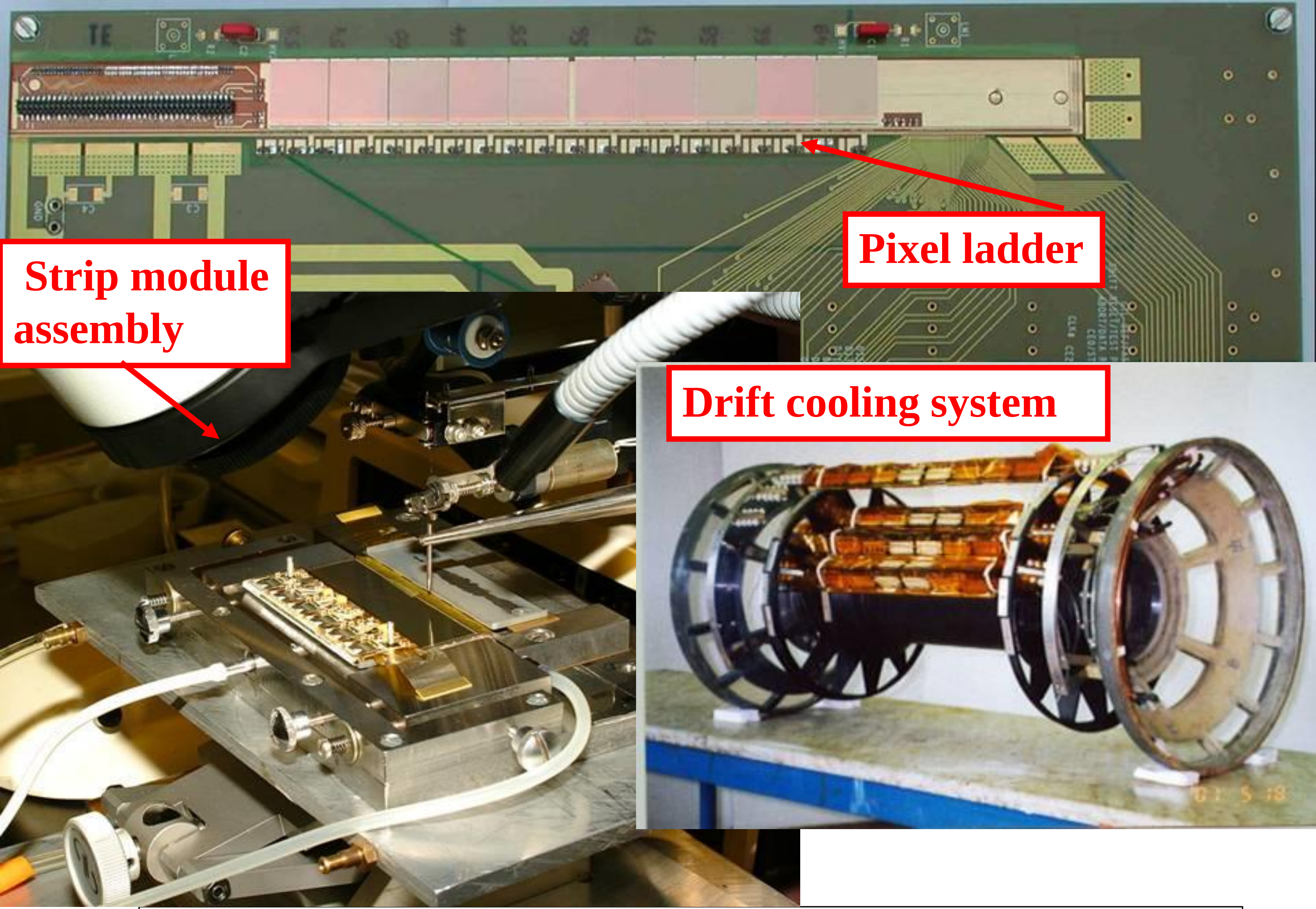




And extreme lightweight interconnection techniques:

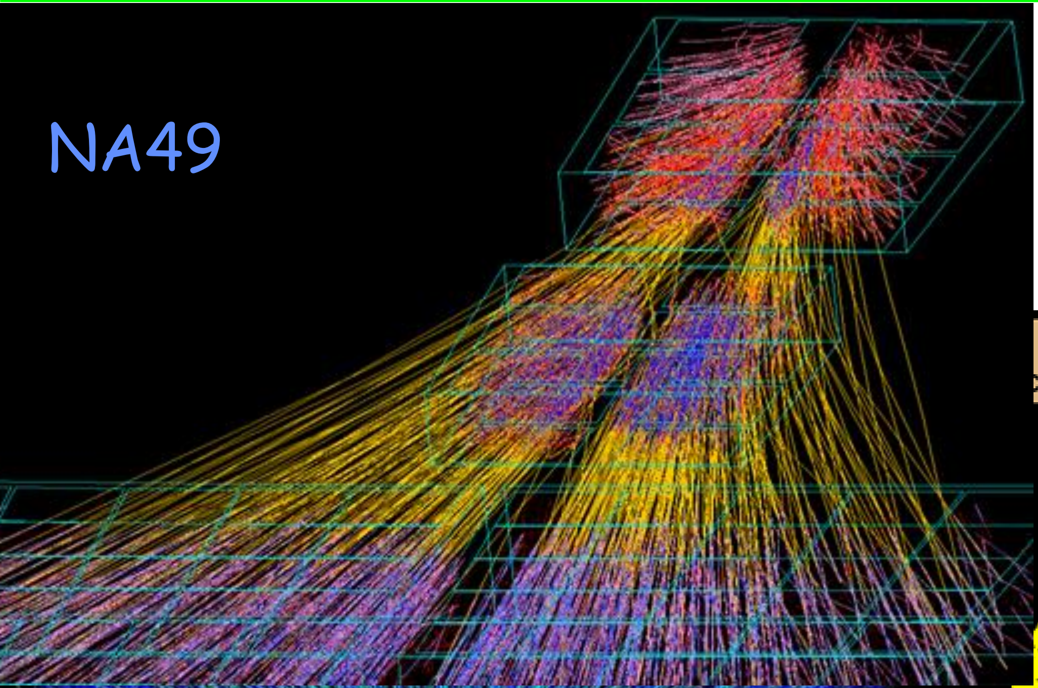
SSD tab-bondable
Al hybrids





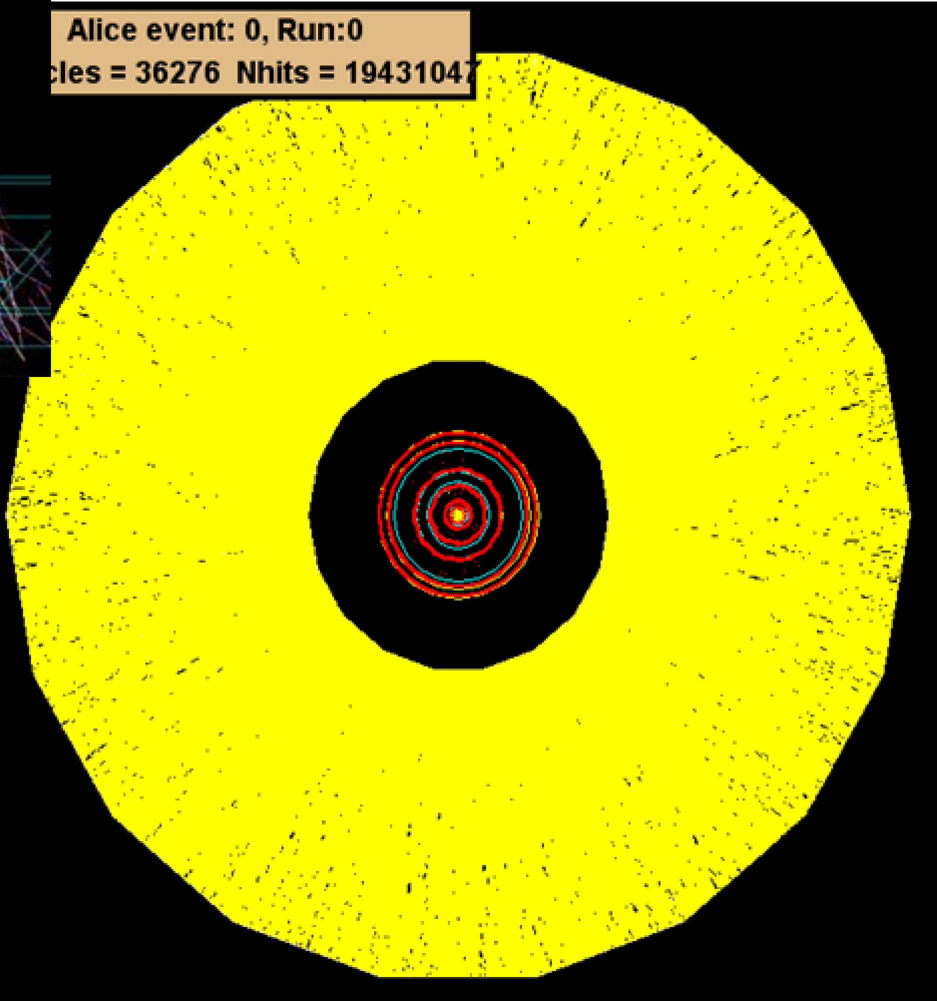
System testing and series production

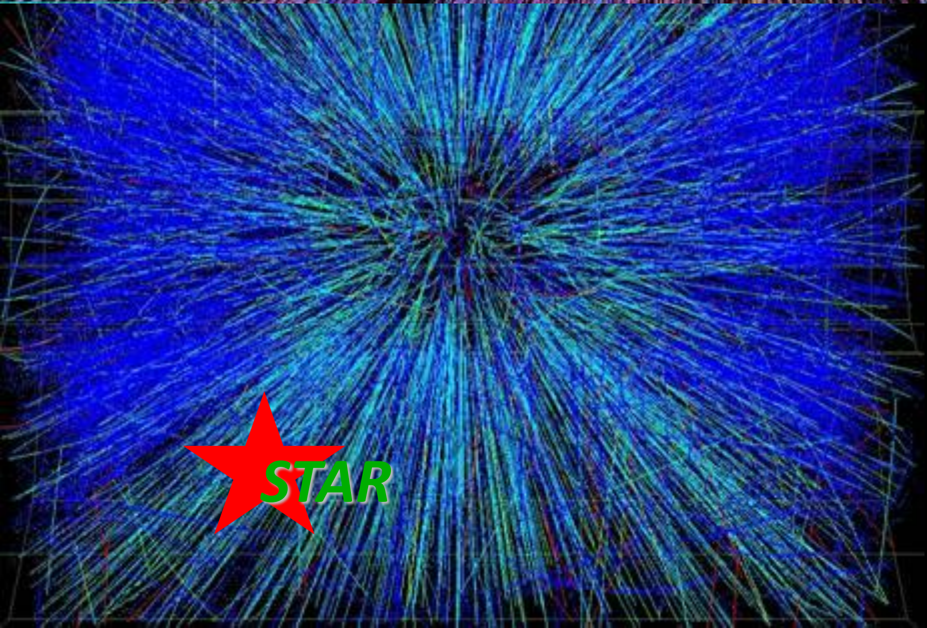
Tracking Challenge



ALICE 'worst case' scenario:

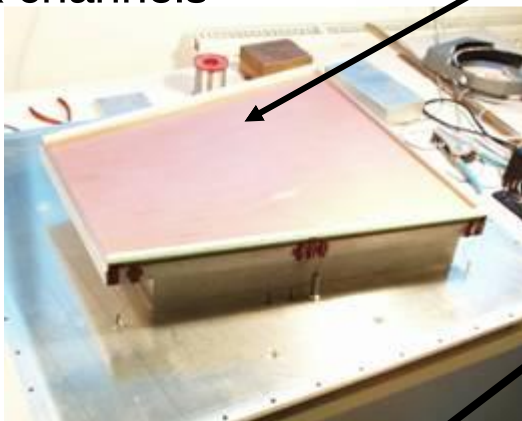
dN/dy_{ch} = 8000

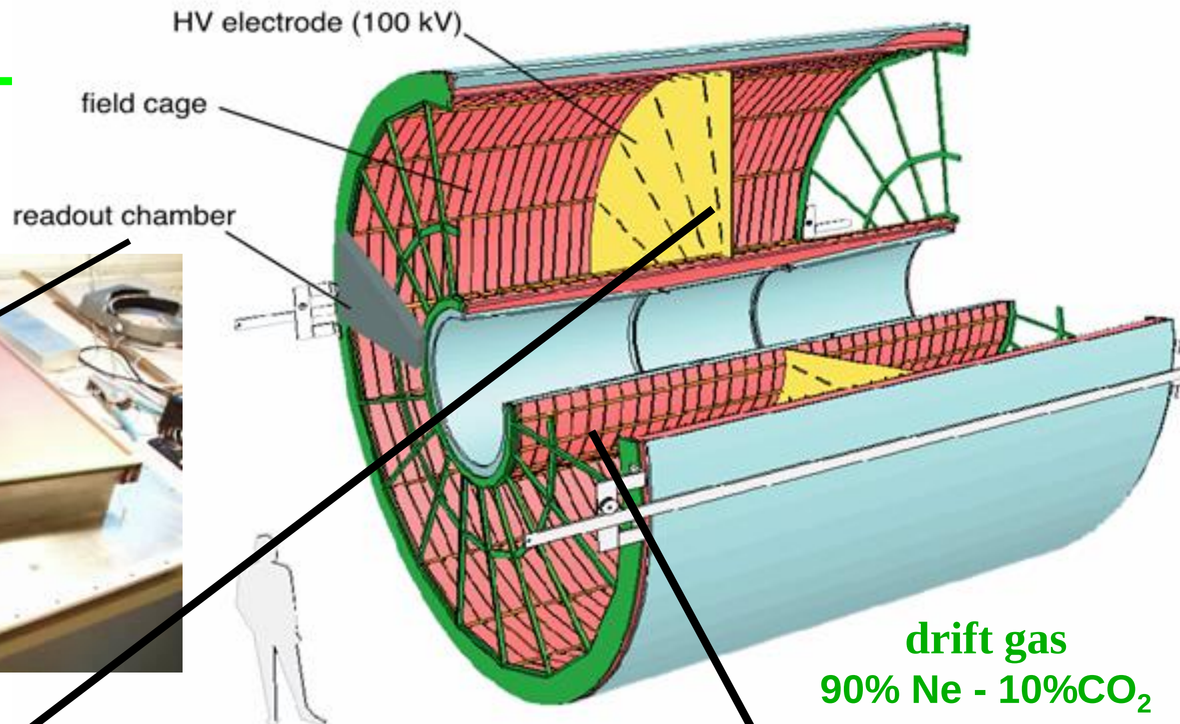




TPC

- **largest ever**
  - ⇨ 88 m^3, 570 k channels

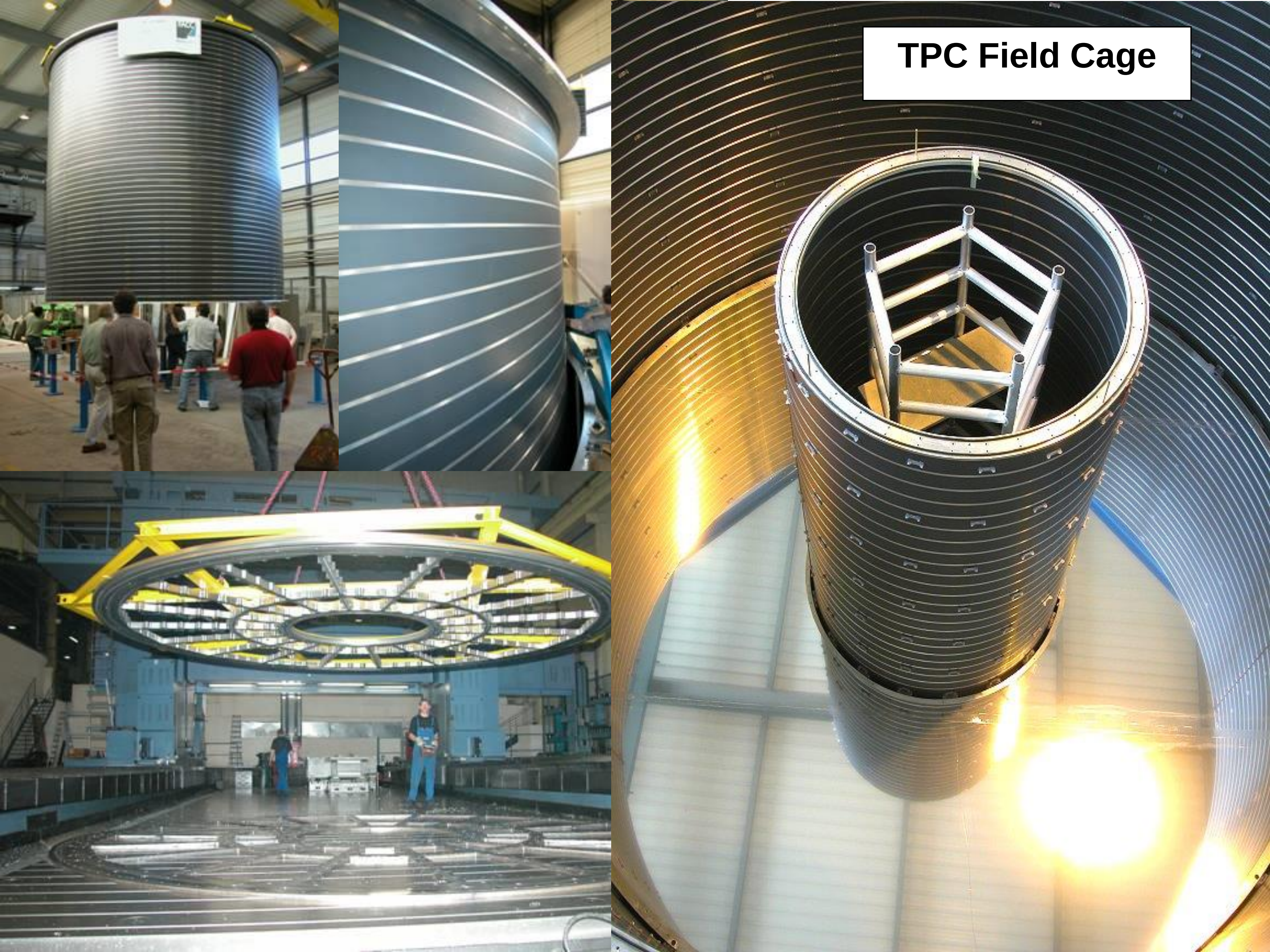


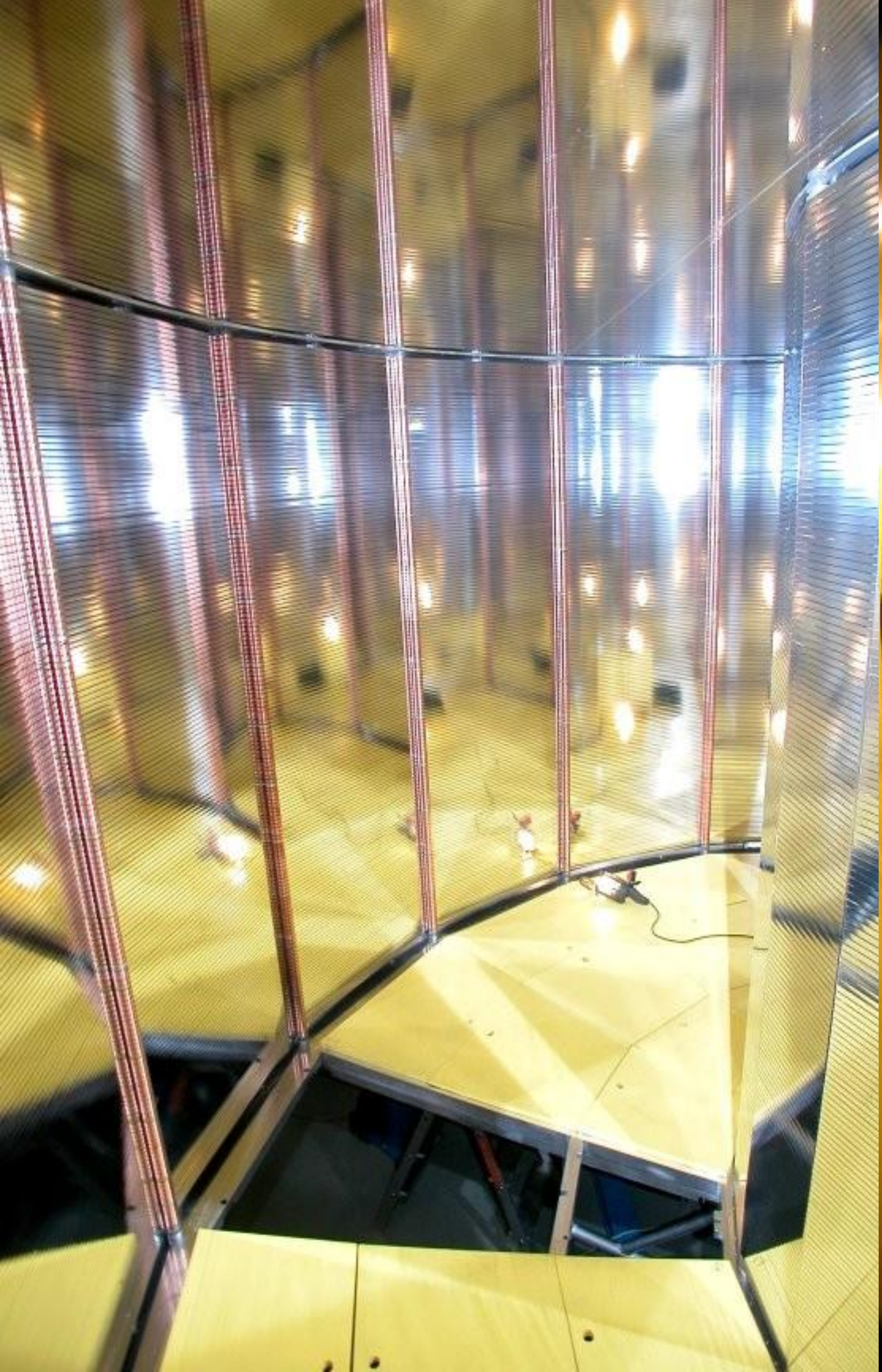


Central Electrode Prototype

25 µm aluminized Mylar on Al frame

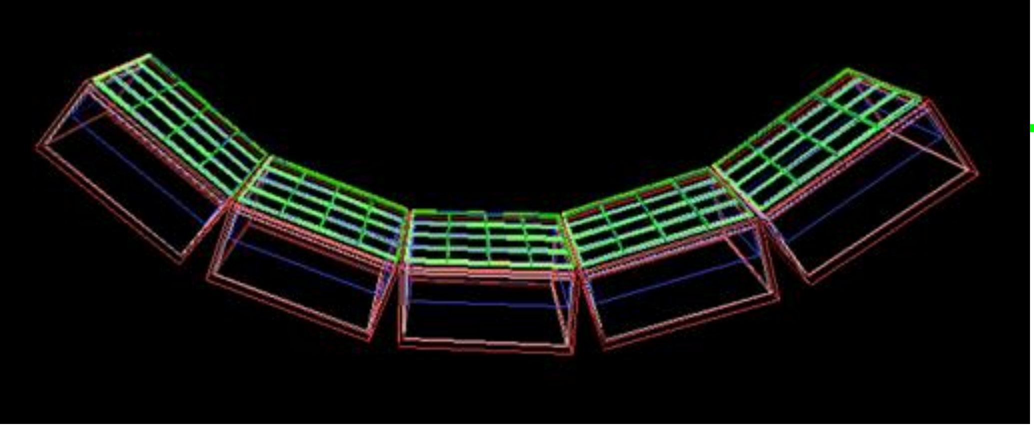
TPC Field Cage






TPC R/O chambers

- **production finished in Bratislava and GSI**



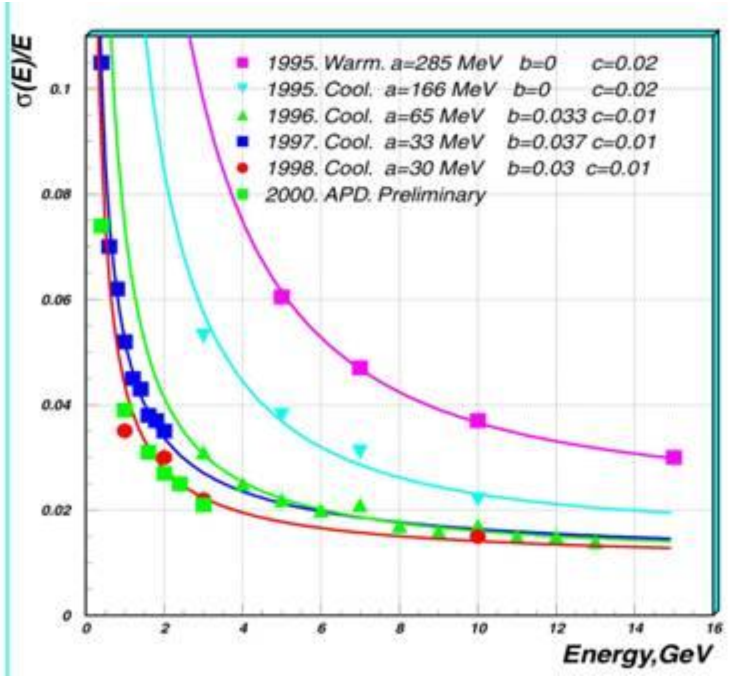
Photon Spectrometer

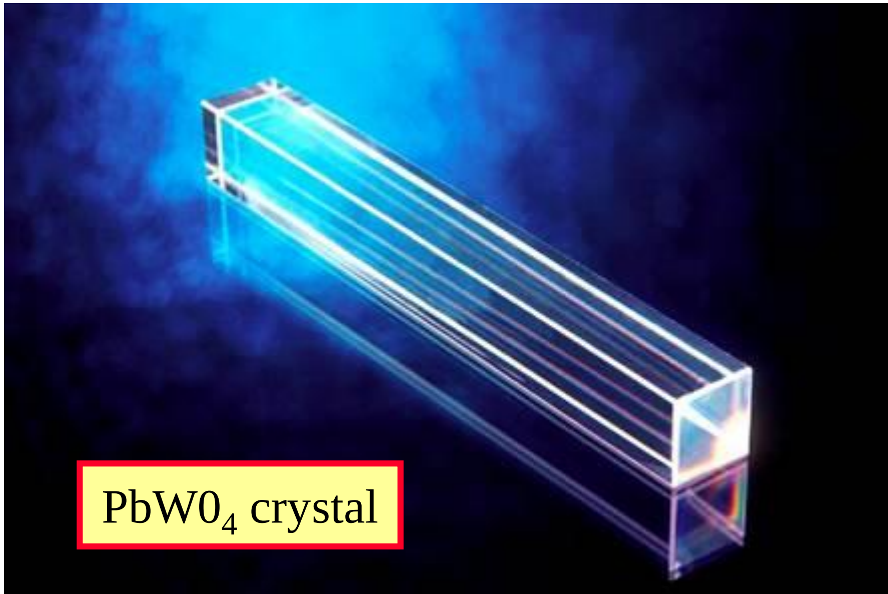
for photons, neutral mesons and γ-jet tagging

- single arm em calorimeter
  - ⇨ dense, high granularity crystals
    - ✪ novel material: $PbW0_4$
  - ⇨ ~ 18 k channels, ~ 8 m²
  - ⇨ cooled to -25°

$PbW0_4$: Very dense: X_0 < 0.9 cm
Good energy resolution (after 6 years R&D):

stochastic	2.7%/$E^{1/2}$
noise	2.5%/E
constant	1.3%

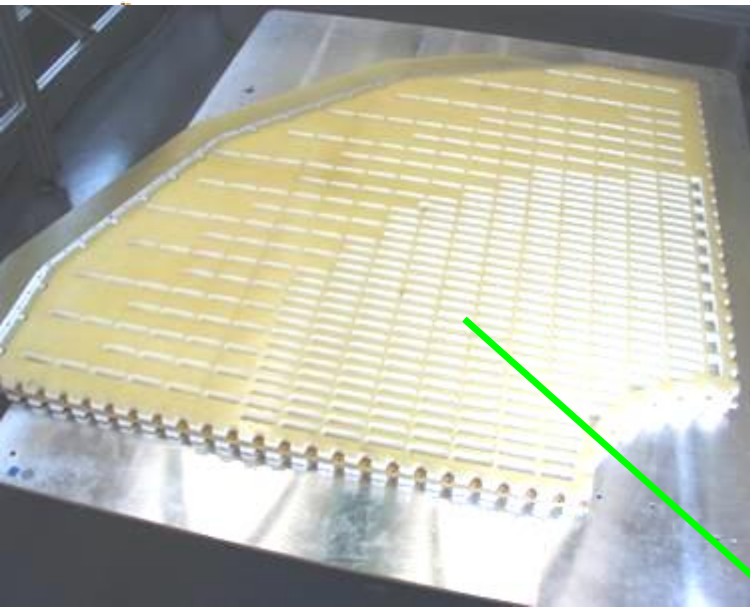




$PbW0_4$ crystal

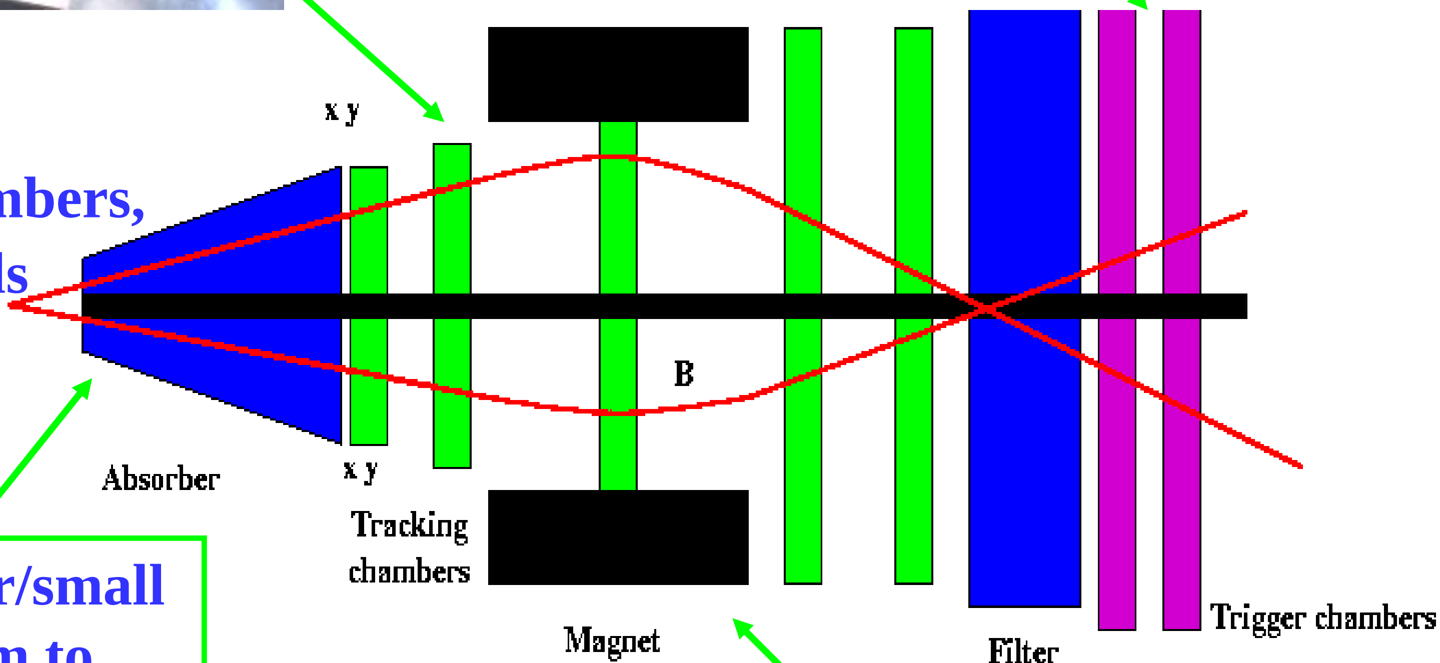
Dimuon Spectrometer

- Study the production of the J/Ψ, Ψ', Υ, Υ' and Υ'' decaying in 2 muons, $2.4 < \eta < 4$
- Resolution of 70 MeV at the J/Ψ and 100 MeV at the Υ



RPC Trigger Chambers

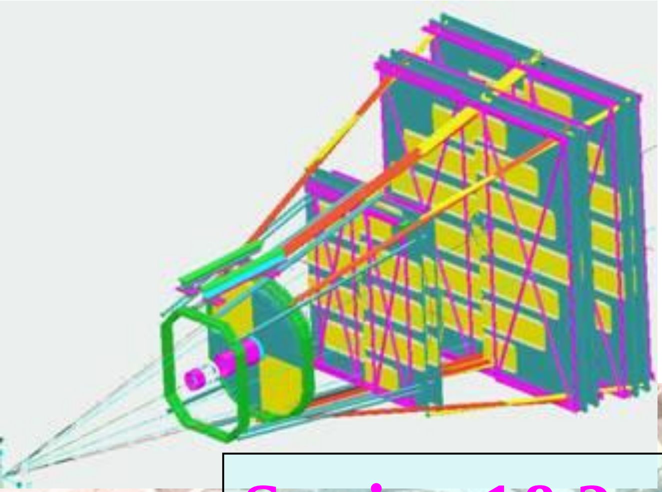
5 stations of high granularity pad tracking chambers, over 800k channels

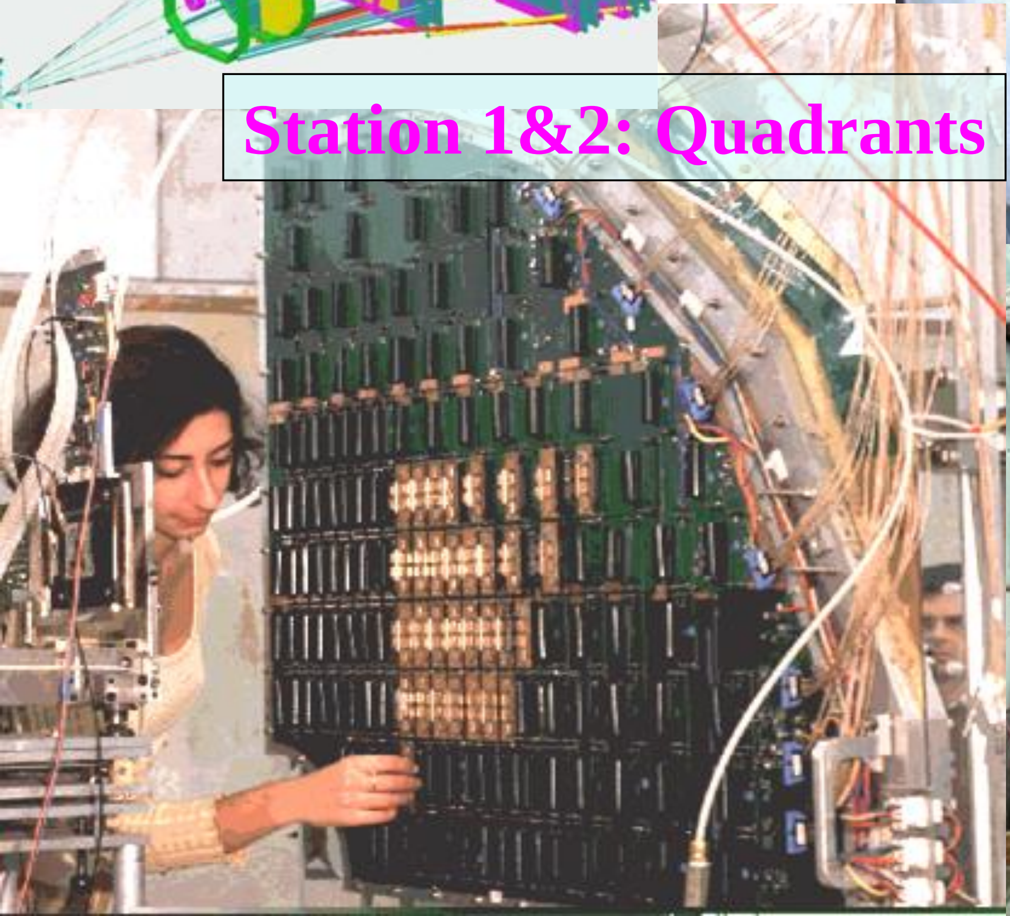


Complex absorber/small angle shield system to minimize background (90 cm from vertex)

Dipole Magnet: bending power 3Tm

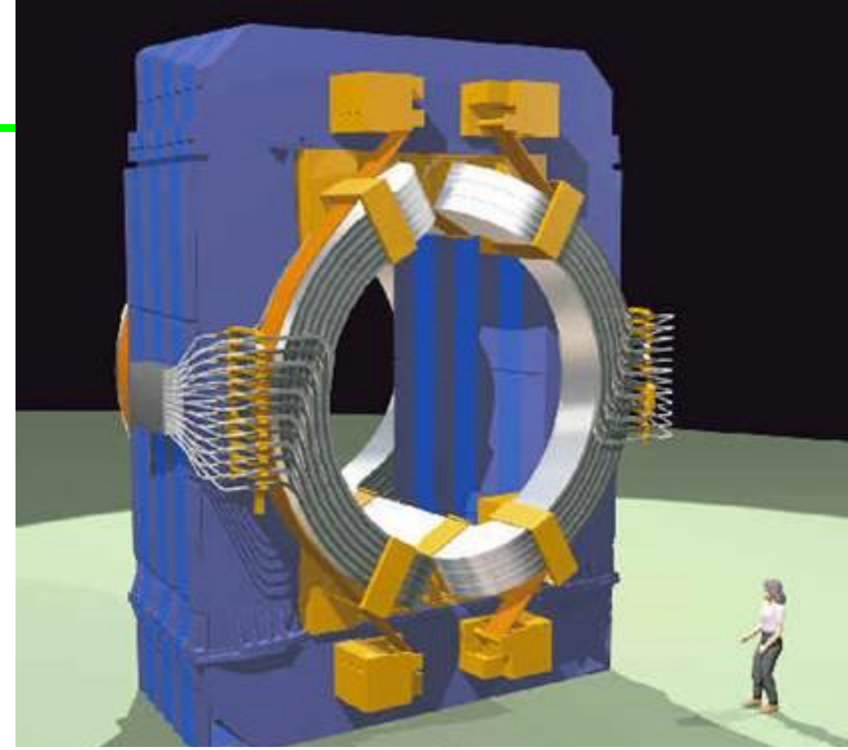
Muon Chambers

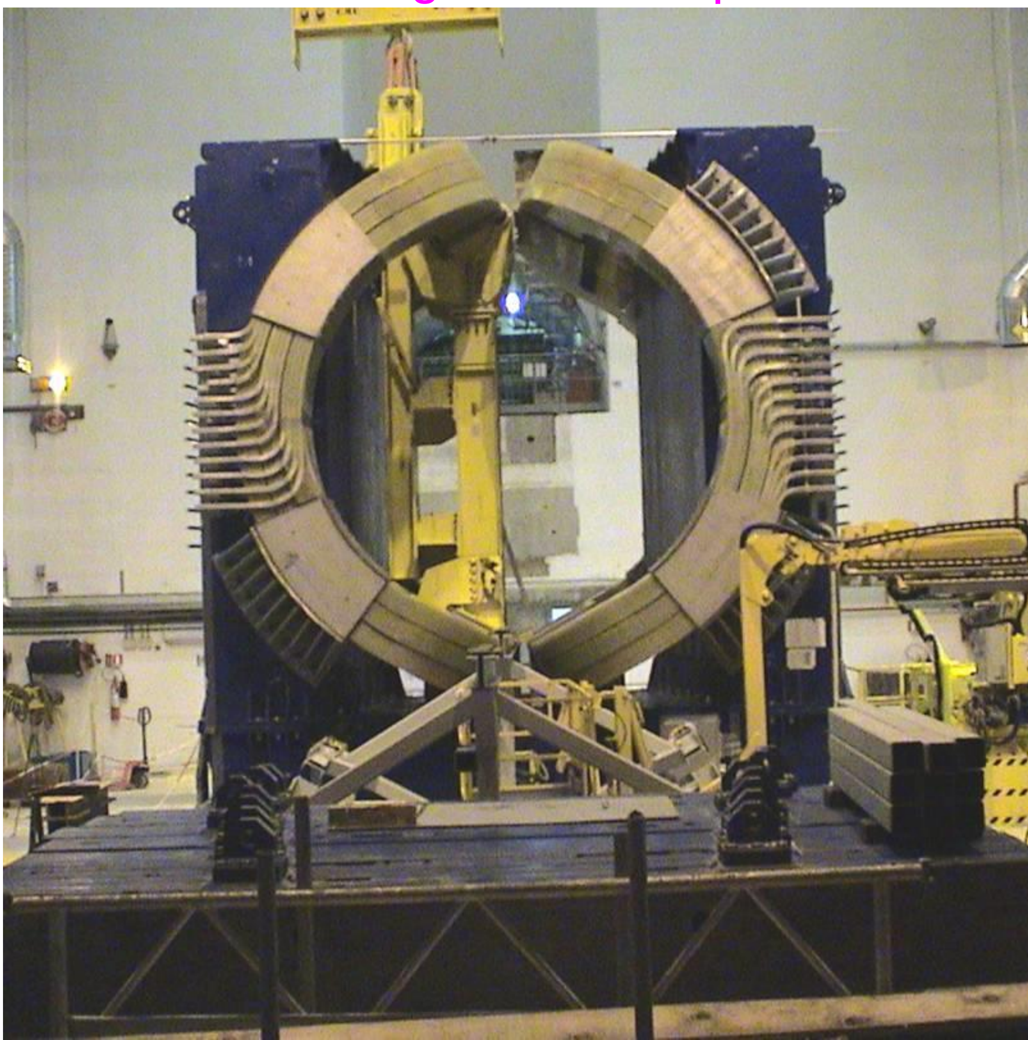




Muon Magnet

- **Dipole Magnet**
  - ⇨ 0.7 T and 3 Tm
  - ⇨ 4 MW power, 800 tons
  - ⇨ World's largest warm dipole





Computing Phase Transition

The Problem:

- **Online: storing up to 1.2 Gbyte/s**
  - ⇨ whole WWW in few hours on tape !
  - ⇨ ~ 10 x RHIC !
- **Offline: 18 MegaSI2000**
  - ⇨ 100,000 PC's in 2000 (500 Mhz)
  - ⇨ ~ 100 x RHIC !!

The Answer:

cheap mass market components

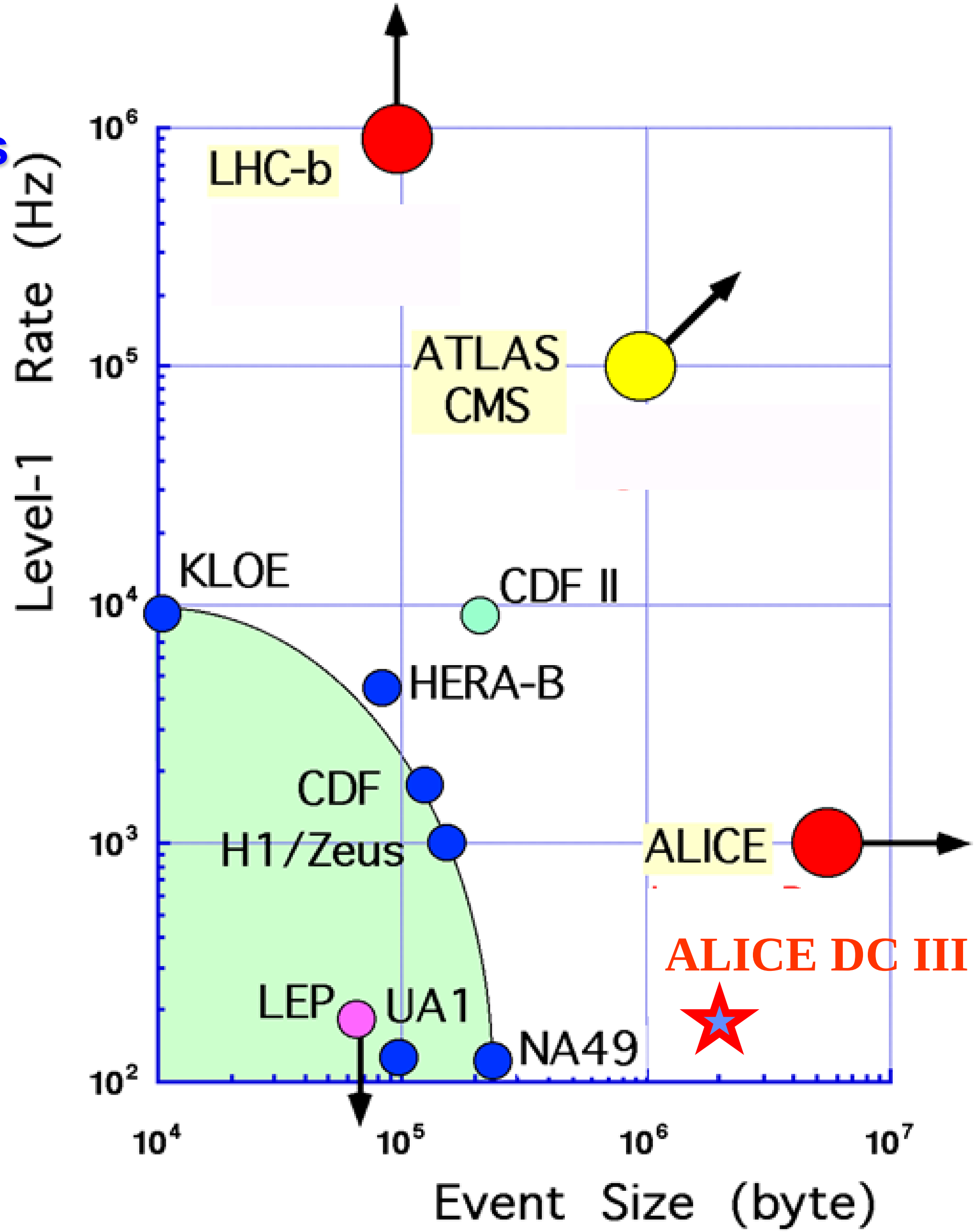
Industry & Moore's law

The Challenge:

make 100,000 mice do the work of one elephant

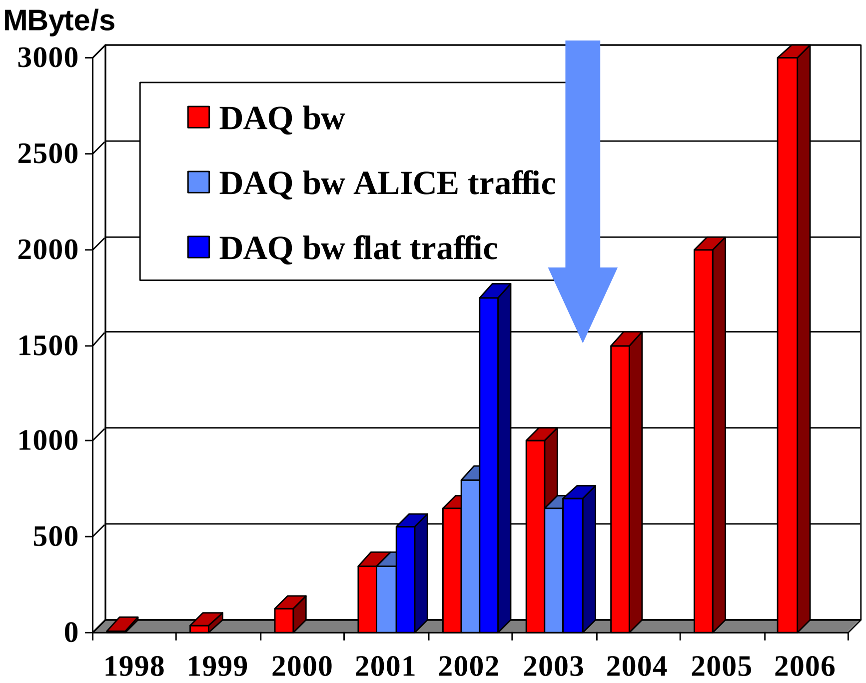
new computing paradigm:

The GRID

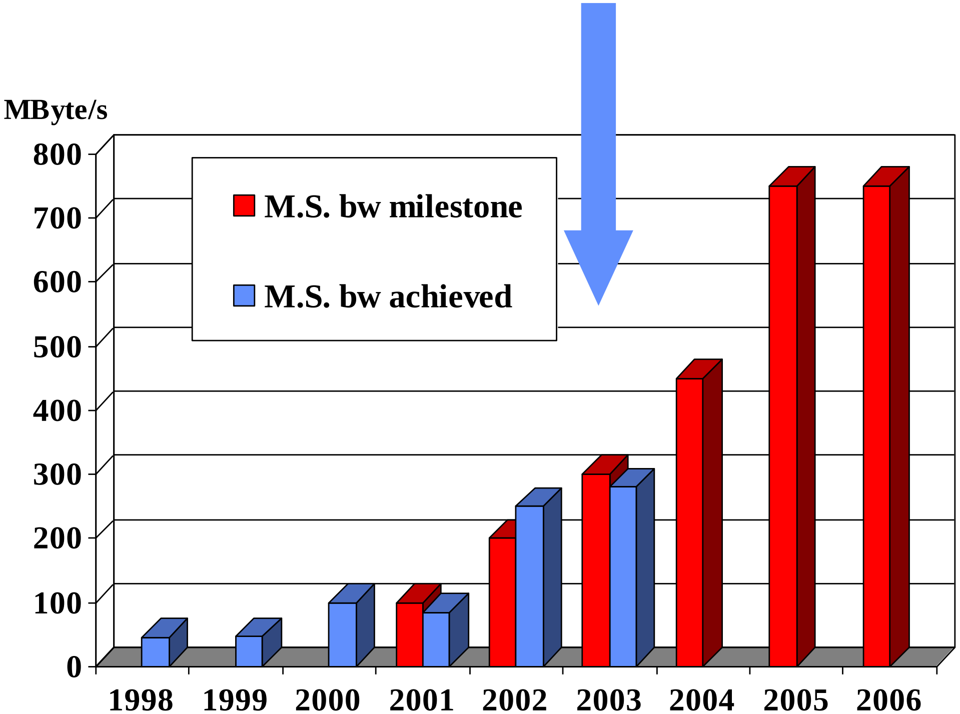


Data Challenges

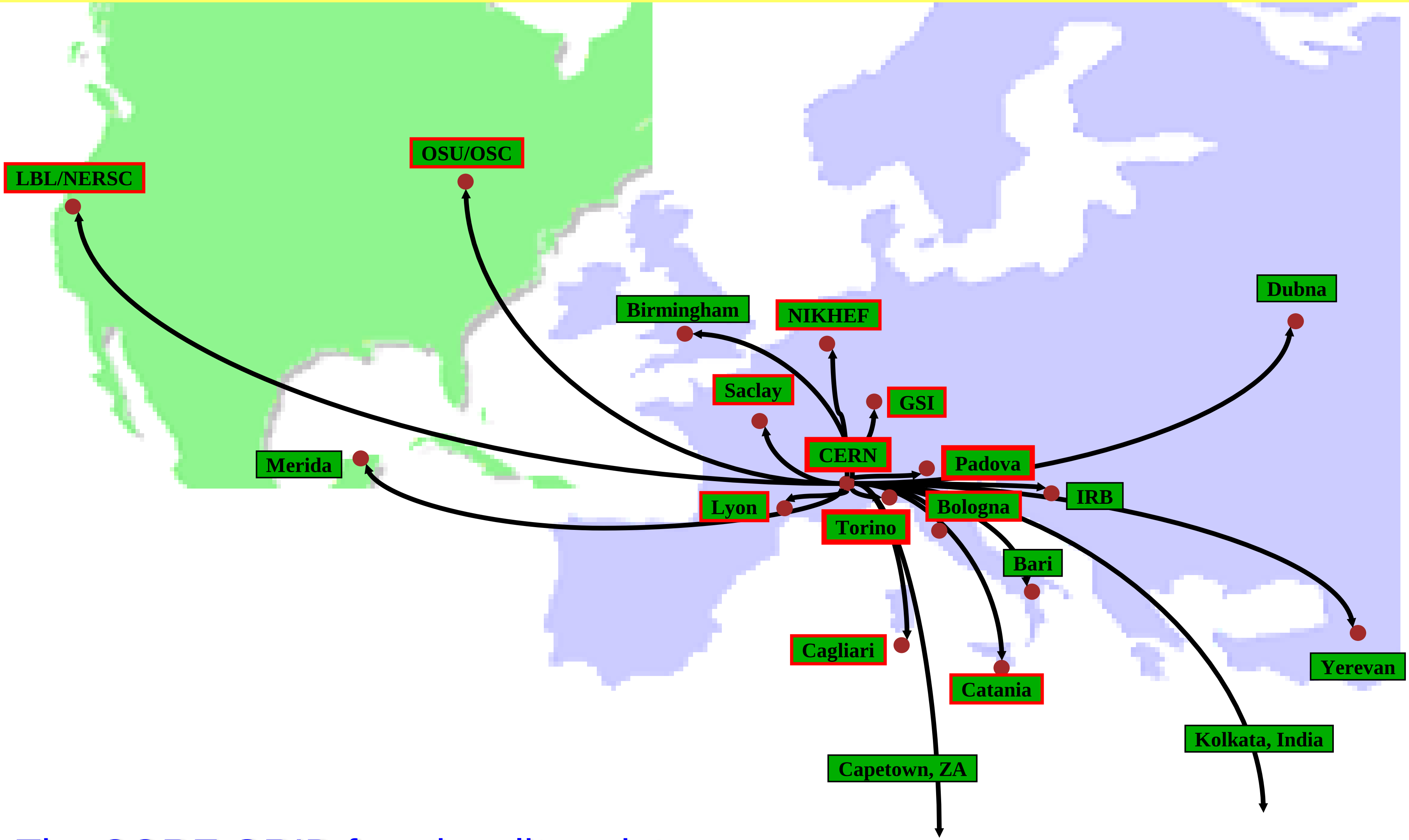
reduced number of components (PC's etc.) available in 2003



reliability of new equipment imperfect



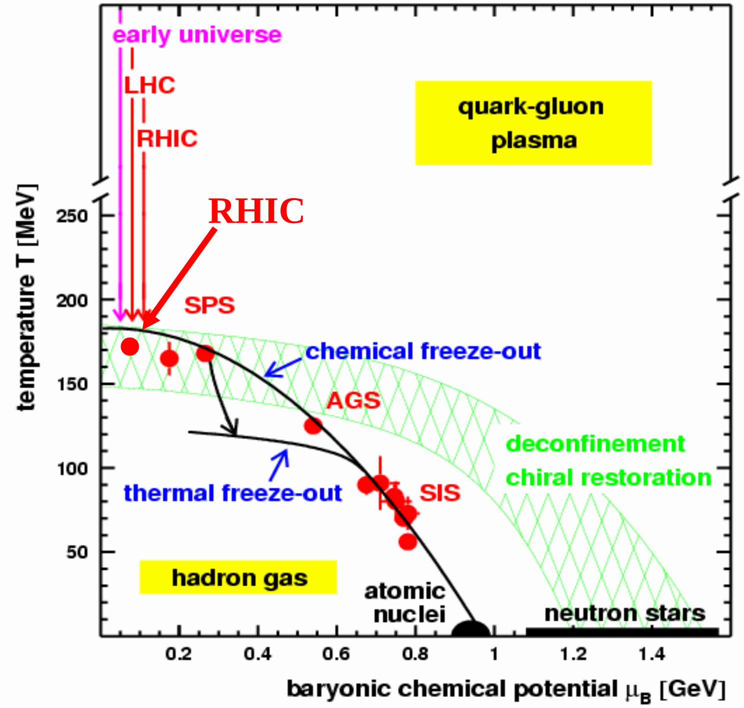
ALICE GRID is there: ALIEN

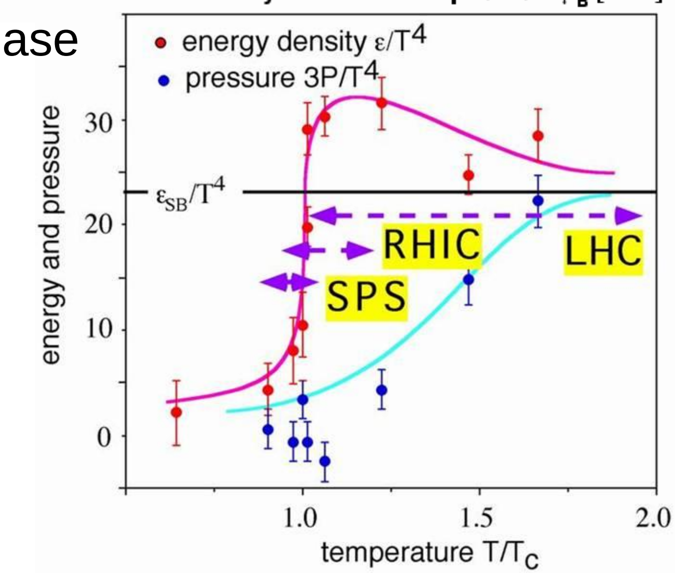


- The CORE GRID functionality exists
- Distributed production working, distributed analysis to be done...

Past-Present-Future

- **AGS/SPS: 1986 – 1994**
  - ⇨ existence & properties of **hadronic phase**
    - ✪ chemical & thermal freeze-out, collective flow,…
- **SPS: 1994 – 2003**
  - ⇨ '**compelling evidence** for **new state of matter** with many **properties** predicted for **QGP**'
    - ✪ J/Ψ suppression (deconfinement ?)
    - ✪ low mass lepton pairs (chiral restoration ?)
- **RHIC: 2000 - ?**
  - ⇨ **compelling evidence** -> **establishing** the **QGP** ?
    - ✪ parton flow, parton energy loss
  - ⇨ <u>**however**</u>: soft ~ semihard; lifetime hadron ~ parton phase
- **LHC: 2007 - ??**
  - ⇨ (semi)hard >> soft, lifetime parton >> hadron phase
  - ⇨ **precision spectroscopy** of '**ideal** plasma '**QGP**
    - ✪ heavy quarks (c,b), Jets, Y, thermal photons





LHC: will open the **next chapter** in HI physics
significant step over & above existing facilities
THE place to do **frontline research** after 2007

● LHC is ... ons

⇨ very sig

⇨ excellen

⇨ not only

● ALICE

⇨ first truly

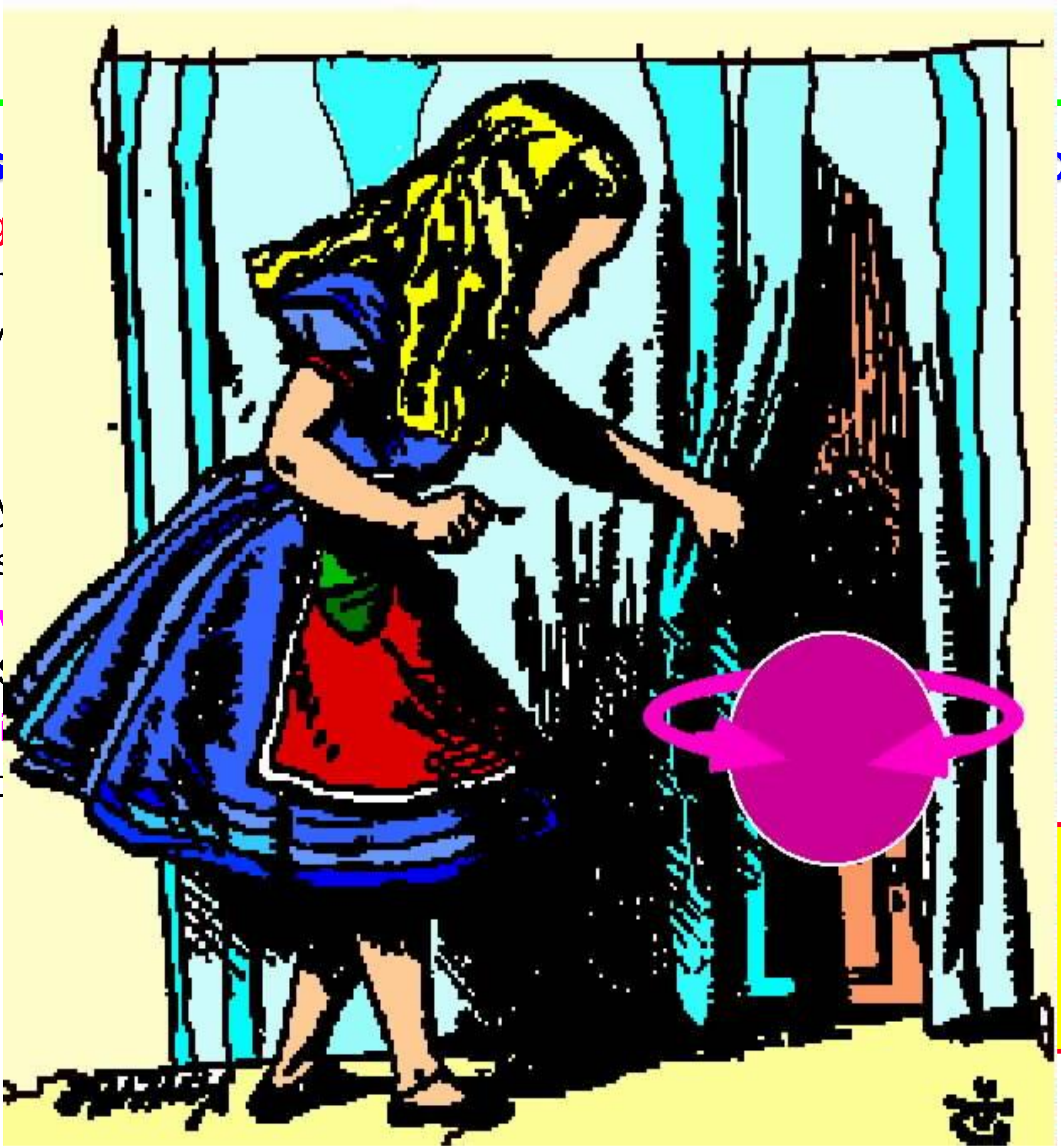
✪ addres

⇨ many ev

✪ SSD, S

⇨ some bi

✪ electro



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