Collision centrality and charged hadron spectra using SMASH

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2026-01-20

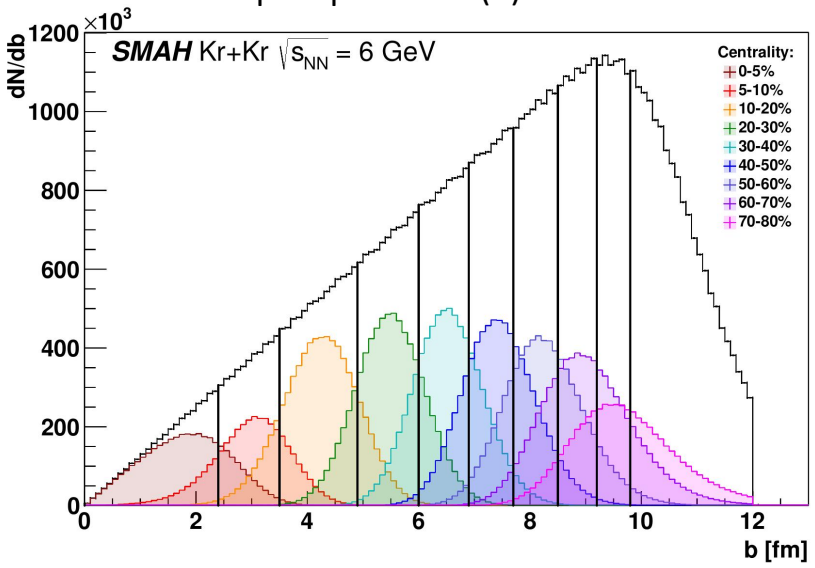
Collision centrality determiantion

- System: **Kr + Kr $\sqrt{s_{NN}}$ = 6 GeV, SMASH 3.3**
- Statistics: ~ 75 M events

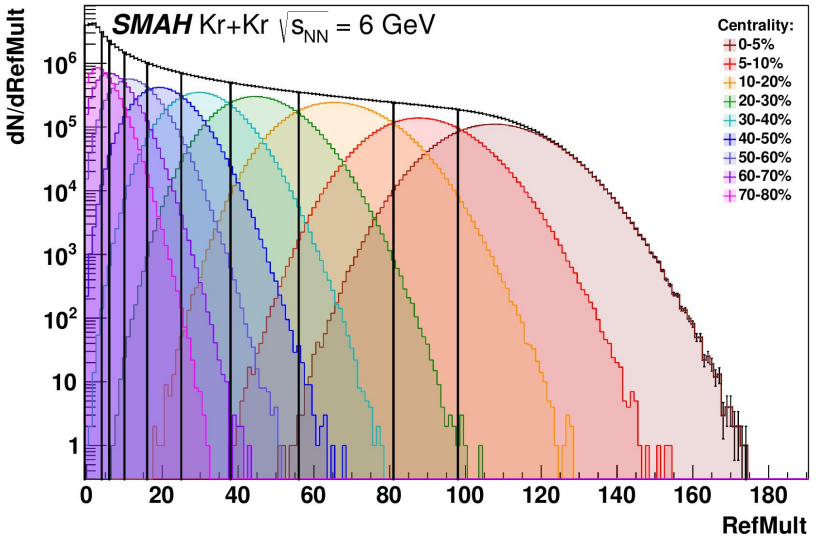
- **Reference multiplicity (RefMult)** is calculated as a number of charged particles with **$|\eta| < 1.0$** and **$p_T > 0.15$ GeV/c**.

Centrality, %	Impact parameter, fm	Reference multiplicity
0 - 5	0,0-2,4	98-174
5 - 10	2,4-3,5	81-98
10 - 20	3,5-4,9	56-81
20 - 30	4,9-6,0	38-56
30 - 40	6,0-6,9	25-38
40 - 50	6,9-7,7	16-25
50 - 60	7,7-8,5	10-16
60 - 70	8,5-9,2	6-10
70-80	9,2-9,8	4-6

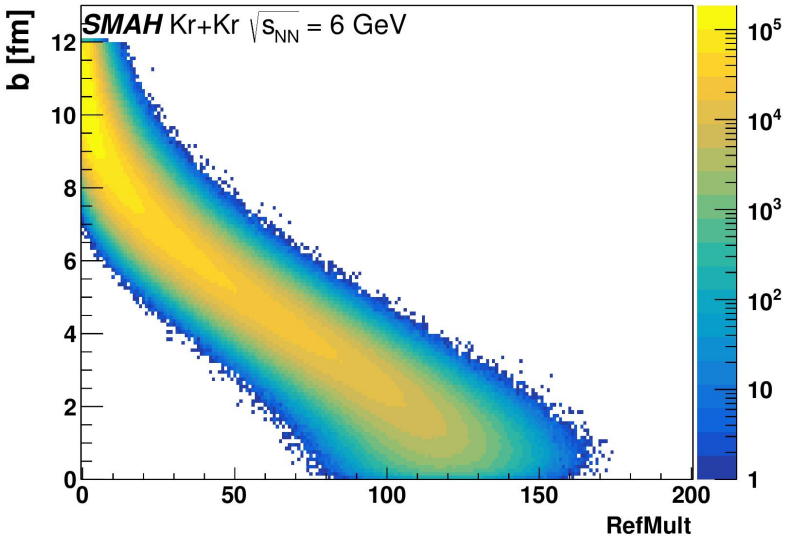
Impact parametr (b) distribution



Reference multiplicity (RefMult) distribution



Impact parametr vs. Reference multiplicity

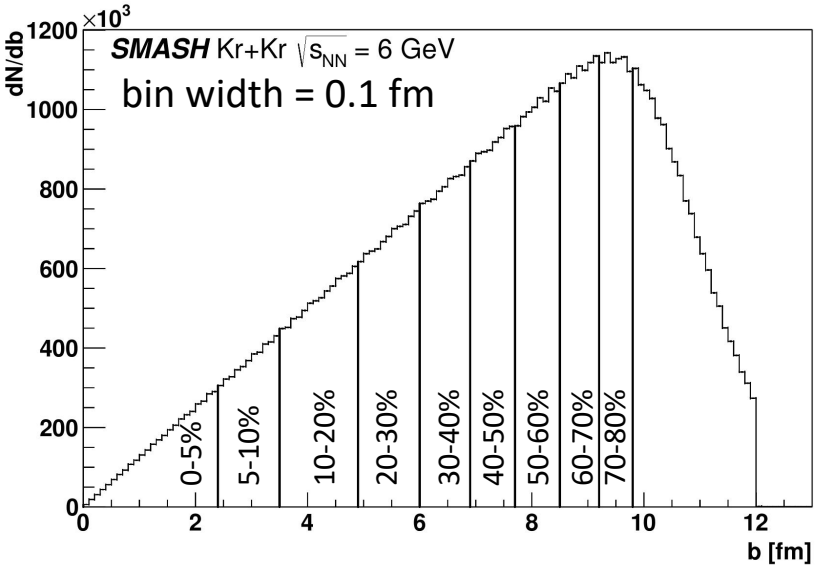


Centrality determination: bin width of the impact parameter distribution

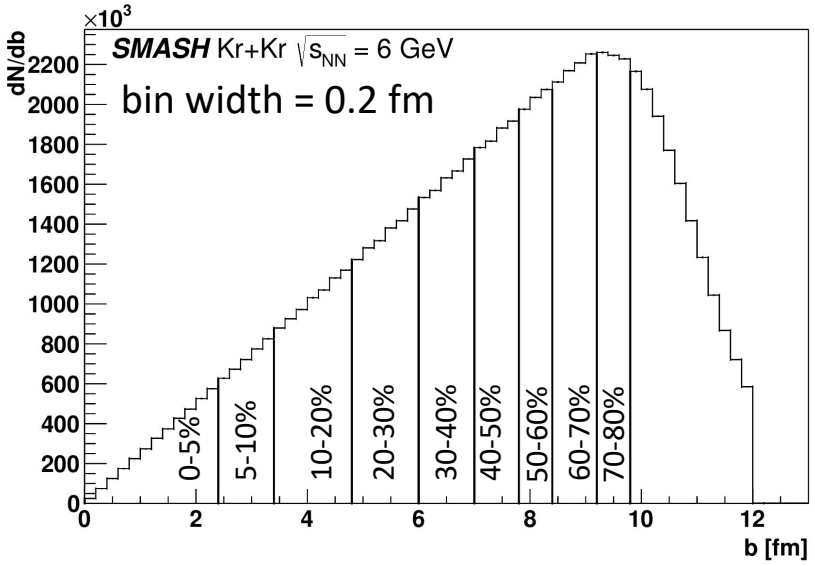
Changing the bin width leads to **0.1-0.2 fm** difference in centrality borders

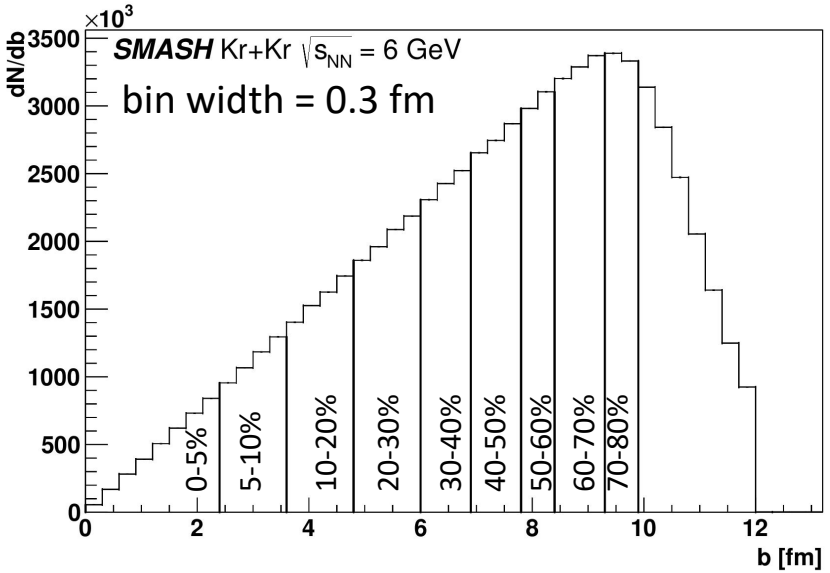
Kr+Kr $\sqrt{s_{NN}}$ = 6 GeV

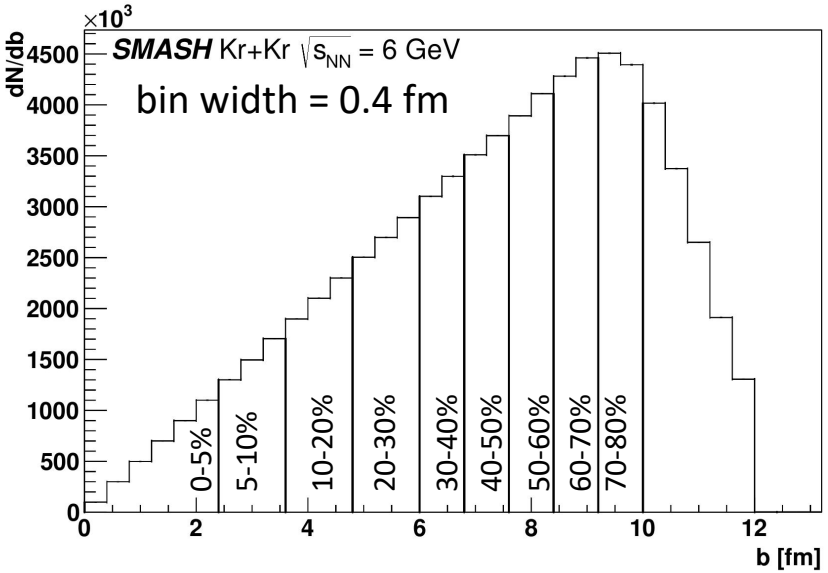
SMASH 3.3



Bin width, fm	0.1	0.2	0.3	0.4
Centrality, %	Impact parameter, fm			
0-5	0,0-2,4	0,0-2,4	0,0-2,4	0,0-2,4
5-10	2,4-3,5	2,4-3,4	2,4-3,6	2,4-3,6
10-20	3,5-4,9	3,4-4,8	3,6-4,8	3,6-4,8
20-30	4,9-6,0	4,8-6,0	4,8-6,0	4,8-6,0
30-40	6,0-6,9	6,0-7,0	6,0-6,9	6,0-6,9
40-50	6,9-7,7	7,0-7,8	6,9-7,8	6,9-7,8
50-60	7,7-8,5	7,8-8,4	7,8-8,4	7,8-8,4
60-70	8,5-9,2	8,4-9,2	8,4-9,3	8,4-9,3
70-80	9,2-9,8	9,2-9,8	9,3-9,9	9,3-9,9

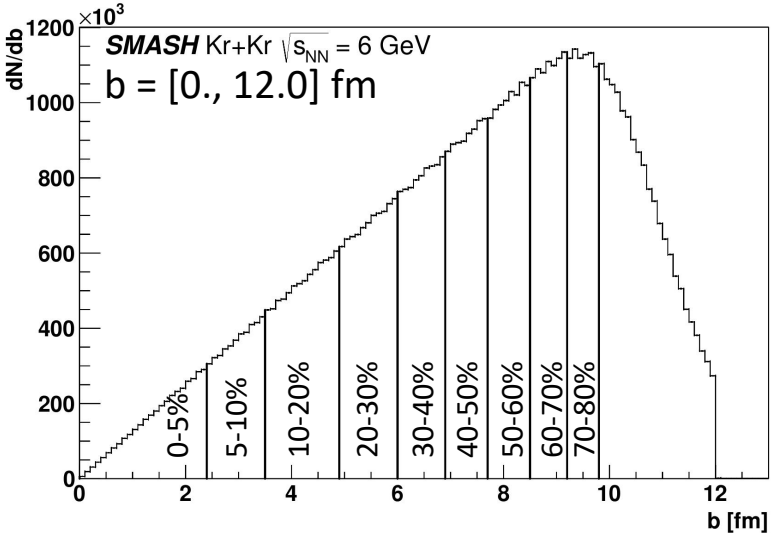


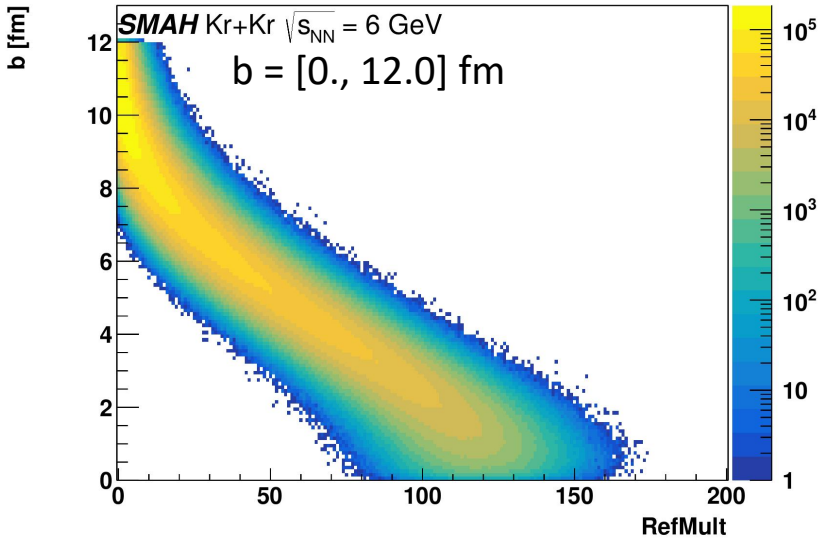


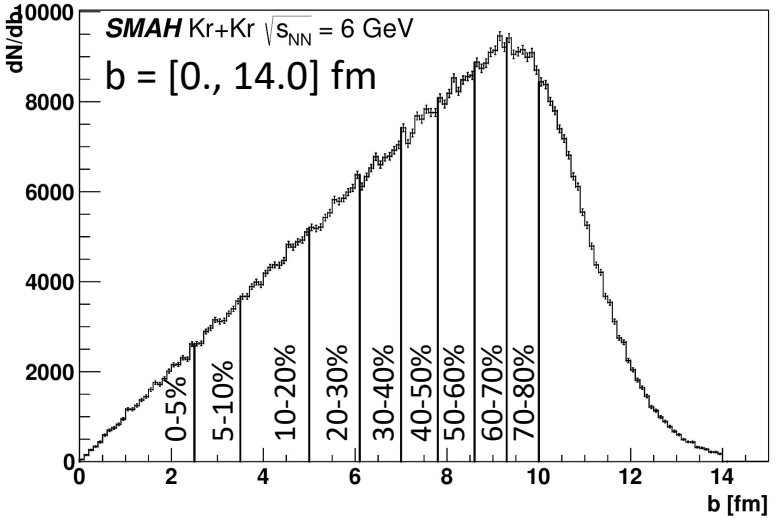


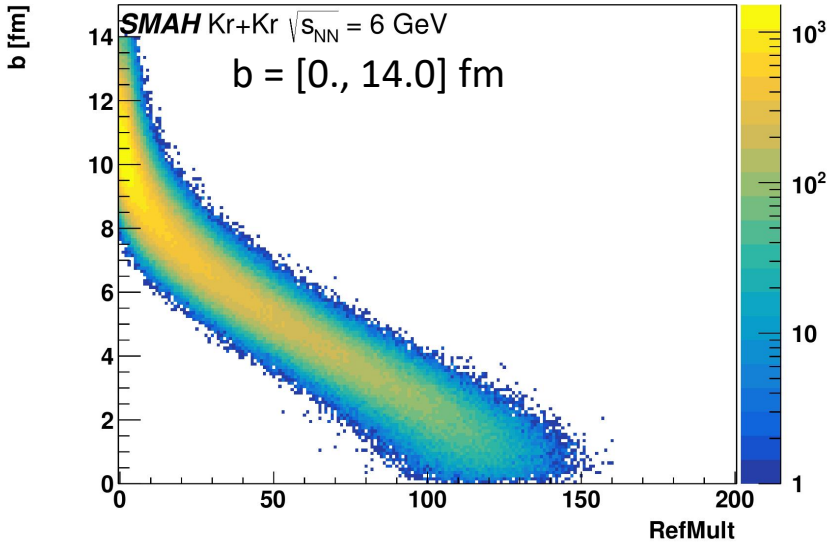
Centrality determination: impact parameter range used for modeling

Changing the impact parameter range used for modeling collisions leads to **0.1 fm** difference in centrality borders









Imp.par. range, fm	[0., 12.0]	[0., 14.0]
Centrality, %	Impact parameter, fm	
0-5	0,0-2,4	0,0-2,5
5-10	2,4-3,5	2,5-3,5
10-20	3,5-4,9	3,5-5,0
20-30	4,9-6,0	5,0-6,1
30-40	6,0-6,9	6,1-7,0
40-50	6,9-7,7	7,0-7,8
50-60	7,7-8,5	7,8-8,6
60-70	8,5-9,2	8,6-9,3
70-80	9,2-9,8	9,3-10,0

Kr+Kr $\sqrt{s_{NN}}$ = 6 GeV

SMASH 3.3

bin width = 0.1 fm

Blast wave fits of identified hadron spectra

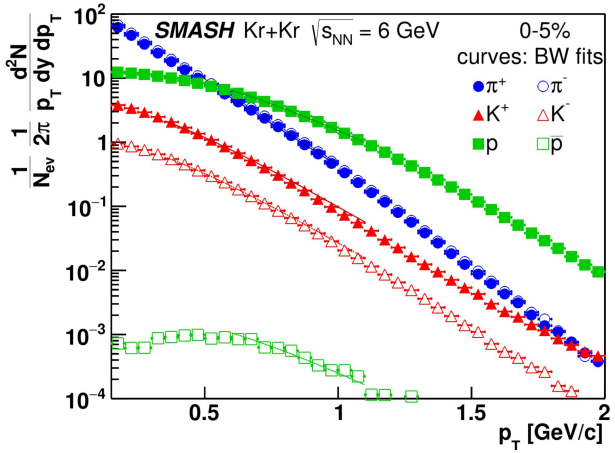
System: **Kr + Kr $\sqrt{s_{NN}}$ = 6 GeV, *SMASH* 3.3**
Statistics: ~ 75 M events

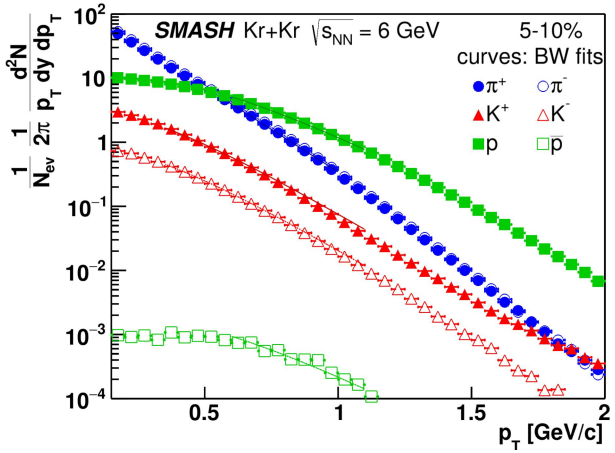
Track cuts:

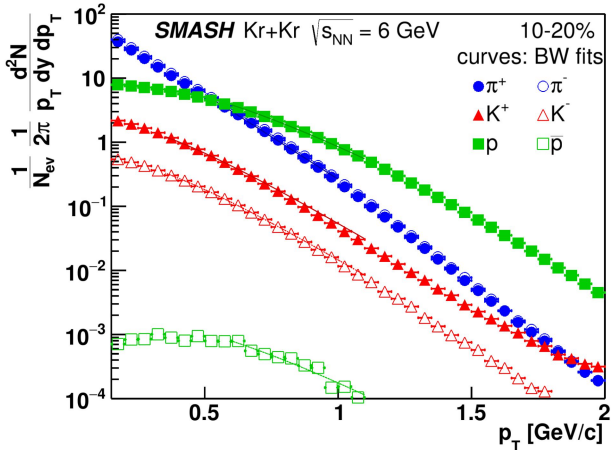
- $|y| < 0.1$
- $|\eta| < 1.0$
- $p_T > 0.15$ GeV/c

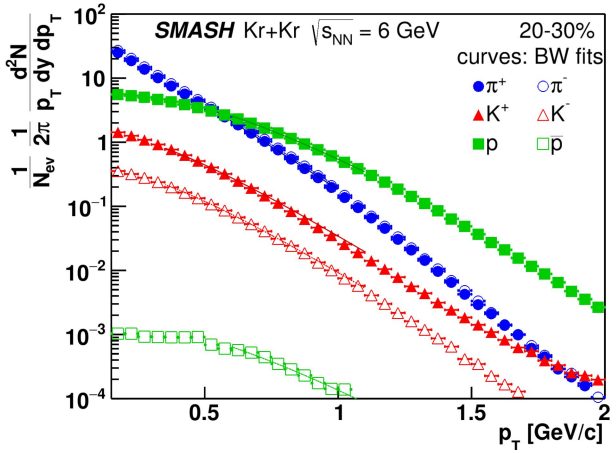
Charged hadrons: $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$

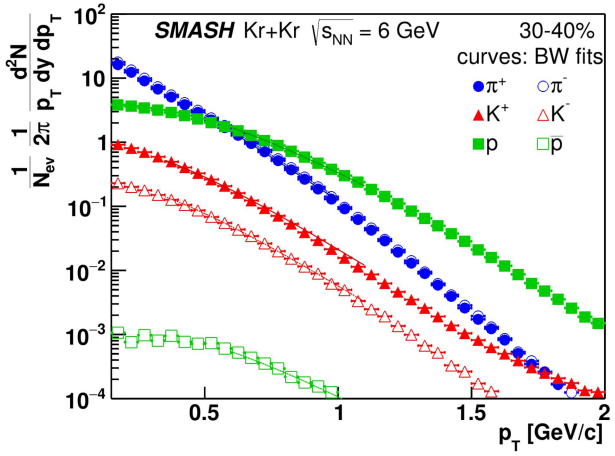
p_T fit ranges:
π: 0.5 - 1.0 GeV/c,
K: 0.35 - 1.1 GeV/c,
p($\bar{p}$): 0.6 - 1.1 GeV/c

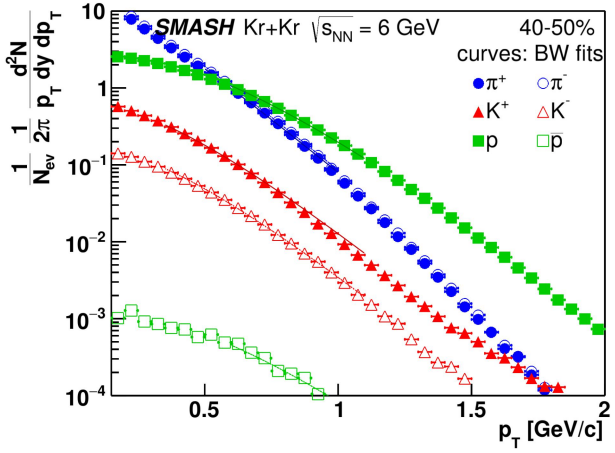


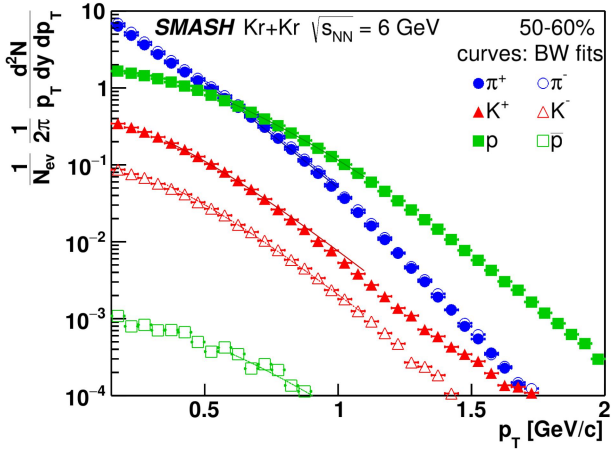


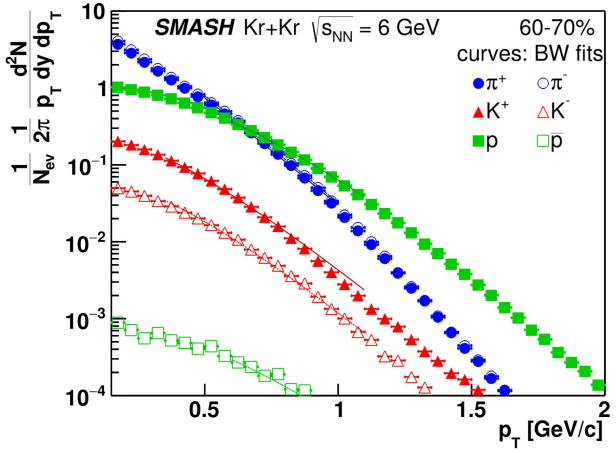










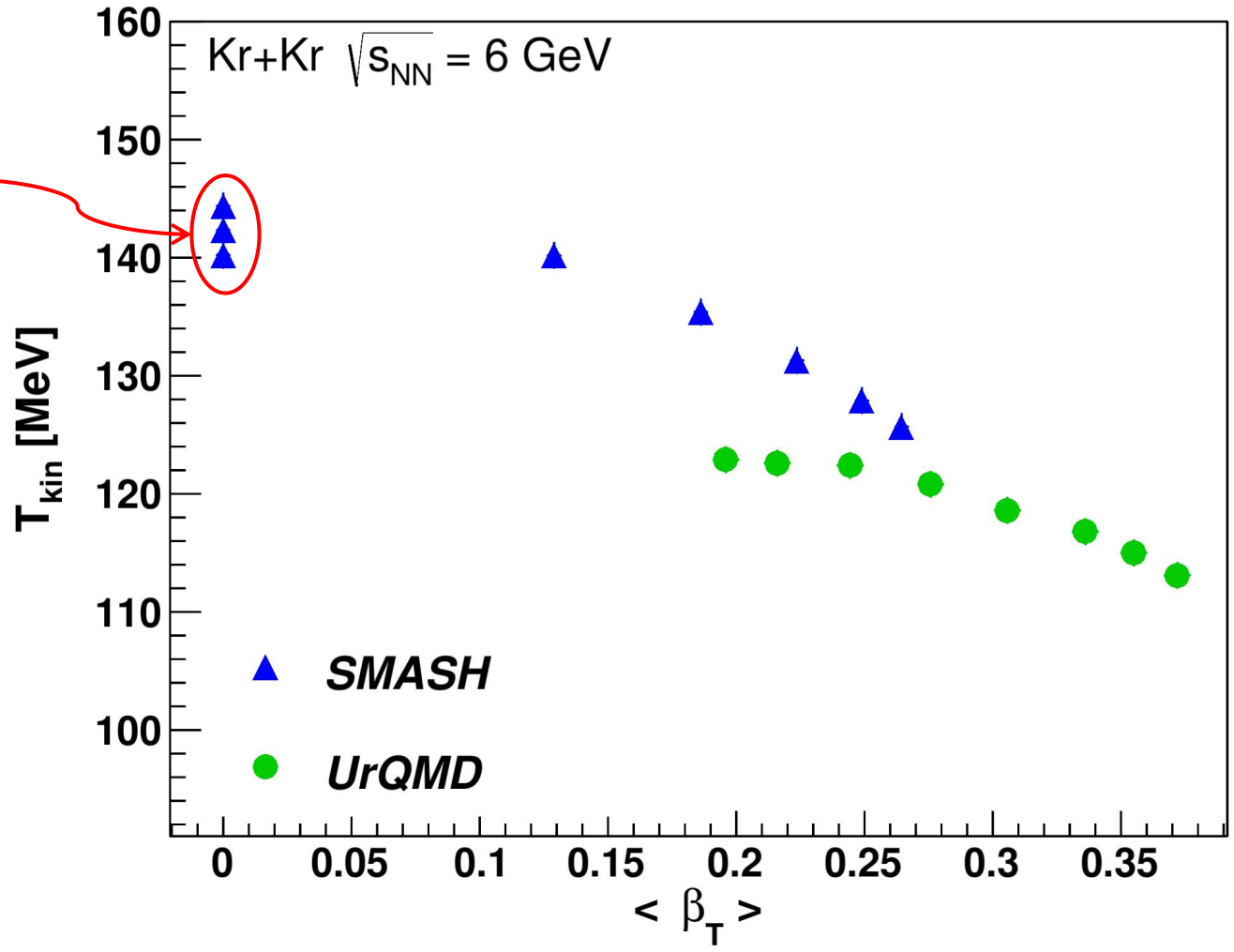


Kinetic freeze-out parameters

System: **Kr + Kr** $\sqrt{s_{NN}}$ **= 6 GeV**, ***SMASH* 3.3**
Statistics: ~ 75 M events

p_T fit ranges:
π: 0.5 - 1.0 GeV/c,
K: 0.35 - 1.1 GeV/c,
p($\bar{p}$): 0.6 - 1.1 GeV/c

- Significantly lower $\langle\beta\rangle$ and higher T_{kin} comparing to the UrQMD results
- $\langle\beta\rangle \approx 0$ for collision centrality 40-50%, 50-60%, 60-70% - probably something is wrong



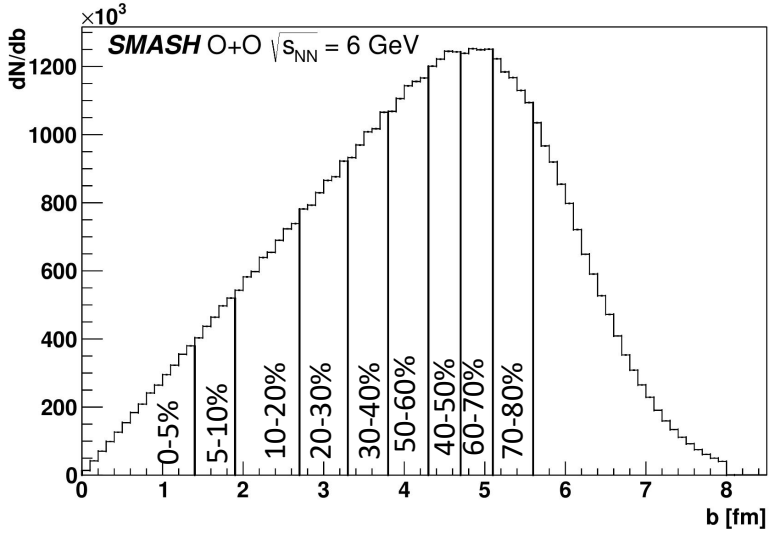
Collision centrality determiantion

- System: **O + O $\sqrt{s_{NN}}$ = 6 GeV, SMASH 3.3**
- Statistics: ~ 52.7 M events

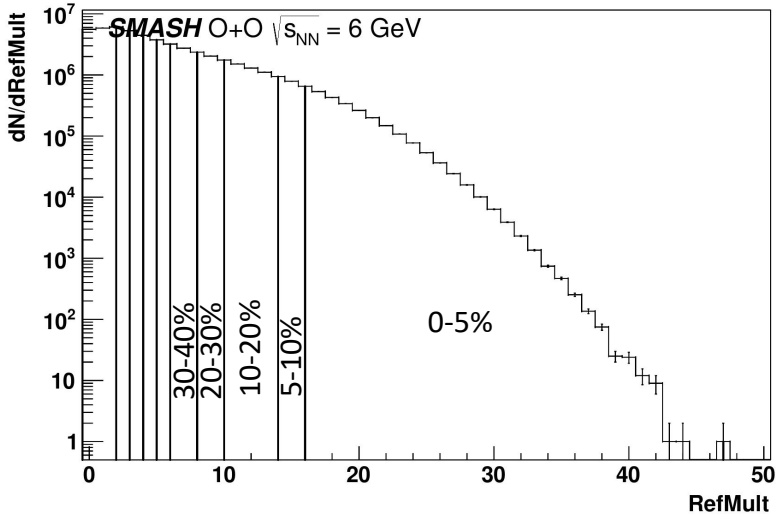
- **Reference multiplicity (RefMult)** is calculated as a number of charged particles with **$|\eta| < 1.0$** and **$p_T > 0.15$ GeV/c**.

Centrality, %	Impact parameter, fm	Reference multiplicity
0 - 5	0,0-1,4	16-47
5 - 10	1,4-1,9	13-16
10 - 20	1,9-2,7	10-13
20 - 30	2,7-3,3	8-10
30 - 40	3,3-3,8	6-8
40 - 50	3,8-4,3	5-6
50 - 60	4,3-4,7	4-5
60 - 70	4,7-5,1	3-4
70-80	5,1-5,6	2-3

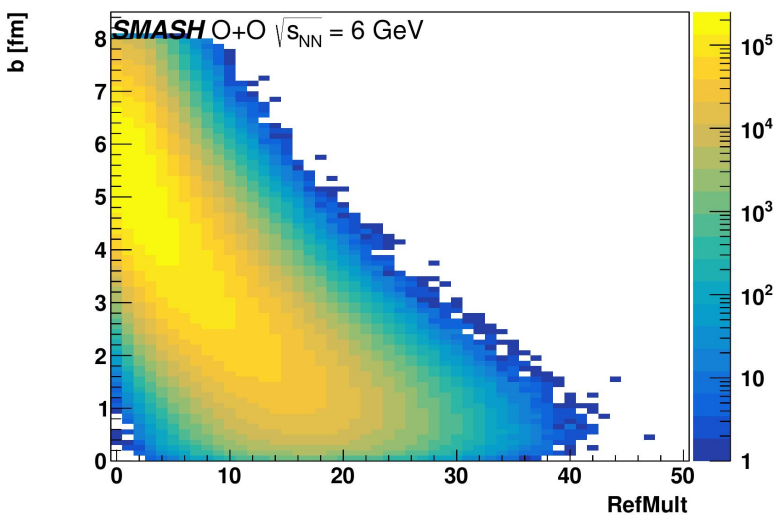
Impact parameter (b) distribution



Reference multiplicity (RefMult) distribution



Impact parametr vs. Reference multiplicity



Backup

Results of blast-wave fits for different centralities

System: **Kr + Kr** $\sqrt{s_{NN}}$ **= 6 GeV**,
***SMASH* 3.3**
Statistics: ~ 75 M events

p_T fit ranges:
π: 0.5 - 1.0 GeV/c,
K: 0.35 - 1.1 GeV/c,
p($\bar{p}$): 0.6 - 1.1 GeV/c

Centrality, %	⟨β⟩	Tkin, MeV	n	χ^2/NDF
0-5	0,2645 ± 0,0008	125,7 ± 0,2	0,5000 ± 0,0013	161,03
5-10	0,2490 ± 0,0010	127,9 ± 0,2	0,500 ± 0,002	122,7
10-20	0,2237 ± 0,0009	131,3 ± 0,2	0,500 ± 0,002	183,85
20-30	0,1862 ± 0,0014	135,4 ± 0,2	0,500 ± 0,005	141,4
30-40	0,129 ± 0,002	140,2 ± 0,2	0,50 ± 0,03	107,99
40-50	6,05434e-08 ± 0,12	144,377 ± 0,012	1,0 ± 0,4	82,3
50-60	1,97455e-08 ± 0,09	142,318 ± 0,016	0,9 ± 0,6	65,53
60-70	4,31614e-08 ± 0,2	140,209 ± 0,003	0,5 ± 0,7	64,38
70-80	7,27313e-08 ± 0,4	138,829 ± 0,002	0,5 ± 0,5	45,27

Centrality determination: bin width of the impact parameter distribution

Kr + Kr $\sqrt{s_{NN}}$ = 6 GeV, *SMASH* 3.3

Bin width = 0.1 fm			
Centrality, %	Impact parameter, fm	Cumulative percent	Percent
0-5	0,0-2,4	0,04799	0,04799
5-10	2,4-3,5	0,10201	0,05402
10-20	3,5-4,9	0,20004	0,09803
20-30	4,9-6,0	0,29989	0,09985
30-40	6,0-6,9	0,39663	0,09674
40-50	6,9-7,7	0,49407	0,09744
50-60	7,7-8,5	0,60193	0,10786
60-70	8,5-9,2	0,70455	0,10262
70-80	9,2-9,8	0,79434	0,08979

Bin width = 0.2 fm			
Centrality, %	Impact parameter, fm	Cumulative percent	Percent
0-5	0,0-2,4	0,04799	0,04799
5-10	2,4-3,4	0,09627	0,04828
10-20	3,4-4,8	0,19197	0,0957
20-30	4,8-6,0	0,29989	0,10792
30-40	6,0-7,0	0,40823	0,10834
40-50	7,0-7,8	0,50685	0,09862
50-60	7,8-8,4	0,58799	0,08114
60-70	8,4-9,2	0,70455	0,11656
70-80	9,2-9,8	0,79434	0,08979

Bin width = 0.3 fm			
Centrality, %	Impact parameter, fm	Cumulative percent	Percent
0-5	0,0-2,4	0,04799	0,04799
5-10	2,4-3,6	0,108	0,06001
10-20	3,6-4,8	0,19197	0,08397
20-30	4,8-6,0	0,29989	0,10792
30-40	6,0-6,9	0,39663	0,09674
40-50	6,9-7,8	0,50685	0,11022
50-60	7,8-8,4	0,58799	0,08114
60-70	8,4-9,3	0,71945	0,13146
70-80	9,3-9,9	0,80905	0,0896

Bin width = 0.4 fm			
Centrality, %	Impact parameter, fm	Cumulative percent	Percent
0-5	0,0-2,4	0,04799	0,04799
5-10	2,4-3,6	0,108	0,06001
10-20	3,6-4,8	0,19197	0,08397
20-30	4,8-6,0	0,29989	0,10792
30-40	6,0-6,8	0,38522	0,08533
40-50	6,8-7,6	0,48131	0,09609
50-60	7,6-8,4	0,58799	0,10668
60-70	8,4-9,2	0,70455	0,11656
70-80	9,2-10,0	0,82321	0,11866

Centrality determination: bin width of the impact parameter distribution

Kr + Kr $\sqrt{s_{NN}} = 6$ GeV,
***SMASH* 3.3**

Impact parameter = [0., 12.0] fm			
Centrality, %	**Impact parameter, fm**	**Cumulative percent**	**Percent**
0-5	0,0-2,4	0,04799	0,04799
5-10	2,4-3,5	0,10201	0,05402
10-20	3,5-4,9	0,20004	0,09803
20-30	4,9-6,0	0,29989	0,09985
30-40	6,0-6,9	0,39663	0,09674
40-50	6,9-7,7	0,49407	0,09744
50-60	7,7-8,5	0,60193	0,10786
60-70	8,5-9,2	0,70455	0,10262
70-80	9,2-9,8	0,79434	0,08979

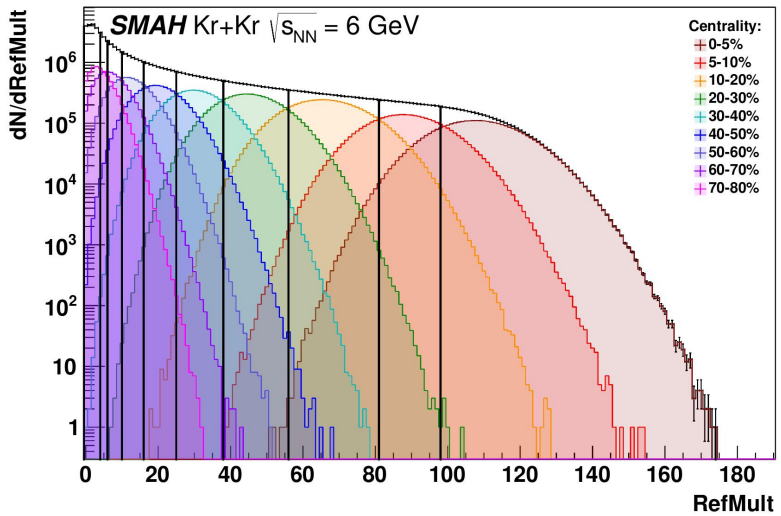
Kr + Kr $\sqrt{s_{NN}} = 6$ GeV,
***SMASH* 3.3**

Impact parameter = [0., 14.0] fm			
Centrality, %	**Impact parameter, fm**	**Cumulative percent**	**Percent**
0-5	0,0-2,5	0,05072	0,05072
5-10	2,5-3,5	0,09963	0,04891
10-20	3,5-5,0	0,20358	0,10395
20-30	5,0-6,1	0,30288	0,0993
30-40	6,1-7,0	0,39804	0,09516
40-50	7,0-7,8	0,49413	0,09609
50-60	7,8-8,6	0,6	0,10587
60-70	8,6-9,3	0,70076	0,10076
70-80	9,3-10,0	0,80172	0,10096

Centrality determination using reference multiplicity distribution

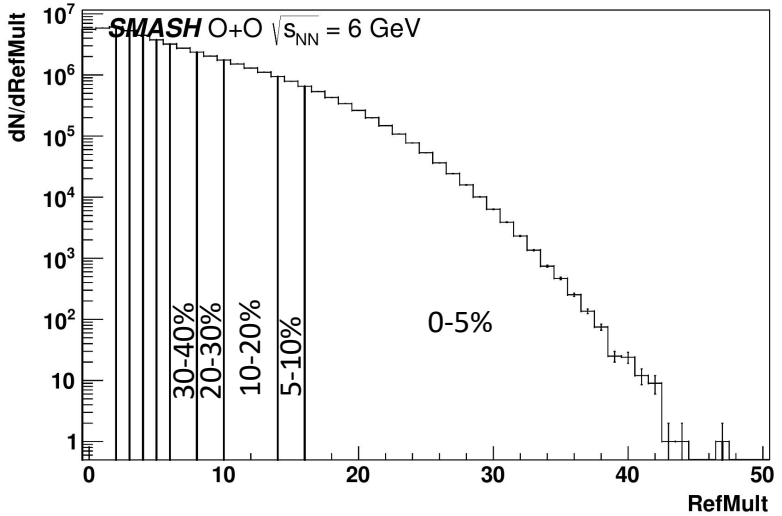
Kr + Kr $\sqrt{s_{NN}} = 6$ GeV, *SMASH* 3.3

Centrality, %	Reference multiplicity, fm	Cumulative percent	Percent
0-5	98-174	0,05088	0,05088
5-10	81-98	0,10017	0,04929
10-20	56-81	0,19857	0,0984
20-30	38-56	0,2999	0,10133
30-40	25-38	0,40353	0,10363
40-50	16-25	0,50659	0,10306
50-60	10-16	0,60728	0,10069
60-70	6-10	0,70943	0,10215
70-80	4-6	0,78554	0,07611



O + O $\sqrt{s_{NN}} = 6$ GeV, *SMASH* 3.3

Centrality, %	Reference multiplicity, fm	Cumulative percent	Percent
0-5	16-47	0,05624	0,05624
5-10	13-16	0,11115	0,05491
10-20	10-13	0,19939	0,08824
20-30	8-10	0,28448	0,08509
30-40	6-8	0,39956	0,11508
40-50	5-6	0,47225	0,07269
50-60	4-5	0,55844	0,08619
60-70	3-4	0,66107	0,10263
70-80	2-3	0,77871	0,11764

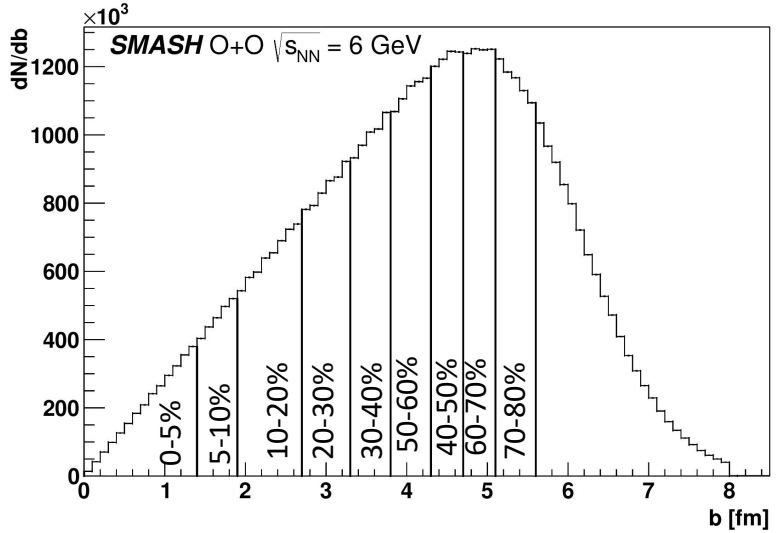


Centrality determination using reference multiplicity distribution

O + O $\sqrt{s_{NN}} = 6$ GeV,
***SMASH* 3.3**

Centrality, %	Impact parameter, fm	Cumulative percent	Percent
0-5	0,0-1,4	0,05336	0,05336
5-10	1,4-1,9	0,0983	0,04494
10-20	1,9-2,7	0,19834	0,10004
20-30	2,7-3,3	0,29645	0,09811
30-40	3,3-3,8	0,39311	0,09666
40-50	3,8-4,3	0,50228	0,10917
50-60	4,3-4,7	0,59734	0,09506
60-70	4,7-5,1	0,69395	0,09661
70-80	5,1-5,6	0,80618	0,11223

Impact parameter (b) distribution



SMASH config file for Kr+Kr collisions at $\sqrt{s_{NN}} = 6$ GeV

```
General:
    Modus: Collider
    End_Time: 200.0
    Delta_Time: 0.1
    Randomseed: -1
    Nevents: 100000

Output:
    Particles:
        Format: ["Oscar2013"]
        Only_Final: Yes
        Extended: True

_
Modi:
    Collider:
        Projectile: {Particles: {2212: 36, 2112: 48}}  # Kr
        Target: {Particles: {2212: 36, 2112: 48}}      # Kr
        Sqrtsnn: 6
        Impact:
            Sample: "quadratic"
            Range: [0.0, 12.0]
            Random_Reaction_Plane: True
        Fermi_Motion: "frozen"
```

SMASH config file for O+O collisions at $\sqrt{s_{NN}}$ = 6 GeV


```
General:
    Modus: Collider
    End_Time: 200.0
    Delta_Time: 0.1
    Randomseed: -1
    Nevents: 10000

Output:
    Particles:
        Format: ["Oscar2013"]
        Only_Final: Yes
        Extended: True

Modi:
    Collider:
        Projectile:
            Particles: {2212: 8, 2112: 8} # O
            Alpha_Clustered:
                Automatic: "True"
        Target:
            Particles: {2212: 8, 2112: 8} # O
            Alpha_Clustered:
                Automatic: "True"
        Sqrtsnn: 6
        Impact:
            Sample: "quadratic"
            Range: [0.0, 8.0]
            Random_Reaction_Plane: True
        Fermi_Motion: "frozen"
```