Simulation study of Σ^0 hyperons production from NICA-MPD experiment

Yulin Wang (王玉林)

For the MPD Collaboration

Shandong University (山东大学)

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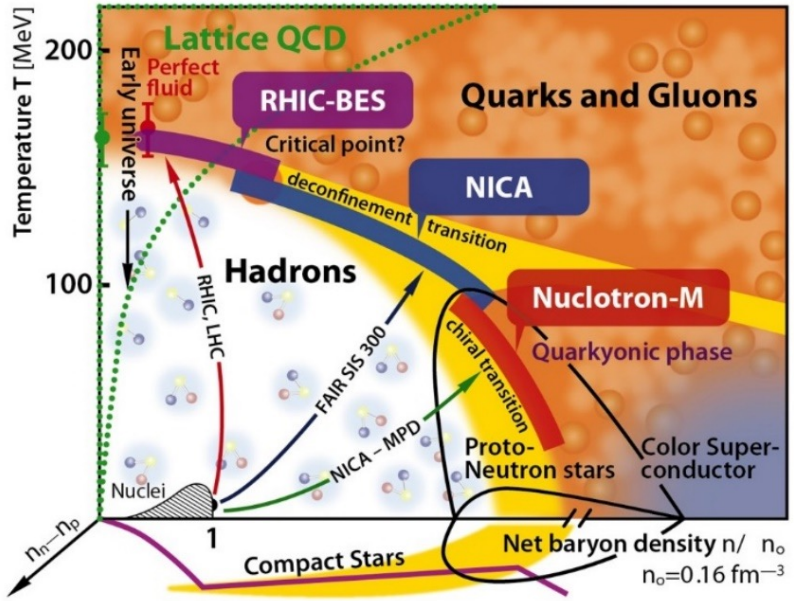
Outline

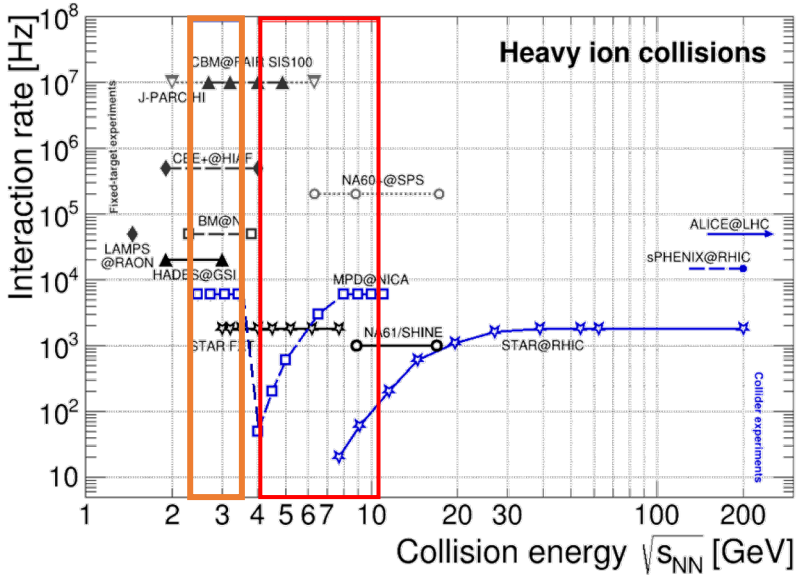
- Motivation
- The NICA-MPD experiment
- Reconstruction methodology
- Summary

Motivation

https://nica.jinr.ru/physics.php



T. Galatyuk, Nucl. Phys. A982(2019)

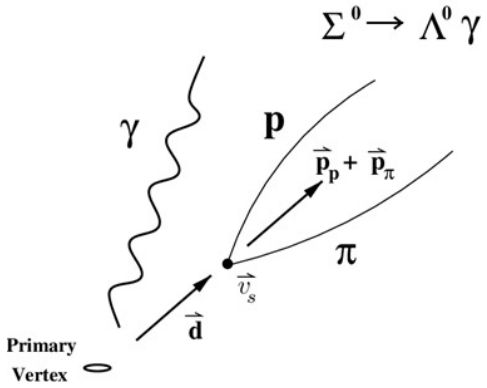


- **QCD phase diagram** describe the phase structure of strongly interacting matter and look for the first order phase transition and critical end-point

- **NICA energy region (4 - 11 GeV):**
  - ✓ Temperature T_{ch} ~ 120-150 MeV
  - ✓ Baryonic chemical potential μ_B = 300 - 600 MeV,
  - ✓ Many ongoing (NA61/Shine, STAR-BES) and future experiments (CBM) in similar energy region

Why Study Σ^0 ?

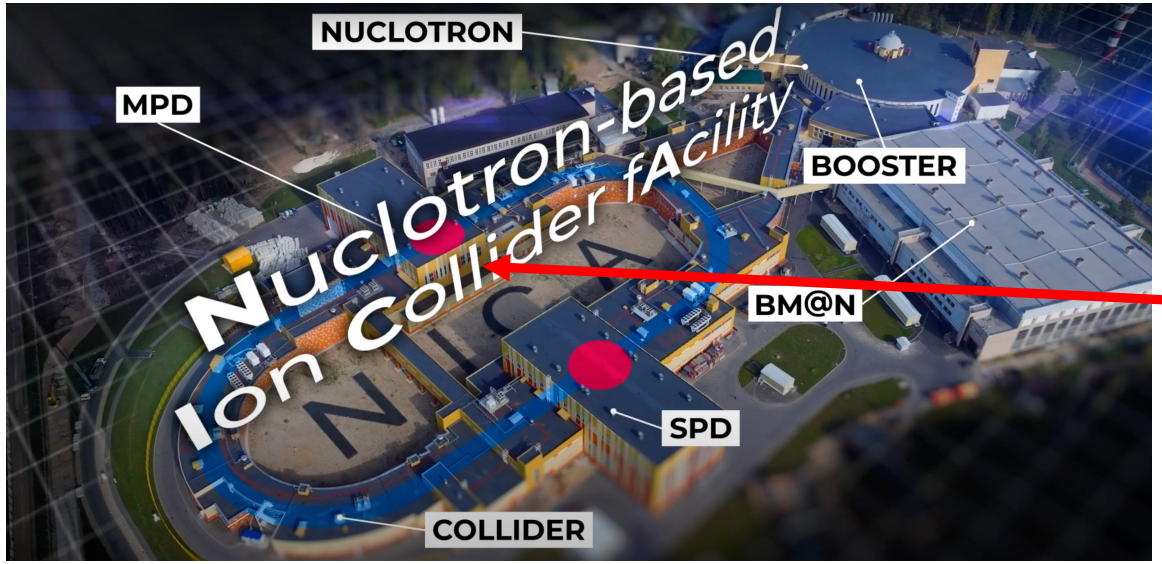
- Σ^0 is an important particle in heavy-ion collisions, reconstruction by the decay channel with $\mathrm{B.R.} \approx 100\%$: $\Sigma^0 \to \gamma\Lambda$
  - ✓ Feed-down contribution to photon and Λ spectrum
  - ✓ Study of strangeness production mechanisms
  - ✓ As a reference to tune the event generators and models

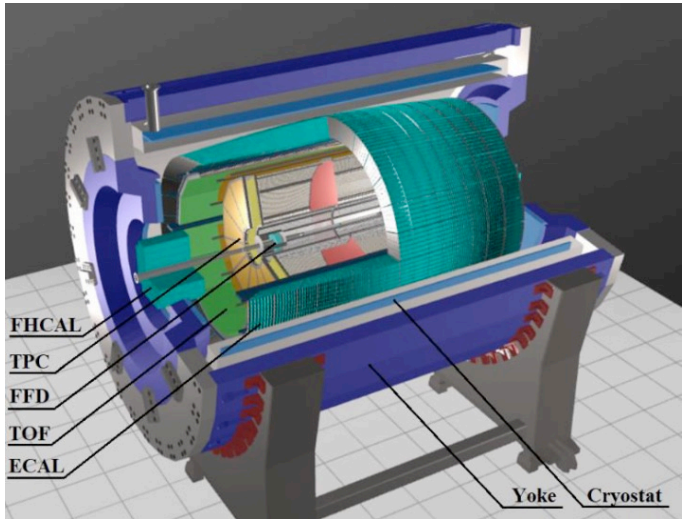


Physics Letters B 479 (2000)

Property	Σ^0	Λ
Quark	uds	uds
Mass	1.192 $\mathrm{GeV/c^2}$	1.116 $\mathrm{GeV/c^2}$
Strangeness (S)	-1	-1
Isospin(I)	1	0
Spin	$\frac{1^+}{2}$	$\frac{1^+}{2}$
Lifetime	$\approx 7.4\times10^{-20}\mathrm{s}$	$\approx 2.6\times10^{-10}\mathrm{s}$
Decay Mode	$\Sigma^0 \to \gamma\Lambda\ (\approx 100\%)$	$\Lambda \to \mathrm{p}\pi^-(\approx 64\%)$ $\Lambda \to \mathrm{n}\pi^0(\approx 36\%)$

Nuclotron-based Ion Collider fAcility





- **NICA**: International research facility in JINR, Dubna, Russia
  - ✓ Already running in the fixed-target mode – **Baryonic Matter @ Nuclotron (BM@N)**
  - ✓ Start of operation in 2025 – **Multi-Purpose Detector (MPD)**
  - ✓ Operating on polarized deuterons later - **Spin Physics Detector (SPD)**

- **MPD**: One of two collider experiments at NICA to study heavy-ion collisions at $\sqrt{s_{NN}}$= 4−11 GeV
  - ✓ Stage I: **TPC+TOF+ECal+FHCal+FFD**
  - ✓ Stage II: **StageI+ITS+EndCap**

- Centralized large scale and centralized Analysis Train was used to process the simulated data.

Photon Reconstruction

Two method for photon reconstruction:

✓ Electromagnetic calorimeter: measure the energy and position of photon

- Number of towers：

$$N_{cell} > 2$$

- Reconstructed energy:

$$E_{cluster} > 0.05\ GeV$$

- Shower shape:

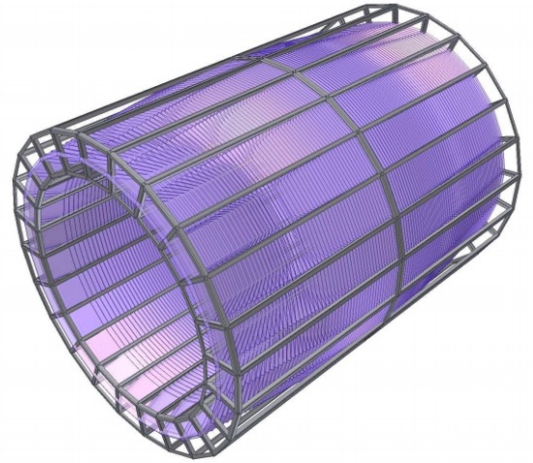
$$\chi^2 < 4.0$$

- Time of flight:

$$T_{cluster} < 2.0\ ns$$

- Charge particle veto:

$$d\phi^{TPC-ECal} > 10\ cm$$
$$dZ^{TPC-ECal} > 10\ cm$$



Electromagnetic calorimeter

✓ Photons Conversion Method (PCM): measured in the tracking system as e^+e^- conversion pairs

The probability of photon conversion strongly depends on the material budget

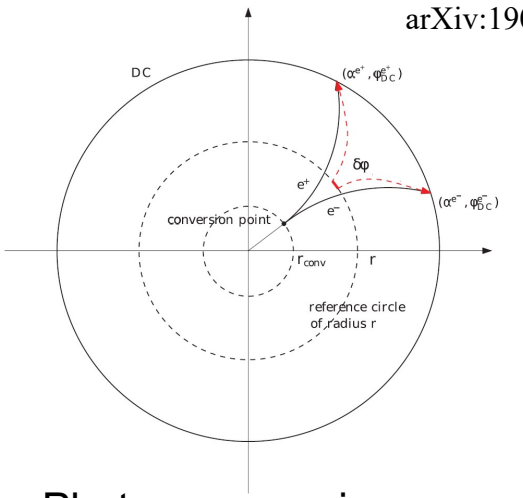
$$P = 1 - \exp(-\frac{7}{9}\frac{x}{X_0})$$

Particles 4.1(2021):55-62.

Beam pipe (r = 4cm): 0.3% X_0

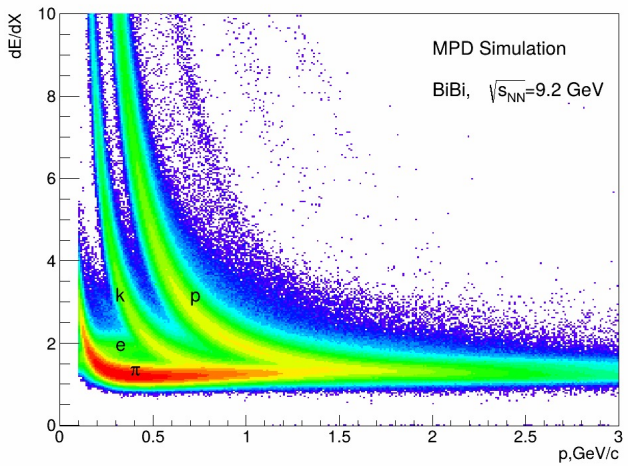
TPC structures(r = 27cm): 2.4% X_0

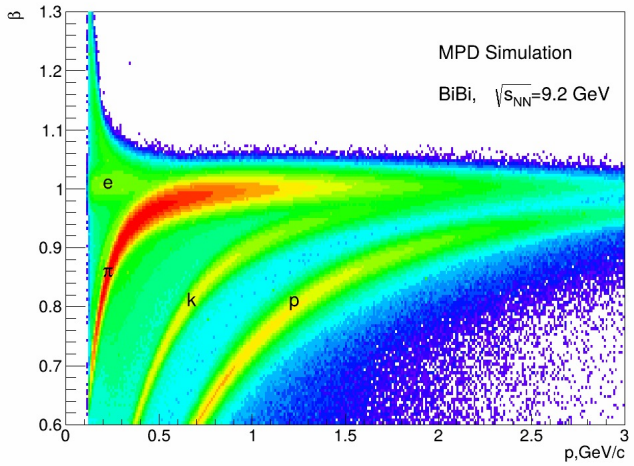
arXiv:1907.08893



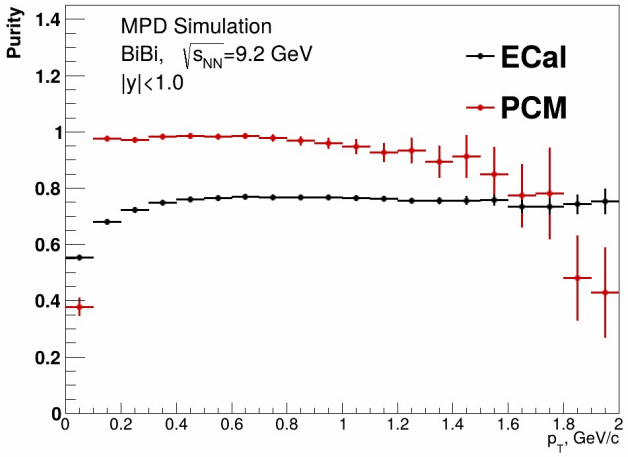
Photon conversion

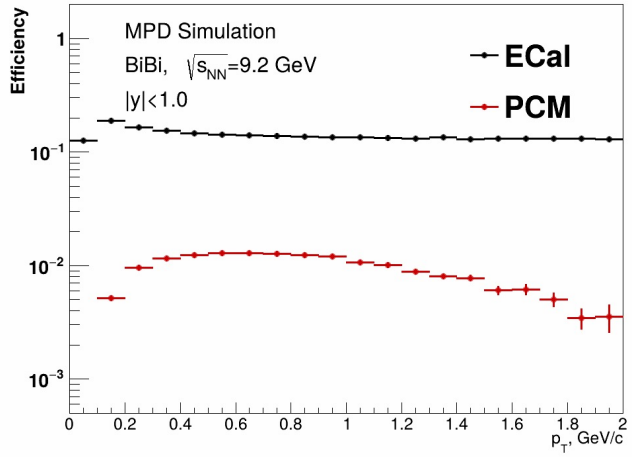
Photon Conversion Method (PCM)





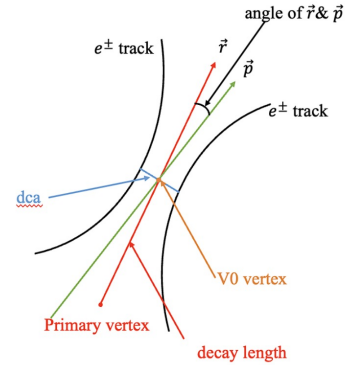
✓ For electron identification, the TPC (dE/dx) and TOF (β) is used





e^+ / e^- tracks:

- $N_{hits}^{TPC} > 10$
- $p_T > 0.03$ GeV/c
- TPC: $2\sigma_{TPC}^{e}$
- TOF: $2\sigma_{TOF}^{e}$ in case of track matching to the TOF

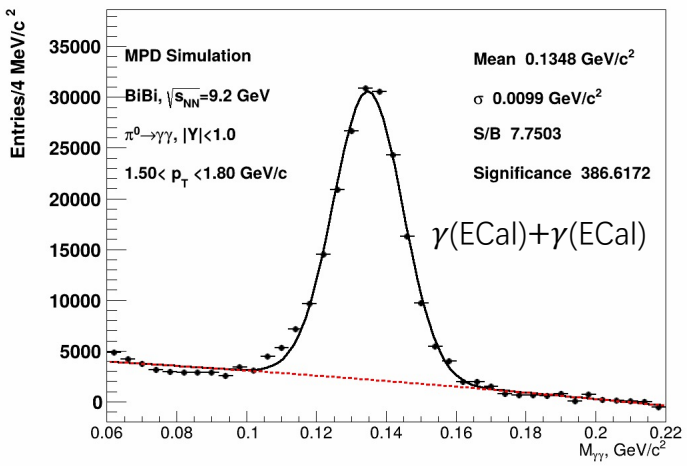


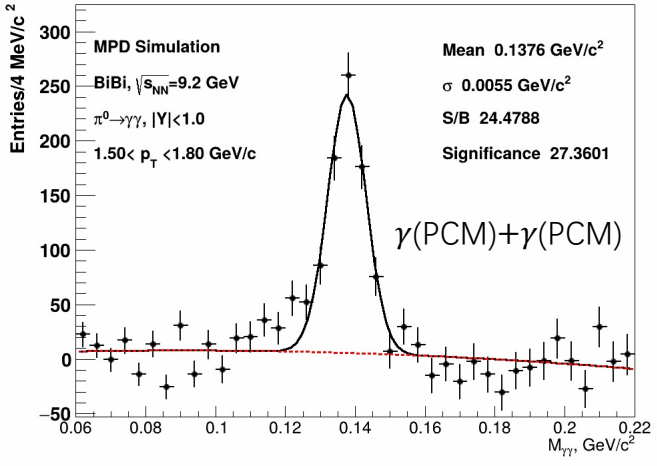
The topological structure of e^+e^- pairs:

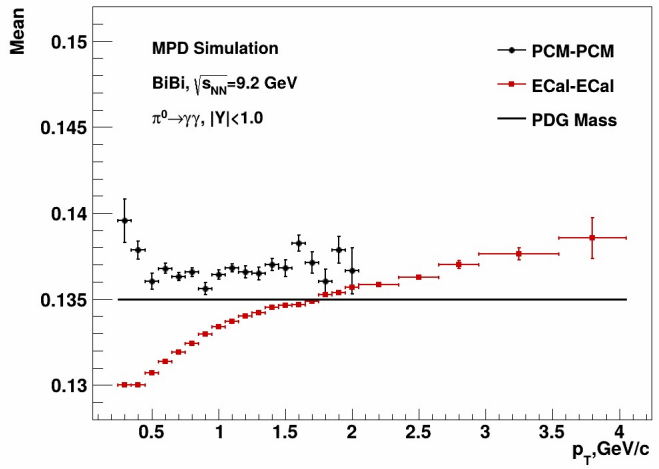
- $dca_{e^+ \text{ to } e^-} < 1.25$ cm
- $\chi^2_{V^0} < 6.0$
- $angle_{e^+e^-} < 0.10$ rad
- $decay_{V^0 \text{ to PV}} > 25$ cm
- $Mass_{e^+e^-} < 0.035$ GeV/c^2
- $\phi_V < 0.25$ rad

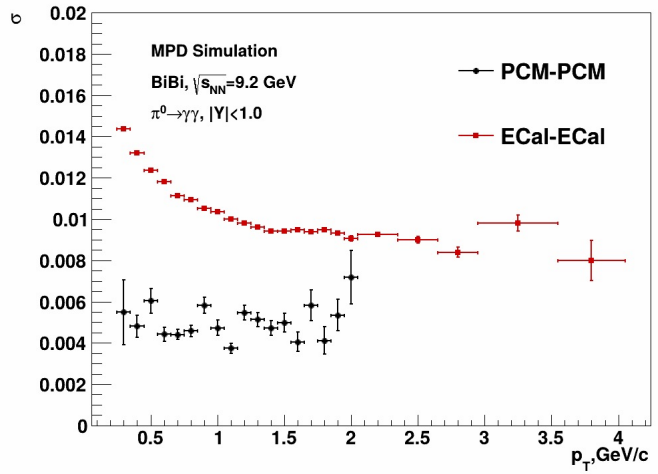
✓ PCM has higher purity but lower efficiency, ECal method is more effective in high energy

π^0 Reconstruction









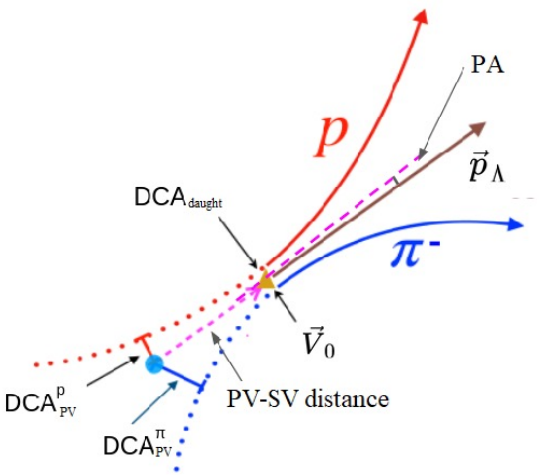
✓ The width of π^0 reconstruction by ECal method are larger than that of by using photon conversion method

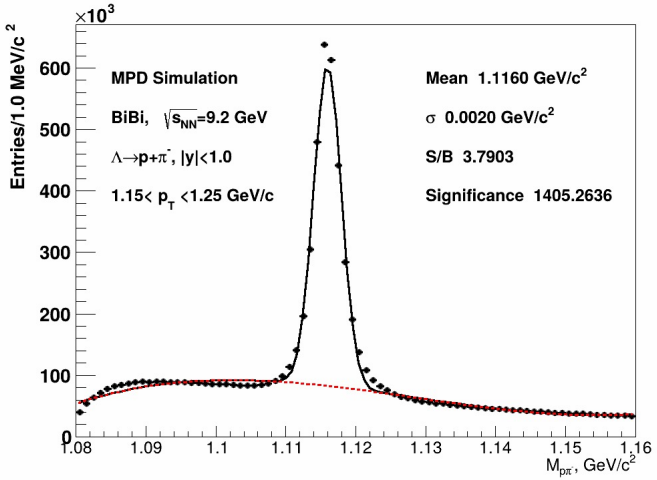
Λ Reconstruction

Λ reconstruction by the decay channel with $\mathrm{B.R.} \approx 64.1\%$:

$$\Lambda \rightarrow p + \pi^-$$

p and π^- are selection by TPC and TOF





p / π^- tracks:

- $N^{TPC}_{hits} > 20$
- $p_T > 0.1$ GeV/c
- $2\sigma^{\pi^-}_{TPC}$ and $2\sigma^{\pi^-}_{TOF}$ in case of track matching to the TOF
- $\chi^2_{\pi^- \text{ to PV}} > 7.0$
- $dca_{\pi^- \text{ to PV}} > 1.5$ cm
- $2\sigma^{p}_{TPC}$ and $2\sigma^{p}_{TOF}$ in case of track matching to the TOF
- $\chi^2_{p \text{ to PV}} > 3.0$
- $dca_{p \text{ to PV}} > 0.4$ cm

$p\ \pi^-$ pairs:

- $dca_{p \text{ to } \pi^-} < 1.25$ cm
- $\chi^2_{V^0} < 6.0$
- $angle_{p\pi^-} < 0.10$ rad
- $decay_{V^0 \text{ to PV}} > 4.0$ cm

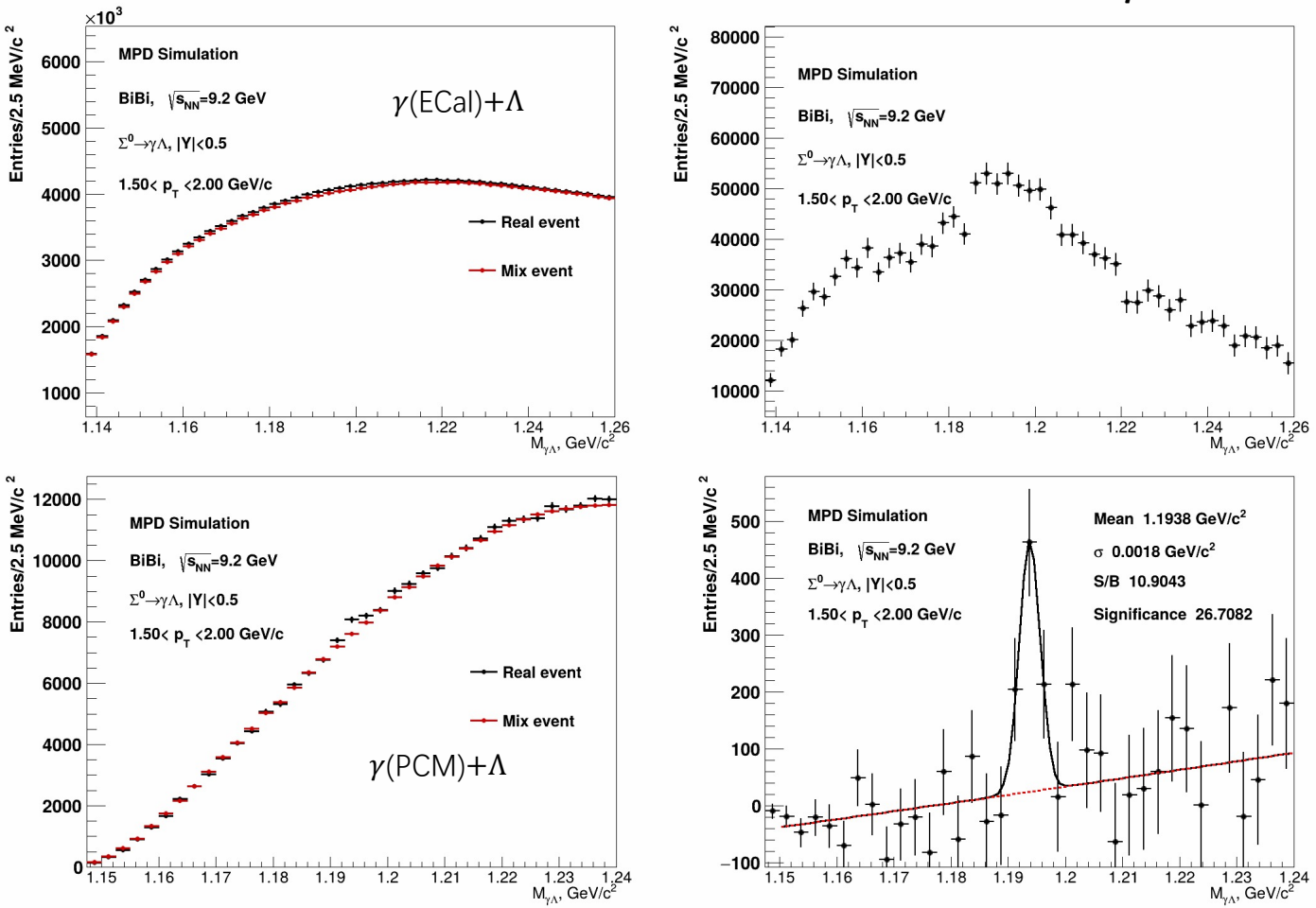
With high S/B and Significance by using the topological structure of Λ decay

The $|M_{p\pi^-} - M_\Lambda| < 2\sigma_\Lambda$ as Λ candidate for Σ^0 reconstruction $\quad M_\Lambda = 1.115683\ \mathrm{GeV/c^2}, \sigma_\Lambda = 0.002\ \mathrm{GeV/c^2}$

Σ^0 Reconstruction

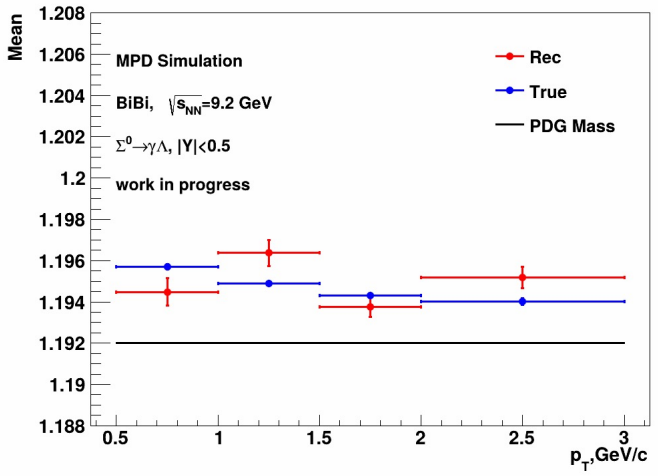
Σ^0 reconstruction by the decay channel with $\mathrm{B.R.} \approx 100\%$:

$$\Sigma^0 \rightarrow \gamma + \Lambda$$

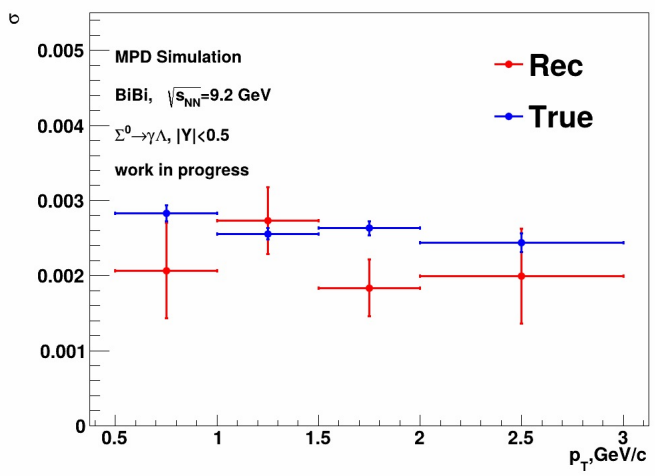


- ✓ The energy of photon from Σ^0 is very soft.
- ✓ Photon conversion method more suitable for Σ^0 reconstruction.
- ✓ The mix event method was used to remove the combinatorial background.
- ✓ Gaussian and polynomial function fitting are used to extract the signal

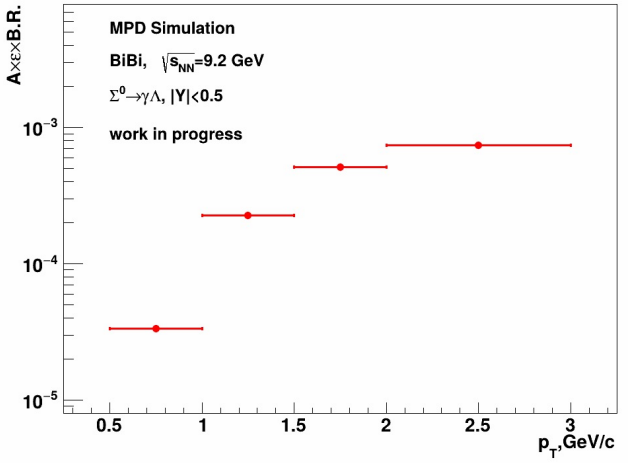
p_T Dependence



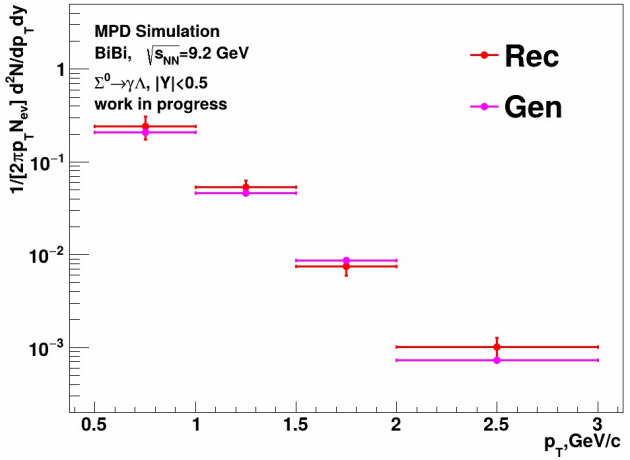
Mean



Width



Efficiency



Yield

$$\text{Yield} = \frac{1}{N_{event}} \cdot \frac{N_{sig}}{2\pi p_T dp_T dy} \cdot \frac{1}{A \times \varepsilon \times B.R.}$$

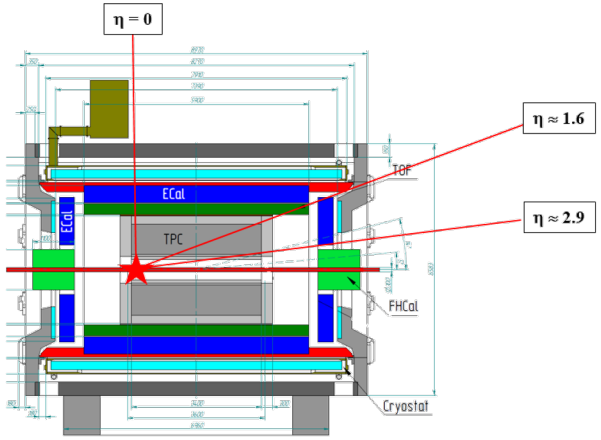
$$N_{sig} = \int_{mean-2\sigma}^{mean+2\sigma} f_{Gaus}(M) dM$$

- ✓ Measurements for Σ^0 are possible starting from p_T ~ 500 MeV/c in a rapidity range |y|<0.5.
- ✓ The yields obtained for Σ^0 by reconstruction are consistent with truly generated.

Summary

- Two methods for photon reconstruction were study：
  - ✓ ECal method is more effective in high energy.
  - ✓ Photon conversion method is a powerful tool at low momentum.
- Λ reconstruction were study with high high S/B and Significance .
- Photon conversion method more suitable for Σ^0 reconstruction.

Outlook：



Fixed-targe mode

- Start of MPD commissioning by the end of 2025.
- Fixed-target mode extends energy range of MPD to $\sqrt{s_{NN}}$ =2.4-3.5 GeV (overlap with HADES, BM@N and CBM).

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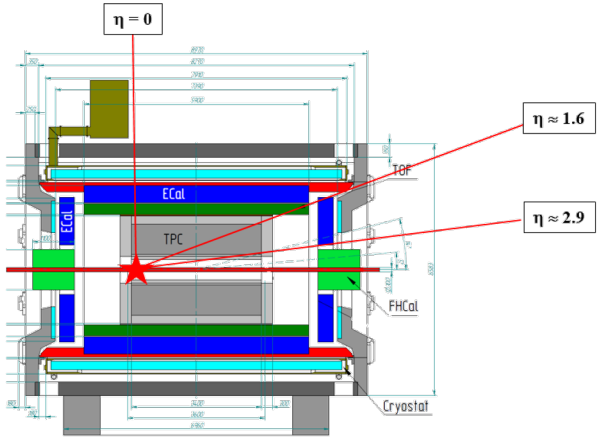

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Thanks!

Backup

Physics program at MPD

G. Feofilov, P. Parfenov

Global observables

- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei

- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

K. Mikhailov, A. Taranenko

Correlations and Fluctuations

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

D. Peresunko, Chi Yang

Electromagnetic probes

- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

Heavy flavor

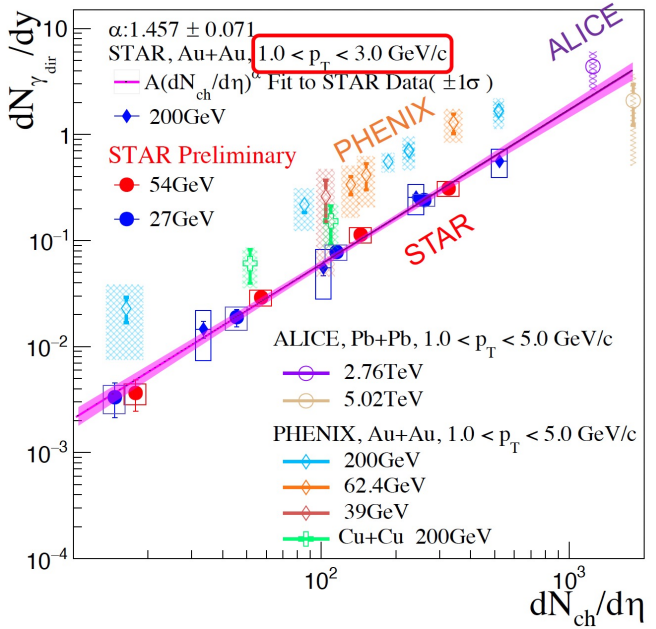
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

- Organized and developed in 5 Physics Working Groups
- Physics feasibility studies using large-scale Monte Carlo productions

Physics in NICA Energy Region

☐ Direct photons

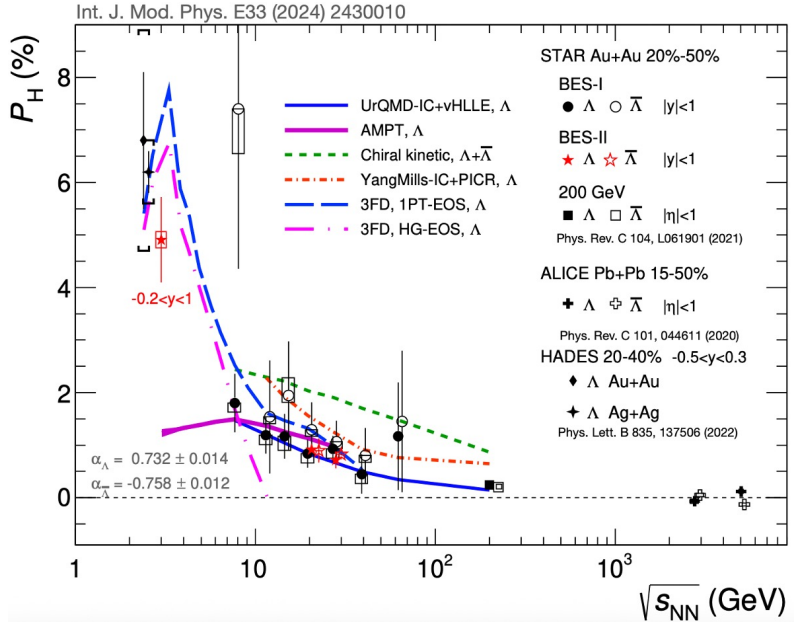
Xianwen Bao @ Hard Probes 2024



- ✓ Measurements of direct photons over centralities and energies
- ✓ Direct photon puzzle still there
- ✓ NICA can extend the study to the lower energies

☐ Λ Global polarization

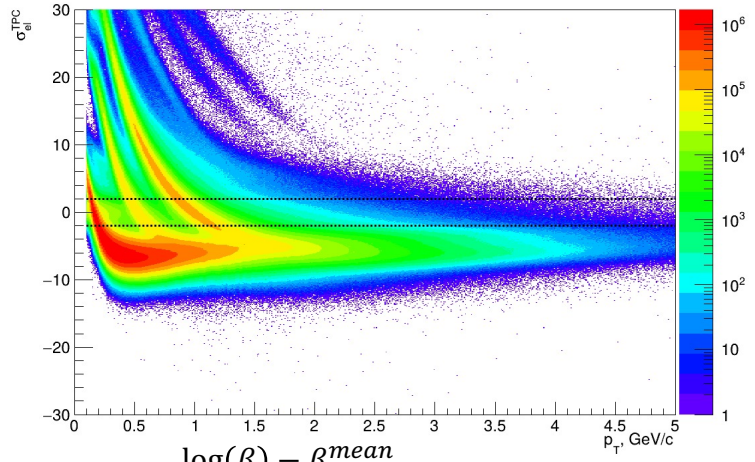
- ✓ Increases towards lower energies
- ✓ Expected to be high at NICA energies



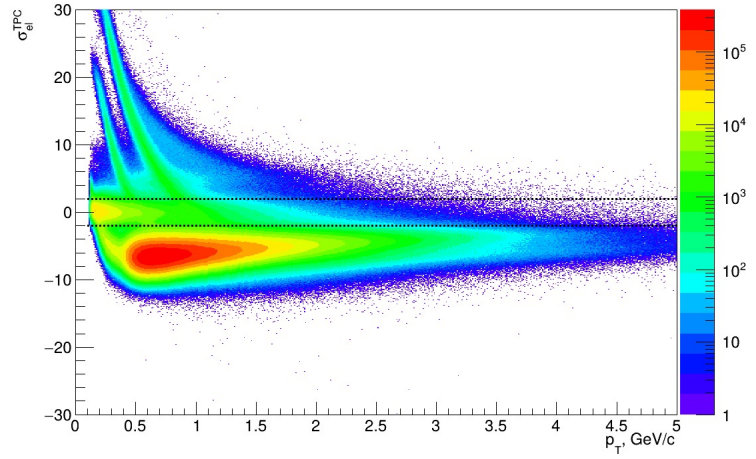
The σ^{TPC} and σ^{TOF}

$$\sigma_{part}^{TPC} = \frac{\log(dE/dx) - dE/dx_{part_{exp}}^{mean}}{dE/dx_{part_{exp}}^{sigma}}$$

No cut

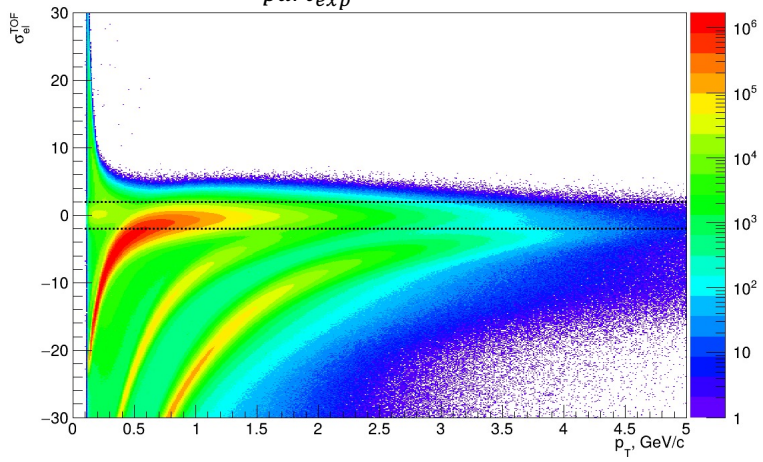


With TOF

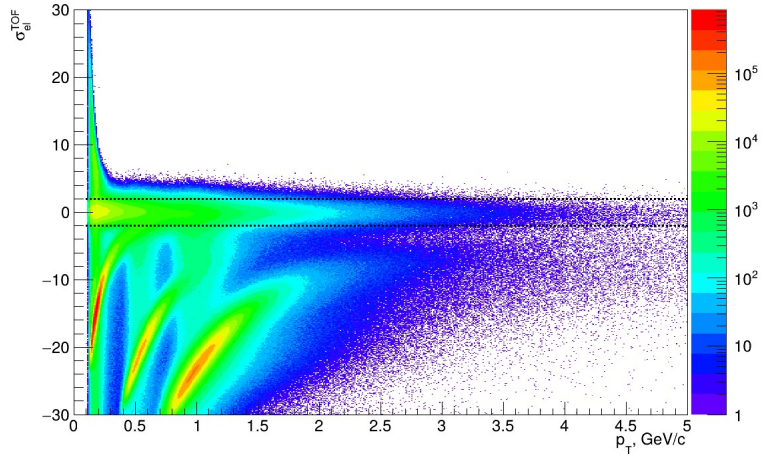


$$\sigma_{part}^{TOF} = \frac{\log(\beta) - \beta_{part_{exp}}^{mean}}{\beta_{part_{exp}}^{sigma}}$$

No cut



With TPC



dE/dx: energy measure in TPC

$dE/dx_{part_{exp}}^{mean}$: the expected mean dE/dx value for a particle

$dE/dx_{part_{exp}}^{sigma}$: the expected sigma dE/dx value for a particle

β: measure in TOF

$\beta_{part_{exp}}^{mean}$: the expected mean β value for a particle

$\beta_{part_{exp}}^{sigma}$: the expected sigma β value for a particle