LXXIV International conference Nucleus-2024:
Fundamental problems and applications
JINR, Dubna, Russia, July 1-5, 2024

Reconstruction of strange particle decays from Xe+CsI interactions with the BM@N spectrometer

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VBLHEP, JINR, Dubna, Russia

JOINT INSTITUTE FOR NUCLEAR RESEARCH

Outline

- ✓ NICA Complex and BM@N experiment
- ✓ Detector performance
- ✓ Reconstruction of strange particle decays
- ✓ Steps toward physics analysis:
  - ✓ Λ m_T-spectra for different rapidities
  - ✓ Λ lifetime measurement as a validation tool
  - ✓ K^0_s m_T-spectra for different rapidities
- ✓ Summary and next steps

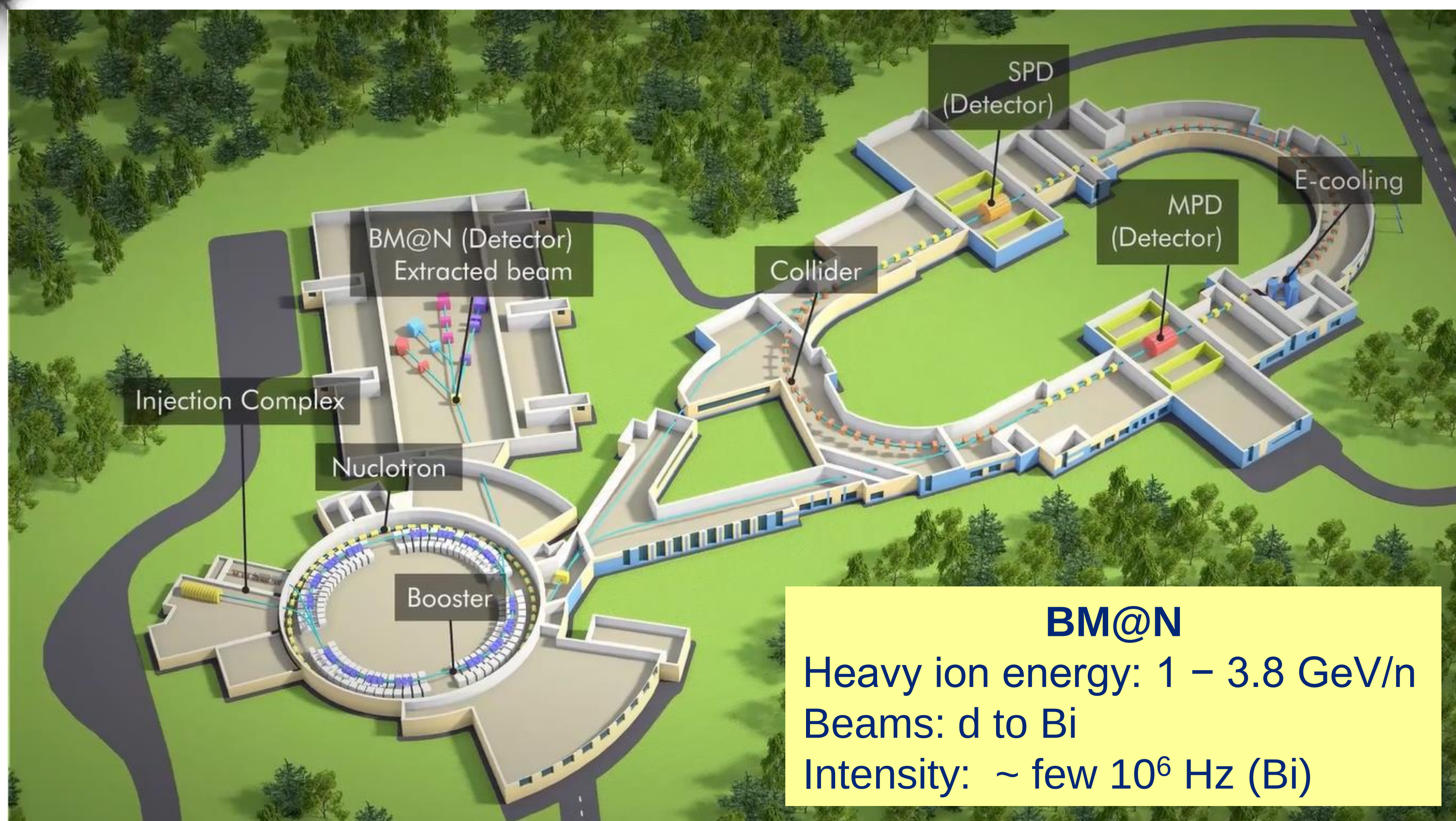
NICA Heavy Ion Complex

Baryonic Matter at Nuclotron (BM@N) Collaboration:

5 Countries, 13 Institutions, 217 participants

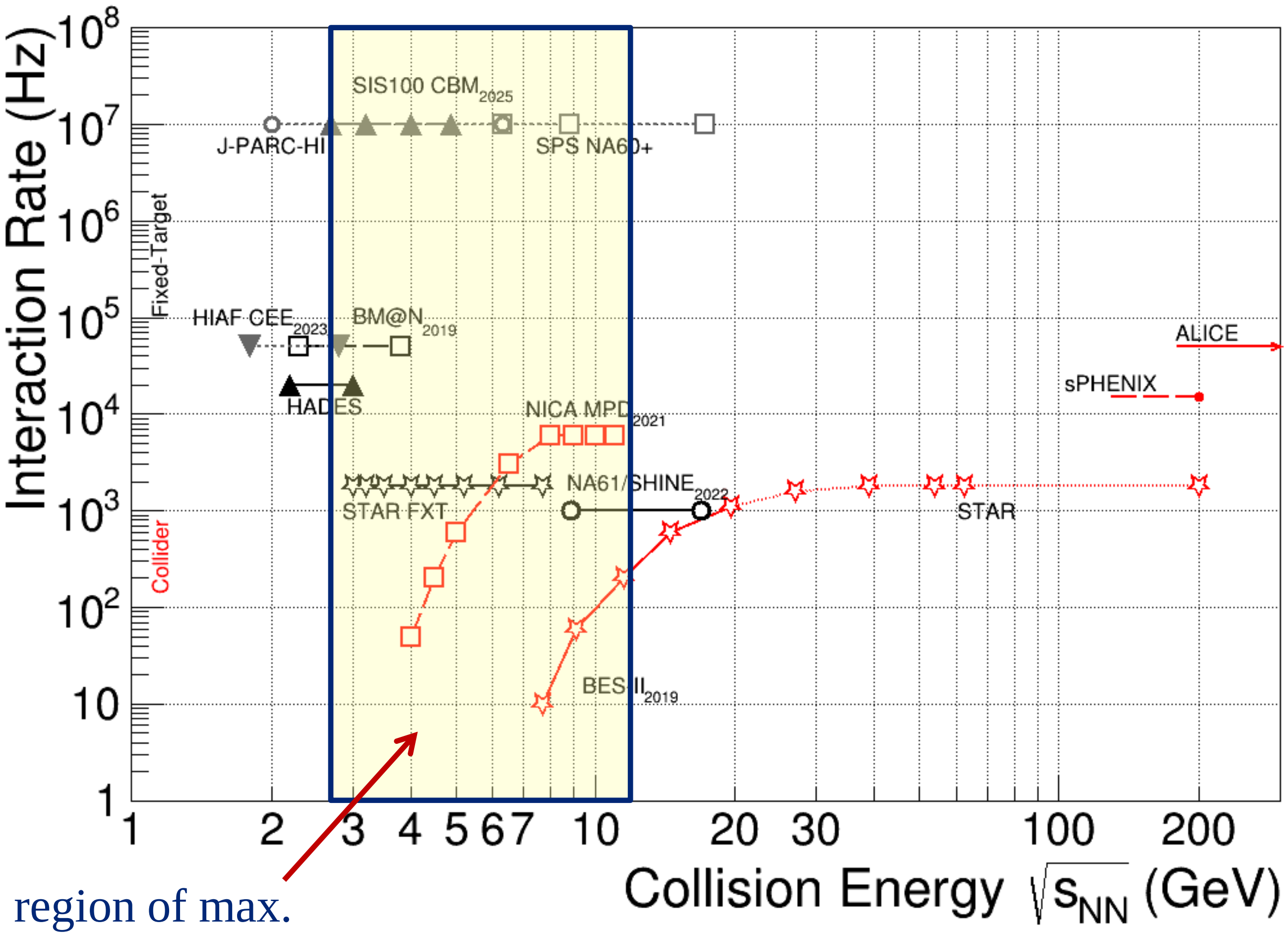
Detectors:

BM@N
MPD
SPD

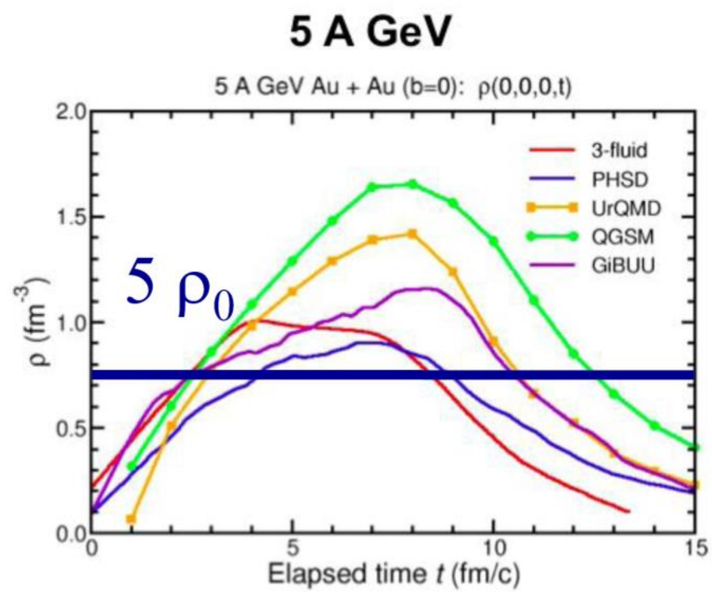


BM@N
Heavy ion energy: 1 − 3.8 GeV/n
Beams: d to Bi
Intensity: ~ few 10^6 Hz (Bi)

Heavy Ion Collision Experiments



region of max. baryonic density



BM@N: $\sqrt{s_{NN}}$ = 2.3 − 3.3 GeV
MPD: $\sqrt{s_{NN}}$ = 4 − 11 GeV

BM@N competitors:

HADES BES (SIS):
Au+Au at $\sqrt{s_{NN}}$ = 2.42 GeV,
Ag+Ag $\sqrt{s_{NN}}$ = 2.42 GeV, 2.55 GeV

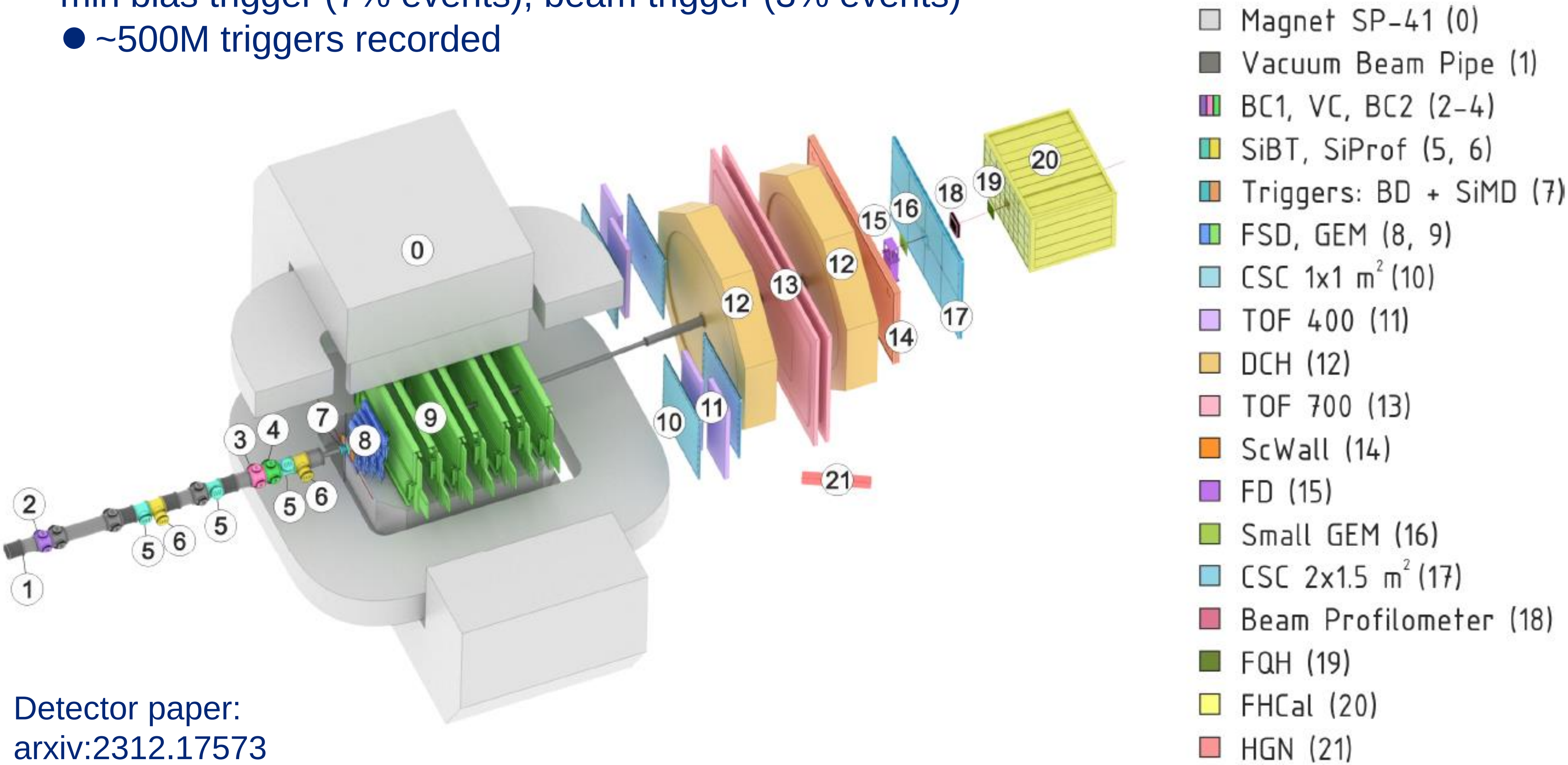
STAR BES (RHIC):
Au+Au at $\sqrt{s_{NN}}$ = 3 − 200 GeV

Configuration of BM@N detector in Xe+CsI run

- First physics run with full configuration Dec. 2022 – Jan. 2023
- Xe^{124} + CsI interactions, beam kinetic energy 3.8A GeV:
- main trigger covers centrality < 70-75% (85% events)

min bias trigger (7% events), beam trigger (3% events)

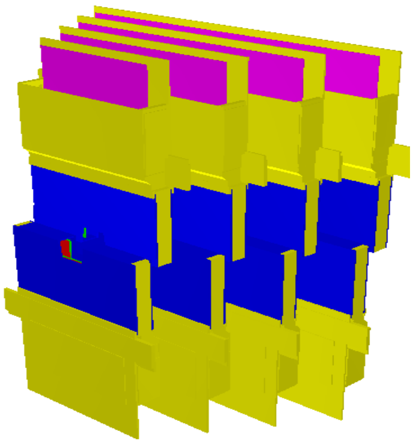
- ~500M triggers recorded

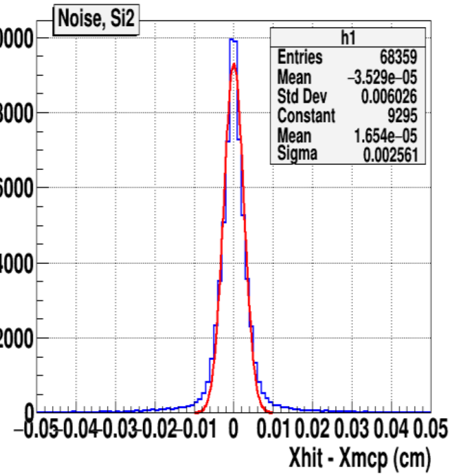


Detector paper:
arxiv:2312.17573

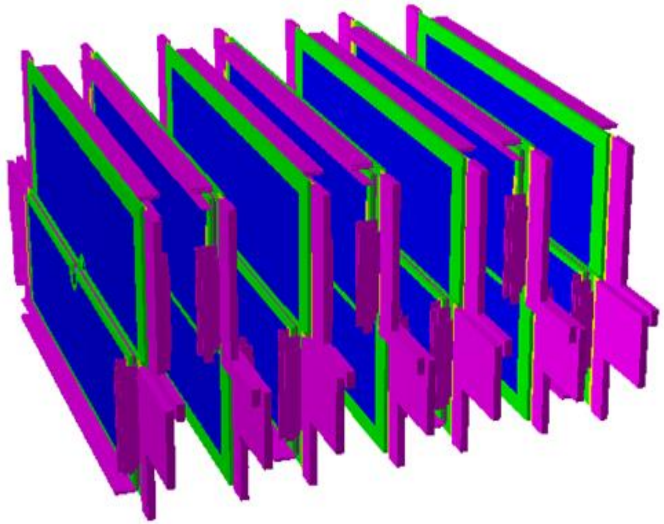
Central tracker performance

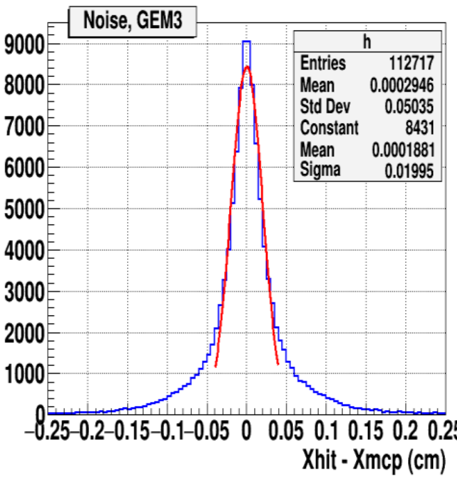
Si tracker



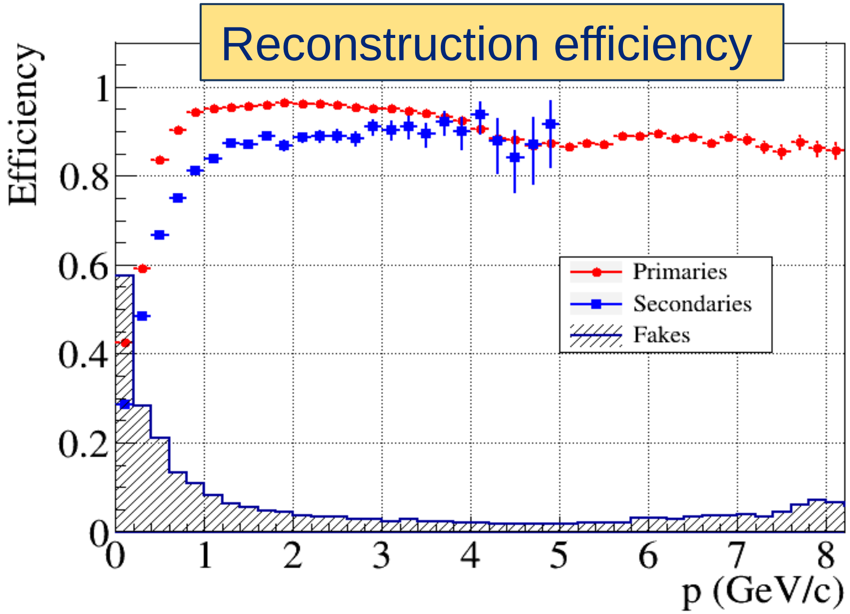


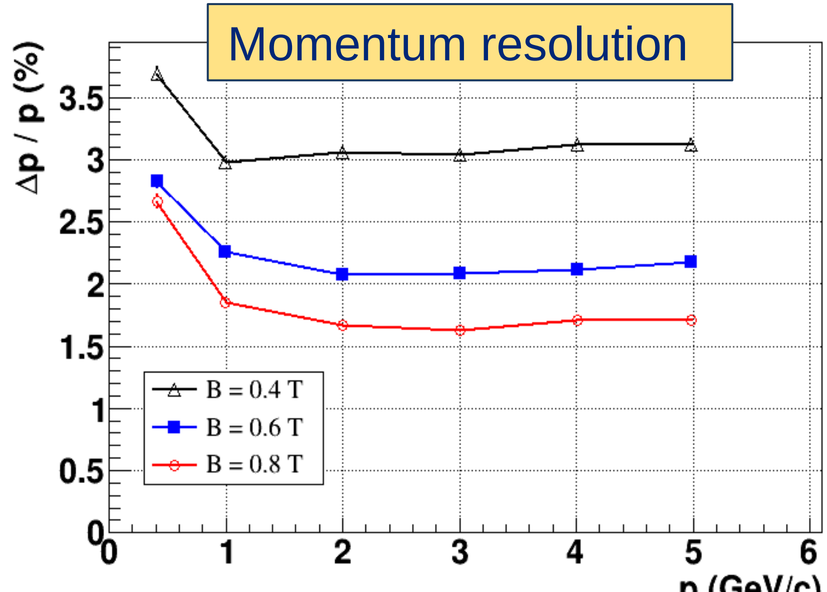
GEMs





Track reconstruction: Vector Finder (VF) – homemade package

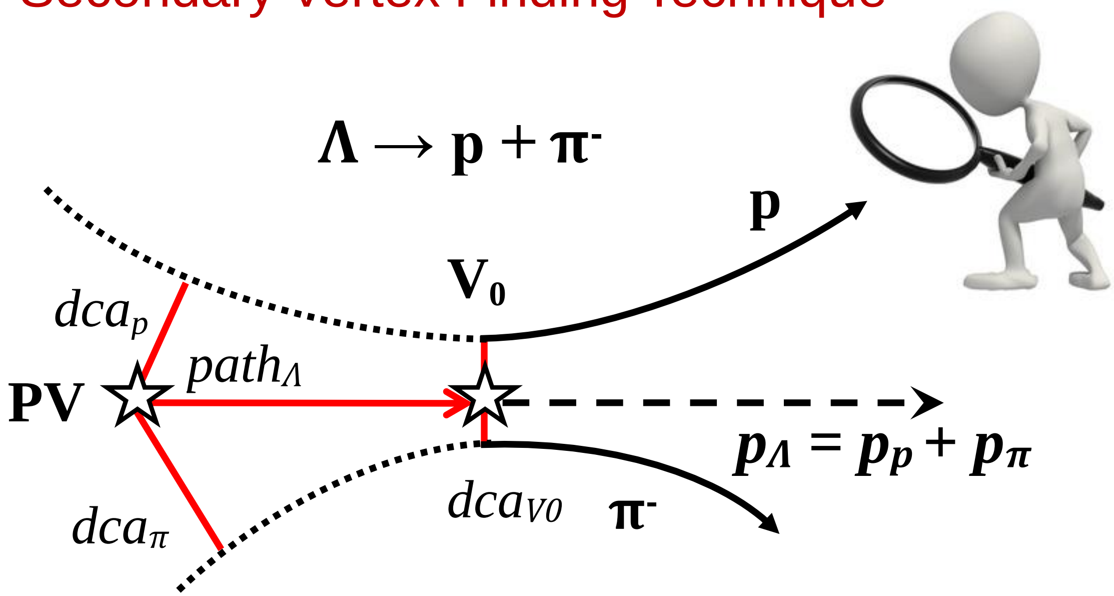


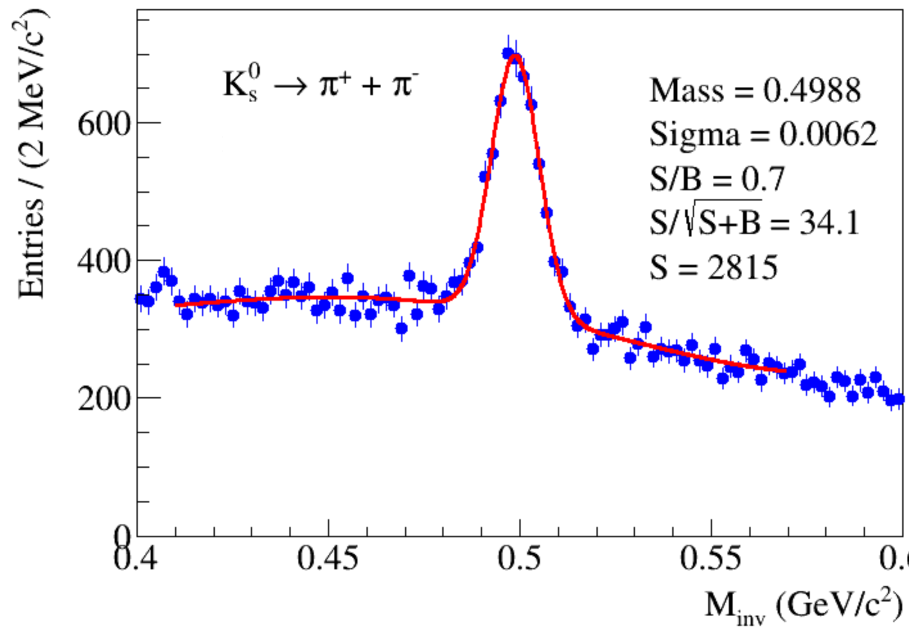


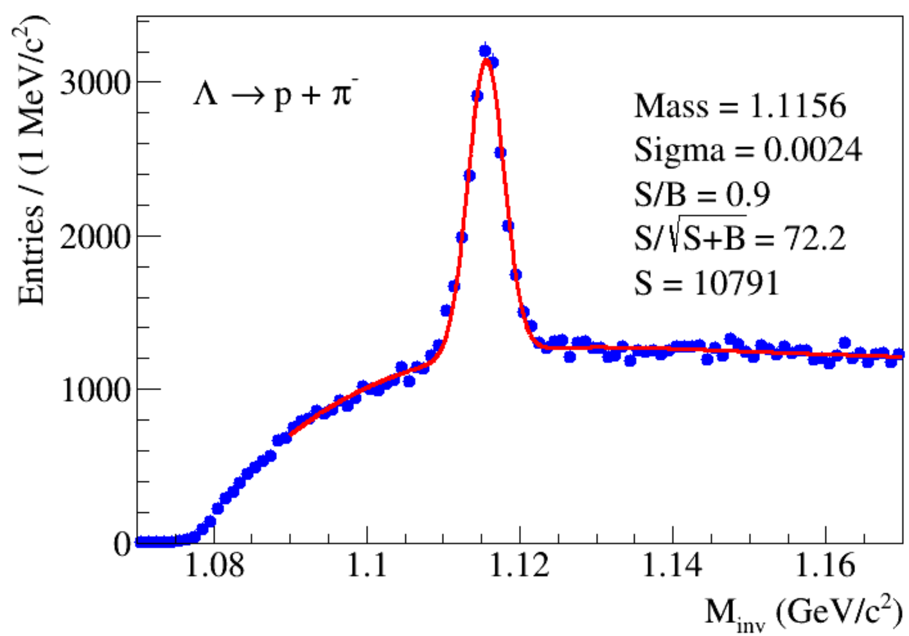
Λ and K^0_s selection

Analysis Method:

Secondary Vertex Finding Technique







Event topology:

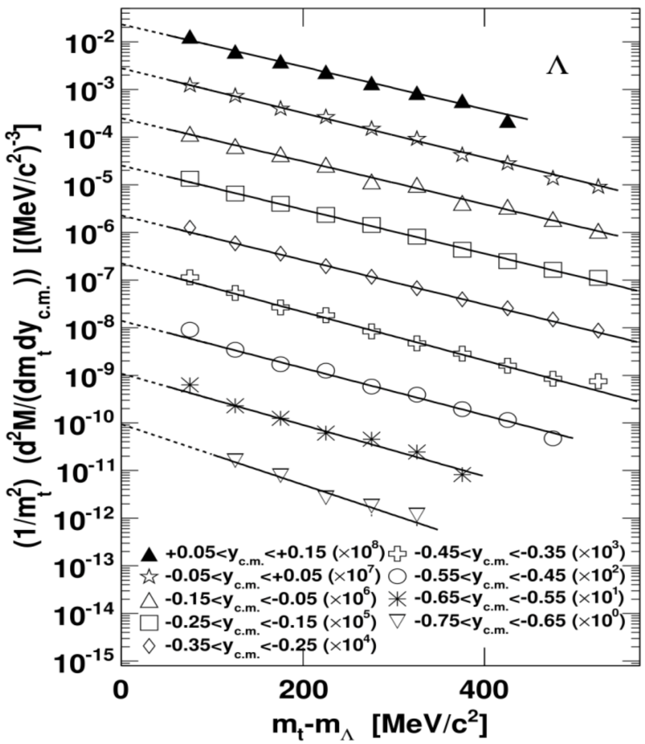
- PV – primary vertex
- V_0 – vertex of hyperon decay
- dca – distance of the closest approach
- path – decay length

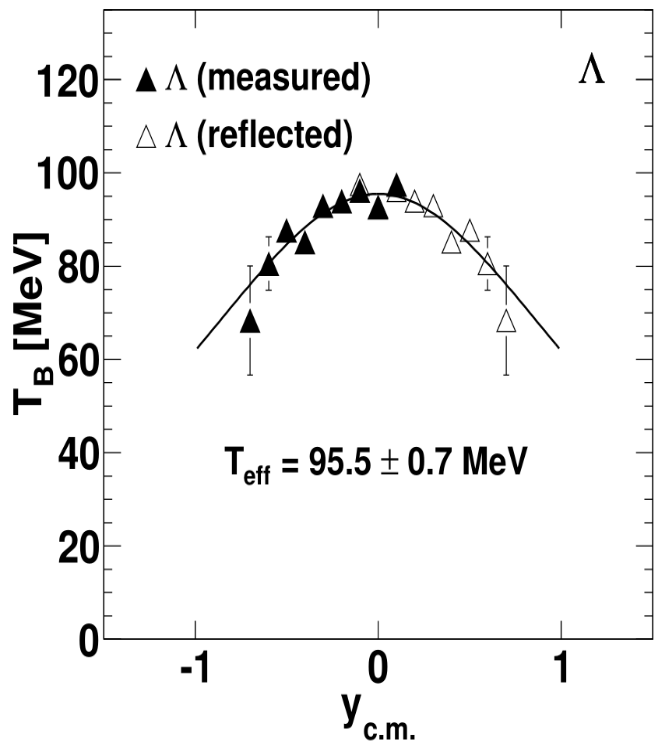
Used cuts:

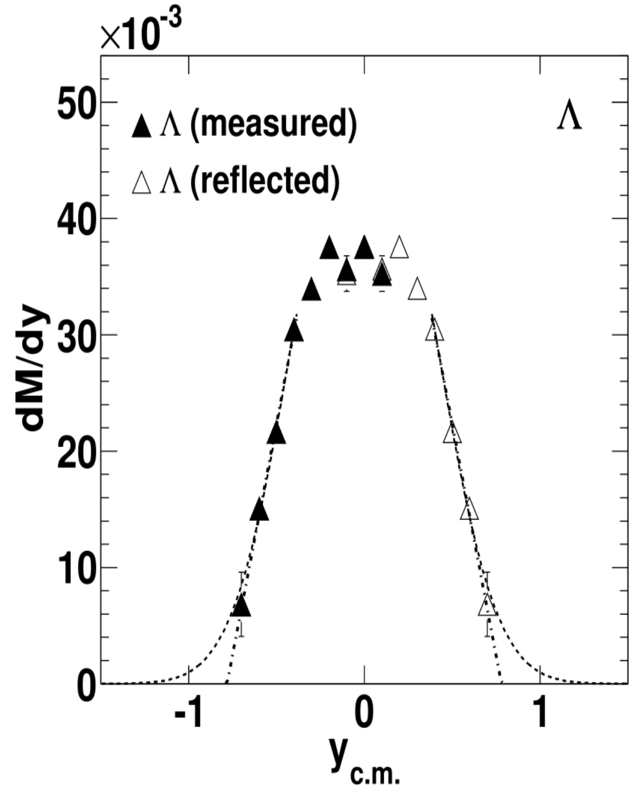
- ch2s[][0] – χ^2 of π w.r.t. primary vertex
- ch2s[][1] – χ^2 of p w.r.t. primary vertex
- c2pv – of Λ w.r.t. primary vertex

HADES strangeness production studies

"Hyperon production in Ar + KCl collisions at 1.76A GeV", *Eur. Phys. J. A 2011, 47, 21.*







Λ m_T-spectra

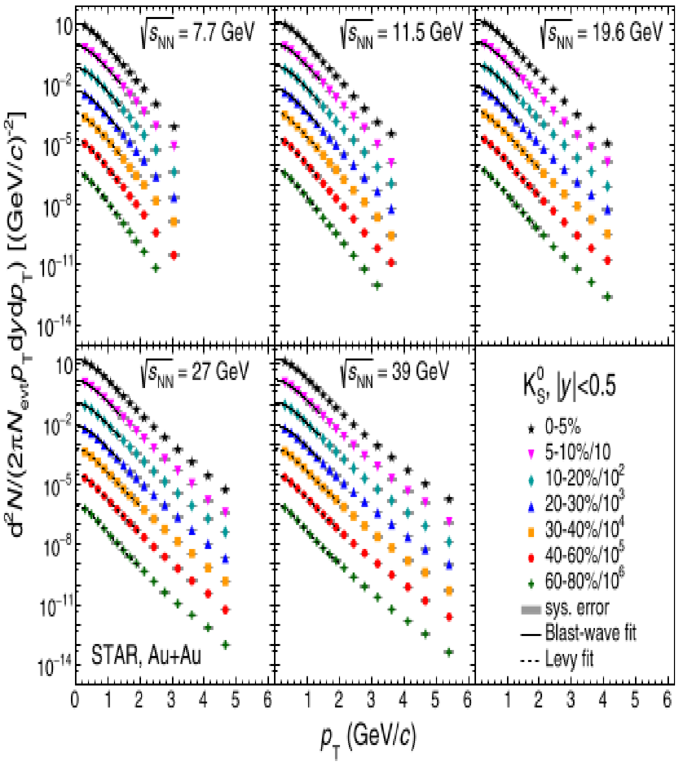
$m_T = \sqrt{m^2 + p^2_T}$

$T_{\rm eff}$ vs y_{cm}

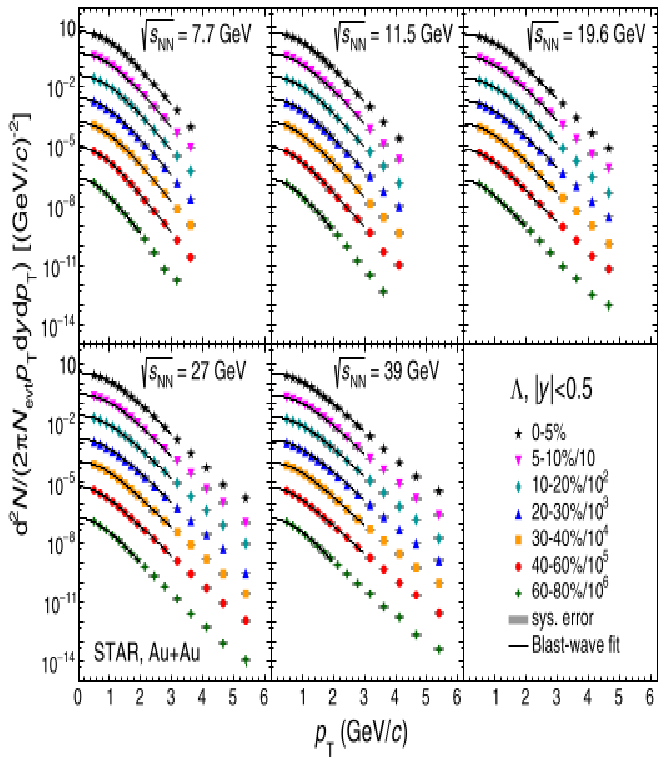
Λ y-spectrum

STAR strangeness production studies

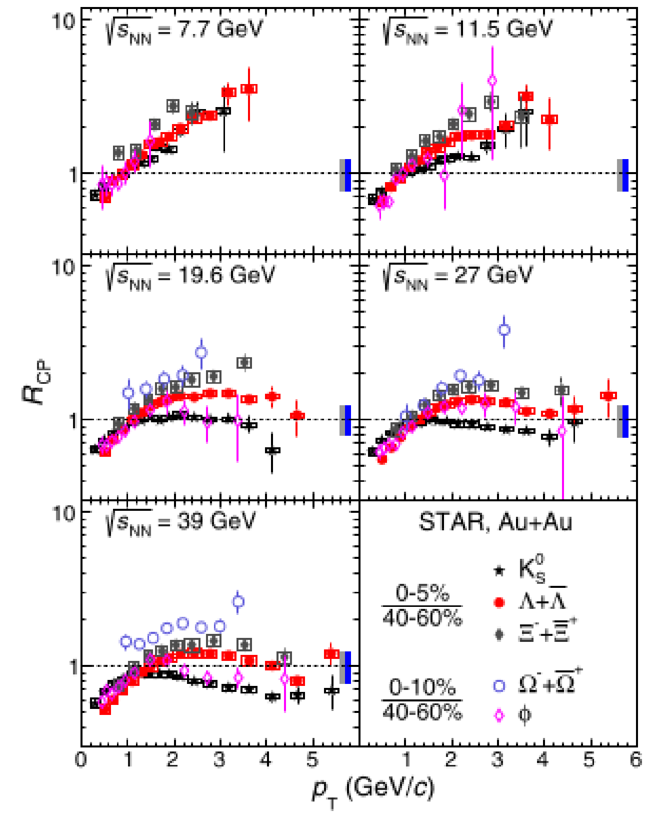
"Strange hadron production in Au + Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27 and 39 GeV", *Phys. Rev. C 2020, 102, 034909.*



K^0_s p_T-spectra

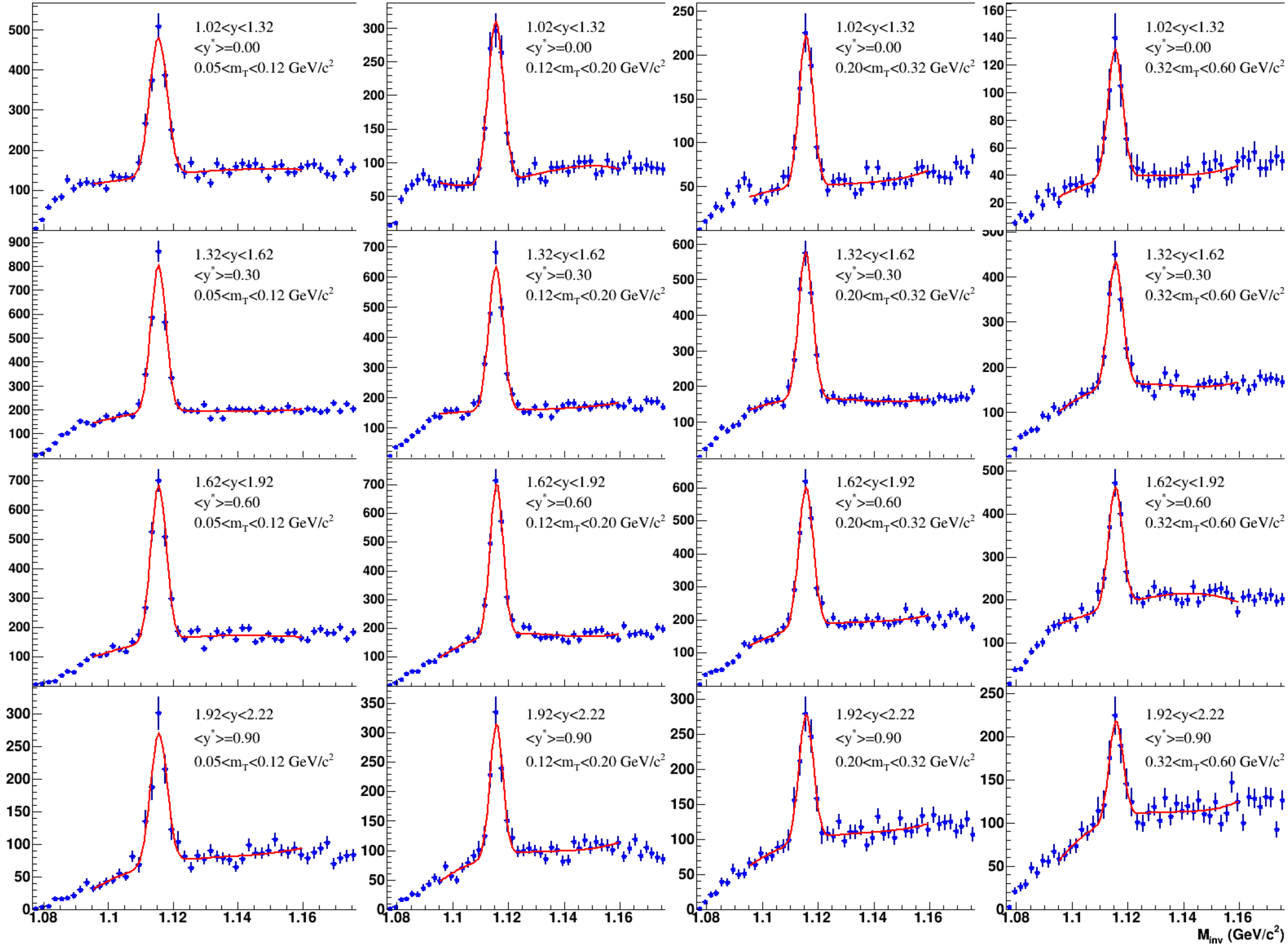


Λ p_T-spectra

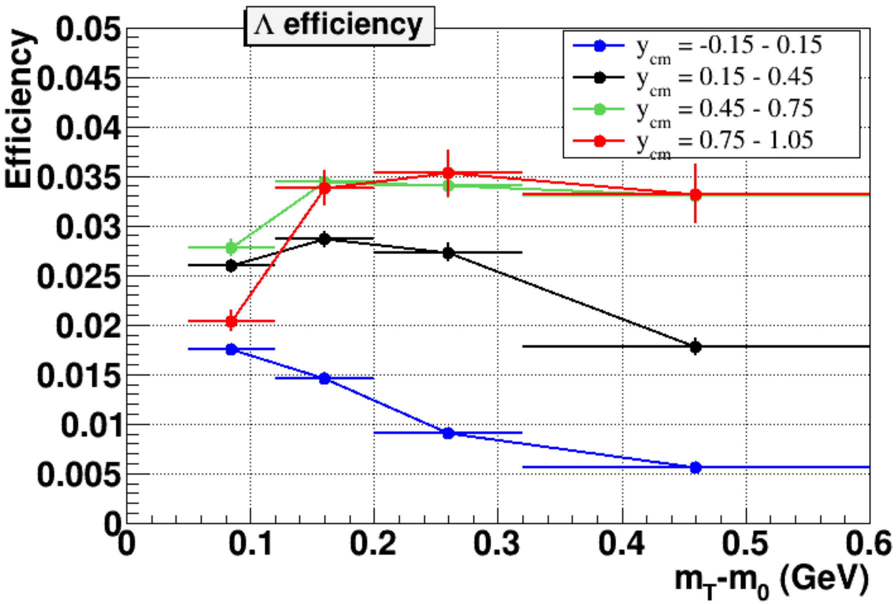


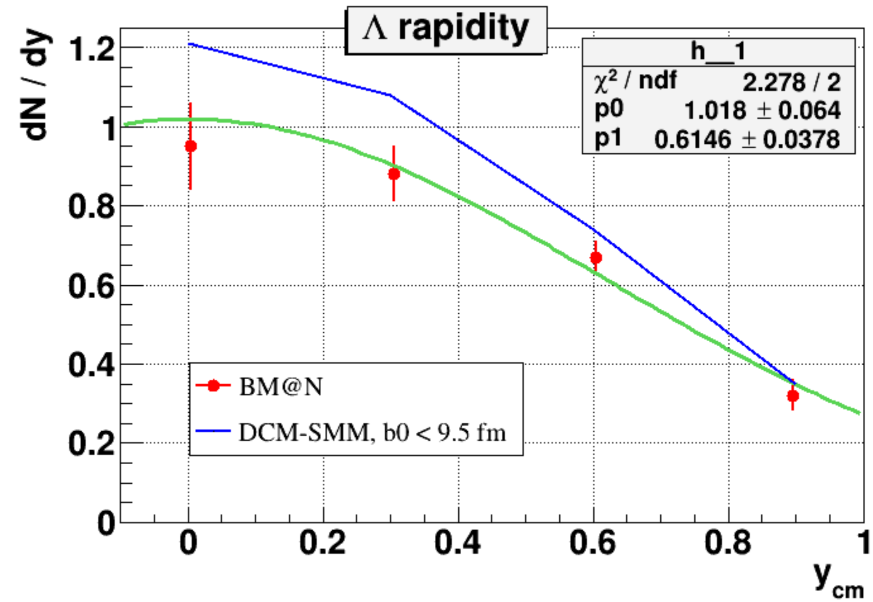
$$R_{CP} = \frac{[(dN/dp_T)/\langle N_{coll}\rangle]_{central}}{[(dN/dp_T)/\langle N_{coll}\rangle]_{peripheral}}.$$

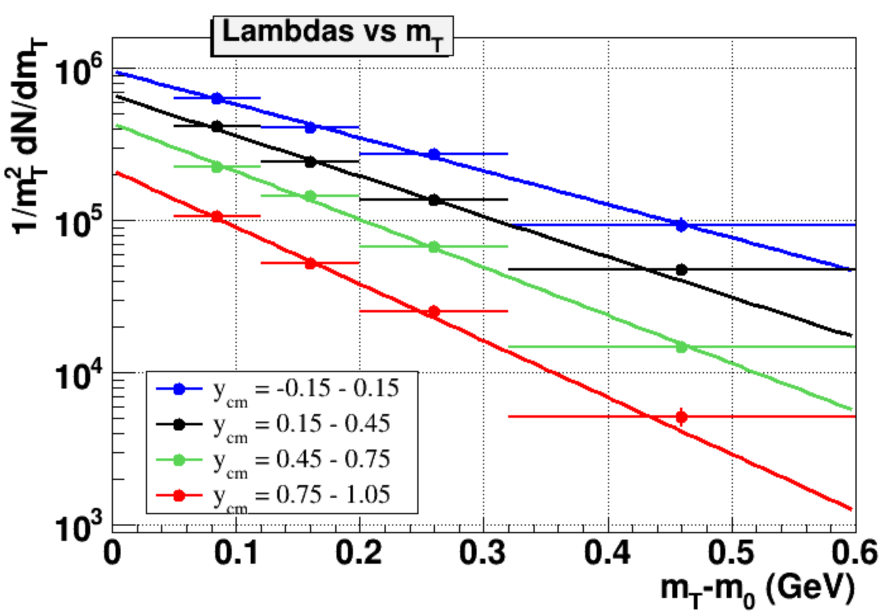
Λ: bins y vs m_T


1.02<y<1.32
<y*>=0.00
0.05<m_T<0.12 GeV/c^2
1.02<y<1.32
<y*>=0.00
0.12<m_T<0.20 GeV/c^2
1.02<y<1.32
<y*>=0.00
0.20<m_T<0.32 GeV/c^2
1.02<y<1.32
<y*>=0.00
0.32<m_T<0.60 GeV/c^2
1.32<y<1.62
<y*>=0.30
0.05<m_T<0.12 GeV/c^2
1.32<y<1.62
<y*>=0.30
0.12<m_T<0.20 GeV/c^2
1.32<y<1.62
<y*>=0.30
0.20<m_T<0.32 GeV/c^2
1.32<y<1.62
<y*>=0.30
0.32<m_T<0.60 GeV/c^2
1.62<y<1.92
<y*>=0.60
0.05<m_T<0.12 GeV/c^2
1.62<y<1.92
<y*>=0.60
0.12<m_T<0.20 GeV/c^2
1.62<y<1.92
<y*>=0.60
0.20<m_T<0.32 GeV/c^2
1.62<y<1.92
<y*>=0.60
0.32<m_T<0.60 GeV/c^2
1.92<y<2.22
<y*>=0.90
0.05<m_T<0.12 GeV/c^2
1.92<y<2.22
<y*>=0.90
0.12<m_T<0.20 GeV/c^2
1.92<y<2.22
<y*>=0.90
0.20<m_T<0.32 GeV/c^2
1.92<y<2.22
<y*>=0.90
0.32<m_T<0.60 GeV/c^2
M_inv (GeV/c^2)

Λ m_T-spectra in bins of y







https://arxiv.org/abs/1010.1675v3

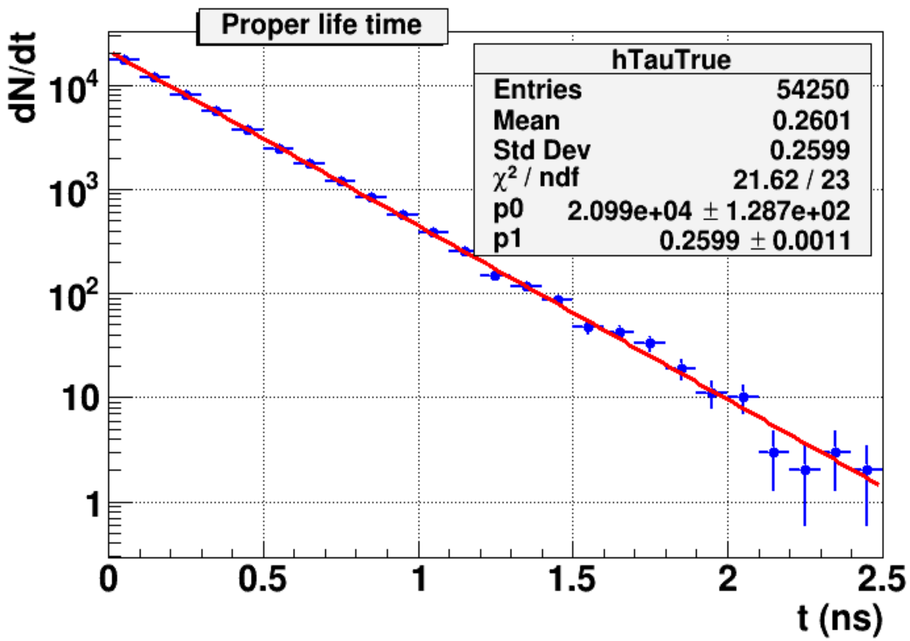
Boltzman distribution from HADES paper:

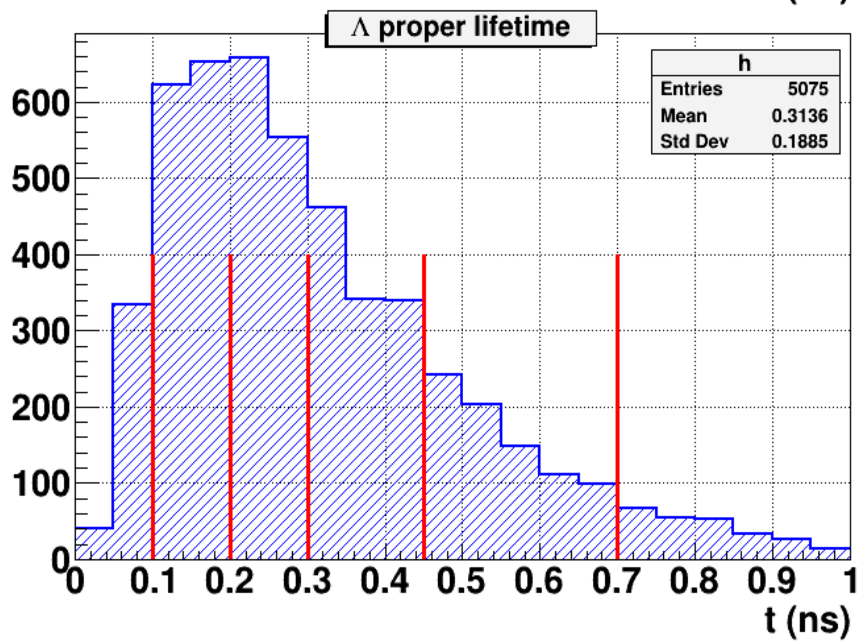
$$\frac{1}{m_t^2}\frac{d^2M}{dm_t dy} = C(y)\exp\left(-\frac{(m_t - m_0)c^2}{T_B(y)}\right)$$

Effective temperature T:

T = 198±12, 164±7, 138±4, 117±6 MeV

Lifetime of Λ: MC





Decay formula:

$dN / dt = N_0 / \tau * exp(-t/\tau)$,

$N_0 = p0 * p1$ = 54574

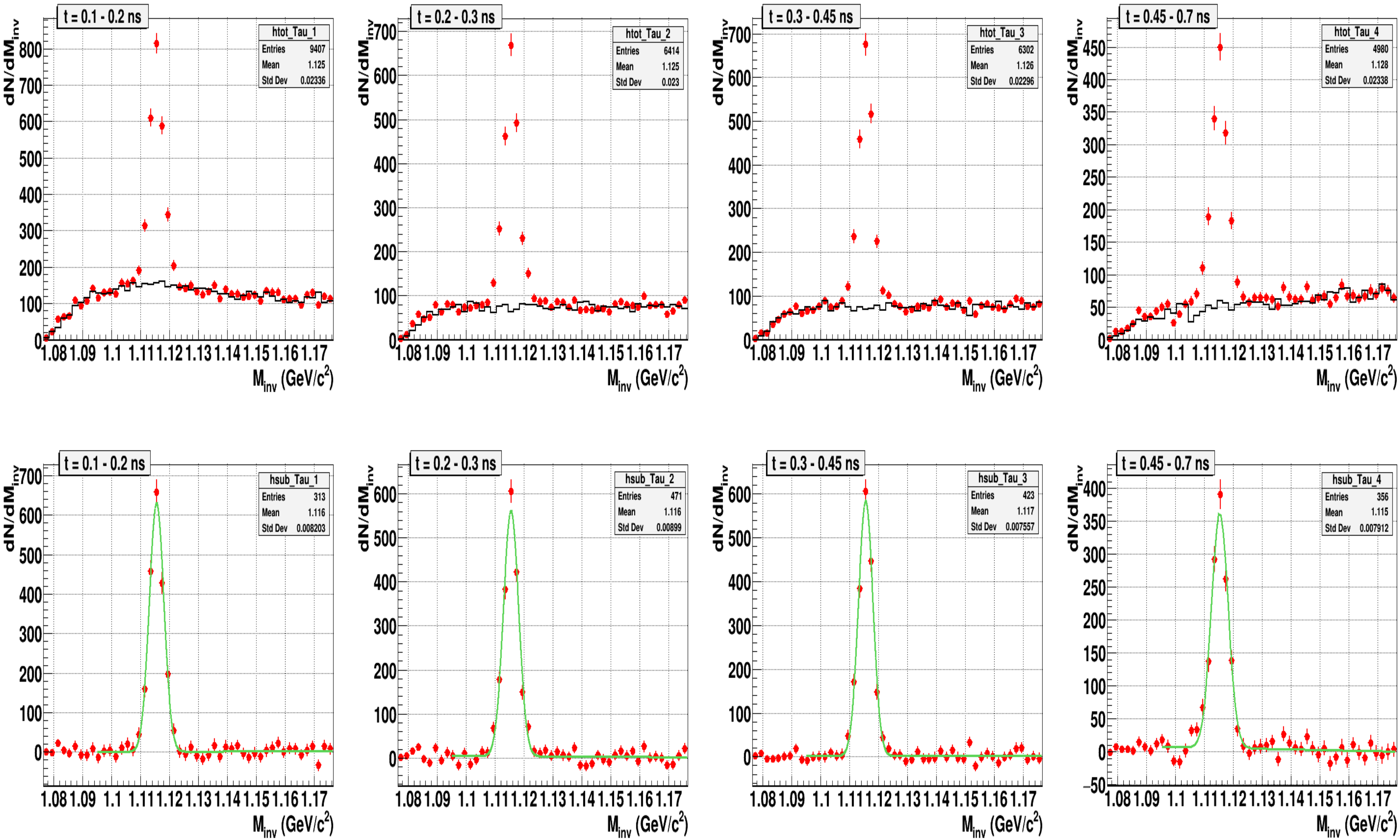
Proper life time:

$\tau = lm / (pc)$

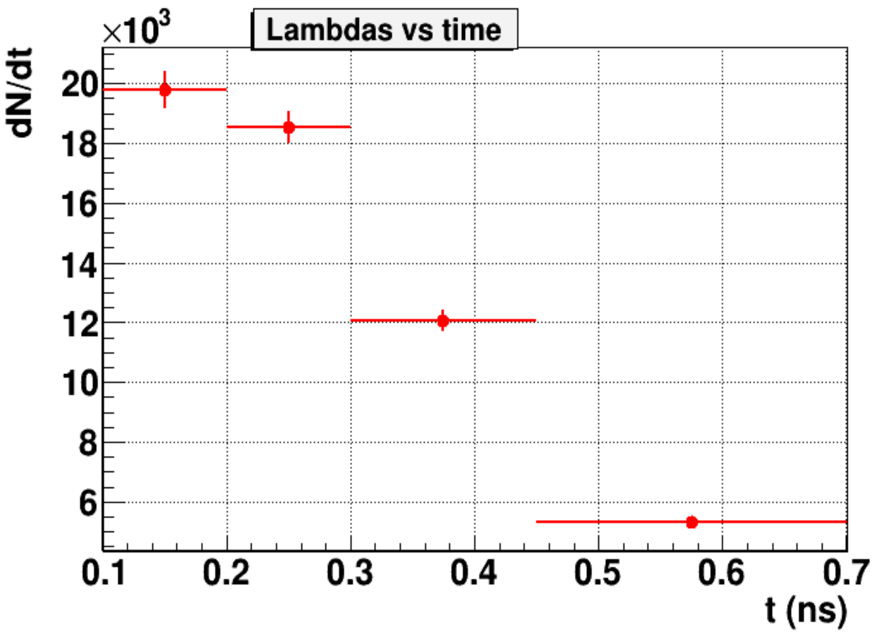
Used statistics:

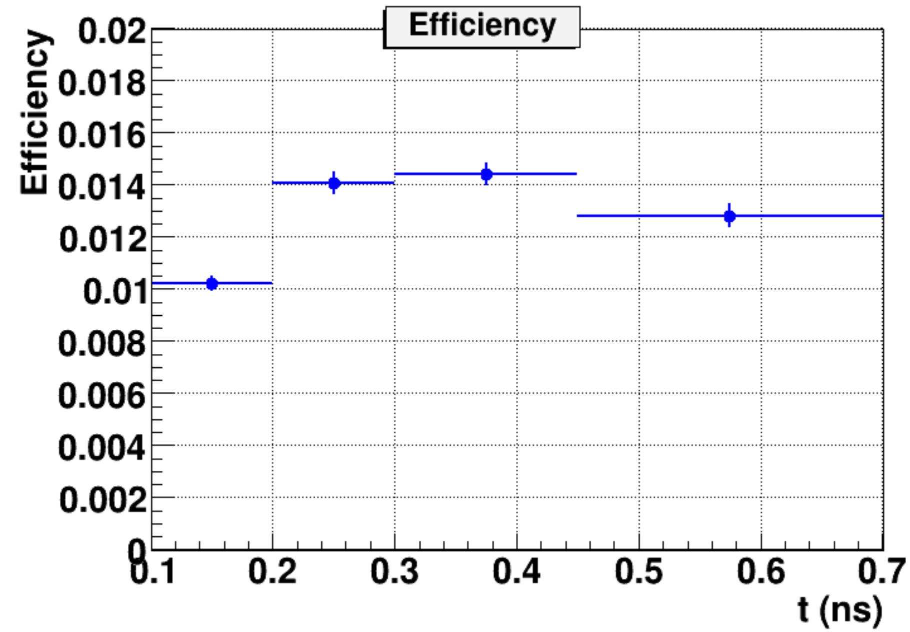
1M MC events
1M exp. data (run 7830)

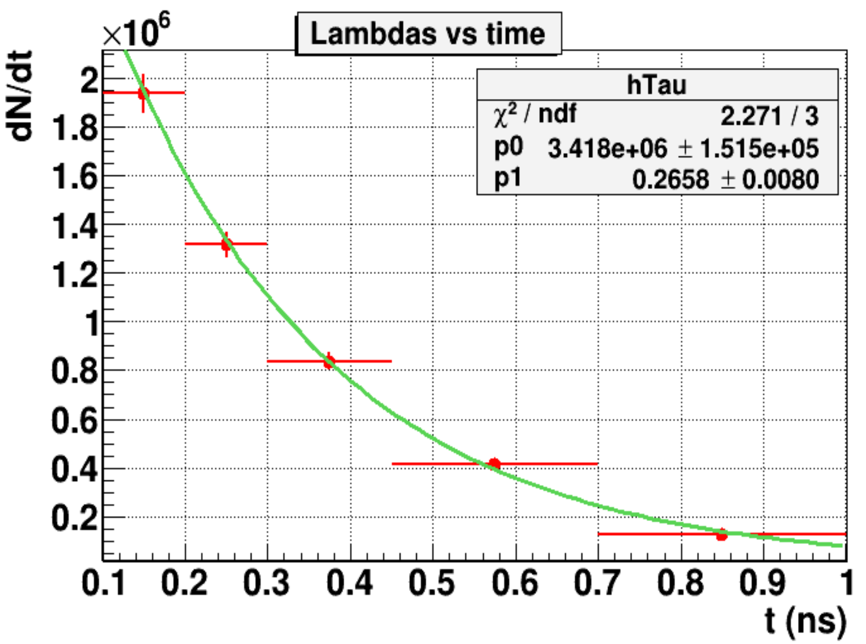
Mixed background subtraction: Data



Λ raw yield and efficiency





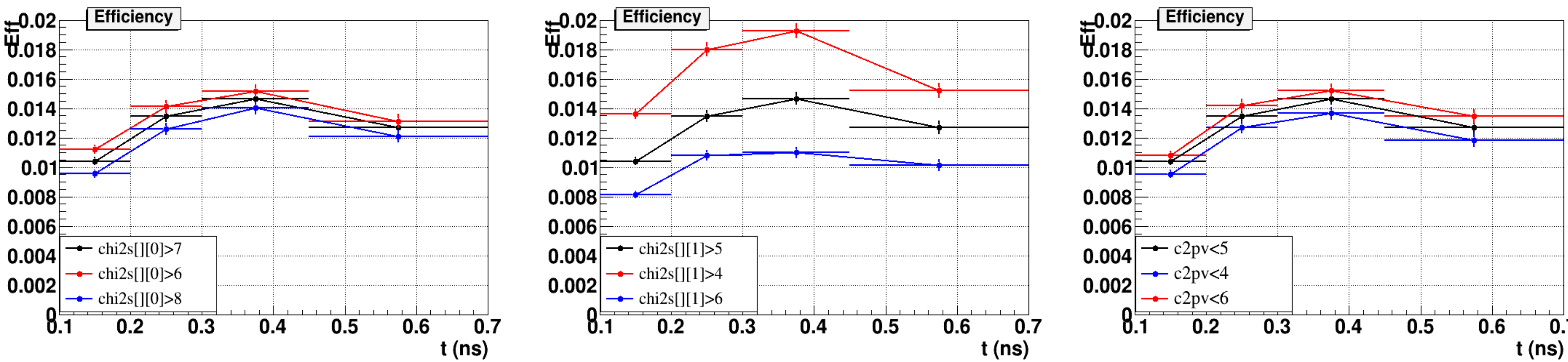


Efficiency-corrected yield vs lifetime

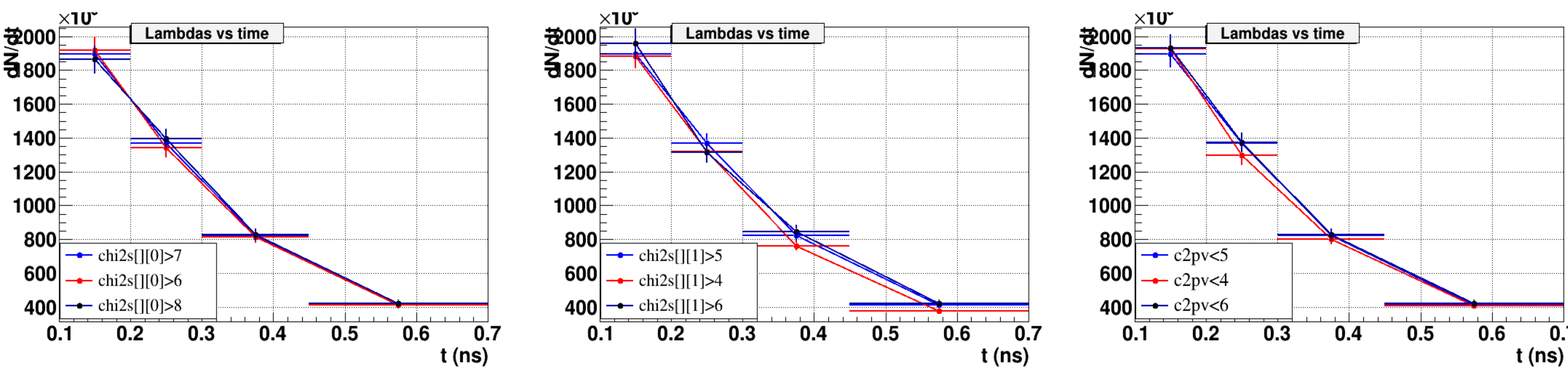
Lifetime of Λ

Cuts: chi2s[][0]>7&&chi2s[][1]>5&&c2pv<5&&pts[][0]>0.05&&pts[][1]>0.1

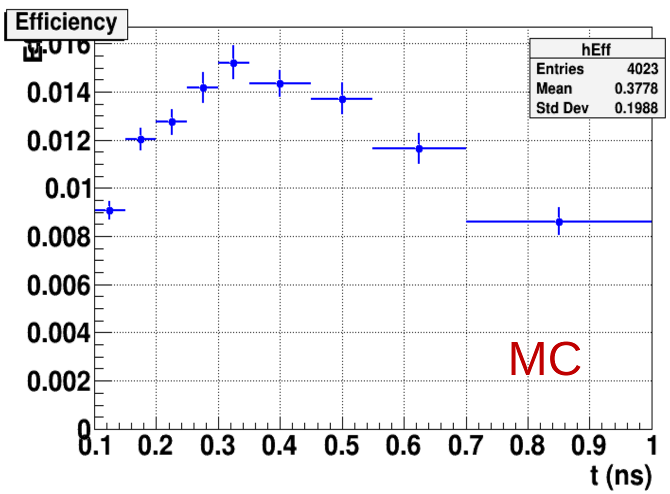
MC

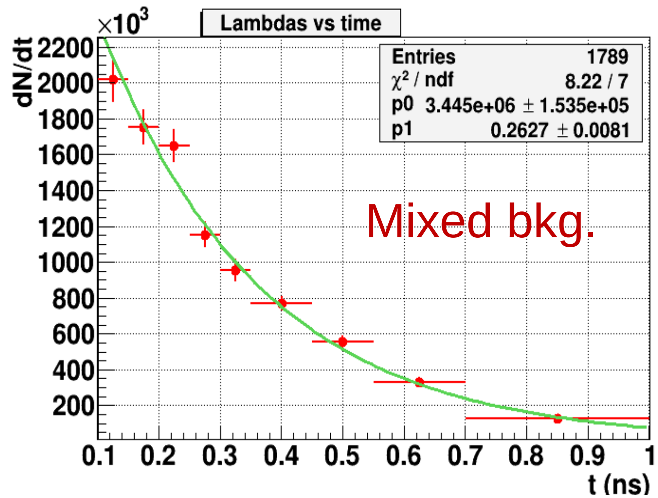


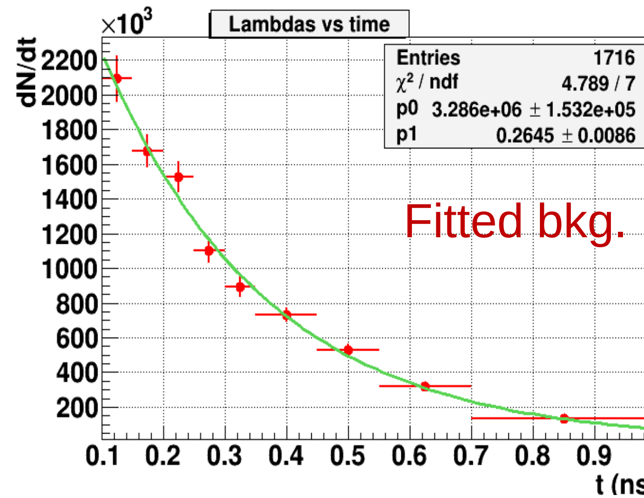
Data corrected for efficiency



Lifetime of Λ



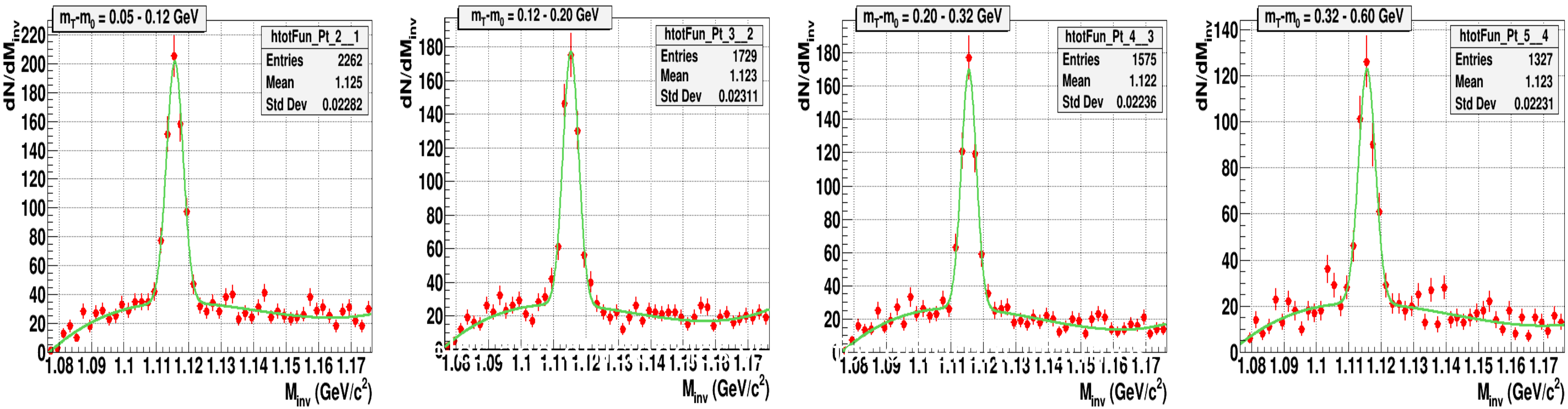




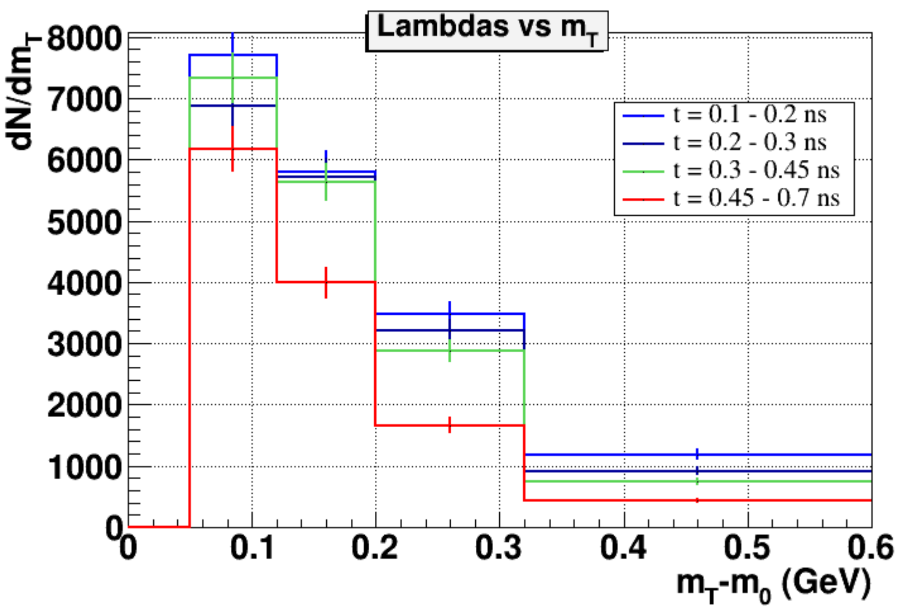
3 cuts:	centr. Value	c2pv<4	c2pv<6	chi2s[1]>4	chi2s[1]>6	chi2s[0]>6	chi2s[0]>8
τ, ns	0.270±0.011	0.262±0.011	0.265±0.011	0.254±0.010	0.263±0.012	0.266±0.011	0.269±0.012
Mult.	1.499±0.100	1.430±0.100	1.460±0.100	1.360±0.090	1.500±0.110	1.420±0.100	1.470±0.100
χ^2/NDF	1.01 / 2	1.00 / 2	0.63 / 2	2.23 / 2	1.49 / 2	0.88 / 2	1.10 / 2

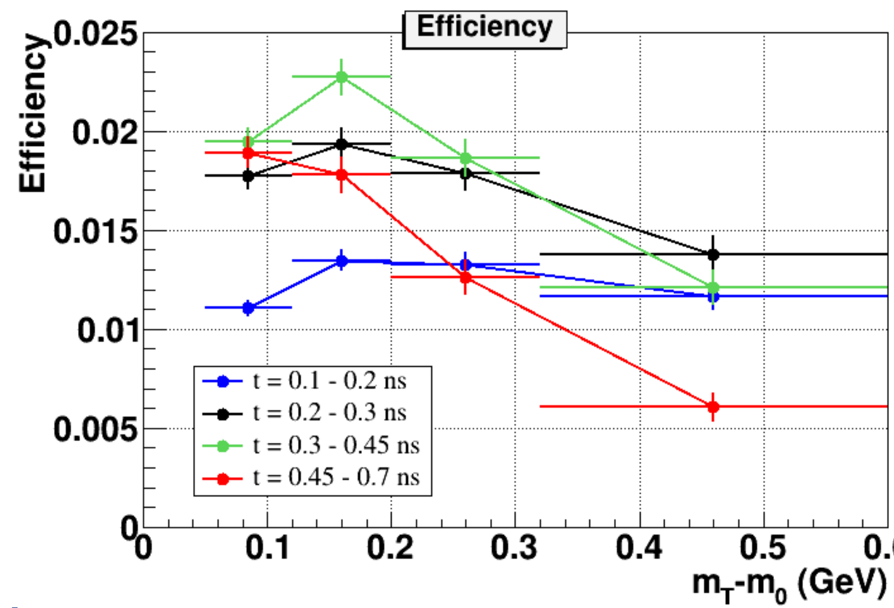
Λ m_T-spectra for different lifetimes

Λ M_{inv} spectra for lifetime 0.1-0.2 ns



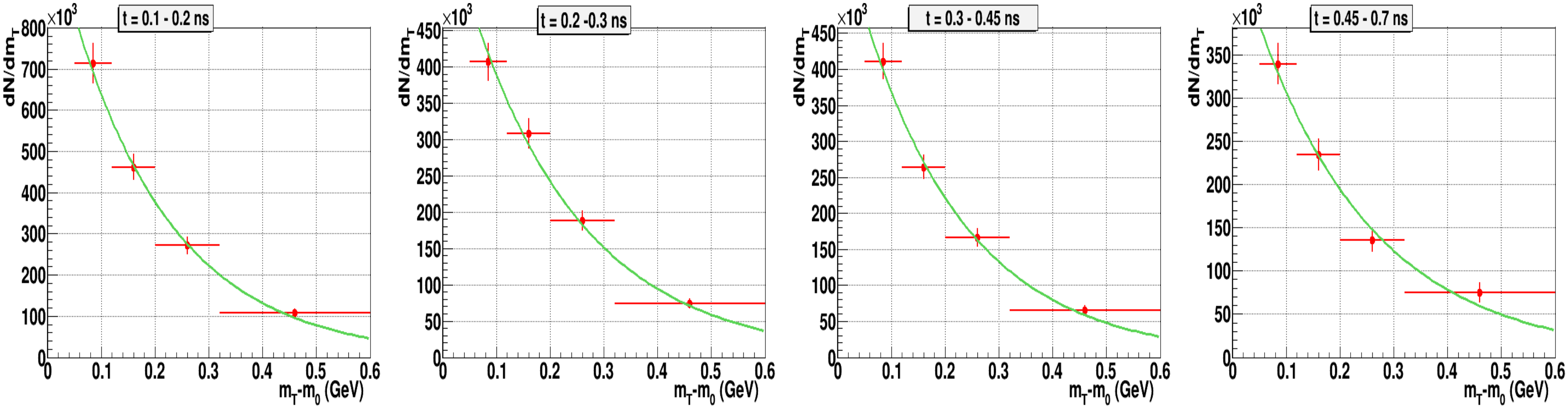
Yields and efficiencies vs m_T for different lifetimes

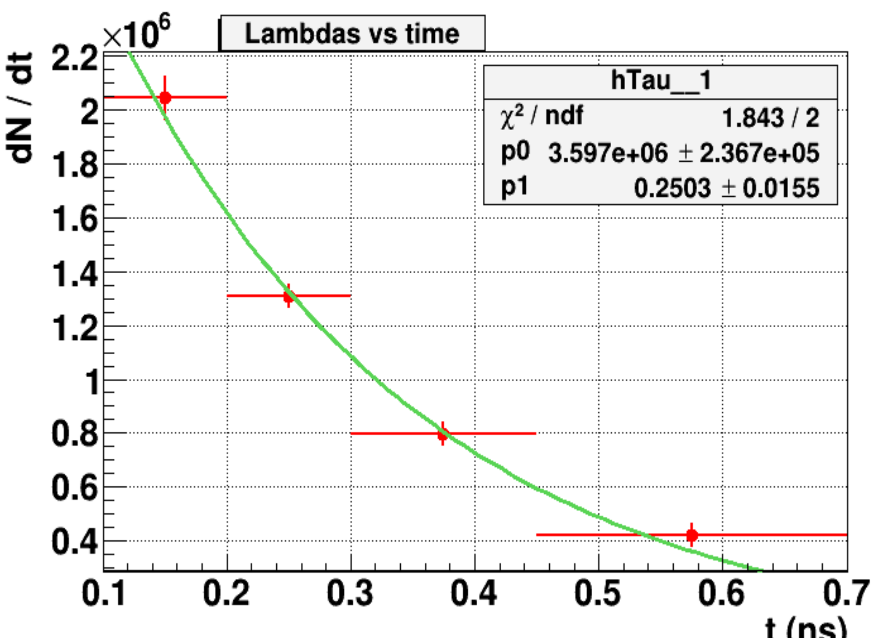




Λ m_T-spectra for different lifetimes

Corrected for efficiency m_T-spectra for different lifetimes





Λ decay curve reconstructed from integrated m_T-spectra

Λ m_T-spectra for different lifetimes

Effective temperatures for different lifetimes

https://arxiv.org/abs/1010.1675v3

Boltzman distribution from HADES paper:

$$\frac{1}{m_t^2}\frac{d^2M}{dm_t dy} = C(y)\exp\left(-\frac{(m_t - m_0)c^2}{T_B(y)}\right)$$

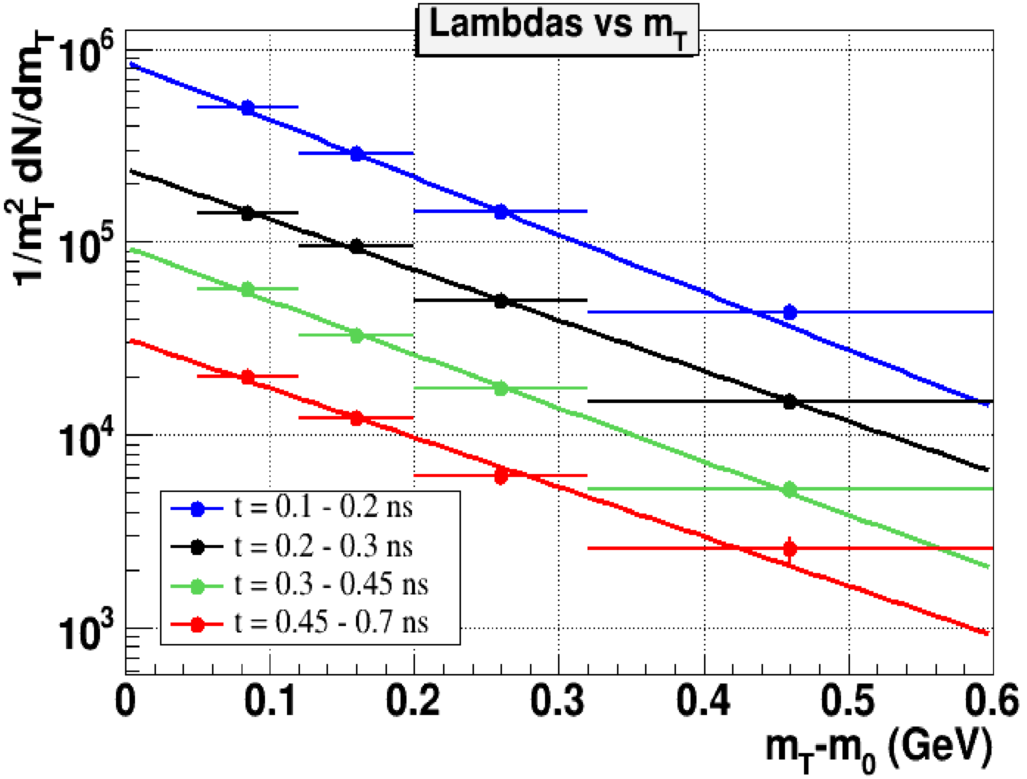
Effective temperature (MeV):

T1 = 146±7

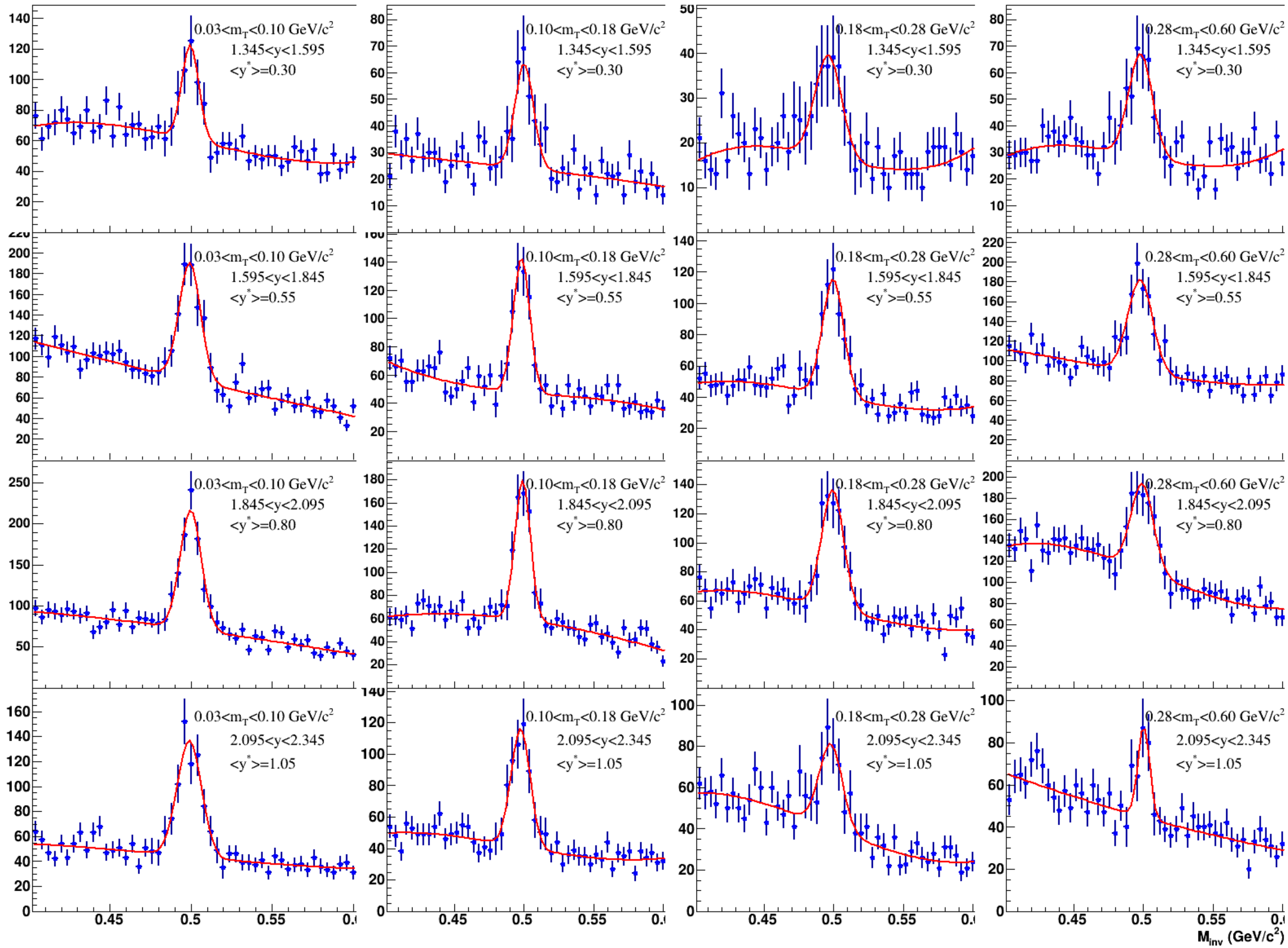
T2 = 158±8

T3 = 149±8

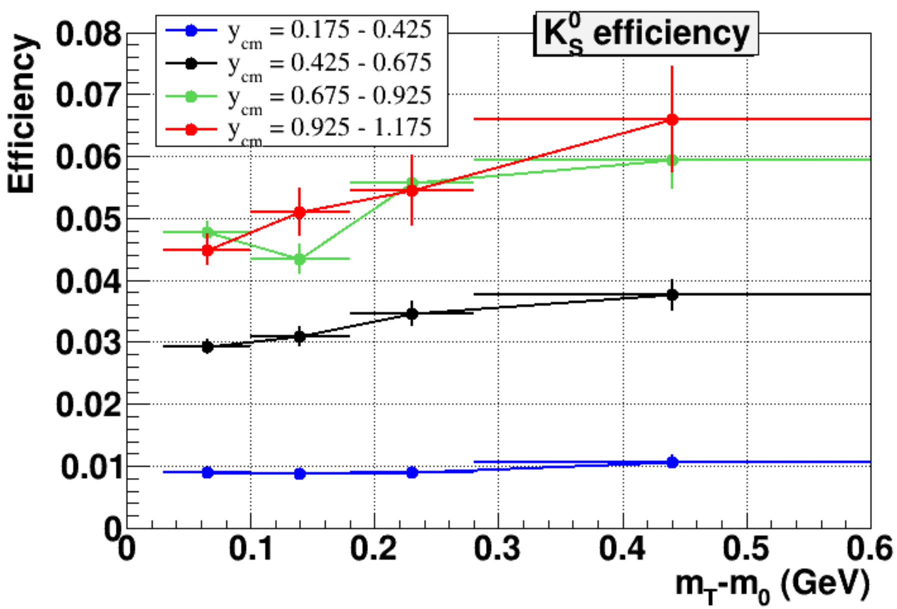
T4 = 163±13

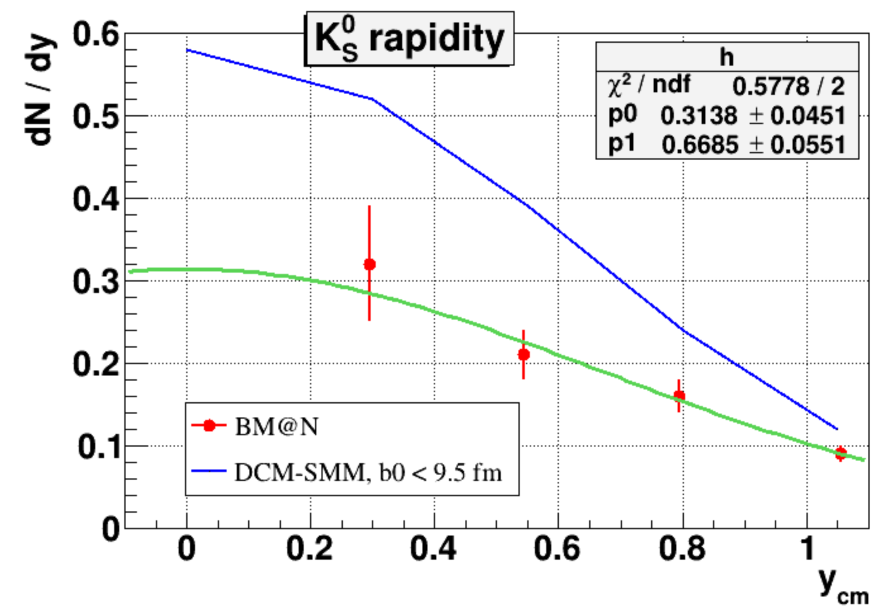


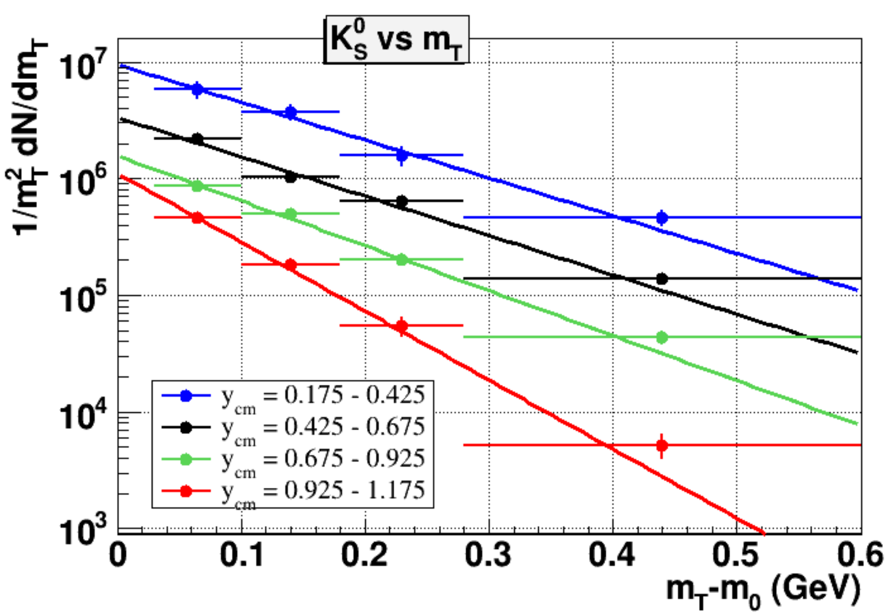
K^0_s: bins y vs m_T



K^0_s m_T-spectra in bins of y







https://arxiv.org/abs/1010.1675v3

Boltzman distribution from HADES paper:

$$\frac{1}{m_t^2}\frac{d^2M}{dm_t dy} = C(y)\exp\left(-\frac{(m_t - m_0)c^2}{T_B(y)}\right)$$

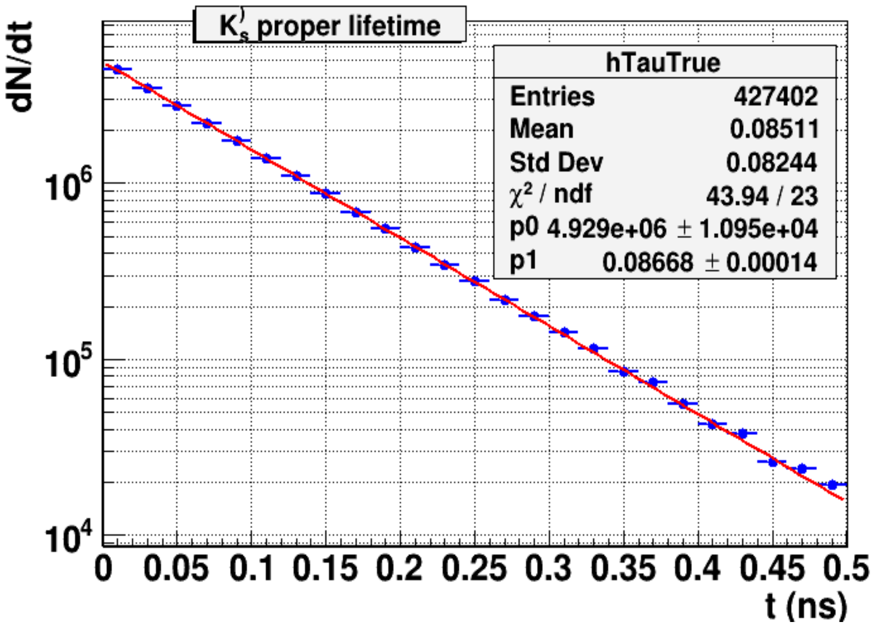
T = 134±13, 129±8, 113±6, 73±4 MeV

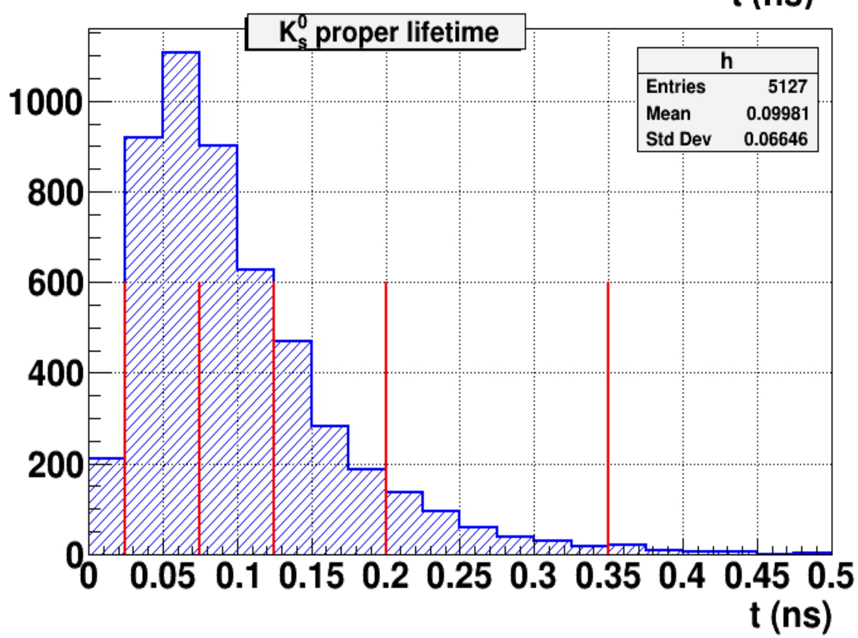
Summary and Look into the future

- ✓ The procedure for Λ and K^0_s analysis in the BM@N experiment was implemented and tested
- ✓ Large-statistics processing is under way
- ✓ Centrality selection and trigger efficiency corrections are being worked on

Backup slides

Lifetime of K^0_s: MC





Decay formula:

$dN / dt = N_0 / \tau * exp(-t/\tau)$,

$N_0 = p0 * p1 = 427241$

Proper life time:

$\tau = lm / (pc)$

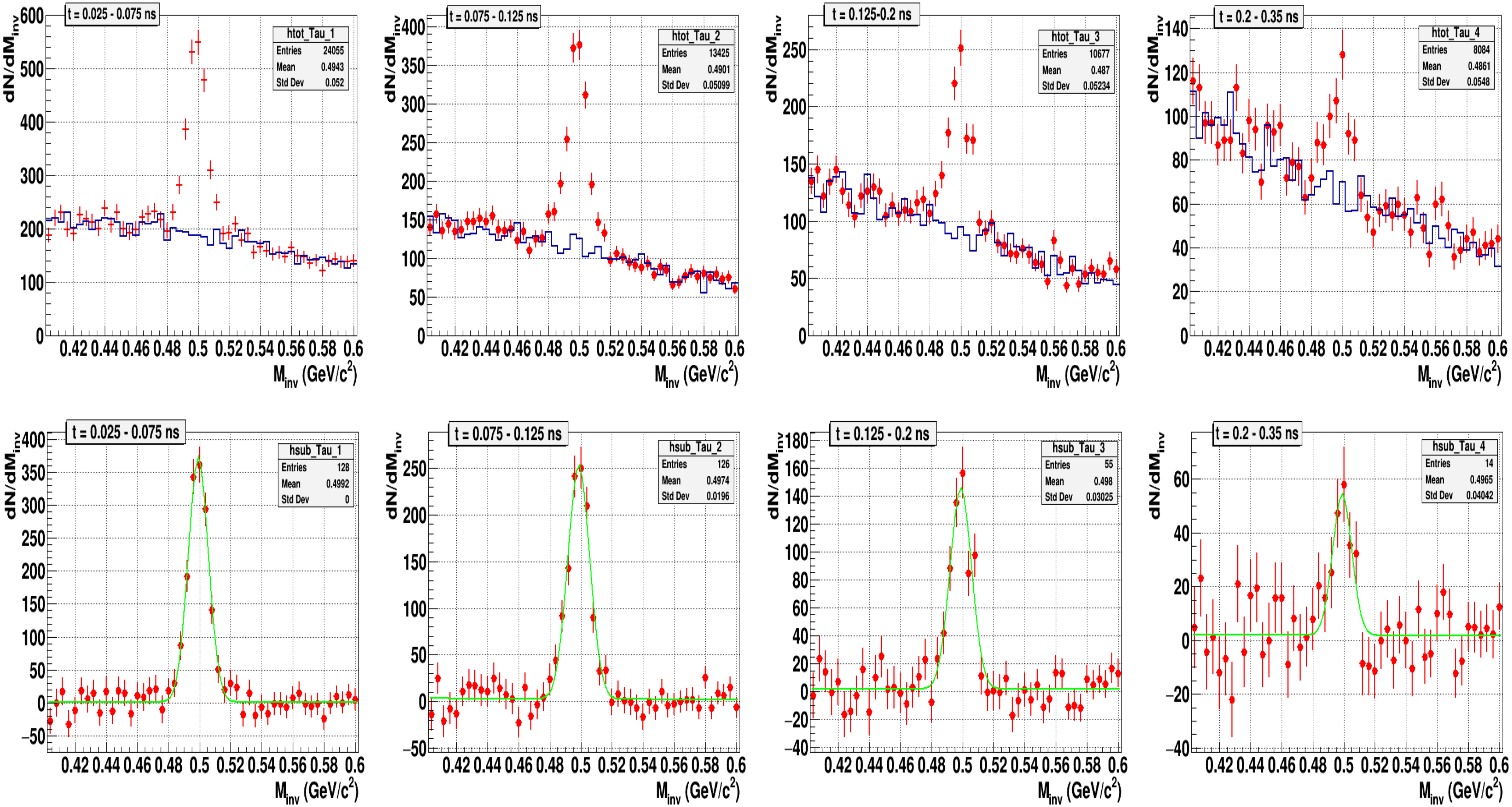
Table value τ= 0.0895 ns

Used statistics:

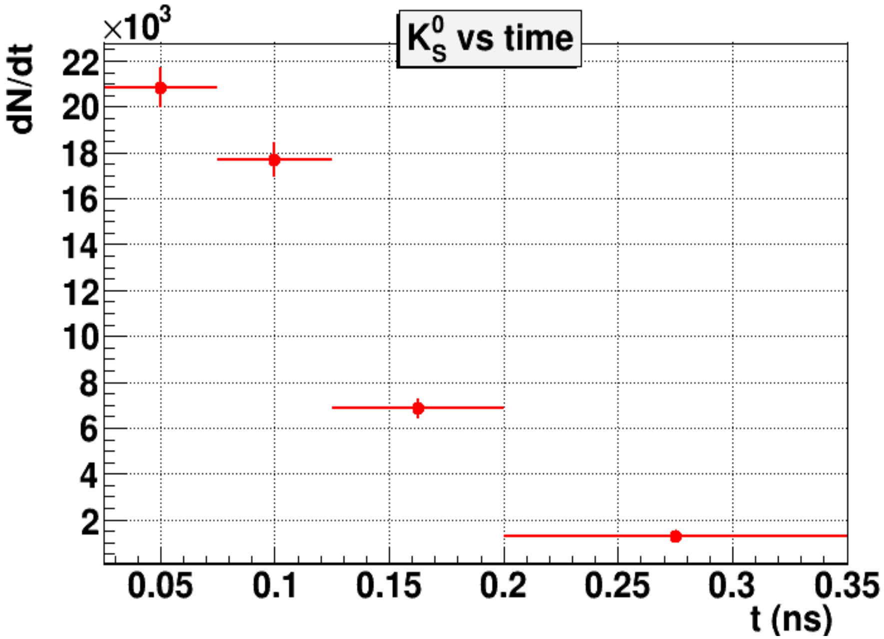
1M MC events
1M exp. data (run 7830)

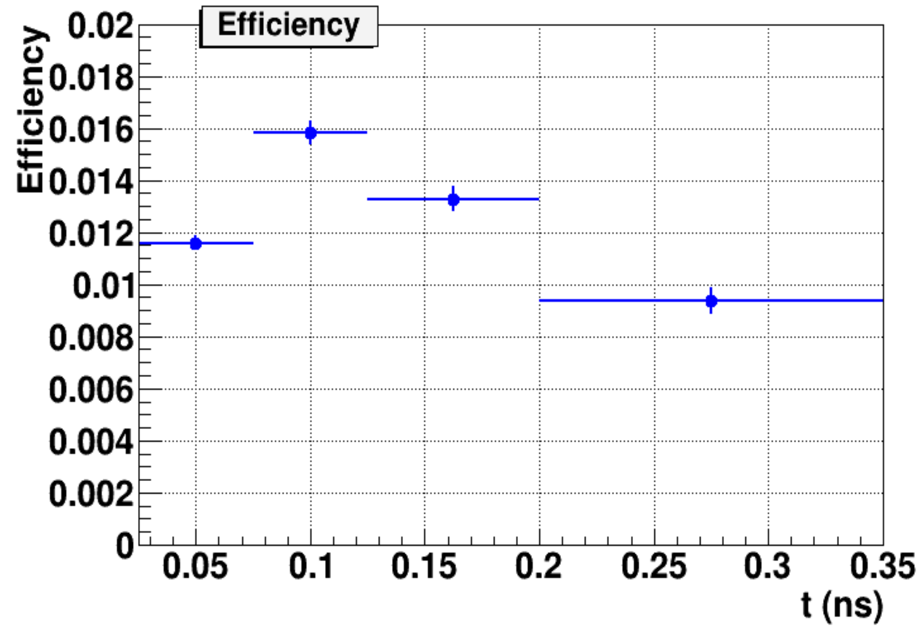
K^0_s invariant mass distributions

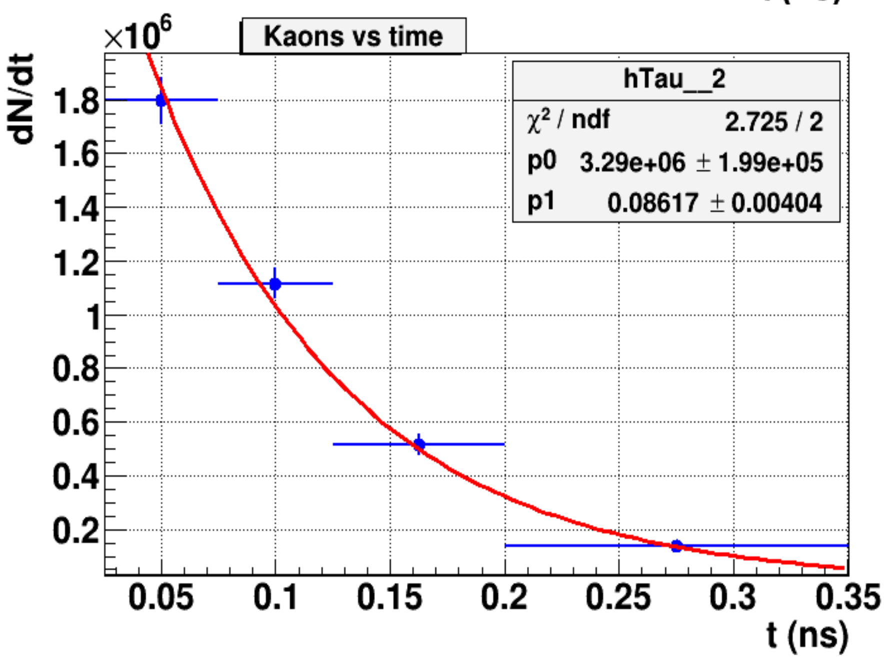
For different lifetimes



K^0_s raw yield and efficiency







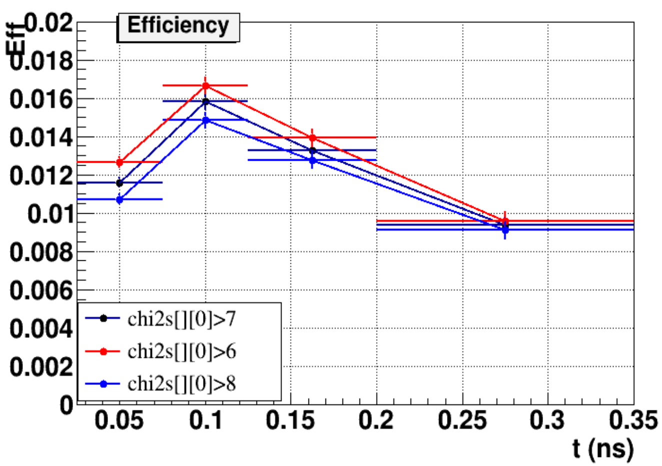
Efficiency-corrected yield vs lifetime

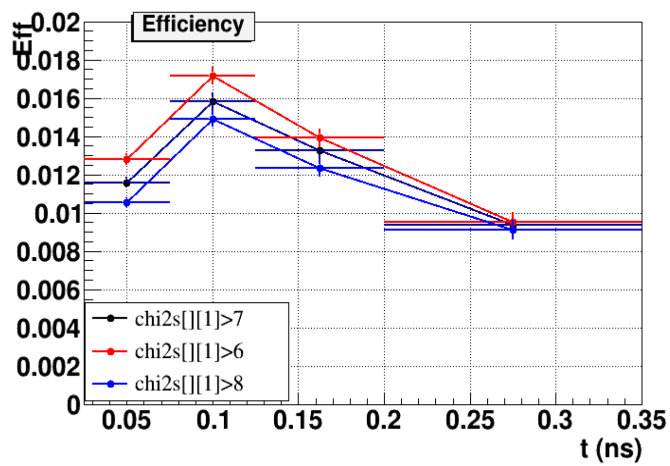
K^0_s: efficiencies and yields

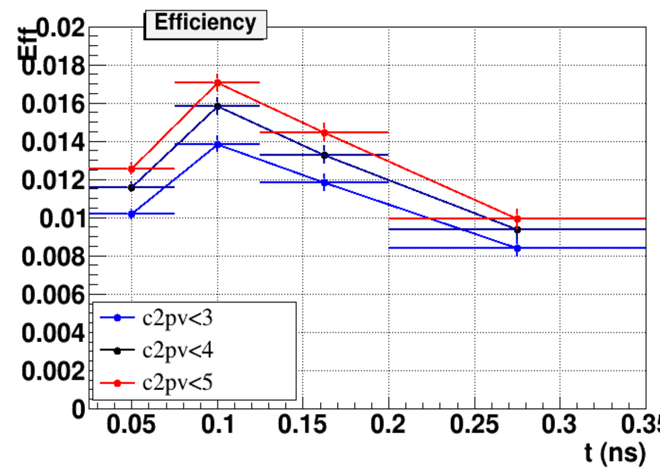
K^0_s efficiencies and corrected yields vs lifetime for different selection cuts

Cuts: $\chi^2_{\pi} > 7 \&\& \chi^2_{\pi} > 7 \&\& \chi^2_{K} < 4 \&\& p_{\pi+} < 3$

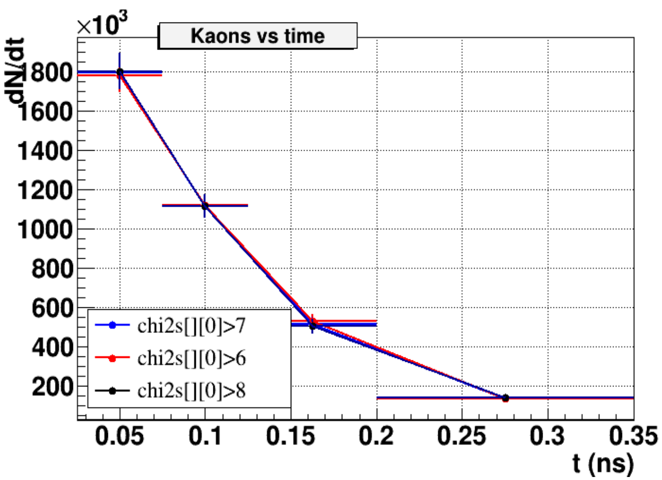
From Monte Carlo

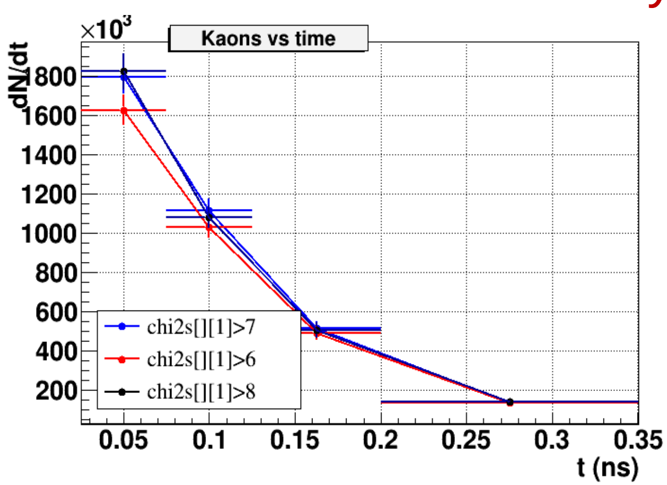


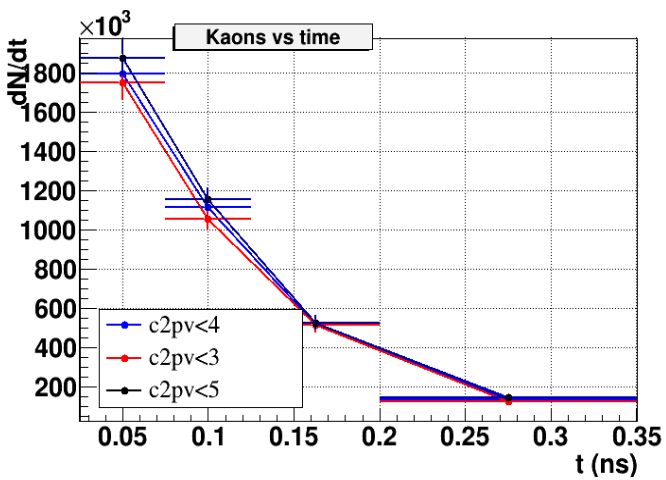




Data corrected for efficiency

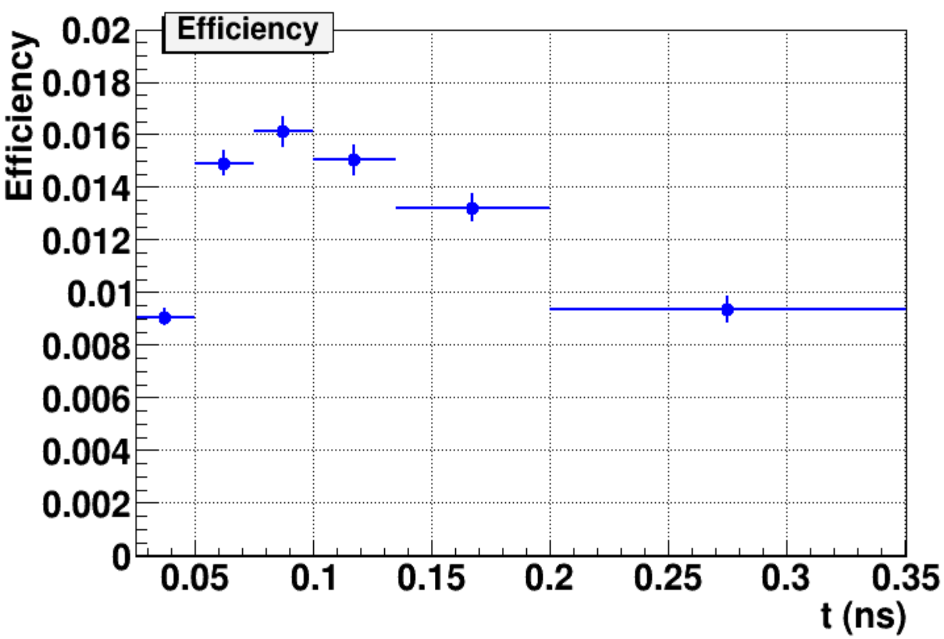






K^0_s: efficiencies and decay curve

For 6 lifetime bins



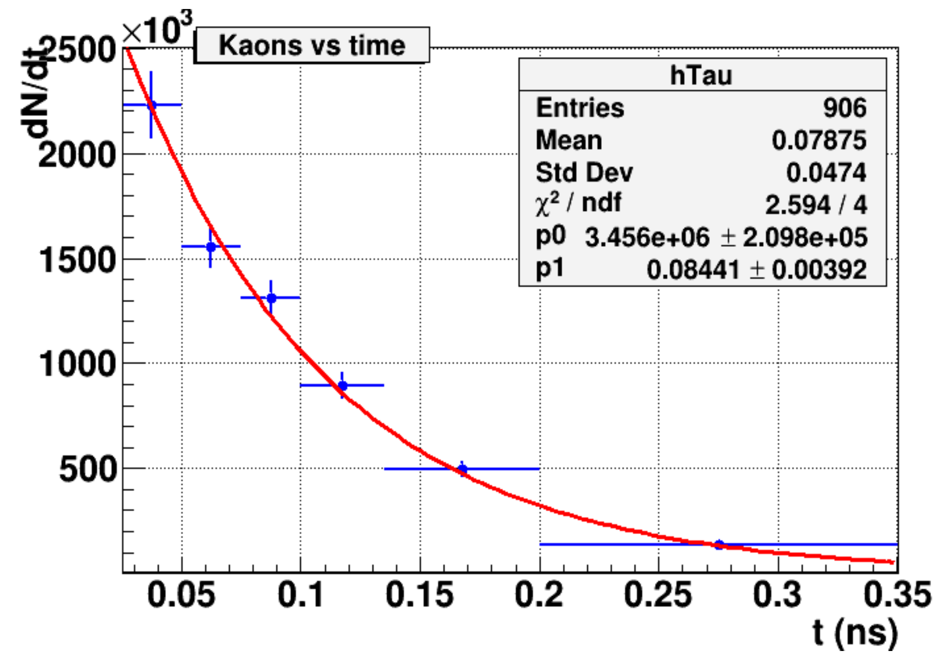
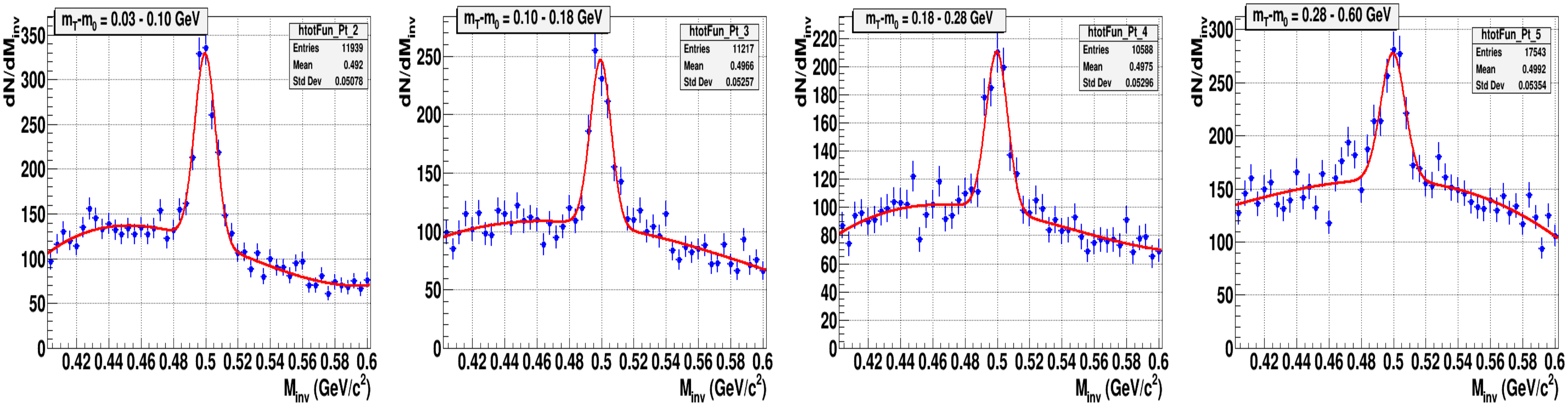


Table mean lifetime value τ = 0.08954 ± 0.00004 ns

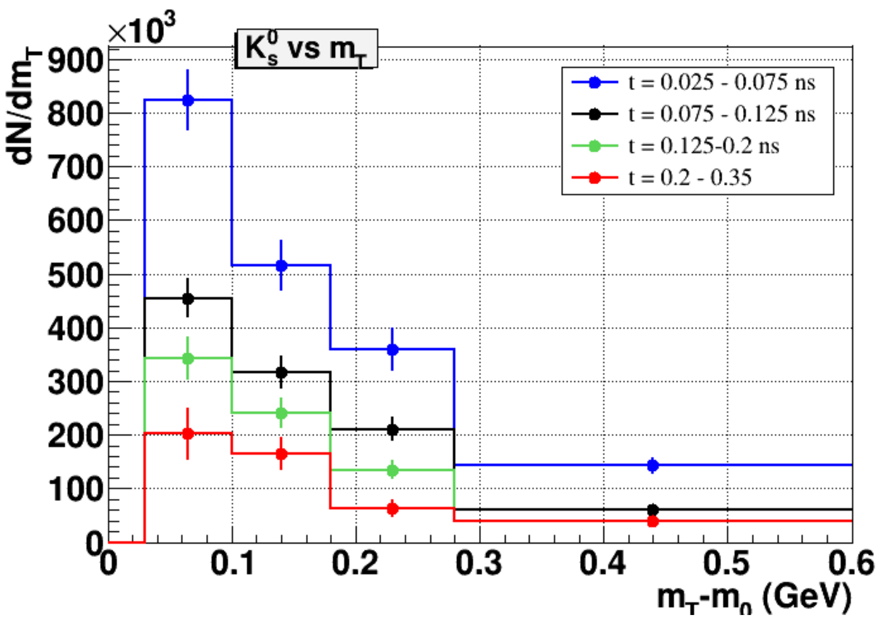
3 cuts:	centr. value	c2pv<3	c2pv<5	chi2s[1]>6	chi2s[1]>8	chi2s[0]>6	chi2s[0]>8
τ, ns	0.082±0.004	0.086±0.004	0.086±0.004	0.090±0.004	0.085±0.004	0.087±0.004	0.086±0.004
Mult.	0.473±0.036	0.457±0.036	0.492±0.038	0.436±0.034	0.471±0.037	0.473±0.035	0.473±0.037
χ^2 / NDF	2.73 / 2	2.27 / 2	2.27 / 2	2.72 / 2	1.06 / 2	3.40 / 2	2.26 / 2

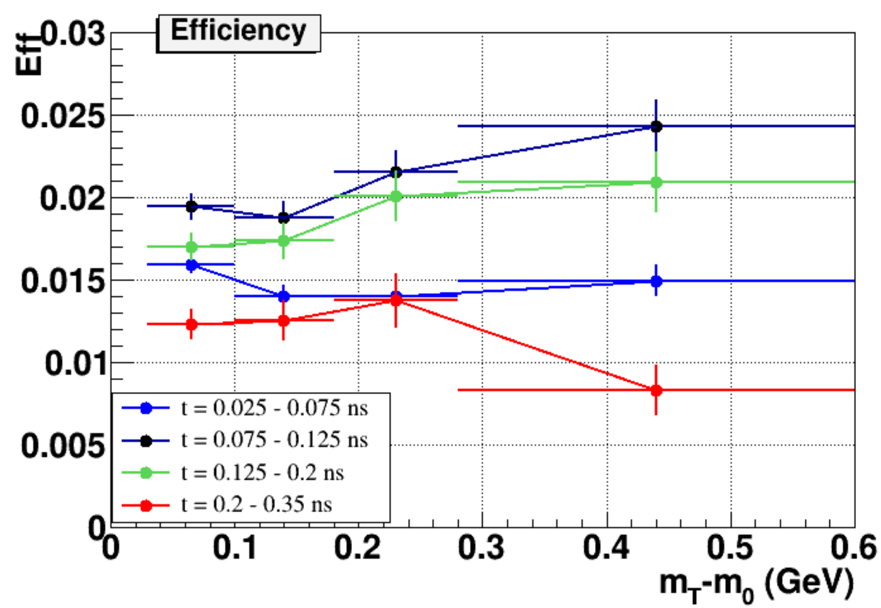
K^0_s spectra

K^0_s M_{inv} spectra for lifetime 0.025-0.075 ns



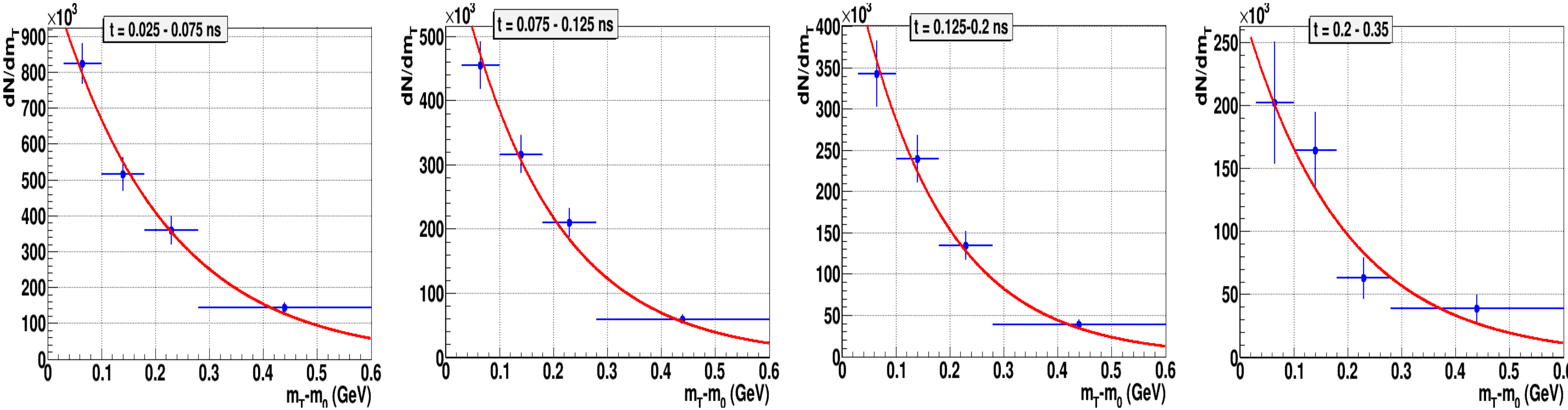
Yields and efficiencies vs m_T for different lifetimes

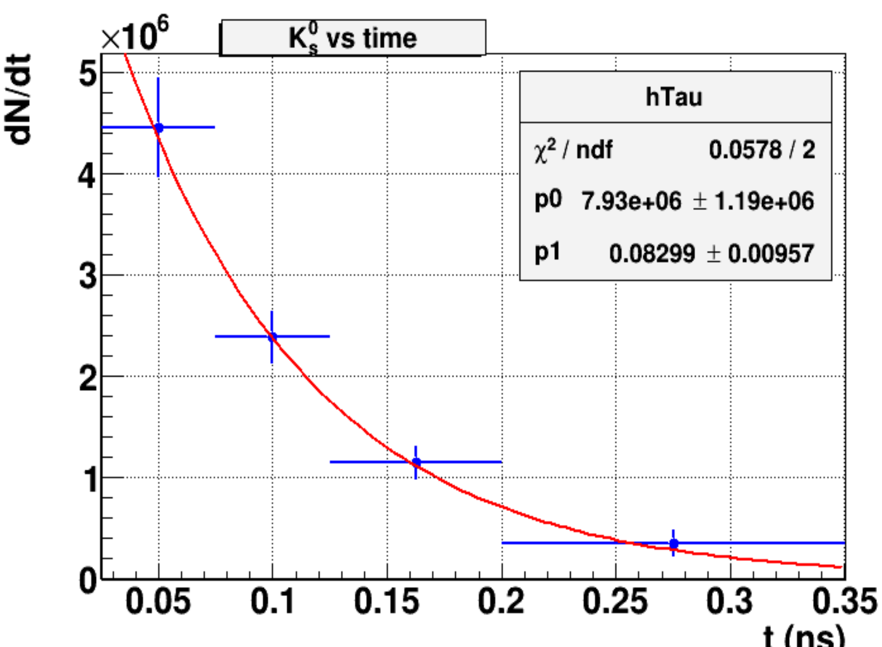




K^0_s spectra

Corrected for efficiency m_T -spectra for different lifetimes





K^0_s decay curve reconstructed from integrated m_T -spectra

K^0_s spectra

Effective temperatures for different lifetimes

https://arxiv.org/abs/1010.1675v3

Boltzman distribution from HADES paper

$$\frac{1}{m_t^2}\frac{d^2M}{dm_t dy} = C(y)\exp\left(-\frac{(m_t - m_0)c^2}{T_B(y)}\right)$$

Effective temperature (MeV):

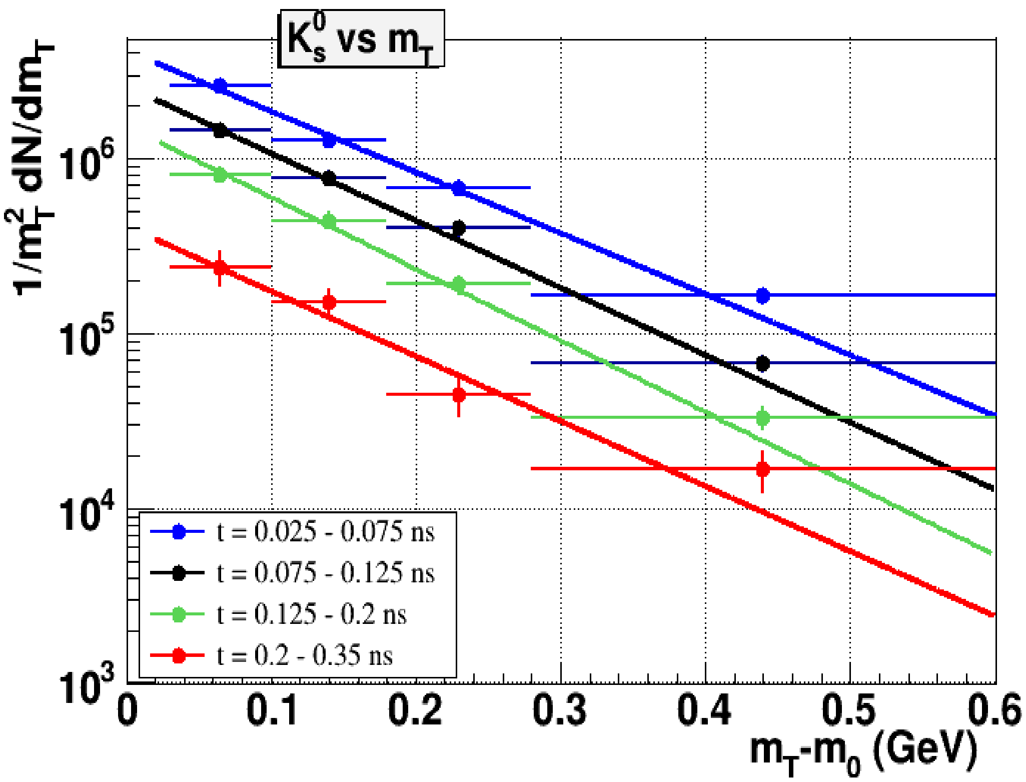
T1 = 117±5

T2 = 113±5

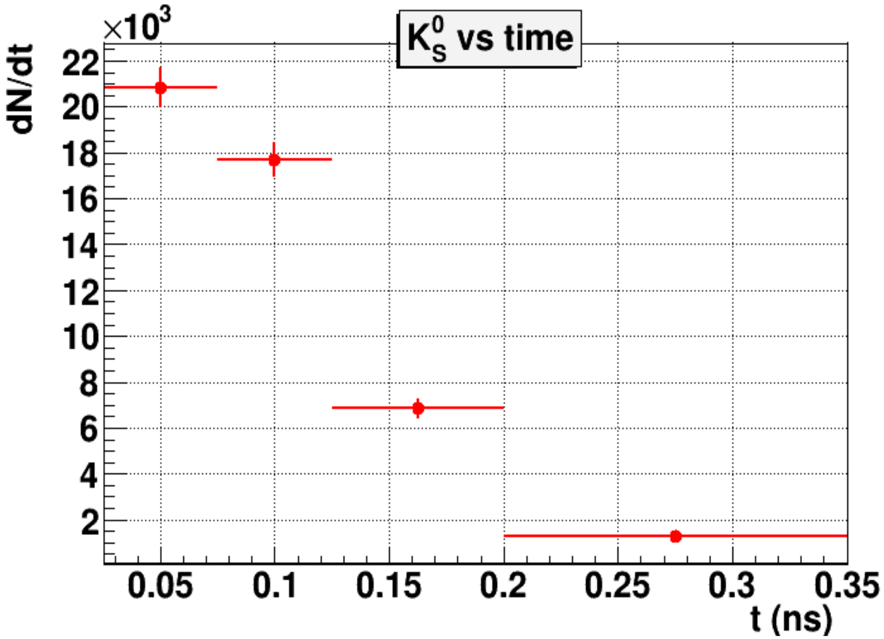
T3 = 108±6

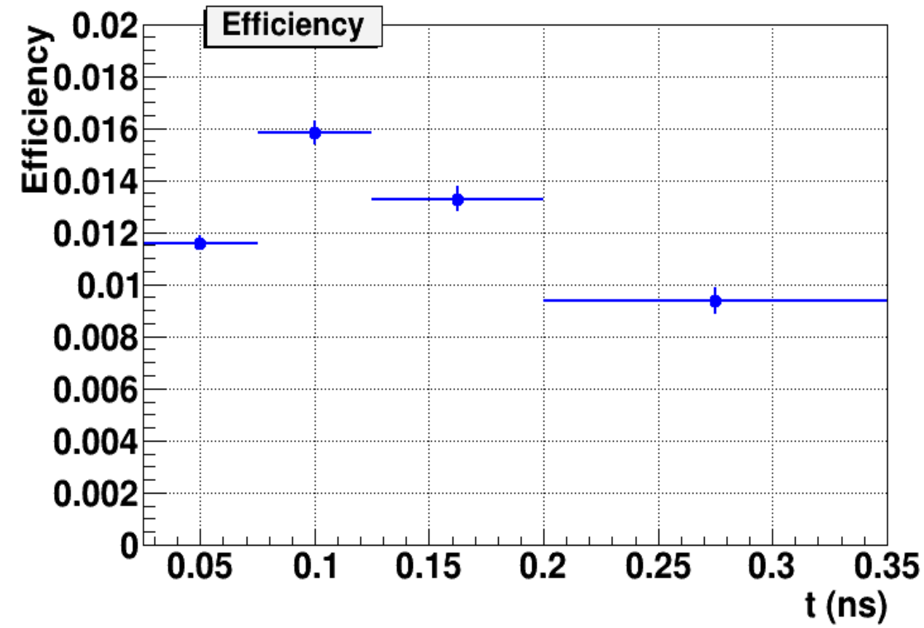
T4 = 125±16

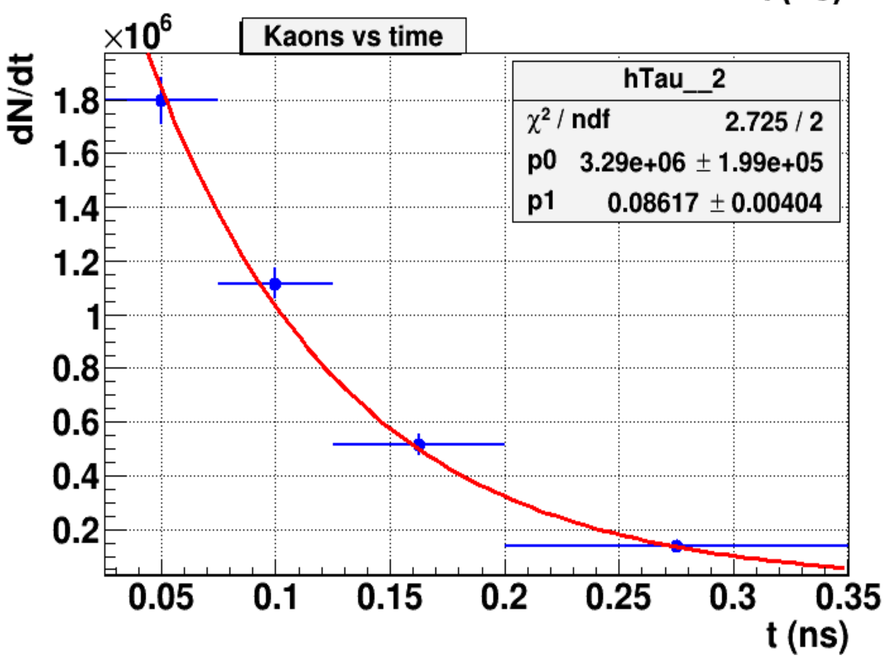
T MC = 97±6



K^0_s raw yield and efficiency







Efficiency-corrected yield vs lifetime