Count what is countable, measure what is measurable, and what is not measurable, make measurable. - Galileo Galilei

October, 2-3 2017, Ferrara (Italy)

Double polarized DD-fusion

Developing simulation and analysis tools for POLFUSION experiment in PNPI, Gatchina

Polina Kravchenko

on behalf of collaboration

Aim of double polarized DD-fusion experiment

$^3He^{2+}\,(^3H^+)$

$\vec{d}^0\ (0.1keV)$

$\vec{d}^+\ (30-100keV)$

$$\sigma_0 = \frac{1}{9}(2\sigma_{1,1} + 4\sigma_{1,0} + \sigma_{0,0} + 2\sigma_{1,-1})$$

Quintet **Triplet** **Singlet**

$n(p)$

Quintet suppression Factor

$$QSF = \frac{\sigma_{1,1}}{\sigma_0}$$

Topics

Mathematical model
Status of experimental data
First test measurements
Monte Carlo studies

Mathematical model

НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЦЕНТР "КУРЧАТОВСКИЙ ИНСТИТУТ"
ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ БЮДЖЕТНОЕ УЧРЕЖДЕНИЕ

ПЕТЕРБУРГСКИЙ ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ им. Б.П.КОНСТАНТИНОВА

УДК 539.17 539.171.017

Partial-wave expansion of the reaction amplitude processes d d → ^{3}He n and d d → ^{3}H p

E. N. Komarov, S. G. Sherman

Abstract

The partial-wave expansion of the amplitude of the nuclear reaction for particles with spins 1 + 1 -> 1/2 + 1/2 is performed with the identical particles in the initial state (for example, d d → ^{3}He n and d d → ^{3}H p).

The reaction amplitude for the low energy range is written taking into account the s-, p- and d-waves only. The work has been done in the frame of POLFUSION experiment.

The work has been performed at the High Energy Physics Department (HEPD).

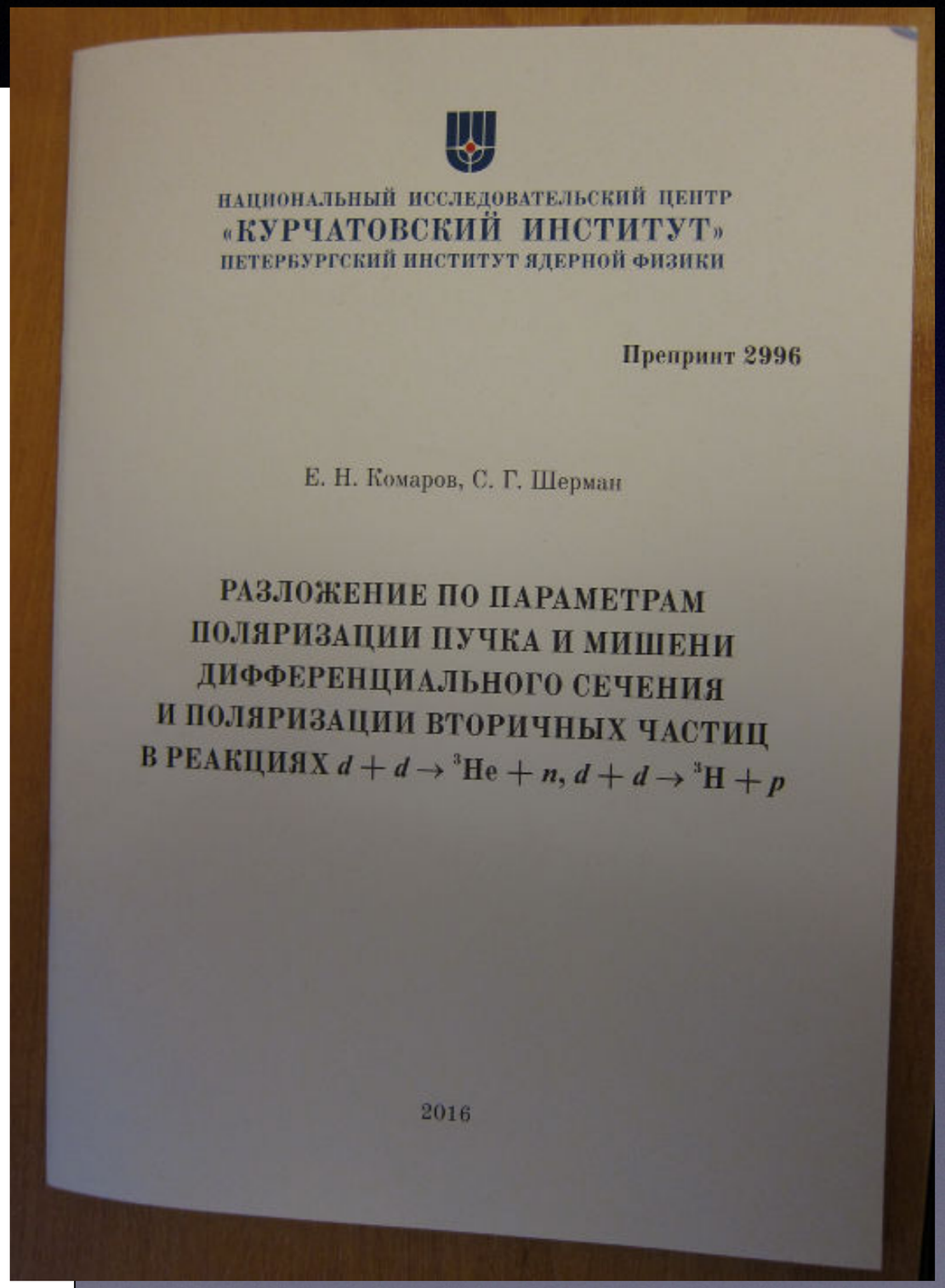
Аннотация

Получено парциально-волновое разложение амплитуды реакции частиц со спинами 1 + 1 -> 1/2 + 1/2 для тождественных частиц в начальном состоянии (например, d d → ^{3}He n and d d → ^{3}H p).

Для случая низких энергий амплитуда выписана в явном виде с учётом вкладов *s*-, *p*- и *d*-волн. Работа выполнена в рамках эксперимента POLFUSION.

Работа выполнена в Отделении физики высоких энергий (ОФВЭ).

ISBN 978-5-86763-352-3



Theory. Partial wave expansion for scattering amplitude two-body reaction with spin 1+1 ⟹1/2+1/2

Differential cross section of the reaction with polarized particles:

$$\frac{d\sigma}{d\Omega} = Spur[\hat{A}\cdot\rho\cdot\hat{A}^{+}]$$

Amplitude: matrix 4×9

$$A = \begin{pmatrix} B^{12}_{12} & B^{12}_{11} & B^{11}_{11} & B^{12}_{10} & B^{11}_{10} & B^{10}_{10} & B^{12}_{1-1} & B^{11}_{1-1} & B^{12}_{1-2} \\ B^{02}_{12} & B^{12}_{01} & B^{11}_{01} & B^{12}_{00} & B^{11}_{00} & B^{10}_{00} & B^{12}_{0-1} & B^{11}_{0-1} & B^{12}_{0-2} \\ B^{02}_{02} & B^{02}_{01} & B^{01}_{01} & B^{02}_{00} & B^{01}_{00} & B^{00}_{00} & B^{02}_{0-1} & B^{01}_{0-1} & B^{02}_{0-2} \\ B^{12}_{-12} & B^{12}_{-11} & B^{11}_{-10} & B^{12}_{-10} & B^{11}_{-10} & B^{10}_{-10} & B^{12}_{-1-1} & B^{11}_{-1-1} & B^{12}_{-1-2} \end{pmatrix}$$

$$B^{s'\,s}_{\sigma'\,\sigma} = \frac{1}{2i\sqrt{k_i k_f}} \sum_{J=0}^{\infty} \sum_{l=|J-s|}^{J+s} \sum_{l'=|J-\sigma|}^{J+\sigma} i^{l-l'} \sqrt{4\pi(2l+1)} C^{JM}_{l0s\sigma} C^{J\sigma}_{l'\sigma-\sigma' s'\sigma'} R^{Js'\,s}_{l'l} Y_{l'\sigma-\sigma'}$$

$$Y_{lm}(\cos\theta,\phi) = \sqrt{\frac{2l+1}{4\pi}} P_{lm}(\cos\theta e^{im\phi})$$

Theory. Partial wave expansion for scattering amplitude two-body reaction with spin 1+1 ⟹ 1/2+1/2

Differential cross section of the reaction with polarized particles:

$$\frac{d\sigma}{d\Omega} = Spur[\hat{A}\cdot\rho\cdot\hat{A}^{+}]$$

Amplitude: matrix 4×9

$$A = \begin{pmatrix} B^{12}_{12} & B^{12}_{11} & B^{11}_{11} & B^{12}_{10} & B^{11}_{10} & B^{10}_{10} & B^{12}_{1-1} & B^{11}_{1-1} & B^{12}_{1-2} \\ B^{02}_{12} & B^{12}_{01} & B^{11}_{01} & B^{12}_{00} & B^{11}_{00} & B^{10}_{00} & B^{12}_{0-1} & B^{11}_{0-1} & B^{12}_{0-2} \\ B^{02}_{02} & B^{02}_{01} & B^{01}_{01} & B^{02}_{00} & B^{01}_{00} & B^{00}_{00} & B^{02}_{0-1} & B^{01}_{0-1} & B^{02}_{0-2} \\ B^{12}_{-12} & B^{12}_{-11} & B^{11}_{-10} & B^{12}_{-10} & B^{11}_{-10} & B^{10}_{-10} & B^{12}_{-1-1} & B^{11}_{-1-1} & B^{12}_{-1-2} \end{pmatrix}$$

$$B^{s'\,s}_{\sigma'\,\sigma} = \frac{1}{2i\sqrt{k_i k_f}} \sum_{J=0}^{\infty} \sum_{l=|J-s|}^{J+s} \sum_{l'=|J-\sigma|}^{J+\sigma} i^{l-l'} \sqrt{4\pi(2l+1)} C^{JM}_{l0s\sigma} C^{J\sigma}_{l'\sigma-\sigma' s'\sigma} R^{Js'\,s}_{l'l} Y_{l'\sigma-\sigma'}$$

$$Y_{lm}(\cos\theta,\phi) = \sqrt{\frac{2l+1}{4\pi}} P_{lm}(\cos\theta e^{im\phi})$$

Factorization using penetrability assumption for energy dependence:

complex partial wave $R^{Js'\,s}_{l'l}(E) = C(E)\hat{R}^{Js'\,s}_{l'l}$

Penetrability function

Energy-independent matrix element

Theory. Partial wave expansion for scattering amplitude two-body reaction with spin 1+1 ⟹ 1/2+1/2

Differential cross section of the reaction with polarized particles:

$$\frac{d\sigma}{d\Omega} = Spur[\hat{A}\cdot\rho\cdot\hat{A}^{+}]$$

Amplitude: matrix 4×9

$$A = \begin{pmatrix} B^{12}_{12} & B^{12}_{11} & B^{11}_{11} & B^{12}_{10} & B^{11}_{10} & B^{10}_{10} & B^{12}_{1-1} & B^{11}_{1-1} & B^{12}_{1-2} \\ B^{02}_{12} & B^{12}_{01} & B^{11}_{01} & B^{12}_{00} & B^{11}_{00} & B^{10}_{00} & B^{12}_{0-1} & B^{11}_{0-1} & B^{12}_{0-2} \\ B^{02}_{02} & B^{02}_{01} & B^{01}_{01} & B^{02}_{00} & B^{01}_{00} & B^{00}_{00} & B^{02}_{0-1} & B^{01}_{0-1} & B^{02}_{0-2} \\ B^{12}_{-12} & B^{12}_{-11} & B^{11}_{-10} & B^{12}_{-10} & B^{11}_{-10} & B^{10}_{-10} & B^{12}_{-1-1} & B^{11}_{-1-1} & B^{12}_{-1-2} \end{pmatrix}$$

$$B^{s's}_{\sigma'\sigma} = \frac{1}{2i\sqrt{k_i k_f}} \sum_{J=0}^{\infty} \sum_{l=|J-s|}^{J+s} \sum_{l'=|J-\sigma|}^{J+\sigma} i^{l-l'} \sqrt{4\pi(2l+1)} C^{JM}_{l0s\sigma} C^{J\sigma}_{l'\sigma-\sigma's'\sigma'} R^{Js's}_{l'l} Y_{l'\sigma-\sigma'}$$

All states with partial waves up to ℓ=4 taken into account

	S→S'		
a	*0→0*	*Singlet-singlet*	$a^J_{l'l}$
b	*0→1*	*Singlet-triplet*	$b^J_{l'l}$
c	*1→0*	*Triplet-singlet*	$c^J_{l'l}$
d	*1→1*	*Triplet-triplet*	$d^J_{l'l}$
e	*2→0*	*Quintet-singlet*	$e^J_{l'l}$
f	*2→1*	*Quintet-triplet*	$f^J_{l'l}$

$$B^{00}_{00} = \frac{1}{i\sqrt{k_f k_i}}[a^0_{00}P_0 + 5a^2_{22} + 9a^4_{44}P_4]$$

$$B^{10}_{10} = \frac{1}{2i\sqrt{k_f k_i}}[\frac{5}{\sqrt{3}}b^2_{22}P_{21} + \frac{9}{\sqrt{10}}b^4_{44}P_{41}]$$

.

.

$$B^{12}_{12} = \frac{1}{2i\sqrt{k_f k_i}}[(-\frac{10}{3}\sqrt{\frac{1}{7}}f^2_{22} + \frac{2}{3}\sqrt{\frac{5}{2}}f^2_{20} - \frac{5}{3}\sqrt{2}f^3_{22} + \frac{1}{3}\sqrt{\frac{5}{7}}f^2_{24} + \frac{2}{3}\sqrt{5}f^3_{24})P_{21} + ...]$$

Theory. Partial wave expansion for scattering amplitude two-body reaction with spin 1+1 ⟹ 1/2+1/2

Differential cross section of the reaction with polarized particles:

$$\frac{d\sigma}{d\Omega} = Spur[\hat{A}\cdot\rho\cdot\hat{A}^{+}]$$

Amplitude: matrix 4×9

$$A = \begin{pmatrix} B^{12}_{12} & B^{12}_{11} & B^{11}_{11} & B^{12}_{10} & B^{11}_{10} & B^{10}_{10} & B^{12}_{1-1} & B^{11}_{1-1} & B^{12}_{1-2} \\ B^{02}_{12} & B^{12}_{01} & B^{11}_{01} & B^{12}_{00} & B^{11}_{00} & B^{10}_{00} & B^{12}_{0-1} & B^{11}_{0-1} & B^{12}_{0-2} \\ B^{02}_{02} & B^{02}_{01} & B^{01}_{01} & B^{02}_{00} & B^{01}_{00} & B^{00}_{00} & B^{02}_{0-1} & B^{01}_{0-1} & B^{02}_{0-2} \\ B^{12}_{-12} & B^{12}_{-11} & B^{11}_{-10} & B^{12}_{-10} & B^{11}_{-10} & B^{10}_{-10} & B^{12}_{-1-1} & B^{11}_{-1-1} & B^{12}_{-1-2} \end{pmatrix}$$

$$B^{s'\,s}_{\sigma'\,\sigma} = \frac{1}{2i\sqrt{k_i k_f}} \sum_{J=0}^{\infty} \sum_{l=|J-s|}^{J+s} \sum_{l'=|J-\sigma|}^{J+\sigma} i^{l-l'} \sqrt{4\pi(2l+1)} C^{JM}_{l0s\sigma} C^{J\sigma}_{l'\sigma-\sigma's'\sigma'} R^{Js's}_{l'l} Y_{l'\sigma-\sigma'}$$

All states with partial waves up to ℓ=4 taken into account

	S→S'		
a	0→0	Singlet-singlet	$a^J_{l'l}$
b	0→1	Singlet-triplet	$b^J_{l'l}$
c	1→0	Triplet-singlet	$c^J_{l'l}$
d	1→1	Triplet-triplet	$d^J_{l'l}$
e			
f			

$$B^{00}_{00} = \frac{1}{i\sqrt{k_f k_i}}[a^0_{00}P_0 + 5a^2_{22} + 9a^4_{44}P_4]$$

$$B^{10}_{10} = \frac{1}{2i\sqrt{k_f k_i}}[\frac{5}{\sqrt{3}}b^2_{22}P_{21} + \frac{9}{\sqrt{10}}b^4_{44}P_{41}]$$

$$\frac{d\sigma_0}{d\Omega} = \frac{1}{9}(|A_{11}|^2 + |A_{12}|^2 + |A_{13}|^2 + |A_{14}|^2 + |A_{15}|^2 + |A_{16}|^2 + |A_{17}|^2 ... + |A_{49}|^2)$$

$$B^{12}_{12} = \frac{1}{2i\sqrt{k_f k_i}}[(-\frac{10}{3}\sqrt{\frac{1}{7}}f^2_{22} + \frac{2}{3}\sqrt{\frac{5}{2}}f^2_{20} - \frac{5}{3}\sqrt{2}f^3_{22} + \frac{1}{3}\sqrt{\frac{5}{7}}f^2_{24} + \frac{2}{3}\sqrt{5}f^3_{24})P_{21} + ...]$$

Observables

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + \sum_{i=1}^{8} A_i^{(b)} b_i + \sum_{i=1}^{8} A_i^{(t)} t_i + \sum_{i,k=1}^{8} C_{ik}^{(bt)} b_i t_k$$

unpolarized cross section

Analyzing powers

Spin-correlation coefficients

Observables

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + \sum_{i=1}^{8} A_i^{(b)} b_i + \sum_{i=1}^{8} A_i^{(t)} t_i + \sum_{i,k=1}^{8} C_{ik}^{(bt)} b_i t_k$$

Experiments		
$^2H(d,p)^3H$ $^2H(d,n)^3He$	σ_0	
$^2H(d,p)^3H$ $^2H(d,n)^3He$	A_y A_{zz} A_{xz}	
$^2H(d,p)^3H$ $^2H(d,n)^3He$	C_{zz} C_{yy} $C_{zz,zz}$ $C_{y,zz}$ $C_{y,xz}$ $C_{zz,xz}$	
$^2H(d,p)^3H$ $^2H(d,n)^3He$	$P^{y'}$	
$^2H(d,p)^3H$ $^2H(d,n)^3He$	$K^{x'}{}_x$ $K^{y'}{}_y$	

Observables

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + \sum_{i=1}^{8} A_i^{(b)} b_i + \sum_{i=1}^{8} A_i^{(t)} t_i + \sum_{i,k=1}^{8} C_{ik}^{(bt)} b_i t_k$$

Experiments		*singlet->singlet*		*singlet->triplet*	*triplet->triplet*	
		a^0_{00} <$^1S_0$|0+|$^1S_0$>	a^2_{22} <$^1D_2$|2+|$^1D_2$>	b^2_{22} <$^1D_2$|2+|$^3D_2$>	.....	d^2_{11} <$^3P_2$|2-|$^3P_2$>
$^2H(d,p)^3H$ $^2H(d,n)^3He$	σ_0	✓				
$^2H(d,p)^3H$ $^2H(d,n)^3He$	A_y A_{zz} A_{xz}	✓	✓ ✓ ✓	✓ ✓ ✓		✓ ✓
$^2H(d,p)^3H$ $^2H(d,n)^3He$	C_{zz} C_{yy} $C_{zz,zz}$ $C_{y,zz}$ $C_{y,xz}$ $C_{zz,xz}$	✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓		✓ ✓ ✓ ✓ ✓
$^2H(d,p)^3H$ $^2H(d,n)^3He$	$P_{y'}$					✓
$^2H(d,p)^3H$ $^2H(d,n)^3He$	$K^{x'}_x$ $K^{y'}_y$					✓ ✓

Observables

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} + \sum_{i=1}^{8} A_i^{(b)} b_i + \sum_{i=1}^{8} A_i^{(t)} t_i + \sum_{i,k=1}^{8} C_{ik}^{(bt)} b_i t_k$$

Experiments		*singlet->singlet*		*singlet->triplet*		*triplet->triplet*
		a^0_{00} <$^1S_0$|0^+|$^1S_0$>	a^2_{22} <$^1D_2$|2^+|$^1D_2$>	b^2_{22} <$^1D_2$|2^+|$^3D_2$>	.....	d^2_{11} <$^3P_2$|2^-|$^3P_2$>
$^2H(d,p)^3H$ $^2H(d,n)^3He$	σ_0	✓				
$^2H(d,p)^3H$ $^2H(d,n)^3He$	A_y		✓	✓		✓
	A_{zz}	✓	✓	✓		✓
	A_{xz}		✓	✓		
$^2H(d,p)^3H$ $^2H(d,n)^3He$	C_{zz}	✓	✓	✓		✓
	C_{yy}	✓	✓	✓		
	$C_{zz,zz}$	✓				✓
	$C_{y,zz}$		✓	✓		✓
	$C_{y,xz}$		✓	✓		✓
	$C_{zz,xz}$					✓
$^2H(d,p)^3H$ $^2H(d,n)^3He$	$P_{y'}$					✓
$^2H(d,p)^3H$ $^2H(d,n)^3He$	$K^{x'}_x$					✓
	$K^{y'}_y$					✓

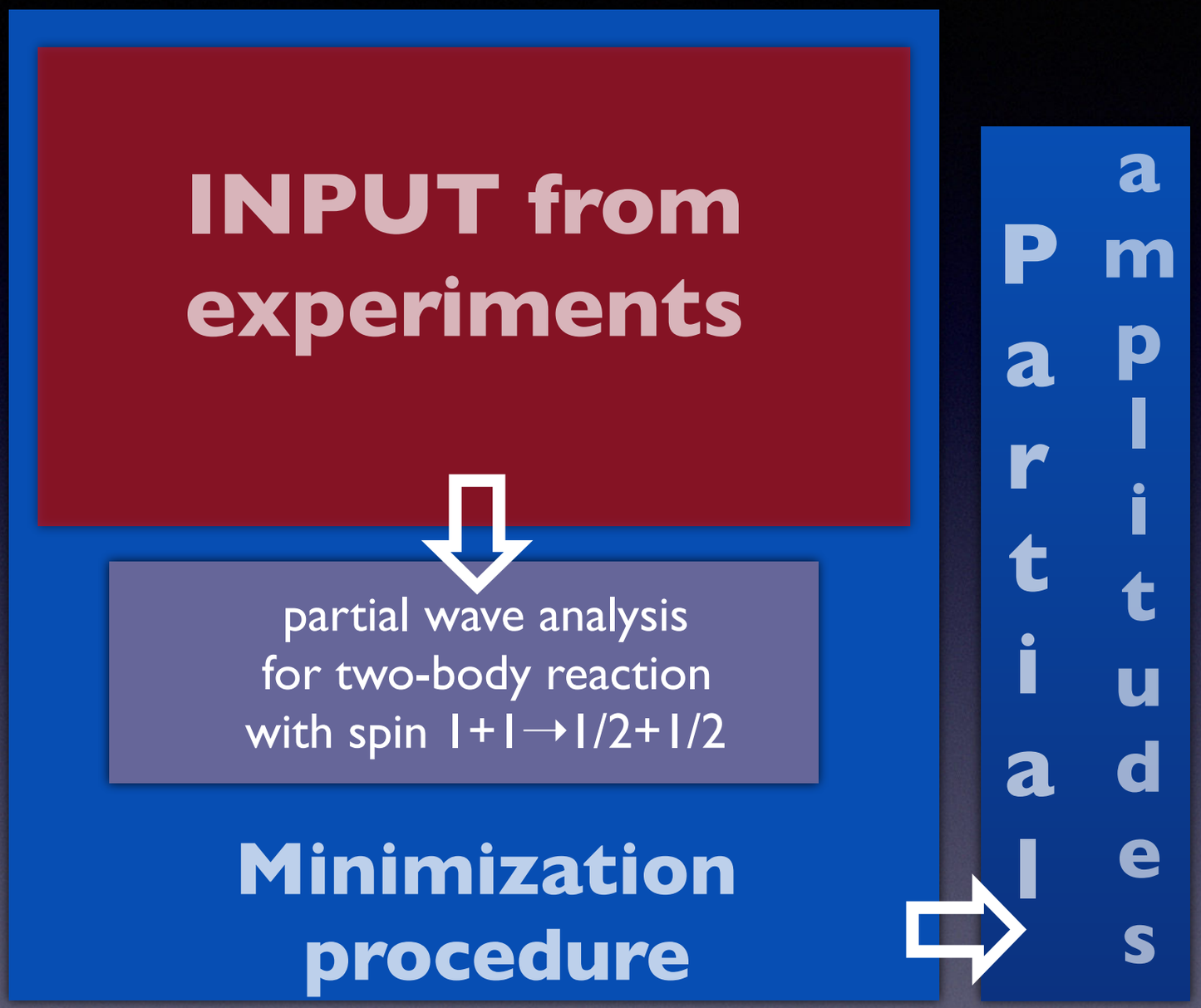
PolFusion

Analysis diagram

INPUT from experiments

partial wave analysis
for two-body reaction
with spin 1+1→1/2+1/2

Analysis diagram



Analysis diagram

INPUT from experiments

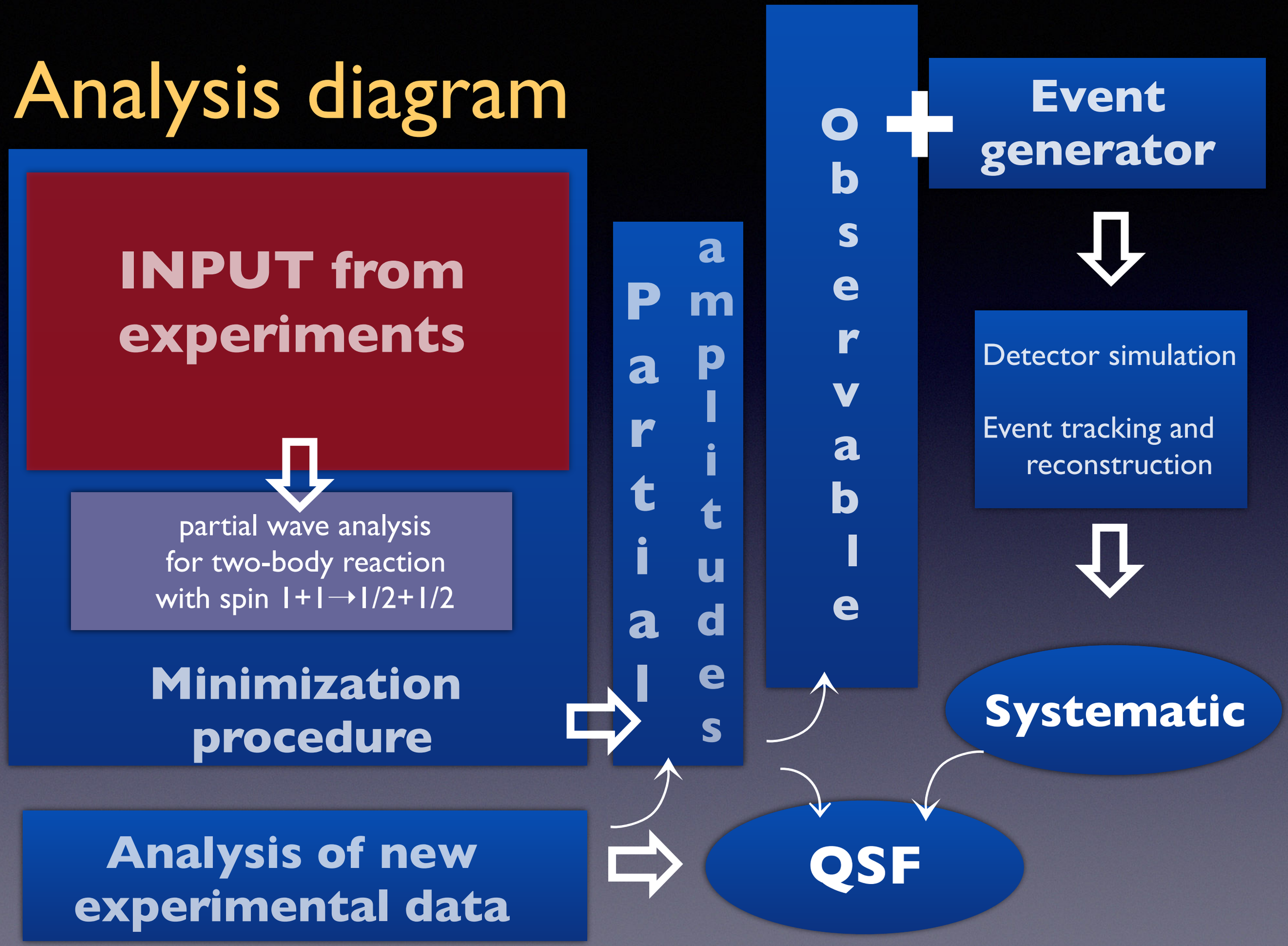
partial wave analysis
for two-body reaction
with spin 1+1→1/2+1/2

Minimization procedure

Partial amplitudes

Observable

Analysis diagram



Analysis diagram

EXPERIMENTS: Reference

Tagishi et al. Phys. Rev. C **46** (1992)
Becker et al. Few Body Sys. **13** (1992)
Imig et al. Phys. Rev. C **73** (2006)
Kurilkin et al. Eur. Phys. J. **162** (2008)
Janek et al. Eur. Phys. J. A **33** (2007)
Leonard et al. Phys. Rev. C **73** (2006)
Fletcher et al. Phys. Rev. C **49** (1994)
Brown et al. Phys. Rev. C **41** (1990)
Gruebler et al. Nucl. Phys. A **369** (1981)
Ying et al. Nucl. Phys. A **206** (1973)
Schulte et al. Nucl. Phys. A **192** (1972)
Roper et al. Few-Body Syst. **47** (2010)
Lisowsky et al. Nucl. Phys. A **242** (1975)
Clegg et al. Phys. Rev. C **8** (1973)
Kozma et al. Nucl. Phys. A **442** (1985)
Dietze et al. Nucl Phys. A **158** (1970)
Alsoraya et al. Nucl. Phys. A **280** (1977)
Behof et al. Nucl Phys. A **108** (1968)
Sikkema et al. Nucl. Phys. A **245** (1975)
Theus et al. Nucl. Phys. **80** (1966)
Wenzel et al. Phys. Rev. **88** (1952)
Hunter et al. Phys. Rev. **76** (1949)
Jeltsch et al. Helv. Phys. Asta **43** (1970)
Steinberg et al. Phys. Rev. **186** (1969)
Krauss et al. Nucl. Phys. A **465** (1987)
Blair et al. Phys. Rev. **74** (1948)
Franz et al. Nucl. Phys. A **122** (1968)

INPUT from experiments

partial wave analysis
for two-body reaction
with spin 1+1→1/2+1/2

Minimization procedure

Analysis of new experimental data

Partial amplitudes

$a^J_{l'l}$ ✓
$b^J_{l'l}$
$c^J_{l'l}$
$d^J_{l'l}$
$e^J_{l'l}$
$f^J_{l'l}$

Observables

σ_0
$d\sigma_0/d\Omega$ ✓
A_y
A_{zz}
A_{xz}
C_{zz}
C_{yy}
$C_{zz,zz}$ $C_{y,zz}$
$C_{y,xz}$
$C_{zz,xz}$
$P_{y'}$
$K^{x'}{}_x$
$K^{y'}{}_y$

+

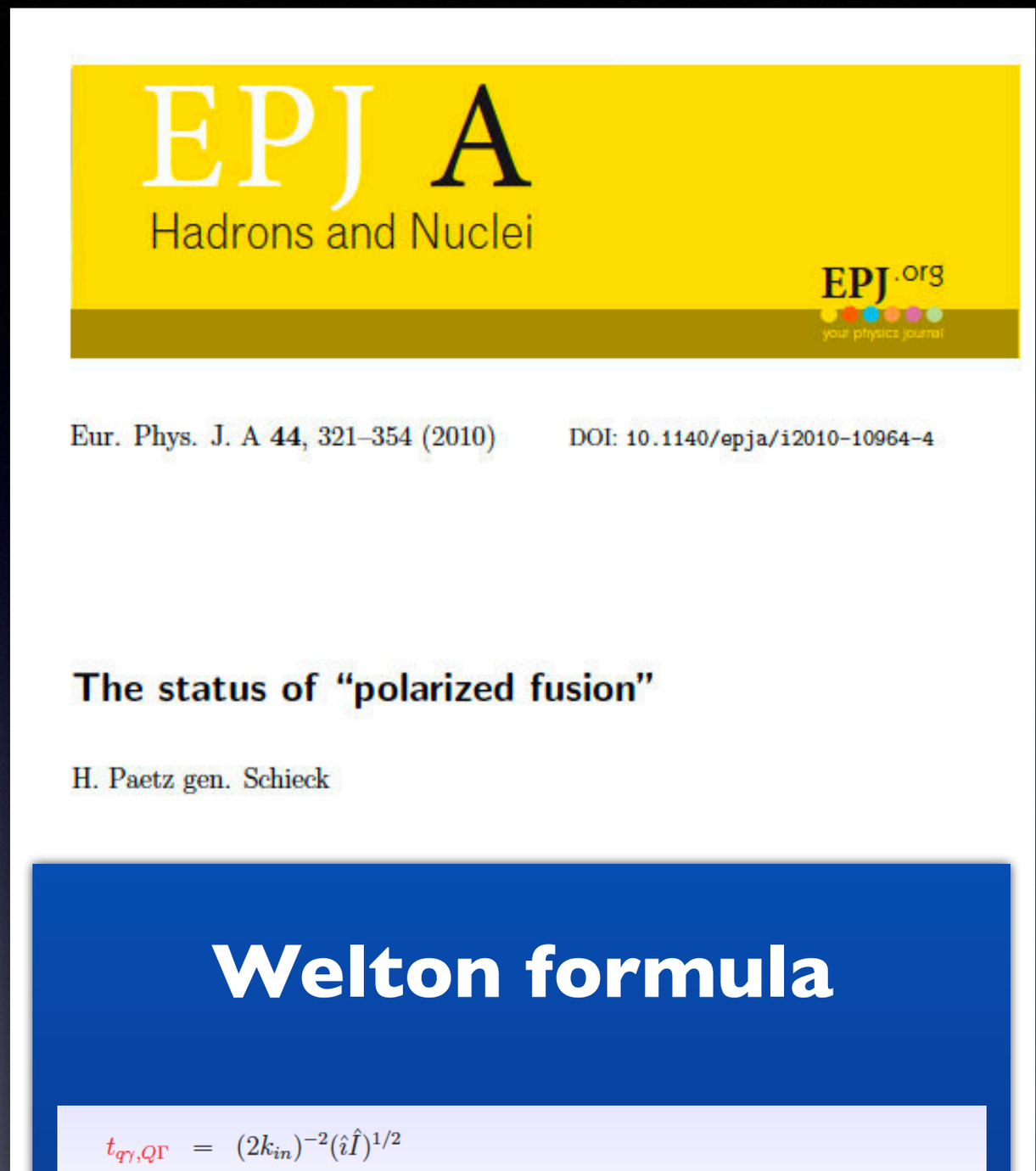
Event generator

Detector simulation

Event tracking and reconstruction

Systematic

QSF



Welton formula

$$
\begin{aligned}
t_{q\gamma,Q\Gamma} &= (2k_{in})^{-2}(\hat{\imath}\hat{I})^{1/2} \\
&\cdot \sum \begin{Bmatrix} i & I & s_1 \\ q & Q & t \\ i & I & s_2 \end{Bmatrix} \begin{Bmatrix} i' & I' & s_1' \\ q' & Q' & t' \\ i' & I' & s_2' \end{Bmatrix} \begin{Bmatrix} l_1 & s_1 & J_1 \\ l & t & L \\ l_2 & s_2 & J_2 \end{Bmatrix} \begin{Bmatrix} l_1' & s_1' & J_1 \\ l' & t' & L \\ l_2' & s_2' & J_2 \end{Bmatrix} \\
&\cdot (l_1 l_2 00|l0)(l_1' l_2' 00|l'0)(lt0\Lambda|L\Lambda) \\
&\cdot (l't'0\Lambda'|L\Lambda')(qQ\gamma\Gamma|t\Lambda)(q'Q'\gamma'\Gamma'|t'\Lambda') \\
&\cdot T^{J_1^{\pi_1}} T^{J_2^{\pi_2}*} D^L_{\Lambda'\Lambda}(\Phi,\Theta,0) \\
&\cdot (\hat{\imath}'\hat{I}')^{-1/2} \\
&\cdot t_{q'\gamma',Q'\Gamma'}
\end{aligned}
$$

Partial amplitudes

$a^J_{l'l}$

$b^J_{l'l}$

$c^J_{l'l}$

$d^J_{l'l}$

$e^J_{l'l}$

$f^J_{l'l}$

Observables

σ_0

$d\sigma_0/d\Omega$

A_y

A_{zz}

A_{xz}

C_{zz}

C_{yy}

$C_{zz,zz}$ $C_{y,zz}$

$C_{y,xz}$

$C_{zz,xz}$

$P_{y'}$

$K^{x'}{}_x$

$K^{y'}{}_y$

Event generator

Detector simulation

Event tracking and reconstruction

Systematic

QSF

EPJ A
Hadrons and Nuclei
EPJ.org
your physics journal

Eur. Phys. J. A **44**, 321–354 (2010) DOI: 10.1140/epja/i2010-10964-4

Solution

The status of "polarized fusion"

H. Paetz gen. Schieck

Welton formula

$$
\begin{aligned}
t_{q\gamma,Q\Gamma} &= (2k_{in})^{-2}(\hat{\imath}\hat{I})^{1/2} \\
&\cdot \sum \begin{Bmatrix} i & I & s_1 \\ q & Q & t \\ i & I & s_2 \end{Bmatrix} \begin{Bmatrix} i' & I' & s_1' \\ q' & Q' & t' \\ i' & I' & s_2' \end{Bmatrix} \begin{Bmatrix} l_1 & s_1 & J_1 \\ l & t & L \\ l_2 & s_2 & J_2 \end{Bmatrix} \begin{Bmatrix} l_1' & s_1' & J_1 \\ l' & t' & L \\ l_2' & s_2' & J_2 \end{Bmatrix} \\
&\cdot (l_1 l_2 00|l0)(l_1' l_2' 00|l'0)(lt0\Lambda|L\Lambda) \\
&\cdot (l't'0\Lambda'|L\Lambda')(qQ\gamma\Gamma|t\Lambda)(q'Q'\gamma'\Gamma'|t'\Lambda') \\
&\cdot T^{J_1^{\pi_1}} T^{J_2^{\pi_2}*} D^L_{\Lambda'\Lambda}(\Phi,\Theta,0) \\
&\cdot (\hat{\imath}'\hat{I}')^{-1/2} \\
&\cdot t_{q'\gamma',Q'\Gamma'}
\end{aligned}
$$

Partial amplitudes

$a^J_{l'l}$
$b^J_{l'l}$
$c^J_{l'l}$
$d^J_{l'l}$
$e^J_{l'l}$
$f^J_{l'l}$

Observables

σ_0
$d\sigma_0/d\Omega$

A_y
A_{zz}
A_{xz}

C_{zz}
C_{yy}
$C_{zz,zz}$ $C_{y,zz}$
$C_{y,xz}$
$C_{zz,xz}$

$P_{y'}$

$K^{x'}{}_x$
$K^{y'}{}_y$

Event generator

Detector simulation

Event tracking and reconstruction

Systematic

QSF

EPJ A
Hadrons and Nuclei

Eur. Phys. J. A **44**, 321–354 (2010) DOI: 10.1140/epja/i2010-10964-4

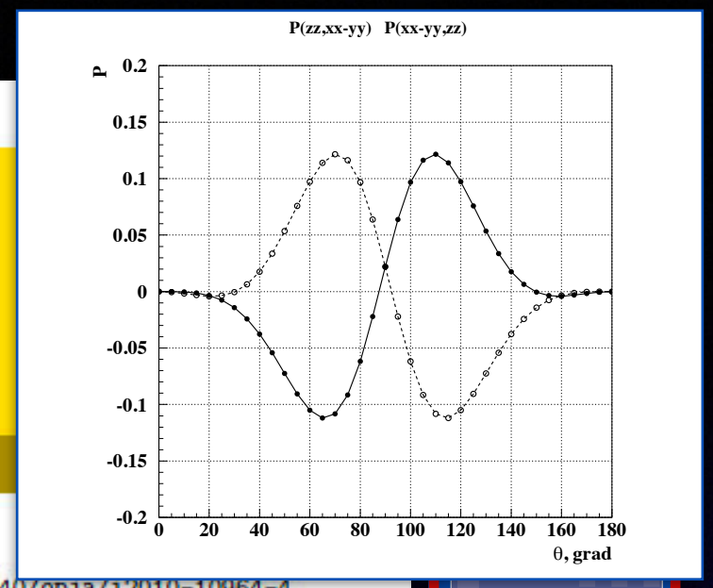
Sol

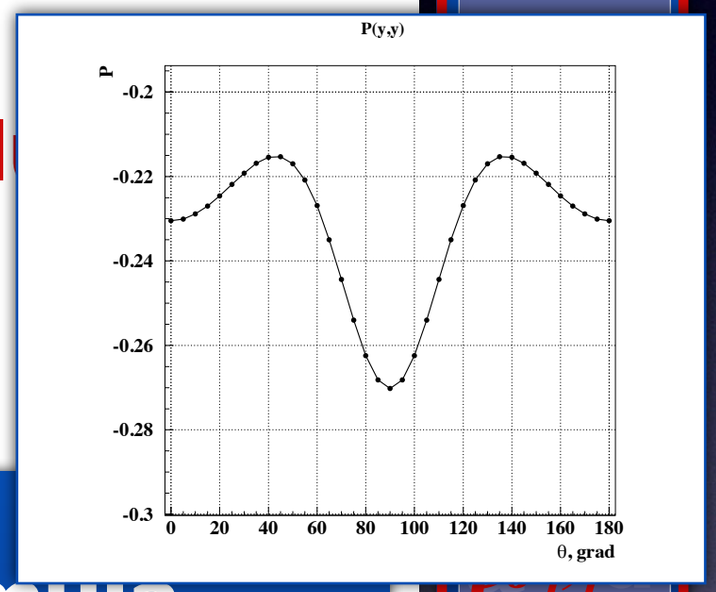
The status of "polarized fusion"

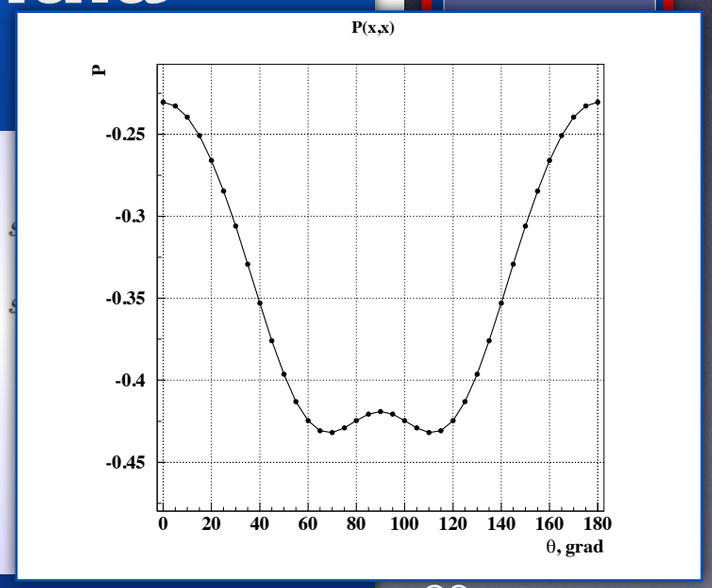
H. Paetz gen. Schieck

Welton formula

$$
\begin{aligned}
t_{q\gamma,Q\Gamma} &= (2k_{in})^{-2}(\hat{i}\hat{I})^{1/2} \\
&\cdot \sum \begin{Bmatrix} i & I & s_1 \\ q & Q & t \\ i & I & s_2 \end{Bmatrix} \begin{Bmatrix} i' & I' & s_1' \\ q' & Q' & t' \\ i' & I' & s_2' \end{Bmatrix} \begin{Bmatrix} l_1 & \\ l & \\ l_2 & \end{Bmatrix} \\
&\cdot (l_1 l_2 00|l0)(l_1' l_2' 00|l'0)(lt0\Lambda|L\Lambda) \\
&\cdot (l't'0\Lambda'|L\Lambda')(qQ\gamma\Gamma|t\Lambda)(q'Q'\gamma'\Gamma'|t'\Lambda') \\
&\cdot T^{J_1^{\pi_1}} T^{J_2^{\pi_2}*} D^L_{\Lambda'\Lambda}(\Phi,\Theta,0) \\
&\cdot (\hat{i'}\hat{I'})^{-1/2} \\
&\cdot t_{q'\gamma',Q'\Gamma'}
\end{aligned}
$$

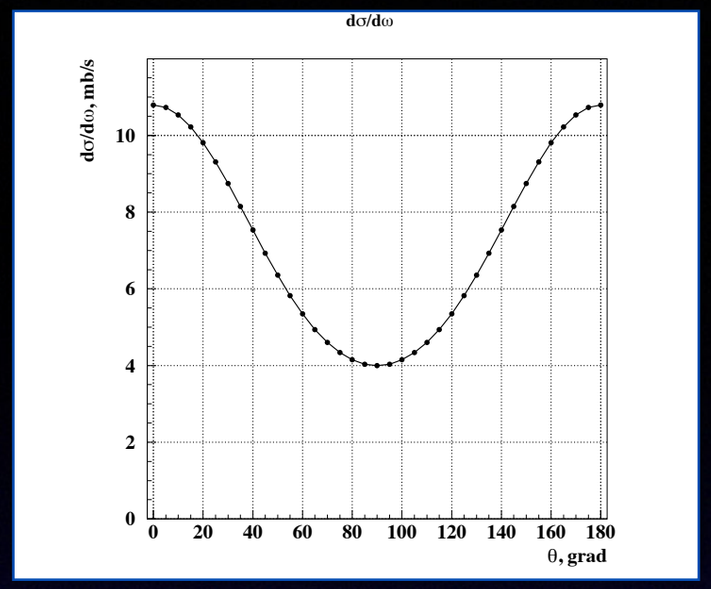


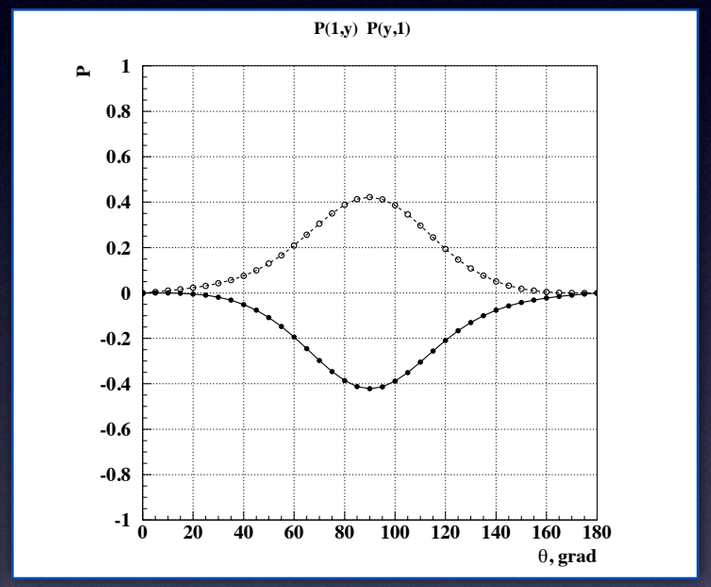


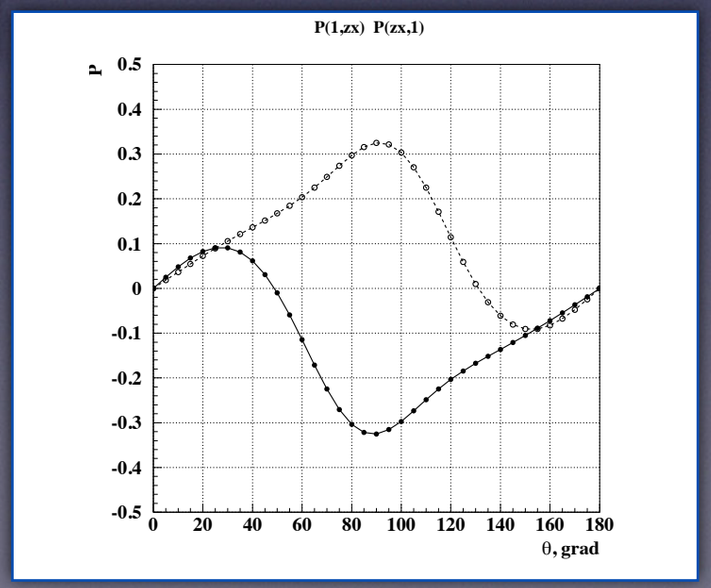


Predicted

Observable







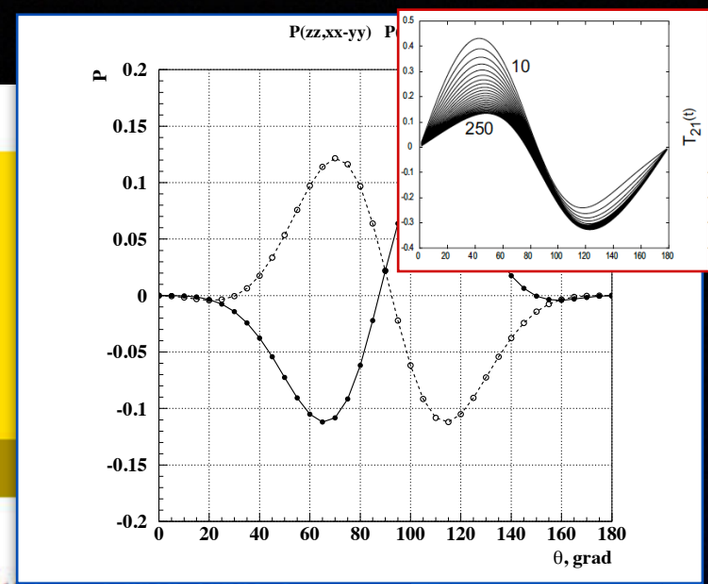
EPJ A
Hadrons and Nuclei

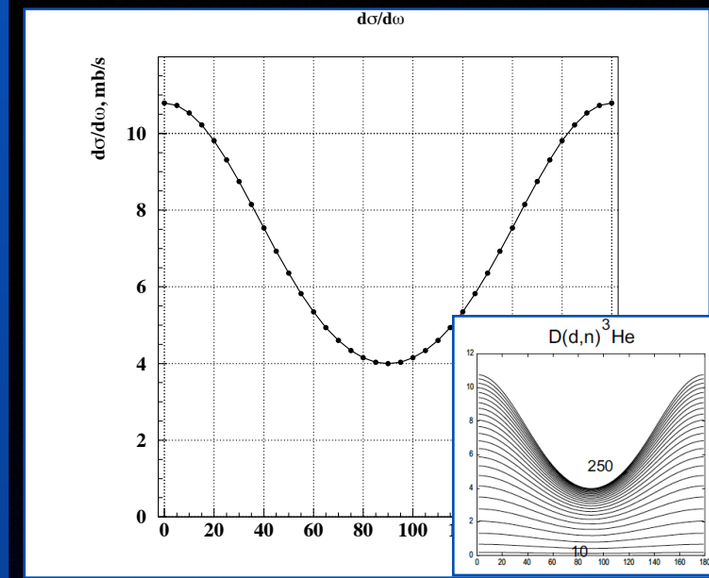
Eur. Phys. J. A 44, 321–354 (2010) DOI: 10.1140/epja/i2010-10964-4

Sol

The status of "polarized fusion"

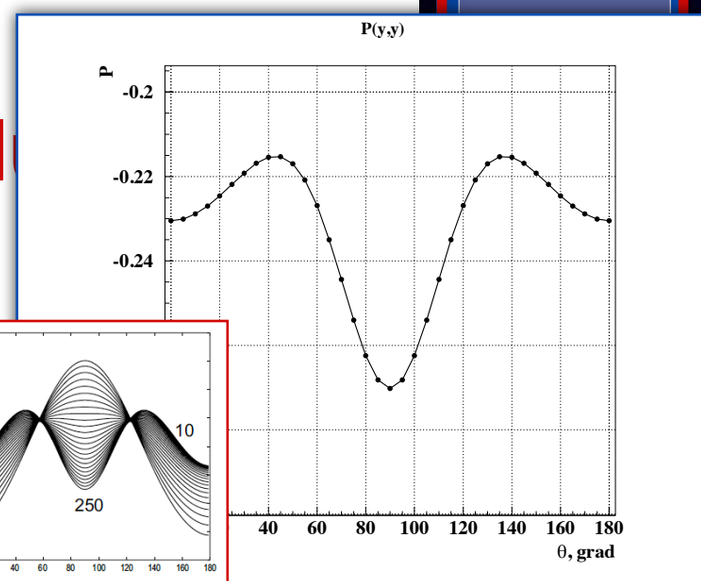
H. Paetz gen. Schieck

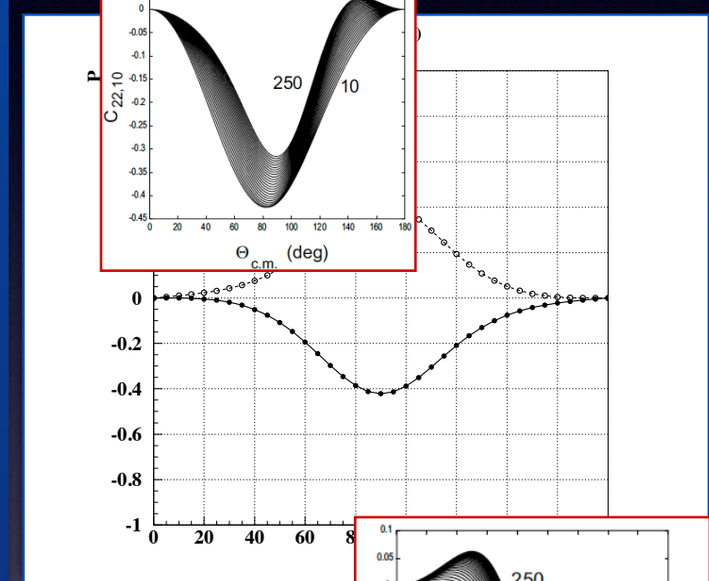




Predicted

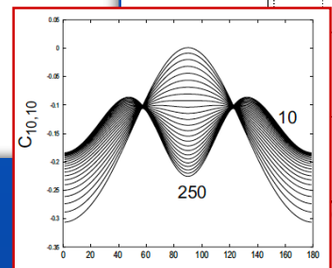
Observable

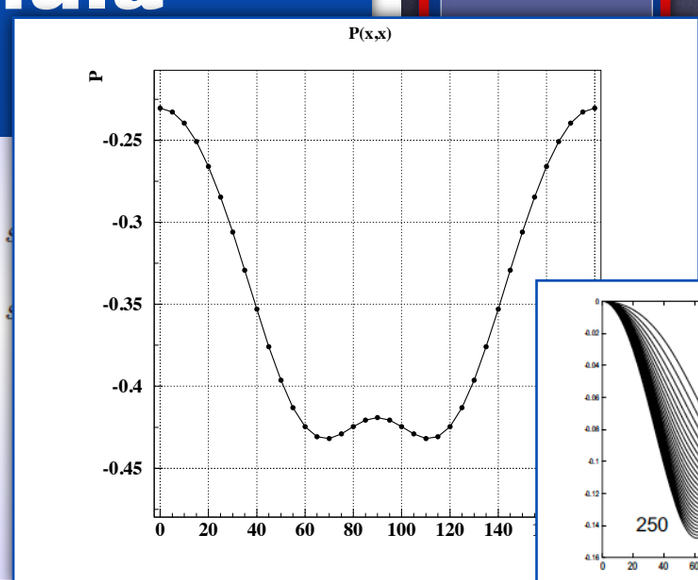


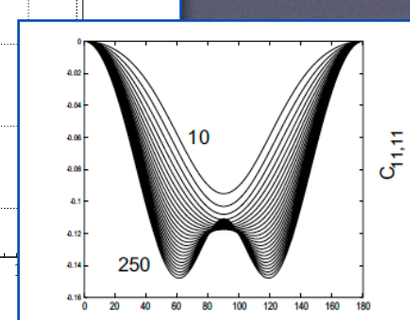


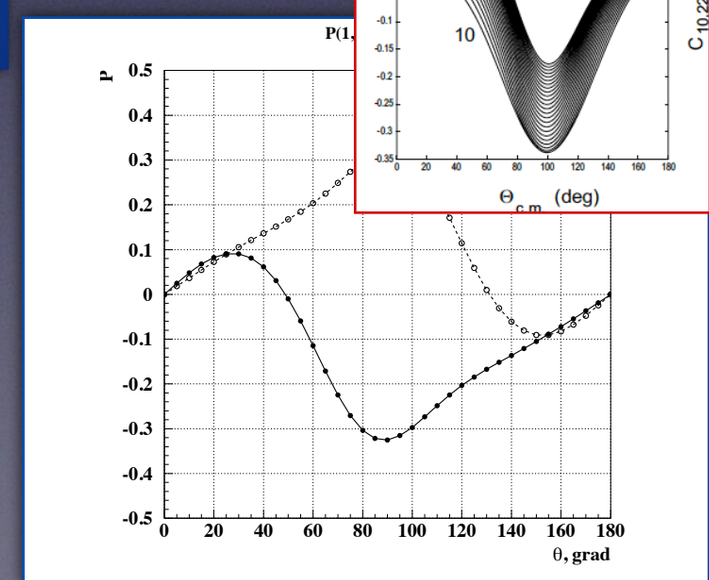
Welton formula

$$
\begin{aligned}
t_{q\gamma,Q\Gamma} &= (2k_{in})^{-2}(\hat{i}\hat{I})^{1/2} \\
&\cdot \sum \begin{Bmatrix} i & I & s_1 \\ q & Q & t \\ i & I & s_2 \end{Bmatrix} \begin{Bmatrix} i' & I' & s_1' \\ q' & Q' & t' \\ i' & I' & s_2' \end{Bmatrix} \begin{Bmatrix} l_1 & \\ l & \\ l_2 & \end{Bmatrix} \\
&\cdot (l_1 l_2 00|l0)(l_1' l_2' 00|l'0)(lt0\Lambda|L\Lambda) \\
&\cdot (l't'0\Lambda'|L\Lambda')(qQ\gamma\Gamma|t\Lambda)(q'Q'\gamma'\Gamma'|t'\Lambda') \\
&\cdot T^{J_1^{\pi_1}} T^{J_2^{\pi_2}*} D^L_{\Lambda'\Lambda}(\Phi,\Theta,0) \\
&\cdot (\hat{i}'\hat{I}')^{-1/2} \\
&\cdot t_{q'\gamma',Q'\Gamma'}
\end{aligned}
$$

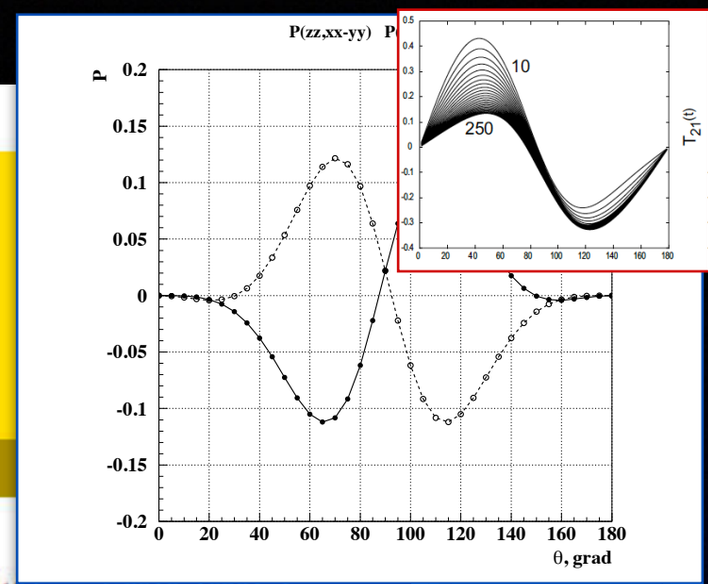


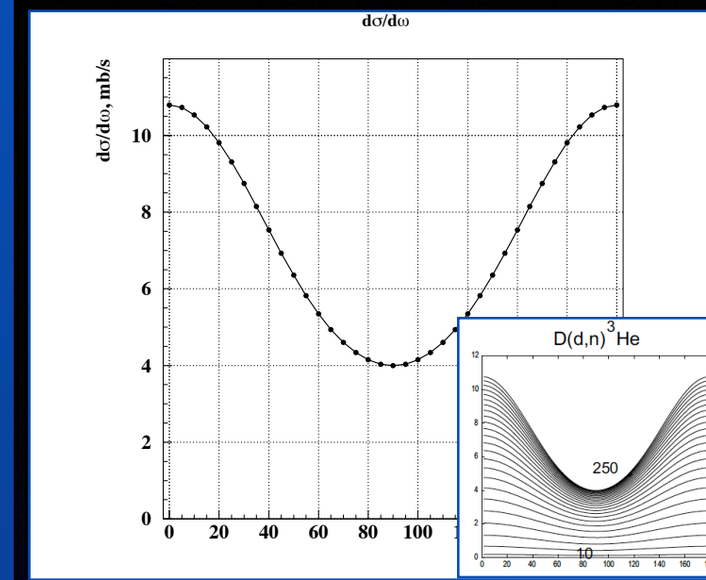






Eur. Phys. J. A 44, 321–354 (2010) DOI: 10.1140/epja/i2010-10964-4





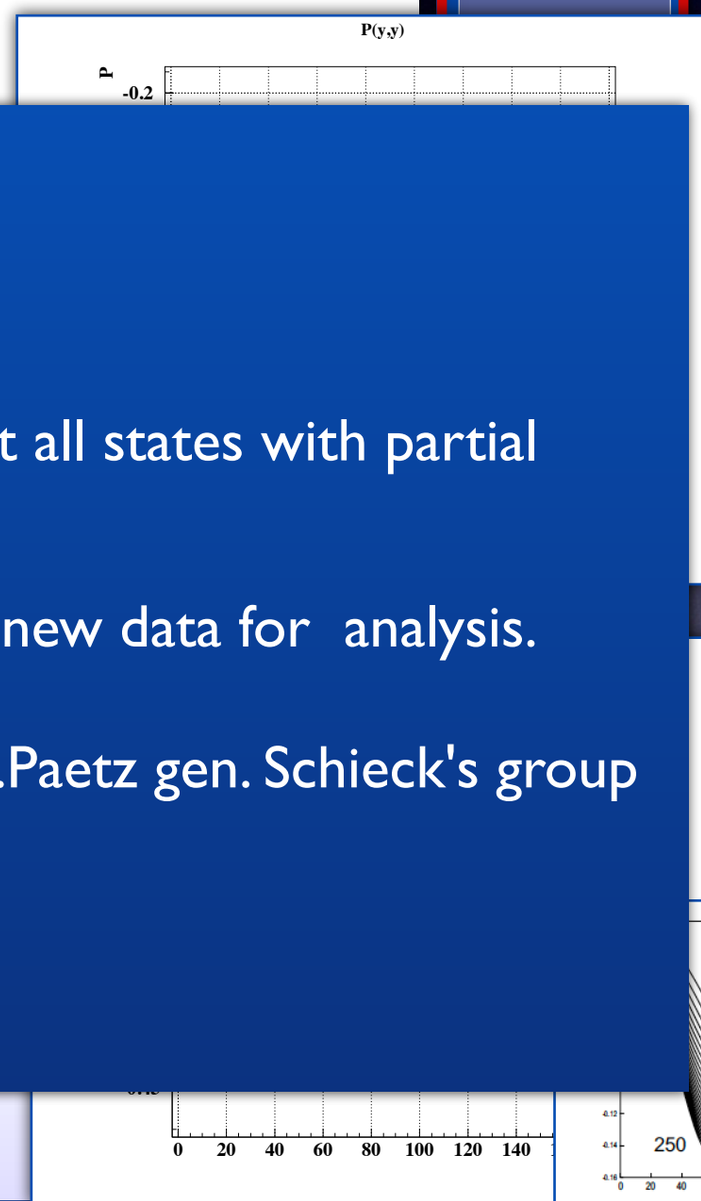
Predicted Observable

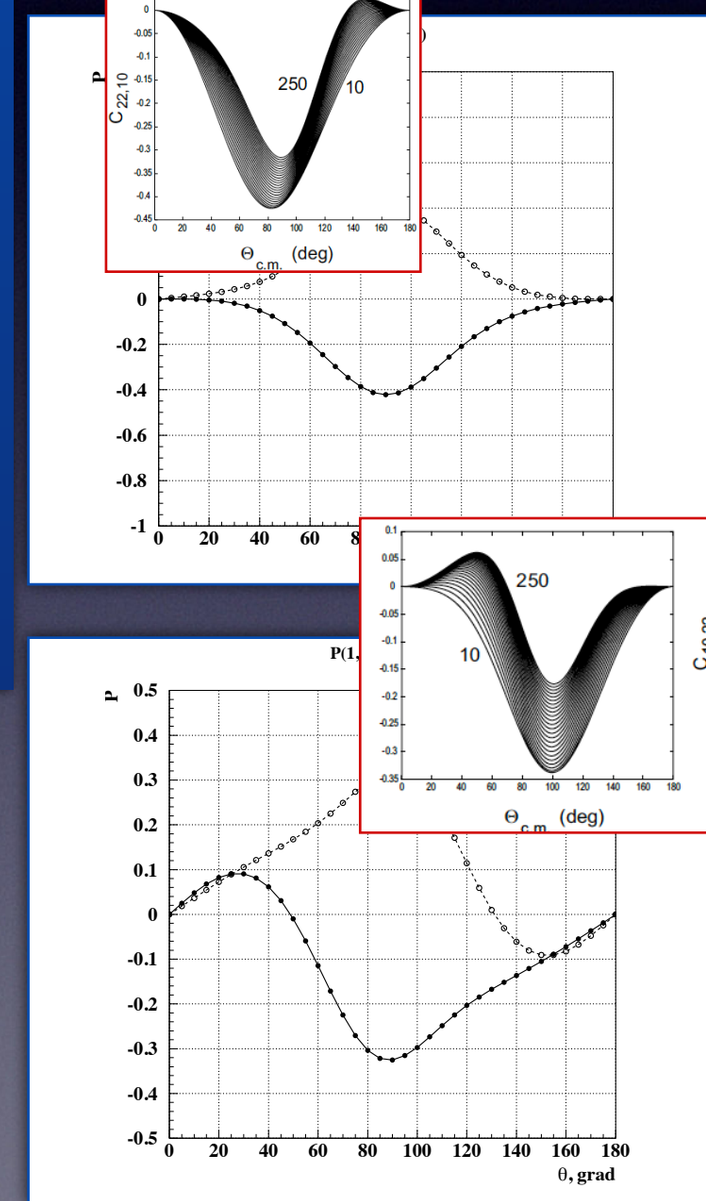
Our model works.

We can take into account all states with partial waves up to ℓ=4.

We are ready to include new data for analysis.

Good agreement with H.Paetz gen. Schieck's group (ℓ=2).





- $(\hat{\imath}'\hat{I}')^{-1/2}$
- $t_{q'\gamma',Q'\Gamma'}$

Analysis diagram

EXPERIMENTS: Reference

Tagishi et al. Phys. Rev. C **46** (1992)
Becker et al. Few Body Sys. **13** (1992)
Imig et al. Phys. Rev. C **73** (2006)
Kurilkin et al. Eur. Phys. J. **162** (2008)
Janek et al. Eur. Phys. J. A **33** (2007)
Leonard et al. Phys. Rev. C **73** (2006)
Fletcher et al. Phys. Rev. C **49** (1994)
Brown et al. Phys. Rev. C **41** (1990)
Gruebler et al. Nucl. Phys. A **369** (1981)
Ying et al. Nucl. Phys. A **206** (1973)
Schulte et al. Nucl. Phys. A **192** (1972)
Roper et al. Few-Body Syst. **47** (2010)
Lisowsky et al. Nucl. Phys. A **242** (1975)
Clegg et al. Phys. Rev. C **8** (1973)
Kozma et al. Nucl. Phys. A **442** (1985)
Dietze et al. Nucl Phys. A **158** (1970)
Alsoraya et al. Nucl. Phys. A **280** (1977)
Behof et al. Nucl Phys. A **108** (1968)
Sikkema et al. Nucl. Phys. A **245** (1975)
Theus et al. Nucl. Phys. **80** (1966)
Wenzel et al. Phys. Rev. **88** (1952)
Hunter et al. Phys. Rev. **76** (1949)
Jeltsch et al. Helv. Phys. Asta **43** (1970)
Steinberg et al. Phys. Rev. **186** (1969)
Krauss et al. Nucl. Phys. A **465** (1987)
Blair et al. Phys. Rev. **74** (1948)
Franz et al. Nucl. Phys. A **122** (1968)

INPUT from experiments

partial wave analysis
for two-body reaction
with spin 1+1→1/2+1/2

Minimization procedure ✓

PolFusion test run

Analysis of new experimental data

Partial amplitudes

$a^J_{l'l}$ ✓
$b^J_{l'l}$
$c^J_{l'l}$
$d^J_{l'l}$
$e^J_{l'l}$
$f^J_{l'l}$

Observables

σ_0
$d\sigma_0/d\Omega$ ✓
A_y
A_{zz}
A_{xz}
C_{zz}
C_{yy}
$C_{zz,zz}$ $C_{y,zz}$
$C_{y,xz}$
$C_{zz,xz}$
$P_{y'}$
$K^{x'}_x$
$K^{y'}_y$

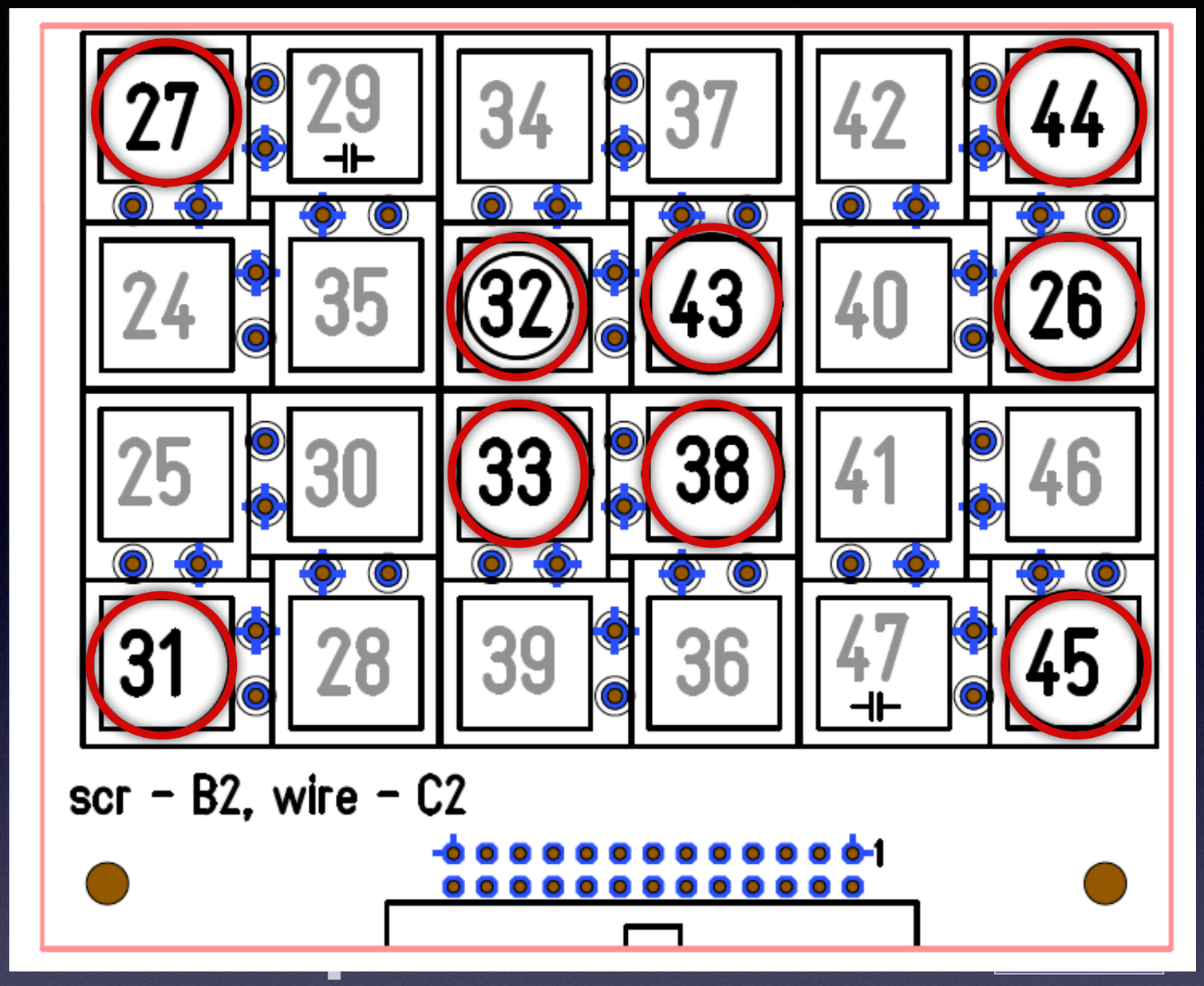
Event generator

Detector simulation

Event tracking and reconstruction

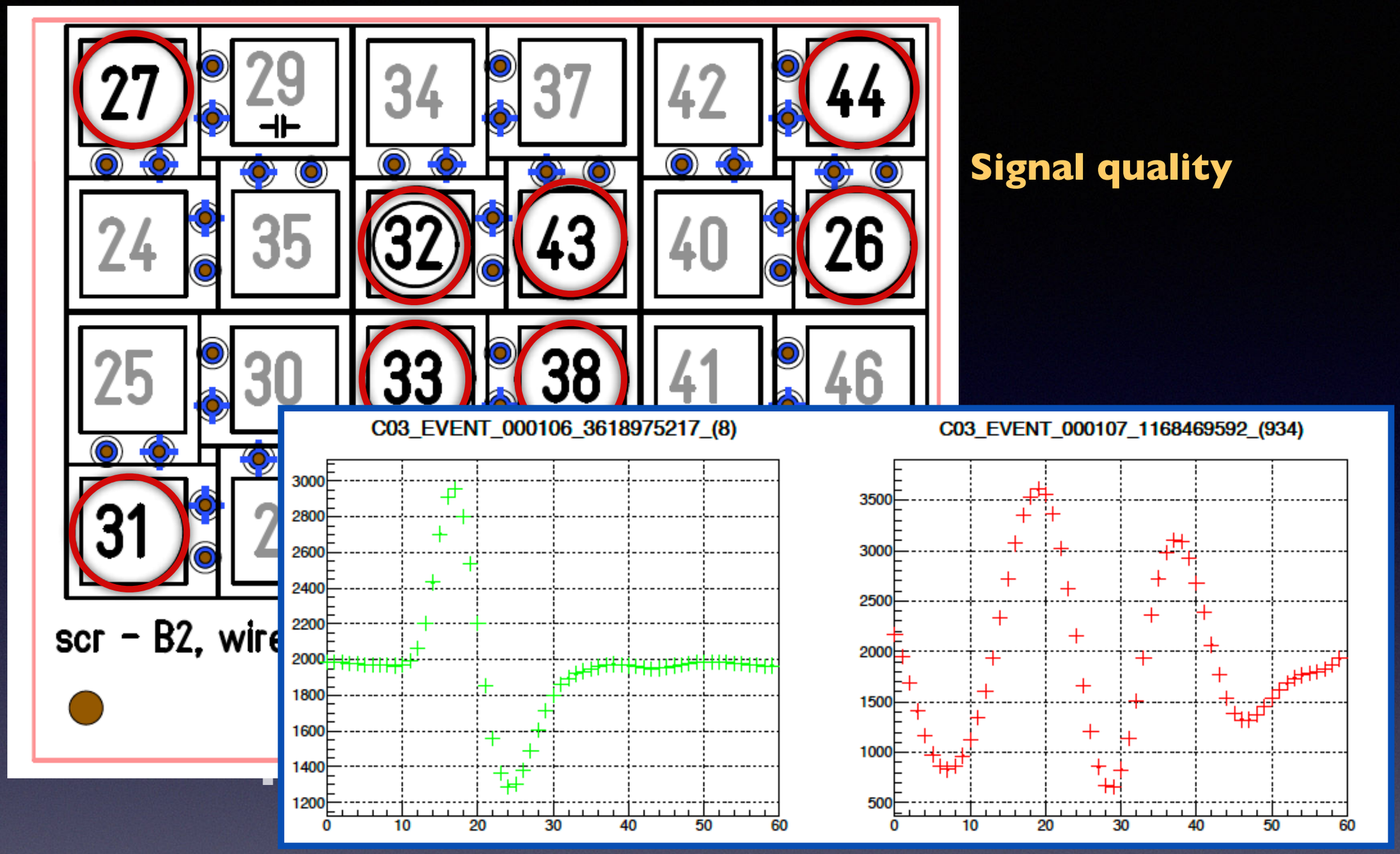
Systematic

QSF



PolFusion test run

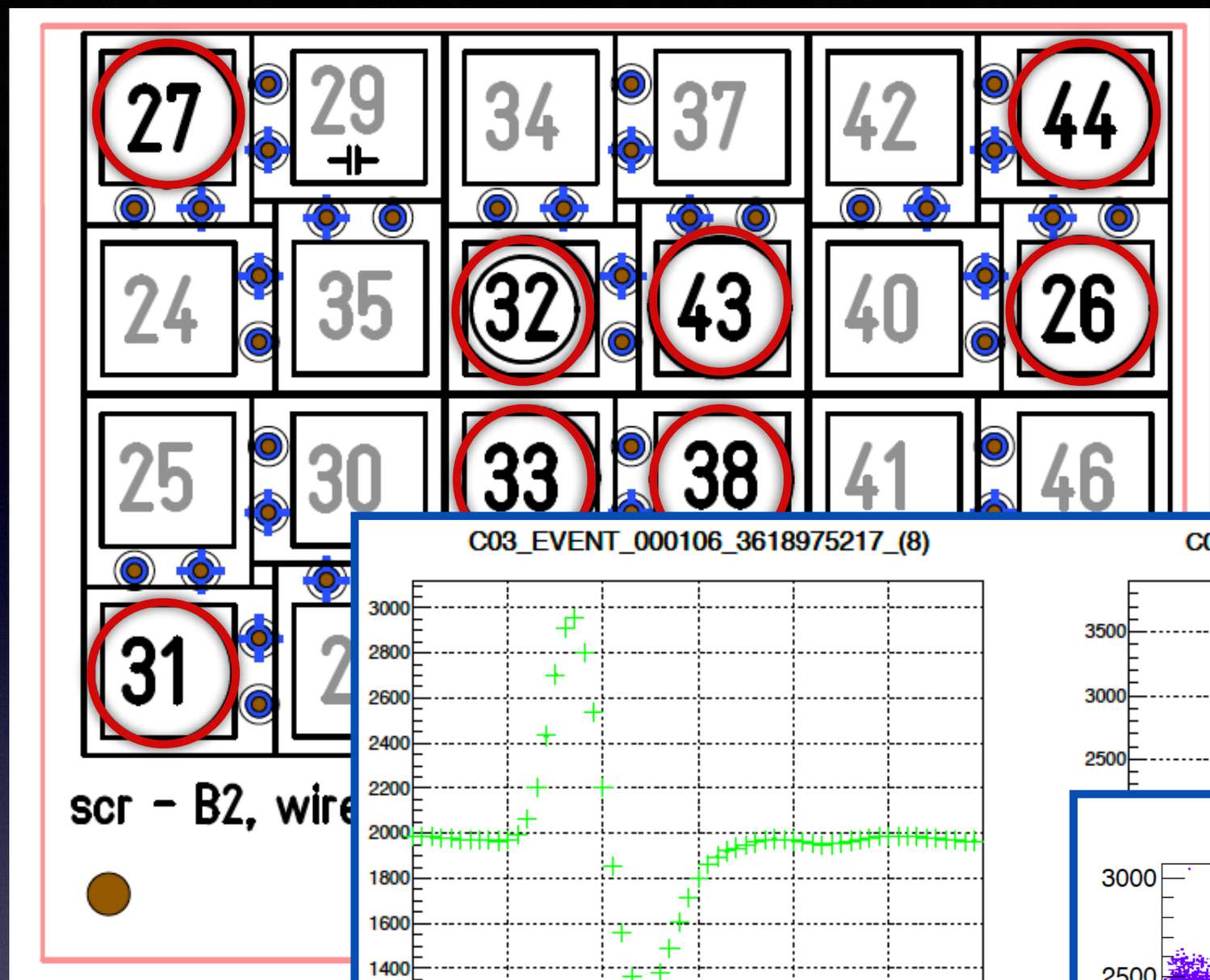
Analysis of new experimental data



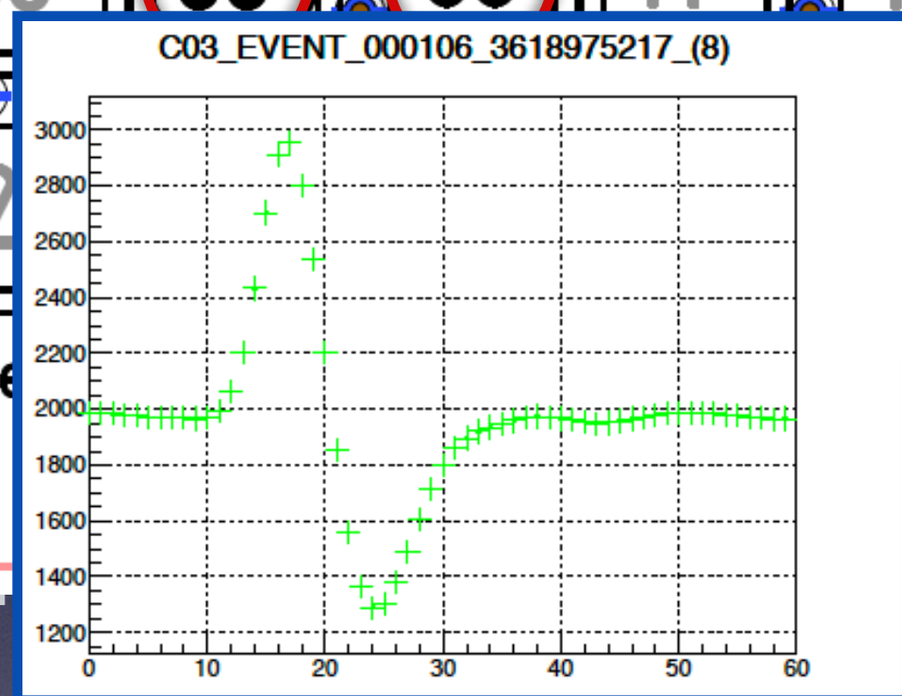
Signal quality

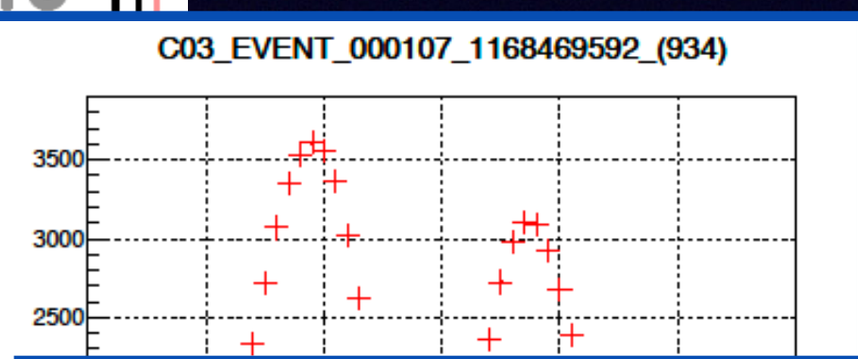
PolFusion test run

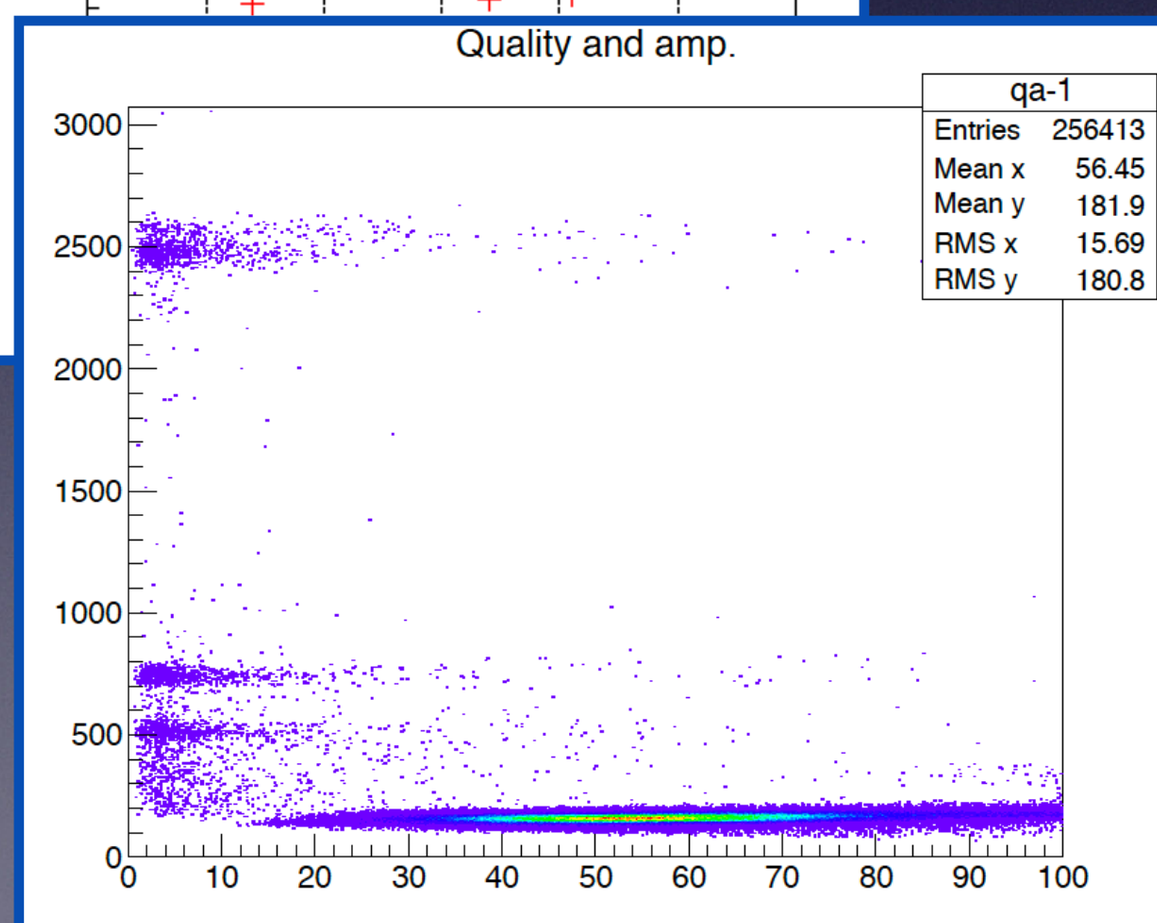
Analysis of new experimental data



Signal quality

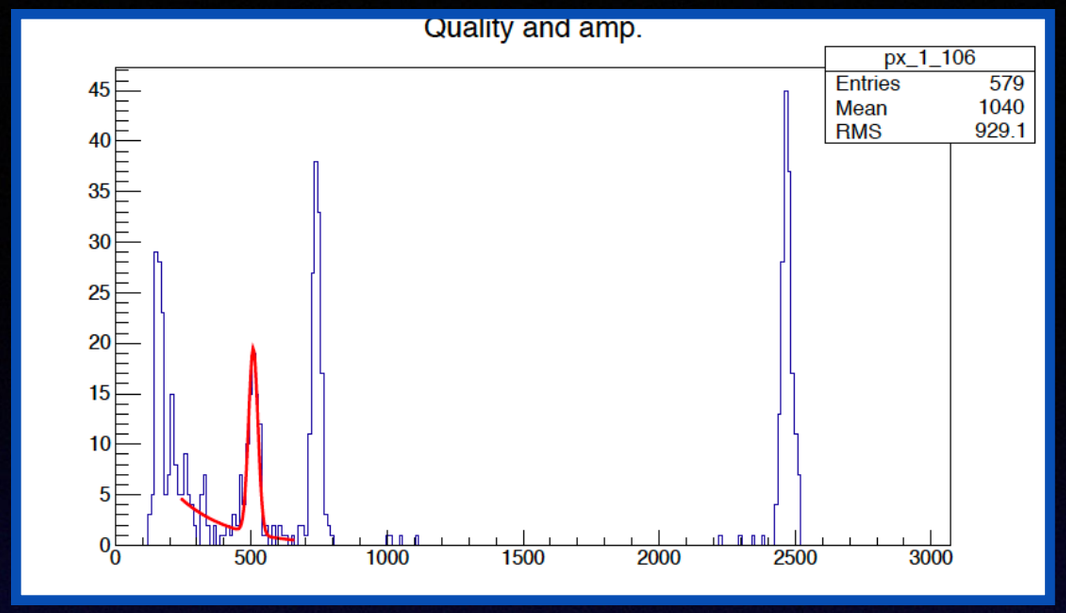


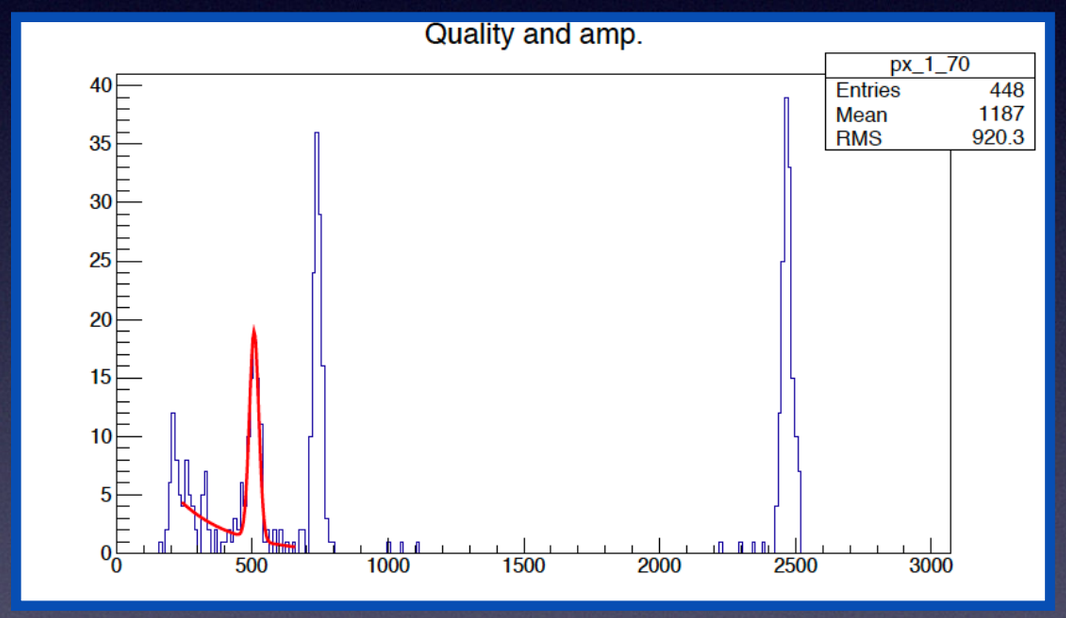




PolFusion test run

Analysis of new experimental data

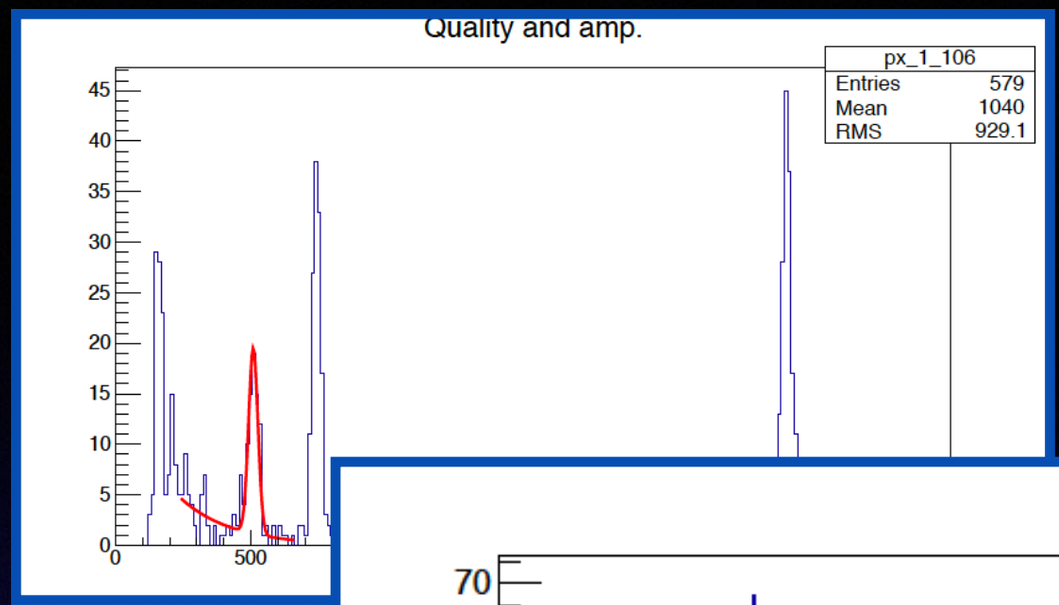


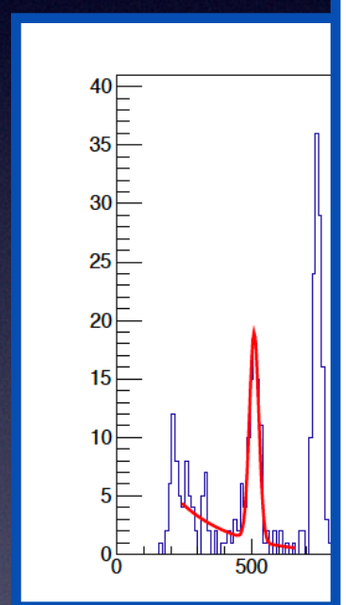


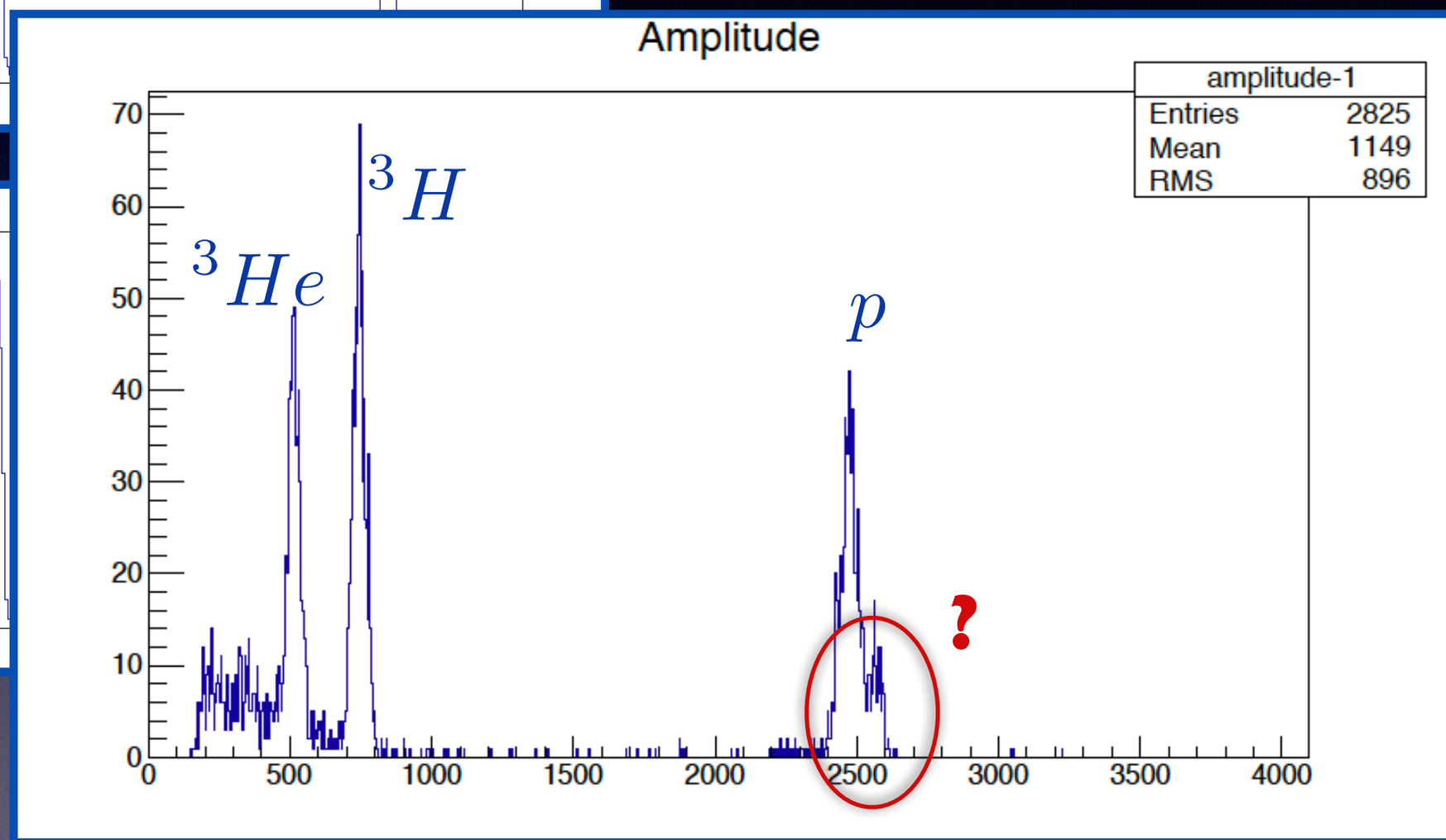
Signal quality
Background shape and sources

PolFusion test run

Analysis of new experimental data







Signal quality
Background shape and sources
Behavior of amplitude spectrums

PolFusion test run

Analysis of new experimental data

Analysis diagram

EXPERIMENTS: Reference

Tagishi et al. Phys. Rev. C **46** (1992)
Becker et al. Few Body Sys. **13** (1992)
Imig et al. Phys. Rev. C **73** (2006)
Kurilkin et al. Eur. Phys. J. **162** (2008)
Janek et al. Eur. Phys. J. A **33** (2007)
Leonard et al. Phys. Rev. C **73** (2006)
Fletcher et al. Phys. Rev. C **49** (1994)
Brown et al. Phys. Rev. C **41** (1990)
Gruebler et al. Nucl. Phys. A **369** (1981)
Ying et al. Nucl. Phys. A **206** (1973)
Schulte et al. Nucl. Phys. A **192** (1972)
Roper et al. Few-Body Syst. **47** (2010)
Lisowsky et al. Nucl. Phys. A **242** (1975)
Clegg et al. Phys. Rev. C **8** (1973)
Kozma et al. Nucl. Phys. A **442** (1985)
Dietze et al. Nucl Phys. A **158** (1970)
Alsoraya et al. Nucl. Phys. A **280** (1977)
Behof et al. Nucl Phys. A **108** (1968)
Sikkema et al. Nucl. Phys. A **245** (1975)
Theus et al. Nucl. Phys. **80** (1966)
Wenzel et al. Phys. Rev. **88** (1952)
Hunter et al. Phys. Rev. **76** (1949)
Jeltsch et al. Helv. Phys. Asta **43** (1970)
Steinberg et al. Phys. Rev. **186** (1969)
Krauss et al. Nucl. Phys. A **465** (1987)
Blair et al. Phys. Rev. **74** (1948)
Franz et al. Nucl. Phys. A **122** (1968)

INPUT from experiments

partial wave analysis
for two-body reaction
with spin 1+1→1/2+1/2

Minimization procedure ✓

Analysis of new experimental data ✓

Partial amplitudes

$a^J_{l'l}$ ✓
$b^J_{l'l}$
$c^J_{l'l}$
$d^J_{l'l}$
$e^J_{l'l}$
$f^J_{l'l}$

Observables

σ_0 ✓
$d\sigma_0/d\Omega$
A_y
A_{zz}
A_{xz}
C_{zz}
C_{yy}
$C_{zz,zz}$ $C_{y,zz}$
$C_{y,xz}$
$C_{zz,xz}$
$P_{y'}$
$K^{x'}_x$
$K^{y'}_y$

MC

Event generator

Detector simulation

Event tracking and reconstruction

Systematic

QSF

MC

Interaction point → **Event generator**

⇩

Detector geometry → Detector simulation

Event tracking and reconstruction

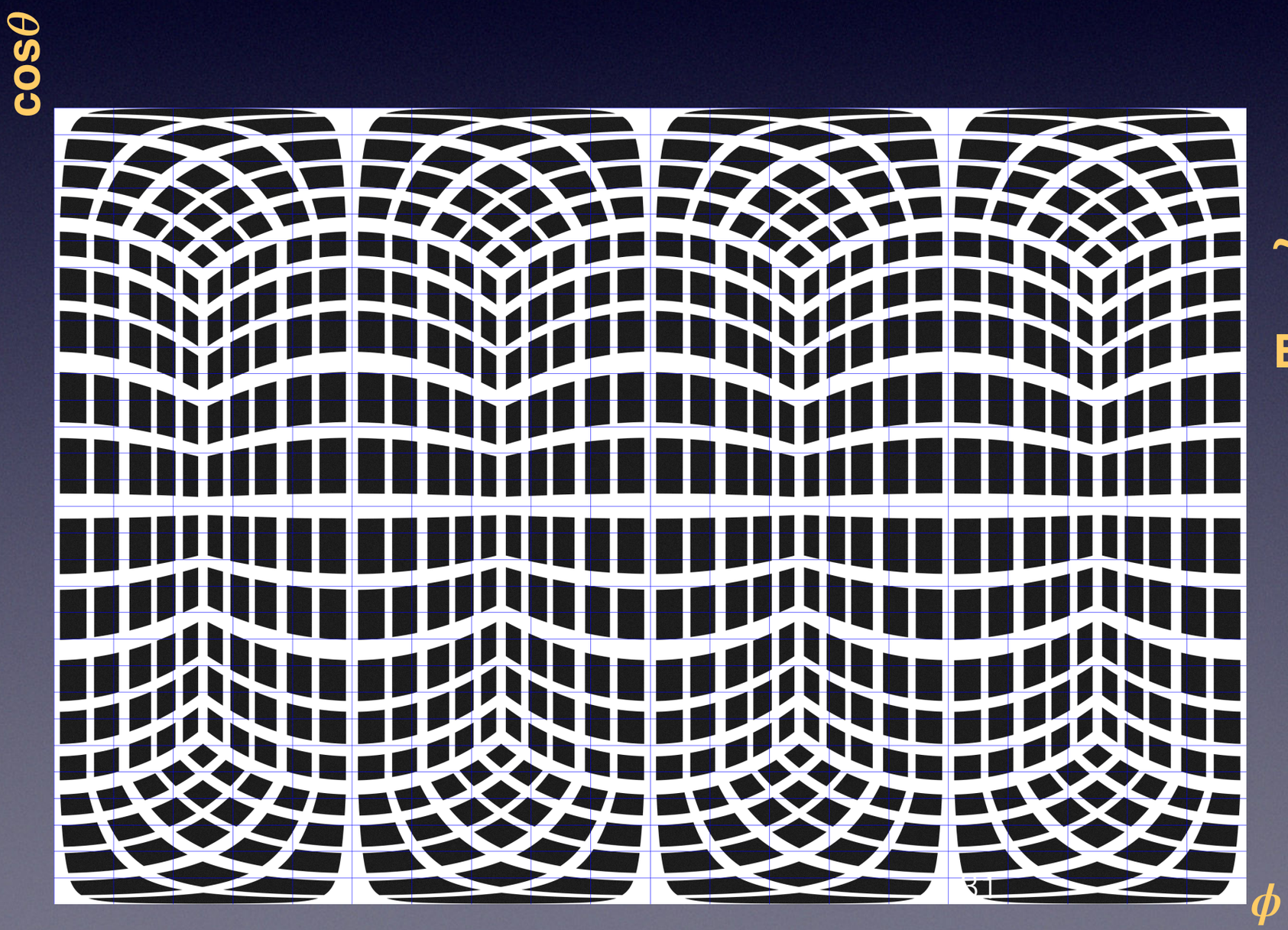
MC

Interaction point → **Event generator**

⇩

Detector geometry → Detector simulation

Event tracking and reconstruction



~50% of events in detector

Event distributions in space θ and ϕ

Acceptance effects and efficiency

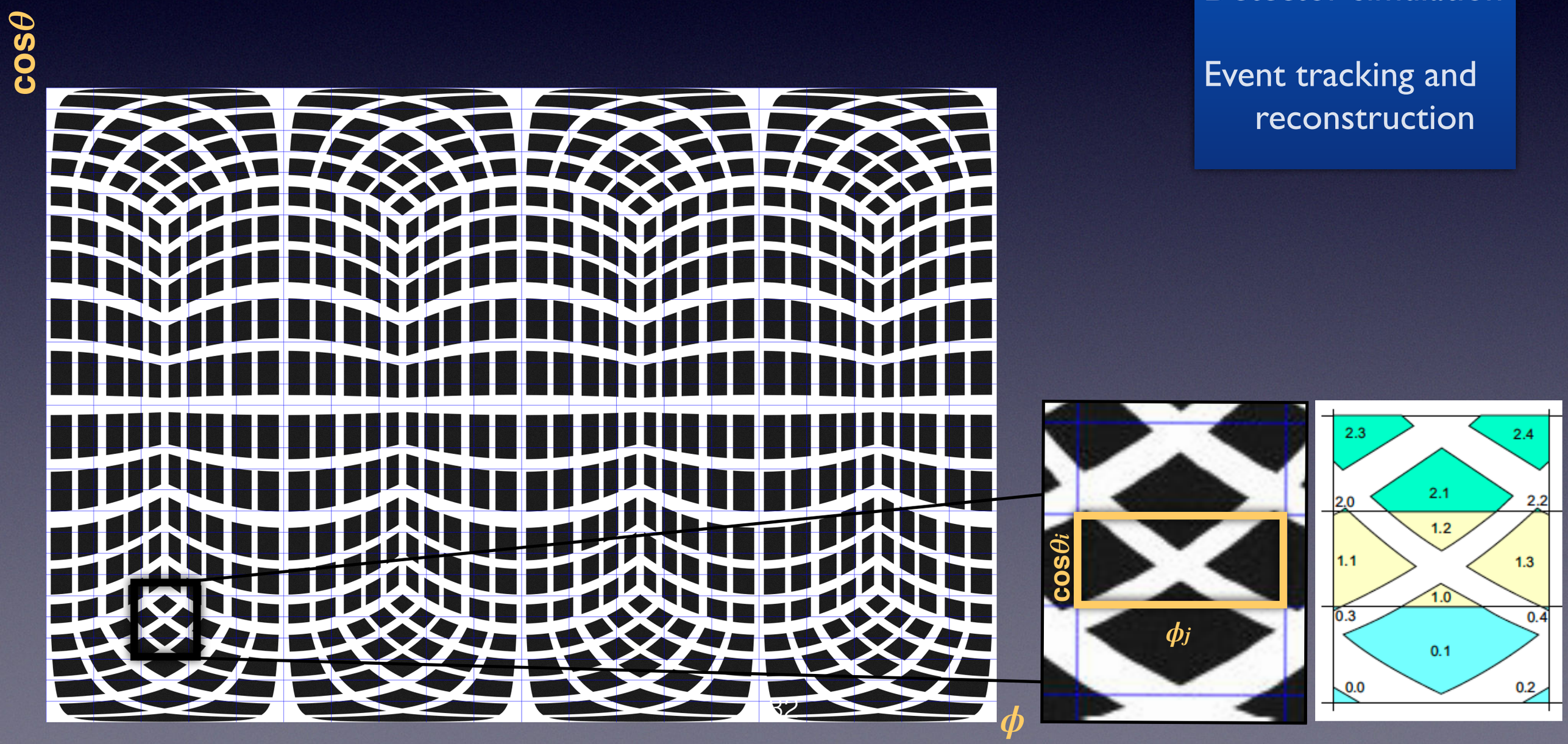
MC

Interaction point → **Event generator**

⇩

Detector geometry → Detector simulation

Event tracking and reconstruction



MC

Interaction point → **Event generator**

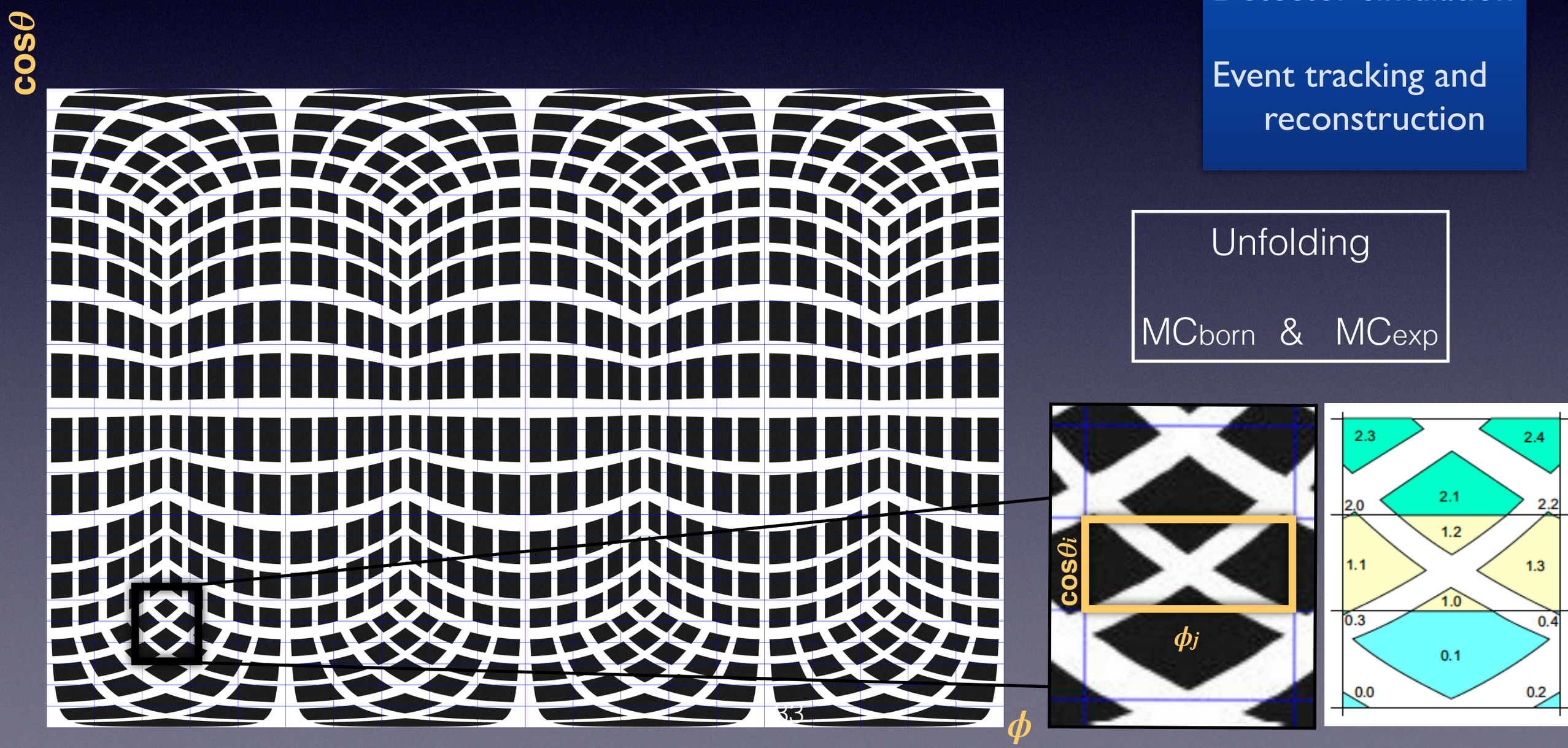
⇩

Detector geometry → Detector simulation

Event tracking and reconstruction

Unfolding

MCborn & MCexp



MC

Interaction point
Beam profiles

Event generator

Detector geometry

Detector simulation

Event tracking and reconstruction

MC

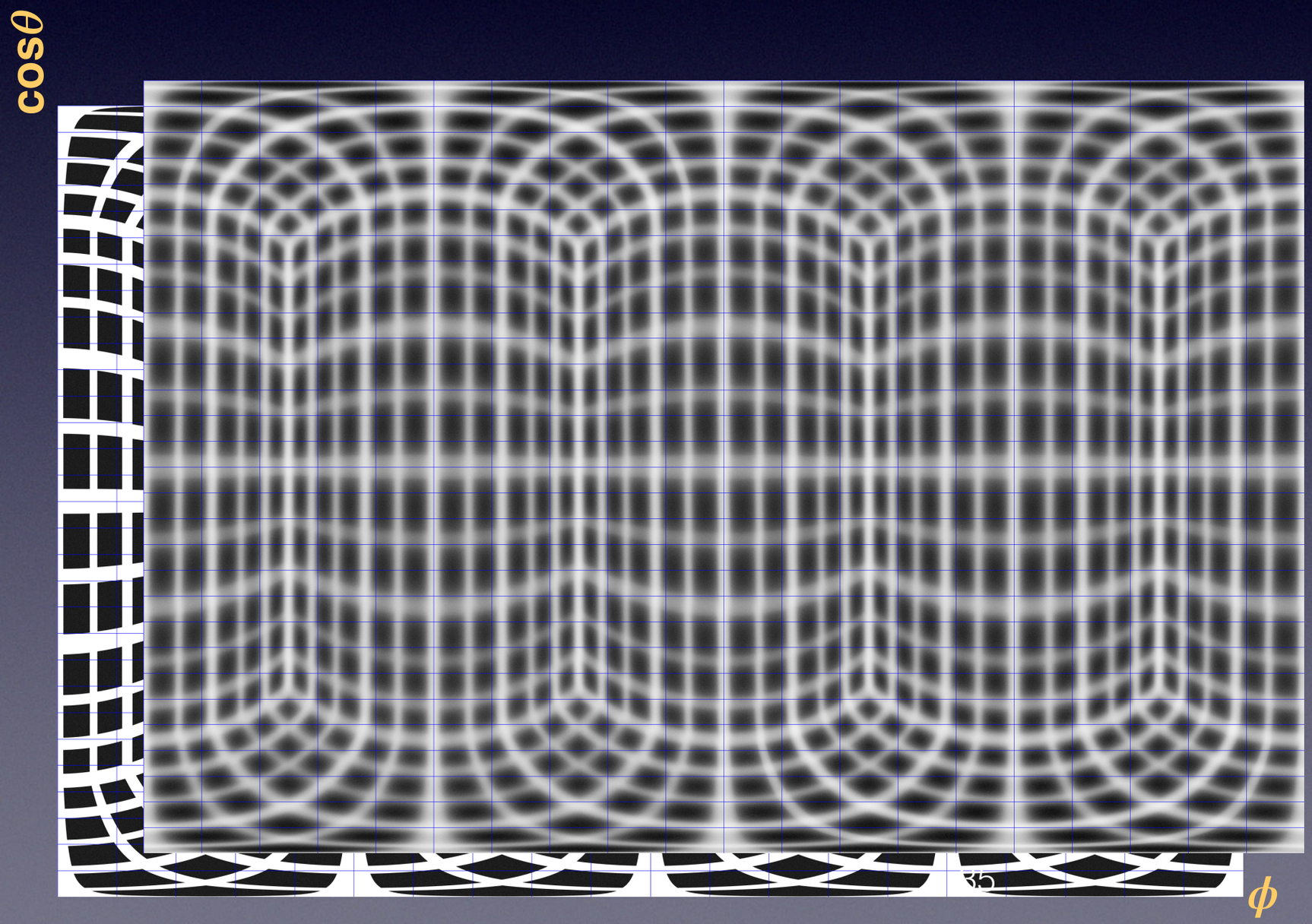
Interaction point
Beam profiles

Event generator

Detector geometry

Detector simulation

Event tracking and reconstruction



Smearing

MC

Interaction point
Beam profiles

Event generator

Detector geometry

Detector simulation

Event tracking and reconstruction

$$\frac{d\sigma(\theta)_{exp}}{d(cos\theta)} \Big/ \frac{d\sigma(\theta)_{born}}{d(cos\theta)}$$

MC

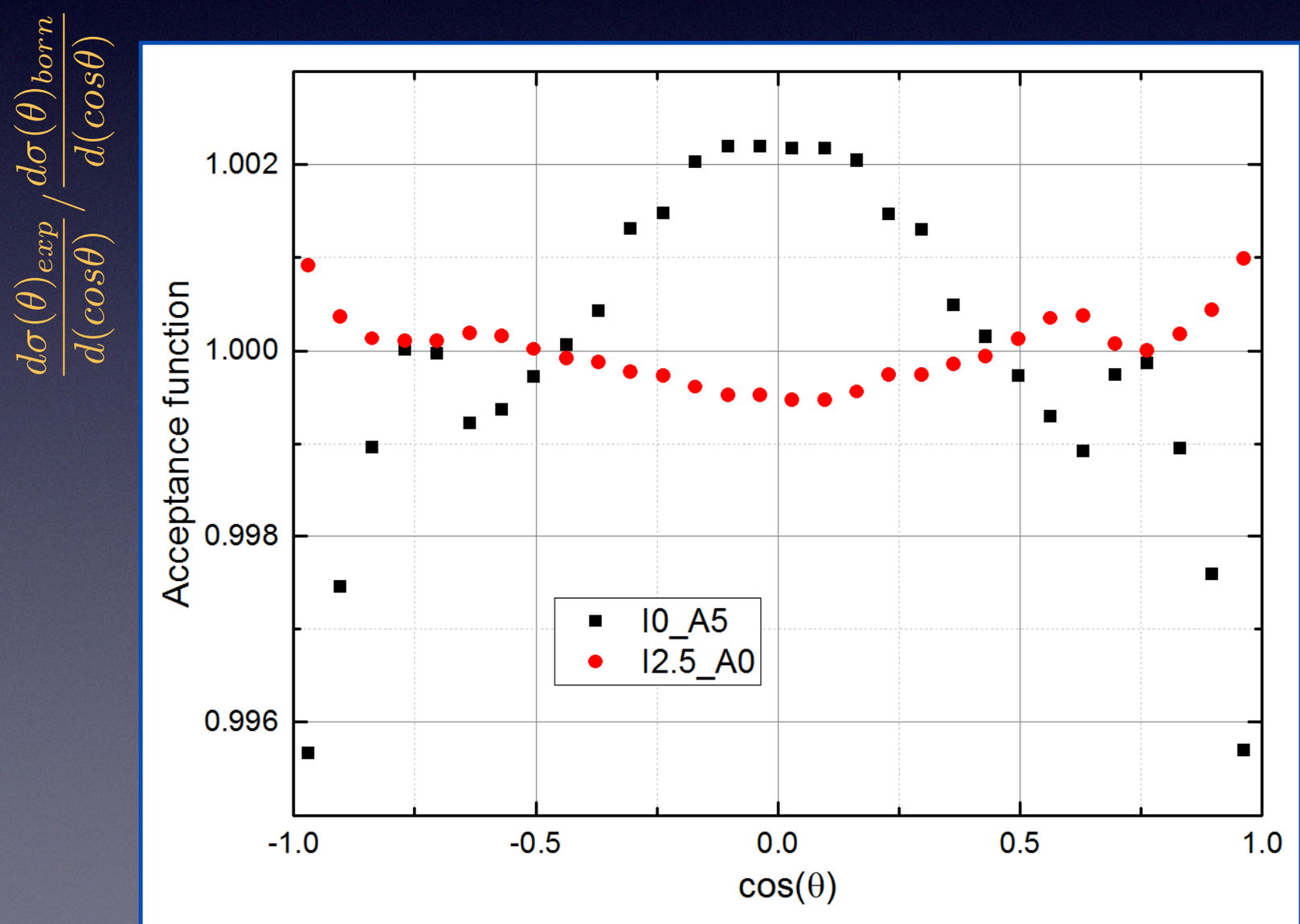
Interaction point
Beam profiles

Event generator

Detector geometry

Detector simulation

Event tracking and reconstruction



MC

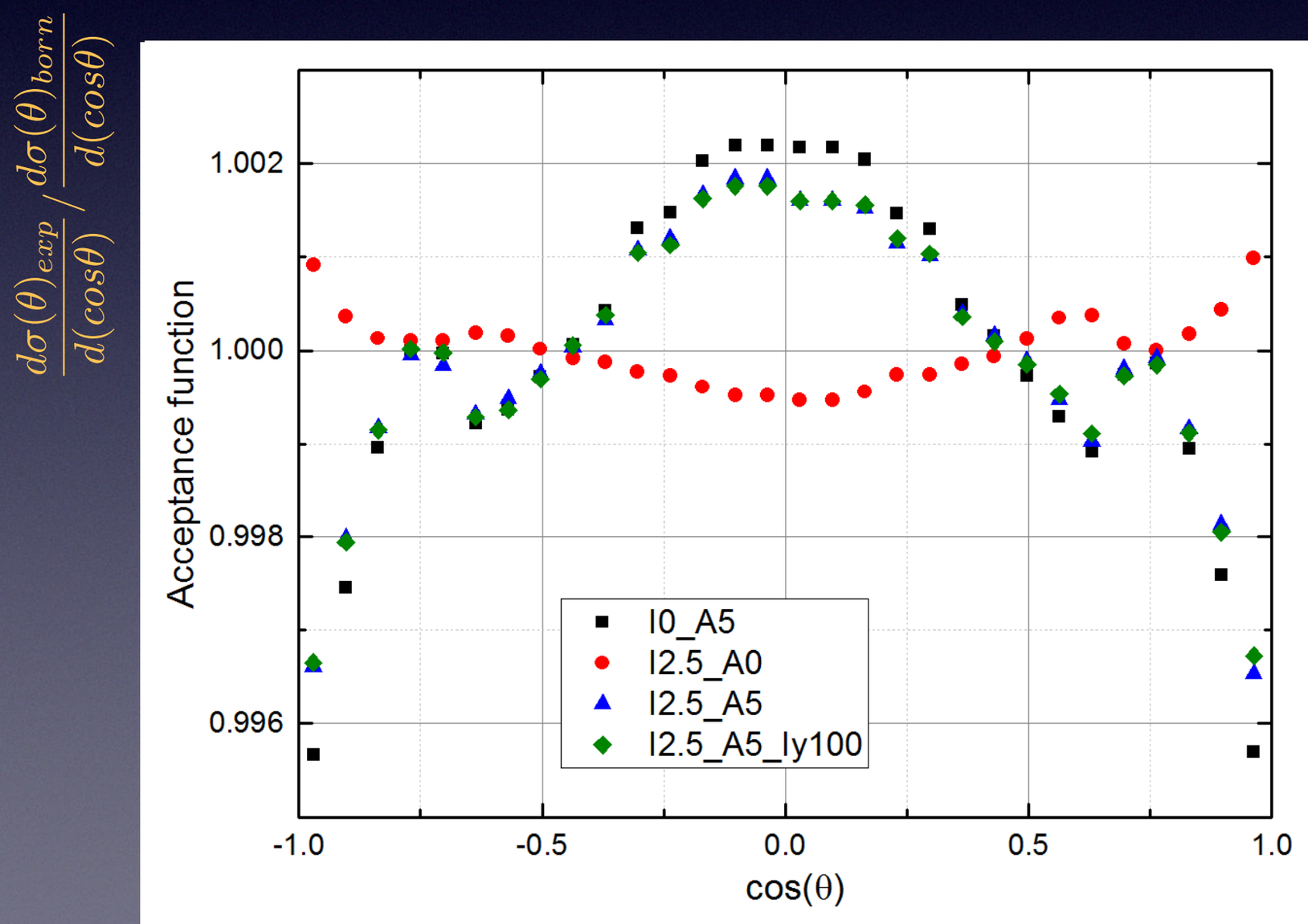
Interaction point
Beam profiles

Event generator

Detector geometry

Detector simulation

Event tracking and reconstruction



MC

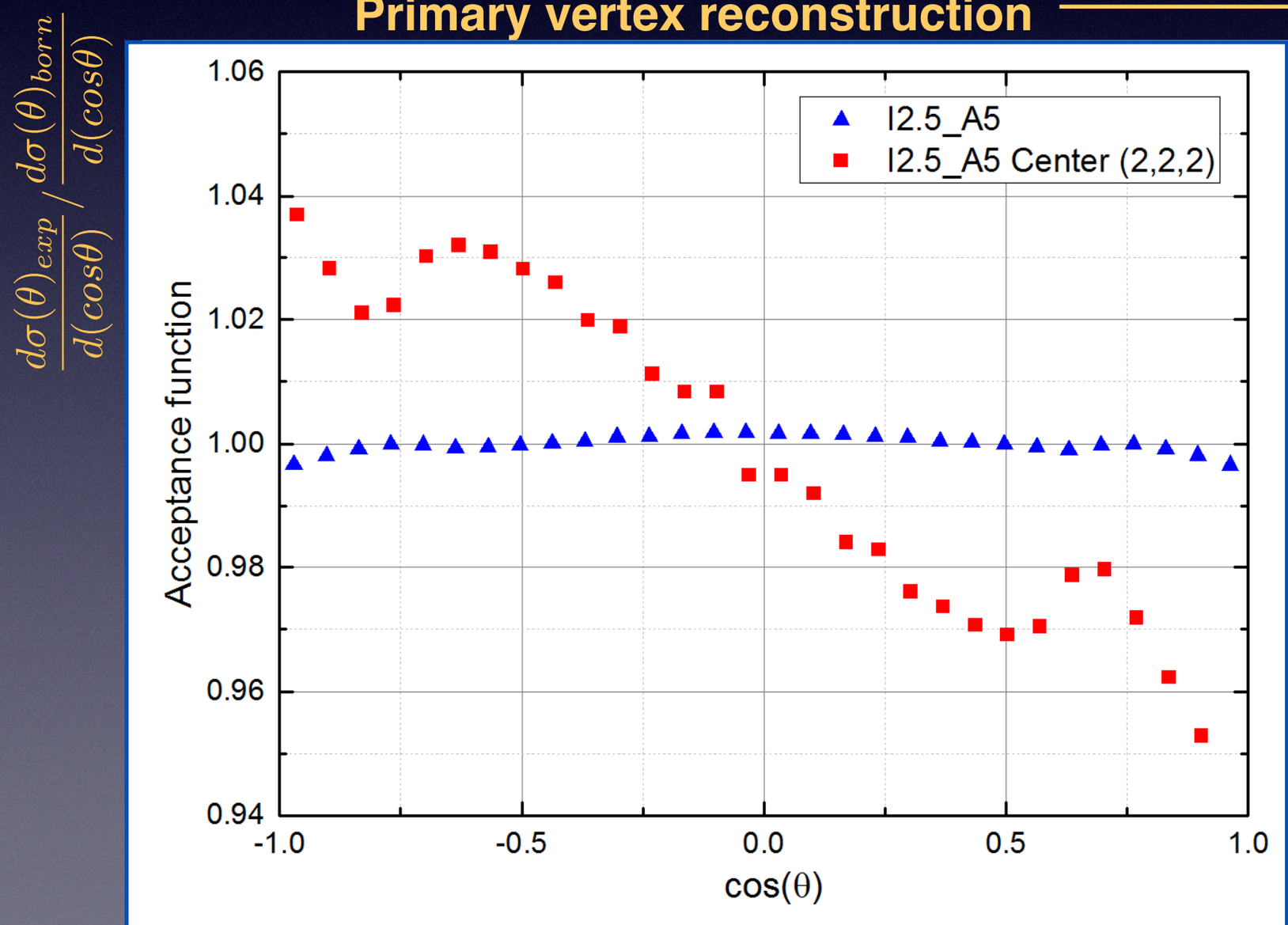
Interaction point
Beam profiles

Event generator

Detector geometry
Primary vertex reconstruction

Detector simulation

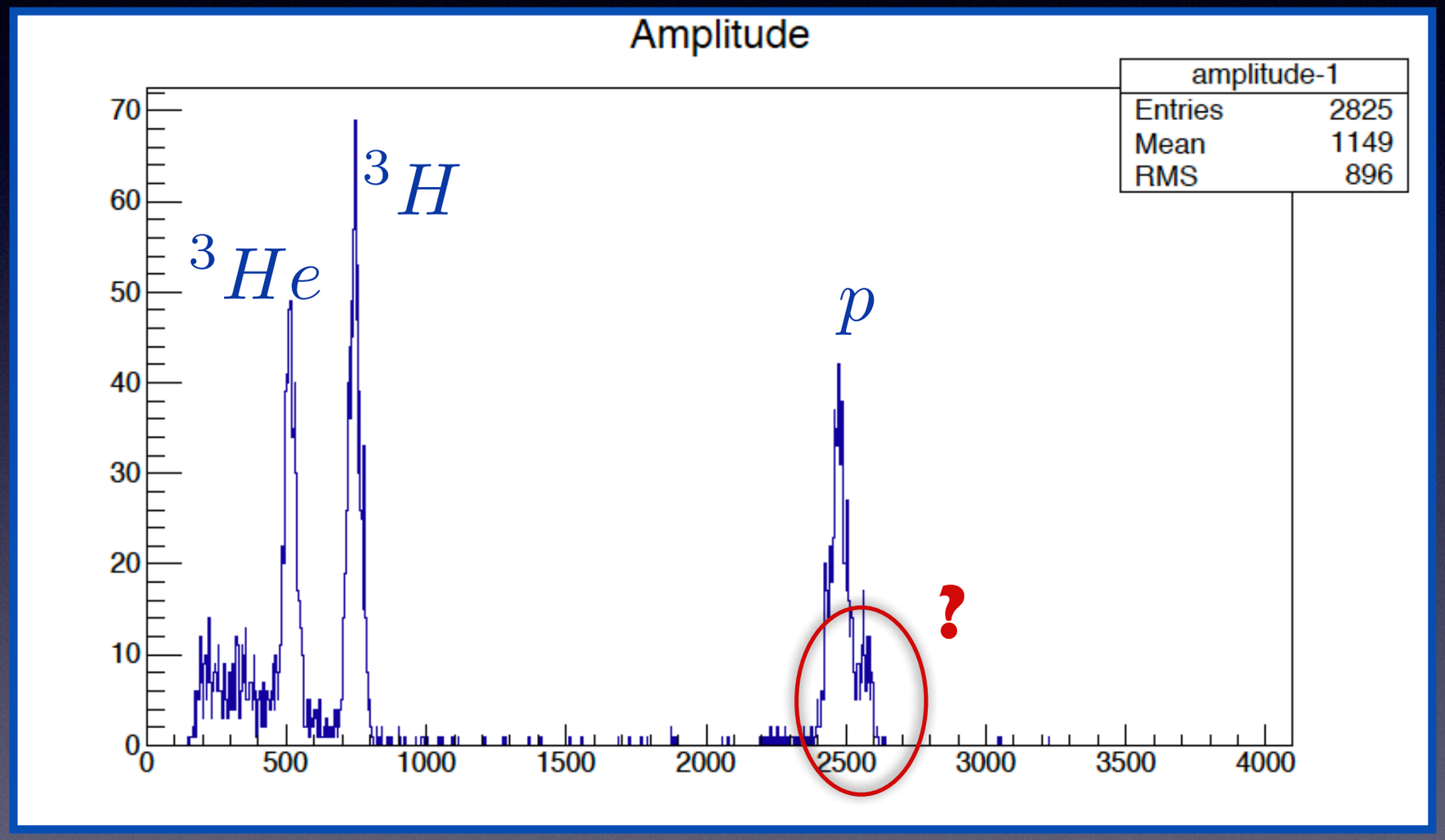
Event tracking and reconstruction



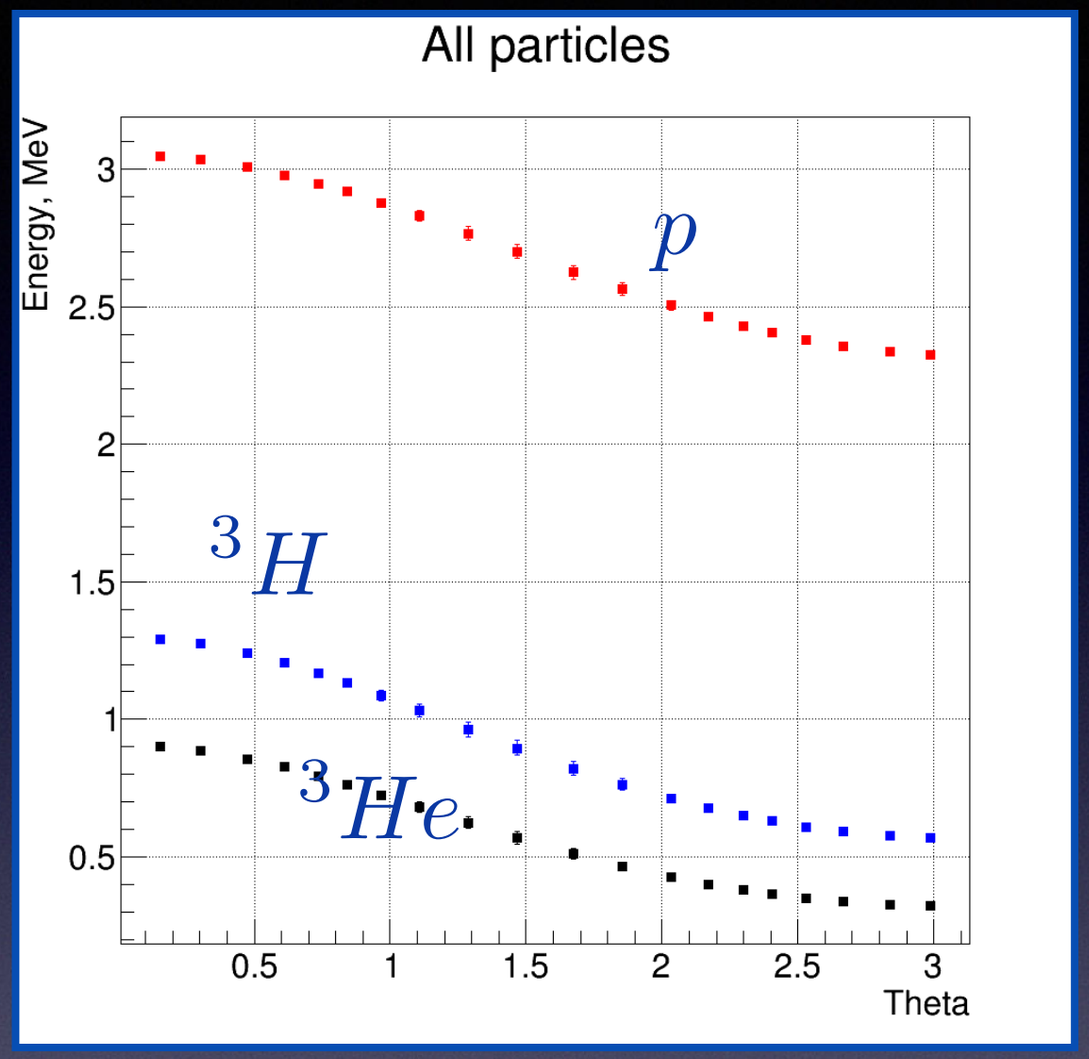
MC

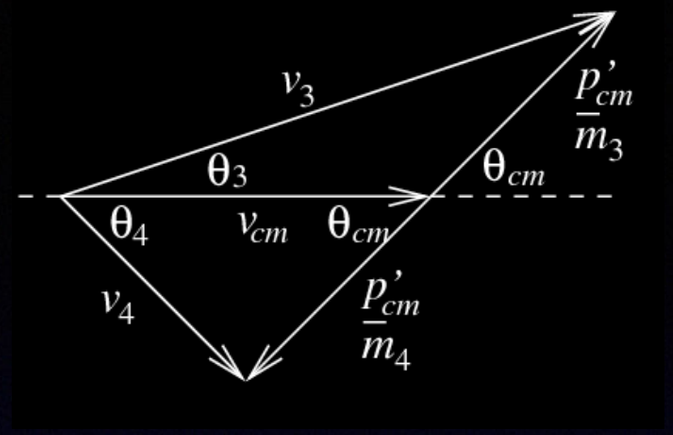
Interaction point
Beam profiles
Kinematics

Event generator

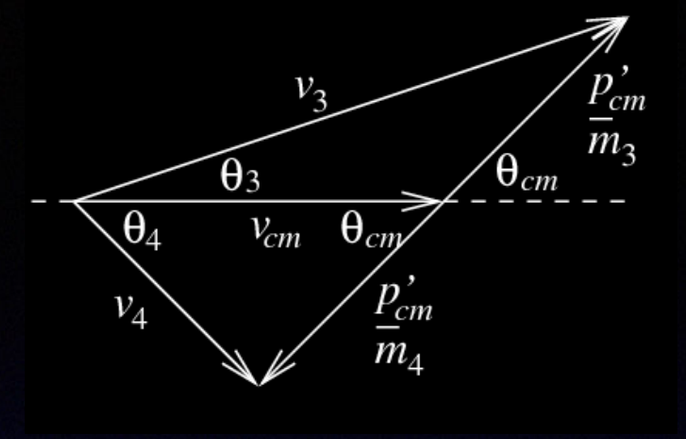


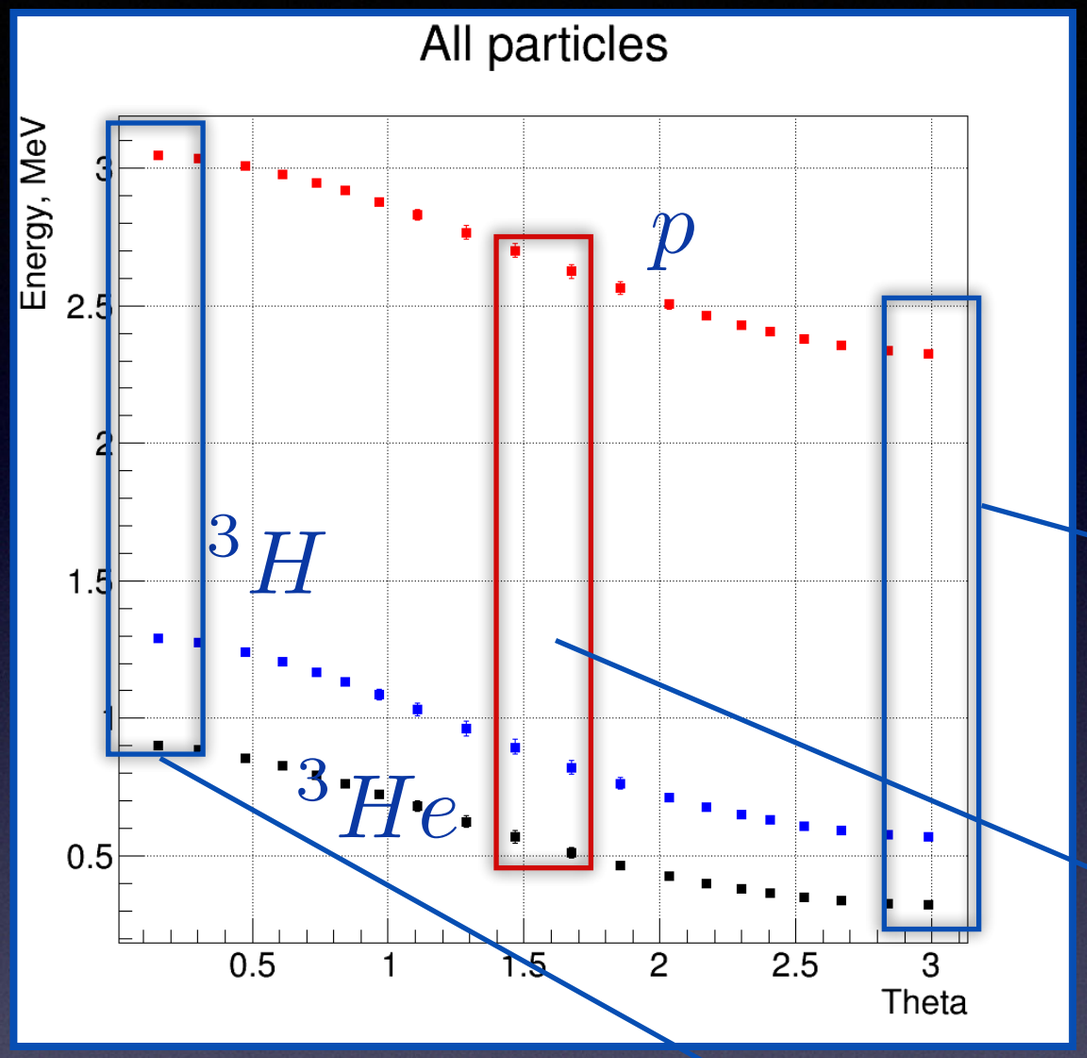
MC

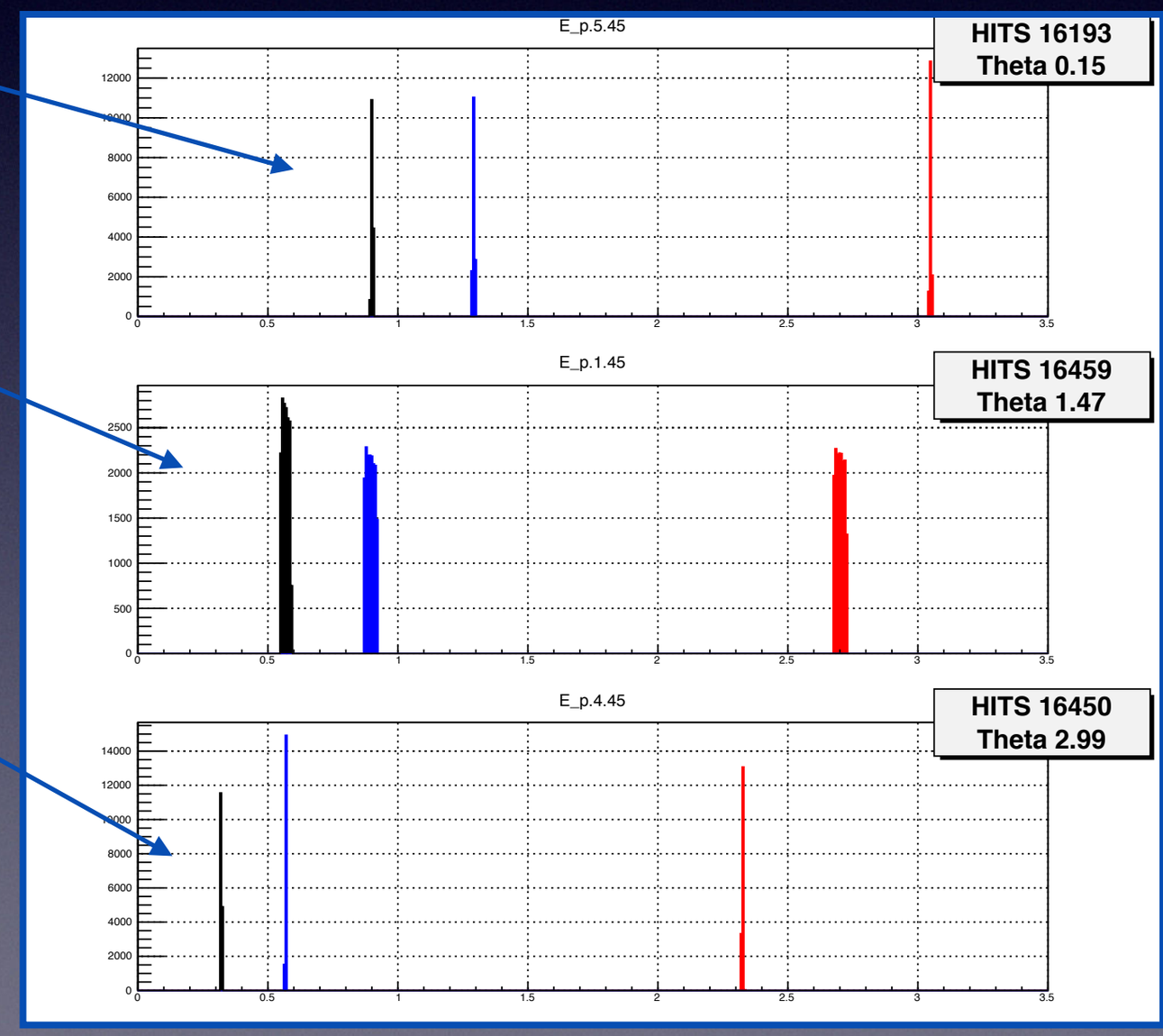

All particles
Energy, MeV
Theta
p
^3H
^3He


v_3
θ_3
θ_4
v_{cm}
θ_{cm}
θ_{cm}
v_4
$\frac{p'_{cm}}{m_3}$
$\frac{p'_{cm}}{m_4}$

MC


v_3
$\frac{p'_{cm}}{m_3}$
θ_3
θ_{cm}
θ_4
v_{cm}
θ_{cm}
v_4
$\frac{p'_{cm}}{m_4}$


All particles
Energy, MeV
Theta
p
^3H
^3He


E_p.5.45
HITS 16193
Theta 0.15
E_p.1.45
HITS 16459
Theta 1.47
E_p.4.45
HITS 16450
Theta 2.99

MC

Interaction point
Beam profiles
Kinematics

Event generator

Detector geometry
Primary vertex reconstruction

Detector simulation

Event tracking and reconstruction

Acceptance effects and efficiency

Unfolding

Smearing

Systematic

Analysis diagram

EXPERIMENTS: Reference

Tagishi et al. Phys. Rev. C **46** (1992)
Becker et al. Few Body Sys. **13** (1992)
Imig et al. Phys. Rev. C **73** (2006)
Kurilkin et al. Eur. Phys. J. **162** (2008)
Janek et al. Eur. Phys. J. A **33** (2007)
Leonard et al. Phys. Rev. C **73** (2006)
Fletcher et al. Phys. Rev. C **49** (1994)
Brown et al. Phys. Rev. C **41** (1990)
Gruebler et al. Nucl. Phys. A **369** (1981)
Ying et al. Nucl. Phys. A **206** (1973)
Schulte et al. Nucl. Phys. A **192** (1972)
Roper et al. Few-Body Syst. **47** (2010)
Lisowsky et al. Nucl. Phys. A **242** (1975)
Clegg et al. Phys. Rev. C **8** (1973)
Kozma et al. Nucl. Phys. A **442** (1985)
Dietze et al. Nucl Phys. A **158** (1970)
Alsoraya et al. Nucl. Phys. A **280** (1977)
Behof et al. Nucl Phys. A **108** (1968)
Sikkema et al. Nucl. Phys. A **245** (1975)
Theus et al. Nucl. Phys. **80** (1966)
Wenzel et al. Phys. Rev. **88** (1952)
Hunter et al. Phys. Rev. **76** (1949)
Jeltsch et al. Helv. Phys. Asta **43** (1970)
Steinberg et al. Phys. Rev. **186** (1969)
Krauss et al. Nucl. Phys. A **465** (1987)
Blair et al. Phys. Rev. **74** (1948)
Franz et al. Nucl. Phys. A **122** (1968)

INPUT from experiments

partial wave analysis
for two-body reaction
with spin 1+1→1/2+1/2

Minimization procedure ✓

Analysis of new experimental data ✓

Partial amplitudes

$a^J_{l'l}$ ✓
$b^J_{l'l}$
$c^J_{l'l}$
$d^J_{l'l}$
$e^J_{l'l}$
$f^J_{l'l}$

Observables

σ_0
$d\sigma_0/d\Omega$ ✓
A_y
A_{zz}
A_{xz}
C_{zz}
C_{yy}
$C_{zz,zz}$ $C_{y,zz}$
$C_{y,xz}$
$C_{zz,xz}$
$P_{y'}$
$K^{x'}_x$
$K^{y'}_y$

Event generator ✓

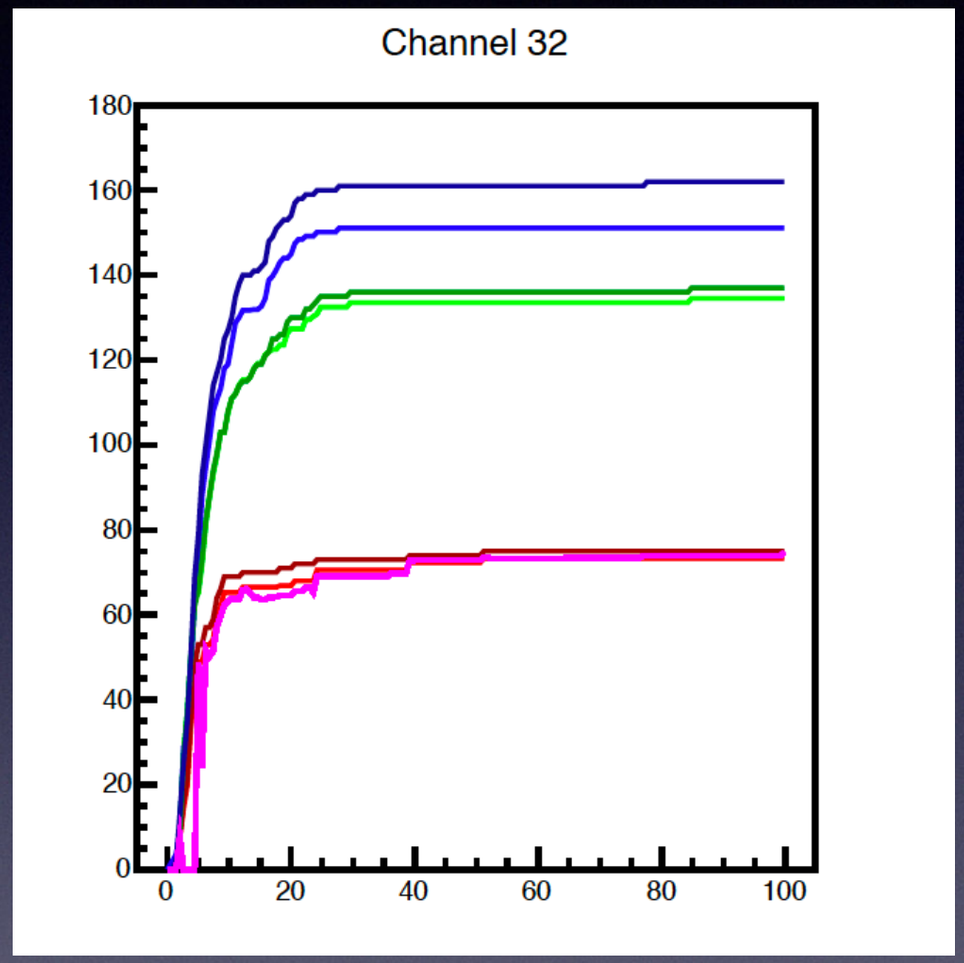
Detector simulation ✓

Event tracking and reconstruction

Systematic ✓

QSF

Thank you!


Channel 32
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100