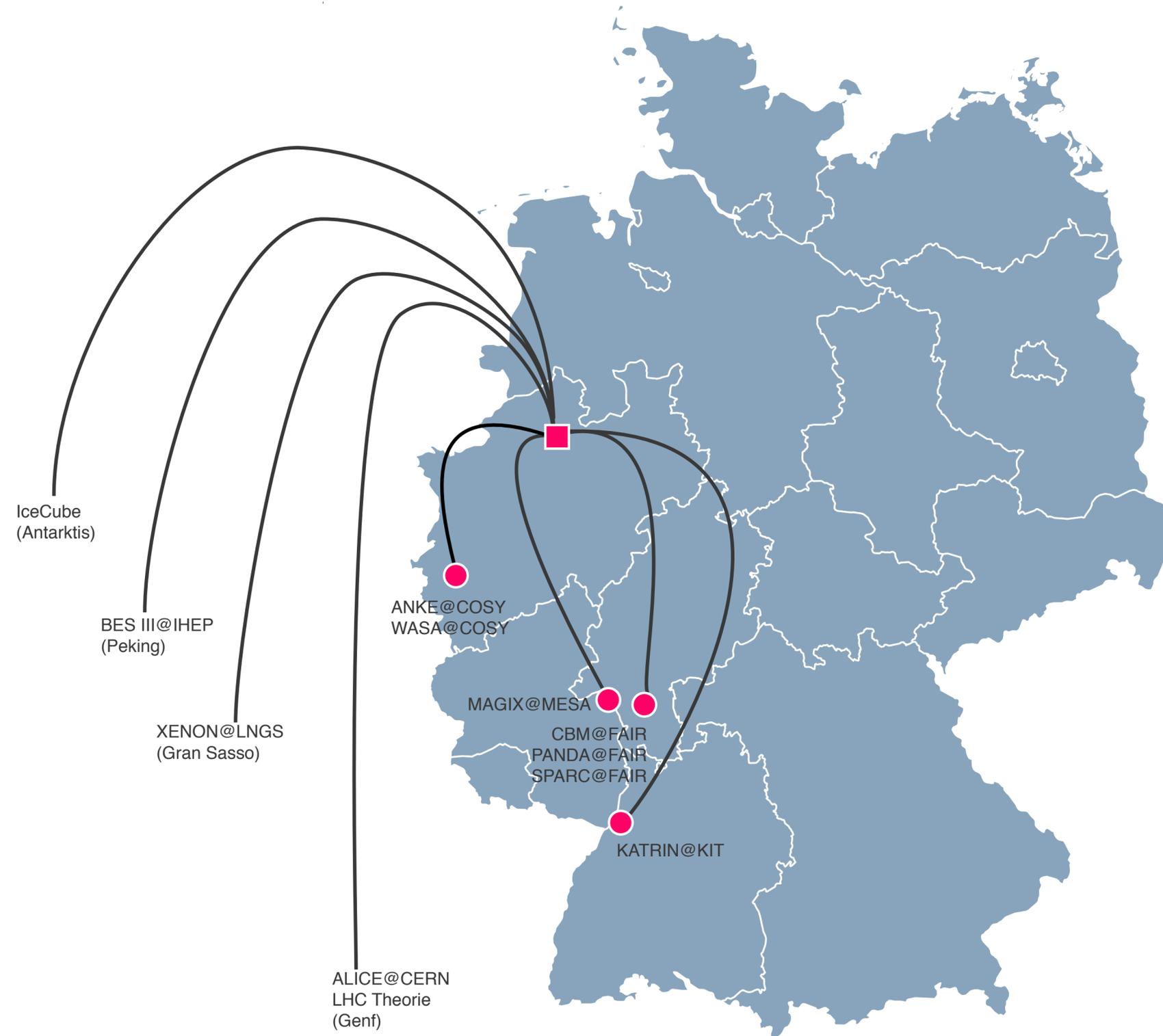# Machine Learning in Münster

Christian Klein-Bösing

IKP Münster

Rüdiger Haake
CERN/Yale
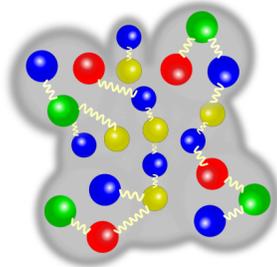
- Broad experimental and theoretical program in particle physics

- Common training program for undergrad and PhD students (DFG-RTG 2149)

"Strong and Weak Interactions – from Hadrons to Dark Matter"

IceCube
(Antarktis)

BES III@IHEP
(Peking)

XENON@LNGS
(Gran Sasso)

ANKE@COSY
WASA@COSY

MAGIX@MESA

CBM@FAIR
PANDA@FAIR
SPARC@FAIR

KATRIN@KIT

ALICE@CERN
LHC Theorie
(Genf)

QCD Matter under
extreme conditions

Quark-Gluon Plasma

- Core analysis areas
  - Hard probes / jets
  - Photons
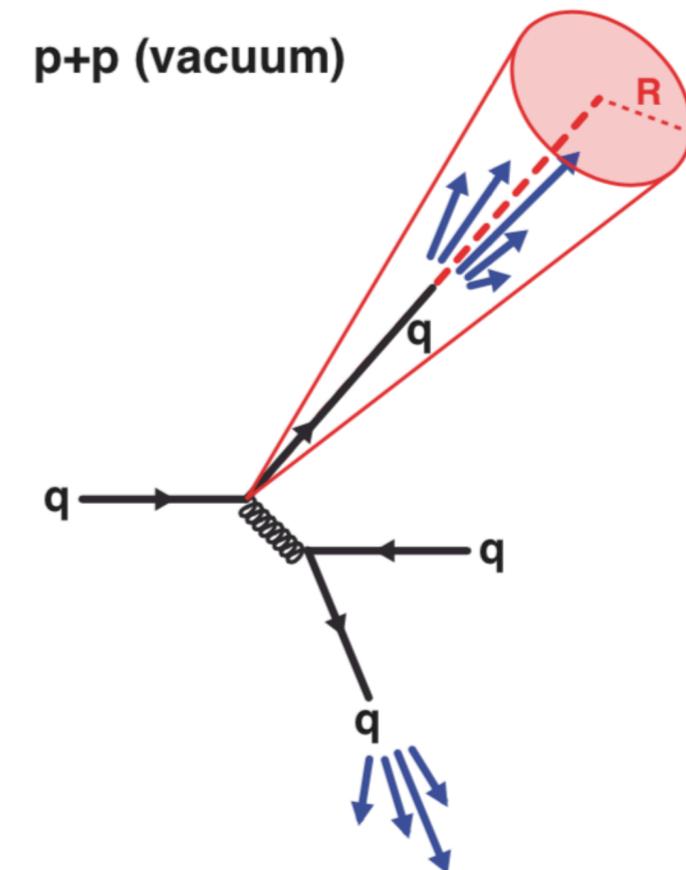 - Quarkonia and Heavy Quarks
- Primary tools
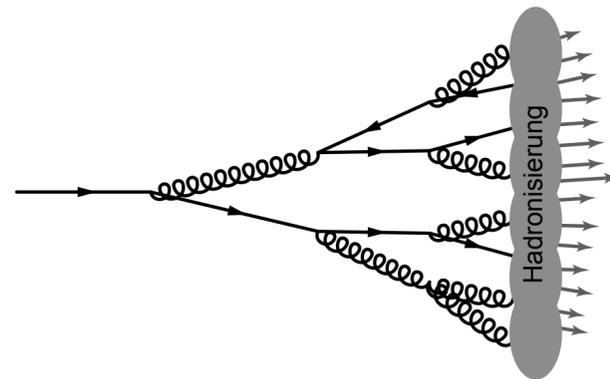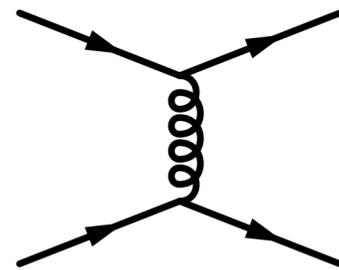 - Electron and photon ID
  - Tracking and calorimeter
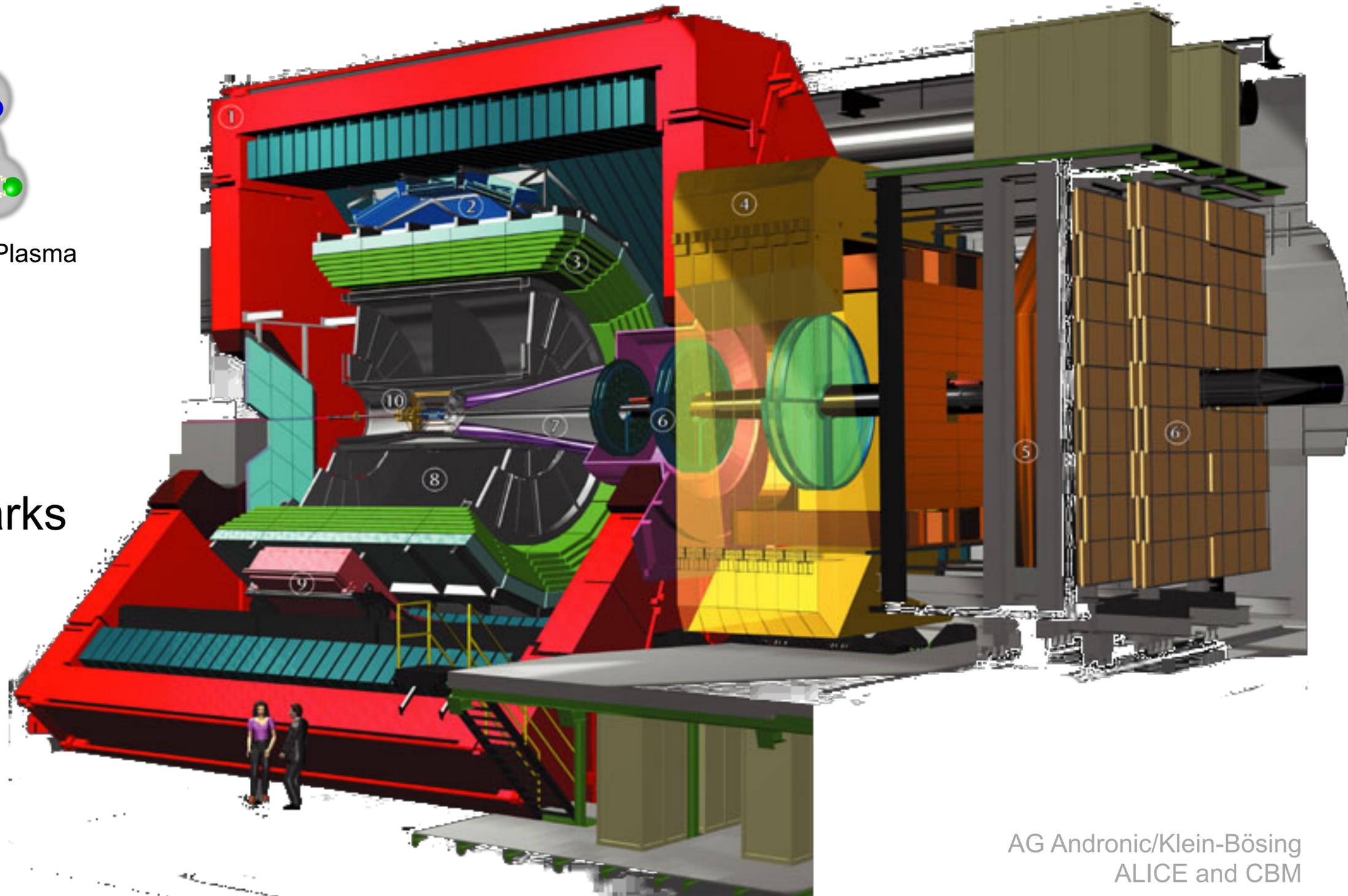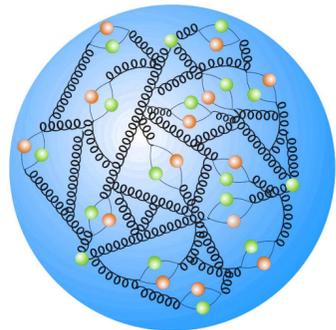
AG Andronic/Klein-Bösing
ALICE and CBM

Hard probes
- Large production scales (mass or momentum)
- Early production ($\ll$ 0.2 fm/c)
- Factorisation

$$PDF \otimes pQCD \otimes FF$$

© DESY

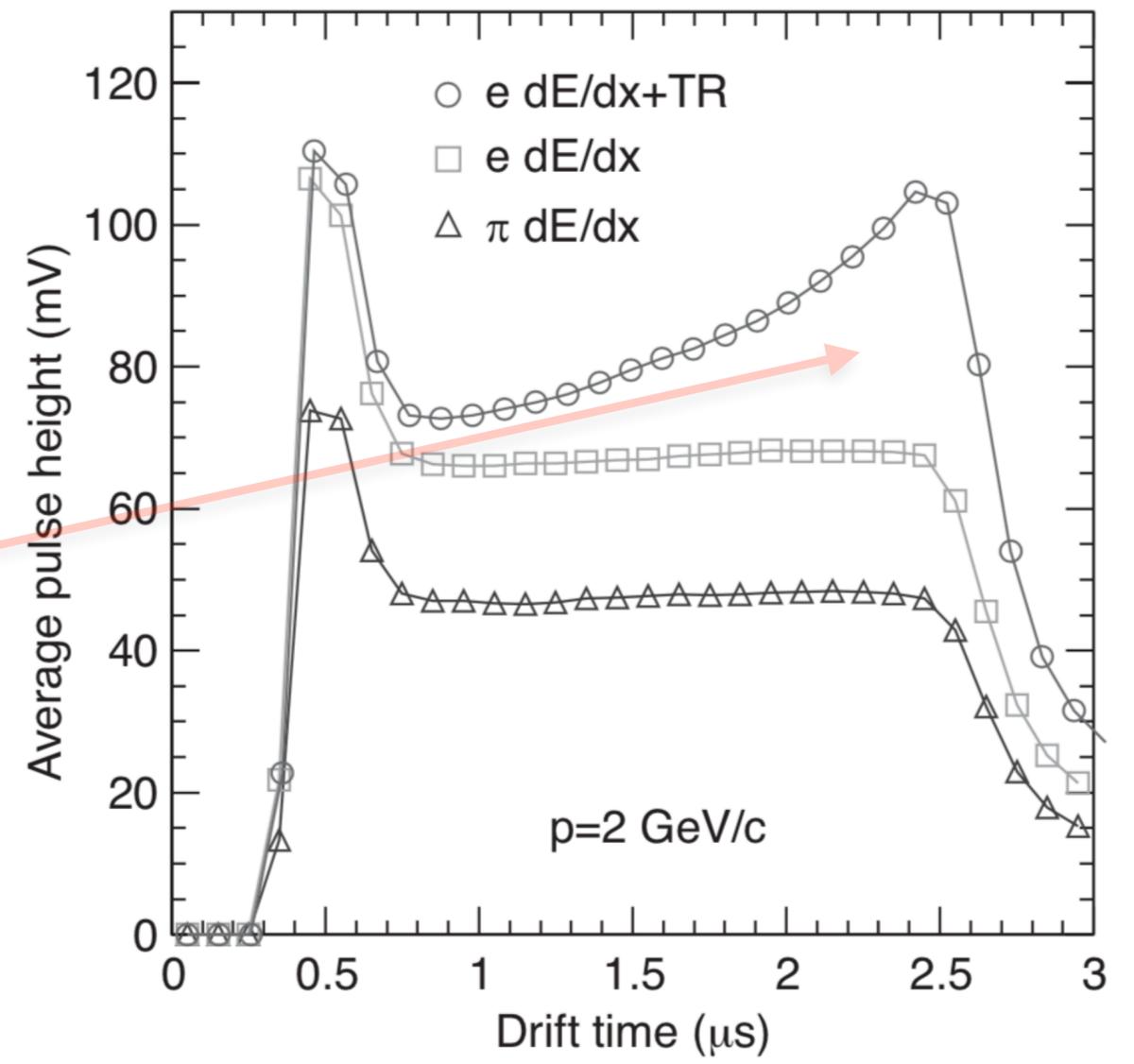p+p (vacuum)

Hadronisierung

Accessible via
- Single particles at large transverse momentum (p_T)
- Reconstructed jets

Differentiate via
- Particle ID
- Jet tagging (heavy flavour, photon…)

WWU
MÜNSTER

Transition Radiation Detector
(TRD)

amplification
region
0.7 cm

drift
region
3.0 cm

radiator
4.7 cm

x

z

cathode pads
anode wires
cathode wires

absorbed
TR photons

drift
electrode

pion   electron

**Electron/pion separation via specific energy loss (Bethe-Bloch)
and (early) transition radiation for electrons (γ > 1000)**

pion

electron
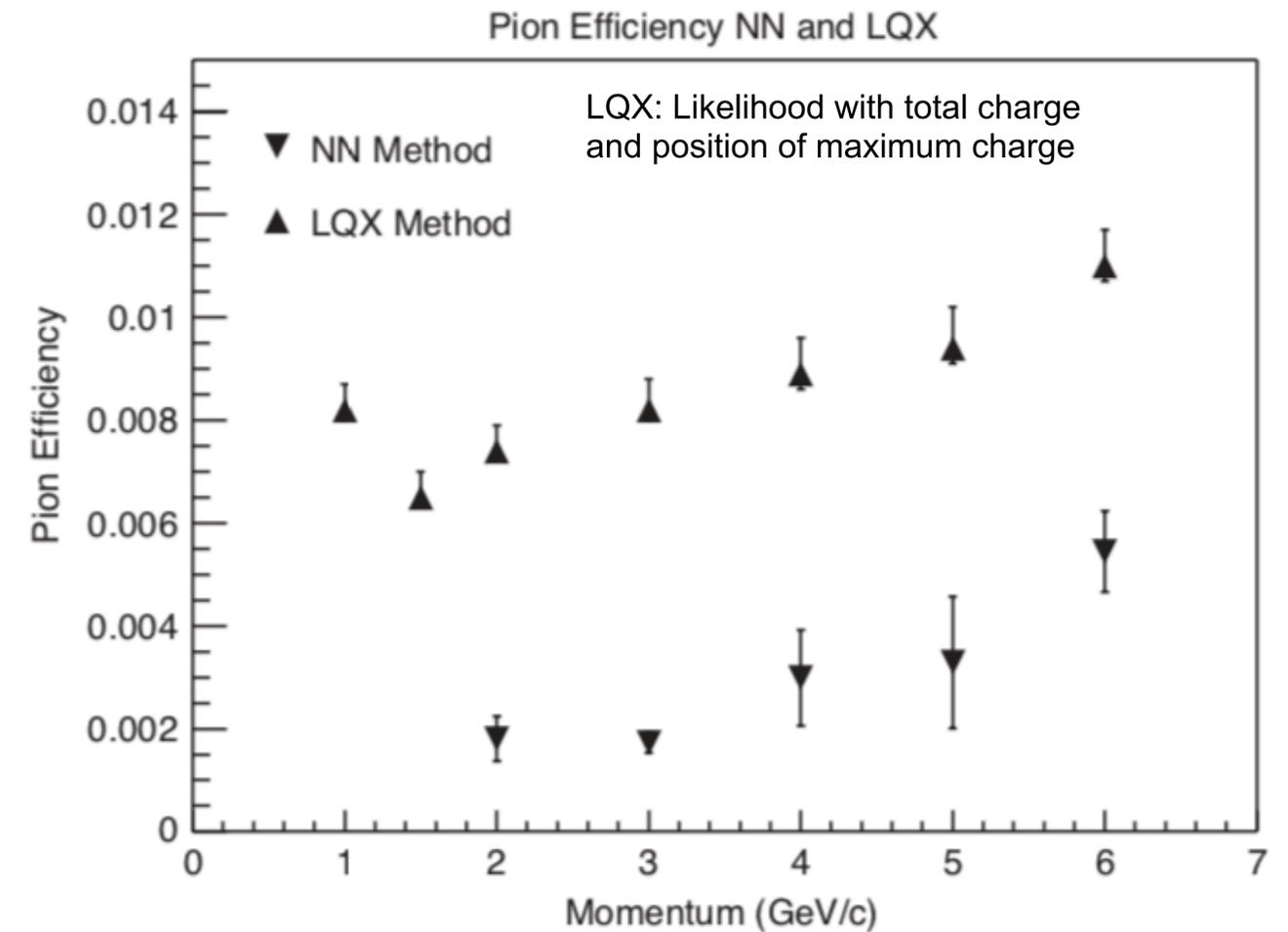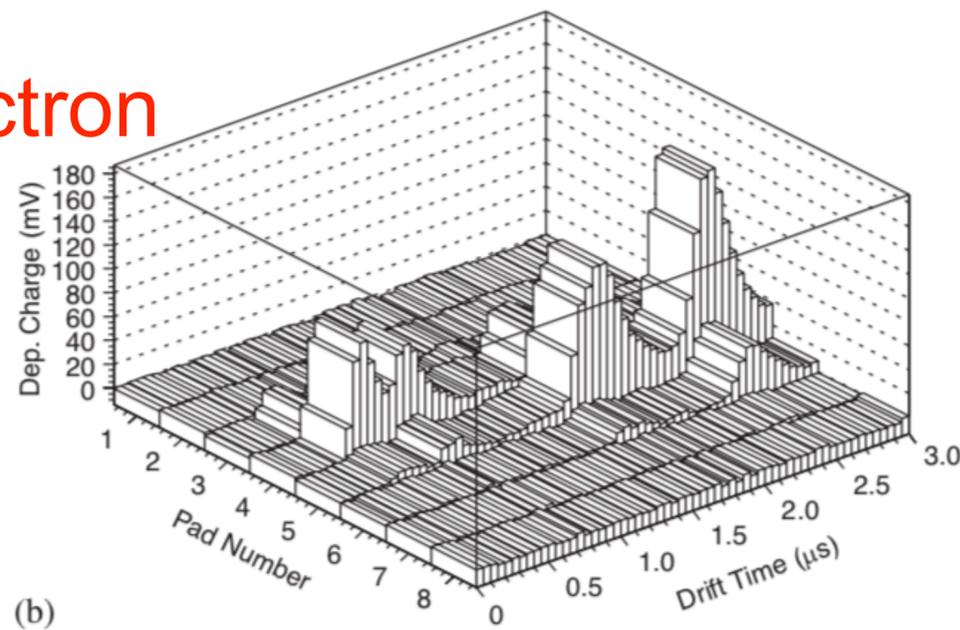
LQX: Likelihood with total charge and position of maximum charge

Pion Efficiency NN and LQX

▼ NN Method
▲ LQX Method

Andronic et al. (MS-PhD A.Wilk)
Nucl. Instrum. Meth. A558 (2006), 516–525 (also NIM A881 (2018), 88–127)

Hard probes
- Large production scales (mass or momentum)
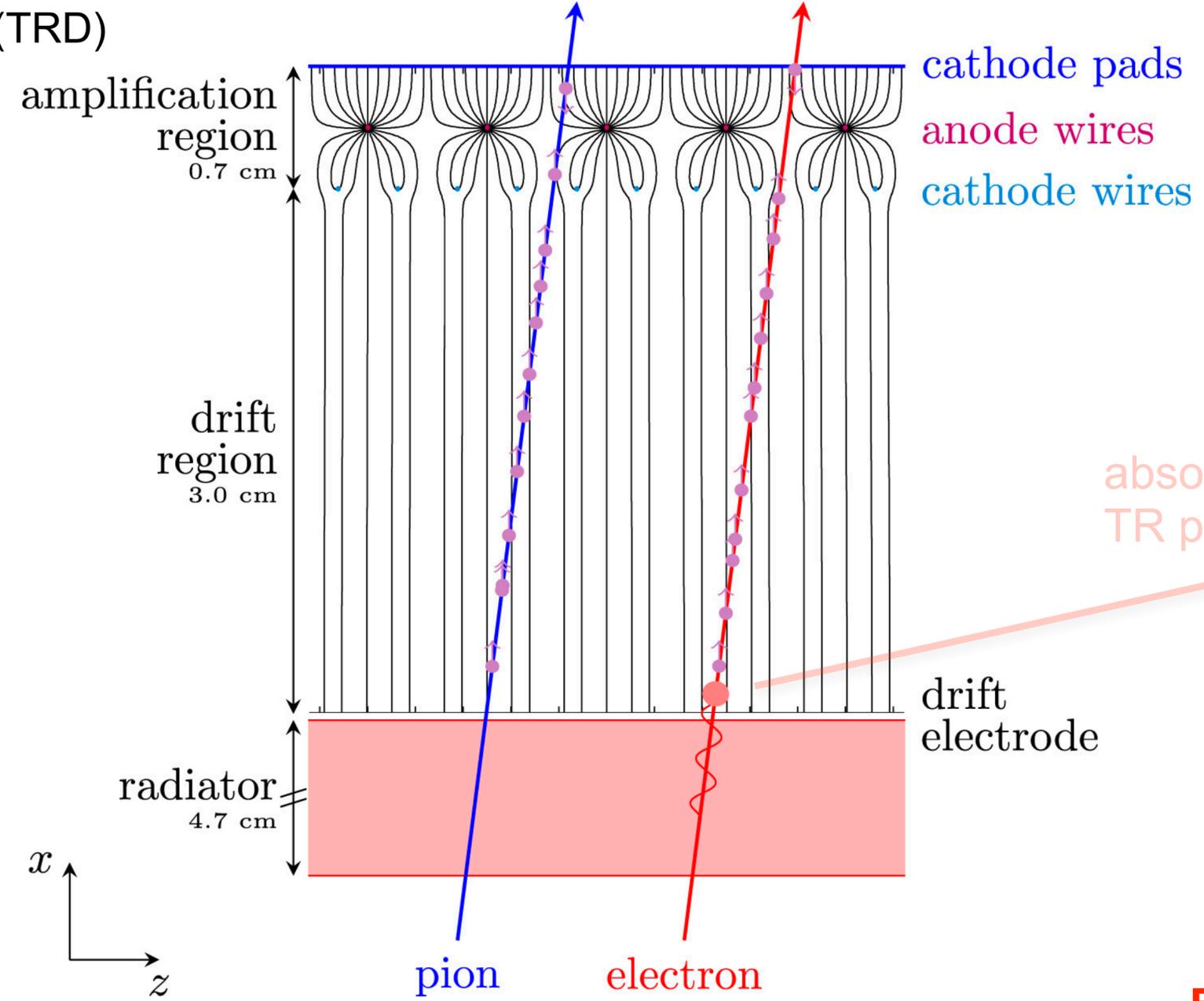- Early production ($\ll 0.2$ fm/c)
- Factorisation

Accessible via
- Single particles at large transverse momentum (p_T)
- Reconstructed jets

Differentiate via
- Particle ID
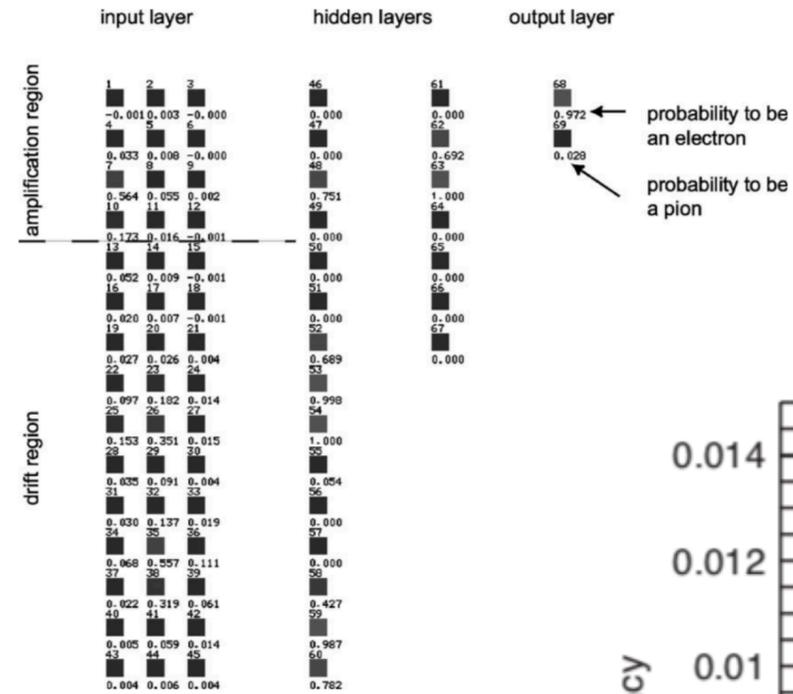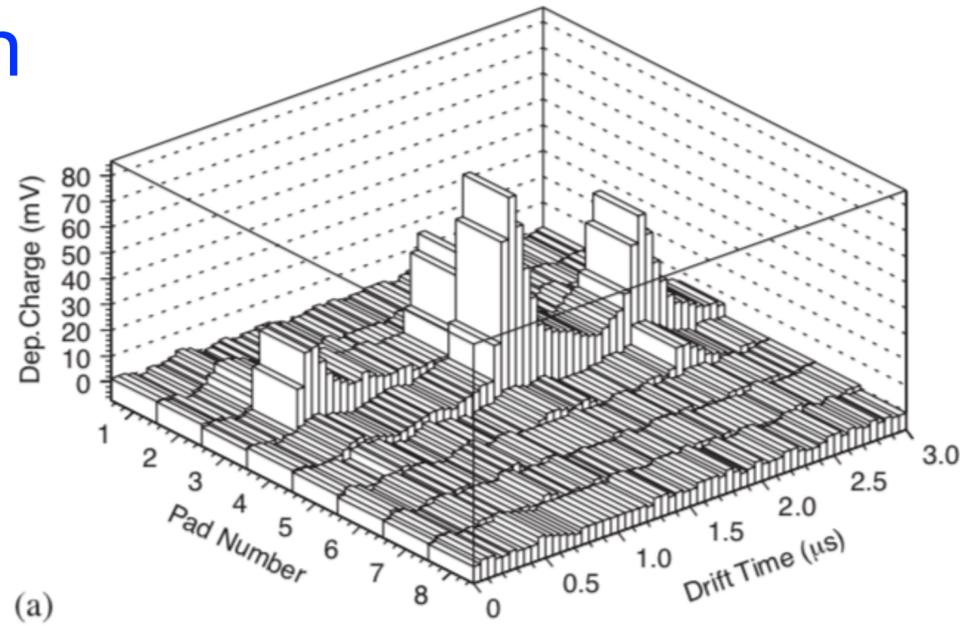- Jet tagging (heavy flavour, photon…)

In heavy ion collisions
- Medium modified parton shower
- Depending on colour charge and parton mass

WWU
MÜNSTER

$$R_{AA} = \frac{\text{Yield}_{AA}}{N_{\text{coll}} \cdot \text{Yield}_{pp}}$$

Legend (in figure):
- h± pPb $\sqrt{s_{NN}}$ = 5020 GeV, -0.3 < η < 1.3 (ALICE)
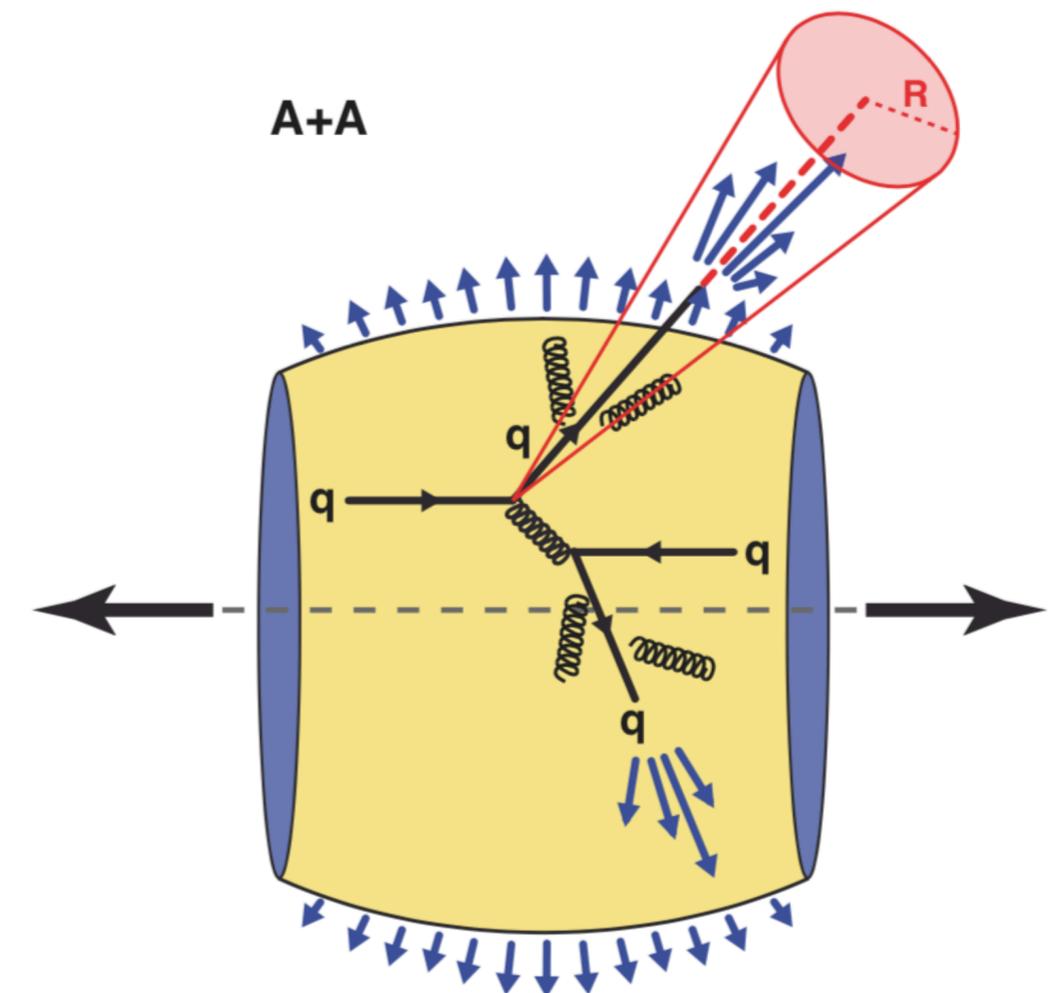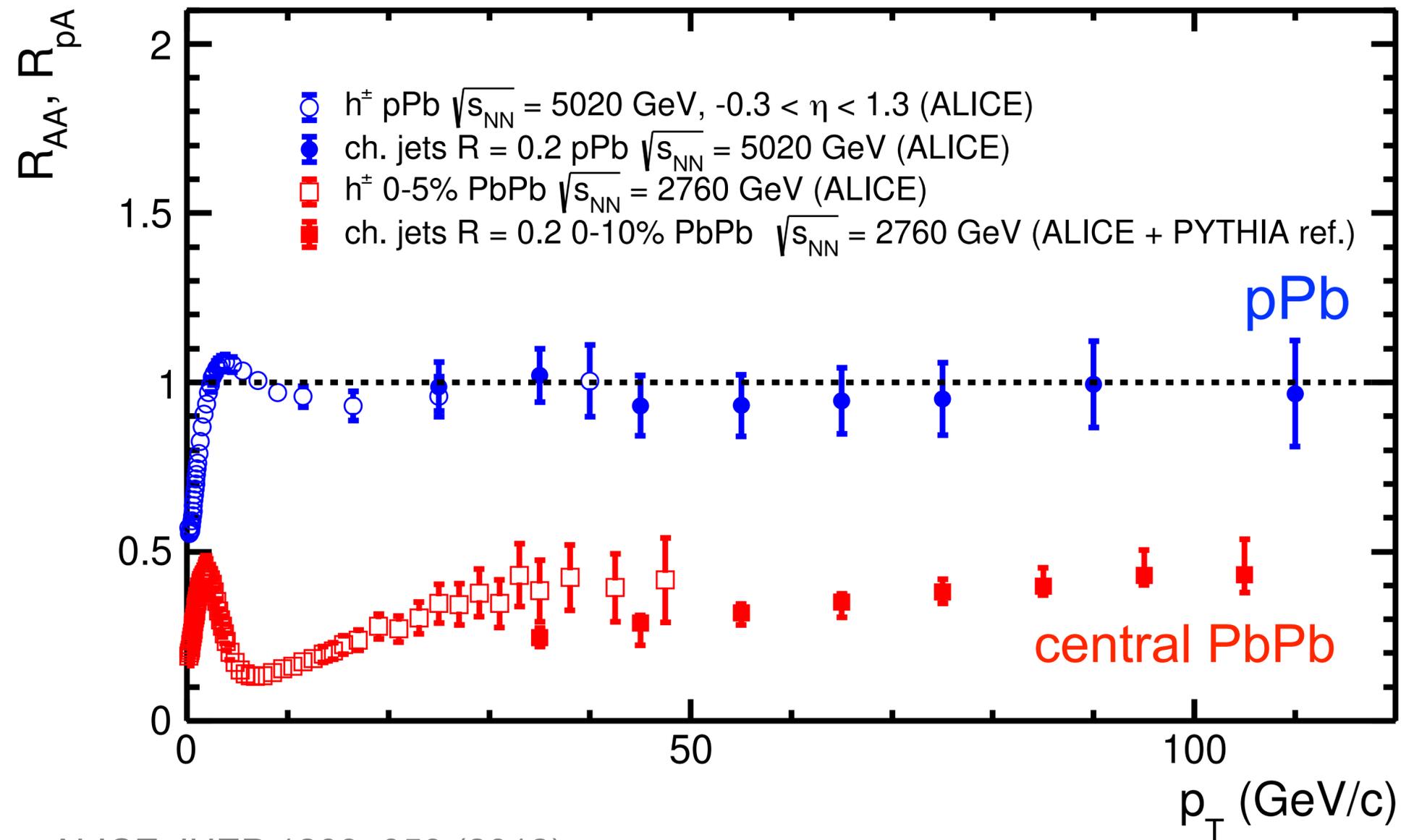- ch. jets R = 0.2 pPb $\sqrt{s_{NN}}$ = 5020 GeV (ALICE)
- h± 0-5% PbPb $\sqrt{s_{NN}}$ = 2760 GeV (ALICE)
- ch. jets R = 0.2 0-10% PbPb $\sqrt{s_{NN}}$ = 2760 GeV (ALICE + PYTHIA ref.)

pPb

central PbPb

p_T (GeV/c)

Strong suppression in central PbPb Jets and Hadrons similar.

Particle correlations show that jet energy is redistributed to particles with $p_T \ll 2$ GeV.
ALICE PLB 763, 238 (2016)

ALICE JHEP 1203, 053 (2012)
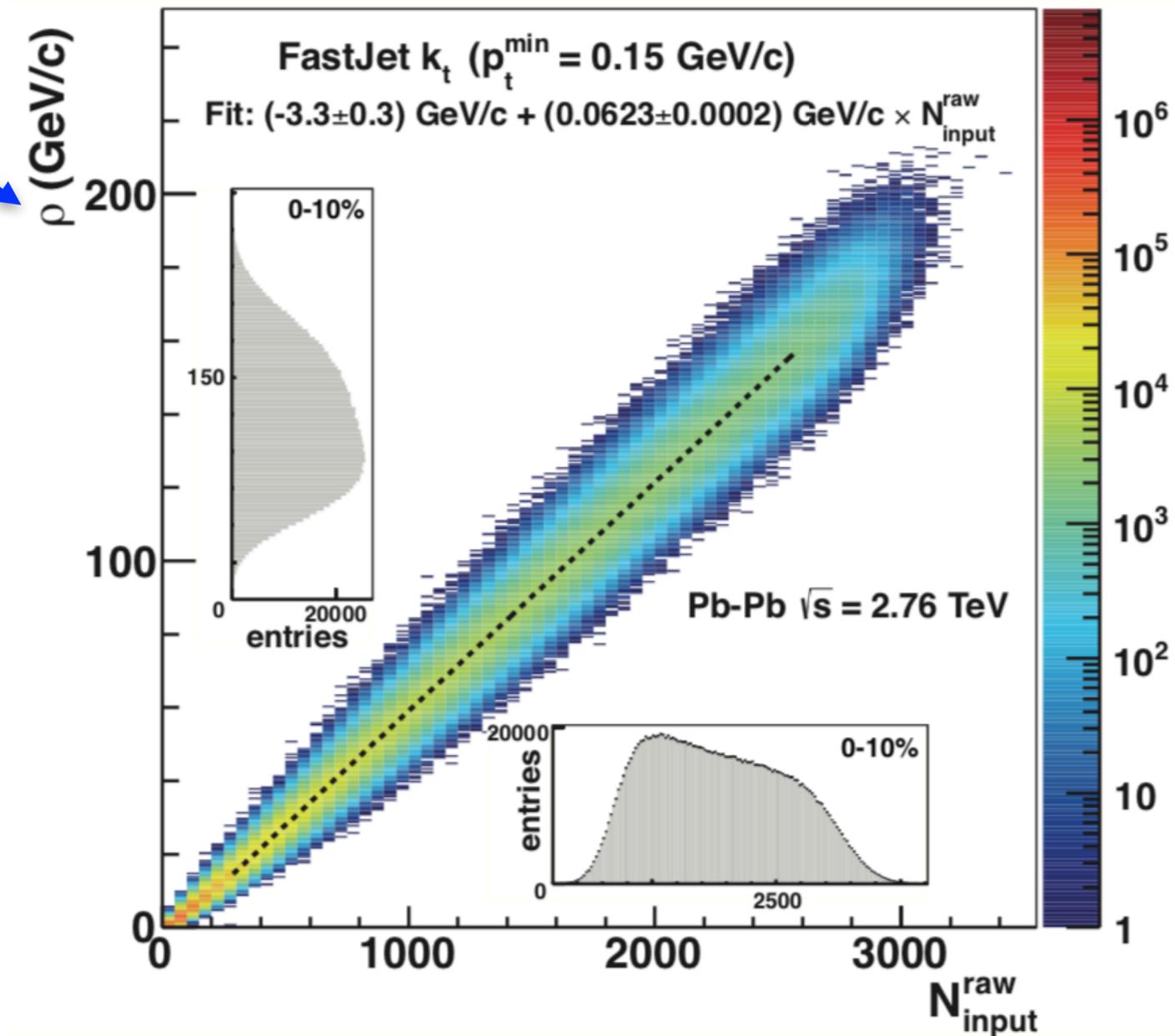ALICE PLB 749 68 (2015) (MS-PhD Haake)
ALICE JHEP 1118, 013 (2018)

- Goal
  - Recover the vacuum jet p_T
  - Minimise biases on fragmentation
  - Low constituent p_T, large radii
  - Area based subtraction

$$p_{T,jet}^{rec} = p_{T,jet} - \rho \cdot A_{jet}$$

- Problem
  - Large background ($N \sim R^2$)
  - Strongly fluctuating ($> \sqrt{N}$)

event wise median

FastJet k_t ($p_t^{min} = 0.15$ GeV/c)

Fit: (-3.3 ± 0.3) GeV/c + (0.0623 ± 0.0002) GeV/c $\times N_{input}^{raw}$

0-10%

Pb-Pb $\sqrt{s} = 2.76$ TeV

ALICE JHEP 1203 (2012), 053
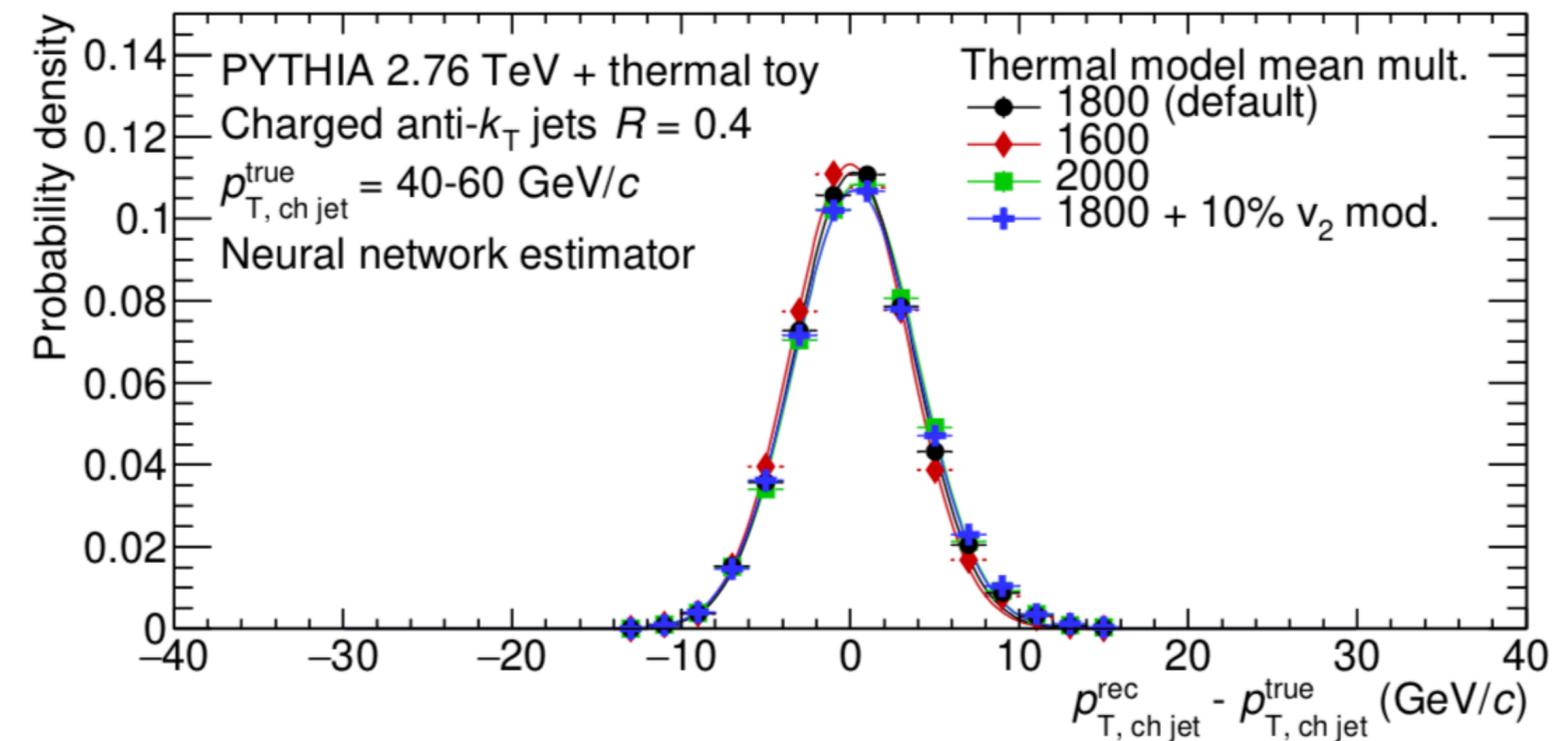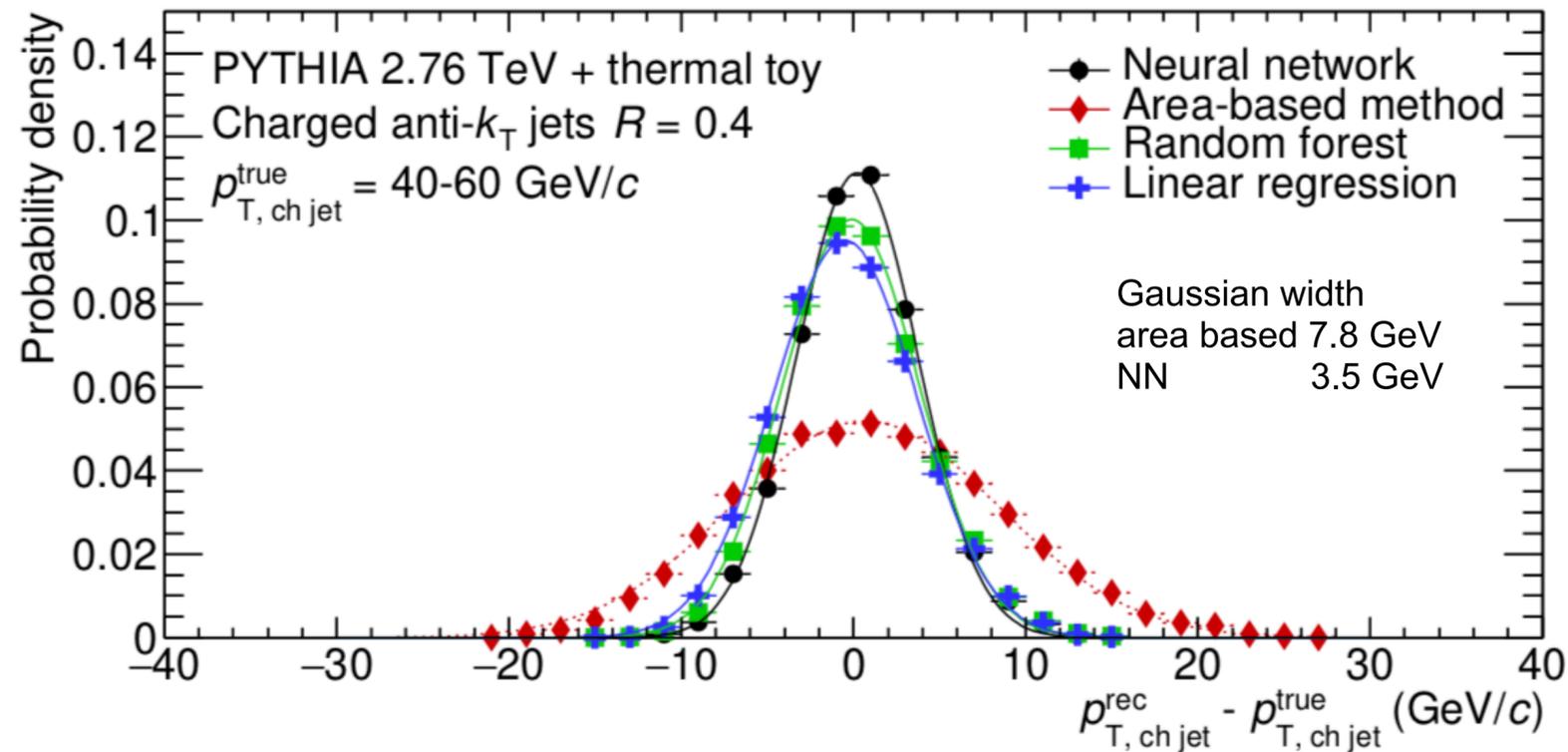
R. Haake (Yale), C. Loizides
submitted to PRC arxiv:1810.06324
(also A. Leifhelm MS-BSc 2017)

Significant improvement with ML methods compared to conventional method
Robust against variation of the underlying event.

- ALICE-EMCal

  - π^0 decay photons merge at high p_T

  - Background to single (direct) photons

  - Topology allows to separate pi0s and direct photons
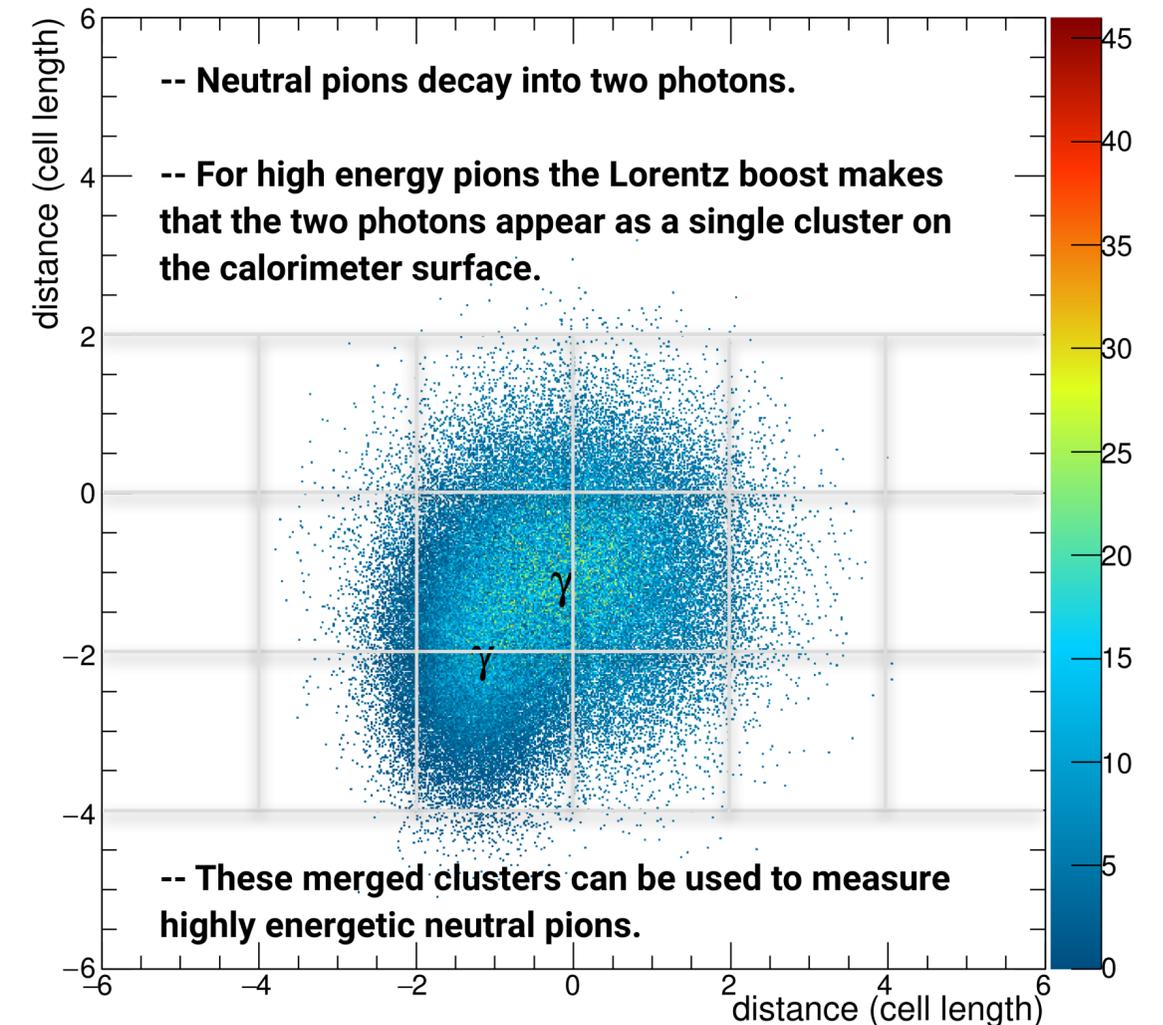
  - Topology changes for η and
    $K^0_S \rightarrow \pi^0\pi^0 \rightarrow \gamma\gamma\ \gamma\gamma$

- New MS-PhD (BMBF-ALICE)

- Neutral mesons and direct photons

- Additional route: J/ψ analysis (Tracking/EMCal)

- Connection to CBM analysis (local TRD group)

-- Neutral pions decay into two photons.

-- For high energy pions the Lorentz boost makes that the two photons appear as a single cluster on the calorimeter surface.

-- These merged clusters can be used to measure highly energetic neutral pions.

Cluster-Klassifikations-Methoden am Elektromagnetischen Kalorimeter des ALICE Detektors mittels Machine-Learning

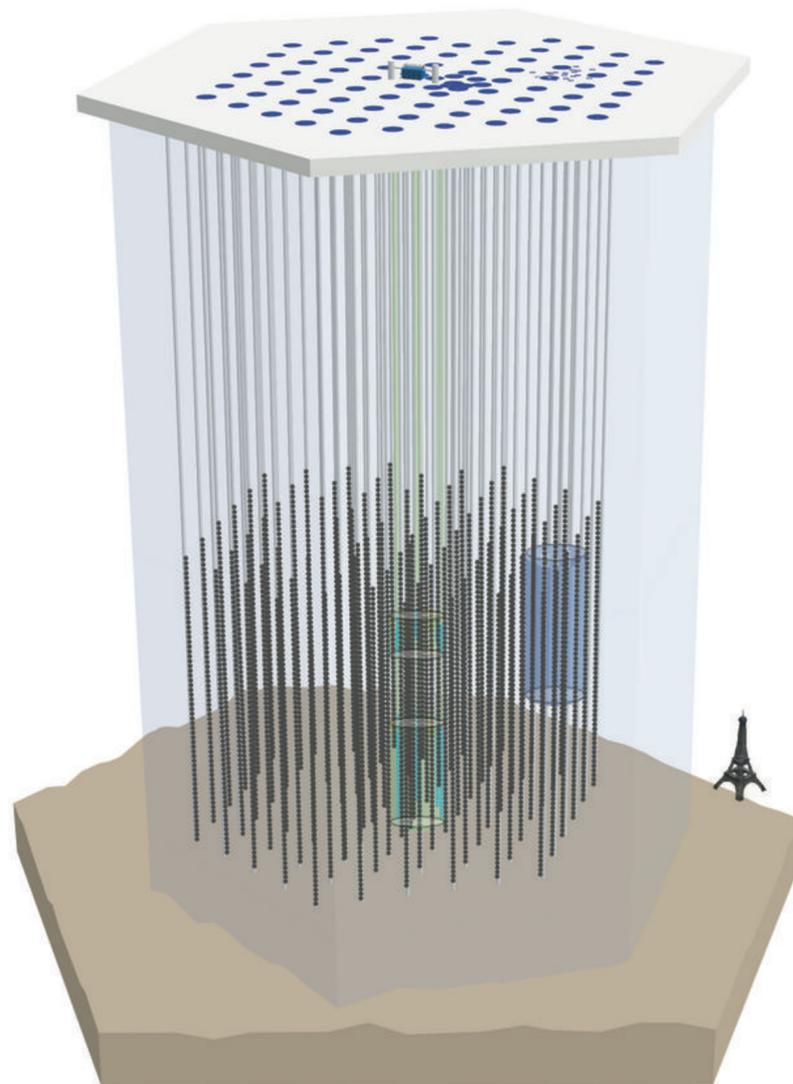Ida Wöstheinrich - Münster - Jugend forscht 2019

Beyond ALICE
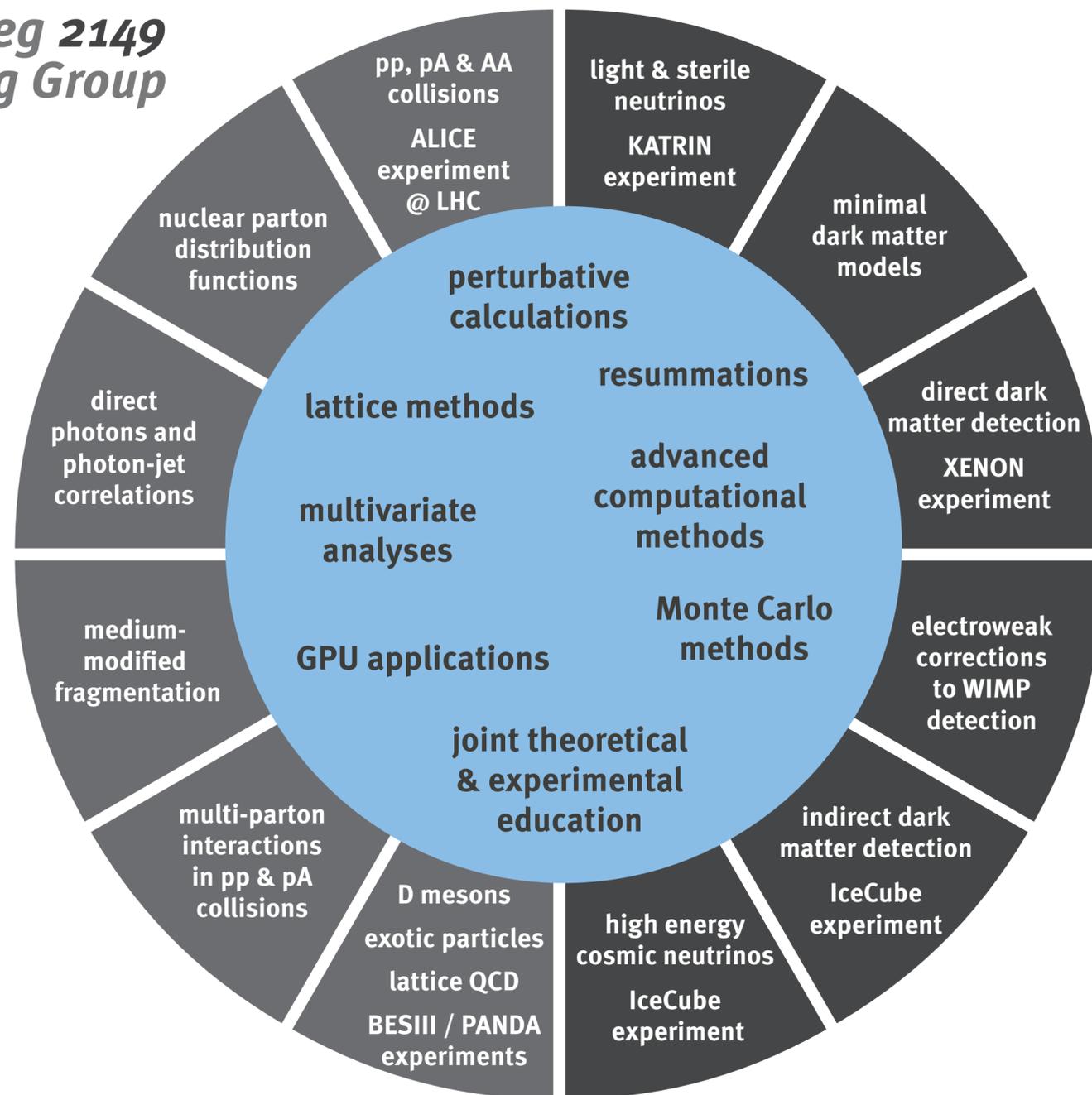
- Broad and highly connected particle physics research program
- Excellent training program
  - Theory, experiment, computing methods
  - Directly associated to computing department (ZIV)
  - Regular topical training workshops also from external experts (e.g. Machine/Deep Learning)
- Deep learning/machine learning
  - Additional connection of research via common methods
  - Highly requested by students

IceCube Neutrino Observatory
MS: AG Kappes

Challenges in data analyses

- Very few signal events compared to background
  (e.g. large flux of muons produced in the atmosphere)

- Event reconstruction with sparsely instrumented detector in
  inhomogeneous medium with significant light scattering
  (classical likelihood methods require significant CPU resources)

Application of deep learning techniques

- Event triggering, filtering, cleaning, splitting
  (e.g. separation of coincident muons, removal of noise hits)

- Event classification (e.g. atm. μ vs. atm. ν vs. cosmic ν)

- Event reconstruction (direction, energy, kinematics)

- Machine learning application in electron PID since 2005
  (lower priority and fluctuating workforce)

- Activity currently ramping up again
  - Dedicated PhD (ALICE)
  - Close collaboration with CERN/Yale

- Research Training Group
  - Cross sectional topic between local research projects
  - Excellent fit to RTG education scope

We look forward to the stimulating exchange within this project