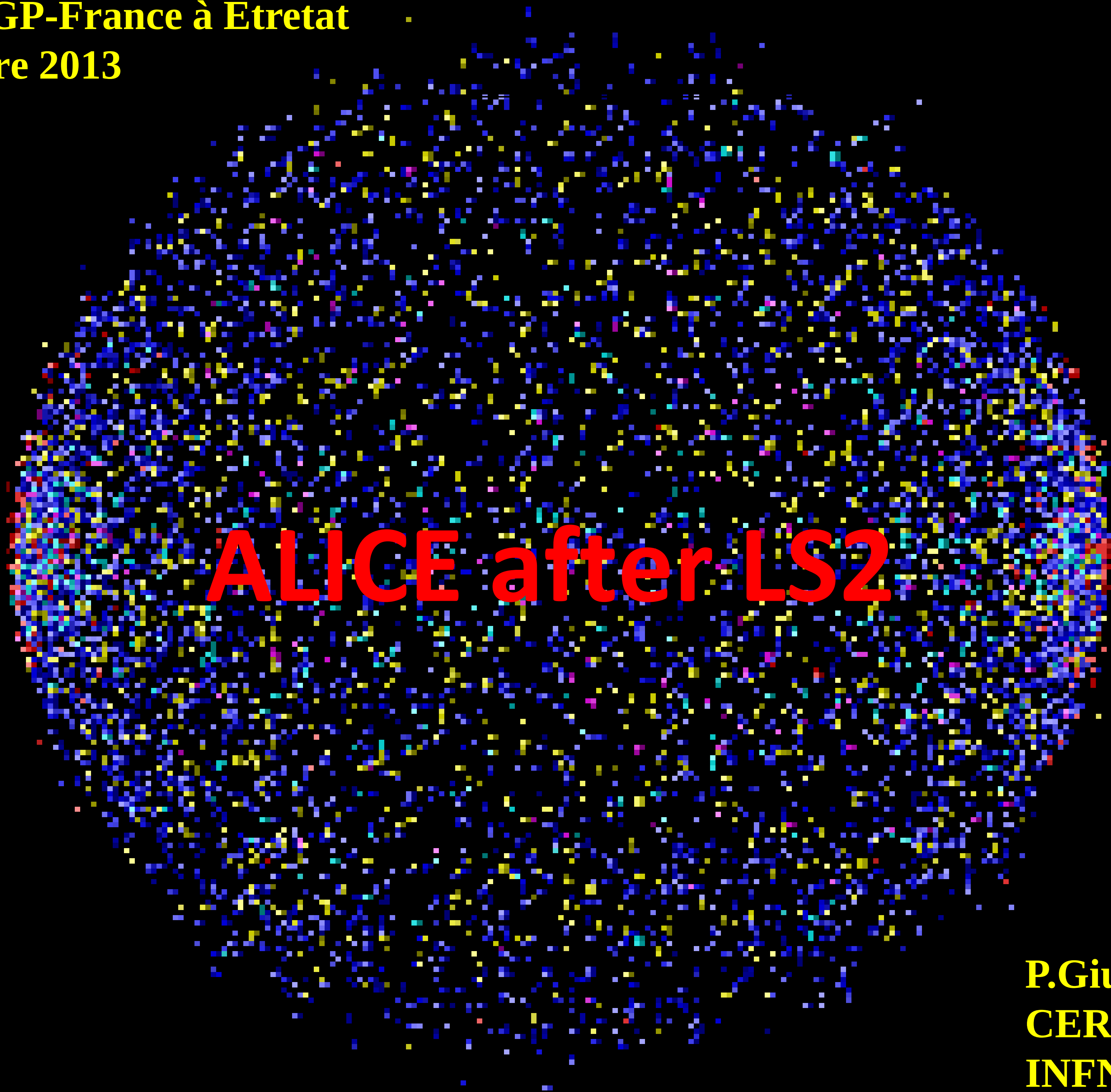
Journées QGP-France à Etretat
11 Septembre 2013



ALICE after LS2

P.Giubellino
CERN and
INFN Torino

Heavy Ions at the LHC…

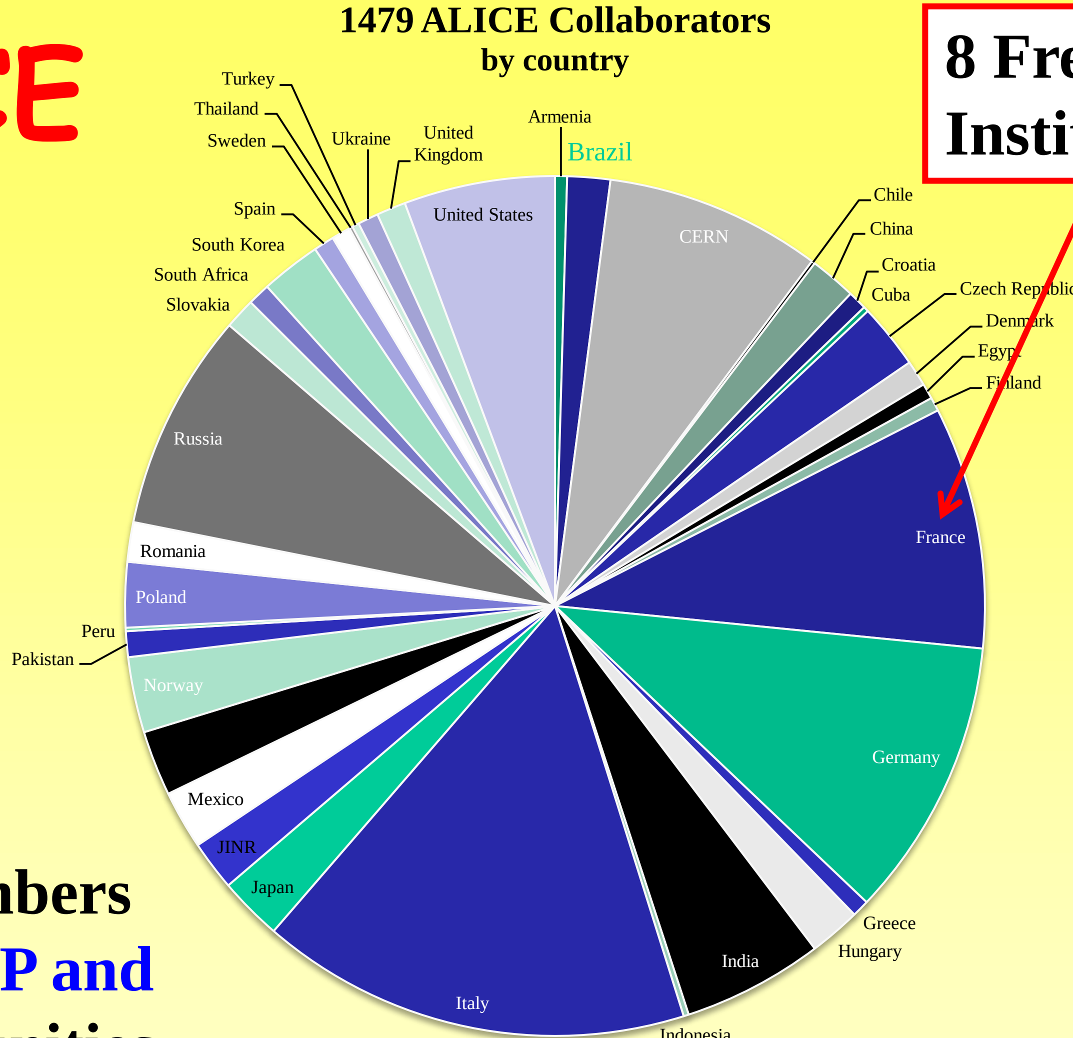
- ALICE
  - Experiment designed for Heavy Ion collision
    - only dedicated experiment at LHC, must be comprehensive and able to cover all relevant observables
    - **VERY robust tracking** for p_T from **0.1 GeV/*c*** to **100 GeV/*c***
      - high-granularity 3D detectors with many space points 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...

A program of major impact

- A very large community of physicists involved
  - over a thousand just in ALICE, hundreds in the other experiments + a lot of theoretical activity
- A huge scientific output
  - 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 13 top cited physics papers at the LHC 5 are from the Heavy Ion program (3 ALICE, 1 CMS and 1 ATLAS)
  - Several hundred presentations at international conferences each year

ALICE



8 French Institutions

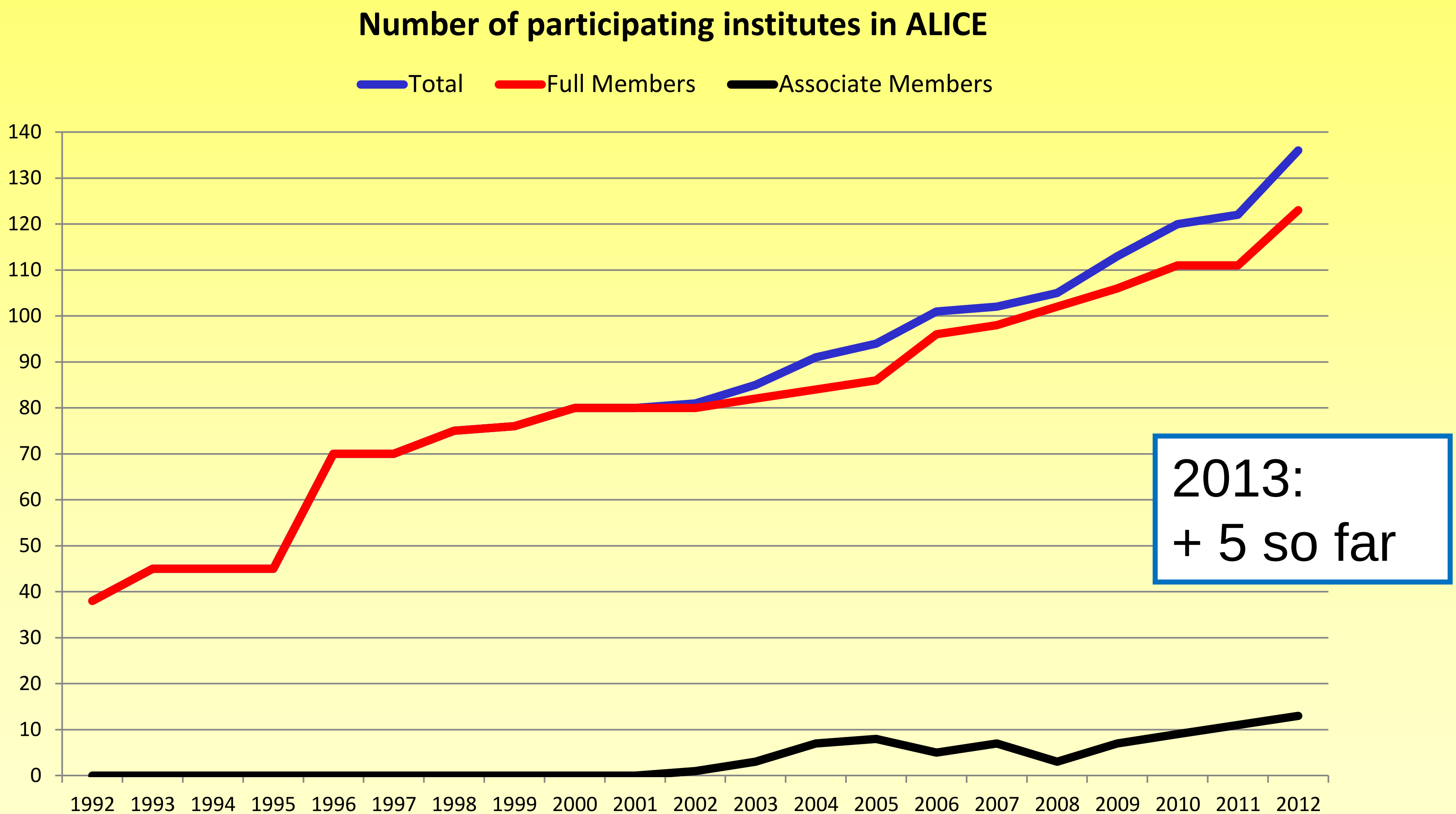
~ 1400 Members from both NP and HEP communities

36 Countries

148 Institutes

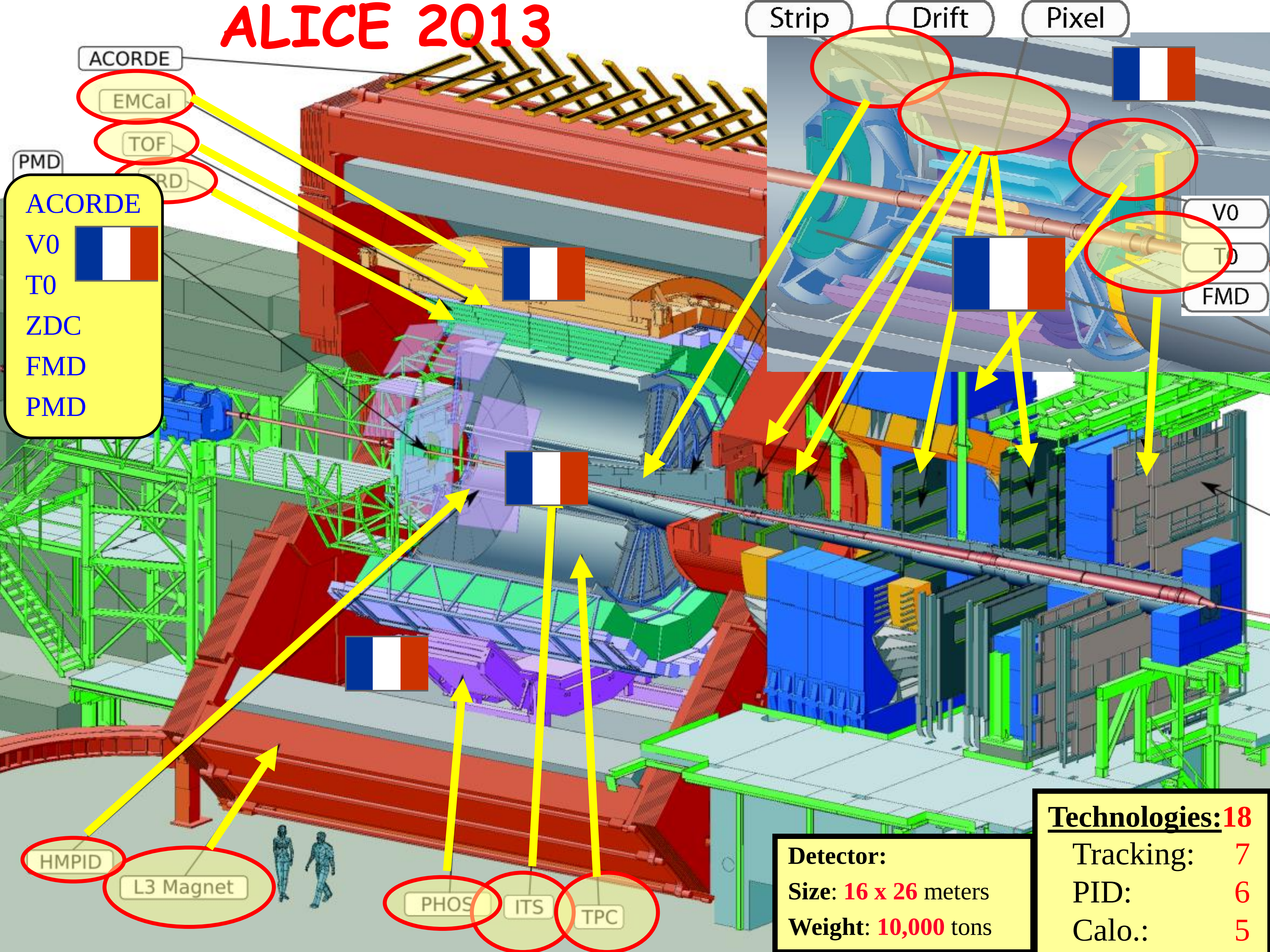
~ 160 MCHF capital cost

ALICE Continues to grow!
PARTICIPATING INSTITUTES (1992-2012)



A scientific and technological program with great prospects!

ALICE 2013



Detector:
Size: **16 x 26** meters
Weight: **10,000** tons

Technologies: 18

Tracking:	7
PID:	6
Calo.:	5

ALICE has already evolved a lot!

- **ALICE history:**
- 1990-1996: Design
- 1992-2002: R&D
- 2000-2010: Construction
- 2002-2007: Installation
- 2008 : Commissioning
- 2009-> Data Taking!
- **4 TP addenda along the way:**
  - 1996 : muon spectrometer
  - 1999 : TRD;
  - 2006 : EMCAL;
  - 2010 : DCAL

Nuclear Beams in the LHC: so far…

- LHC had till now two heavy-ion runs
  - In 2010 – exploratory run
  - in 2011 – already above nominal instant luminosity!
- This year (2013, as last section of 2012) p–Pb run

year	system	energy $\sqrt{s_{NN}}$ TeV	integrated luminosity
2010	Pb – Pb	2.76	~ 10 μb^{-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

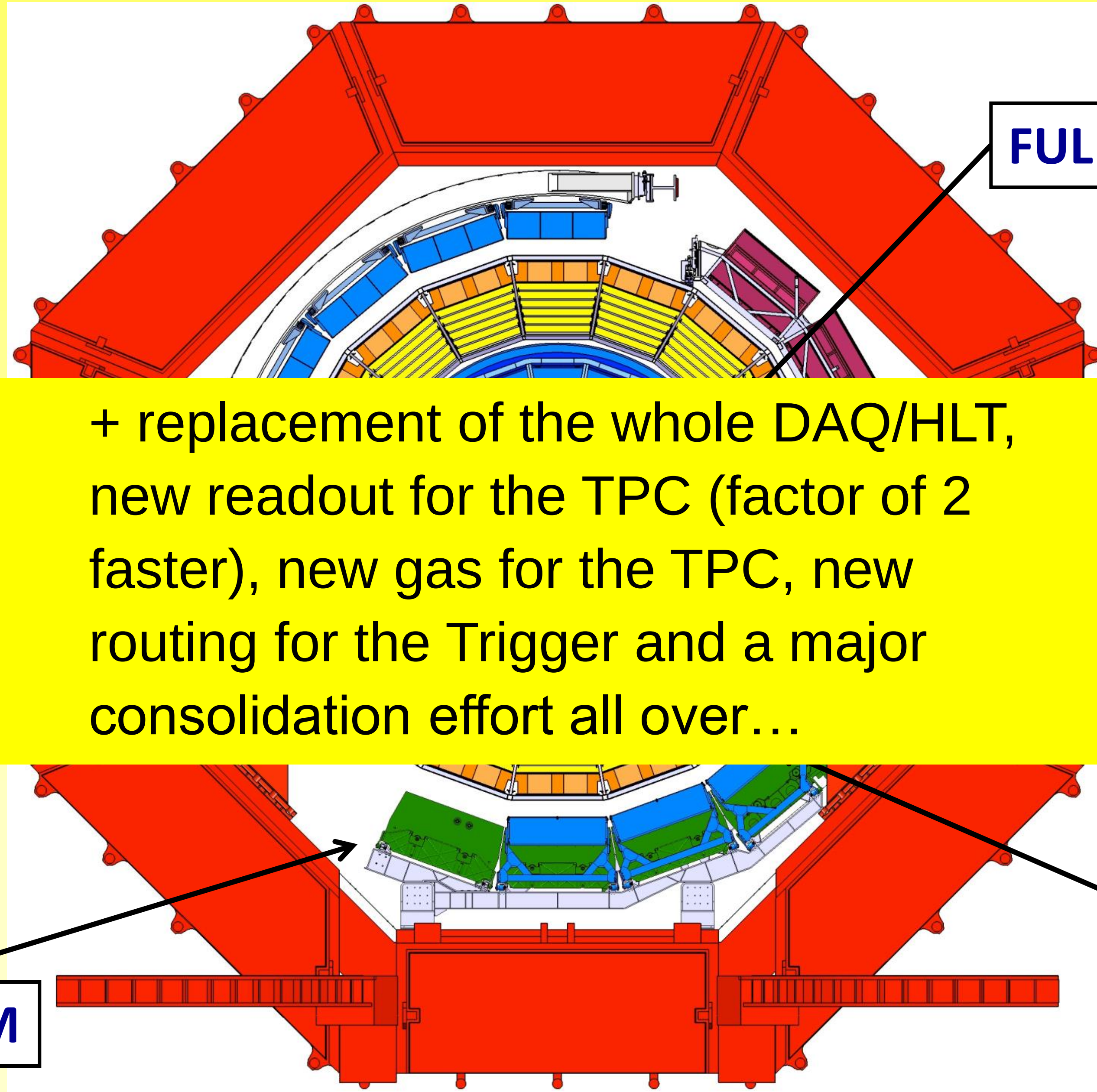
- RUN3 + RUN4 (19, 20, 21 and 24, 25, 26): 10 nb^{-1} with major detector improvements

- 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 the whole DAQ/HLT, new readout for the TPC (factor of 2 faster), new gas for the TPC, new routing for the Trigger and a major consolidation effort all over…

Long term future of the LHC HI Program

- All experiments are building on the success of RUN1 and learning from the results
- June 29th 2012 Town meeting of the whole HI community (at CERN)
  - Very important meeting, resulting in a common document of the Community submitted to the Cracow European Strategy Meeting, and indicating clearly the extension of the LHC HI program, including the ALICE upgrade, as its first priority. Remarkable coherence of ALICE, ATLAS and CMS
    - "***The top priority for future quark matter research in Europe is the full exploitation of the physics potential of colliding heavy ions in the LHC.***"
- All 3 experiments would benefit from the PbPb luminosity upgrade, and in their upgrades would strengthen their complementarity
- **NUPECC** also submitted a document to Cracow,
  - Stresses the commitment of the Nuclear Physics Community to the ALICE long term programs, "top priority for European Nuclear Physics"

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: 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

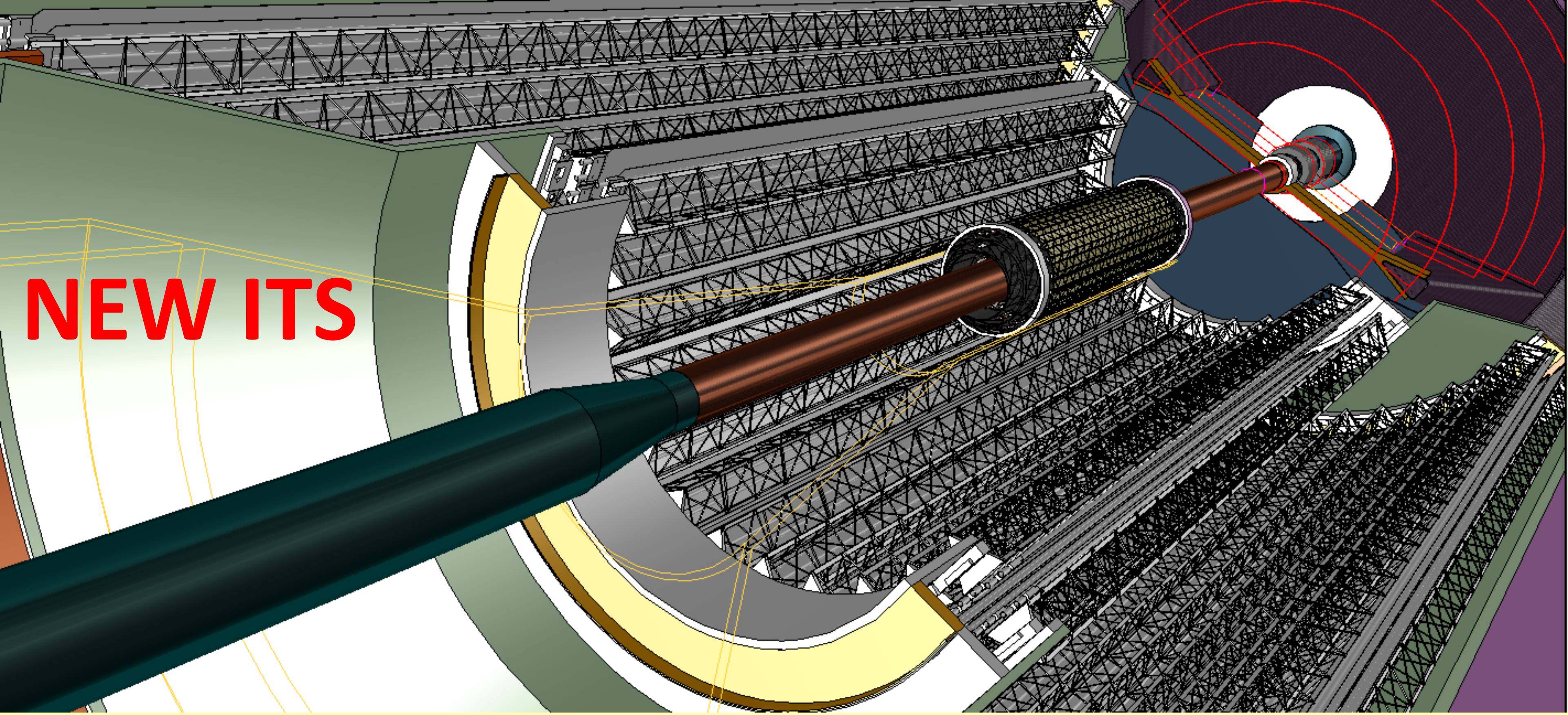
➢ **low-transverse momentum observables** (complementary/orthogonal to the general-purpose detectors)

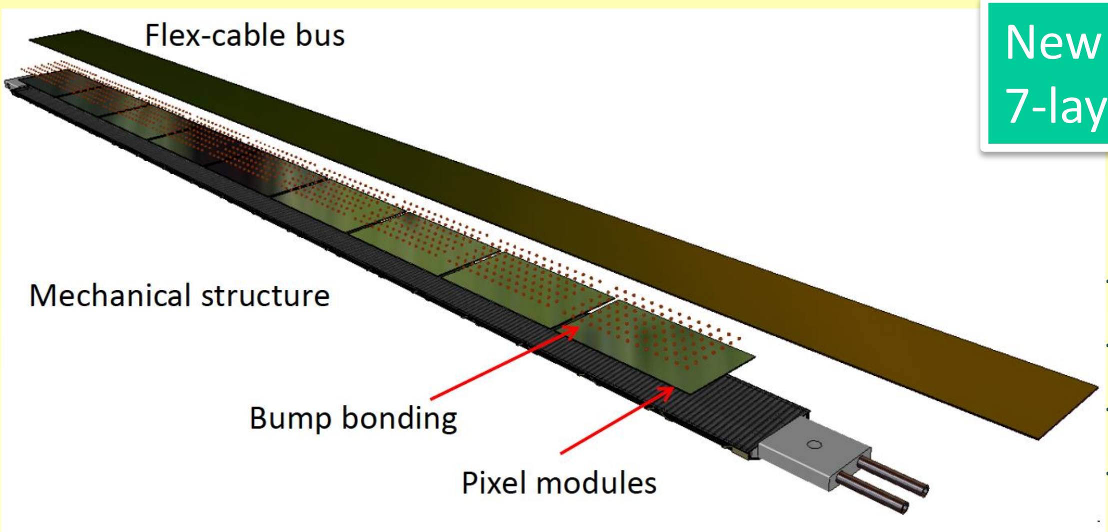
- not triggerable => need to examine full statistics.

- **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. $L = 6x10^{27}$ $cm^{-1}s^{-1}$), 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

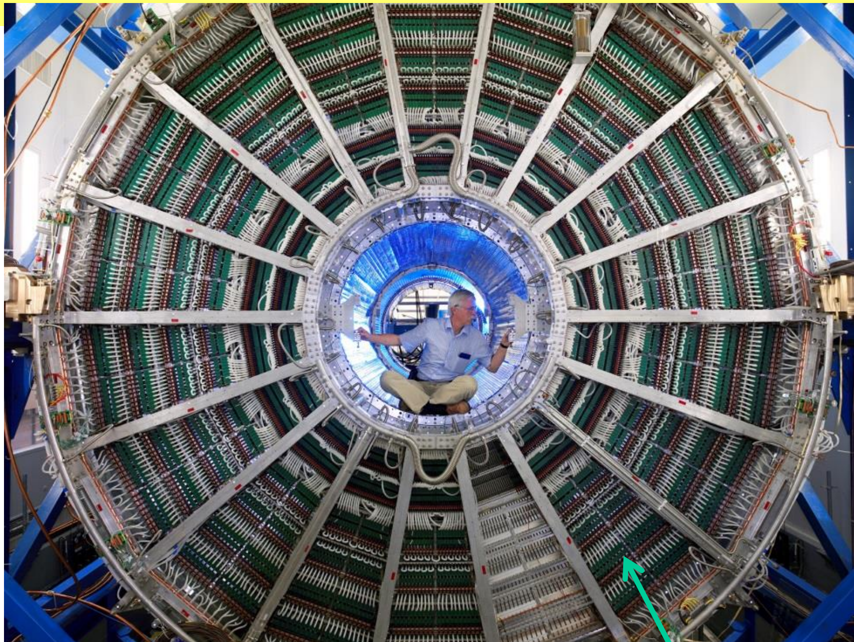




New Inner Tracking System
7-layer silicon tracker based on MAPS

Detector module consists of
- Carbon fiber support structure
- Cooling unit
- Polyimide cable
- Silicon chips (monolithic pixels)

TPC Upgrade with GEMs



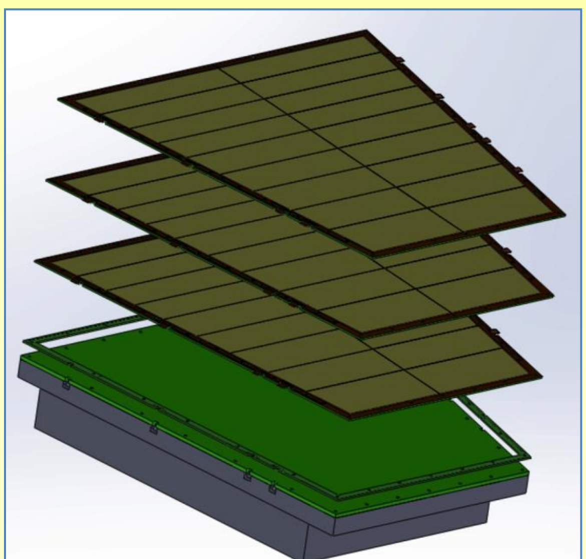
Replacement of wire-chambers with GEM-chambers

- 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

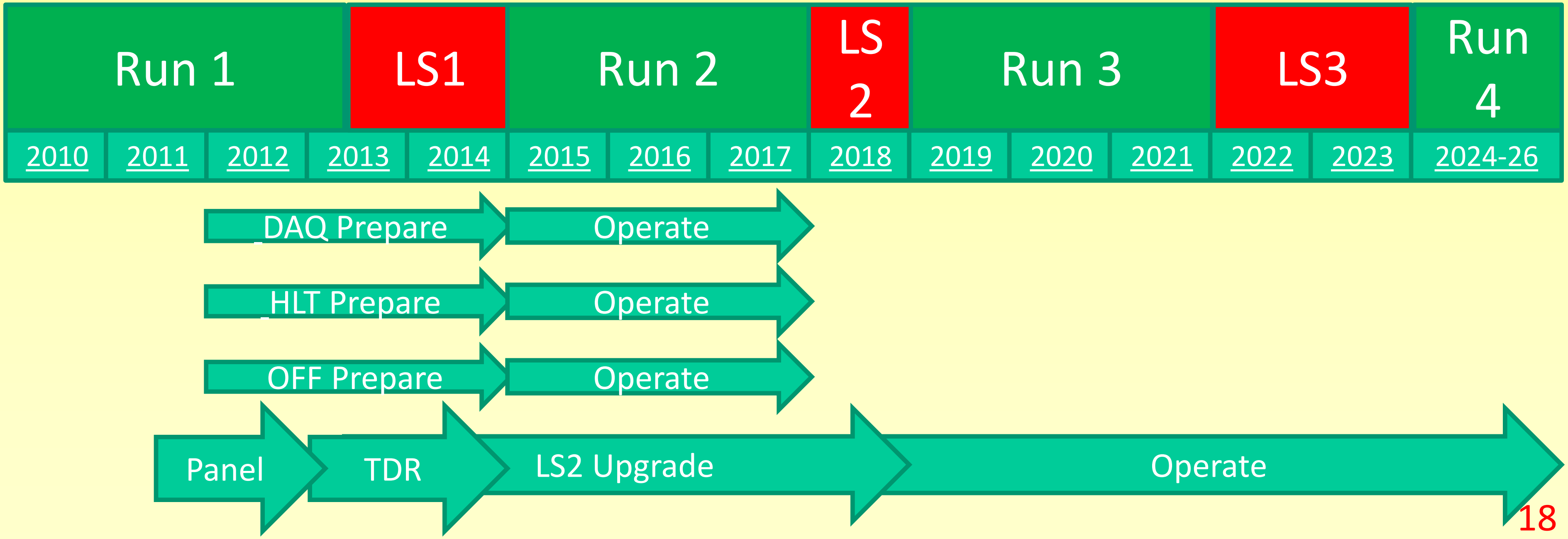
Cost: 5.5 MCHF



Replace wire chambers
With triple-GEM or
quadruple-GEM chambers

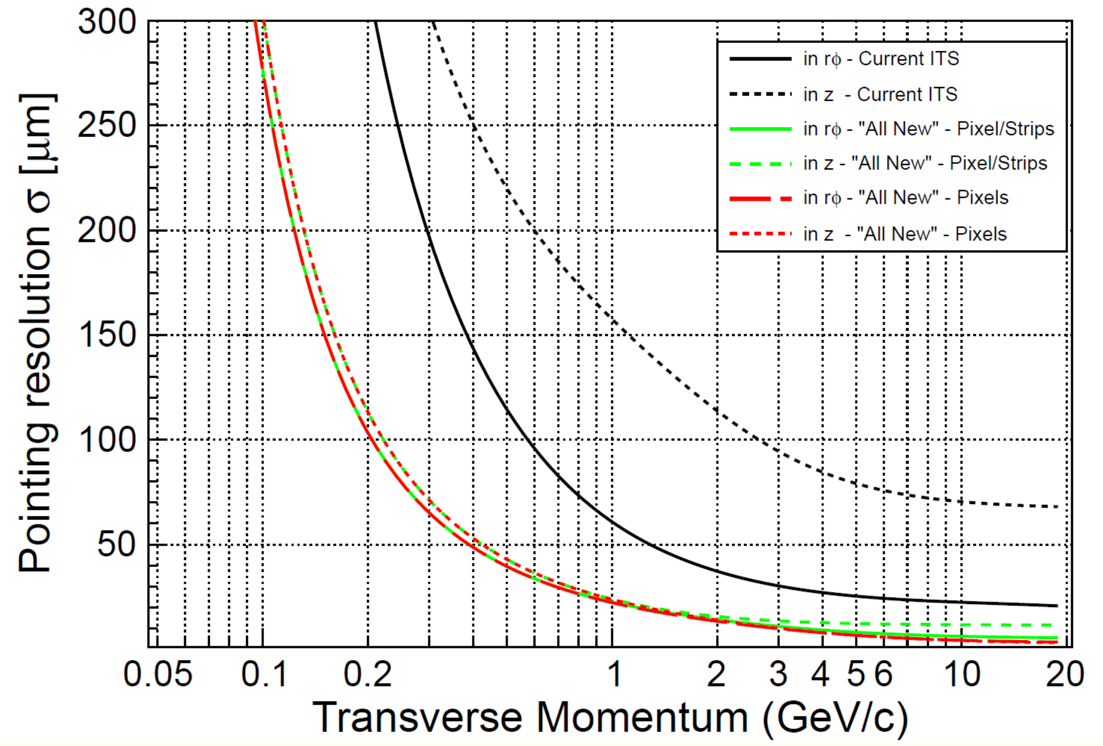
Online-Offline Computing (O^2)

- 3 projects: DAQ, HLT, Offline
  - Run 2 : Prepare (update) and operate 3 independent systems
- LS2 upgrade (re-design and implement)
  - "Upgrade of the ALICE Experiment", Letter Of Intent (LoI), CERN-LHCC-2012-12)
  - ALICE Computing software framework for LS2 Upgrade, ALICE-INT-2013-001
  - Run 3 :
    - 1 common new online and offline computing system
    - Common computing farm and software framework
  - Common Technical Design Report (TDR) by September 2014



Performance improvement I

New ITS & beampipe: Improvement of impact parameter resolution



Simulations for two upgrade layouts

Option A: 7 pixel layers

•Resolutions: $\sigma_{r\phi}$ = 4 μm, σ_z = 4 μm for all layers

•Material budget: X/X_0 = 0.3% for all layers

radial positions (cm): 2.2, 2.8, 3.6, 20, 22, 41, 43

Same for both layouts

Option B: 3 layers of pixels + 4 layers of strips

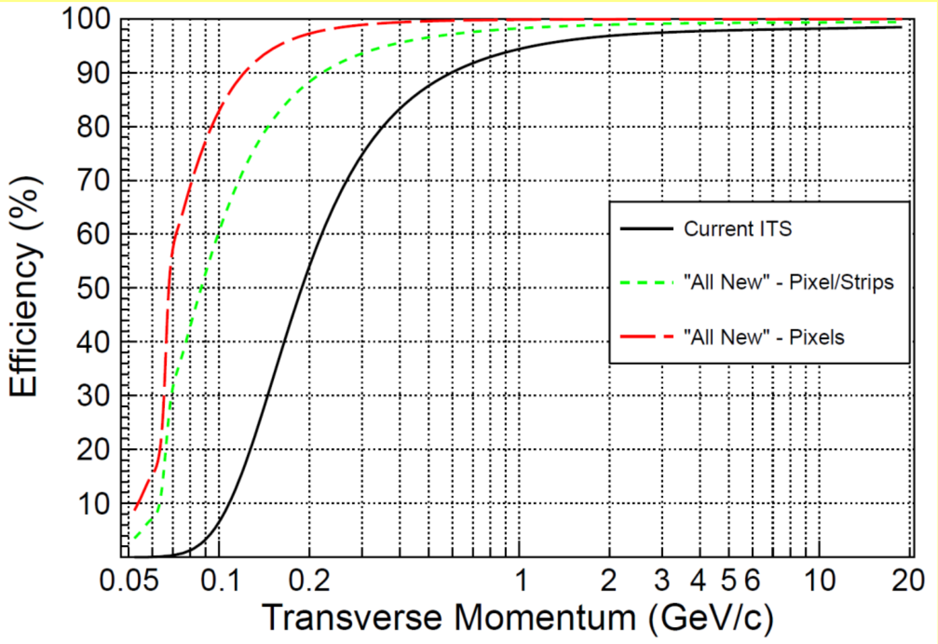
•Resolutions: $\sigma_{r\phi}$ = 4 μm, σ_z = 4 μm for pixels; $\sigma_{r\phi}$ = 20 μm, σ_z = 830 μm for strips

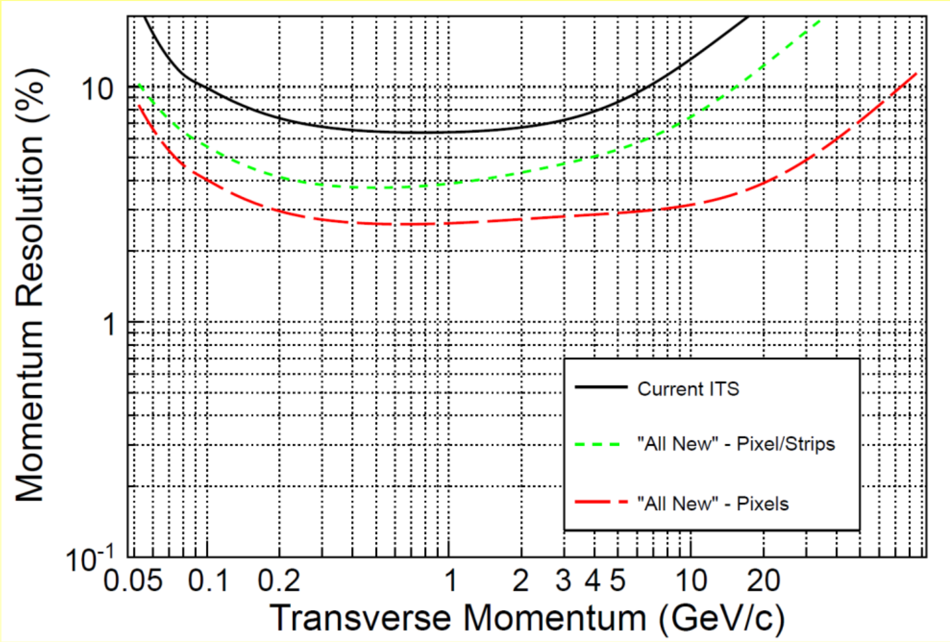
•Material budget: X/X_0 = 0.3% for pixels; X/X_0 = 0.83% for strips

Performance improvement II

ITS standalone tracking efficiency

Central events at sqrt(s_{NN}) = 5.5 TeV

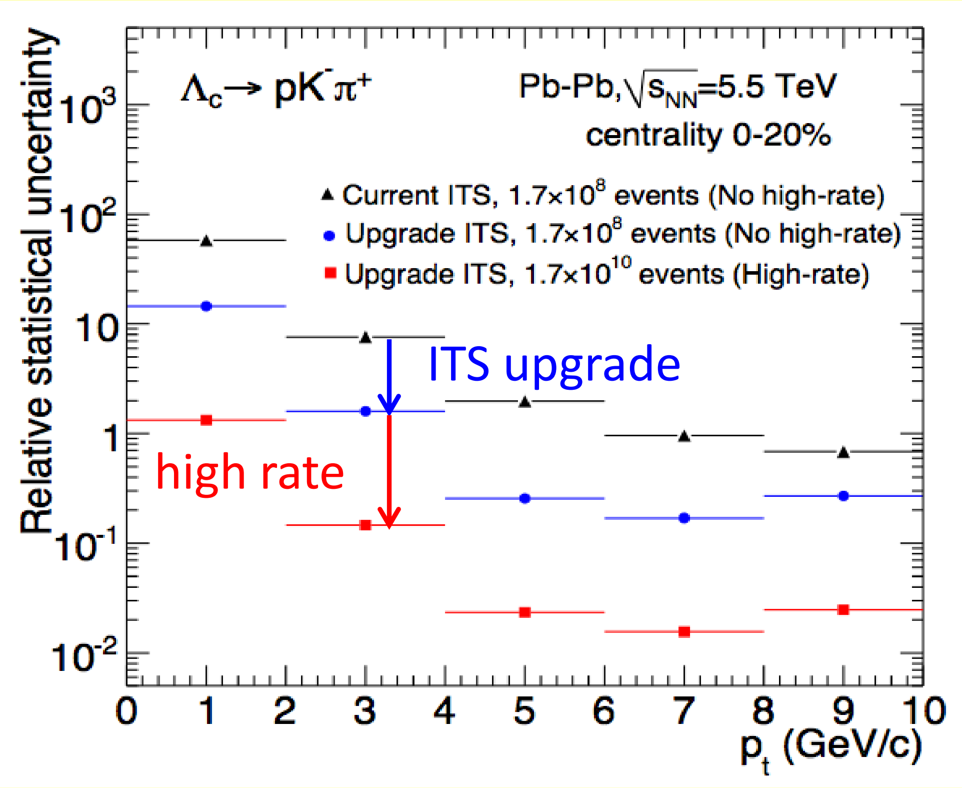




Simulations for two upgrade layouts

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

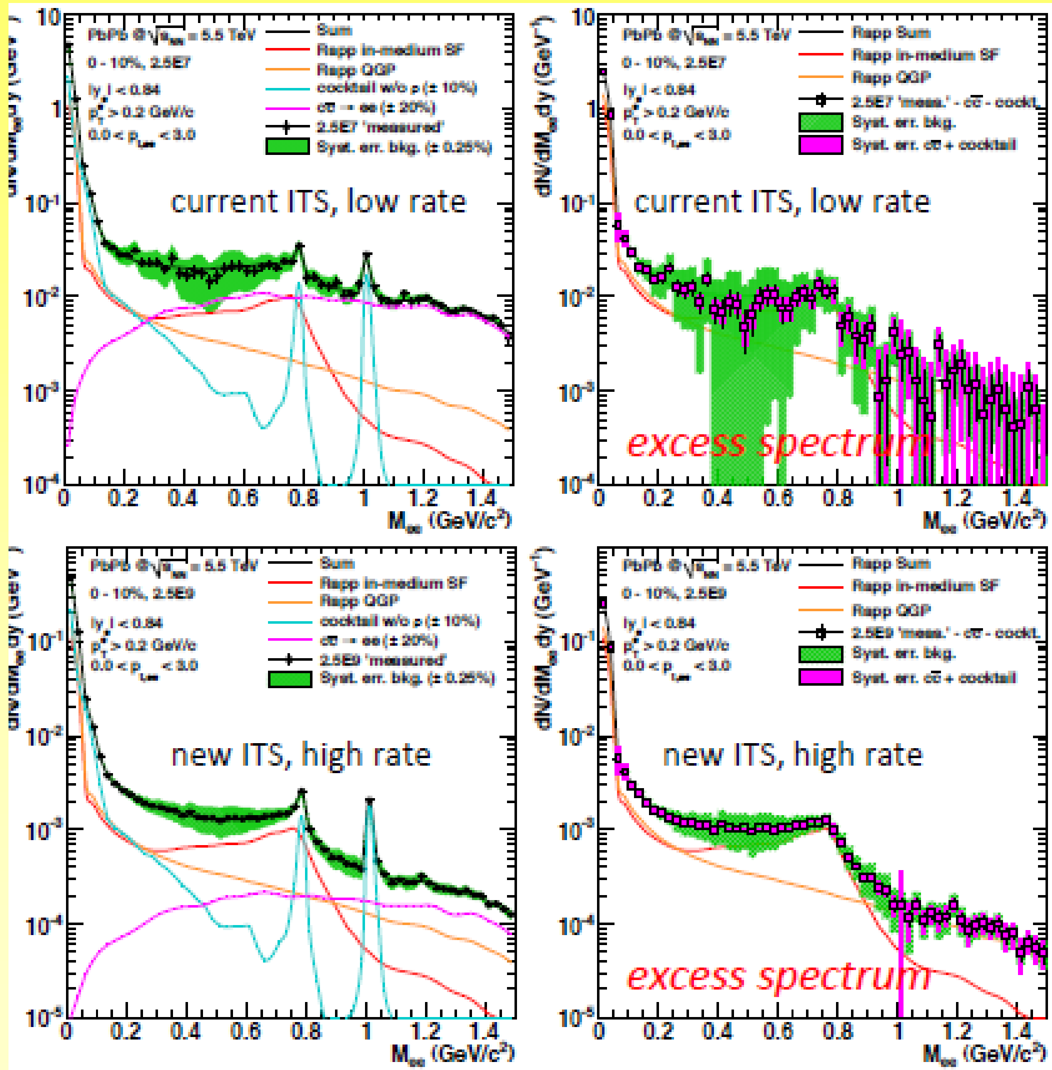
- Λ_c $c\tau$=60 μm, to be compared with D^+ $c\tau$=300 μm
  → practically impossible in Pb-Pb with current ITS



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

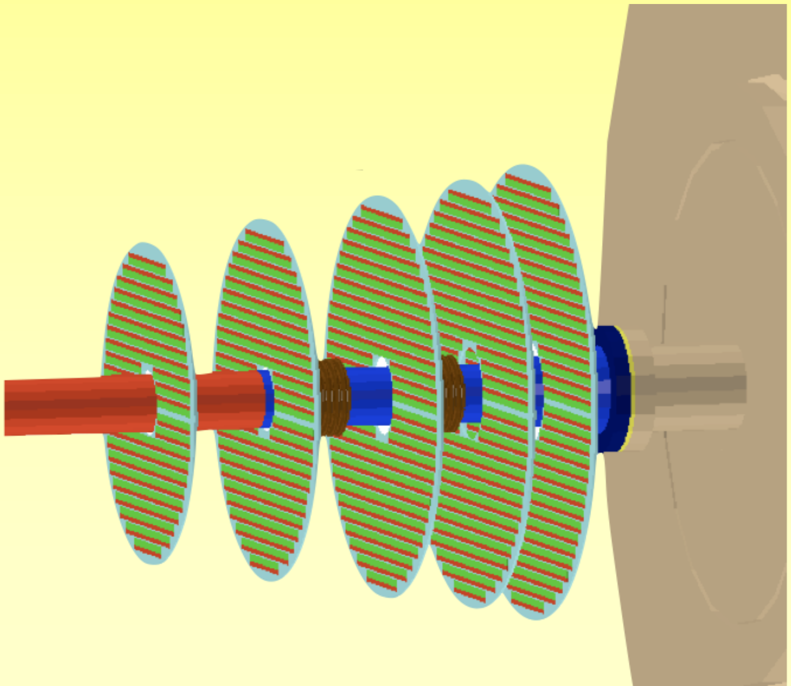


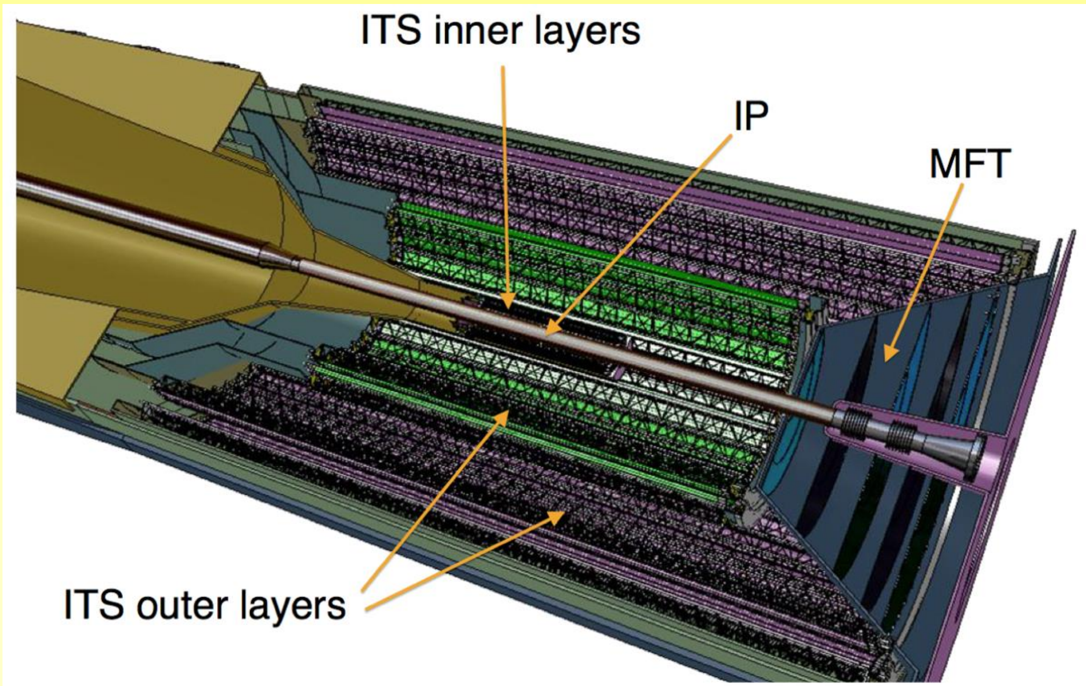
Additional Upgrades

- Decisions taken in Collaboration Board on March 21st 2013
- VHMPID
  - High momentum hadron identification with focusing RICH: further enhancement of specific ALICE strength
  - Interesting physics case, but not considered strong and unique enough given the possibility to perform most of the proposed measurements with existing ALICE PID, although with lesser precision
  - Not approved for submission to the LHCC
- FoCal
  - Electromagnetic calorimeter for forward direct photon measurement: low-x physics
  - physics case: gluon saturation in p+A
  - Needs further study: stronger physics case in A+A and digestion of first p+A results
  - Postpone decision and, if approved, installation (after LS2)
- MFT
  - Silicon tracker to enhance forward muon measurement: displaced vertex detection and enhanced background rejection
  - Improve ψ' measurement, add charm/beauty separation
  - **Approved by collaboration prepare submission to LHCC**

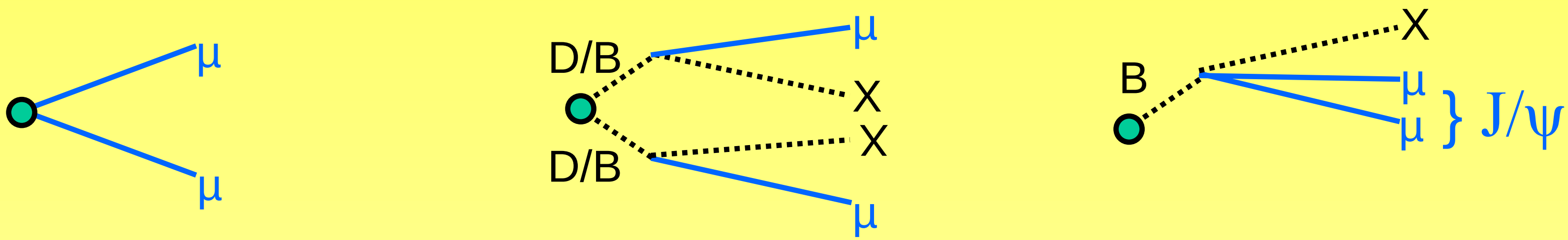
The Muon Forward Tracker apparatus

- 5 planes of CMOS silicon pixel sensors
- Placed between IP and front absorber
- Covering most of the MUON acceptance (3°< θ < 9°, -3.6<η<-2.5)
- Same Technology as for new ITS ⇒ numerous synergies in R&D / production





Add displaced vertex measurement to MUON



- Good pointing resolution
  - Identification of single muons from D (cτ~150 μm) and B (cτ~500 μm)
  - Discrimination between prompt and displaced dimuons (J/ψ from B)
- Background rejection
  - Cut on the matching quality between MUON / MFT
- Improvement of invariant mass resolution at low mass
- Better measurement of the opening angle of the two muons

- **Impact on ALICE Physics Capabilities:**
  - Separate Charm and Beauty to low pT in single muon and dimuon
  - Access Beauty down to zero pT thanks to displaced J/ψ measurement

  ⇒ Test heavy quarks energy loss models
  - Improved S/B allows precise ψ'/ ψ measurement

  ⇒ Discrimination between statistical and transport models

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

Running scenario after the upgrade

- Pb–Pb
  - int. luminosity per year 2.85 nb^{-1} (peak $L = 7x10^{27}$ $cm^{-2}s^{-1}$)
  - needed int. luminosity 10 nb^{-1}, statistics $8x10^{10}$ 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 ($L = 3x10^{30}$ $cm^{-2}s^{-1}$)
  - needed int. luminosity 6 pb^{-1}, statistics $4x10^{11}$ 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.

A *possible* running scheme

- ALICE plans to run 6 years with upgraded detector, i.e. until 2026 (assuming start in 2019 and 2 years break of LS3)
- Possible scenario:
  - 2019 – Pb–Pb 2.85 nb^{-1}
  - 2020 – Pb–Pb 2.85 nb^{-1} (low magnetic field)
  - 2021 – pp reference run
  - 2022 – LS3
  - 2023 – LS3
  - 2024 – Pb–Pb 2.85 nb^{-1}
  - 2025 – ½ Pb–Pb 1.42 nb^{-1} + ½ p–Pb 50 nb^{-1}
  - 2026 – Pb–Pb 2.85 nb^{-1}
- This would not require pp running during high-luminosity runs, only a short time before a heavy-ion run for setting up and commissioning.

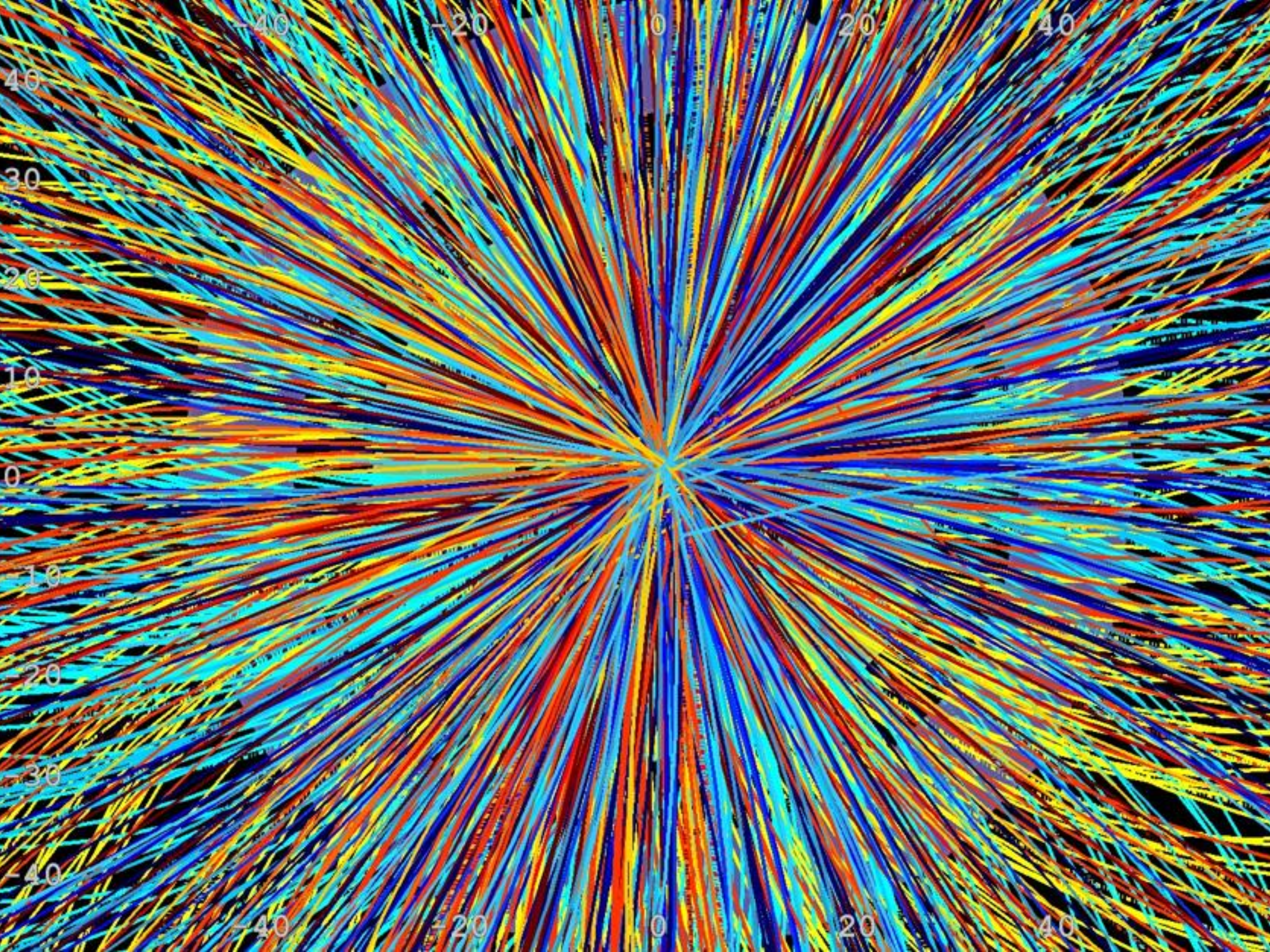
LoI and ITS CDR for the Upgrades, Submitted to the LHCC sept 6th 2012

- **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."*

Upgrades: next steps

- September 8: a draft of the **MFT LoI** sent to the LHCC referees
- September 24: presentation of the **MFT LoI** for a decision on the approval; Presentation of the status of the ITS, TPC and High Luminosity Electronics upgrade
- End of October beginning of November: **submission** of the ITS, TPC and Electronics upgrade **TDRs** to the LHCC referees
- December 4: **presentation of the ITS, TPC and Electronics TDRs** for a decision on the approval.
  - TDRs will contain the technical descriptions, but also the construction plans, work sharing and commitments
  - O^2 TDR in a year

- FoCal:
  - preparing to update material for internal review
  - more performance simulations, etc.
  - discussions with TC on beam pipe and integration ongoing



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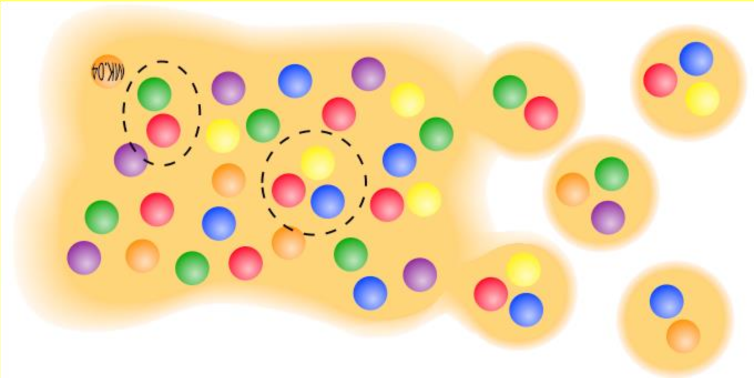
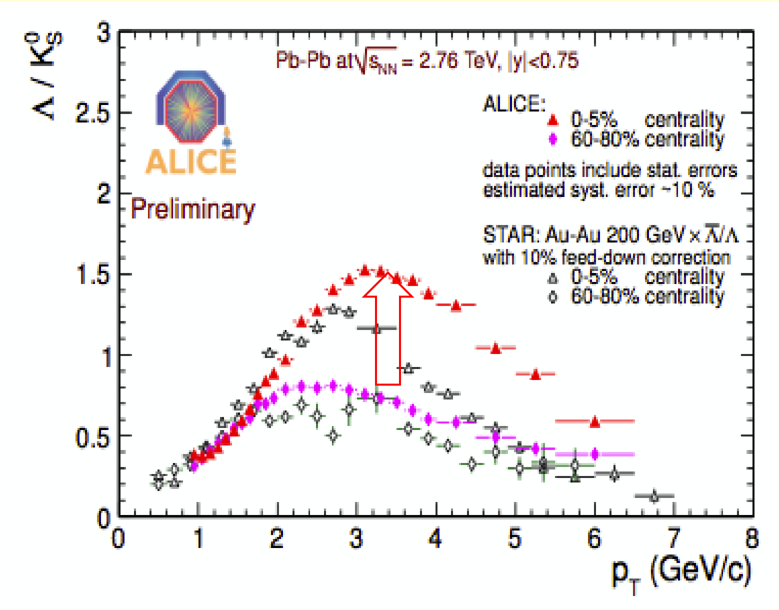
HF thermalization and in-medium hadronization: Λ_c and D_s as probes

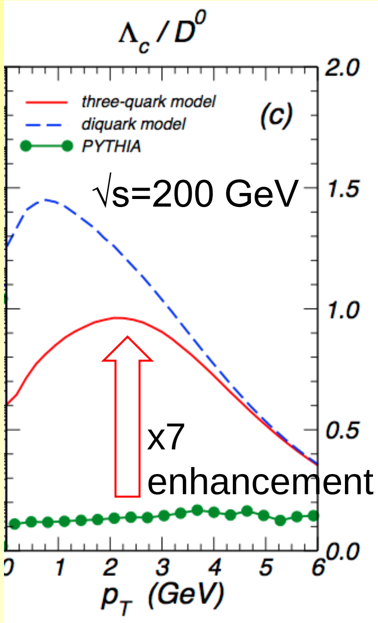
- Baryon/meson enhancement and strangeness enhancement → indication of light-quark hadronization from partonic system

➡ Charm baryons (Λ_c)

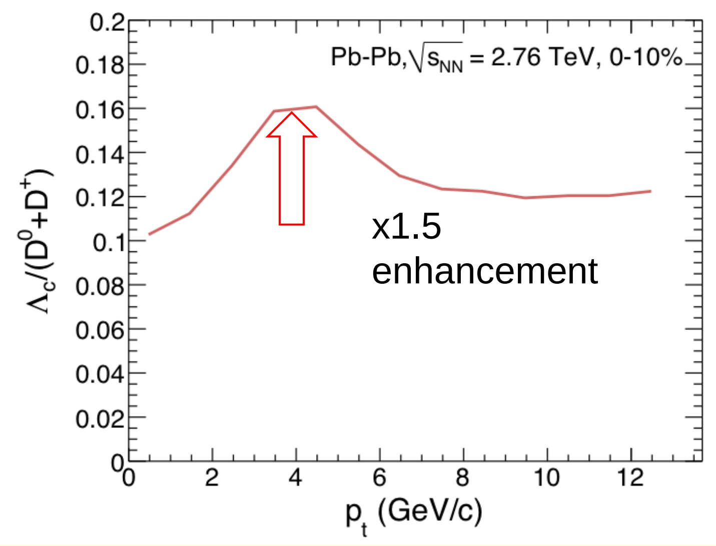
- Λ_c/D enhancement predicted by coalescence models. Size of effect depends strongly on details of c quark thermalization







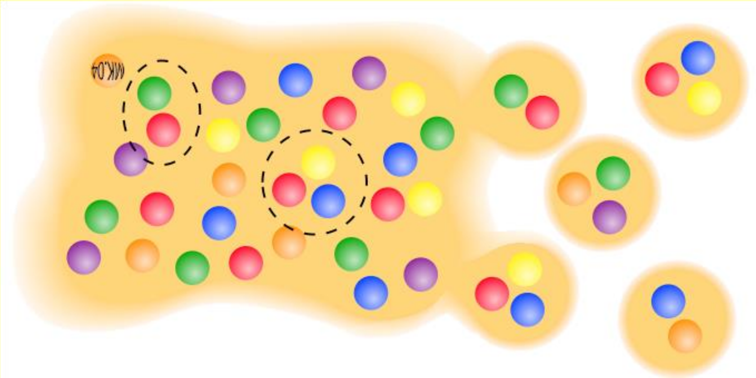
C.M.Ko et al. PRC79



R. Rapp et al. PRC86

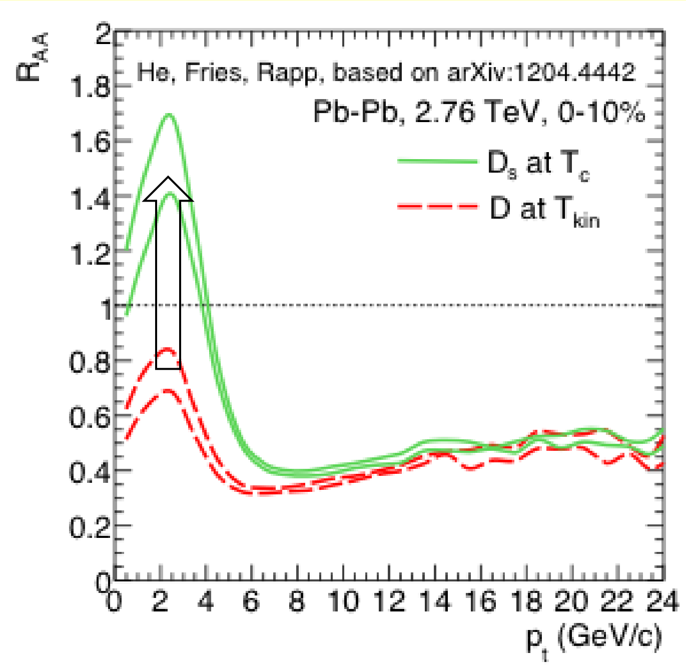
HF thermalization and in-medium hadronization: Λ_c and D_s as probes

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

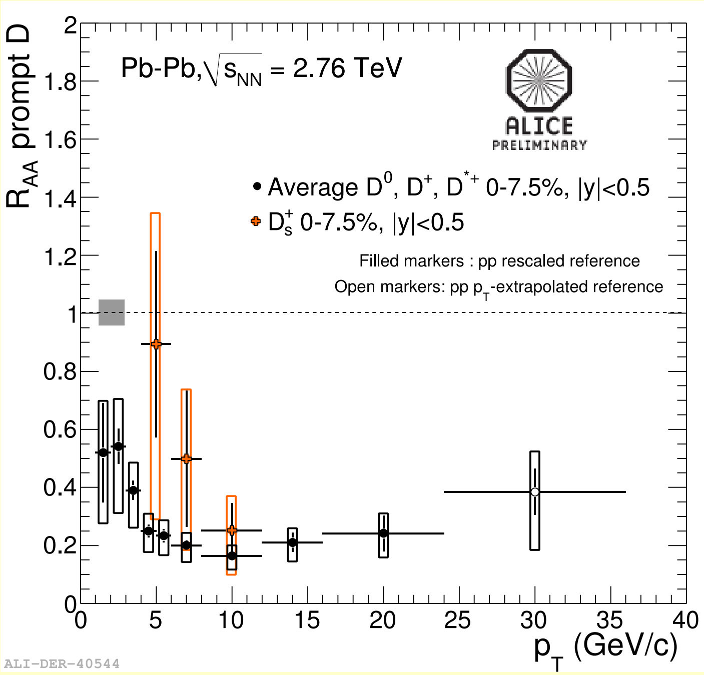


➡ Charm-strange mesons (D_s)

Factor 2 enhancement for D_s/D predicted by coalescence

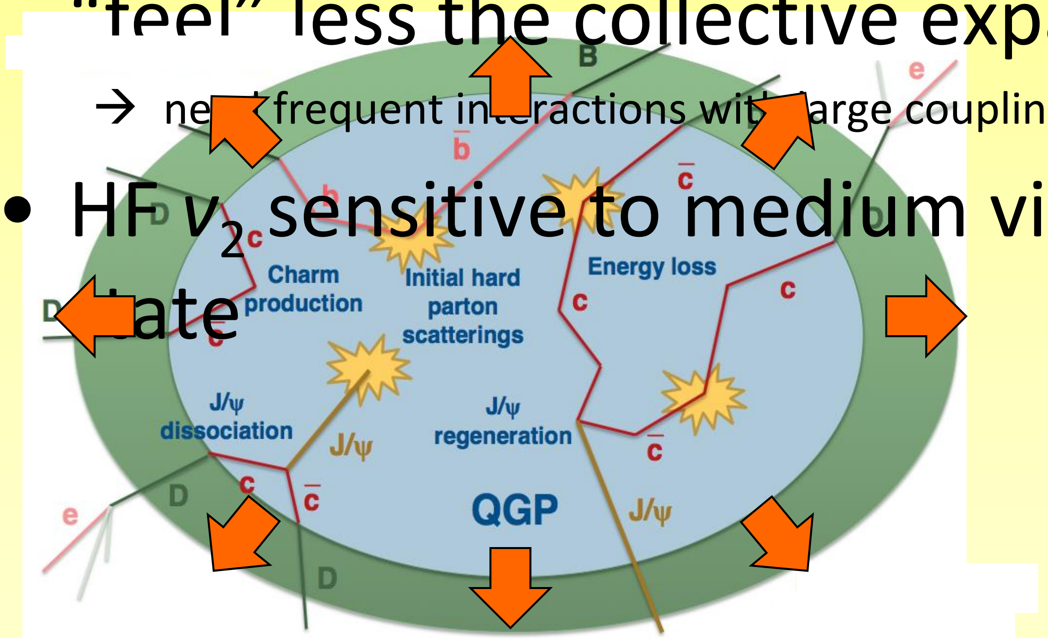


Our first measurement is intriguing, but not conclusive

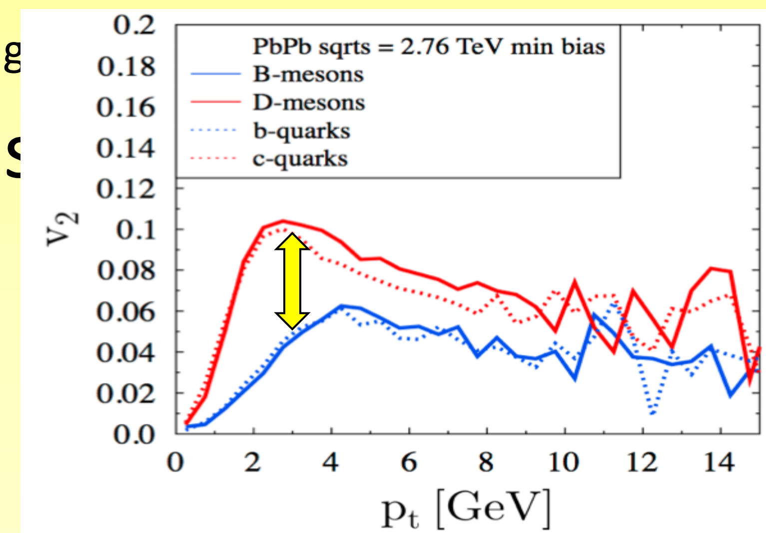


Heavy flavour v_2

- 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
  - → ne frequent interactions wit large coupling
- HF v_2 sensitive to medium vis of state

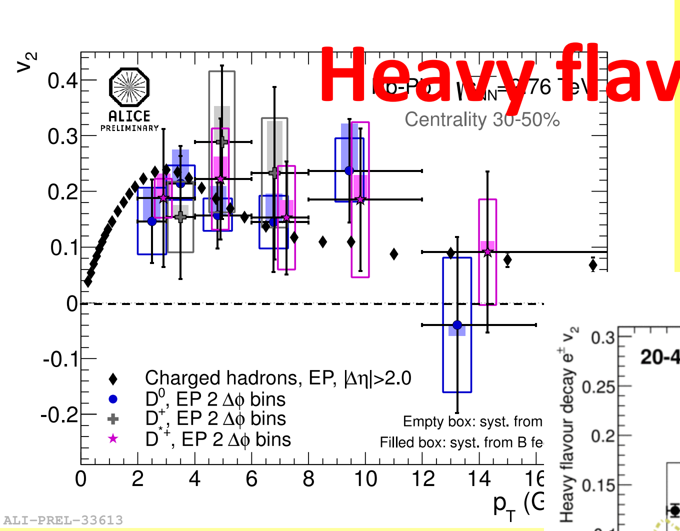


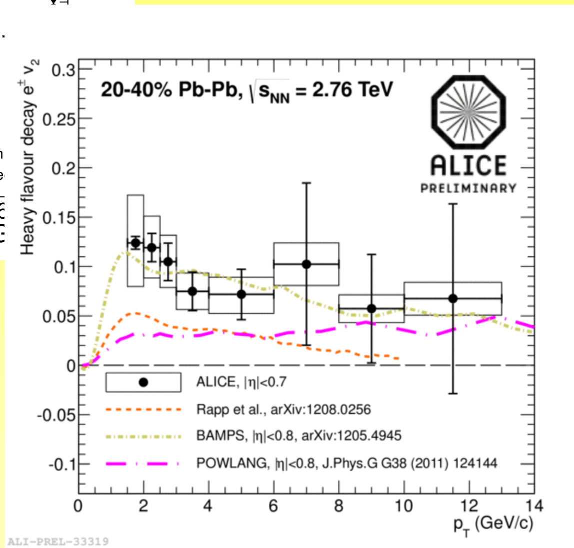
See also J. Uphoff et al., R. Rapp et al., A. Beraudo et al.



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

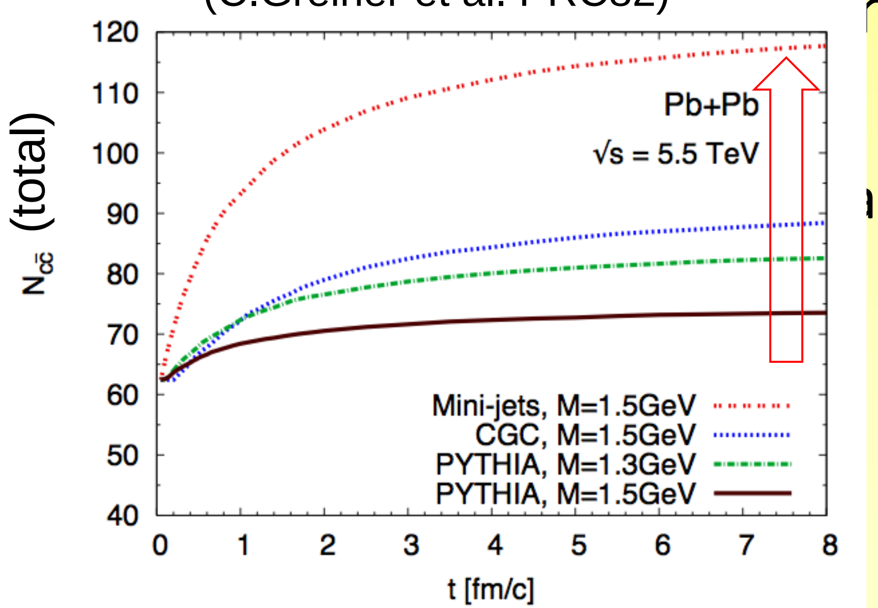
→ **Need precise measurement of v_2 of D and B mesons to answer these questions:**

- 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

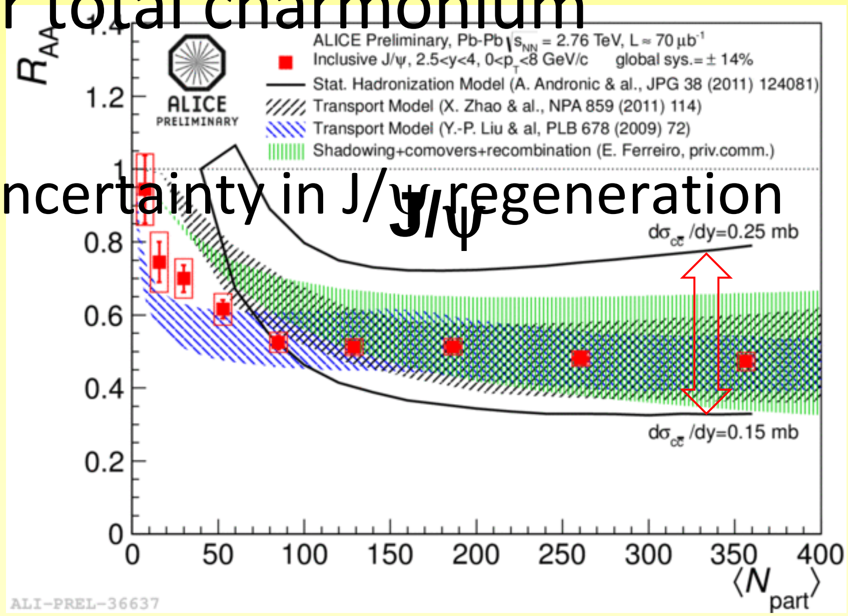
- Reaching $p_T \rightarrow 0$ in central Pb-Pb provides:
  - Handle on the possibility to detect thermal charm production
    - May increase low-p_T yields by up to 50-100%
    - Sensitive to initial temperature of the QGP

(C.Greiner et al. PRC82)



n for total charmonium

ain uncertainty in J/ψ regeneration

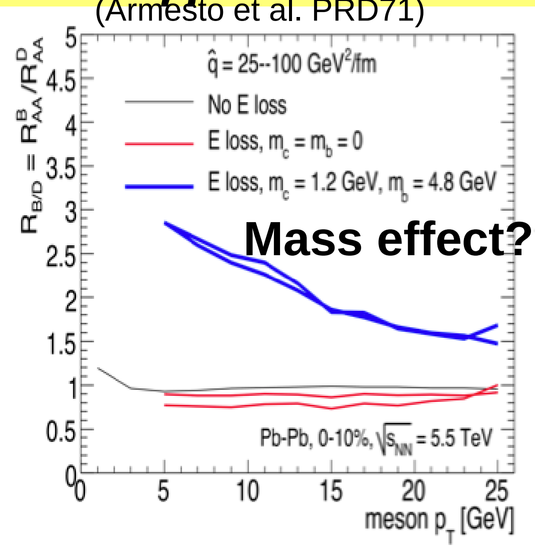


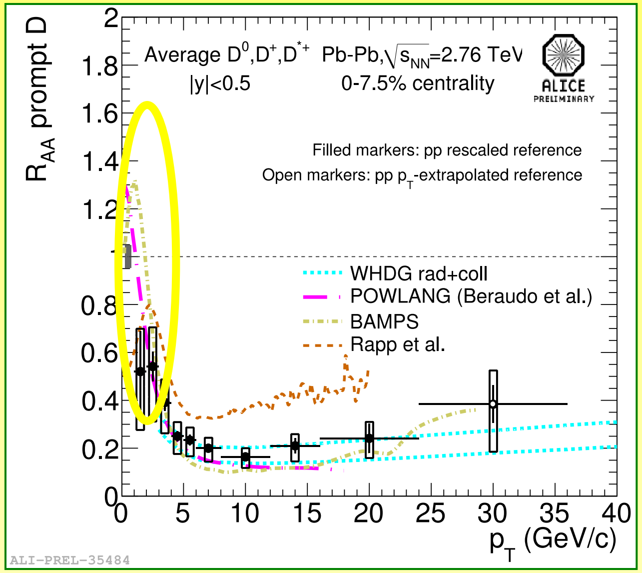
(see also C.M.Ko et al. PRC77)

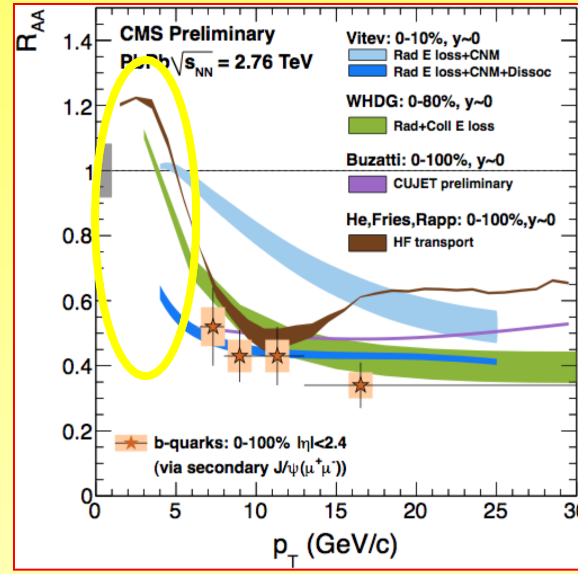
Heavy-flavour quenching

- Goal: measure D and B separately down to low

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





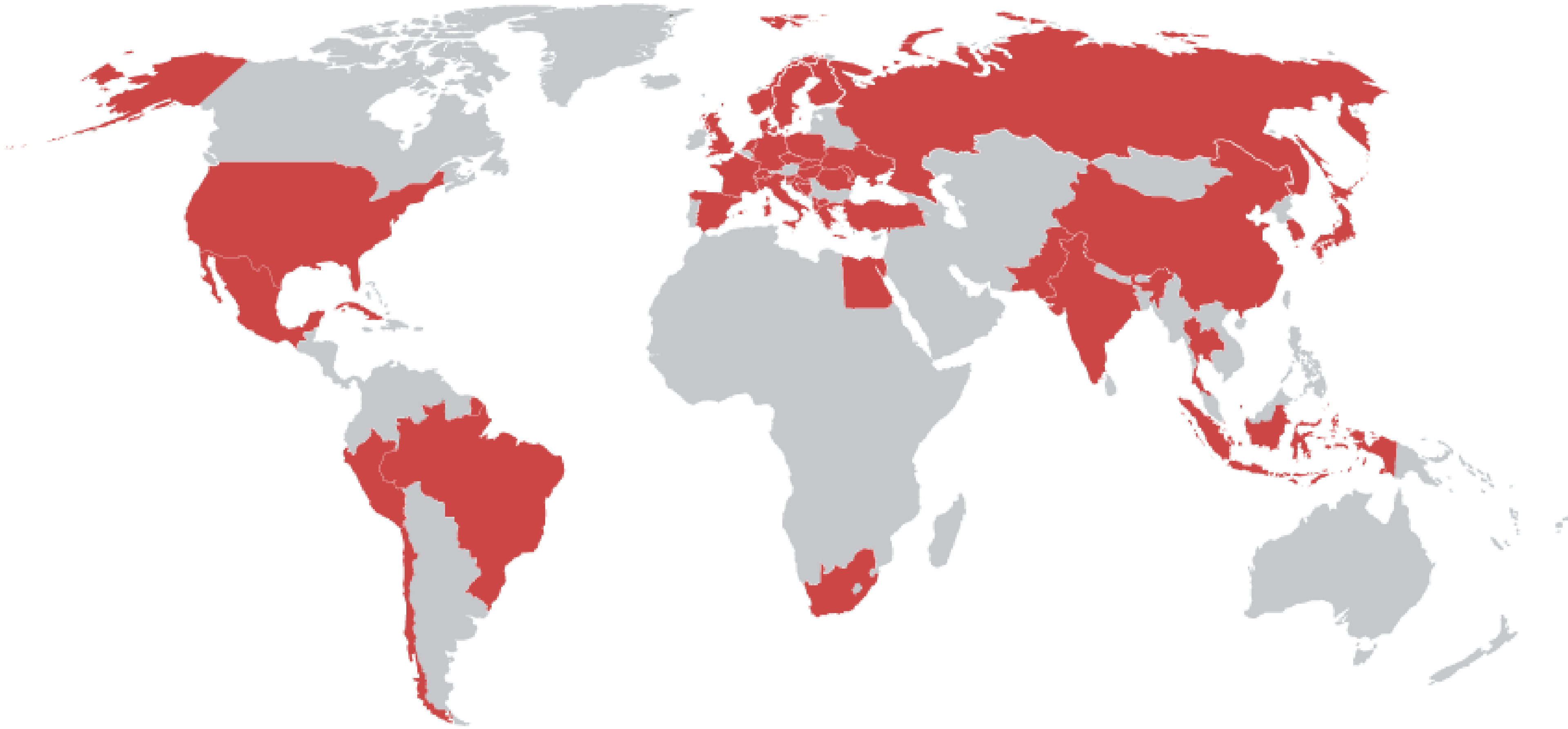


- Latest ALICE (charm) and CMS (beauty) data from QM2012: not conclusive in comparison with models at low p_T
- Overcome current ALICE limits:
  - charm difficult for $p_T \rightarrow 0$ (background is too large)
  - indirect B measurement via electrons (loose correlation p_T^B vs p_T^e)
- **Build on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

The ALICE Upgrade

- **Four Pillars (each in a Technical Design Report, now in preparation):**
    - Completely new Silicon Inner Tracking System
    - New or upgraded readout for all detectors to cope with the higher rate
    - New readout chambers for the Time Projection CHamber
    - New Data Acquisition System and High Level Trigger to handle the continuous readout

ALICE today



- 36 COUNTRIES – 149 INSTITUTES – 160’653 KCHF CAPITAL COST

New Inner Tracking

seven layers silicon tracker

pointing resolution improved ~ 3 times

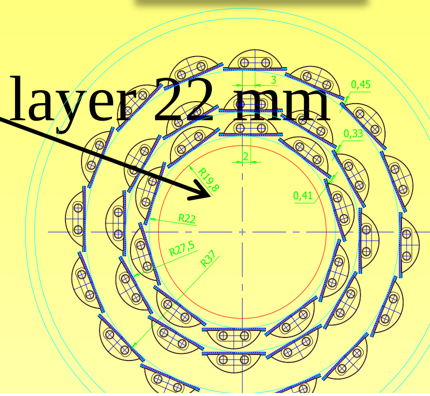
- very close to the interaction point – innermost layer 22 mm

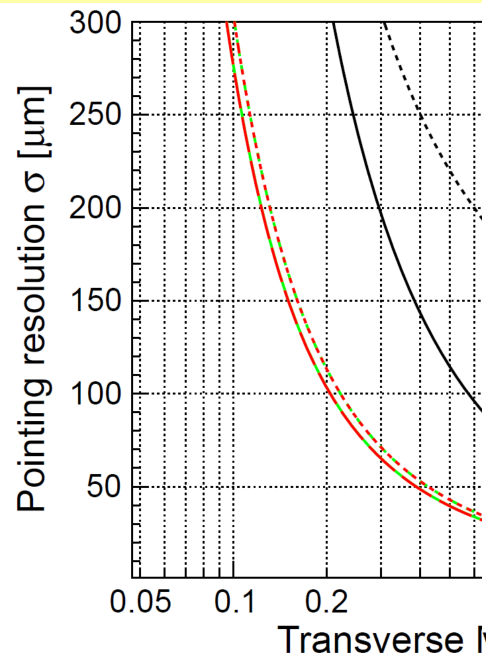
low material bu

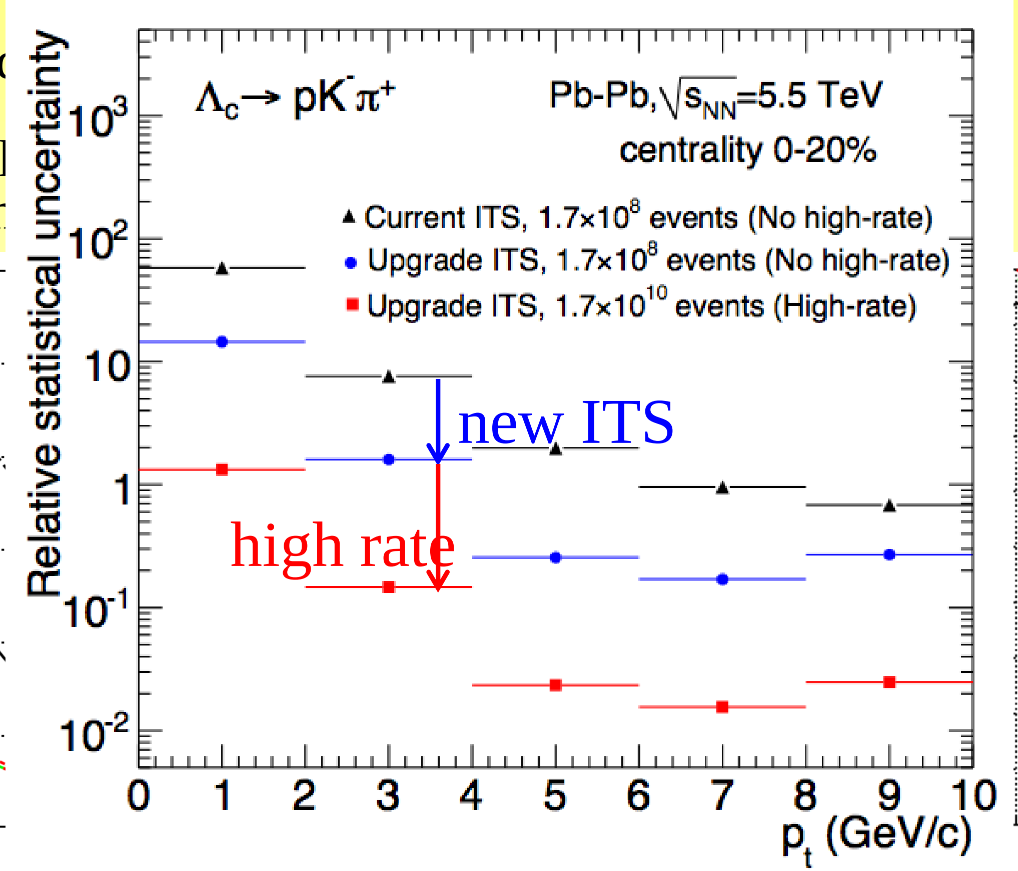
substantially im

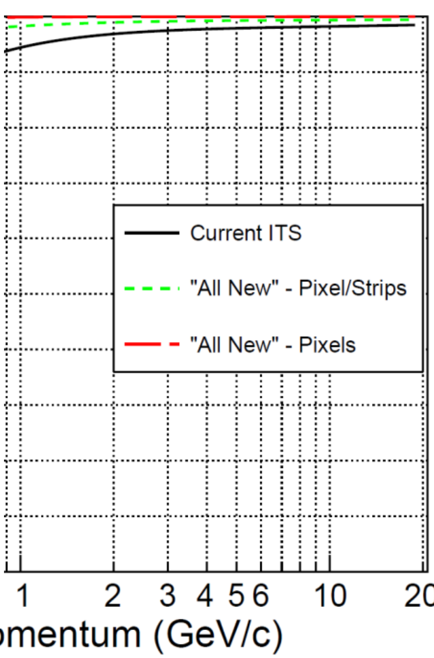
and p_t resolution

inner barrel









Upgrades: cost estimates, materials only

ALICE Upgrade Sub-Systems	Estimated Cost [MCHF]
ITS option 1 a)	10,0
ITS option 2 b)	16,0
TPC c)	5,5
TRD	0,6
TOF	0,7
PHOS d)	0,8
Muon Spectrometer	2,1
Online systems e)	9,3
Offline	0,5
Trigger Detectors	1,0
Common Projects	5,5
Total with ITS option 1	**36,0**
Total with ITS option 2	**42,0**

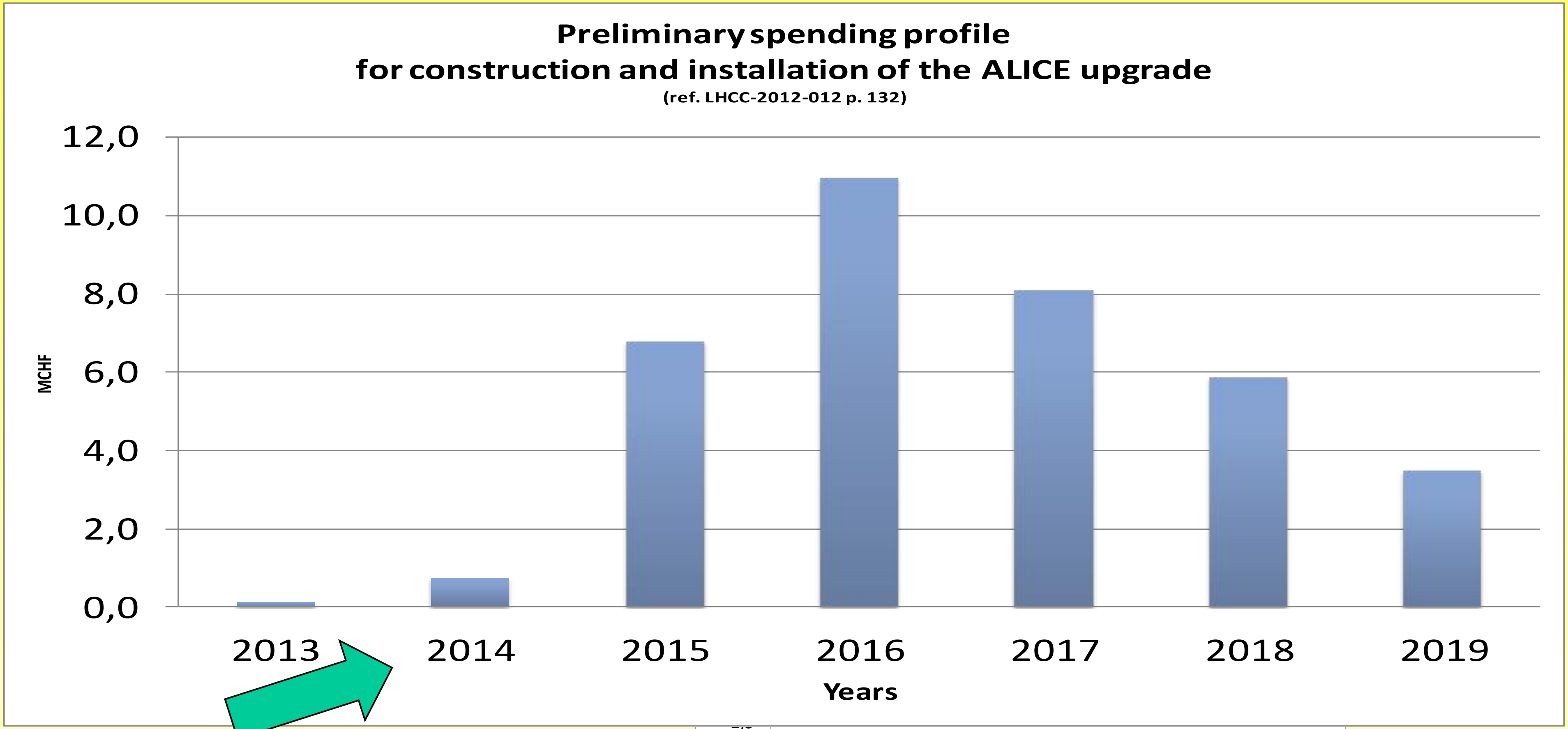
Table 1: Cost estimates for the ALICE Upgrade

In case of approval of the MFT by the LHCC
The total for the ALICE LS2 upgrade
Would go to just below 40 MCHF

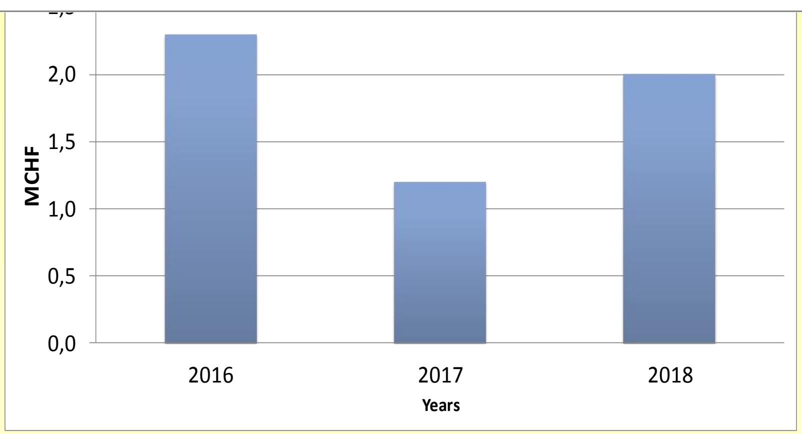
st is 4.5 MCHF since existing readout chamber are reused
ce studies ongoing.
CHF

- From the LoI, chapter 5 (where much more detail can be found)
- R&D, about 15% of cost, ***not*** included, following CORE conventions.
  - Managed via agreements within each project
  - Ongoing, with strong support from participating FA

Time profile for expenditures



- **Total**
  - details project by project and plans in LoI Chapter 5
  - Includes both projects and Com Fund
- Common projects



MFT Cost estimate

ALICE

- Many items in common with ITS (pixel chips, readout,etc), with much smaller surface
- Reduced cost compared to a completely standalone detector

Item	Cost (MCHF)
CMOS	0.65
Thinning, dicing and mounting	0.43
MCM	0.33
Flex cables, FEE	0.49
Cables, connectors	0.49
Mechanics, cooling	0.52
Low voltage regulation	0.15
Power supply	0.25
Total	**3.31**

- Modest impact on Common Fund => ~ 300 kCHF