CZECH PARTICIPATION AT FACILITY

FOR ANTIPROTON AND ION RESEARCH (FAIR)

Neutral mesons flow and yields in AgAg@1.58 A Gev at HADES

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EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

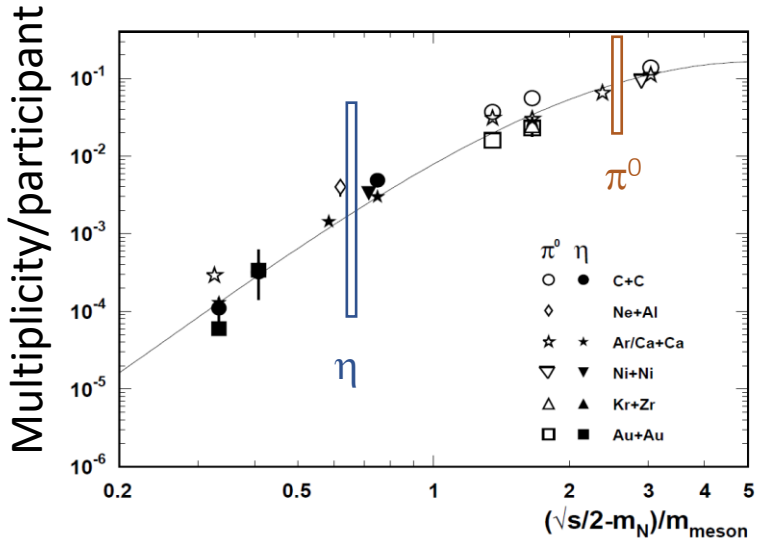
MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Outline

- Motivation : Equation of State
- HADES overview with ECAL
- Data analysis and calibration
- Neutral pion yields
- Flow

Motivation

- Study of particle production from fireball and constrains of EOS
- Neutral meson production important observable to study reaction mechanism
- With ECAL -> studying of various reaction channels with photons (e.g. hyperons)
  - π^0/ η-> $\gamma\gamma$



**Phys.Rec. C67 (2003) 024903

Equation of state

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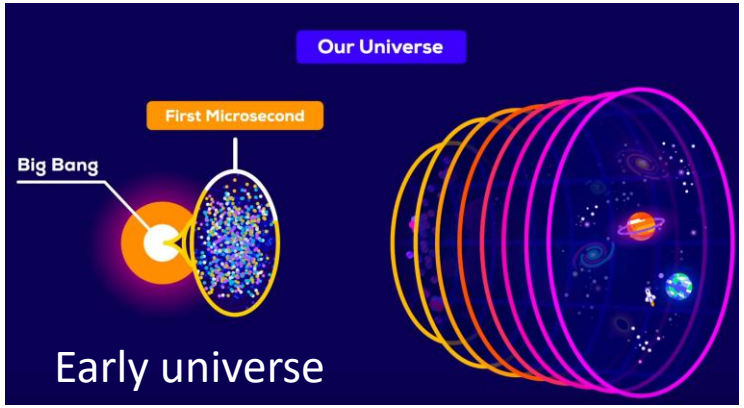

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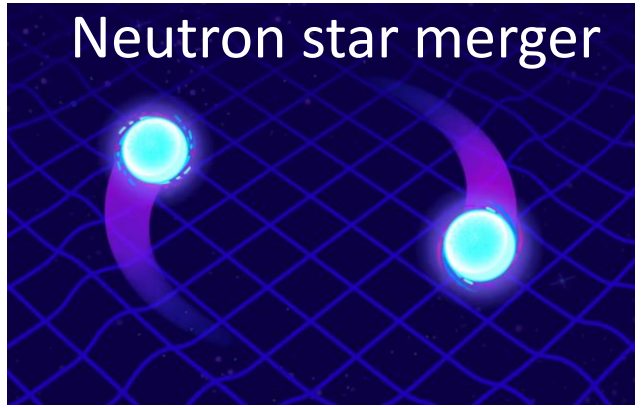
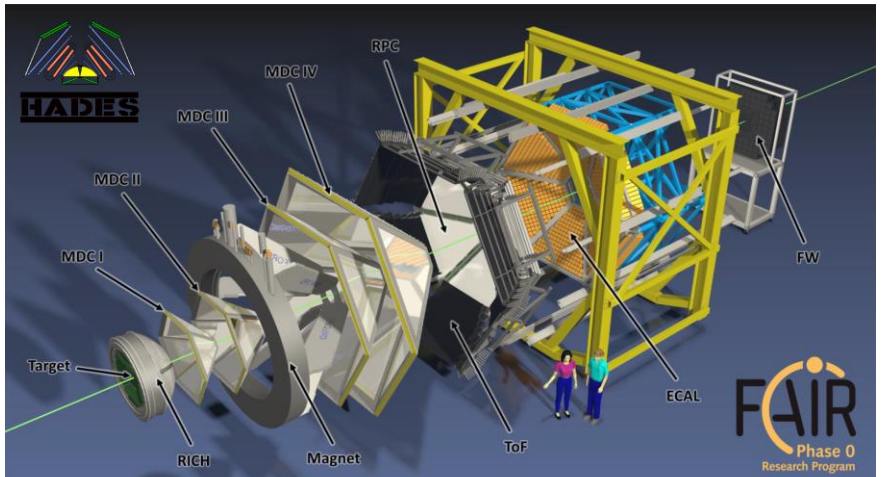
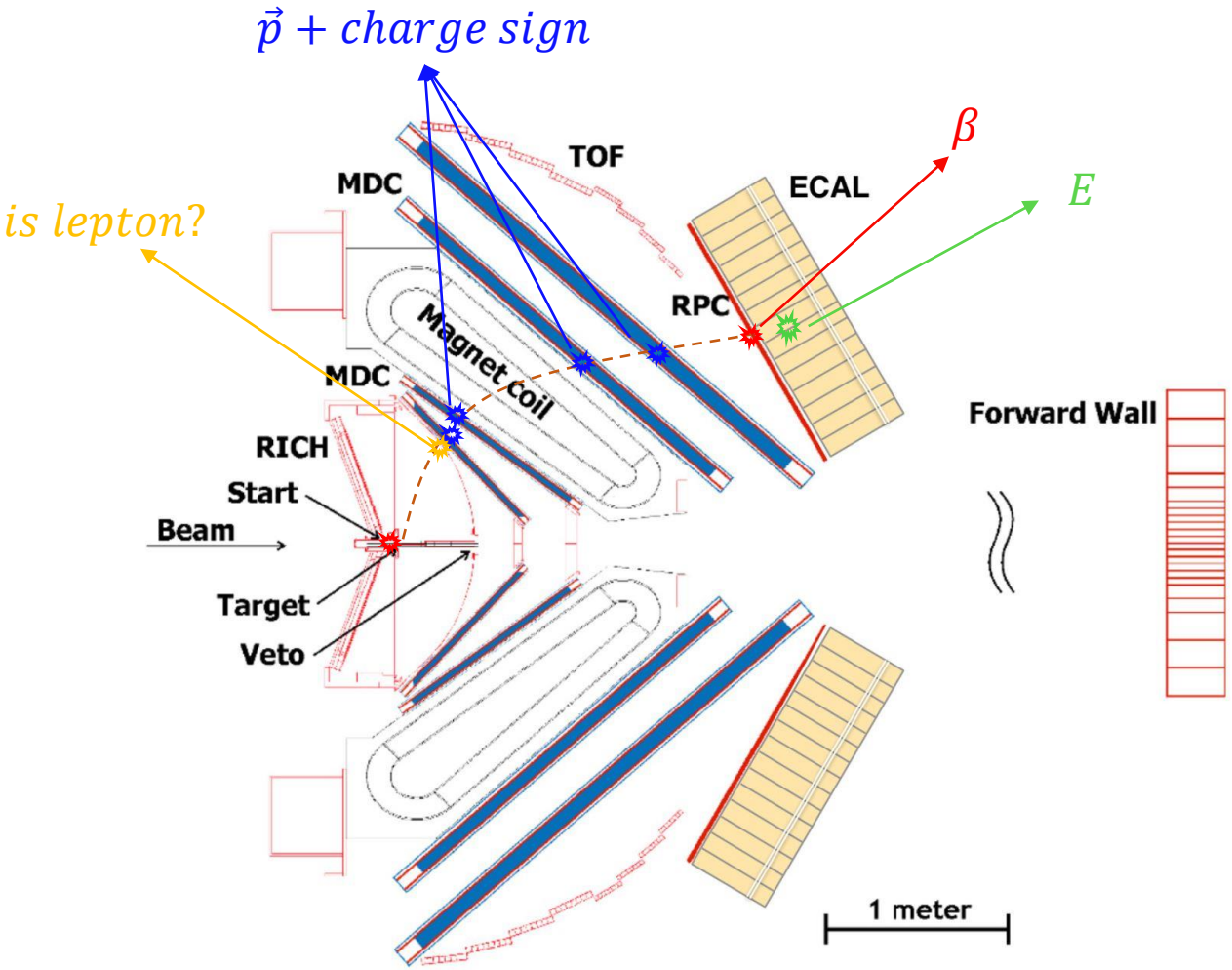


* kurzgesagt.org

High Acceptance Di-Electron Spectrometer

- Fixed target experiment at SIS18 (GSI, Germany)
- Almost full azimuthal angle and polar angles between 18° and 85° covered
- RICH – for identifying leptons
- MDC – for tracking
- ECAL – for electron + photon energy
- TOF+RPC – velocity





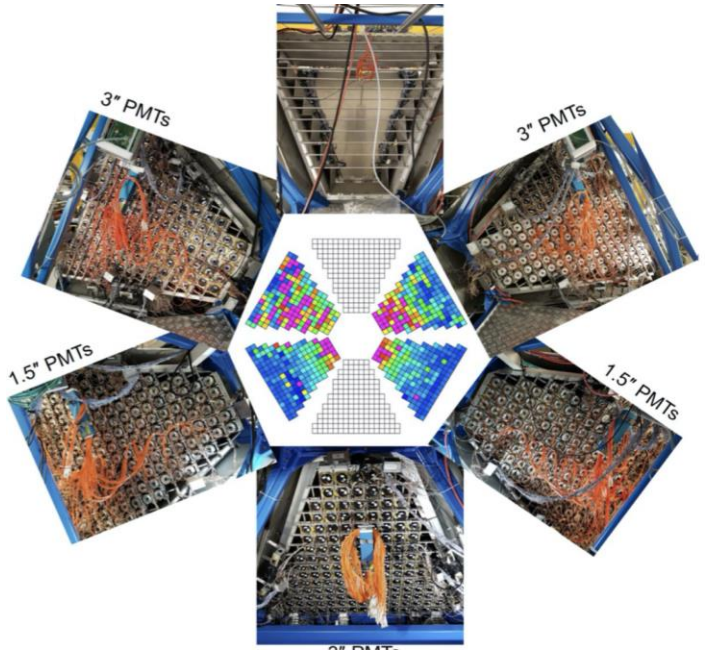
HADES vertical cross section

Ag+Ag@1.58 A GeV beam time 2019 and perfomance

March 2019 → Ag+Ag@1.58AGeV → 14 billion events

π^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
2γ	(98.823±0.034) %	S=1.5	67
$e^+ e^- \gamma$	(1.174±0.035) %	S=1.5	67
γ positronium	(1.82 ±0.29) × 10^{-9}		67
$e^+ e^+ e^- e^-$	(3.34 ±0.16) × 10^{-5}		67
$e^+ e^-$	(6.46 ±0.33) × 10^{-8}		67

ECAL in 2019



- Collected about **14 billion events** in **Ag+Ag@1.58A GeV** experiment in March 2019
- New electromagnetic calorimeter **ECAL** is based on lead-glass modules -> detection of direct photons
- **ECAL** was used for the first time
  - 4 sectors were installed in March 2019
  - by end of 2022 – full setup

Phase space and event characterization

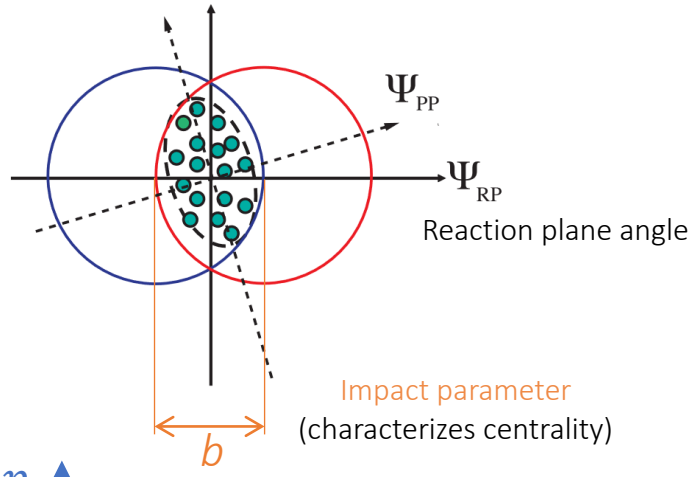
Rather than describe particle distribution, or phase space, in radial momentum coordinates with 3 variables, one can make a use of symmetry in an azimuthal angle and use 2 variables instead:

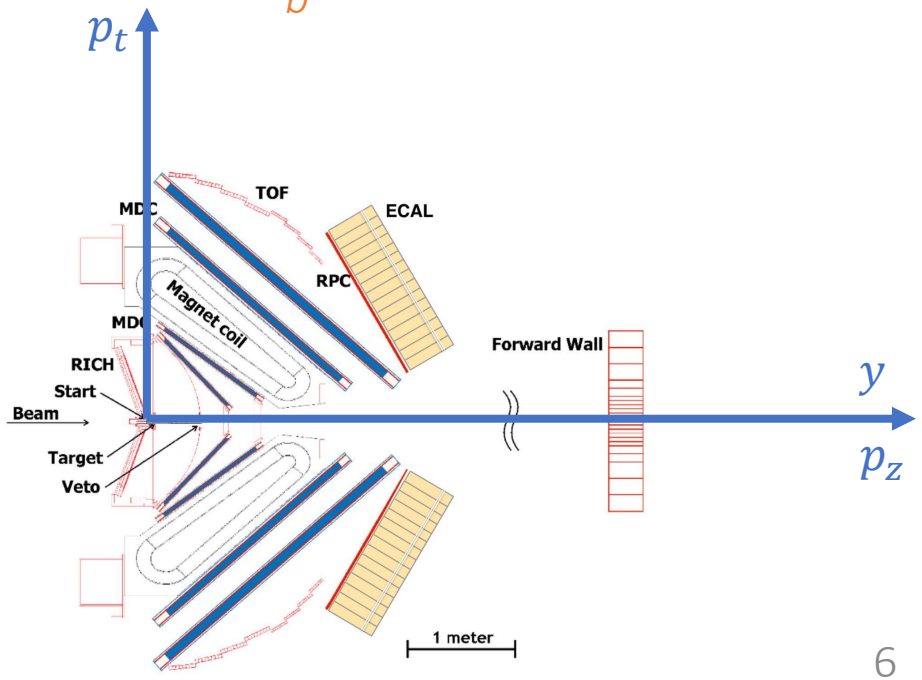
- For azimuthal component : $p_t = \sqrt{{p_x}^2 + {p_y}^2}$

- And along z axis, it is rapidity $y = \ln \frac{E + p_z}{E - p_z}$

which is more usable than velocity β of a particle.

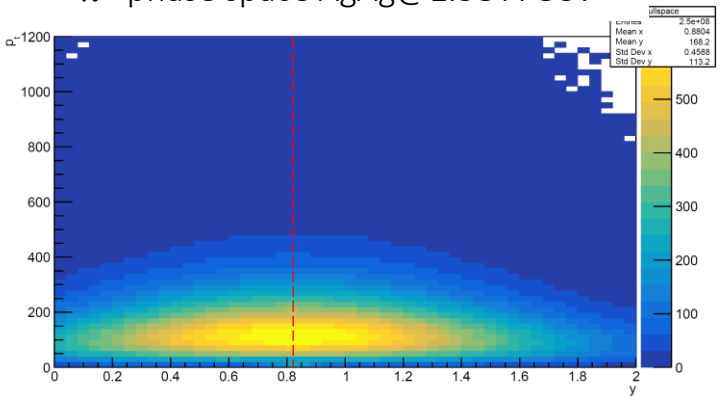
Transverse momentum p_t and a rapidity difference Δy are invariant under Lorentz boosts along z.



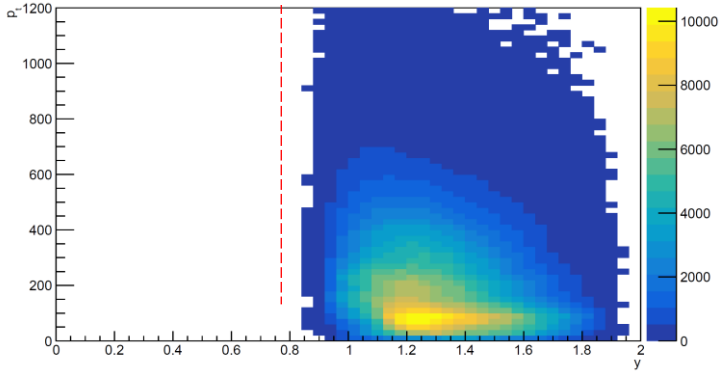


Electromagnetic calorimeter

π^0 phase space AgAg@1.58 A GeV



phase space in acceptance of ECAL

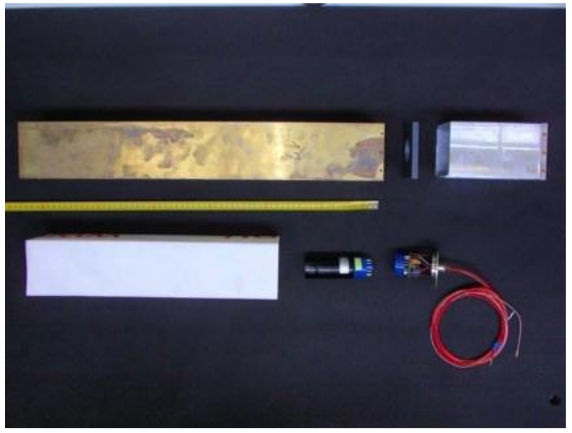


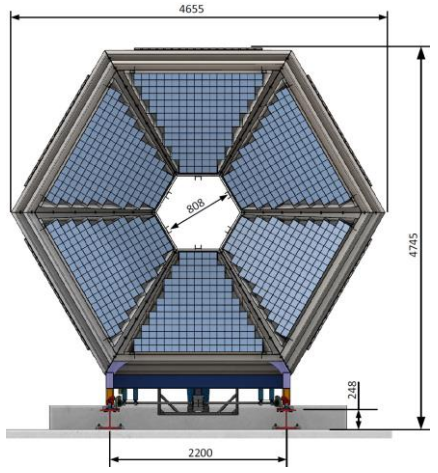
Detectors modules

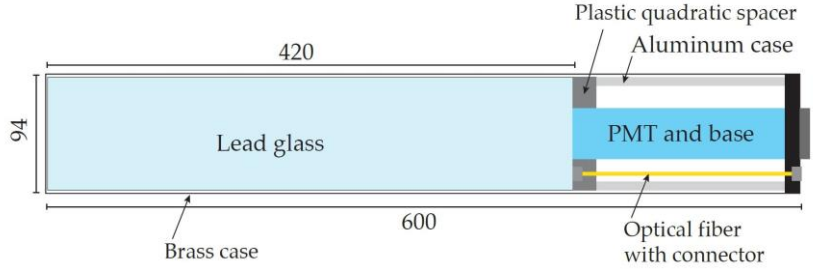
- 6 sectors covering 12˚ < θ < 45 ˚
- Cherenkov lead glass modules from OPAL end cap calorimeter (163 modules x 6 sectors = 978 each 16 kg)
- Module dimenstions : 9.4 x 9.4 x 60 cm^3

PMT read out (with two different types)

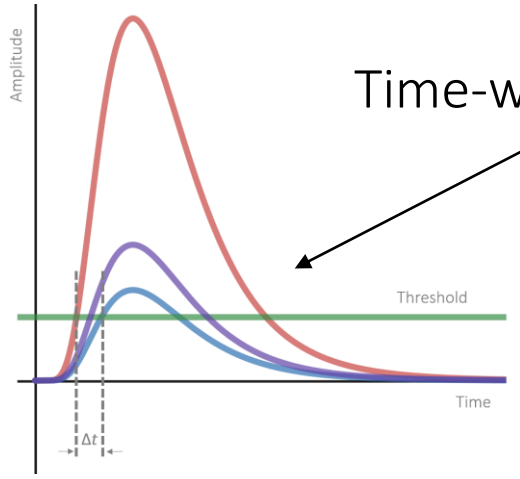
- EMI 9903kB (1.5”)
- Hamamatsu R6091 (3”)







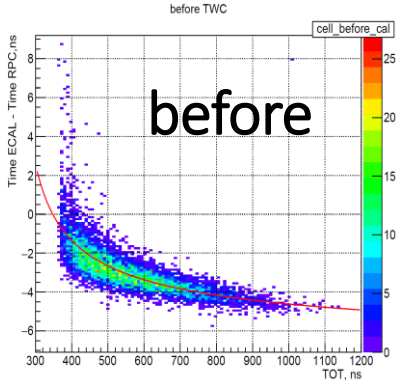
Calibration of ECAL by leptons

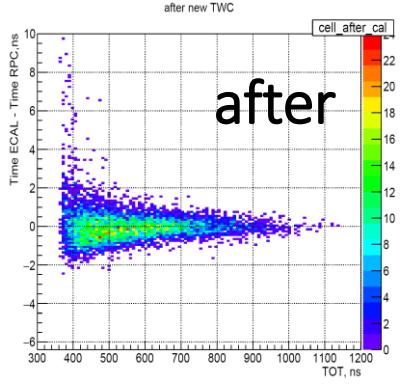


Time-walk effect

leptons develop in ECAL elmg. shower like photons

$$TWC = Time_{\mathrm{ECAL}} - Time_{RPC} = a_0 + \frac{a_1}{\sqrt{TOT - a_2}}$$

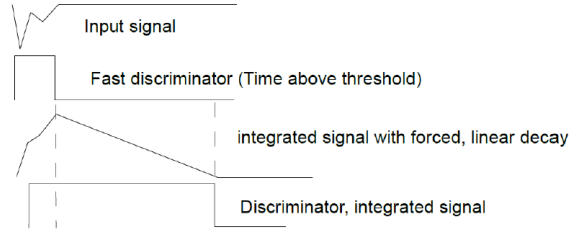




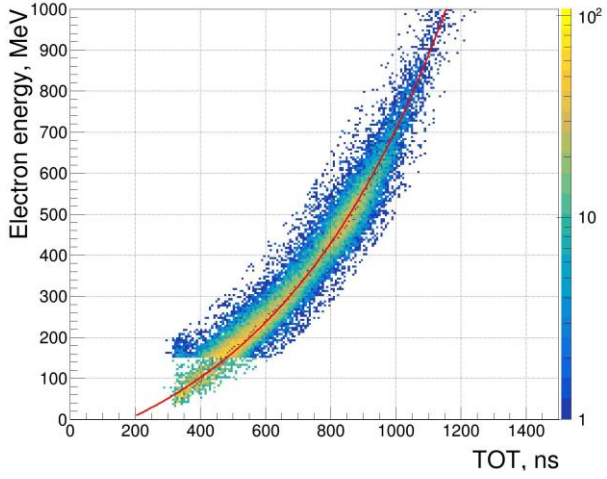
Time precision - 200ps

COME & KISS * : Charge Measurement with an FPGA

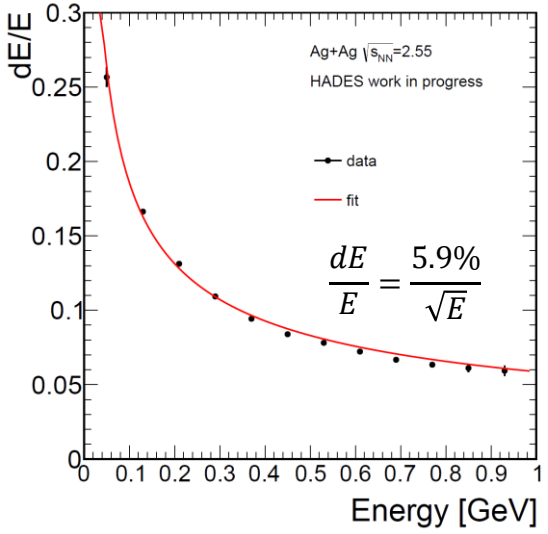
- **Idea:** Modified Wilkinson ADC
- Integrate input signal with a capacitor
- Discharge via a current source
  → fast crossing of zero
- **Q2W**: Measure time to reach zero
  ~Q using an **FPGA-TDC**



$$E = a_0 + \exp(a_1 + a_2 TOT)$$



E ∝ the charge of PMT signal
∝ Time-over-Threshold



Energy precision - 5.9%

* use commercial elements and keep it small & simple

Neutral pion reconstruction via γγ decay

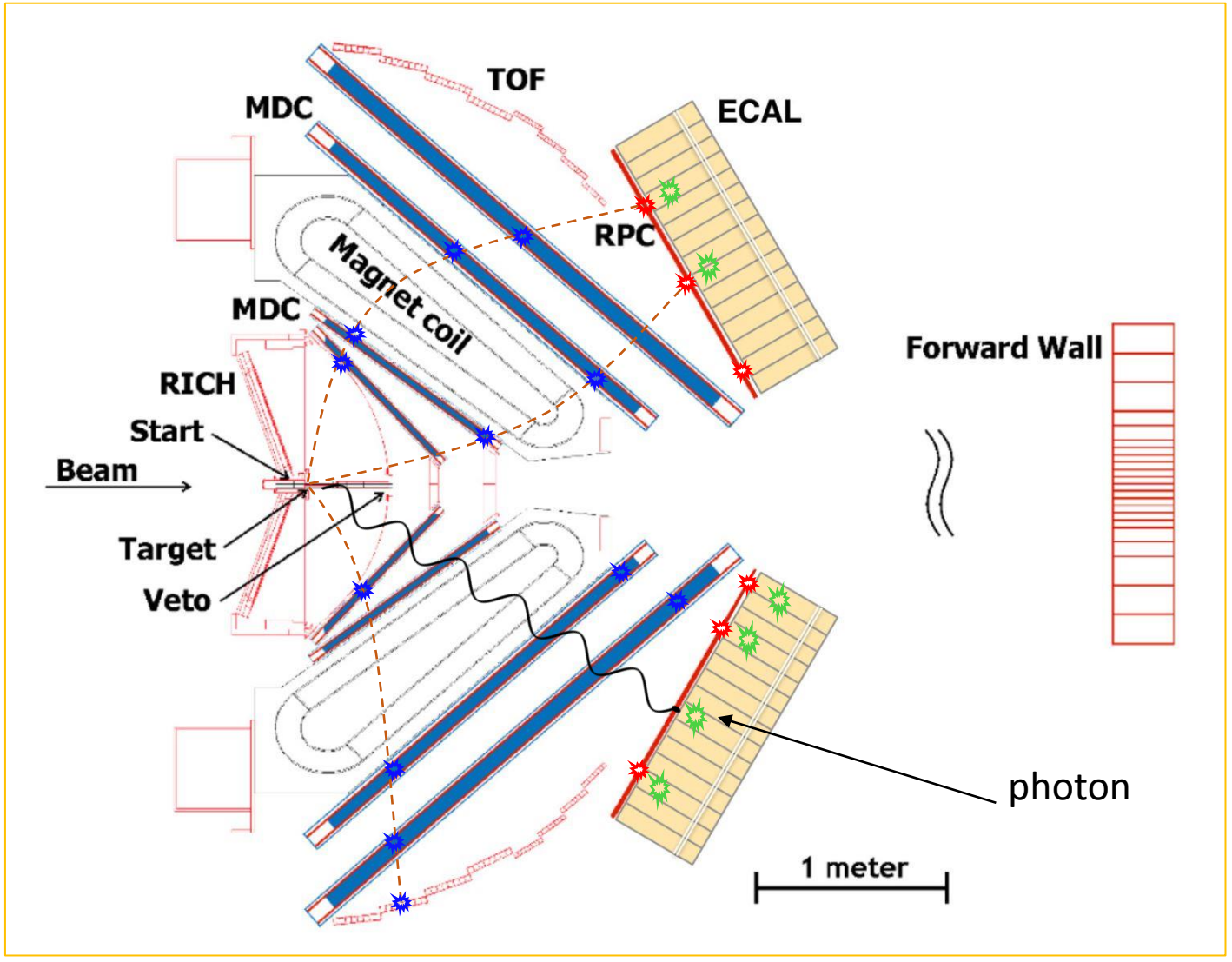
Photon definition :

- No match with charged particle tracks
- No match with charged hit
- Signal in ECAL
  Minimum energy 100 MeV

Photon pair cut:
opening angle θ_{op} cut > 6°

Phase space region:

- $0.1 < y_{cm} < 0.9$ – forward rapidity, almost covering midrapidity
- Access for low p_t region via 2-photon decay reconstruction



Diphoton combinations

Events classification used for mixing:

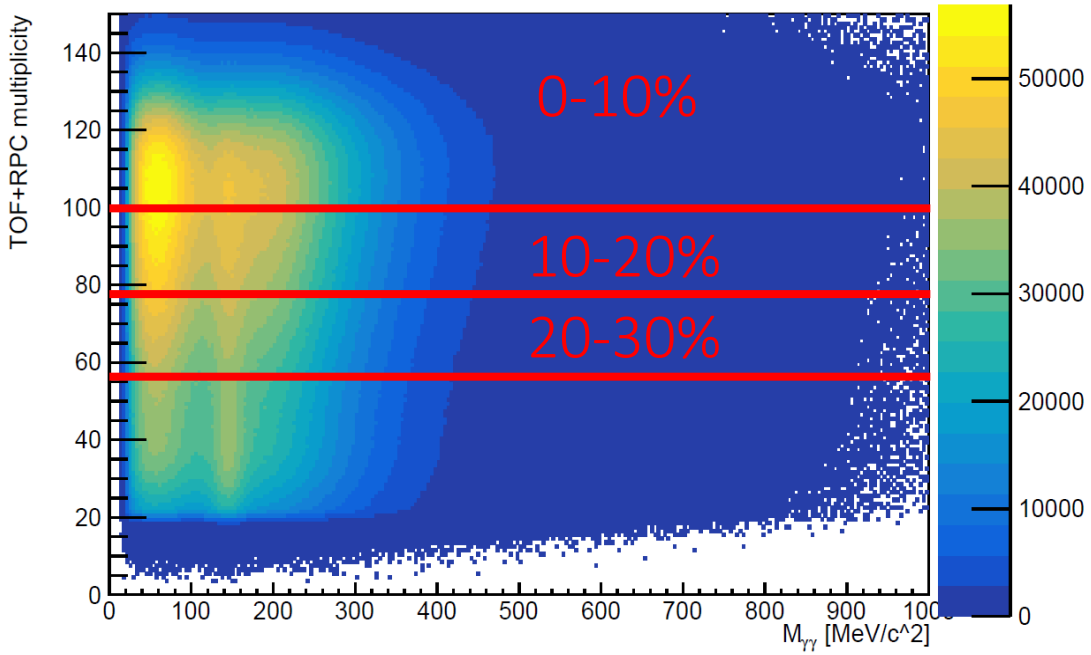
- centrality class
- photon multiplicity
- target segment

All – experimental data

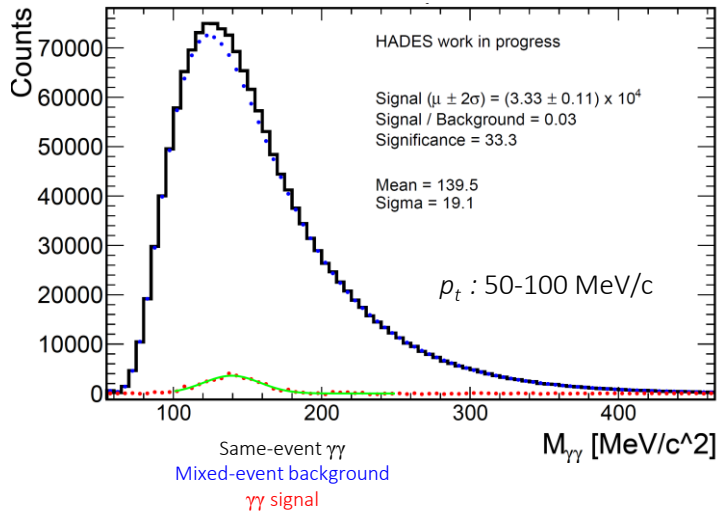
CB – mixed-event combinatorial background

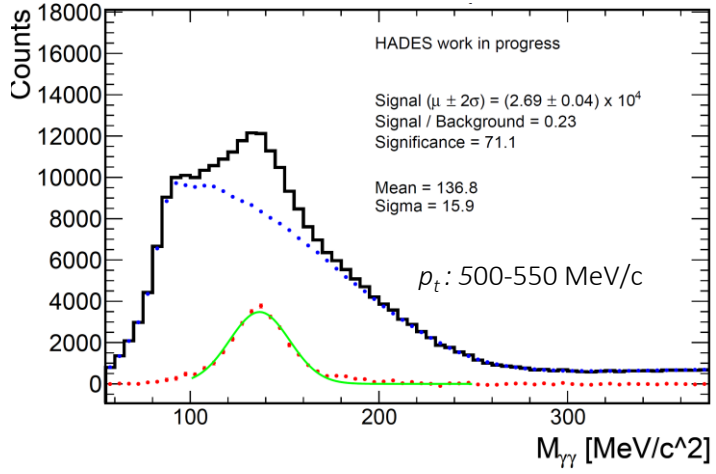
Sig – signal

Centrality



y_{cm} 0.35-0.45, centrality 20-30%





Calibration with pi0 peak position

- Iteration steps:
- For each cell, fill invariant mass distribution, where one photon is in the cell, second – anywhere in ECAL

- Find π_0 peak position by mixed-event CB subtraction

- Calculate correction factor $c_i = (m_{\pi 0} / m_i)^n$

- Recalculate mass with new energies and repeat iterations $E_{corr} = c_i * E_{i-1}$

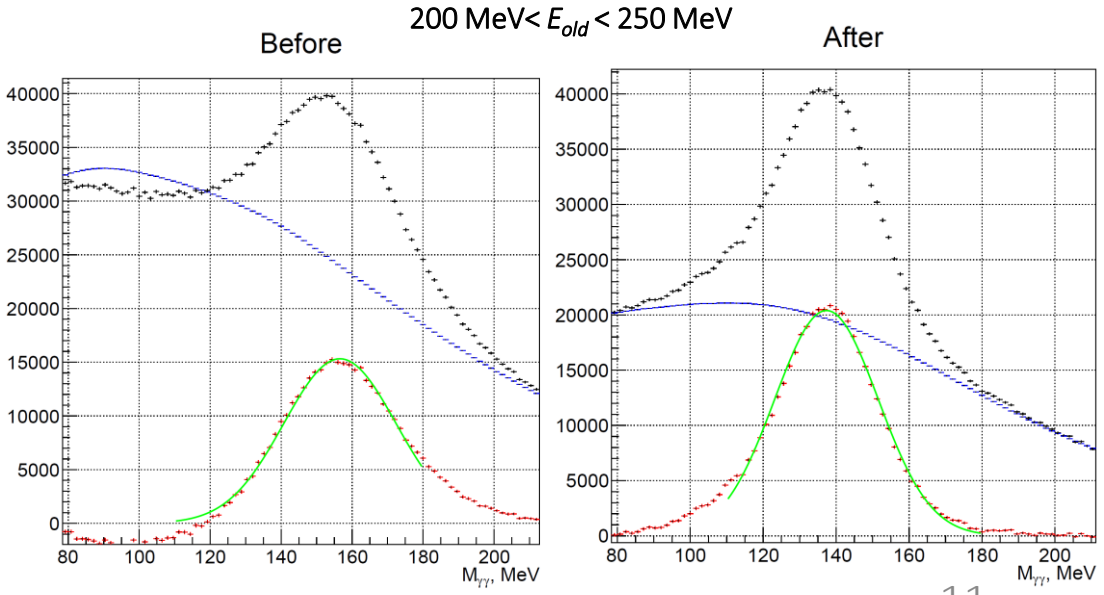
- In this case, $c_i = c_i(E_{old})$

$$m_{\gamma\gamma} = \sqrt{2E_{\gamma,1}E_{\gamma,2}(1-\cos\theta_{12})}$$

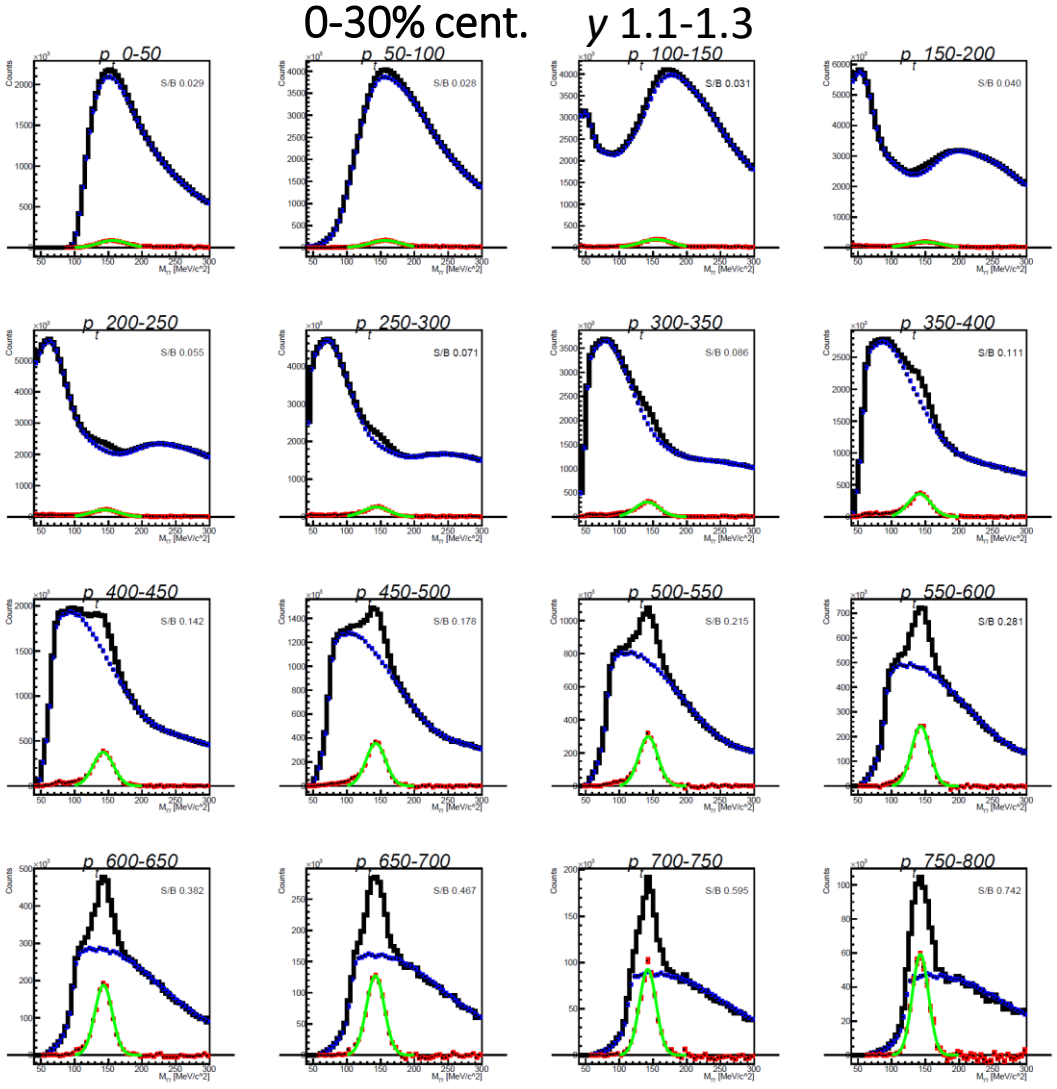
All – experimental data

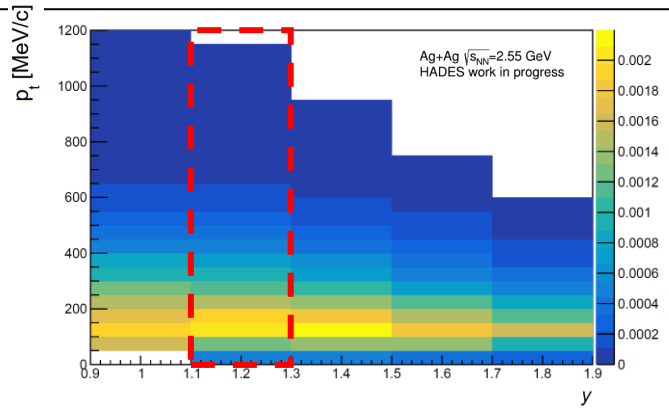
CB – mixed-event combinatorial background

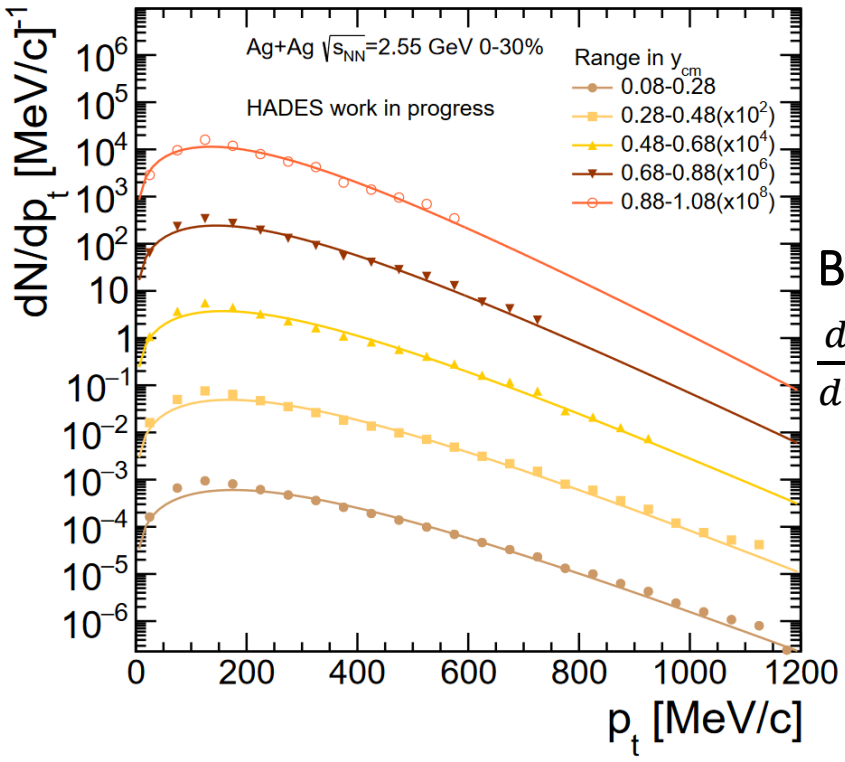
Sig – signal



Multi-differential analysis





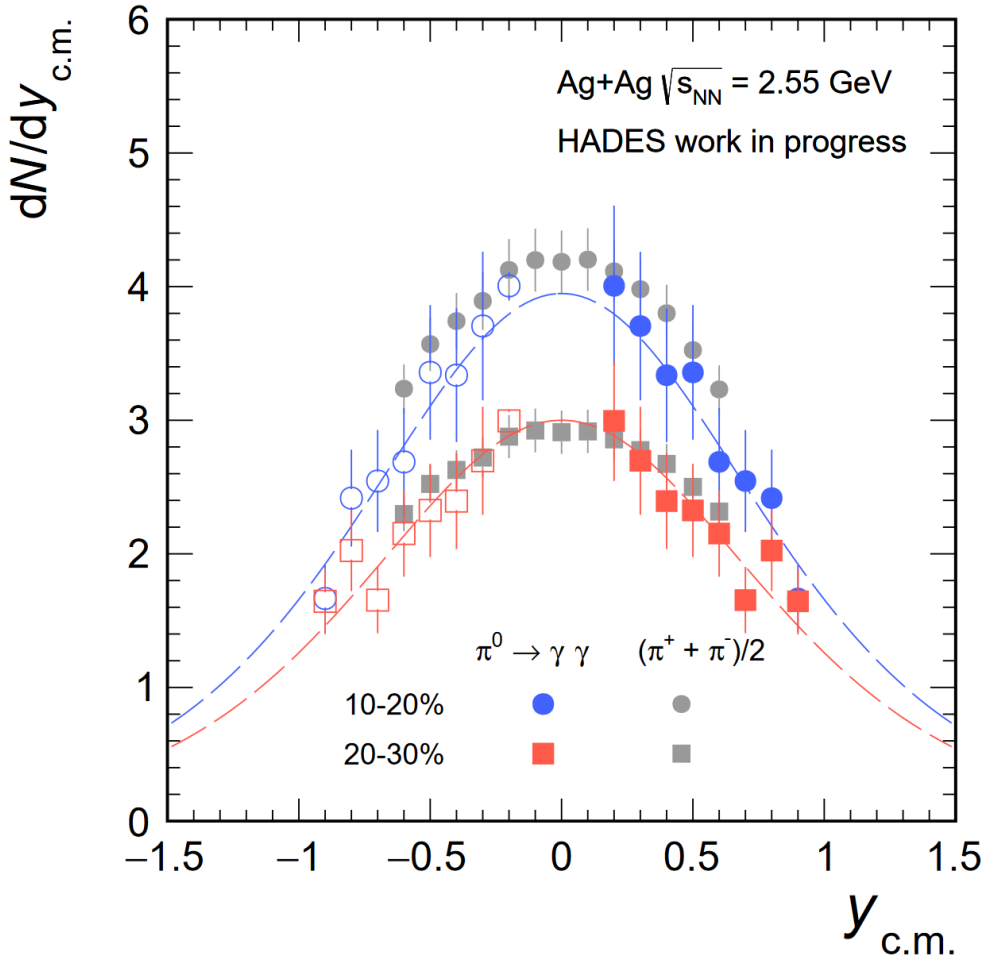


Boltzmann function:

$$\frac{dN}{dp_t} = C\, p_t\, m_t e^{-\frac{m_t}{T}}$$

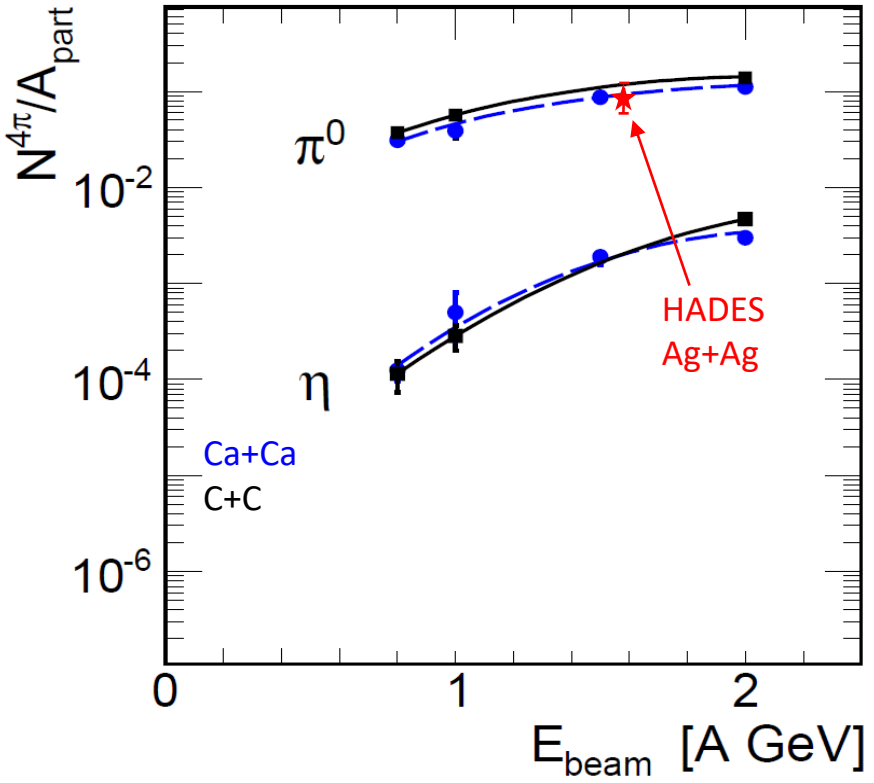
Normalized pion multiplicity comparison for different collision systems

- Comparison with an average of charged pions yields
- Error bars represent the systematic uncertainties
- Quantitative agreement for selected centrality bins
- Most central bin 0-10% is not shown
  - Efficiency with high charged track occupancy is still under investigation



Normalized pion multiplicity comparison for different collision systems

- HADES presented data extrapolated to 4π using model (UrQMD)
- Consistency with world data (TAPS Collaboration)
- Systems are normalized by number of participants

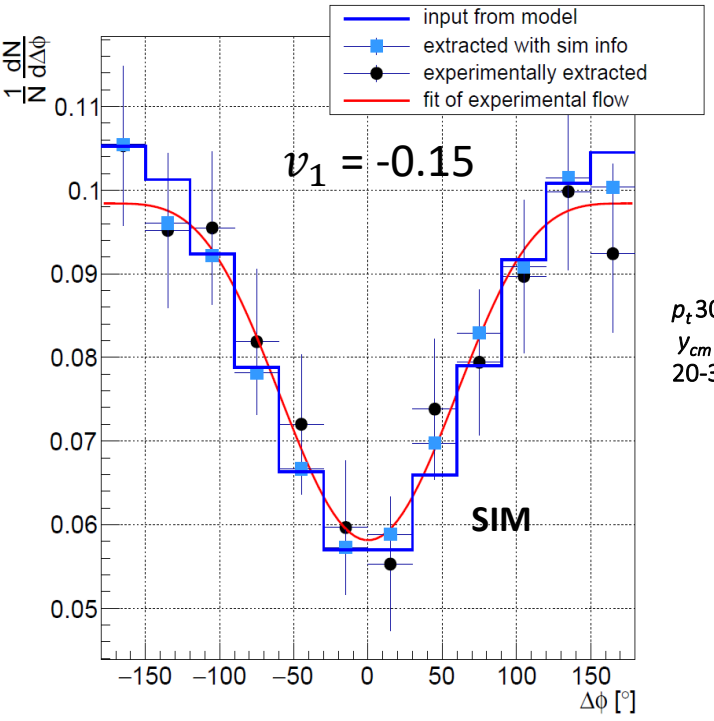


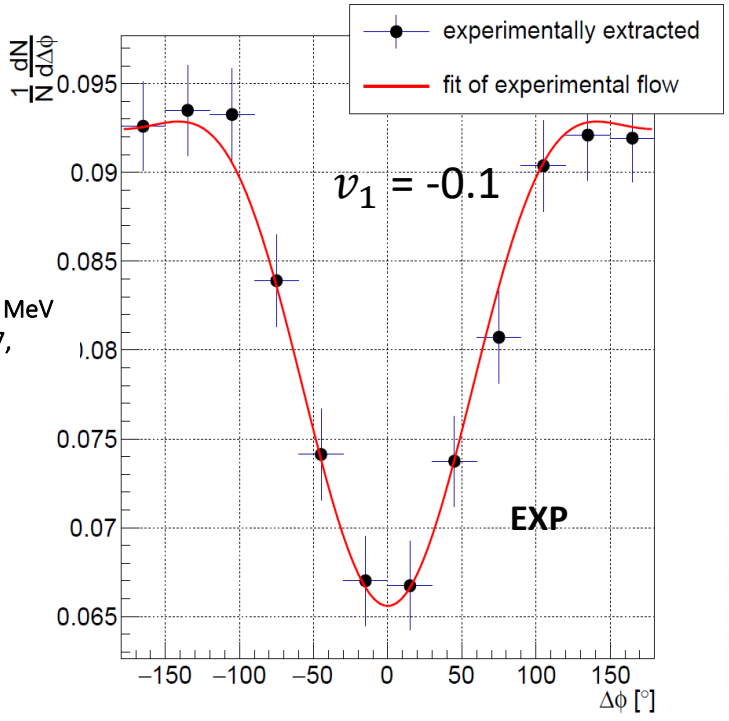
Phys.Rev. C84 (2011) 014902

Directed and Elliptic flow of neutral pion

Fourier decomposition:

$$\frac{dN}{d\Delta\varphi} \sim \left(1 + 2\sum v_n \cos(n\,\Delta\varphi)\right)$$



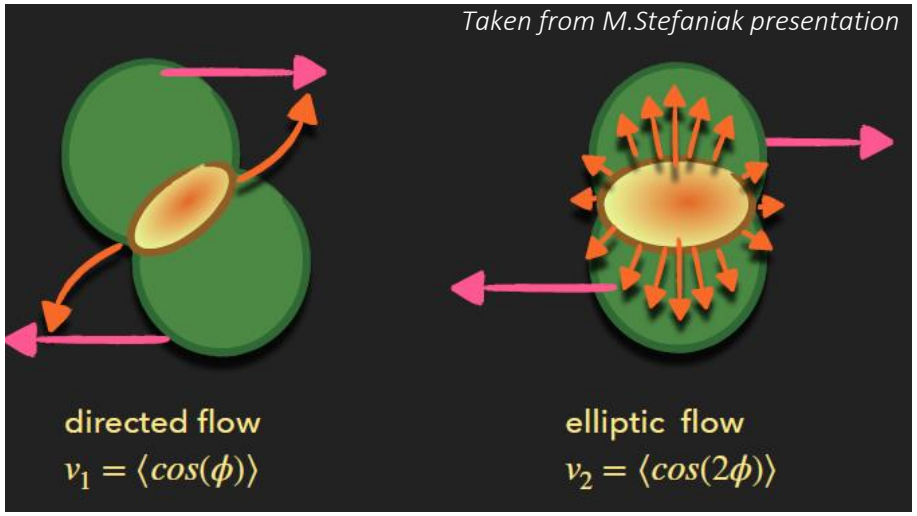


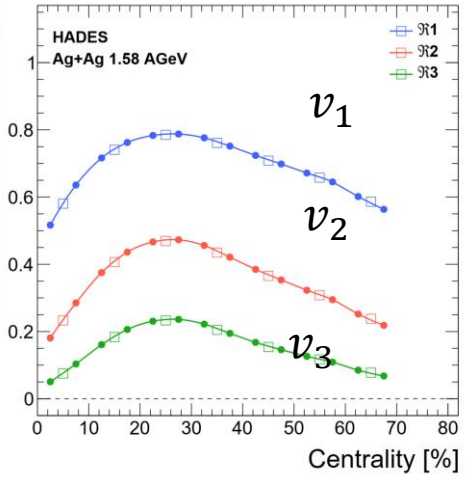
p_t 300-500 MeV
y_{cm} 0.5-0.7,
20-30%

$$\frac{dN}{d\Delta\varphi} = c * [1 + 2v_1 \cos(\Delta\varphi) + 2v_2 \cos(2\Delta\varphi)]$$

Directed flow

Elliptic flow

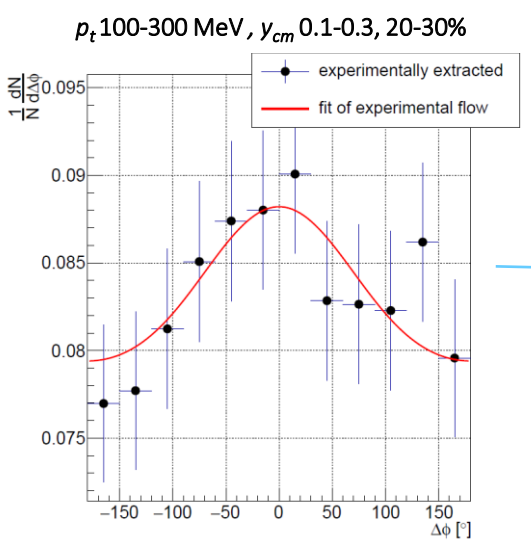


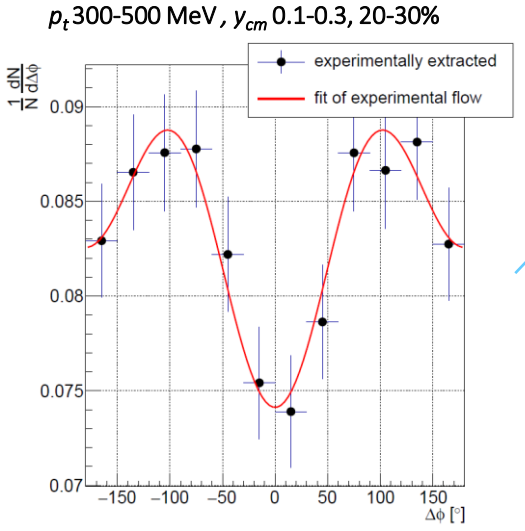


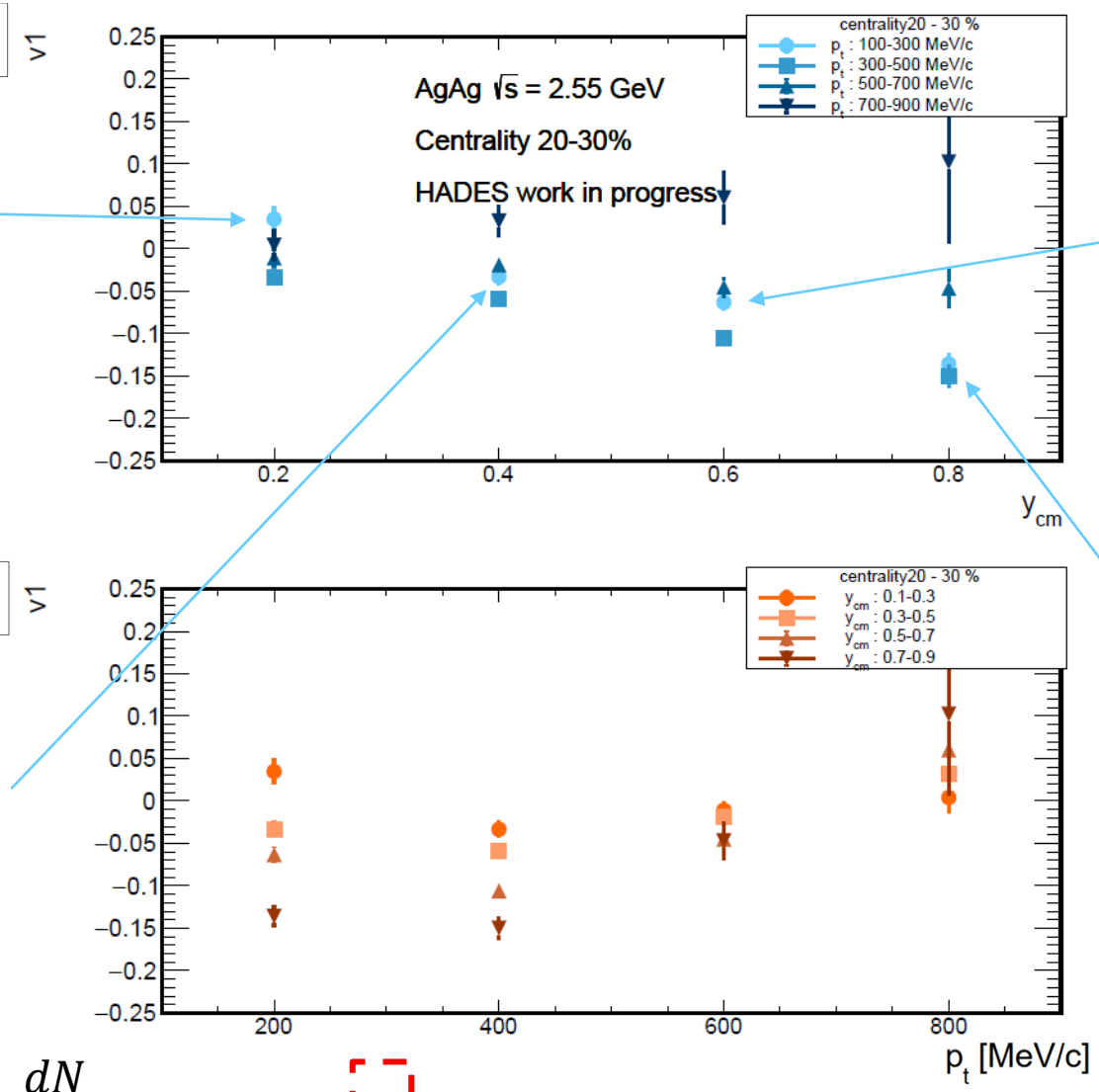
- Reaction plane angle is reconstructed using Forward Wall Detector
- Event plane resolution determined from sub-event resolution and is accounted for. Based on Ollitrault method

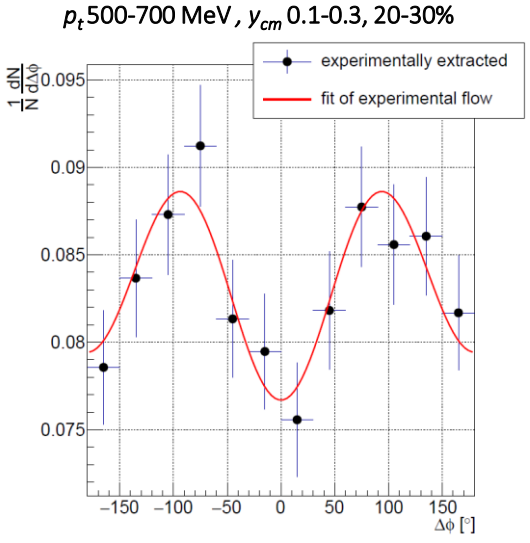
arXiv:nucl-ex/9711003

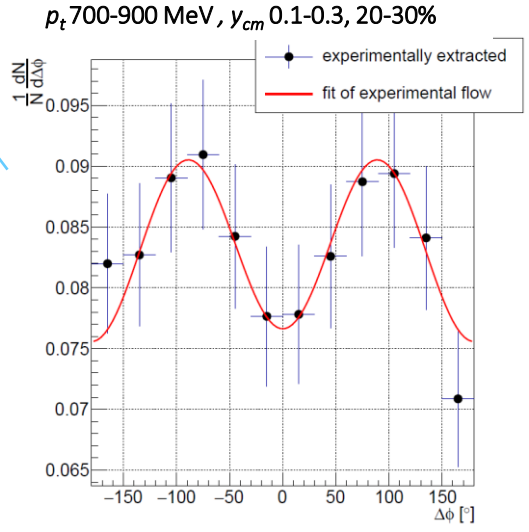
Directed flow of neutral pion





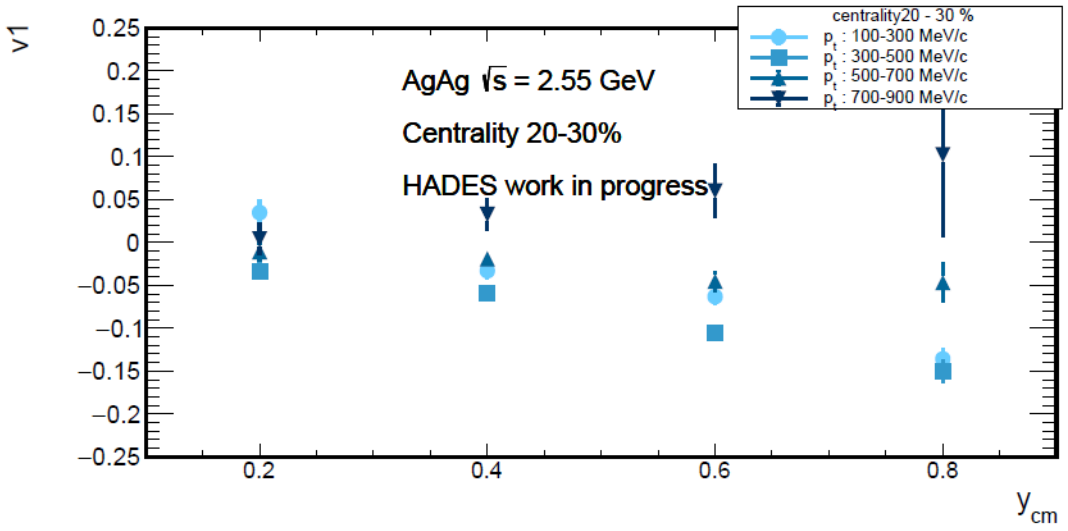


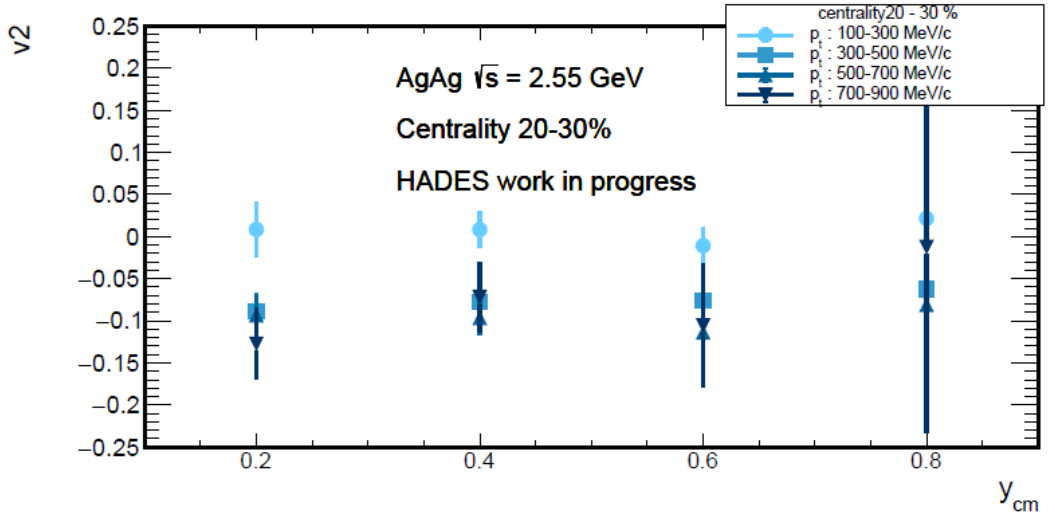


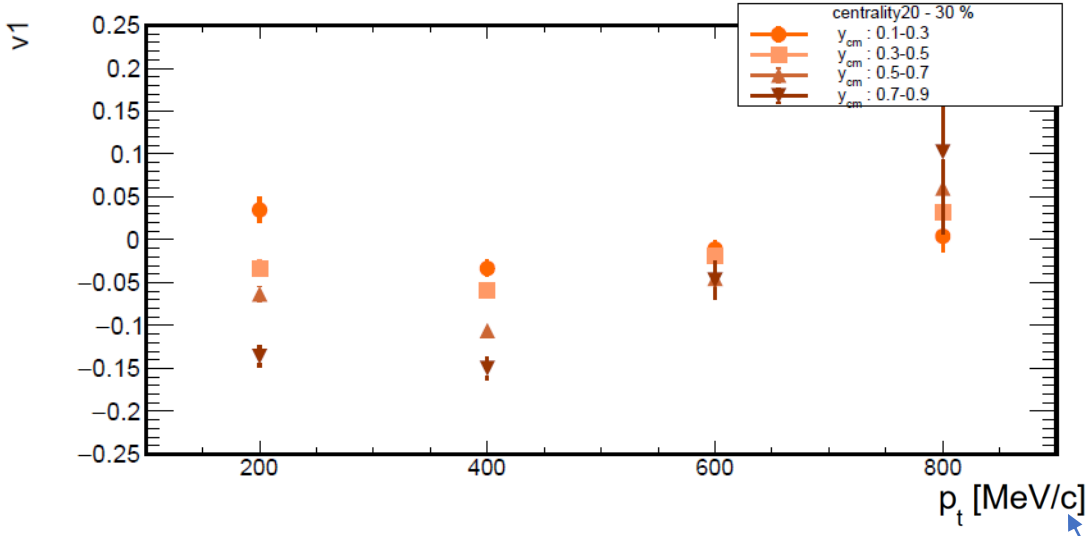


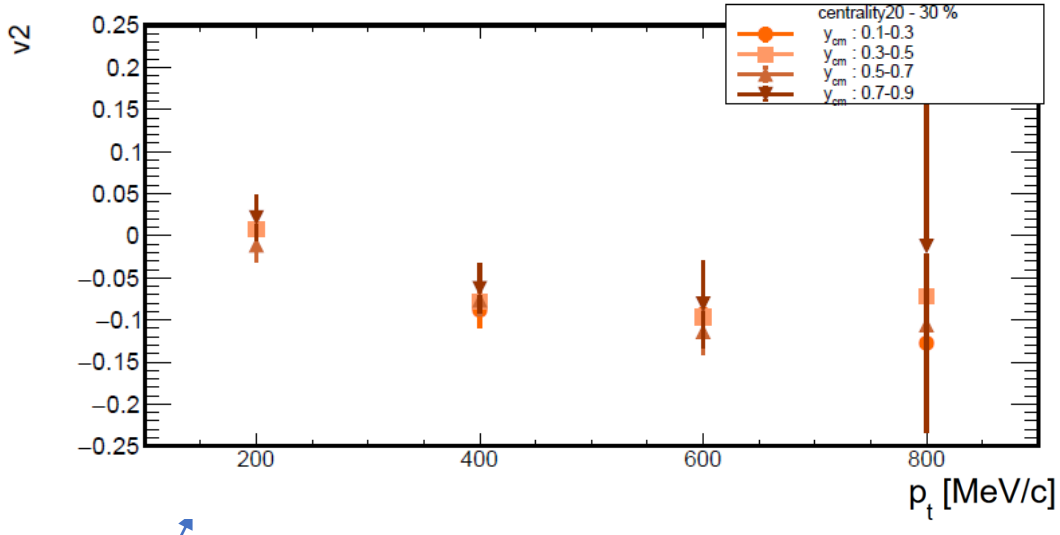
$$\frac{dN}{d\Delta\varphi} = c * [1 + 2\boldsymbol{v_1}\cos(\Delta\varphi) + 2v_2\cos(2\Delta\varphi)] \qquad \widetilde{v_1} = \frac{v_1}{R_{corr}} = \frac{v_1}{0.8}$$

Directed and Elliptic flow of neutral pion





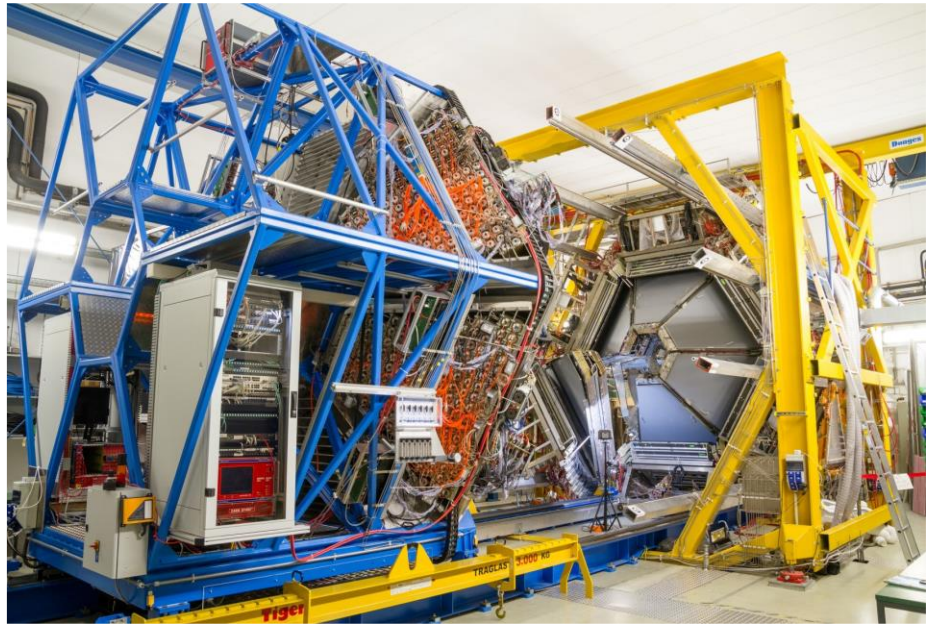




$$\frac{dN}{d\Delta\varphi} = c * [1 + 2\boldsymbol{v_1}\cos(\Delta\varphi) + 2\boldsymbol{v_2}\cos(2\Delta\varphi)]$$

Summary and Outlook

- A newly installed electromagnetic calorimeter was successfully used in experiment
- A calibration of ECAL based on leptons and pi0 peak was performed – achieved 5,9% energy precision
- First results on neutral pion yields at such energies in heavy projectile-target collision system and comparison to the world data – an input to world systematics
- Preliminary flow results of neutral pions is presented and will be compared to various transport models.



Thank you for your attention!

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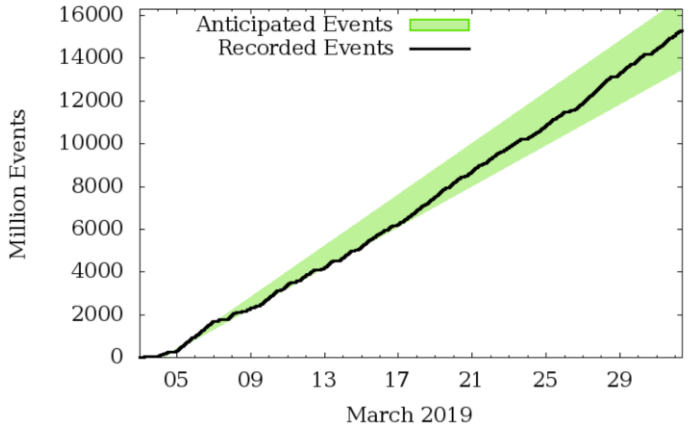
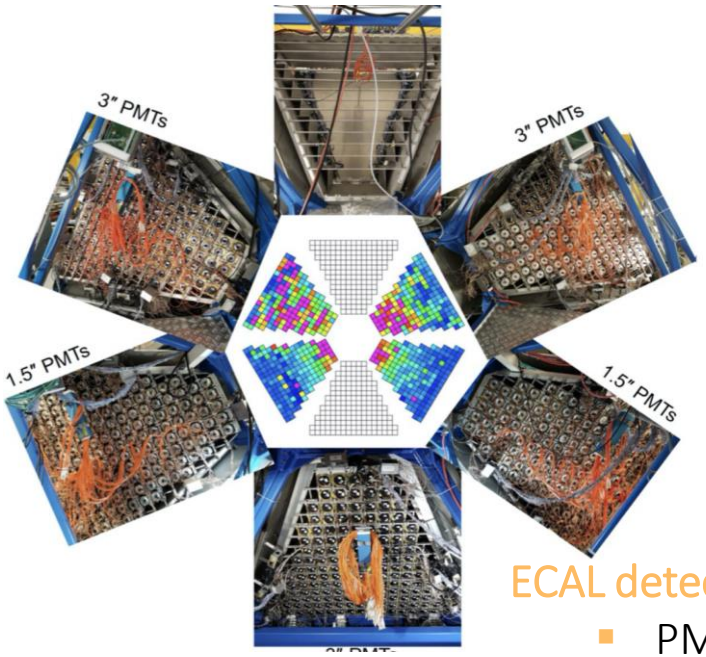
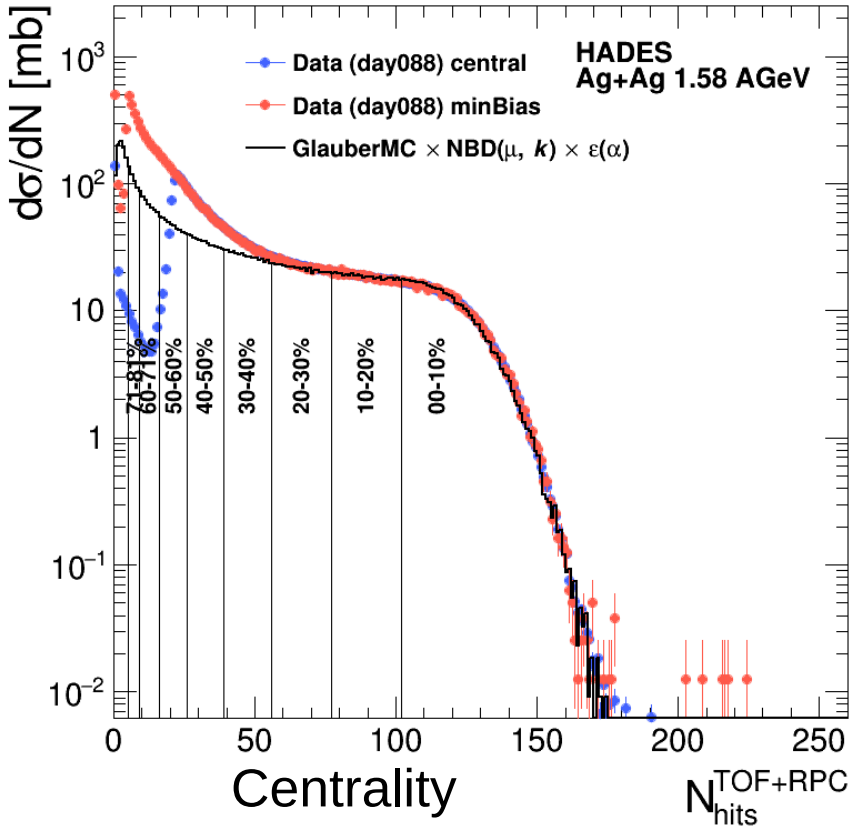
- MEYS CZ - LM2018112 grant
- FAIR-CZ-OP grant CZ.02.1.01/0.0/0.0/16_013/0001677
- LTT17003

Ag+Ag@1.58 AGeV beam time 2019 and perfomance

- In March of 2019 - experiment Ag+Ag at 1.58 AGeV
- 15 billion events collected
- 16-18 kHz event rate
- FAIR Phase-0 program







- 0-30% most central
- Deduced from a Glauber MC model

ECAL detector was used for the first time

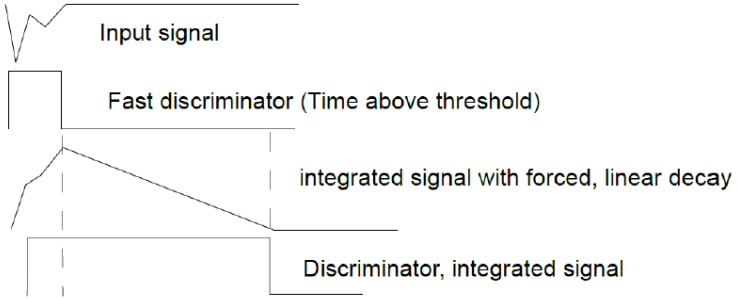
- PMT readout with two different types
- 4 sectors ready for beamtime in 2019
- 5th ready now, 6th in 2022

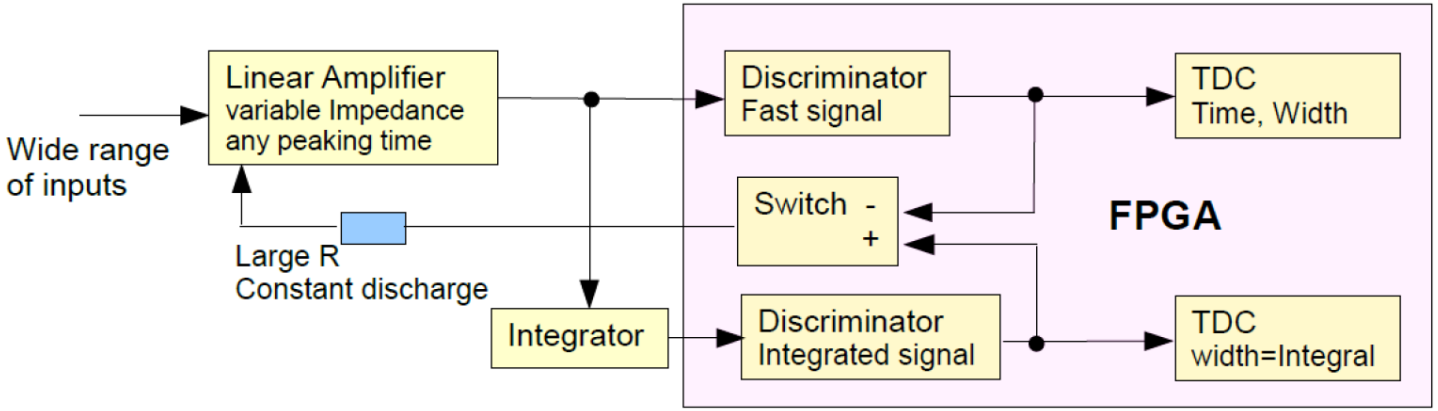
COME and KISS

COME & KISS: Charge Measurement with an FPGA

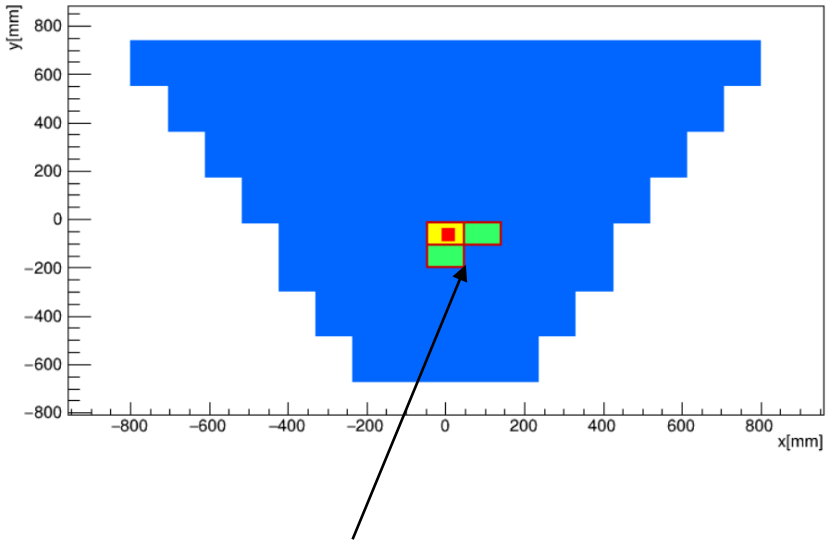
TECHNISCHE UNIVERSITÄT DARMSTADT

- **Idea:** Modified Wilkinson ADC
- Integrate input signal with a capacitor
- Discharge via a current source
  → fast crossing of zero
- **Q2W**: Measure time to reach zero
  ~Q using an **FPGA-TDC**





Clustering in ECAL

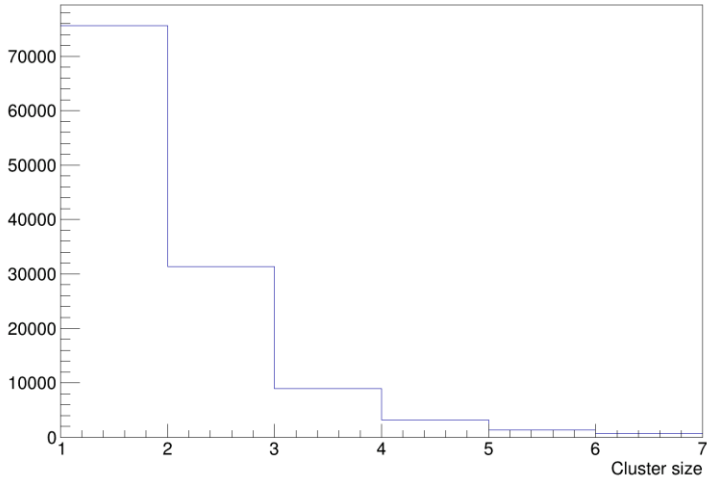


Cluster size 3 photon

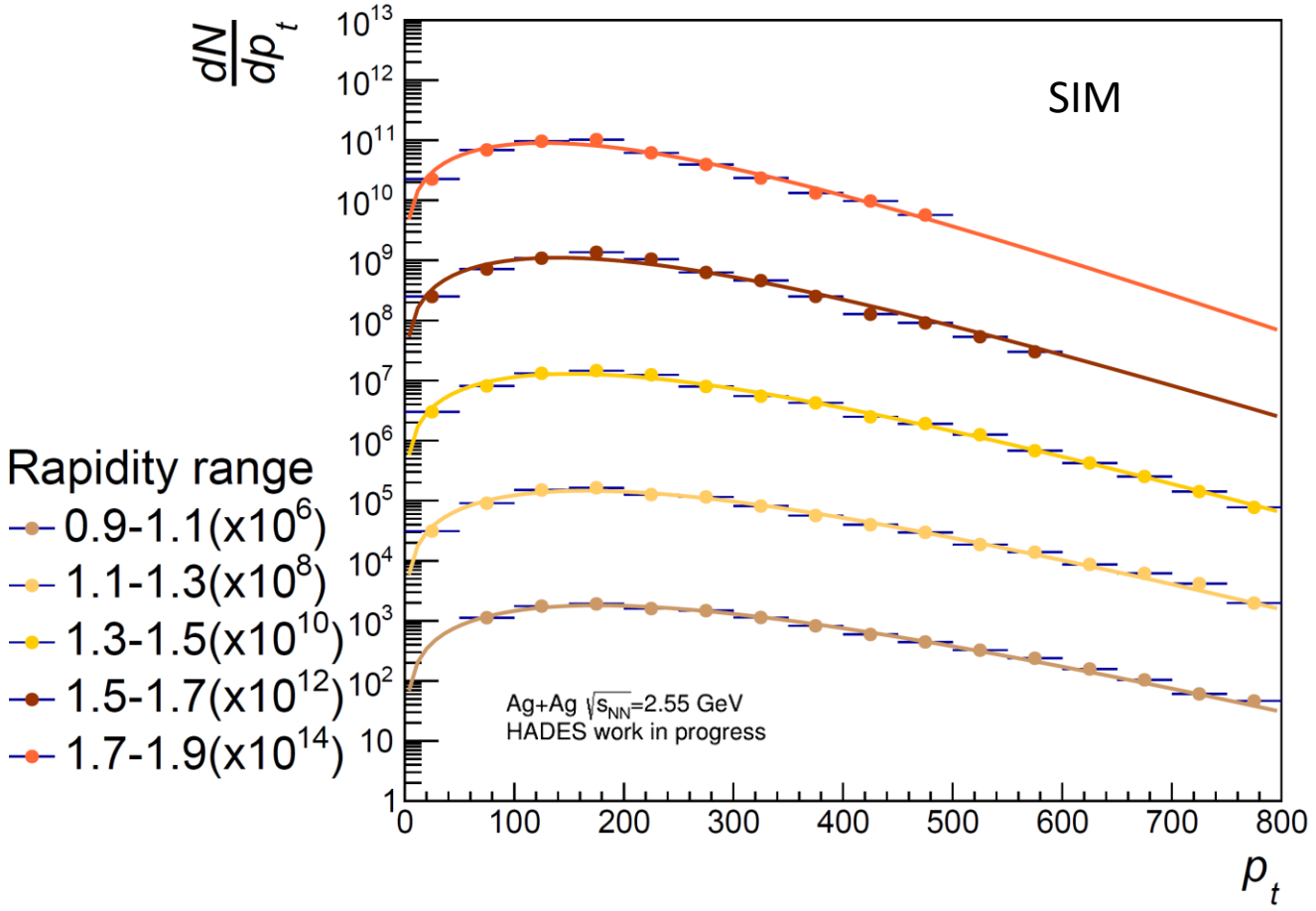
Several adjacent fired modules are grouped in so-called **clusters**.

For the calibration ->
use only cluster size 1 leptons

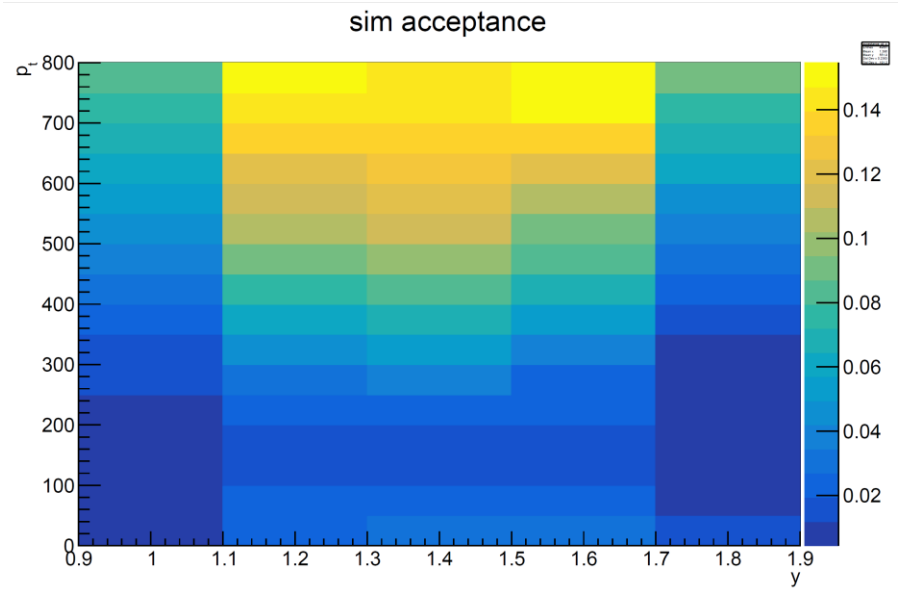
Photon cand distribution

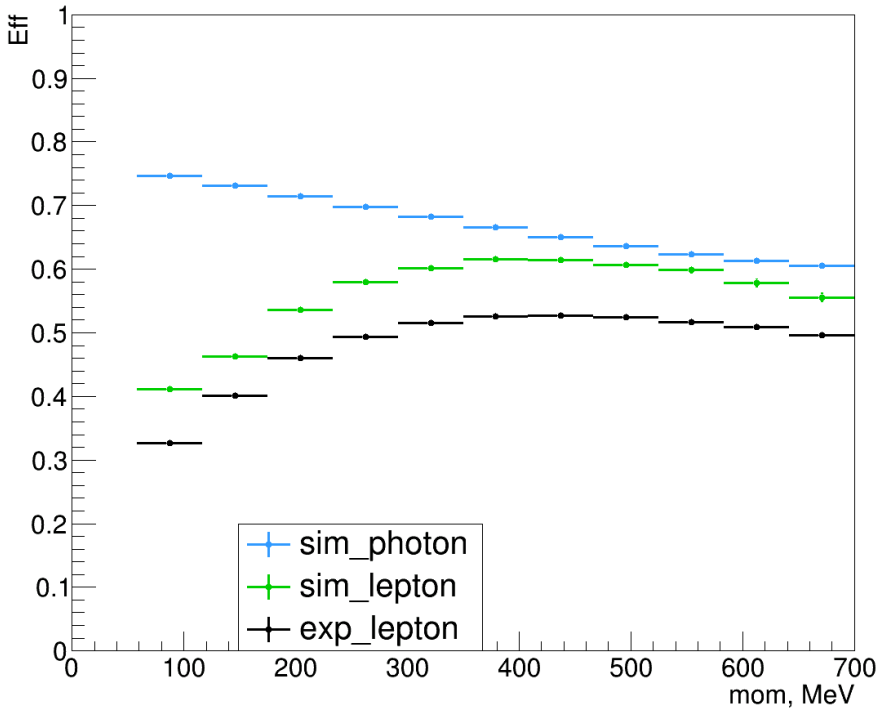


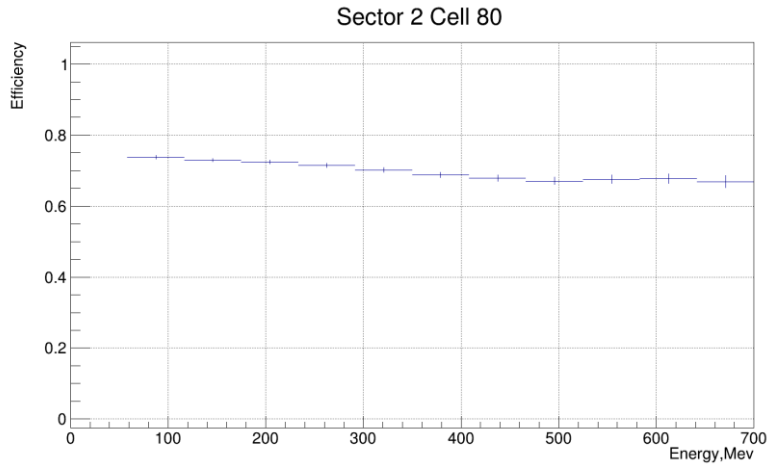
GEANT+analyzed+eff.correcred+acceptance corrected



Efficiency







$$Efficiency_{\gamma} = \frac{identified\ photons\ from\ primary\ \pi_0}{all\ emmited\ photons\ from\ primary\ \pi_0}$$

$$Efficiency_{e^{\pm}} = \frac{identified\ leptons\ in\ ECAL}{identified\ leptons\ in\ HADES}$$

(wrt. photon acceptance)