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Presentation Script: dpol_breakup Experiment Optimization

dpol_breakup

Date / : November 26, 2025
Presenter / : Tian
Audience / : Mizuki, Aki

Opening /

English: Good morning everyone. Today I'd like to present our progress on optimizing the dpol_breakup experiment configuration. This work focuses on determining the optimal experimental setup through systematic simulation and analysis.

: dpol_breakup

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1. Research Objectives /

English: Let me start by outlining our main objectives. We aim to answer four key questions:

First, what is the optimal target position for different magnetic field strengths?

Second, how does the beam deflection angle affect our detection efficiency?

Third, what momentum resolution can we achieve with the current PDC setup?

And finally, how can we improve both reconstruction speed and accuracy?

:

PDC

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2. System Architecture /

English: Now let's look at our complete simulation framework. As you can see in this diagram, we have a four-stage pipeline:

Starting from QMD raw data - that's about 2 million events per configuration. After applying physical cuts and sampling, we reduce this to around 30,000 events for Geant4 input.

Then the Geant4 simulation processes these events at roughly 120 events per second, generating hit trees and energy deposit information.

Finally, the PDC reconstruction stage performs track fitting - currently this is our bottleneck, running at only 0.05 to 1 event per second.

:

QMD - 200 3 Geant4

Geant4 120

PDC - 0.05 1

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3. Performance Status /

English: Speaking of performance, let me show you where we currently stand.

The Geant4 simulation performs quite well at 120 events per second. However, the PDC reconstruction is significantly slower - between 0.05 and 1 event per second using TMinuit.

This slow speed is a major bottleneck. Moreover, we're seeing poor performance on some events with systematic momentum bias.

Our target is to achieve over 10 events per second with momentum resolution better than 5%, while maintaining detection efficiency above 80% for the physics-relevant phase space.

:

Geant4 120 PDC - TMinuit 0.05 1

10 5% 80%

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4. QMD Data Processing / QMD

English: Let me explain our data processing strategy.

The initial challenge is the massive data volume - approximately 2 million events per target and gamma configuration. This is simply too much to process efficiently.

So we applied physical cuts to focus on the region of interest. Specifically, we used momentum cuts on the proton and neutron, requiring the y-component difference to be less than 150 MeV/c, and the sum of x-components to be less than 200 MeV/c.

We also applied angular cuts based on the rotation angle phi.

As shown in this table, these cuts reduced our dataset dramatically - from 2 million to 500,000 with momentum cuts, and finally down to 30,000 events after angular selection.

This makes the analysis computationally feasible while preserving the physics we care about.

:

- gamma 200

y 150 MeV/c x 200 MeV/c

phi

- 200 50 3

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5. Geant4 Simulation Results / Geant4

English: Now let's look at the Geant4 simulation results.

Our current configuration uses a target position based on 5-degree beam deflection in a 1.2 Tesla magnetic field. The detector geometry includes PDC1, PDC2, and the NEBULA array.

Figure 1 shows the visualization of 5000 accumulated events - you can clearly see the particle trajectories curving in the magnetic field.

Figure 2 presents our detection efficiency as a function of angle. An event is counted as detected if it registers any energy deposit in the Geant4 tree.

For comparison, Figures 3 and 4 show reference data from previous papers and presentations. Our results are consistent with these references.

Moving forward, we plan to scan different parameters - magnetic fields from 0.8 to 1.6 Tesla, various target positions, and beam angles from 3 to 7 degrees.

: Geant4

1.2 5 PDC1 PDC2 NEBULA

1 5000 -

2 Geant4

3 4

- 0.8 1.6 3 7

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6. PDC Reconstruction - Methodology / PDC -

English: Let me explain our reconstruction methodology in detail.

The PDC system primarily determines the particle direction. To get the momentum magnitude, we use a clever approach - we back-propagate the track to the target position and minimize the distance.

We've implemented three algorithms:

First, grid search - this is robust and finds the global minimum, but it's computationally expensive.

Second, gradient descent - much faster, but it can get stuck in local minima and is sensitive to noise.

Third, TMinuit from ROOT - this is currently our primary method, using the MIGRAD and SIMPLEX algorithms.

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PDC -

-

-

ROOT TMinuit - MIGRAD SIMPLEX

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7. Current Challenges /

English: However, we're facing some significant challenges.

First, reconstruction quality is inconsistent. While many events are reconstructed correctly, a subset shows poor results.

Second, we observe a systematic momentum bias. When we plot the momentum residuals - that's reconstructed minus true momentum - we see a double-peak structure. One peak is centered at zero, which is good. But there's a second peak around minus 200 MeV/c, indicating systematic underestimation for some events.

Third, the speed is a real bottleneck. Reconstruction takes anywhere from 1 to 20 seconds per event, which is far too slow for production analysis.

Figure 5 shows the comparison between reconstructed and input neutron momentum. Figure 6 displays the TMinuit optimization steps. Figures 7 and 8 show our 3D event display - you can see the particle trajectories and PDC hit positions clearly.

:

- - 200 MeV/c

1 20

5 6 TMinuit 7 8 3D - PDC

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8. Example Case Analysis /

English: Let me walk you through a specific example to illustrate the problem.

For a proton with true momentum of 629 MeV/c, we start with an initial guess of 800 MeV/c.

The MIGRAD algorithm fails with error code 4, so we fall back to SIMPLEX.

The final result gives us 618 MeV/c - which is actually quite close to the true value. However, look at the uncertainty: plus or minus 2850 MeV/c! This huge uncertainty indicates the minimization is having convergence problems.

The final distance to target is about 4.8 millimeters, and the estimated distance to minimum is very small, suggesting we're near a minimum - but probably a local one, not the global minimum.

Figure 9 shows the 2D correlation between true and reconstructed momentum. Figure 10 displays the residual distribution with that characteristic double-peak I mentioned.

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629 MeV/c 800 MeV/c

MIGRAD 4 SIMPLEX

618 MeV/c - 2850 MeV/c

4.8 -

9 2D 10

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9. Technical Deep Dive /

English: For those interested in the technical details, let me briefly explain our core algorithms.

The PDC hit reconstruction uses a center-of-mass weighted energy deposition method. We process U and V layer hits independently, apply Gaussian smearing for detector resolution - about 200 micrometers - and reconstruct 3D positions.

The trajectory calculation uses 4th-order Runge-Kutta integration for solving particle motion in magnetic fields. We implement the full relativistic kinematics and Lorentz force equations.

The current step size is 1 millimeter. This is a trade-off - smaller steps give higher accuracy but slower computation. We can probably optimize this to 2-5 millimeters for better speed.

For neutrons, we use a completely different approach based on time-of-flight, since they're neutral and unaffected by the magnetic field.

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PDC U V - 200 - 3D

-

1 - 2-5

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10. Optimization Strategy /

English: So what's our plan to address these challenges?

We have a six-point strategy:

First, algorithm optimization - we're adjusting the Runge-Kutta step size and magnetic field integration precision.

Second, batch processing - implementing memory-efficient analysis by discarding unnecessary objects.

Third, parallel computing - enabling multi-threading to process multiple events simultaneously.

Fourth, I/O optimization - using asynchronous logging to prevent blocking.

Fifth, smart initial guess - using the PDC direction and typical momentum range to help TMinuit converge better.

And sixth, adaptive step size - making the RK step size depend on magnetic field strength and trajectory curvature.

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- -

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I/O -

- PDC TMinuit

- RK

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11. Next Steps and Priorities /

English: Let me outline our next steps, organized by priority.

High priority tasks: First, complete QMD data sampling and generate final ROOT files for Geant4 input. Second, continue optimizing the simulation and reconstruction code for speed. Third, systematically test different configurations - varying magnetic field, target position, and beam angle.

Medium priority: Investigate isovector effects in deuteron simulations. Evaluate systematic uncertainties in momentum reconstruction. Compare our results with experimental data if available.

Low priority: Complete technical documentation for all tools. Refactor and optimize the codebase for better maintainability.

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QMD Geant4 ROOT -

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12. Summary and Conclusions /

English: Let me summarize what we've accomplished and what challenges remain.

On the achievement side: We have a complete, operational simulation framework from QMD through Geant4 to reconstruction. We've implemented and tested multiple reconstruction algorithms. We've identified the key bottlenecks - reconstruction speed and systematic bias. And we've established baseline performance benchmarks.

Current challenges: Reconstruction speed is only 0.05 to 1 Hz - we need to reach over 10 Hz. The double-peak momentum bias needs to be understood and corrected. We need large statistical samples for thorough configuration optimization.

Our key milestones are: Complete QMD sampling for production-scale input. Optimize reconstruction to achieve 10 Hz performance. Run systematic configuration scans. And validate against experimental data.

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QMD Geant4 -

0.05 1 - 10

QMD 10 Hz

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13. Questions and Discussion /

English: That concludes my presentation. I'd be happy to take any questions or discuss any aspects in more detail.

Some specific points we could explore: - The physics behind the momentum cuts - Alternative reconstruction algorithms - Computational optimization strategies - Comparison with other experiments

Thank you for your attention.

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Backup Slides /

Additional Technical Details /

English: If anyone is interested, I have additional slides with more technical details about: - Detailed Runge-Kutta implementation - TMinuit configuration parameters - Memory profiling results - Parallelization strategies

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Contact Information /

English: For further discussion or collaboration: - Email: tbt23@mails.tsinghua.edu.cn - Repository: github.com/tianbaiting/Dpol_smsimulator - Branch: restructure-cmake

: - tbt23@mails.tsinghua.edu.cn - github.com/tianbaiting/Dpol_smsimulator - restructure-cmake

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End of Presentation /