A Charged Particle Veto in the Central Detector Using Only CND and CTOF

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for the CLAS Collaboration

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Overview

- Background and Motivation
- Development and Evolution
- Results
- Implementation
- Further Ideas and Considerations
**Central Neutron Detector**
Plastic scintillator
3 radial layers, total ~10 cm
Angular coverage $40^\circ < \theta < 120^\circ$
Azimuthal coverage $2\pi$
Neutron detection efficiency ~10%

**Central Time-of-Flight Detector**
Plastic scintillator
~3 cm thick
Angular coverage $35^\circ < \theta < 125^\circ$
Azimuthal coverage $2\pi$
Potential neutron detection efficiency ~3%
Motivation

- Tracking in the CVT is neither 100% efficient nor uniform
  - $\rightarrow$ CND sees charged particle contamination

Can an effective charged particle veto be constructed using only CTOF and CND? *(spoiler: yes!)*
Development and Evolution

- **Requirements:**
  - Veto charged particles without losing neutrons
  - May only use position and energy deposition information from CTOF and CND
  - Cannot rely on vertex tracking

- **ROOT macro → TSelector → CND clustering → COATJAVA (EventBuilder)**

- **Start with what we observed in single-particle, single-momentum simulations**
  - Neutrons at 400-1000 MeV
  - Protons from 400-1000 MeV*
  - π+ from 400-1000 MeV*

*RG-A shows we won’t see many above 800 MeV
We tried many different criteria...
Development and Evolution

- **Interesting trials**
  - **Sector/φ**
    - **Criteria:** Charged particles have curved tracks – if φ changes more than (5, 10, &c.) degrees or (1, 2) sectors, apply veto
    - **Problem:** Particles frequently “graze” multiple sectors, making this a fuzzy and unreliable cut
  - **Layer ordering**
    - **Criteria:** If hits within an event trigger layers in order radially, apply veto
    - **Problem:** In real life, we won’t know which hit was first
Milestone trials
- Hit and layer multiplicities defined
  - Allow for a cut to be made based on how many hits within an event, or how many layers were triggered (regardless of number of hits)

- Total event energy deposition defined
  - Allow for a cut to be made based on the total energy deposition of an event
  - Also defined total event energy per detector (very useful in conjunction with hit/layer multiplicity cuts)
Development and Evolution

- The veto today
  - Two main sections
  - Section 1 defines useful quantities (total event energy, hit and layer multiplicity…)

```cpp
for(int i=0; i<size; i++)
{  
    if(CND_hits_energy[i]>1)  
    {  
        counts++;  
        if(CND_hits_layer[i]==1)  
        {  
            counts_l1++;  
        }  
    }  
}  

for(int i=0; i<size; i++)
{  
    if(CND_hits_energy[i]>1)  
    {  
        total_event_energy += CND_hits_energy[i];  
        total_cnd_energy += CND_hits_energy[i];  
        cnd_only_counts++;  
    }  
}  

for(int i=0; i<ctof_size; i++)
{  
    if(CTOF_hits_energy[i]>1)  
    {  
        ctof_counts++;  
    }  
}  
```

```cpp
if(counts>0 && ctof_counts==0)
{  
    for(int i=0; i<size; i++)  
    {  
        if(CND_hits_energy[i]>1)  
        {  
            total_event_energy += CND_hits_energy[i];  
            total_cnd_energy += CND_hits_energy[i];  
            cnd_only_counts++;  
        }  
    }  
}  
```
The veto today

- Section 2 applies the veto using the quantities defined in section 1 – an example:

```cpp
else if(cnd_only_counts>0)
{
  if(total_cnd_energy>10 && counts<3)
  {
    neutron++;
    cnd_only_neutron_counts++;
  }
  if(total_cnd_energy<=10 && counts<4)
  {
    neutron++;
    cnd_only_neutron_counts++;
  }
}
```

Events only in CND
- CND total event energy > 10 MeV, and hit multiplicity less than 3

Increment two counters – neutrons and CND only neutrons
### The veto today

- If an event was in CTOF only:
  - total energy for the event is \(< 13 \text{ MeV}\) and hit multiplicity is \(< 3\)

- If an event was in CND and CTOF:
  - CND event energy is \(< 30 \text{ MeV}\), and
  - CTOF event energy is \(< 13 \text{ MeV}\), and
  - layer multiplicity is exactly 1
  - total event energy is \(< 10 \text{ MeV}\), and
  - CTOF event energy is \(< 10 \text{ MeV}\), and
  - layer multiplicity is exactly 2

- If an event was in CND only:
  - total event energy > 10 MeV and hit multiplicity is < 3

- Total event energy ≤ 10 MeV and hit multiplicity is < 4
### Results

**Baseline**

Very few pions of all momenta were detected in only CND…

…or only in CTOF…

…almost all were detected in both CND and CTOF

#### Charged Particle Veto for the CD Using CND & CTOF

<table>
<thead>
<tr>
<th>Particle</th>
<th>Energy</th>
<th>CND baseline</th>
<th>CND only</th>
<th>% of CND baseline</th>
<th>CND-only % of total</th>
<th>CTOF baseline</th>
<th>CTOF only</th>
<th>% of CTOF baseline</th>
<th>CTOF-only % of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>neutron</td>
<td>400</td>
<td>8318</td>
<td>6996</td>
<td>84.11%</td>
<td>56.67%</td>
<td>5350</td>
<td>4028</td>
<td>75.29%</td>
<td>32.63%</td>
</tr>
<tr>
<td>neutron</td>
<td>500</td>
<td>8836</td>
<td>7122</td>
<td>80.60%</td>
<td>56.27%</td>
<td>5534</td>
<td>3820</td>
<td>69.03%</td>
<td>30.18%</td>
</tr>
<tr>
<td>neutron</td>
<td>600</td>
<td>9439</td>
<td>7431</td>
<td>78.73%</td>
<td>56.18%</td>
<td>5797</td>
<td>3789</td>
<td>65.36%</td>
<td>28.64%</td>
</tr>
<tr>
<td>neutron</td>
<td>700</td>
<td>10110</td>
<td>7832</td>
<td>77.47%</td>
<td>55.48%</td>
<td>6296</td>
<td>4006</td>
<td>63.76%</td>
<td>28.36%</td>
</tr>
<tr>
<td>neutron</td>
<td>800</td>
<td>10404</td>
<td>7951</td>
<td>76.42%</td>
<td>54.77%</td>
<td>6566</td>
<td>4112</td>
<td>62.64%</td>
<td>28.30%</td>
</tr>
<tr>
<td>neutron</td>
<td>900</td>
<td>11596</td>
<td>8639</td>
<td>74.48%</td>
<td>53.69%</td>
<td>7453</td>
<td>4483</td>
<td>60.28%</td>
<td>27.92%</td>
</tr>
<tr>
<td>neutron</td>
<td>1000</td>
<td>12717</td>
<td>9092</td>
<td>71.49%</td>
<td>52.38%</td>
<td>8267</td>
<td>4642</td>
<td>56.15%</td>
<td>26.74%</td>
</tr>
<tr>
<td>proton</td>
<td>400</td>
<td>1105</td>
<td>488</td>
<td>44.16%</td>
<td>0.50%</td>
<td>96386</td>
<td>95771</td>
<td>99.36%</td>
<td>98.86%</td>
</tr>
<tr>
<td>proton</td>
<td>500</td>
<td>95925</td>
<td>192</td>
<td>0.20%</td>
<td>0.19%</td>
<td>99066</td>
<td>3297</td>
<td>3.33%</td>
<td>3.32%</td>
</tr>
<tr>
<td>proton</td>
<td>600</td>
<td>97788</td>
<td>155</td>
<td>0.16%</td>
<td>0.16%</td>
<td>99355</td>
<td>1722</td>
<td>1.73%</td>
<td>1.73%</td>
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<tr>
<td>proton</td>
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<td>247</td>
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<td>0.25%</td>
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<td>1.10%</td>
<td>1.09%</td>
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<tr>
<td>proton</td>
<td>800</td>
<td>98884</td>
<td>395</td>
<td>0.40%</td>
<td>0.40%</td>
<td>99302</td>
<td>813</td>
<td>0.79%</td>
<td>0.82%</td>
</tr>
<tr>
<td>proton</td>
<td>900</td>
<td>98956</td>
<td>199</td>
<td>0.20%</td>
<td>0.20%</td>
<td>99642</td>
<td>783</td>
<td>0.79%</td>
<td>0.79%</td>
</tr>
<tr>
<td>proton</td>
<td>1000</td>
<td>99084</td>
<td>715</td>
<td>0.72%</td>
<td>0.72%</td>
<td>99039</td>
<td>670</td>
<td>0.68%</td>
<td>0.67%</td>
</tr>
</tbody>
</table>

All files: 100,000 particles

$\phi = 0$

$\theta = 60$
Results

**400 MeV neutrons**

- **Energy deposition vs. layer, NO veto applied**
  - **Ensemble:** 578468
  - **Mean:** x = 1.55
  - **Mean:** y = 8.663
  - **Std Dev:** x = 1.12
  - **Std Dev:** y = 7.34

- **Energy deposition vs. layer, veto applied**
  - **Ensemble:** 2254
  - **Mean:** x = 0.82
  - **Mean:** y = 7.092
  - **Std Dev:** x = 0.9187
  - **Std Dev:** y = 6.192

**400 MeV protons**

- **Energy deposition vs. layer, NO veto applied**
  - **Ensemble:** 579463
  - **Mean:** x = 1.346
  - **Mean:** y = 46.58
  - **Std Dev:** x = 1.152
  - **Std Dev:** y = 27.86

- **Energy deposition vs. layer, veto applied**
  - **Ensemble:** 2254
  - **Mean:** x = 0.6278
  - **Mean:** y = 29.94
  - **Std Dev:** x = 0.9041
  - **Std Dev:** y = 32.23

**400 MeV π⁺**

- **Energy deposition vs. layer, NO veto applied**
  - **Ensemble:** 579463
  - **Mean:** x = 1.346
  - **Mean:** y = 46.58
  - **Std Dev:** x = 1.152
  - **Std Dev:** y = 27.86

- **Energy deposition vs. layer, veto applied**
  - **Ensemble:** 2254
  - **Mean:** x = 0.6278
  - **Mean:** y = 29.94
  - **Std Dev:** x = 0.9041
  - **Std Dev:** y = 32.23

---

**Total Detected**

- **n**
  - **12346**
  - **11553**
  - **93.58%**

- **p**
  - **12656**
  - **11750**
  - **92.84%**

- **π⁺**
  - **13228**
  - **12125**
  - **91.66%**

- **Cut 47**
  - **14118**
  - **12866**
  - **91.13%**

- **14516**
  - **13126**
  - **90.42%**

- **16092**
  - **14343**
  - **89.13%**

- **17359**
  - **15166**
  - **87.37%**

---

**Percentages**

- **n**
  - **1689**
  - **1.74%**

- **p**
  - **695**
  - **0.70%**

- **π⁺**
  - **540**
  - **0.54%**

- **Cut 47**
  - **409**
  - **0.41%**

- **403**
  - **0.40%**

- **437**
  - **0.44%**

- **417**
  - **0.42%**

- **π⁺**
  - **1242**
  - **1.25%**

- **956**
  - **0.96%**

- **699**
  - **0.70%**

- **675**
  - **0.68%**

- **706**
  - **0.71%**

- **445**
  - **0.45%**

- **358**
  - **0.36%**

---

Charged Particle Veto for the CD Using CND & CTOF
Results

Charged Particle Veto for the CD Using CND & CTOF

600 MeV neutrons
600 MeV protons
600 MeV π^+ MeV

phi vs. layer, NO veto applied

phi vs. layer, veto applied

<table>
<thead>
<tr>
<th>total detected</th>
<th>Cut 47</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>12346</td>
<td>11553</td>
<td>93.58%</td>
</tr>
<tr>
<td>12656</td>
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<tr>
<td>17359</td>
<td>15166</td>
<td>87.37%</td>
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<tr>
<td>96875</td>
<td>1689</td>
<td>1.74%</td>
</tr>
<tr>
<td>99222</td>
<td>695</td>
<td>0.70%</td>
</tr>
<tr>
<td>99510</td>
<td>540</td>
<td>0.54%</td>
</tr>
<tr>
<td>99656</td>
<td>409</td>
<td>0.41%</td>
</tr>
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<td>99697</td>
<td>403</td>
<td>0.40%</td>
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<tr>
<td>99741</td>
<td>437</td>
<td>0.44%</td>
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<tr>
<td>99754</td>
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<td>0.42%</td>
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<tr>
<td>99155</td>
<td>1242</td>
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<tr>
<td>99561</td>
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<tr>
<td>99816</td>
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</tr>
<tr>
<td>99865</td>
<td>358</td>
<td>0.36%</td>
</tr>
</tbody>
</table>
Further testing is underway to ensure that the veto is suitable for use in reconstruction of real data:

- Testing on Monte Carlo simulations of particles at all appropriate angles and momenta
- Inclusion of kaons
- Tests on already-reconstructed RG-B data
Implementation

- Implementation will go in parallel with optimization and testing – we don’t anticipate any changes to the structure of the veto, likely just energy and multiplicity refinements to the already-defined criteria!
Implementation

Tentative plan (as of yesterday):

At the beginning of the **CLUSTERING** for CND and CTOF, the following quantities must be defined, if not present already, for hits that qualify to be in the **same cluster**:

- Total energy
- Hit multiplicity, including the proper edep threshold
- Layer multiplicity, including the proper edep threshold

Then the clustering should be done (needs to be checked and maybe optimized), and the above quantities, on which the veto is based upon, should be **passed to EventBuilder**.

In **EventBuilder**: for CD neutral candidates, i.e. hits in CND and/or CTOF, which are NOT matched to CVT tracks (but it can be done also for those that are):

- Distinguish between the three cases: CTOF only, CND only, CTOF+CND
- For each case, create a « neutral » flag, based upon the veto criteria
- For events for which the neutral flag is on, proceed to neutron PID check: low and high b AND edep cut (right now only high b cut is present for CND)
- Include also PID for neutrons in CTOF (not present yet)

**Other ideas/plans:**

- Study additional veto criteria for **photons**, on top of beta/edep cut
- Include PID for photons in EB, not present yet (just reverse neutron cut)
- ID of pions and protons (with rough momentum/angle reconstruction)
Summary

- Refining and testing of a CTOF/CND-only charged particle veto is underway

- At present, the veto has been tested on single-particle, single momentum simulations*

- Implementation into the CND clustering algorithm will go in parallel with further testing