

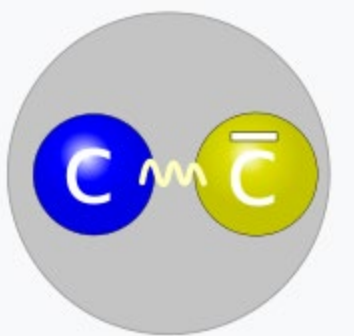
Modeling of J/ψ Production and $\pi^+ \pi^- \rightarrow \mu^+ \mu^-$ Background for SPD at NICA

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J/ψ and π Mesons

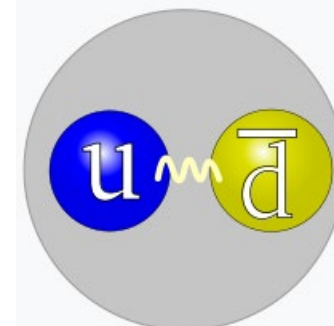


J/ψ

Mass	5.5208×10^{-27} kg
	3.096 916 GeV/c ²
Decay width	92.9 keV

Electric charge 0 e

Br: $J/\psi \rightarrow \mu^+ \mu^- = 0.05961$



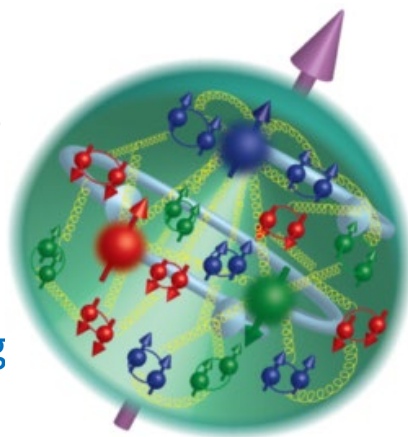
π

Mass	π^\pm : 139.570 39(18) MeV/c ² [1]
	π^0 : 134.9768(5) MeV/c ² [1]
Mean lifetime	π^\pm : 2.6×10^{-8} s
	π^0 : 8.5×10^{-17} s
Electric charge	π^\pm : ± 1 e

Br: $\pi \rightarrow \mu \bar{\nu}_\mu = 0.99987$

Why J/ψ Is Interesting?

- Gluon structure of proton
- TMD parton distribution functions (with polarized beams)
- QCD sub-processes not well-described at SPD energy range
- Clean signal $J/\psi \rightarrow \mu^+ \mu^-$ and big statistic



	unpolarized	longitudinally pol.	transversely pol.
unpolarized	f_1 number density		f_{1T}^\perp Sivers
longitudinally pol.		g_{1L} helicity	g_{1T}
transversely pol.	h_1^\perp Boer-Mulders	h_{1L}^\perp 	h_1 transversity
		h_{1L}^\perp 	h_{1T}^\perp pretzelosity



PYTHIA8 Parameters for J/ψ ($pp, \sqrt{s} = 27$ GeV)

Processes: "Charmonium:all =on"

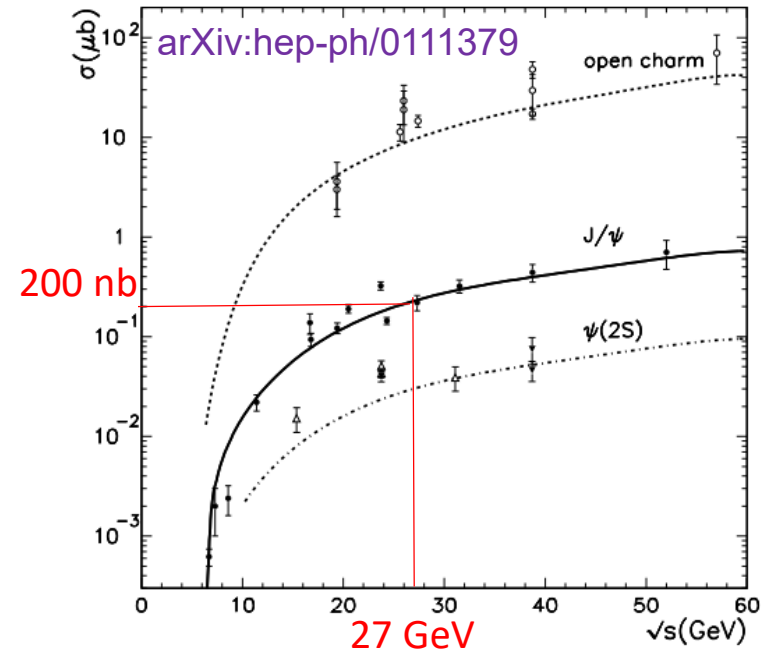
nEvents: 1 000 000 000

PDF: "MRST2004qed_proton"

```

----- PYTHIA Event and Cross Section Statistics -----
Subprocess                                Code      sigma +- delta
                                           (estimated) (mb)
-----
g g -> ccbar(3S1)[3S1(1)] g              401      4.887e-06 9.831e-09
g g -> ccbar(3S1)[3S1(8)] g              402      3.891e-07 2.697e-09
q g -> ccbar(3S1)[3S1(8)] q              403      6.447e-07 3.401e-09
q qbar -> ccbar(3S1)[3S1(8)] g           404      1.679e-07 1.714e-09
g g -> ccbar(3S1)[1S0(8)] g              405      1.964e-06 5.846e-09
q g -> ccbar(3S1)[1S0(8)] q              406      7.032e-07 3.400e-09
q qbar -> ccbar(3S1)[1S0(8)] g           407      7.432e-09 3.449e-10
g g -> ccbar(3S1)[3Pj(8)] g              408      3.647e-06 7.685e-09
q g -> ccbar(3S1)[3Pj(8)] q              409      1.337e-06 4.806e-09
q qbar -> ccbar(3S1)[3Pj(8)] g           410      6.961e-08 1.115e-09
g g -> ccbar(3Pj)[3Pj(1)] g              411      5.479e-05 3.013e-08
q g -> ccbar(3Pj)[3Pj(1)] q              412      1.563e-05 1.511e-08
q qbar -> ccbar(3Pj)[3Pj(1)] g           413      9.155e-07 4.153e-09
g g -> ccbar(3Pj)[3S1(8)] g              414      2.502e-08 6.985e-10
q g -> ccbar(3Pj)[3S1(8)] q              415      5.302e-08 9.926e-10
q qbar -> ccbar(3Pj)[3S1(8)] g           416      1.714e-08 5.473e-10
g g -> ccbar(3Dj)[3Dj(1)] g              417      1.383e-08 5.319e-10
g g -> ccbar(3S1)[3S1(1)] gamma          441      1.702e-07 1.810e-09
sum                                       8.543e-05 3.750e-08

```



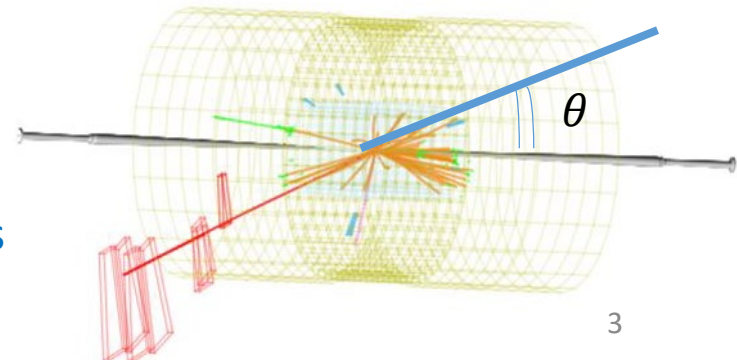
Selection Conditions

- Two opposite charged muons from J/ψ decay
- $|\cos \theta_{\mu^-\mu^+}| < 0.9$
- Resolution 1.5 % ON

✓ 39 576 030 dimuon events were selected

✓ After normalisation to $L_{\text{int}} = 1 \text{ fb}^{-1}$: 7 915 210 Events

✓ $\sigma_{J/\psi \rightarrow \mu^+\mu^-} = 7.915 \text{ nb}$





Why Background Study is Important

1 2 3 4

1 2 3 4



$\pi^+\pi^-\rightarrow\mu^+\mu^-$ Background

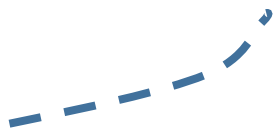
1. Both of pions decayed inside the detector (before Range System)

SPD TDR

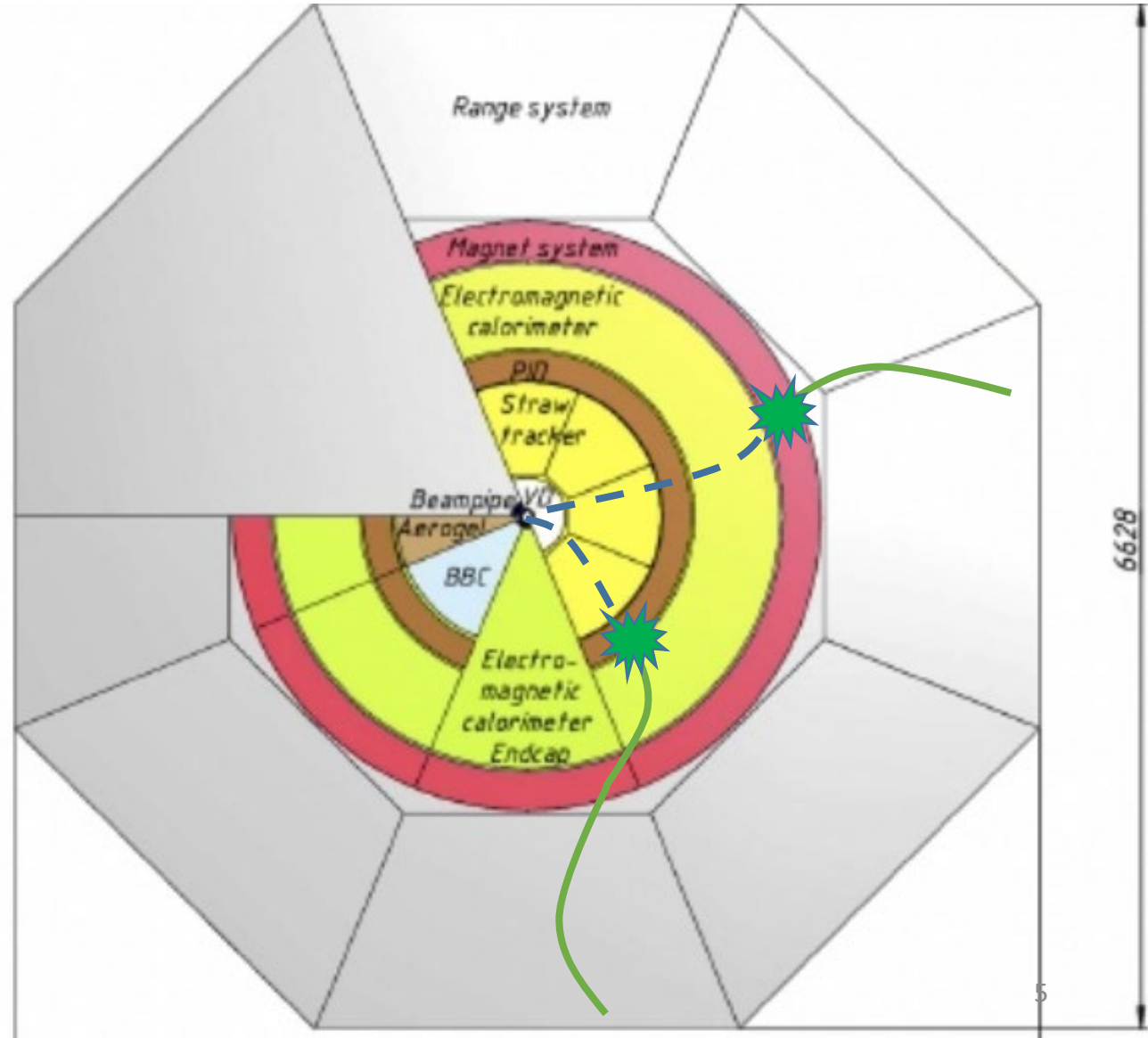
μ track



π track



$\pi \rightarrow \mu$
decay point





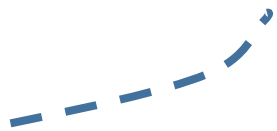
$\pi^+ \pi^- \rightarrow \mu^+ \mu^-$ Background

2. The first pion decayed before RS. The second one was misidentified in RS as muon

μ track



π track

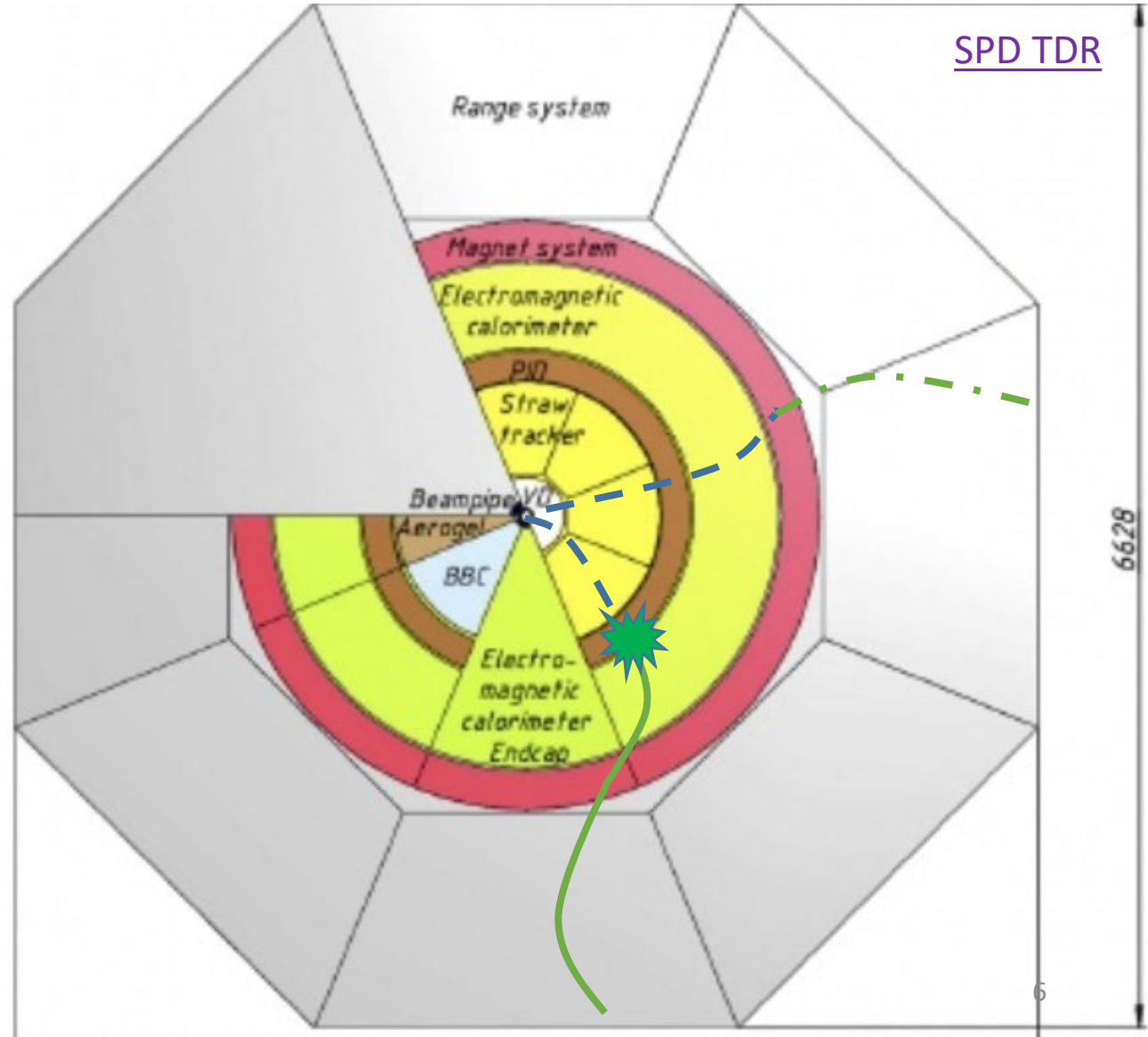


π track

Identified as μ



$\pi \rightarrow \mu$
decay point





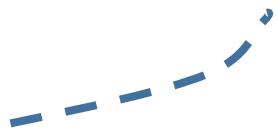
$\pi^+ \pi^- \rightarrow \mu^+ \mu^-$ Background

3. Both of pions were misidentified in RS as muons

μ track



π track

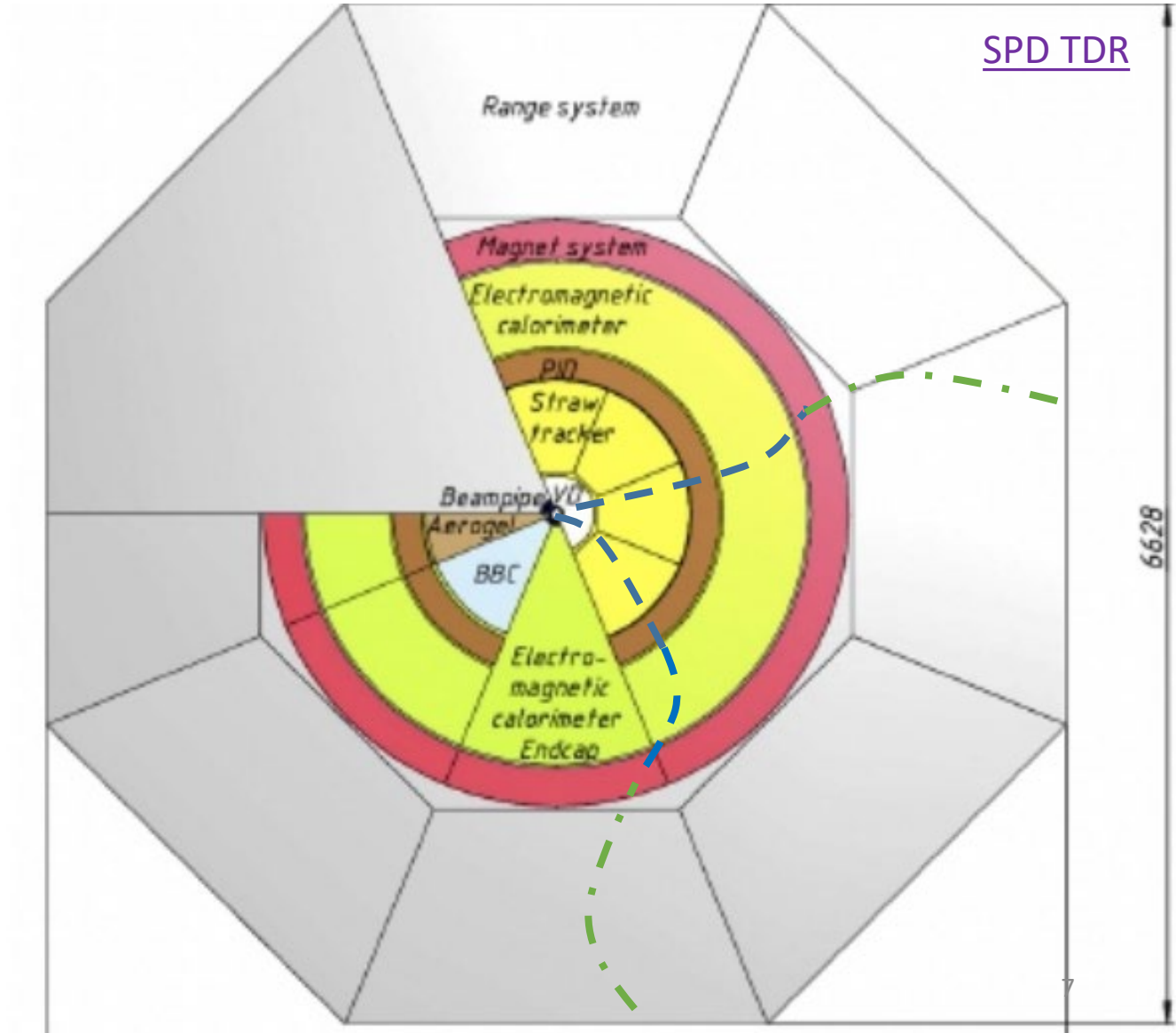


π track

Identified as μ



$\pi \rightarrow \mu$
decay point

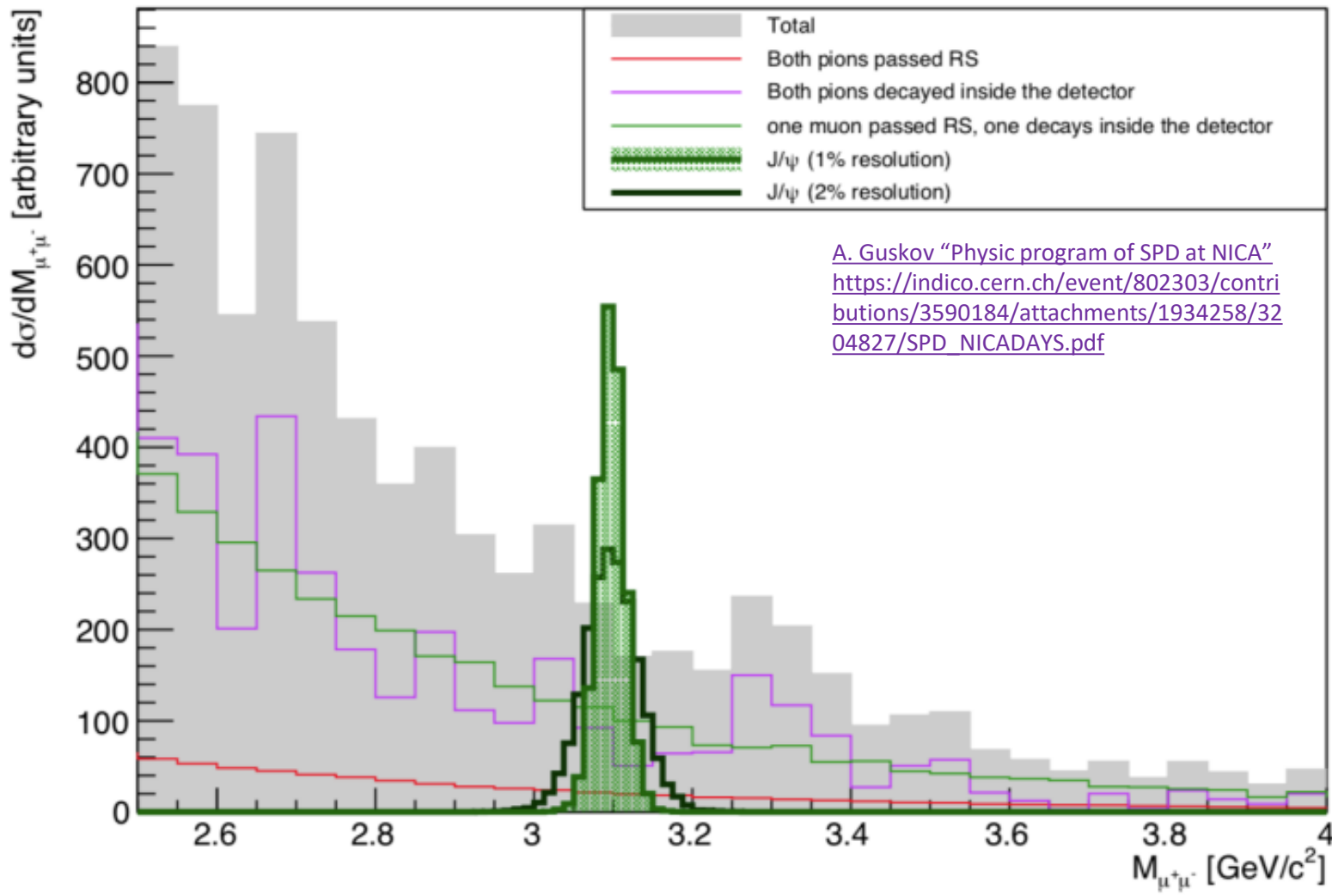




$\pi^+\pi^-\rightarrow\mu^+\mu^-$ Background

Types of Pions Background

1. Both of pions decayed inside the detector (before Range System)
2. The first pion decayed before RS. The second one was misidentified in RS as muon
3. Both of pions were misidentified in RS as muons





PYTHIA8 Parameters for Background (pp, $\sqrt{s} = 27$ GeV)

Processes: "HardQCD:all =on"

PDF: "MRST2004qed_proton"

nEvents: 10 000 000 000

```
*----- PYTHIA Event and Cross Section Statistics -----*
```

Subprocess	Code	Number of events			sigma +- delta (estimated) (mb)	
		Tried	Selected	Accepted		
g g -> g g	111	2101050	300917	300904	1.081e+00	1.070e-03
g g -> q qbar (uds)	112	22223	3802	3802	1.403e-02	1.253e-04
q g -> q g	113	4038530	504003	503985	1.813e+00	1.435e-03
q q(bar)' -> q q(bar)'	114	1730020	189152	189142	6.783e-01	8.219e-04
q qbar -> g g	115	6177	1090	1090	3.956e-03	6.544e-05
q qbar -> q' qbar' (uds)	116	2257	374	374	1.339e-03	3.856e-05
g g -> c cbar	121	3951	548	548	1.972e-03	4.912e-05
q qbar -> c cbar	122	942	114	114	4.153e-04	2.221e-05
g g -> b bbar	123	2	0	0	0.000e+00	0.000e+00
q qbar -> b bbar	124	0	0	0	0.000e+00	0.000e+00
sum		7905152	1000000	999959	3.594e+00	1.976e-03

```
*----- End PYTHIA Event and Cross Section Statistics -----*
```

Pions decay:

- Pions decay ON

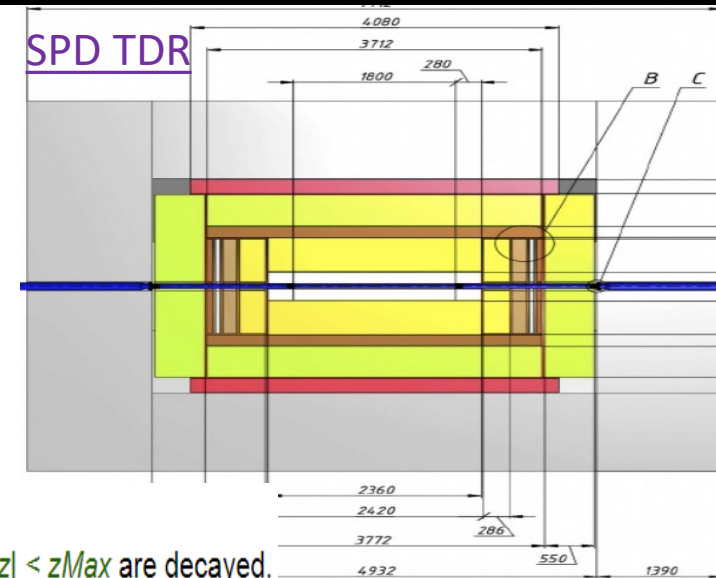
```
pythia.readString("211:mayDecay = true");
pythia.readString("-211:mayDecay = true");
```

- Cylindrical volume which pions can decay in

```
pythia.readString("ParticleDecays:limitCylinder = on ");
pythia.readString("ParticleDecays:xyMax =4446.3 ");
pythia.readString("ParticleDecays:zMax = 3856. ");
```

flag ParticleDecays:limitCylinder (default = off)

When on, only particles with a decay within a volume limited by $\rho = \sqrt{x^2 + y^2} < xyMax$ and $|z| < zMax$ are decayed.





Dimuons Selection in Background

Selection conditions

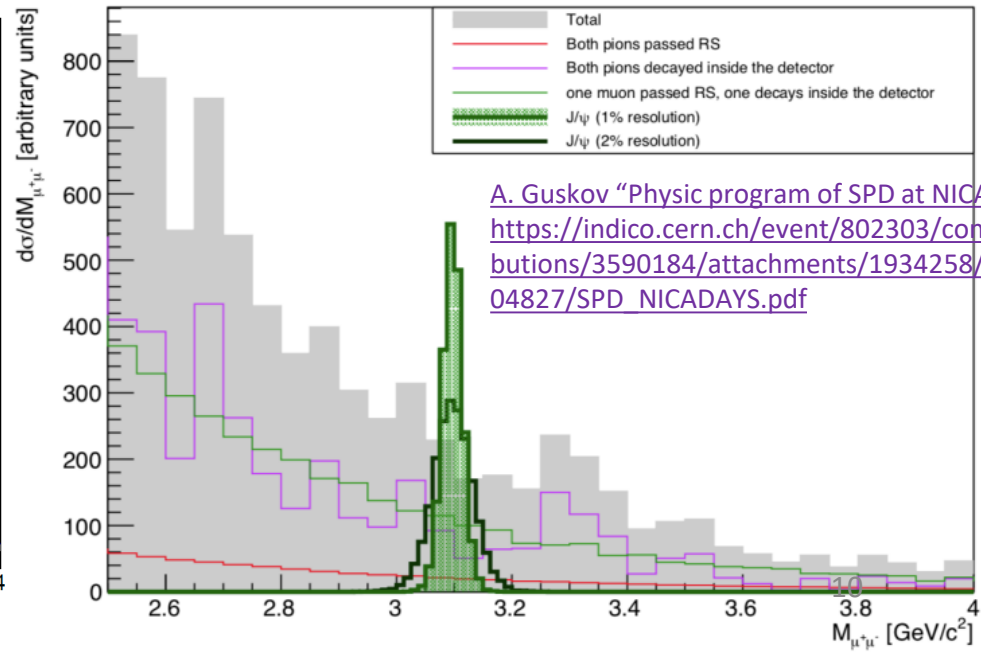
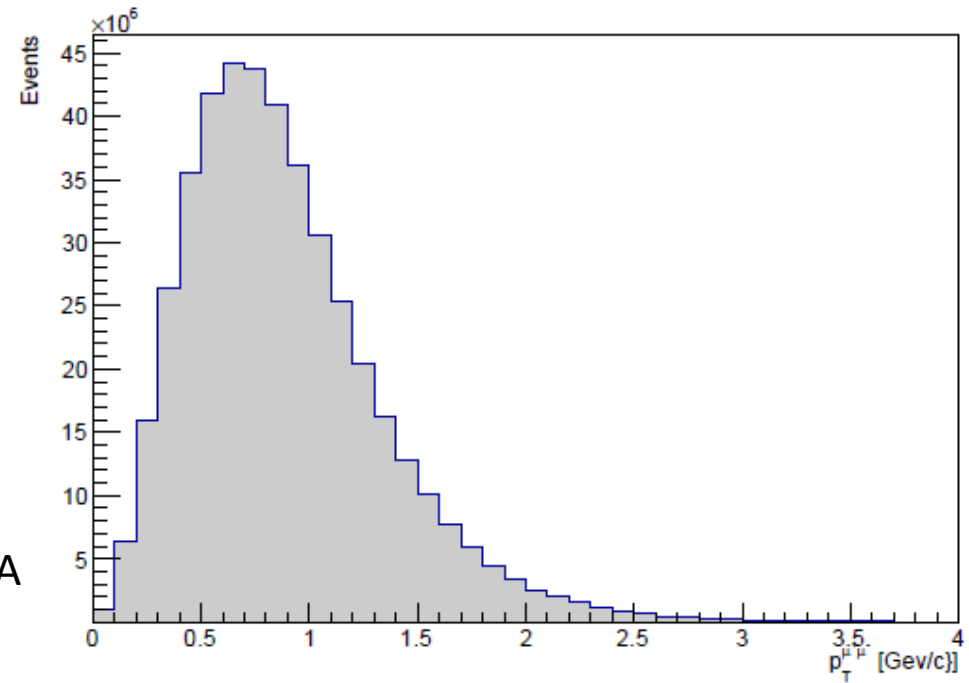
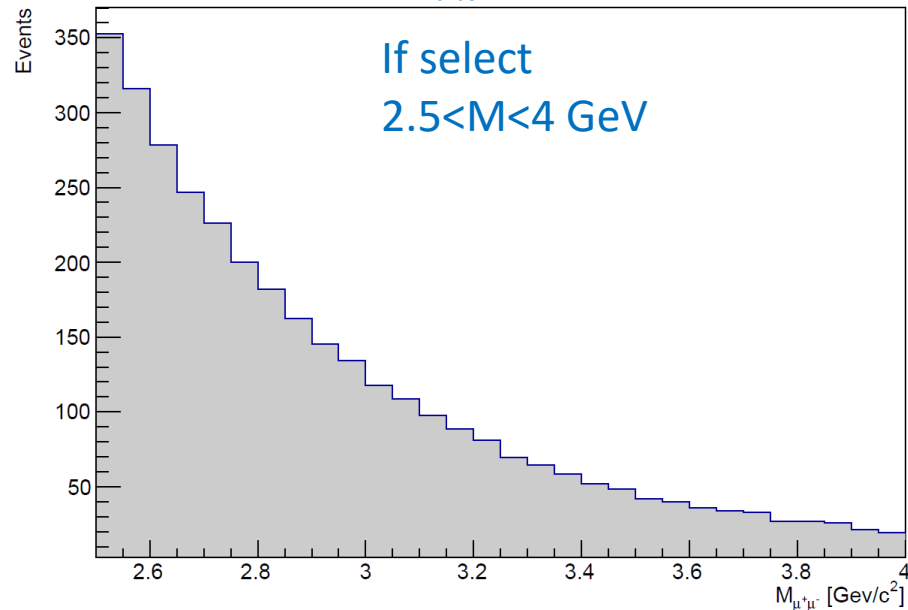
- Muon should be from pion decay
- Just one couple of opposite charged muons in one events was selected (but in one event could be more)
- Different combinations of muons were considered. Couple with $2.9 < M < 3.3$ GeV and $|\cos \theta_{\mu^- \mu^+}| < 0.9$ was selected

Events selected: 1 222 993 events

439 788 089 expected at NICA

Cross Section: $\sigma = 440$ nbn

Normalized to $L_{int} = 1 fb^{-1}$ is presented





First Signal/Background Comparison

Cross sections at $2.9 < M < 3.2$ GeV

$$\sigma_{J/\psi \rightarrow \mu^+\mu^-} = 7.915 \text{ nb}$$

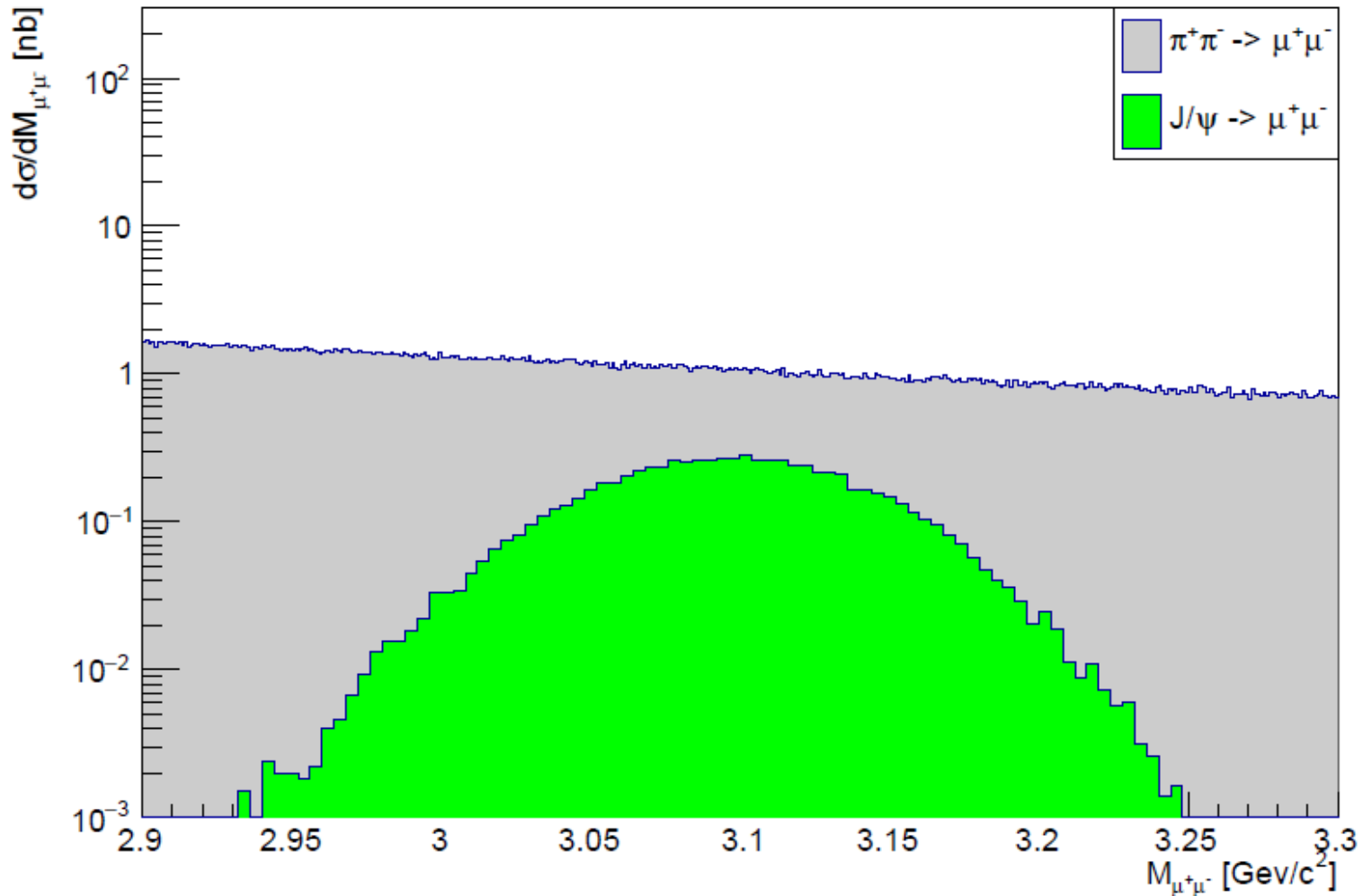
$$\sigma_{\pi^+\pi^- \rightarrow \mu^+\mu^-} = 440 \text{ nb}$$

$$\frac{\sigma_S}{\sigma_B} \sim 0.018$$

After normalization to $L_{\text{int}} = 1 \text{ fb}^{-1}$:

$$J/\psi \rightarrow \mu^+\mu^- = 7\,915\,210 \text{ events}$$

$$\pi^+\pi^- \rightarrow \mu^+\mu^- = 439\,788\,089 \text{ events}$$





Kinematic of Signal and Background

Normalized to $L_{int} = 1 \text{ fb}^{-1}$ is presented

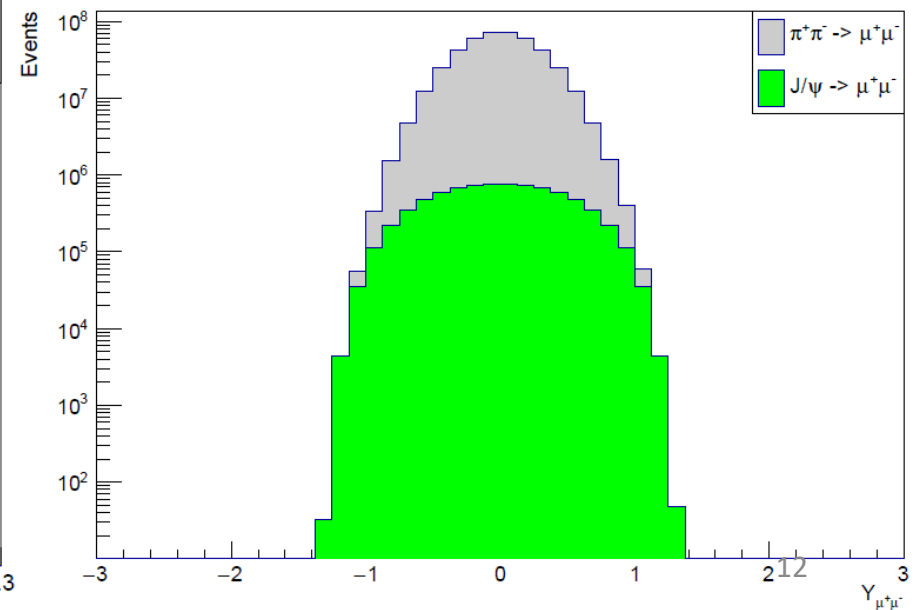
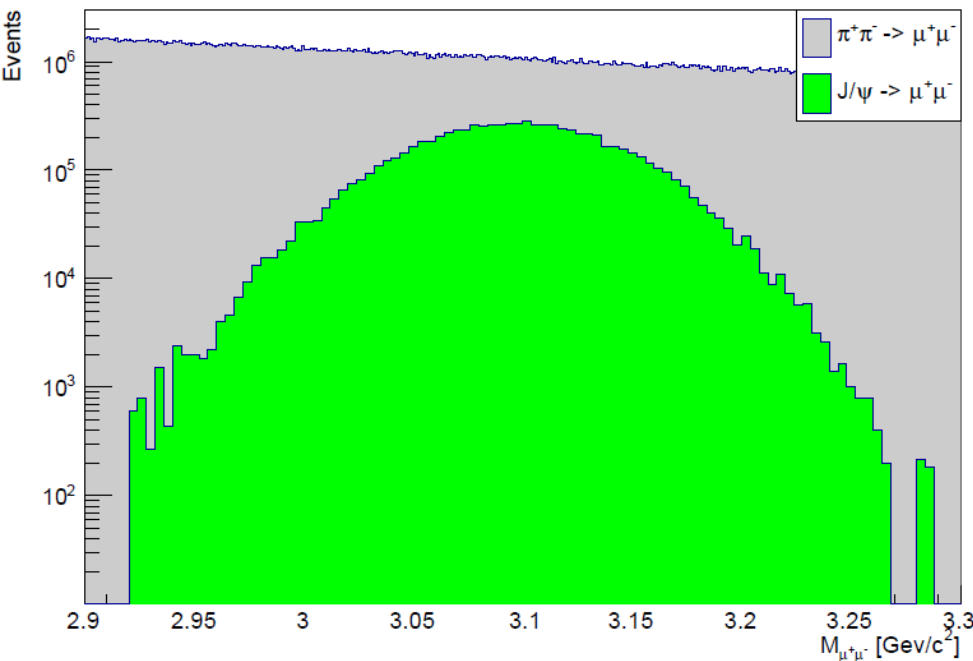
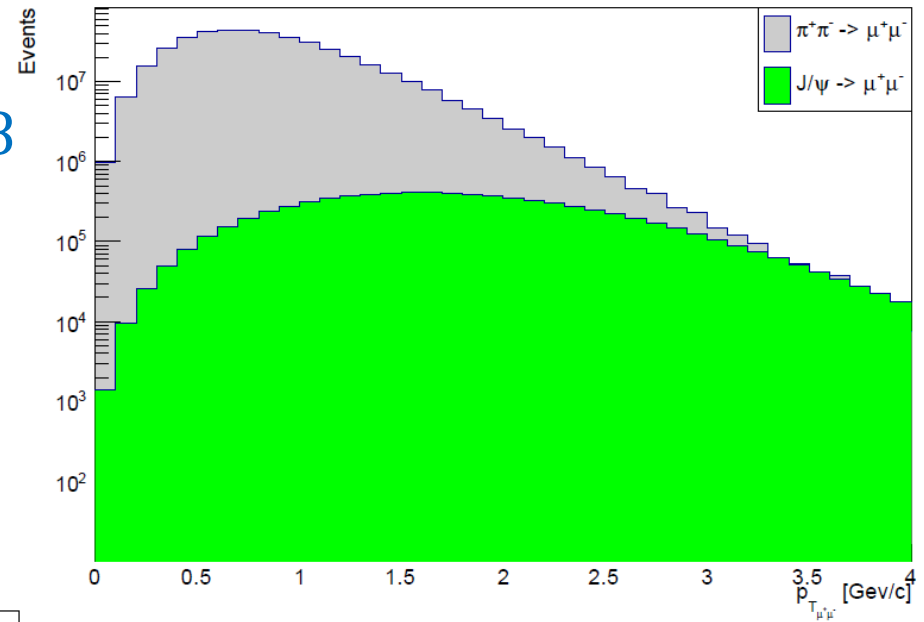
Cross sections at $2.9 < M < 3.2 \text{ GeV}$

$$\sigma_{J/\psi \rightarrow \mu^+\mu^-} = 7.915 \text{ nb} \quad \frac{\sigma_S}{\sigma_B} \sim 0.018$$
$$\sigma_{\pi^+\pi^- \rightarrow \mu^+\mu^-} = 440 \text{ nb}$$

Events expected at $2.9 < M < 3.2 \text{ GeV}$

$$J/\psi \rightarrow \mu^+\mu^- = 7\,915\,210 \text{ events}$$

$$\pi^+\pi^- \rightarrow \mu^+\mu^- = 439\,788\,089 \text{ events}$$





Conclusions

J/ ψ production at NICA conditions was studied with PYTHIA8:

- ✓ 1 000 000 000 Charmonium:all events were generated
- ✓ 39 576 030 Events were selected
- ✓ After normalisation to $L_{\text{int}} = 1 \text{ fb}^{-1}$: 7 915 210 Events
- ✓ $\sigma_{J/\psi \rightarrow \mu^+\mu^-} = 7.915 \text{ nb}$

An "upper estimate" of the background cross section for the observation of J/ ψ from pairs of charged pions was made using a MC generator PYTHIA8

- ✓ 10 000 000 000 QCD:all events were generated
- ✓ 1 222 993 were selected
- ✓ 439 788 089 expected at NICA per year
- ✓ Ratio $\frac{\sigma_{J/\psi \rightarrow \mu^+\mu^-}}{\sigma_{\pi^+\pi^- \rightarrow \mu^+\mu^-}} \sim 0.018$ (From results we have at this moment at $2.9 < M < 3.3 \text{ GeV}$)

First steps in J/ ψ simulation using SPDRoot were also done:

- ✓ First kinematic plots for $J/\psi \rightarrow \mu^+\mu^-$ and $J/\psi \rightarrow e^+e^-$ were obtained

- Continue work with SPDRoot: Using batch systems to achieve more statistics
- Background Simulation with SPDRoot
- Background separation to different categories



Dimuons Selection in Background

Cross sections at $3.095 < M < 3.0995$ GeV

$$\sigma_{J/\psi \rightarrow \mu^+\mu^-} = 1.256 \text{ nb} \quad \frac{\sigma_S}{\sigma_B} \sim 0.14$$
$$\sigma_{\pi^+\pi^- \rightarrow \mu^+\mu^-} = 9.34 \text{ nb}$$

Cross sections at $3.096 < M < 3.0978$ GeV

$$\sigma_{J/\psi \rightarrow \mu^+\mu^-} = 1.256 \text{ nb} \quad \frac{\sigma_S}{\sigma_B} \sim 0.66$$
$$\sigma_{\pi^+\pi^- \rightarrow \mu^+\mu^-} = 1.9 \text{ nb}$$

Normalized to $L_{int} = 1 \text{ fb}^{-1}$ is presented

