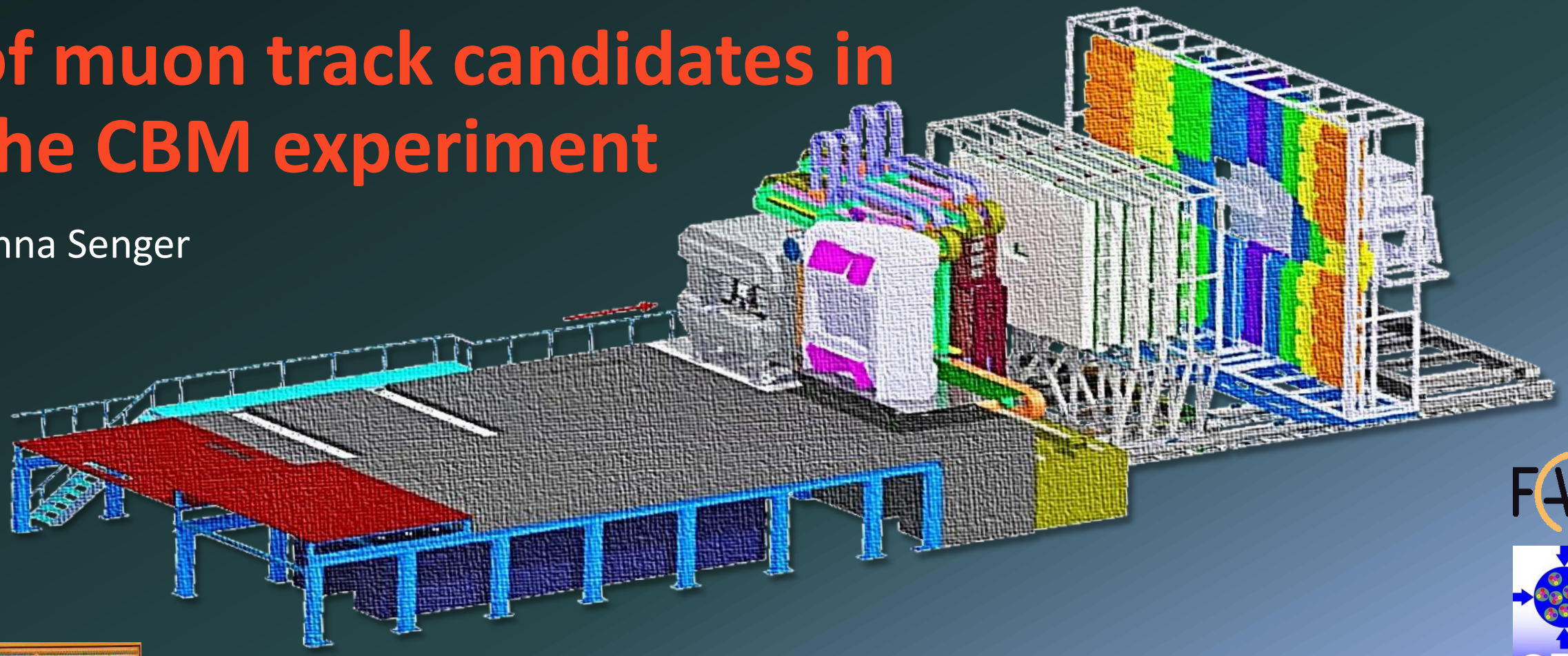
A machine learning procedure for the selection of muon track candidates in the CBM experiment

Anna Senger



10th International Conference on New Frontiers in Physics (ICNFP 2021)

FAIR

CBM

CREMLIN PLUS

Connecting Russian and European Measures for Large-scale Research Infrastructures

Outline

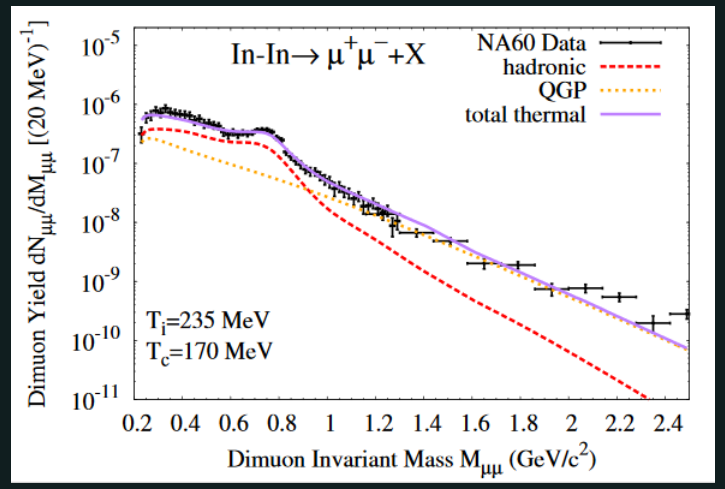
"The Compressed Baryonic Matter (CBM) Experiment at FAIR"
K. Agarval, Tuesday 31. August, 17:30, Room 1

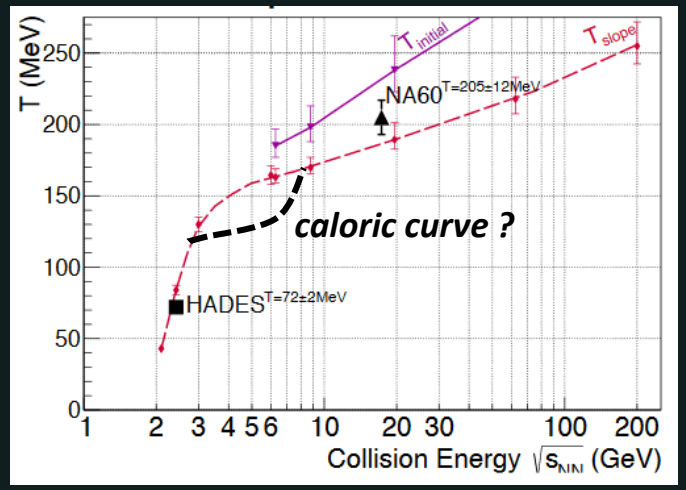
- Dilepton physics
- Muon setup of CBM
- Muon identification
- Cut optimization with machine learning procedure
- Reconstruction results
- Conclusions
- Next steps

Dimuon physics: highlights

- **Thermal radiation**

Thermal Dileptons as Fireball Thermometer and Chronometer
Ralf Rapp, Hendrik van Hees
arXiv:1411.4612
Fireball model
T. Galatyuk et al.
Eur. Phys. J. A 52 (2016) 131

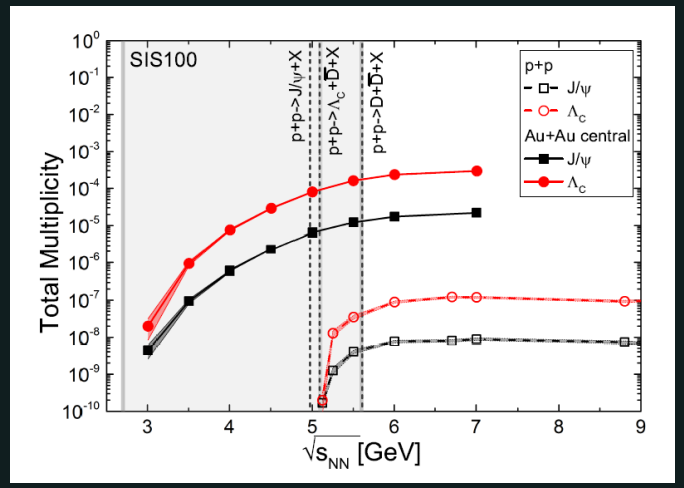




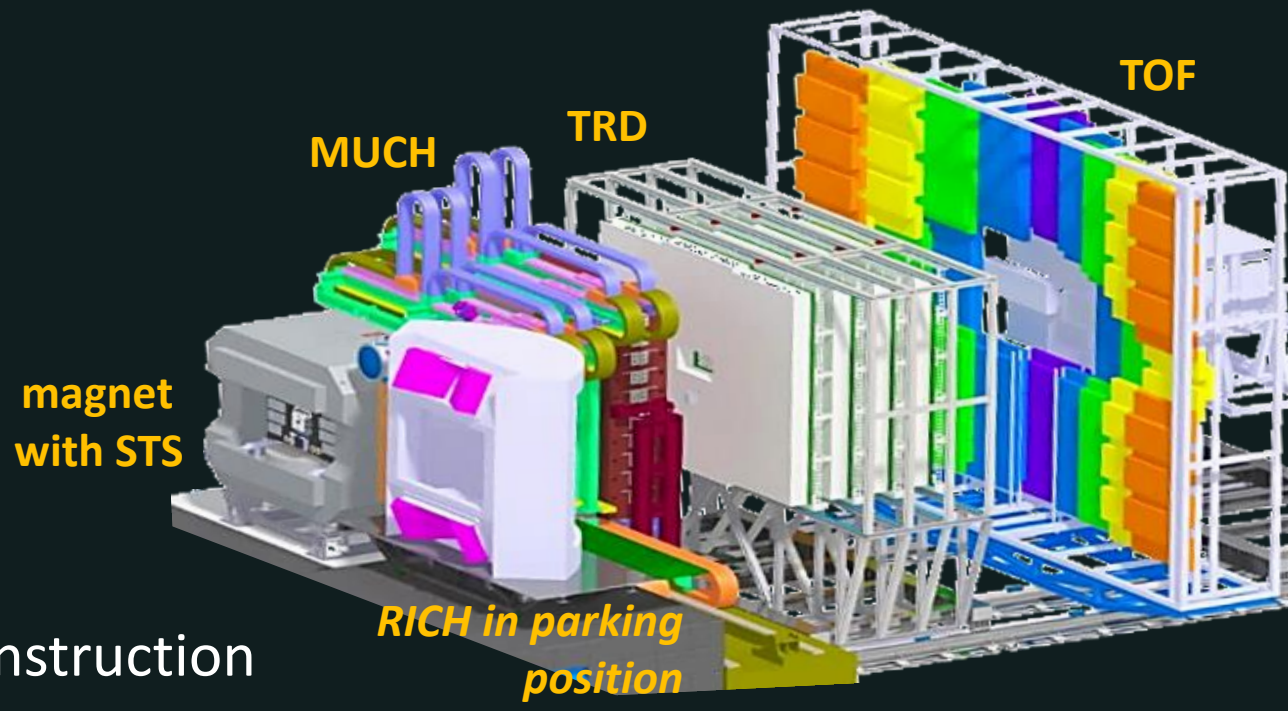
- **Charm production at threshold energies in cold and dense matter:**

sub-threshold charm production via
$N^* \rightarrow \Lambda_c + D$
$N^* \rightarrow N + J/\psi$

Sub-threshold charm production in nuclear collisions
J. Steinheimer, A. Botvina, M. Bleicher, arXiv:1605.03439



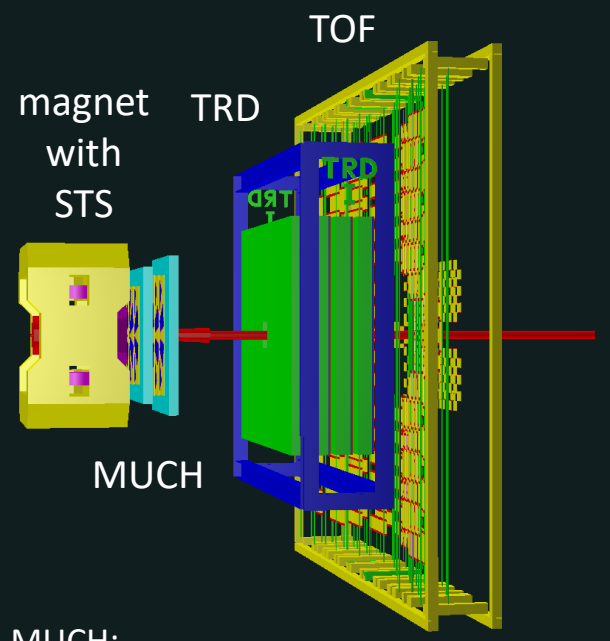
Muon setup



Silicon Tracking System (STS)	track, vertex and momentum reconstruction
Muon Chamber System (MUCH)	global tracking, muon identification via hadron absorption in massive material
Transition Radiation Detector (TRD)	global tracking
Time of Flight Detector (TOF)	particle identification via time measurement

Configurations

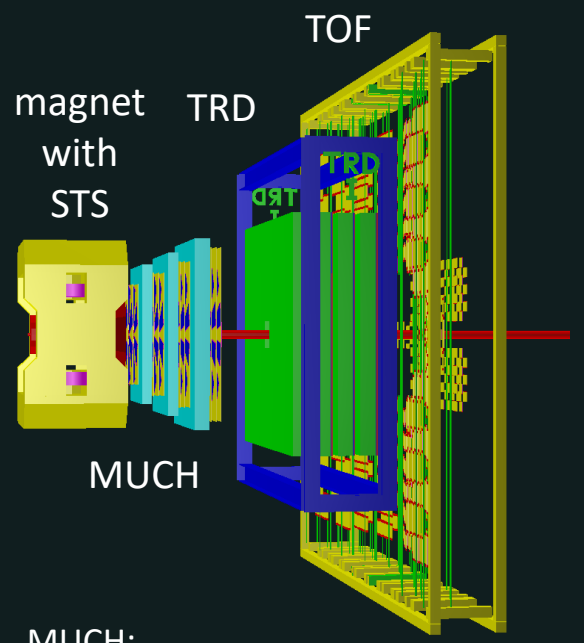
low beam energies
(up to 4 AGeV for Au beam)



MUCH:
2 GEM stations
absorbers:
58 cm C + concrete
(20+20) cm Fe

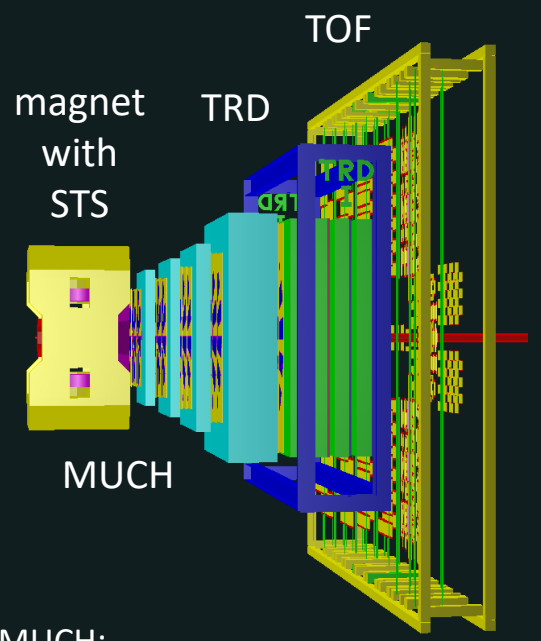
beam energies
above 4 AGeV for Au beam

low
invariant mass region



MUCH:
2 GEM + 2 RPC stations
absorbers:
58 cm C + concrete
(20+20+30) cm Fe

intermediate and high
invariant mass region



MUCH:
2 GEM + 2 RPC stations
absorbers:
58 cm C + concrete
(20+20+30+100) cm Fe

μ reconstruction chain

STS track reconstruction
↓
extrapolation of the tracks through downstream detectors up to TOF

→

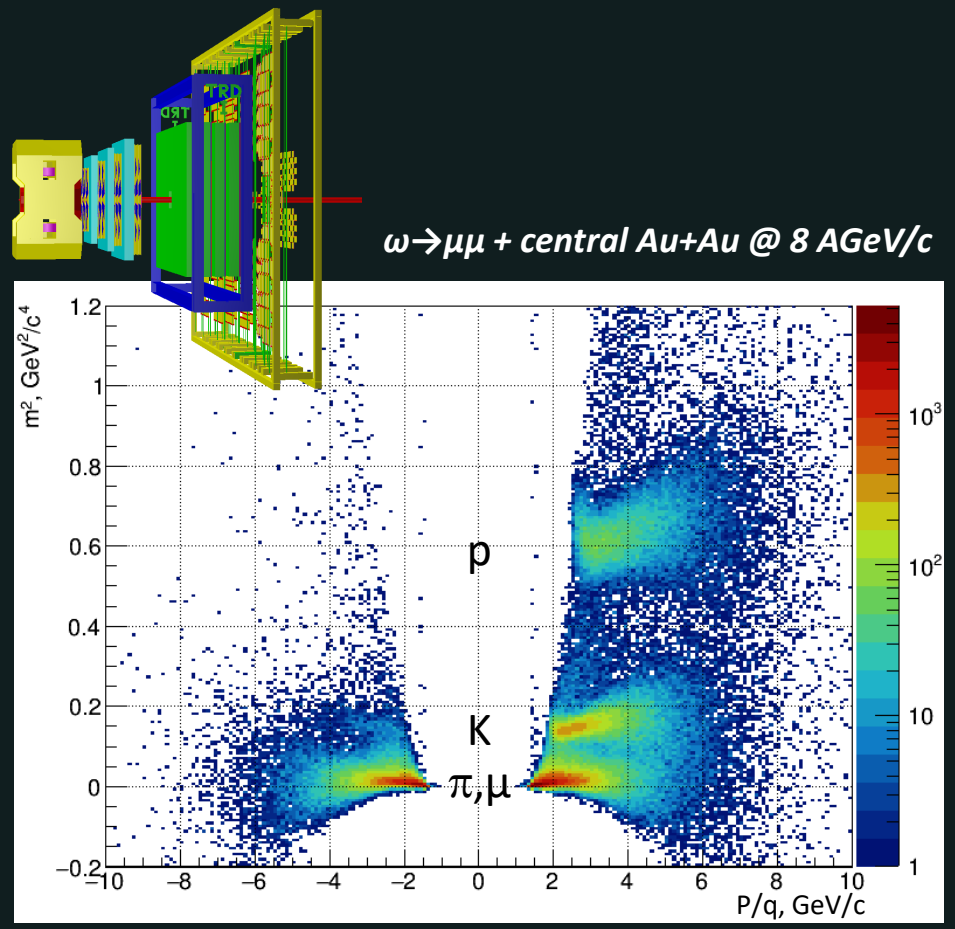
selection of the muon track candidates

→

calculation of the invariant mass spectra

Parameters for muon track candidate selection

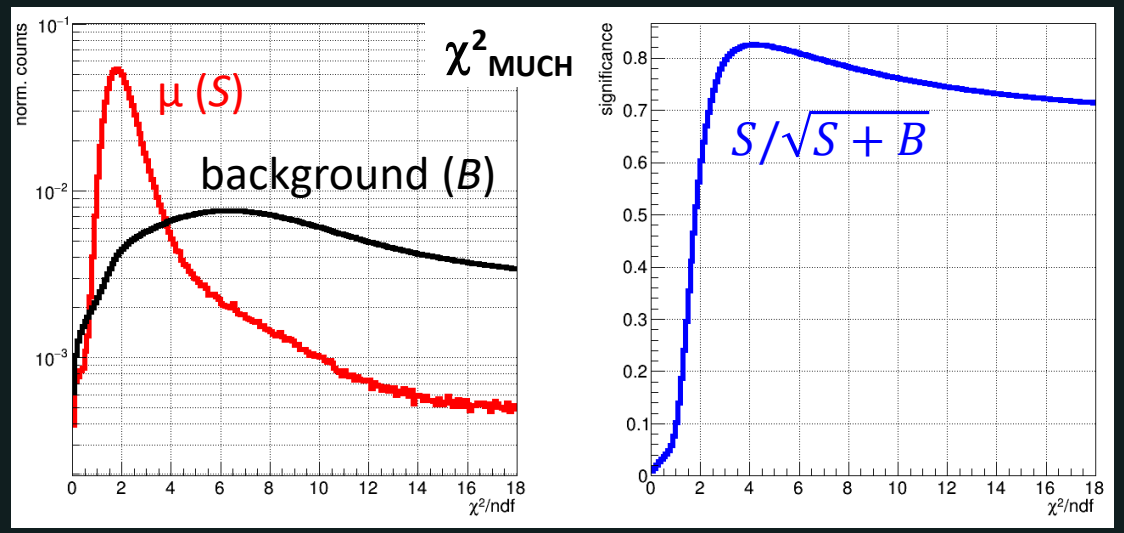
- Vertex
  - χ^2/NDF
- STS
  - number of hits
  - χ^2/NDF
- MUCH
  - number of hits
  - χ^2/NDF
- TRD
  - number of hits
  - χ^2/NDF
- TOF*
  - mass cut

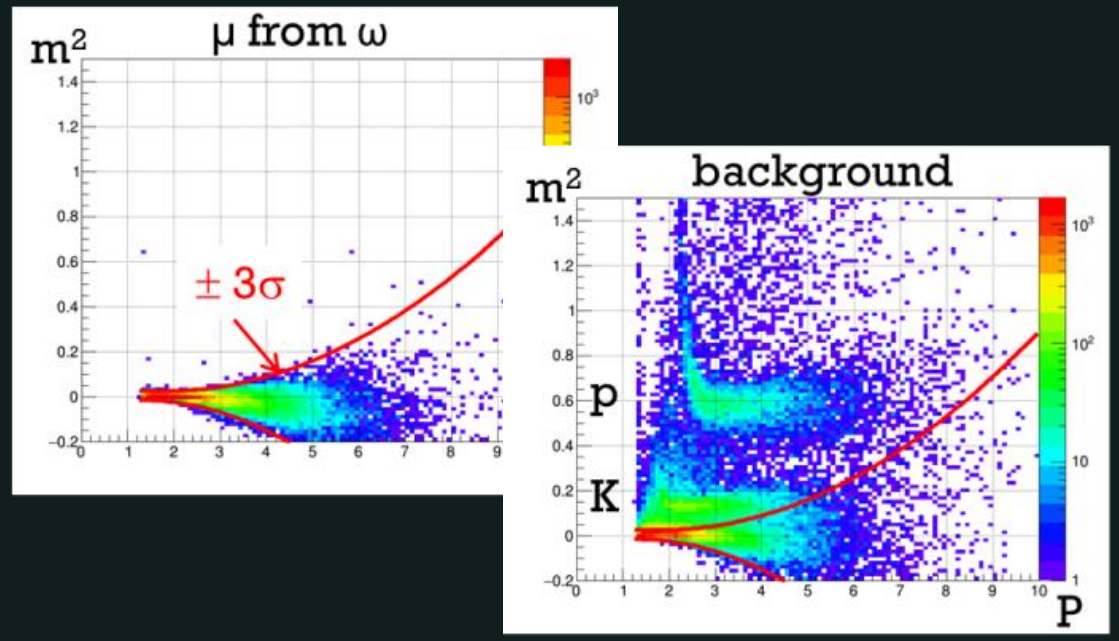


** rejection of punch through hadrons*

Cut optimization

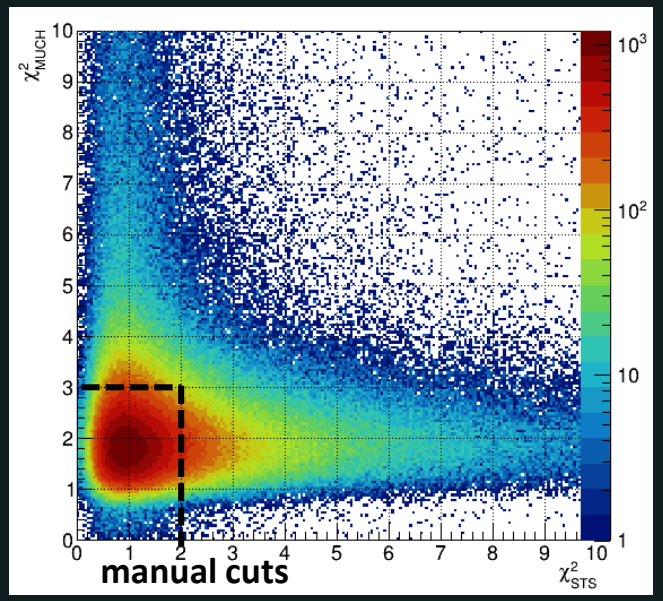
- <u>Manual:</u>
  - χ^2 of the reconstructed tracks
  - mass cut in TOF
- <u>Artificial Neural Network</u>



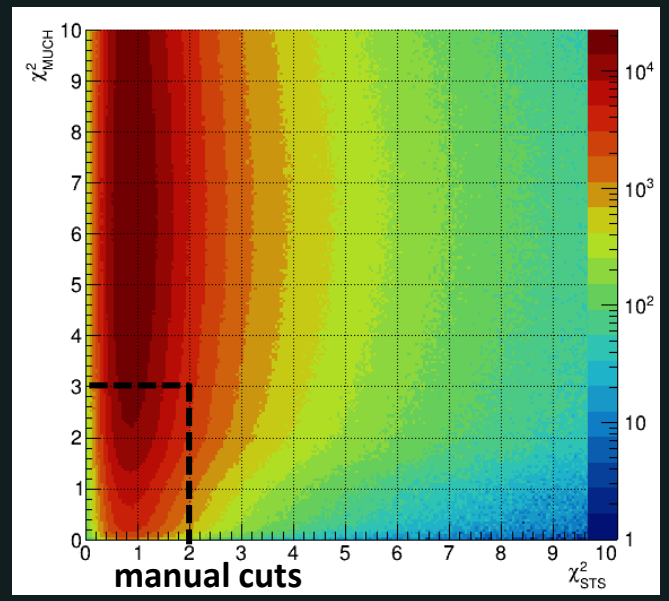


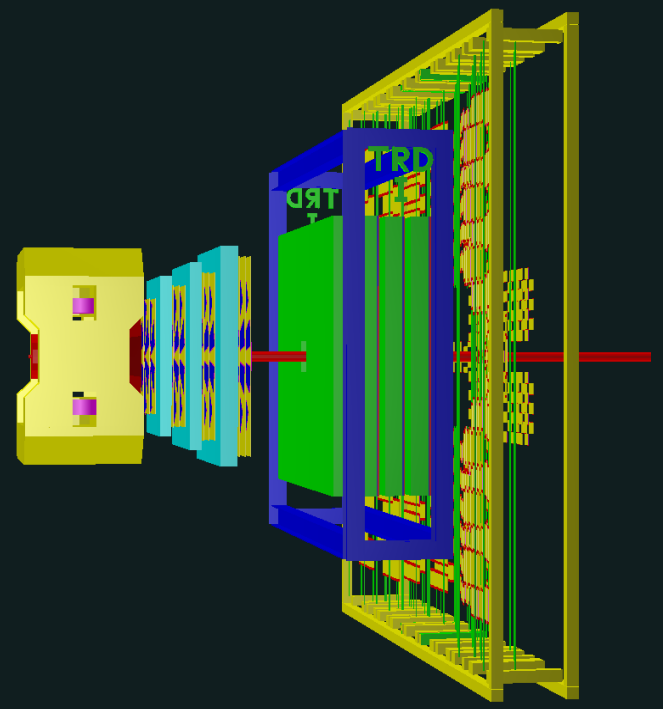
χ^2_{MUCH} vs. χ^2_{STS}

signal muons



background





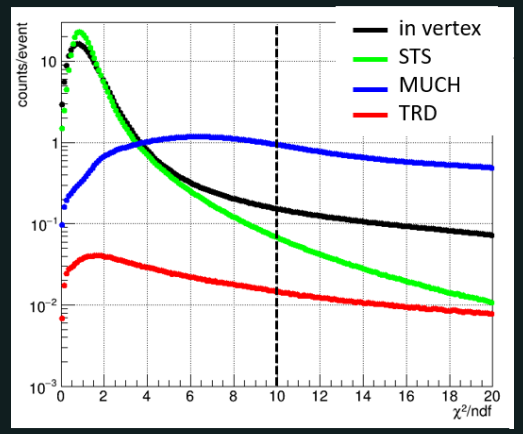
Test of ANN for ω→μμ reconstruction

Background: central UrQMD events @ 8 AGeV/c
ω→μμ from PLUTO generator
TMultiLayerPerceptron *https://root.cern.ch/doc/master/classTMultiLayerPerceptron.html*

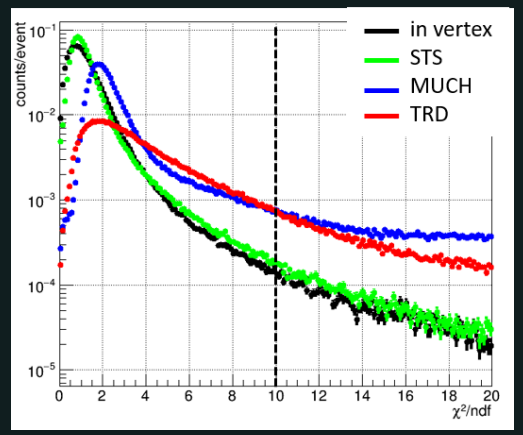
ANN input: preselection

- χ^2/ndf
  - in primary vertex < 10
  - in STS < 10
  - in MUCH < 10
  - in TRD < 10
- Number of hits
  - in STS > 5
  - in MUCH > 8
  - in TRD > 0
  - in TOF > 0

background



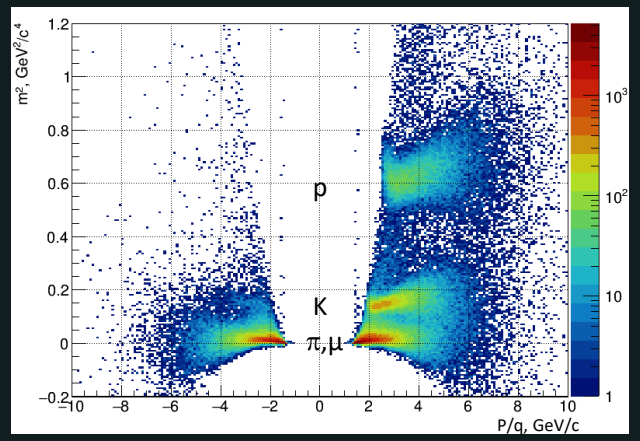
μ from ω



input parameters

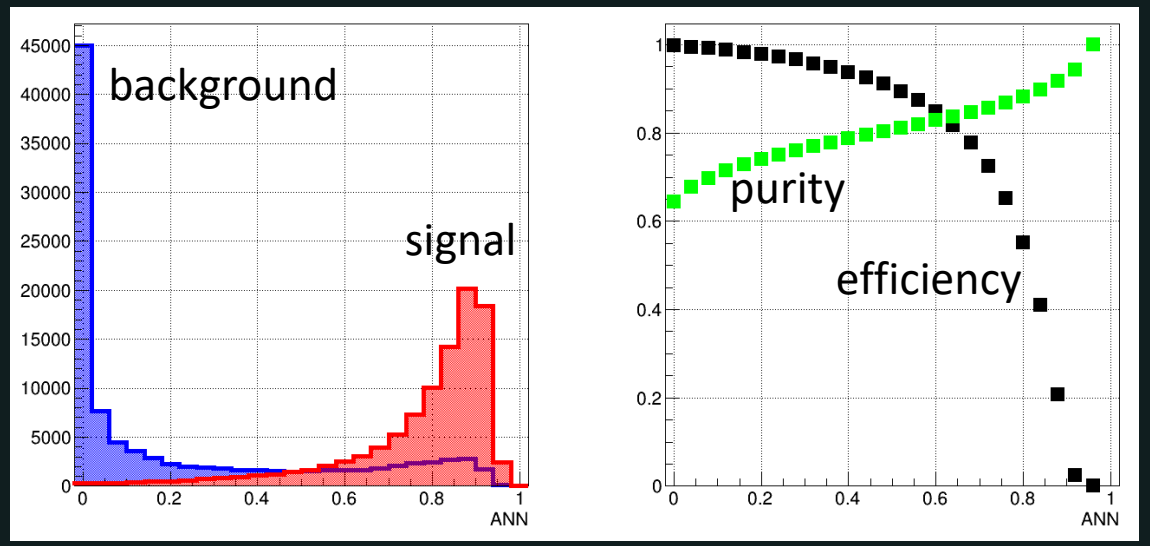
positive and negative tracks separately

- χ^2/ndf
  - in primary vertex
  - in STS
  - in MUCH
  - in TRD
- momentum
- m_{TOF}

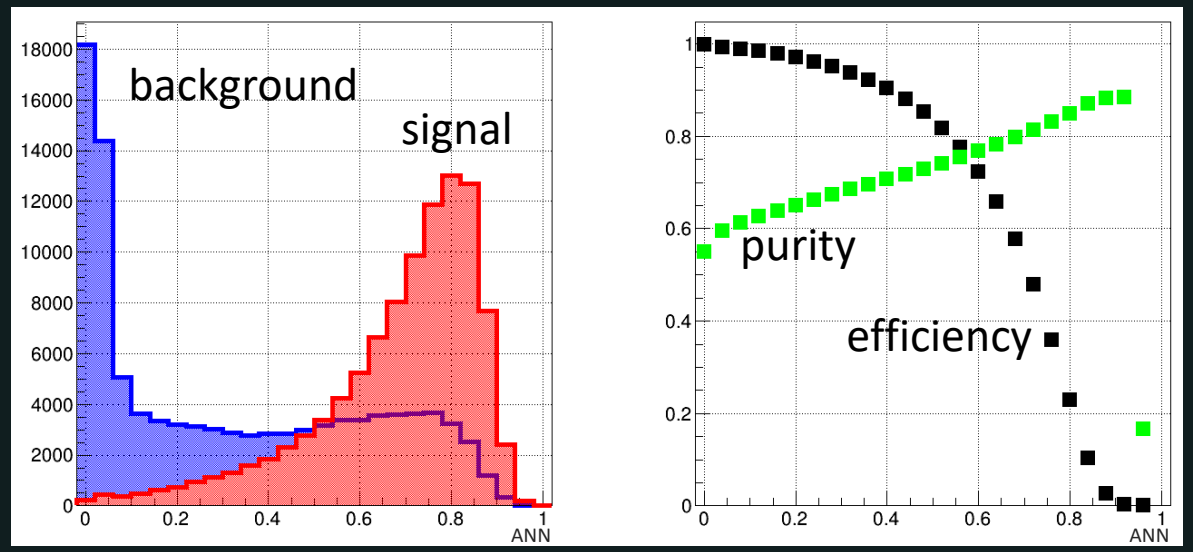


ANN output

Positive tracks



Negative tracks

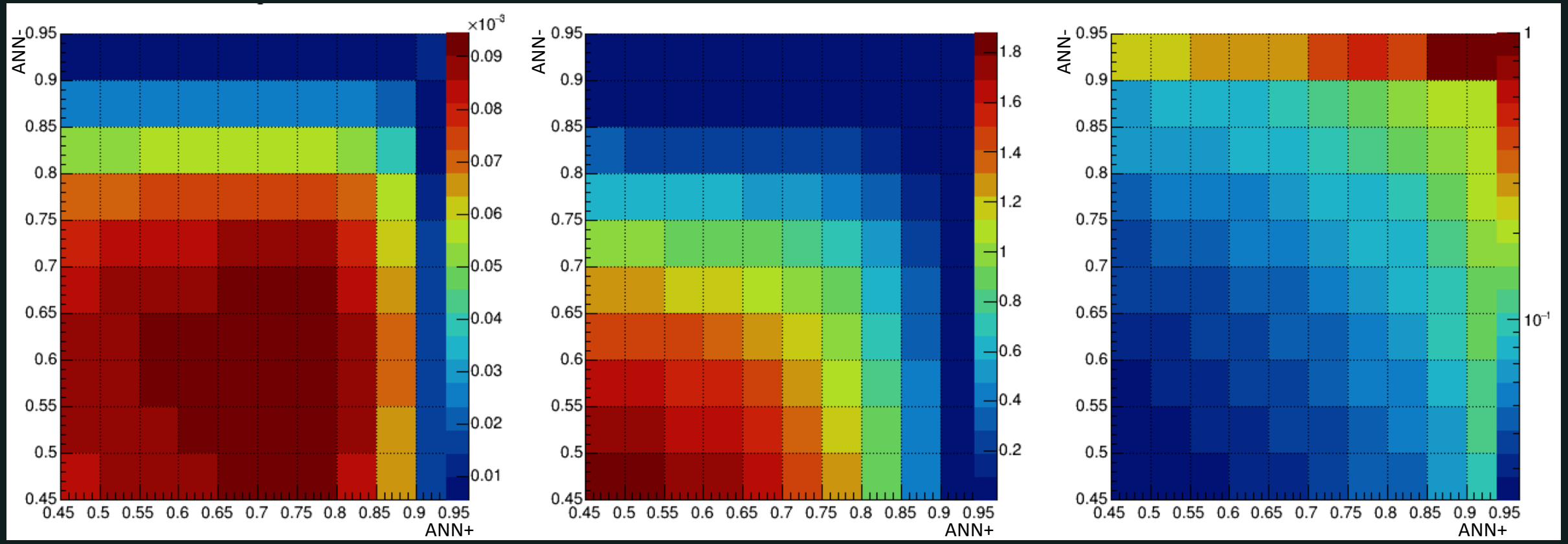


efficiency = signal passing ANN cut / total signal
purity = signal passing ANN cut / (signal+background passing ANN cut)

Analysis results

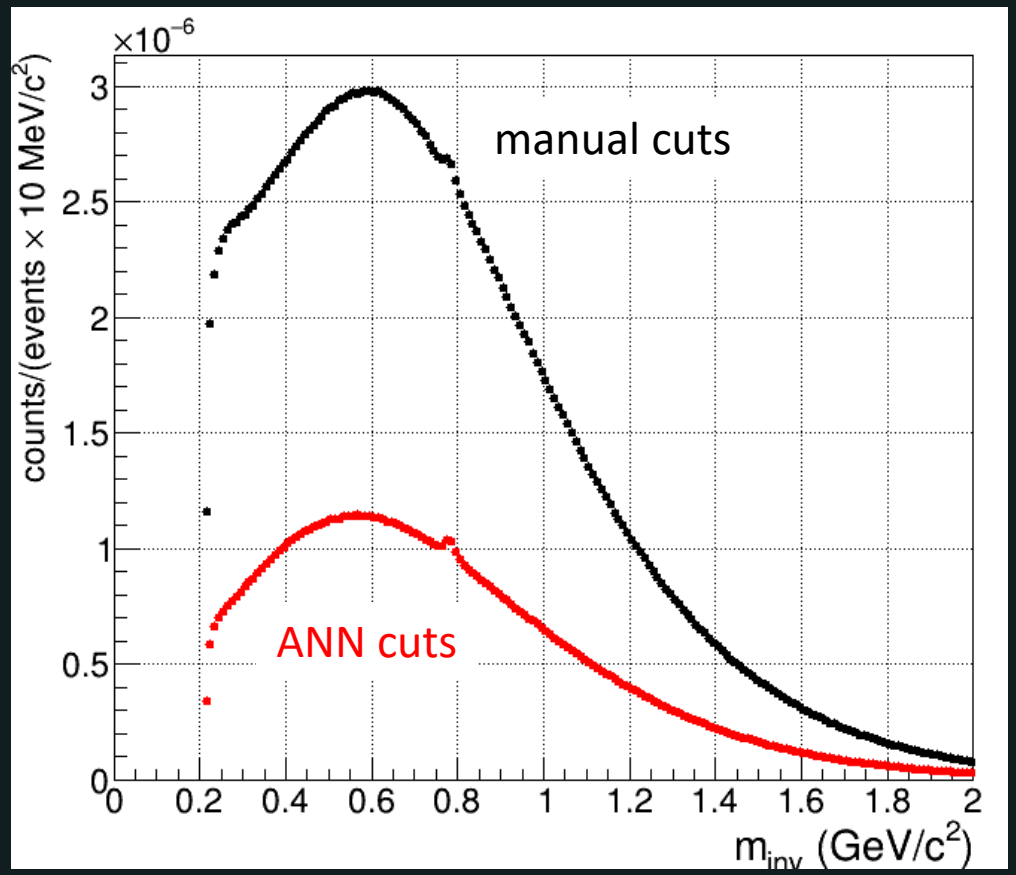
ω + central Au+Au @ 8 A GeV/c

significance **ω efficiency, %** **ω/background ratio**



Comparison with manual cuts

cuts	ε_ω %	$\frac{\omega}{\text{background}}$ ratio	norm. significance
manual	**1.21**	**0.016**	**1**
ANN ±	**1.21**	**0.040**	**1.58**



<u>manual cuts</u>

$\chi^2_{Vertex}<3$, $\chi^2_{STS}<3$, $\chi^2_{MUCH}<3$

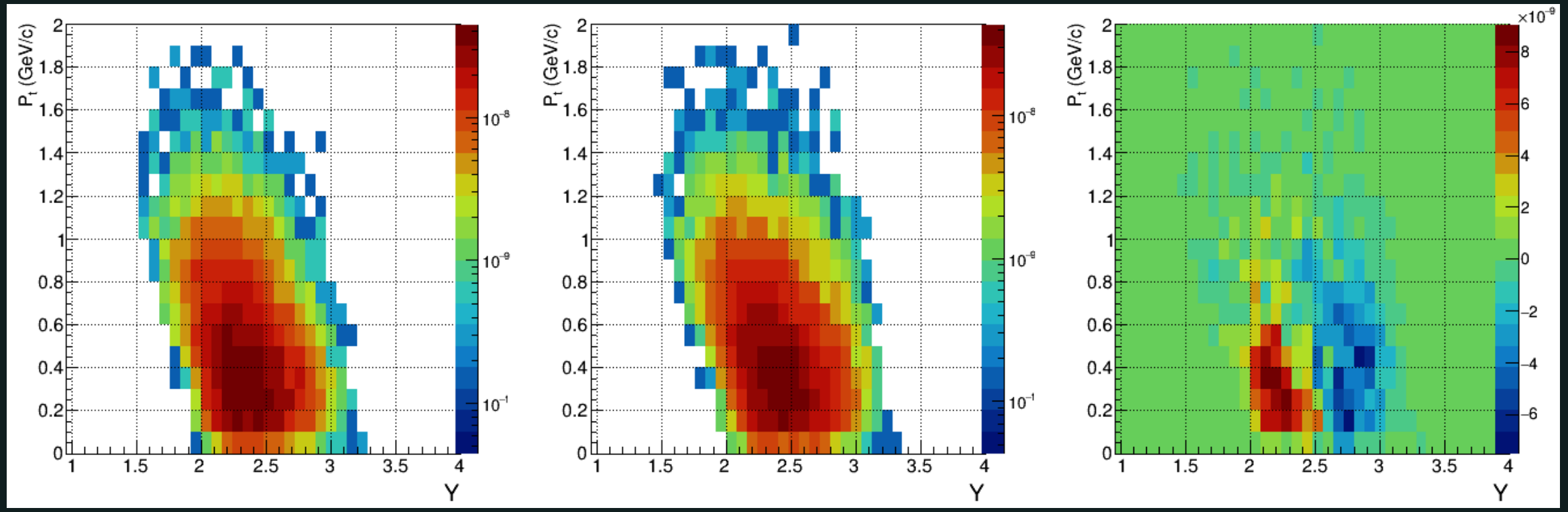
STS>6, MUCH>9, TRD

$\sigma_{TOF}=3$

ω + central Au+Au @ 8 A GeV/c

Comparison with manual cuts (for same efficiency)

manual cuts (1) **ANN cuts (2)** **1-2**

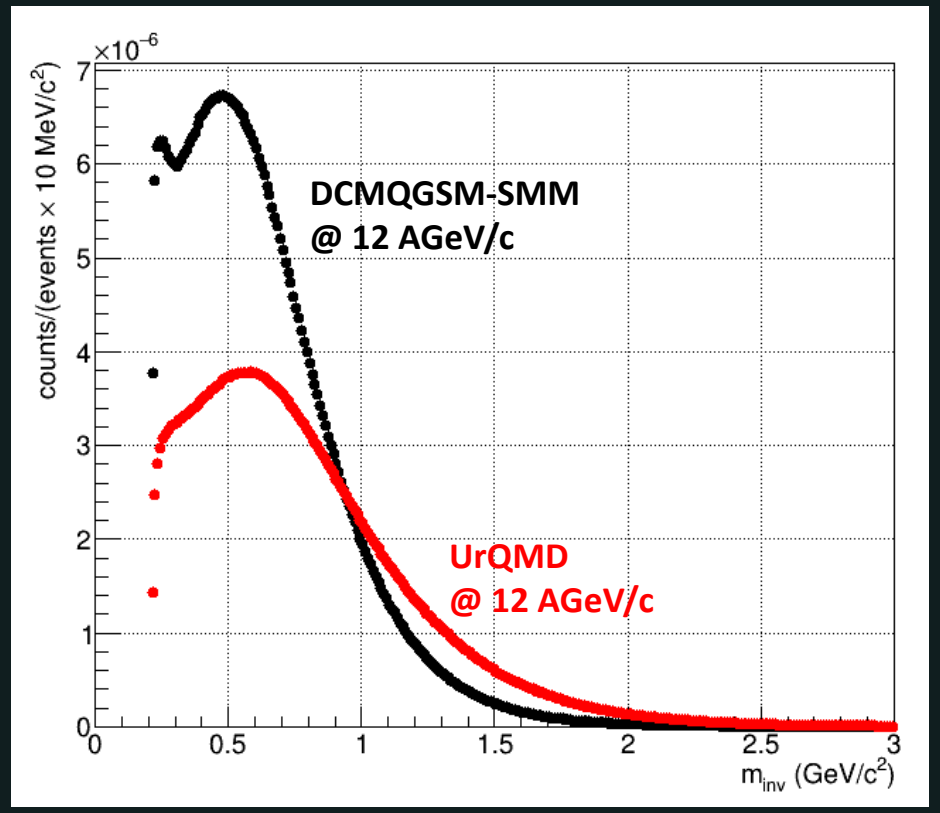


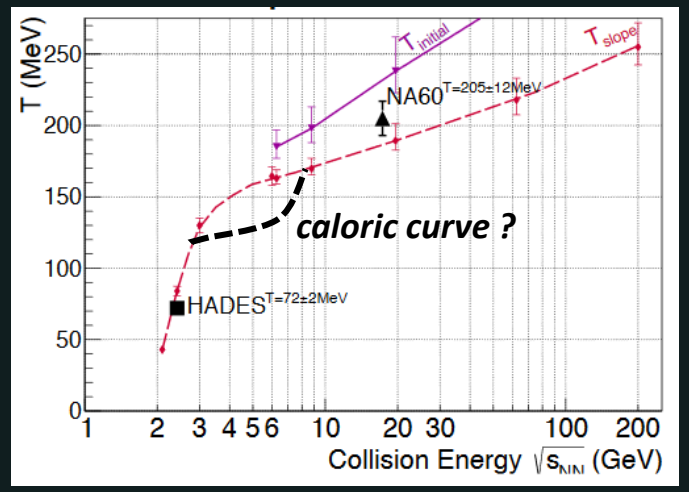
Robustness of ANN

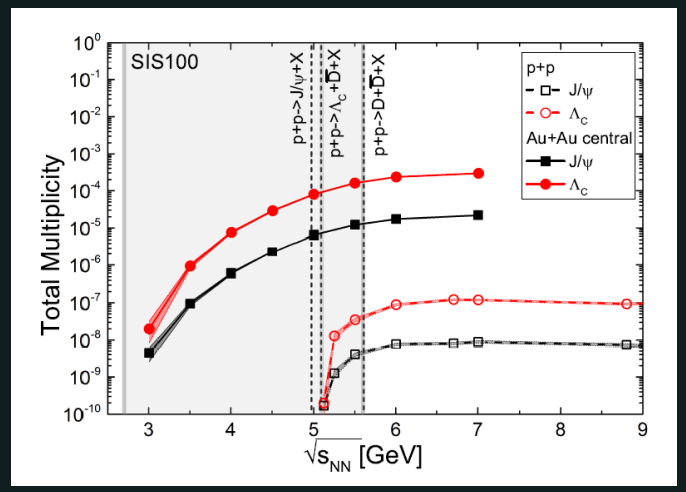
- ANN was trained using for UrQMD+PLUTO+GEANT3
- The output weights were used for DCMQGSM-SMM+PLUTO+GEANT4

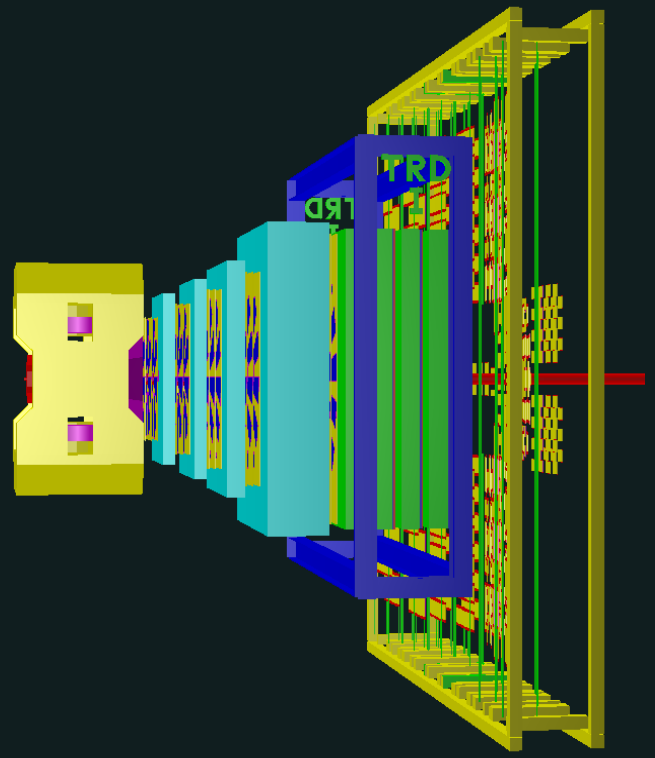
ANN cuts	ε_ω %	$\frac{\omega}{\text{background}}$ ratio	norm. significance
from training of DCMQGSM-SMM with G4	**1.0**	**0.018**	**1**
from training of UrQMD with G3	**1.0**	**0.018**	**0.98**

reconstructed background using the same set of manual cuts





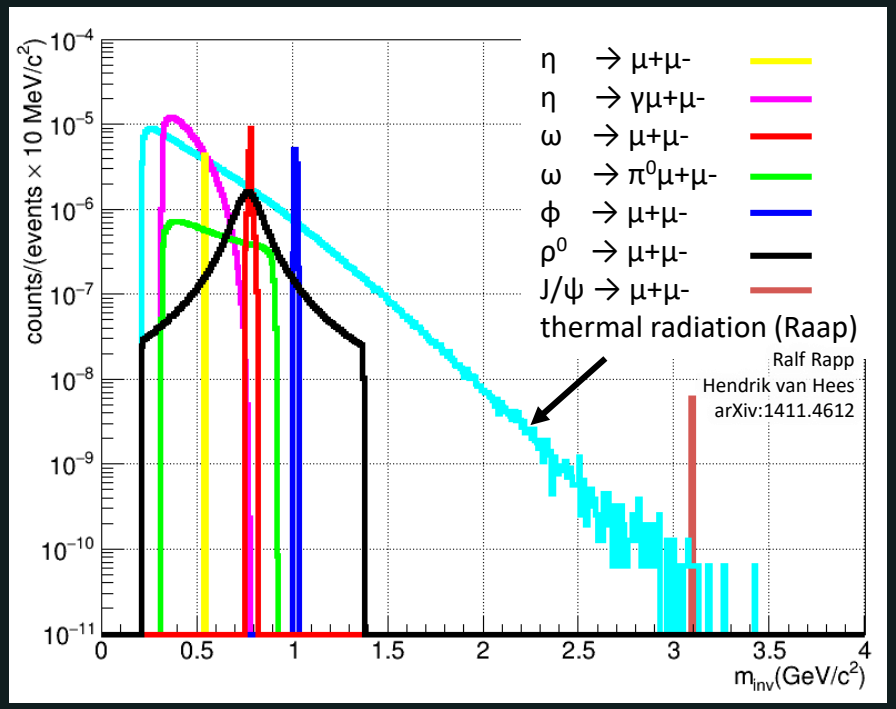




ANN for physics performance

Simulation input for Au+Au @ 8 AGeV/c

- Dimuon signals – PLUTO
  - empirical angular-distribution parametrizations for selected processes
  - resonance excitation in hadronic interactions
  - nucleon-nucleon elastic scattering

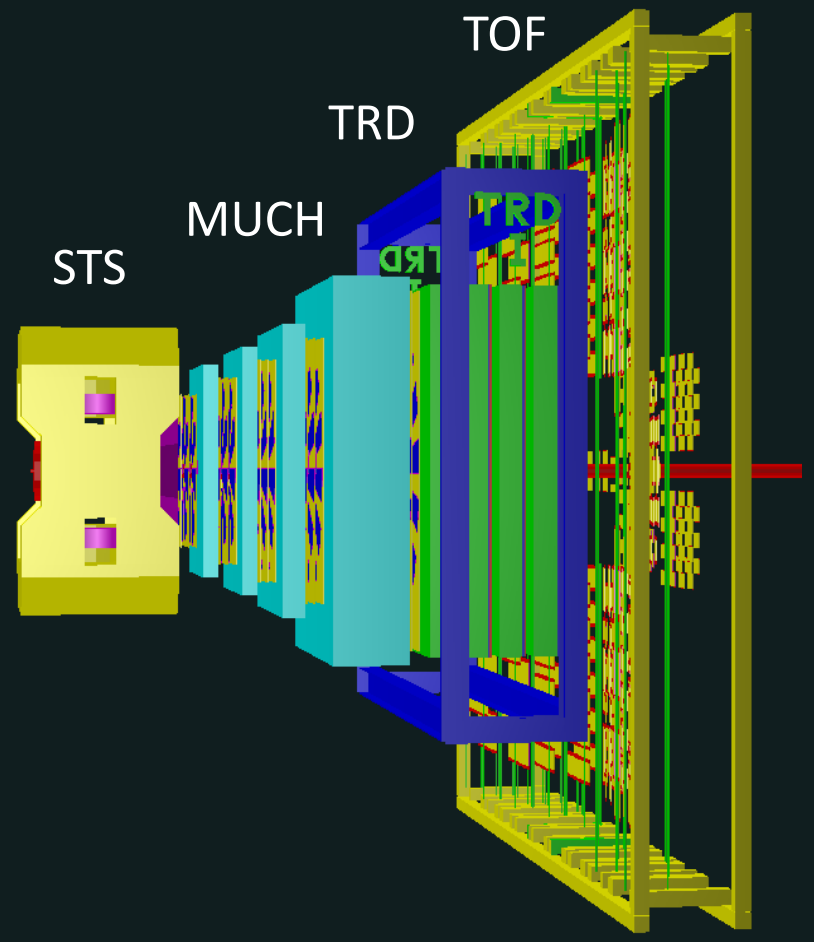


- Multiplicities from Thermal-FIST and UrQMD

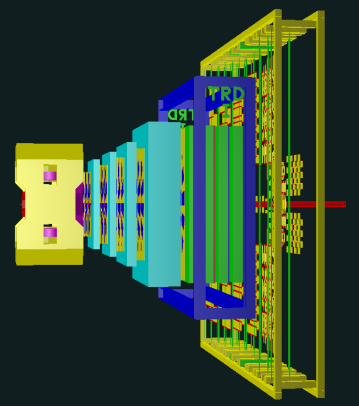
- Background – UrQMD
  - low and intermediate energies ($\sqrt{s}$<5 GeV): the interactions between known hadrons and their resonances
  - high energies ($\sqrt{s}$>5 GeV): excitation of colour strings and their subsequent fragmentation into hadrons

Reconstruction steps

- CBM setup with thick absorber for measurements of intermediate and high dimuon mass regions
- Track, momentum and vertex reconstruction in STS
- Track extrapolation through MUCH and TRD up to TOF
- Selection of the μ-track candidates using ANN training for MUCH with thick (1m) absorber

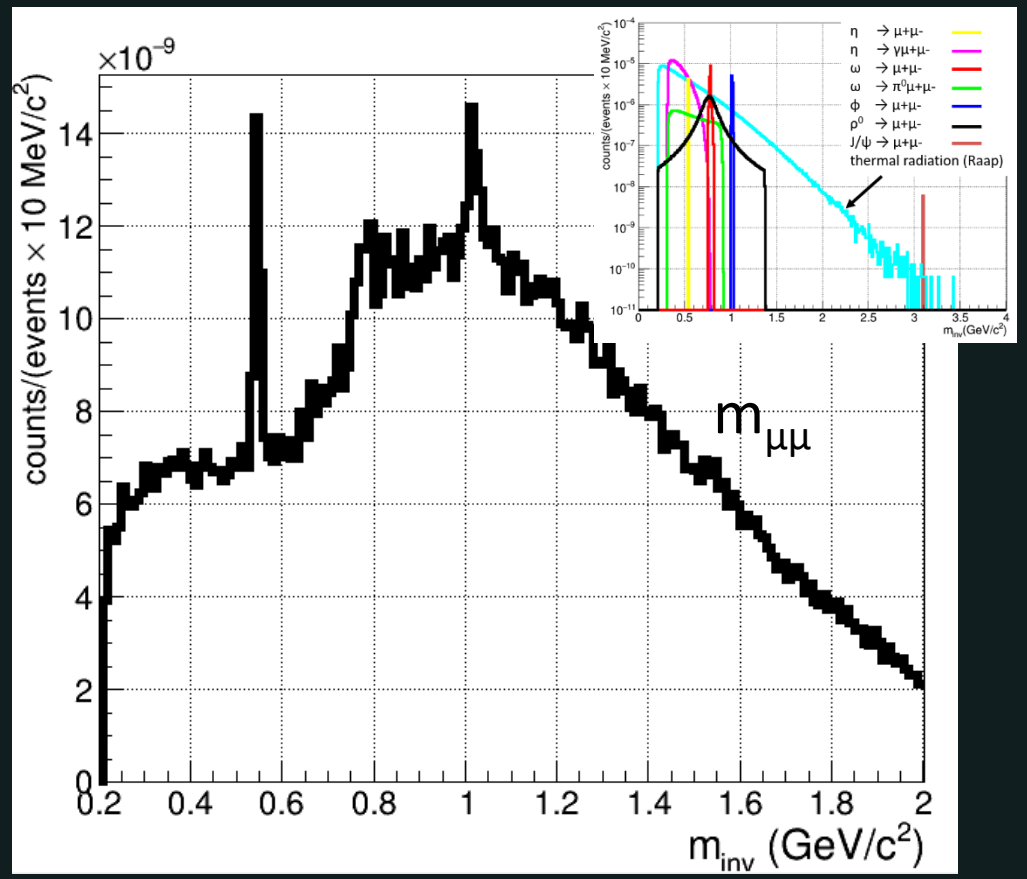


Low and intermediate mass region

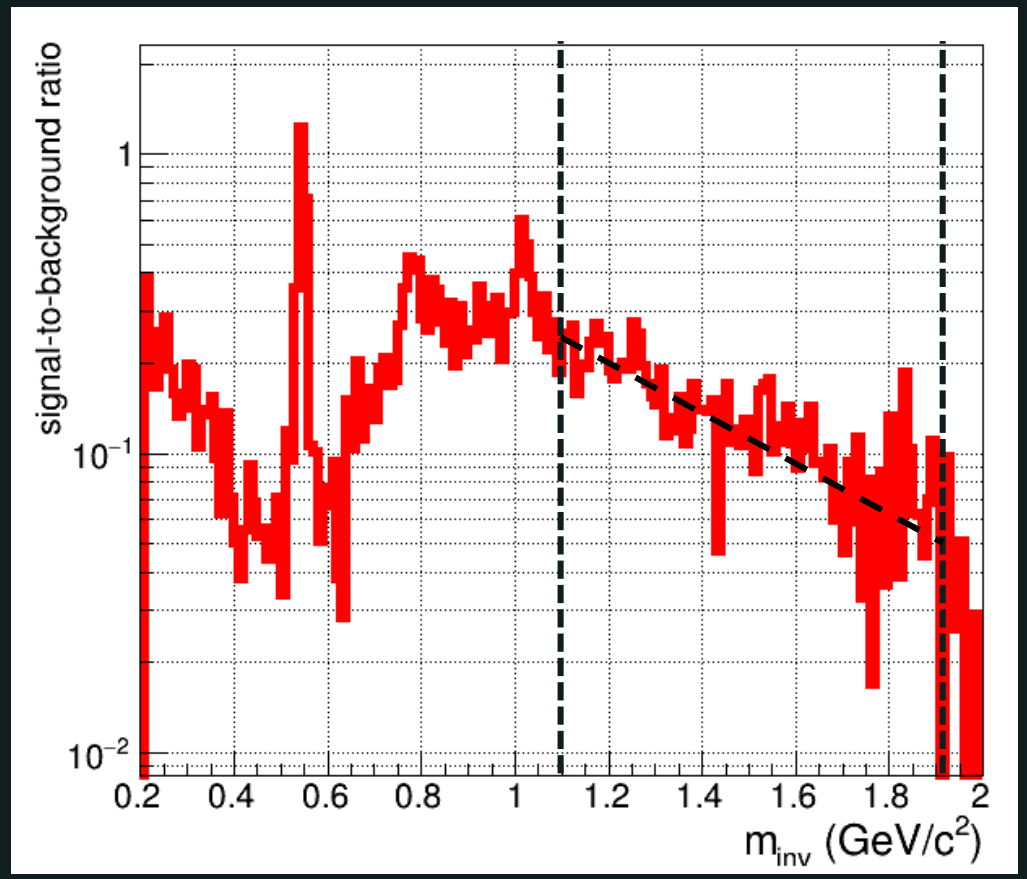


central Au+Au @ 8 AGeV/c with dimuon signals

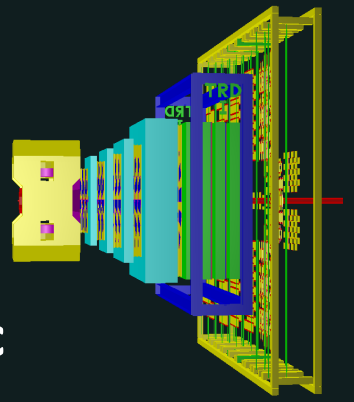
invariant mass



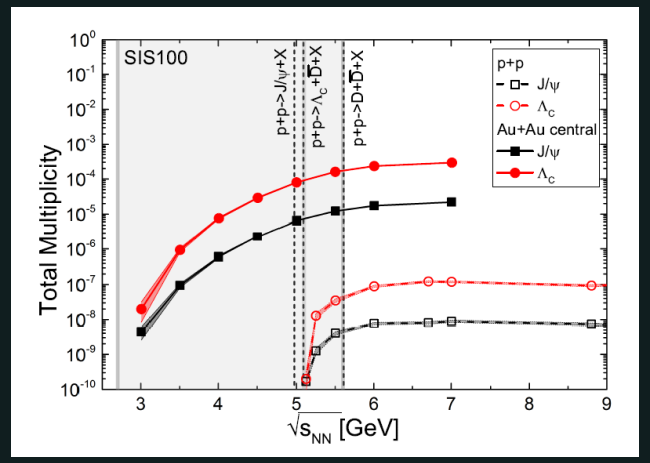
signal-to-background ratio



J/ψ results

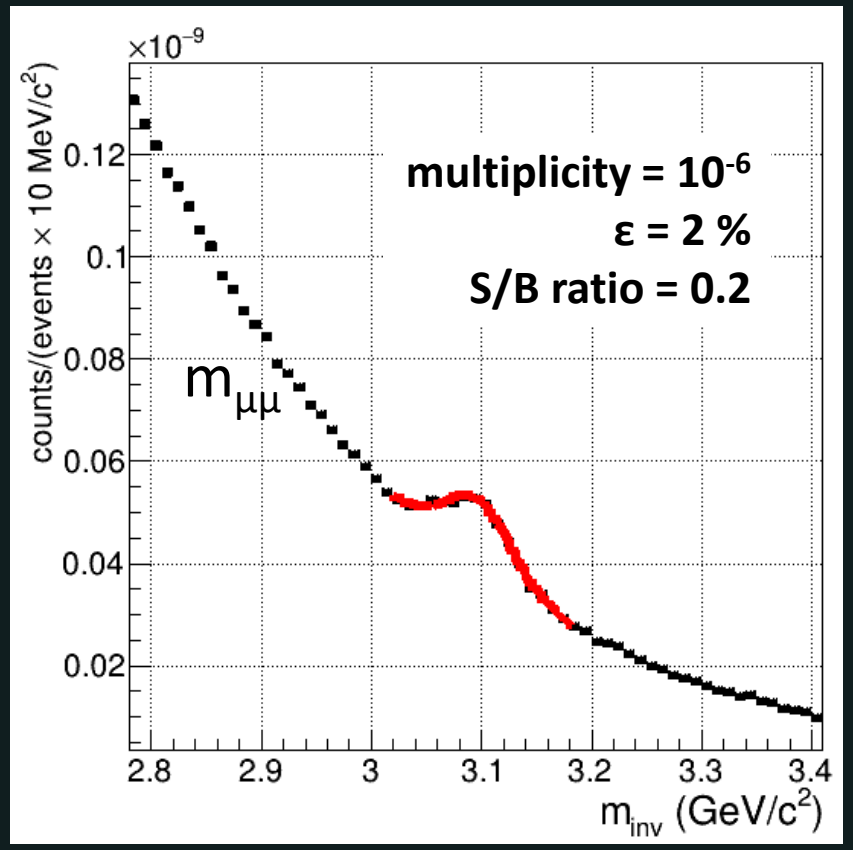


Sub-threshold charm production in nuclear collisions
J. Steinheimer, A. Botvina, M. Bleicher, arXiv:1605.03439

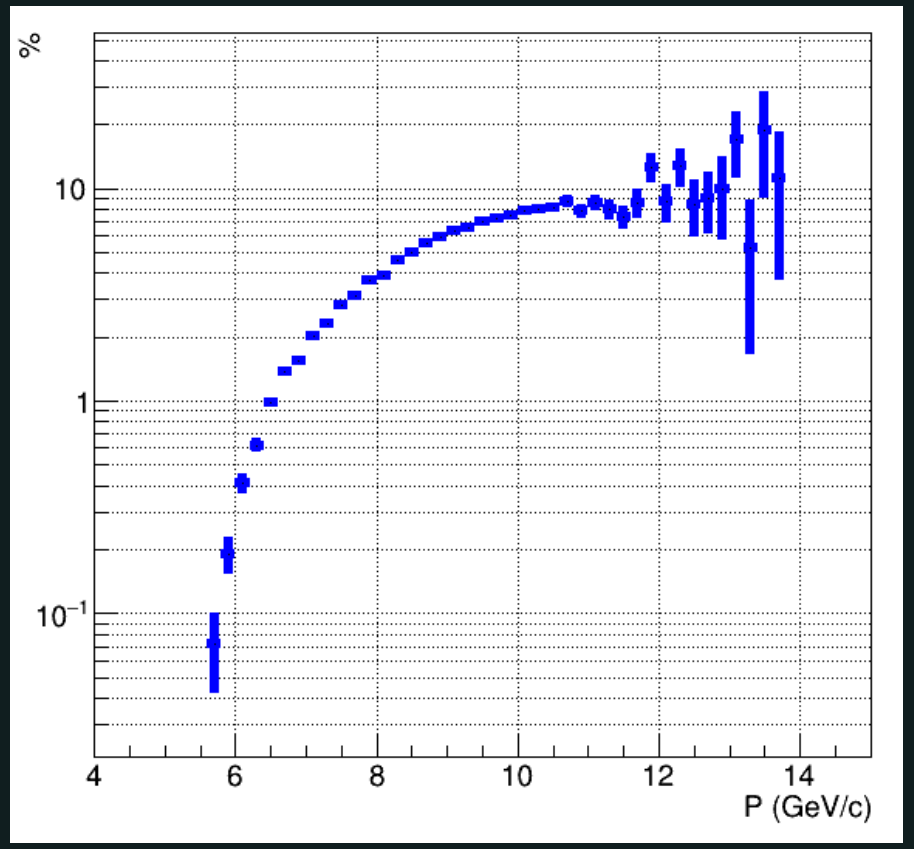


central Au+Au @ 8 AGeV/c

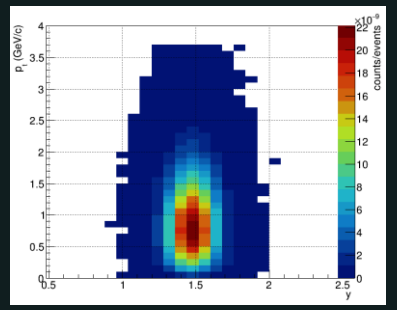
invariant mass



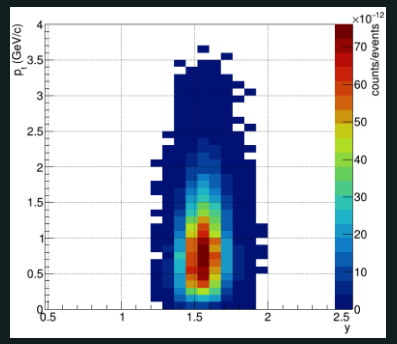
efficiency



PLUTO input



reconstructed J/ψ

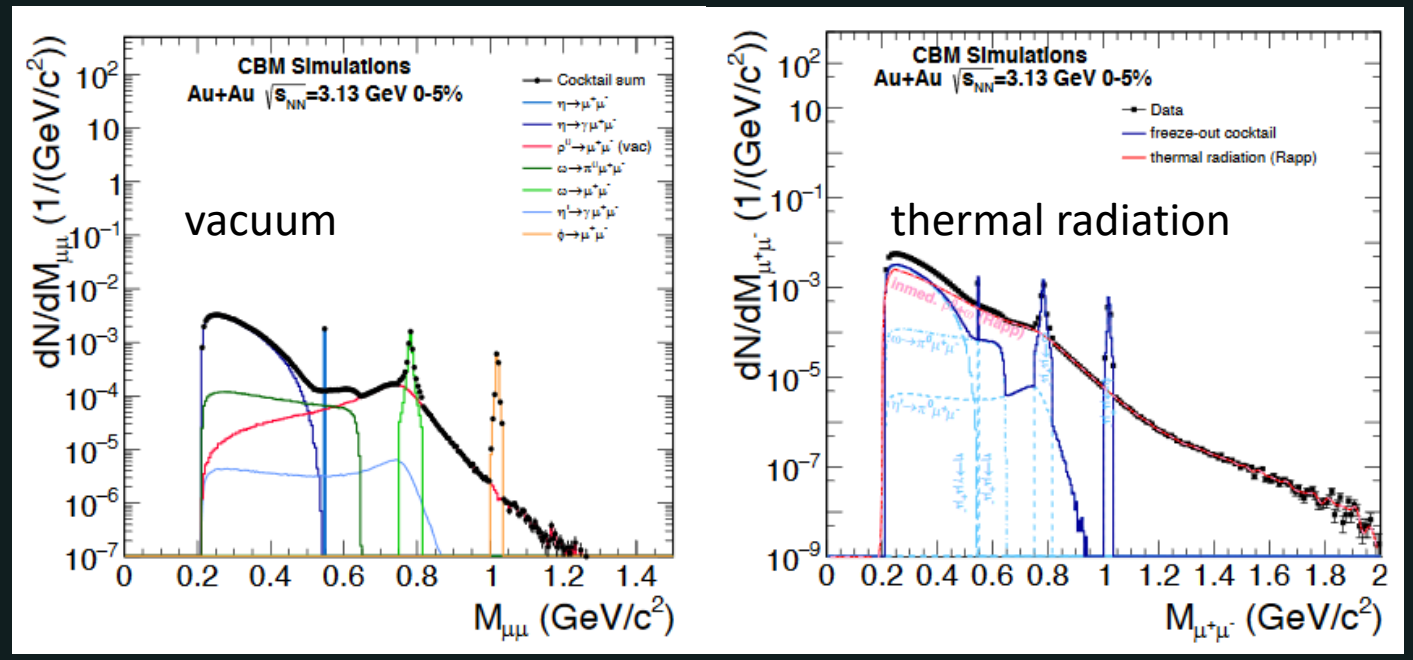


Conclusions

- ANN was successful used for optimization of the selection cuts for muon analysis.
- ANN selection gives 3 times better ω-to-background ratio and 60% better significance for the same ω reconstruction efficiency as with manual set of cuts.
- The set of weights produced using ANN for simulation setup UrQMD+PLUTO+GEANT3 was tested for DCMQGSM-SMM+PLUTO+GEANT4. The results are comparable.

Next steps

- Input update
  - PLUTO
  - DCMQGSM-SMM
  - GEANT4



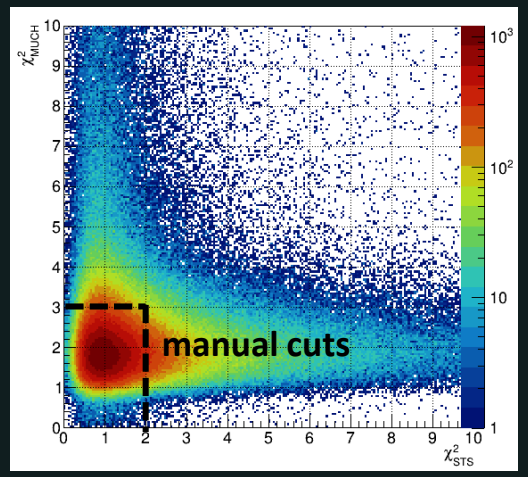
- Signal reconstruction via background subtraction
- Multi-differential analysis

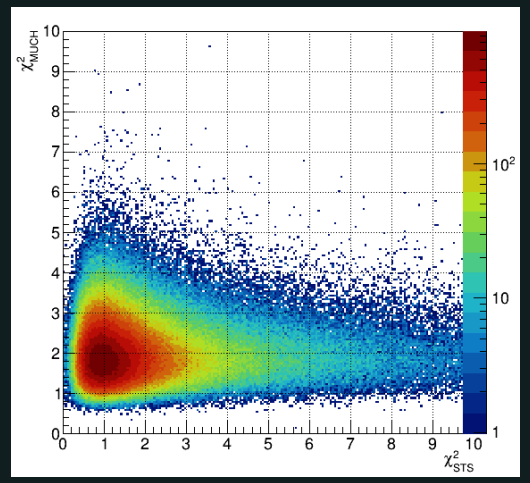
Backup

χ^2_{MUCH} vs. χ^2_{STS}

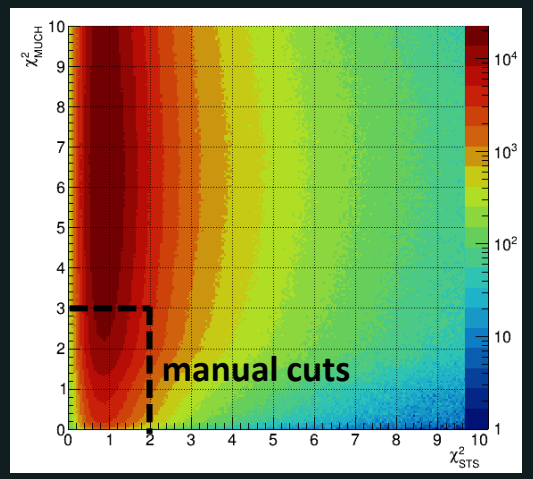
without selection | **ANN PID**

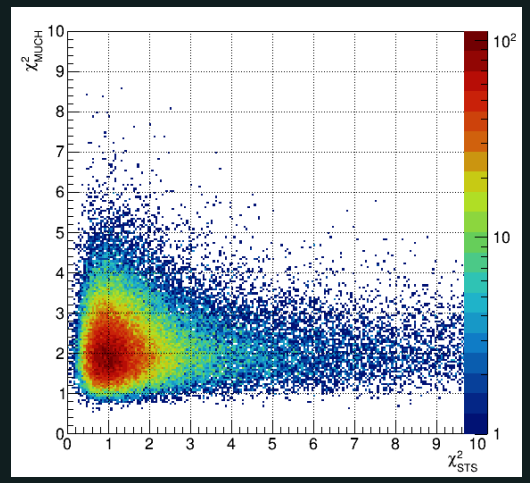
μ from J/ψ



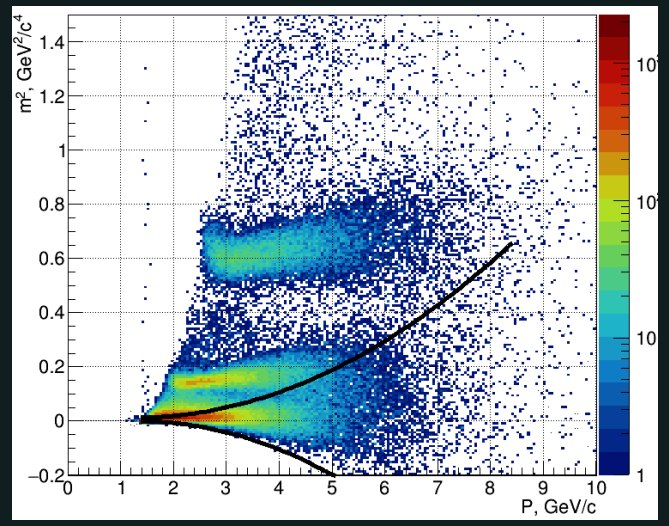


background

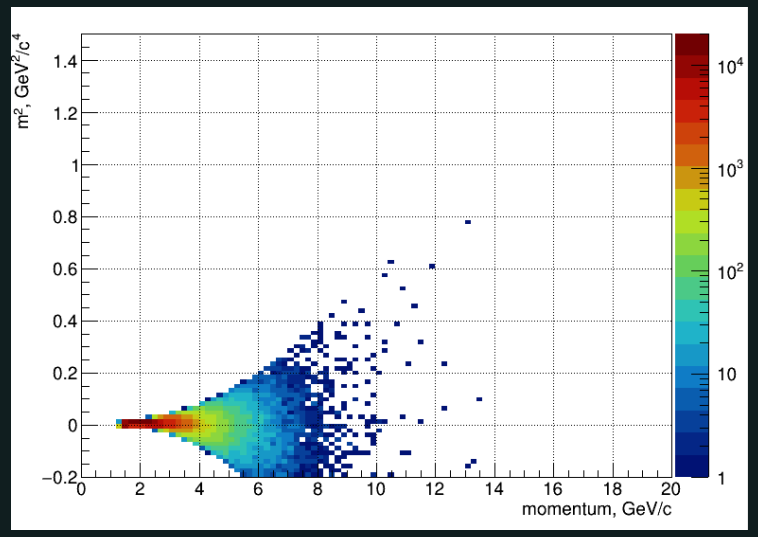




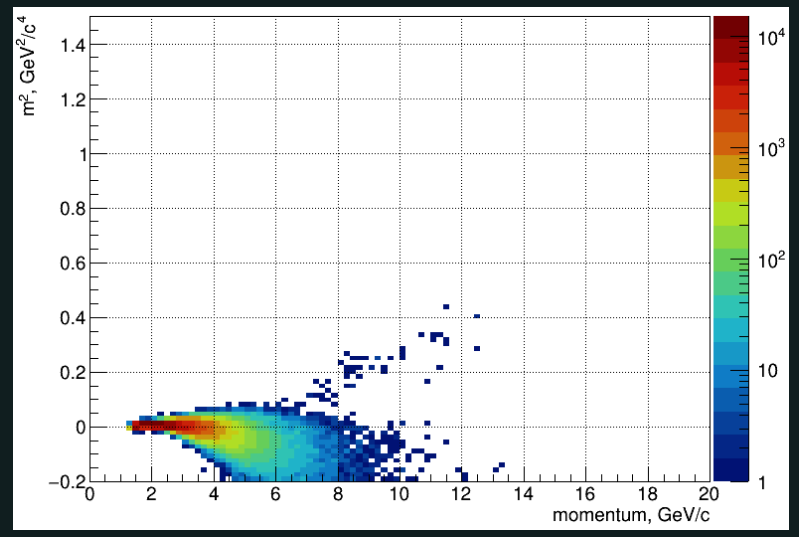
Selection of μ^+_ω



manual cut from fit



cut from ANN



Track reconstruction

- STS track reconstruction (general for all physics cases). The π-mass hypothesis (m_π = 139.57018(35) MeV/c^2) will be used for:
  - track finder procedure;
  - momentum reconstruction;
  - primary vertex reconstruction.
- Extrapolation of the STS reconstructed tracks through downstream detectors (MUCH, TRD, TOF). The μ-mass hypothesis (m_μ = 105.6583755(23) MeV/c^2) will be used for calculation of energy loss of particles in thick materials (absorbers in MUCH), see Bethe-Bloch equation.
- The primary tracks passing through all detector subsystems will be selected as muon track candidates.