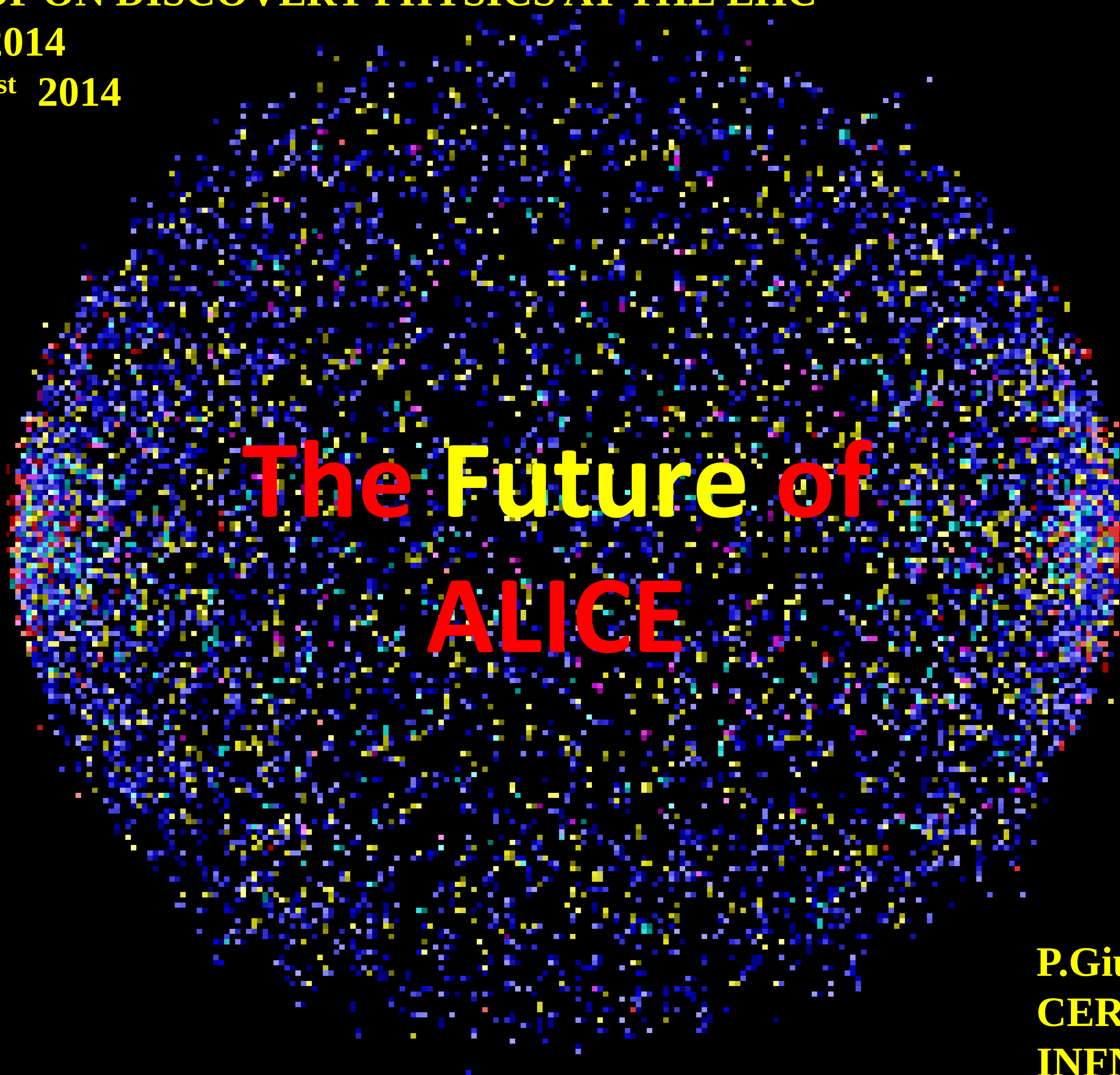
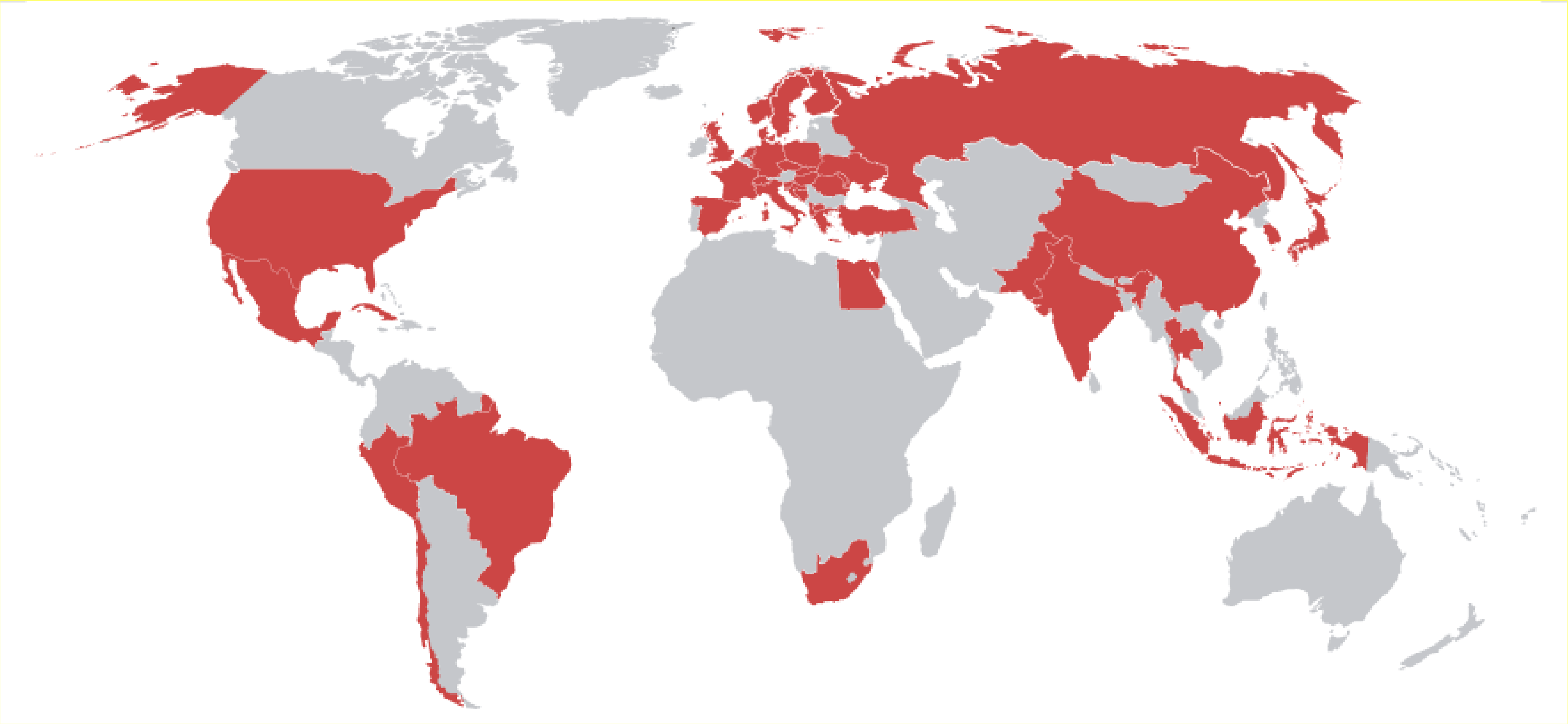
WORKSHOP ON DISCOVERY PHYSICS AT THE LHC
KRUGER-2014
December 1st 2014



The Future of ALICE

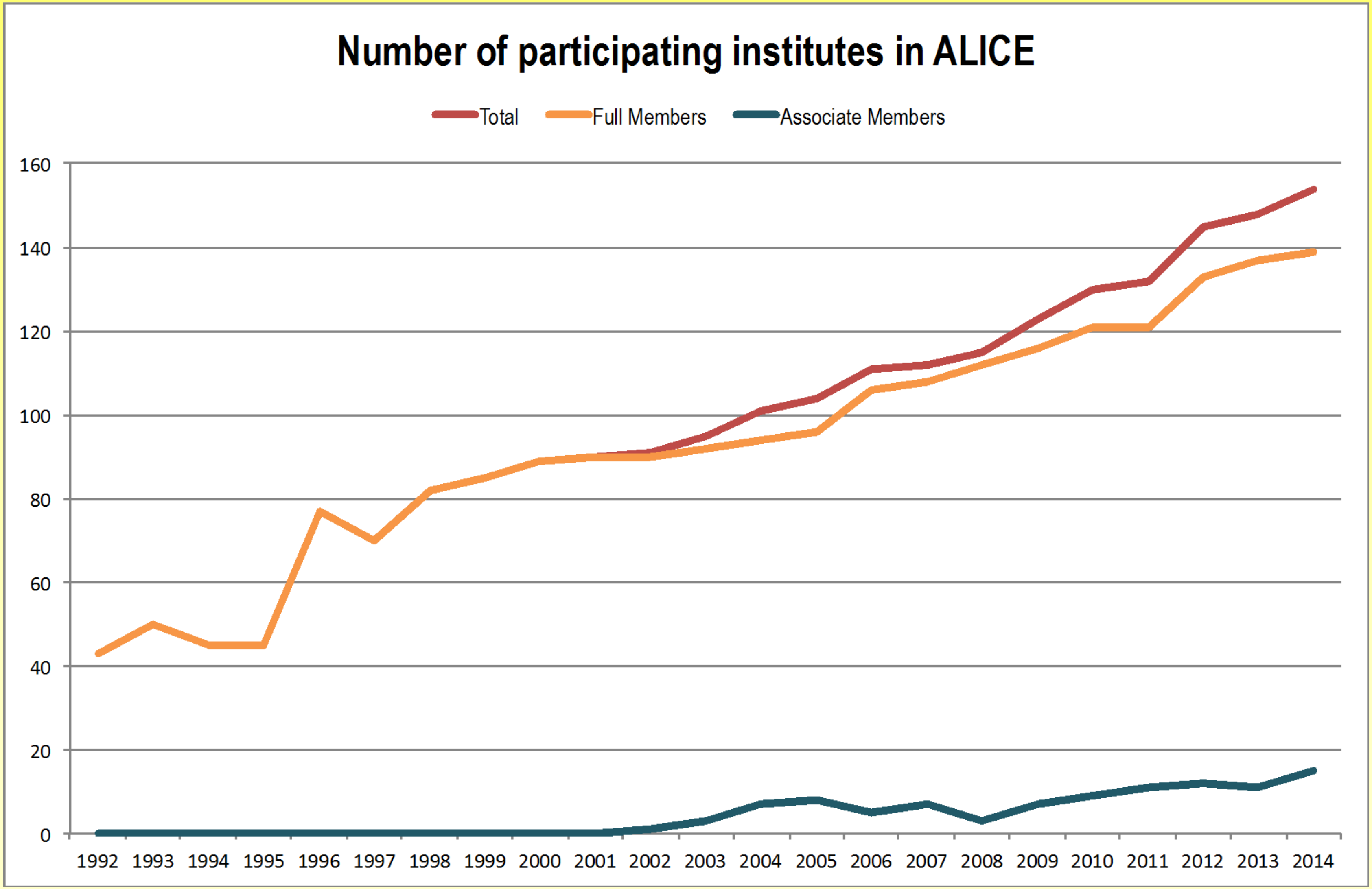
P.Giubellino
CERN and
INFN Torino

ALICE: a world-wide effort



37 COUNTRIES – 154 INSTITUTES – 161’451 KCHF CAPITAL COST

ALICE Continues to grow!



A scientific and technological program with great prospects!

THE ALICE COLLABORATION

History of the ALICE Experiment:

1990-1996 Design

199

200

200

200

200

4 T

2012 LoI for the Upgrade

2

2

2016-2017 Integration, pre-commissioning

2018-2019 Installation, commissioning

2019-2020 Full deployment of DAQ/HLT

ALICE has already evolved a lot!!

More than 1500 Collaborators

SOUTH AFRICA: 10 Collaborators from 3 Institutes:

- University of Cape Town (UCT), Cape Town
- iThemba LABS, Somerset West
- University of the Witwatersrand (WITS), Johannesburg

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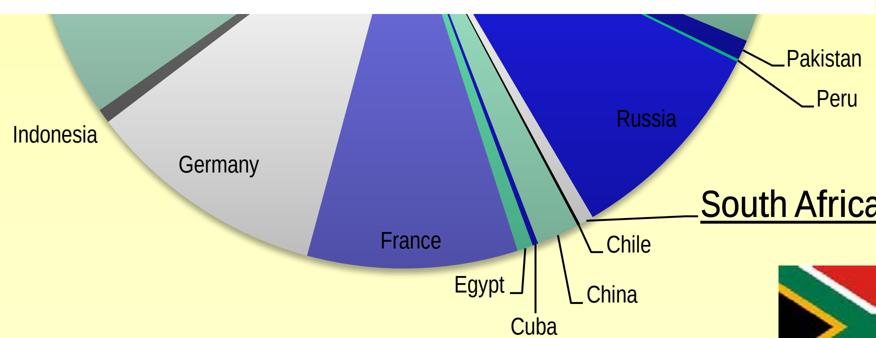


South Africa in ALICE

Historical Events

- ❖ UCT joined ALICE in 2001, and became UCT-CERN Research Centre in 2003.

- ❖ iThemba LABS joined in 2008

- ❖ Launch of the National SA-CERN Programme in 2008.

SOUTH AFRICA ALICE GROUP

Tom Dietel (UCT) Team-Leader, Member of the Collaboration Board and of the Conference Committee

Jean Cleymans (UCT and iThemba LABS) Deputy-Team Leader, Member of Institutional Board (Muons), Chairman of SA-CERN Program

Zinhle Buthelezi (iThemba LABS) Member

Siegfried Förtsch (iThemba LABS) Deputy-Team Leader

Deon Steyn (iThemba LABS) Member

Francesco Bossù (iThemba LABS) Post-doctoral Member, Convener of PAG-HFM

SOUTH AFRICA Group

New Member – Wits

Wits joined ALICE

- 28 March 2014
- unanimous vote of the ALICE Collaboration Board
- in association with UCT

Developing the strategy to build a group. Post-doc positions will be available soon.

SOUTH AFRICA Group: Student Activities

Sean Murray (UCT and iThemba LABS) PhD, Interim System Administrator of CHPC
Research topic: *High-Level Trigger for the ALICE Muon Detector*

Kgotlaesele Johnson Senosi (UCT and iThemba LABS) PhD
Research topic: *W production in pp,P-Pb and Pb-Pb collisions at LHC energies*

Sibaliso Mhlanga (UCT and iThemba LABS) MSc
Research topic: *Heavy Flavour production vs multiplicity at forward rapidity with ALICE*
Attended CERN Summer School 16 June - 8 August 2014

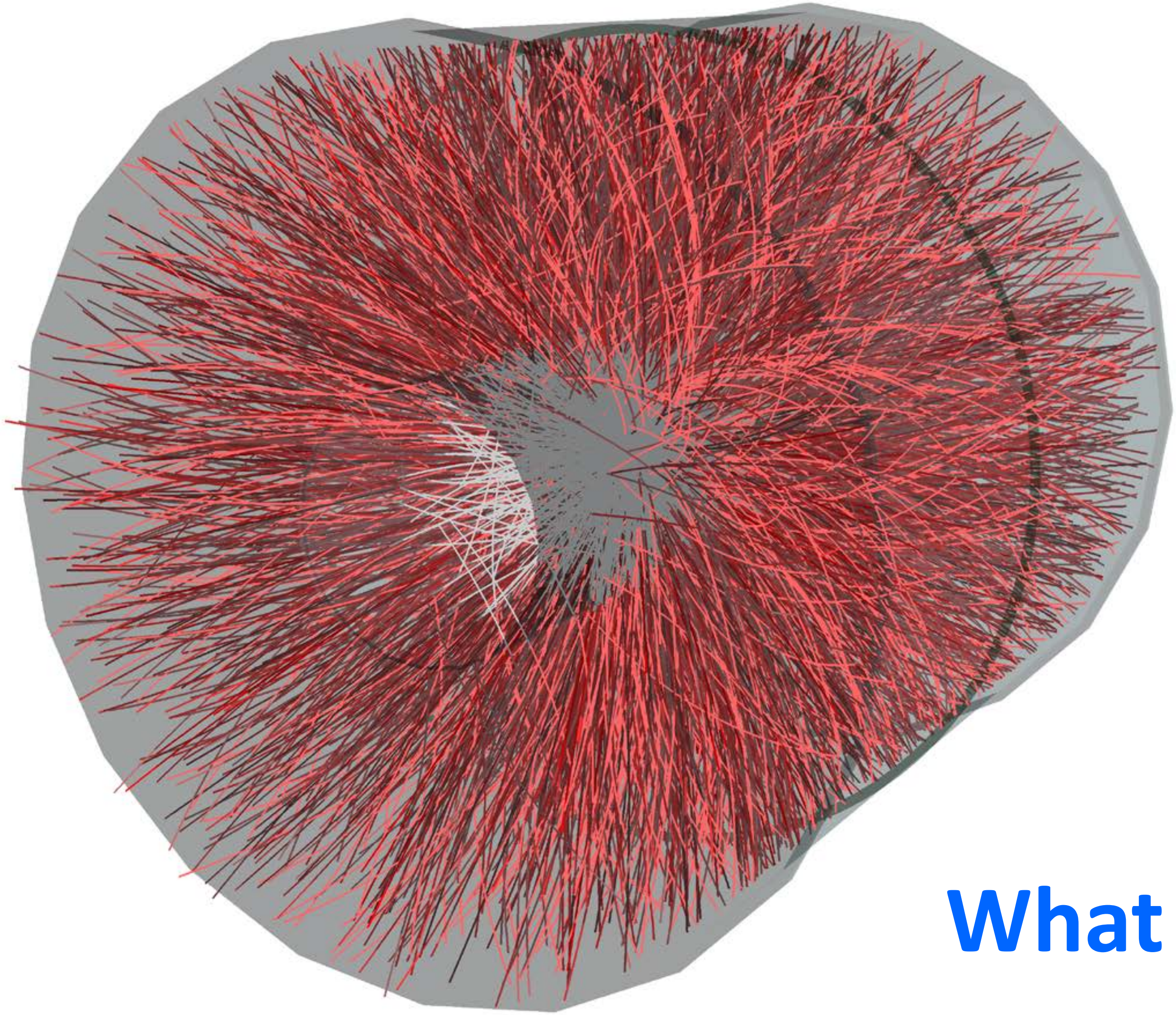
And more starting!

Rhodes University
Extending the Geographical footprint…

RHODES UNIVERSITY
Where leaders learn

Interest to join SA-CERN by Department for Physics and Electronics
→ Ongoing discussion.

A worldwide effort to study the world's most energetic and most complicated collisions

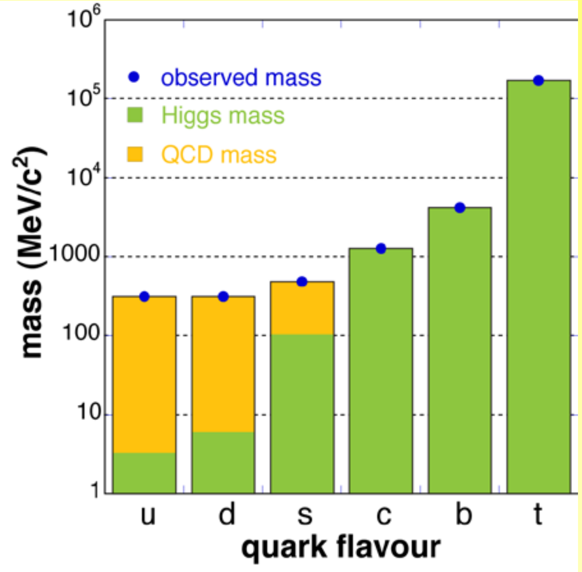


What for?

Why HI Collisions?

- What are the fundamental properties of strongly interacting matter as a function of temperature and density?
- What are the microscopic mechanisms responsible for them?
  - What are the microscopic degrees of freedom and excitations of matter at ultra--high temperature and density?
  - Which are its transport properties and equation of state?

- How did its properties influence the evolution of the early universe?
- How is mass modified by the medium it moves in?
- How do hadrons acquire mass?
- What is the structure of nuclei when observed at the smallest scales, i.e. with the highest resolution?



Most of the observed mass of light quarks is generated by the spontaneous breaking of chiral symmetry

•**Heavy-Ion collisions:**

Laboratory studies of the bulk properties of non-Abelian matter

•...with deep connections to other fields in physics:

String Theory, Cosmology, Condensed Matter Physics, Ultra--Cold Quantum Gases

A long way...

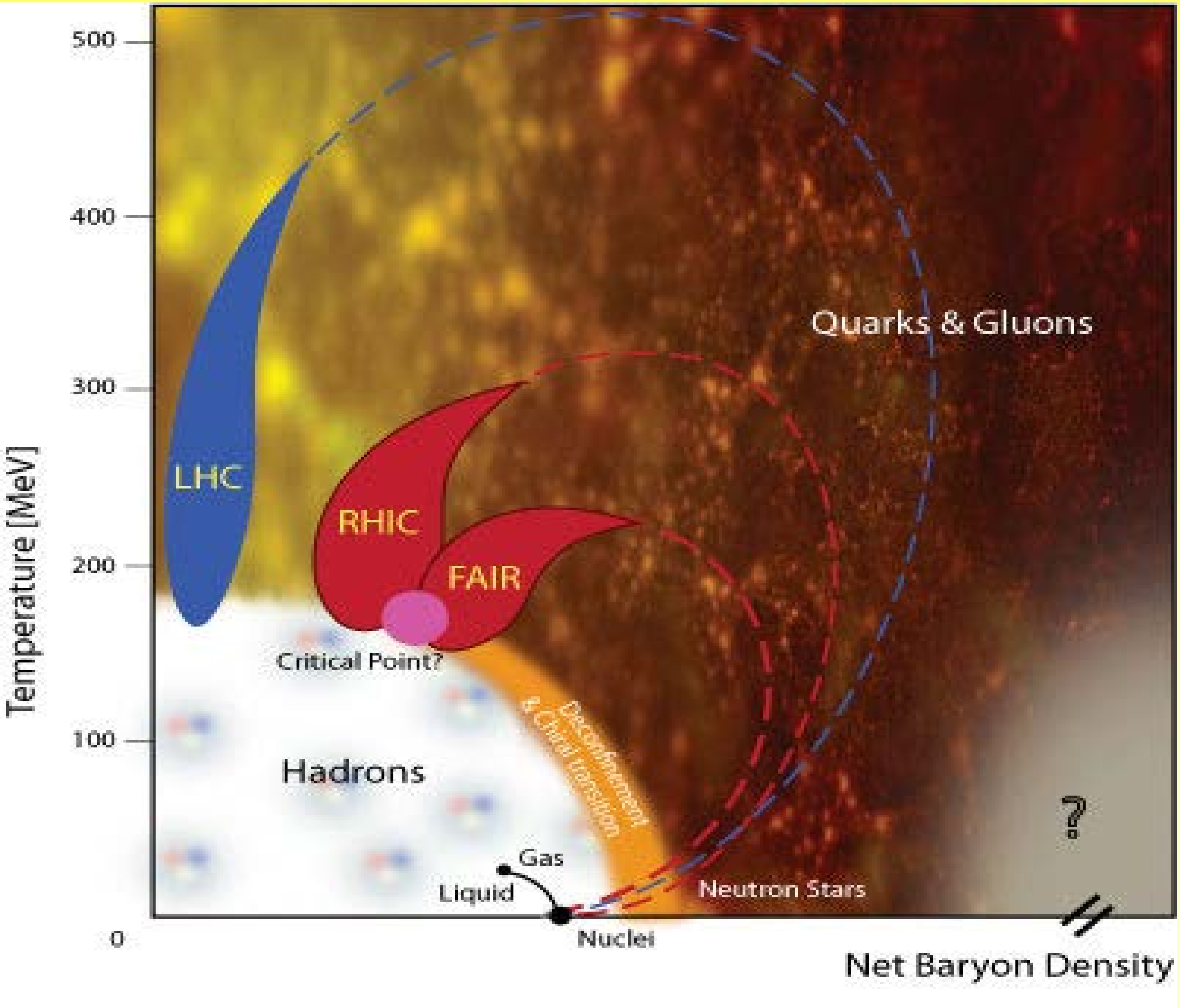
- Hagedorn 1965: mass spectrum of hadronic states $\rho(m) \propto m^{a} \exp(m/B)$
  => Critical temperature T_c=B
- QCD 1973: asymptotic freedom
  - D.J.Gross and F.Wilczek, H.D. Politzer
- 1975: asy... q... and gluons

Prize motivation: "for the discovery of asymptotic freedom in the theory of the strong interaction"

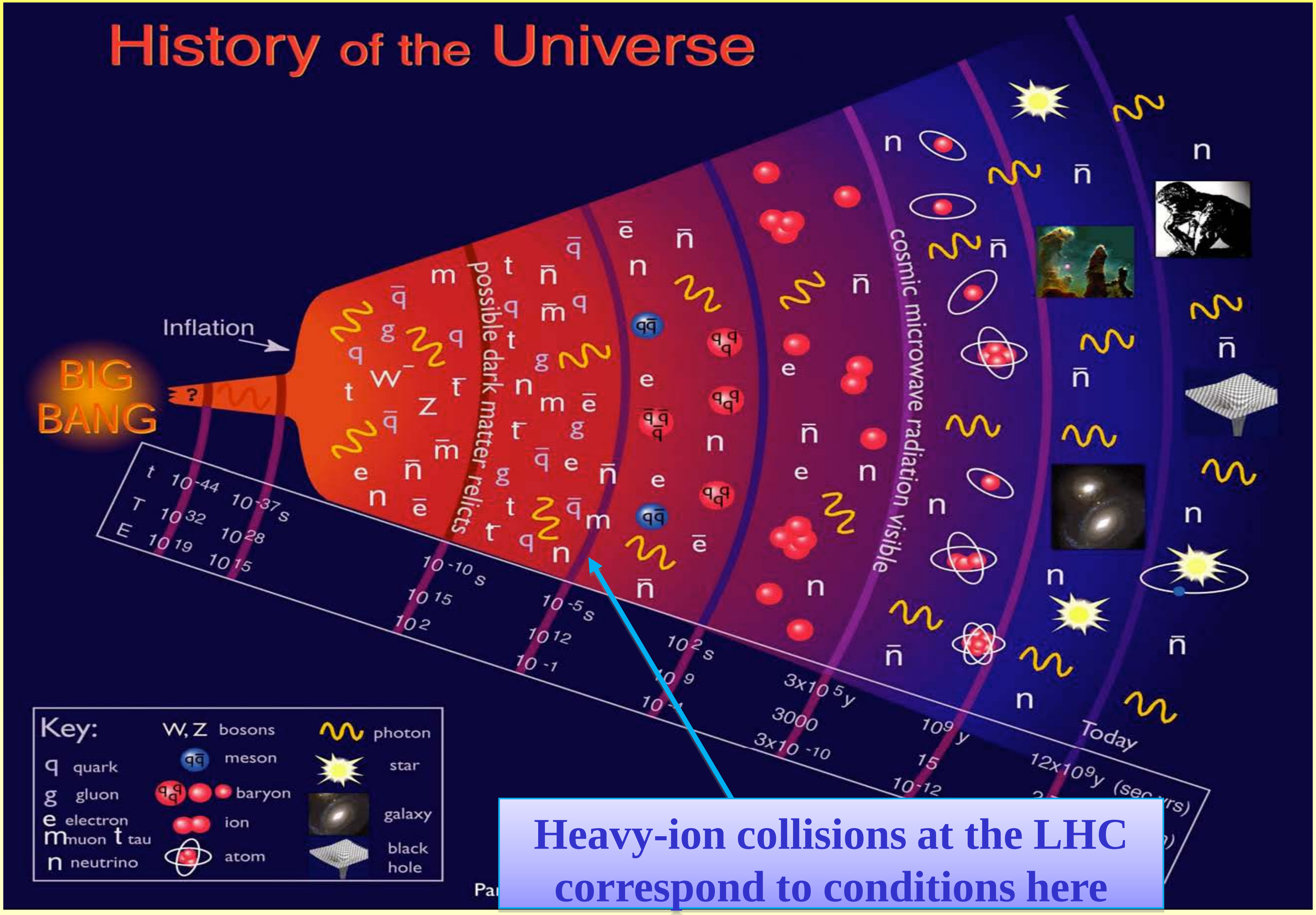
Nobel Prize in Physics 2004

David J. Gross H. David Politzer Frank Wilczek

The Phase Diagram of Nuclear Matter



Brief History of Our Universe



Heavy-ion collisions at the LHC correspond to conditions here

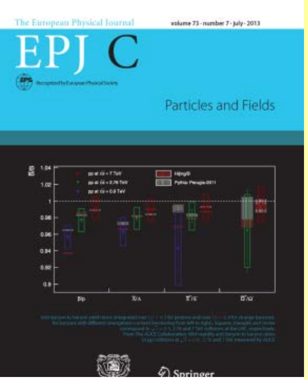
Many critical features of our universe were established in these very early moments.

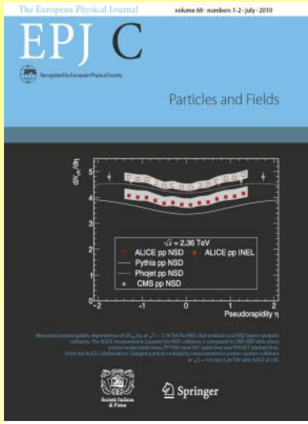
Why Heavy Ions @ LHC?

- It is a different matter as compared to RHIC (and even more to SpS)
  - Larger temperature, volume, energy density and lifetime
    - Study QGP properties vs T …
  - large cross section for '**hard probes**' : high p_T, jets, heavy quarks,…
  - small net-baryon density at mid-rapidity ($\mu_B \approx 0$), corresponding to the conditions in the early universe
  - First principle methods (pQCD, Lattice Gauge Theory) more directly applicable
  - new generation, large acceptance state-of-the-art detectors
    - Atlas, CMS, ALICE, [LHCb, for pA]
- A comprehensive program, complementary to the ones at lower energy

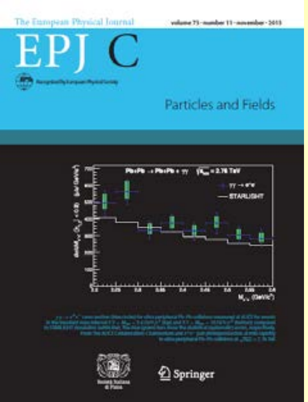
A program of major impact

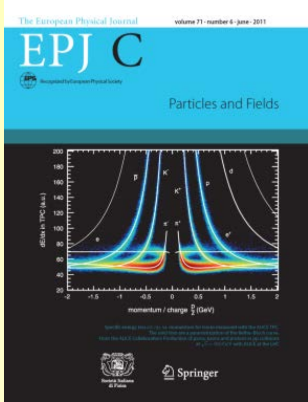
- A very large community of physicists involved
  - over a thousand just in ALICE, hundreds in the other LHC experiments
  - Very many theorists



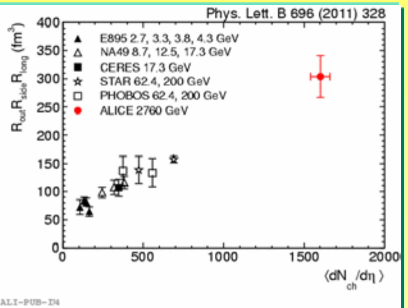


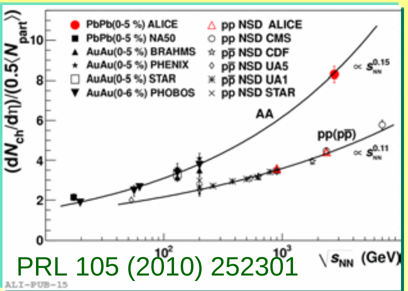
- A huge scientific output
  - **100 ALICE papers on arXiv** (~ the whole RHIC program in the same time span)
  - **High impact papers:** the top cited paper at the LHC after the Higgs discovery ones is the ALICE paper on flow in HI collisions, and out of the 10 top cited physics papers at the LHC 3 are from ALICE and one from ATLAS-Heavy Ion program (source: ISI)
  - **Several hundred** presentations at international conferences *each year*

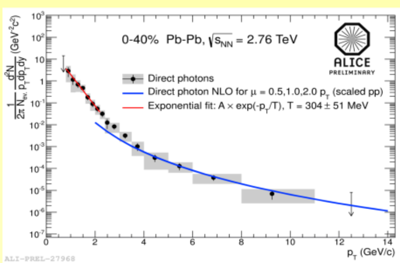




A lot of results already from RUN1





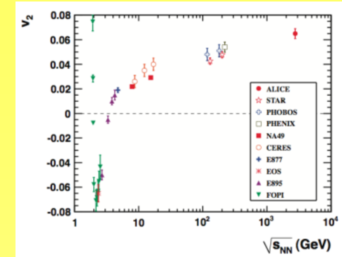


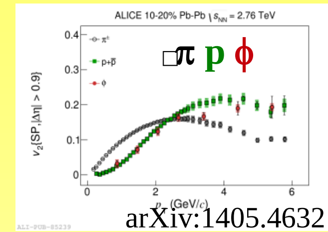
A continuous flow of new results

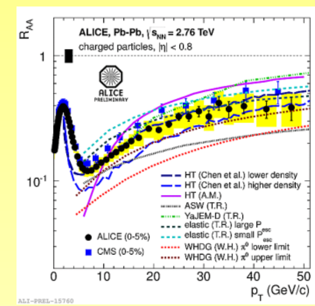
- global features defined
- QGP strongly interacting liquid even at higher T, access to transport coefficients
- energy loss of partons in QGP: wealth of data from leading particles and reconstructed jets, including heavy quarks
- Heavy quarks also appear to thermalize!
- rich results on charmonium, well on the way towards proof of deconfinement
- Access to low-x PDF from UPC

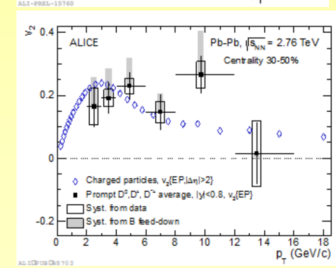
Intriguing, unexpected results from the pA run

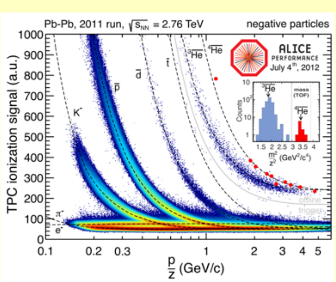
- How small a QGP serving to observe collective behaviour?

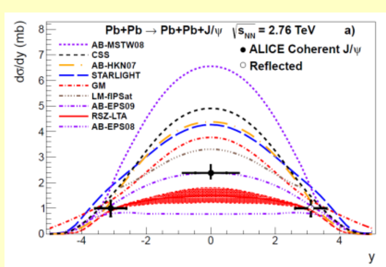


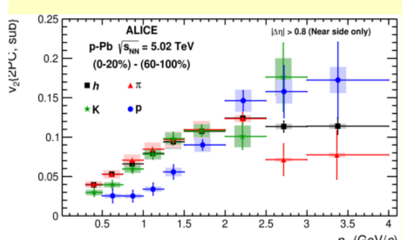


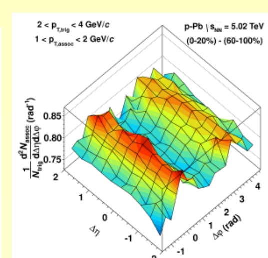


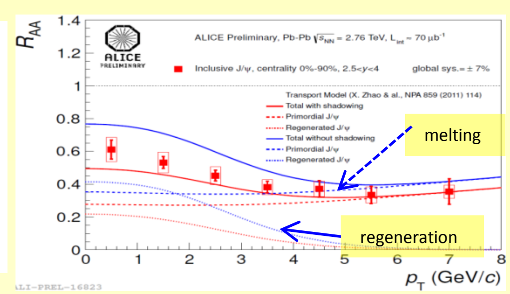










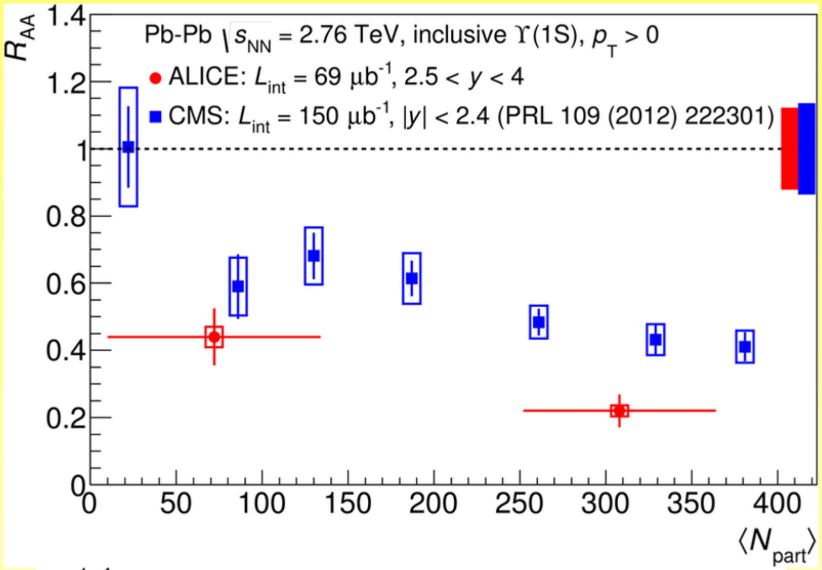


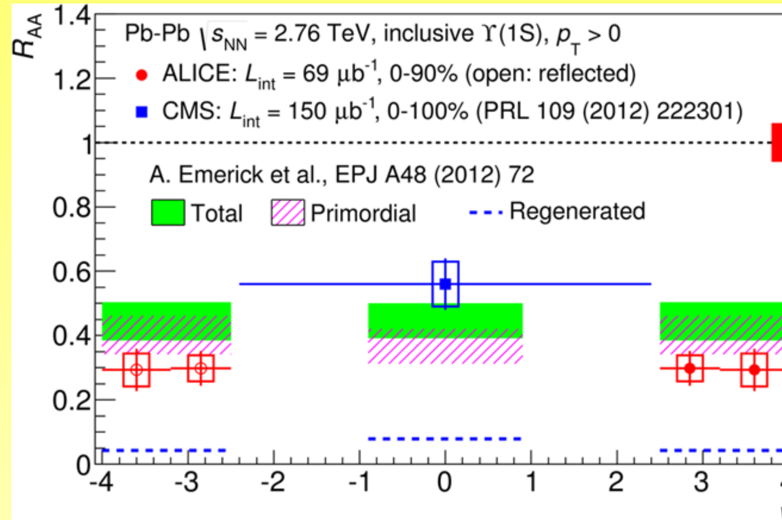
Lots of results at this conference!

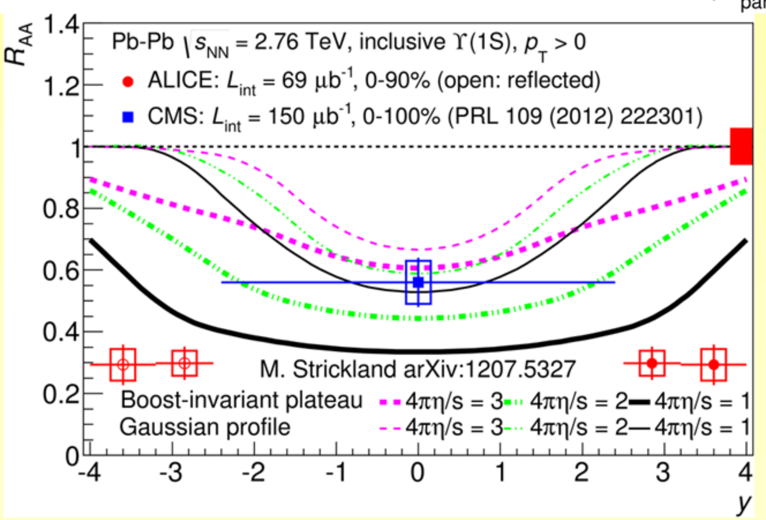
- Don’t miss the presentations (in order of appearance) by:
  - H. Oeschler
  - N. Sharma
  - S. Bufalino
  - I. Arsene
  - H. Yang
  - K. Senosi
  - S. Masciocchi
  - M. Masera
  - M. Floris
  - K. Reygers
  - J. Harris
- And J. Schukraft’s review of the whole field at the end of the conference….

ALICE Physics in South Africa

- Di-Muons: Upsilon Study







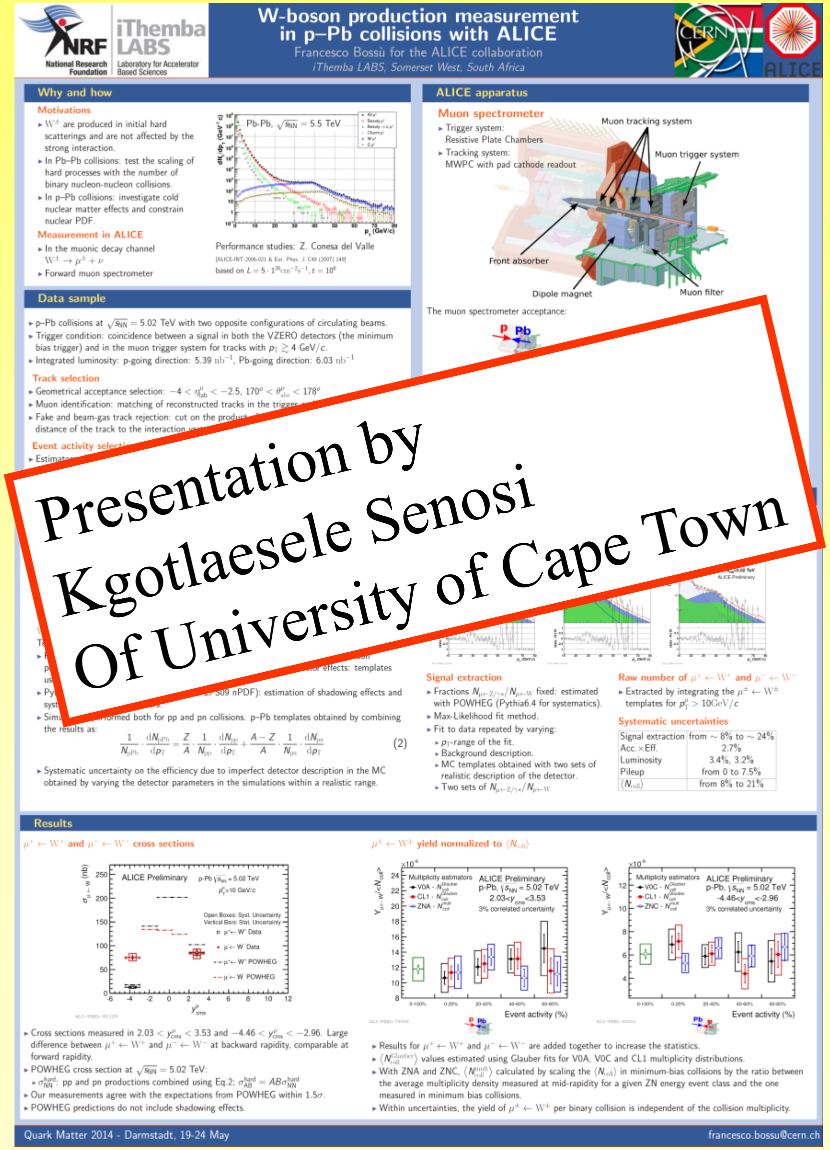
Published: Phys Lett B 738 (2014) 361–372

Upsilon study: *Suppression of Y(1S) at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV*

- Strong suppression in forward direction
- Not reproduced by models

Physics (continued):

- W boson production measurement in p-Pb collisions with ALICE:



❖ $W^{\pm}$ are produced in initial hard scatterings, not affected by the strong interaction.

❖ In Pb-Pb collisions: test the scaling of hard processes with the number of binary nucleon-nucleon collisions.

❖ In p-Pb collisions: investigate cold nuclear matter effects and constrain nuclear PDF.

❖ Measured in the muonic decay channel $W^{\pm} \rightarrow \mu^{\pm} + \nu$

<u>Preliminary results presented at QM2014, Darmstadt, 19-24 May 2014. full paper now in final preparation</u>

❖ Yield of W versus event activity → test the dependence of this
hard process with the event activity.

❖ Cross-section → sensitive to cold nuclear matter effects (shadowing).

❖ Comparison with theoretical predictions based on pQCD NLO with and without shadowing shown in JHEP 1103 (2011) 071 → Shadowing effects are more pronounced at forward rapidity.

Physics (continued):

- Heavy Flavour Muons:

❑ The study of the production of single muons from heavy flavour decays as a function of charged particle multiplicity in pp collisions at 8 TeV at forward rapidity

❖ The study is motivated by *J/ψ Production as a Function of Charged Particle Multiplicity in pp Collisions at √s = 7 TeV* [PLB 712, (2012)165] as well as the ongoing analysis of charm production multiplicity dependence at central rapidity in pp collisions at 7 TeV.

❖ This will allow us to gain insight into the processes occurring in the collision at microscopic level and the interplay between hard and soft mechanisms in particle production.

–

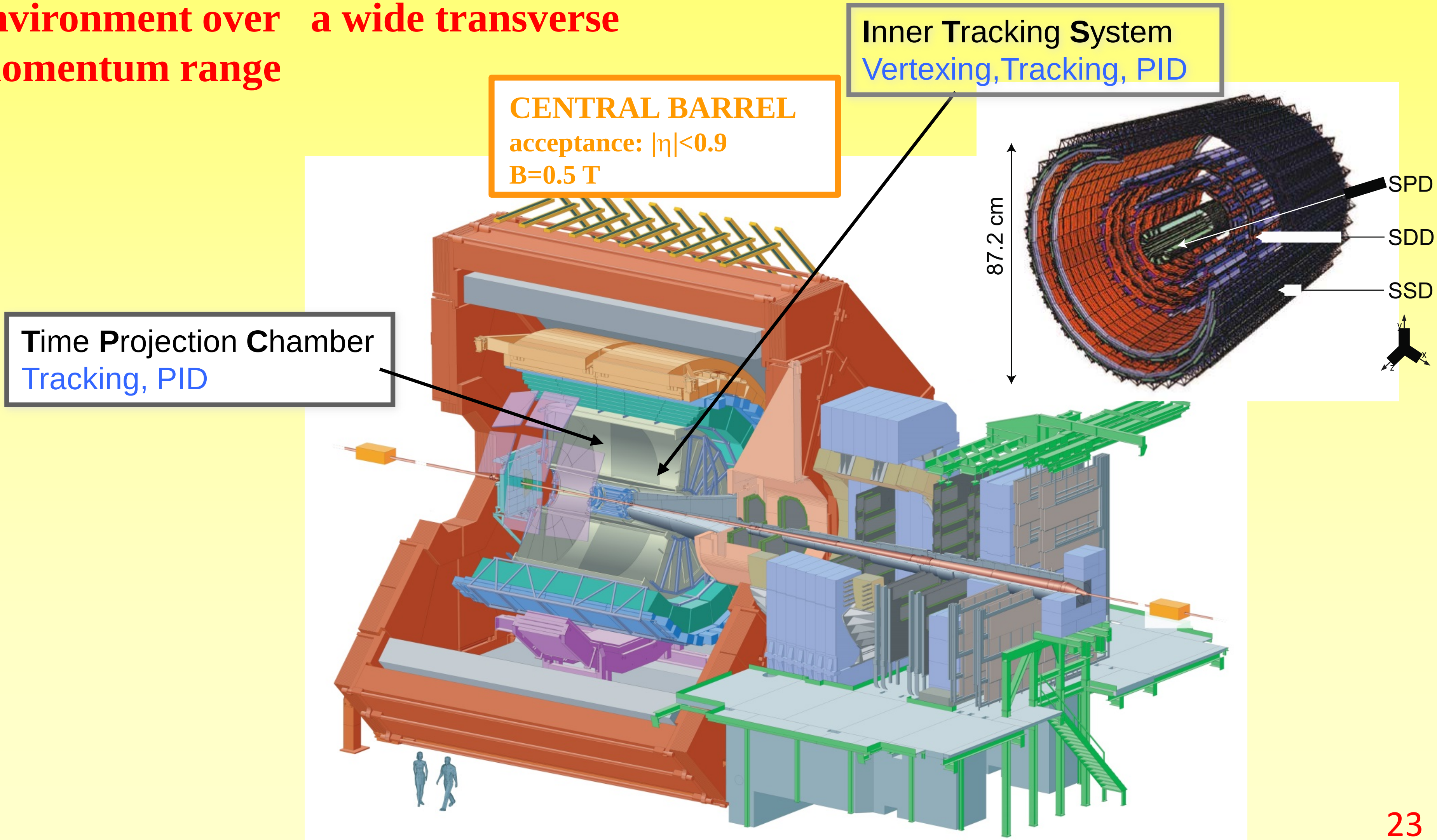
Experiments at the LHC…

- ALICE
  - Experiment designed for Heavy Ion collision
    - only dedicated experiment at LHC, must be comprehensive and able to cover all relevant observables
    - **VERY robust tracking** for p_T from **0.1 GeV/*c*** to **100 GeV/*c***
      - high-granularity 3D detectors with many space points per track (**560 million** pixels in the TPC alone, giving 180 space points/track)
      - **very low material budget** (**< 10%X_0** in r < 2.5 m)
    - **PID** over a very large p_T range
      - use of essentially all known technologies: TOF, dE/dx, RICH, TRD, topology
    - Hadrons, leptons and photons + Excellent vertexing
- ATLAS and CMS
  - General-purpose detectors, optimized for hard processes
    - Excellent Calorimetry = > Jets
    - Excellent dilepton measuremens, especially at high pT
- Now Joined by LHCb for pPb

Each required 20 years of work by a worldwide collaboration...

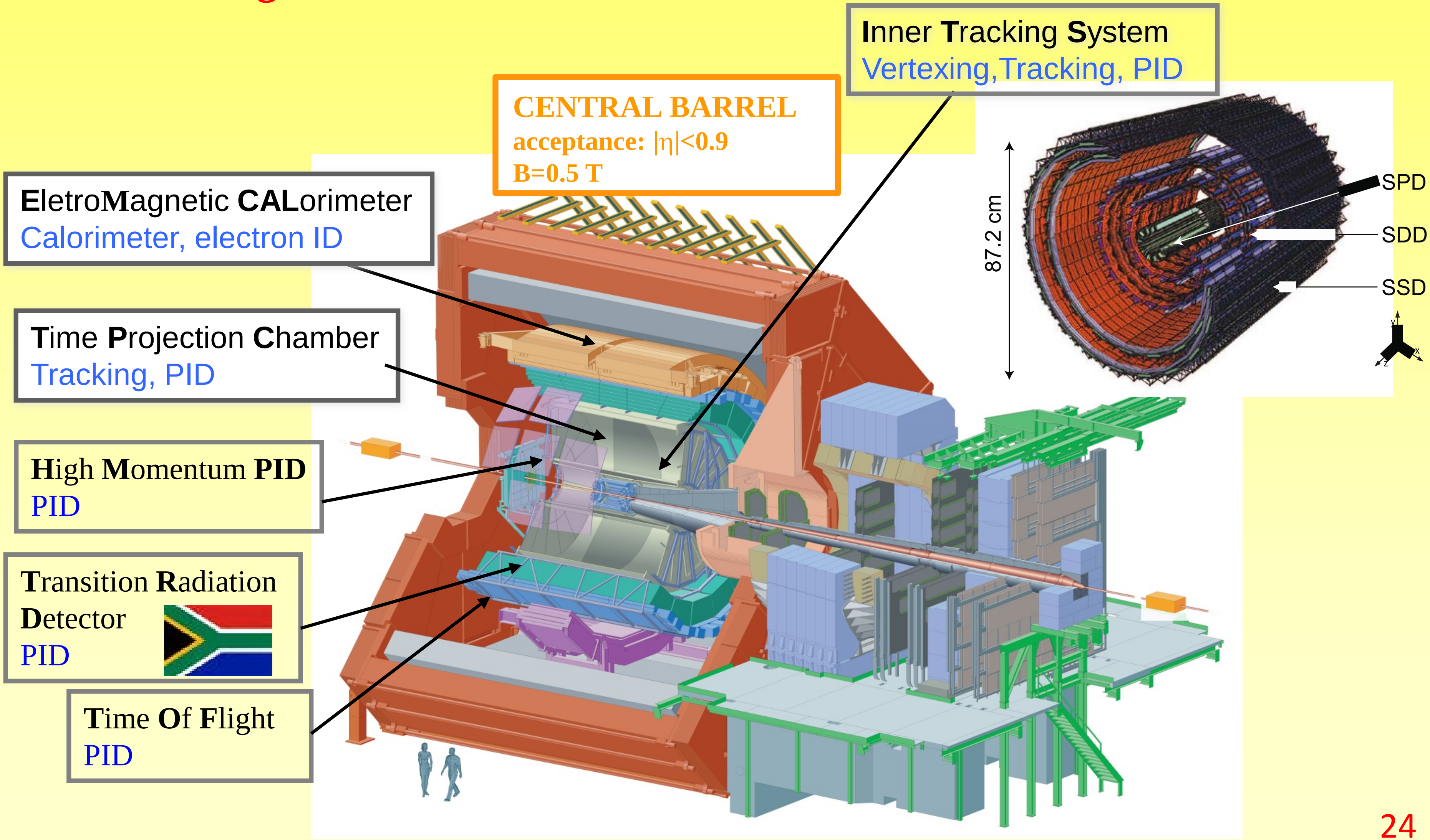
ALICE detector specificities

Excellent track and vertex reconstruction capabilities (TPC, ITS) in a high multiplicity environment over a wide transverse momentum range



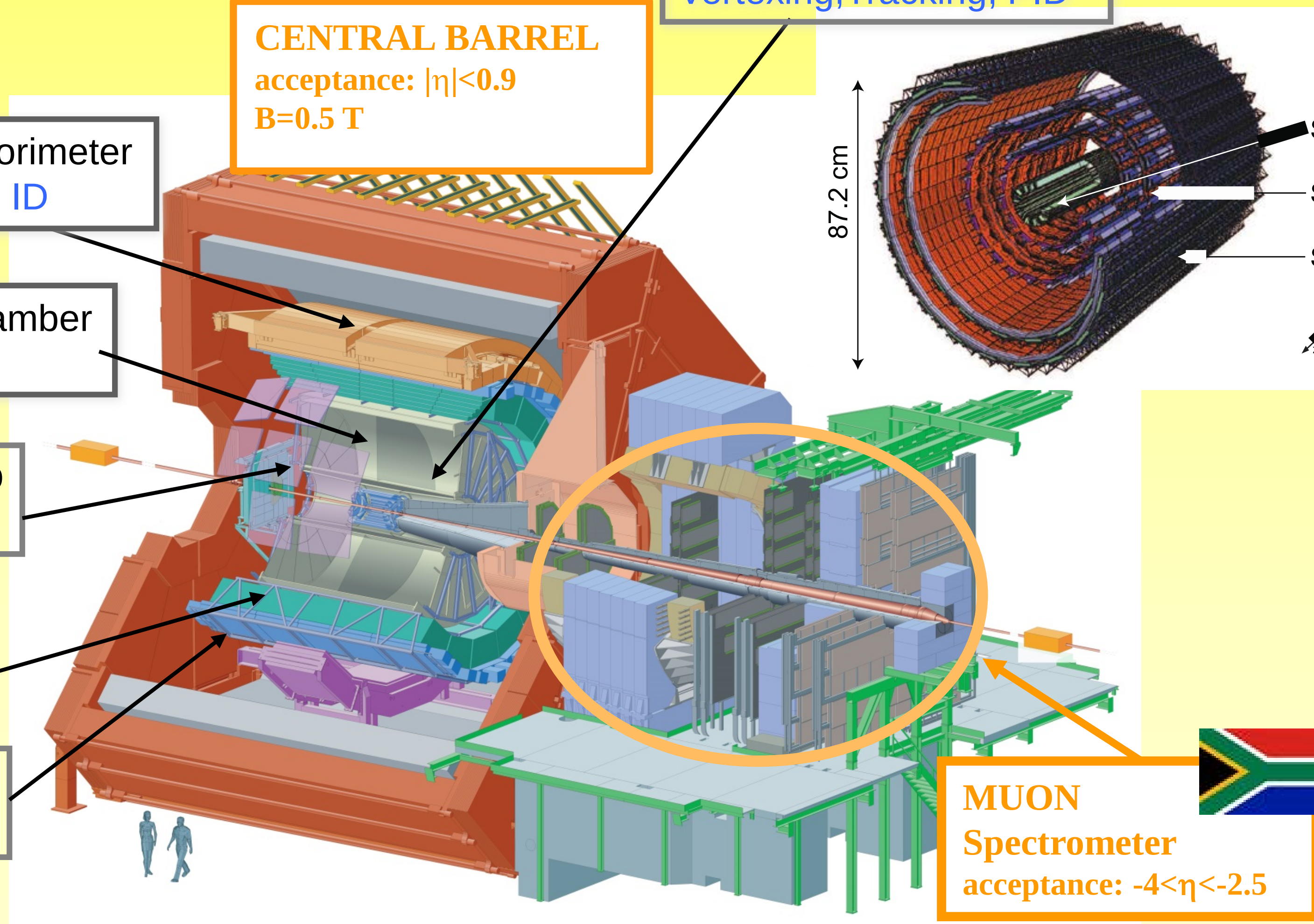
ALICE detector specificities

Particle identification over a wide momentum range



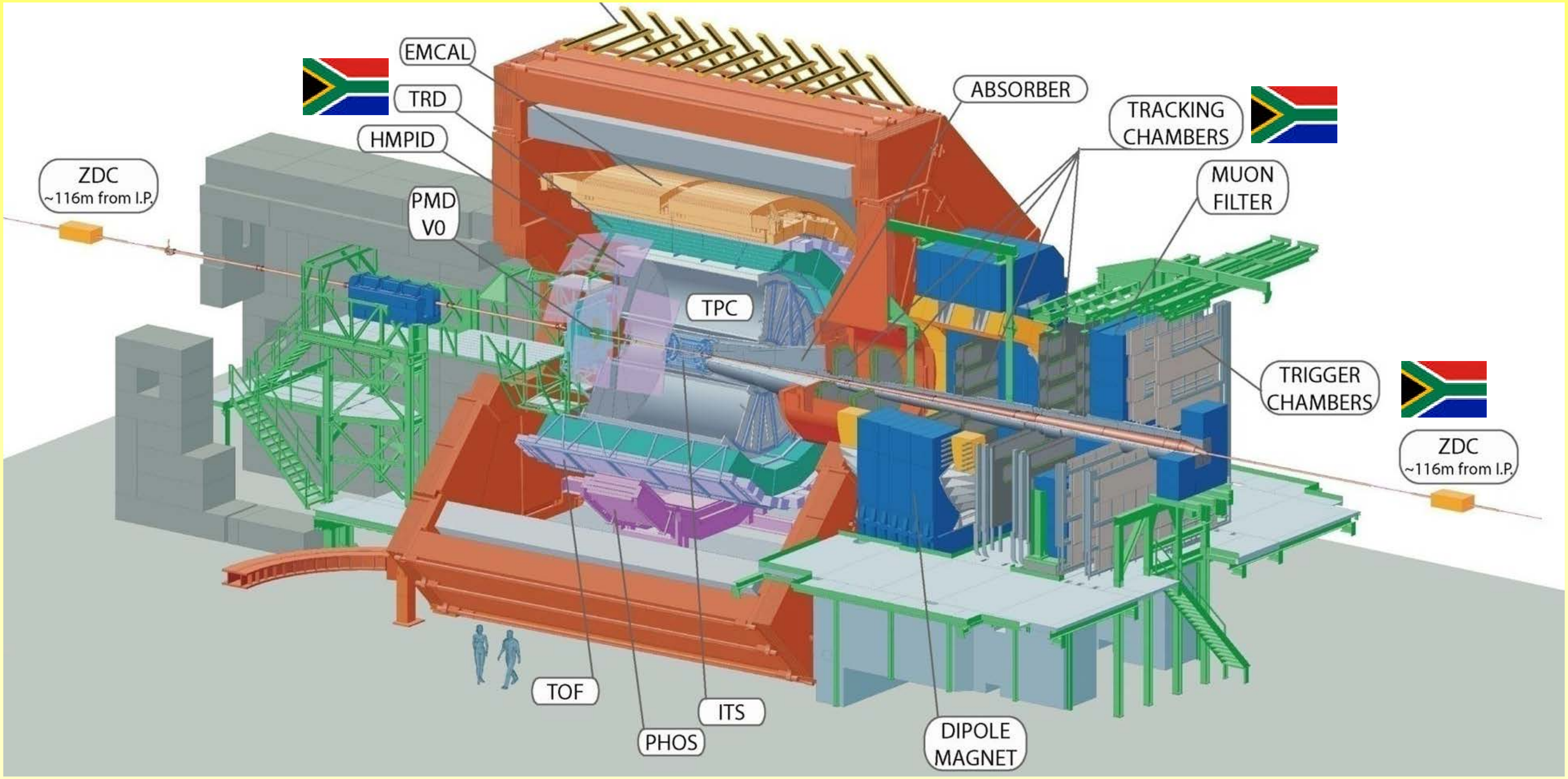
ALICE detector specificities

Excellent muon identification down to low p_T at forward rapidity



SOUTH AFRICA IN ALICE

DEEPLY INVOLVED IN THE INSTRUMENTAION

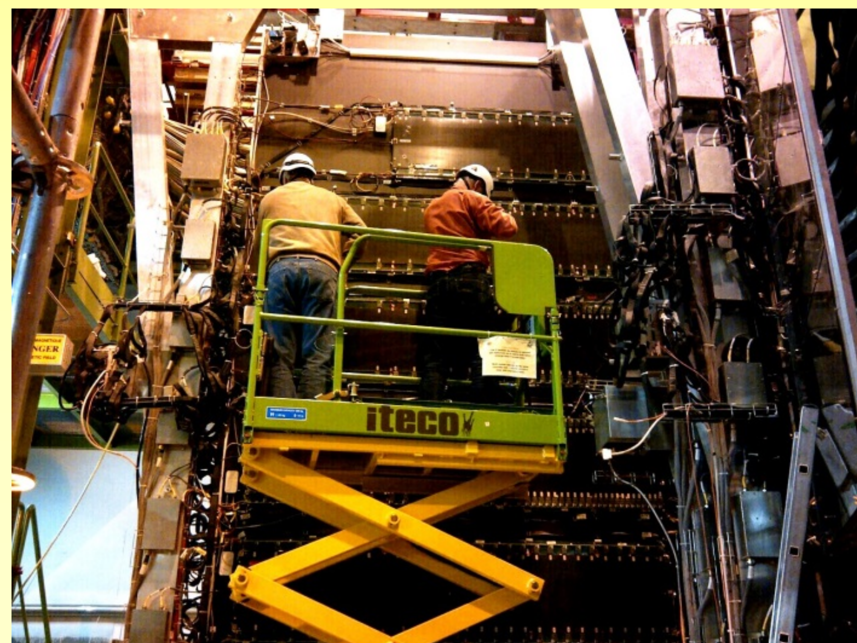


Muons Tracking and Trigger
TRD
Muon High Level Trigger (HLT)

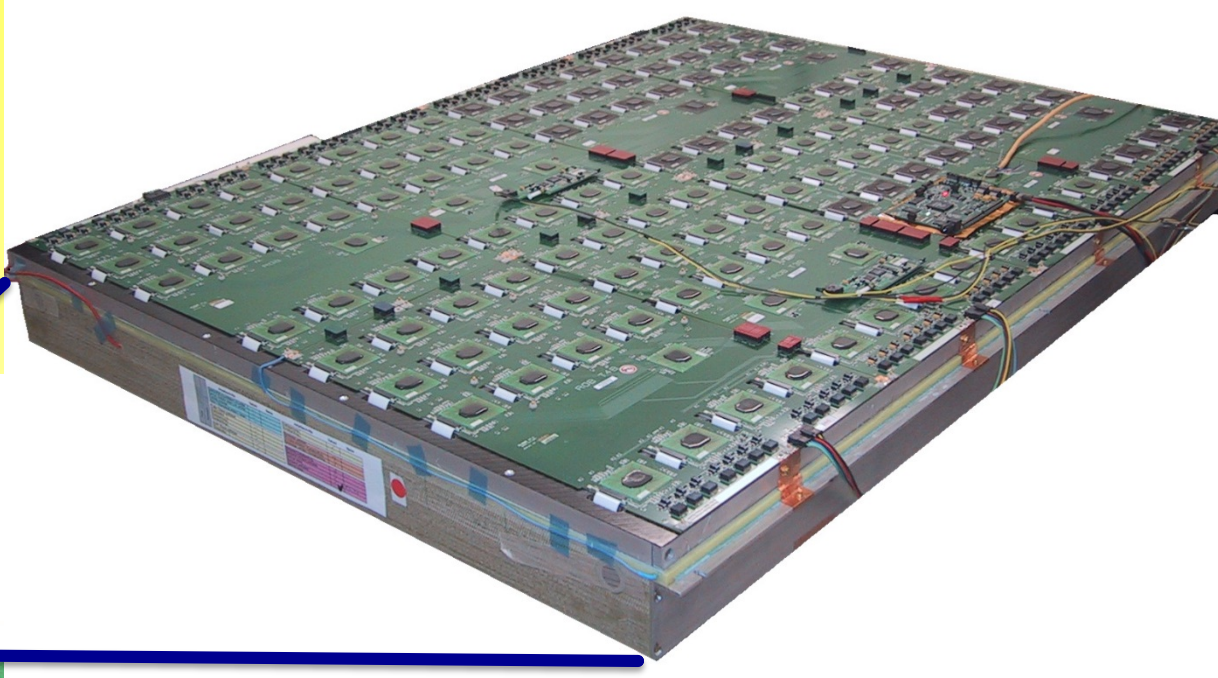
ALICE

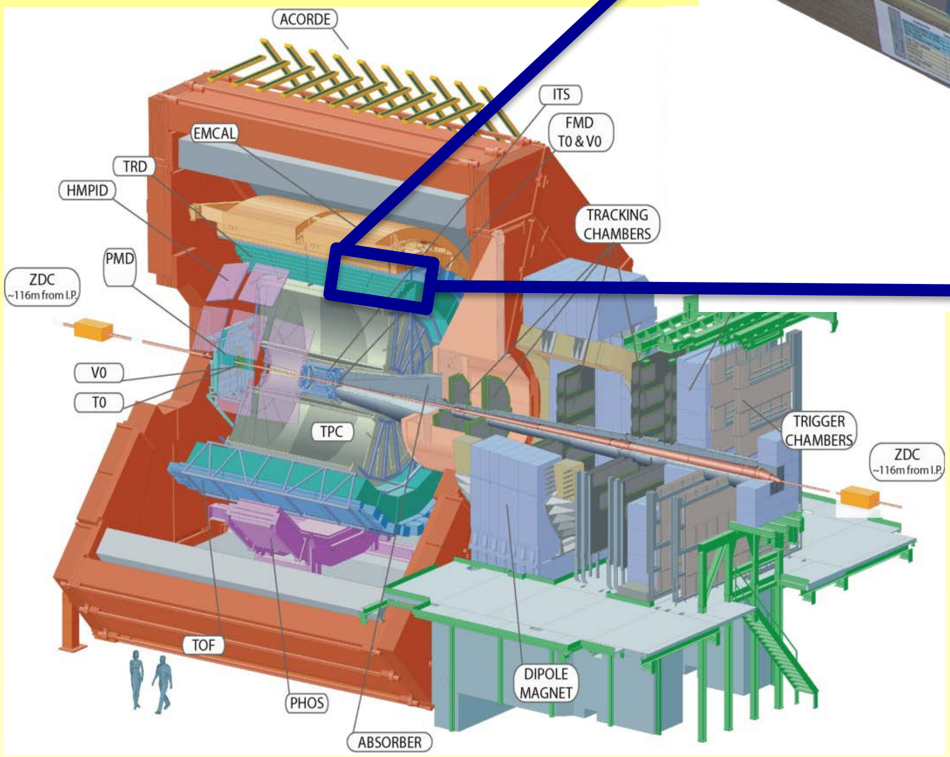
LS1: Muon Tracking Chambers

- Essential part of the consolidation work for the Muon Arm



Transition Radiation Detector for UCT





ALICE TRD

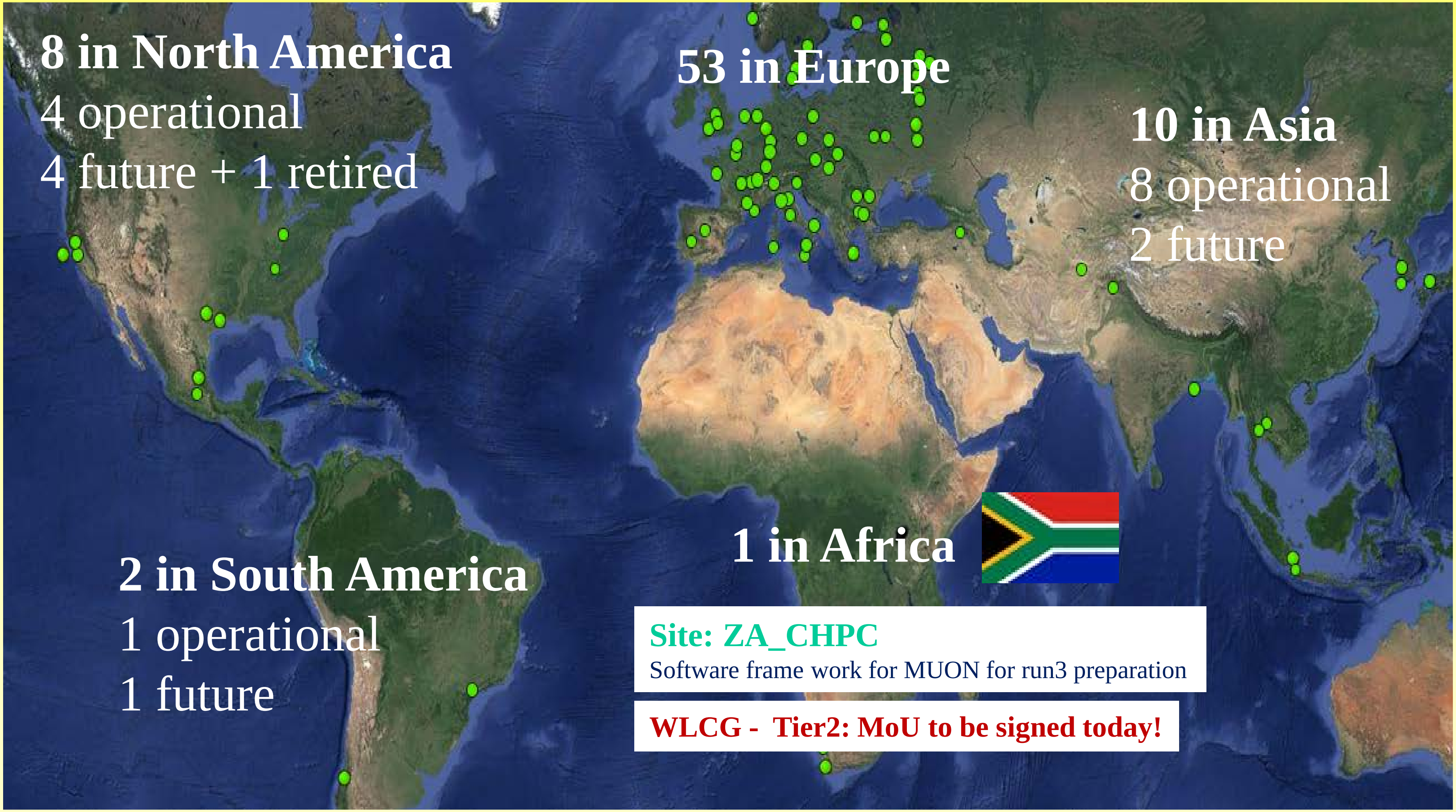
(Transition Radiation Detector) is in UCT

Development of Control Software

And Training of students

STORING, PROCESSING AND ANALYSIS OF THE DATA:

The ALICE GRID



THE ALICE GRID IN SOUTH AFRICA

- ALICE grid requires sustained and reliable bandwidth to sites.
- The SA Tier2 was processing MC data 2004-2009 with contributed resources.
- Grown to full service from 2012 onwords (600 Cores). The network (100 Mb/s) proved reliable and sustainable. But it is not sufficient to serve the newly installed computing power (2000 Cores), which was validated by having 500 Mb/s for a limited time
- The national grid infrastructure and national network in South Africa implies the possibility of a much higher level of service can to ALICE
- Re-negotiation of resource commitments in the light of the national grid and potential development of national Tier1
- Deployment of ALICE VO to more sites in South Africa to continue the success of previous years

GRID cluster at CHPC

- ZA_CHPC, installed at CHPC in Cape Town (Director Happy Sithole)

Approaching Tier 2 Status: Signature of MoU with WLCG NOW!

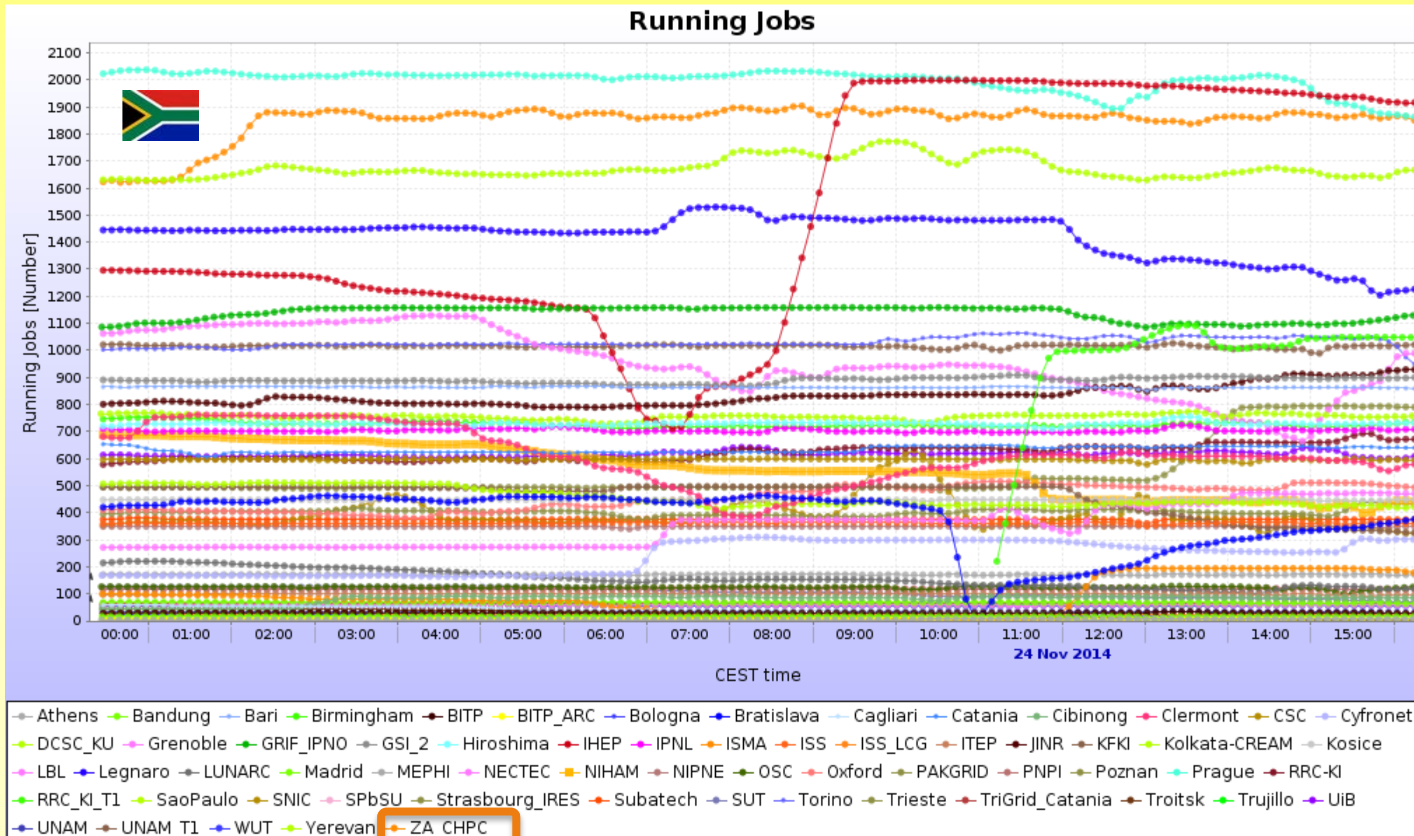
CENTRE FOR HIGH PERFORMANCE COMPUTING

Hardware

84 comp. nodes

2000 phys. Cores

800 TB storage



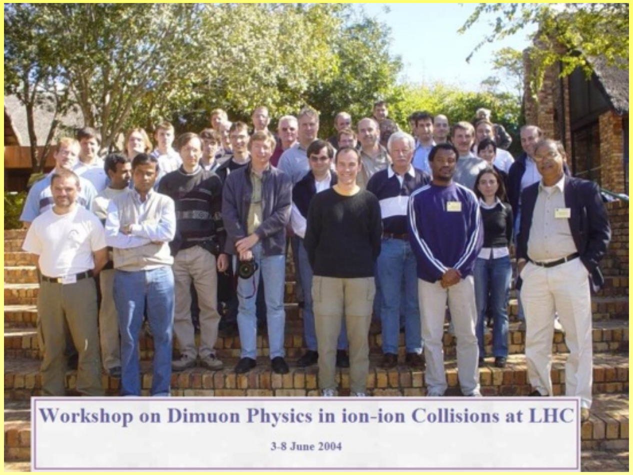
Increased network bandwidth: 100 → 500 Mbps (for a limited time) allowed to validate the full power of the center

OUTREACH

International Master Class on 5 April 2014

- "Looking for Strange Particles in ALICE"
  - Organized by SA-ALICE and iThemba LABS Community, Interaction and Training
  - 24 students from 6 schools
  - International video discussion with Cairo, Geneva and Warsaw

Events organised in South Africa



- <u>June 2004</u>
  - ALICE Dimuon workshop (Berg-en-Dal, Kruger National Park) ~ 50 ALICE physicists
- 2004 – dHLT Review (University of Cape Town)
- <u>September 2004</u>
  - "Strangeness in Quark Matter International Conference"
  - 120 international physicists
- <u>May 2012</u>
  - ALICE Muon Meeting (iThemba LABS)

- <u>December 2012</u>
  - International Workshop on Discovery Physics at LHC (KRUGER2012), Kruger Gate Hotel, Mpumalanga
- <u>November 2013</u>
  - 6th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions (Hard Probes 2013), Stellenbosch

SA Officials visiting CERN

- 1992: Signing of first Co-operation Agreement by FRD President R Arndt and CERN DG C Rubbia.

- 2005: Visit by Minister Mangena

- 2007: Visit by the Director General of DST Dr Mjwara

- 2011: Visit by Minister N Pandor

- 2014: Minister N Pandor joined CERN DG et al. at the UN on the occasion of the 60th anniversary of CERN

The future

- So far:

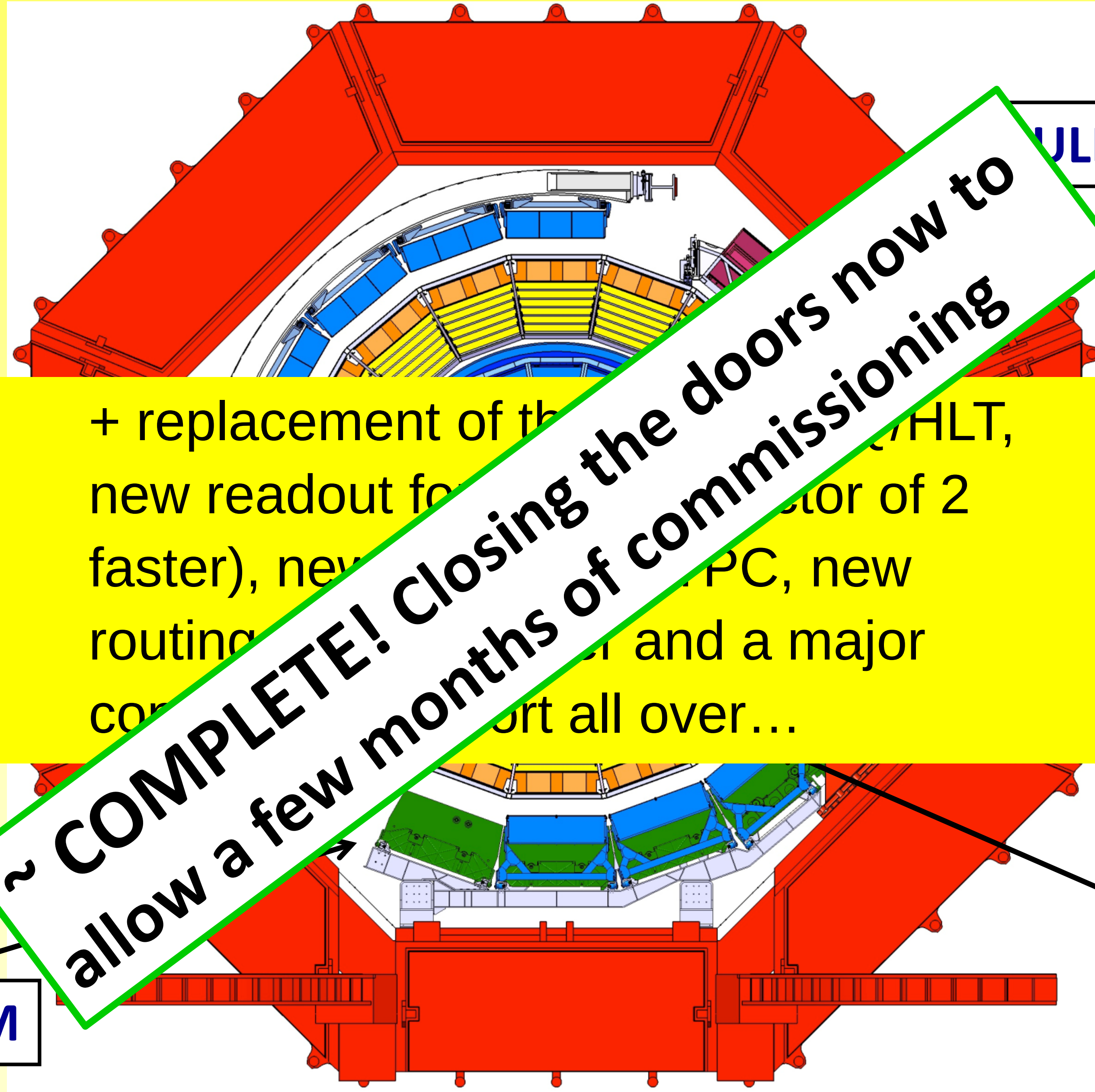
year	system	energy $\sqrt{s_{NN}}$ TeV	integrated luminosity
2010	Pb – Pb	2.76	~ 0.01 nb^{-1}
2011	Pb – Pb	2.76	~ 0.1 nb^{-1}
2013	p – Pb	5.02	~ 30 nb^{-1}

- The future:
  - **RUN2 (2015, 2016, 2017)** : will allow to approach the **1 nb^{-1}** for PbPb collisions, with improved detectors and double energy
  - **RUN3 + RUN4 (2020, 21, 22 and 25, 26, 27): 10 nb^{-1}** with major detector improvements (plus a dedicated low-field run and pPb)
- So: three phases, each jumping one order of magnitude in statistics and progressively improving the detectors

Short-term: LS1 plan, preparation for RUN2

New installations

- 5 TRD modules
- 8 DCal modules (approved in 2010)
- Add 1 PHOS module



+ replacement of th[illegible] /HLT, new readout fo[illegible] ctor of 2 faster), ne[illegible] PC, new routing [illegible] and a major co[illegible] ort all over…

~ COMPLETE! Closing the doors now to allow a few months of commissioning

ALICE goals for Run 2

- complete the originally approved heavy ion program, i.e. collection of **1/nb in Pb-Pb collisions at top energy (13 TeV p equivalent (5.5 TeV))** x10 current statistics
- pp reference running @ 13 TeV
  - Two main goals
    - reference rare trigger sample for 1/nb Pb-Pb
    - increase reference unbiased sample
  - 48 weeks running with rare triggers :
    - 60/pb (1.5 equivalent int lumi of 1/nb Pb-Pb → not dominant in uncertainty)
  - 24 weeks running with min bias
    - 10 G events → better significance than Pb-Pb for D^0
- pp reference running @ 5 TeV (limited sample)
  - Min bias => direct reference at low p_T -> $O(10^9)$ events
    - Charm, identified particles, correlations, … Trigger correction for triggered sample
  - Triggered=> validate/constrain reference at high p_T -> O(1/pb)
    - R_{pPb} high p_T charged particles, jets, quarkonia,…
- another p-Pb run, given the exciting results of the first one :
  - p-Pb run in Run 2 requested by all experiments
    - Goal: 1 G events **(x10 current)**
      - would ~ match pp significance for D^0

The European Strategy

– 2012 Cracow European Strategy Meeting

- Heavy Ion Physics an integral part of the future LHC program till at least the mid 2020s

– Erice final document on the European Strategy for Particle Physics

- Heavy Ions are an integral part of the top priority of the plan: *"Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics* ***and the quark-gluon plasma."***

ALICE Upgrade for RUN3 and RUN4 (after LS2)

- Focus on rare probes, study their coupling with QGP medium and their (medium-modified) hadronization process
  - precision studies of charm and beauty mesons and baryons and quarkonia at low-p_T
  - low mass lepton pairs and thermal photons
  - gamma-jet and jet-jet with particle identification from low momentum up to 30 GeV.
  - heavy nuclear states

➢ **low-transverse momentum observables** (complementary to the general-purpose detectors)

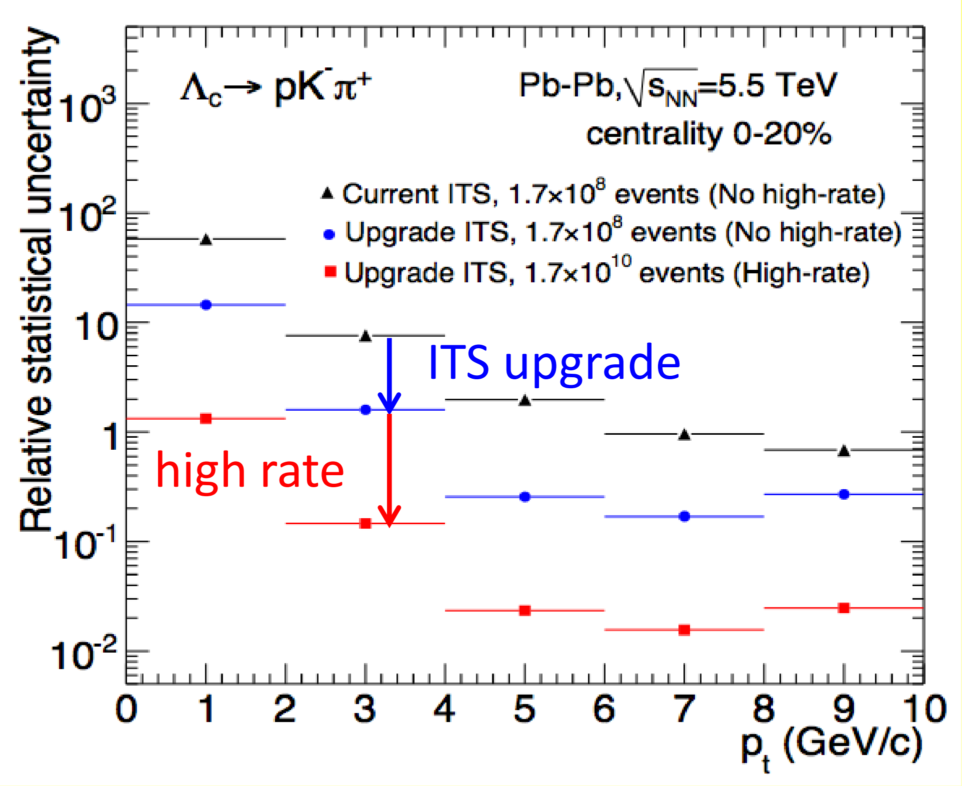
- not triggerable => need to examine full statistics.
- Target:
  - Pb-Pb recorded luminosity ≥ 10 nb^{-1} ➡ 8 x 10^{10} events
  - pp (@5.5 Tev) recorded luminosity ≥ 6 pb^{-1} ➡ 1.4 x 10^{11} events

o Gain a factor **100** over the statistics of the approved programme

- **Operate ALICE at high rate while preserving its uniqueness, superb tracking and PID, and enhance its vertexing capability and tracking at low-p_T**

Example of performance studies: $\Lambda_c \rightarrow pK\pi$

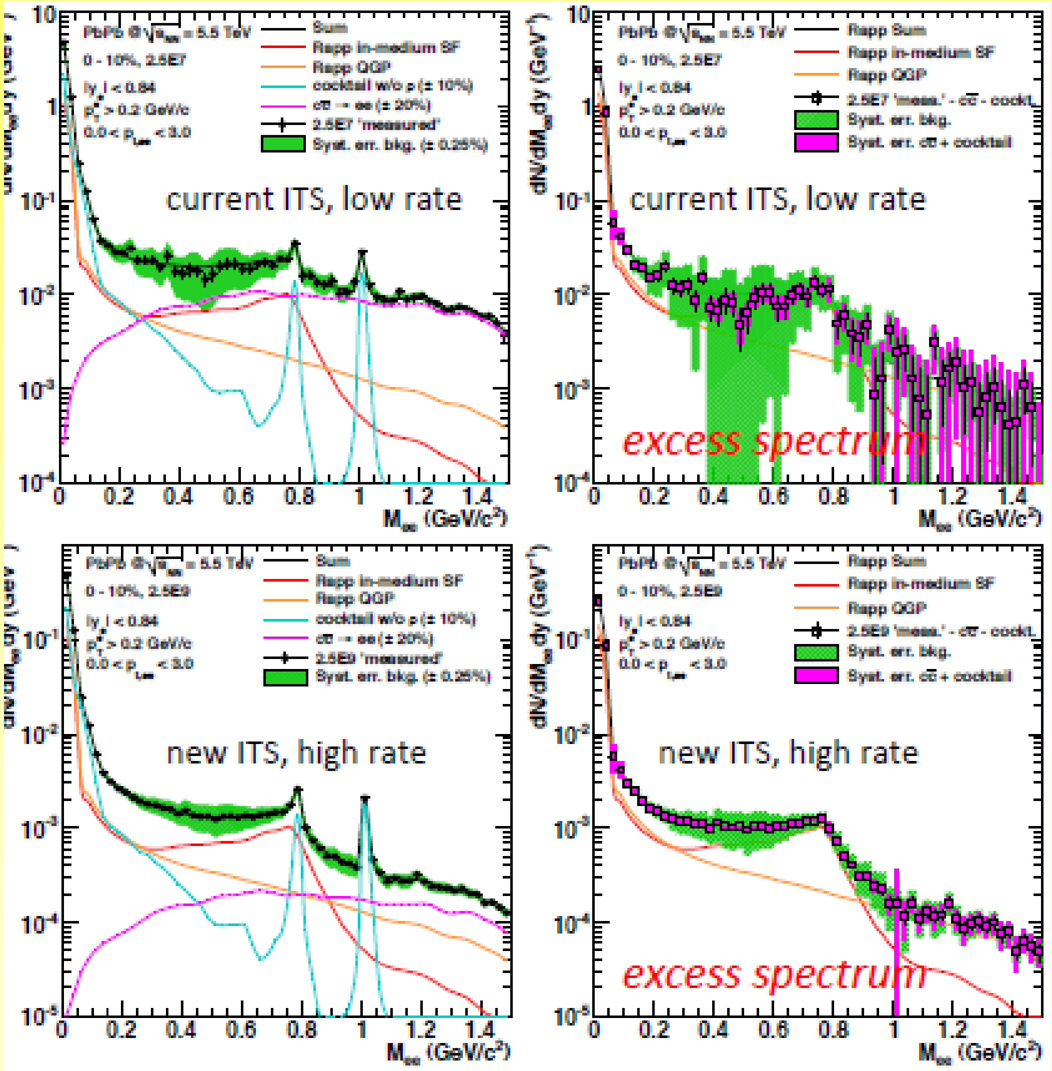
- Λ_c $c\tau$=60 μm, to be compared with D^+ $c\tau$=300 μm
  → practically impossible in Pb-Pb with current ITS



With new ITS and high-rate, measurement down to 2 GeV/*c*

Example of performance studies: low-mass e^+e^-

- e-PID in TPC and TOF
  - Needs high-rate readout
- Dalitz rejection, conversion and charm suppression
  - New ITS improves major sources of systematic uncertainties



ALICE Upgrade Physics Reach: summary

p_T coverage (p_T^{min}) and statistical error for current ALICE with approved programme and upgraded ALICE with extended programme. Error in both cases at p_T^{min} of "approved".

Topic	Observable	Approved (1/nb delivered, 0.1/nb m.b.)	Upgrade (10/nb delivered, 10/nb m.b.)
Heavy flavour	D meson R_{AA}	p_T>1, 10%	p_T>0, 0.3%
	D from B R_{AA}	p_T>3, 30%	p_T>2, 1%
	D meson elliptic flow (for v_2=0.2)	p_T>1, 50%	p_T>0, 2.5%
	D from B elliptic flow (for v_2=0.1)	not accessible	p_T>2, 20%
	Charm baryon/meson ratio (Λ_c/D)	not accessible	p_T>2, 15%
	D_s R_{AA}	p_T>4, 15%	p_T>1, 1%
Charmonia	J/ψ R_{AA} (forward y)	p_T>0, 1%	p_T>0, 0.3%
	J/ψ R_{AA} (central y)	p_T>0, 5%	p_T>0, 0.5%
	J/ψ elliptic flow (forward y, for v_2 =0.1)	p_T>0, 15%	p_T>0, 5%
	ψ'	p_T>0, 30%	p_T>0, 10%
Dielectrons	Temperature IMR	not accessible	10% on T
	Elliptic flow IMR (for v_2=0.1)	not accessible	10%
	Low-mass vector spectral function	not accessible	p_T>0.3, 20%
Heavy nuclei	hyper(anti)nuclei, H-dibaryon	35% ($^4_\Lambda$H)	3.5% ($^4_\Lambda$H)

ALICE Upgrade Physics Reach: MFT

p_T coverage (p_T^{min}) and statistical error for current ALICE with approved programme and upgraded ALICE with extended programme. Error in both cases at p_T^{min} of "approved".

Topic	Observable	MUON Upgrade (10/nb delivered, 10/nb m.b.)	MUON + MFT Upgrade (10/nb delivered, 10/nb m.b.)
Heavy flavour	J/ψ from B R_{AA}	-	p_T>0, 10% @ 1 GeV (to be improved "a la LHCb")
	J/ψ from B v_2	-	Not evaluated yet
	μ decays from charmed hadrons	-	p_T>1, 7% @ 1 GeV
	μ decays from beauty hadrons	-	p_T>2, 10% @ 2 GeV
Charmonia	Prompt J/ψ R_{AA}	-	p_T>0, 10% @ 1 GeV
	Prompt J/ψ v_2	-	Not evaluated yet
	ψ'	p_T>0, 30%	p_T>0, 10% @ 1 GeV
Dielectrons	Low mass spectral func. and QGP radiation	-	p_T>1, 20% at 1 GeV

The LS2 ALICE upgrades

ALICE

New Inner Tracking System (ITS)
- improved pointing precision
- less material -> thinnest tracker at the LHC

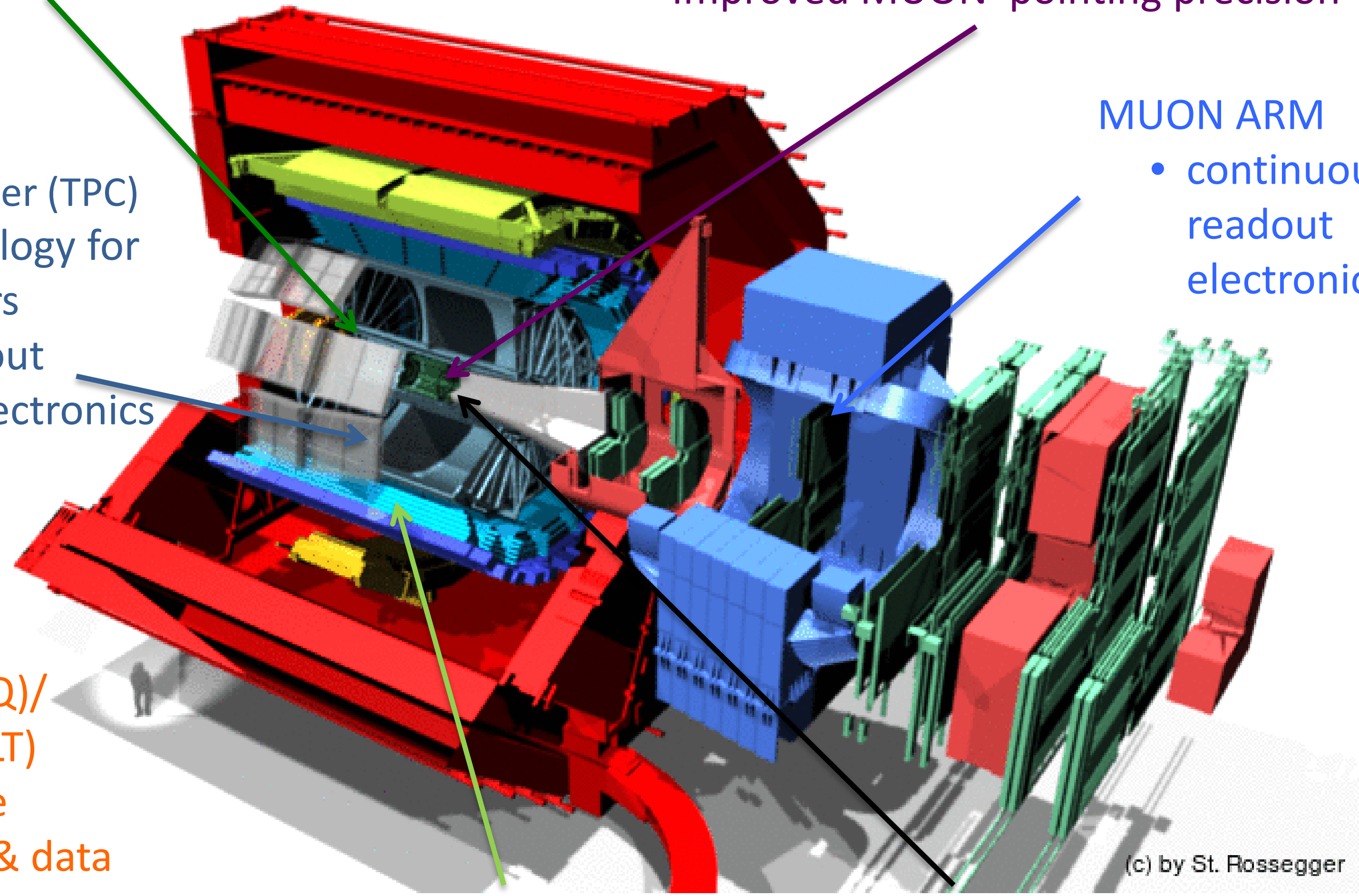
Muon Forward Tracker (MFT)
- new Si tracker
- Improved MUON pointing precision

MUON ARM
- continuous readout electronics

Time Projection Chamber (TPC)
- new GEM technology for readout chambers
- continuous readout
- faster readout electronics

New Central Trigger Processor

Data Acquisition (DAQ)/ High Level Trigger (HLT)
- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate



TOF, TRD, ZDC
- Faster readout

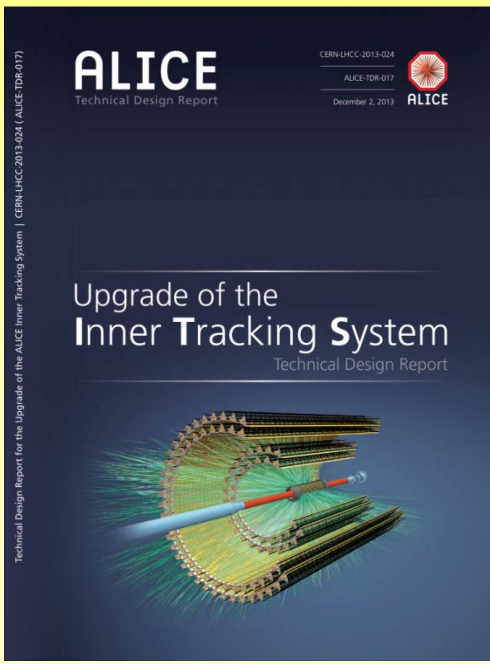
New Trigger Detectors (FIT)

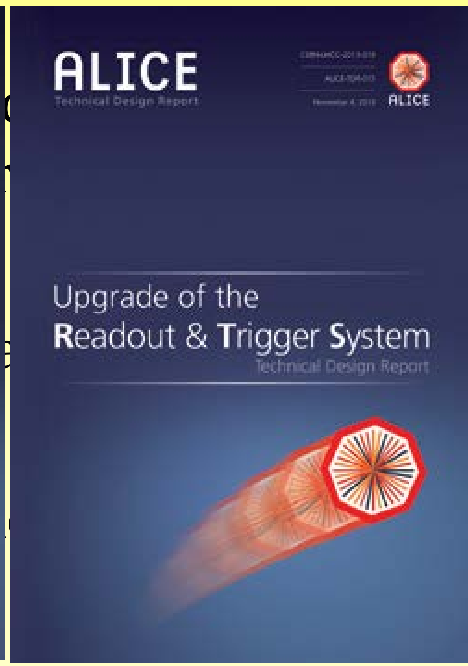
The ALICE LS2 Upgrade

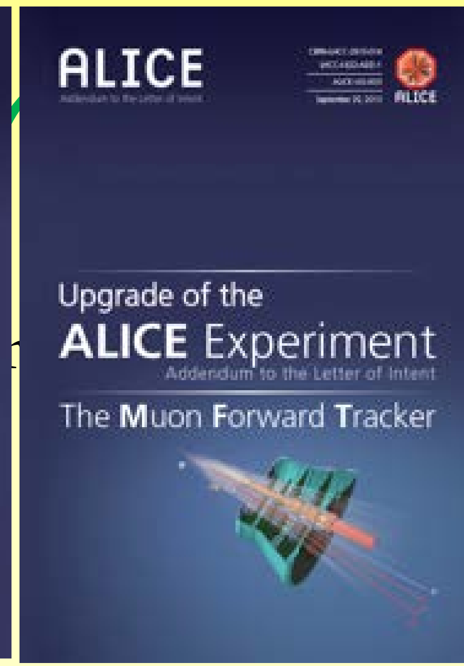
Five Pillars (each in a Technical Design Report):

- Completely new Silicon Inner Tracking System

✓ **TDR approved by LHCC, UCG and RB**



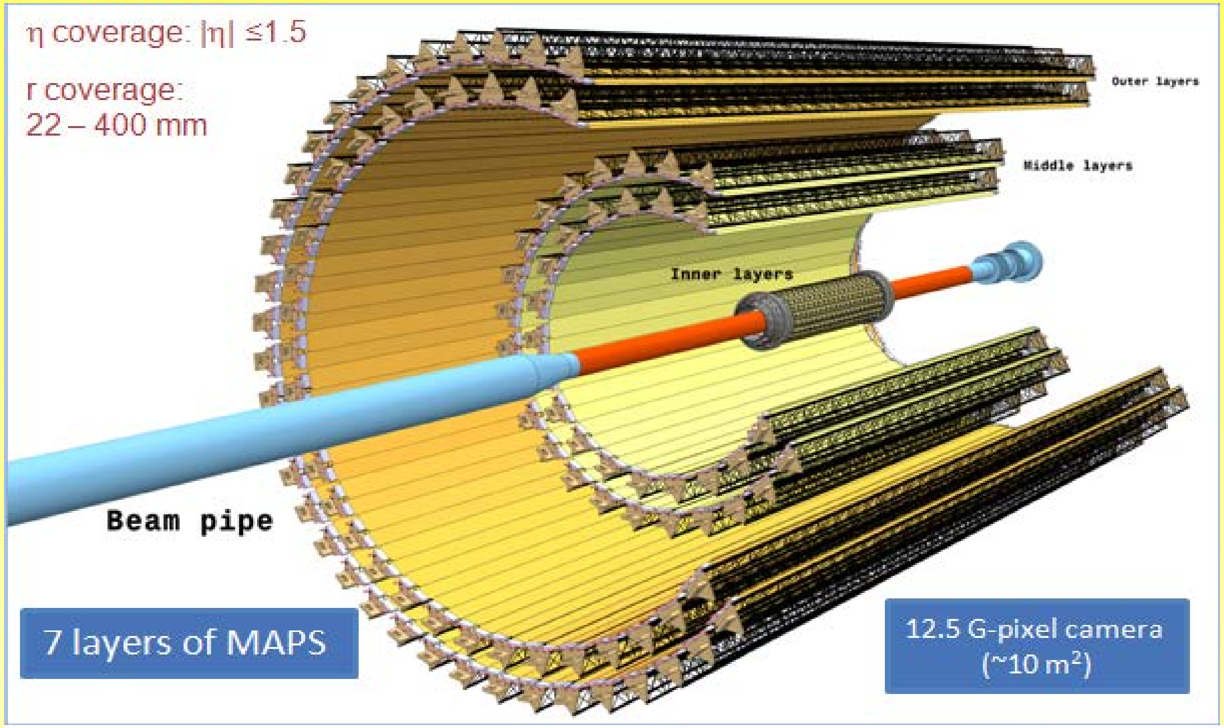


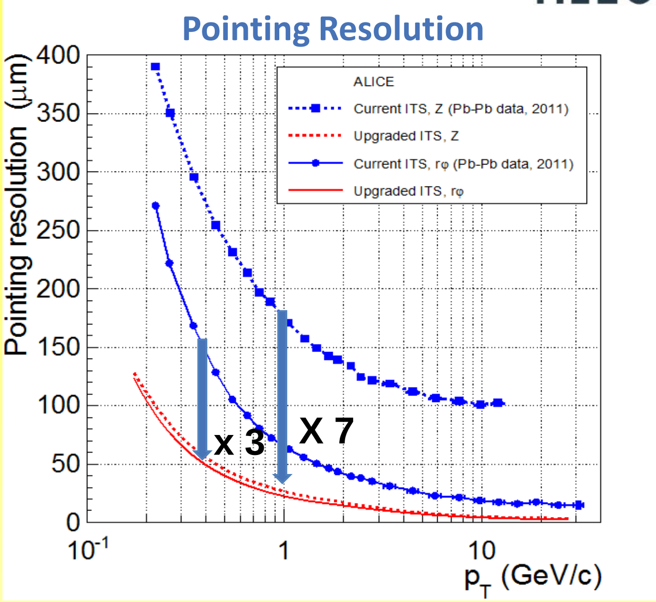


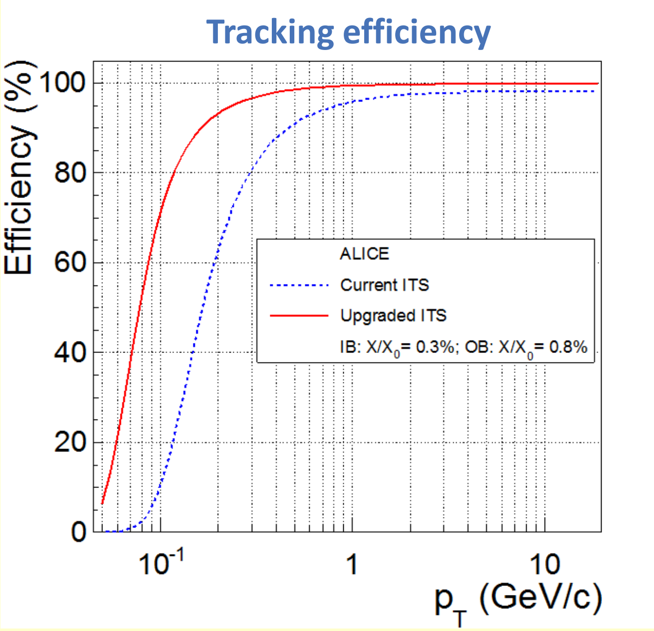
- New Data Acquisition System and High Level Trigger to handle the continuous readout, new Offline

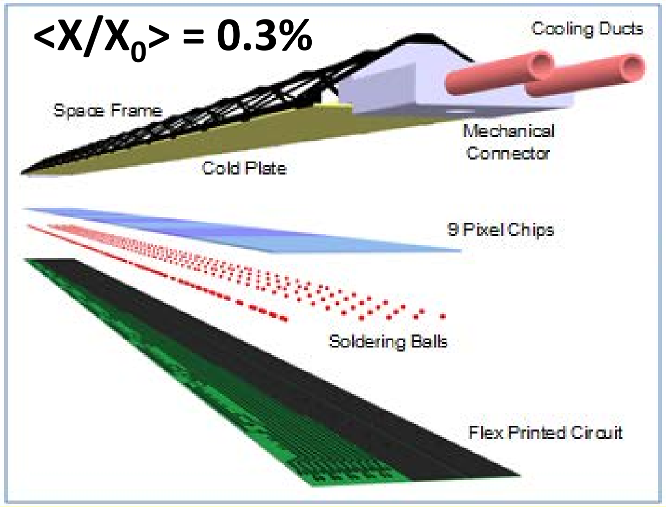
TDR in mid 2015

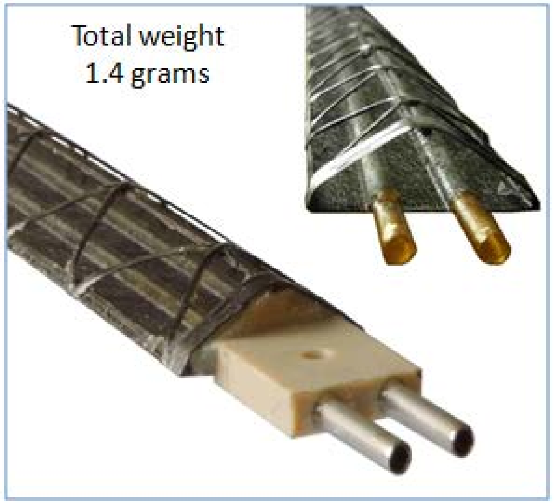
LS2 upgrade: new Inner Tracking System



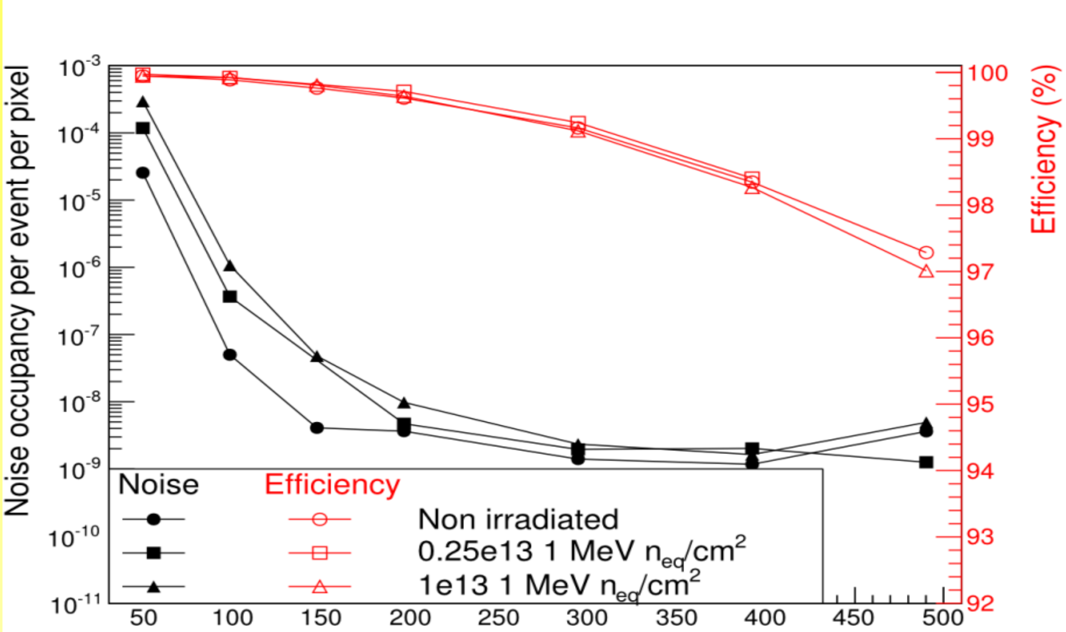


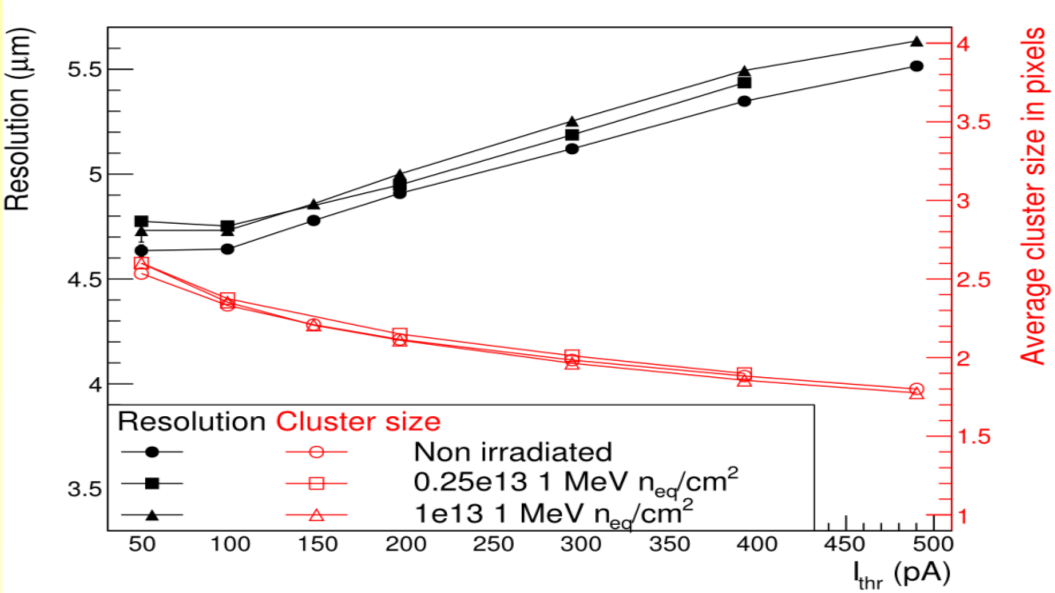


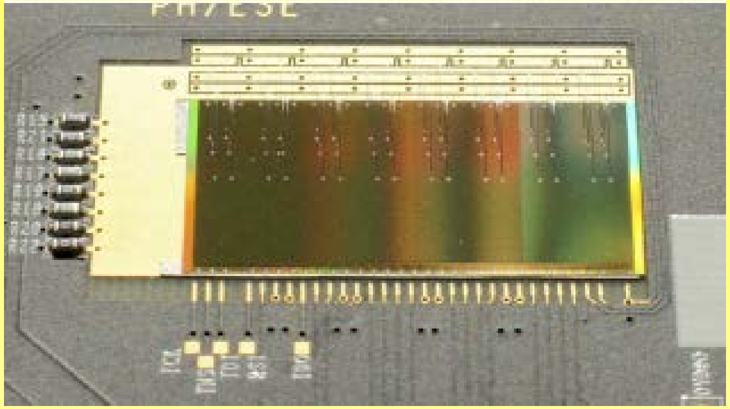




Full-scale prototype chip for the ITS: beam-test results

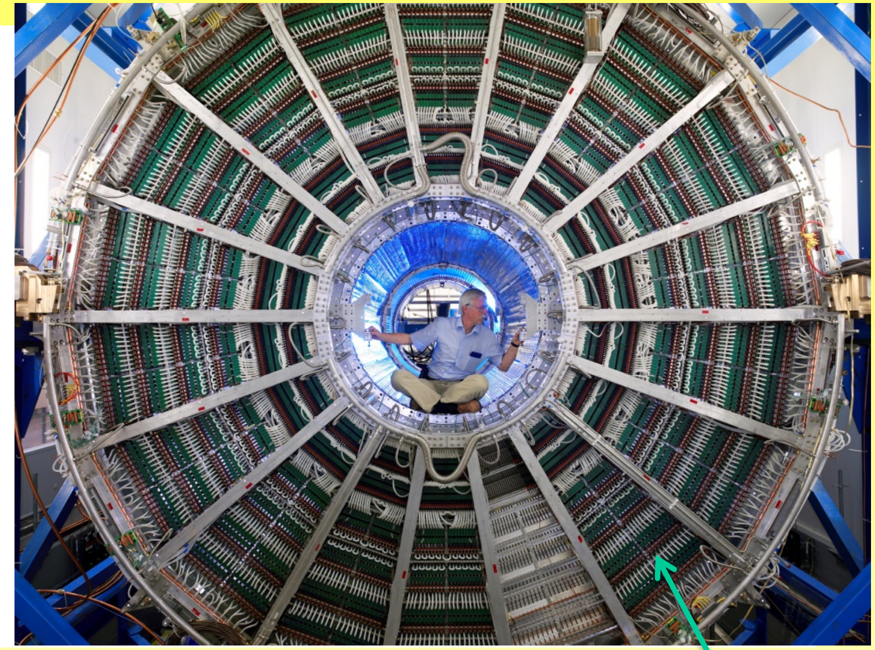






- Measurements at PS with 5-6 GeV/c p- beam
- Results refer to **50 mm thick chips**: non irradiated and **irradiated with neutrons** (0.25×10^{13} and 10^{13} 1MeV n_{eq} / cm^2)
- Resolution < 5.5 mm
- Fake hits < 10^{-4} /evt / pixel @ 99% efficiency

TPC Upgrade with GEMs

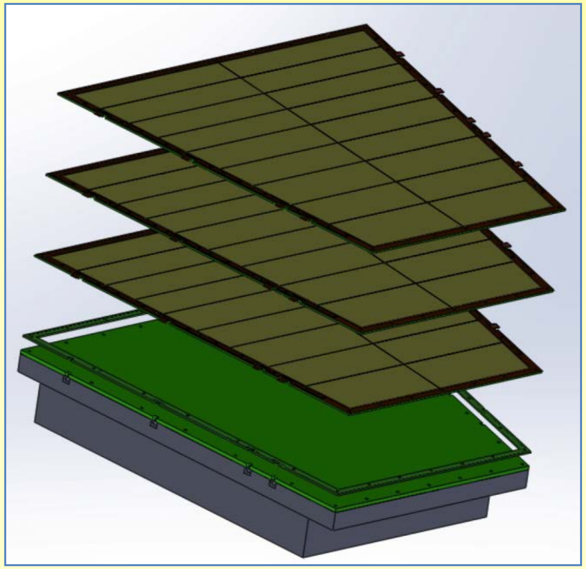


World Largest TPC
ALICE key tracking and PID instrument
500 million pixels

Replacement of wire-chambers with GEM-chambers

- 100 m^2 single-mask foils
- Limit Ion-Back-Flow into drift volume
- Maintain excellent dE/dx resolution

New readout electronics
Keep all other subsystems

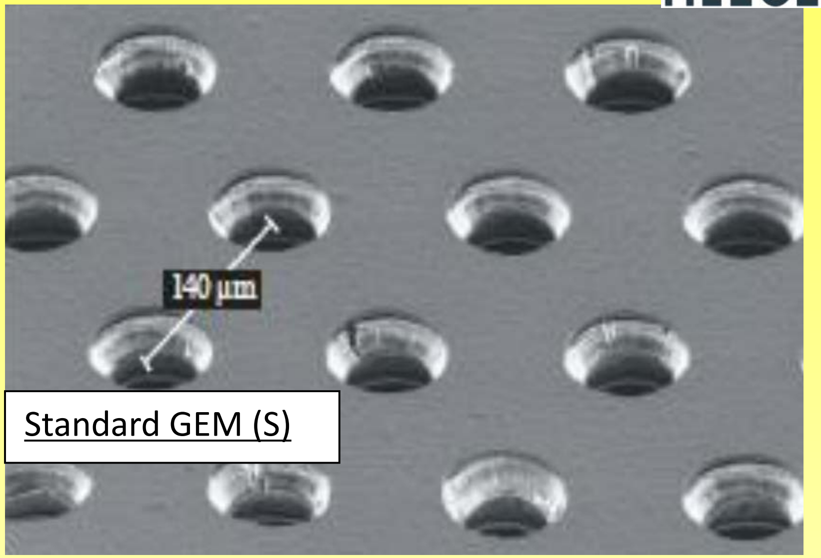


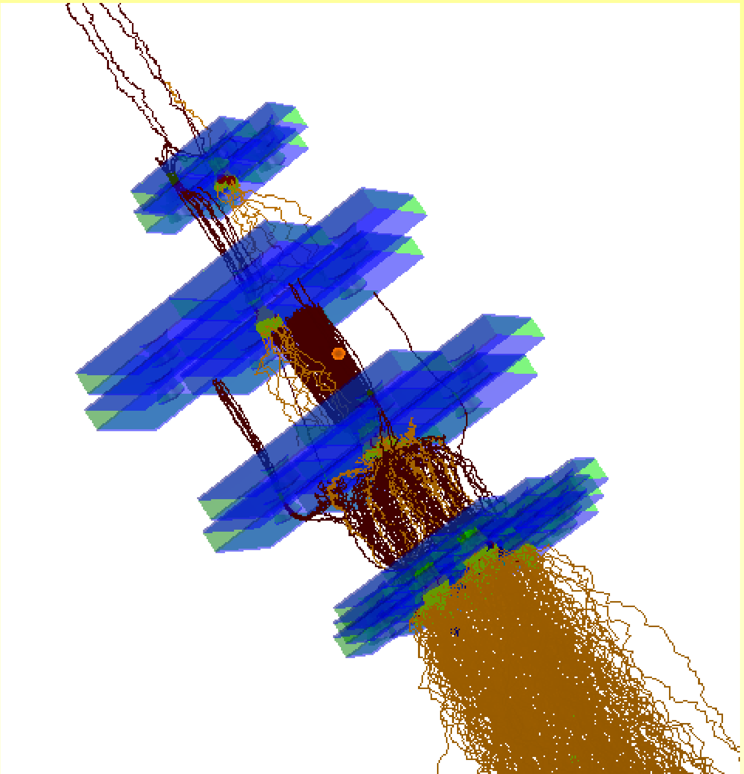
Replace wire chambers with quadruple-GEM or 2 GEMs + Micro Megas
(full scale prototypes for both in beam in late 2014)

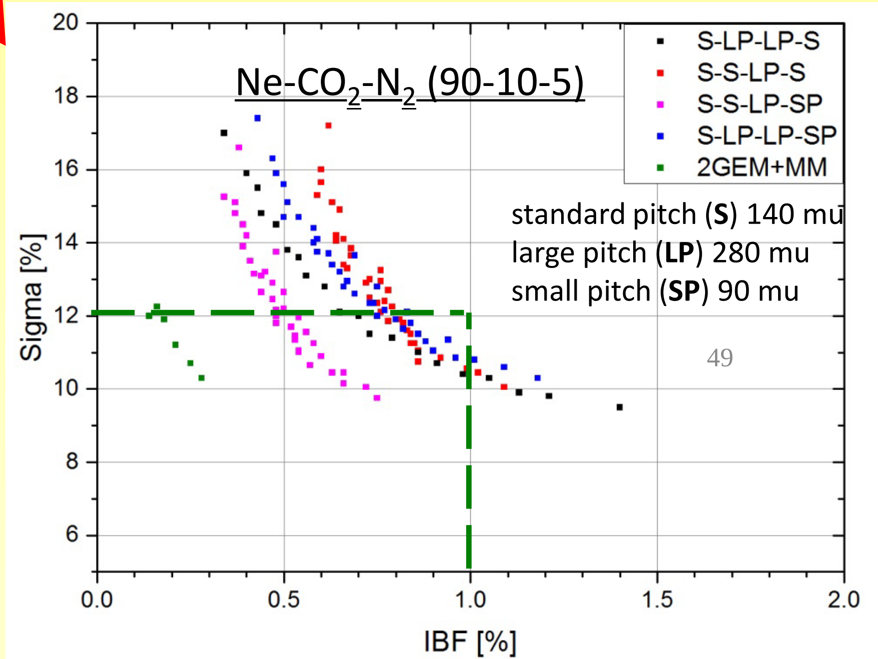
TPC upgrade progress

Replace existing wire chambers by **micro-pattern detectors** to cope with 50 kHz Pb-Pb collision rate in RUN3

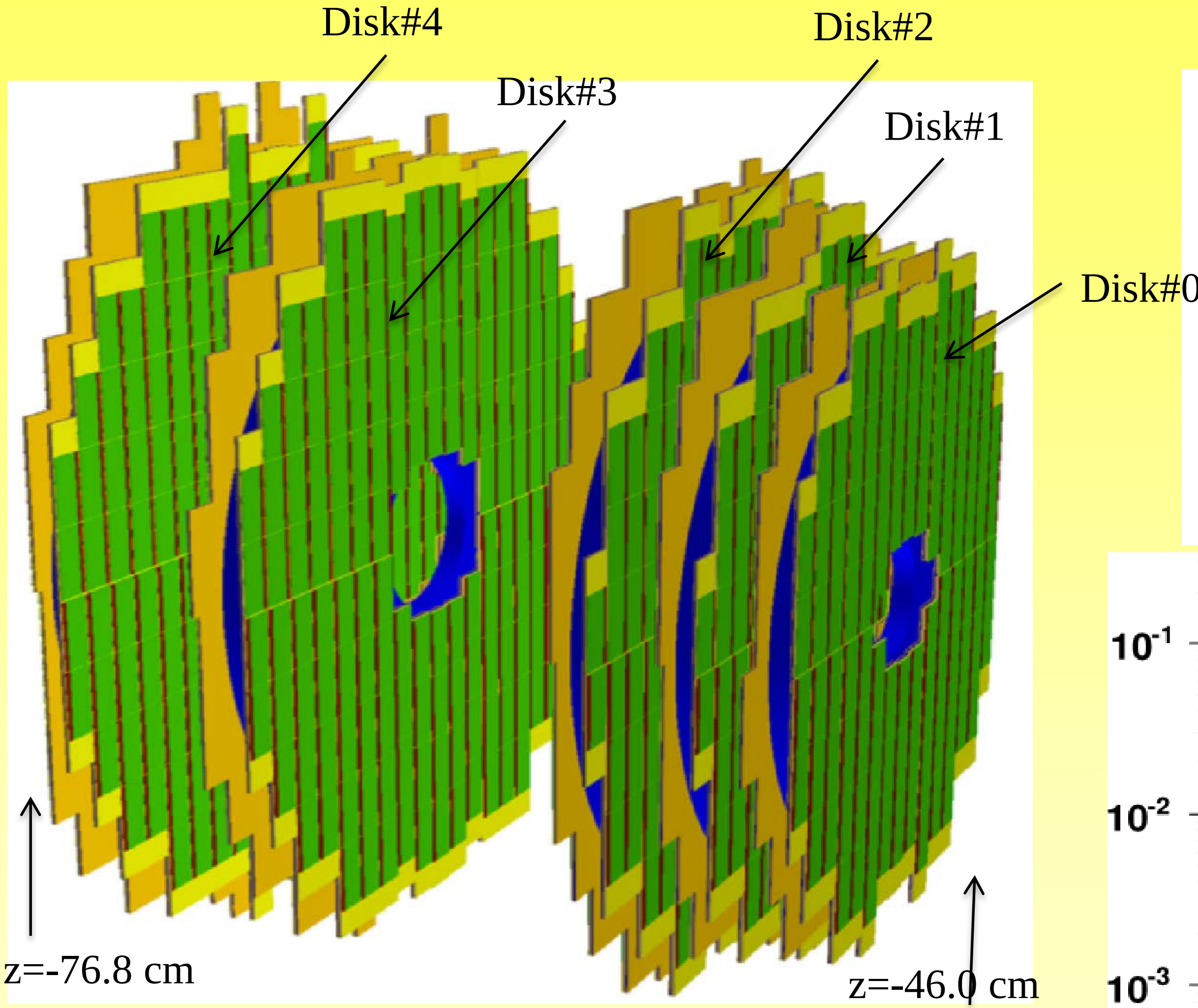
Significant R&D to optimize key figures: Energy resolution and Ion Backflow



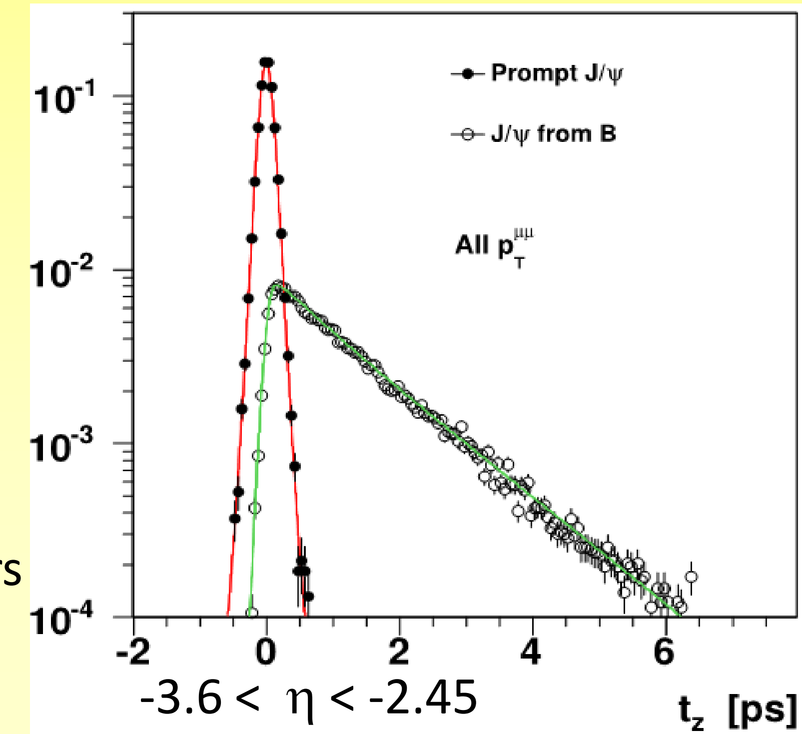




LS2 upgrade: Muon Forward Tracker

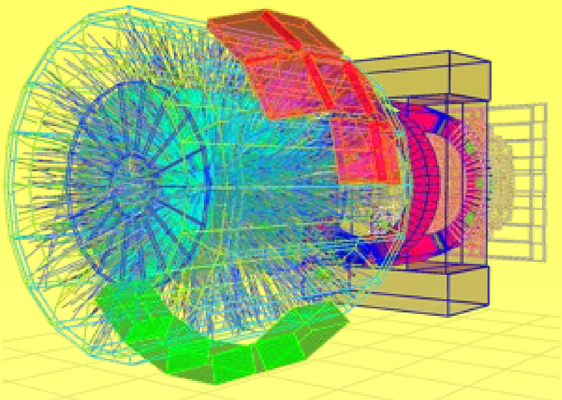


Secondary vertexing for the muon spectrometer
- $c \rightarrow \mu$
- $b \rightarrow J/\psi$
- low mass di-muons
- $\psi(2S)$
- ...



- **10 Half-disks** of 2 detection planes each
- 896 **silicon pixel sensors** (0.4 m^2) in 280 ladders
- **Common pixel chip development with ITS**

A flood of data…



50 kHz

1 TByte/s
into PC farm

Reconstruction
+
Compression

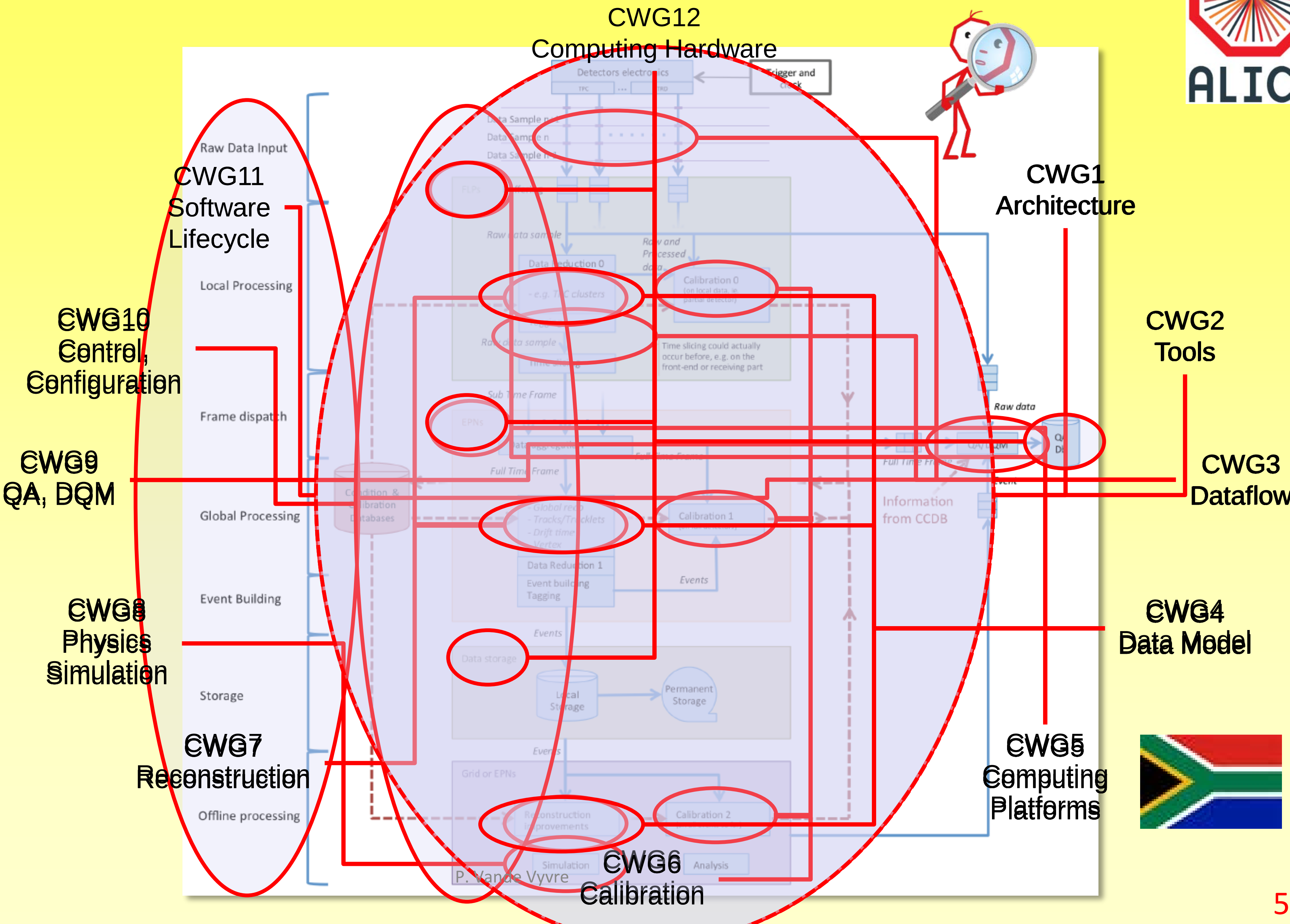
O^2 (Online Offline) System

Storage

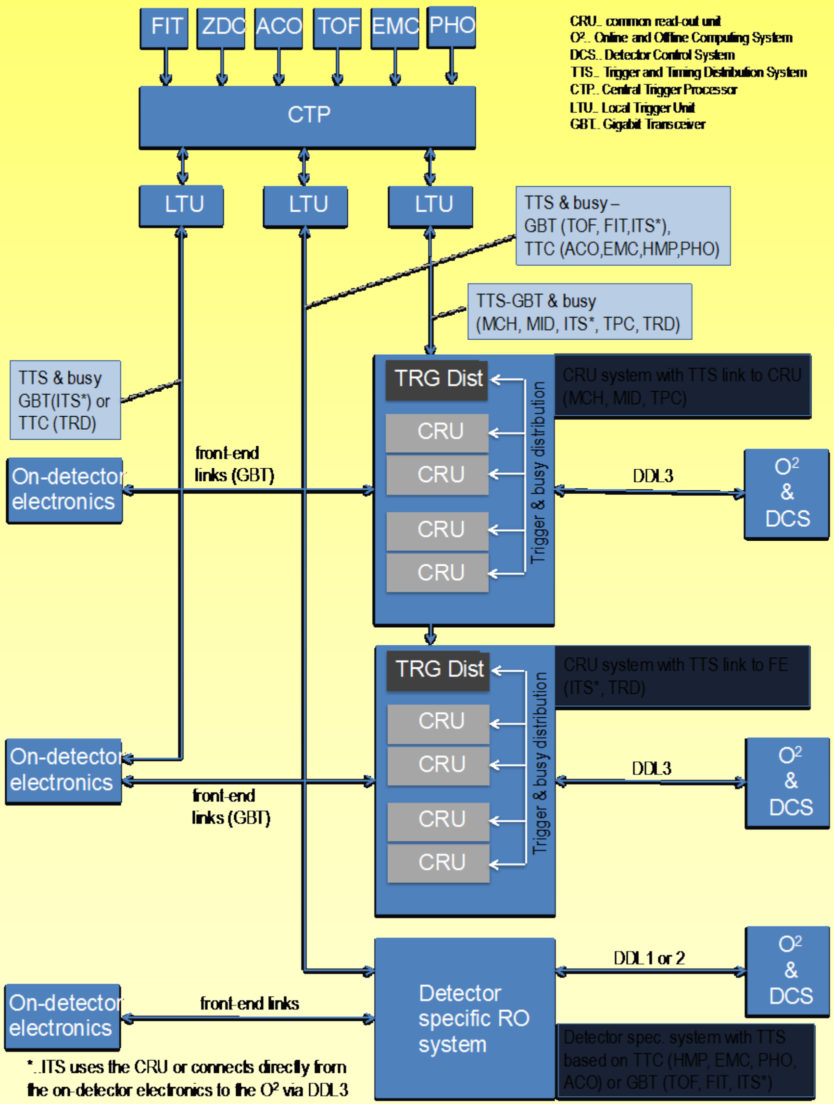
75 GB/s

← PEAK OUTPUT
(20 GB/s average)

O^2 Computing Working Groups



New readout system



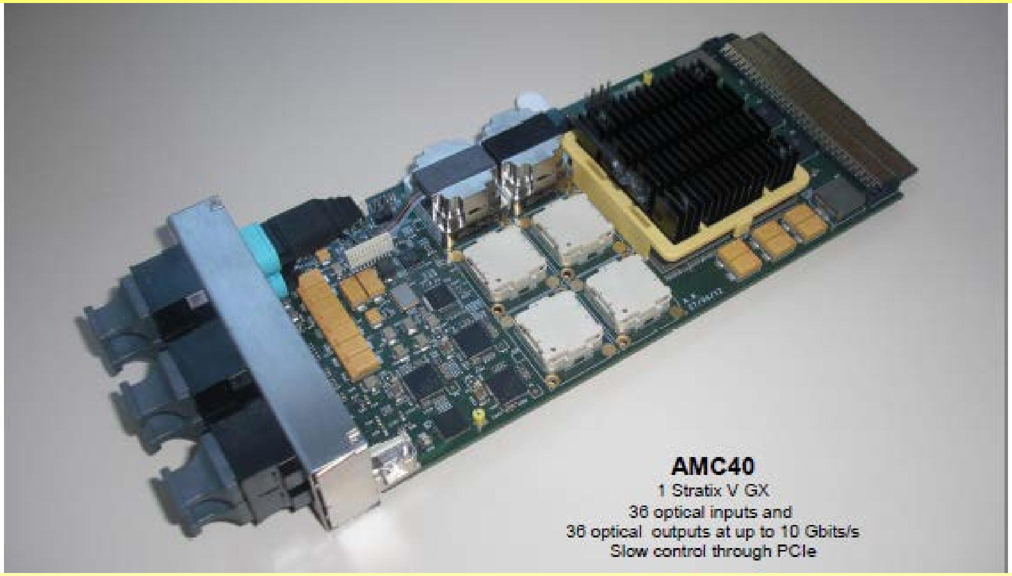
Upgrade / replacement needed for TPC, MCH, TRD, (ITS)

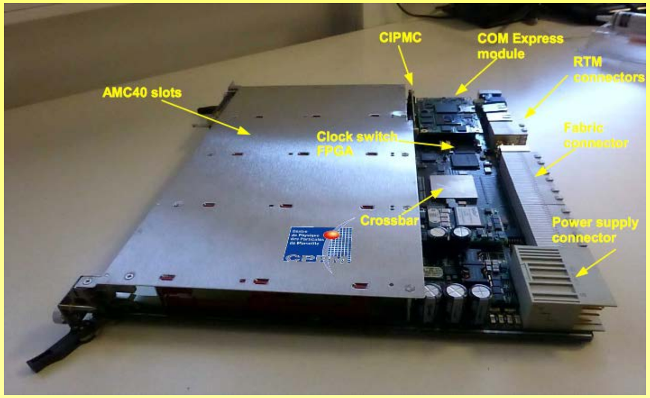
Use common hardware where possible:

Common Readout Unit

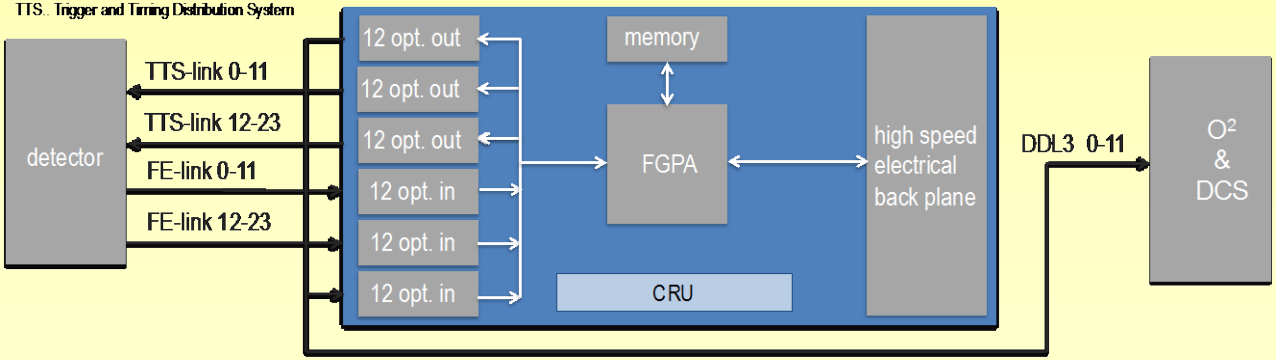
- FPGA-based
- opt links to FEE/DAQ
- firmware (VHDL) will contain common and detector-specific code

CRU prototype: AMC40 (LHCb)





CRU.. common read-out unit
O^2.. Online and Offline Computing System
DCS.. Detector Control System
TTS.. Trigger and Timing Distribution System



Firmware development for the CRU for TRD and Muon Spectrometer

Running scenario after the upgrade

- Pb–Pb
  - int. luminosity per year 2.85 nb^{-1} (peak L = 7×10^{27} $cm^{-2}s^{-1}$)
  - needed int. luminosity 10 nb^{-1}, statistics 8×10^{10} events
  - 3.5 month of running
  - +1 month of special run at low field for dileptons
- p–Pb
  - max event rate 200 kHz, flat (L = 10^{29} $cm^{-2}s^{-1}$)
  - needed int. luminosity 50 nb^{-1}, statistics 10^{11} events
  - 0.5 month of dedicated p–Pb run
- pp
  - max event rate 200 kHz, flat (L = 3×10^{30} $cm^{-2}s^{-1}$)
  - needed int. luminosity 6 pb^{-1}, statistics 4×10^{11} events
  - ~ 2 months of dedicated pp run

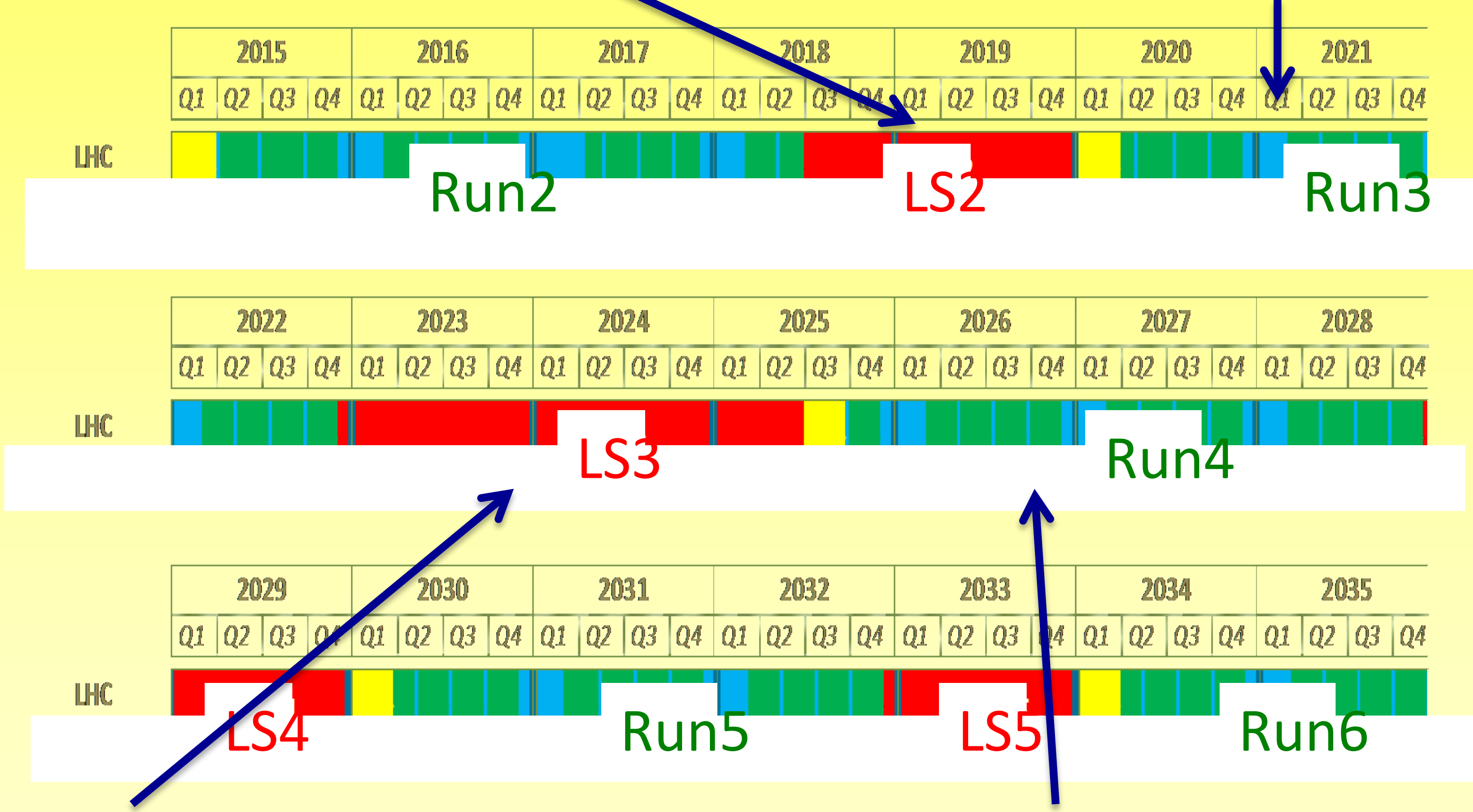
The list above fulfills the ALICE physics program as presented in the LoI.

A run with lower mass nuclei (e.g. Ar) could be considered in addition, if a physics case for it would emerge.

Long Term Schedule

PHASE I Upgrade
ALICE, LHCb major upgrade
ATLAS, CMS ‚minor' upgrade

Heavy Ion Luminosity from 10^{27} to 7 x10^{27}



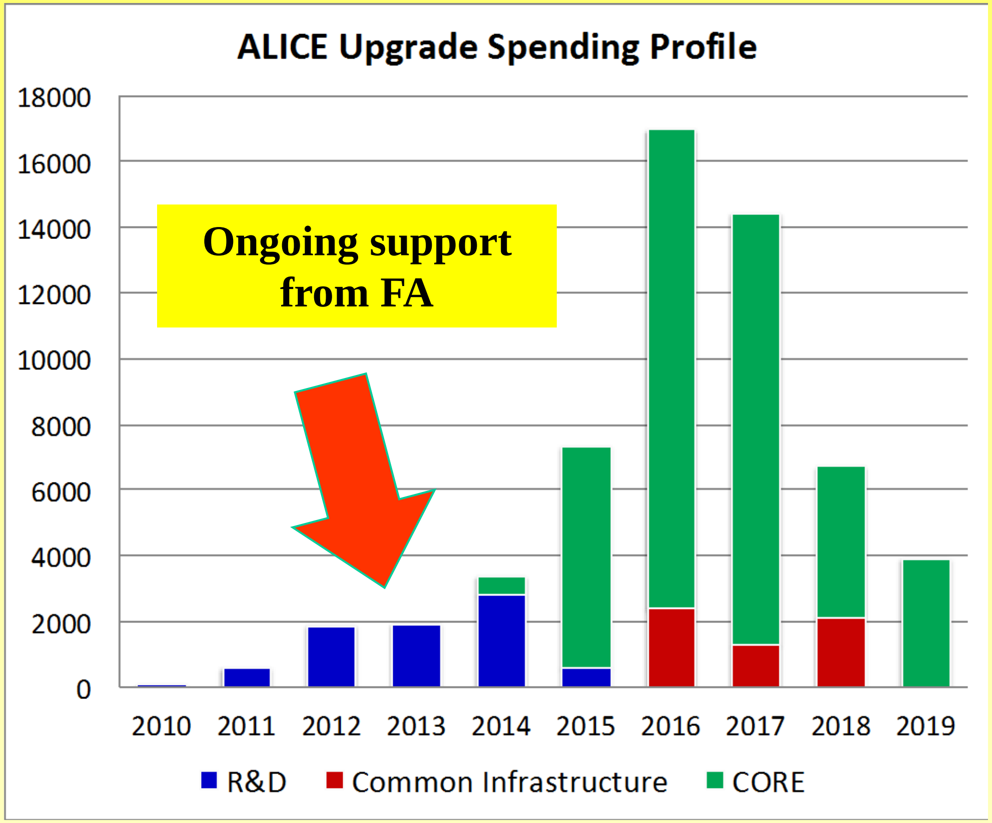
PHASE II Upgrade
ATLAS, CMS major upgrade

HL-LHC, pp luminosity from 10^{34} (peak) to 5 x10^{34} (levelled)

ALICE will operate beyond LS3 in the HL-LHC era

Upgrades: CORE investment estimates & timelines

ALICE upgrade subsystem	CORE cost (MSF)
1. ITS	13.4
2. TPC	9.1
3. MFT	4.1
4. Other projects (Muon, TRD, TOF, etc..)	7.5
5. O2 (online/offline)	9.3
6. Common infrastructure	5.8
Total (MSF)	49.2
R&D costs MSF	7.85
GRAND TOTAL including R&D	57.0



- current best estimate (in 2014 values), final values appear progressively in the TDRs and UCG report.
- Sharing within the projects fixed on the basis of responsibilities, as detailed in the TDRs.
- Strong commitment from the collaboration: the know-how and human resources necessary to carry each of the upgrade projects exist. All projects backed by the commitment of large consortia of strong groups. The indications from the funding agencies in response to the group's funding requests are encouraging, and give us confidence that the necessary funds will be available.

Conclusions

- **A rich harvest of Physics results from RUN2 with still a lot to come!**
  - A leding role of South African scientist in several imortant analyses
- **A promising RUN2**
  - SA playing a big role in both preparation and commissioning
- **An exciting plan for the years to come**
  - SA groups in the frontline
- **A major role for South African scientists, and growing fast!**

-40
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40

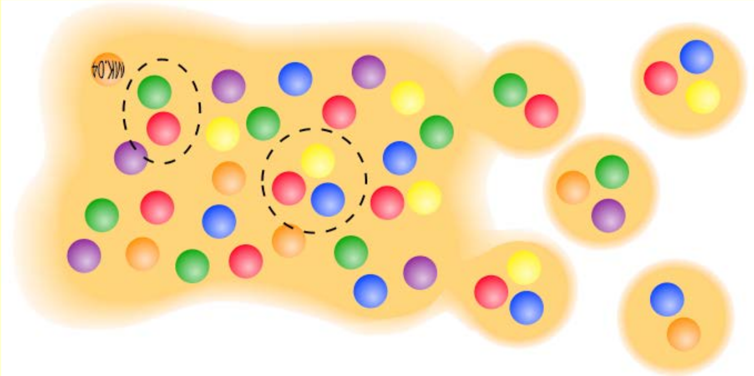
spares

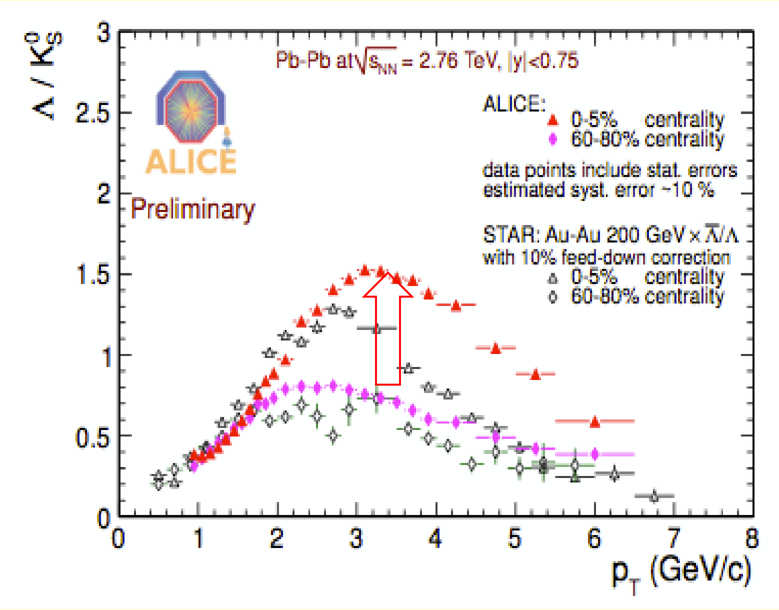
HF thermalization and in-medium hadronization: Λ_c and D_s as probes

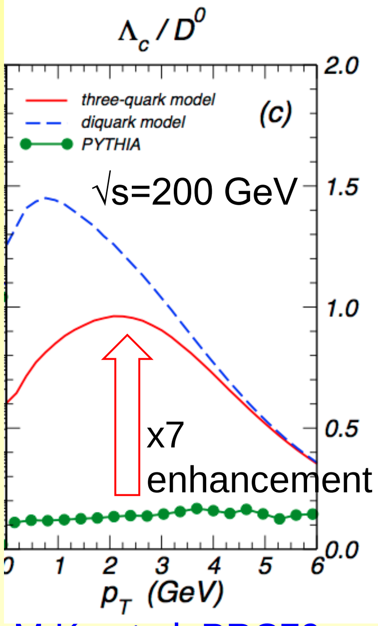
- Baryon/meson enhancement and strangeness enhancement → indication of light-quark hadronization from partonic system

➡ Charm baryons (Λ_c)

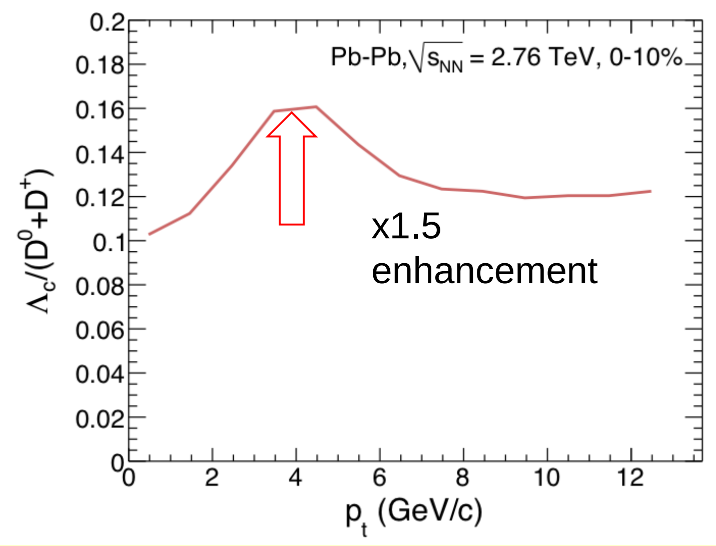
- Λ_c/D enhancement predicted by coalescence models. Size of effect depends strongly on details of c quark thermalization







C.M.Ko et al. PRC79

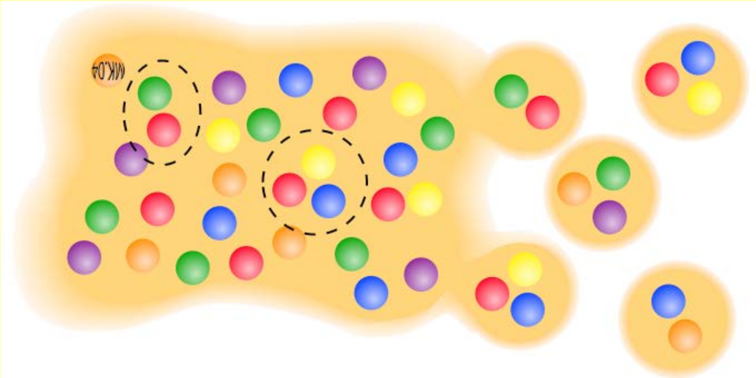


R. Rapp et al. PRC86

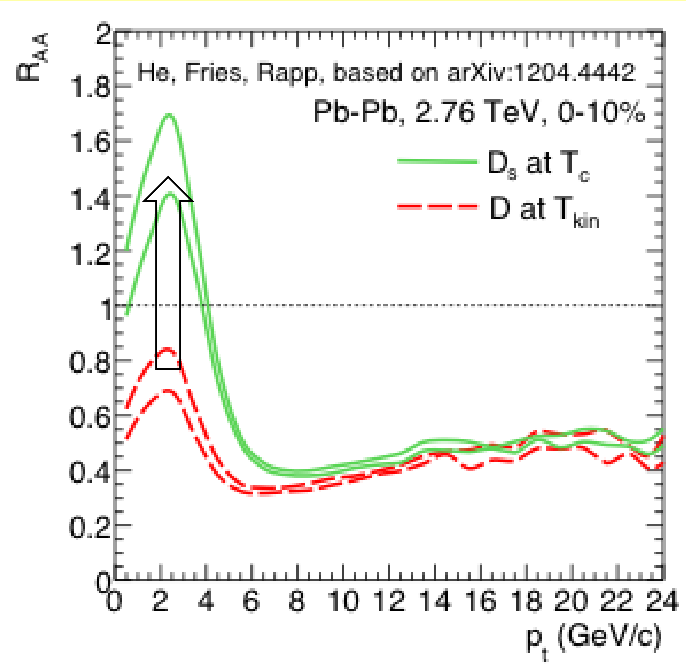
HF thermalization and in-medium hadronization: Λ_c and D_s as probes

- Baryon/meson enhancement and strangeness enhancement → indication of light-quark hadronization from partonic system

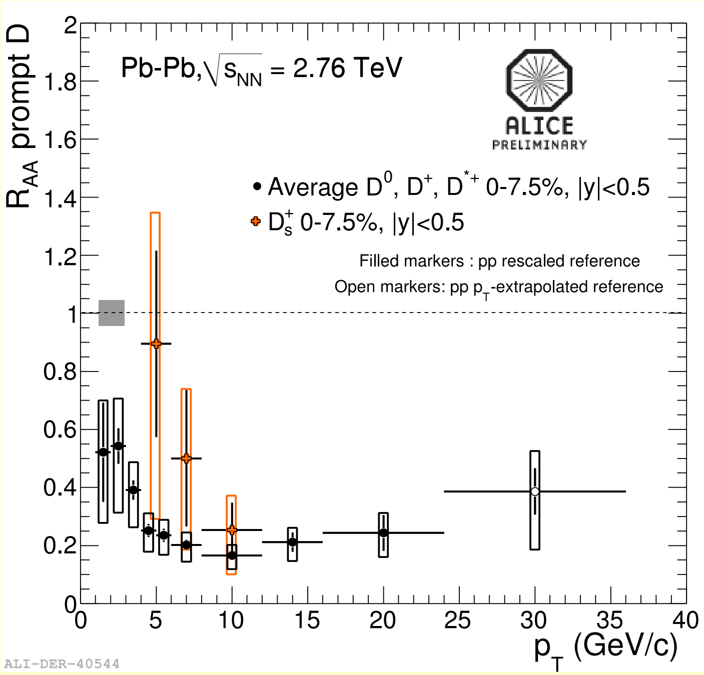
➡ Charm-strange mesons (D_s)



Factor 2 enhancement for D_s/D predicted by coalescence

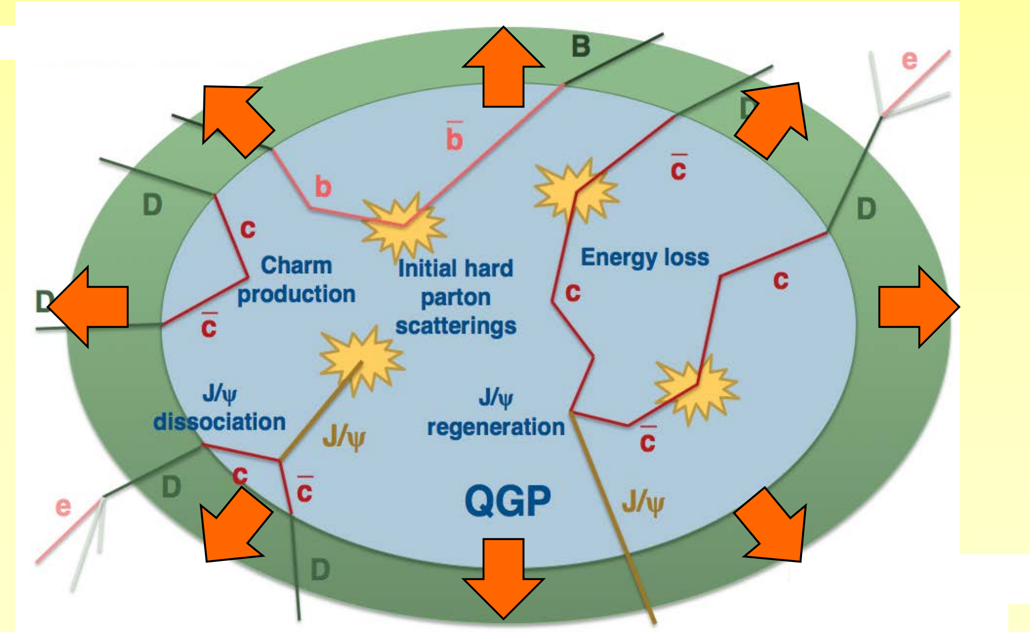


Our first measurement is intriguing, but not conclusive

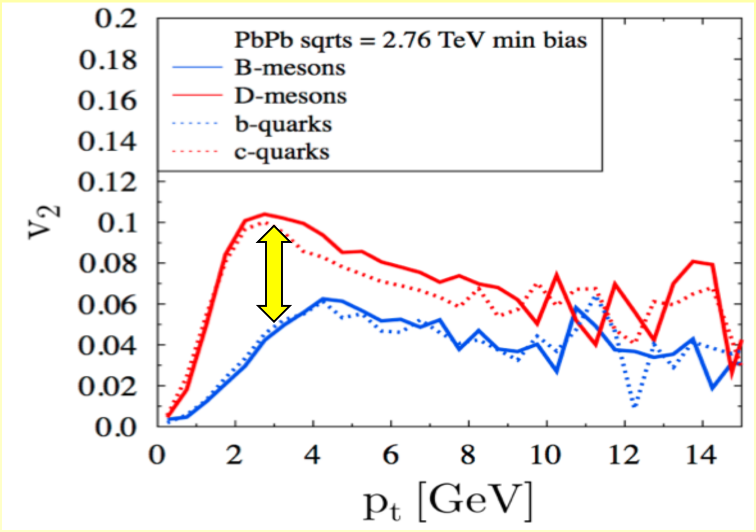


Heavy flavour v_2

- Uniqueness of heavy quarks: cannot be "destroyed/created" in the medium → transported through the full system evolution
- Due to their large mass, c and b quarks should "feel" less the collective expansion
  - → need frequent interactions with large coupling to build their v_2 → $v_2^b < v_2^c < v_2^q$
- HF v_2 sensitive to medium viscosity and equation of state

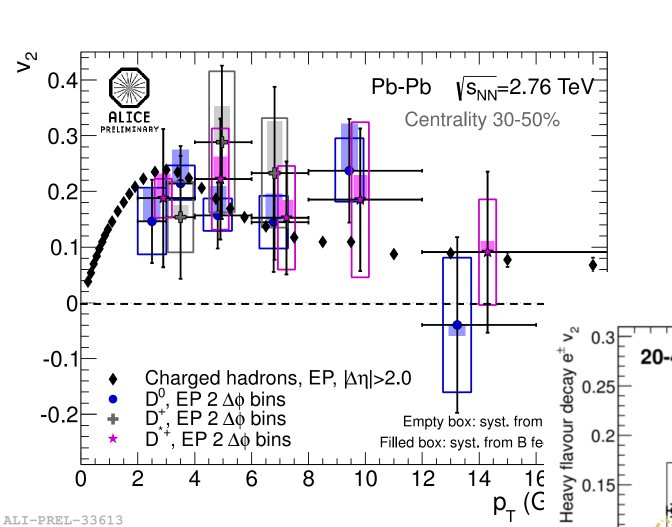


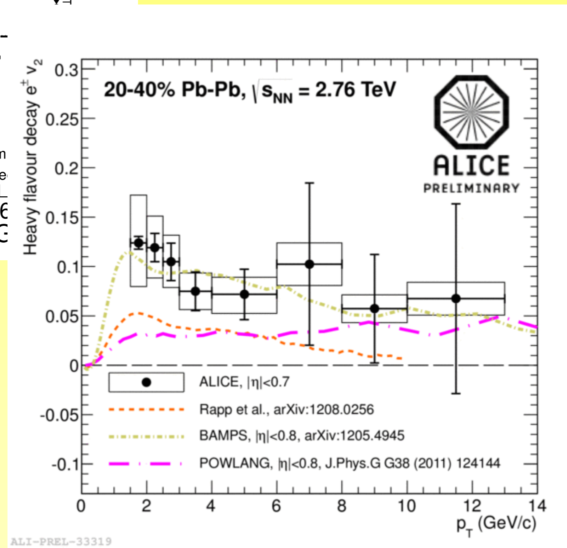
See also J. Uphoff et al., R. Rapp et al., A. Beraudo et al.



J. Aichelin et al. in arXiv:1201:4192

Heavy flavour v_2: present and future





- ALICE preliminary results with full 2011 sample (10^7 events in 30-50%)
- Indication of non-zero v_2
- But uncertainties are substantial
  - Reduction by x0.6 expected with 2015-16 data

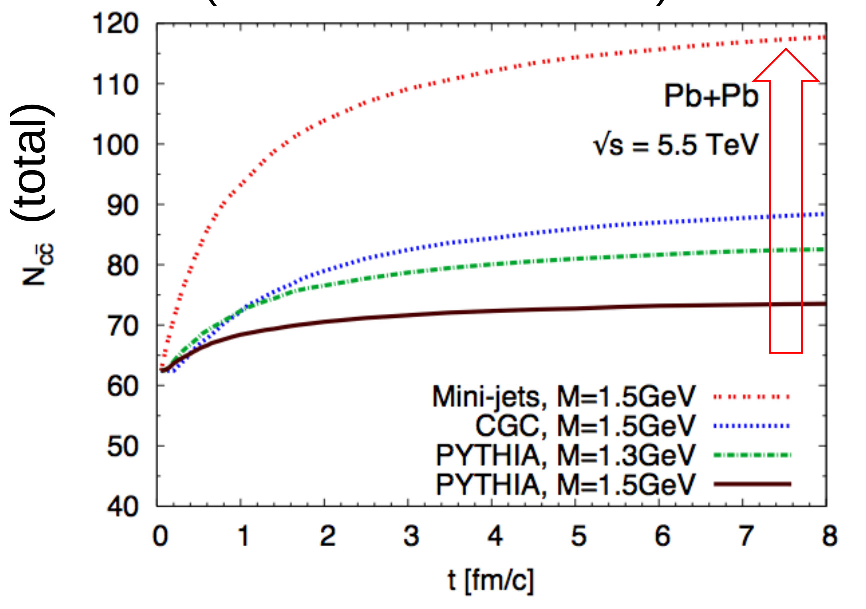
→ Need precise measurement of v_2 of D and B mesons to answer these questions:

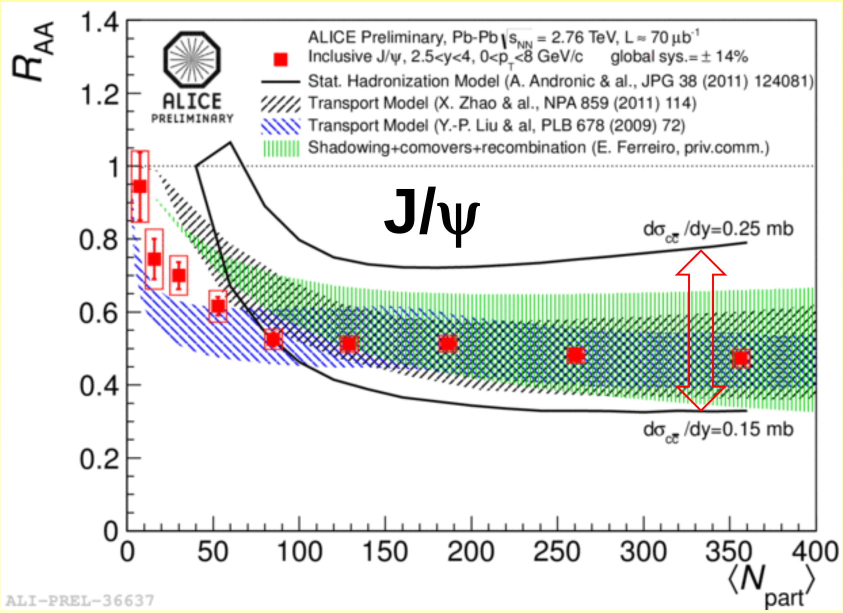
- is v_2 of charm the same as of pions?
- is v_2 of beauty smaller than of charm?
- comparison with models → HQ transport coefficient of QGP

Measuring the total charm production

- Reaching $p_T \rightarrow 0$ in central Pb-Pb provides:
  - Handle on the possibility to detect thermal charm production
    - May increase low-p_T yields by up to 50-100%
    - Sensitive to initial temperature of the QGP
  - Natural normalization for total charmonium production
    - Total charm yield: main uncertainty in J/ψ regeneration models

(C.Greiner et al. PRC82)



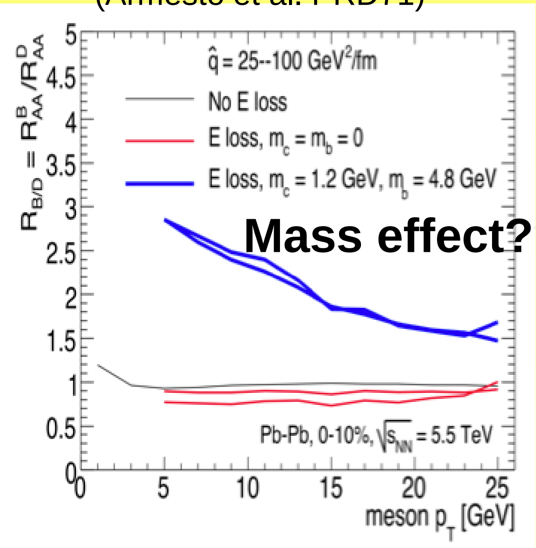


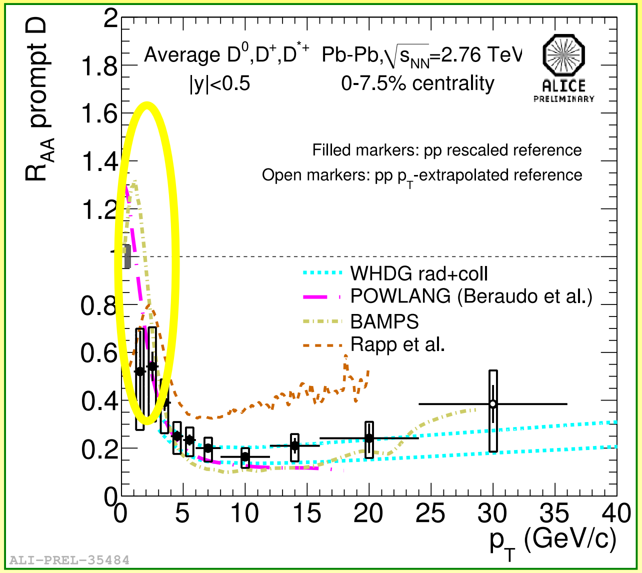
(see also C.M.Ko et al. PRC77)

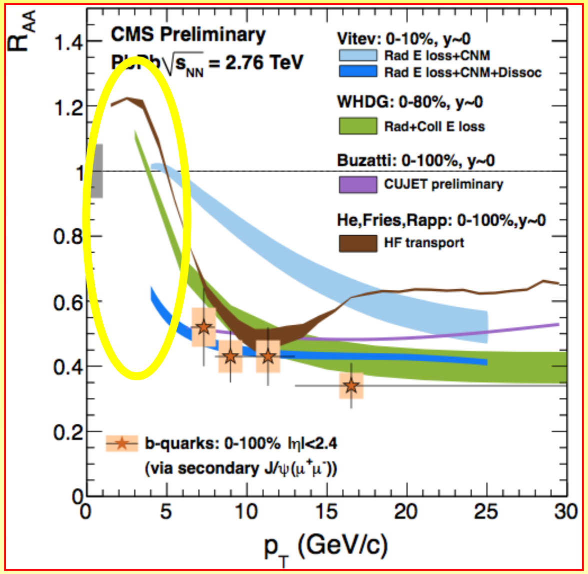
Heavy-flavour quenching

- Goal: measure D and B separately down to low p_T

B/D R_{AA}
(Armesto et al. PRD71)







- Latest ALICE (charm) and CMS (beauty) data from QM2012: not conclusive in comparison with models at low p_T
- Overcome current ALICE limits:
  - charm difficult for $p_T \rightarrow 0$ (background is too large)
  - indirect B measurement via electrons (loose correlation p_T^B vs p_T^e)
- **Build on ALICE uniqueness at low p_T: PID, low material and B field**

ALICE Upgrade: Objectives

(a subset!! The upgrade opens many more opportunities!)

- **Detailed characterization of the Quark-Gluon-Plasma**
- **Measurement of heavy-flavour transport parameters**
  - Diffusion coefficient (QGP eq. of state, η/s) → HF azimuthal anisotropy and R_{AA}
  - In-medium thermalization and hadronization → HF baryons and mesosn
  - Mass dependence of energy loss → HF R_{AA}
- **Measurement of low-mass and low-p_t di-electrons**
  - Chiral symmetry restoration → ρ spectral function
  - γ production from QGP (temp.) → low-mass dilepton continuum
  - Space-time evolution of the QGP → radial and elliptic flow of emitted radiation
- **J/ψ , ψ', and χ_c states down to zero p_t**
  - statistical hadronization vs. dissociation/recombination scenario
  - transition between low and high transverse momenta
  - density dependence – central vs. forward production
- **Heavy nuclear states**
  - mass-4 and -5 (anti-)hypernuclei
  - search for H-dibaryon, Λn bound states, etc.

➡ requires high statistics and precision measurements

ALICE Upgrade: target LS2 (2018)

- Primary scope:
  - precision studies of charm and beauty mesons and baryons and charmonia
  - low mass lepton pairs and thermal photons
  - gamma-jet and jet-jet with particle identification from low momentum up to 30 GeV.
  - heavy nuclear states

➢ **low-transverse momentum observables** (complementary/orthogonal to the general-purpose detectors)

- not triggerable => need to examine full statistics.

- **Operate ALICE at high rate while preserving its uniqueness, superb tracking and PID, and enhance its secondary vertex capability and tracking at low-p_T**

Experimental Strategy

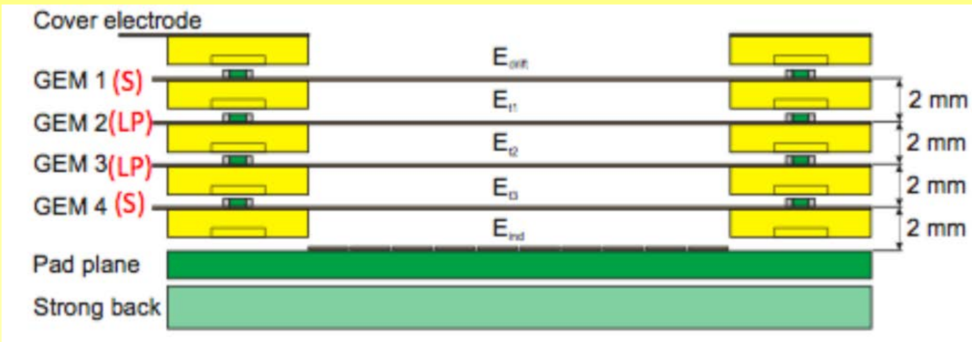
- run ALICE at 50kHz Pb-Pb (i.e. $L = 6 \times 10^{27}\ cm^{-1}s^{-1}$), with minimum bias (pipeline) readout (max readout with present ALICE set-up ~500Hz)
  - Gain a factor of 100 in statistics over current program: x 10 integrated luminosity, $1nb^{-1}$ => $10\ nb^{-1}$, x 10 via pipelined readout allowing inspection of all collisions, namely inspect $O(10^{10})$ central collisions instead of $O(10^8)$
- improve vertexing and tracking at low p_t
- This entails a major upgrade of the whole apparatus:
  - New, smaller radius beam pipe
  - New inner tracker (ITS) (scope and rate upgrade)
  - High-rate upgrade for the readout of the TPC, TRD, TOF, CALs, DAQ/HLT, Muons and Trigger detectors
- Furthermore, three proposals have been considered by the collaboration to extend the scope of the ALICE upgrade: VHMPID, MFT, and FoCal
  - new high momentum PID capabilities
  - b-tagging for J/ψ, low-mass di-muons
  - low-x physics with identified γ/π^o

TPC prototypes and test beams

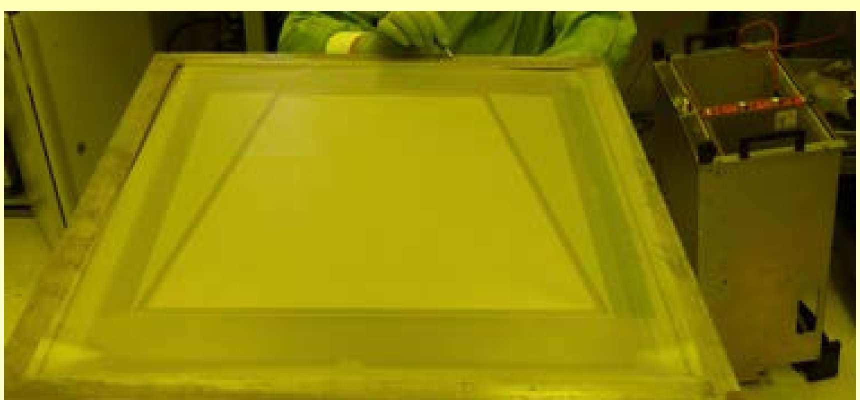
Test beam campaign in Nov/Dec 2014 at PS and SPS

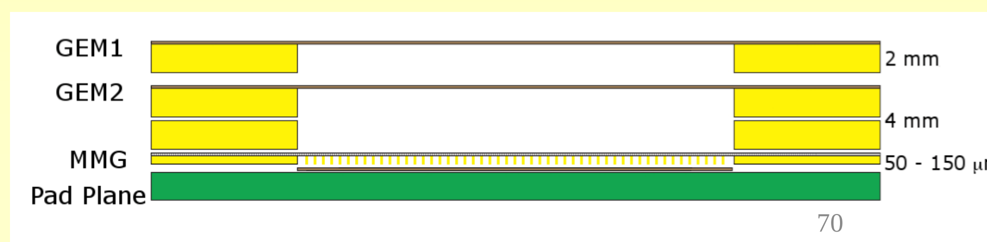
Two full-size IROC prototypes being prepared:

- **4 single-mask GEMs: S-LP-LP-S**

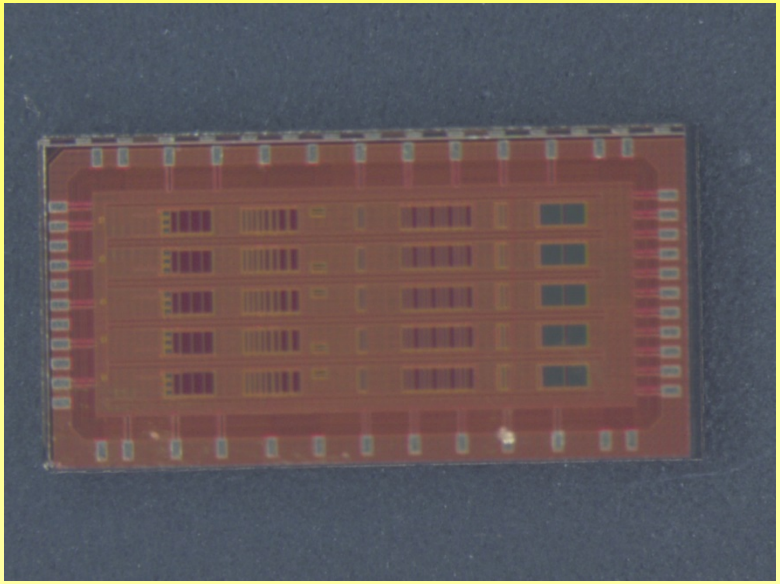


- **MM-S-S: MicroMegas (400 LPI) + two standard GEMs**





TPC/MCH read-out ASIC: SAMPA



Multi project wafer run 1

ASIC 1, 5 front-end channels

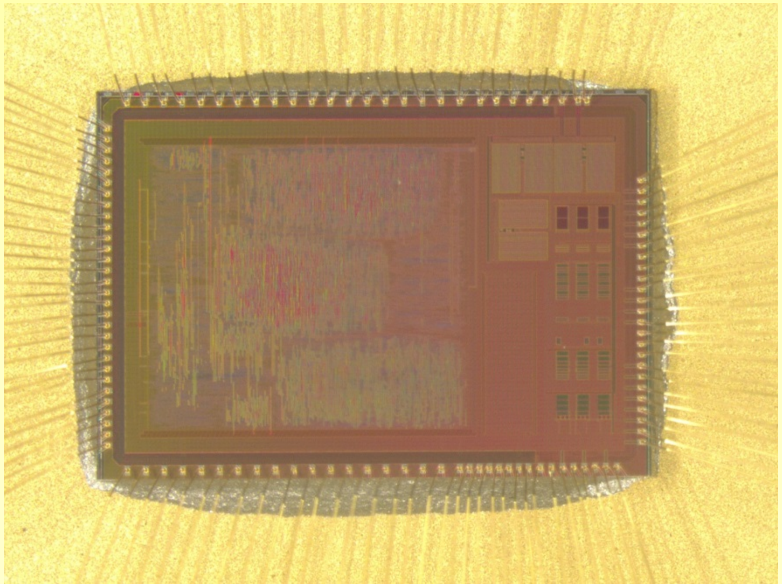
ASIC 2, ADC and SLVS driver

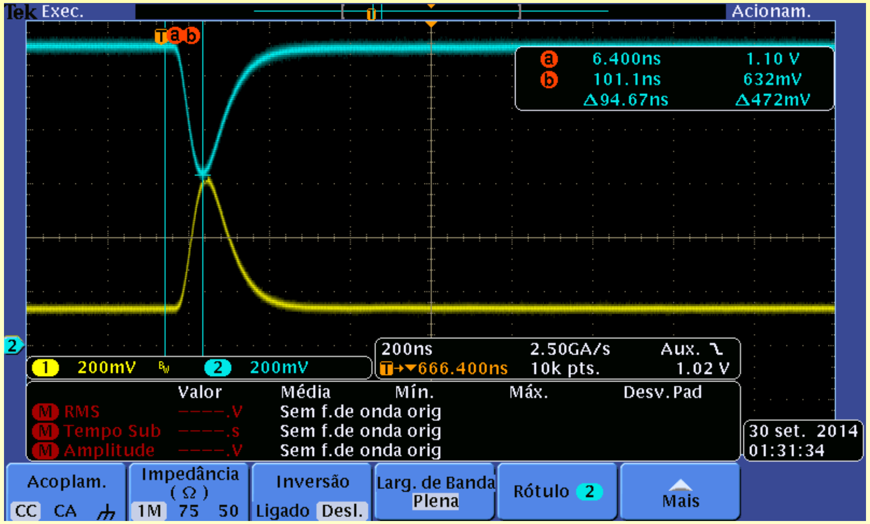
ASIC 3, 3 channels including DSP and read-out

Submission June 2014

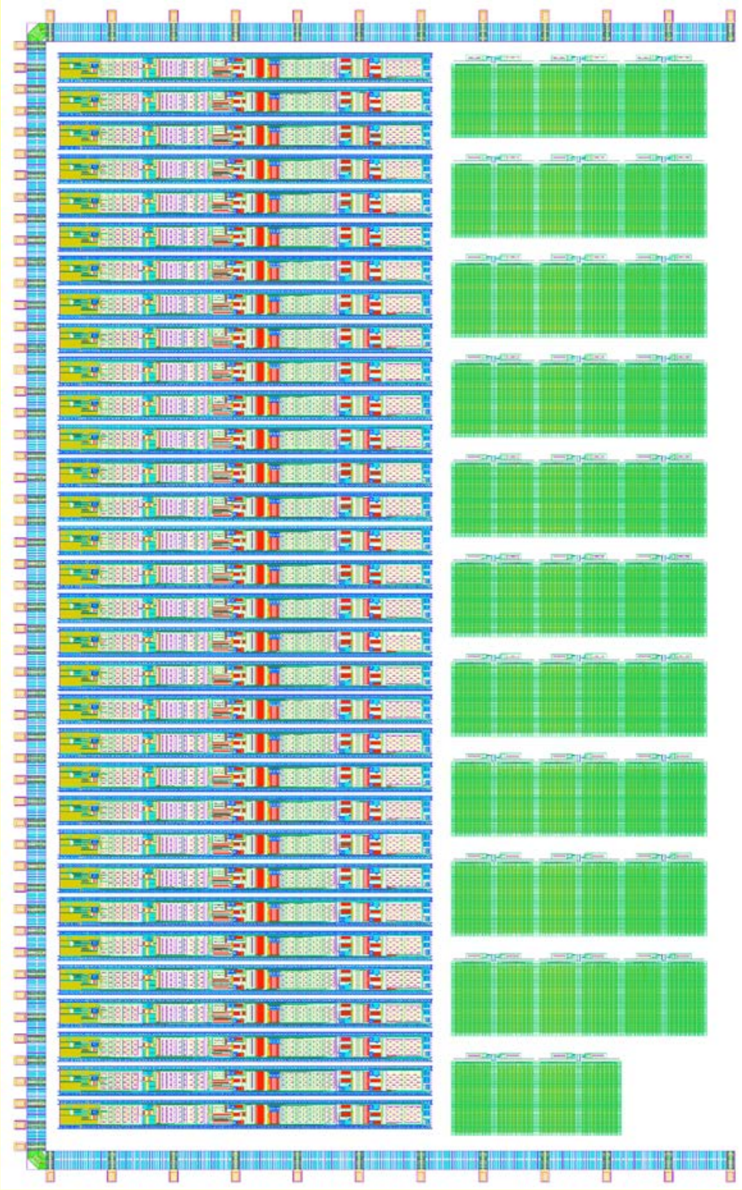
Delivery Sept 2014

ASIC 1 already under test





TPC/MCH read-out ASIC: SAMPA



Multi project wafer run 2

Full size, 32-channel,
full functionality ASIC

Presently under design
Submission 2014/15

LoI and ITS CDR for the Upgrades, Submitted to the LHCC sept 6th 2012

- **Endorsed by the LHCC** Sept 27th , 2012:
  "The LHCC commends this joint approach to heavy ion physics and endorses the upgrade plans of the ALICE collaboration. The committee is looking forward to the seeing the detailed technical solutions presented in the respective TDRs. ***"***
- **Approved by Research Board** Nov 28th 2012
  "The Research Board approved the upgrade of ALICE for the physics case that has been made in the LoI, *based on up to 10 nb-1 of data taken with lead ions, implying that* ***the experiment will continue to run beyond 2018****. The CERN accelerator departments should assess the feasibility of delivering the requested integrated luminosity."*