Exclusive Light Meson Production at the LHC

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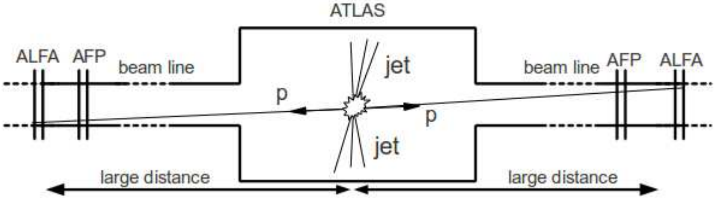
Motivation

- 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 ρ_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

- **A**bsolute **L**uminosity **F**or **A**TLAS
- vertically inserted Roman Pots
- 237 and 245 m from ATLAS IP
- soft diffraction (elastic scattering)
- special runs (high β^* optics)
- tracking detectors, resolution: $\sigma_x = \sigma_y = 30\ \mu m$

AFP

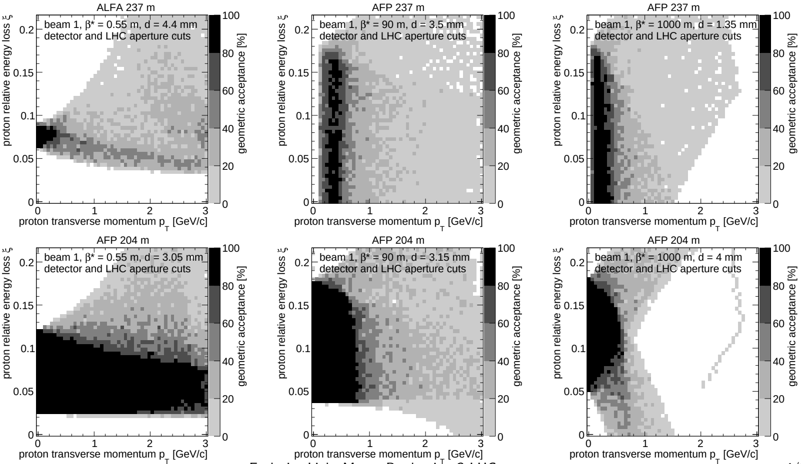
- **A**TLAS **F**orward **P**roton
- horizontally inserted RPs
- 204 and 217 m from ATLAS IP
- hard diffraction
- nominal runs (collision optics)
- tracking detectors, resolution: $\sigma_x = 10\ \mu m$, $\sigma_y = 30\ \mu m$
- timing detectors, resolution: $\sigma_t \sim 20$ ps

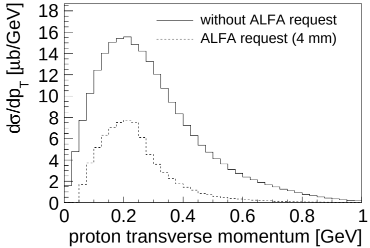
Ratio of the number of protons with a given relative energy loss (ξ) and transverse momentum (p_T) that crossed the active detector area to the total number of the scattered protons having ξ and p_T.

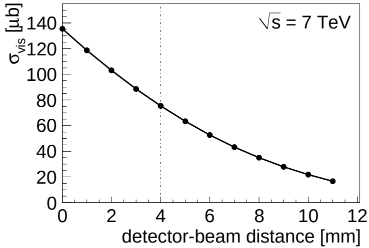
optics	$\beta^* = 0.55$ m nominal (*collision*) distance: 15σ	$\beta^* = 90$ m special (*high-β^**) distance: 5σ	$\beta^* = 1000$ m special (*high-β^**) distance: 5σ

ALFA

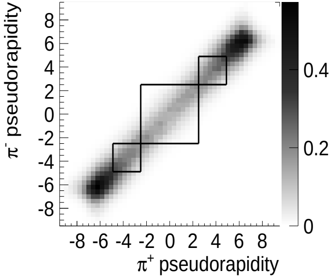
AFP







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

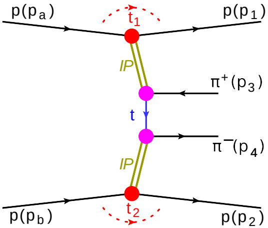
GenEx MC Generator

- 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`.

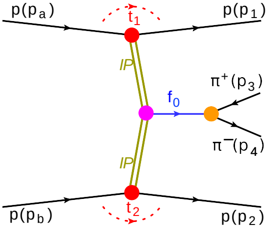
Process Type 1: Non-resonant Pion Pair Production



- $pp \to p\pi^+\pi^- p$ (continuum),
- model based on: Phys. Rev. D **93** (2016) 054015,
- off-shell pion exchanged in the t-channel,
- tensor Pomeron exchange,
- absorptive nor re-scattering corrections are off,
- spin polarization.

$\mathcal{M}^{(\hat{t})}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\pi^+\pi^-} =$	matrix element
$(-i)\bar{u}(p_1,\lambda_1)i\Gamma^{(IPpp)}_{\mu_1\nu_1}(p_1,p_a)u(p_a,\lambda_a)\times$	proton-Pomeron vertex
$i\Delta^{(IP)\mu_1\nu_1,\alpha_1\beta_1}(s_{13},t_1)\times$	Pomeron propagator
$i\Gamma^{(IP\pi\pi)}_{\alpha_1\beta_1}(p_t,-p_3)\times$	Pomeron-pion vertex
$i\Delta^{(\pi)}(p_t)\times$	pion propagator
$i\Gamma^{(IP\pi\pi)}_{\alpha_2\beta_2}(p_4,p_t)\times$	pion-Pomeron vertex
$i\Delta^{(IP)\alpha_2\beta_2,\mu_2\nu_2}(s_{24},t_2)\times$	Pomeron propagator
$\bar{u}(p_2,\lambda_2)i\Gamma^{(IPpp)}_{\mu_2\nu_2}(p_2,p_b)u(p_b,\lambda_b)$	Pomeron-proton vertex

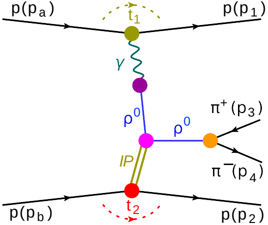
Process Type 2: Pion Pair Production via f_0 Resonance



- $pp \rightarrow p(f_0 \rightarrow \pi^+\pi^-)p$,
- model based on: Phys. Rev. D **93** (2016) 054015,
- tensor Pomeron exchange,
- absorptive nor re-scattering corrections are off,
- spin polarization.

$\mathcal{M}^{(I\!PI\!P \rightarrow f_0 \rightarrow \pi^+\pi^-)}_{\lambda_a\lambda_b \rightarrow \lambda_1\lambda_2\pi^+\pi^-} =$	matrix element
$(-i)\bar{u}(p_1,\lambda_1) i\Gamma^{(I\!Ppp)}_{\mu_1\nu_1}(p_1,p_a)u(p_a,\lambda_a)\times$	proton-Pomeron vertex
$i\Delta^{(I\!P)\mu_1\nu_1,\alpha_1\beta_1}(s_1,t_1)\times$	Pomeron propagator
$i\Gamma^{(I\!PI\!Pf_0)}_{\alpha_1\beta_1,\alpha_2\beta_2}(q_1,q_2)\times$	Pomeron-f_0 vertex
$i\Delta^{(f_0)}(p_{34})\times$	f_0 propagator
$i\Gamma^{(f_0\pi\pi)}(p_{34})\times$	f_0-pion vertex
$i\Delta^{(I\!P)\alpha_2\beta_2,\mu_2\nu_2}(s_2,t_2)\times$	Pomeron propagator
$\bar{u}(p_2,\lambda_2) i\Gamma^{(I\!Ppp)}_{\mu_2\nu_2}(p_2,p_b)u(p_b,\lambda_b)$	Pomeron-proton vertex

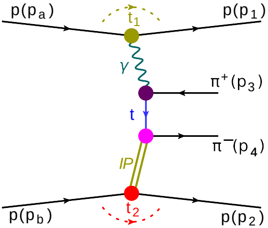
Process Type 3: ρ^0 Photoproduction



- $pp \to p\pi^+\pi^- p$ via $\gamma p \to (\rho^0 \to \pi^+\pi^-)p$,
- model based on: arXiv:1412.3677,
- tensor Pomeron exchange,
- absorptive nor re-scattering corrections are off,
- spin polarization.

$\mathcal{M}^{(\gamma I\!P)}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\pi^+\pi^-} =$	matrix element
$(-i)\bar{u}(p_1,\lambda_1)i\Gamma^{(\gamma pp)}_{\mu}(p_1,p_a)u(p_a,\lambda_a)\times$	proton-photon vertex
$i\Delta^{(\gamma)\mu\sigma}(q_1)\times$	photon propagator
$i\Gamma^{(\gamma\to\rho)}_{\sigma\nu}(q_1)\times$	photon-ρ vertex
$i\Delta^{(\rho)\nu\rho_1}(q_1)\times$	ρ propagator
$i\Gamma^{(I\!P\rho\rho)}_{\rho_2\rho_1\alpha\beta}(p_{34},q_1)\times$	ρ-Pomeron vertex
$i\Delta^{(\rho)\rho_2\kappa}(p_{34})\times$	ρ propagator
$i\Gamma^{(\rho\pi\pi)}_{\kappa}(p_3,p_4)\times$	ρ-pion vertex
$i\Delta^{(I\!P)\alpha\beta,\delta\eta}(s_2,t_2)\times$	Pomeron propagator
$\bar{u}(p_2,\lambda_2)i\Gamma^{(I\!Ppp)}_{\delta\eta}(p_2,p_b)u(p_b,\lambda_b)$	Pomeron-proton vertex

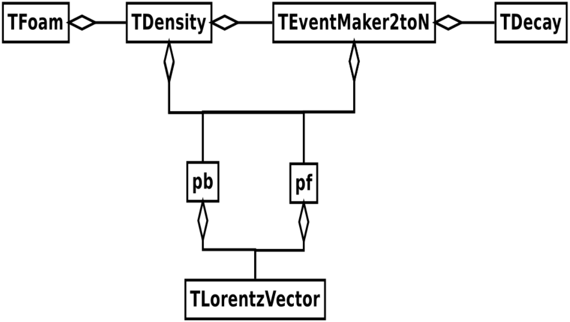
Process Type 4: Photon-induced Continuum



- $pp \to p\pi^+\pi^- p$,
- model based on: arXiv:1412.3677,
- off-shell pion exchanged in the *t*-channel,
- tensor Pomeron exchange,
- absorptive nor re-scattering corrections are off,
- spin polarization.

$\mathcal{M}^{(t)}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\pi^+\pi^-} =$	matrix element
$(-i)\bar{u}(p_1,\lambda_1)i\Gamma^{(\gamma pp)}_{\mu}(p_1,p_a)u(p_a,\lambda_a)\times$	proton-photon vertex
$i\Delta^{(\gamma)\mu\nu}(q_1)\times$	photon propagator
$i\Gamma^{(\gamma\pi\pi)}_{\nu}(p_t,-p_3)\times$	photon-pion vertex
$i\Delta^{(\pi)}(p_t)\times$	pion propagator
$i\Gamma^{(IP\pi\pi)}_{\alpha\beta}(p_4,p_t)\times$	pion-Pomeron vertex
$i\Delta^{(IP)\alpha\beta,\delta\eta}(s_2,t_2)\times$	Pomeron propagator
$\bar{u}(p_2,\lambda_2)i\Gamma^{(IPpp)}_{\delta\eta}(p_2,p_b)u(p_b,\lambda_b)$	Pomeron-proton vertex

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

```
NumberOfEventsToGenerate  = 100000
IntegratorSetup = 1  #1 - FOAM (adaptive Monte Carlo integrator)

SaveEventDataRoot = 1
SaveEventDataLHE_XML = 0
SaveEventDataLHE_TXT = 0

idA = 2212 #PDG code of particle A
EA  = 6500.0
idB = 2212 #PDG code of particle B
EB = 6500.0

eventGenerationStrategy = 2 # 2 - generation by Lebiedowicz and Szczurek prescription (limited to 4 final particles)

##Matrix Element - MODEL of REACTION
#  1 - Lebiedowicz & Szczurek 2p -> 2p + pi+ + pi-
#  2 - Lebiedowicz & Szczurek 2p -> 2p + K+ + K-
#  3 - Phase Space Integral; ME = 1
#  4 - Gauss matrix element exp(-alpha sum_i pt^2 )
weightStrategy = 1
Model1ConfFile = MODEL_DATA/LSpipi.dat
```

Usage

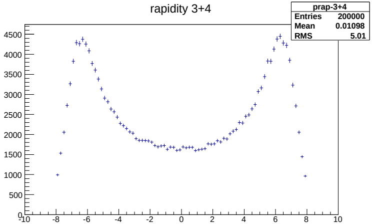
```
make all
vi Generator.dat #modify steering card
make run
```

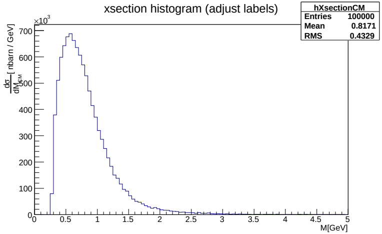
Event files:

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

Histograms:

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





Summary

- Exclusive light meson production should be visible at LHC. Especially in data taken during special, high-β^* 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 ρ_0),
  - spin (polarization) effects,
  - absorption and re-scattering corrections.

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