Outer Tracker detector (TPOT) to monitor space charge distortions in the TPC

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sPHENIX Collaboration Meeting, January 22, 2021

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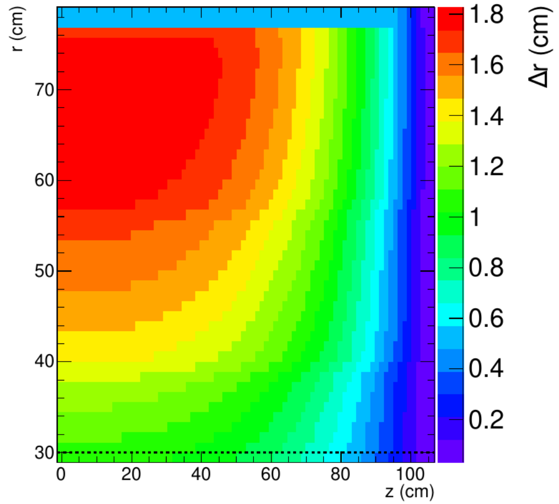
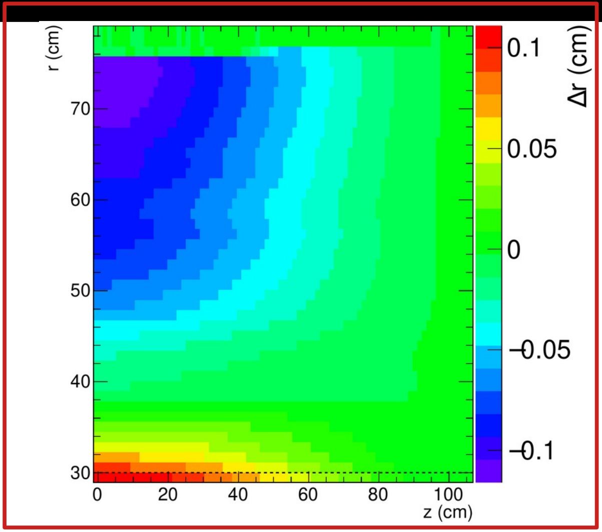
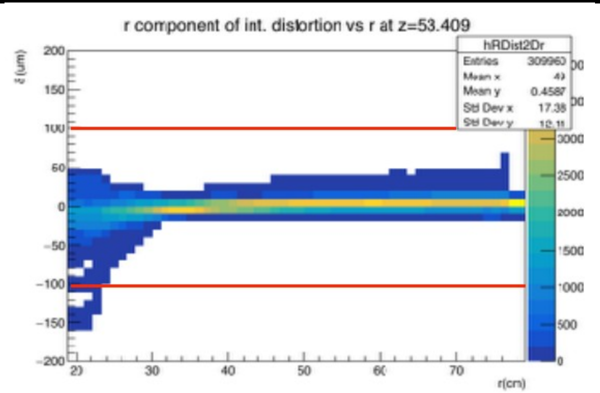
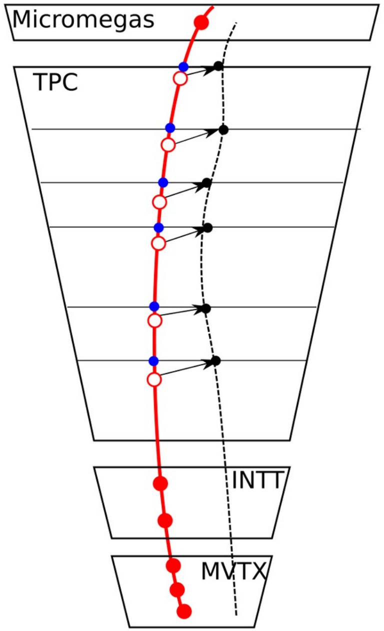
Context









<u>Three types of distortions</u>:

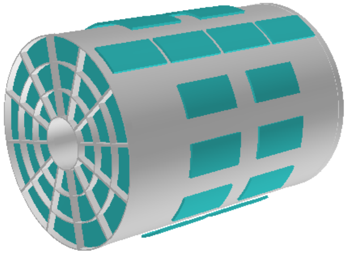
- static, O(cm)
- beam-induced, time-averaged O(mm)
- event-by-event fluctuations < 100um

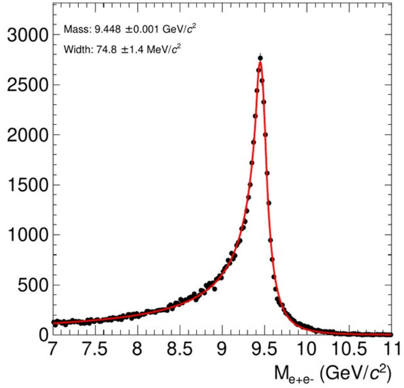
Use tracks to measure the beam induced distortions

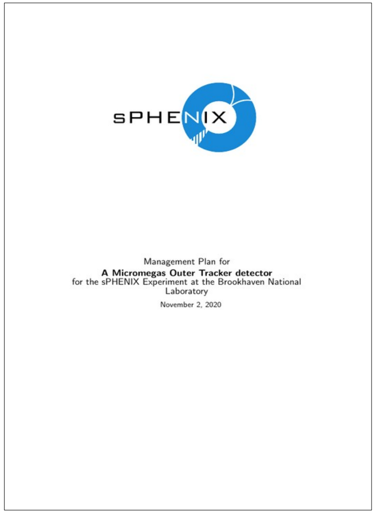
INTT and MVTX alone are not sufficient for a precise enough extrapolation in the TPC
Need extra space-point, outside of the TPC, at least over a fraction of the acceptance

What is new since the last collaboration meeting (July 2020)

- converged on a baseline configuration for the Outer Tracker
- complete chain in place in fun4all to incorporate, reconstruct and evaluate TPC distortions using tracks
- *management plan* document to define the project scope, cost, schedule, management structure etc.
- first internal review on the TPOT project



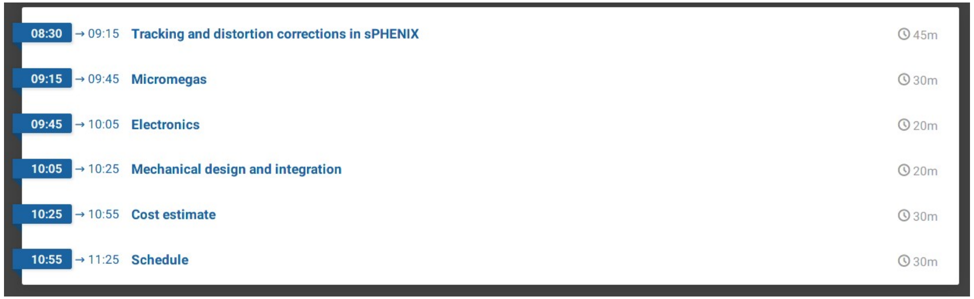




sPHENIX

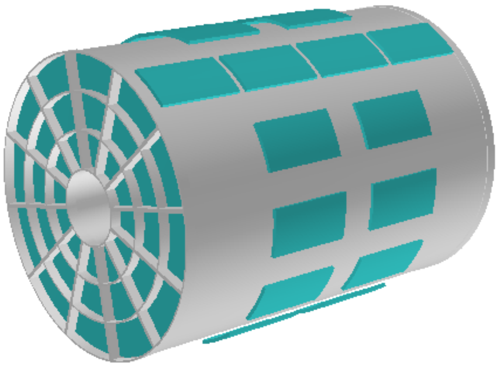
Management Plan for
A Micromegas Outer Tracker detector
for the sPHENIX Experiment at the Brookhaven National Laboratory

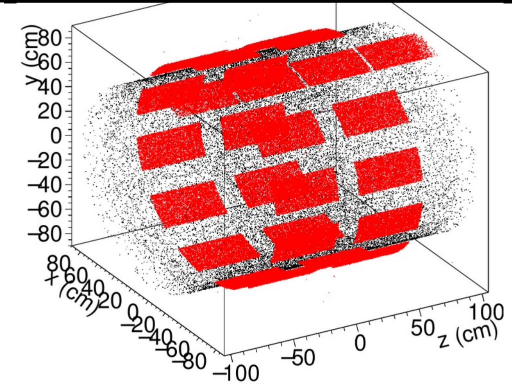
November 2, 2020



08:30	→ 09:15	Tracking and distortion corrections in sPHENIX	45m
09:15	→ 09:45	Micromegas	30m
09:45	→ 10:05	Electronics	20m
10:05	→ 10:25	Mechanical design and integration	20m
10:25	→ 10:55	Cost estimate	30m
10:55	→ 11:25	Schedule	30m

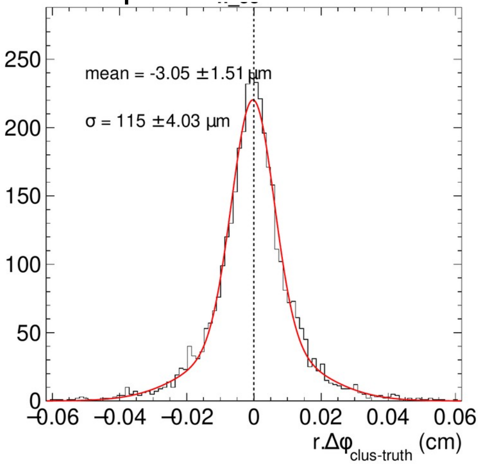
Detector configuration and simulated performances



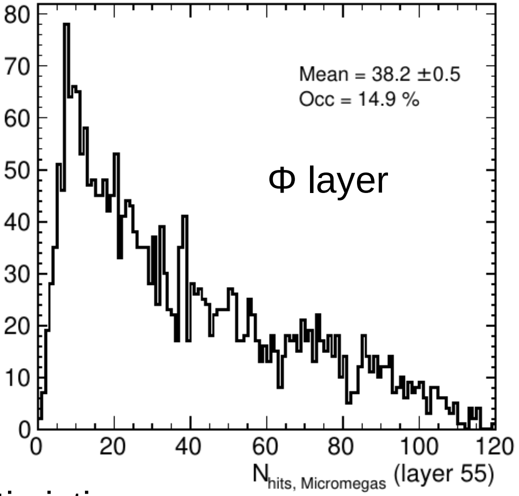


- one MM module per sector and TPC side to monitor sector-to-sector IBF variations
- one sector fully equipped with 4 MM module to provide z dependence

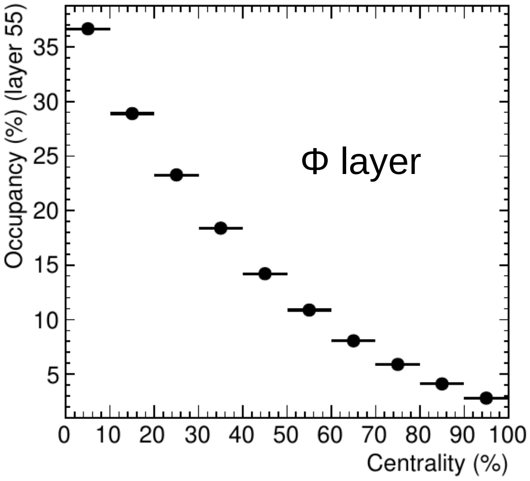
Spacial resolution



Mean occupancy



Centrality dependence



115 μm resolution. probably too optimistic

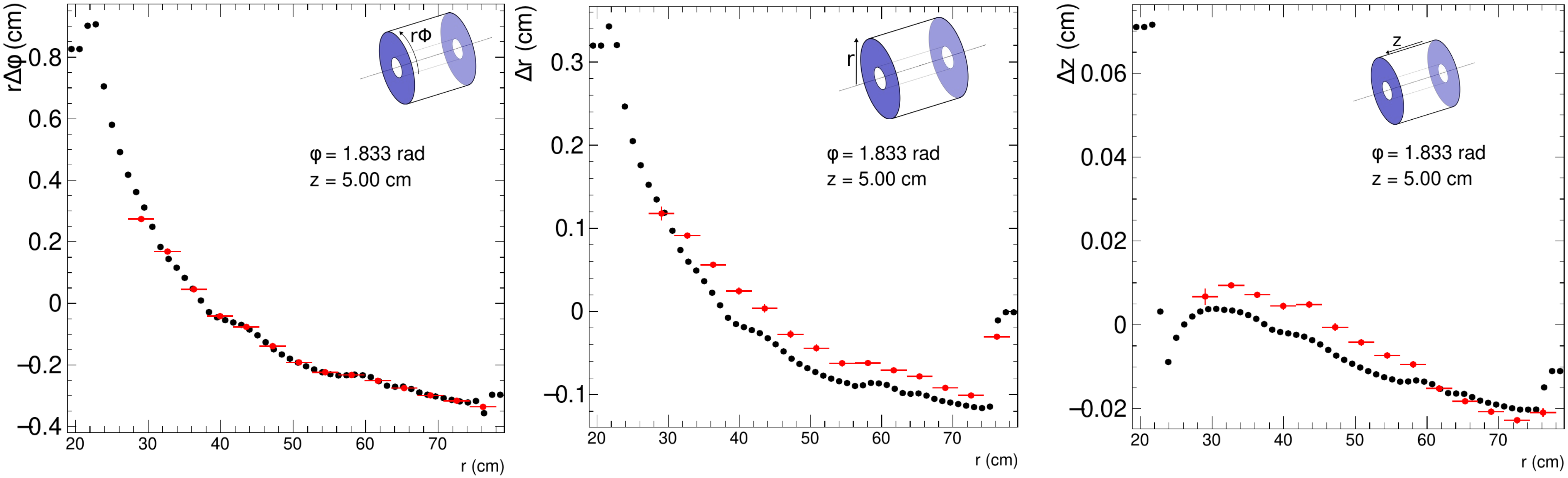
expect rather something of order 200 μm in Φ and 300 μm in z

Should not be a problem for the detector nor FEE
Tracking can handle it

Ability to reconstruct the TPC distortions in TPOT acceptance

Focusing on time-averaged beam-induced distortions in the Micromegas acceptance

black: input, red: reconstructed



Distortions are up to 3 mm in Φ, 2 mm in r and 20 0μm in z

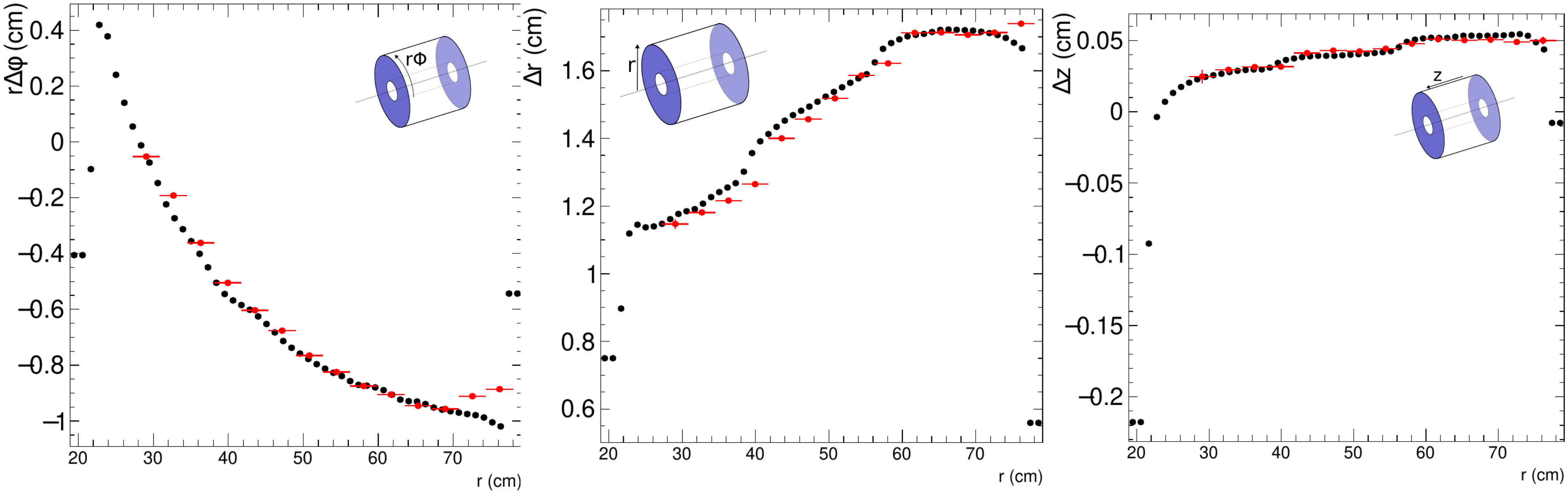
ΔΦ distortions properly reconstructed

There remain ~ 50 - 100 μm discrepancies for Δr and Δz, under investigation

Ability to reconstruct the TPC distortions in TPOT (cont.)

Ability to reconstruct static + time-averaged beam-induced distortions in the Micromegas acceptance

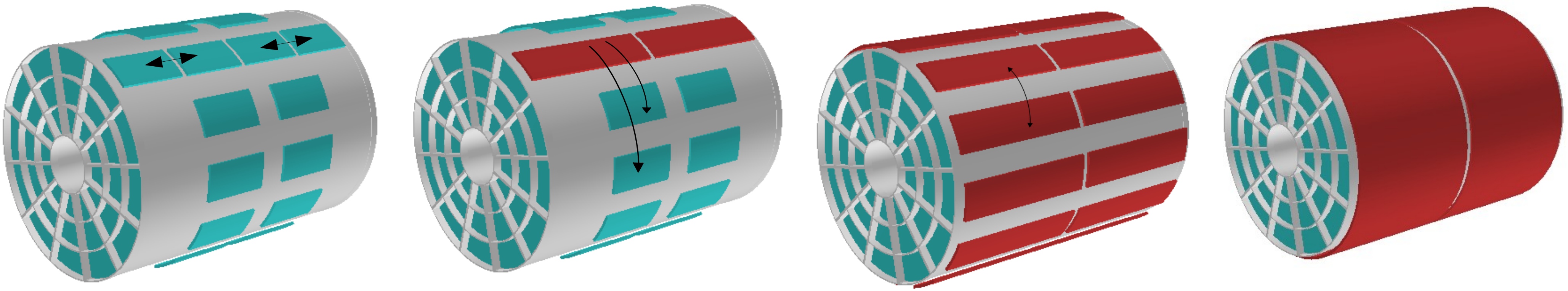
black: input, red: reconstructed



Distortions are up to -1 cm in Φ, 2 cm in r and 500 μm in z

Even if static distortions are not fully subtracted away using directed lasers, one should be able to correct for them at the track level

Extrapolation to full acceptance



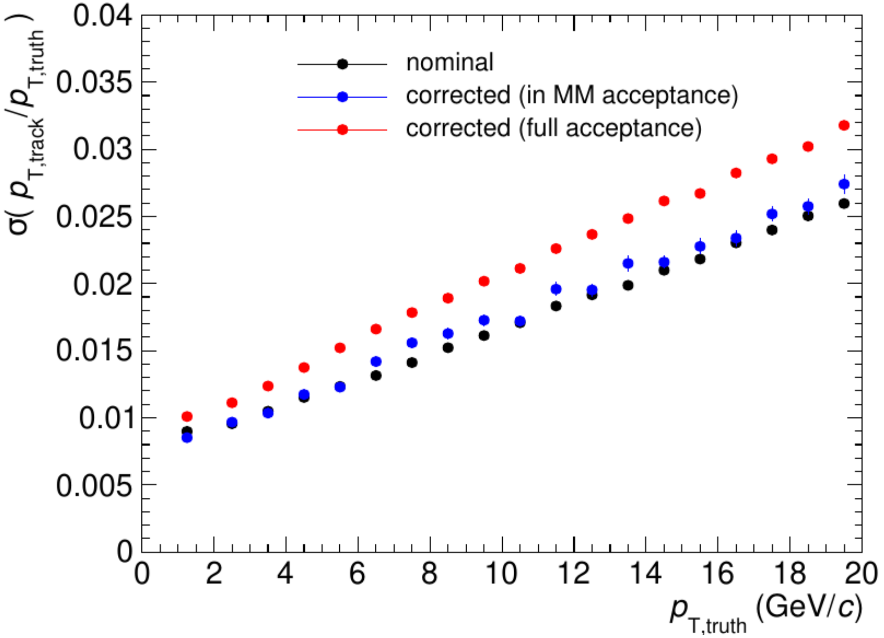
1. small z interpolation between MM modules

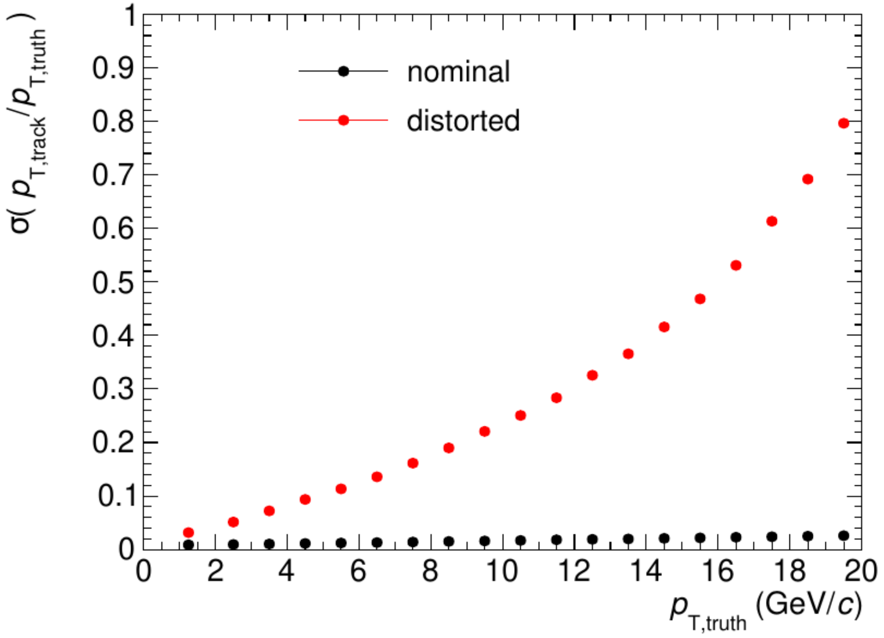
2. copy z dependence in fully equipped sector to other sectors, normalized by local measurement

3. interpolate between sectors to cover full acceptance

Impact on momentum resolution

Focusing on time-averaged beam-induced distortions, O(mm)



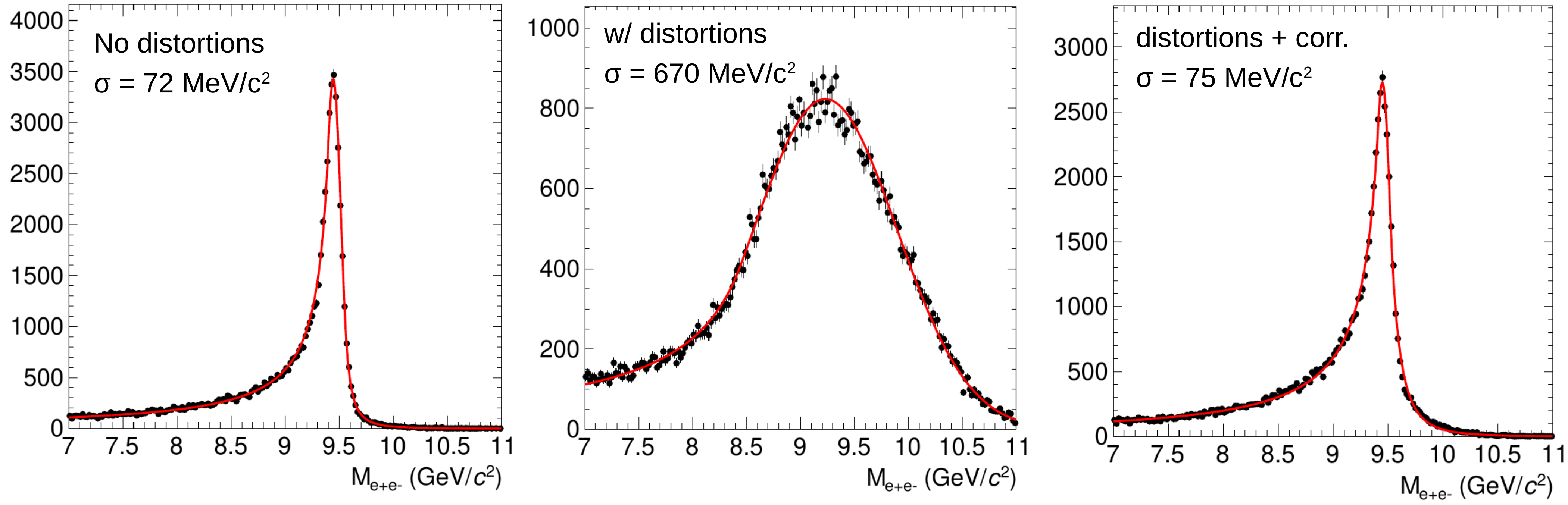


left: momentum resolution vs p_T
Very little difference between nominal (= no distortion) and after distortion+correction in MM acceptance
Slight degradation (~25%, relative) when extrapolating to the full acceptance

right: for book keeping, comparison between nominal (= no distortion) and distorted mom. res, if no correction is applied

Impact on Upsilon invariant mass resolution

Focusing on time-averaged beam-induced distortions, O(mm)



Using track-base correction in MM acceptance + extrapolation procedure, one is able to recover almost completely the Upsilon invariant mass resolution.

The invariant mass distribution exhibits slightly larger tails though, especially at high mass.

A few words about the *management plan*

Defines project scope, deliverable, key and ultimate performance parameters, first cost and schedule estimate and management structure

	z layer	ϕ layer
Radial position (min.) (mm)	800	820
Radial position (max.) (mm)	820	840
Detector dimension (sensitive area) (mm^2)	250×500	250×500
Number of strip per detector	256	256 (512)
Strip length (mm)	250	500 (250)
Strip pitch (mm)	1.95	0.98
Number of detectors	26+4	26+4

Table 3: Summary of the main design parameters of the Outer Tracker

Radiation length	$< 10\%$ of x_0
Active strips	$> 90\%$
Hit efficiency	$> 90\%$
Hit resolution	$< 200\ \mu m$ (ϕ layer), $< 300\ \mu m$ (z layer)
Noise hits per detector	TBD
Read-out trigger rate	> 15 kHz

Table 1: Outer Tracker Key Performance Parameters (KPP)

Item	Quantity	Spares
Micromegas detectors	52 (26 z layer, 26 ϕ layer)	8 (4 z layer, 4 ϕ layer)
Support structures	26	0
HV Power lines	260 input channels (208 pos. polarity, 52 neg. polarity)	40 input channels (32+, 8-)
HV Power supplies	6 (5 pos. polarity, 1 neg. polarity)	1
Gas system	1	0
Front-end electronic (FEE)	26×3 SAMPA FE boards	3×3 FE boards
FEE-to-detector Flex	78	22
FEE housing	26	TBD
LV power supply	1 MegaPak (10 DC-DC mods)	TBD
Cooling for electronics	78 Cooling plates	TBD
Back-end electronics	3 FELIX boards	TBD
TPC-EBDC computers	3 Commodity server	TBD

Table 2: Outer Tracker deliverables

https://www.overleaf.com/6995556719hnccmsgwsmzf

A few words about first internal TPOT review

Internal review on December 2, 2020 (https://indico.bnl.gov/event/10116/)

Presenters: Maxence Vanderbroucke, Takao Sakaguchi, Stephan Aune, HP

Committee: Jim Mills, Russ Feder, Bob Azmoun, Klaus Dehmelt, Tom Hemmick, Craig Woody, Joe Osborn, Jin Huang, John Kuczewski, John Haggerty

Some *unofficial* recommendations:

- fund and construct a full size prototype Micromegas module

  → see presentation from Maxence
- begin support structure engineering studies.
  - can the detector be decouple from the TPC ?
  - can the module be installed after the TPC is in place ?

  → ongoing work at BNL (Rich Ruggiero, Russ Feder, Dan Cacace, etc.)
- demonstrate methods to extrapolate to the full acceptance

  → this presentation
- assess the performances on reconstructing the distortions in pp collisions

  → ongoing. pp simulations ready, via MDC
- study reducing the scope of the project

  → ongoing

Conclusion, outlook

- The Outer Tracker (now TPOT) project has matured a lot since last collaboration meeting
- It is an essential part of the envisioned strategy for reconstructing the SC distortions, in a timely manner, together with existing systems (directed and diffuse lasers, digital currents in the GEMs)
- Software wise, we are confident that it should allow to reconstruct beam-induced distortions to a level that allows to recover satisfactory momentum and invariant mass resolutions

<u>Immediate TODO (software)</u>:

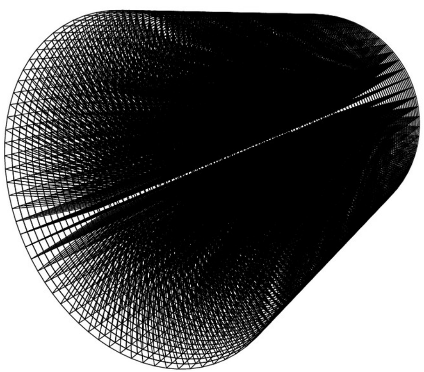
- assess the performances on reconstructing the distortions in pp collisions
- understand the remaining (50-100um) discrepancies between input and reconstructed distortions
- integrate in a global scheme to reconstruct all distortions (static, bean-induced, fluctuations) using all available tools

<u>Other challenges include</u>:

- fund the project (both a prototype and the complete detector system)
- design and build the detector in time for first data taking
- integrate into sPHENIX

Backup

Method for getting distortions from tracks



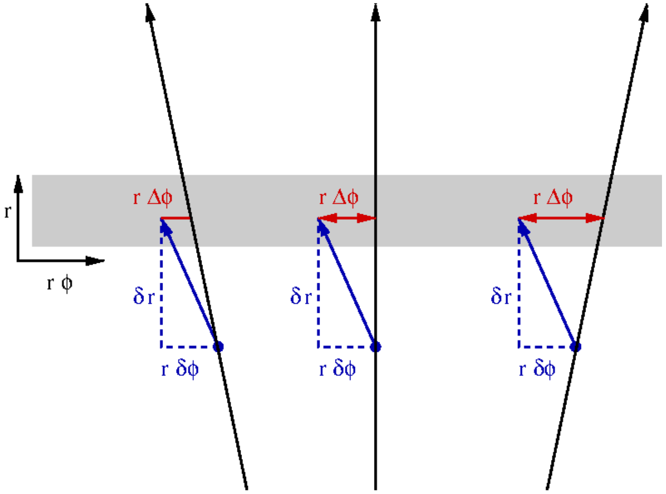
For each volume element, there are distortions in all three directions δΦ, δr and δz

In the TPC we only measure coordinates along Φ and z

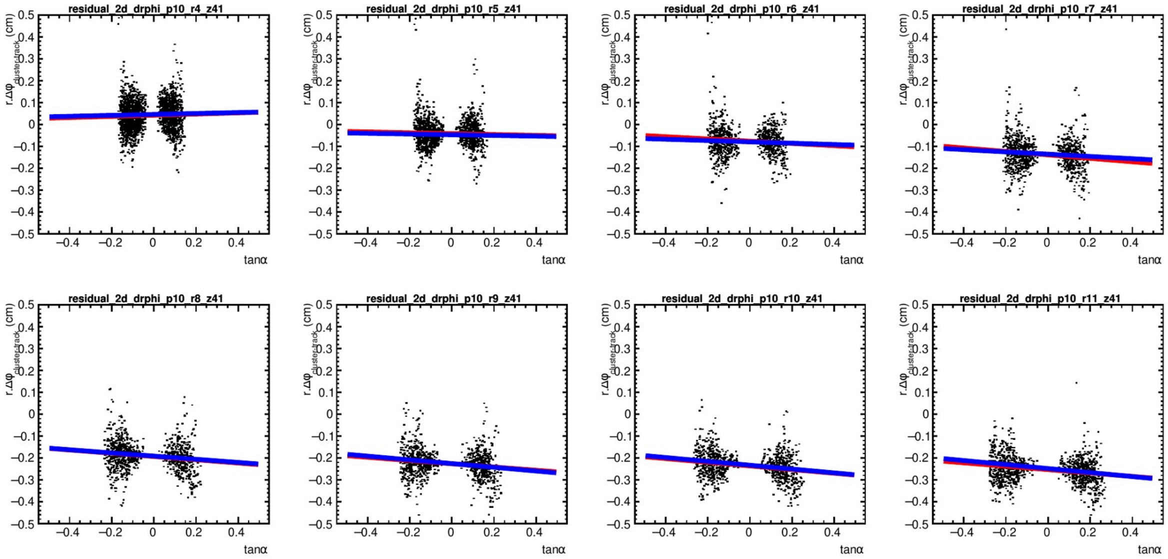
One can access distortions along r by looking at the correlation between ΔΦ and Δz with track angles

In the (r, Φ) plane, for a non zero δr distortion there is a linear relation between the measured residual rΔΦ and the track angle α:

$$r\,\Delta\phi = r\,\delta\phi + \delta r\,.\tan\alpha$$



Also seen in the simulations:



The same is true in the (r,z) plane:

$$\Delta z = \delta z + \delta r\,.\tan\beta$$

Method for getting distortions from tracks (cont.)

- one must perform 2D fits of rΔΦ vs tan(α) and Δz vs tan(β)
- ideally must be a combined fit, because the same δr enters both distributions
- there are at least 36 (Φ) x 16 (r) x 80 (z) = 46080 fits to perform for each distortion map (one per volume element)
- Cannot realistically use Minuit for this. Prefer analytic solution

$$r\,\Delta\phi = r\,\delta\phi + \delta r\,.\tan\alpha$$
$$\Delta z = \delta z + \delta r\,.\tan\beta$$

$$\chi^2 = \sum_{clusters,tracks} \frac{\left[r\,\Delta\phi - \left(r\,\delta\phi_0 + \delta r_{0.}\tan\alpha\right)\right]^2}{\sigma^2_{r\phi}} + \frac{\left[\Delta z - \left(\delta z_0 + \delta r_{0.}\tan\beta\right)\right]^2}{\sigma^2_z}$$

With:

- rΔΦ, Δz: residuals (measured)
- α, β the local track angles (measured)
- $\delta\Phi_0$, δr_0 and δz_0 the distortions in given volume element

To minimize, one sets the χ^2 partial derivatives on the three unknowns $\delta\Phi_0$, δr_0 and δz_0 to zero

Since χ^2 is quadratic in $\delta\Phi_0$, δr_0 and δz_0, this results in a set of linear equations:

$$\begin{pmatrix} \sum_{cl,tr}\frac{1}{\sigma^2_{r\phi}} & 0 & \sum_{cl,tr}\frac{\tan\alpha}{\sigma^2_{r\phi}} \\ 0 & \sum_{cl,tr}\frac{1}{\sigma^2_z} & \sum_{cl,tr}\frac{\tan\beta}{\sigma^2_z} \\ \sum_{cl,tr}\frac{\tan\alpha}{\sigma^2_{r\phi}} & \sum_{cl,tr}\frac{\tan\beta}{\sigma^2_z} & \sum_{cl,tr}\frac{\tan^2\alpha}{\sigma^2_{r\phi}}+\frac{\tan^2\beta}{\sigma^2_z} \end{pmatrix} \cdot \begin{pmatrix} r\,\delta\phi_0 \\ \delta z_0 \\ \delta r_0 \end{pmatrix} = \begin{pmatrix} \sum_{cl,tr}\frac{r\,\Delta\phi}{\sigma^2_{r\phi}} \\ \sum_{cl,tr}\frac{\Delta z}{\sigma^2_z} \\ \sum_{cl,tr}\frac{r\,\Delta\phi\,.\tan\alpha}{\sigma^2_{r\phi}}+\frac{\Delta z\,.\tan\beta}{\sigma^2_z} \end{pmatrix}$$

So the minimization results in inverting a 3x3 matrix for each volume element where there are tracks