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

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### **Overview**

- Background and Motivation
- Development and Evolution
- Results
- Implementation
- Further Ideas and Considerations



### Background



### **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° < θ <125° Azimuthal coverage 2π Potential neutron detection efficiency ~3%

### Motivation

Tracking in the CVT is neither 100% efficient nor uniform
→ CND sees charged particle contamination



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



- 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  $\rightarrow$  TSelector  $\rightarrow$  CND clustering  $\rightarrow$  COATJAVA (EventBuilder)
- Start with what we observed in single-particle, singlemomentum simulations

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- Neutrons at 400-1000 MeV
- Protons from 400-1000 MeV\*
- $\pi$ + from 400-1000 MeV\*

Charged Particle Veto for the CD Using CND & CTOF

\*RG-A shows we won't see many above 800 MeV



#### Cut 34 7203 59 120 50 120 50 100

Cut 17

0.47%

Develo

			8140	56 0 %	71	36 50	10		Cut 15	%	Cur 10	4 2106	58	1 35%			
			800	56 .05%		22 56 679	Cut	20/	%	0006	532	4.31%	171	2.05%			
		· · · · · · · ·	93650	55 11%	(43	1 50.27%	100	90	4029	32.65%	365	2.00%	271	2.03%			
			9<62	50.00%	(832	50.18%	1080	93	6 3828	30.25%	362	2.1470	358	2.0476			
		and the second	510	3.36%	(951	35.48%	1088	88 220	A 7928	28.94%	399	2.83%	418	2.00%			
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	955 0.03	1700	1534%	909		04	Cut 44	70		02	07%	11367	92.0176	11750	32.84%	%	
	90978 91.40	05	04	Cut 4	13	70		02 71%	11367	34	7404	11611	91.74%	12125	91.66%	97%	Cut
	92355 92.01	Cut 42	70		00.0	2206	11570	93.7170	11611	91	.14%	11000	90.64%	12125	01 13% 3.9	1%	
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	66818 67.3	12095	00.95%	129	72 91	0070	13149	90.58%	14150	8	7.93%	14145	86 17%	15166	01.01.00%	13	342
	86428 86.81	1282	90.0370	131	61: 90	.67%	14455	89.83%	14100	8	6 17%	14958	00.11		6.	146	35
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	92523 92.6	1514	4 01.247		1		1075	1.94%	144		0.63%	620	0.0004	540	0.54%	66.	
	7863 7			4	075. 1	94%	1015	1 3 3 9/	62	8	0.4004;	457	0.46%	409	0.41%	404	
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	06	143	0.669	1	320:	1.0070	1044	1.05%	10	9	0.41%:	000	0.39%	403	0.40%	508	
-	70	6	53 0.007	1	1046	1.05%	1127	7. 1.139	6		0.42%	300	0.0006	437	0.44%	120	0
20		5	04 0.51	/0:	1128	1.13%	212	0.890	4	16	0.63%	622	0.6270	417	0.42%	1000	0.6
36	0.46%		72: 0.47	%	1120	0.89%	88	9.00	6	27	0.0370	512	0.51%		1	1022	. 1.3
109	0.00		0.46	96	889	0.000/	89	9: 0.90	70:	25	0.53%				1 2506		1.63
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	Q.55	4	186 0.49	/70	771	0.77%				····· + ······	1 26%	1229	1.2470	95	6 0.96%	0 5	3.320.
	0.3470	·····	499 0.50	<u>}%</u>				0.47	12	247	1.2070	899	0.90%	c0	0.70%	6	300
	45 0.4470	·····				0 5206	245	52 2.41	70	918	0.92%	66	0.66%	03	0.68%	10	210%
	71 0.53%			104	2504	2.53%	13	85 1.39	9%	662	0.66%	00	0.66%	67	5 0.007		1%
	92	1	692 1.7.	170	1602	1.61%	10	20 1.0	3%	002	0.67%	65	6 0.0070	70	6 0.719	136	1%
	0.00%		731 3.7	5%	4412	1.12%	10	29	80%	664	0.0174	70	0 0.70%		0.459	6 100	%6
	2. 18.06%		028 1.0	4%	1113	1 2006	10	80: 1.0	070	713	0.71%		8 0.43%		0.369	Vn 2009	5
	17923 2 34%		1.030	150%	1274	1.2070		1.0	1%	137	0.44%		0.36%	6 3	0.00	1776%	%
	2326 1 36%		1449: 1.4	1070	3967	3.97%		0.7	3%	401	0.37%	30	1048	1.26%			16
	1360 0.89%		9953 9.9	37%	020	0.84%		0.6	30%	3/1:	0.01	6.46%	1542	1.65%		3.579	6
	883 0 39%		928 0.8	83%	000	0.72%		601: 0.1	0% 51329	51.5%	0.75		1573	1.55%			
	387 0.07%		020	66%	716	0.1270	1729	1.80% 6.7	9% 77221	51.56%	9/20	9.80%		1.58%			/
*****	173 0.41		658: 0.	22666	65.57	9/0	1794 9	11.10	6480		6244	6.27%	1680		625	1.46%	
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	1.60	3447	4 23.31%	601381	053	3%	07	35 8 75	30251	42.03%		3 1000	970	1.2204	2993		
	1645 0.71	232	60 67 21%	2430	2: 20.0			5.15	7350	30.31%	4572	4 500	1070	0.98%	1245		
	703 0.5	190	90 01 37%	2529					1000	7.36%	5211	5 220	1422	1.08%	910	1.25%	
	510 0.4	42%	205 91.219	10:							4337	1.22%	1421	1 420	720	0.91%	
	418 0	42% 91	178. 20.22									4.34%	1525	1 5200	960	0.73%	
	420	34% 2	o for the	e CD Llsi	ing CN	ND & C	CTOF	6					1/17:	1 7200	800	0.97%	X
	343	0 27%		0 00 001	ing OI			0						1.12%	646	0.810	$\frown$
	067	0.0													046	101%	

### Interesting trials

- Sector/ $\phi$ 
  - 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)



### The veto today

- Two main sections
  - Section 1 defines useful quantities (total event energy, hit and layer multiplicity...)

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### The veto today

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







- If an event was in CTOF only:
  - total energy for the event is < 13 MeV and hit multiplicity is < 3</li>
- If an event was in CND and CTOF:
  - CND event energy is < 30 MeV, and CTOF event energy is < 13 MeV, and layer multiplicity is exactly 1
  - total event energy is < 10 MeV, and CTOF event energy is < 10 MeV, and layer multiplicity is exactly 2
- If an event was in CND only:
  - total event energy > 10 MeV and hit multiplicity is < 3</li>
  - Total event energy ≤ 10 MeV and hit
- multiplicity is < 4



### **Results**

#### Baseline

		Very few	pions of all on	momenta were de ly CND…	etected in		or only	in CTOF		almos detected i and	st all were n both CND CTOF	CND + CTOF + CND&CTOF
				1		<u> </u>						
Particle	Energy	CND baseline	CND only	% of CND baseline	CND-only % of total	CTOF baseline	CTOF only	% of CTOF baseline	CTOF-only % of total	CND & CTOF	detected in both % of total	total detected
neutron	400	8318	6996	84.11%	56.67%	5350	4028	75.29%	32.63%	1322	10.71%	12346
neutron	500	8836	7122	80.60%	56.27%	5534	3820	69.03%	30.18%	1714	13.54%	12656
neutron	600	9439	7431	78.73%	56.18%	5797	3789	65.36%	28.64%	2008	15.18%	13228
neutron	700	10110	7832	77.47%	55.48%	6286	4008	63.76%	28.39%	2278	16.14%	14118
neutron	800	10404	7951	76.42%	54.77%	6565	4112	62.64%	28.33%	2453	16.90%	14516
neutron	900	11599	8639	74.48%	53.69%	7453	4493	60.28%	27.92%	2960	18.39%	16092
neutron	1000	12717	9092	71.49%	52.38%	8267	4642	56.15%	26.74%	3625	20.88%	17359
proton	400	1105	488	44.16%	0.50%	96388	95771	99.36%	98.86%	617	0.64%	¥ 96876
proton	500	95925	192	0.20%	0.19%	99065	3297	3.33%	3.32%	95733	96.48%	99222
proton	600	97788	155	0.16%	0.16%	99355	1722	1.73%	1.73%	97633	98.11%	99510
proton	700	98567	247	0.25%	0.25%	99409	1089	1.10%	1.09%	98320	98.66%	99656
proton	800	98884	395	0.40%	0.40%	99302	813	0.82%	0.82%	98489	98.79%	9969
proton	900	98958	199	0.20%	0.20%	99542	783	0.79%	0.79%	98759	99.02%	99743
proton	1000	99084	715	0.72%	0.72%	99039	670	0.68%	0.67%	98369	98.61%	99754
pi+	400	96651	969	1.00%	0.98%	98186	2504	2.55%	2.53%	95682	96.50%	99155
pi+	500	98367	1114	1.13%	1.12%	98447	1194	1.21%	1.20%	97253	97.68%	99561
pi+	600	98856	415	0.42%	0.42%	99276	835	0.84%	0.84%	98441	98.75%	99691
pi+	700	99070	1443	1.46%	1.45%	98327	700	0.71%	0.70%	97627	97.85%	99770
pi+	800	99238	1718	1.73%	1.72%	98106	586	0.60%	0.59%	97520	97.69%	99824
pi+	900	99318	549	0.55%	0.55%	99267	498	0.50%	0.50%	98769	98.95%	99816
pi+	1000	99437	1794	1.80%	1.80%	98071	428	0.44%	0.43%	97643	97.77%	99865

All files:

100,000 particles

 $\phi = 0$ 

 $\theta = 60$ 



### Results



#### 400 MeV prestoross

class

### Results



#### 600 MeV preattooas



Energy deposition vs. layer, veto applied

		<u>.</u>	
	%	Cut 47	total detected
	93.58%	11553	12346
	92.84%	11750	12656
←I	91.66%	12125	13228
	91.13%	12866	14118
	90.42%	13126	14516
	89.13%	14343	16092
	87.37%	15166	17359
	1.74%	1689	96876
	0.70%	695	99222
←	0.54%	540	99510
	0.41%	409	99656
	0.40%	403	99697
	0.44%	437	99741
	0.42%	417	99754
	1.25%	1242	99155
	0.96%	956	99561
←1	0.70%	699	99691
	0.68%	675	99770
	0.71%	706	99824
	0.45%	445	99816
	0.36%	358	99865







- 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)





- 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

