SND@LHC UPGRADE TOWARDS HL-LHC

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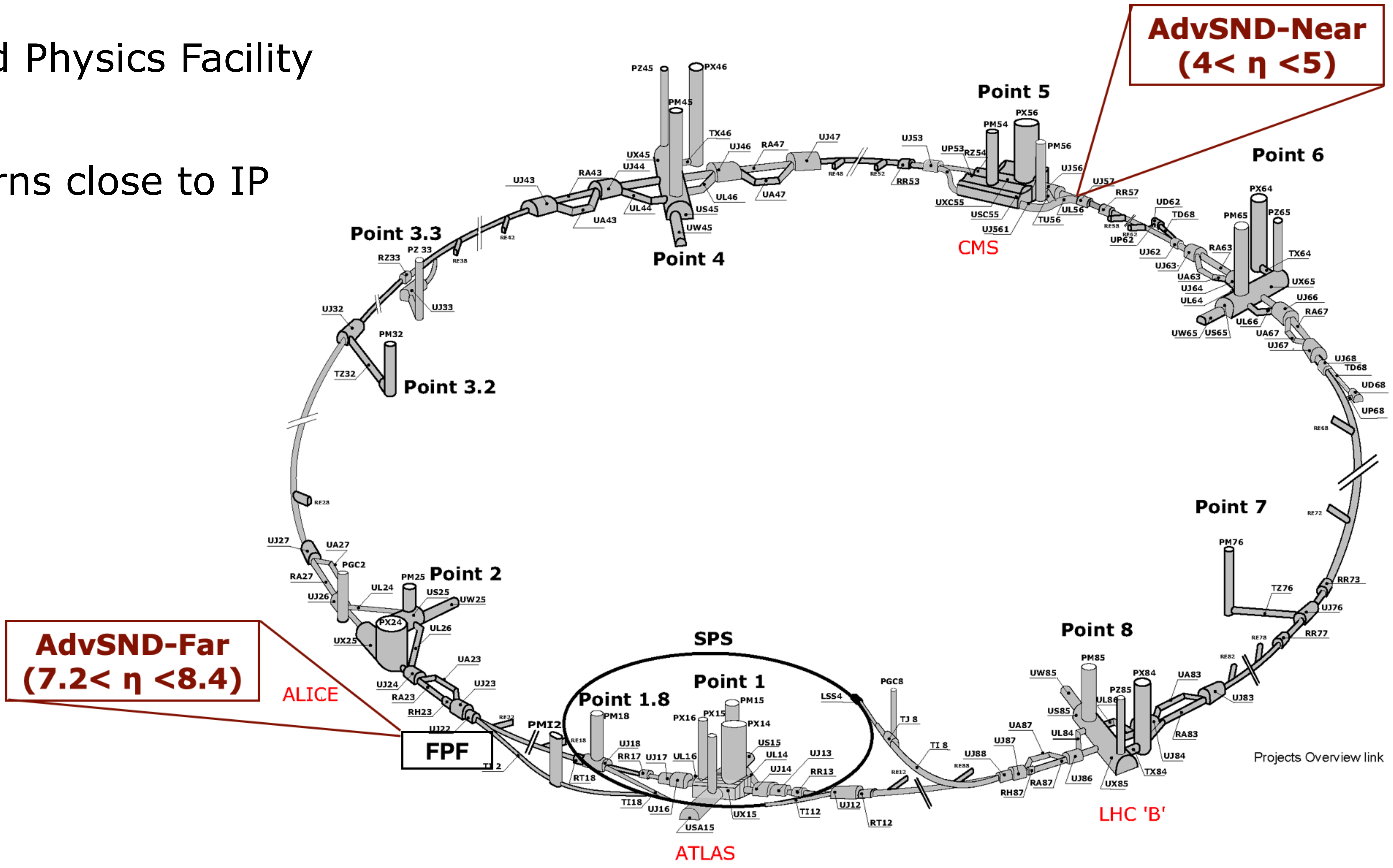
ADVANCED SND@LHC

- Upgrade of SND@LHC in view of an extended run during Run 4:
  - Extension of the physics case
  - New technologies and detector layout
  - Two detectors
    - **AdvSND-Far** (7.2<η<8.4)

      Possible locations: TI18, Forward Physics Facility
    - **AdvSND-Near** (4<η<5)

      Possible locations: existing caverns close to IP

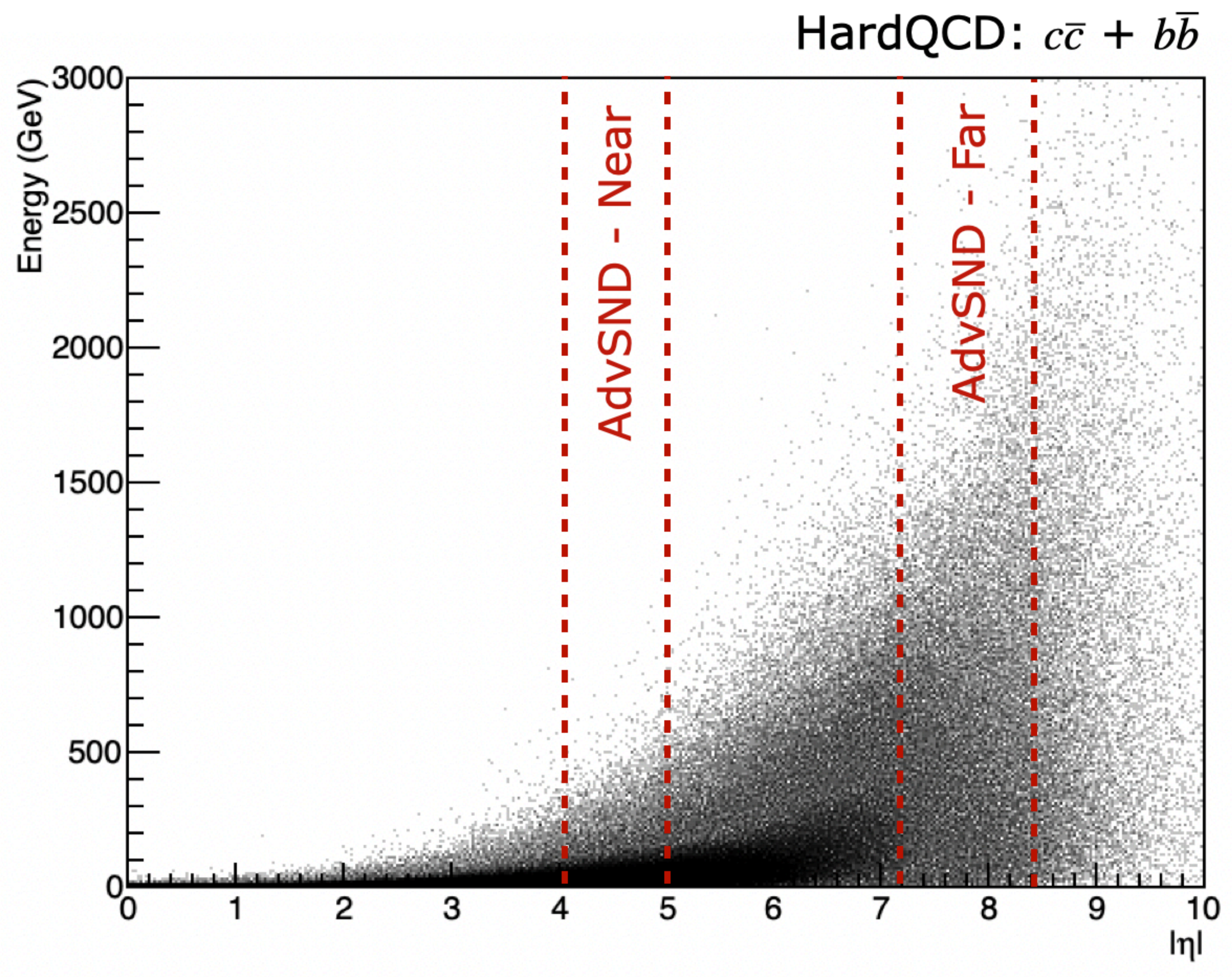


ADVANCED SND@LHC

- Upgrade of the detector in view of an extended run during Run 4:
- **Two** off-axis forward detectors:

- **AdvSND-Near:** $4<\eta<5$
  - Overlap with LHCb pseudo-rapidity coverage
  - Reduction of systematic uncertainties
  - Neutrino cross-section measurement
  - charm measurements in the region of interest for prompt ν fluxes

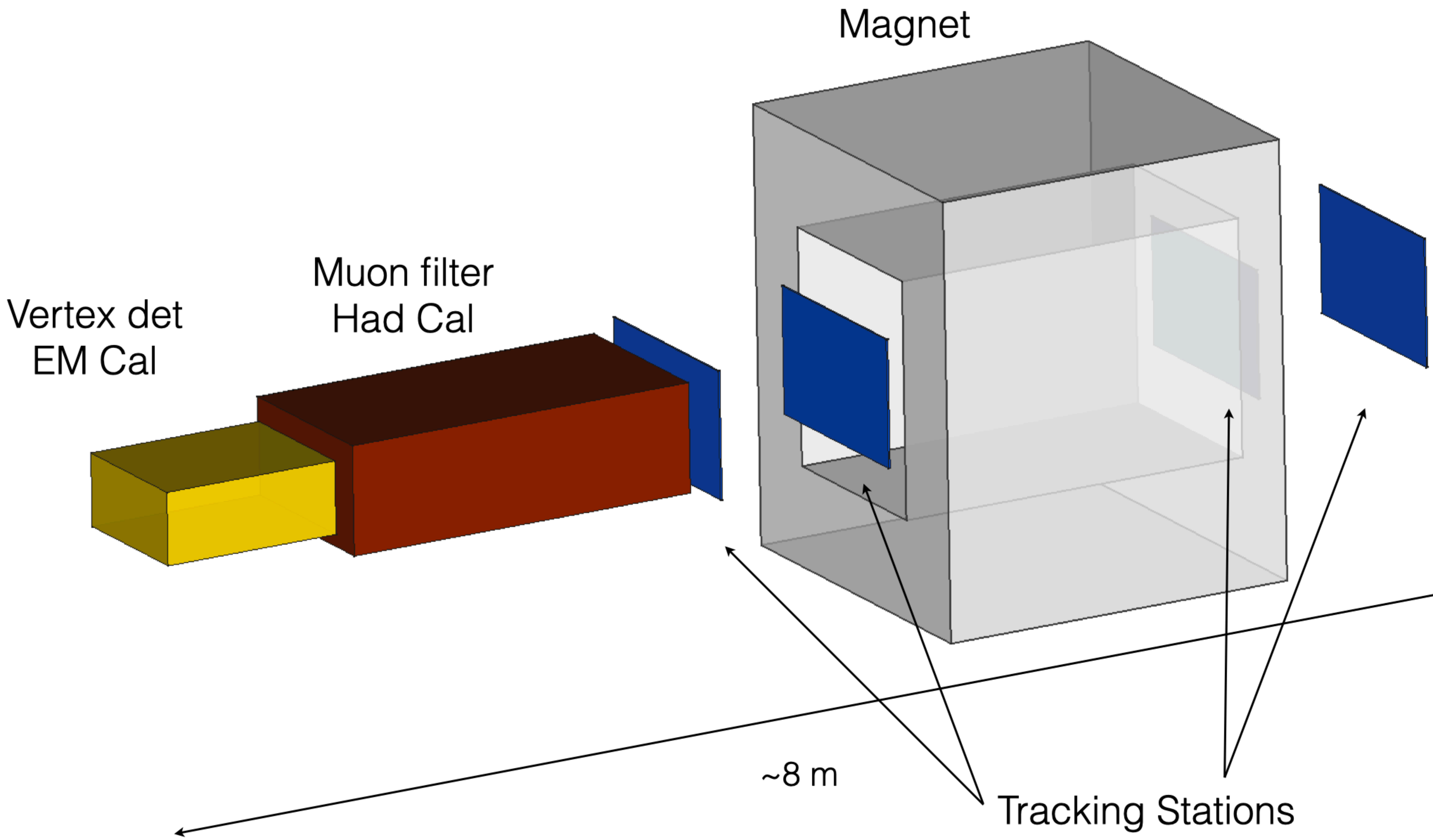
- **AdvSND-Far**: $7.2<\eta<8.4$
  - Acceptance similar to SND@LHC
  - Charm production measurements
  - Lepton flavour universality



ADVANCED SND@LHC: Detector layout

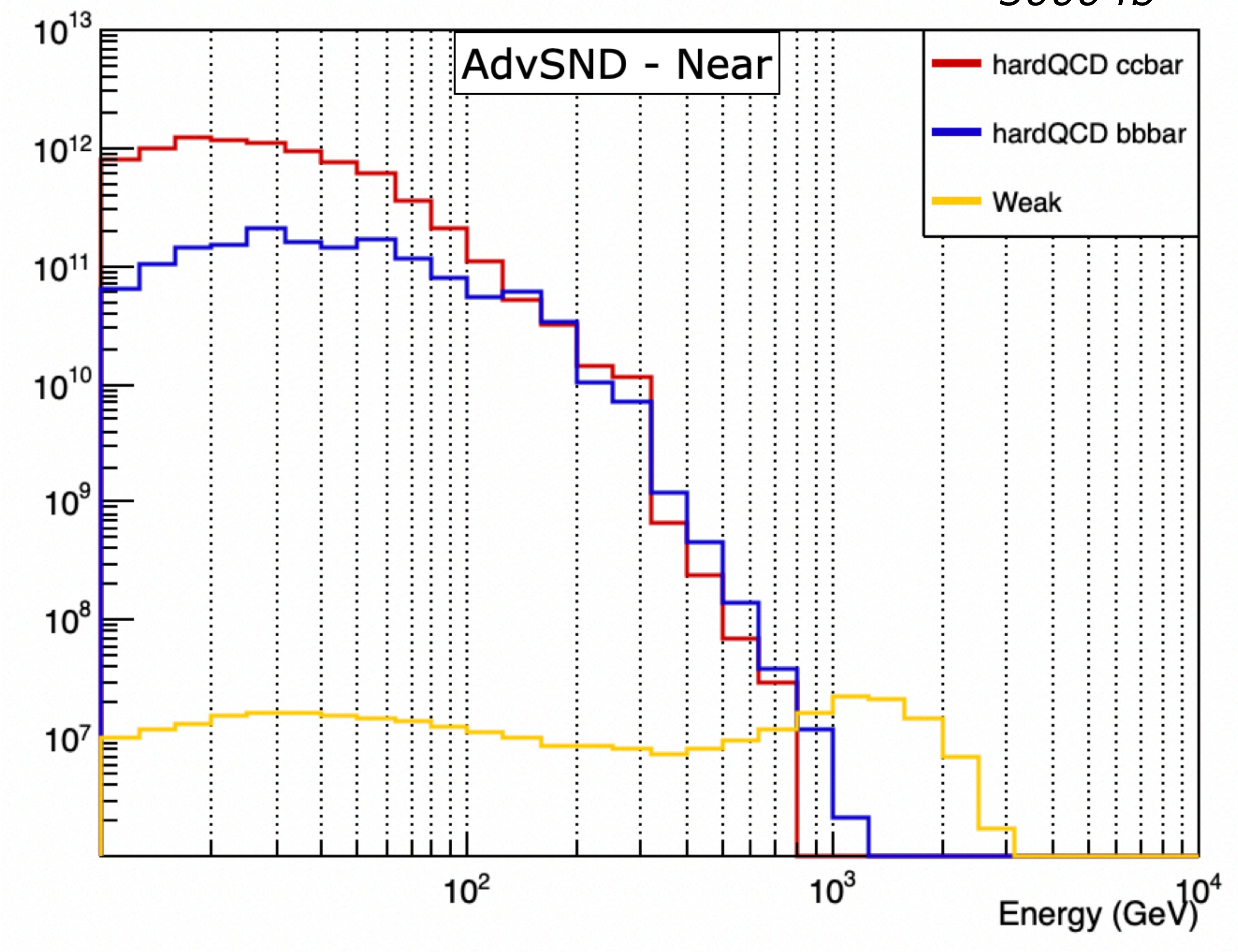
1) Target region:
   - Vertex identification and electromagnetic calorimeter
   - Thin sensitive layers interleaved with Tungsten plates
   - Replace emulsions with compact electronic trackers to cope with high intensity muon rates
2) Muon ID system and hadronic calorimeter
   - 10 interaction lengths
3) Magnetic spectrometer
   - measure charge of the muon (ν_μ/anti-ν_μ, ν_τ/anti-ν_τ in the $\tau \rightarrow \mu$ channel)
   - 2 tracking stations, each made of 2 planes

	AdvSND - NEAR	AdvSND - FAR
η	[4.0, 5.0]	[7.2,8.4]
mass (ton)	5	5
surface (cm^2)	120×120	100×40
distance (m)	55	630



ADVANCED SND@LHC - Near detector

Neutrinos in AdvSDN-Near acceptance
3000 fb^{-1}



AdvSND-Near:

η	[4.0, 5.0]
mass (ton)	5
surface (cm^2)	120×120
distance (m)	55

AdvSND - NEAR

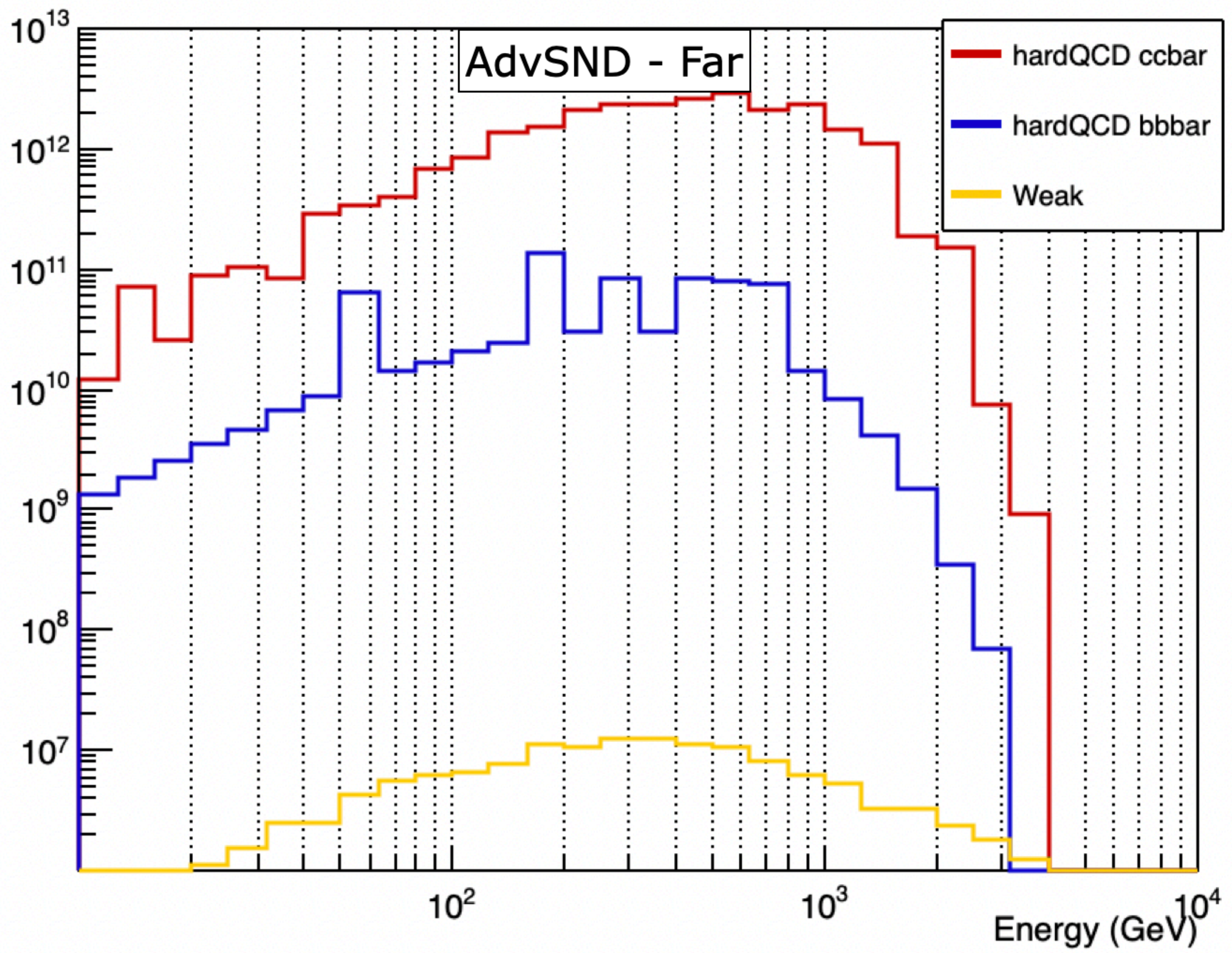
Flavour	ν in acceptance hardQCD: $c\bar{c}$	hardQCD: $b\bar{b}$	CC DIS hardQCD: $c\bar{c}$	hardQCD: $b\bar{b}$
$\nu_\mu + \bar{\nu}_\mu$	2.1×10^{12}	3.3×10^{11}	980	200
$\nu_e + \bar{\nu}_e$	2.2×10^{12}	3.3×10^{11}	1000	200
$\nu_\tau + \bar{\nu}_\tau$	2.7×10^{11}	1.4×10^{11}	80	50
Tot	5.4×10^{12}		2.5×10^3	

Expectations in **3000 fb^{-1}**
Generator: Pythia8

- Average energy for neutrinos form charm and beauty decays: ~30 GeV
- Measurement of **neutrino cross-section** for three flavours, given the measurement of the neutrino flux provided by LHCb
- Expected statistical error: a few % for electron and muon neutrinos, ~10% for tau neutrinos

ADVANCED SND@LHC - Far detector

Neutrinos in AdvSDN-Far acceptance
3000 fb⁻¹



AdvSND-Far:

η	[7.2,8.4]
mass (ton)	5
surface (cm^2)	100×40
distance (m)	630

Flavour	ν in acceptance hardQCD: $c\bar{c}$	ν in acceptance hardQCD: $b\bar{b}$	CC DIS hardQCD: $c\bar{c}$	CC DIS hardQCD: $b\bar{b}$
$\nu_\mu + \bar{\nu}_\mu$	6.3×10^{12}	1.5×10^{11}	1.2×10^{4}	200
$\nu_e + \bar{\nu}_e$	6.7×10^{12}	1.7×10^{11}	1.2×10^{4}	220
$\nu_\tau + \bar{\nu}_\tau$	7.1×10^{11}	4.7×10^{10}	880	40
Tot	1.4×10^{13}		2.5×10^{4}	

Expectations in **3000 fb⁻¹**
Generator: Pythia8

- Contribution from W/Z decays negligible
- Average energy for neutrinos form charm and beauty decays: ~400 GeV

- Test of **lepton flavour universality** measuring there ratio **R_{13}**
- Statistical uncertainty reduced to 5%
- Systematic uncertainty given by charm quark hadronisation factor: 20%

$$R_{13} = \frac{N_{\nu_e+\bar{\nu}_e}}{N_{\nu_\tau+\bar{\nu}_\tau}} = \frac{\sum_i \tilde{f}_{c_i} \tilde{Br}(c_i \to \nu_e)}{\tilde{f}_{D_s} \tilde{Br}(D_s \to \nu_\tau)}$$

- Test of **lepton flavour universality** measuring there ratio **R_{12}**
- Statistical uncertainty: a few %
- Systematic uncertainty given by contamination of pion/kaons

$$R_{12} = \frac{N_{\nu_e+\bar{\nu}_e}}{N_{\nu_\mu+\bar{\nu}_\mu}} = \frac{1}{1+\omega_{\pi/k}}.$$

QCD MEASUREMENTS

- Electron neutrinos mostly produced by charm decays
- ν_e ca be used as a probe of **charm production** in a region where charm yield has large uncertainties

- Electron neutrinos measurements can constraint the uncertainty on the gluon PDF in $x<10^{-5}$ region

- Extraction of gluon PDF in very small x-region relevant for:
  1. Future Circular Colliders
  2. Reduction of uncertainty on the flux of very-high-energy atmospheric neutrinos

- **AdvSND-Near:** $4<\eta<5$:
  reduce systematic uncertainties in the correlation between neutrinos and charmed mesons comparing with LHCb direct charm measurements

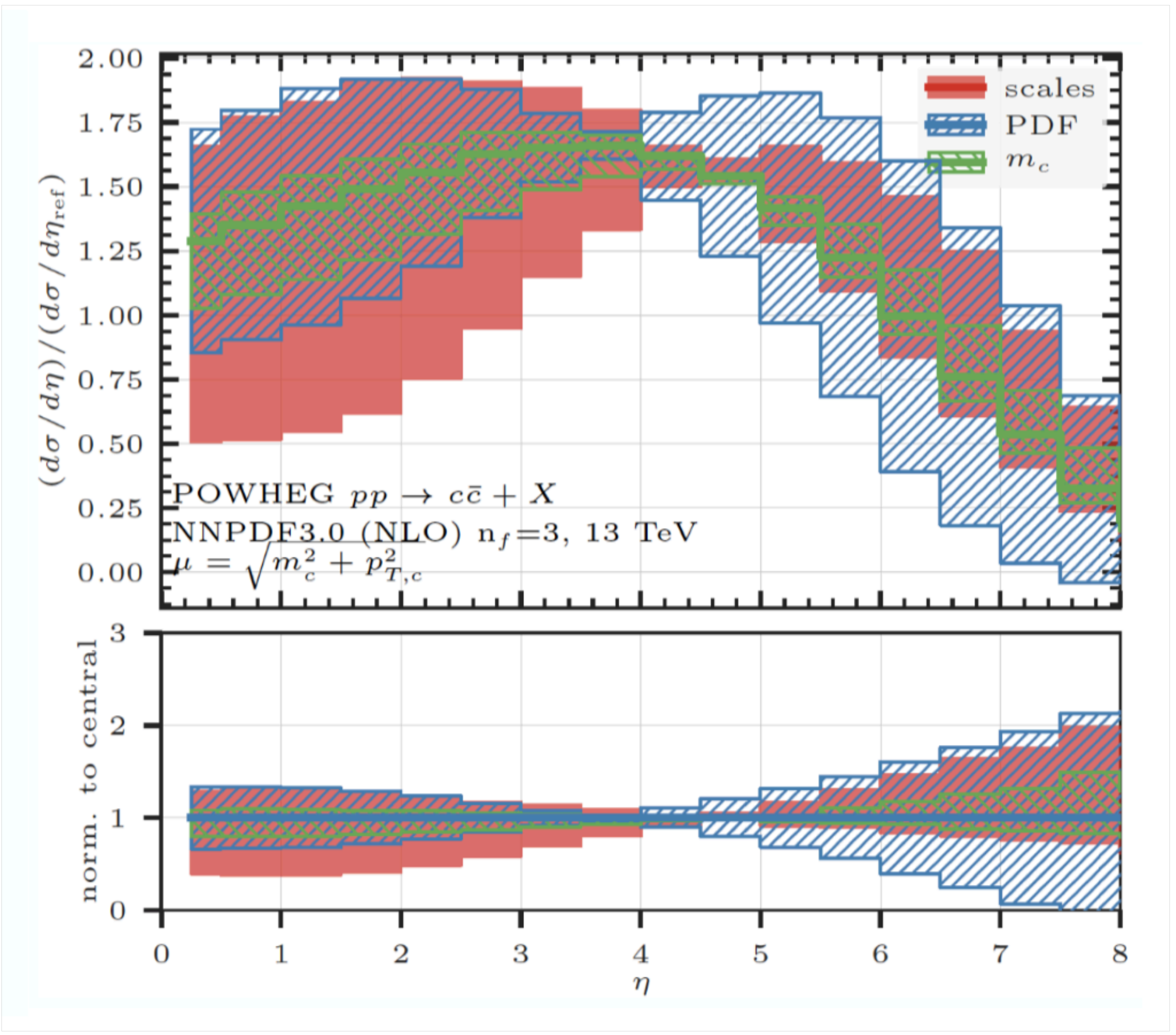
- **AdvSND-Far:** $7.2<\eta<8.4$:
  reduce statistical uncertainties

Ratio between the cross-section measurements at different pseudo-rapidities, normalised to LHCb measurements

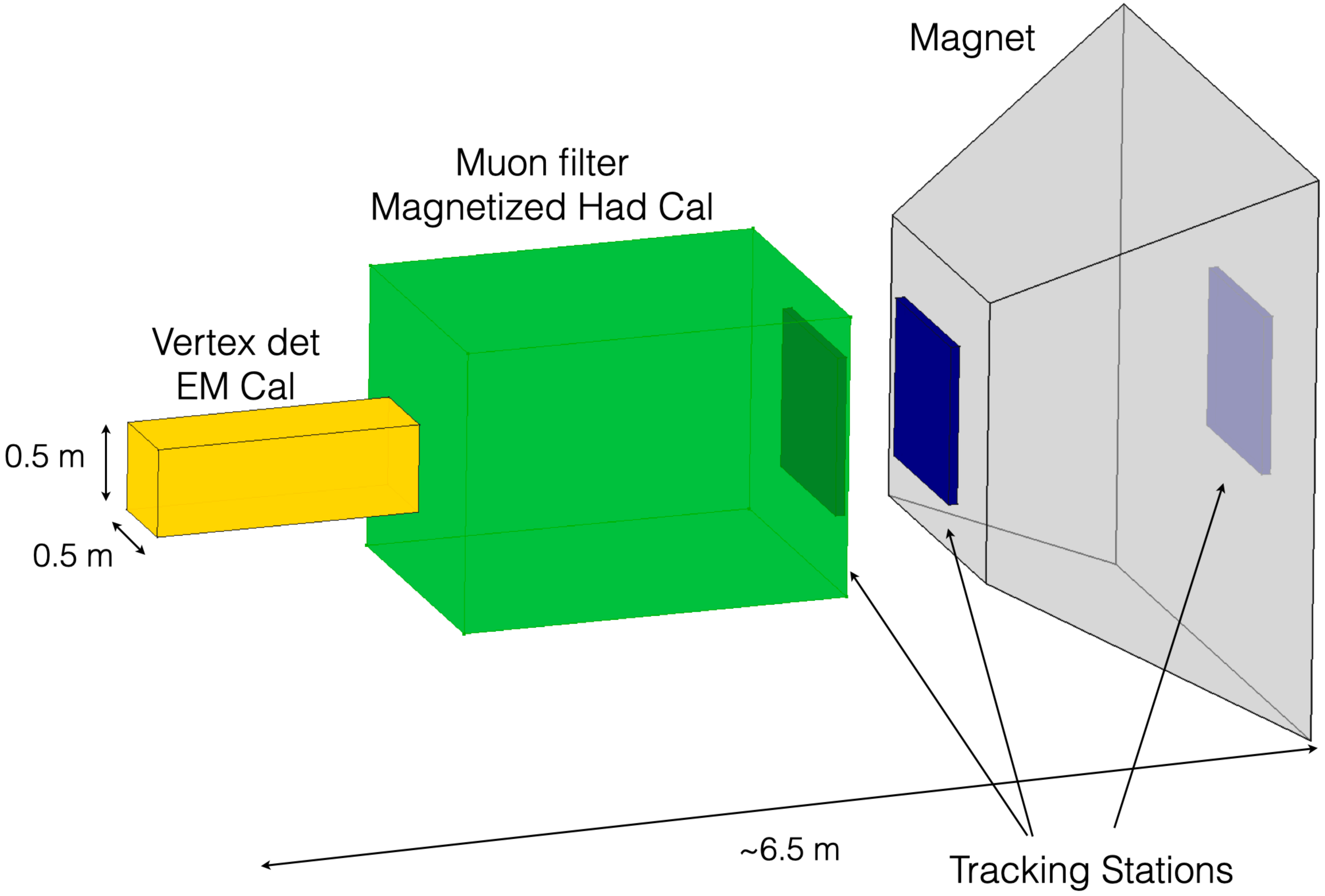
$$R = \frac{d\sigma/d\eta(13\,TeV)}{d\sigma/d\eta_{ref}(7\,TeV)}$$

$$\eta_{ref} = [4{,}4.5]$$

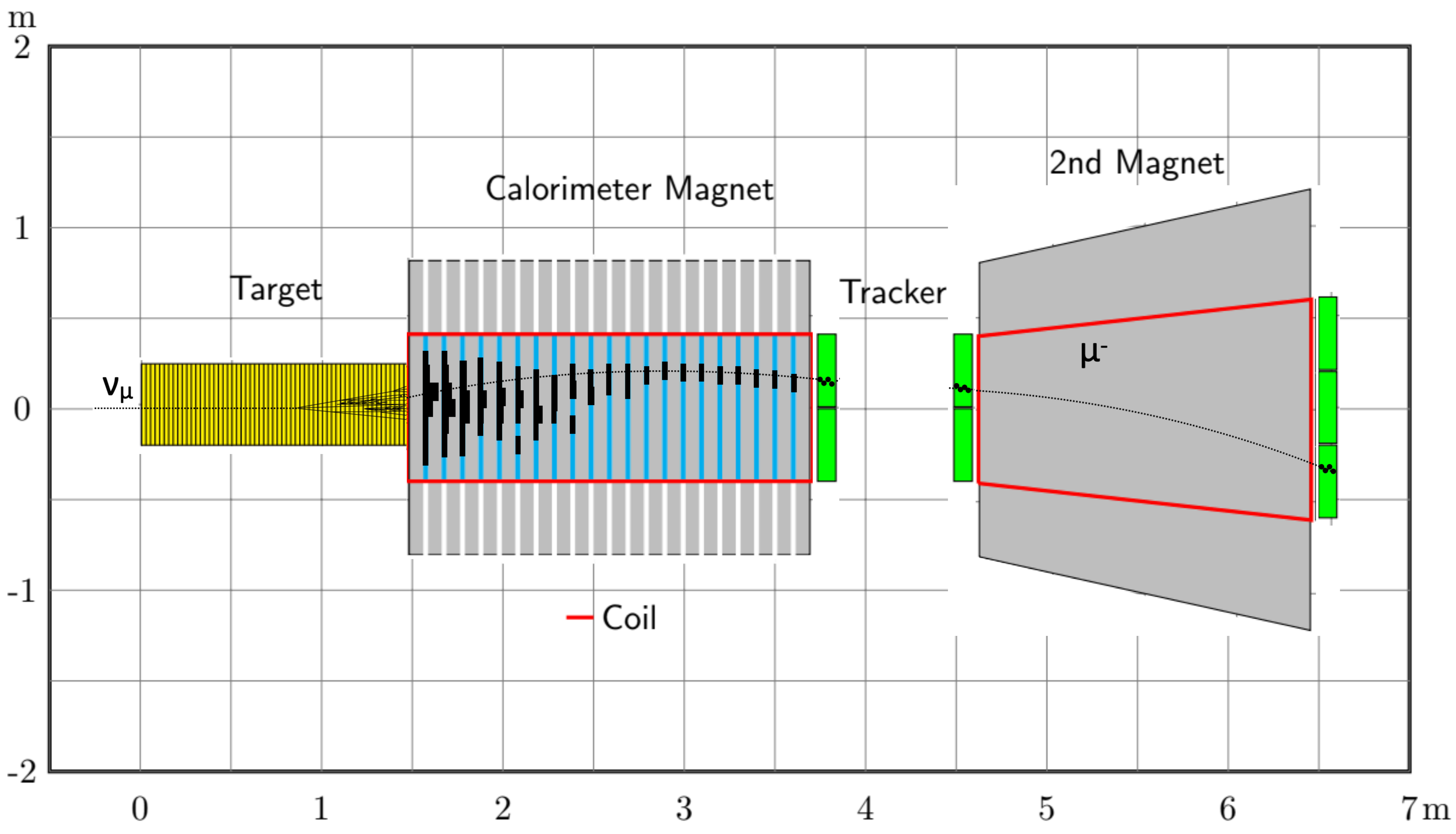
arxiv:1510.01707



DETECTOR LAYOUT

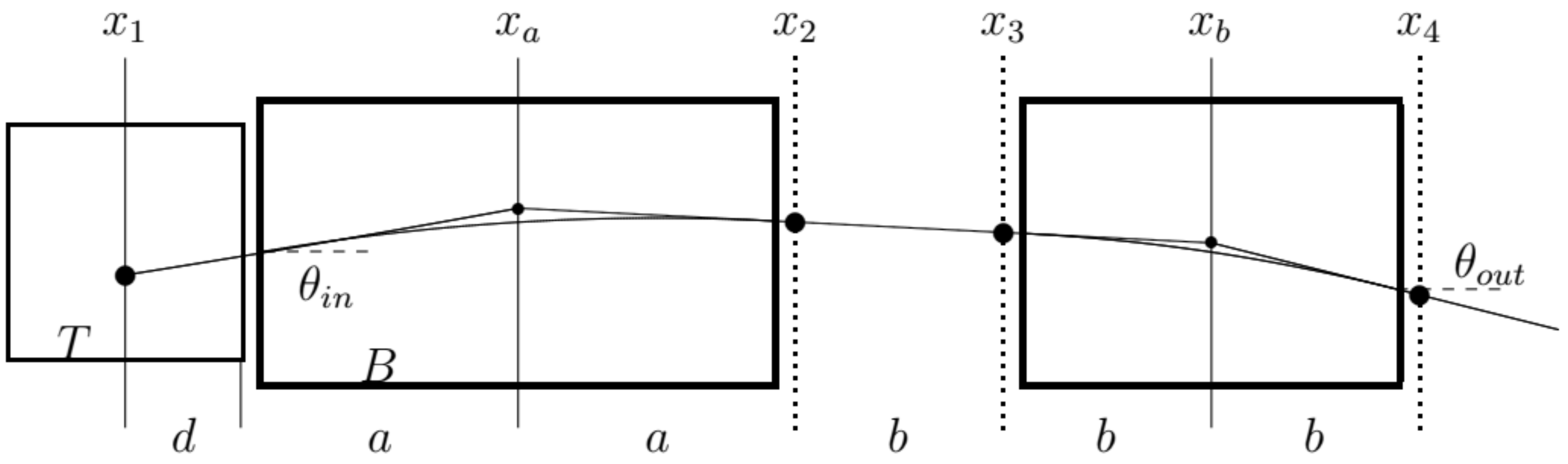


DETECTOR LAYOUT



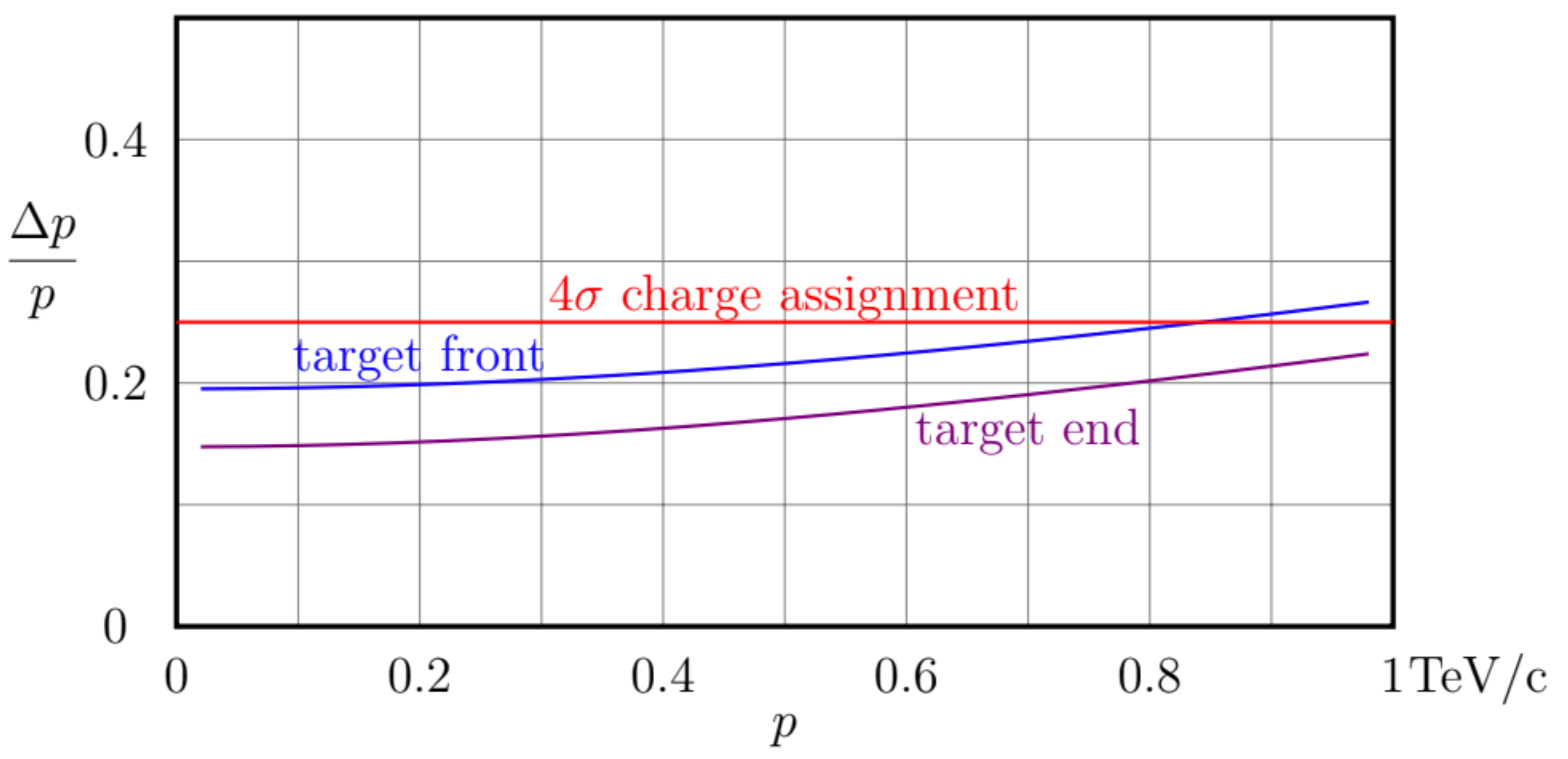
SPECTROMETER LAYOUT

Iron core magnet



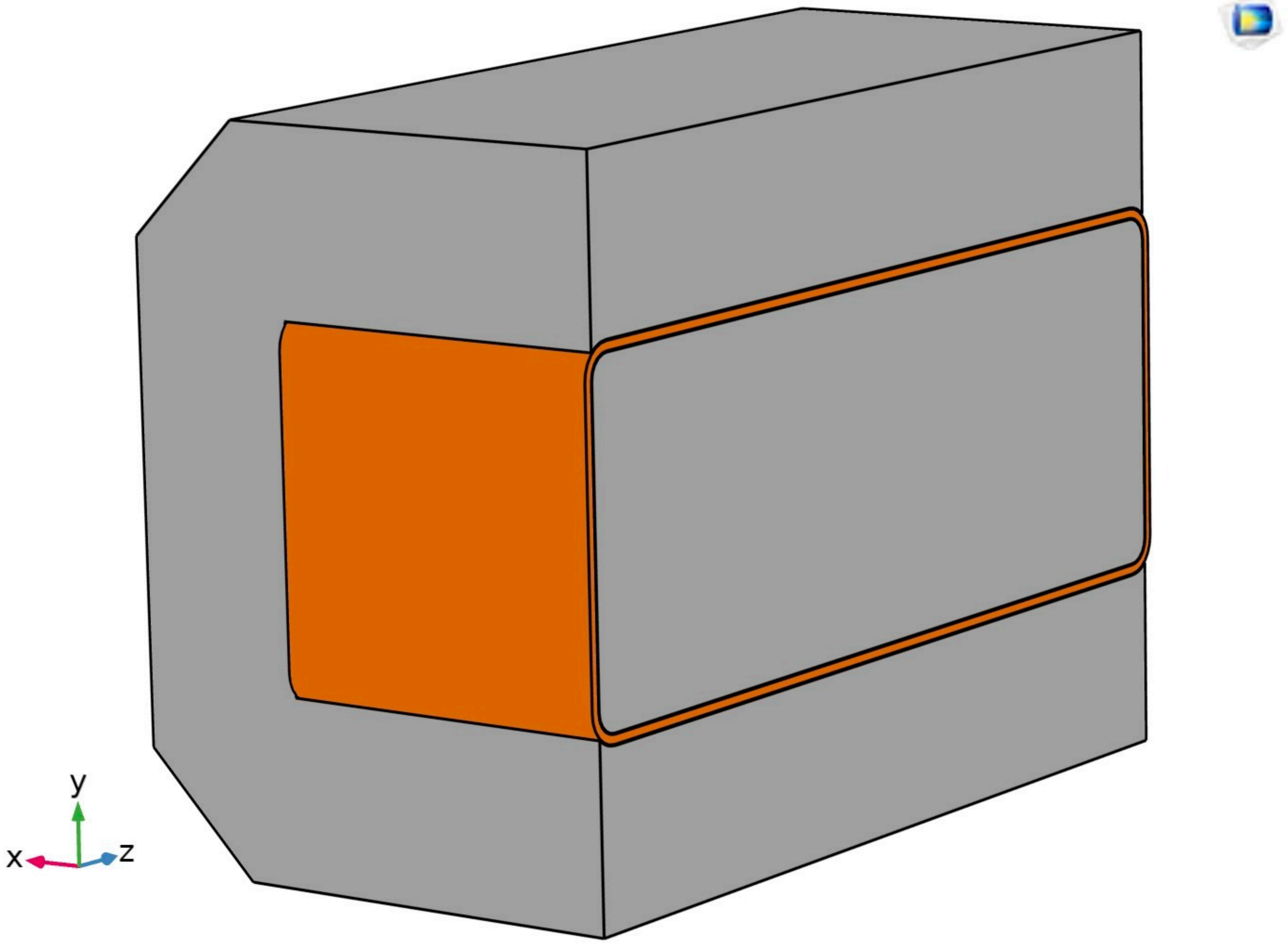
- Two magnetised volumes:
  - One as hadronic calorimeter
  - One as magnetic spectrometer
- Three drift chambers to measure muon track coordinates
- B = 1.5 T
- Total iron mass: 57 t
- Power consumption: 1kW

$$\frac{\Delta p}{p} = \frac{\sqrt{\Delta\theta_C^2 + \Delta\theta_{MS}^2}}{\theta} = \frac{1}{eB\ell}\sqrt{(\Delta\theta_C\, p)^2 + \frac{4}{3}\,(14\,\mathrm{MeV/c})^2\left(\frac{0.5d}{X_W} + \frac{\ell}{X_{Fe}}\right)} \tag{10}$$

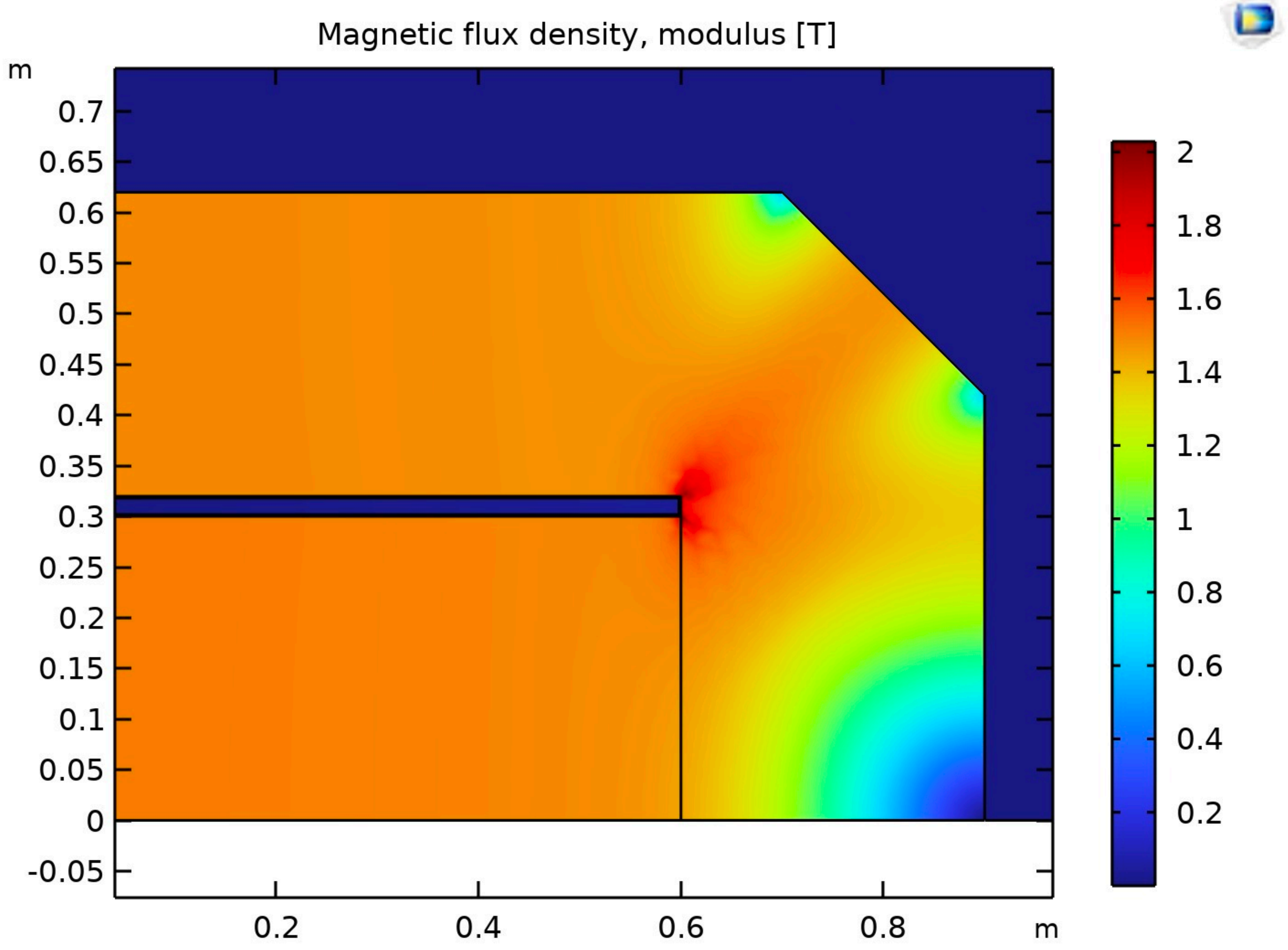


CALORIMETER MAGNET DESIGN

3D model of the Iron core magnet
(segmentation in slabs not yet implemented)



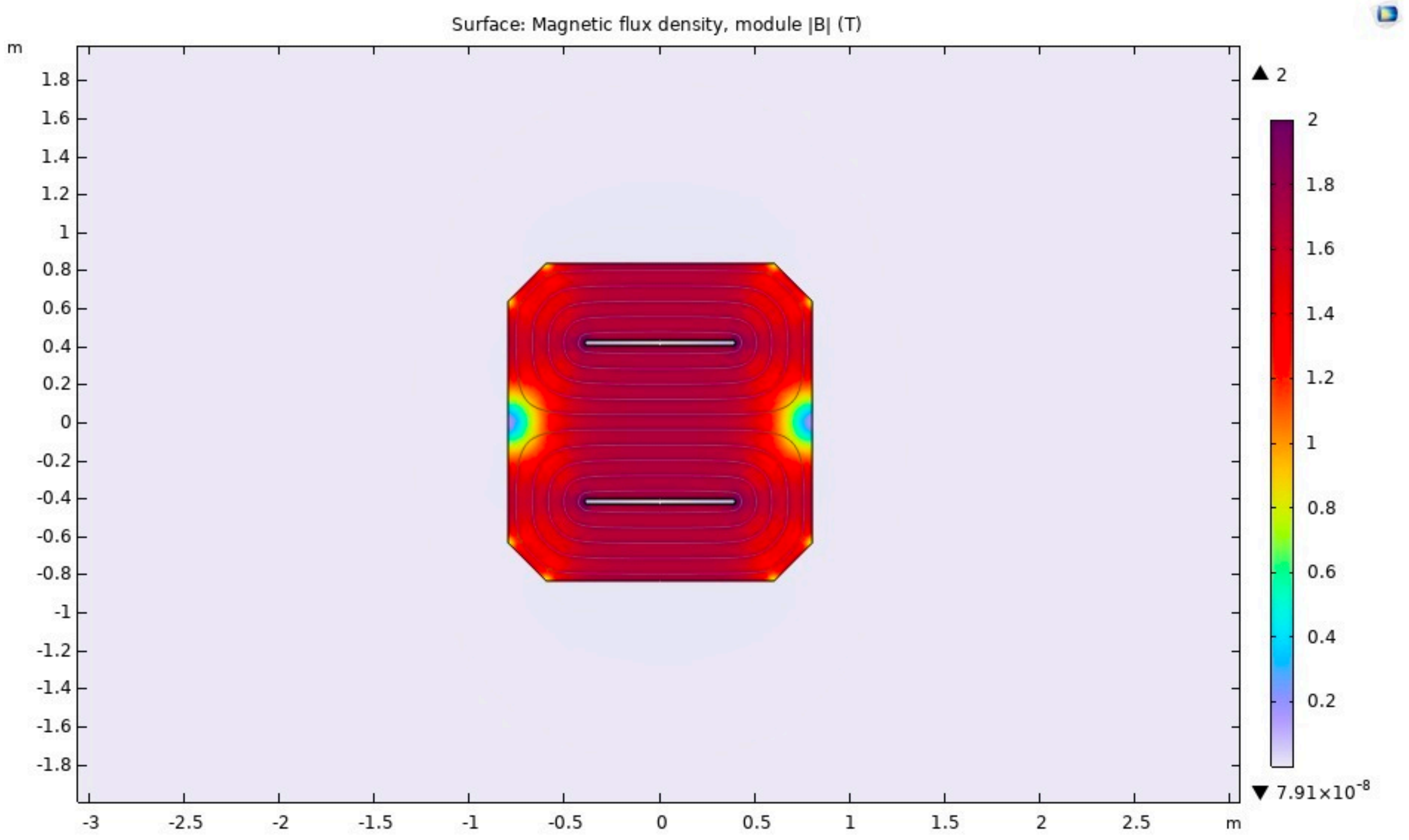
3D FEM simulation of the magnetic flux density



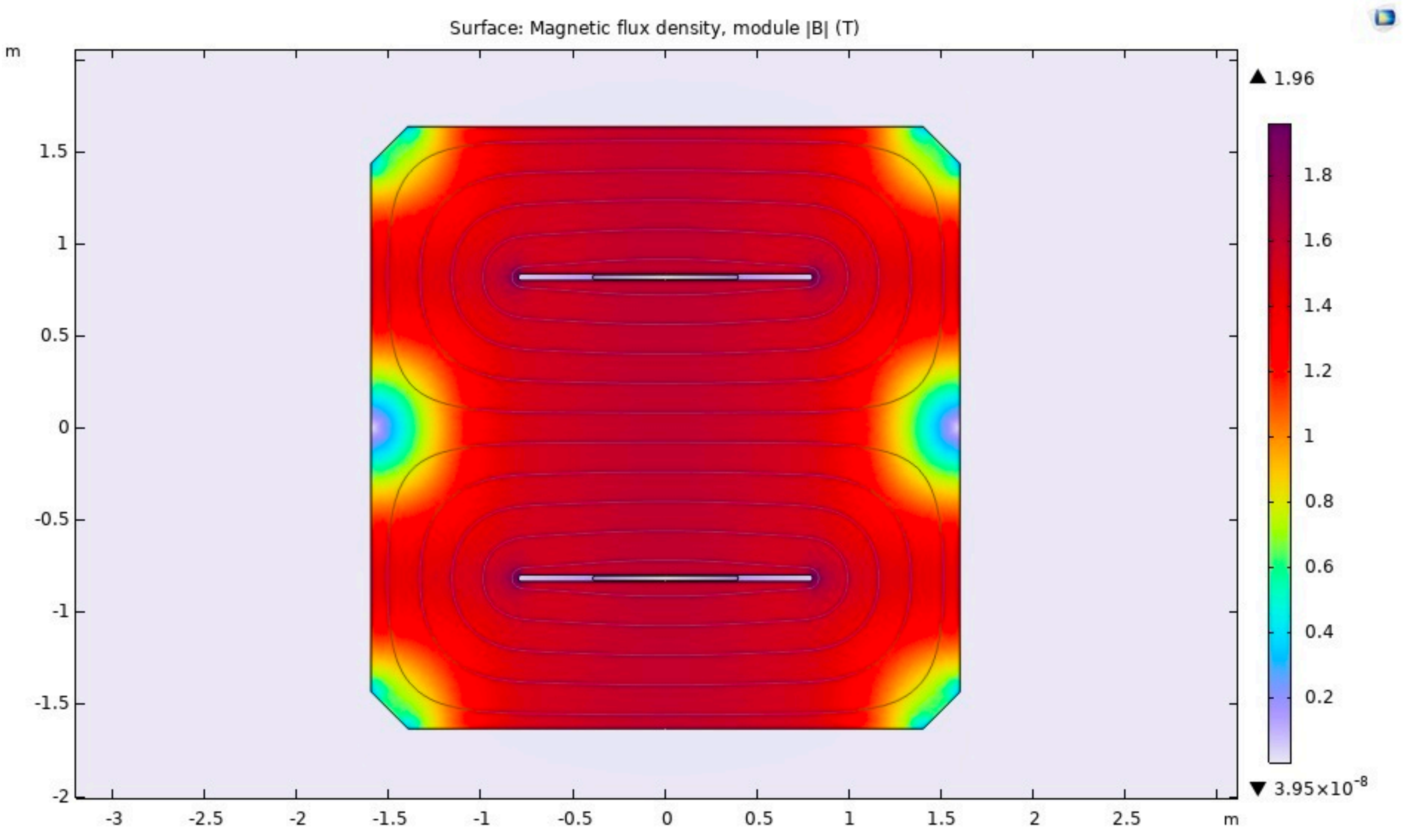
CONICAL MAGNET DESIGN

2D field maps in the conical magnet

UPSTREAM END



DOWNSTREAM END



CONCLUSIONS

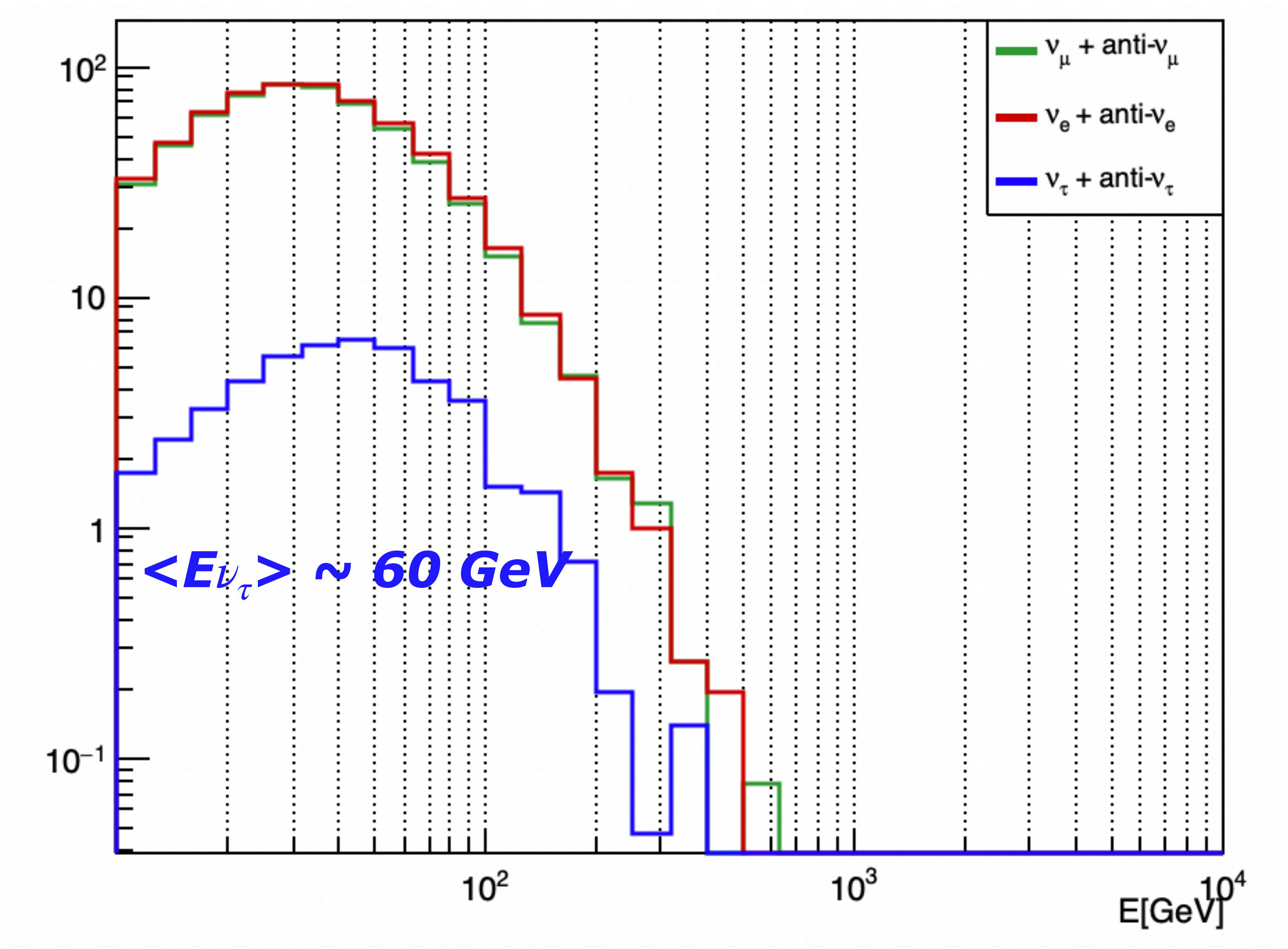
- Upgrade of SND@LHC in view of an extended run during Run 4:
  - Extension of the physics case
  - Two detectors
    - AdvSND-Far ($7.2<\eta<8.4$)
    - AdvSND-Near ($4<\eta<5$)
  - New technologies and detector layout
    - Magnetic spectrometer
    - New technologies for vertex detector

BACKUP SLIDES

VERTEX DETECTOR

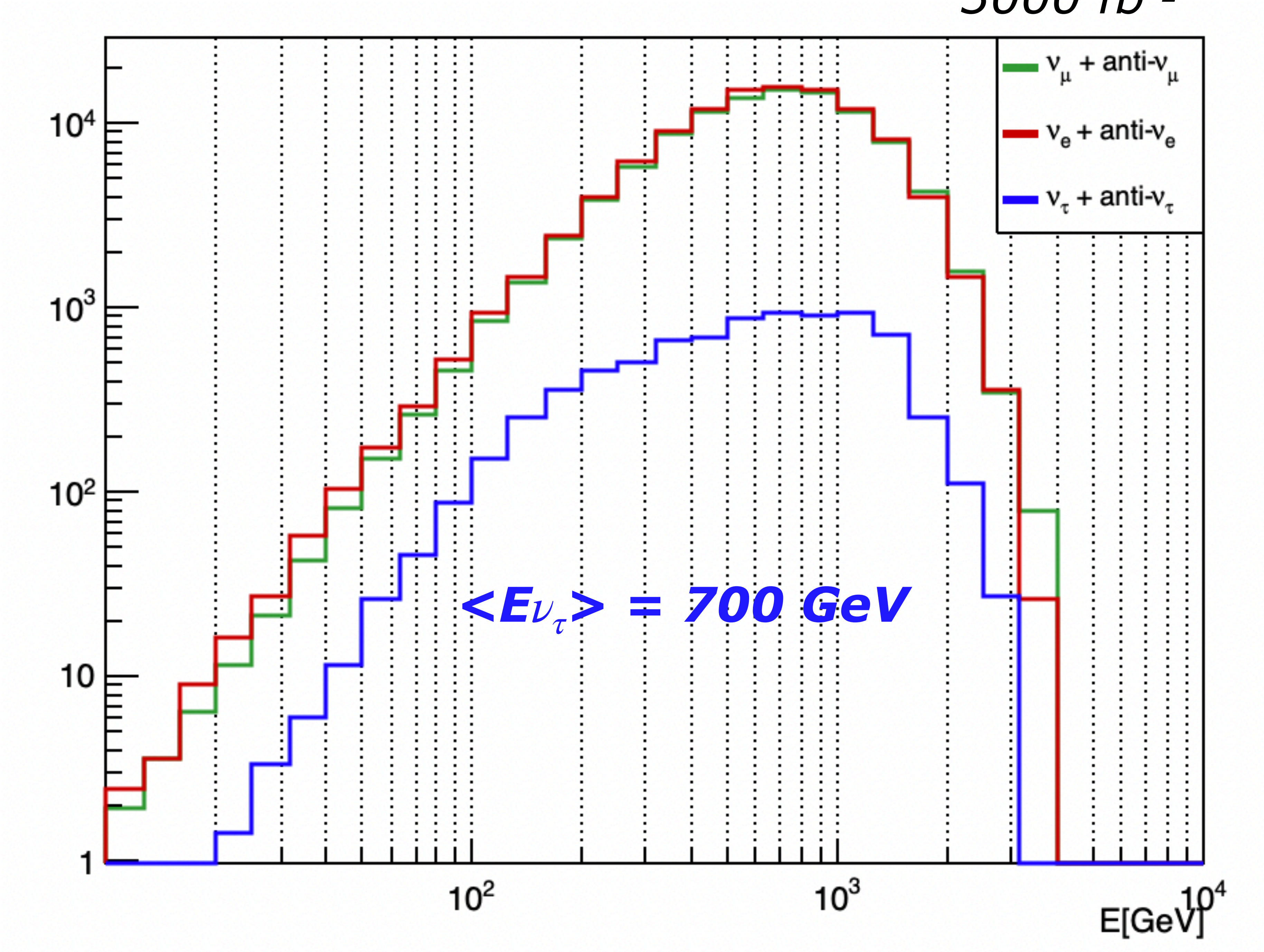
- Main task of vertex detector:
  - Reconstruction of neutrino interaction vertex
  - Identification of **tau lepton** decay vertex

Neutrino CC interactions ***@AdvSND-Near***
hardQCD: cc + bb
3000 fb^{-1}



Average tau neutrino energy $<E\nu_\tau>$ ~ 60 GeV
Average tau lepton $<E\tau>$ ~ 30 GeV
Average tau lepton decay length **$<L\tau>$ ~ 3 mm**

Neutrino CC interactions ***@AdvSND-Far***
hardQCD: cc + bb
3000 fb^{-1}



Average tau neutrino energy $<E\nu_\tau>$ ~ 700 GeV
Average tau lepton $<E\tau>$ ~ 350 GeV
Average tau lepton decay length **$<L\tau>$ ~ 3.5 cm**

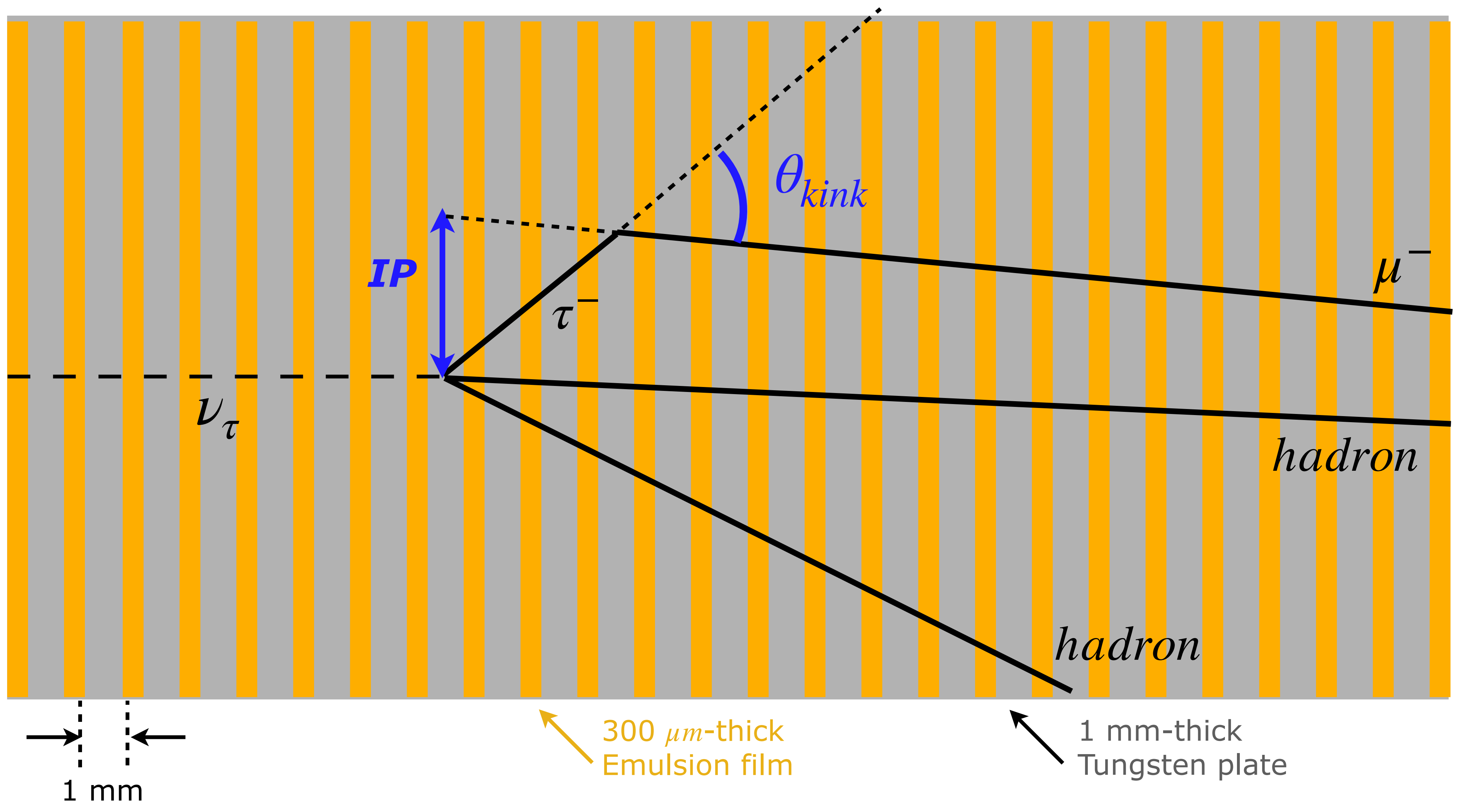
VERTEX DETECTOR

- Decay vertex identification performed by searching for:
  - large kink angle
  - large impact parameter

Average impact parameter **$\langle IP \rangle \sim 100\ \mu m$**

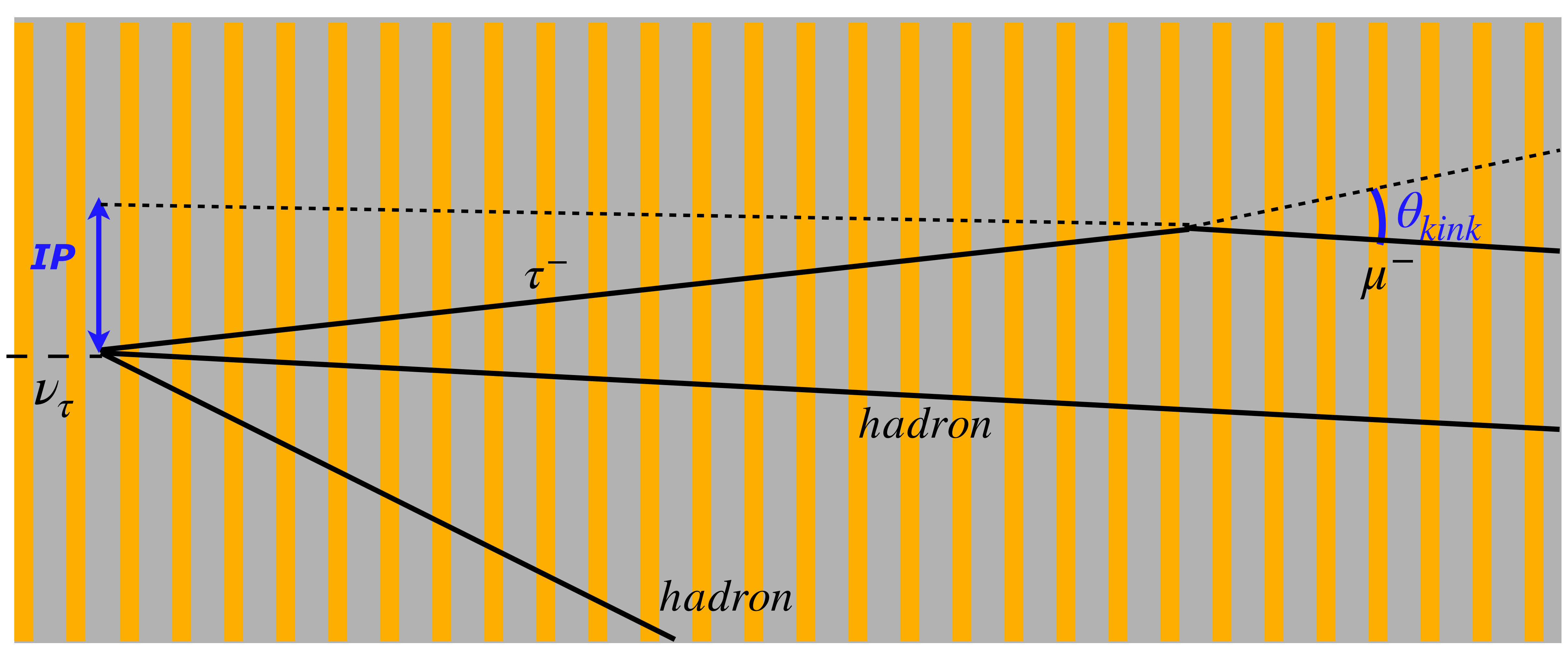
AdvSND-Near

Average tau lepton decay length **$\langle L_\tau \rangle \sim 3$ mm**
Average kink angle **$\langle \theta_{kink} \rangle \sim 30$ mrad**

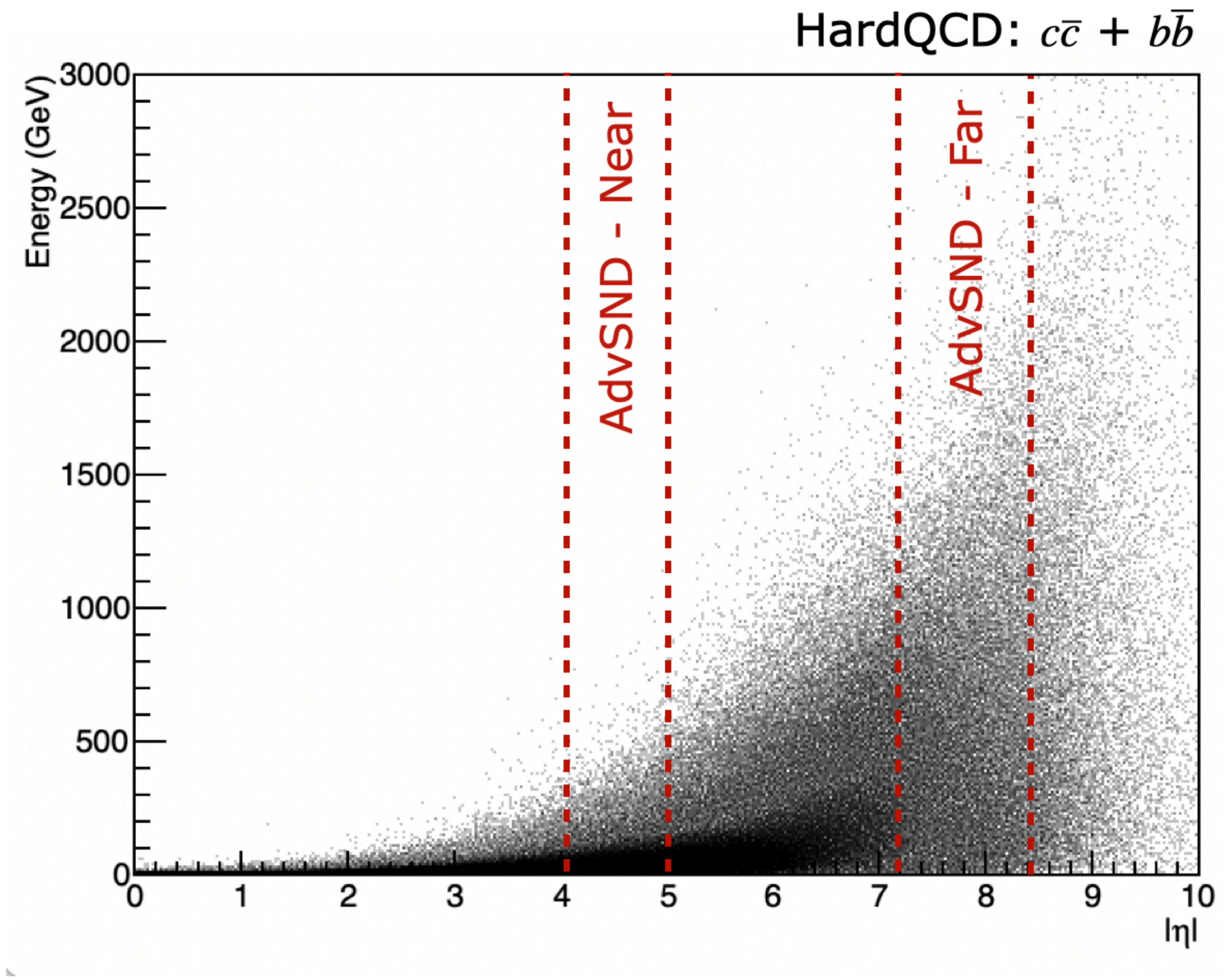


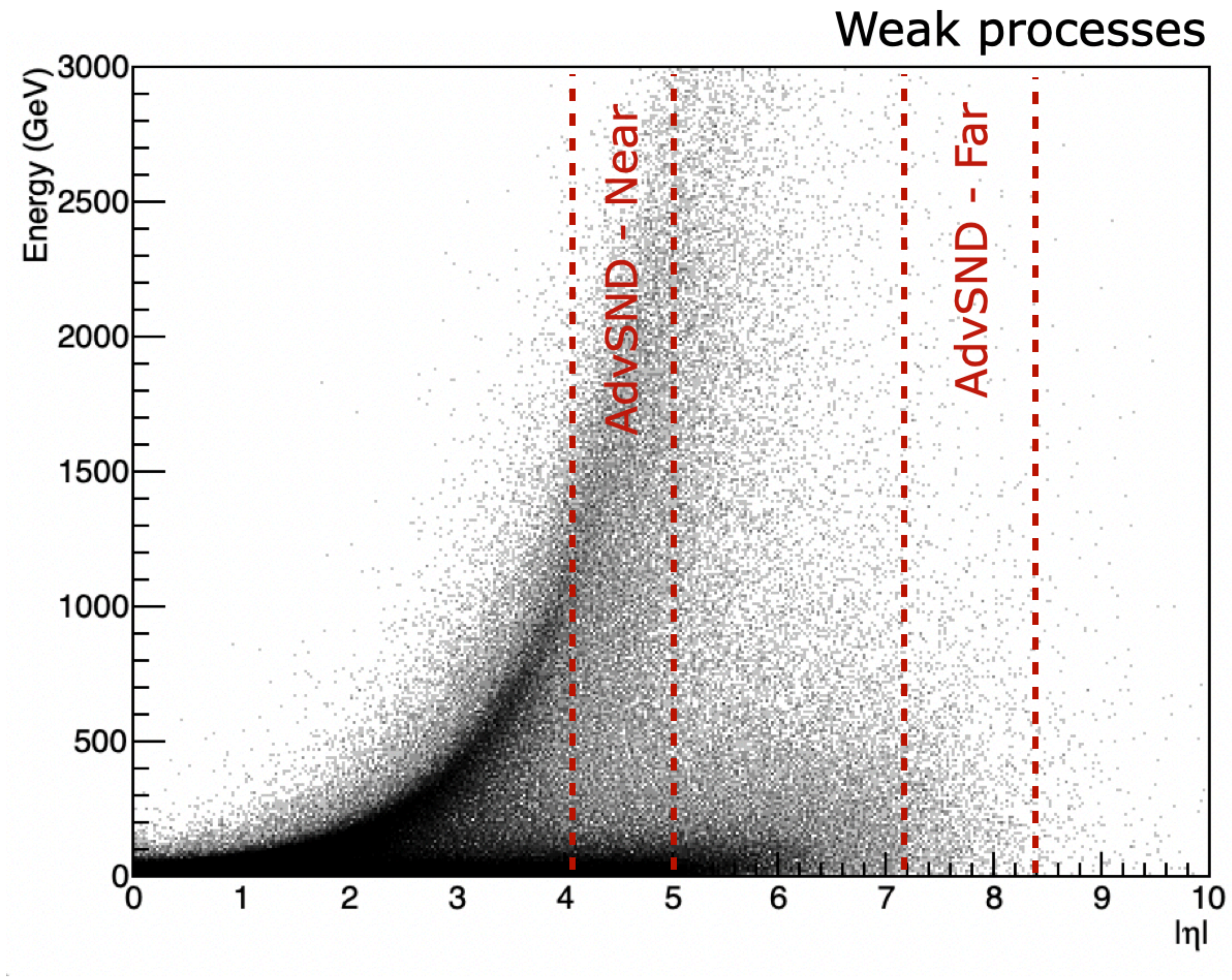
AdvSND-Far

Average tau lepton decay length **$\langle L_\tau \rangle \sim 3.5$ cm**
Average kink angle **$\langle \theta_{kink} \rangle \sim 3$ mrad**



SND@LHC Emulsion Cloud Chamber


HardQCD: $c\bar{c}$ + $b\bar{b}$
Energy (GeV)
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10
|η|
AdvSND - Near
AdvSND - Far


Weak processes
Energy (GeV)
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10
|η|
AdvSND - Near
AdvSND - Far