The Upgrade of the ALICE detector

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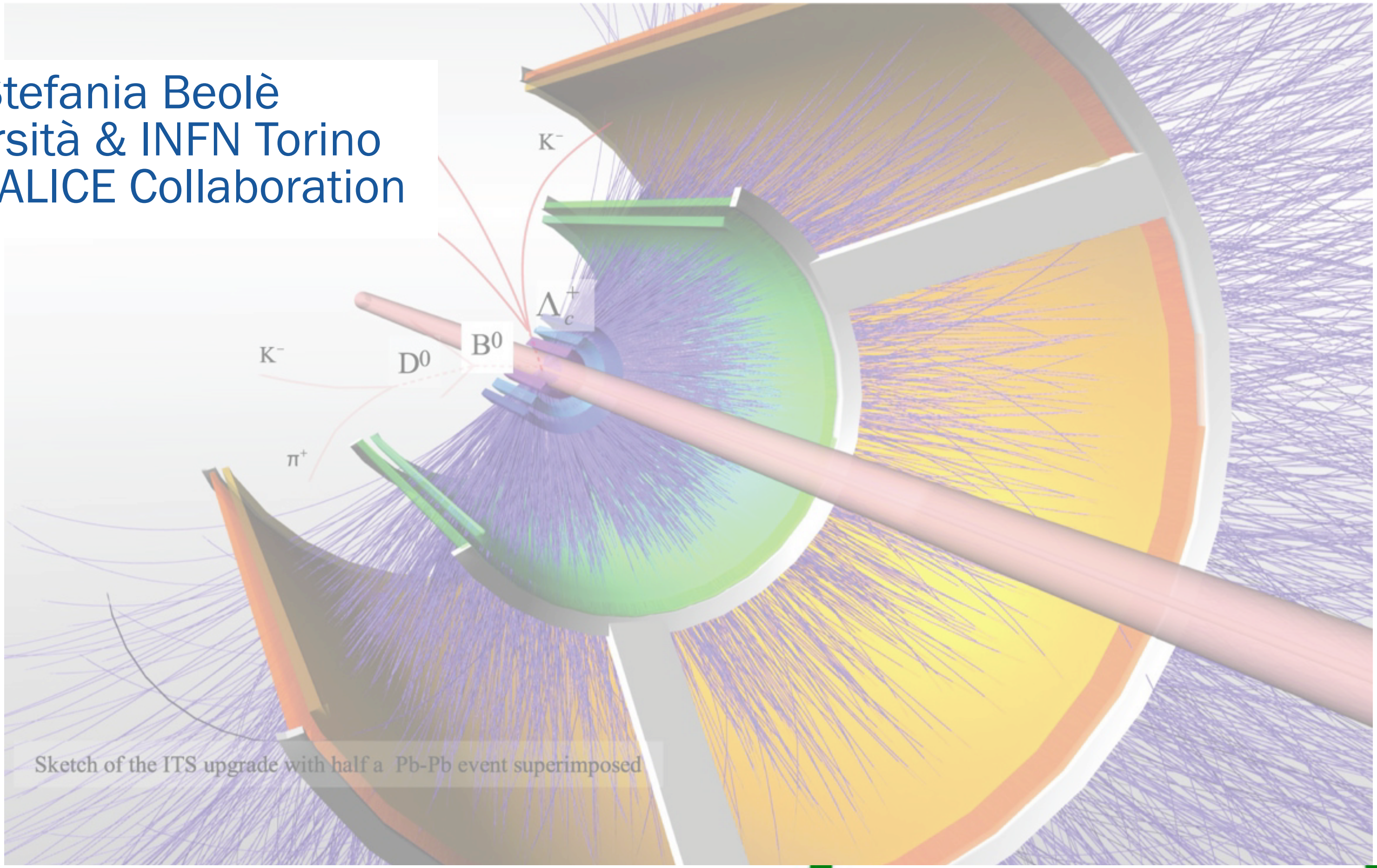
for the ALICE Collaboration



Sketch of the ITS upgrade with half a Pb-Pb event superimposed

IFD2014
INFN Workshop on
Future Detectors for HL-LHC
Trento, March 11-13, 2014

OUTLINE

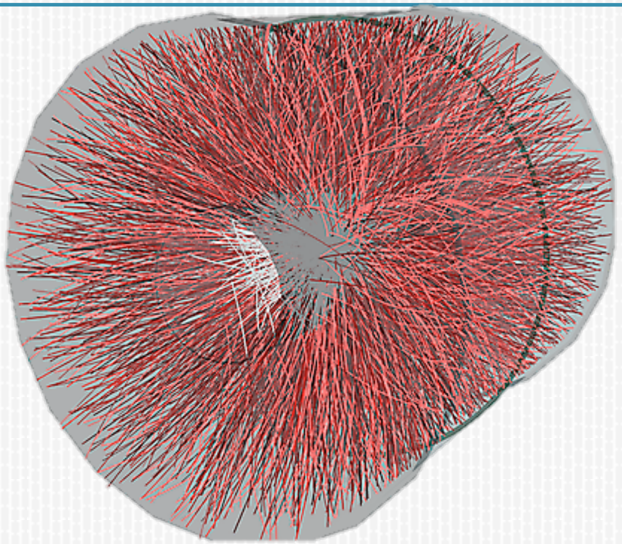
- ALICE upgrade physics motivation
- Upgrade strategy and schedule – focus on central barrel
  - Core upgrade: ITS, High Rate Capabilities (TPC, Electronics, O^2, …) – Muon Forward Tracker
- ITS upgrade
  - Design goals
  - Physics Performance of the upgraded apparatus – examples
  - Technology issues
  - Construction & installation

ALICE UPGRADE PHYSICS MOTIVATION

Main physics topics that are unique of the upgraded ALICE (in operation after LHC Long Shutdown 2):

1. **Heavy-flavour transport parameters in the QGP**
   - Heavy-quark diffusion coefficient (→ QGP equation of state, viscosity of the QGP fluid)
   - Heavy-quark thermalization and hadronization in the QGP
   - Mass dependence of parton energy loss in QGP medium
2. **Low-mass dielectrons: thermal photons and vector mesons from the QGP**
   - Photons from the QGP ($\gamma \rightarrow e^+e^-$) → map temperature during system evolution
   - Modification of ρ spectral function ($\rho \rightarrow e^+e^-$) → chiral symmetry restoration
3. **Charmonia (J/ψ and ψ') down to zero p_T**
   - Only the comparison of the two states can shed light on the suppression/ regeneration mechanism
   - Study QGP-density dependence with measurements at central and forward rapidity

ALICE CENTRAL BARREL AND ITS UPGRADE GUIDELINES



- Focus on observables for which ALICE is unique: *low-p_T heavy flavour, charmonia, and di-leptons* (all have very high background conditions)
- ***Requirements:***
  - Low field and low material (precise measurements at low p_T)
  - High tracking precision (heavy flavour vertices)
  - Particle identification (electrons and hadrons, ALICE's special)
  - High-rate capability (no trigger possible due to low S/B → store all events)

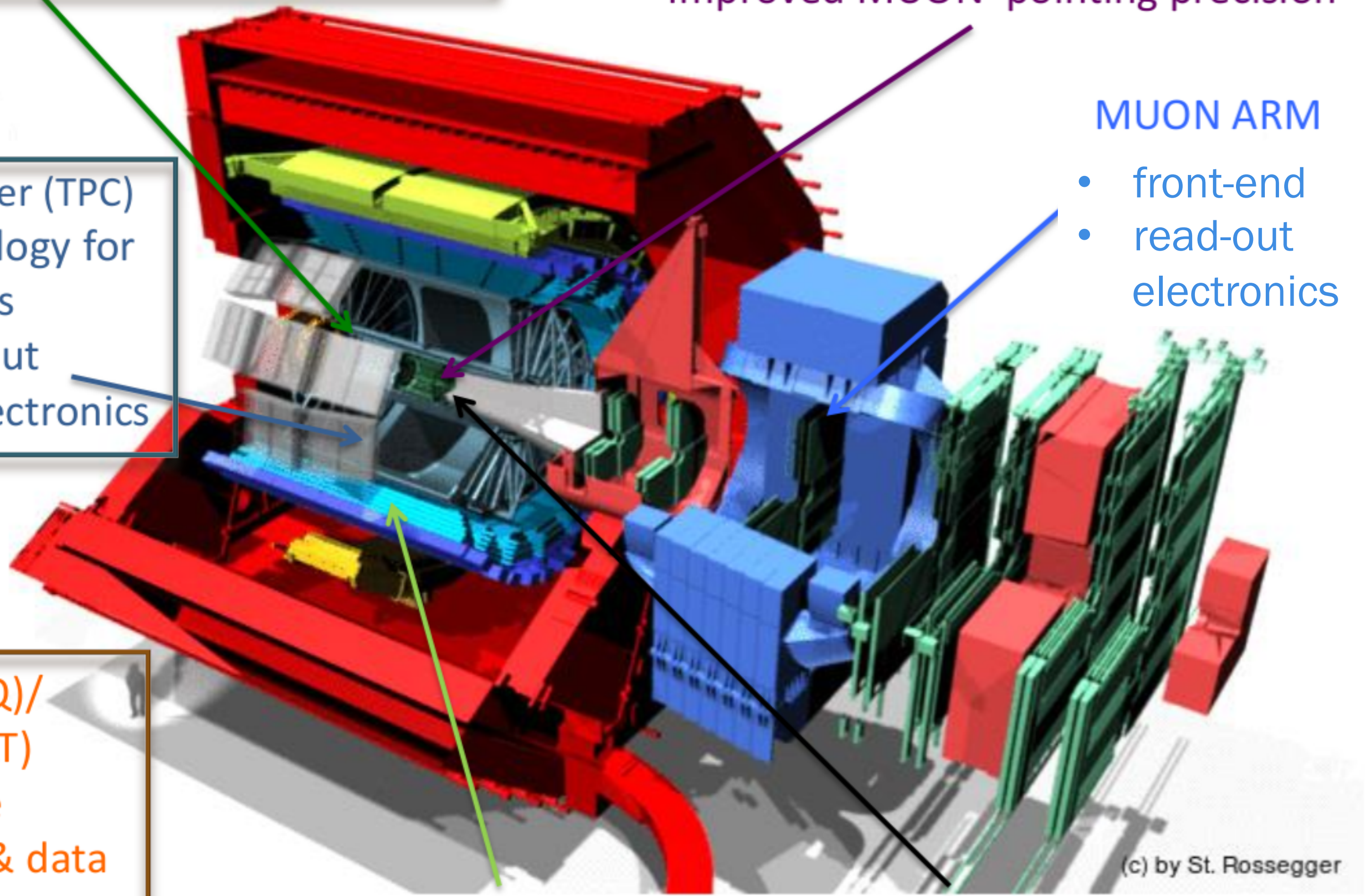
→ Upgraded read-out for TPC, TOF, TRD, MUON, ZDC, Upgraded DAQ/HLT/ Offline with High-rate capability

- Target LHC Pb-Pb luminosity after LS2 (~6×10^{27} $cm^{-2}s^{-1}$= 10 x current)
- Upgraded ALICE records Pb data at 50 kHz (currently <0.5 kHz)
- Integrate L_{int}=10 nb^{-1} after LS2 (~10^{11} minium-bias Pb-Pb events)

→ New ITS with largely improved resolution (x3), especially at low p_T

- Closer (3.9 cm → 2.2 cm)
- Thinner (1% → 0.3% of X_0 / layer in inner barrel)
- Smaller pixels (50x425 μm^2 → O(20x20) μm^2 cell size)

ALICE DETECTOR UPGRADES



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
- front-end
- read-out electronics

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

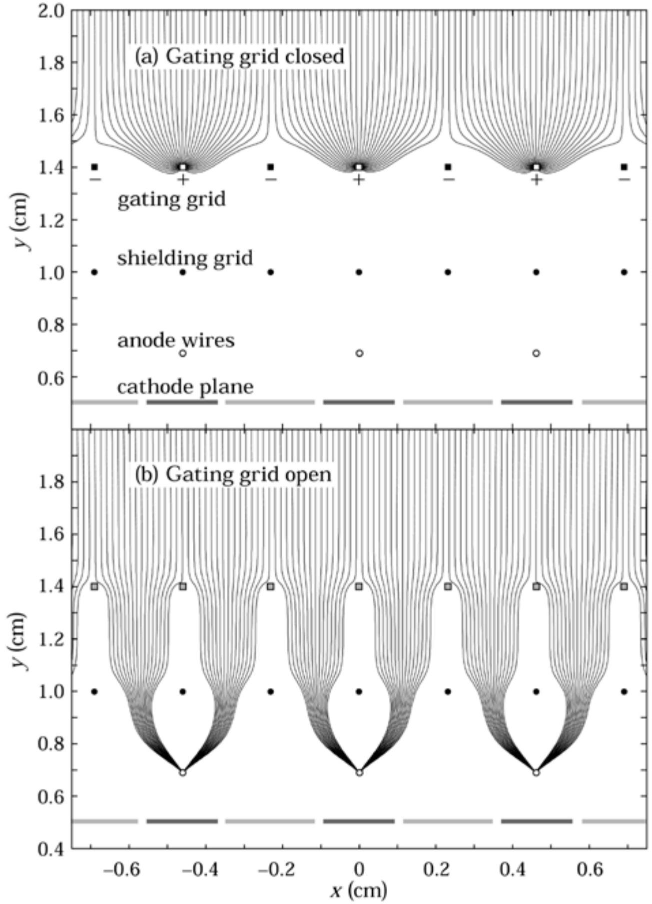
Data Acquisition (DAQ)/ High Level Trigger (HLT)
- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate

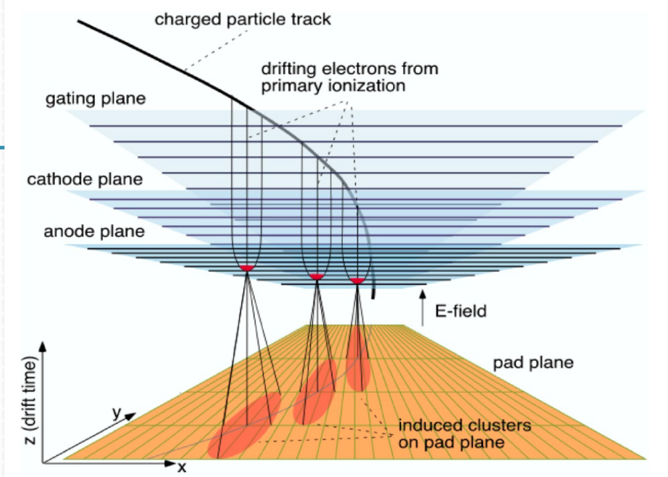
(c) by St. Rossegger

TOF, TRD
- Faster readout

New Trigger Detectors (FIT)

CURRENT TPC LIMITS

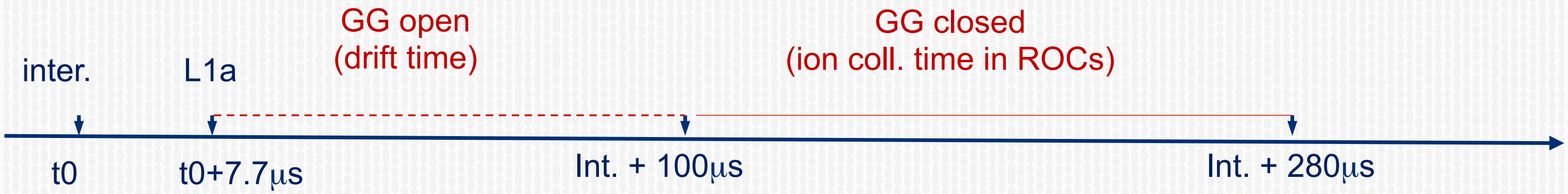




- current TPC is read out by MWPCs
- gating grid of readout chambers closed to avoid ion feedback
  - Limit space charge to tolerable level
  - Effective dead time ~280μs, maximum readout rate: 3.5 kHz
- alternative: gating grid always open
  - Ion feedback ~10^3 x primary ions generated in drift volume
  - Large space charge effects (of the order of electrical field)

  Space point distortions (at 50kHz) of order of 1 m

  –> not tolerable!!



GG open (drift time)

GG closed (ion coll. time in ROCs)

inter.

L1a

t0

t0+7.7μs

Int. + 100μs

Int. + 280μs

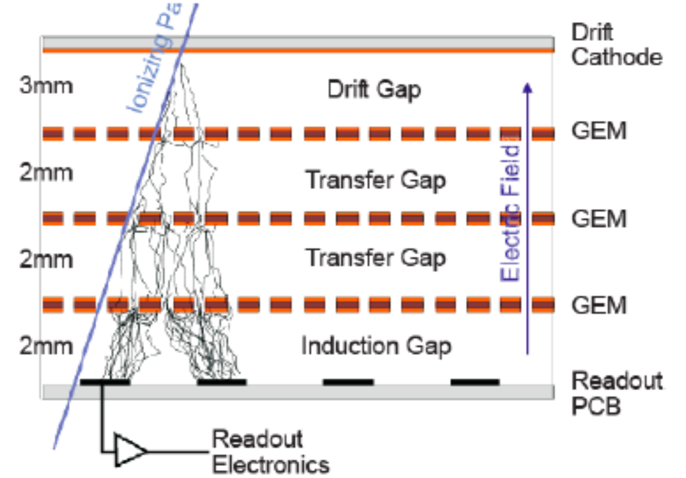
TPC UPGRADE

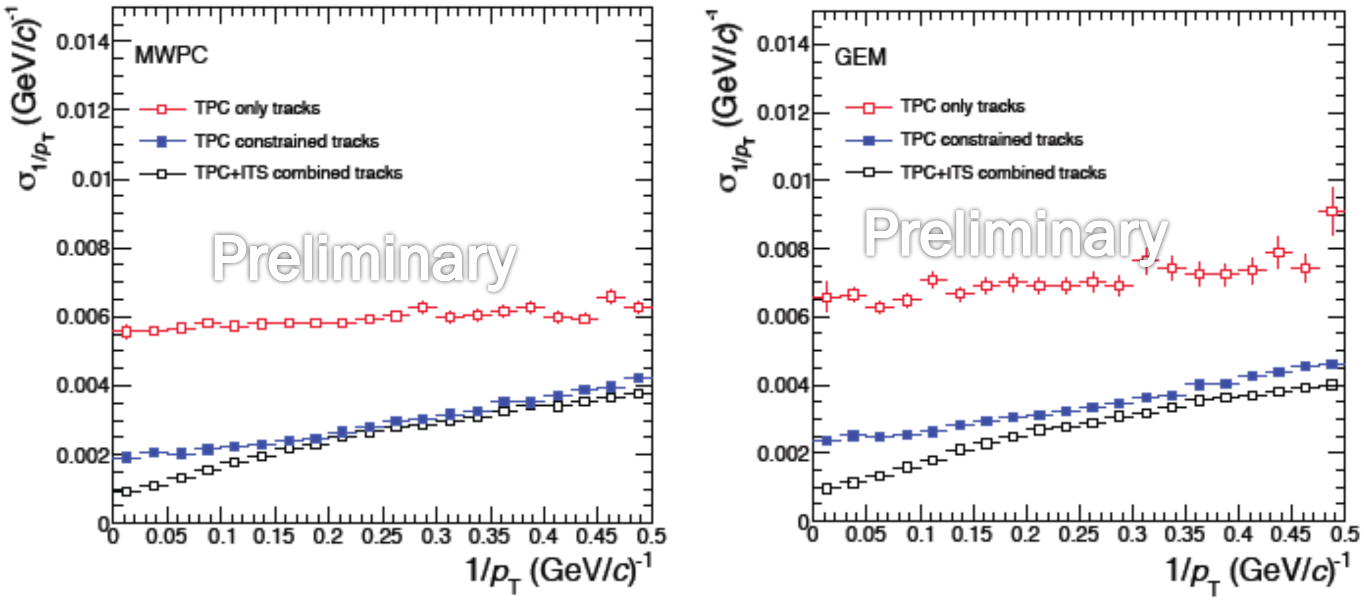
New readout chambers: MWPC replaced with GEM (Gas Electron Multiplier)

- No gating, small ion feed-back (see next slide)
- Studying optimization of pad-planes to maintain standalone momentum resolution

… but existing pad-planes could still be used

- limited degradation of point spatial resolution for $|\eta|<0.75$
- w/o affecting momentum resolution for TPC + ITS tracks





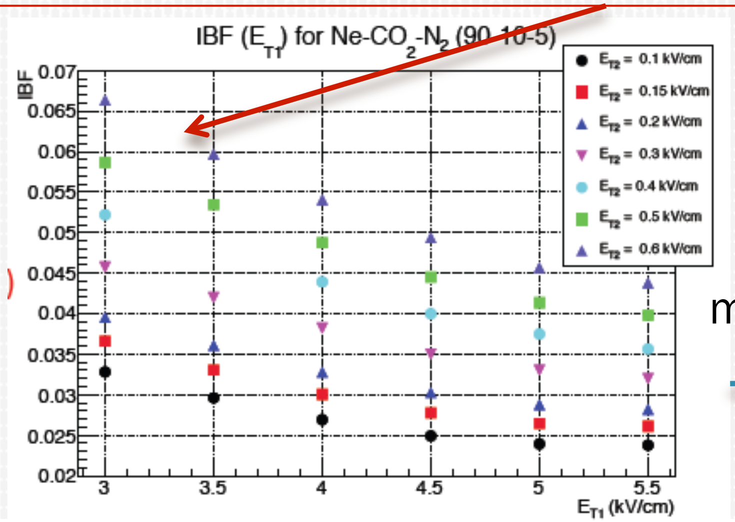
ONGOING R&D - ION BACKFLOW

Results for 3-GEM

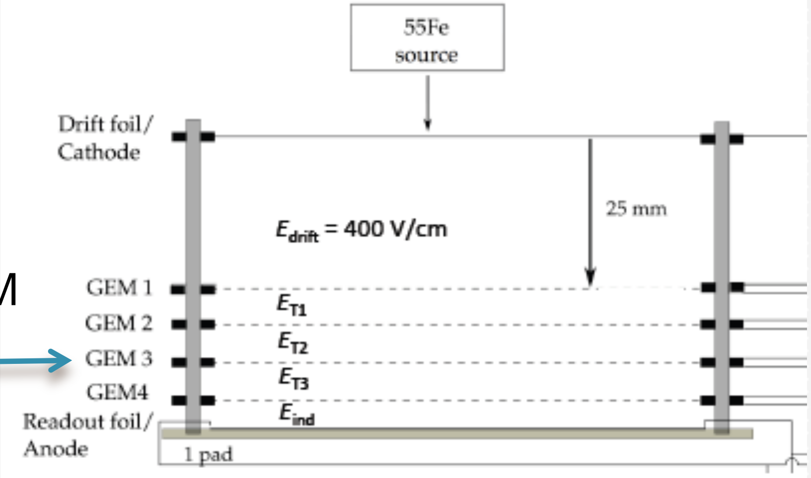
Ion back-flow (IBF) and ε do not fulfill ALICE requirements

(IBF ≤ 1%, ε ≤ 10 at gain 1000-2000 in Ne-based mixture)

ε : number "back-drifting" ions per electron reaching the GEM stack

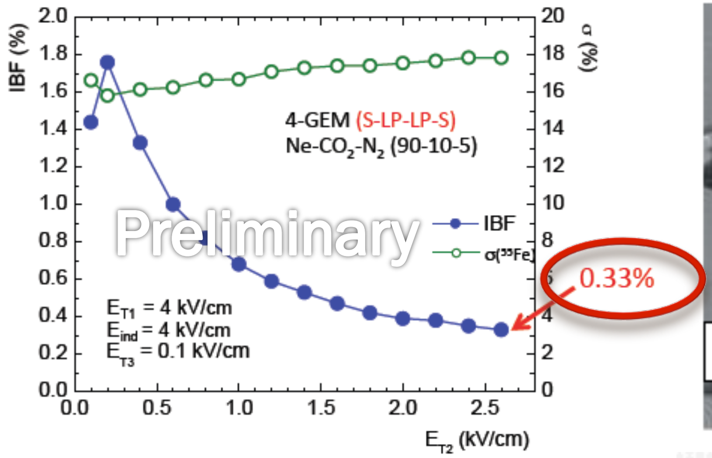


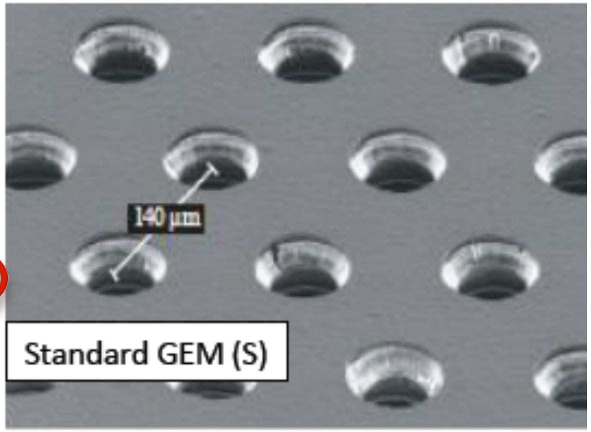
move to 4-GEM

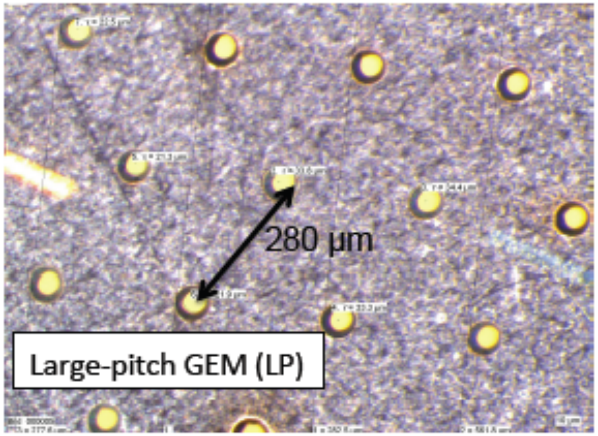


R&D

Preliminary results for 4-GEM system with larger pitch (S-LP-LP-S)

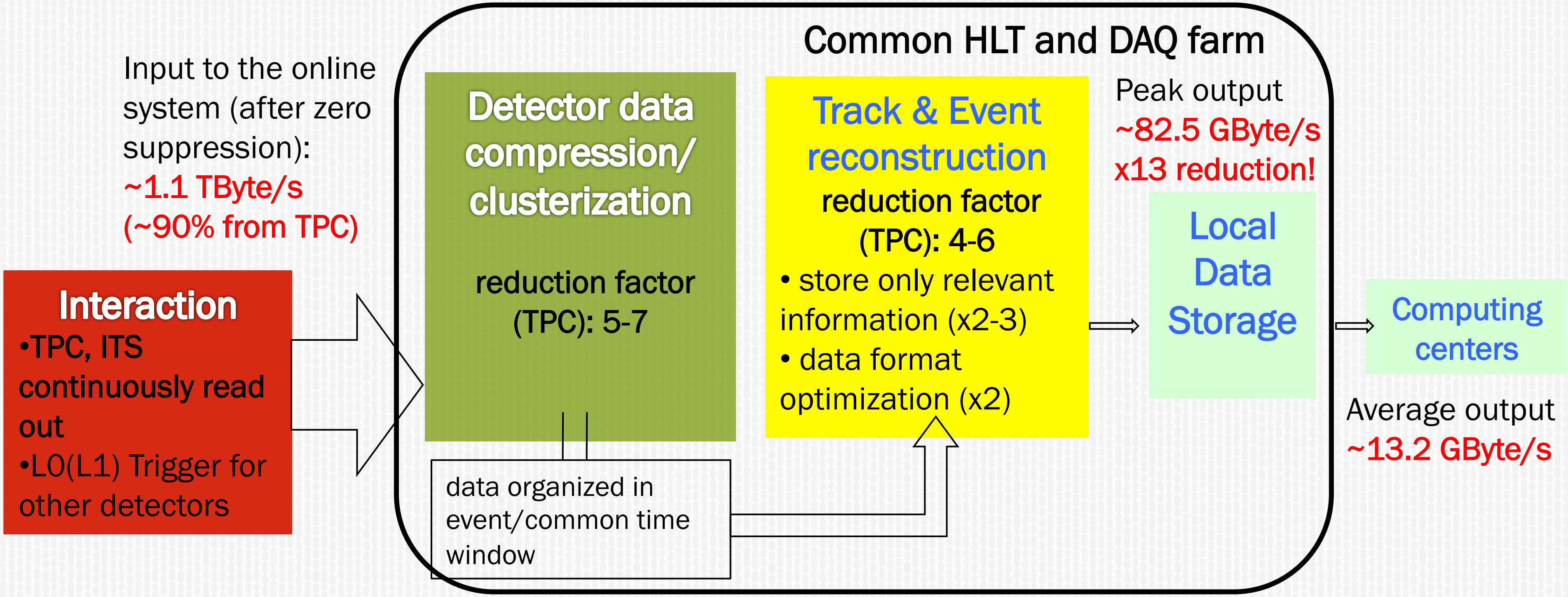






DATA FLOW, THE NEW DAQ AND HLT SYSTEMS

- Continuous read out of 50kHz of Pb-Pb interactions
  - Increase of number of events to be recorded by ~2 orders of magnitude
  - Severe requests to the online & offline systems (O^2 project)
- New DAQ and HLT systems



Input to the online system (after zero suppression): ~1.1 TByte/s (~90% from TPC)

Interaction
•TPC, ITS continuously read out
•L0(L1) Trigger for other detectors

Common HLT and DAQ farm

Detector data compression/ clusterization

reduction factor (TPC): 5-7

data organized in event/common time window

Track & Event reconstruction

reduction factor (TPC): 4-6
- store only relevant information (x2-3)
- data format optimization (x2)

Peak output ~82.5 GByte/s x13 reduction!

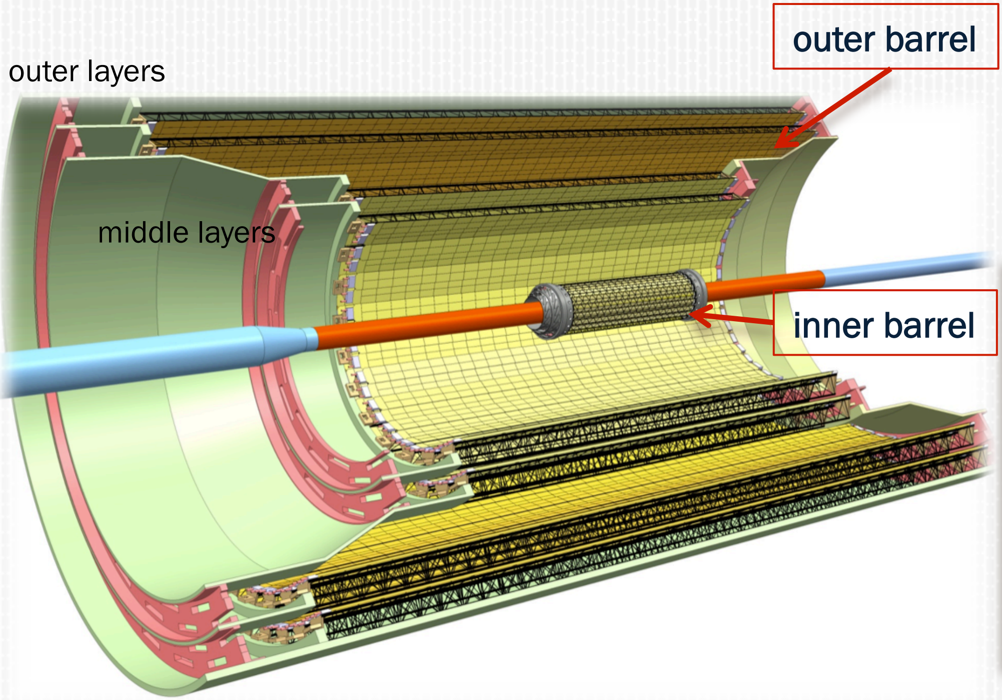
Local Data Storage

Computing centers

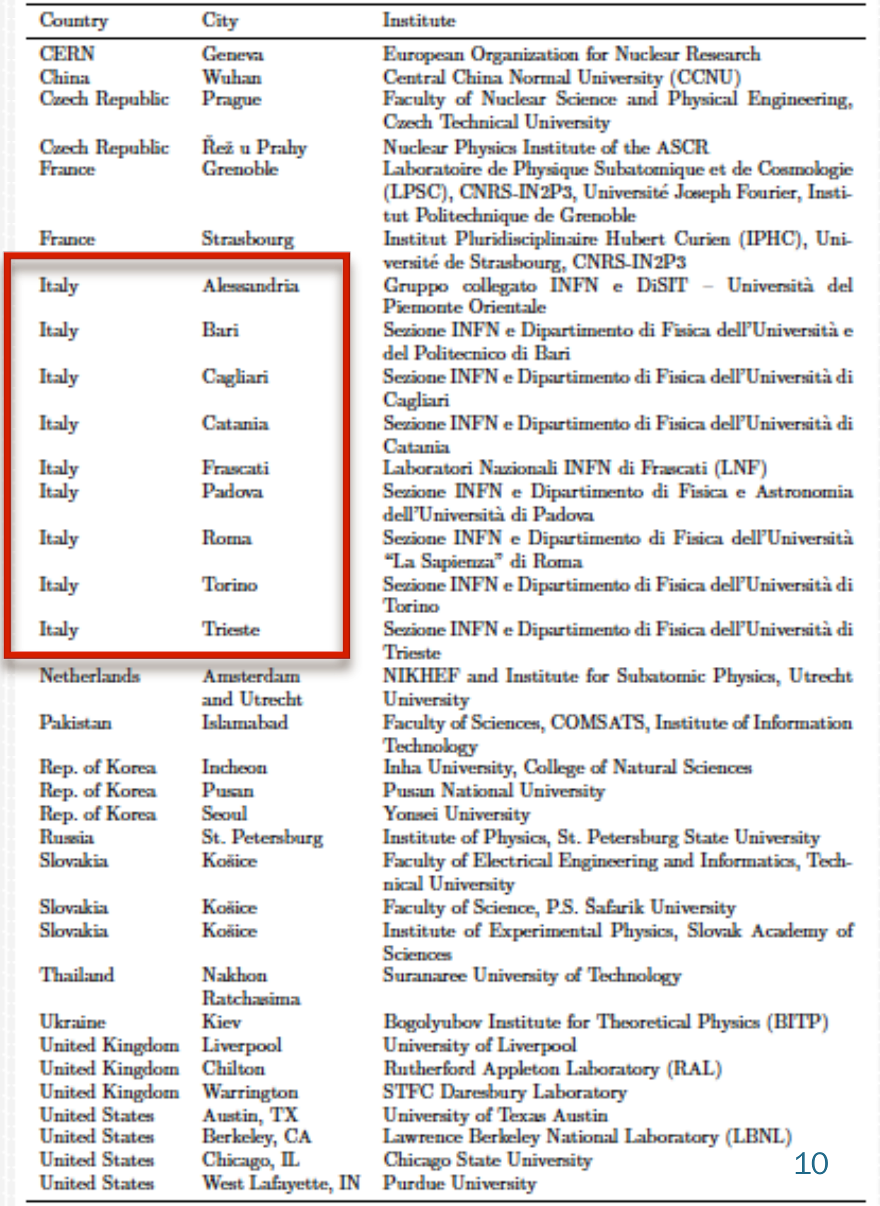
Average output ~13.2 GByte/s

dedicated talk by Silvia Amerio in Trigger Session, Thursday

ITS UPGRADE



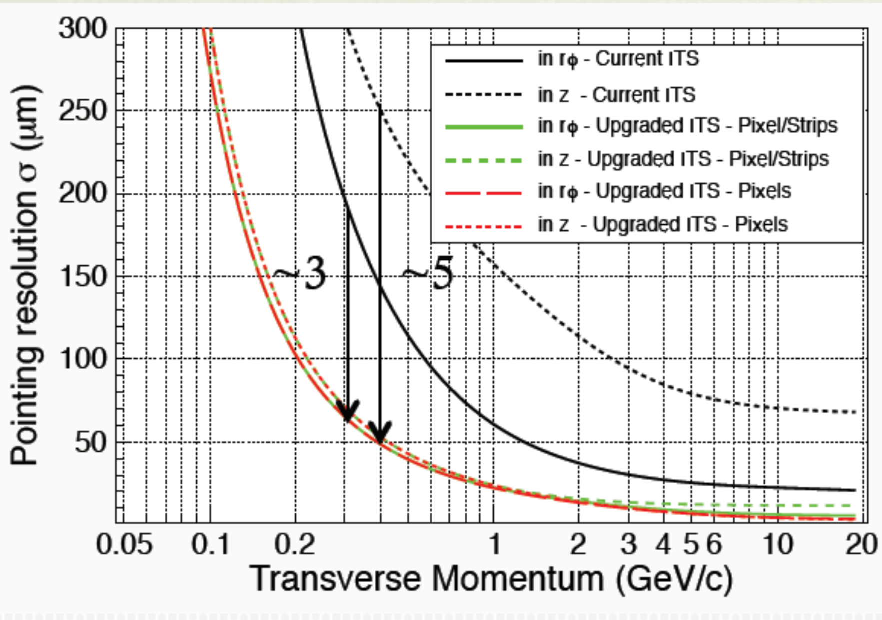
- 7 layers of monolithic silicon pixel detectors (MAPS)
  - inner barrel (3 layers around interaction point)
  - outer barrel (2 middle + 2 outer layers)
- Italy mainly involved in:
  - chip design
  - outer barrel:
    - contruction (30-40% of outermost layers)
    - design of support structure
    - assembly and commissioning

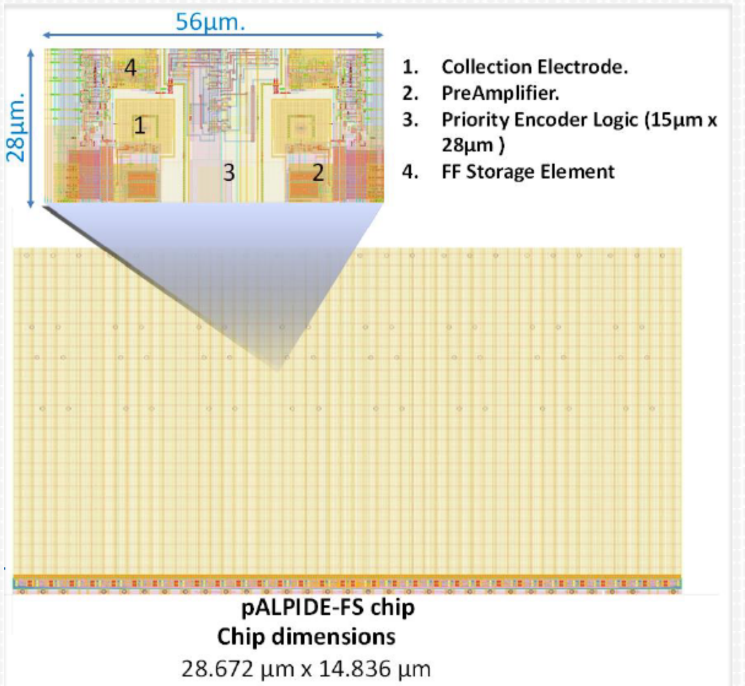


Country	City	Institute
CERN	Geneva	European Organization for Nuclear Research
China	Wuhan	Central China Normal University (CCNU)
Czech Republic	Prague	Faculty of Nuclear Science and Physical Engineering, Czech Technical University
Czech Republic	Řež u Prahy	Nuclear Physics Institute of the ASCR
France	Grenoble	Laboratoire de Physique Subatomique et de Cosmologie (LPSC), CNRS-IN2P3, Université Joseph Fourier, Institut Politechnique de Grenoble
France	Strasbourg	Institut Pluridisciplinaire Hubert Curien (IPHC), Université de Strasbourg, CNRS-IN2P3
Italy	Alessandria	Gruppo collegato INFN e DiSIT – Università del Piemonte Orientale
Italy	Bari	Sezione INFN e Dipartimento di Fisica dell'Università e del Politecnico di Bari
Italy	Cagliari	Sezione INFN e Dipartimento di Fisica dell'Università di Cagliari
Italy	Catania	Sezione INFN e Dipartimento di Fisica dell'Università di Catania
Italy	Frascati	Laboratori Nazionali INFN di Frascati (LNF)
Italy	Padova	Sezione INFN e Dipartimento di Fisica e Astronomia dell'Università di Padova
Italy	Roma	Sezione INFN e Dipartimento di Fisica dell'Università "La Sapienza" di Roma
Italy	Torino	Sezione INFN e Dipartimento di Fisica dell'Università di Torino
Italy	Trieste	Sezione INFN e Dipartimento di Fisica dell'Università di Trieste
Netherlands	Amsterdam and Utrecht	NIKHEF and Institute for Subatomic Physics, Utrecht University
Pakistan	Islamabad	Faculty of Sciences, COMSATS, Institute of Information Technology
Rep. of Korea	Incheon	Inha University, College of Natural Sciences
Rep. of Korea	Pusan	Pusan National University
Rep. of Korea	Seoul	Yonsei University
Russia	St. Petersburg	Institute of Physics, St. Petersburg State University
Slovakia	Košice	Faculty of Electrical Engineering and Informatics, Technical University
Slovakia	Košice	Faculty of Science, P.S. Šafarik University
Slovakia	Košice	Institute of Experimental Physics, Slovak Academy of Sciences
Thailand	Nakhon Ratchasima	Suranaree University of Technology
Ukraine	Kiev	Bogolyubov Institute for Theoretical Physics (BITP)
United Kingdom	Liverpool	University of Liverpool
United Kingdom	Chilton	Rutherford Appleton Laboratory (RAL)
United Kingdom	Warrington	STFC Daresbury Laboratory
United States	Austin, TX	University of Texas Austin
United States	Berkeley, CA	Lawrence Berkeley National Laboratory (LBNL)
United States	Chicago, IL	Chicago State University
United States	West Lafayette, IN	Purdue University

NEW ITS: UPGRADE DESIGN GOAL

- Improve pointing resolution by a factor ~3(5) in rφ(z)
  - inner layer as close as possible to IP (39mm -> 22 mm)
  - smaller beam pipe (R = 19 mm)
  - smaller pixel size MAPS O(20µmx20µm)
- High standalone tracking efficiency and p_T resolution
  - Increase granularity: 6 layers -> 7 layers of smaller pixels
  - Spatial resolution σ(rφ,z) ~ 4-6 µm
  - Increase radial extension: 39-430 mm -> 22-430 (500) mm
- Fast readout:
  - readout of Pb-Pb interactions at > 50 kHz and pp up to 1 MHz



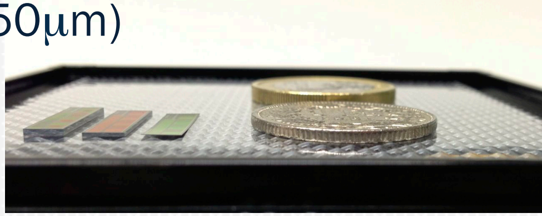


1. Collection Electrode.
2. PreAmplifier.
3. Priority Encoder Logic (15µm x 28µm)
4. FF Storage Element

pALPIDE-FS chip
Chip dimensions
28.672 µm x 14.836 µm

- Less material budget: thin sensors, 7 layers of monolithic pixel detectors (area 1.5x3 cm^2; thickness=50µm)

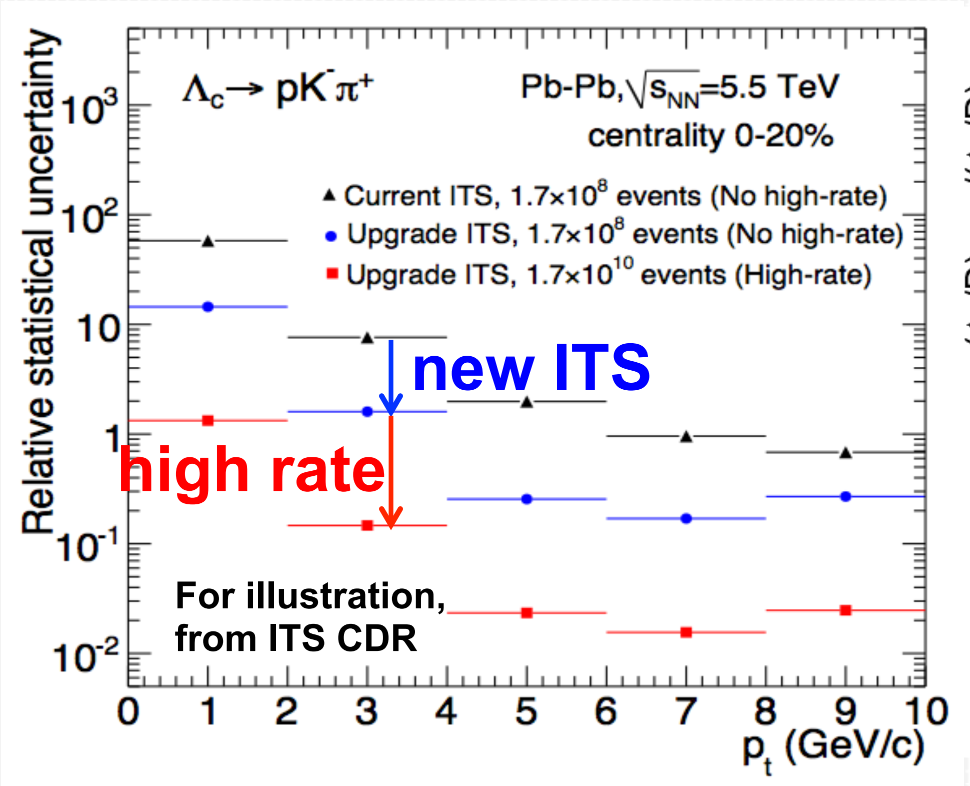
goal:
  - 0.3% X_0 inner layers
  - 0.8% X_0 outer layer



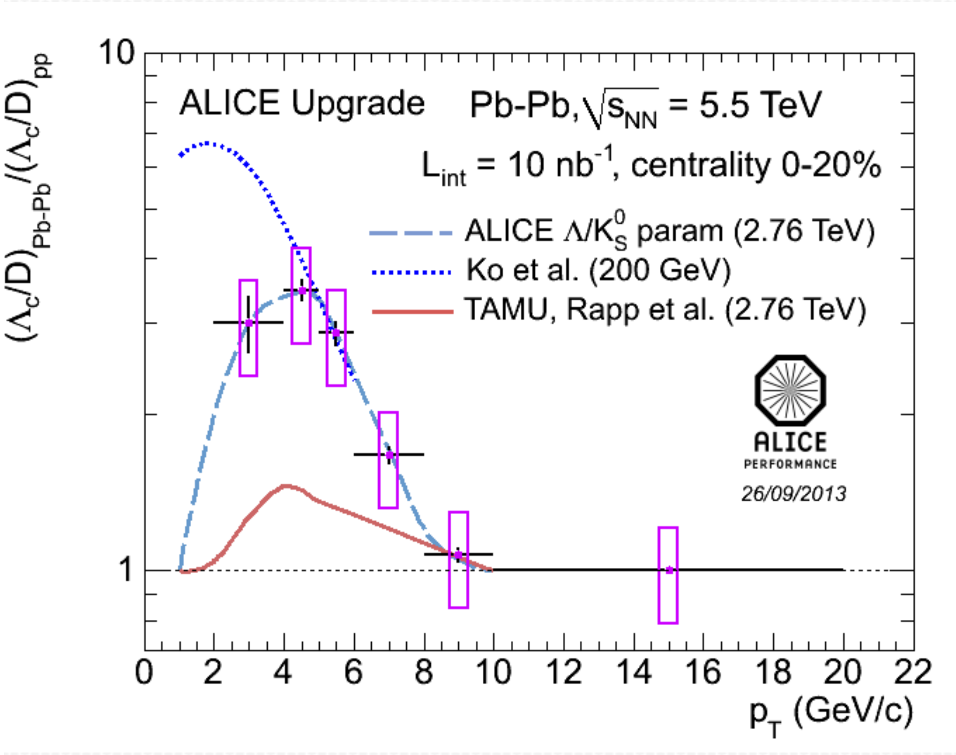
- Fast access for yearly maintenance:
  - insertion/removal during yearly LHC shutdown

PERFORMANCE EXAMPLE: Λ_c

- Λ_c $c\tau$=60 μm, to be compared with D^+ $c\tau$=300 μm
  → Measurement not possible in Pb-Pb with current ITS



For illustration, from ITS CDR



With new ITS and high-rate, measure charm baryon/meson enhancement from 2 GeV/c

DI-ELECTRONS FROM QGP AND VECTOR MESONS

Physics Signals:

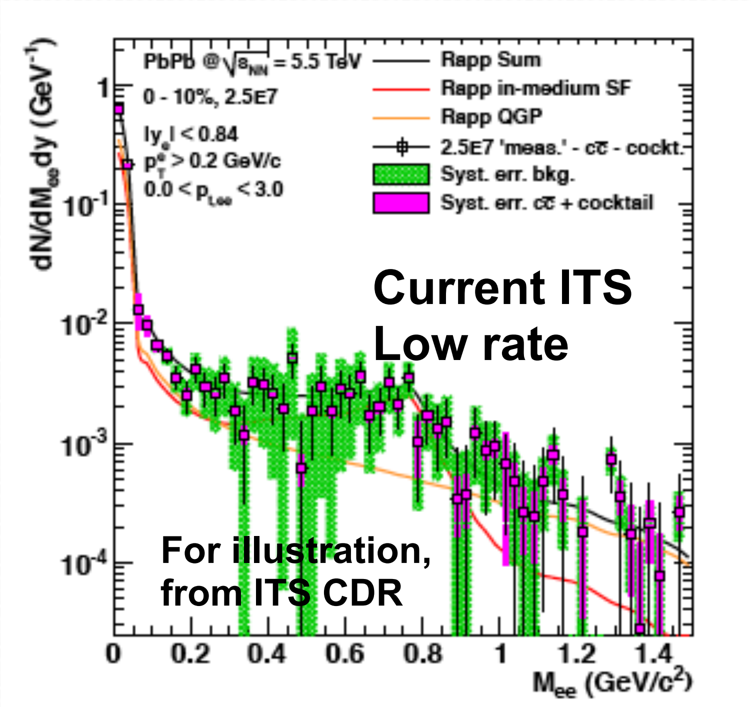
- Direct γ→e^+e^- (QGP radiation)
- Vector mesons (ρ) →e^+e^- (chiral symmetry restoration)

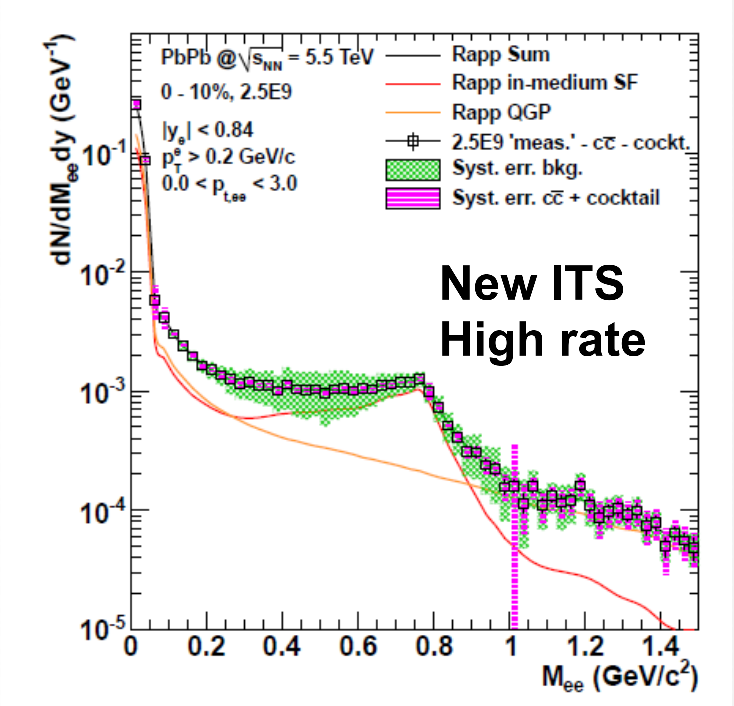
✖ Main backgrounds:

- Conversions in the material (from π^0→γγ)
- Charm decays (D→e with cτ~100 μm)

✖ Role of new ITS:

- Smaller material thickness → less conversions
- High tracking efficiency → measure conversions
- Resolution → subtract displaced charm electrons
- Allow for high rate → statistical significance x10





Di-electrons mass spectrum after bkg subtraction

NEW ITS: DETAILS ABOUT TECHNOLOGY

- Detector: monolithic silicon pixels for all layers
  - chip architecture developed in collaboration between different institutes (CERN, INFN, INPC Strasbourg, RAL, Wuhan)
  - R&D in progress
  - decision foreseen by the end of 2014

dedicated talk by Gianluca Usai in Vertexing & Tracking Detectors 1

- Mechanichal support: Carbon Fibre reinforced structure with embedded polyimide cooling pipes
  - inner barrel ->
    - 300mm length, 1.6 g weight
    - tubes inner diameter: 1.024mm; wall thickness: 25 μm
  - outer barrel ->
    - 1500mm length, 80 g weight
    - tubes inner diameter: 2.67mm; wall thickness: 65 μm
- Cooling baseline: water in leakless mode
  - Requirements:
    - Stave operative temperature shall not exceed 30°C, ΔT~5°C
    - max power dissipation: 300mW/cm^2 (IB); 100mW/cm^2 (OB)
  - Test results
    - IB: water flow rate below 31lh^{-1}
    - OB: water flow rate below 12lh^{-1}

INNER BARREL

Overall material budget per layer X/X_0: present SPD ~1.14% ➡ ~ 0.3%

Inner Barrel (IB): 3 layers pixels

Radial position (mm): 22, 30, 38

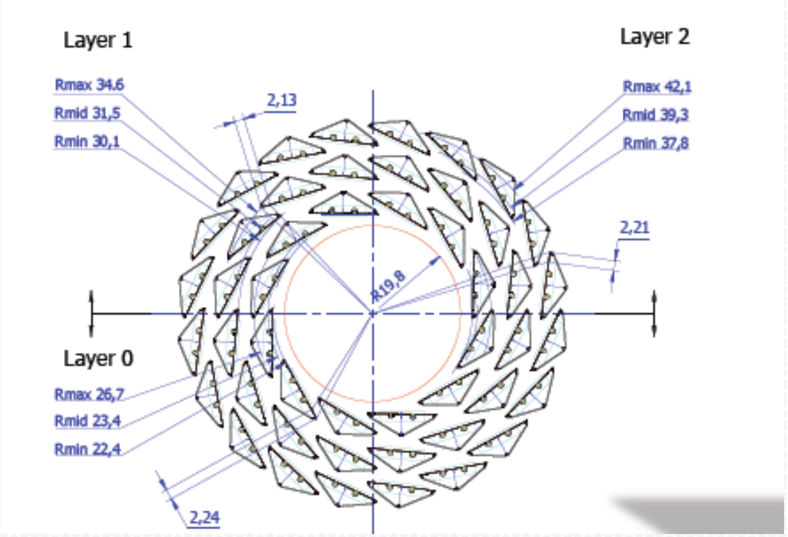
Length in z (mm): 271

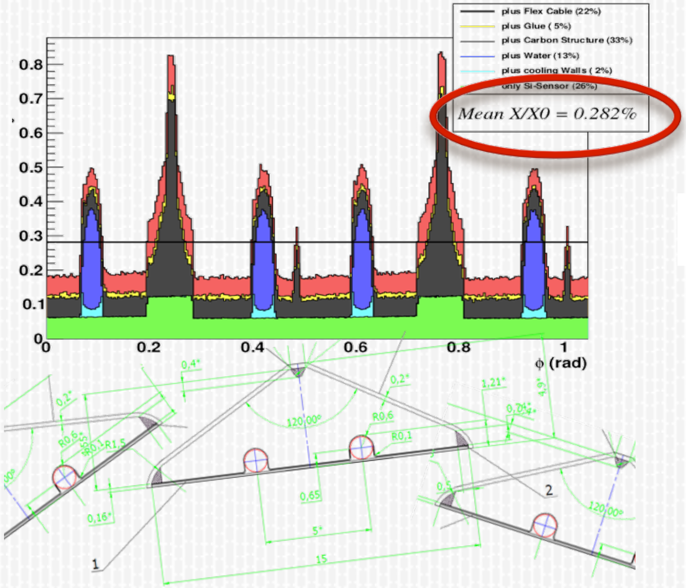
Nr. of staves: 12, 16, 20

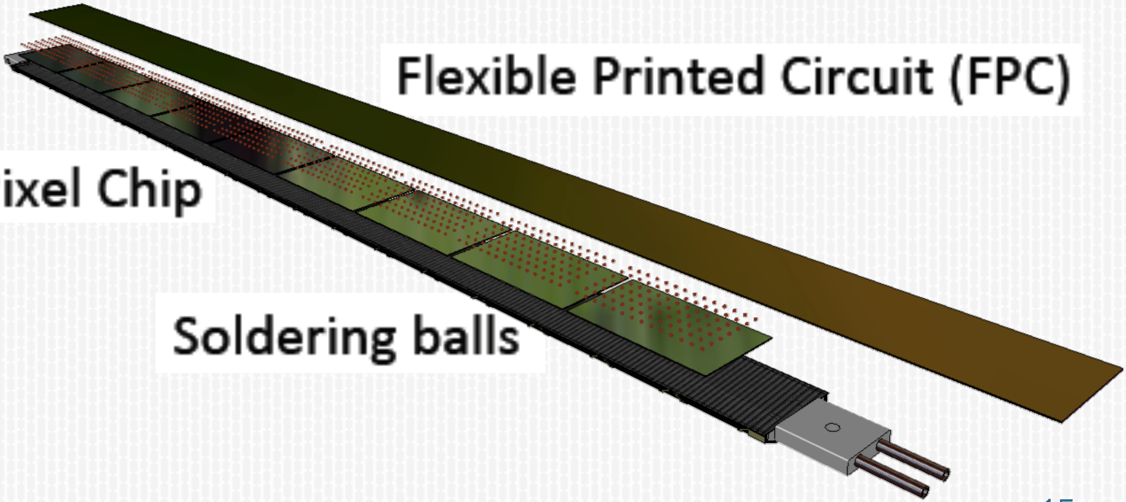
Nr. of chips/stave: 9

Nr. of chips/layer: 108, 144, 180

Material thickness: ~ 0.3% X_0

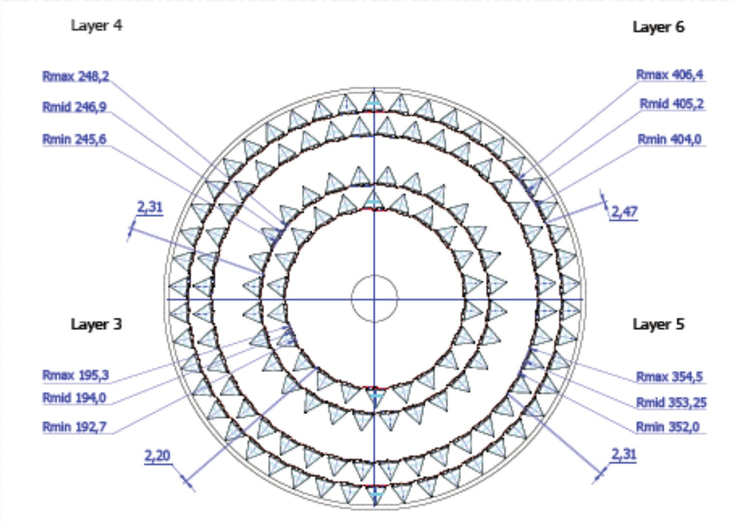


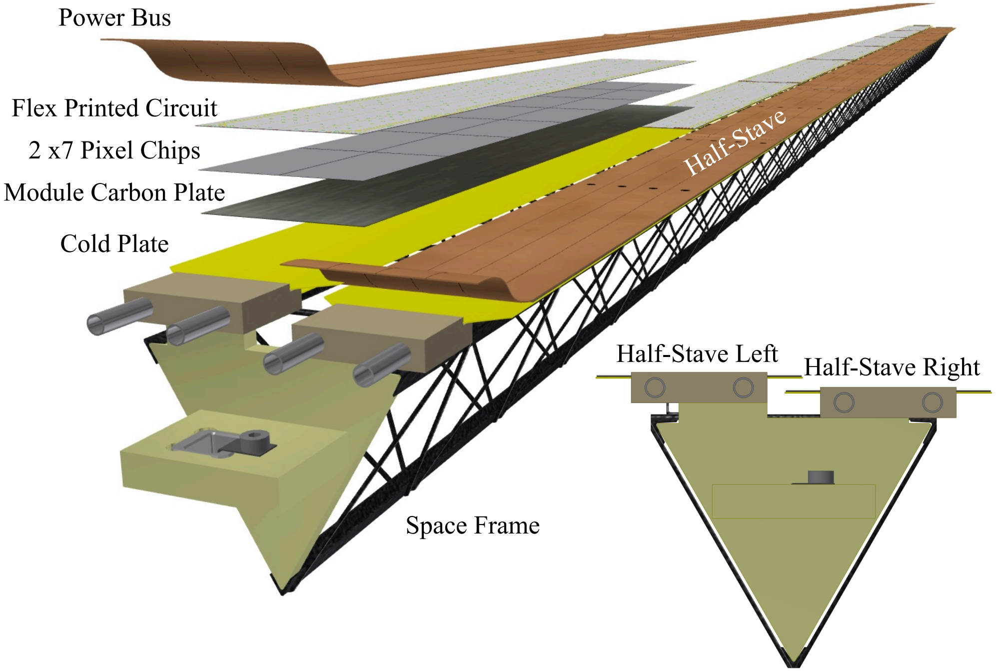




OUTER BARREL

Overall material budget per layer X/X_0: ~ 0.8-1 %





Outer Barrel (OB): 4 layers pixels

Radial position (mm): 195, 244, 342, 392

Length in z (mm): 843, 1475

Nr. of staves: 24, 30, 42, 48

Nr. of chips/stave: 112, 112, 196, 196

Nr. of chips/layer: 2688, 3360, 8232, 9408

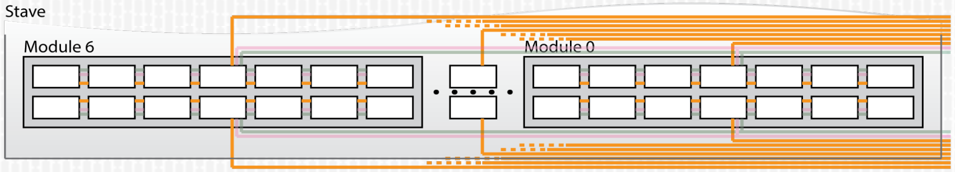
Material thickness: ~ 0.8% X_0

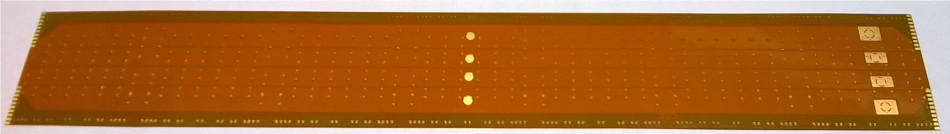
- STAVE: assembly of 2 half-staves
- HALF-STAVE:
  - middle layers: 4 modules
  - outer layers: 7 modules
- MODULE: 7x2 chips for all layers
- FPC (Flex Printed Circuit): Al or Cu on polymide (X/X_0: ~ 0.8->1 %)
- POWER BUS: Al on polymide

OUTER BARREL MODULE

Module: 2x7 pixel chips

- Flex Printed Circuit open points:
  - Al (or Cu?) on polimyde
  - 2 main read-out options under study
    - Daisy chain of 49 chips (TDR); assuming 20 Mb/s chip, 1 Gb/s total bandwidth in each segment -> high speed necessary along all data paths (and drivers)
    - Masters parallel: every masters drives its data line at 160 Mb/s max; Low speed communication from neighborhood chips to the master

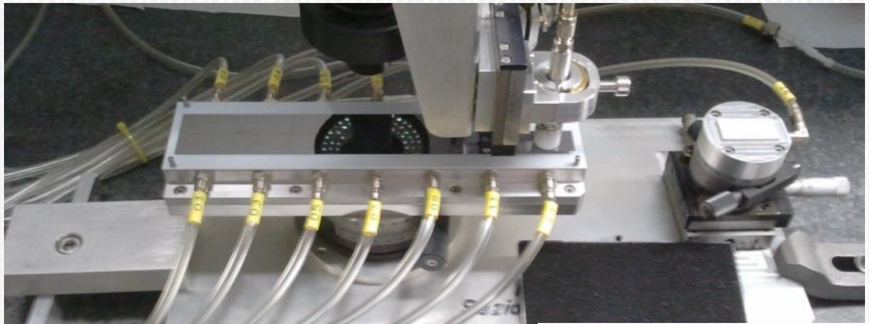




- Module assembly procedure: main constraints are precision (final chip position tolerance ~ 5-10 μm) and time
  - manual chip positioning: procedure developed in INFN Bari (1 module per day)
  - automatic chip positioning: procedure under study in collaboration with VEA company (CERN):
    - Linear Positioning Stages (X,Y,Z) have been preferred to robotic arms (faster but less precise)
    - time estimate:

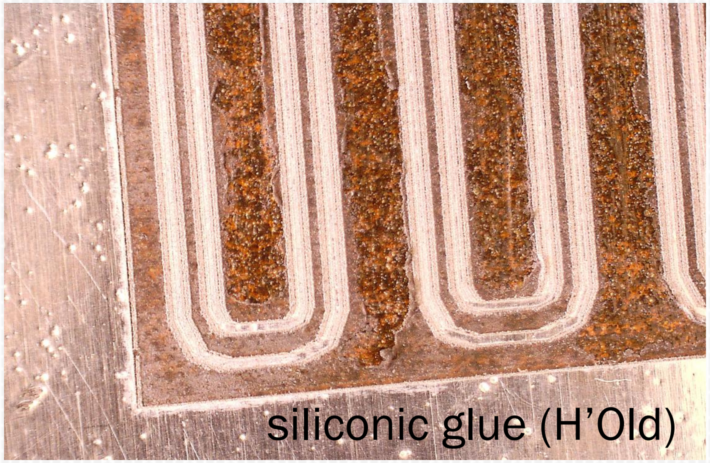
      for IB: 9 chips → ~ 2 h 20’

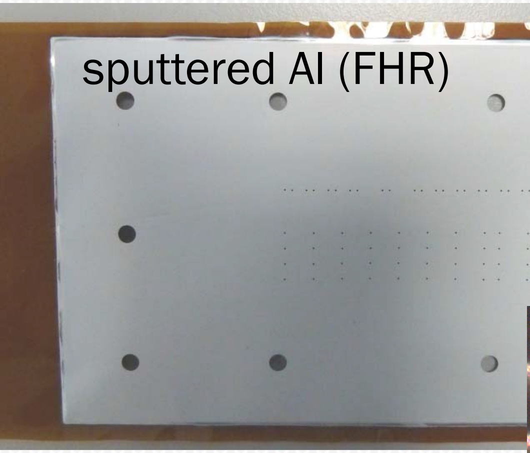
      for OB: 2x7 chips → ~ 3 h 38’

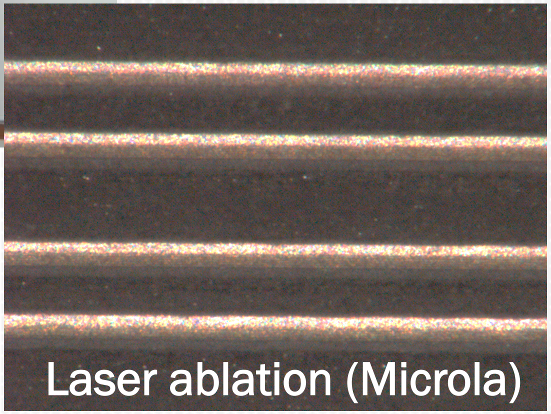


MATERIAL PROCUREMENT AND CIRCUIT MANIFACTUING ISSUES

- Material: Al on polymide
  - sputtering (FHR, Dephis)
  - local deposition (Trustech)
  - laminated polymide (H'Old)
    - siliconic glue
    - acrylic glue (mono/bi-component)


siliconic glue (H'Old)


sputtered Al (FHR)

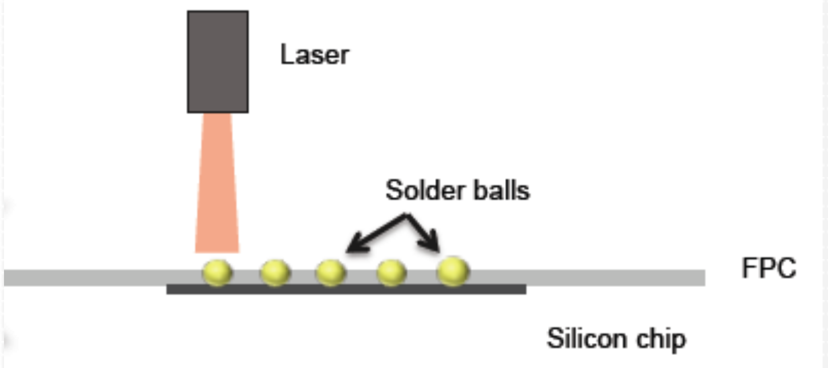

Laser ablation (Microla)

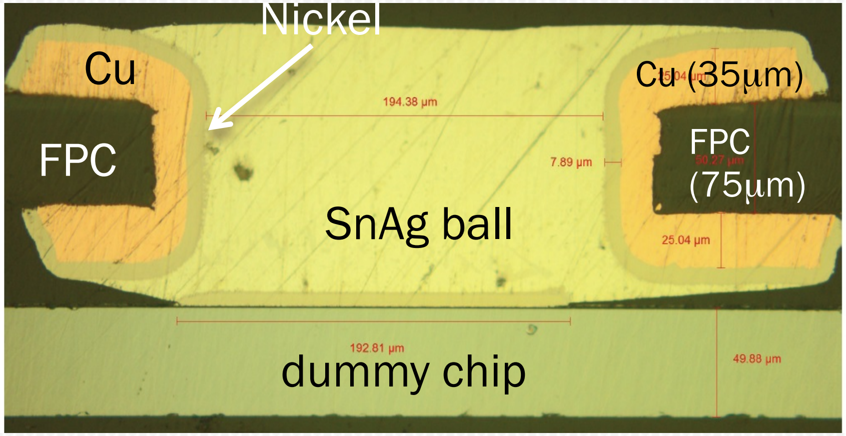
- Manifacturing:
  - chemical etching
    - not easy to find companies willing to modify production lines (Cu-> Al)
  - laser ablation (Microla Optoelectronics, LaserPoint)
    - laser power tuning
    - laser beam focus optimization
    - file format compatibility (Gerber to AutoCAD)

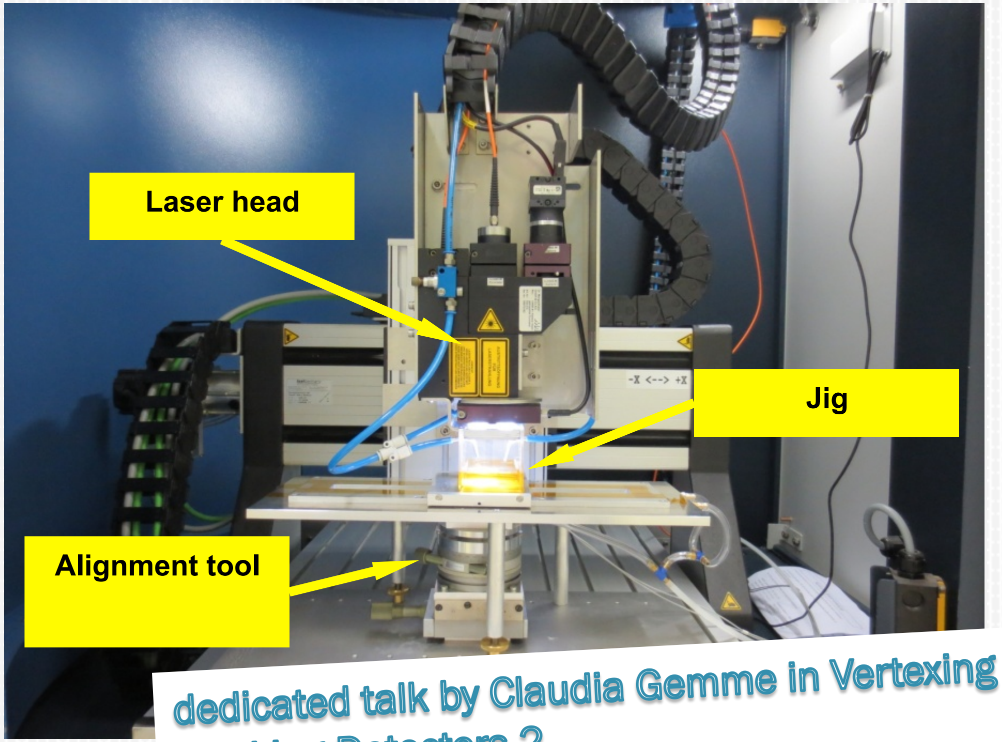
FPC TO CHIP INTERCONNECTION

Baseline:

- laser soldering of SnAg soldering balls with commercial machine developed br Dr. Mergentaler company
- optimized @ CERN (CERN + INFN Bari)
- very good results obtained after 6 months R&D (100% good contacts on 5 single chip FPCs in the same batch)







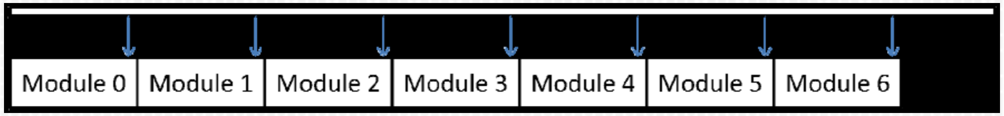
dedicated talk by Claudia Gemme in Vertexing & Tracking Detectors 2

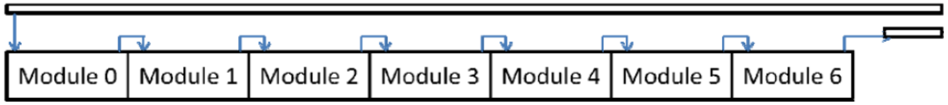
Extensive test to tune the laser profile and validate the procedure

- Electrical daisy-chain test of 50 contacts
- Microscope inspection
- Metallurgical cross-section analysis + SEM

POWER BUS OPEN ISSUES

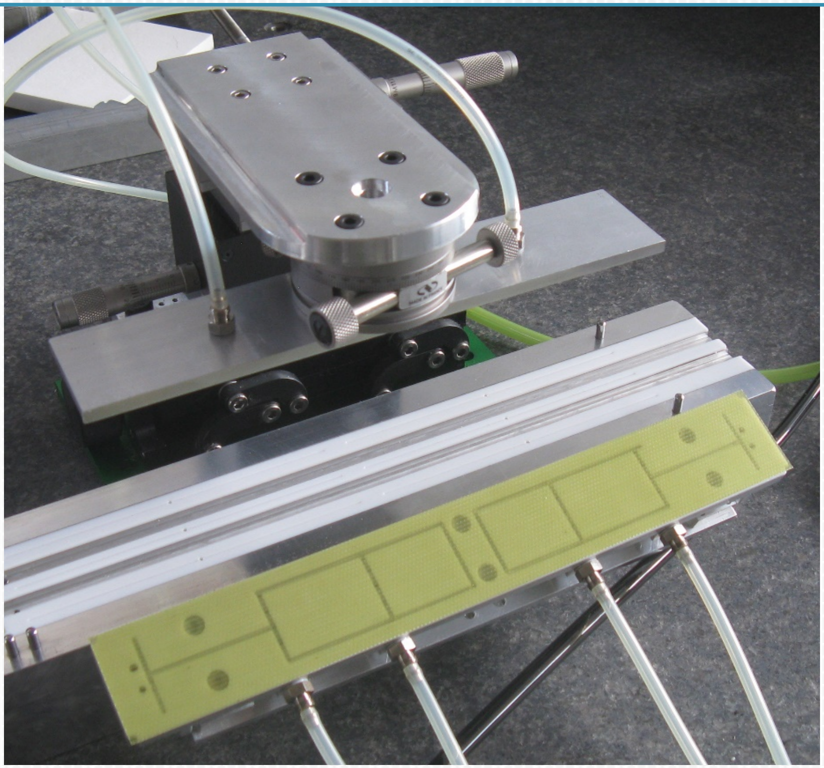
- Guidelines:
  - material budget goal: X/X_0 ~0.8% -> NO COPPER
  - maximum voltage drop allowed on chip: 200mV
  - chip power consumption: 70-100mW/cm^2
    - 14x7x2 chips per stave -> ~30-45W per stave
- TDR layout:
  - parallel powering
  - ~50-100μm Al + 50μm Polymide + ~50-100μm Al long BUS
- Alternative solution:
  - serial powering (@ NIKHEF)
  - Using shunt regulators on module
    - Discrete
    - External FET, control in chip
    - Fully integrated in chip
- Fabrication issues:
  - material procurement: laminated alluminum?
  - chemical ablation
    - @ CERN?
    - looking for commercial partners
  - holes metallization and pad plating
    - critical on Al laminated polymide
    - feasible with sputtered Al
- Interconnectio PB to FPC:
  - Sn soldering
  - Laser soldering

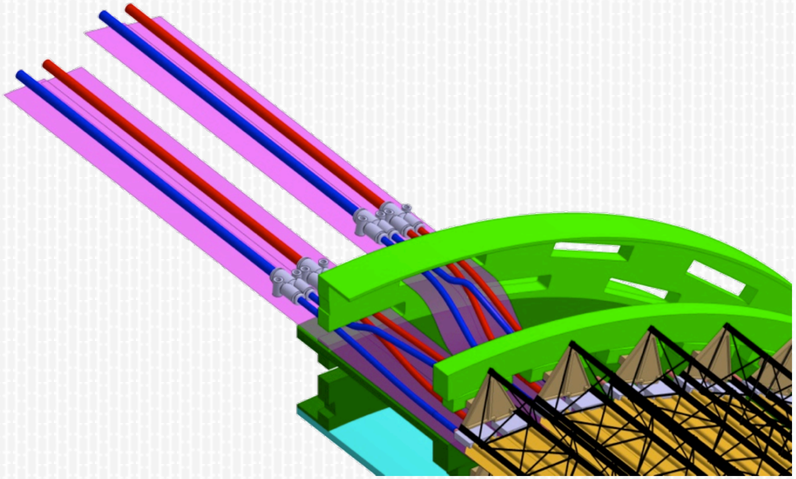




CONSTRUCTION @ INFN

- Goal: 30-40% of the outermost layers
- Baseline:
  - 2 centers for MODULE production
  - 1 center for STAVE assembly (LNF)
    - stave assembly developed in INFN Torino + Cagliari
- Timeline:
  - production starts 2015
  - module & stave construction ends 2017

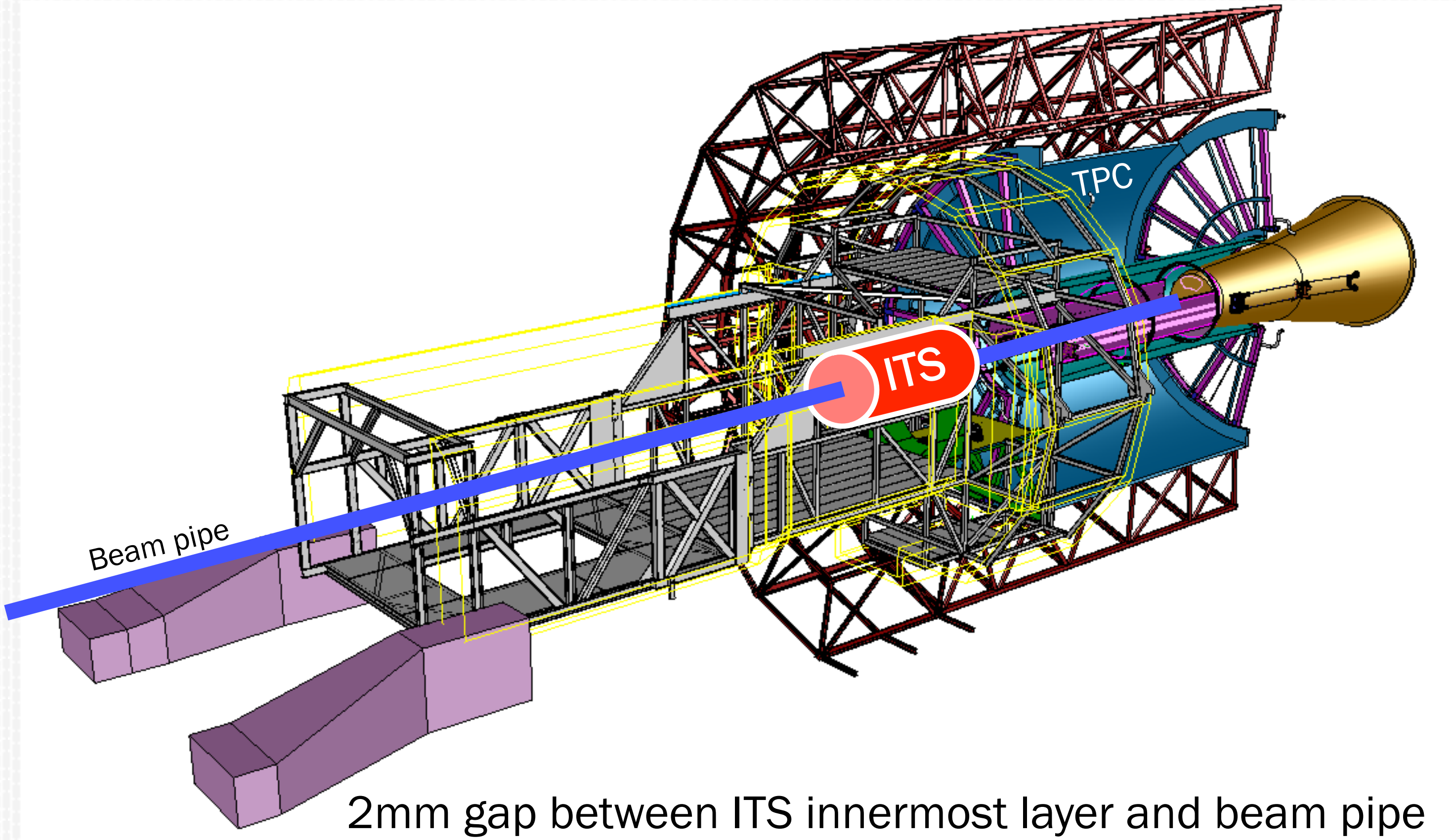




- outer barrel support cones and end-wheels designed in INFN Padova
- half barrel and barrel assembly @ CERN 2017/2018
- installation & commissioning 2018/2019

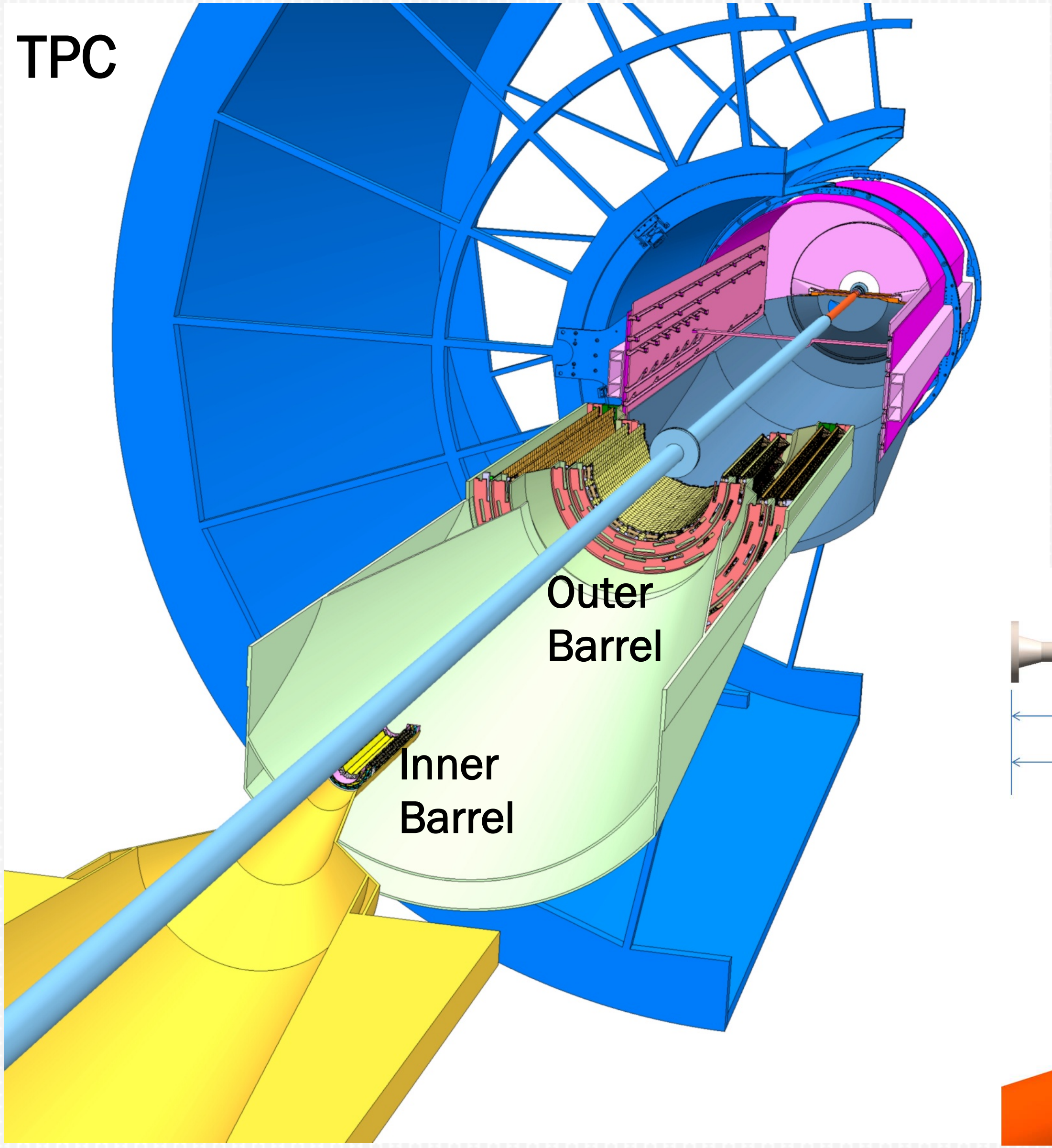
ITS INSTALLATION GUIDELINES

- RAPID ACCESS for yearly mainteinance
  - 3-4 months time (LHC yearly shut down)
- excludes the possibility of displacing the surrounding detectors
  - the new ITS has to be translated approximately 3 meters along the beampipe to allow for this accessibility (out of the TPC)

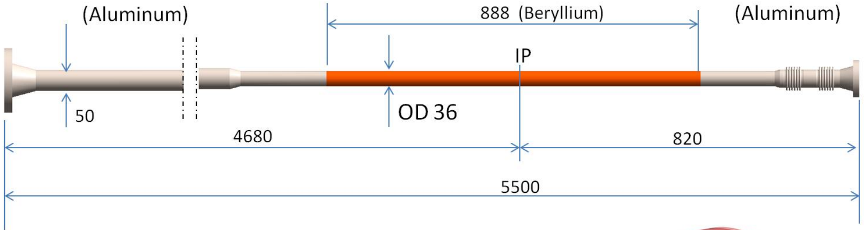


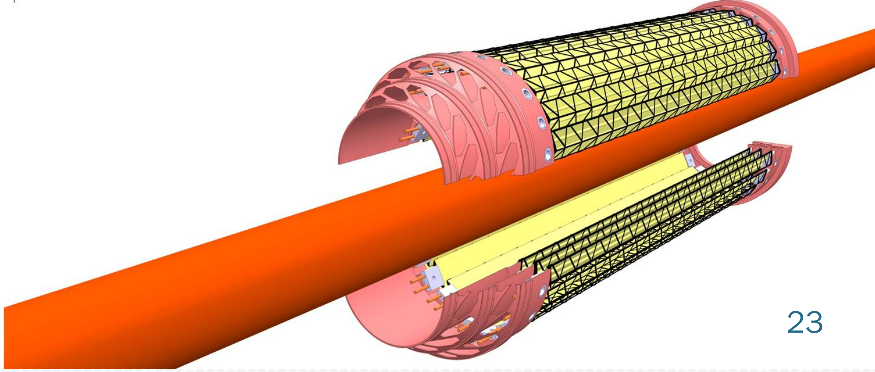
2mm gap between ITS innermost layer and beam pipe

PRELIMINARY INSTALLATION SEQUENCE

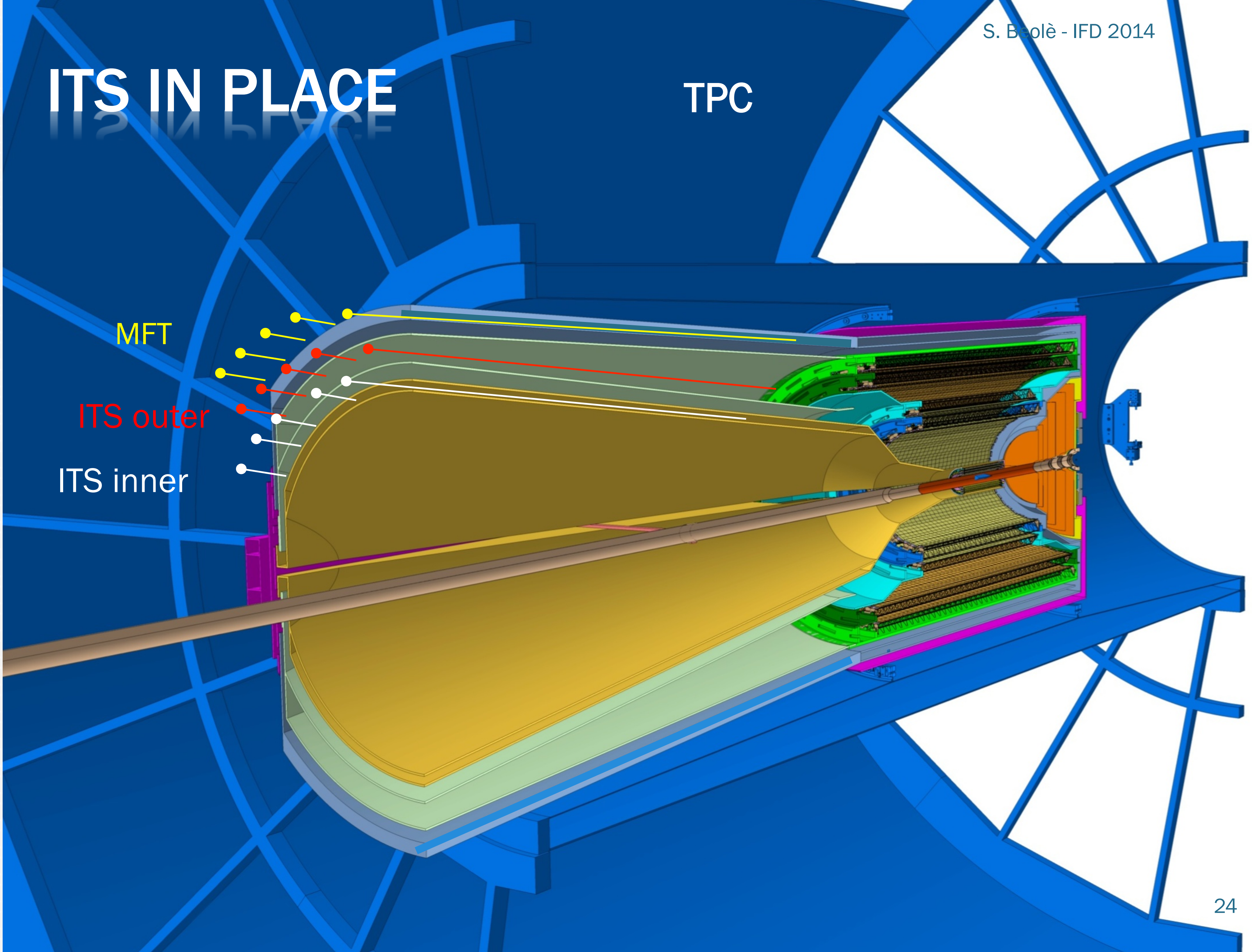


- TPC in parking position
- Two temporary rails fixed to the Absorber
- Beampipe under vacuum to verify flange connection
- TPC back to nominal position
- Beampipe alignment
- Outer barrel installation
- Inner barrel installation





ITS IN PLACE



TPC

MFT

ITS outer

ITS inner

BACKUP

EVENT SIZE AND RATES

- Event size of major systems, I/O rates of online system

Detector	Event size (Mbyte)		Input to online system (Gbyte/s)	Peak output to local data storage (Gbyte/s)	Average output to computing centers (Gbyte/s)
	After zero suppression	After data compression			
ITS	0.8	0.2	40	10.0	1.6
TPC	20.0	1.0	1000	50.0	8.0
TRD (20kHz)	0.3	0.1	6	2.0	0.8
Others (1)	0.5	0.25	25	12.5	2.0
Total	21.6	1.55	1071	74.5	12.4

Data format	Data reduction factor	Event size (Mbyte)
Raw data	1	700
Zero suppression (FEE)	35	20
Clustering (HLT)	5-7	~3
Remove clusters not associated to tracks (HLT)	2	1.5
Data format optimization (HLT)	2-3	<1

Optimize data reduction for TPC: clustering, data format