BROOKHAVEN NATIONAL LABORATORY

BeAST solenoid magnetic field calculation and accompanying studies

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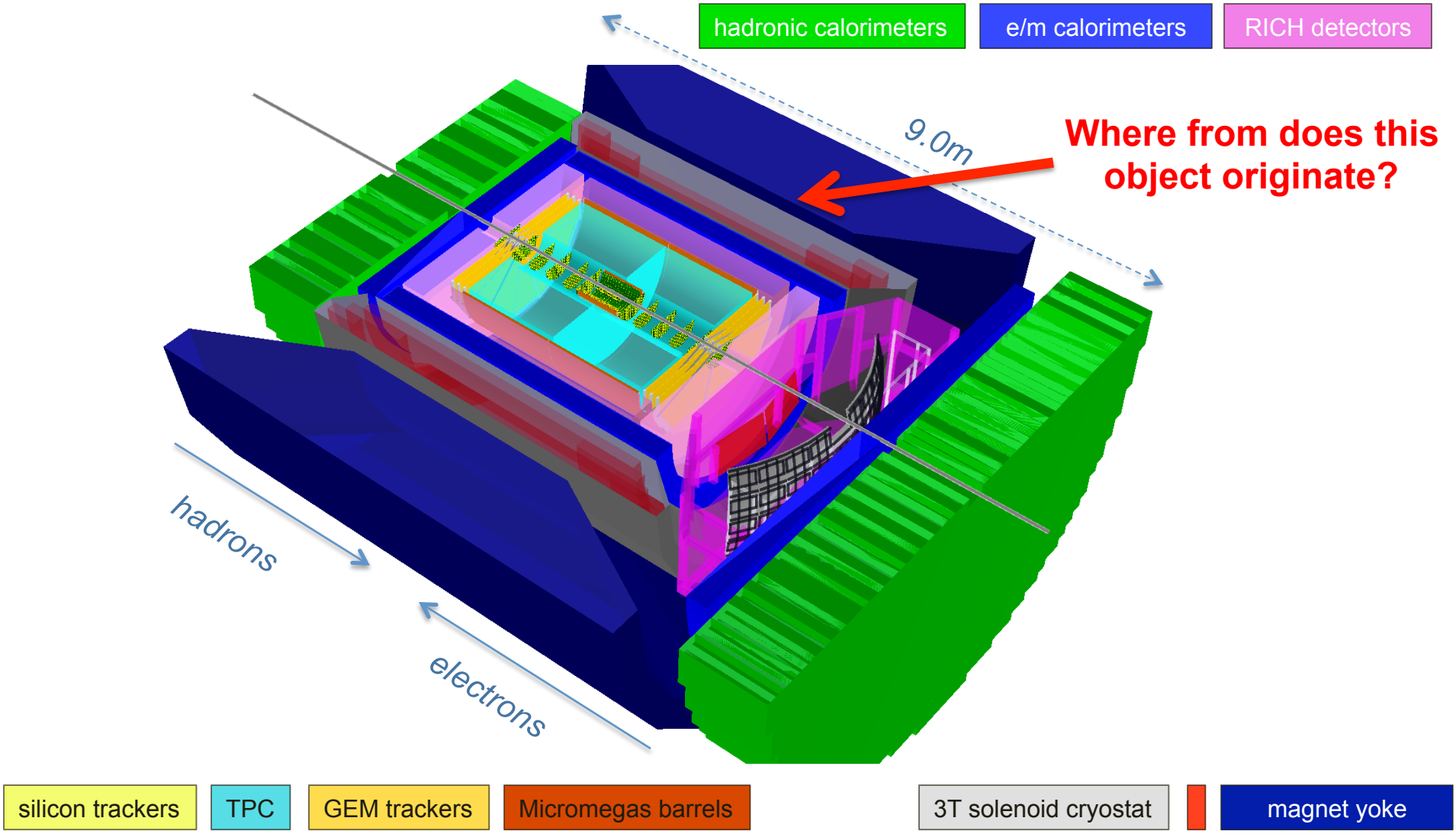
Remote “Temple” EICUG YR Meeting Mar,20 2020

BeAST detector layout

-3.5 < η < 3.5: Tracking & e/m Calorimetry (hermetic coverage)



Outline of the talk

- Original EicRoot solenoid field (R.Darienzo / B.Parker)
- Exercise with the Detector-Integrated Dipole

- BeAST magnetic field: motivation and calculation technique
- Gaseous RICH performance in the BeAST fringe field

- Path forward?

Original EicRoot 3T field

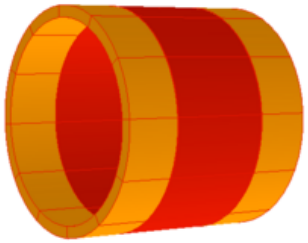
- Calculated by Rick Darienzo (Elke's intern at BNL) back in 2013 with the help of Brett Parker
  - OPERA 2D software suite
  - simple "Belle" coil configuration
  - no yoke

Bifurcated EncLosed LinEar solenoid: BELLE

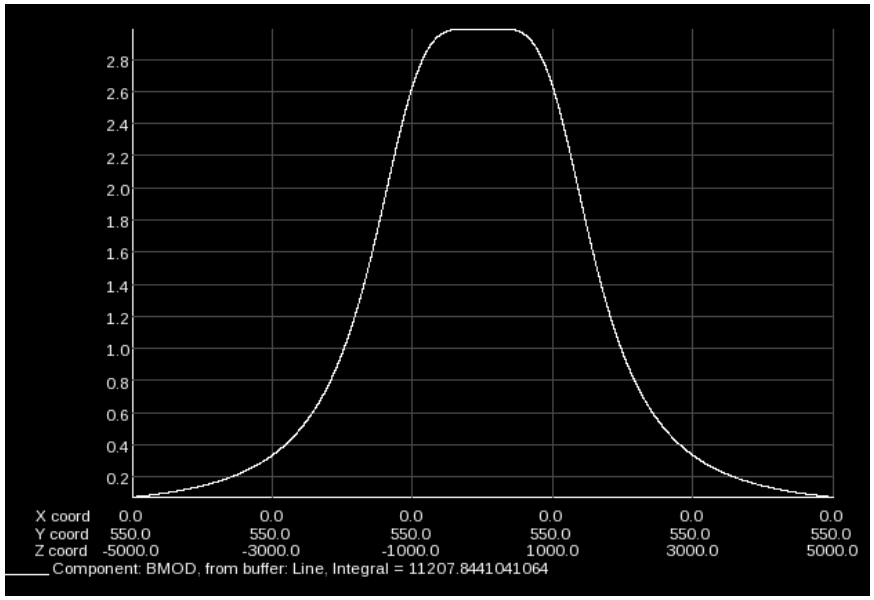
Our most current working design is the 2.477 m long Bifurcated EncLosed LinEar solenoid (BELLE). This design was preceded by the Multiple Ring Solenoid version B1 (MRS-B1). A poster which describes the comparison between the BELLE and the MRS-B1 in detail may be seen here. The magnet modeling and some of the particle trajectory simulations are completed in COBHAM's OPERA-3d software suite.

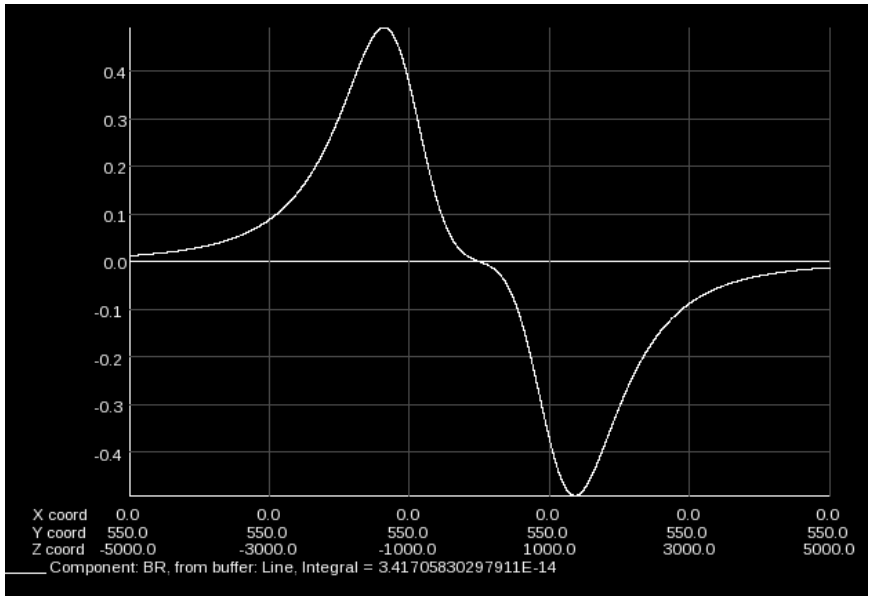
BELLE Conductor Specifications				
	Length [mm]	Inner Radius [mm]	Outer Radius [mm]	Current Density [A/mm^2]
Inner Solenoid	1200.0	1220.0	1320.0	25.0
Outer Solenoid (each side)	638.5	1200.0	1340.0	33.0

Sample Magnetic Field Values		
(x,y,z) [mm]	$B_{modulus}$ [T]	B_{radial} [T]
(0, 0, 0)	2.9	0.0
(0, 0, ±1300)	2.0	0.0



Original EicRoot 3T field





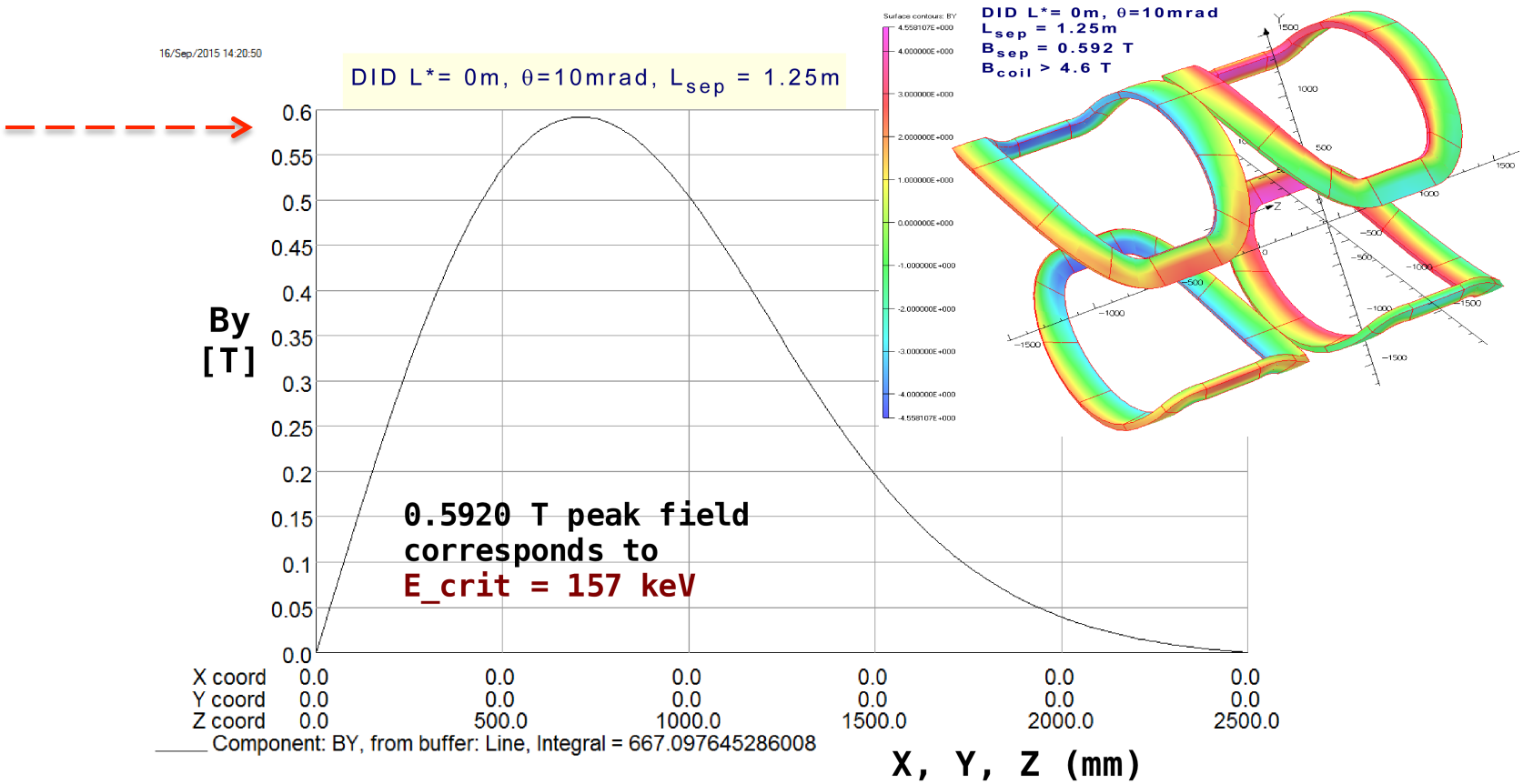
Longitudinal field component (3T max)

Transverse field component (large!)

- Quite a step forward compared to the constant 3T box field, but ...
- ... more like a toy model ...
- ... transverse field in the TPC volume would be too large (?)

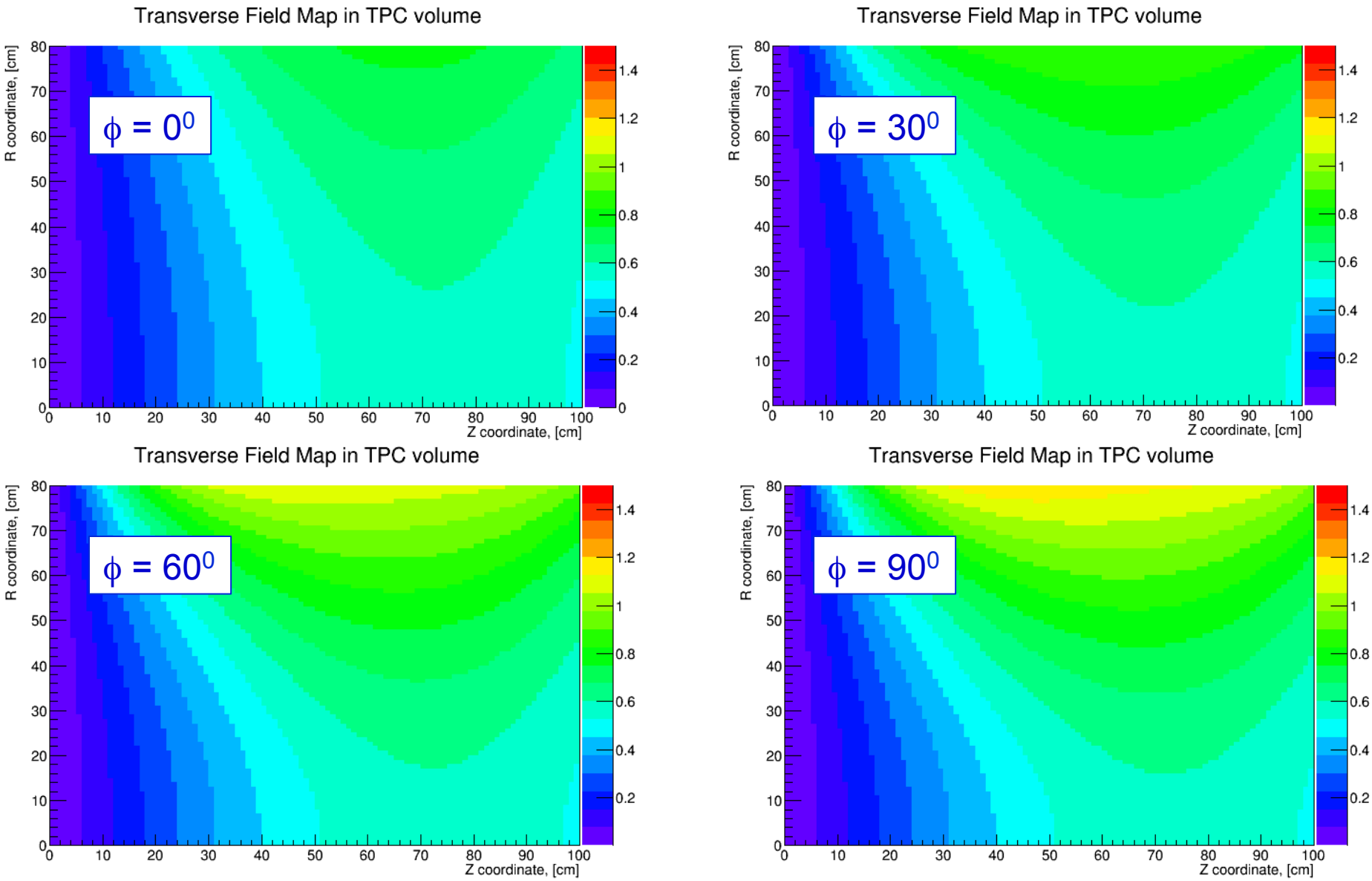
Detector-integrated dipole (DID) excursion

- The primary objective: mitigate the risk of eRHIC machine by replacing crab cavities with a separation dipole combined with the main solenoid



This did not really work well (see the next two slides)

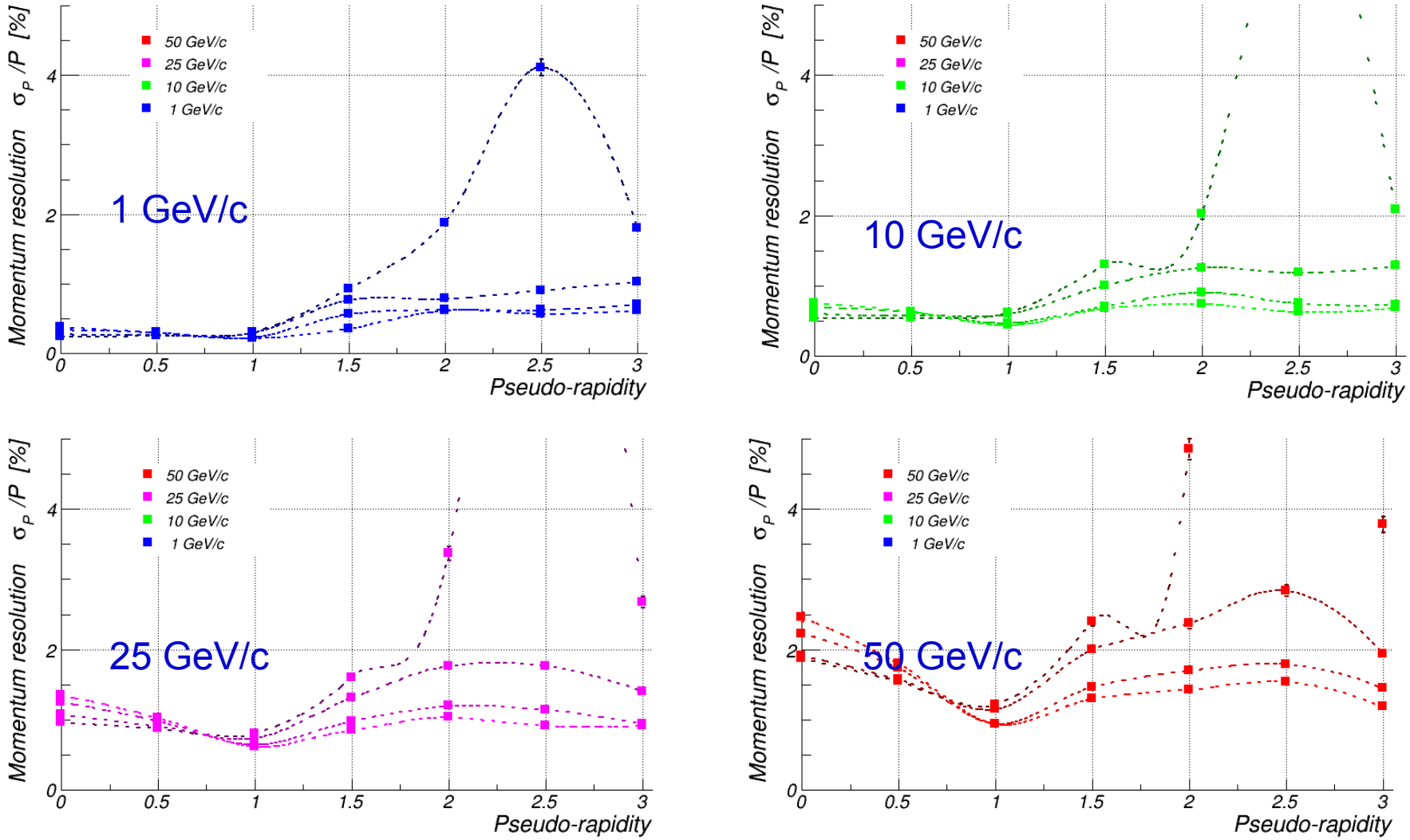
DID: transverse field in the TPC volume



Highly non-uniform and ϕ-dependent transverse field component

DID: momentum resolution at forward η

- Four curves on every plot: $\phi = 0^0, 30^0, 60^0, 90^0$

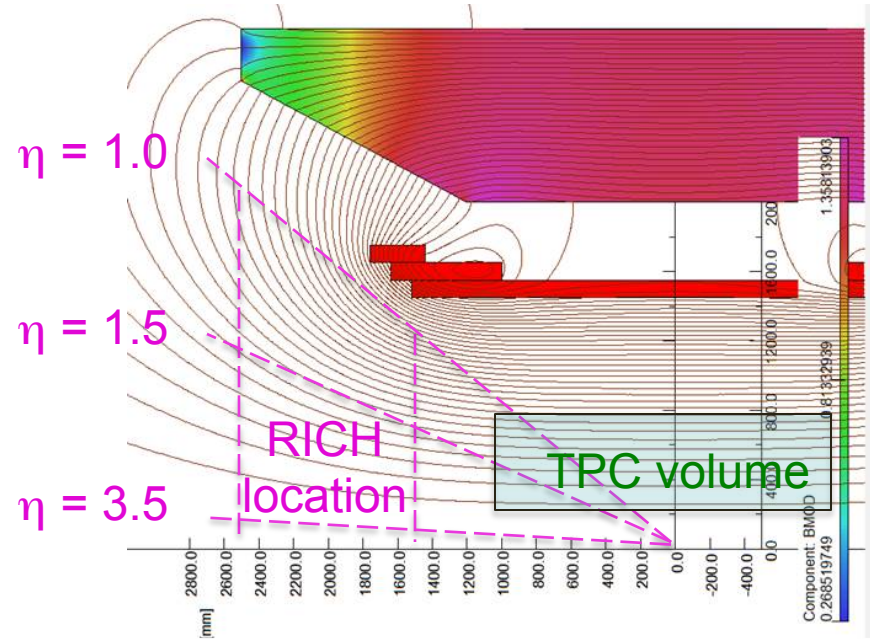


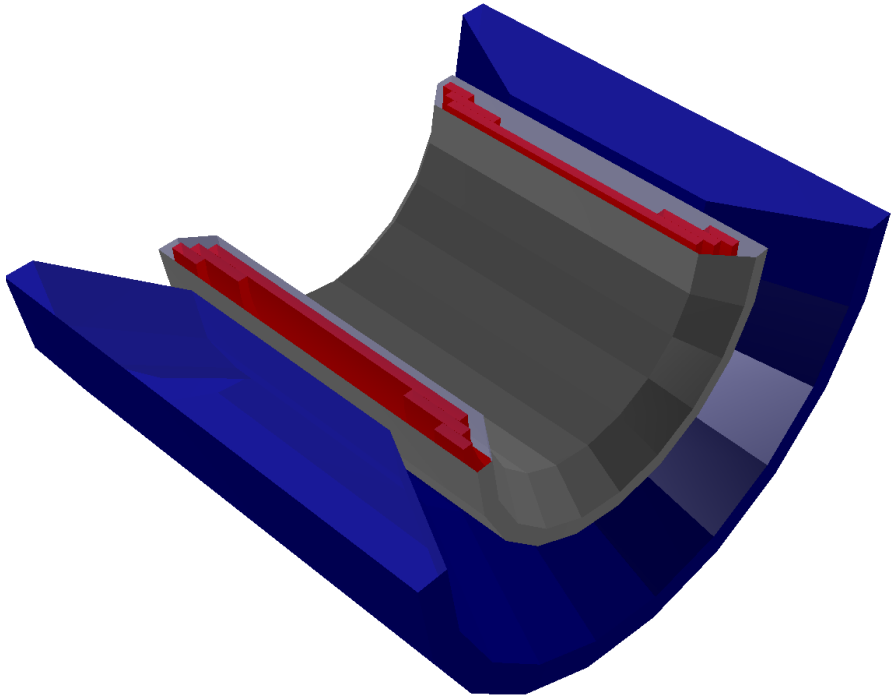
No azimuthal symmetry; very poor resolution at forward rapidities and unfortunate ϕ where solenoid and dipole fields cancel each other

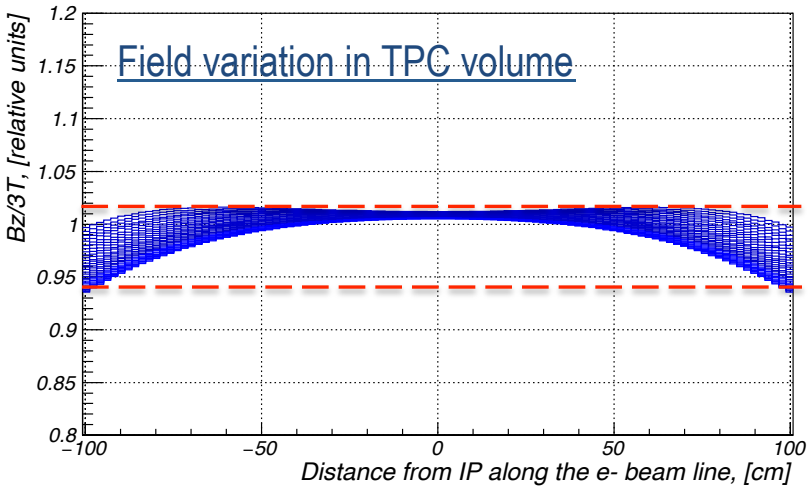
BeAST magnetic field

Goal:

- Implement in the same compact design:
  - homogeneous ~3T field in the TPC
  - hadron-track-aligned field in the RICH
- Keep it simple (no dual solenoid configuration; no reversed current coils; no flux return through HCal; no warm coils between RICH and EmCal)







Method overview

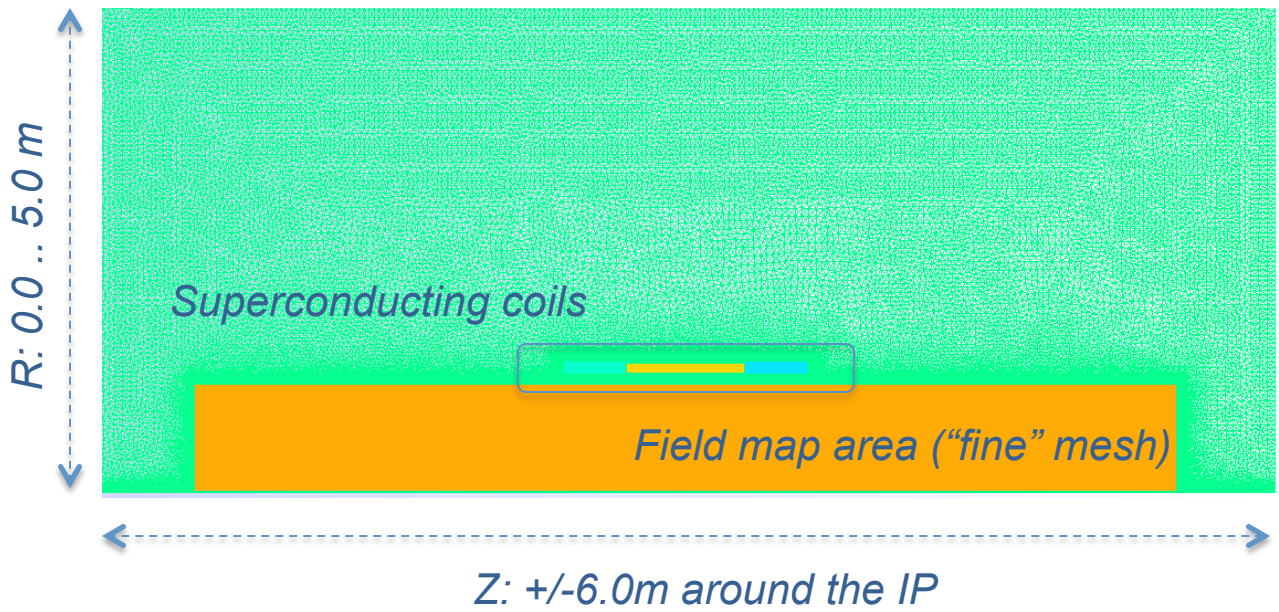
- Use Open Source tools instead of Opera 2D/3D and such:
  - Custom *ROOT* scripts for geometry creation
  - *Netgen* library for meshing
  - *Elmer* for magnetostatic calculations
  - *Gmsh* and *Paraview* for visualization

-> since everything is done in (almost) the same Linux environment, it can be very flexible and is natively interfaced to the rest of the simulation codes

-> allowed for very short turn-around times per coil+yoke geometry configuration (literally hundreds of options were tried out) where expert cross-check was required only at the end

Details of the model

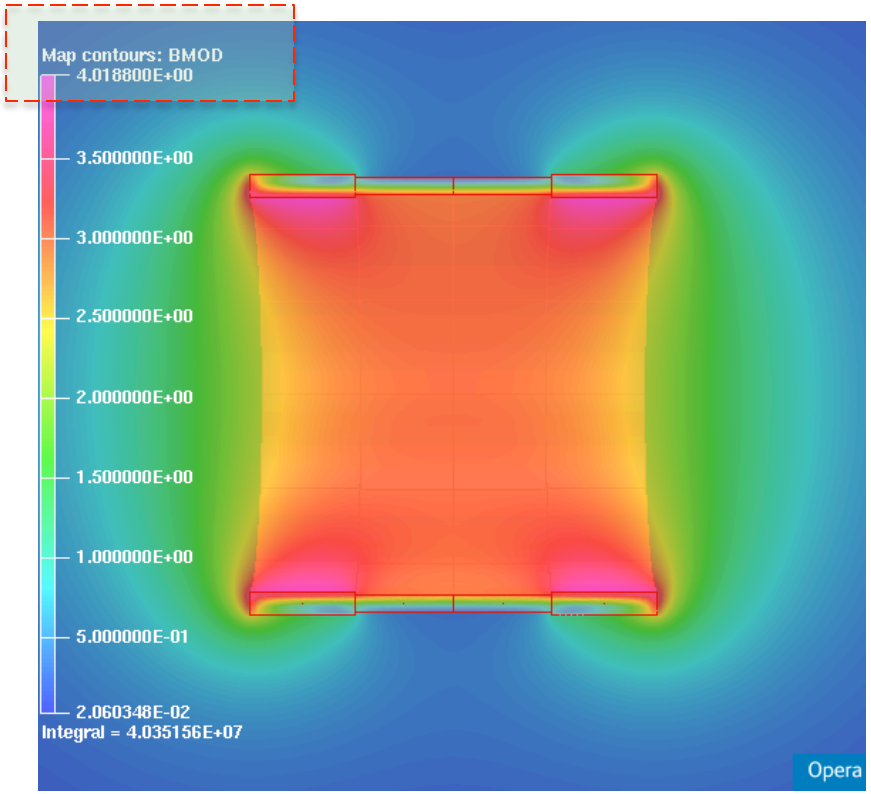
- Use 2D formalism (yes, axially symmetric field configuration)
  - Indeed helps a lot to save CPU time!
- Typically ~5x12m^2 area in {R,Z} with natural boundary conditions
- Essential map region is meshed in triangles <1cm in size



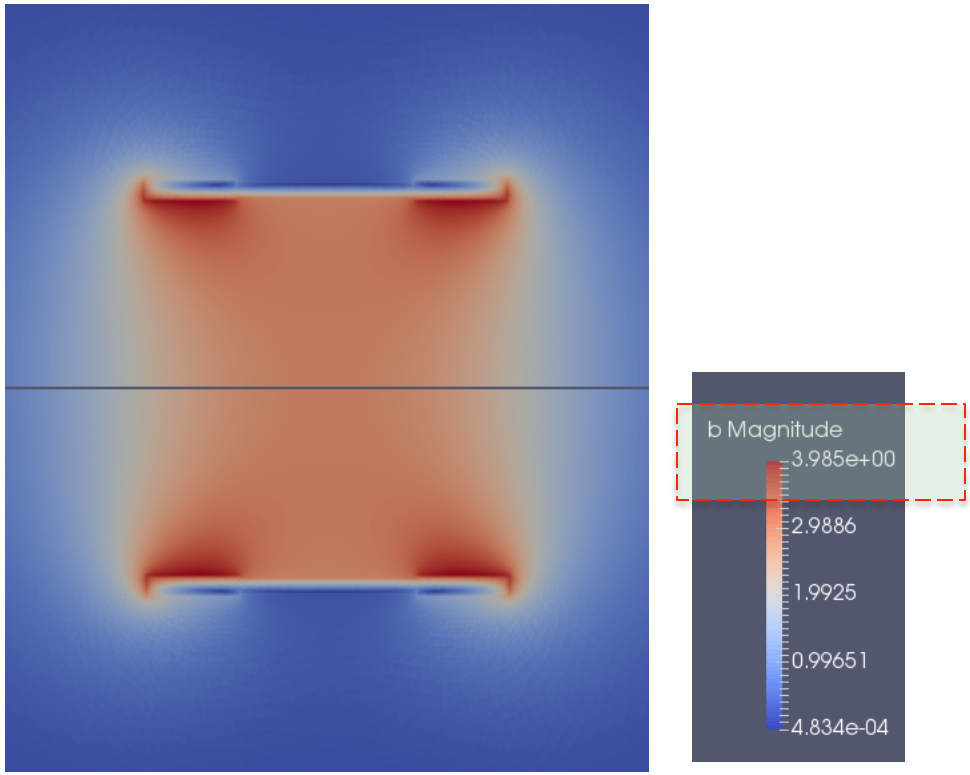
-> execution requires up to 4GB of RAM; a typical configuration takes ~2-3 minutes of processing time on Intel Xeon W3520 2.67GHz (single thread)

“Belle” configuration X-check: 2D field

OPERA



Elmer

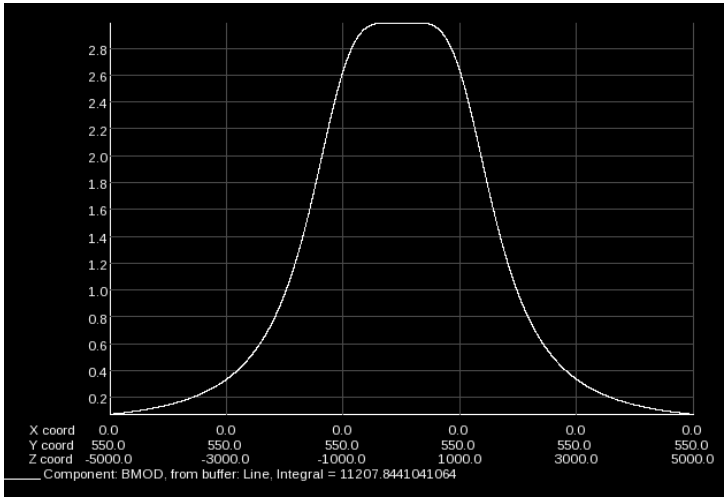


- Look similar and the scale (max.field ~4T at the coils) is correct

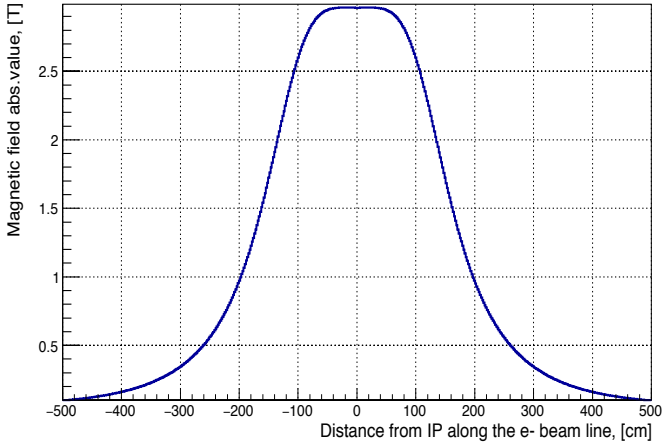
“Belle”: field abs.value

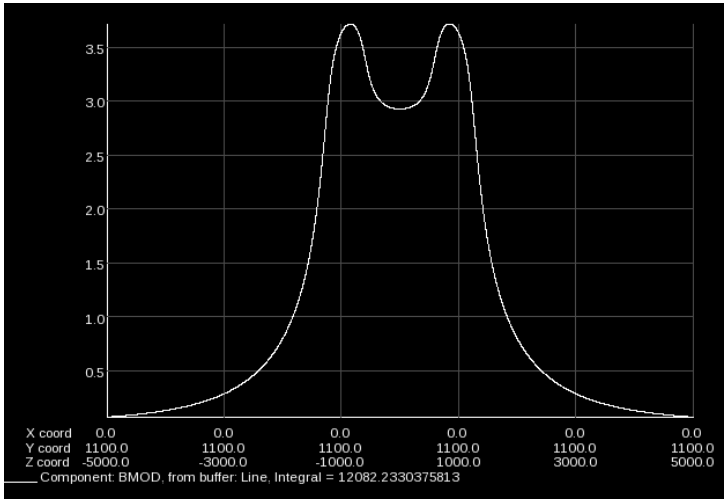
OPERA

Elmer

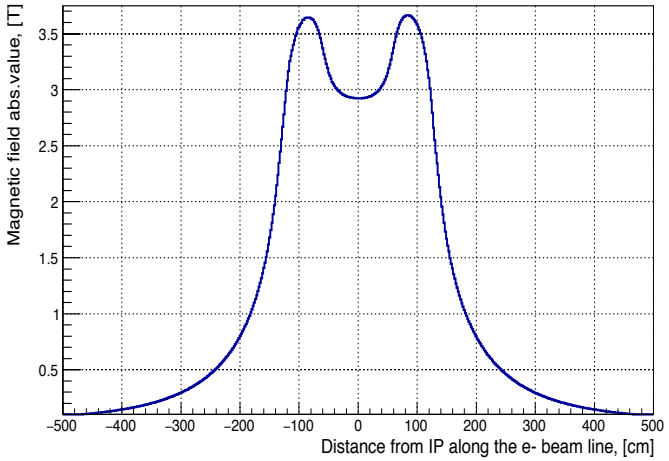


R = 55 cm





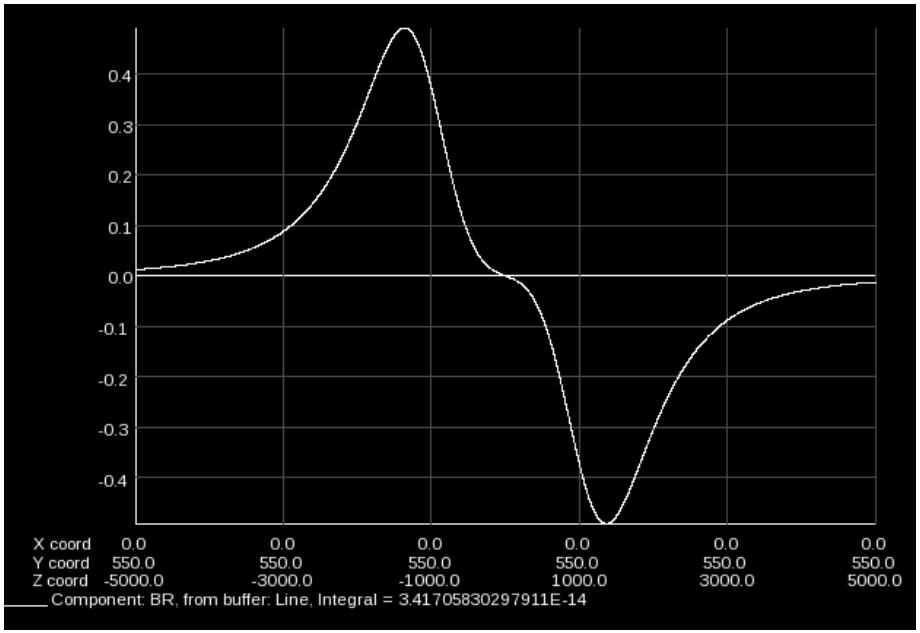
R = 110 cm



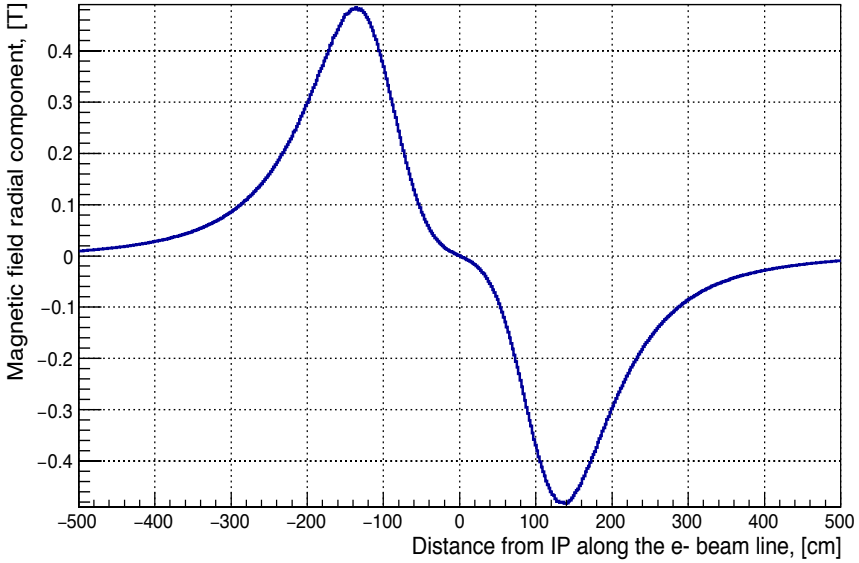
- Also pretty much the same …

“Belle”: radial component @ R=55cm

OPERA



Elmer



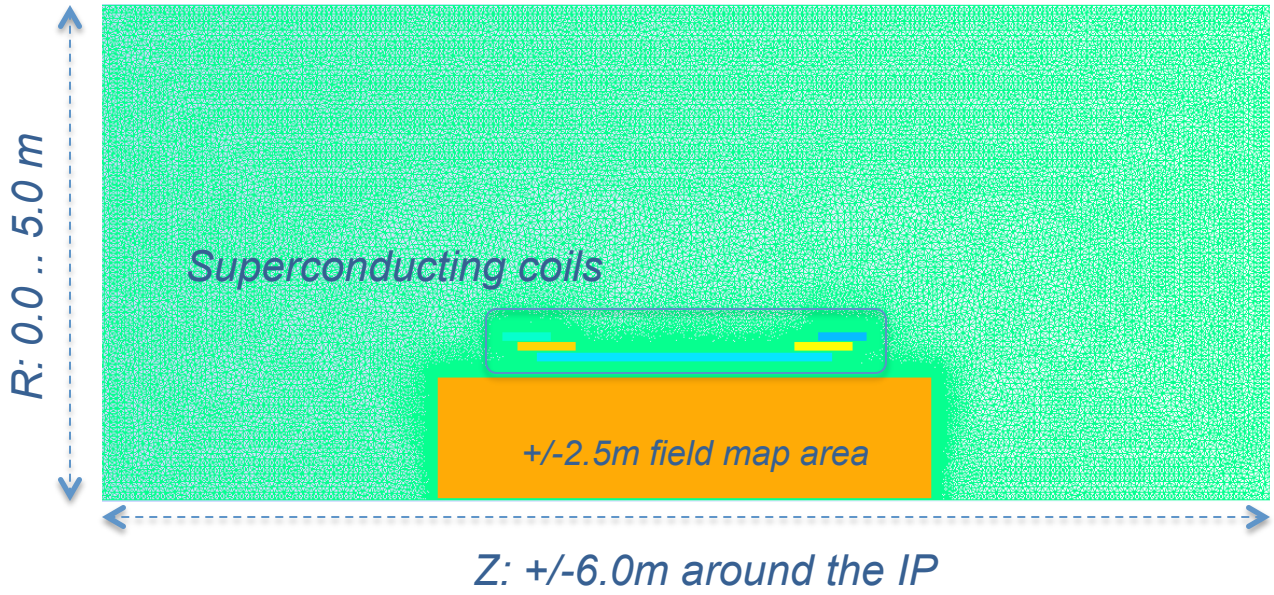
- Even the small radial component comes out ~identical in both packages (yes, Maxwell equations are sort of universal :-)

-> this means further plots more or less make sense as well

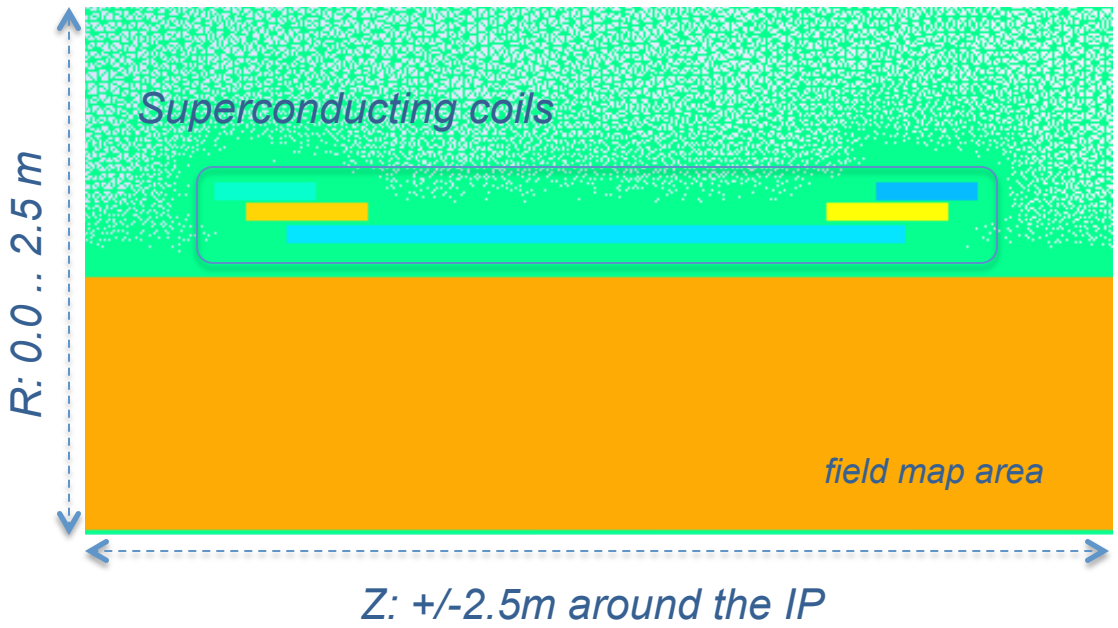
BeAST: optimize for the TPC first

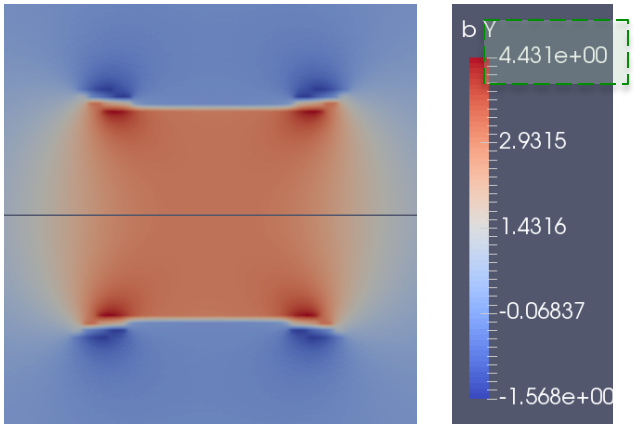
- Use pretty much the same procedure as for the “Belle” calculations

- Field homogeneity on the level of few % in |Z|<1m and R~[0.2 .. 0.8]m region
- Fiducial volume limitations for coil placement:
  - >1400mm or so in radius (do not disturb barrel detectors)
  - $|\eta| < 1.0$ or so in polar angle (do not disturb endcap detectors)



Coil configuration (optimized for TPC)



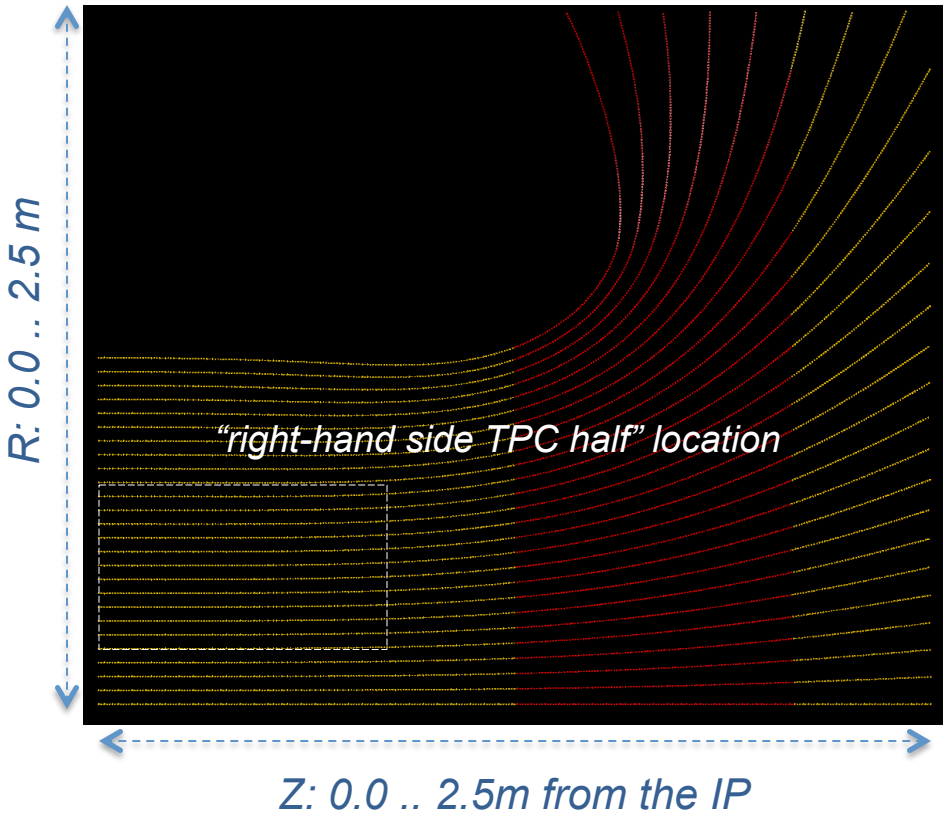


- Max. field ~4.4T -> should work?

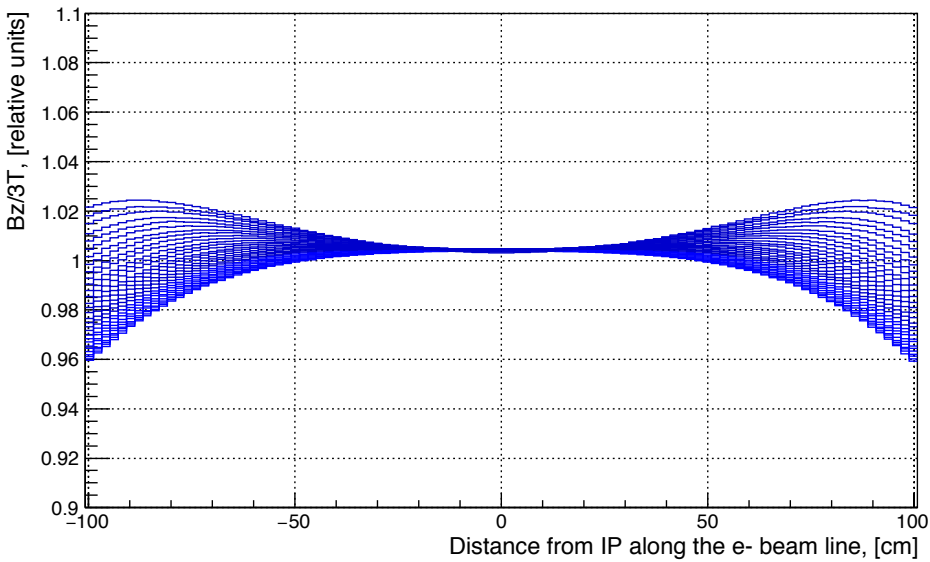
R_{min}, [mm]	R_{max}, [mm]	Length, [mm]	Z-offset, [mm]	Current, [A/mm^2]
1610	1700	500	1600	12
1510	1600	600	1400	36
1400	1500	3000	0	24
1510	1600	600	-1400	36
1610	1700	500	-1600	12

Field in the TPC volume

Magnetic field lines



Field homogeneity in R [0.2 .. 0.8] m

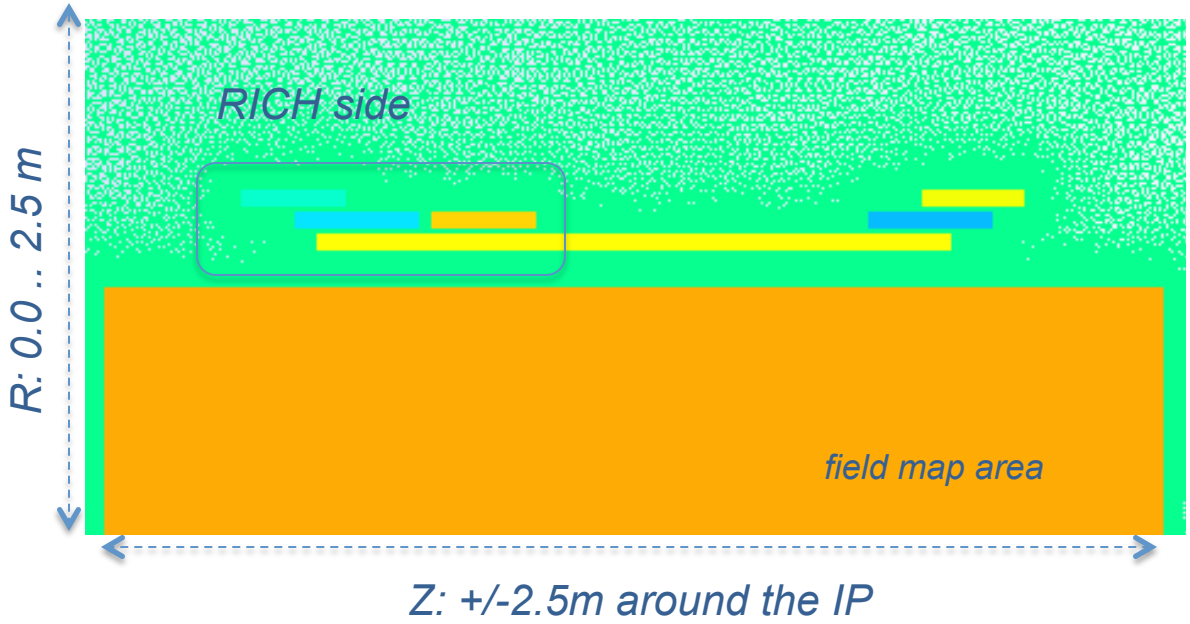


- Pretty much within ~3% in the whole volume -> fine!

- Approximate CF_4 RICH location (1.5 .. 2.5m from the IP) indicated in red

-> and RICH is not happy! – see next slide

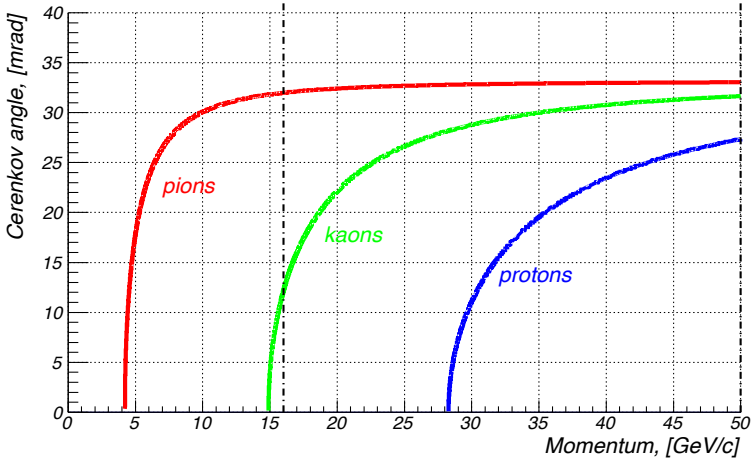
Coil configuration (optimized for RICH)



- RICH side (hadron-going direction) gets tuned
- The other side stays almost the same as before

R_{min}, [mm]	R_{max}, [mm]	Length, [mm]	Z-offset, [mm]	Current, [A/mm^2]
1610	1700	500	1600	-20
1510	1600	500	700	12
1510	1600	600	1300	40
1400	1500	3000	0	24
1510	1600	600	-1400	34
1610	1700	500	-1600	12

Will gas radiator RICH work in this field?



Consider configuration inspired by the RD6 test run:

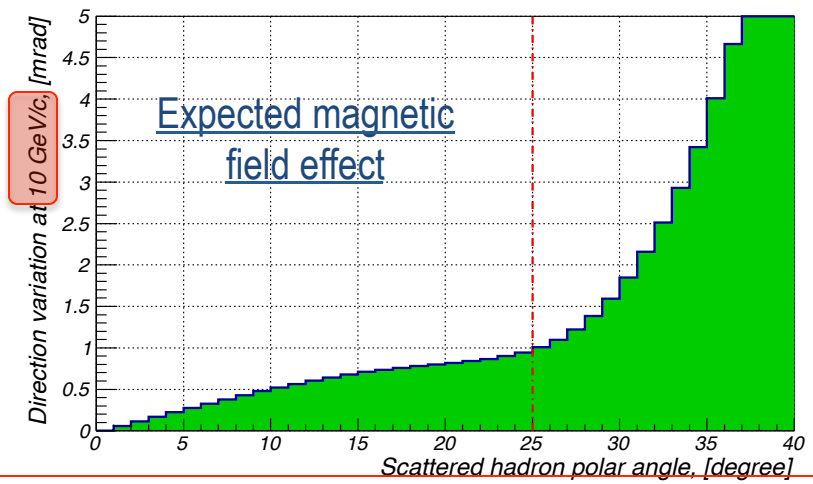
- 1m long CF_4 gas volume [1.5 .. 2.5]m from the IP
- 1m focal length; ~33mm ring radius at $\beta \sim 1$
- GEM readout; effective 2.5mm hexagonal pads
- Assume on average 12 photons per ring at $\beta \sim 1$
- Additional 300 μrad instrumental resolution

EIC R&D project

"Back-of-the-envelope" Monte-Carlo study:

- Realistic solenoid magnetic field
- Realistic tracker momentum resolution
- Cerenkov angle smearing in the field
- CsI quantum efficiency $\varepsilon(\lambda)$ dependence
- Refractive index $n(\lambda)$ variation
- Finite readout board "pixel" size

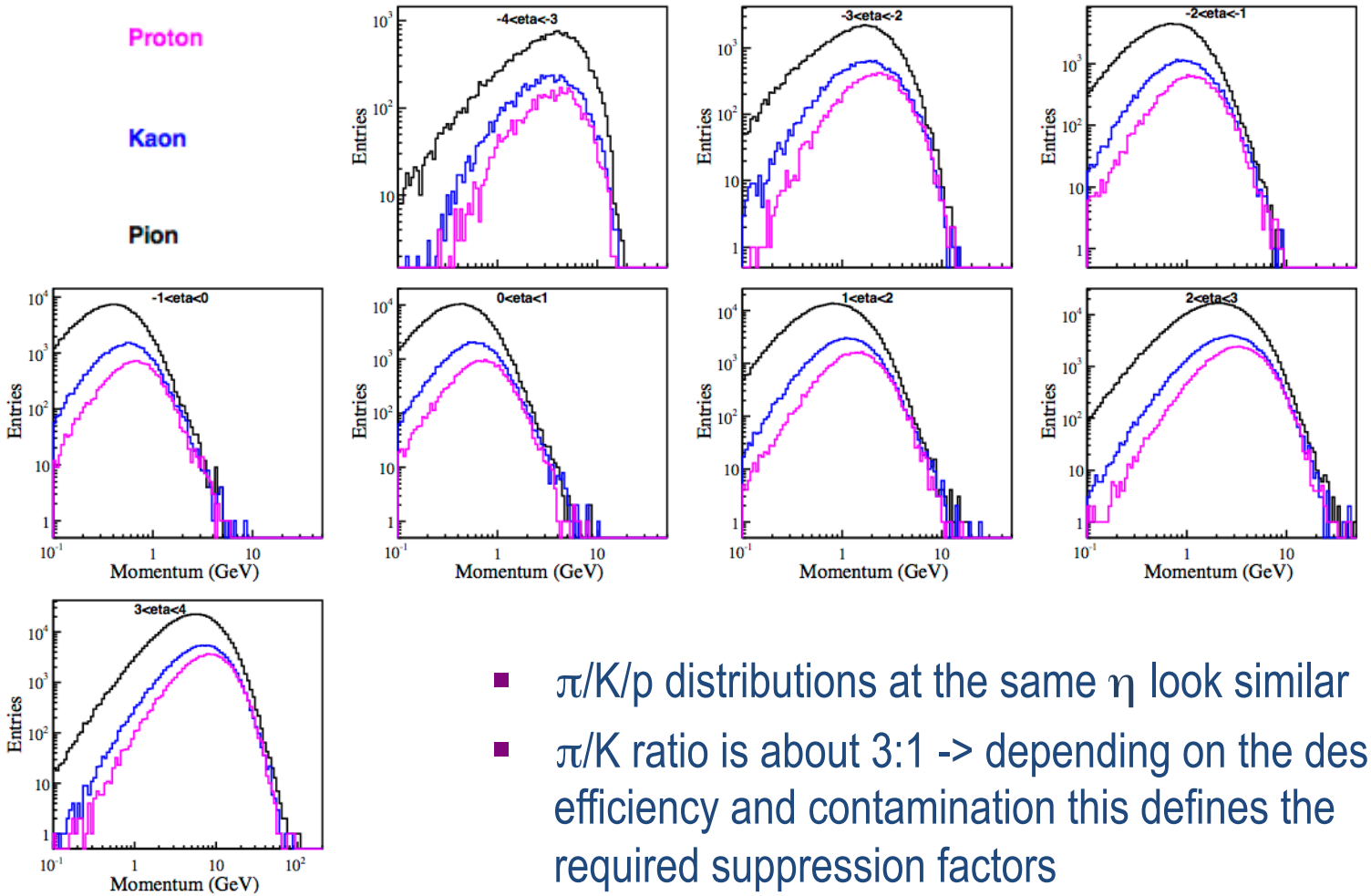
- ROOT TMVA-based output evaluation



NB: this spread is in principle noticeable compared to the intrinsic single-photon angular resolution of ~1 mrad

Relative pion/kaon/proton yields

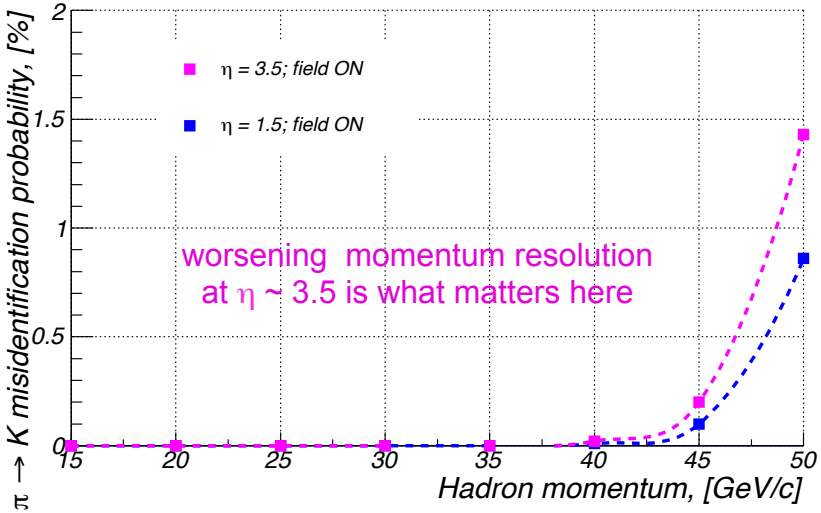
20x250 GeV configuration; yields versus momentum in the 4 < η < 4 range:

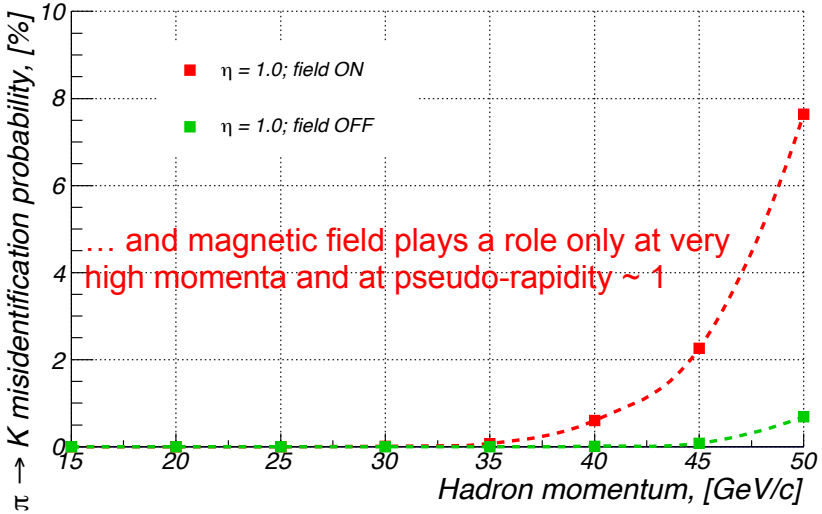


- π/K/p distributions at the same η look similar
- π/K ratio is about 3:1 -> depending on the desired efficiency and contamination this defines the required suppression factors

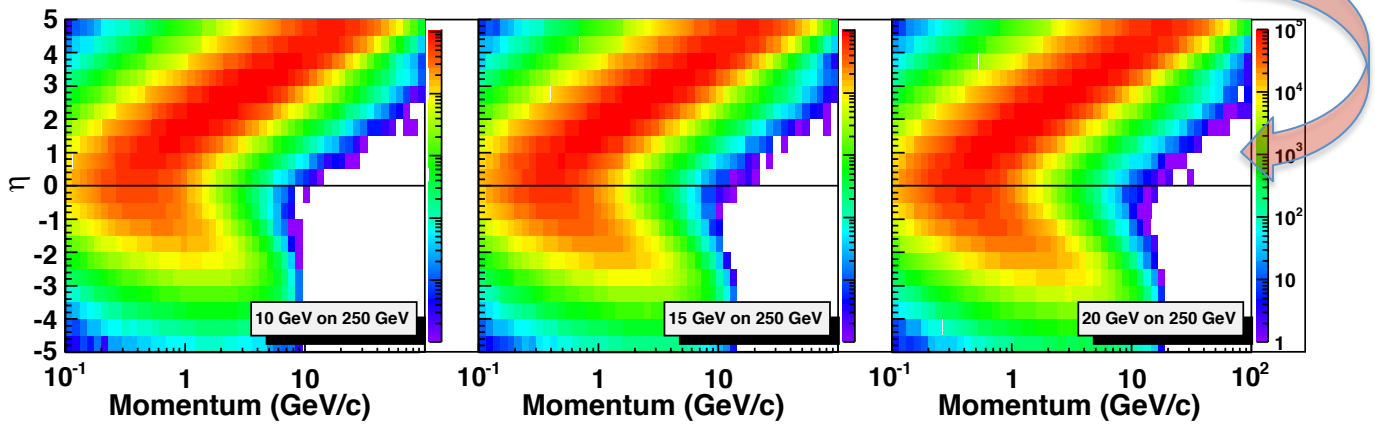
Gas radiator RICH in the magnetic field

Require 95% kaon positive identification efficiency





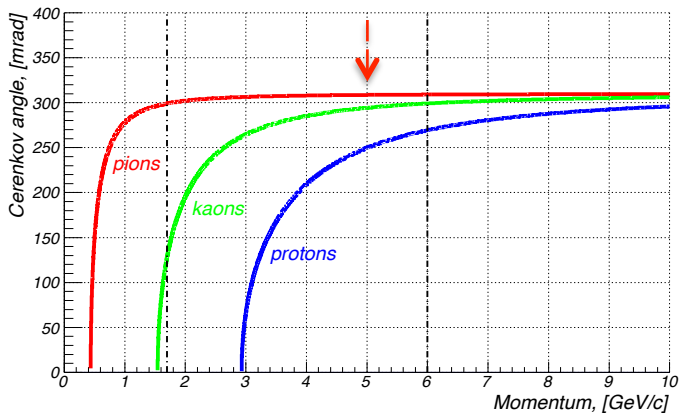
But we do not expect any SIDIS hadrons there:



So yes, RICH with a long enough gas radiator should work just fine in this solenoid stray field

Will aerogel RICH work in such a field?

NB: at 3T full track bending in aerogel volume is >5 mrad at 5 GeV/c!



Consider end-cap case in proximity-focusing configuration:

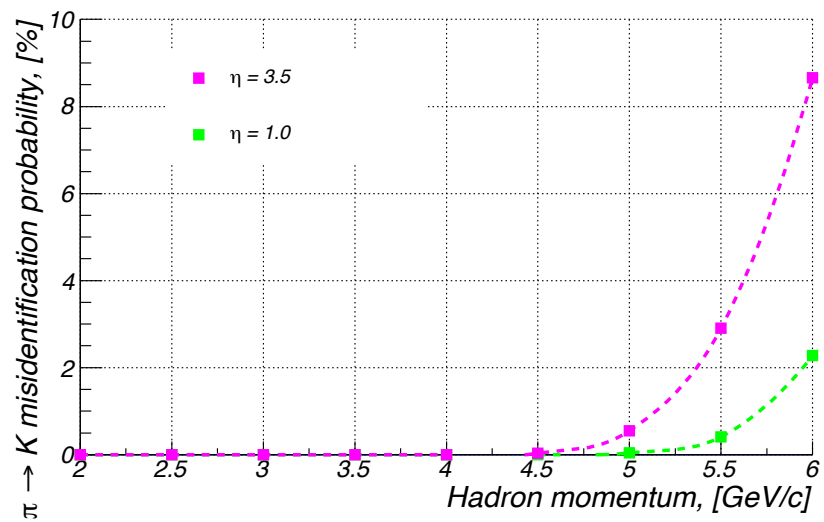
- 3cm thick aerogel; 20cm expansion volume
- $\langle n_0 \rangle = 1.05$
- ~5cm attenuation length
- SiPM array readout; 5mm^2 "pixel" size
- Assume on average 15 photons per ring at $\beta \sim 1$

Aerogel RICH R&D for Belle II upgrade

"Back-of-the-envelope" Monte-Carlo study:

- Constant $B_z \sim 3T$
- Asymmetric (ϕ-dependent) attenuation
- ϕ-dependent Cerenkov angle smearing in the field
- SiPM quantum efficiency $\varepsilon(\lambda)$ dependence
- Refractive index $n(\lambda)$ variation
- Emission point uncertainty (thick radiator)
- Finite readout board "pixel" size

- TMVA-based output evaluation



Require 95% kaon positive identification efficiency

Questions & path forward

- Can we come up with a better (non-Babar) model for the YR?

- Which max field?
- Homogeneous field in the ”TPC” volume really needed?
- Flux return through HCal?

- Feasible fringe field configuration in the RICH volume?
- Active compensation coils between EmCal & HCal?

- Field clamps, stray field in the hall

- Compensation for beam optics (new task force led by Vasiliy)