ALICE at LHC : Detector and Physics

- Overview
  - The LHC as Ion collider
  - SPS-RHIC-LHC
  - Global properties in the LHC regime
- ALICE and its experimental strategy
  - Suite of detectors
  - Performance
  - Status
- Examples of ALICE' physics potential
  - Jets and jet suppression
  - Heavy Quarks
  - Direct photons

LHC as Ion Collider

- Running conditions:

Collision system	$\sqrt{s_{NN}}$ (TeV)	$\mathcal{L}_0$ ($cm^{-2}s^{-1}$)	$<\mathcal{L}>/\mathcal{L}_0$ (%)	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

$^*\mathcal{L}_{max}$(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).

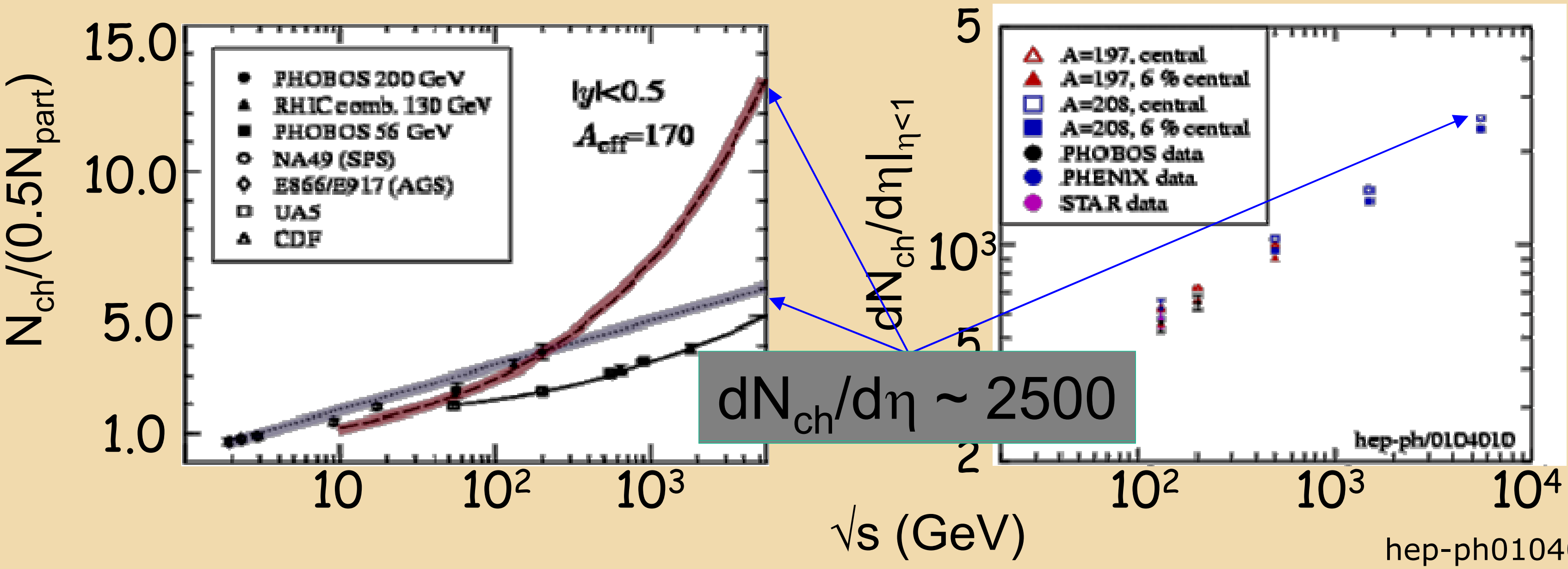
From SPS to RHIC to LHC 'hotter – bigger – longer lived'

Formation time τ_0 3 times shorter than RHIC
Lifetime of QGP τ_{QGP} factor 3 longer than RHIC
Initial energy density ε_0 3 to 10 higher than RHIC

Central collisions	SPS	RHIC	LHC
$s^{1/2}$(GeV)	17	200	5500
dN_{ch}/dy	500	850	2–8 $\times 10^3$
ε (GeV/fm^3)	2.5	4–5	15–40
V_f(fm^3)	10^3	7×10^3	2×10^4
τ_{QGP} (fm/c)	<1	1.5–4.0	4–10
τ_0 (fm/c)	~1	~0.5	<0.2

Novel aspects… Multiplicity

(from K.Kajantie, K.Eskola)

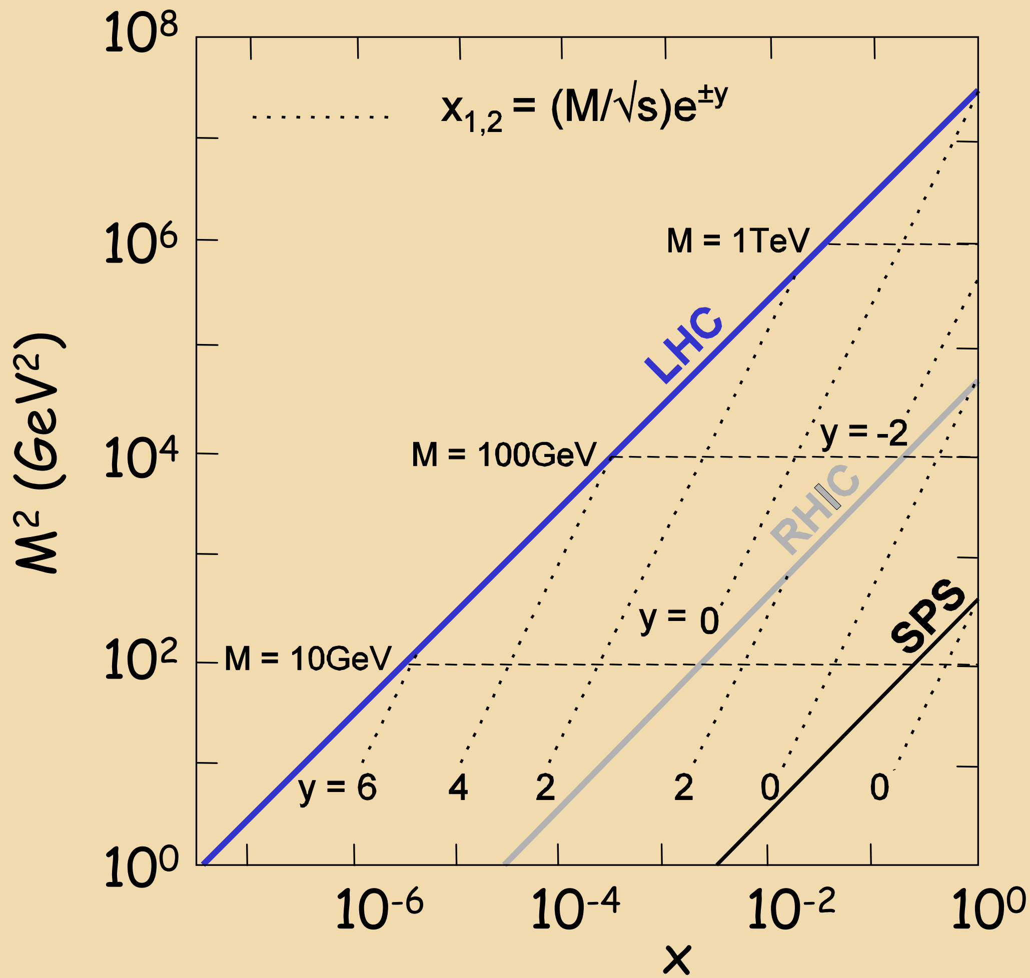


hep-ph0104010

Even with RHIC data extrapolation to LHC uncertain
Expect multiplicity in range dN/dy (charged) ~ 1500 to 6000
ALICE optimized for dN/dy(charged) 4000; operational up to ~ 8000

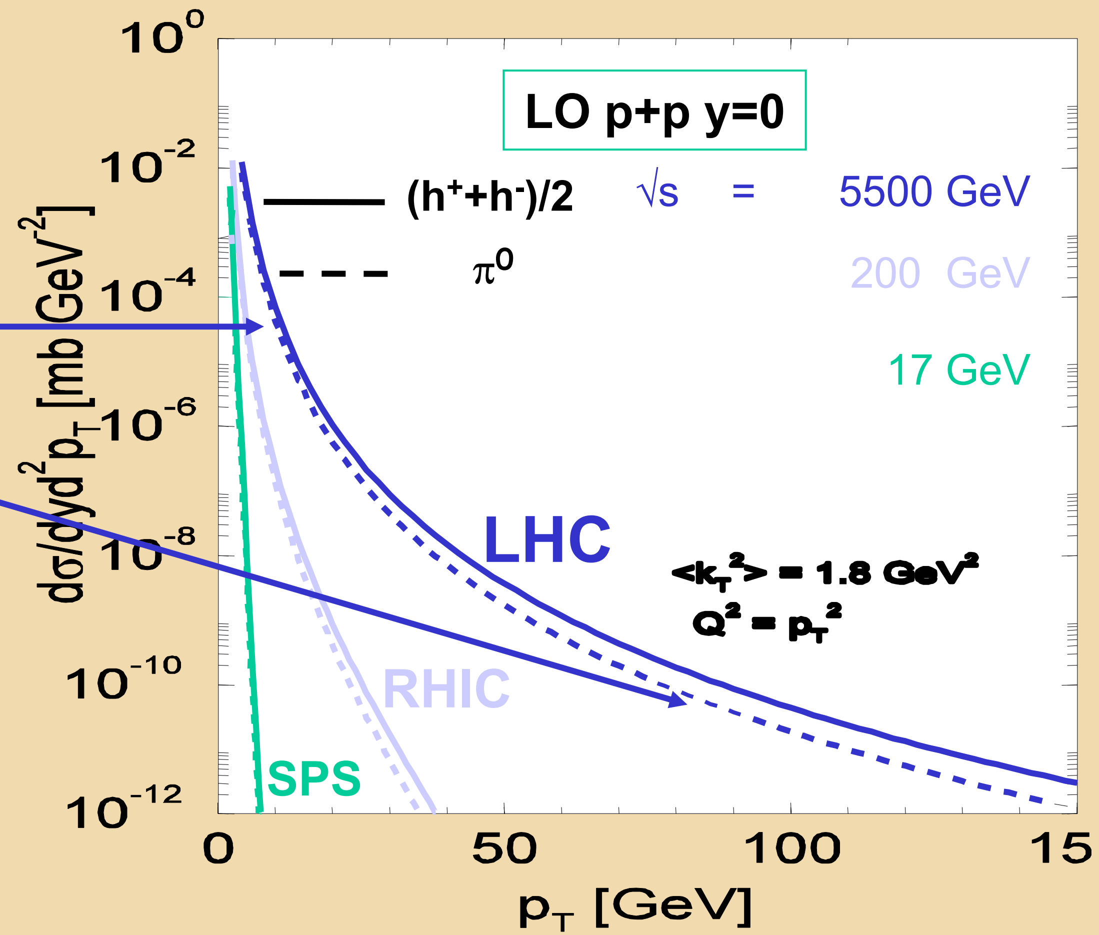
Novel Aspects… soft processes

- Probe initial partonic state in a novel Bjorken-x range (10^{-3} - 10^{-5}):
  - nuclear shadowing,
  - high-density saturated gluon distribution.
- Larger saturation scale ($Q_S=0.2A^{1/6}\sqrt{s}^{\delta}= 2.7$ GeV): particle production dominated by the saturation region.



Novel Aspects…Hard processes

- Hard processes contribute significantly to the total AA cross-section (σhard/σtot = 98%)
  - ⇨ Bulk properties dominated by hard processes
  - ⇨ Very hard probes are abundantly produced
- Weakly interacting probes become accessible (γ, Z^0, $W^{\pm}$)



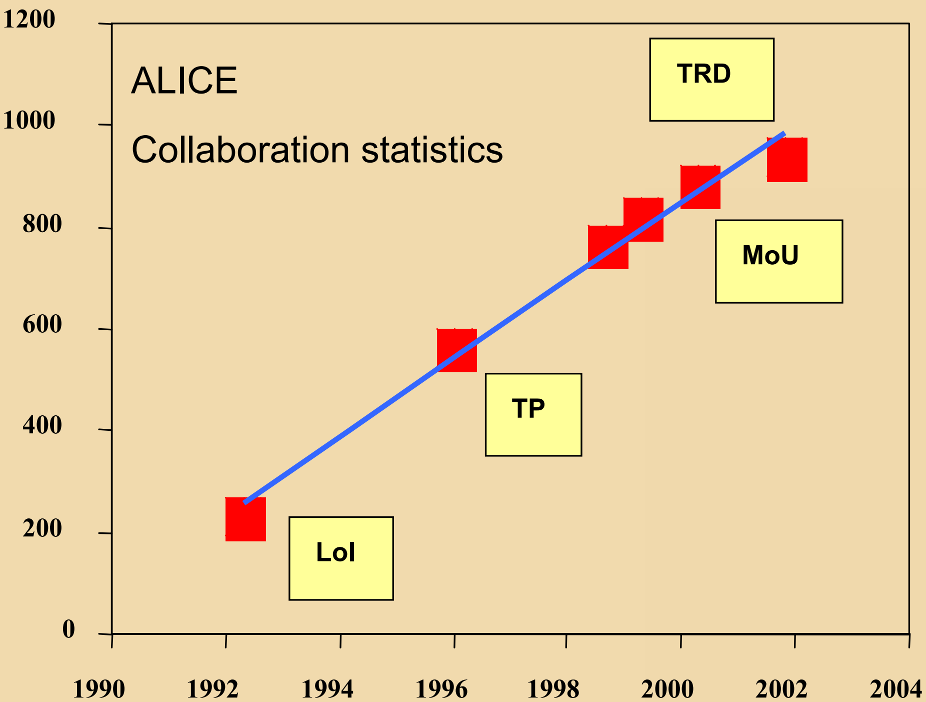
ALICE Physics Reach…

- Global properties
  - Multiplicities, η distributions
- Degrees of Freedom vs Temperature
  - Hadron ratios and spectra
  - Dilepton continuum
  - Direct photons
- Collective effects
  - Elliptic flows
- De-confinement
  - Charmonium, bottonium spectroscopy
- Chiral symmetry restoration
  - Neutral to charge ratio
  - Resonance decays
- Partonic energy loss in QGP
  - Jet quenching, high p_T spectra
  - Open charm and beauty
- Geometry of emission
  - HBT, zero-degree energy flow
- Fluctuations and critical behavior
  - Event-by-event particle composition and spectroscopy

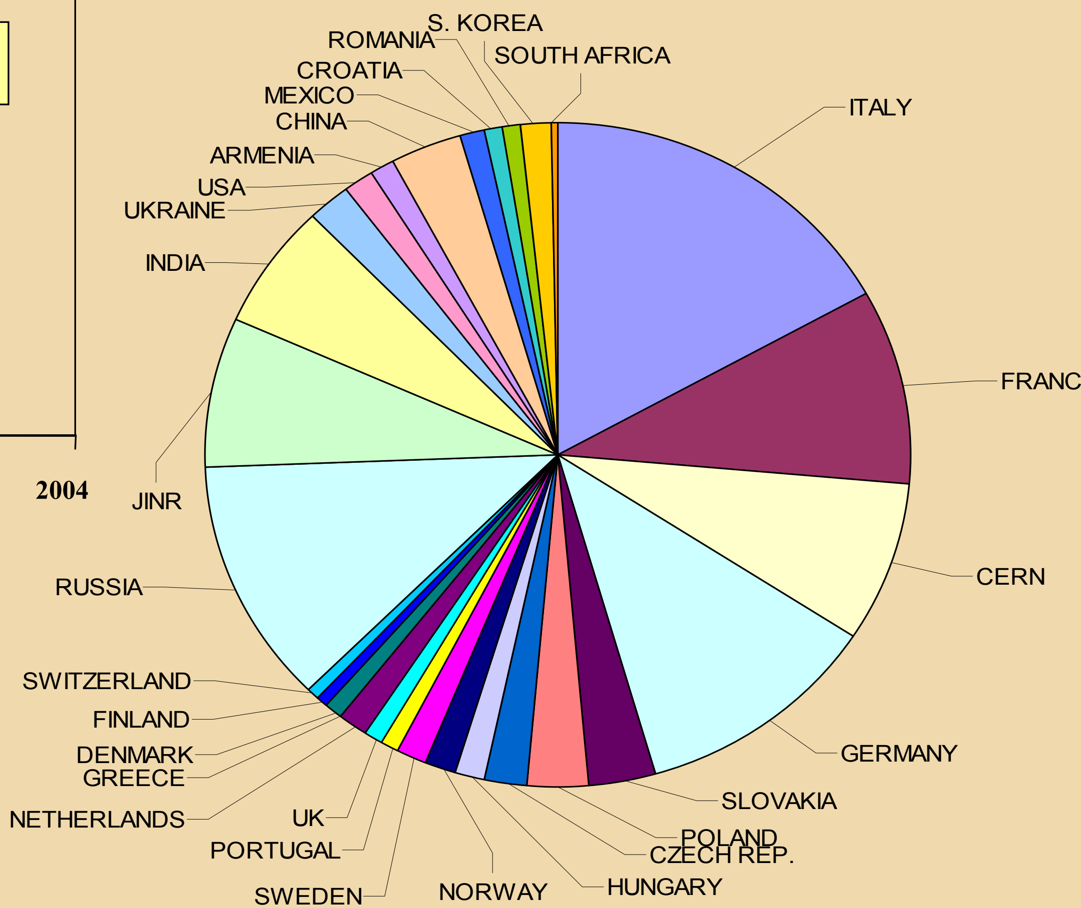
...and experimental consequences for ALICE

- Large Acceptance Coverage
- Large Momentum Coverage (from 100 MeV/c to > 100 GeV/c)
- High Granularity (designed for dN/dy ~ 8000, i.e. 15 000 particles in acceptance)
    - Spectroscopy and Identification of
        - hadrons and leptons
- c-, b- vertex recognition
- Excellent photon detection (in $\Delta\varphi = 45^0$ and $\eta = 0.1$)
- Large acceptance em calorimetry very desirable, for which only the infrastructure exists, but not yet the detector

ALICE collaboration

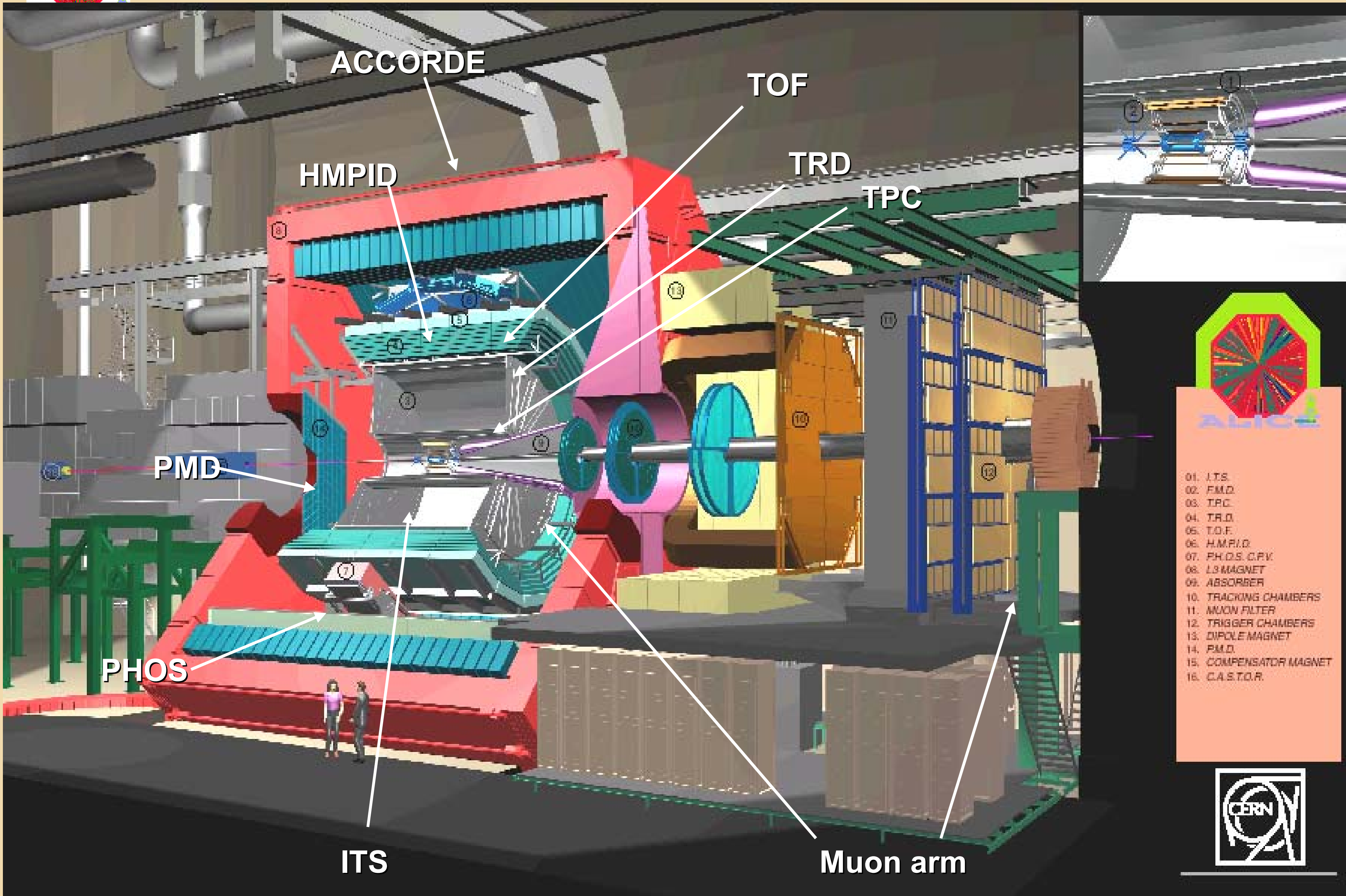


After more than 10 years of life, still healthy and growing!

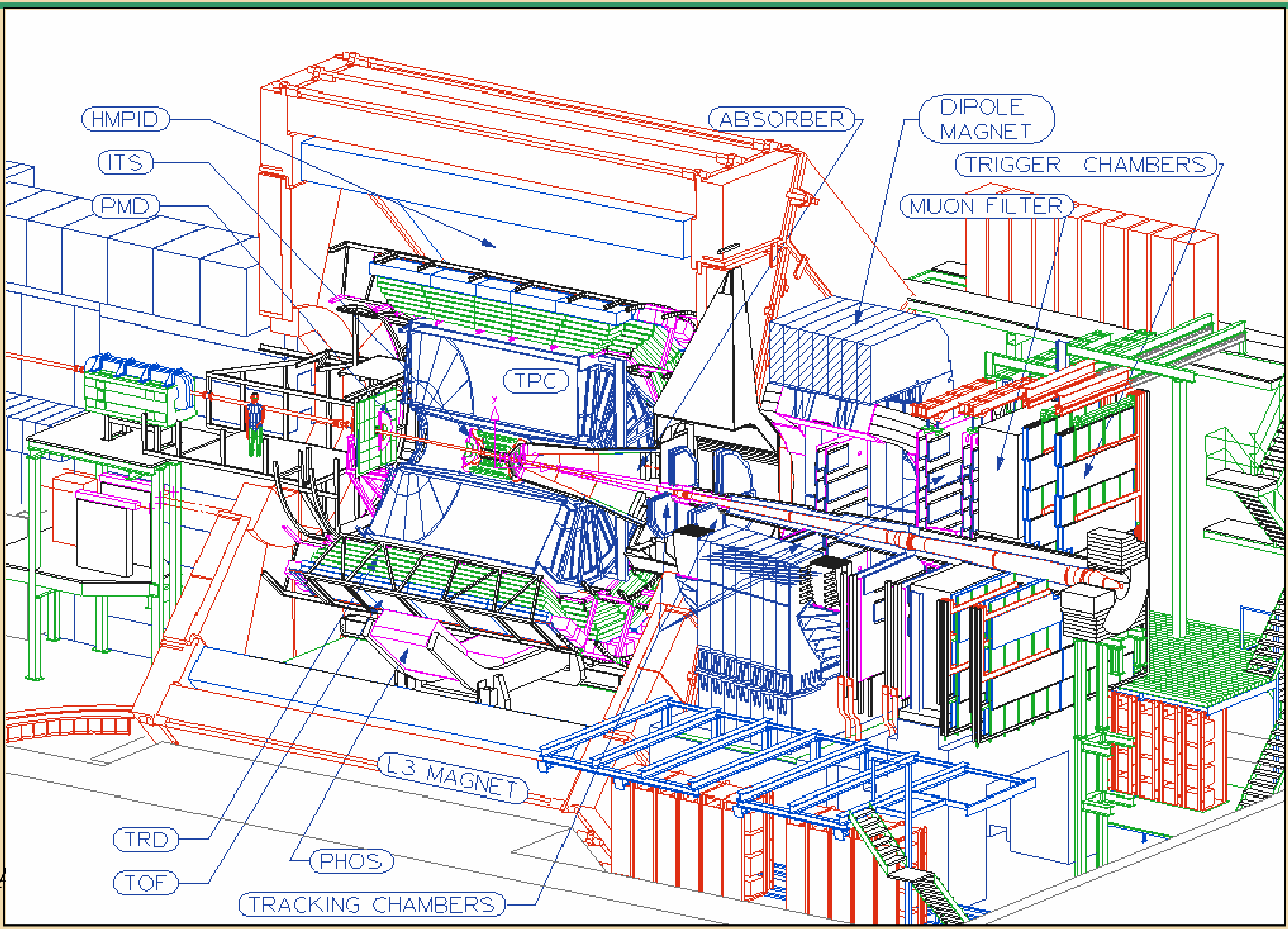


- 937 members
- 77 Institutions
- Discussion with China, Japan, US

ALICE Detector



Stable Layout; Services (Cables, Cooling, Gas…)being installed



ALICE Detector Suite: selected highlights

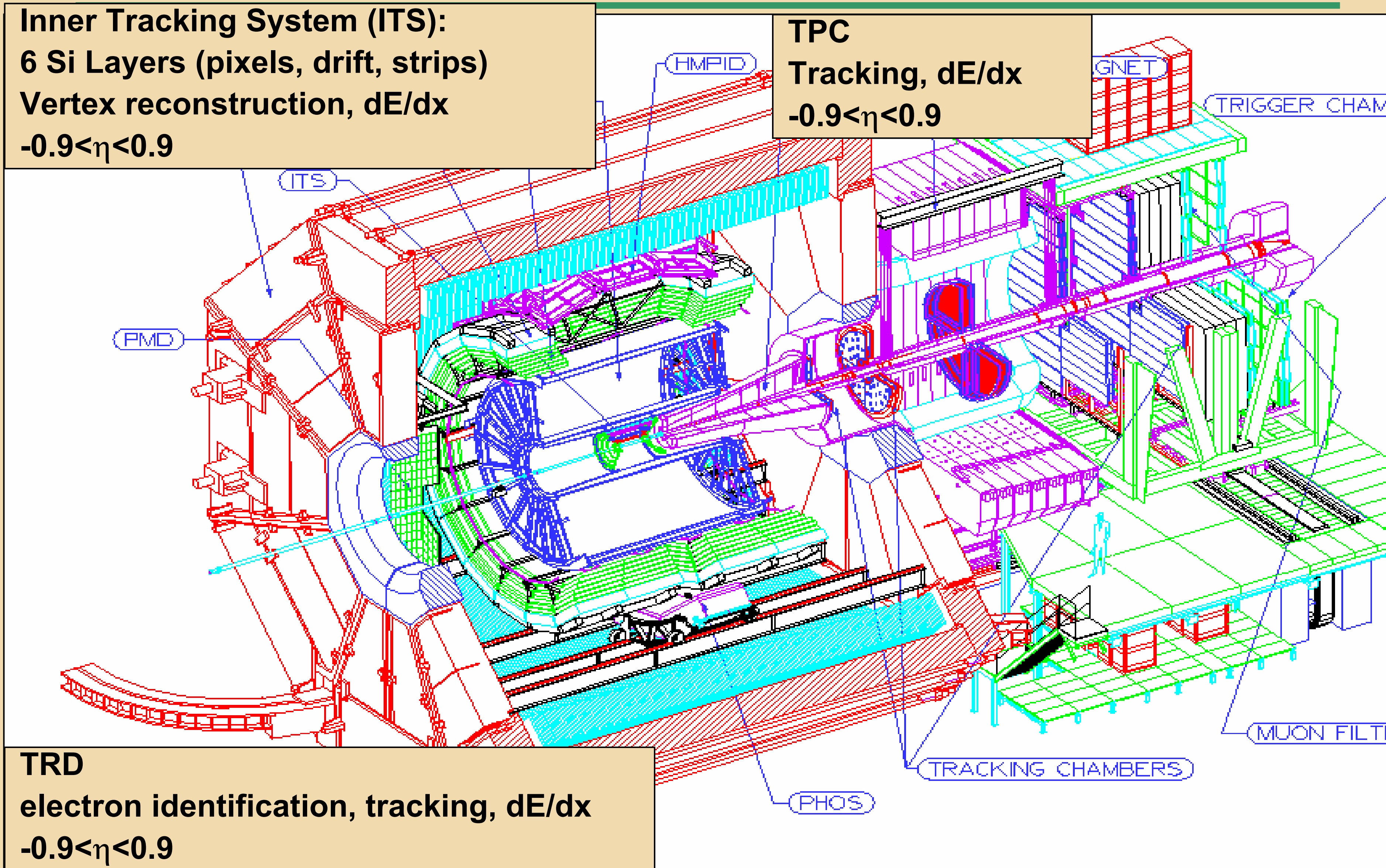
- **Inner Silicon Tracker**
  - **Pixels, Si- Drift, Si- strips**
- **TPC : the world's largest**
  - **Very ambitious performance specifications**
  - **Highly integrated readout electronics**
- **Transition radiation detector**
  - **$1.2*10^6$ channels; trigger capability; (need collaborators for completion; discussions with Japan)**
- **HMPID : large area RICH with CsI photo-cathodes**
- **FMD: large area Si- multiplicity detector array to complement central tracking**
- **PHOS : a 20 000 $PbWO_4$ crystal calorimeter (need collaborators for completion; discussions with China and Japan)**
- **Muon Spectrometer**
  - **with the world's largest warm dipole**
  - **Advanced $1.2*10^6$ channel precision tracker**
- **Infrastructure for large EM Calorimeter installed**
  - **In discussion with US groups**
- **And, and … arrays of specialized detectors**

Inside the Solenoid for the central detectors; L3 legacy of LEP

ALICE Layout: Tracking (and event characterization)

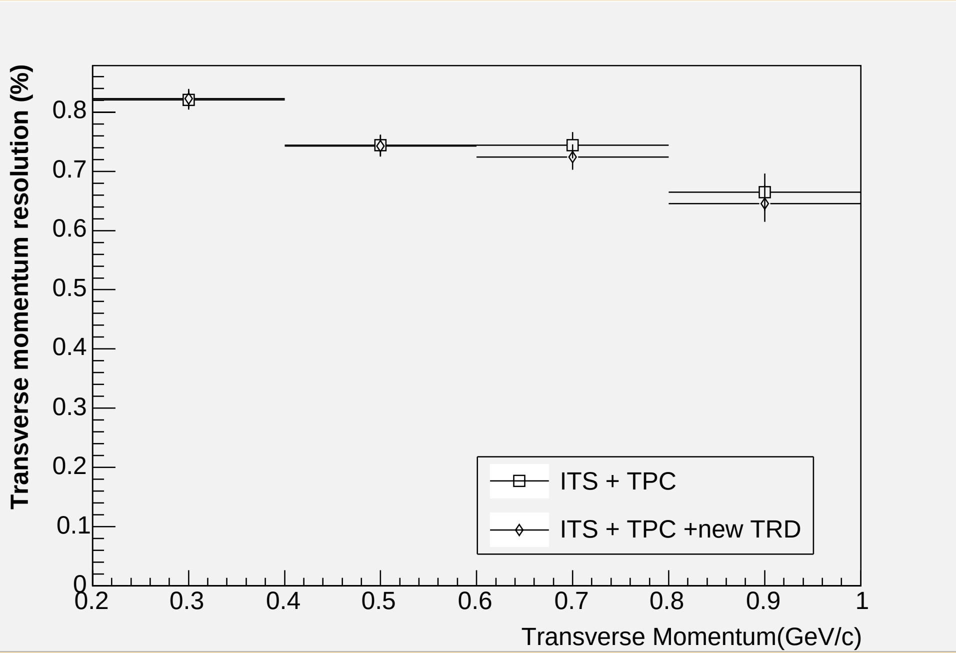
Inner Tracking System (ITS):
6 Si Layers (pixels, drift, strips)
Vertex reconstruction, dE/dx
-0.9<η<0.9

TPC
Tracking, dE/dx
-0.9<η<0.9



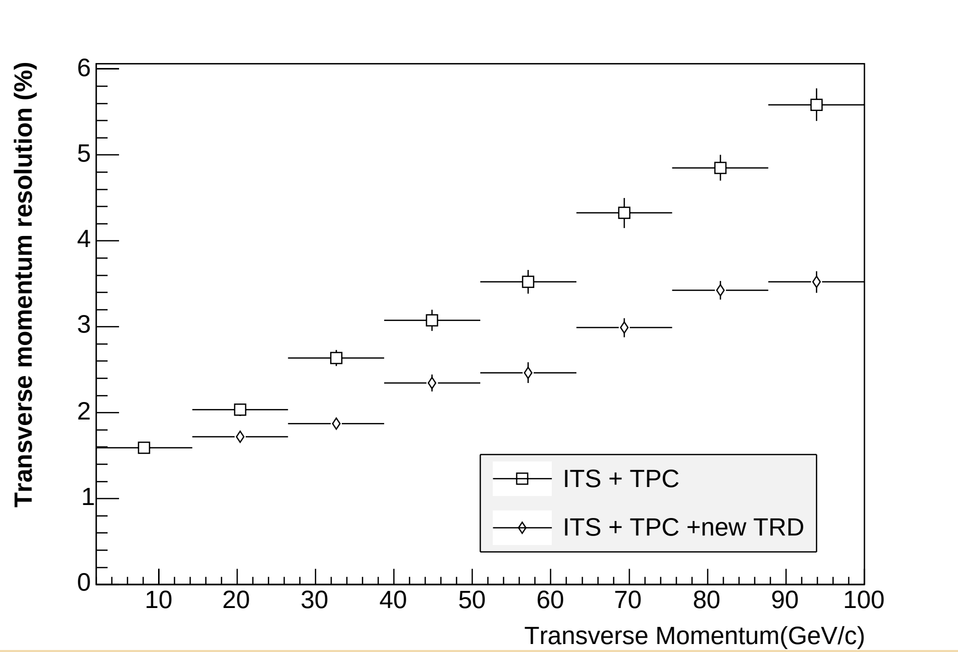
TRD
electron identification, tracking, dE/dx
-0.9<η<0.9

Combined momentum resolution



at low momentum dominated by

- ionization-loss fluctuations
- multiple scattering



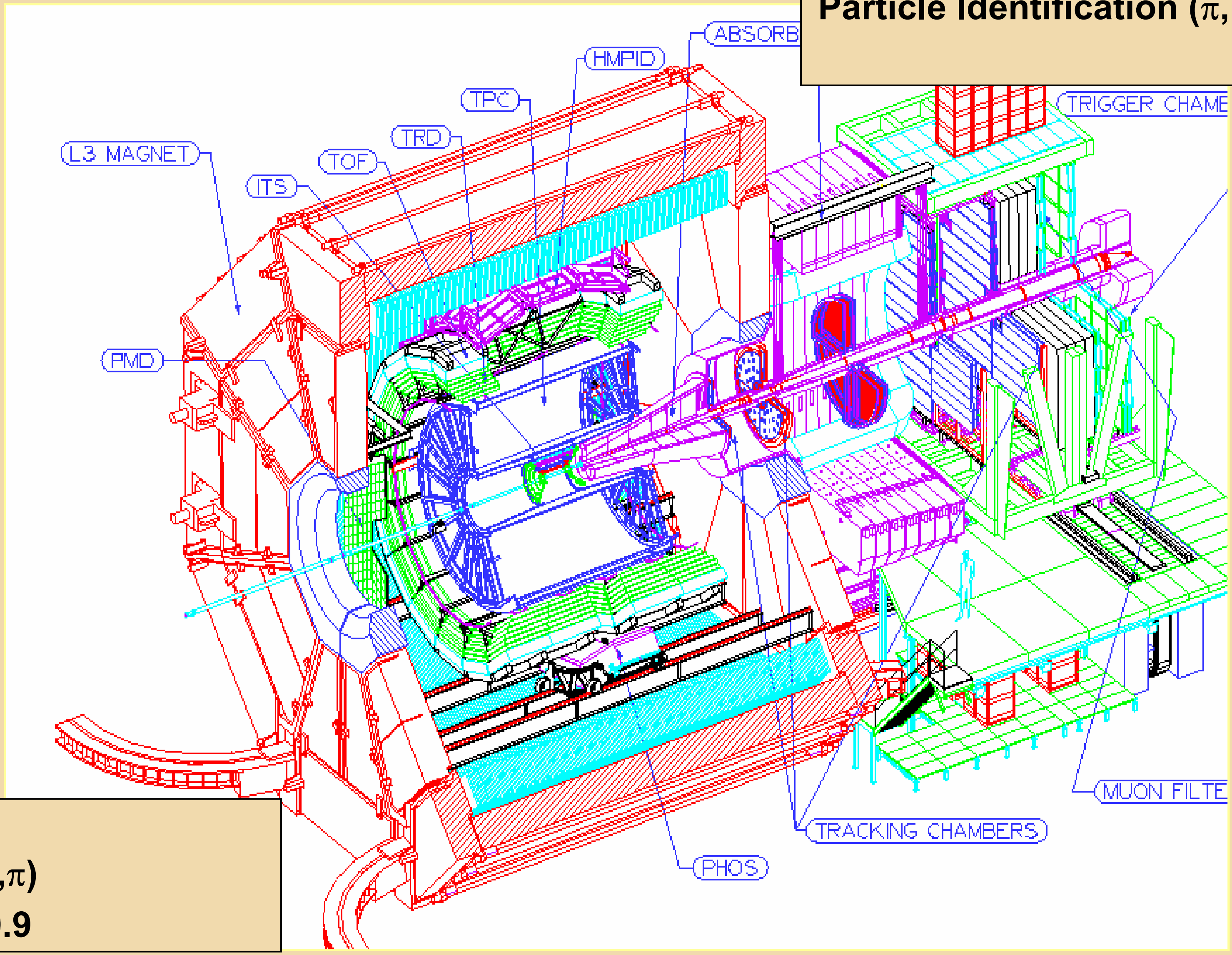
at high momentum determined by

- point measurement precision
- and the alignment & calibration
(*which is here assumed ideal*)

resolution ~ 7% at 100 GeV/c
excellent performance in hard region!

ALICE LAYOUT: PID

HMPID: High Momentum Particle Identification (π, K, p)



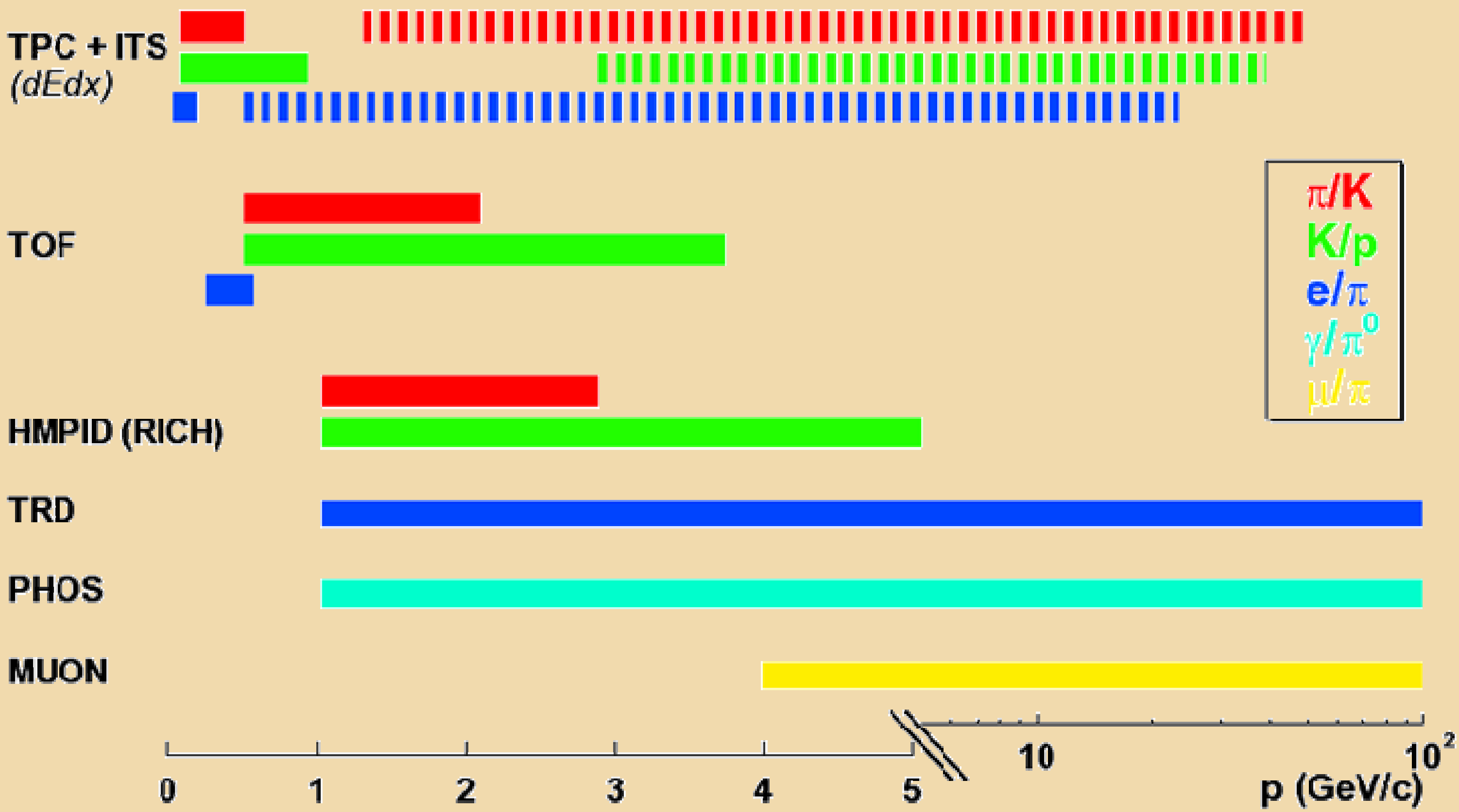
TOF

PID (K,p,π)

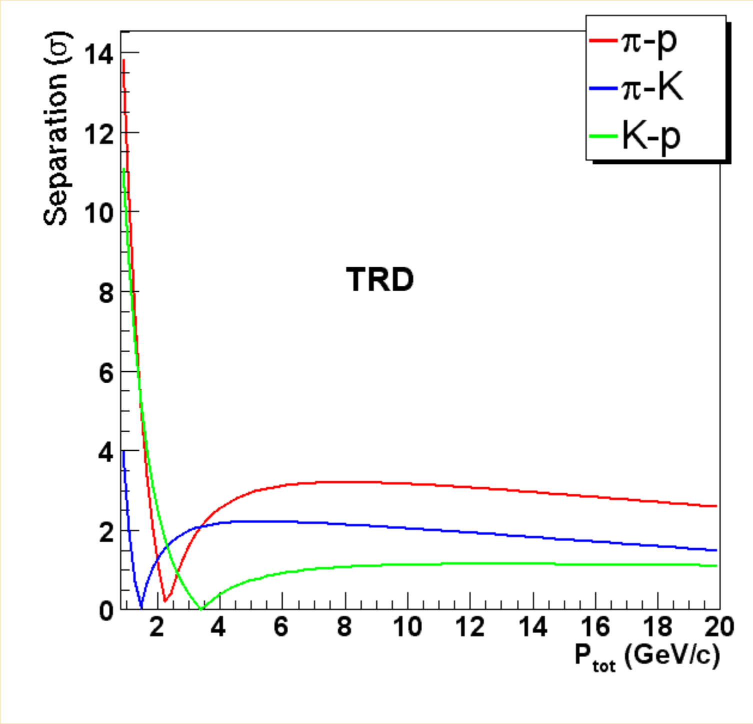
$-0.9<\eta<0.9$

Hadron and Lepton Identification

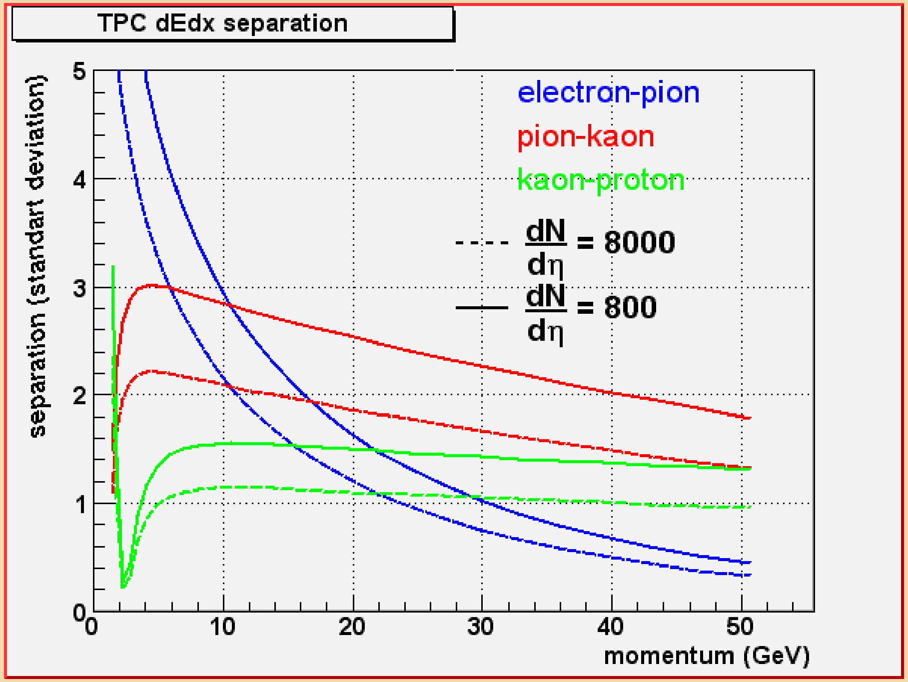
ALICE PPR CERN/LHCC 2003-049

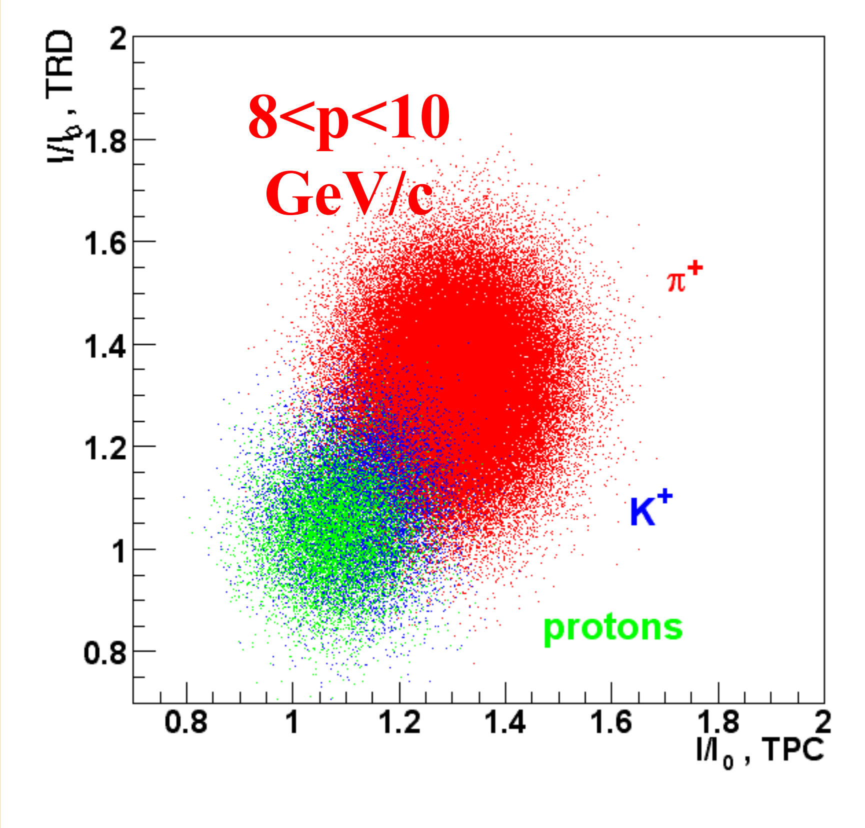


Under study: extension of PID to higher momenta



- Combine TPC and TRD dE/dx capabilities (similar number of samples/track) to get statistical ID in the relativistic rise region

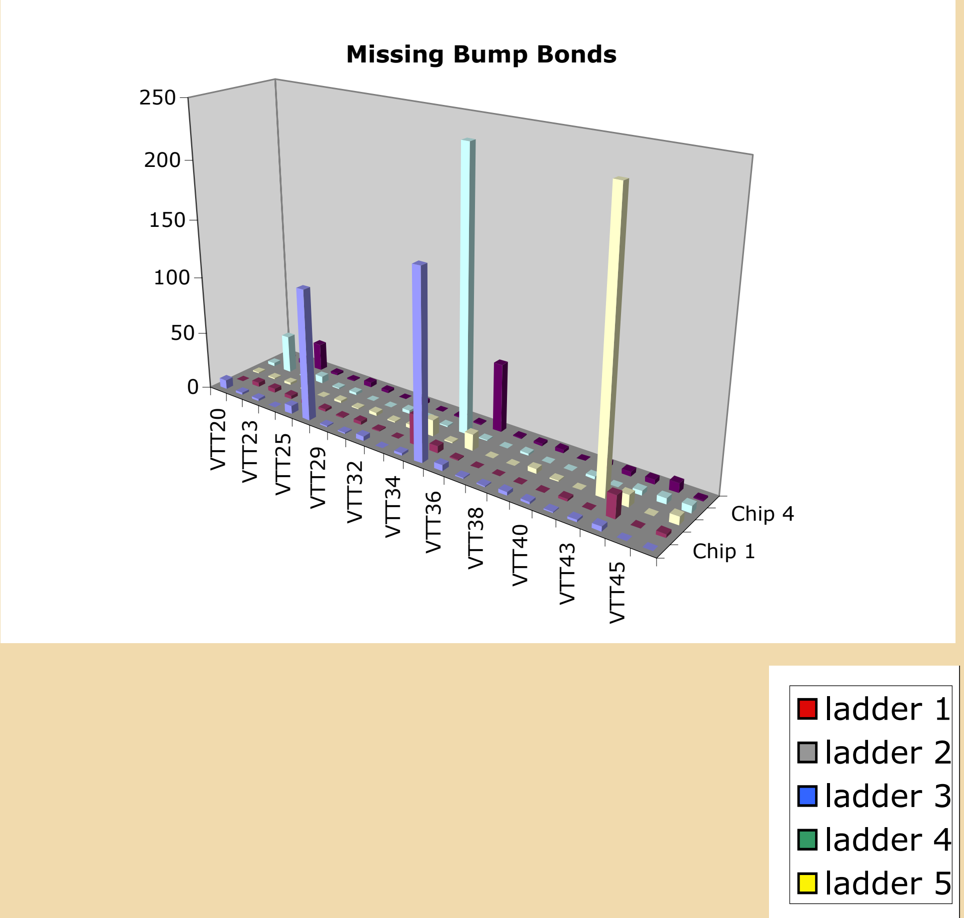




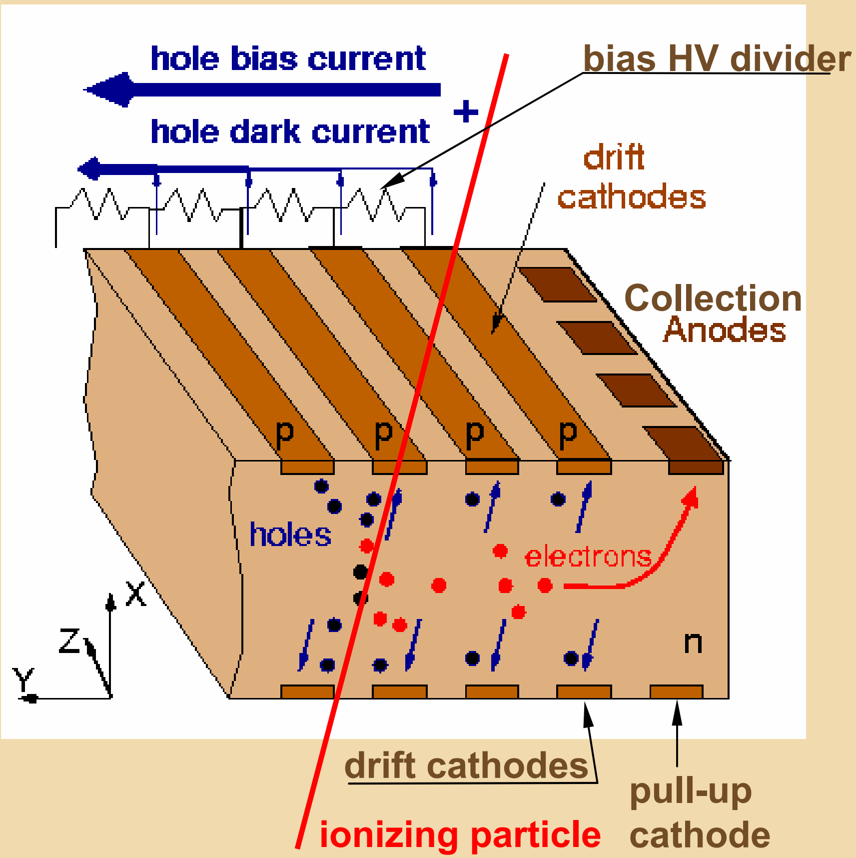
Silicon Pixel Detector SPD

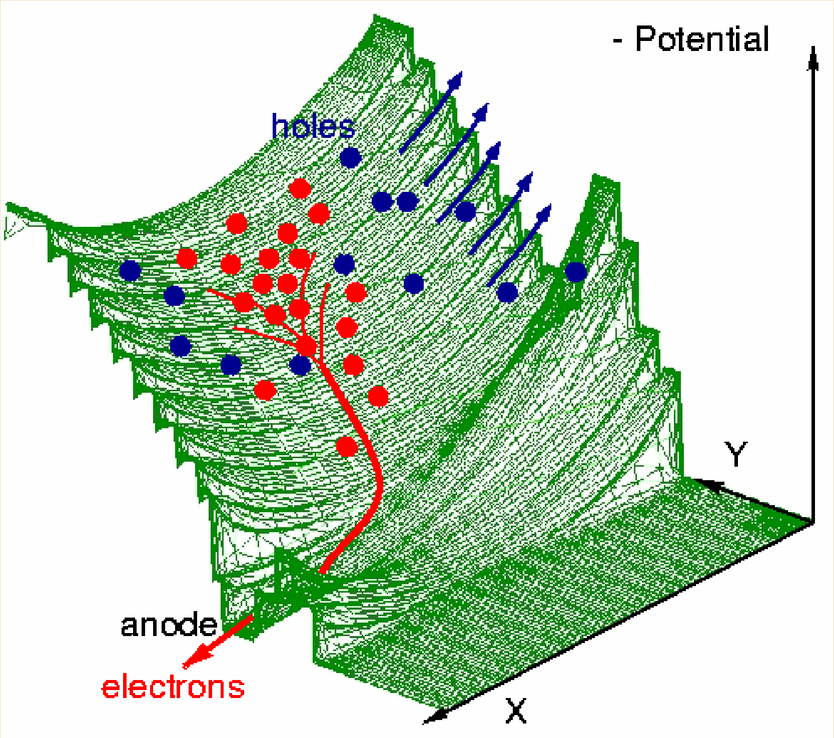
- successful system beam test Oct. ’04
  - including full FEE and DAQ, DCS, ECS
  - Combined with the other Silicon detector systems
- bump bonding at VTT (Finland)
  - series production started (ε > 99%)
- Three assembly sites operational
- Status
  - ready for installation : Oct 2006
  - viable schedule, but tight & little contingency

Bump Bonding efficiency ε
ε > 99.9 %



ALICE Si Drift detector : principle

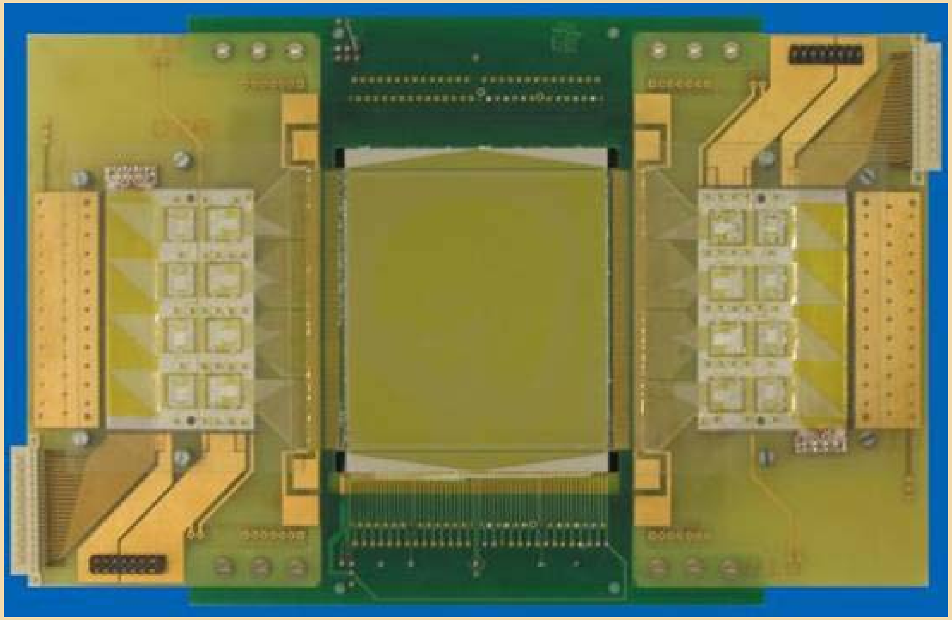




Si-Drift Detectors in production
Front end electronics in production
Assembly at four sites (Italy, US) started

Si-Drift Detector : Assembly

- **Hybrids :**
  - **520 needed; production from 04/05 to 04/06; done in industry**
- **Modules:**
  - **260 needed; production from 05/05 to 04/06**
- **Ladders:**
  - **36 needed; production from 07/05 to 04/06**
- **Mechanics**
  - **Components ready for assembly**
- **SDD ready for integration with SSD : 07/06**

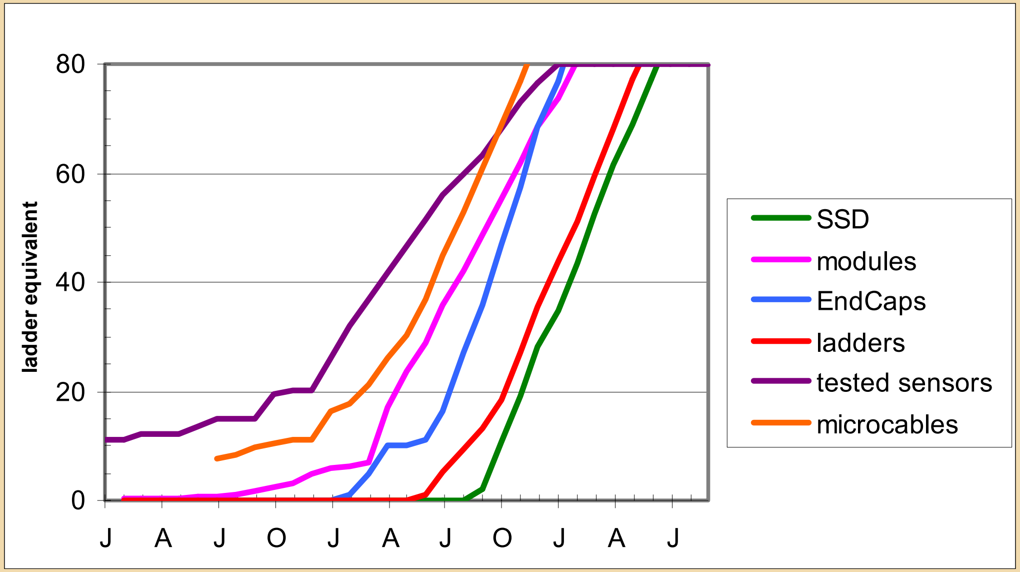


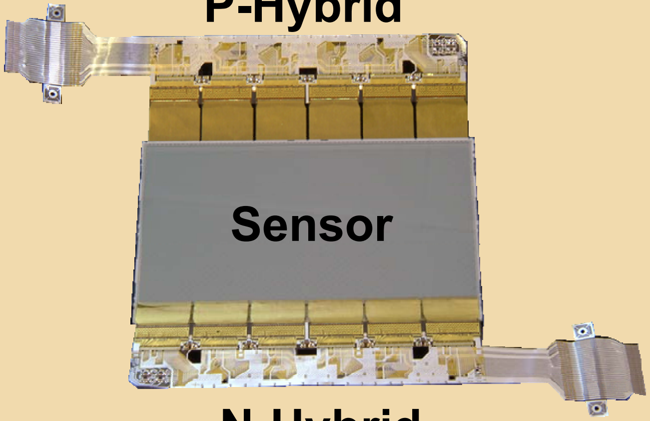
View of modules with two hybrids; Was used in 2004 beam test

Silicon Strip Detector SSD

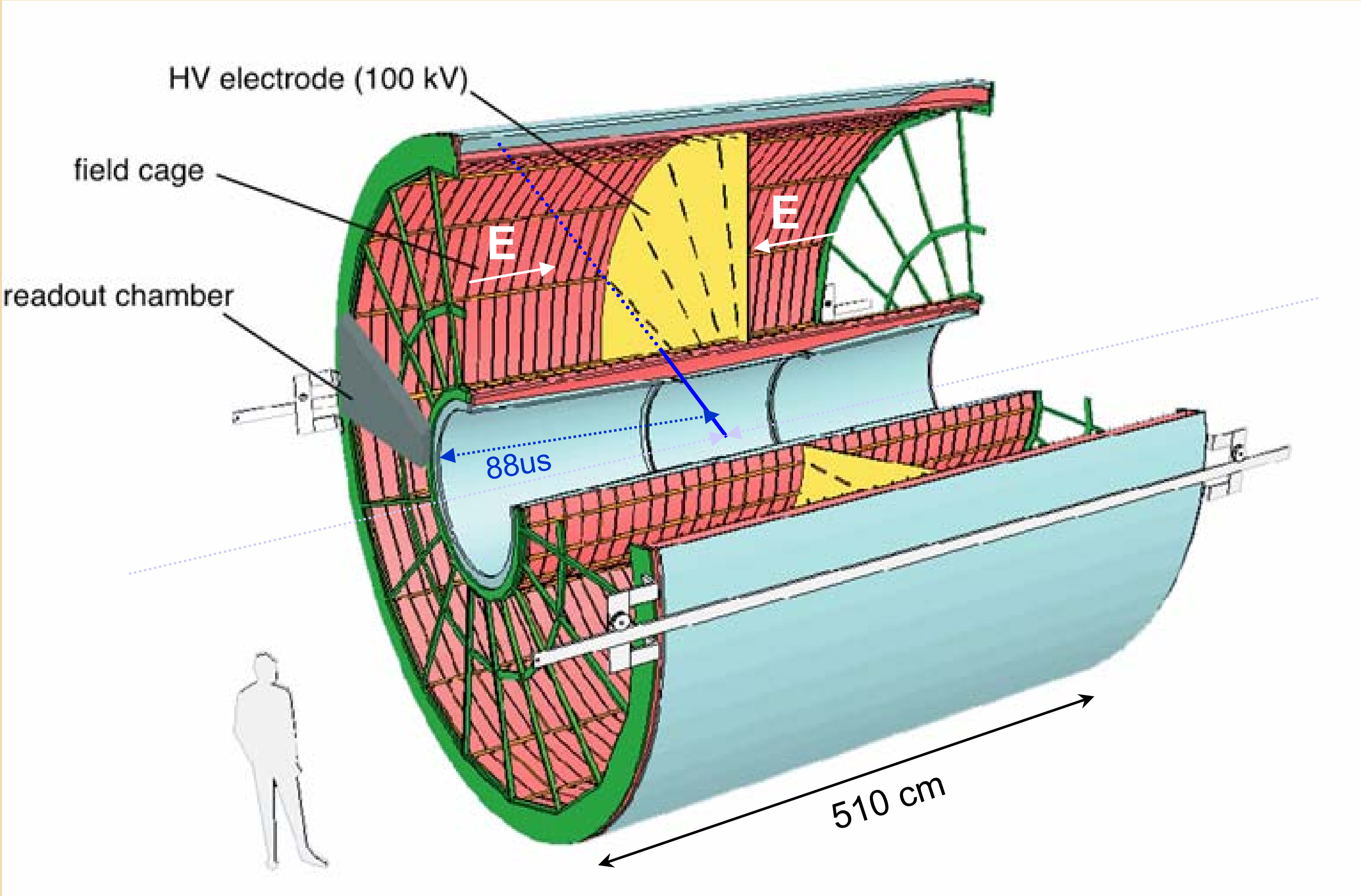
- **Production:**
  - sensors from three vendors under production
  - FEE electronics: all chips in production
  - micro-cables & hybrids (Ukraine):
    - very advanced technology;
- **Assembly**
  - shared between 4 (later 5) sites (Finland, France, Italy); pre-production validated
- **Status**
  - Needs to be ready for integration with SSD: 07/06
  - viable, but very tight schedule

Ramping of component delivery and assembly





TPC layout



GAS VOLUME
88 m^3

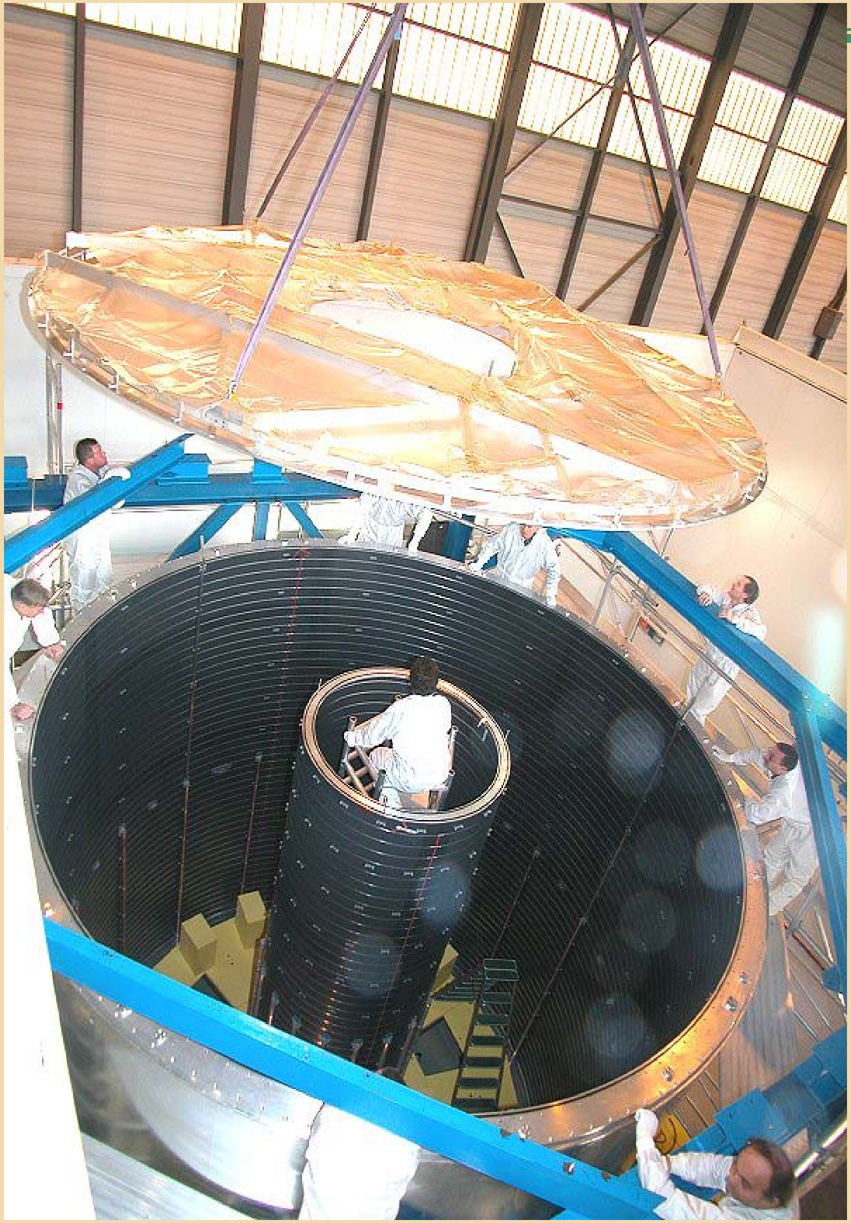
DRIFT GAS
90% Ne - 10%CO_2
Field cage finished
FEE finished
Read out chamber finished
At present pre-integration of field cage into experiment

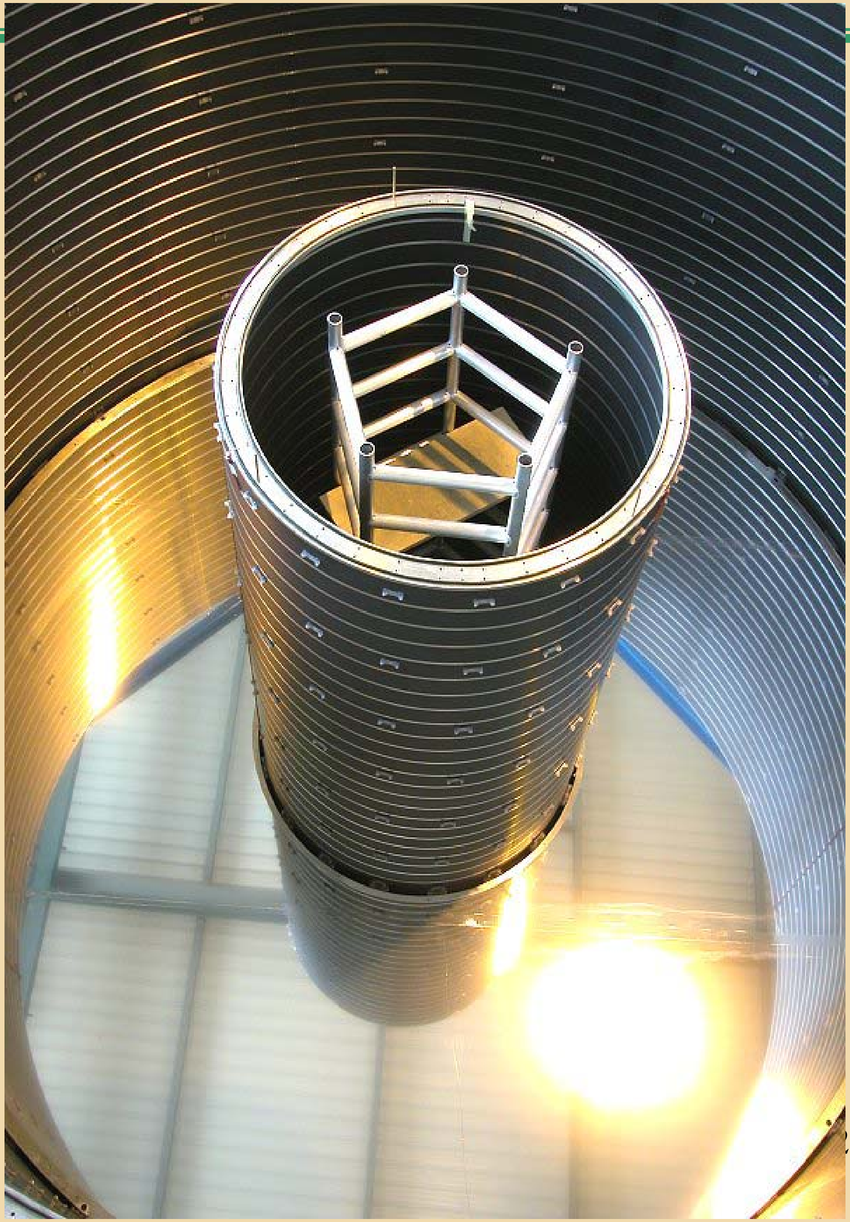
Readout plane segmentation

18 trapezoidal sectors

each covering 20 degrees in azimuth

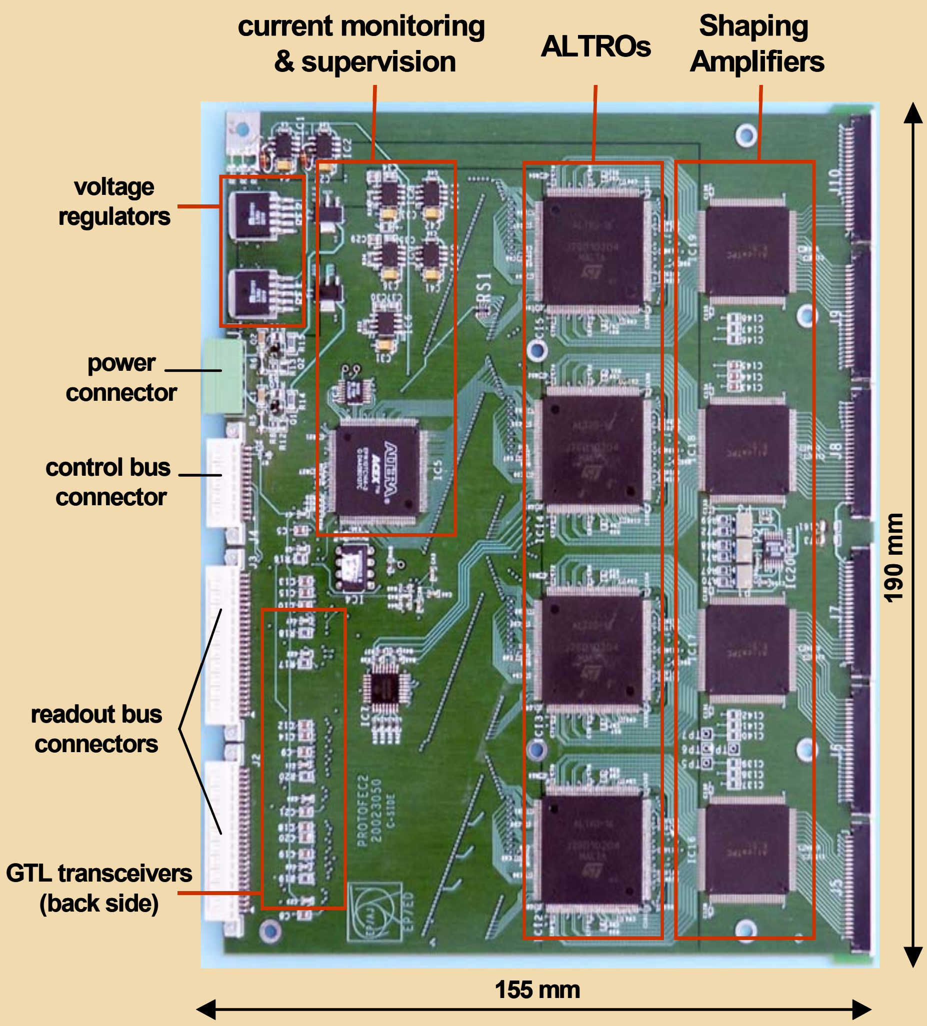
Mounting the TPC Central Electrode With 10^{-4} parallelism to readout chambers



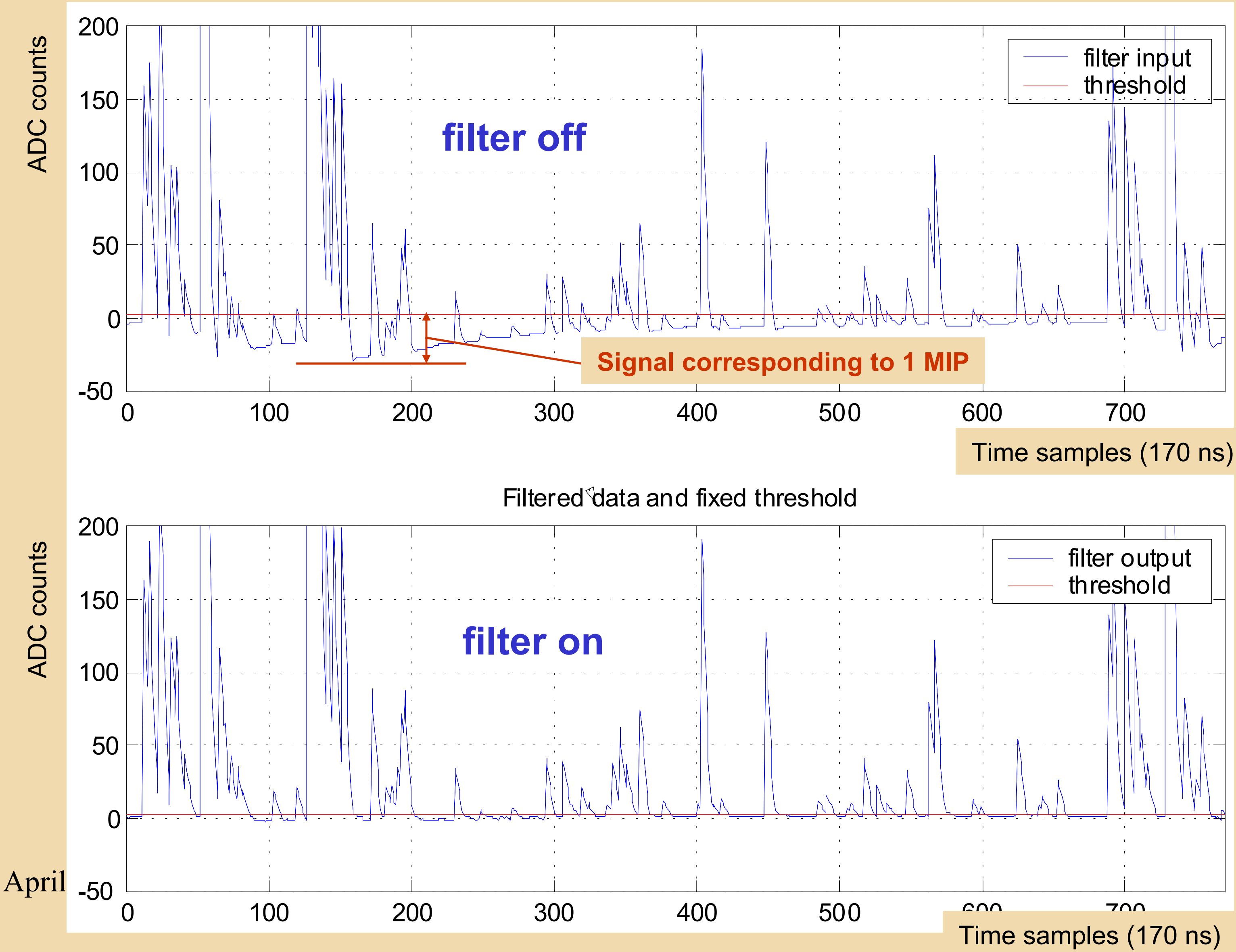


TPC – FEE

- FEE:
  - 48 channels with digital signal processing
- Serves also for other ALICE Detectors:
  - •PHOS, FMD
  - •Also considered for RHIC detector upgrades

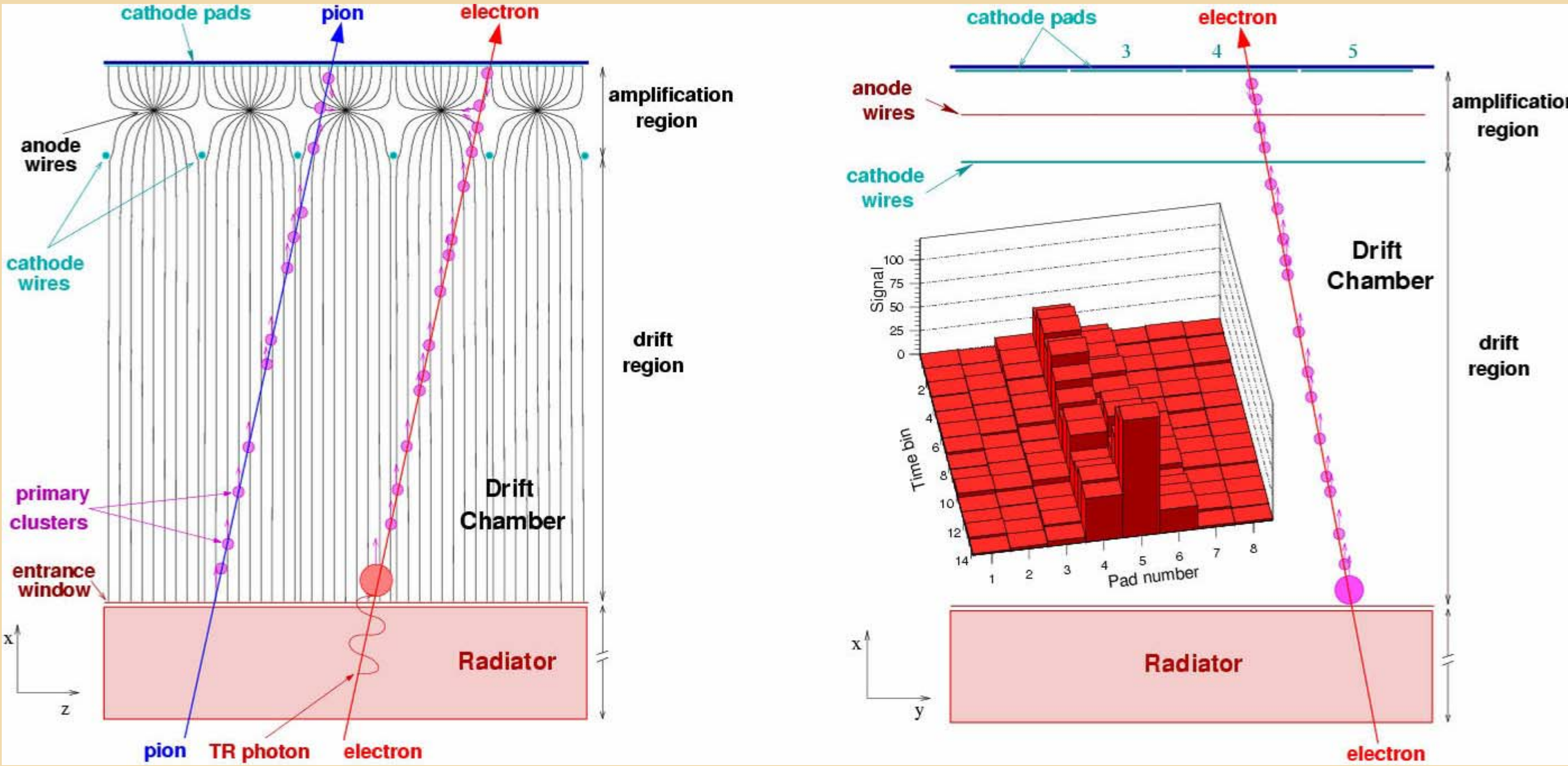


The Ion–Tail Problem: Digital tail Cancellation Performance



ALICE TRD : Ionization, Tracklet, Triggering

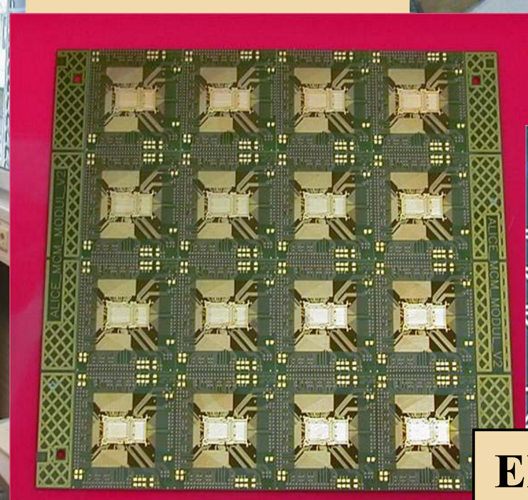
Pad chambers with a total of 1 200 000 channels

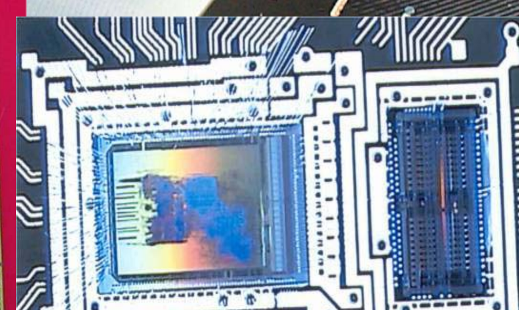


TRD ; Chamber production in Heidelberg,GSI, Dubna, Bucharest

Chamber production in Heidelberg

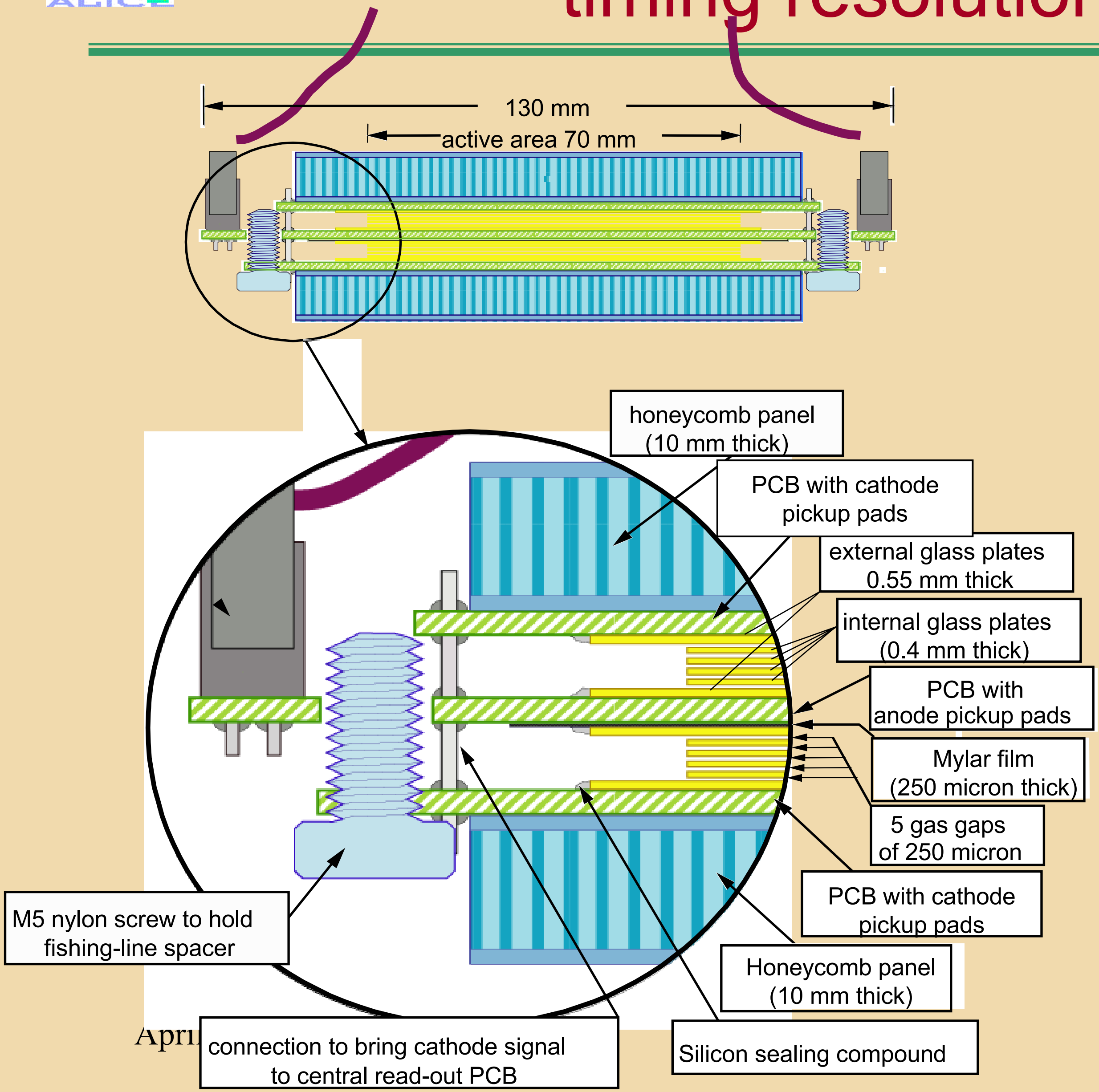
Chamber production lab in JINR





Electronics and MCM bonding at FZ Karlsruhe

Concept of Multigap RPC for improved timing resolution

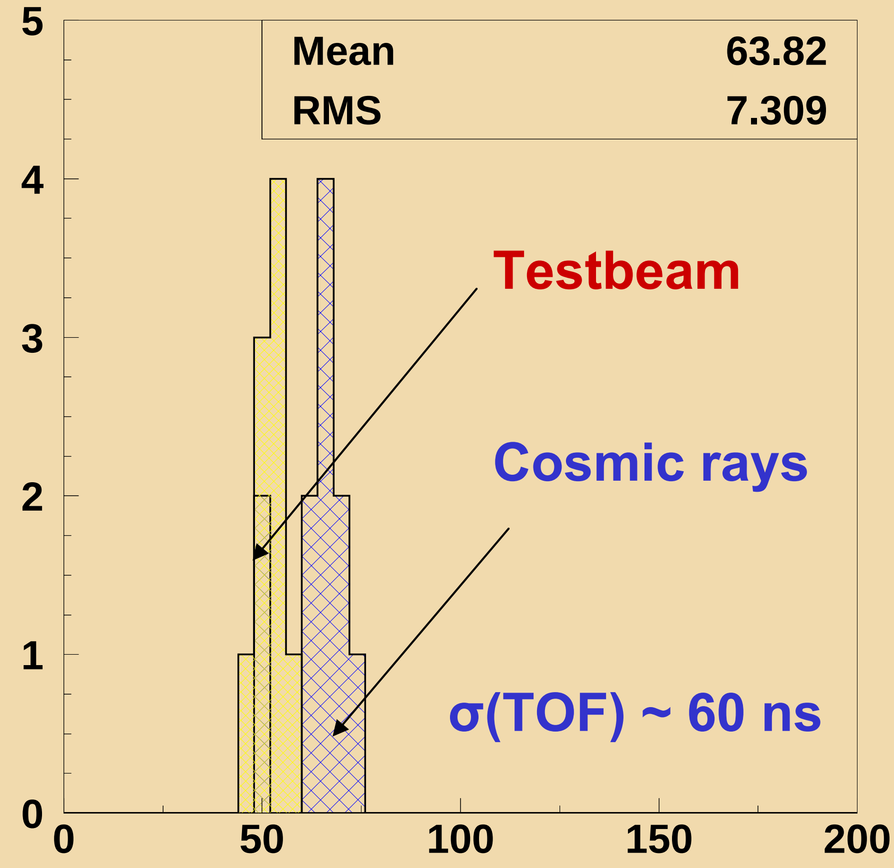


High performance achieving 50 ps Timing resolution

Revolutionizing TOF identification

TOF: performance and construction

- **Detector**
  - **Strip production: 20/week to increase to 40/week with 2nd automated assembly line**
  - **Finished : 11/06**
  - **Module assembly : start 06/05; finish : 11/06**
  - **Supermodules : installation test with mock-up done successfully**
  - **First 8 supermodules to be installed : 02/06 to 07/06**



HMPID (High Momentum Particle Identification) Results from Test Beam

Sensitivity of 4 cathodes
Required : > 12 clusters
Measured :> 18 clusters for relativistic particles

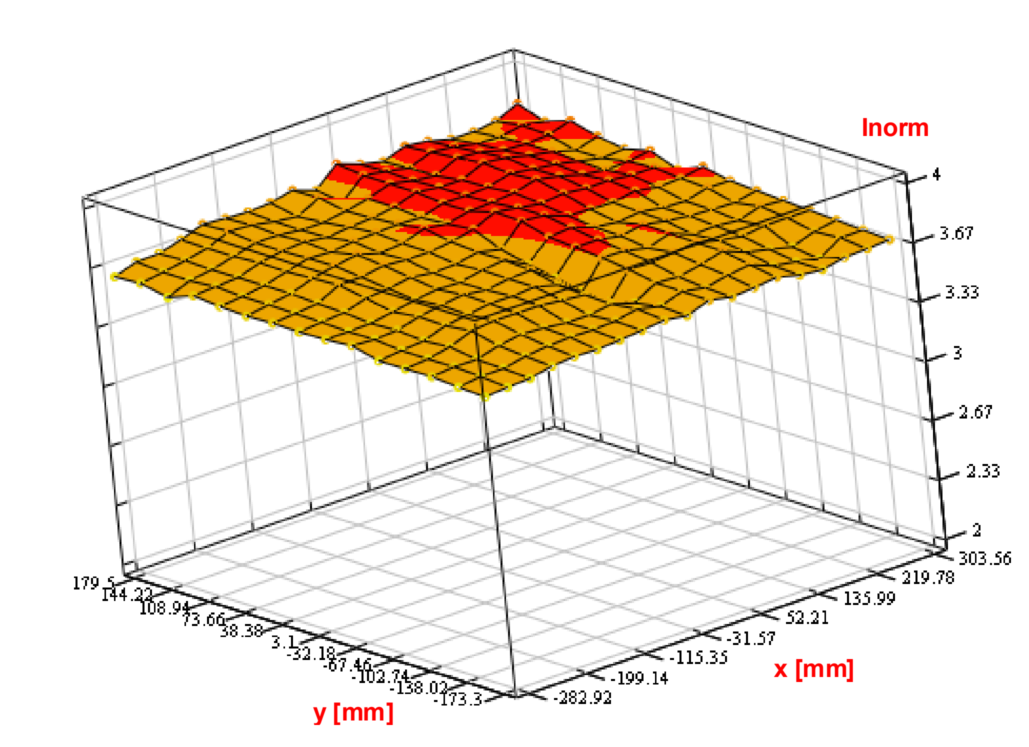
Cathode uniformity ~ 5 %

4 of 7 modules tested at SPS

Production finished 06/05

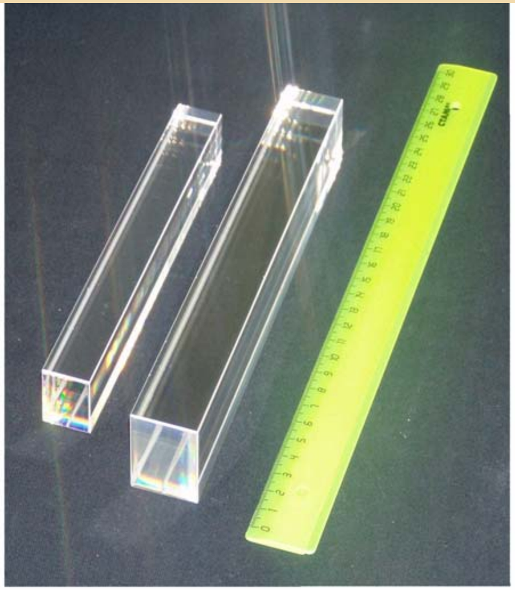
CsI-cathode performance better than specified

Ready for Installation :
Dec 2005



PHOS : Photon and Electron Crystal calorimeter

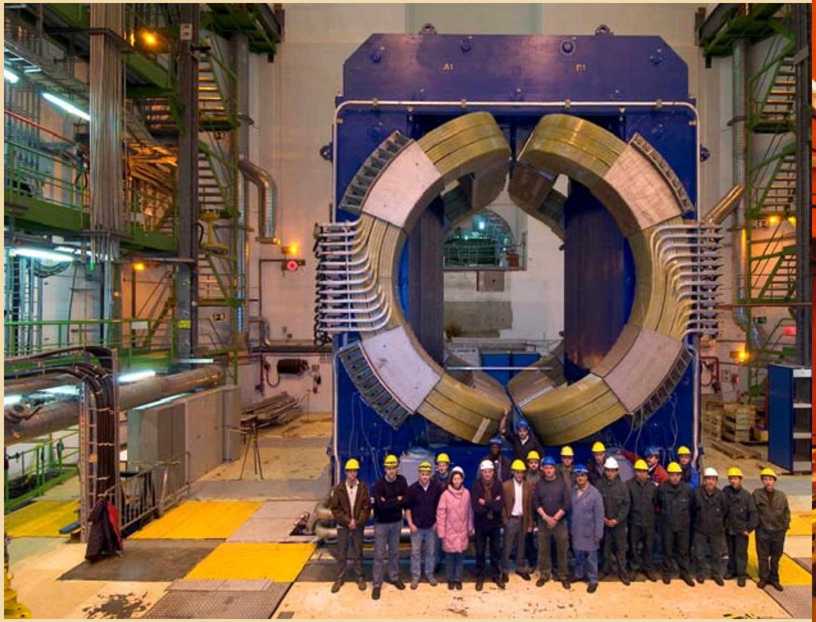
- Complete system will have ~ 20 000 $PbWO_4$ crystals
  - Energy resolution ~ 3% / √ E
  - Dynamic range from ~ 100 MeV to ~ 100 GeV
  - Timing resolution of ~ 1.5 ns / √ E
  - Trigger capability at first level
  - More than 9000 crystals accepted
- Readout electronics
  - Reuse of major parts of TPC electronics
- First module (of 5) : end 2005
- For completion :
  - Need additional collaborators



PHOS crystals from Apatity

Muon Magnet :world's largest warm dipole

Pre-assembly

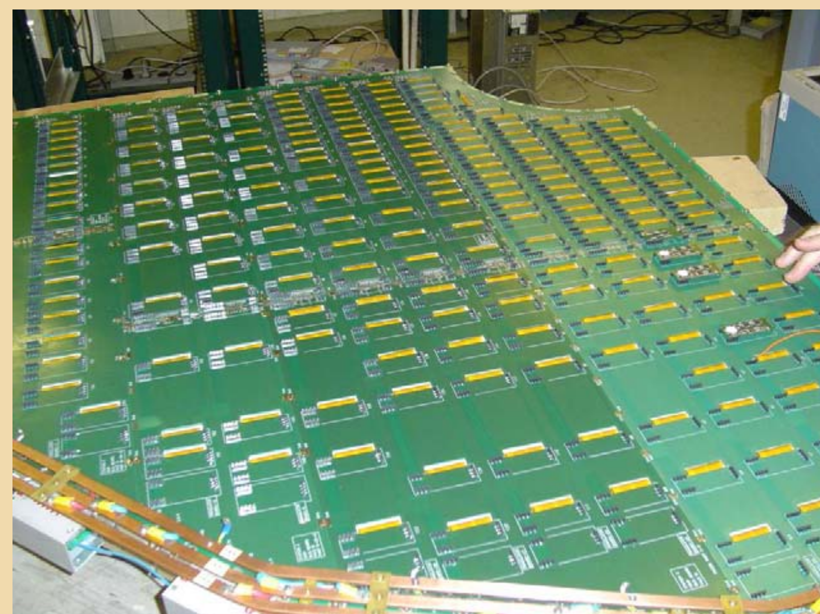


Nov 29, 2004

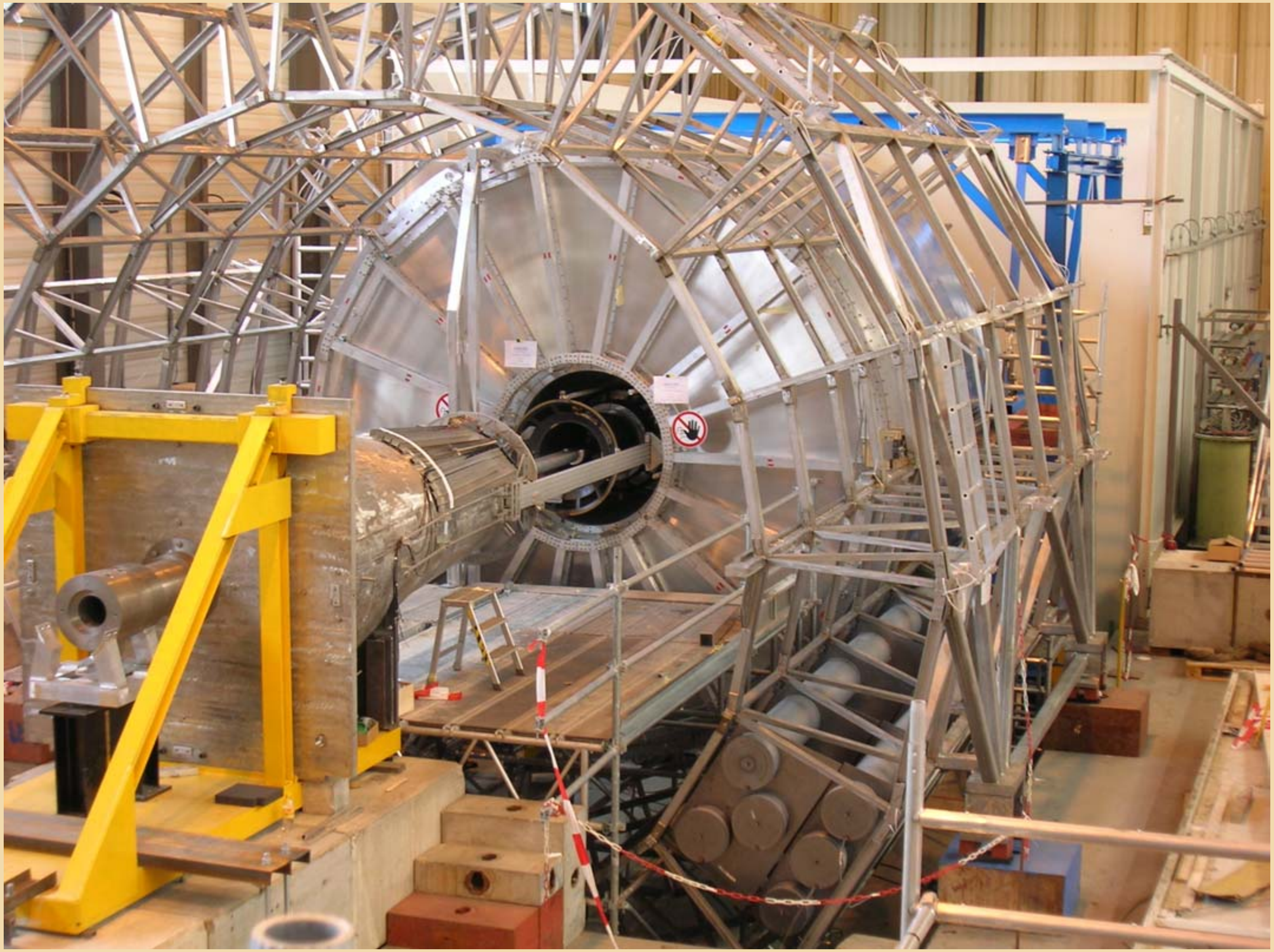
April 19, 2005

Muon Tracking System

- Advanced 'Pad-chamber' system with
  - $1.2 * 10^6$ readout channels
  - Sagitta resolution of < 50 μm for
  - Mass resolution of ~ 80 MeV at Upsilon
- Production of chambers in
  - France, India, Italy, Russia
  - Scheduled to be finished end 2005



TPC/ITS/TRD/TOF Pre-Integration



Pre-Integration of ITS/TPC/TRD/TOF/vacuum chamber

ongoing at present moment

ALICE Offline: Physics Data Challenges

Period (milestone)	Fraction of the final capacity (%)	Physics Objective
06/01-12/01	1%	pp studies, reconstruction of TPC and ITS
06/02-12/02	5%	• First test of the complete chain from simulation to reconstruction for the PPR • Simple analysis tools • Digits in ROOT format
01/04-06/04	10%	• Complete chain used for trigger studies • Prototype of the analysis tools • Comparison with parameterised MonteCarlo • Simulated raw data
05/05-07/05	15%	• Test of condition infrastructure and FLUKA • To be combined with SDC 3 • Speed test of distributing data from CERN
01/06-06/06	20%	• Test of the final system for reconstruction and analysis

Physics benchmarks : a few (difficult) examples

- Jets and Jets Quenching
- Heavy quarks
- Direct photons

Jets and Jet quenching (I)

- Jets : reflect interactions of partons in partonic matter
- Effects
  - Reduction of single inclusive high p_t particles
    - Parton specific (stronger for gluons than quarks)
    - Flavour specific (stronger for light quarks)
    - Measure identified hadrons (p, K, p, Λ, etc.) + heavy partons (charm, beauty) at high p_T
  - Change of fragmentation function for hard jets (p_t >> 10 GeV/c)
    - Transverse and longitudinal fragmentation function of jets
    - Jet broadening → reduction of jet energy, dijets, g-jet pairs

Jets and Jet Quenching (II)

- Experimental Consequences
  - Measurement of Jet Energy is important
    - In present configuration Alice measures only charged particles (and electromagnetic energy in PHOS)
    - Large EM Calorimeter would provide significant performance bonus
  - Measurement of Jet Structure very important
    - Requires good momentum analysis from ~ 1Gev/c to ~100 Gev/c
    - Alice excells in this domain
  - pp and pA measurements essential as reference for physics in cold nuclear matter

Energy domains for jet reconstruction

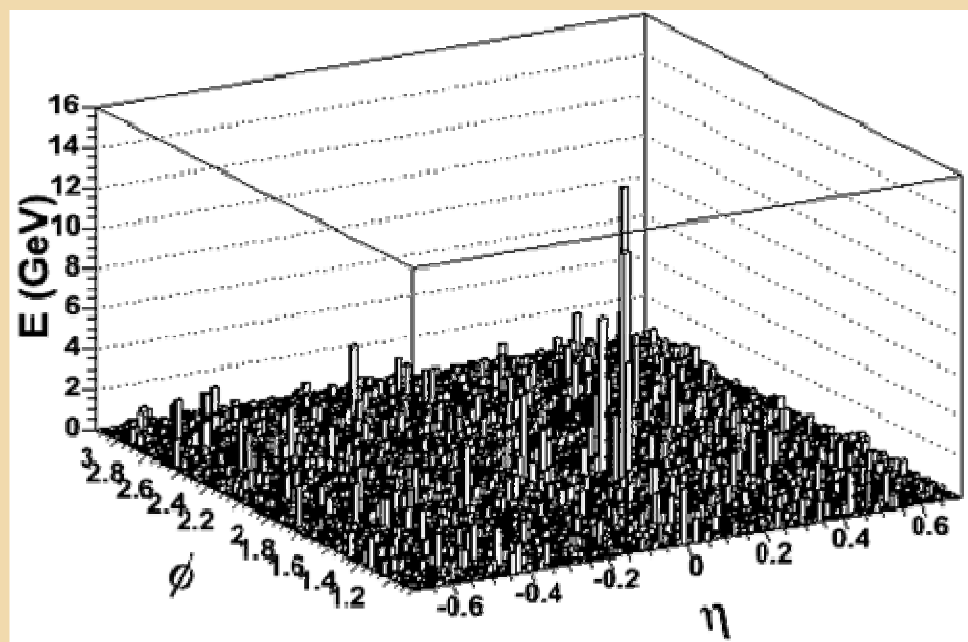
2 GeV **20 GeV** **100 GeV** **200 GeV**

Mini-Jets 100/event **1/event** **100k/month**

Event structure and properties at p > 2GeV/c
Correlation studies
Limit is given by underlying event

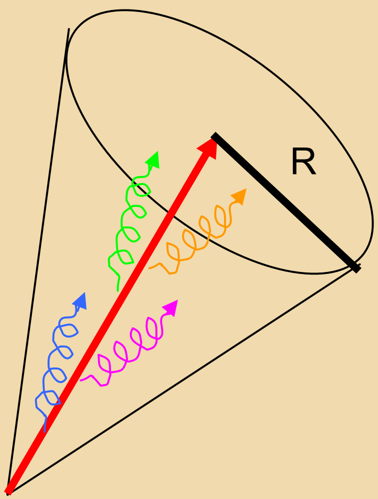
Reconstructed Jets
Event-by-event well distinguishable objects

Example :
100GeV jet +
Underlying event

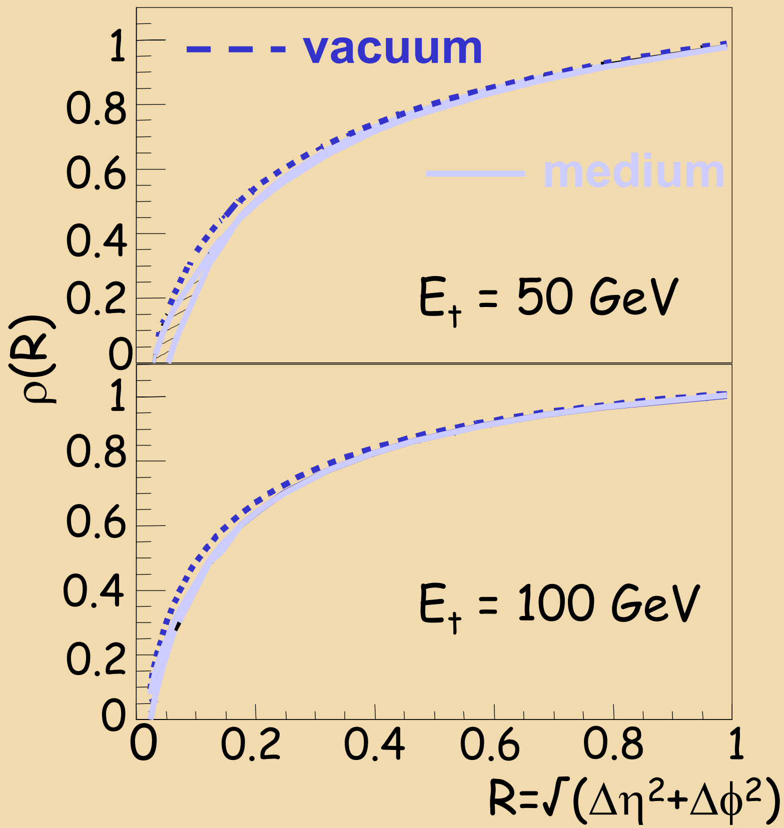


Jet quenching

- Excellent jet reconstruction… but challenging to measure global medium modification …



Medium induced redistribution of jet energy occurs inside cone

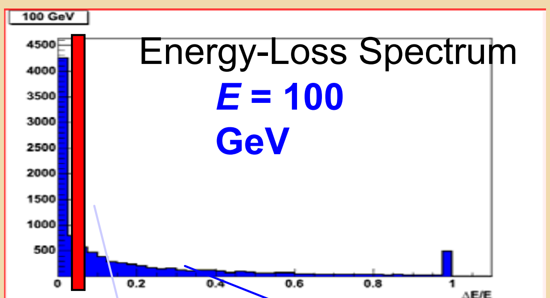


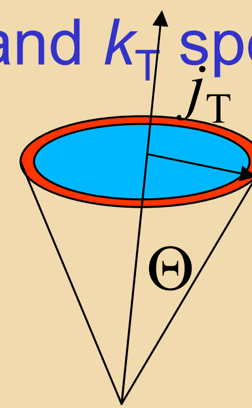
C.A. Salgado, U.A. Wiedemann hep-ph/0310079

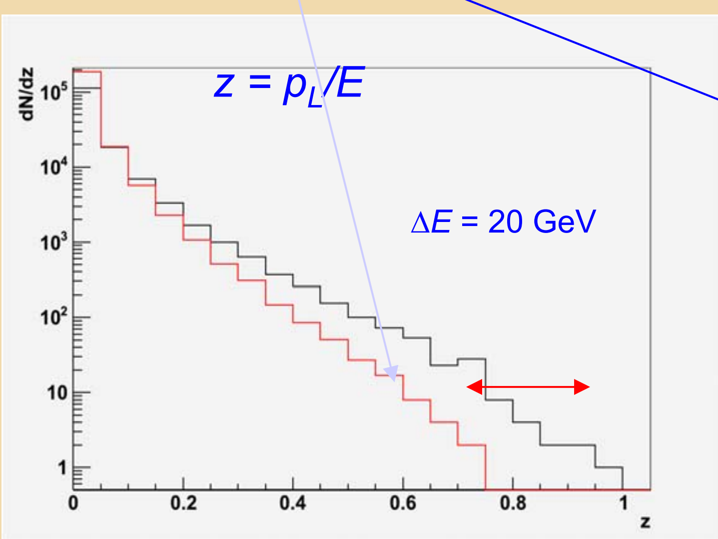
- E_t=100 GeV (reduced average jet energy fraction inside R):
  - Radiated energy ~20%
  - R=0.3 : DE/E=3%

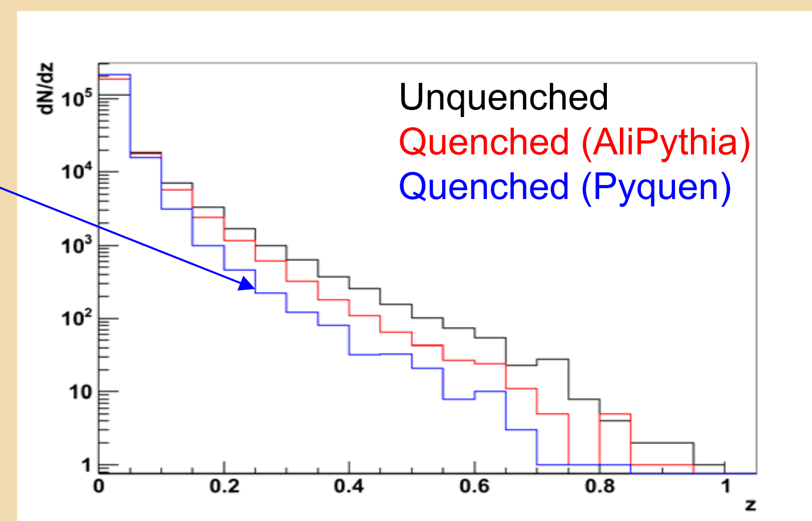
Jet structure observables at the LHC

- Measurement of jet energy measures unquenched parton energy.
- energy loss and transverse heating determined by measuring the fragmentation function and k_T spectra.

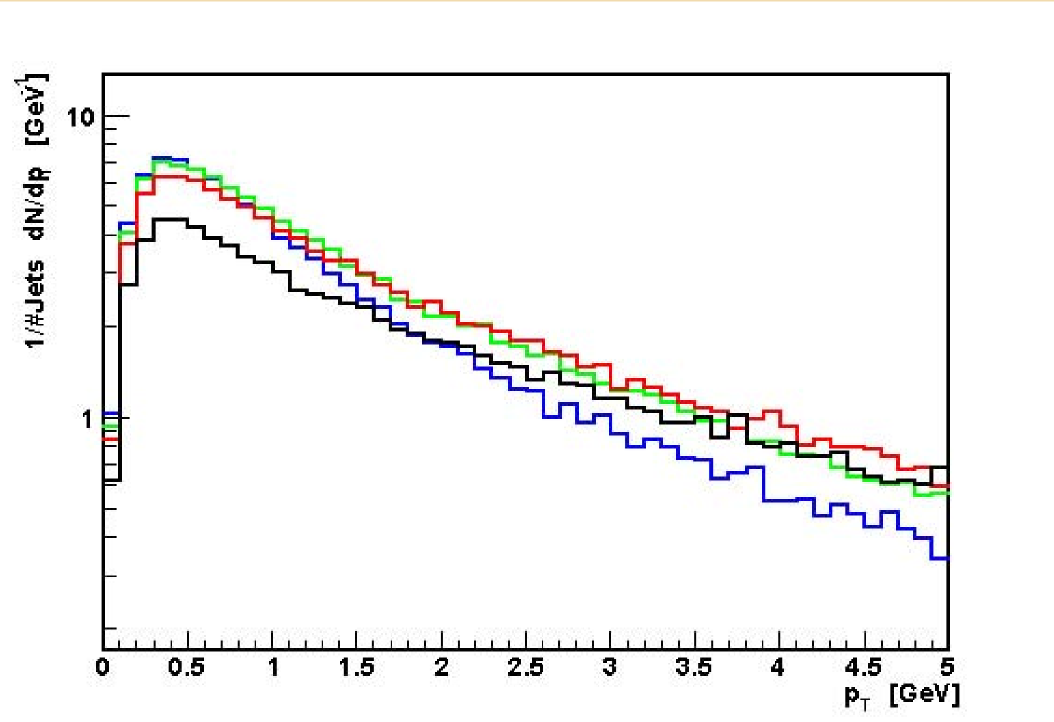








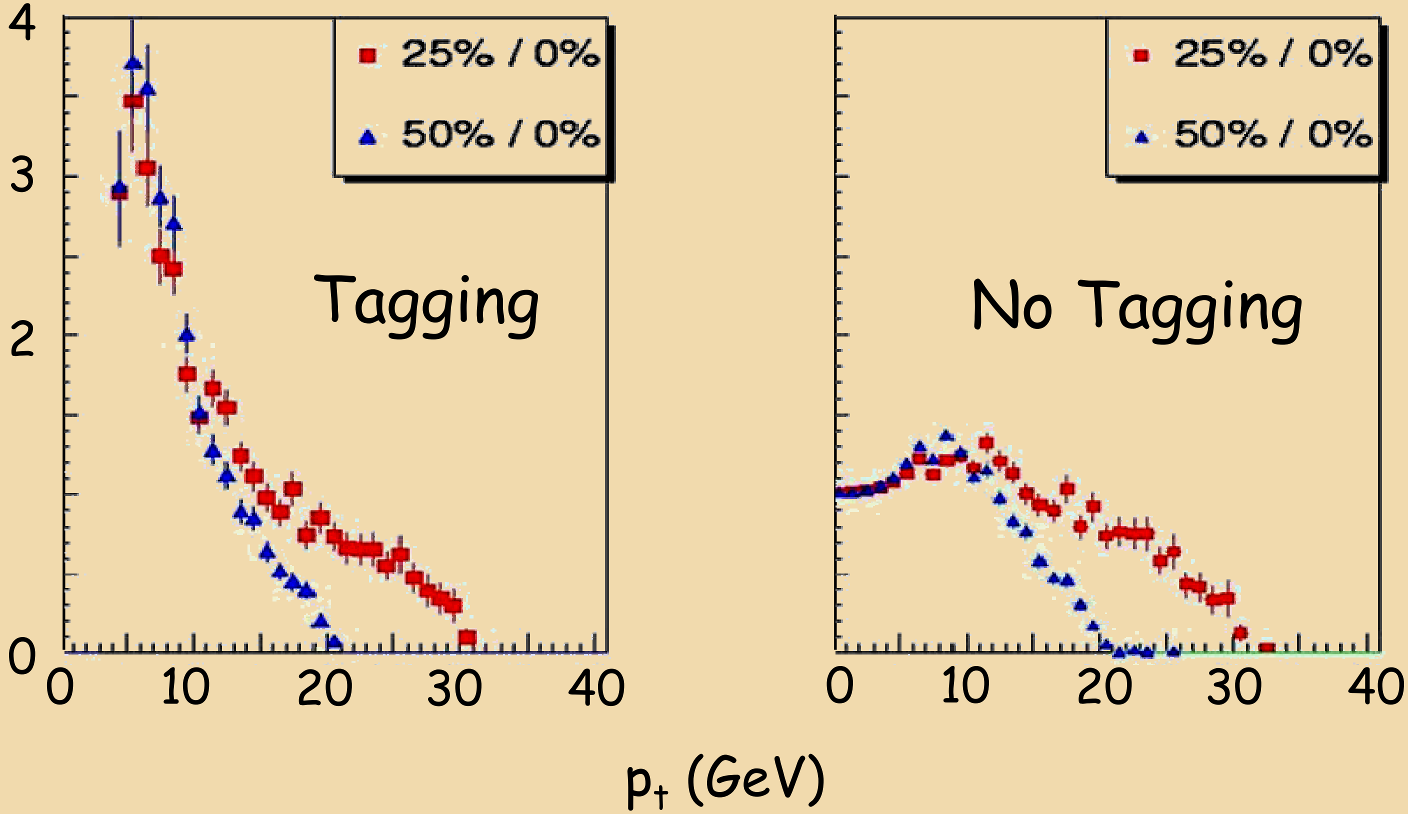
Relevance of low-p_T Tracking for quenching studies



Simple quenching model:
The energy loss of a 100 GeV jets is simulated by reducing the energy of the jet by 20% and replacing the missing energy by:
1 x 20 GeV gluon
2 x 10 GeV gluons
4 x 5 GeV gluons
Jets have been simulated with Pythia.

Exclusive Jets : tagged with Photon

- PbPb Collisions : photon tag of 40 GeV



Heavy Quarks and Quarkonia

- **Heavy quarks** with momenta < 20–30 GeV/*c* $\rightarrow$ $v << c$

- **Gluon radiation is suppressed at angles <** m_Q/E_Q

  → **"dead-cone" effect**

  - Due to destructive interference (inside cone gluon with v=c would violate causality)
  - Contributes to the harder fragmentation of heavy quarks and implies lower energy loss for heavy quarks relative to light quarks

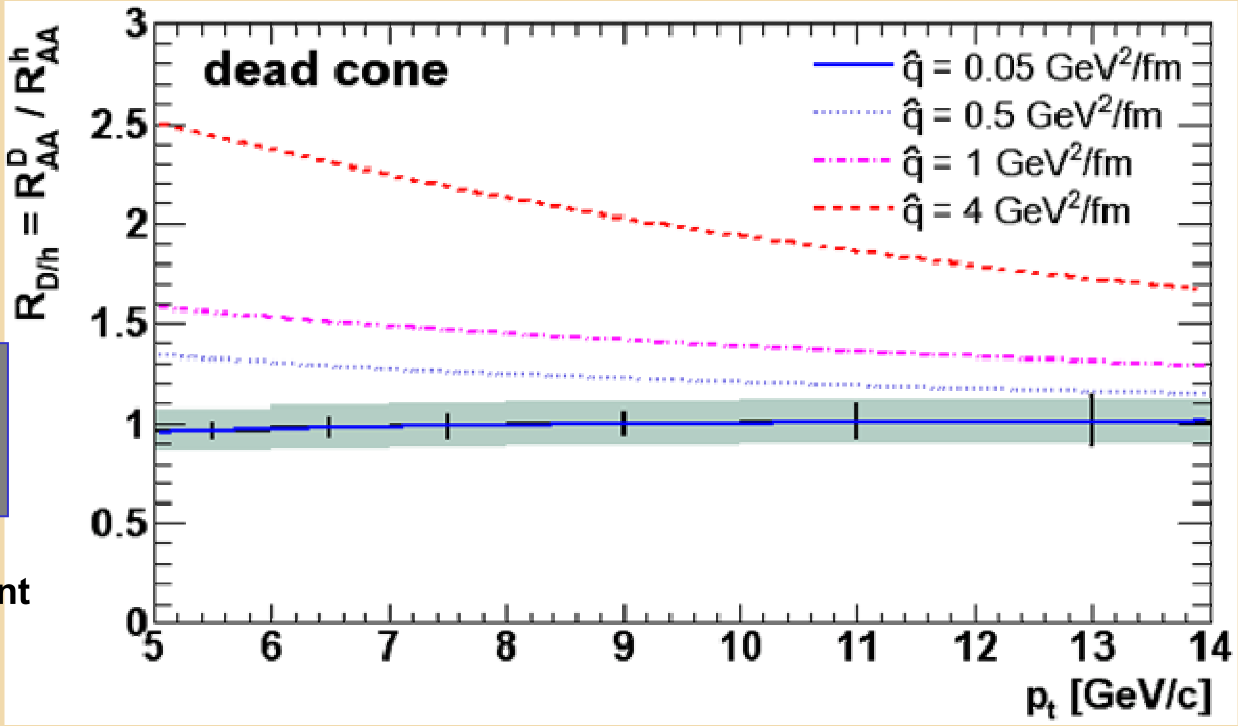
→ **D mesons quenching reduced**

→ **Ratio D/hadrons (or D/π^0) enhanced and sensitive to medium properties**

Yu.L.Dokshitzer and D.E.Kharzeev, Phys. Lett. **B519** (2001) 199 [arXiv:hep-ph/0106202].

D quenching ($D^0 \rightarrow K^- p^+$)

A.Dainese nucl-ex/0311004



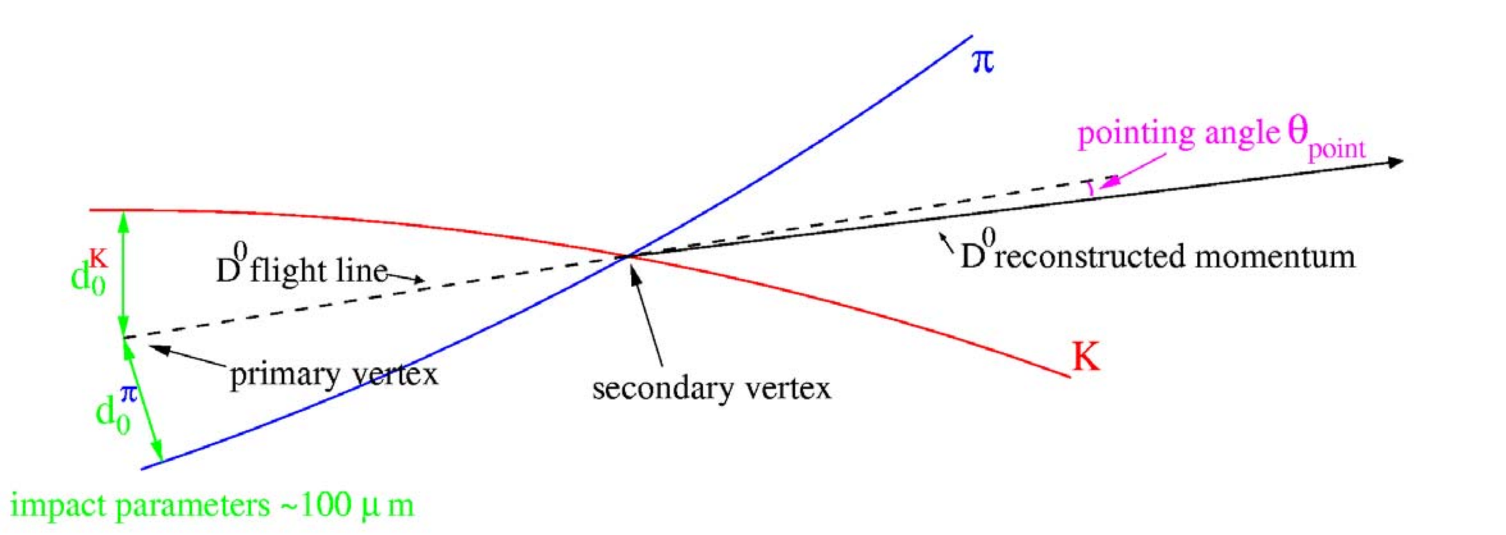
$$R_{AA} = \frac{1}{N_{coll}} \times \frac{dN_{AA} / dp_t}{dN_{pp} / dp_t}$$

q …medium transport coefficient depends on gluon density, momenta

- Ratio D/hadrons (or D/π^0) enhanced and sensitive to medium properties

Detection strategy for $D^0 \rightarrow K^- p+$

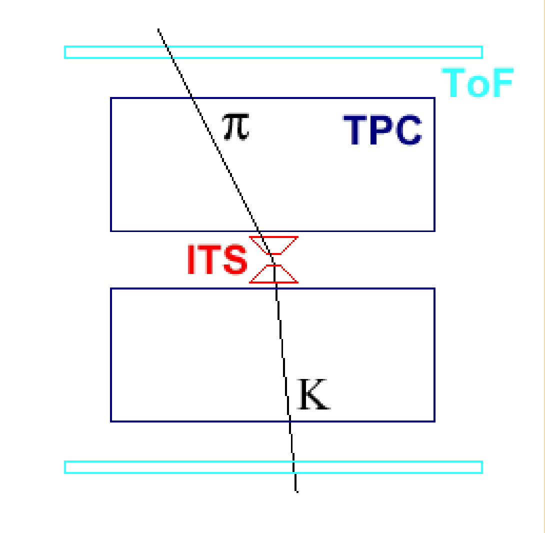
- **Weak decay with mean proper length ct = 124 μm**
- **Impact Parameter (distance of closest approach**
- **of a track to the primary vertex) of the decay products d_0 ~ 100 μm**

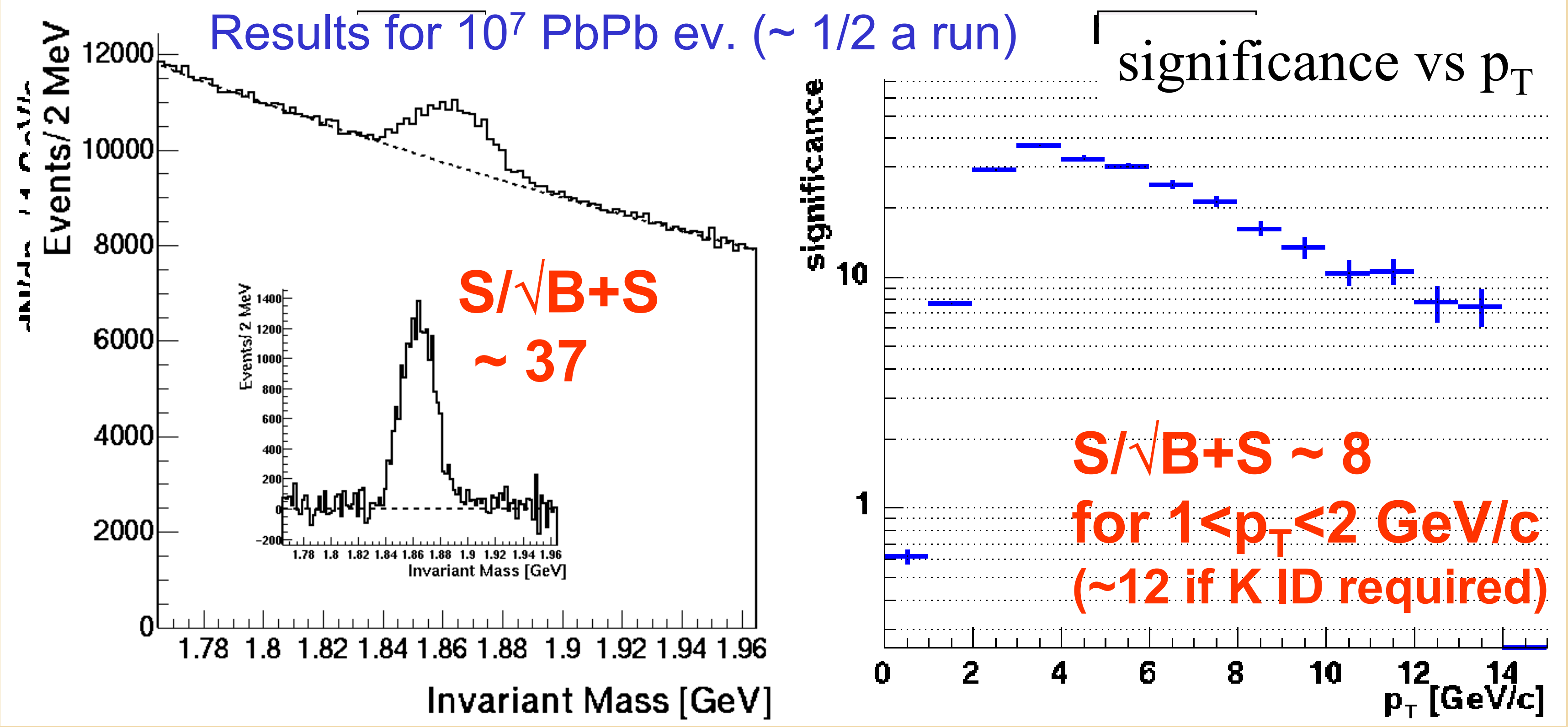


- **STRATEGY: invariant mass analysis of fully-reconstructed topologies originating from (displaced) secondary vertices**
  - **Measurement of Impact Parameters**
  - **Measurement of Momenta**
  - **Particle identification to tag the two decay products**

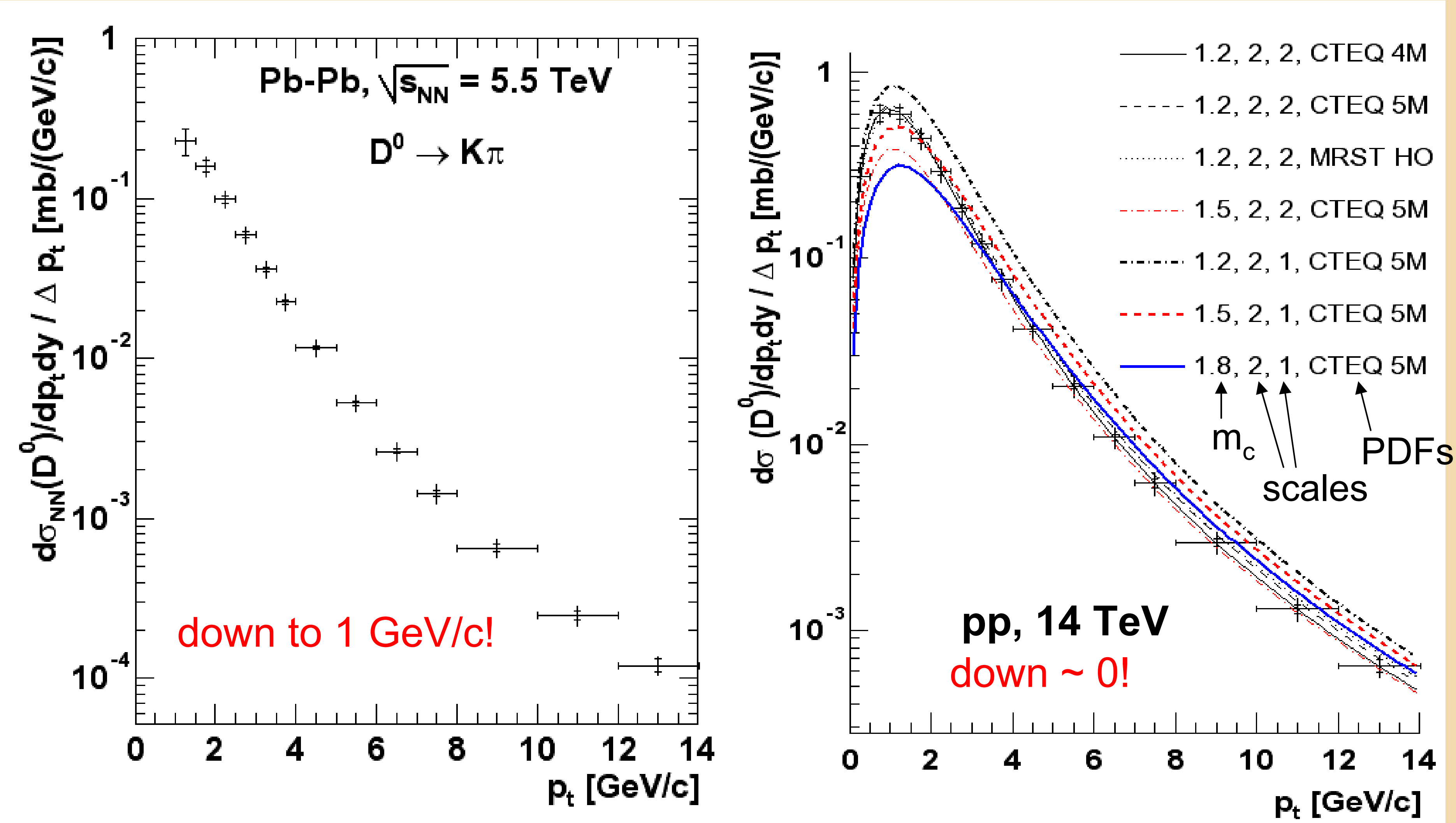
Hadronic charm

Combine ALICE tracking + secondary vertex finding capabilities (s_{d0}~60mm@1GeV/c p_T) + large acceptance PID to detect processes as $D^0 \rightarrow K^-\pi^+$ ~1 in acceptance / central event ~0.001/central event accepted after rec. and all cuts





D^0 Cross section measurement



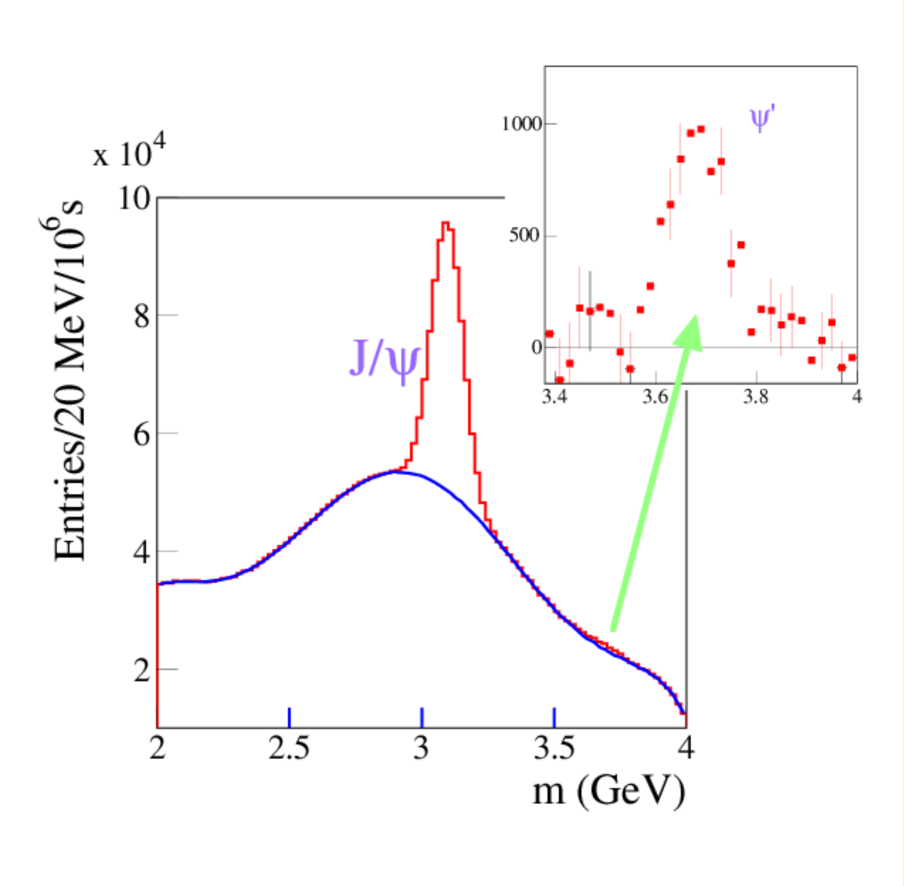
Heavy flavor quenching observables

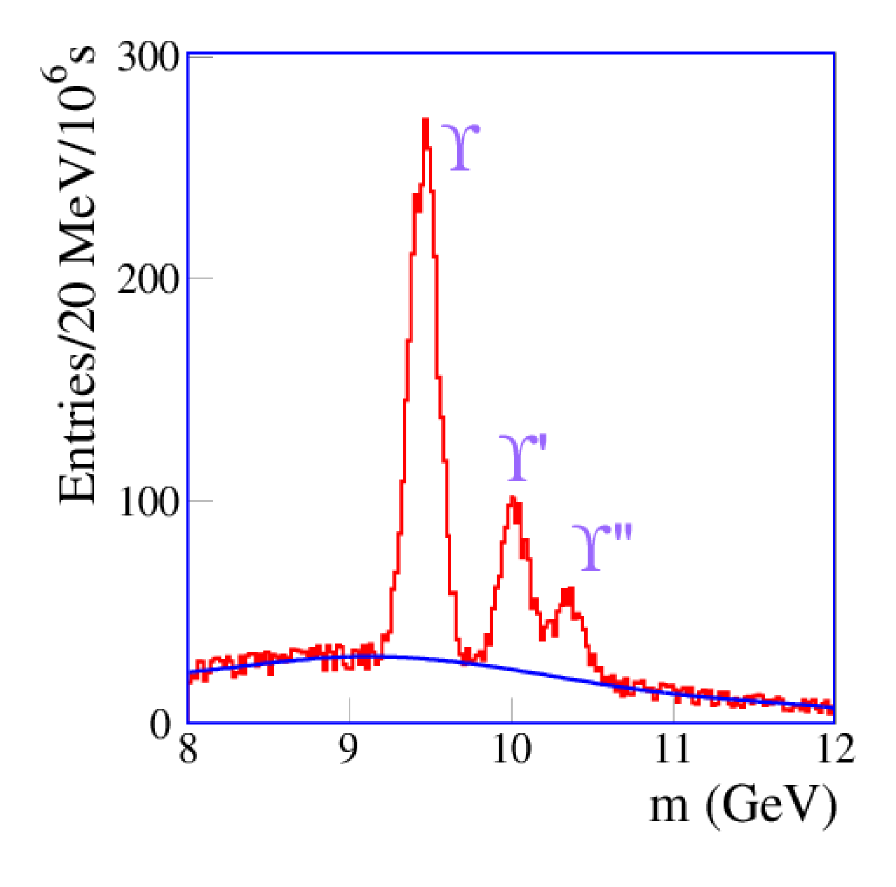
- Inclusive:
  - Suppression of dilepton invariant mass spectrum ($DD \rightarrow l^+l^-$, $BB \rightarrow l^+l^-$, $B \rightarrow D^+ \rightarrow l^+)l^-$
  - Suppression of lepton spectra

- Exclusive jet tagging:
  - High- p_T lepton ($B \rightarrow Dl\nu$) & displaced vertex
  - Hadronic decay (ex. $D^0 \rightarrow K^-p^+$) & displaced vertex

c/b Quarkonia

- 1 month statistics of PbPb √sNN=5.5 TeV

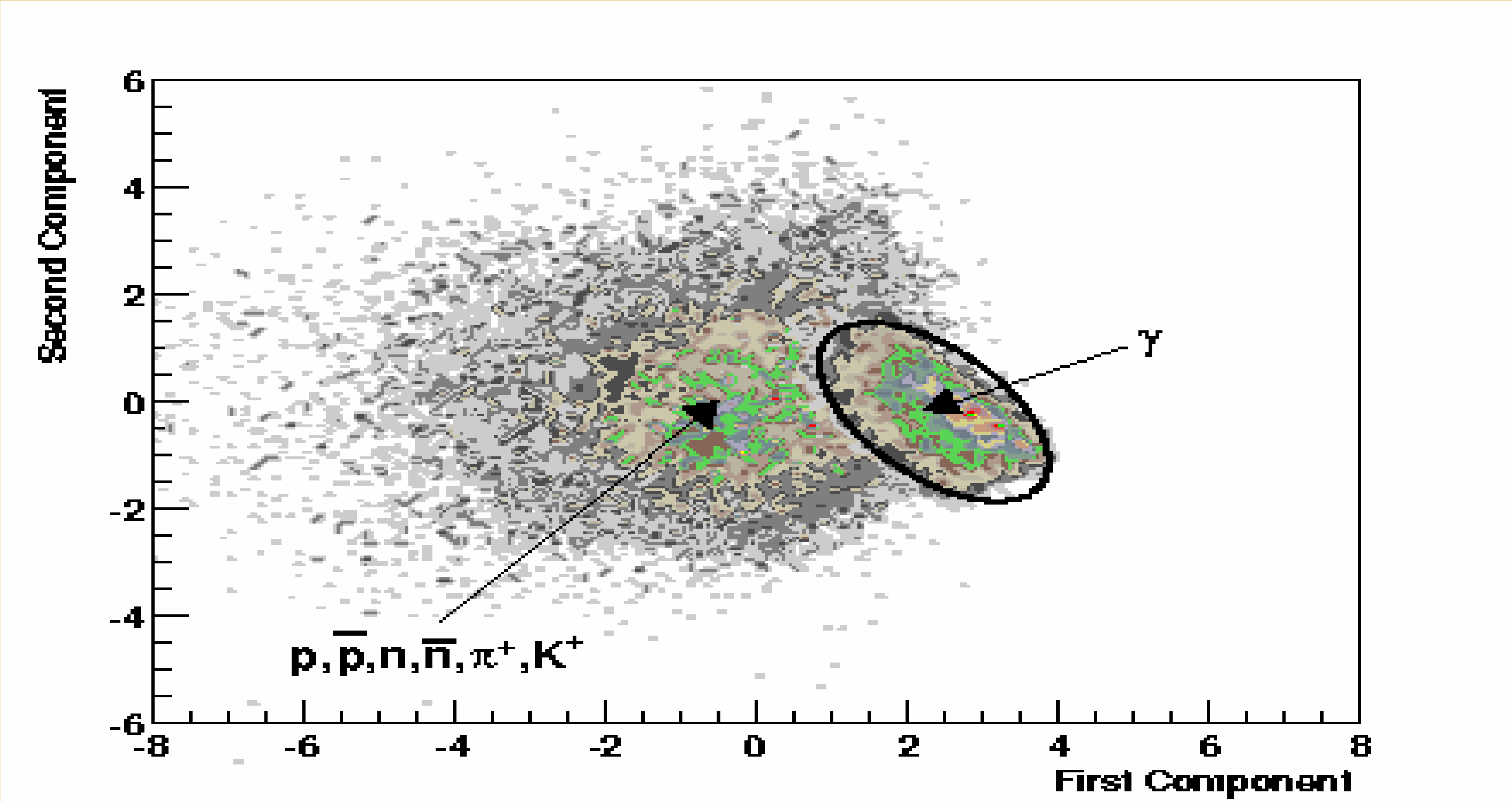




Photon identification with PHOS

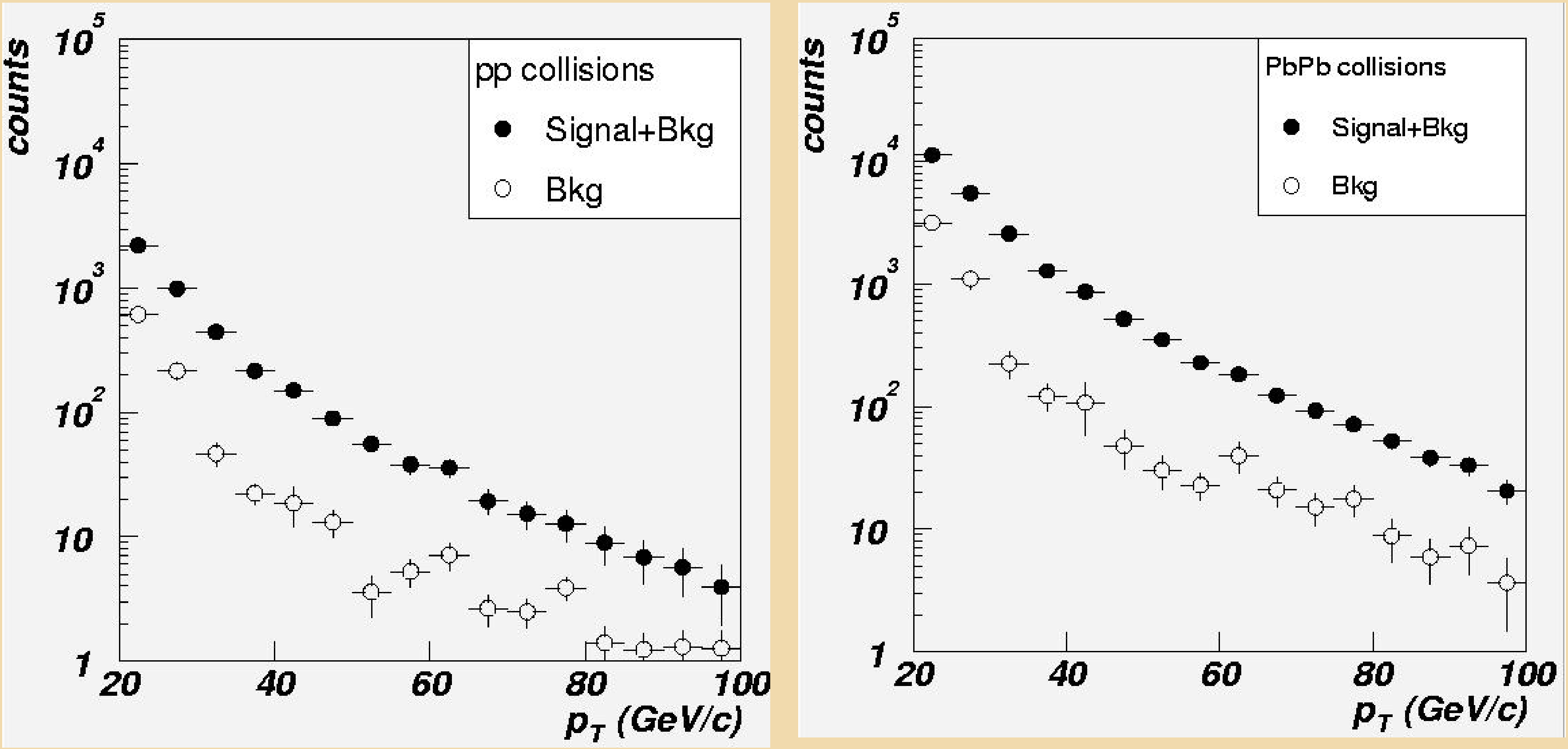
- PHOS identification:
  - CPV detector: Charged particle rejection.
  - TOF : Rejection of massive low p_T particles.
  - PHOS : Hadron rejection via shower topology.
- Shower topology methods:
  - Principal component analysis (PCA).
    three levels of γ ‘ purity ‘ defined:
  - Shower lateral dispersion.
- Isolation cuts
  - Required for improved background rejection

Particle Identification: Principal Component Analysis (PCA)



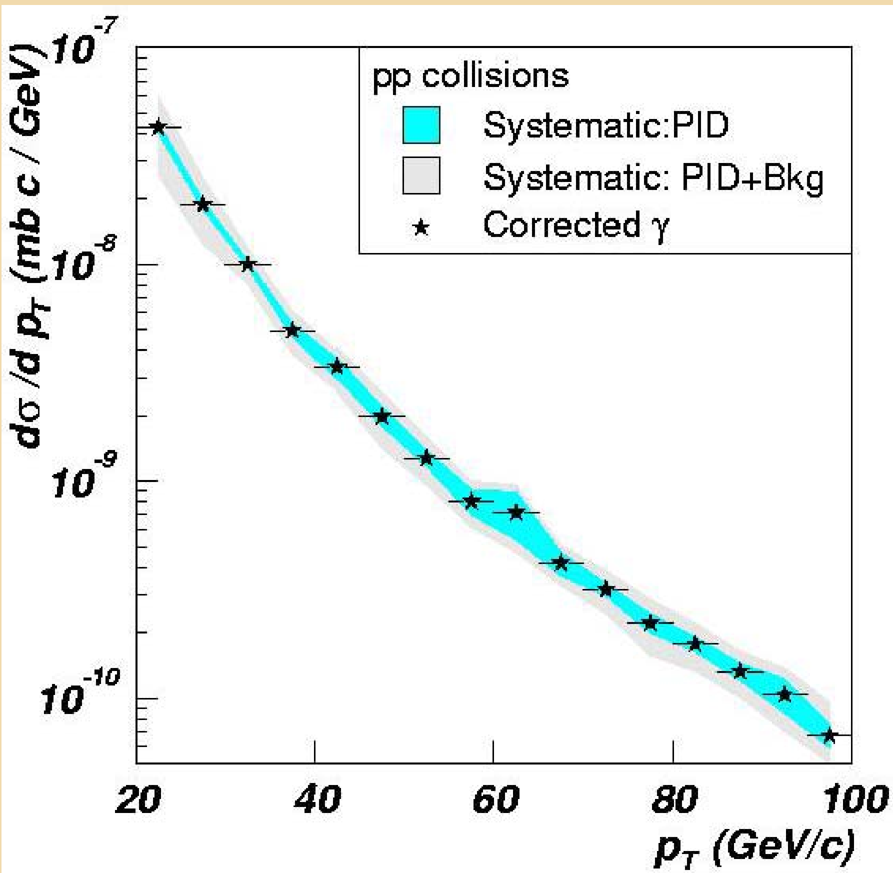
Seven parameters used; optimization in 7-dim.space;
Further rejection provided by timing capability of PHOS

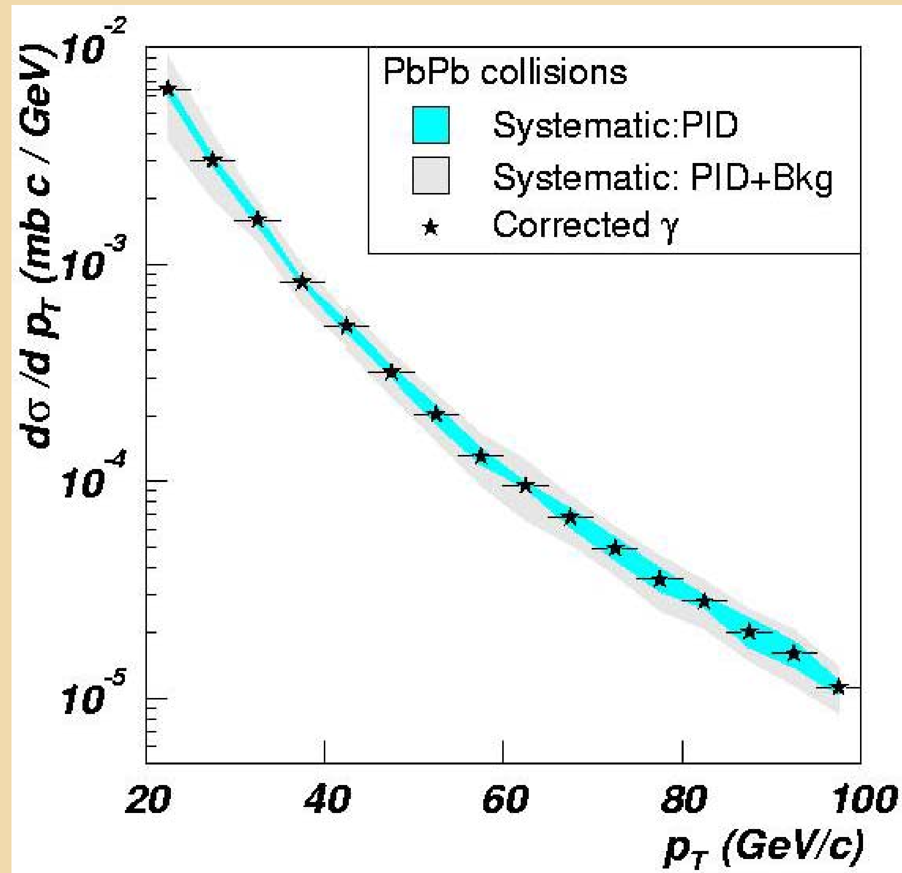
Prompt Photon Spectrum (One Year of Running)



Conclusion : high p_T (>20 Gev/c) well within reach of Alice

Cross section for Prompt Photon Production





Looking forward to first operation

- to a timely completion of LHC and experiments construction in April 2007;
  - Accelerators and experiments are in the production phase.
- For an exciting decade of HI physics in a new regime physics
  - Detailed physics program is taking shape (Physics Performance Reports, Yellow Report,..)
- The 2005 – 2007 challenge:
  - Keep the detector construction on its rather tight time scale
  - Continue preparation and bring to ready-state the physics analysis programs
  - demonstrate world-wide distributed Monte-Carlo production and data analysis.