Hidden neutrons in HADES pion data

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Fairness 2016

4^{th} International Workshop for young scientists

with research interests focused on physics at FAIR

Garmisch-Partenkirchen, Germany

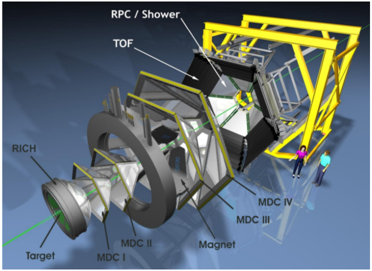
Outline

1. Introduction
   - HADES overview
   - Pion beam experiment
2. Elementary reactions
   - $\pi^- + \mathrm{p} \rightarrow \pi^- + \pi^+ + \mathrm{n}$
   - $\pi^- + \mathrm{p} \rightarrow \mathrm{n} + \eta \rightarrow \mathrm{n} + \pi^- + \pi^0 + \pi^+$

HADES spectrometer

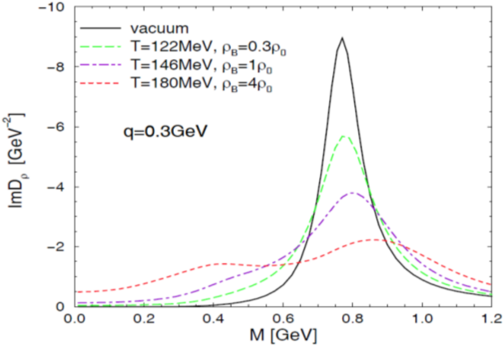
High Acceptance Di-Electron Spectrometer

- divided into 6 identical sectors
- individual parts: START, RICH, MDC I-IV, Magnet, TOF & RPC, Pre-Shower (going to be replaced by ECAL) and Forward Wall
- measurements at SIS18:
  C+C @ $1\,\mathrm{GeV/u}$,
  Ar+KCl @ $1.756\,\mathrm{GeV}$,
  Au+Au @ $1.23\,\mathrm{GeV/u}$,
  p+p @ $1.25\,\mathrm{GeV}$ and $3.5\,\mathrm{GeV}$,
  d+p @ $1.25\,\mathrm{GeV}$, π^-+A



Purpose of HADES

- measuring in-medium broadening of vector-meson resonances
- investigate di-leptons probes from HI collisions
- determine properties of strange hadrons
- detecting particle flow from heavy-ion interactions
- but what if we will use this tool for something else?



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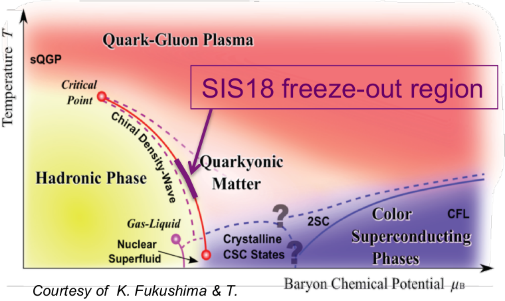

Courtesy of K. Fukushima & T. Hatsuda

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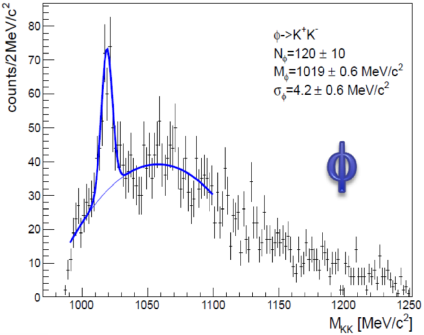

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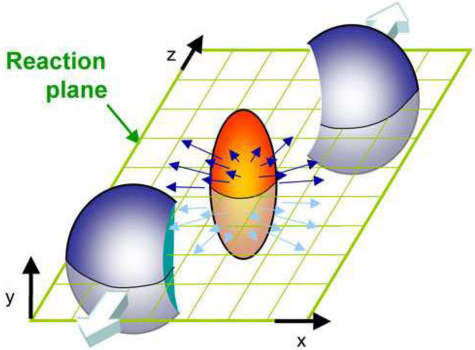

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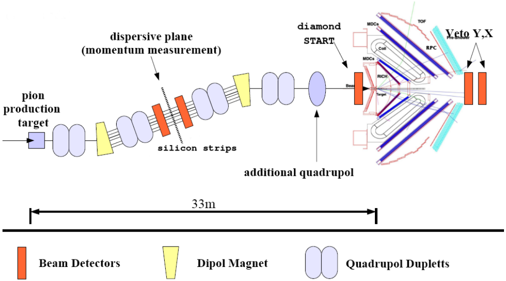
  $\Rightarrow$ detection of neutrons

HADES π-beam experiment



- Strangeness program with $p_\pi = 1.7\,\mathrm{GeV}/c$ and targets
  - tungsten
  - carbon
- Baryonic resonances program with $p_\pi \in \{656; 690; 748; 800\}\,\mathrm{MeV}/c$ and targets
  - polyethylene
  - carbon

Motivation & Plan of work for neutron detection

- Motivation
  - Study of exclusive reactions: $\pi^- + \mathrm{p} \rightarrow \mathrm{n} + \pi^0/\eta/\omega$
  - Study of short range NN correlations
- Plan of work
  - Find optimal cuts on neutron hits: $\pi^- + \mathrm{p} \rightarrow \mathrm{n} + \pi^- + \pi^+$
  - Investigate the efficiency of these cuts: $\pi^- + \mathrm{p} \rightarrow \mathrm{n} + \eta$
  - Analyse $\pi^- + \mathrm{A}@1.7\,\mathrm{GeV/c}$ data $\Rightarrow$ SRC

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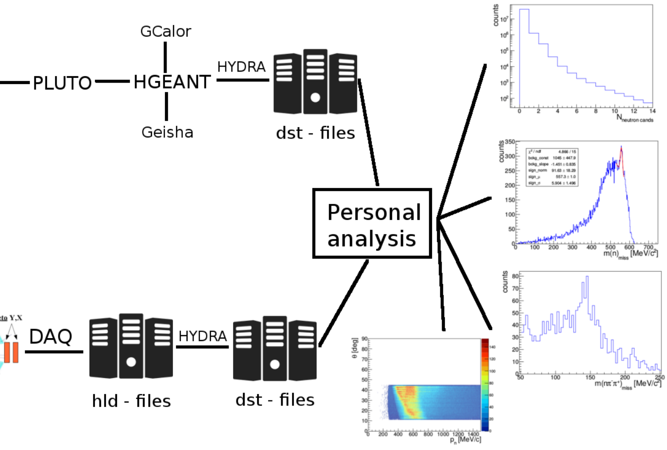
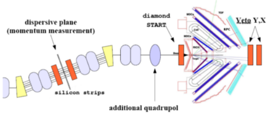
Analysis scheme

SIM

$\pi^- + p \rightarrow$	p_{beam}[MeV/c] 666.8	699.7	748.4	799.1	source
$n + \pi^0$	8.71	8.42	7.17	5.28	[1]
$n + \pi^0 + \pi^0$	1.53	2.29	2.50	2.66	[2]
$n + \pi^0 + \pi^0 + \pi^0$	0.003	0.009	0.014	0.020	[3]
$n + \eta$	0.0	1.5	2.6	2.6	[4]
$n + \pi^- + \pi^+$	5.49	5.96	6.19	6.60	[2]
$p + \pi^- + \pi^0$	2.43	4.22	4.83	4.82	[2]
$n + \pi^0 + \pi^+ + \pi^-$	0.8	0.8	0.8	0.8	estimation



REAL



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Looking for cuts

What can be used:

- charged particle identification and selection of pairs $\pi^- + \pi^+$
- missing momentum (difference in θ and $\phi < 5°$)

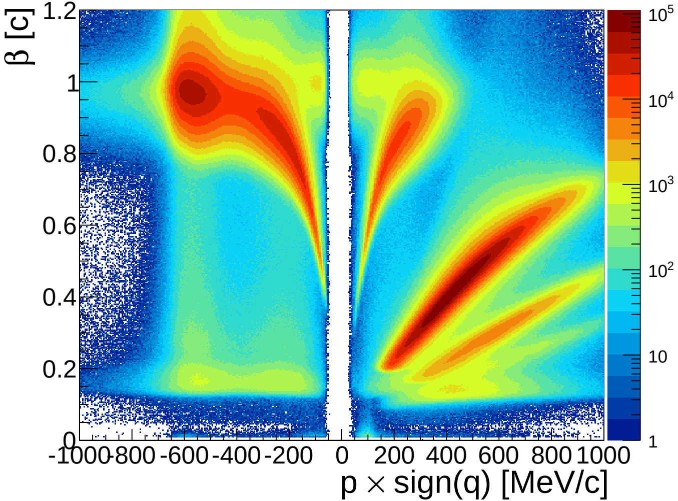
$$\vec{p}_{\mathrm{n}} = \vec{p}_{\mathrm{p}} + \vec{p}_{\mathrm{beam}} - \vec{p}_{\pi^-} - \vec{p}_{\pi^+}$$

- time of flight - from TOF/RPC
  `H(Tof/Rpc)Cluster->getTof() > 7.5`
- MDC as VETO for cluster sector
  - ◇ `HParticleEvtInfo->getMdcWiresUnusedSec(isec)` ≤ 2 (might be biased by noise per sector)
- Particle candidates as VETO for cluster index
  - ◇ `HParticleCand->getTofClstInd()`
  - ◇ or `HParticleCand->getRpcInd()`

All analysis shown here is for $p_{\mathrm{beam}} = 690\,\mathrm{MeV/c}$ and PE target

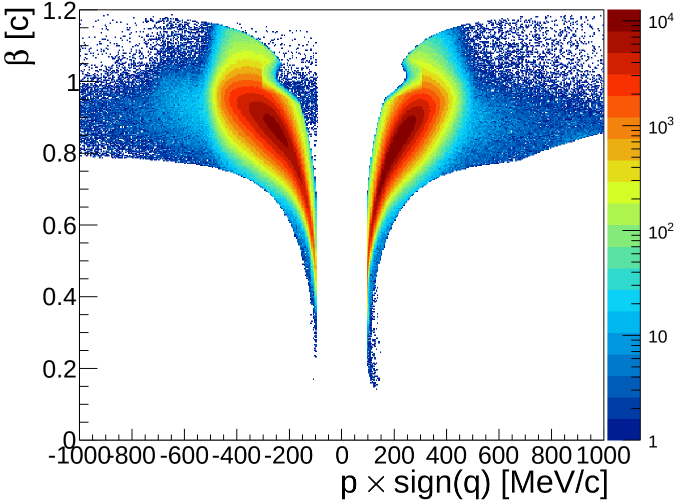
Charged particle selection

From particle candidate info we get:



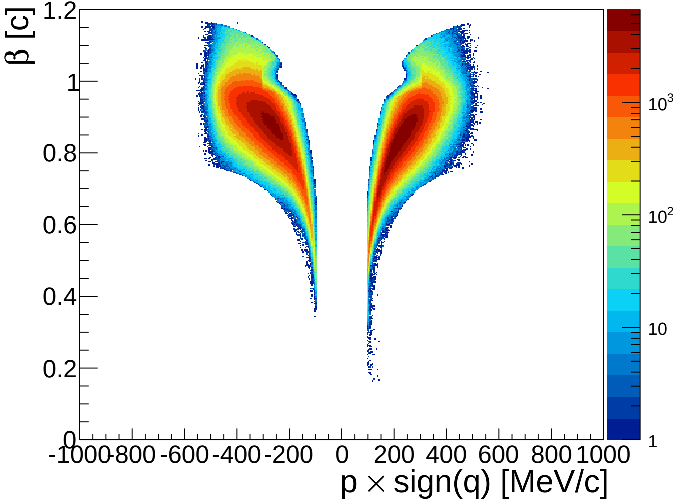
Charged particle selection

Cut on π^- and π^+ region ($\frac{p}{\sqrt{m_\pi^2+p^2}} - 0.2 < \beta < \frac{p}{\sqrt{m_\pi^2+p^2}} + 0.2$):



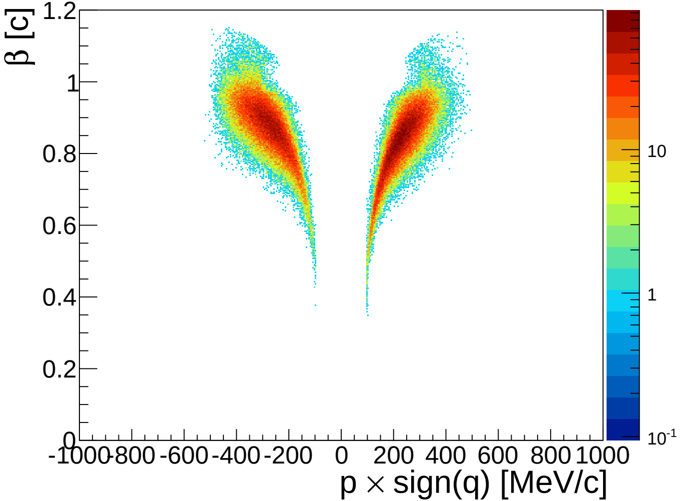
Charged particle selection

Cut on missing mass ($900\,\mathrm{MeV/c^2} < m\,(\pi^-\pi^+)_{\mathrm{miss}} < 980\,\mathrm{MeV/c^2}$):



Charged particle selection

If we find hit in TOF/RPC with right position (difference in θ and $\phi < 5°$):

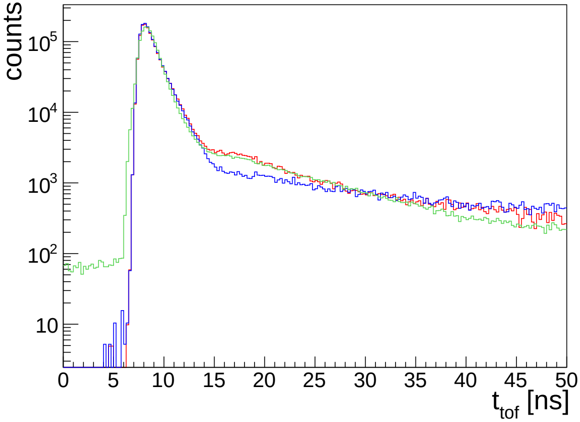


Time Of Flight cuts efficiency for TOF

Geisha GCalor real data

ALL hits

- histogram scaling in the given range histograms have the same number of entries
- MDC veto is not very powerful
- GCalor agrees better with real data



Time Of Flight cuts efficiency for TOF

Geisha GCalor real data

MDC unused wires cut

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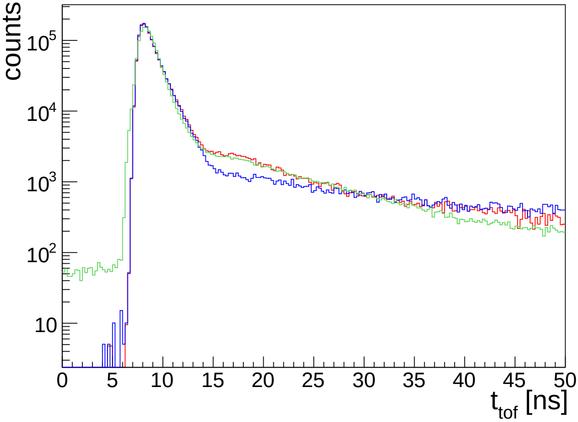

Time Of Flight cuts efficiency for TOF

Geisha GCalor real data

ParticleCands cut

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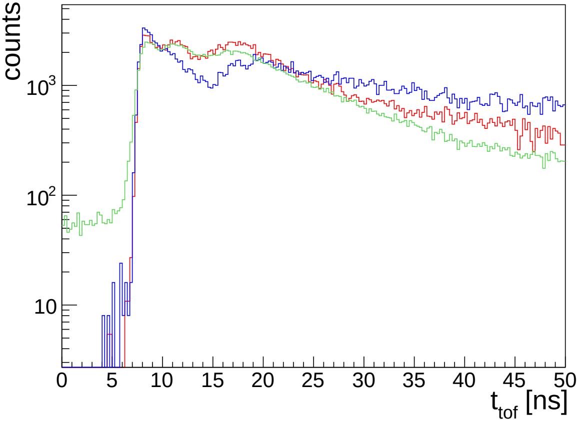
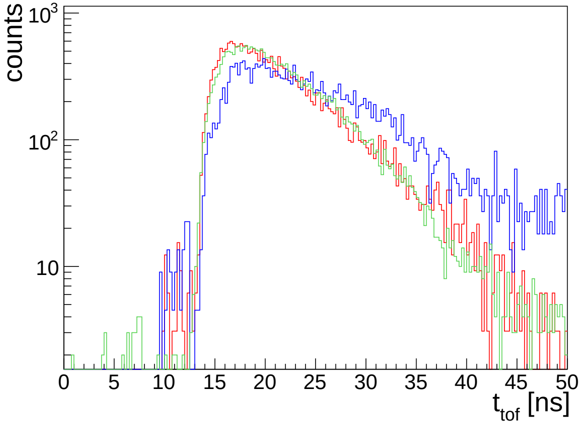


Time Of Flight cuts efficiency for TOF

Geisha GCalor real data

position (θ and ϕ) cut

- histogram scaling
- MDC veto is not very powerful
- GCalor agrees better with real data

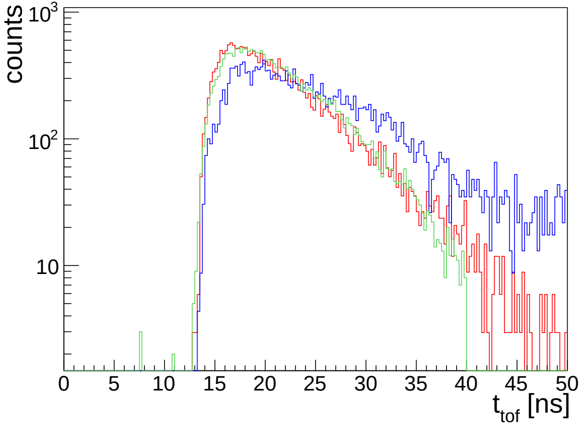


Time Of Flight cuts efficiency for TOF

Geisha GCalor real data

final combined cut

- histogram scaling
- MDC veto is not very powerful
- GCalor agrees better with real data



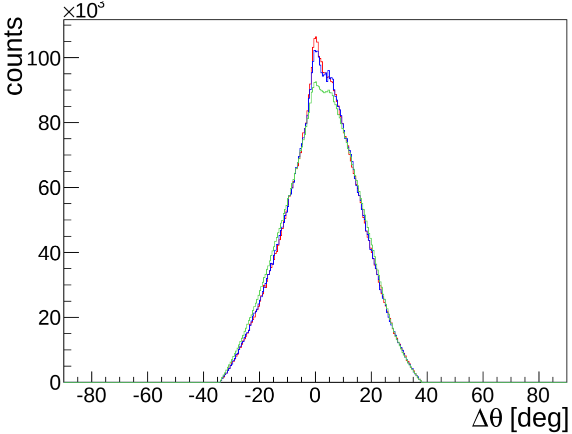
⇒ most important cut on ParticleCand and position

Difference in θ angle: $\theta_{\mathrm{expected}} - \theta_{\mathrm{cluster}}$

Geisha GCalor real data

ALL hits

- histogram scaling in the given range histograms have the same number of entries
- small difference between real data and sim



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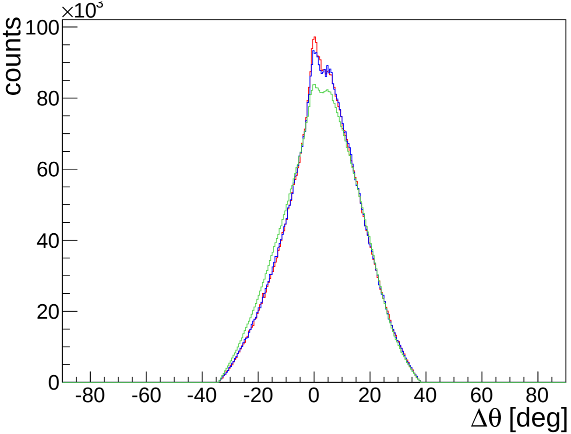
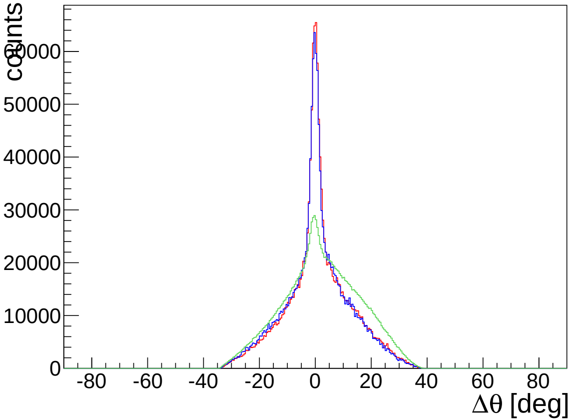


Difference in θ angle: $\theta_{\text{expected}} - \theta_{\text{cluster}}$

Geisha GCalor real data

ParticleCands cut

- histogram scaling
- small difference between real data and sim still visible correspondence around $0°$



$\Rightarrow$ nice correlation in θ angle

Difference in ϕ angle: $\phi_{\text{expected}} - \phi_{\text{cluster}}$

Geisha GCalor real data

ALL hits

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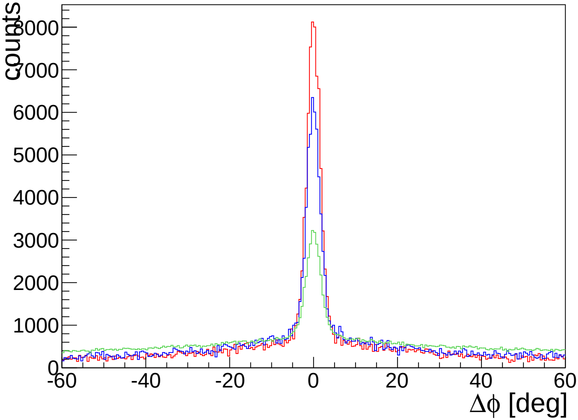

Difference in ϕ angle: $\phi_{\text{expected}} - \phi_{\text{cluster}}$

Geisha GCalor real data

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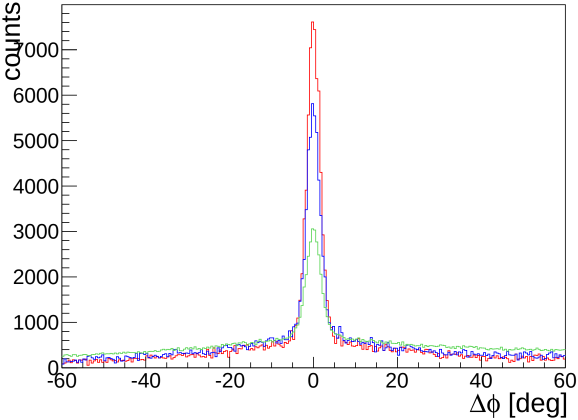

Difference in ϕ angle: $\phi_{\text{expected}} - \phi_{\text{cluster}}$

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ParticleCands cut

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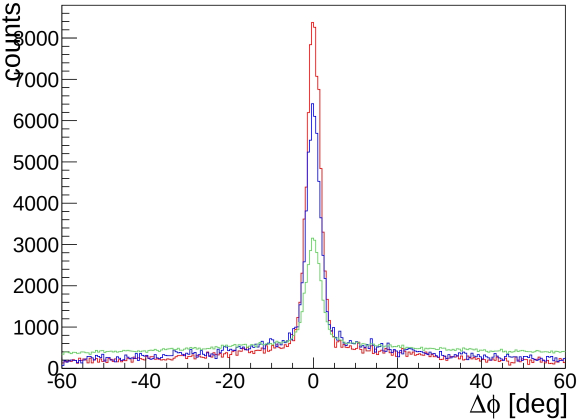


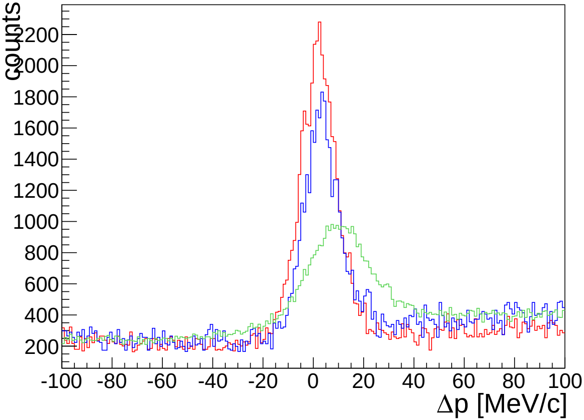
$\Rightarrow$ nice correlation in ϕ angle

Difference in $\|\vec{p}_n\|$ momentum: $\|\vec{p}_n\|_{expected} - \|\vec{p}_n\|_{cluster}$

Geisha GCalor real data

ALL hits

- histogram scaling
- visible shift of real data from $\Delta p = 0\,\mathrm{MeV/c}$ possible explanations: imperfect measurement of p_{beam} and/or energy loss corrections inside target
- nice cutting of the pedestal



Difference in $\|\vec{p}_\mathrm{n}\|$ momentum: $\|\vec{p}_\mathrm{n}\|_\mathrm{expected} - \|\vec{p}_\mathrm{n}\|_\mathrm{cluster}$

Geisha GCalor real data

position (θ and ϕ) cut

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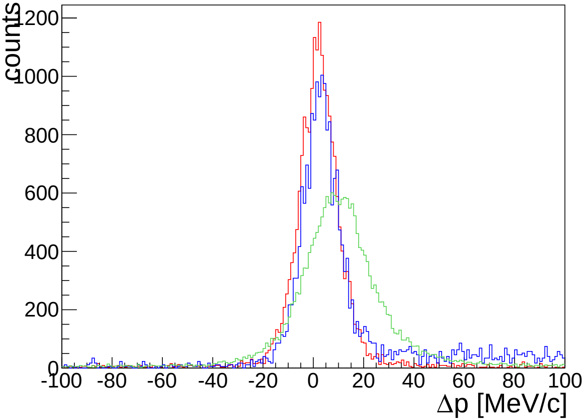
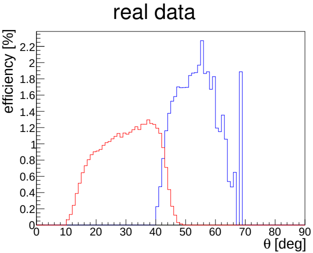
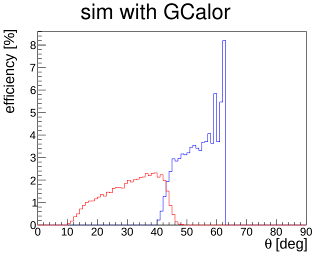
- visible shift of real data from $\Delta p = 0\,\mathrm{MeV/c}$
- nice cutting of the pedestal

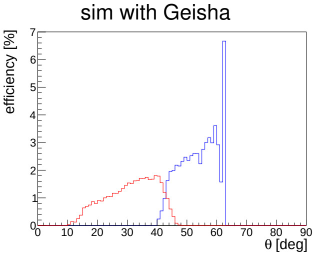


$\Rightarrow$ good performance of position cuts

Neutron detection efficiency as a function of θ







TOF

- SIM/REAL ≈ 1.5 (might be due to background in data)
- GCalor/Geisha ≈ 1.33

RPC

- SIM/REAL ≈ 1.6 (might be due to background in data)
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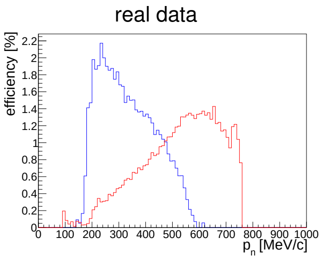
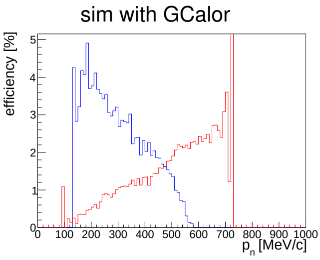
Neutron detection efficiency as a function of $\|\vec{p}_n\|$





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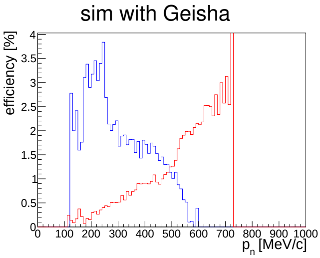

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   - $\pi^- + \mathrm{p} \to \mathrm{n} + \eta \to \mathrm{n} + \pi^- + \pi^0 + \pi^+$

Why η channel?

$\pi^- + \mathrm{p}$

$\to \mathrm{n} + \pi^0$

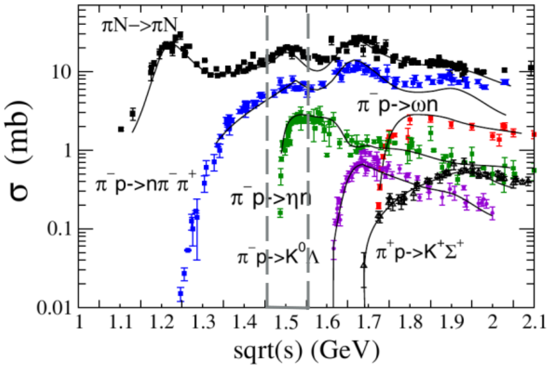
- $+$ high XS
- $-$ detection of $\pi^0 \to 2\gamma$ decay (98.8% without ECAL difficult, conversion probability $\sim 1\%$)

$\to \mathrm{n} + \eta$

- $+$ around threshold
- $+$ detection of $\eta \to \pi^-\pi^+\pi^0$ decay (22.9%)

$\to \mathrm{n} + \omega$

- $-$ too much below threshold
- $+$ detection of $\eta \to \pi^-\pi^+\pi^0$ decay (89.2%)



$p_{\mathrm{threshold}} = 685\,\mathrm{MeV/c} \Rightarrow$ showing results for $p_{\mathrm{beam}} = 800\,\mathrm{MeV/c}$

Cross section of reaction channels used in simulation

$\pi^- + \mathrm{p} \to$	$p_{\mathrm{beam}}[\mathrm{MeV/c}]$ 666.8	699.7	748.4	799.1	source
$\mathrm{n} + \pi^0$	8.71	8.42	7.17	5.28	[1]
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$\mathrm{p} + \pi^- + \pi^0$	2.43	4.22	4.83	4.82	[2]
$\mathrm{n} + \pi^0 + \pi^+ + \pi^-$	0.8	0.8	0.8	0.8	estimation

data are in mb

[1] Landolt-Börnstein: *New Series I/12a*, 1972.

[2] D. M. Manley et al.: *Isobar-model PWA $\pi N \to \pi\pi N$ in the c.m. energy range* $1320 - 1930\,\mathrm{MeV}$, Phys. Rev. D 30, 1984.

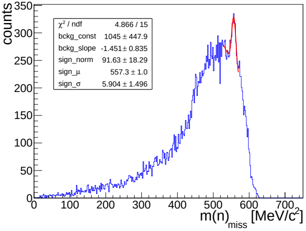
[3] A. Starostin et al. (Crystal Ball): *Measurement of the $\pi^-\mathrm{p} \to 3\pi^0\mathrm{n}$ total cross section from threshold to* $0.75\,\mathrm{GeV/c}$,

Phys. Rev. C 67, 2003.

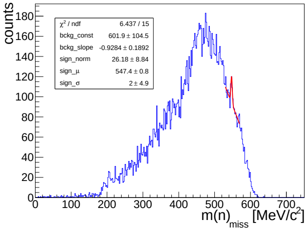
[4] S. Prakhov et al.: *Measurement of the $\pi^-\mathrm{p} \to \eta\mathrm{n}$ from threshold to* $p_{\pi^-} = 747\,\mathrm{MeV/c}$, Phys. Rev. C 72, 2005.

Missing mass ($m_\eta = 547.9\,\mathrm{MeV/c^2}$)

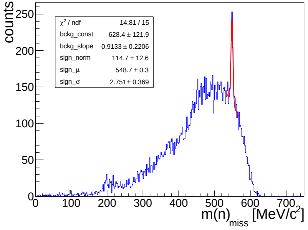
real data



sim with Geisha

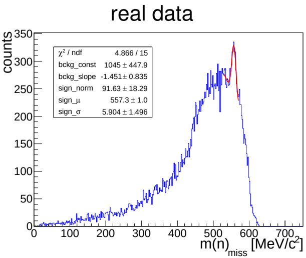


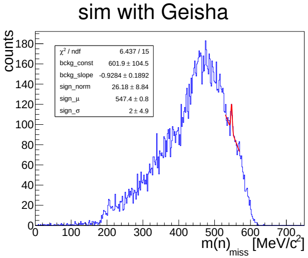
sim with GCalor

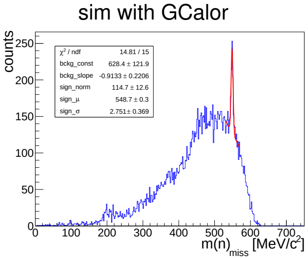


- requirement to reconstruct π^+ and π^-
- hits only in RPC ($11^\circ < \theta < 45^\circ$) due to kinematics
- hits without matched track
- $11\,\mathrm{ns} < t_{\mathrm{tof}} < 28\,\mathrm{ns}$
- MDC unused wires ≤ 2

Missing mass ($m_\eta = 547.9\,\mathrm{MeV/c^2}$)



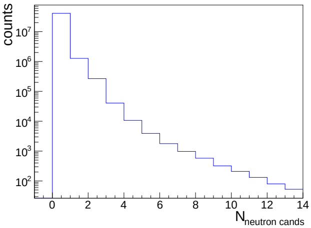




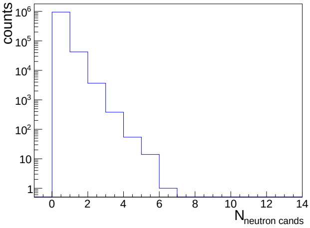
- peak in real data is shifted ($\mu = 557.3\,\mathrm{MeV/c^2}$) due to same reason as for Δp above
- very good agreement in sim ($\mu_{\mathrm{GCalor}} = 548.7\,\mathrm{MeV/c^2}$ and $\mu_{\mathrm{Geisha}} = 547.4\,\mathrm{MeV/c^2}$)

Number of neutron candidates in one event

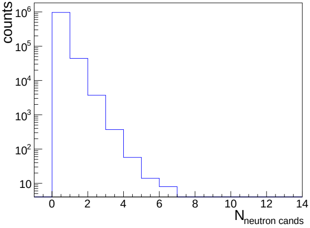
real data



sim with Geisha

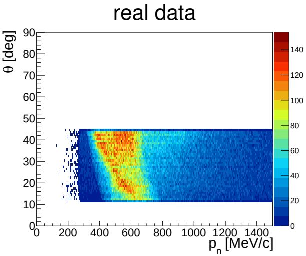


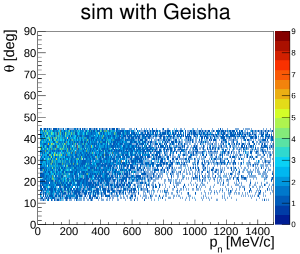
sim with GCalor

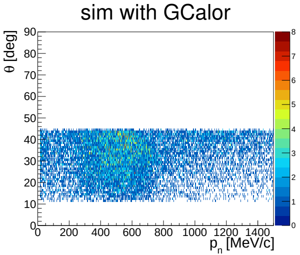


- selected neutron with cuts ($\pi^+\pi^-$, $11^\circ < \theta < 45^\circ$, $11\,\mathrm{ns} < t_{\mathrm{tof}} < 28\,\mathrm{ns}$, no track matched with hit, MDC unused wires ≤ 2)
- more powerful MDC VETO is nescessary

θ vs. p distribution of neutrons



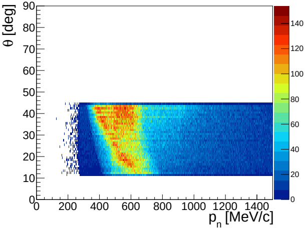




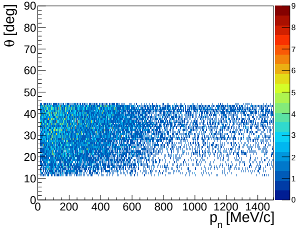
- selected neutron with cuts ($\pi^+\pi^-$, $11^\circ < \theta < 45^\circ$, $11\,\mathrm{ns} < t_{\mathrm{tof}} < 28\,\mathrm{ns}$, no track matched with hit, MDC unused wires ≤ 2)
- better agreement of real data and GCalor

θ vs. p distribution of neutrons

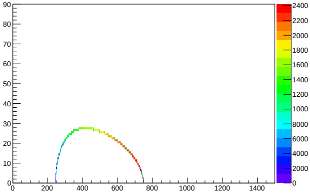
real data



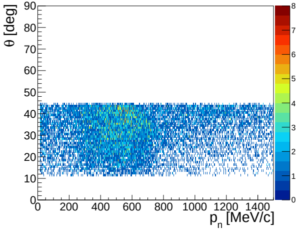
sim with Geisha



Pluto - only $\pi^- \mathrm{p} \rightarrow \eta \mathrm{n}$



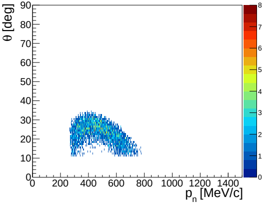
sim with GCalor



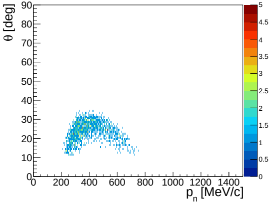
θ vs. p distribution of neutrons

+ cut: $528\,\mathrm{MeV/c^2} < m(\mathrm{n})_{\mathrm{miss}} < 568\,\mathrm{MeV/c^2}$

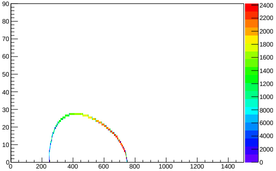
real data



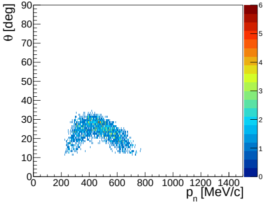
sim with Geisha



Pluto - only $\pi^- \mathrm{p} \to \eta \mathrm{n}$



sim with GCalor



Summary and Outlook

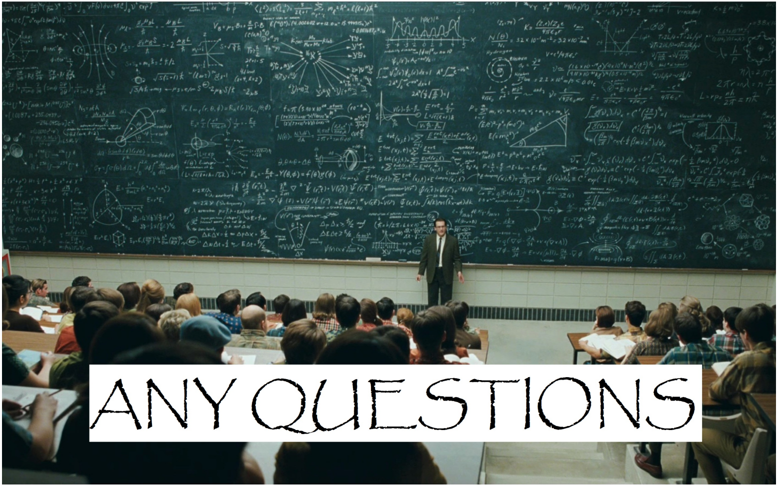
$\pi^- + \mathrm{p} \rightarrow \pi^- + \pi^+ + \mathrm{n}$

- tuned cuts for neutron selection
- qualitative agreement of SIM and REAL in neutron detection efficiency
- TO DO
  - ◇ improve MDC VETO procedure

$\pi^- + \mathrm{p} \rightarrow \eta + \mathrm{n}$

- TO DO
  - ◇ improve neutron hit selection procedure

Thank you for your attention!



Miscellaneous

Calculation of p_{n}

$$\frac{l_{\mathrm{path}}}{t_{\mathrm{tof}}} = \beta = \frac{p}{\sqrt{p^2 + m^2}}$$

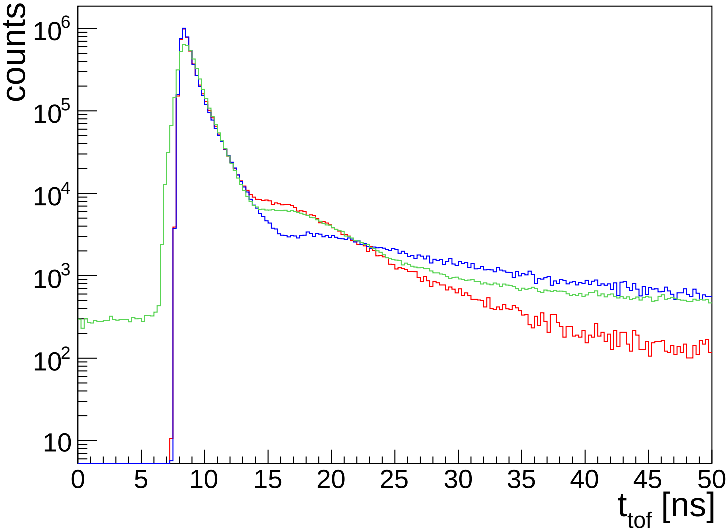
$$l_{\mathrm{path}} = \sqrt{(x_{\mathrm{ver}} - x_{\mathrm{cluster}})^2 + (y_{\mathrm{ver}} - y_{\mathrm{cluster}})^2 + (z_{\mathrm{ver}} - z_{\mathrm{cluster}})^2}$$

Neutron t_{tof} to p_{n}

p_{n} [MeV/c]	β	t_{tof} [ns]
100	0.11	69.0
200	0.21	36.1
350	0.35	21.7
500	0.47	16.1
700	0.60	12.7
900	0.69	11.0

Time Of Flight cuts efficiency for RPC

Geisha GCalor real data

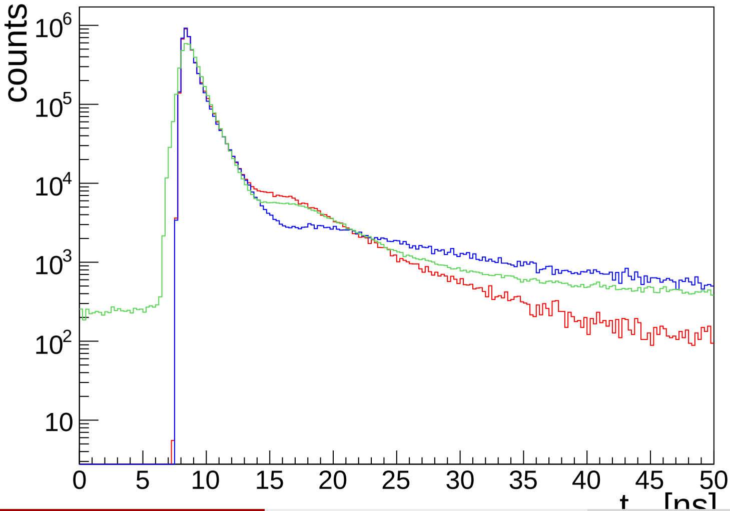


ALL hits

Time Of Flight cuts efficiency for RPC

Geisha GCalor real data

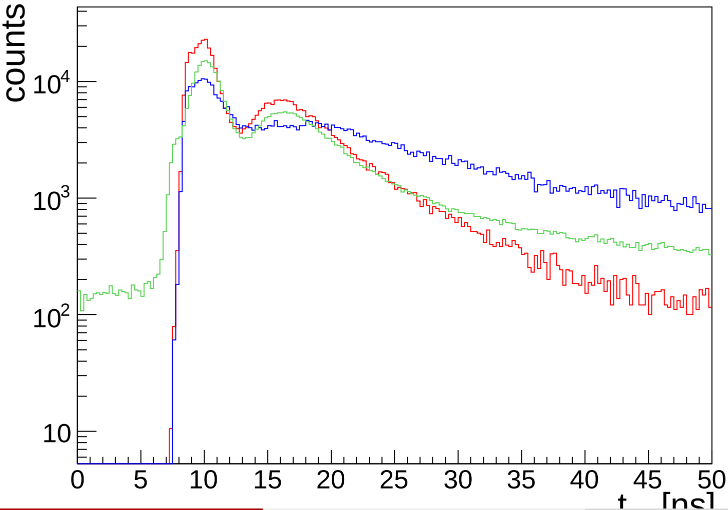
MDC unused wires cut



Time Of Flight cuts efficiency for RPC

Geisha GCalor real data

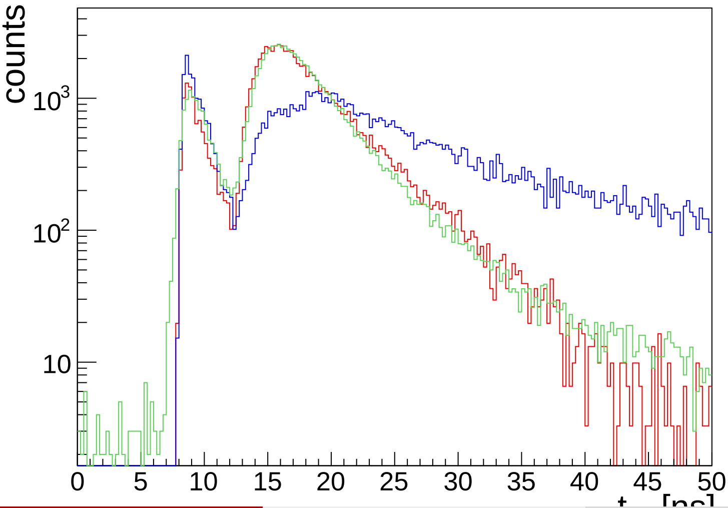
ParticleCands cut



Time Of Flight cuts efficiency for RPC

Geisha GCalor real data

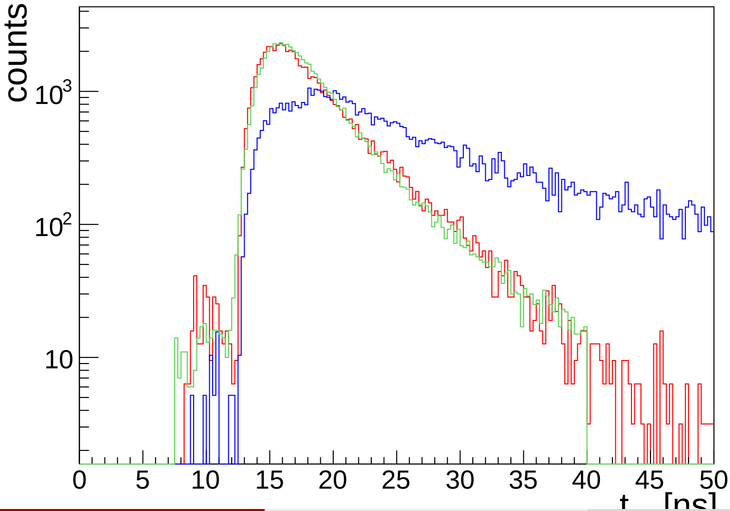
position (θ and ϕ) cut



Time Of Flight cuts efficiency for RPC

Geisha GCalor real data

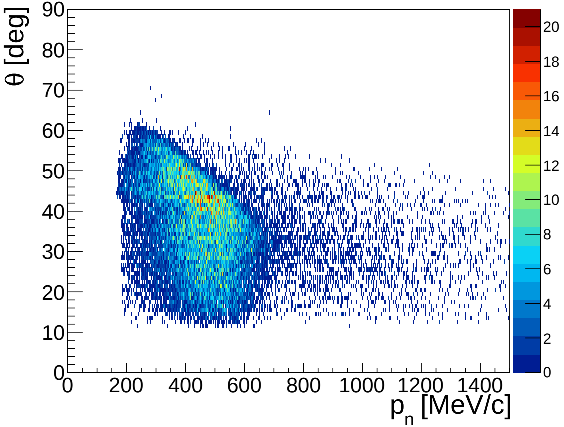
final combined cut



Neutron hit θ vs. $\|\vec{p}_{\mathrm{n}}\|$ distribution

real data

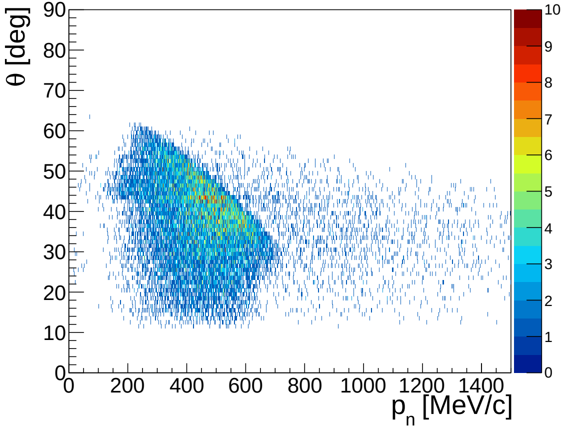
- REAL: cutted at low p
- GCalor: very good agreement with REAL
- Geisha: more hits with lower p
- all: bit bluring in higher p (exceeding $\sqrt{s}$)



Neutron hit θ vs. $||\vec{p}_{\mathrm{n}}||$ distribution

sim with GCalor

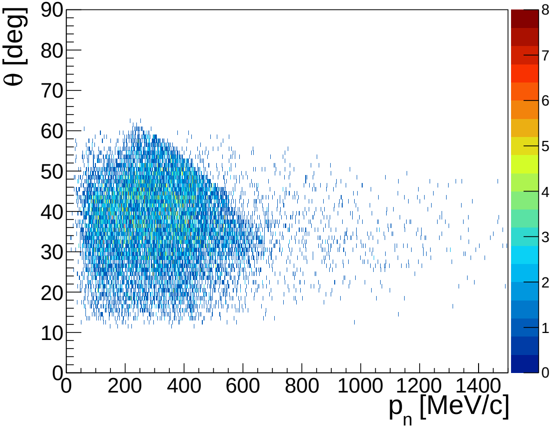
- REAL: cutted at low p
- GCalor: very good agreement with REAL
- Geisha: more hits with lower p
- all: bit bluring in higher p (exceeding $\sqrt{s}$)



Neutron hit θ vs. $||\vec{p}_\mathrm{n}||$ distribution

sim with Geisha

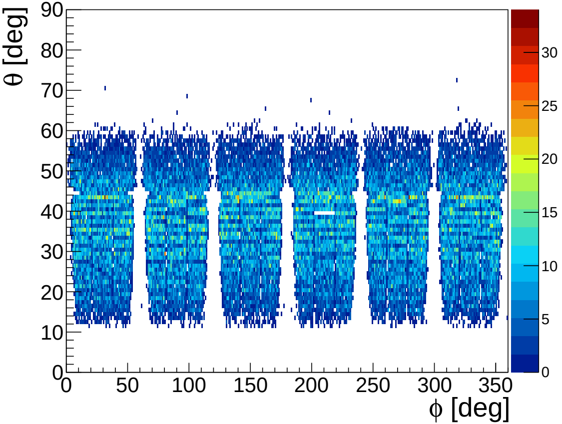
- ◇ REAL: cutted at low p
- ◇ GCalor: very good agreement with REAL
- ◇ Geisha: more hits with lower p
- ◇ all: bit bluring in higher p (exceeding $\sqrt{s}$)



Neutron hit θ vs. ϕ distribution

real data

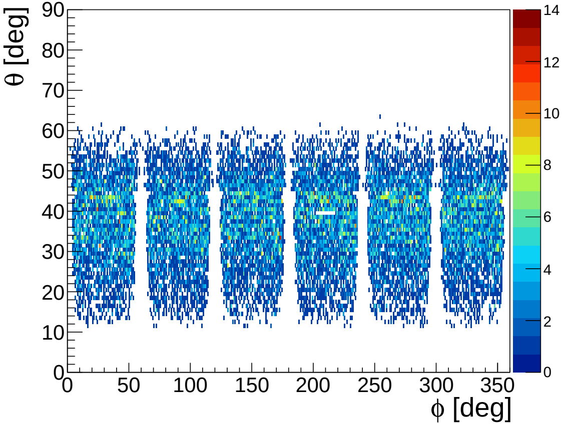
◇ good agreement between all three cases



Neutron hit θ vs. ϕ distribution

sim with GCalor

- good agreement between all three cases



Neutron hit θ vs. ϕ distribution

sim with Geisha

- good agreement between all three cases