

# GenEx – Exclusive Meson Generator

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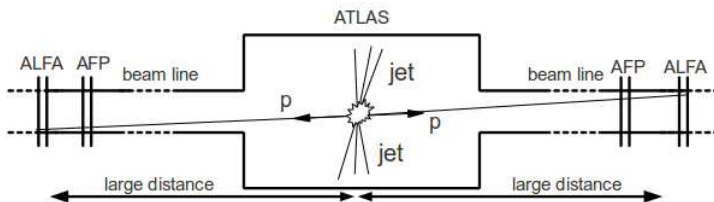
**EDS Blois 2017**

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- Exclusive meson production is possible to be measured by RHIC and LHC experiments.
- Monte Carlo generator is needed in order to include detector effects (acceptance, efficiency) in theory-data comparison.
- There are few MC generators available, e.g. SuperCHIC, DIME.
- We would like to introduce a tool complementary to the existing ones in terms of implemented processes and calculation methods.
- For now, implemented models are based mainly on work of P. Lebiedowicz, A. Szczurek & co.
- This includes:
  - non-resonant (continuum) pion and kaon pair production,
  - $f_0(500)$ ,  $f_0(980)$ ,  $f_0(1370)$ ,  $f_0(1500)$ ,  $f_2(1270)$ ,  $f_2'(1520)$  and  $\rho_0$  particles and their decays into two pions or kaons.

# Measurement Idea (with ATLAS as an example)

**Signature:** mesons measured in ATLAS and both protons in forward detectors (ALFA or AFP).



## ALFA

- Absolute Luminosity For ATLAS
- vertically inserted Roman Pots
- 237 and 245 m from ATLAS IP
- soft diffraction (elastic scattering)
- special runs (high  $\beta^*$  optics)
- tracking detectors, resolution:  
 $\sigma_x = \sigma_y = 30 \mu\text{m}$

## AFP

- ATLAS Forward Proton
- horizontally inserted RPs
- 204 and 217 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- tracking detectors, resolution:  
 $\sigma_x = 10 \mu\text{m}, \sigma_y = 30 \mu\text{m}$
- timing detectors, resolution:  
 $\sigma_t \sim 20 \text{ps}$

# Geometric Acceptance

Ratio of the number of protons with a given relative energy loss ( $\xi$ ) and transverse momentum ( $p_T$ ) that crossed the active detector area to the total number of the scattered protons having  $\xi$  and  $p_T$ .

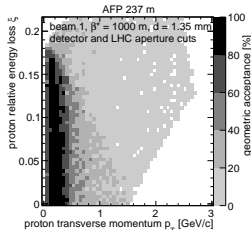
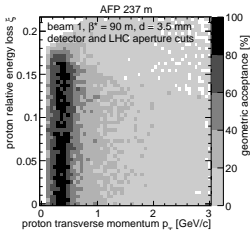
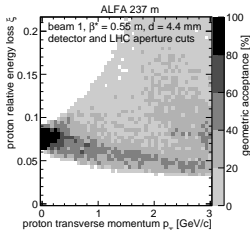
optics

$\beta^* = 0.55$  m  
nominal (*collision*)  
distance:  $15\sigma$

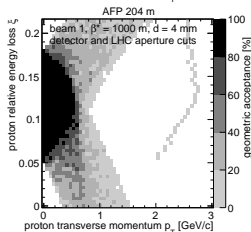
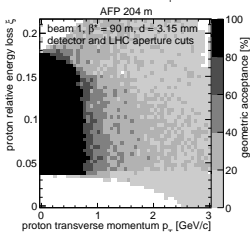
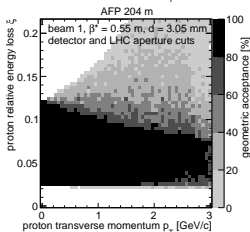
$\beta^* = 90$  m  
special (*high- $\beta^*$* )  
distance:  $5\sigma$

$\beta^* = 1000$  m  
special (*high- $\beta^*$* )  
distance:  $5\sigma$

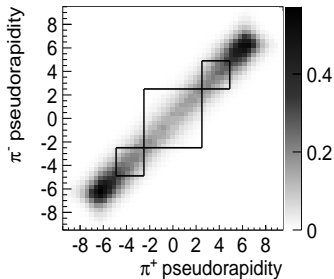
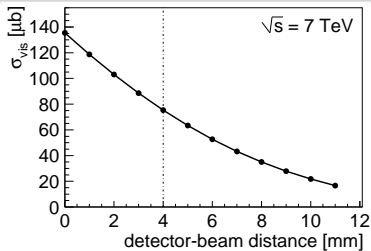
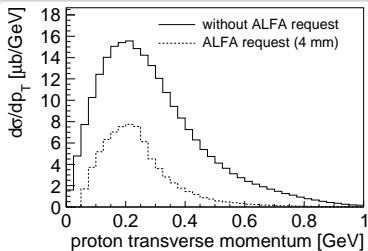
ALFA



AFP



# Predictions for ALFA



Cross section visible in the ALFA detectors (both protons tagged) as a function of the distance between the detectors and the beam centre.

Majority of outgoing protons are in ALFA acceptance region.

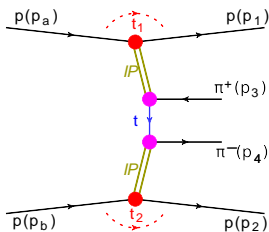
Large correlation between pions pseudorapidity.

Should be measurable in ALFA!

Full analysis: Acta Physica Polonica B **42** (2011) 1861

- GenEx – a C++ class structure for the construction of a Monte Carlo event generators which can produce unweighted events within relativistic phase space.
- Generator is self-adapting to the provided matrix element and acceptance cuts.
- Existing and planned features:
  - resonant and non-resonant exclusive meson production processes,
  - scalar, vector and tensor Pomeron,
  - $pp$  and  $p\bar{p}$  collisions,
  - spin (polarization) effects,
  - absorption and re-scattering corrections,
  - simple, user friendly interface,
  - output in formats usable by experiments (LesHouches, HEPMC, ...).
- First version (basic features) is already available:  
<https://github.com/rkycia/GenEx>.

# Process Type 1: Non-resonant Pion Pair Production



- $pp \rightarrow p\pi^+\pi^-p$  (continuum),
- model based on: Phys. Rev. D **93** (2016) 054015,
- off-shell pion exchanged in the  $t$ -channel,
- tensor Pomeron exchange,
- absorptive corrections are not considered yet,
- spin polarization.

$$\mathcal{M}_{\lambda_a \lambda_b \rightarrow \lambda_1 \lambda_2 \pi^+ \pi^-}^{(\hat{t})} =$$

$$(-i)\bar{u}(p_1, \lambda_1) i\Gamma_{\mu_1 \nu_1}^{(IPpp)}(p_1, p_a) u(p_a, \lambda_a) \times$$

$$i\Delta^{(IP)\mu_1 \nu_1, \alpha_1 \beta_1}(s_{13}, t_1) \times$$

$$i\Gamma_{\alpha_1 \beta_1}^{(IP\pi\pi)}(p_t, -p_3) \times$$

$$i\Delta^{(\pi)}(p_t) \times$$

$$i\Gamma_{\alpha_2 \beta_2}^{(IP\pi\pi)}(p_4, p_t) \times$$

$$i\Delta^{(IP)\alpha_2 \beta_2, \mu_2 \nu_2}(s_{24}, t_2) \times$$

$$\bar{u}(p_2, \lambda_2) i\Gamma_{\mu_2 \nu_2}^{(IPpp)}(p_2, p_b) u(p_b, \lambda_b)$$

matrix element

proton-Pomeron vertex

Pomeron propagator

Pomeron-pion vertex

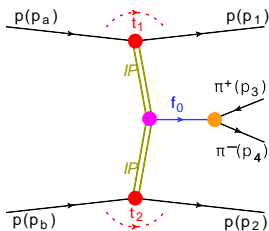
pion propagator

pion-Pomeron vertex

Pomeron propagator

Pomeron-proton vertex

# Process Type 2: Pion Pair Production via $f_0$ Resonance



- $pp \rightarrow p(f_0 \rightarrow \pi^+ \pi^-)p$ ,
- model based on: Phys. Rev. D **93** (2016) 054015,
- tensor Pomeron exchange,
- absorptive corrections are not considered yet,
- spin polarization.

$$\mathcal{M}_{\lambda_a \lambda_b \rightarrow \lambda_1 \lambda_2 \pi^+ \pi^-}^{(IPIP \rightarrow f_0 \rightarrow \pi^+ \pi^-)} =$$

$$(-i) \bar{u}(p_1, \lambda_1) i \Gamma_{\mu_1 \nu_1}^{(IPpp)}(p_1, p_a) u(p_a, \lambda_a) \times$$

$$i \Delta^{(IP)\mu_1 \nu_1, \alpha_1 \beta_1}(s_1, t_1) \times$$

$$i \Gamma_{\alpha_1 \beta_1, \alpha_2 \beta_2}^{(IPIP f_0)}(q_1, q_2) \times$$

$$i \Delta^{(f_0)}(p_{34}) \times$$

$$i \Gamma^{(f_0 \pi \pi)}(p_{34}) \times$$

$$i \Delta^{(IP)\alpha_2 \beta_2, \mu_2 \nu_2}(s_2, t_2) \times$$

$$\bar{u}(p_2, \lambda_2) i \Gamma_{\mu_2 \nu_2}^{(IPpp)}(p_2, p_b) u(p_b, \lambda_b)$$

matrix element

proton-Pomeron vertex

Pomeron propagator

Pomeron- $f_0$  vertex

$f_0$  propagator

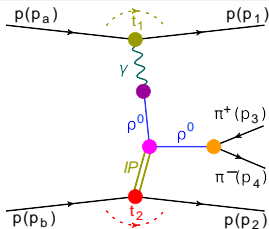
$f_0$ -pion vertex

Pomeron propagator

Pomeron-proton vertex



# Process Type 3: $\rho^0$ Photoproduction



- $pp \rightarrow p\pi^+\pi^-p$  via  $\gamma p \rightarrow (\rho^0 \rightarrow \pi^+\pi^-)p$ ,
- model based on: arXiv:1412.3677,
- tensor Pomeron exchange,
- absorptive corrections are not considered yet,
- spin polarization.

$$\begin{aligned}
 \mathcal{M}_{\lambda_a \lambda_b \rightarrow \lambda_1 \lambda_2 \pi^+ \pi^-}^{(\gamma IP)} = & \\
 & (-i) \bar{u}(p_1, \lambda_1) i \Gamma_{\mu}^{(\gamma PP)}(p_1, p_a) u(p_a, \lambda_a) \times \\
 & i \Delta^{(\gamma)}_{\mu\sigma}(q_1) \times \\
 & i \Gamma_{\sigma\nu}^{(\gamma \rightarrow \rho)}(q_1) \times \\
 & i \Delta^{(\rho)\nu\rho_1}(q_1) \times \\
 & i \Gamma_{\rho_2 \rho_1 \alpha \beta}^{(IP \rho \rho)}(p_{34}, q_1) \times \\
 & i \Delta^{(\rho)\rho_2 \kappa}(p_{34}) \times \\
 & i \Gamma_{\kappa}^{(\rho \pi \pi)}(p_3, p_4) \times \\
 & i \Delta^{(IP)\alpha\beta, \delta\eta}(s_2, t_2) \times \\
 & \bar{u}(p_2, \lambda_2) i \Gamma_{\delta\eta}^{(IP PP)}(p_2, p_b) u(p_b, \lambda_b)
 \end{aligned}$$

matrix element

proton-photon vertex

photon propagator

photon- $\rho$  vertex

$\rho$  propagator

$\rho$ -Pomeron vertex

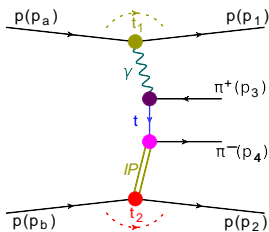
$\rho$  propagator

$\rho$ -pion vertex

Pomeron propagator

Pomeron-proton vertex

# Process Type 4: Photon-induced Continuum



- $pp \rightarrow p\pi^+\pi^-p$ ,
- model based on: arXiv:1412.3677,
- off-shell pion exchanged in the  $t$ -channel,
- tensor Pomeron exchange,
- absorptive corrections are not considered yet,
- spin polarization.

$$\mathcal{M}_{\lambda_a \lambda_b \rightarrow \lambda_1 \lambda_2 \pi^+ \pi^-}^{(t)} =$$

$$(-i)\bar{u}(p_1, \lambda_1) i\Gamma_{\mu}^{(\gamma PP)}(p_1, p_a) u(p_a, \lambda_a) \times$$

$$i\Delta^{(\gamma)\mu\nu}(q_1) \times$$

$$i\Gamma_{\nu}^{(\gamma\pi\pi)}(p_t, -p_3) \times$$

$$i\Delta^{(\pi)}(p_t) \times$$

$$i\Gamma_{\alpha\beta}^{(IP\pi\pi)}(p_4, p_t) \times$$

$$i\Delta^{(IP)\alpha\beta, \delta\eta}(s_2, t_2) \times$$

$$\bar{u}(p_2, \lambda_2) i\Gamma_{\delta\eta}^{(IPpp)}(p_2, p_b) u(p_b, \lambda_b)$$

matrix element

proton-photon vertex

photon propagator

photon-pion vertex

pion propagator

pion-Pomeron vertex

Pomeron propagator

Pomeron-proton vertex

# Process Type 5: Diffractive Bremsstrahlung



- Pomeron or photon induced process.
- Production described by models of e.g.:
  - Khoze-Lamsa-Orava-Ryskin, JINST **6** (2011) P01005,
  - Lebedowicz-Szczurek, Phys. Rev. D **87** (2013) 114013.
- Implemented in e.g. GENEX MC generator (arXiv:1411.6035).
- Measurement idea:
  - measure protons in ALFA and photon in ZDC,
  - described in: [1] Eur. Phys. J. C **77** (2017) 216.

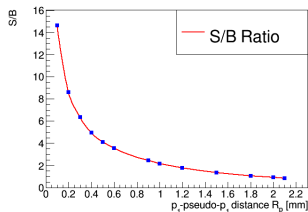
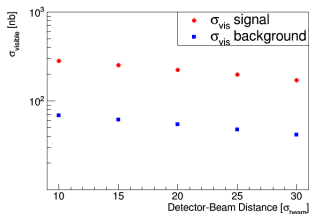
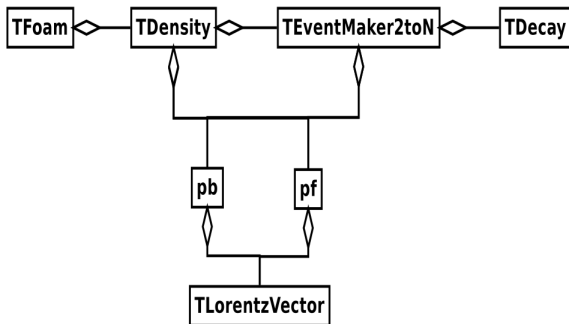


Fig. Predictions for ATLAS. **Left:** visible cross-sections for signal and background as a function of beam-detector distance. **Right:** signal to background ratio. From [1].

# Generator Structure



- *pb* and *pf* are event tables containing beam and final particles,
- TFOAM – class of adaptive Monte Carlo simulator,
- TDENSITY – class with integrand function (calculated accordingly to a given event),
- TEVENTMAKER2TON – generates two leading particles and a central blob which then is decayed by TDECAY into  $N - 2$  remaining particles.

# GenEx – Non-resonant Pion Pair Generation – Example

```
1  NumberOfEventsToGenerate = 100000
2  IntegratorSetup = 1 #1 - FOAM (adaptive Monte Carlo
   integrator)
3
4  SaveEventDataRoot = 1
5  SaveEventDataLHE_XML = 0
6  SaveEventDataLHE_TXT = 0
7
8  idA = 2212 #PDG code of particle A
9  EA = 6500.0
10 idB = 2212 #PDG code of particle B
11 EB = 6500.0
12
13 eventGenerationStrategy = 2 # 2 - generation by Lebedowicz
   and Szczurek prescription (limited to 4 final particles)
14
15 ##Matrix Element - MODEL of REACTION
16 # 1 - Lebedowicz & Szczurek  $2p \rightarrow 2p + \pi^+ + \pi^-$ 
17 # 2 - Lebedowicz & Szczurek  $2p \rightarrow 2p + K^+ + K^-$ 
18 # 3 - Phase Space Integral; ME = 1
19 # 4 - Gauss matrix element  $\exp(-\alpha \sum_i p_t^2)$ 
20 weightStrategy = 1
21 Model1ConfFile = MODEL_DATA/LSpypi.dat
```

# GenEx – Non-resonant Pion Pair Generation – Results

## Usage

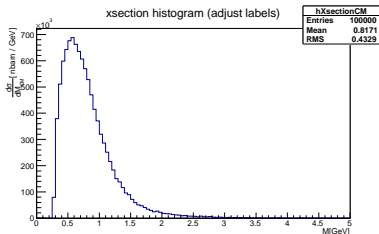
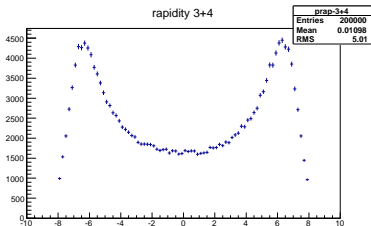
```
1 make all
2 vi Generator.dat #modify steering card
3 make run
```

## Event files:

```
1 maciek@laptop:~/GenEx-master$ ls -ltrh EVENTS/
2 -rw-rw-r-- 1 maciek maciek 7,3M lut 27 08:15 events.txt
3 -rw-r--r-- 1 maciek maciek 14M lut 27 08:15 events.root
4 -rw-rw-r-- 1 maciek maciek 15M lut 27 08:15 events.lhe
```

## Histograms:

```
1 maciek@laptop:~/GenEx-master$ ls -ltrh
2 -rw-r--r-- 1 maciek maciek 44K mar 1 10:18 histograms.root
```



- Exclusive light meson production should be visible at LHC. Especially in data taken during special, high- $\beta^*$  runs when forward detectors (like ALFA or TOTEM) were inserted.
- A Monte Carlo generator containing continuum and resonances would be useful to understand data.
- One of such generators is GenEx – its first version is already available for tests: <https://github.com/rkycia/GenEx>.
- It contains the generator structure and pion/kaon continuum production processes.
- In the near future a new version would allow to:
  - generate resonant production ( $f_0(500)$ ,  $f_0(980)$ ,  $f_0(1370)$ ,  $f_0(1500)$ ,  $f_2(1270)$ ,  $f_2'(1520)$  and  $\rho_0$ ),
  - spin (polarization) effects,
  - absorption and re-scattering corrections.

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