Study of charge symmetry breaking in dd collisions with WASA-at-COSY

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Physics Motivation

- **Isospin Symmetry**
  - invariance under any rotation in isospin space
  - approximate symmetry in QCD
  - **broken** due to static and dynamic effects

static observables		**dynamical observables**
$m^2_{\pi^{+-}} - m^2_{\pi^0} = \frac{2C}{f_\pi^2} e^2$	purely electromagnetic	πN scattering length
$m_p - m_n = \Delta m_{ud} + \Delta m_{em}$	strong + electromagnetic	πNN vertex

  - ISB observables **dominated by pion mass difference**
- **Charge Symmetry** (subset of IS)
  - invariance under rotation by 180° around I_2 axis in isospin space, interchange of *u* and *d* quarks
  - **broken** due to
    - electromagnetic effects
    - ***up-down* quark mass differnce**

Physics Motivation 2

- **CSB**
  - dominated by up-down quark mass difference
  - pion mass difference does not contribute
  - small electromagnetic contributions
  - **insight into light quark mass differnce – a fundamental parameter of SM**

- **Experimental task:**
  - choose appropriate reaction and observables that would vanish in charge symmetric world → “null experiments"

“Null experiments" on CSB

- Reaction $dd \rightarrow {}^4He\pi^0$
  - violates isospin conservation (0+0→0+1)
  - violates CS ($1 \cdot 1 \rightarrow 1 \cdot (-1)$)
  - in CSC world $\sigma=0$
  - $\sigma \sim |M_{CSB}|^2$
- Reaction $np \rightarrow d\pi^0$
  - in CSC world cross section symmetric
  - any forward-backward asymmetry is a measure of CSB

“Null experiments” - world results

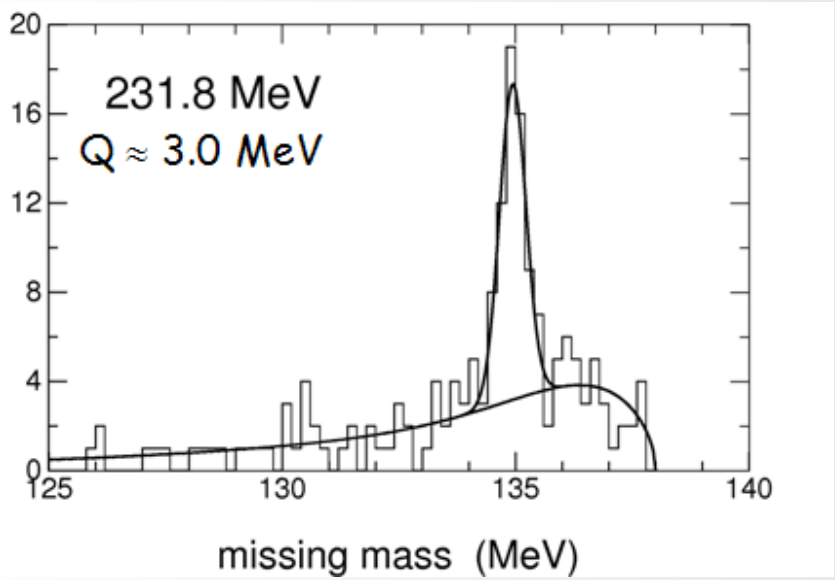
- IUCF data on **dd→^{4}He π^0** near threshold

  E.J.Stephenson et al., Phys. Rev. 91 (2003) 142302

  σ(Q=1.4 MeV) = (12.7 ±2.2) pb

  σ(Q=3.0 MeV) = (15.1 ±3.1) pb

- results consistent with s-wave

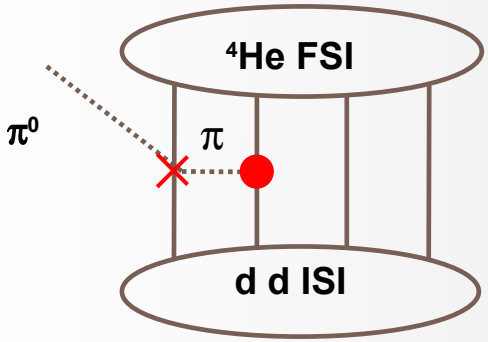


- TRIUMF data on forward-backward asymmetry in **np→dπ^0**
- A.K. Opper et al. PRL 91 (2003) 212302

A_{fb} = (17.2±8.0±5.5) ·10^{-4}

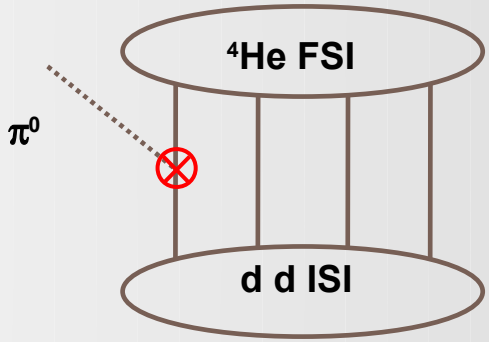
Theory status

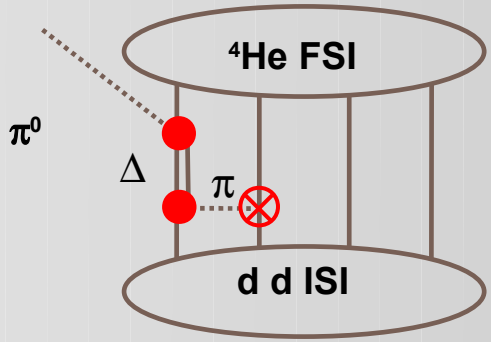
- ambitious CSB theory collaboration formed
- main goal: consistent description of **dd→^{4}He π^0** and **np→dπ^0** within ChPT
- rigorous calculations including ISI and FSI up to NNLO
- results on σ near threshold consistent with experimental values



LO
(dominating in n p → d π^0)

the only allowed for s-wave production suppressed due to specific selection rules in dd





NNLO

dominating for p-wave

A. Nogga *et al.*, Phys. Lett. B 639, 465 (2006)
A. Gardestig *et al.*, Phys. Rev. C 69, 044606 (2004)
T. A. Lahde and G. A. Miller, Phys. Rev. C 75, 055204 (2007)
A. C. Fonseca *et al.*, Phys. Rev. C 80, 027001 (2009)

Experimental program

Goal: determine **p-wave contribution for dd→^{4}He π^0** (Q=60 MeV)

- predicted σ(Q=60 MeV) = **75 pb** (phase-space scaling of IUCF data)
- estimated σ_{tot}^{dd}(Q=60 MeV) = 80 mb
- other open channels: dd →(dd, pnd, pnpn, tp, n^{3}He) + π^0
  - measure to validate calculations!

Experimental requirements:

- high luminosity
- high trigger selectivity
- very good background suppression
- after check of feasibility with unpolarized beam, use of polarized deuteron beam to unambiguosly extract p-wave contribution
- angular distributions

Status of experiments

- 1 week of beam time in Nov 2007
  - focus on CS conserving reactions **dd → N ^{3}A π**
    - tuning of apparatus
    - check of feasibility
    - cross section

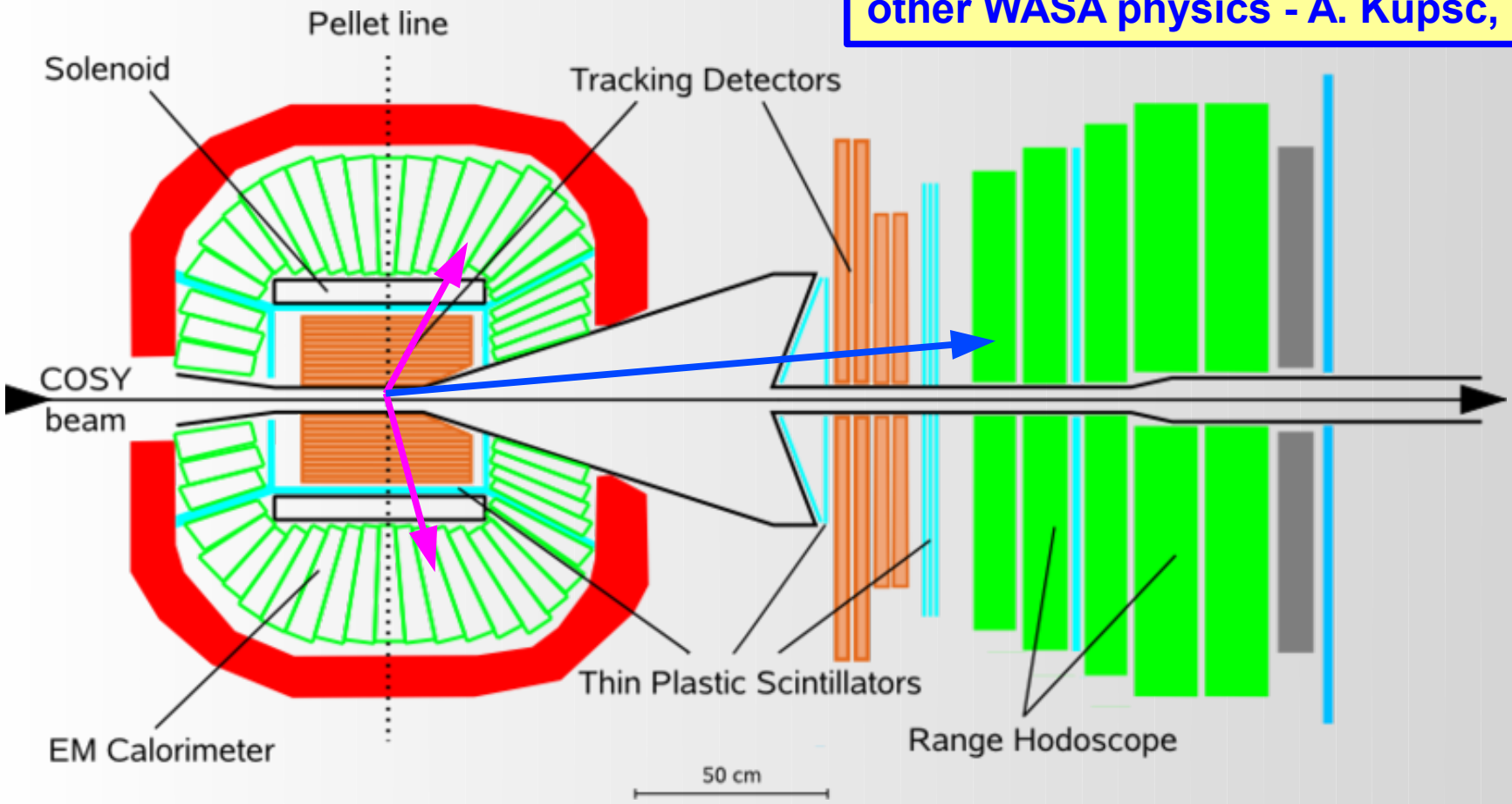
Analysis: P. Podkopal

- **2 weeks of beam time in June 2008**
  - **focus on dd→^{4}He π^0**
  - **unpolarized total cross section**

Analysis: V. Hejny

Experimental technique

other WASA physics - A. Kupsc, Thu 11:30



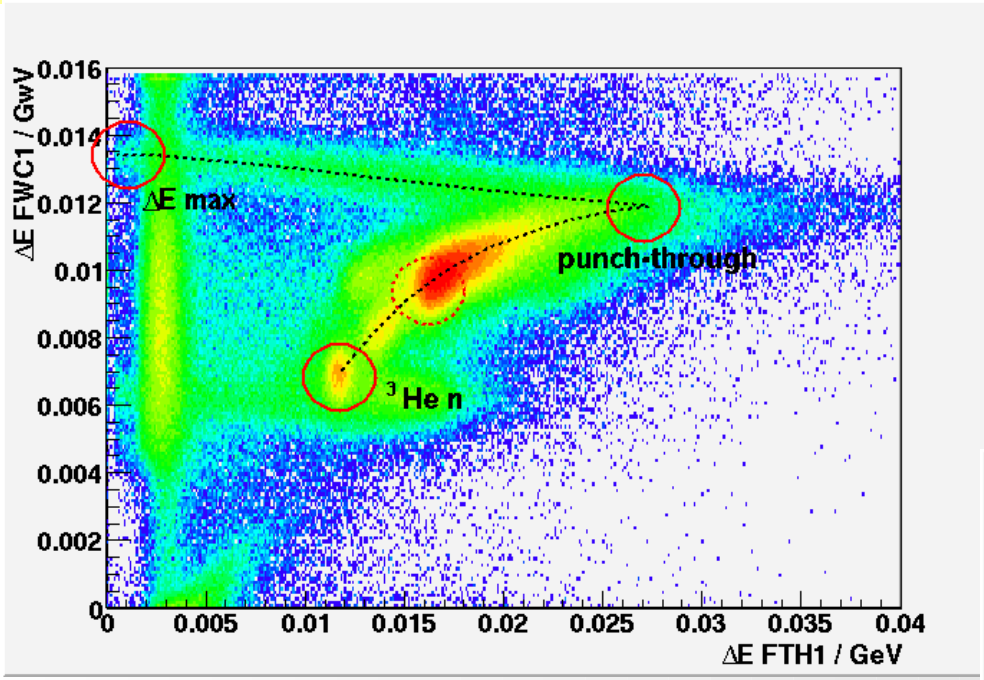
- $\pi^0 \rightarrow \gamma\gamma$ in CsI calorimeter

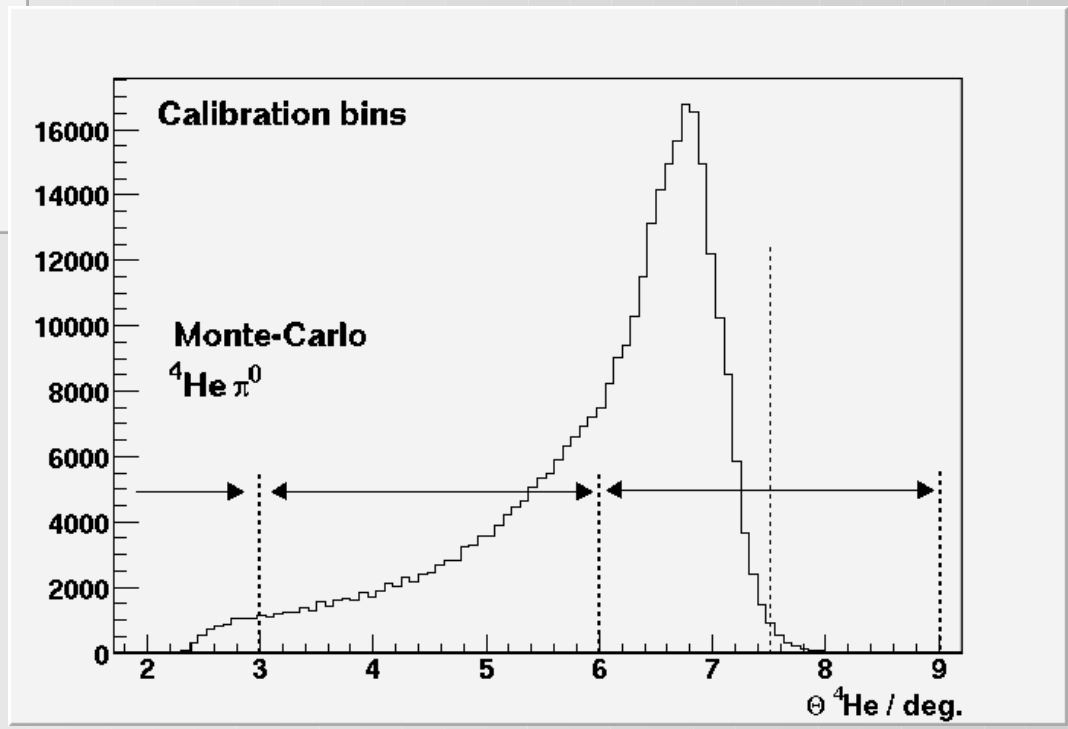
  θ = 20° … 170°, full azimuthal acc.

- He in Forward Detector

  θ = 3° … 18°, tracker resolution 0.2°

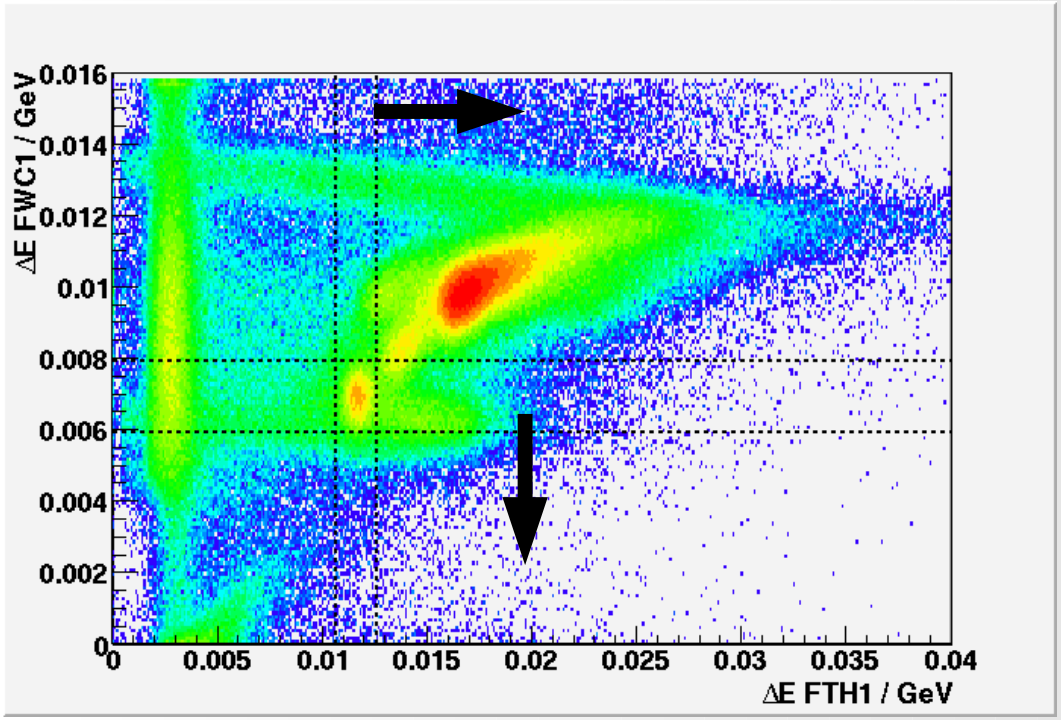
Identification of He

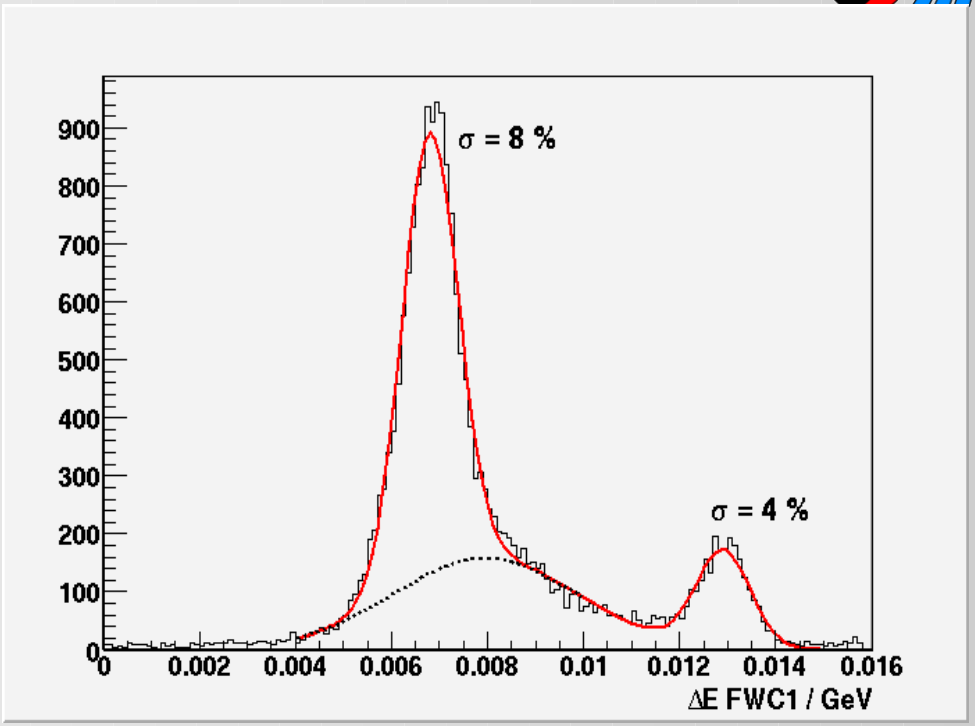


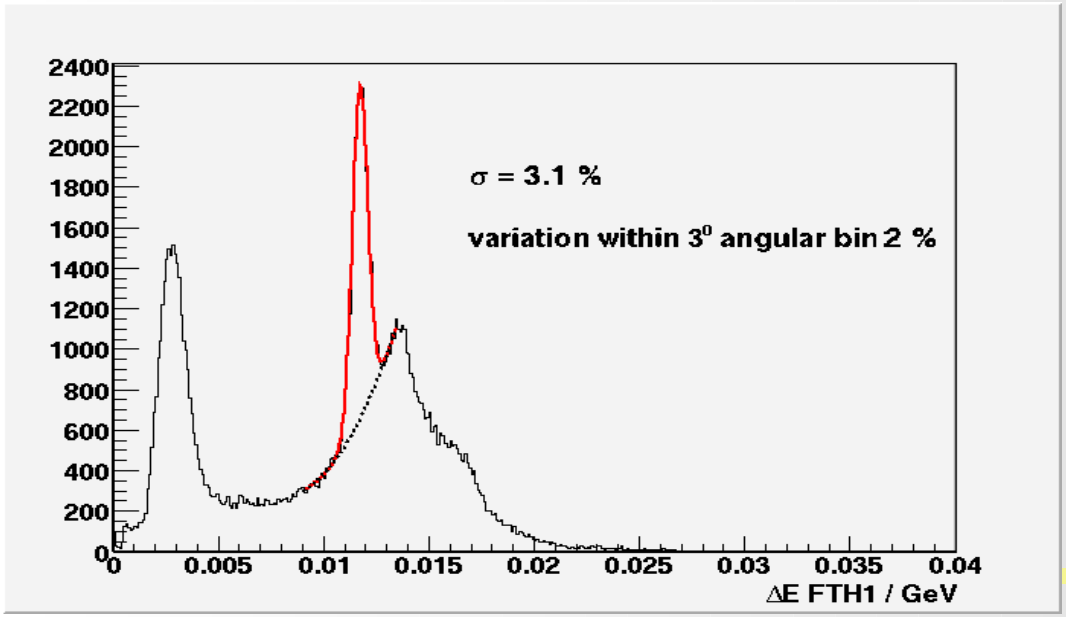


- low-energetic ^{3}He
- ΔE from 3 layers of scintillator
- MC based ΔE calibration
- use of characteristic points
- energy reconstraction based on $E_{kin}(\Delta E_i)$ tables from MC

Energy calibration for He

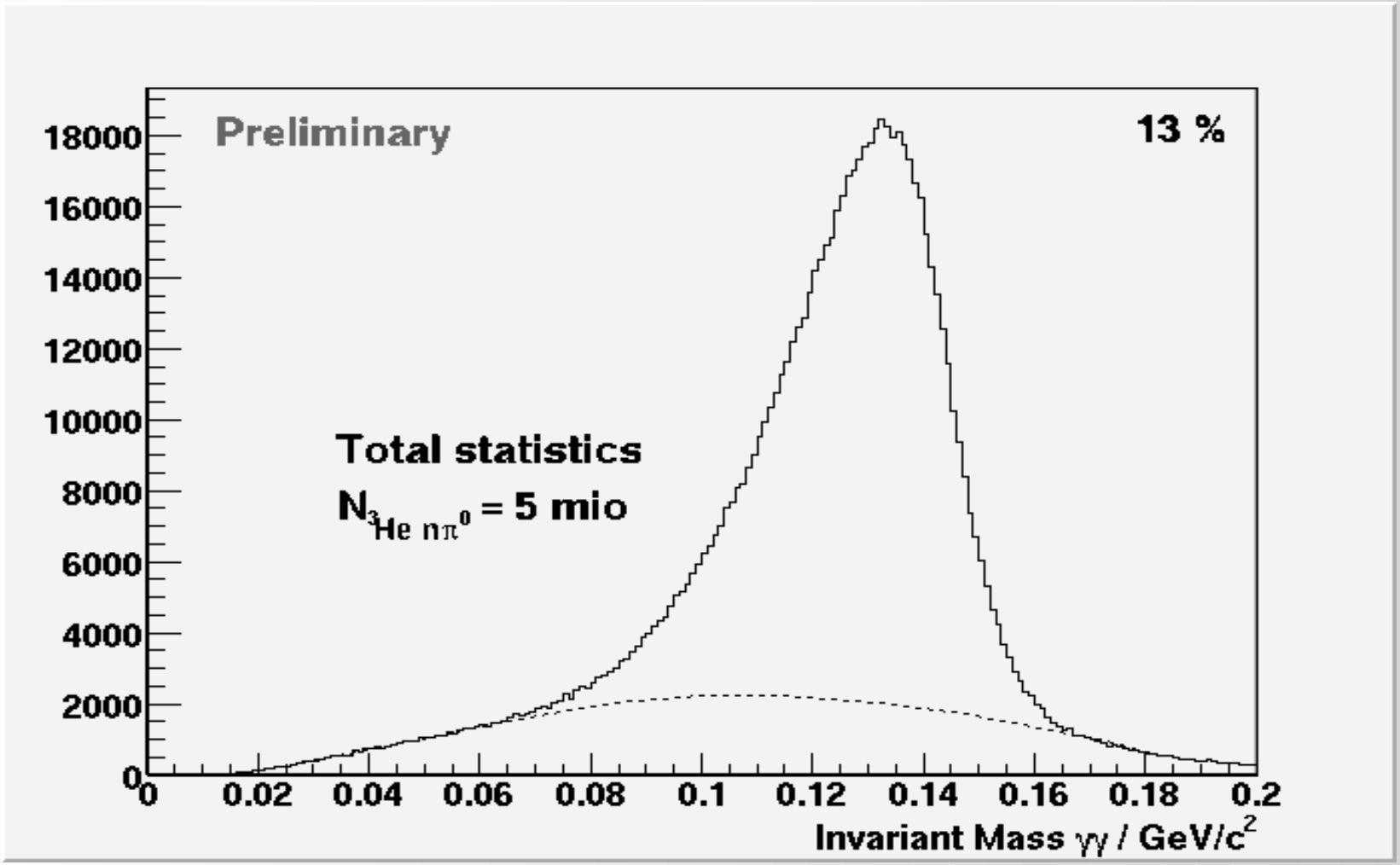






- Energy resolution based on dd→^{3}He n in one angular bin (6-9 °)

Collected statistics

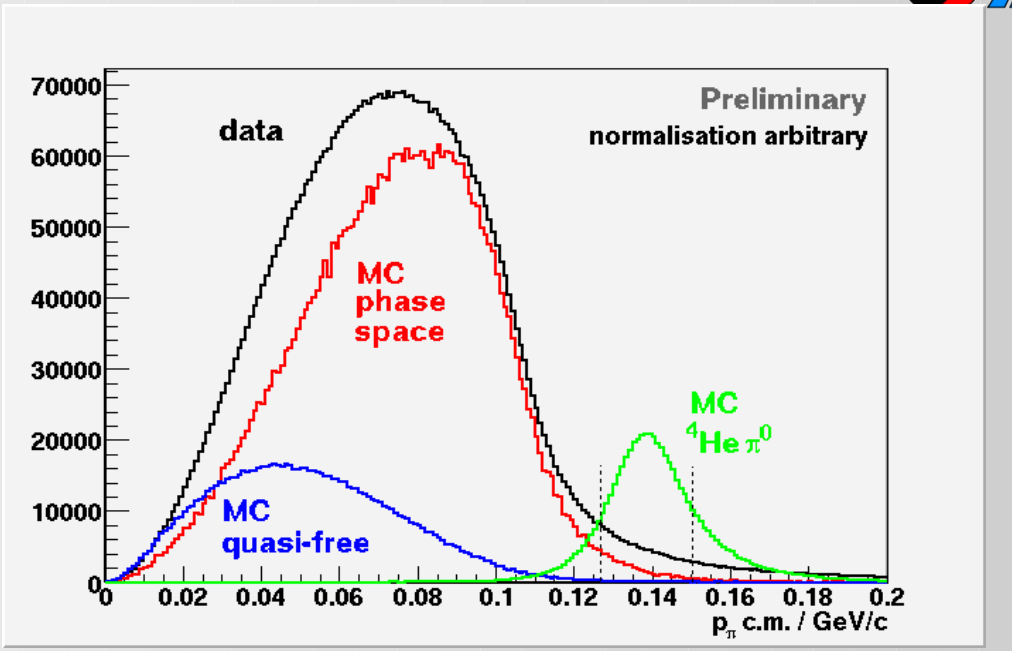


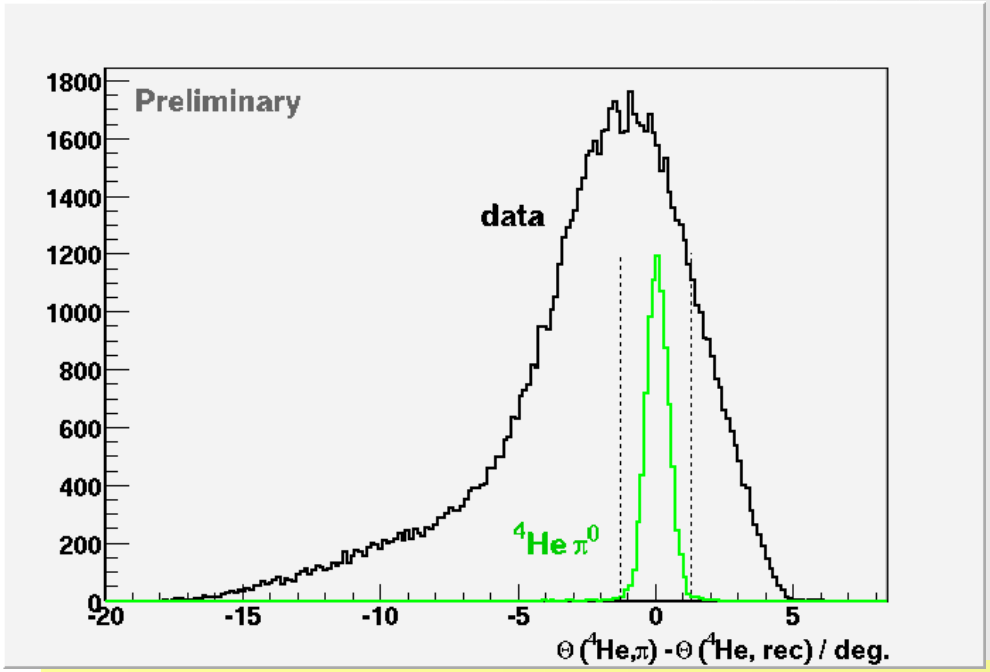
→ expected number of dd→^{4}He π^0 events ~ 300
(based on the cross section-ratio to dd→^{3}He n π^0)

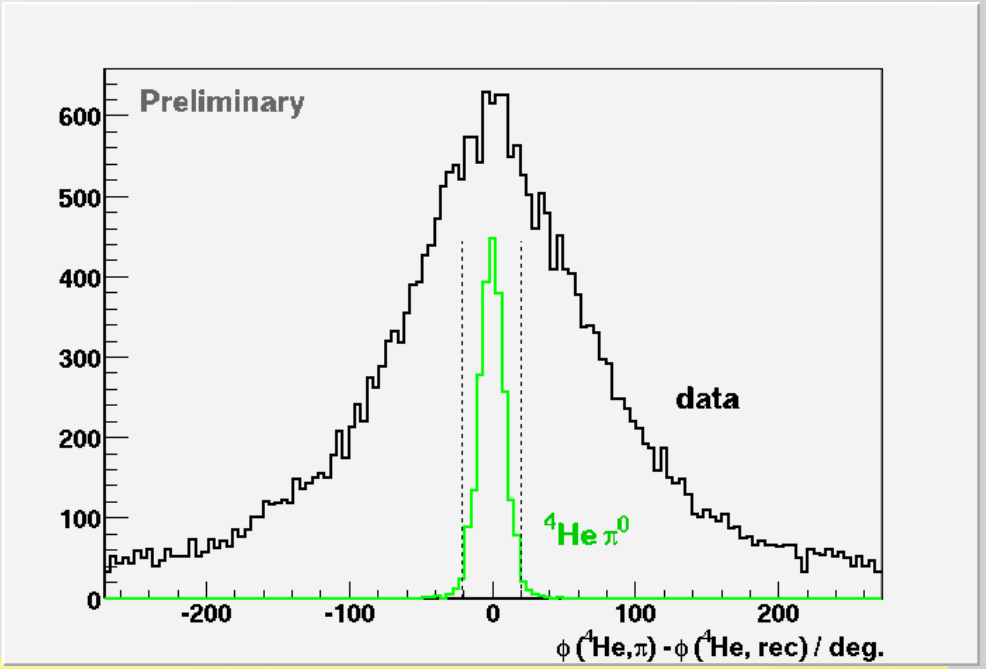
Event selection

dd→^{4}He π^0 is binary, thus

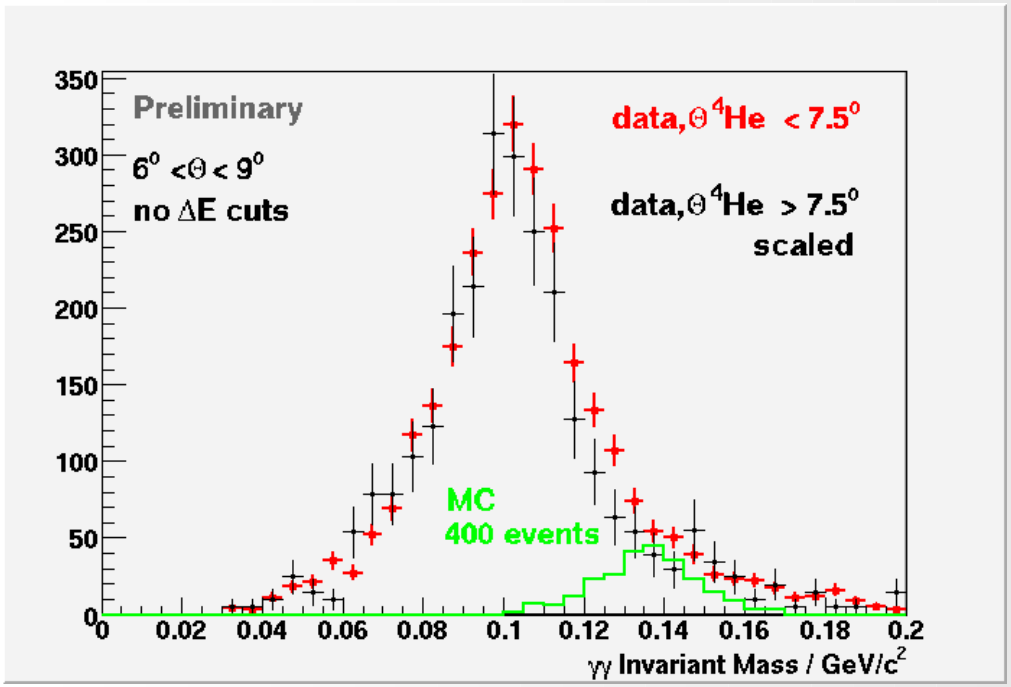
- **fixed cm momentum**
- **fixed Δθ**
- **fixed Δϕ**

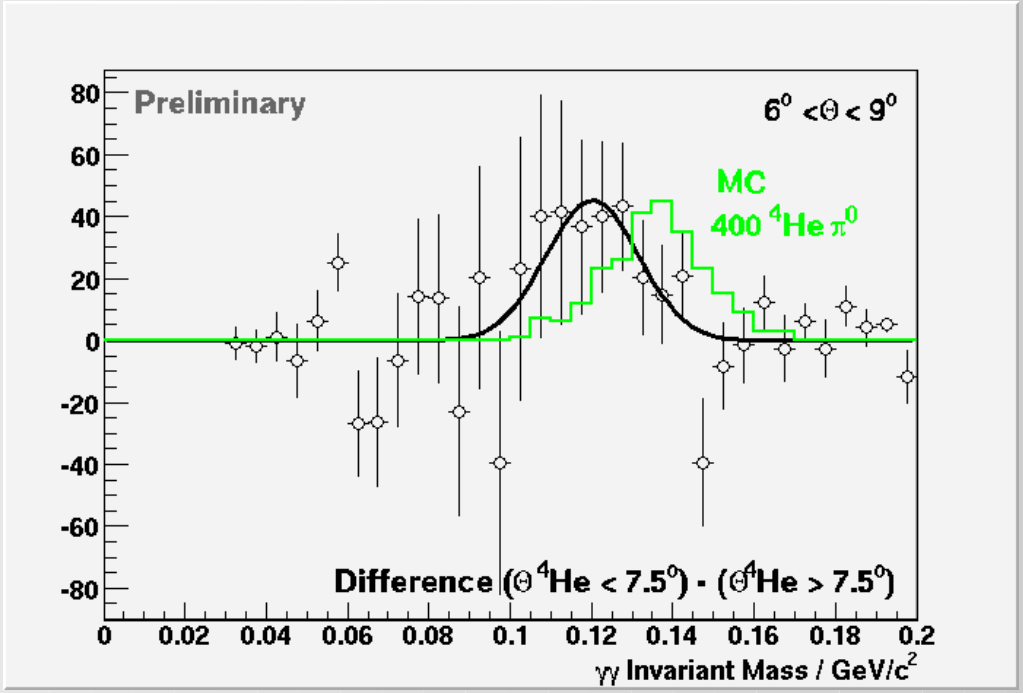






Preliminary results - γγ invariant mass

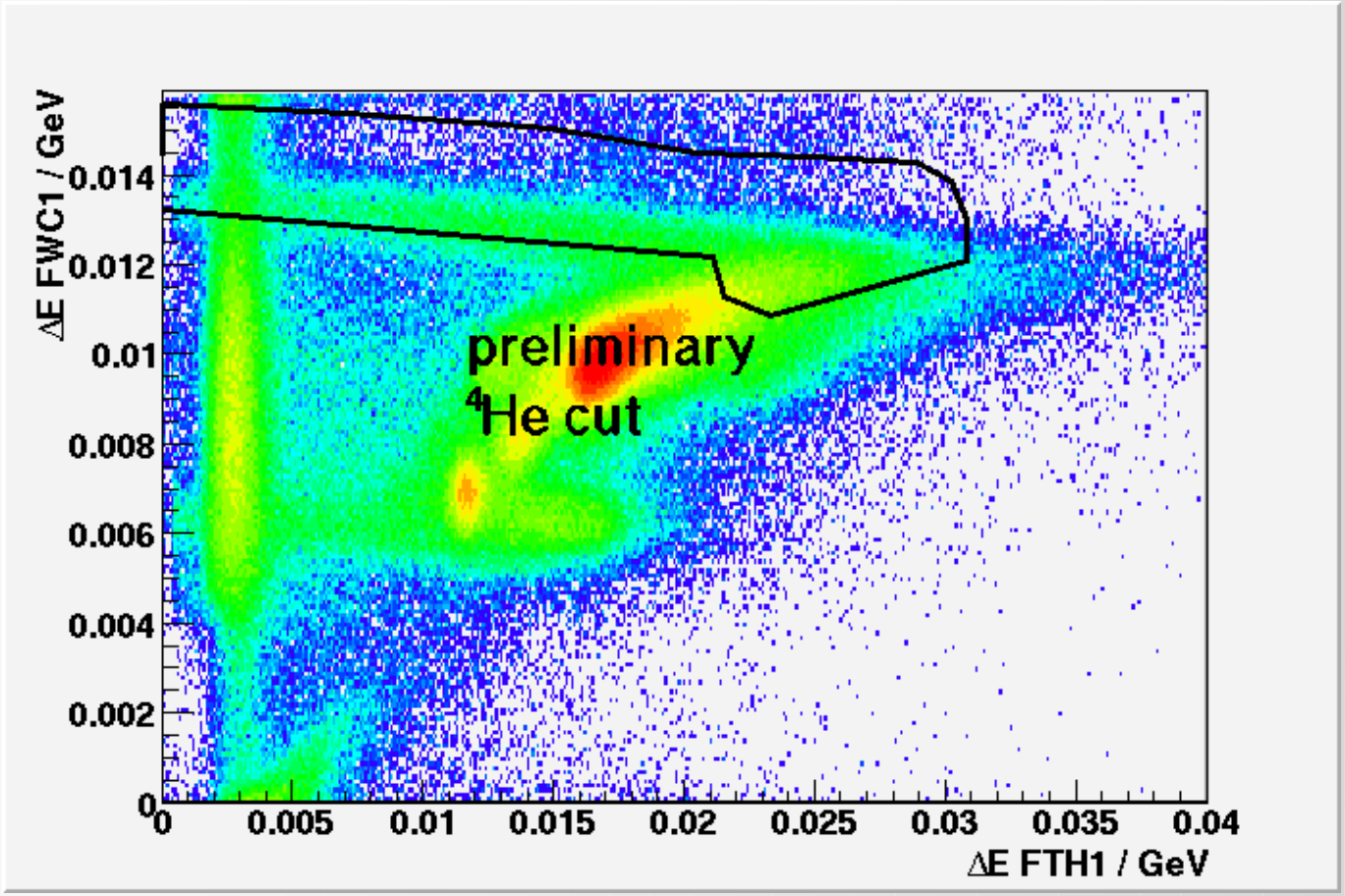




- for these plots the information on **He E_{kin} unused** (no cut)
- data consistent with a signal of about the **expected strength**, but position slightly off

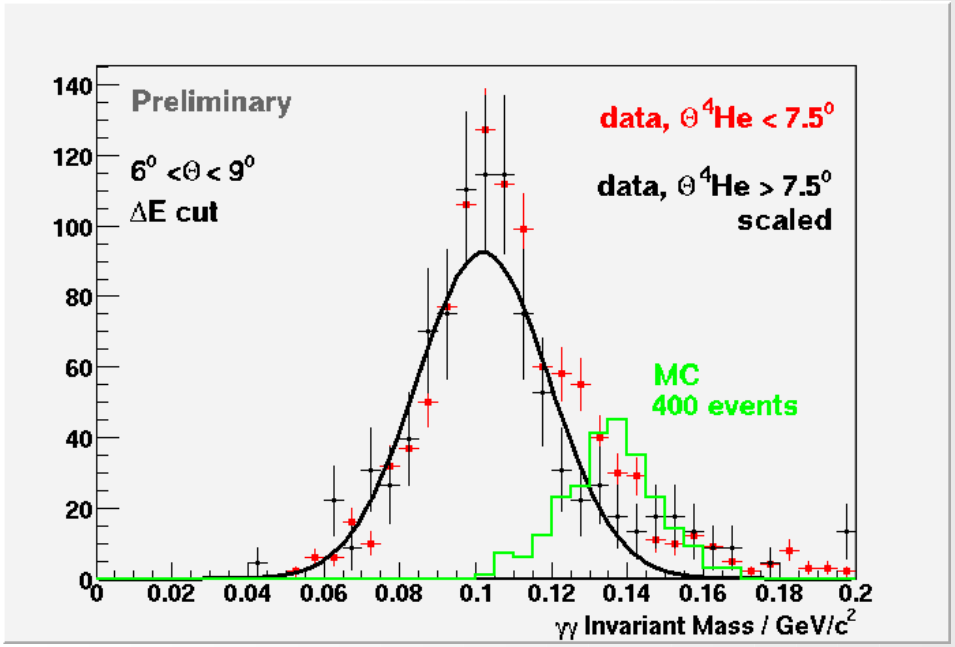
Event selection - further conditions

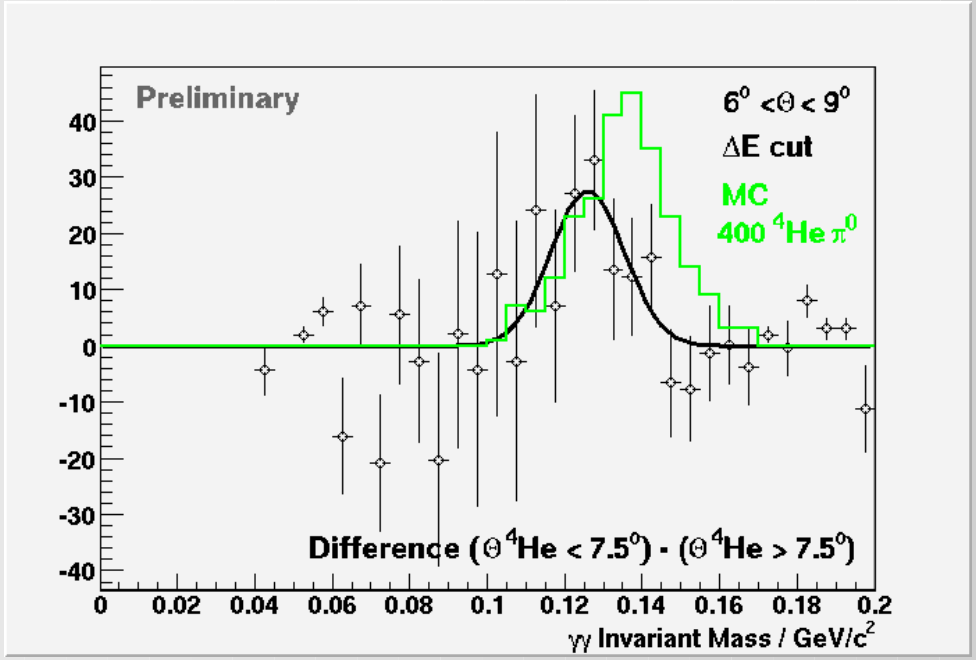
- exploit the ΔE information for better background suppression



Preliminary results

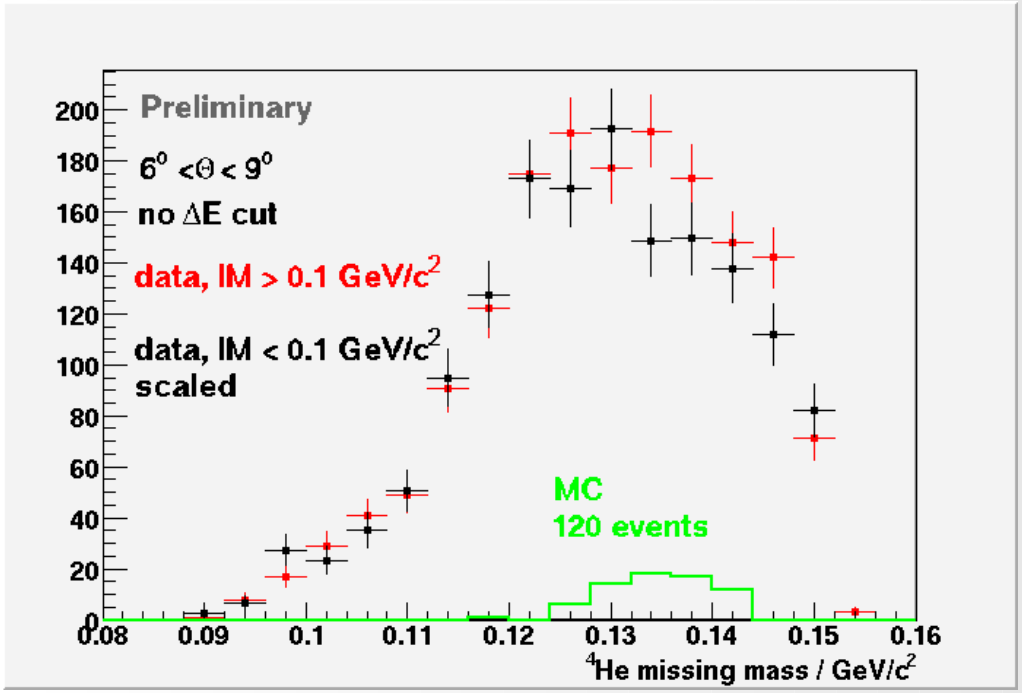
$\gamma\gamma$ invariant mass spectra **with cut on ^{4}He ΔE-ΔE band**

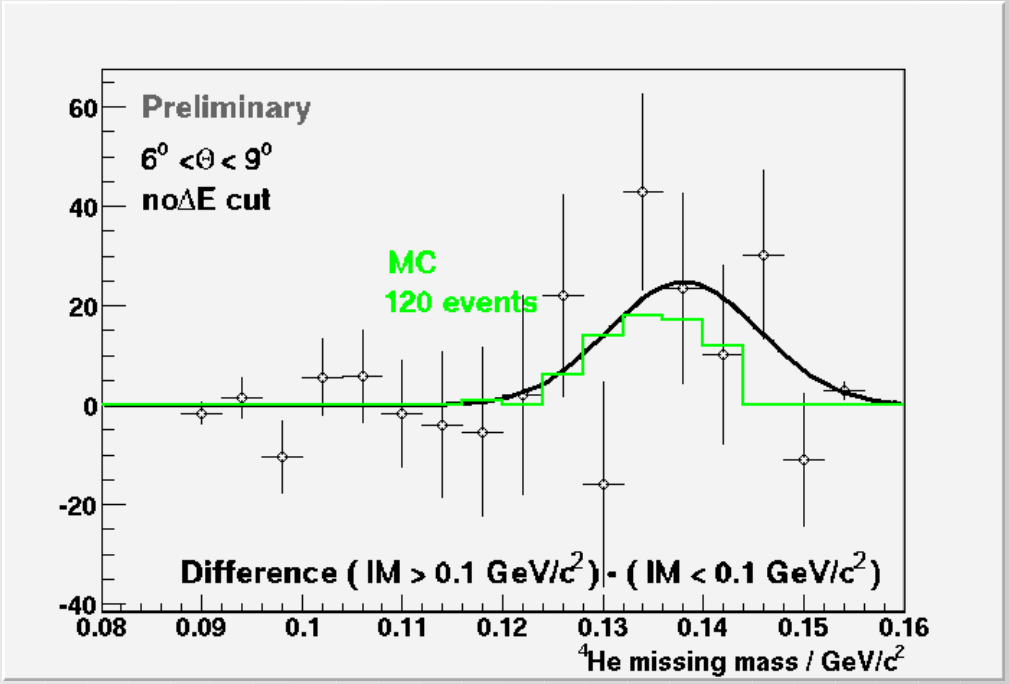




→ reduction of the signal

Preliminary results - ^{4}He missing mass

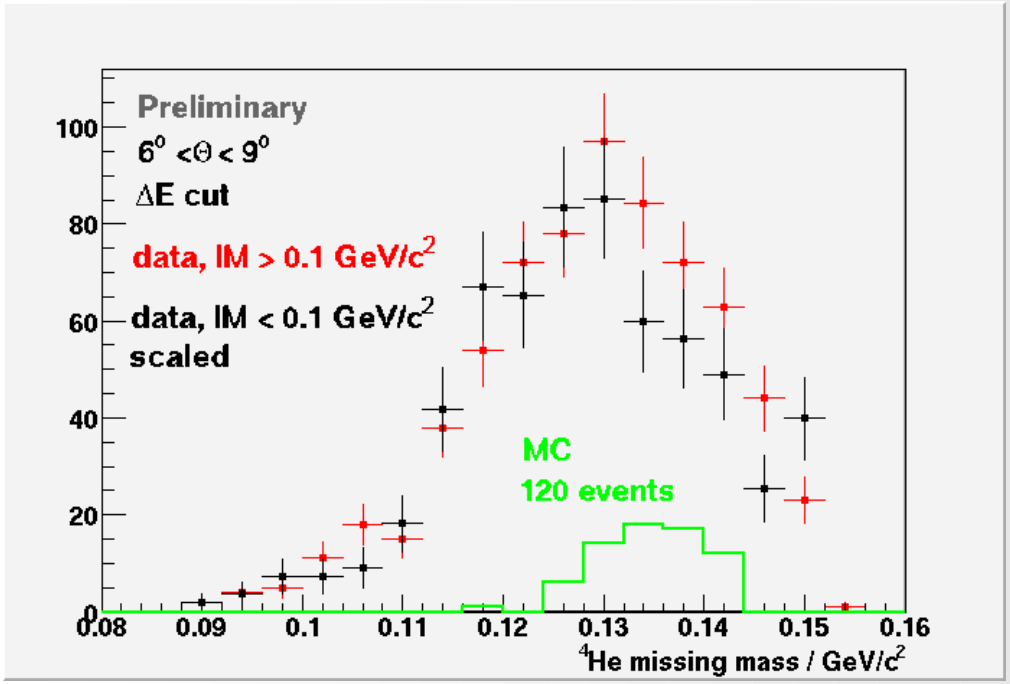


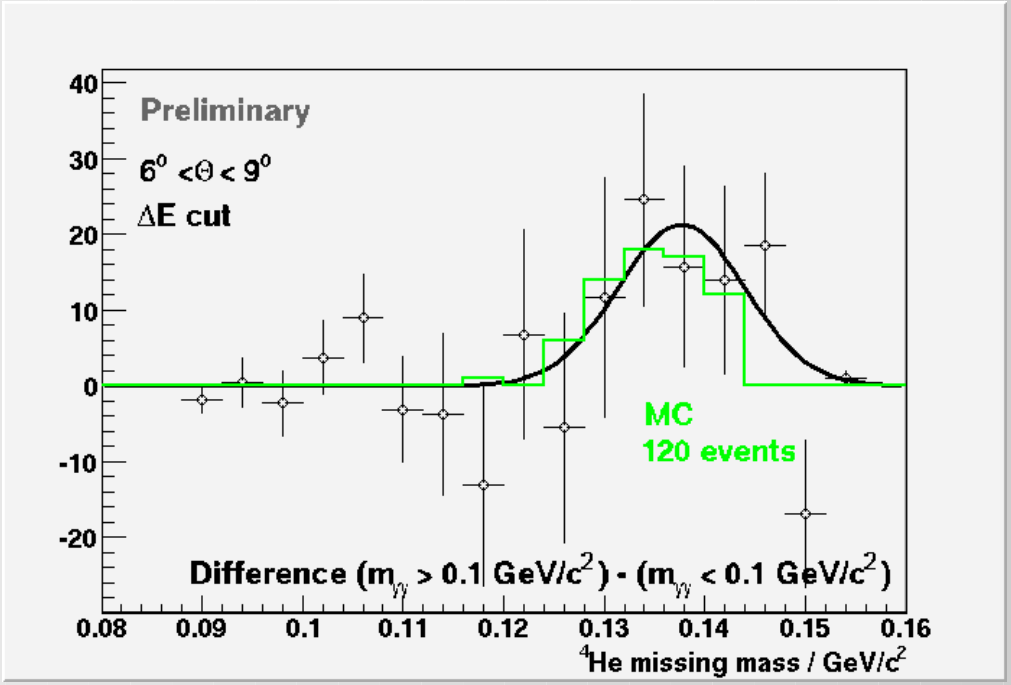


- only p_{cm} cut and angular correlations demanded
- data consistent with a smaller signal than from inv. mass spectra (but right position)

Preliminary results 4

^{4}He missing mass spectra **with cut on ^{4}He ΔE-ΔE band**





→ signal persists

Summary

- Charge Symmetry Breaking - a tool to study quark masses
- theoretical analysis of dd processes in progress
- in total 3 weeks of beam time on **dd**$\rightarrow$**^{4}He π^0** and **dd**$\rightarrow$**^{3}He n π^0** have been performed (unpolarized) with WASA-at-COSY
- data reveal a hint of a signal of **dd**$\rightarrow$**^{4}He π^0** however further analysis needed to understand the source of inconsistencies
  - further background suppression (inclusion of hodoscope 3rd layer, other cuts)
  - kinematic fit

Outlook

- analysis of experimental data on **dd→^{3}He n π^0** close to be finalized (this year)
  - test of theoretical predictions

- continuation of the measurements for **dd→^{4}He π^0** **with polarized beam** depends on the final results of the presented analysis