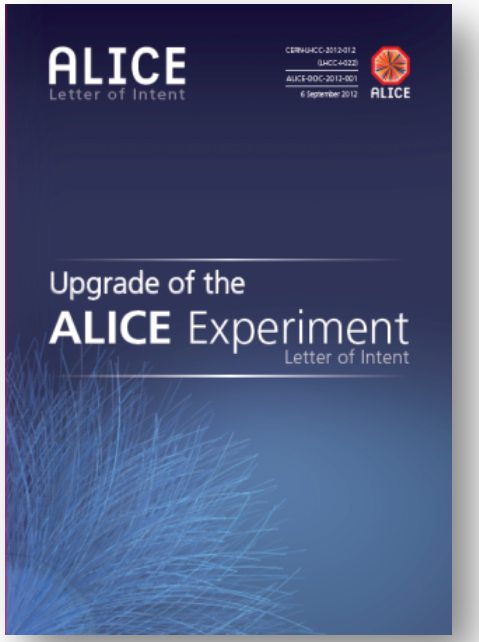
ALICE Upgrade Program

David Silvermyr, ORNL
for the ALICE collaboration

Outline

- The ALICE detector now
- ALICE upgrade strategy for LHC Runs 3 (& 4)
- ITS upgrade*
- Muon system upgrade
- TPC upgrade*
- Read-out system upgrade
- The ALICE online farm for Run 3
- Summary and Outlook

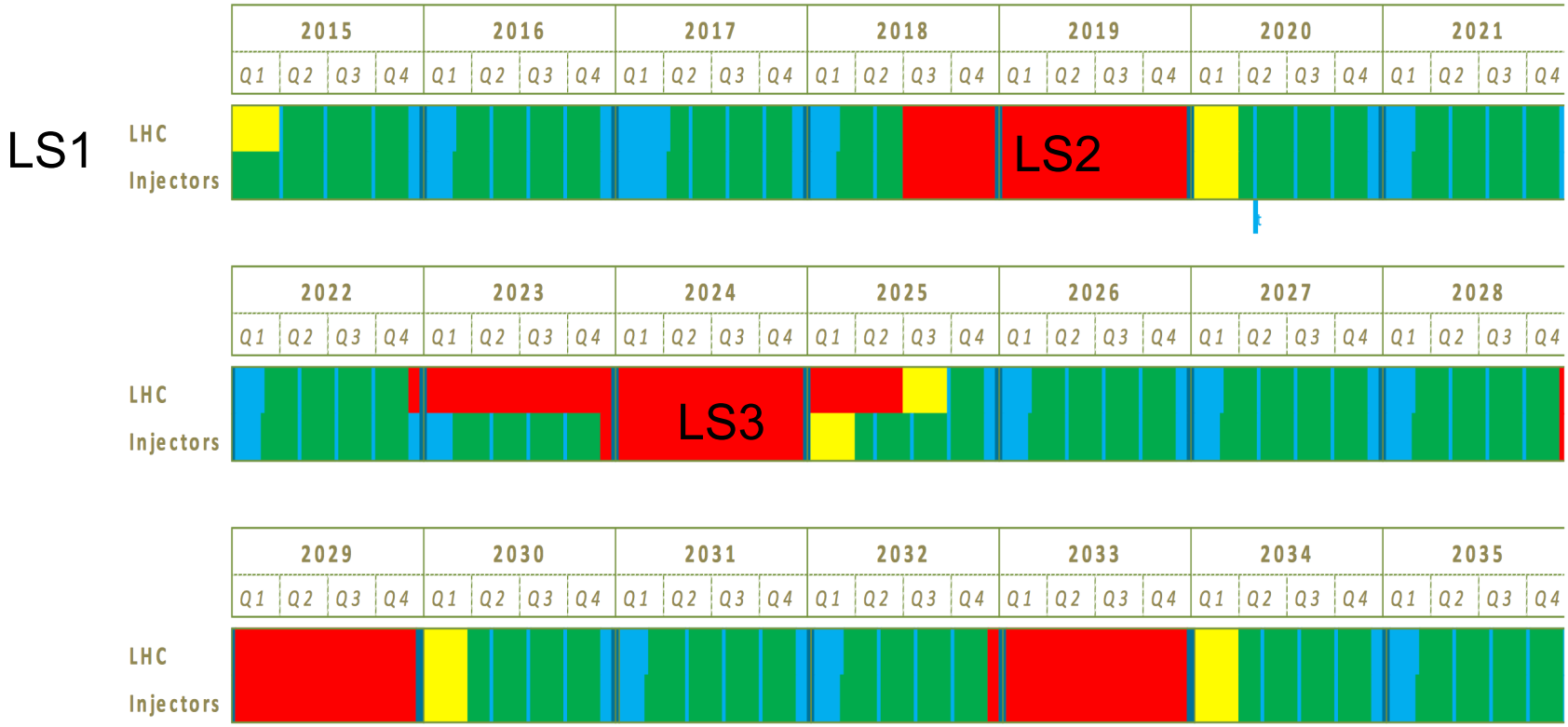
ALICE upgrade Letter of Intent



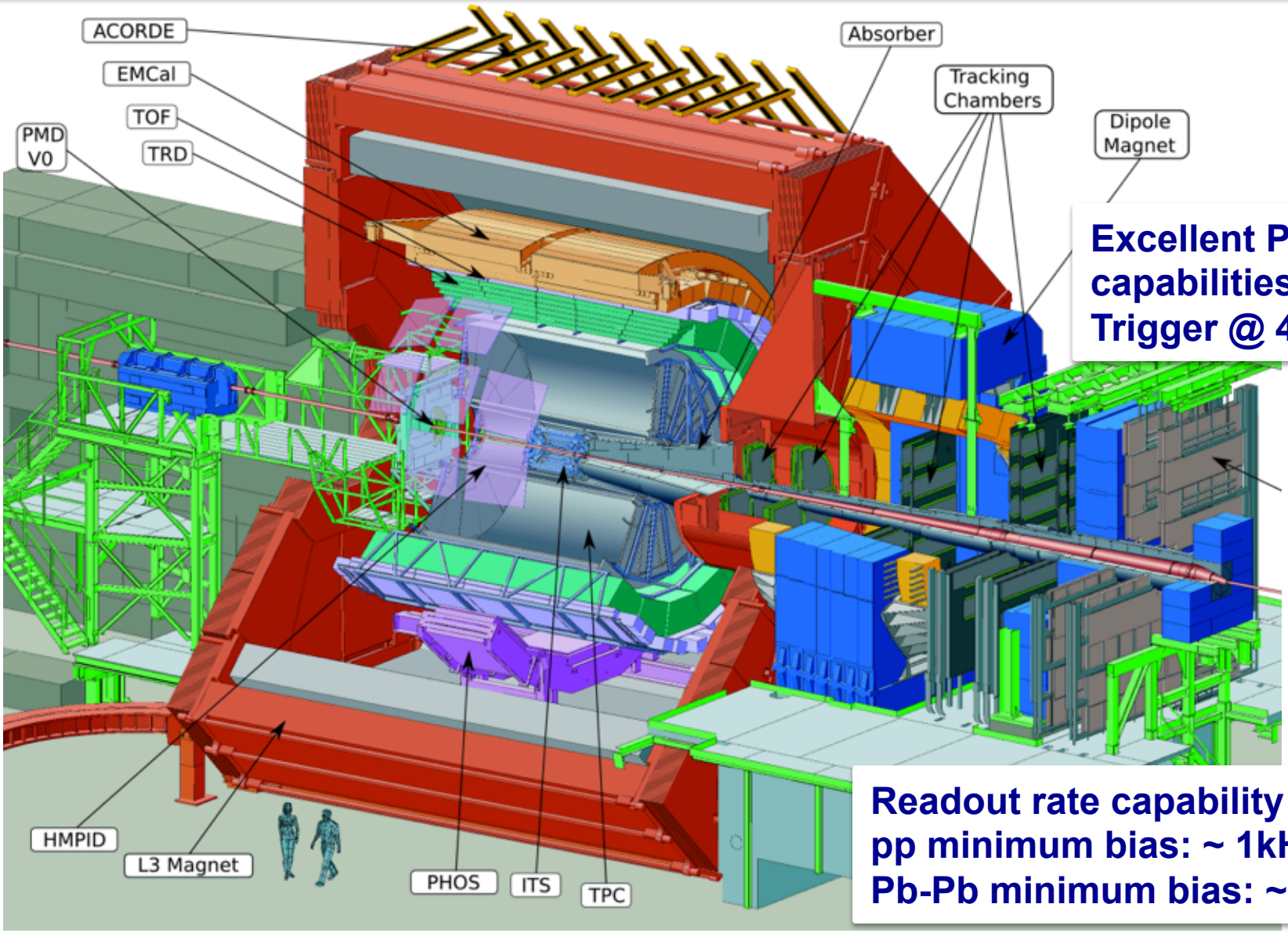
[* = special emphasis today; relevant for RHIC upgrades, and significant proposed ALICE-USA involvement]

LHC schedule

- LHC Long shutdown 2 = LS2:
  - Starts in July 2018
  - Duration: 18 months + 3 months beam commissioning
  - After LS2: LHC Run3



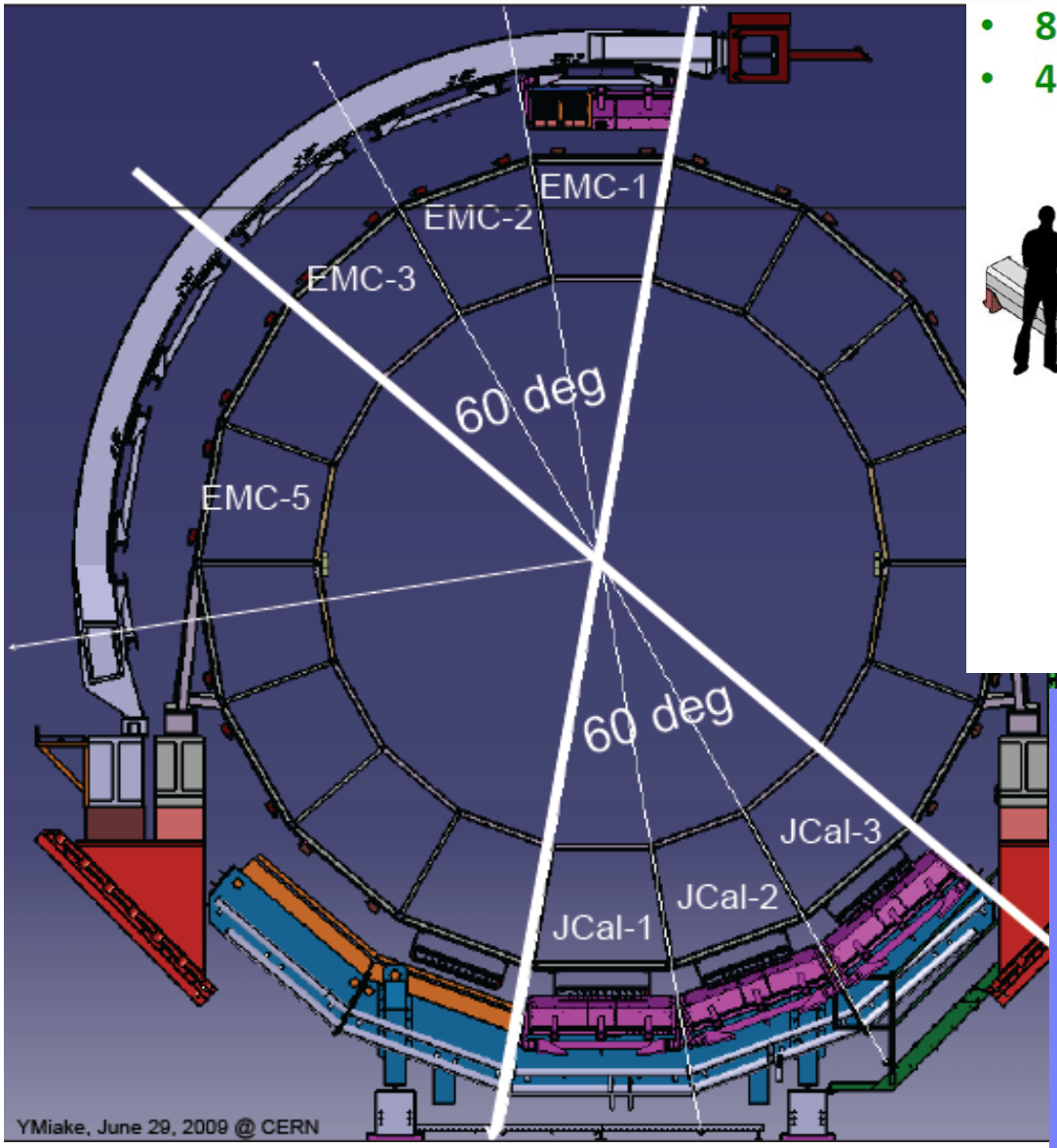
The ALICE detector now

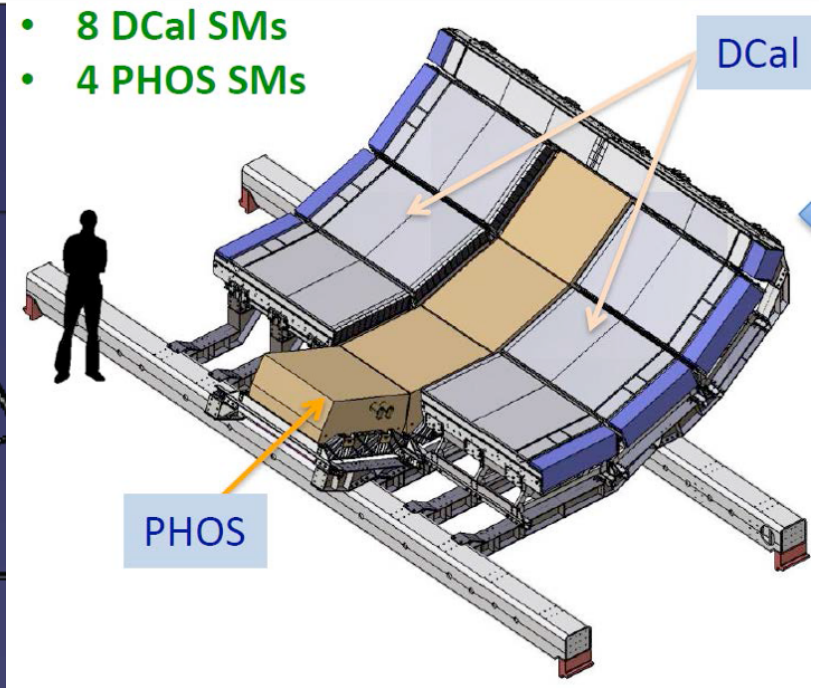


Excellent PID capabilities
Trigger @ 40 MHz

Readout rate capability
pp minimum bias: ~ 1kHz
Pb-Pb minimum bias: ~500 Hz

LS1: EMCal Extension/Upgrade

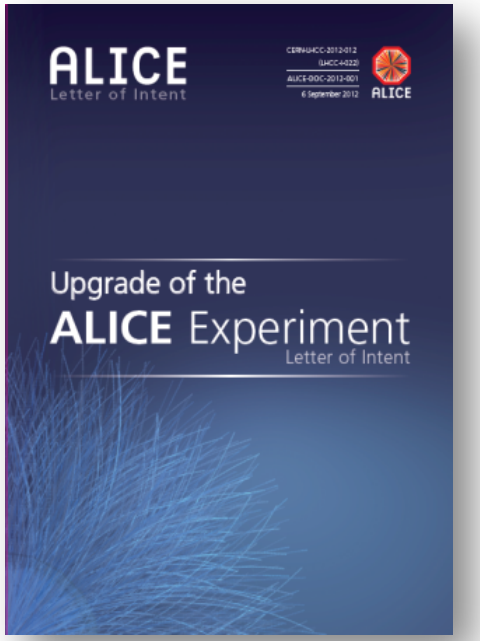




DCal (Di-jet Calorimeter):
Same modules as the EMCAL, shorter SuperModules in η.
Including PHOS, acceptance is $\Delta\eta=1.4$, $\Delta\varphi=67^{\circ}$
Enhance di-jet yield (w/ jet trigger)
To be completed installation in 2013-2014 shutdown.

ALICE upgrade strategy (1)

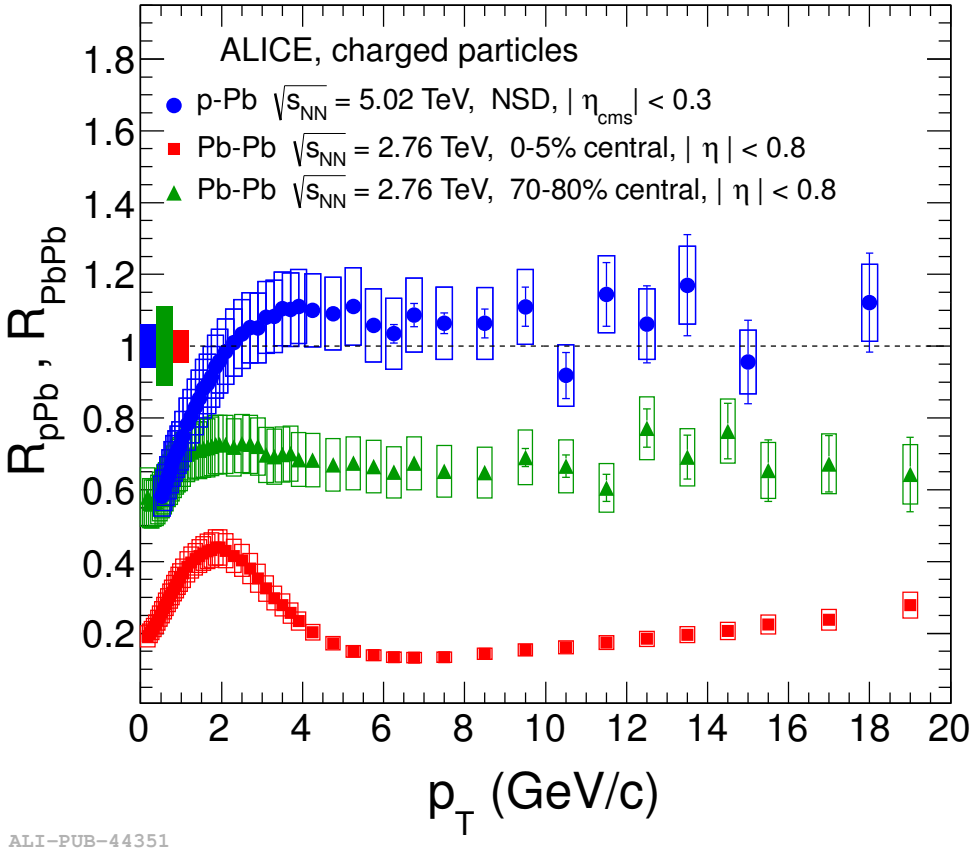
- ALICE is the dedicated heavy-ion experiment at the LHC
- Upgrade motivation: ALICE will focus on high precision measurements of rare probes at low and intermediate p_T
  - needs large sample of events recorded on tape
  - can not be selected with a trigger
- Target: Pb-Pb recorded luminosity: ≥ 10 nb^{-1} plus pp and p-A data
  - gain in statistics over approved program: factor 100!
- Strategy:
  - read out all Pb-Pb interactions at a maximum rate of 50 kHz with a minimum bias trigger or even continuously (TPC)
  - perform online data reduction
- Targeted for LHC 2nd Long Shutdown – LS2, 2018/19
- Upgrade Letter Of Intent : CERN-LHCC-2012-12
- MFT Addendum to the LoI: CERN-LHCC-2013-014



ALICE upgrade Letter of Intent

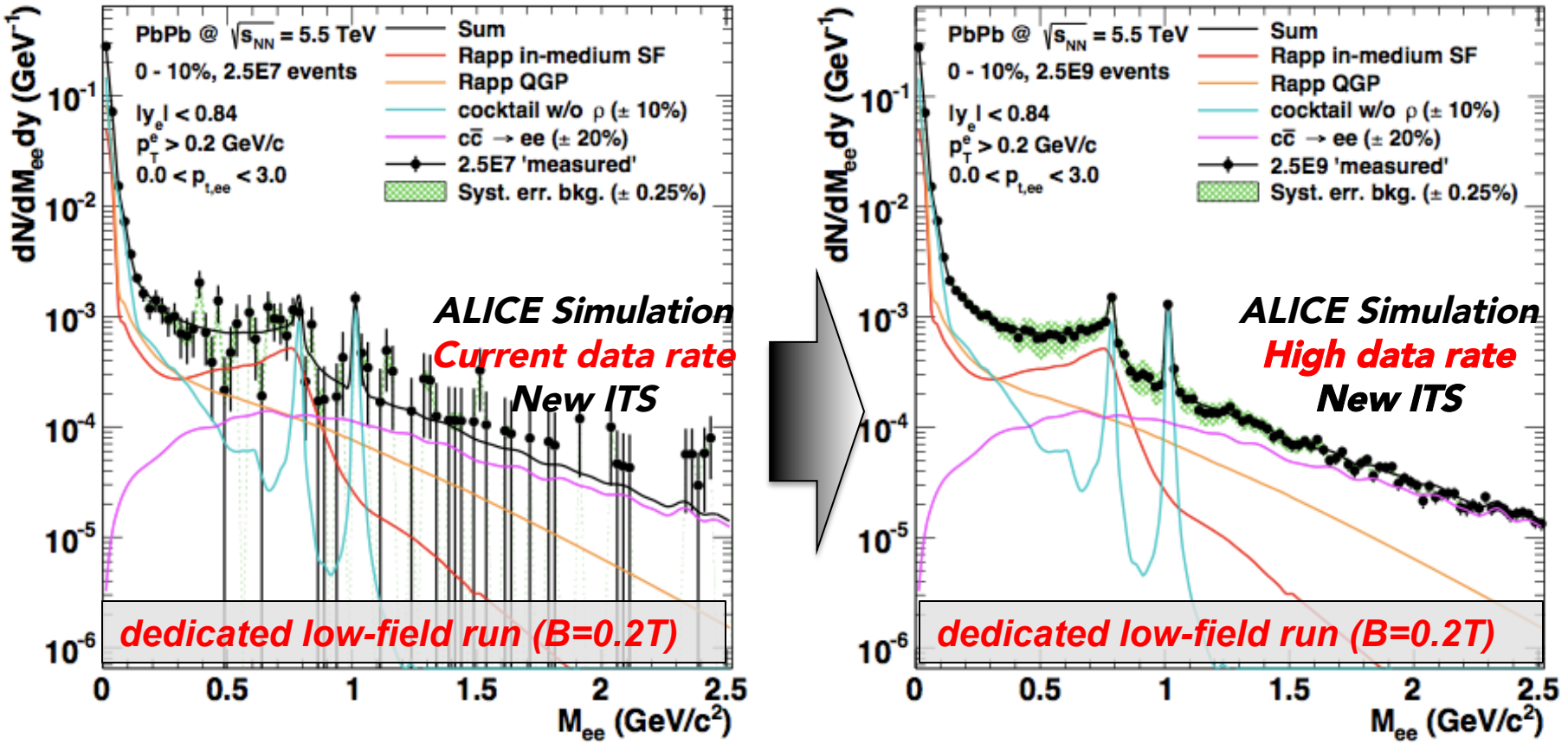
“Semi-hard” Observables

- Observables between bulk (min bias physics) and hard probes : interesting regime for heavy-ion vs pp comparisons
- Not as easy to trigger on
- Examples:
  - charm production
    - hydro-dynamics
    - charm quark energy loss / jet quenching
    - J/ψ suppression
  - thermal photons at low and intermediate p_T



Example: Low mass di-electrons

- Increase statistics
- Suppress combinatorial background (π^0 Dalitz decays, photon conversion)
- Reduce systematic uncertainty from semi-leptonic charm decays
  - Improved secondary vertex resolution



ALICE upgrade strategy (2)

- The ALICE LS2 upgrade plans:
  - new, high-resolution, low-material Inner Tracking System (ITS)
  - upgrade of Time Projection Chamber (TPC)
  - new silicon telescope in front of hadron absorber in the acceptance of the Muon Spectrometer (Muon Forward Tracker, MFT)
  - upgrade of the online systems (O^2)
  - upgrade of the forward trigger detectors (FIT) and ZDC
  - upgrade of read-out electronics of: TRD, TOF, PHOS and Muon Spectrometer
  - upgrade of the offline reconstruction and analysis framework

Collection of ALICE upgrade TDRs plus MFT LOI addendum

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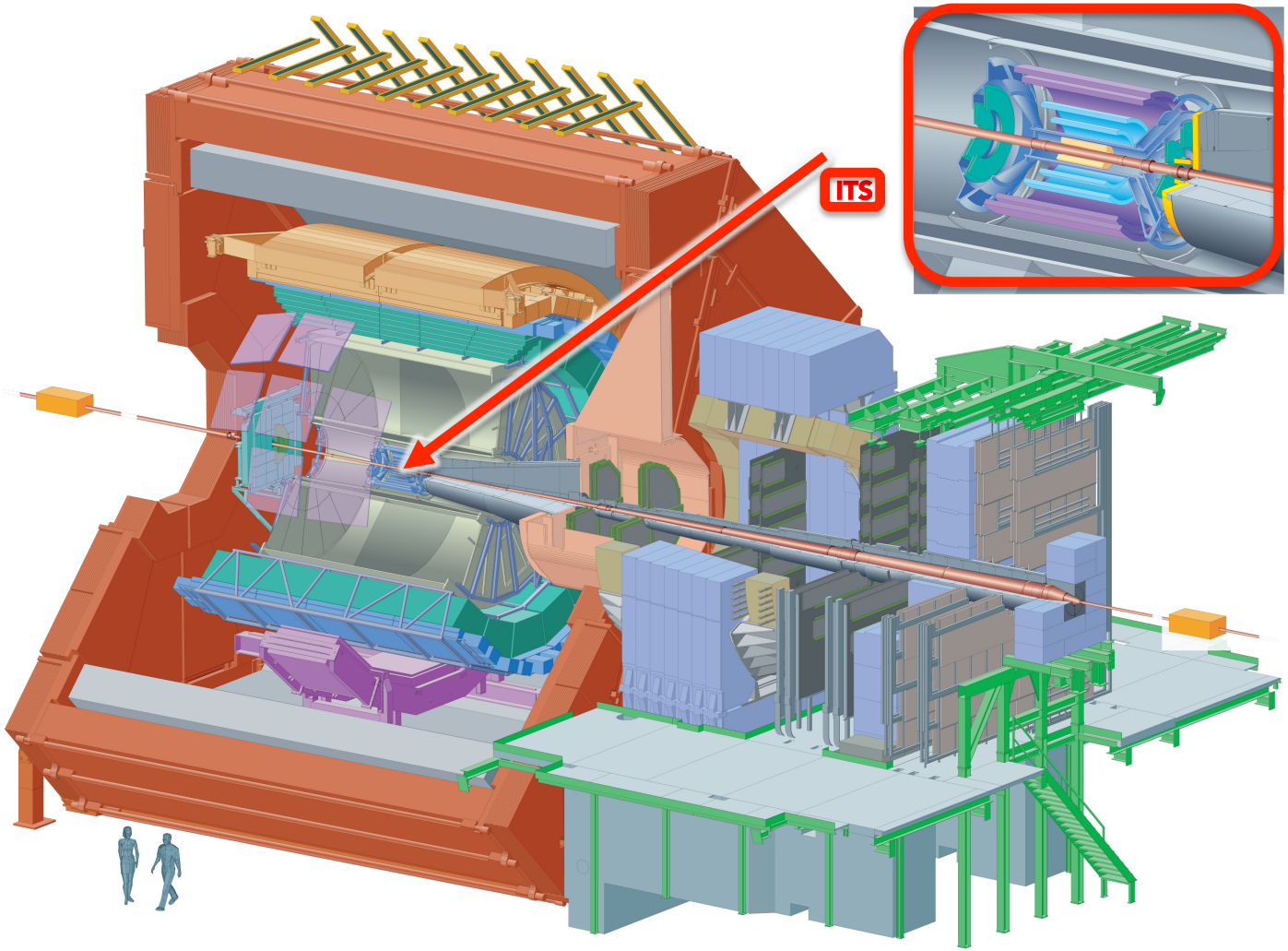
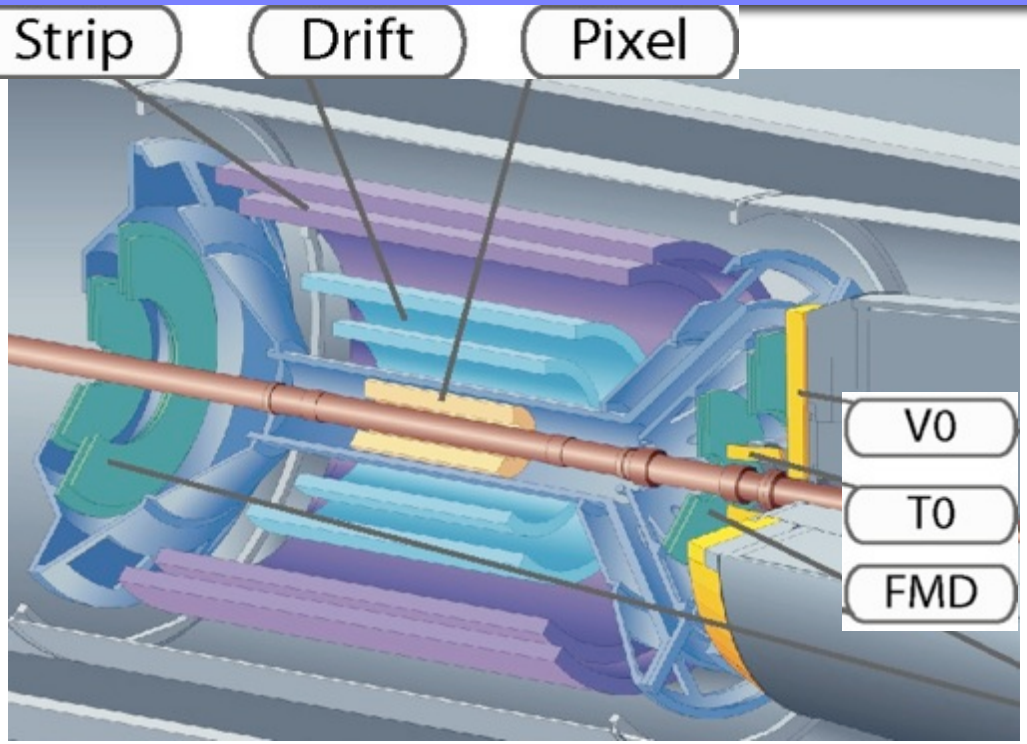
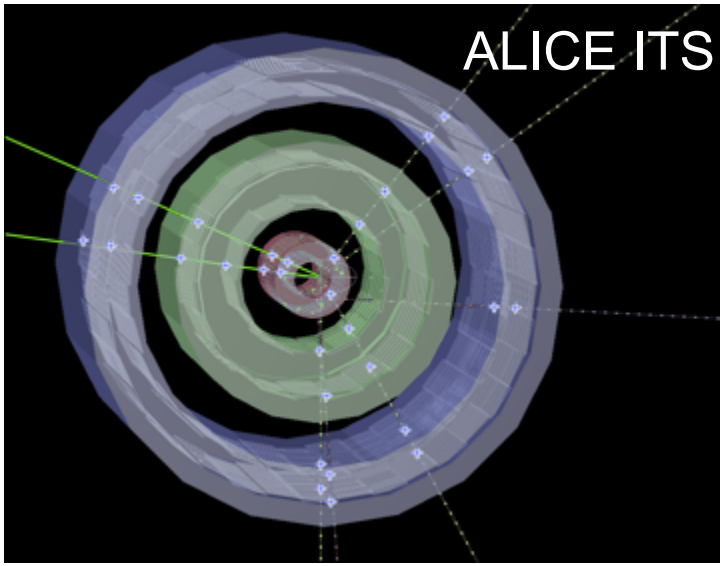
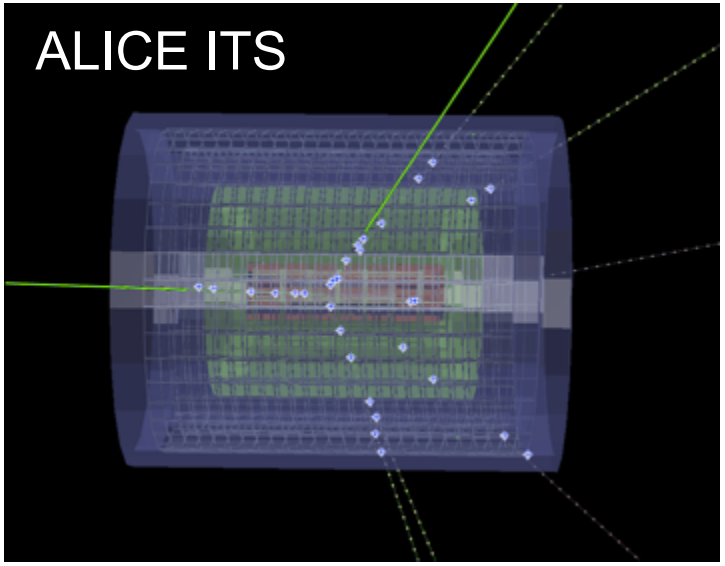
ALICE ITS upgrade



Current ALICE Inner Tracking System







Current ITS

6 concentric barrels, 3 different technologies

- 2 layers of silicon pixel (SPD)
- 2 layers of silicon drift (SDD)
- 2 layers of silicon strips (SSD)

ITS upgrade objectives (1)

- Current ITS: 2 layers each of Silicon Pixel, Silicon Drift and Silicon micro-Strip Detectors. Rate limitation: around 1kHz
- ITS upgrade objectives:
  1. Improve track DCA resolution, in particular at low p_T
  2. improve tracking efficiency and p_T resolution at low p_T
  3. increase read-out rate: 1 kHz ➔ 50 kHz in Pb-Pb, 200 kHz in pp
  4. easier maintenance

ITS upgrade objectives (2)

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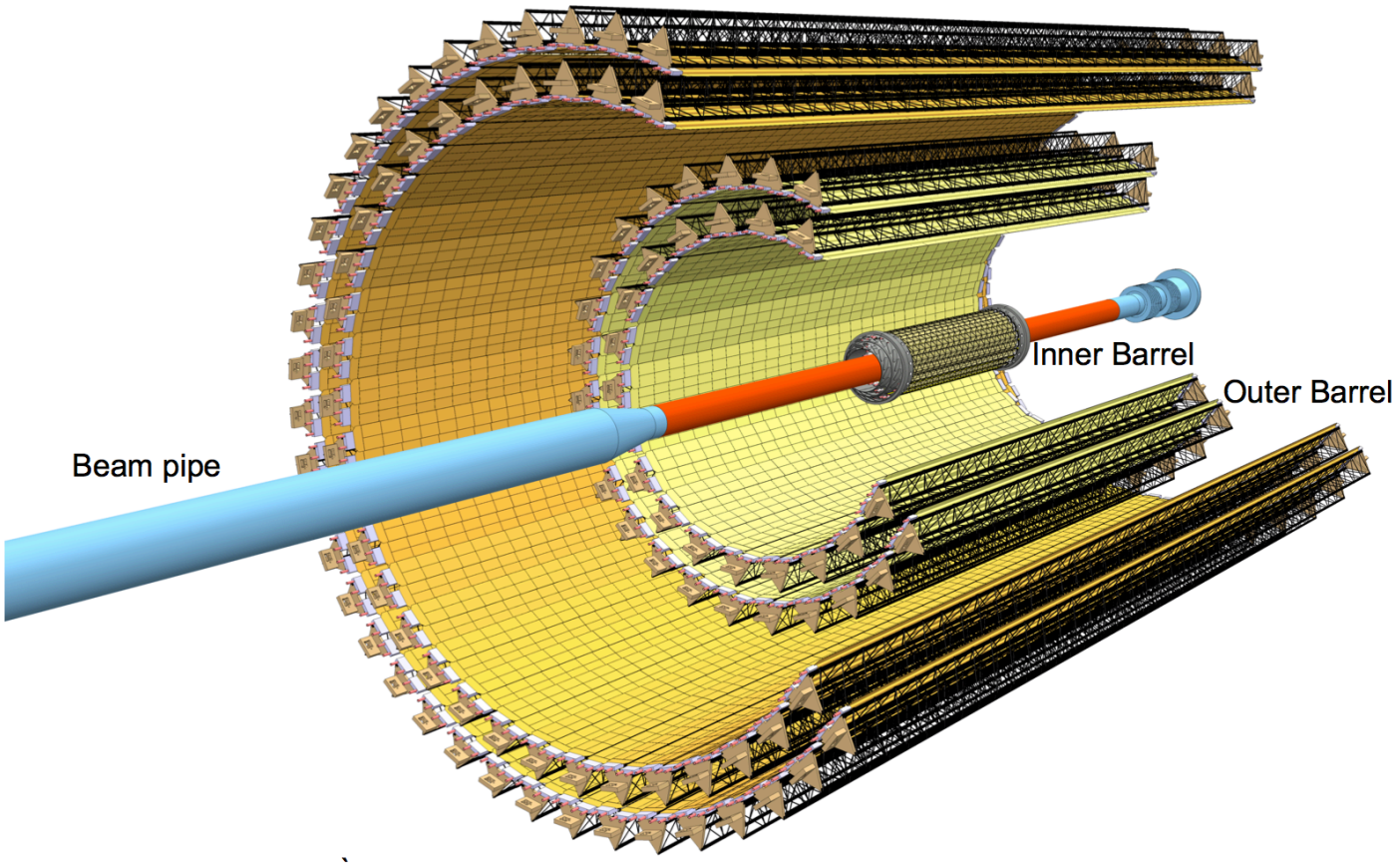
  2. improve tracking efficiency and p_T resolution at low p_T
  3. increase read-out rate: 1 kHz ➔ 50 kHz in Pb-Pb, 200 kHz in pp
  4. easier maintenance
- Implementation:
  - 7-layer barrel geometry of Monolithic Active Pixel Sensors (MAPS)
  - first layer closer to IP (r_0= 39 mm ➔ 22 mm)
    - smaller beam pipe: 29 mm ➔ 18.2 mm
  - reduced material budget, in particular for the 3 innermost layers
    - X / X_0 = 1.14 % ➔ 0.3 % for the first layers
    - Silicon thickness: 50 μm
  - smaller pixel size: 50 × 425 μm^2 ➔ *o* (30 × 30 μm^2)
  - increase number of layers: 6 ➔ 7
- Note: MAPS technology also successfully used for STAR HFT PXL layers

New ITS layout



25 Gpixels,

Area: ~10m^{2,}

Inner barrel: 3 layers;

Outer barrel: 2+2 layers;

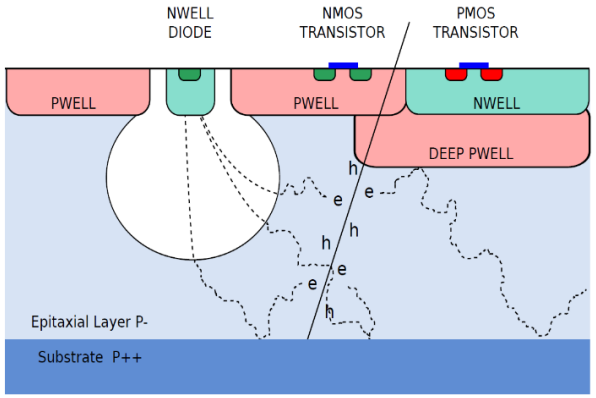
$|\eta| \leq 1.22$ for tracks from 90% most luminous region;

***r* coverage: 22 – 430 mm**

Pixel Technology

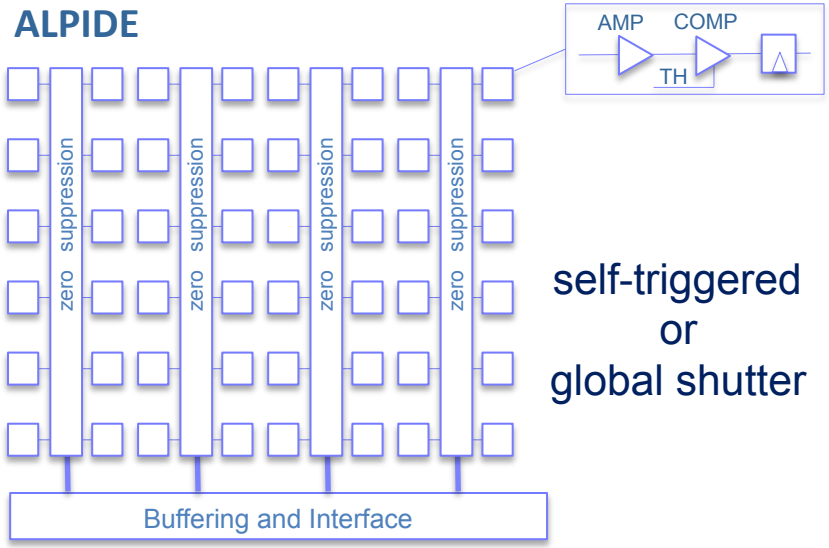
Pixel choice: Monolithic Active Pixel Sensors (MAPS) using Tower Jazz 0.18 µm

- Chip size: 15 mm x 30 mm
- Pixel pitch ~ 30 µm
- Si thickness: 50 µm
- Spatial resolution ~ 5 µm
- Power density < 100 mW/cm^2
- Integration time < 30 µs



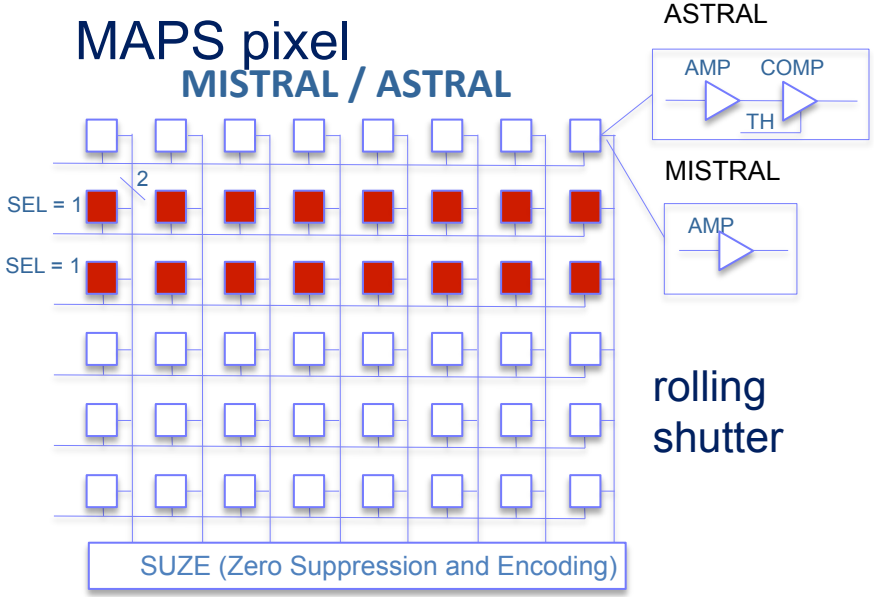
Schematic cross section of a MAPS pixel

ALPIDE



self-triggered
or
global shutter

MISTRAL / ASTRAL

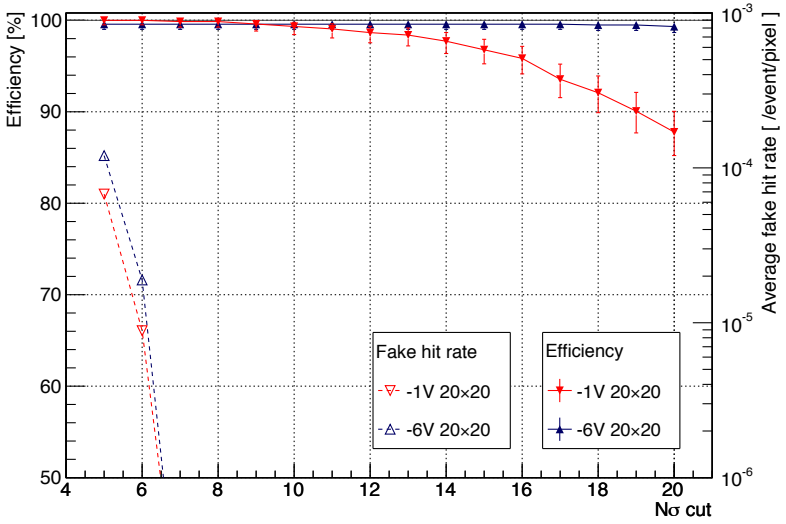


rolling
shutter

Pixel Prototypes: Experimental Results

ALPIDE

ALICE, CERN-LHCC-2013-024



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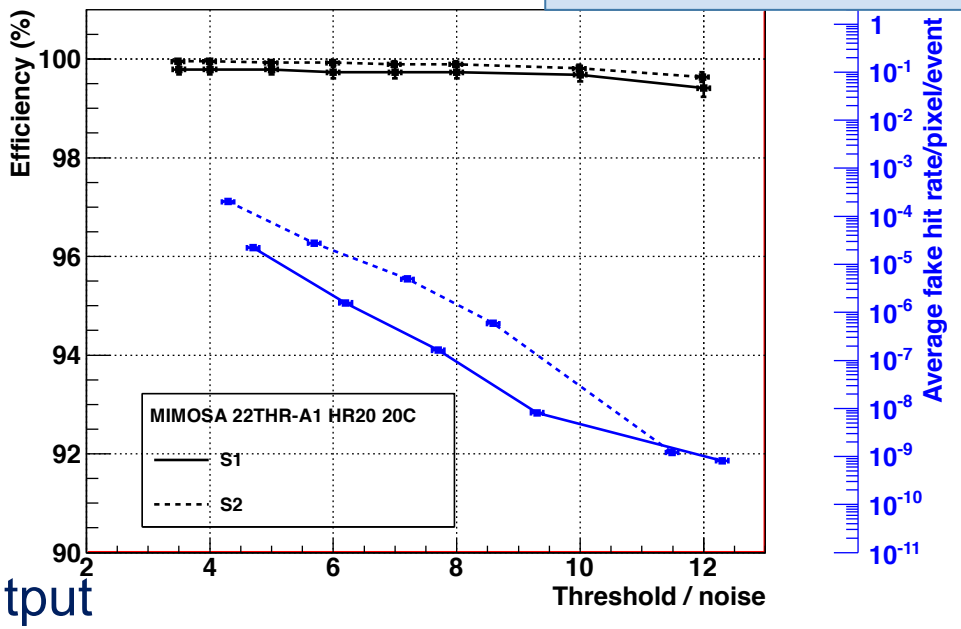


Explorer: prototype with analogue output

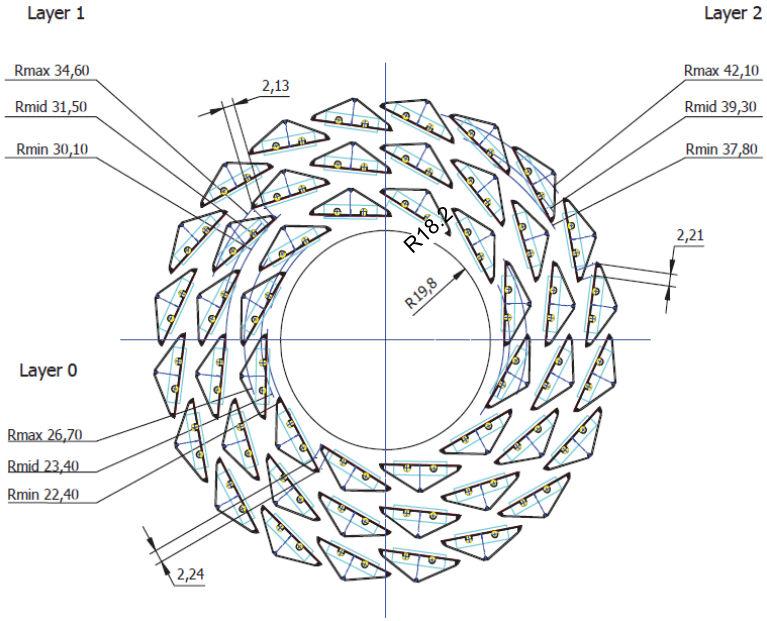
pALPIDE: sizeable prototype of final chip (digital output) , pixel size: 22 x 22 μm^2

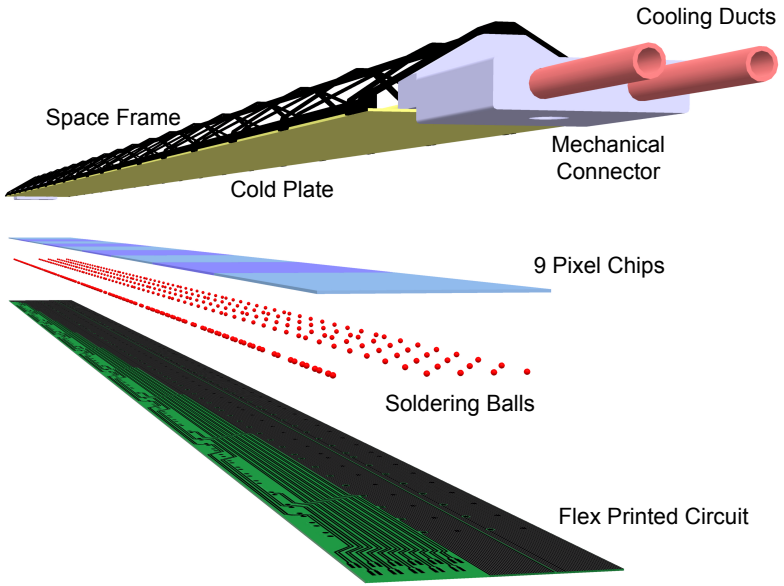
At Threshold / Noise: 20
Detection efficiency: 99.7 %
Fake hit rate < 10^{-8} hits/event
Spatial resolution ~ 5 μm

MIMOSA-22-THR-A1 performance from digital output pixel size (22 x 33 μm^2) for two design options

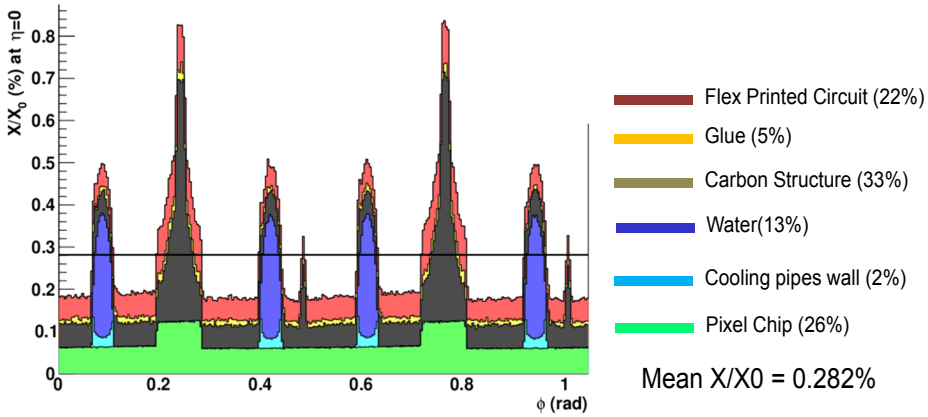
Measurements at DESY with 3-6 GeV/c electron and positron beam

Inner Barrel

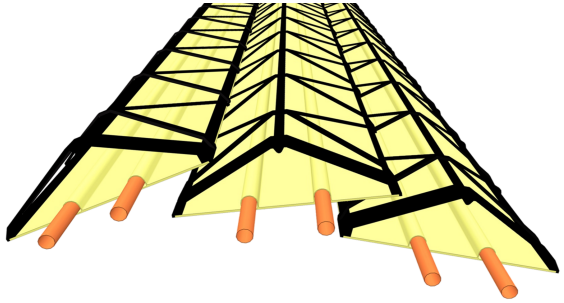


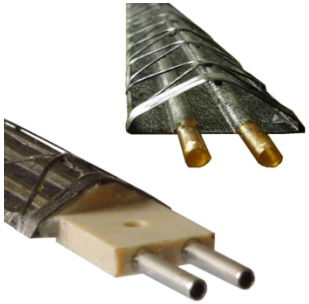


Material budget: ~ 0.3 % X_0 per layer

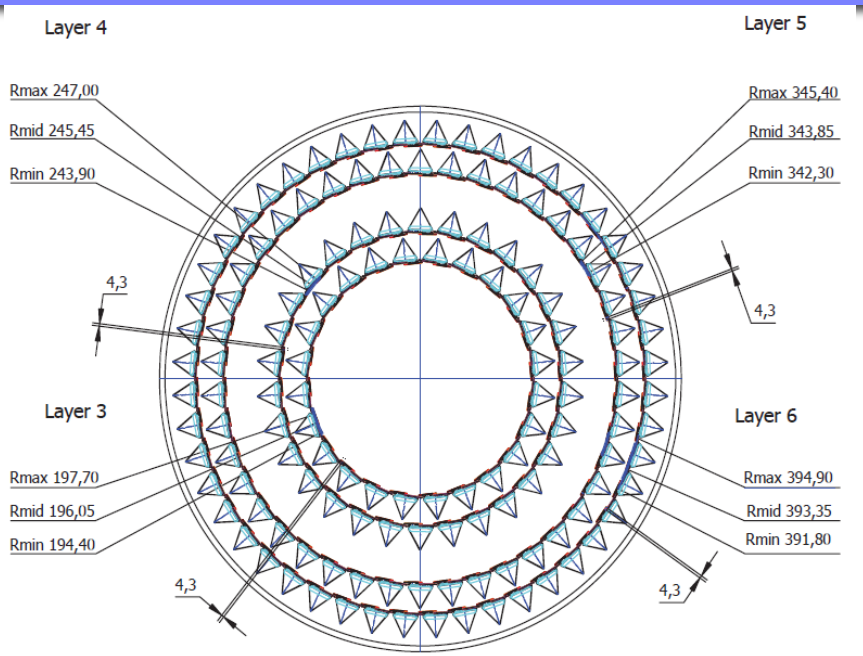


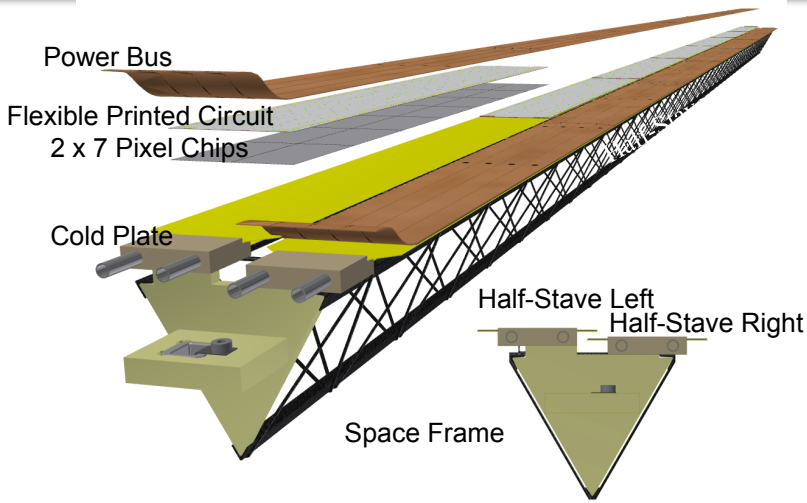
Inner Barrel Stave





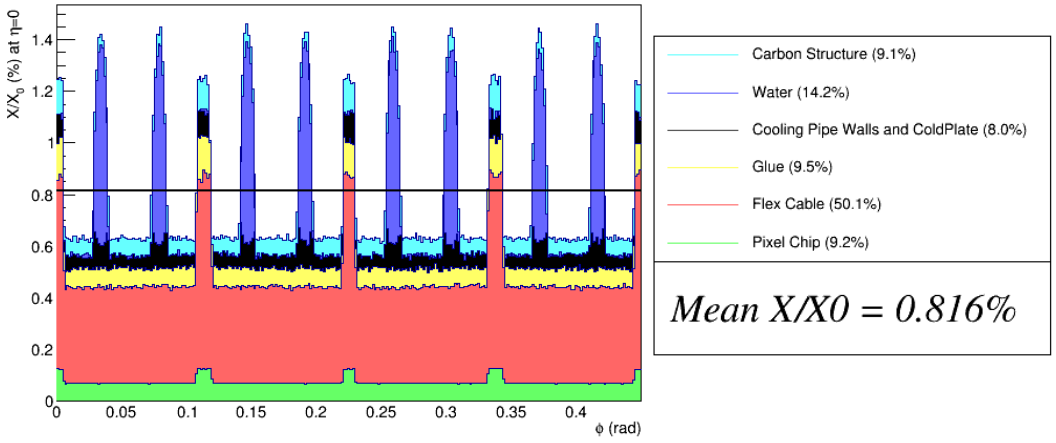
Outer Barrel

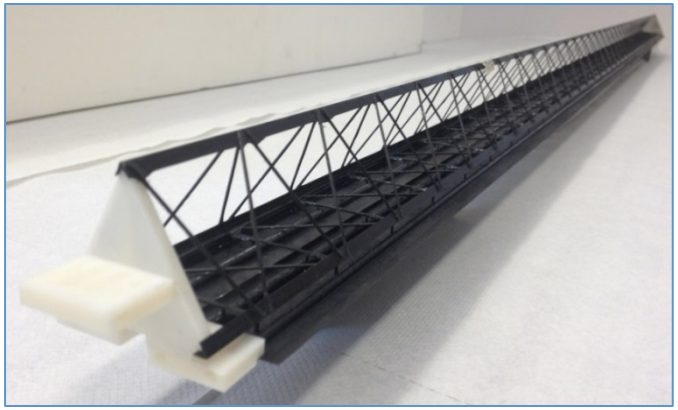




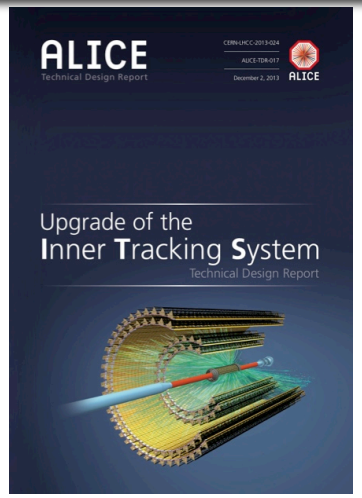
Outer Barrel Stave

Material budget: ~ 0.8 % X_0 per layer



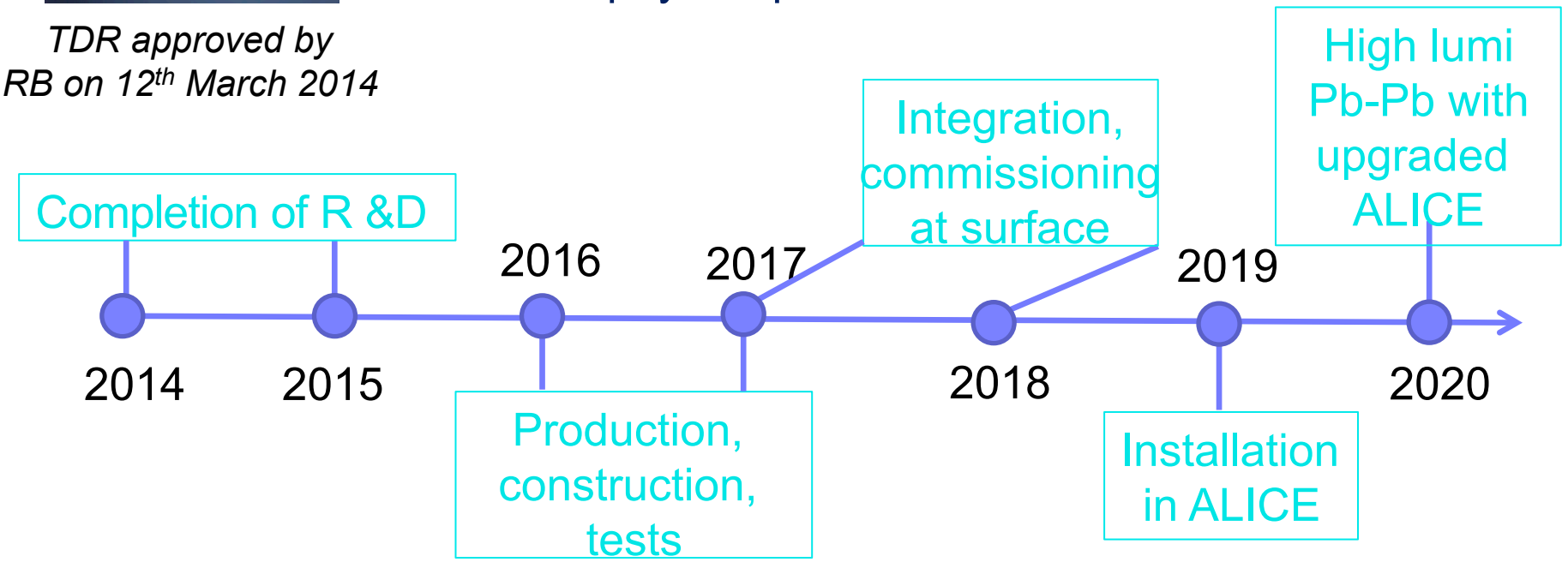


ITS Summary/Outlook

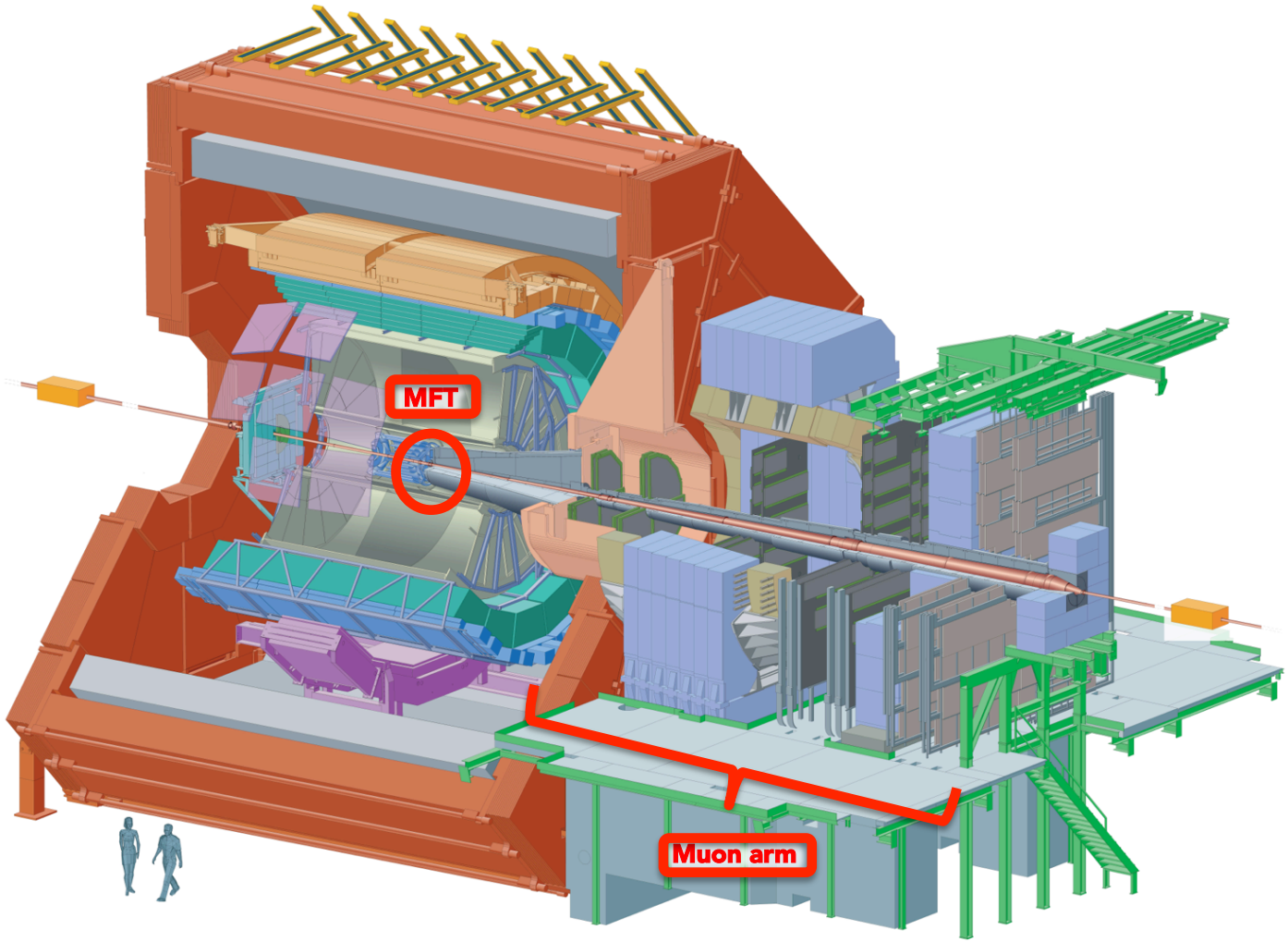


TDR approved by RB on 12th March 2014

- Detector layout and important technological aspects defined
- Integration and installation aspects studied in detail
- Detailed Monte Carlo simulations verified the detector and physics performances

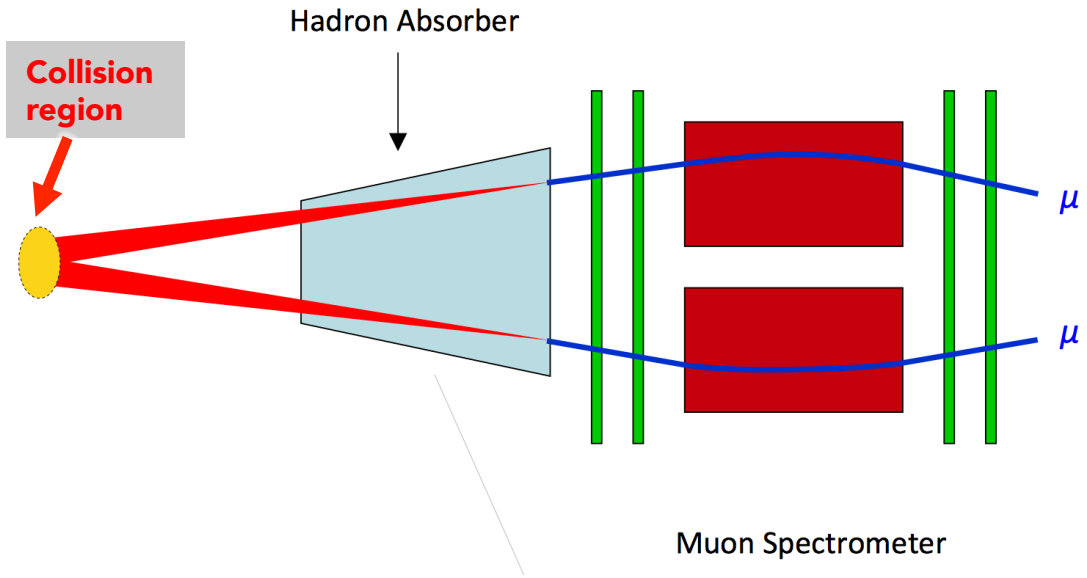


ALICE MFT upgrade



MFT concept (1)

- ALICE muon arm: detect muons in forward **range -4.0 < η < -2.5**
- Muon Forward Tracker (MFT) design objectives: Increase pointing accuracy for the muon tracks, in particular at low p_T



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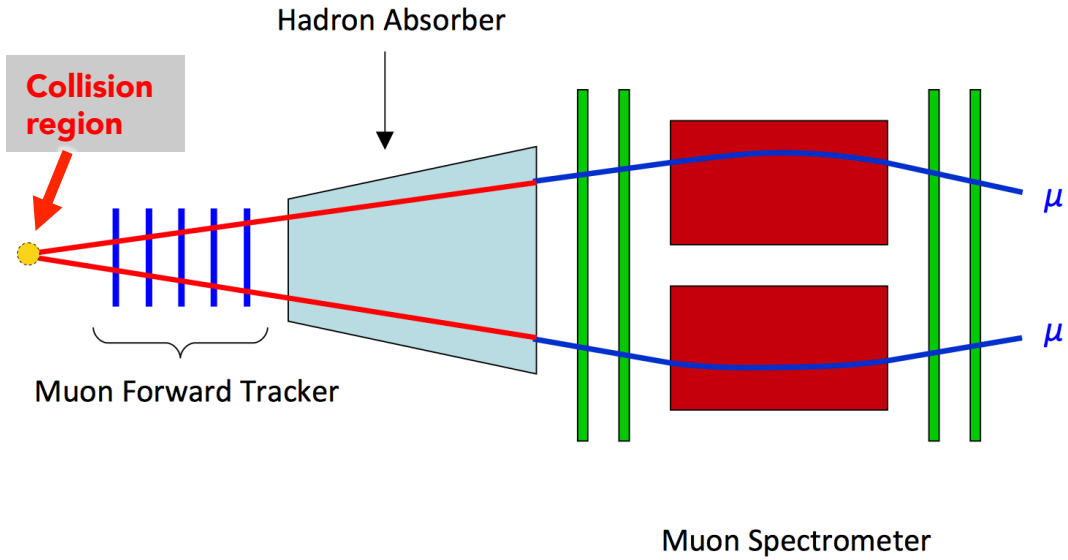

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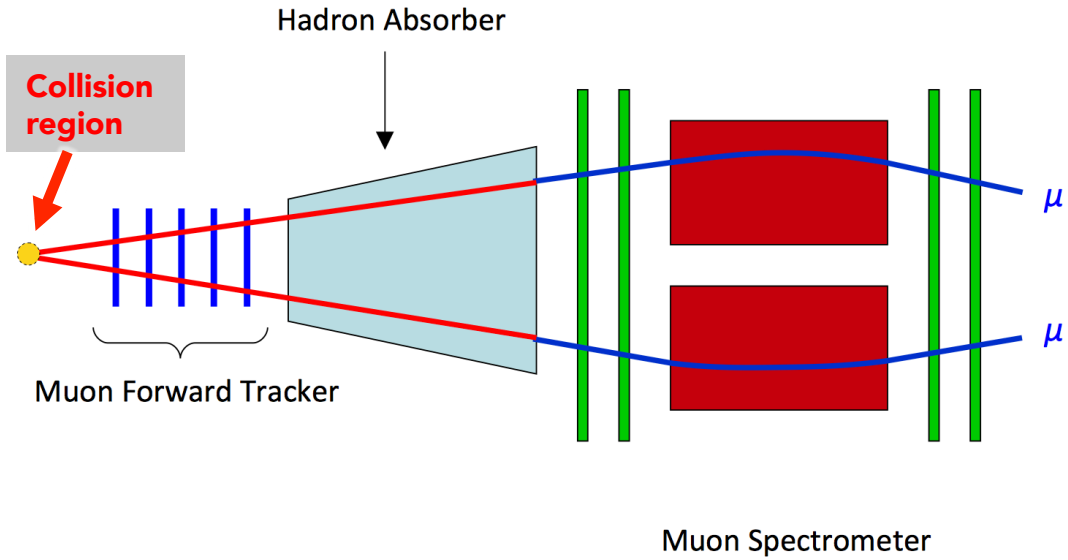
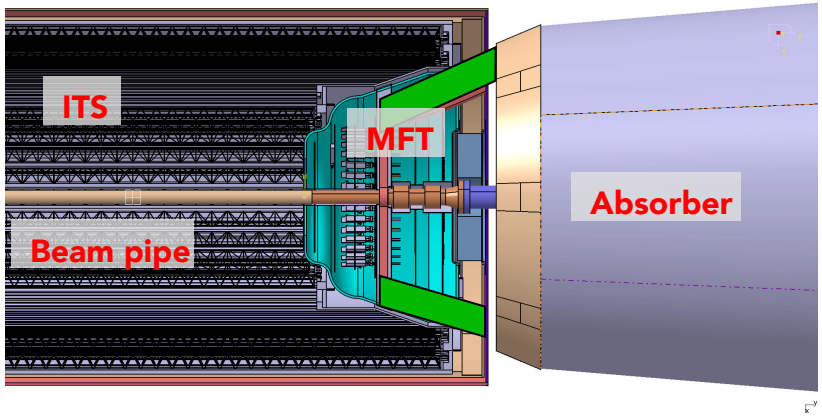
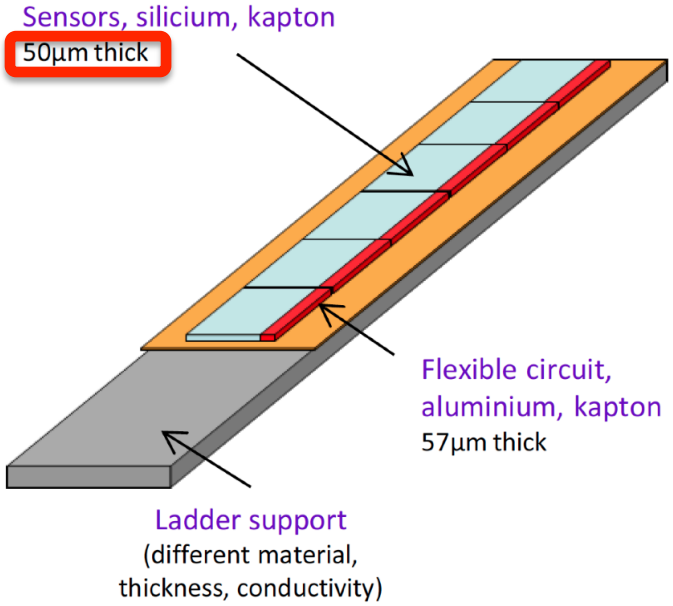


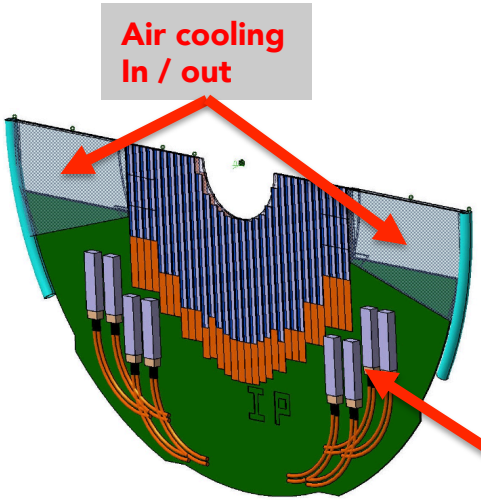


Plane	Int. radius (cm)	Ext. radius (cm)	Z location (cm)	Pixel pitch (μm)	Thickness (% of X_0)
0	2.5	11.0	-50		
1	2.5	12.3	-58		
2	3.0	13.7	-66	25	0.4
3	3.5	14.6	-72		
4	3.5	15.5	-76		

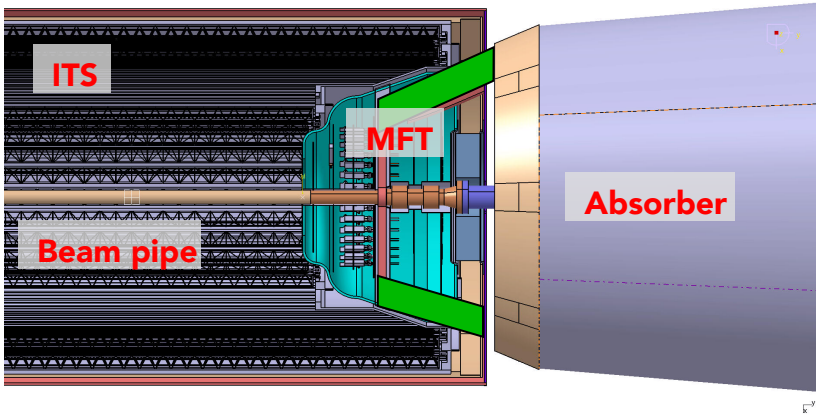
MFT baseline simulation set-up

MFT layout



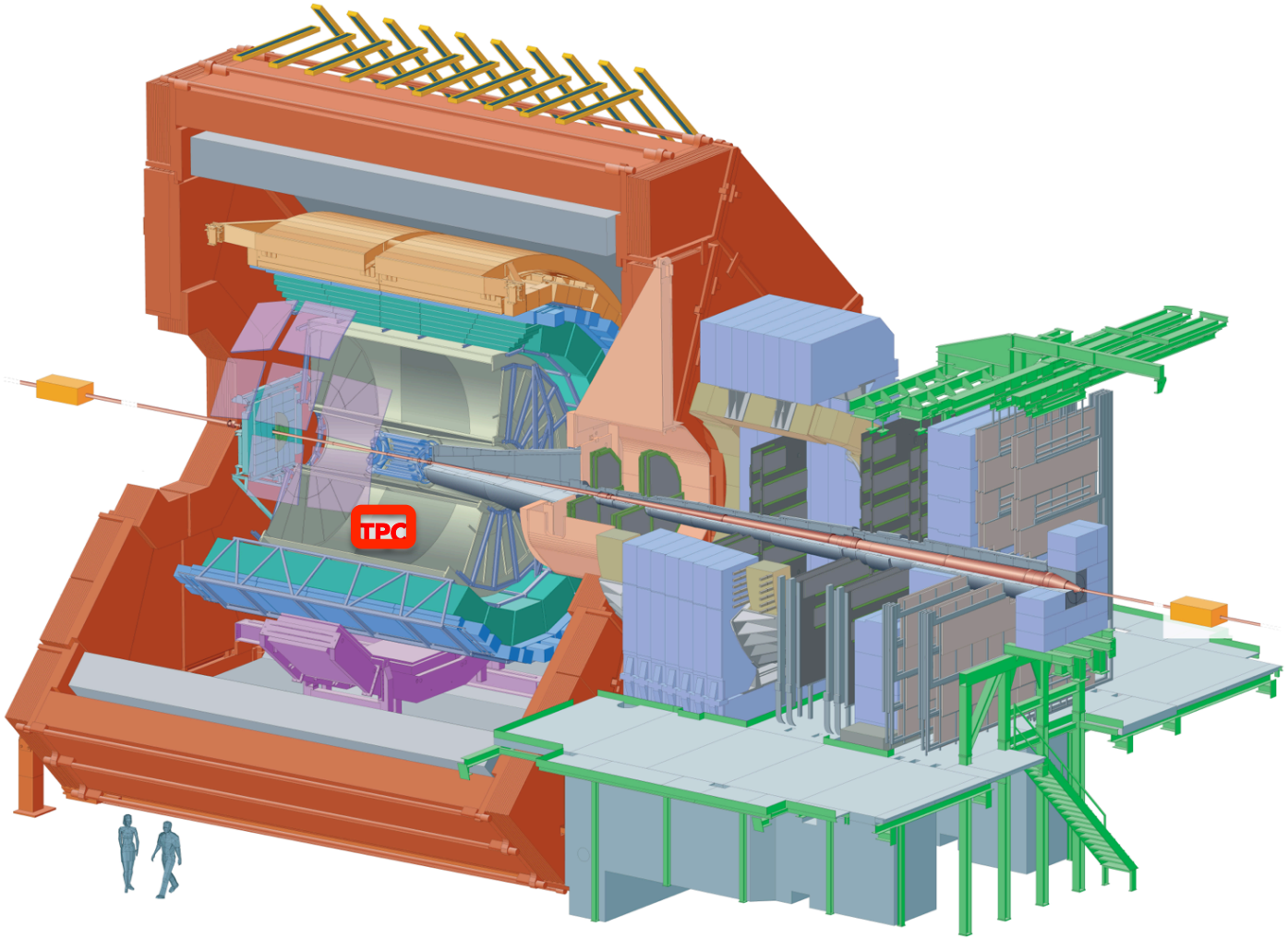


Example of the structure of a half disk assembled from ladders



- Pixel sensors assembled on flexible circuits to form ladders
- 5 planes assembled from ladders
- Pixel chip: Same technology as for ITS (MAPS)
- Optimized for low-material thickness

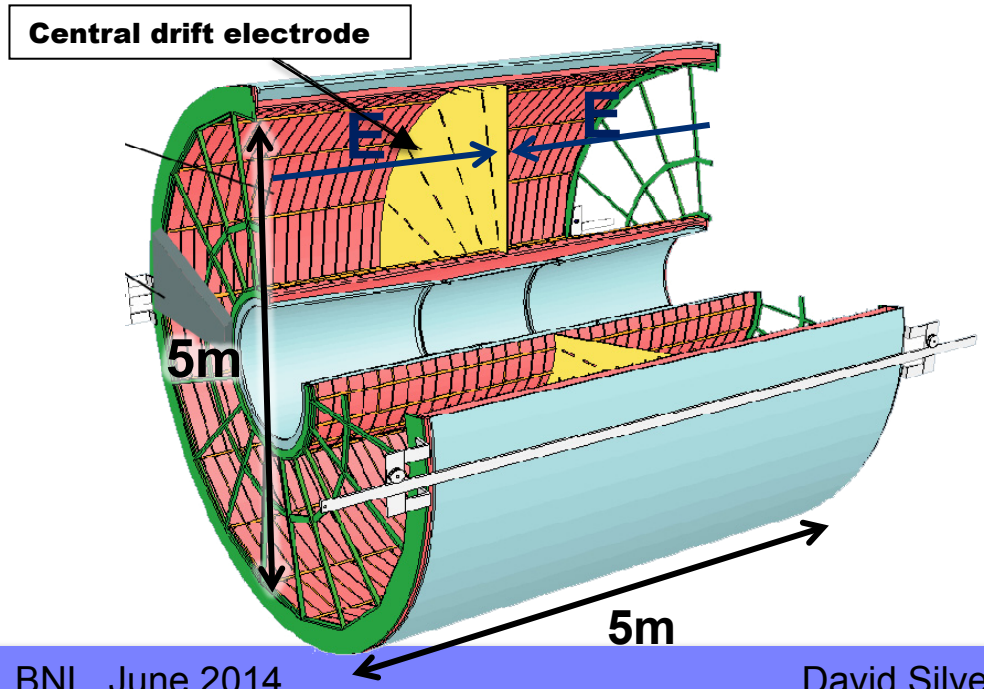
ALICE TPC upgrade

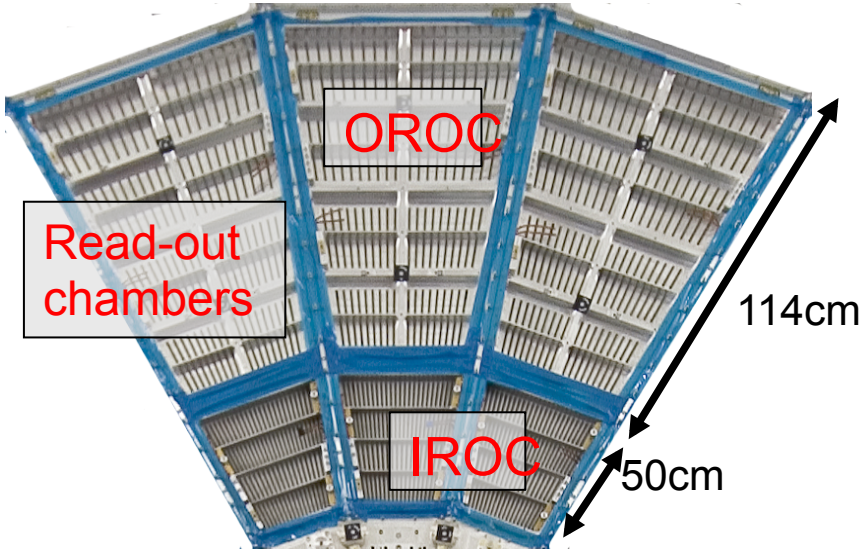


TPC overview

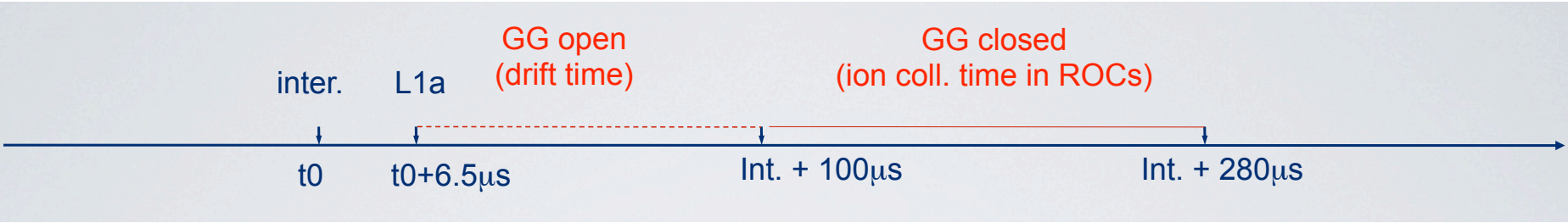
- Diameter: 5 m, length: 5 m
- Acceptance: $|\eta| < 0.9$, $\Delta\phi = 2\pi$
- Gas: Ne-CO_2 (90-10) in Run1
- Drift field = 400V/cm
  - Diffusion: $\sigma_T \approx \sigma_L \approx 0.2$ mm/$\sqrt{\text{cm}}$
  - $v_d \approx 2.7$ cm/μs, max. drift time: 92 μs

- **Read-out Chambers: Total = 36 × 2**
  - **outer (OROC): 18 × 2**
  - **inner (IROC): 18 × 2**
- **Pad sizes: 4 × 7.5 mm², 6 × 10 (15) mm²**
- **Channel number: 557 568**
- **In Run1 & Run2: MWPC + gating grid operation**
  - **Rate limitation: few kHz**





Existing TPC: Rate Limitations



- gating grid
  - open during drift time to allow electrons into MWPC
  - closed afterwards to prevent ion back-flow
  - limits readout rate to 3.5 kHz
- opening GG permanently not possible
  - ion back flow creates large space charge
  - space point distortions up to 1 m – not tolerable

TPC upgrade objectives

- Main objective: Retain physics performance in high rate operation
  - continuous read-out of Pb-Pb events at 50 kHz collision rate

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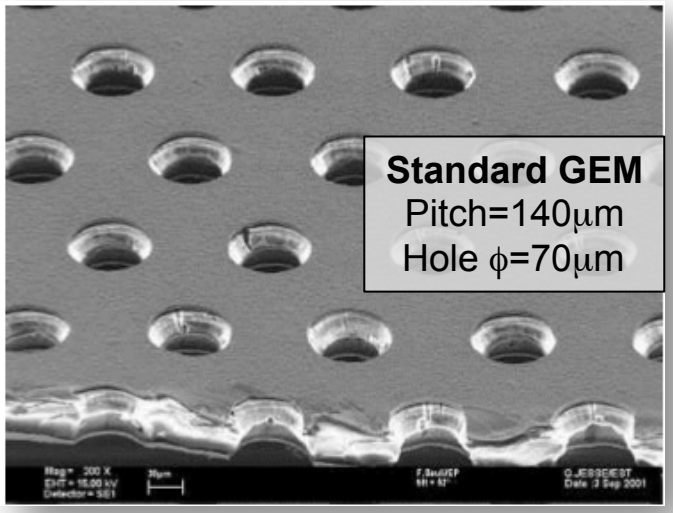
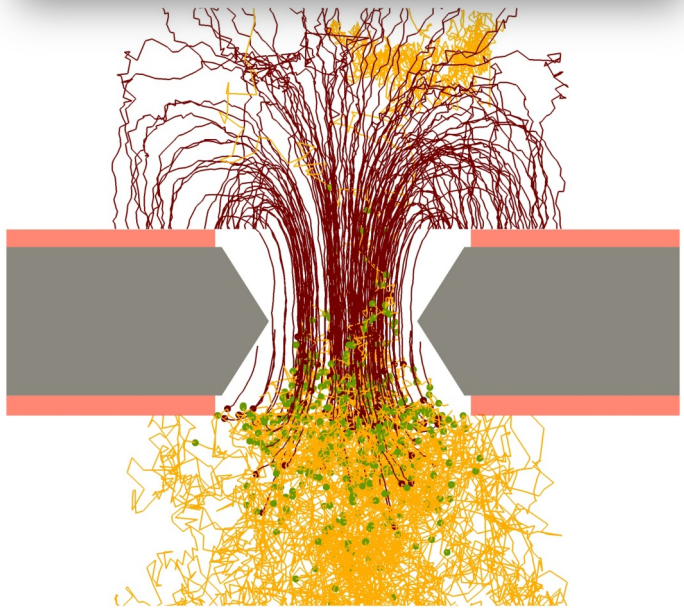
- Main objective: Retain physics performance in high rate operation
  - continuous read-out of Pb-Pb events at 50 kHz collision rate
- Operation of MWPC without gating grid would lead to massive space-charge distortions due to back-drifting ions
- Instead: Continuous read-out with micro-pattern gaseous detectors
- Advantages:
  - reduced ion backflow (IBF)
  - high rate capability
  - no long ion tail

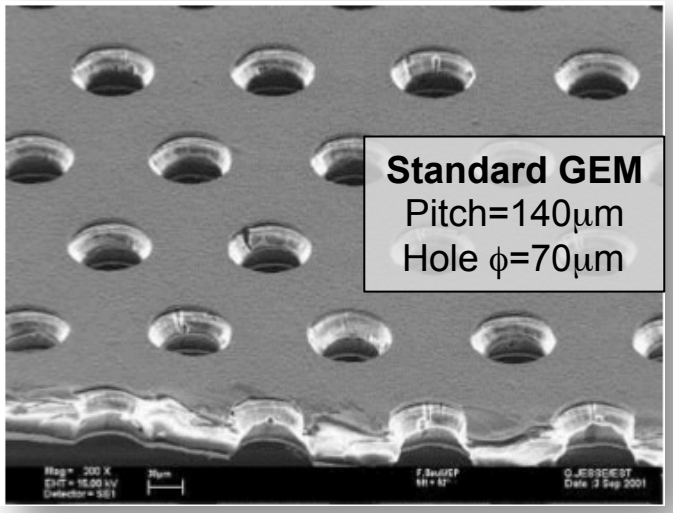


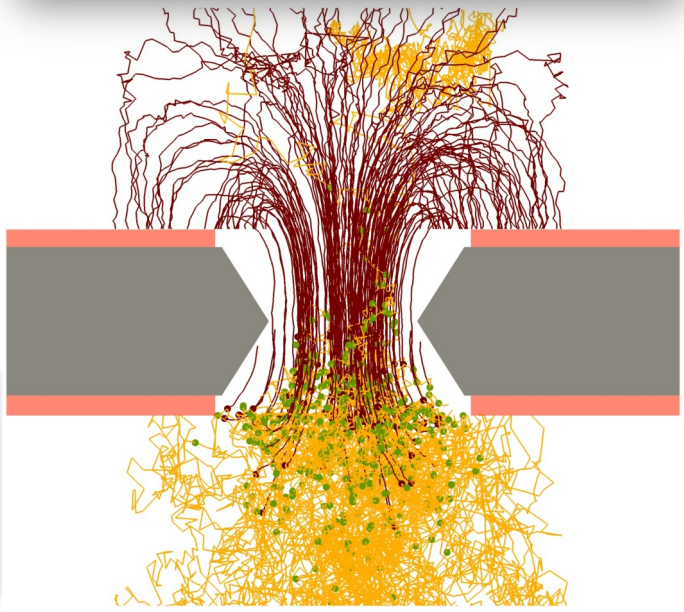


TPC upgrade objectives

- Main objective: Retain physics performance in high rate operation
  - continuous read-out of Pb-Pb events at 50 kHz collision rate
- Operation of MWPC without gating grid would lead to massive space-charge distortions due to back-drifting ions
- Instead: Continuous read-out with micro-pattern gaseous detectors
- Advantages:
  - reduced ion backflow (IBF)
  - high rate capability
  - no long ion tail

- Requirements for read-out system:
  - **IBF < 1% at gain 2000**
  - **d*E*/d*x* resolution < 12% for ^{55}Fe**
  - **Stable operation under LHC conditions**

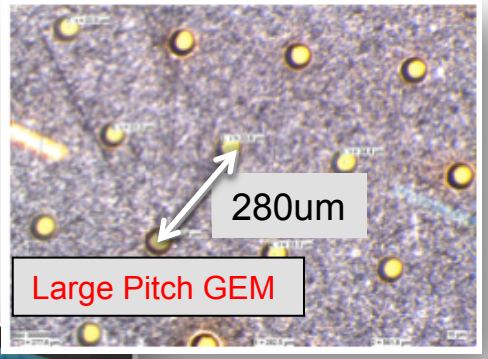


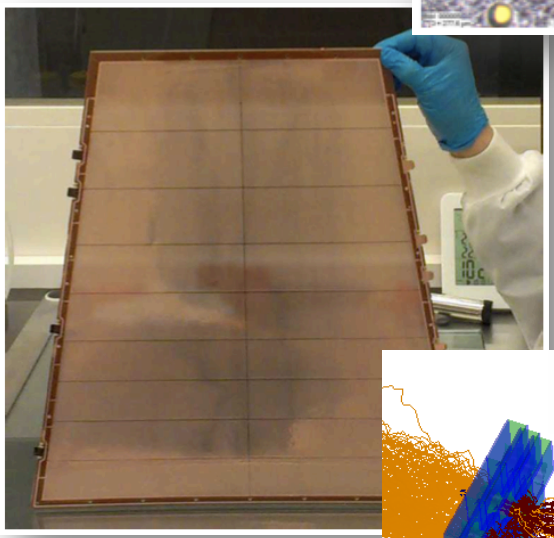


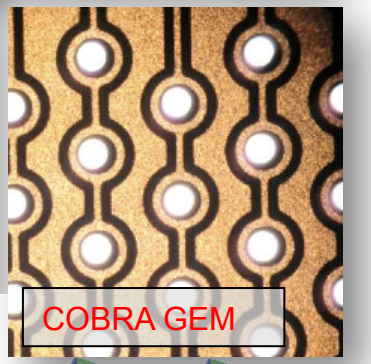
GEM TPC R&D Program

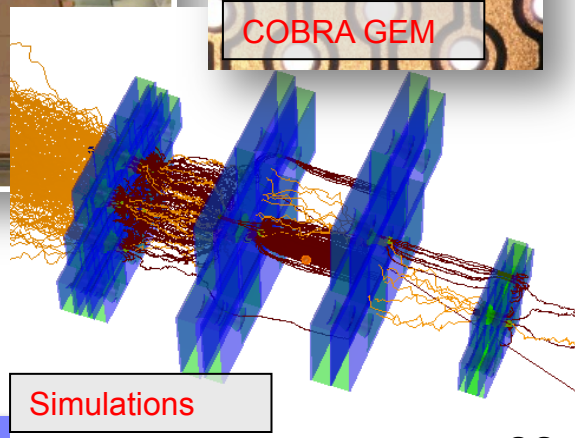
- Extensive studies started in 2012
  1. technology choice
     - Baseline: Stacks of standard (S) and large-pitch (LP) GEM foils
     - 2 GEM + MicroMegas (MMG)
     - COBRA-GEM
  2. ion backflow
  3. gain stability
  4. discharge probability
  5. large-size prototype
     - single mask technology
  6. electronics R&D
  7. garfield simulations
  8. physics and performance simulations
- Collaboration with RD51 at CERN

(e.g. meeting this week @ CERN…)





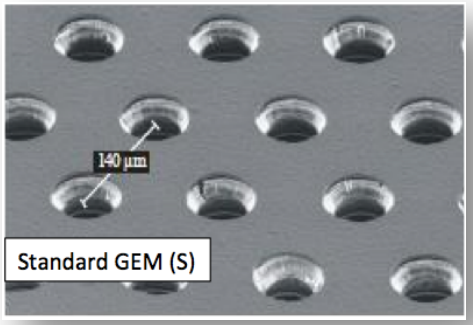


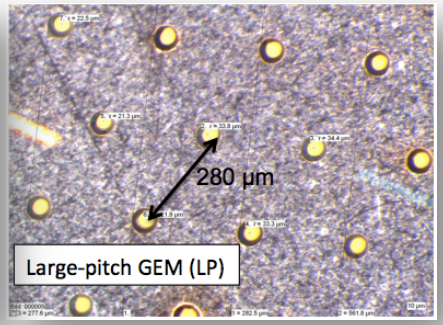


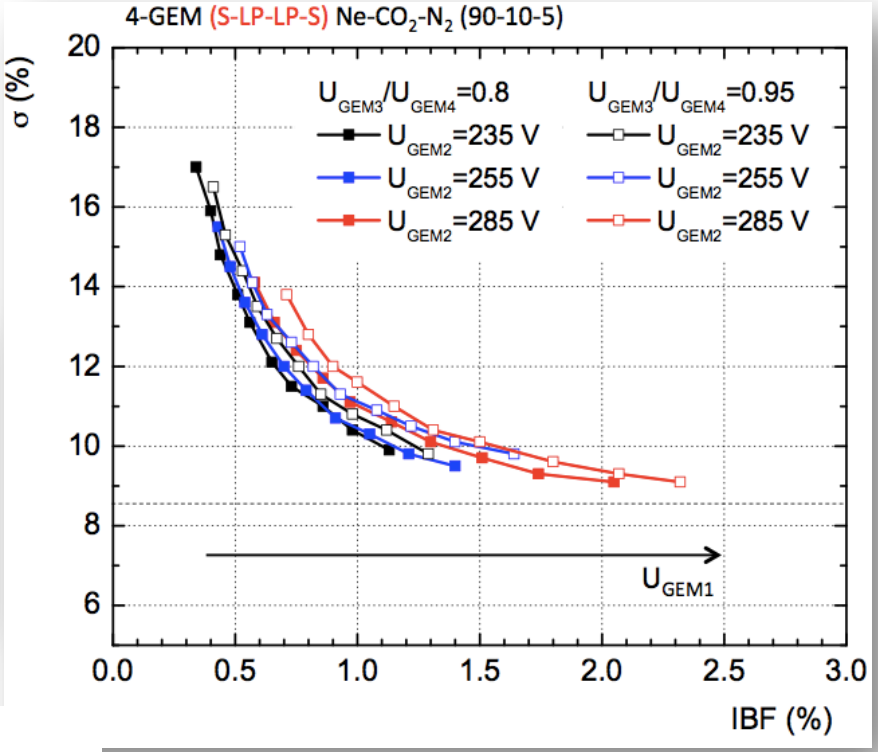
4GEM setup with S and LP foils

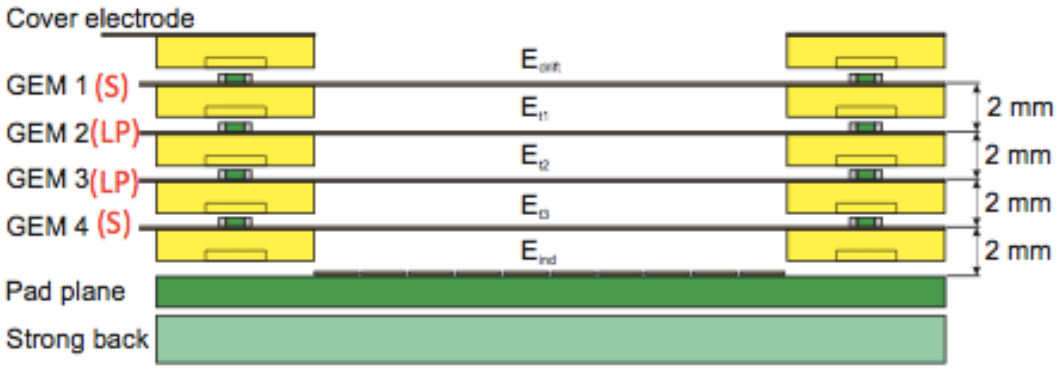
IBF and energy resolution studies for baseline solution (4GEM stack)

- different foil configurations, V_{GEM} , E_T (transfer fields)





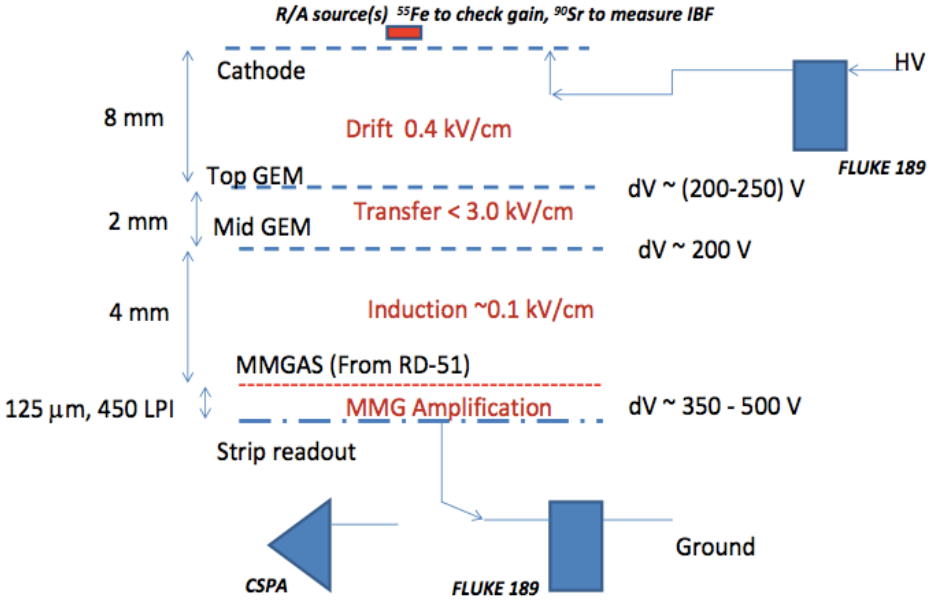




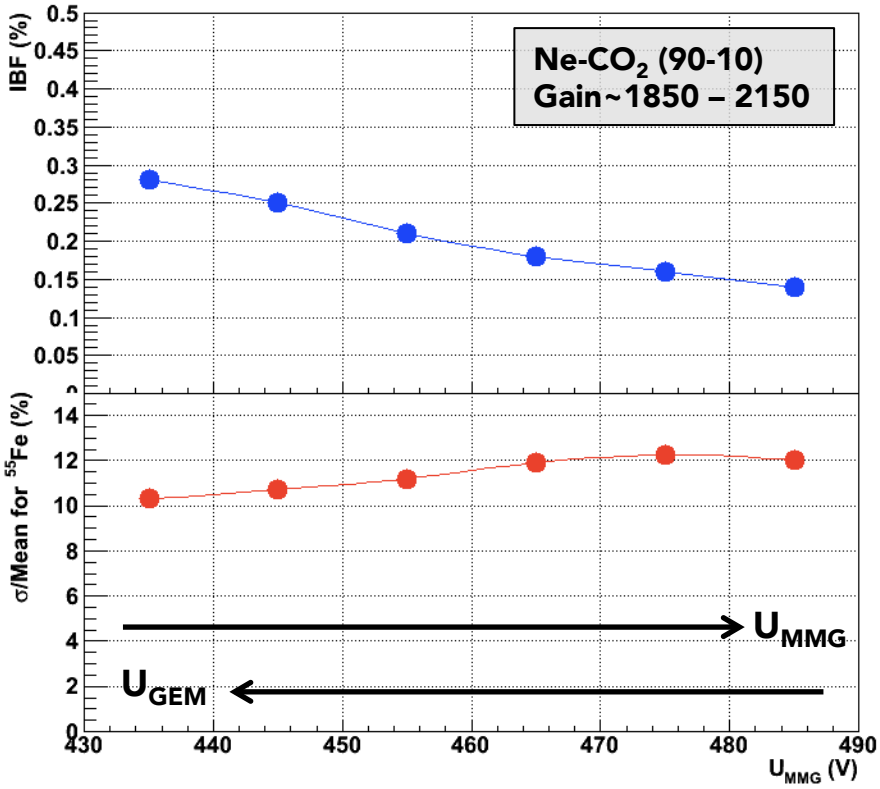
- **IBF optimized settings: High E_{T1} & E_{T2} , low E_{T3} , $V_{GEM1} \approx V_{GEM2} \approx V_{GEM3} << V_{GEM4}$**
- **Achieved performance: 0.6 - 0.8 % IBF at σ (5.9 keV) ~ 12 %**

Alternative: 2 GEM + MicroMegas

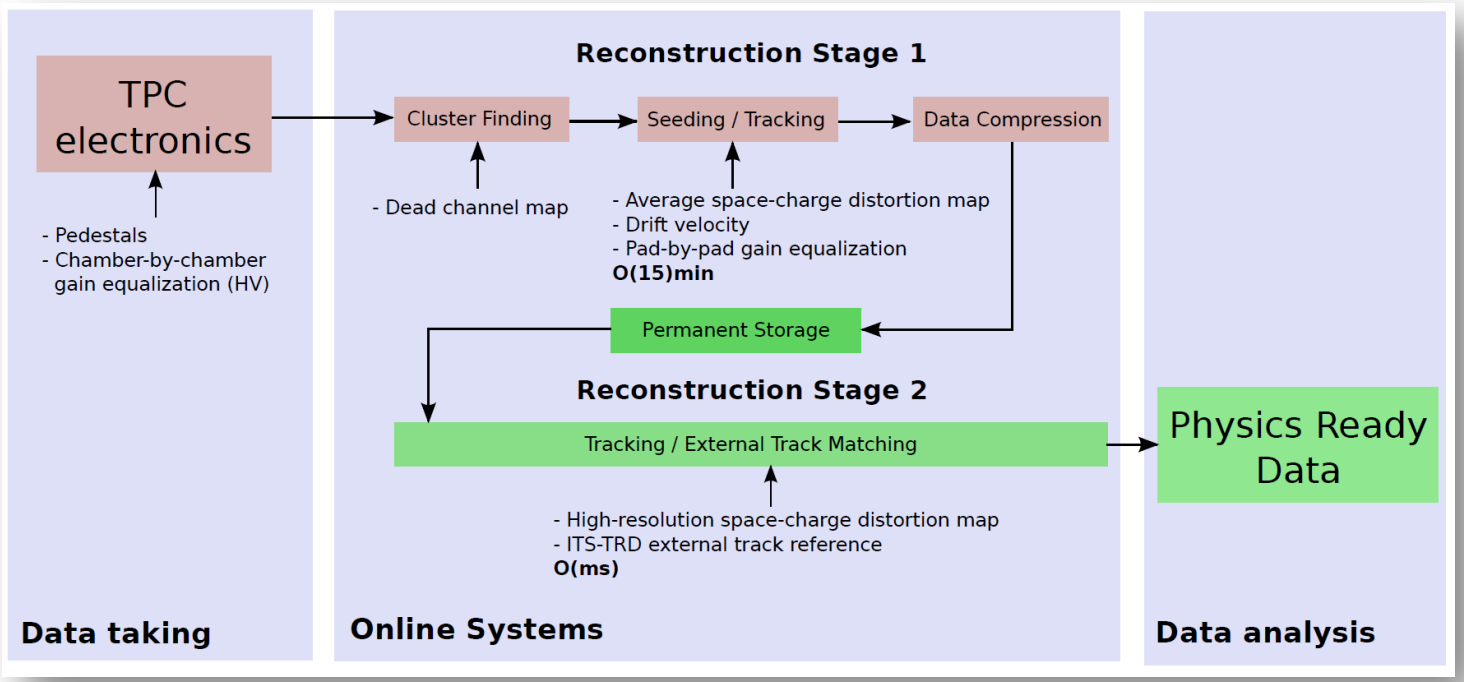
- IBF and Resolution studies
  - V_{MMG} , V_{GEM} , transfer field E_T
  - **IBF < 0.2% at σ(5.9keV) ~12 % feasible**



Large-scale solution and operational stability still to be verified



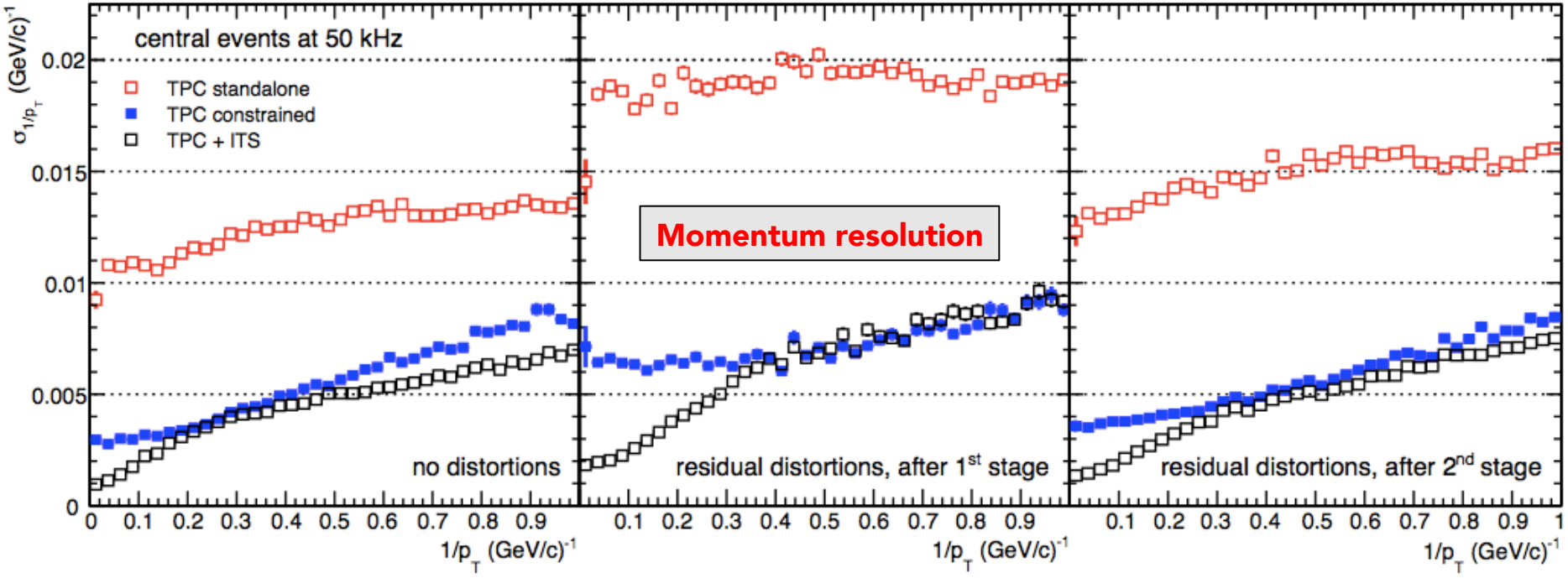
TPC reconstruction scheme



- Two stage reconstruction scheme:
  1. Cluster finding and cluster-to-track association in the TPC
     - data compression by factor 20 : 1 TB/s → 50 GB/s
     - use scaled average space-charge distortion map
  2. Full tracking with matching to inner and outer detectors (ITS and TRD)
     - use high resolution space-charge map (time interval~5 ms) for full distortion calibration

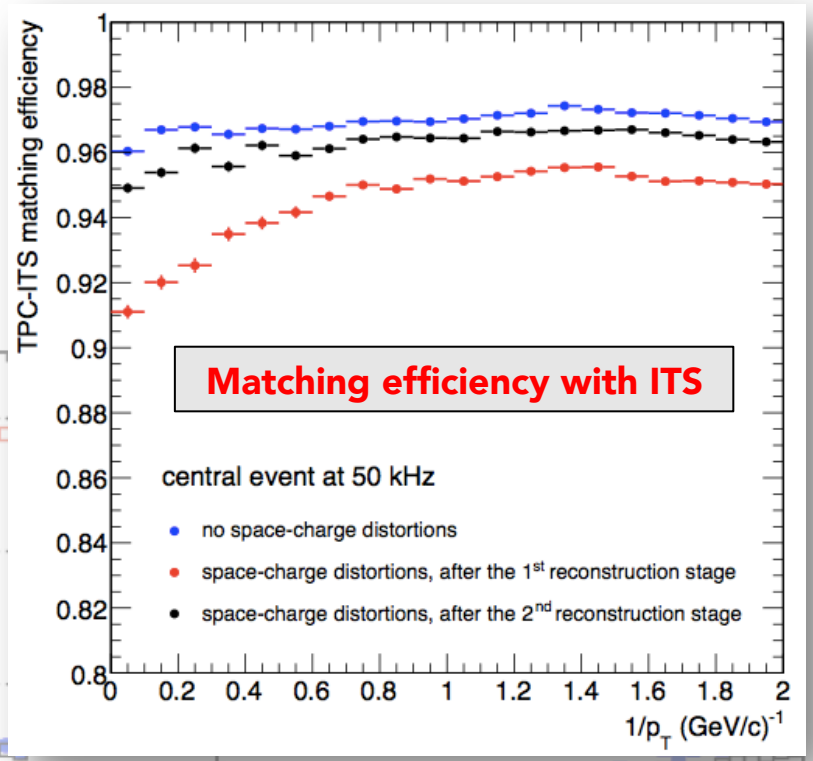
Expected TPC performance (1)

- Space charge fluctuations (~3%) are taken into account (N_{evt},$dN_{ch}/d\eta$,etc)
- **p_T resolution practically recovered after 2nd reconstruction stage**



Expected TPC performance (2)

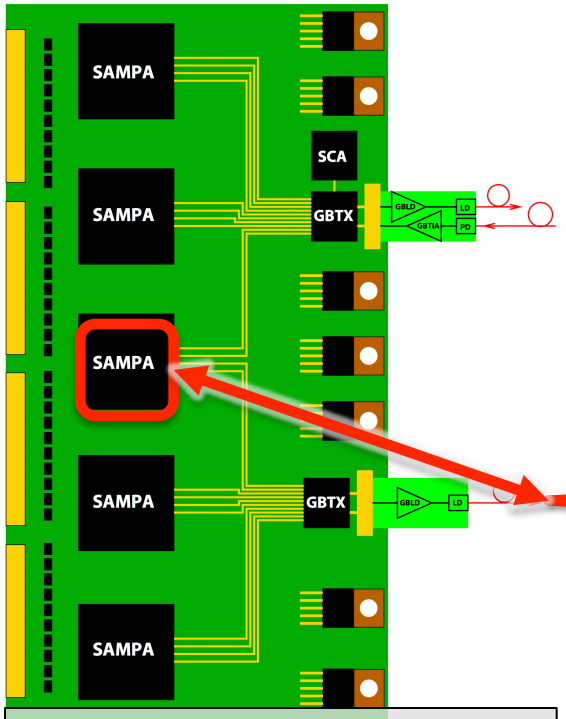
- Space charge fluctuations (~3%) are taken into account (N_{evt},$dN_{ch}/d\eta$,etc)
- **p_T resolution practically recovered after 2nd reconstruction stage**
- **ITS-TPC track matching retained**



TPC read-out ASIC: SAMPA

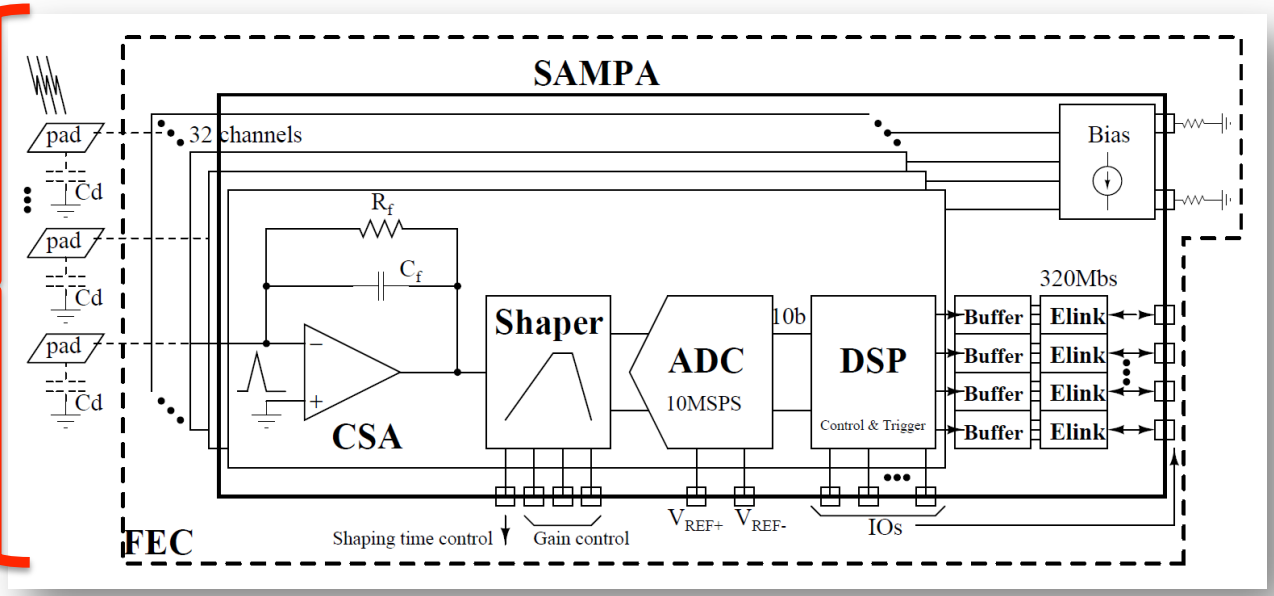
- Integrate functionality of present preamplifier / shaper and ALTRO ADC + DSP
  - Pos/ neg. polarity
  - continuous / triggered read-out
  - SAR ADC (10 or 20 MSPS)

- **First MPW submission in April**



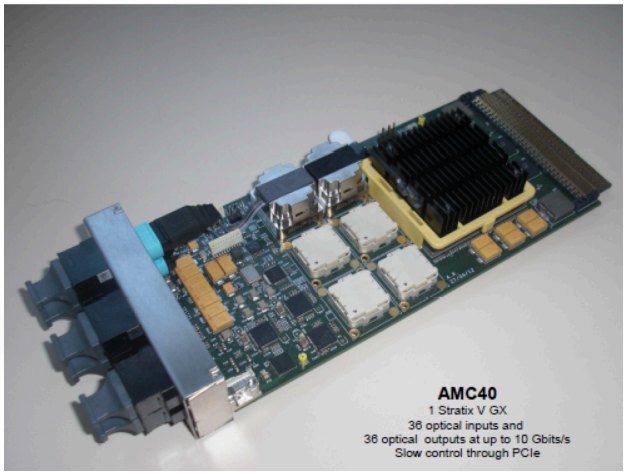
Schematic of Front End Card with 5 SAMPA chips and GBT system

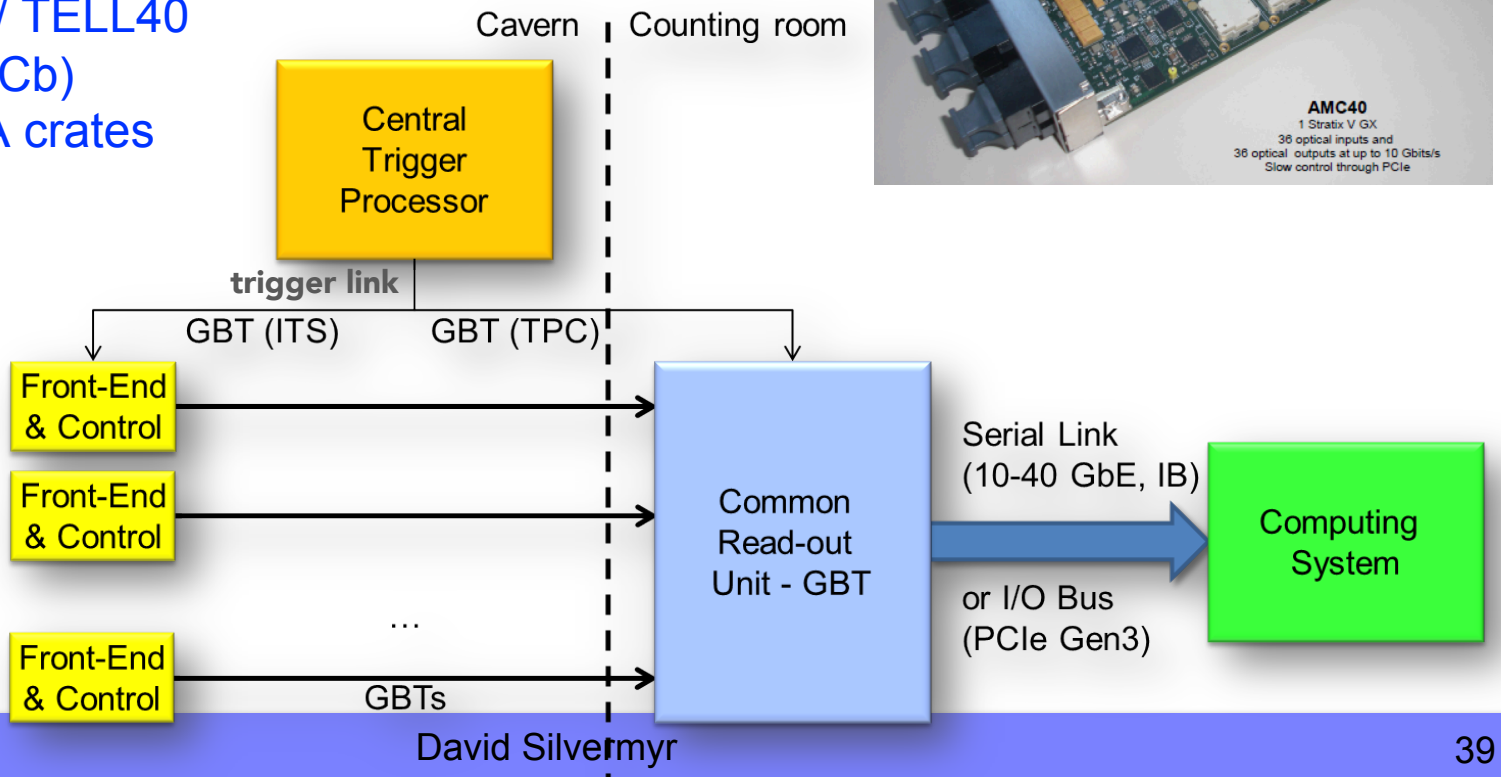
SAMPA functional blocks



ALICE read-out system

- GBT: custom radiation-hard optical link
- Common Read-out Unit
  - interfaces on-detector electronics, online farm (O^2) and trigger system
  - high performance FPGA processors, multi-gigabit optical I/O
  - system evaluation based on AMC40 / TELL40 system (LHCb) using ATCA crates





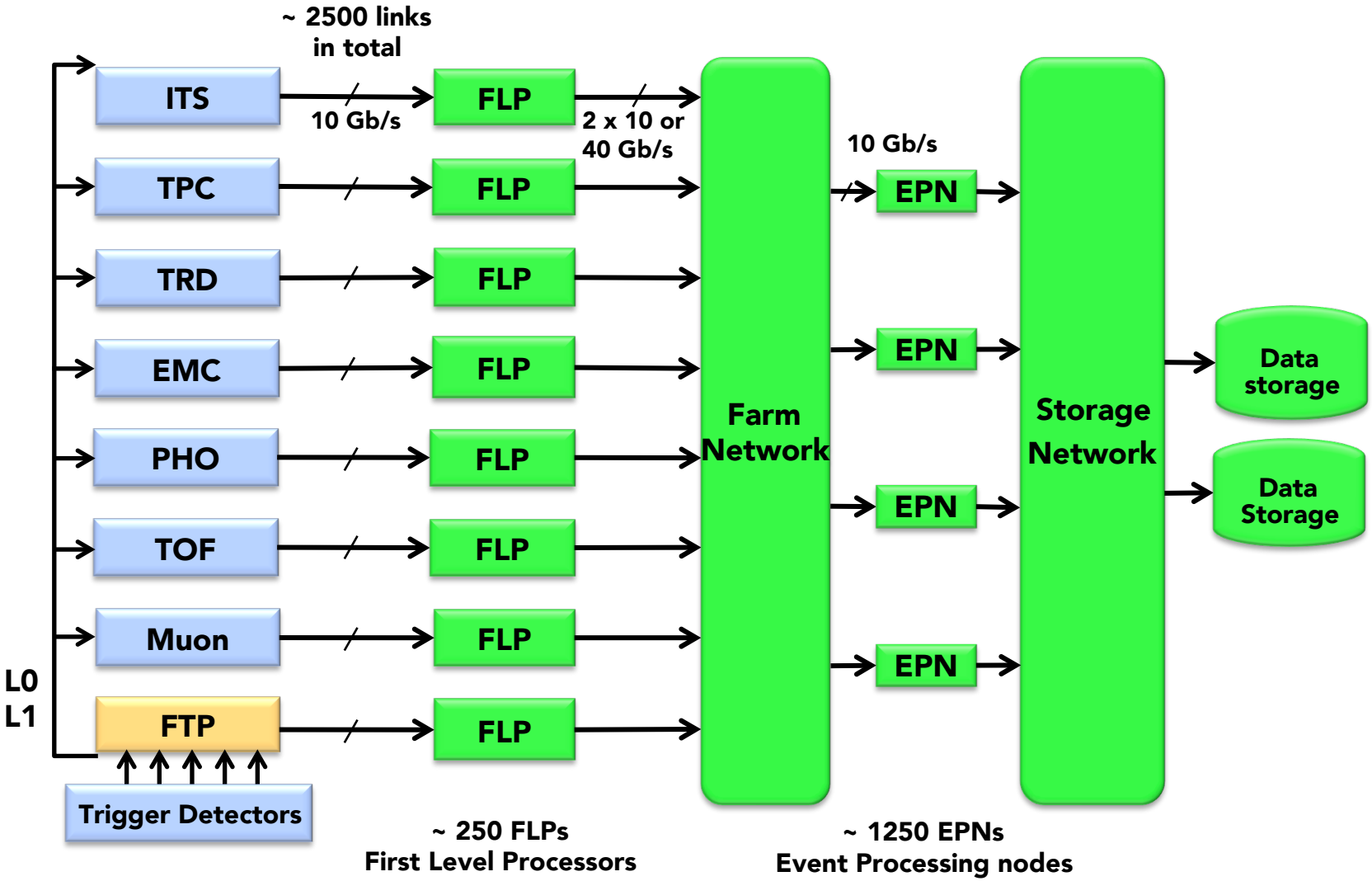
Online systems (1)

- Two reconstruction stages are carried out on the O^2 computing farm
  - first reconstruction stage (aimed at data reduction) online
  - second reconstruction stage (aimed at obtaining final performance) asynchronous
- Data bandwidth:

Detector	Input to Online System (GByte/s)	Peak Output to Local Data Storage (GByte/s)	Avg. output to computing center (GByte/s)
TPC	1000	50.0	8.0
TRD	81.5	10.0	1.6
ITS	40	10.0	1.6
Others	25	12.5	2.0
Total	1146.5	82.5	13.2

- LHC luminosity variation during fill and efficiency taken into account for average output to computing center

Online systems (2)

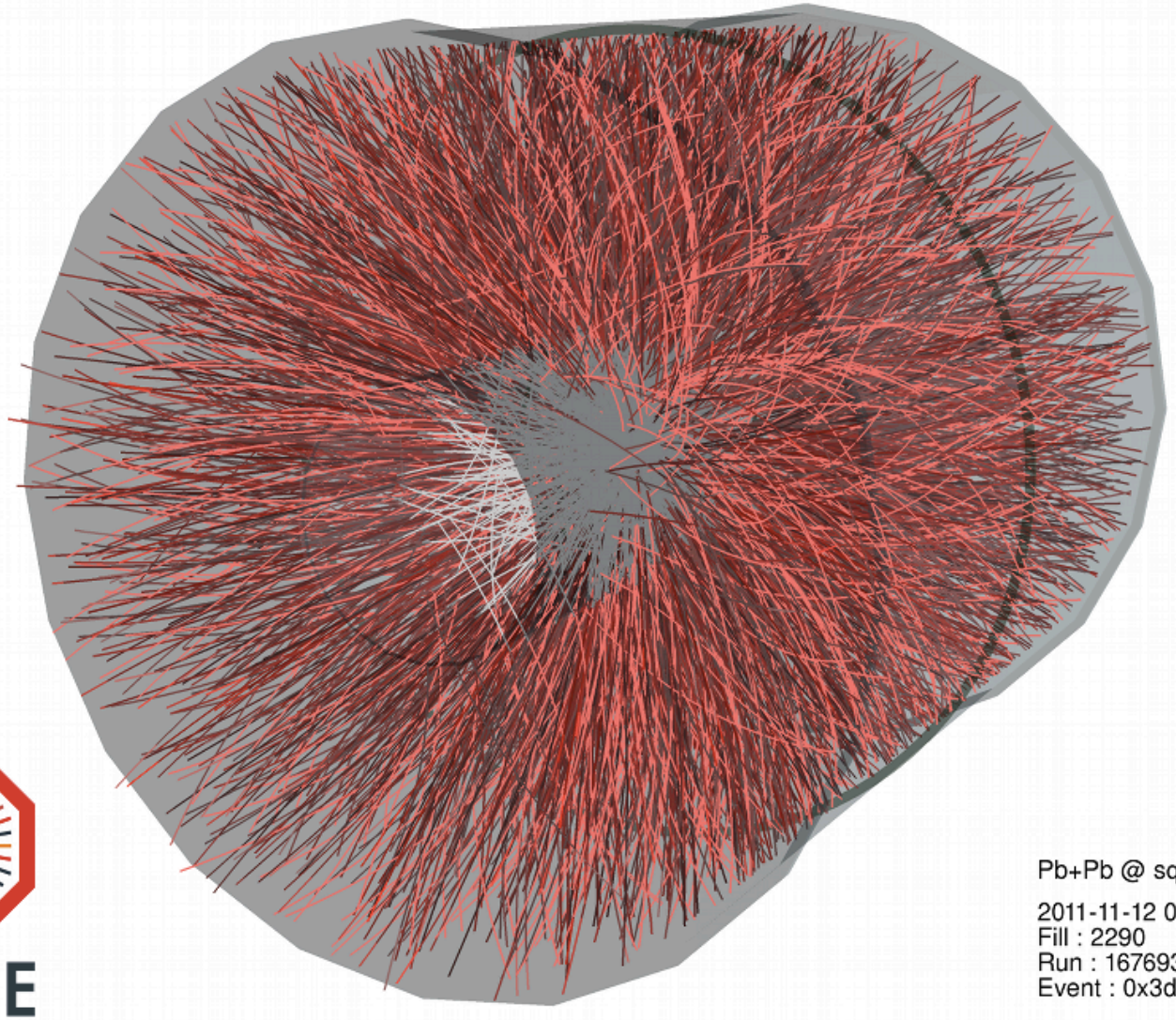


Summary

- Major upgrade of the ALICE detector for installation in 2018/19
  - high statistics, high precision measurements in Pb-Pb give access to rare channels
- Detector modifications to inspect up to 50 kHz Pb-Pb collisions
  - ship all data to online systems either continuously or upon minimum-bias trigger
- Key detector items:
  - New ITS, based on MAPS (7 layers, around 10 m^2)
  - New TPC endplates, based on micro-pattern gaseous detectors and new electronics for continuous read-out
  - New 5-plane muon silicon telescope, based on MAPS, in front of hadron absorber, in the acceptance of the Muon Spectrometer
- Online system (O^2 farm) upgrade integrates DAQ, online and offline facilities
- Technical Design Reports (define construction design)
  - ITS TDR accepted in spring 2014
  - Readout + trigger system and TPC TDRs submitted in autumn 2013 / spring 2014
  - O^2 TDR to be presented in Sep 2014

acknowledgments to all collaborators – and especially C. Lippmann and S. Siddhanta for TIPP'14/QM'14 material

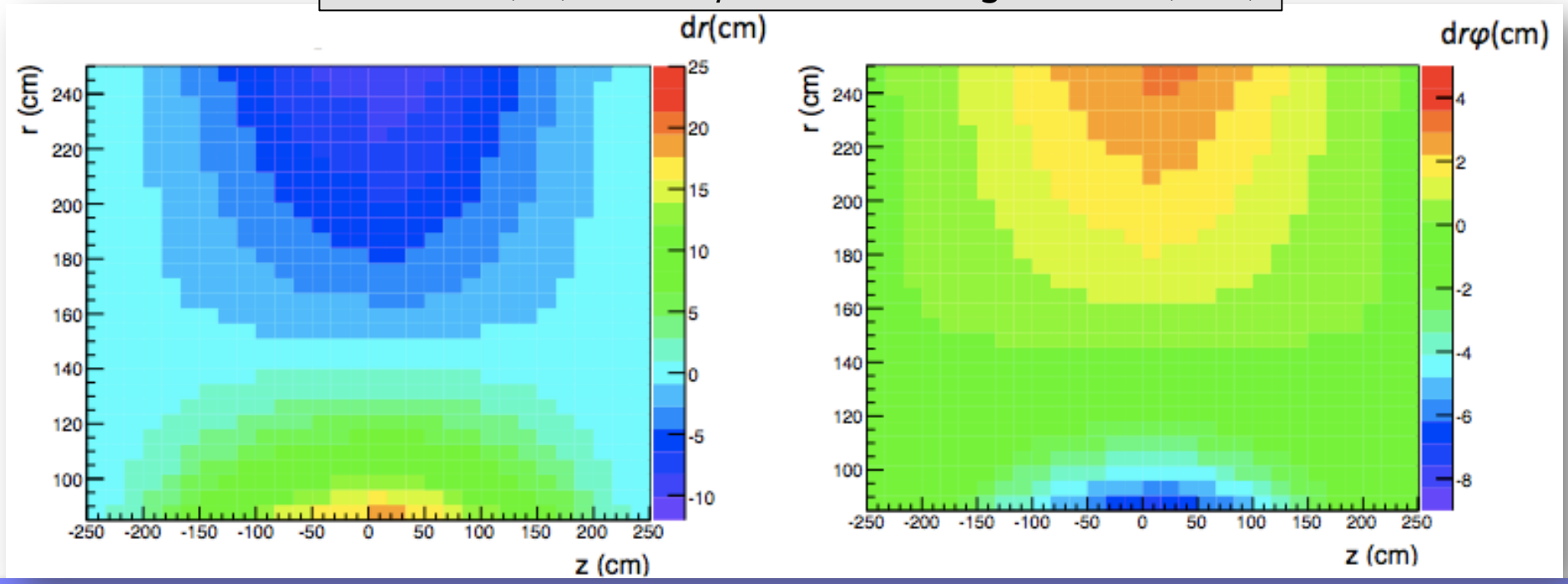
50 kHz of these…



Space Charge Distortions

- For 50kHz Pb-Pb collisions ion pile-up in the drift volume from on average 8000 events (t_{ion}=160ms)
- At small *r* and *z*, d*r* = 20 cm and d$r\phi$ = 8 cm
  - For the largest fraction of drift volume: d*r*<10 cm
- Corrections to a few 10^{-3} are required to achieve final resolution ($\sigma(r\phi) \approx 200$ μm)

Distortions (cm) in *r* and $r\phi$ for 1% of IBF at gain = 2000 (ε=20)



New ITS

smaller material budget
- reduced multiple scattering
- reach lower p_T
- increase 2ndary vertexing capabilities

better vertex resolution
- closer to beam line
- improve heavy flavor measurements

Similarities with STAR HFT upgrade (MAPS technology)