International Conference on Technology and Instrumentation in Particle Physics

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TIPP '14

Upgrade of the ALICE detector

3rd June 2014

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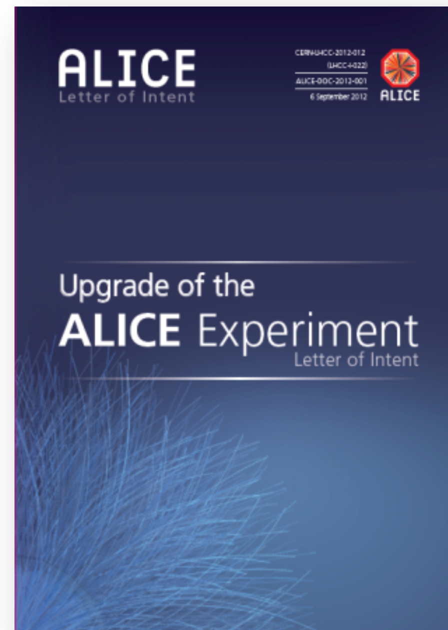
GSI

on behalf of the ALICE collaboration

Content

- The ALICE detector
- ALICE upgrade strategy for LHC Runs 3 (& 4)
- Key upgrade items:
  - Inner Tracking System upgrade
  - Muon system upgrade with MFT
  - Time Projection Chamber upgrade
    - Reconstruction scheme and expected performance
- Summary and Outlook

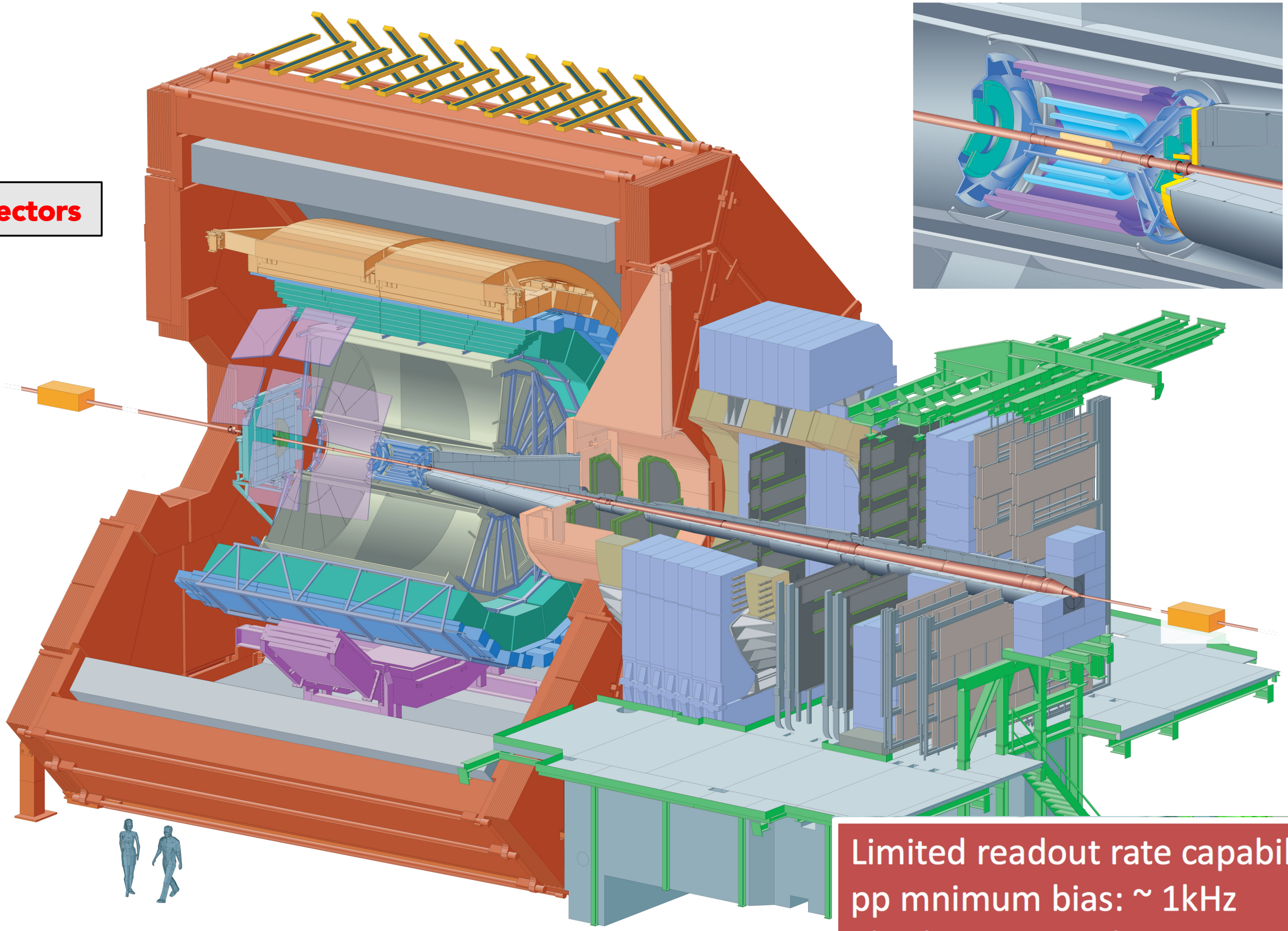
ALICE upgrade Letter of Intent



The ALICE detector now

ALICE is the dedicated heavy-ion experiment at the LHC

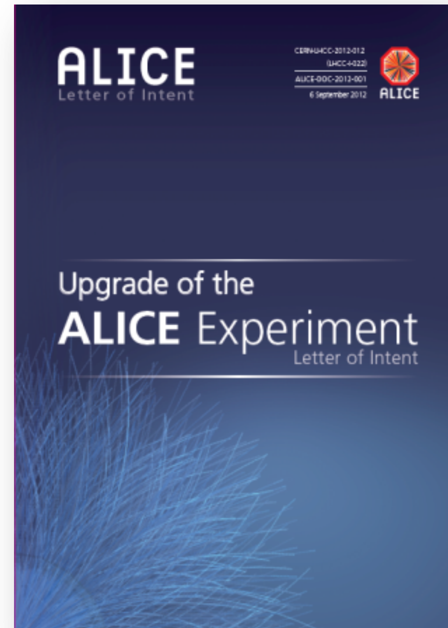
18 sub-detectors



Limited readout rate capability
pp mnimum bias: ~ 1kHz
Pb-Pb minimum bias: ~500 Hz

ALICE upgrade strategy (1)

- **Motivation:** Focus on high-precision measurements of rare probes at low p_T
  - can not be selected with hardware trigger
  - need to record large sample of events
- **Target:** Pb-Pb recorded luminosity: $\geq$ 10 nb^{-1}
  - gain in statistics: factor 100 for selected probes!
  - plus pp and p-A data
- **Strategy:**
  - read out all Pb-Pb interactions at a maximum rate of 50 kHz with a minimum-bias trigger or continuously (TPC)
  - perform online data reduction
- **When**: 2nd LHC Long Shutdown (LS2): 2018/19
- Upgrade Letter Of Intent : CERN-LHCC-2012-12
- MFT Addendum to the LoI: CERN-LHCC-2013-014

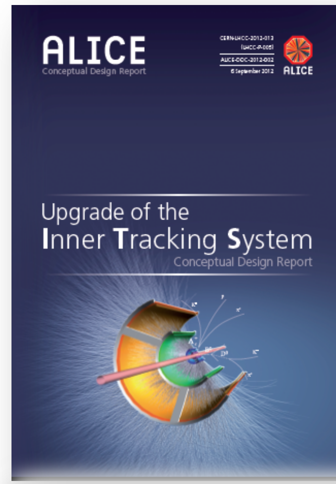


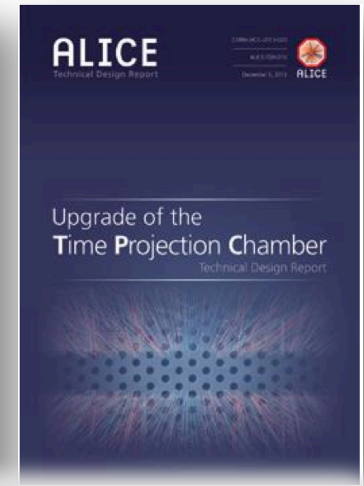
ALICE upgrade Letter of Intent

ALICE upgrade strategy (2)

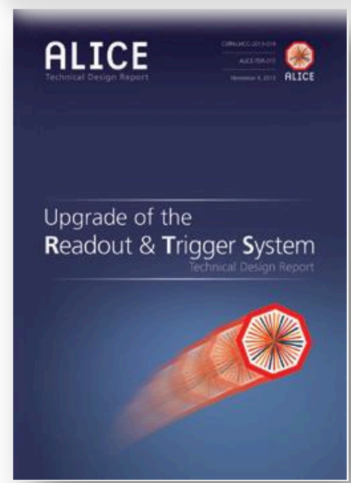
- **ALICE key upgrade items discussed here**
  - **new, high-resolution, low-material Inner Tracking System (ITS)**
  - **upgrade of Time Projection Chamber (TPC)**
  - **new Muon Forward Tracker (MFT): a silicon telescope in front of hadron absorber in the acceptance of the Muon Spectrometer**

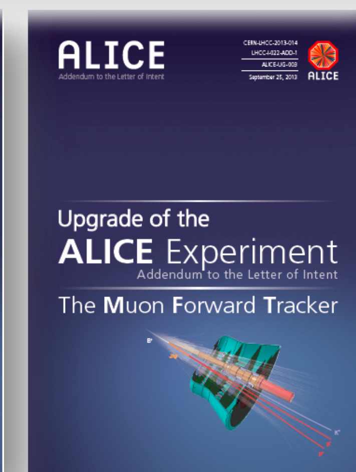
- **More upgrade items**
  - **upgrade of the online systems (O^2)**
  - **upgrade of the forward trigger detectors (FIT) and ZDC**
  - **upgrade of read-out electronics of: TRD, TOF, PHOS and Muon Spectrometer**
  - **upgrade of the offline reconstruction and analysis framework**





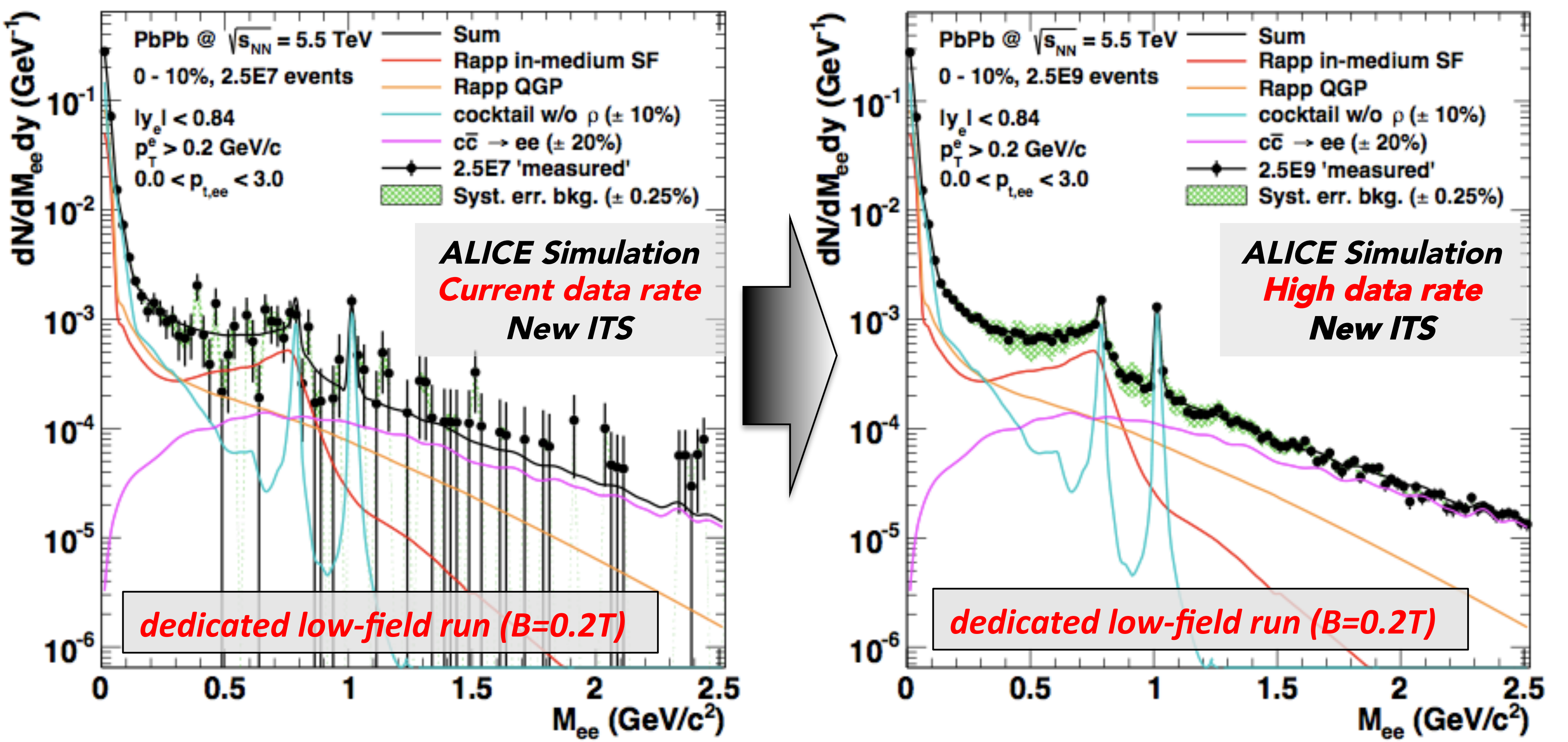
ALICE upgrade TDRs, MFT LOI addendum



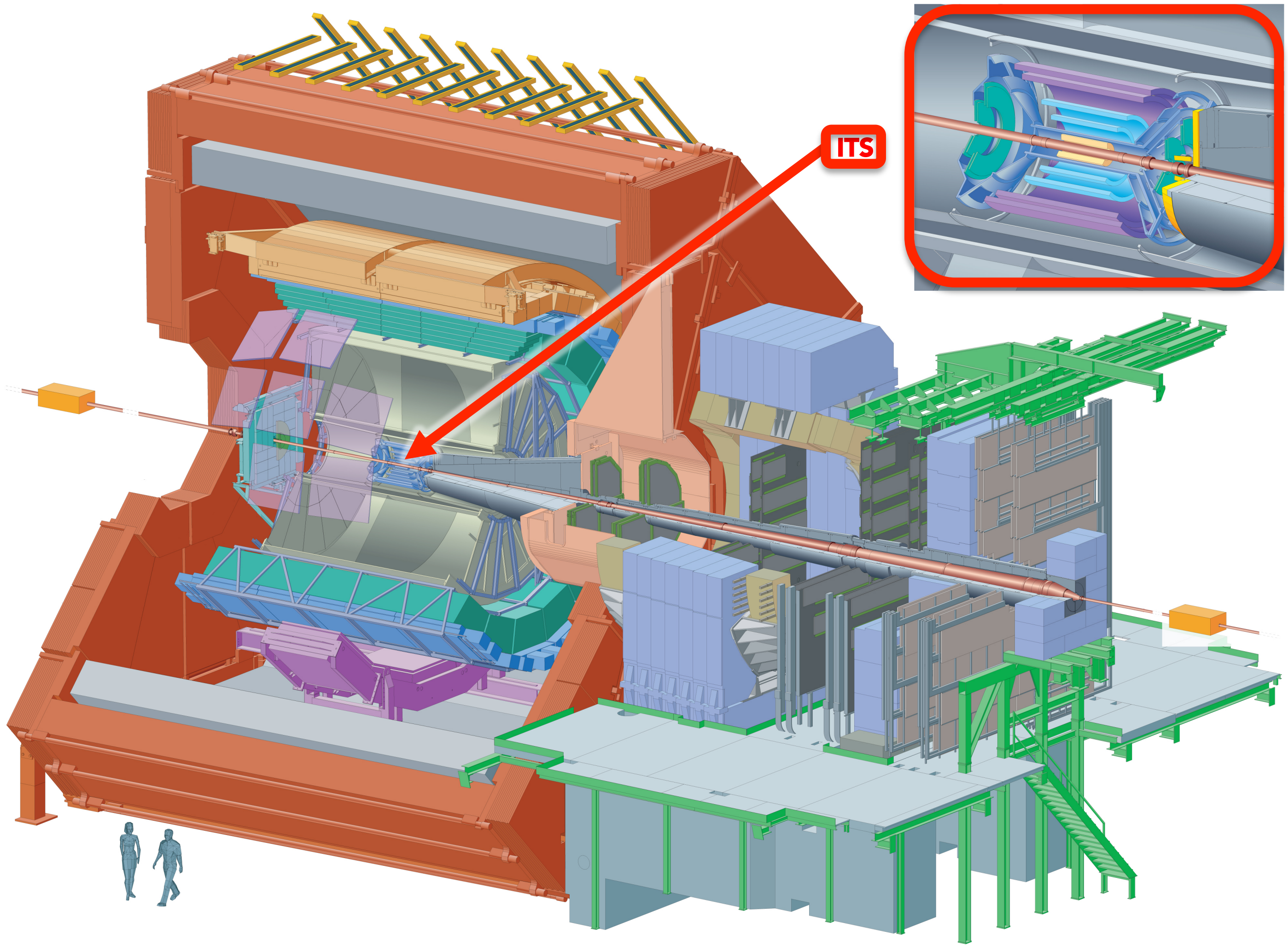


Example: Low mass di-electrons

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



ALICE ITS upgrade



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 impact parameter 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**

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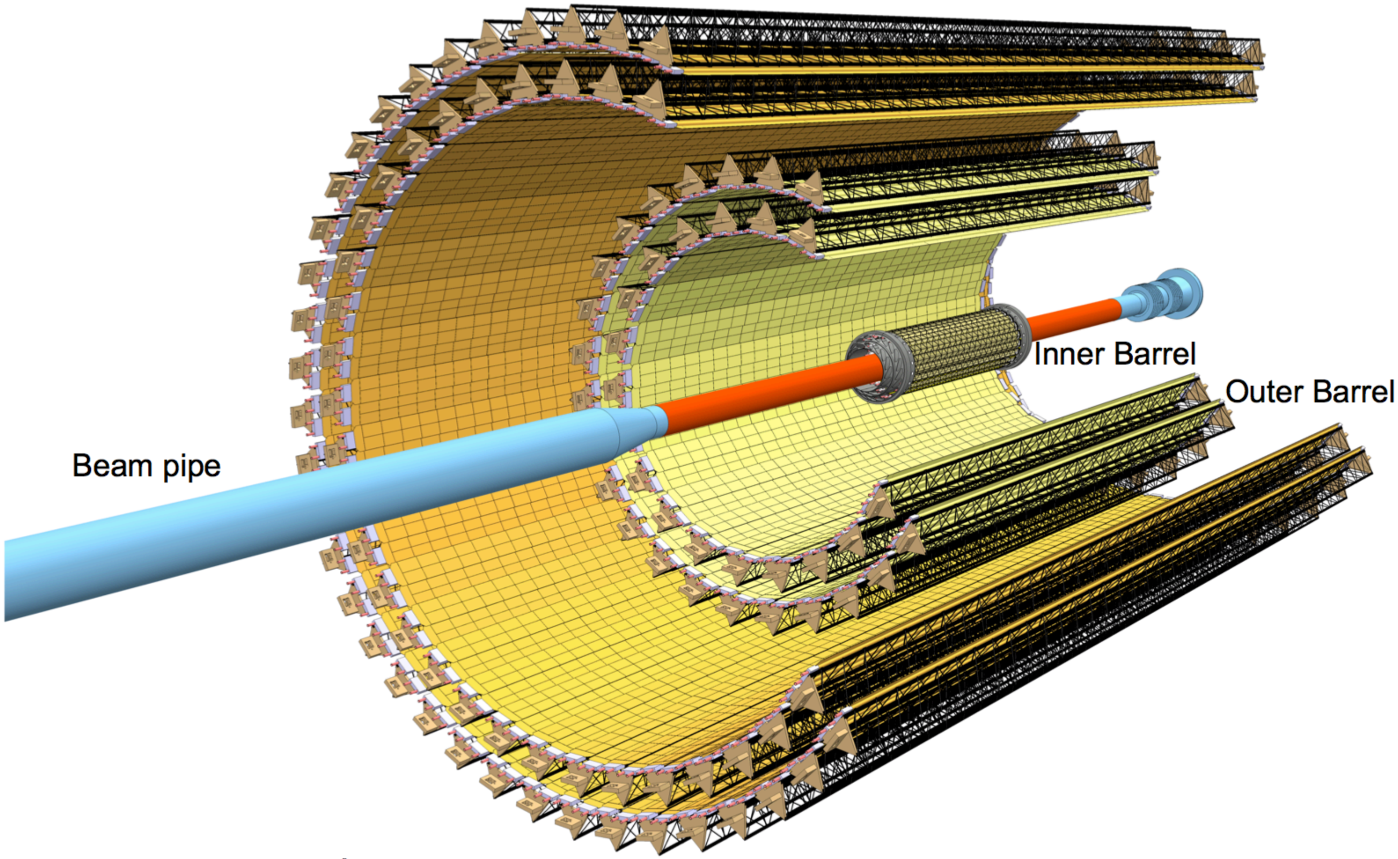
  4. **easier maintenance**

- **Implementation:**
  - **Monolithic Active Pixel Sensors (MAPS)**
  - **increase number of layers: 6 → 7**
  - **reduced pixel size: $50 \times 425\ \mu m^2$ → $\mathcal{O}$ ($30 \times 30\ \mu m^2$)**
  - **reduced material budget, in particular for the 3 innermost layers**
    - **silicon thickness: 50 μm**
    - **X / X_0 = 1.14 % → 0.3 % per layer for the first layers**
  - **first layer closer to IP (r_0= 39 mm → 22 mm)**
    - **smaller beam pipe: 29 mm → 18.2 mm**

New ITS layout



25 Gpixels

Area: ~10m²

Inner barrel: 3 layers

Outer barrel: 2+2 layers

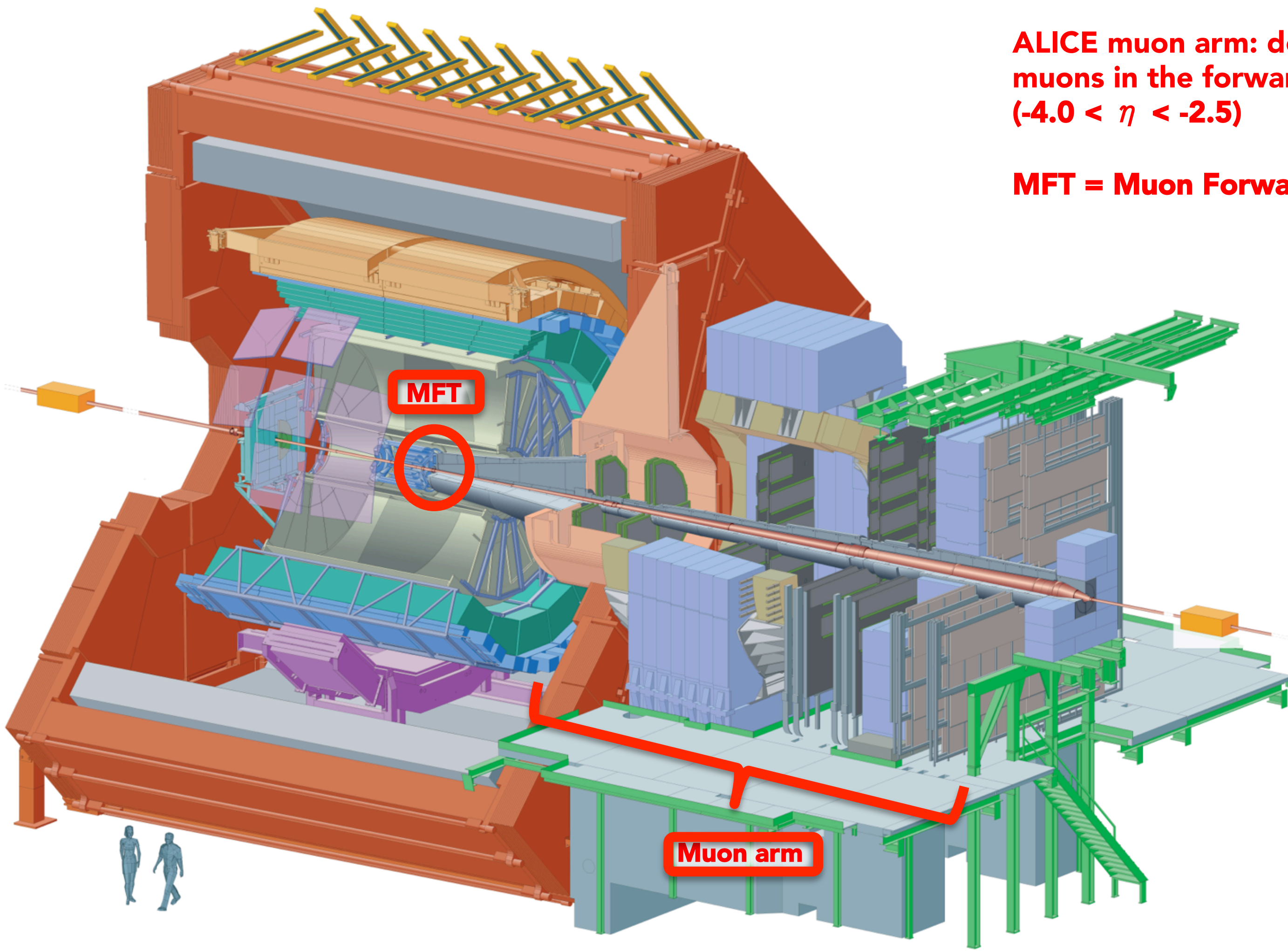
|η| ≤ 1.22 for tracks from 90% most luminous region

***r* coverage: 22 – 430 mm**

For more details see:

- **Presentation by J. W. Van Hoorne, Tue 3 Jun, 17:10 and**
- **Poster by A. Collu**

ALICE MFT upgrade

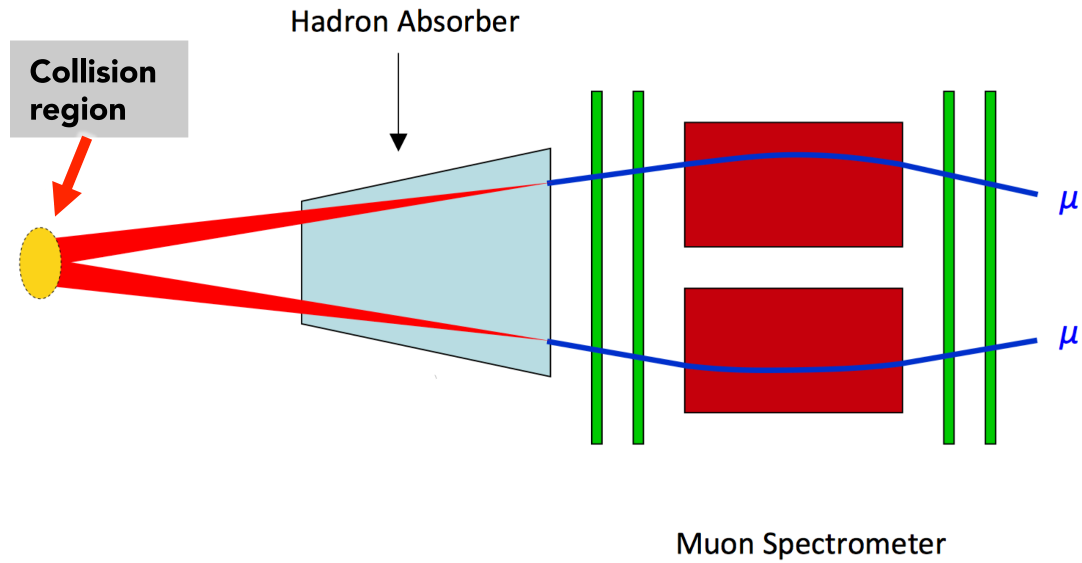


ALICE muon arm: detect muons in the forward range ($-4.0 < \eta < -2.5$)

MFT = Muon Forward Tracker

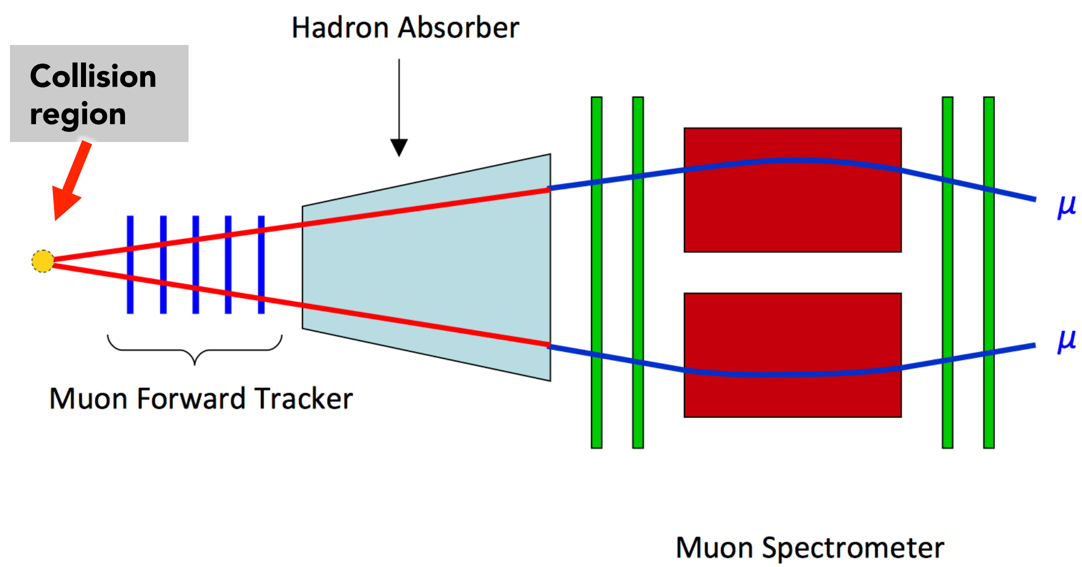
MFT concept (1)

- **Muon Forward Tracker (MFT) design objectives: Increase pointing accuracy for the muon tracks, in particular at low p_T**



MFT concept (2)

- **Muon Forward Tracker (MFT) design objectives: Increase pointing accuracy for the muon tracks, in particular at low p_T**
- **Implementation: 5-plane silicon telescope in front of the hadron absorber**



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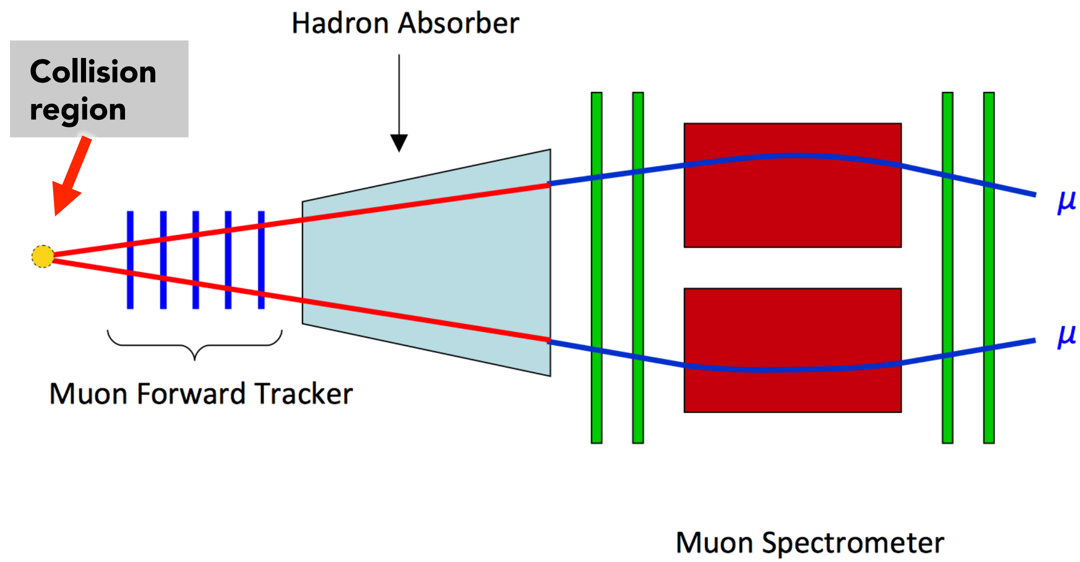
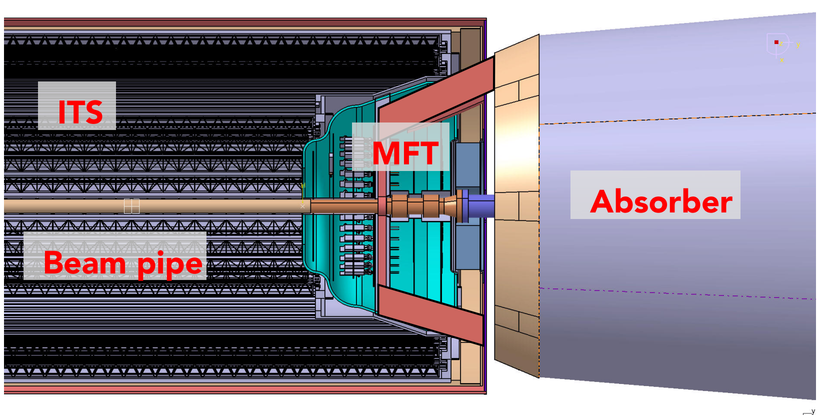
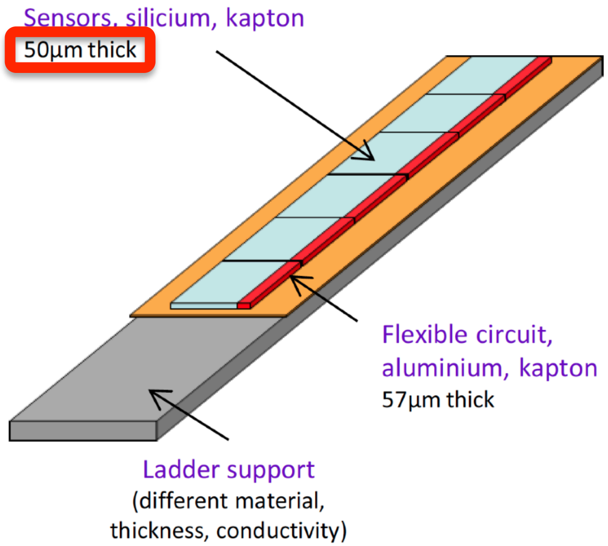


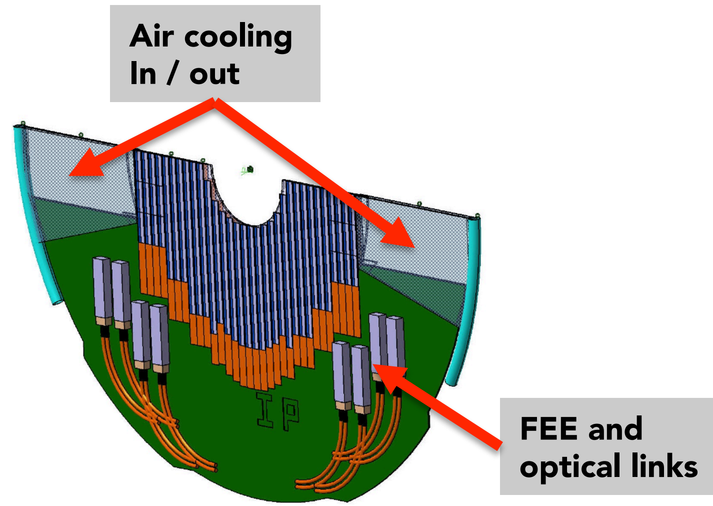


Plane	Int. radius (cm)	Ext. radius (cm)	Z location (cm)	Pixel pitch (μm)	Thickness (% of X_0)
0	2.5	11.0	-50		
1	2.5	12.3	-58		
2	3.0	13.7	-66	25	0.4
3	3.5	14.6	-72		
4	3.5	15.5	-76		

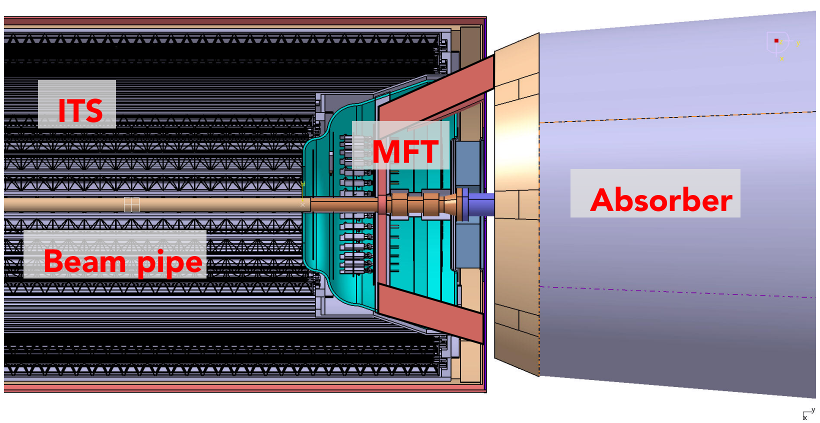
MFT baseline simulation set-up

MFT layout



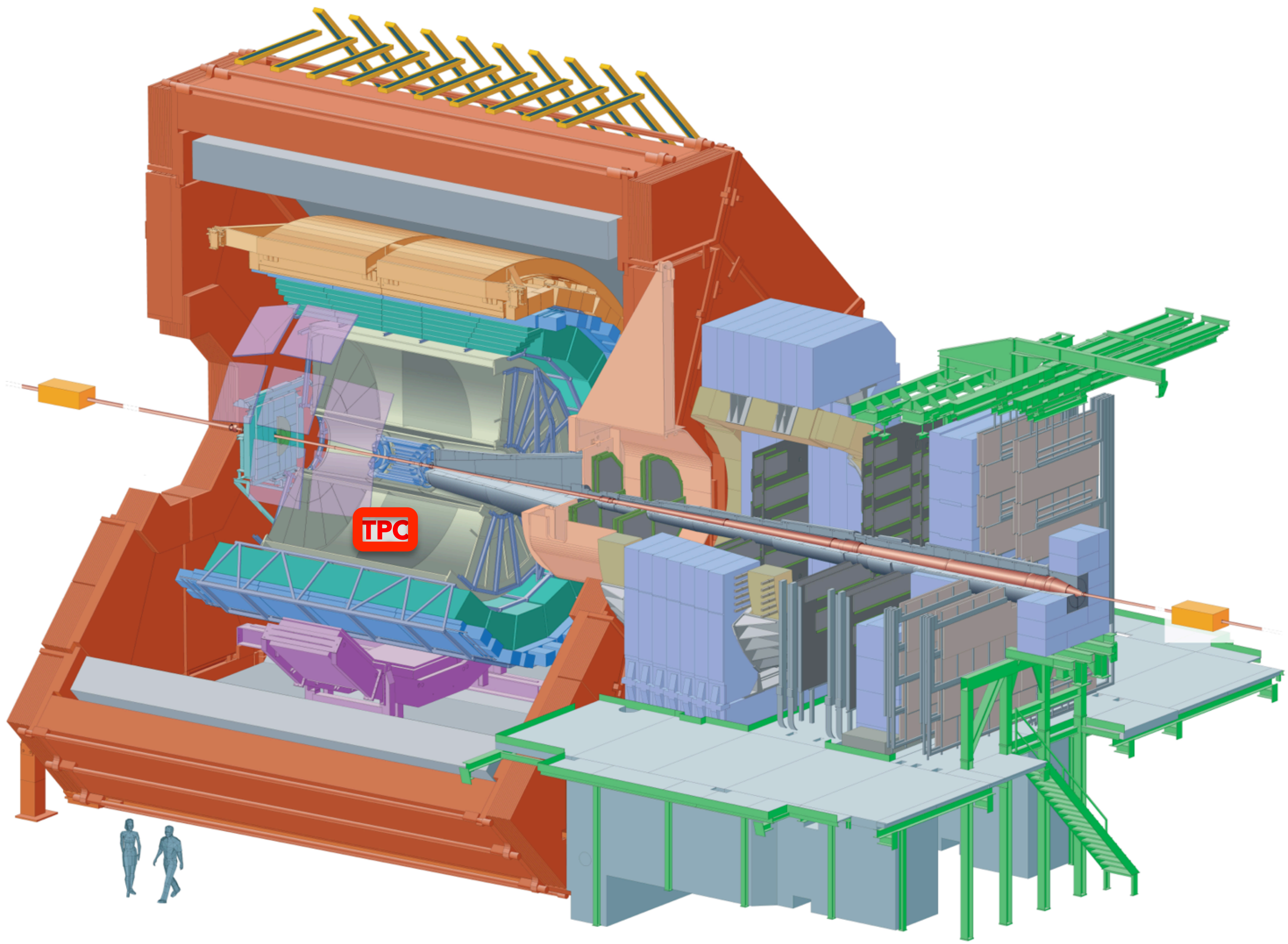


Example of the structure of a half disk assembled from ladders



- **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**

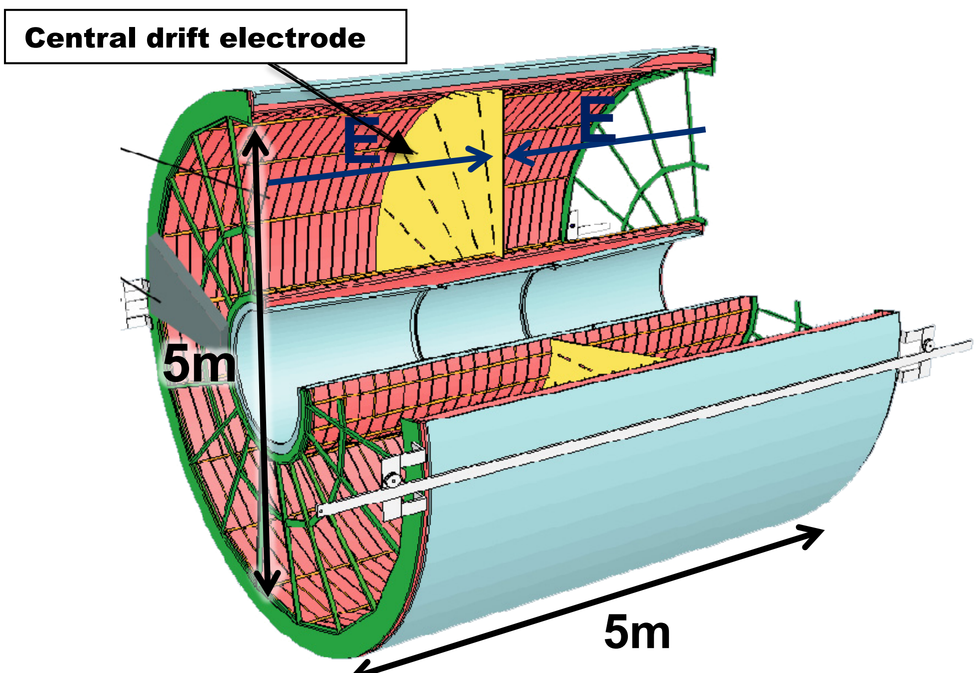
ALICE TPC upgrade

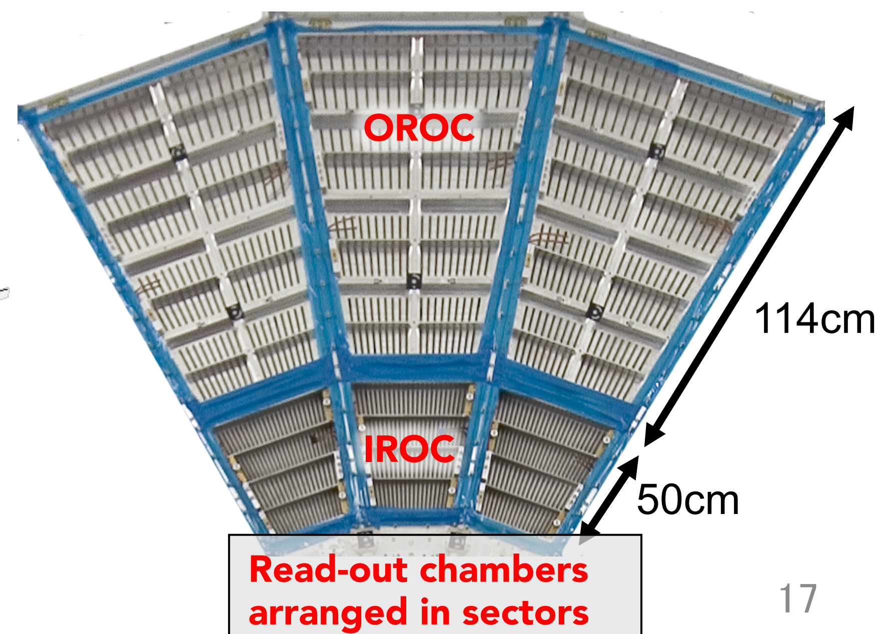


TPC overview

- Diameter: 5 m, length: 5 m
- Acceptance: $|\eta| < 0.9$, $\Delta\phi = 2\pi$
- Gas: Ne-CO_2 (90-10) in Run1
- Drift field = 400 V/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

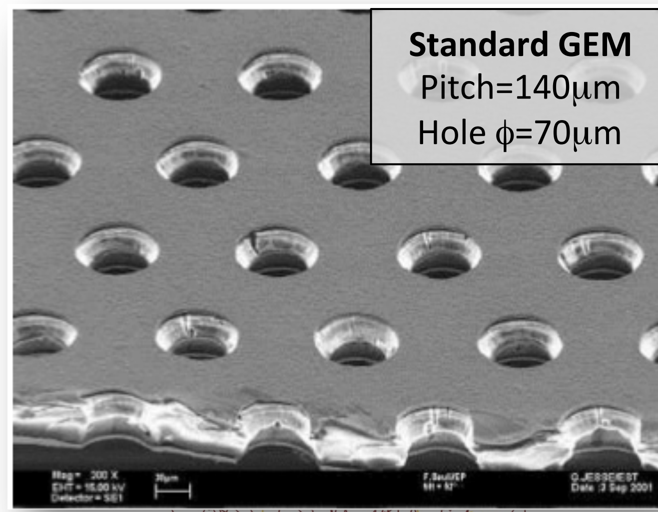
- Read-out Chambers: Total = 36 × 2
  - outer (OROC): 18 × 2
  - inner (IROC): 18 × 2
- Pad sizes: 4 × 7.5 mm^2, 6 × 10 (15) mm^2
- Channel number: 557 568
- Currently: MWPC + gating grid operation
  - Rate limitation: few kHz

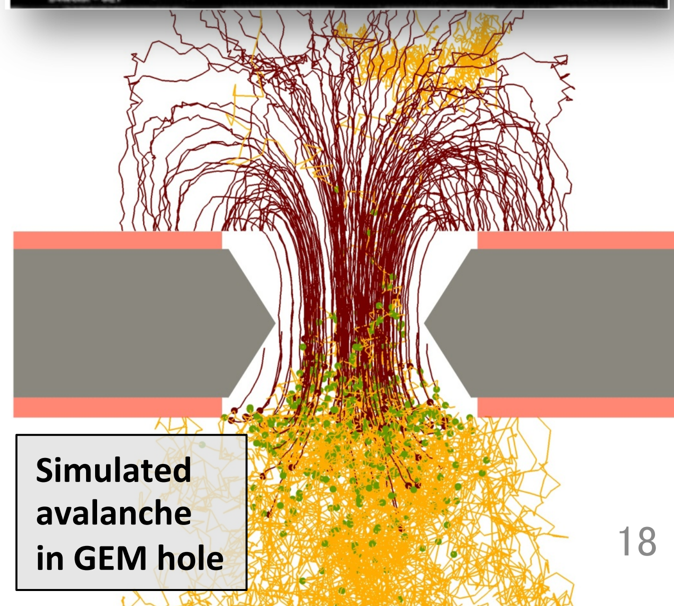




TPC upgrade objectives

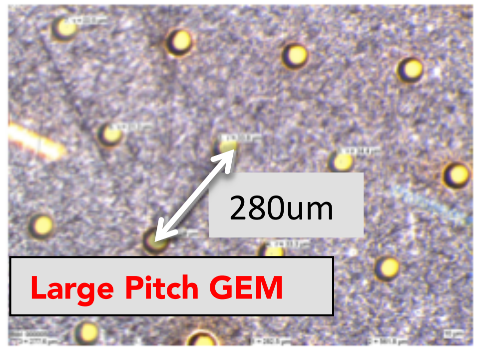
- TPC upgrade objectives:
  - continuous read-out
  - retain physics performance
- Replace MWPC read- out system with micro-pattern gaseous detectors
- Advantages:
  - reduced ion backflow (IBF)
  - high rate capability
  - no long ion tail
- Requirements for read-out system:
  - IBF < 1% at gain 2000
  - d*E*/d*x* resolution < 12% (σ) for ^{55}Fe
  - Stable operation under LHC condition

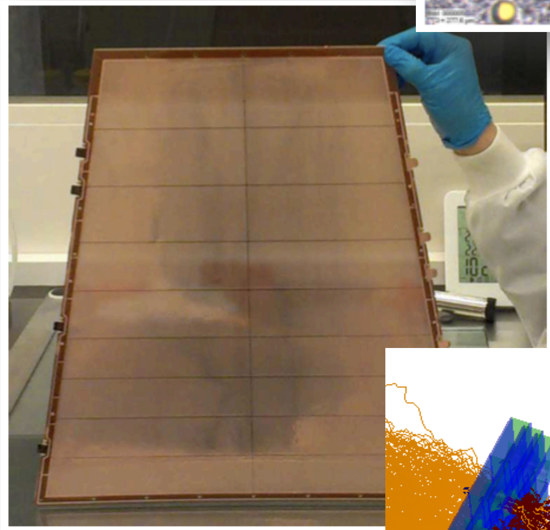


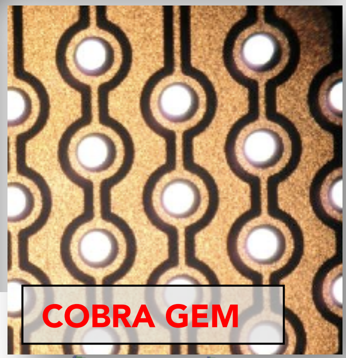


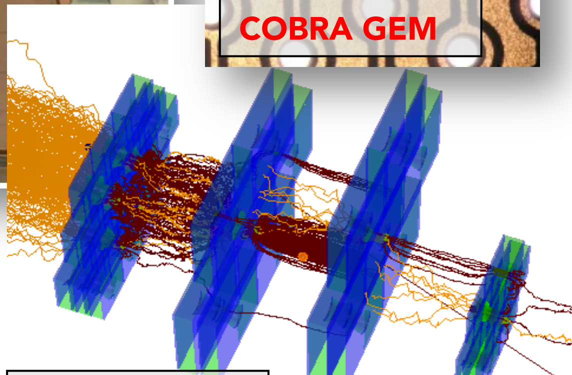
TPC upgrade R&D program

- **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**





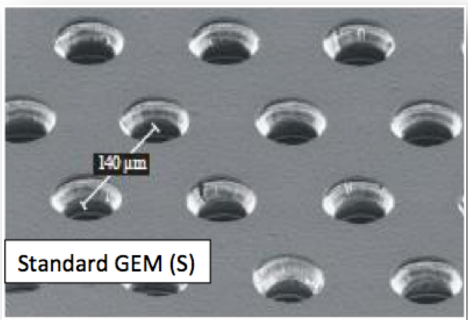


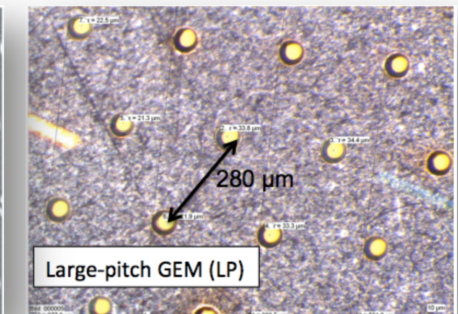

Simulations

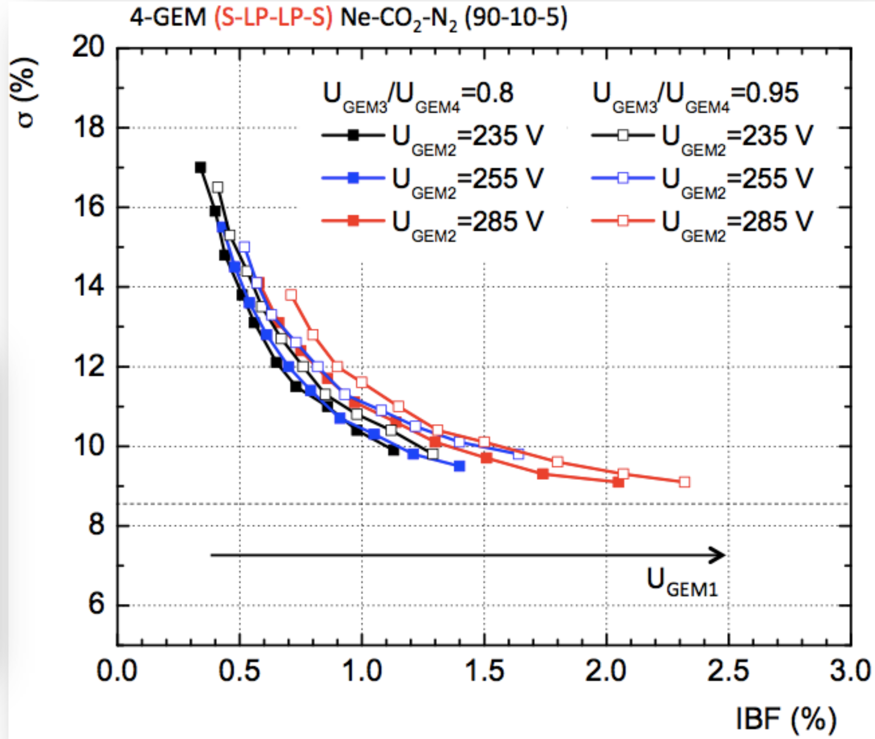
Baseline 4GEM setup

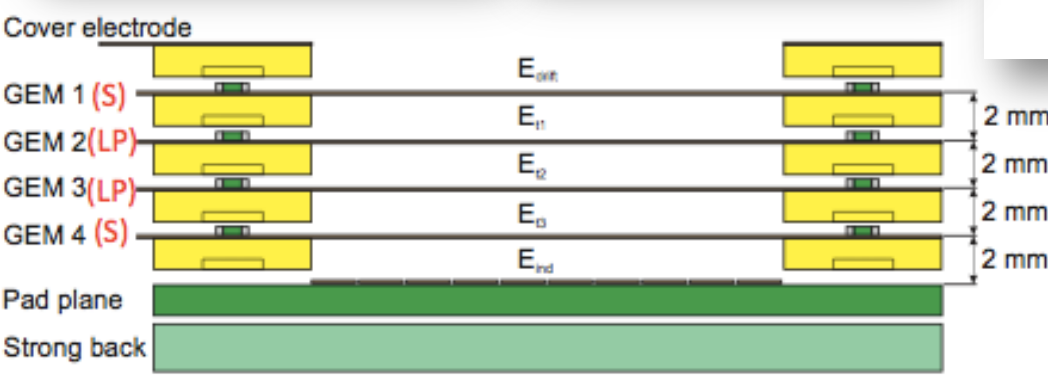
IBF and energy resolution studies for baseline solution (4 GEM stack)

- **S-LP-LP-S configuration**
  - **S: standard GEM foils**
  - **LP: large Pitch**
- **different V settings: V_{GEM} , E_T (transfer fields)**







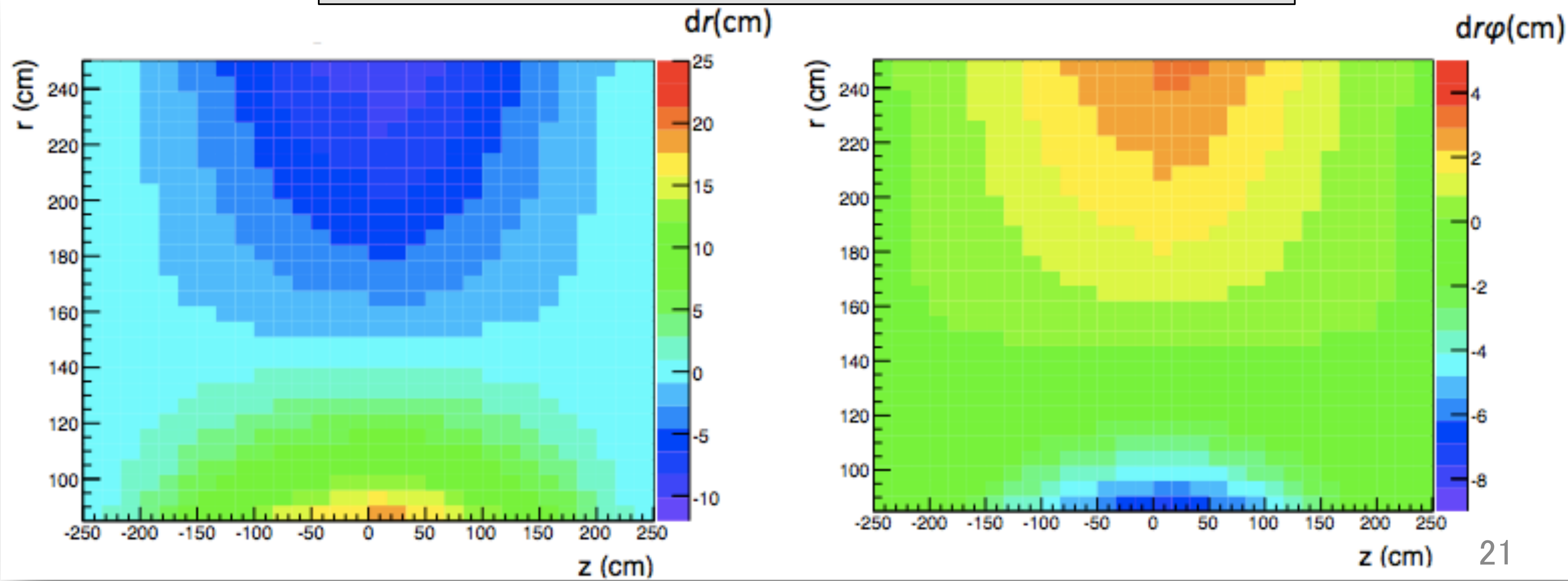


- IBF optimized settings: High E_{T1} & E_{T2} , low E_{T3} , $V_{GEM1} \approx V_{GEM2} \approx V_{GEM3} << V_{GEM4}$
- Achieved performance: **0.6 - 0.8 % IBF at σ (5.9 keV) ~ 12 %**

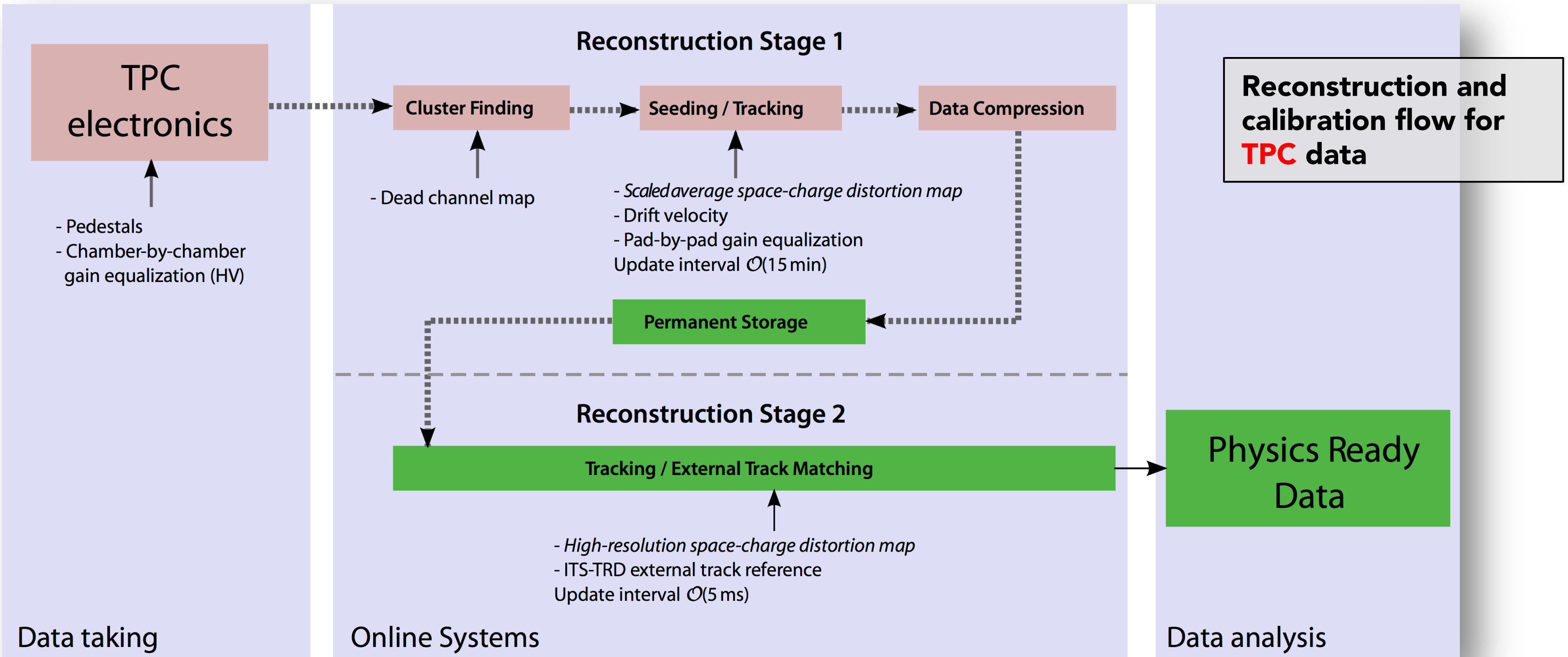
Space charge distortions

- With required **IBF < 1%** still considerable space charge in TPC
  - 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, dr = 20 cm and d$r\phi$ = 8 cm
  - For the largest fraction of drift volume: dr<10 cm
- **Corrections to 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)



Run3 reconstruction scheme

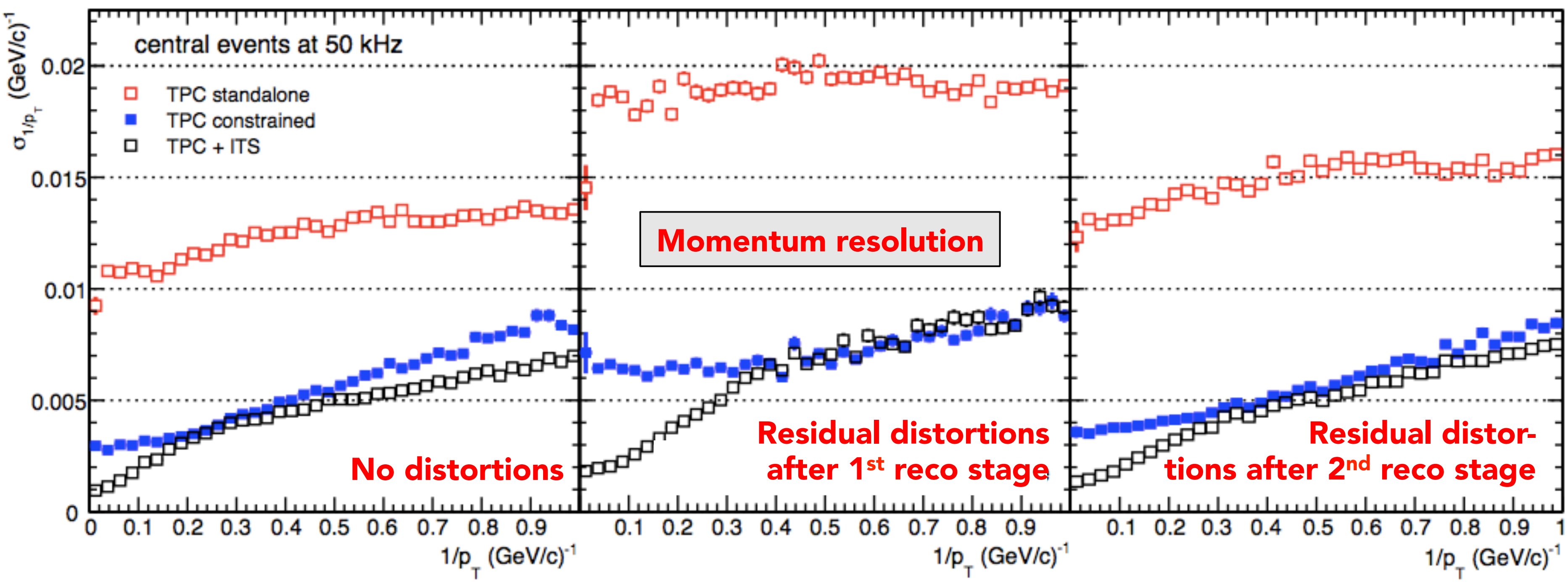


- **Two stage reconstruction scheme**
  1. **Cluster finding and cluster-to-track association in the TPC**
     - **data compression by factor 20 : 1 TB/s → 50 GB/s**
     - **use scaled average space-charge distortion map**
  2. **Full tracking with matching to inner and outer detectors (ITS and TRD)**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

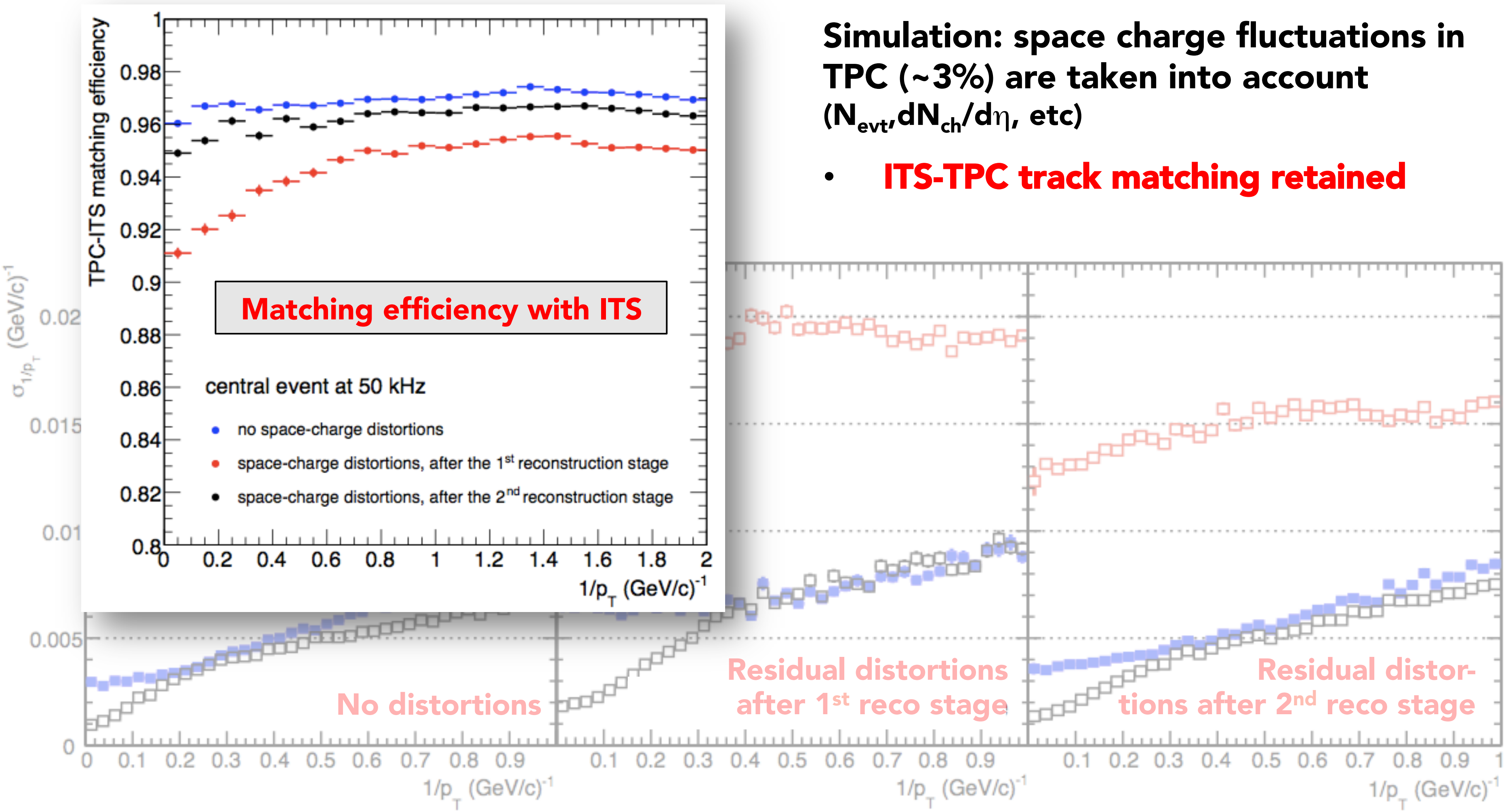
Expected TPC performance (1)

- p_T resolution practically recovered after 2^{nd} reconstruction stage

Simulation: space charge fluctuations in TPC (~3%) are taken into account (N_{evt}, $dN_{ch}/d\eta$, etc)



Expected TPC performance (2)



Simulation: space charge fluctuations in TPC (~3%) are taken into account (N_{evt},$dN_{ch}/d\eta$, etc)

- **ITS-TPC track matching retained**

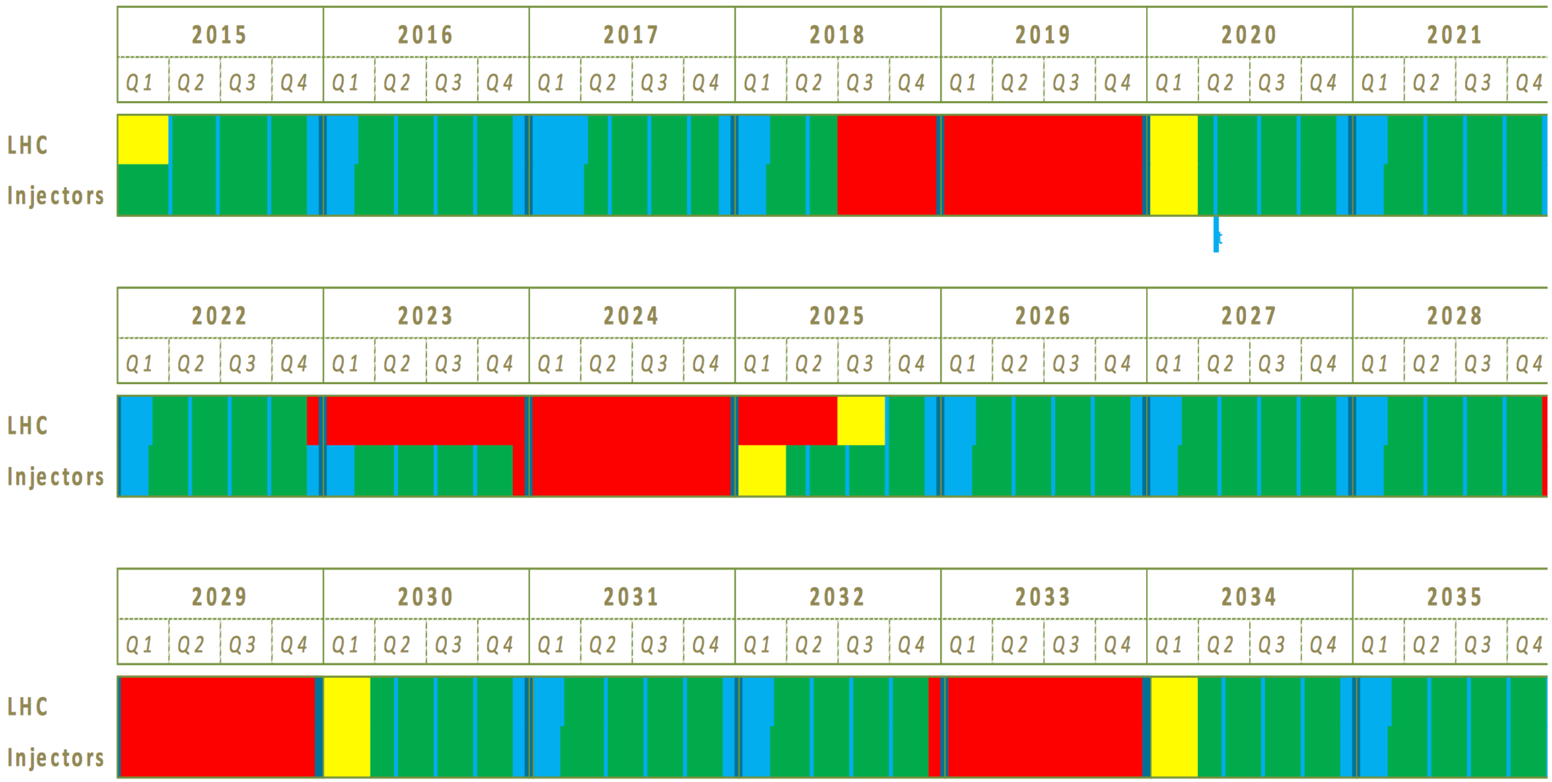
Summary and outlook

- 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 Muon Forward Tracker (5-plane muon silicon telescope, based on MAPS) in front of hadron absorber, in the acceptance of the Muon Spectrometer
- Technical Design Reports (define construction design)
  - ITS TDR accepted in spring 2014
  - Readout + trigger system TDR and TPC TDR submitted

More slides

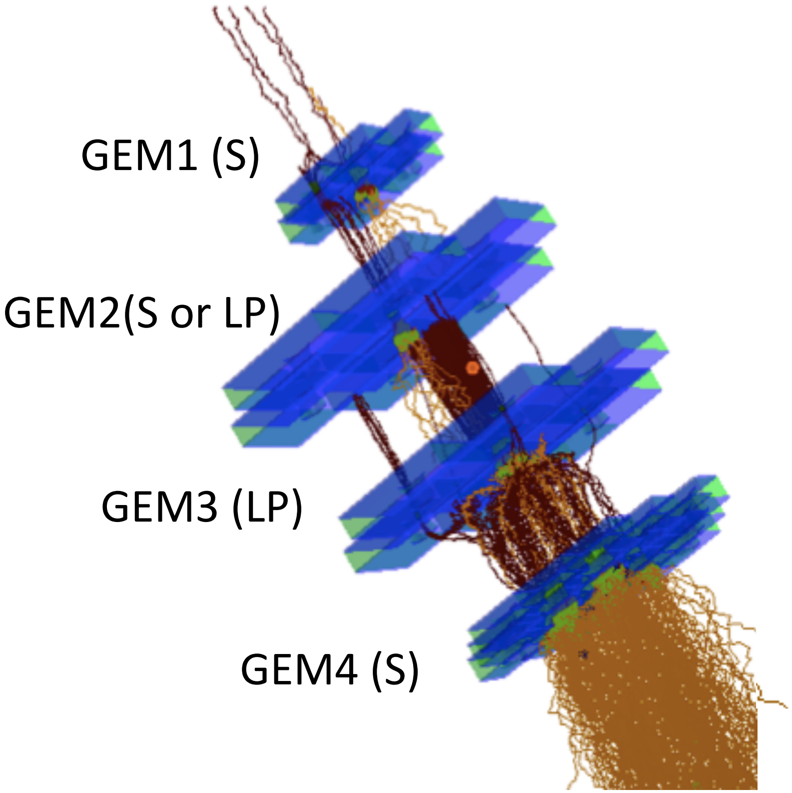
LHC schedule

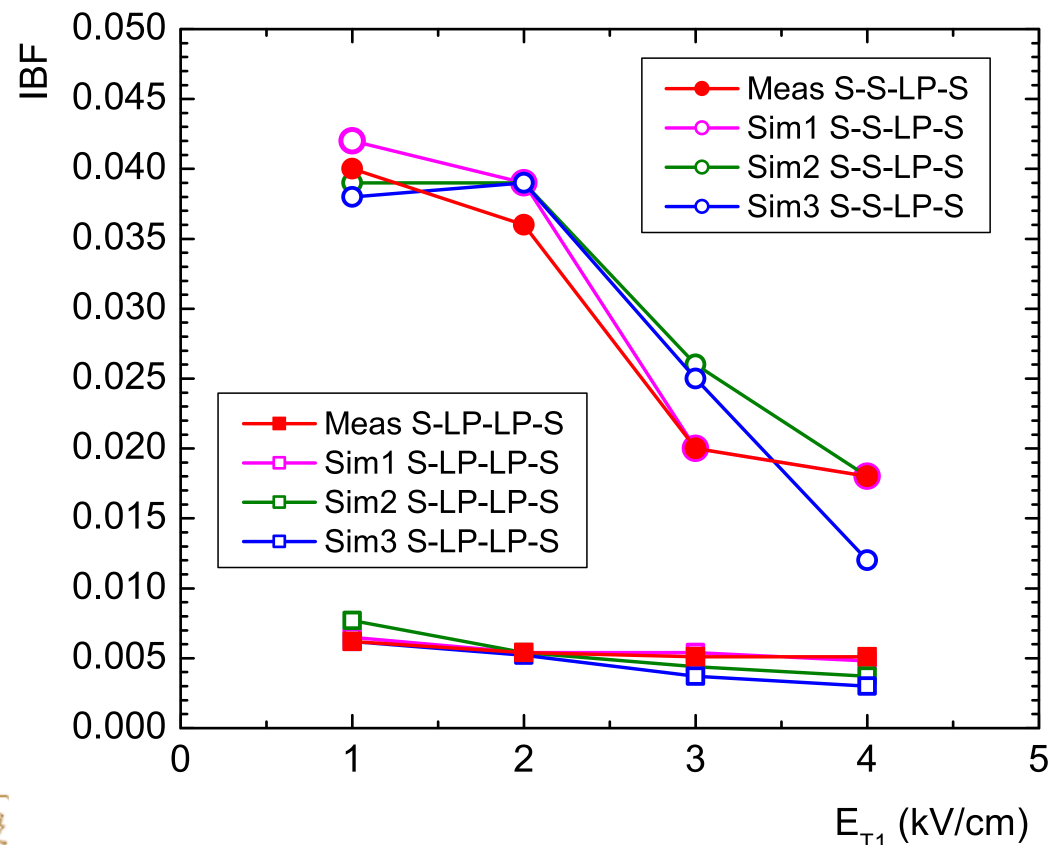
- **LHC Long shutdown 2:**
  - **Starts in July 2018**
  - **Duration: 18 months + 3 months beam commissioning**



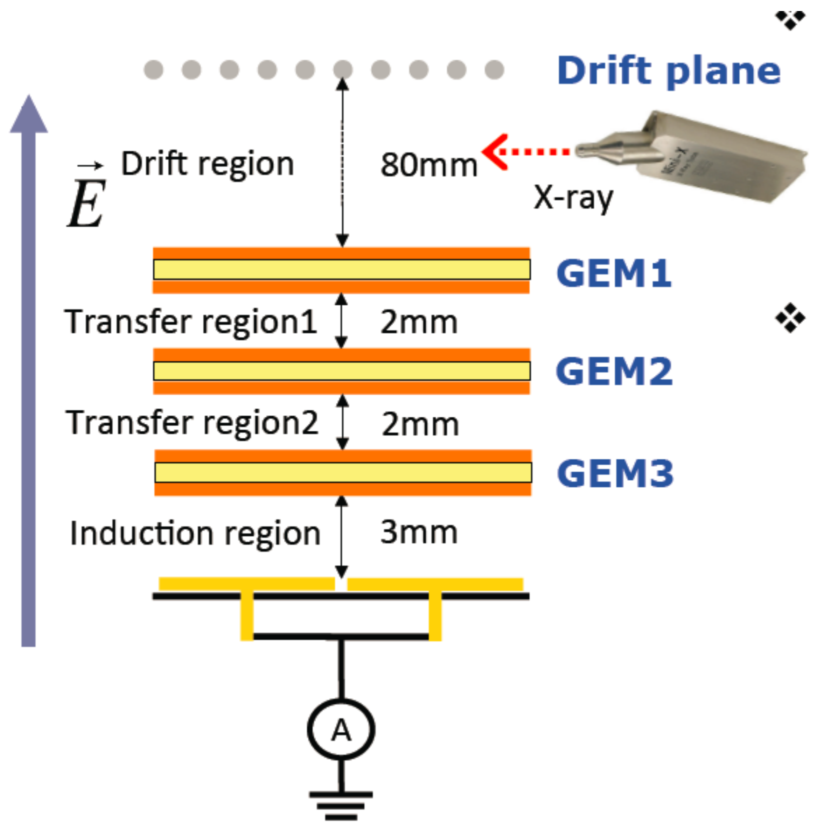
TPC: Garfield Simulations

- **Garfield++/Magboltz simulations for different 4GEM setups (S-LP-LP-S)**
  - **Field calculation by ANSYS**
  - **IBF quantitatively well described by simulations using Garfield++**

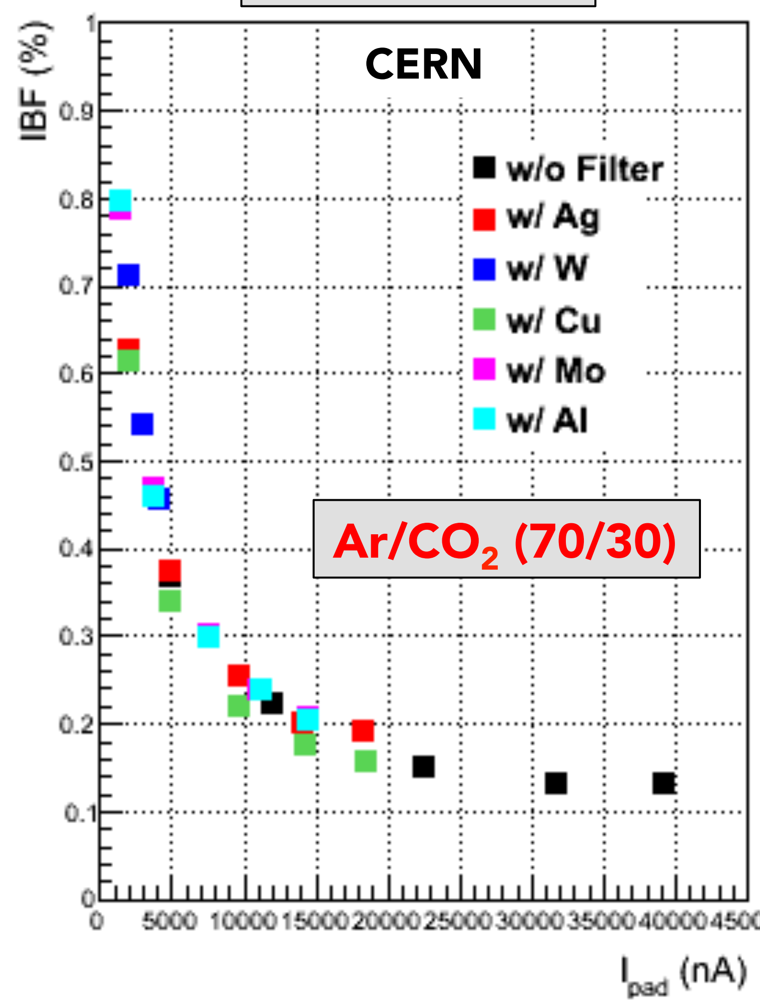




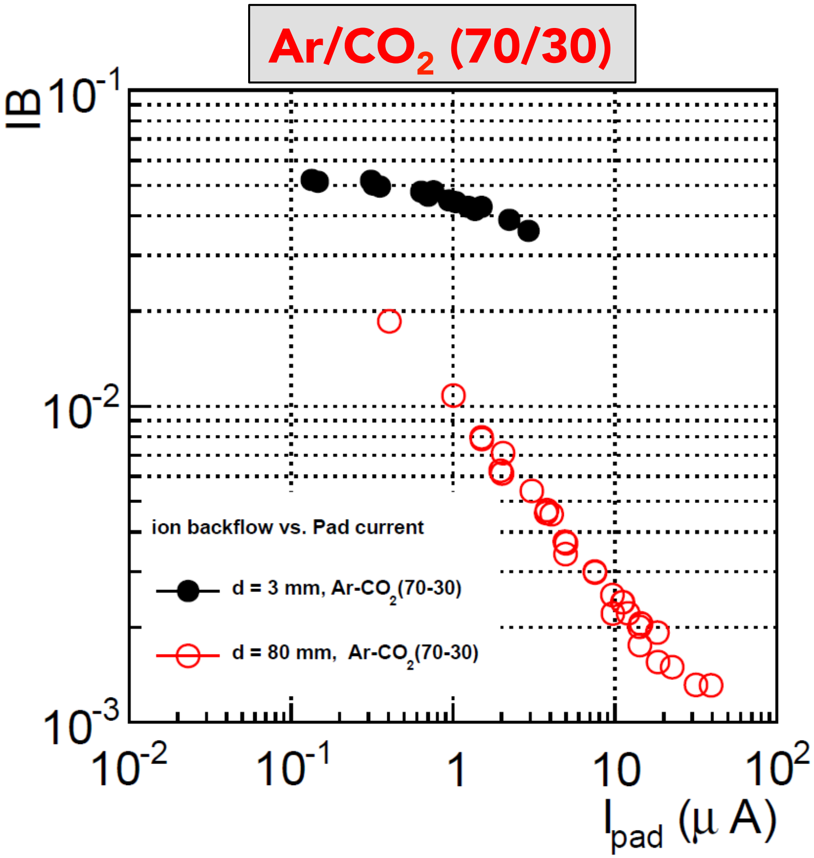
TPC: IBF – Rate Dependence (1)



Measurement



TPC: IBF – Rate Dependence (2)



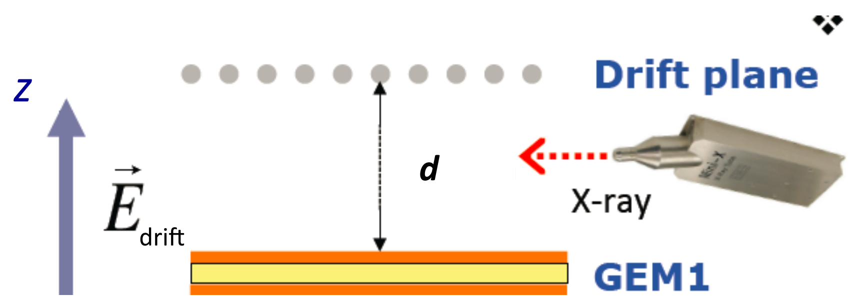
Poisson equation:

$$\Delta\varphi(\boldsymbol{r}) = -\frac{\rho(\boldsymbol{r})}{\varepsilon\varepsilon_0}$$

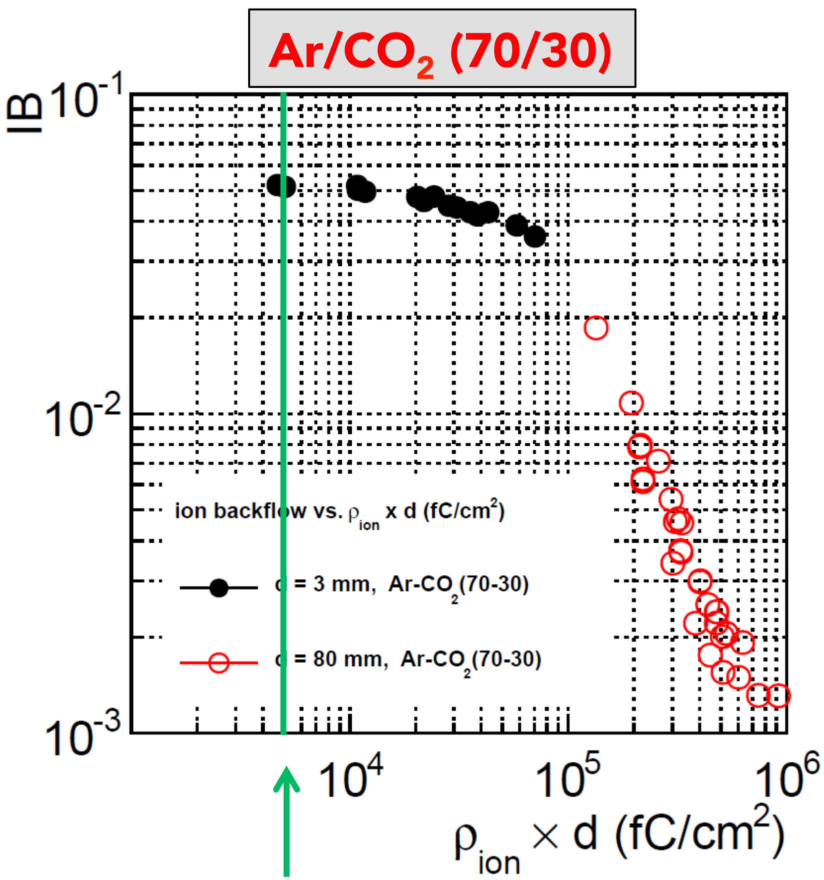
For homogenous space charge density and parallel plate boundary conditions:

$$E(z) = E_{\mathrm{drift}} - \frac{\rho d}{2\varepsilon\varepsilon_0} + \cancel{\frac{\rho z}{\varepsilon\varepsilon_0}}$$

$z \ll d$



TPC: IBF – Rate Dependence (3)



Expected after LS2: 5000 fC/cm²

Poisson equation:

$$\Delta\varphi(\boldsymbol{r}) = -\frac{\rho(\boldsymbol{r})}{\varepsilon\varepsilon_0}$$

For homogenous space charge density and parallel plate boundary conditions:

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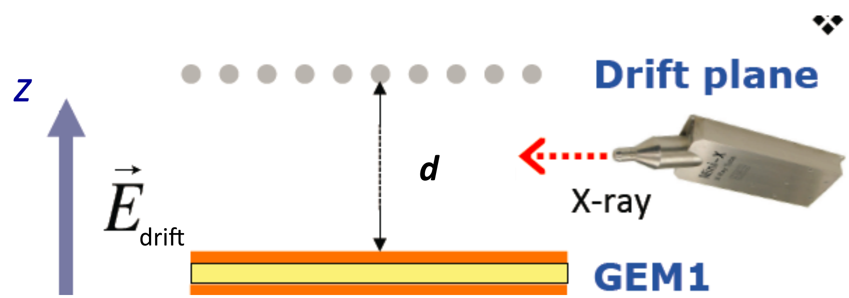
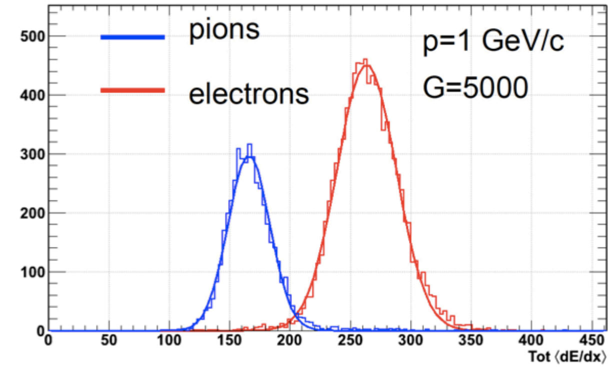
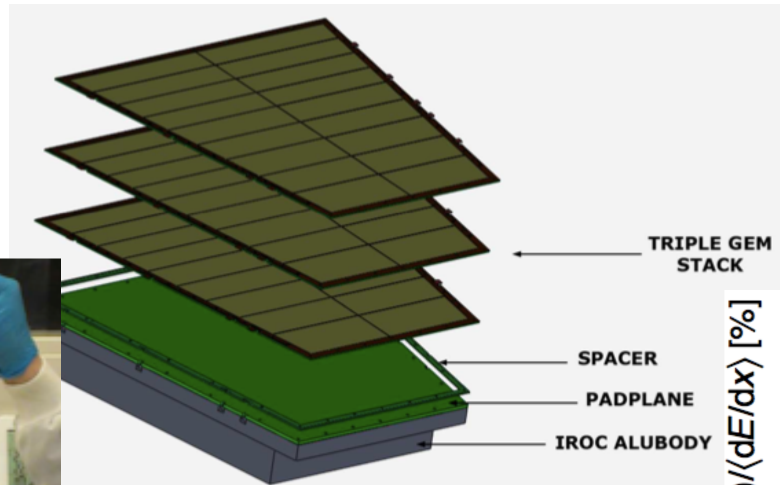
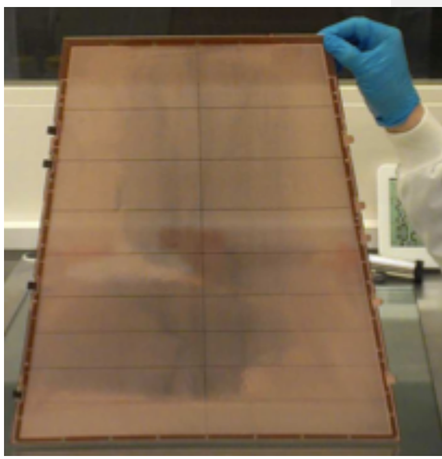
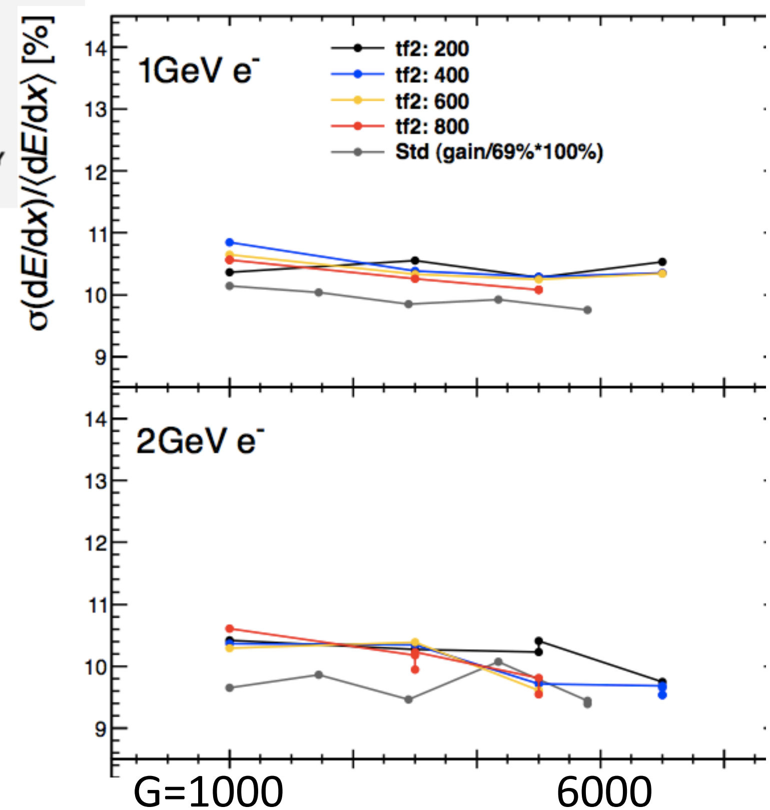


TPC: dE/dx with 3GEM Prototype







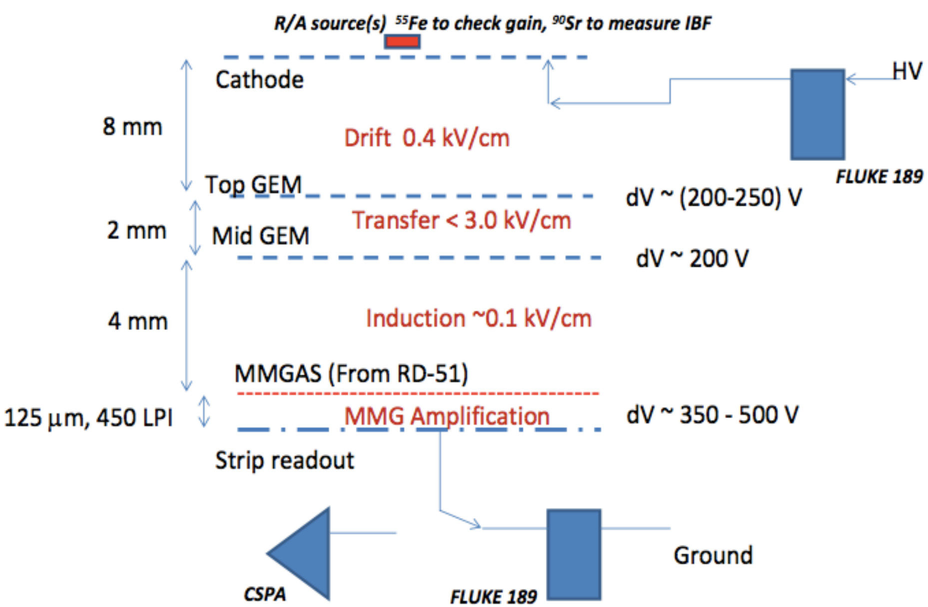


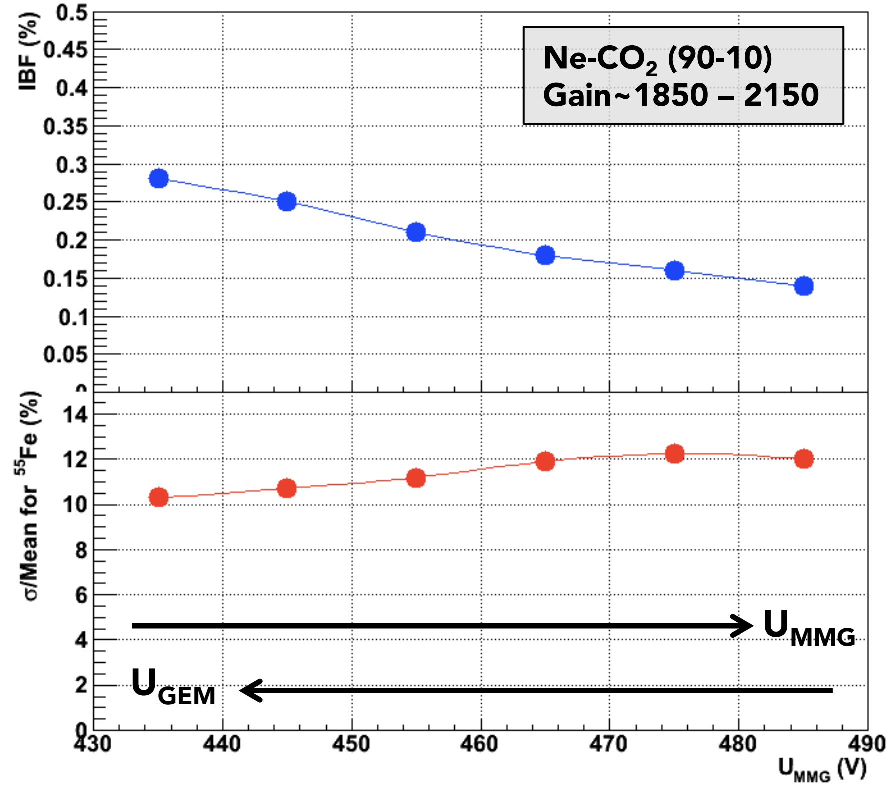
- Prototype IROC with 3 singlemask GEMs
  - Beam test at CERN Proton Synchrotron (e/π/p) in 2012
- Good e/π separation
- $\sigma_{dE/dx}$/<dE/dx> ~ 10.5%
  - Comparable to the current TPC resolution (~9.5% with IROC)

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**

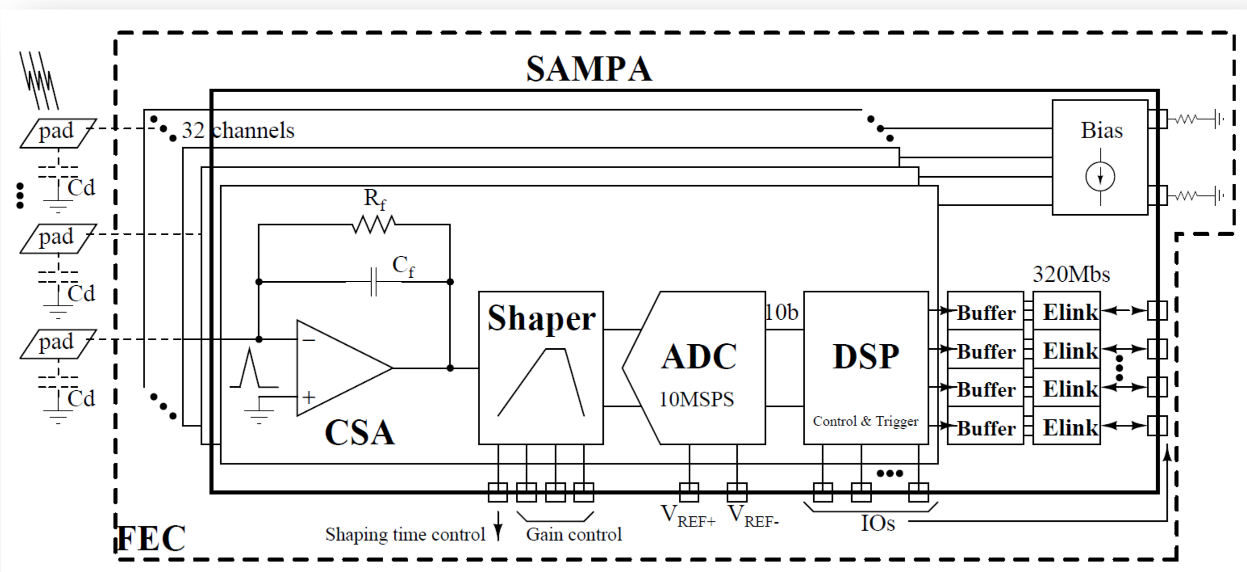
Large-scale solution and operational stability still to be verified



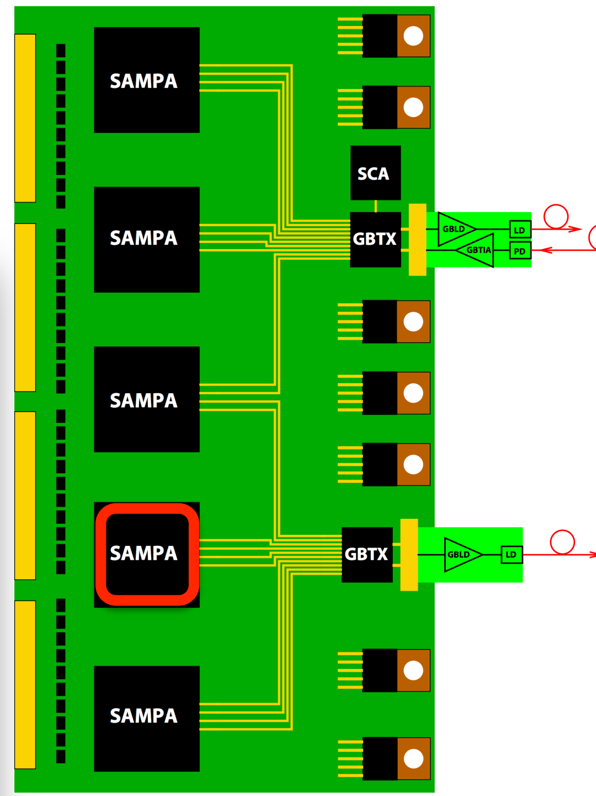


TPC read-out ASIC: SAMPA

- SAMPA ASIC integrates preamplifier/shaper and ALTRO ADC + DSP
  - pos / neg polarity
  - continuous / triggered read-out
  - SAR ADC (10 or 20 MSPS)
- First MPW submission in April



SAMPA functional blocks



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

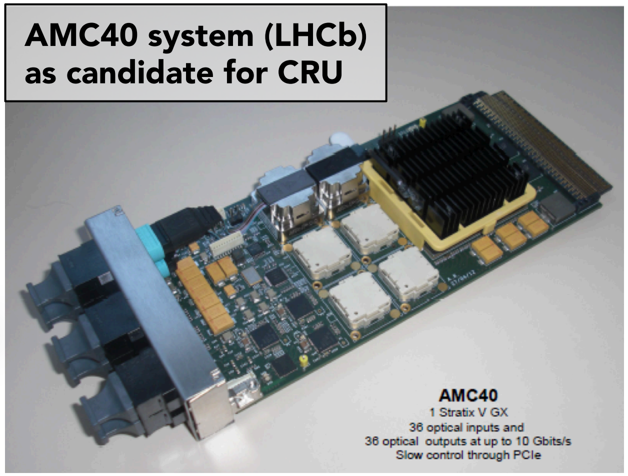
TPC: SAMPA parameters

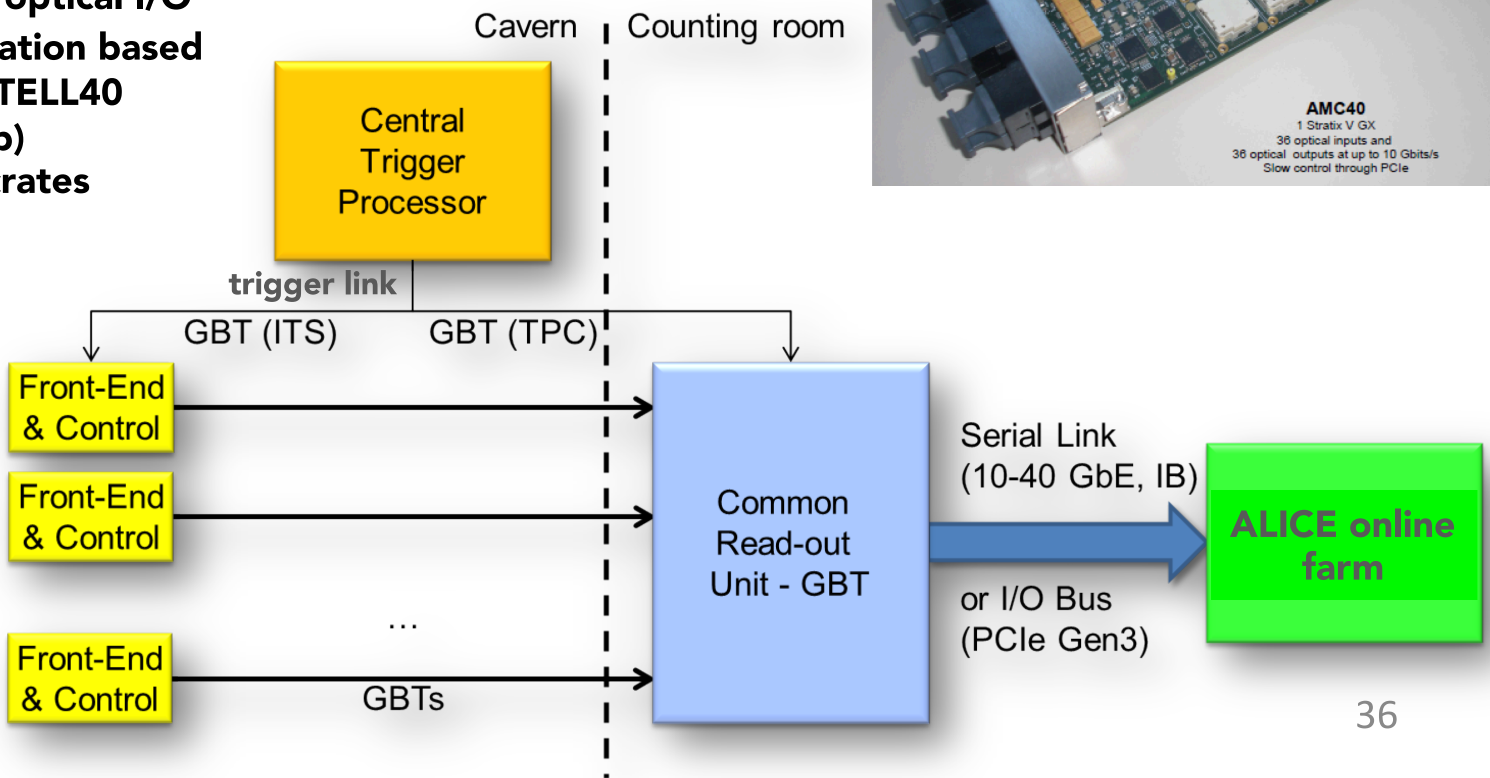
		Run 1 (measured)	Run 3 (requirement)
Signal polarity		Pos	Neg
Detector capacitance (range)	(pF)	12 – 33.5	12 – 33.5
S:N ratio for MIPs (IROC)		14:1	20:1
(OROC $6\times10\,\mathrm{mm}^2$ pads)		20:1	30:1
(OROC $6\times15\,\mathrm{mm}^2$ pads)		28:1	30:1
MIP signal	(fC)	1.5 – 3[14]	2.1 – 3.2
System noise (at 18.5 pF, incl. ADC)		670 e	670 e
PASA conversion gain (at 18 pF)	(mV/fC)	12.74	20 (30)
PASA return to baseline	(ns)	< 550	< 500
PASA average baseline value	(mV)	100	100
PASA channel-to-channel baseline variation (σ)	(mV)	18	18
PASA shaping order		4	4
PASA peaking time	(ns)	160	160 (80)
PASA crosstalk		< 0.1 %[15]	< 0.2 %
PASA integrated non-linearity		0.2 %	< 1 %
ENC (PASA only, at 12 pF)		385 e	385 e
ADC voltage range (differential)	(V)	2	2
ADC linear range (differential)	(fC)	160	100 (67)
ADC number of bits		10	10
ADC sampling rate	(MHz)	10 (2.5, 5, 20)	10 (20)
Power consumption (analog & digital)	(mW/ch)	35	< 35

Parameters for the current FE chips (measured) and for Run3 (SAMPA)

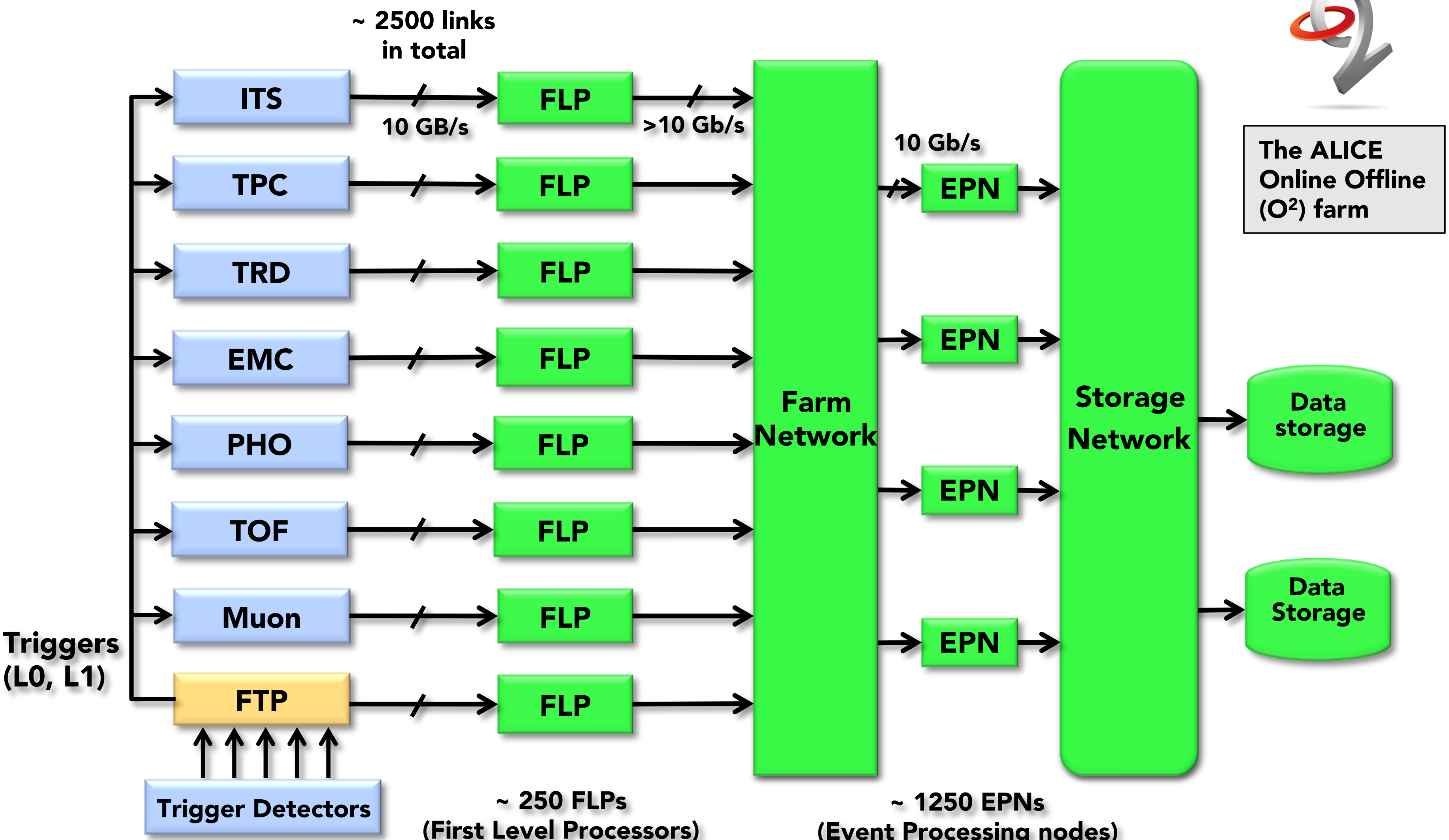
ALICE read-out system

- GBT: custom radiation-hard optical link
- Common Read-out Unit (CRU)
  - 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





ALICE online farm in Run3



ALICE online systems in Run3 (2)

- The 2 reconstruction stages are carried out on the O^2 computing farm
- 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