



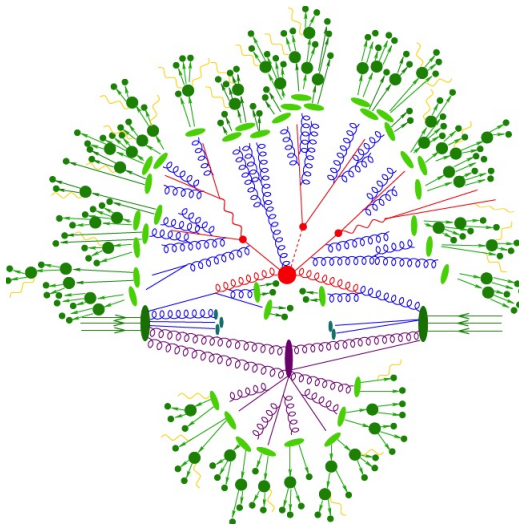
Hadronic Rescattering in Pythia

With a focus on low-energy processes

Marius Utheim

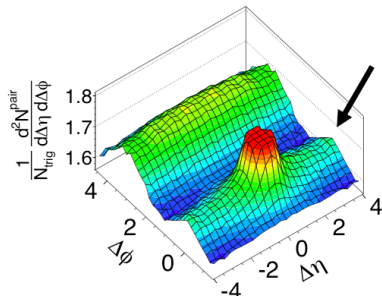
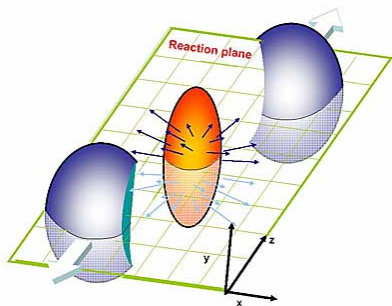
Supervisor: Torbjörn Sjöstrand

What is rescattering?



Why is rescattering important?

Phenomena: Flow, jet quenching, strangeness enhancement



What causes these phenomena in pA and pp collisions?

Rescattering should contribute somehow

Outline

Motivation

The rescattering algorithm

Low-energy interactions and the string model

Cross sections

Results

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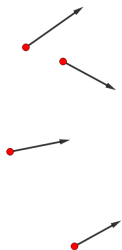
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Low-energy interactions and the string model

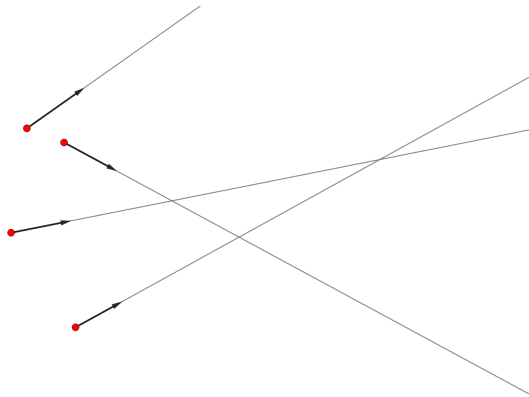
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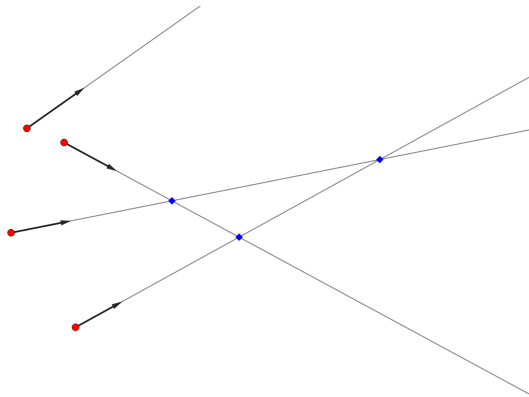
The rescattering algorithm



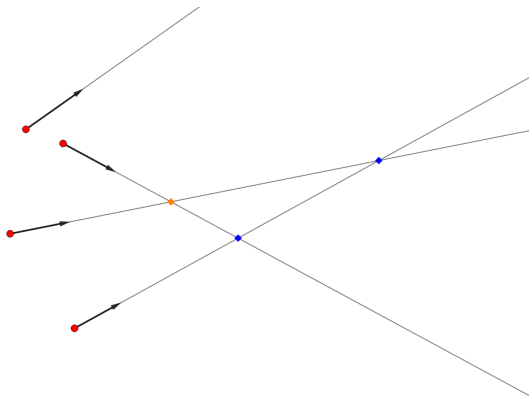
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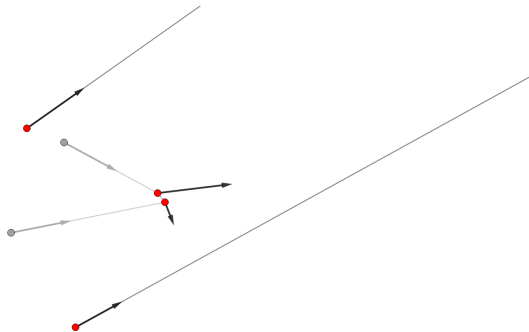
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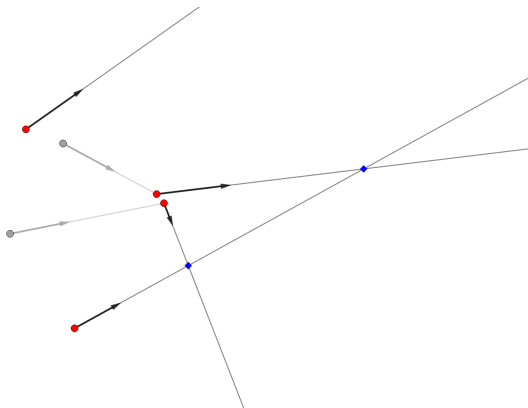
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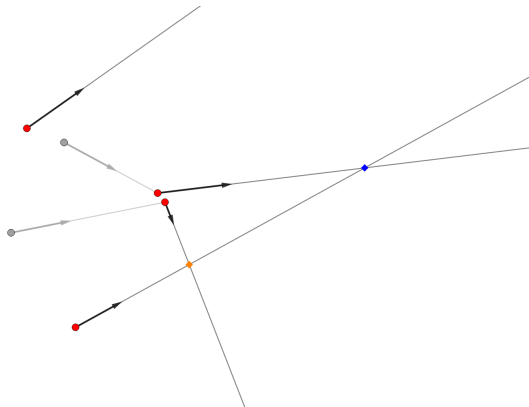
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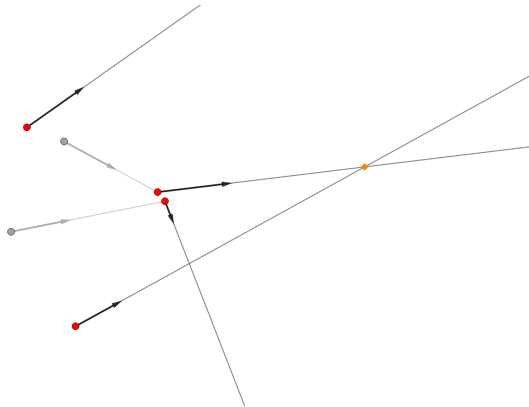
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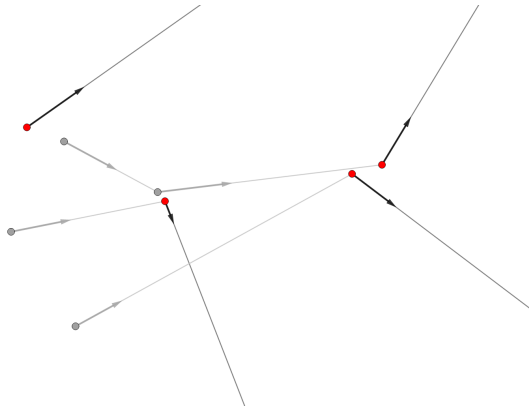
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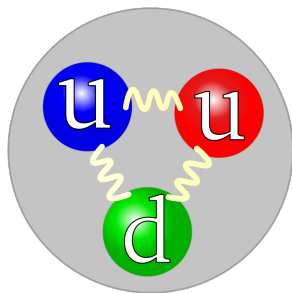
Results

The strong force

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	u up	c charm	t top	g gluon	H Higgs boson
QUARKS	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	d down	s strange	b bottom	γ photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	e electron	μ muon	τ tau	Z Z boson	
LEPTONS	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$1/2$	$1/2$	$1/2$	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
				GAUGE BOSONS	

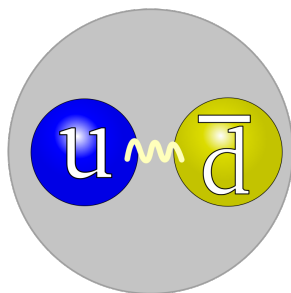
Hadrons

Proton p



Baryons: $r + g + b = \text{neutral}$

Pion π^+

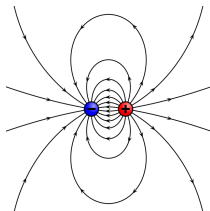


Mesons: $b + \bar{b} = \text{neutral}$

Electromagnetism vs. the strong force

Electromagnetism

$$V(r) = \frac{k}{r}$$



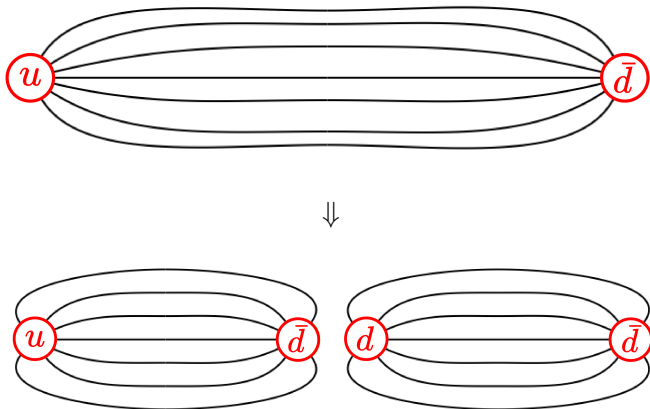
Strong force

$$V(r) = \kappa r$$

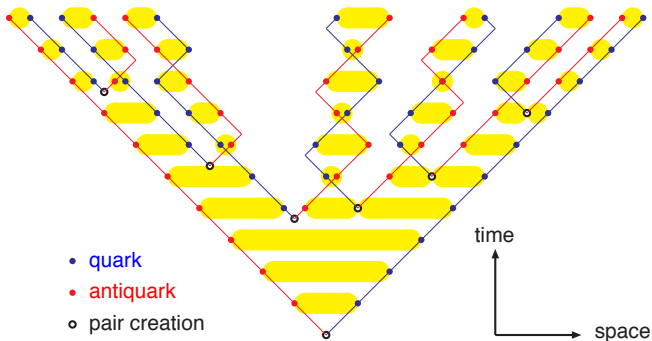


$$\lim_{r \rightarrow \infty} V(r) = \infty$$

String breaking



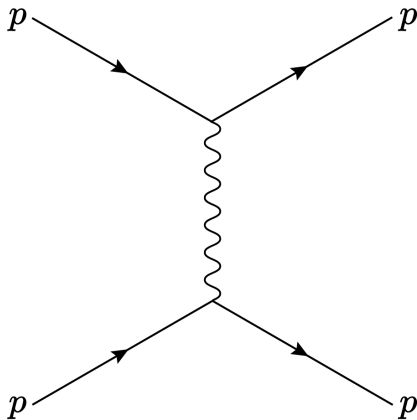
String breaking



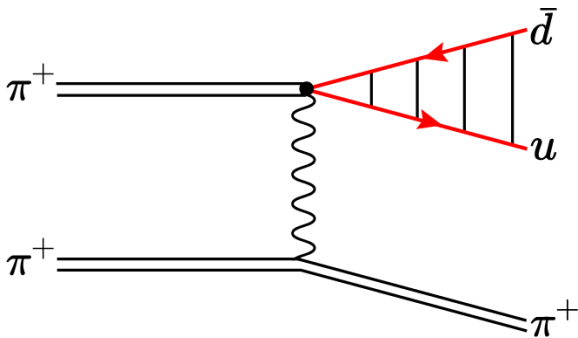
Low-energy processes

- ▶ Elastic scattering
- ▶ Diffractive scattering
- ▶ Non-diffractive scattering
- ▶ Baryon annihilation
- ▶ Resonance formation

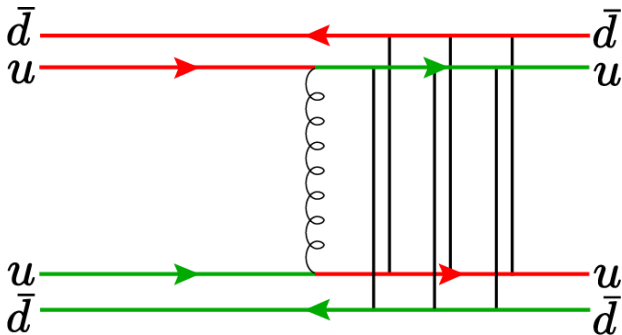
Elastic scattering



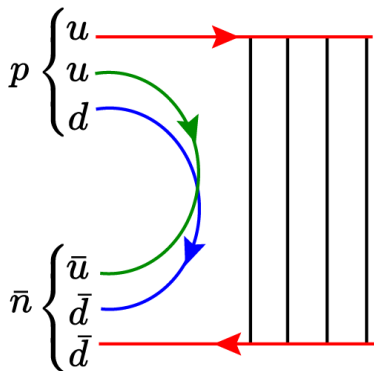
Diffraction scattering



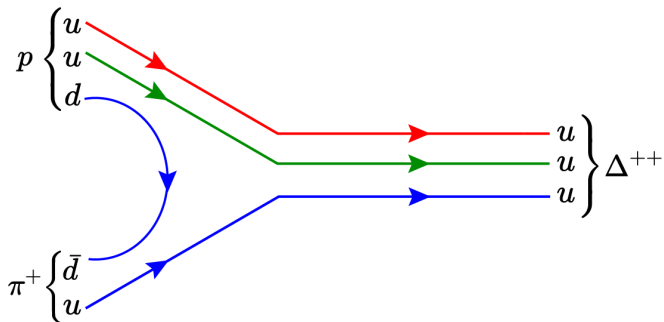
Non-diffractive scattering



Baryon annihilation



Resonance formation



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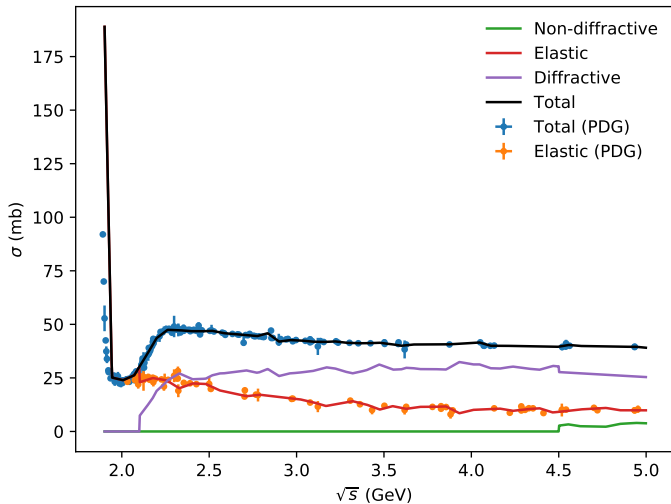
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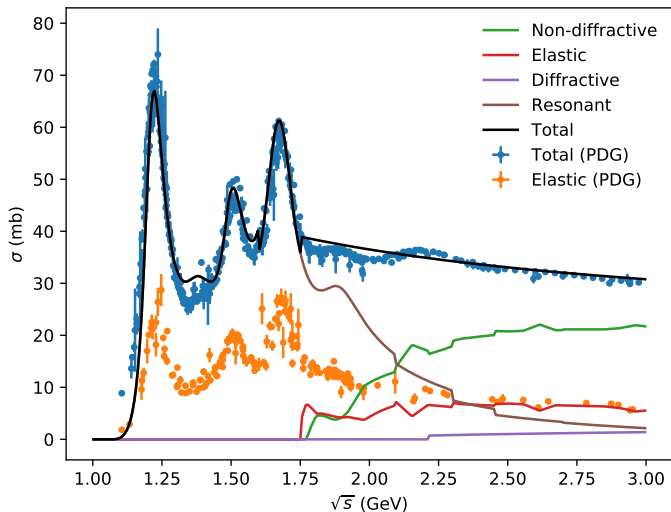
Cross sections

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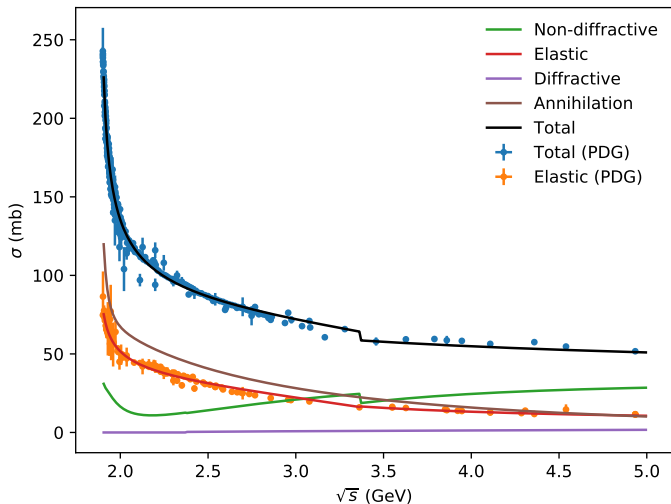
pp cross sections



$p\pi^-$ cross sections



$p\bar{p}$ cross sections



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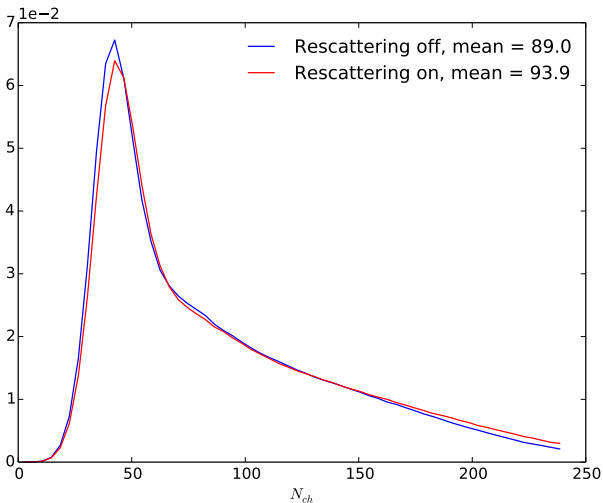
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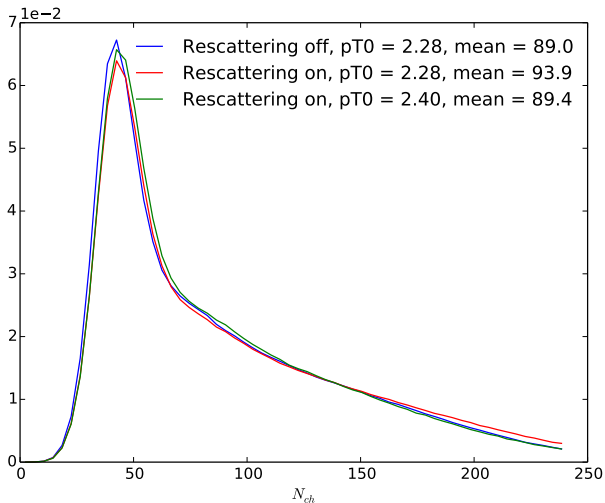
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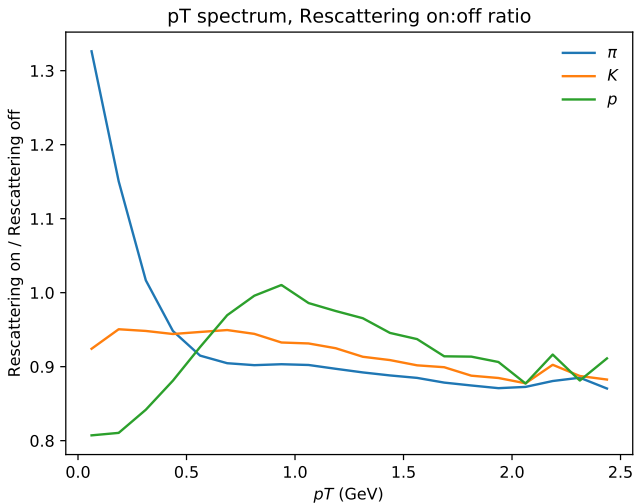
Results - Number of outgoing charged particles



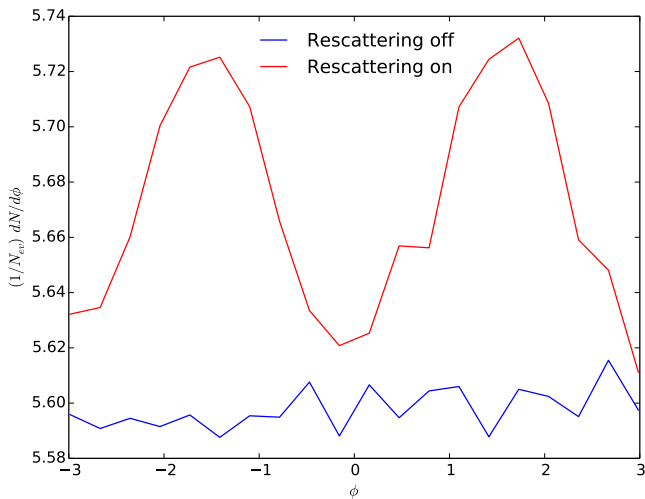
Results - Number of outgoing charged particles



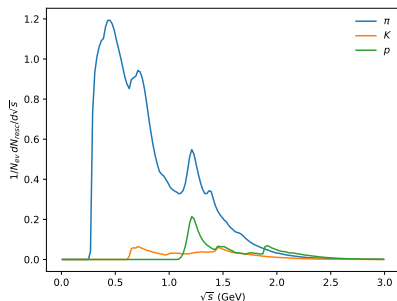
Results - Pion wind



Flow



Process frequency



Proc	Ratio	Type	N/event
Res	47.32 %	$\pi\pi$	24.41
ND	31.11 %	$N\pi$	4.49
Ela	20.56 %	$\rho\pi$	4.27
Ann	0.97 %	$K\pi$	3.22
Diff	0.04 %	$\Sigma\pi$	0.55
		$N\bar{N}$	0.53
		NK	0.49
		$\Lambda\pi$	0.38
		NN	0.06

Outlook

- ▶ We see that rescattering produce some of the expected phenomena, but we have not yet compared to data, so it is hard to quantify how significant these effects are.
- ▶ When the first paper is done, the natural next step is looking at rescattering in Angantyr.
- ▶ Another direction is using the rescattering framework to study cosmic rays.
- ▶ The code will hopefully be released in Pythia 8.302.